NSAC Subcommittee on the Comparison of RIA and the GSI Project Opportunities and Capabilities

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RIA and GSI Future Facility

- Each facility has strong endorsement of planning committees
- Each has gone through extensive reviews
- Both have been viewed positively by their respective funding agencies – GSI has approval for 75% funding and RIA is tied for 3rd among 28 projects chosen for DOE Office of Science 20 year facilities plan
- But – the costs each approach or exceed $1B

Charge – Compare RIA and GSI Project

Given previously identified scientific opportunities:

- What are the rare isotope capabilities that are unique to each facility ?
- What are the rare isotope scientific opportunities offered by each facility ?
- Are there U.S. nuclear physics programs or national considerations that are relevant to the two facilities ?
- What are the relative costs and benefits of U.S. investments in the two facilities, including possible upgrades that extend the scientific reach of GSI ?

The Bottom Line

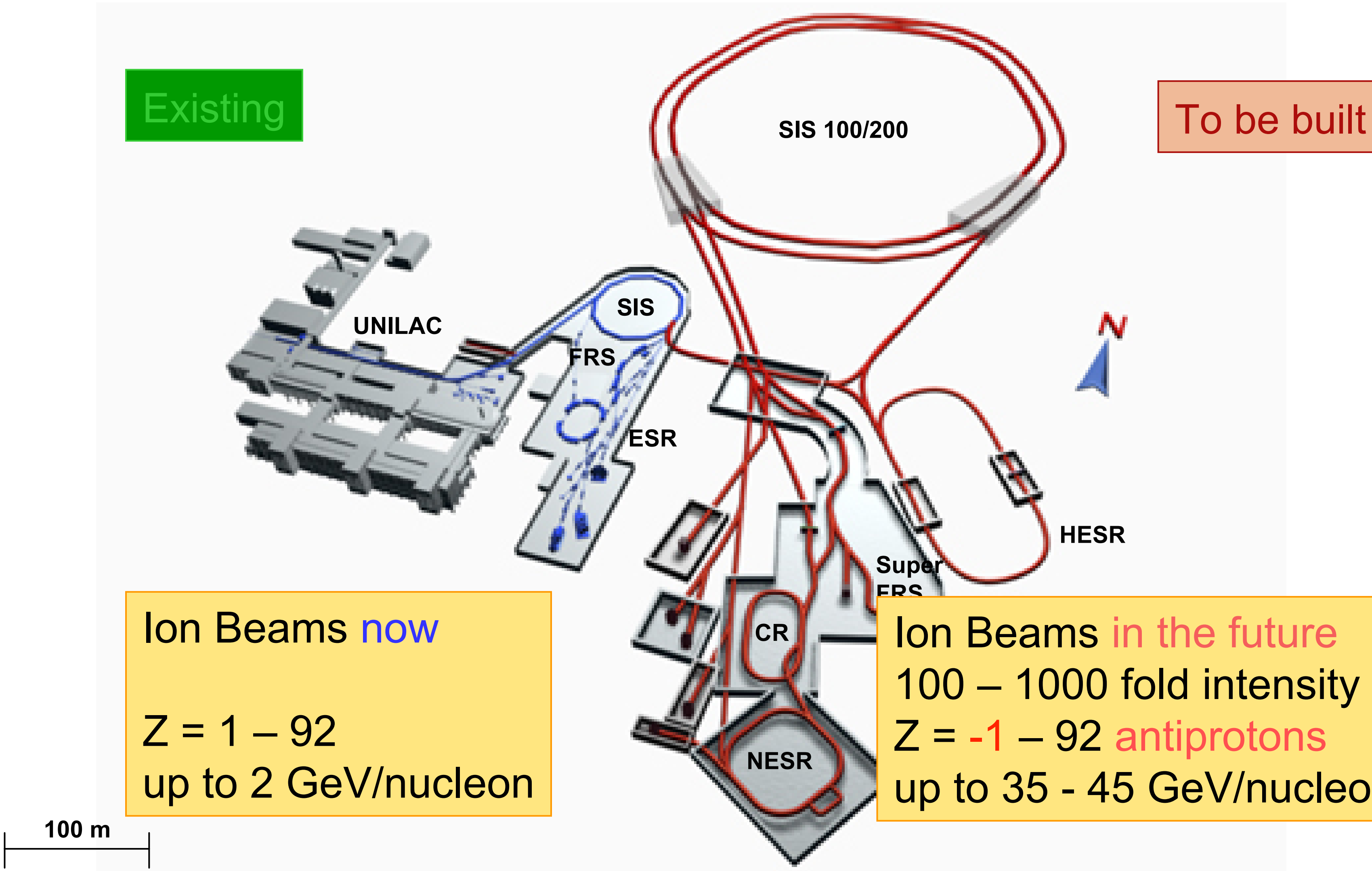
- RIA and the GSI future facility each have distinct capabilities that offer forefront opportunities for the study of rare isotopes
- There is some overlap in fast beam capabilities but RIA's yields and reacceleration capability would not be reproduced at GSI even with additional investment
- The GSI facility will offer opportunities to U.S. researchers in several other science areas
- Both would impact areas of local national importance – especially training

SubCommittee Process

- Utilized information on the web sites
  - GSI facility has a CDR
  - RIA had a wealth of information, but scattered
    - recommend a reorganization of the RIA web-site and production of a single document would be very helpful
- Sent questions to both facilities – very helpful responses
- Joint RIA-GSI document was completed during process
- Had presentations by and met with proponents of RIA and the GSI Director

Accepted stated technical performance goals

The Future International Facility at GSI: Beams of Ions and Antiprotons

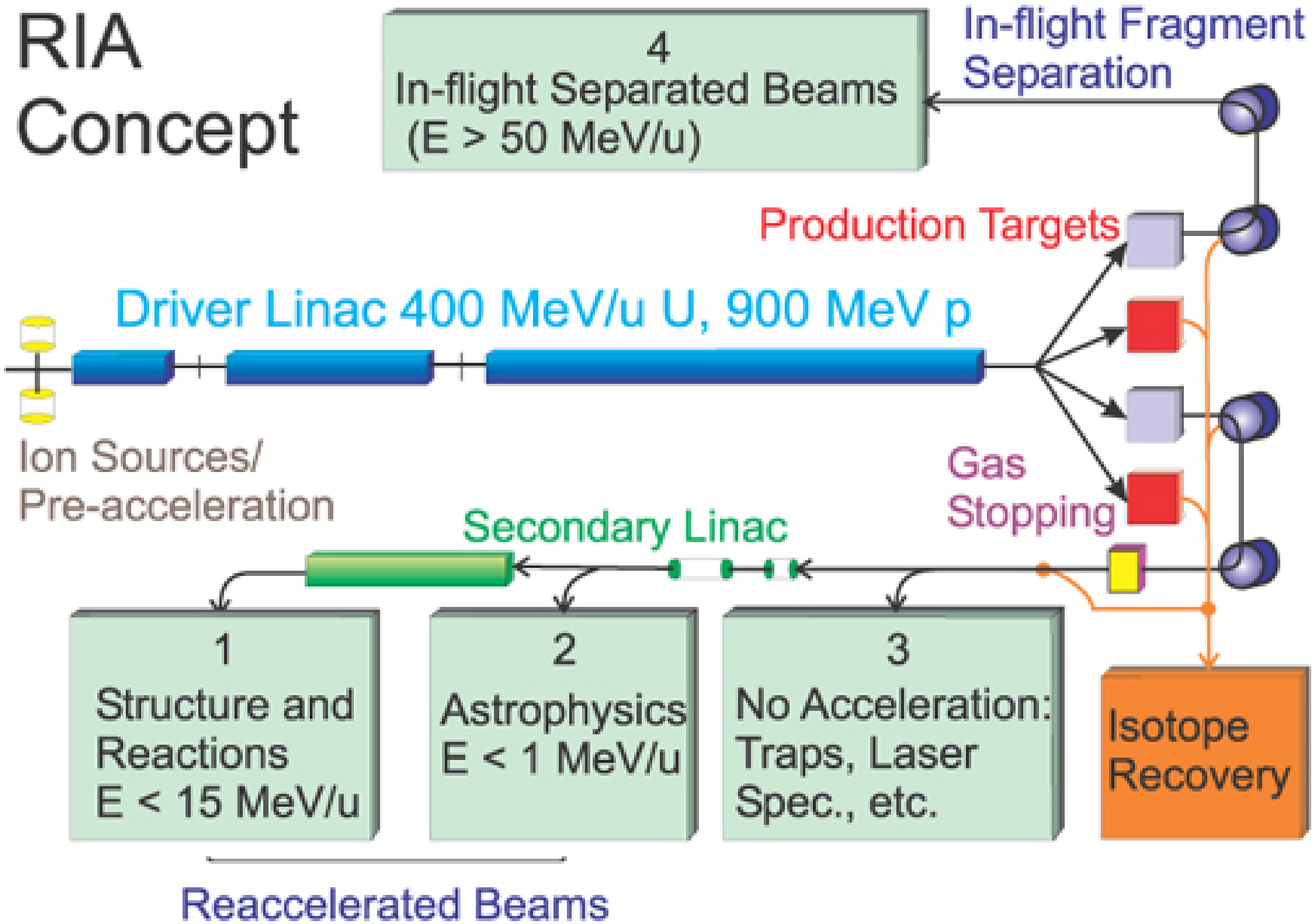


Ion Beams now

Z = 1 – 92
up to 2 GeV/nucleon

Ion Beams in the future
100 – 1000 fold intensity
Z = -1 – 92 antiprotons
up to 35 - 45 GeV/nucleon

The RIA Concept



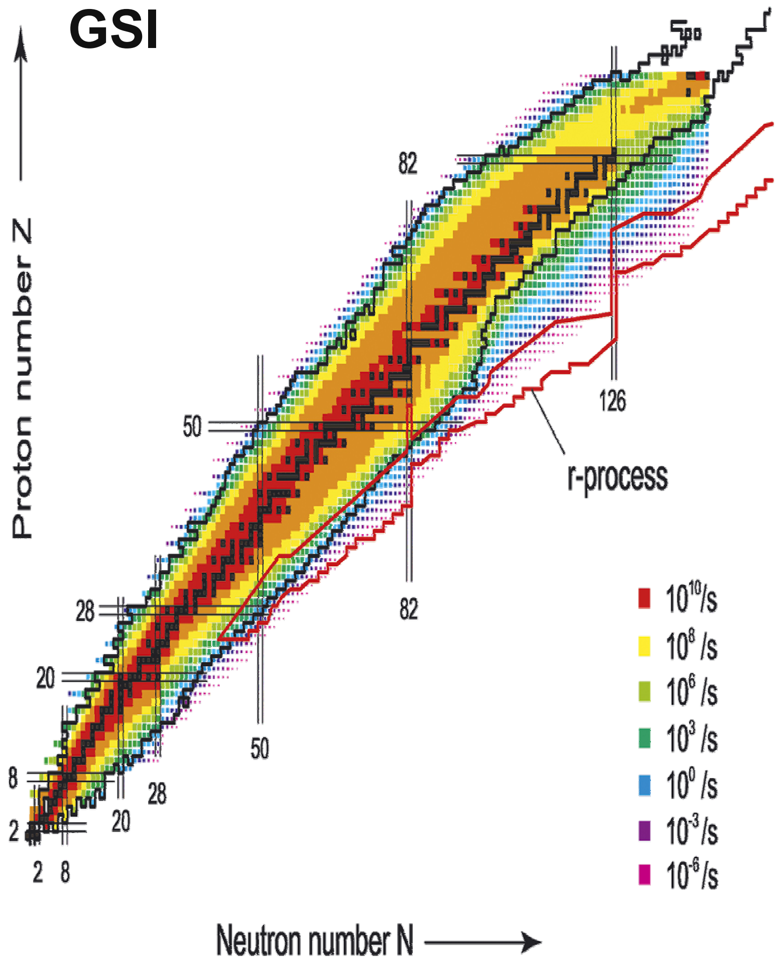
Each of the four target areas is required for important physics

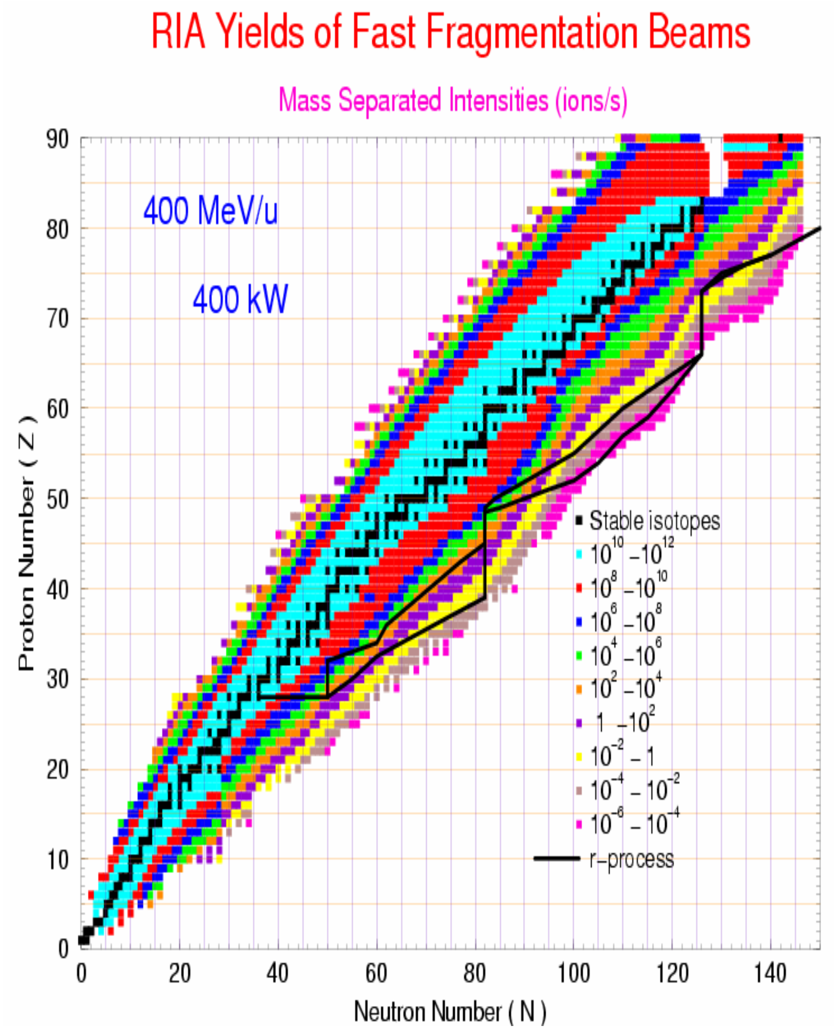
Facilities and Capabilities

- **RIA** – focus on rare isotopes
  - 400 MeV/A linac, 400 kW primary beam
  - Flexible production mechanisms (fast beams, ISOL)
  - Study fast-beam rare isotopes in-flight, at rest
  - Capability to reaccelerate stopped beams
- **GSI** – multi-faceted facility
  - Upgraded 2 GeV/A synchrotron, 100kW primary beam
  - Additional synchrotrons, cooler and storage rings
  - Study fast-beam rare isotopes in-flight, at rest
  - Also physics of RHI, antiprotons, plasma, atomic

Both have fast beam rare isotope production capability

Fast Beam Comparison





Fast beam production comparison

- Both RIA and GSI allow study of in-flight and stopped rare isotopes
- Intensity of secondary beams – RIA 10-100 times higher than GSI due to the choice of a linac vs synchrotrons
- Reach from stability – yields in the r-process region indicate the RIA advantage (~1-3 more neutrons)
- GSI cooler and storage rings and eA capability give it advantage for certain experiments
- Only RIA would reaccelerate rare isotopes

Science Opportunities

- We reaffirm the strong science case for study of rare isotopes

  Nuclear Structure

  Astrophysics

  Fundamental Symmetries

  - There will be some applications

- GSI will also provide capabilities in other science areas

- ***GSI project and RIA were designed for different purposes – they are not equivalent***

Science of Rare Isotopes

- **Nuclear Structure**
  - Map structure out to drip lines – single particle states, collectivity, charge distributions, magic numbers, masses
  - Halo nuclei, neutron “skins”
  - Isospin dependent equation of state (“neutron” matter)
  - Formation of superheavies, determine fission barriers
- **Fundamental Symmetries**
  - Utilize specific isotopes to carry out precise “model-independent” measurements, EDM, atomic parity violation
  - QED in high Z environments - single electron
  - Anti-hydrogen

Science of Rare Isotopes (cont.)

- **Application to Astrophysics**

  Measure quantities crucial to understanding processes in the stars

  - Improve understanding of the origin of specific elements and their ratios
  - Refine key nuclear uncertainties that directly affect astronomical observables such as the light curves of Type I X-ray bursts.
  - Enable a better understanding of core-collapse supernovae where weak interactions and super-nuclear equation of state play a key role.
  - Calibrate a *diagnostic tool*, the theory of stellar nucleosynthesis, that can tell us about the nature of cosmic explosions and the history of stellar evolution in our galaxy and others.
  - Lead to a more physical description of the structure of neutron stars, especially their crusts.

Capability and Rare Isotope Science

- **Stopped/slow nuclei**
  - Mass measurements, e.g. for r-process, rp-process
  - Beta decay studies of rare nuclei
  - Utilization for fundamental symmetries measurements
  - Collect longer lived isotopes as targets

- **Reaccelerated nuclei (only RIA)**
  - Direct measurements of key astrophysical processes, e.g. rp-process
  - Classical nuclear structure studies at extreme N/Z, e.g. shell structure
  - Physics at the proton drip line
  - Utilize very neutron rich beams for possible superheavy elements
  - Indirect measurements of astrophysical processes

Capability and Science (cont.)

- **Cooled/Stored Beams (only GSI)**
  - Measure wide range of mass and lifetime (effect of bare nuclei)
  - Charge, mass distributions of rare isotopes (e, p scattering)
  - Select and study isomeric isotopes

- **Fast beam production**
  - Greatly extend known nuclei to limits of stability (drip lines), Z~40
  - Decay studies at the limits of stability
  - Produce nuclei with halos and neutron skins
  - Indirect measurements of astrophysical processes,e.g. G-T
  - Nuclear equation of state, neutron rich

Compare capabilities to carry out science of rare isotopes

Nuclear Structure Studies

- **RIA strength**:
  - higher intensity of unstable isotopes
  - reaccelerated beam capability - critically important to a large part of the nuclear structure program
  - Full panoply of nuclear physics techniques applied to rare isotopes

- **GSI strength**:
  - Simultaneous measurement of wide range of mass
  - May have cleaner separation for high masses
  - Colliding-beam eA studies of nuclear charge distributions

r-process

Need masses, lifetimes, cross sections

- **RIA strength**:
  - Higher intensities allow more sensitive and higher quality structure and life-time measurements
  - Can probe 2-3 neutrons deeper than GSI into the unknown neutron rich regions
  - Proposed reaction studies, e.g. (d,p) to probe (n,γ) reaction rates, can also be performed over a wide energy range.
- **GSI strength**:

  Storage ring allows simultaneous multi-mass measurement

Both can probe Coulomb dissociation

rp-process and Nova Explosions

- **rp-process in Type I x-ray bursts**
  - RIA appears favored for studies of rp-process because of higher beam intensity and the consequent ability to measure small (p,γ) cross sections on a broader range of interesting nuclei
  - GSI and RIA can measure gamma dissociation, β decays
- **Nova explosions** (similar to rp at lower masses and temp)
  - GSI and RIA can measure Coulomb dissociation (γ,p) etc
  - RIA has an advantage because it can determine (p,γ) cross sections on the relevant nuclei more accurately

Supernova Diagnostics/Explosions

- **Supernova Diagnostics**
  - RIA's ability to harvest and reaccelerate high intensity beams of long-lived radionuclides,e.g. ^{26}Al, ^{44}Ti to measure p and α capture rates gives it an advantage
  - Both RIA and GSI can measure gamma dissociation

- **Supernova Explosions**
  - Equation of state is key and both facilities will be important
  - GSI able to access higher densities (up to about 4 times normal nuclear vs 2 for RIA). Both will address a comparable range of isospin (esp. neutron rich).
  - RIA may be superior for the (p,n) cross sections needed to constrain the Gamow-Teller strength function (e-capture rates)

p-process/γ process/s-process

- **p- and γ processes**
  - Both facilities comparable in the application of Coulomb dissociation techniques,
  - RIA seems more versatile with possibility of measuring inverse proton and alpha capture reactions and use detailed balance

- **s-process**
  - Not clear how well either will do here as neutron capture experiments with radioactive beams are very challenging.
  - Higher beam intensities give RIA advantage for measuring (n,γ) reactions on implanted long-lived (>1d) radioactive isotopes *were an external neutron beam available*
  - Direct (n,γ) studies on short-lived isotopes are not possible with presently available techniques on either facility

Fundamental Symmetries

- **RIA strength**:
  - higher intensities and multiple separation techniques give RIA an advantage over GSI because larger quantities of isotopes will be available, e.g. Fr, especially for the atomic parity violation and EDM measurements
- **GSI strength**:
  - clearly competitive in experiments limited by challenges other than intensity
  - storage ring will make possible QED studies on highly ionized ions and probe QED in the strong field regime
  - antiproton facility and the host of fundamental experiments on antimatter will be possible at GSI

Applications (focus on just two)

Applications not the basis for RIA, but may be relevant

- Stockpile Stewardship
  - Measure unknown cross sections to better understand historical data and improve computer codes
  - Harvest isotopes, add neutron generator (NNSA funds)
  - Measurements valuable, but not crucial as most uncertainty in primary, not secondary
- Medical Isotopes
  - Will have capability for producing research and production isotopes
  - Case must be made better: cost effectiveness, energy, need

Other science opportunities

- CEBAF and RHIC provide unique U.S. facilities utilized by the world community – RIA would be in the same class for rare isotopes
- GSI project provides distinct opportunities in variety of complementary areas that are likely to attract U.S. researchers who may propose to contribute to experimental equipment

Antiproton Physics (GSI)

- GSI program extends antiproton programs carried out at the CERN LEAR facility in the 80's and 90's with an increase of energy to explore the charm sector
  - charmed states not easily made at an e+e- machine
  - extends work begun at Fermilab to higher energy with higher luminosity and is complementary to planned CLEO-c program
  - search for charmed hybrid mesons complements planned searches for light-quark hybrid mesons at CEBAF following its planned 12 GeV upgrade.

Relativistic Heavy Ions (GSI)

- AGS and CERN in 80’s and 90’s explored fixed target region from 10 GeV/A to 160 GeV/A– deduced maximum baryon density at about 30 GeV/A
- GSI to expand the study of RHI in this high baryon density region 1-40 GeV/A, e.g. continue search for multiply strange objects
- Complementary to low baryon density at RHIC/LHC
- Likely to attract some U.S. researchers although most are focused on higher energy

Plasma and Atomic Physics (GSI)

- DOE Fusion Program has formal agreement with GSI so clearly will participate
- GSI storage rings will allow high precision measurements of QED in high fields and also provide many “applied” atomic physics needs

Training

- For all areas of science training of new researchers is key to development of field. Scientific communities often argue that their field is important and survival of their field requires the funding of a particular project.

The case here has a special focus.

- Broad range of societal areas that require training in low energy nuclear physics, e.g. Medical, Industrial applications, Homeland Security, NNSA
- Unique science of CEBAF and RHIC has shifted training focus in U.S. from low energy, but many applied societal needs remain at low energy

International Collaborations/Users

- International Cooperation is particularly important for expensive facilities – GSI and U.S. institutions collaborating and extensive RIA-GSI collaborations
  - Examples - fragment separators, high resolution magnetic spectrographs, trapping of nuclei, gas stopping of fast nuclei, improving predictions for yields of nuclei produced by fragmentation, high power liquid lithium targets.

- **Are there enough users ?**
  - User bases are distinct
  - GSI 1100 and projected to be 2000 (~40% rare isotopes)
  - RIA now at 600 projects about 1000
  - Neither facility could accommodate the total user base

Costs-benefits of U.S. investments

- In order to exploit the science of unique CEBAF and RHIC facilities, NSAC LRP stated RIA construction cost would largely have to come from new money added to the nuclear physics budget. Thus essential, e*specially in the current budget environment*, to avoid duplication of effort and minimize costs where possible

Costs-benefits of U.S. investments

- Why build RIA ? Why not use other facilities ?
- Cede fast beams to GSI ?
- U.S. invest in reacceleration at GSI ?
- Drop ISOL capability ?

Why build RIA ? Use other facilities ?

- Researchers are using other facilities, but RIA would have unmatched performance characteristics with outstanding scientific opportunities

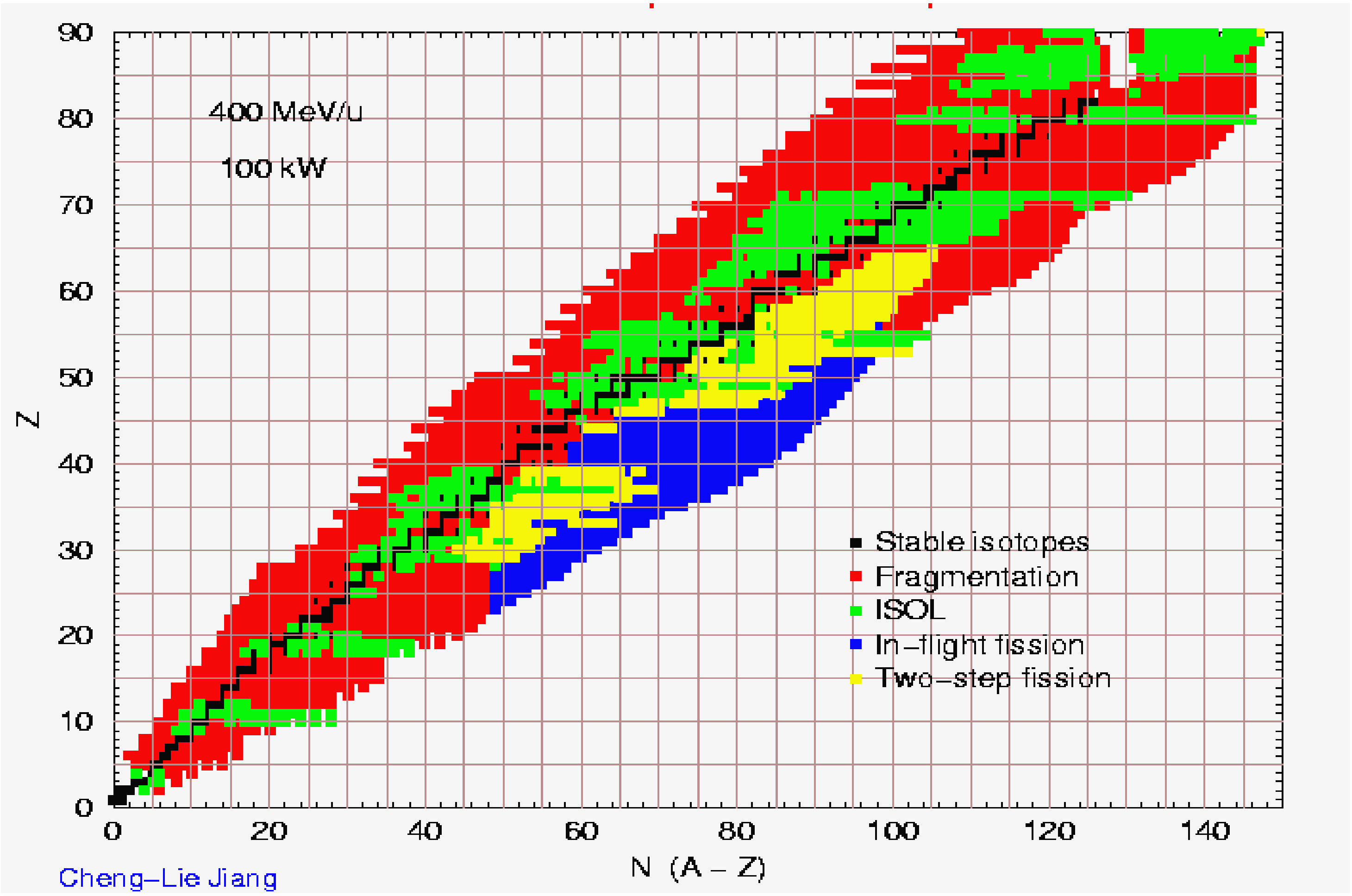
- The Committee knows of no way in which more modest investment in upgrades of U.S. or other overseas facilities could match the capabilities of a dedicated, state-of-the-art facility like RIA

Cede fast beams to GSI ?

- Both RIA and GSI produce fast beams
- Inherent accelerator design differences (linac vs synchrotrons) make RIA’s rare isotope yields much higher than GSI and there is no upgrade at GSI that would change this significantly
- Would lose many capabilities and remove one of the key justifications for RIA

Maximum Reaccelerated Beam Production

(red/blue fast beams; green/yellow ISOL)



U.S. invest in GSI reacceleration ?

- GSI has evaluated reaccelerating their stopped rare isotopes produced via fast beams
- As a result of the choice of synchrotrons and the wide range of science of their extensive user community, GSI management stated they cannot justify reacceleration and will not pursue it
- RIA’s capabilities in reaccelerated isotopes produced via fast beams and ISOL are unmatched

Drop ISOL at RIA ?

- Capability does not exist at GSI
- Cost savings would be 10-15%, but lose
  - the highest intensity secondary beams
  - some key elements for tests of fundamental symmetries
  - only way to produce very high intensity (>10^{10}) re-accelerated secondary beams for heavy element research
  - workhorse for the production of targets of some rare isotopes

Other U.S. Investments in GSI

- U.S. is already working with GSI on a number of machine issues
- Likely proposals from the U.S. research community to invest in experimental equipment at GSI

Summary

- Reaffirm the strong science case for rare isotopes
- RIA and GSI facilities are quite distinct in their strengths
- RIA has a much larger reach as a rare isotope facility
- GSI facility remarkably versatile and multifaceted - provides variety of science opportunities that will likely attract U.S. research community (broader than NP)
- GSI future facility, by itself, does not justify de-scoping rare isotope capability of RIA as there is only modest overlap in their rare isotope capabilities.