REPORT OF THE 1989 NSAC INSTRUMENTATION SUBCOMMITTEE

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I.1. INTRODUCTION

This is the report of the Nuclear Science Advisory Committee (NSAC) Subcommittee on Instrumentation in Nuclear Physics. The committee was appointed in March, 1988. The charge to the subcommittee, established in March 25, 1988, was as follows:

Charge

> The subcommittee shall evaluate the present status of instrumentation in basic nuclear physics research and identify future needs and opportunities in this area. The purview of the committee is broad. It includes magnetic, solid state, and gaseous devices for detection and measurement of nuclear radiations; polarized sources and targets; high charge state ion sources; data acquisition and analysis systems; and, in general, instrumentation for both non-accelerator and accelerator based research. The subcommittee shall pay special attention to areas in which rapidly changing technologies present fundamentally new scientific opportunities or more effective means of exploring such opportunities.
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> The subcommittee also shall review and evaluate proposals for large experimental equipment projects that may be presented to it from time to time.

The subcommittee met three times in the last 12 months. During the first meeting on April 24, 1988, in Baltimore, the committee decided to form subgroups to investigate the status of instrumentation in the various subfields of nuclear physics and to identify major new opportunities in the field. These subgroups are each chaired by a subcommittee member. Their membership is listed at the beginning of each subgroup report. The subgroups proceeded with information gathering during Summer and Fall of 1988. Reports and findings of the subgroups were discussed at a second meeting in Santa Fe on Oct. 14, 1988 and in detail in a meeting at Stony Brook on Jan. 8-9, 1989. The write-ups of each group, given in section III, form the major basis of the present report. Each write-up contains a set of recommendations specific for the corresponding subfield. In addition, there emerged several issues which transcended the boundaries of the subfield. These issues led to the formulation of the major recommendations of this report, listed below. Questions relevant to funding of research and development of instrumentation in general and of funding modes of user groups in particular were discussed from time to time during the various committee meetings and are summarized in section II.

I.2. SUMMARY OF FINDINGS

The overall status of instrumentation in Nuclear Physics laboratories and groups has substantially improved during the 6 years since the last instrumentation report. In particular, the continued evolution of advanced computer hardware has brought a dramatic improvement in the availability of CPU power for most nuclear physicists. Furthermore, the coming on line of new facilities for electron and high energy heavy ion research has led to a first stage in the development of complex new equipment for such studies. In our deliberations we have explicitely excluded discussions concerning priorities for specific detectors and other instrumentation projects but rather focussed on areas where new developments or technologies would provide new opportunities.

Such major new opportunities for the field are opening up through the development of:

(1) High quality internal targets and polarized internal and external targets for electron and hadron scattering facilities,

(2) new and innovative detectors for the study of ultrarelativistic nuclear collisions at presently available accelerators and at the planned collider,

(3) intense low energy neutrino beams and corresponding detection facilities,

(4) novel and large scale detectors for the study, with unprecedented resolution, of extraterrestrial neutrino spectra and the structure of nuclei at high spin.

The highest priority recommendations of this report reflect a common themes running through essentially all reports of the individual subgroups. For example, a continued concern emerging from the discussions in all subgroups and from the deliberations of the committee as a whole is the lack of qualified technical support in most groups for the design and standardization of hardware. Instrumentation development in all fields of nuclear physics is done at the forefront of technology and proper technical support can provide enormous paybacks for the field. Similarly, there is a lack of a coherent approach towards development, maintenance and standardization of software which leads to a large duplication of efforts by many groups. The development of sophisticated computer hardware over the past 5 years has proceeded at a very rapid pace and led to a much improved availability of high speed computing for most nuclear physics groups as is evident from the reports of the subgroups on data acquisition and data analysis. Efficient use of this hardware will benefit greatly from the development of generalized software packages which can be made readily available to the community as a whole. Another finding which appears in many of the subgroup reports is the need for standardization and documentation of instrumentation developed in different laboratories and the need for improved communications (by computer networks, e.g.).

Hence we make the following two highest priority recommendations:

We recommend that groups actively involved in the research toward and development of new instrumentation be given a major increase in funds to provide the necessary infrastructure and qualified technical support for such endeavors. This should include:

1) Funds for mechanical and electrical engineering projects as part of major new instrumentation projects (identified by competitive peer review)
2) funds for documentation and standardization of developed instrumenation
3) funds to encourage information exchange and, when appropriate, collaboration with researchers from other relevant subfields of physics and industry.
4) funds to help rebuild the technical support staff and instrumentation and research facilities at universities

We recommend that an effort be directed at software development which is comparable in scope (and will be comparable in cost) to the massive upgrading of data analysis hardware which has taken place over the past 5 years. Elements of such an effort should include:

1) Funds for the purchase of high quality commercially available software, both for laboratories and off-site users;
2) funds to ensure that high quality personnel involved in software development (identified by competitive peer review) have adequate resources to produce and disseminate (including assistance to users) documented, standardized code;
3) creation of a professionally maintained database/software library charged with maintaining standards and maximizing the exchange of information among users and developers of software for the analysis of data in nuclear science.

II. REMARKS ABOUT INSTITUTIONAL FRAMEWORKS AND FUNDING MECHANISMS

The 1983 NSAC Instrumentation Report discussed in some detail the framework within which usergroups mount and perform experiments at appropriate accelerator centers. Most of the findings there are still very relevant especially since the fraction of users within the nuclear physics community has grown substantially in the past five years. Here we add remarks and comments relevant to the ways and means by which instrumentation is developed within the nuclear physics community in the U.S.

(1) it is only recently that specific research projects designed towards developing novel instrumentation have received direct grant support. These programs should be strengthened to provide incentives for investigators to enter the field of detector and instrumentation design. The University Research Instrumentation program recently started by the DoE and the specific R&D monies made available recently for work on new detector concepts in the field of ultrarelativistic heavy ions are first steps in this direction. Such programs need to be taken up also by the NSF and be expanded in size and scope. The impact on the field is likely to be large and positive.

(2) in a time where more and more nuclear physics University groups join large collaborations centered at big accelerator facilities it is important to develop efficient modes of funding of (capital) equipment projects to be undertaken by the user groups. This needs an integrated, interagency approach. While detailed funding pattern may vary from case to case we feel it important that such equipment funding generally be directed to and managed by the user groups.

(3) industrial participation in the development of instrumentation is crucial for the field. The SBIR program provides an important link between research groups and industry. However, the limitation of this program to companies of small size is often a serious drawback, especially in view of the fact that many small companies have recently been taken over by larger companies thereby eliminating the possibility of cooperative research. To provide more attractive markets for equipment developed by industry it may be useful and cost-effective for the field to set up funding patterns which make it more attractive to buy new equipment rather than build it internally.

(4) R&D projects for instrumentation and detectors to be placed at new accelerator facilities need to be funded in a time frame closely tied to the time frame for large facility and/or experiment proposals at such accelerators. Increasingly, the complexity of experiments and detector facilities approaches that of the accelerator itself. Instrumentation development has to be included as an integral part of the accelerator facility right from the beginning of the project.

III. THE STATUS OF INSTRUMENTATION IN U.S. NUCLEAR PHYSICS

The status of the field is best judged by detailed surveys of various subareas. In the following we collect the information from the subgroups charged with surveying the subareas. Each section contains its own set of recommendations.

III.1. REPORT OF THE SUBCOMMITTEE ON ACCELERATOR INSTRUMENTATION

J. Alonso (Chair), J. Nolen, W. Haeberli

This Subcommittee concentrated on a study of instrumentation needs for accelerators, storage rings and transport lines: an assessment of whether technical problems exist in any of these areas, what the climate for meeting these problems is, and recommending ways of expediting work in the field.

Two very broad areas were considered, beam monitoring and diagnostic instrumentation, and instrumentation and techniques for accelerator control systems.

III.1.1. ACCELERATOR CONTROL SYSTEMS

i) Background

The extremely rapid evolution of computer technology has thoroughly revolutionized the field of accelerator controls. Distributed intelligence, dedicating a sophisticated processor to the local control of even very small simple elements of an accelerator system are now possible, bypassing to a large extent the need for a large concentration of computing power in one central processor. This new technology has redefined the main issues in an accelerator control system to the following areas: effective networking, for adequate data flow to all elements of the control system; efficient management of the data base, whether central or distributed, with proper access by all elements requiring information; and user friendliness of the operator interface.

There are many ways of addressing these issues, and unfortunately there has been little cooperation between the many groups working at different accelerator centers to exchange ideas and work towards the evolution of an optimal generic approach to accelerator controls.

Fortunately, trends in the controls industry, covering a field much broader than that of accelerators, are moving rapidly towards standardization of hardware architecture and software protocols, and accelerator control experts are beginning to realize that their interests are best served by following these trends, and applying the growing inventory of off-the-shelf subsystems into the accelerator environment. Advantages of this approach are obvious: availability of a broad vendor base, ensuring product quality at competitive prices; existence of well-debugged system and low-level coding, allowing concentration of effort on the application-specific areas of the project; well-defined upgrade paths, as new, faster processor boards are designed to be compatible with industry-wide bus protocols.

ii) Need

Standardization of control techniques, equipment interfaces, and operator "look-feel" for accelerators in all fields of research, even industry, is a worthy goal to pursue. The existence of a generic control system philosophy and implementation implies high efficiency in cost and production, as well as high reliability from a system which has been implemented in many environments. Standard architecture, high level development tools and interfaces also allows for easy transport of controls personnel between projects.

iii) Recommendation

One method to achieve this goal is to form (most probably under the auspices of the IEEE) a Standards Committee for accelerator control systems. Such groups have proven very effective in establishing standards in many areas, for example, NIM, CAMAC, FASTBUS, etc. The difficulty of such a committee reaching a consensus must not be underestimated, hence extreme care must be taken in the constitution of the committee. Nevertheless, the potential benefits are so great that the exercise should definitely be undertaken.

III.1.2.BEAM MONITORING AND DIAGNOSTIC INSTRUMENTATION

i) Background

Beam diagnostic instrumentation is vital to the operation of any particle accelerator. Parameters of the beam which must be measured include: the centroid position of the beam, its profile in transverse planes, its energy (momentum) and energy spread, its emittance, both transverse and longitudinal, its intensity, and time structure.

The general state of the field is that techniques and instruments are for the most part adequate to perform these missions. There do not appear to be any critical areas where a gap in technology is severely hampering an accelerator's performance. That is not to say that developments in certain areas would not be beneficial. Examples of such areas are: sensitivity to very low intensity beams, particularly in non-destructive monitors; improved dynamic range, instruments offering linear response over a large span of beam intensities; improved position resolution, many applications now require micro-meter sensitivities; absolute beam intensity and energy measurements; improved frequency response.

Technology has been advancing rapidly in this field. Sensitivity is being improved by development of low-noise high- gain front ends, with more emphasis being placed on custom- designed chips. Until recently, specialized chip fabrication was economically viable only for large quantities. Trends now, however, are that costs for lots of a few hundred are low enough to make this technology competitive with discrete component designs.

The development of techniques in beam bunch resolution, control and beam cooling is showing a definite need for improvement in microwave beam monitoring instrumentation. High sensitivity wide-band amplifiers of extremely low noise and high gain are required, with good frequency response well into the gigahertz region. The great importance of this area of accelerator technology, and the increasing number of people who are working in it augurs well, though, for rapid progress.

Signal and control system analysis employing frequency- domain techniques has also been making impressive headway in accelerators. FFT and other digital signal processing techniques are being applied successfully in accelerator tuning and trouble- shooting. The sophistication of commercial devices, and decreasing costs and increasing flexibility of these instruments is leading to more widespread use by engineers and physicists, and even operators in accelerator control rooms.

Taking a different perspective on the subject of accelerator instrumentation, the overall sociology and the national health of the field is not without its problems, and many opportunities are being missed.

In looking at accelerators designed to serve different disciplines, it is clear that although beam species and characteristics vary over a wide range, the beam properties to be measured, and the principles for these measurements are quite similar. Much can be gained by sharing techniques across the many fields where accelerators are used. Although sharing of designs and concepts does in fact exist, the implementation of these concepts has often been very different at different accelerator laboratories. Optimization for a certain critical parameter, or conformation to a certain physical characteristic of the beam has the effect of driving specific designs quite far from where the resulting instrument could have general applicability. This phenomenon, of instrumentation groups attached to an accelerator developing devices specifically tailored to their machine, does effectively address the needs of that particular machine, but in the global picture is often wasteful as much duplication of effort results. However, as is indicated below, rationale for this mode of operation has not been without solid foundation.

First, and perhaps most important, there is not much of an industrial base directly addressing needs of accelerator instrumentation. The picture appears to be much worse in the United States than in other parts of the world; one needs simply to look at advertisements in the CERN Courier, or even Physics Today, to see that European industry is much more tightly coupled to accelerator needs. Recent emphasis on Technology Transfer from National Labs to the private sector, and the SBIR programs are aimed at rectifying this situation, but as will be discussed later, these programs still require refinement and better definition to achieve this objective. Because of the lack of a sufficiently diverse commercial source of instruments, accelerator groups will most often opt for the "build" side of the "build/buy" question. Conversely, without suitable stimulus and a large-enough market there is little chance of expanding the commercial base in the field.

Fiscal arguments also play an important role. The price-tag on commercially available instruments is seen as much higher than the costs of local fabrication. In addition, the argument is used that local manpower is available, and "already paid for" so development costs are free. Very seldom is this last point valid. Perhaps the most important argument is that equipment money is much more scarce than operations funds, so that purchase of commercial instrumentation drains resources more effectively used in other areas.

One ray of light is this somewhat grey landscape comes from a group formed following the last (1987) Particle Accelerator Conference. Spearheaded by Witkover and Bennett of Brookhaven, with active participation from many national labs and university accelerator centers, this group is attempting to organize a series of workshops on accelerator beam instrumentation. Aiming first at improved communication of instrumentation needs and techniques across many disciplines via tutorials, presented papers and discussions, the eventual goal of its organizers is to broaden and unify the base of the community to increase the efficiency of resource utilization in the field. One area of particular interest is in commercial interactions, exploring ways of facilitating flow of ideas from laboratories to industry, and providing a stable-enough market to merit commercialization of these ideas.

Workshops such as mentioned above could be held under the auspices of the Particle Beam Physics Topical Interest Group of the APS. These workshops could be coordinated with or have sessions in the major accelerator-related conferences in the US: the Particle Accelerator Conference, the Conference on Applications of Accelerators to Research and Industry, and the spring meeting of the APS when it is joint with the Particle Beam Physics Topical Interest Group. Such workshops and special conference sessions would naturally lead to increased communication and standarization within this specialty.

ii) Recommendations

From the above discussion, several points can be drawn. First, the tight fiscal climate being experienced by the entire research community calls for searches for the most effective way of utilizing available resources. The best possible communications, cross- fertilization of ideas and new technologies, and where possible standardization are all methods of achieving these goals. Possibilities worth exploring are the creation of an Accelerator/Beam Diagnostics Topical Interest Group and also creating a centralized data base of references and reports related to this topic.

The "Workshop on Accelerator Beam Instrumentation" group mentioned above should receive as much backing and support as possible. The contributions it can make to the field can multiply many-fold any investments made.

Ways of increasing industrial participation must be sought. The SBIR program is one approach to this, but lacks one essential component. The Phase I and Phase II grants are aimed at product development, with the funding programs playing a significant role in the process by outlining areas where technical innovations will be of use in their field. The missing ingredient is that there is no guarantee of a market for the product after it has been developed. As a result many small companies are not interested in pursuing a large development effort if it cannot recoup its investments. Developing such a market could be done in several ways: a Phase III grant specifically aimed at marketing products developed under the other Phases; standardization among accelerator laboratories to ensure that such a product could have applications in many areas; and a funding balance for such laboratories which makes it more favorable to purchase such products rather than build them internally.

III.2. REPORT OF THE SUBCOMMITTEE ON ELECTRONICS AND DATA ACQUISITION

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III.2.1. INTRODUCTION

In a modern, large scale nuclear physics project, the electronics and data acquisition hardware represents roughly 30% of the total hardware costs. Similarly, the software effort required for such a project, including the on-line monitoring to ensure that experiments are working properly, is a significant fraction of the effort required for data analysis. Electronics and data acquisition limit the capabilities of many experiments, both in technical capability and in sheer cost. Nuclear physics has evolved from a state where most experiments had similar requirements (high rate acquisition of a small number of parameters with limited on-line processing power) to a much more complicated set of requirements. The number of parameters range from 1 to 10^5. The count rate requirements approach and exceed instantaneous rates of 10^6/s. To this must often be coupled sophisticated real-time control and variation of experimental parameters. CAMAC has had a major impact in providing a hardware and bus standard for electronics and data acquisition. Today, CAMAC is gradually being supplemented with other standards, due both to a desire for increased power and cost effectiveness. With these changes, it is necessary to reassess the role of electronics and data acquisition instrumentation in nuclear physics experiments. There are several opportunities for advancement in instrumentation which will significantly improve our ability to do physics, and there are several problems which can be identified which have cost the community much. Many of these issues were pointed out in the Electronics, Data Acquisition and Data Analysis Instrumentation (EDADAI) survey circulated by this subcommittee. Compilations of the results of the EDADAI survey are available from D. F. Geesaman and D. Balamuth.

III.2.2. ELECTRONICS

There is a wide variety of commercial electronics on the market, some of very high quality, which can meet the needs of many of the experimental efforts in Nuclear Physics. The inventory of approximately $18M in commercial electronics, spread over the groups which responded to the EDADAI survey, is testimony to this fact. Most of this inventory is in the NIM and CAMAC standards, which is flexible and useful for experiments with a modest number of detector channels. While most respondents in the survey feel that NIM and CAMAC will continue to be employed in the future, it is clear that fields that will mount experiments with very large numbers of channels (e.g., relativistic heavy ion physics) will need to move to other systems with higher bandwidth and density. There is already a move to FASTBUS and VME systems; however, it is not clear that digitization after long cable runs will be an acceptable solution for experiments where space and power are at a premium. One important difference between the university groups and the laboratory groups, evident from the EDADAI survey, is that most of the equipment purchased in either FASTBUS or VME is to be found at the laboratories. Indeed, only 0.3% of the inventory of the university groups is in either of these standards, whereas the corresponding number for the laboratory groups is 16%.

This fact raises the spectre of university groups which are unable to contribute meaningfully to modern detector systems because of the lack of in-house facilities in VME and FASTBUS. Such a situation, is clearly not indicative of the detector research and development foreseen by the 1983 NSAC Instrumentation Subcommittee with "vigorous university participation".

Another interesting fact which emerged from the EDADAI survey is the distribution of technical manpower for development and maintenance The total manpower/year listed in the survey is 61.8, of which 31.4 are concentrated at two national laboratories. The other responding institutions share the remainder, leading to an average of about 0.7 people/year per institution. If developmental effort is to be carried out in any broad-based way, this manpower problem needs to be addressed. This point has also been addressed in the 1983 report of this subcommittee.

The role of electronic pools is signficant in the field. About 2/3 of the respondents indicated that they use the pools; however, 2/3 of these cite inadequacies: outdated equipment, not enough equipment , etc.. It is clear that electronics pools represent an extremely cost-effective way to mount experiments at the labs. Not only can equipment be obtained on short notice (if it is available), but the technical support, useful for either setting up the equipment or maintaining it, is of inestimable value. Because the existence of pools has an effect on equipment purchases throughout the field, it would seem important to review the lab policies regarding the support of the pools and to encourage the expansion of their base wherever necessary.

The major challenge in electronics has moved from capability to cost effectiveness. In general, discrete component systems exist with the gain, noise levels and timing characteristics to match detector systems, but often at total costs of several thousand dollars per channel. Custom and semi-custom chip and circuit board design using large scale integration can and have reduced these costs to approximately ten dollars a channel. These technologies require significant technical expertise and startup costs, but appear to be the only way to mount future experiments in a cost effective manner. More nuclear physics groups must have the resources to take advantage of these technologies. As experiments grow in size, electronics design to meet the needs of individual experiments will become much more essential. The lack of experienced design personnel was consistently sited in the EDADAI survey as a major shortcoming, particularly for user groups.

There are several generic devices, such as high resolution time digitizers and analog to digital converters for which there is a large relatively unique demand in nuclear physics, but spread over many institutions.Means must be found to identify such products and stimulate commercial production.

III.2.3. DATA READ-OUT AND TRIGGERING

Several trends have evolved for data readout which change the requirements for a data acquisition system and highlight the need to move beyond CAMAC. New experiments (for example GAMMASPHERE or MEGA) envision total event rates and throughput up to a order of magnitude larger than that possible in present systems. This requires a much faster bus structure than CAMAC, much more intelligent triggers and front-end readout systems, higher throughput bus-bus interfaces and either higher throughput data recording devices or efficient on-line filtering (higher level triggering). FASTBUS and VME have both emerged as possible successors to CAMAC. Both systems have advantages and their supporters in the community. FASTBUS is a higher speed 32 bit bus with a well conceived multi-segment capability. Its larger physical size and power supplies make it well suited for high density applications. However, the hardware which is currently available is limited and there is a need of more sophisticated front-end intelligence. VME has a much larger commercial base (though not consistently interchangeable) and developed intelligence and software tools. But the expansion to multicrate, distributed-intelligence systems is not well defined.

It appears likely that, rather than adapting a single standard, commercialization will force the community to deal with three buses, CAMAC, FASTBUS and VME for the next ten years. Essentially all the groups surveyed foresaw extensive continued use of CAMAC. The choice of FASTBUS and VME has usually been made strictly on economic grounds, for example, where are the cheapest ADC per dollar. Here one sees the direct conflict of hardware costs versus system integration costs.

What is needed to make such mixed architecture systems viable are efficient bus to bus connections: readout controllers, buffers and software. In this area as in the other areas, the hardware costs of computing power are small, but the design effort in hardware-software integration, and the software efforts can be expensive. Once such connections exist, then a modular system will be able to include any of these data buses, and the prototype will have been developed for including new developments.

At the heart of the readout control is the trigger system. This is usually the most cost effective site to apply resources. To date, the technology involved has been fast electronics, memory lookup units and simple sequencers. Gains in the selectivity of the trigger reduce experiment dead-time, throughput requirements, recording media requirements, and analysis time. Constructing triggers with minimal biases, or at least, well understandable biases will always be a major source of effect in an experiment. Here again there are several tools which need to be expanded including larger and faster memory lookup units and faster reduced instruction set processers. At a higher level, it is now possible to include massive parallelism to partially analyze every event. This technology appears essential in the continuing push to extend studies of rare processes (for example MEGA).

III.2.4. ON-LINE COMPUTING AND DATA STORAGE

The cost of mainframe and microprocessor cpus have decreased substantially in the past five years. From the EDADAI survey, essentially all groups have recently upgraded their computing capability. In this section only the computing needs for data acquisition and monitoring will be considered. The substantial data analysis computing requirements are discussed in the next section. As the result of the improvement in bus speed and parallelism in the front-end, mainframe data acquisition computers are often no longer able to deal with the total event rate and throughput. At the most basic level, this is a bus limit, at least for UNIBUS or Q-BUS machines. Increasingly, much more CPU power is available in parallel front-ends (for example, DAPHNE) for analysis or sorting, and parallel data recording systems (through VME , for example) are being considered. In this environment the host mainframe(s) serve for control functions and monitoring. For these applications they are ideal. The well developed operating systems and advanced system tools make software development and applications much more efficient and user-friendly.

For several years, the 6250 BPI magnetic tape has been an effective standard for data storage. To date, no other media has developed which has the combination of capacity and throughput. It appears quite likely that one of the newer technologies such as helical scan tapes or VHS recording will soon match the throughput of conventional magnetic tape with an order of magnitude greater capacity. It is too early to forecast the appropriate standard for the next five years, but one is likely to emerge in the near future.

III.2.5. SOFTWARE DEVELOPMENT

In the past on-line software usually involved directing the data acquisition computer to read out the electronics, log the data to a storage media and perform on-line analysis. The functionality remains the same, but now the intelligence often is distributed over many subsystems: software for the trigger processer, readout controllers, parallel on-line analysis engines, media storage, histograming, graphics and centralized communications and message reporting. No longer can this usually be accomplished by a single multipurpose data acquisition system. It is straightforward to separate the analysis and graphics functions from the data readout and control, and excellent analysis packages have been developed which are used at several laboratories (for example: Q, XSYS, DAPHNE).

It is this type of modularity which offers the only hope of allowing data acquisition to follow advances in hardware without an excessive cost in software development. 30% of the groups in the EDADAI survey responded that their software investment at this time made it prohibitively expensive to consider change to more powerful systems. Front-end intelligence is one of the fastest moving areas in development, and it is unlikely to expect the technology to stabilize in the near future. Only if different front-ends (or analysis engines or programmable triggers) can be easily incorporated into existing structures will any but the largest experiments be able to take advantage of future improvements.

The concern of how to avoid duplicating software effort within the field was stressed in the 1983 Instrumentation subcommittee report. Some of the solutions are obvious: program in standard high level language (Fortran, C, Pascal), use code management systems with allow machine dependent features to be easily modified (PATCHY, HISTORIAN) , use standard subroutine libraries (CERNLIB, SLAC UGS) for utility subroutines rather than machine dependent language extensions. A more significant change in attitude is that documentation and support must be counted on for a system to be viably ported to other institutions. In this regard the Q system was a real success. It is now used by 34% of the groups responding to the survey. While this may in part be arise from the large LAMPF user community, it is also due to the existence of a commitment from Los Alamos to document, distribute and support Q. Such commitment for future systems should be encouraged and recognized by the funding agencies because of the enormous economies involved.

III.2.6. OTHER ISSUES

High Energy Physics has been the source of much of the new technology for Nuclear Physics in the past decade. An important example is the dependency on the High Energy Physics HEPNET network for remote login capability. High Energy Physics has a significant strategic advantage in developing new electronics and data acquisition tools. Namely, much of the effort is centralized in a few large facilities. This allows for significant economies with hardware and software development groups, sharing of needs and ideas, and de facto, if not explicit, standardization of hardware and software, yet enough unique experimental diversity to explore alternative directions. The importance of standardizing software, as exemplified by the heavily used CERNLIB package, in minimizing software effort and ensuring code portability between facilities cannot be overemphasized.

Nuclear physics has developed such standards and tools to a lesser extent. Indeed, there is a perceived failure of the nuclear physics community to encourage the development of state of the art components and systems to a production stage where the community can depend on their reliability. An example of a successful nuclear physics system is the microprogramable branch driver (MBD) which is used by over 17 groups even though it is now a quite dated product. It is still used because it does what it is supposed to do. The MBD has played a major role in the standardization that does exist in the field. Certainly successful commercialization of the products is desirable, but by no means necessary or sufficient to ensure the usefulness of a product.

Many nuclear physics experiments do not involve large data acquisition efforts. Often smaller scale experiments, or component testing for larger scale experiments require flexible, portable data acquisition systems and several groups have duplicated the effort in developing such systems. A pooling of this software and hardware capability is also important.

The 1983 Instrumentation Subcommittee identified the lack of qualified manpower in data acquisition hardware and software as a serious problem in the field. The level of complexity of acquisition systems has grown markedly since that time and manpower resources continue to limit the scope and effectiveness of experiments. As data acquisition and electronics issues continue to grow in the execution of experiments, it will be important to remember the need for skilled manpower in the training of students and the allocation of resources.

III.2.7. RECOMMENDATIONS

A. There is a serious need for increased access to technical manpower at all levels in both electronics and software and in design and support.

This is particularly important at universities where the technical capabilities of user groups has often not kept up with developments at accelerator laboratories. This shortage leads either to limiting the scope of projects which can be undertaken, inefficient use of physicists as engineers and technicians or often less reliable and more expensive end products.

B. Incentives must be created to make successful development projects widely available.

Production reliability and documentation must be considered as essential concerns in such projects and be adequately funded. Commercialization may be desirable but is not essential to ensuring that technology can be transferred within the field. One means to encourage this is to use attention to final technology transfer as a specific criterion in rating new proposals.

C. There needs to be increased standardization in data acquisition and electronics in nuclear physics.

Such standardization does not come simply by fiat. It will only occur if the community understands the large price it is paying for diversity, and can count on well documented and maintained products being available. This will probably only happen if data acquisition centers are funded whose responsibilities include the maintenance and support of useable products. The community must be willing to incur relatively small overhead costs for the establishment of such centers or for commercial packages to conserve the human effort. An effective data acquisition center would need to maintain significant device independence. This can only be done with a relatively host independent code management framework and a modular concept of data acquisition hardware and software. Despite the current overwhelming investment in Digital Equipment Corporation products, it would be a serious mistake to tie the community to one vendor. This does not imply that parts of data acquisition systems should not be tailored to individual products. In many cases, they must be to take advantage of unique capabilities. There is an important balance between the enormous gain in productivity that can be attained by adapting and conforming to standards and the significant advances which result from investigating alternative approaches. In general, the nuclear community has done too little of the former to have sufficient resources to effectively pursue the latter course in those cases where the potential for advances can be identified.

D. Increased communication within the field for electronics and data acquisition issues must continue to be encouraged. Also the ties with other research communities in this area should be strengthened.

This echoes the concern of the last instrumentation subcommittee and was consistently sited in the EDADAI survey responses. Funds must be available for travel and inovative efforts. The Computer Applications in Nuclear and Plasma Sciences IEEE Real Time conferences are widely appreciated. There is a widespread call for the pooling of information, talent and resources.

III.3. REPORT OF DATA ANALYSIS AND NETWORKING SUBCOMMITTEE

D. Balamuth(Chair), P. Braun-Munzinger, C. Gould, D. Geesaman, G. Young

III.3.1. SOFTWARE ISSUES

The enormous increases in event complexity which will accompany nuclear physics experiments in the 1990s will require substantial advances in both hardware and software capabilities for data analysis. Many of the hardware problems are addressed by the powerful multiprocessor systems now being developed (see below). Partly as a result of these important breakthroughs in hardware design, software has now become the rate-limiting step in analyzing the results of most nuclear physics experiments. This point is graphically illustrated by the results of a survey undertaken last summer jointly by the Electronics and Data Acquisition subcommittee and our group (hereafter referred to as "the survey.") The average age of a data analysis computer reported by the respondents was 3.1 years, reflecting the recent proliferation of 32-bit minis and workstations made possible by a combination of dramatically lower hardware prices and the recognition by the funding agencies that replacement of 10-year old systems was (and is) essential. The same survey also showed, however, that the exportable software in routine use (e.g. Q, XSYS) is for the most part much older. As a result, the software packages most widely used for data analysis are not able to take advantages of recent advances in hardware development, most notably massive parallelism.

Another interesting result from the survey is that what little professional programming assistance is available to the nuclear physics community is heavily concentrated in the area of data acquisition (and even there many respondents reported the level as inadequate.) In the area of data analysis, most of the programming is being done by physicists and students. While it is entirely appropriate that the physicists who conceive and execute an experiment should drive the analysis process, in the subcommittee's judgment there are real needs for professional assistance in the area of data analysis software which are not being met.

Note that this assistance can take many forms. An obvious one is reliance to the maximum extent possible on high quality commercially available software; this is particularly important for software whose applications go beyond nuclear physics, since then the substantial development costs can be spread over a larger community of users. Examples here include graphics packages, data base management systems, and software designed for industrial process control applications. To put the problem in perspective, the subcommittee believes that the total software costs will likely exceed the hardware costs over the life of a typical data analysis system within the next 5 years. Funding agencies need to allow for this in their planning and allocation decisions.

Greater reliance on commercial software will produce new demands for systems integration skills on the part of software professionals. There will be a high premium on knowing what is available, and on being able to provide the hooks and filters needed to adapt the available code to the task at hand. Not everything needed for data analysis is likely to be available commercially, of course. Even with massive parallelism, there will always be time-critical tasks whose performance can be enhanced by careful identification of the rate-limiting step(s) and optimization of the relevant code.

III.3.2. HARDWARE ISSUES

In 1983 this committee's predecessor recognized that the increasing complexity of nuclear physics experiments would require an increase of nearly two orders of magnitude in data analysis capability. Accordingly, it was recommended that parallel multiprocessor architectures, viewed as the only hope to achieve such an increase, be given high priority for funding. The five years which have passed since 1983 have witnessed the beginning of the fulfillment of this prophecy. The proceedings of the 1987 Real Time Data Acquisition Conference contain numerous descriptions of parallel processing systems. Specific implementations have included both the development of special purpose hardware and systems which rely on commercially available products such as VMEbus. There is no question that the bulk of the CPU cycles for the analysis of the most demanding nuclear physics experiments of the 1990s will be provided by parallel systems of both types.

Continued development of these systems should receive high priority for funding. In particular, attention should be paid to areas in which the needs of nuclear physics experiments may differ from those in other fields, e.g. high energy physics. As an example, analysis of data from a detector such as the proposed GAMMASPHERE will require hundreds of megabytes of memory which is accessible simultaneously by all processors in a multiprocessor system; duplication of histograms in each processor would be prohibitive since each 4K x 4K histogram requires 16 Mbytes, and many tens of histograms will be needed. This precludes architectures in which each processor is entirely self-contained, as is the case in the most widely used system developed for high energy physics (Fermilab ACP). In general, however, it is essential to make maximum effort to coordinate with related developments in fields such as high energy physics. There are cases, such as experiments proposed for RHICC, where the data analysis needs for nuclear physics and high energy physics are nearly indistinguishable, because the physics is nearly the same. In this context it is important to note that the nuclear physics component of any joint development effort must be sufficiently robust and well-funded to be able to ensure that adequate priority is given to the needs of nuclear physics.

An additional recommendation which links hardware and software concerns is that some standardization be achieved in the utilization of ultra high density recording media for event-mode data. The survey undertaken last summer shows that 6250 bpi magnetic tape is still used by the overwhelming majority of nuclear physics experiments. In the subcommittee's opinion the change to recording media capable of Gbyte storage is inevitable, and has already begun to take place. Prompt efforts to settle on a recording technology and to develop appropriate, shareable software could, if done in time, prevent the proliferation of multiple incompatible standards. Funds should be awarded competitively to groups willing to work on this problem, with the clear understanding that once a clearly optimum solution emerges it will be provided to all.

III.3.3. NETWORKING

The growth of group size and the increasing number of inter-institutional collaborations will clearly require that nuclear physicists make use of computer networking at an unprecedented level in the near future. Our survey showed that 96% of the respondents are already using BITNET for electronic mail. About 40% are using HEPnet as well. More than half of those surveyed are using the remote login capability of HEPnet, and most of the rest would like to have this capability. Present use of NSFnet is negligible among the respondents to the survey. Note that this latter point may reflect only the fact that the survey respondents were nearly all experimentalists. Very little supercomputer usage was reported in the survey; one of the principal focusses of NSFnet at present is to provide high speed access to supercomputers for users. The subcommittee recognizes that the general problem of providing high speed, high quality networking to the entire scientific community is receiving attention on a national level, and that NSFnet will play a central role in providing these services.

In the subcommittee's opinion, networking is one area where the model provided by our colleagues in high energy physics is appropriate for nuclear physics. Access to the services which are currently provided by HEPnet, i.e. moderate-speed communications, remote log-on, etc. are indispensable to successful research in nuclear science. The subcommittee understands that DOE has created a Nuclear Physics Panel on Computer Networking which is considering these issues. We support the goals suggested by the charge to that body, with the important exception that in our view the network must include the entire nuclear physics community, not just the portion supported by DOE. The subcommittee urges the funding agencies to develop a mechanism whereby access to high quality networking services be guaranteed to every practicing nuclear scientist, independent of the source of his or her support. Implementation of this recommendation will require coordination among the funding agencies in order to allocate resources and costs in a rational and effective way. This coordination and allocation should include the principle that agencies charged with the funding of nuclear physics should pay the fair share of use of common resources by nuclear scientists. For example, if participation in HEPnet is chosen as the mechanism to use, then some of the professionals at Fermilab who maintain the HEPnet system should be supported by the nuclear physics program and be responsible for ensuring that nuclear scientists make use of the network in an effective and efficient way.

III.3.4. RECOMMENDATIONS

We recommend that an effort be directed at software development which is comparable in scope (and will be comparable in cost) to the massive upgrading of data analysis hardware which has taken place over the past 5 years. Elements of such an effort should include:

1) Provision of funds to purchase high quality commercially available software, both for laboratories and for off-site users.
2) Provision of funds for additional software development personnel.To avoid duplication of effort, this assistance should be concentrated at institutions identified by competitive, peer-reviewed proposals. Sufficient funds should be provided to ensure the development, documentation, and standardization of software to the point where it is easily portable. In addition, money should be available to permit travel by the software developers

to consult with potential users and for users to visit the developers to provide feedback on needs and goals. One or more of these groups could also be charged with consideration of longer range issues, such as the possible adoption of operating systems that are truly hardware independent.

3) Creation of a database/software library maintained and updated by professionals, which contains information on the usage of commercially available and home-written software modules for data analysis in nuclear physics. This group needs to develop and circulate standards and, most importantly, design incentives for physicists to meet these standards. (Access to the system could be made contingent on agreeing to meet reasonable standards in newly written software, for example.) The group charged with creating and maintaining this database would obviously make maximum use of what already exists in the high energy physics community (e.g. CERN) to avoid duplication of effort.

We further recommend that:

i)the funding agencies develop a funding mechanism whereby access to an appropriate computer network is provided to every practicing nuclear scientist.

ii) continued development of massively parallel systems for data analysis should receive high priority for support

hardware and software standards be developed for ultrahigh density storage media such as optical disks, helical scan tapes etc.

III.4. REPORT OF THE SUBCOMMITTEE ON SOURCES FOR HIGH CHARGE STATE IONS, POLARIZED IONS AND POLARIZED ELECTRONS

J. Alonso, D. Geesaman, C. Gossett, W. Haeberli (Chair)

Ion sources, both for high charge state heavy ions and for polarized beams of ions and electrons, will play a crucial role in future research programs in nuclear physics. Very good performance for these types of sources has been demonstrated in the Laboratory, and in currently operating accelerators. However much more development effort is required to improve further their performance and reliability.

Resources are urgently needed for dedicated development efforts for improved performance of these ion sources. The goals of these efforts would be to further optimize performance, to improve reliability, and to engineer the technology for easy replication of sources.

The method of stimulating this development should be to provide adequate funds for the centers of excellence in these techniques, currently several small laboratory and university groups, to allow them to continue development efforts towards the above-mentioned goals. Also, strong encouragement of these groups should be given to develop industrial partners in their endeavors, for instance through SBIR programs, to contribute to engineering design solidification.

The performance of accelerators depends critically on the capabilities of the ion source. Often the ion source limits the performance of the accelerator system, and improved source output yields significant savings in operating cost of the accelerator, and allows new types of experiments not presently feasible. The subcommittee identified three areas where development of ion sources promises important advances.

III.4.1. HIGH CHARGE STATE IONS

Effective acceleration of heavy ions in cyclotrons, synchrotrons or linear accelerators requires injection of high charge state ions. Such ions can be produced by acceleration of low charge state ions, followed by removal ("stripping") of additional electrons when the ions pass through a foil. Examples of this method are (a) tandem accelerators, injecting multiply charged heavy ions into linear accelerators at a number of laboratories (ANL, U of Washington, Stony Brook, Florida State) and into a synchrotron (BNL) and (b) preacceleration of low charge state ions in a cyclotron, followed by stripping before injection into a second cyclotron (e.g. Ganil). Alternatively, high charge state ions can be produced directly in certain types of ion sources such as the ECR (electron cyclotron resonance) source. ECR sources are in use at three heavy ion cyclotrons in the US (LBL, MSU, Texas A&M). At ANL, the tandem injector of the linear accelerator (ATLAS) is presently being replaced by an ECR source combined with a low-velocity superconducting linear accelerator stage. The design of current ECR sources is based on a highly successful source developed at Grenoble about a decade ago. Electrons and ions are confined in a magnetic field configuration produced by combining an axial field from solenoids with a multipole field, either hexapole or octupole. For ionization of gases, two stages are used in succession. Electrons in the trap are heated by a microwave field of 6 to 16 GHz. The required microwave power is of the order 1kW.

Solid materials are ionized by extending a wire of the material into the plasma. ECR sources are relatively simple and compact. They can supply microamperes of multicharged heavy ions (e.g. Ar^{14+}, Cu^{12+}, Kr^{20+}, Bi^{29+}) to an accelerator, and can often operate for weeks without interruption. Higher charge states yet have been obtained with Electron Beam Ion Sources (EBIS), first proposed and developed at the USSR Joint Institute for Nuclear Research. In modern EBIS sources, several amperes of electrons are injected into a long (~1m) superconducting solenoid in which the electron beam is compressed radially to produce a beam density of some 10^3 A/cm^2. Completely ionized Ar has been produced, as well as e.g. Kr^{34+} and Xe^{44+}. The principal disadvantage of the EBIS is, besides considerable technical complication, the low output, which is typically 10^{10} to 10^{11} elementary charges per pulse for light and medium weight elements, and of the order 10^9 elementary charges for heavy elements. In the US the development of EBIS is being pursued at this time for atomic physics studies rather than as a potential accelerator ion source. The benefit of ion source development is clearly illustrated by the performance of the Michigan State superconducting cyclotron, where installation of an ECR source instead of the earlier planned PIG source roughly doubled the beam energy for the heavier ions, with great improvement in intensity and reliability. The development of ECR sources has also permitted a change in operating philosophy in that modest further increases in ECR charge state will permit the larger cyclotron to be operated in a stand-alone mode, thus freeing the K500 injector cyclotron to be used as a separate machine on it's own. In fact, with an improved ECR source, for very heavy ions the energy of the K800 cyclotron alone will be at least twice as large as was envisioned in 1976 for the combined K500/K800 cyclotrons. Similarly, at ANL, installation of the ECR-based injection system will double the beam energy of heavy ions and increase the beam intensity by about a factor 100.

III.4.2. POLARIZED IONS

A large fraction of present light ion reaction studies make use of polarized beams of protons or deuterons. These beams are used, in addition, to provide polarized fast neutrons by polarization transfer reactions. Polarized beams have played a special role in the study of basic symmetries (parity non-conservation, charge-symmetry breaking). In the US, polarized beams are supplied by tandem accelerators (Notre Dame, TUNL, Washington, Wisconsin), by the LAMPF linear accelerator and by the IUCF cyclotron. In addition the Brookhaven AGS is equipped with a polarized-ion source. Polarized $^{6,7}Li$ beams are available at two tandems (Wisconsin, Florida State). US physicists also are making use of the rather intense beams of polarized protons and secondary beams of polarized neutrons at TRIUMF. Most US laboratories have not kept pace with the improved polarized beam intensities which have become available abroad (Europe, USSR, Japan). At KEK, intense beams of polarized protons have been produced by charge exchange of H^+ ions in Na vapor polarized by optical pumping. This scheme has been further improved in the USSR by use of multiple charge exchange to yield a record beam current of about 1mA in a pulsed mode. An optically pumped source for LAMPF is presently under development, and a source of the same type has been installed at TRIUMF. However, the degree of polarization (60%) provided by these devices is significantly lower than the polarization that is achieved with atomic-beam sources ($P = 90\%$). Ion sources based on the atomic-beam method (Stern-Gerlach separation of spin states in a inhomogeneous magnetic field) are preferred if the source is to supply deuteron beams as well as proton beams, since these sources allow more flexibility in spin state selection (RF transitions between hyperfine states) than do optically-pumped sources. Steady progress has been made during the last decade in the efficiency of ionizing the polarized neutral atoms. The best conventional electron-bombardment ionizers produce about 100μA polarized positive ions for injection into cyclotrons. At PSI (Switzerland) polarized beam intensity on target of 5μA has been maintained for long periods of time. It has been proposed that significantly higher ionization efficiency may be achieved with ECR ionizers, but it was questionable whether the polarization would survive in the intense RF field of the ionizer. Last year extraction of a polarized beam from an ECR ionizer was demonstrated for the first time in a pilot experiment at PSI. Negative polarized ions were first produced to meet the need of tandem accelerators, but negative ions are also in use at larger facilities (LAMPF, TRIUMF, AGS). Stripping of negative ions in a thin foil to produce positive ions allows efficient extraction from cyclotrons (TRIUMF) and permits multiturn injection (beam stacking) in synchrotrons (AGS). At the AGS, negative polarized ions are produced by the method developed at Wisconsin, in which a polarized atomic beam of hydrogen atoms is bombarded with an intense beam of fast, neutral Cs atoms, producing negative ions by electron transfer from Cs to H. Pulsed operation of atomic beam and Cs beam permits beam currents of 30μA or more for injection into the AGS. The same ionization method is applied in the new polarized ion source installed at the University of Washington tandem accelerator. A new ion source is also being tested, prior to installation, at the TUNL tandem laboratory. The novel aspect of this source is the use of an ECR ionizer, followed by charge exchange in alkali vapor to form negative ions. First tests have produced negative ion currents in d.c. operation in excess of 10μA. Beam polarization and beam emittance have not yet been measured, but if they meet expectations this will become the method of choice for accelerators requiring d.c. beam of polarized negative hydrogen and deuterium ions. There appears to be no long term development programs for polarized ion sources in the US, except for an activity at the Brookhaven AGS which explores the use of intense cold atomic beams and of new ionization methods (ring magnetron). All other source development occurs in connection with construction projects, and by necessity development stops as soon as the device is performing well enough to be installed on the machine.

III.4.3. POLARIZED ELECTRONS

Experiments with beams of polarized electrons will be a very important part of electronuclear physics of the next decade. About half of the experimental effort proposed for CEBAF will require polarized electrons. Also experiments with polarized electrons are in progress at BATES. The importance of experiments with polarized electron beams was beautifully illustrated by the parity violation experiments at SLAC. Many of the next generation experiments will require polarized targets as well as polarized electron beams. The most frequent applications of polarized electrons are in the field of atomic physics and solid state physics. In fact, the development of the photoemission source originated in the solid state group at ETH (Switzerland). Photoemission from GaAs induced by circularly polarized light yields copious amounts of electrons (of the order mA) with polarization 30-40%. The sign of polarization is readily reversed by reversing the circular polarization of the incident light. Applications in nuclear and high energy physics require a significantly higher polarization if the interesting effects are to be measured with sufficient accuracy in a reasonable length of time (i.e. weeks rather than months). Low polarization can not be compensated by higher beam intensity, because either the target or the accelerator impose intensity limits, particularly for polarized targets which radiation damage rapidly. Thus, the next generation electronuclear physics experiments will need sources yielding the highest possible polarization, a high degree of freedom from systematic effects from polarization reversal, and the capability to deliver high currents for periods of time matched to the experiments, i.e. many hundreds of hours. As part of an effort to increase the polarization of electrons from photoemission sources, the question has been studied why the electron polarization from GaAs photoemitters falls short of the value of -50% expected theoretically for the transition between the $p_{3/2}$ valence band and the $s_{1/2}$ conduction band. The conjecture that electrons loose part of their polarization in diffussing from the interior of the semiconductor to the surface was confirmed some years ago at Julich, where it was shown that a very thin sample (<1μm) yields a polarization of 49%. More recently, a number of samples of different thicknesses were prepared by molecular beam epitaxy and were tested by a Illinois, Wisconsin, SLAC, CEBAF collaboration. The results showed that any thickness less than 0.4μm will give an electron polarization very near the theoretical limit of 50%. Current interest centers on improving the polarization beyond the limit imposed by the degeneracy at the top of the valence band. Several ways have been proposed to accomplish this, including application of mechanical stress, growth of multilayer semiconductor heterostructures, and the use of materials in which the degeneracy is naturally absent. Measurements on the polarization of conduction band electrons in multilayers (GaAs - AlGaAs) by means of photoluminescense are promising, as are studies of GaAs strained by growing thin layers or Si (4% lattice mismatch). However, none of these samples have been prepared and tested as photoemitters. There also are promising candidates among materials for which the valence band degeneracy is absent, such as the so-called chalcopyrites (e.g. $ZnGeAs_2$ or $CdSiAs_2$). Besides crystal growth, problems of preparation of a photoemitting surfaces must be solved. Some work in this direction at the University of Illinois is presently funded by CEBAF. The problems are also being pursued by groups in Europe and Japan. Low intensity beams of (~1μA) of highly polarized electrons (~80%) have been produced by means of optical pumping of ^3He atoms, producing ^3He atoms in the metastable ^3S state which are highly polarized in electron spin. Subsequently the metastable atoms are ionized by collisions with a gas such as CO_2. This method was developed at Rice University as a byproduct of research on the spin dependence in atomic interactions. Recently, CEBAF has funded a small joint feasibility study between the University of Illinois and Rice University to determine whether the method may lend itself to the required intensity improvement of several orders of magnitude.

III.4.4. RECOMMENDATIONS

ECR and EBIS technologies are both relatively young and thus offer opportunities for improvement. For ECR sources the anticipated increase in charge state with increase in microwave frequency from 10GHz to 16GHz has been demonstrated. Further increase in frequency is a promising area of development but hampered by increasing cost of the high power microwave equipment. Increases can also result from unexpected discoveries, such as the observed benefit derived from gas mixtures instead of pure gases. For pulsed operation (e.g. injection into RHIC) injection schemes based on different combinations of preaccelerators and ion sources may be useful as an alternative to injection from large tandem accelerators.

Systematic development work on optically pumped sources and on ECR ionizers for polarized atomic beams would be particularly promising. One of the beneficiaries of the development of more intense sources would be the IUCF installation, where exploitation of the new cooler ring urgently requires an upgrade of the present polarized ion source.

The present modest US investment in the development of polarized electron sources is insufficient to provide polarized electron beams of the quality required for the future program in electronuclear physics. A comprehensive program of pilot studies is needed in order to explore different promising approaches.

III.5. REPORT OF THE SUBCOMMITTEE ON INTERNAL TARGETS AND POLARIZED INTERNAL AND EXTERNAL TARGETS

J. Alonso, C. Gossett, C. Gould, R. Redwine (Chair), A. Sandorfi

The progress on the development of polarized targets and internal targets in general over the past few years has been a real success story for nuclear physics. Several of the most significant developments have taken place at nuclear laboratories with high-quality reputations in work of this type. These developments have occurred at a time when improvements in accelerator capabilities are either now available or expected within a few years, in particular at IUCF, Bates, and CEBAF. We are thus presented with an opportunity to push our advantage in such developments and to reap the physics benefits of the previous investments in such research.

Internal targets are of crucial importance to the utilization of the storage rings and stretcher rings which are now becoming available to nuclear scientists. With the appropriate internal targets, certain types of experiments, such as those involving the detection of massive recoil particles, will become possible for the first time. One particularly important parameter in experiments involving internal targets is that of polarization. Indeed, it is expected that experiments using polarized beams and targets will take place on storage rings and stretcher rings during the next several years. Furthermore, polarized external targets continue to play an important role in nuclear physics experiments. Some of the same techniques that are used to produce polarized internal targets have close analogues with those used to produce polarized external targets.

One hardly needs to be reminded that the use of polarization observables has been of great importance to nuclear physics. The essential elements of reactions are often only exposed when one looks at such observables. It is useful to remember that in the Report of the 1983 NSAC Instrumentation Subcommittee, one of the 5 main recommendations was " . . . a few development programs with the objective of providing polarized nuclear targets with high polarization and low sensitivity to radiation damage." It is gratifying that such development programs have indeed gone ahead and the field is now at the point of being able to take advantage of the developed technologies (see below). In this report we try to describe the opportunities that now exist and the resources which are needed to take advantage of them.

III.5.1 CURRENT PROJECTS IN THE UNITED STATES

A. Unpolarized Internal Targets

Internal targets have become of increasing importance for high energy physics and nuclear physics since the development of storage rings and stretcher rings. Most such targets have consisted of gas jets. This is a technology which has had a number of years of development, and which is now being taken into nuclear physics labs which have appropriate beams. For example, IUCF now has an operational gas jet target for Cooler experiments. It typically works for diatomic gases, such as H2, D2, N2, etc., and for Ar. The density is about 10E14 atoms/cm2. IUCF also is attempting to use a dust target for some experiments. This will have the advantage of having a smaller effect on the Cooler vacuum, but the disadvantage of not being a pure target because of the carrier gas. The severity of this disadvantage is now under investigation.

Internal targets are also used for diagnostic purposes in various accelerators. For example, fiber targets are used to measure beam profiles and in some cases to check the polarization of beams during tuneup.

B. Polarized Internal Targets

This is an area of rapid development. In anticipation especially of the opportunity to perform precision measurements of electromagnetic properties of nucleons and nuclei, a number of groups have been making excellent progress on target development. The most popular targets so far are hydrogen, deuterium, and ^{3}He. The Argonne group is developing a source for polarized hydrogen and deuterium using the method of spin-exchange optical pumping. The polarized source would then be used for injection into a storage cell for use in an electron ring. The group, in collaboration with the group at Novosibirsk, has recently demonstrated the feasibility of using such a storage cell. A very important possible future use of this technique would be for measurements of the proton and neutron spin-structure functions at HERA. The technique clearly also has promise for use in other rings, such as Bates and IUCF. The Wisconsin group has been working on the development of polarized proton and deuterium targets appropriate for internal use by using the technique of storage of the beams produced in conventional polarized atomic beam sources. The feasibility of such storage cells was demonstrated several years ago by this group. One of the proposed uses of the Wisconsin cells would be to polarize the circulating antiproton beam in the antiproton ring at LEAR by passing the beam through the polarized proton target and taking advantage of the spin-selective attenuation of the antiprotons.

Recent progess in polarizing ^{3}He gas has produced a lot of excitement about several future experiments. Much of this excitement is based on the picture that a polarized ^{3}He nucleus is in some ways like a polarized neutron, as in the simple shell model the spin of the nucleus comes only from the spin of the neutron. The Caltech group uses the method of optical pumping of metastables to polarize ^{3}He atoms in a Pyrex cell. The cell is connected by a capillary to a copper cell which can then be used for external target experiments. They anticipate that it should be possible to construct targets of 50% polarization with foil windows or windowless targets for internal beams. This technique is viewed as especially promising for internal beam experiments at facilities such as BATES and HERA. Groups at MIT and at Wisconsin are also pursuing polarized ^{3}He targets using the same technique as that at Caltech. An alternative approach for polarizing ^{3}He has been developed at Princeton. In this approach Rb is optically pumped and then allowed to spin-exchange with ^{3}He. This technique seems capable of quite high densities for external beam experiments; its promise for internal beam experiments is less clear, but is under investigation. Other nuclei which appear promising for polarized internal targets are mostly the alkalis.

C. Polarized External Targets

Significant efforts have gone into providing polarized external targets for a variety of nuclear physics experiments over the past several years. These include the polarized proton target at IUCF, used so far for an experiment to measure charge-symmetry-breaking in n-p scattering. This target consists of an yttrium ethyl sulphate sample at 0.5 K in a field of 10 kG, and will soon be available for other experiments. At LANL a number of polarized nuclear targets have been used for a variety of experiments. For example, proton and deuteron targets using the technique of dynamic nuclear polarization (DNP) have been used for N-N scattering experiments. More recently, a ^{13}C target has been constructed for the study of pion-nucleus scattering and proton-nucleus scattering.The LANSCE facility has employed a polarized proton target (using a lanthanum magnesium nitrate crystal) to produce a polarized epithermal neutron beam for studies of parity and time reversal violations. At TUNL polarized targets of a variety of nuclei have been achieved using brute force methods (very high field, very low temperature) for studies of the spin-spin dependence in neutron cross sections. As a final example, the nuclear orientation facility at ORNL is used to study decay schemes of short-lived nuclei implanted directly into an orienting environment.

There are a number of development projects underway to provide additional capabilities of polarized external targets. These include a project at TUNL to build a solid 3He target for neutron-induced reactions. At LANL there are plans to replace the old LMN polarizer with a dynamically-pumped alcohol system. Additional projects at TUNL, LANL, and U. Texas are underway to build polarized and aligned targets for nuclear physics research.

A continuing problem in many of the polarized targets in use or under consideration is that of radiation damage. For many experiments, especially those involving high-current primary beams of charged particles, the need for radiation-resistant polarized targets remains critical.

III.5.2. EFFORTS OUTSIDE THE UNITED STATES

It is not our intention to produce a comprehensive list of internal target and polarized external target projects outside the United States. However, we believe that it is appropriate to place in context the efforts in the United States, and to that end we will mention some of the competition.

Internal gas jet targets exist at a number of laboratories. Recently the emphasis has been on polarized gas jets. There are efforts underway at LEAR and at Novosibirsk to build polarized H jet targets. LEAR is also building a deuterium gas jet (unpolarized). We mentioned above the collaboration between Argonne and Novosibirsk to produce a polarized deuterium gas cell for internal target work. Heavier gas jets include a project at Frascati to build an Ar jet target.

External polarized targets have often had the disadvantage of being complex. Examples of this include the deuterated butanol targets at TRIUMF and at PSI for π-d and other studies and the NH_3/ND_3 targets at Bonn. Mainz is now in the process of building a target similar to the Bonn target. While the complexity of the target does pose problems for many experiments, one should remember that in many cases this has been the only way to obtain the required degree of polarization and density. In many of these technologies, efforts abroad have been ahead of those in the United States.

It is clear that developments in internal targets and polarized external targets are occuring at many laboratories around the world. The physics opportunities presented by storage and stretcher rings and by polarization observables are obvious, and in many cases will be available first to those who implement available technologies for appropriate targets.

III.5.3. GENERAL COMMENTS

There are some very important physics opportunities associated with polarized external targets and both polarized and unpolarized internal targets. One often thinks of many of these in connection with electron machines, but in fact the opportunities span much of nuclear physics. We are enthusiastic about taking advantage of these opportunities.

In the course of our investigations and discussions we have heard a number of specific requests for additional funding to begin, speed up, or complete a particular project involving polarized targets or internal targets. Essentially all of these requests have seemed to us to have merit. To pick an example of one internal target and one external target project, we can mention the new initiative at MIT to provide internal targets for the stretcher ring at Bates and the need at LANSCE to replace the outdated proton target for production of epithermal polarized neutron beams. However, there are other projects of roughly equal merit as well. The important point is that with a relatively small amount of resources one can produce significant physics impact.

III.5.4. RECOMMENDATIONS

1. In general, our field has impressively demonstrated techniques for developing and constructing polarized targets and internal targets. With the new opportunites at IUCF, Bates, and CEBAF, it is critical that developments of such targets be carried through to working, efficient instruments. Sufficient resources must be made available for this second, sometimes less glamorous phase of such R&D programs.

2. Priority should be given to continuing R&D projects in this field. We recognize that it is sometimes easier to provide resources for specific experiments than for general development projects. However, we believe that high-quality research and development of the type discussed here should be given priority in funding decisions.

III.6. REPORT OF THE SUBCOMMITTEE ON ELECTROMAGNETIC FACILITIES

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III.6.1. INTRODUCTION

The main theme of electromagnetic nuclear physics is the precision study of the properties of the nuclear many-body system and the structure of the nuclear constituents. In the U.S., several facilities are presently available, under construction, or planned for the experimental investigation of these problems.

Facility	E_{max} [GeV]	duty-cycle [%]	completion
MIT Bates (linear accelerator)	1	1	1974
SLAC (NPAS)	6	0.03	1985
BNL LEGS (photon beam)	0.4	10-80	1988
MIT Bates (South Hall Ring)	1	$\geq$ 85	1992
CEBAF	4	100	1994
SLAC PEP (internal target)	15		?

Note that there is also considerable activity in Europe. New accelerator facilities are coming into operation in The Netherlands (830 MeV stretcher/storage ring at NIKHEF-K) and in W.-Germany (840 MeV Mainz microtron, 3.5 GeV stretcher ring at Bonn). Plans are being developed for new facilities in Italy and in France (a 2-3 GeV superconducting accelerator at Saclay to replace the ALS).

Two main trends in experimental techniques at electron accelerators can be distinguished:

1) The experiments concentrate more and more on relatively small (but important) physical effects that are more easily accessible via interference effects. Measurements of this type may require the use of polarized beams, polarized targets, or the measurement of the ejectile polarization. Interference effects between the transverse and the longitudinal component of the virtual photon are responsible for the small Φ-modulation of the coincidence cross section in (e,e′X) reactions that can be measured by detecting the reaction products out of the scattering plane (out-of-plane measurements). Since the effects are generally small, the main problem is the development of experimental techniques (both procedures and instrumentation) to keep systematic errors under control.

2) The advent of high duty-cycle accelerators will give a dramatic boost to particle detection systems that are limited in instantaneous luminosity. This includes non-magnetic detectors in close proximity to the target and large acceptance magnetic spectrometers. The main experimental challenge is to understand the origin of the luminosity limitation (based on a detailed knowledge of the radiation environment) and to improve the performance of these detectors (resolution, coverage, and luminosity).

The following report will give a brief description of the facilities in electromagnetic nuclear physics and the major instrumentation projects. A discussion of the necessary research and development for detector components will follow.

III.6.2. ELECTROMAGNETIC FACILITIES

i) MIT Bates linear accelerator
The MIT Bates linear accelerator delivers electron beams with 1% duty factor up to 1 GeV energy, at average currents of up to 50 μA.There are 4 experimental areas in use:
a) the north hall with the high resolution spectrometer ELSSY, b) the Z line (the parity experiment is located there now) c) beam line B (with the 3 magnetic spectrometers MEPS, OHIPS, and Bigbite), and d) beam line C which can be run in the low-flux or high-flux pure photon mode (Bigbite and other smaller setups).The photon line will be compromised at least somewhat by the stretcher ring installation.

The South Hall Stretcher Ring will provide an extracted beam with a duty factor of about 85%. The beam can be put into line B right away and into other areas with additional resources. An internal target facility will be an important part of the stretcher ring.

ii) SLAC NPAS
The Nuclear Physics At SLAC program uses the downstream sectors of the SLAC linear accelerator to provide electrons up to 6 GeV. With the new high-power klystrons, 2.5 μsec long pulses with peak currents of 50 mA are available. The standard instrumentation of End Station A (magnetic spectrometers with maximum momenta of 8 and 1.6 GeV/c) can be used for experiments.

iii) BNL LEGS
The Laser-Electron-Gamma-Source (LEGS) at the Brookhaven National Laboratory will produce photon beams up to 420 MeV by backscattering laser light from a 2.5-2.8 GeV electron storage ring. The gamma-ray flux is 10**7/sec, and their energy is determined to 5 MeV by tagging in a spectrometer with a 130 MeV/c momentum bite. The photons are almost 100% (linearly or circularly) polarized; the polarization state can be flipped rapidly. One high-resolution large-solid-angle gamma-ray spectrometer for measuring scattering or neutral-pion production is nearly complete, and additional detectors will be requested.

iv) CEBAF
The Continuous Electron Beam Accelerator Facility (CEBAF) is presently under construction in Newport News, Virginia. It is based on two parallel superconducting electron accelerators joined by recirculator arcs. Electron beams with up to 4 GeV energy, 100% duty-cycle, an energy spread of less than 10^{-4}, and a maximum current of up to 200 μA can be used simultaneously for scattering experiments in three end stations.

The three experimental areas will house complementary experimental equipment: two high-resolution magnetic spectrometers in Hall A, a large acceptance magnetic spectrometer in Hall B, and a variety of instruments initiated and mounted by users in Hall C are planned at present.

III.6.3. PLANS FOR MAJOR INSTRUMENTATION PROJECTS

i) High Resolution Spectrometers for CEBAF

CEBAF's high quality beam facilitates the performance of high resolution coincidence measurements, in particular (e,e'p), spanning a broad kinematical range. For that purpose, high resolution magnetic spectrometers are required. The present plan calls for a pair of identical 4 GeV/c spectrometers each with a solid angle of about 8 msr, momentum acceptance of 10%, and a momentum resolution of $5*10^{-5}$ (Fwhm).

The proposed solution is a vertically bending QQDQ design which relies on a pair of quadrupoles followed by a dipole magnet with focusing entrance and exit faces. Additional focusing is introduced through the use of a field gradient in the dipole. The required field strengths can be reached with iron-dominated, normal-conducting magnetic elements.

ii) Large Acceptance Spectrometer at CEBAF

A large acceptance detector is planned for the study of reactions with several particles in the final state and for experiments in which only limited luminosity can be utilized (e.g. tagged photon beam experiments, polarized solid state or gaseous targets).

The proposed solution is a magnetic multi-gap spectrometer based on a large iron-free toroid with six superconducting coils. The particle detection system consists of drift chambers to determine the tracks of charged particles, scintillation counters for the trigger and for time-of-flight, and shower counters to identify electrons and detect photons. The expected momentum resolution is less than 0.5 % [Fwhm] for momenta up to 4 GeV/c; the detector should be able to operate at a maximum luminosity of 10^{34} $cm^{-2}sec^{-1}$

iii) Out-of-plane Spectrometry

In electron scattering experiments, the detection of coincident hadrons out of the plane defined by incident and outgoing electron ('out-of- plane') allows the measurement of small but interesting pieces of the scattering cross section. Therefore, out-of-plane detection systems have become increasingly important for the research programs of electron accelerators.

A significant research and development effort is called for to study (e.g. through Monte Carlo simulation) the systematic errors introduced by different out-of-plane detection schemes and to explore the design of large solid angle spectrometers (e.g. superconducting symmetric multi-gap toroids).

iv) Improved Instrumentation for the Bates External and Internal Beams

High-duty-factor operation at the Bates accelerator should be accompanied by improvements of the line B spectrometers. In addition to upgrades of the MEPS and OHIPS (installation of a focal plane polarimeter) spectrometers, there is an effort underway to provide out-of-plane spectrometers. To make full use of the potential of the South Hall Ring, internal (polarized and unpolarized) targets have to be implemented. Polarized targets of great current interest include hydrogen, deuterium, ^{3}He, and alkalis. There is work going on at a variety of laboratories on such targets. Resources must be made available to implement the technology in a timely, professional way. Detectors that have been discussed for internal target experiments include magnetic spectrometers (at least one of the line B spectrometers, Bigbite, can be moved to line C), large-solid-angle spectrometers, recoil spectrometers, toroidal spectrometers, and out-of-plane spectrometers.

v) An Internal Target Facility for PEP

An internal target facility at the PEP storage ring at SLAC has been proposed to study multi-particle final states in electron scattering reactions on nucleons and nuclei. The PEP kinematical range will allow the study of the x-scaling regime, where virtual photons and quarks couple in a point-like way. One of the main themes of the proposal is the study of quark propagation and hadronization, using nuclei as a laboratory to measure the formation length and quark-nucleon cross section.

The facility would consist of a gas jet target, a forward magnetic spectrometer with >800 msr solid angle for the detection of electrons, hadrons, and photons, and arrays of CsI, silicon and scintillation counters around the target suitable for detecting low energy neutrons, protons, and fragments from the decay of the spectator nucleus.

vi) Instrumentation for the LEGS Facility

Elastic photon scattering and neutral-pion photoproduction can be used to study the deformations of nucleons and the polarizabilities of nucleons and pions. High-resolution large-solid-angle photon spectrometers are needed, particularly for photon scattering where the cross sections are small. One such gamma-ray spectrometer is under construction. Two additional spectrometers are being considered, as well as an array of low-energy photon detectors which would allow simultaneous measurements of neutral-pion production and elastic scattering.

The scattering of circularly-polarized photons off polarized targets could be used to extract helicity amplitudes. A particularly attractive target is being developed by a group at the University of Syracuse who have produced ortho-deuterium, either liquid or solid, and HD ice, in which the polarization of the H and the D can be varied independently, thus making an excellent neutron spin target.

vii) Instrumentation to Measure Spin-dependent Structure Functions at HERA

A collaboration has formed to pursue measurements of deep-inelastic spin-dependent structure functions at HERA. These structure functions contain the information on how the spin of the nucleon is carried by the fundamental constituents, quarks and gluons. Recent results from CERN on the proton suggest that either the strange quarks or the gluons (or both) play a much larger role in the spin structure of the proton than expected. HERA offers the possibility of reducing the uncertainties in the proton structure functions and obtaining data of comparable precision on the neutron.

The experiment would utilize polarized gas targets in storage rings. The detection system must cover the angular range $40 < \theta < 200$ mrad and the momentum range 5-30 GeV/c for the scattered electrons. Electron identification will be accomplished by a combination of a shower counter and a transition-radiation detector. The construction of this detection system will require funds on the order of $6M, of which about half is expected from the US collaborators.

III.6.4. R&D FOR DETECTOR COMPONENTS

i) Luminosity Limitations for Open Detector Systems

In electromagnetic nuclear physics, the need for detectors covering a large fraction of 4 π, and detectors with an open geometry for neutron or photon detection has become evident. The statistical significance of the measurements will depend critically on the maximum luminosity that these devices will be able to tolerate. The performance of detectors with open geometries (direct view of the target) depends on the background situation. In an intense high-energy electron beam, the main sources of background are low energy electrons and photons produced via electromagnetic processes. The yield depends on target material and geometry. The response of the detector to background particles depends on the experimental arrangement.

While some of these aspects can be simulated using Monte Carlo codes (EGS, GEANT), others need to be studied under realistic experimental conditions both at existing electron accelerators and at higher energy machines in the future. A concerted R&D effort will be required to understand the limitations and optimize the running conditions for these detectors.

ii) Neutron Detection Systems.

At electron accelerators, two experimental techniques should be applicable to neutron detection and energy determination: time-of-flight and proton recoil detection. For a resolution of the order of 5 MeV, neutron time-of-flight systems such as those in use at IUCF or the new NTOF facility at LAMPF will probably be suitable for neutron energies up to a few hundred MeV. Higher resolution at reduced efficiency (10^{-4}) can be achieved by using a scintillator as an active converter and detecting the recoiling proton in a magnetic spectrometer. A system of this type has been developed at the Bates accelerator for (γ,n) studies. For $(e,e'n)$ reactions, a pair of high resolution spectrometers will be required to achieve better than 1 MeV overall energy resolution for $E_n >$ 300 MeV.

R&D is required to determine the operating conditions for these methods in the background environment of an electron accelerator.

iii) High-Energy Gamma-Ray and Neutral-Meson Detectors

For the detection of high-energy gamma rays (0.1 to 1.0 GeV) from (γ,γ) or $(e,e'\gamma)$ reactions on nuclei in the region of the baryon resonances, large solid angles (several hundred msr) and good energy resolution (1-2 %) are needed.

The resolution of a photon detector based on scintillating material is largely determined by size and uniformity of the detector volume. R&D to reduce the cost of scintillating materials and to eliminate non-uniformities (or, more likely, to learn how to cope with their presence) is needed.

Present neutral-pion detectors at LAMPF and Bates have fairly good energy resolution and a modest efficiency-solid-angle product. R&D will be needed to significantly increase efficiency and solid angle, and to improve resolution in the next generation of detectors for photonuclear reactions.

iv) Non-magnetic Detectors for Charged Particles

Non-magnetic devices are not only indispensable for detection of neutral particles, but also cost effective for charged particle detection. Two types of detectors are currently in use: scintillation and solid state detectors.

Scintillators with their fast response are the principal choice for neutral particle detection in a high flux environments. Large acceptances in both solid angle and momentum can be obtained. Protons between 30 and 250 MeV are identified and analyzed at NIKHEF at several

MHz rates in the vicinity of a mA (peak) electron beam (the resolution is about 5 MeV at 70 MeV).

Solid state detectors offer excellent energy resolution for charged particles. Because of their slow response, electron beam currents are typically limited to 30 μA (peak). Resolutions around 100 keV are obtained with pulse widths of 200 nsec.

These instruments may become competitive with magnetic spectrometers. However, improvements in resolution, shielding, and gain and baseline stabilization are required.

v) High-Power Cryogenic Targets

Modern electron accelerators will produce currents up to 200 mA and a beam diameter of about 0.1 mm. At luminosities of the order of $2*10^{38}$ cm^{-2} sec^{-1}, the power dissipation in a ^4He target is about 1 kW. Density changes due to local beam heating cause the counting rates to be beam current dependent. R&D efforts will have to concentrate on reducing this effect by flowing the target material past the beam and by rastering the beam on the target. (Liquid hydrogen targets at SLAC and Bates have successfully used flow rates up to 2 m/s at spot sizes of the order of a few mm.)

vi) Low-Mass Focal-Plane Detectors

Current focal-plane detectors for high-resolution spectrometers require an exit foil between the spectrometer vacuum and the drift chambers which operate at atmospheric pressure. If drift chambers could be operated at substantially reduced pressure, only a thin membrane between the spectrometer vacuum and the detector would be required. A factor of ten reduction in gas pressure could yield up to a factor of twenty reduction in necessary foil thickness, with a four-fold reduction in multiple scattering.

To realize these potential gains, studies must be performed to determine the critical operating parameters of the drift chamber as a function of pressure.

vii) Focal-Plane Polarimetry

The measurement of the polarization of protons emitted in electron scattering reactions such as (e,e′p) will open up new possibilities in spin physics. Proton polarimetry in the proton energy range from 200 to 800 MeV is a relatively mature technology. The standard analyzer is ^{12}C which shows a large analyzing power for protons scattered into the angular range 5° to 20°. With increasing proton energy, ^{12}C becomes less efficient. Lighter nuclei (such as liquid hydrogen or lithium hydride) may be more suitable as analyzers and have to be investigated.

Clearly, with the demand for higher energy proton focal-plane polarimetry in the near future, research and development in the technology of suitable analyzers is highly desirable.

III.6.5. RECOMMENDATIONS

1. To make proper and efficient use of the existing electromagnetic facilities and of those under construction, high quality experimental equipment will be required.
2. Increasingly, experiments at electromagnetic facilities concentrate on small but important pieces of the cross sections. The corresponding experimental techniques are becoming more and more sophisticated, involving the use of polarized beams, polarized (internal or external) targets, the measurement of

recoil polarization, or the measurement of out-of-plane structure functions. Both hardware and procedures have to be developed, tested, and implemented in a professional way.

3. The advent of high duty-cycle accelerators makes large-acceptance detectors with open geometries much more efficient and attractive. R&D efforts are required to explore the background environment at an electron beam and to derive the optimum operating conditions for open detector systems.

III.7. REPORT OF THE SUBGROUP ON PROTON ACCELERATOR FACILITIES

M. Cooper (Chair), O. Hausser, R. McKeown, B. Mecking

The vitality of the proton accelerators at IUCF, LAMPF and TRIUMF depends on having state-of-the-art detector facilities. Each of these laboratories has had a good record of construction of new apparatus. It should be recognized that all these detectors require adequate manpower to be properly exploited and funding the necessary staff is very important for efficient use of these instruments.

III.7.1. DETECTOR R & D AT IUCF, LAMPF AND TRIUMF

A description of the status of detector development at intermediate energy proton accelerators needs to be broken into two categories: Large detector facilities such as spectrometers and the individual detection elements that comprise them. For the most part, these large facilities are representative of where the push for new instrumentation is required.

i) Facilities

The IUCF consists of the somewhat conventional cyclotron facility and the new cooler. Four major facilities are currently on line; they include the K-600 magnetic spectrometer, a neutron time-of-flight area, a polarized neutron capability, and a fission facility. To a large extent, these are mature projects, and upgrades are not too extensive and are planned with current funding.

The cooler is a new accelerator. It was built on budget, but no money was allocated for detectors. The old low energy spectrometer is being moved to the cooler to detect recoil nuclei. A tagging facility, two magnetic spectrometers, and a 2π detector are planned to realize the potential of the high resolution beam. One interesting challenge is to shield the beam from the fringe field of the magnetic spectrometers. It is likely that a superconducting magnetic shield will be necessary to prevent distorting the beam orbits. Money and manpower for detectors at the cooler are essential to the proper utilization of this machine.

At LAMPF there are a number of major detector systems. The HRS, EPICS, and Clamshell spectrometers provide a broad range of capabilities for protons and charged pions. The π^0-spectrometer gives up to 2 MeV resolution for neutral pions. New projects include the medium resolution spectrometer, the neutron time-of-flight beam line, and the MEGA experiment for $\pi - \mu - \gamma$ studies. A major new opportunity is opened by the availability of high intensity, low energy ν beams. The Large Cerenkov Detector (LCD) project is the first big proposal for this new facility. Another window of opportunity that could be pursued is the construction of a newer π^- -spectrometer with 200 keV resolution. Also under discussion is a multi-particle detector for studying pion induced reactions, especially absorption.

The Medium Resolution Spectrometer (MRS) upgrade highlights improvements to the experimental facilities at TRIUMF. Included are a front end chamber (FEC) for ray-tracing and dispersion matching of the beam to the spectrometer. The background at the focal plane is greatly reduced and the resolution is improved to better than 100 keV. A charge exchange facility using the MRS as a recoil spectrometer has been built and has resulted in a very strong program of (n,p) and (p,n) reactions. The beam line has been recently upgraded to include two superconducting spin precession solenoids which make available a beam of protons polarized in any direction. This upgrade, together with the new focal plane polarimeter on the MRS, allows a full set of spin observables to be measured. Elsewhere, an isotope separator has been installed that will lead eventually to development of a radioactive beams facility. TRIUMF has new facilities which are proposed or nearing completion. A second arm spectrometer with a large acceptance is being built. It will be located at the same target location as the MRS and will be used both for coincidence experiments and on its own for low count rate experiments. The stringing of a new drift chamber for radiative muon capture (RMC) is almost done. Finally, a proposal has been made for a large acceptance superconducting pion spectrometer (CLASS).

ii) Detector Elements

Inevitably some aspect of the detector elements, either resolution or rate capability, limit the performance of any experiment. Neither Indiana nor LAMPF has a detector development group like those found at some particle physics laboratories. Hence, advances in detector technology are usually in response to the specific needs of the individual experiments. Sometimes lack of money or manpower limits the detector challenges undertaken for experiments at these laboratories. Certainly the contributions to detector technology are slower at medium energy proton machines than from particle physics experiments.

It should be noted that to take full advantage of any possible detector advances, corresponding improvements will be needed in data acquisition and electronic systems that are attached to these devices. A number of areas have been identified where improved detectors would benefit experiments. Two types of wire chamber research are relevant. Individual channel readout of cathode strips might be kept at a reasonable cost by multiplexing the signals into analog-to-digital converters using FET switches. Such chambers at the entrance to spectrometers would increase their rate capability. Another chamber initiative is to develop small-celled drift chambers with fast gases to improve rate response. The field of inorganic scintillator calorimetry is undergoing a resurgence now, and a new π^0-spectrometer might be a good way to advance this field because it demands a sophisticated calorimeter.

Fast, pure scintillators may provide good resolution with substantially better response times than the characteristic 1 μs currently available. Some examples of such crystals are given in Table I. Silicon strip detectors have possibilities for application in medium energy experiments for recoiling heavy nuclear fragments. Even a new standard photomultiplier and base that would available as a stock item at the laboratories would be of benefit to users. Some project specific developments may have wider application. Some examples include the central chambers of the MEGA experiment that push a large system to rates of 10^4 Hz/mm^2, the need for an 8-10" photomultiplier tube for LCD that is low priced, and improved neutron detectors for NTOF and IUCF. For the neutron systems, the current standards are 6-8% efficiency, 3 cm FW position resolution, and 300 ps FW timing; any improvements would be welcome.

By contrast, at TRIUMF, there is a detector group that has been very active in the last few years. In addition to the new RMC chamber and the FECs for the MRS, a segmented target box for (n,p) studies has been built. The box consists of 6 targets interleaved with 8 wire planes permitting the identification of the target layer in which the reaction took place. This arrangement allows thick secondary targets to be used while retaining good resolution. A second box of similar design has been made for gas targets. It runs at a pressure of 20 atmospheres giving a usable target thickness. New high rate wire chambers have been developed for use with the QQD pion spectrometer. These chambers have run reliably in the pion beam at counting rates of 70 MHz with an efficiency of 90%. The detector group also builds detectors for use outside TRIUMF. Among these are the drift chamber for E787 at Brookhaven and the calorimeter for the SLD at SLAC. Finally, the electronics group has been working on new detectors based on GaAs technology. Among the projects under way are the development of GaAs CCDs and the construction of a planar GaAs detector.

iii) STAFFING AND FUNDING

With a few exceptions, there was a general feeling of inadequate funding and manpower to develop new systems. Experienced technicians are often in short supply. One method for minimizing the manpower is to seek an industrial partner to share development costs. MEGA is developing its FASTBUS electronics in this way, and LCD plans its photomultiplier tube development in conjunction with manufacturers. New inorganic scintillators will certainly require close industrial liaisons. Such schemes are workable if sufficient quantities will be required that an order can be placed.

Table I - Inorganic Scintillator Properties

Table I - Inorganic Scintillator Properties
Information collated by Barrie Hughes of Stanford

Detector Material	Light Yield	Radiation Length	Decay Time	Peak Emission	Cost
	(Photons/MeV)	(cm)	(ns)	(nm)	($/cm^2/r.l.)
NaI(Tl)	4×10^4	2.5	250	410	5.2
BGO	2.8×10^3	1.1	300	480	16.5
CsI(Tl)	4.5×10^4	1.8	600	550	7.7
CsI(pure)	1.8×10^3	1.8	8	310	7.7
BaF_2	2×10^3	2.1	0.6	220	16.8
CeF_3	1.2×10^3	1.7	27	330	—

III.7.2. RECOMMENDATIONS

Instrumentation development geared towards exploiting the new cooler facility, increasing detector capabilities for pion physics and utilizing the unique, high intensity, low energy neutrino facility available to physicists should receive a high funding priority.

The large detectors and facilities available in our proton accelerator centers at Los Alamos and Bloomington require an increased support for development and maintenance of detectors if one is to simultaneously exploit these instruments and to aggressively develop the new systems crucial to the vitality of these facilities.

III.8. REPORT OF THE SUBCOMMITTEE ON LOW AND INTERMEDIATE ENERGY HEAVY ION FACILITIES

D. Balamuth, O. Haeusser, J. Nolen (Chair), D. Sarantites

This subgroup was charged with addressing the developments in instrumentation for low and intermediate energy heavy ion labs in the US which are not considered by other subgroups of this subcommittee, such as those on electronics, and non-accelerator-specific detector development. Some issues which are relevant to these labs, but also have significant overlap with the charges of some of the other subgroups are discussed below. A wide range of labs fall into this subgroup, about 14 in all, including both national labs and universities.

Since 1983 several of these labs have had major accelerator upgrades, some of which are still in progress: Linacs added to Argonne, Seattle, Florida State, and Stony Brook; the new Yale tandem; new superconducting cyclotrons at MSU and Texas A&M; and the ECR ion source injection system at the LBL 88" Cyclotron. New ECR ion sources at the MSU and LBL cyclotrons, new polarized ion sources at TUNL and Seattle, and a positive ion injector at ANL are currently under construction. There have also been significant investments by the funding agencies in new apparatus for nuclear science at several of these labs. For the past two years the DOE has funded a program to provide badly needed capital equipment to several of its labs. This idea of incremental funding for high priority equipment or instrumentation projects is excellent and should be extended to NSF labs as well. Such new equipment can greatly help labs stay competitive and maintain their vitality by allowing them to do state of the art nuclear science. The students which are trained in the smaller university labs must have access to modern equipment since they are often the source of the post-docs and research staffs of the larger national facilities. Programs and laboratories which are worth funding should be funded to do world-class research. The appropriate funding balance between large user-oriented facilities and smaller University based research groups is an important aspect of this scenario and should be discussed by NSAC within the framework of the new long range plan.

All types of nuclear science research are becoming more complicated, with this being especially true for heavy ion experiments. It is common for experiments in either heavy ion reaction mechanisms or nuclear structure to involve (or need) 50 or more detectors. Research at the larger facilities tends to be even more sophisticated. To remain current in the use of forefront technology, nuclear science must continuously upgrade its equipment through R&D and construction of new instrumentation. Apparatus R&D and new equipment construction and commissioning provide challenging and relevant projects in which to involve graduate students. In Germany, for example, most graduate students in experimental nuclear physics begin their careers with equipment development projects.

As mentioned above, in addition to the accelerator and ion source projects which were funded in the past few years there have been several significant equipment grants to the low and intermediate energy heavy ion labs of the US. Some of these are listed here: Barium-fluoride arrays have been funded at Seattle, Texas A&M, and ORNL. A BGO-supressed Ge detector system has been funded at Seattle and one is finished at Stony Brook. Recoil-mass-separators of various designs have been funded recently at ANL, Texas A&M, and ORNL. A new split-pole magnetic spectrograph is nearing completion at Yale. An "8π" detector is under construction at ANL and a large TPC system is under construction at LBL to be used with HISS. The user group at the University of Michigan has been funded to build a large superconducting solenoid spectrometer system. And as part of the phase II construction at MSU, either in operation or nearing completion are the reaction product mass separator, a 92" diameter scattering chamber, a 4π detector system, and a superconducting beam analysis/fragment separator system. This list is not intended to be complete, but to illustrate that there has been a trend recently to bring new equipment into this group of labs. As stated above this must continue, and specific examples of additional requested apparatus are given below.

Each of the 14 or so labs represented by this subgroup has a list of needs for new equipment or instrumentation R&D. These requests will not be discussed in detail in this report, but presented here are some examples to indicate the kind of apparatus that these labs plan to build to remain competitive and to train students in the use of up to date technology. Seattle and ANL are both interested in developing detectors to carry out new experiments related to the e^+/e^- data from GSI. FSU has a long-range plan for new equipment to use with their upgraded accelerator facility; it consists of a unique 1π sr light/heavy ion Bragg-curve detector, a general-purpose scattering chamber, additional beam transport system, a high-spin detector array, and additional electronics. Similarly, Stony Brook is formulating plans for new apparatus: a plastic scintillator array to use as an internal pair creation 4π spectrometer, an on-line ion-guide isotope separator, continued R&D on pressurized-gas expansion cryocoolers for Ge detectors, a BaF_2 based γ-detection system and possibly a recoil mass separator to use in conjunction with their existing BGO-suppressed Ge detectors. Similar lists would be available from the other labs in this category.

A separate subgroup is reviewing the needs for sources of high-charge-state heavy ions and polarized ions, both of which are critical to the capabilities of the accelerators included in this subgroup. In particular, the advanced ECR ion source projects at LBL and MSU will certainly produce large incremental gains for their respective accelerators as well as for ECR technology in general and should, therefore, be funded. These projects have the potential to allow the US to take the world lead in ECR ion source technology.

There are also non-accelerator-specific novel detectors which include many devices, such as the Washington University "Dwarf Ball" and other multi-detector arrays, which are of interest to the laboratories of this subgroup. Of special importance to this subgroup is detector R&D on position-sensitive gas counters. Developments in this area have the potential for large incremental gains for small incremental investmentments because of their application as focal-plane detectors in large magnetic spectrographs. There is the need for heavy ion position resolution in the 100 μm range, and this capability has yet to be demonstrated for medium energy heavy ions.

Similarly, large-area gas detectors with good time and energy resolution for heavy ion particle ID must continue to be improved.

The subgroup on electronics and computers for nuclear physics also has a large overlap with the interests and needs of this subgroup. Advances are needed for the low and intermediate energy areas just as they are in the AGS and RHIC energy domaines. The rapidly increasing complexity of heavy ion experiments is creating the need for higher density and more specialized electronics and more advanced data aquisition systems, as detailed in the other subgroup reports.

A technology which has begun to play a major role in nuclear physics within the past 10 years is superconductivity. The largest applications are in the new superconducting heavy ion cyclotrons and the superconducting cavities used mainly as post accelerators for heavy ions following tandems. The 5 T superconducting cyclotron magnets are about 20 times less massive than conventional magnets of the same bending power. R&D in this area could lead to even further size reductions through the use of 7-10 T magnets. Superconducting cavities for linear accelerators continue to be developed at ANL (niobium) and Stony Brook and Seattle (lead). The ANL developments are making possible the replacement of the tandem by the positive ion injector and could also lead to beam sharing by the use of superconducting cavities as beam switchers. Superconducting magnets are also being used extensively in the phase II beamlines at MSU. These are very efficient magnets capable of bending and focussing 1.6 GeV/c beams. The first section of this beamline has been operational since the fall of 1988. MSU is also proposing to build a large superconducting magnetic spectrograph, involving two large aperture quadrupoles and two 75 ton dipoles. This project could be a prototype for possible future larger devices which may be required for nuclear physics.

The low and intermediate energy heavy ion laboratories of the US face stiff competition from well-funded laboratories in Europe and Japan. The flagship laboratories of this category in Europe are GANIL in France and GSI in Germany. Both of these are currently in the process of major accelerator upgrades, and they are simultaneously building large new pieces of experimental apparatus. There is also much new money for upgrades and new instrumentation going into smaller facilities such as Strassbourg, Groningen/Orsay (the AGOR project), Berlin(Vicksi), Daresbury, Milan/Catania, Legnaro, and Saclay. In Japan, both RIKEN and Osaka are building large new magnetic spectrographs and other apparatus as part of their new heavy ion accelerator projects. The large investments being made in these European and Japanese facilities both indicate the vitality of the field and provide a strong challenge to the US to remain competitive in this area.

RECOMMENDATION

We recommend that DoE and NSF provide a funding profile which insures continuous modernization of instrumentation in these laboratories. Over and above the present operating grants funds of the order of 10-15% of these operating funds should be earmarked annually for funding of major upgrades of ion sources, accelerator components, or other capital equipment items on an open competition basis.

III.9. REPORT OF THE SUBCOMMITTEE ON RELATIVISTIC HEAVY ION FACILITIES

P. Braun-Munzinger, W.E. Cleland, A. Sandorfi, G.R. Young (Chair)

III.9.1. INTRODUCTION

Experiments with ultra-relativistic heavy ions are a recent addition to nuclear physics research. Much of the instrumentation presently in use in experiments at the BNL AGS and CERN SPS has its roots in apparatus developed for use in high energy physics experiments, and much of the apparatus presently thought to be needed for work at the proposed Relativistic Heavy-Ion Collider (RHIC), to be built at BNL, has an analog in devices in use at present high-energy colliders. However, the needs in the field are driven by the principle sharp distinction between nucleus-nucleus collisions and proton-proton collisions at ultra-relativistic energies, which is the orders-of-magnitude larger multiplicity of secondary particles in the nucleus-nucleus case. This leads to some basic changes in how a given detector technique is implemented and drives strongly the need for highly segmented devices. A second distinction is the need for global event characterization in the nucleus-nucleus case to select broad classes of events such as central and peripheral collisions. This has led all present and planned experiments to include at least one device with very broad solid-angle coverage which can cover at least 2π in the c.m. frame, if not also the lab frame. This need leads to a great interest in inexpensive methods to instrument large areas with large numbers of readout channels.

Similar needs will also exist for the Superconducting Super Collider (SSC) because of the density of particles in jets, but the proposed detector budgets there are an order of magnitude larger than those for RHIC. The SSC development must concentrate on very high-speed devices, due to the very high luminosity of that machine. The development for RHIC must concentrate on very high segmentation at low cost; the lesser need for extreme speed at RHIC is a help in being able to develop the needed devices and electronics at a more reasonable cost.

In the following, a short description is given of the types of probes useful in studying what happens in ultrarelativistic heavy-ion collisions. This is followed by a list of useful areas for detector R&D, where considerable stress is laid on segmentation, two-dimensional readouts and development of inexpensive electronics. Finally, we address briefly the present levels of manpower and funding for detector development in this area and comment on perceived needs in these areas. In a separate Appendix available as internal report from one of us (Glenn Young) we give a survey of the experimental devices presently in use by the various experiments at BNL and CERN. These devices are grouped by type of measurement, such as charged particle tracking, electromagnetic calorimetry, or lepton identification. A detailed list of R&D topics can also be found in the Appendix.

III.9.2. EXPERIMENTAL PROBES FOR NEW STATES OF MATTER FORMED IN ULTRA-RELATIVISTIC HEAVY-ION COLLISIONS

The present interest in heavy-ion collisions at ultrarelativistic energies stems from the idea that a state of matter may be created in the laboratory in which the quarks and gluons making up the familiar nucleons of nuclear physics become deconfined from their parent nucleons and free to travel over a large volume. It is thought that such a state of matter existed in the period roughly one microsecond after the Big Bang. This "quark-gluon plasma" then ceased to exist as the Universe cooled and the quarks and gluons were "frozen" into the protons and neutrons that we know. Because the conditions for creating such a state of matter in the laboratory appear to require that large amounts of energy be deposited over an extended volume, it has been proposed to build a dedicated colliding beams machine to be able to investigate this physics. The proposed Relativistic Heavy-Ion Collider (RHIC), to be built at BNL, would collide beams of up to mass = 200 nuclei at energies of up to 100 GeV/nucleon per beam (equivalent to a 20 TeV/nucleon fixed-target accelerator) in order to achieve the conditions thought to be needed to create a quark-gluon plasma.

The final state created in collisions of such high-energy nuclei is much more complex than that encountered in accelerator experiments to date. This is so principally because of the multiplicity of final state particles produced, which may reach 20,000 in gold-gold collisions at top energy at RHIC. It is thus crucial to find efficient means of sorting through these complex final states for evidence for creation of a quark-gluon plasma. It is also crucial to identify signals giving information about whether the quarks and gluons are truly deconfined and about the conditions of the state created.

The methods used to characterize these collisions may be divided into three broad categories:

i) Penetrating probes, giving direct information from the plasma
ii) Indicators of a phase transition
iii) Global event parameters.

PENETRATING PROBES include direct photons, lepton pairs and high-Pt jets of particles. The number and Pt spectra of these reflect directly the conditions in a plasma and depend on the entropy density and initial temperature of a system and on the thermal history of the plasma. Information on structure function changes is contained in the real and virtual photon spectra. The properties of the 'real sea' of quarks and gluons will be reflected in the hadronization of high P_T jets.

INDICATORS OF A PHASE TRANSITION include production of strange particles and antibaryons (indicates attainment of chemical equilibrium), local charge correlations and heavy vector-meson suppression (indicates a change in color screening relative to normal matter), and production of stable multiquark states (indicates ease of assembling multiquark final states.)

GLOBAL EVENT PARAMETERS include correlations of multiple particles in space-time (which could signal the long-range correlations and macroscopic fluctuations characteristic of a first-order phase transition), measurements of inclusive particle spectra and particle distributions in phase space (which give information on the final state of the event and any large-scale phenomena) and measurements of energy flow in the final state (which gives information on the centrality of the event and the total transverse energy production, which may characterize the energy density attained.)

A short list of detector techniques useful in performing experiments concentrating on these methods follows:

General Category	Specific Probe	Detector Capability
Penetrating Probes	Lepton pairs	e,μ Identification
	Direct photons	Single photon Identification
	High Pt jets	Particle ID and Tracking within Jets plus large solid-angle calorimetry to tag jets
Indicators of Phase Transition	Strange particles and antibaryons	π/K/P separation 'Vee' identification Tracking in Mag. Fields, esp. near Target
	Charge correlations	Tracking in magnetic fields over large areas
	Vector meson spectra	Electron and/or muon Identification
	Multiquark states	Full particle ID and momentum measurement, possibly over small solid angle
Global Event Parameters	Space-Time Correlation	Precise Momentum Meas. and Part. ID over several Regions of limited solid angle.
	Spectra of Particles	Tracking in Magn. Fields and/or neutral Part. ID
	Multiplicity in θ, φ	Tracking with high θ, φ Resolution
	Transverse, Forward and Total Energy	Electromagn. and Hadr. Calorimetry

Instrument design to carry out the above measurements needs to place emphasis on high levels of segmentation and pixel oriented read-out schemes. The need for development of such techniques becomes obvious when the present vs. future particle multiplicities are considered, as shown below.

Facility	Date	Beam and energies	Multiplicity
BNL AGS	present	16-O, 28-Si, 15 GeV/u	50 - 200
CERN SPS	present	16-O, 32-S, 60 & 200 GeV/u	150 - 950
BNL AGS	1992	197-Au, 12 GeV/A	up to 1000
CERN SPS	1993	208-Pb, 160 GeV/A	up to 4000
RHIC	1995	197-Au+197-Au, 100 GeV/A each	up to 20,000

The needs of RHIC thus diverge from those of the SSC on three important points. The SSC will need to identify a few hundred particles per event but with a high probability of event overlaps, with emphasis on very energetic particles. RHIC will need to handle over ten thousand particles per event, at modest event rates, with a need to keep information from the many soft particles.

III.9.3. R&D AREAS FOR FUTURE INSTRUMENTATION FOR ULTRA-RELATIVISTIC HEAVY-ION EXPERIMENTS

The following gives a brief list of R&D topics of particular interest for the RHIC as well as the ongoing AGS and SPS programs. Areas of interest are given together with the general thrust of investigation needed. A detailed list of R&D questions in these same areas is given in the Appendix (available as separate special report from G.R. Young at ORNL).

A. Particle identification : This includes electron,muon,pion,kaon and proton identification

- RICH counters with true 2-D 'pixel' readout
- Triggering techniques for advanced 2-D pixel readouts
- Transition radiation counters with thresholds as low as $\gamma = 500$
- Quantification of background behind hadron absorbers for muon Identification
- Two-dimensional hodoscopes for fast road-finding
- High resolution photon calorimeters with small pixel size
- Homogeneous, fast, highly segmented calorimeters of, e.g., CsI or BaF_2
- Time-of-flight elements useful for a 2-D pixel geometry
- Monolithic circuits including CFD, delay, precise TDC, readout logic
- Large area, multianode phototubes with minimal cross-talk
- Large area microchannel plates and image intensifiers

B. Tracking : This is needed for any momentum measurement, for hyperon reconstruction, for vector meson identification and for lepton pair reconstruction

- TPC chambers with fast gases suitable for heavy-ion experiments
- Monolithic electronics for TPC readout and digitization
- Multiwire chambers with 2-D pad readout
- Monolithic electronics for pad chamber readout, with low noise and large dynamic range
- Straw drift chambers with pads on the straw body
- Plastic optical-fiber chambers with 30 micron fibers

Silicon drift chambers with integral electronics, performing in a heavy-ion environment

C. Calorimetry : This is needed for global event characterization and for identification of photons and jets

Highly segmented calorimeters with optical fiber readout

Study of response of calorimeters to soft hadrons

Development of jet isolation algorithms, segmentations needed for jet and photon identification

Coupling to highly segmented readout devices, be they optical, silicon or gas-based

Coarse 2-D calorimetry (possibly gas-based) for hadron absorbers and muon identifiers

Fast, homogeneous crystalline EM calorimeters at a reasonable cost

D. Multiplicity : This is needed for global event characterization and charged particle tagging

Development of gas drift devices with small cell sizes

Monolithic or hybrid circuit development for low gas gain, good rate capability

Hodoscopes with true 2-D readout

Monolithic electronics for silicon pad counters

Parallel electronics for CCD readout in under 100 μsec

E. Electronics : This is needed for all of the above - the main emphasis is to decrease present costs per channel, as one million channels at present costs is not feasible within projected budgets. Development of standard analog cells for monolithic devices, including preamplifiers, shaping amplifiers, capacitor arrays, comparators, discriminators, time-voltage converters and ADCs.

Development of high density ADCs and flash ADCs/waveform recorders

III.9.4. MANPOWER AND FUNDING LEVELS

Much of the detector development discussed above needs to be carried out in timely fashion both for the 2nd generation experiments at BNL and CERN and in preparation of the planned Relativistic Heavy Ion Collider at BNL. Especially for RHIC it is useful to consider the following timeline for an electronics development project in order to obtain an idea of the timescale that would produce useful devices in time for their inclusion in first-generation experiments.

Timeline (from W. Cleland's summary talk, 1988 RHIC Detector Workshop)

1989	Design start, group assembled
1990	First chip element protoypes, System design started
1991	Complete protyping and testing of chip elements, System design completed
1992	Prototypes of system produced. Full bench tests of system units.
1993	Early production modules available for test beam trials. Design refinements. Arrangements for full scale production
1994	Full production Installation into completed detector elements Calibration of detector elements in test beams

1995 Assembly of full detector. Detector systems tests. First operation with collider beams

At the recent RHIC Detector Workshop (July 1988, BNL), over two dozen areas for detector R&D were identified for investigation. Much of the contents of Section III above was taken from these discussions. Typical projects were estimated to need effort equivalent to 2-4 full-time persons per year for the next 2-3 years. This usually corresponds to three to four times as many total people involved, many working part time on R&D and the rest of their time on ongoing experiments. Just multiplying these numbers results in a manpower level of 50-75 full-time equivalents, or perhaps 200-300 persons involved on a part-time basis. This represents a significant fraction, over 50%, of the present total number of physicists involved in relativistic heavy ion experiments at the AGS and SPS. It seems necessary to attract persons not presently involved in those programs. This in fact appears to have occurred at the above-mentioned workshop, but it needs to be encouraged further.

The scale of detectors planned for RHIC is very large by any standards; they are comparable to experiments being mounted presently at LEP. The design, construction, assembly, testing, and calibration of even one subsystem will require the efforts of a quite substantial group. The detailed design and analysis of devices on this scale can only be performed by professional engineers. Professional help will also be required for the coordination of the work of the different groups to ensure that these large detectors can fit and function together in an experiment.

During the RHIC Workshop it was mentioned repeatedly that successful R&D efforts will need continuing support over a number of years and will need a dedicated pool of technical manpower to accomplish the desired goals. In view of the need for development of professional support for the design and construction of RHIC detectors, a particularly pressing need is evident for technical support staff, including engineering and technician help. This need is evident both at the national laboratories and at the universities; the need is particularly acute in the latter, due to the small size of the groups and the lack of expertise in the design of large detectors. All the R&D projects discussed could use the dedicated services of engineers and technicians. Having those persons in place for R&D work would ensure a strong technical base for the ensuing construction of the detectors themselves for RHIC. In order to have experienced persons available at the beginning of actual detector construction so that it can proceed in a timely manner, it would be wise to begin assembling this technical manpower now.

The R&D projects which need to be performed can serve as the focal point for building the required technical manpower base. In order to make efficient use of this manpower, a buildup is also needed of the various 'tools of the trade', such as shop facilities, CAD/CAM tools, specialized tooling and test equipment. At present, such infrastructure is only found at nuclear physics laboratories which have recently constructed or presently operate an accelerator. Support of this type will also be required at laboratories which have user groups; user groups which happen to be located at institutions which have in-house accelerators need assured access to their in-house technical staff. Institutions with several groups might be able to support a central pool of technical manpower. Single groups may be able to benefit from the ability to hire technicians at the central lab, but they will need technical support at their home institutions also if they are to contribute meaningfully to the construction of RHIC detectors.

Estimated costs per project ranged from $50K to over $0.8M. Assuming an average of two projects in each of the two dozen areas listed in Section III and an average cost of ~$0.4M each, a total R&D expenditure of ~$20M over a 5 year period results. It was emphasized repeatedly that in order for such projects to have an effect on the design of first generation experiments at RHIC, results would have to be forthcoming within 2-3 years. This includes operation of full scale prototypes in test beams and preferably in experiments, so that 'real-life' behavior of new detector devices can be understood before they are included in the large collider detectors proposed for RHIC. This accordingly would require that significant funds for the R&D work be made available over the same time frame.

III.9.5. RECOMMENDATIONS

1. The RHIC R&D effort required is highly nontrivial. A large, varied number of projects were identified. Funds of the order of $20M over a 4-5 year period are recommended to bring a major fraction or all of these projects to completion. This will require a level of effort of about 100 FTEs, corresponding to the involvement of perhaps 300 physicists and engineers for part of their time. There need to be significant results by 1991-1992 in order to have an impact on detector construction for RHIC, assuming RHIC operation in 1996.

2. There exists a particular need for electronics development, particularly in the design of analog electronics using monolithic and hybrid techniques. Access is needed to university and industrial electronic engineering expertise.

3. The basic detector elements, such as calorimeters, tracking chambers, multiplicity counters, and timing/triggering detectors, all need dedicated R&D work in particular aimed at both obtaining devices which offer a large number of pixels per unit area and at developing readout techniques which couple efficiently to these pixels.

4. The R&D work should be supported over sustained periods, ranging from 2-5 years, depending on the task. This permits a coherent group to carry through design, prototyping, testing, test beam work and trials in real experiments.

5. A significant build-up of 'infrastructure', including both people and hardware, is needed. There is a present lack of technical staff and mechanical and electronic engineering staff, particularly in the university groups. The needed infrastructure includes shop facilities, CAD/CAM tools, specialized tooling and test equipment. This infrastructure forms the basis for the construction of detectors for RHIC.

III.10. REPORT OF THE SUBGROUP ON NON-ACCELERATOR BASED DETECTORS

P. Braun-Munzinger, C. Gossett, G. Young

A number of nuclear physics experiments do not require use of accelerated beams in order to obtain their initial states of interest. Nevertheless, quite sophisticated instrumentation is needed in order to observe the sought for rare events or make precise measurements. A short survey is given of some present experiments and associated instrumentation in this area, followed by recommendations for improvements and developments.

III.10.1. DOUBLE BETA DECAY

Studies of nuclear double β-decay provide the possibility to study the character of the electron neutrino which may or may not be its own antiparticle. In most recent discussions the electron neutrino is assumed to be a Dirac neutrino, distinct from its antiparticle, although as yet there is not very compelling evidence for this assumption. If the electron neutrino is instead a Majorana particle and therefore its own antiparticle then a neutrino emitted in a beta-decay could be 'reabsorbed' and induce a second beta decay. This would result in a double beta-decay with no neutrino emission, as opposed to the (Dirac) case of double-beta decay with accompanying emission of two electron neutrinos. A well-suited system to examine for such decays is a pair of stable even-even nuclei with the same mass but atomic number differing by two. Two such pairs have been studied in particular, namely the ^{76}Ge + ^{76}Se pair, by observing a large volume of Ge formed into a Ge detector, and the ^{82}Se + ^{82}Kr pair, by observing a mass of ^{82}Se deposited on a central wire plane in a special-purpose TPC. The Ge experiments typically involve forming a large mass of Ge into a germanium detector which is then placed in a mine and surrounded with a thick shield of low-activity material. The desired neutrinoless double beta decay would be observed via a two-electron transition giving a sharp line in the detector. That is, the material of interest acts as its own detector due to the semiconductor properties of Ge. Present experiments have managed only to place very large lower limits ($>10^{22}$ years) on the half-life of double-beta decay in this system. Improvements to this method include separating a large volume of ^{76}Ge in the Oak Ridge centrifuges to prepare an enriched ^{76}-Ge detector. This improves on the 7.6% natural abundance of ^{76}Ge. The group of M.Moe at Irvine has constructed a novel TPC in which to observe the decay of ^{82}Se. By placing the TPC in a magnetic field, they are able to observe electrons emitted from an ^{82}Se source which is coated onto a central wire plane in the chamber. Full trajectory information is obtained, as well as the charge sign of observed tracks and the momentum of the particles. The background rejection of this technique is superb, and the group has evidence for the observation of the two-neutrino double-beta decay of ^{82}Se. Excellent spectral and half-life information on this decay is obtained, providing a first direct check on theoretical studies of these decays. No evidence has yet been obtained for neutrinoless double beta decay. The group can also investigate other pairs, such as the ^{100}Mo + ^{100}Ru pair, which will help greatly in pinning down the physics of such decays.

III.10.2. REACTOR-BASED EXPERIMENTS

i) Neutrino oscillations

The neutrino eigenstates of the weak-interaction Lagrangian may not in fact 'match' the observed neutrino eigenstates. There may instead be mixing of the eigenstates of the Lagrangian to form the observed neutrinos, as pointed out by Pontecorvo and Wolfenstein. This could lead to 'oscillations' of neutrinos in one physical eigenstate with those in another (if there is a non-zero mass difference between the eigenstates), giving the experimental consequence that one type neutrino would be observed to change into another. Many experiments to search for this phenomenon have been performed at LAMPF and high-energy accelerators. It is also attractive to perform such searches at fission reactors, where extremely intense sources of electron antineutrinos and long pathlengths for oscillation amplitudes to build-up are available. A recent series of measurements searching for neutrino oscillations have been performed by Boehm and collaborators using the Gosgen reactor in Switzerland. This is a particularly high-power reactor, providing a large antineutrino flux. Measurements at more than one distance were possible, removing much of the systematic uncertainty in previous such experiments caused by incomplete knowledge of the reactor antineutrino spectrum. To date, no positive signal is reported by these experiments, although a large part of the possible parameter space in mass-difference vs mixing angle can be excluded with good confidence limits. Likely further improvements in mixing parameters will come from solar neutrino experiments, with their extremely long pathlengths.

ii) Neutron half life and beta-decay asymmetry

Precise measurements of the half-life and beta-decay asymmetry parameters can be made using beams of cold neutrons. Presently the best such beams are obtained at the ILL reactor in Grenoble, France, using the beams guided from the cold neutron source there. Novel experimental techniques are possible. For example, cold neutrons can be guided in a storage ring using the fact that the neutron's magnetic dipole moment couples to external magnetic fields. In this case, the normal dipoles of a charged-particle storage ring are replaced by quadrupoles and the focussing quadrupoles are replaced by sextupoles, as the ring interacts with a dipole moment and not a charge. Due to the small size of the neutron magnetic dipole moment, feasible rings are possible only for very slow neutrons, such as the cold neutrons available at ILL. Storing the neutrons thus allows long observation times and accurate half-life measurements. It is also possible to store ultra-cold neutrons ($v \sim 5$m/s) in a 'bottle' and perform very careful checks of its interactions with applied external electric fields. The best present measurements of the (limit on the) neutron's electric dipole moment come from such experiments, also performed at ILL. A nonzero neutron EDM would have profound implications for unified theories of fundamental interactions. It is clear that such measurements benefit directly from increased fluences of cold neutrons as could be obtained from a several 100 MW heavy-water high flux reactor with associated cold sources.

iii) On-line isotope separators

Isotope separators coupled to accelerators provide an abundant source of nuclei off the beta-stability line which may be separated, implanted and studied using a variety of optical, magnetic and electronic techniques. At accelerators it is easiest to study neutron-deficient isotopes, via the use of (ion,xn) reactions to create the nuclei of interest. An isotope separator placed at a reactor, such as the TRISTAN facility at the BNL High Flux Beam Reactor, gives the possibility to study nuclei populated by neutron capture also. This has permitted studying a broad range of nuclei, leading, for example, to studies of symmetry properties by Casten and collaborators. Coupling other devices, such as orientation refrigerators or optical-pumping setups to these separators leads to a broad range of spectroscopy topics which can be studied. The raw yield of nuclei of interest can be increased by coupling the isotope separator to the highest-flux reactor accessible.

III.10.3. TRITIUM ENDPOINT MEASUREMENTS

Since the report by Lubimov in 1980 of an anomaly in the endpoint of the beta-decay spectrum of tritium, a veritable industry has grown up of sophisticated tritium beta-decay measurements. The excitement is of course caused by the possibility that the electron antineutrino could have a nonzero rest mass, which would require a reworking of the Standard Model. A review of the status of this field has recently been given by R.G.H. Robertson and D.A. Knappe (Annual Review of Nuclear and Particle Science 38(1988)185. At present there is no conclusive evidence for a nonzero rest mass, but the only consistent statement that can be made is that the rest mass must be below 30 eV. Both magnetic and electrostatic spectrometers are employed in present measurements. A premium is placed on precise control of systematic effects and on knowledge of the detailed response of the spectrometer to monoenergetic electrons. Given the importance of the result and the convenient value of the 3-H - 3-He mass difference, continued effort to improve such devices and the sources used is quite desirable.

III.10.4. DETECTORS FOR SOLAR NEUTRINO EXPERIMENTS

The experiments of R.Davis to measure to flux of neutrinos emanating from the sun have consistently yielded a value which is about one-third of the calculated flux of solar neutrinos using best present information on solar physics. The experiment uses a large underground tank of perchlorethylene to measure the inverse beta decay of 37Cl + neutrino --> 37Ar. The 37Ar is periodically removed and counted. This reaction has a threshold that is so high that the neutrinos emitted from the basic solar burning process, the p+p reaction, cannot be detected. Instead, only those neutrinos at the upper end of the neutrino energy spectrum from the sun, corresponding to 8-B, can be seen. In addition, only electron-type neutrinos can be detected due to the choice of reaction. Given the apparent challenge to our understanding of the best known star, two experiments are underway to measure the p+p neutrinos using a large gallium detector, and proposals exist for improved water Cerenkov detectors to measure the neutrino spectrum in real time and in a neutrino-flavor independent manner. The former experiments require sophisticated radiochemical techniques while the latter require an advance in the state of the art for background in water Cerenkov detectors. Both require the existence of large underground laboratories to provide the needed detector volume and cosmic ray shielding. The Ga experiments use existing areas at Gran Sasso and Baksan. These large underground laboratories also offer the possibility to do other low-background measurements.

III.10.5. ULTRALOW TEMPERATURE DETECTORS

New opportunities are opening up with the development of special ultralow temperature bolometric detector systems for use as particle detectors. Such devices promise lower thresholds and better resolution in energy than any other detector available now. Present focus of developments is on the detection of ballistic phonons generated following energy deposition by a charged particle in an ultralow temperature crystal. Such phonons can be detected, e.g. by voltage pulses in superconducting lines deposited on the surface of the crystal. Energy resolutions of $\Delta E/E < 10^{-3}$ should be achievable in the 1 MeV range. This would also allow detection of neutral particles by measuring recoil energy. Active programs presently exist at Stanford and Princeton. Other possibilites are in development of superconducting tunnel junctions and super Schottky diodes. Such instrumentation programs require close collaboration with the semiconductor industry to produce state of the art solid state devices.

These programs, also quite small at present, are one area where investment in funds for R&D projects might lead to significant paybacks for the field.

III.10.6. RECOMMENDATIONS

It is difficult to write general recommendations for this topic due to the unique nature of the various experiments. In general, however, these efforts benefit from monies to try out novel and even odd approaches. Many topics of interest have already been examined, meaning future efforts will require apparatus with better acceptance, better precision, and better readouts if present techniques are merely developed. Close collaboration with industry is nearly always required. Novel techniques can bring strides in what can be done, but require patience and development time and funding to come to fruition. It is important that funding patterns are flexible enough to support new and innovative projects even if they fall into new areas.

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