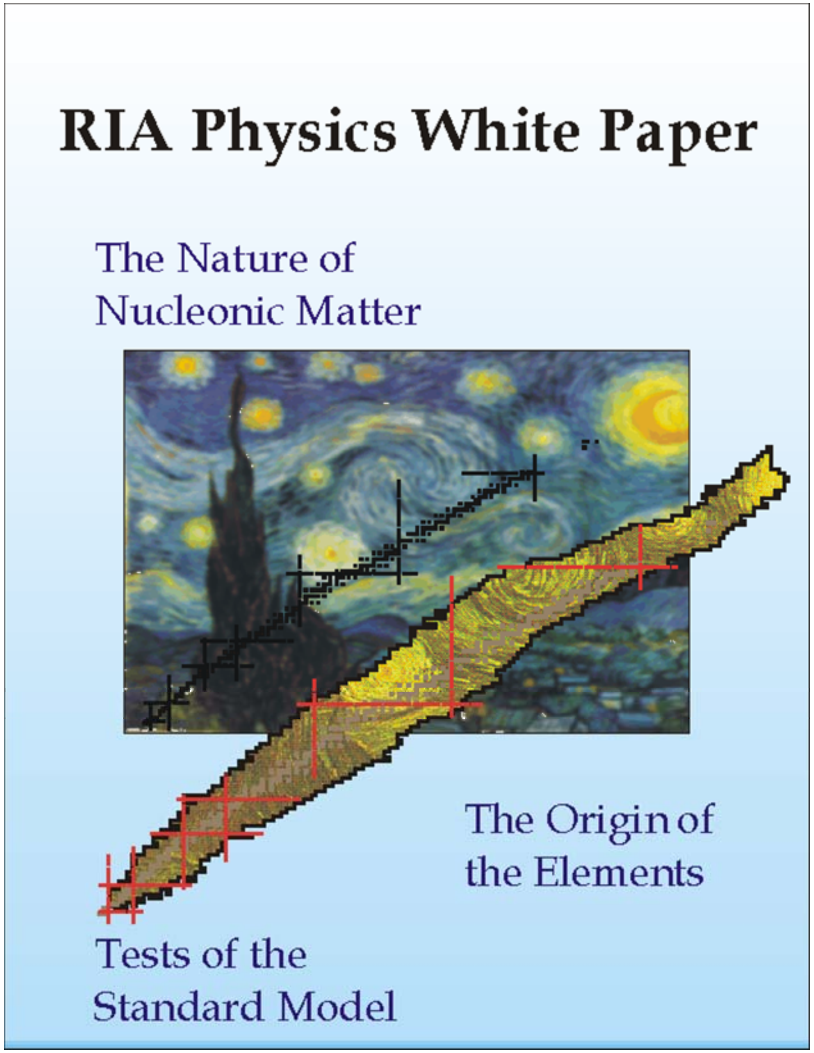
Rare Isotope Production at RIA

G. Bollen
National Superconducting Cyclotron Laboratory NSCL
Michigan State University

- **RIA – an overview**
  - RIA-Science
  - Rare Isotope Production
  - RIA Facility
- **RIA target issues**
  - Fragmentation targets
  - Beam dumps
  - ISOL targets
- **Conclusion**

RIA – an intense source of rare isotope

Corner stones of the RIA Science Case



- The Nature of Nucleonic Matter
- The Origin of the Elements and Energy Generation in Stars
- Tests of the Standard Model and of Fundamental Conservation Laws
- Isotopes to Meet Societal Needs

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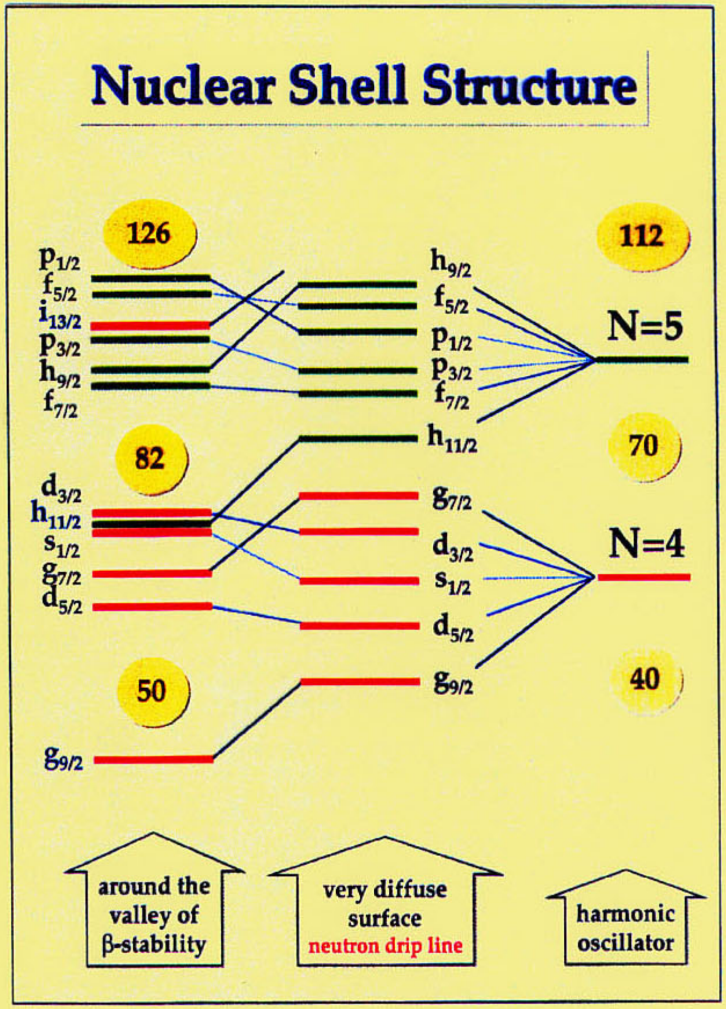
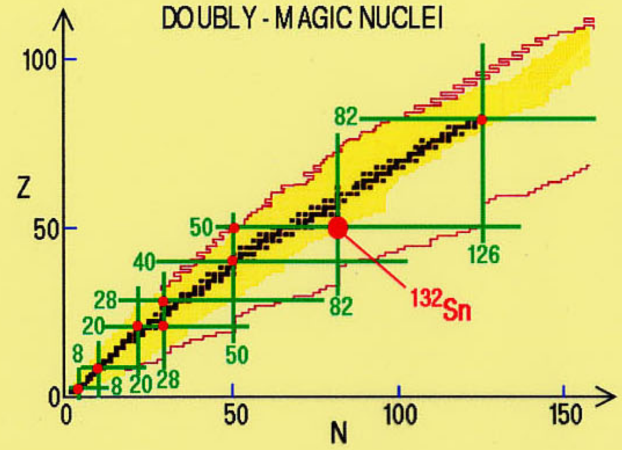
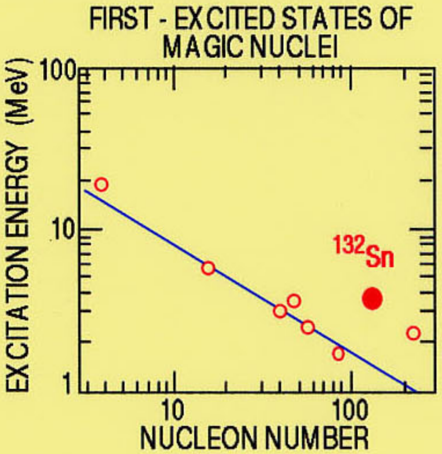
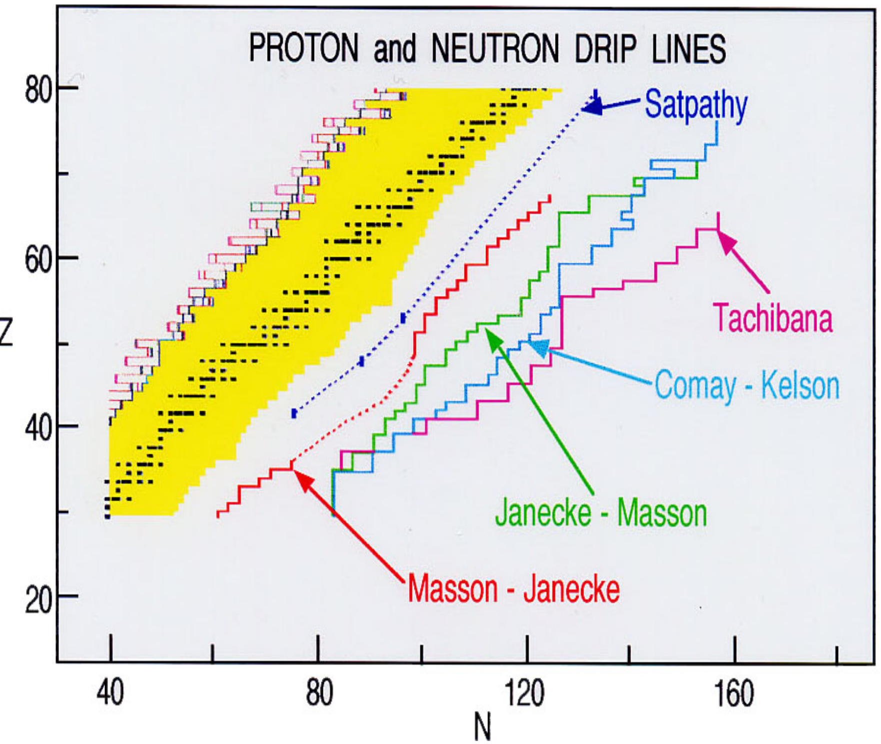
Nature of Nucleonic Matter - Nuclear Structure

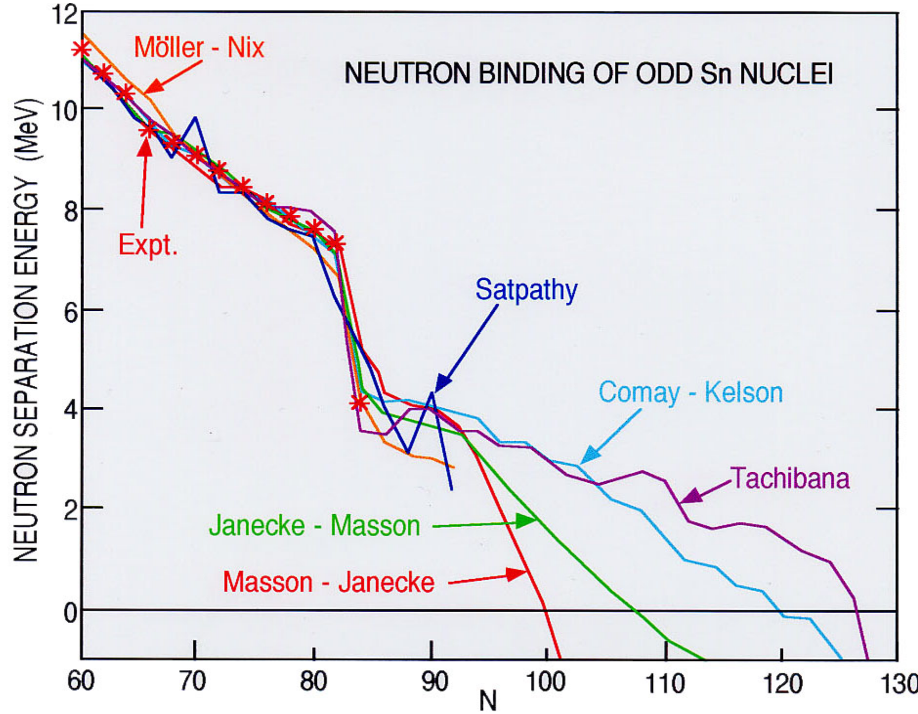






Nature of Nucleonic Matter - Binding Energies





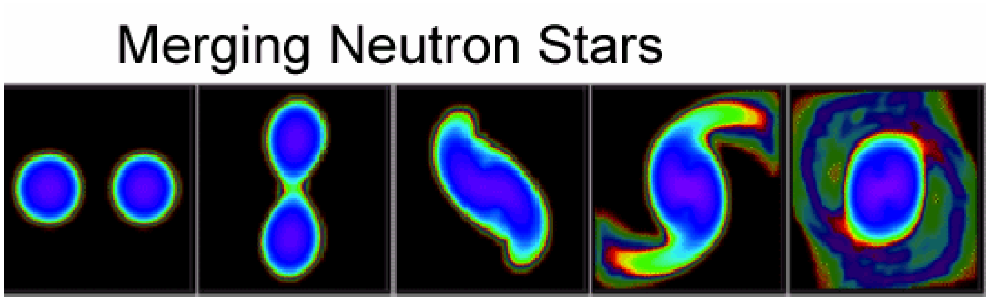
Masses and Trends in nuclear binding energies

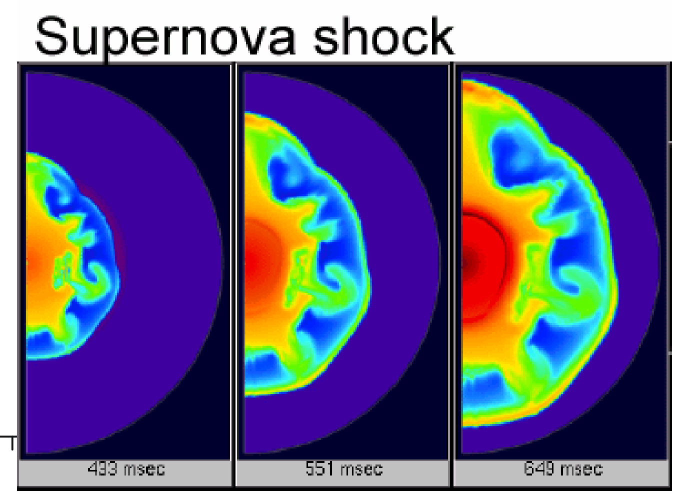
Limits of stability

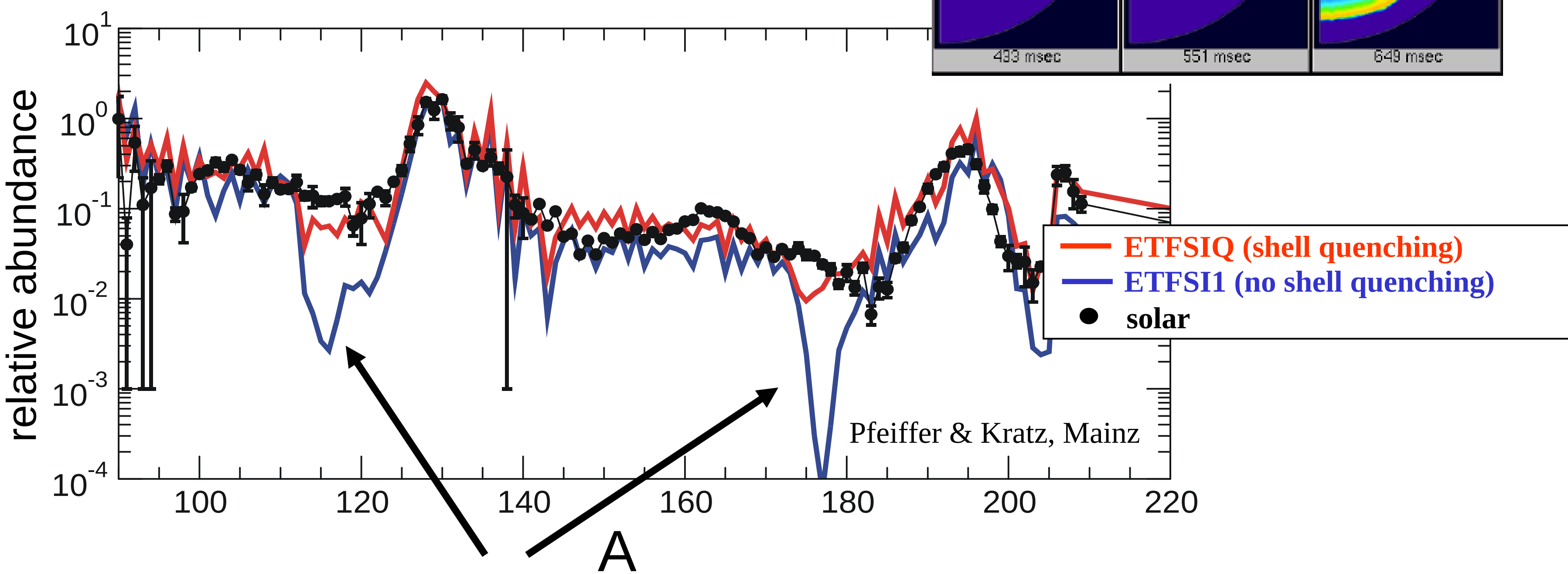
Key data for nuclear astrophysics

Nuclear structure

How were the heavy elements from iron to uranium made?







Question: Is this difference due to shell quenching for neutron-rich nuclei, or a problem with astrophysical model?

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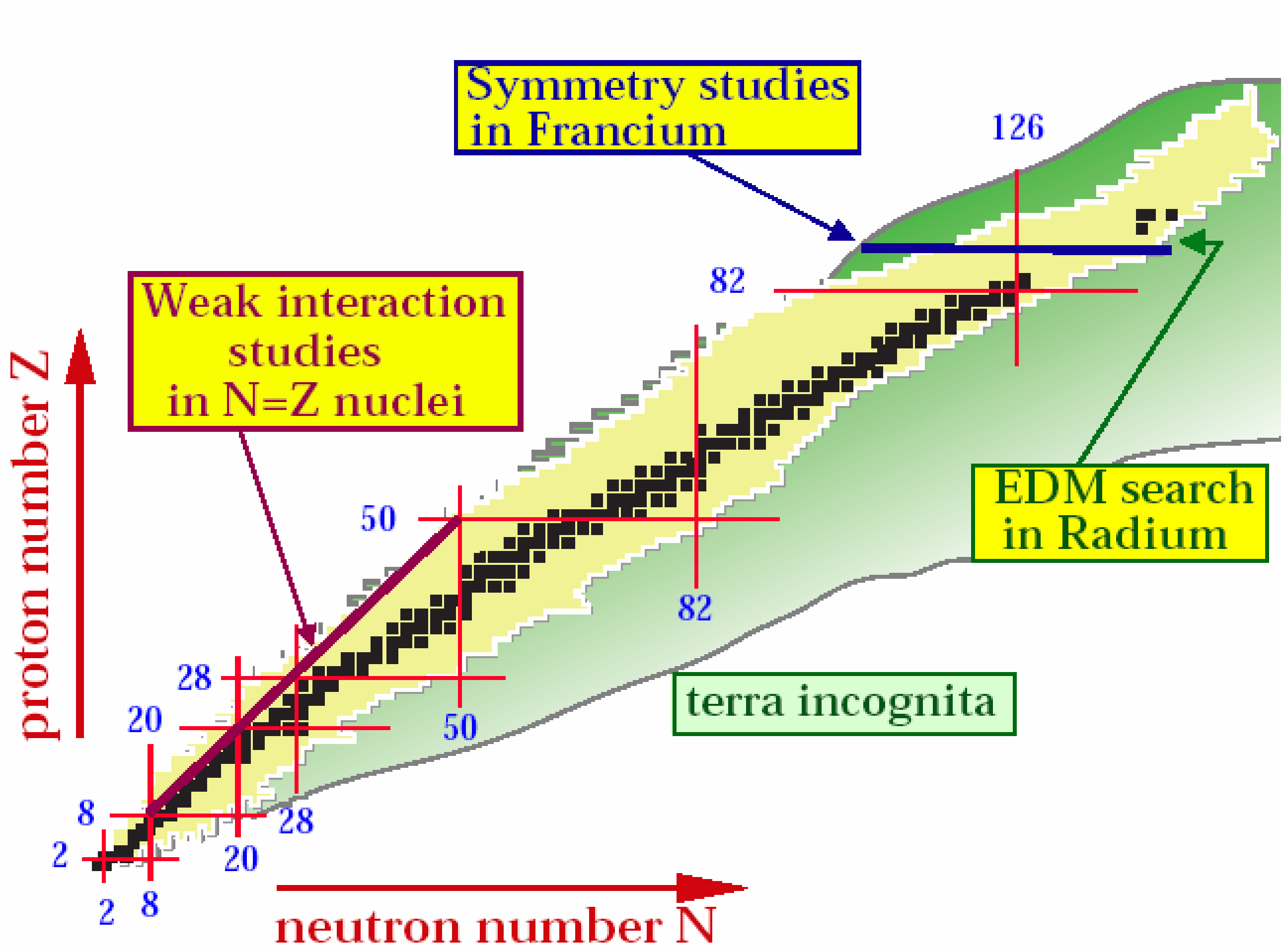
Tests of the Fundamental Symmetries in Nature



Specific nuclei offer new opportunities for precision tests of:

- CP and P violation – baryon asymmetry in the Universe

Standard Model Tests:

- Unitarity of CKM matrix
- Physics beyond V-A
- $\sin^2\Theta_W$ at low q

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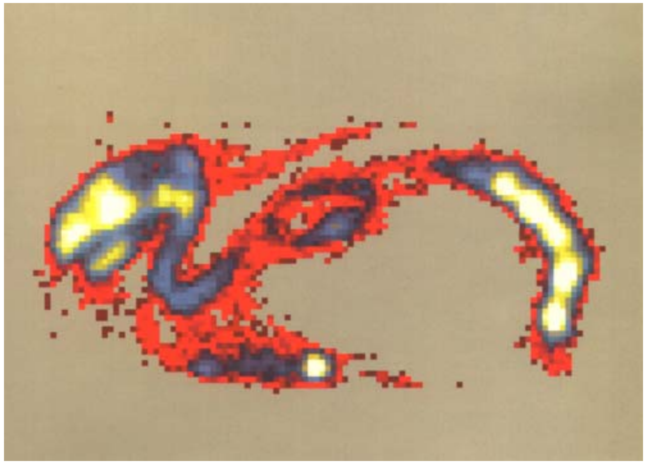
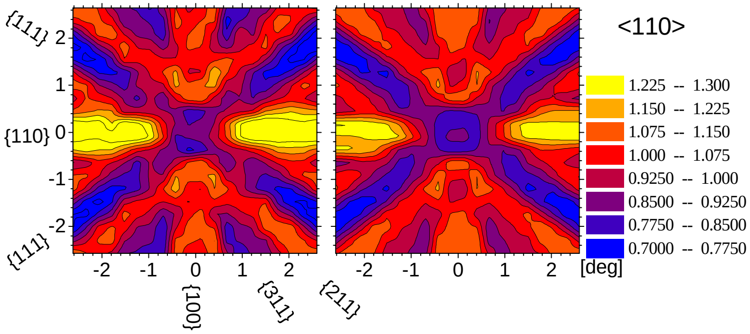
Applications of nuclides from RIA

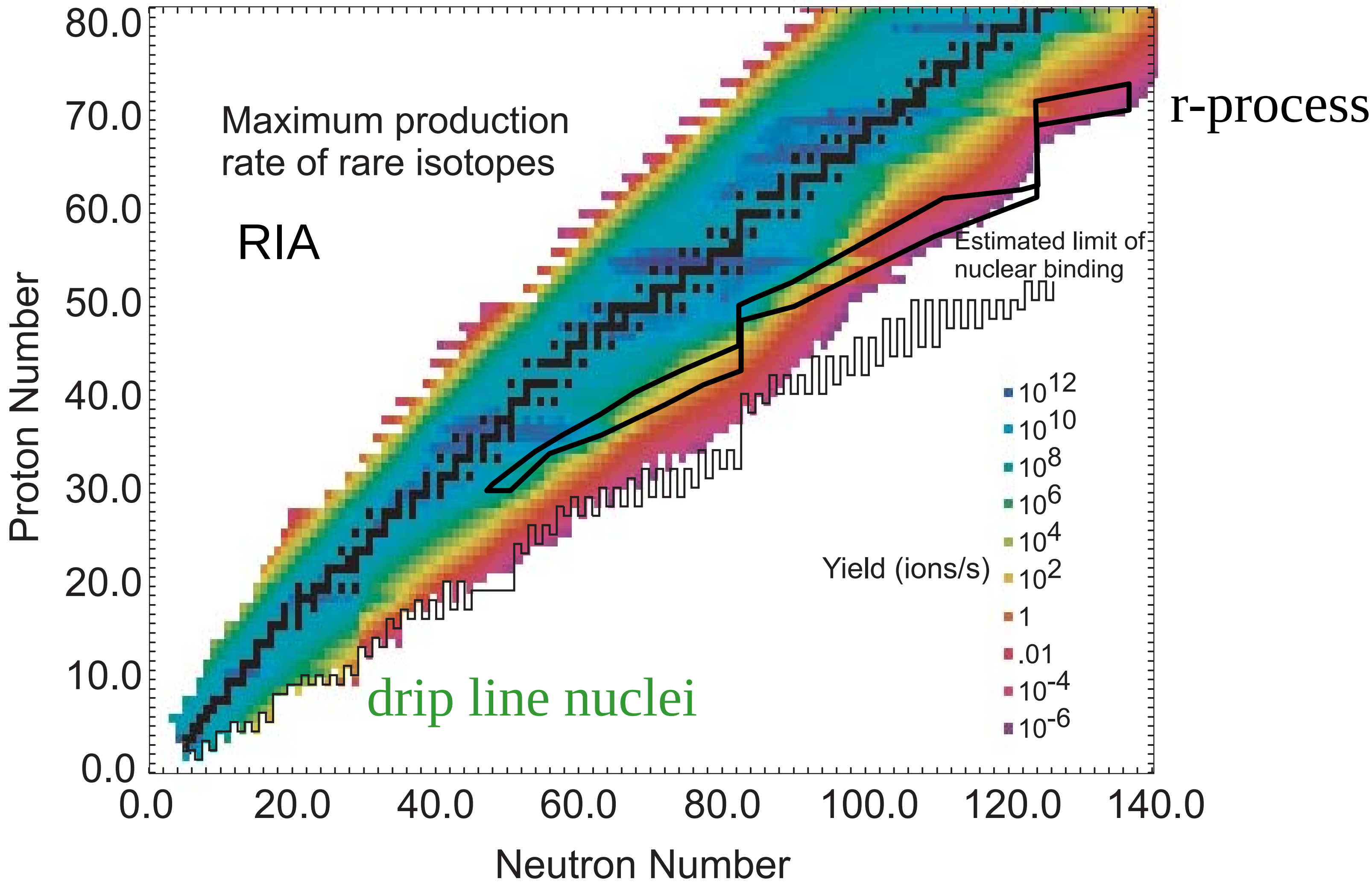
- Development of techniques and manpower for dealing with radioisotopes.
- Stockpile stewardship – allow measurements of necessary cross sections to insure the reliability of simulations.
- Allow testing of new radioisotopes for medicine.
- Tracers for various studies.
- Soft doping, etc.





Workshops at Los Alamos and Lawrence Livermore Labs

Goal: one facility for most of the key nuclei



G. Bollen, Targetry Workshop, Long Island, 2003

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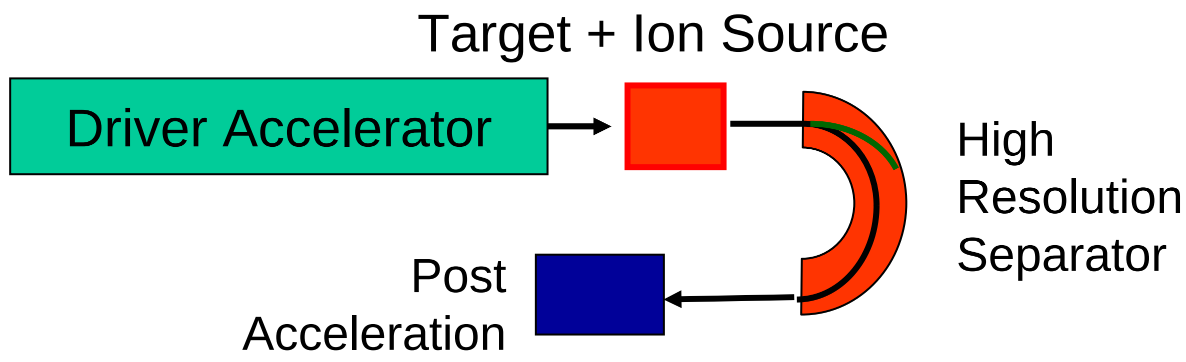
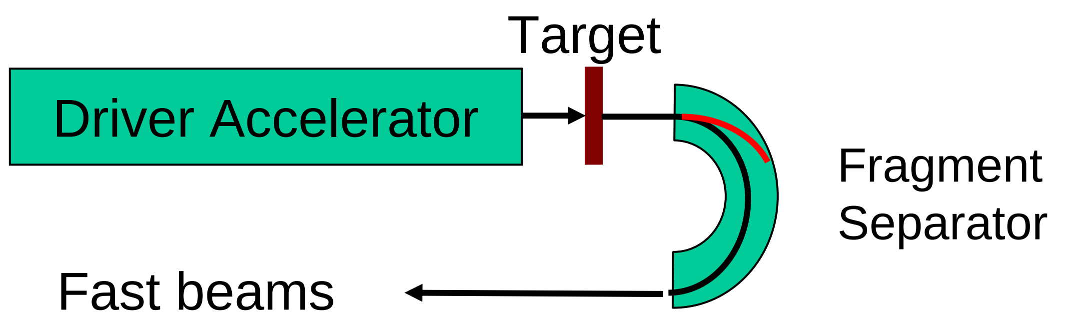
Recipe: Combine Production Mechanisms

ISOL

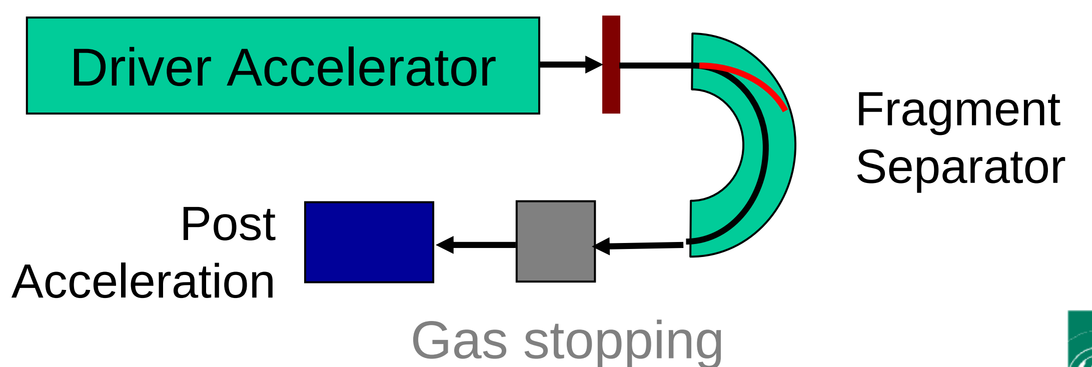


In-Flight



Gas-Stopping

NEW



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ISOL - In-Flight - Gas Stopping

ISOL:
ISOLDE
HRIBF
ISAC
…

- Highest intensities closer to stability and very good beam quality
- Post-accelerated beams with small beam energy spread for fusion studies and nuclear astrophysics
- Can use chemistry and selective laser-ionization to limit the elements released
- Production targets optimized for element and isotope

In-flight:
GSI
RIKEN
NSCL
GANIL

- Provides beams with energy near that of the primary beam
  - For experiments that use high energy reaction mechanisms
  - Thick secondary targets, kinematic focusing
  - Individual ions can be identified
- Efficient, Fast (100 ns), chemically independent separation
- Capture in storage rings
- Production target is relatively simple

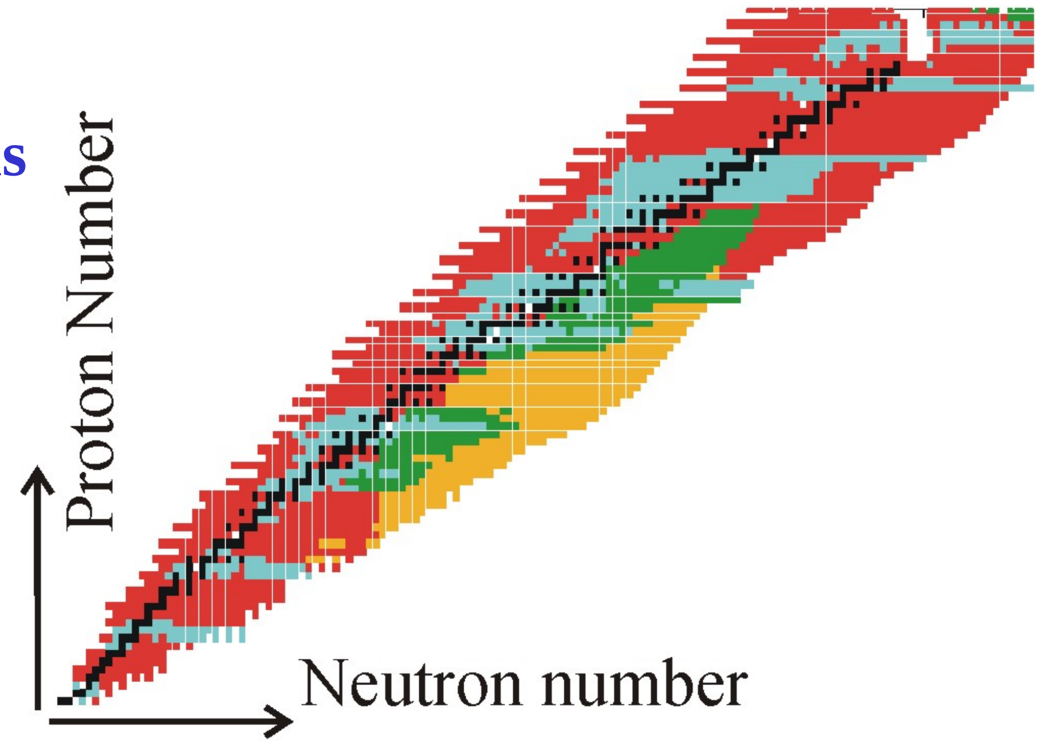
Gas-Stopping:
ANL
MSU
RIKEN

- Beams from in-flight production
- Chemically independent
- Intensity limits – half-life limitation ← still to be studied

Optimum Mechanism for Each Isotope

Optimum production method for low-energy beams

- Standard ISOL technique
- Two-step fission ISOL
- In-flight fission + gas cell
- Fragmentation + gas cell



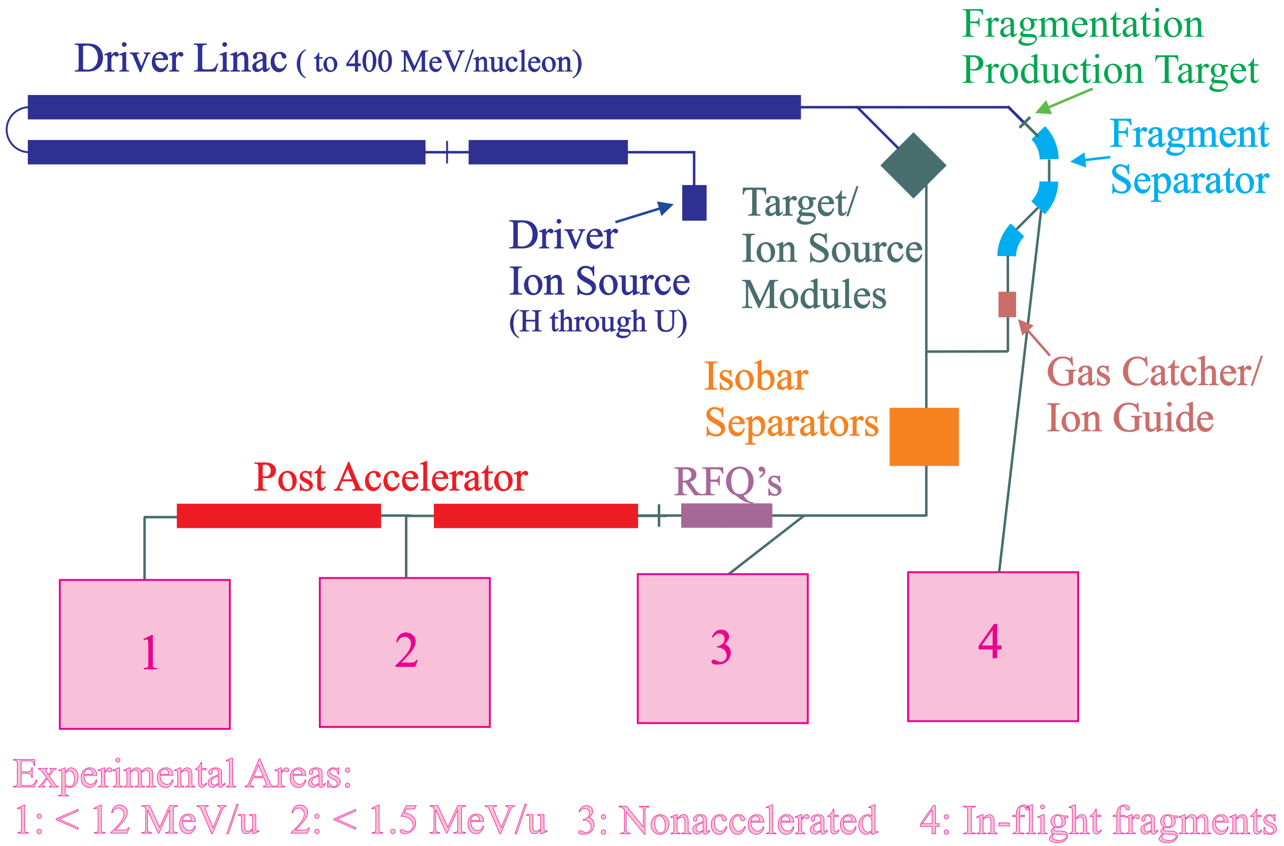
+ Fast beams with high intensities

Worldwide Unique Feature

most other facilities have only one production mechanism

Rare Isotope Accelerator - RIA

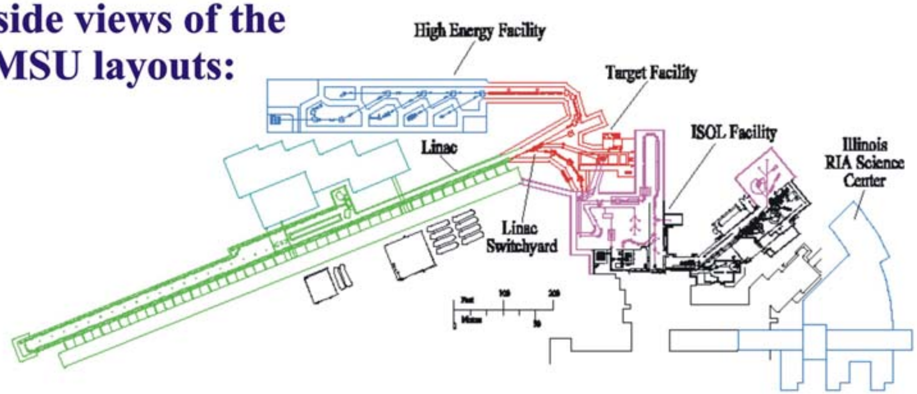
- Most intense source of rare isotopes
  - ➢ **High power primary beams** protons to U at 100 kW and E > 400 MeV/nucleon.
  - ➢ Possibility to **optimize the production method** for a given nuclide.
- Four Experimental Areas (simultaneous users)

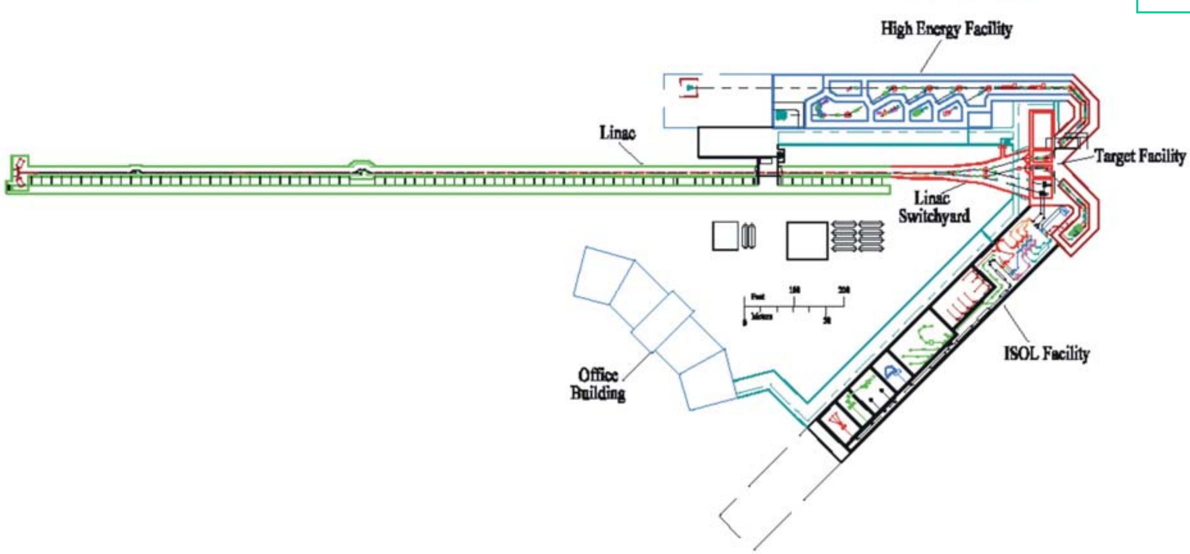


Towards realizing RIA

- R&D work going on (Accelerators, Sources, Targets, …) (DOE + local)
  RIA R&D Workshop Washington August 2003
- Layout options under study at ANL and MSU

Side-by-side views of the ANL & MSU layouts:



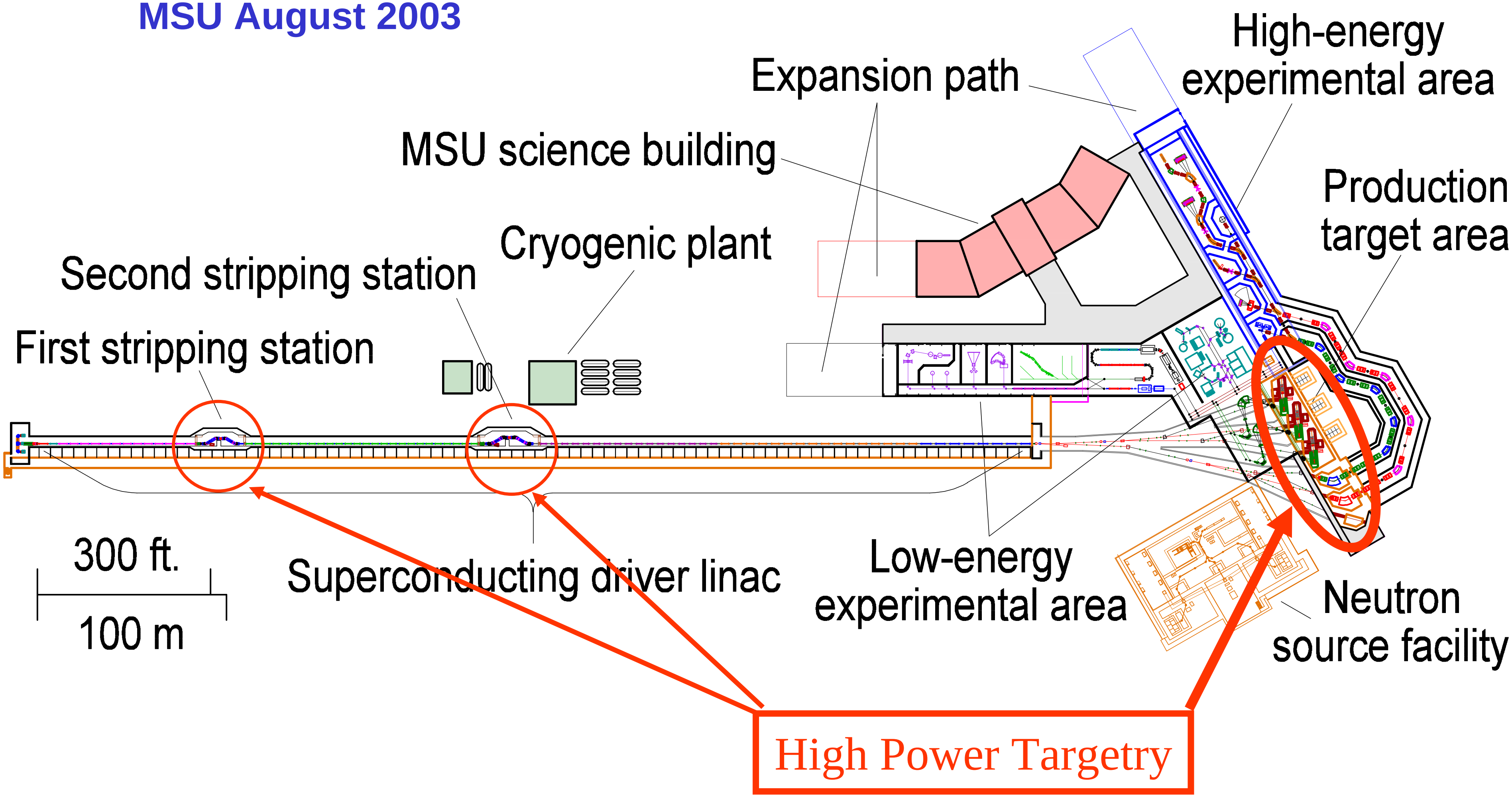


- **2 Fragment separators**
  - **Fast beam**
  - **Gas stopping**
- **2 ISOL stations**

  → 3 in latest MSU layout

RIA Layout

MSU August 2003



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Driver Linac Beam Parameters

Ion	A	Q	I_{ECR} (pμA)	E_{final}/A (MeV)	Final Beam Power (kW)	
					1 charge state	2 charge states
H	1	1	540	1019	**400**	-
Xe	136	17	12	470	**400**	-
Au	197	23+24	5.5		**241**	**483**
U	238	28+29	1.5	400	**77**	**154**

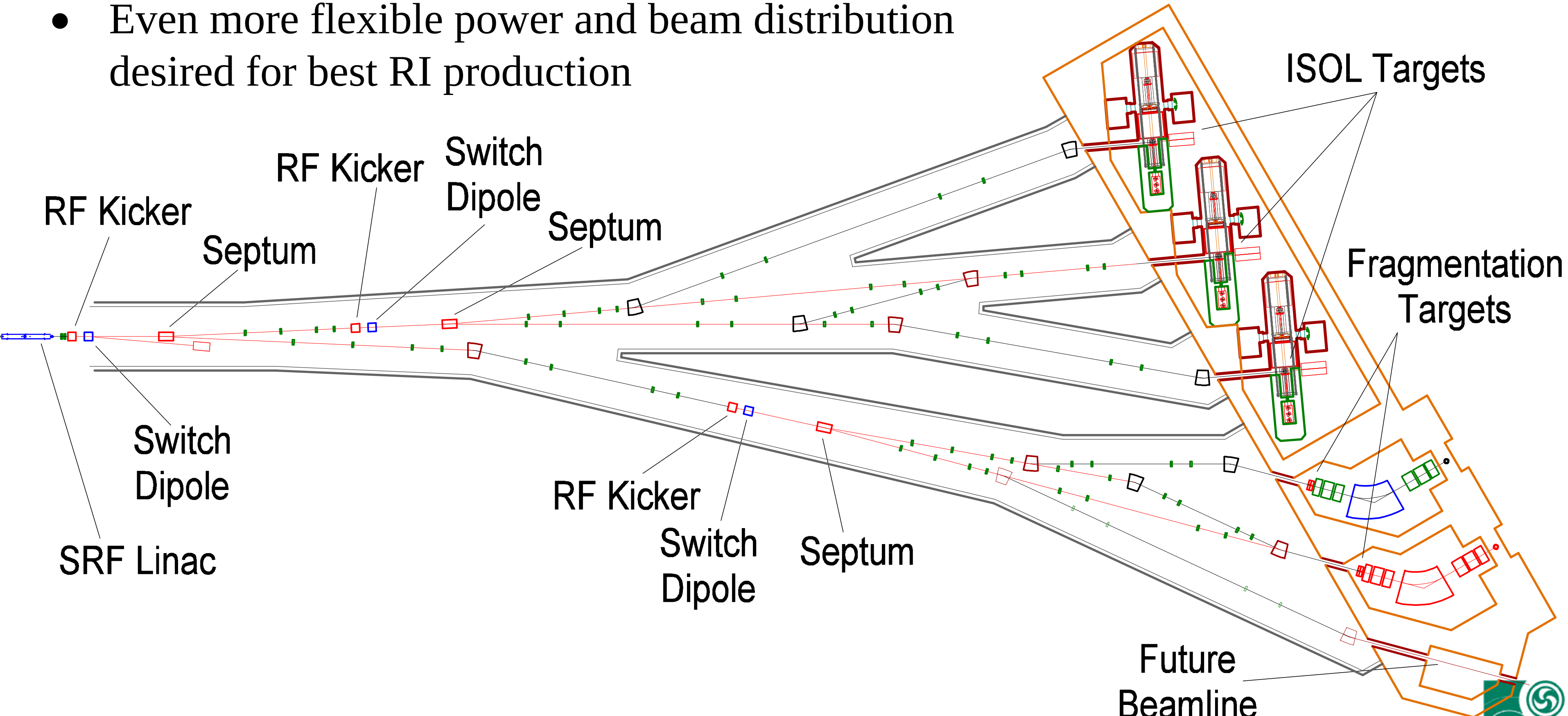
Beams from protons to Uranium

Beam power up to 400 kW or more

Beam distribution to targets

- Accommodate target area developments & to increase flexibility
  - 100% to any one, 50%/50% to any two, 50%/25%/25% to any three, 25%/25%/25%/25% to any four

- Even more flexible power and beam distribution desired for best RI production



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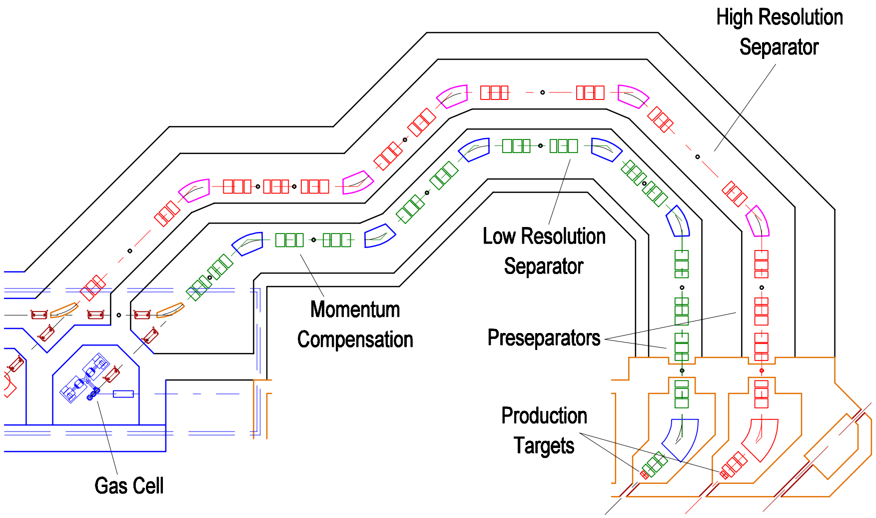
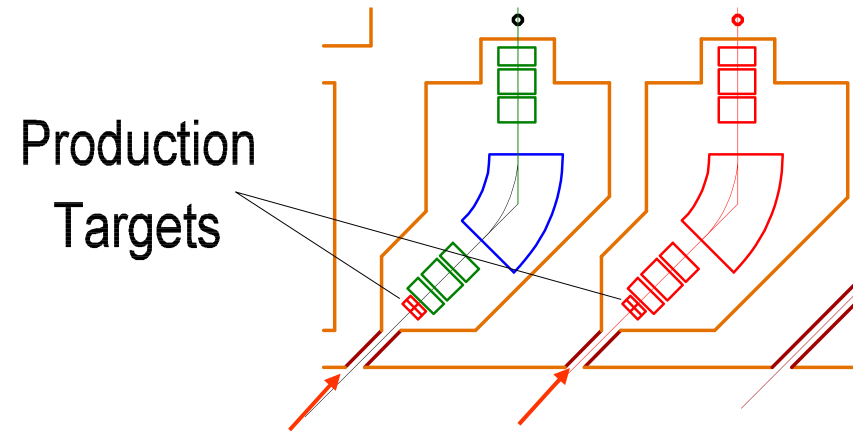
Fragmentation Area Layout





- Productions Targets
  - Very high power density - ~ 4 MW/cm^3
    - Small spot size – reduce geometric aberrations
    - ~20% of beam power lost in target
- Beam dumps
  - medium spot size, high power density ~ 50 kW/cm^3 , not localized
- High performance & radiation resistant magnets required – R&D challenge
- Characterization of radiation fields – required to support R&D efforts

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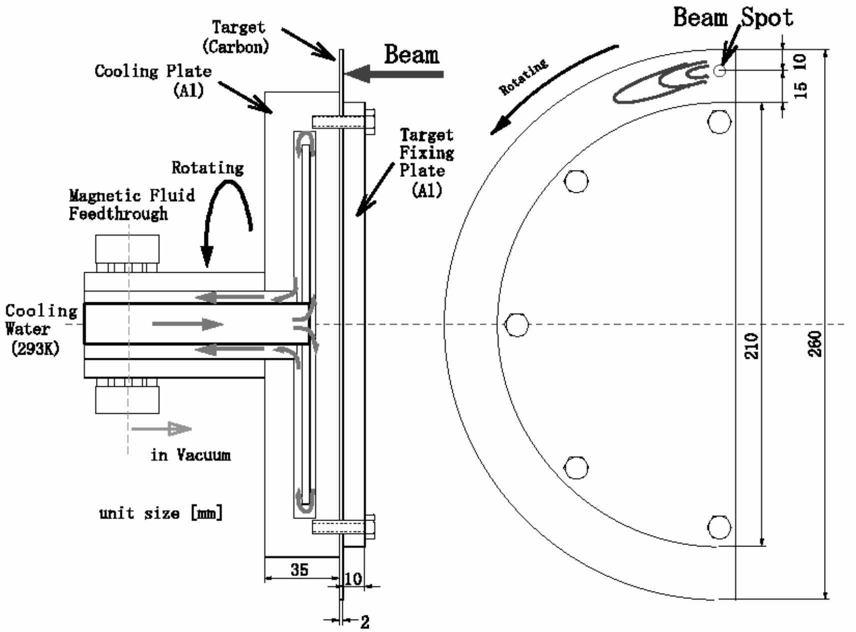
High power fragmentation targets

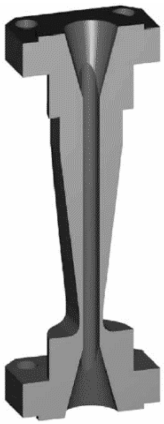
Solid targets

Rotating carbon target for up to 100 kW beam power (RIKEN)



T. Kubo, NIM B204 (2003)97
A. Yoshida et al, RIKEN Accel. Prog. Rep. 35 (2002) 152

Li-cooled Be target
for 4 kW beams at the NSCL
ANL – MSU development



J.A Nolen et al., NIM B204 (2003) 298

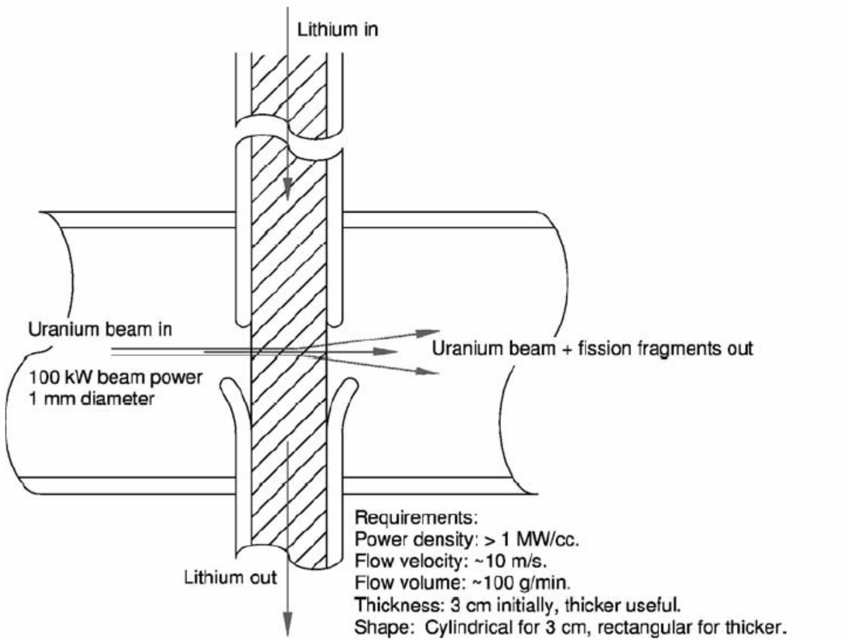
→ talk by J Nolen

High power fragmentation targets

Windowless liquid metal targets
ANL – development

J.A Nolen et al., NIM B204 (2003) 293

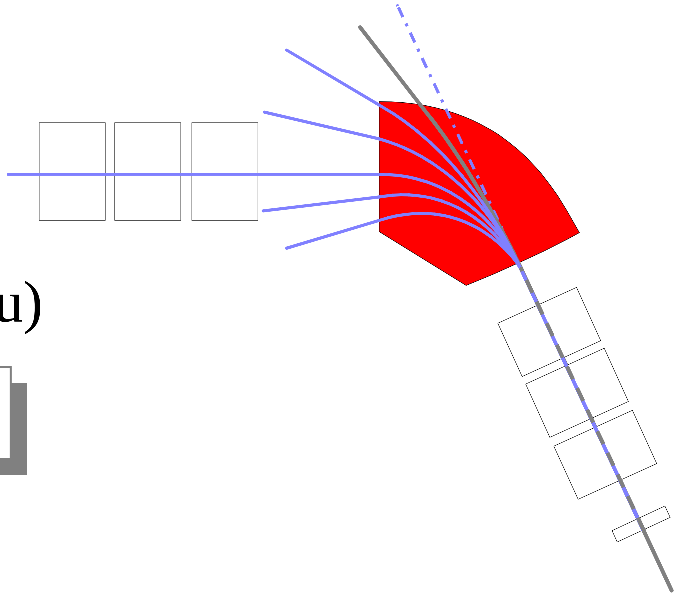
→ talk by J Nolen



- Very high power density - ~ 4MW/cm^3
  - Small spot size – reduce geometric aberrations
  - ~20% of beam power lost in target

- Development of targets for lighter beams required !

Fragmentation beam dumps



Unreacted primary beam ….

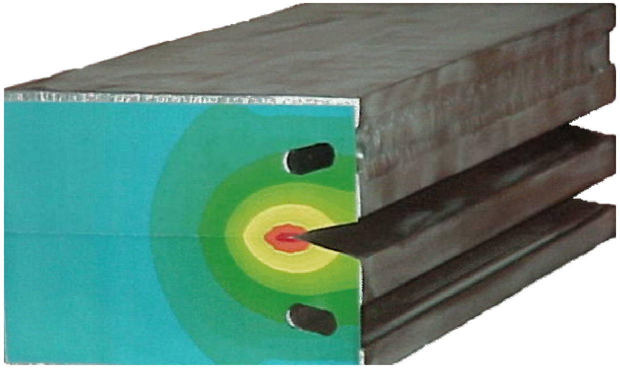
80% of initial beam power goes into dump

Range of U (400 MeV/A) ≈ 5 -10 mm (C - Cu)

Needs R&D

… and unwanted secondary ions

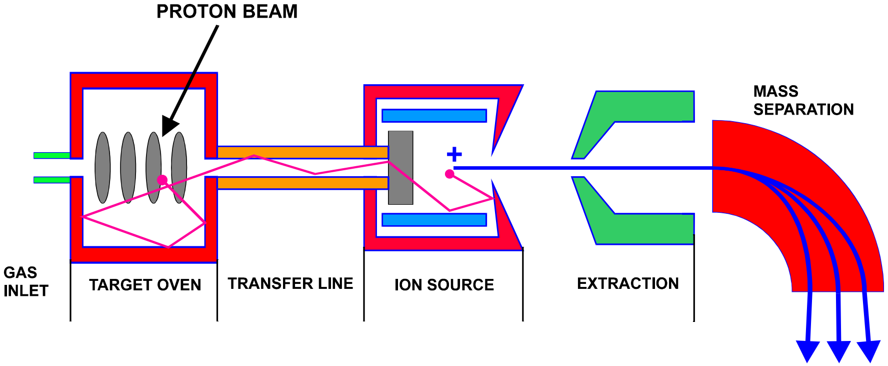
Typically a few kW beam power



NSCL A1900 beam catcher-bar for 4 kW

ISOL beam production

Basic Scheme:



- **Realized at ISOLDE, HRIBF (<10 kW), ISAC (<50kW)**
- **Planned for RIA (400 kW), EURISOL (100kW + 4 MW)**

ISOL target/ion source development has happened since > 30 years

- More elements
- Shorter release and higher yields,
- Higher selectivity and efficiency
- Higher power

→ H. Ravn, R. Bennet

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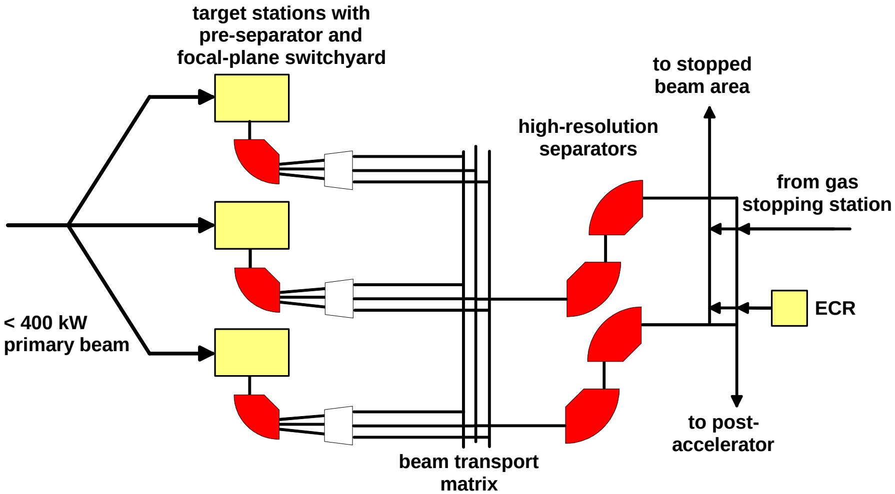
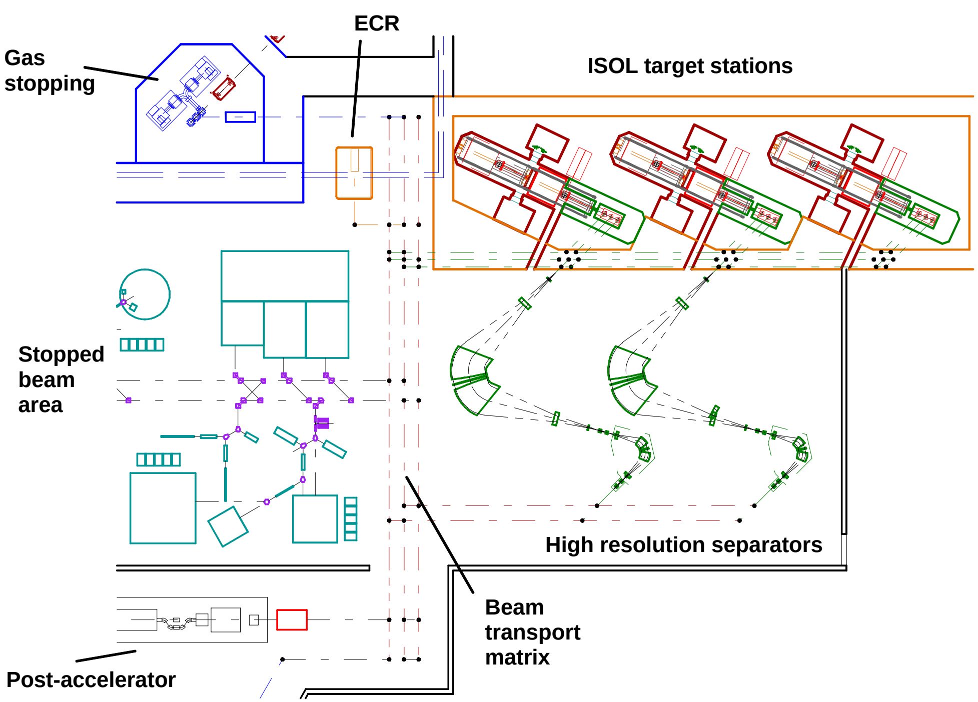
ISOL beam production at RIA





- 3 ISOL stations with pre-separators
  - 400 kW capability
  - Staged realization likely
- 2 high resolution mass separators
- 2 experimental areas
  - Stopped beam experimental area
  - Post-accelerated beams

R&D issues target area

- Targets + beam dumps
- Remote handling
- Classification

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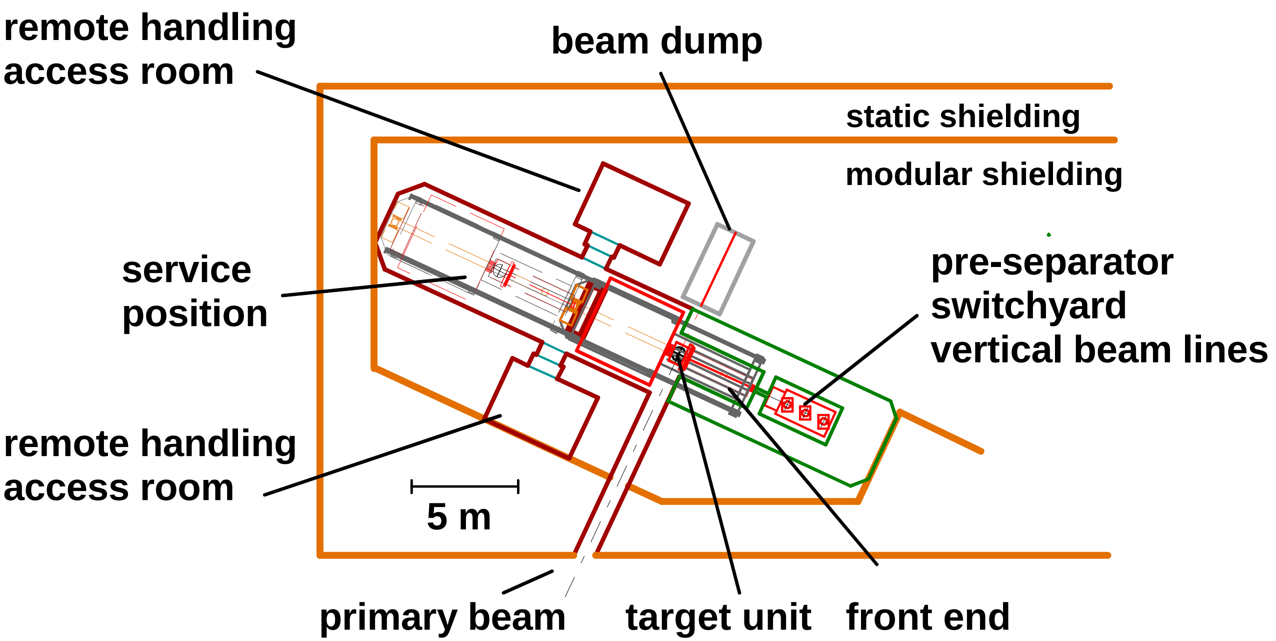
ISOL Target station



- ≤ 400 kW ISOL station:
  - Vertical vs horizontal system, shielding, how many stations
  - Remote handling - fast target changes – lifetime of components
  - …
- Needs more detailed design studies and R&D - **Now!**

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ISOL targets for RIA

- **Targets for spallation reactions**
  - Metal foil targets (RIST/ISOLDE, J. Bennet, P. Drumm, H. Ravn, ISAC, P. Bricault, M. Dombsky)
  - Oxide-Fiber targets, Composite targets (ORNL, ISOLDE)
  - …
- **Production of fission isotopes**
  - 2-step UC targets with neutron converters (ISOLDE, ANL, ORNL)

- Targets for Heavy Ion Beams

High power capability

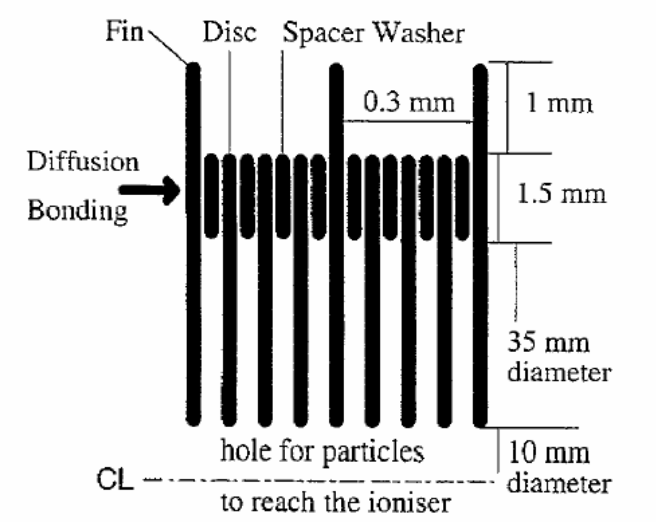
Short release times

High efficiencies

Metal foil targets

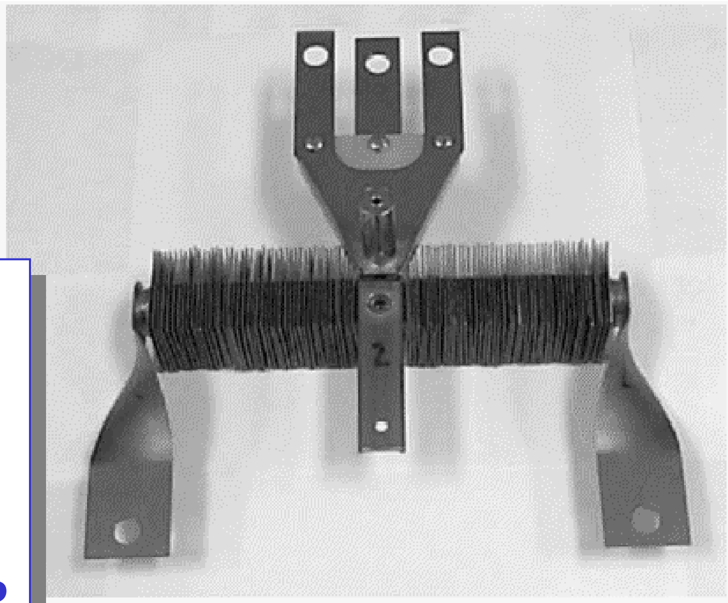
RIST target: Ta foil target
100 kW beam power (30 kW dissipated)

J.R.J Bennet et al, NIM B126 (1997) 105



ISAC Ta foil target for 50 kW beam

P. Bricault et al, NIM B204 (2003) 219



Radiation cooling good at high powers (~ T^{4})

Max. 450 W/cm^2 at 3000 K

Realistic: 30 W/cm^2 at 2000 K

Which cooling schemes at higher beam power?

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Targets for fission products

Low beam powers: protons on UCx target matrix

Principle of 2-stage targets:

- Neutron converter for neutron production and dissipation of beam power
- Surrounding blanket of fissionable material

In use at ISOLDE → H. Ravn

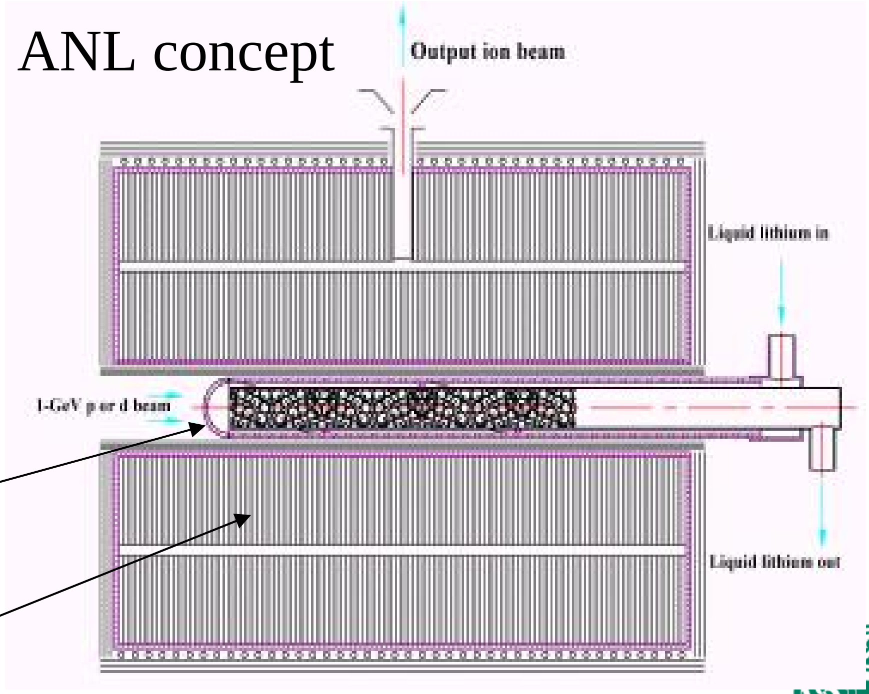
RIA R&D:

Prototype for ISAC (50 kW)

Full system under study for RIA

ANL-Techsource-ORNL

→ J. Nolen



Li cooled Tungsten converter

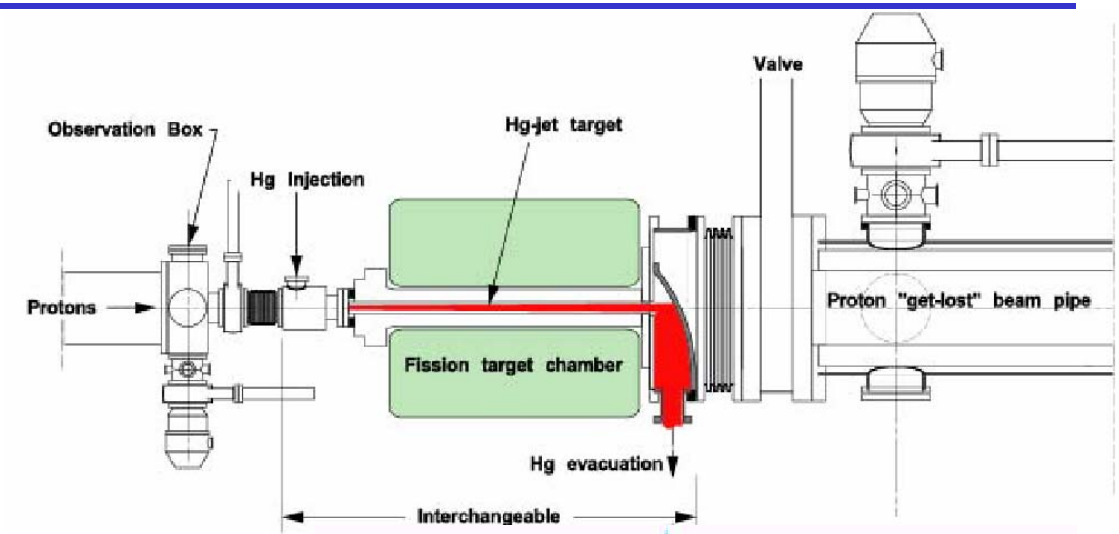
UCx blanket

Alternative: Mercury converter targets

EURISOL www.ganil.fr/eurisol/

Neutrino beam development

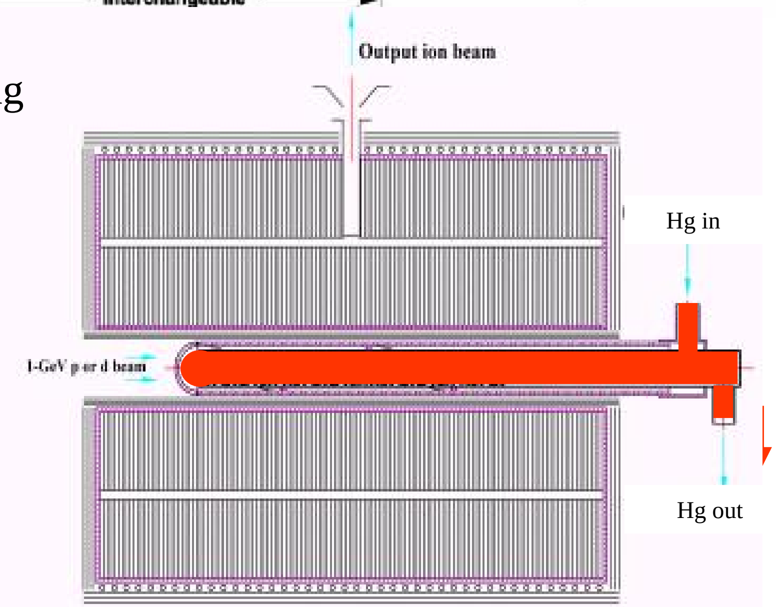
→ H. Ravn



Key advantages of Mercury

- It remains liquid which eases target changes and handling
- It is not flammable, which is a decisive safety point
- Increased potential for isotope recovery

…



Window-less or window version?

⇕

Benefit from SNS work

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Status of RIA – Targetry

- R&D has started but it is at its very beginning
- 100 kW concepts appear realistic
- It remains open which > 100 kW targets can be built and how they will look like
- Continue with present R&D – get and follow new ideas
- Benefit from R&D at other RI facilities, spallation neutron sources, neutrino beam facilities, …

This workshop !

- Important at early stage:
  - consider impact of possible target options including remote handling, safety etc
  - Make a flexible and expandable layout of RIA

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ISOL target development for RIA – a wide field

ISOL target R&D

High power issues

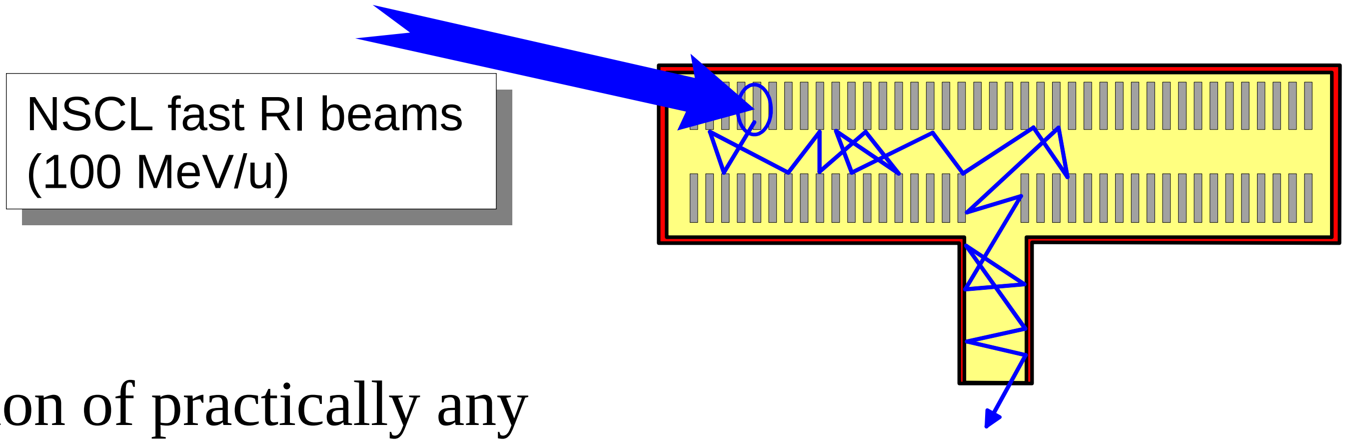
Production and release

- Evaluation of **Cooling schemes**
- **Material research:** experimental tests of known and new materials for targets and target containers
- Considering **target options** – solid or liquid metal converters?
- Further development of codes for the **modeling** of target issues
- Design of **prototype targets**
- **Power tests,** study of **release times** of prototype targets and **yield** measurements
- …

- **Develop tools** that can help to make target development more efficient

ISOL target development with fragment beams

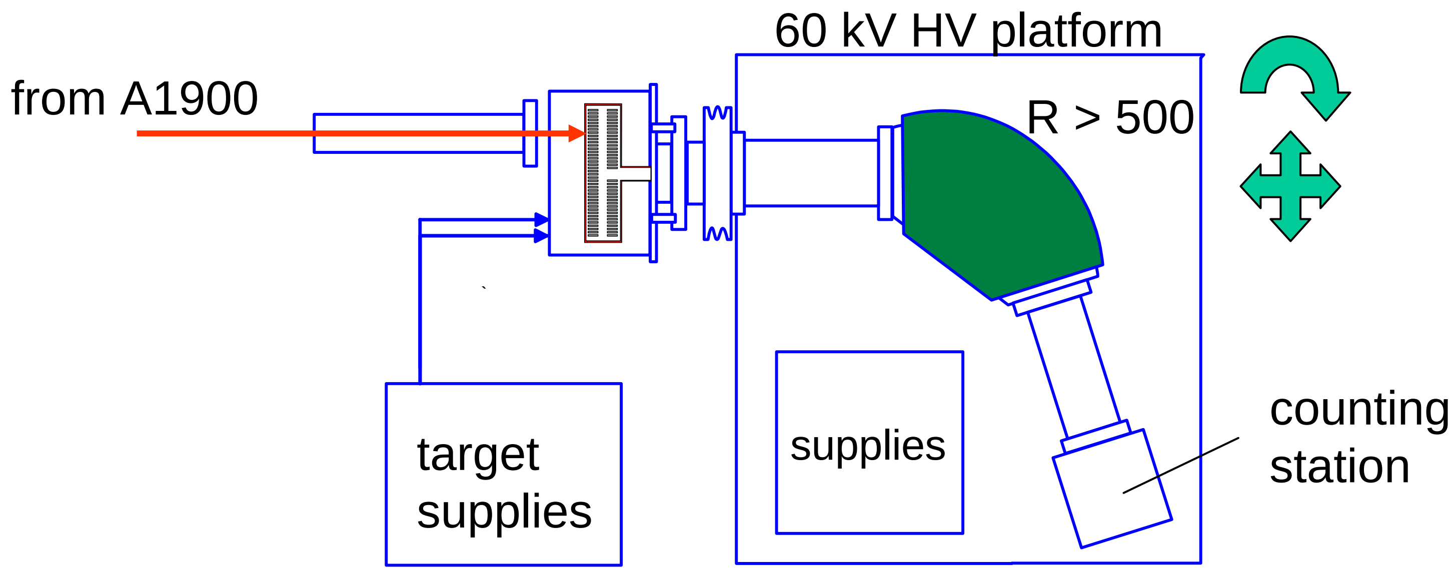
Proposed scheme



- Implantation of practically any isotope into target materials, target systems, prototypes …
- Localized implantation
- Tests very close to realistic conditions if target heated
- Low radiation level and radioactivity build up – **Hands-on** experiments - Fast iterations

Not a replacement of on-line tests but will help to do fast prototyping

Scenario for an ISOL test station at the NSCL



- Flexible front end design for mounting different types of targets
- Mass separator with modest resolving power
- Counting station for RI identification
- Rotation and translation degrees of freedom

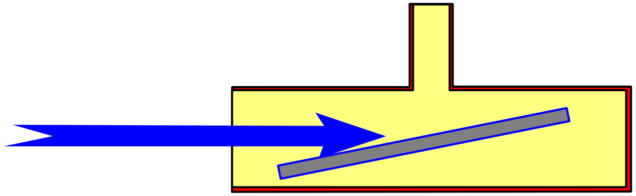
ISOL R&D opportunities with fragment beams

Examples:

- Diffusion and effusion studies (different materials, geometry and temperature)
- Investigation of formation of molecular sidebands
  (*C + TaO = Ta + *CO, *S + Sn = Sn*S, *Si + CeS = *SiS + Ce, *O + C = C*O, or *Al + F = *AlF)
- Disentanglement of long-term effects of temperature and radiation damage on target performance
- Test of RIA target prototypes
- Test of targets used or under development at other ISOL facilities

ISOL R&D opportunities with fragment beams

- Fast fragments for ISOL beam production in parasitic mode
  - Low-power primary beam + fragmentation target
    or beam from fragment separators
  - Catchers optimized for fast release
  - Not a primary production scheme
    for RIA, but may enhance facility output

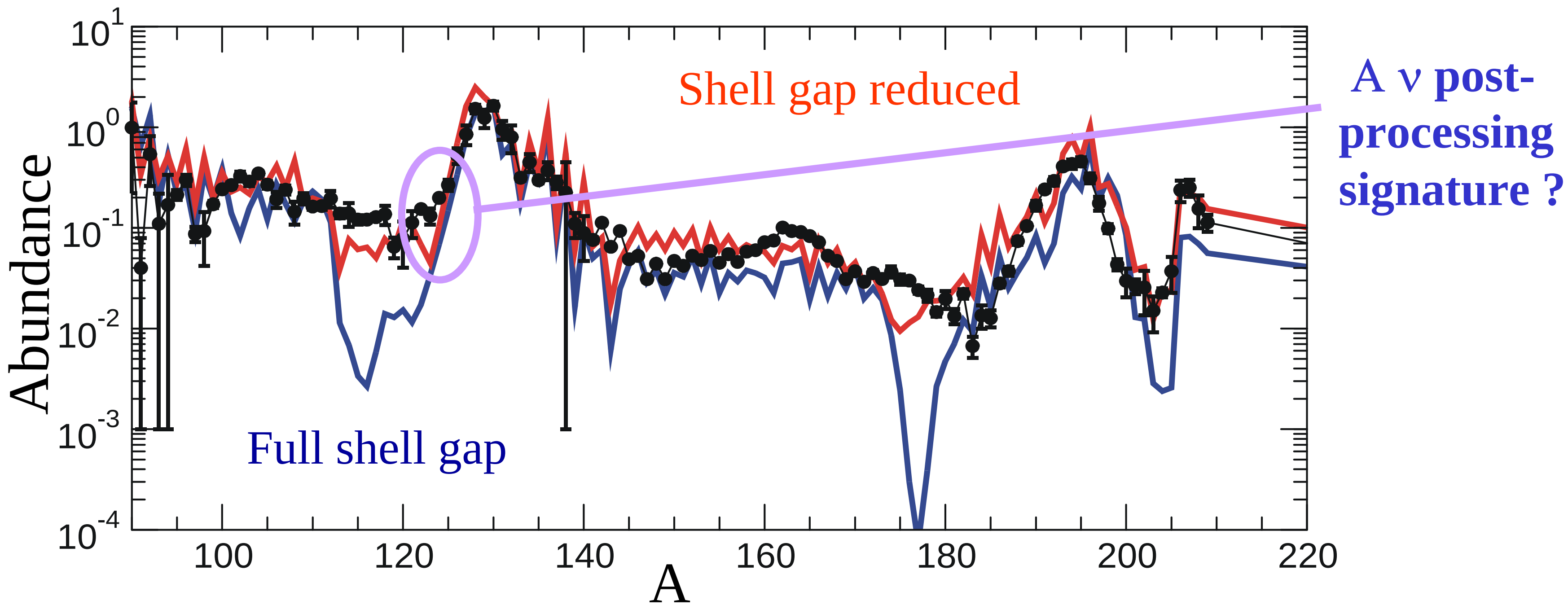


Fast beams can become a valuable tool for ISOL R&D

starting at the NSCL and continuing at RIA

Importance of Nuclear Physics in the r-process

In r-process model calculations shell structure affects the results.



<u>Need to determine experimentally</u>:

- Are shells reduced far from stability?
- Are the astrophysical models wrong?
- What does the abundance distribution tell us about the site?

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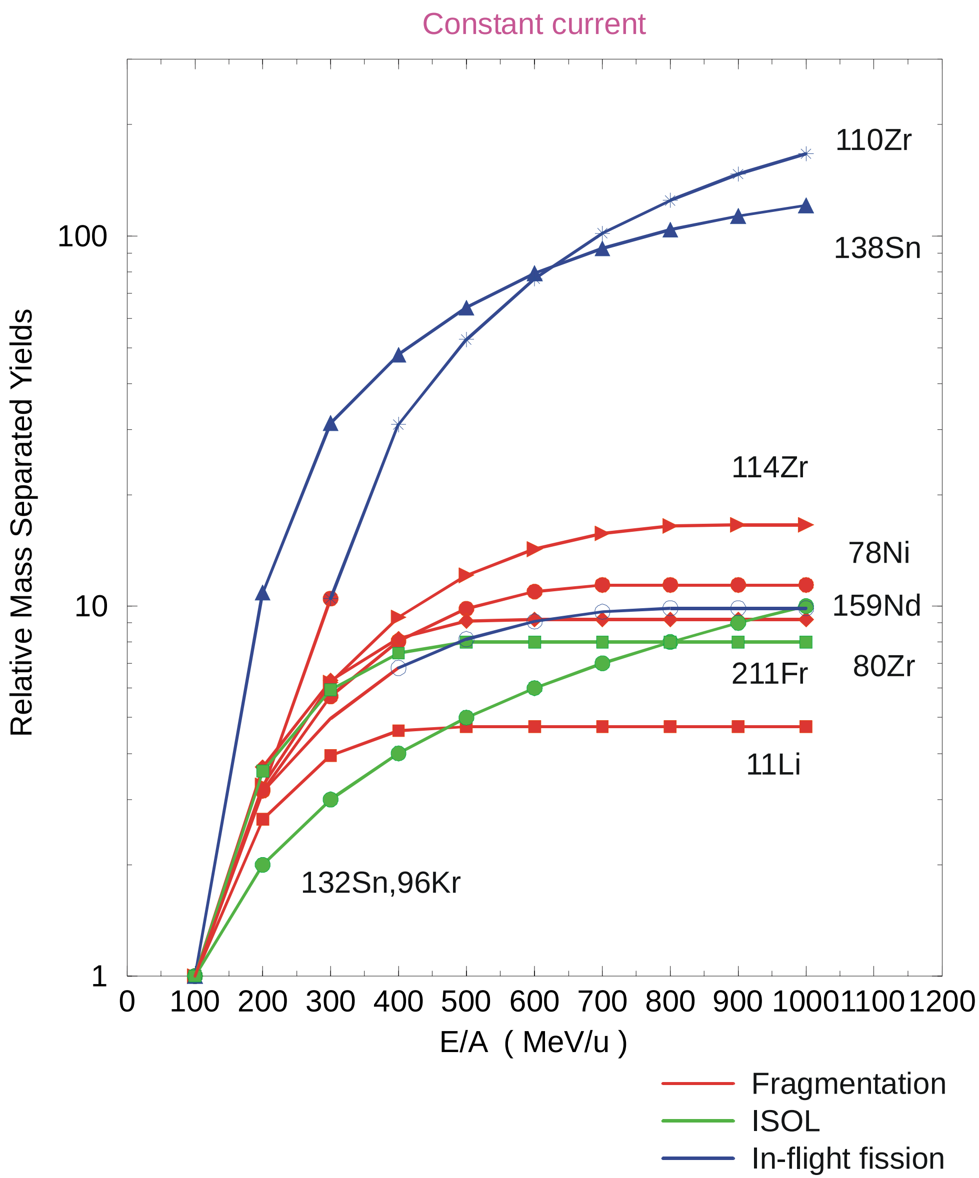
Energy Dependence of RI Production: RIA Example



The turn over point depends on the fragment separator acceptance.

A smaller acceptance fragment separator produces a later turnover.

G. Bollen, Targetry Workshop, Long Island, 2003

Table 1
Comparative target power dissipation (taken from Ref. [13])

Primary particle			Target, bombarded by 1 particle μA over 1 cm^2			
Type	Energy (MeV)	Energy loss (MeV/g cm^2)	Element	Thickness (g/cm^2)	Total power (W)	Power density (W/cm^3)
n	thermal	160/fission	^{235}U	1	160	32
p	1000	1.2	^{238}U	110	420	7
p	30	16.7	carbon	0.9	30	75
^{12}C	1152	200	tin	4	800	1200
^{36}Ar	3456	2351	carbon	0.9	2100	5250

J.R.J Bennet et al, NIM B126 (1997) 105

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RIA Science Case

- **Nature of Nucleonic matter**
- **Origin of the Elements**
- **Tests of the Fundamental Symmetries of Nature**
- **Isotopes for Applications**