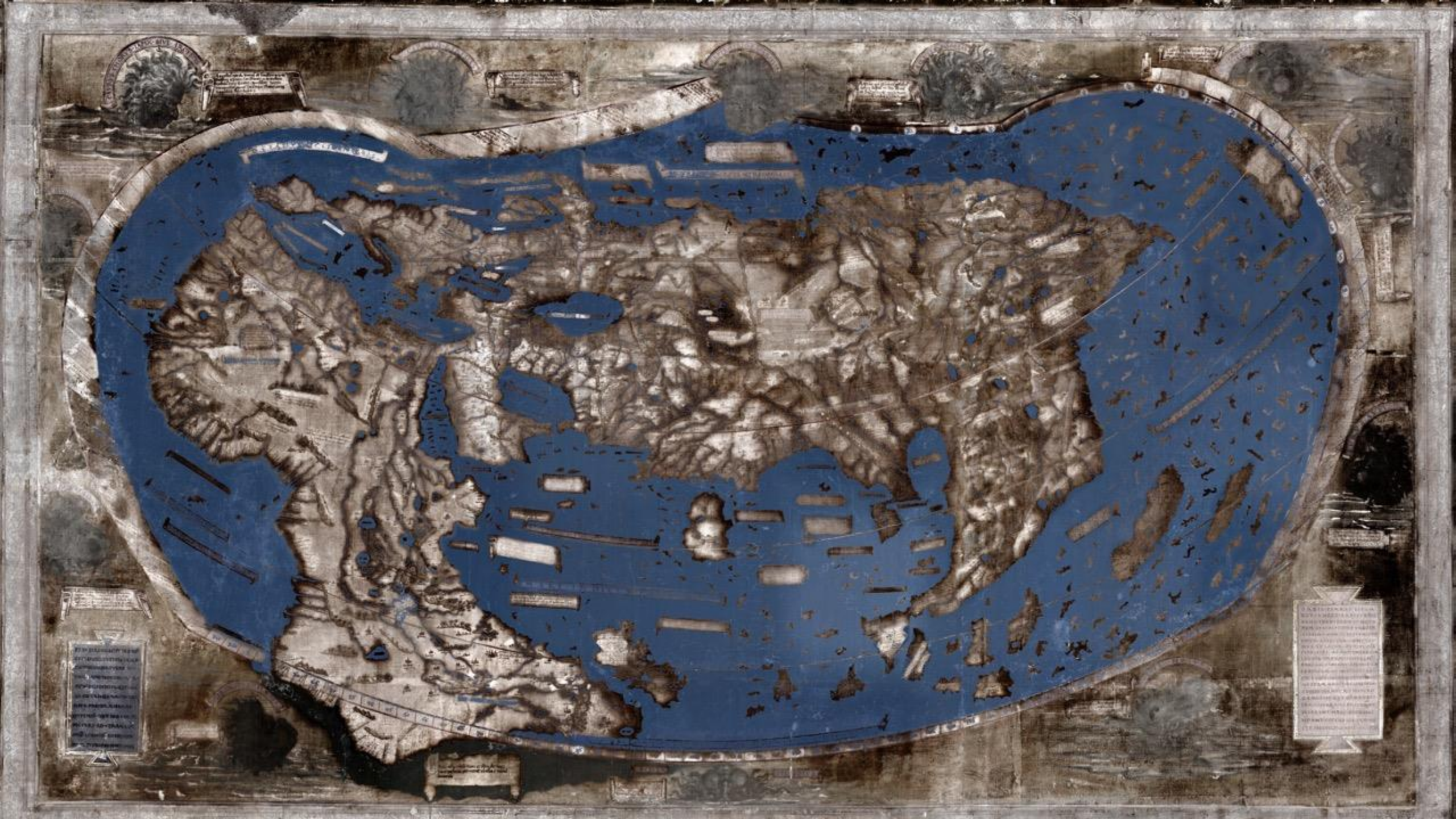
50 Years of SHIP

A Journey to the Edge of the World

Ferdinand Magellan's fleet
North Wind Picture Archives/Alamy

Rolf-Dietmar Herzberg (University of Liverpool)



Making Gold


Peter Armbruster


Sigurd Hofmann


Gottfried Münzenberg

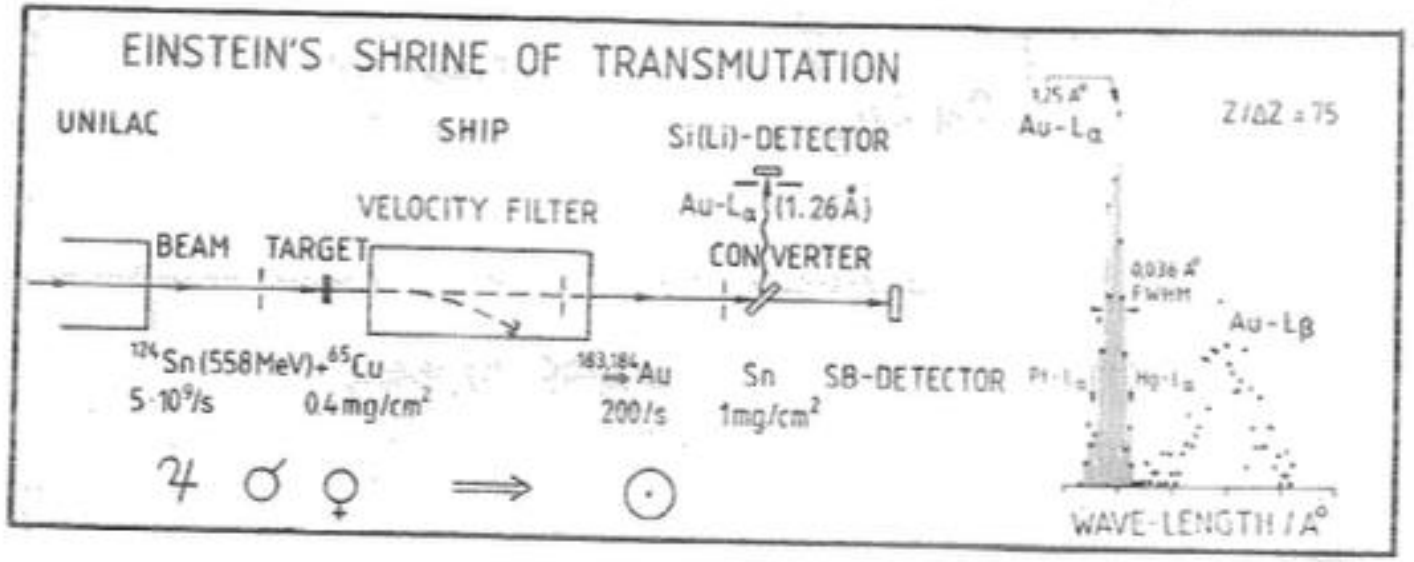


Fig. 1: Einstein's shrine of transmutation- a spectrum of Apollo's glitter.

<u>Transmutation of the Copper-Tin System into Gold</u>
P. Armbruster, S. Hofmann, and G. Münzenberg
GSI Darmstadt

[1] Aristotle (400 BC) cited in "Physica et mystica" by Bolos of Mende (200 BC)
[2] Comp. of Alchem. Writings, Byzantium AD 700
[3] Einstein, A., Ann. d. Physik 18, (1906)
[4] Newton, J. Philosophiae naturalis principia mathematica (1687)
[5] Moseley H.G., Phil. Mag. 26 (1913) 1024
[6] Wien, W., Verh. dt. phys. Ges. 16 (1897) 165
[7] Schönfeldt, A., Diss., Univ. zu Köln (1981)

Jahresbericht 80 p 11

Separator Design 101 - Why a Velocity Filter?

Electric field: Particles get deflected according to **energy**

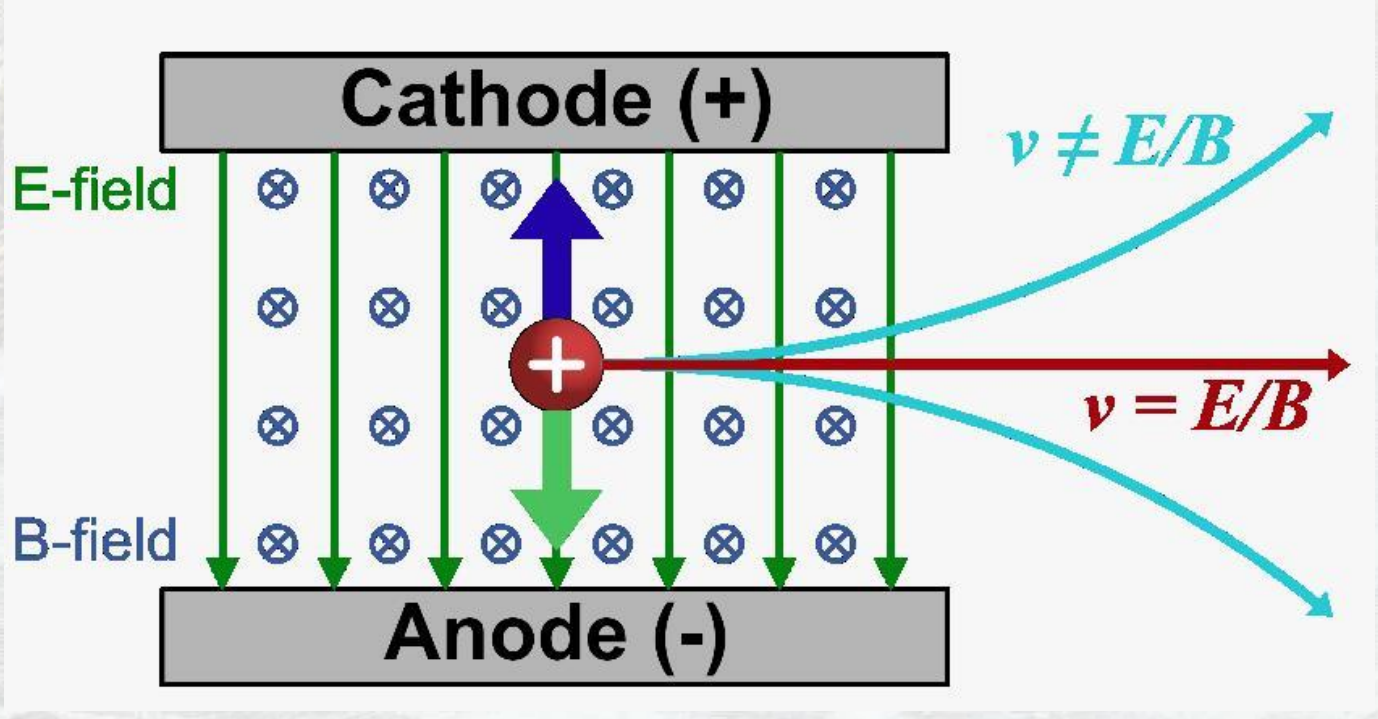
Magnetic field: Particles get deflected according to **momentum**

combine the two into a Wien filter: separate by **velocity**

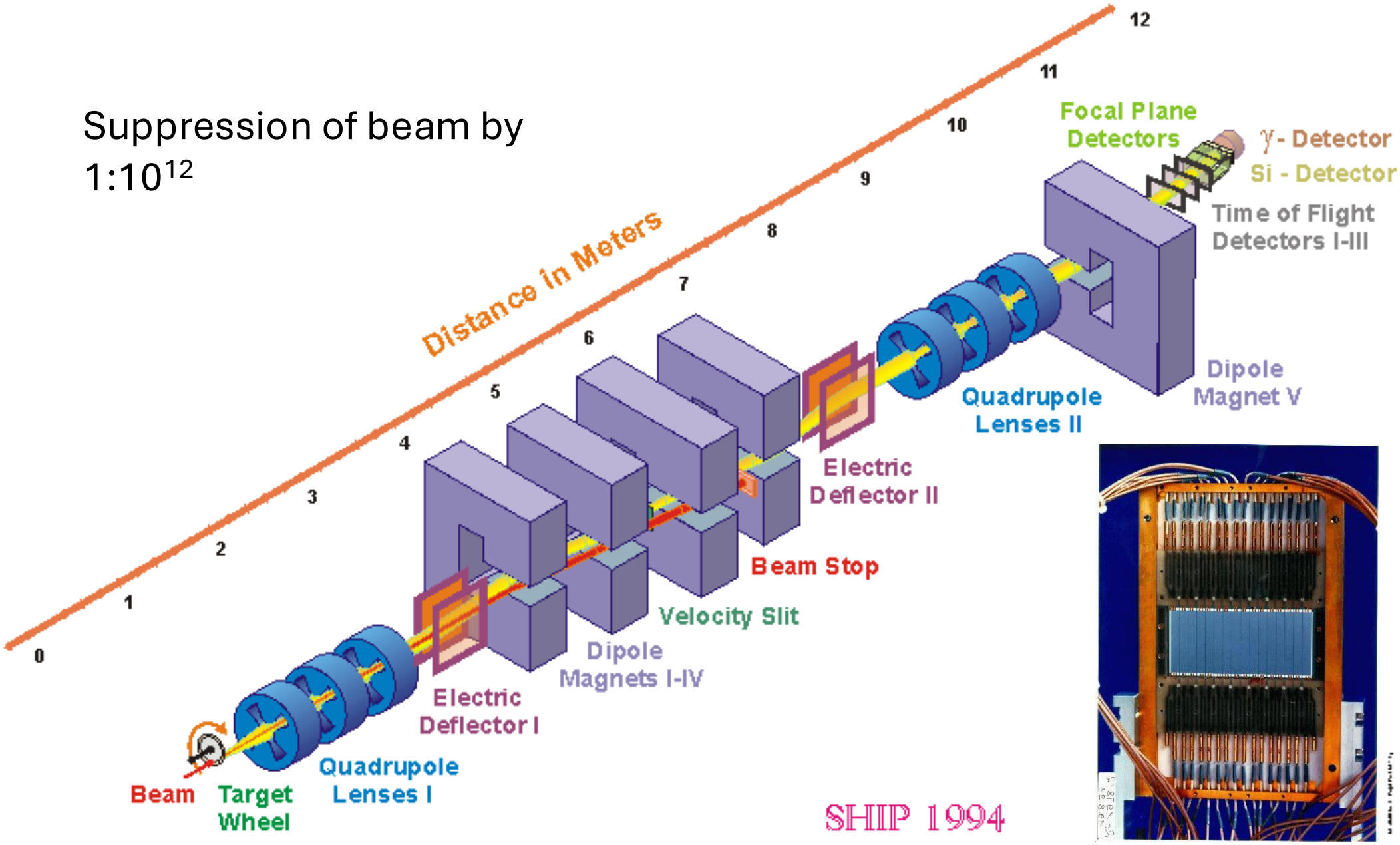
Advantages:

Very high efficiency,

independent of charge state

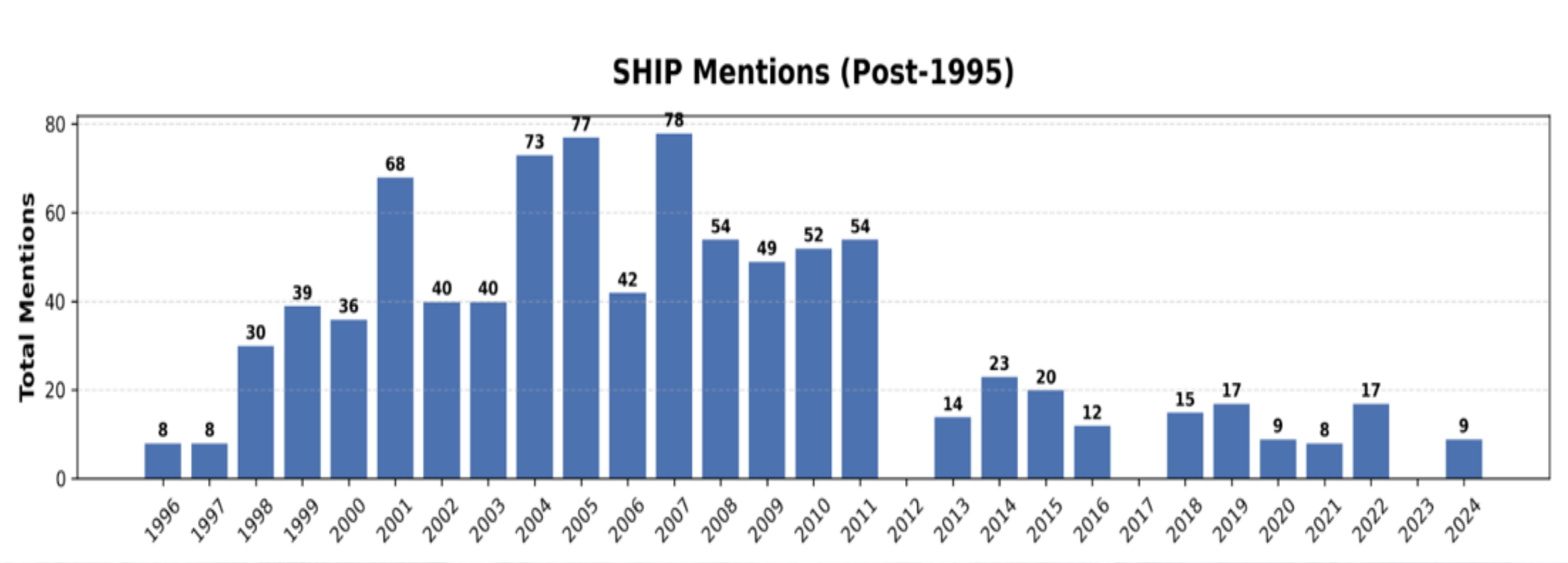


Suppression of beam by $1:10^{12}$



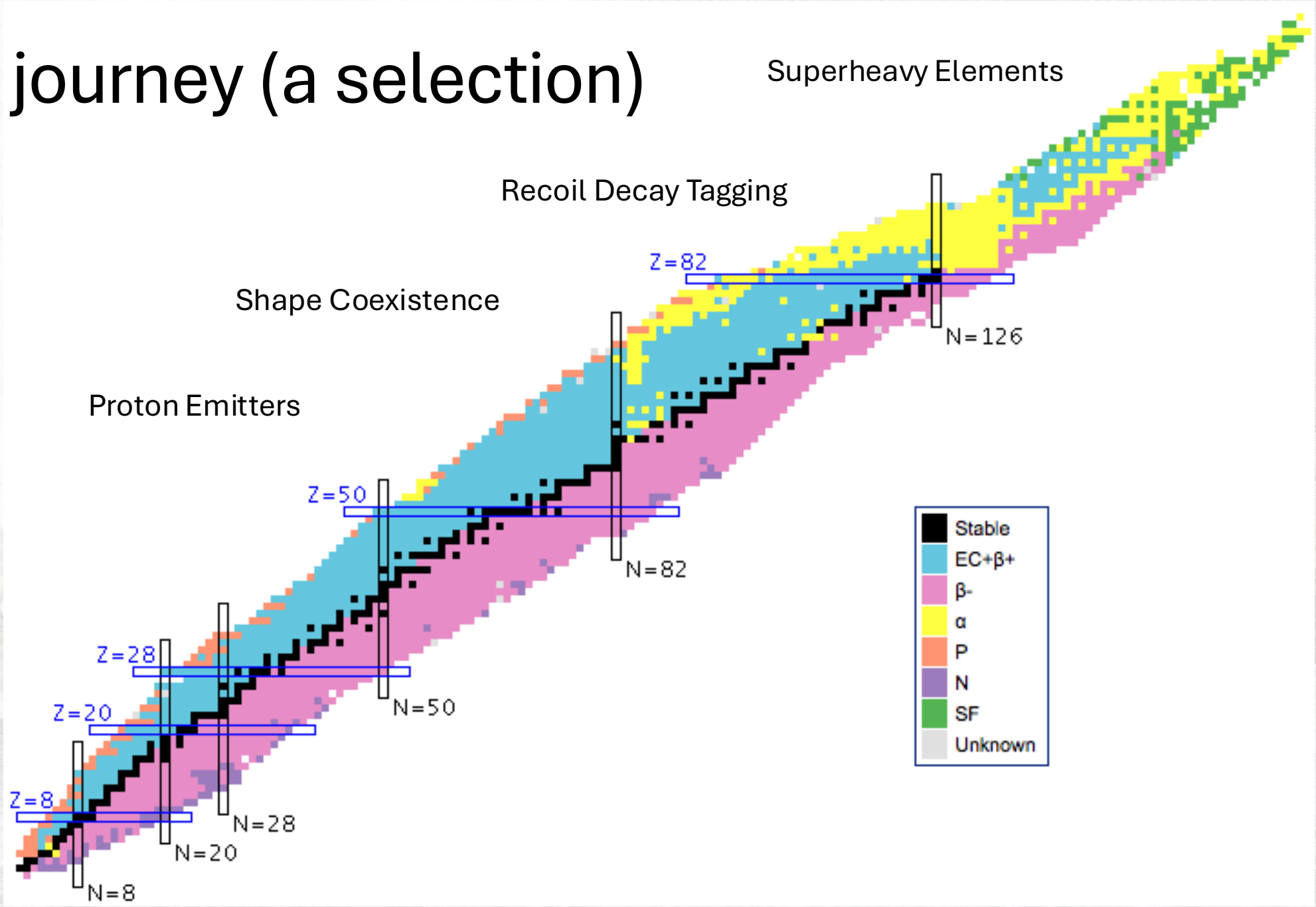
A real workhorse

Jahresberichte (Annual Reports) since 1995*:



* before that only scanned images of pages are available and OCR really struggles.

The journey (a selection)



Proton Radioactivity

Predicted since the 1960s
(Goldansky, Ann. Rev. Nucl. Sci **16**, 1)

First glimpse in ^{53m}Co, (K. P. Jackson, from an isomeric state. Phys. Lett **33B** 281 (1970))

1981: First observation of **ground state proton decay** in ^{151}Lu at SHIP

Hofmann S, Münzenberg G, Faust W, Hessberger F P, Reisdorf, Schneider J R H, Armbruster P. Gutter K and Thuma B
1981 Proc. 4th Int. Conf. on Nuclei Far From Stability (Geneva, 1981) (Geneva: CERN 81-09) p 190

Hofmann S, Reisdorf W. Münzenberg G, Hessberger F P, Schneider JR H and Armbruster P: Z. Phys. **A 305** 111 (1982)

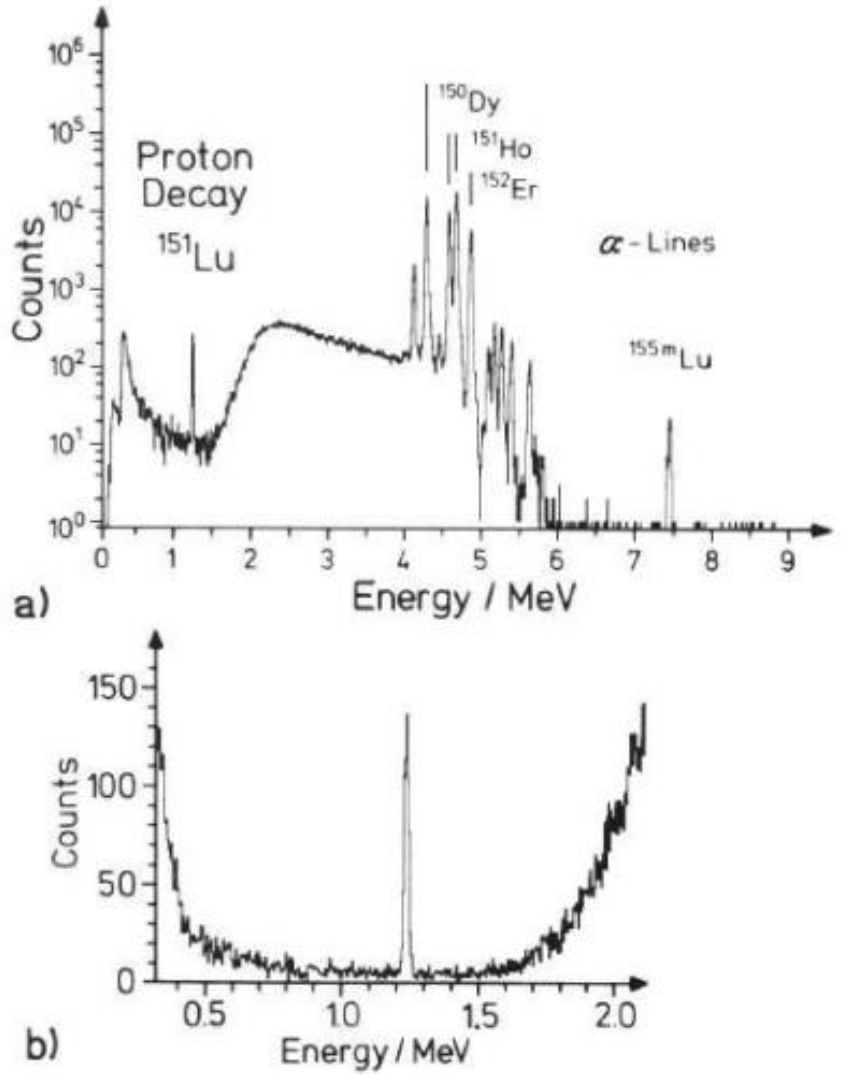


Figure 3.9. (a) Energy spectrum obtained during the irradiation of a ^{96}Ru target (97.9% enrichment) with 261 MeV ^{58}Ni projectiles at SHIP. The ^{151}Lu proton decay line was observed at 1.23 MeV far below the α decay lines of other reaction products. The α line from the ^{155}Lu^{m} decay originates from target impurities of heavier ruthenium isotopes. The impurities were avoided in an irradiation using mass-separated targets. (b) Expanded part of the spectrum showing the ^{151}Lu proton decay line. The resolution is 19 keV FWHM measured with a 45.5 μm thick silicon surface barrier detector. (From [11].)

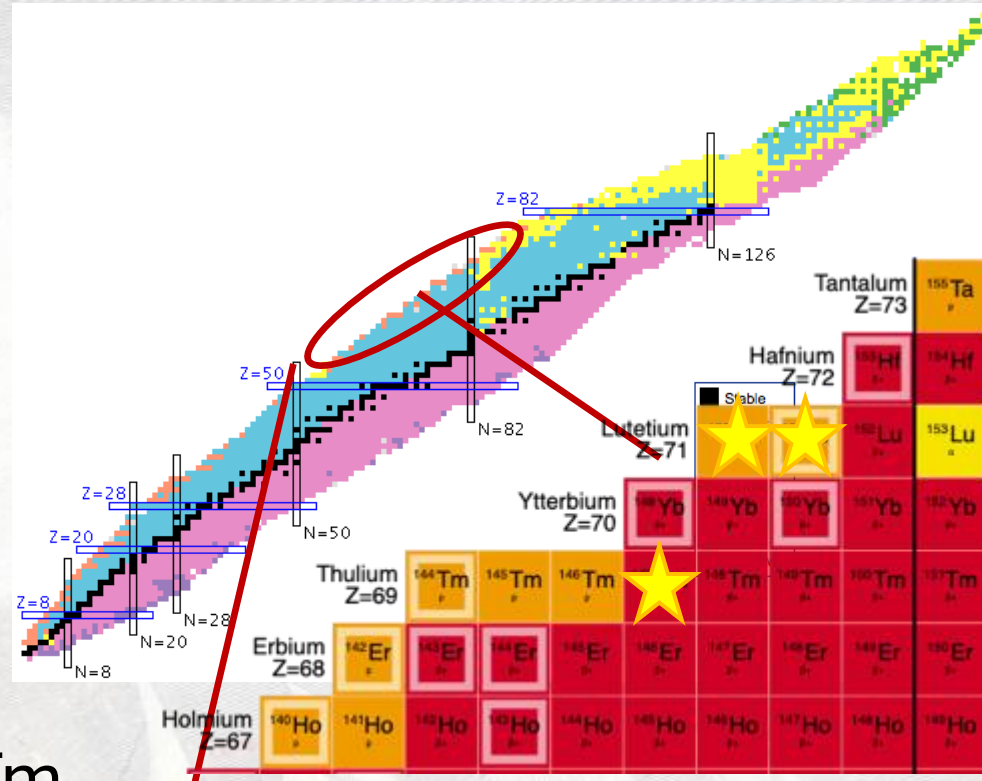
Rapid progress

Hofmann S, Reisdorf W. Münzenberg G, Hessberger F P,
Schneider JR H and Armbruster P: Z. Phys. **A 305** 111 (1982)

^{151}Lu

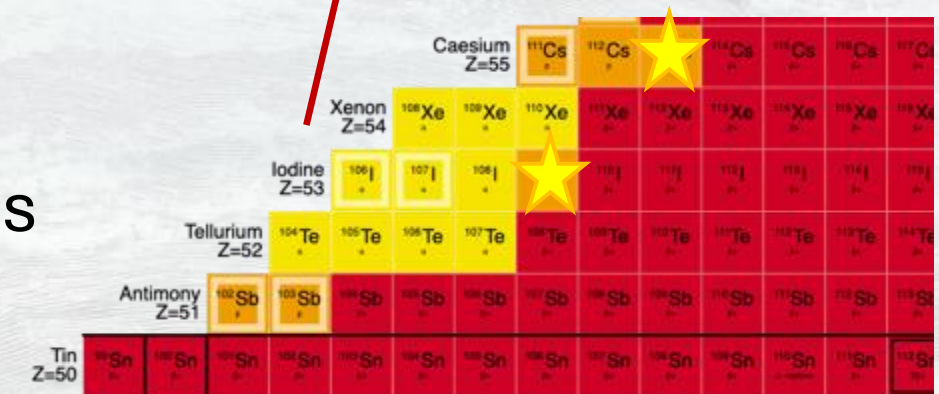
Klepper O, Batsch T, Hofmann S, Kirchner R,
Kurcewicz W, Reisdorf W, Roeckl E,
Schardt D and Nyman G,
Z. Phys. **A 305** 125, (1982)

^{150}Lu ^{147}Tm ^{147m}Tm



Faestermann T, Gillitzer A, Hartel K, Kienle P, Nolic E,
Phys. Lett. **137B,** 23 (1984)

^{109}I ^{113}Cs



Proton emitters today

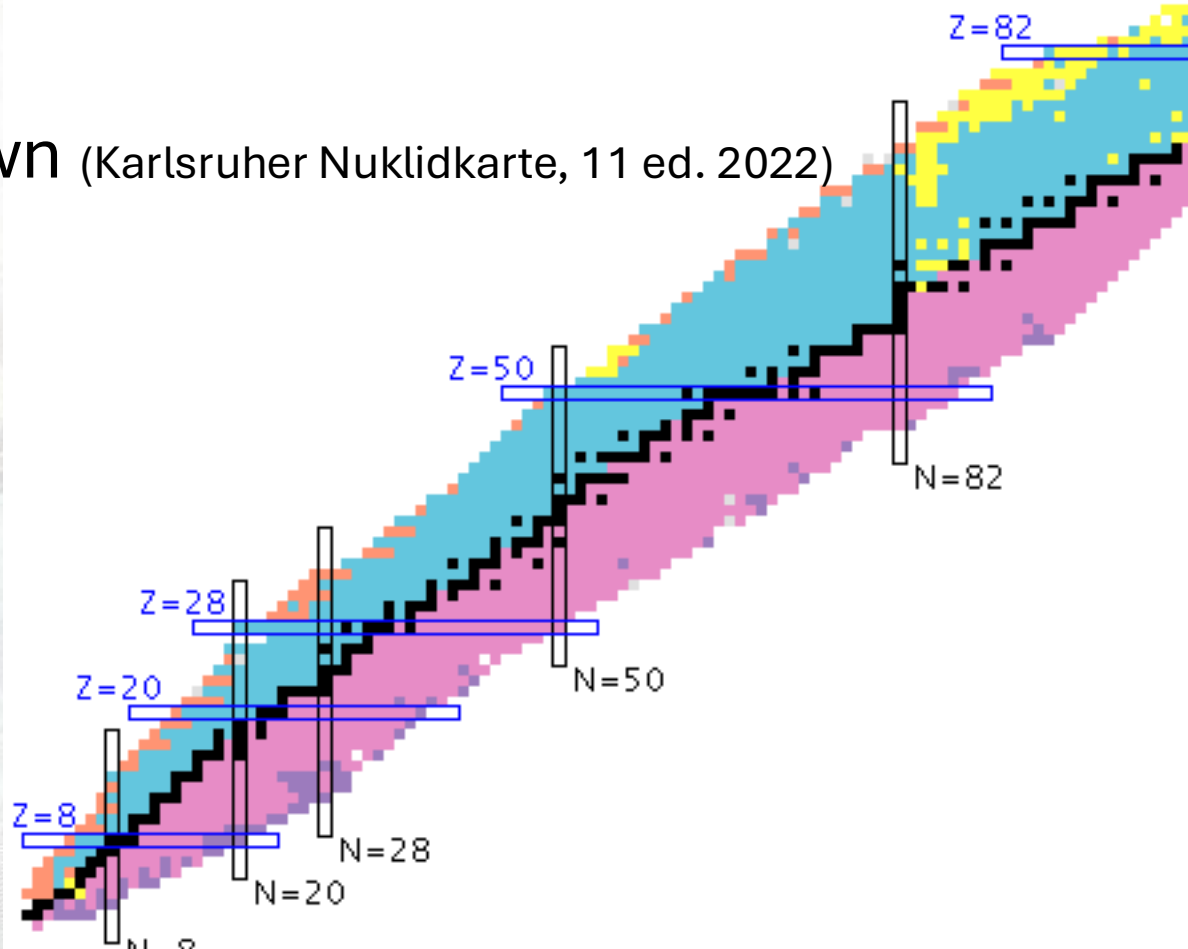
We have mapped out most of the proton dripline up to Bi

A total of 85 proton emitters are known (Karlsruher Nuklidkarte, 11 ed. 2022)

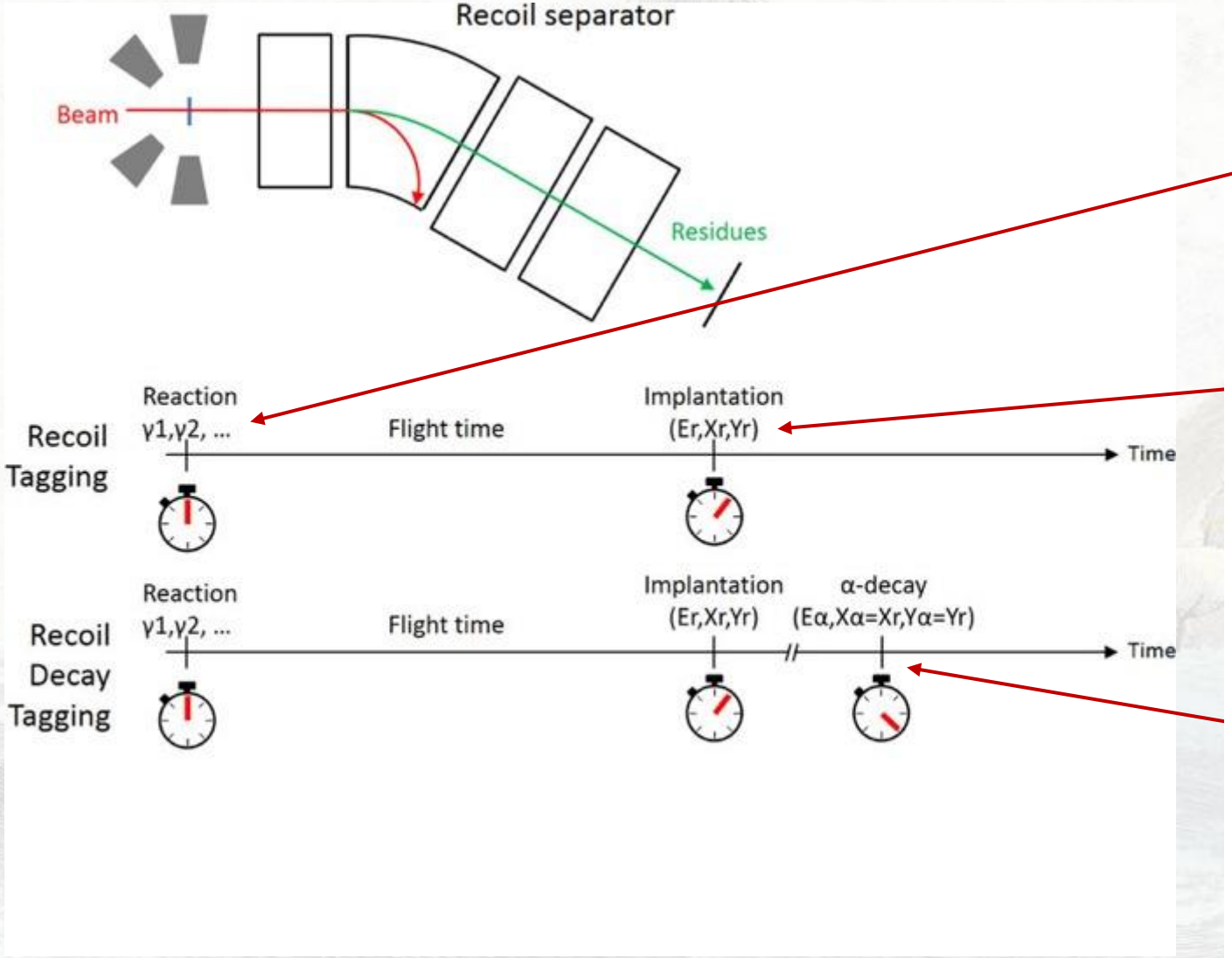
Several proton emitting isomers

Two-proton radioactivity

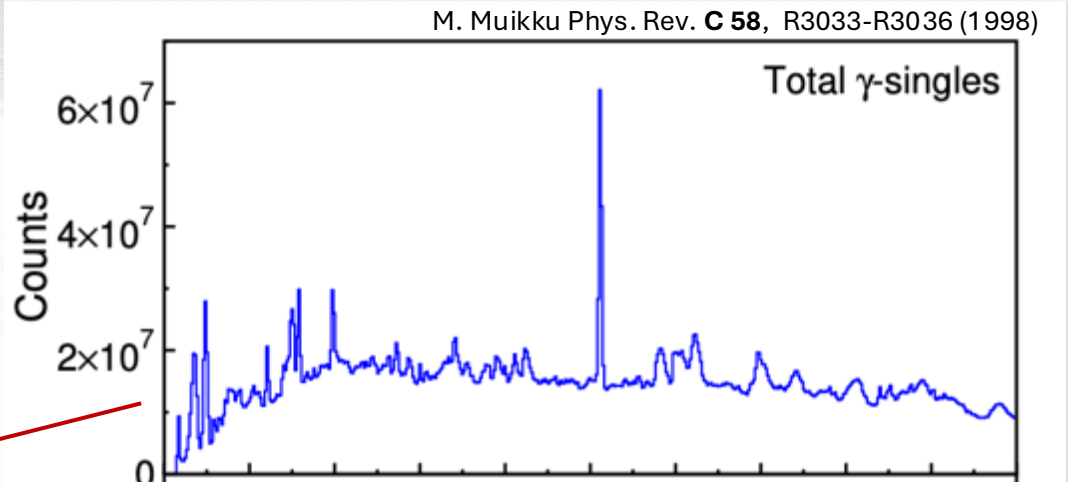
A very rich legacy, indeed



Recoil Decay Tagging



M. Muikku Phys. Rev. **C 58**, R3033-R3036 (1998)



Recoil Decay Tagging - Darmstadt

Z Phys A 325, 197 (1986)

GAMMA-SPECTROSCOPIC INVESTIGATIONS IN THE RADIATIVE FUSION REACTION $^{90}Zr + ^{90}Zr$

K.-H. SCHMIDT, R.S. SIMON, J.-G. KELLER, F.P. HESSBERGER, G. MÜNZENBERG, B. QUINT

Gesellschaft für Schwerionenforschung, D-6100 Darmstadt, Fed. Rep. Germany

H.-G. CLERC, W. SCHWAB, U. GOLLERTHAN and C.-C. SAHM

Institut für Kernphysik, Technische Hochschule Darmstadt, D-6100 Darmstadt, Fed. Rep. Germany

Received 3 July 1985

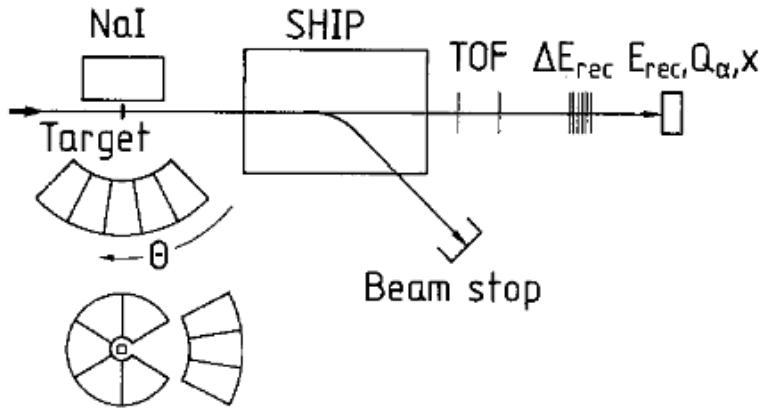


Fig. 1. Layout of the experiment showing the velocity filter SHIP, the recoil telescope behind SHIP and the NaI detectors around the target. The detector telescope provides time-of-flight (TOF), energy loss (ΔE_{rec}), energy (E_{rec}) and position (x) of the implanted heavy reaction products and registers their subsequent α decay (Q_α). The 15 crystal ball modules for the observation of individual γ rays each cover 1/162 of 4π at a distance of 25 cm from the target and roughly form a matrix of 3×5 which subtends the angles from $\theta = 40°$ to $130°$ with respect to the direction of the recoiling ^{180}Hg

Phys Lett **168B**, 39 (1986)

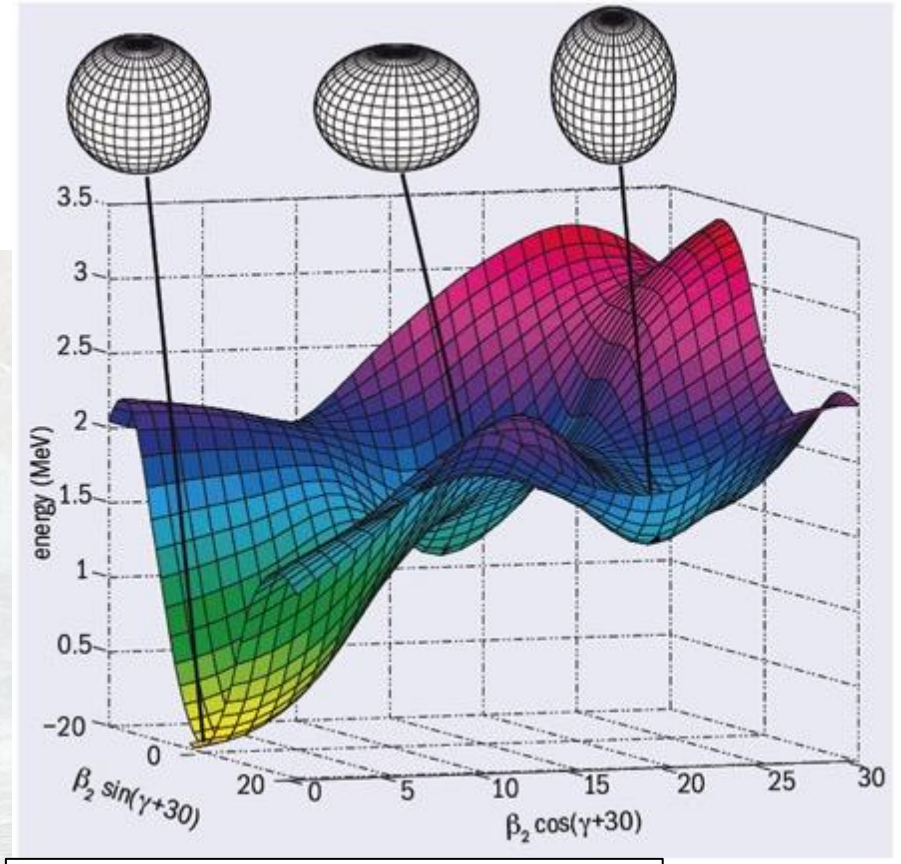
Evidence for Nuclear Shape Coexistence in ^{180}Hg

R.S. Simon, K.-H. Schmidt, F.P. Heßberger, S. Hlavac *, M. Honusek **, and G. Münzenberg

Gesellschaft für Schwerionenforschung, Darmstadt, Federal Republic of Germany

H.-G. Clerc, U. Gollerthan, and W. Schwab

Institut für Kernphysik, Technische Hochschule Darmstadt, Federal Republic of Germany



A.N. Andreyev, nature 405, 430 (2000)

Recoil Decay Tagging - Liverpool

PHYSICAL REVIEW C VOLUME 51, NUMBER 1 JANUARY 1995

In-beam γ-ray spectroscopy above ^{100}Sn using the new technique of recoil decay tagging

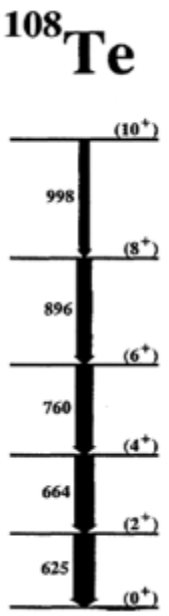
E. S. Paul,[2] P. J. Woods,[1] T. Davinson,[1] R. D. Page,[1] P. J. Sellin,[1] C. W. Beausang,[2] R. M. Clark,[3] R. A. Cunningham,[4] S. A. Forbes,[2] D. B. Fossan,[5] A. Gizon,[6] J. Gizon,[6] K. Hauschild,[3] I. M. Hibbert,[3] A. N. James,[2] D. R. LaFosse,[5] I. Lazarus,[4] H. Schnare,[5] J. Simpson,[4] R. Wadsworth,[3] and M. P. Waring[5]

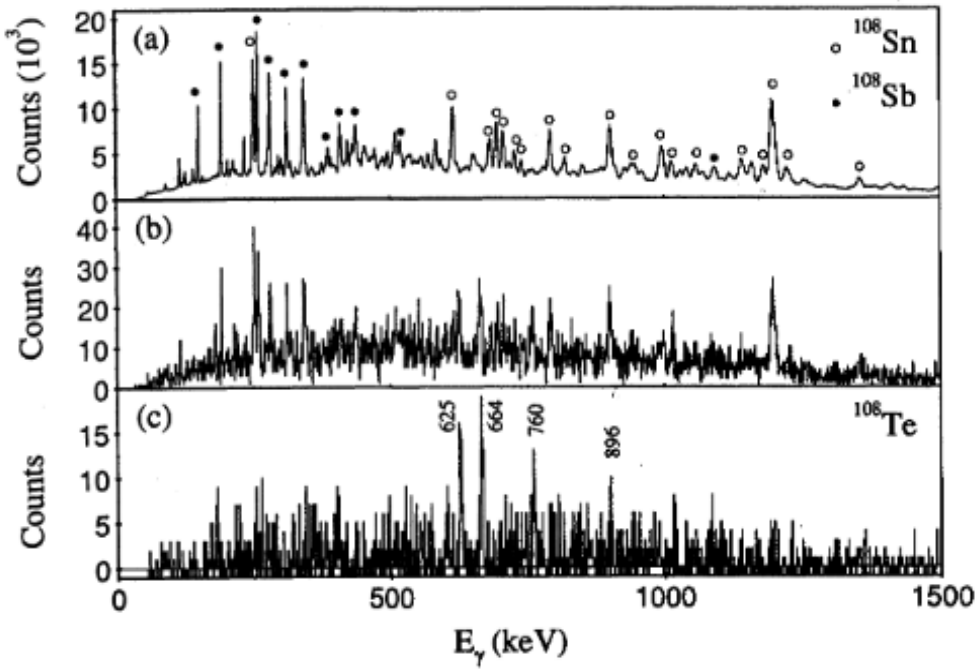
[1]*Department of Physics, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*
[2]*Oliver Lodge Laboratory, University of Liverpool, PO Box 147, Liverpool L69 3BX, United Kingdom*
[3]*Department of Physics, University of York, Heslington, York YO1 5DD, United Kingdom*
[4]*SERC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, United Kingdom*
[5]*Department of Physics, State University of New York at Stony Brook, New York 11794*
[6]*Institut des Sciences Nucléaires, IN2P3-CNRS/Université Joseph Fourier, Grenoble, France*

(Received 26 August 1994)

A novel method of selecting γ-ray transitions in heavy nuclei (A >100) at the proton drip-line has been attempted. The characteristic charged-particle radioactivity of these nuclei (alpha decay, ground-state proton decay, and β-delayed proton emission) has been used to tag γ-ray transitions recorded by the highly efficient Eurogam spectrometer. The ^{58}Ni + ^{54}Fe and ^{58}Ni + ^{58}Ni fusion-evaporation reactions, at a beam energy of 240 MeV, have been used to populate specific states of these neutron-deficient nuclei and results are presented for ^{108,109}Te, ^{109}I, and ^{113}Xe, where γ-ray transitions have been identified. In the case of ^{109}I, this represents the first observation of γ-rays from a ground-state proton emitter.

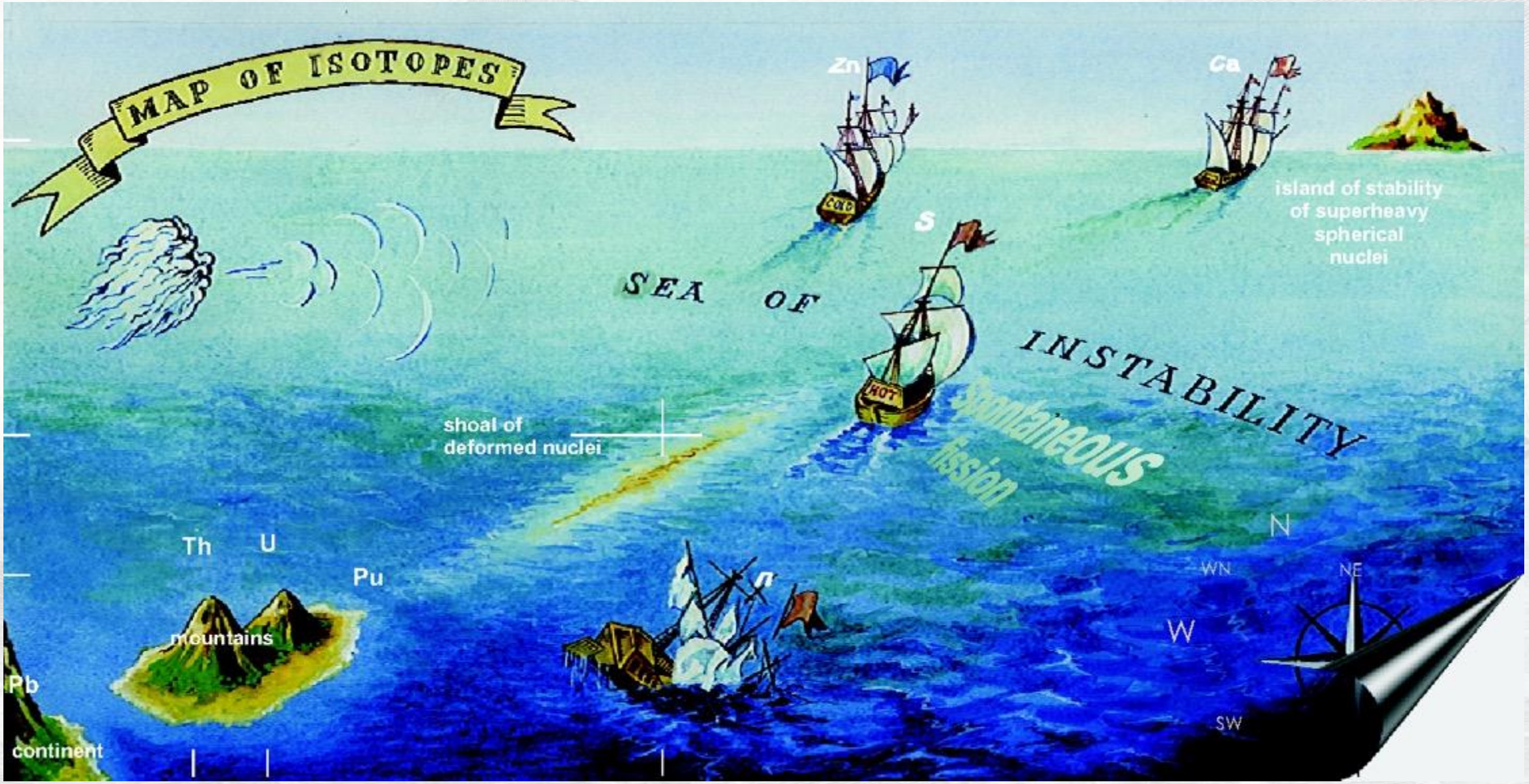
PACS number(s): 21.10.Re, 27.60.+j, 23.20.Lv





RDT: Liverpool vs Darmstadt

Superheavies: the Island of Stability



Reif für die Insel

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 944 (2015) 5–29

www.elsevier.com/locate/nuclphysa

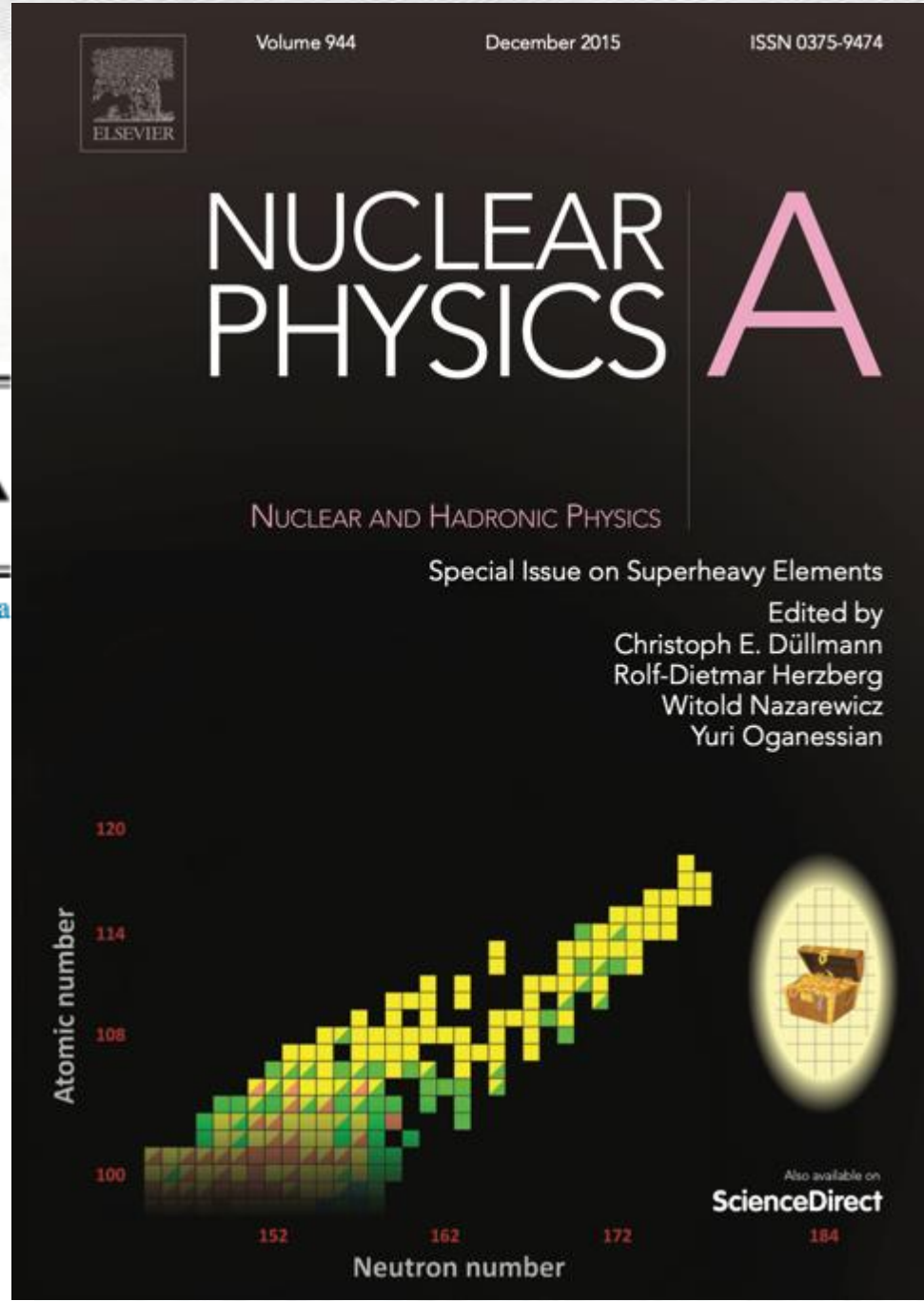
From bohrium to copernicium and beyond SHE research at SHIP

G. Münzenberg [a,b,*]

[a] *GSI Helmholtzzentrum für Schwerionenforschung, Planckstrasse 1, 64291 Darmstadt, Germany*
[b] *Manipal Centre for Natural Sciences, Manipal University, Manipal 576104, Karnataka, India*

Received 15 April 2015; received in revised form 17 May 2015; accepted 14 June 2015

Available online 18 June 2015



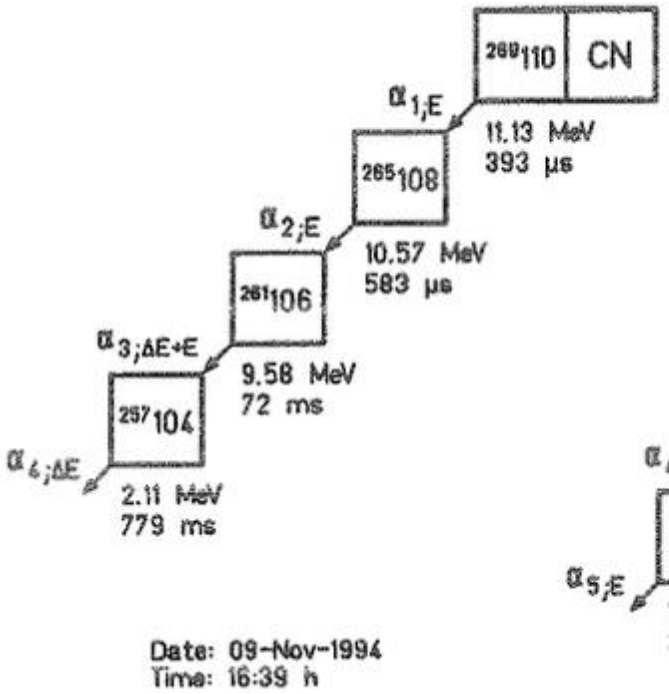
Darmstadtium

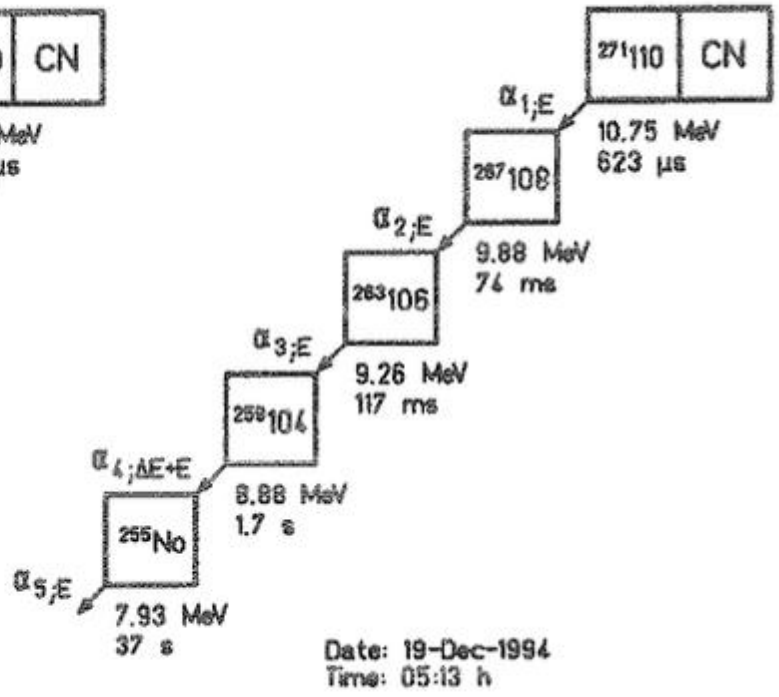
$^{208}Pb + {}^{62}Ni \rightarrow {}^{269}Ds + n$

On Wednesday, November 9, 1994 at 4:39 pm, the first nucleus of element 110 was measured.

Production and Decay of $^{269}110$ and $^{271}110$

S. Hofmann, V. Ninov, F.P. Heßberger, P. Armbruster, H. Folger, G. Münzenberg, H.J. Schött (GSI)
A.G. Popeko, A.V. Yeremin, A.N. Andreyev (FLNR, Dubna)
S. Šaro, R. Janik (Comenius University, Bratislava)
M. Leino (University of Jyväskylä)

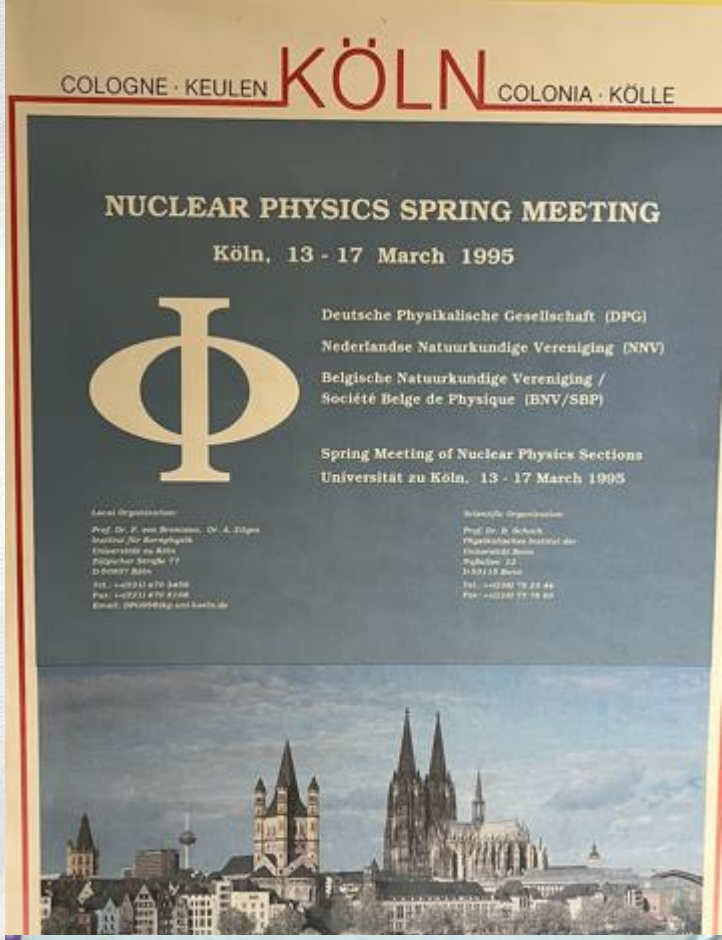




Superheavy Element 111 (Rg)

S. Hofmann, V. Ninov, F. P. Hessberger, P. Armbruster, H. Folger, G. Münzenberg, H. J. Schött, A. G. Popeko, A. V. Yeremin, A. N. Andreyev, S. Śaro, R. Janik, M. Leino.
"The new element 111",
Z. Phys. A 350, 281–282 (1995).

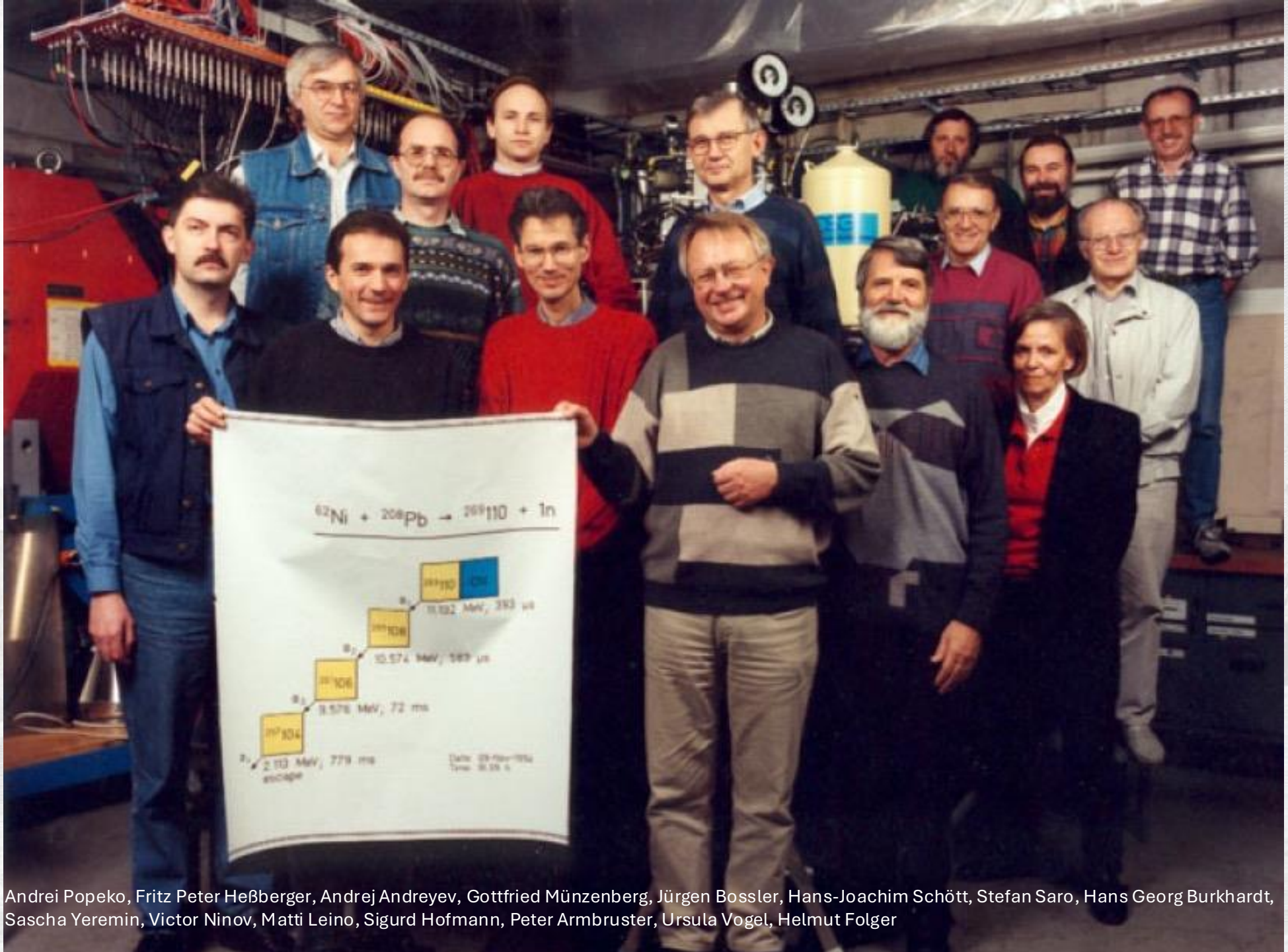
S. Hofmann, F. P. Hessberger, D. Ackermann, G. Münzenberg, S. Antalic, P. Cagarda, B. Kindler, J. Kojouharova, M. Leino, B. Lommel, R. Mann, A. G. Popeko, S. Reshitko, S. Śaro, J. Uusitalo, A. V. Yeremin.
"New results on elements 111 and 112",
Eur. Phys. J. A 14, 147–157 (2002).



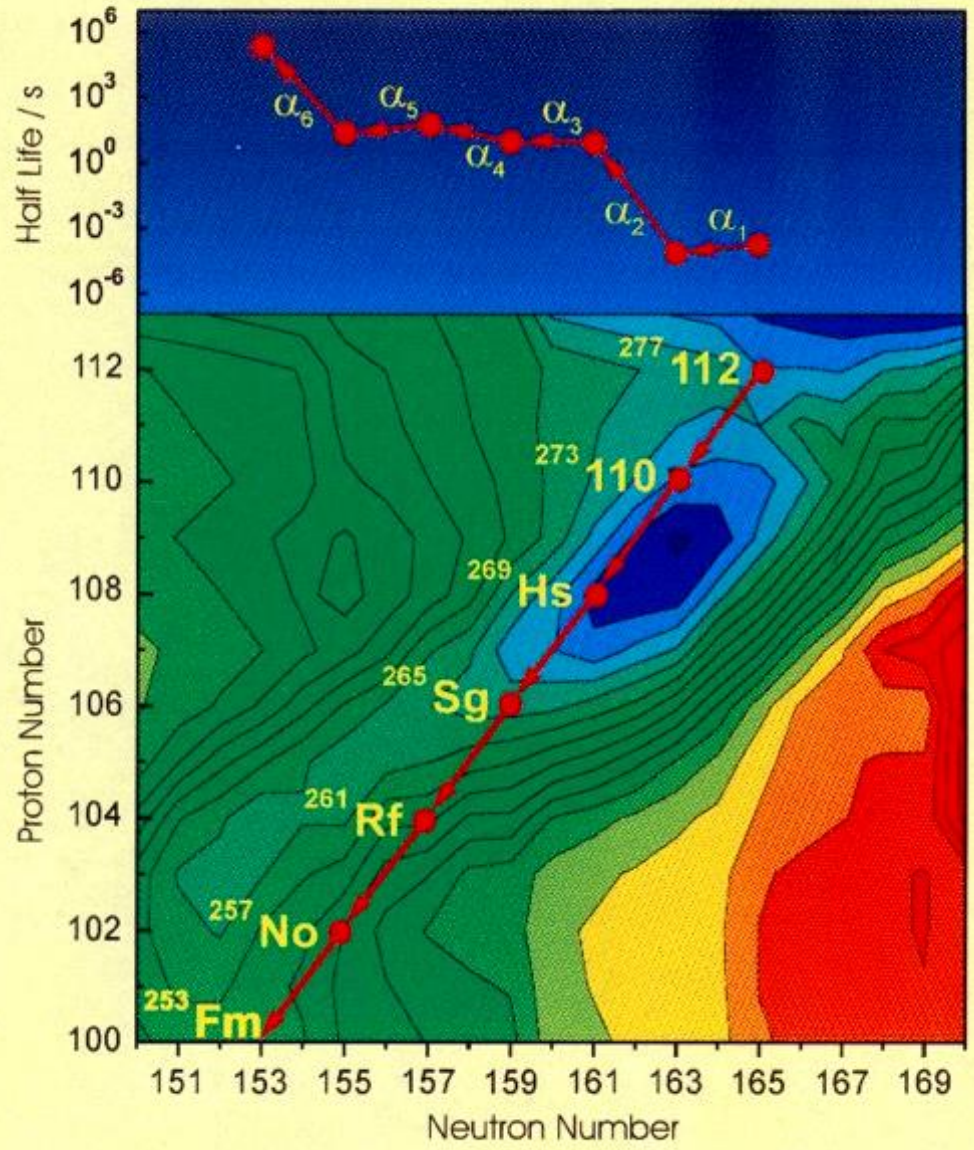
RECOMMENDATION

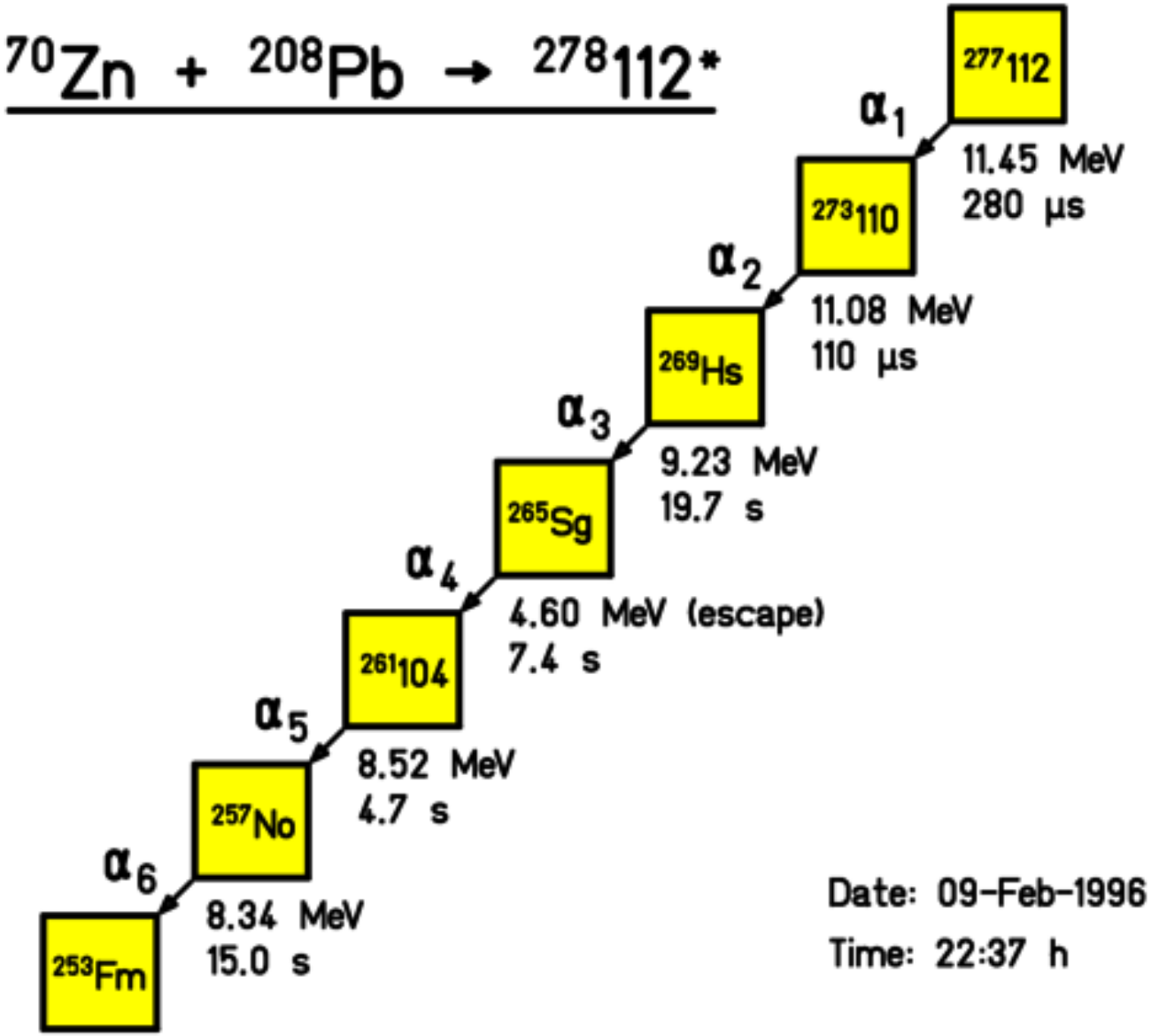
The 2003 JWP report [7] concluded that the criteria for discovery of an element had been fulfilled only in the case of element 111 and this by the collaboration of Hofmann et al. [8,9]. Following this assignment and in accordance with the procedures established by IUPAC for the naming of elements [10], the discoverers at GSI were invited to propose a name and symbol for element 111. The discoverers propose the name roentgenium and the symbol Rg.

Pure Appl. Chem., Vol. 76, No. 12, pp. 2101–2103, 2004



Andrei Popeko, Fritz Peter Heßberger, Andrej Andreyev, Gottfried Münzenberg, Jürgen Bossler, Hans-Joachim Schött, Stefan Saro, Hans Georg Burkhardt, Sascha Yeremin, Victor Ninov, Matti Leino, Sigurd Hofmann, Peter Armbruster, Ursula Vogel, Helmut Folger


Half Life / s
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
α_6
α_5
α_4
α_3
α_2
α_1
Proton Number
112
110
108
106
104
102
100
277 112
273 110
269 Hs
265 Sg
261 Rf
257 No
253 Fm
151 153 155 157 159 161 163 165 167 169
Neutron Number


$^{70}Zn + ^{208}Pb \rightarrow ^{278}112^{*}$
$^{277}112$
α_1
11.45 MeV
280 µs
$^{273}110$
α_2
11.08 MeV
110 µs
^{269}Hs
α_3
9.23 MeV
19.7 s
^{265}Sg
α_4
4.60 MeV (escape)
7.4 s
$^{261}104$
α_5
8.52 MeV
4.7 s
^{257}No
α_6
8.34 MeV
15.0 s
^{253}Fm
Date: 09-Feb-1996
Time: 22:37 h

Element 112: Copernicium, Cn

Pure Appl. Chem., 2009, Vol. 81, No. 7, pp. 1331-1343
doi:10.1351/PAC-REP-08-03-05
Published online 2009-05-19

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY
INORGANIC CHEMISTRY DIVISION

INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS
IUPAC/IUPAP JOINT WORKING PARTY ON DISCOVERY OF ELEMENTS

Discovery of the element with atomic number 112 (IUPAC Technical Report)

Robert C. Barber[1], Heinz W. Gäggeler[2], Paul J. Karol[3], Hiromichi Nakahara[4], Emanuele Vardaci[5] and Erich Vogt[6]*

[1] Department of Physics and Astronomy, University of Manitoba, Manitoba R3T 2N2, Canada
[2] Paul Scherrer Institute, CH-5232 Villigen, Switzerland
[3] Department of Chemistry, Carnegie Mellon University, Pittsburgh, PA 15213, USA
[4] Chemistry Department, Tokyo Metropolitan University, Tokyo 192-03, Japan
[5] University of Naples "Federico II" and Istituto Nazionale di Fisica Nucleare, Napoli, Italy
[6] TRIUMF, Vancouver, BC V6T 1W5, Canada

Abstract: The IUPAC/IUPAP Joint Working Party (JWP) on the priority of claims to the discovery of new elements has reviewed the relevant literature pertaining to several claims. In accordance with the criteria for the discovery of elements previously established by the 1992 IUPAC/IUPAP Transfermium Working Group (TWG), and reiterated by the 1999 and 2003 IUPAC/IUPAP JWPs, it was determined that the 1996 and 2002 claims by the Hofmann et al. research collaborations for the discovery of the element with atomic number 112 at Gesellschaft für Schwerionenforschung (GSI) share in the fulfillment of those criteria. A synopsis of Z = 112 experiments and related efforts is presented. A subsequent report will address identification of higher-Z elements including those of odd atomic number.

Prof. Kazuyuki Tatsumi
President of the Inorganic Chemistry Division, IUPAC
Research Center for Materials Science
Nagoya University
Furo-cho, Chikusa-ku
Nagoya, 464-8602
JAPAN

Re: Naming of the element with atomic number 112

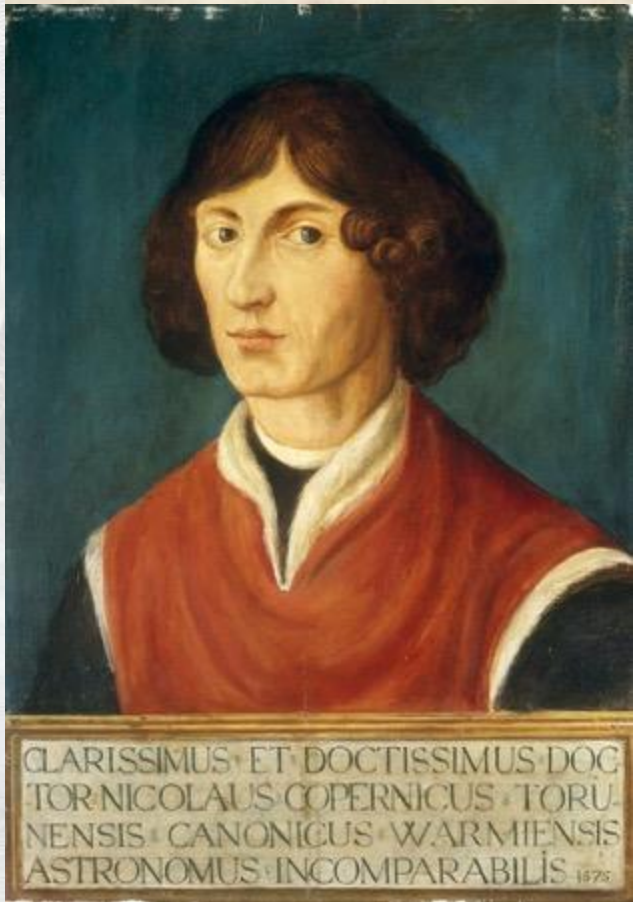
Dear Professor Tatsumi,

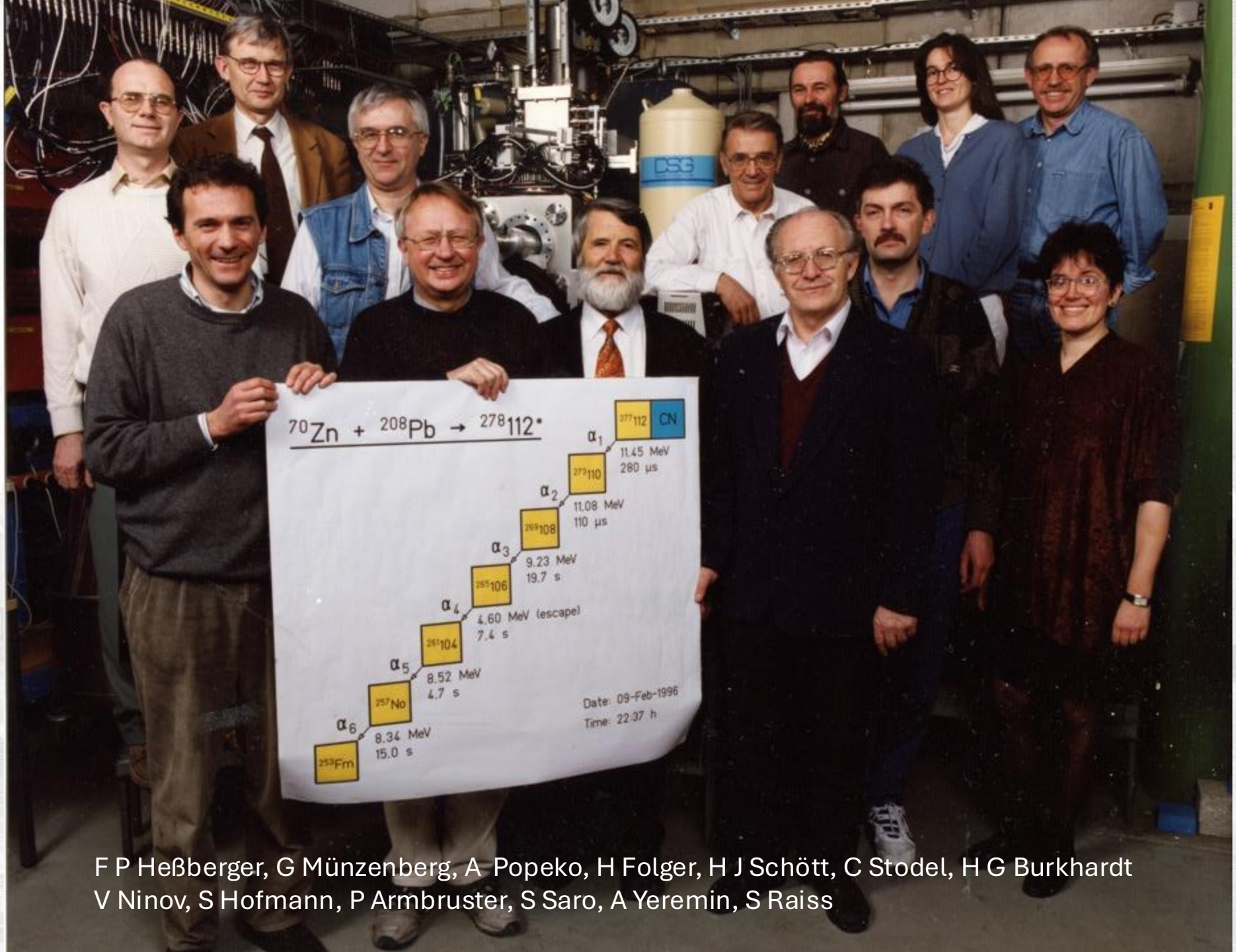
This letter will inform you of our choice of the name for the new element with atomic number 112.

For the name we propose "copernicium", symbol "Cp".

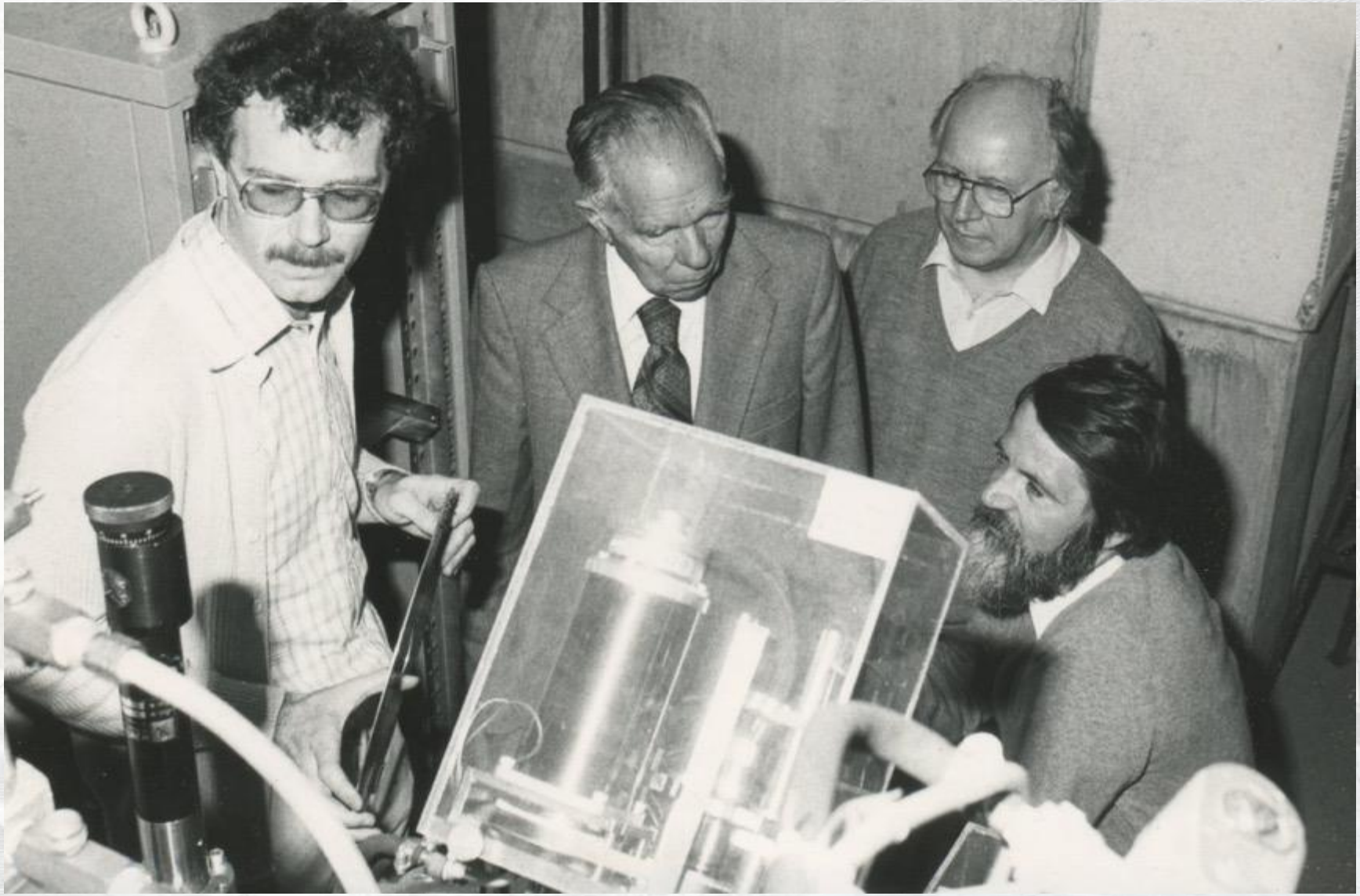
The justification is as follows:

With our suggestion we want to honour a scientist, an astronomer, Nicolaus Copernicus, who lived in the period of the transition from the middle ages to modern times. He was born on February 19th, 1473, in Toruń, Poland, and died on May 24th, 1543, in Frombork/Frauenburg. His work was of exceptional influence on the political and philosophical thinking of people and on the rise of modern science based on results of experiments.





F P Heßberger, G Münzenberg, A Popeko, H Folger, H J Schött, C Stodel, H G Burkhardt
V Ninov, S Hofmann, P Armbruster, S Saro, A Yeremin, S Raiss

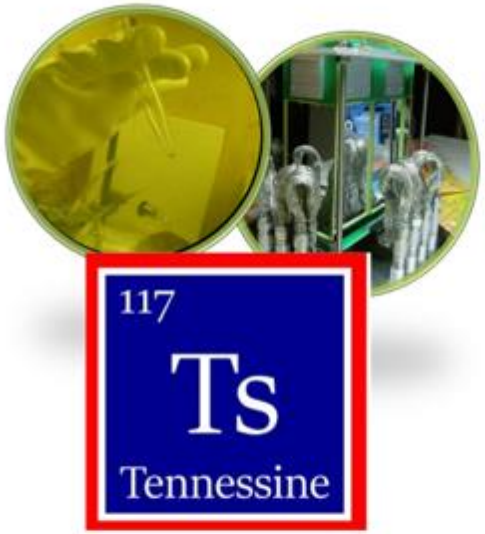


Visit by Glenn Seaborgs at SHIP (July 3rd 1981)
F.P. Heßberger, Glenn Seaborg, Günther Herrmann, P. Armbruster

What engages the public in science?

- Better lives
- Economic benefits
- Health benefits
- Excitement ★

Importance of Basic Research



WOW !!!

Super Heavy Elements and Nuclei
made with ORNL materials and studied with ORNL-UTK data ACQ
(WOW: 200,000 letters to IUPAC/IUPAP about naming element 117)

LBNL Dec 2025

Krzysztof Rykaczewski

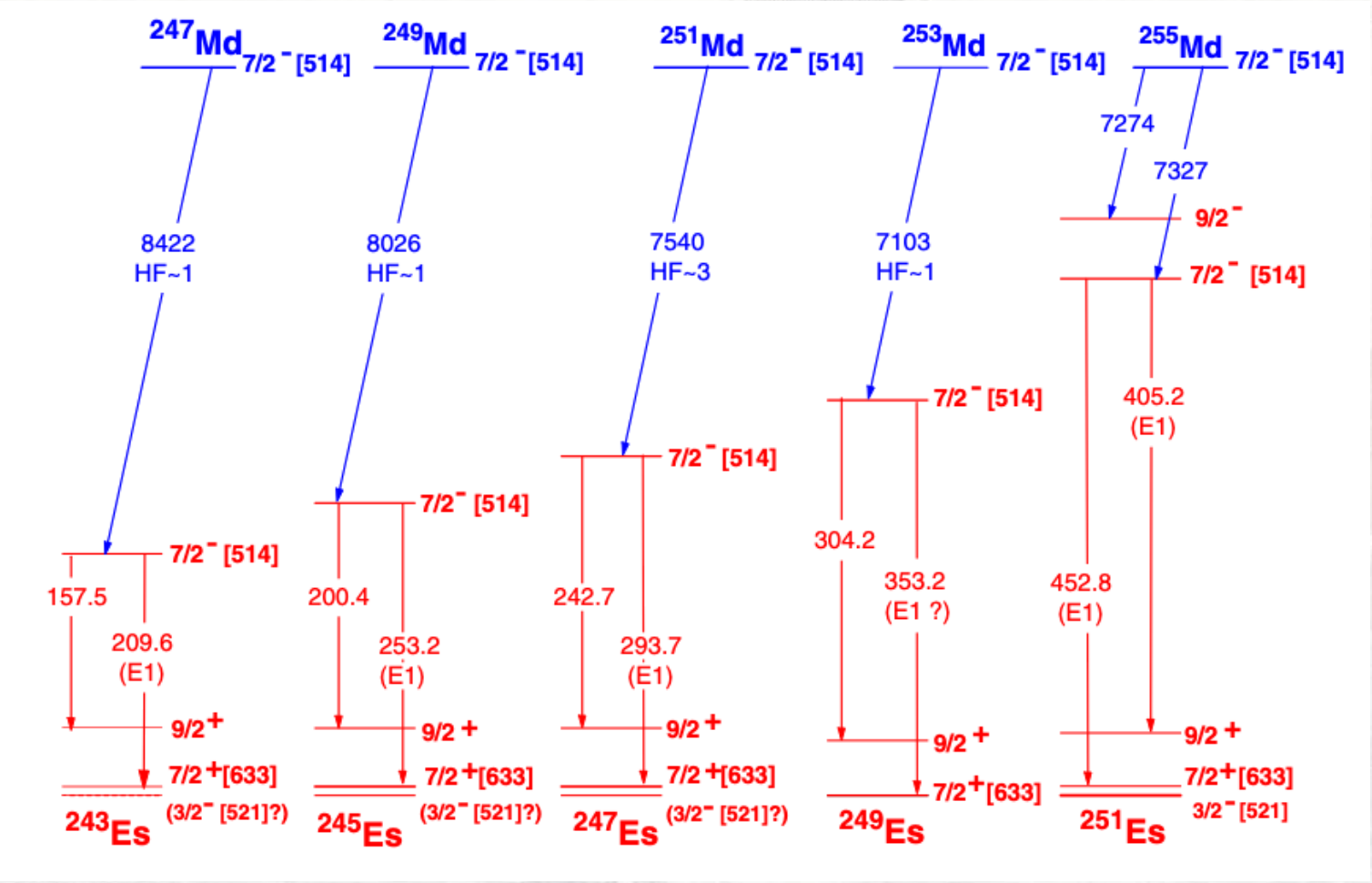
Motorhead fans want newly discovered periodic element named after Lemmy

23/2/26

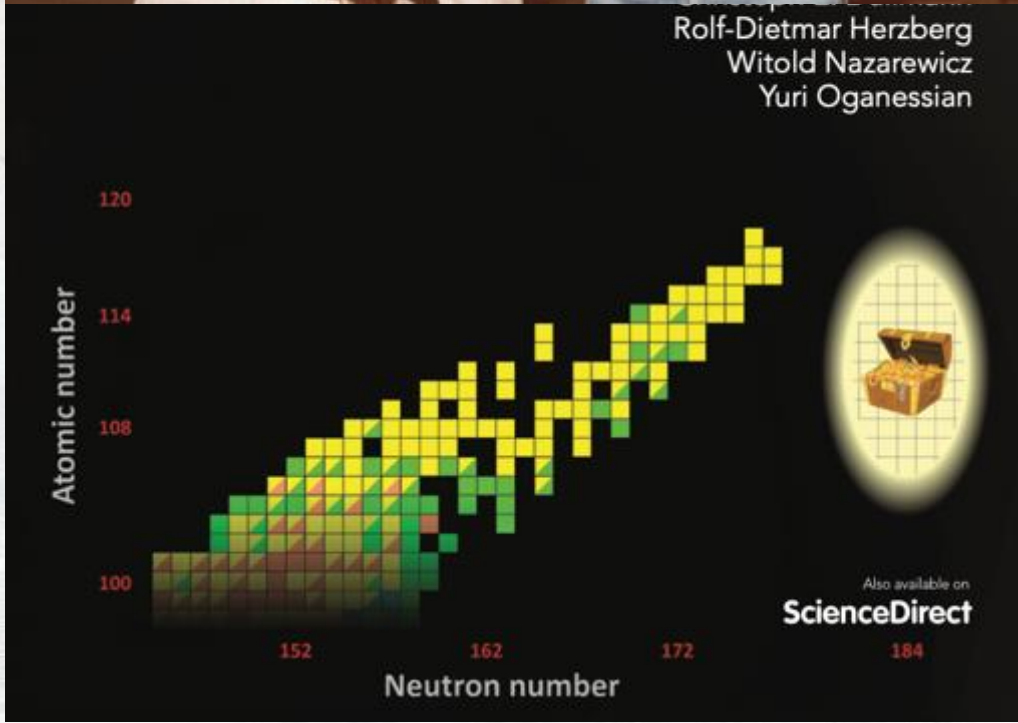
156.587

verified signatures

Spectroscopy



E.g.: Heßberger F P et al 2005 Eur. Phys. J. A 26 233
and many more



Let’s put Lasers on our SHIP

Wikimedia – US NAVY

Laserspectroscopy at SHIP - timeline

In gas-cell (RADRIS)

- First principal idea from Hartmut Backe / Werner Lauth et al. Based on the work on fission isomers at Mainz/Heidelberg [https://doi.org/10.1103/PhysRevLett.80.920]
- 2004/2005/2006/2007/2012 test beamtimes, setup traveling from Mainz
- From 2012 permanent installation of laser at GSI
- 2014/2015 beamtime – 2015 No transition discovered
- Beamtime 2016, 2019,2020, 2021, 2022, 2024, 2025
  - More nobelium isotopes, fermium & californium isotopes

In-gas-jet (JetRIS)

- 2017: started project on gas-jet laser spectroscopy
- 2019: first test beamtime
- 2022: ground state of No-254 in-jet spectroscopy
- 2025: 266ms 8- K isomer in No-254 with laser spectroscopy

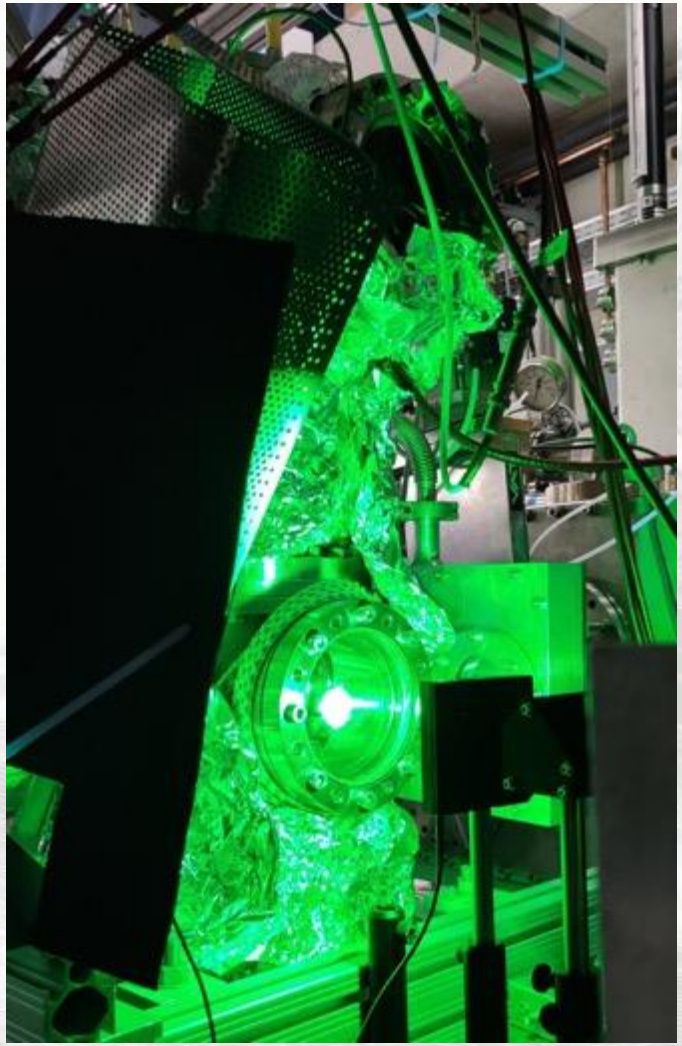
RADRIS

LETTER

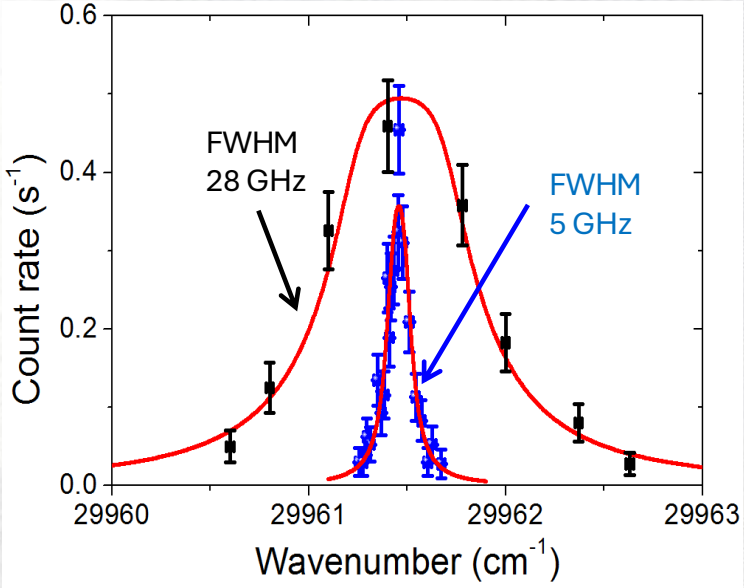
doi:10.1038/nature19345

Atom-at-a-time laser resonance ionization spectroscopy of nobelium

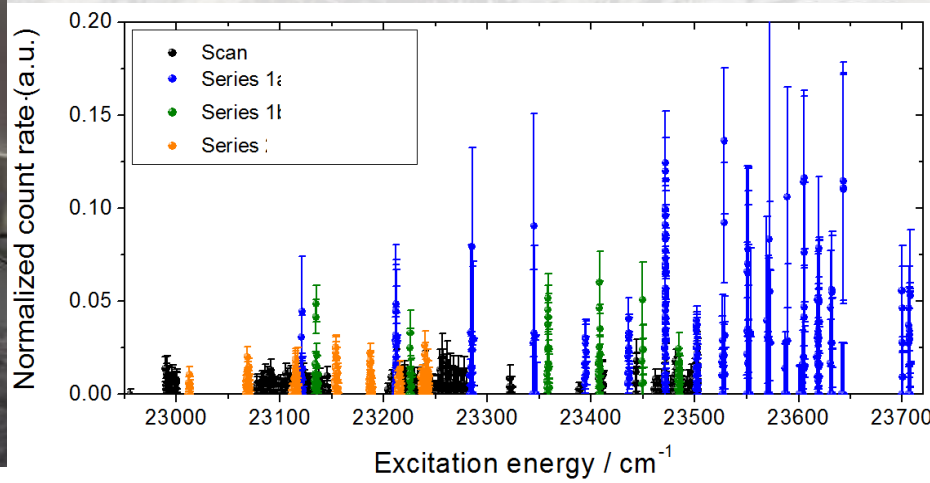
Mustapha Laatiaoui[1,2], Werner Lauth[3], Hartmut Backe[3], Michael Block[1,2,4], Dieter Ackermann[2]†, Bradley Cheal[5], Premaditya Chhetri[6], Christoph Emanuel Düllmann[1,2,4], Piet Van Duppen[7], Julia Even[1]†, Rafael Ferrer[7], Francesca Giacoppo[1,2], Stefan Götz[1,2,4], Fritz Peter Heßberger[1,2], Mark Huyse[7], Oliver Kaleja[2,8], Jadambaa Khuyagbaatar[1,2], Peter Kunz[9], Felix Lautenschläger[6], Andrew Kishor Mistry[1,2], Sebastian Raeder[1,2,7], Enrique Minaya Ramirez[1]†, Thomas Walther[6], Calvin Wraith[5] & Alexander Yakushev[1,2]

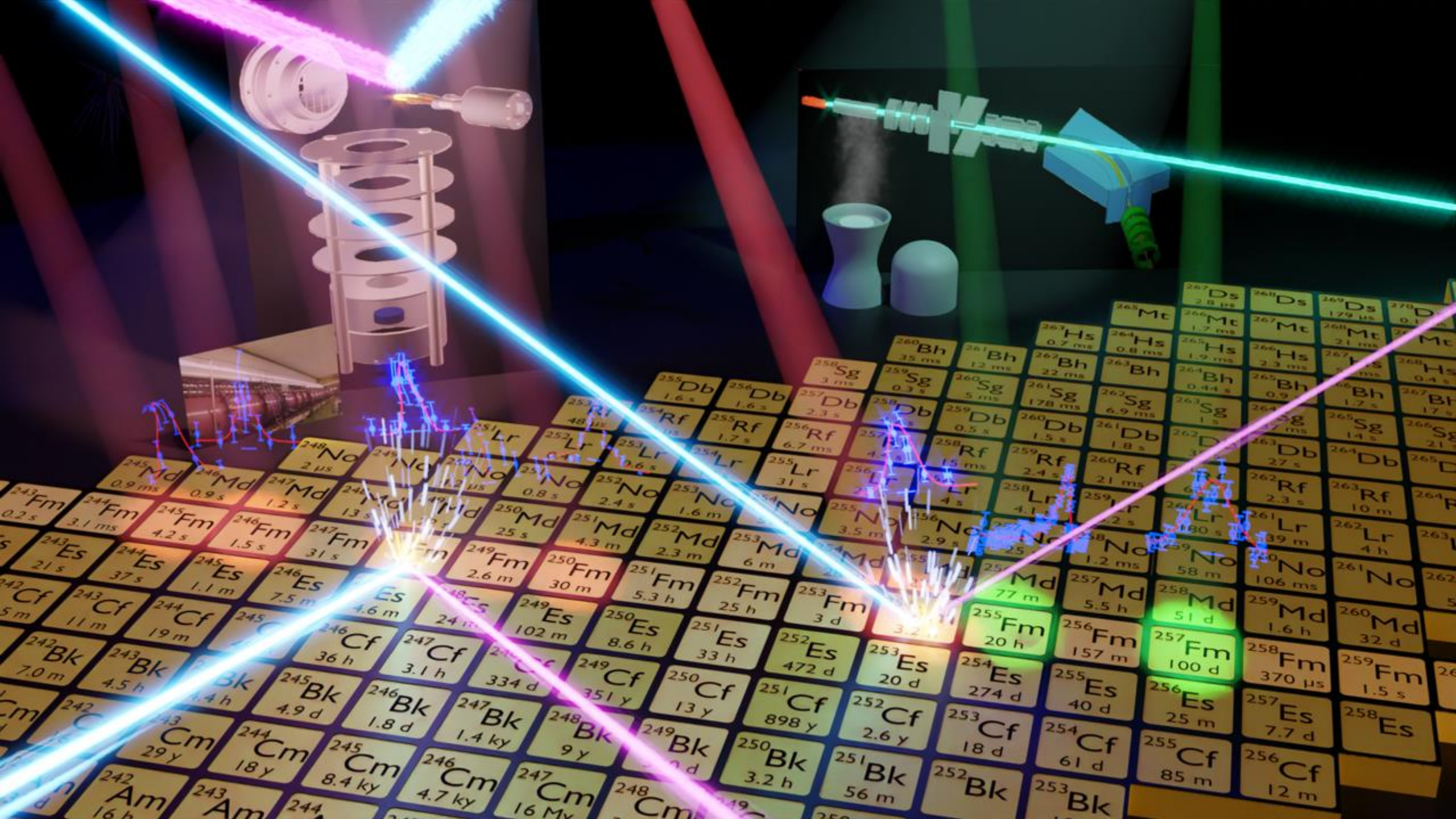


Nobelium resonance 2015



Rydberg series in Nobelium





The Fm chain of isotopes

Article

Smooth trends in fermium charge radii and the impact of shell effects

https://doi.org/10.1038/s41586-024-08062-z

Received: 20 December 2023

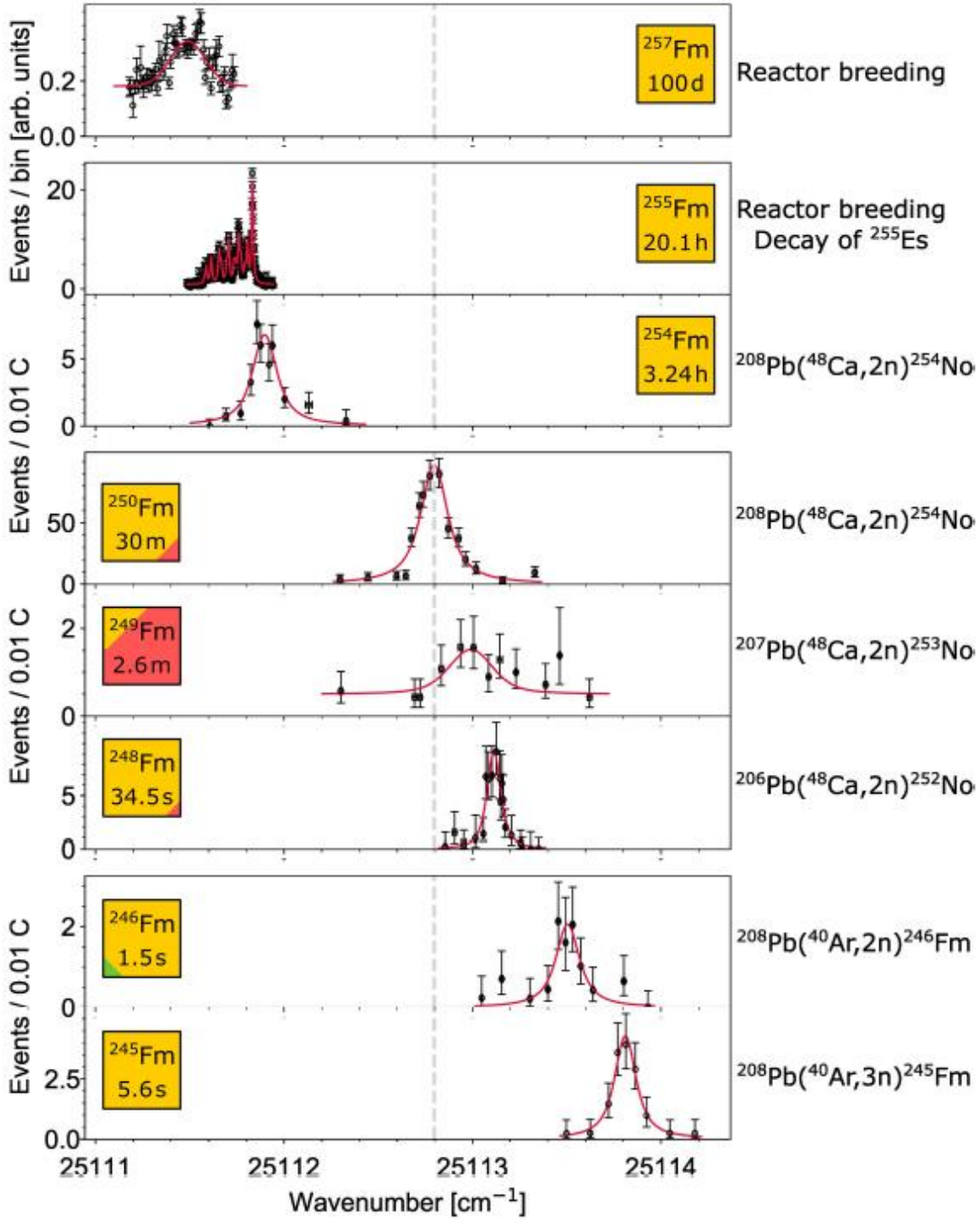
Accepted: 17 September 2024

Published online: 30 October 2024

Open access

Check for updates

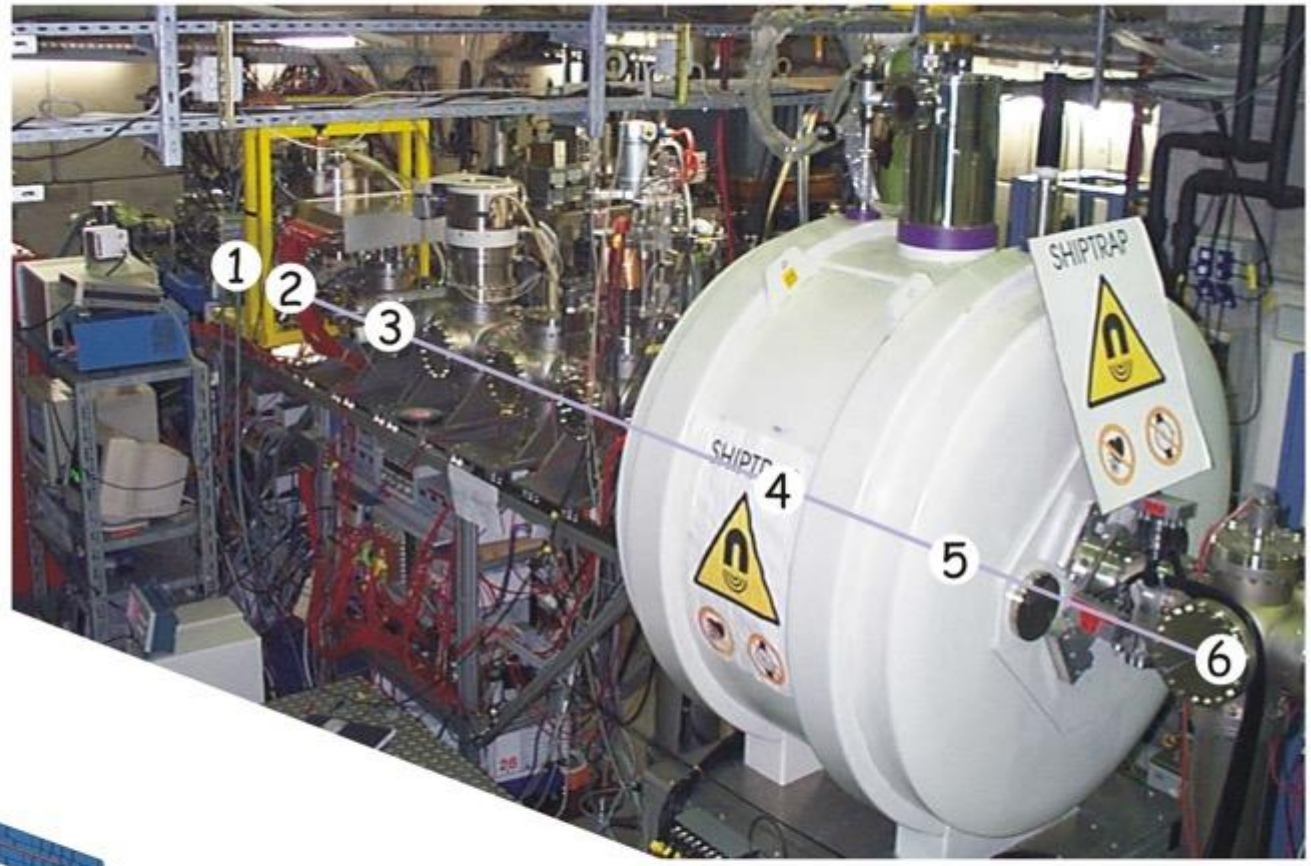
Jessica Warbinek[1,2,3,28] ✉, Elisabeth Rickert[1,2,3], Sebastian Raeder[1,3] ✉, Thomas Albrecht-Schönzart[4], Brankica Andelic[1,3,5], Julian Auler[2], Benjamin Bally[6], Michael Bender[7], Sebastian Berndt[2], Michael Block[1,2,3], Alexandre Brizard[8], Pierre Chauveau[1,3], Bradley Cheal[9], Premaditya Chhetri[1,3,10], Arno Claessens[10], Antoine de Roubin[10], Charlie Devlin[9], Holger Dorrer[2], Christoph E. Düllmann[1,2,3], Julie Ezold[11], Rafael Ferrer[10], Vadim Gadelshin[12], Alyssa Gaiser[13,14], Francesca Giacoppo[1,3], Stephane Goriely[15], Manuel J. Gutiérrez[1,3], Ashley Harvey[11], Raphael Hasse[12], Reinhard Heinke[12], Fritz-Peter Heßberger[1], Stephane Hilaire[16,17], Magdalena Kaja[12], Oliver Kaleja[1,18], Tom Kieck[1,2,3], EunKang Kim[2], Nina Kneip[12], Ulli Köster[19], Sandro Kraemer[10], Mustapha Laatiaoui[2], Jeremy Lantis[2], Nathalie Lecesne[8], Andrea Tzeitel Loria Basto[2,3], Andrew Kishor Mistry[1,20,21], Christoph Mokry[2,3], Iain Moore[22], Tobias Murböck[1,3], Danny Münzberg[1,2,3], Witold Nazarewicz[13,23], Thorben Niemeyer[12], Steven Nothhelfer[1,2,3], Sophie Péru[16,17], Andrea Raggio[22], Paul-Gerhard Reinhard[24], Dennis Renisch[2,3], Emmanuel Rey-Herme[25], Jekabs Romans[10], Elisa Romero Romero[2], Jörg Runke[1,2], Wouter Ryssens[15], Hervé Savajols[8], Fabian Schneider[2], Joseph Sperling[4], Matou Stemmler[12], Dominik Studer[1,3,12], Petra Thörle-Pospiech[2,3], Norbert Trautmann[3], Mitzi Urquiza-González[26,27], Kenneth van Beek[21], Shelley Van Cleve[11], Piet Van Duppen[10], Marine Vandebrouck[25], Elise Verstraelen[10], Thomas Walther[21], Felix Weber[12] & Klaus Wendt[12]

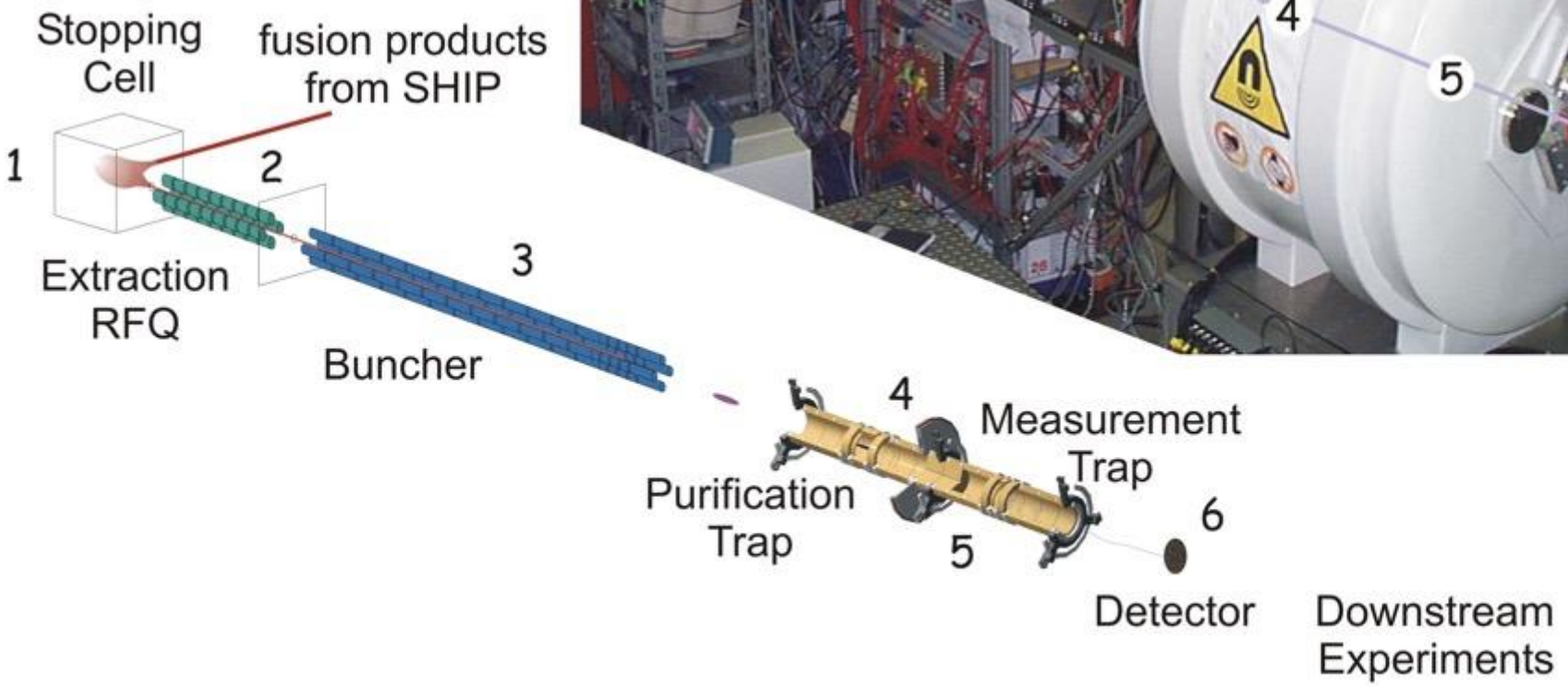


SHIPTRAP setup

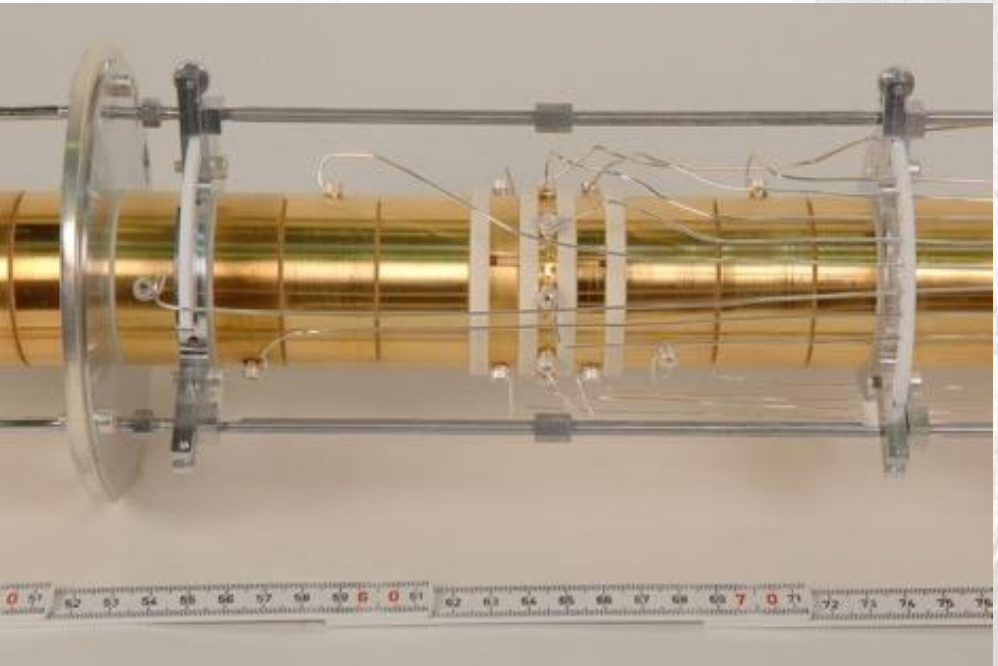
Commissioned 2001

deceleration
cooling
accumulation
purification
storage





SHIPTRAP

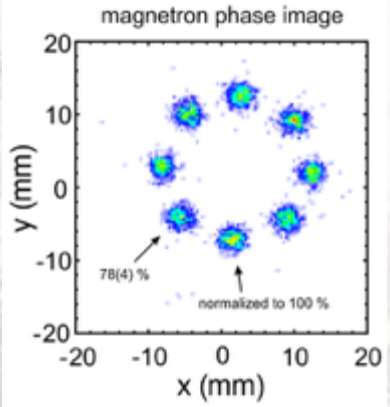


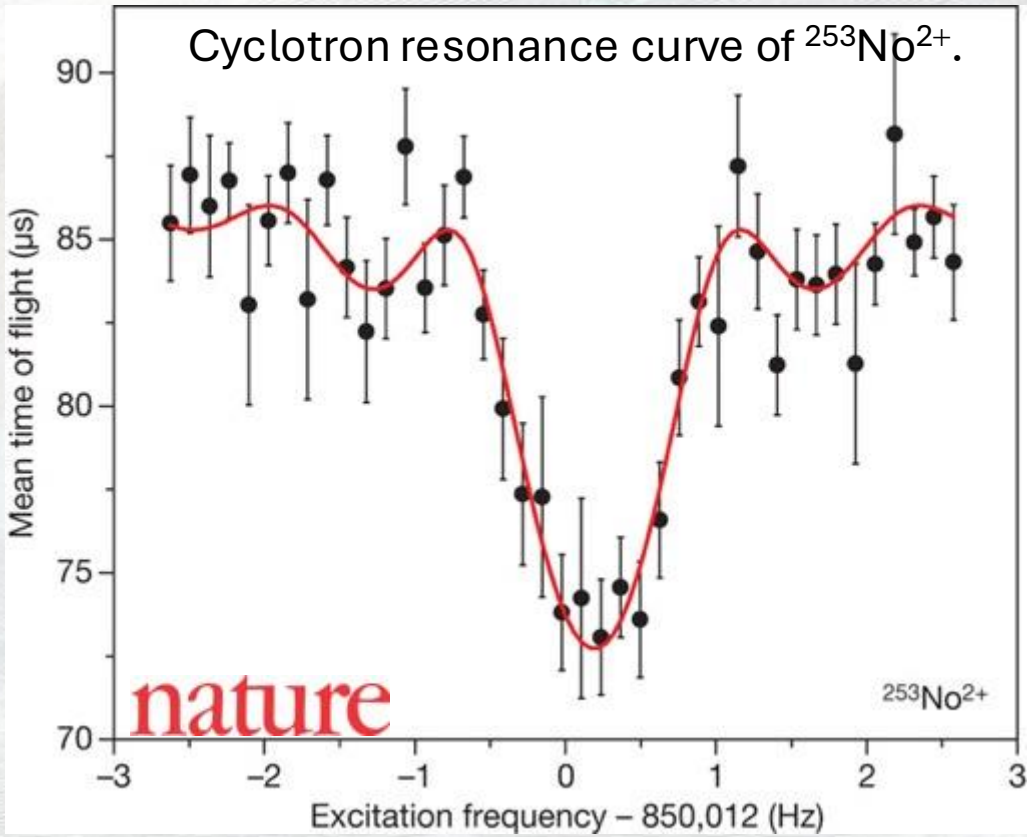
LETTER

doi:10.1038/nature19345

Atom-at-a-time laser resonance ionization spectroscopy of nobelium

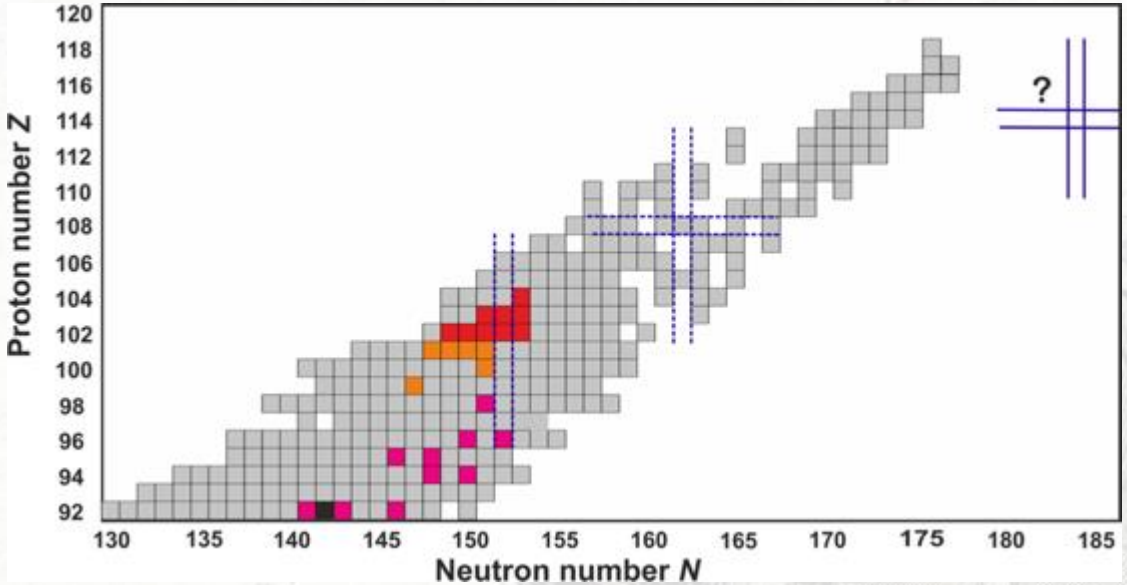
Mustapha Laatiaoui[1,2], Werner Lauth[3], Hartmut Backe[3], Michael Block[1,2,4], Dieter Ackermann[2]†, Bradley Cheal[5], Premaditya Chhetri[6], Christoph Emanuel Düllmann[1,2,4], Piet Van Duppen[7], Julia Even[1]†, Rafael Ferrer[7], Francesca Giacoppo[1,2], Stefan Götz[1,2,4], Fritz Peter Heßberger[1,2], Mark Huyse[7], Oliver Kaleja[2,8], Jadambaa Khuyagbaatar[1,2], Peter Kunz[9], Felix Lautenschläger[6], Andrew Kishor Mistry[1,2], Sebastian Raeder[1,2,7], Enrique Minaya Ramirez[1]†, Thomas Walther[6], Calvin Wraith[5] & Alexander Yakushev[1,2]





M Block *et al. Nature* **463**, 785-788 (2010) doi:10.1038/nature08774

Direct Mass Measurements of $^{252\text{-}254}$No, $^{254\text{-}256}$Lr, ^{257}Rf



- direct mass spectrometry $Z > 100$ established: SHIPTRAP/GSI 2008
- mass measurements to study nuclear shell structure around $Z = 100$, $N = 152$
- measurements performed with detected rates of ≈ 0.00002/s and 5 detected ions
- high mass resolving power of SHIPTRAP allows identifying nuclear isomers

SHIPTRAP measurements in (trans)actinides:

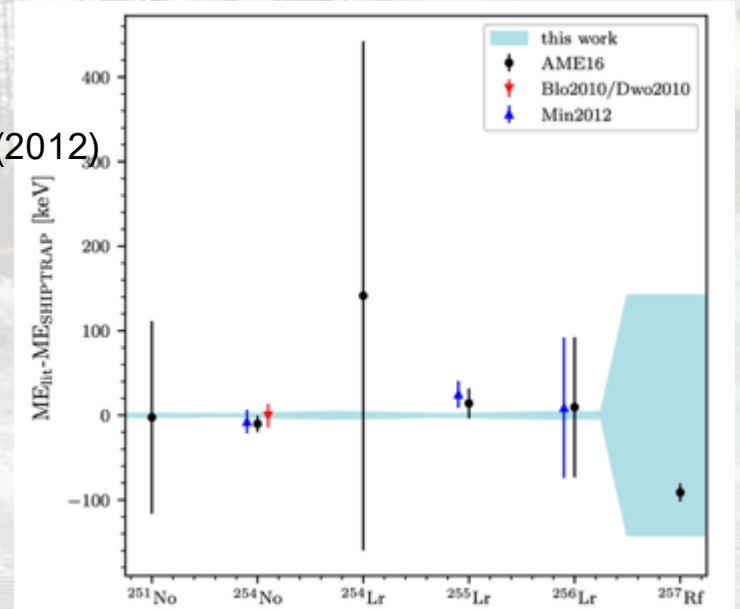
- O. Kaleja, Phys. Rev. C (2022) 054325
- E. Minaya Ramirez et al. Science 337, 1207 (2012)
- M. Block et al., Nature 463, 785 (2010)

TRIGA-TRAP, JGU Mainz:

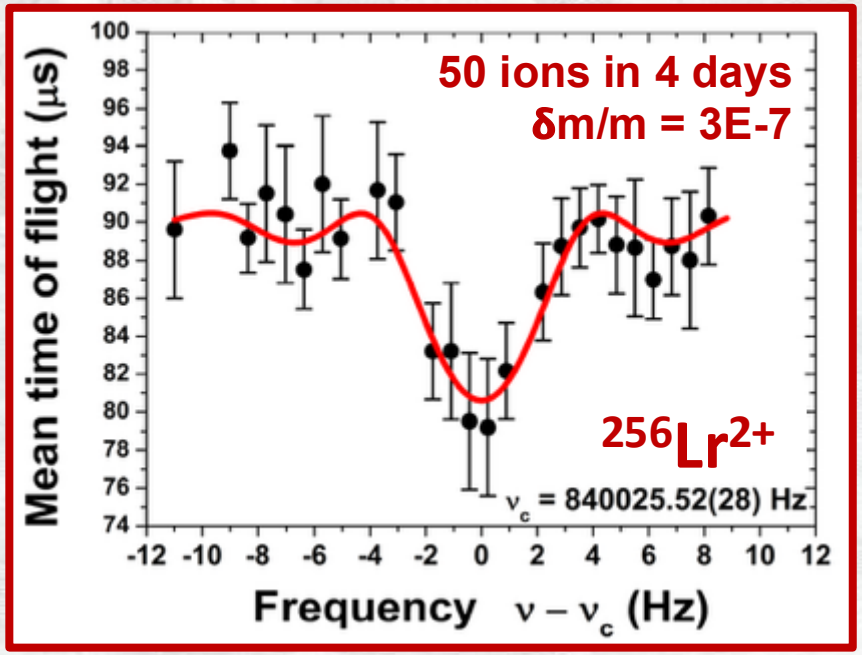
- M. Eibach et al., Phys. Rev. C 89, 064318 (2014)
- S. Chenmarev *et al.*, Eur. Phys. J. A 60, 204 2024

RIKEN/KEK (Japan):

- P. Schury et al., Phys. Rev. C 104, L021304 (2022)
- Y. Ito et al., Phys. Rev. Lett. 120, 152501 (2018)



PhD Brankica Anđelić, Groningen 2022

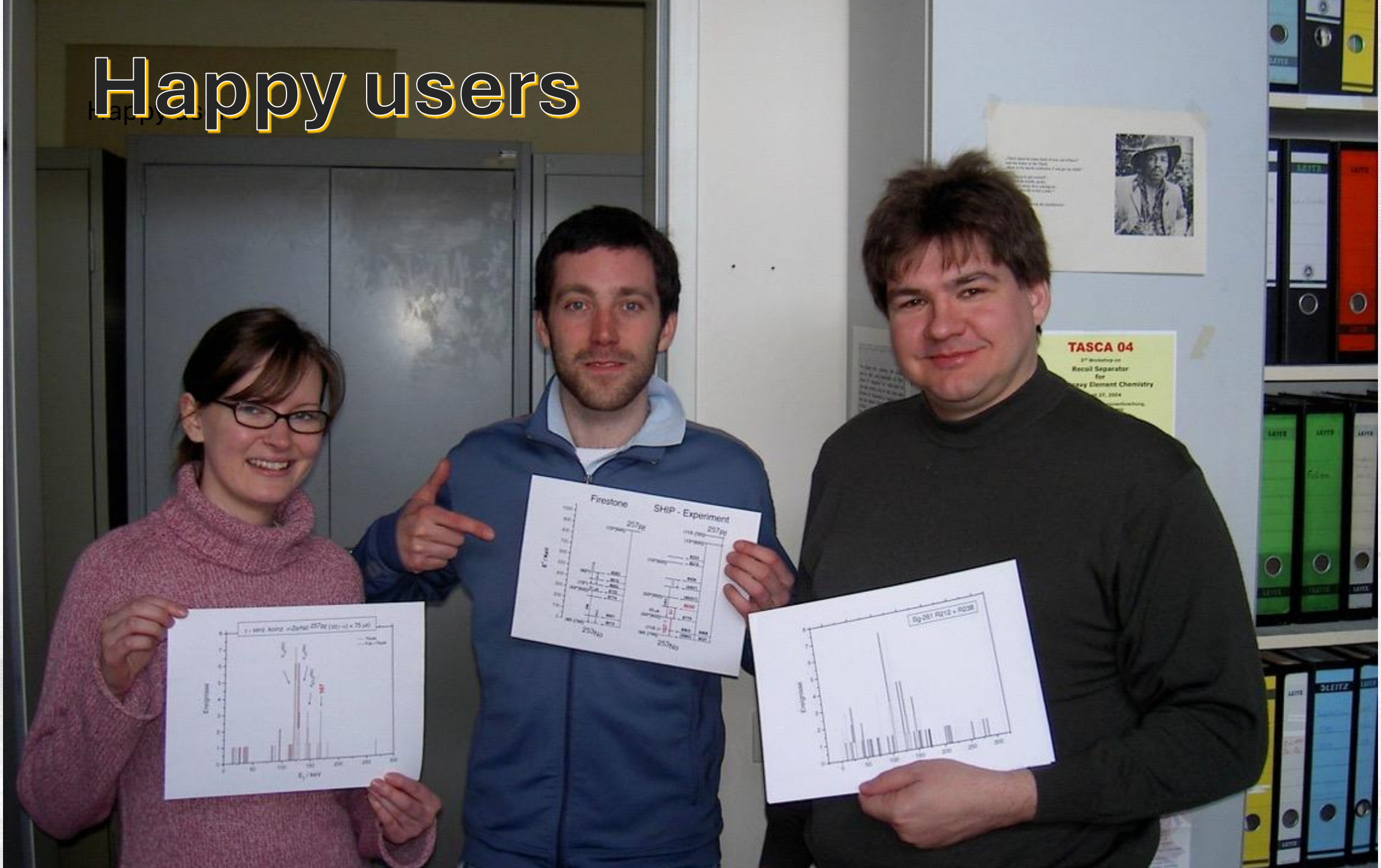


The intrepid Crew

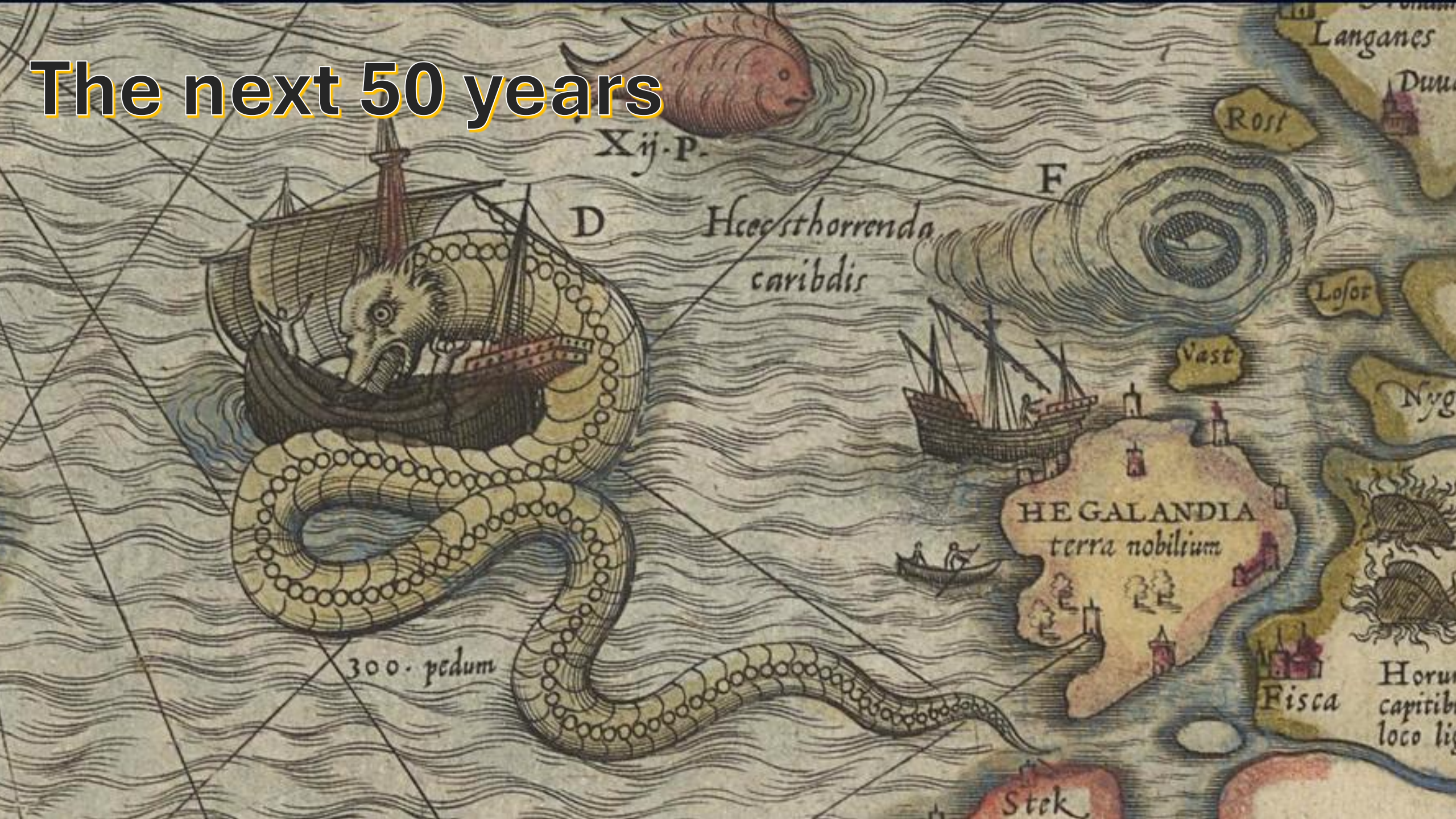
10 years SHIP,
March 1986

Personen (von links nach rechts) Stehend: Jürgen Zienert, Wolfgang Faust, Klaus Güttner, Peter Armbruster, Fritz Peter Heßberger, Sigurd Hofmann, Paul Kienle, Christoph Schmelzer, Heinz Ewald, Karl-Heinz Schmidt, Hans-Joachim Schött. Gottfried Münzenberg
Sitzend/kniend: Izabella Zychor, Hans Geissel, Steffi Lüttges, Bruno Quint, Gerhard Berthes, Eckhard Hanelt

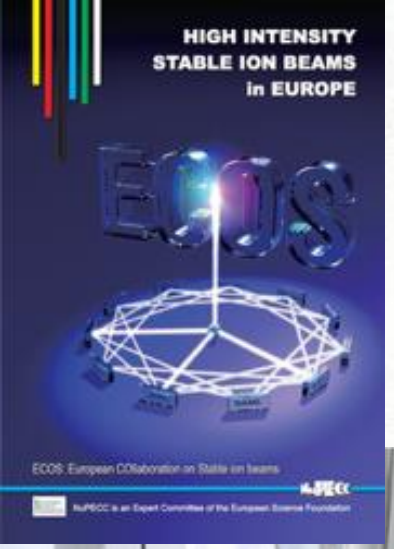
Happy users



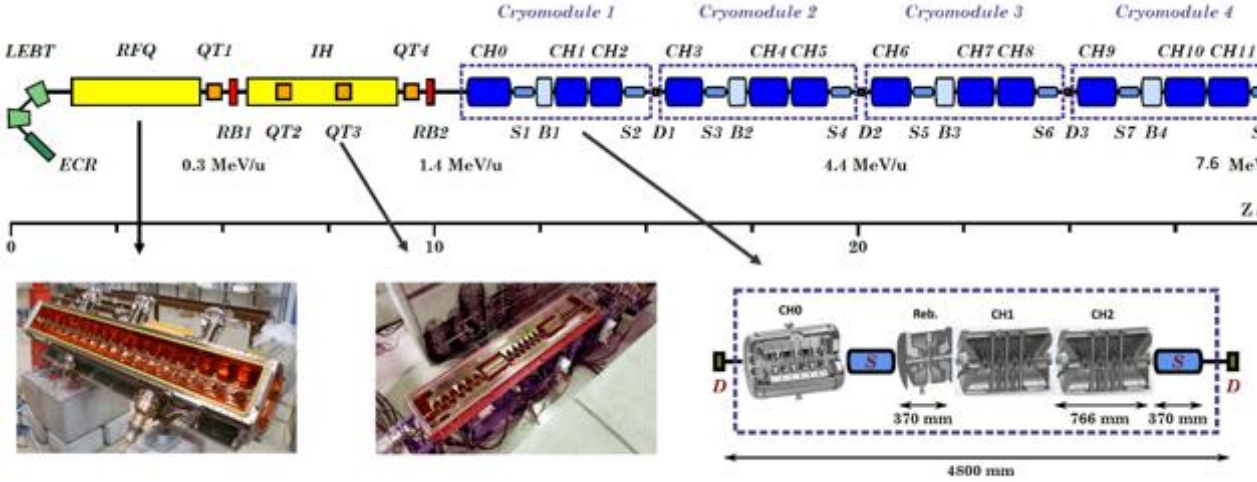
The next 50 years



A FAIR wind in the sails



HELIAC project manager Dr. Maksym Miski-Oglu works at the demonstrator.
Photo: G. Otto, GSI/FAIR



Design parameters sc cw-LINAC		
A/q		≤ 6
Frequency	MHz	216.816
Beam current	mA	≤ 1
Injection energy	MeV/u	1.4
Output energy	MeV/u	3.5-7.6
Length	m	20
CH cavities	#	12
Rebuncher	#	4
Solenoids	#	8

Layout properties

- Short multigap CH cavities: length <1 m), transverse dimensions <0.5 m
- Modular construction: 4 cryomodules each with 3 CH, 1 buncher, 2 solenoids
- Compact Linac design ($E_a \geq 7.1$ MV/m)

Maximum energy per CM

Cryo Module	Output energy (MeV/u			
	A/Z=8.5	A/Z=6	A/Z=3	A/Z=1
CM1	2.6	2.9	3.6	4.6
CM2	3.5	4.2	5.5	7.7
CM3	4.5	5.8	7.8	10.9
CM4	5.55	7.6	10.5	14.6
CM4 + CH12	6	8	11.4	15.6

Thank you!