Exotic Beam Production and Facilities I

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Lecture I

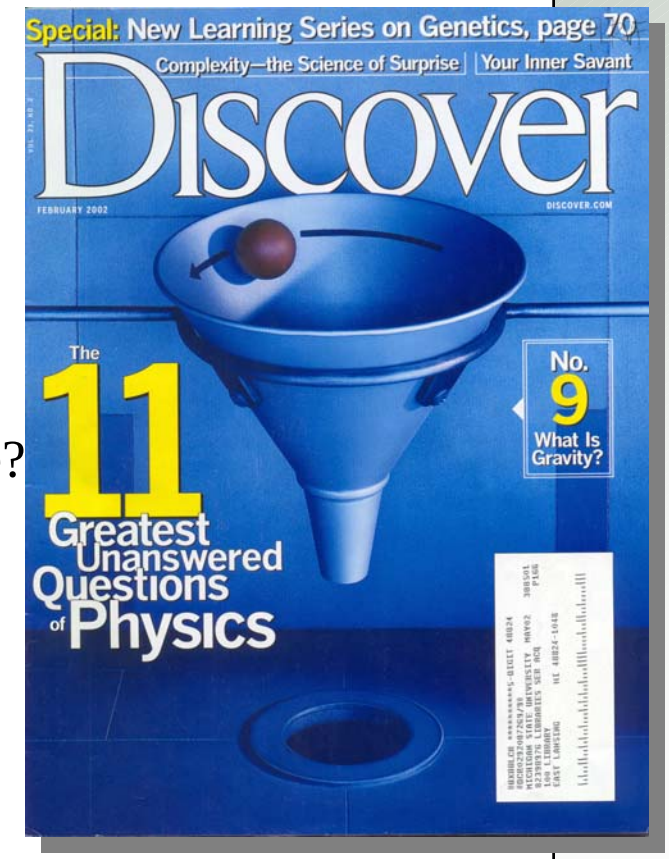
- The Rare Isotope Accelerator Concept
- Some history and background
- The status of exotic beam plans in the USA

Lecture II

- Methods of exotic beam production
- Production mechanisms (e.g. fragmentation)
- Current world situation for exotic beams

Connecting Quarks to the Cosmos

Eleven Science Questions for the New Century (2003) – National Academy Study, Chair M. Turner



—What is dark matter?

—What is the nature of the dark energy?

—How did the Universe begin?

—Did Einstein have the last word on gravity?

—What are the masses of the neutrinos and how have they shaped the evolution of the universe?

—How do cosmic accelerators work?

—Are protons unstable?

—Are there new states of matter at exceedingly high density and temperature?

—Are there additional space-time dimensions?

✓ **How were the heavy elements from iron to uranium made?**

—Is a new theory of matter and light needed at the highest energies?

Why Study Exotic Nuclei?

The study of mesoscopic systems are at the forefront of science.

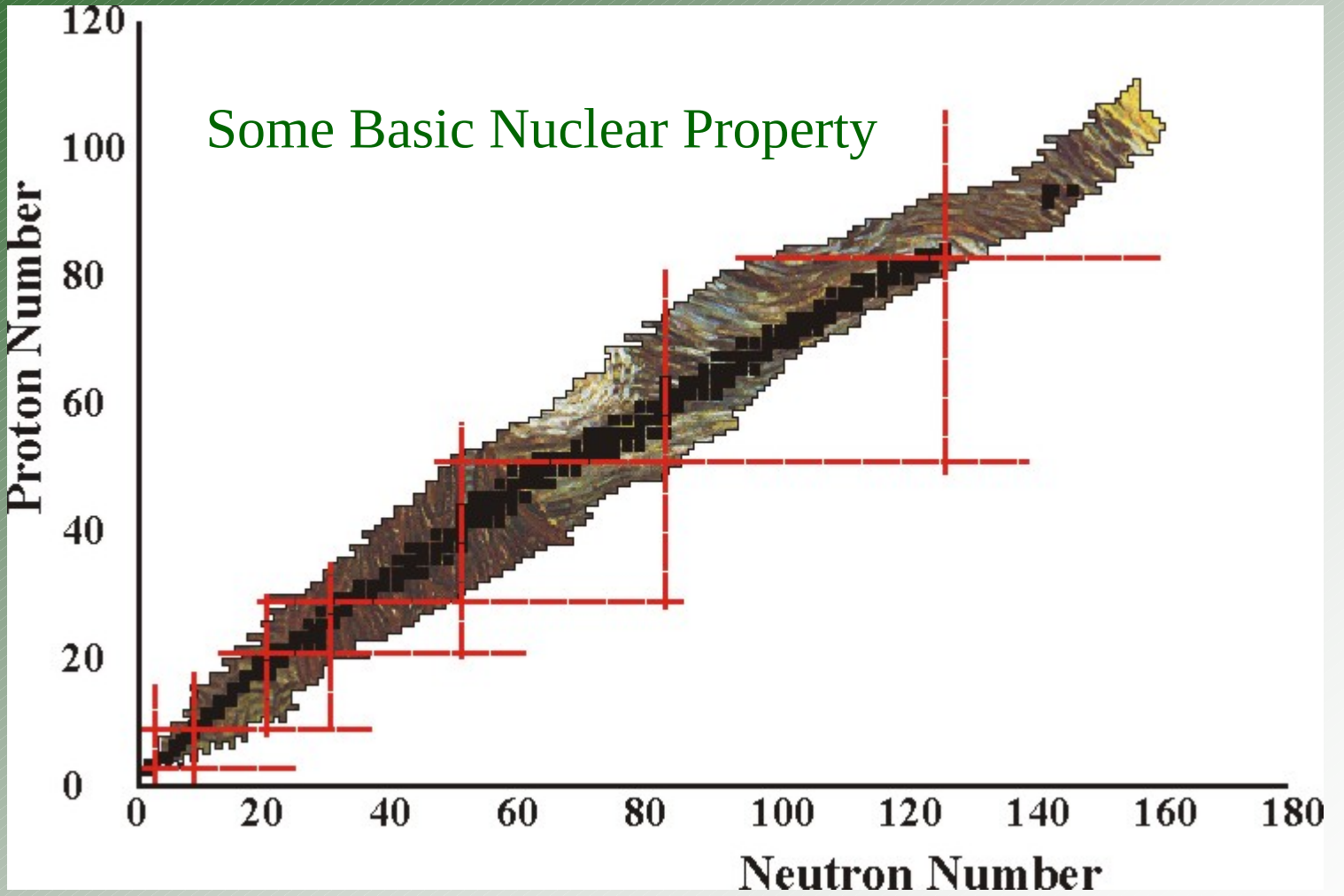
- Nanoscience – quantum dots, trapped atoms/ions, metallic clusters
- Biology – proteins, molecular interactions, self assembly
- Nuclear Physics – nuclei

Nuclei are unique systems: Strong short-range force, isolated, open

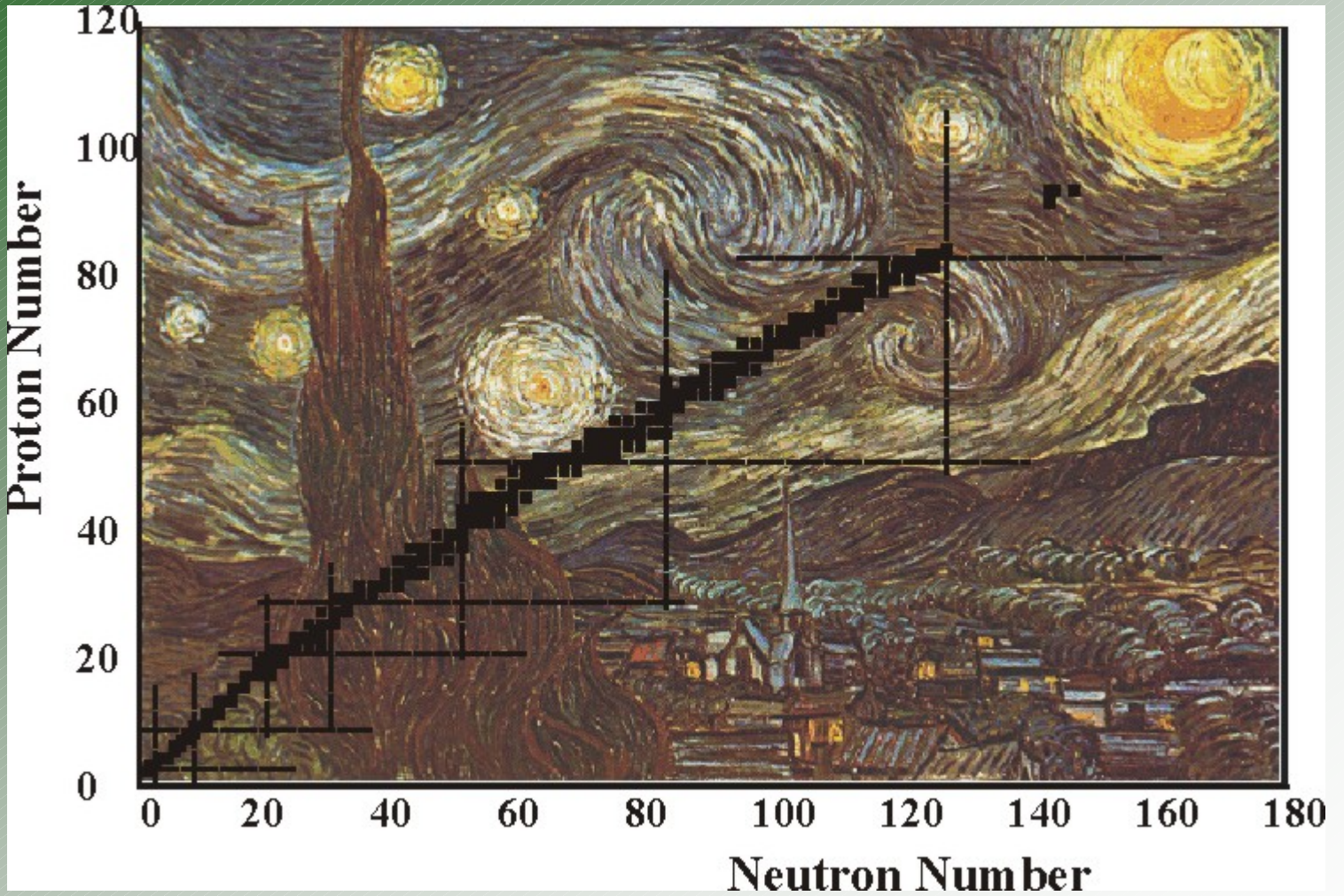
Presently, most nuclear quantities have to be measured. This means that nuclear science is primarily still a phenomenological, experimental science.

It now appears possible to develop a comprehensive theory that will allow approximations to be quantified. However, this is only possible by measurements of very neutron and proton rich nuclei.

At the moment we are limited in our view of the atomic nucleus



RIA Will Greatly Expand Our Horizons



The Scientific Justification for Exotic Beams

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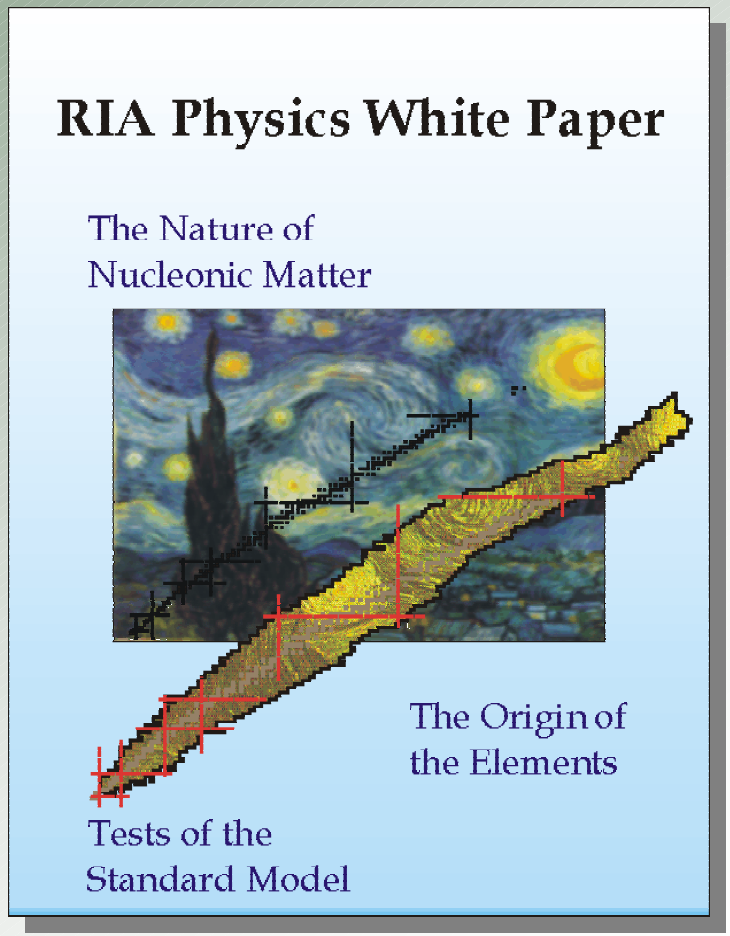
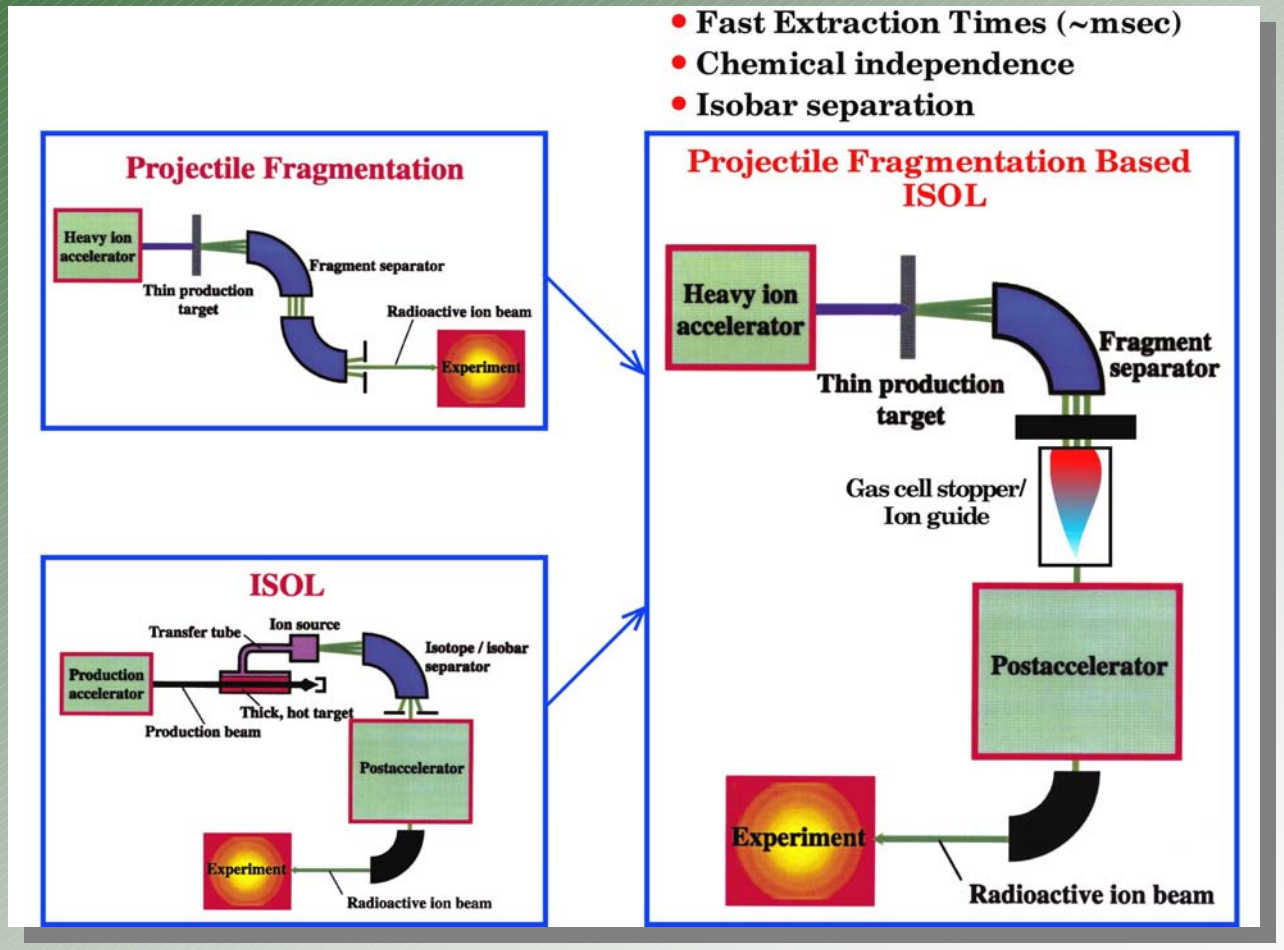
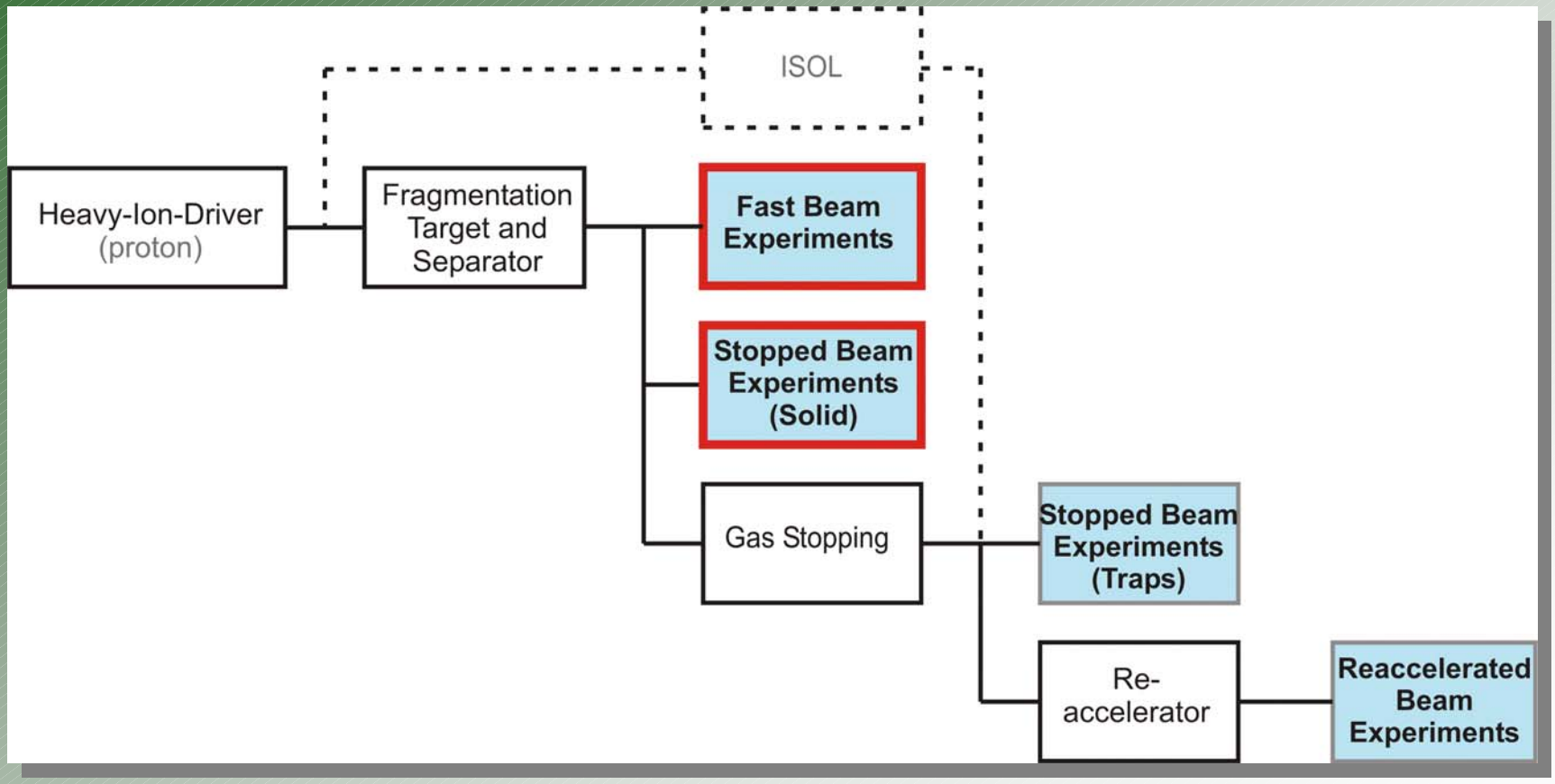
- Atomic Nuclei – Femto Science
- The Chemical History of the Universe and the Origin of the Elements
- Test of the Fundamental Symmetries of Nature Using Nuclei



Methods of Exotic Beam Production



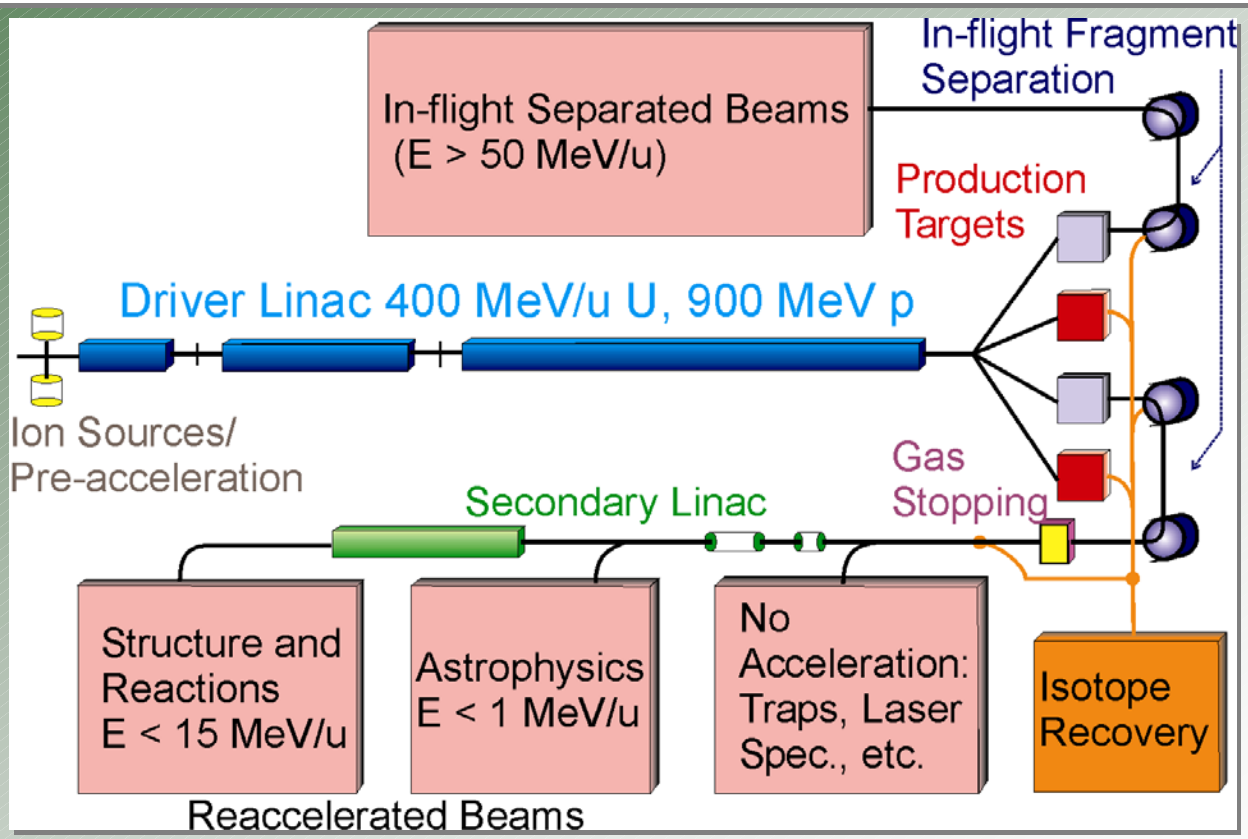
Building Blocks of a Research Facility



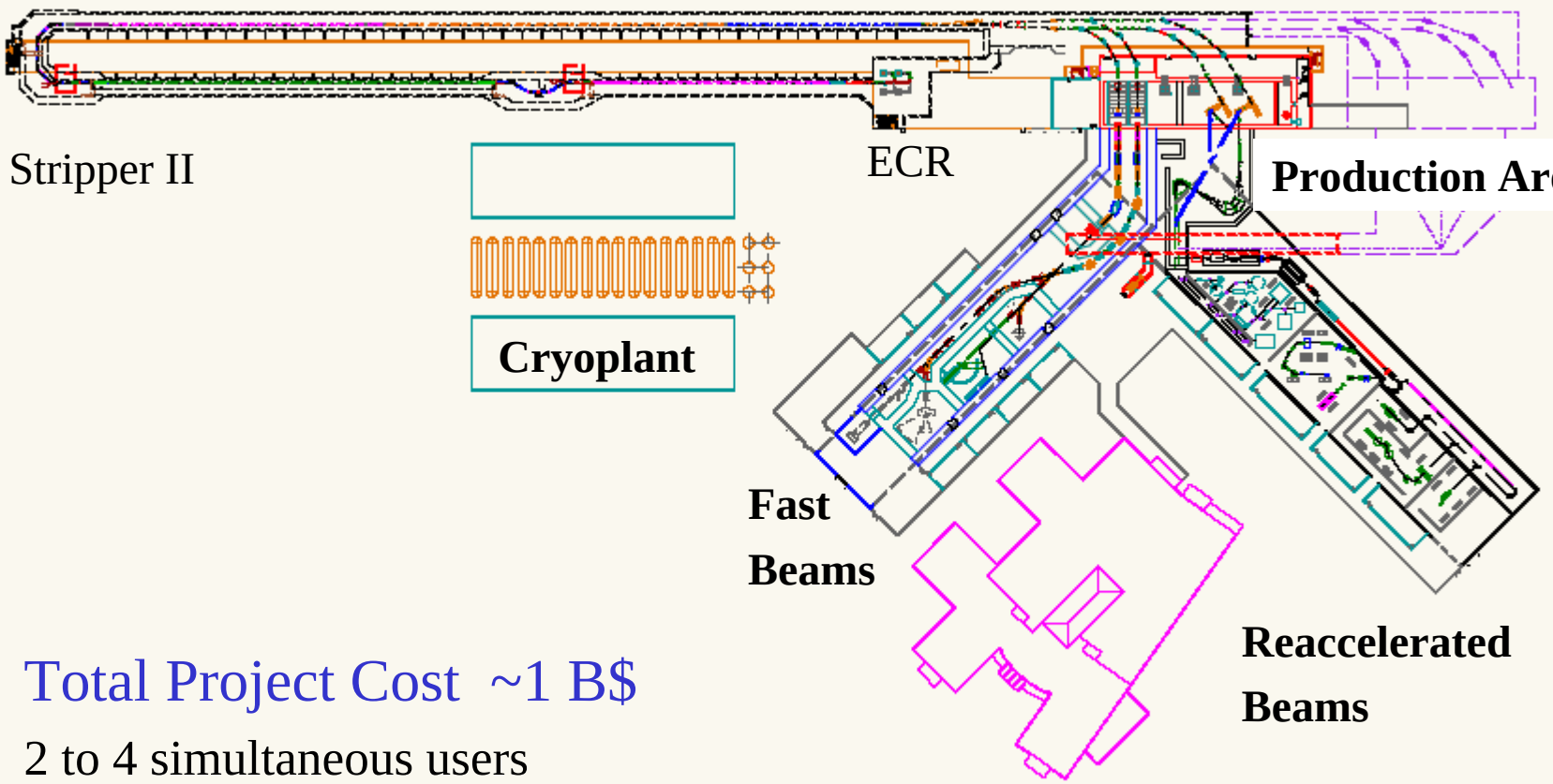
M. Thoennessen

The RIA Concept

- **400 MeV/u Uranium, 1 GeV protons, 400 kW**.
- Up to 4 simultaneous users.
- Secondary beams at energies from 60 kV to 400 MeV/u .



Generic RIA Facility Layout

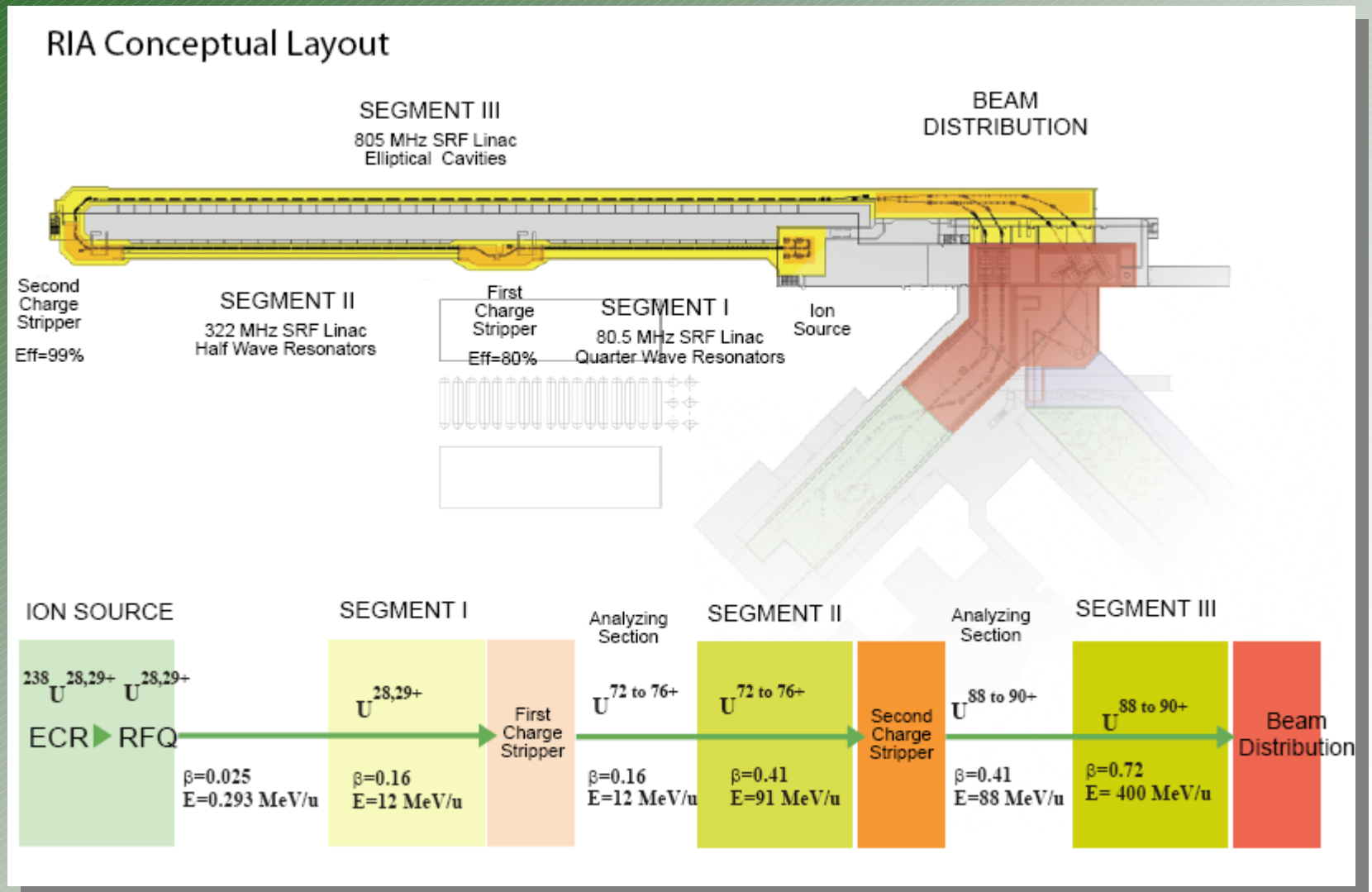


Total Project Cost ~1 B$

2 to 4 simultaneous users

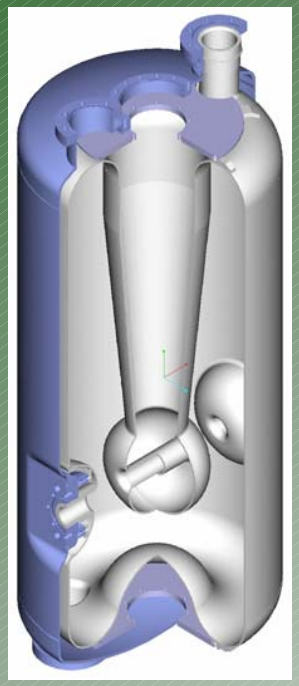
Both ANL and Michigan State University Developed detailed plans.

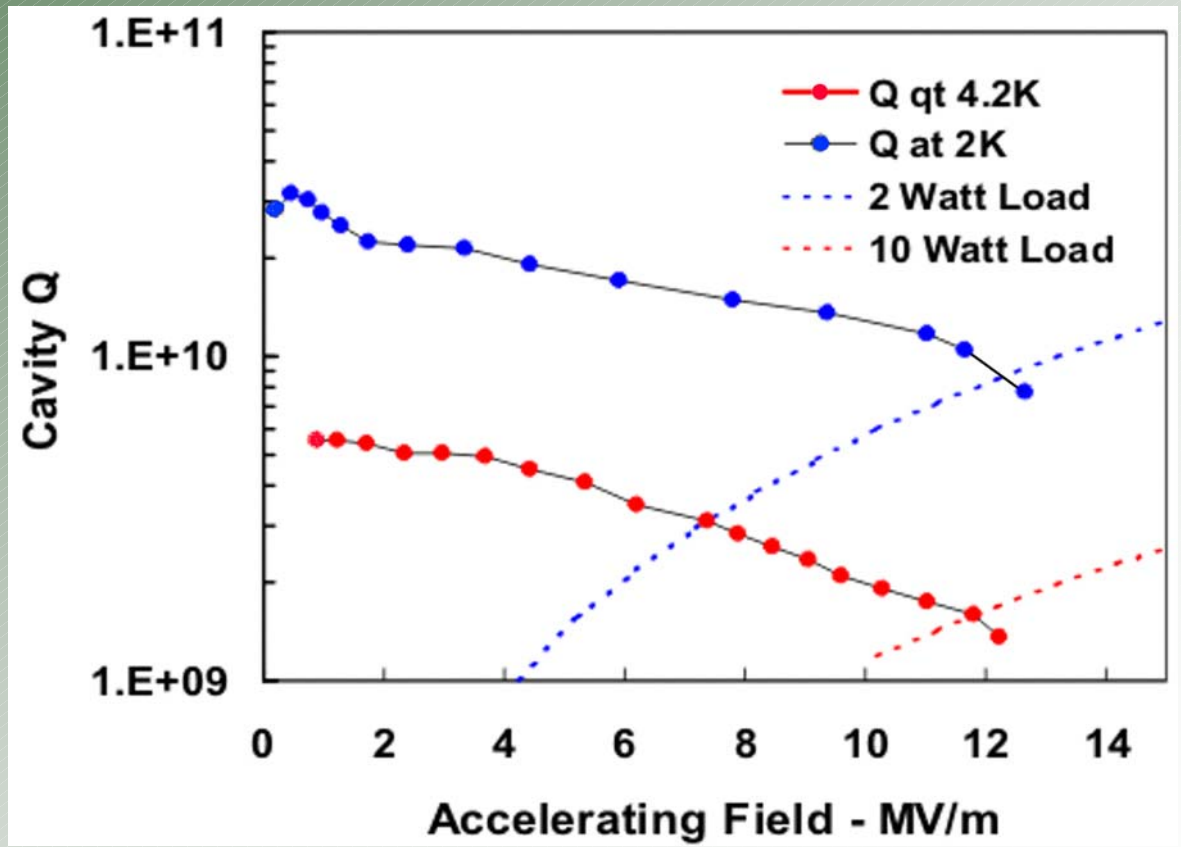
RIA Heavy-Ion Accelerator Layout



ANL and MSU designs are similar

Prototype 109 MHz QWR cavity for RIA and ATLAS



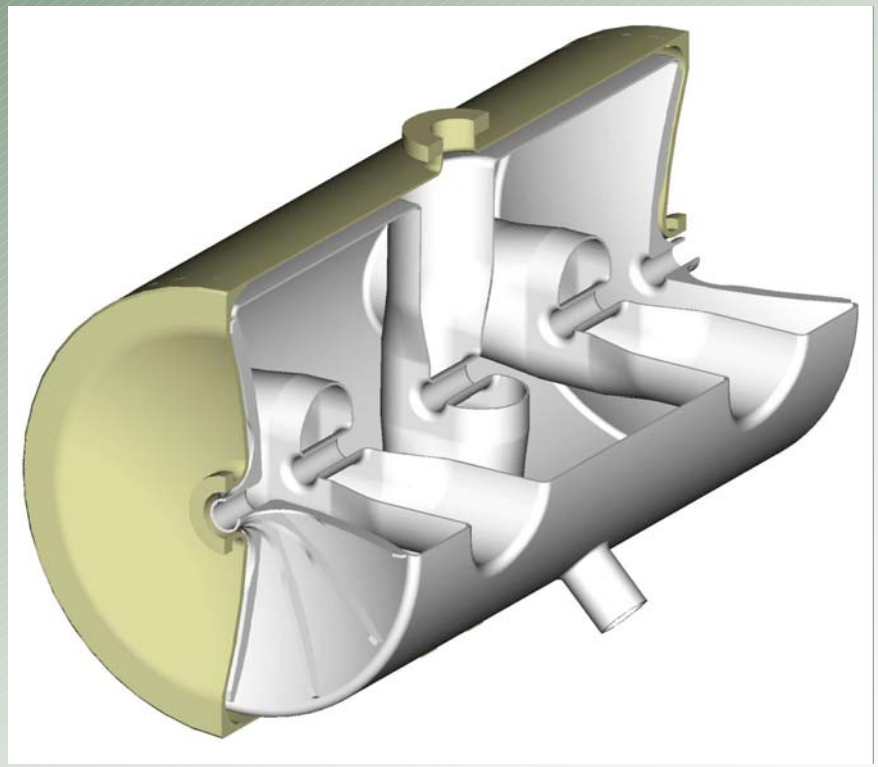


QWR 109 Parameters		
Frequency	109.125	MHz
Geometric Beta	0.144	v/c
Active Length	25	cm
QRs	40	ohm
Epeak/Eacc	3.2	
Bpeak@ 1 MV/m	58.3	Gauss
RF Energy/Eacc^2	0.1662	Joule

J. Nolen ANL

ANL Concept for a Triple-spoke Resonator

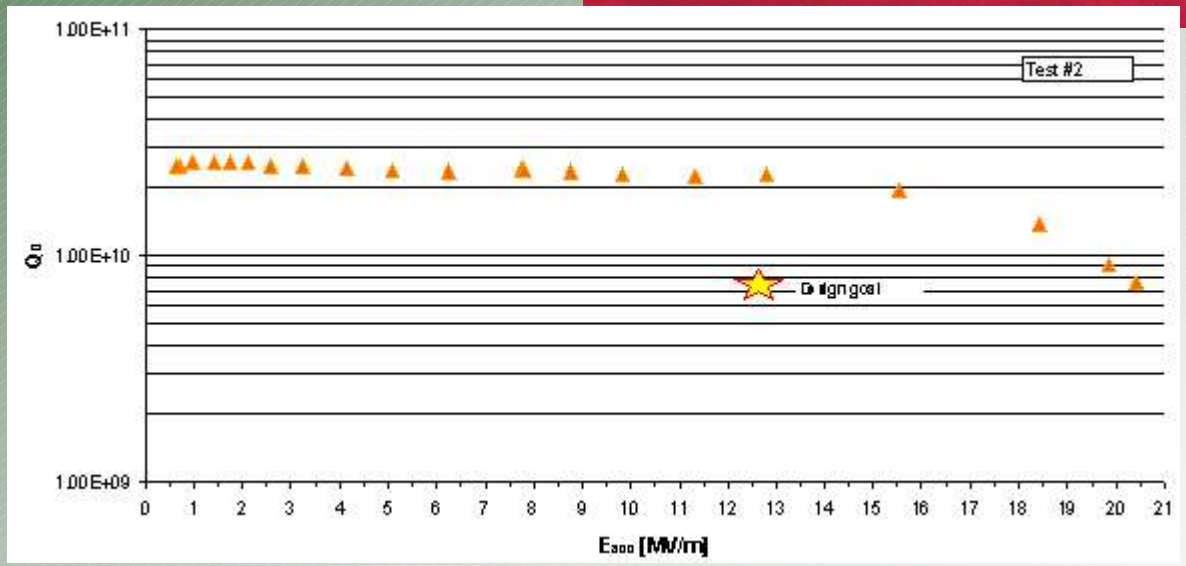
- A 345-MHz triple-spoke resonator has been developed



J. Nolen ANL

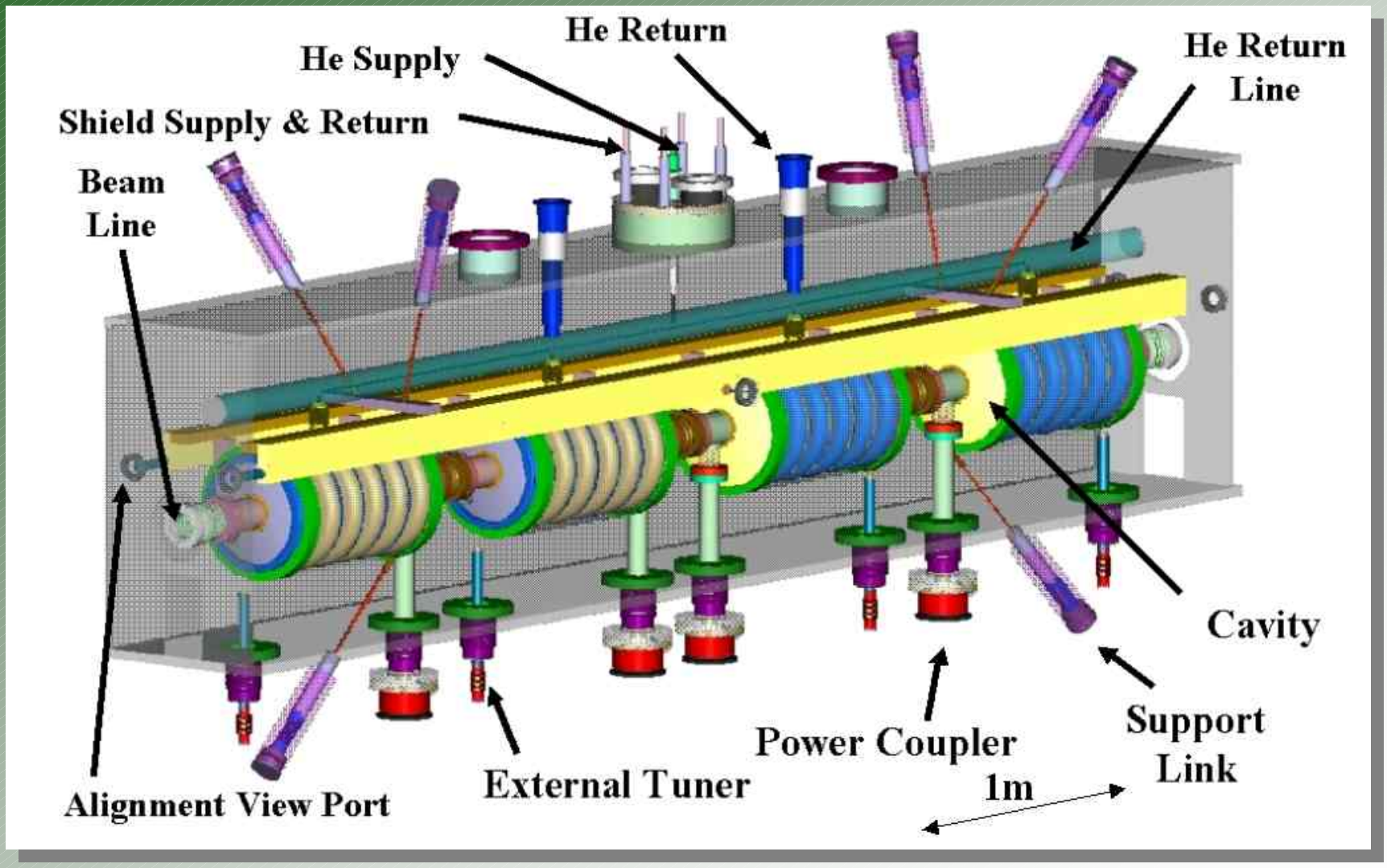
Elliptical-cell high-beta cavities

Beta 0.61 & 0.81 cavities developed by JLab for the SNS



Beta 0.48 cavities developed by NSCL & JLab for RIA

Segment III Cryostats



RIA Driver Beams

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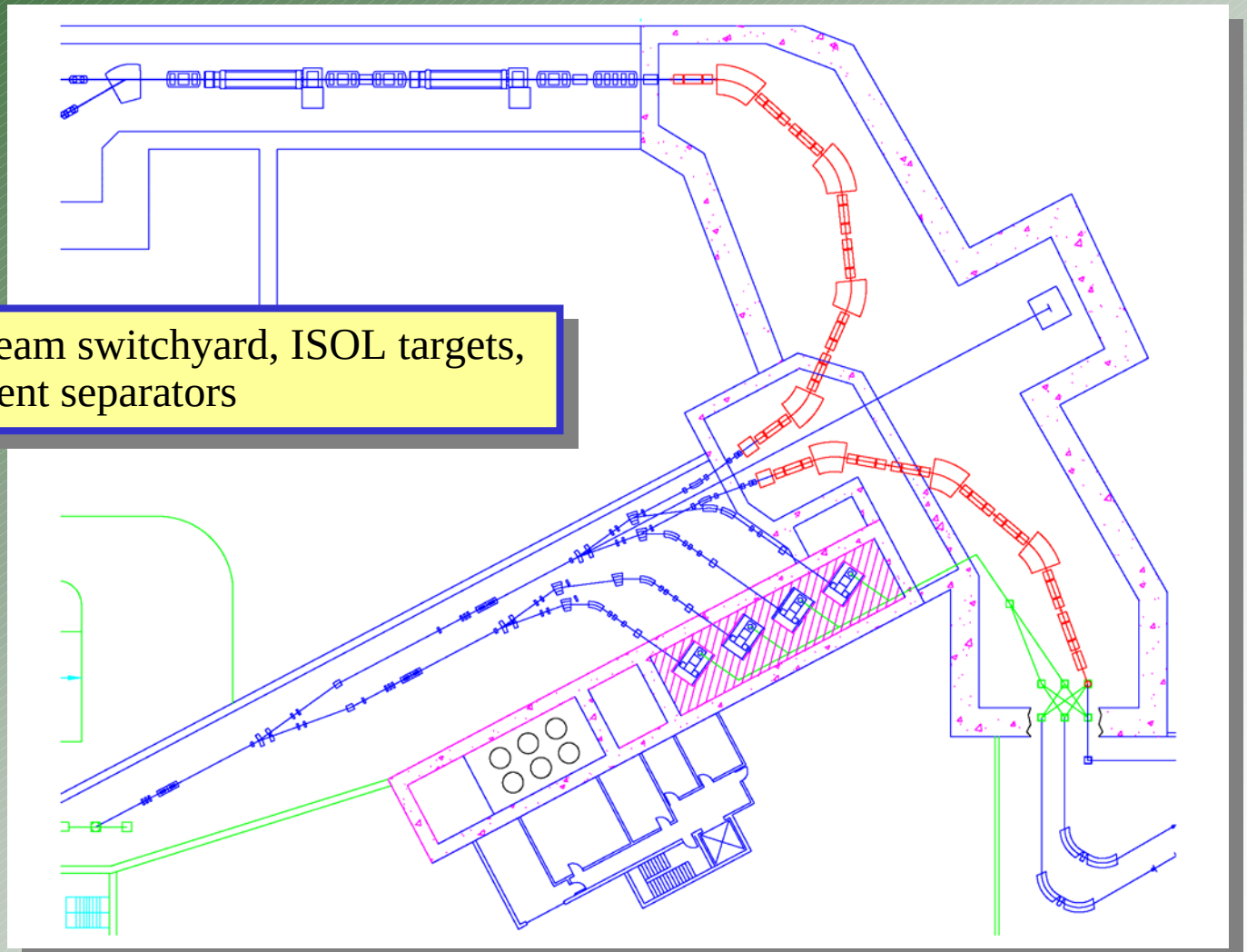
Ion	A	Z	Ion Source Current (pμA)	Charge State from Ion Source	Charge State Segment 2	Charge State Segment 3	Energy (MeV/u)	Final Beam Power (kW)
H	1	1	613	1	1	1	1020	400
D	2	1	500	1	1	1	622	403
^{3}He	3	2	237	2	2	2	777	401
O	18	8	62	8	8	8	560	406
Ar	40	18	27	11	17,18	17,18	566	397
Kr	86	36	17	15	31-35	36	510	481
Xe	136	54	11	18	47-49	53,54	470	354
Au	197	78	8.2	24	63-68	76,77	464	400
U	238	92	8*	29	71-75	87-89	400	400

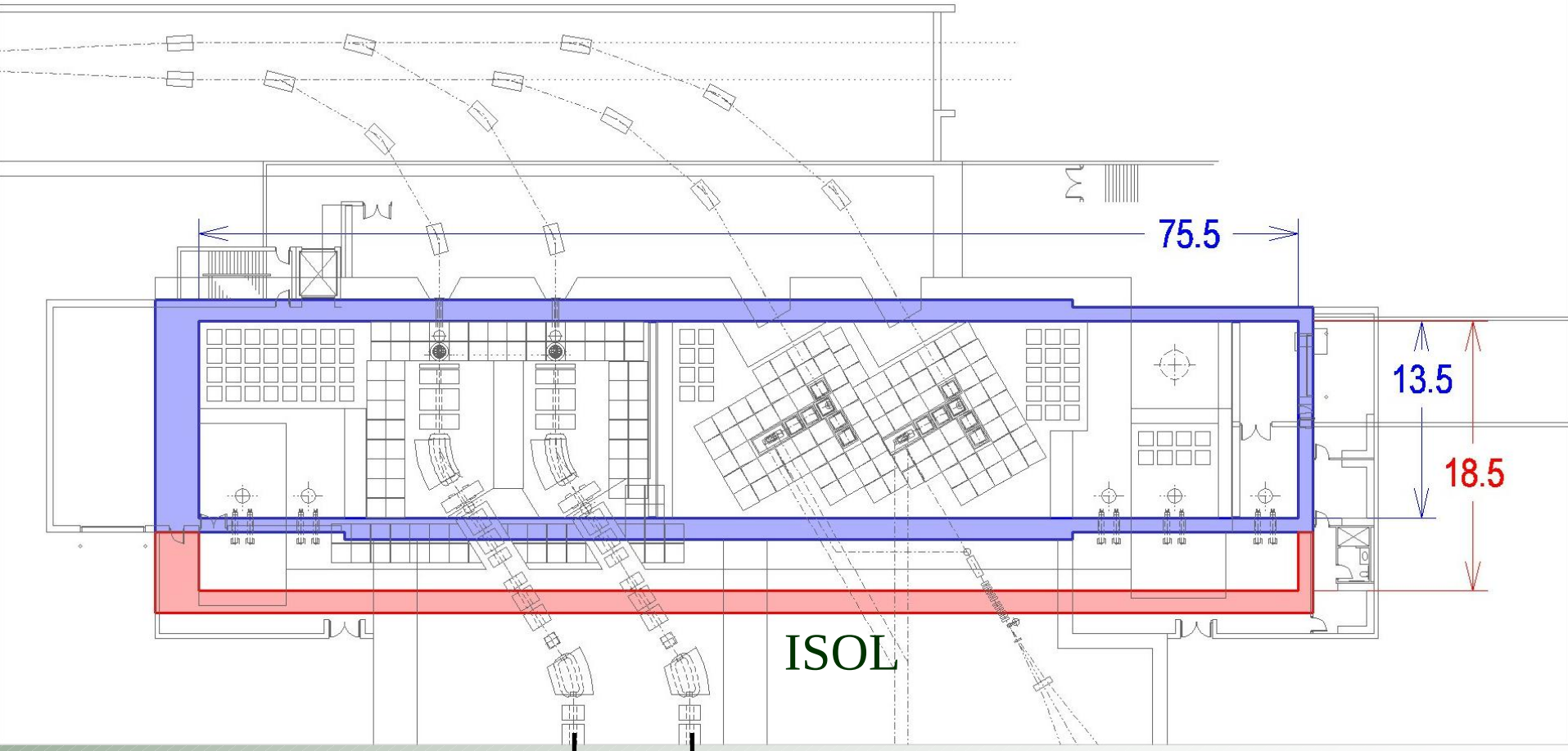
* Extrapolated from measured Bi source performance obtain with the VENUS source at LBL.

ANL Rare Isotope Production Area



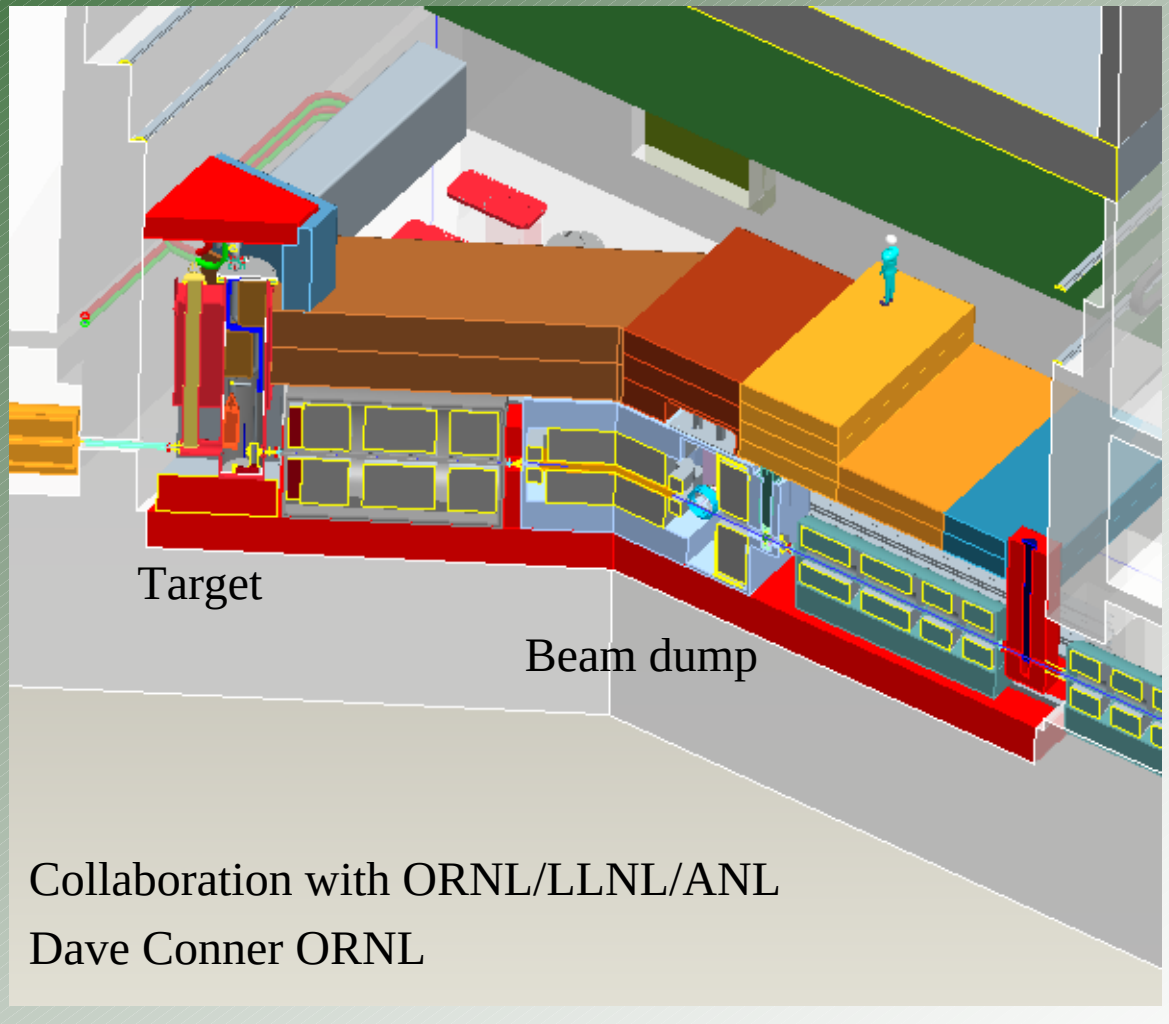
- Driver beam switchyard, ISOL targets, & fragment separators

RIA Production Target Area



Gas Cell Fast Beam Area

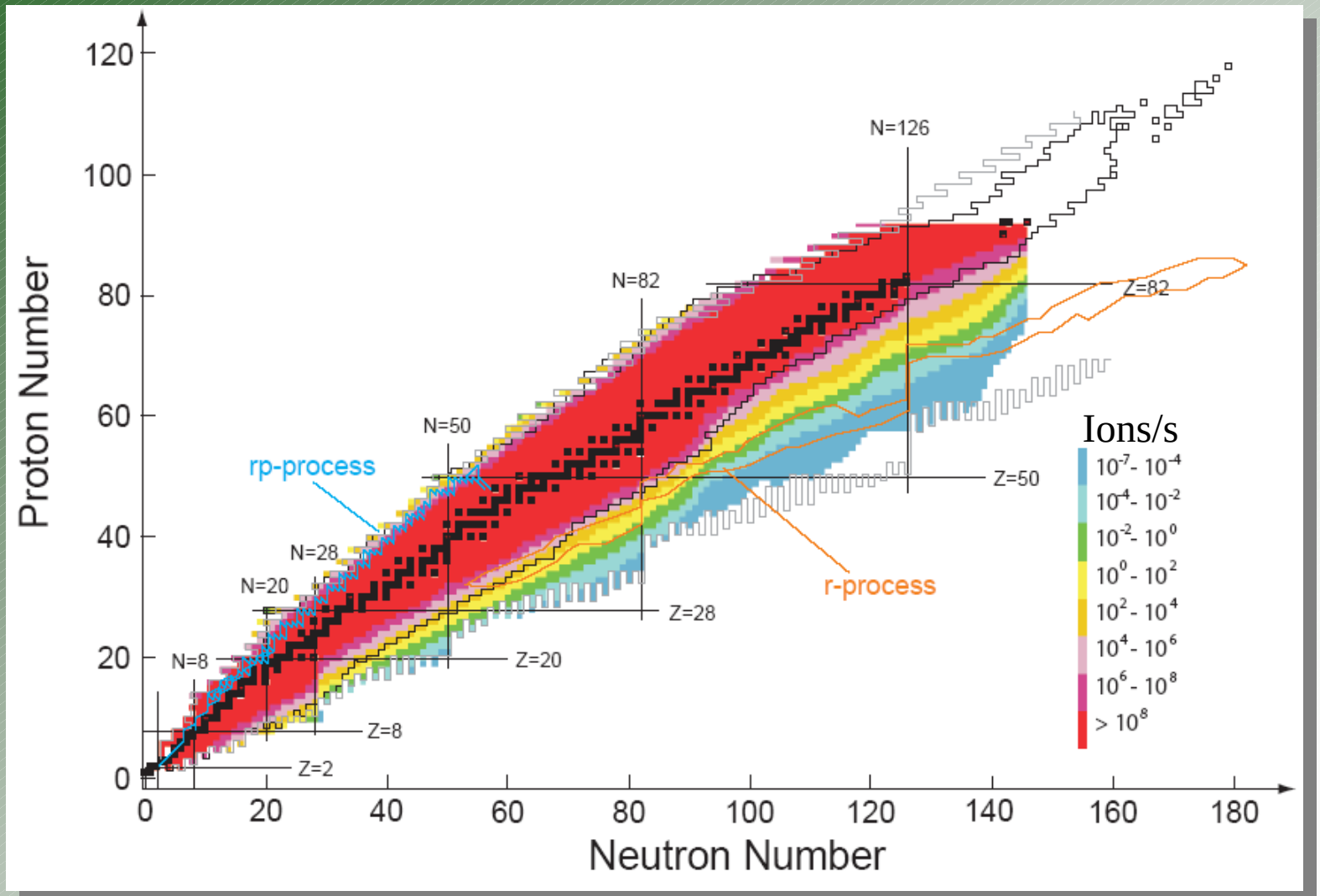
Schematic Layout of the Pre-Separator



Collaboration with ORNL/LLNL/ANL

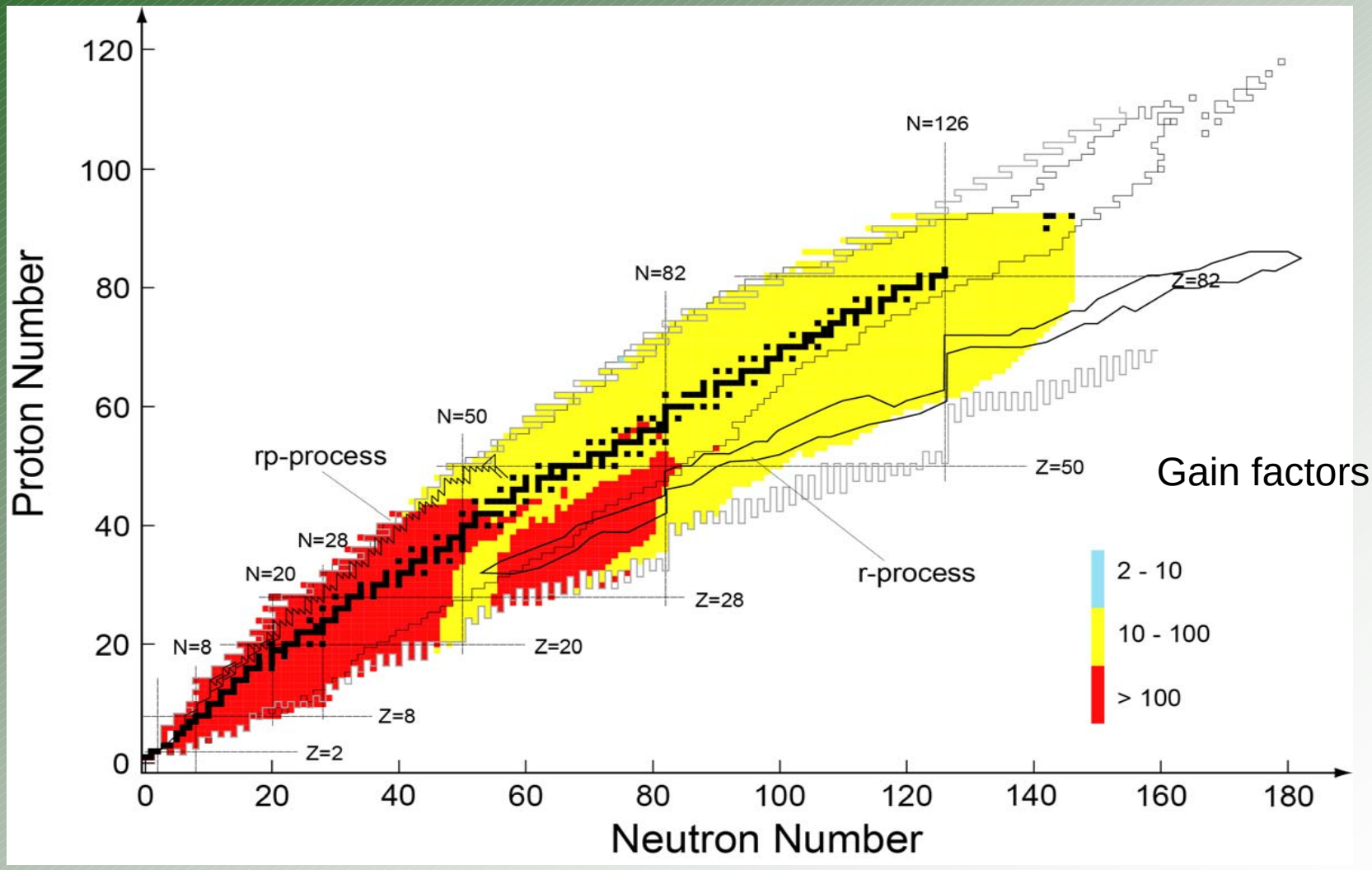
Dave Conner ORNL

Fragments from Heavy Ion Beams at RIA

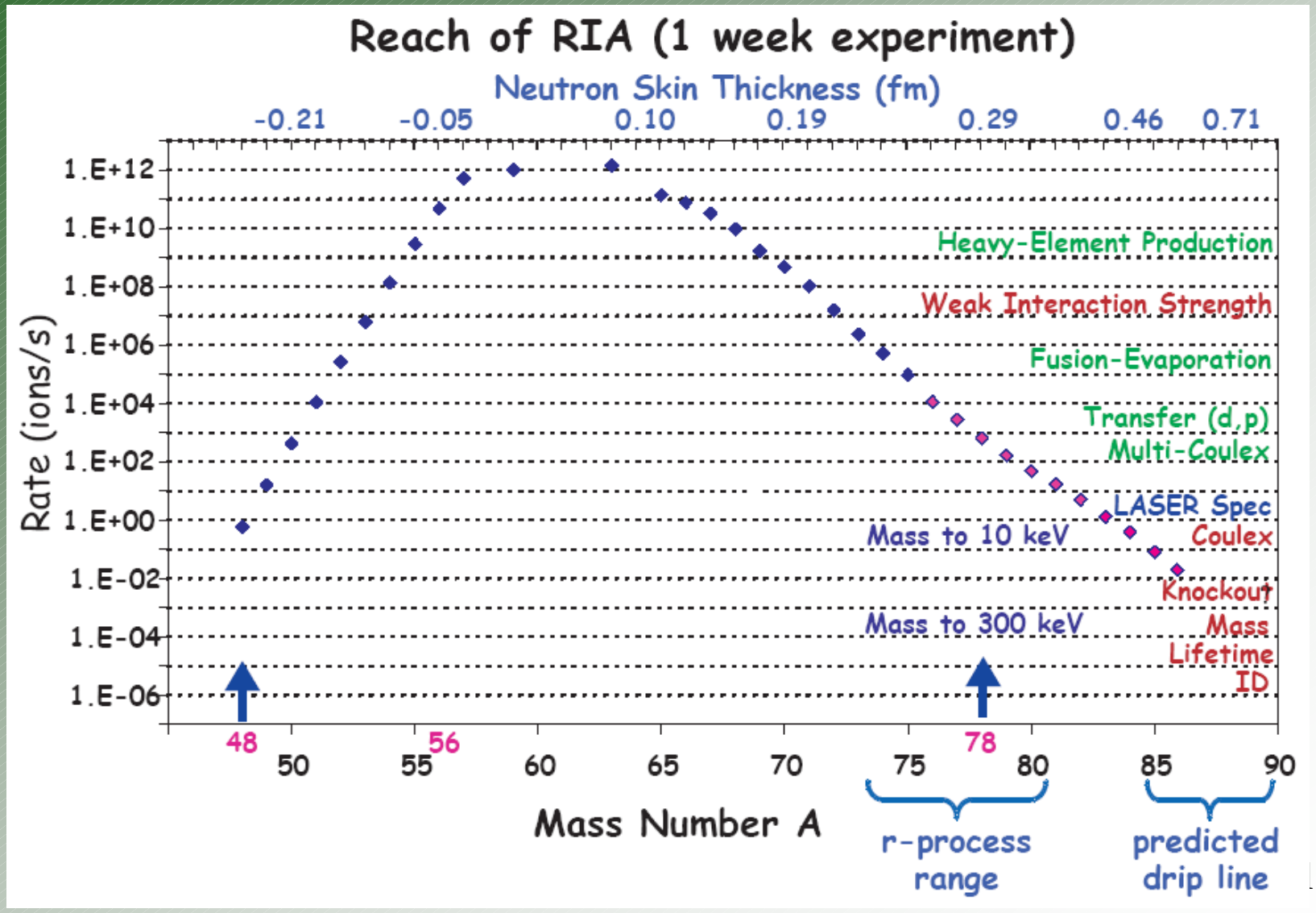


How this was calculated will be presented in lecture II.

Intensity Gains for RIA over FAIR at GSI



Intensity Requirements for Experiments



History of RIA Part I

- 1985 Workshop at the Washington APS meeting (Nitschke)
- 1989 Workshop at ANL (part of the NSAC LRP) – first discussion of an ISOL RNB facility in the US
- 1989 Workshop on an RNB facility at Los Alamos – The Isospin Laboratory Steering Committee was founded (WP/users group/NL).
- The 1996 US Long range plan endorsed the idea of advanced radioactive ion beam facilities
  - Upgrade the NSCL in-flight facility
  - Pursue an advanced ISOL facility
- ANL/ORNL proposals for NISOL
- Grunder NSAC Subcommittee Committee – recommends we build the Rare Isotope Accelerator based on a heavy-ion linac
- 2002 LRP "RIA is the top major new construction priority"

History of RIA Part II

- January 04 NSAC Comparison of RIA and GSI: “very strong science case”, “upgrade of GSI will not duplicate the capability of RIA”.
- 2004 DOE releases it’s 20-year facility plan: *Facilities for the Future of Science: A 20 Year Plan* – RIA is tied for 3rd out of 50 projects.
- February 2004 – RIA received a statement of mission need from the DOE (CD0)
- 2004 An Interagency Task Force on *Physics of the Universe* notes that RIA will be an important facility: “… a next generation facility will be needed to access the nuclear reactions involving the heavier elements.”
- October 2004 – DOE releases a draft Request for Proposals. The RFP is cancelled in December 2004
- 2005 Energy Policy Act directs the Secretary of Energy to commence construction of RIA no later than Sept. 30, 2008.
- February 2005 – Secretary Bodman announces funds are not available to build RIA

The Status of RIA Now

- DOE has decided that there are not funds to build a 1 B$ facility. The head of the DOE Office of Science has said “stop using the name RIA”.
- The science of RIA is under evaluation by a US National Academy committee, RISAC, RIA Scientific Assessment Committee. A report is due in October, with a draft report due any day.
- With a positive report the DOE is hoping to start Project Engineering Design on a $600M exotic beam facility in 2011. Completion could be 6 to 7 years after that date.
- DOE may invest up to $50M in international projects during the time the new exotic beam facility is under development

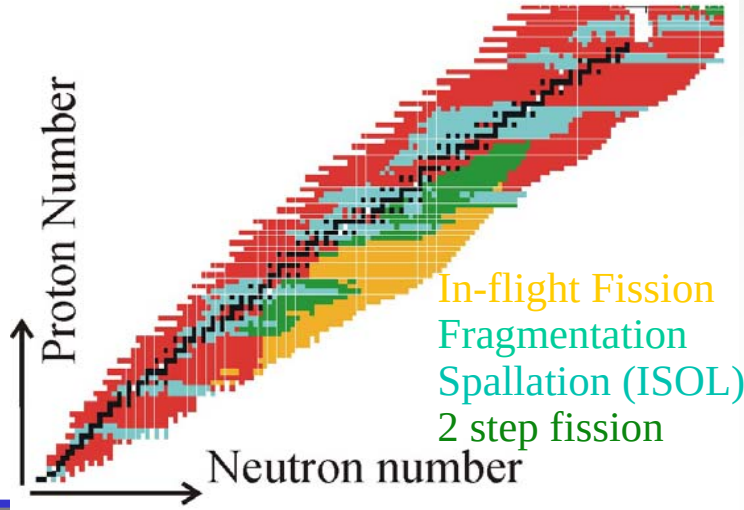
Overall Picture

- DOE continues to express interest to construct a next generation facility for the US (but starting in 2011)
- The National Science Foundation currently funds the NSCL, they might consider an upgrade of those capabilities
- The international context is important.
  - $1B facility must be unique and transformational
  - $600M facility must make sense in the international context
  - <$500M may not have constraints except that it should enable outstanding science
- The OECD forum chaired by Dennis Kovar (US DOE) reviewing the international scene

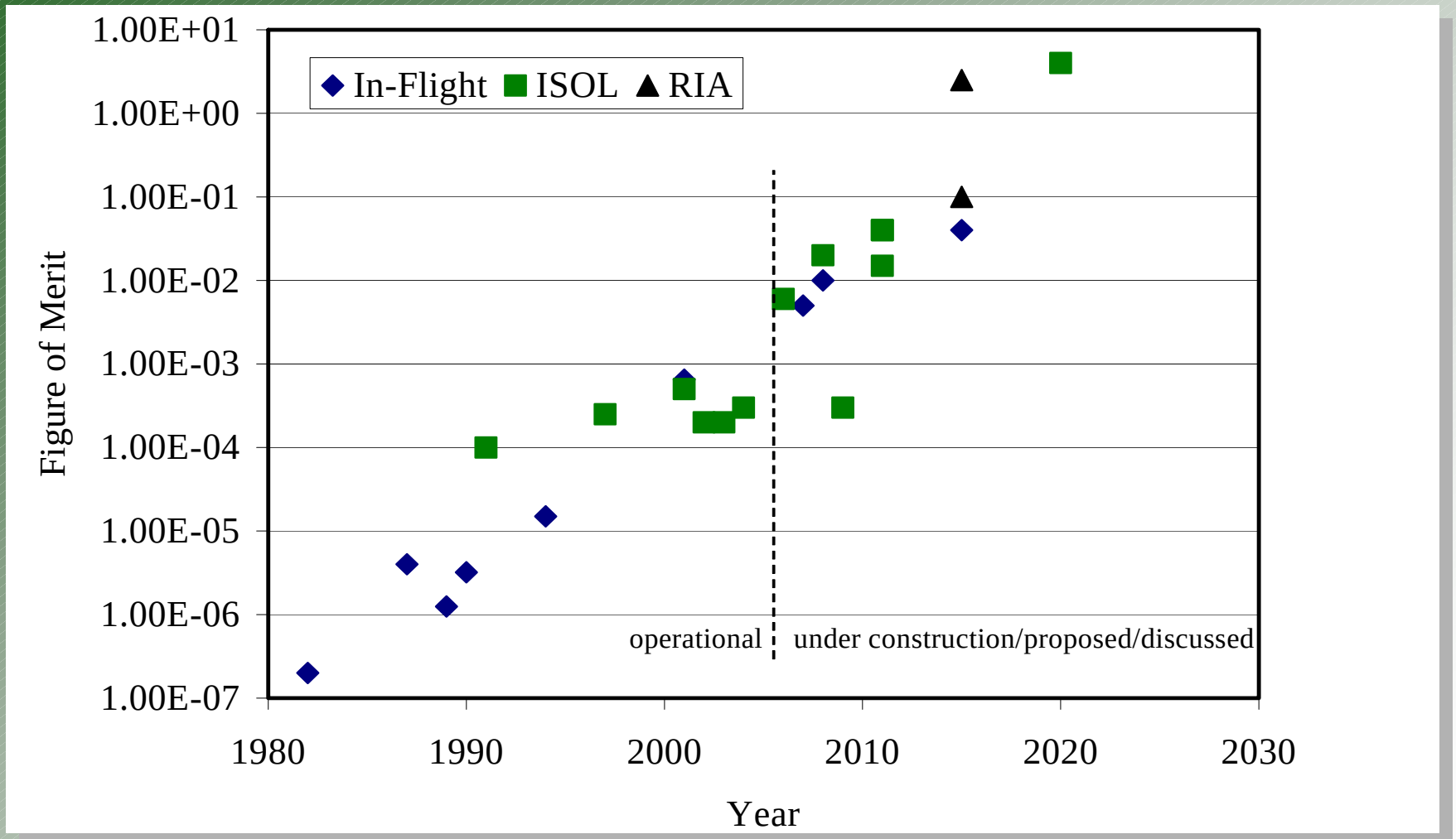
Study of Nuclei – Future of the Field

- Current facilities with modest upgrades will have a 5-10 year window to continue forefront science
  - NSCL, HRIBF, ANL, Texas A&M, Notre Dame
  - Continue utilization of ISAC, RIKEN, GSI, GANIL
  - TUNL, Yale, Florida State, Seattle, Stony Brook
  - Applied program at LBL

- The future US program rests on having facilities with capabilities like RIA
  - World leading capability
  - Most key nuclei; farthest from stability
  - Drives theory
  - New faculty positions
  - Students and Post Docs with futures
  - User program not on same scale (not unique)



Summary of Rare Isotope Facilities vs Time



FOM is the product of # of simultaneous users, intensity relative to RIA, and the fraction of beams relative to RIA.

Thoughts for a New Plan

- The heavy-ion LINAC driver is unique and is the one feature that should be preserved
- At the $600M level, it will be necessary to limit the top energy to around 200 MeV/u
- Multi-user capability is not possible
- The goal is to operate at or above 100kW. Such a facility will provide competitive yields for most isotopes.
- Experimental capabilities (at $600M it is probably possible to include all by reuse of equipment)
  - ISOL
  - Gas stopping and reacceleration
  - Fast beams
- ANL and Michigan State have developed plans for facilities that meet the constraints.

Possible Option 1: NSCL Upgrade

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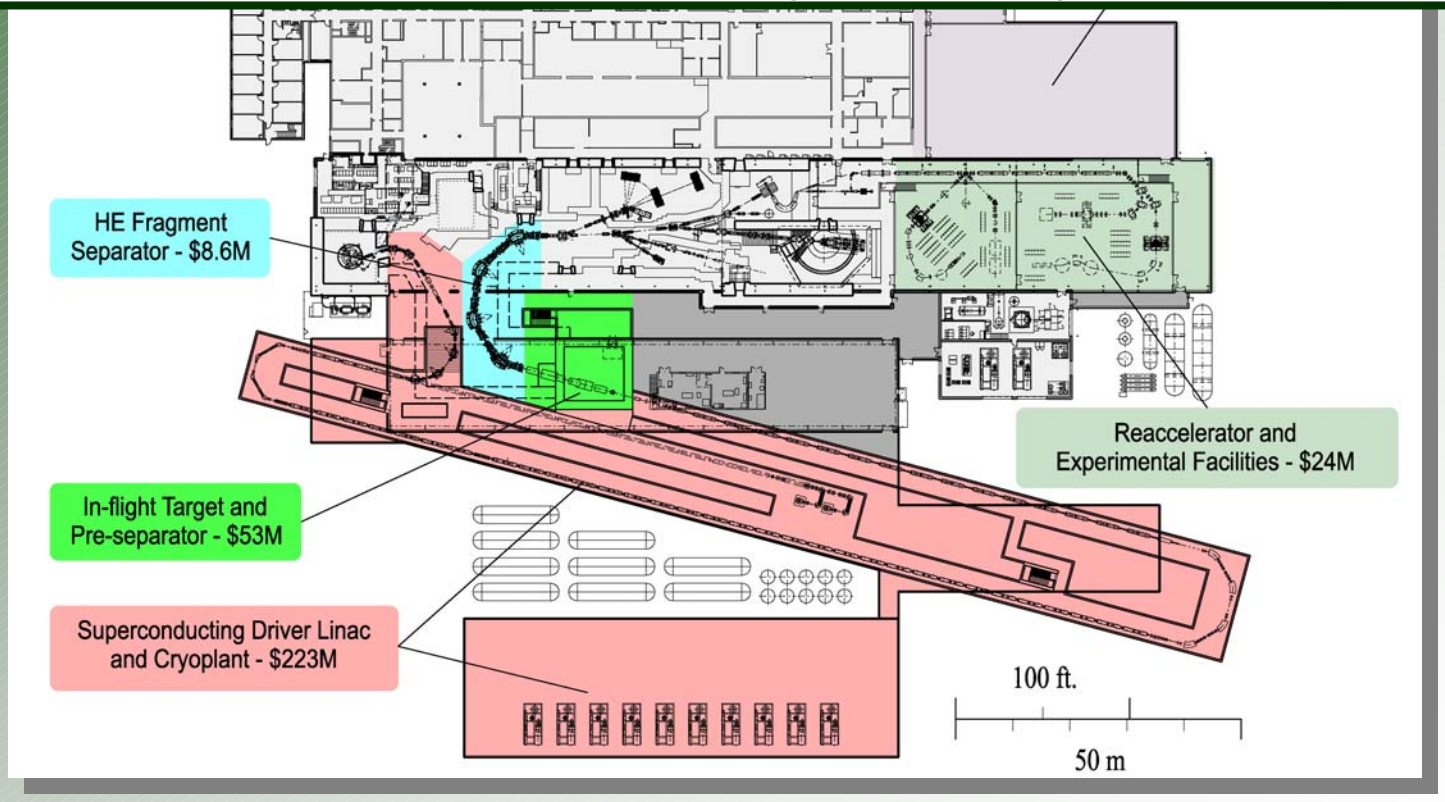
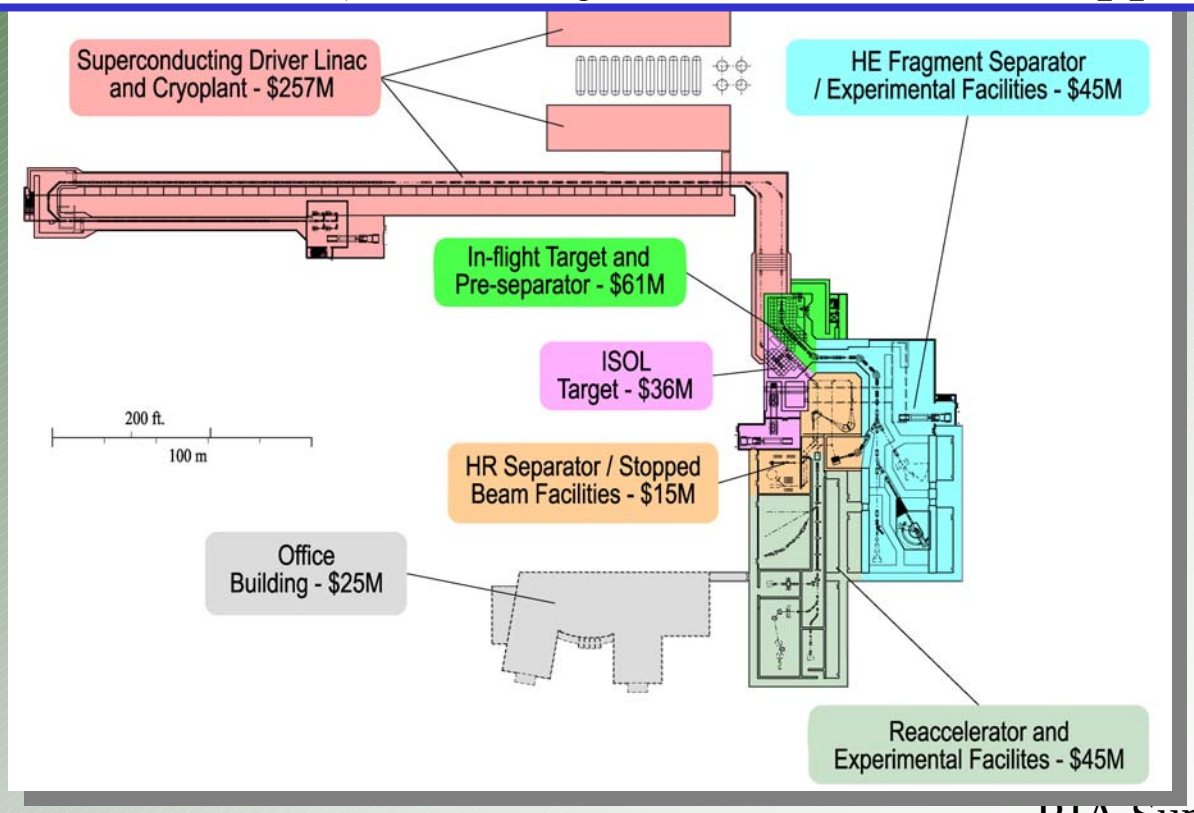
- Fast beams, gas stopping, reaccelerated beams – no ISOL
- Energy/nucleon: 180 MeV ^{238}U, 227 MeV ^{129}Xe, 300 MeV ^{3}He, 340 MeV ^{1}H
- Power 80-100 kW (limited by K1200 cyclotron injector)



School 2006

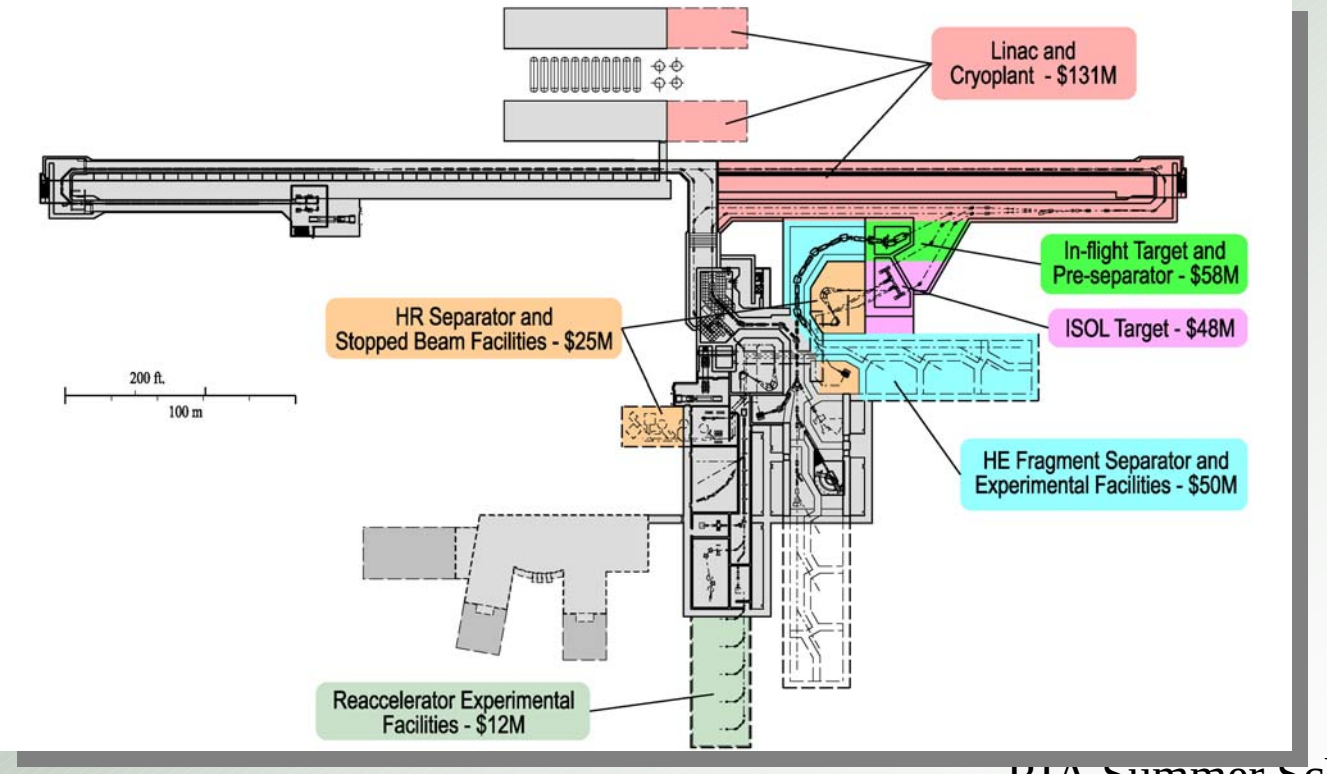
Option 2: South Campus Facility

- Fast beams, gas stopping, reaccelerated beams – plus ISOL
- Energy/nucleon: 180 MeV ^{238}U, 227 MeV ^{129}Xe, 300 MeV ^{3}He, 340 MeV ^{1}H
- Power ≥ 200 kW (limited by ion source and stripper)



Future SCF Upgrade Options

- Multi-user capability, flexible science-driven selection of upgrade elements
- Energy/nucleon: 400 MeV ^{238}U, 539 MeV ^{129}Xe, 1122 MeV ^{1}H
- Power 400 kW



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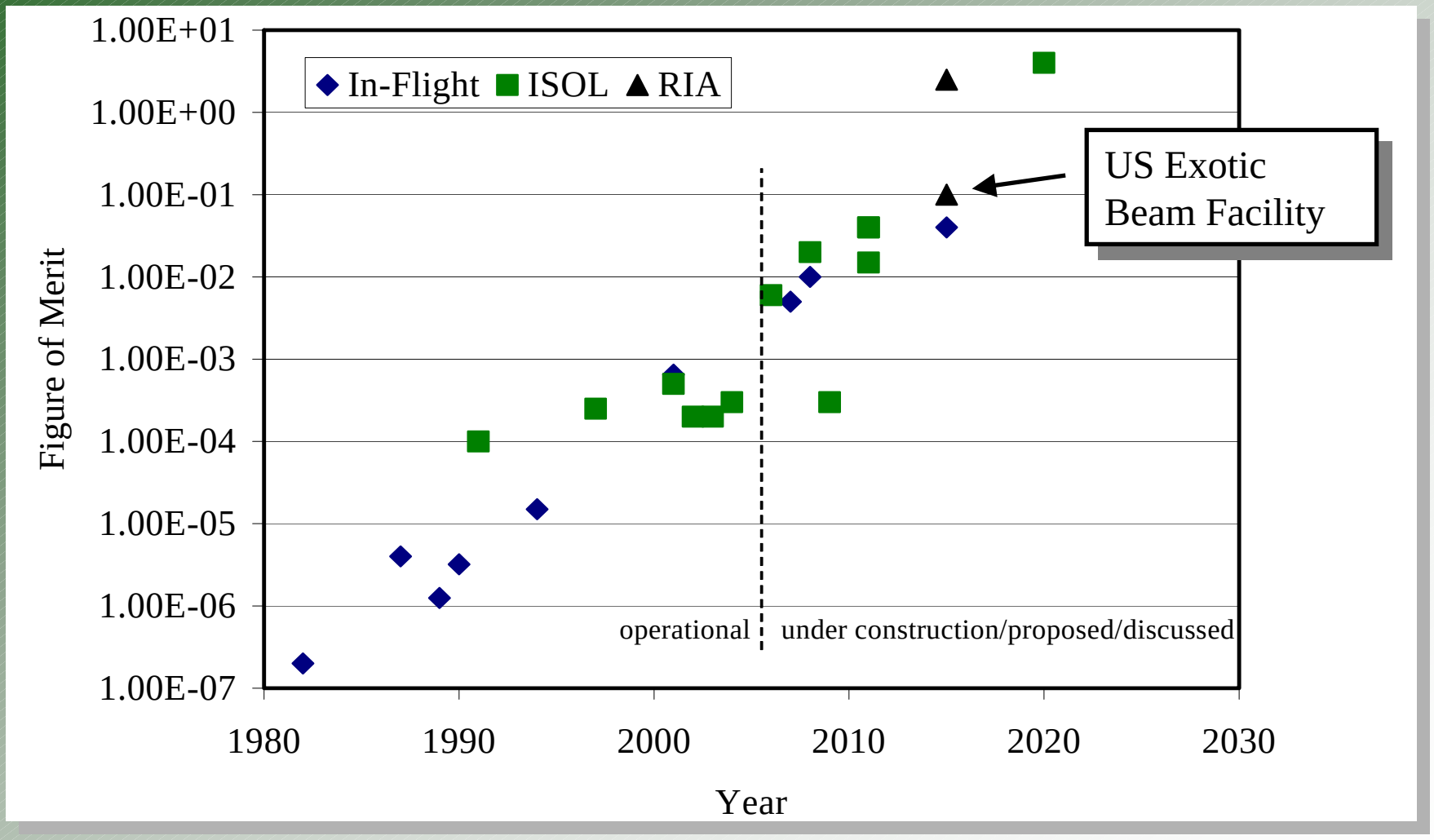

Summary of Lecture I

- A next generation of exotic beam facility is scientifically well justified
- An exotic beam facility based on a superconducting LINAC heavy-ion driver would provide new capabilities for the field
- Despite a recent slow down of the process, there is still optimism that we can move forward with the key parts of the RIA concept intact
- Plans have been developed for the next steps …