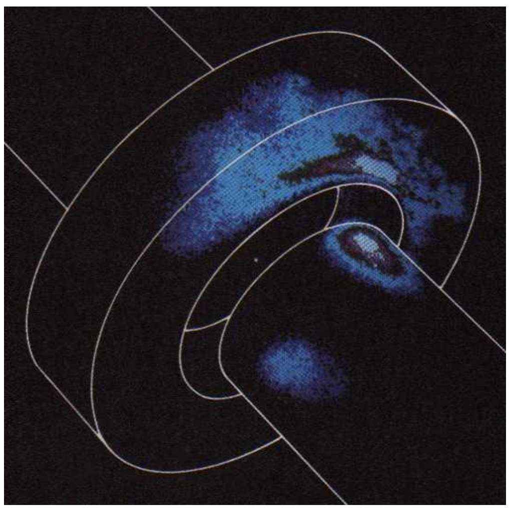
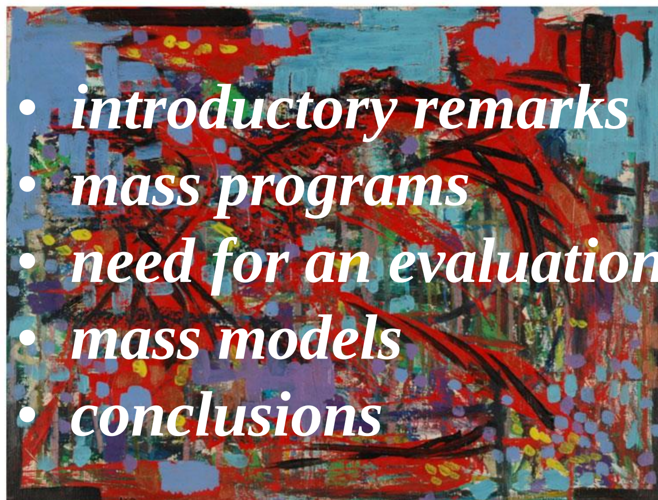
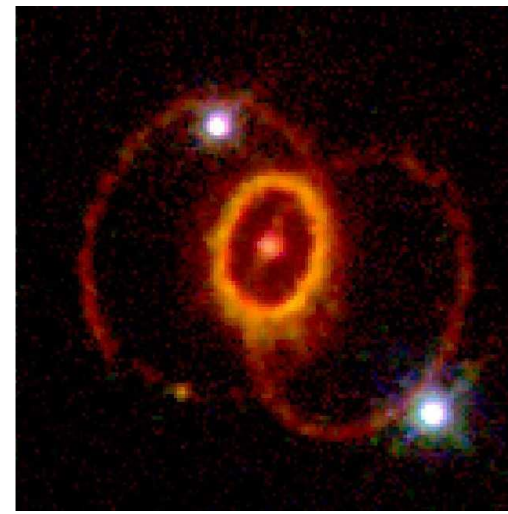
Mass determinations for nuclear and astrophysics

David Lunney - CSNSM (IN2P3/CNRS) - Université de Paris Sud - Orsay





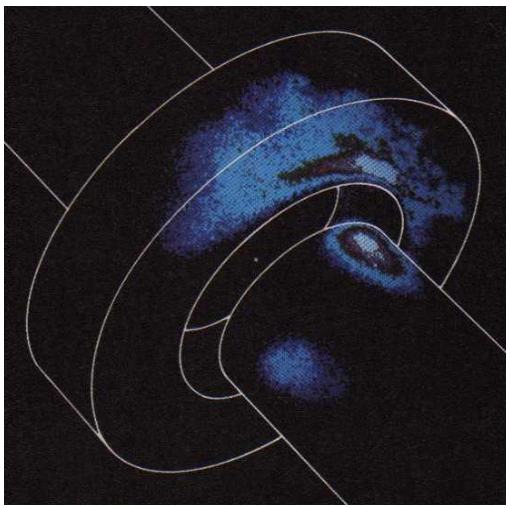
- *introductory remarks*
- *mass programs*
- *need for an evaluation*
- *mass models*
- *conclusions*

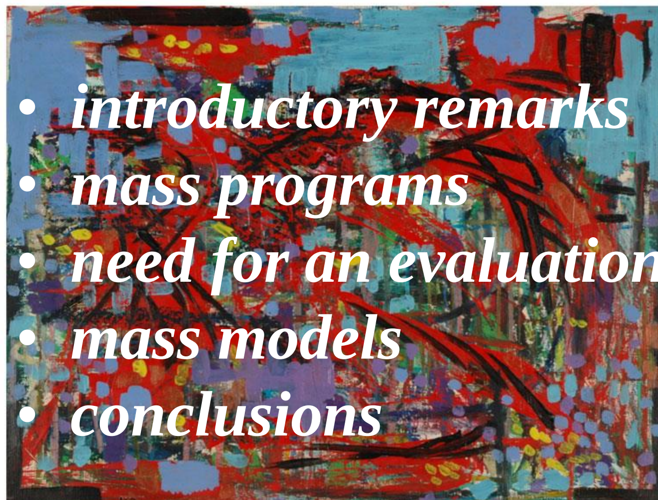


P(ND)^2

Mass determinations for nuclear and astrophysics

David Lunney - CSNSM (IN2P3/CNRS) - Université de Paris Sud - Orsay





- *introductory remarks*
- *mass programs*
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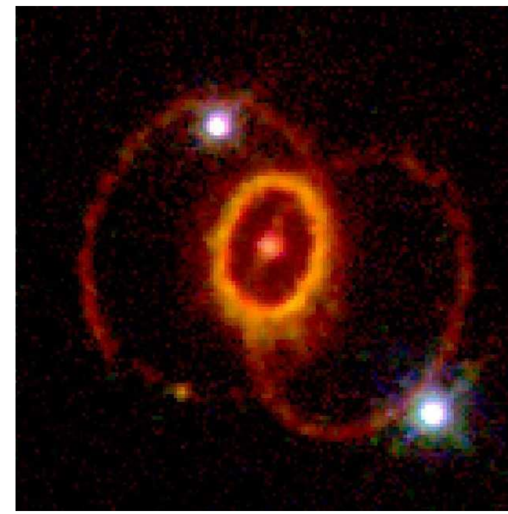
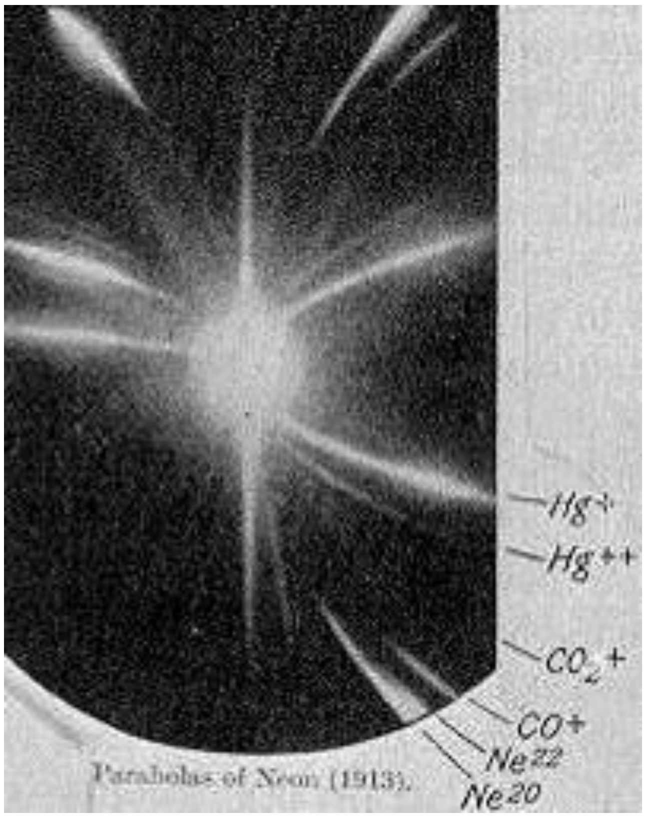


P(ND)^2-2

100 years ago:
The birth of mass spectrometry (and nuclear astrophysics!)

J.J. Thomson (1913):
isotopes $^{20,22}Ne$



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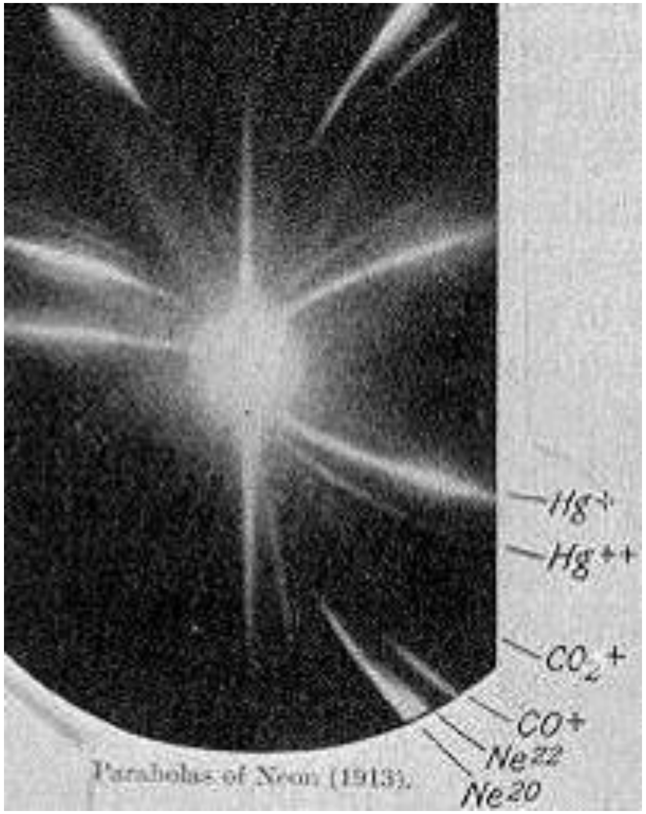


F.W.Aston (~1920's): 212 isotopes & the *packing fraction*

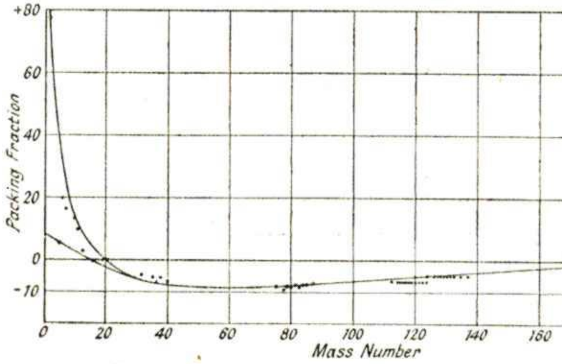
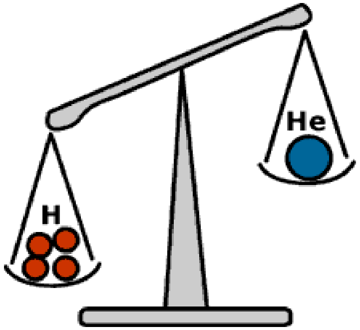


FIG. 20.—Aston's Original Packing Fraction Curve

$$E = mc^2$$



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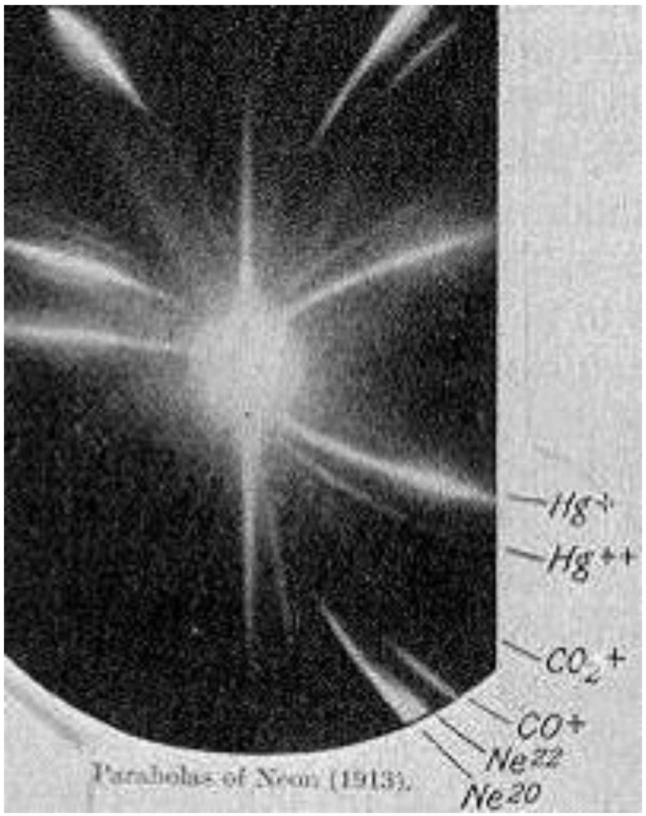

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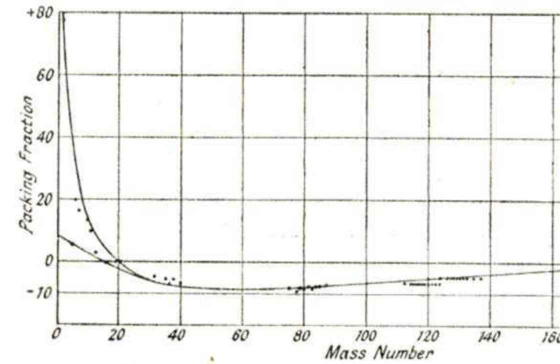
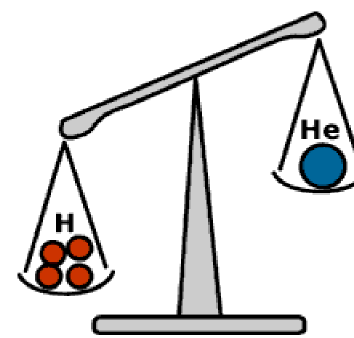


FIG. 20.—Aston's Original Packing Fraction Curve (1

A. Eddington (~1920) Stellar combustion

$E = mc^2$



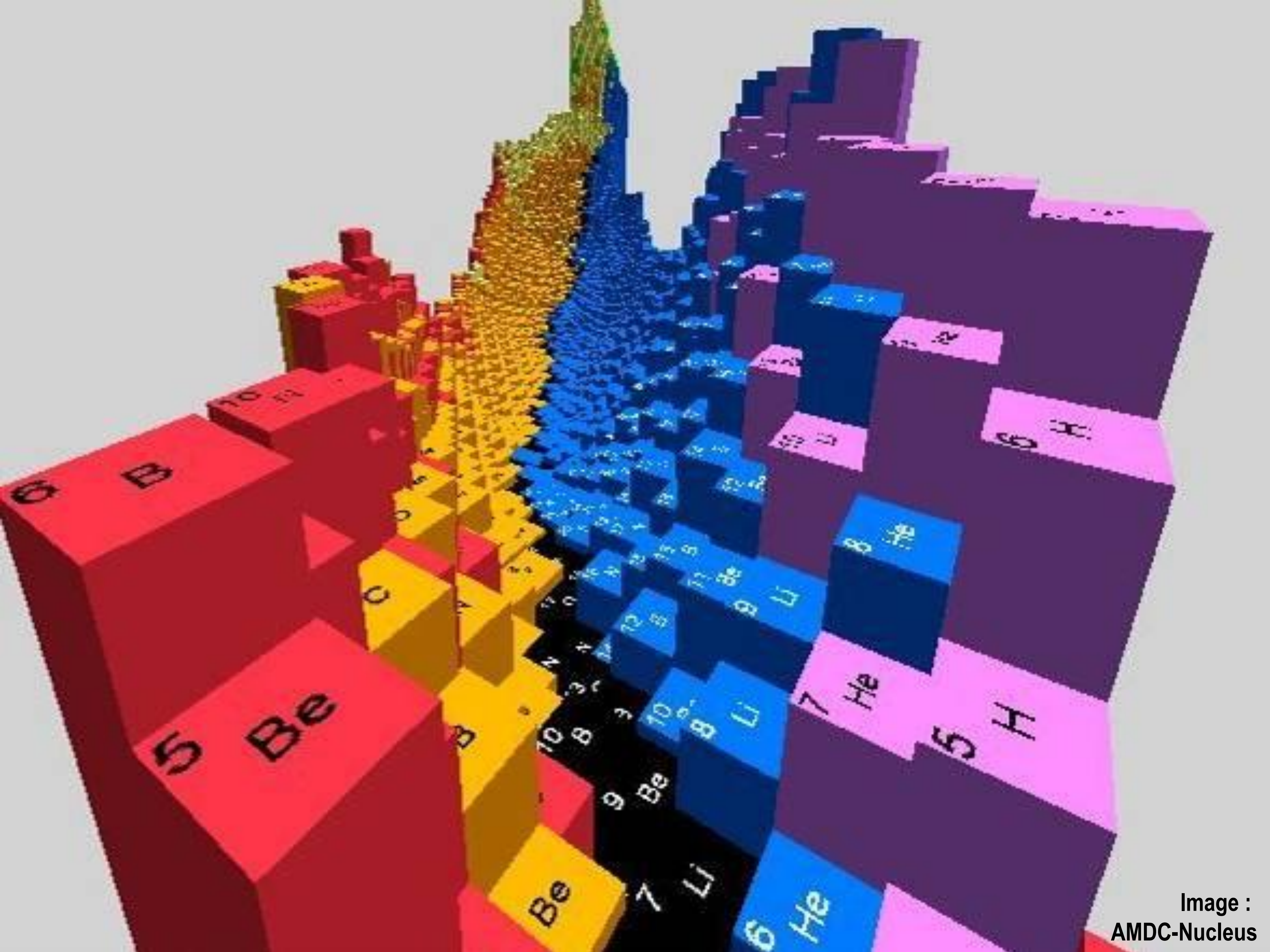
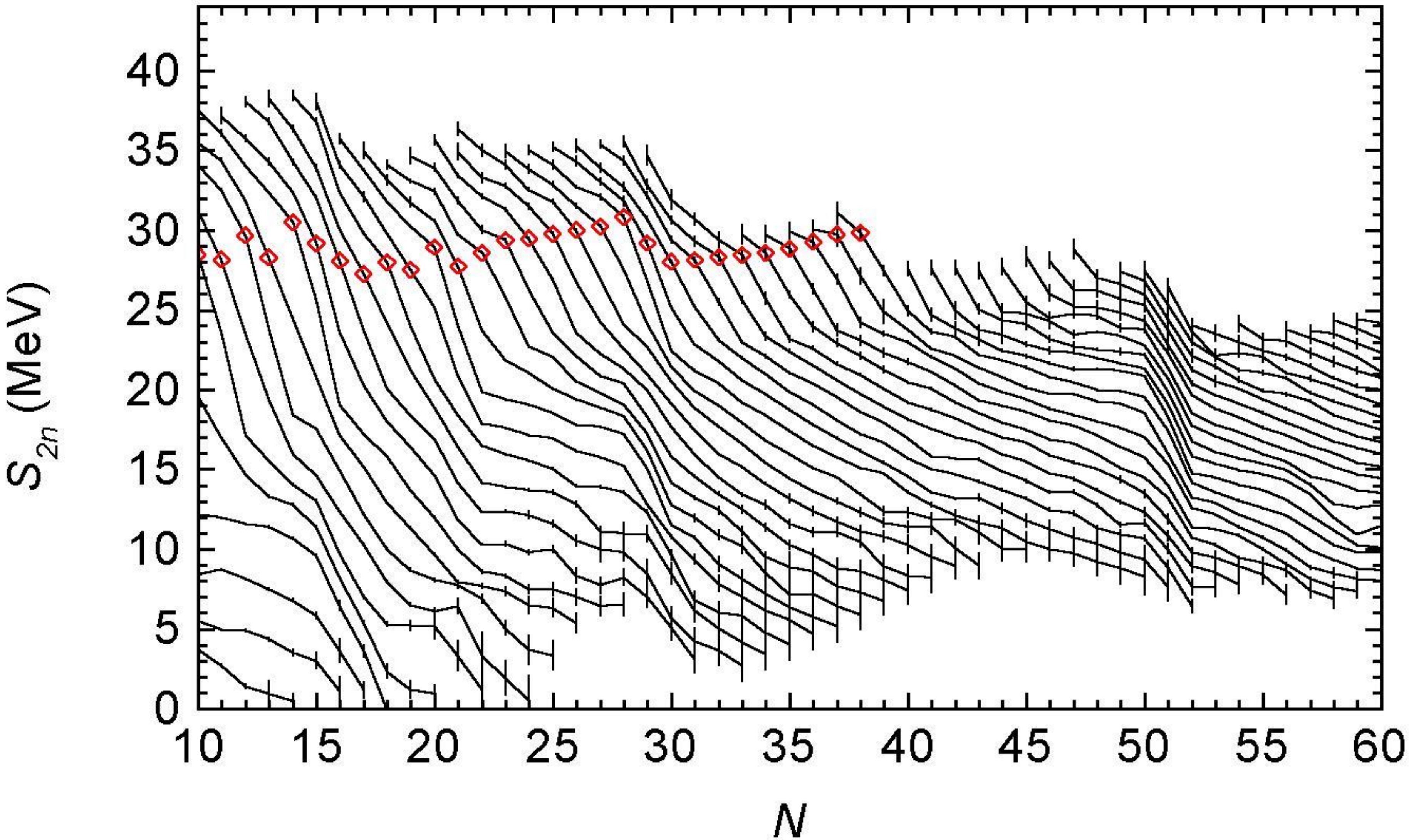
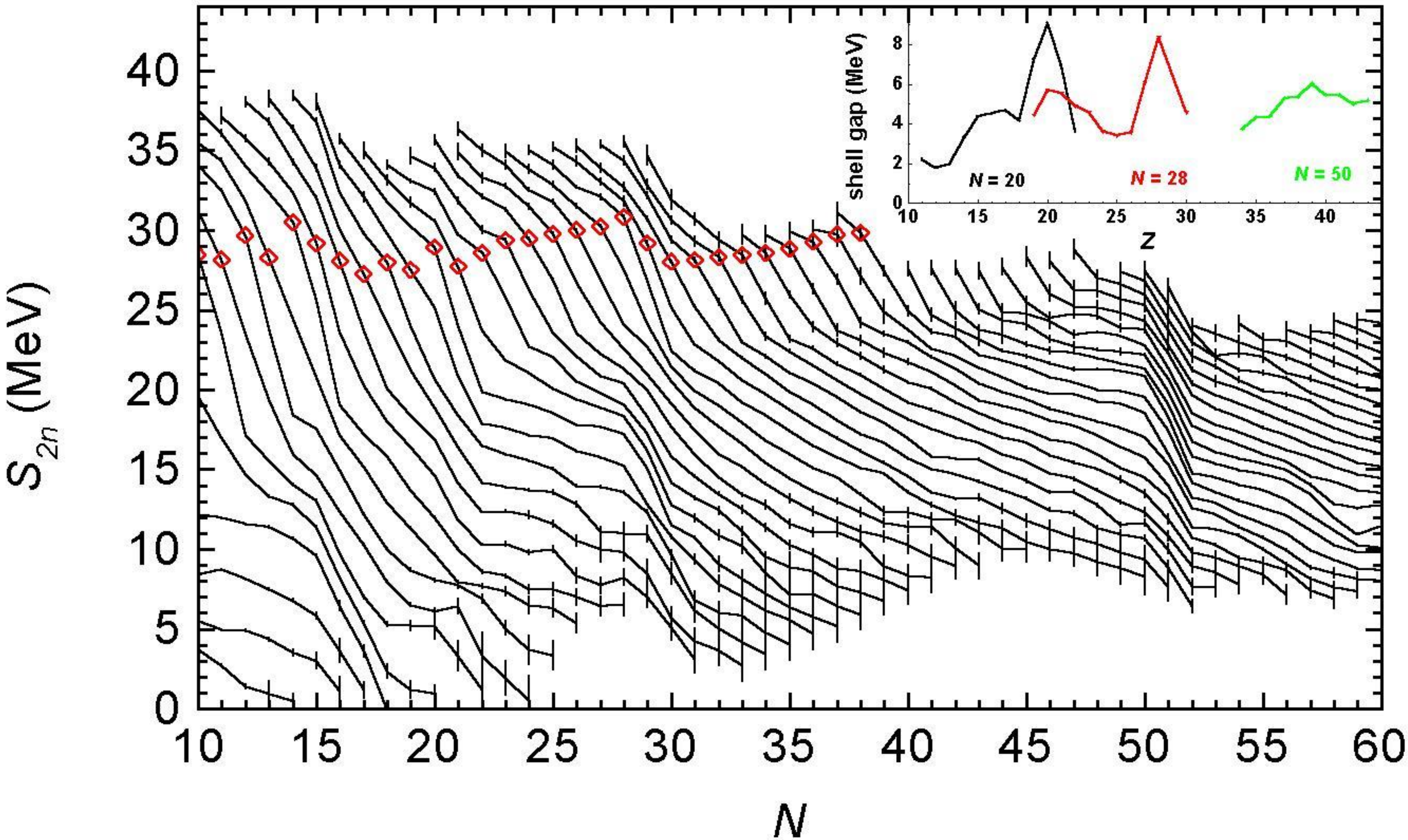


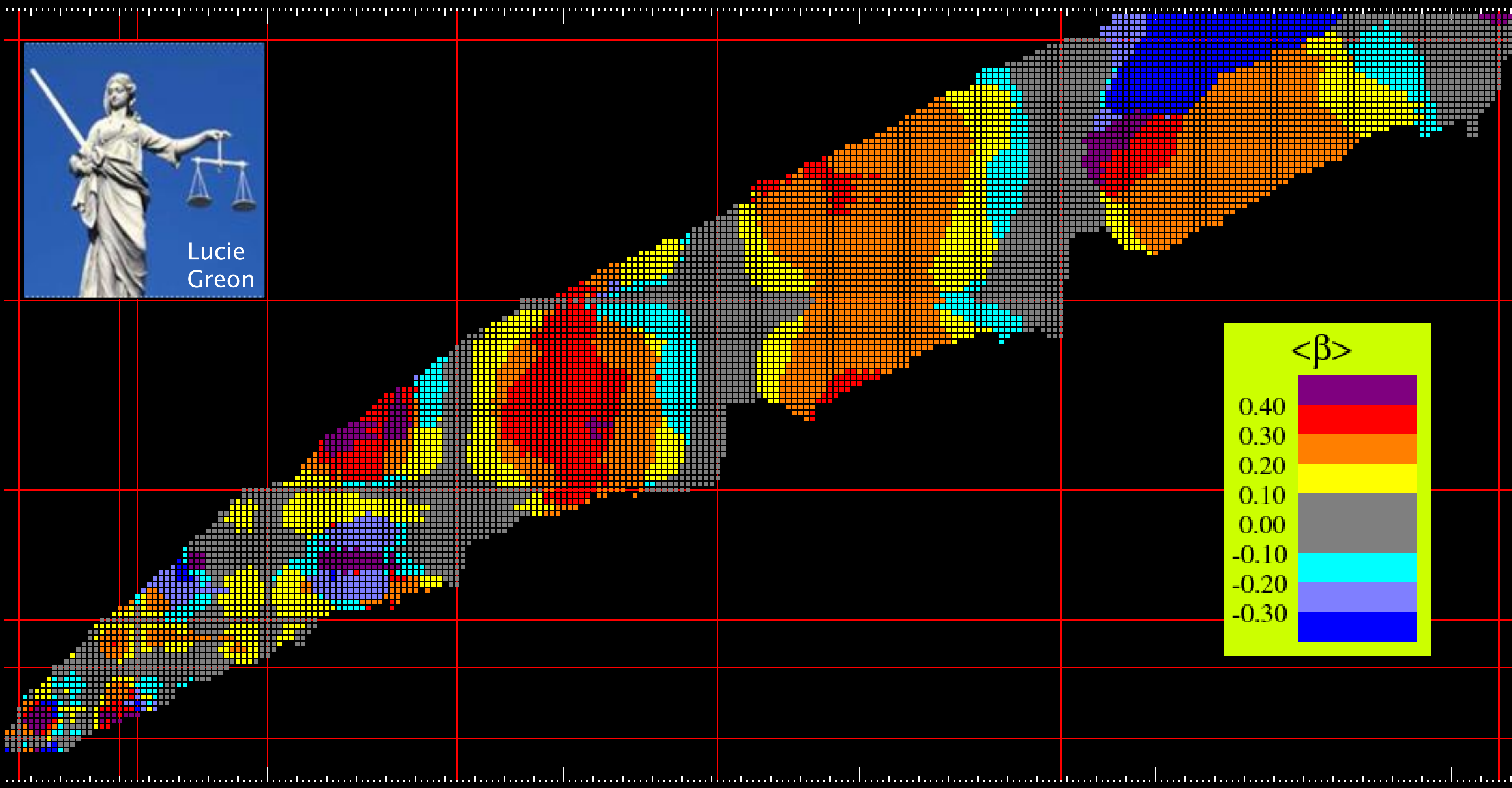
Image : AMDC-Nucleus

nuclear structure from the mass surface

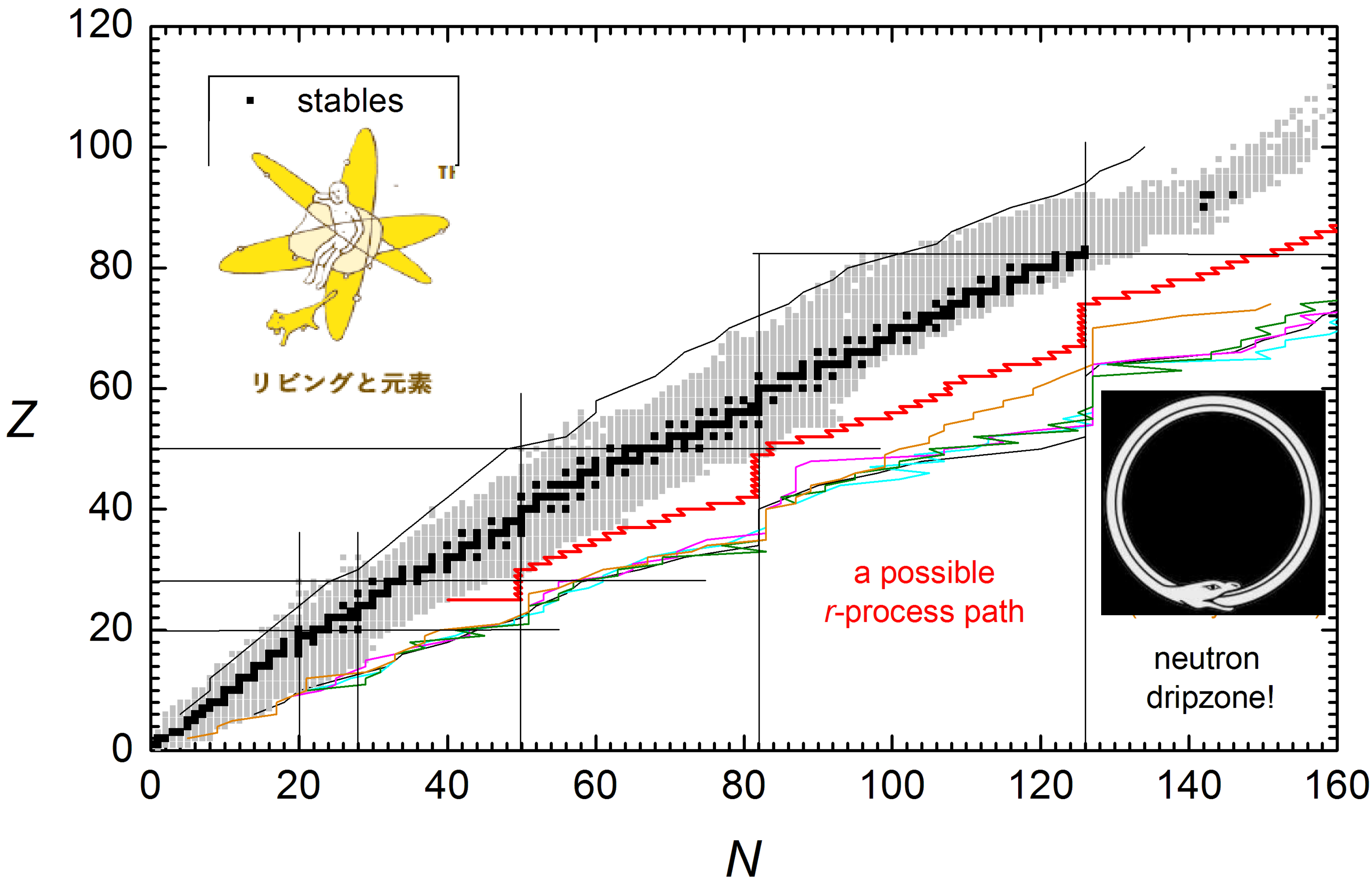


nuclear structure from the mass surface



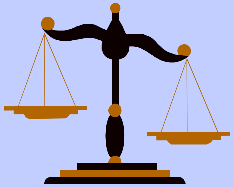


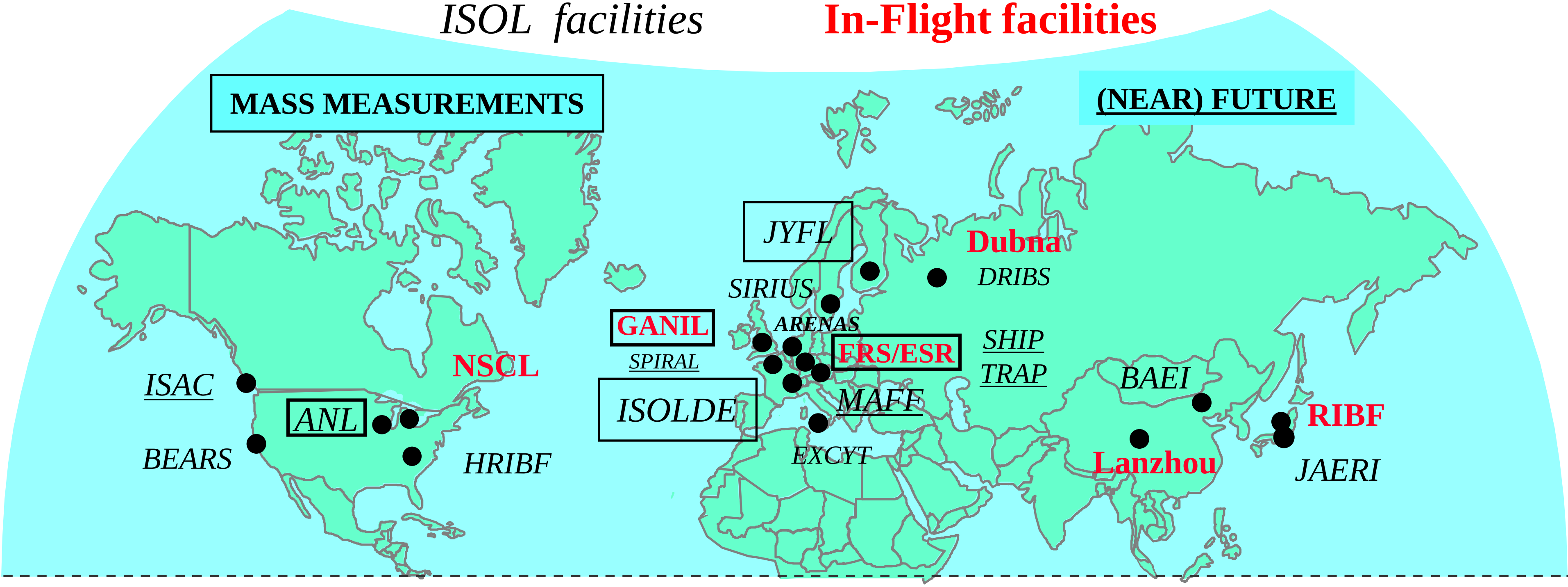
S. Hilaire & M. Girod (D1S-Gogny/AMADEE)



See also:
"The limits of the Nuclear Landscape"
J. Erler et al., Nature (2012)

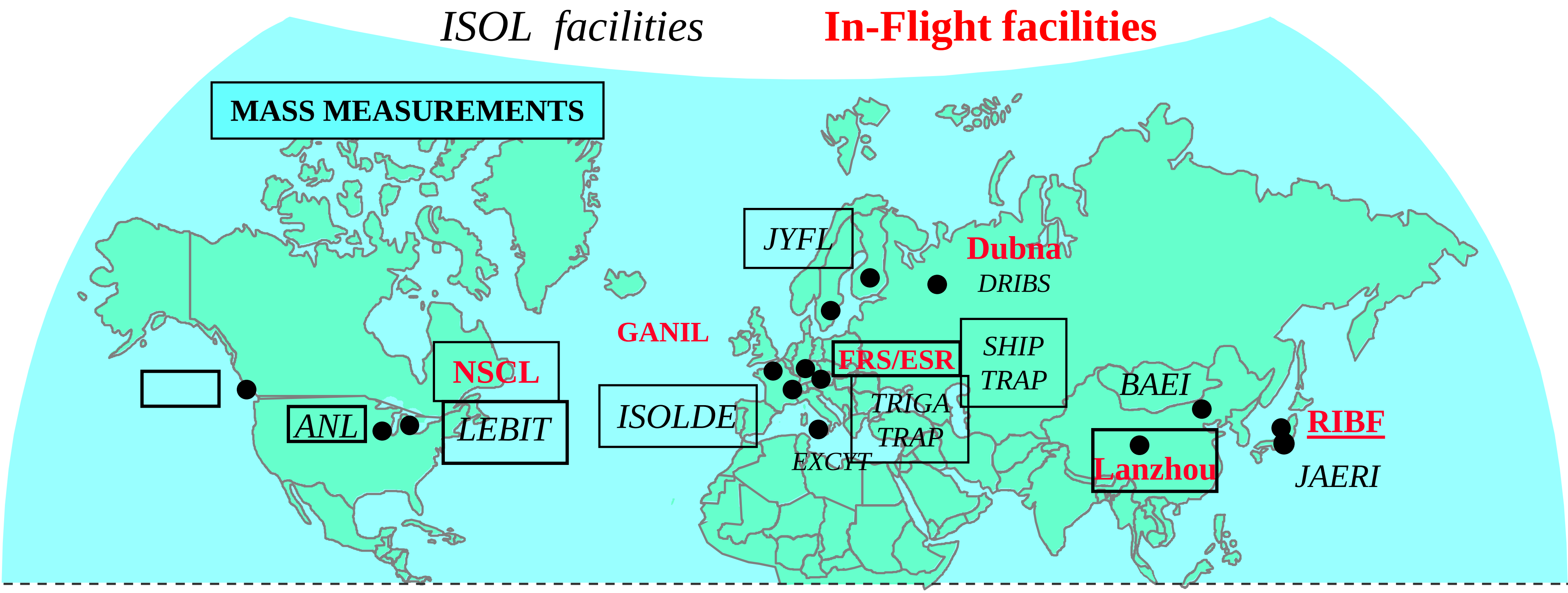
Masses: a global market





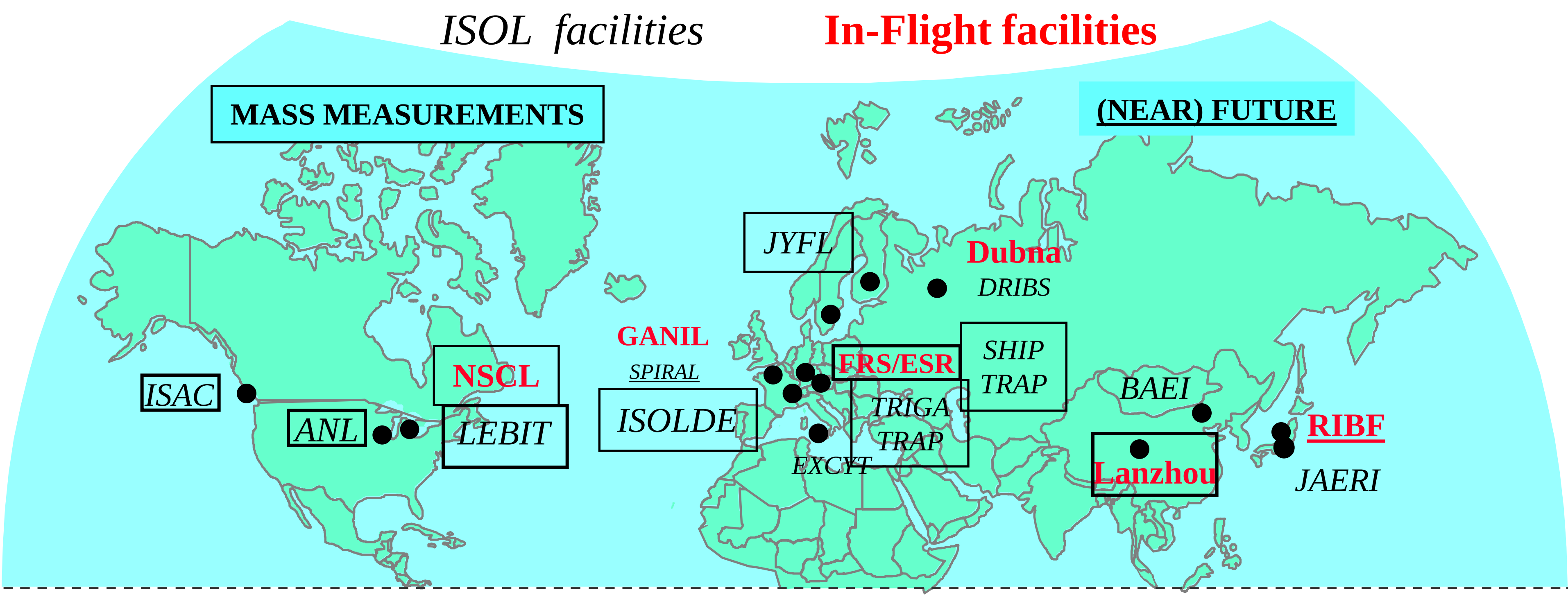
dedicated experimental programs

Masses: a global market



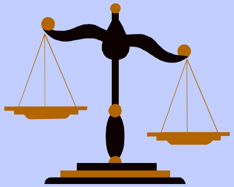
dedicated experimental programs

Masses: a global market



dedicated experimental programs

Techniques



Indirect

(energy)

<u>reactions:</u>

$A(a,b)B$

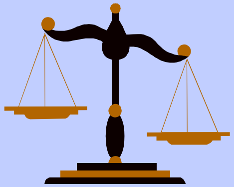
$Q = M_A + M_a - M_b - M_B$

<u>decays:</u>

$A \rightarrow B + \alpha$

$Q_\alpha = M_B - M_A$

Techniques



Indirect
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reactions:

$A(a,b)B$

$Q = M_A + M_a - M_b - M_B$

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$Q_\alpha = M_B - M_A$

Direct
(mass spectrometry)

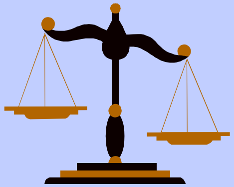
time of flight:

$TOF = (m/q)\,(L/B\rho)$

cyclotron frequency:

$f_c = qB/m$

Techniques



Indirect (energy)	*Direct* (mass spectrometry)	*PRODUCTION SCHEME*

Indirect *(energy)*

reactions:

$A(a,b)B$

$Q = M_A + M_a - M_b - M_B$

decays:

$A \rightarrow B + \alpha$

$Q_\alpha = M_B - M_A$

Direct *(mass spectrometry)*

time of flight:

$TOF = (m/q)\,(L/B\rho)$

cyclotron frequency:

$f_c = qB/m$

PRODUCTION SCHEME

FIFS (MeV)

ISOL (keV)

better sensitivity ↑

better precision ↓

Techniques

Indirect
(energy)

reactions:

$A(a,b)B$

$Q = M_A + M_a - M_b - M_B$

decays:

$A \rightarrow B + \alpha$

$Q_\alpha = M_B - M_A$

Direct
(mass spectrometry)

time of flight:

$TOF = (m/q)\,(L/B\rho\,)$

cyclotron frequency:

$f_c = qB/m$

PRODUCTION SCHEME

FIFS (MeV)

gas cell RFQ

ISOL (keV)

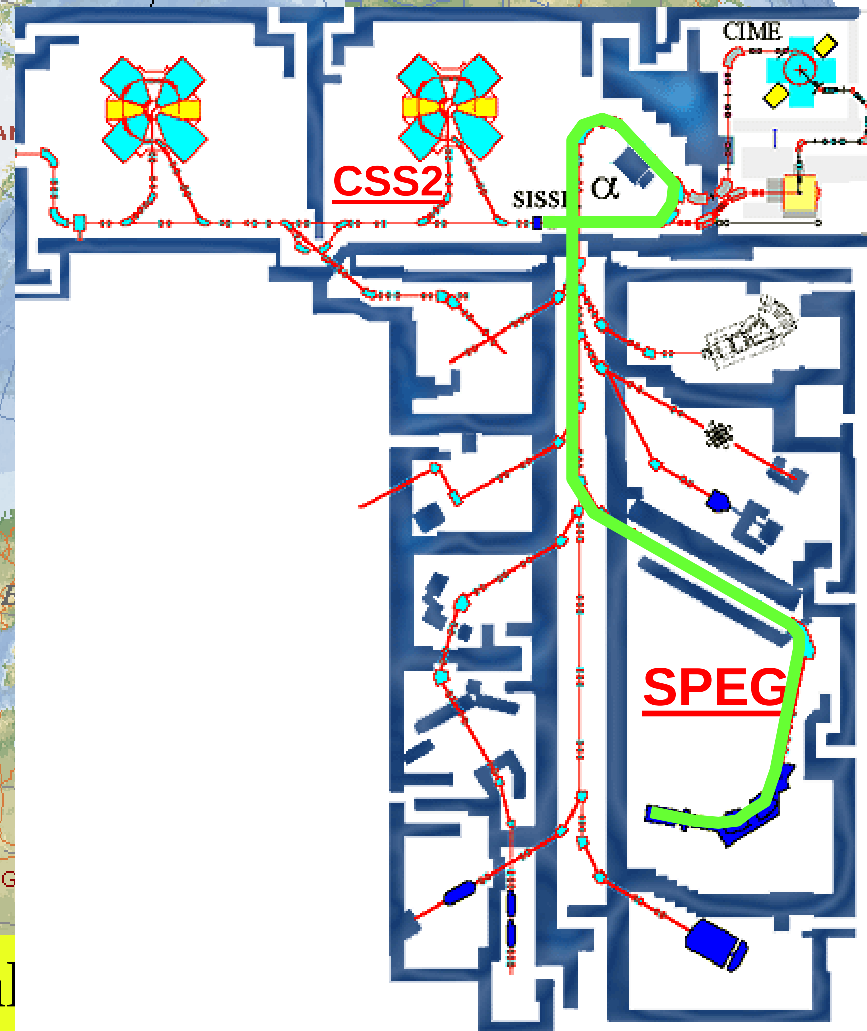
better sensitivity

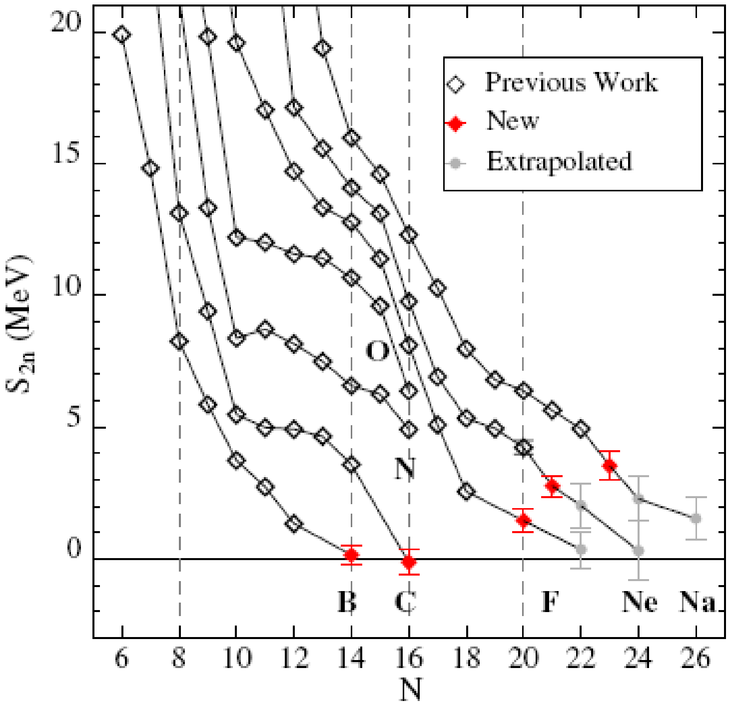
better precision

'the best of both worlds'

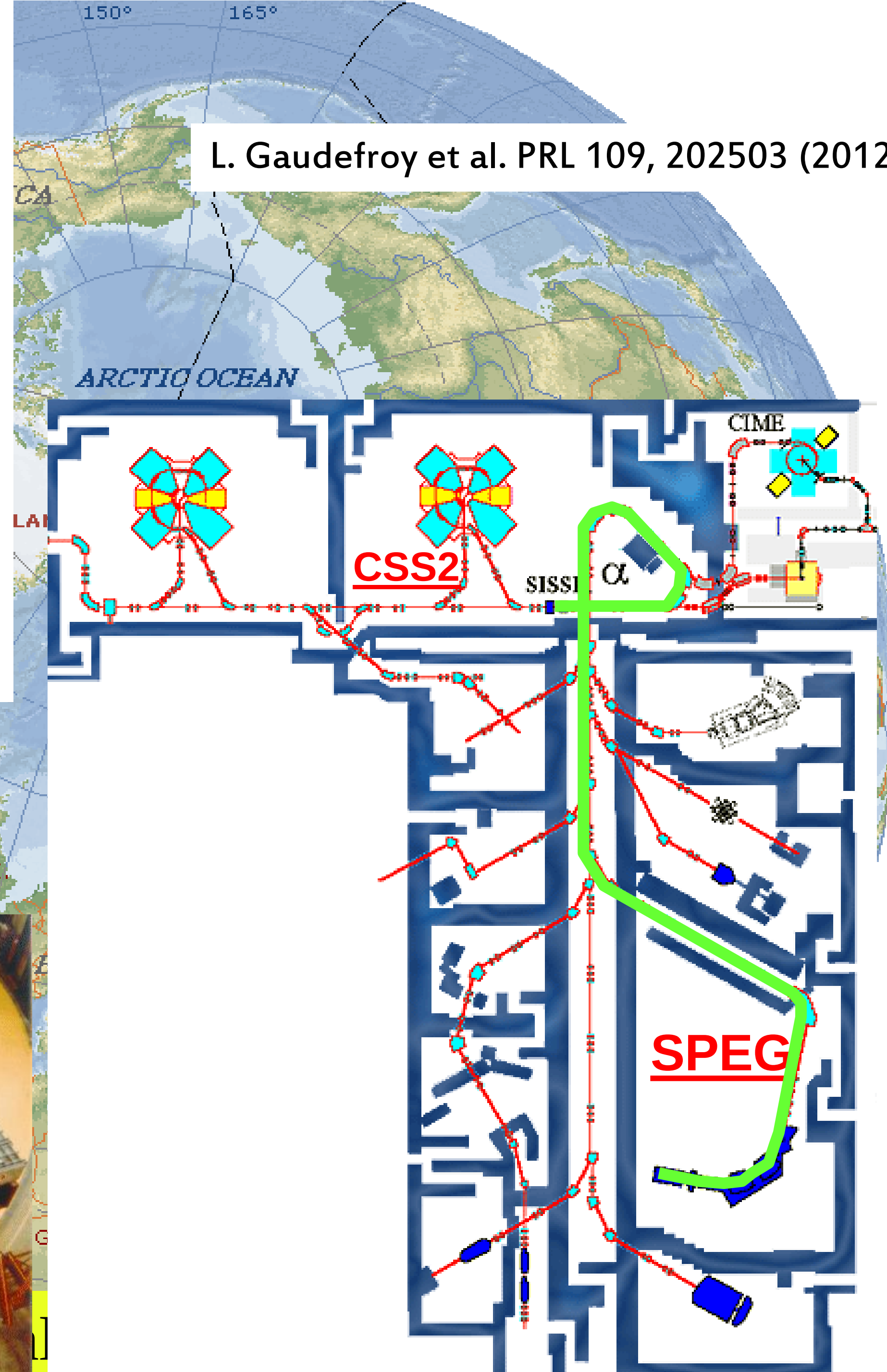
The global mass market

SPEG
CSS2
(GANIL)



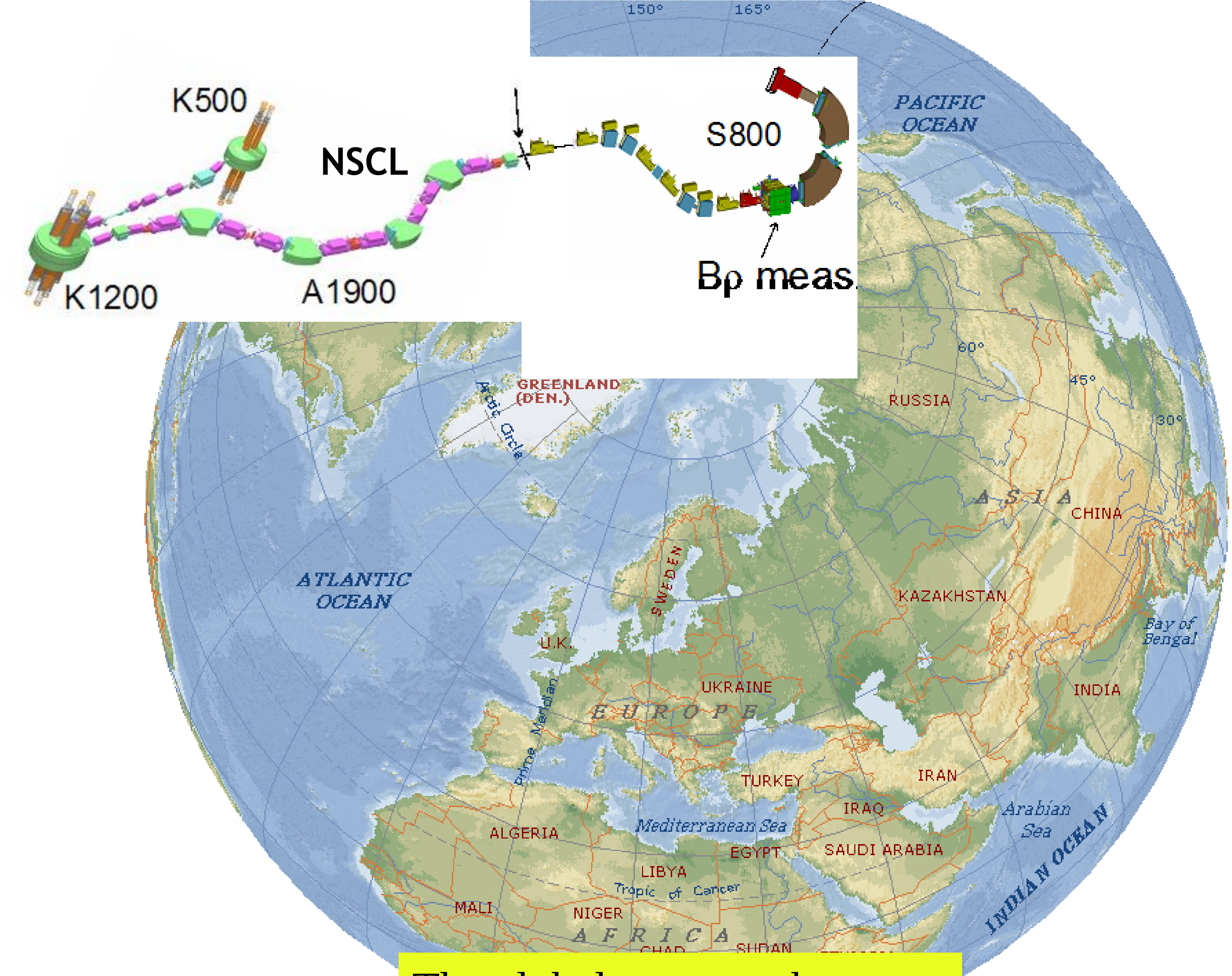


L. Gaudefroy et al. PRL 109, 202503 (2012)

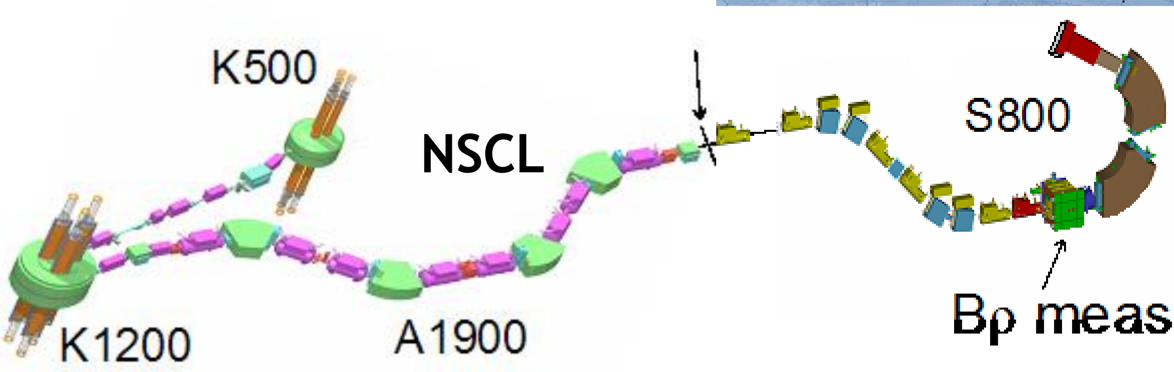


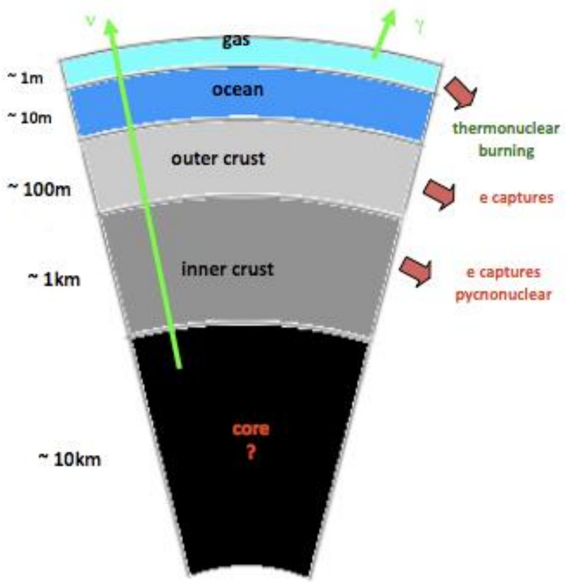
SPEG
CSS2
(GANIL)

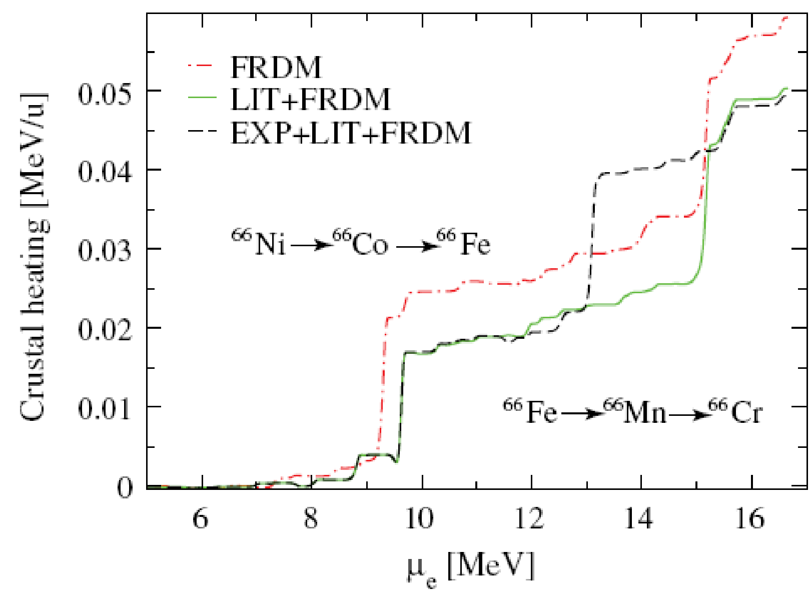
The global mass market



The global mass market





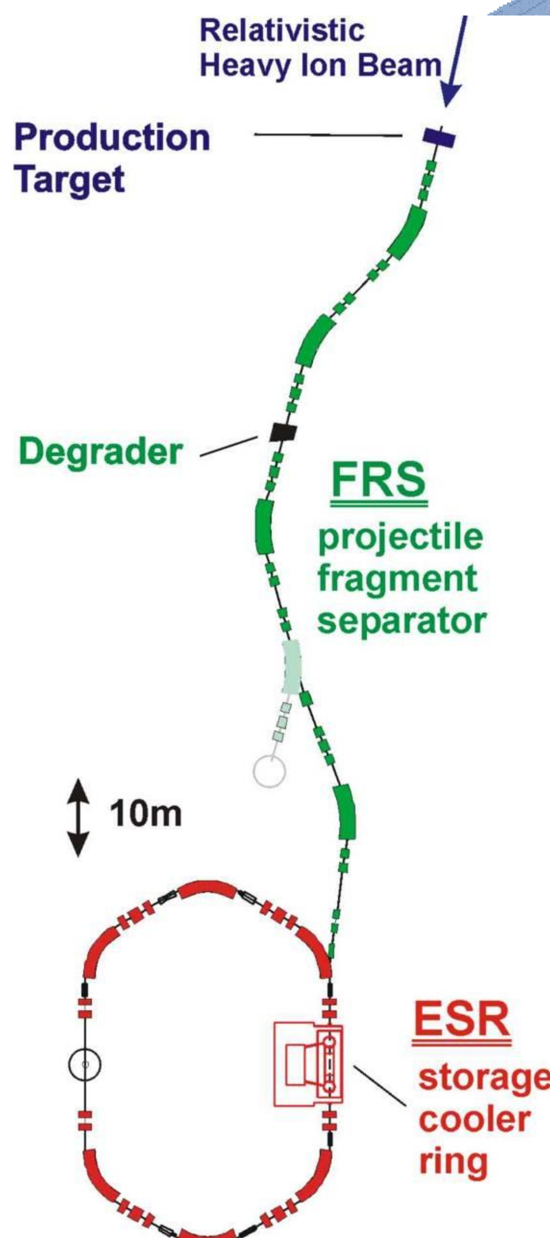


A. Estrade et al. PRL 107, 172503 (2011)

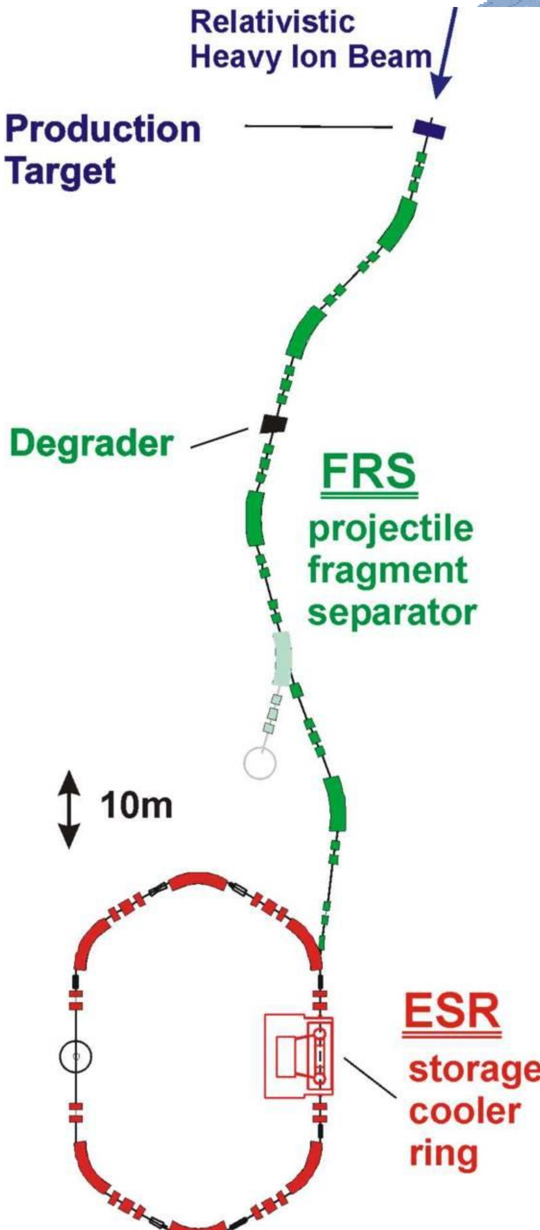
The global mass market


ESR-FRS (GSI)
PACIFIC OCEAN
NORTH AMERICA
UNITED STATES
CANADA
ARCTIC OCEAN
North Pole
GREENLAND (DEN.)
Arctic Circle
75°
60°
45°
30°
150°
165°
RUSSIA
ASIA
CHINA
KAZAKHSTAN
Bay of Bengal
INDIA
ATLANTIC OCEAN
SWEDEN
U.K.
UKRAINE
EUROPE
Prime Meridian
TURKEY
IRAN
IRAQ
Arabian Sea
INDIAN OCEAN
Mediterranean Sea
ALGERIA
EGYPT
SAUDI ARABIA
LIBYA
Tropic of Cancer
MALI
NIGER
AFRICA
CHAD
SUDAN
ETHIOPIA
NIGERIA
Equator
15°
30°

ESR-FRS (GSI)

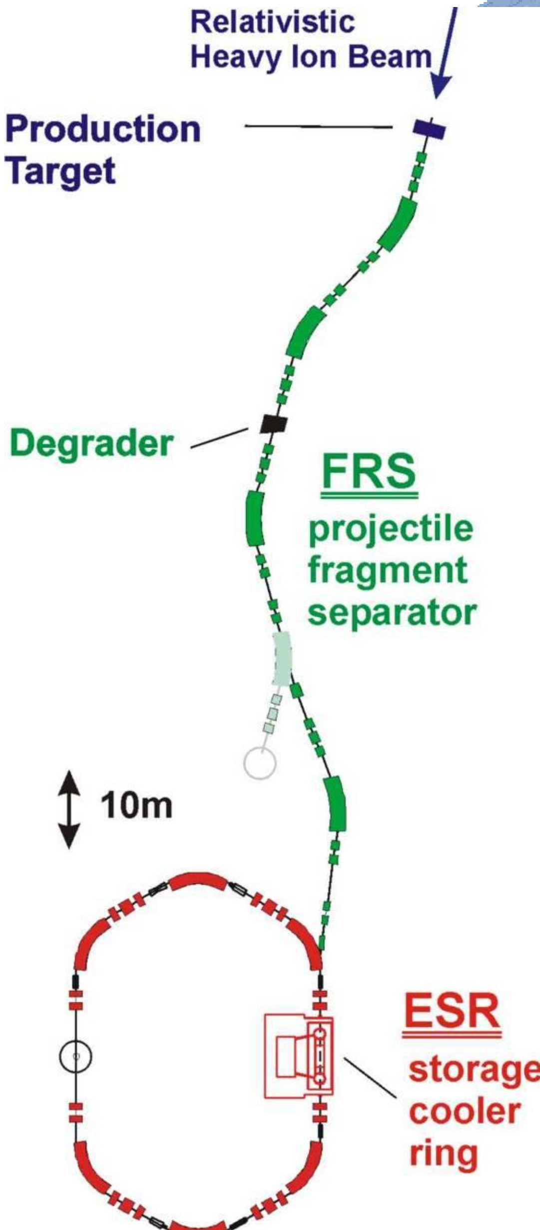

Relativistic
Heavy Ion Beam
Production
Target
Degrader
FRS
projectile
fragment
separator
10m
ESR
storage
cooler
ring

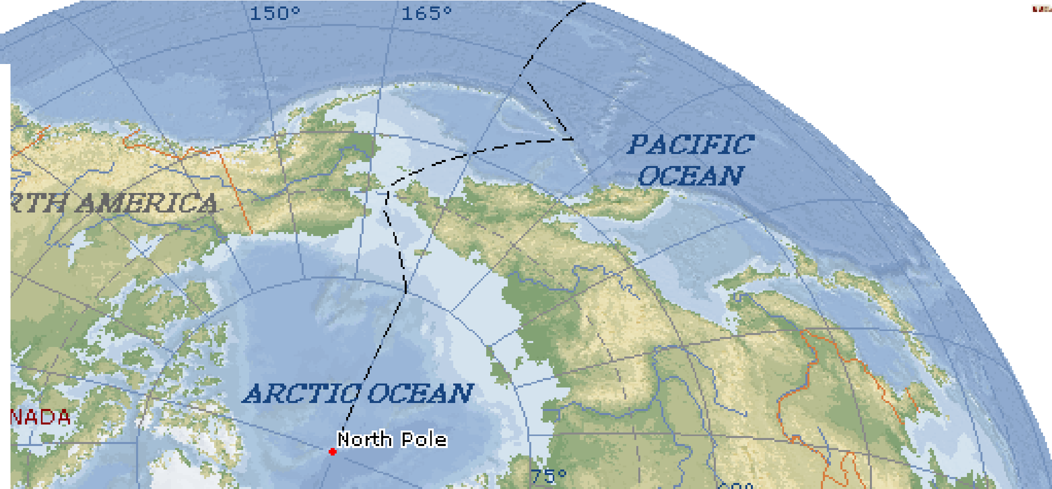

150°
165°
PACIFIC
OCEAN
NORTH AMERICA
ARCTIC OCEAN
North Pole
NADA
75°
60°
45°
30°
GREENLAND
(DEN.)
Arctic Circle
RUSSIA
A S I A
CHINA
SWEDEN
KAZAKHSTAN
Bay of
Bengal
U.K.
UKRAINE
INDIA



NESR (FAIR)

ESR-FRS (GSI)

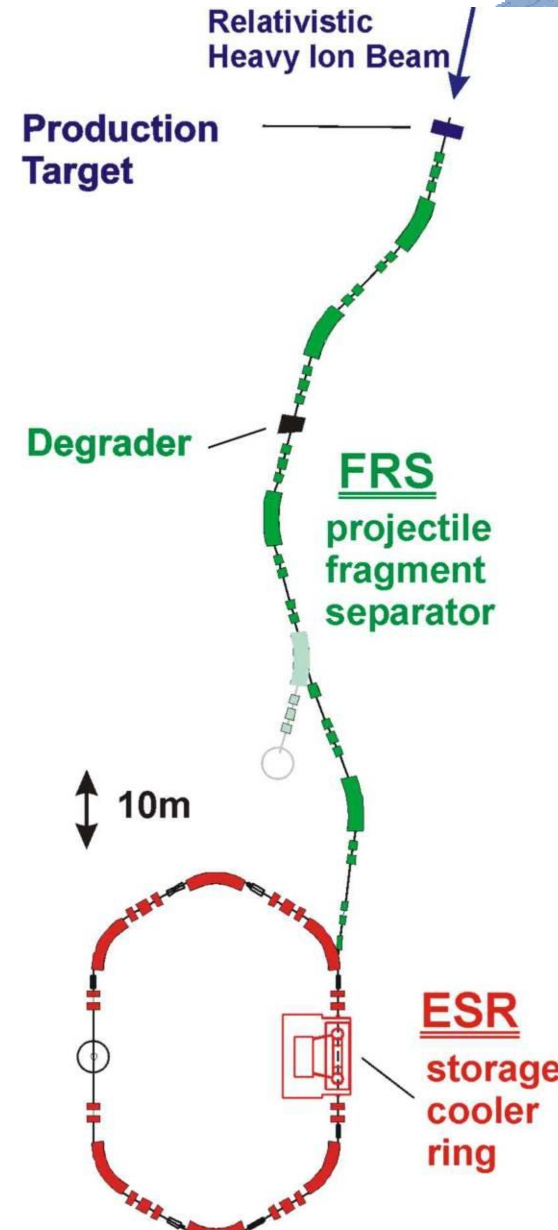




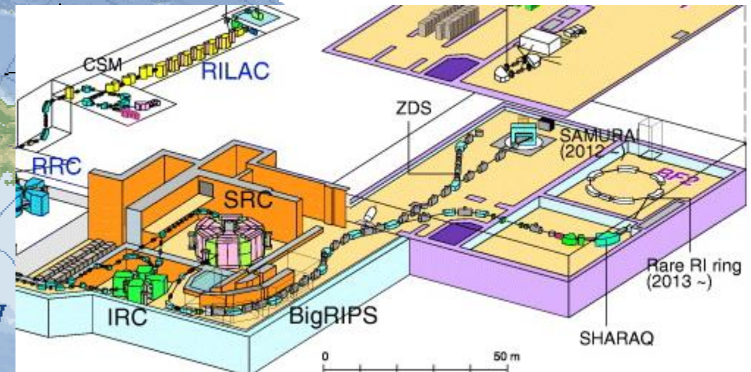
CSR-HIRFL (Lanzhou)

NESR (FAIR)

ESR-FRS (GSI)



Rare Isotope Ring (RIKEN)



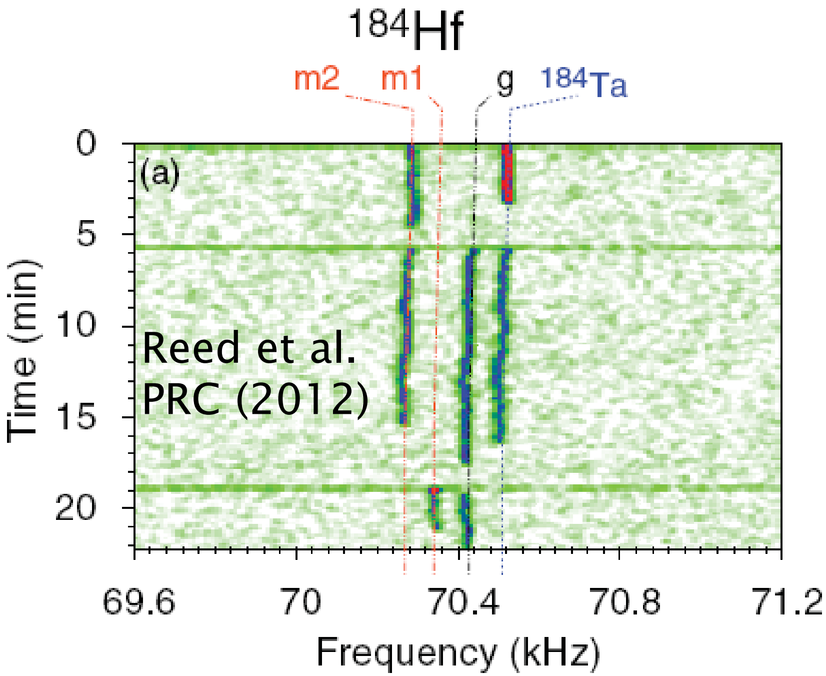
CSR-HIRFL (Lanzhou)

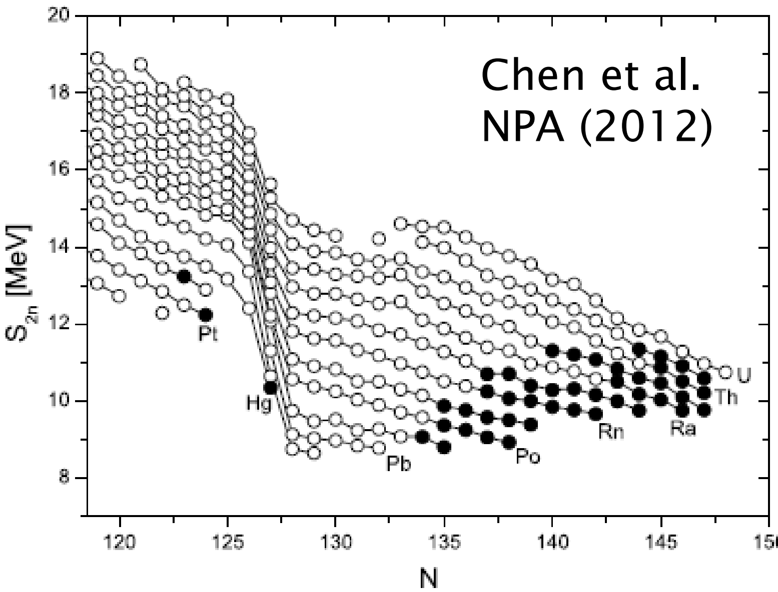
NESR (FAIR)

ESR-FRS (GSI)

ESR @ GSI-Darmstadt:

year	article	physics	nuclides
2010	M.W. Reed et al. PRL 105, 172501	structure	long-lived Hf & Ta isomers
2012	M.W. Reed et al. PRC 86, 054321	structure	Z=72-76 isomers
2012	M.W. Reed et al. JPCP 381, 012058	structure	192Re isomer
2012	L. Chen et al., Nucl. Physics A 882	structure	238U fragments (SMS)
2013	D. Shubina et al. PRC 88, 024310	structure	197Au fragments (SMS)
2013	L. Chen et al. PRL 110, 122502	structure	212Bi isomers & decay

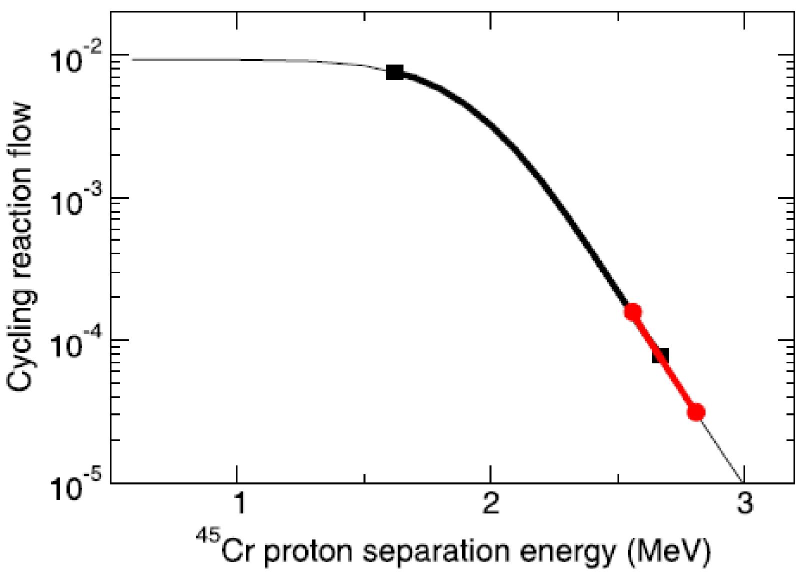


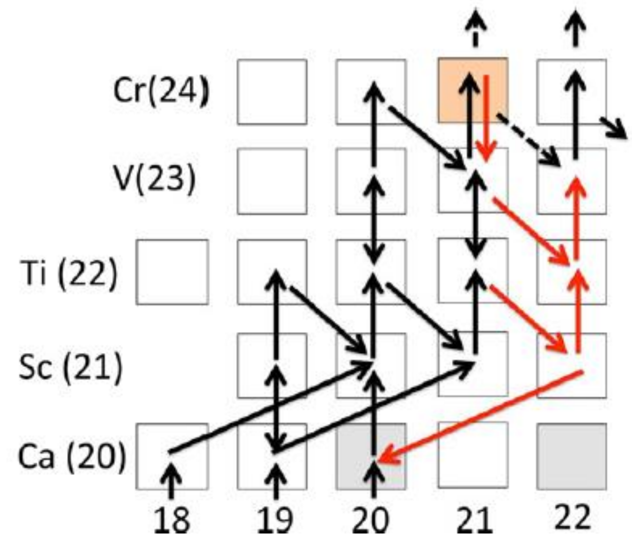


CSR @ IMP-Lanzhou:

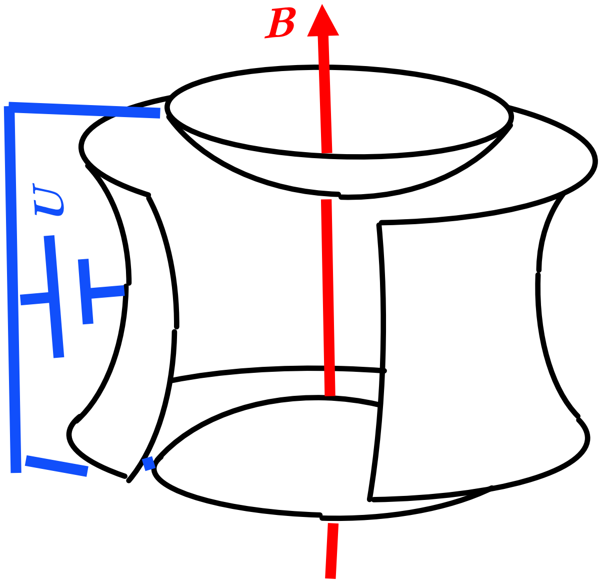
year	article	physics	nuclides
2011	X.L. Tu et al., Phys. Rev. Lett. 106	*rp* process	63Ge, 65As, 67Se, 71Kr
2012	Y.H. Zhang et al., Phys. Rev. Lett. 109	IMME	41Ti, 49Fe, 53Ni
2013	X.L. Yan et al. Astrophys. J. Lett. 766	X-ray bursts	43V, 45Cr, 47Mn, 49Fe, 55Cu
2014	P. Shuai et al. arXiv:1404.1187	structure	51Co

The Astrophysical Journal Letters, 766:L8 (4pp), 2013 March 20



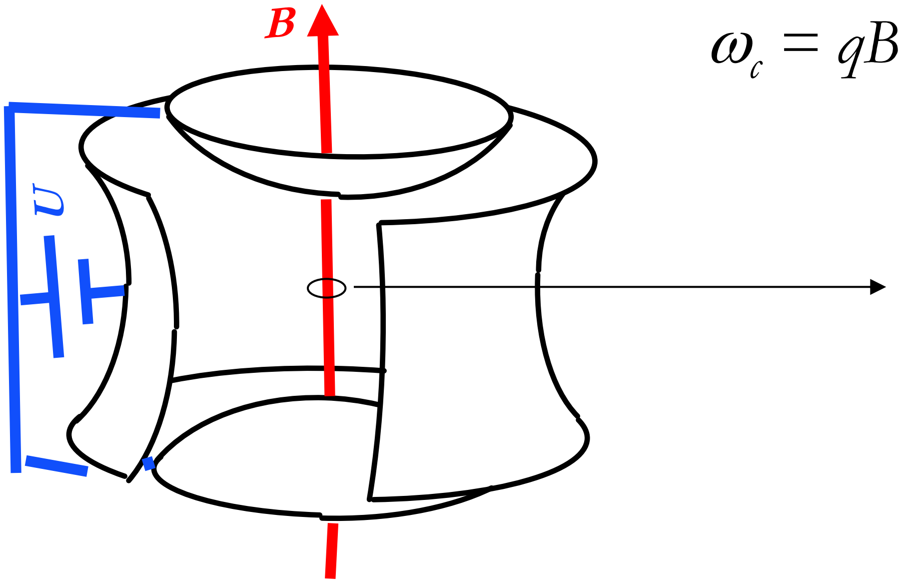


Penning Trap

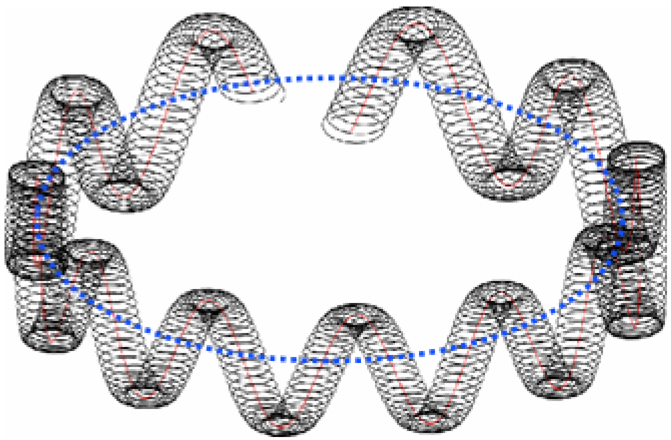


$$\omega_c = qB/m$$

Penning Trap



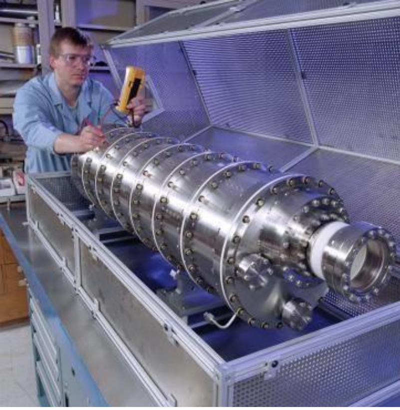
$$\omega_c = qB/m$$

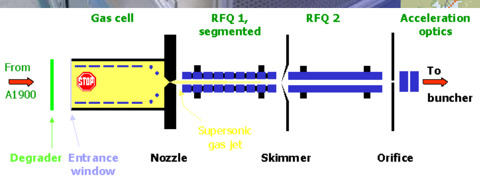


$$\omega_c = \omega_+ + \omega_-$$

in a quadrupole field

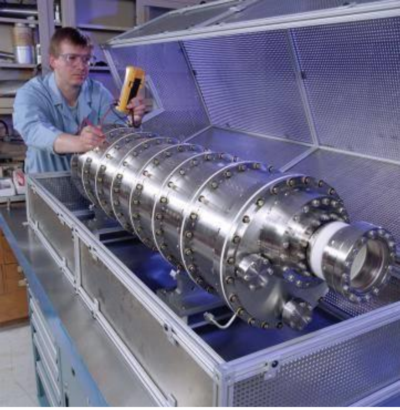
ISOLTRAP (CERN)

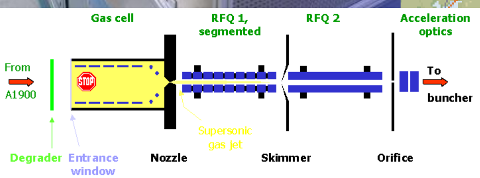




CPT (ANL)

ISOLTRAP (CERN)

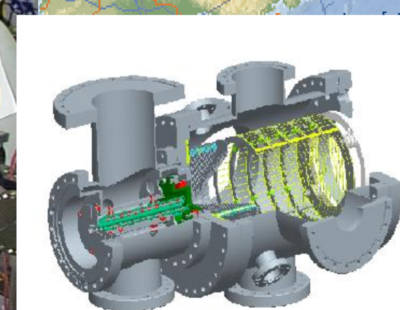


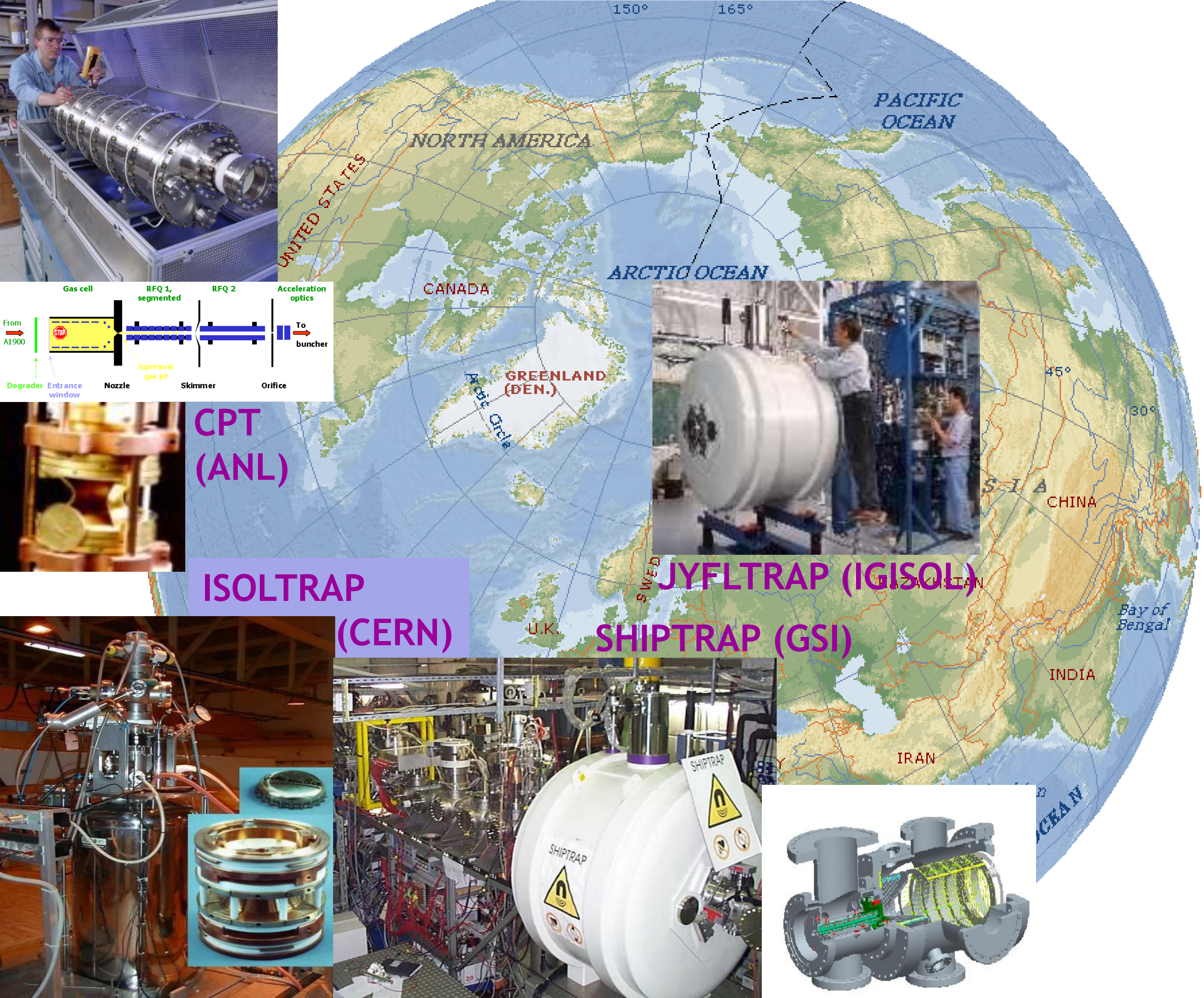


CPT (ANL)

ISOLTRAP (CERN)

SHIPTRAP (GSI)



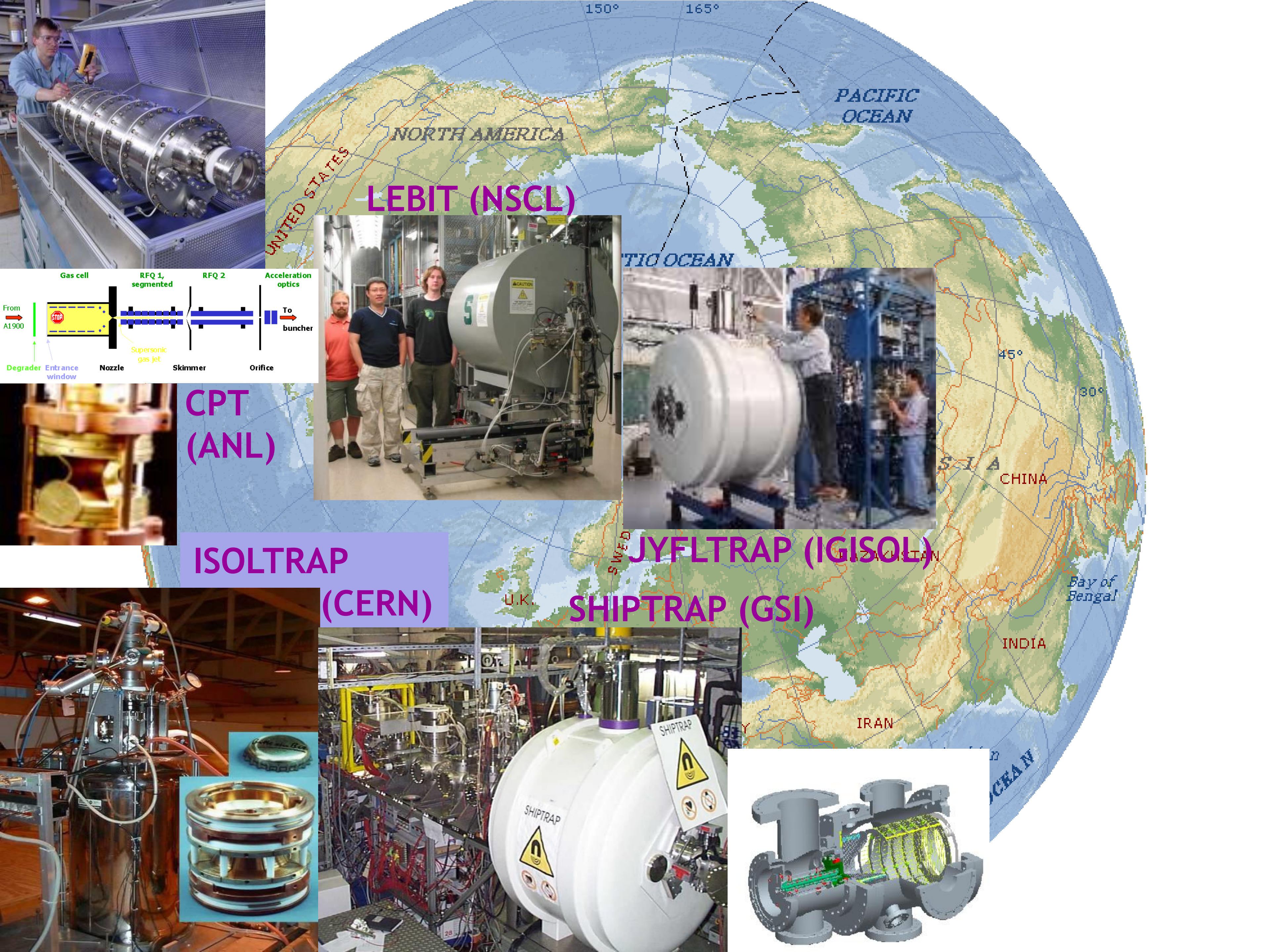


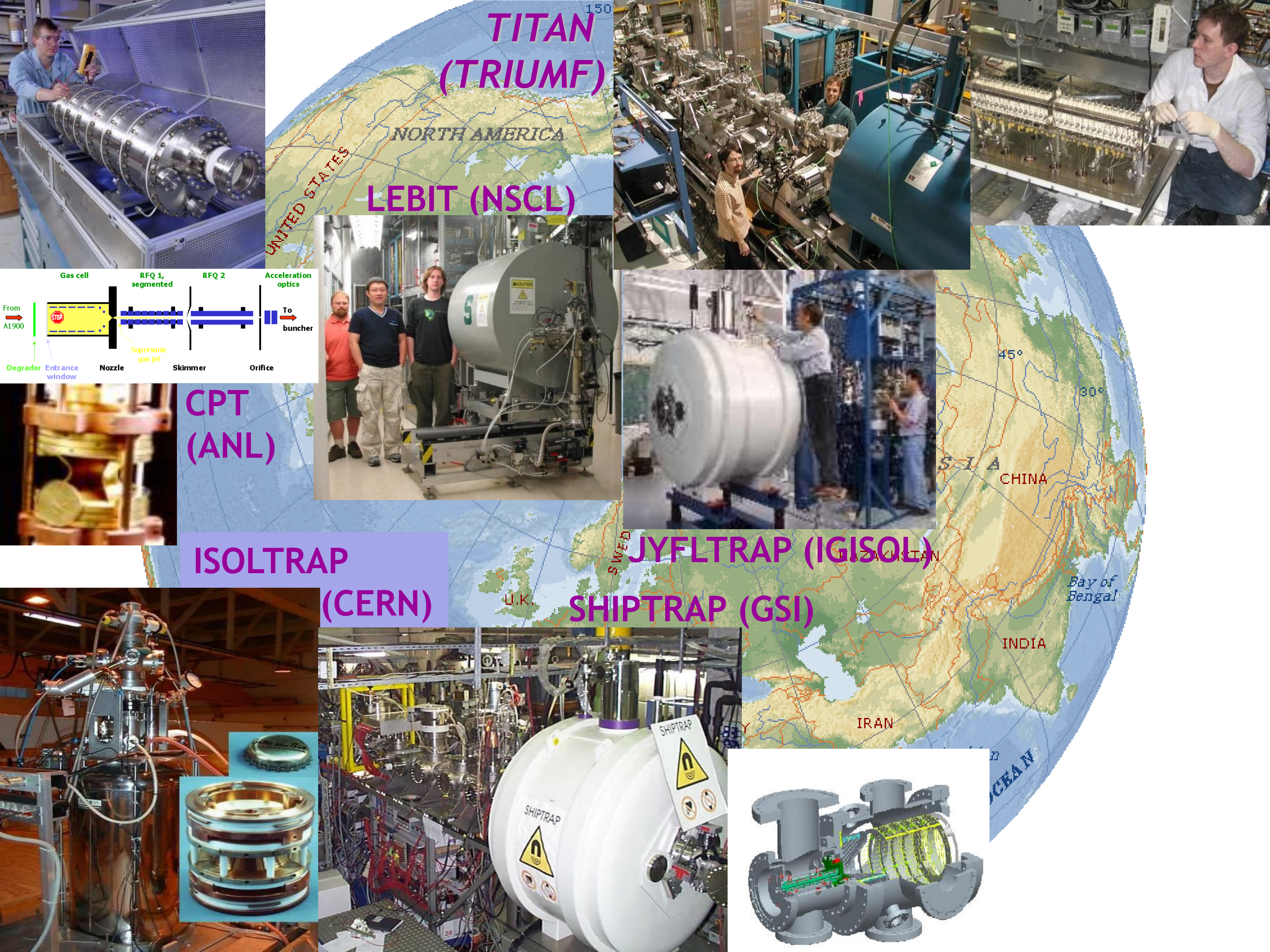
CPT (ANL)

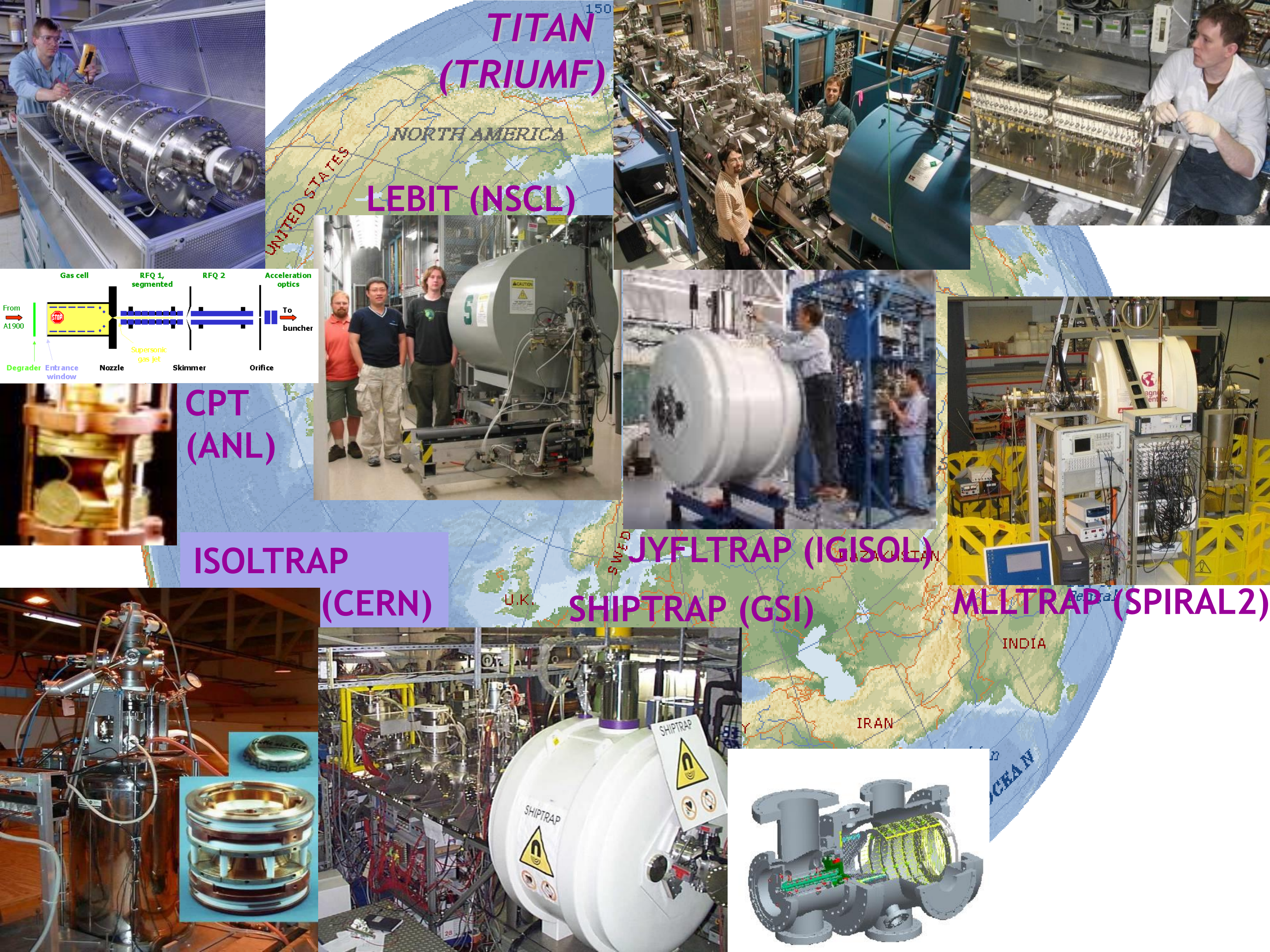
ISOLTRAP (CERN)

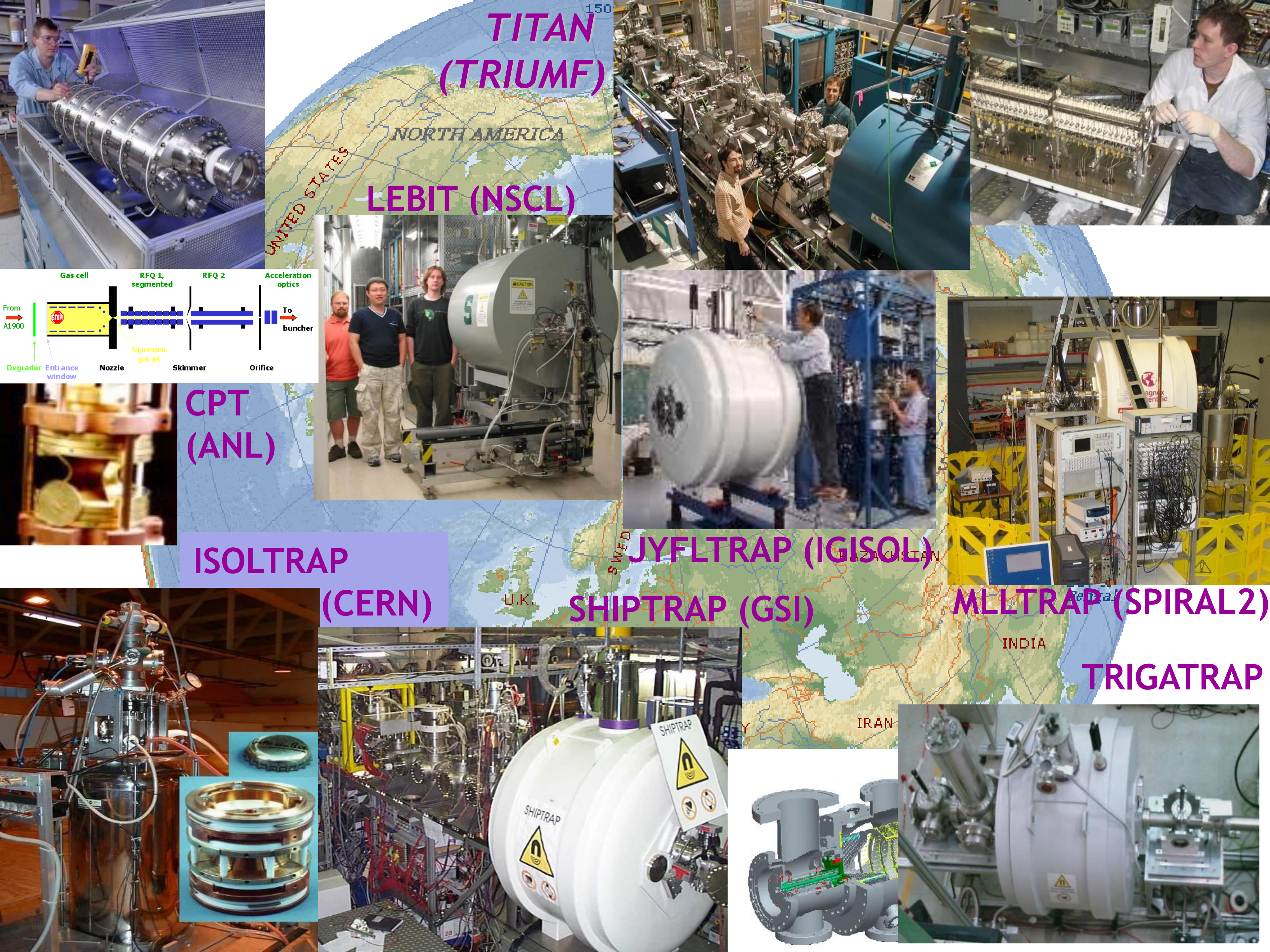
JYFLTRAP (IGISOL)

SHIPTRAP (GSI)


LEBIT (NSCL)
CPT (ANL)
ISOLTRAP (CERN)
JYFLTRAP (IGISOL)
SHIPTRAP (GSI)
Gas cell
RFQ 1, segmented
RFQ 2
Acceleration optics
From A1900
To buncher
Degrader
Entrance window
Nozzle
Skimmer
Orifice
150°
165°
PACIFIC OCEAN
NORTH AMERICA
UNITED STATES
45°
30°
CHINA
INDIA
IRAN
U.K.
Bay of Bengal
SHIPTRAP
SHIPTRAP


TITAN (TRIUMF)
LEBIT (NSCL)
CPT (ANL)
ISOLTRAP (CERN)
JYFLTRAP (IGISOL)
SHIPTRAP (GSI)
Gas cell
RFQ 1, segmented
RFQ 2
Acceleration optics
From A1900
To buncher
STOP
Supersonic gas jet
Degrader
Entrance window
Nozzle
Skimmer
Orifice
NORTH AMERICA
UNITED STATES
150
45°
30°
CHINA
INDIA
IRAN
Bay of Bengal
U.K.
SHIPTRAP


TITAN (TRIUMF)
LEBIT (NSCL)
CPT (ANL)
ISOLTRAP (CERN)
JYFLTRAP (IGISOL)
SHIPTRAP (GSI)
MLLTRAP (SPIRAL2)
Gas cell
RFQ 1, segmented
RFQ 2
Acceleration optics
From A1900
To buncher
Supersonic gas jet
Degrader
Entrance window
Nozzle
Skimmer
Orifice
NORTH AMERICA
UNITED STATES
U.K.
INDIA
IRAN
SHIPTRAP


TITAN (TRIUMF)
LEBIT (NSCL)
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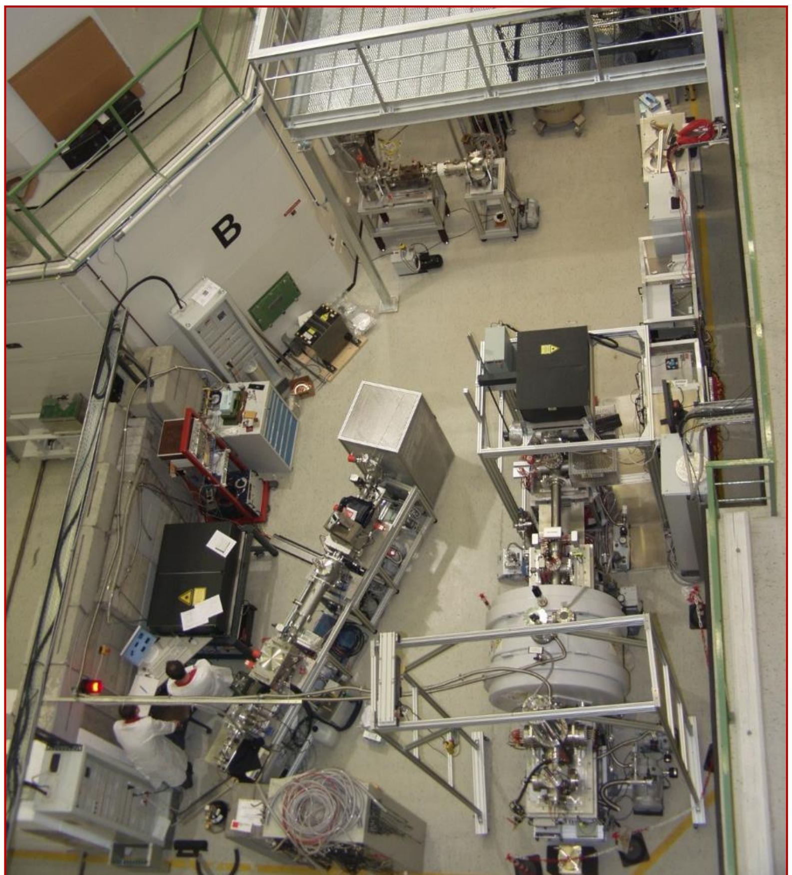
ISOLTRAP (CERN)
JYFLTRAP (IGISOL)
SHIPTRAP (GSI)
MLLTRAP (SPIRAL2)
TRIGATRAP
NORTH AMERICA
UNITED STATES
U.K.
INDIA
IRAN
150
Gas cell
RFQ 1, segmented
RFQ 2
Acceleration optics
From A1900
To buncher
Degrader
Entrance window
Nozzle
Skimmer
Orifice
Supersonic gas jet
SHIPTRAP

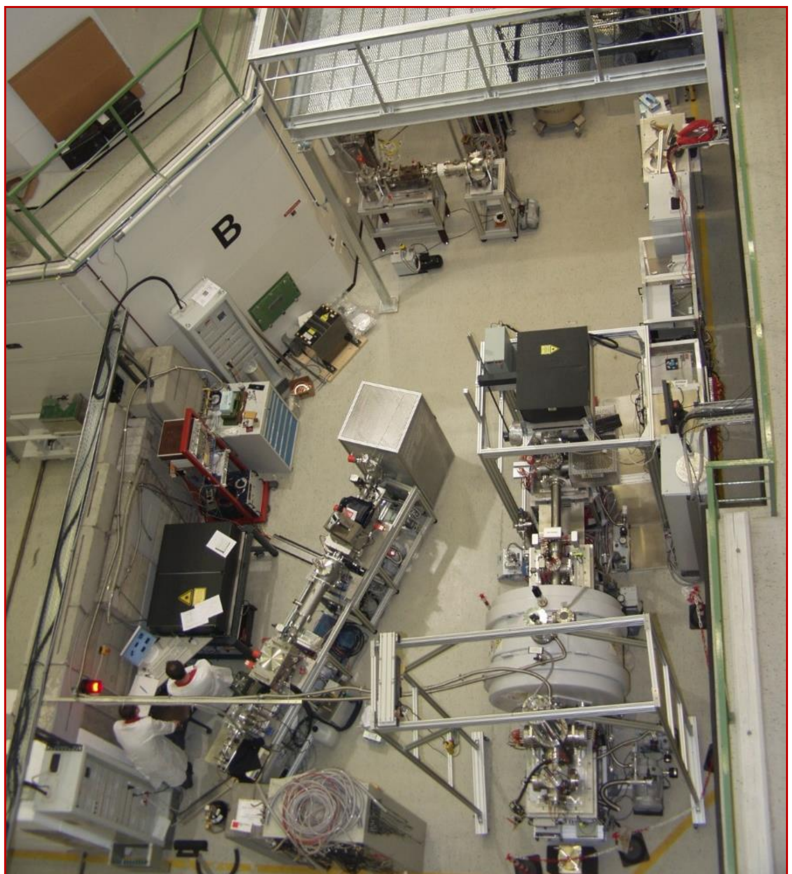
TRIGATRAP @ IKC-Mainz (TRIGA reactor)

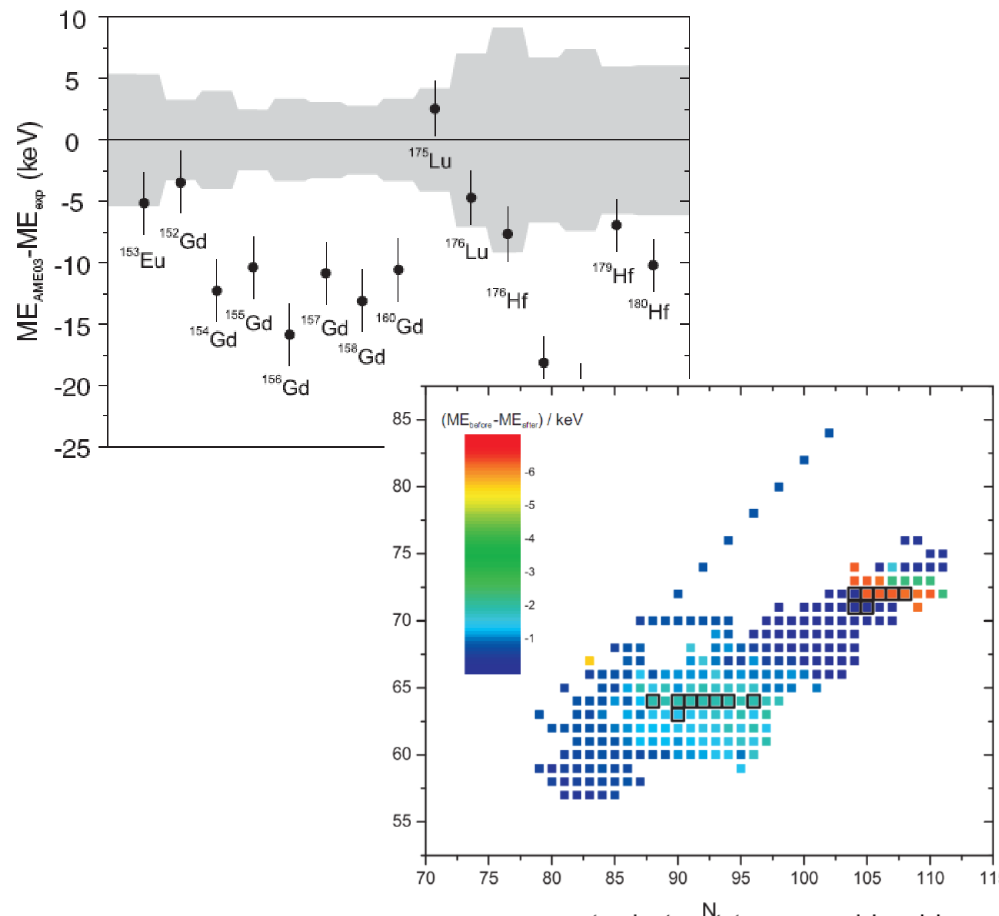
year	article	physics	nuclides
2011	J. Ketalaer et al. PRC 84	mass surface	153Eu; 152-160Gd; 175,176Lu; 176-180Hf
2012	Ch. Smorra et al. PRC 85	0v2B/neutrino	106,108,110Pd/Cd
2012	Ch. Smorra et al. PRC 86	0v2EC/neutrino	184Os; 184W



TRIGATRAP @ IKC-Mainz (TRIGA reactor)

year	article	physics	nuclides
2011	J. Ketalaer et al. PRC 84	mass surface	153Eu; 152-160Gd; 175,176Lu; 176-180Hf
2012	Ch. Smorra et al. PRC 85	0v2B/neutrino	106,108,110Pd/Cd
2012	Ch. Smorra et al. PRC 86	0v2EC/neutrino	184Os; 184W

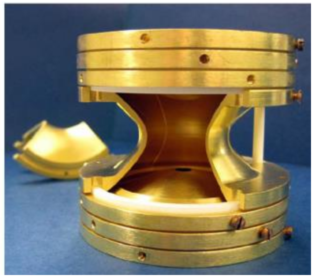




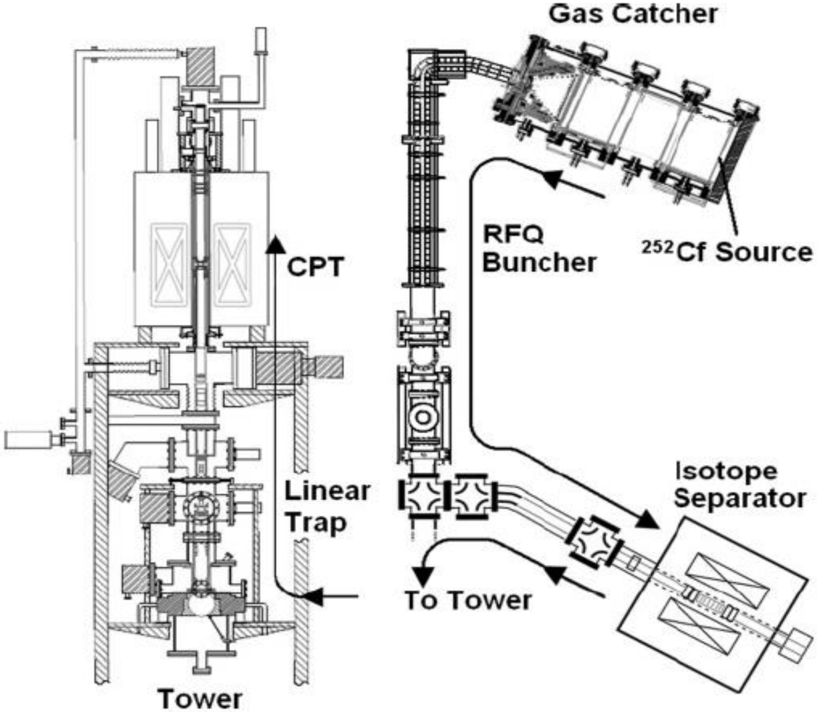
CPT @ Argonne National Lab

year	article	physics	nuclides
2011	J. Fallis et al. PRC 84, 045807	rp process	90Mo; 90Tc; 90Ru; 92Rh
2012	J. Van Shelt et al. PRC 85, 045805	r process	Z=51-55; 59-64; 141-142Cs
2013	J. Van Schelt et al. PRL 111, 061102	r process	N = 82; Z = 49-55

Physics Viewpoint



ATLAS → CARIBU



CPT @ Argonne National Lab

year	article	physics	nuclides
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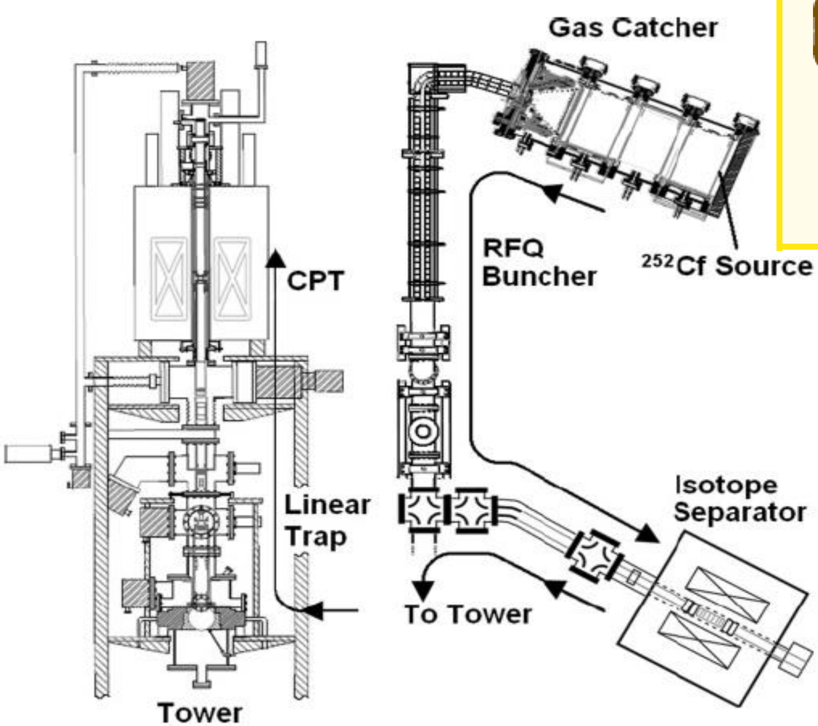
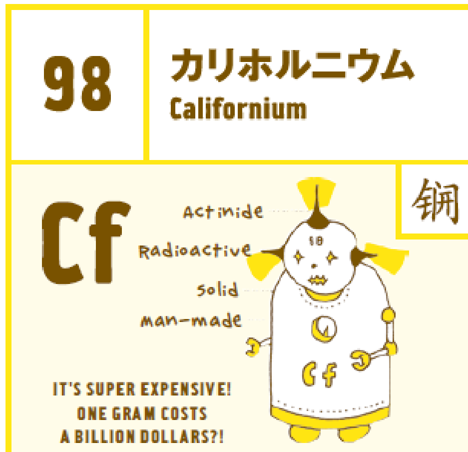
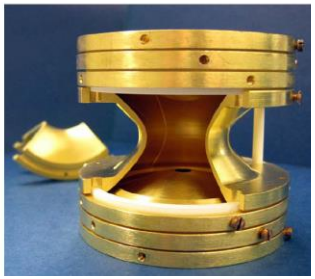
2012	J. Van Shelt et al. PRC 85, 045805	r process	Z=51-55; 59-64; 141-142Cs
2013	J. Van Schelt et al. PRL 111, 061102	r process	N = 82; Z = 49-55

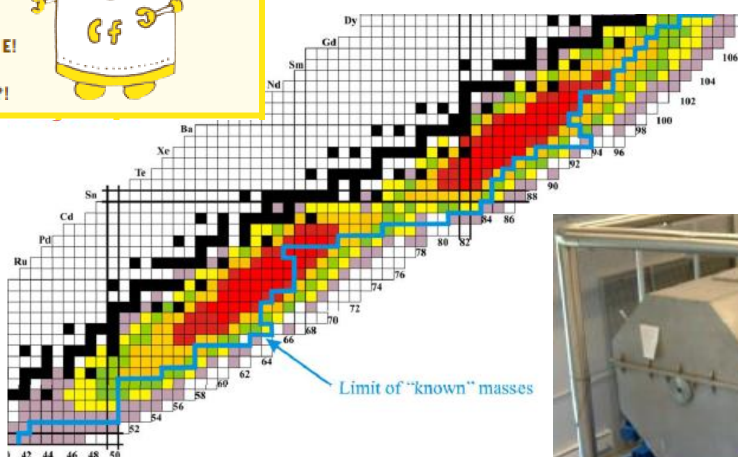
ATLAS → CARIBU

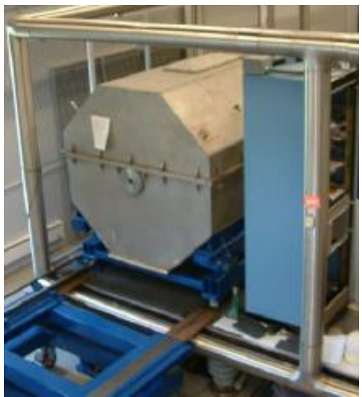




Physics Viewpoint







CPT @ Argonne National Lab

year	article	physics	nuclides
2011	J. Fallis et al. PRC 84, 045807	rp process	90Mo; 90Tc; 90Ru; 92Rh
2012	J. Van Shelt et al. PRC 85, 045805	r process	Z=51-55; 59-64; 141-142Cs
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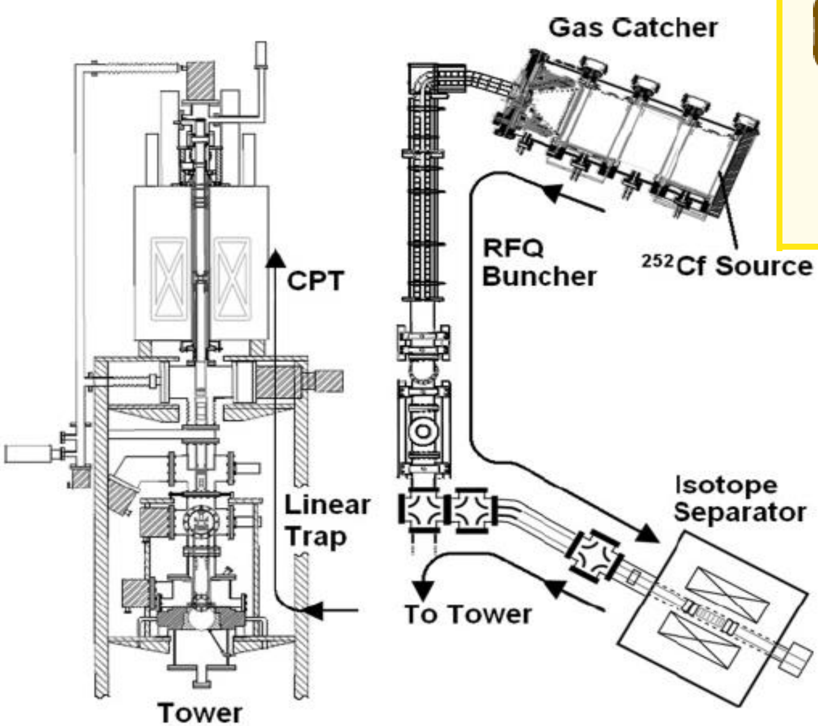
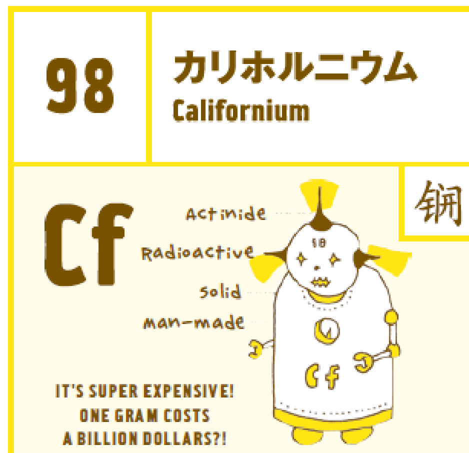
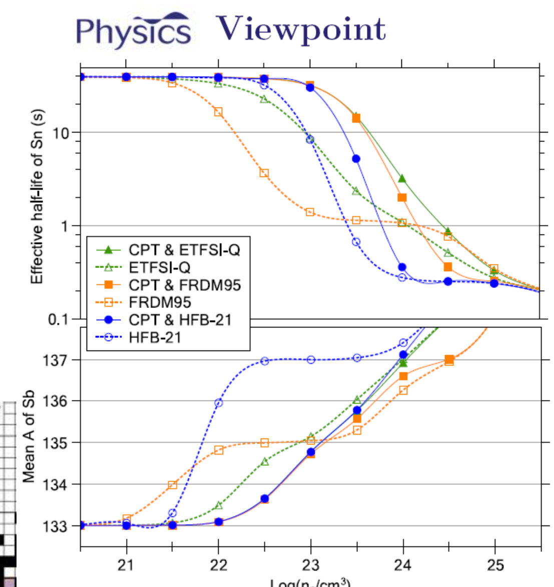
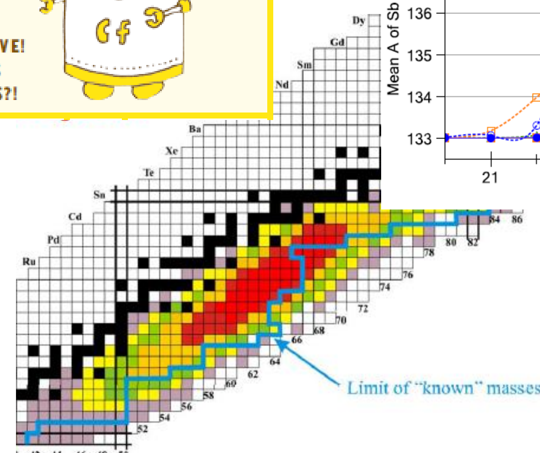
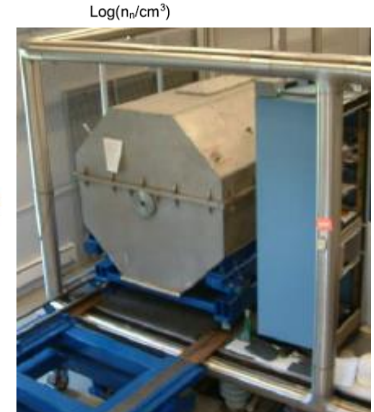
ATLAS → CARIBU





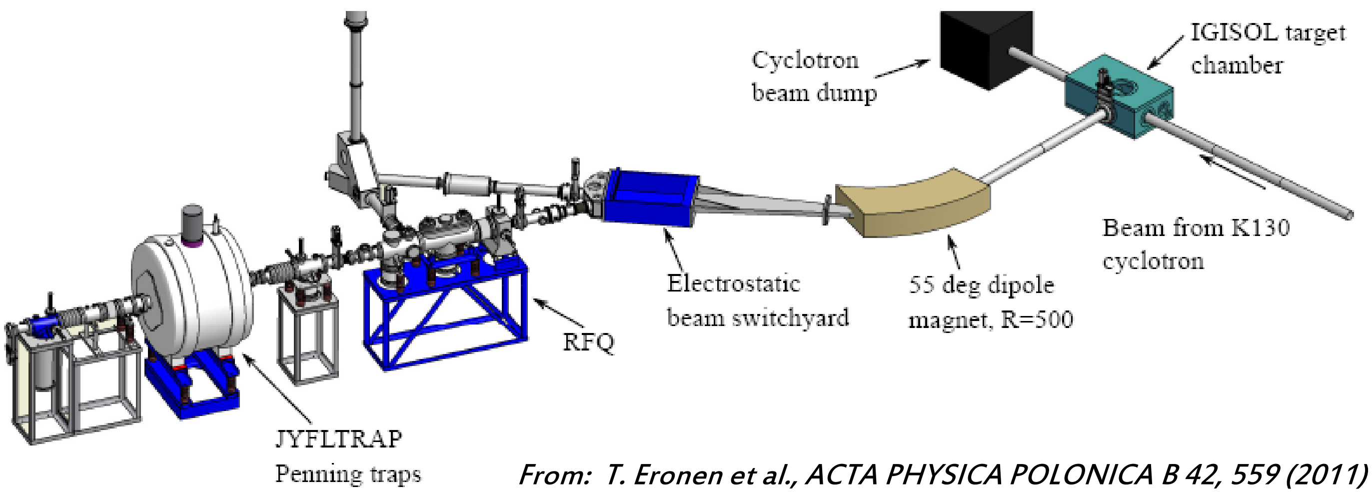






JYFLTRAP @ IGISOL-Jyvaskyla

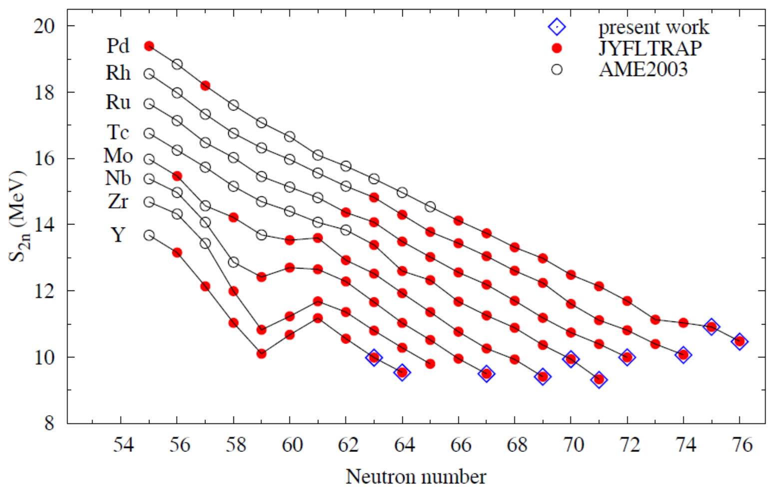
year	article	physics	nuclides
2011	J. Souin et al., Eur. Phys. J. A 47	weak interaction	30S
2011	J. Hakala et al., Eur. Phys. J. A 47	structure	103Y,108Nb,111Mo, 114Tc 116Ru, 119Rh, 121,122Pd
2012	J. Hakala et al., Phys. Rev. Lett. 109	structure	128Cd,131In,135Sn, 136Sb, 140Te
2013	A. Kankainen et al., Phys. Rev. C 87	isomers	121,123,125Cd, 133Te, 129,131In, 130Sn, 134Sb
2014	A. Kankainen et al., arXiv:1403.4073	structure	Q(49Mn-49Cr); (45V-45Ti)

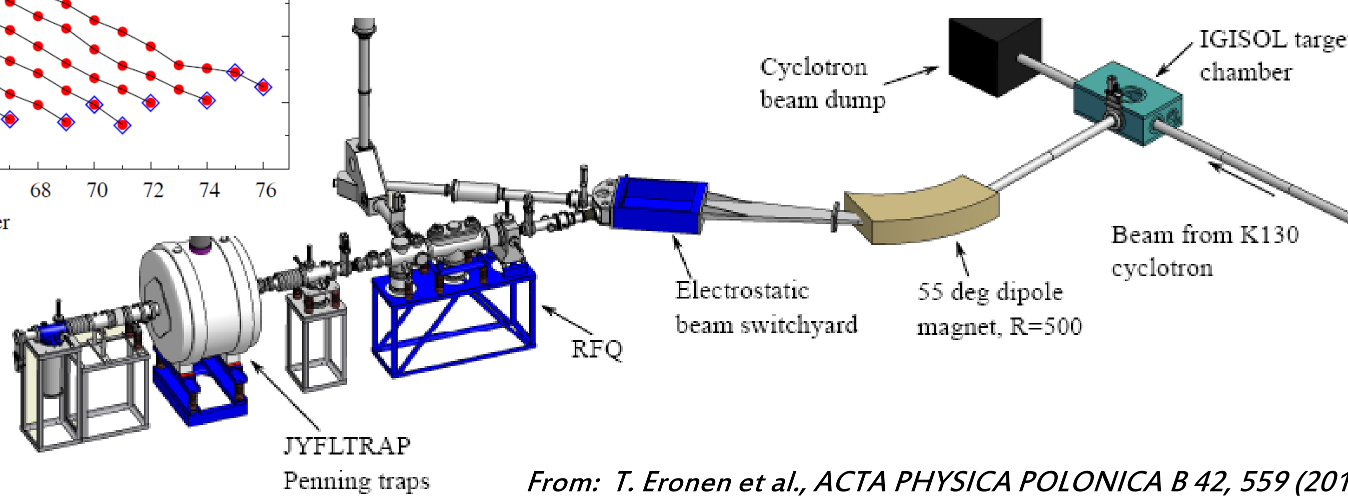


From: T. Eronen et al., ACTA PHYSICA POLONICA B 42, 559 (2011)

JYFLTRAP @ IGISOL-Jyvaskyla

year	article	physics	nuclides
2011	J. Souin et al., Eur. Phys. J. A 47	weak interaction	30S
2011	J. Hakala et al., Eur. Phys. J. A 47	structure	103Y,108Nb,111Mo, 114Tc 116Ru, 119Rh, 121,122Pd
2012	J. Hakala et al., Phys. Rev. Lett. 109	structure	128Cd,131In,135Sn, 136Sb, 140Te
2013	A. Kankainen et al., Phys. Rev. C 87	isomers	121,123,125Cd, 133Te, 129,131In, 130Sn, 134Sb
2014	A. Kankainen et al., arXiv:1403.4073	structure	Q(49Mn-49Cr); (45V-45Ti)

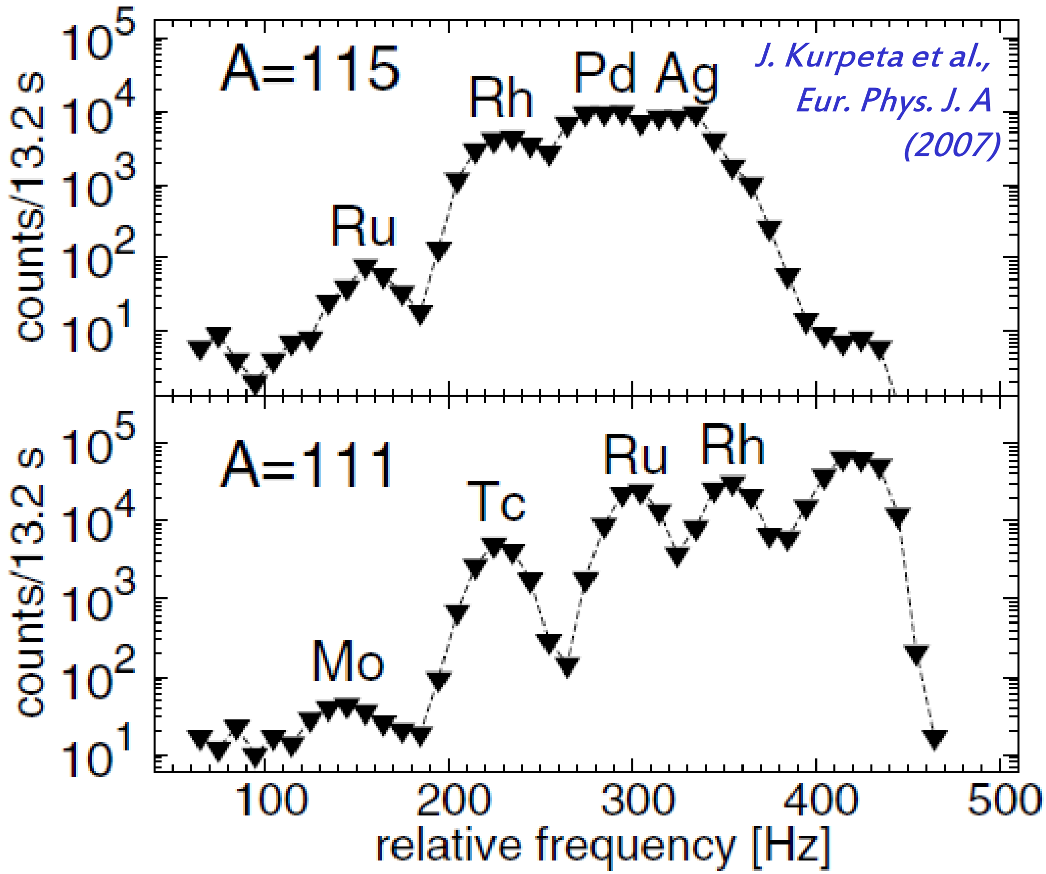


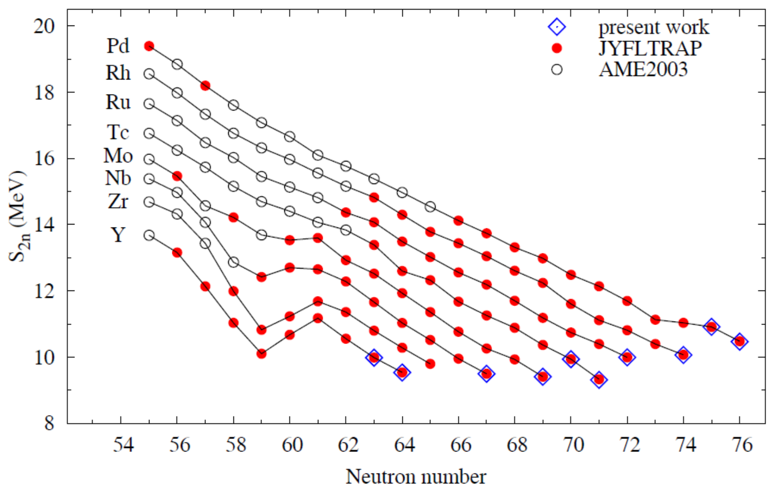


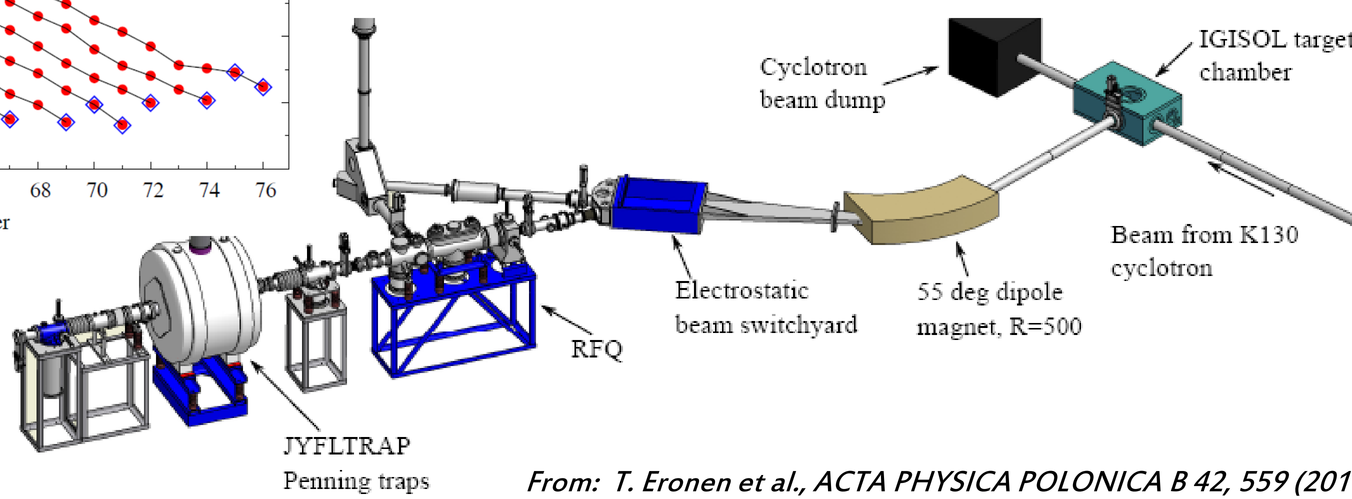
From: T. Eronen et al., ACTA PHYSICA POLONICA B 42, 559 (2011)

JYFLTRAP @ IGISOL-Jyvaskyla

year	article
2011	J. Souin et al., Eur. Phys. J. A 47
2011	J. Hakala et al., Eur. Phys. J. A 47
2012	J. Hakala et al., Phys. Rev. Lett. 109
2013	A. Kankainen et al., Phys. Rev. C 87
2014	A. Kankainen et al., arXiv:1403.4073



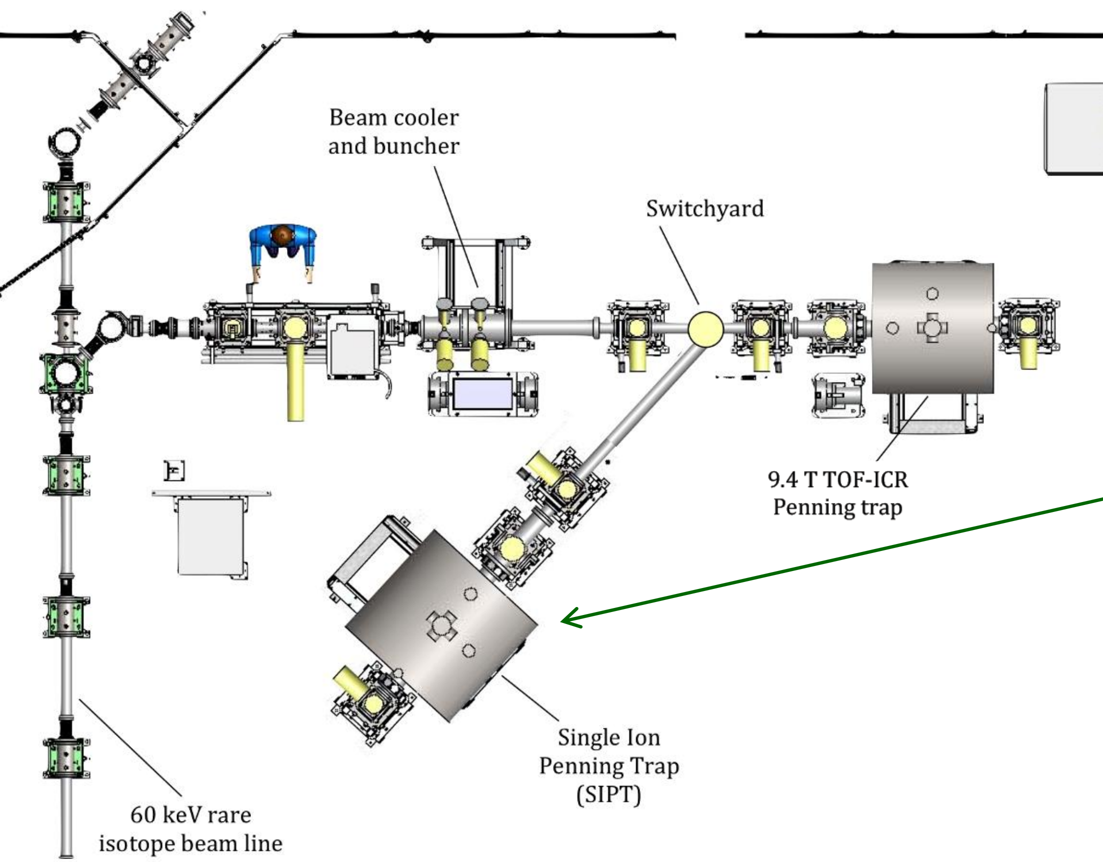


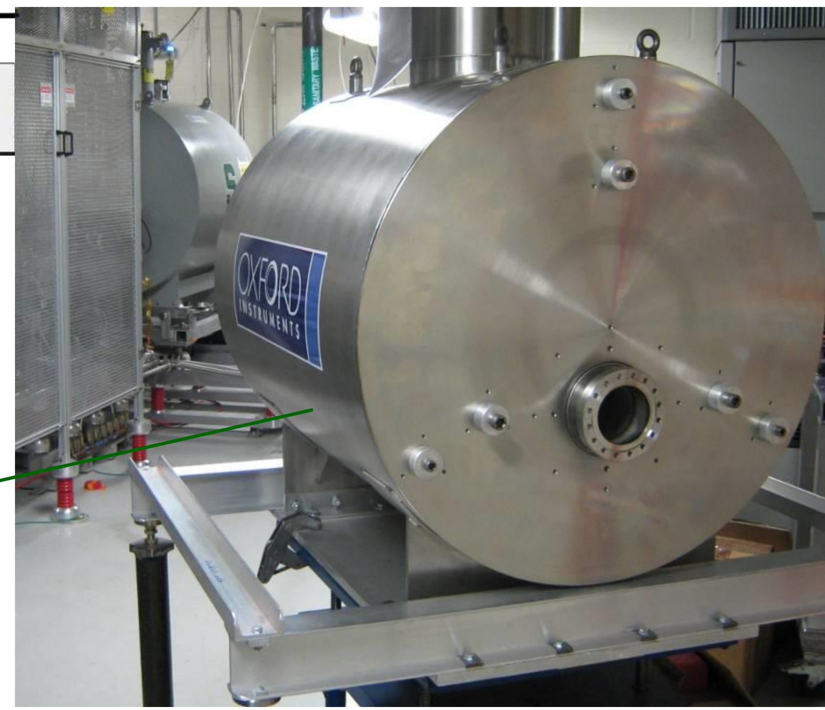


From: T. Eronen et al., ACTA PHYSICA POLONICA B 42, 559 (2011)

LEBIT @ NSCL-MSU (ions trapped after fragmentation):

year	article	physics	nuclides
2012	M. Redshaw et al., Phys. Rev. C 86 0v2B-	neutrino	48Ca
2013	D.L. Lincoln et al., Phys. Rev. Lett. 110	neutrino	82Se
2013	S. Bustabad et al., Phys. Rev. C 88	resonant 2EC	78Kr/78Se
2013	S. Bustabad et al., Phys. Rev. C 88	0v2B-neutrino	48Ca/48Ti





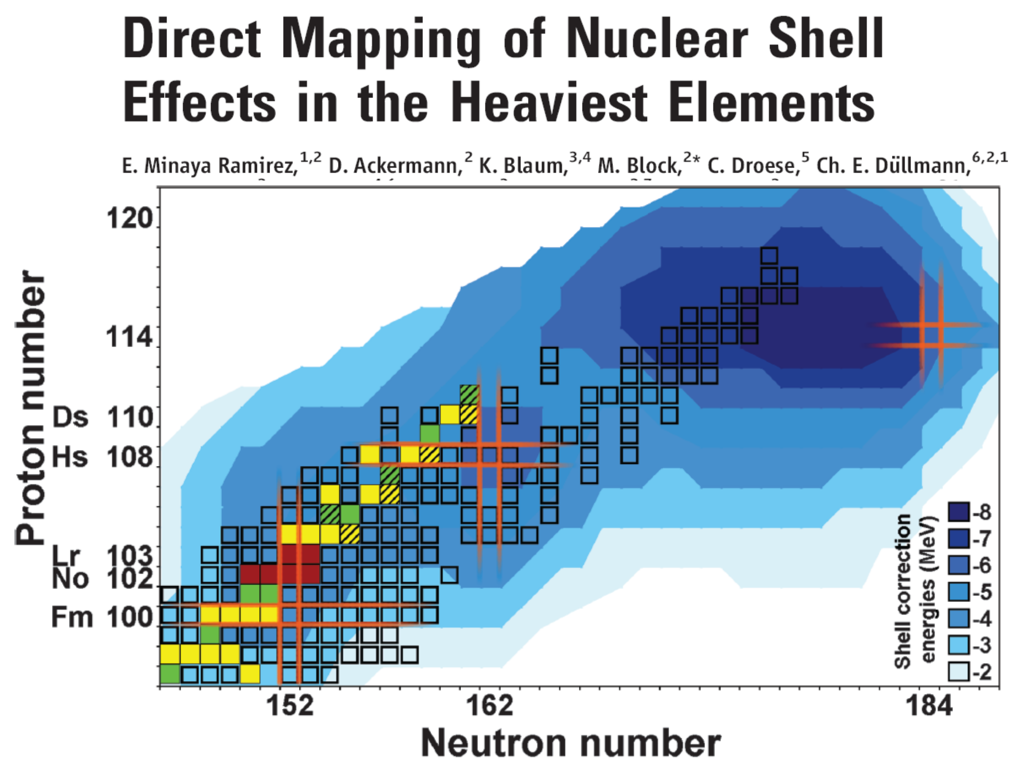
R. Ringle, PS1-A064

SHIPTRAP @ GSI-Darmstadt:

year	article	physics	nuclides
2011	S. Eliseev et al., PRC 83, 038501	neutrino physics	96Ru, 162Er, 168Yb
2011	S. Eliseev et al., PRL 106, 052504	neutrino physics	152Gd
2012	D. Nesterenko et al., PRC 86, 044313	0v2B; 0v2EC	A = 124, 130, 136
2012	Ch. Droese et al., Nucl. Phys. A 875, 1	0v2EC	180W-180Hf
2012	E. Minaya Ramirez et al. Science	structure	252-255No, 255-256Lr
2013	Ch. Droese et al. EPJA 49, 13	structure	203-207Rn; 213Ra

SHIPTRAP @ GSI-Darmstadt:

year	article	physics	nuclides
2011	S. Eliseev et al., PRC 83, 038501	neutrino physics	96Ru, 162Er, 168Yb
2011	S. Eliseev et al., PRL 106, 052504	neutrino physics	152Gd
2012	D. Nesterenko et al., PRC 86, 044313	0v2B; 0v2EC	A = 124, 130, 136
2012	Ch. Droese et al., Nucl. Phys. A 875, 1	0v2EC	180W-180Hf
2012	E. Minaya Ramirez et al. Science	structure	252-255No, 255-256Lr
2013	Ch. Droese et al. EPJA 49, 13	structure	203-207Rn; 213Ra



SHIPTRAP @ GSI-Darmstadt:

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2011	S. Eliseev et al., PRC 83, 038501	neutrino physics	96Ru, 162Er, 168Yb
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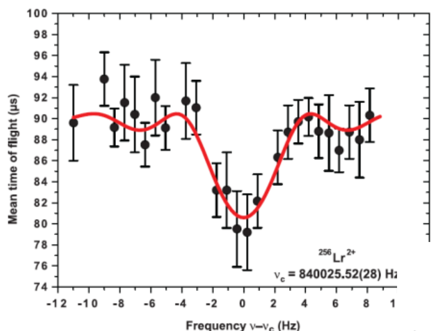
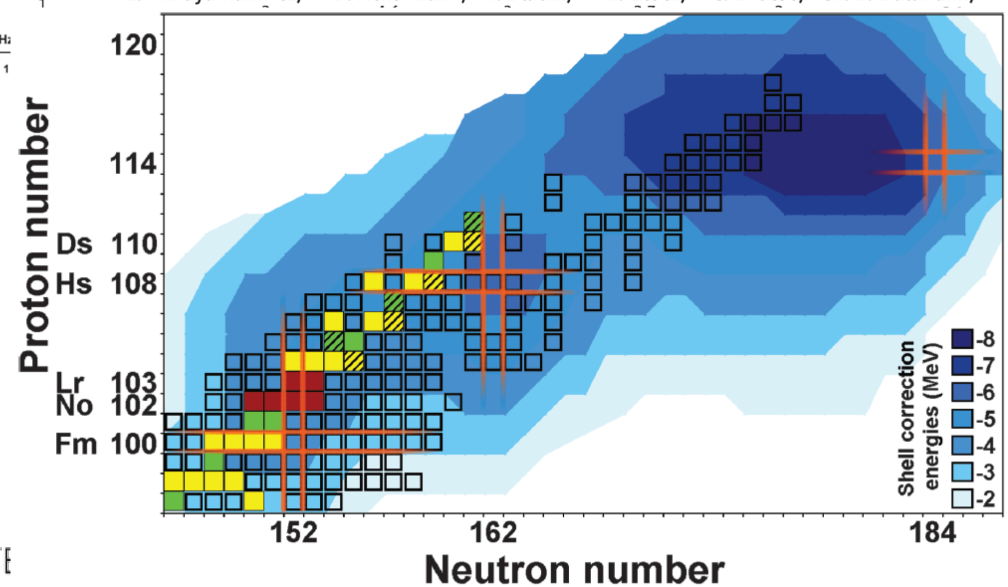
2012	D. Nesterenko et al., PRC 86, 044313	0v2B; 0v2EC	A = 124, 130, 136
2012	Ch. Droese et al., Nucl. Phys. A 875, 1	0v2EC	180W-180Hf
2012	E. Minaya Ramirez et al. Science	structure	252-255No, 255-256Lr
2013	Ch. Droese et al. EPJA 49, 13	structure	203-207Rn; 213Ra



Direct Mapping of Nuclear Shell Effects in the Heaviest Elements

E. Minaya Ramirez,[1,2] D. Ackermann,[2] K. Blaum,[3,4] M. Block,[2*] C. Droese,[5] Ch. E. Düllmann,[6,2,1]



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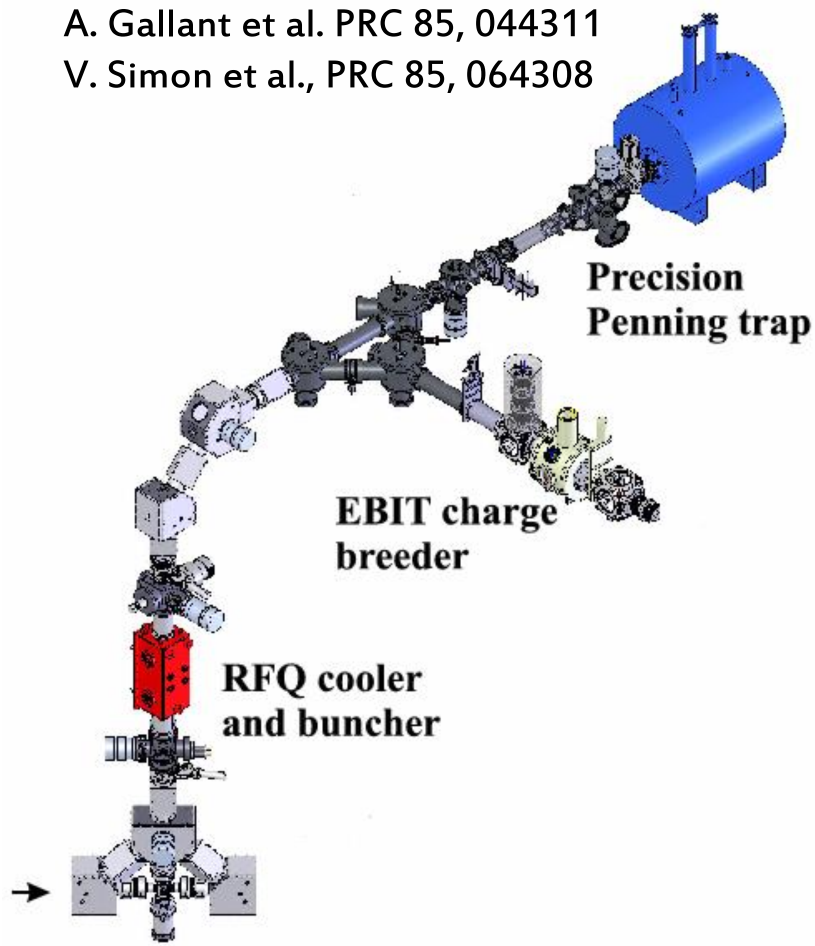
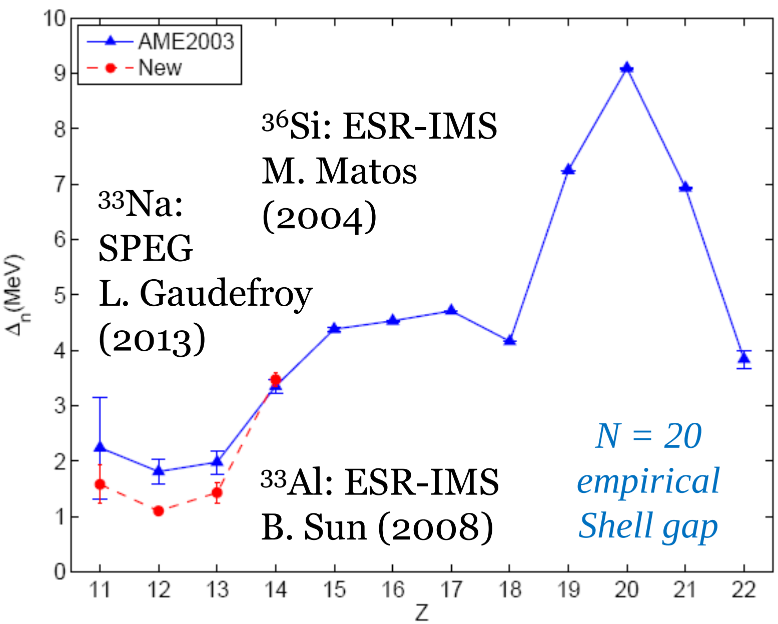
TITAN @ TRIUMF-ISAC:

year	article	physics	nuclides
2011	S. Ettenauer et al. PRL 107, 272501	CVC	74-76Rb, 74Ga (8+ state)
2012	A. Lapierre et al. PRC 85, 024317	structure (N=28)	44-50K; 49-50Ca
2012	M. Brodeur et al. PRL 108, 052504	structure (halos)	8He; 6He
2012	M. Brodeur et al. PRL 108, 212501	IMME	9Li; 9Be
2012	A. Gallant et al. PRC 85, 044311	structure	78mRb (8+)
2012	V. Simon et al., PRC 85, 064308	r process	94,97,98Rb, 94,97-99Sr

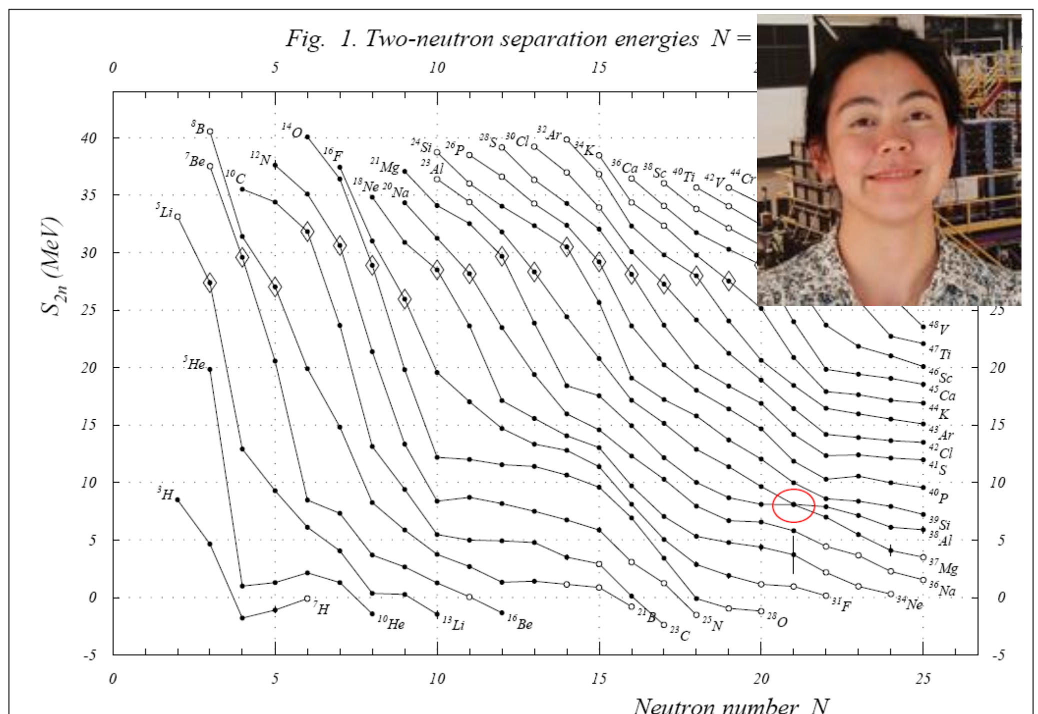


TITAN @ TRIUMF-ISAC:

year	article	physics	nuclides
2012	A. Gallant et al. PRL 109, 032506	structure/theory	51K, 51-52Ca
2013	A. Kwiatkowski et al. Ann. Phys.	CVC	10C; 10B
2013	A. Chaudhuri et al. PRC 88, 054317	structure (N=20)	29-31Na; 30-34Mg
2013	D. Frekers et al. Phys. Lett. B 722	EC/neutrino	71Ga; 71Ge (21+ states)
2014	T. Macdonald et al. PRC 89, 044318	EC/neutrino	51Cr; 51V (6+ states)
2014	A. Kwiatkowski et al. PRC 89, 045502	0v2B/neutrino	48Ca; 48Ti
2014	A. Kwiatkowski et al. PRL (submitted)	structure (N=20)	27-34Al

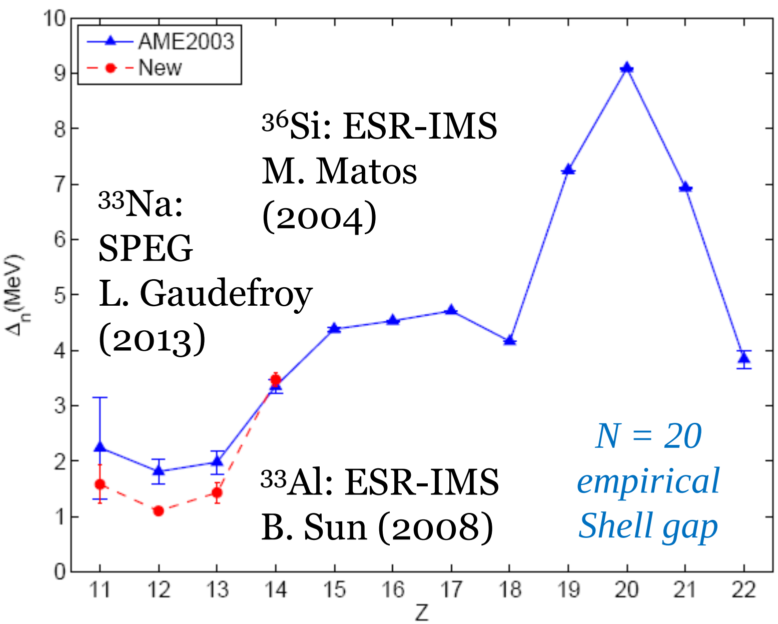


^{32,34}Mg/^{31}Na: TITAN;
A. Chaudhuri et al. (2013)

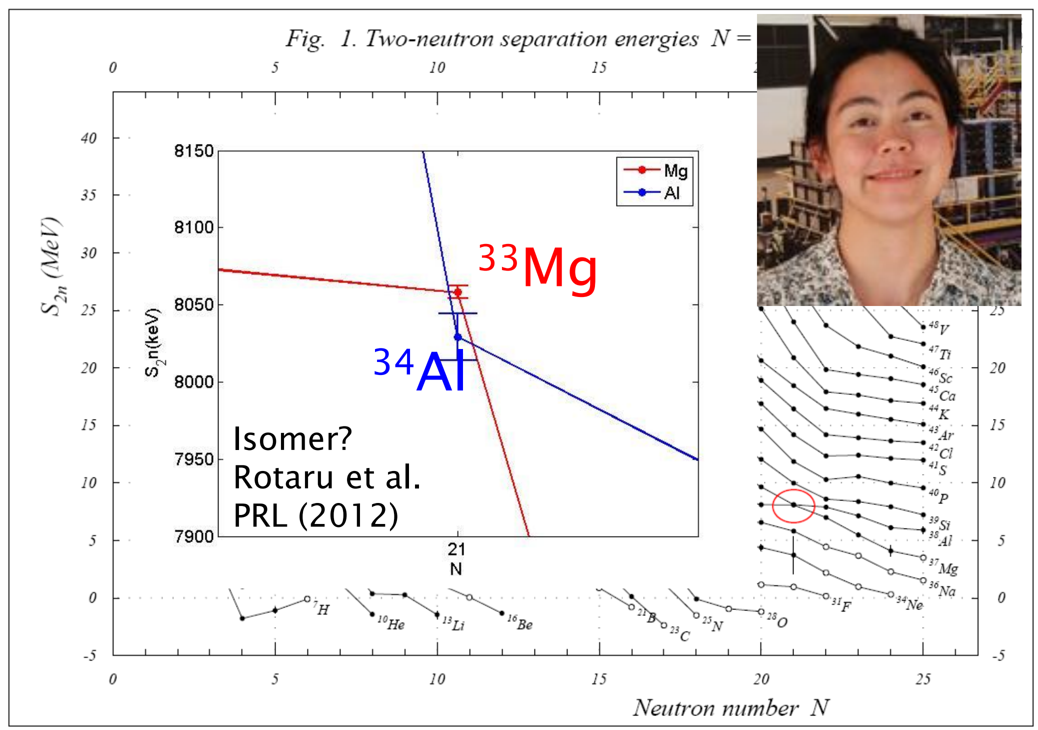


TITAN @ TRIUMF-ISAC:

year	article	physics	nuclides
2012	A. Gallant et al. PRL 109, 032506	structure/theory	51K, 51-52Ca
2013	A. Kwiatkowski et al. Ann. Phys.	CVC	10C; 10B
2013	A. Chaudhuri et al. PRC 88, 054317	structure (N=20)	29-31Na; 30-34Mg
2013	D. Frekers et al. Phys. Lett. B 722	EC/neutrino	71Ga; 71Ge (21+ states)
2014	T. Macdonald et al. PRC 89, 044318	EC/neutrino	51Cr; 51V (6+ states)
2014	A. Kwiatkowski et al. PRC 89, 045502	0v2B/neutrino	48Ca; 48Ti
2014	A. Kwiatkowski et al. PRL (submitted)	structure (N=20)	27-34Al



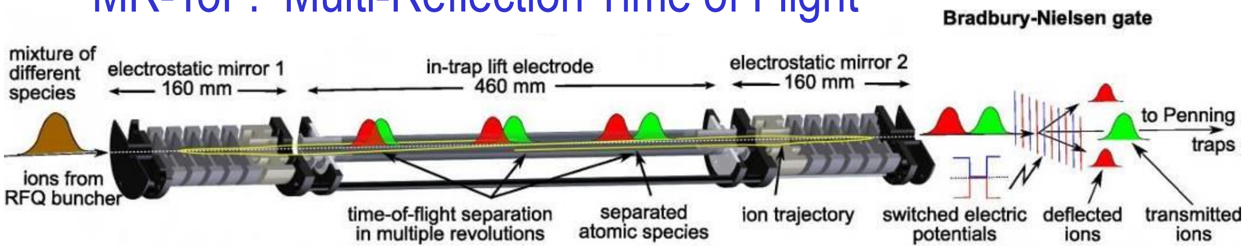
^{32,34}Mg/^{31}Na: TITAN;
A. Chaudhuri et al. (2013)



ISOLTRAP @ CERN-ISOLDE

year	article	physics	nuclides
2012	S. Naimi et al., PRC 86	structure (N = 40)	58-66Mn
2012	A. Herlert et al. EPJA	recoil-ion trapping	61-63Fe
2012	F. Herfurth et al., EPJA	rp process	Z > 32 p-rich
2012	D. Fink et al., PRL 108, 062502	0v2B/neutrino	110Pd-110Cd
2013	R. Wolf et al. PRL 110, 041101	neutron-star crust	82Zn

MR-ToF: Multi-Reflection Time of Flight



ISOLTRAP @ CERN-ISOLDE

year	article	physics	nuclides
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2012	A. Herlert et al. EPJA	recoil-ion trapping	61-63Fe
2012	F. Herfurth et al., EPJA	rp process	Z > 32 p-rich
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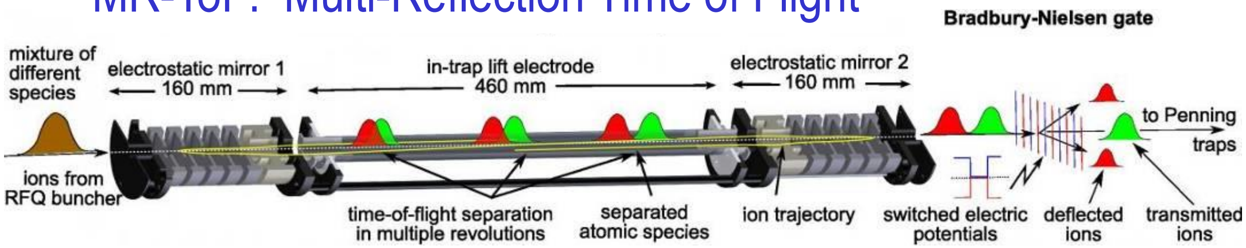
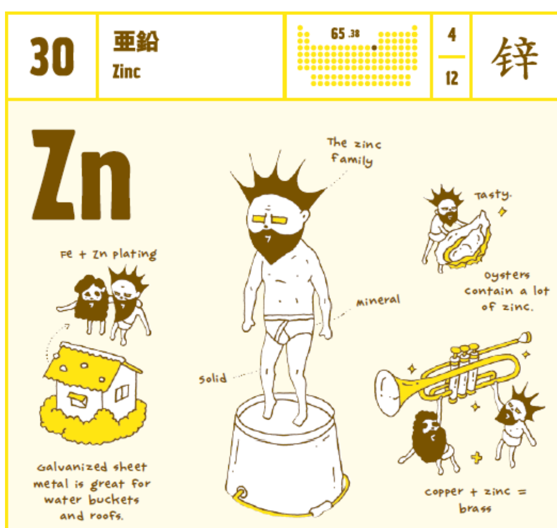
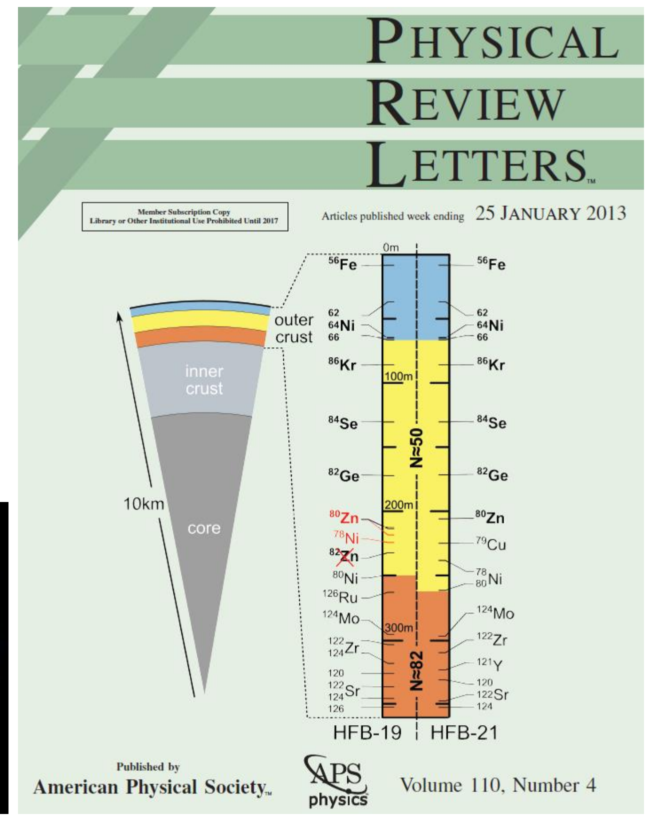
MR-ToF: Multi-Reflection Time of Flight

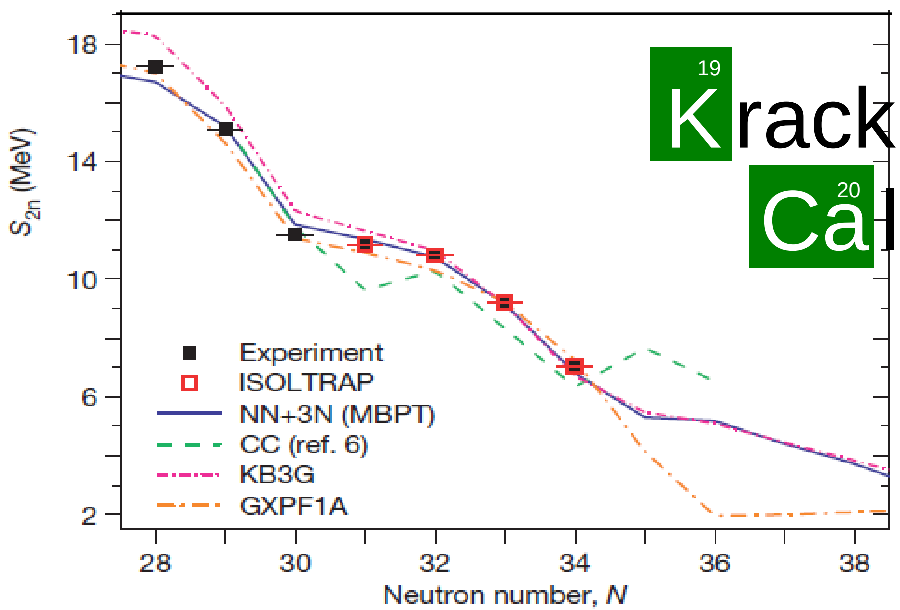






ISOLTRAP @ CERN-ISOLDE

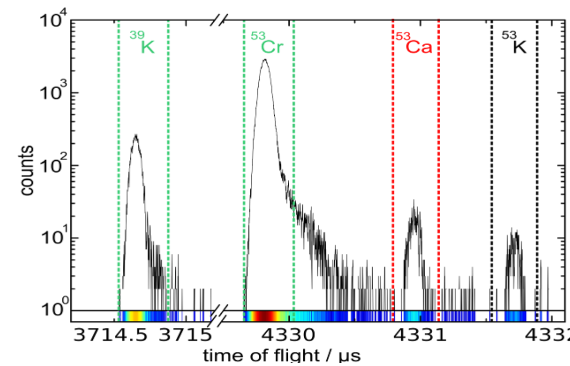
year	article	physics	nuclides
2013	F. Wienholtz et al., Nature	structure	52-54Ca (MR-ToF)
2013	R. Wolf et al. Int. J. Mass Spec. 349, 123	proof of principle	137Eu
2013	J. Stanja et al. PRC 88, 054304	structure (spectro)	190mTl; 194(m)Tl; 198At
2013	V. Manea et al. PRC 88, 054322	structure	98-100Rb
2014	Ch. Boehm et al. PRC (submitted)	structure	190Tl
2014	S. Kreim et al. PRC (submitted)	structure	233Fr

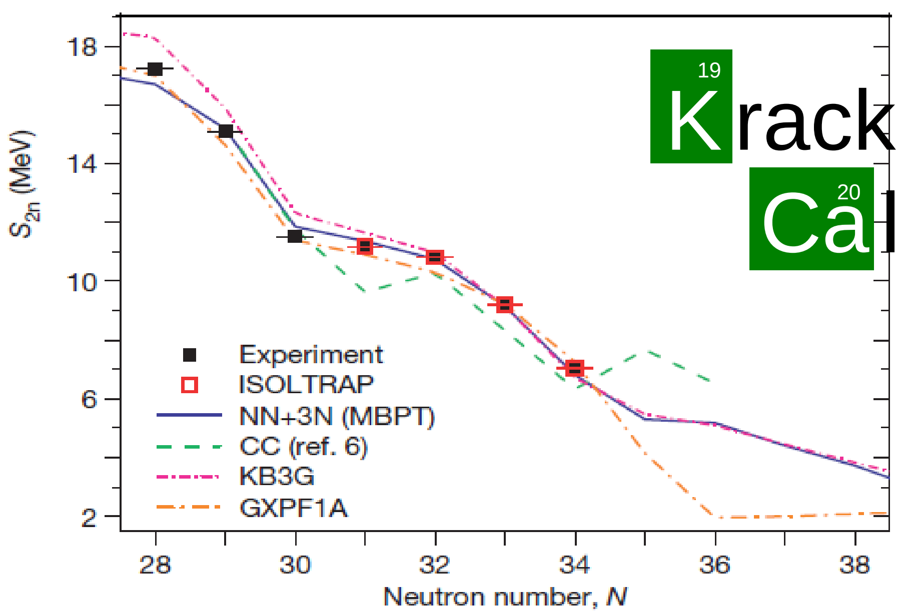


19
Kracking
20
Calcium

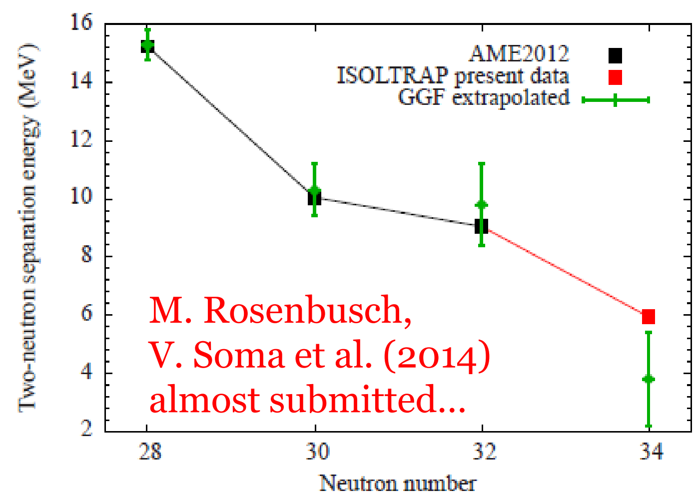
ISOLTRAP @ CERN-ISOLDE

year	article	physics	nuclides
2013	F. Wienholtz et al., Nature	structure	52-54Ca (MR-ToF)
2013	R. Wolf et al. Int. J. Mass Spec. 349, 123	proof of principle	137Eu
2013	J. Stanja et al. PRC 88, 054304	structure (spectro)	190mTl; 194(m)Tl; 198At
2013	V. Manea et al. PRC 88, 054322	structure	98-100Rb
2014	Ch. Boehm et al. PRC (submitted)	structure	190Tl
2014	S. Kreim et al. PRC (submitted)	structure	233Fr



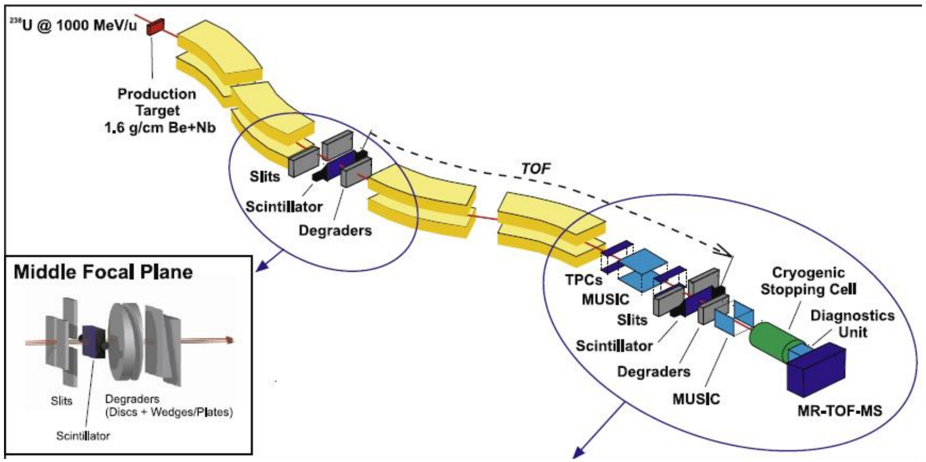


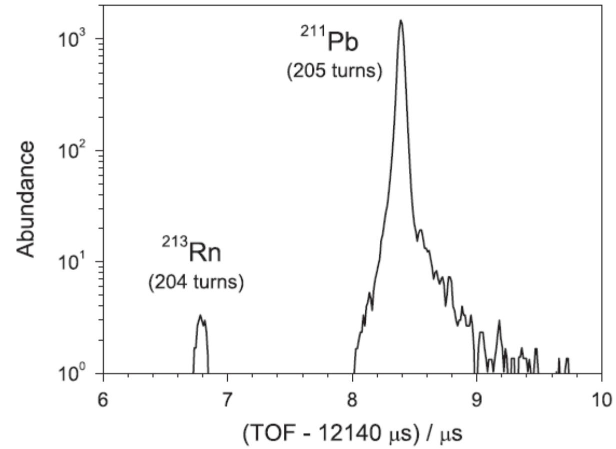
19 Kracking
20 Calcium



MR-TOF-MS @ FRS-GSI

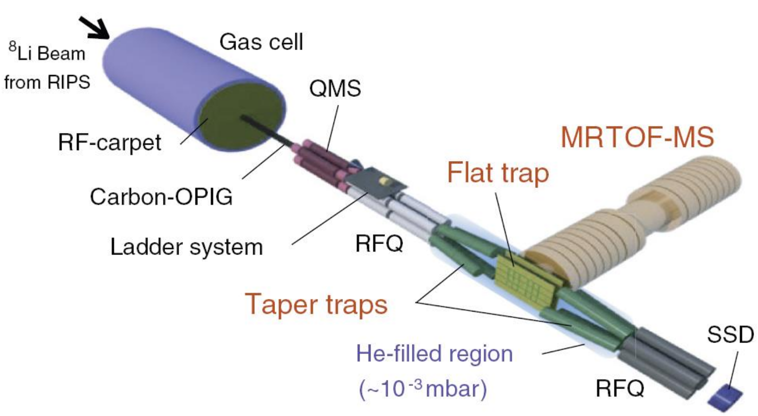
year	article	physics	nuclides
2013	W. Plass et al., NIMB 317, 457	structure	213Rn spectrum (211Pb)

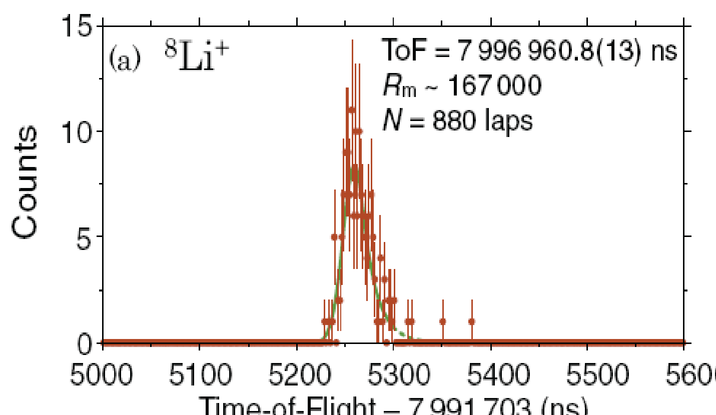




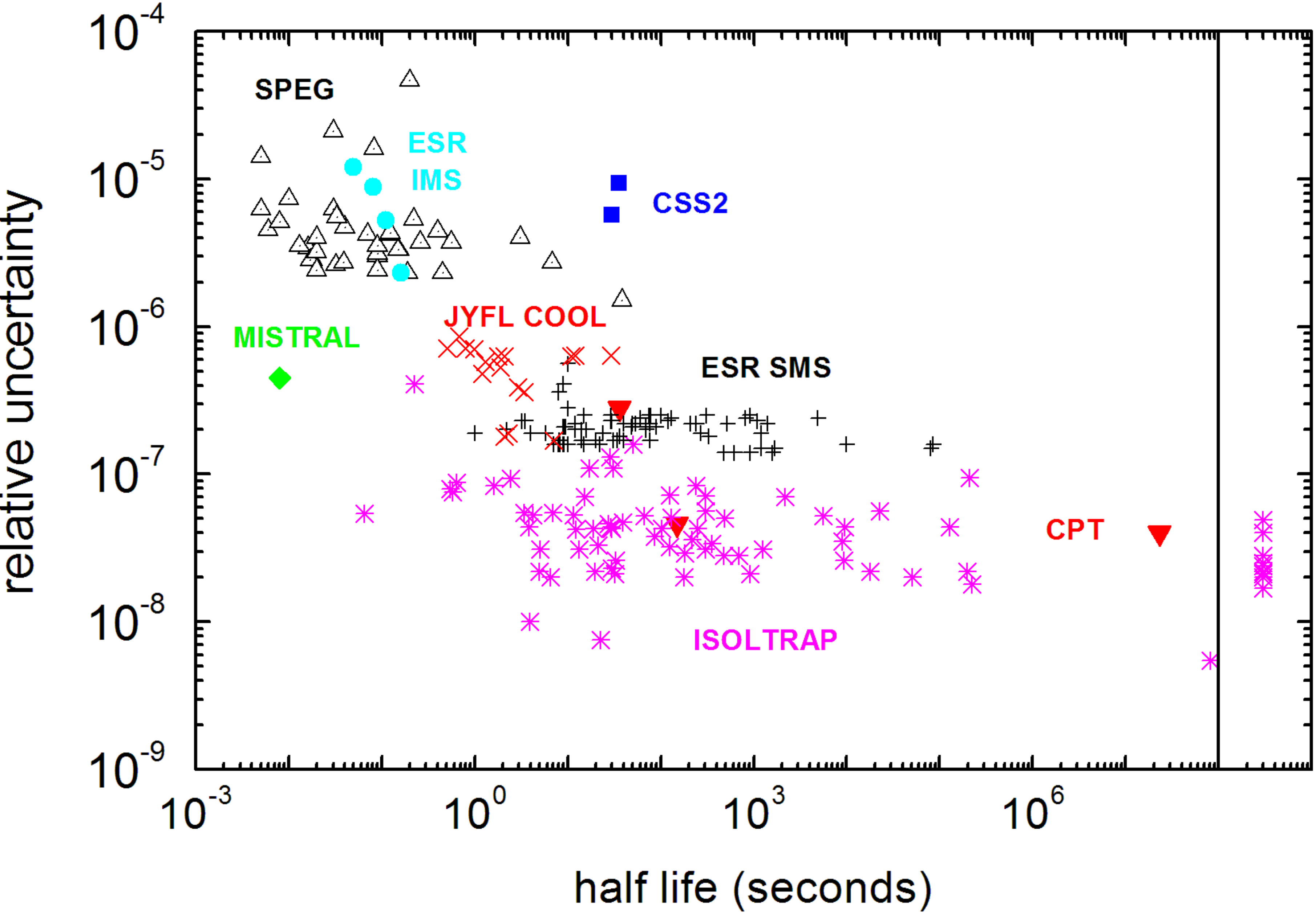
SLOWRI @ RIKEN

year	article	physics	nuclides
2013	Y. Ito et al. PRC 88, 011306(R)	structure	8Li



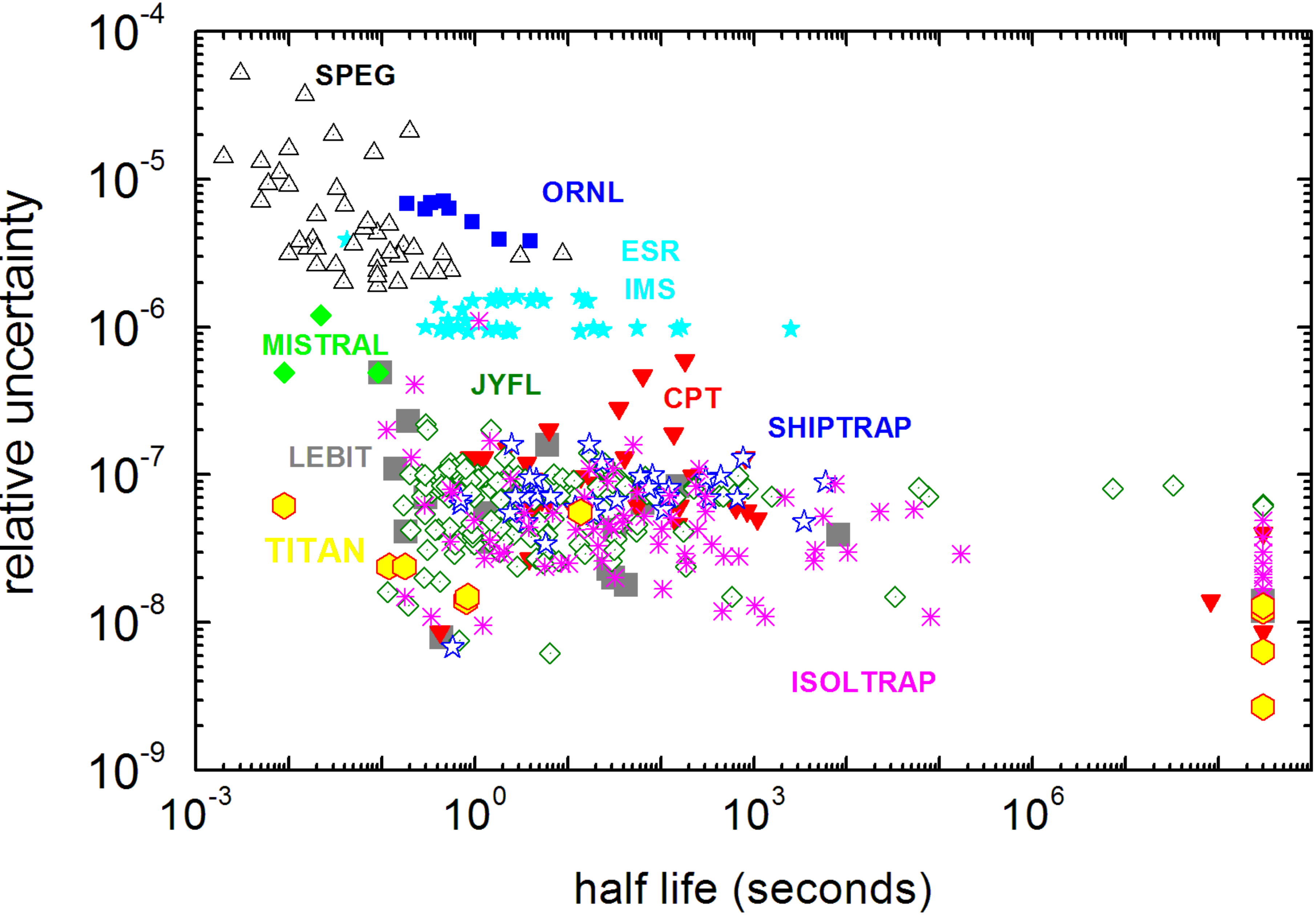


P[ND]^2 2005



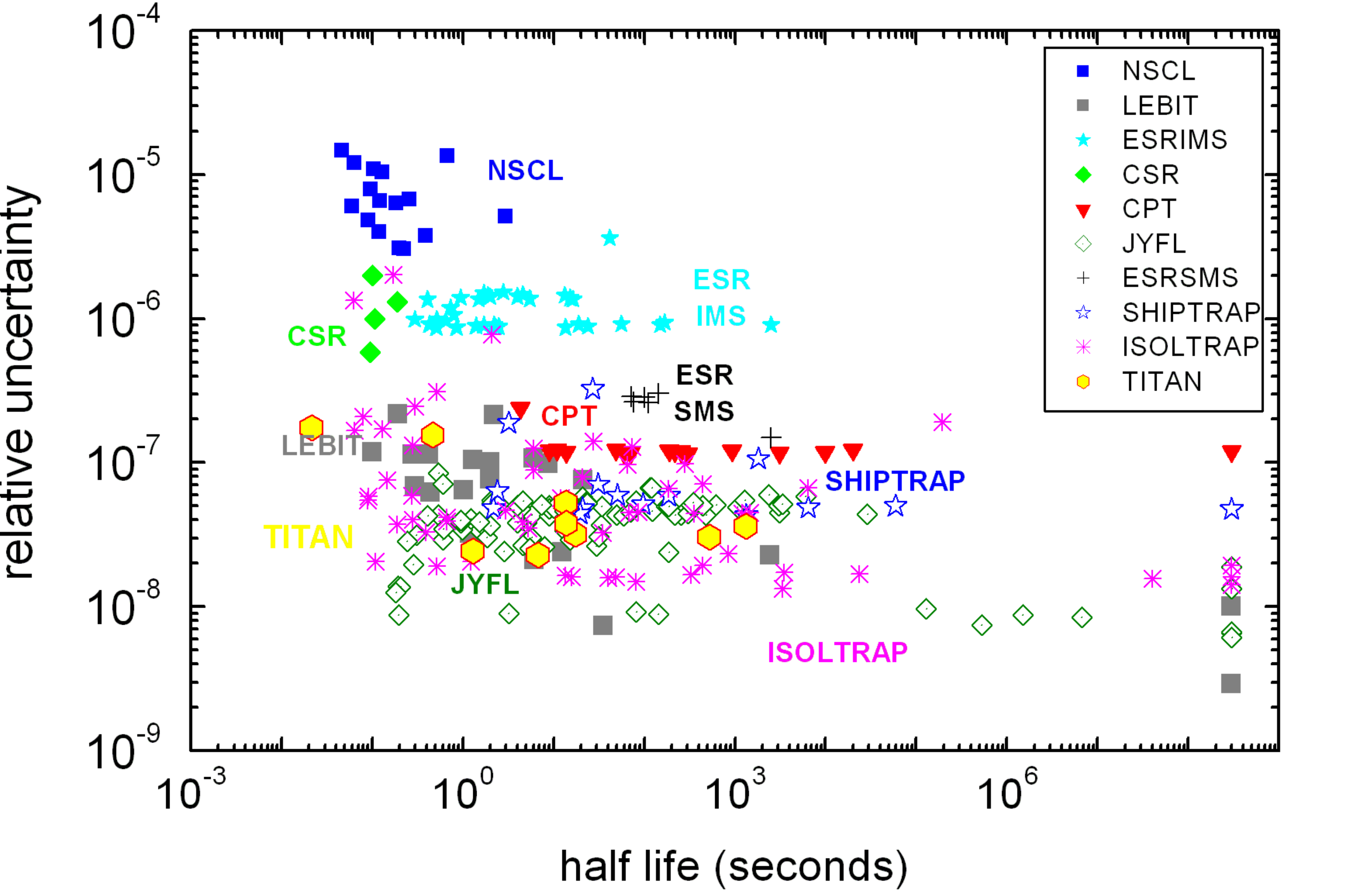
SPEG
ESR
IMS
CSS2
MISTRAL
JYFL COOL
ESR SMS
CPT
ISOLTRAP
relative uncertainty
half life (seconds)
10-4
10-5
10-6
10-7
10-8
10-9
10-3
100
103
106

ENAM 2008

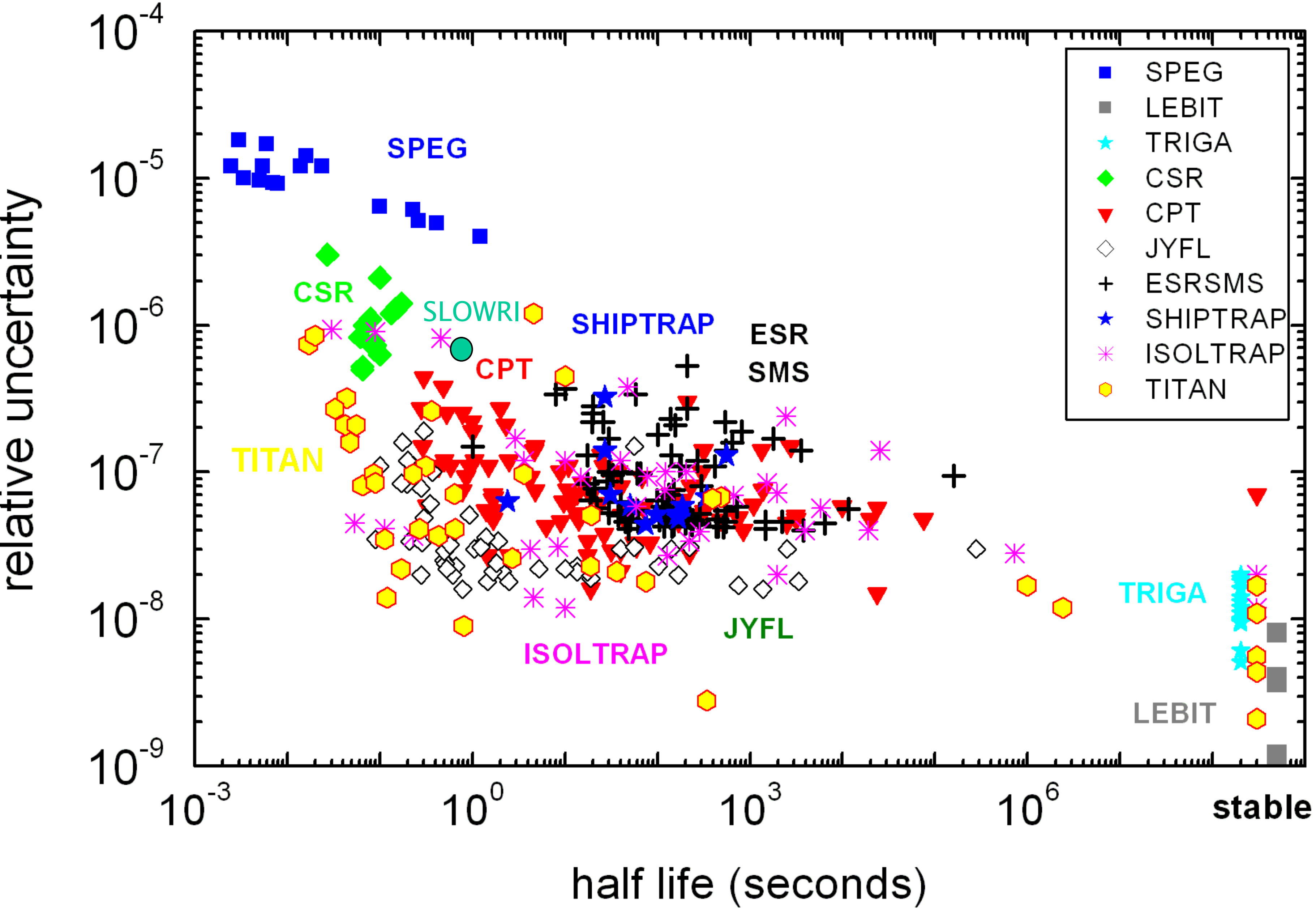


10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
relative uncertainty
SPEG
ORNL
ESR
IMS
MISTRAL
JYFL
CPT
SHIPTRAP
LEBIT
TITAN
ISOLTRAP
10^-3
10^0
10^3
10^6
half life (seconds)

ARIS 2011


NSCL
ESR
IMS
CSR
ESR
SMS
CPT
LEBIT
SHIPTRAP
TITAN
JYFL
ISOLTRAP
NSCL
LEBIT
ESRIMS
CSR
CPT
JYFL
ESRSMS
SHIPTRAP
ISOLTRAP
TITAN
relative uncertainty
half life (seconds)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-3}
10^{0}
10^{3}
10^{6}

ARIS 2014



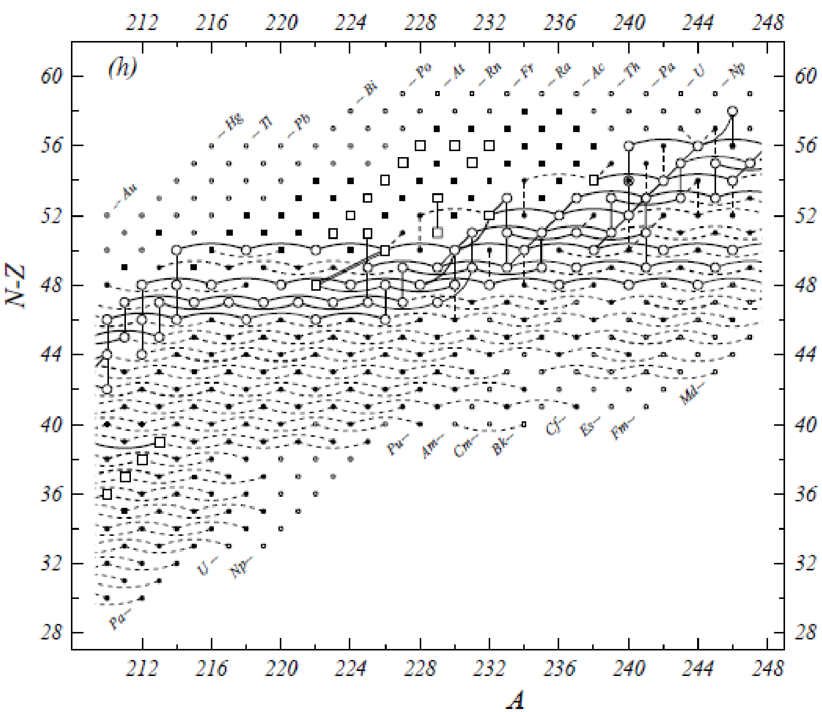
relative uncertainty
half life (seconds)
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-3
10^0
10^3
10^6
stable
SPEG
CSR
SLOWRI
SHIPTRAP
ESR
SMS
CPT
TITAN
ISOLTRAP
JYFL
TRIGA
LEBIT
SPEG
LEBIT
TRIGA
CSR
CPT
JYFL
ESRSMS
SHIPTRAP
ISOLTRAP
TITAN

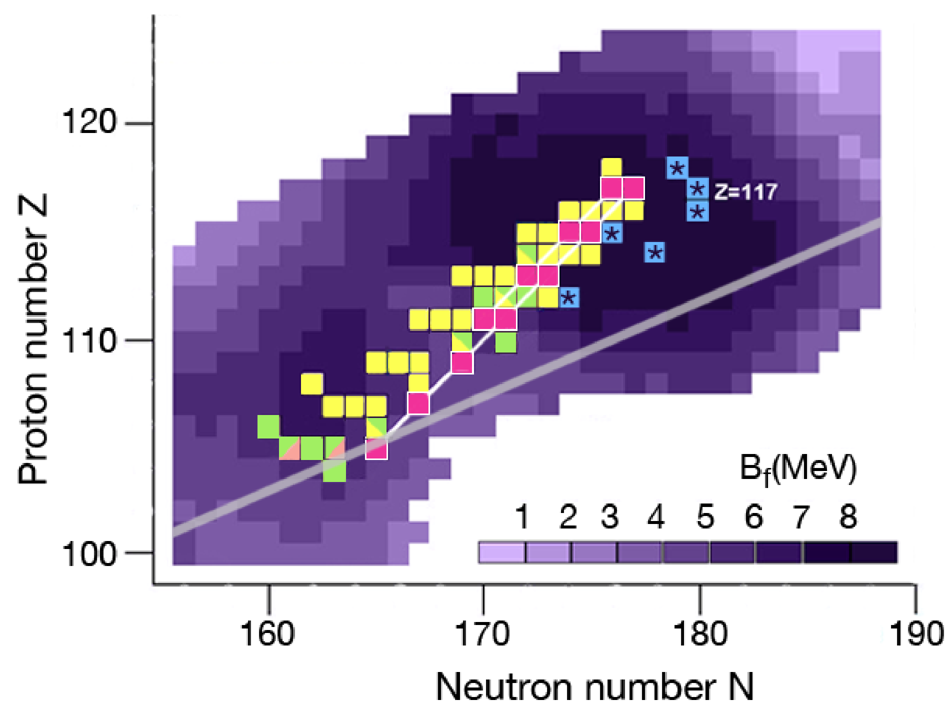
CPC(HEP & NP), 2012, **36**(12): 1287–1602 **Chinese Physics C** Vol. 36, No. 12, Dec., 2012

The AME2012 atomic mass evaluation *

(I). Evaluation of input data, adjustment procedures

G. Audi[1,§], M. Wang[1,2,3], A.H. Wapstra[4,†], F.G. Kondev[5], M. MacCormick[6], X. Xu[2,7], and B. Pfeiffer[8,‡]





Observations and statistics (from results *published* 2011-2012):

(source: AME2012)

Total of about 447 direct measurements (total data):

TOF (99) : ESR (65); CSR (18); NSCL (16);

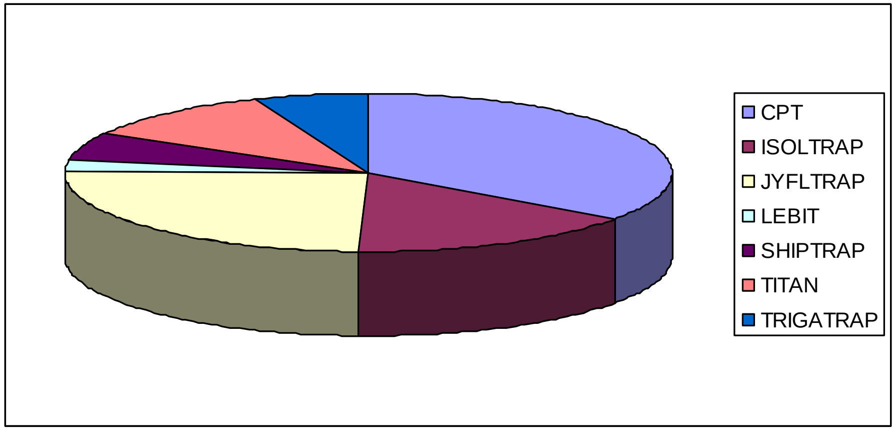
TRAPS (348):

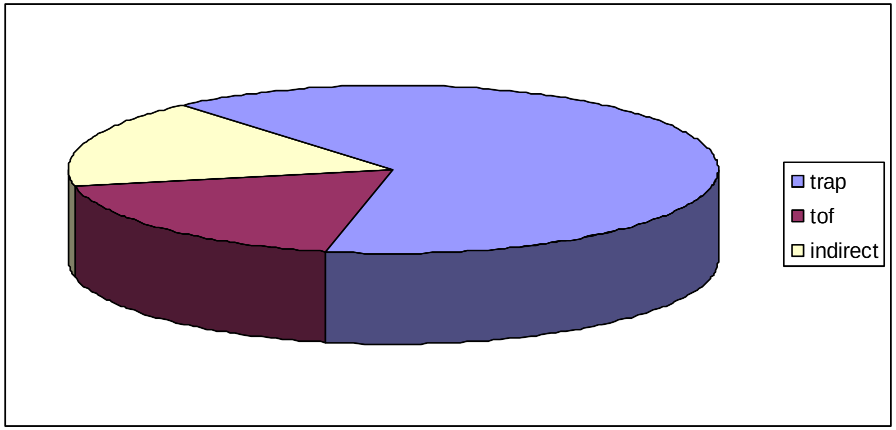
CPT	(122)
ISOLTRAP	(54)
JYFL	(86)
LEBIT	(8)
SHIPTRAP	(20)
TITAN	(37)
TRIGATRAP	(21)

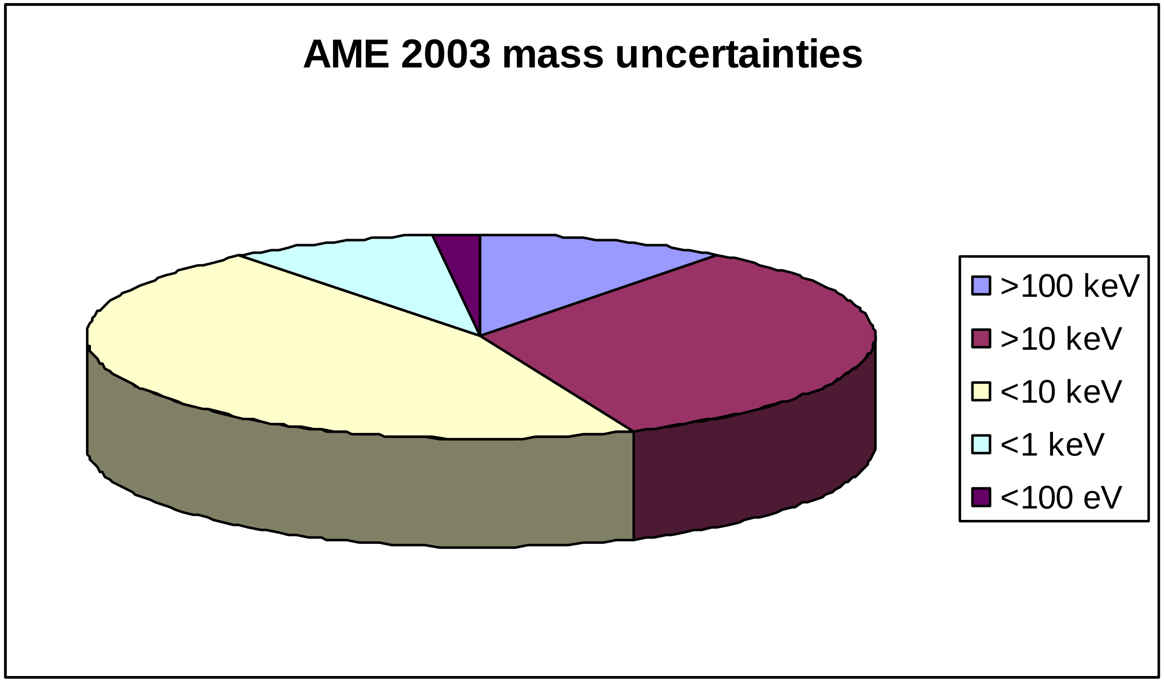
93 new reaction/decay data from:
RIKEN, JYFL, GSI, JINR, et al.

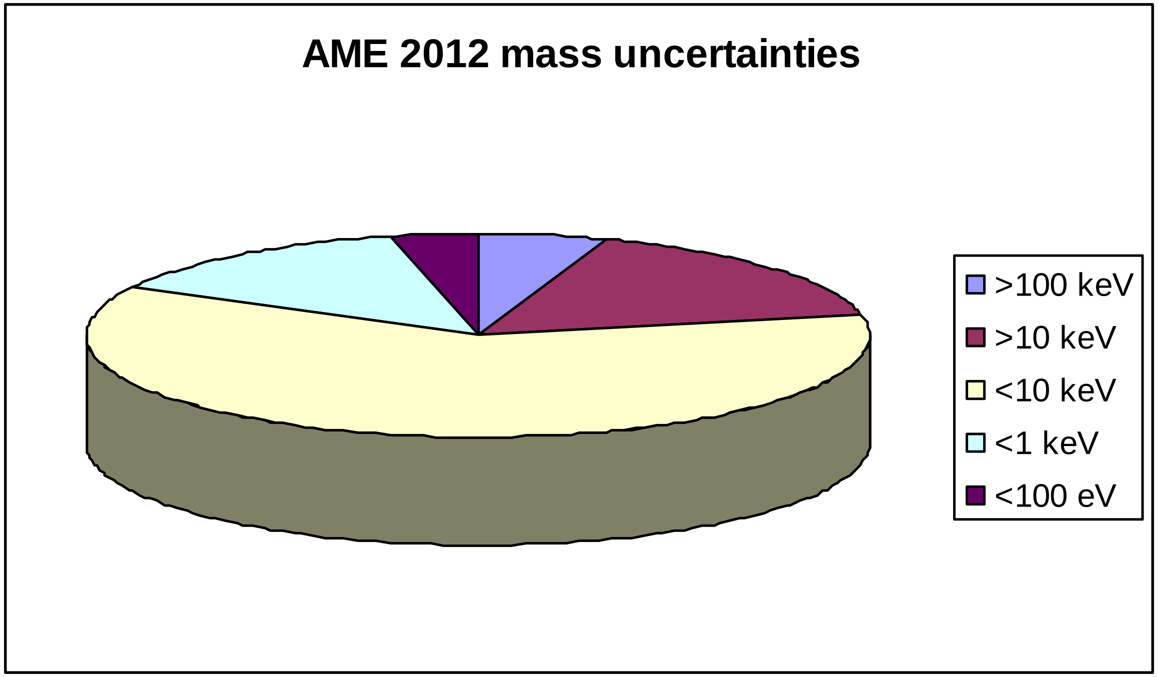
For comparisons see:
A. Kankainen et al. JPG (2012)

AME2003–2012
Direct: +416
Indirect: +150









Data Getting Better!

The AME: the stepping stone to theory

	AME2003
Total data	7773
Used (-BCDFU)	6169
Equations	1381
Parameters	847
X^2 expected	534
X^2 obtained	814
gs masses	2228
gs estimations	951
isomers	201
iso estimations	122
Reactions/decays	967
Mass spectrometry	414
X-indirect	1.27
X-direct	1.16

The AME: the stepping stone to theory

	AME2003	AME2012
Total data	7773	12437
Used (-BCDFU)	6169	5556
Equations	1381	1947
Parameters	847	1176
X^2 expected	534	771
X^2 obtained	814	765
gs masses	2228	2438
gs estimations	951	915
isomers	201	336
iso estimations	122	128
Reactions/decays	967	1117
Mass spectrometry	414	830
X-indirect	1.27	1.02
X-direct	1.16	0.96

Data getting better (not going as far…)

A (very) simplified overview of mass models

physics input →

algebraic formulas	*micro*scopic sculpturings of a *macro*scopic blob	microscopic nucleon-nucleon interaction

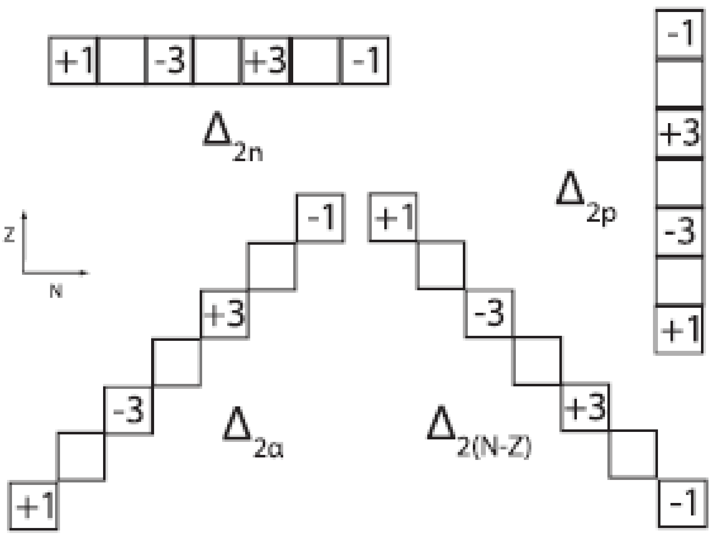
← ease of use

Garvey-Kelson + others (2013)	FRDM WS4 (2014)	HFB (27!) D1M (2009)

PHYSICAL REVIEW C 87, 044313 (2013)
Empirical formulas for nucleon separation energies
M. Bao, Z. He, Y. M. Zhao, and A. Arima

PHYSICAL REVIEW C 87, 044313 (2013)
Empirical formulas for nucleon separation energies
M. Bao, Z. He, Y. M. Zhao, and A. Arima

PHYSICAL REVIEW C 87, 024319 (2013)
Extrapolations of nuclear binding energies from new linear mass relations
D. Hove, A. S. Jensen, and K. Riisager



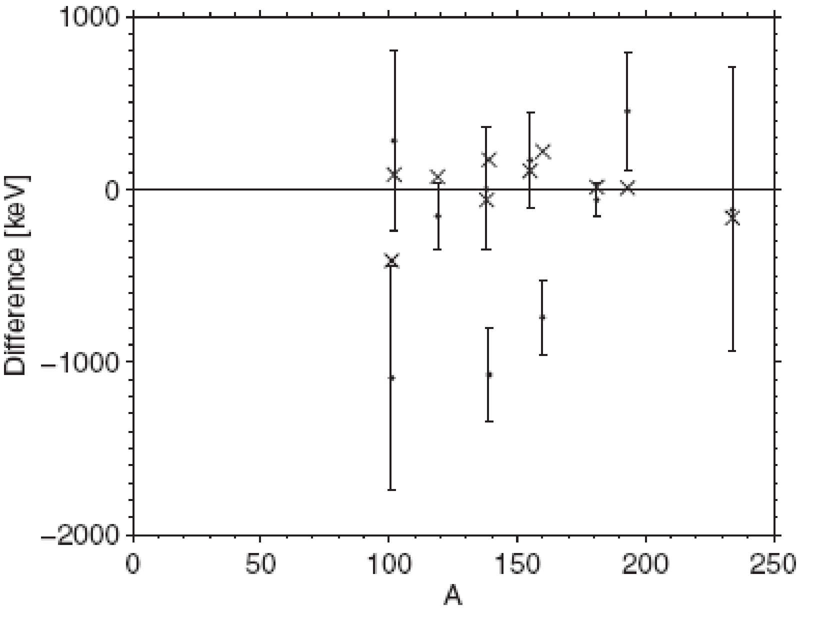


FIG. 5. The differences between our extrapolations and the measured values where the error bars are based solely on the extrapolated uncertainties. The crosses indicate the difference between Audi and Meng's extrapolations and the measurements.

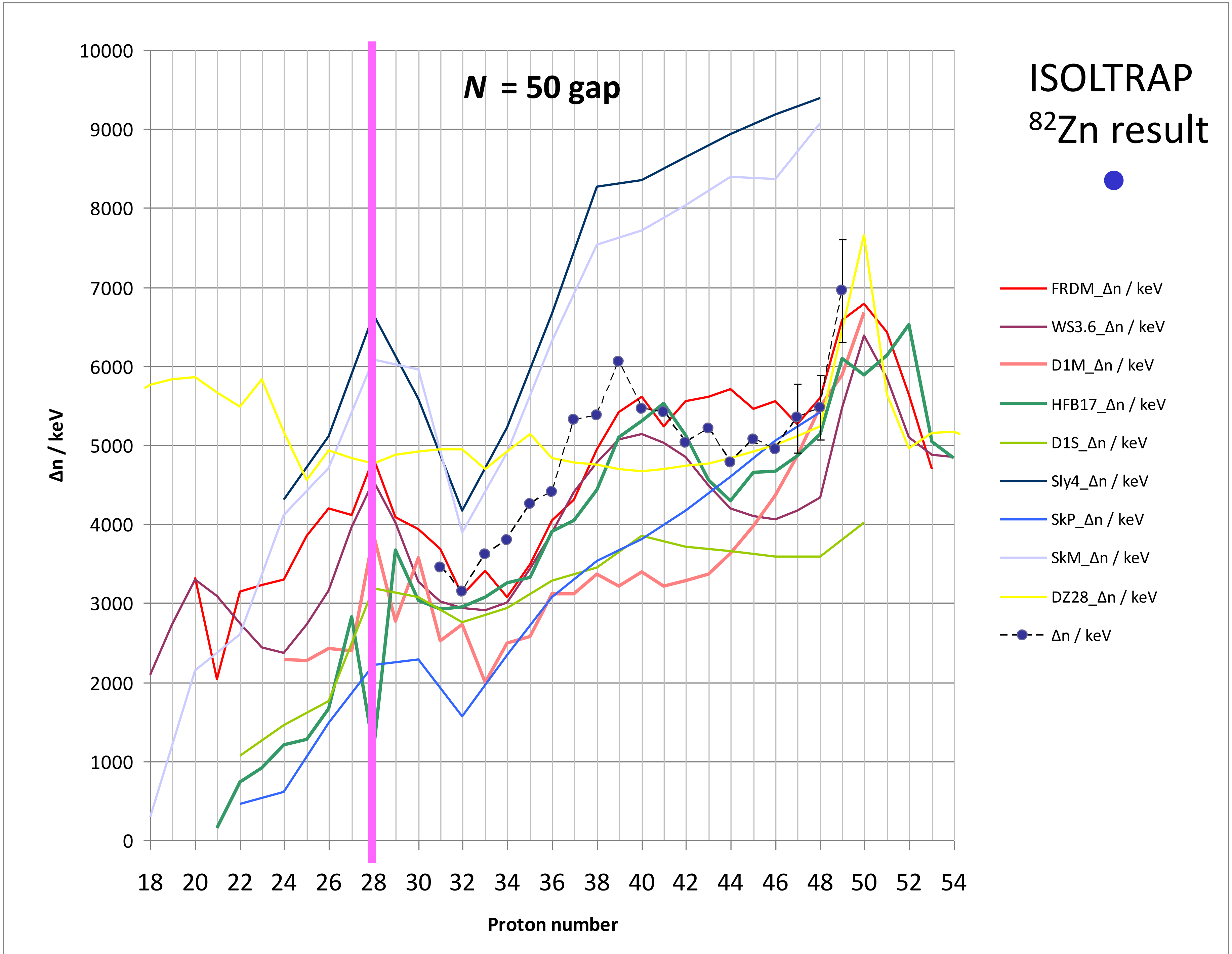
Theoretical Mass Models: Macroscopic - Microscopic / Liquid Drop

FRDM: Finite Range Droplet Model - New fit to 2011 AME! (2012?)
P. Moller J.R. Nix, W.D. Myers, W.J. Swiatecki,
At. Data Nuc. Data Tables 59 (1995) 185

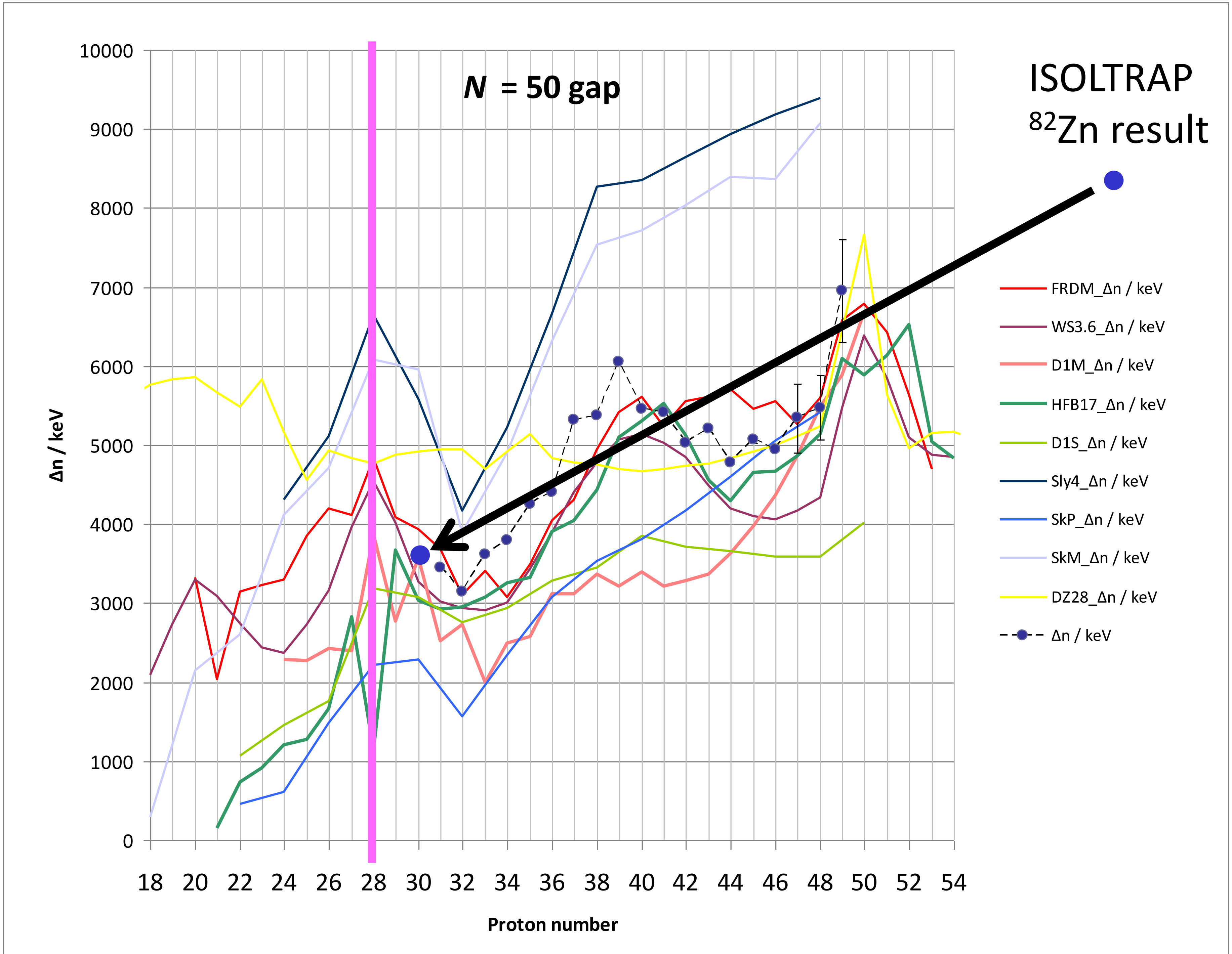
Kazuhiro Oyamatsu, Kei Iida, Hiroyuki Koura, Phys. Rev. C 82 (2010) 027301
Kazuhiro Oyamatsu, Kei Iida, Phys. Rev. C 81 (2010) 054302

Ning Wang, Zuoying Liang, Min Liu, Xizhen Wu, Phys. Rev. C 82 (2010) 044304
Ning Wang, Min Liu, Xizhen Wu, Phys. Rev. C 81 (2010) 044322

Wigner-Kirkwood (only 10 parameters but even-even cases only!):
A. Bhagwat, X. Vinas, M. Centelles, P. Schuck, R. Wyss, Phys. Rev. C 81 (2010) 044321
A. Bhagwat, X. Vinas, M. Centelles, P. Schuck, R. Wyss, Phys. Rev. C 86 (2012) 044316



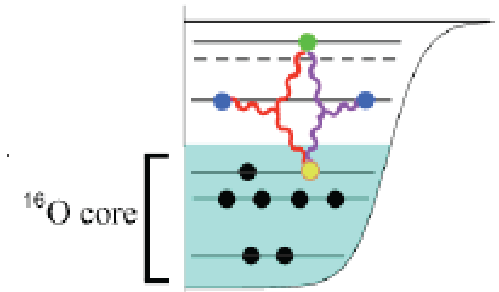
ISOLTRAP
^{82}Zn result
N = 50 gap
Δn / keV
Proton number
FRDM_Δn / keV
WS3.6_Δn / keV
D1M_Δn / keV
HFB17_Δn / keV
D1S_Δn / keV
Sly4_Δn / keV
SkP_Δn / keV
SkM_Δn / keV
DZ28_Δn / keV
Δn / keV



N = 50 gap
ISOLTRAP
82Zn result
Δn / keV
Proton number
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
FRDM_Δn / keV
WS3.6_Δn / keV
D1M_Δn / keV
HFB17_Δn / keV
D1S_Δn / keV
Sly4_Δn / keV
SkP_Δn / keV
SkM_Δn / keV
DZ28_Δn / keV
Δn / keV

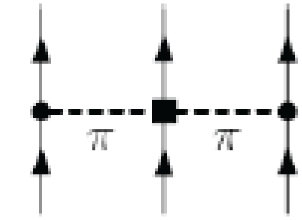
Some new theoretical approaches

Hagen, Hjorth-Jensen, Jansen, Machleidt, Papenbrock
Phys. Rev. Lett. 108 (2012)
Continuum effects & 3N forces – coupled cluster



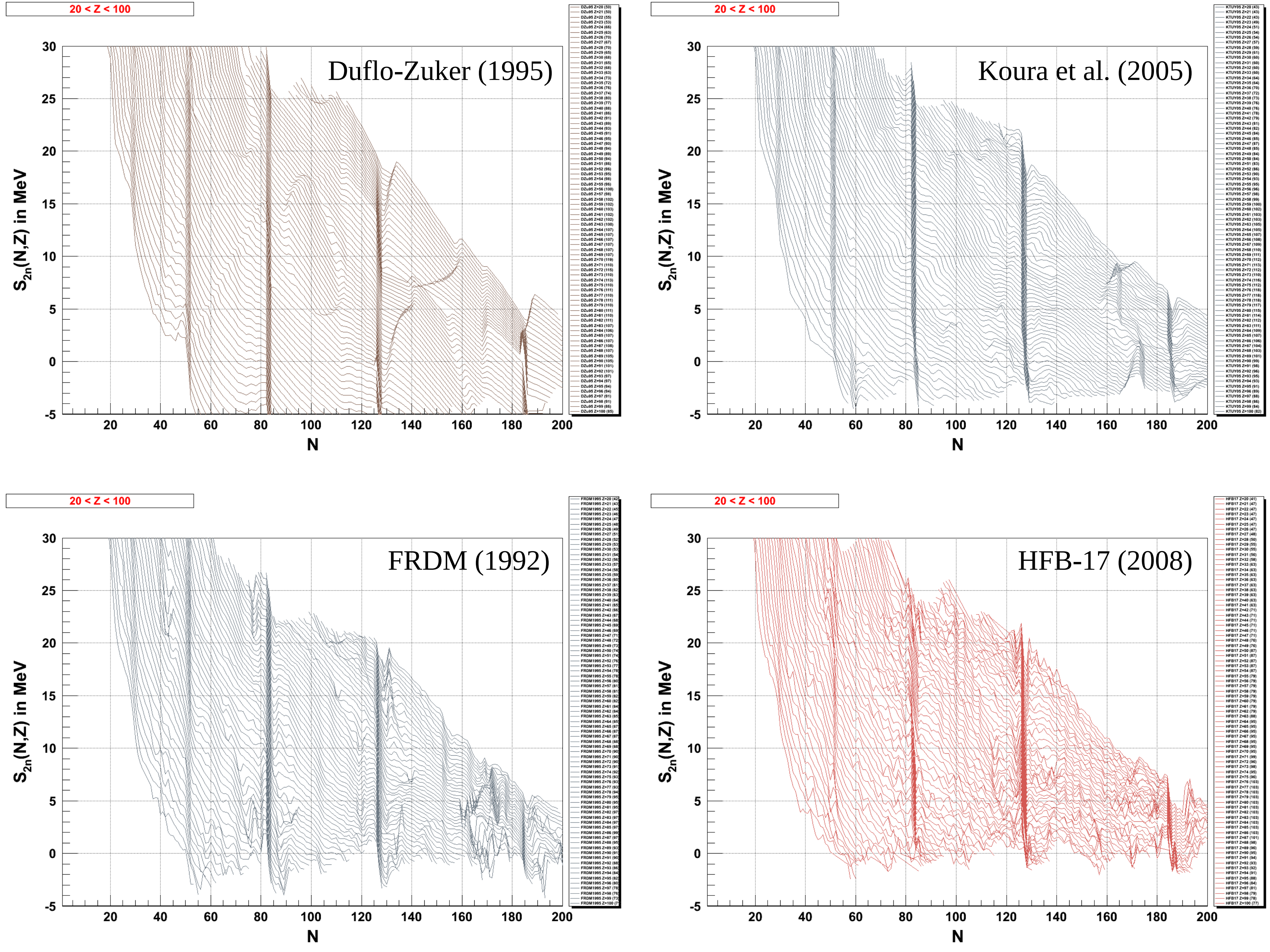
T. Otsuka et al. Phys. Rev. Lett. (2010)
Renewal of the tensor force

Nature (2013): *N* = 32 shell closure in Ca
F. Wienholtz and the ISOLTRAP Collaboration
J.D. Holt, A. Schwenk et al.
Chiral (3-body) EFT calculations of Ca isotopes

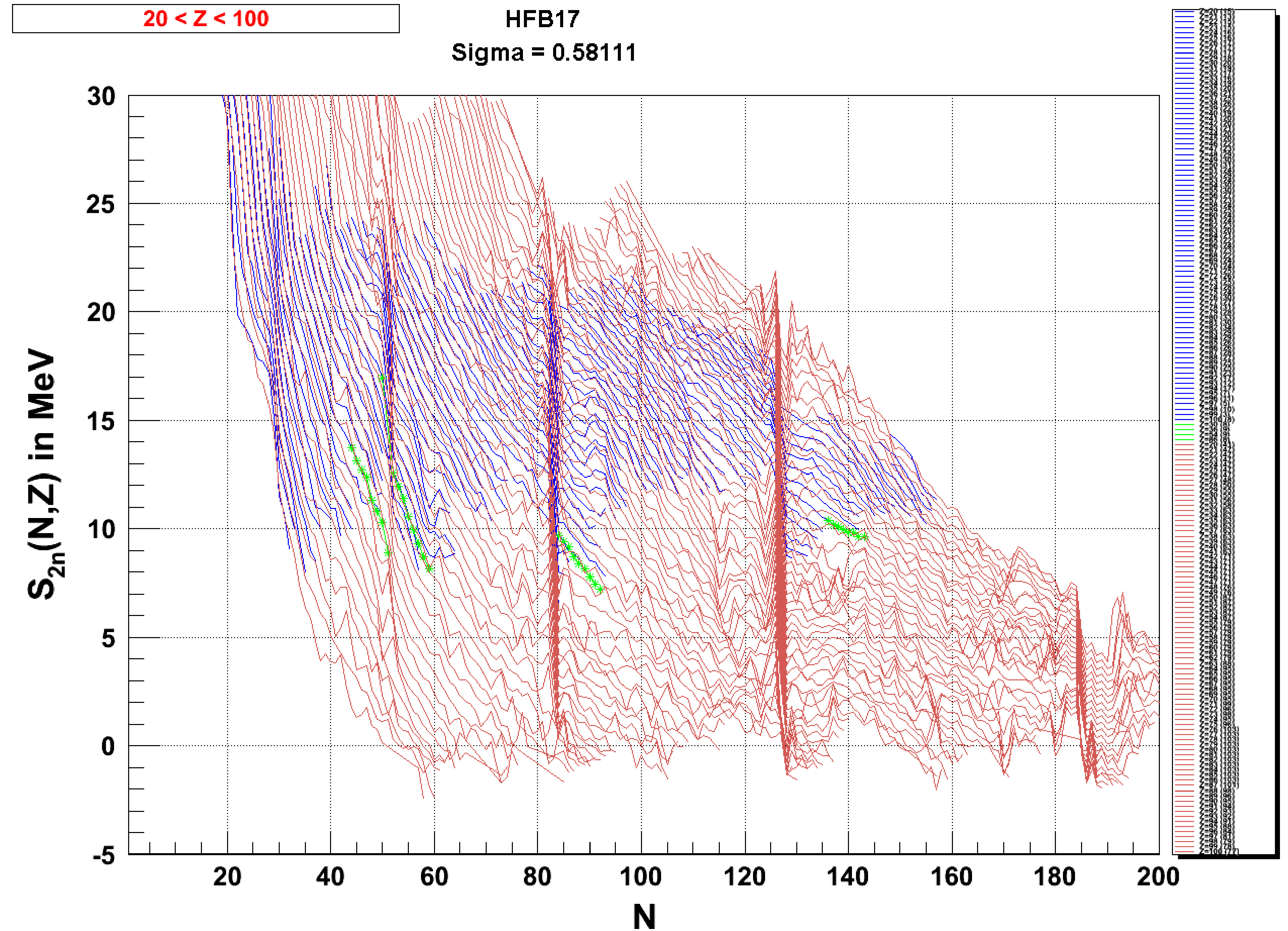


Phys. Rev. C (2013)
New K masses across N = 32
V. Soma, C. Barbieri, Th. Duguet et al.
Gorkov-Green's function approach

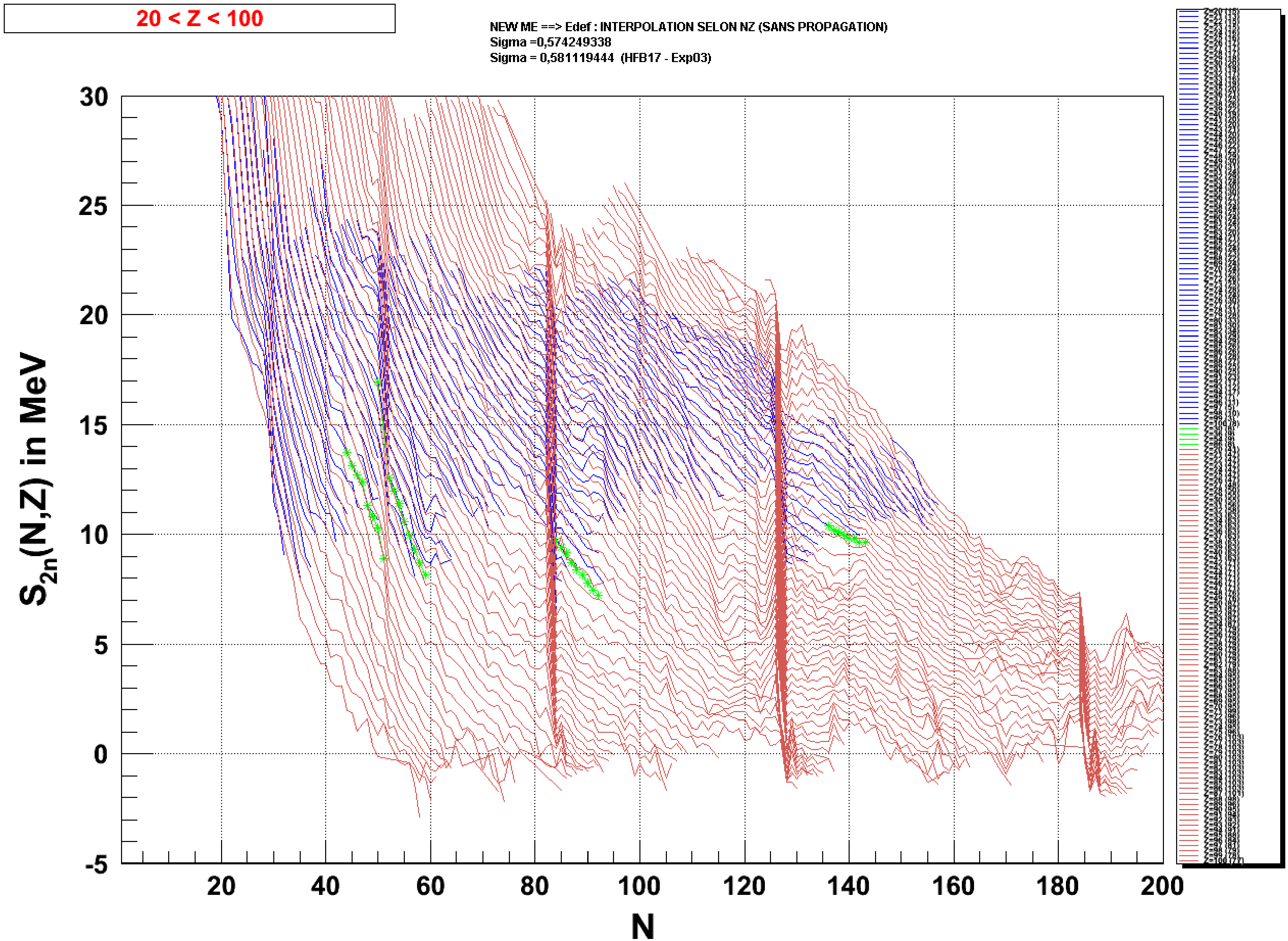
Phys. Rev. C 87, 021303(R) (2013)
Ab initio calculations of medium-mass nuclei with explicit chiral 3N interactions
Sven Binder, Joachim Langhammer, Angelo Calci, Petr Navrátil, and Robert Roth



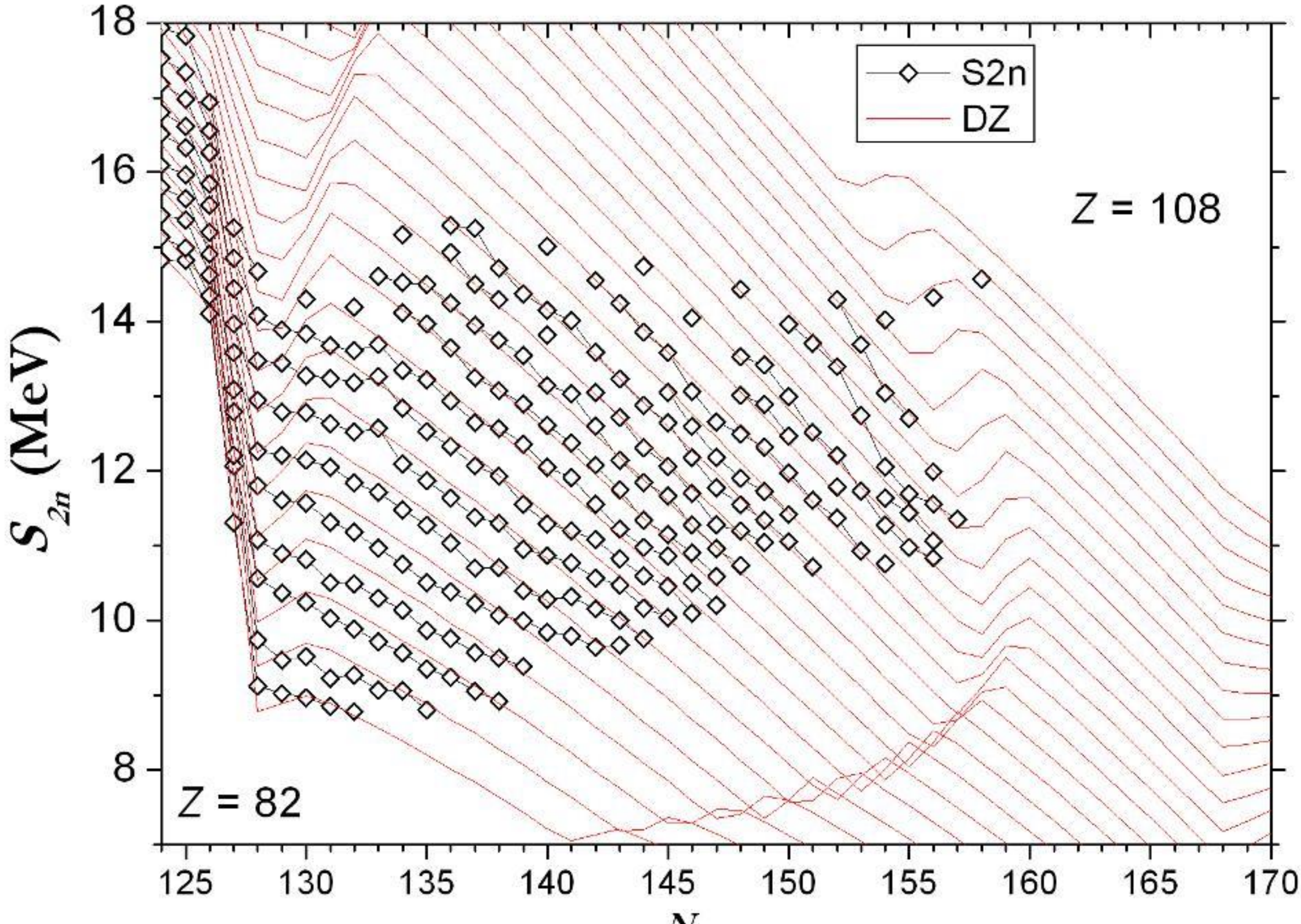
20 < Z < 100
Duflo-Zuker (1995)
$S_{2n}(N,Z)$ in MeV
N
20 < Z < 100
Koura et al. (2005)
$S_{2n}(N,Z)$ in MeV
N
20 < Z < 100
FRDM (1992)
$S_{2n}(N,Z)$ in MeV
N
20 < Z < 100
HFB-17 (2008)
$S_{2n}(N,Z)$ in MeV
N



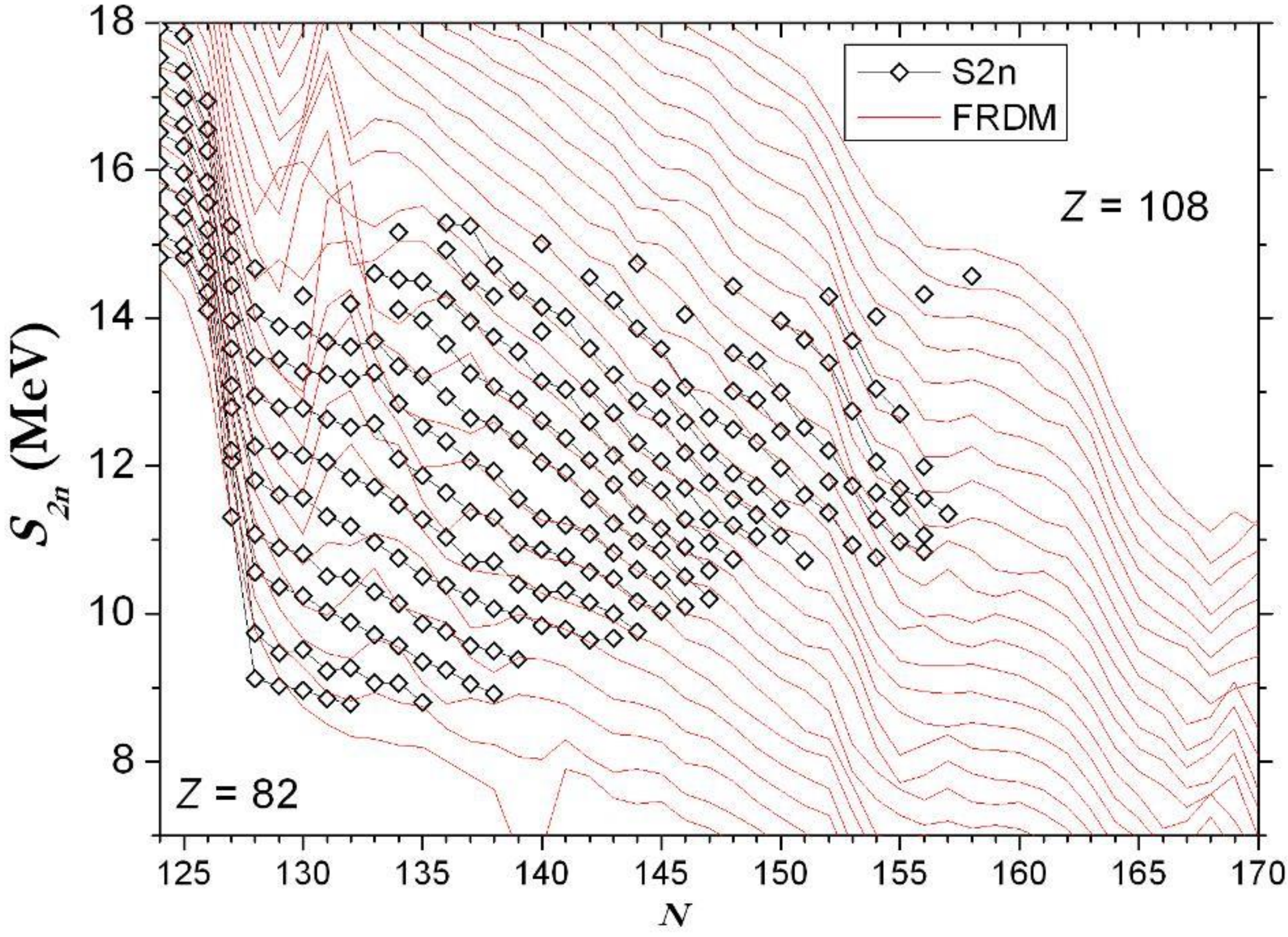
20 < Z < 100
HFB17
Sigma = 0.58111
$S_{2n}(N,Z)$ in MeV
N
30
25
20
15
10
5
0
-5
20
40
60
80
100
120
140
160
180
200



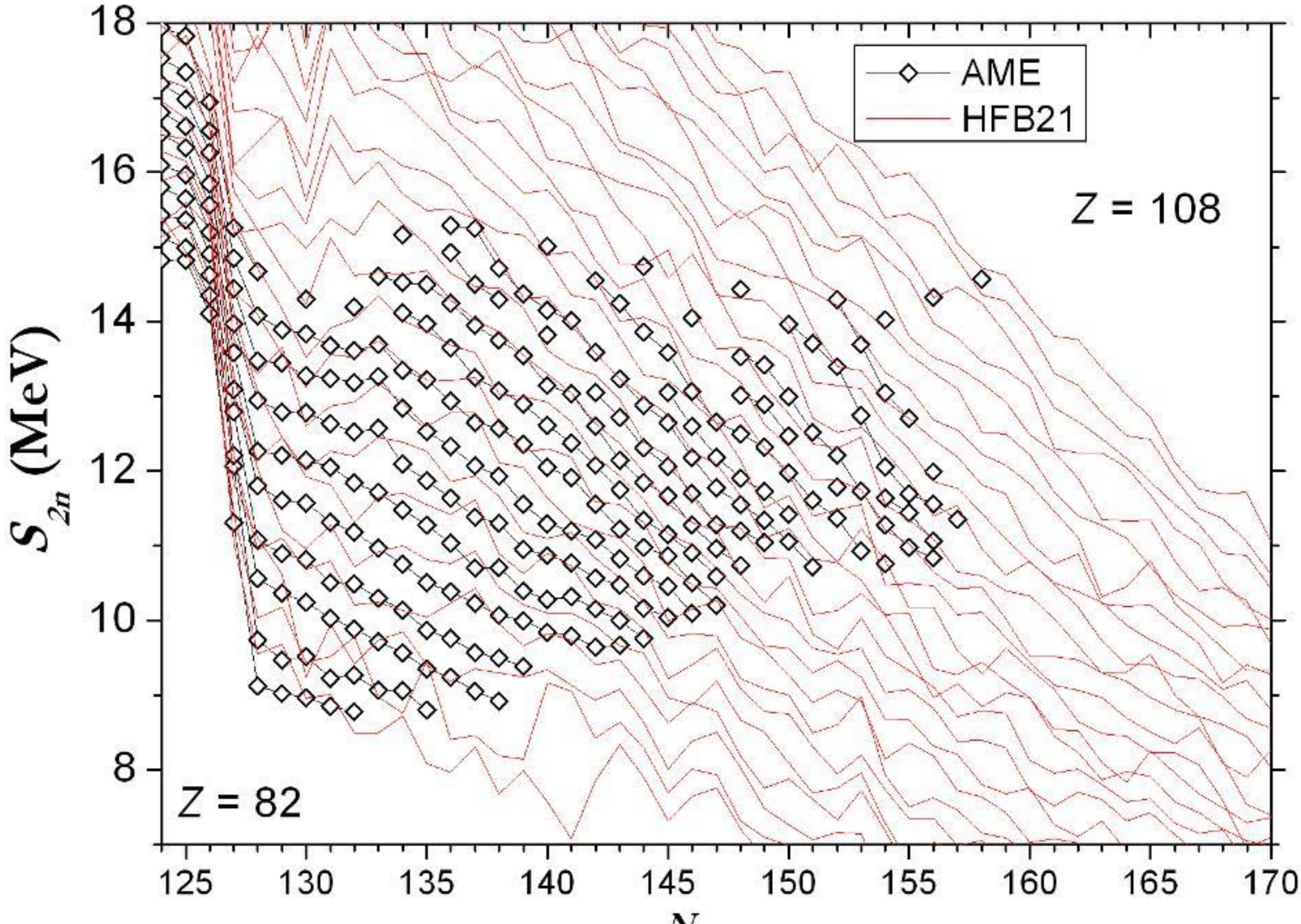
20 < Z < 100
NEW ME ==> Edef : INTERPOLATION SELON NZ (SANS PROPAGATION)
Sigma =0,574249338
Sigma = 0,581119444 (HFB17 - Exp03)
30
25
20
15
10
5
0
-5
$S_{2n}(N,Z)$ in MeV
20
40
60
80
100
120
140
160
180
200
N



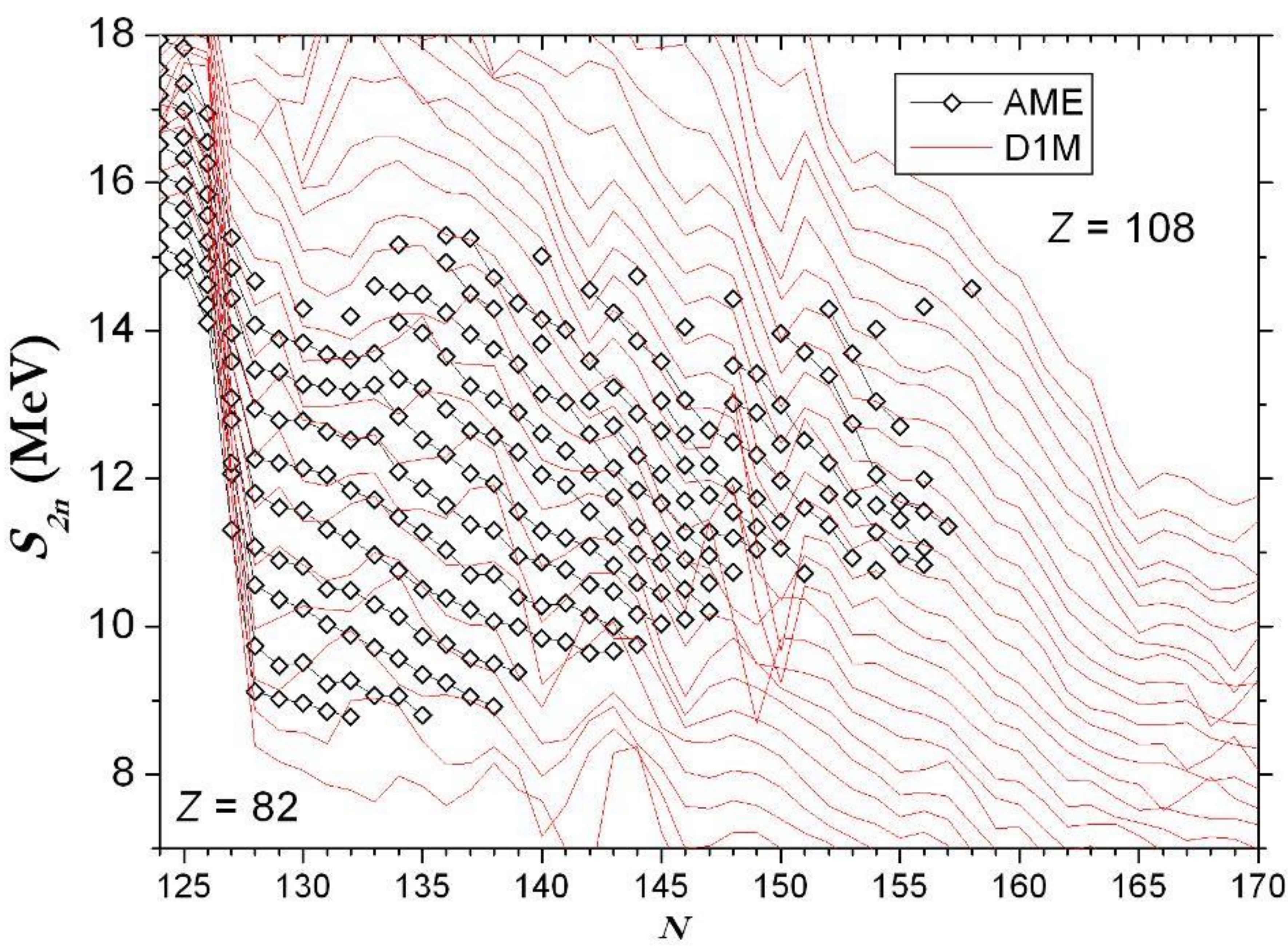
S2n
DZ
Z = 108
Z = 82
S_{2n} (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170



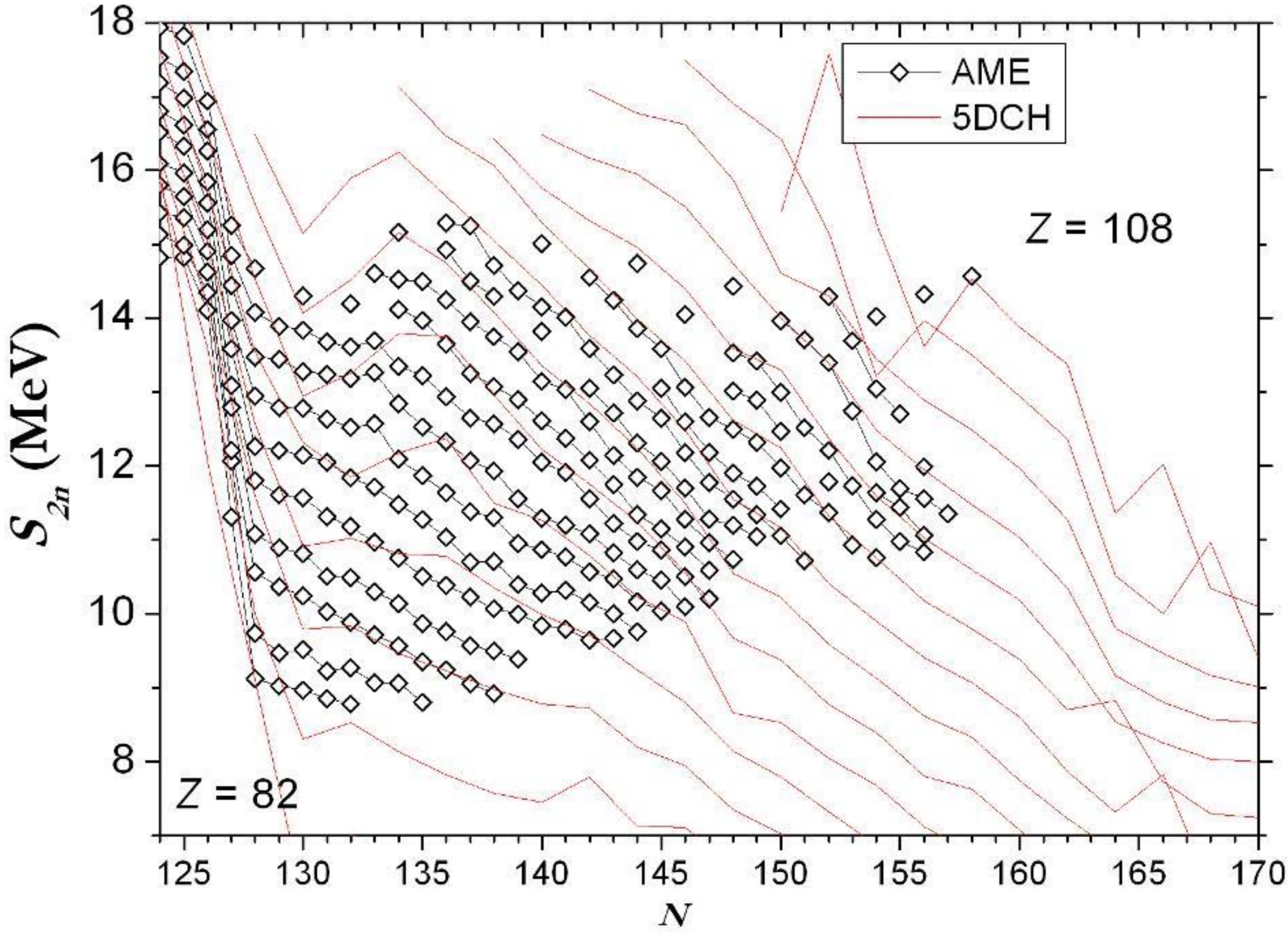
S2n
FRDM
Z = 108
Z = 82
S_{2n} (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170



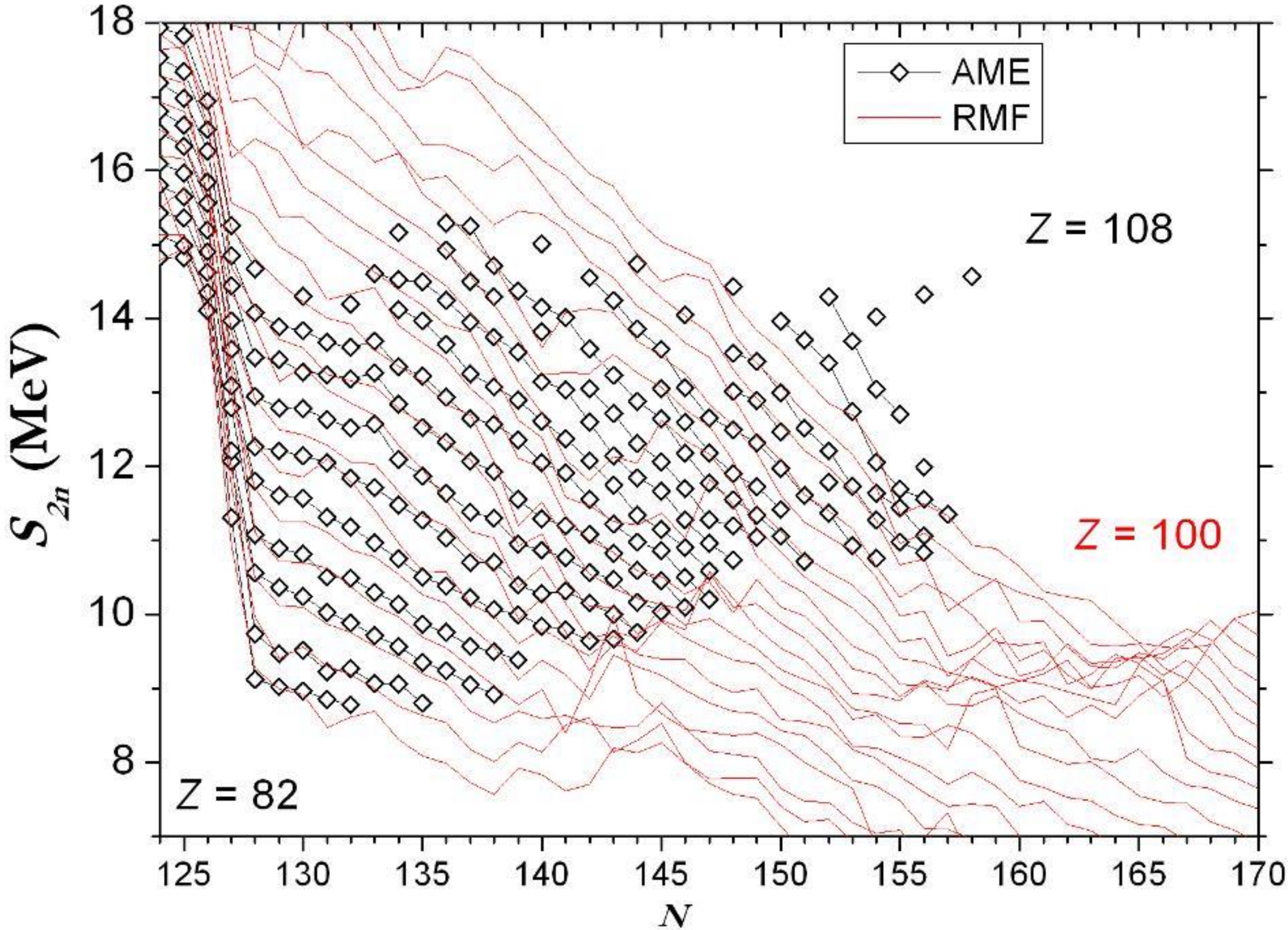
AME
HFB21
Z = 108
Z = 82
S_{2n} (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170



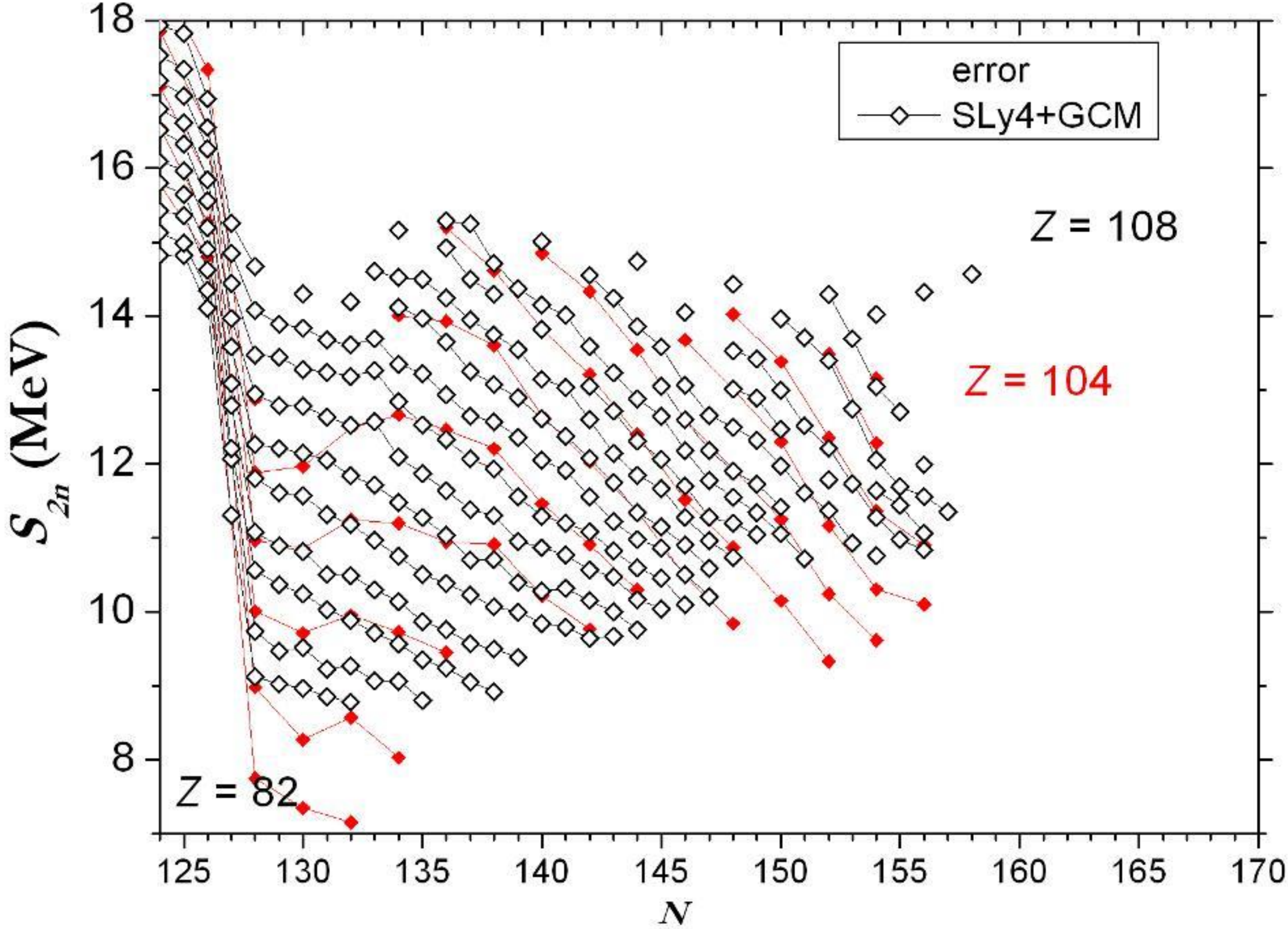
AME
D1M
Z = 108
Z = 82
S2n (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170



AME
5DCH
Z = 108
Z = 82
S_{2n} (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170

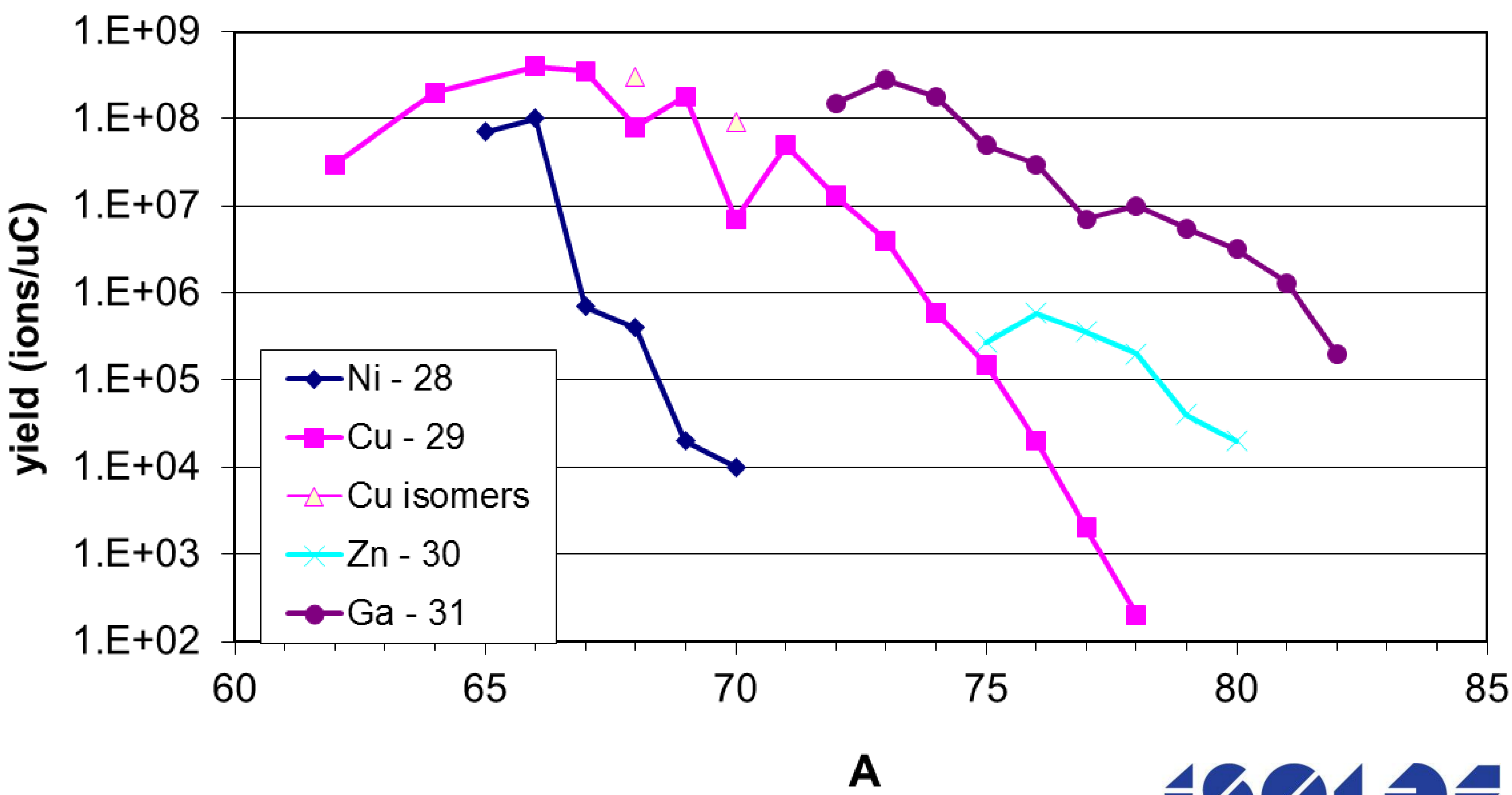


AME
RMF
Z = 108
Z = 100
Z = 82
S_{2n} (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170

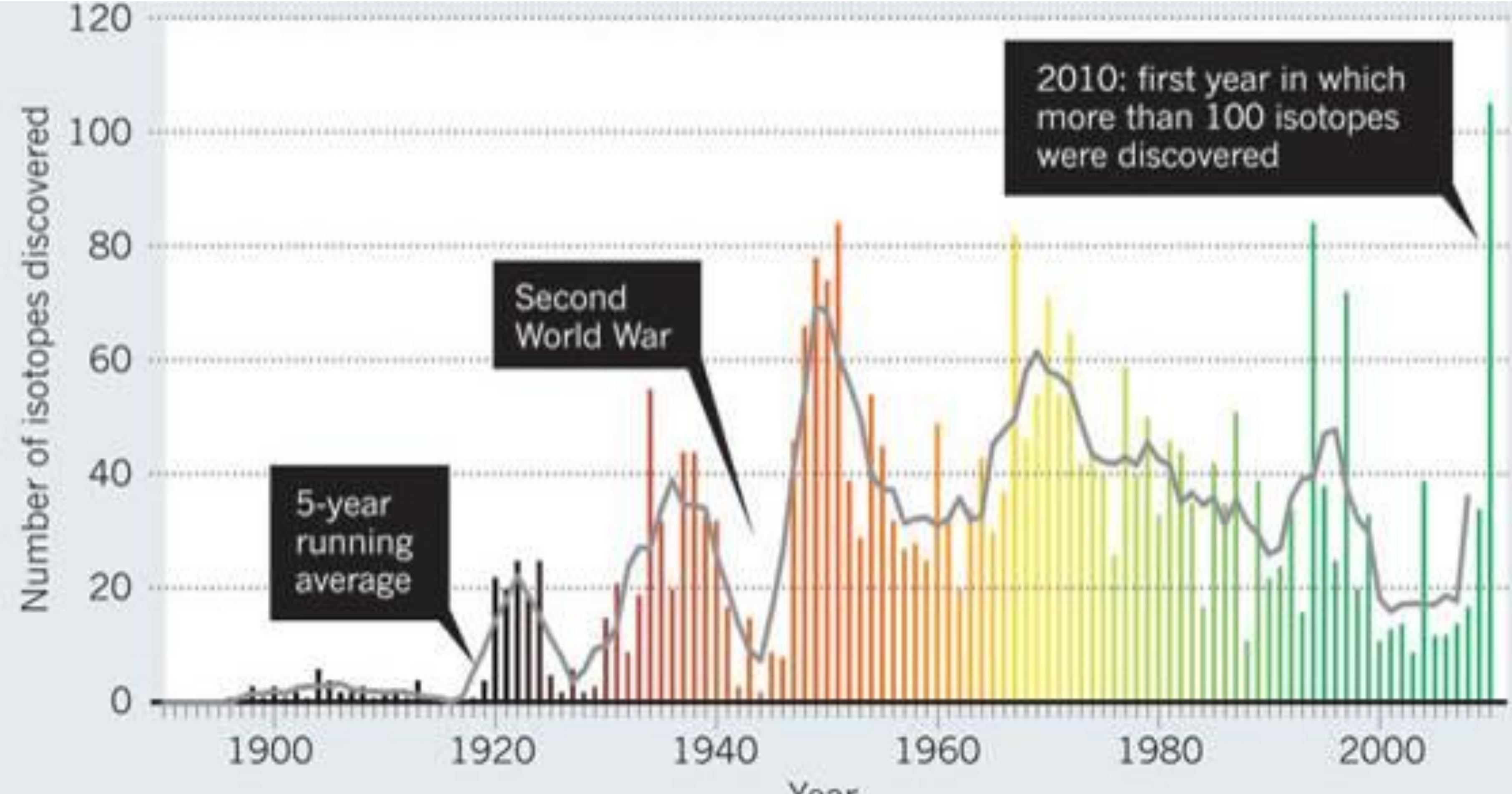


error
SLy4+GCM
Z = 108
Z = 104
Z = 82
S_{2n} (MeV)
N
18
16
14
12
10
8
125
130
135
140
145
150
155
160
165
170

Will new radioactive-beam facilities solve the problem?



RIBF@RIKEN, Japon



M. Thoennessen & B. Sherrill, Nature 473, 25 (2011)

Conclusions

Mass Measurements
new programs;
better performance;
more (quality) data

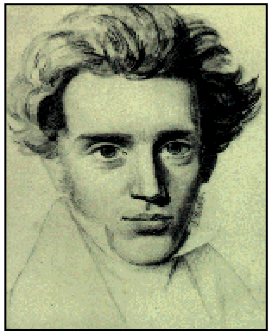
Lichtenberg:
To find something new,
build something new.

Conclusions

Mass Measurements
new programs;
better performance;
more (quality) data

Mass Models
microscopic era;
extrapolation
still uncertain…

Lichtenberg:
To find something new,
build something new.



Kierkegaard:
I must find a truth
that is true for me.

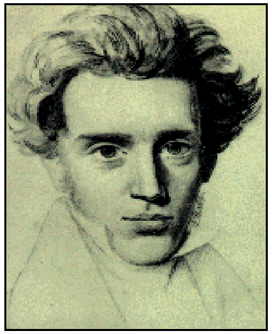
Conclusions

Mass Measurements
new programs;
better performance;
more (quality) data

AME

Mass Models
microscopic era;
extrapolation
still uncertain…

Lichtenberg:
To find something new,
build something new.



Kierkegaard:
I must find a truth
that is true for me.

Conclusions

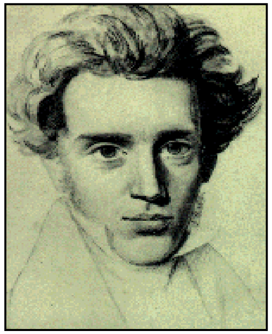
<u>Mass Measurements</u>
new programs;
better performance;
more (quality) data

AME

<u>Mass Models</u>
microscopic era;
extrapolation
still uncertain…

Lichtenberg:
To find something new,
build something new.

Confucius: When it is obvious that goals cannot be reached, don't adjust the goals, adjust the actions.



Kierkegaard:
I must find a truth
that is true for me.