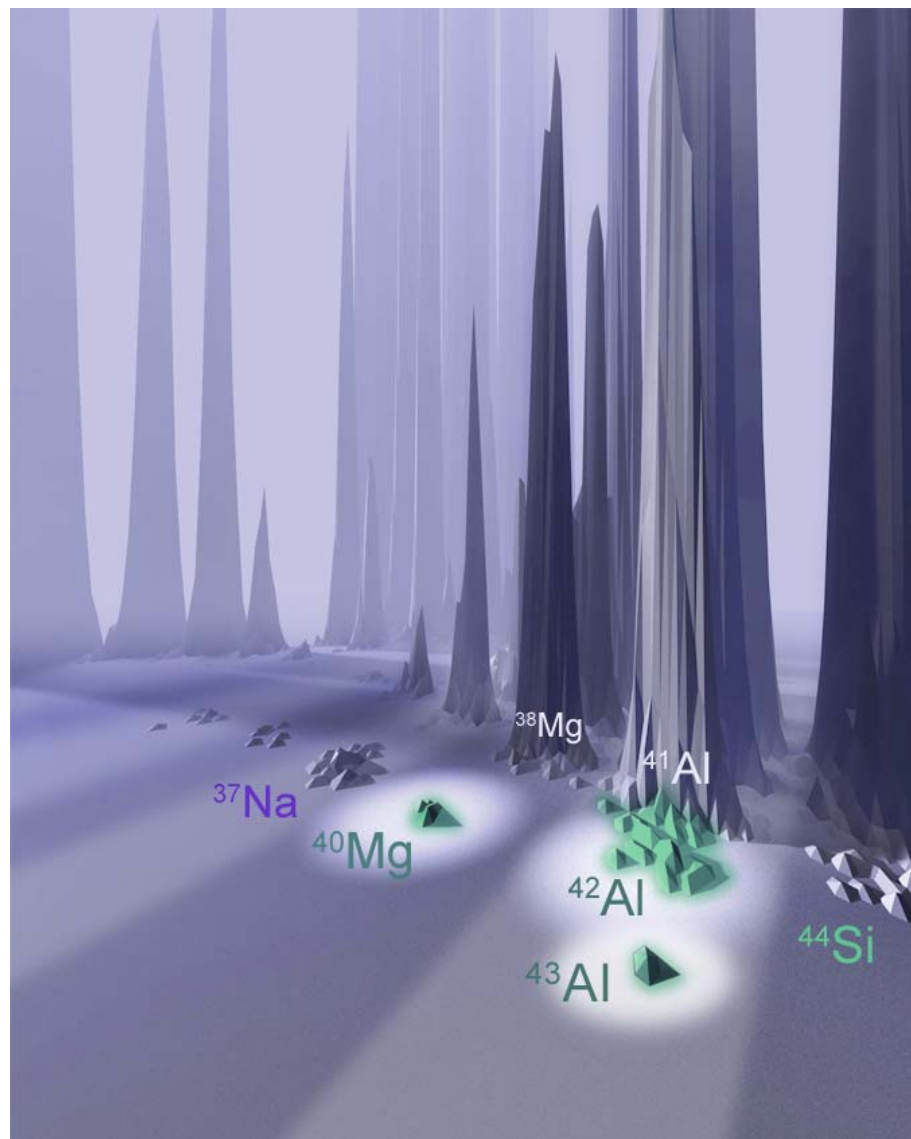
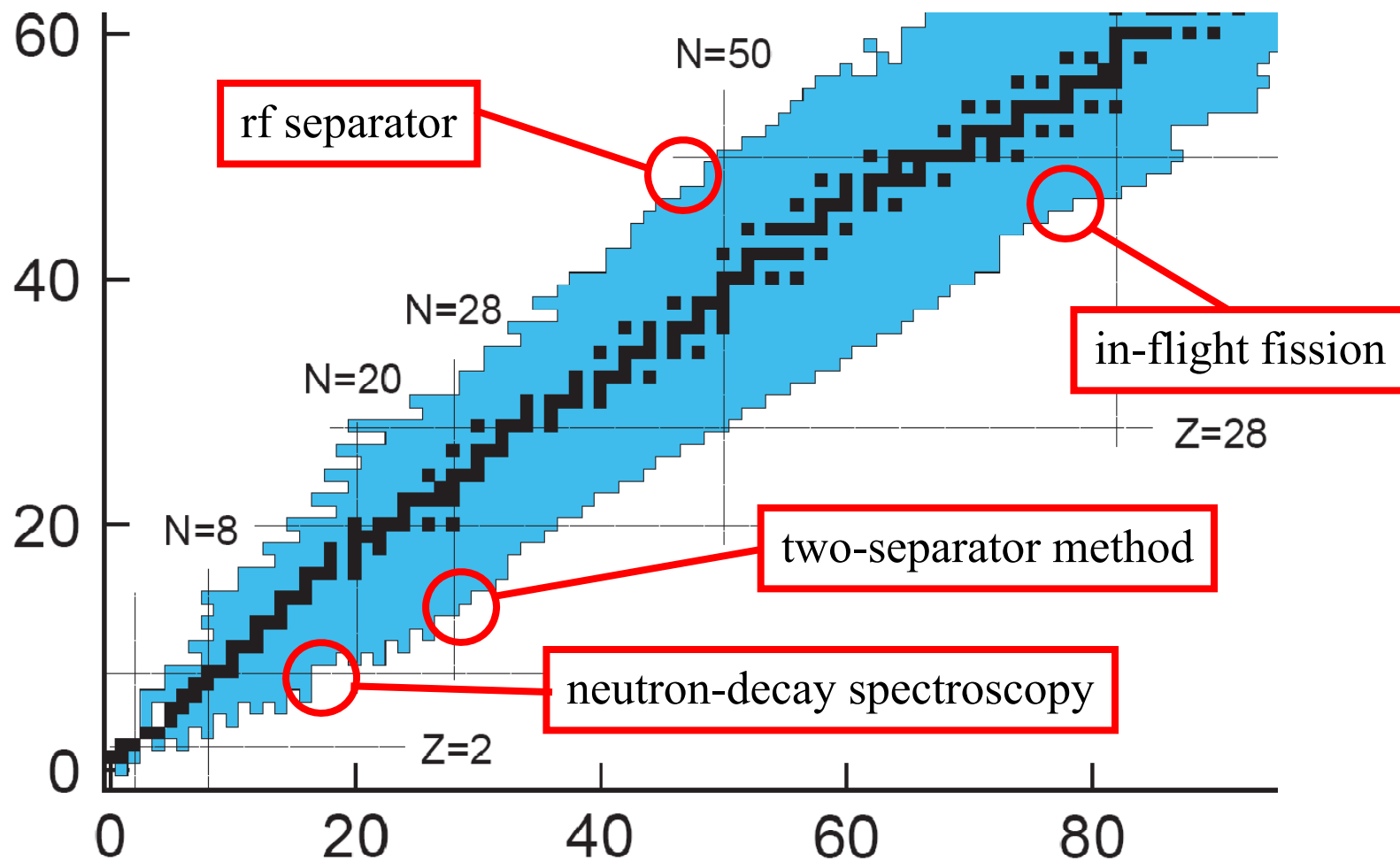


# Exploration of the Driplines at the NSCL

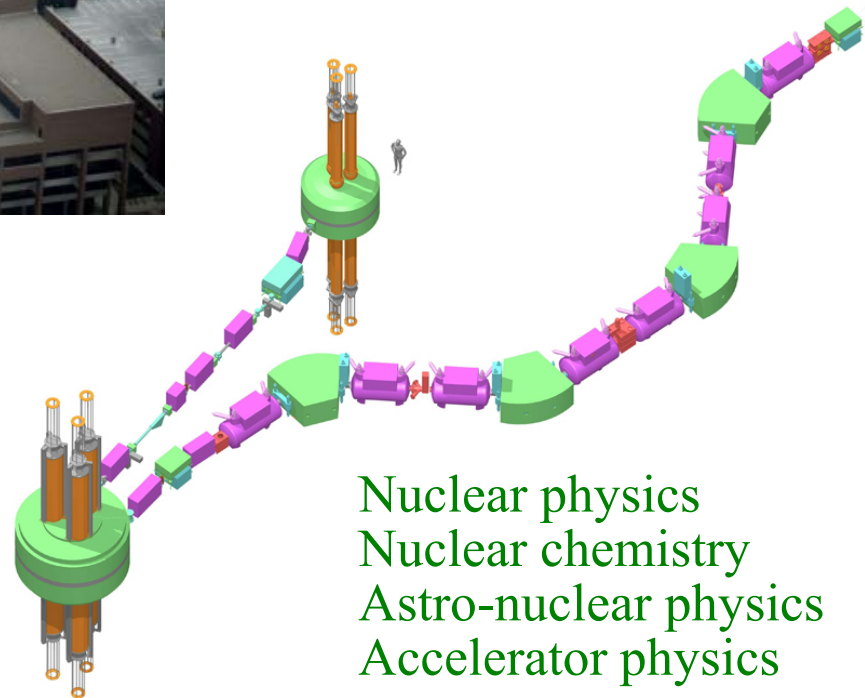




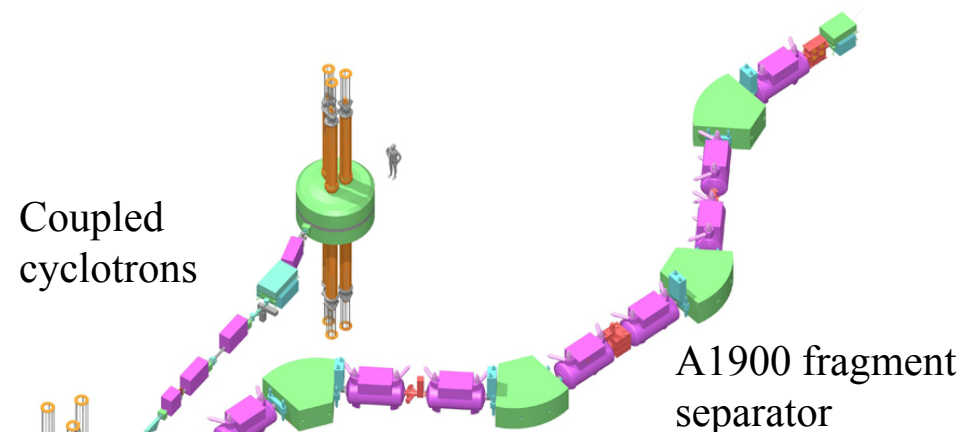


The Coupled Cyclotron Facility user group has 683 registered users

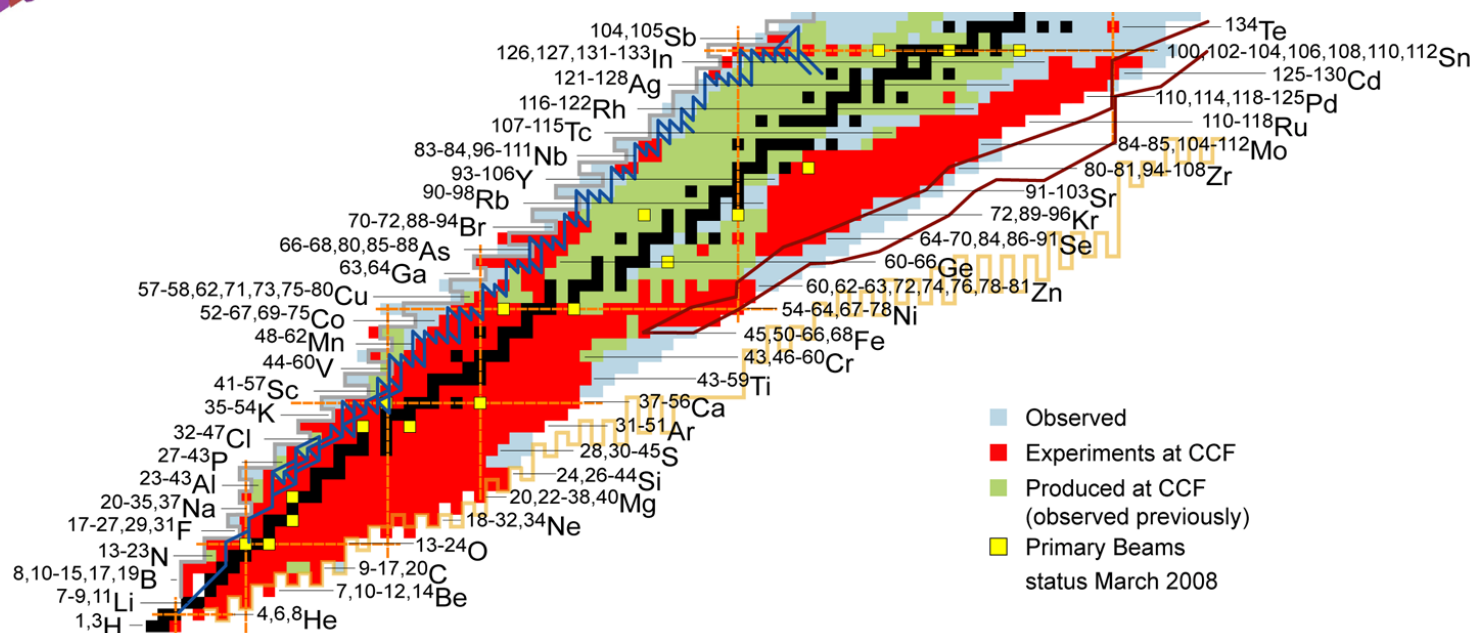
46 Undergraduate students  
57 Graduate students  
13 Postdocs  
30 Faculty

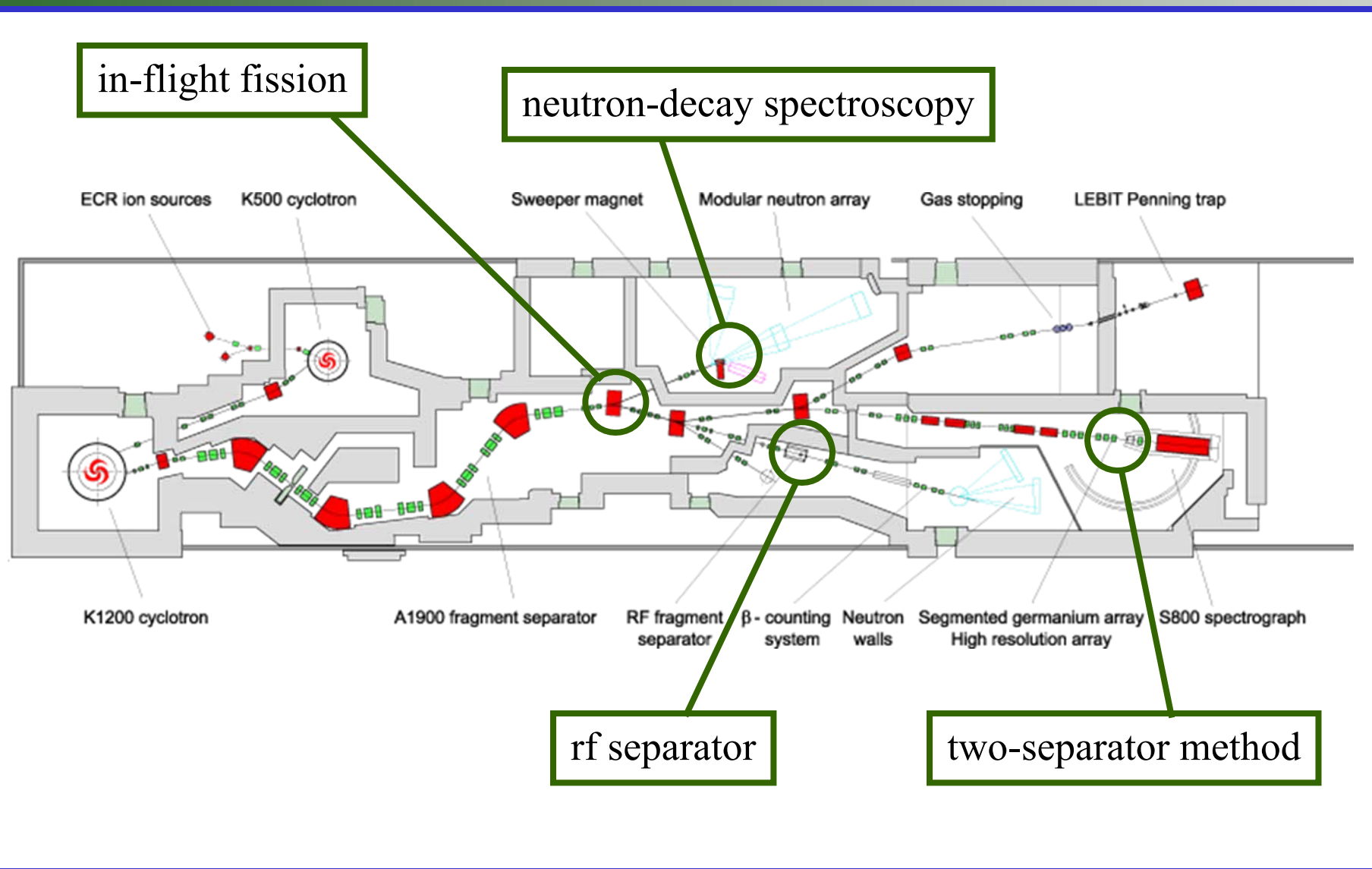


Nuclear physics  
Nuclear chemistry  
Astro-nuclear physics  
Accelerator physics



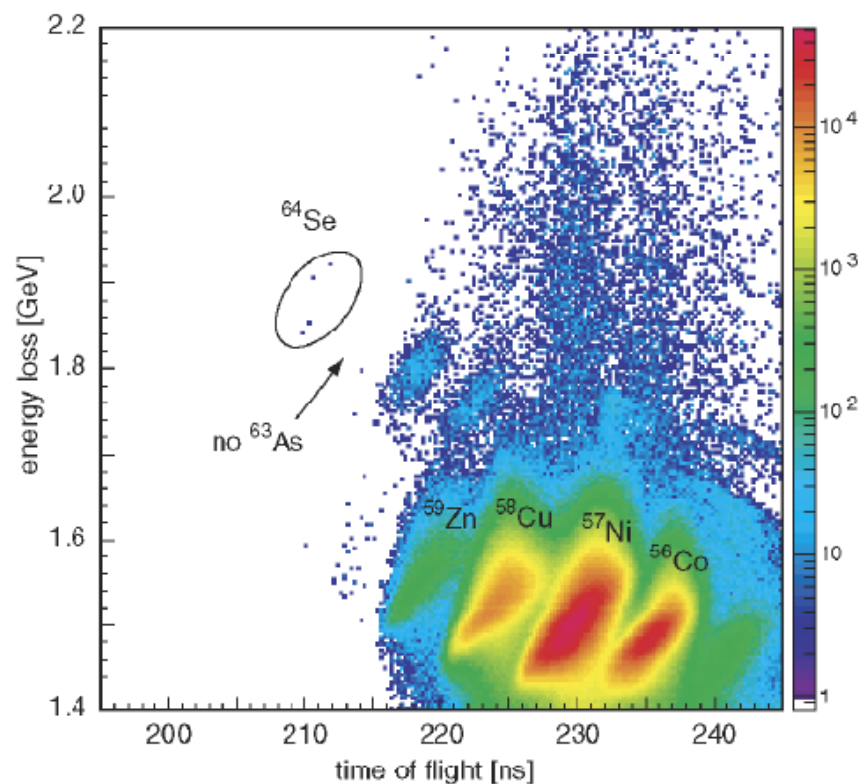
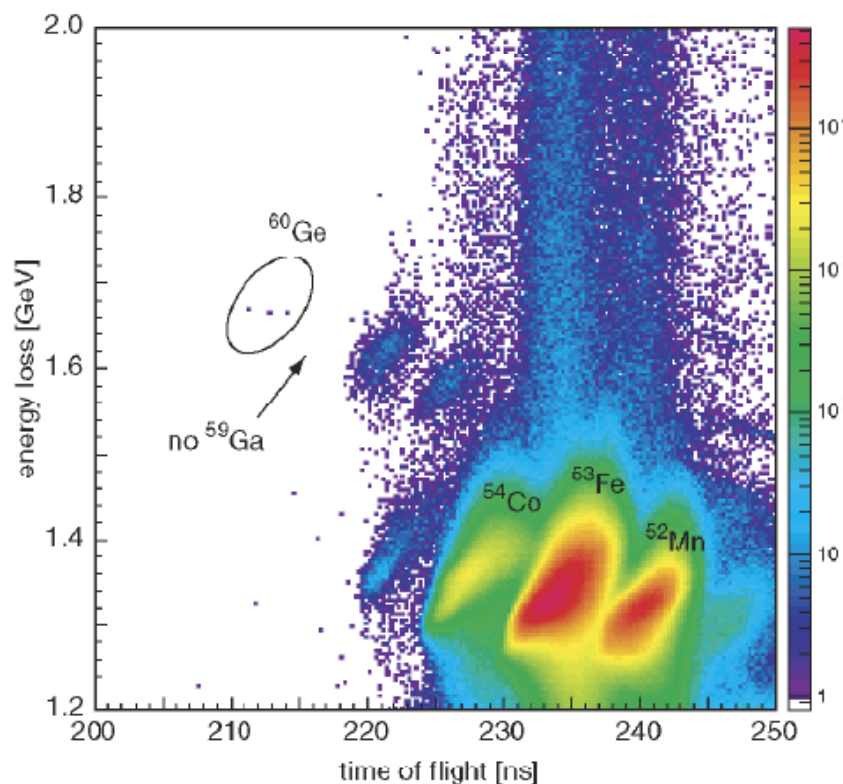
- Production of rare isotopes with projectile fragmentation
- Over 600 rare isotope beams to users since 2001





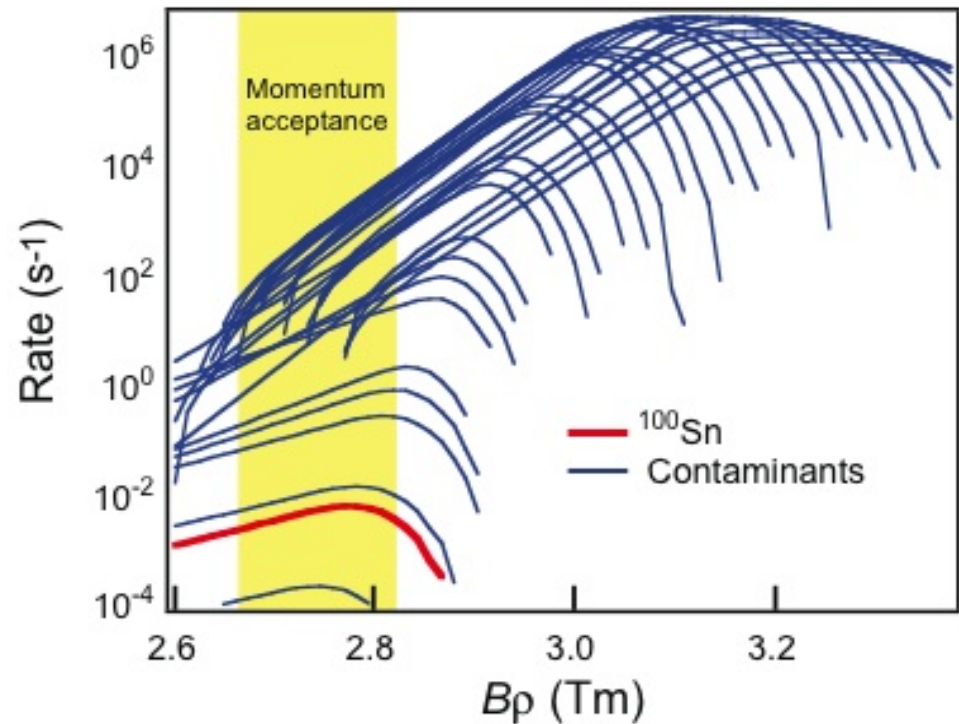


## First Observation of $^{60}\text{Ge}$ and $^{64}\text{Se}$



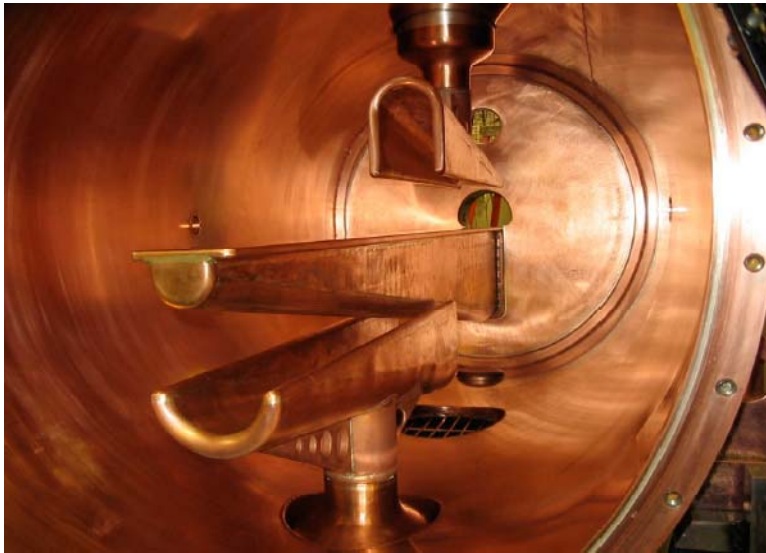
- Low momentum exponential tails:
  - Proton-rich fragments have lower rigidity
  - Tails of fragments closer to stability overlap with fragments of interest
- Fragment separator
  - Selection provided by the achromatic wedge insufficient
  - Additional filtering needed

Momentum distributions of the transmitted fragments at the exit of the A1900



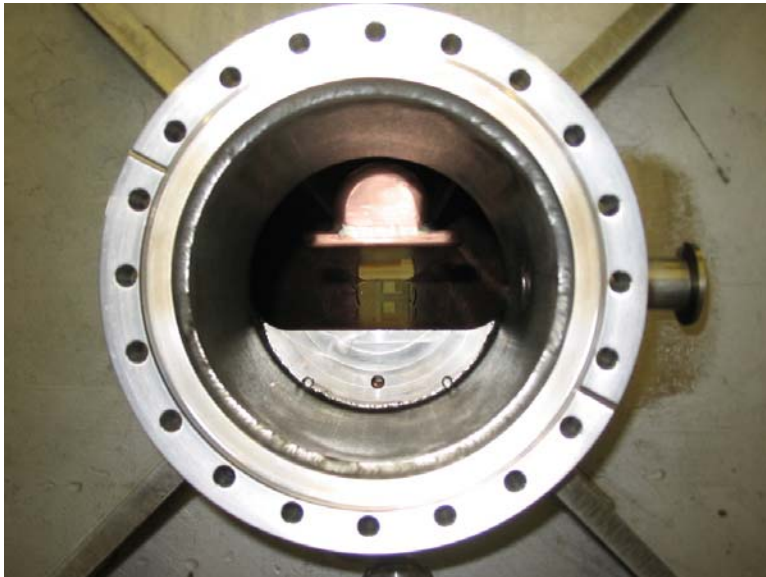
—————→ **rf fragment separator**

# rf-Separator

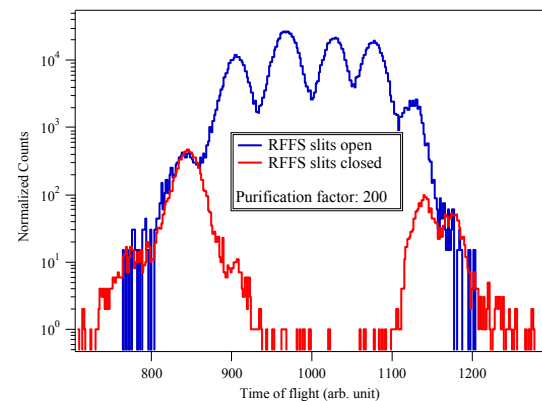
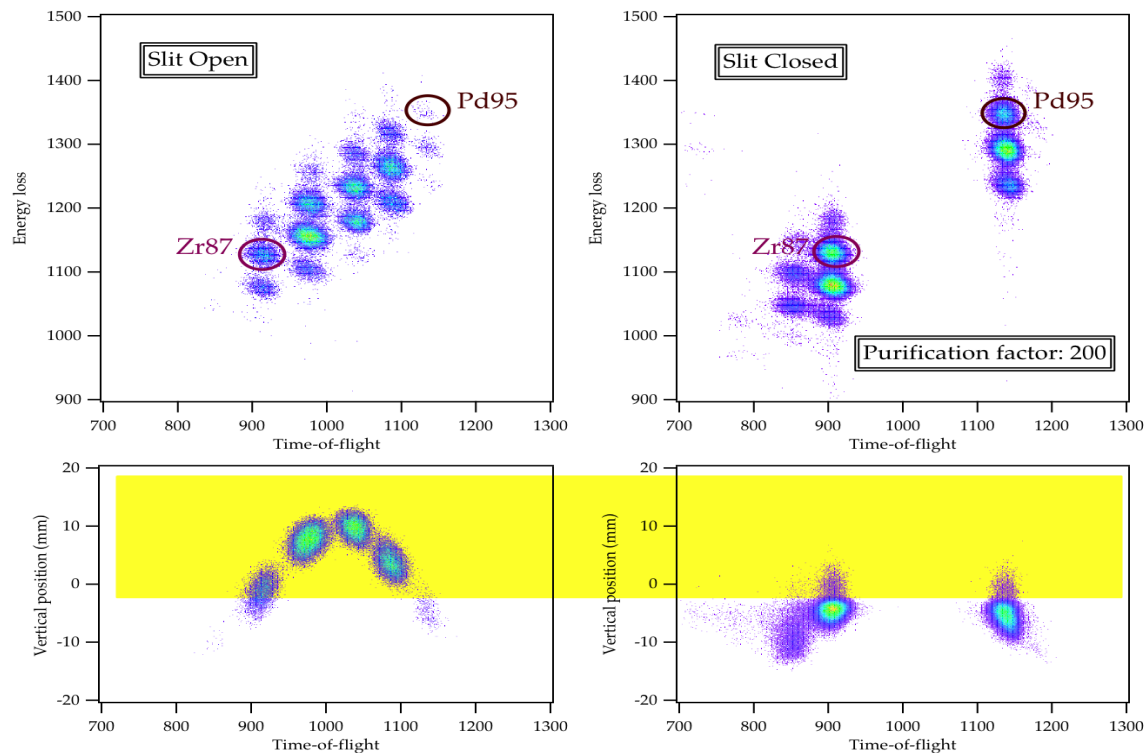


rf system:

- 18 to 28 MHz
- 100 kV
- gap: 5 cm
- length: 1.5 m
- power: 6 to 14 kW

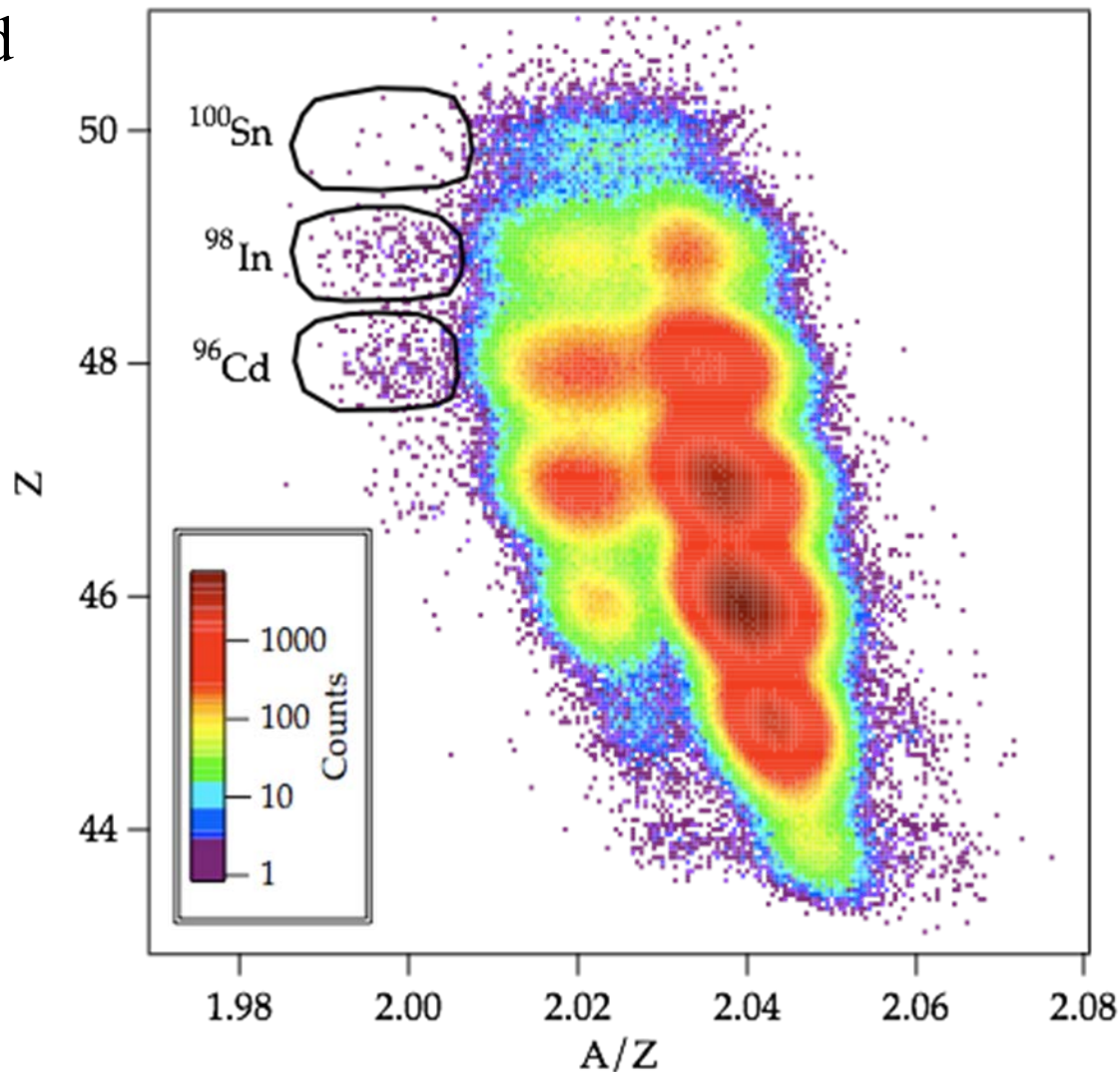






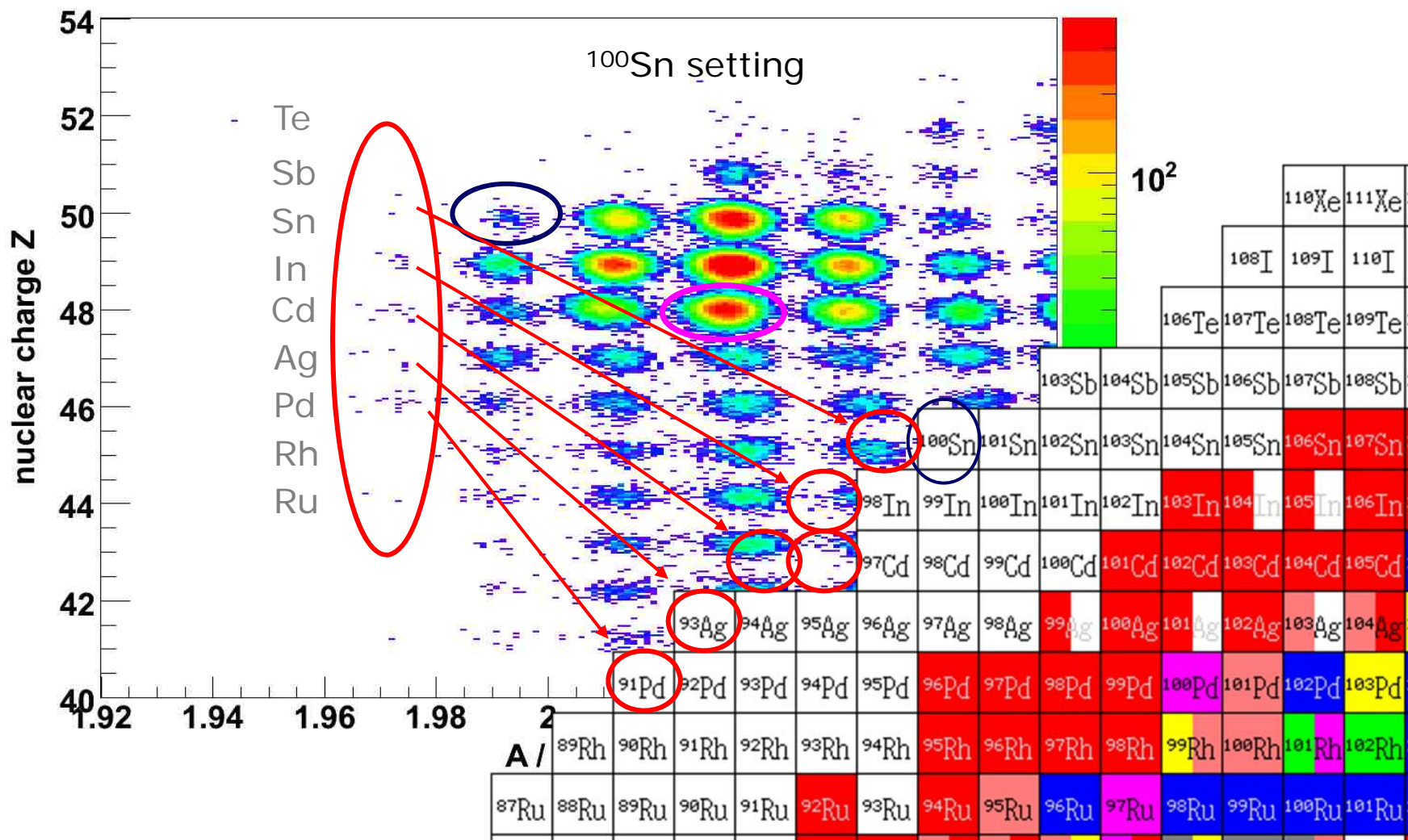
## First observation of $^{96}\text{Cd}$

120 MeV/u  $^{112}\text{Sn}$ , 10 pnA  
 195 mg/cm<sup>2</sup> Be target  
 1% momentum acceptance



D. Bazin, A. Becerril Reyes *et al.*

# Competition from GSI



M.Górska, T.Faestermann, K.Eppinger, C.Hinke, et al. (Rising Collaboration)

kft.umcs.lublin.pl/wfj/transp/2008/Gorska/Kazimierz08\_gorska.ppt

$^{238}\text{U}^{69+}$

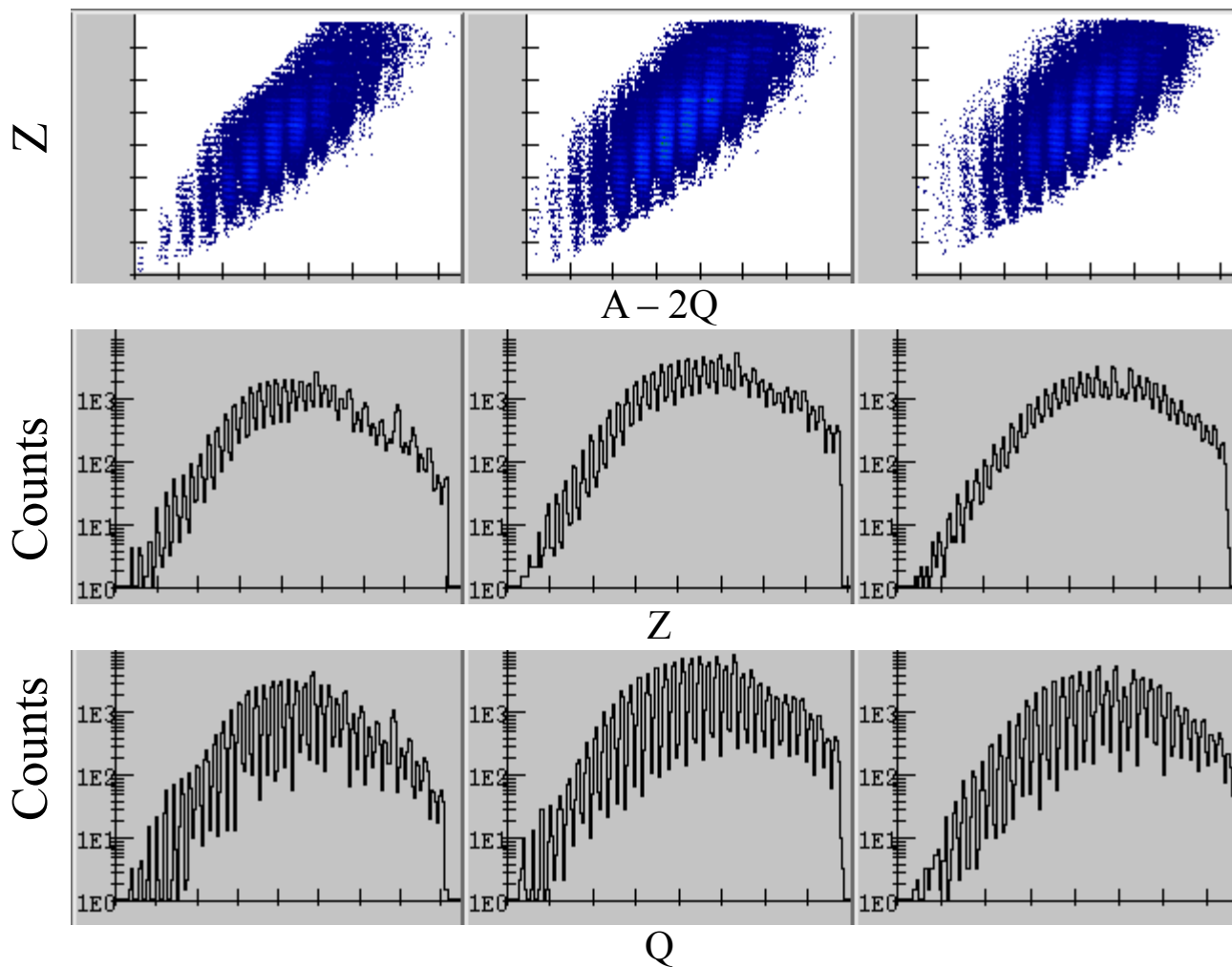
81.3 MeV/u,

$\langle I \rangle = 0.1$  pA

Fully Stripped

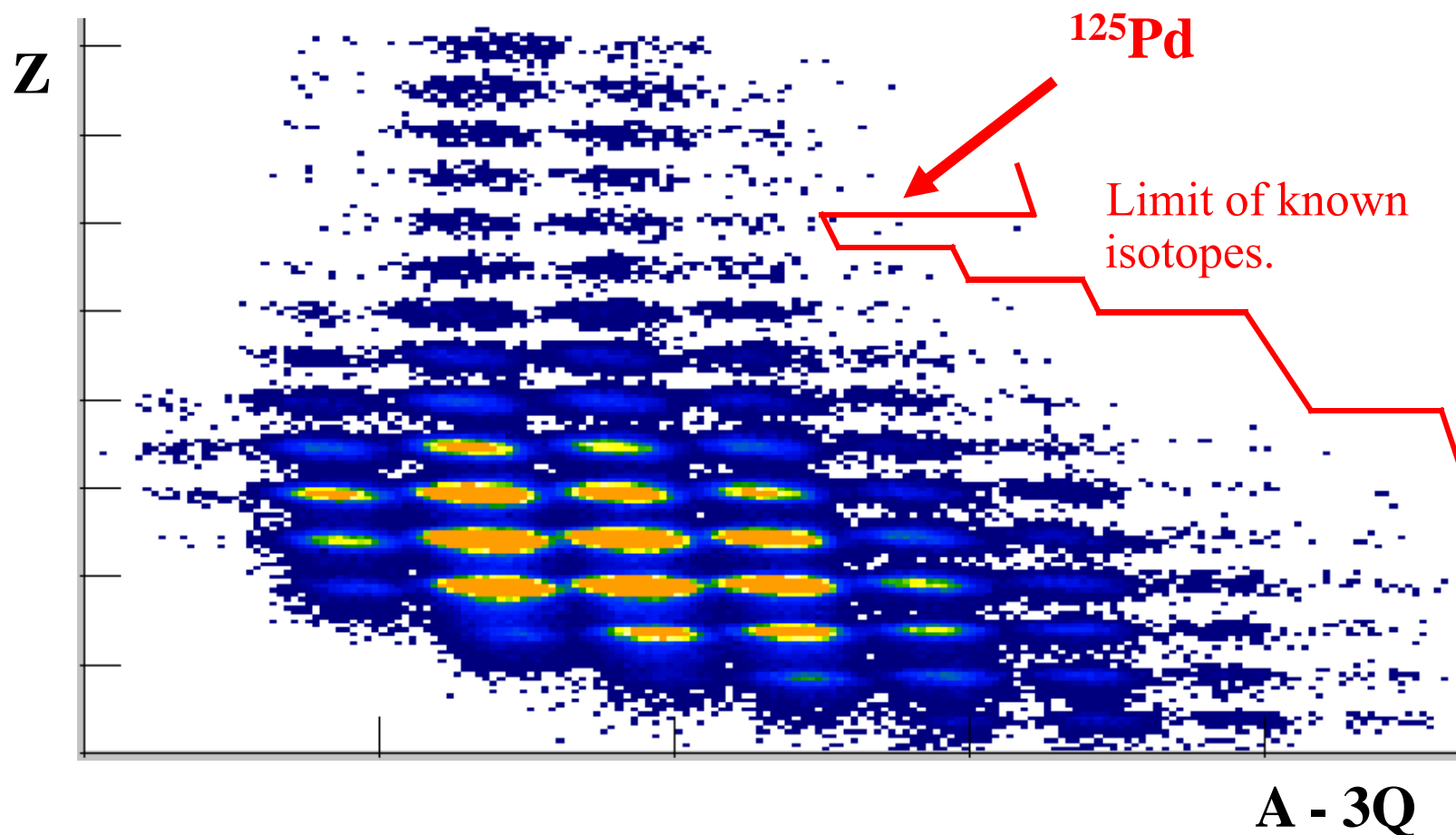
H-Like

He-Like





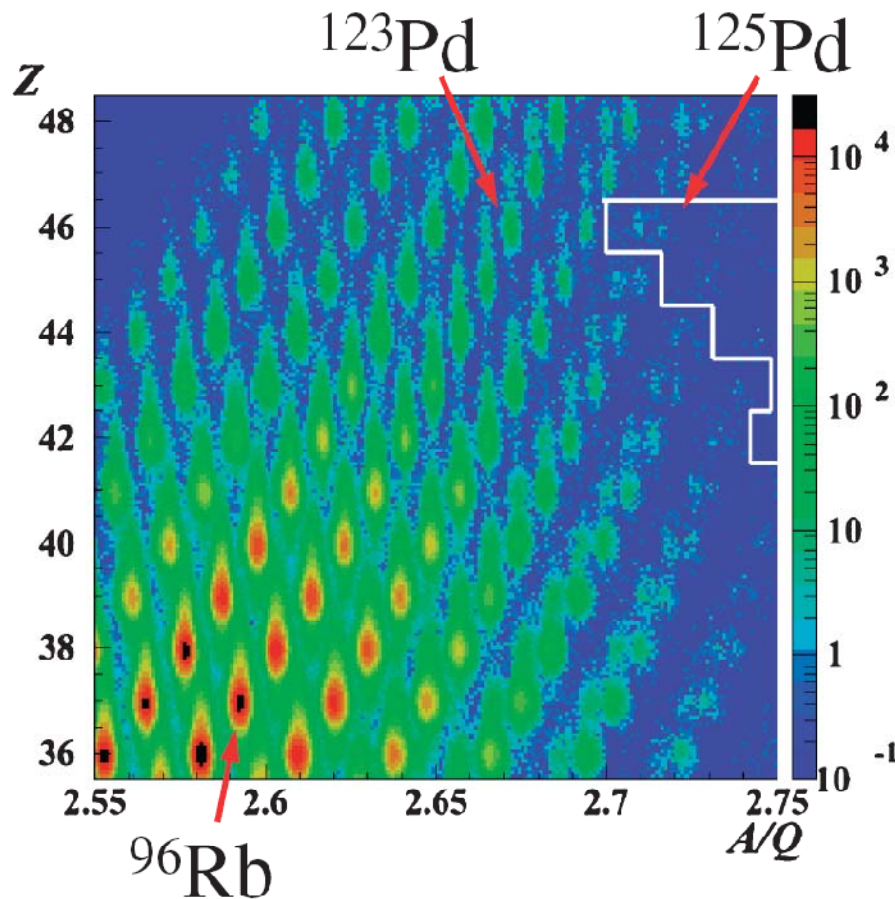
## Observation of $^{125}\text{Pd}$



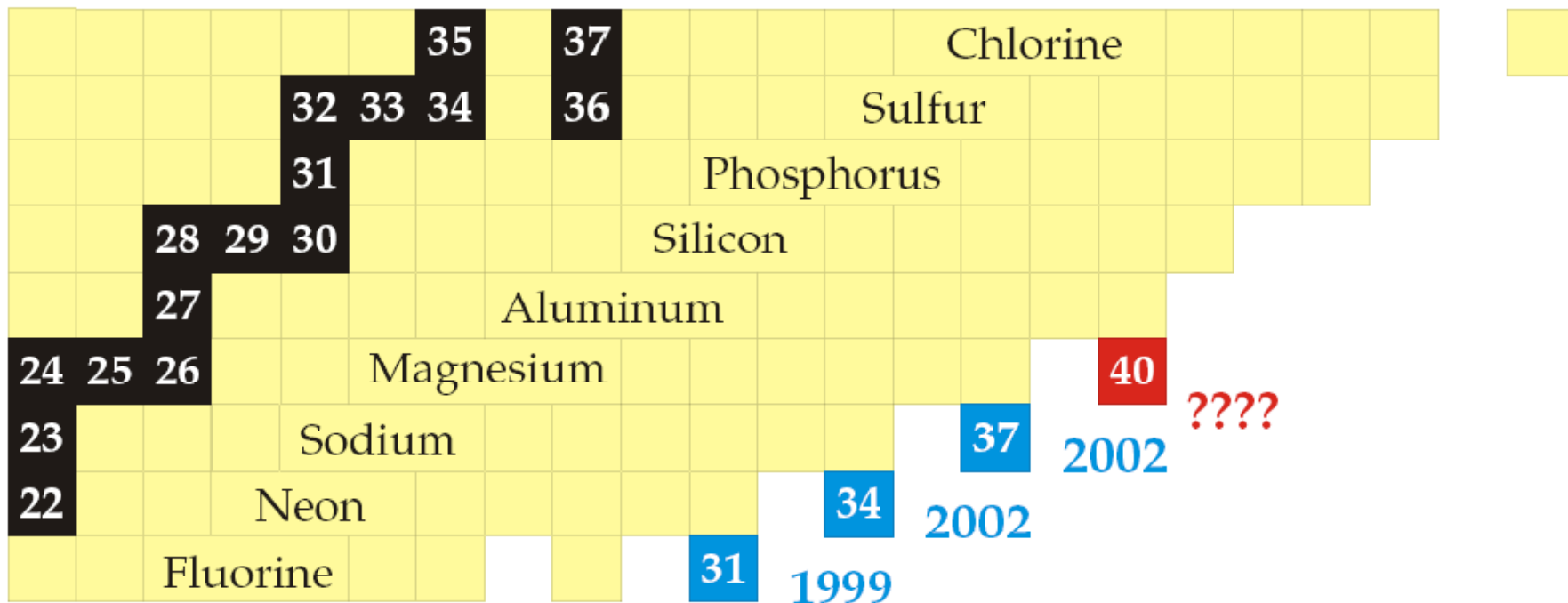
C.M. Folden III *et al.* (MSU, RIKEN, OSU, ANL, TAMU)

# Competition from RIKEN

Identification of New Isotopes  $^{125}\text{Pd}$  and  $^{126}\text{Pd}$  Produced by In-Flight Fission of 345 MeV/nucleon  $^{238}\text{U}$ : First Results from the RIKEN RI Beam Factory



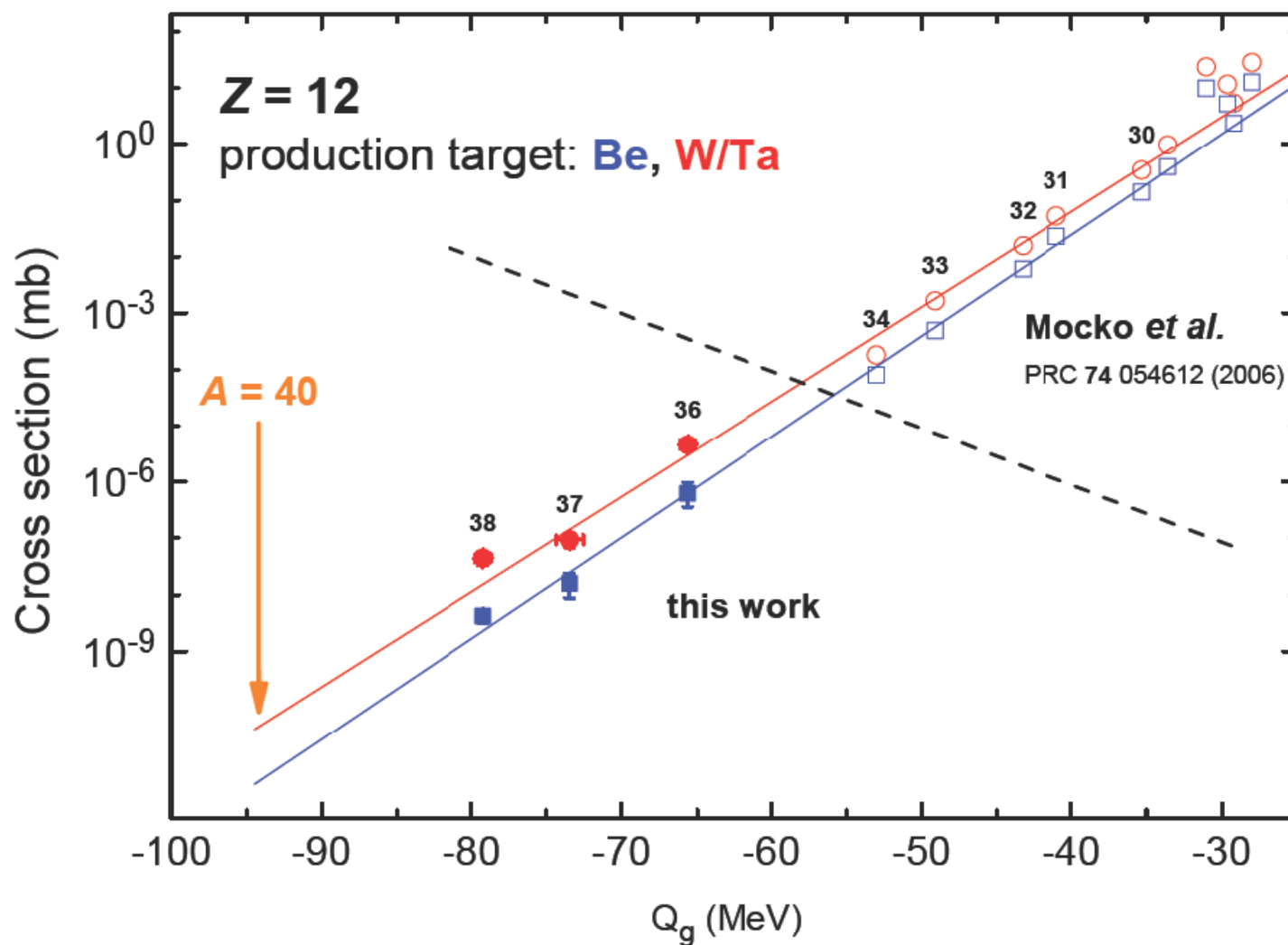
T. Onishi et al., J. Phys. Soc. Japan 77 (2008) 083201



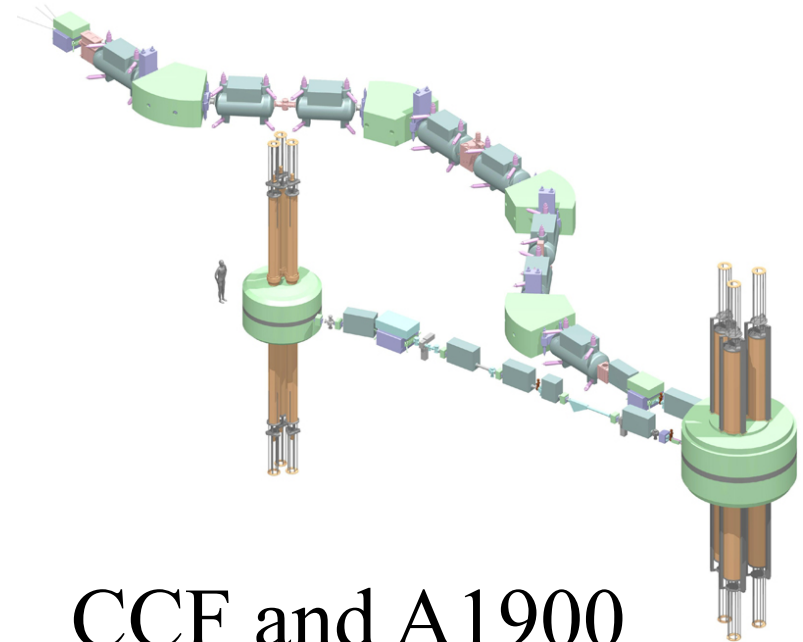
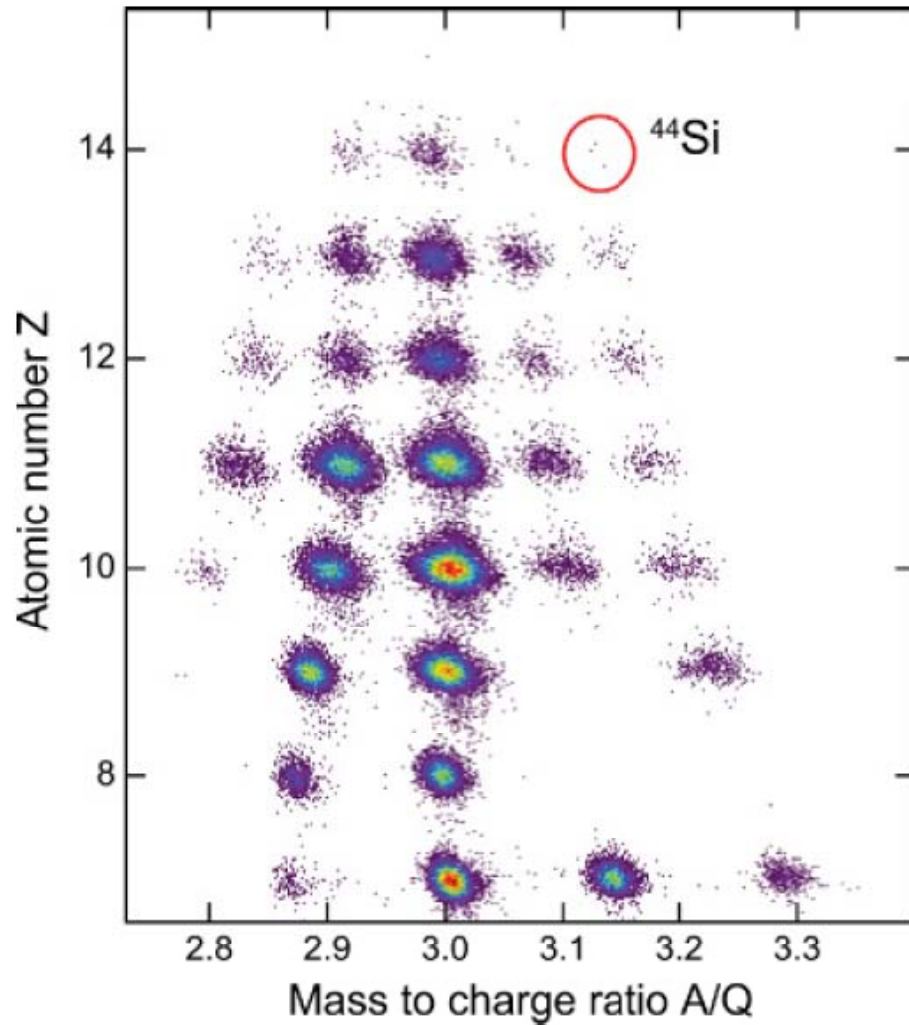
H. Sakurai et al., PLB 448 (1999) 180

M. Notani et al., PLB 542 (2002) 49

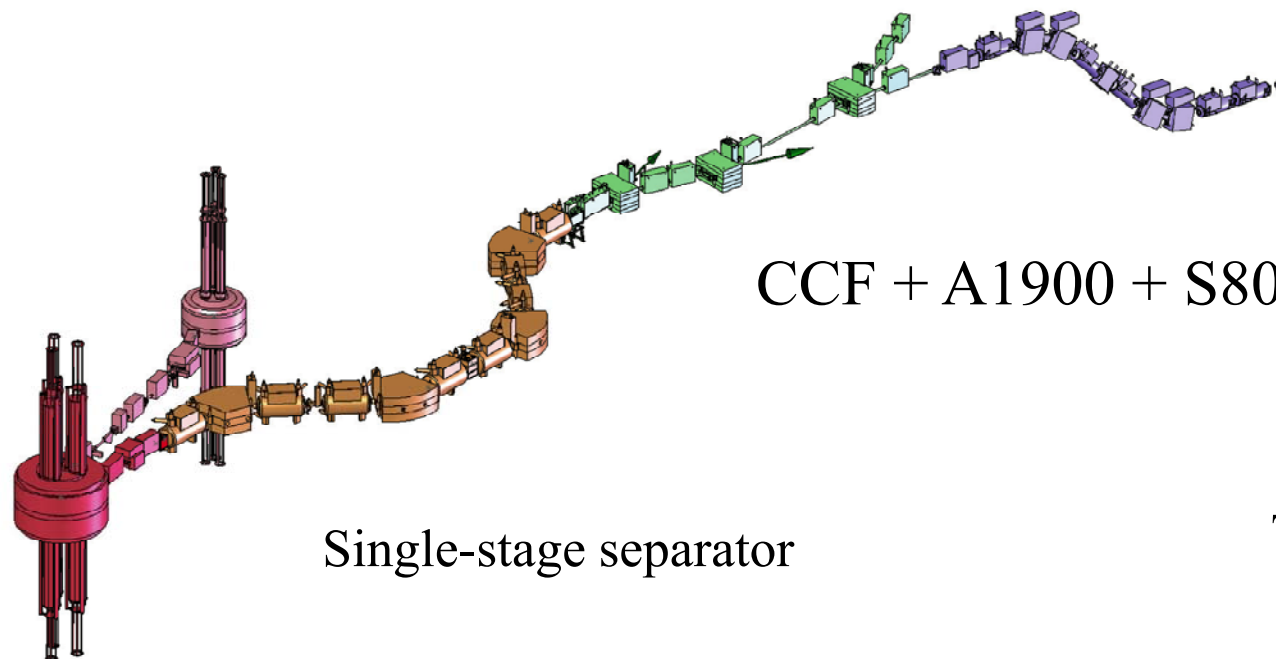
S.M. Lukyanov et al., JPG 28 (2002) L41







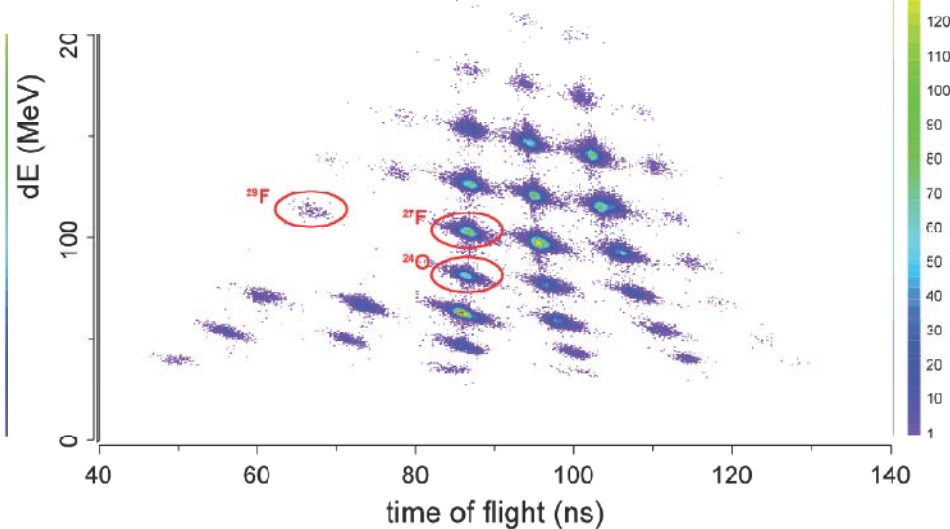
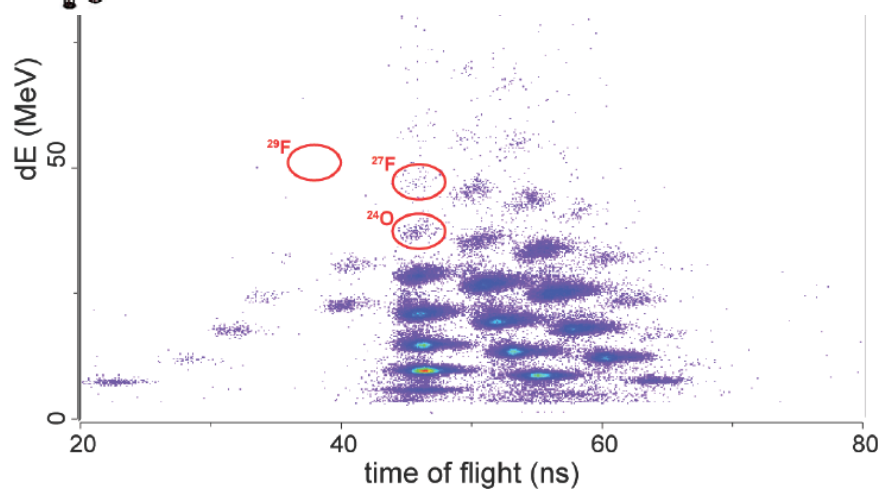
CCF and A1900

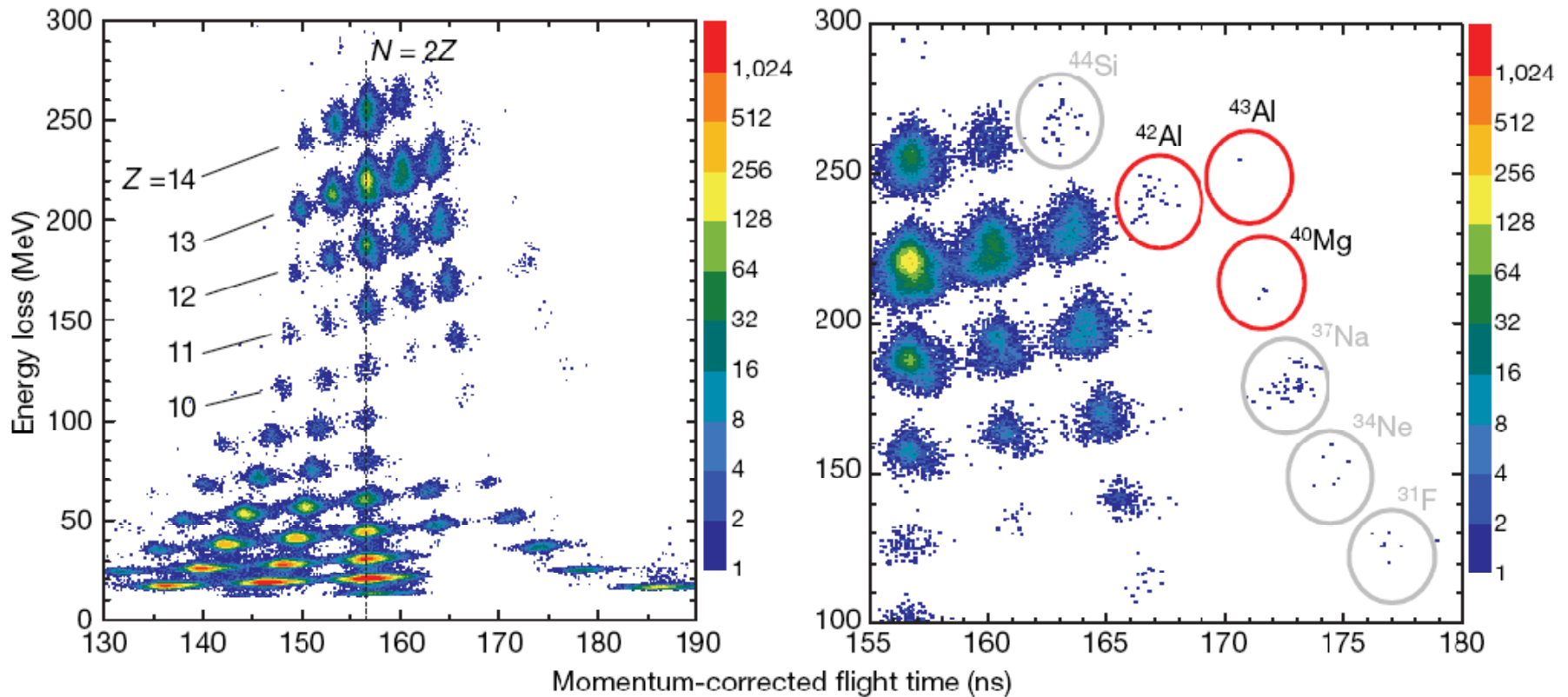


CCF + A1900 + S800 analysis line

Single-stage separator

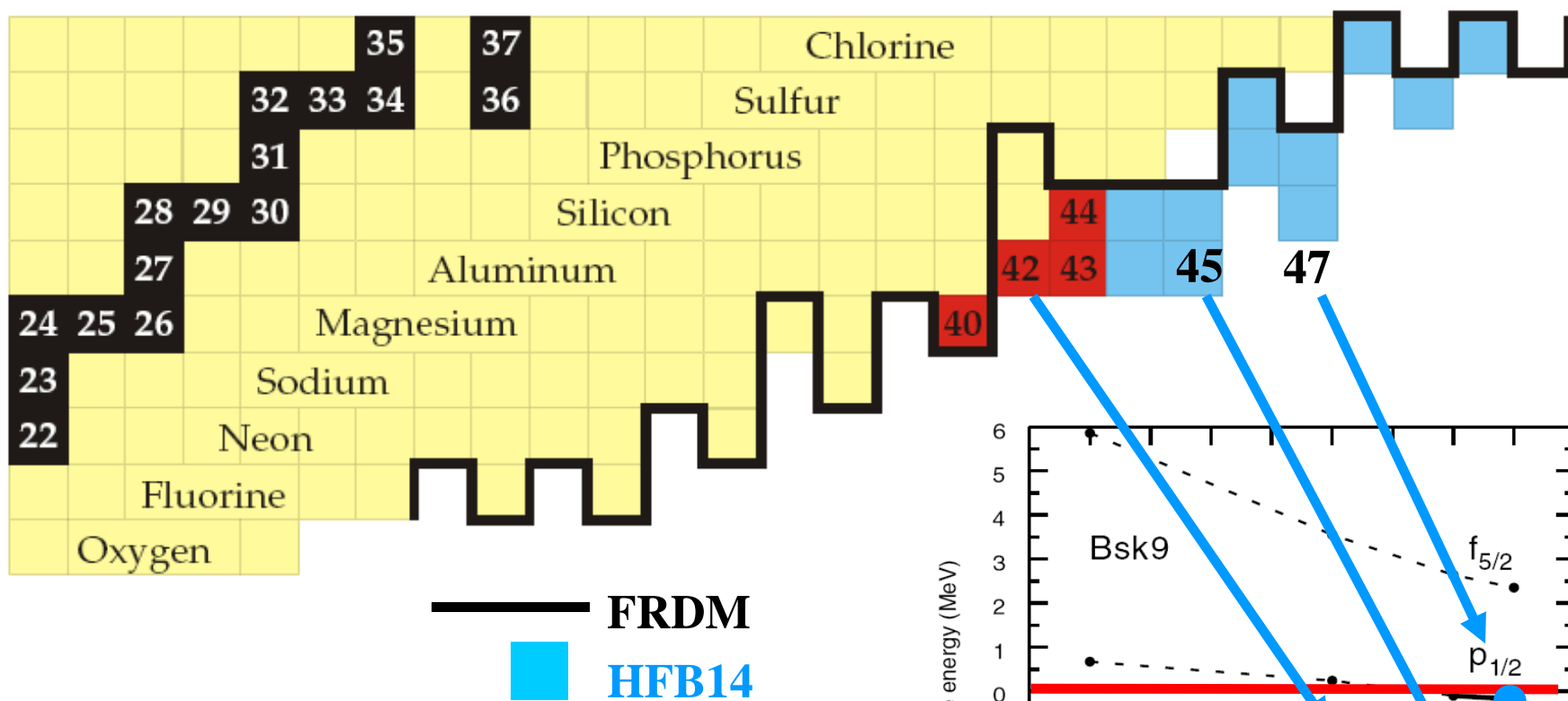
Two-stage separator



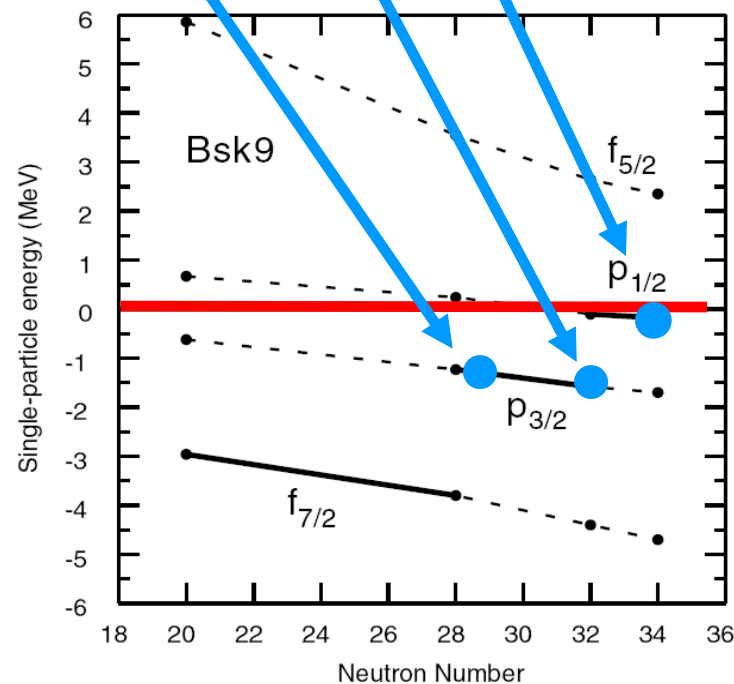


T. Baumann *et al.*, Nature **449** (2007) 1022

# Dripline Extends Further than Believed



Starting with  $^{42}\text{Al}$  the  $p_{3/2}$  shell is filled, indicating that  $^{45}\text{Al}$  is bound; and even  $^{47}\text{Al}$  could be bound ( $p_{1/2}$ )

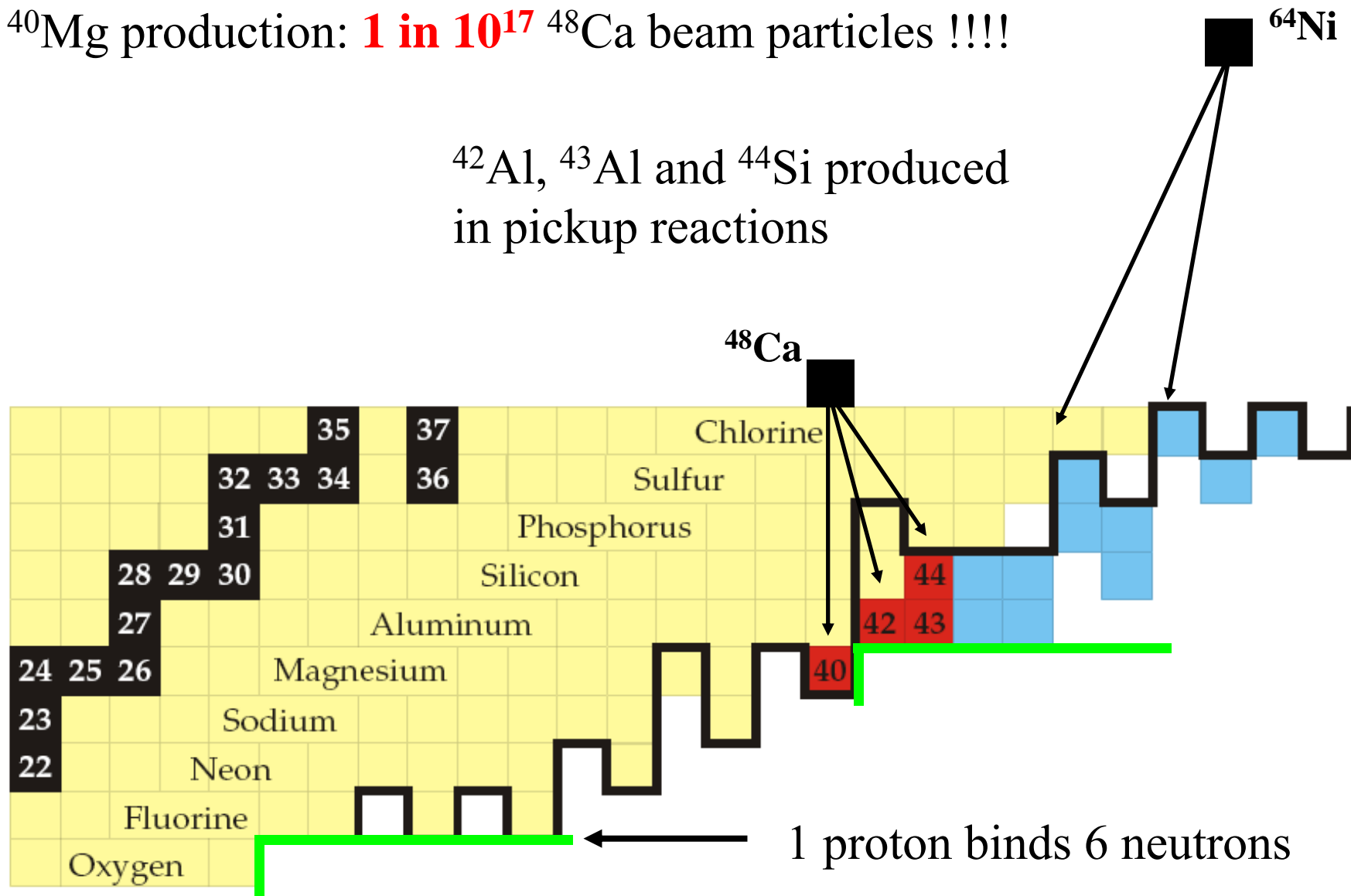




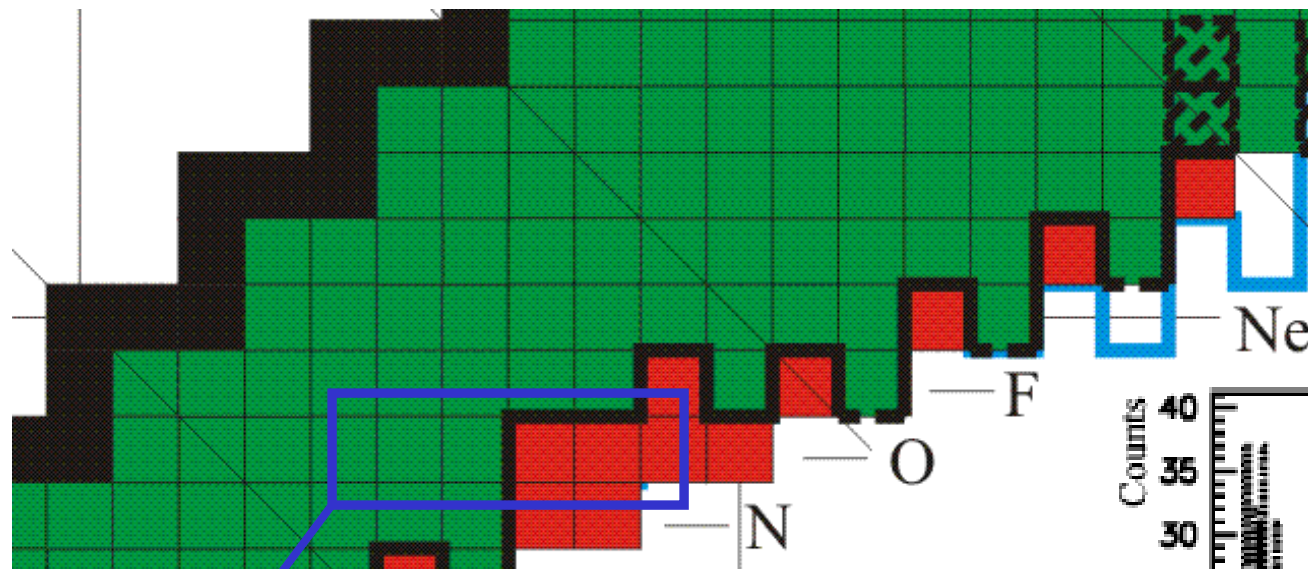
# One Proton Makes a Huge Difference!!

$^{40}\text{Mg}$  production: **1 in  $10^{17}$**   $^{48}\text{Ca}$  beam particles !!!!

$^{42}\text{Al}$ ,  $^{43}\text{Al}$  and  $^{44}\text{Si}$  produced in pickup reactions



1 proton binds 6 neutrons

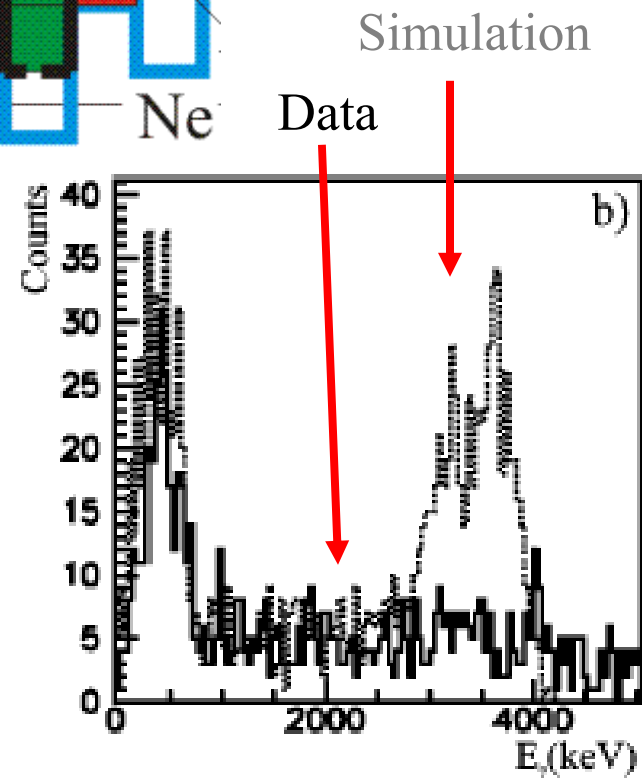


$^{23}\text{O}$  —  $^{24}\text{O}$  —  $^{25}\text{O}$  —  $^{26}\text{O}$



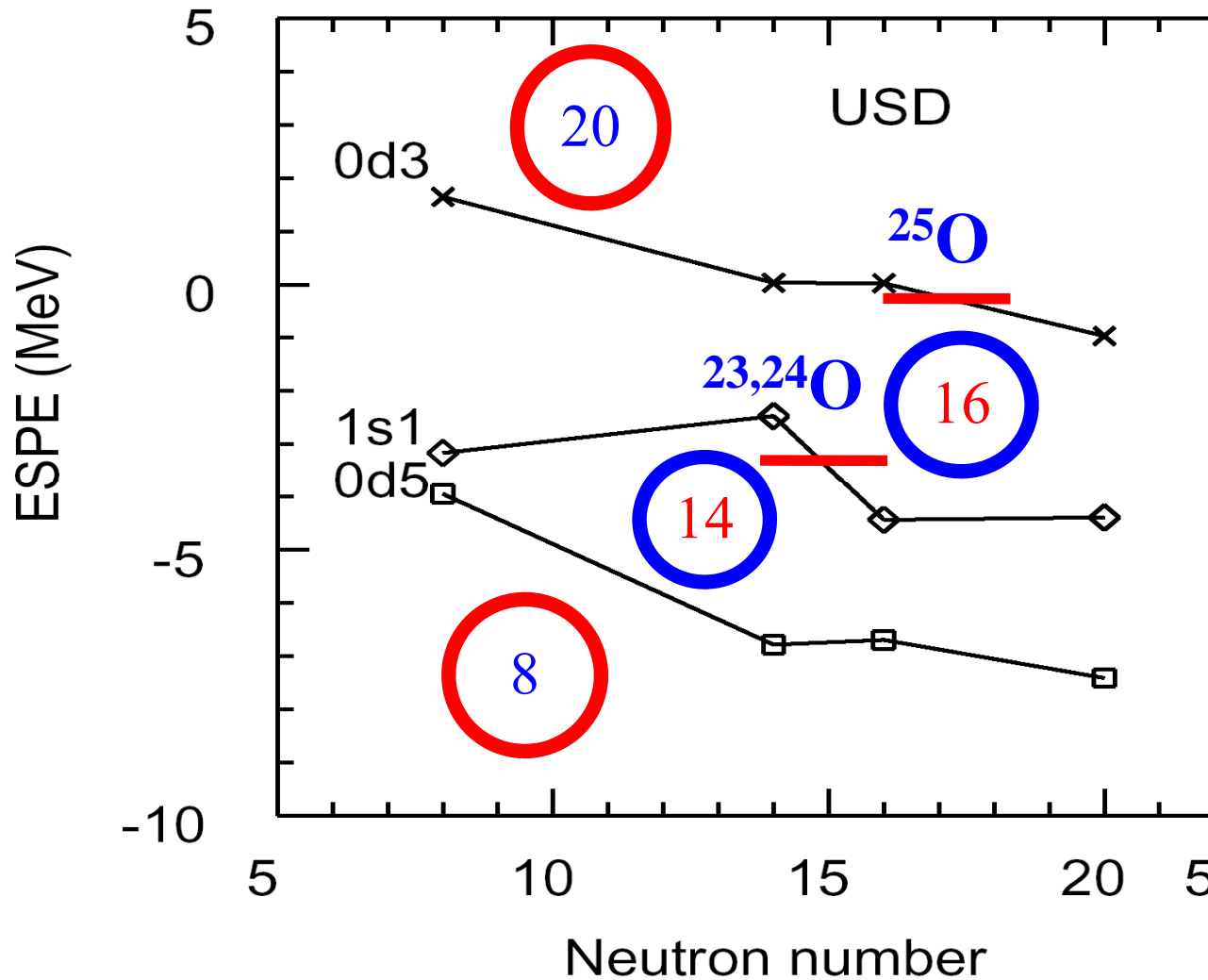
No bound  
excited states

Unbound



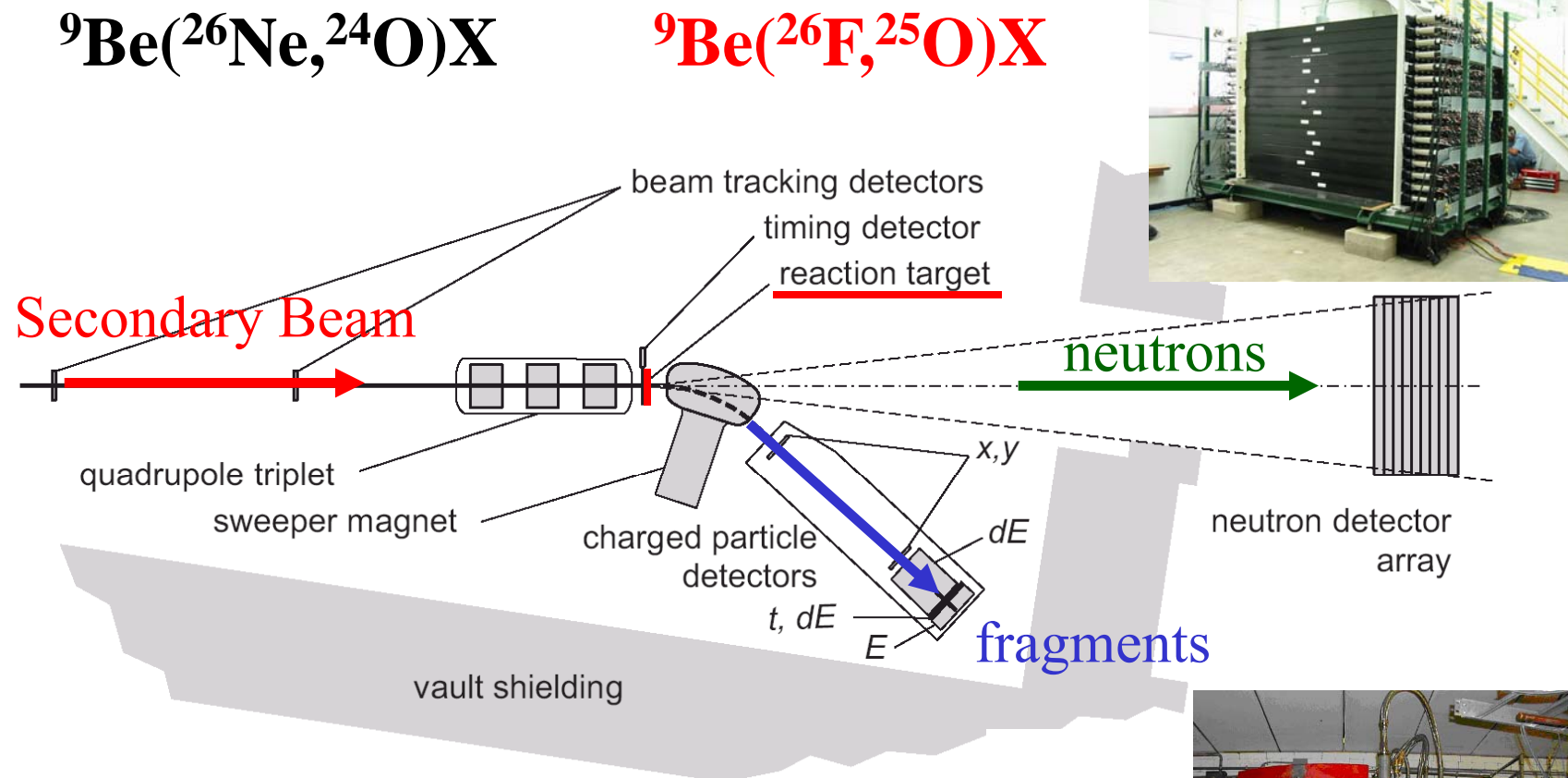
Search for the first excited state in  $^{24}\text{O}$

M. Stanoiu, *et al.* PRC **69**, 034312 (2004)



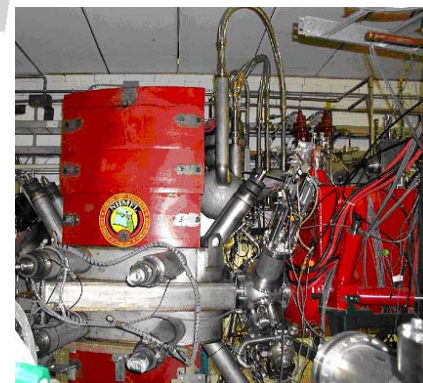
B.A. Brown and W.A. Richter, PRC **72**, 057301 (2005).

# MoNA – Sweeper Setup



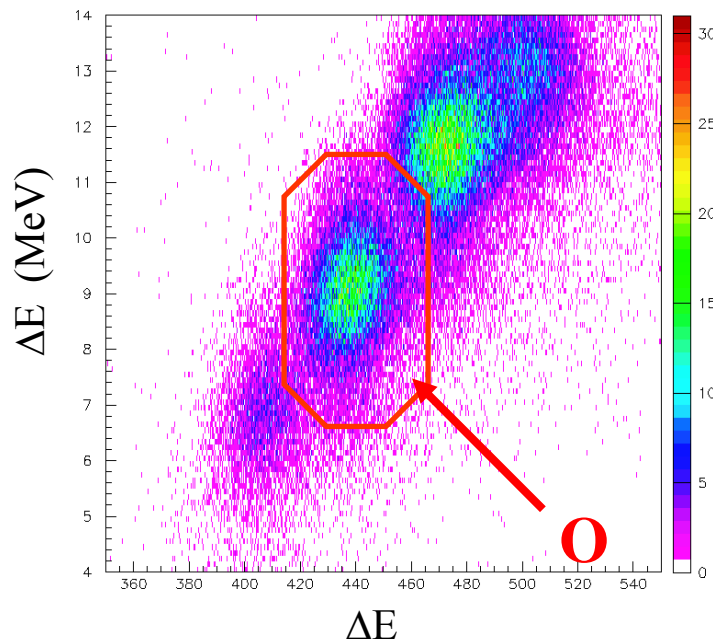
Invariant Mass Spectroscopy:

$$E_{\text{decay}} = \sqrt{m_f^2 + m_n^2 + 2[E_f E_n - p_f p_n \cos(\Theta_{\text{open}})]} - m_f - m_n$$

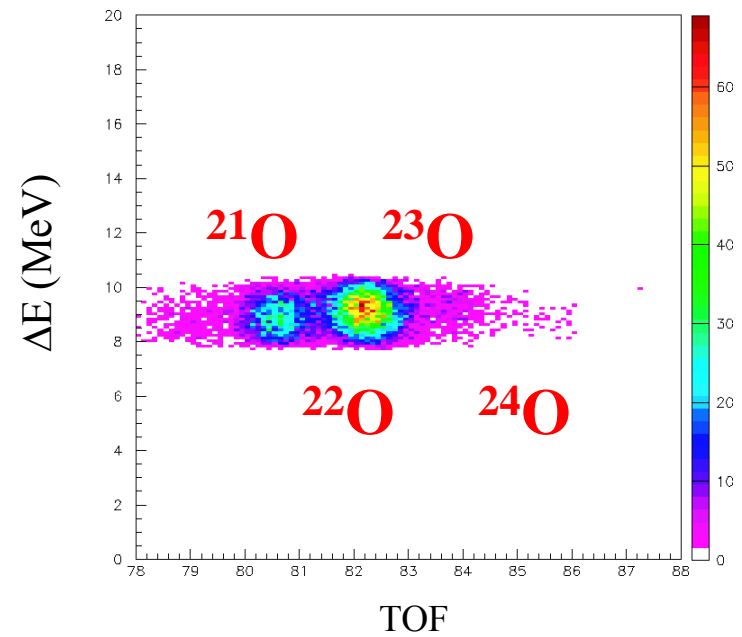




Z - Identification



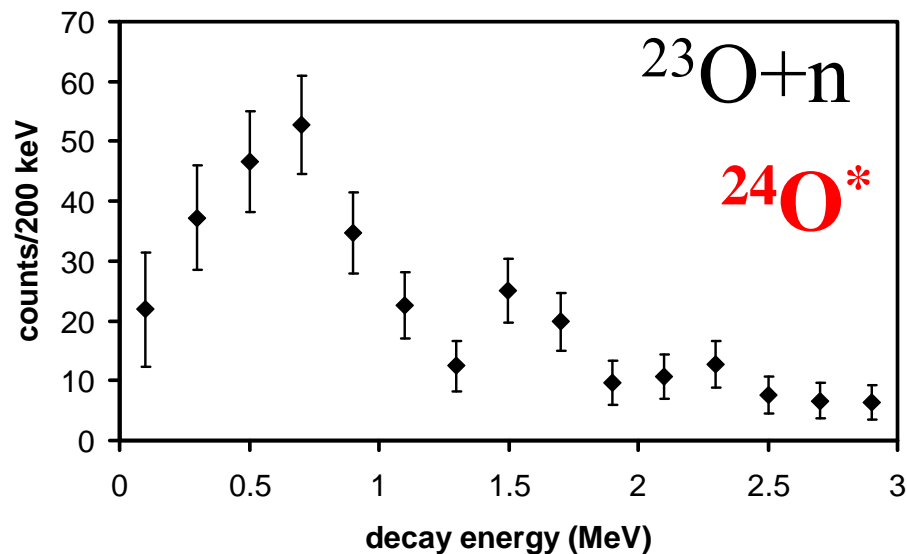
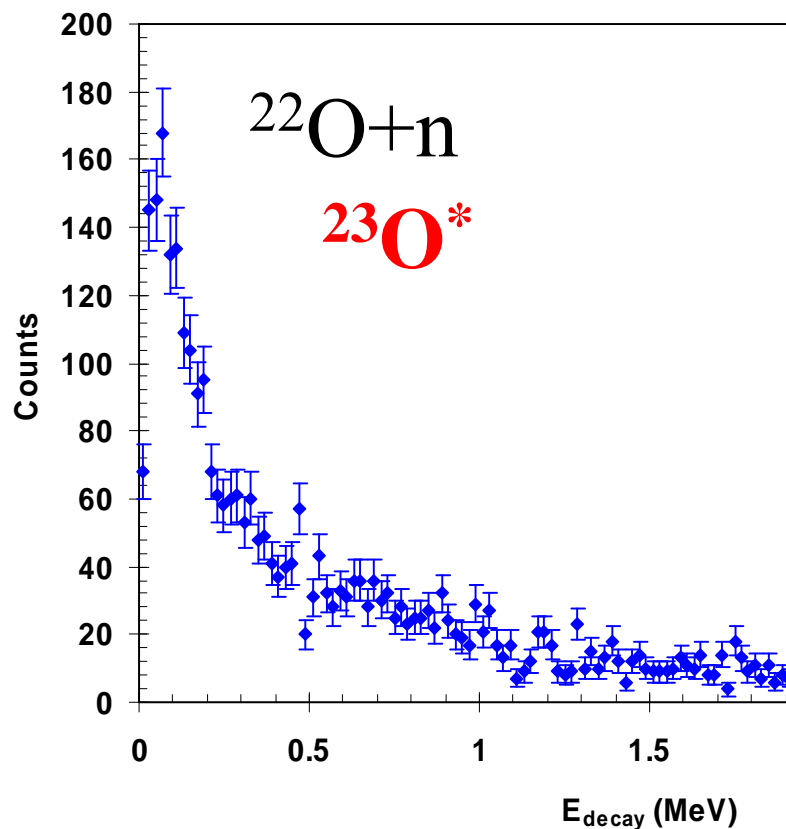
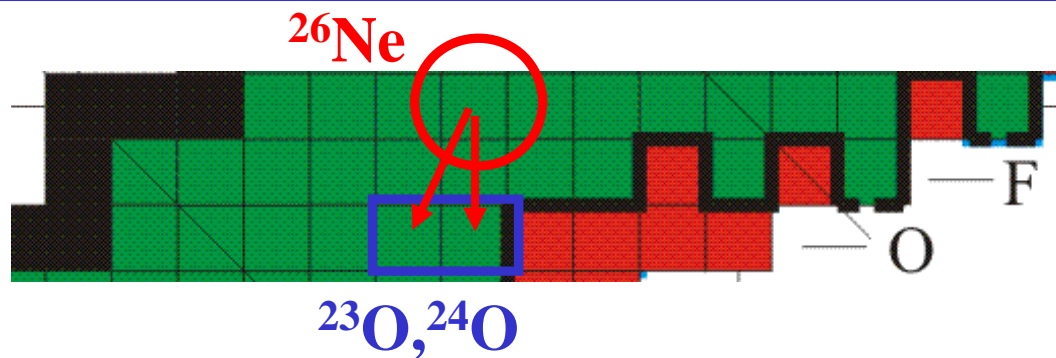
Isotope - Identification

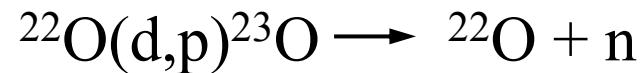
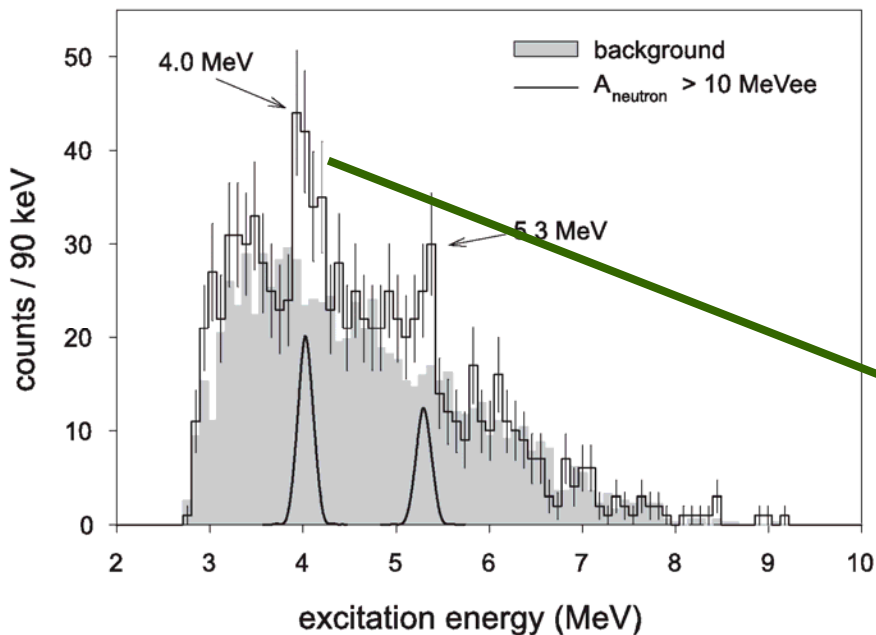




# Decay Energy Spectra

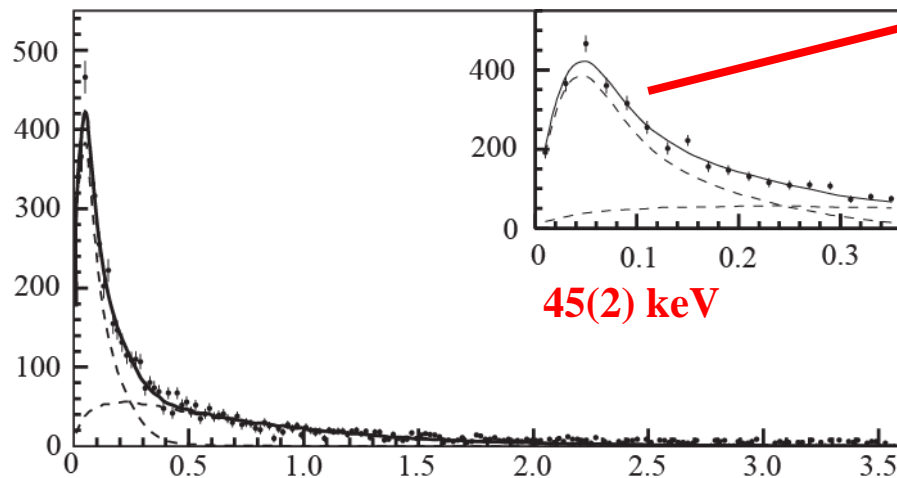
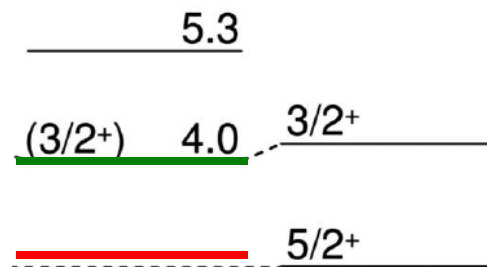
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$d_{3/2}$  particle state

$\frac{3/2^+}{5/2^+}$   
 $\frac{7/2^+}{}$



$d_{5/2}$  hole state

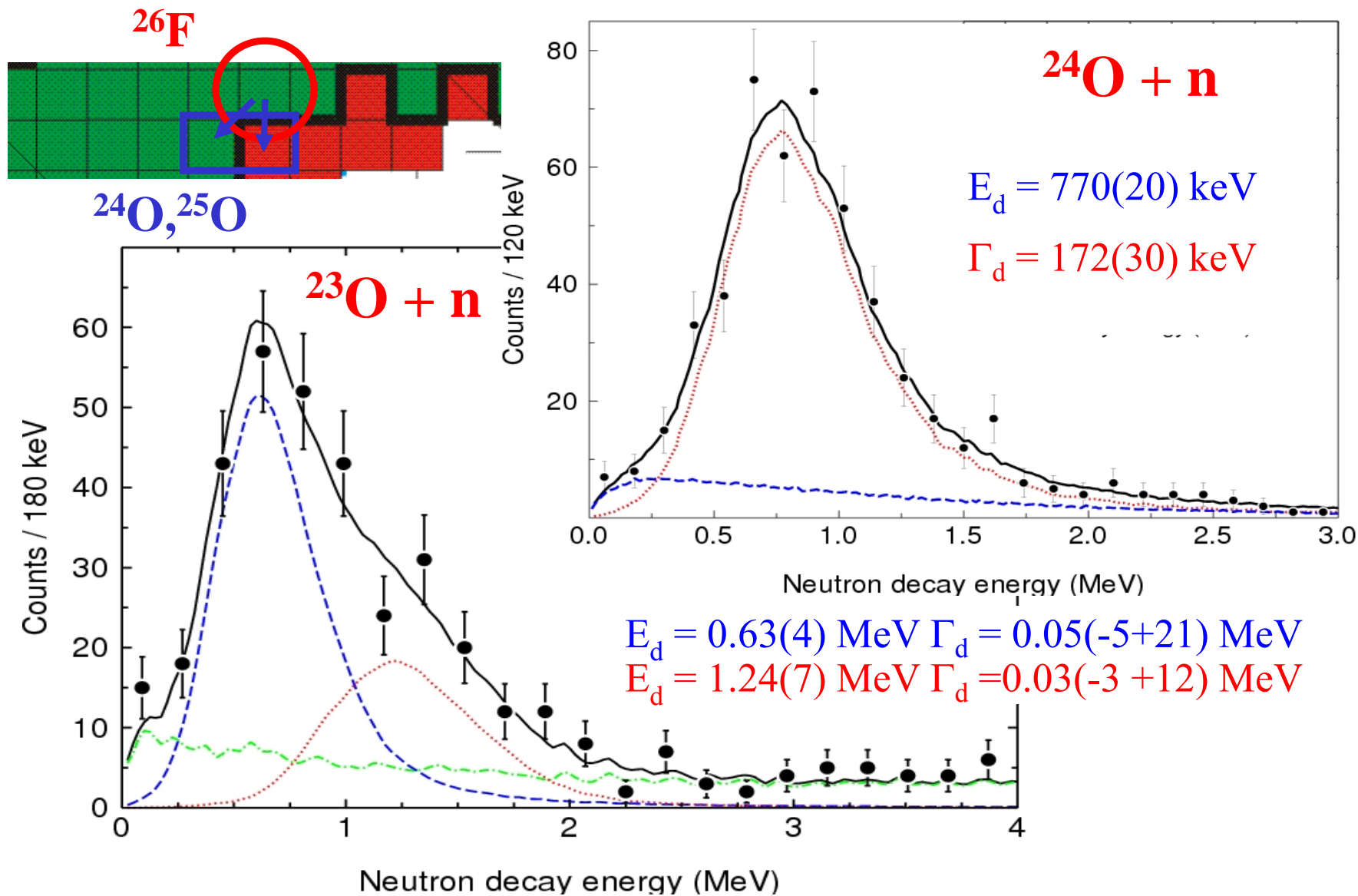
$\frac{1/2^+}{\text{EXP}}$   $\frac{0}{\text{USD05}}$   $\frac{1/2^+}{\text{USD05}}$

Z. Elekes et al., PRL **98** (2007) 102502

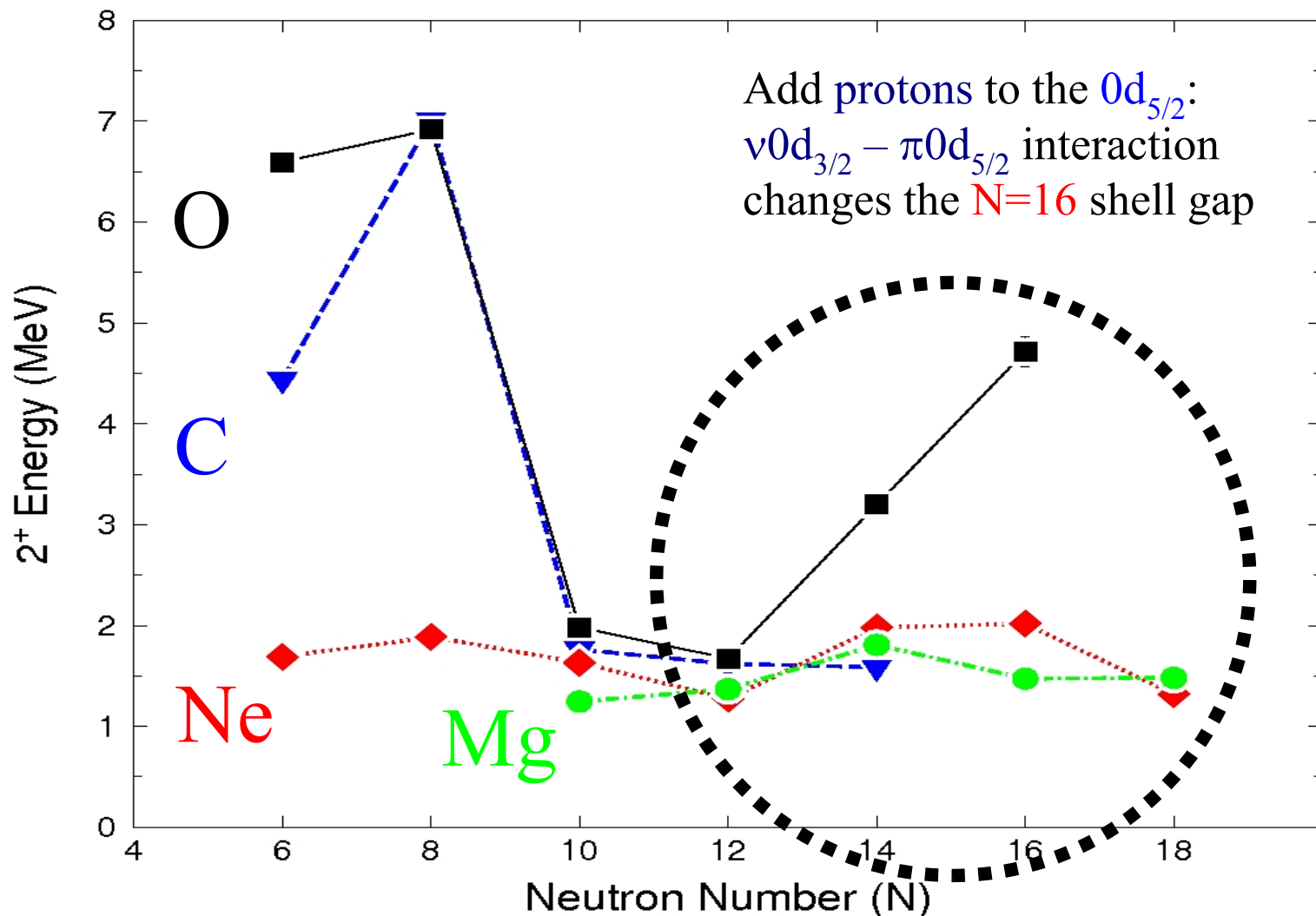
A. Schiller *et al.*, PRL **99** (2007) 112501

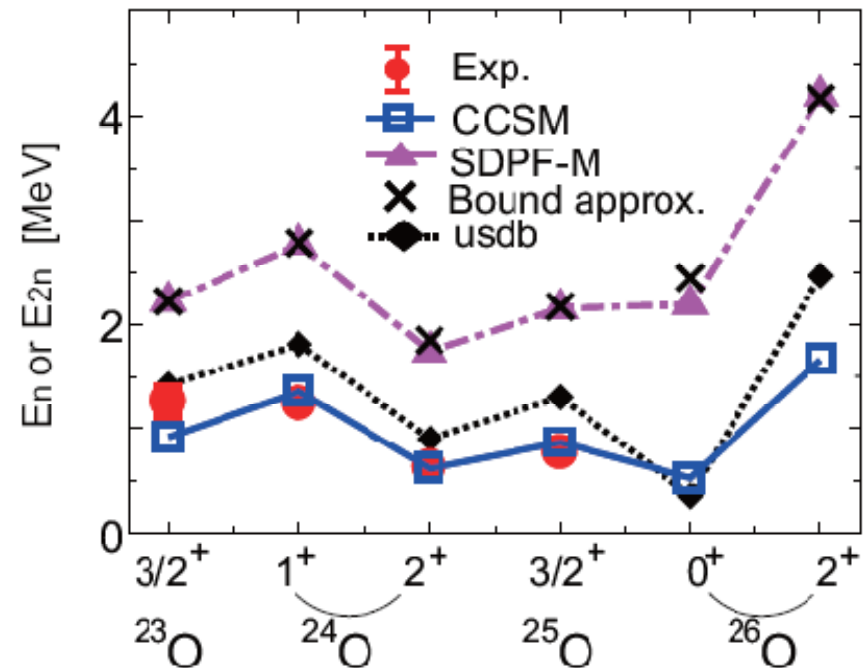
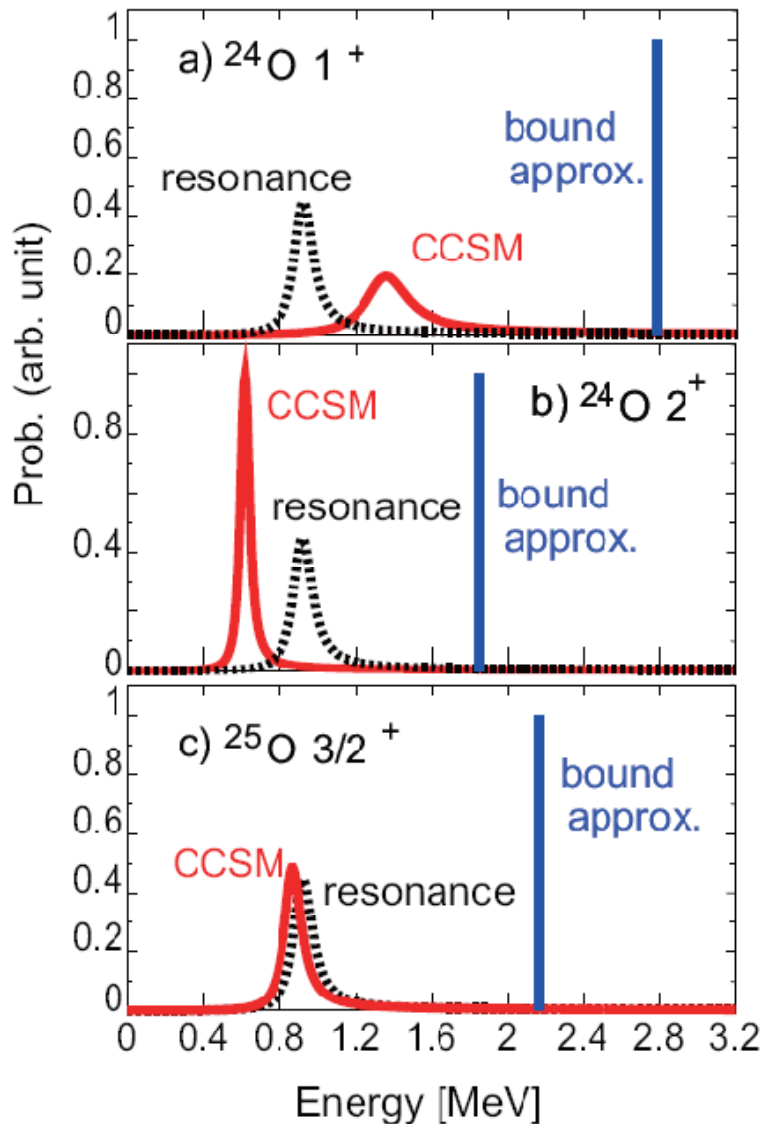
# One-Proton Knockout to $^{24,25}\text{O}$

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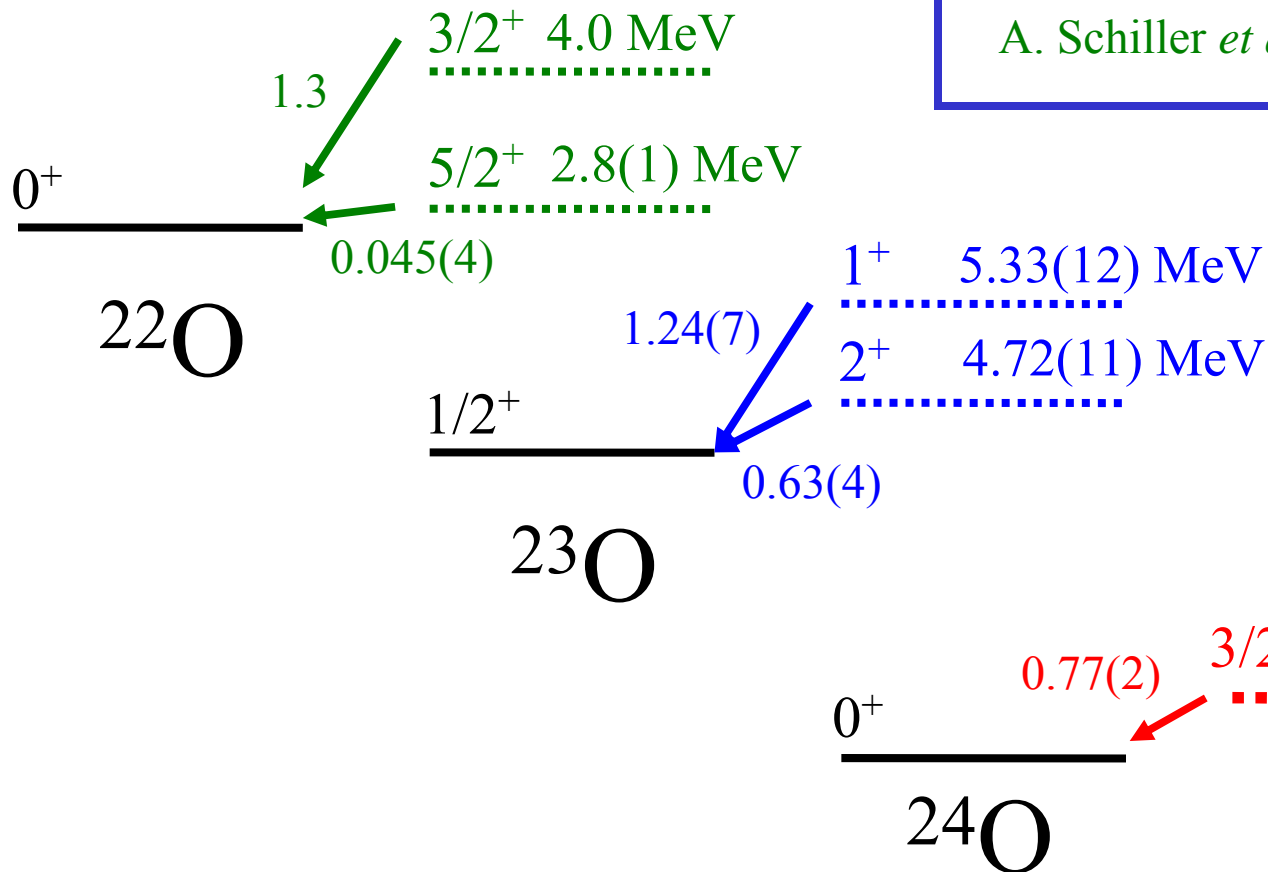
# N = 16 Shell Gap





K. Tsukiyama, T. Otsuka and R. Fujimoto,  
 subm. to Phys. Rev. Lett.





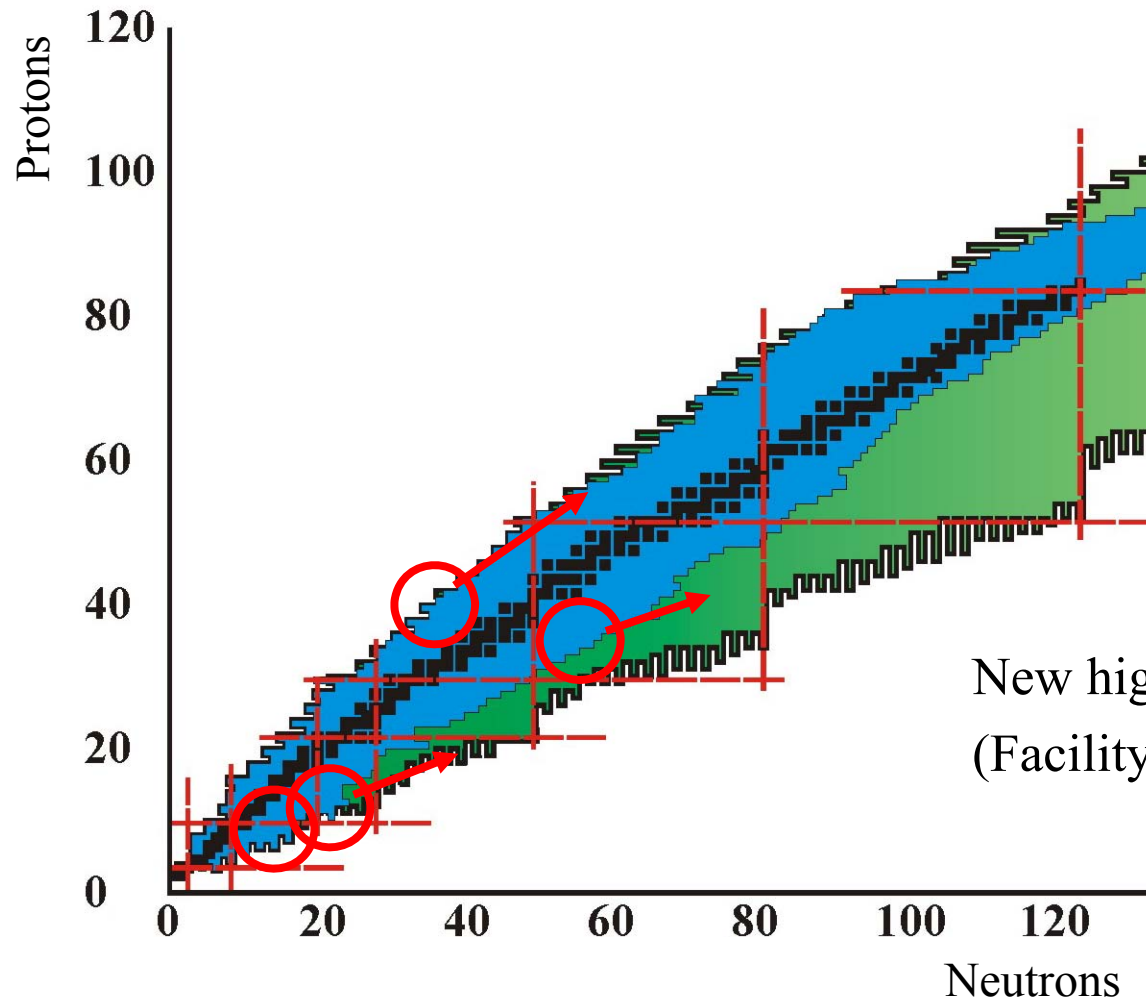
Z. Elekes *et al.*, PRL **98** (2007) 102502

A. Schiller *et al.*, PRL **99** (2007) 112501

C.R. Hoffman *et al.*,  
PLB subm. (2008)

C.R. Hoffman *et al.*,  
PRL **100** (2008) 152501

# Reaching the Driplines for Heavier Nuclei



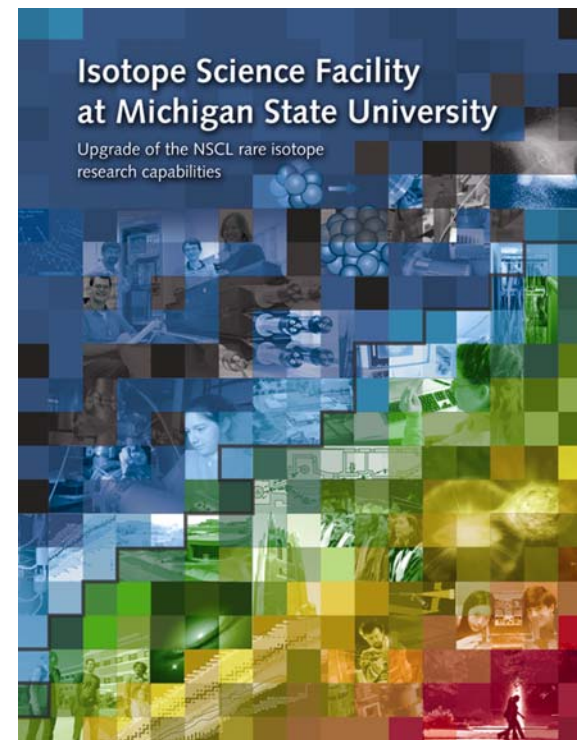
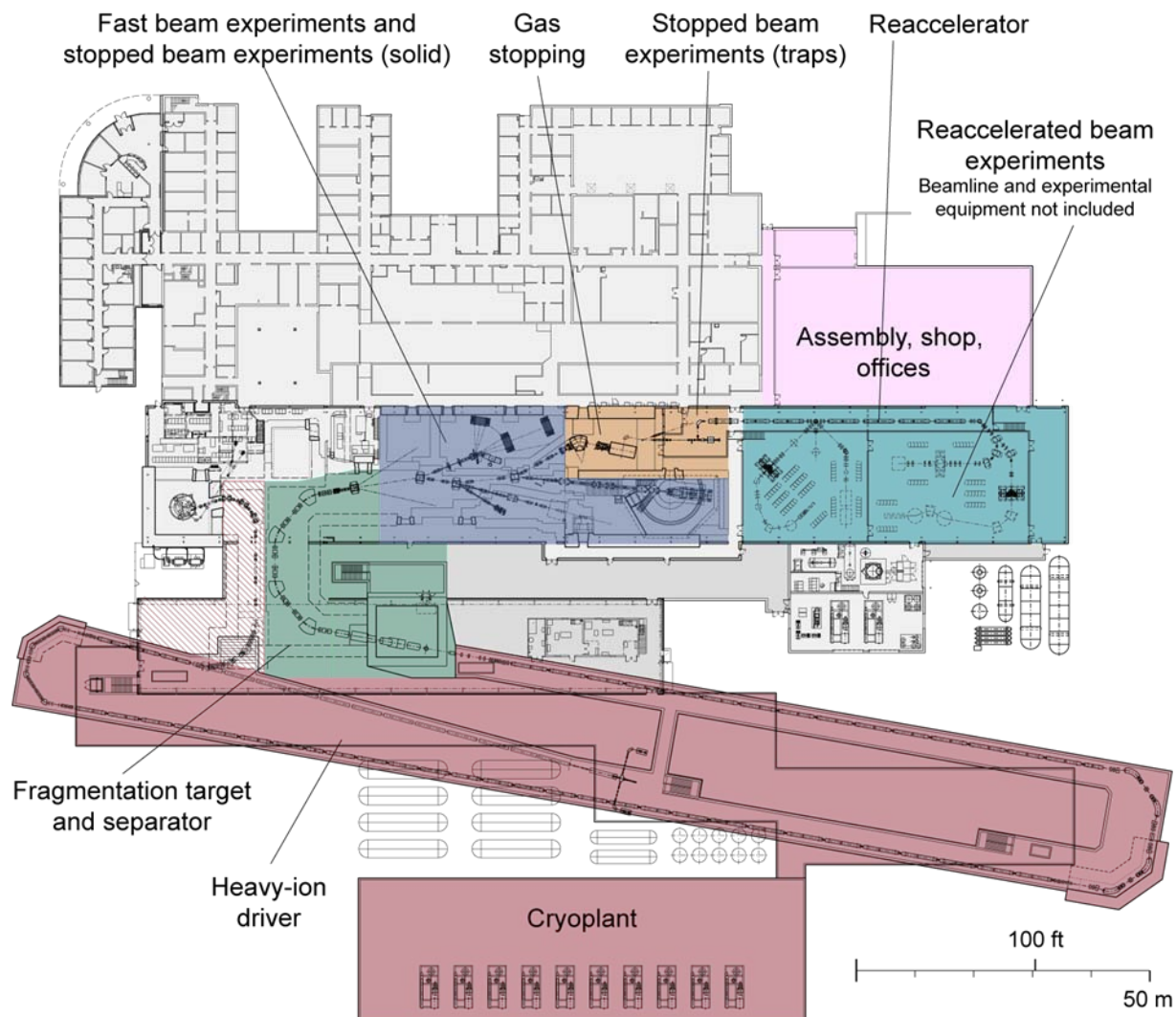
New higher intensity driver: FRIB  
(Facility for Rare-Isotope Beams)



# FRIB at MSU: Isotope Science Facility

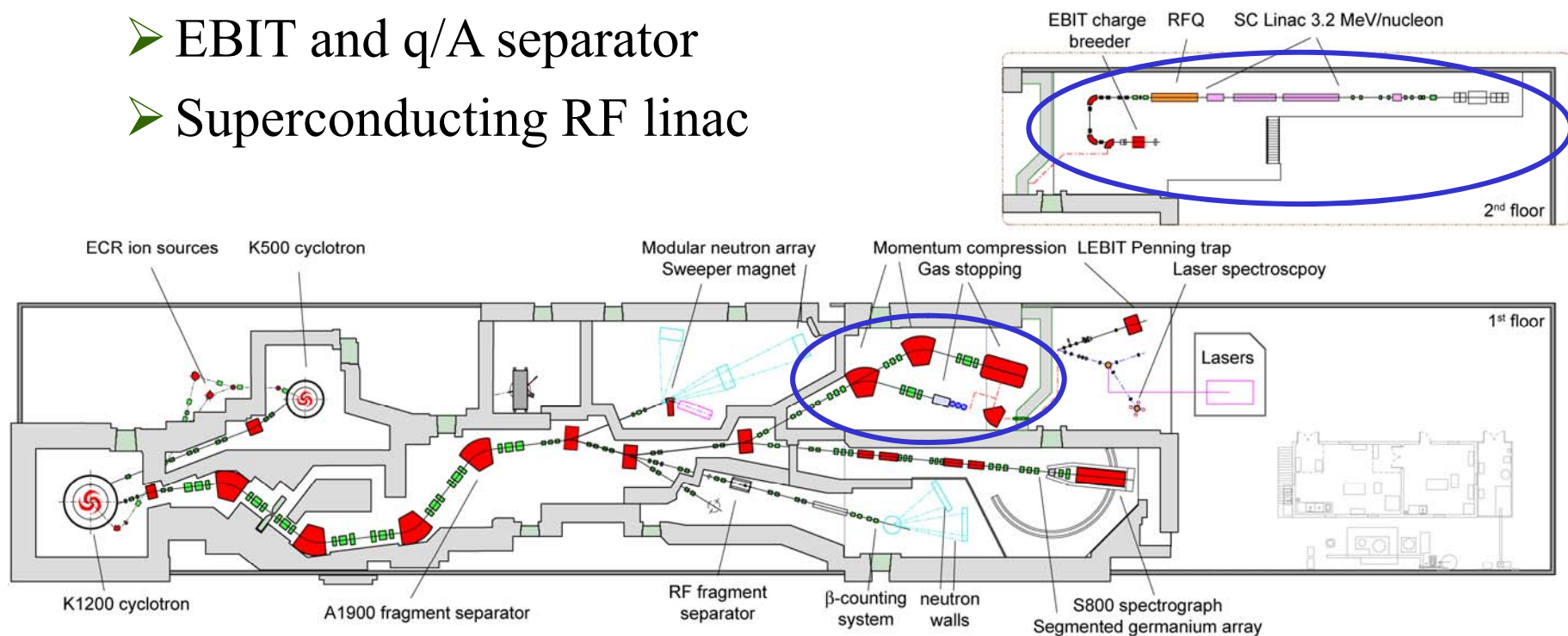


NSCL MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

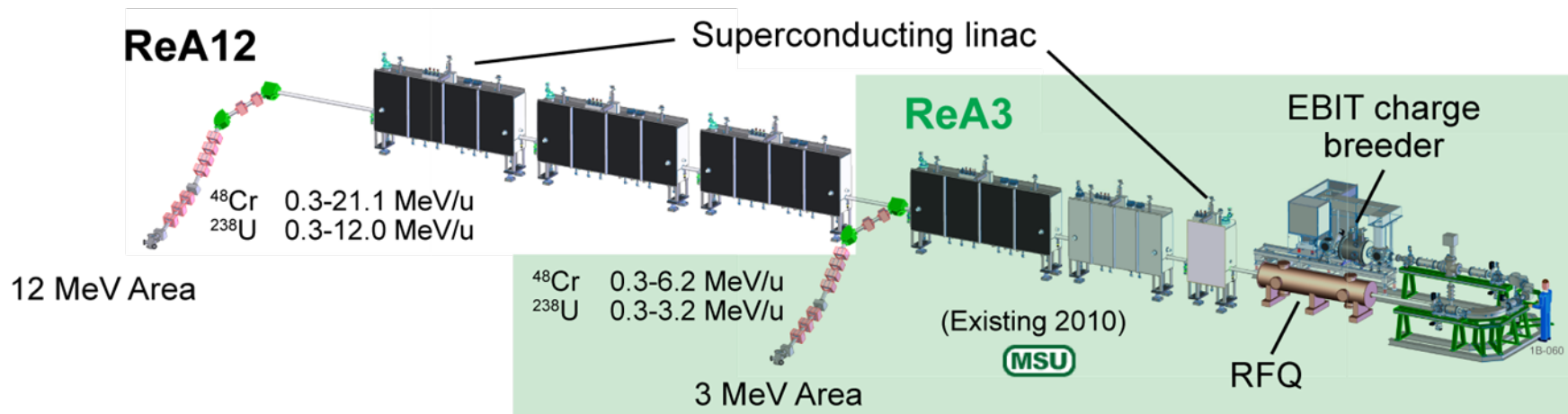


[www.nscl.msu.edu/isf/](http://www.nscl.msu.edu/isf/)

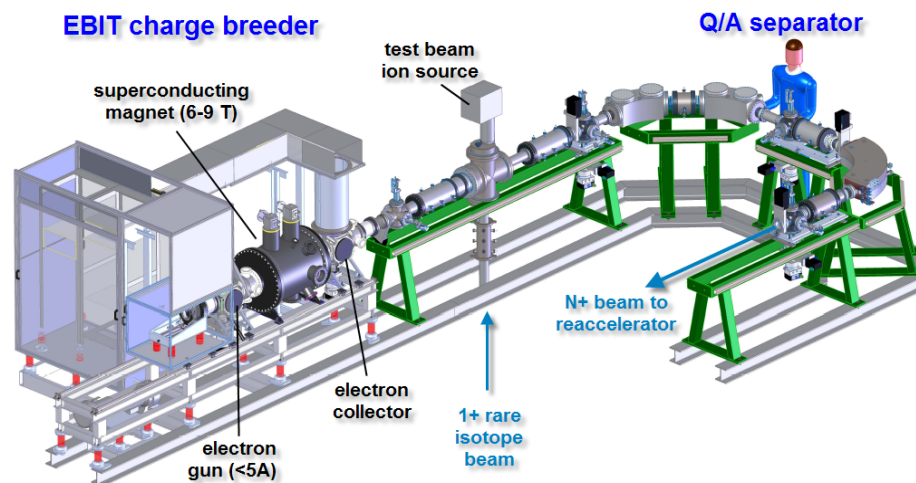
- Re-acceleration (0.3-3 MeV/u) by 2010  
(Upgrade planned to 12 MeV/u):
  - Momentum compression
  - Mass analyzer and beam transport
  - EBIT and q/A separator
  - Superconducting RF linac







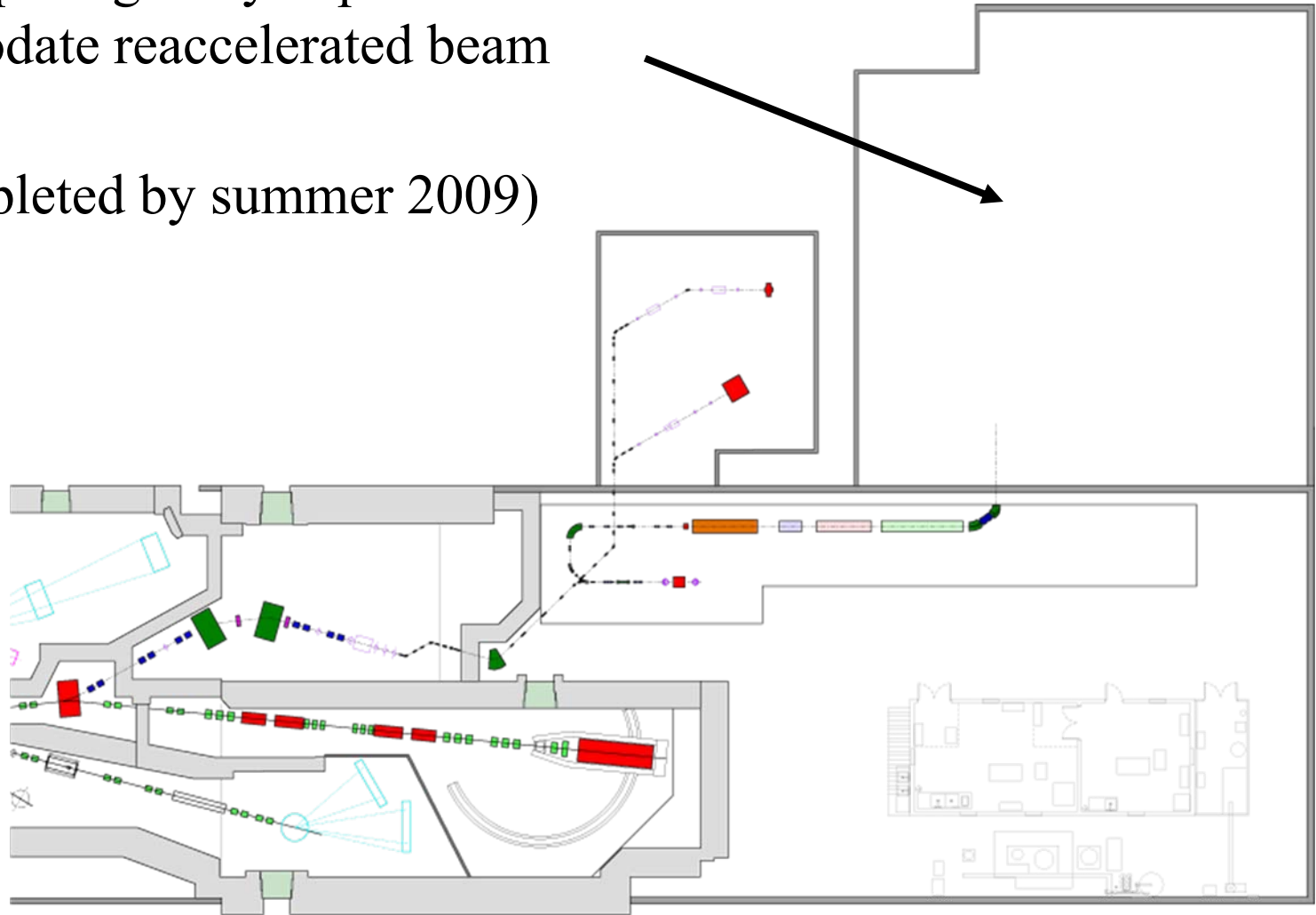
- LEBT with multi-harmonic buncher
- Radio frequency quadrupole (RFQ)
- Superconducting linac
  - 80 MHz  $\lambda/4$  resonators
  - $\beta_{\text{opt}} = 0.041$  and  $\beta_{\text{opt}} = 0.085$
  - Superconducting solenoids for focusing
- HEBT with rebuncher



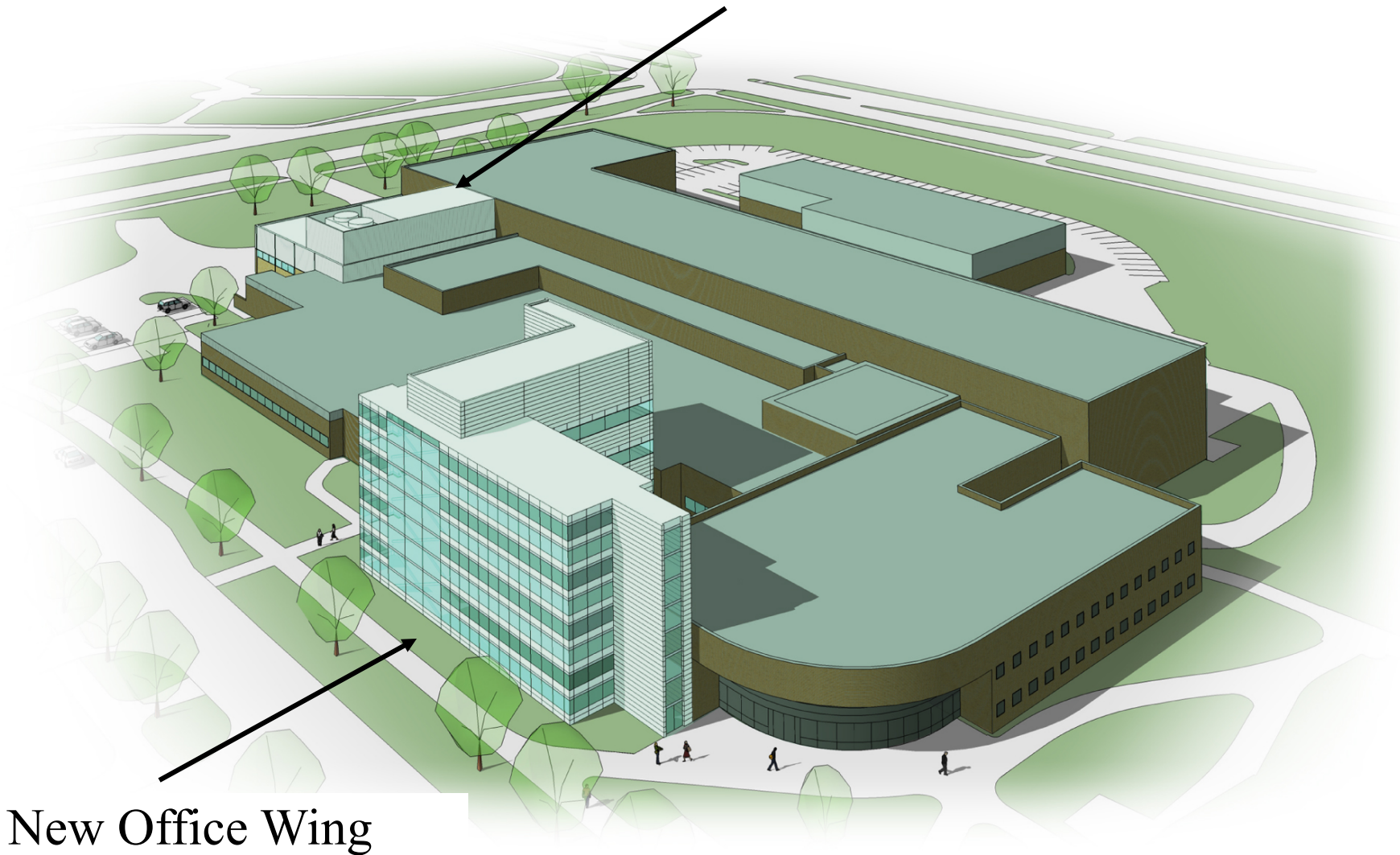


10,000 sqft. high-bay expansion to  
accommodate reaccelerated beam  
program

(completed by summer 2009)



Experimental area for reaccelerated beams



New Office Wing

- Minimum technical specifications:
  - 200 MeV/u, 400 kW superconducting heavy-ion driver linac
  - Fragmentation of fast heavy-ion beams combined with gas stopping and reacceleration
- TPC < \$550M then-year
- Anticipated notice of selection by end of December 2008
- “Hypothetical assumptions” in FOA
  - R&D, conceptual design  $\geq$  FY09
  - Construction  $\geq$  FY13, five years
  - Pre-operations  $\geq$  FY16

## FINANCIAL ASSISTANCE FUNDING OPPORTUNITY ANNOUNCEMENT



U. S. Department of Energy

Office of Nuclear Physics

Facility for Rare Isotope Beams

Funding Opportunity Number: DE-PS02-08ER41535

Announcement Type: Initial

CFDA Number: 81.049

Issue Date:

05/20/2008

Letter of Intent Due Date:

Not Applicable

Pre-Application Due Date:

Not Applicable

Application Due Date:

07/21/2008

- $^{96}\text{Cd}$ : A. Becerril, D. Bazin, *et al.*
- $^{125}\text{Pd}$ : C.M. Folden, B. M. Sherrill, *et al.*
- $^{40}\text{Mg}$ : T. Baumann, O. Tarasov, *et al.*
- $^{23,24,25}\text{O}$ : A. Schiller, N. Frank, C.R. Hoffman, MoNA Coll., *et al.*

## The MoNA Collaboration:

