Instrumentation and Computing Frontiers

Snowmass Summary

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On behalf of

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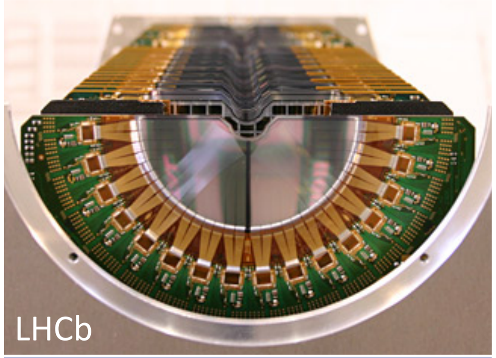
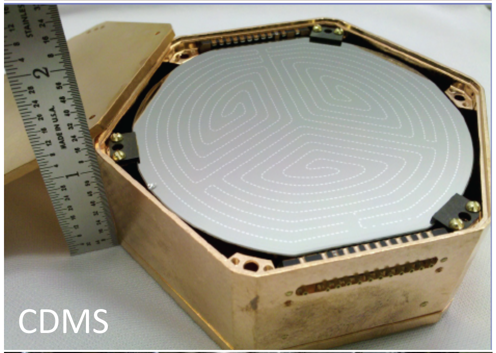
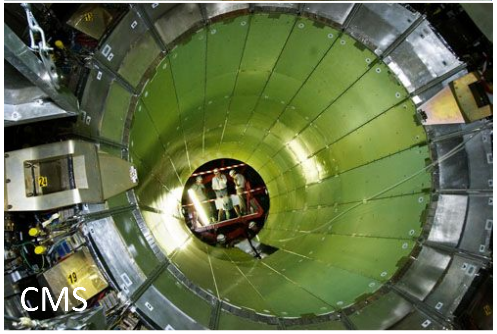
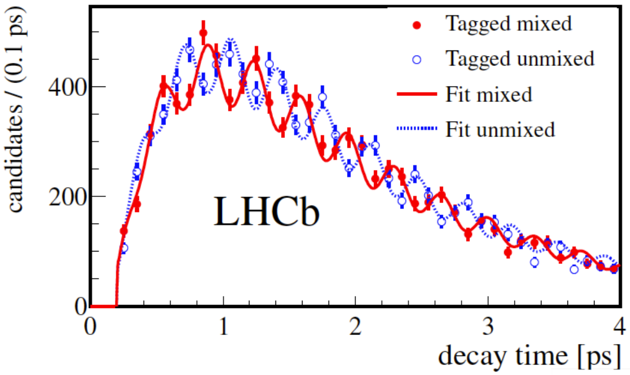
Instrumentation and Computing in HEP

- HEP has a long history of inventing detectors and building computing infrastructure to address the science needs and advance these technologies to large scale

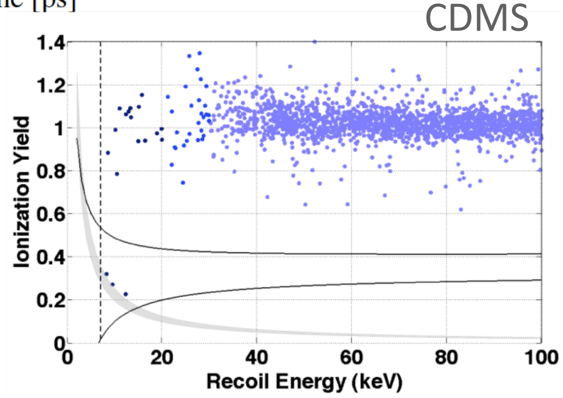


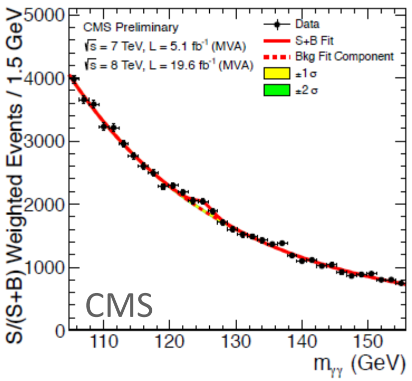






$\Delta m_s = 17.768 \pm 0.023$ (stat) $\pm\ 0.006$ (syst) ps^{-1}





$m_H\ (\gamma\gamma) = 125.4 \pm 0.6 \pm 0.6$ (GeV)

Instrumentation Organization and Input

- Organized as matrix of technologies and frontiers for Snowmass

	CPAD
Sensors	Artuso Seiden
Gaseous	Gilchriese Wagner
Systems	Blucher Lissauer
Electronics	Heintz Lipton
Emerging	Alexander MacFarlane

With 43 liaisons
at the intersection
of technologies
and frontiers

Contributed Papers
Energy Frontier: 11
Cosmic Frontier: 12
Intensity Frontier: 7
Technologies: 30
Facilities: 3
Total: ~63

David Lissauer	Intensity
Juan Estrada	Cosmic
Ulrich Heintz	Energy
Erik Ramberg	Capabilities

Approach

- Study of the instrumentation needs of the field now and in the future
- Study of our current capabilities and efforts
- Identify our challenges and areas where we will fall short
- Propose a strategy to address some of these issues

Instrumentation Challenges

- Experiments increasingly put extraordinary demands on detectors, DAQ systems and associated engineering, often at very large scale
- Our scientific approaches are broadening now including experiments covering: low energy, ultra-low background, very large volume detectors, cosmic energy and matter, high intensity and of course high-energy experiments
- Paradigm altering advances are happening in other branches of science, which hold the potential to lead to transformative new technologies for HEP, which are not taken advantage of
- Substantial investments in R&D are being made outside of the US and there is a perception the US is lagging
- Instrumentation expertise, and corresponding infrastructure, is eroding
- The current funding portfolio approaches subsistence levels and leaves very little flexibility to address the needs of the country
- In tight budgetary times there is enormous pressure on “discretionary” funding

Instrumentation Program

- Major challenge for instrumentation is to design a program that will enable the US to maintain leadership in many key areas of a broad international program while at the same time investing in technology developments for future leadership experiments

1. **Develop balanced Instrumentation, based on our strengths, aligned with research priorities, aimed at innovation**

2. **Balanced funding level between projects and R&D and a program with appropriate "portfolio of risk"**

3. **Develop process for integrating universities, national laboratories, other branches of science and industry**

4. **Create opportunities for providing careers in HEP instrumentation**

5. **Identify opportunities for technology transfer and collaboration with other sciences**

Elements of a Balanced Instrumentation Program

- Ideally, generic instrumentation program should carry out detector R&D at multiple levels at the same time
- R&D in evolution of existing technologies
  - By necessity project driven and low-risk
  - Critical to maintain leadership in current experimental efforts
- R&D motivated by common goals among various experiments
  - Generally longer term and higher risk
  - Benefits multiple experimental areas at the same time
- R&D motivated by transformational change
  - Can lead to incremental or significant improvements in cost reduction and/or scientific reach
  - High risk – high reward R&D with potential to lead to scientific breakthroughs
  - Long time scale

- **Program needed with a balanced portfolio of risk between evolutionary and revolutionary detector R&D and an appropriate level of 'generic' project related detector R&D**

A New Program

- Missing from the current program is the investment in transformative technologies
- Suggest to initiate a new detector development program, outside the existing R&D funding, for long-term investment in more challenging but potentially high impact research (Grand Challenges):
  - Issued periodically, nation-wide
  - Call addresses key technological issues that currently limit science reach
  - Adopts an innovative approach that could prove transformational if successful
  - Has emphasis on multi-disciplinary approach
  - Builds on close collaboration with universities and national laboratories
  - Be subject to review with funding at a substantial level for at least three years

- Areas where existing technologies would be cost-prohibitive for meeting the goals of future experiments would be good candidate research areas

Benefits of a New Program

- Transformational technologies can only be developed with funding for high-risk, high-reward detector R&D in grand challenge solicitations
- It provides a highly visible, challenging opportunity with direct impact on the field
- Through its university – national lab collaboration:
  - Enables and encourages tapping into the broad range of expertise at each participating institution
  - Allows universities to train students in complicated design projects
- It provides a means to reconstitute the infrastructure at universities
  - Reduces engineering and technical loads on labs for major projects
  - Allows university researchers to become more involved
- Provides a path to keep up with advances in industrial technology and for the US to make substantial contributions to future detectors
- Provides a way to have uncommitted reserves to enable opportunistic investments or unexpected difficulties
- **Would focus the creative power of the community and make instrumentation a most attractive setting which provides a challenging environment, to develop, recruit, and retain the best and brightest throughout the world**

Training and Career Path

- **Underpinning these R&D efforts is the urgent need for training the next generation of instrumentation experts**

- **Without these experts, there can be no long-term future!**

- **This requires:**
  - **Challenging projects to attract the best and brightest**
  - **A career path, both at laboratories and universities, for an instrumentation oriented career**
  - **Training opportunities and adequate mentoring**

Strategic Areas

- From the plethora of technologies and needs of all the frontiers, identified key candidate areas for strategic investment that could form pillars of a future HEP program
- Experiments, physics goals and technologies considered: HL-LHC, ILC, CLIC, Muon collider, neutrino detectors, DM detctors, CMB and dark energy studies, rare decay experiments, high energy cosmic ray observations, heavy flavor factories
- Criteria applied:
  - Hold promise of substantial cost saving
  - Hold promise of being breakthrough technology
  - If successful, should have enormous impact on the science reach
  - Based on the existing strengths and capabilities in the country
  - Preferably have impact in fields other than HEP

List of Strategic Areas

Instrumentation Area	Possible Technology	Energy F.	Intensity F.	Cosmic F.	Nucl. Phys.	BES	Applied
ASICs	Waveform sampling, 3D assemblies, high channel – high data rate, radiation hard	✓	✓	✓	✓	✓	✓
Calorimetry	Crystal EM calorimetry, compensating	✓	✓		✓	✓	
High Speed DAQ	ATCA, high-speed optical links	✓	✓	✓	✓	✓	✓
Large Volume Detectors	Neutron veto detectors, low background materials, photo-det.		✓	✓	✓		✓
Photodetectors	LAPPD or SiPM	✓	✓	✓	✓	✓	✓
Pixelated Sensors	Built-in intelligence, novel trigger primitives	✓	✓	✓	✓	✓	✓
Power and Mass	Carbon, G-pixel Si, power delivery	✓	✓		✓		✓

It is expected that CPAD will be engaged to identify a complete set of grand challenges

Snowmass Computing Frontier Study

Conveners: Lothar Bauerdick (FNAL), Steven Gottlieb (Indiana U)

The charge:

- What are the computational **requirements for carrying out the experiments** that will lead to advances in our physics understanding?
- What are the computational **requirements for theoretical computations and simulations** that will lead to advances in our physics understanding?
- What **facility and software infrastructure** must be in place in order to meet these requirements, and what **research investments** does it require in computing, storage, networking, application frameworks, algorithms, programming, etc. to provide that infrastructure?
- What are the **training requirements** to assure that personnel are available to meet the needs?

Subgroups for "user needs" **Computing needs of physics**

- CpF E1 Cosmic Frontier
  - Alex Szalay (Johns Hopkins), Andrew Connolly (U Washington)
- CpF E2 Energy Frontier
  - Ian Fisk (Fermilab), Jim Shank (Boston University)
- CpF E3 Intensity Frontier
  - Brian Rebel (Fermilab), Mayly Sanchez (Iowa State), Stephen Wolbers (Fermilab)
- CpF T1 Accelerator Science
  - Estelle Cormier (Tech-X), Panagiotis Spentzouris (FNAL); Chan Joshi (UCLA)
- CpF T2 Astrophysics and Cosmology
  - Salman Habib (Chicago), Anthony Mezzacappa (ORNL); George Fuller (UCSD)
- CpF T3 Lattice Field Theory
  - Thomas Blum (UConn), Ruth Van de Water (FNAL); Don Holmgren (FNAL)
- CpF T4 Perturbative QCD
  - Stefan Hoeche (SLAC), Laura Reina (FSU); Markus Wobisch (Louisiana Tech)

Subgroups for "infrastructure" **Technical capability mapping to needs**

- CpF I2 Distributed Computing and Facility Infrastructures
  - Ken Bloom (U.Nebraska/Lincoln), Sudip Dosanjh (LBL), Richard Gerber (LBL)
- CpF I3 Networking
  - Gregory Bell (LBNL), Michael Ernst (BNL)
- CpF I4 Software Development, Personnel, Training
  - David Brown (LBL), Peter Elmer (Princeton U.); Ruth Pordes (Fermilab)
- CpF I5 Data Management and Storage
  - Michelle Butler (NCSA), Richard Mount (SLAC); Mike Hildreth (Notre Dame U.)

… and participation from the wider community

HEP Computational Challenges

- Challenging resource needs require efficient and **flexible use of all resources**
  - HEP needs both **Distributed High-Throughput Computing** (experiment program) and **High-Performance Computing** (mostly theory/simulation/modeling)
    - emerging experiment programs might consider a mix to fulfill demands
    - programs to fund these resources need to continue
  - **Sharing** and **opportunistic use** help address resource needs, from all tiers of computing, eventually including commercial clouds etc
  - More need for **data intensive computing**, including at HPC, for data analytics, combining simulations and observational data etc.
- To stay on the Moore's law curve, need to proactively make full/better use of **advanced architectures:** multi-threading, GPU environments, low-energy CPUs
  - With the need for more parallelization the **complexity of software and systems** continues to **increase**: frameworks, workload management, physics code
  - Important needs for **developing and maintaining expertise** across field, including re-engineering of frameworks, libraries and physics codes, adapting key software tools
- Unless corrective action is taken we could be frozen out of cost effective computing solutions on a time scale of 10 years.
  - There is a large code base to re-engineer
  - We currently do not have enough people trained to do it

HEP Data Challenges

- The growth in HEP data drives the need for continued R&D investment in **data management, data access methods, networking**
  - Storage cost are not scaling with huge increases in future demand
  - Need continued evolution to take advantage of network capabilities
  - Ensure efficiency and robustness of the global data federations
  - Contain the level of effort needed for operations
- Data intensive distributed computing enabled by networks
  - Network capabilities and data access technologies improve our ability to **use resources independent of location**, over the network
  - Enables use of a **large spectrum of resources**: dedicated facilities, universities, opportunistic use, commercial clouds, leadership-class HPC,...
  - Distributed **data and processing management systems** unify resources into a usable system
    - emerging solutions are based on **content delivery networks** approach, **dynamic data placement** across federated storage, **remote data access** over the network
    - treat **networks as resource**, include their capabilities in computing models
- These technologies require investments, but already pay big dividends!

Need for Training and Career Paths

- Encourage and support training, as a continuing activity
  - Use certification to document expertise and encourage learning new skills
  - Use mentors to spread scientific software development standards
  - Involve computing professionals in training of scientific domain experts
  - Use online media to share training
  - Use workbooks and wikis as evolving, interactive software documentation

- We need to provide young scientists with opportunities to learn computing and software skills that are **marketable** for non-academic jobs

- We need training and **career paths** (including tenure stream) for researchers who work at the forefront of computation techniques and science is critical

Outlook Instrumentation and Computing

- Successes in HEP have always been closely tied to advances in instrumentation and computing
- We need to push in both areas for using new technologies and approaches that are transformative
  - Instrumentation: grand challenge approach
  - Computing: Distributed computing, networks, parallelization, virtualization, GPUs etc
- Industry has caught up to us, and in cases has surpassed us. We need to take advantage of the progress in industry and of advances in other science disciplines
  - For Computing: Ubiquitous Big Data is good news, clouds are good news...there is much to leverage!
- CPAD, as representative of the community, can play an important role in addressing instrumentation development in collaboration with universities and industry.
- Computing is investing in community planning to solve common problems in a partnership approach

- **Corrective action needs to be taken now, both in computing and instrumentation, to retain a scientific leadership position for the field**

Backup

Voice of Instrumentation

- The Coordinating Panel for Advanced Detector has been appointed as advocate of instrumentation to articulate, promote, coordinate and implement the strategic goals for instrumentation

- CPAD can play an important role to implement a balanced instrumentation program benefiting both the universities and the national labs.

- CPAD can bring different science disciplines and industry together for a multi-disciplinary approach to the advancement of instrumentation

Innovation Through Partnerships

Materials Science

Nano Technology

Photonics

Electrical Engineering

National Laboratories

Ames Laboratory
Argonne National Laboratory
Brookhaven National Laboratory
Fermilab
Idaho National Laboratory
Berkeley Lab
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
NETL
NREL
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
PPPL Princeton Plasma Physics Laboratory
Sandia National Laboratories
SRNL
SLAC National Accelerator Laboratory
Jefferson Lab

Academia

Industry

RMD A Dynasil Company
ziptronix
INCOM
VOXTEL OPTO