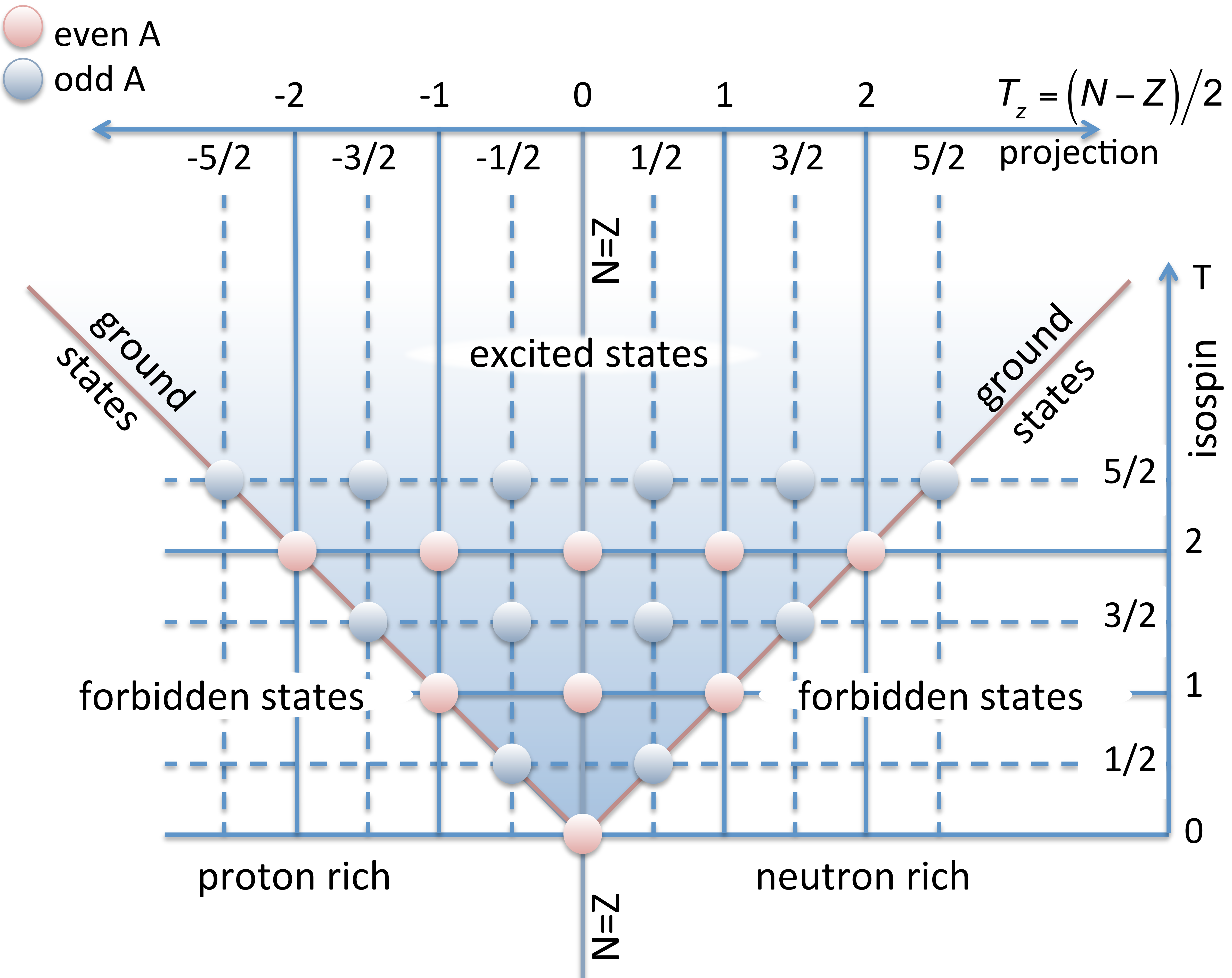
Probing isospin non-conserving interactions in nuclei through study of isobaric triplets

David Jenkins

Isobaric Spin (Isospin)



For T=1 triplets:

$$\mathrm{MED}_J = E^*_{J,T_z=-1} - E^*_{J,T_z=+1}.$$

Mirror energy differences are isovector and sensitive to:
single-particle Coulomb shifts, electromagnetic spin-orbit interaction,
changes of shape/radius of nuclei

$$\mathrm{TED}_J = E^*_{J,T_z=-1} + E^*_{J,T_z=+1} - 2E^*_{J,T_z=0}.$$

Isotensor energy differences reflecting differences between nn, pp and pn force.
Not sensitive to one-body terms but only two-body
i.e. sensitive to Coulomb multipole and isospin-nonconserving forces

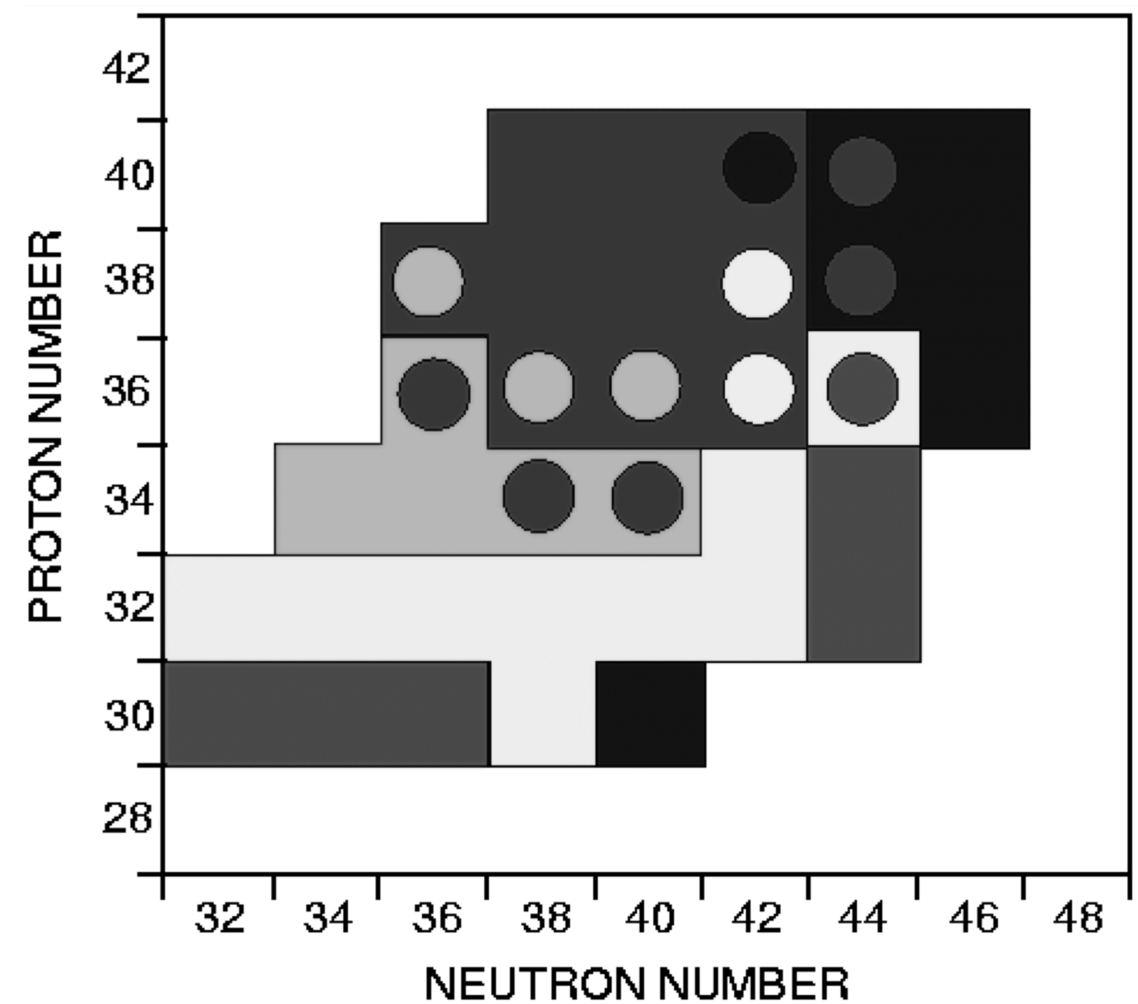
Shapes of N=Z nuclei

Very Prolate
Oblate
Triaxial

Very, very sensitive to underlying quantum structure…

The original phenomonological "M-M" theory, (Microscopic Macroscopic) was very sound.

P. Moller and J.R. Nix. At. Nuc. Data Tables, 26 (1981) 1965
S. Aberg. Phys Scr. 25 (1982) 23
W. Nazarewicz. Nucl. Phys A435 (1985) 397.
R. Bengtsson. Conf on the structure in the zirconium region, 1988

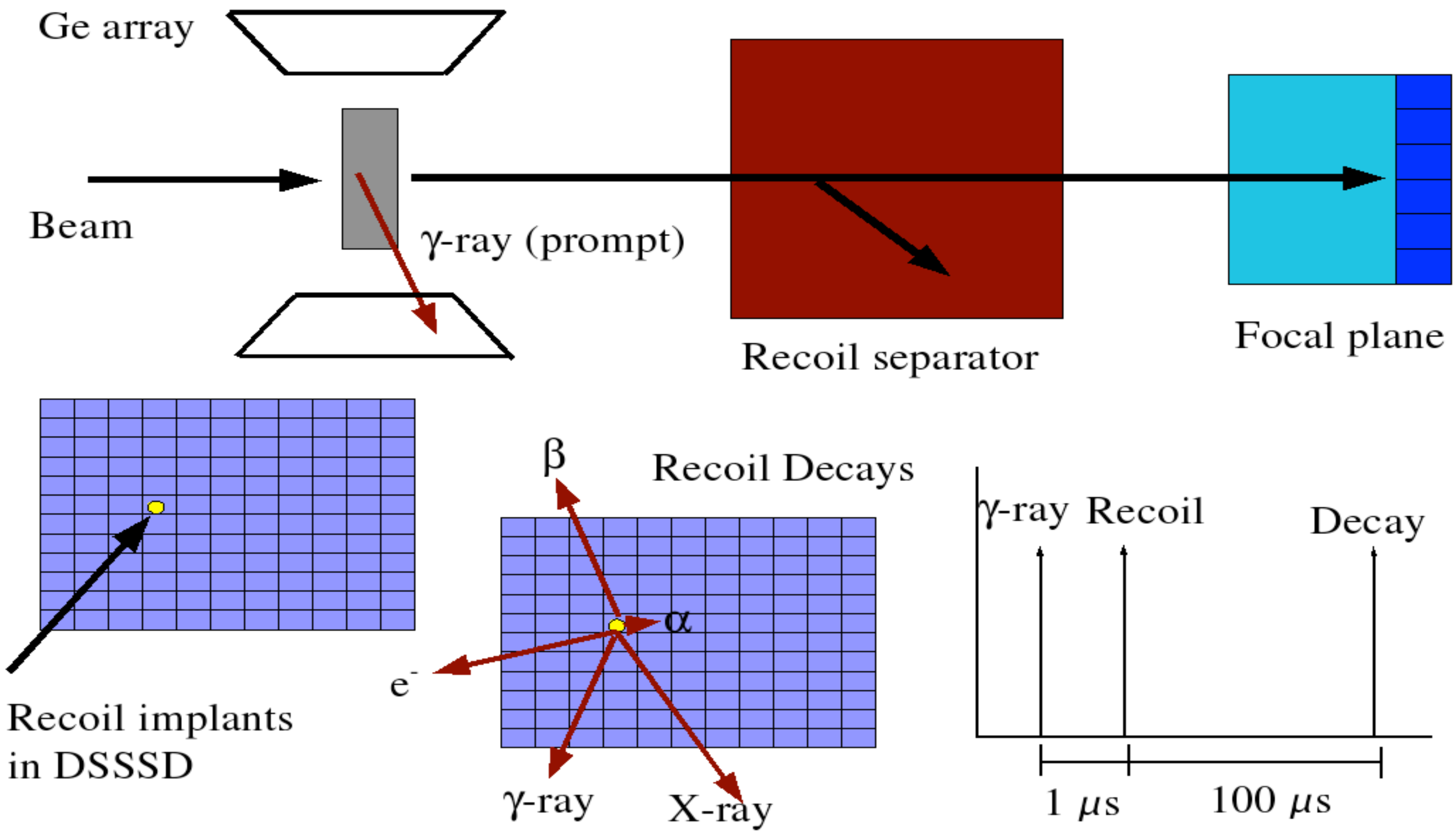


{Classic "Potential Energy Surface" calculations

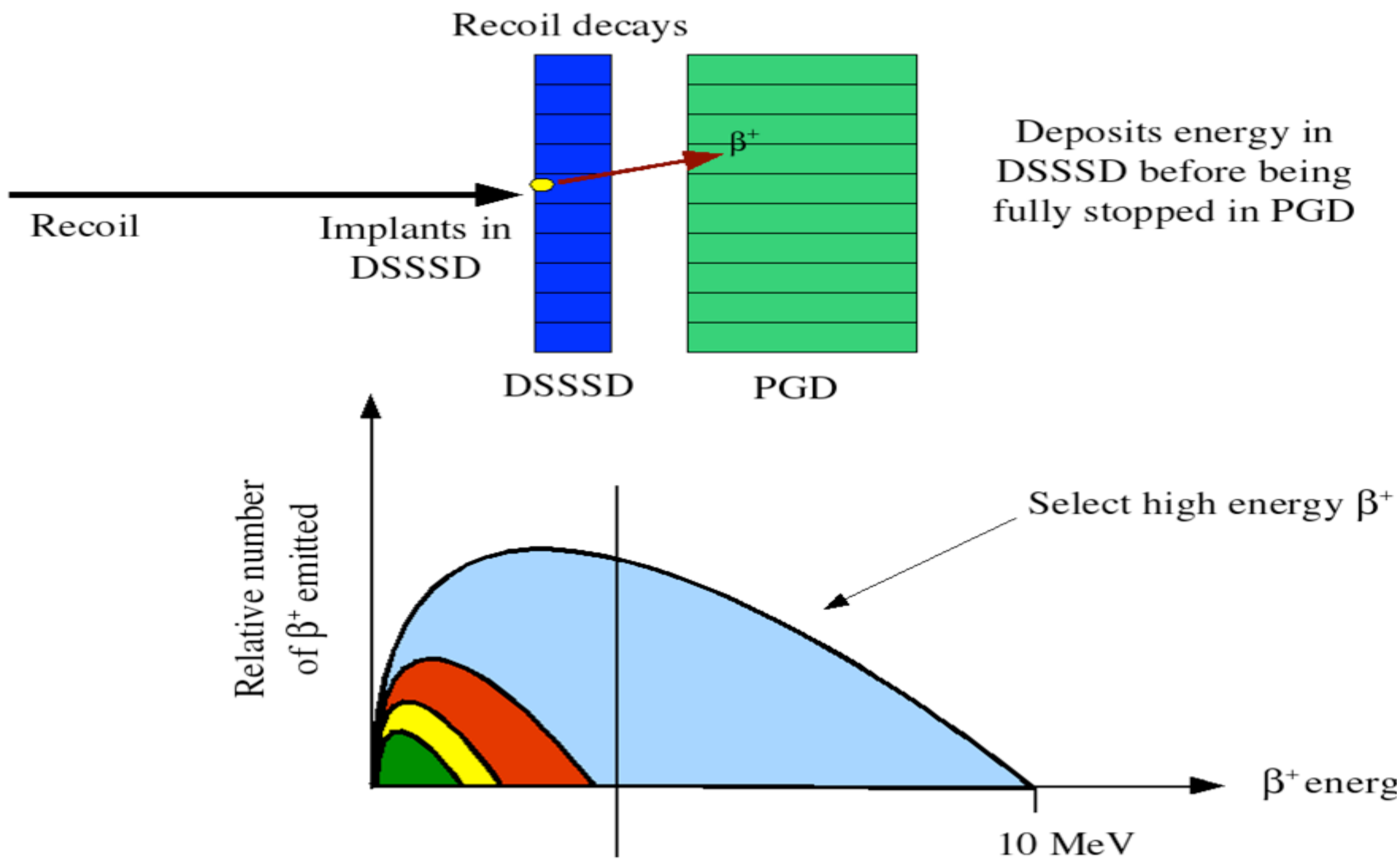
…. BUT

The whole concept of isolated "shapes" is naive: there are multiple shapes with lots of mixing, as the barriers between shapes are not high.

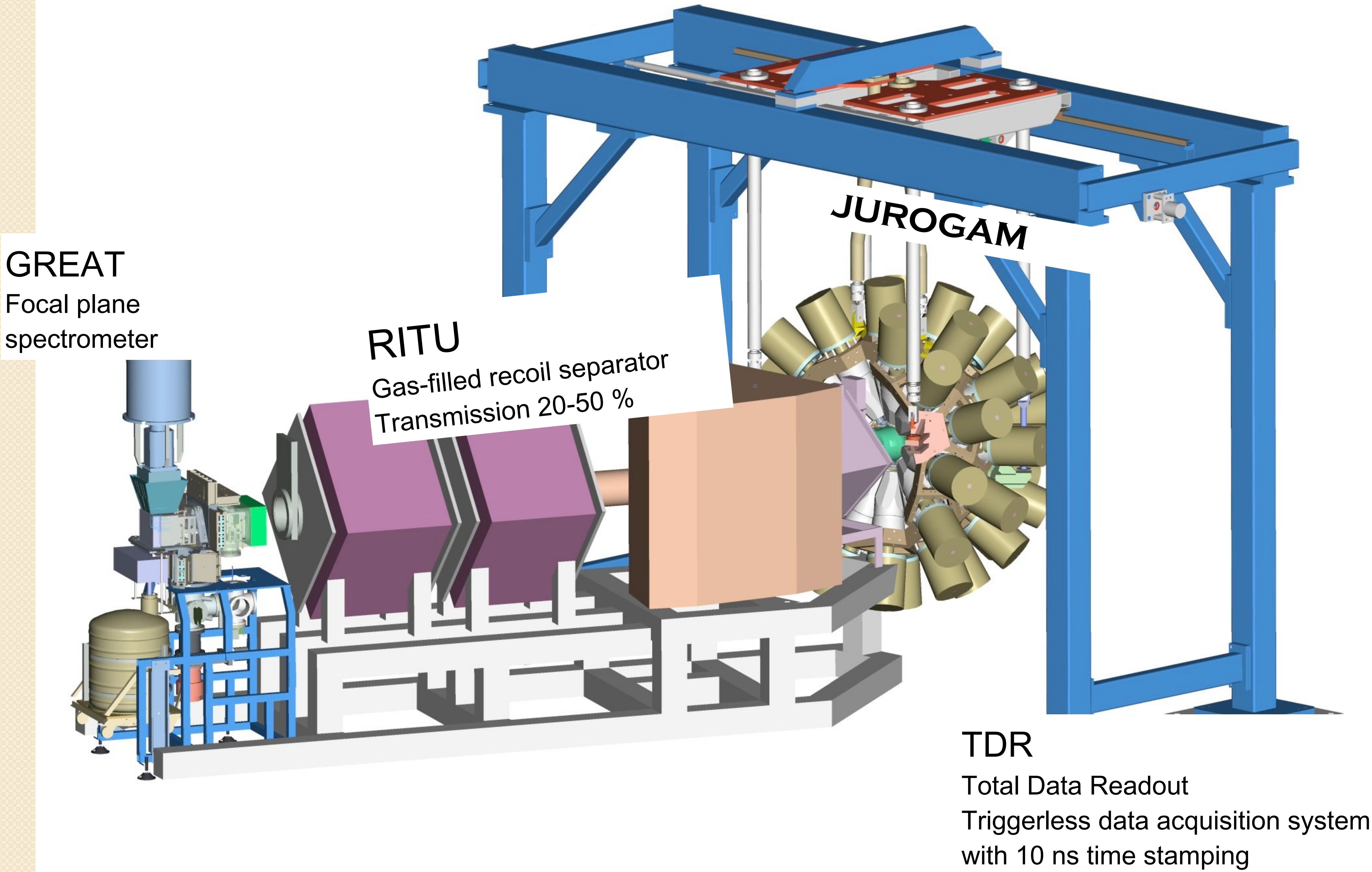
Recoil-decay tagging



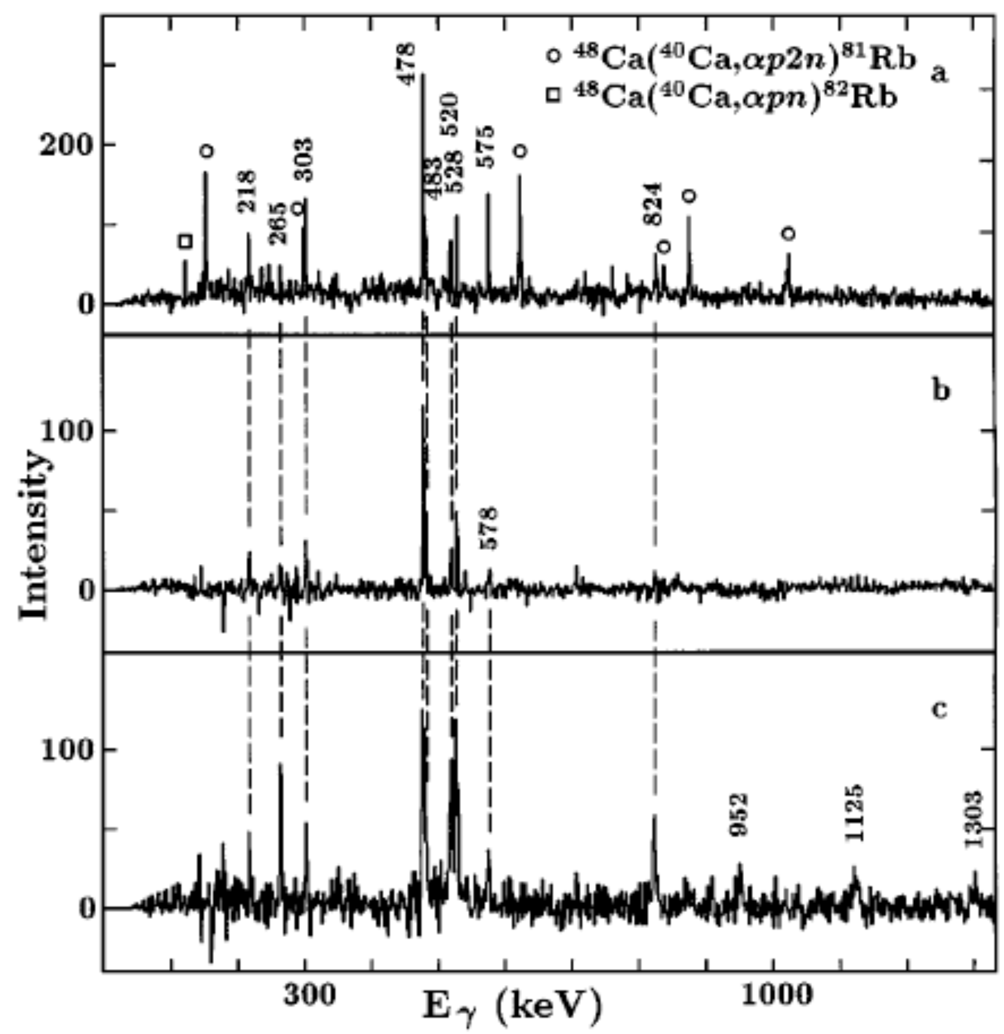
Recoil-beta tagging

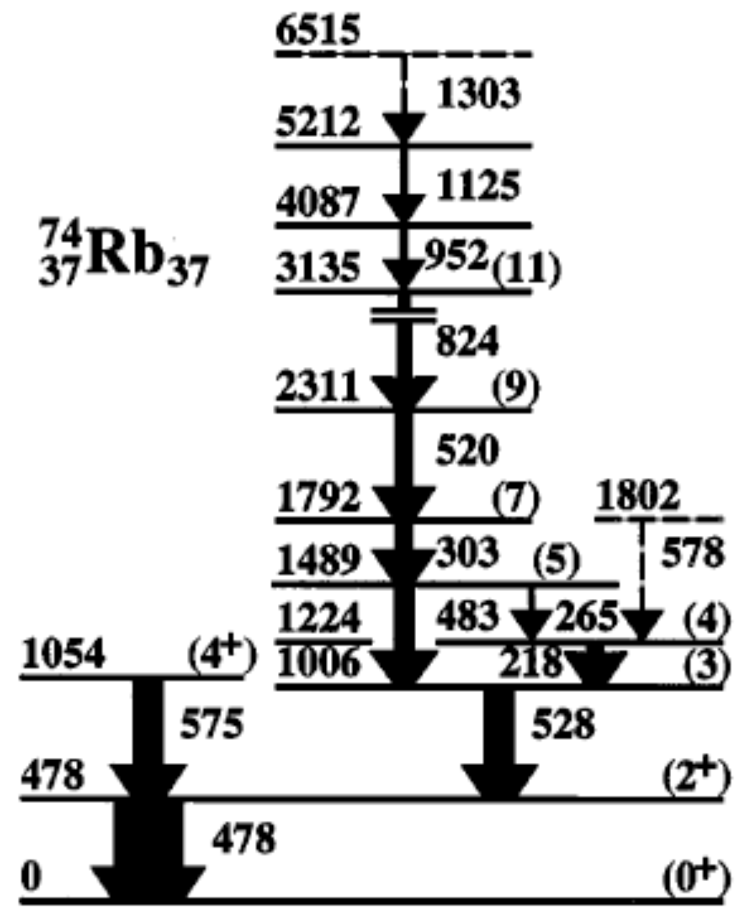


RDT Instrumentation at JYFL



Test case: ^{74}Rb





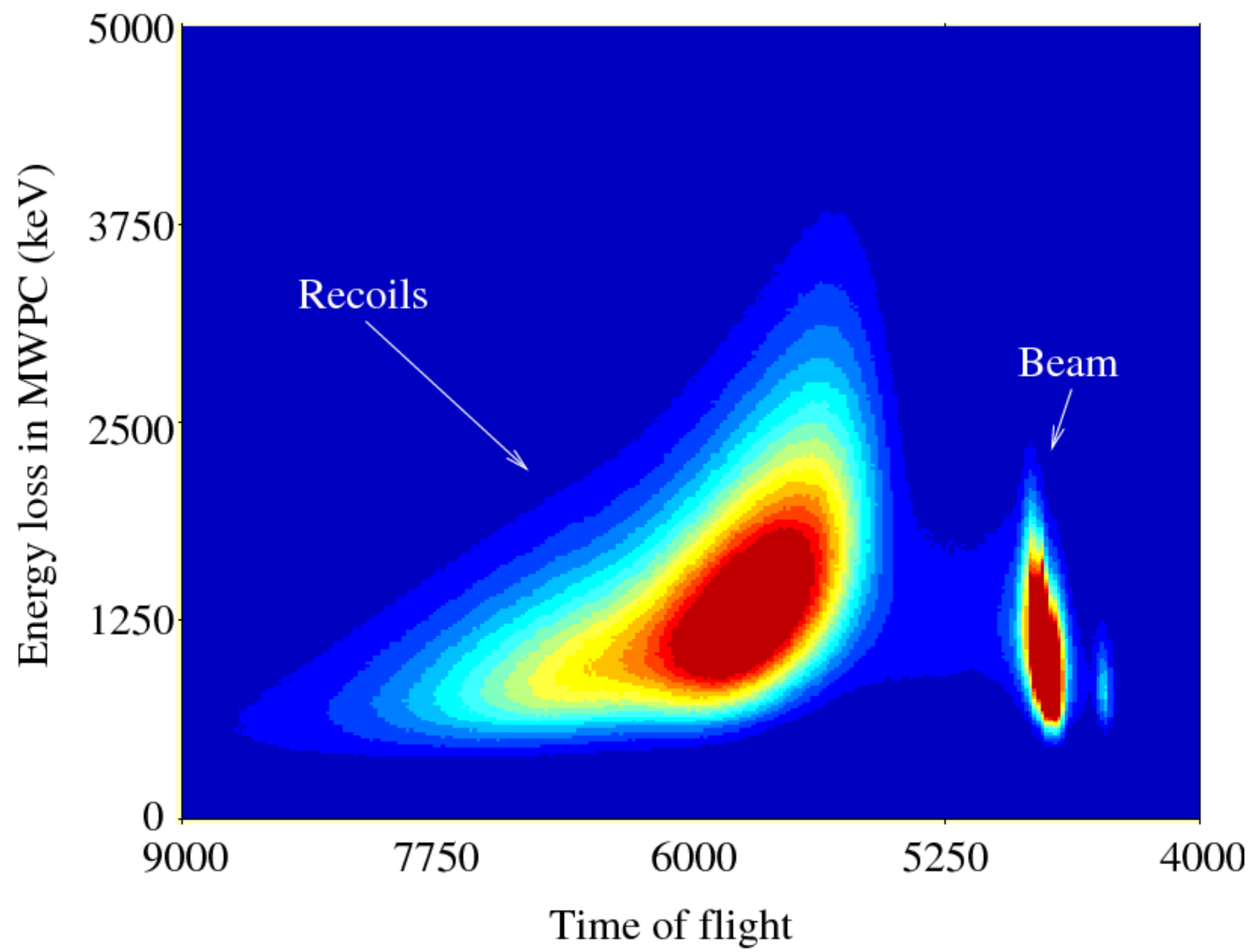
VOLUME 76, NUMBER 3 PHYSICAL REVIEW LETTERS 15 JANUARY 1996

Identification of $T = 0$ and $T = 1$ Bands in the $N = Z = 37$ Nucleus ^{74}Rb

D. Rudolph,[1,*] C. J. Gross,[2,3] J. A. Sheikh,[4] D. D. Warner,[5] I. G. Bearden,[6] R. A. Cunningham,[5] D. Foltescu,[7] W. Gelletly,[8] F. Hannachi,[5,†] A. Harder,[1] T. D. Johnson,[1,‡] A. Jungclaus,[1] M. K. Kabadiyski,[1] D. Kast,[1] K. P. Lieb,[1] H. A. Roth,[7] T. Shizuma,[6] J. Simpson,[5] Ö. Skeppstedt,[7] B. J. Varley,[9] and M. Weiszflog[1]

Proof-of-principle

- $^{nat}Ca\ (^{36}Ar, pn)\ ^{74}Rb$
- E_{beam} = 103 MeV
- $\tau_{1/2}(^{74}Rb)$ = 65 ms
- $\beta^{+}_{endpoint}$ ~ 10 MeV
- σ ~ 10 μb



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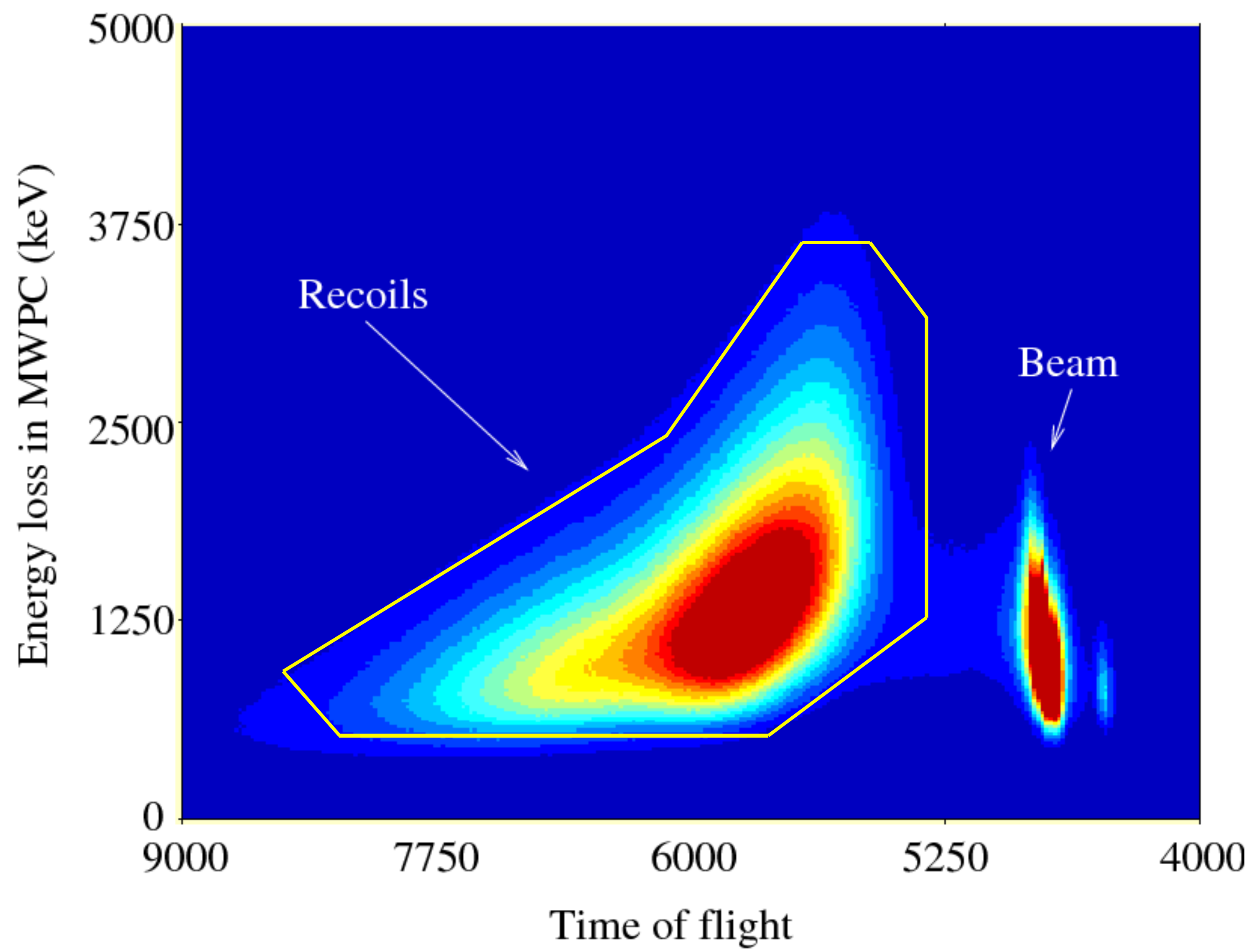
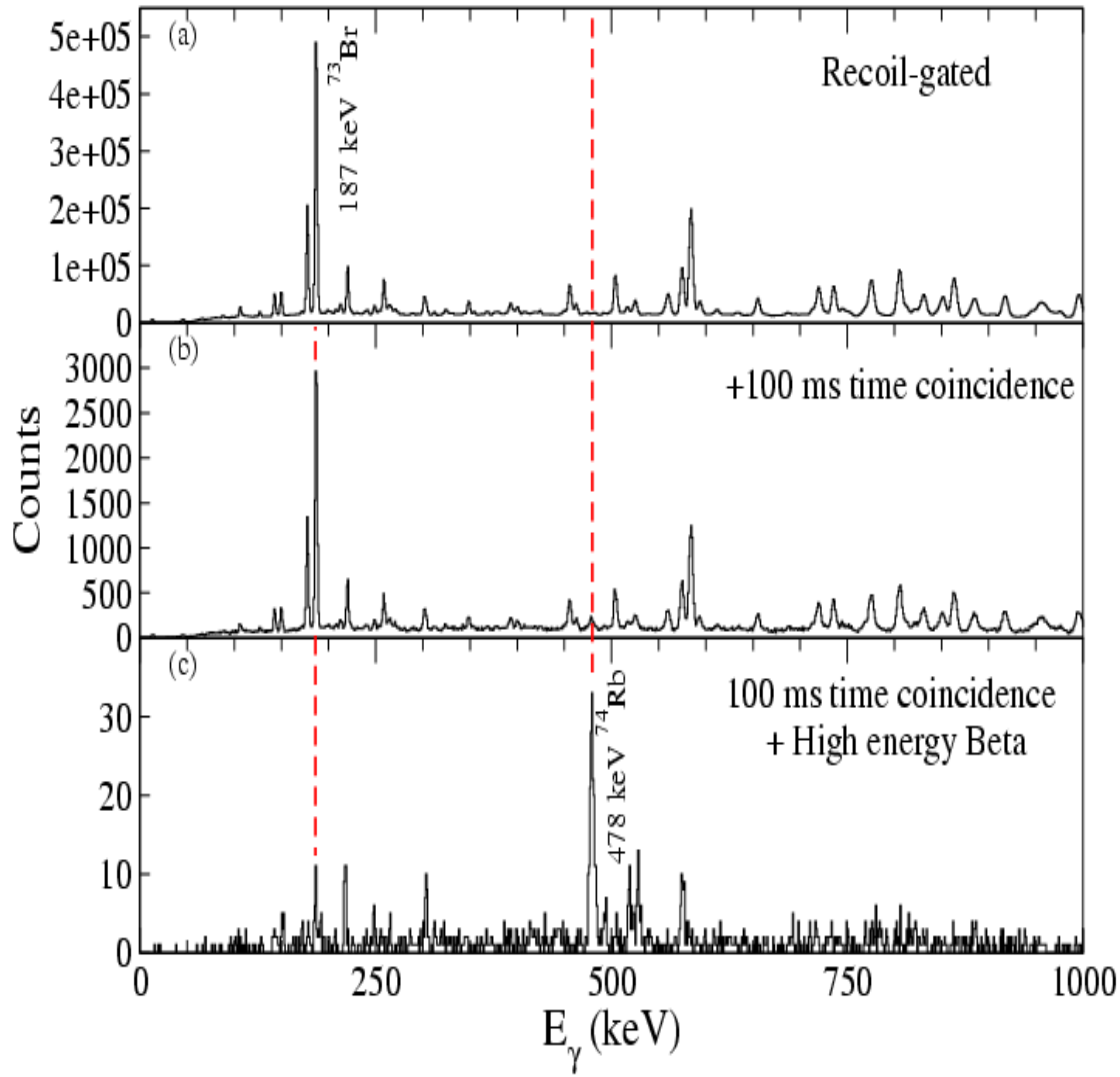


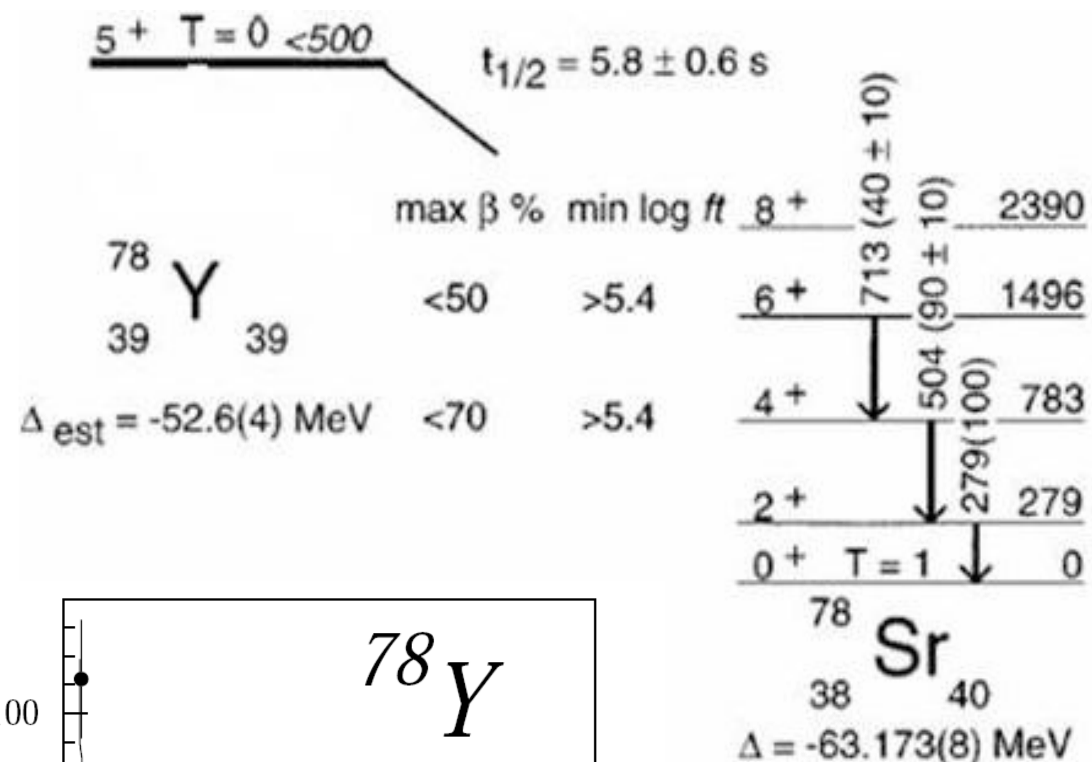
^{74}Rb

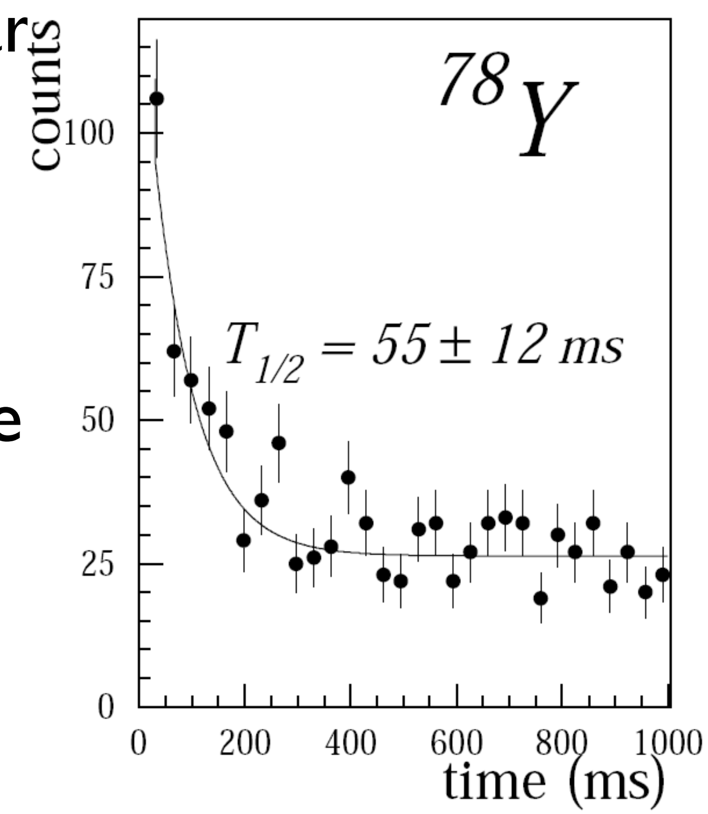


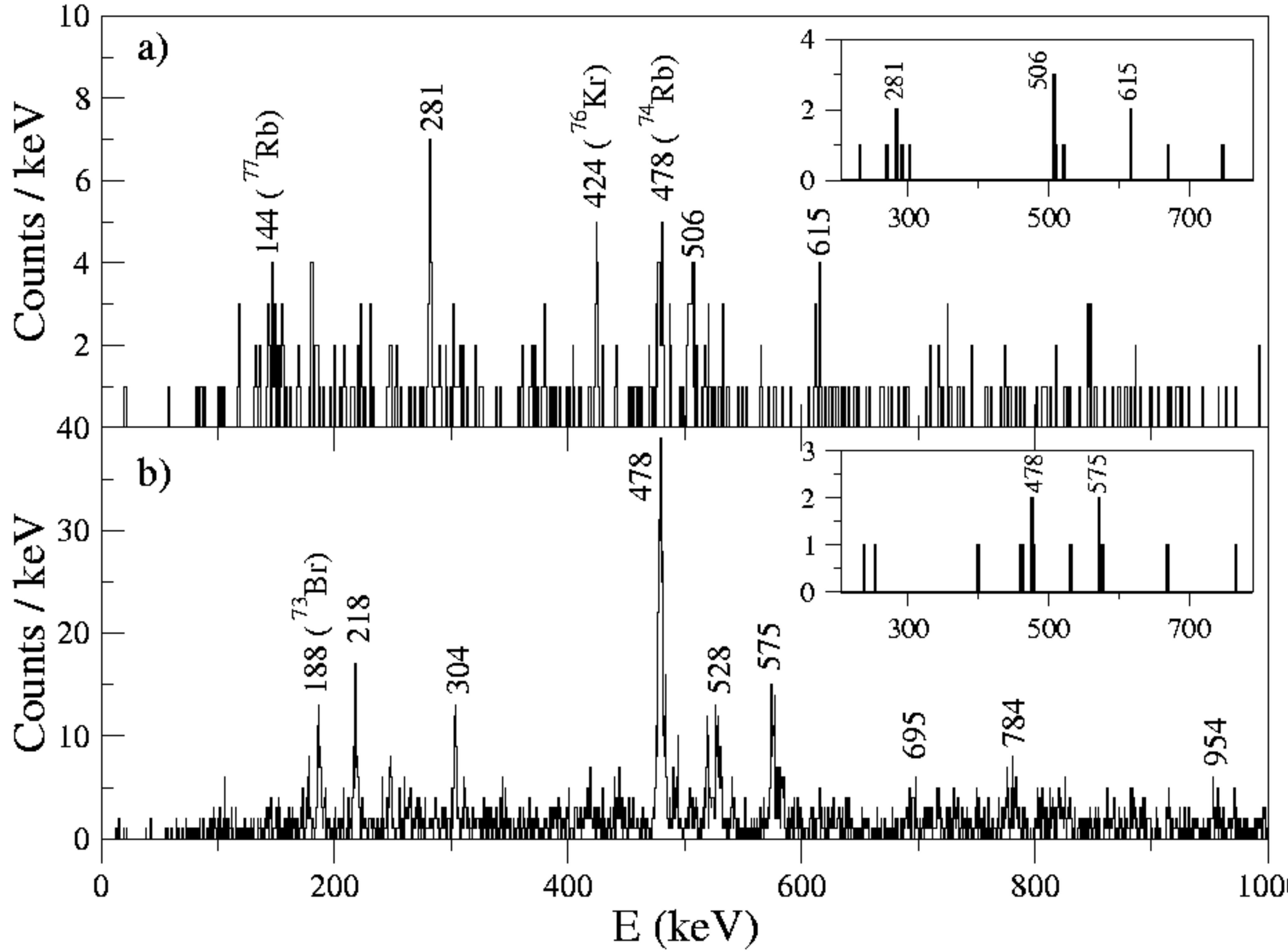
(a)
187 keV ^{73}Br
Recoil-gated
(b)
+100 ms time coincidence
(c)
478 keV ^{74}Rb
100 ms time coincidence
+ High energy Beta
Counts
5e+05
4e+05
3e+05
2e+05
1e+05
0
3000
2500
2000
1500
1000
500
0
30
20
10
0
0
250
500
750
1000
E_γ (keV)

Unknown case: ^{78}Y

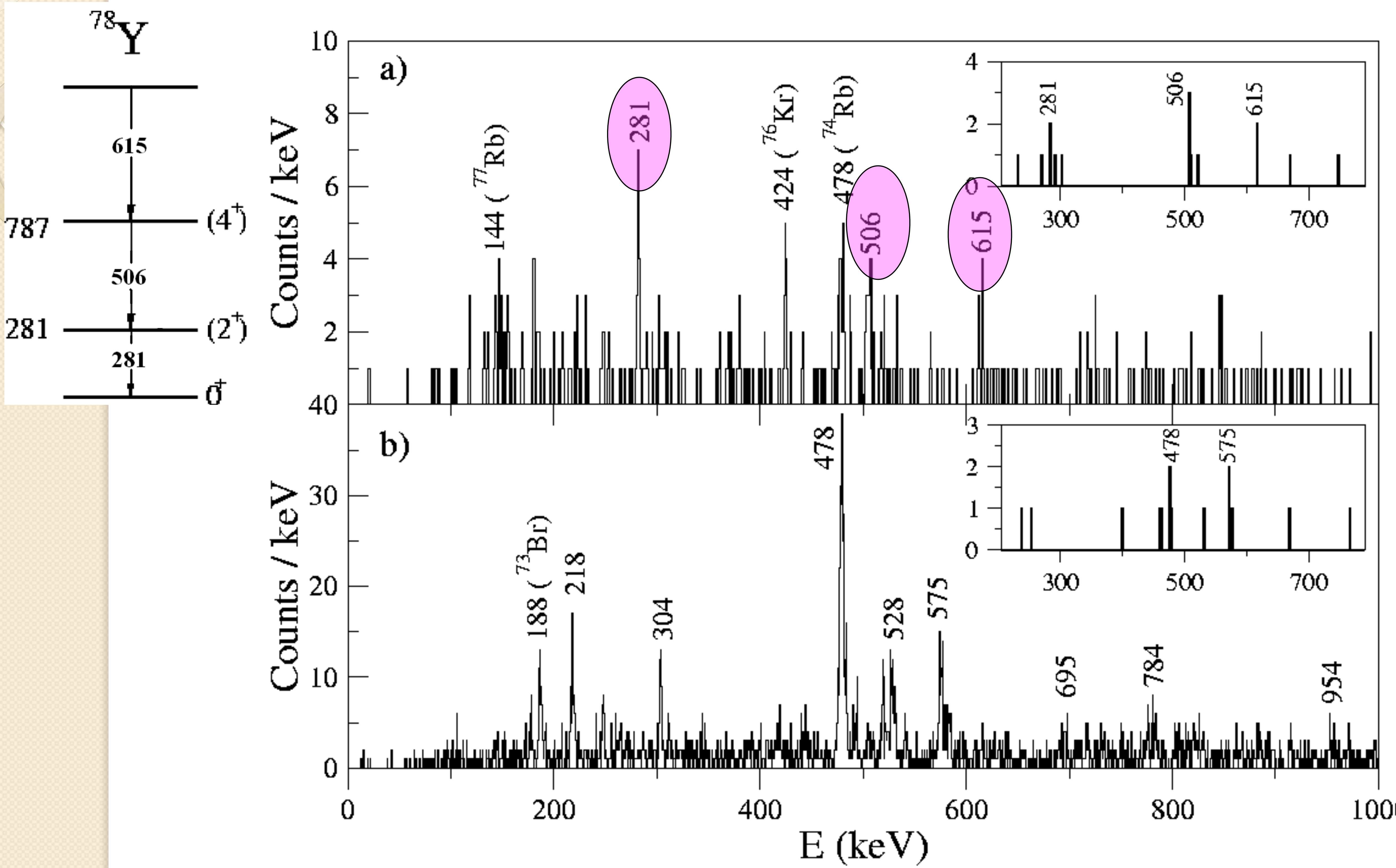
- Nothing known about ^{78}Y except 0+ superallowed decay and (5+) beta-decaying isomer
- RBT technique applied using ^{40}Ca(^{40}Ca,pn)^{78}Y reaction
- Cross-section should be very similar to ^{74}Rb
- 90% of flux proceeds to low-lying isomer
- Isomer is too long-lived for effective tagging







B.S. Nara Singh et al., Phys. Rev. C 75, 061301 (2007).

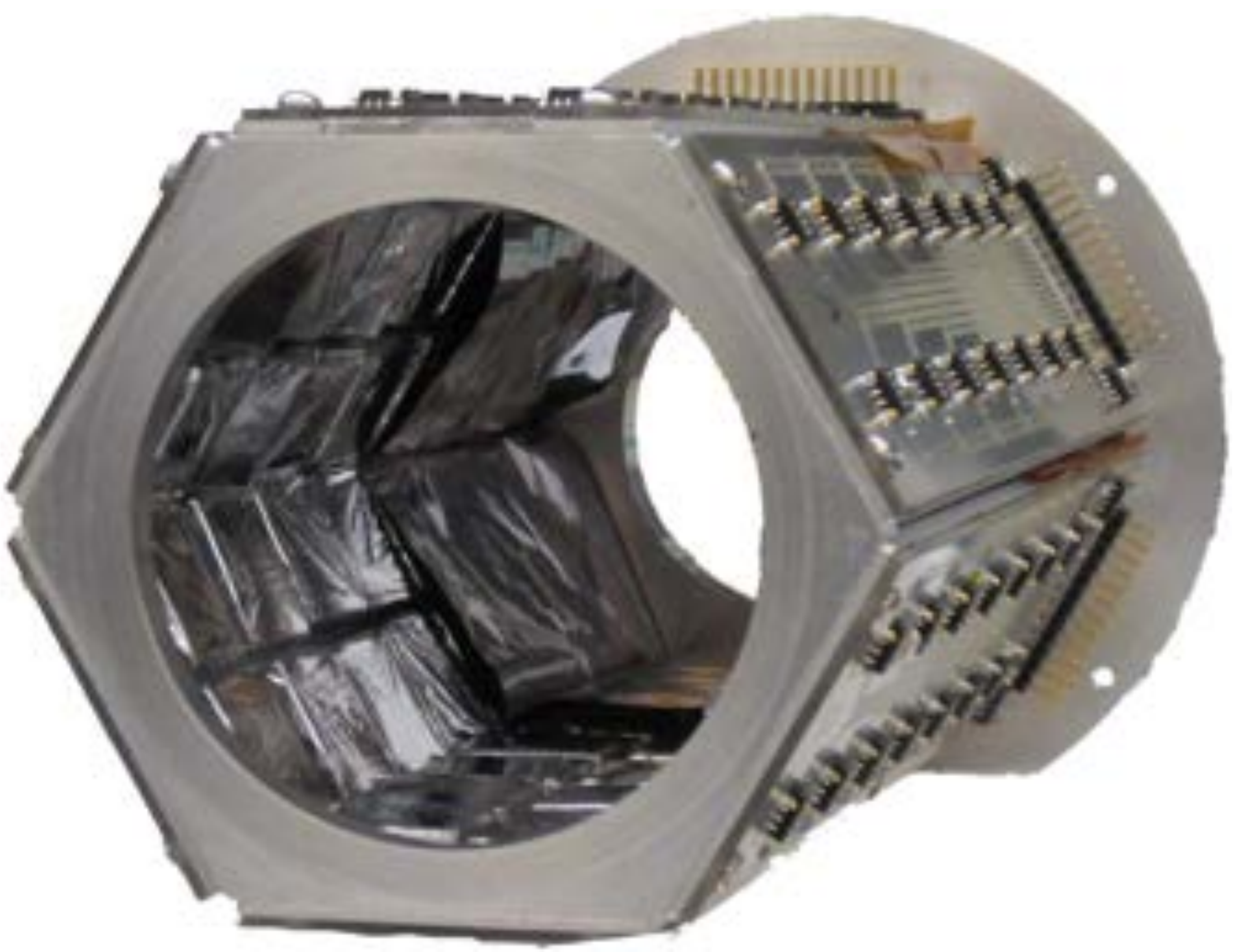


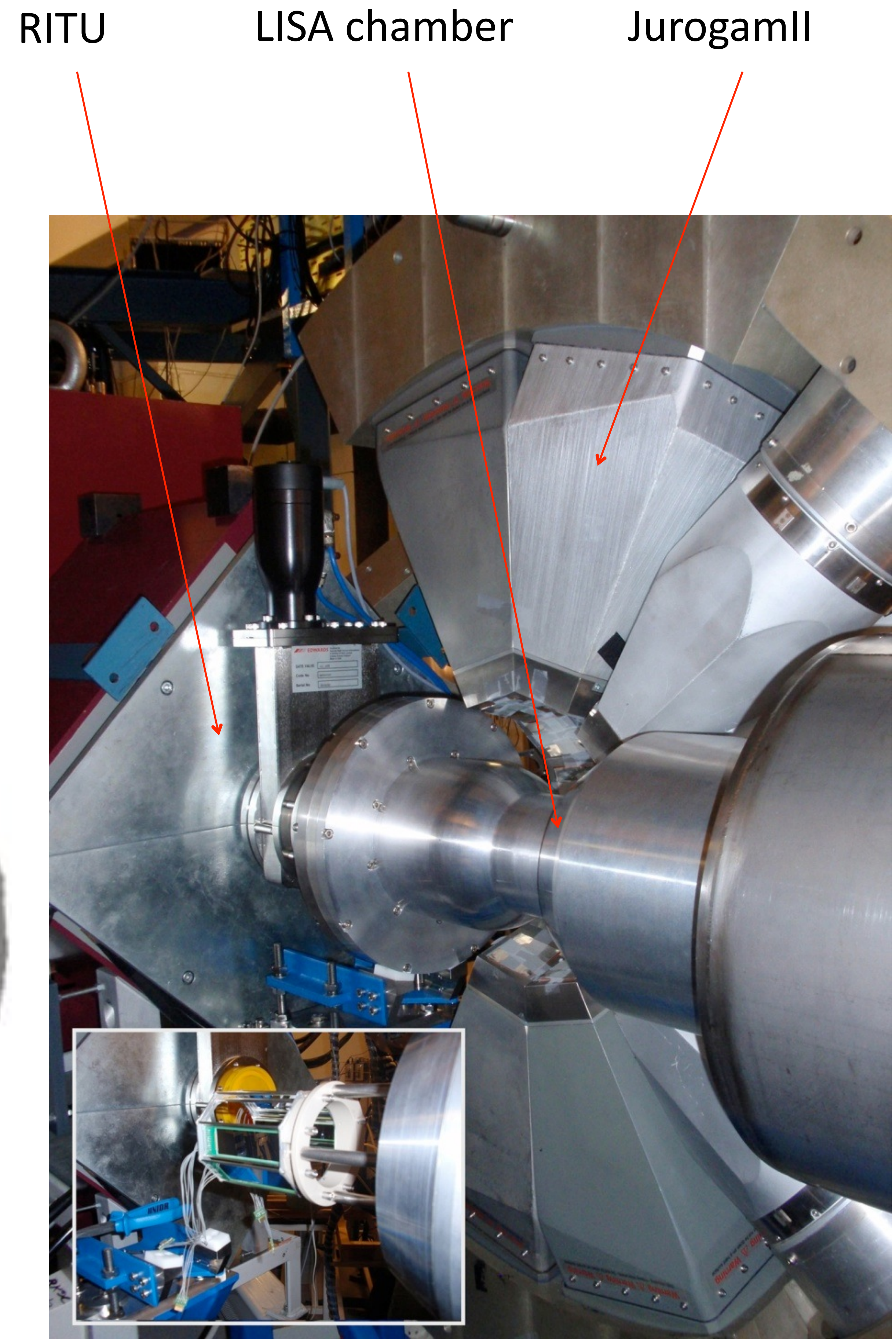
B.S. Nara Singh et al., Phys. Rev. C 75, 061301 (2007).

Crossing the line of N=Z

UoY Tube

- Designed to suppress events associated with cp evaporation channels.
- Consists of 96 20 x 20 mm CsI crystals (Hamamatsu) divided into 6 flanges (8 x 2 crystals in each flange).
- Signal chain: Mesytech preamplifiers -> ”GO-box” -> Lyrtech ADCs.
- Measured detection efficiency for 1 charged particle is 80-90 %.





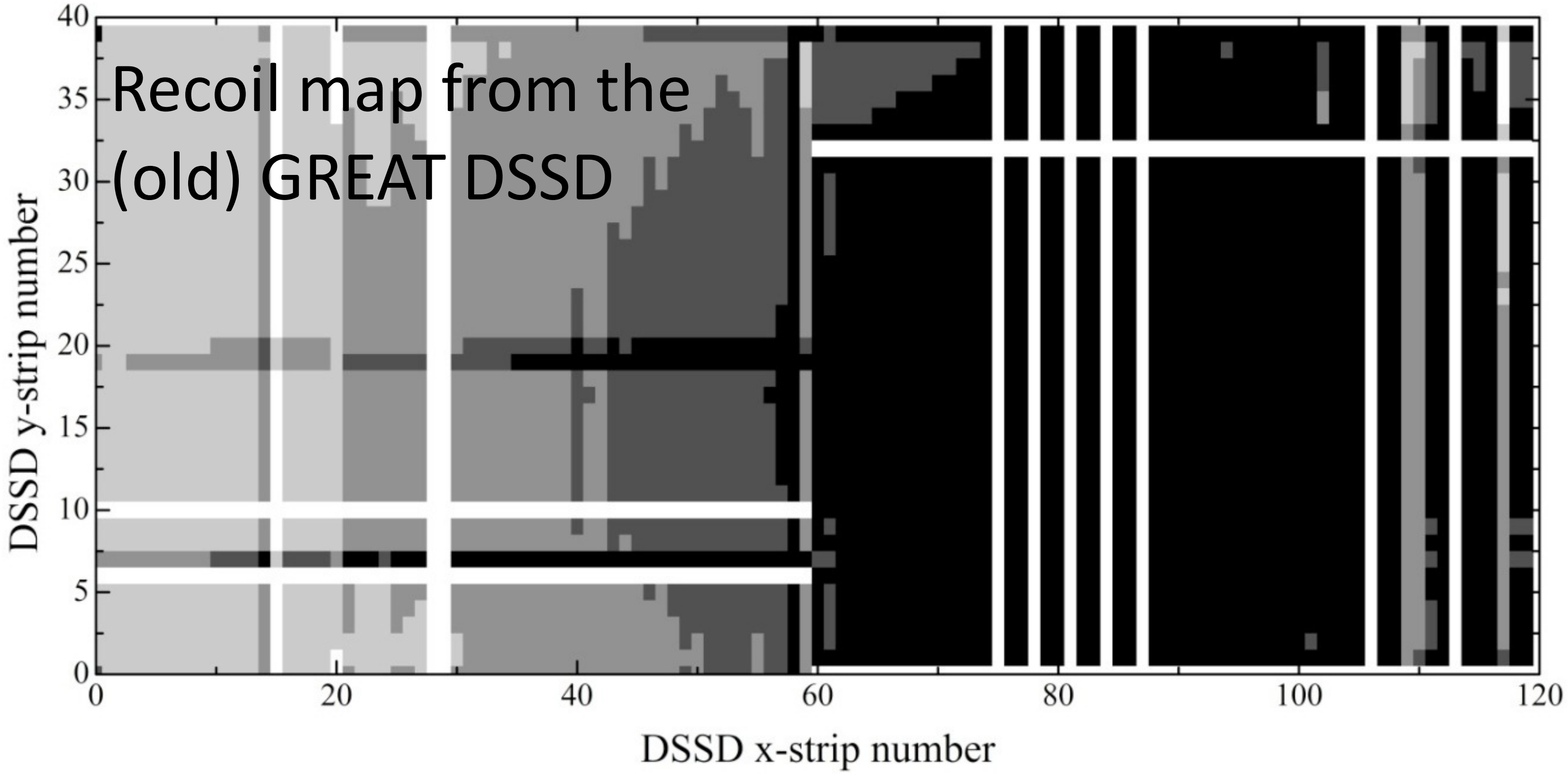
New DSSD

- As RITU is designed to operate on heavy mass regions, recoil separation is not anymore optimal in the A~70 region.

- Recoil distribution is focused on the right hand side of the DSSD (beam and scattered components follow closely the recoil distribution so it can not be centered).

- 8 kHz rate is impinged only on the half of the active area of the DSSD which in turn increases risk of random correlations!

- Device was tested with ^{28}Si + ^{40}Ca reaction at E_b=75 MeV with various different beam intensities (simultaneously with phoswich or planar ge set-up).



New DSSD design

- Only right hand side works as an active detector.

- Consists of 120 x 80 strips with strip pitch of 0.480 mm

- 500 mm thick

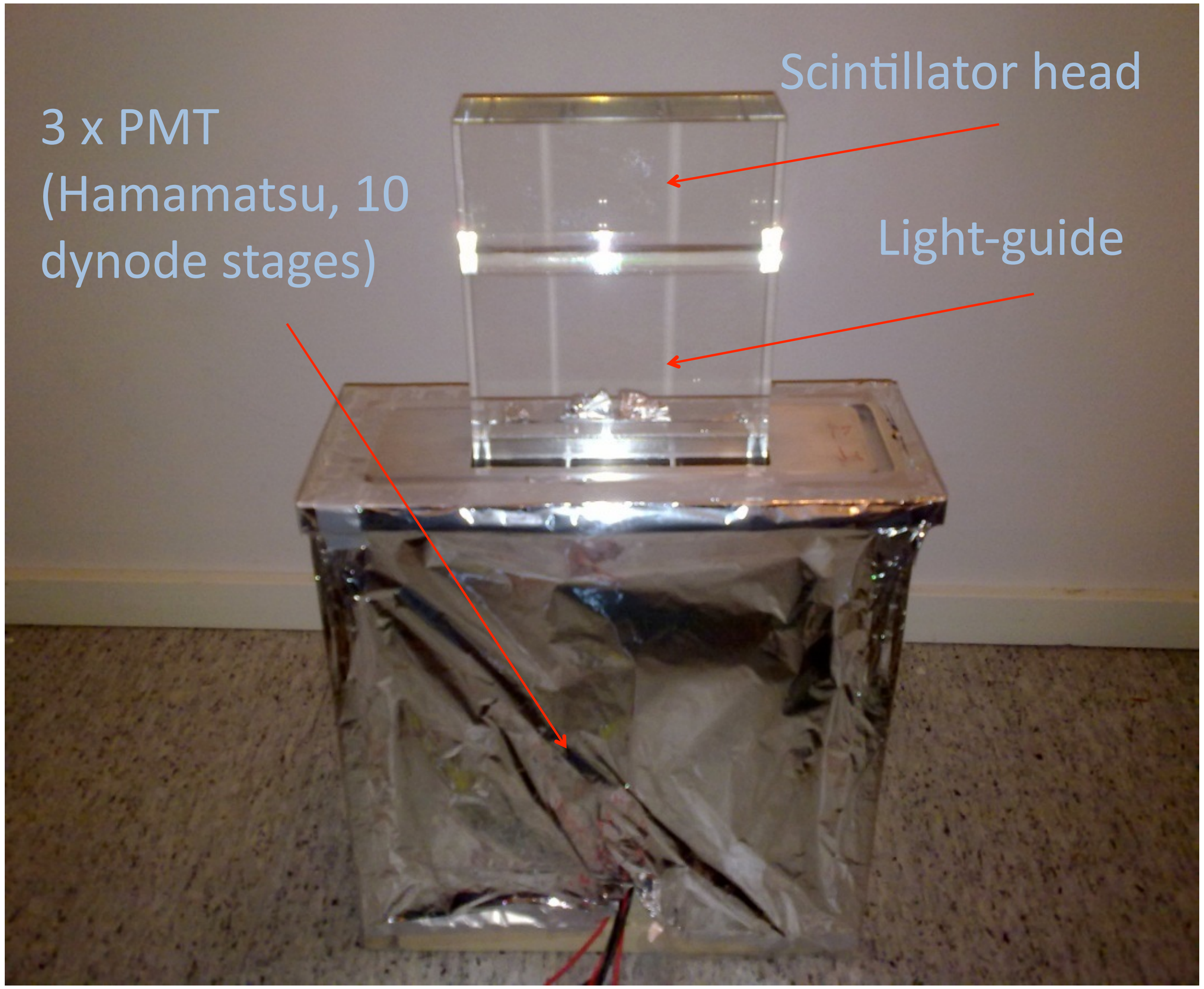
- In total ~10000 pixels!

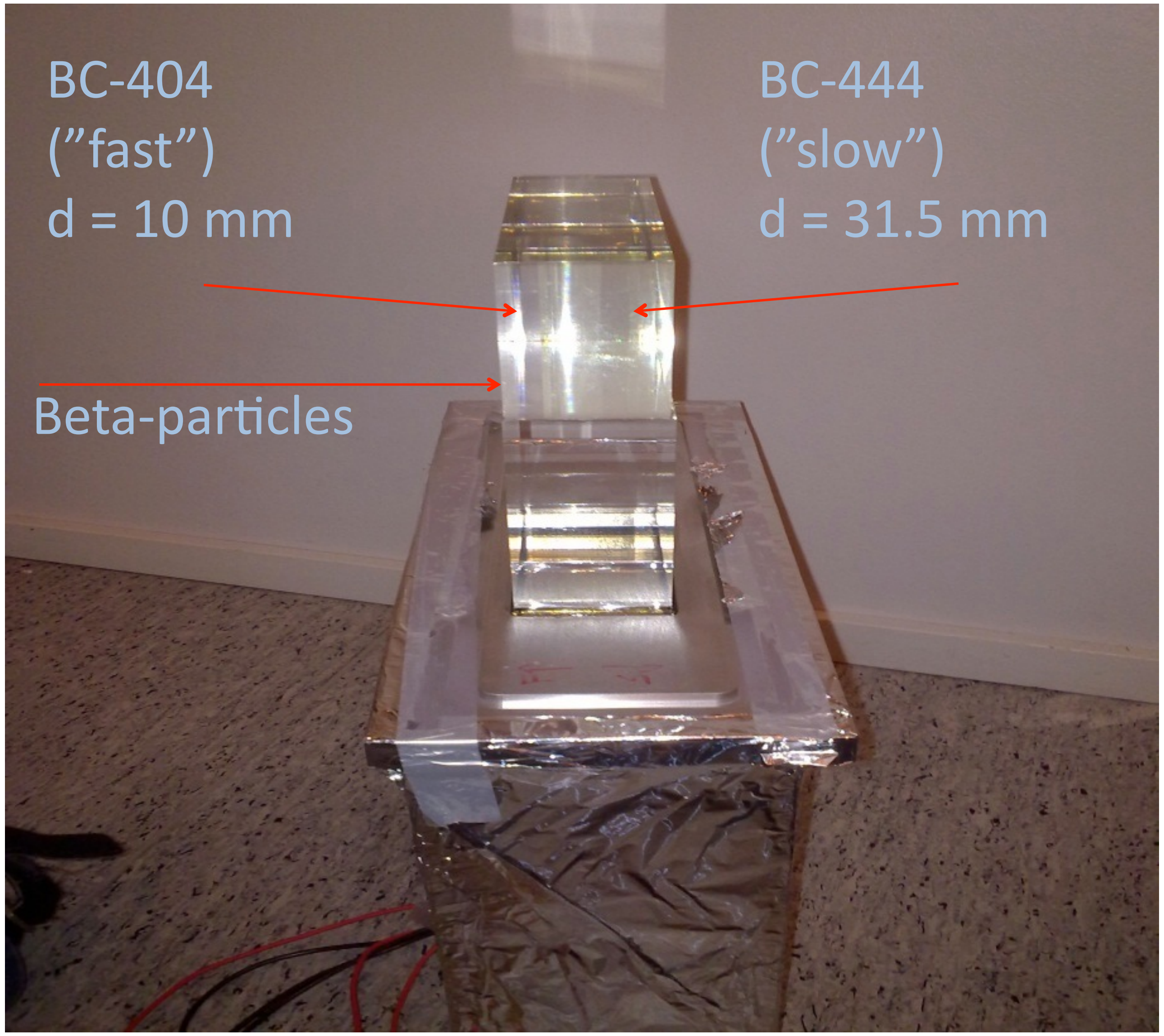
- -> 0.8 Hz recoil rate / pixel.

Slides from Panu Ruotsalainen

Phoswich scintillator

- High/low energy beta-particle detection and discrimination: Direct energy & full pile-up discrimination
- Beta/gamma discrimination
- Discriminations can be done on the basis of pulse shape analysis.





- BC-404: rise time ~ 0.7 ns, decay time ~ 1.8 ns, light output 68 % of anthracene
- BC-444: rise time ~ 19.5 ns, decay time ~ 285 ns, light output 41 % of anthracene

^{66}Se


Physics Letters B 701 (2011) 417–421

Contents lists available at ScienceDirect

Physics Letters B

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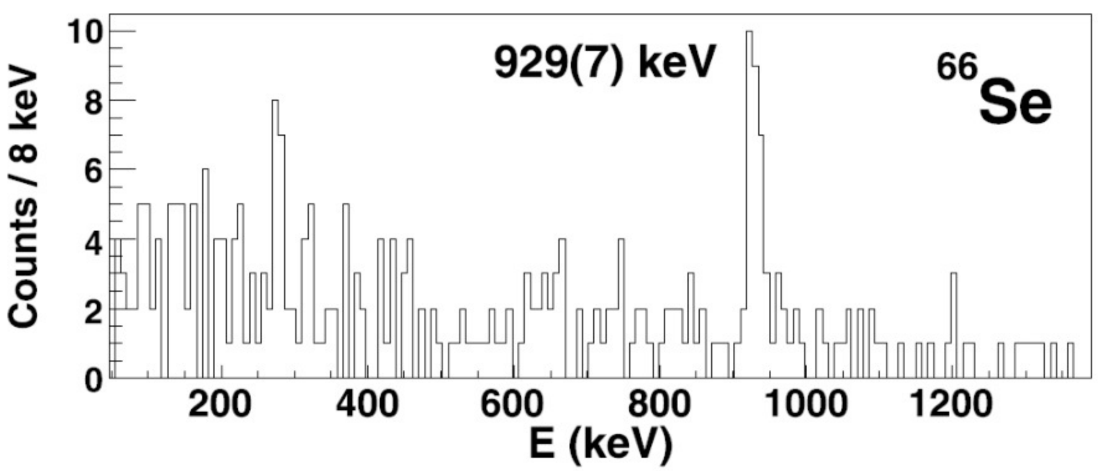
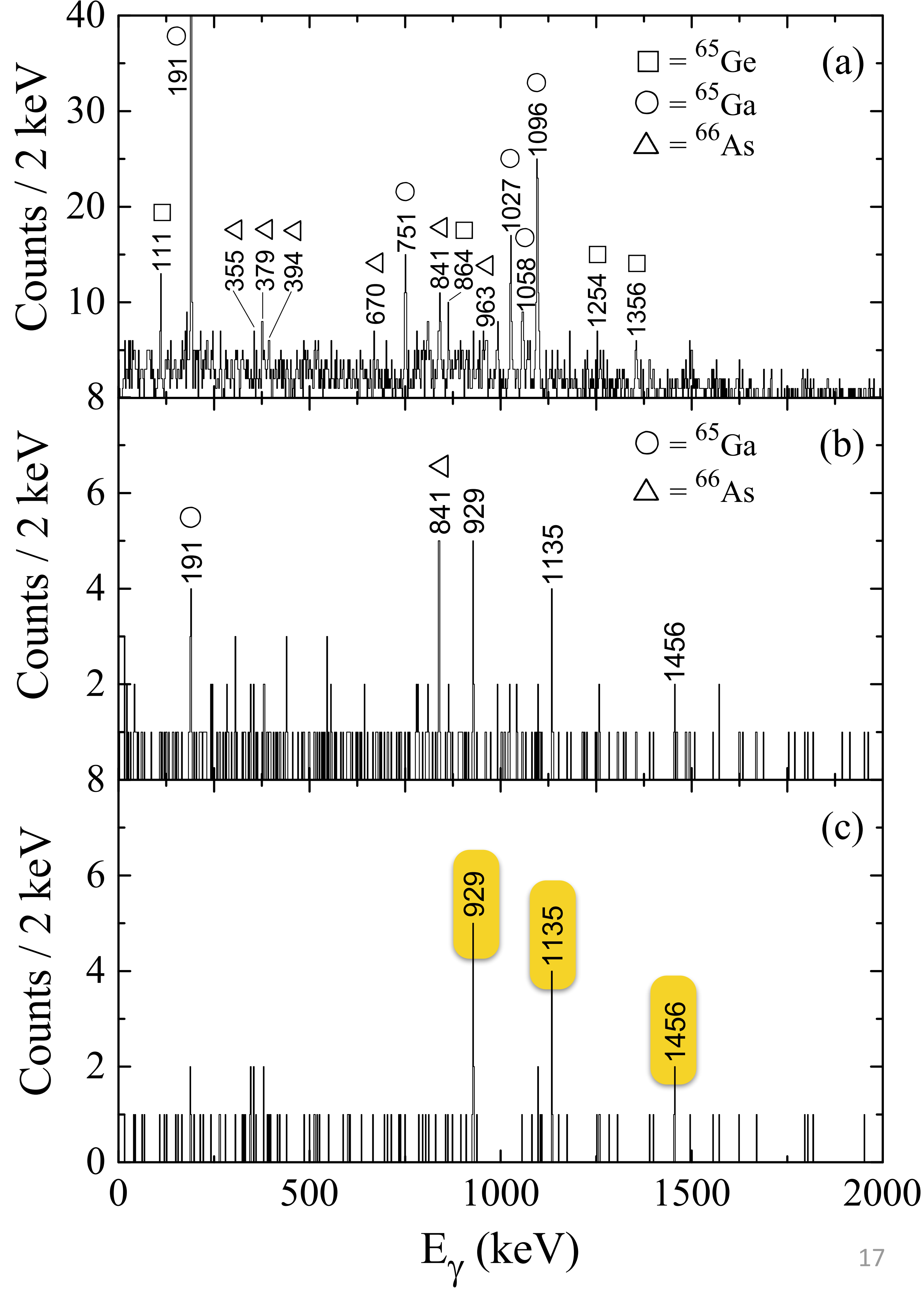
First spectroscopy of ^{66}Se and ^{65}As: Investigating shape coexistence beyond the $N = Z$ line

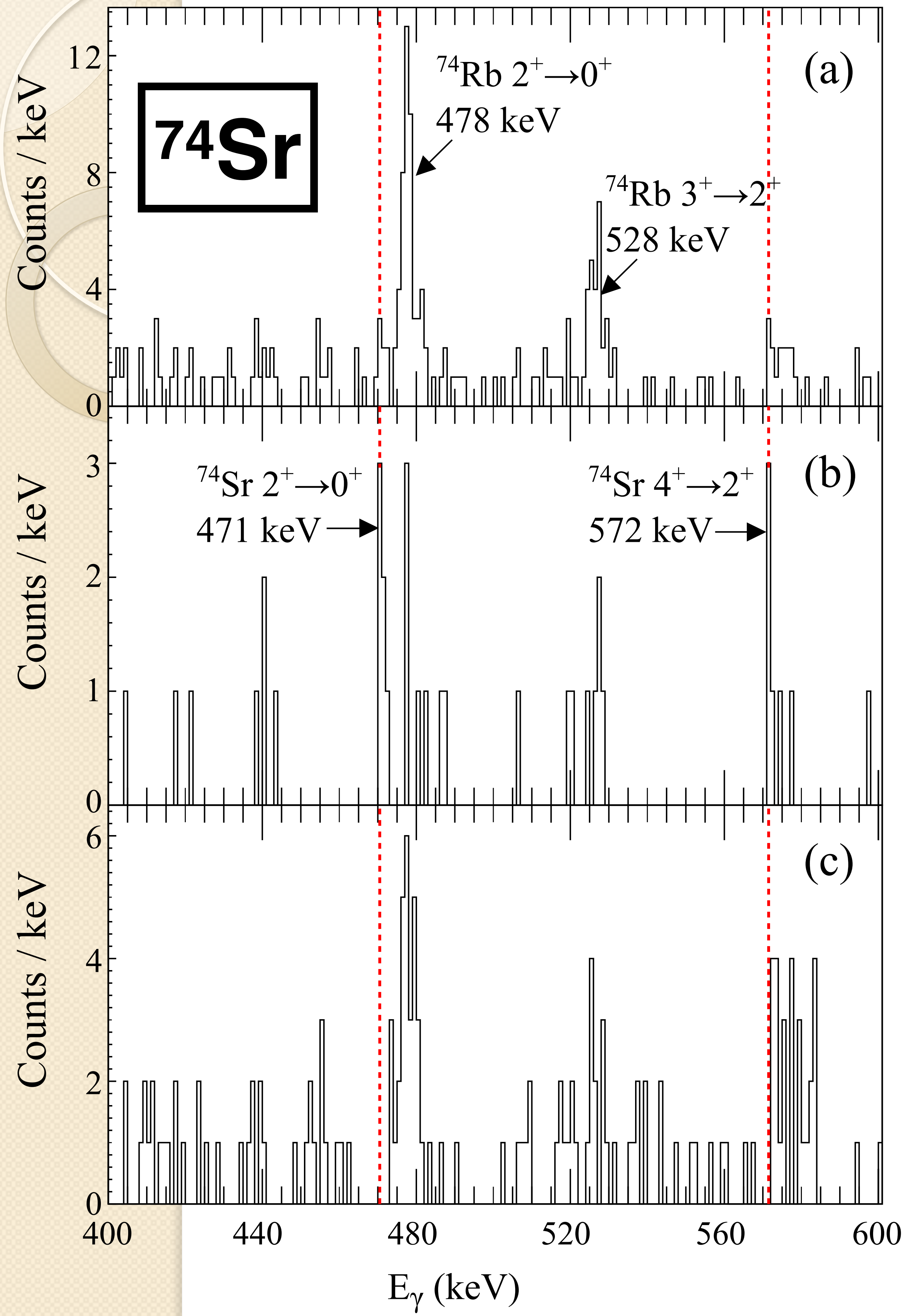
A. Obertelli[a,*], T. Baugher[b], D. Bazin[b], S. Boissinot[a], J.-P. Delaroche[d], A. Dijon[e], F. Flavigny[a], A. Gade[b,c], M. Girod[d], T. Glasmacher[b,c], G.F. Grinyer[b], W. Korten[a], J. Ljungvall[a], S. McDaniel[b,c], A. Ratkiewicz[b,c], B. Sulignano[a], P. Van Isacker[e], D. Weisshaar[b]

[a] CEA, Centre de Saclay, IRFU/Service de Physique Nucléaire, F-91191 Gif-sur-Yvette, France
[b] National Superconducting Cyclotron Laboratory, East Lansing, MI, USA
[c] Michigan State University, East Lansing, MI, USA
[d] CEA, DAM, DIF, F-91297 Arpajon, France
[e] Grand Accélérateur National d'Ions Lourds, CEA/DSM–CNRS/IN2P3, BP 55027, F-14076 Caen Cedex 5, France

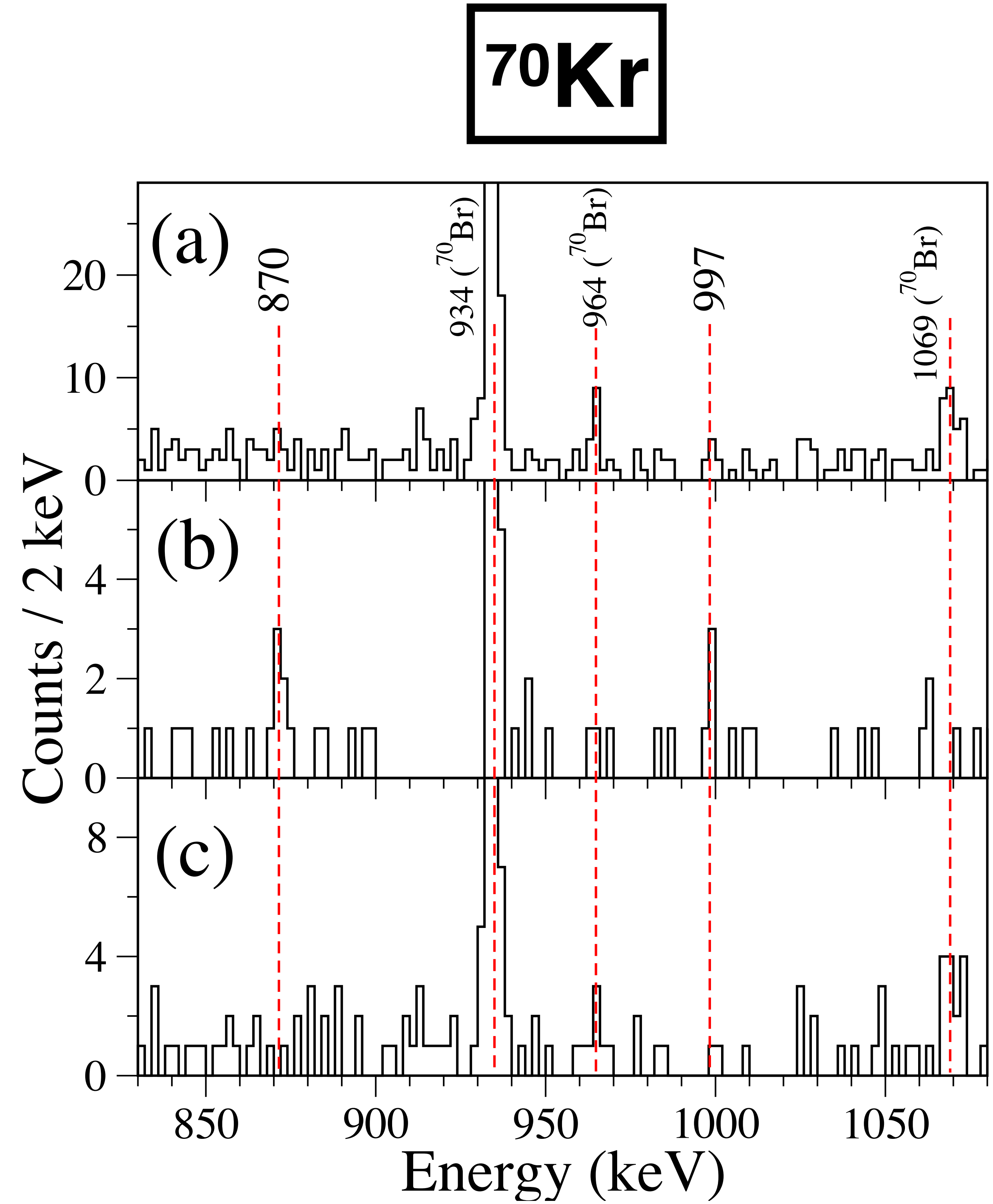




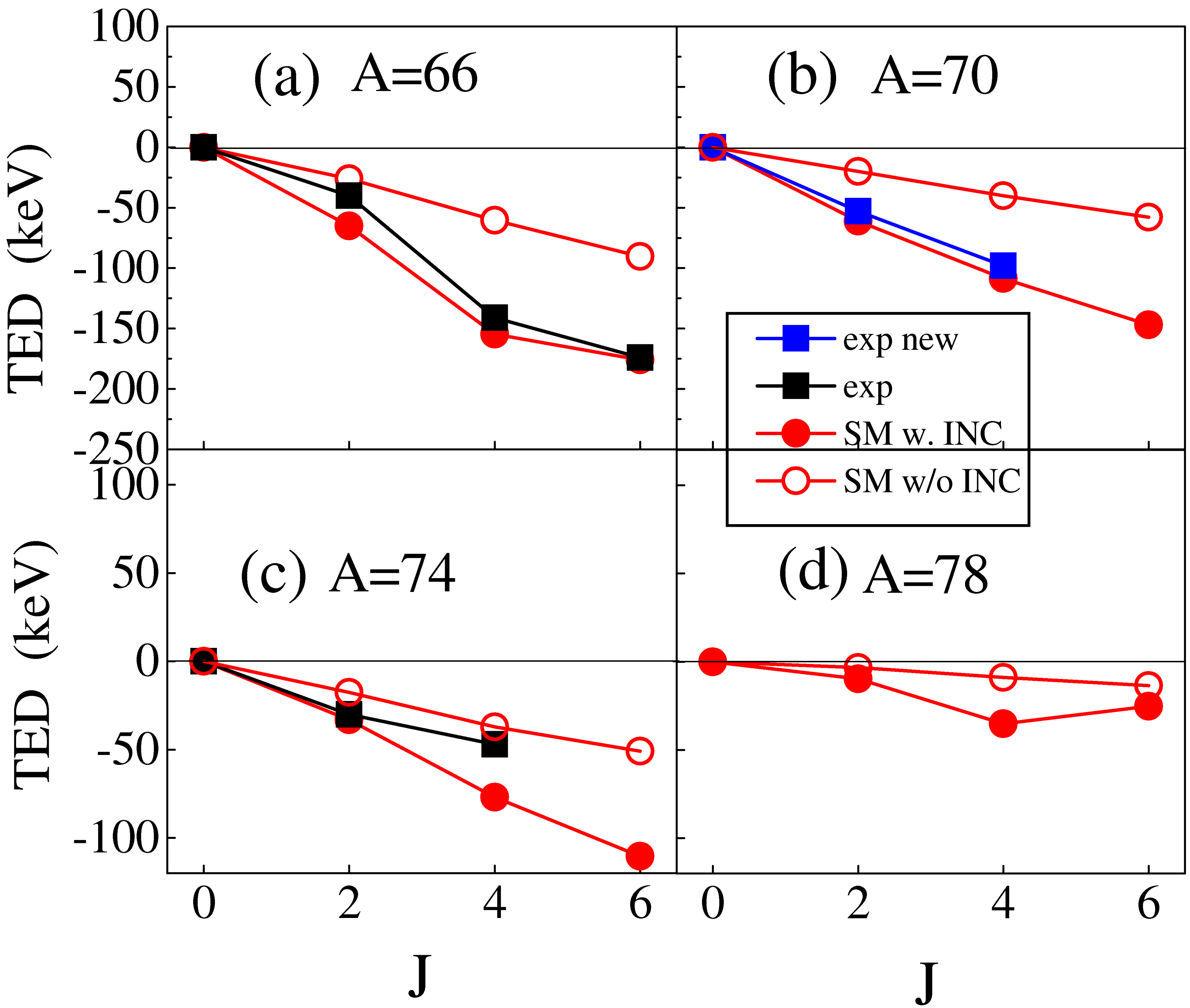
P. Ruotsalainen et al., Phys. Rev. C 83, 037303 (2013)



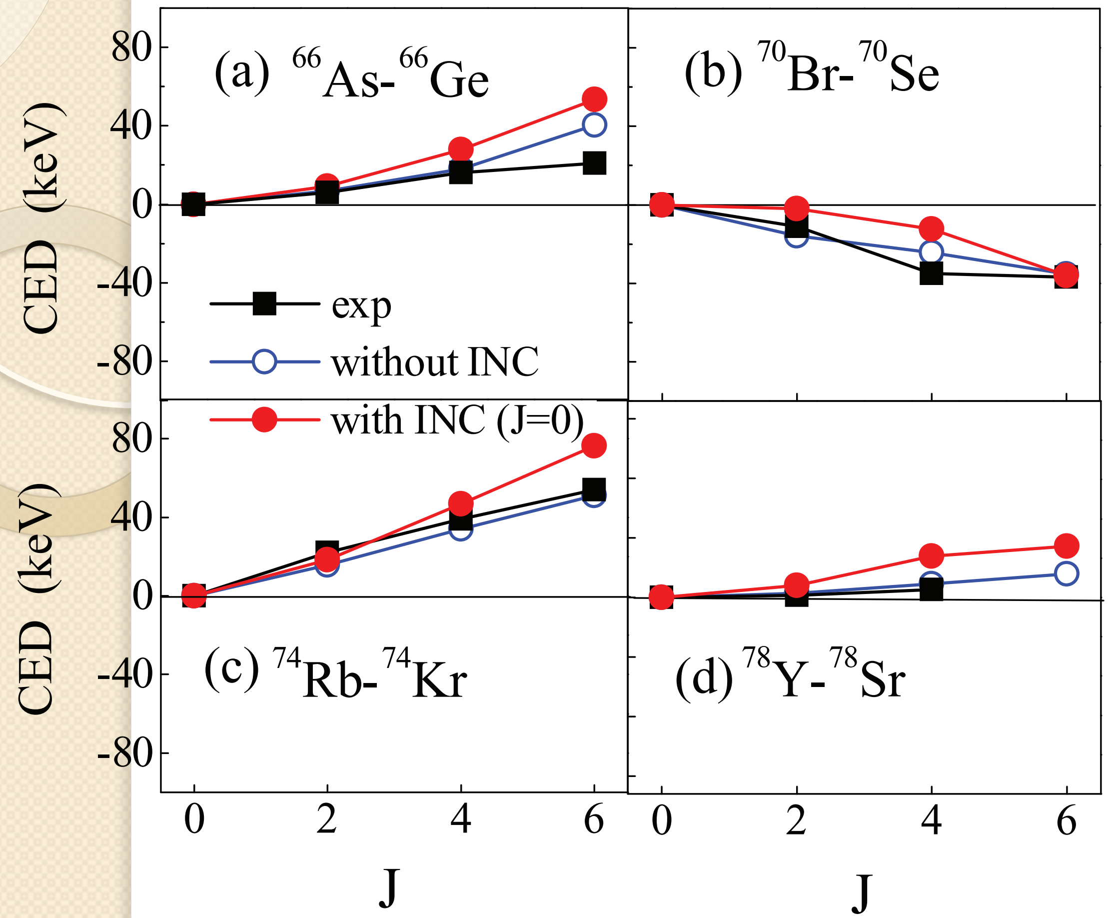
74Sr
(a)
74Rb 2+→0+
478 keV
74Rb 3+→2+
528 keV
(b)
74Sr 2+→0+
471 keV
74Sr 4+→2+
572 keV
(c)
Counts / keV
Eγ (keV)

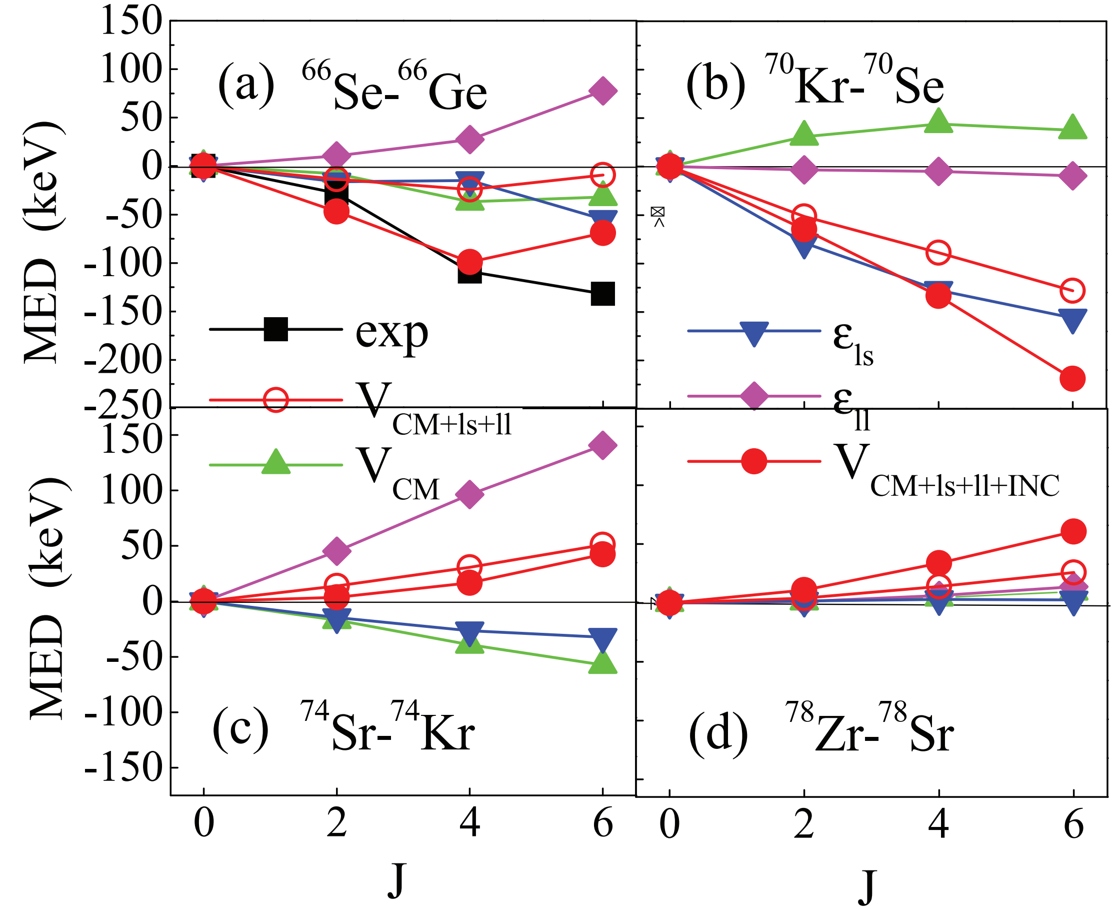


70Kr
(a)
870
934 (70Br)
964 (70Br)
997
1069 (70Br)
(b)
(c)
Counts / 2 keV
Energy (keV)



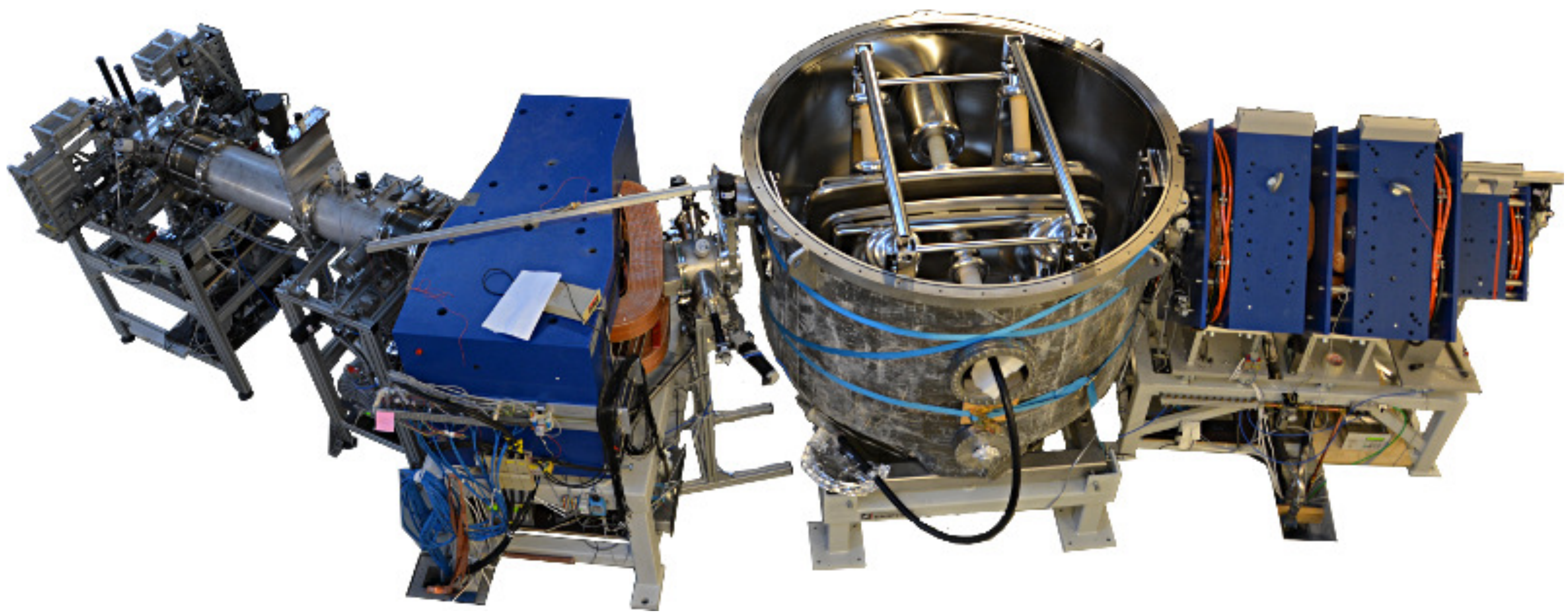
(a) A=66
(b) A=70
(c) A=74
(d) A=78
TED (keV)
TED (keV)
J
J
100
50
0
-50
-100
-150
-200
-250
100
50
0
-50
-100
0
2
4
6
0
2
4
6
exp new
exp
SM w. INC
SM w/o INC

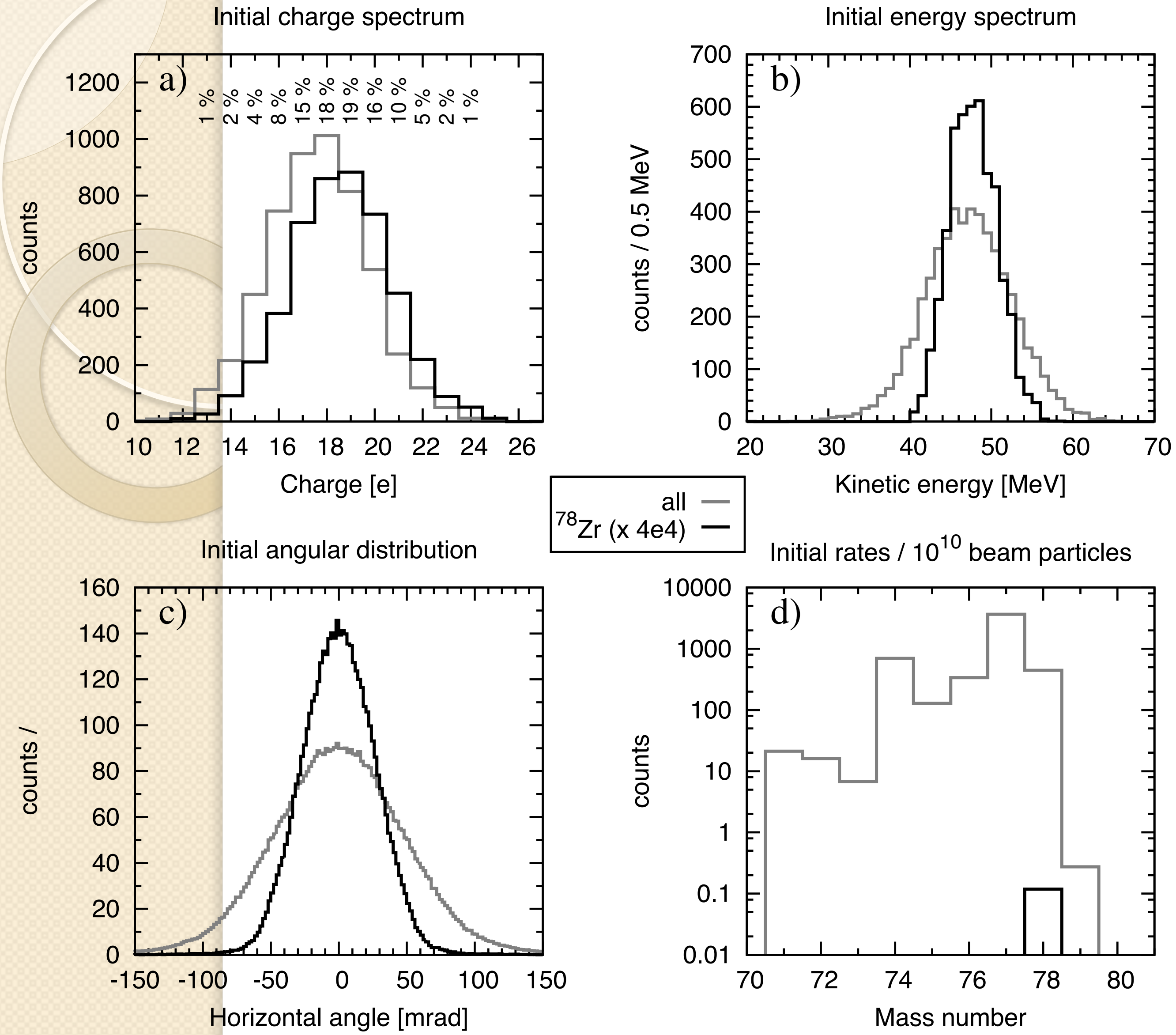


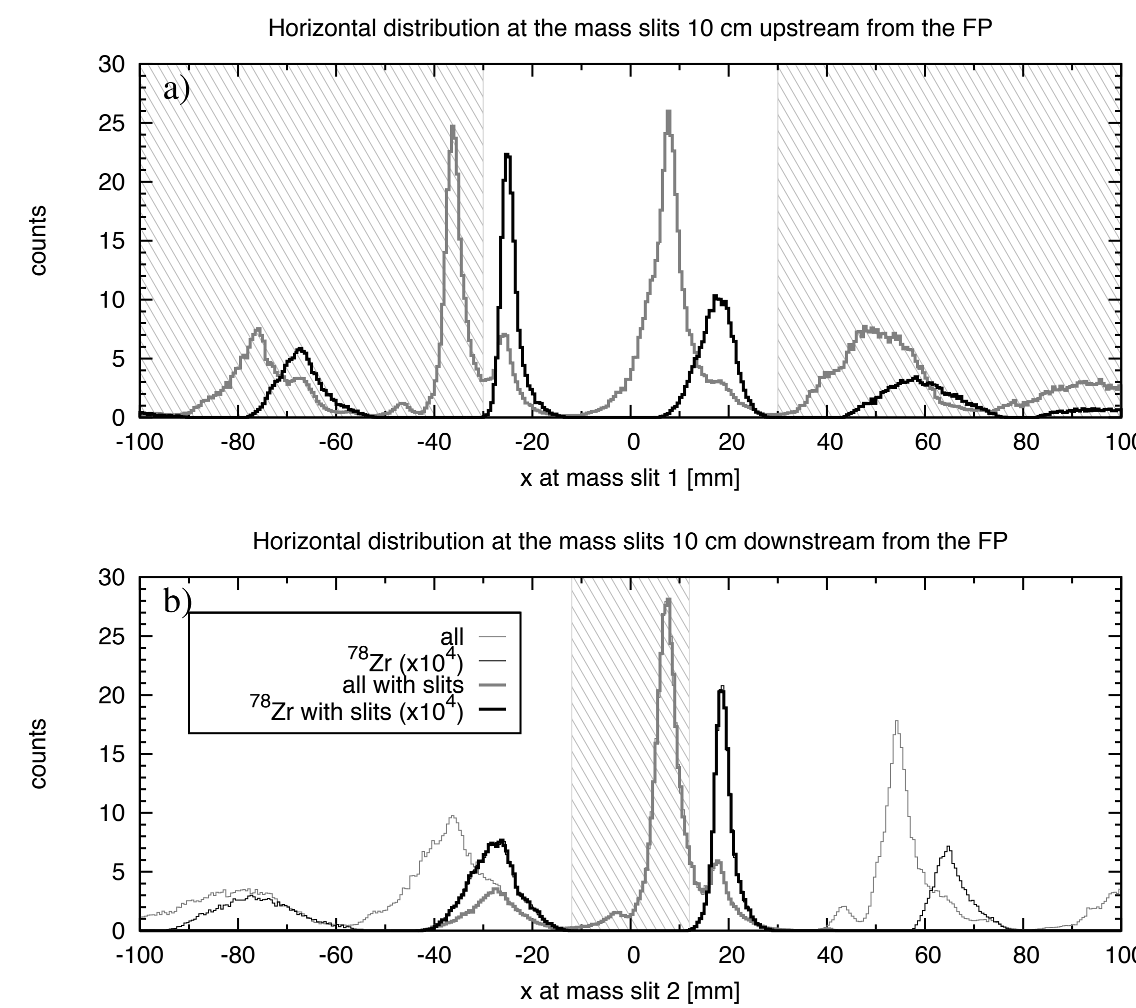


K. Kaneko et al., Phys. Rev. C 89, 031302 (2014)

Prospects with MARA

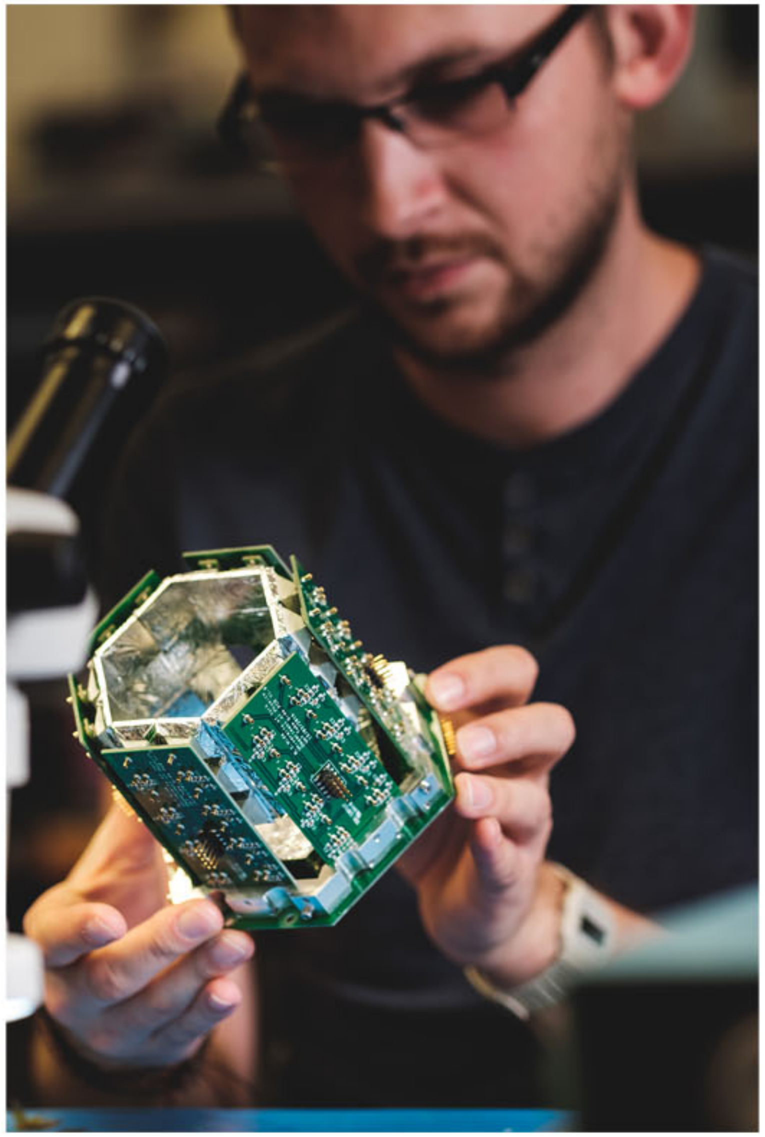






Detailed investigation of $^{40}Ca(^{40}Ca,2n)^{78}Zr$ in J. Saren thesis

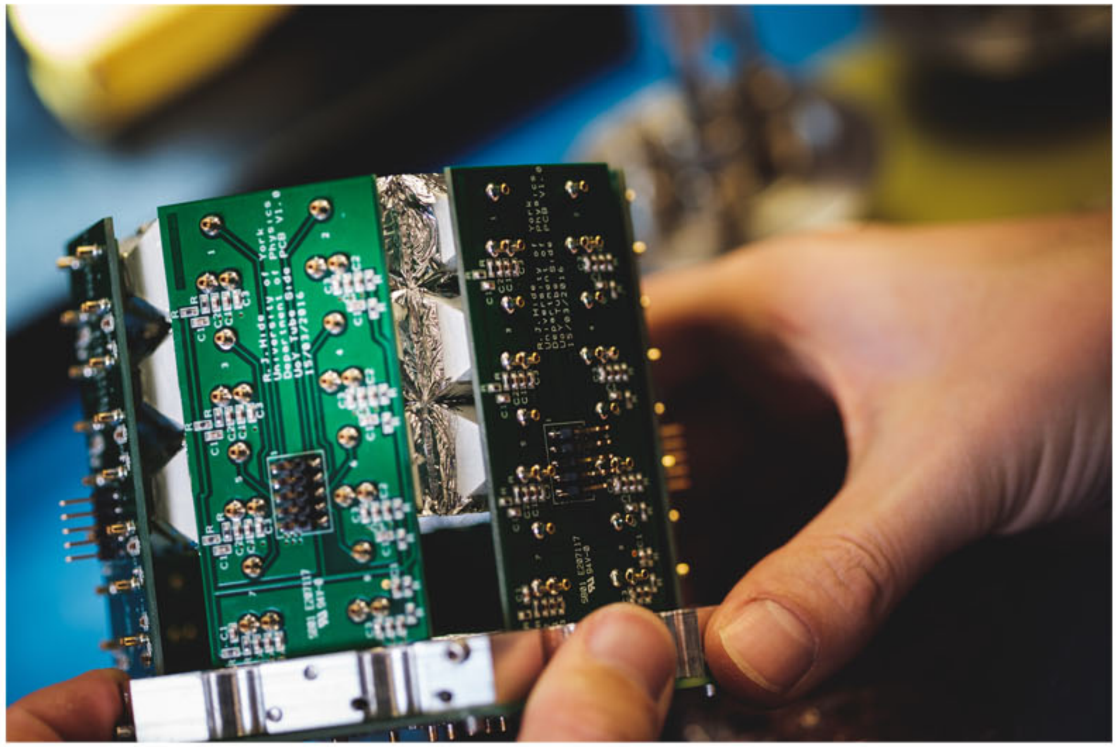
New UoYtube



Change from CsI(TI) to fast plastic plus silicon photomultiplier (SiPM)

No need to preamplify signals - significant simplification to electronics chain

Very fast counting rates possible



Future directions

- Using MARA should be significantly cleaner for 2n channel:
  - A/q selection can remove 3p channel completely and this was the largest contaminant of our spectra
  - New UoYtube may provide improved vetoing
  - MARA is optimised for symmetric reactions
  - Scattered beam may be much less limiting
  - We can carry out a real excitation function as we were limited before by which recoils RITU could transport
  - Focal plane silicon detector is large - at least two charged states may be collected

- Accelerated ISOL beams:
  - Unsafe Coulomb excitation to populate levels for mirror symmetry comparison (IOP workshop of Nara Singh - 16/1/18 Manchester)
  - Safe Coulomb excitation to obtain and compare EM matrix elements across isospin multiplets

Conclusions

New techniques developed to study structure of nuclei beyond the line of N=Z:

- Beta-tagging
- Charged particle veto
- Highly-pixellated silicon detectors

Results obtained on excited states of N=Z-2 nuclei: ^{66}Se, ^{70}Kr and ^{74}Sr

TED extracted and compared with shell model calculations

TED appear to need additional isospin-nonconserving component to reproduce them as earlier shown in $f_{7/2}$ shell

TED can be reproduced using 100 keV INC term irrespective of orbitals involved e.g. fp for ^{66}Se and $g_{9/2}$ for ^{74}Rb

What is the origin of this INC component in terms of nuclear force?

Prospects to extend studies to e.g. ^{78}Zr are very favourable with MARA