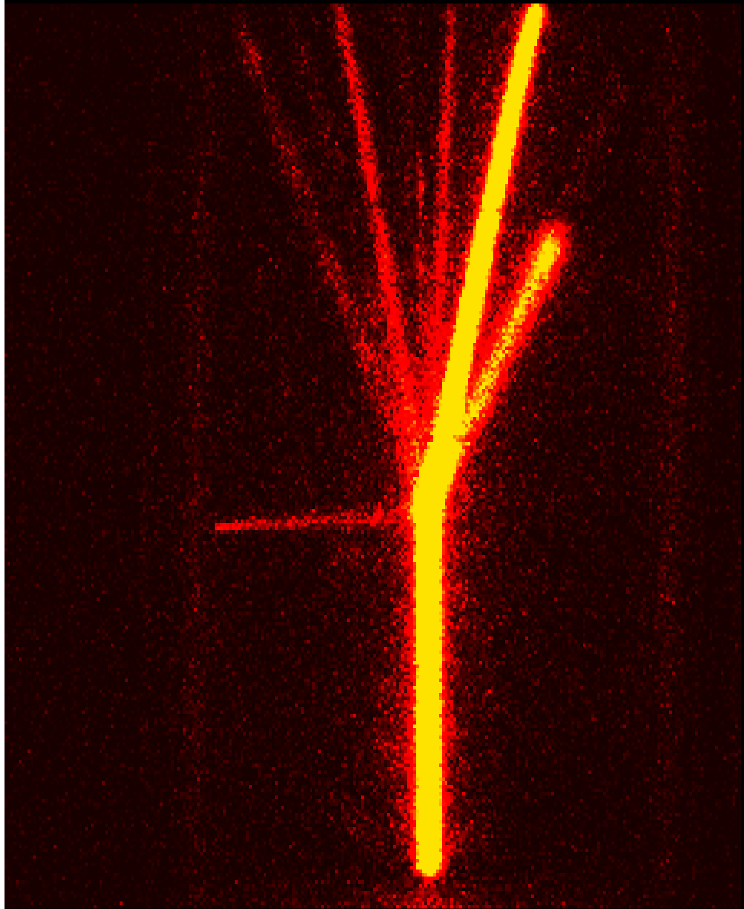


Ode to Projectile Fragmentation

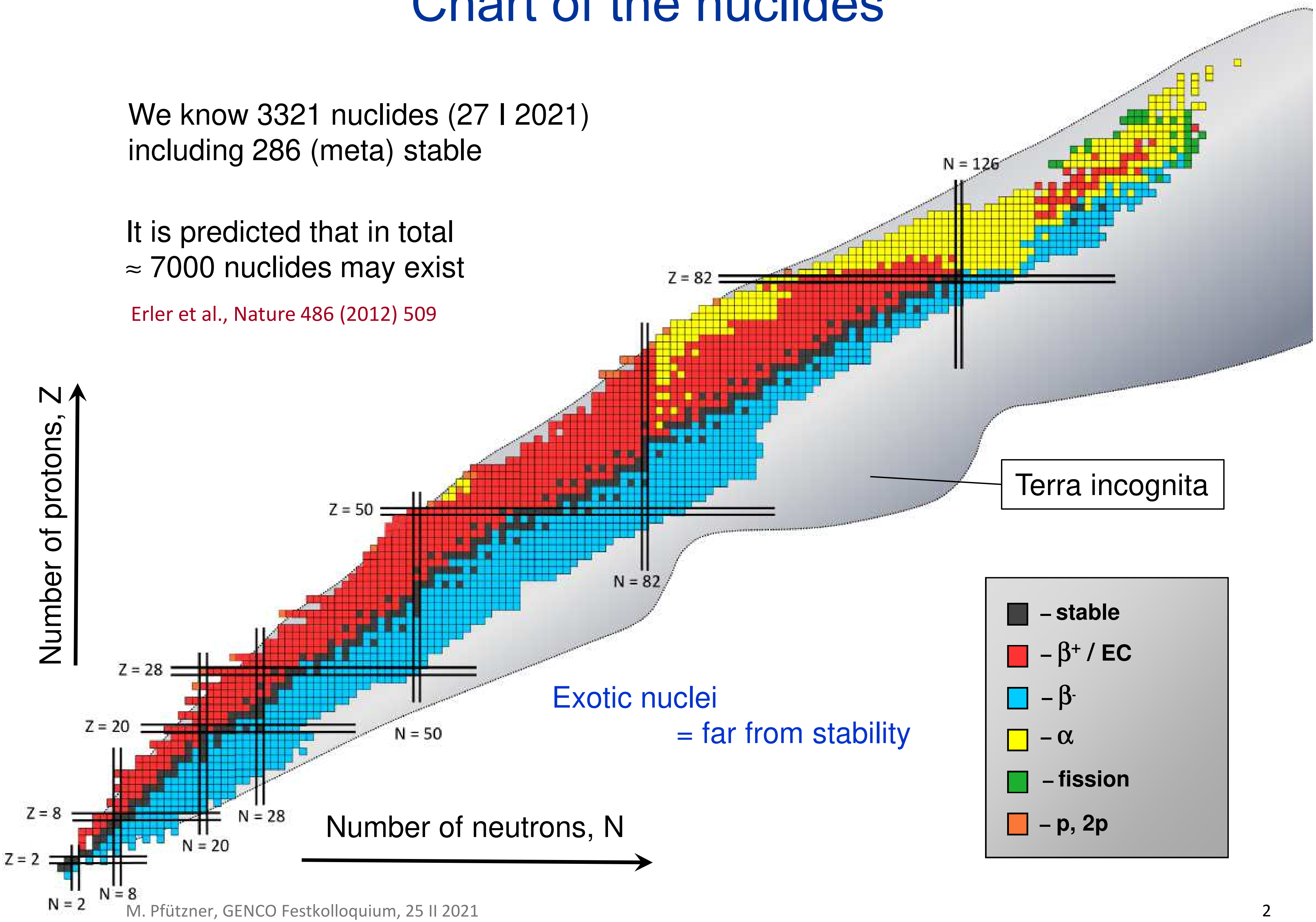
Marek Pfützner
University of Warsaw

Chart of the nuclides

We know 3321 nuclides (27 I 2021)
including 286 (meta) stable

It is predicted that in total
≈ 7000 nuclides may exist

Erler et al., Nature 486 (2012) 509

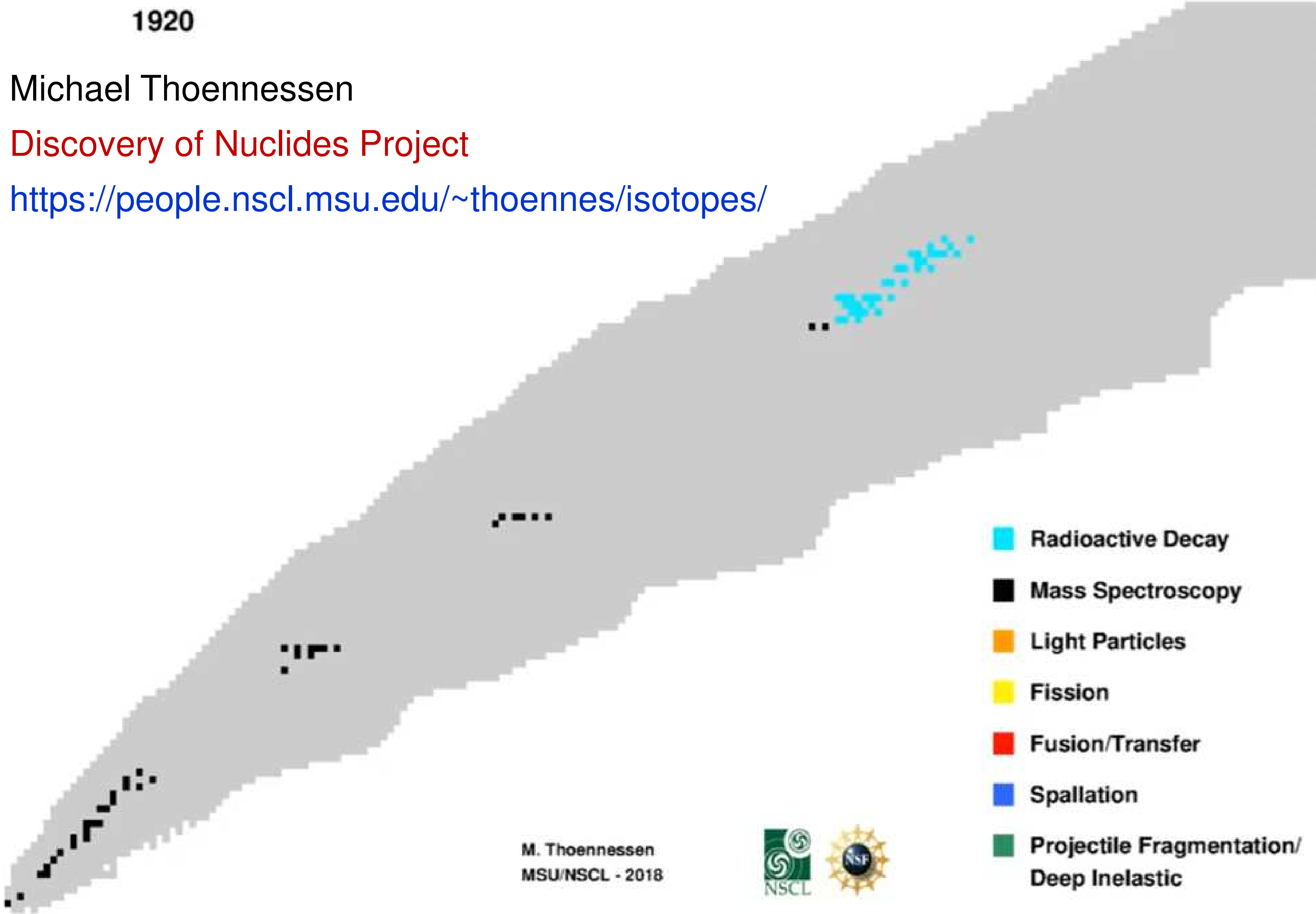


History of the chart

Michael Thoennessen

Discovery of Nuclides Project

https://people.nscl.msu.edu/~thoennes/isotopes/

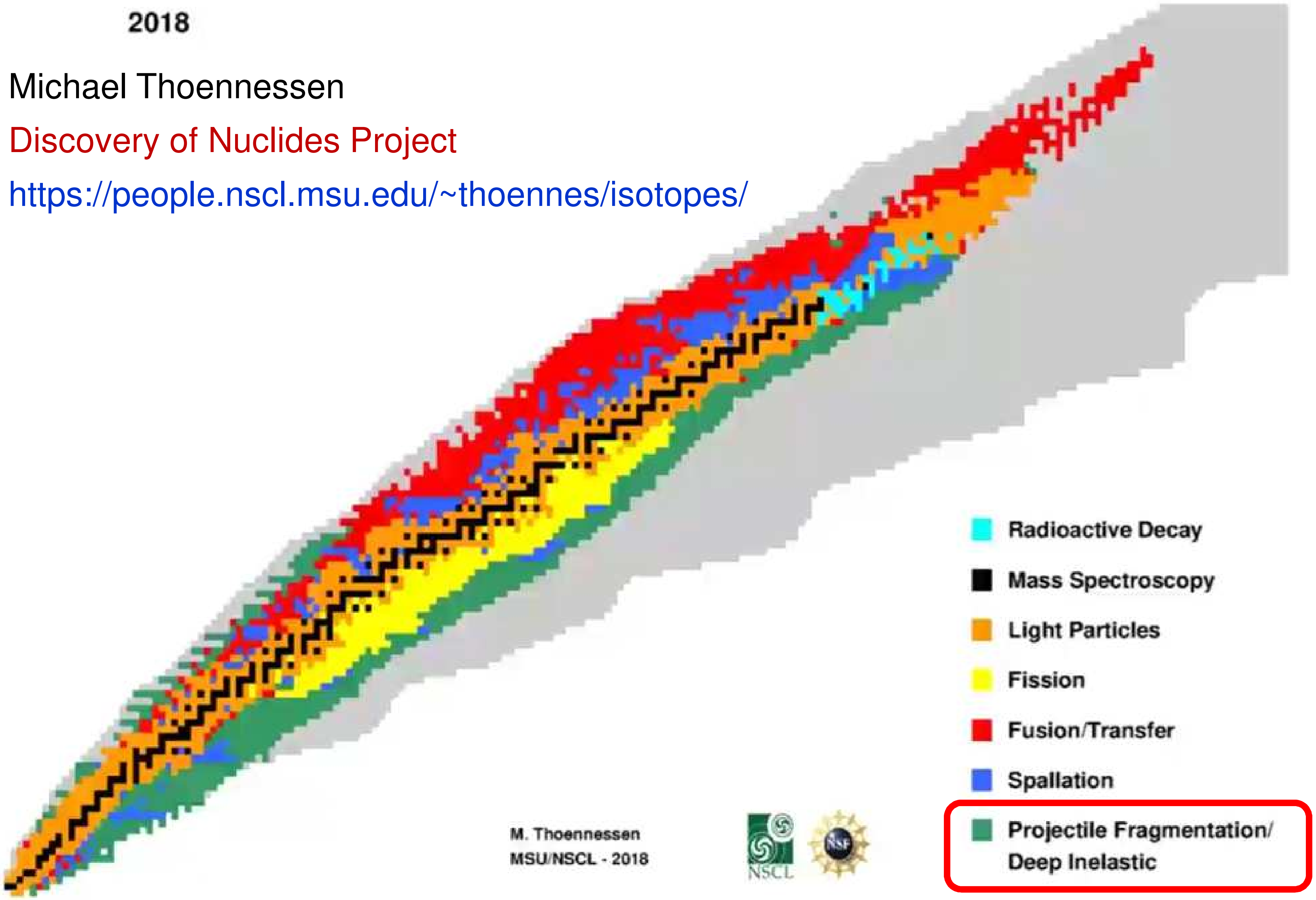


History of the chart

Michael Thoennessen

Discovery of Nuclides Project

https://people.nscl.msu.edu/~thoennes/isotopes/



Projectile Fragmentation

Pioneered at Bevalac (LBNL, Berkeley)

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

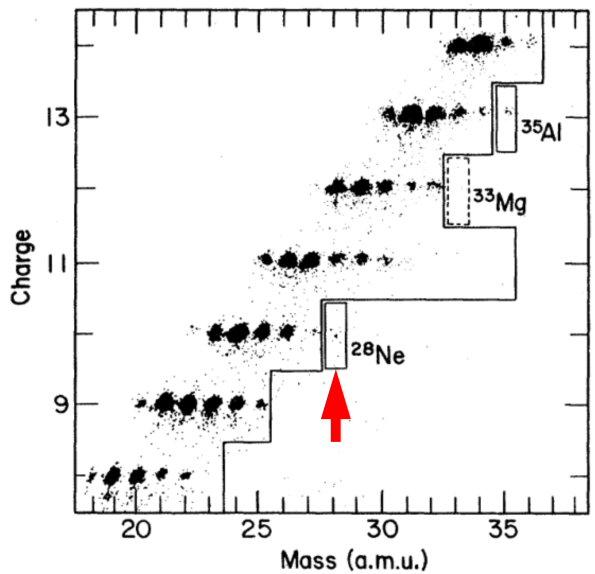
T. J. M. Symons, Y. P. Viyogi,[a] G. D. Westfall, P. Doll,[b] D. E. Greiner, H. Faraggi,[c] P. J. Lindstrom, and D. K. Scott
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

and

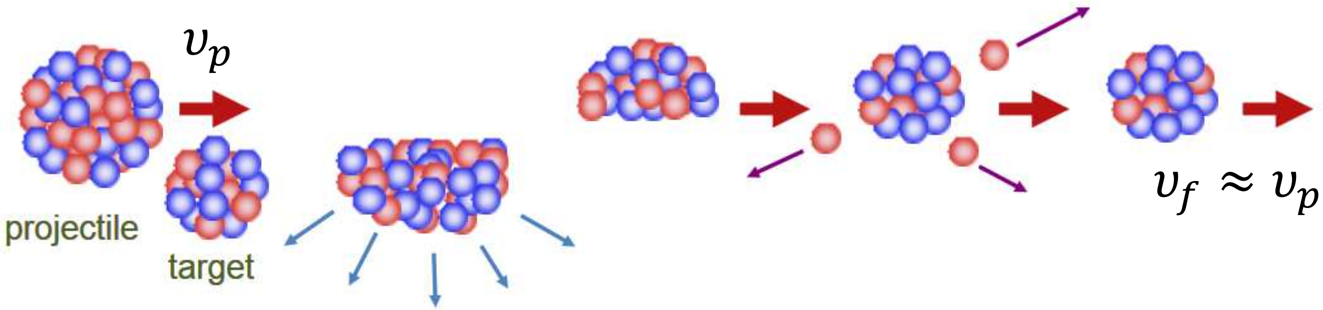
H. J. Crawford and C. McParland
Space Sciences Laboratory, University of California, Berkeley, California 94720

(Received 1 November 1978)

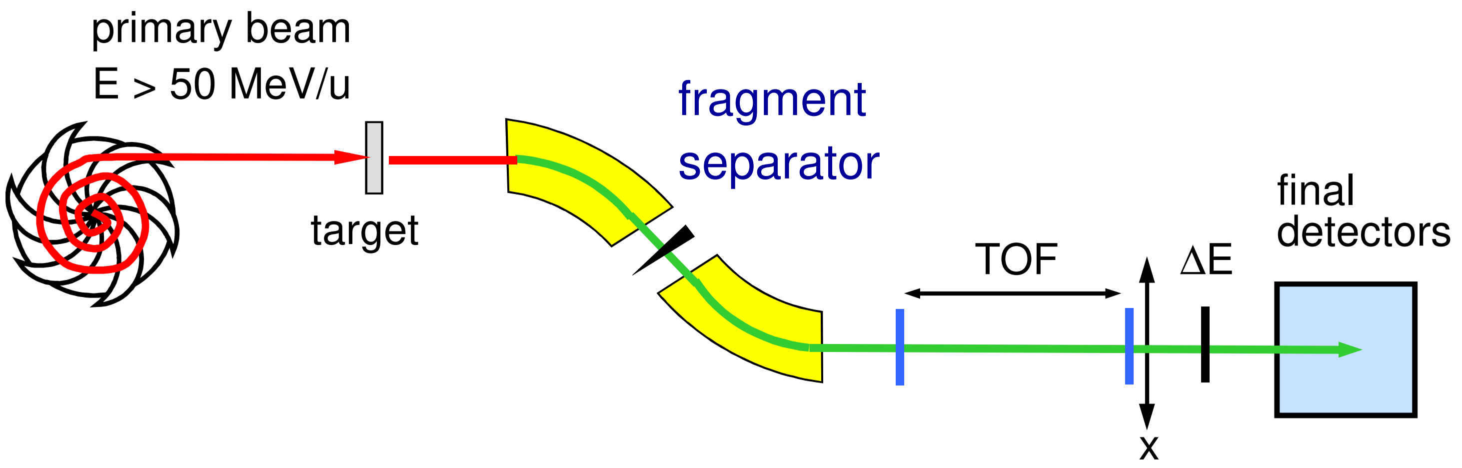
Yields of projectile fragments have been measured at 0° for the reaction of 205-MeV/nucleon ^{40}Ar ions on an 860-mg-cm^{-2} carbon target. Mass resolution was achieved using a combination of magnetic analysis and energy-loss measurements. The isotopes ^{28}Ne and ^{35}Al have been observed for the first time.



Projectile energy/nucleon larger than Fermi energy (> 50 MeV/u)



Projectile Fragmentation



Key advantages

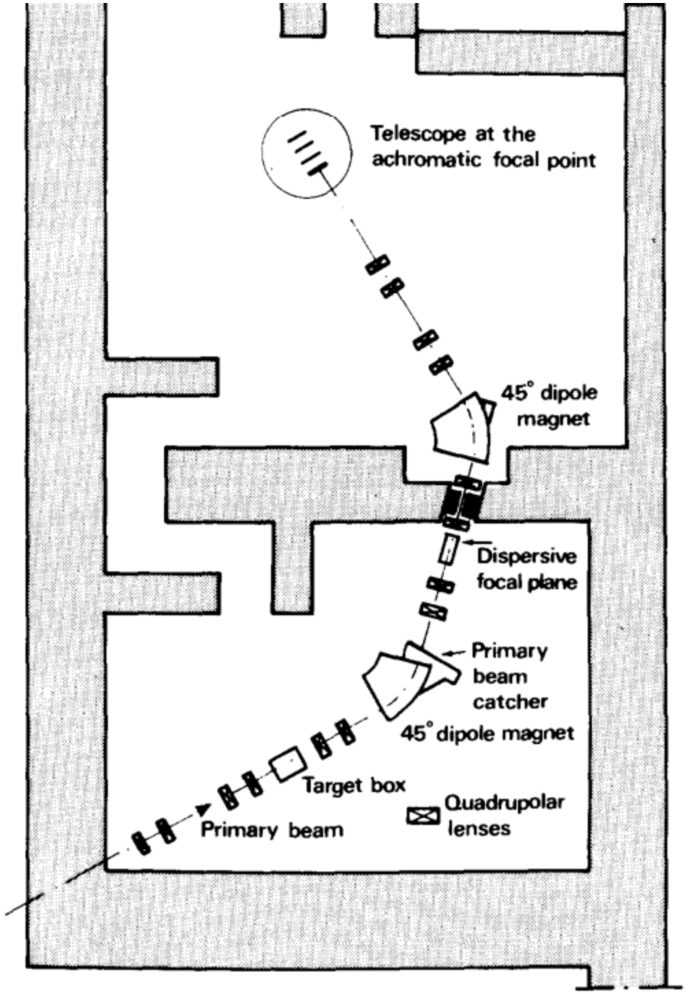
- thick targets (large yields)
- chemical independence
- full identification of single ions in-flight
- fast transport (μs)
- implantation into thick detectors
- ready for secondary reactions
- cocktail beams

However

- large and expensive facility
- low intensity of heavy projectiles
- large range straggling
- bad ion-optical properties of secondary beams
- products are lighter than projectiles

Fragment Separators

LISE at GANIL - the first fragment separator dedicated to production of exotic nuclei



Primary beams up to U, 30-100 MeV/u

Volume 150B, number 1,2,3 PHYSICS LETTERS 3 January 1985

➤ Discovery of ^{23}N, ^{29}Ne, and ^{30}Ne

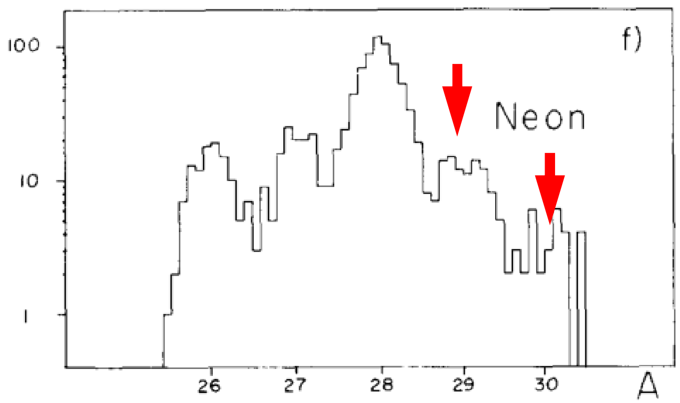
PRODUCTION OF NEUTRON-RICH NUCLEI AT THE LIMITS OF PARTICLE STABILITY BY FRAGMENTATION OF 44 MeV/*u* ^{40}Ar PROJECTILES ☆

M. LANGEVIN, E. QUINIOU, M. BERNAS, J. GALIN, J.C. JACMART, F. NAULIN, F. POUGHEON
Institut de Physique Nucléaire, BP 1, 91406 Orsay, France

and

R. ANNE, C. DÉTRAZ, D. GUERREAU, D. GUILLEMAUD-MUELLER and A.C. MUELLER
GANIL, BP 5027, 14021 Caen Cedex, France

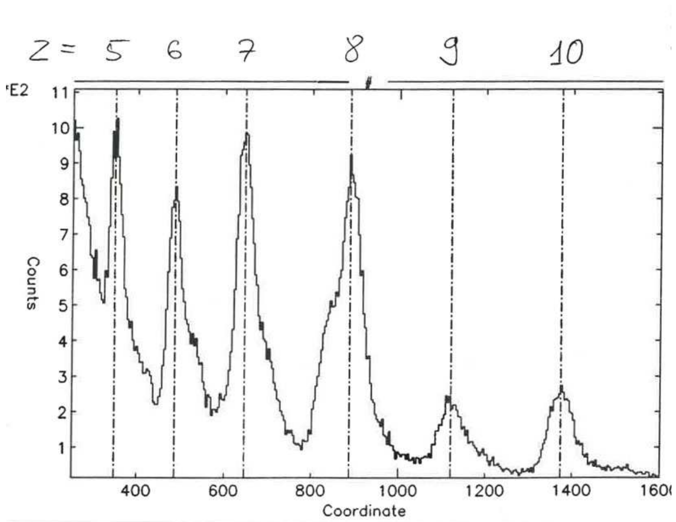
Received 15 October 1984



Fragment Separators

➤ Boom on fragment separators started soon

- RIPS at RIKEN (1990) 135 MeV/u
- A1200 at NSCL/MSU (1991) 50-200 MeV/u
- FRS at GSI (1991) 0.5 - 2 GeV/u
- Acculinna at FLNR (1996) 50 MeV/u
- RIBLL at HIRFL (1998) 60 MeV/u
- Fribs at LNS (2001) 50 MeV/u



FRS, Run 1: ^{20}Ne @ 150 MeV/u, 7 Feb 1990

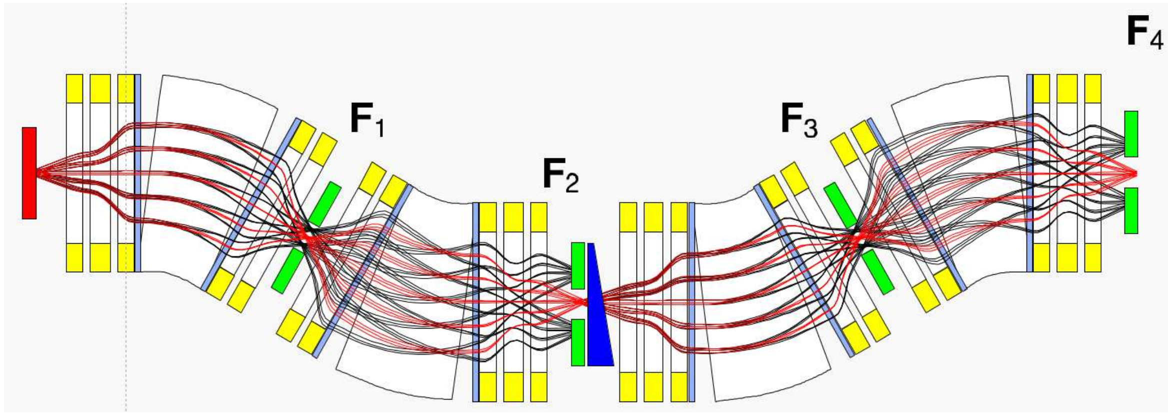
➤ Second generation

- A1900 at NSCL/MSU (2003) 50-200 MeV/u
- BigRIPS at RIKEN (2007) 350 MeV/u

➤ Third generation

- ARIS at FRIB 400 MeV/u
- SuperFRS at FAIR 1.5 GeV/u

....



Nuclear halo

Spectacular result from Bevalac

LBL: ^{11}B and ^{20}Ne @ 0.8 GeV/u + Be

- Interaction cross sections on various targets
  - → determination of rms radii
  - → discovery of large radius of ^{11}Li

VOLUME 55, NUMBER 24 PHYSICAL REVIEW LETTERS 9 DECEMBER 1985

Measurements of Interaction Cross Sections and Nuclear Radii in the Light *p*-Shell Region

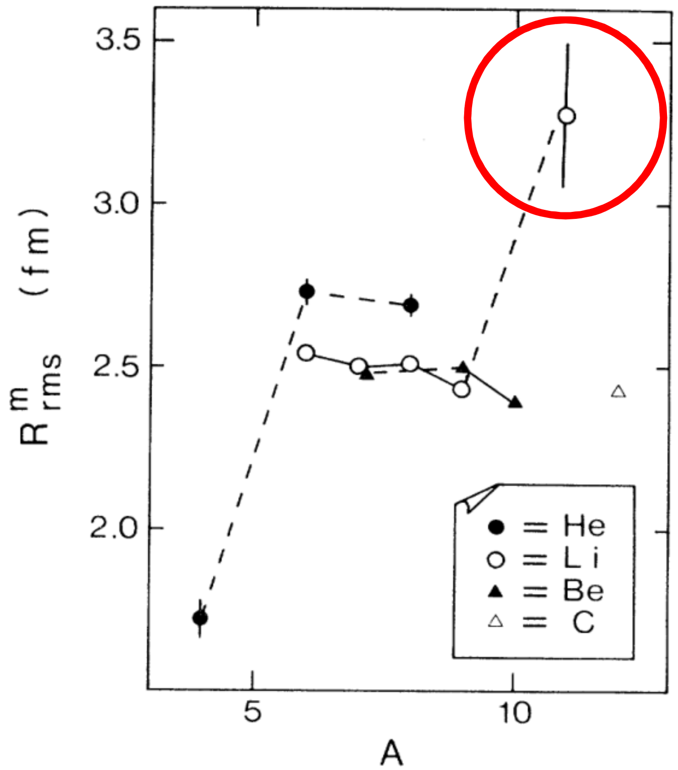
I. Tanihata,[a] H. Hamagaki, O. Hashimoto, Y. Shida, and N. Yoshikawa
Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan

K. Sugimoto,[b] O. Yamakawa, and T. Kobayashi
Nuclear Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

and

N. Takahashi
College of General Education, Osaka University, Toyonaka, Osaka 560, Japan
(Received 11 July 1985; revised manuscript received 17 September 1985)

Interaction cross sections (σ_I) for all known Li isotopes (^{6}Li–^{11}Li) and ^{7}Be, ^{9}Be, and ^{10}Be on targets Be, C, and Al have been measured at 790 MeV/nucleon. Root mean square radii of these isotopes as well as He isotopes have been deduced from the σ_I by a Glauber-type calculation. Appreciable differences of radii among isobars (^{6}He-^{6}Li, ^{8}He-^{8}Li, and ^{9}Li-^{9}Be) have been observed for the first time. The nucleus ^{11}Li showed a remarkably large radius suggesting a large deformation or a long tail in the matter distribution.



- Opened new fields of research
  - → studies of nuclear halos
  - → systematic measurements of nuclear interactions

New isotopes

Massive production of new isotopes with ^{238}U beam (projectile fission) @ GSI

GSI: ^{238}U@750 MeV/u + Pb → 53 new isotopes

N·H
ELSEVIER
30 June 1994
PHYSICS LETTERS B
Physics Letters B 331 (1994) 19–24

Projectile fission at relativistic velocities: a novel and powerful source of neutron-rich isotopes well suited for in-flight isotopic separation

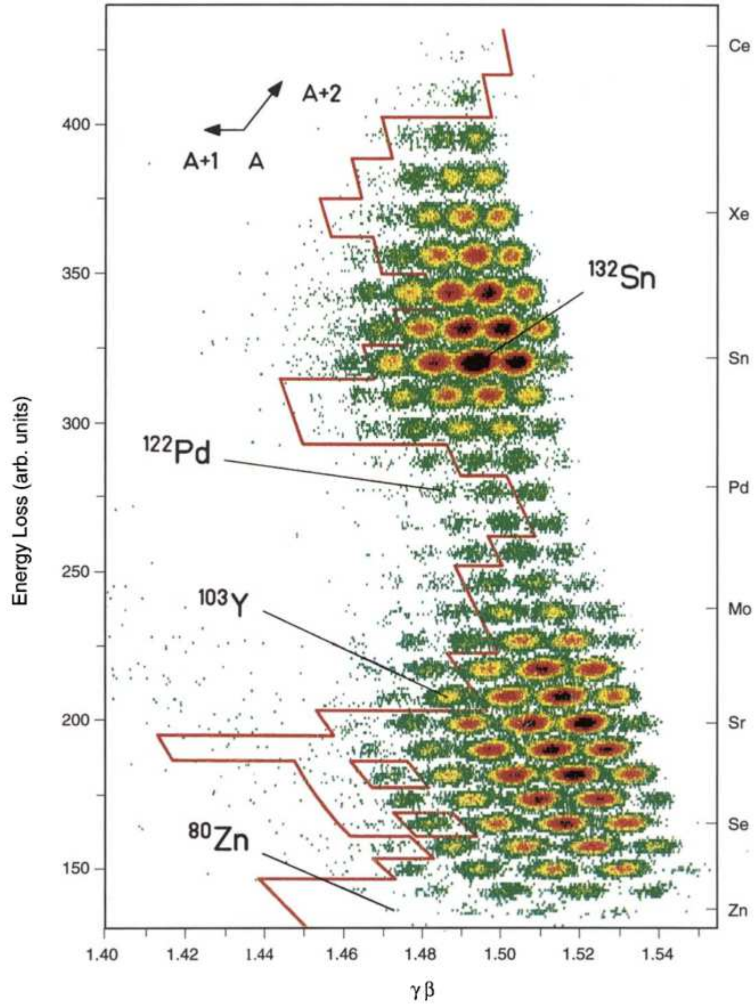
M. Bernas [a], S. Czajkowski [b], P. Armbruster [b], H. Geissel [b], Ph. Dessagne [c], C. Donzaud [a], H-R. Faust [d], E. Hanelt [e], A. Heinz [e], M. Hesse [d], C. Kozhuharov [b], Ch. Miehe [c], G. Münzenberg [b], M. Pfützner [b], C. Röhl [e], K.-H. Schmidt [b], W. Schwab [b], C. Stéphan [a], K. Sümmerer [b], L. Tassan-Got [a], B. Voss [e]

GSI: ^{238}U@750 MeV/u + Be → 58 new isotopes

N·H
ELSEVIER
11 December 1997
PHYSICS LETTERS B
Physics Letters B 415 (1997) 111–116

Discovery and cross-section measurement of 58 new fission products in projectile-fission of 750 · A MeV ^{238}U [1]

M. Bernas [a], C. Engelmann [b], P. Armbruster [b], S. Czajkowski [c], F. Ameil [a], C. Böckstiegel [f], Ph. Dessagne [d], C. Donzaud [a], H. Geissel [b], A. Heinz [b], Z. Janas [e], C. Kozhuharov [b], Ch. Miehé [d], G. Münzenberg [b], M. Pfützner [e], W. Schwab [b], C. Stéphan [a], K. Sümmerer [b], L. Tassan-Got [a], B. Voss [f]



New isotopes

The record: the largest number of new isotopes in a sigle paper!

GSI: ^{238}U @1 GeV/u + Be → 60 new isotopes

Physics Letters B 717 (2012) 371–375

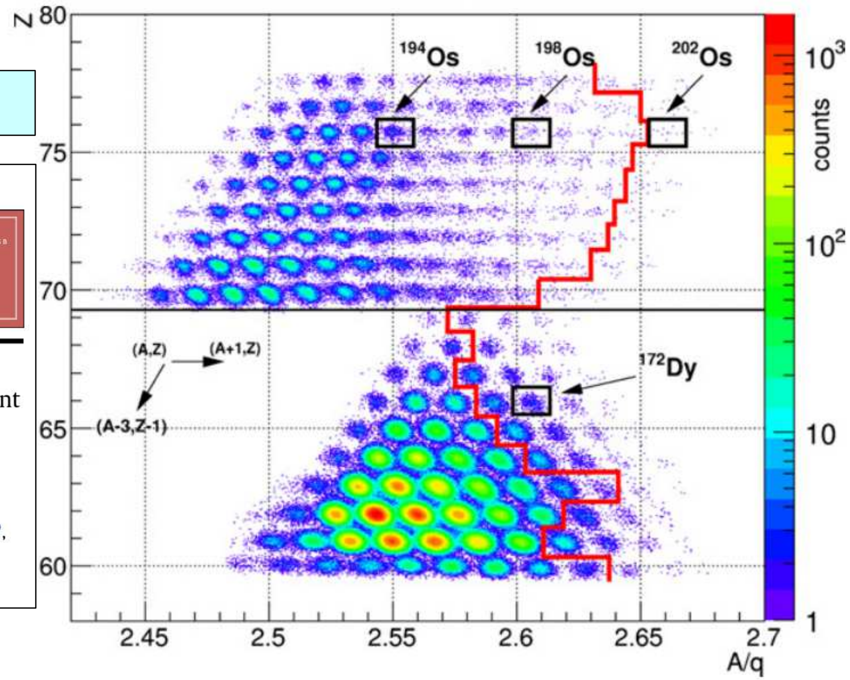
Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Discovery and cross-section measurement of neutron-rich isotopes in the element range from neodymium to platinum with the FRS

J. Kurcewicz[a,*], F. Farinon[a,b,1], H. Geissel[a,b], S. Pietri[a], C. Nociforo[a], A. Prochazka[a,b], H. Weick[a], J.S. Winfield[a], A. Estradé[a,c], P.R.P. Allegro[d], A. Bail[e], G. Bélier[e], J. Benlliure[f], G. Benzoni[g], M. Bunce[h], M. Bowry[h], R. Caballero-Folch[i], I. Dillmann[a,b], A. Evdokimov[a,b], J. Gerl[a], A. Gottardo[j], E. Gregor[a], R. Janik[k], A. Kelić-Heil[a], R. Knöbel[a], T. Kubo[l], Yu.A. Litvinov[a,m], E. Merchan[a,n], I. Mukha[a], F. Naqvi[a,o], M. Pfützner[a,p], M. Pomorski[p], Zs. Podolyák[h], P.H. Regan[h], B. Riese[a,b], M.V. Ricciardi[a], C. Scheidenberger[a,b], B. Sitar[k], P. Spiller[a], J. Stadlmann[a], P. Strmen[k], B. Sun[b,q], I. Szarka[k], J. Taïeb[e], S. Terashima[a,l], J.J. Valiente-Dobón[j], M. Winkler[a], Ph. Woods[r]

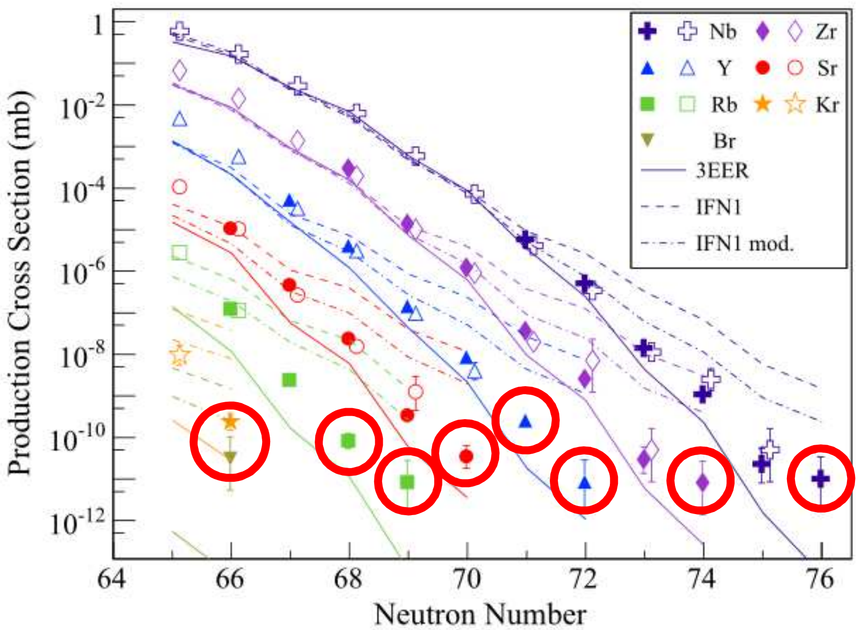


Uranium - the gold of GSI

New isotopes

The hunt continues!

RIKEN: ^{238}U @345 MeV/u + Be → ^{108}Y



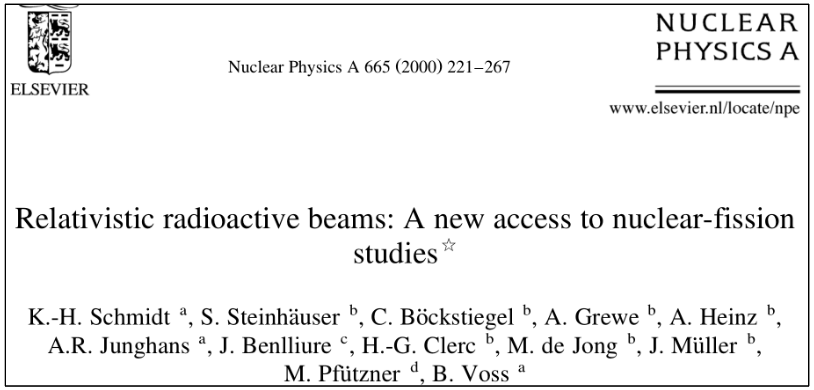
Sumikama et al., Phys. Rev. C 103 (2021) 014614

9 new istotopes published 27 Jan 2021
cross sections down to 10 fb

Fission

Fission properties of short-lived radioactive nuclei

GSI: ^{238}U @1 GeV/u + Be ➔ 70 fissile nuclides ➔ Pb ➔ fission fragments


ELSEVIER

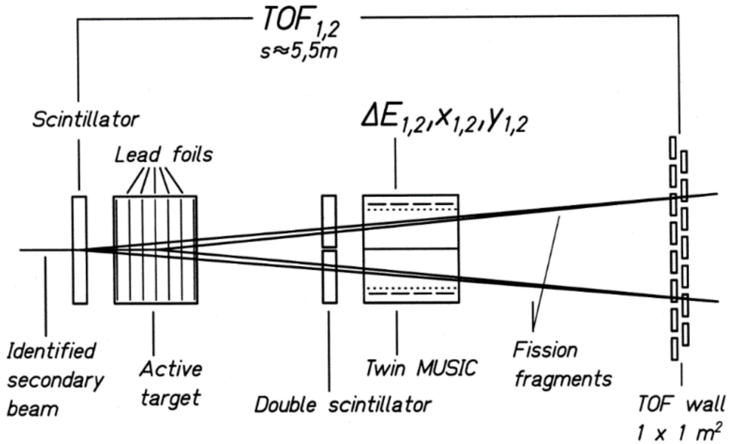
Nuclear Physics A 665 (2000) 221–267

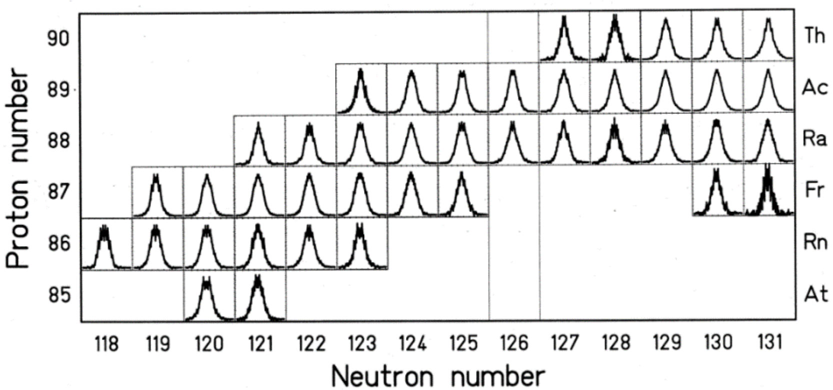
NUCLEAR PHYSICS A

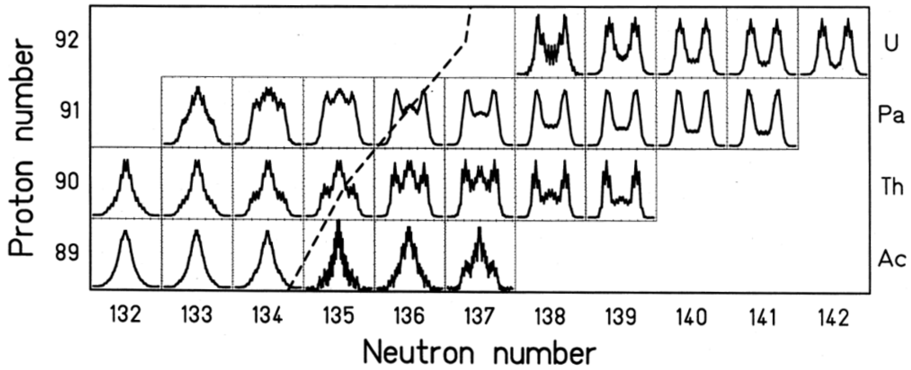
www.elsevier.nl/locate/npe

Relativistic radioactive beams: A new access to nuclear-fission studies ☆

K.-H. Schmidt [a], S. Steinhäuser [b], C. Böckstiegel [b], A. Grewe [b], A. Heinz [b], A.R. Junghans [a], J. Benlliure [c], H.-G. Clerc [b], M. de Jong [b], J. Müller [b], M. Pfützner [d], B. Voss [a]







Doubly-magic milestone - ^{100}Sn

Race for the discovery of exotic doubly-magic ^{100}Sn

GSI: ^{124}Xe @1 GeV/u + Be → ^{100}Sn

Short note

Production and identification of ^{100}Sn

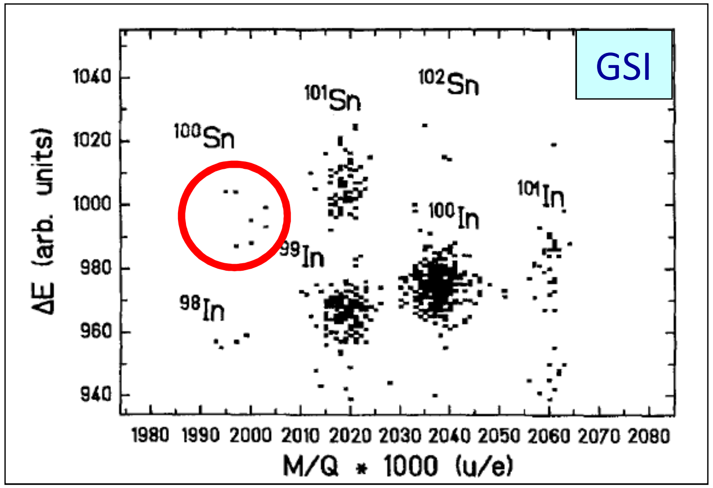
R. Schneider[1], J. Friese[1], J. Reinhold[1], K. Zeitelhack[1], T. Faestermann[1], R. Gernhäuser[1], H. Gilg[1], F. Heine[1], J. Homolka[1], P. Kienle[1], H.J. Körner[1], H. Geissel[2], G. Münzenberg[2], K. Sümmerer[2]

[1] Technische Universität München, Germany
[2] Gesellschaft für Schwerionenforschung mbH Darmstadt, Postfach 110552, D-64220 Darmstadt, Germany

Received: 27 April 1994

7 events in 11 days

Schneider et al., Z. Phys. A 348 (1994) 241



GANIL: ^{112}Sn @63 MeV/u + Ni → ^{100}Sn

Identification of the doubly-magic nucleus ^{100}Sn in the reaction $^{112}Sn + {}^{nat}Ni$ at 63 MeV/nucleon

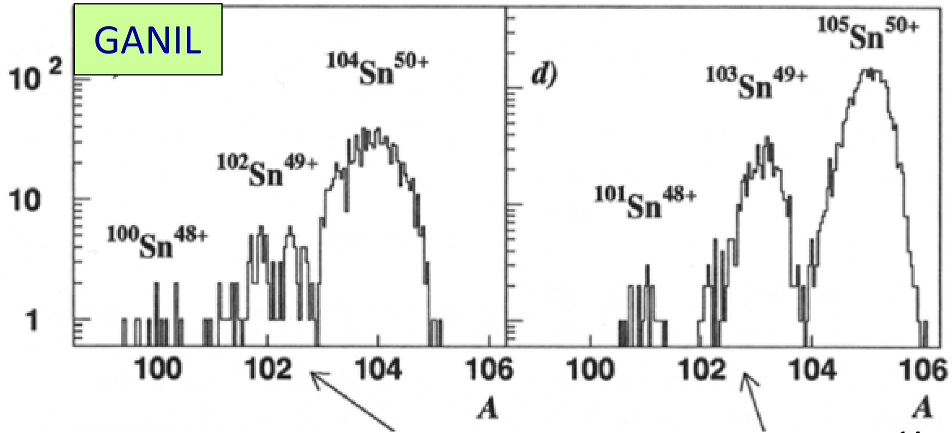
M. Lewitowicz[a], R. Anne[a], G. Auger[a], D. Bazin[a], C. Borcea[b], V. Borrel[c], J.M. Corre[a], T. Dörfler[d], A. Fomichov[e], R. Grzywacz[f], D. Guillemaud-Mueller[c], R. Hue[a], M. Huyse[g], Z. Janas[h,1], H. Keller[h], S. Lukyanov[e], A.C. Mueller[c], Yu. Penionzhkevich[e], M. Pfützner[f], F. Pougheon[c], K. Rykaczewski[f], M.G. Saint-Laurent[a], K. Schmidt[h], W.D. Schmidt-Ott[d], O. Sorlin[c], J. Szerypo[g,1], O. Tarasov[e], J. Wauters[g], J. Żylicz[f]

[a] *GANIL, BP 5027, 14021 Caen Cedex, France*
[b] *IAP, Bucharest-Magurele P.O.Box MG6, Romania*
[c] *IPN, 91406 Orsay Cedex, France*
[d] *University of Göttingen, D-3400 Göttingen, Germany*
[e] *FLNR, JINR 141980 Dubna, Moscow region, Russia*
[f] *IFD, Warsaw University, 00681 Wars*
[g] *IKS KU, B-3001 Leuven, Belg*
[h] *GSI, Postfach 110552, D-64220 Darms*

Received 7 June 1994

11 events in 2 days

M Lewitowicz et al. / Physics Letters B 332 (1994) 20–24

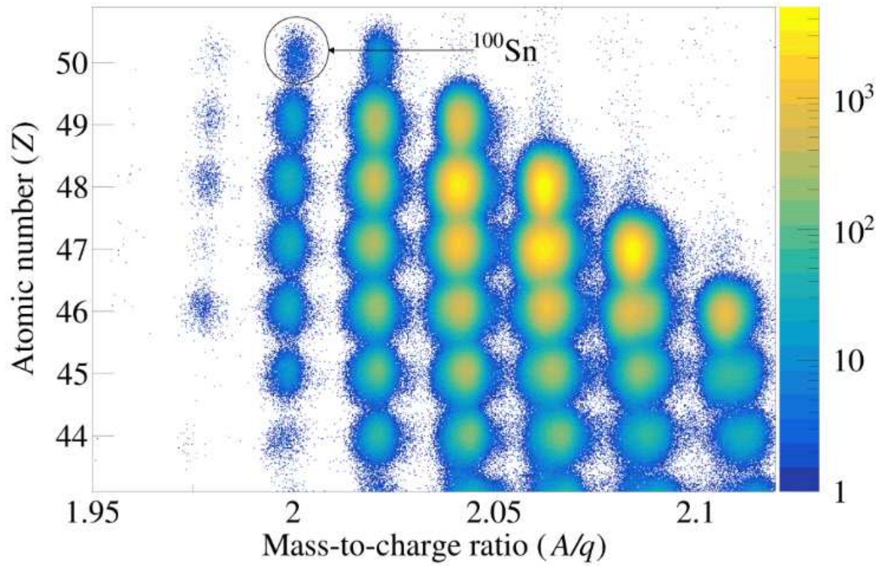


Doubly-magic milestone - ^{100}Sn

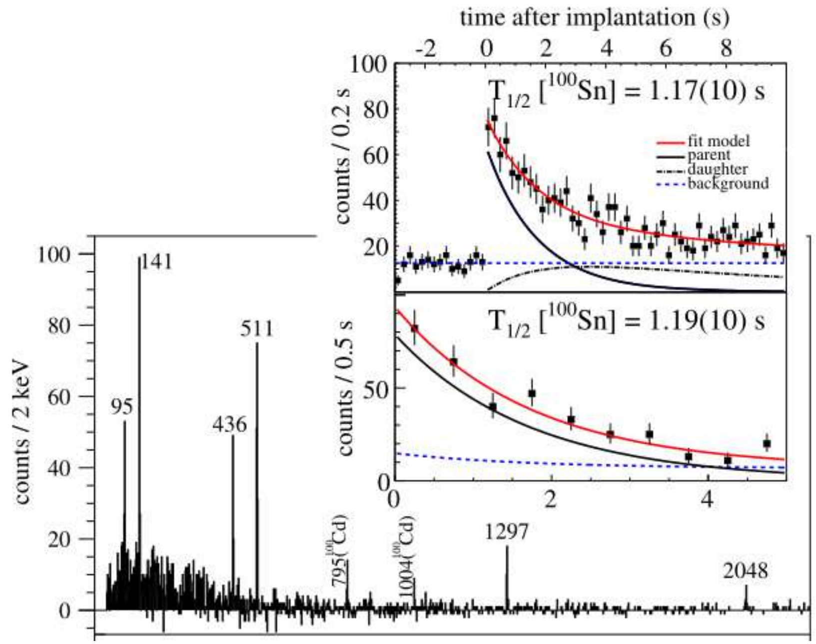
Present state-of-the-art

RIKEN: ^{124}Xe @345 MeV/u + Be → ^{100}Sn

2500 events in 8 days



Park et al., Phys. Rev. C 99 (2019) 034313



Lubos et al., Phys. Rev. Lett. 122 (2019) 222502

Doubly-magic milestone - ^{78}Ni

Discovery of another exotic doubly-magic nucleus among fission fragments

GSI: ^{238}U@750 MeV/u + Be → ^{78}Ni

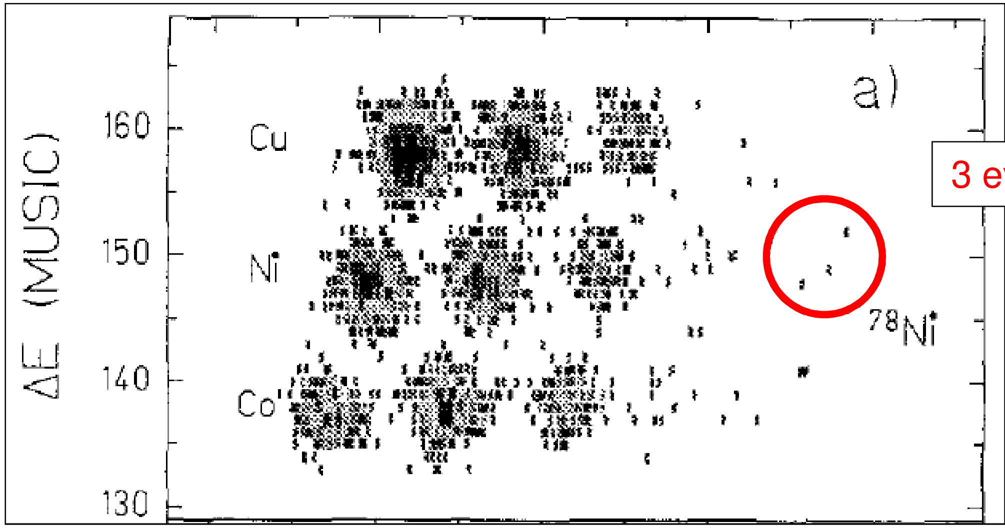
Z. Phys. A 352, 351–352 (1995)

ZEITSCHRIFT FÜR PHYSIK A

Short note

Production and identification of heavy Ni isotopes: evidence for the doubly magic nucleus $^{78}_{28}$Ni

Ch. Engelmann[1], F. Ameil[1,2], P. Armbruster[1], M. Bernas[2], S. Czajkowski[3], Ph. Dessagne[4], C. Donzaud[1,2], H. Geissel[1], A. Heinz[1], Z. Janas[5], C. Kozhuharov[1], Ch. Miehé[4], G. Münzenberg[1], M. Pfützner[1,5], C. Röhl[6], W. Schwab[1], C. Stéphan[2], K. Sümmerer[1], L. Tassan-Got[2], B. Voss[6]

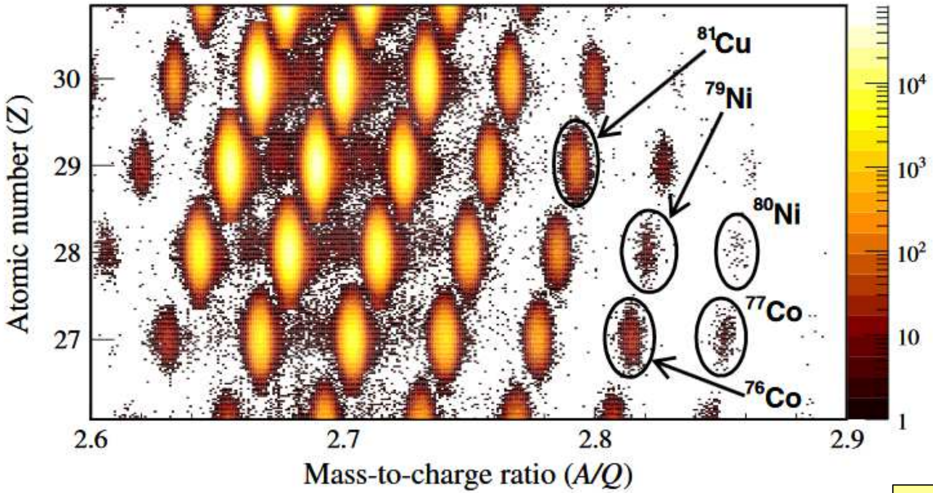


3 events in 2 days

Engelmann et al., Z. Phys. A352 (1995) 351

Doubly-magic milestone - ^{78}Ni

Present state-of-the-art



Xu et al., Phys. Rev. Lett. 113 (2014) 032505

RIKEN 2014: ^{238}U@345 MeV/u + Be → ^{78}Ni

12 000 events in 13 days

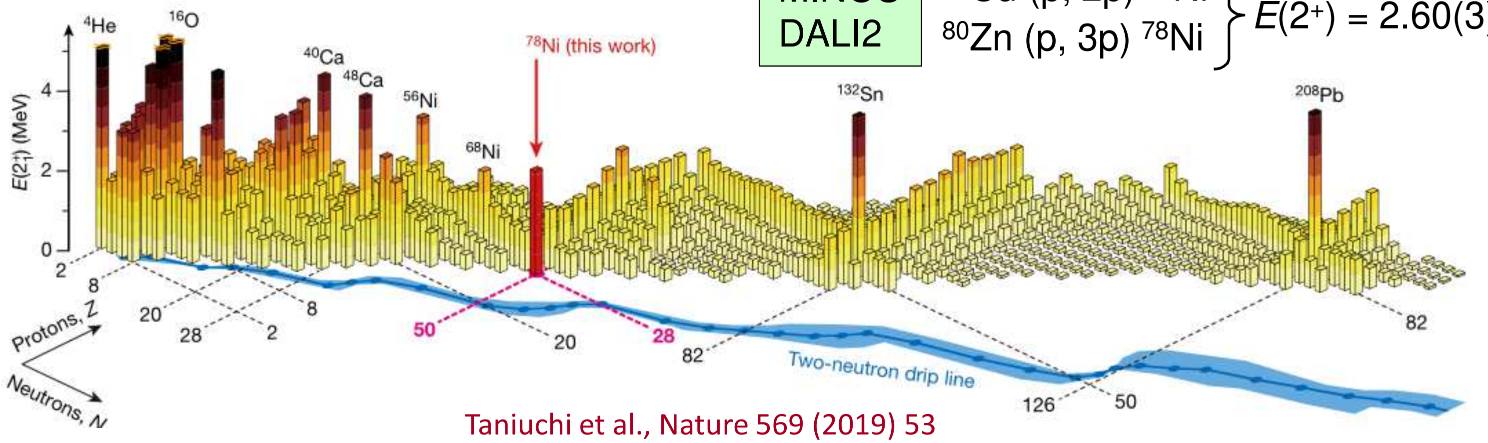
→ $T_{1/2}$ = (122 ± 5.1) ms

RIKEN 2019: ^{238}U@345 MeV/u + Be → ^{79}Cu, ^{80}Zn

MINOS DALI2

^{79}Cu (p, 2p) ^{78}Ni
^{80}Zn (p, 3p) ^{78}Ni

$E(2^+)$ = 2.60(3) MeV



Taniuchi et al., Nature 569 (2019) 53

Isomers

Efficient production of μs-isomers in projectile fragmentation

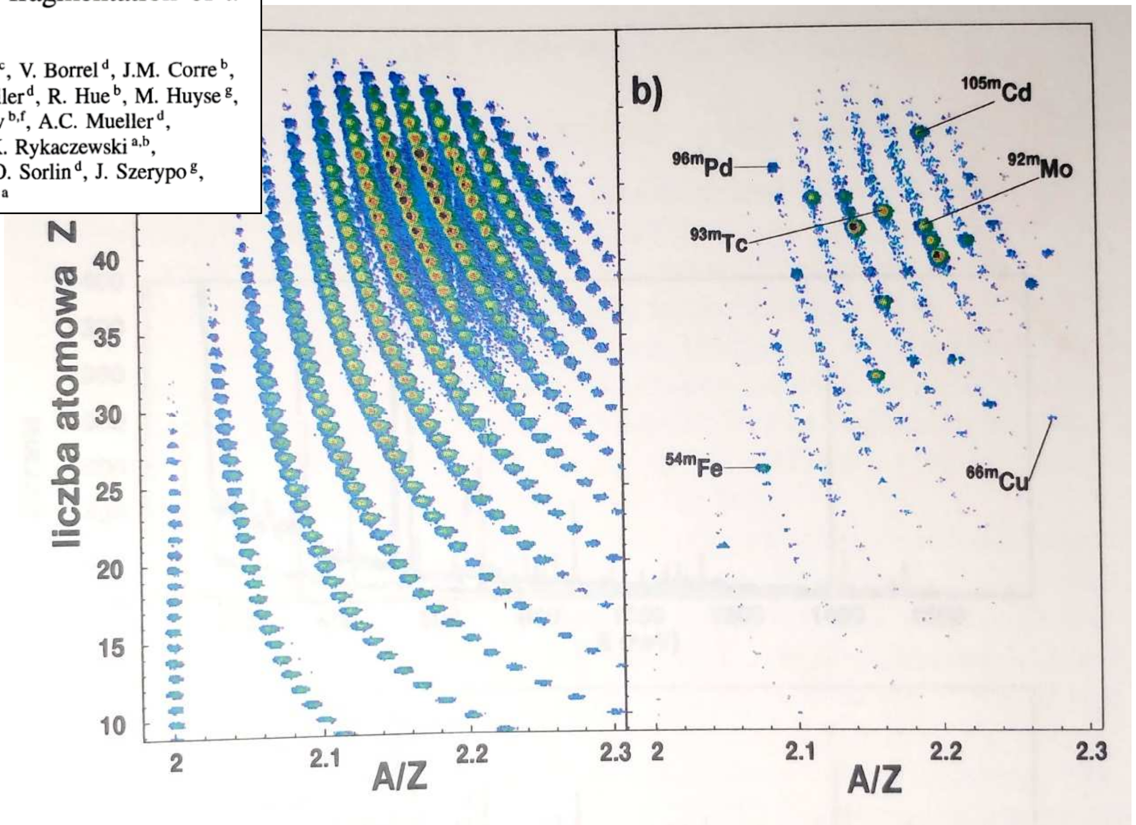
3 August 1995
PHYSICS LETTERS B
ELSEVIER
Physics Letters B 355 (1995) 439–446

Identification of μs-isomers produced in the fragmentation of a ^{112}Sn beam

R. Grzywacz[a,b], R. Anne[b], G. Auger[b], D. Bazin[b], C. Borcea[c], V. Borrel[d], J.M. Corre[b], T. Dörfler[e], A. Fomichov[f], M. Gaelens[g], D. Guillemaud-Mueller[d], R. Hue[b], M. Huyse[g], Z. Janas[h,1], H. Keller[h], M. Lewitowicz[b], S. Lukyanov[b,f], A.C. Mueller[d], Yu. Penionzhkevich[f], M. Pfützner[a], F. Pougheon[d], K. Rykaczewski[a,b], M.G. Saint-Laurent[b], K. Schmidt[h], W.-D. Schmidt-Ott[e], O. Sorlin[d], J. Szerypo[g], O. Tarasov[b,f], J. Wauters[g], J. Żylicz[a]

GANIL: ^{112}Sn @63 MeV/u + Ni → ^{100}Sn

Grzywacz Plot

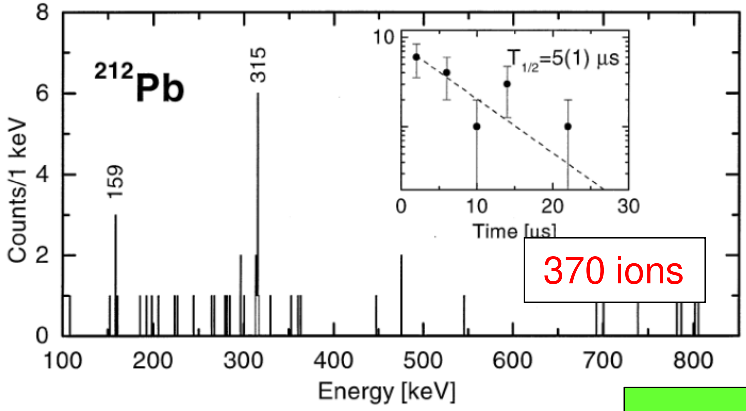


Isomers

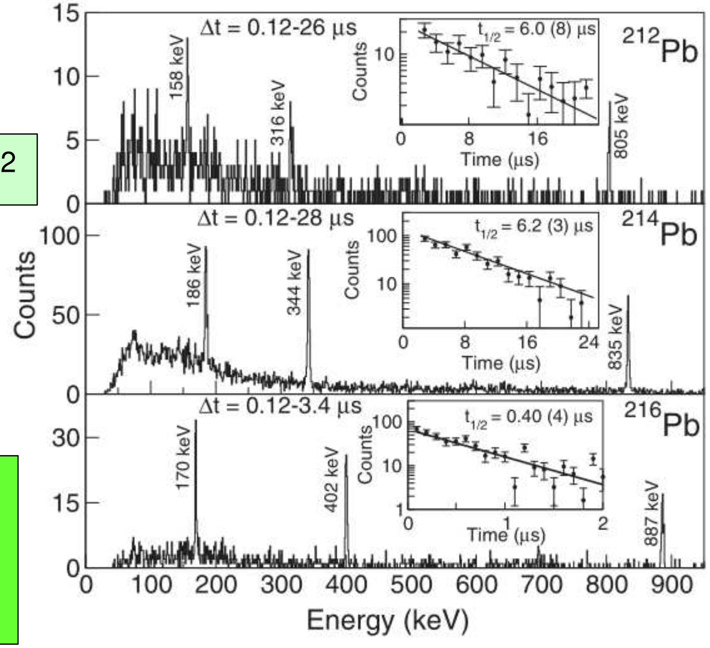
Isomers are produced in high-energy fragmentation, too

GSI: ^{238}U @1 GeV/u + Be

MP et al., Phys. Lett B 444 (1998) 32

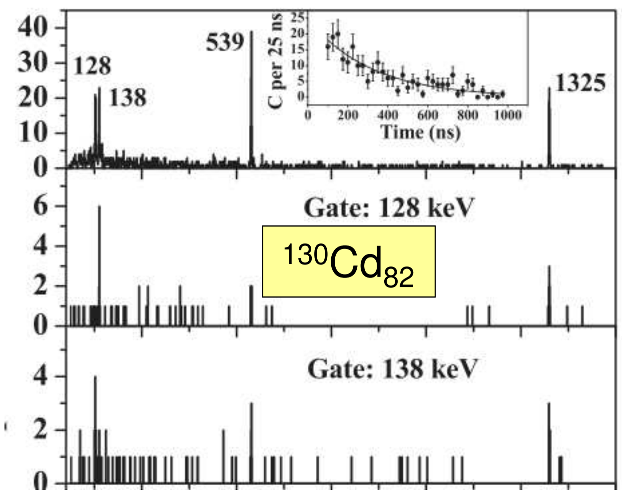


Gottardo et al., Phys. Rev. Lett 109 (2012) 162502



$\nu(g_{9/2})^2$

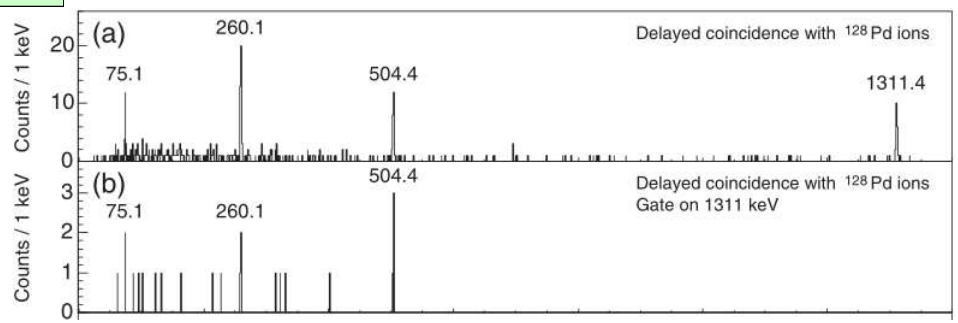
Who will make
^{126}Ru$_{82}$?
^{124}Mo$_{82}$?



Jungclaus et al., Phys. Rev. Lett 99 (2007) 132501

$\pi(g_{9/2})^2$

RIKEN: ^{238}U@345 MeV/u + Be ➔ ^{128}Pd$_{82}$



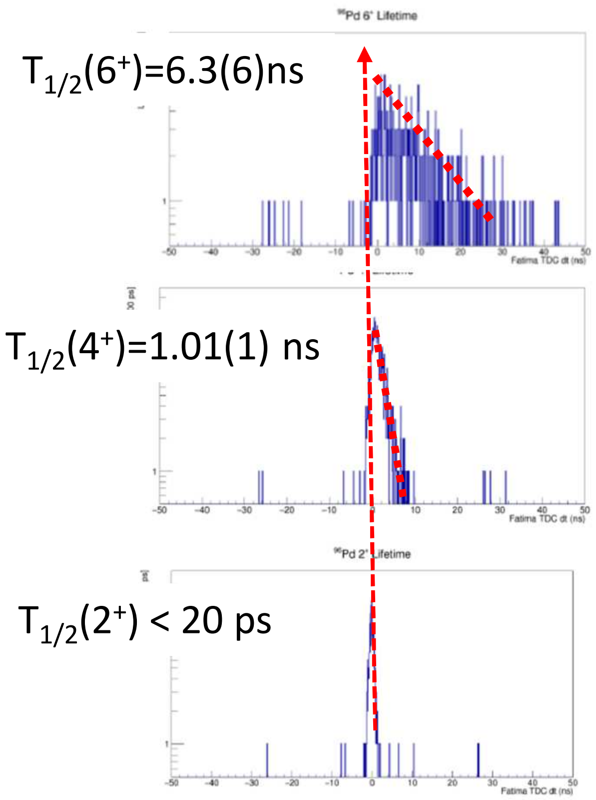
Watanabe et al., Phys. Rev. Lett 111 (2013) 152501

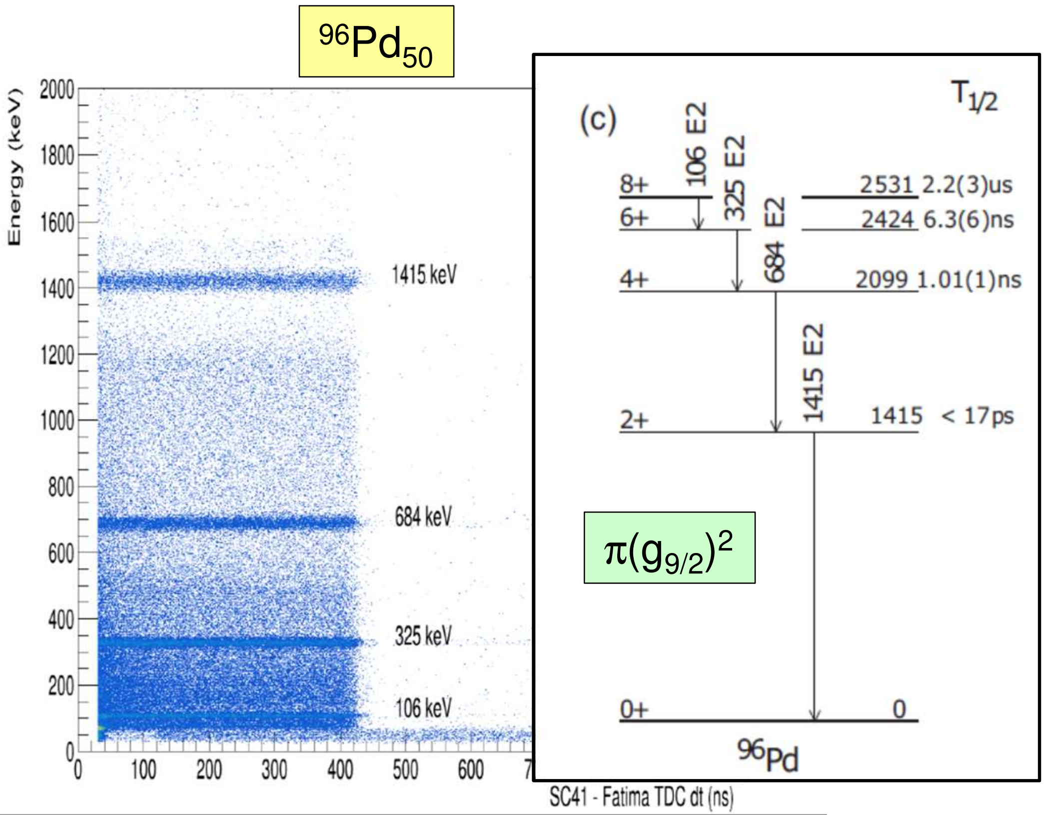
Isomers

Next step in isomeric spectroscopy

GSI: ^{124}Xe @0.85 GeV/u + Be

Fast timing array (FATIMA) used to measure half-lives of states below the isomer (March 2020)

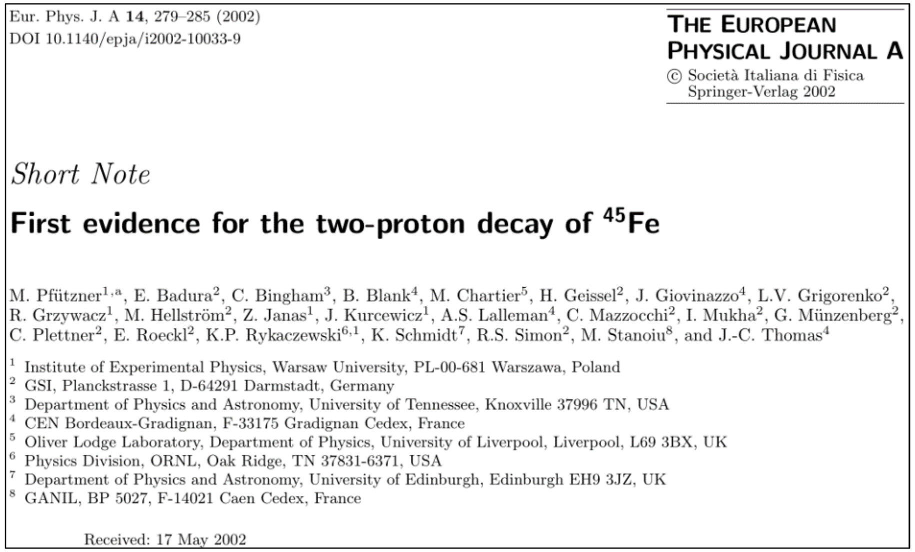




S480, M.Górska, P.H.Regan, J. Jolie, B. Cederwall et al., figure courtesy of S. Jazrawi et al.,

2p radioactivity

Two-proton emission discovered in ^{45}Fe


Eur. Phys. J. A **14**, 279–285 (2002)
DOI 10.1140/epja/i2002-10033-9

The European Physical Journal A
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Springer-Verlag 2002

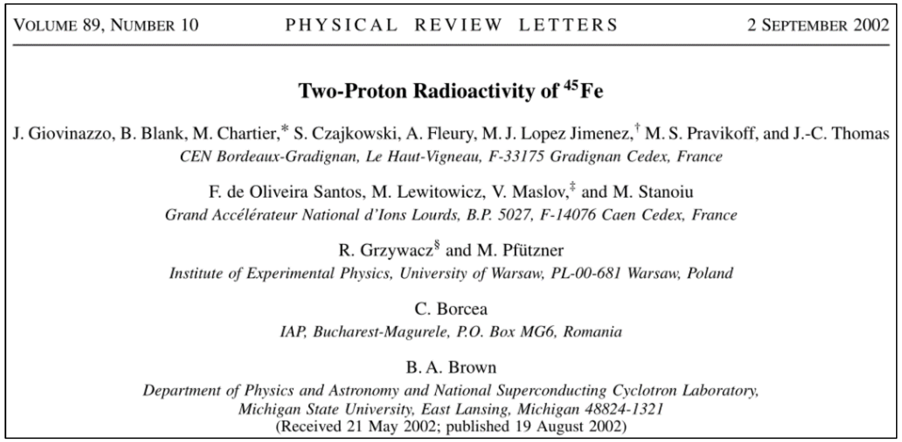
Short Note

First evidence for the two-proton decay of ^{45}Fe

M. Pfützner[1,a], E. Badura[2], C. Bingham[3], B. Blank[4], M. Chartier[5], H. Geissel[2], J. Giovinazzo[4], L.V. Grigorenko[2], R. Grzywacz[1], M. Hellström[2], Z. Janas[1], J. Kurcewicz[1], A.S. Lalleman[4], C. Mazzocchi[2], I. Mukha[2], G. Münzenberg[2], C. Plettner[2], E. Roeckl[2], K.P. Rykaczewski[6,1], K. Schmidt[7], R.S. Simon[2], M. Stanoiu[8], and J.-C. Thomas[4]

[1] Institute of Experimental Physics, Warsaw University, PL-00-681 Warszawa, Poland
[2] GSI, Planckstrasse 1, D-64291 Darmstadt, Germany
[3] Department of Physics and Astronomy, University of Tennessee, Knoxville 37996 TN, USA
[4] CEN Bordeaux-Gradignan, F-33175 Gradignan Cedex, France
[5] Oliver Lodge Laboratory, Department of Physics, University of Liverpool, Liverpool, L69 3BX, UK
[6] Physics Division, ORNL, Oak Ridge, TN 37831-6371, USA
[7] Department of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3JZ, UK
[8] GANIL, BP 5027, F-14021 Caen Cedex, France

Received: 17 May 2002


Volume 89, Number 10 PHYSICAL REVIEW LETTERS 2 September 2002

Two-Proton Radioactivity of ^{45}Fe

J. Giovinazzo, B. Blank, M. Chartier,* S. Czajkowski, A. Fleury, M. J. Lopez Jimenez,† M. S. Pravikoff, and J.-C. Thomas
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R. Grzywacz§ and M. Pfützner
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C. Borcea
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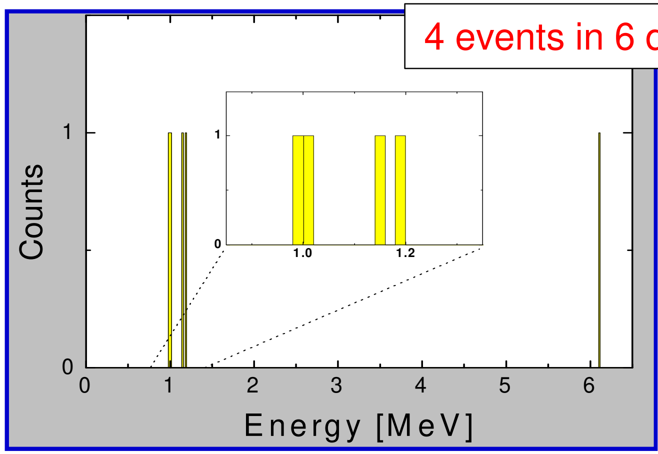
Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321
(Received 21 May 2002; published 19 August 2002)

GANIL: ^{58}Ni @ 75 MeV/A +Ni → ^{45}Fe

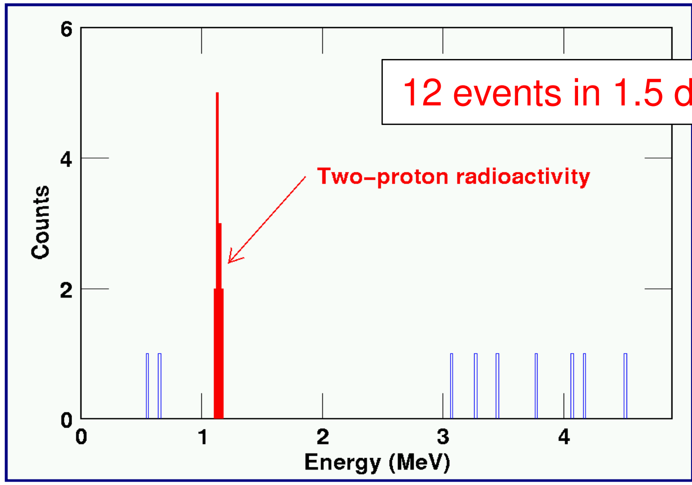
GSI: ^{58}Ni @ 650 MeV/A +Be → ^{45}Fe

4 events in 6 days



$T_{1/2}$ = 2.6 ms

12 events in 1.5 days

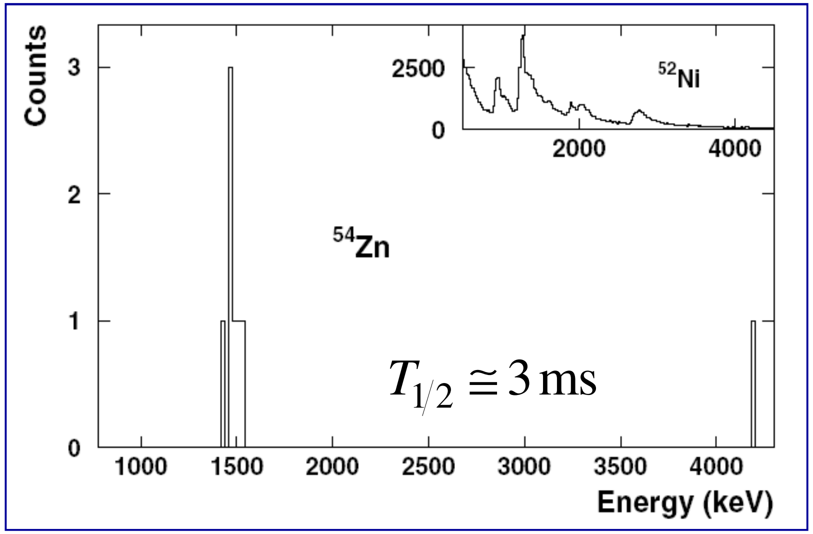


Decay inside Si detector
→ only total energy and time measured

2p radioactivity

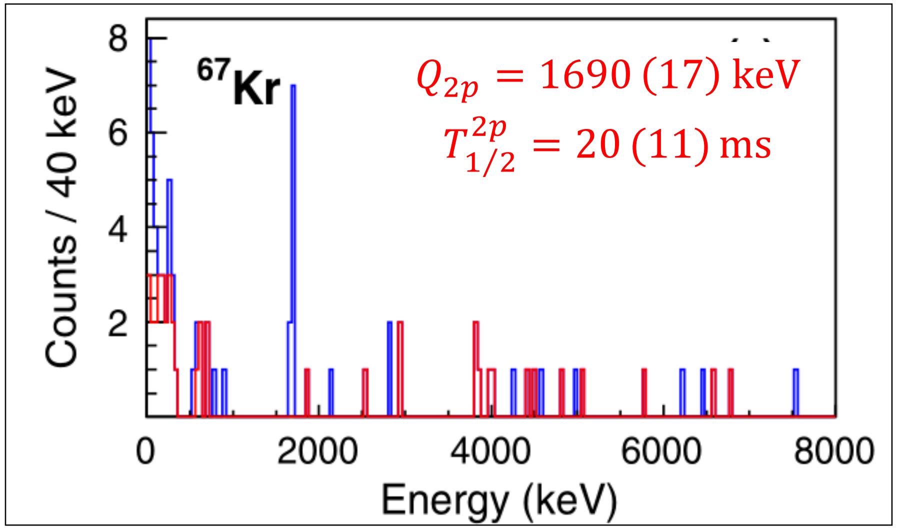
Two more cases of 2p emission discovered with Si detetctors

GANIL: ^{58}Ni @ 75 MeV/A +Ni → ^{54}Zn



Blank et al., PRL 94 (2005) 232501

RIKEN: ^{78}Kr @ 345 MeV/A +Be → ^{67}Kr



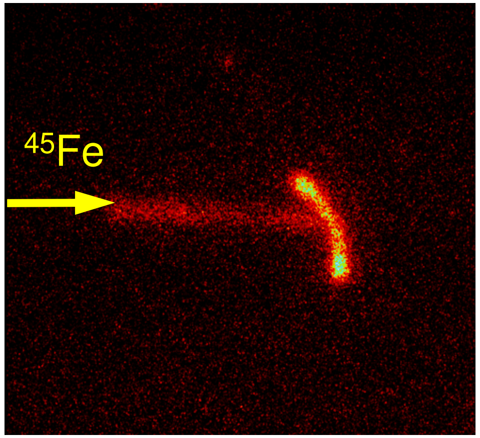
Goigoux et al., PRL 117 (2016) 162501

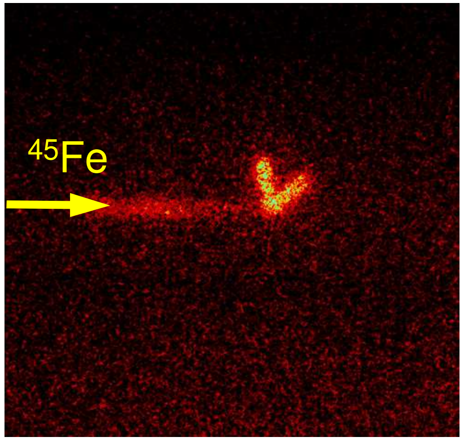
Mechanism of 2p emission

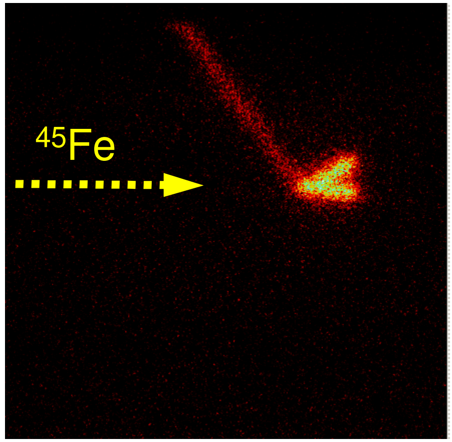
p-p correlations for ^{45}Fe measured with the OTPC detector

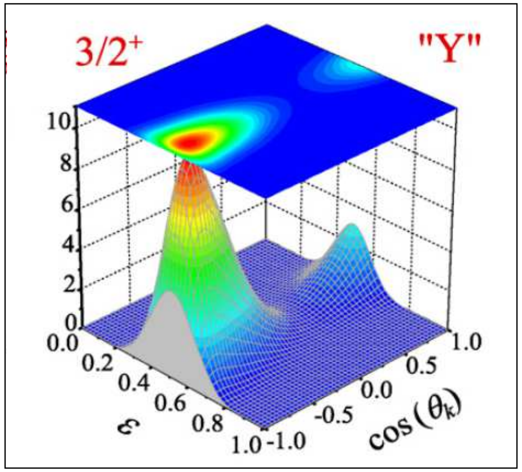
NSCL: ^{58}Ni @ 161 MeV/u + Ni → ^{45}Fe

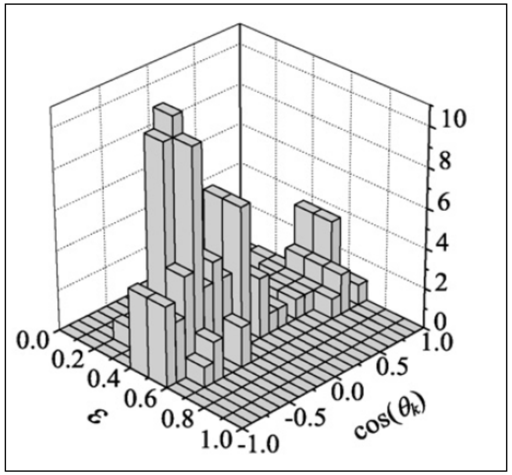
Miernik et al., Phys. Rev. Lett. 99 (2007) 192501











87 events reconstructed

Grigorenko *et al.*, Phys. Lett. B 667 (2009) 30

Doubly-magic (?) milestone - ^{48}Ni

Third exotic doubly-magic and most proton-rich nucleus produced

GANIL: ^{48}Ni @ 75 MeV/u + Ni → ^{48}Ni

VOLUME 84, NUMBER 6 PHYSICAL REVIEW LETTERS 7 FEBRUARY 2000

Discovery of Doubly Magic ^{48}Ni

B. Blank, M. Chartier, S. Czajkowski, J. Giovinazzo, M. S. Pravikoff, and J.-C. Thomas
CEN Bordeaux-Gradignan, Le Haut-Vigneau, F-33175 Gradignan Cedex, France

G. de France, F. de Oliveira Santos, and M. Lewitowicz
Grand Accélérateur National d'Ions Lourds, B.P. 5027, F-14076 Caen Cedex, France

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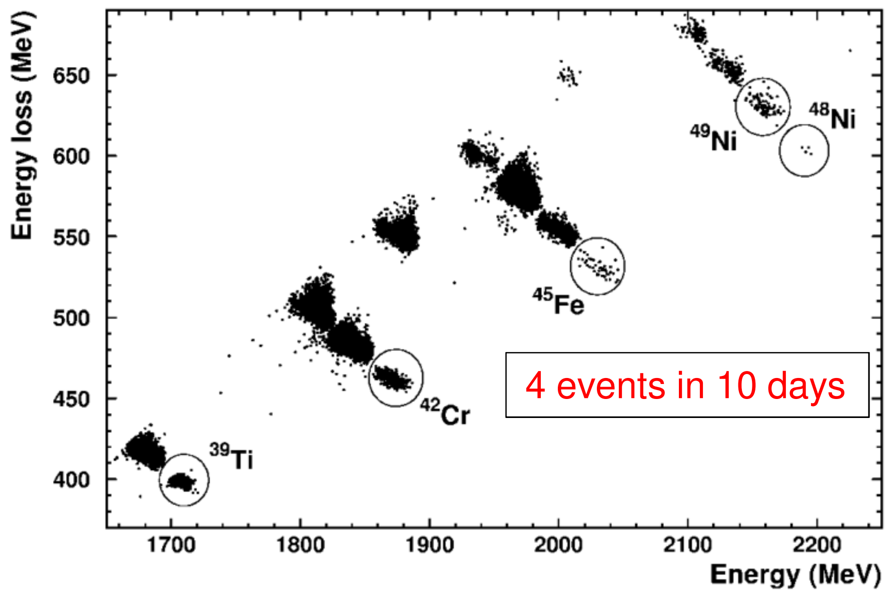
R. Grzywacz,* Z. Janas, and M. Pfützner
Institute of Experimental Physics, University of Warsaw, PL-00-681 Warsaw, Hoza 69, Poland
(Received 20 October 1999)

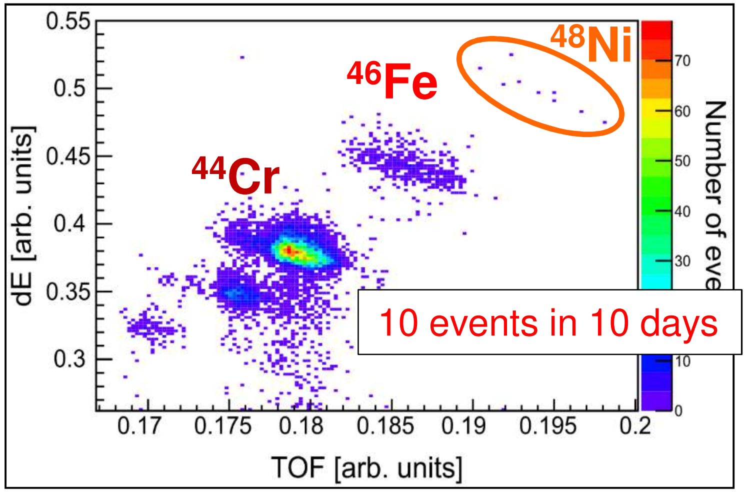


4 events in 10 days

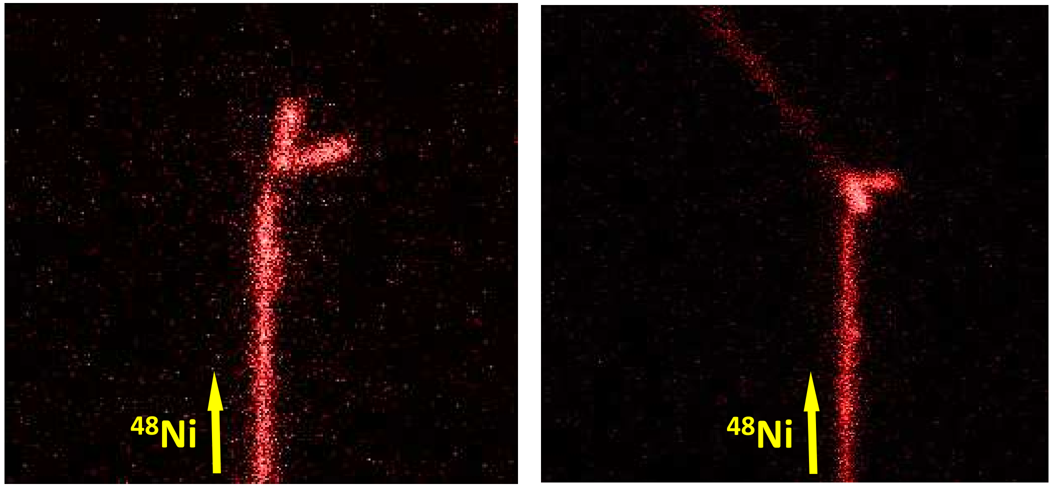
2p radioactivity of ^{48}Ni

Decay of ^{48}Ni studied with the OTPC detector

NSCL: ^{58}Ni @ 161 MeV/u + Ni → ^{48}Ni



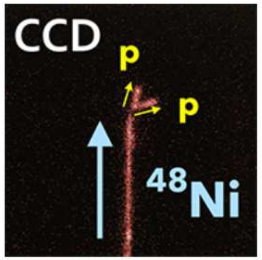
$T_{1/2}$ = 2 ms



Pomorski et al., PRC 83 (2011) 061303(R)

Physical Review C 50th Anniversary Milestones

50 YEARS PHYSICAL REVIEW C



First observation of two-proton radioactivity in ^{48}Ni

A rare form of radioactivity, in which a proton-laden nucleus decays toward stability via the simultaneous emission of two protons, was observed for ^{48}Ni. Using an optical time-projection chamber, the two-proton emission of four ^{48}Ni nuclei produced at the National Superconducting Cyclotron Laboratory was captured for the first time on CCD camera, marking a new era of optical detection of sub-atomic charged-particle processes in nuclear physics.

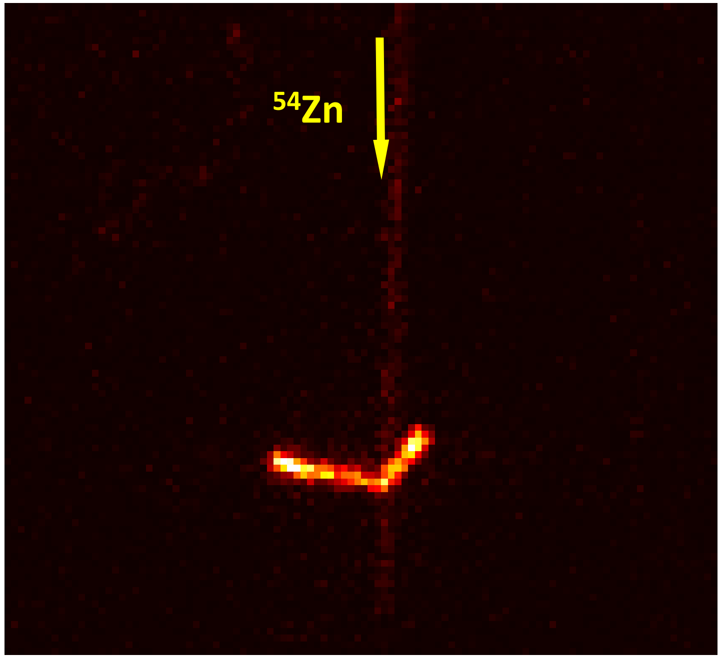
First observation of two-proton radioactivity in ^{48}Ni

M. Pomorski, M. Pfützner, W. Dominik, R. Grzywacz, T. Baumann, J. S. Berryman, H. Czyrkowski, R. Dąbrowski, T. Ginter, J. Johnson, G. Kamiński, A. Kuźniak, N. Larson, S. N. Liddick, M. Madurga, C. Mazzocchi, S. Mianowski, K. Miernik, D. Miller, S. Paulauskas, J. Pereira, K. P. Rykaczewski, A. Stolz, and S. Suchyta

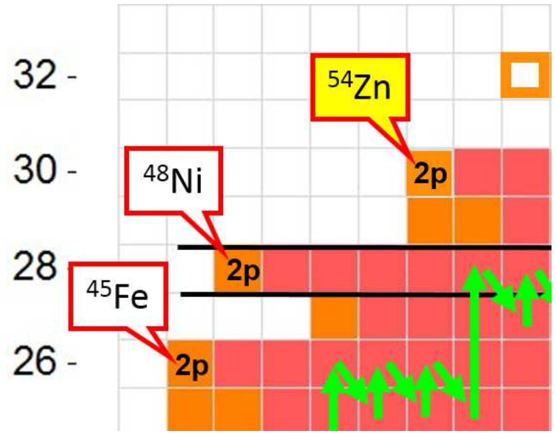
2p decay of ^{54}Zn

Can 2p emission tell us something on Z=28 shell closure?

RIKEN, 2019: ^{78}Kr @ 350 MeV/u + ^{9}Be → ^{54}Zn



Kubiela et al., to be published

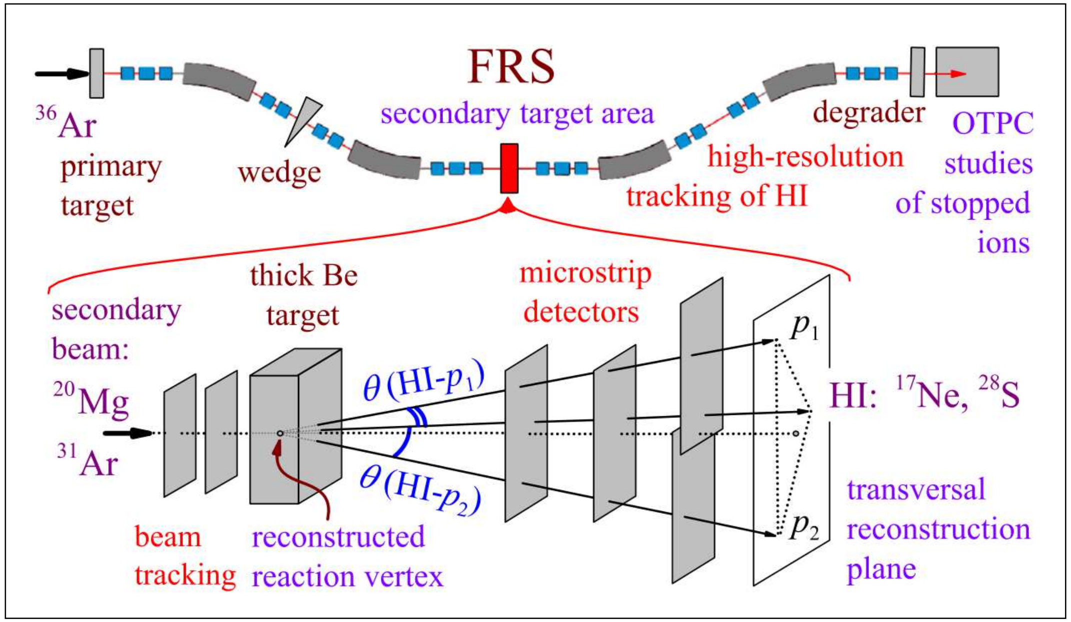


The production cross section:
$\sigma = 3.5 \pm 0.8 \pm 0.7$ fb

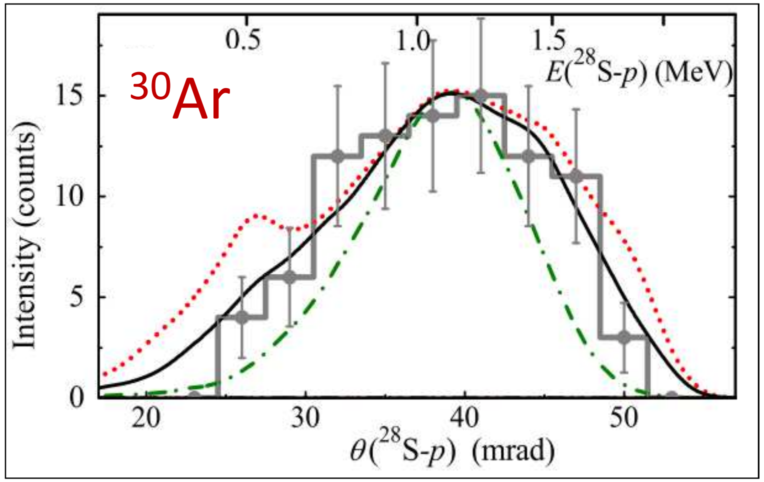
In-flight at GSI

Study of in-flight 2p emission and the decay at rest simultaneously

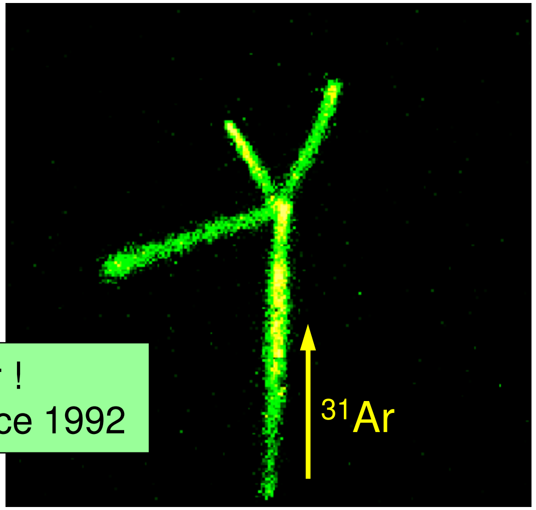
GSI: ^{36}Ar @ 885 MeV/A +Be → ^{31}Ar



Mukha et al., PRL 115 (2015) 202501



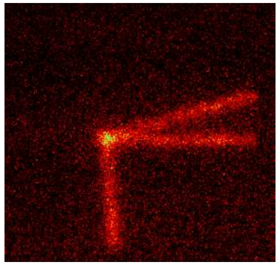
In-flight approach applied @ GSI
to study decays of ^{16}Ne, ^{19}Mg, ^{30}Ar



β3p decay of ^{31}Ar !
It was hunted since 1992

Lis et al., PRC 91 (2015) 064309

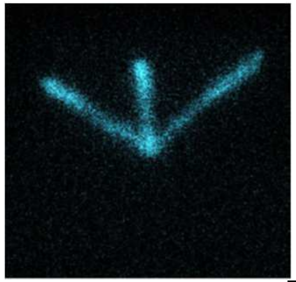
All known cases of β3p



^{45}Fe

NSCL 2007

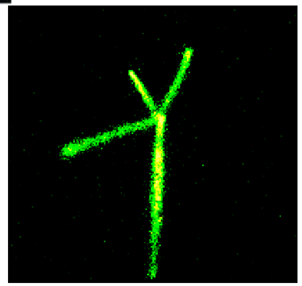
Miernik et al., PRC 76 (2007) 041304(R)



^{43}Cr

NSCL 2007

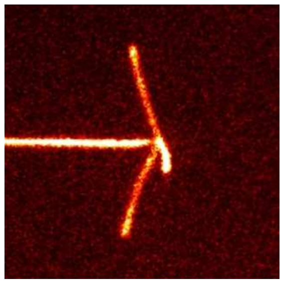
Pomorski et al., PRC 83 (2011) 014306



^{31}Ar

GSI 2012

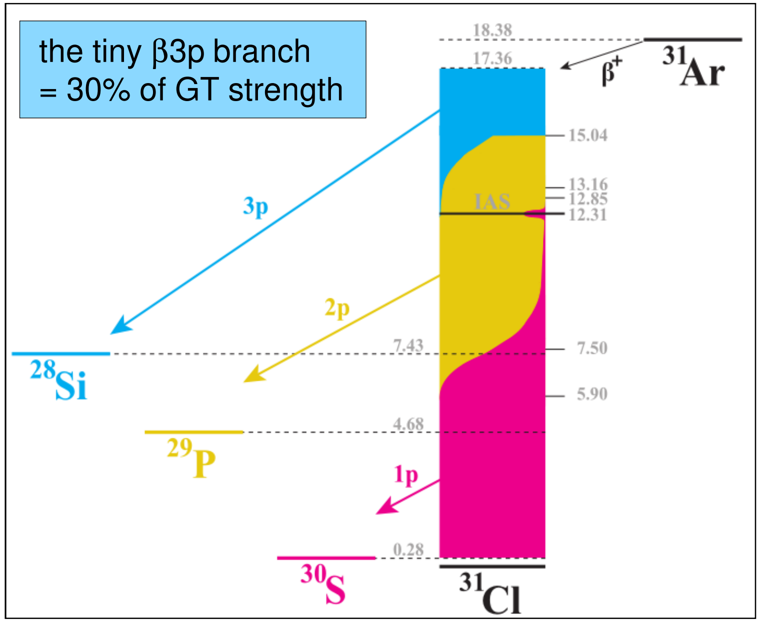
Lis et al., PRC 91 (2015) 064309



^{23}Si

Texas A&M 2017

Ciemny et al., to be published

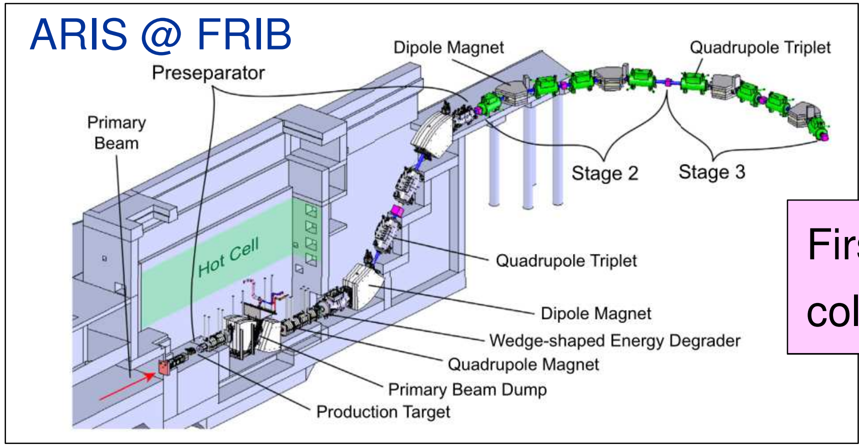


Koldste et al., PRC 89 (2014) 064315

We need much more statistics
to study decay schemes in detail

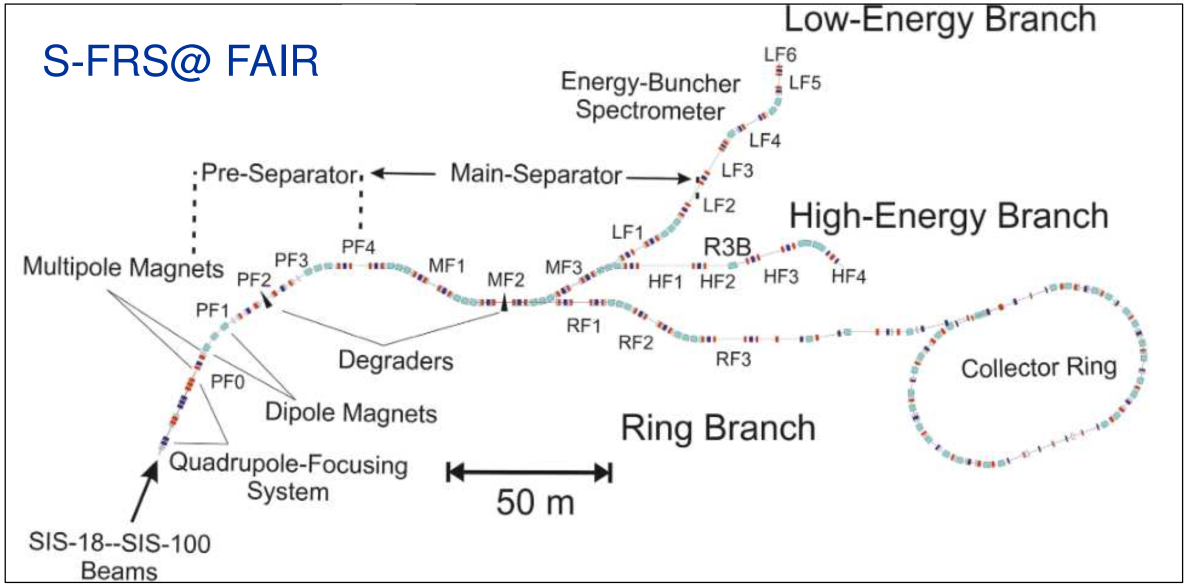
The next level

Higher luminosities, more complex detection arrays...



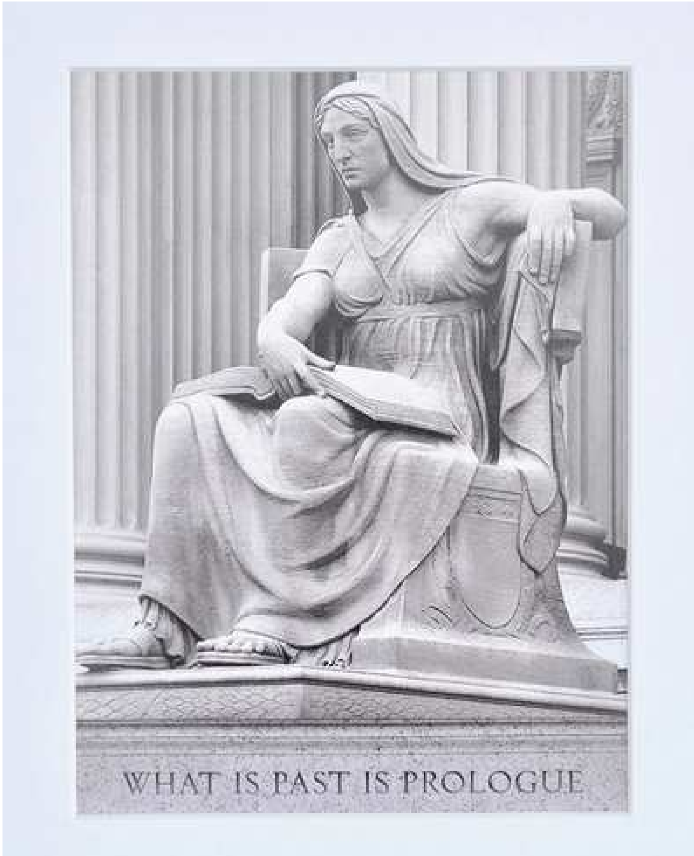
First proposals collected this week

Hausmann et al., NIM B 317 (2013) 349



Winfield et al., NIM B 491 (2021) 38

The future



A statue of Future at the National Archives, Washington D.C.