Nuclear structure with exotic beams

Lecture 4:

Techniques

Production and Detection

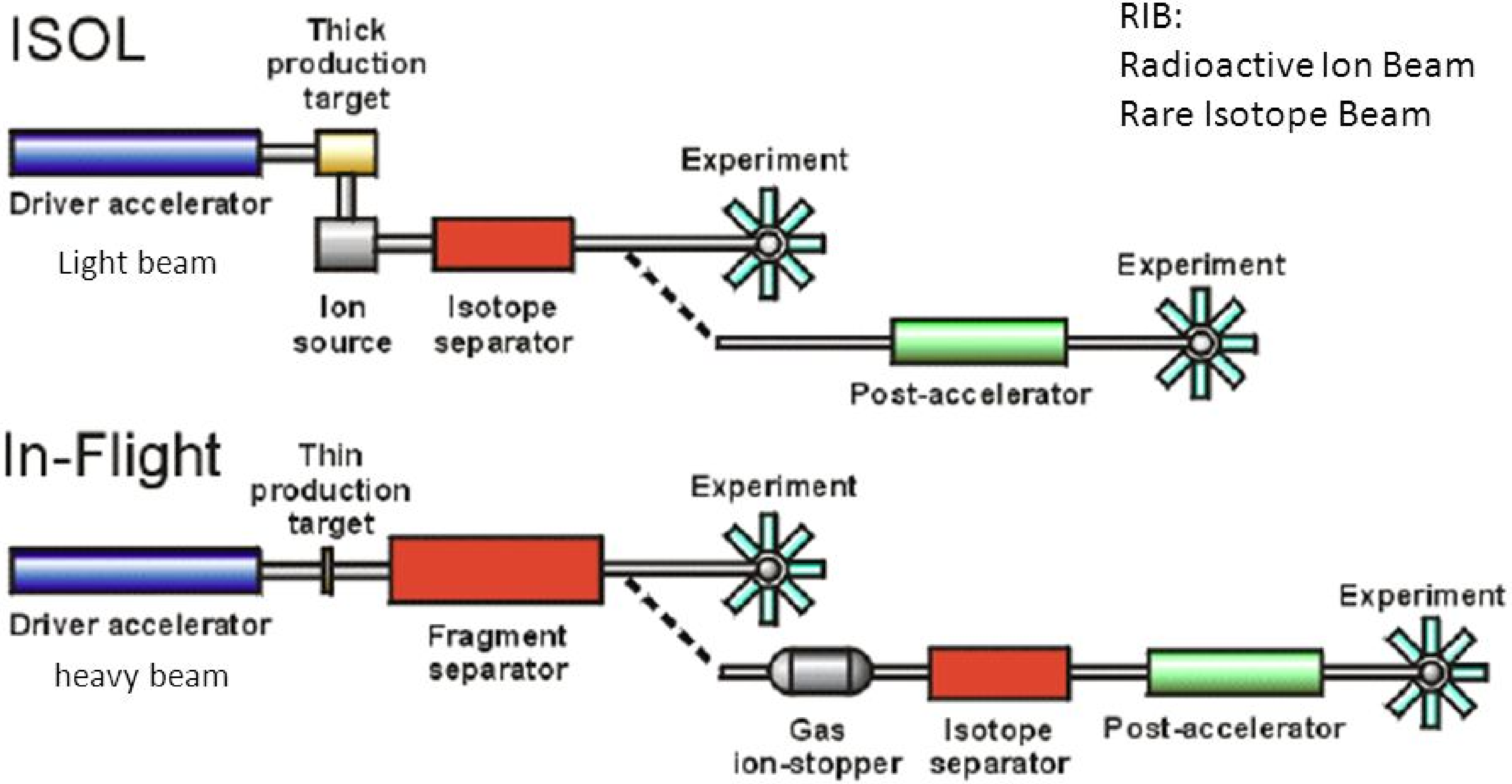
A. Wuosmaa
University of Connecticut
Department of Physics

CNSSS19 Japan

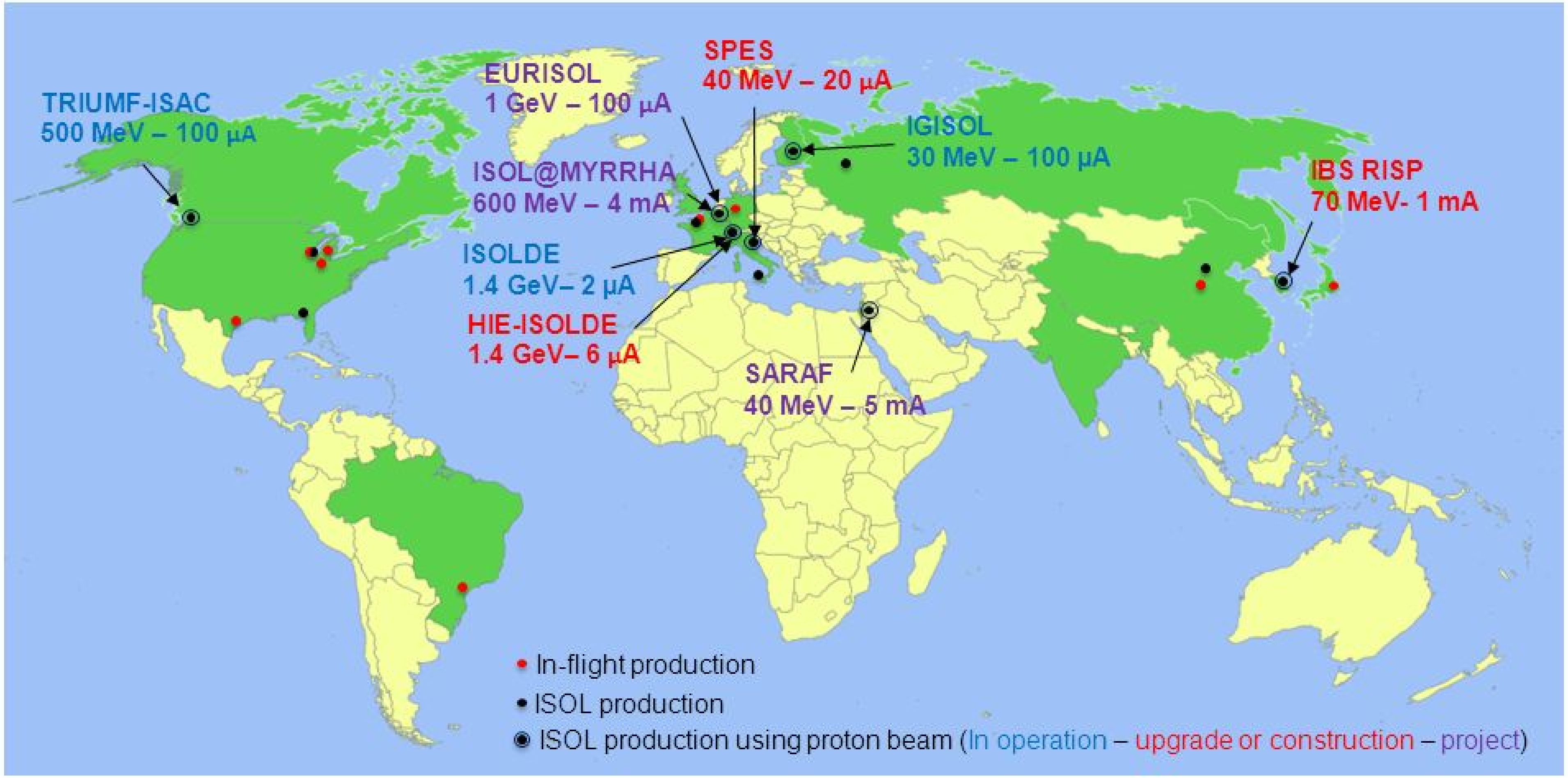
RIB facilities

- Two main types of (complementary) RIB facilities:
  - ISOL (Isotope Separation On-Line) and In-Flight

RIB:
Radioactive Ion Beam
Rare Isotope Beam



Facility for Rare Isotope Beams in the world



TRIUMF-ISAC
500 MeV – 100 µA

EURISOL
1 GeV – 100 µA

ISOL@MYRRHA
600 MeV – 4 mA

SPES
40 MeV – 20 µA

IGISOL
30 MeV – 100 µA

IBS RISP
70 MeV- 1 mA

ISOLDE
1.4 GeV– 2 µA

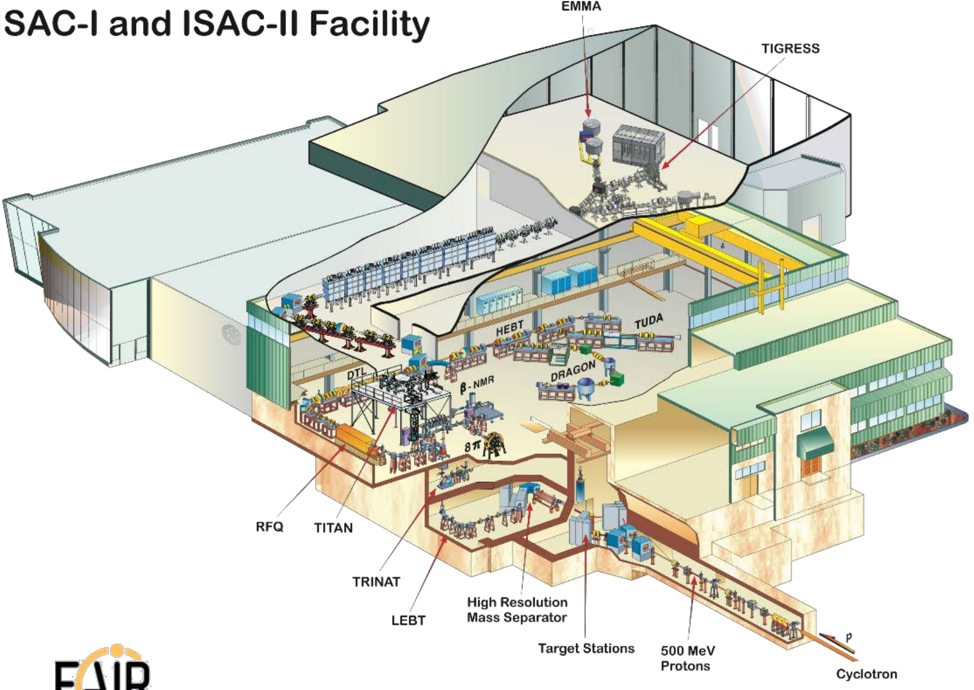
HIE-ISOLDE
1.4 GeV– 6 µA

SARAF
40 MeV – 5 mA

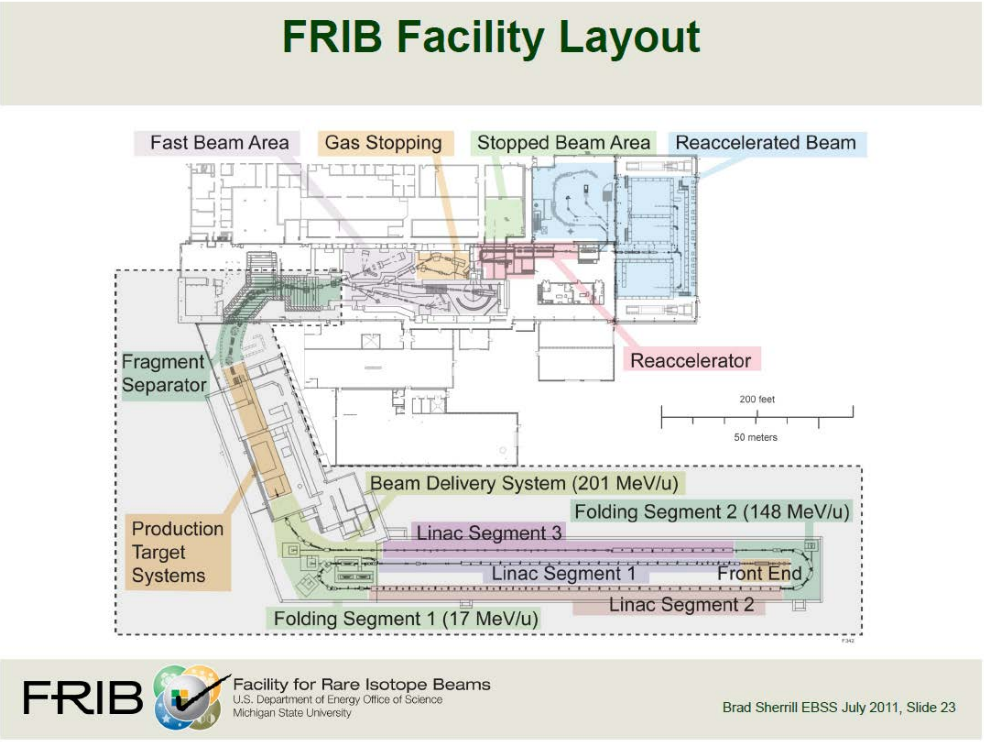
- • In-flight production
- • ISOL production
- ◉ ISOL production using proton beam (In operation – upgrade or construction – project)

TRIUMF

ISAC-I and ISAC-II Facility



FRIB Facility Layout

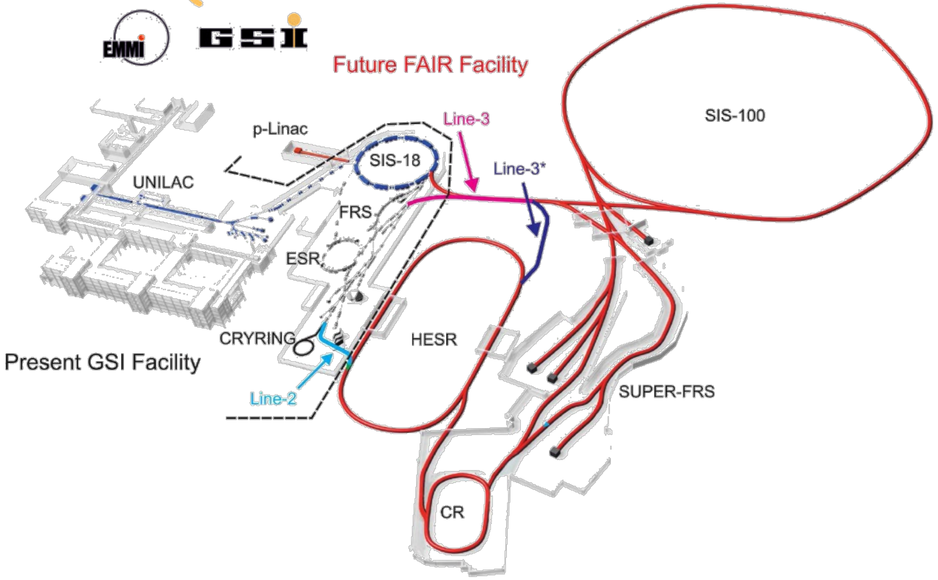


FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

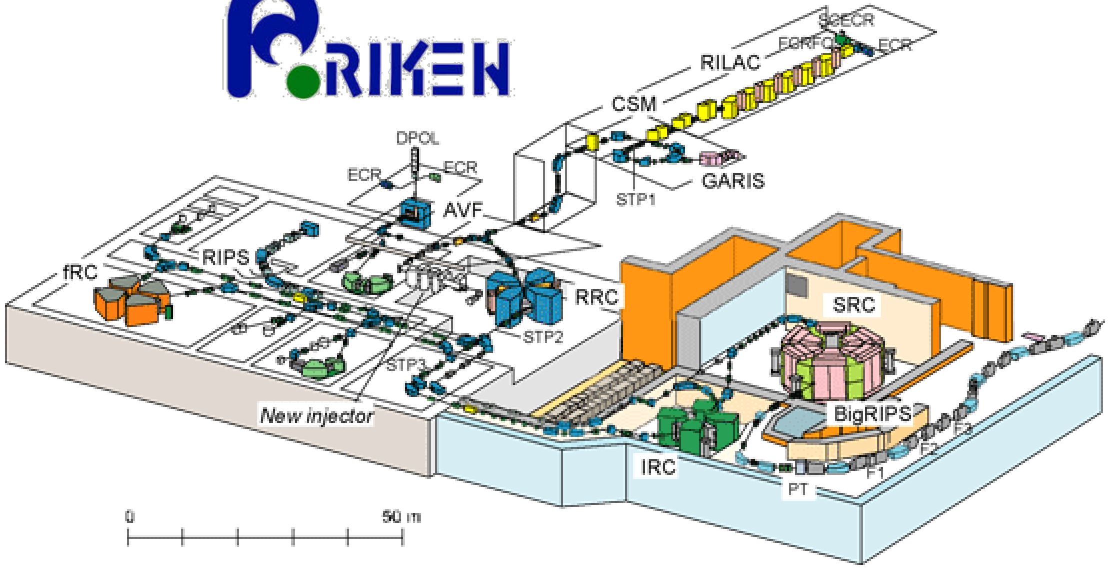
Brad Sherrill EBSS July 2011, Slide 23

FAIR

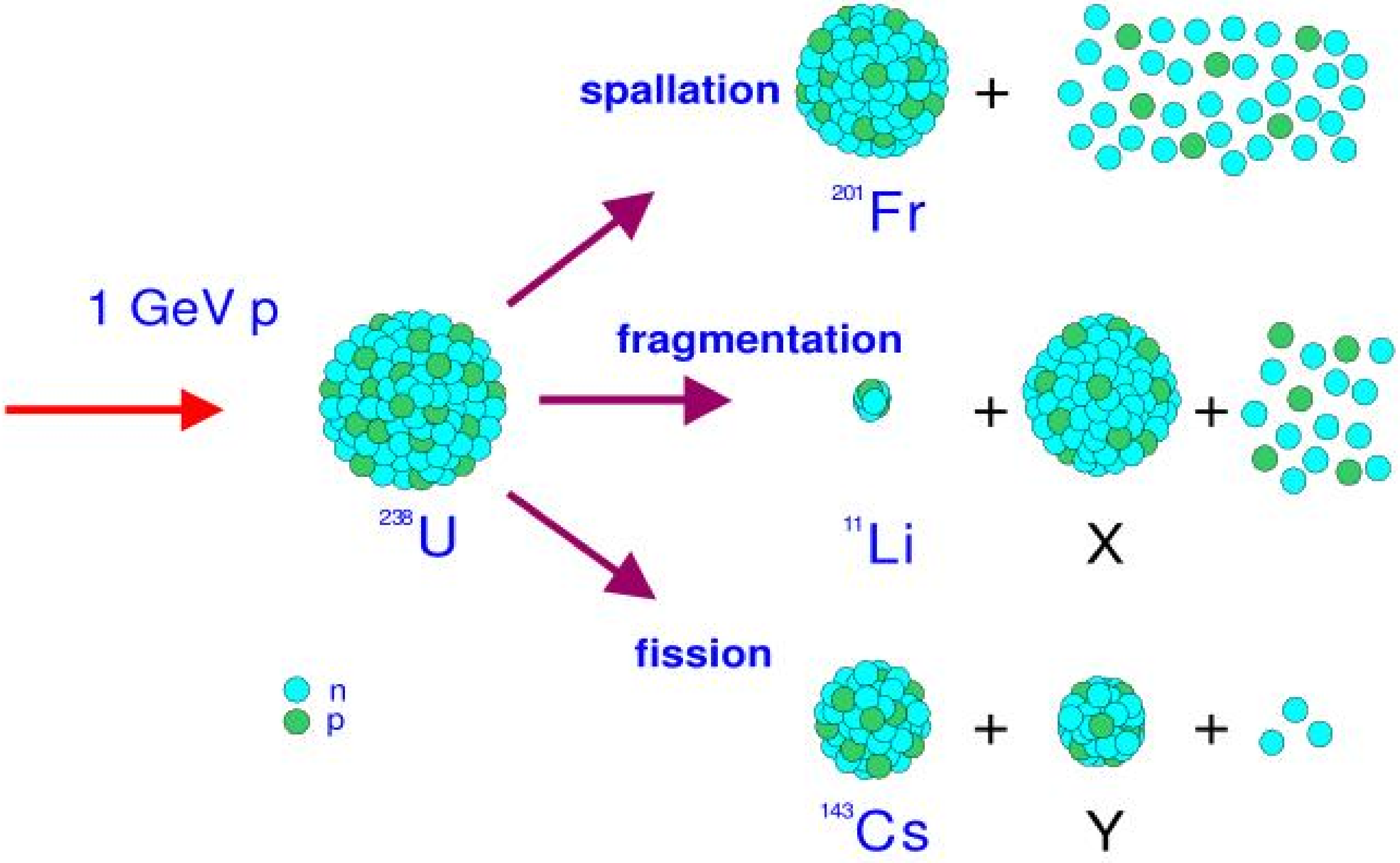
EMMI GSI



RIKEN



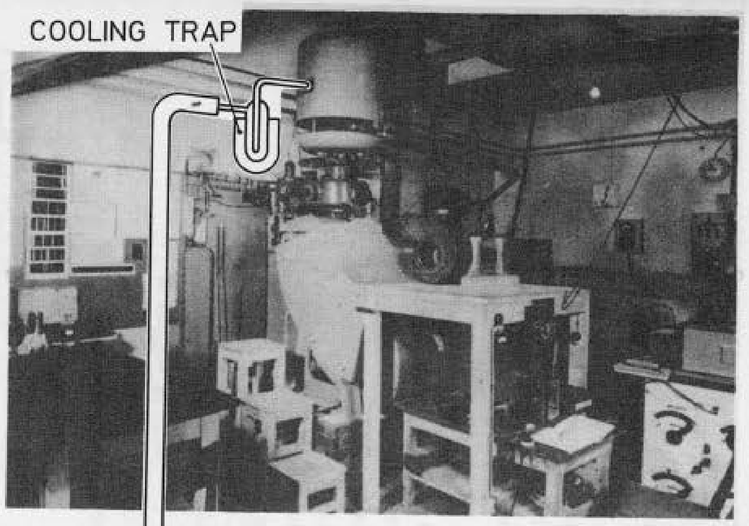
ISOTOPE production in ISOL method

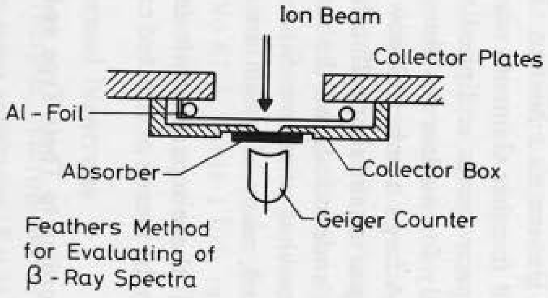


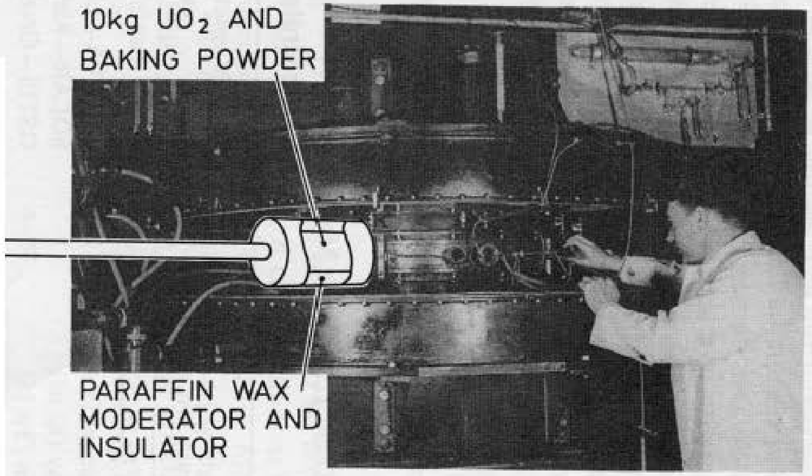
High intensity,
high quality,
energy tunable

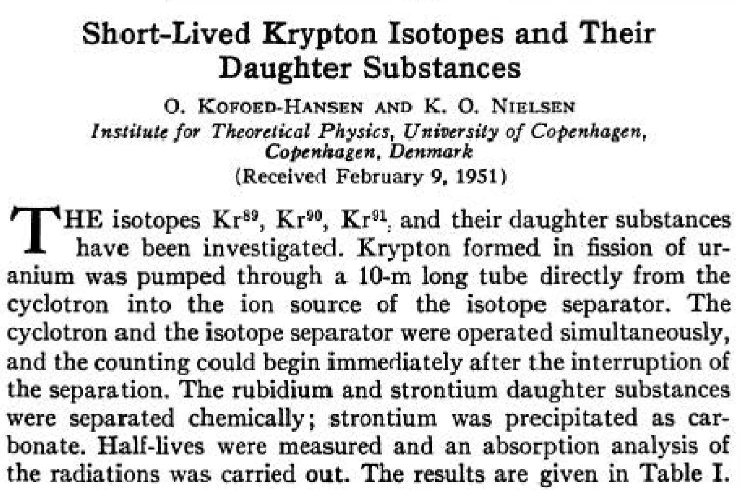
Chemically selective
not all beams are
possible

ISOL: History









Short-Lived Krypton Isotopes and Their Daughter Substances

O. Kofoed-Hansen and K. O. Nielsen
Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark

(Received February 9, 1951)

THE isotopes Kr^{89}, Kr^{90}, Kr^{91}, and their daughter substances have been investigated. Krypton formed in fission of uranium was pumped through a 10-m long tube directly from the cyclotron into the ion source of the isotope separator. The cyclotron and the isotope separator were operated simultaneously, and the counting could begin immediately after the interruption of the separation. The rubidium and strontium daughter substances were separated chemically; strontium was precipitated as carbonate. Half-lives were measured and an absorption analysis of the radiations was carried out. The results are given in Table I.

Kofoed-Hansen & Nielsen Phys Rev 82 (1951) 96

Re-accelerated ISOL Beams

PHYSICAL REVIEW C VOLUME 42, NUMBER 3 SEPTEMBI

Production of intense radioactive ion beams using two accelerators

D. Darquennes,(1) P. Decrock,(2) Th. Delbar,(1) W. Galster,(1) M. Huyse,(2) Y. Jongen,(1) M. Lacroix,(1) P. Leleux,(1) I. Licot,(1) E. Liénard,(1) P. Lipnik,(1) M. Loiselet,(1) G. Ryckewaert,(1) Sindano Wa Kitwanga,(1) P. Van Duppen,(2) J. Vanhorenbeeck,(3) J. Vervier,(1) and S. Zaremba(1)

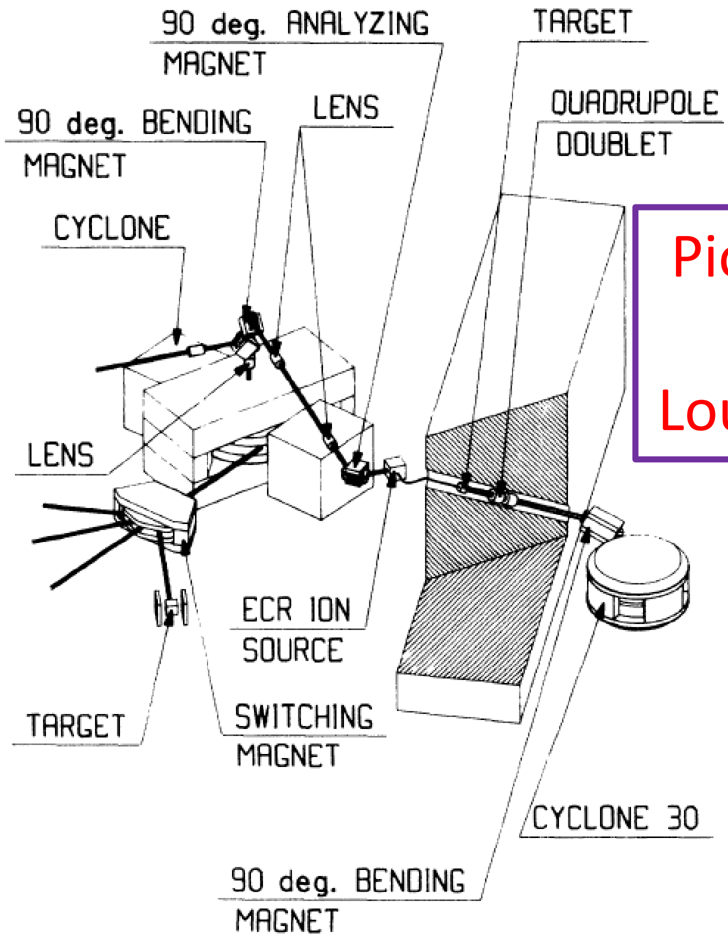


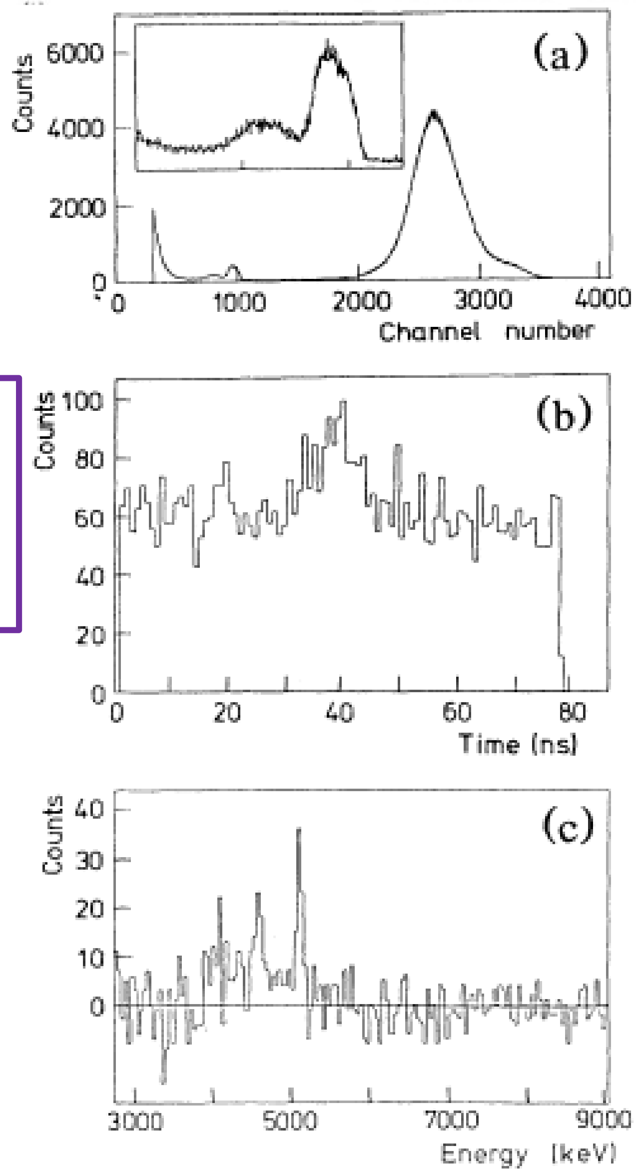
FIG. 1. General layout of the radioactive ion beam facility.

Pioneering work done at Louvain-La-Neuve

VOLUME 67, NUMBER 7 PHYSICAL REVIEW LETTERS 12 AUGUST 1991

Determination of the ^{13}N$(p,\gamma)^{14}$O Reaction Cross Section Using a ^{13}N Radioactive Ion Beam

P. Decrock,(2) Th. Delbar,(1) P. Duhamel,(3) W. Galster,(1) M. Huyse,(2) P. Leleux,(1) I. Licot,(1) E. Liénard,(1) P. Lipnik,(1) M. Loiselet,(1) C. Michotte,(1) G. Ryckewaert,(1) P. Van Duppen,(2) J. Vanhorenbeeck,(3) and J. Vervier(1)

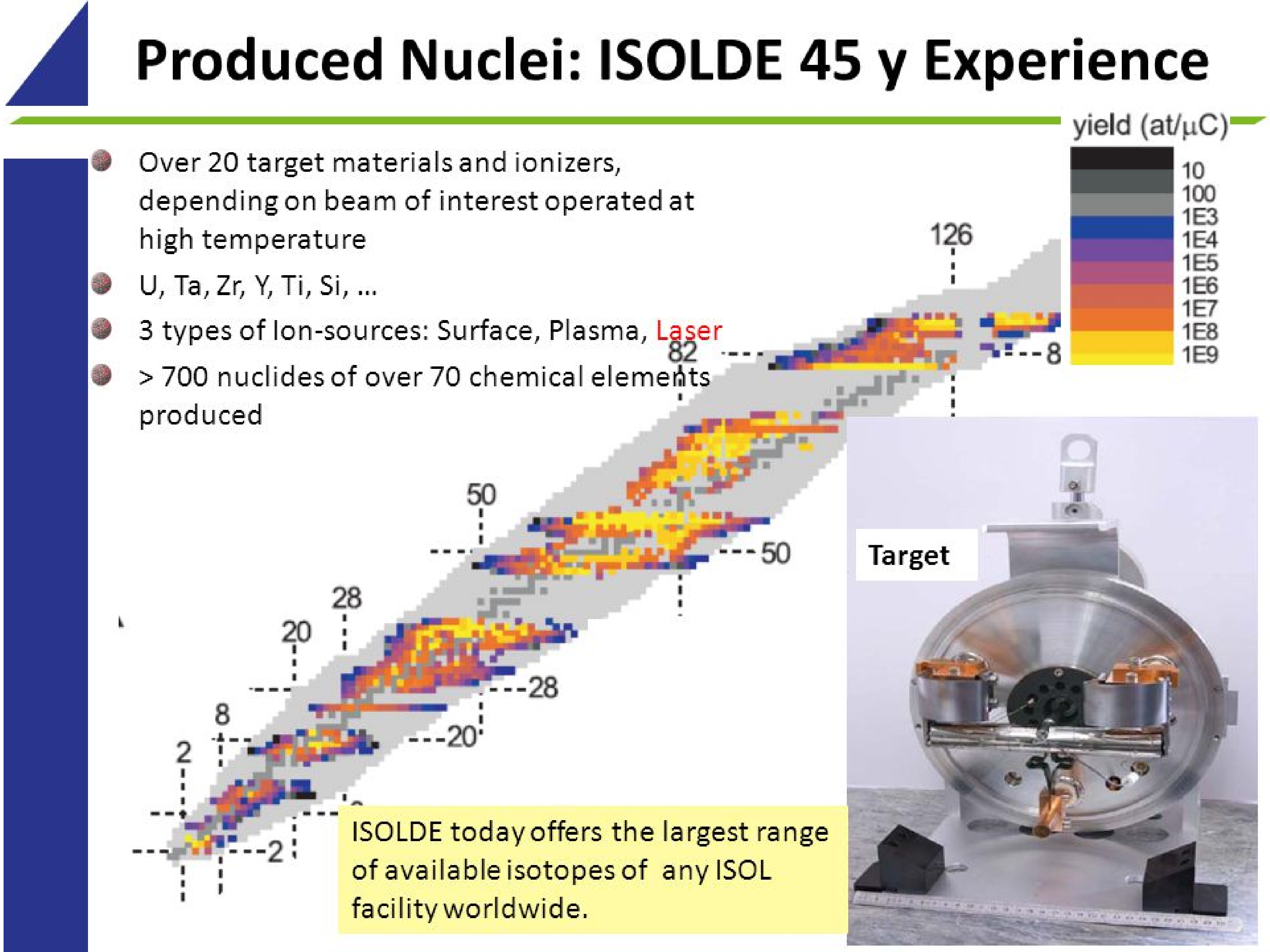


Charged-particle spectrum

Time-coincidence spectrum

Prompt γ-ray spectrum

Modern Facility: ISOLDE @ CERN

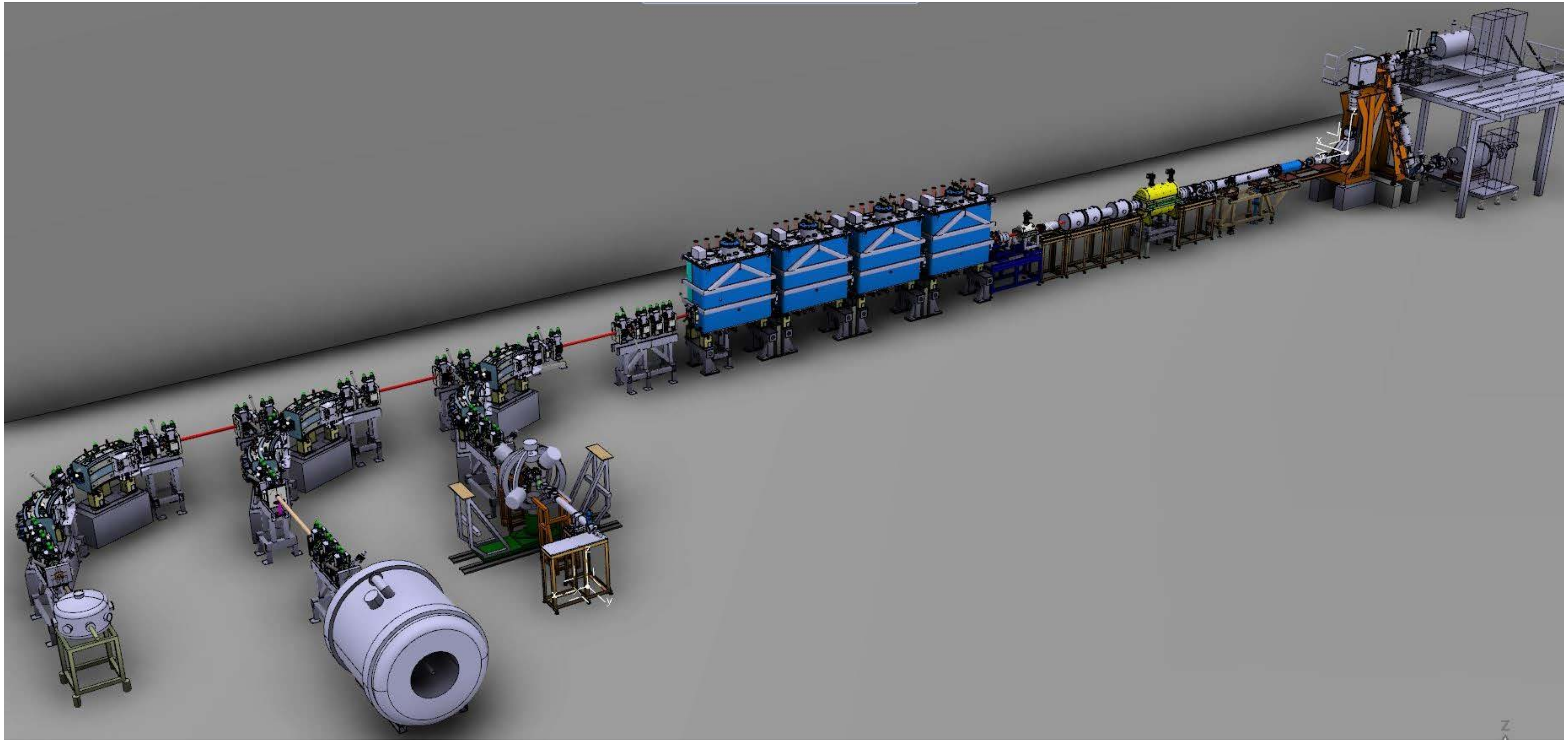


Produced Nuclei: ISOLDE 45 y Experience

- Over 20 target materials and ionizers, depending on beam of interest operated at high temperature
- U, Ta, Zr, Y, Ti, Si, …
- 3 types of Ion-sources: Surface, Plasma, Laser
- > 700 nuclides of over 70 chemical elements produced

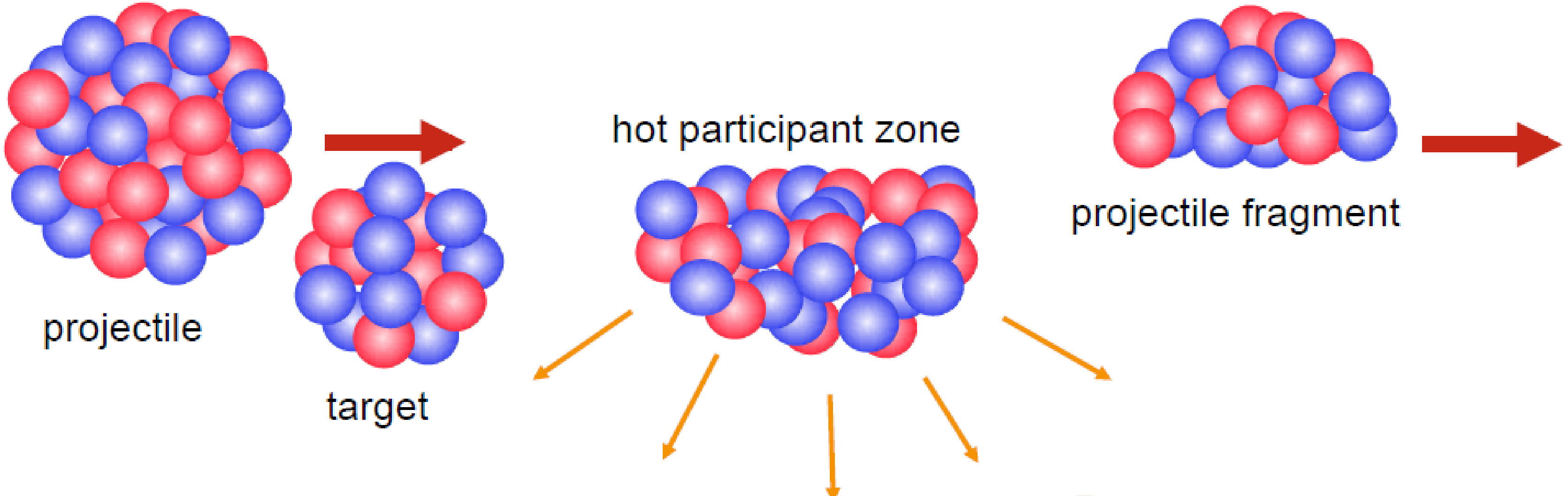
ISOLDE today offers the largest range of available isotopes of any ISOL facility worldwide.

HIE-ISOLDE: Upgraded to accelerate to 10 AMeV

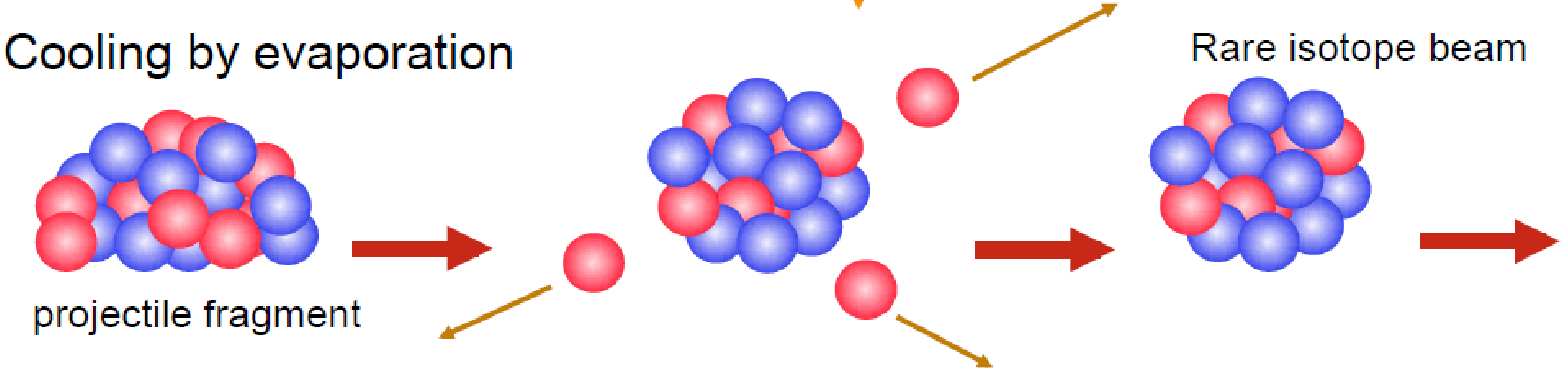


Production of Rare Isotopes in Flight

1. Accelerate heavy ion beam to high energy and pass through a thin target to achieve random removal of protons and neutrons in flight



2. Cooling by evaporation



(M. Thoennesen)

Pioneering work at the LBNL Bevelac

All species possible, Can go far from stability, high (100s of AMeV) energies

Poorer emittance and beam quality, high energies

VOLUME 42, NUMBER 1 PHYSICAL REVIEW LETTERS 1 JANUARY 1979

Observation of New Neutron-Rich Isotopes by Fragmentation of 205-MeV/Nucleon ^{40}Ar Ions

T. J. M. Symons, Y. P. Viyogi,(a) G. D. Westfall, P. Doll,(b) D. E. Greiner, H. Faraggi,(c) P. J. Lindstrom, and D. K. Scott
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

and

H. J. Crawford and C. McParland
Space Sciences Laboratory, University of California, Berkeley, California 94720
(Received 1 November 1978)

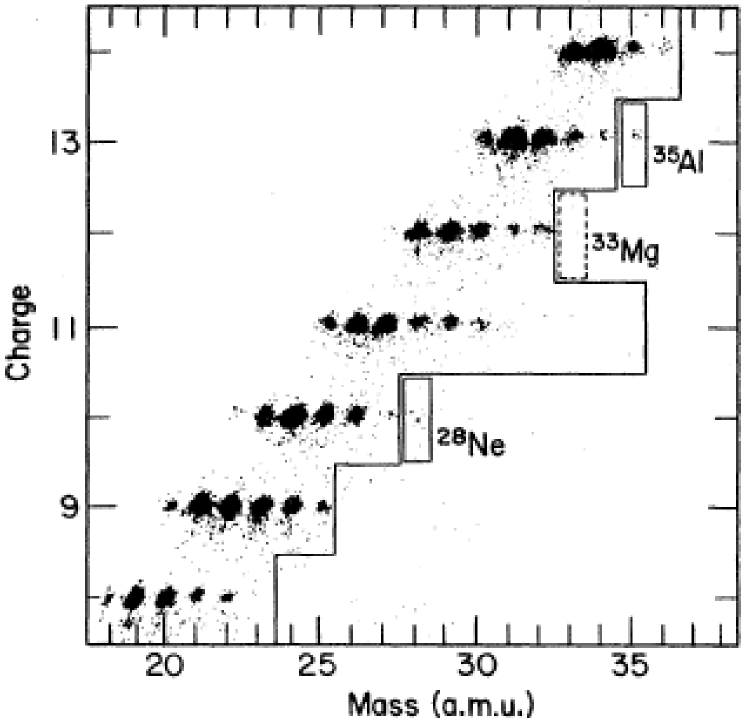


FIG. 1. Scatter plot of data obtained from the reaction of 205-MeV/nucleon ^{40}Ar ions on a carbon target. The line running through the figure indicates the previously known limit of stability.

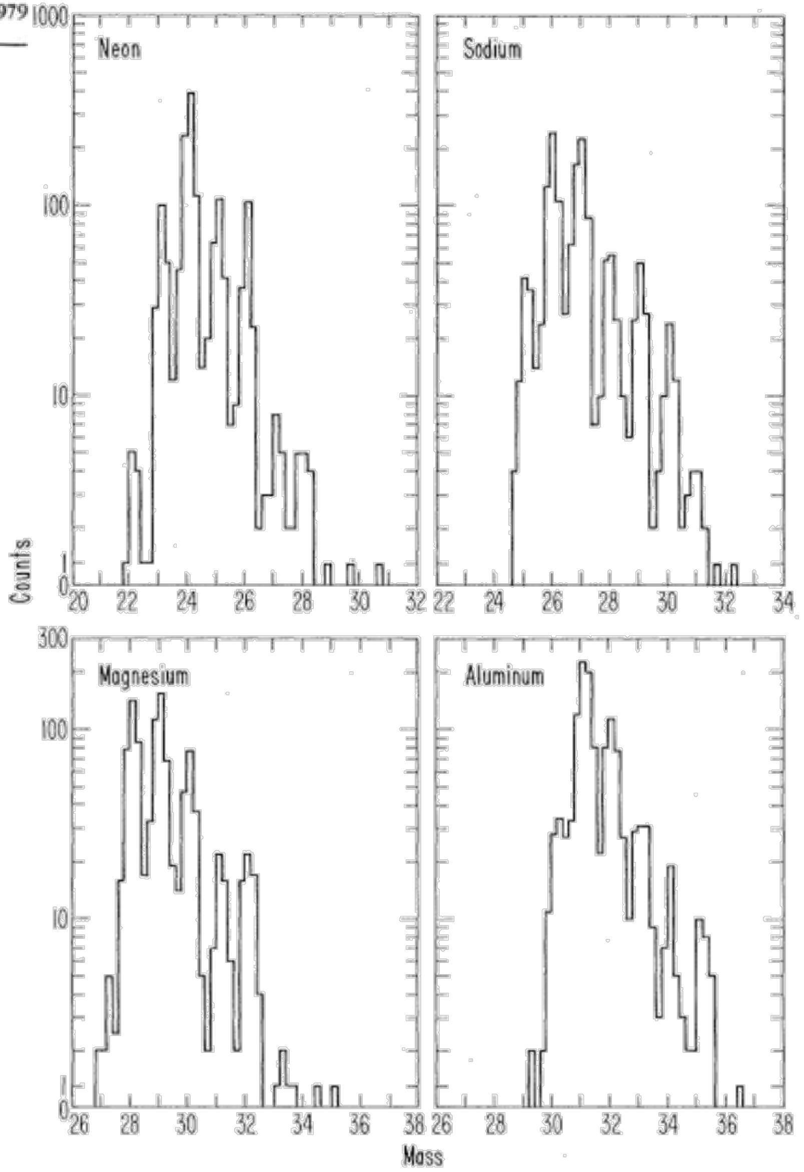
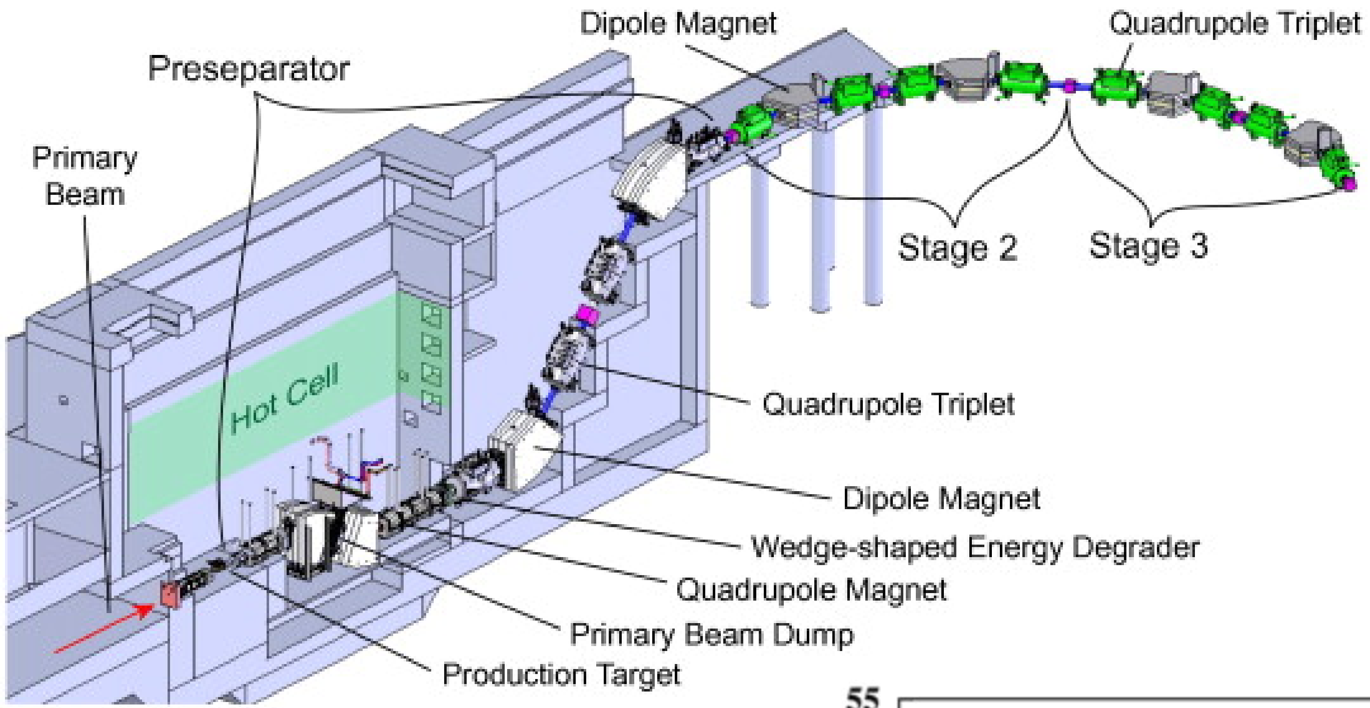
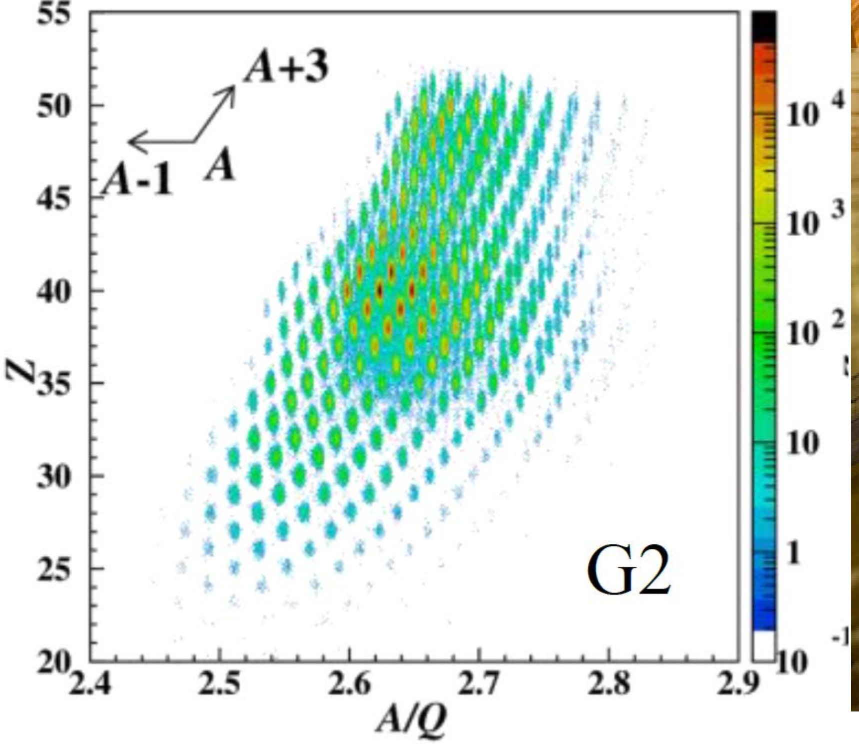


FIG. 2. Mass histograms for the elements Ne, Na, Mg, and Al, measured by the bombardment of a carbon target by 205-Mev/nucleon ^{40}Ar ions. The spectra are projections of the data in Fig. 1 with charge gates of ±0.2 units.



FRIB Target and A1900 Separator



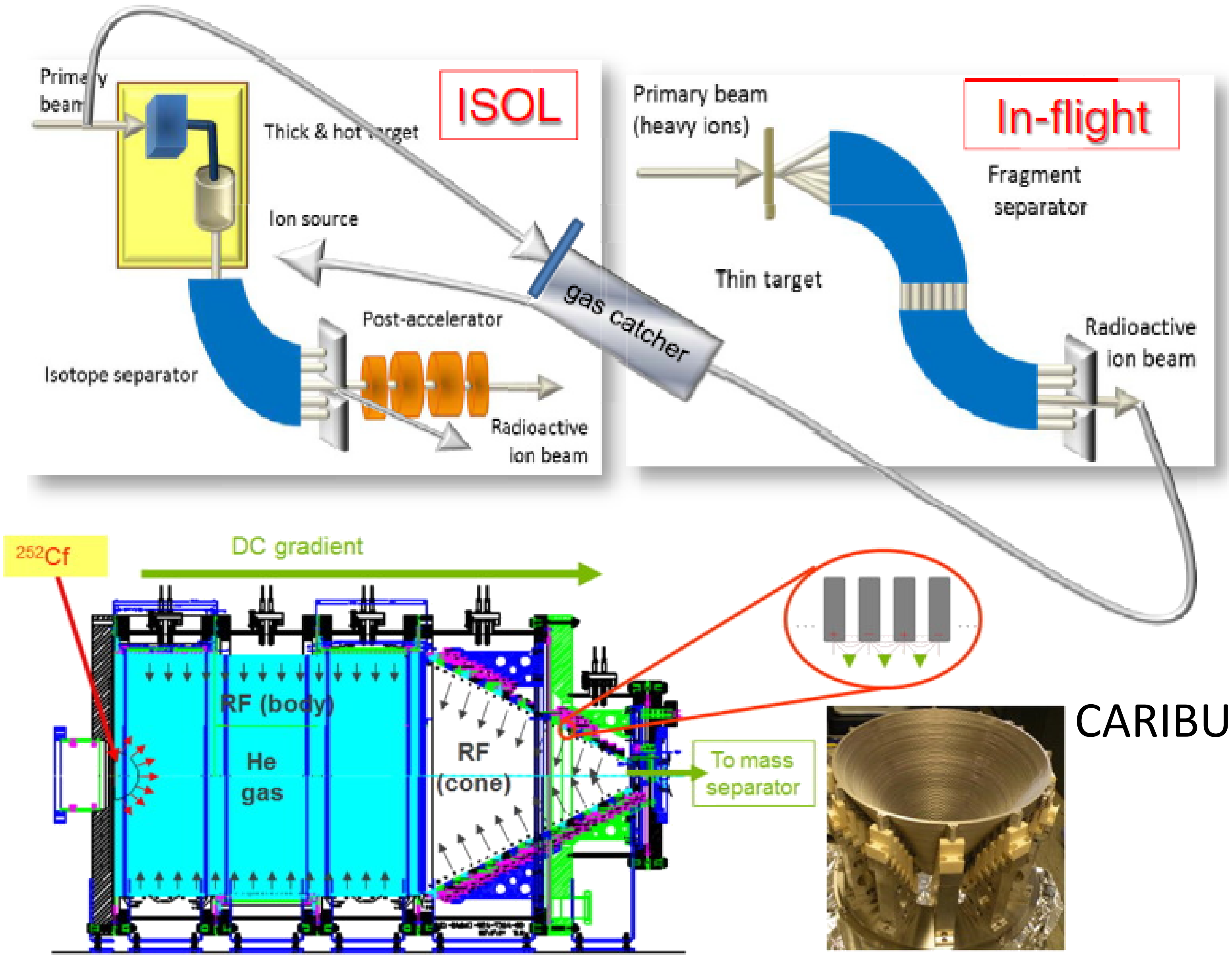
Many many nuclei are produced!
(BIGRIPS, ^{238}U+^{9}Be)

T. Ohnishi et al.,
J.Phys.Soc.Jpn. 79, 073201 (2010)

BIGRIPS @ RIKEN

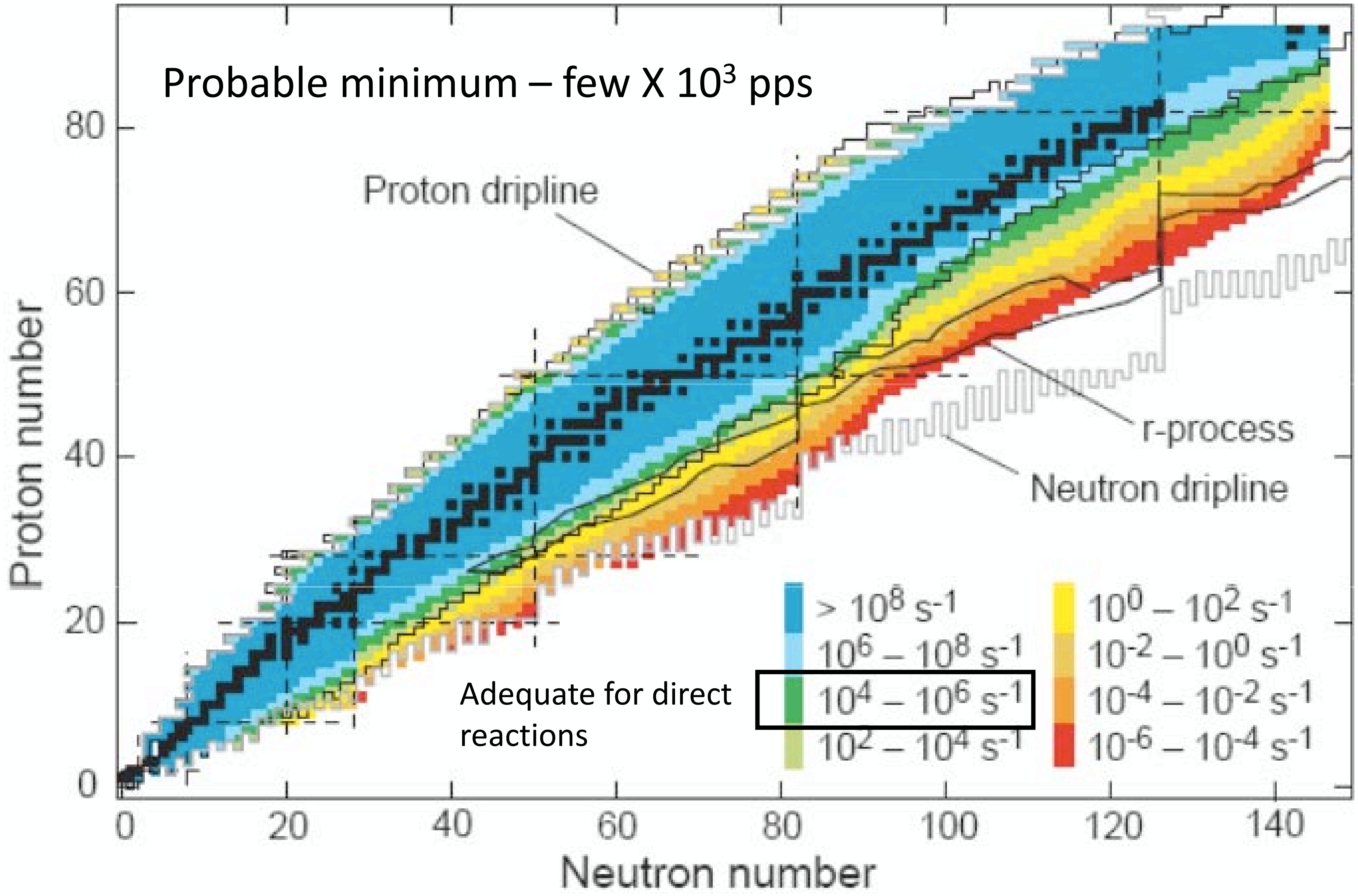
Re-accelerating Fast Fragmentation beams

Phys. Scr. **T152** (2013) 014023 Y Blumenfeld *et al*



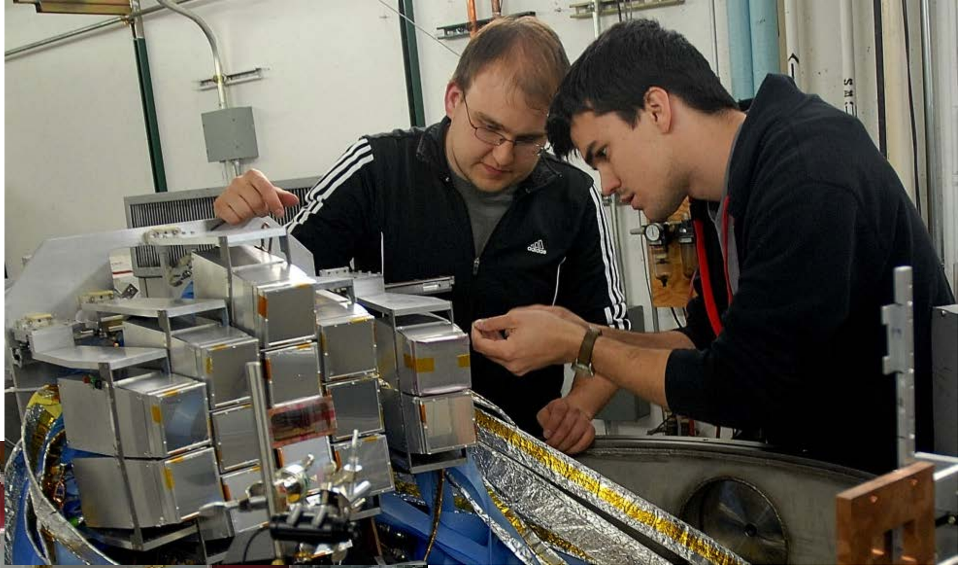
CARIBU Gas Catcher at ANL

Expected FRIB/ReA beam yields

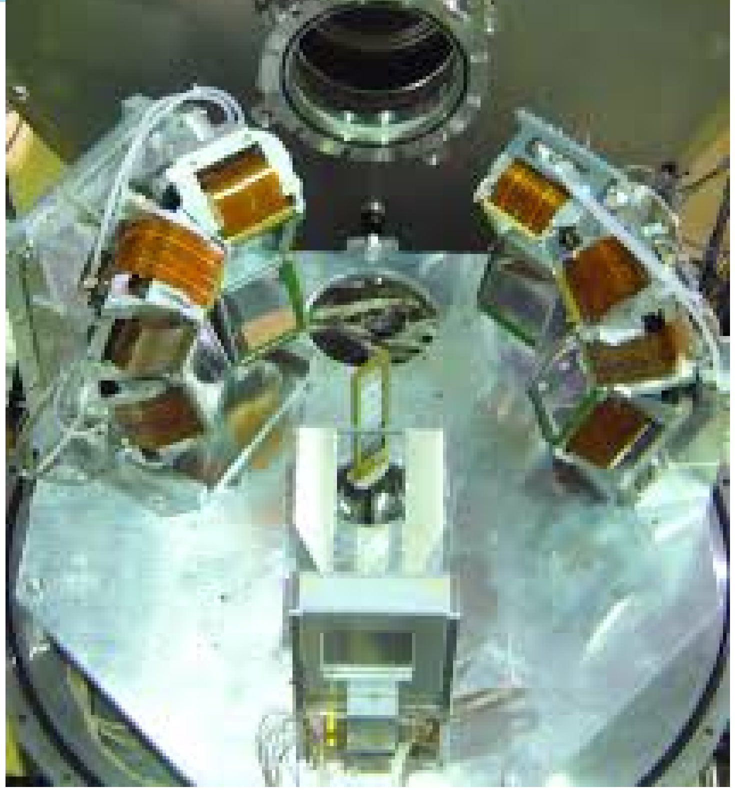


Probable minimum – few X 10^3 pps

Adequate for direct reactions

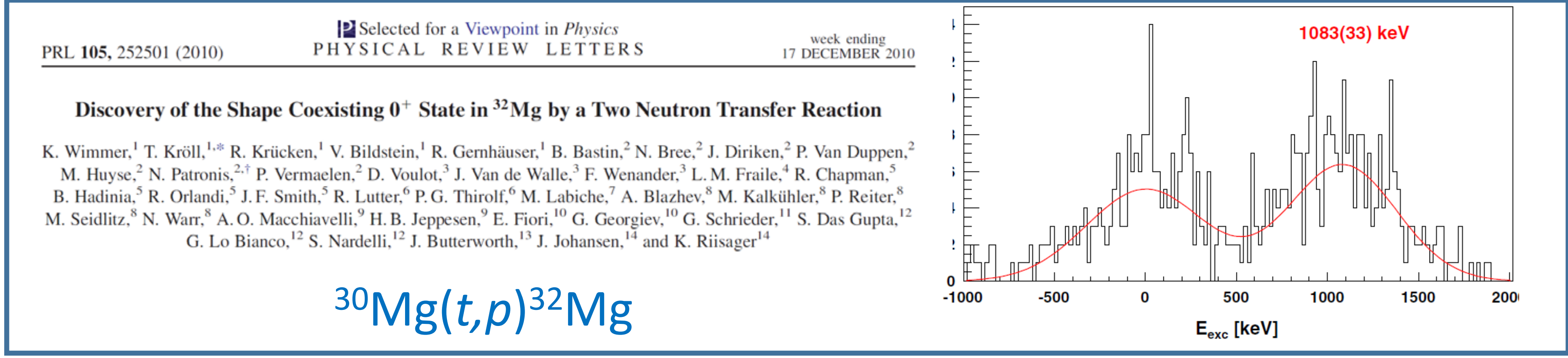


Detecting charged Particles: Silicon-detector arrays



Silicon-array CP detection

- Familiar technology
- Resolution challenged in Inverse kinematics

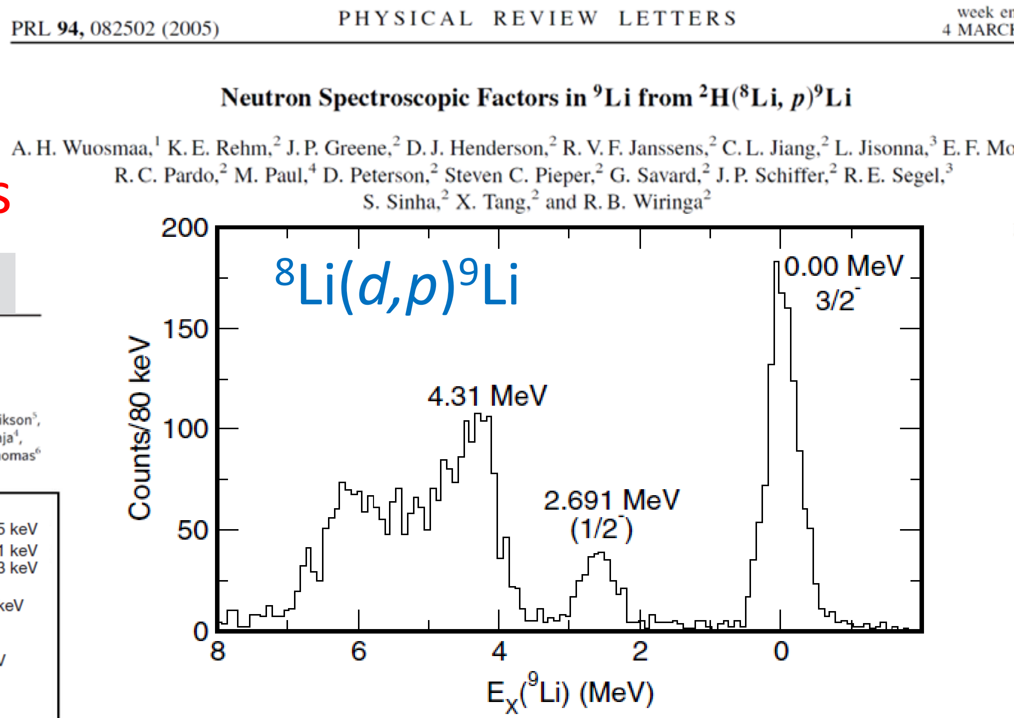


PRL **105,** 252501 (2010) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 17 DECEMBER 2010

Discovery of the Shape Coexisting 0^+ State in ^{32}Mg by a Two Neutron Transfer Reaction

K. Wimmer,[1] T. Kröll,[1,*] R. Krücken,[1] V. Bildstein,[1] R. Gernhäuser,[1] B. Bastin,[2] N. Bree,[2] J. Diriken,[2] P. Van Duppen,[2] M. Huyse,[2] N. Patronis,[2,†] P. Vermaelen,[2] D. Voulot,[3] J. Van de Walle,[3] F. Wenander,[3] L. M. Fraile,[4] R. Chapman,[5] B. Hadinia,[5] R. Orlandi,[5] J. F. Smith,[5] R. Lutter,[6] P. G. Thirolf,[6] M. Labiche,[7] A. Blazhev,[8] M. Kalkühler,[8] P. Reiter,[8] M. Seidlitz,[8] N. Warr,[8] A. O. Macchiavelli,[9] H. B. Jeppesen,[9] E. Fiori,[10] G. Georgiev,[10] G. Schrieder,[11] S. Das Gupta,[12] G. Lo Bianco,[12] S. Nardelli,[12] J. Butterworth,[13] J. Johansen,[14] and K. Riisager[14]

^{30}Mg(*t*,*p*)^{32}Mg

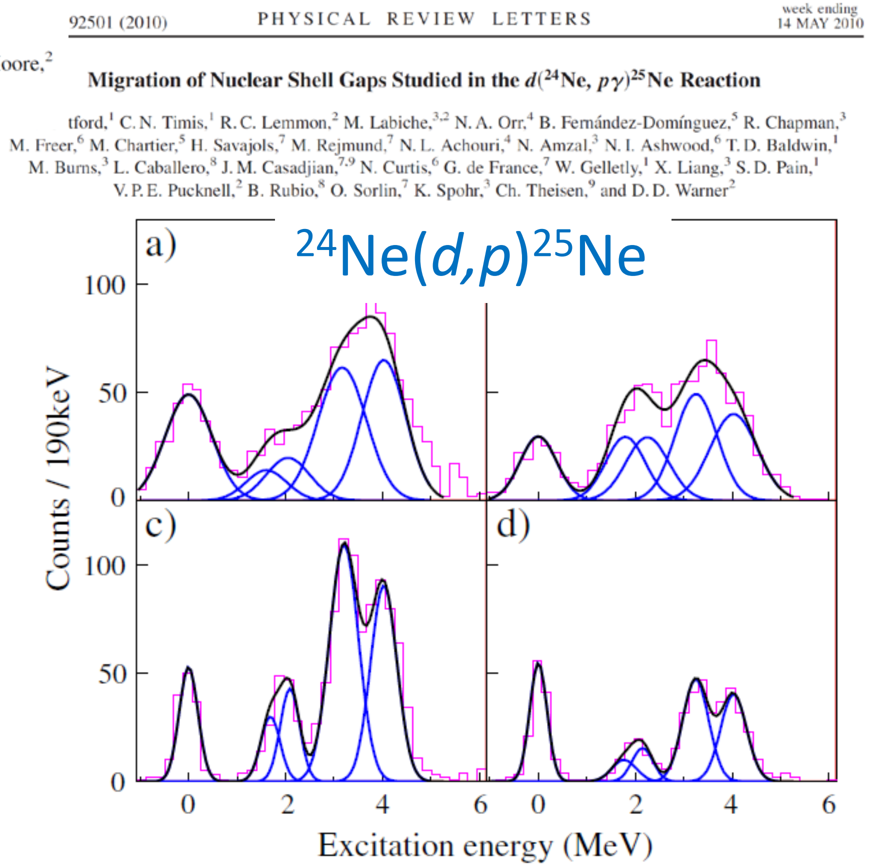


PRL **94,** 082502 (2005) PHYSICAL REVIEW LETTERS week ending 4 MARCH 2005

Neutron Spectroscopic Factors in ^{9}Li from ^{2}H(^{8}Li, p)^{9}Li

A. H. Wuosmaa,[1] K. E. Rehm,[2] J. P. Greene,[2] D. J. Henderson,[2] R. V. F. Janssens,[2] C. L. Jiang,[2] L. Jisonna,[3] E. F. Moore,[2] R. C. Pardo,[2] M. Paul,[4] D. Peterson,[2] Steven C. Pieper,[2] G. Savard,[2] J. P. Schiffer,[2] R. E. Segel,[3] S. Sinha,[2] X. Tang,[2] and R. B. Wiringa[2]

^{8}Li(*d*,*p*)^{9}Li

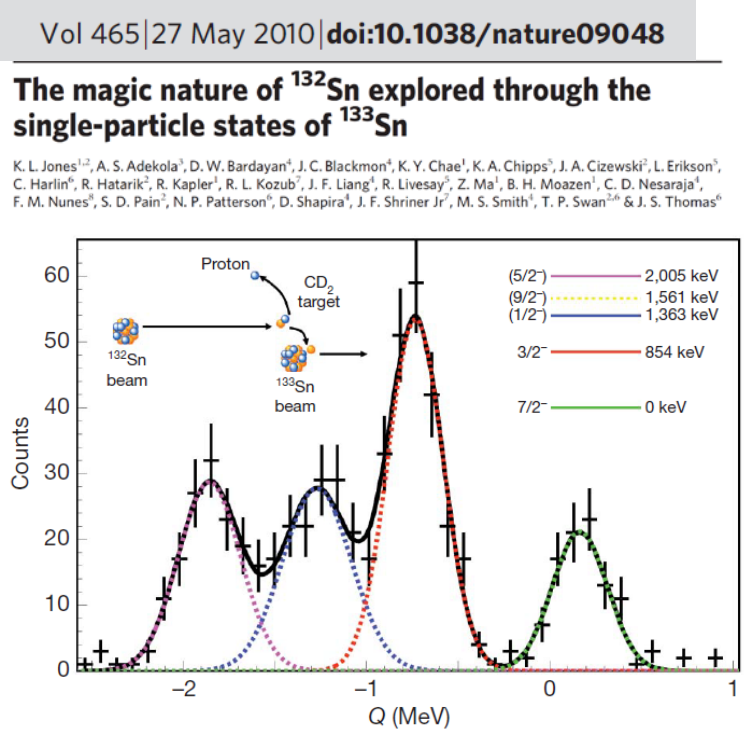


92501 (2010) PHYSICAL REVIEW LETTERS week ending 14 MAY 2010

Migration of Nuclear Shell Gaps Studied in the d(^{24}Ne, $p\gamma$)^{25}Ne Reaction

tford,[1] C. N. Timis,[1] R. C. Lemmon,[2] M. Labiche,[3,2] N. A. Orr,[4] B. Fernández-Domínguez,[5] R. Chapman,[3] M. Freer,[6] M. Chartier,[5] H. Savajols,[7] M. Rejmund,[7] N. L. Achouri,[4] N. Amzal,[3] N. I. Ashwood,[6] T. D. Baldwin,[1] M. Burns,[3] L. Caballero,[8] J. M. Casadjian,[7,9] N. Curtis,[6] G. de France,[7] W. Gelletly,[1] X. Liang,[3] S. D. Pain,[1] V. P. E. Pucknell,[2] B. Rubio,[8] O. Sorlin,[7] K. Spohr,[3] Ch. Theisen,[9] and D. D. Warner[2]

^{24}Ne(*d*,*p*)^{25}Ne



Vol 465|27 May 2010|**doi:10.1038/nature09048**

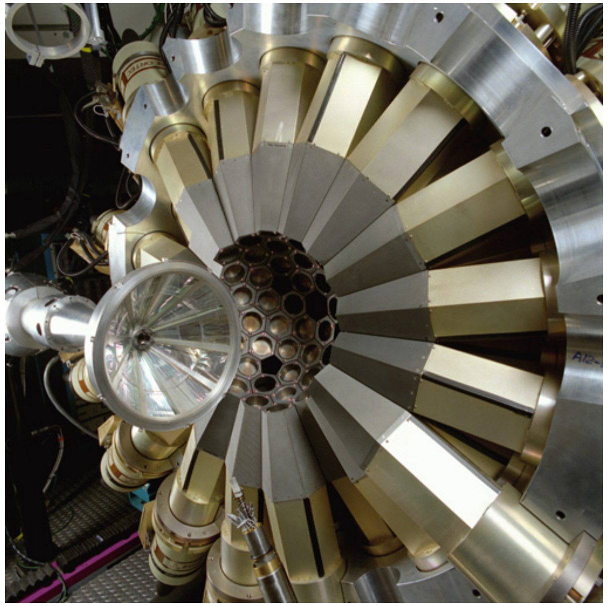
The magic nature of ^{132}Sn explored through the single-particle states of ^{133}Sn

K. L. Jones[1,2], A. S. Adekola[3], D. W. Bardayan[4], J. C. Blackmon[4], K. Y. Chae[1], K. A. Chipps[5], J. A. Cizewski[2], L. Erikson[5], C. Harlin[6], R. Hatarik[2], R. Kapler[1], R. L. Kozub[7], J. F. Liang[4], R. Livesay[5], Z. Ma[1], B. H. Moazen[1], C. D. Nesaraja[4], F. M. Nunes[8], S. D. Pain[2], N. P. Patterson[6], D. Shapira[4], J. F. Shriner Jr[7], M. S. Smith[4], T. P. Swan[2,6] & J. S. Thomas[6]

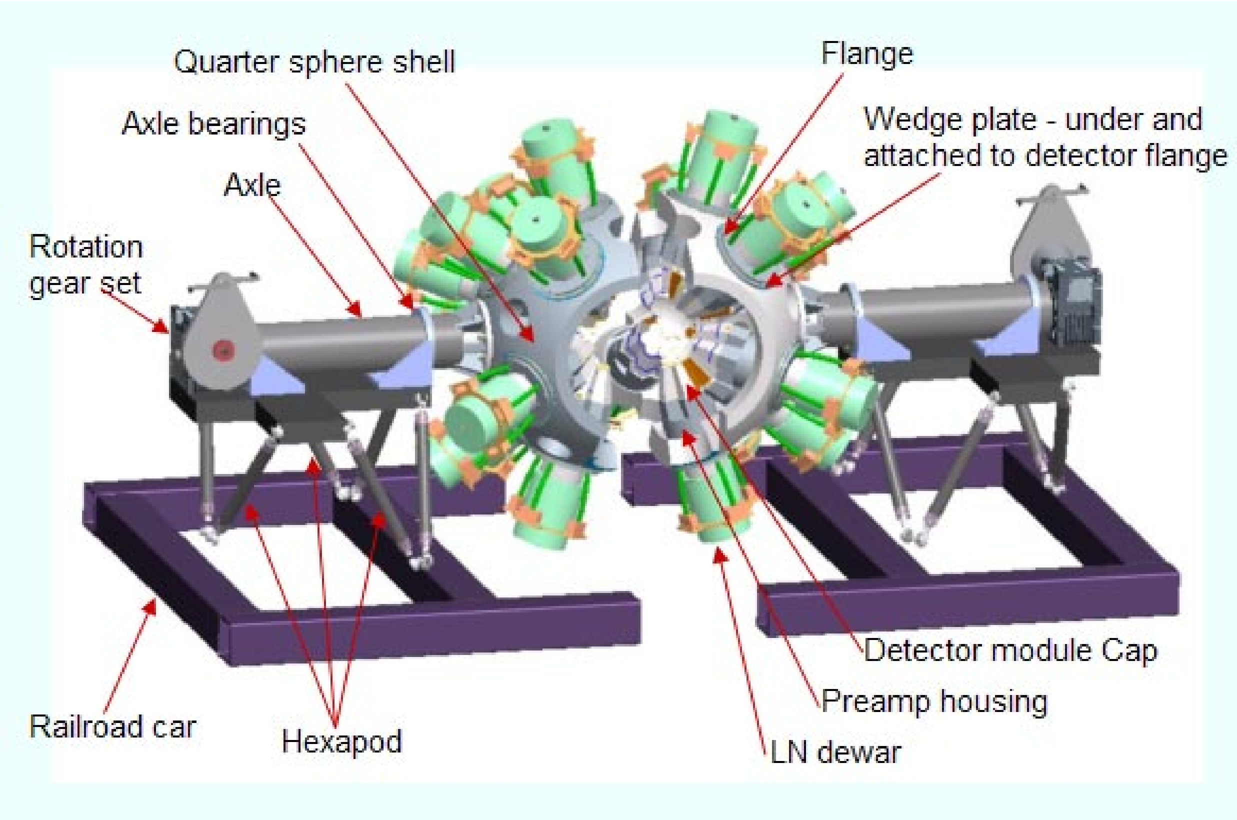
^{132}Sn(*d*,*p*)^{133}Sn

Detecting Photons

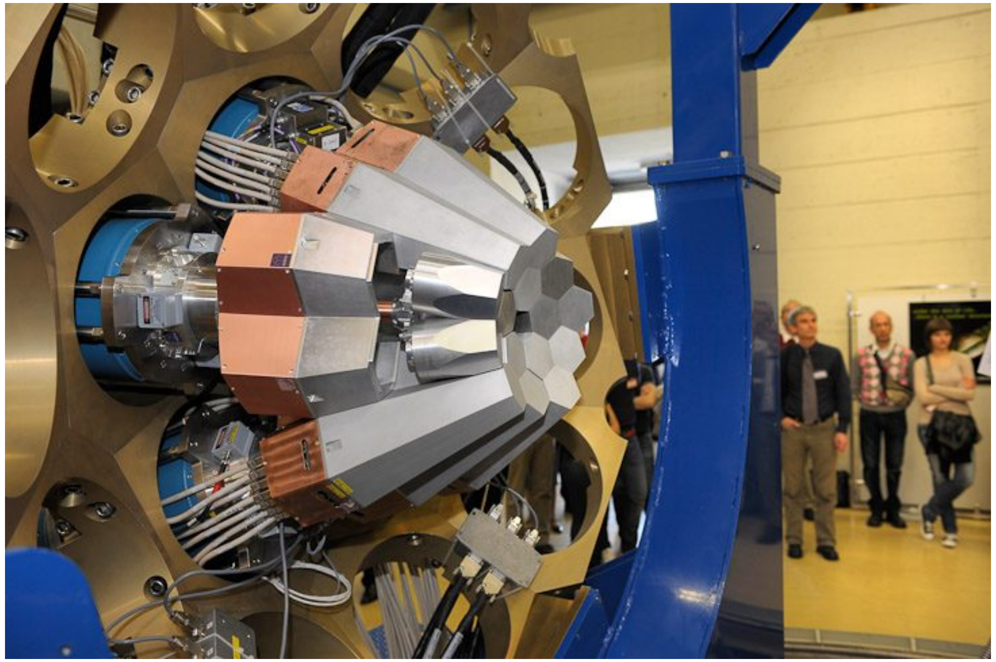
GAMMASPHERE
~100 Compton-supressed
Ge detectors



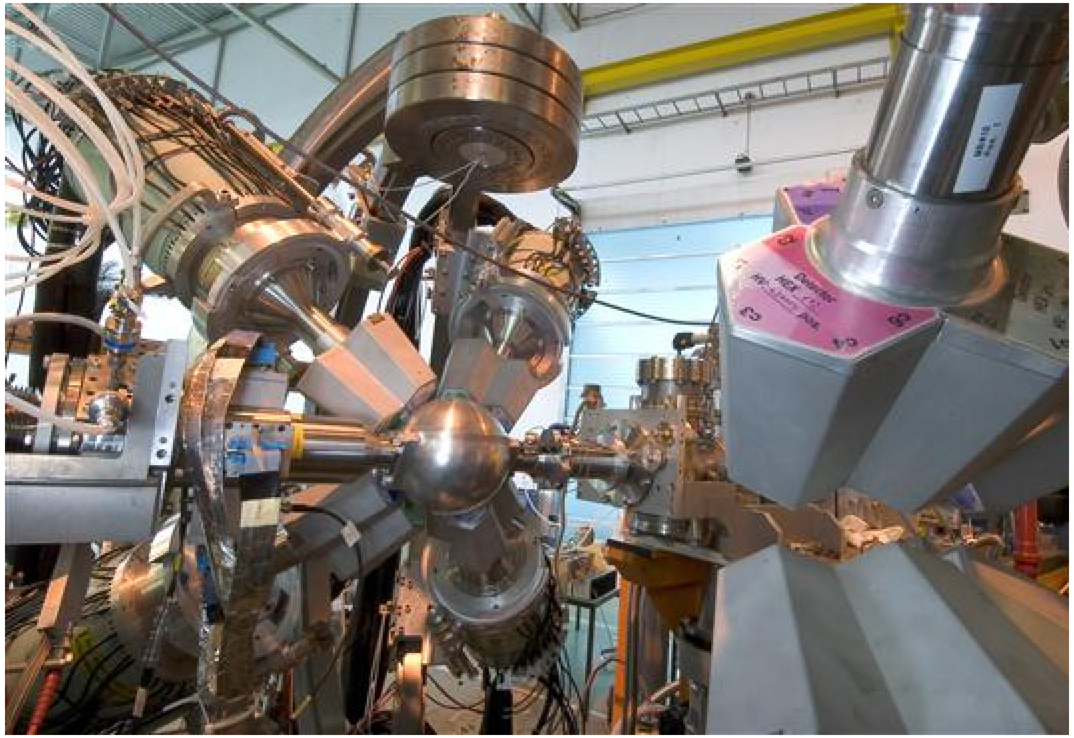
GRETINA/GRETA – Gamma-ray tracking



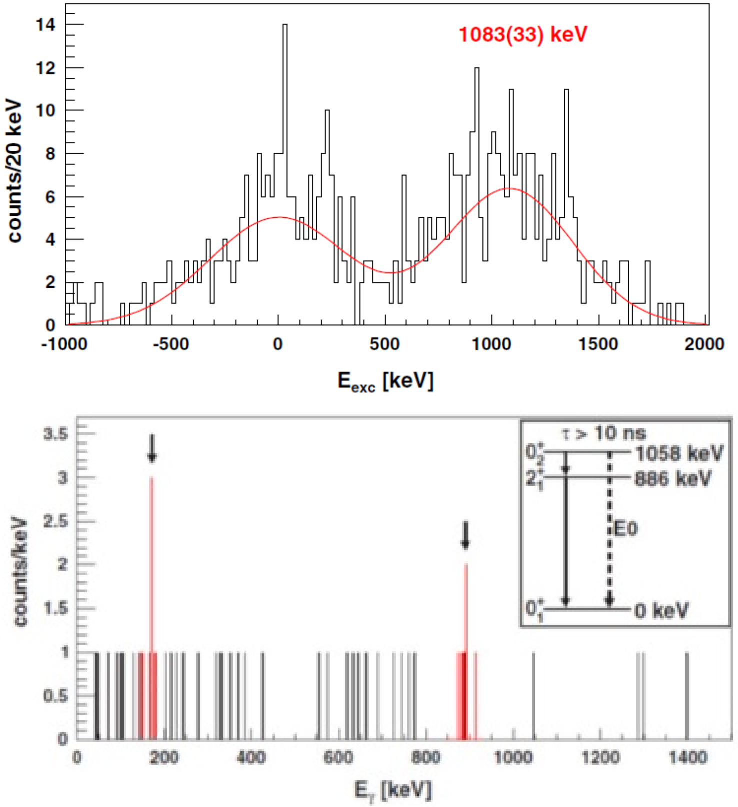
AGATA – Gamma-ray tracking

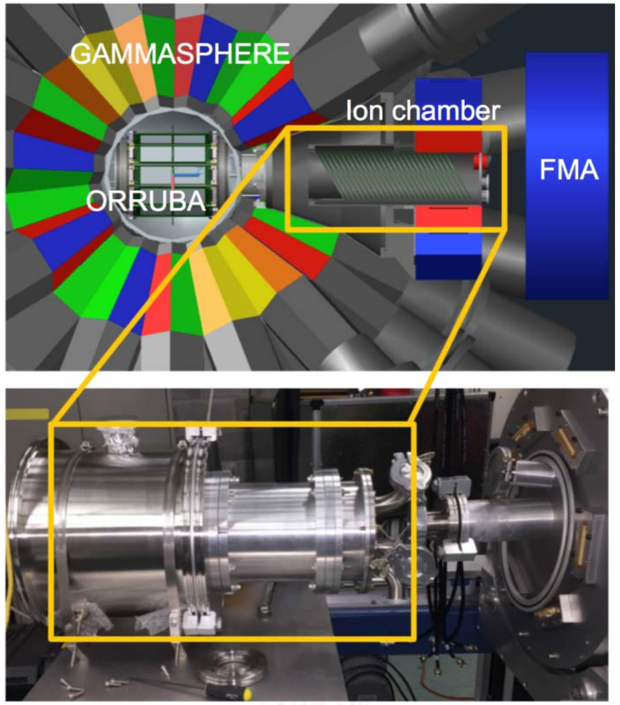


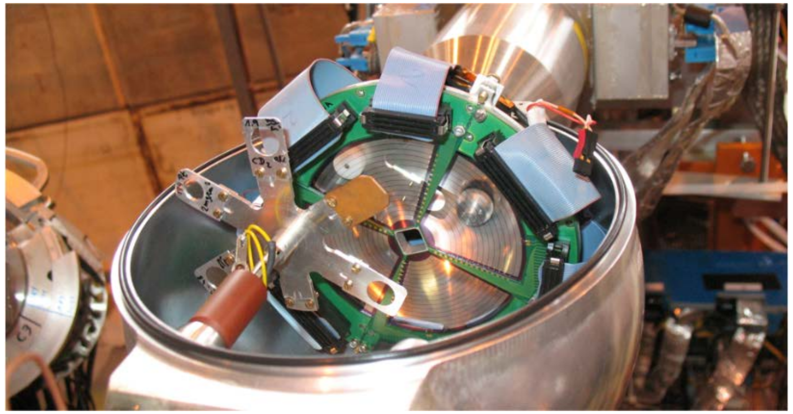
Detecting charged particles and gamma rays together



$^{30}Mg(t,p\gamma)^{32}Mg$

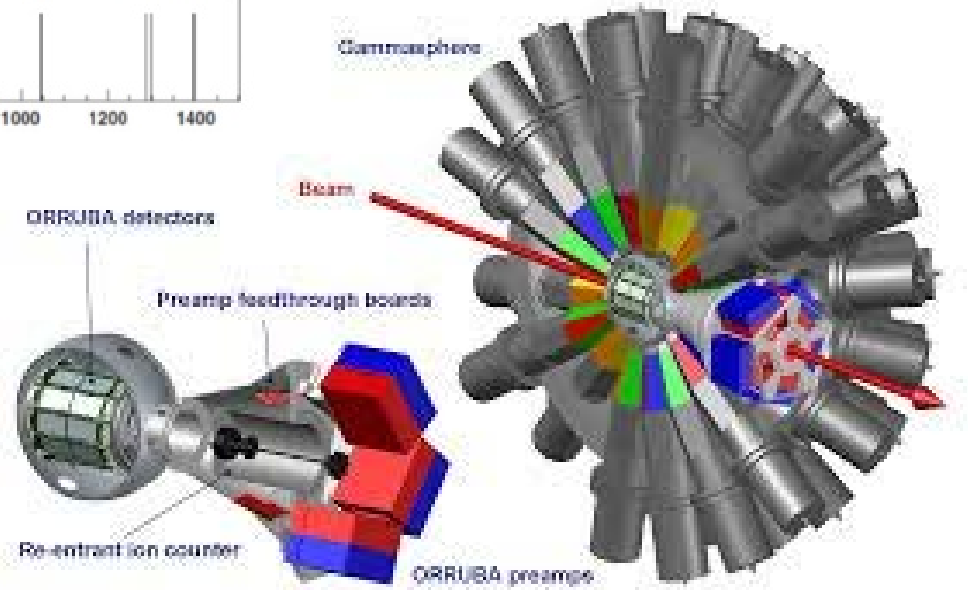






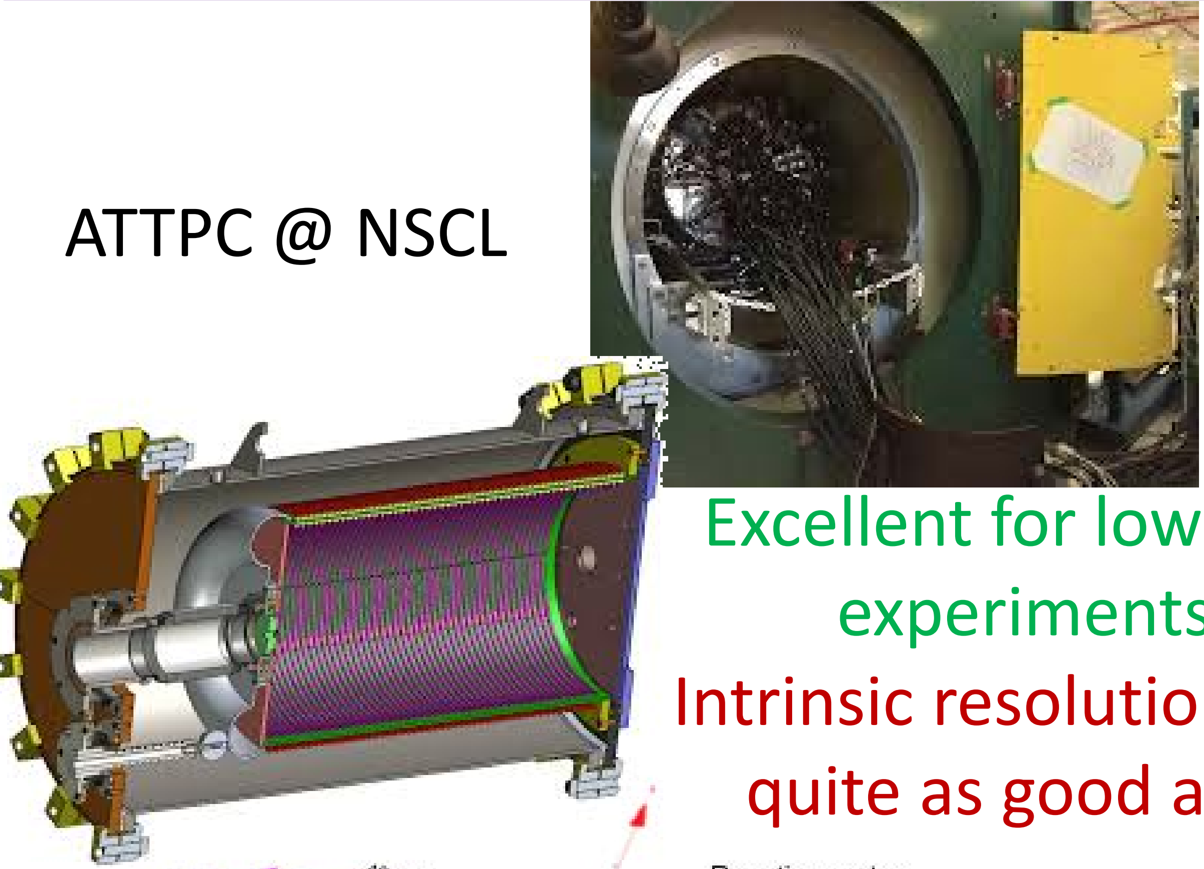
MINIBall @
CERN-ISOLDE

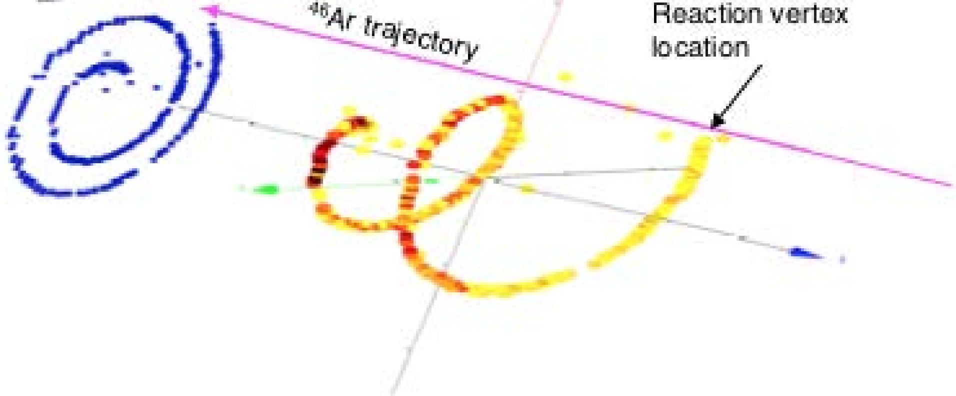
ORRUBA/GODESS
ORNL/ANL



Tracking and Active Targets

ATTPC @ NSCL

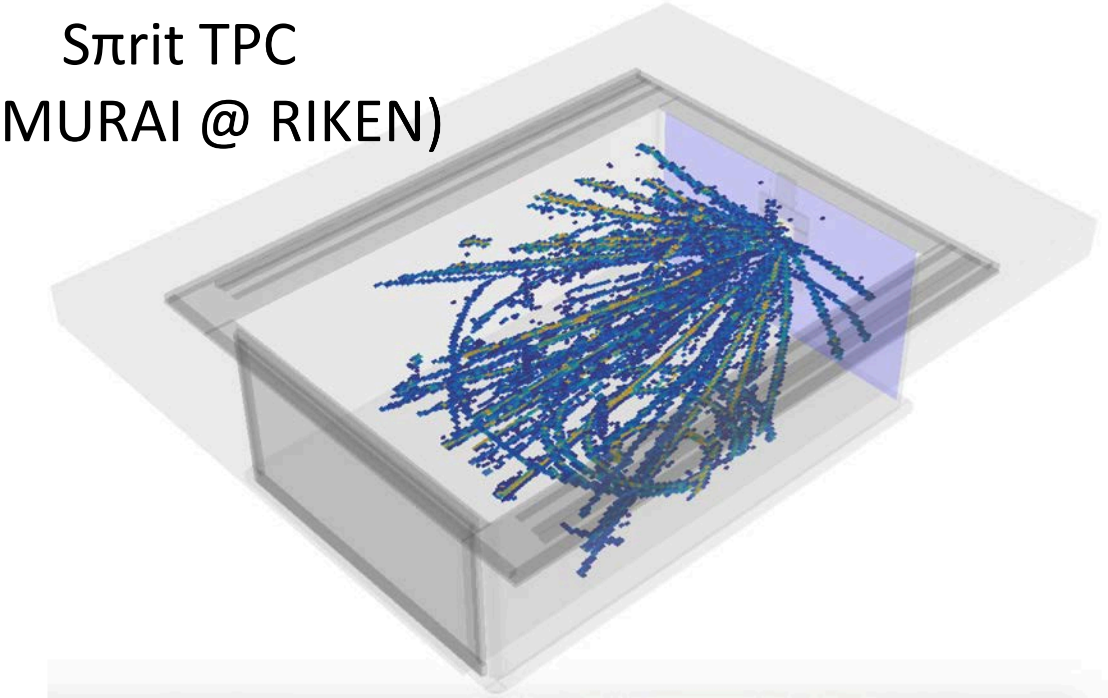




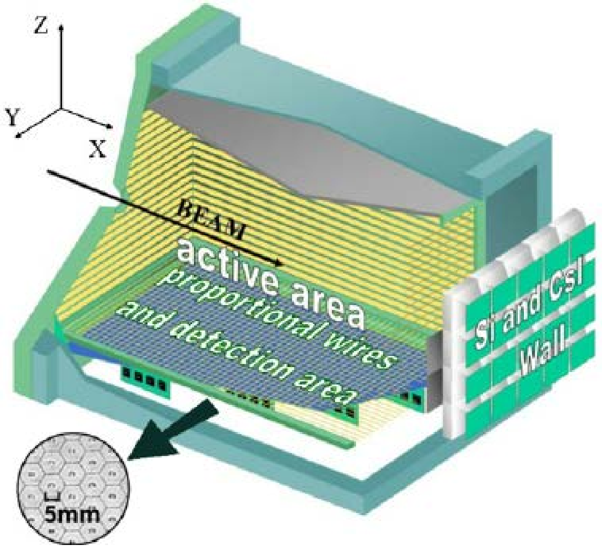
Excellent for low-rate experiments

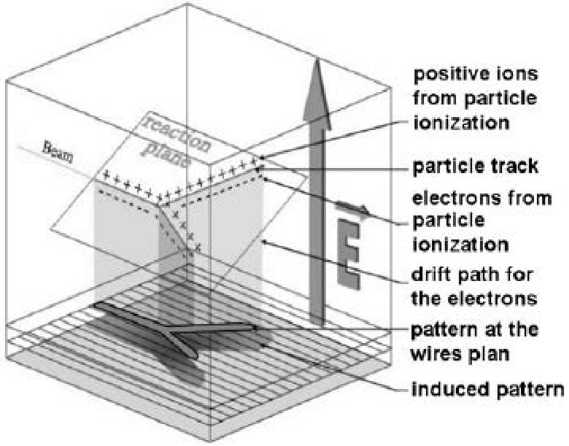
Intrinsic resolution not quite as good as Si

Sπrit TPC
(SAMURAI @ RIKEN)

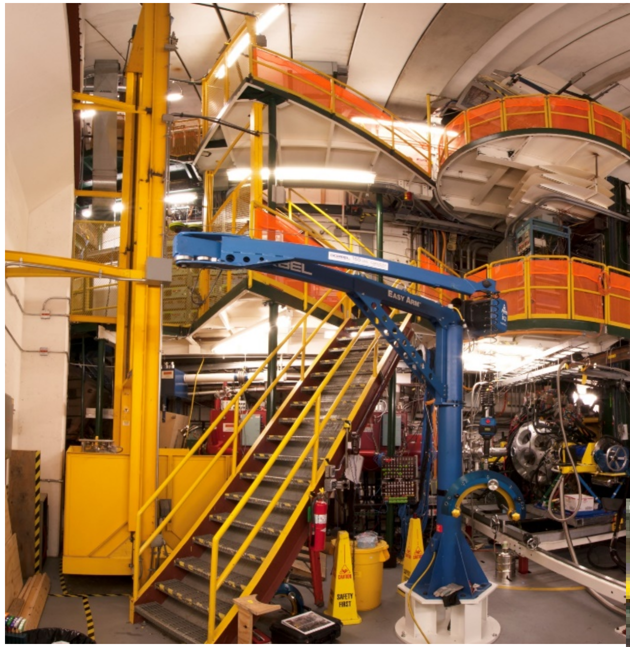


MAYA TPC
@ GANIL

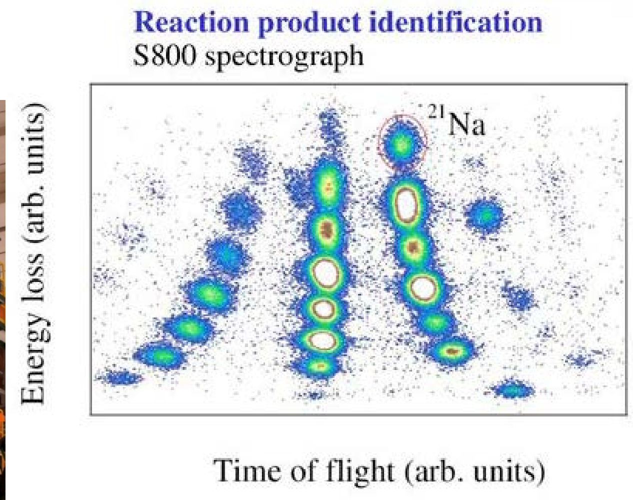




Magnetic Spectrometers

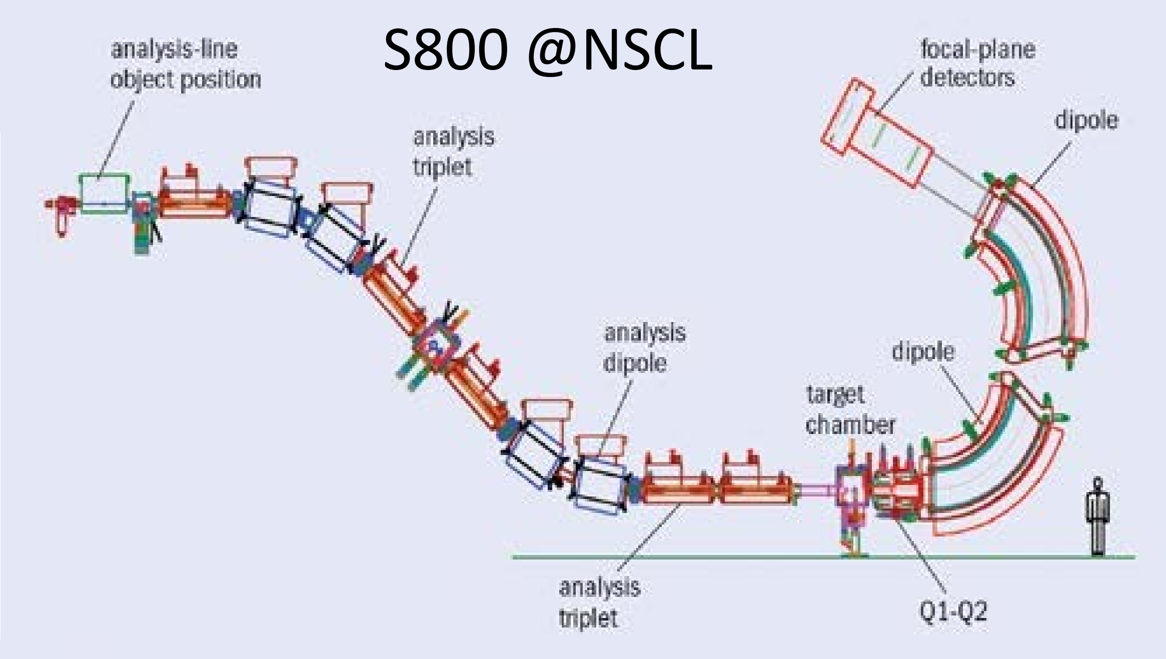


S800 @NSCL

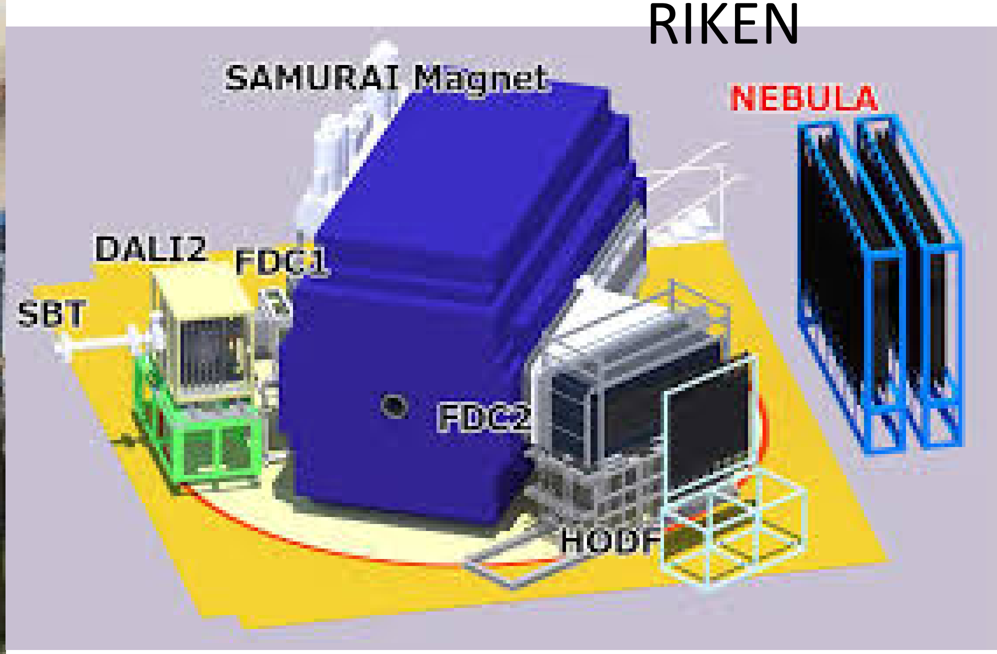


Reaction product identification
S800 spectrograph

S800 @NSCL

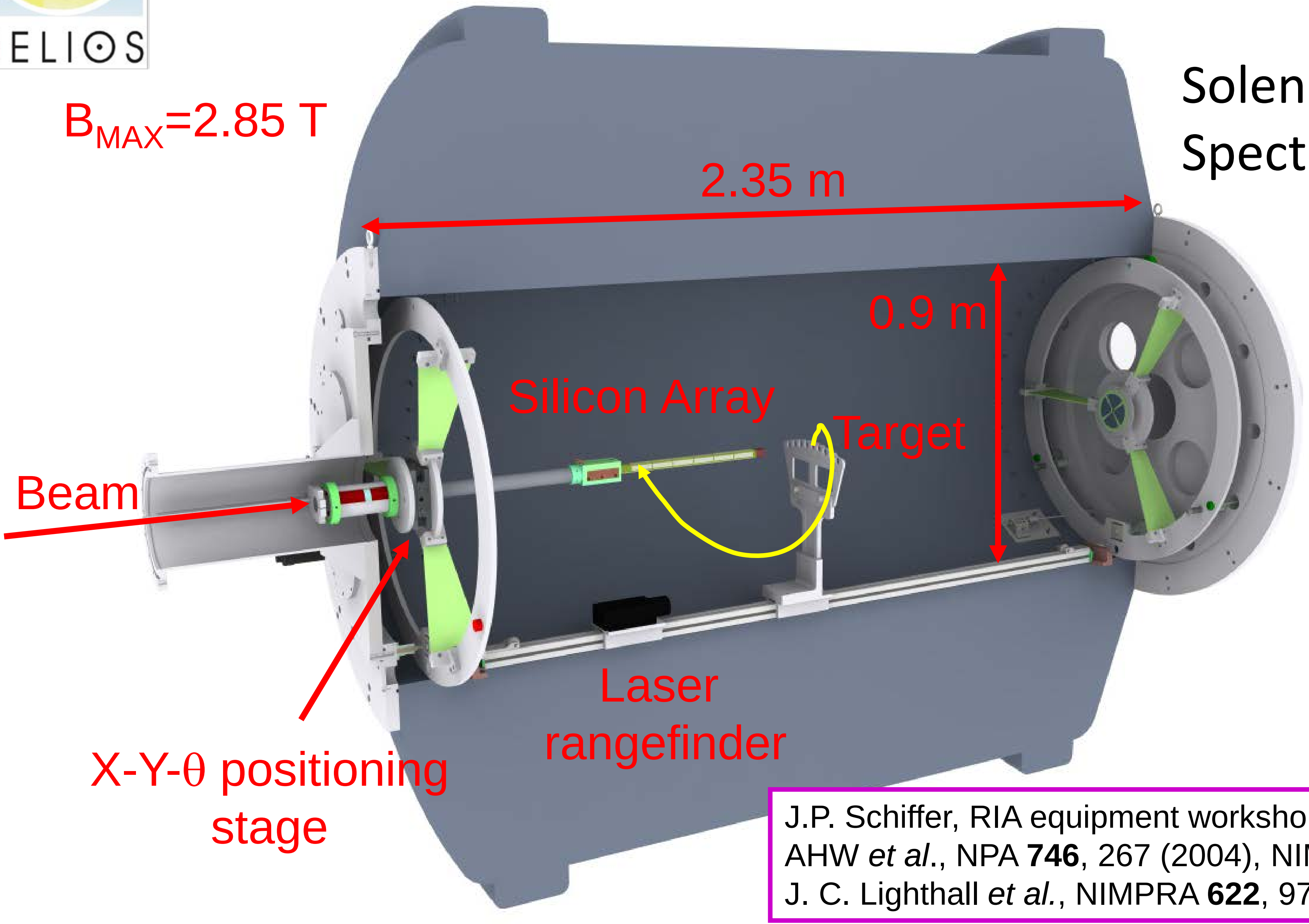


SAMURAI @ RIKEN



SAMURAI @ RIKEN

HELIcal Orbit Spectrometer -HELIOS

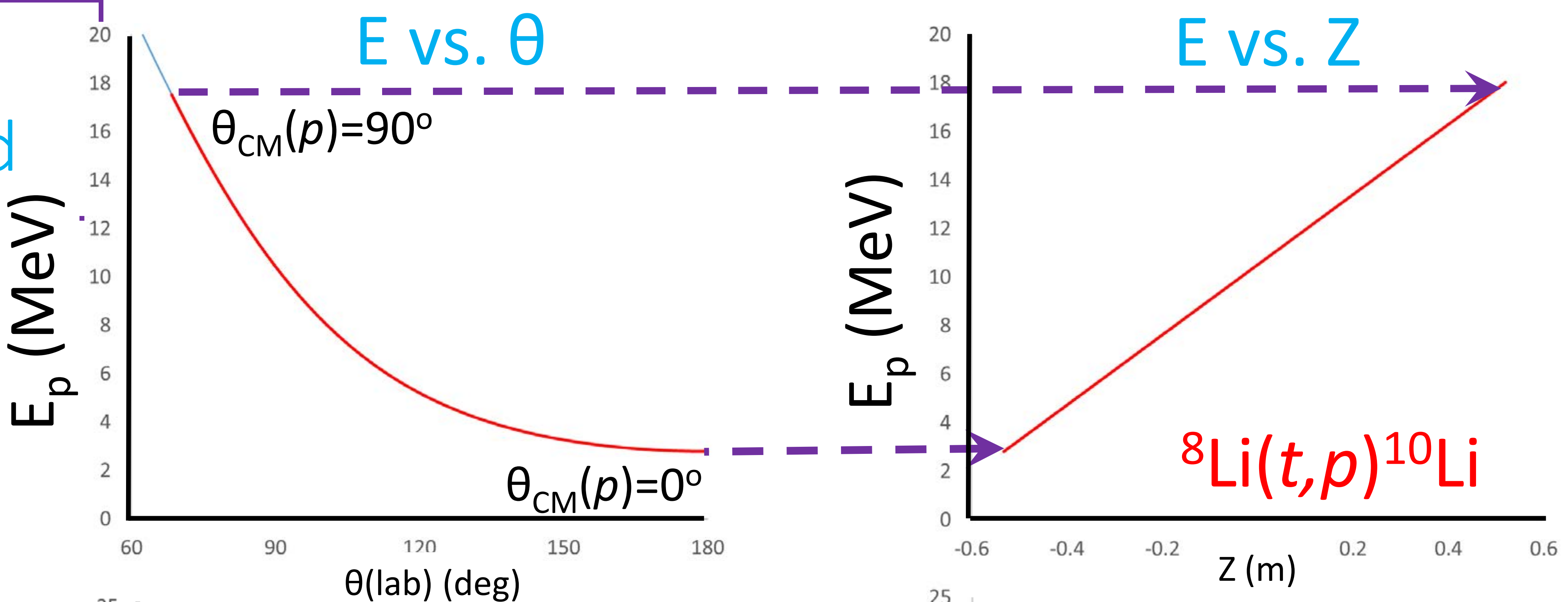


Solenoid Spectrometer

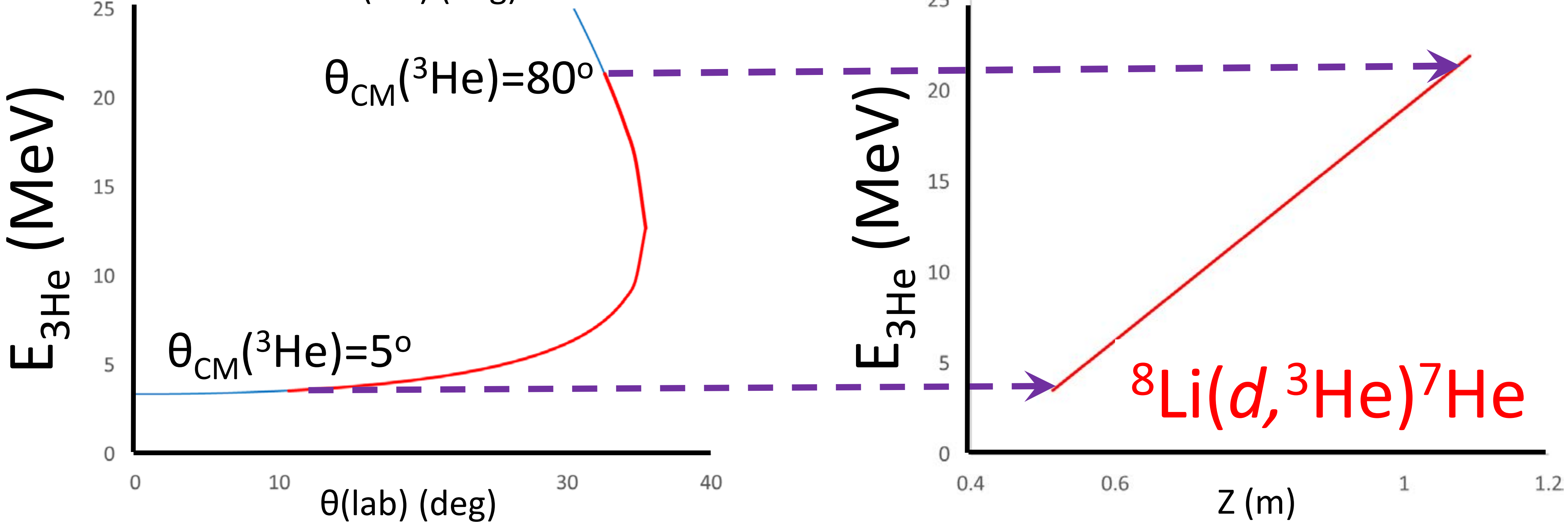
J.P. Schiffer, RIA equipment workshop 1999
AHW *et al*., NPA **746**, 267 (2004), NIMPRA **580**, 1290 (2007)
J. C. Lighthall *et al.*, NIMPRA **622**, 97 (2010)

Kinematics in a solenoid

“backward”

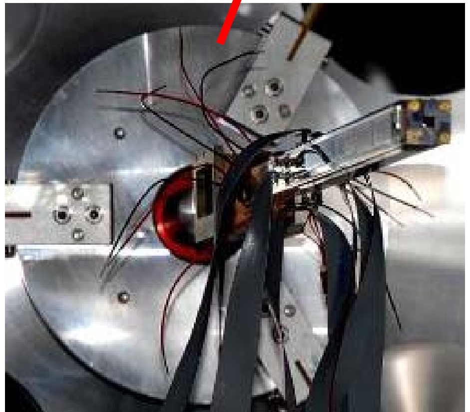


“forward”

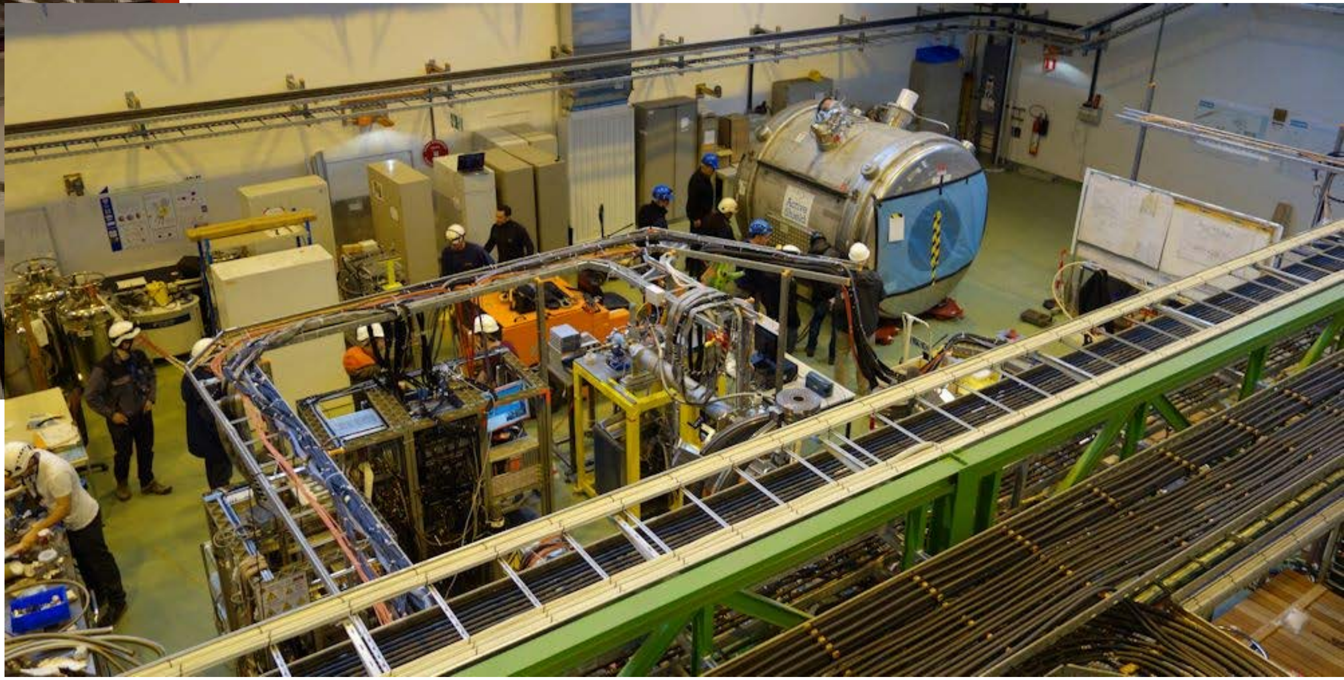


Solenoid Spectrometers in Action

HELIOS at ATLAS (ANL) (2008)



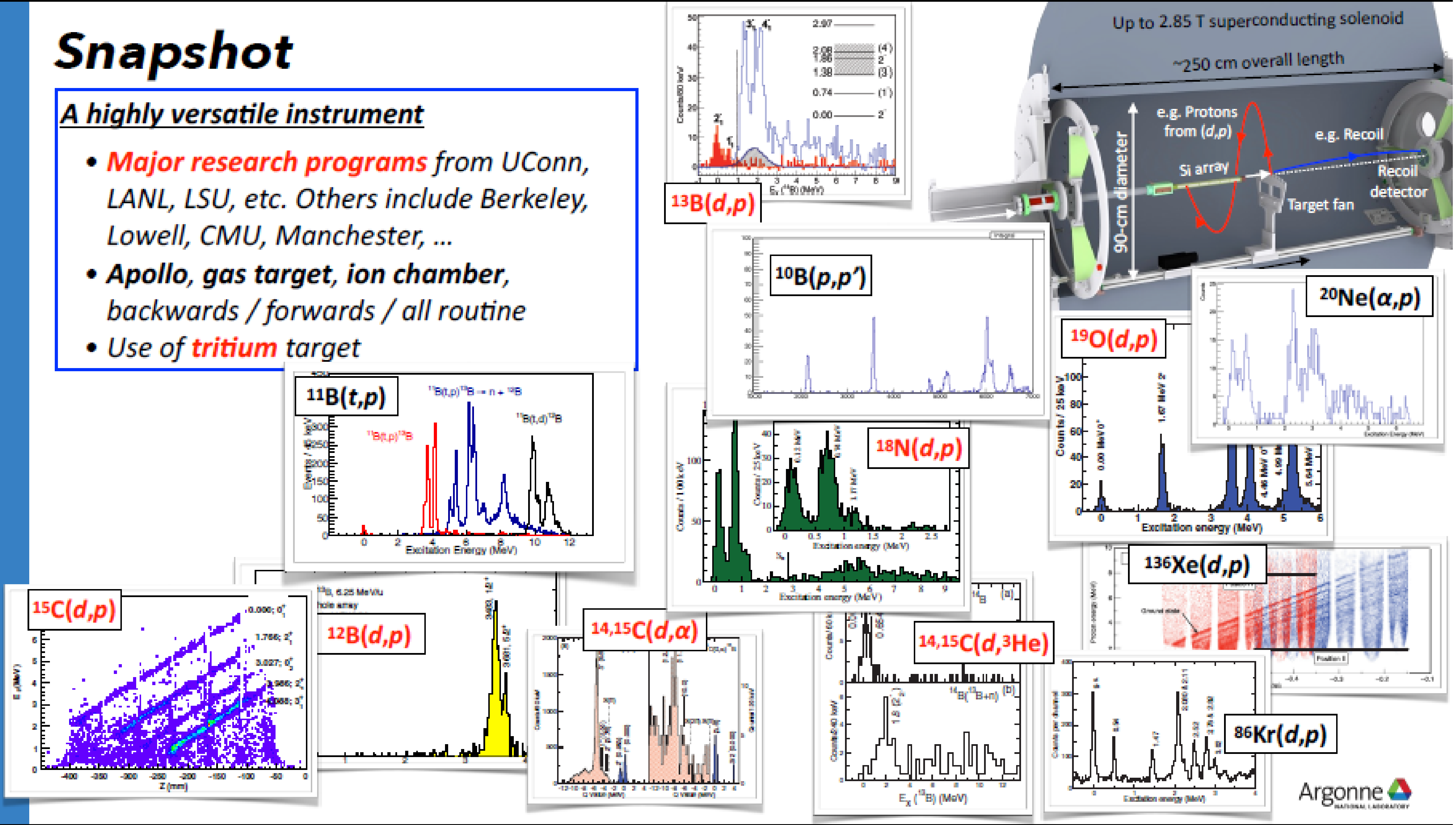
and ISS at CERN-
HIE - ISOLDE (2018)



Snapshot

A highly versatile instrument

- *Major research programs from UConn, LANL, LSU, etc. Others include Berkeley, Lowell, CMU, Manchester, …*
- ***Apollo, gas target, ion chamber,*** *backwards / forwards / all routine*
- *Use of* ***tritium*** *target*



Argonne

Preaching and Conclusion

- Remember history – basic understanding embedded in early work, often obscured by nuance and details accumulated over the years
- Put results in context – nuclear physics progresses by the assembly of a puzzle with many parts, individual measurements are pieces but don’t lose sight of the Big Picture
- Technical advances can help provide better data, but equally important are imagination and insight in the design of experiments and the interpretation of data.
- There is a *lot* that I did not cover. Take this and run with it!