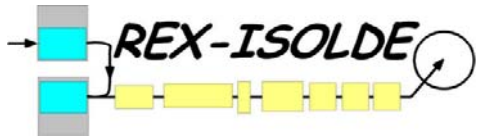
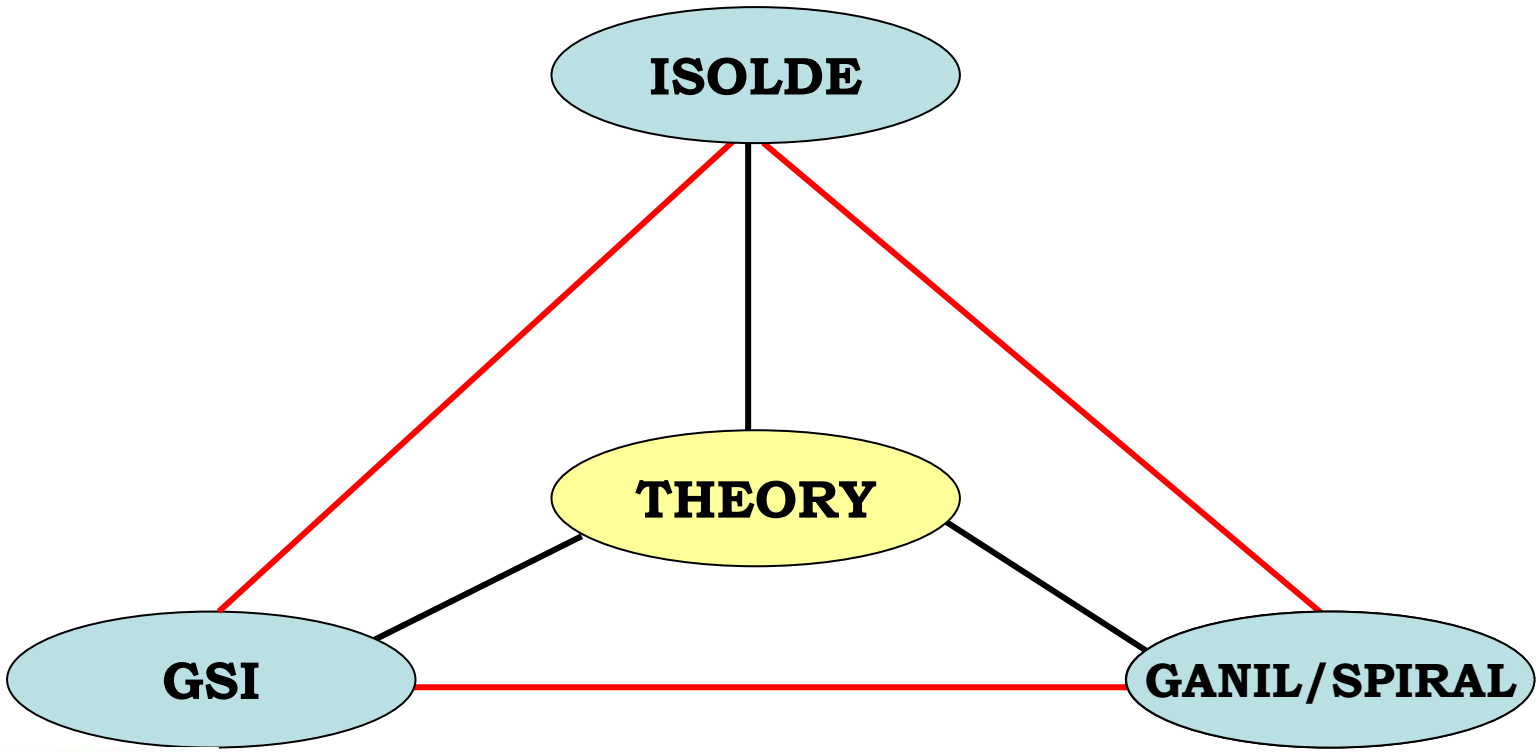
The first 40 years of physics at ISOLDE

ISOLDE PHYSICS WORKSHOP
AND
USERS MEETING
December 17 - 19, 2007

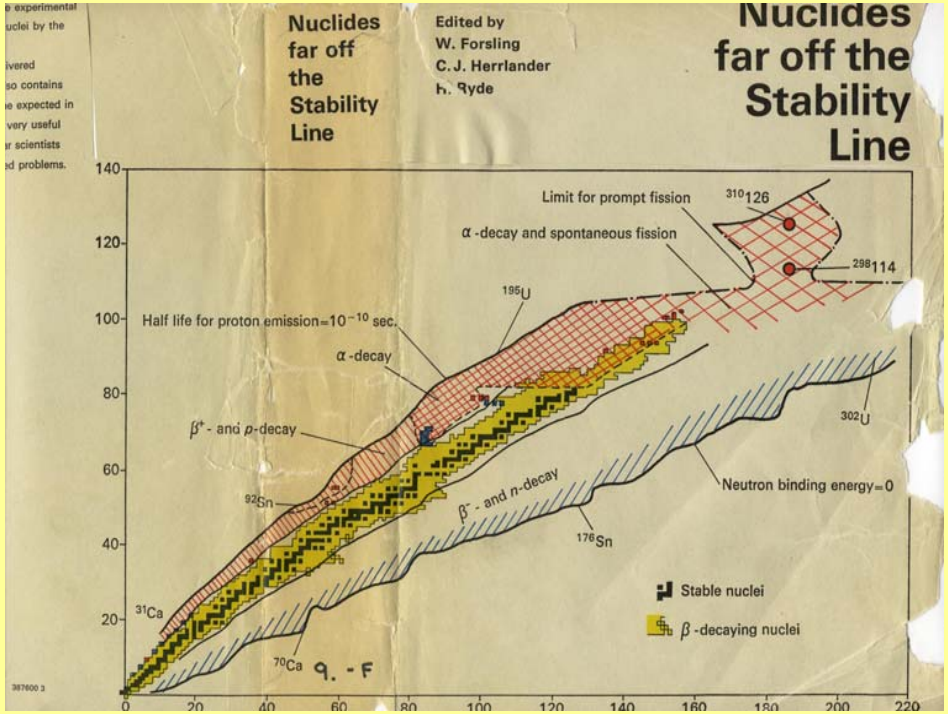
HIE-ISOLDE

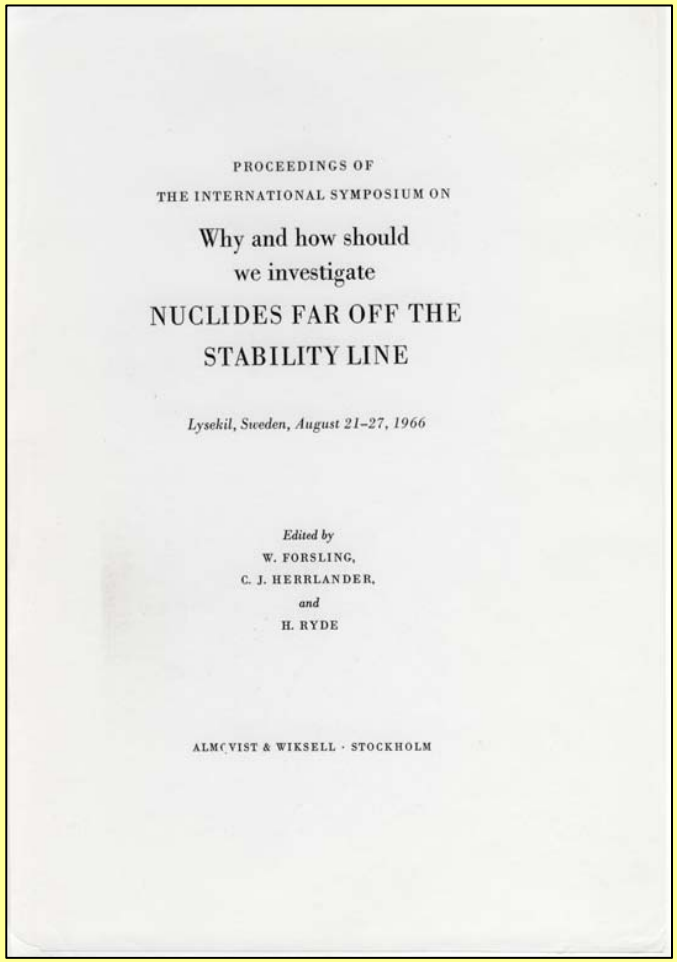




FAIR

Spiral2





PROCEEDINGS OF
THE INTERNATIONAL SYMPOSIUM ON

Why and how should
we investigate

NUCLIDES FAR OFF THE
STABILITY LINE

Lysekil, Sweden, August 21–27, 1966

Edited by
W. FORSLING,
C. J. HERRLANDER,
and
H. RYDE

ALMQVIST & WIKSELL · STOCKHOLM

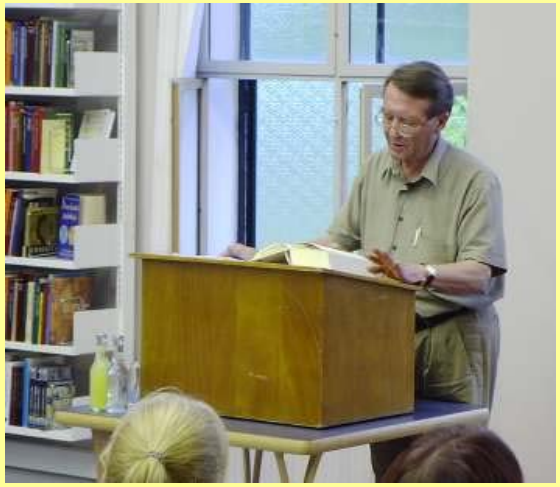
Introduction to the Lysekil Symposium, 1966
By INGMAR BERGSTRÖM

”In the development of physics it has been a general tendency and perhaps even a sport to search for new objects……The history of physics has convinced us that frequently the discoveries and studies of these rare objects in unexpected ways have added to our knowledge of the laws of nature….”

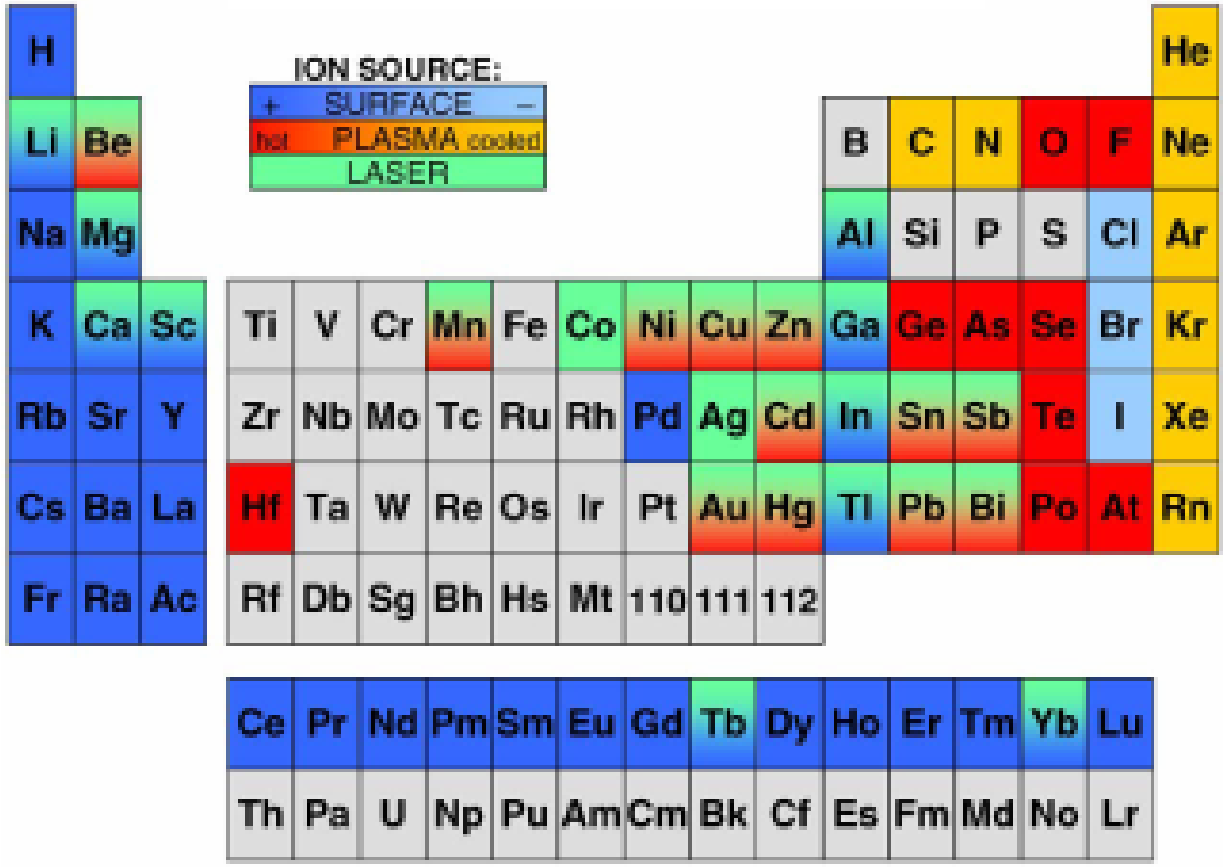
I do not know much about anything;
what I know is already commonplace.
Wouldn't it be nice to know just one fact,
for example the proportions of the spots of
the ladybird.

Jeg kender ikke meget til meget;
det jeg kender til er i forvejen meget udbredt.
Tænk at vide bare een bestemt ting,
for eksempel forholdet mellem mariehønens
pletter.

Benny Andersen,
Viden
1965

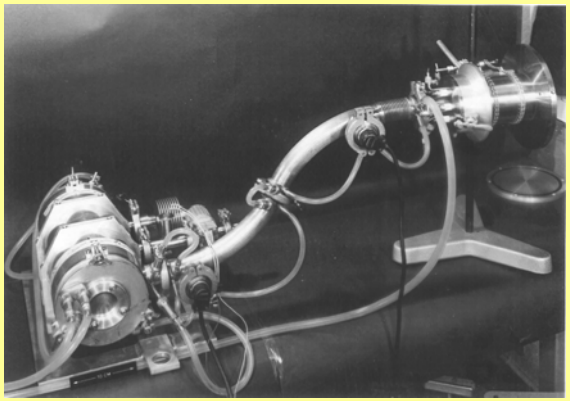


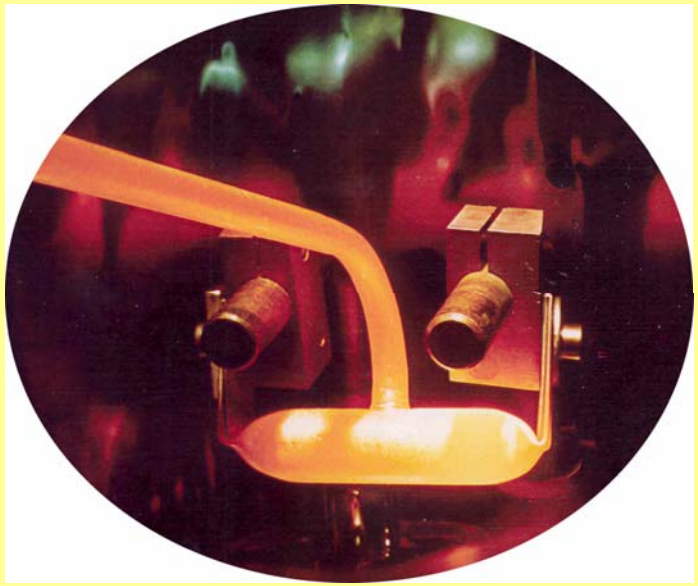
ISOLDE TABLE OF ELEMENTS

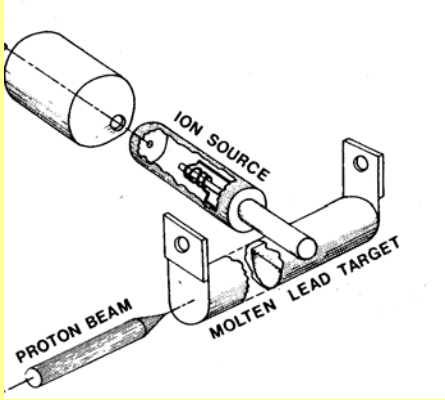


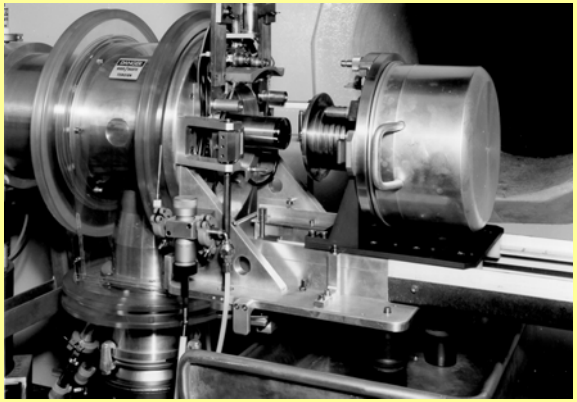
”CERN’s longest serving experimental facility”,
Juha Äystö, Phys. Rep. 403-404 (2004) 459

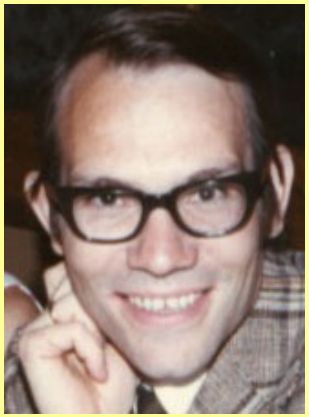
ISOLDE TARGETS and ION SOURCES

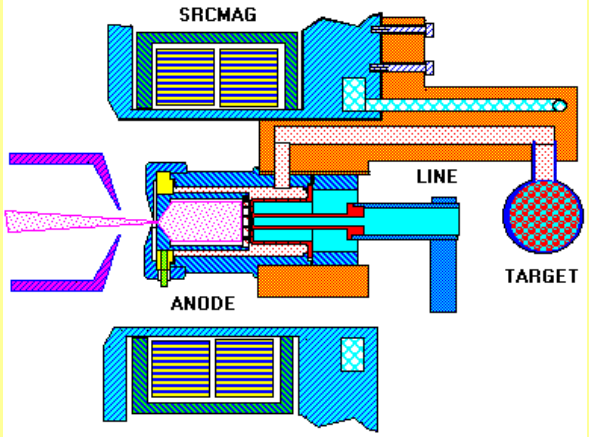




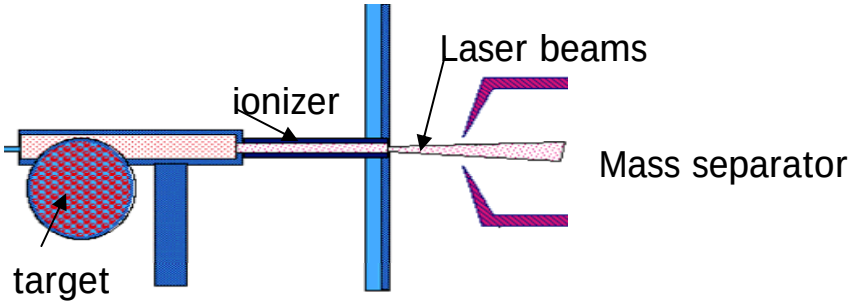




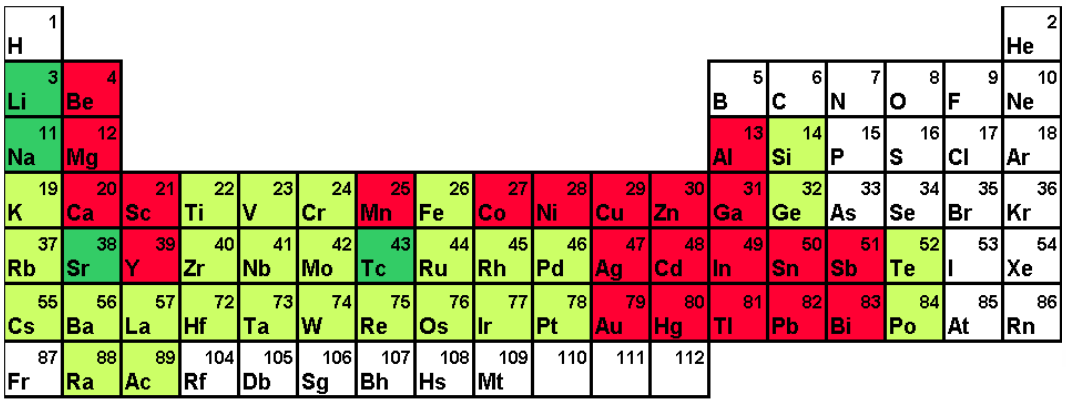


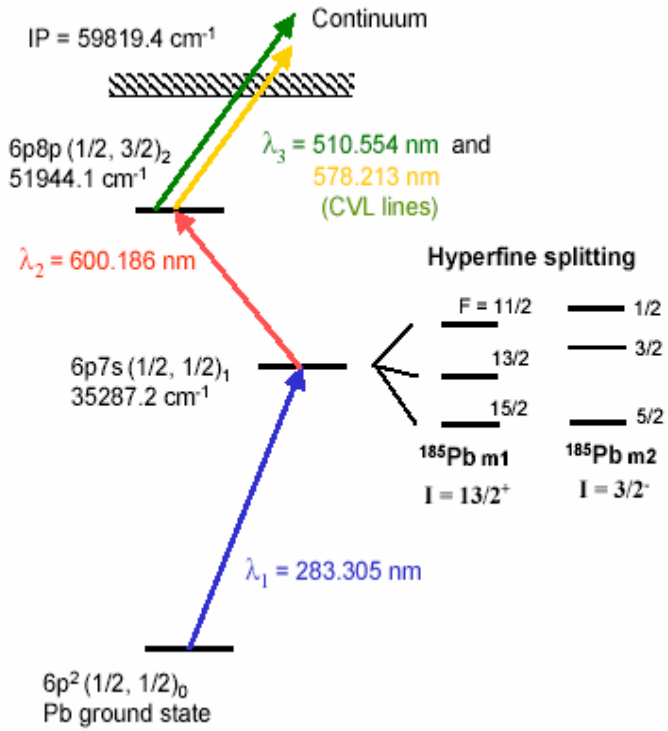


RILIS at ISOLDE



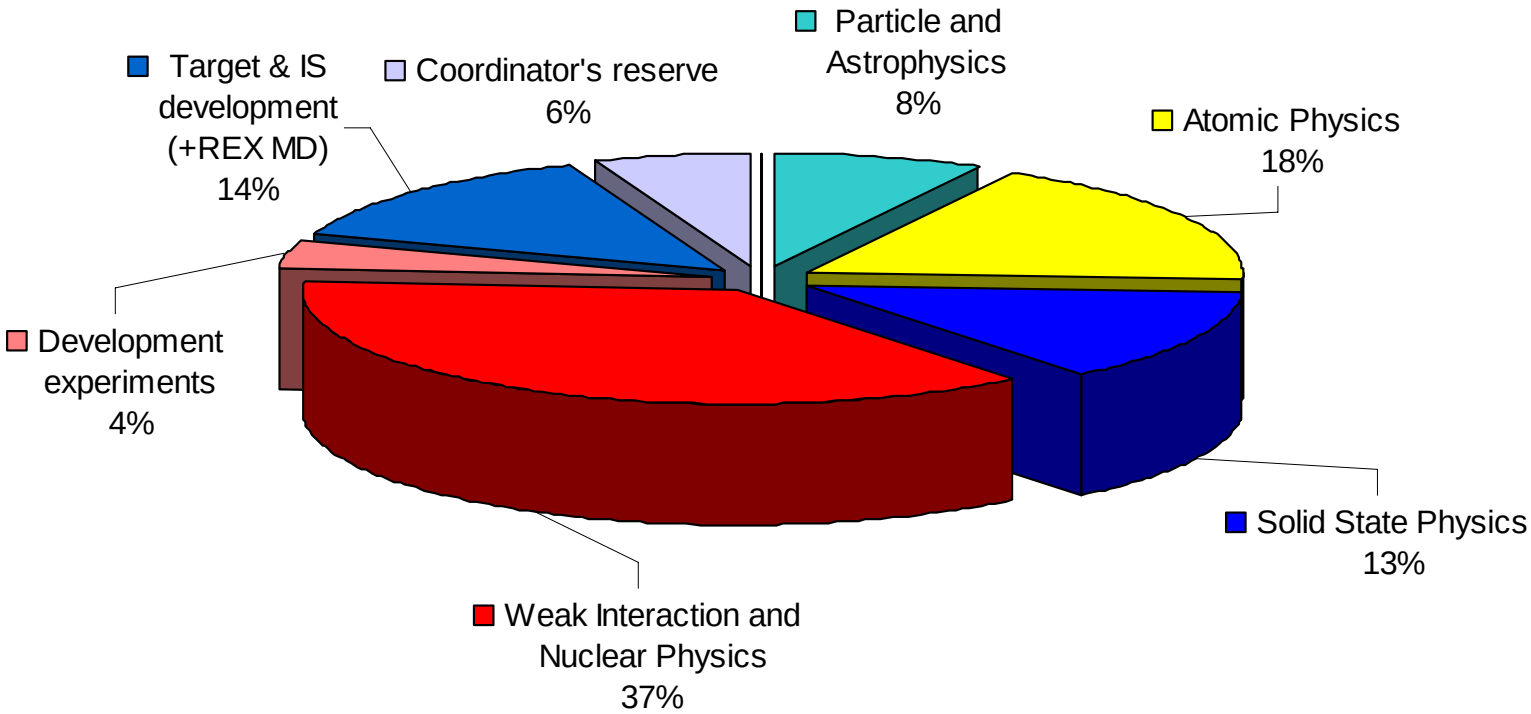
Laser Ion Source (LIS)



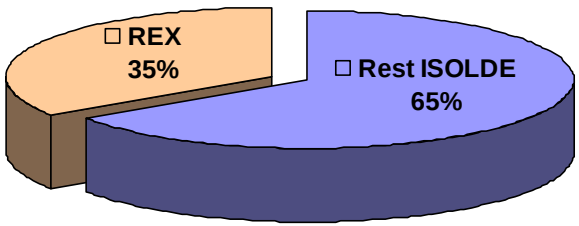


Andreyev et al.
Eur. Phys. J A14 (2002) 63

ISOLDE shift distribution 2005



REX % from *INTC shifts* 2005



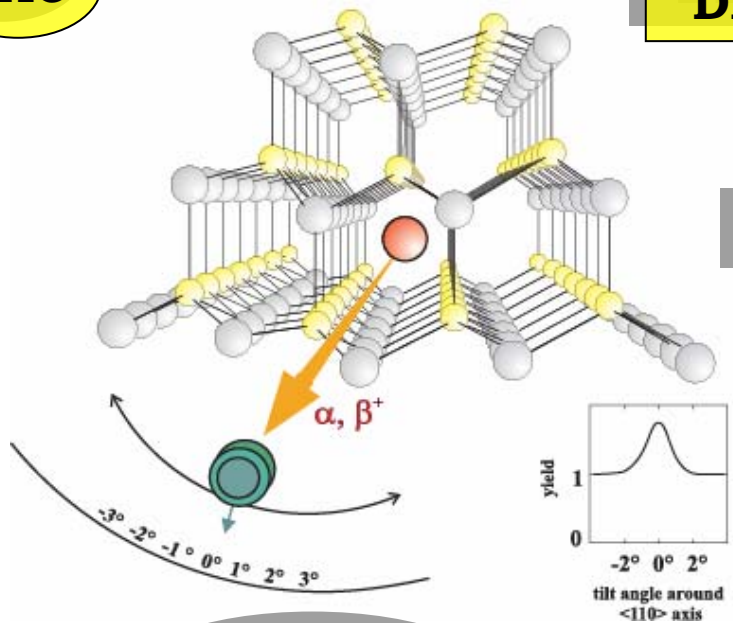
Channeling
Blocking

PAC

DLTS

NO

Diffusion



PL

ESR

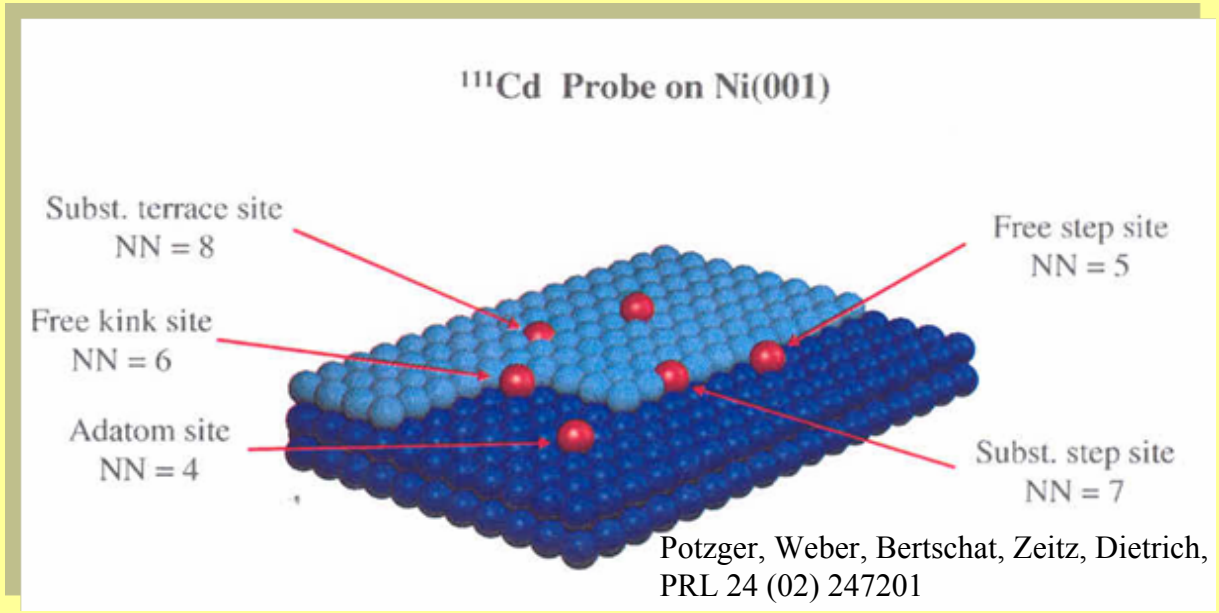
Mössbauer

SOLID STATE PHYSICS at ISOLDE

- Semiconductor
- Surface
- Bio, Molecular
- Magnetic materials
- Metals
- Superconductors

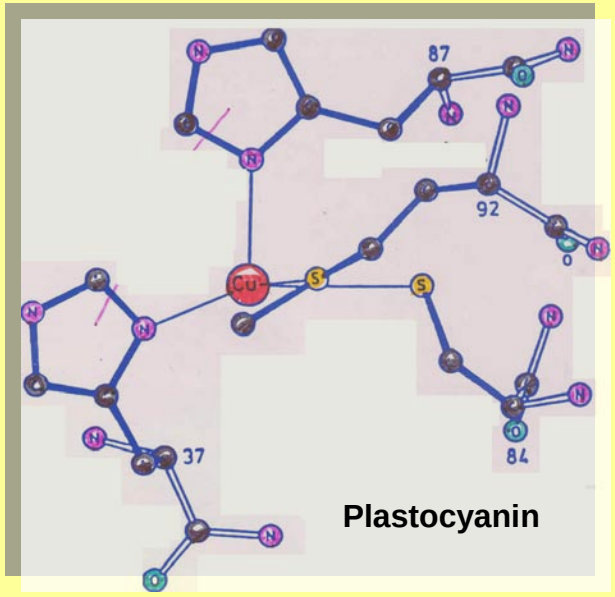
Doris Forkel-Wirth,
Rep. Prod. Phys. 62 (99) 527

HIE ISOLDE → **Higher beam** → **energy**, **quality**, **intensity**



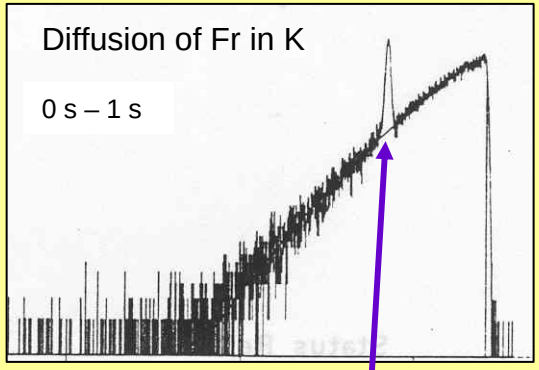
Potzger, Weber, Bertschat, Zeitz, Dietrich, PRL 24 (02) 247201

BIOPHYSICS



Blue Oxidases
-Multi Cu Enzymes
MW ~ 10^5, 4 Cu

Replace Cu with ^{111m}Cd or ^{199m}Hg and measure the η asymmetry of the electric field tensor



^{205}Fr ($T_{1/2}$=3.7 s) ↝ **^{201}At**

ATOMIC PHYSICS

^{223}Fr

$T_{1/2}$=21.8 m

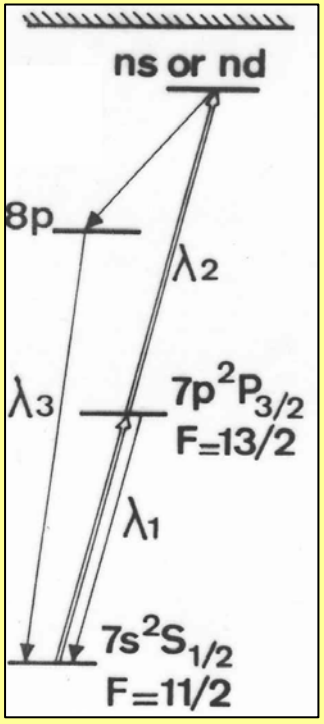
1.2 x10^9 s^{-1}

First evidence for an optical transition in francium atoms

D_2(7s $^2S_{1/2}$ ↔ 7p $^2P_{3/2}$)

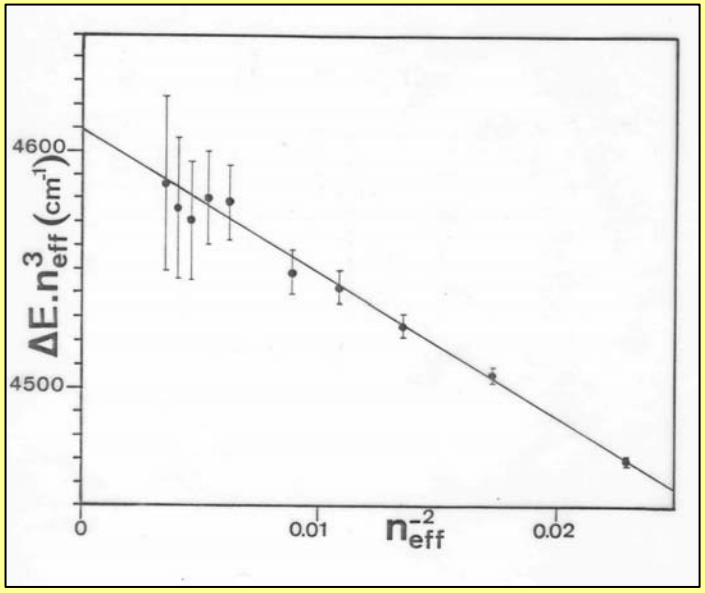
Comptes Rendus des séances hebdomadaires
de l'Academie des Sciences
Liberman et al., Serie B 286 (1978) 253
Pierre Jacquinot

Rydberg levels
ns(n=12-22),
nd(n=10-20)



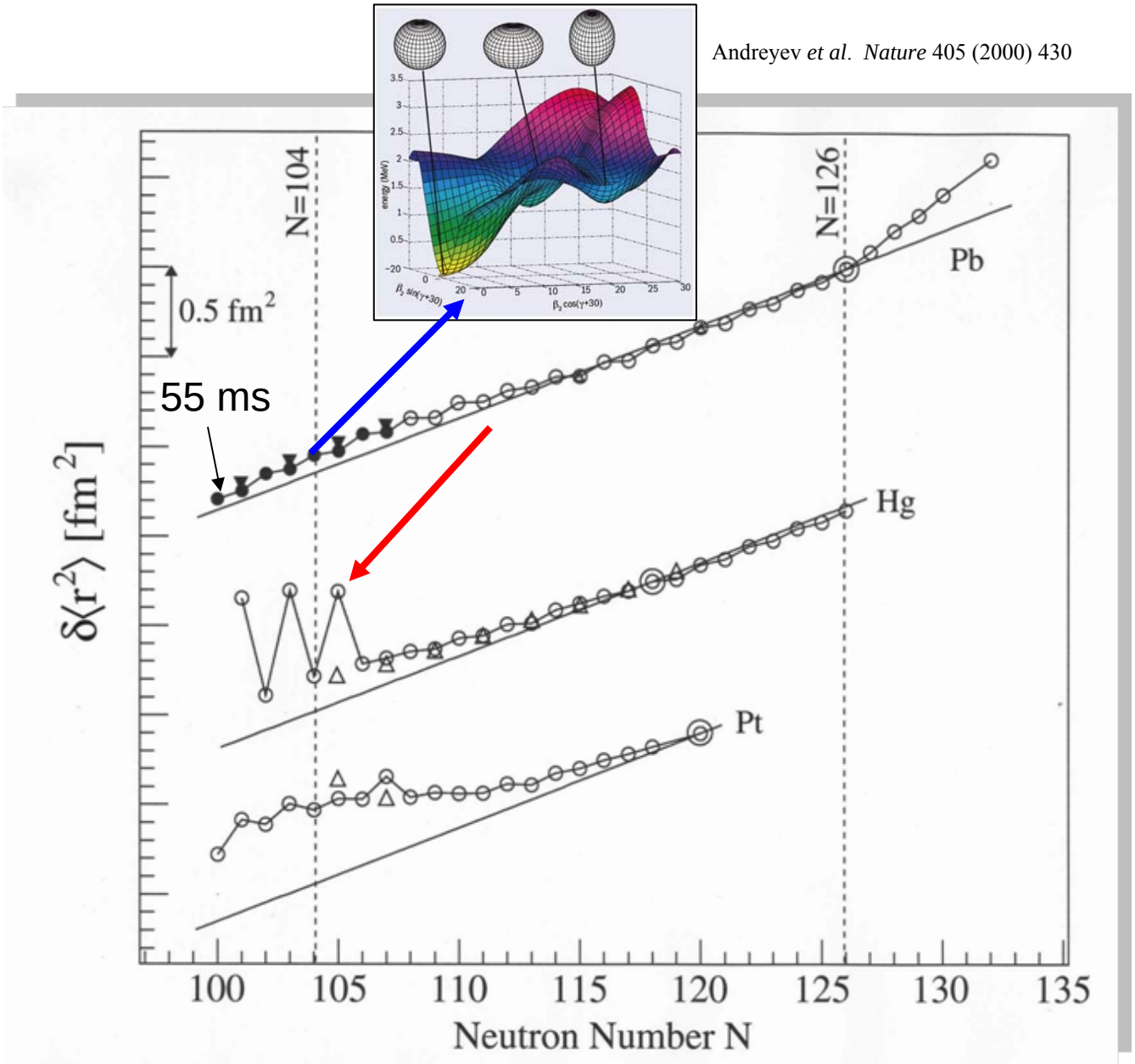
PRA 22(1980)2732
D_2 λ = 717.97±0.01 nm

ΔE(nd) of nd$^2D_{3/2,5/2}$

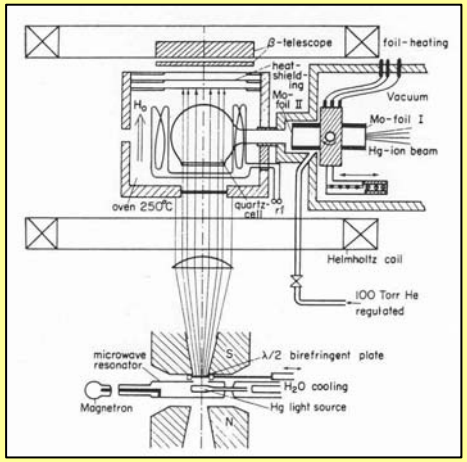


Arnold et al.,
J. Phys. B22(1989) L391

Andreyev *et al*. *Nature* 405 (2000) 430

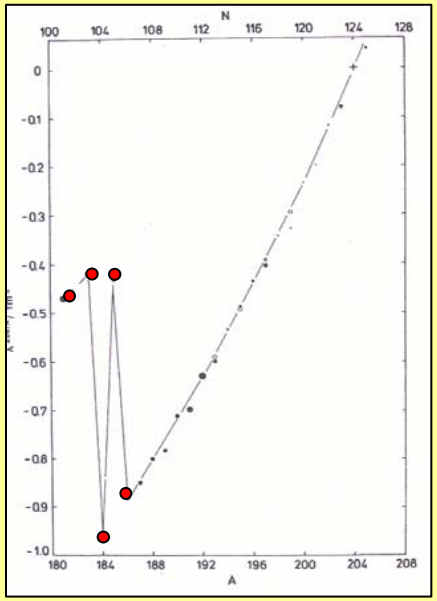


De Witte et al, PRL 98 (2007)112502



The following quantities have been determined by optical pumping with the spectral line **2537 Å**: 183Hg: $I = 1/2$, $\mu I = 0.513(9)$ nm, isotopic shift (^{183}Hg – ^{204}Hg) = 18.9(8) GHz; ^{185}Hg: $I = 1/2$, $\mu I = 0.449(4)$ nm, isotopic shift (^{185}Hg – ^{204}Hg) = 19.2(4) GHz. The isotopic shifts for ^{183,185}Hg deviate very strongly from an extrapolation from the heavier mercury isotopic (including ^{187}Hg). This indicates that a large increase in the effective nuclear volume of Hg occurs in going from $N = 107$ to $N = 105$.

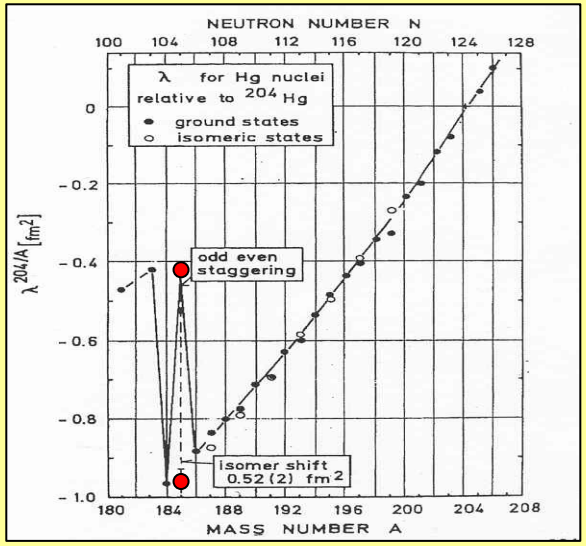
J. Bonn et al., PL 38B (1972) 308



PRL 39 (77) 180

Nuclear Shape Staggering in Very Neutron-Deficient Hg Isotopes Detected by Laser Spectroscopy[a]

T. Kühl, P. Dabkiewicz, C. Duke,[b] H. Fischer, H.-J. Kluge, H. Kremmling, and E.-W. Otten
Institut für Physik, Universität Mainz, Mainz, Germany
(Received 1 April 1977)



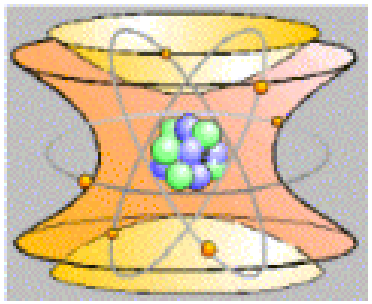
PL 82B (79) 199

NUCLEAR SHAPE ISOMERISM IN ^{185}Hg DETECTED BY LASER SPECTROSCOPY ☆

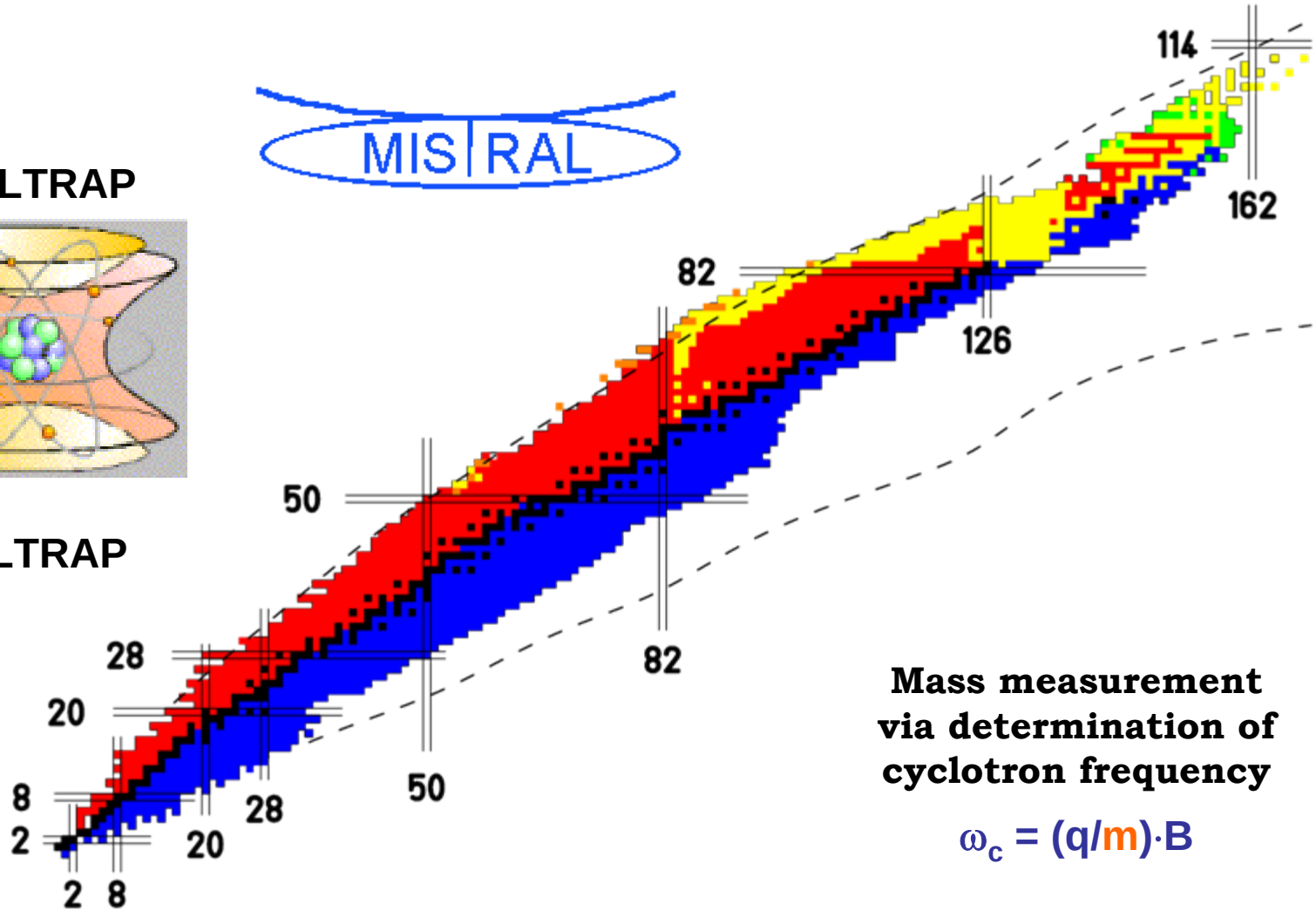
P. DABKIEWICZ, F. BUCHINGER, H. FISCHER, H.-J. KLUGE, H. KREMMLING, T. KÜHL, A.C. MÜLLER and H.A. SCHUESSLER [1]

The Nuclear Mass Surface

ISOLTRAP



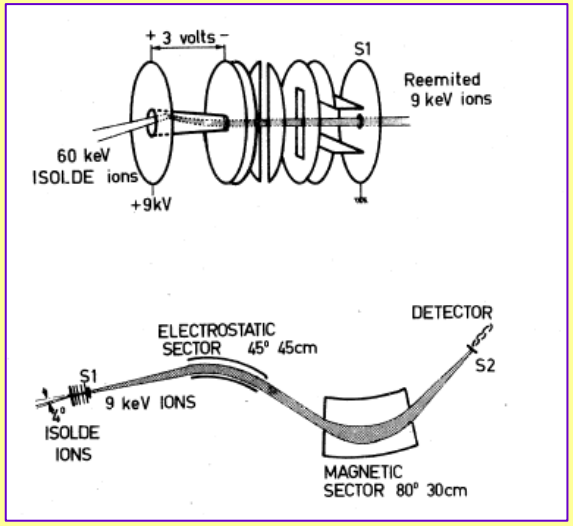
JYFLTRAP



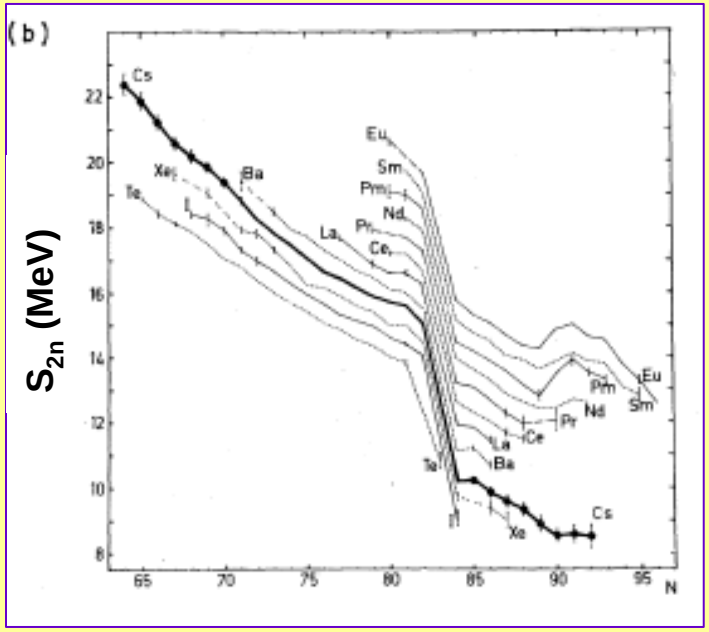
Mass measurement via determination of cyclotron frequency

$\omega_c = (q/m) \cdot B$

K. Blaum, Phys. Rep. 425 (2006) 1-78



M. Epherre, G. Audi, C. Thibault *et al.*
PRC 19 (1979) 1504



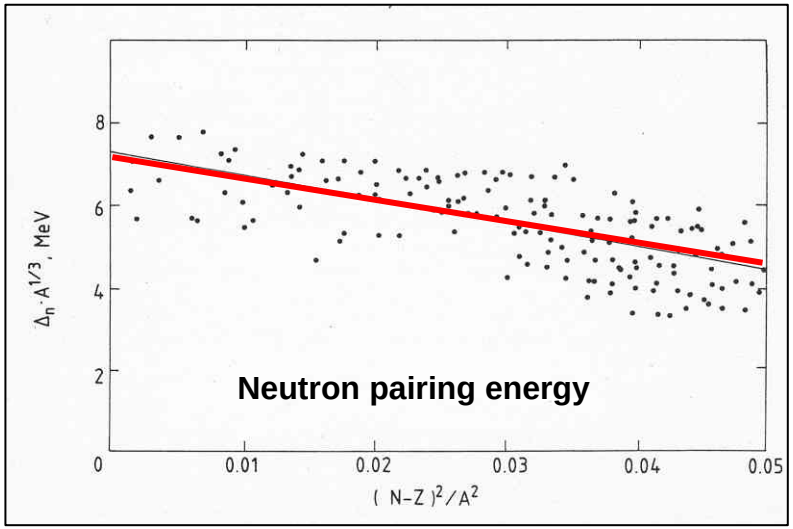
Hyperfine Interactions, 38 (**1987**) 793

ISOLTRAP: a tandem Penning trap system for accurate on-line mass determination of short-lived isotopes
G. Bollen, S. Becker, H. -J. Kluge et al.
NIM 368 (1996) 675

H.-J. Kluge, 16.35

MASS RELATIONS

+1	-3	+3	-1



Pairing energy for neutron pairs

¼ x

+1		-3		+3		-1

Δ_{2n}

Jensen et al., NP A431(1984)393

¼ x

-1
+3
-3
+1

Pairing energy for proton pairs

Δ_{2p}

α-clustering

½ x

+1		-1
-2		+2
+1		-1

Δ_{2p2n}

½ x

-1		+2		-1
+1		-2		+1

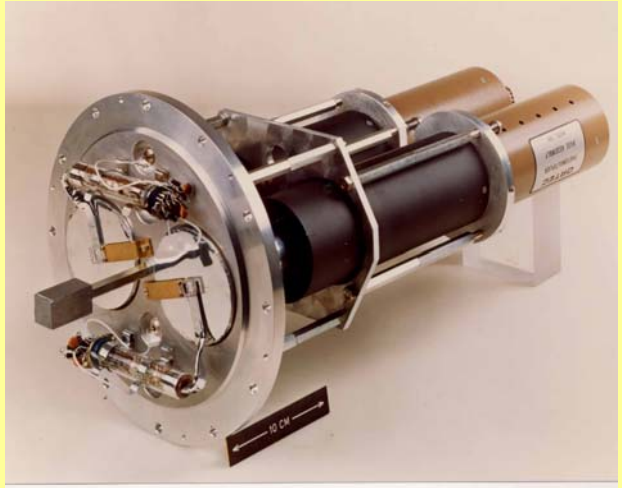
Δ_{2n2p}

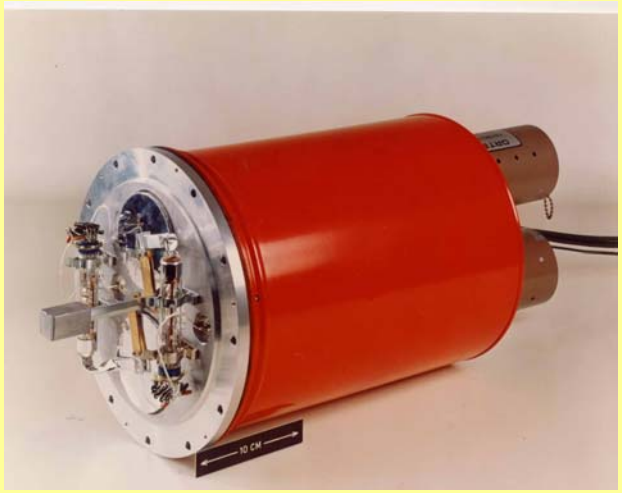
¼ x

-1		+1
+1		-1

δV_{pn}

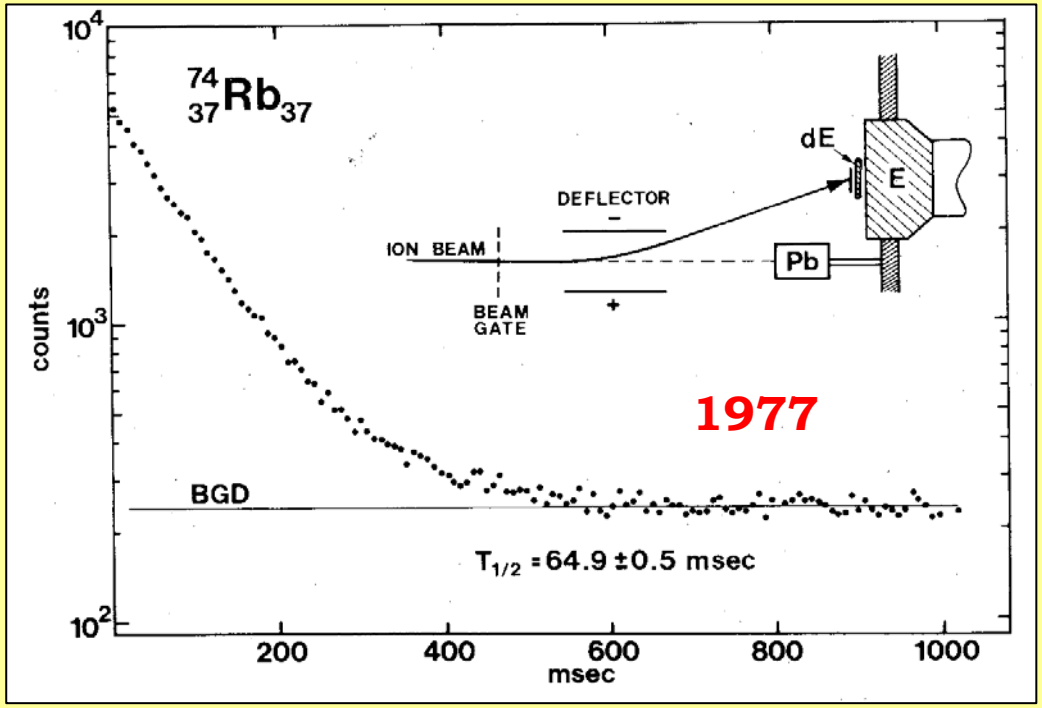
IS 461





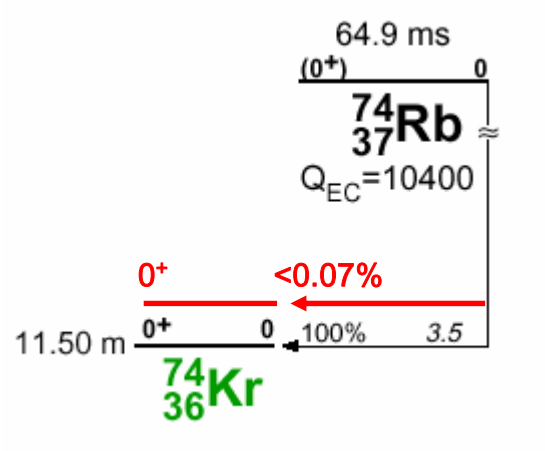
^{74}Rb, T,I$^{\pi}$=1,0^{+}

D'Auria et al.,Phys. Lett. **66B** (1977) 233



^{93}Nb(p,5p15n)^{74}Rb

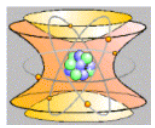
Complete spectroscopy on Fermi β-emitter ^{74}Rb



Results:

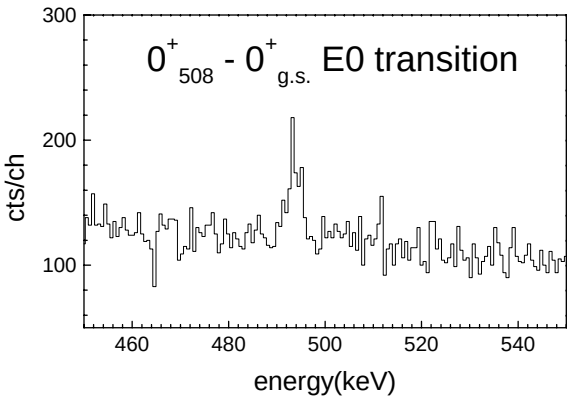
1) non-analog $0^+ \rightarrow 0^+$ transition observed
   → estimate for the Coulomb mixing
2) mass of ^{74}Rb (ISOLTRAP & MISTRAL)
3) mass of the daughter ^{74}Kr (ISOLTRAP)

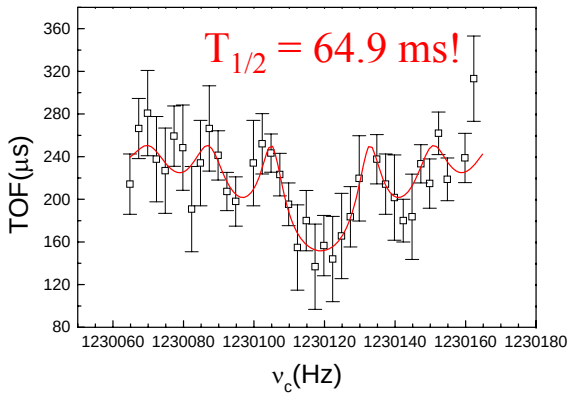
2) & 3) → Q_{EC} value

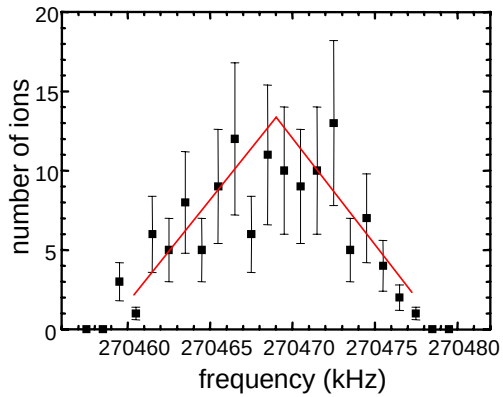


ISOLTRAP

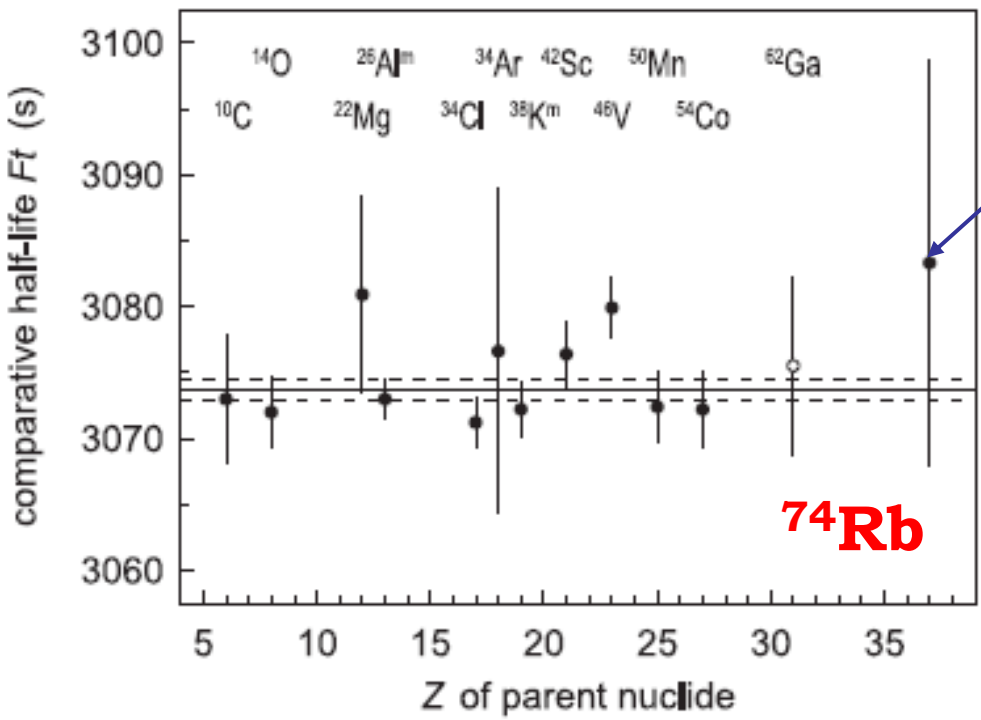
MISTRAL







Ft-values of Superallowed Transitions



Kellerbauer et al., PRC 76 (2007)04550

$T_{1/2}$
Q_β
Branching

$$Ft = ft(1+\delta_R')(1+\delta_{NS}-\delta_C) = K/2G_F^2V_{ud}^2(1+\Delta_R^V)$$

$$Ft = 3072.7 \pm 0.8s$$

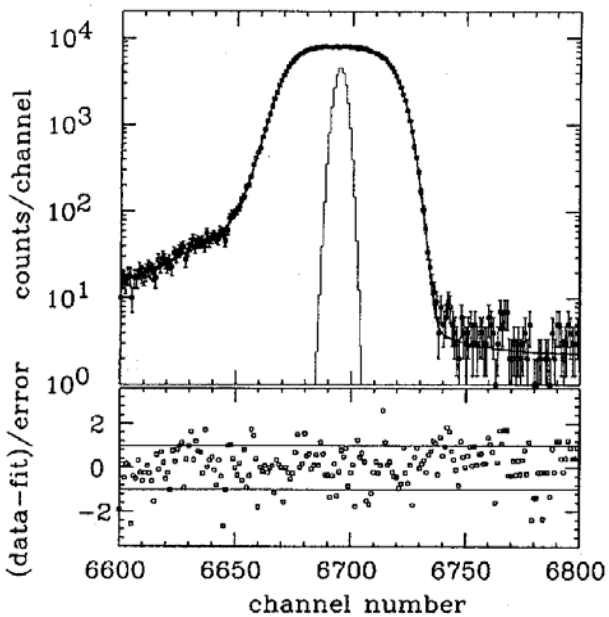
$$V_{ud} = 0.97418 \pm 0.00026$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1.0000 \pm 0.0011$$

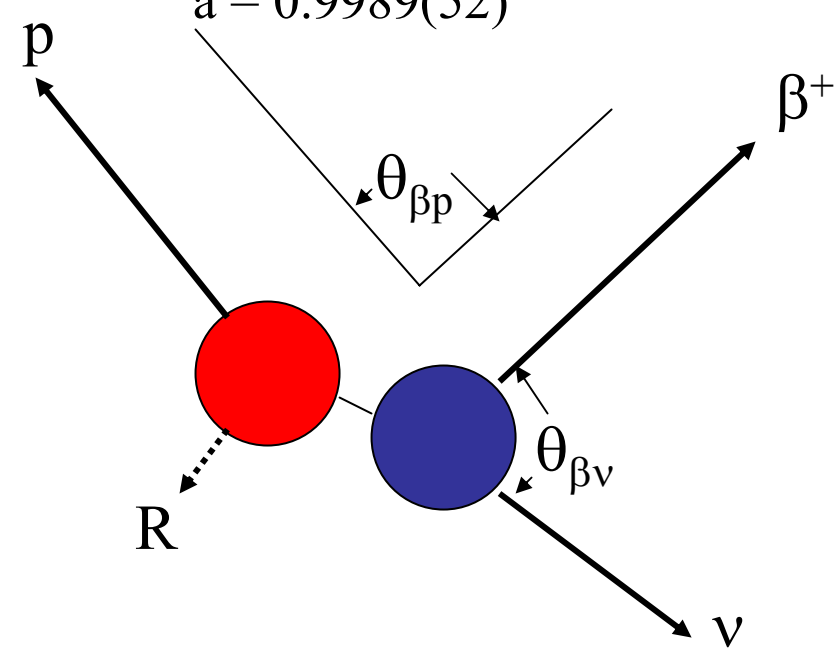
Towner, Hardy, arXiv:0710.3181, 16/10 07

^{22}Mg, ^{34}Ar, ^{26}Si, ^{38}Ca

Positron-Neutrino Correlation in the $0^+ \rightarrow 0^+$ Beta Decay of ^{32}Ar



eν correlation coeff.
a = 0.9989(52)



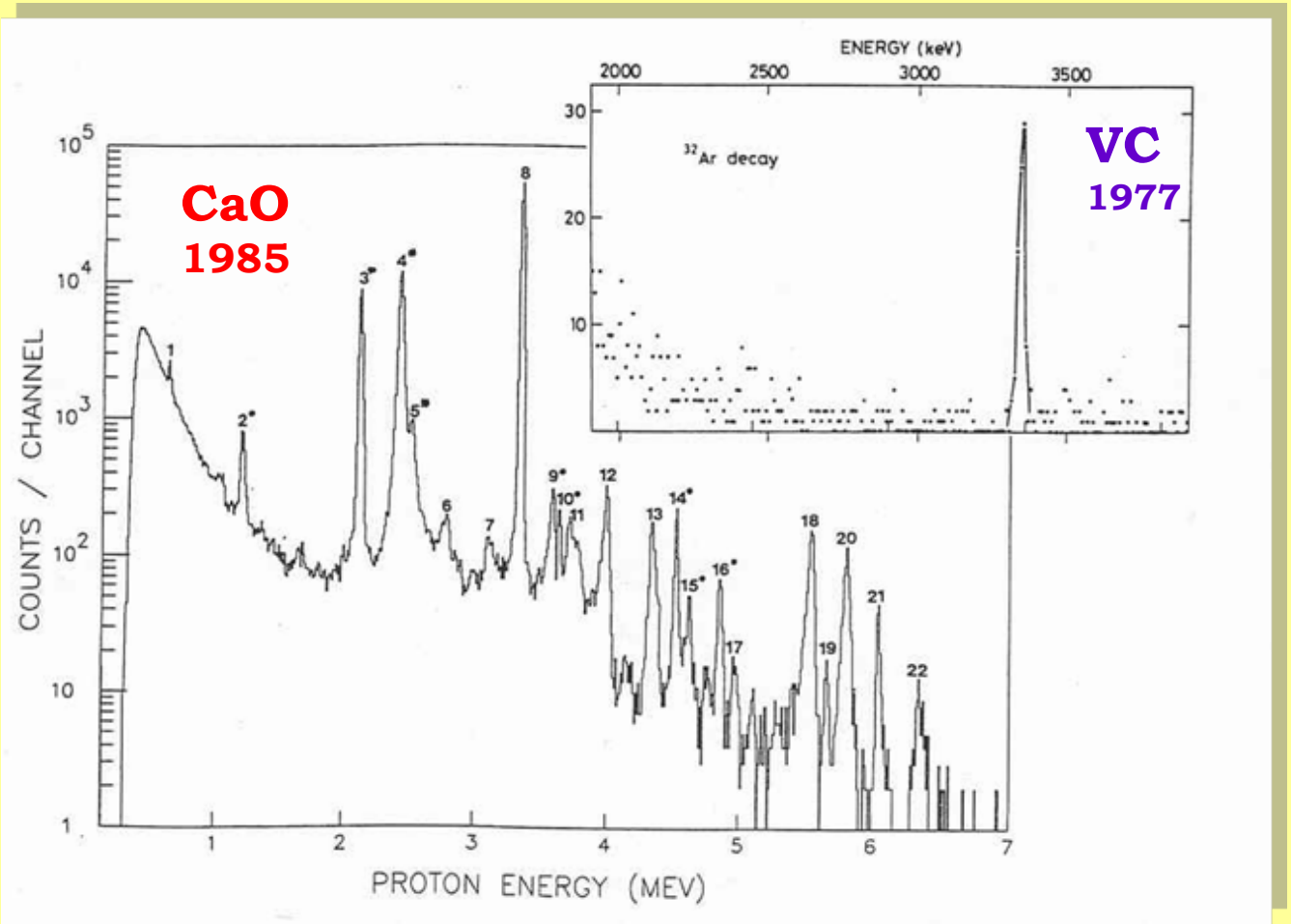
E. Adelberger et al., PRL83 (1999) 1299

$M_S \geq 4.1\ M_W$

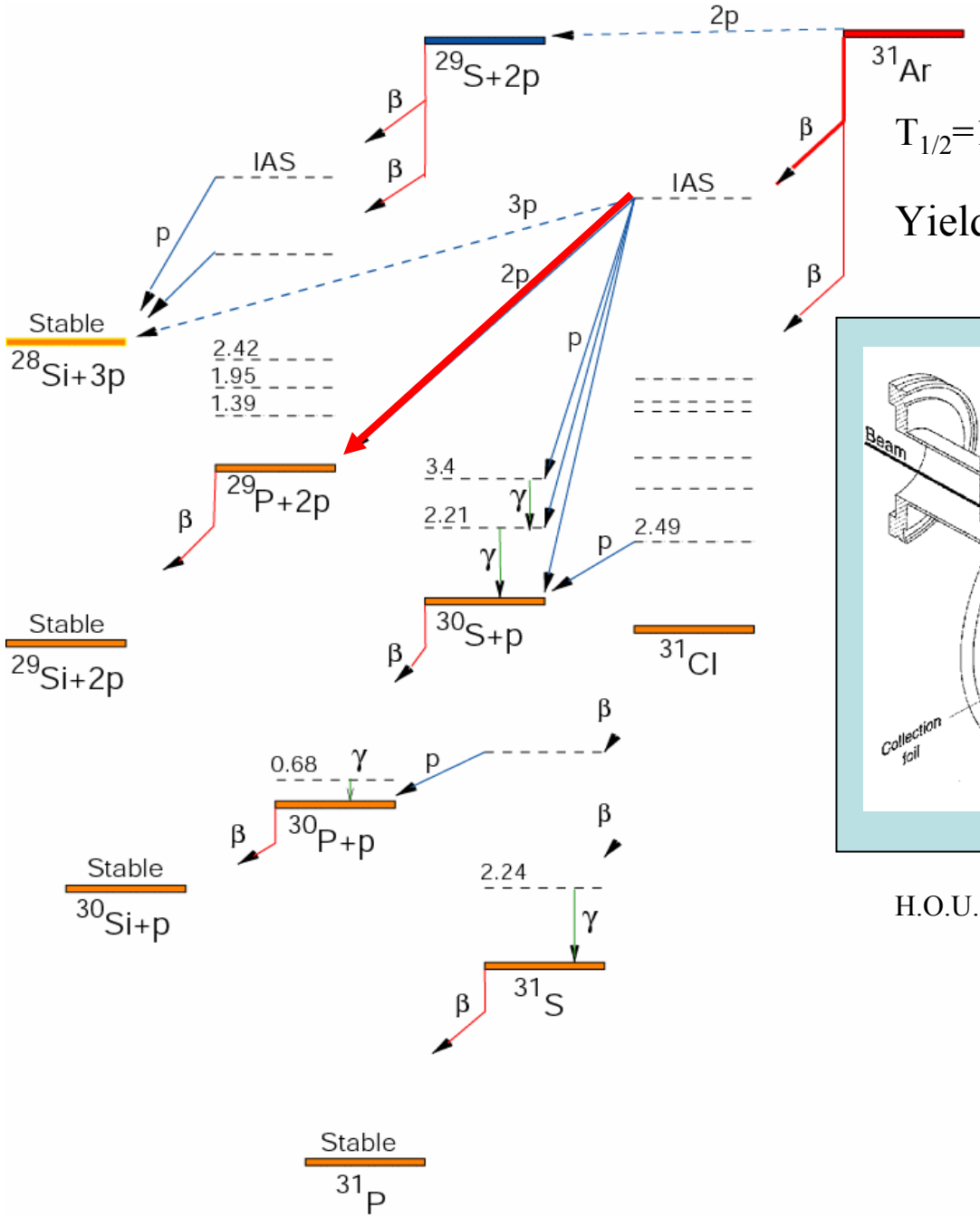
a = 1.0050(52)
Blaum, PRL91(03)260801

IMME

Hagberg et al.,
Phys. Rev. Lett. 39 (1977) 792

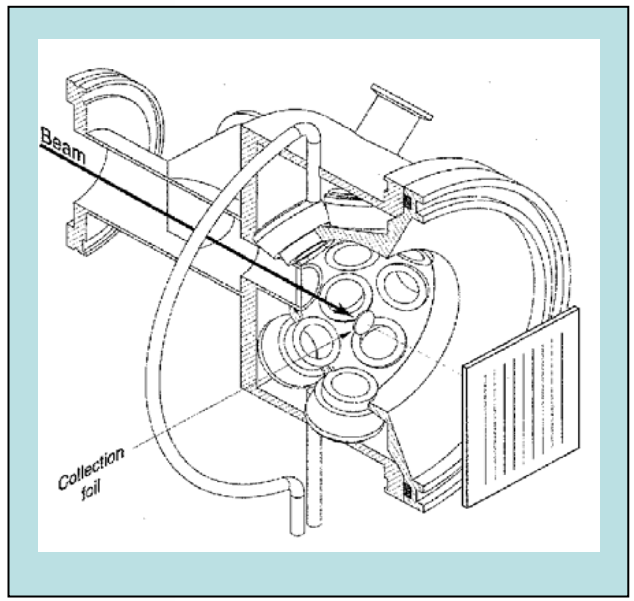


Bjørnstad et al.,
Nucl. Phys. A443 (1985) 283



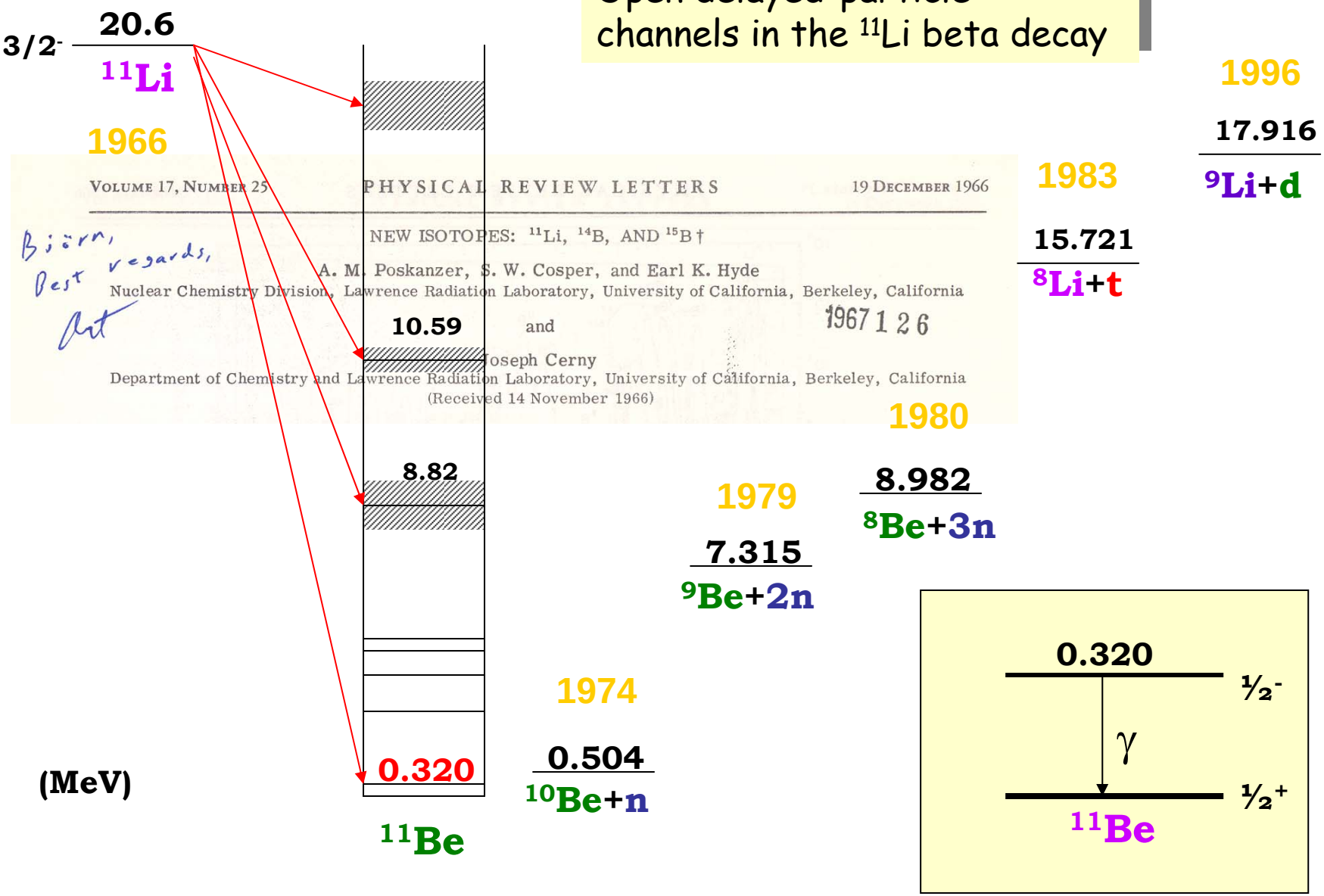
$T_{1/2}$=14.1(7) ms

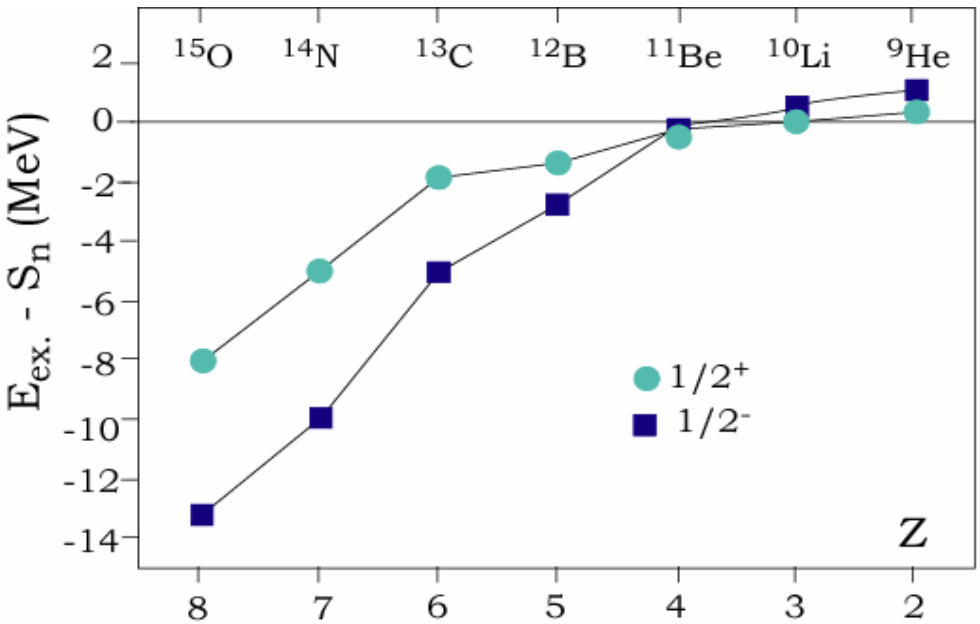
Yield 3 atoms/s

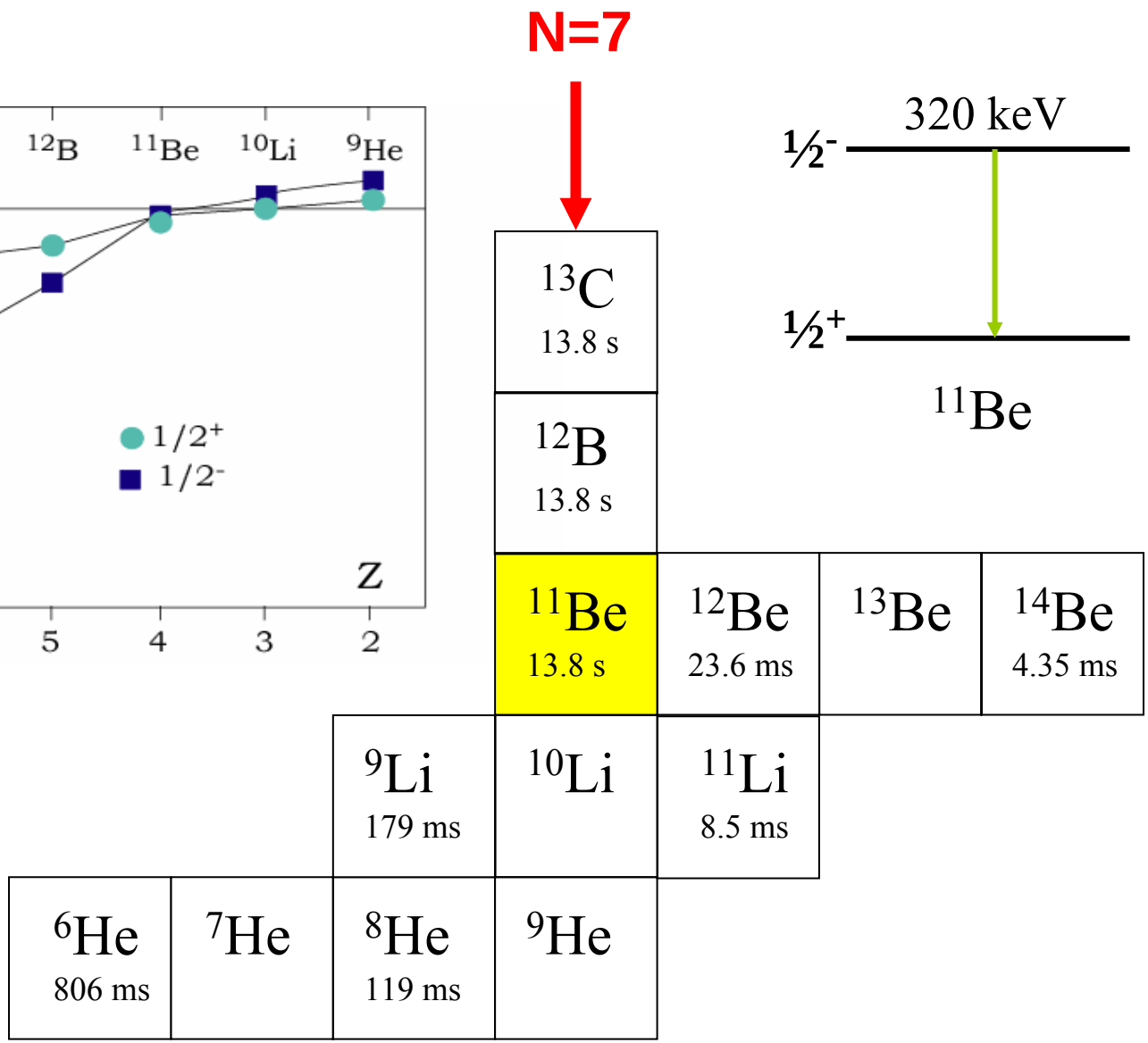


H.O.U. Fynbo et al., NPA 677 (00) 38

Open delayed-particle channels in the ^{11}Li beta decay

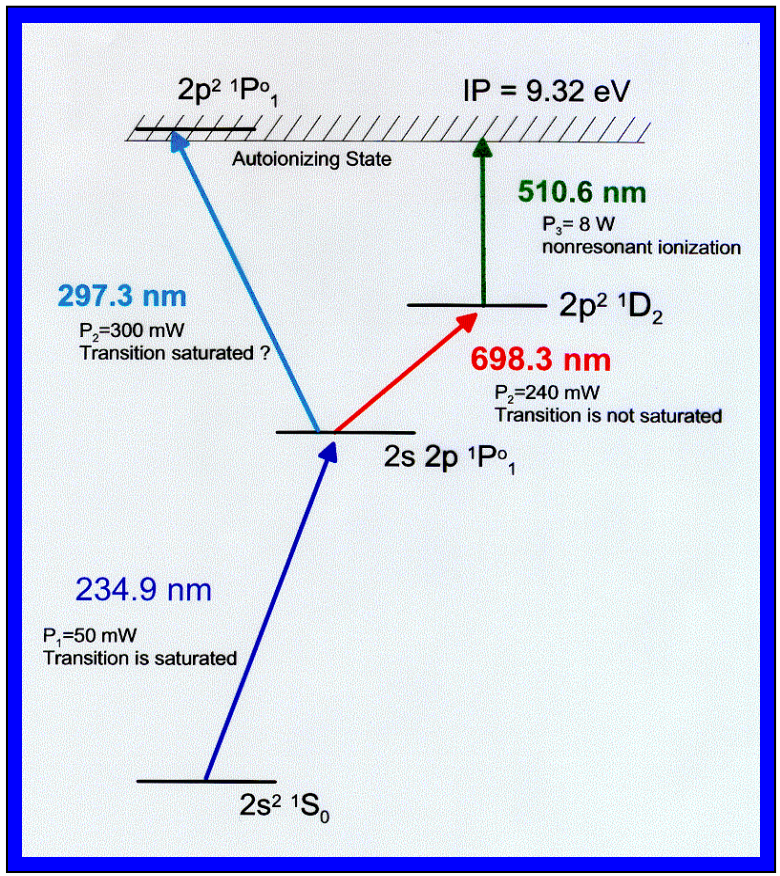



^{15}O
^{14}N
^{13}C
^{12}B
^{11}Be
^{10}Li
^{9}He
$E_{ex.} - S_n$ (MeV)
2
0
-2
-4
-6
-8
-10
-12
-14
1/2$^+$
1/2$^-$
Z
8
7
6
5
4
3
2

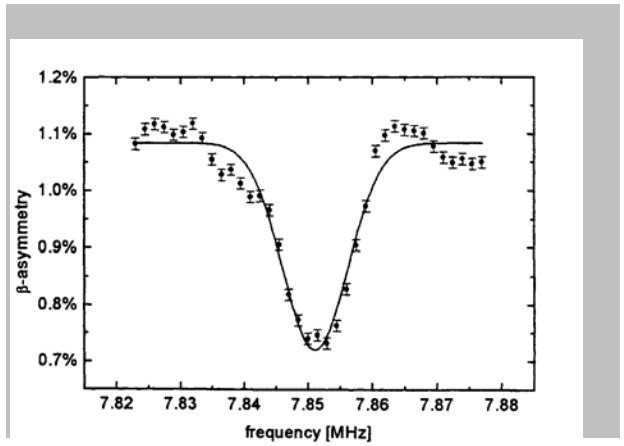

N=7
^{13}C
13.8 s
^{12}B
13.8 s
^{11}Be
13.8 s
^{12}Be
23.6 ms
^{13}Be
^{14}Be
4.35 ms
^{9}Li
179 ms
^{10}Li
^{11}Li
8.5 ms
^{6}He
806 ms
^{7}He
^{8}He
119 ms
^{9}He
320 keV
½$^-$
½$^+$
^{11}Be

Magnetic Dipole Moment of ^{11}Be

ISOLDE



W. Geithner et al., PRL 83 (1999) 3793



$$\mu = -1.6816(8)\ \mu_N$$

T. Susuki et al., Phys. Lett. B 364 (1995) 69

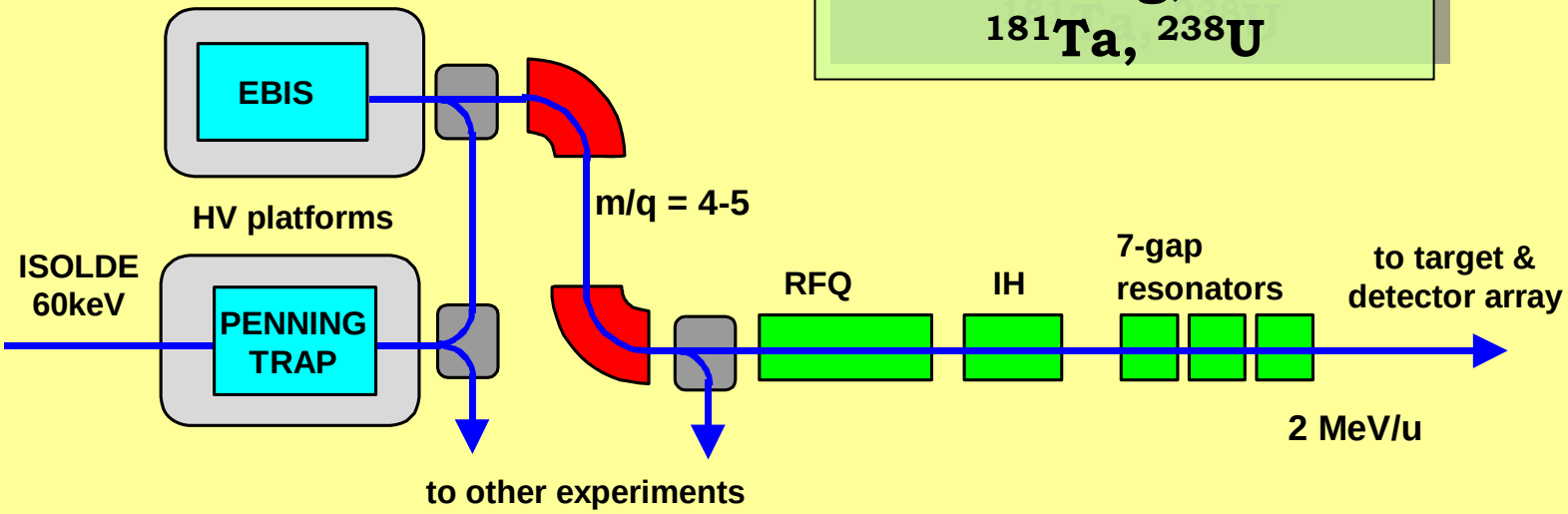
/o=CERN/ou=First Administrative Group/cn=Recipients/cn=tnilsson

From: owner-isolde@listbox.cern.ch on behalf of Thomas Nilsson
Sent: 31 October 2001 00:24
To: ISOLDE - Information List; E-MAIL LIST FOR THE REX EXPERIMENT
Subject: Post-accelerated radioactive beams in REX-ISOLDE

Tonight, the first radioactive beam was successfully post-accelerated at REX-ISOLDE. A beam of 26Na (T1/2 = 1.07 s) from the ISOLDE High Resolution Separator was accelerated to 2 MeV/u (using only two out of three 7-gap resonators) and delivered to the reaction target of a nuclear spectroscopy set-up, including one MINIBALL unit and detectors for charged particles. All systems for beam cooling, charge breeding and post acceleration behaves according to expectation. This important step will be immediately followed by further commissioning, beam characterization and data taking.

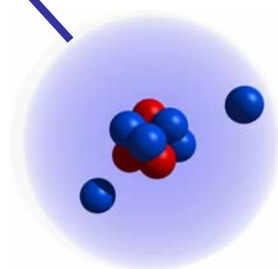
The REX-ISOLDE team

^{184,186,188}Hg, ^{208}Pb – ^{181}Ta, ^{238}U

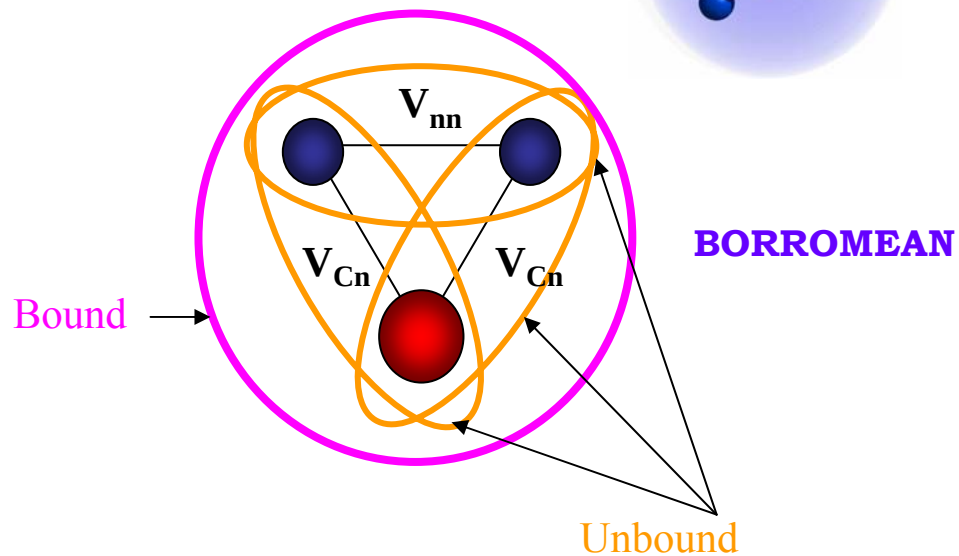


Unbound Light Nuclei

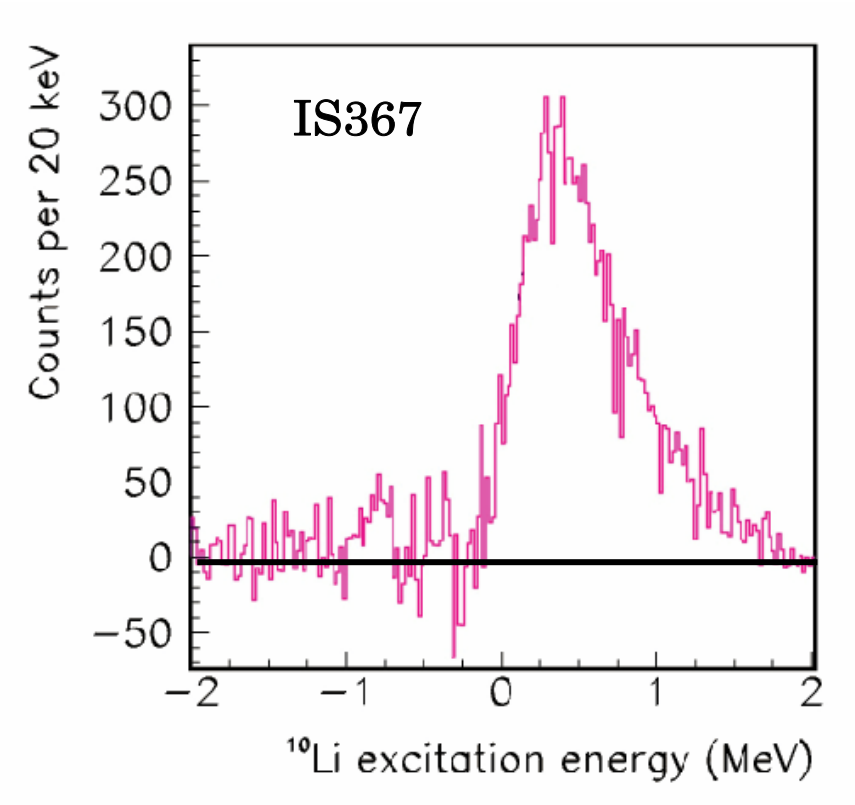
			^{7}Be	^{8}Be unbound	^{9}Be	^{10}Be 1.6 10^{6} y	^{11}Be 13.8 s	^{12}Be 23.6 ms	^{13}Be unbound	^{14}Be 4.35 ms
			^{6}Li	^{7}Li	^{8}Li 840 ms	^{9}Li 179 ms	^{10}Li unbound	^{11}Li 8.5 ms	^{12}Li unbound	^{13}Li unbound
	^{3}He	^{4}He	^{5}He unbound	^{6}He 808 ms	^{7}He unbound	^{8}He 119 ms	^{9}He unbound	^{10}He unbound		
^{1}H	^{2}H	^{3}H 12.3 y		^{5}H unbound		^{7}H unbound				
	n									

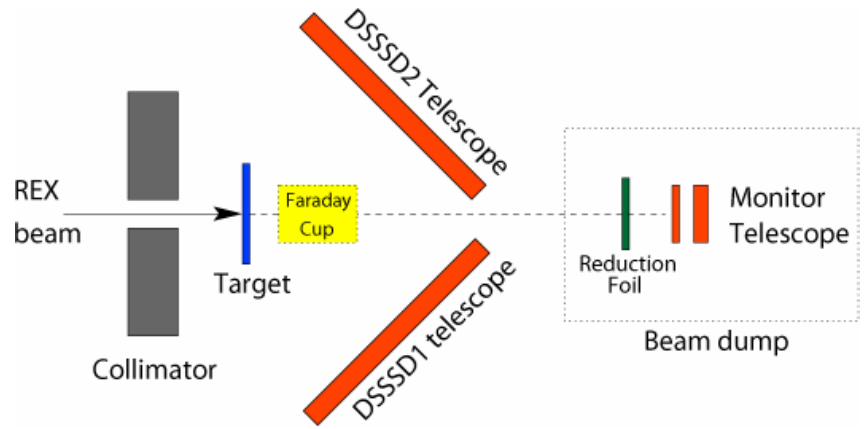


Berkeley 1985
Tanihata et al.,



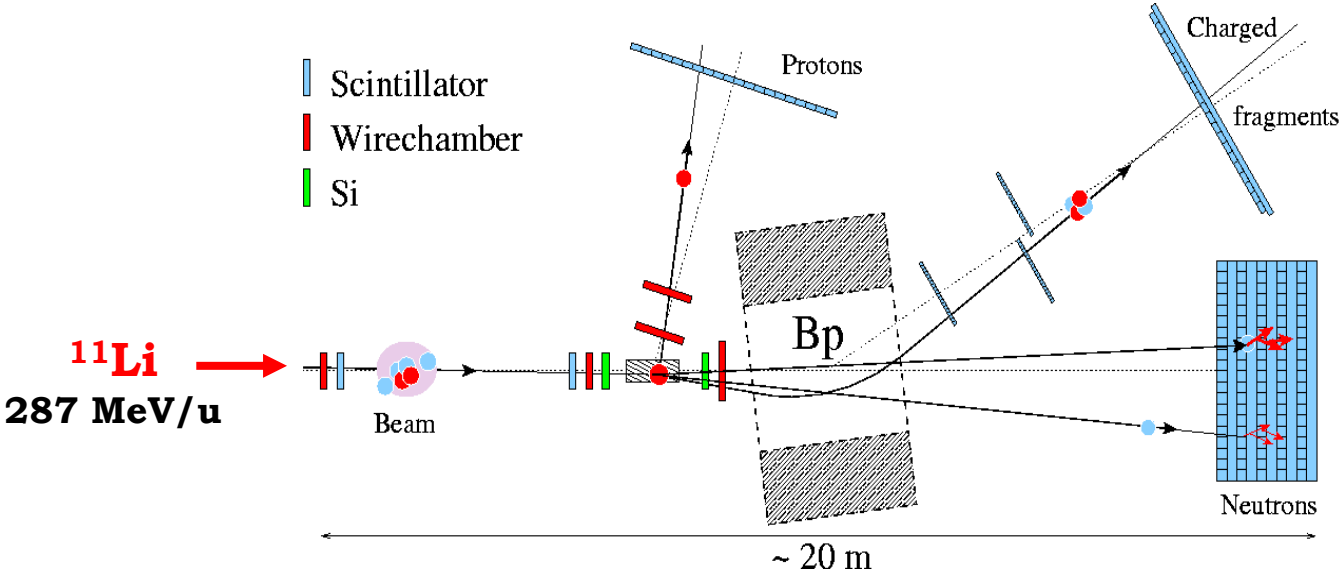
$d(^{9}Li,p)^{10}Li$



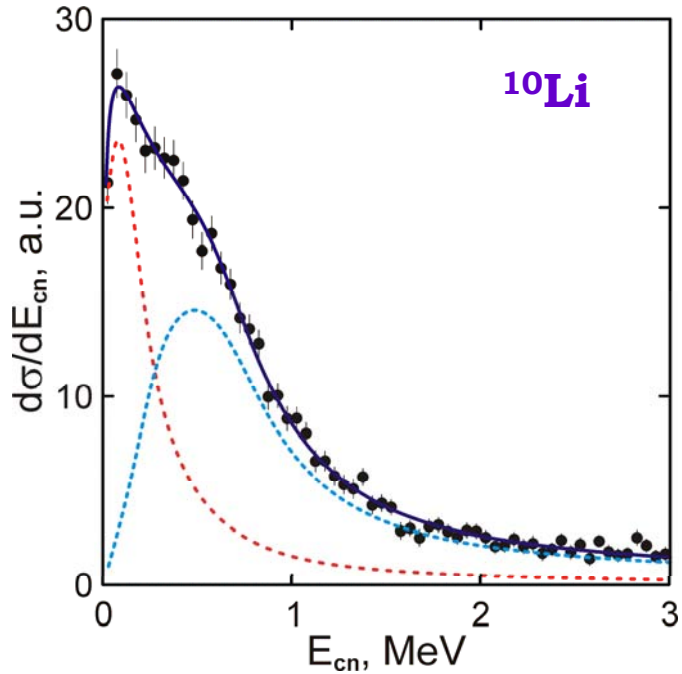


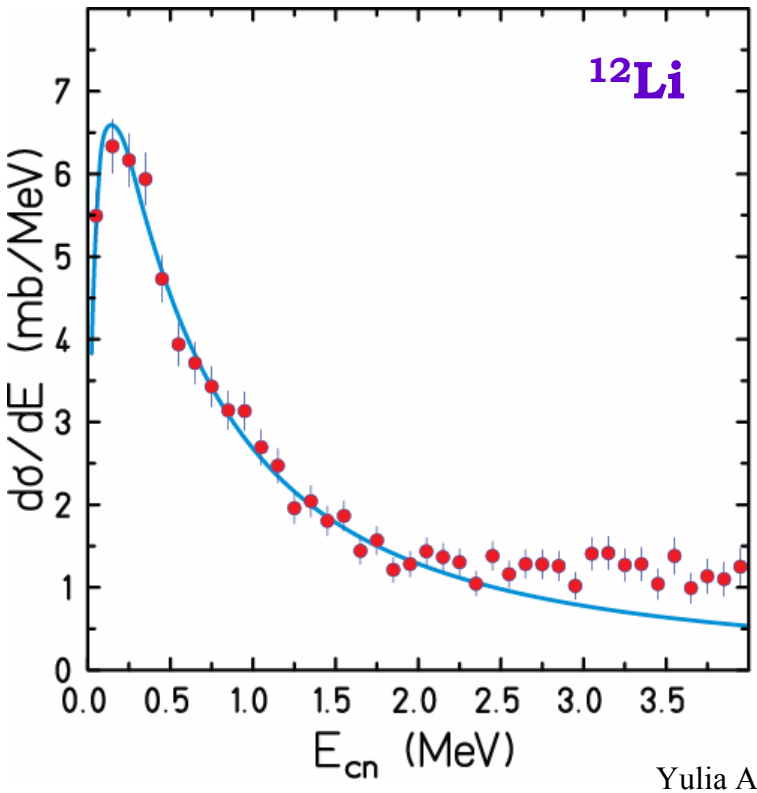
Kirsebom et al., to be published.

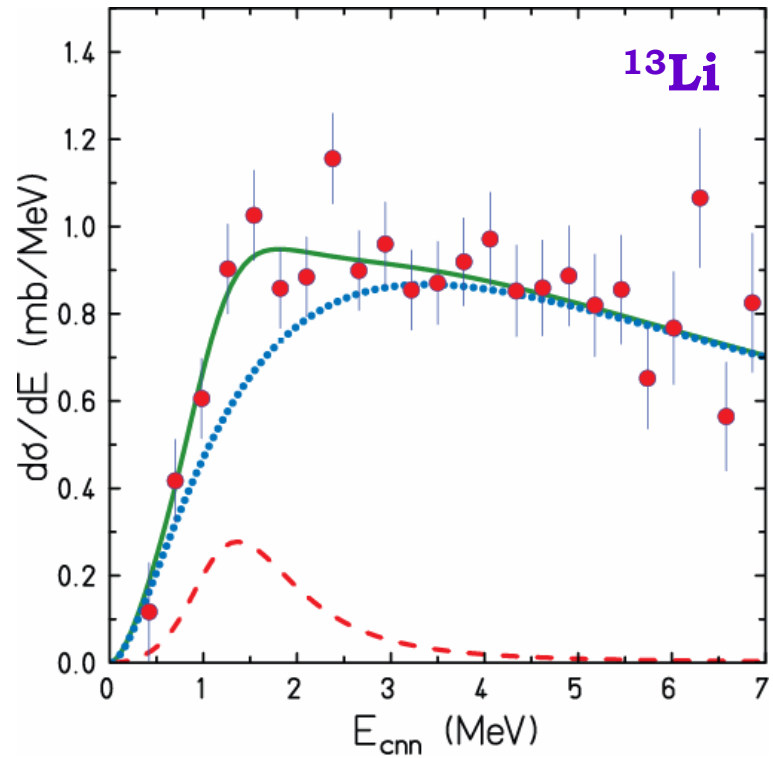
2.77 MeV/u



FRS-ALADIN-LAND@GSI





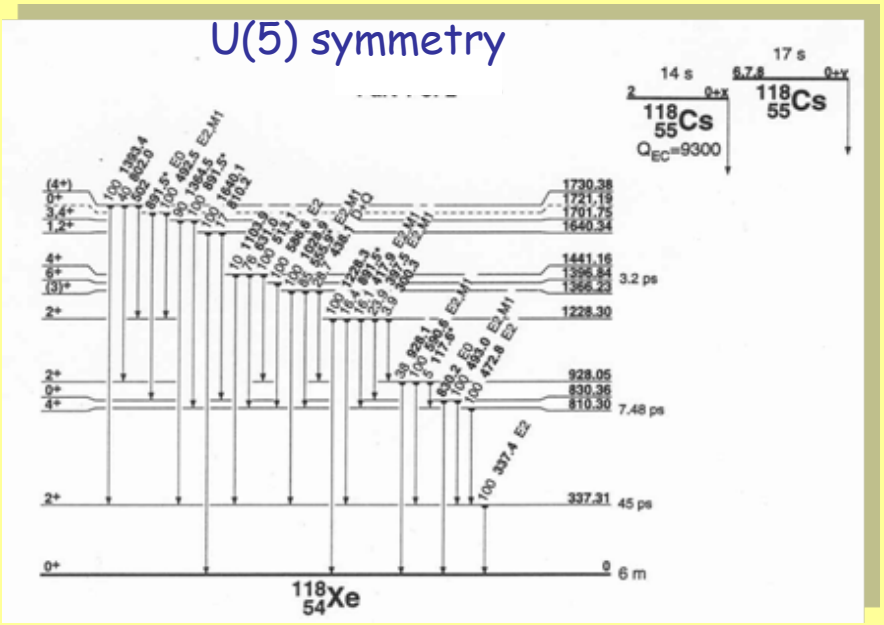


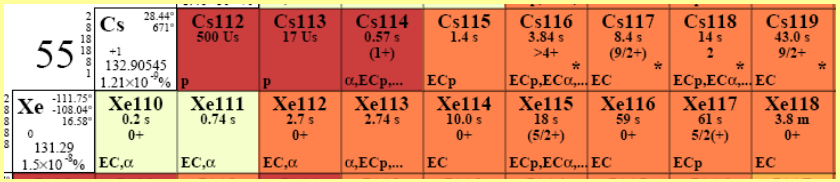
Yulia Aksyutina et al.,
to be published

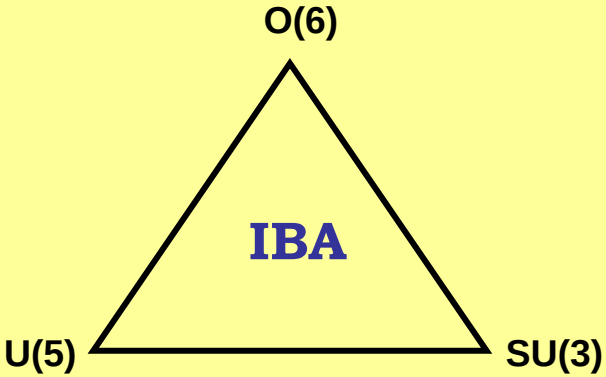
$d(^{11}Li,p)^{12}Li$

$t(^{11}Li,p)^{13}Li$

HIE ISOLDE





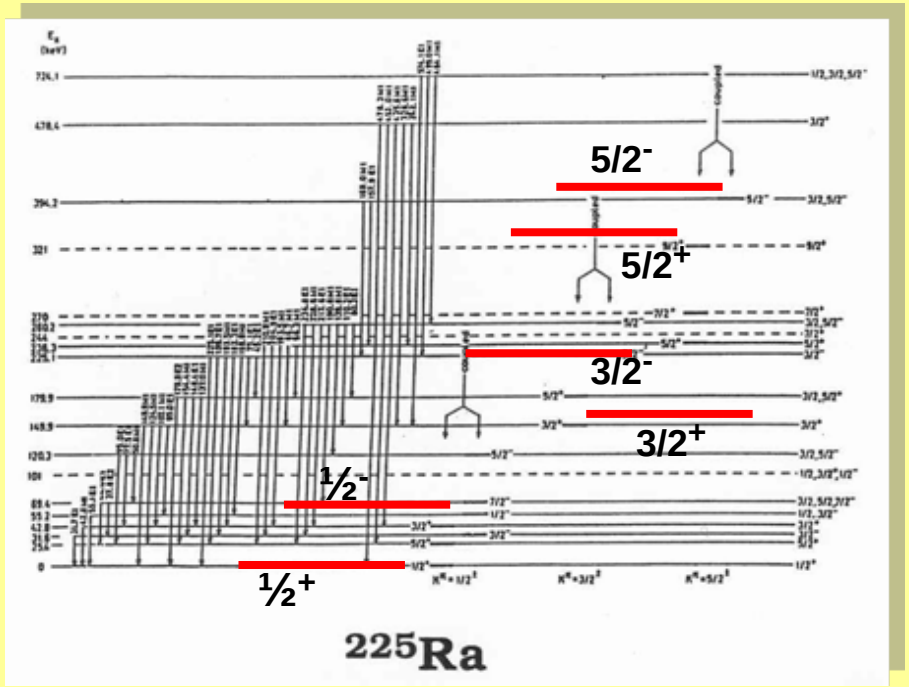


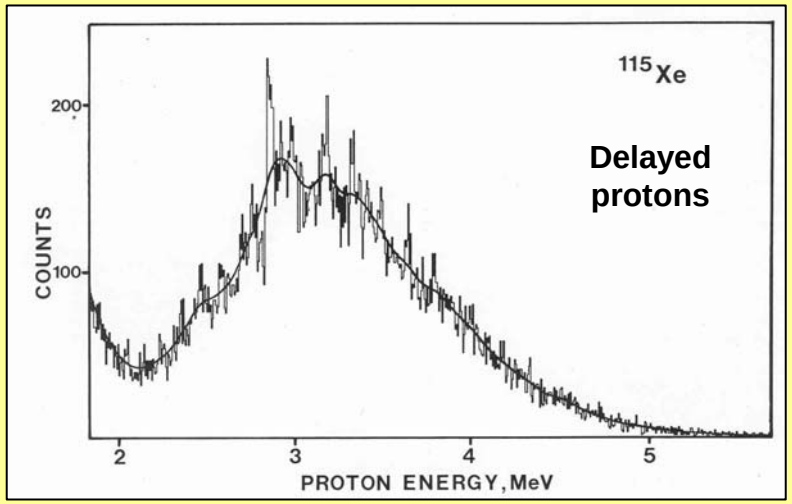
Octupole shapes

Ra224 3.66 d 0+ α,14C	Ra225 14.9 d 1/2+ β-	Ra226 1600 y 0+ α,14C	Ra227 42.2 m 3/2+ β-	Ra228 5.75 y 0+ β-	Ra229 4.0 m 5/2(+) β-	Ra230 93 m 0+ β-	Ra231 103 s (7/2-,1/2+) β-
Fr223 21.8 m 3/2(-) β-,α	Fr224 3.33 m 1- β-	Fr225 4.0 m 3/2- β-	Fr226 49 s 1- β-	Fr227 2.47 m 1/2+ β-	Fr228 38 s 2- β-	Fr229 50 s β-	Fr230 19.1 s β-

Parity doublets

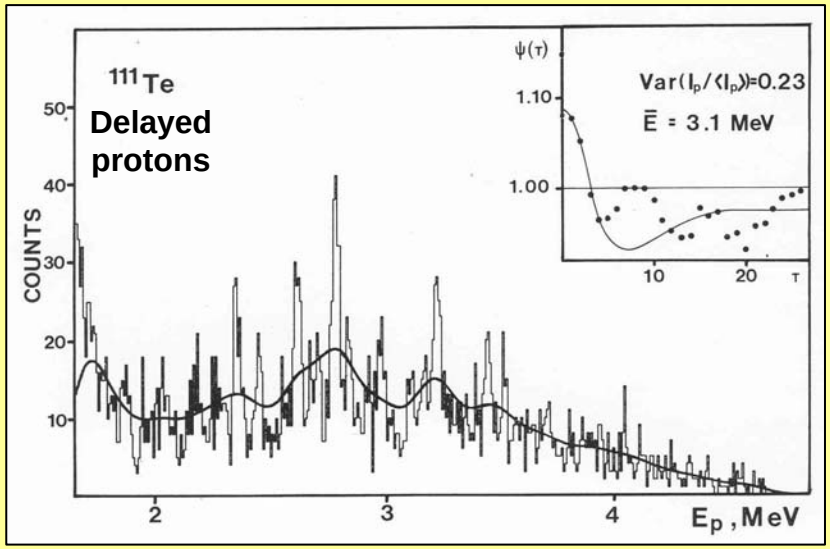
½± , 3/2± , 5/2±

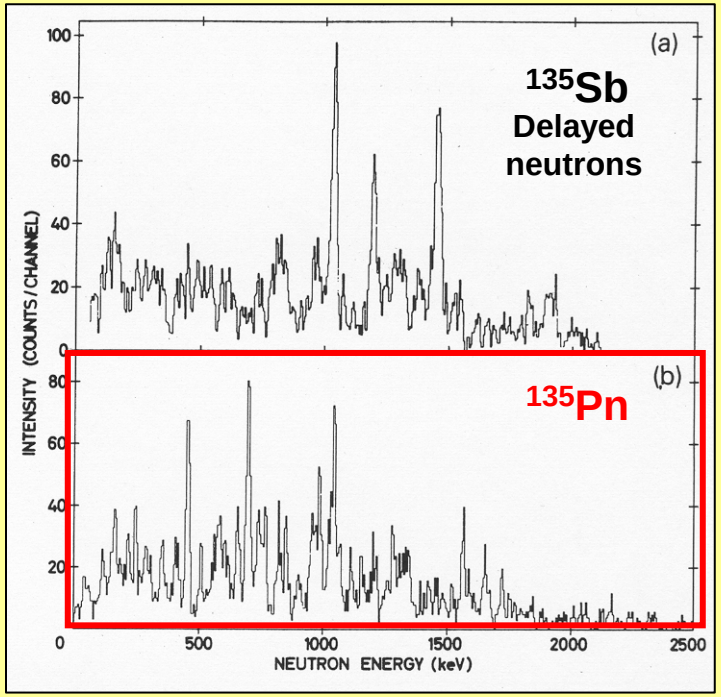




$$\psi_d(\tau) = 1 + \frac{\alpha D}{2\pi^{\frac{1}{2}}\sigma} \times \left[e^{-\frac{\tau^2}{4\sigma^2}} + \frac{e^{-\frac{\tau^2}{4\sigma^2 y^2}}}{y} - \frac{2\sqrt{2}}{\sqrt{y^2+1}} e^{-\frac{\tau^2}{2\sigma^2(1+y^2)}} \right].$$

Hansen et al., Nucl. Phys. A518 (1990) 13



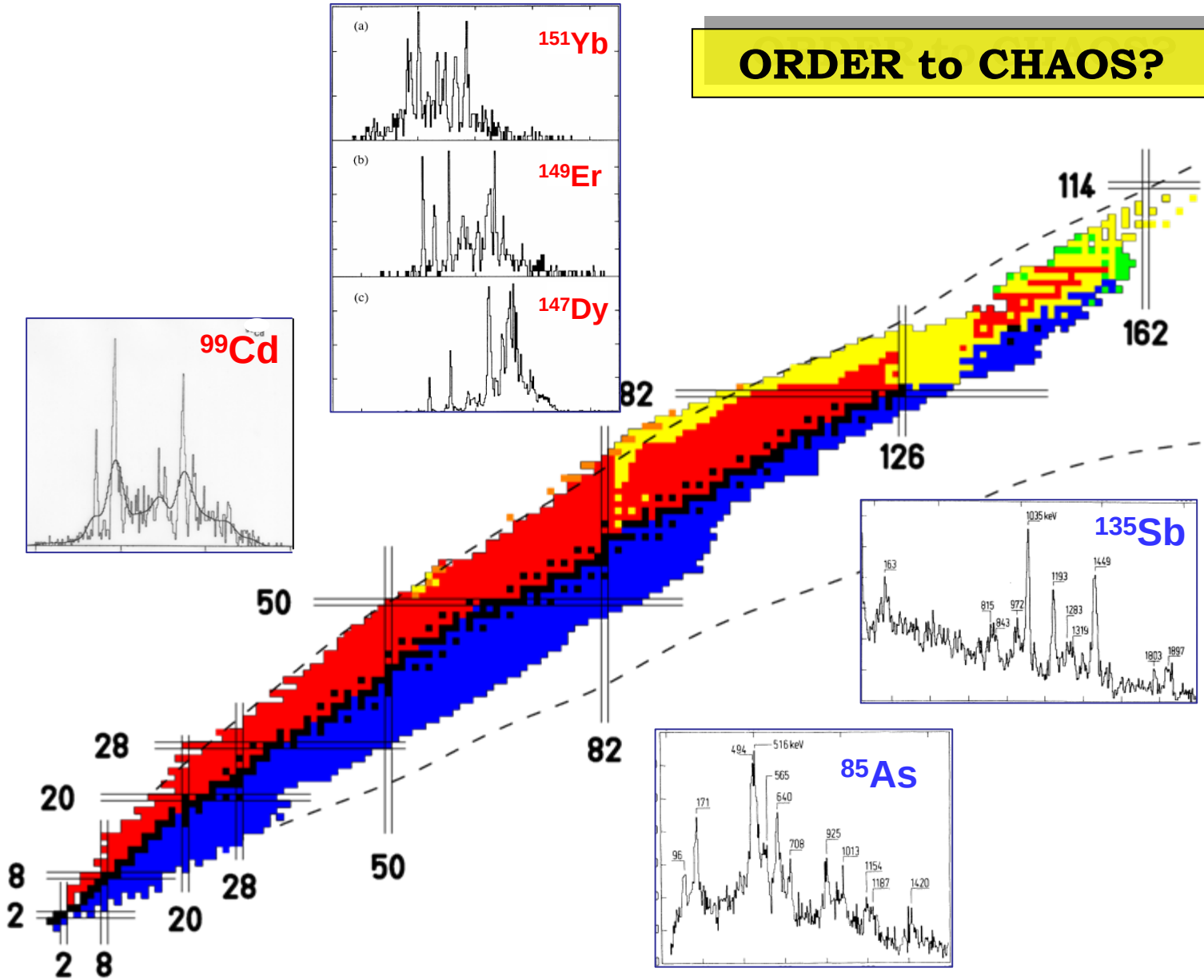


"The rest were all
Far to the inland retired, about the walls
Of ***Pandemonium*** *city and proud seat*
Of Lucifer"

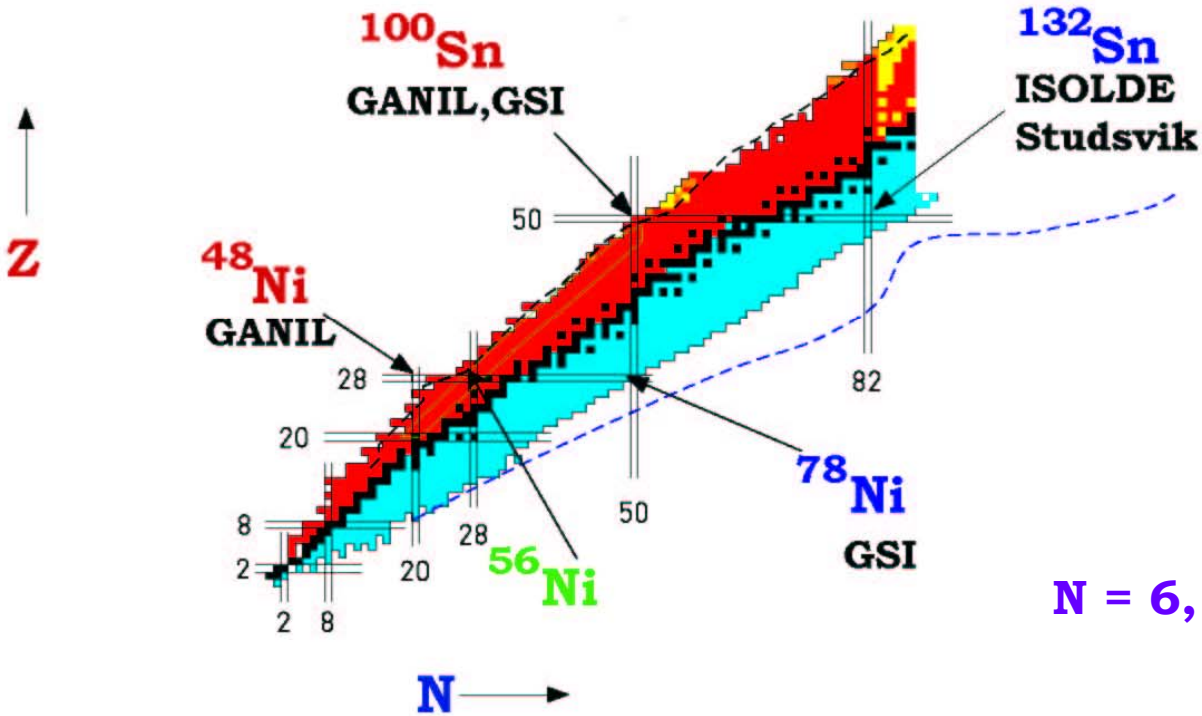
J. Milton in Paradise Lost X (1667) line 424

Hardy et al., Nucl. Phys. A305 (1978) 15

ORDER to CHAOS?

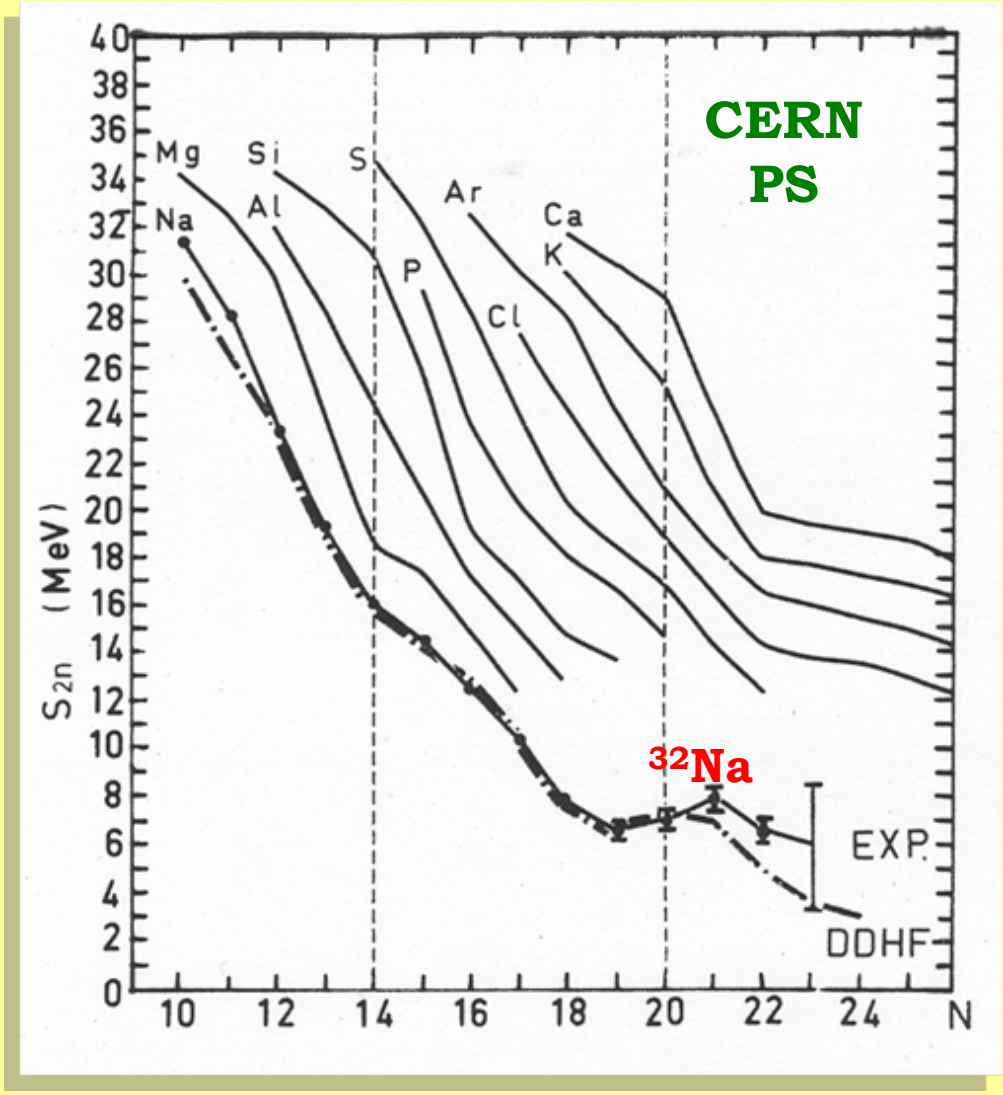


Exotic doubly-magic nuclei



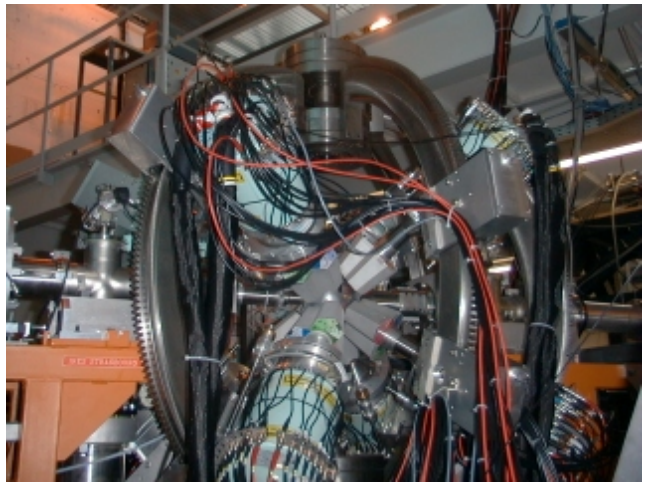
N = 6, 16

^{11}Li, ^{12}Be

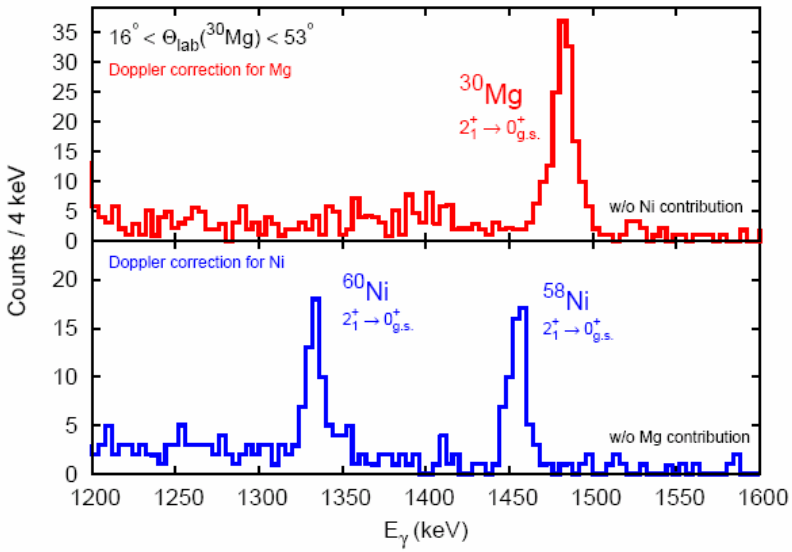


Thibault et al., Phys. Rev. C 12 (1975) 644

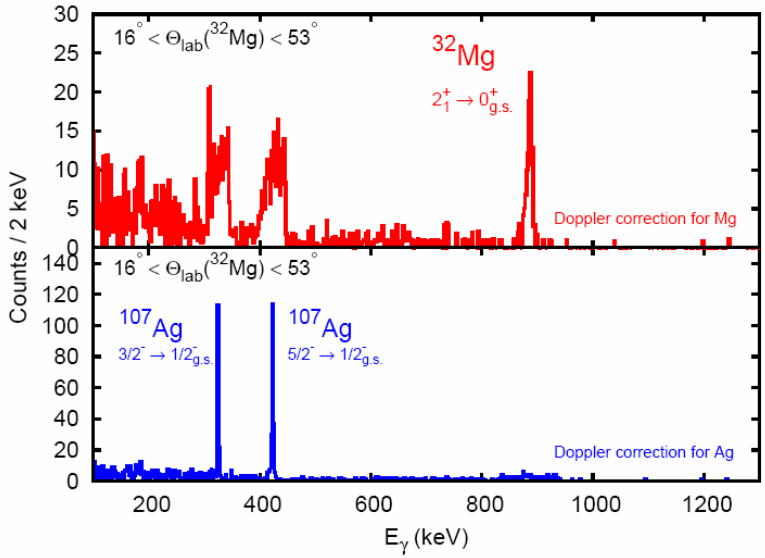
REX-MINIBALL at REX-ISOLDE



^{30}Mg

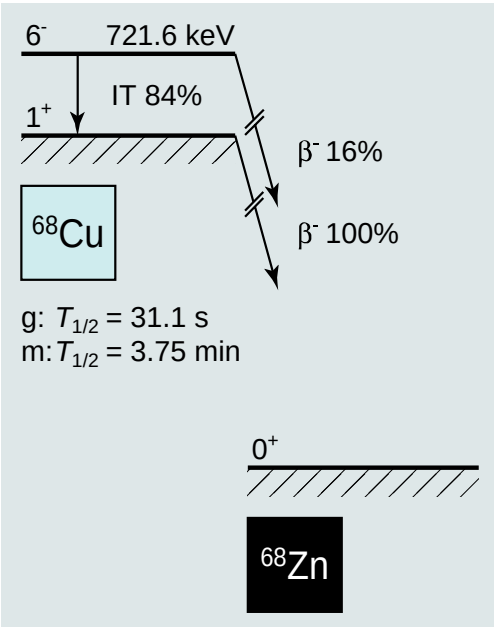


^{32}Mg



Niedermaier et al. PRL 94 (05) 172501

Isomers in ^{68}Cu

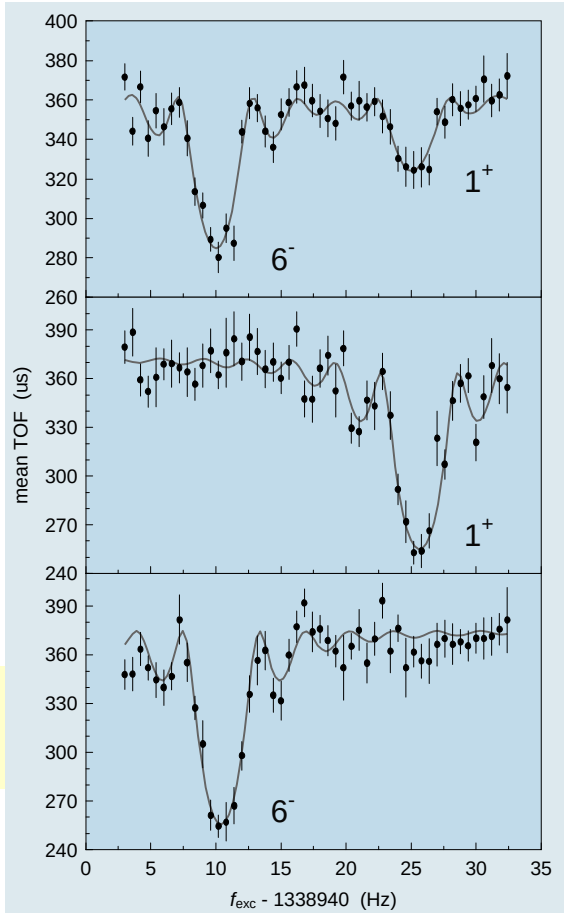


K. Blaum *et al*., Europhys. Lett. 67, 586 (2004)

as produced by ISOLDE

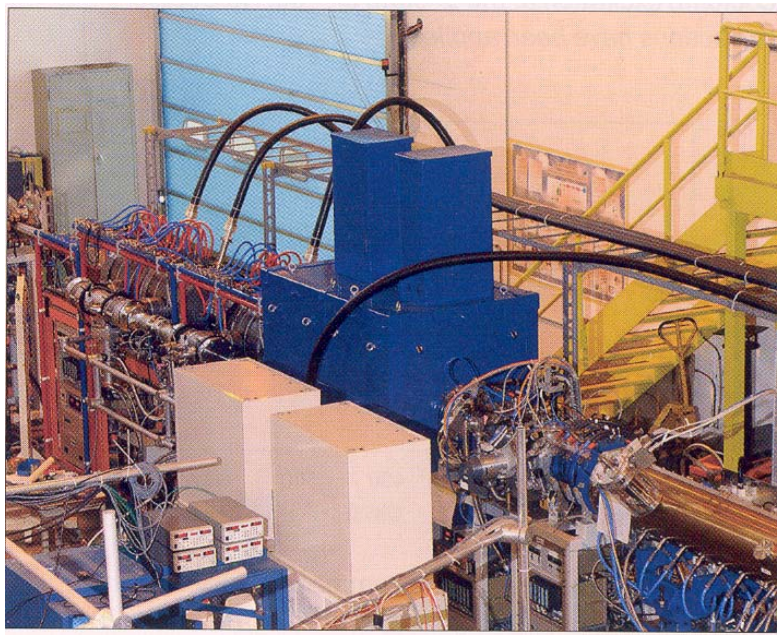
isolation of the 1^+ ground state

isolation of the 6^- isomeric state

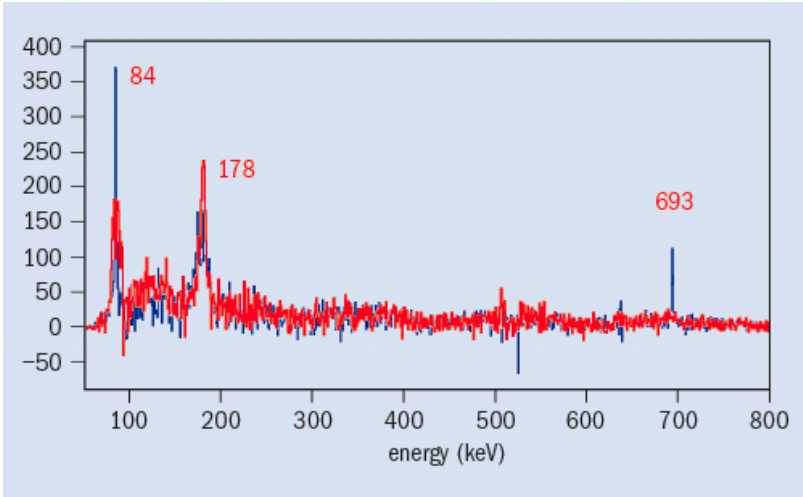


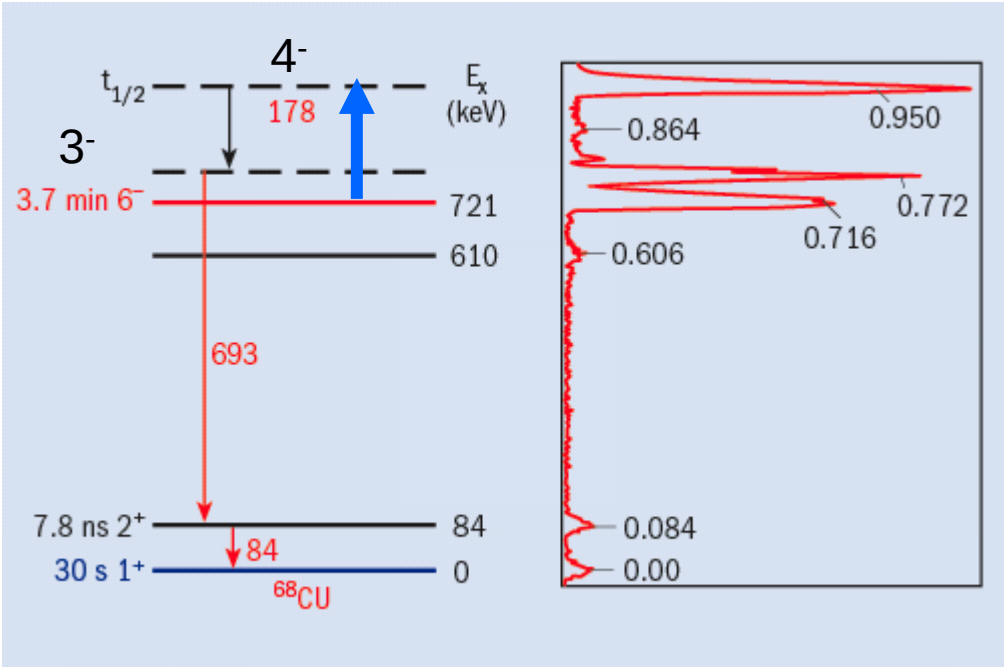
Isomeric Radioactive Beam

REX ISOLDE

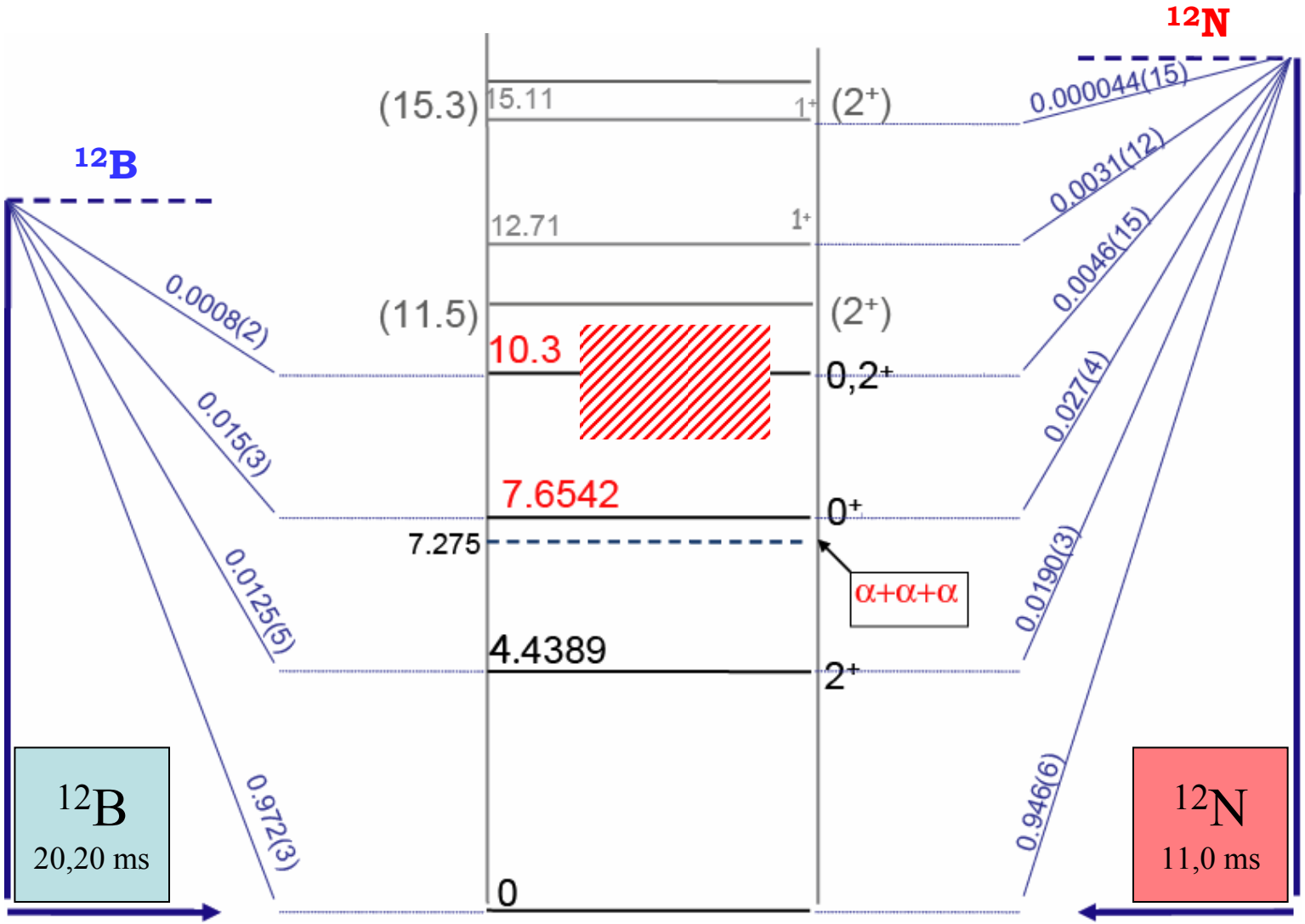


^{68}Cu, 2.83 MeV/u





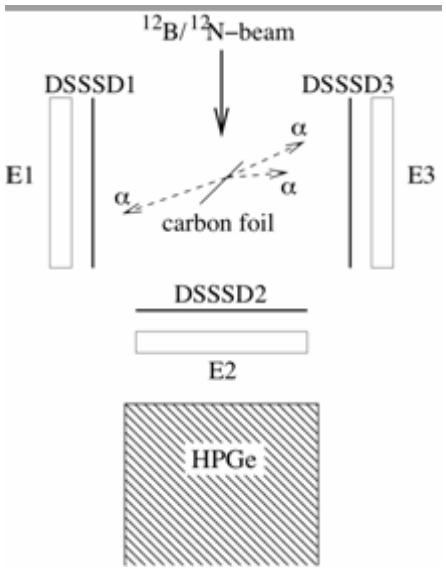
Stefanescu et al.,
Phys.Rev.Lett. 98, 122701 (2007)

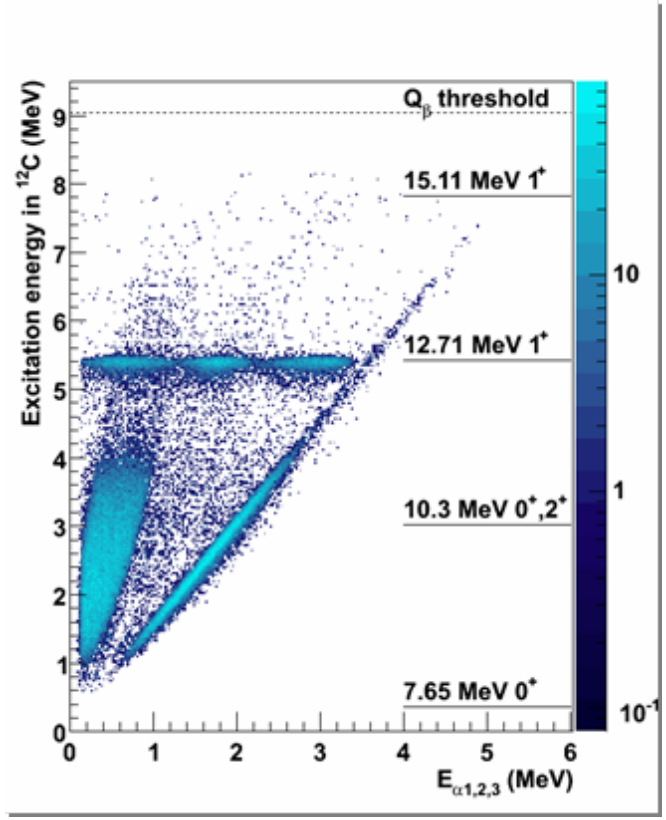


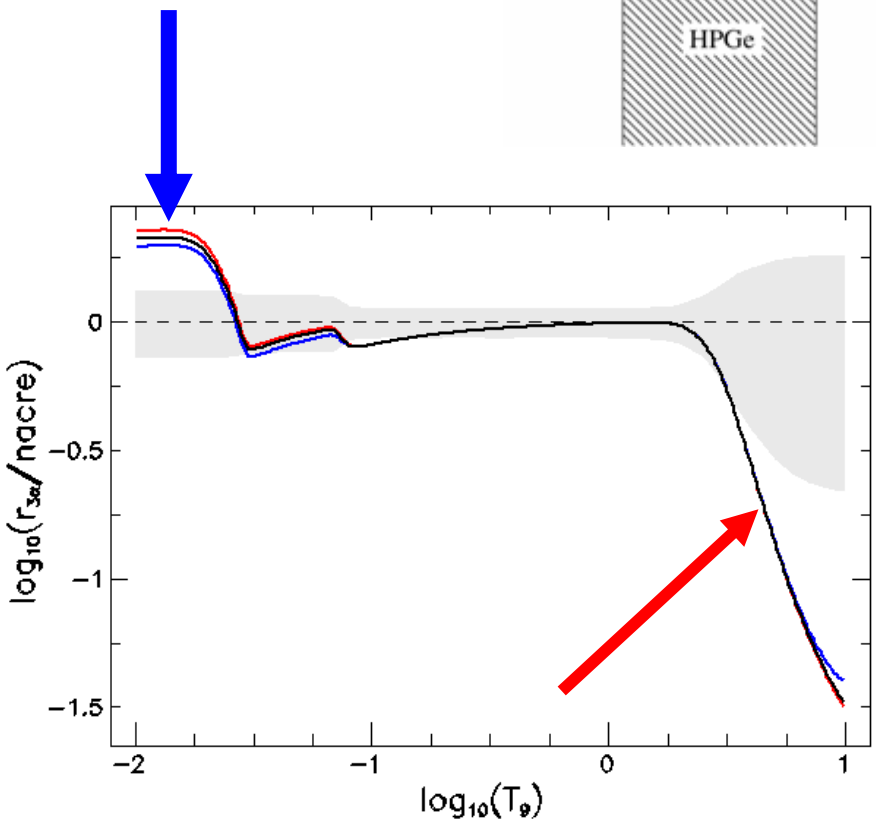
ISOLDE, CERN

IGISOL

H. Fynbo et al., Nature 433 (2005) 136

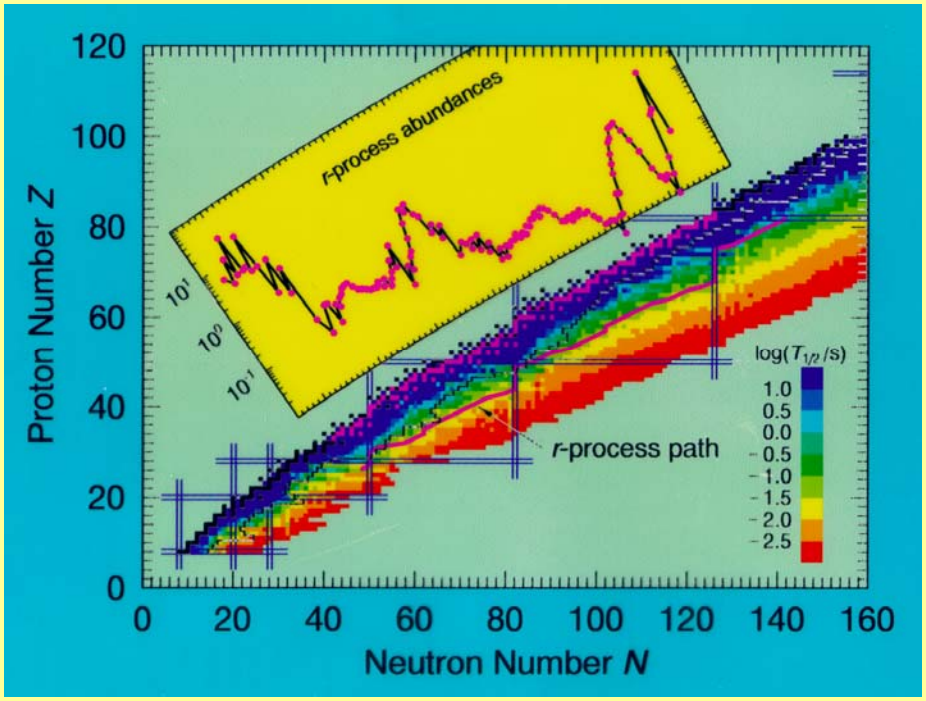






Nuclear **A**strophysics **C**ompilation of **RE**action Rates,

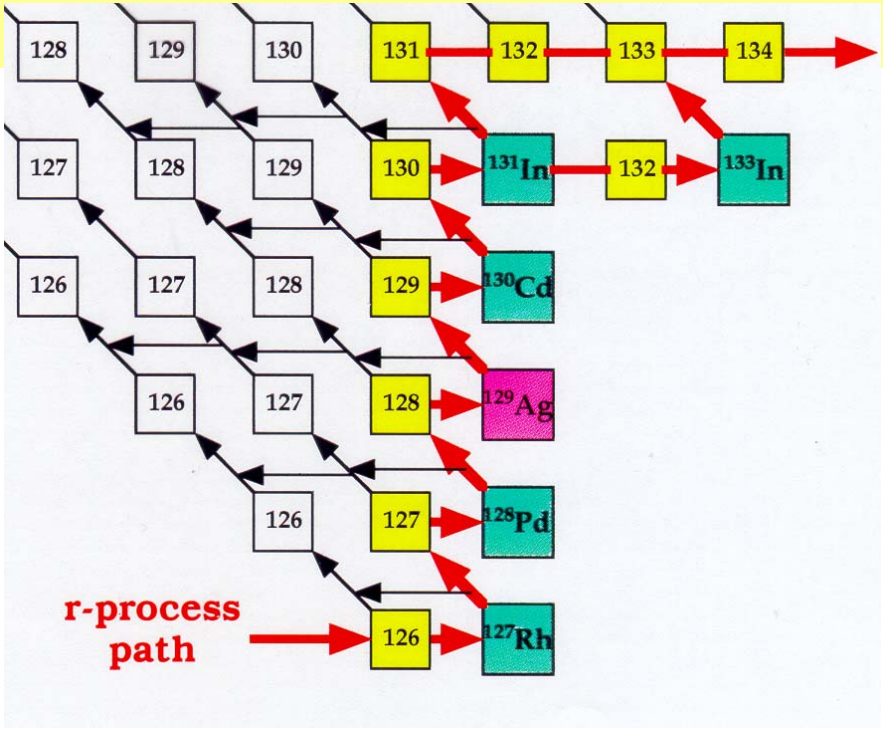
C. Angulo et al.., NPA **656** (1999) 3



^{130}Cd

$T_{1/2}$ = 195 ms

B. Pfeiffer, K.-L. Kratz, and F.-K. Thielemann, Z. Phys. A **357**, 235 (1997).



^{129}Ag

$T_{1/2}$ = 46 ms

Kratz et al., Hyperfine Interactions 129 (00) 185

^{26}Si ^{27}Si ^{28}Si

^{25}Al ^{26}Al ^{27}Al

^{21}Mg ^{22}Mg ^{23}Mg ^{24}Mg ^{25}Mg ^{26}Mg

^{20}Na ^{21}Na ^{22}Na ^{23}Na

Mg - Al

^{18}Ne ^{19}Ne ^{20}Ne ^{21}Ne ^{22}Ne

Hot CNO

^{17}F ^{18}F

Ne -Na

^{14}O ^{15}O ^{16}O

^{13}N ^{14}N ^{15}N

^{12}C ^{13}C

CNO

This is Man's wonderful ability:
to be able to grasp the inner essence of phenomena,
not what they appear to be, but what they mean,
and the reality we see with our eyes
is a symbol only of something higher.

Ty detta är det herrliga hos menskan
att hon kan fatta tingens inre väsen,
ej hvad de synas, men hvad de betyda;
och verkligheten, hvart vårt öga ser,
den är symbolen endast af ett högre.

Esaias Tegnér,
Magisterpromotionen i Lund
1820

Thanks to

Georg Bollen, Peter Butler, Rick Casten,
Doris Forkel-Wirth, Luis Fraile, Heinz Haas,
John Hardy, Kris Heyde, Jürgen Kluge,
Thomas Nilsson, Göran Nyman, Ernst Otten,
Ingemar Ragnarsson, Karsten Riisager,
Piet Van Duppen, Fredrik Wenander,
Sven Åberg, Juha Äystö

”The ISOLDE concept”