Fast beta-gamma timing of Zr isotopes at RIKEN

Frank Browne
University of Brighton

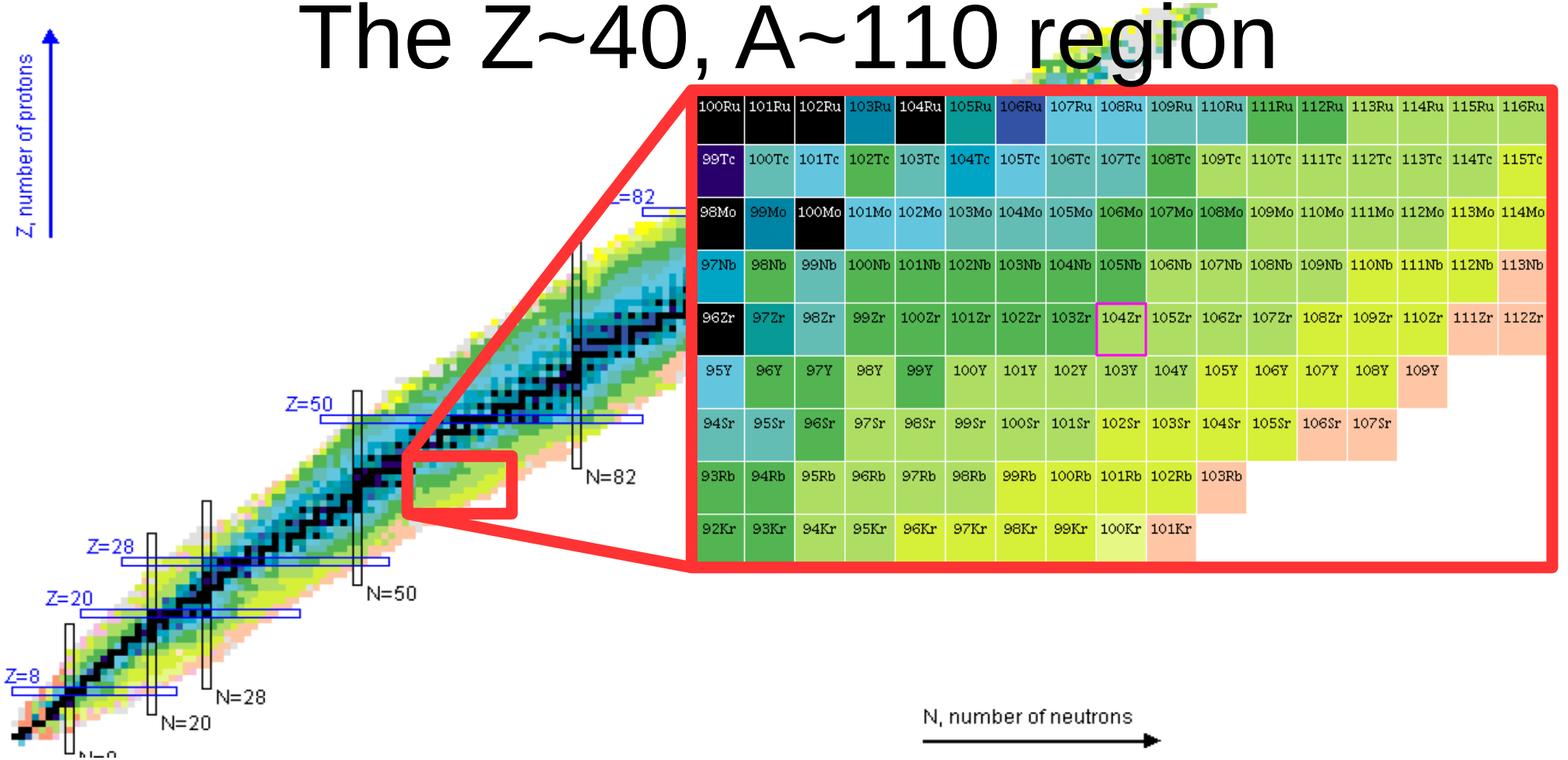
University of Brighton

Workshop on Physics Opportunities Using Arrays of Fast-Timing Gamma-ray Detectors, March 2015

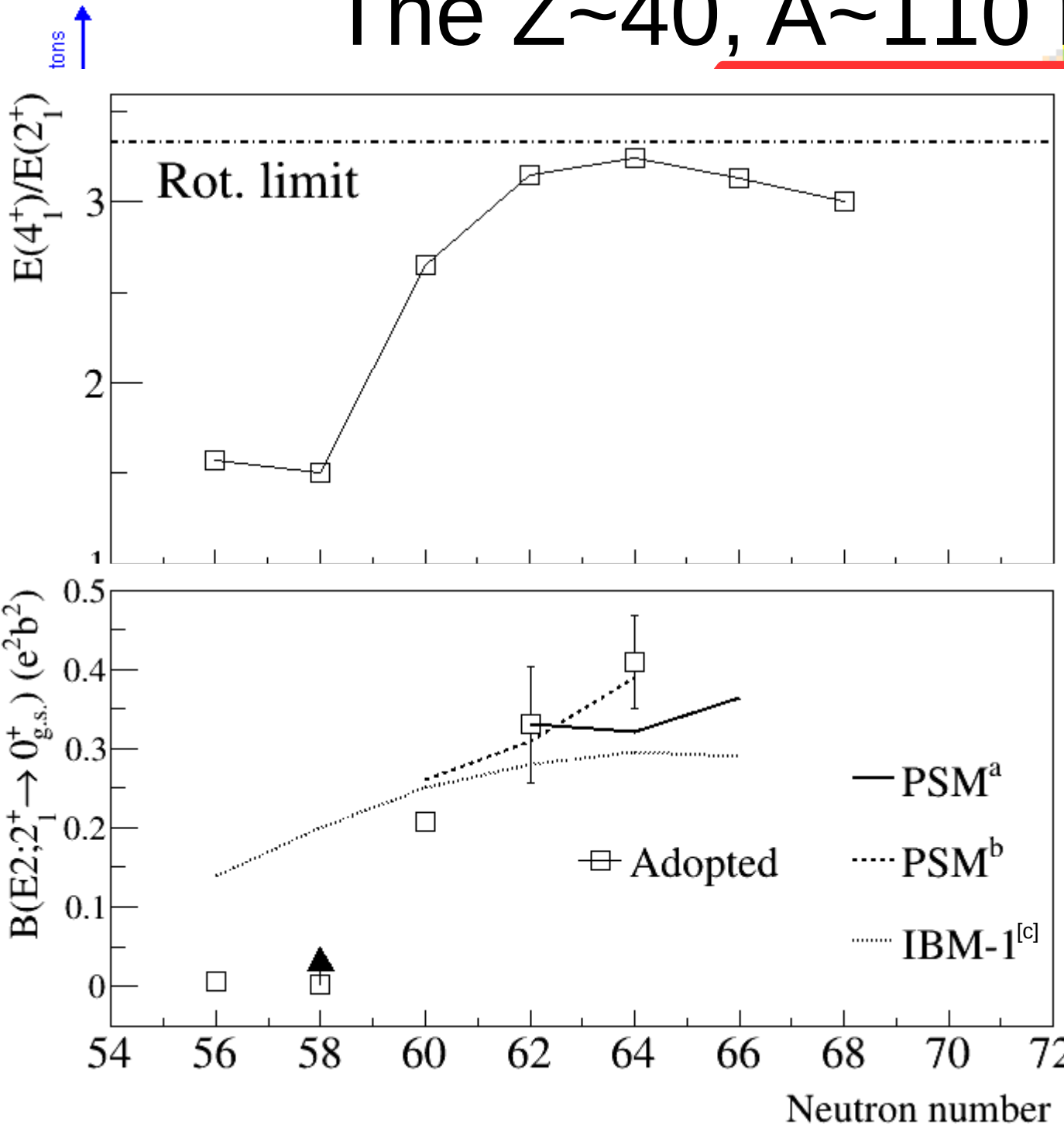
Overview

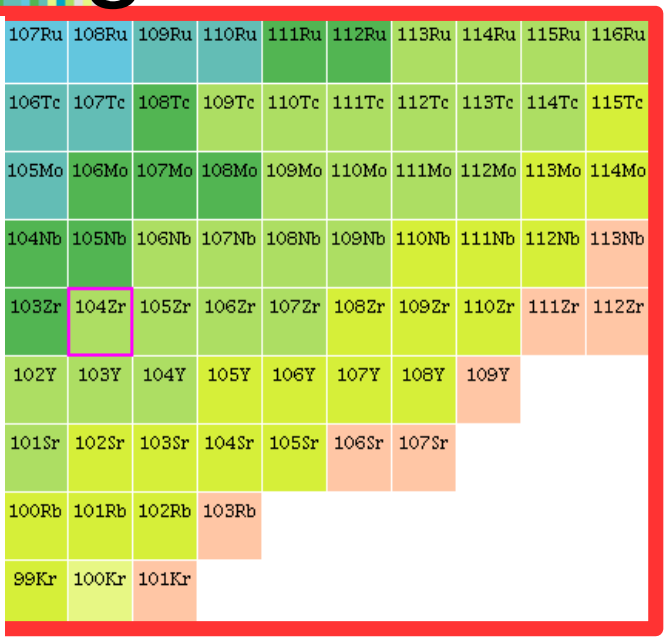
- Neutron-rich Zr region
  - Sudden onset of quadrupole deformation at N≥60
  - Fast-timing of levels → insights to collectivity
- Experimental set-up
  - Isotope production and separation
  - Implantation and β-decay measurement
  - Fast-timing configuration:
    - Beta-electron detection – β-electrons
    - Lanthanum bromide array – γ-rays
- Data analysis
  - Position dependence of
- Selected results

The Z~40, A~110 region



The Z~40, A~110 region





[a] Y.-X. Liu, Y. Sun, X.-H. Zhao, Y.-H. Zhang, S.-Y. Yu, Y.-C. Yang, and H. Jin, Nucl. Phys. A858, 11 (2011).
[b] S. Verma, P. Ahmad, and R. Devi, Phys. Rev. C. 77, 024308 (2008).
[c] M. B˙oy˙ukata, P. V. Isacker, and I.Uluer, J. Phys. G: Nucl. Part. Phys. 37, 105102 (2010).
[d]

Ground-state transition lifetimes

- Combined with transition energy, gives B(E2) values,

$$B(\mathrm{EL}, I_i \rightarrow I_f) = \frac{e^2}{(2I_i + 1)} \left| \langle \psi_{I_f} \| \hat{Q}_L \| \psi_{I_i} \rangle \right|^2$$

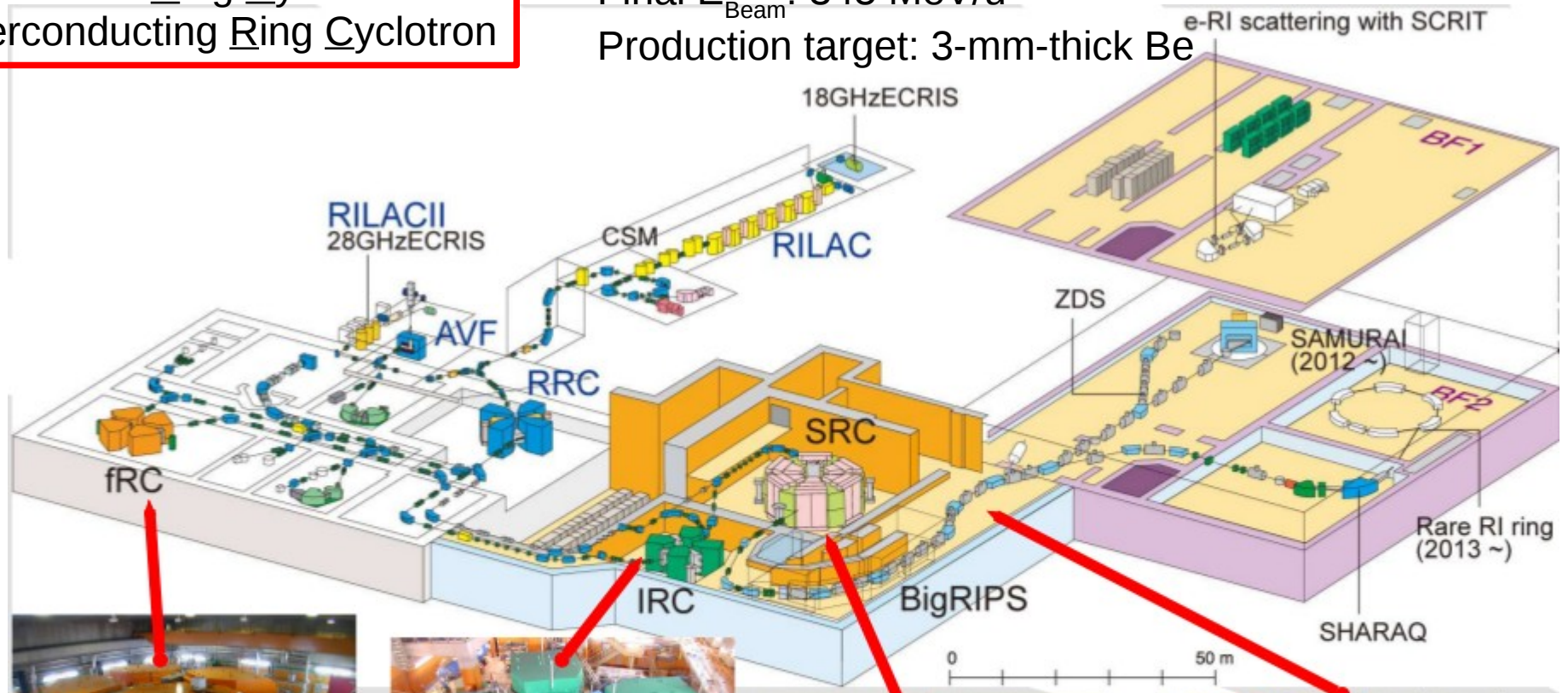
  - Direct test of ground-state shell model wavefunction
  - If nucleus is axially symmetric can give g.s. deformation

$$\beta_2 = \left(4\pi / 3 Z R_0^2\right) [B(E2)\uparrow / \mathrm{e}^2]^{1/2}.$$

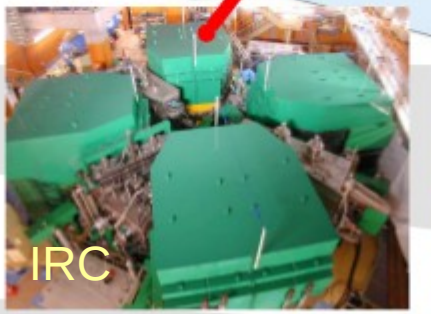
Accelerator system

fixed-frequency Ring Cyclotron
Intermediate Ring Cyclotron
Superconducting Ring Cyclotron

$I_{Beam}(^{238}U)$: ~10 pnA
Final E_{Beam}: 345 MeV/u
Production target: 3-mm-thick Be

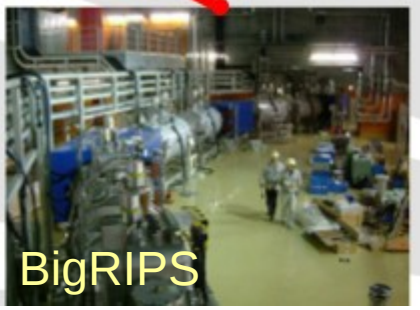


K-value :570 MeV
E_{Beam}: 50.7 MeV/u



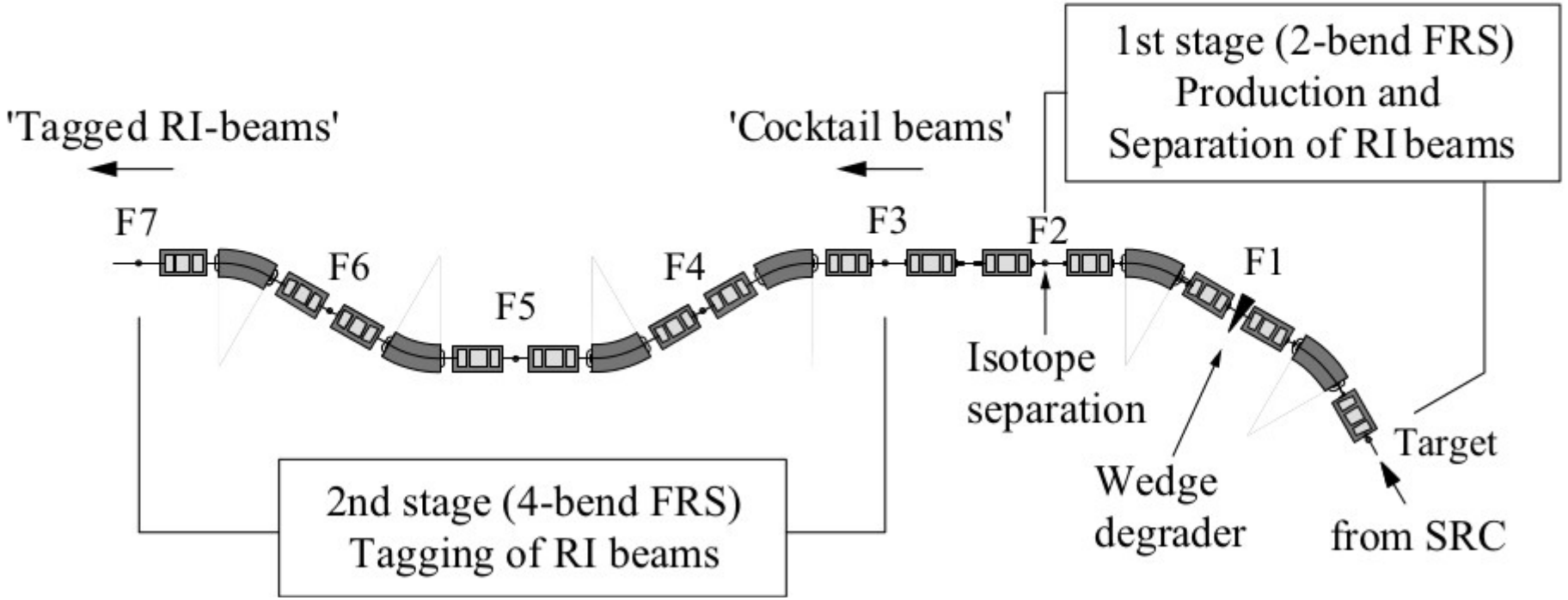
K-value: 980 MeV
E_{Beam}: 127 MeV/u

K-value: **2600 MeV**
E_{Beam}: **345 MeV/u**



Big RIKEN Projectile Fragment Separator

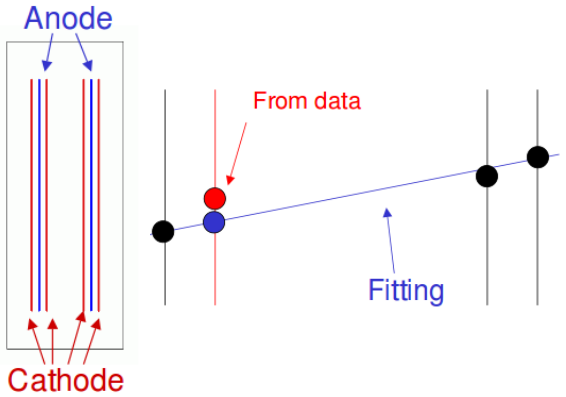
BigRIPS



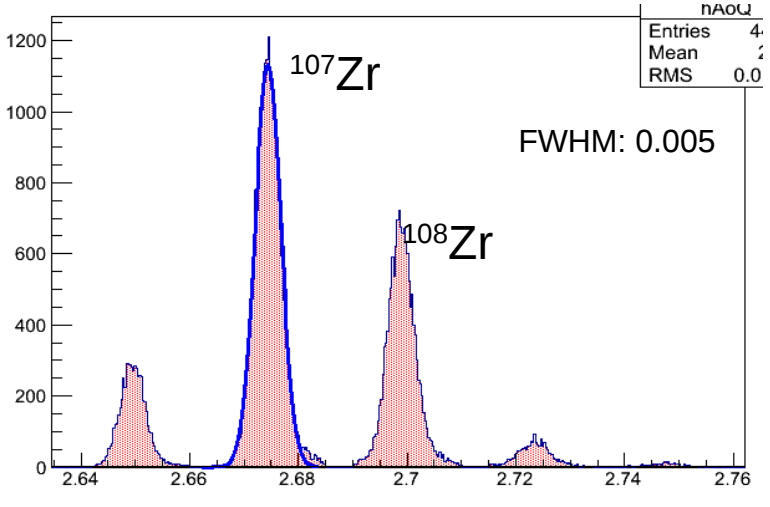
Bρ-TOF: F3, F5 &F7

Delay-Line PPACs: F3-F5-F7
Dual-layers
Active area: 240x150 mm^2
XY res.: <0.5 mm

Timing plastics: F3-F7
Thickness: 0.2 mm
Distance: 47 m
Res.: ~50 ps
ToF: ~245 ns

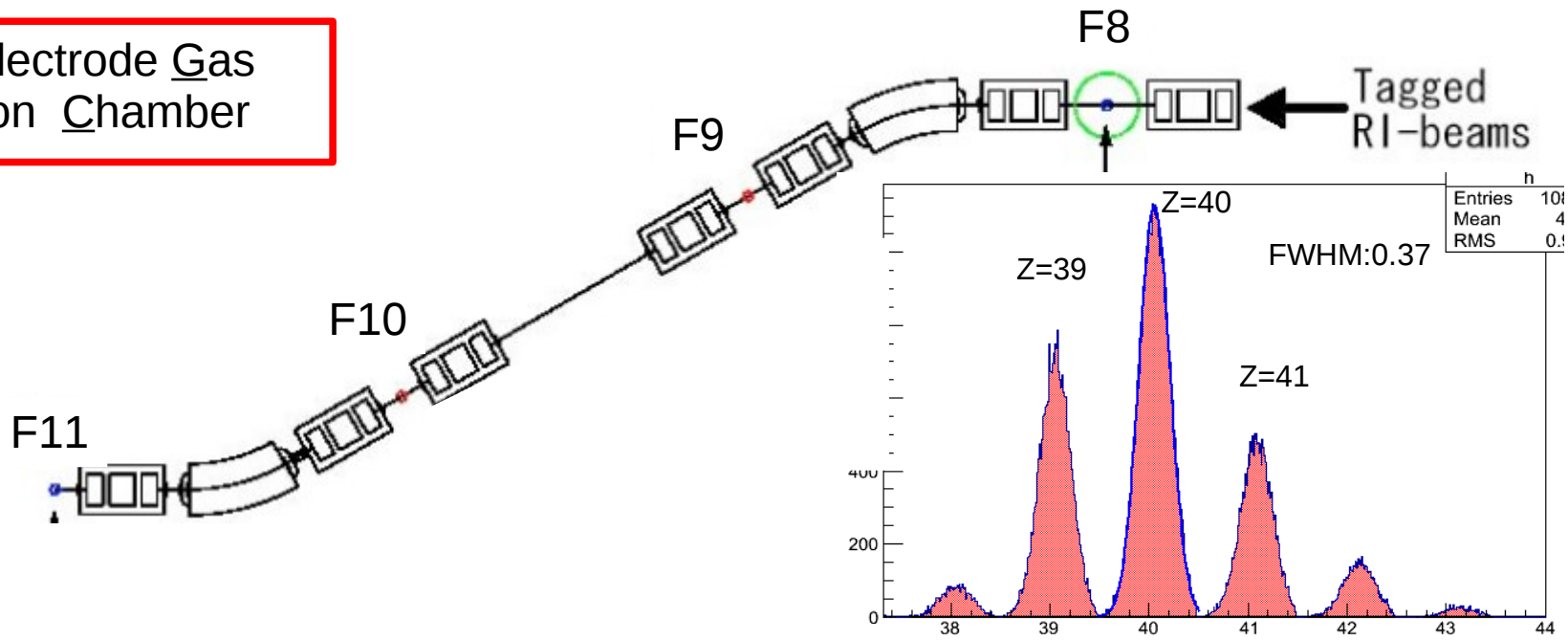


$$\frac{A}{Q} = \frac{B\rho}{\beta\gamma uc}$$



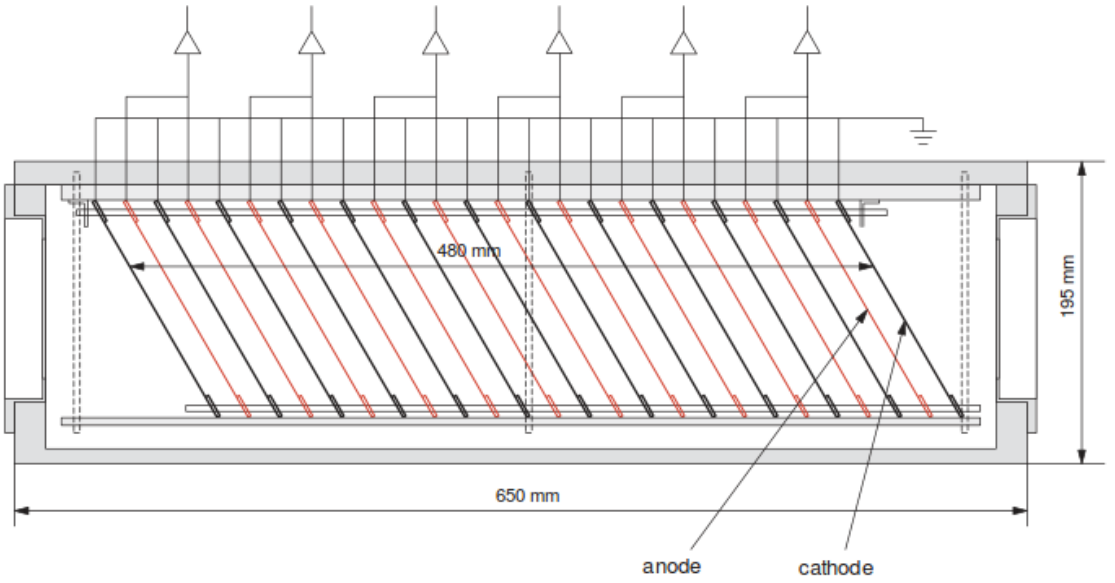
ZeroDegree “spectrometer”

Tilted Electrode Gas Ionisation Chamber

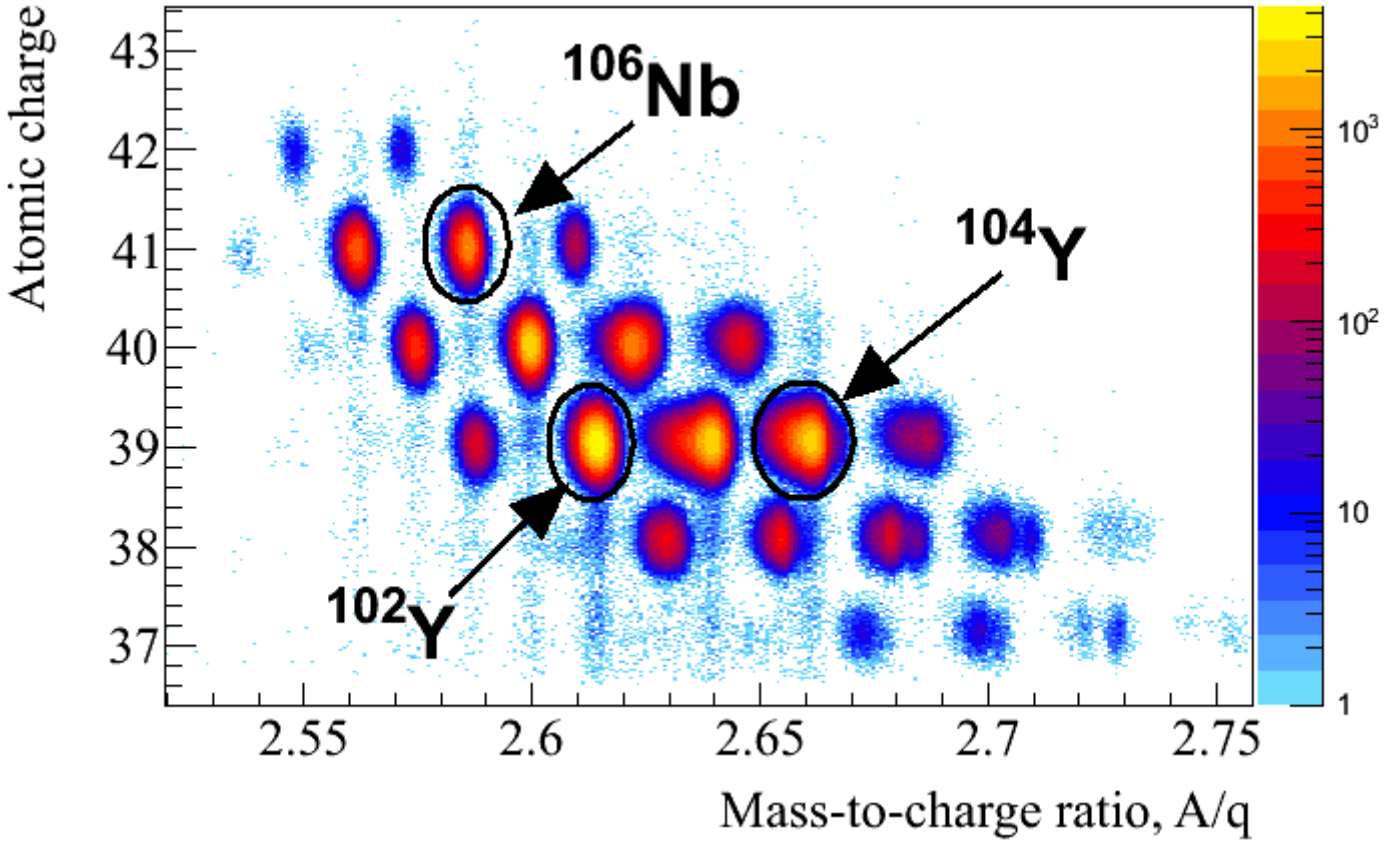


ΔE: F3, F7 & F11

TEGIC:
24-cavity MUSIC at F11
Cavity width: 25 mm
Only anode signal used
Beta: Between F3 and F7
Fill gas: Ar-CF_4 (90%, 10%)



Nuclei studied



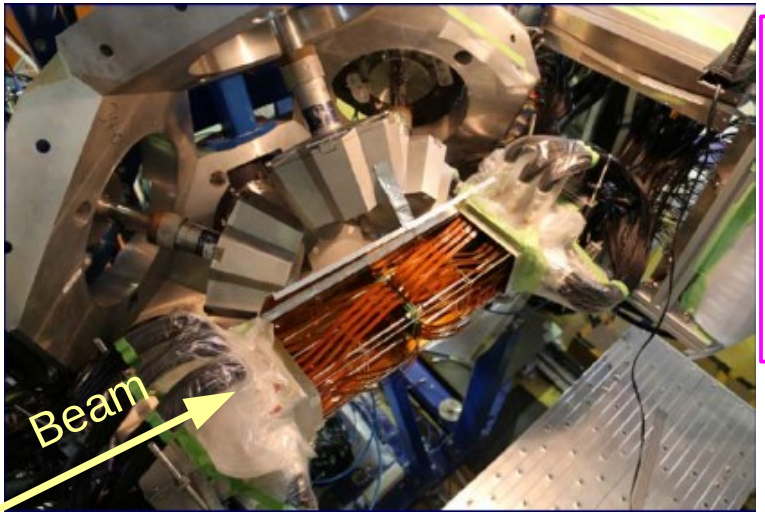
1.30x10^5 ^{106}Nb ions

3.77x10^6 ^{104}Y ions

5.0x10^5 ^{102}Y ions

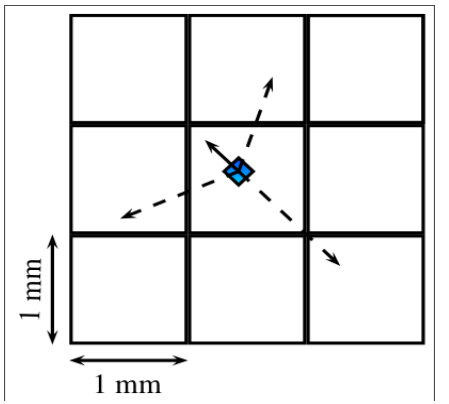
Wide-range Active Silicon-Strip Stopper Array for Beta and ion detection

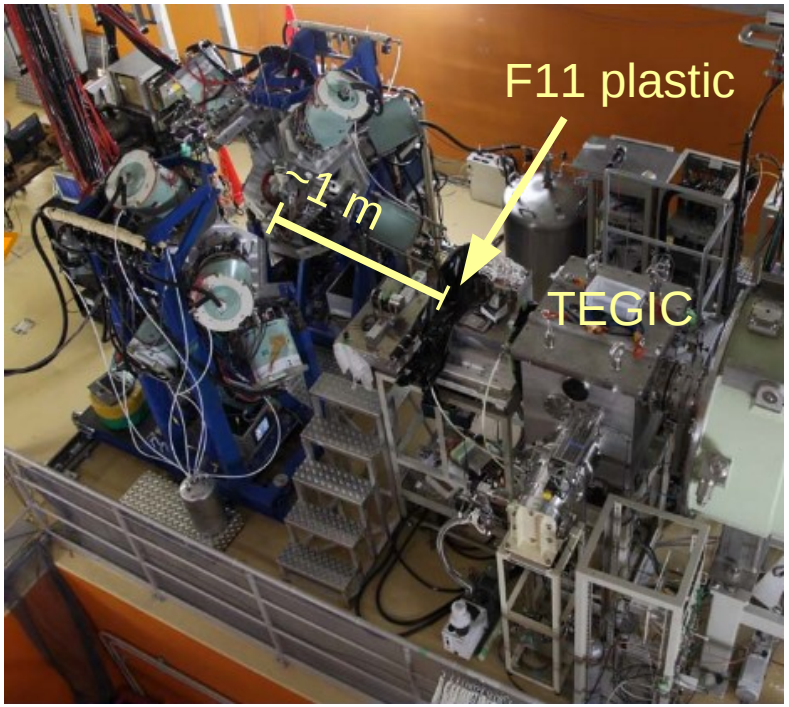
WAS3ABi

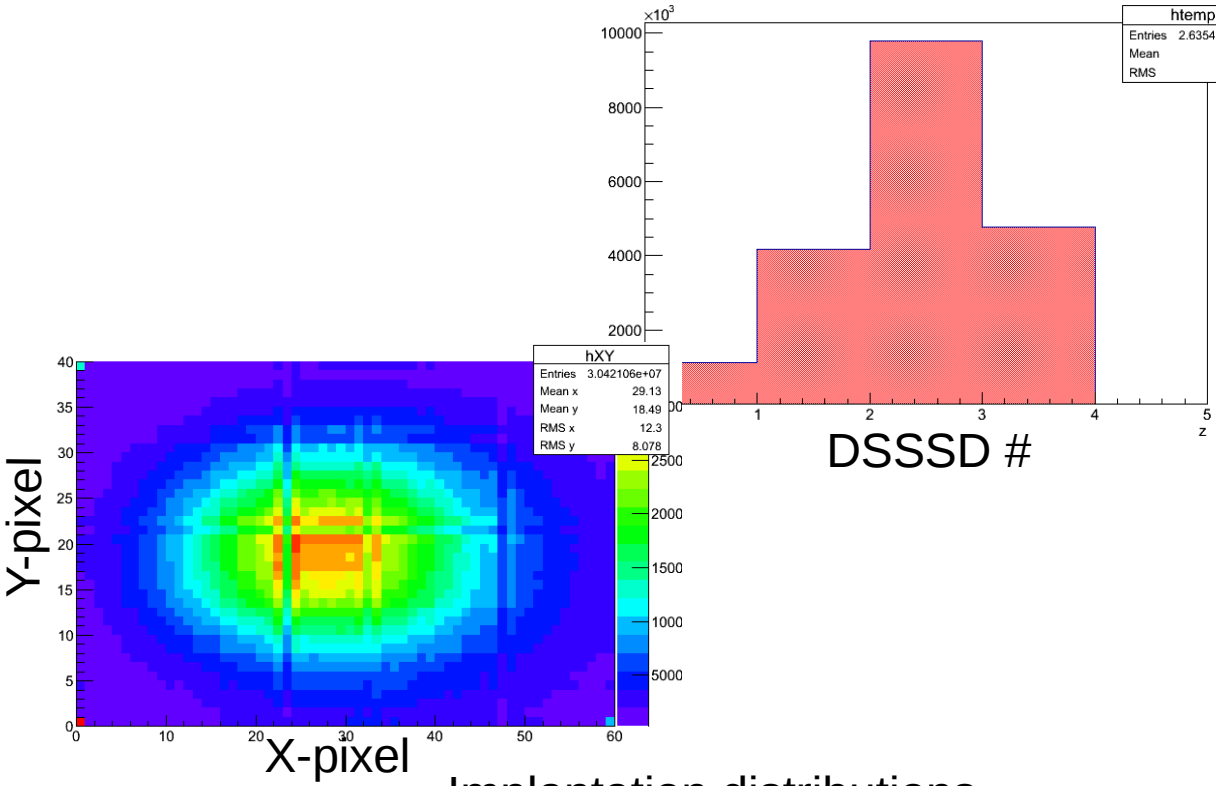


Active silicon stopper array:
5 DSSSDs, 1 mm thick
60x40 strips, each 1 mm wide
Spacing: 0.5 mm
Pos. res.: 1 mm
Time res.: ~200 ns

Same-pixel correlation



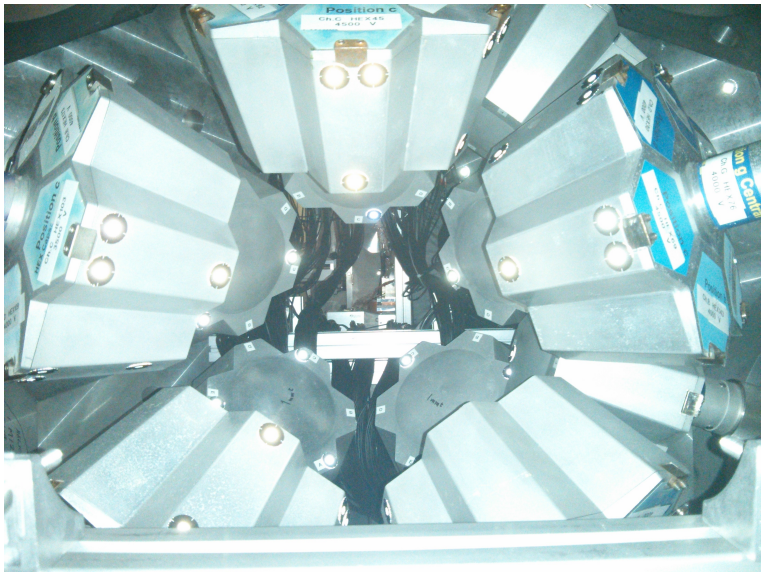




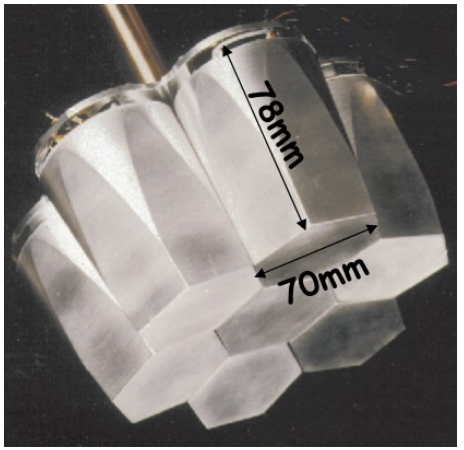
Implantation distributions

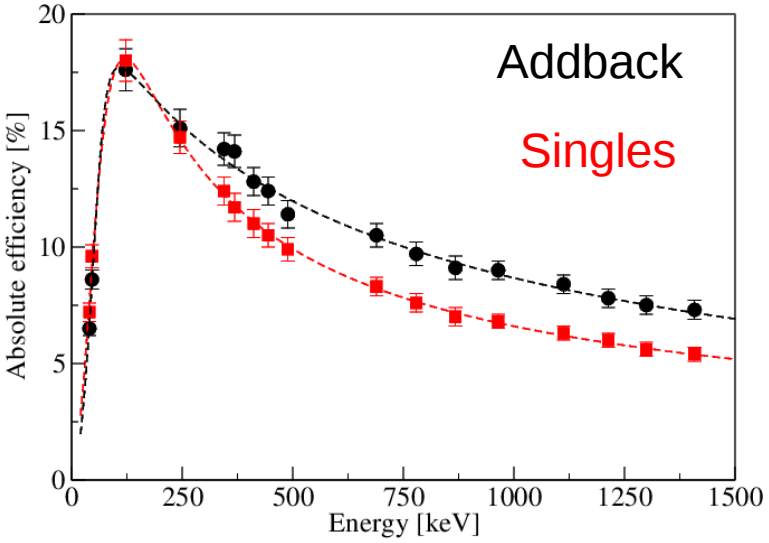
EUROBALL-RIKEN
Cluster Array

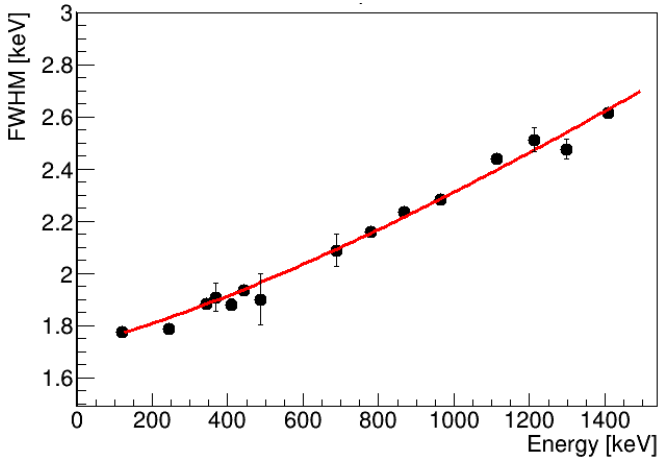
EURICA



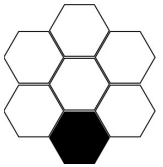
Co-axial HPGe array:
Total 84 crystals, 81 operational, in 12 clusters
Hexagonal tapered shape
Ave. distance from stopper centre:
~23 cm
Close-pack, enables addback
Crystal dimensions:
Length = 68 mm
$Ø_{front}$=48.5 mm
$Ø_{back}$ =58.9 mm

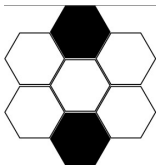


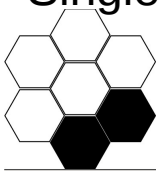


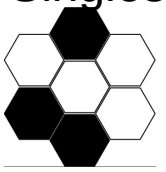


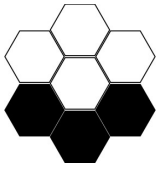
Hit patterns:

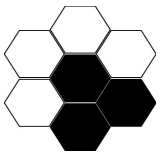

Single


2 Singles


Addback


Addback+single





Beta-gamma timing set-up

Beta-plastics:
2 mm thick, 65x45 mm^2 area
~1 mm up- and downstream of WAS3ABi
BC-418
Time res.: ~200 ps
Efficiency: ~30%

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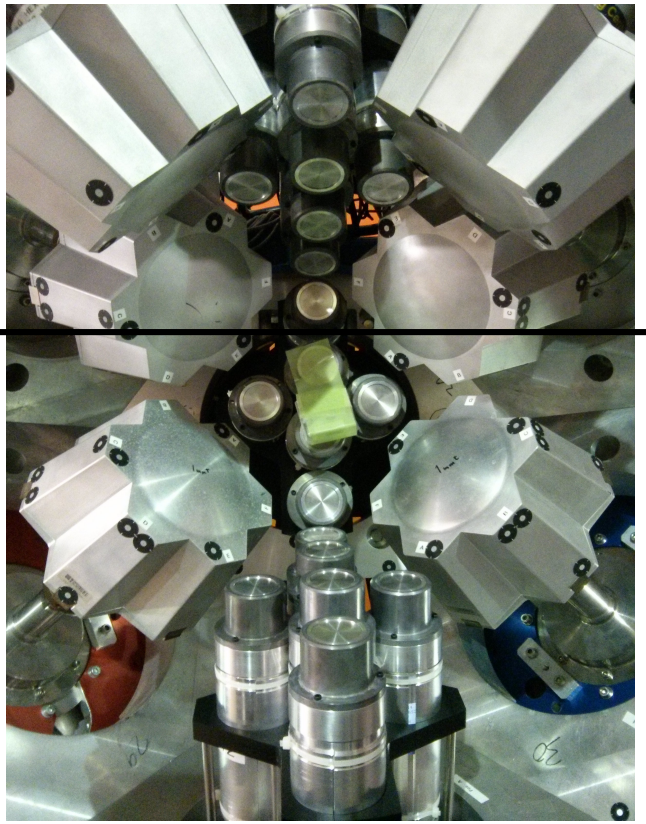

Beam

$LaBr_3$(Ce) array:
18 cylindrical crystals
Ø= 38.1 mm, length = 50.8 mm
Lead shield: passive anti-compton
Ave. distance from array centre:
~25 cm
Efficiency @ ~150 keV ~4%

Beta-gamma timing set-up

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BC-418
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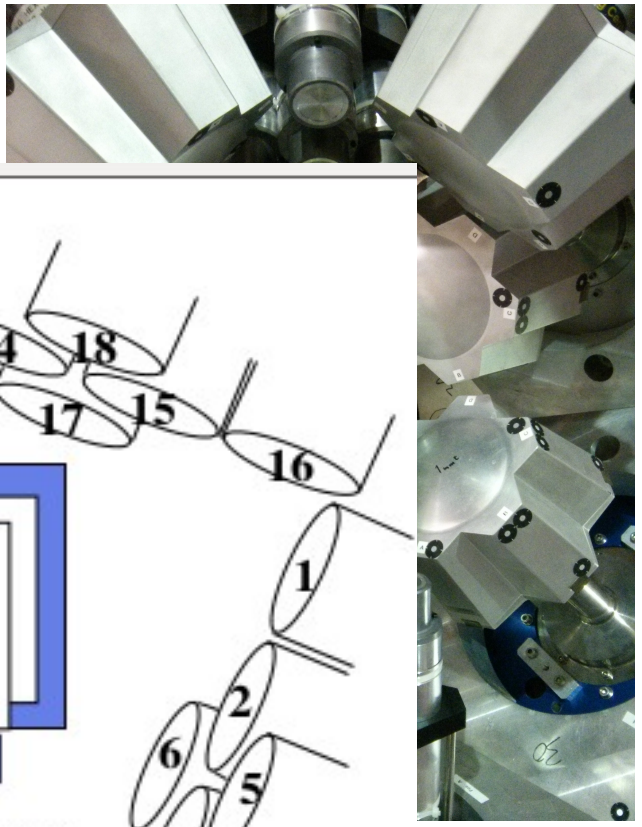
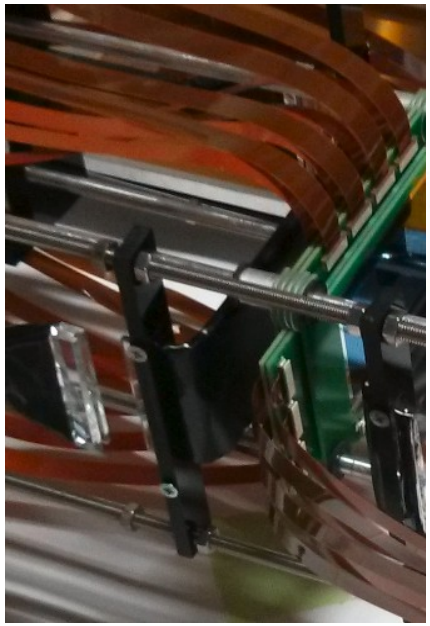




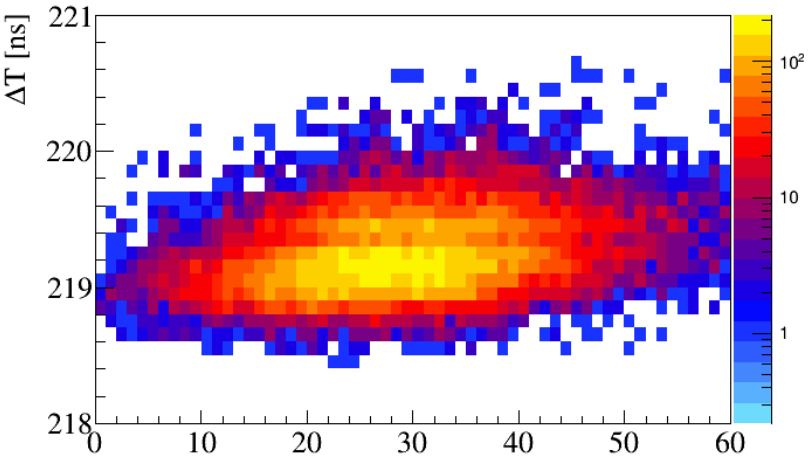
50.8 mm
anti-compton
Ave. distance from array centre:
~25 cm
Efficiency @ ~150 keV ~4%

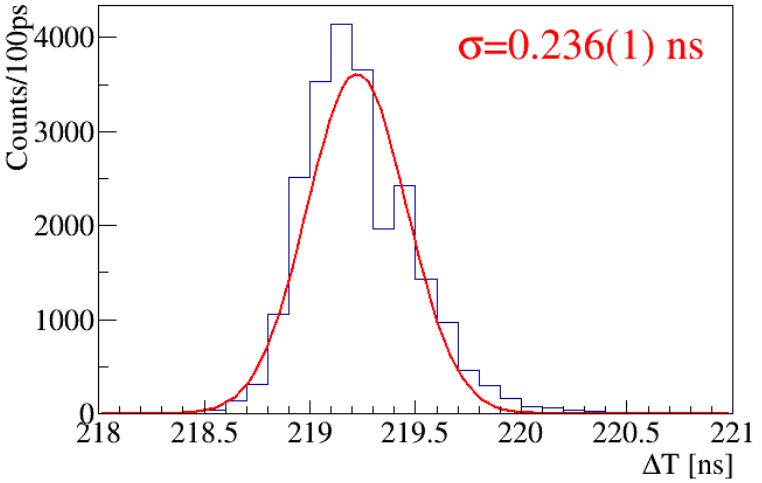
Beta-timing

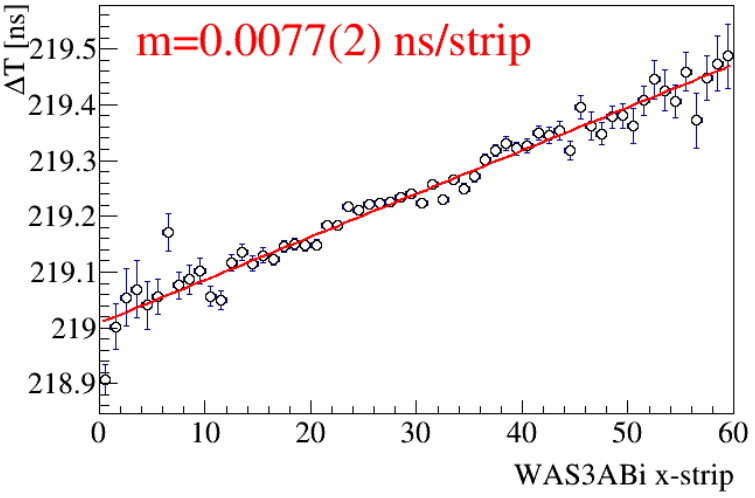
- Use average of left and right PMT

$$\Delta T = \frac{T_{\beta L} + T_{\beta R}}{2}$$

  - Should be position independent
  - Slight dependence on x-strip

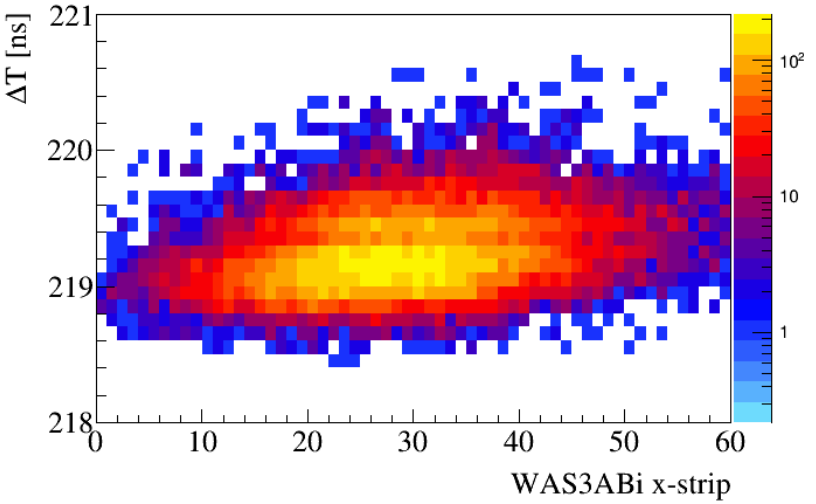


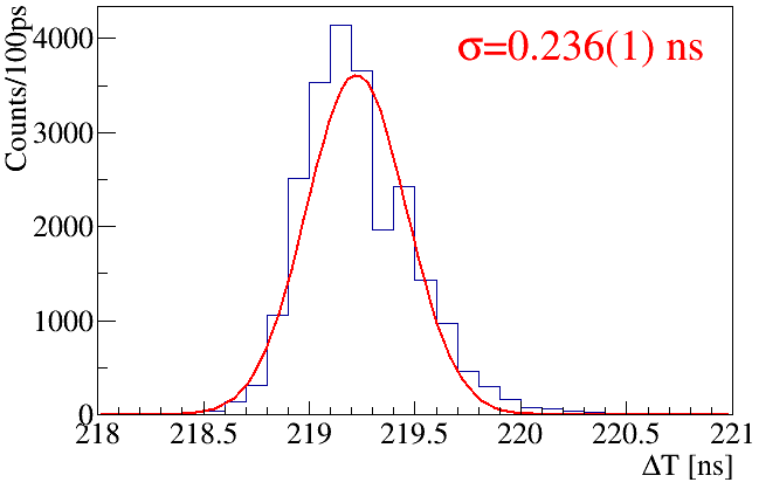




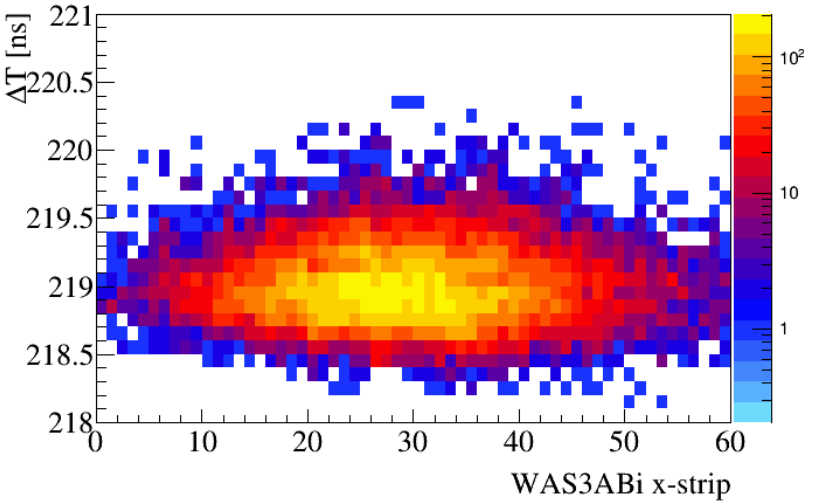
Beta-timing

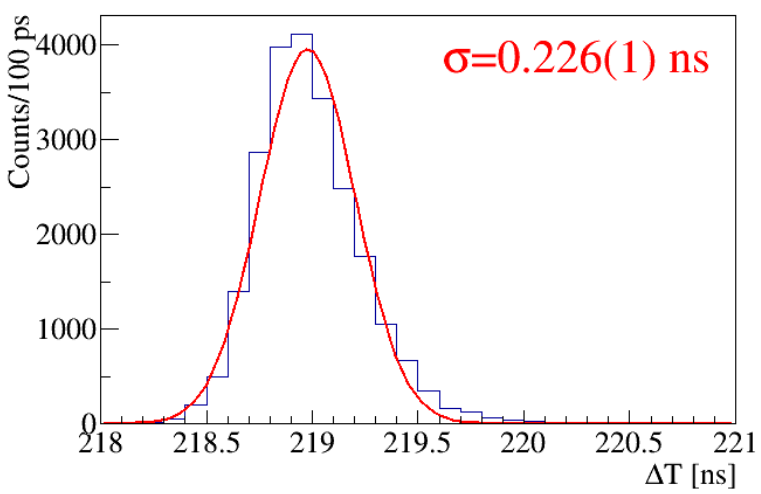
Before correction:





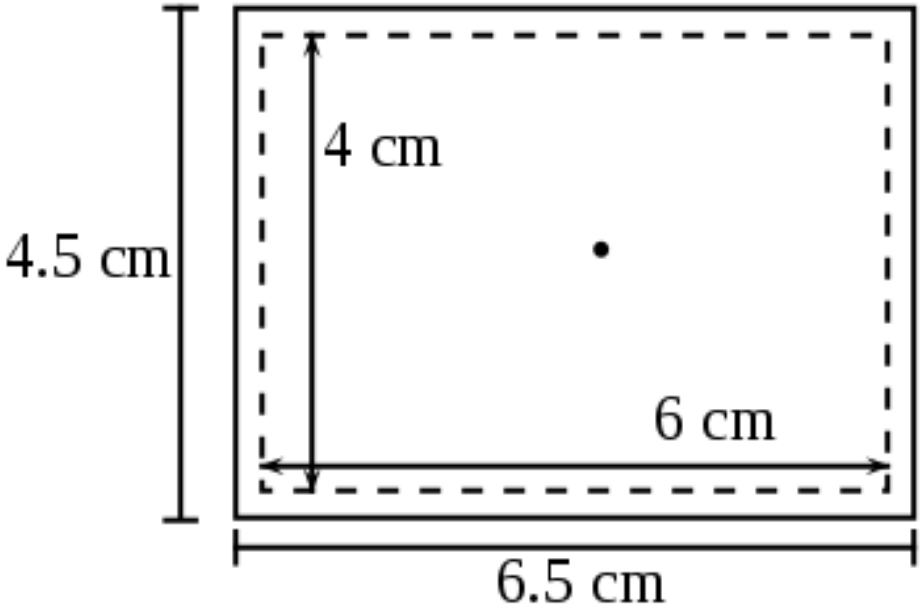
After correction:

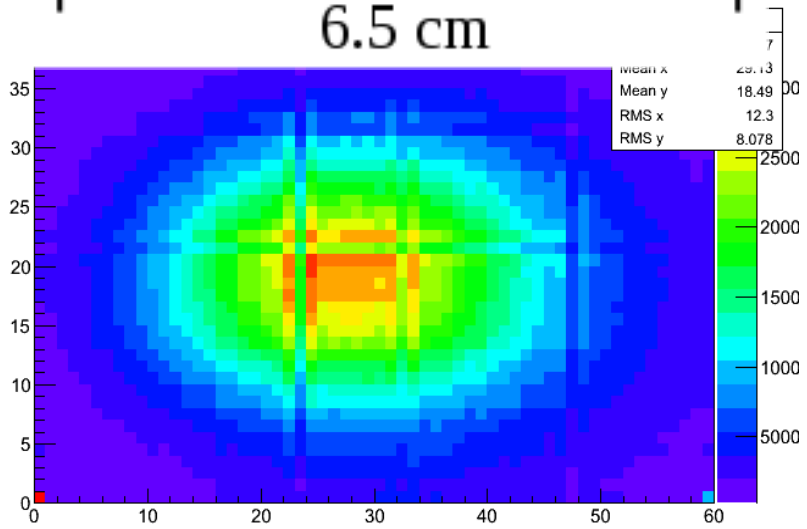




Gamma-timing

- Does the time-of-flight to gamma-detectors have an effect?





Worst case:
Difference in implantation position across the diagonal:
$(4^2+6^2)^{0.5}$ ~ 7 cm

C=$3 \cdot 10^{10}$ cm/s, or 30 cm/ns

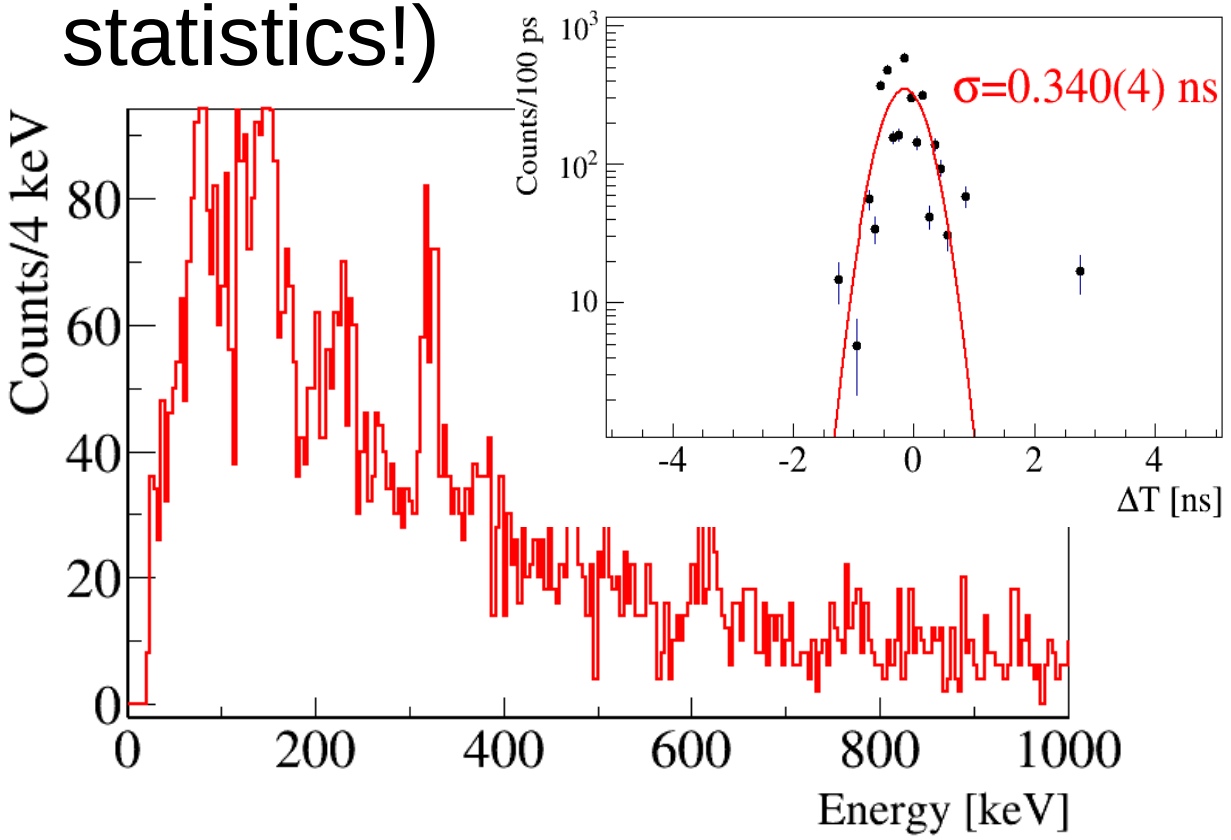
Across 7 cm, the time difference is:
T = 7/30 approx. 0.23 ns

However, based on beam spot diameter of ~3 cm
T = 3/30 approx. 0.1 ns

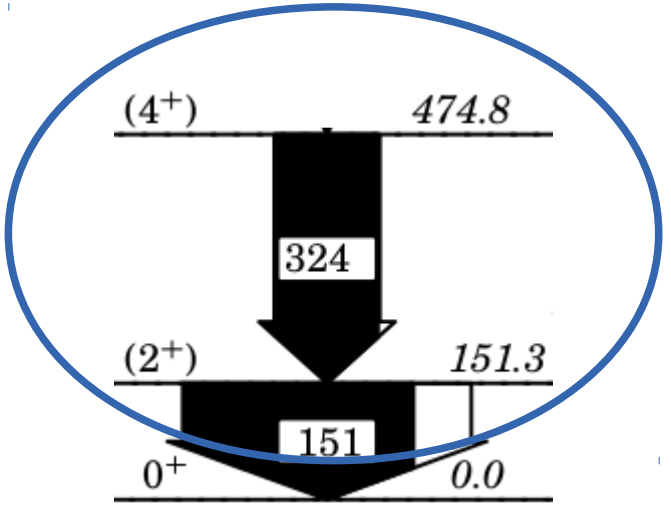
Do we observe?

Gamma-timing

- Should see time resolution increase as function of area used on DSSD
- Need a clean prompt transition (with good statistics!)

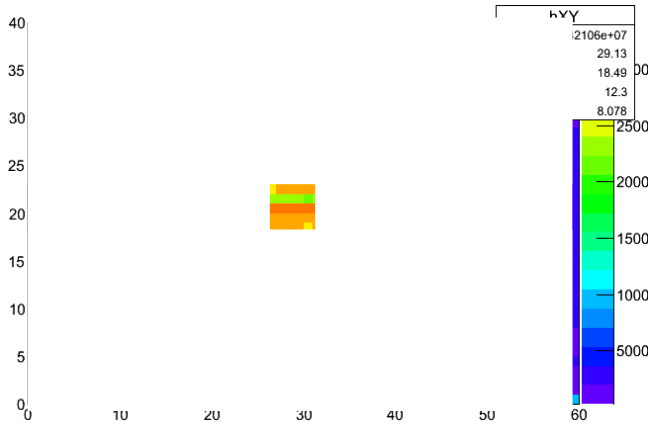


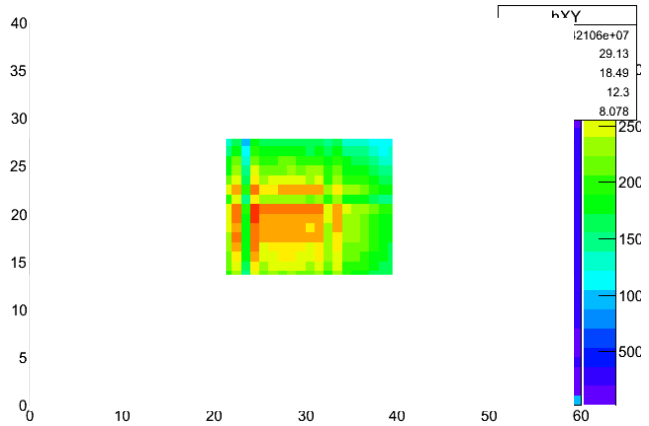
$4^+ \rightarrow 2^+$ in ^{106}Zr

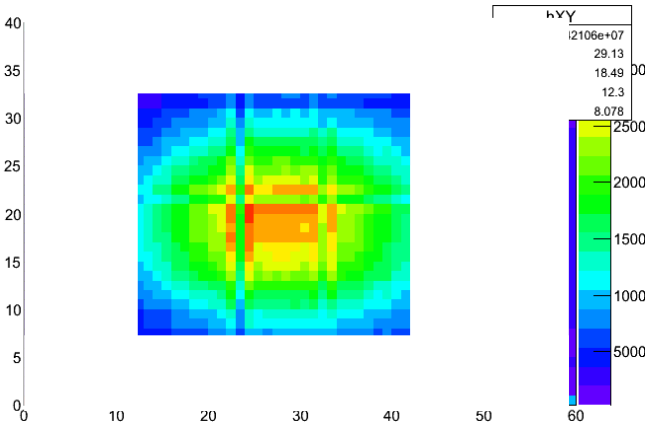


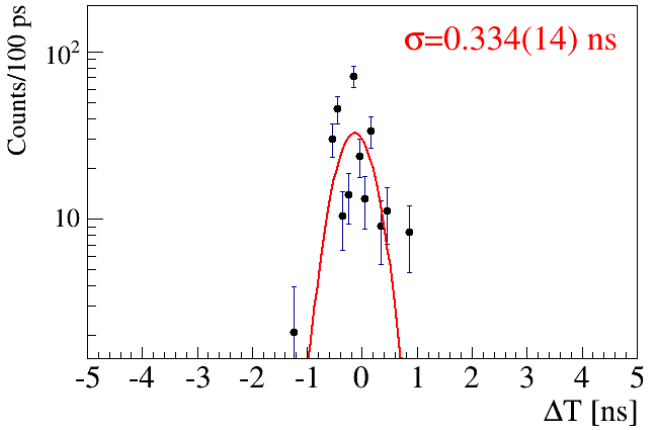
Gamma-timing

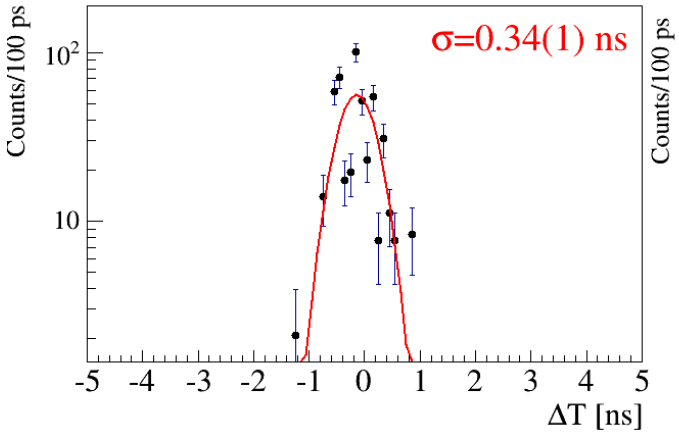
- Vary DSSD area as function of pixel

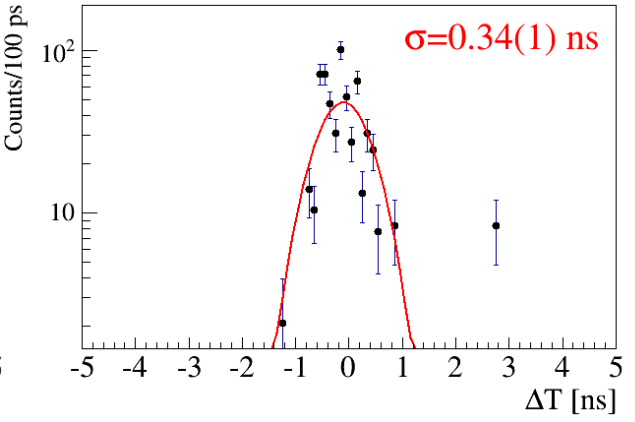






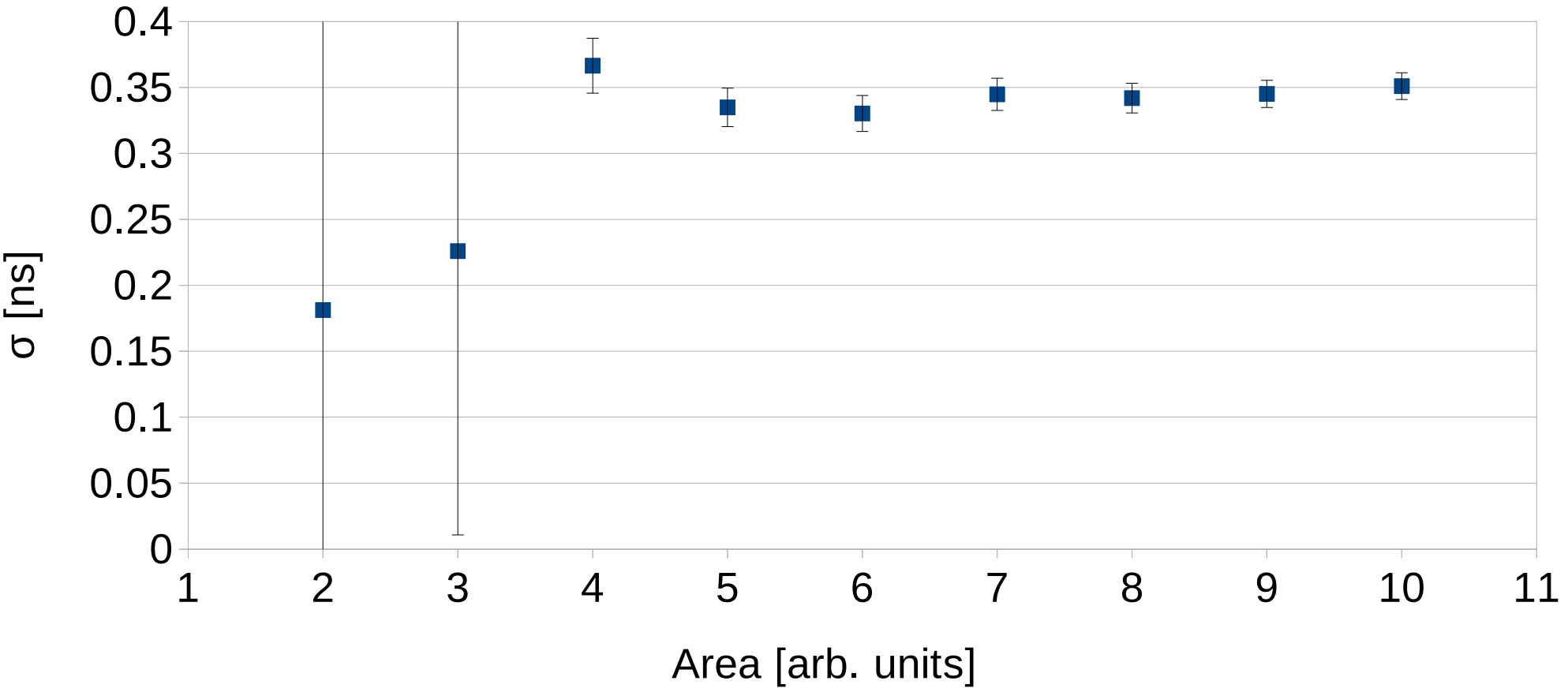






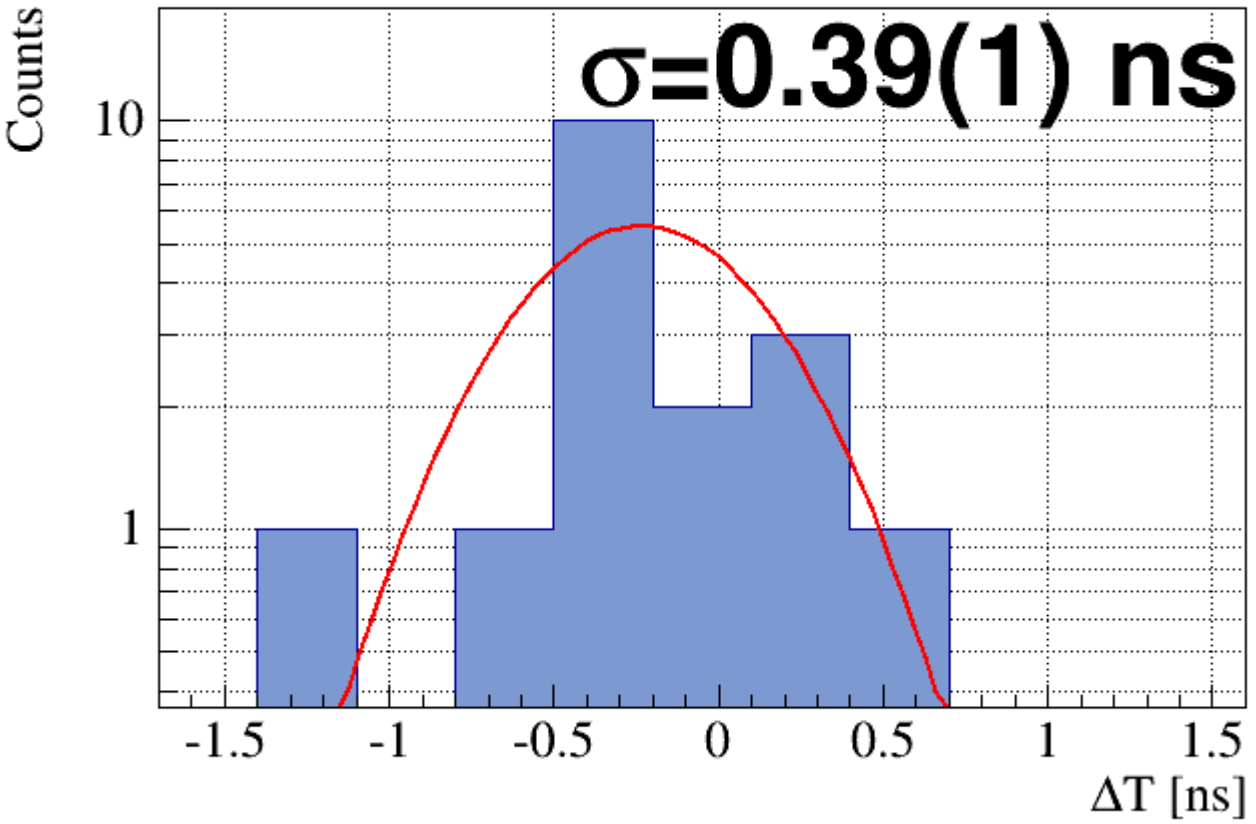
Gamma-timing

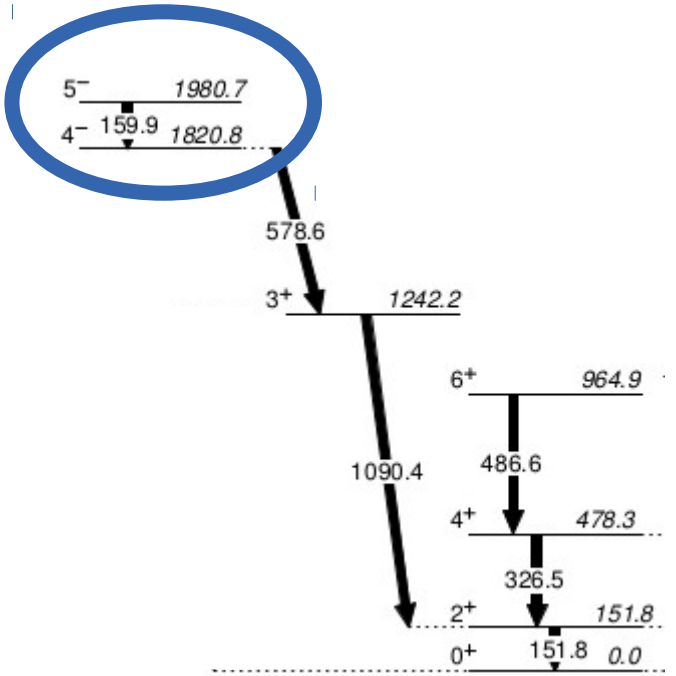
- Vary DSSD area as function of pixel



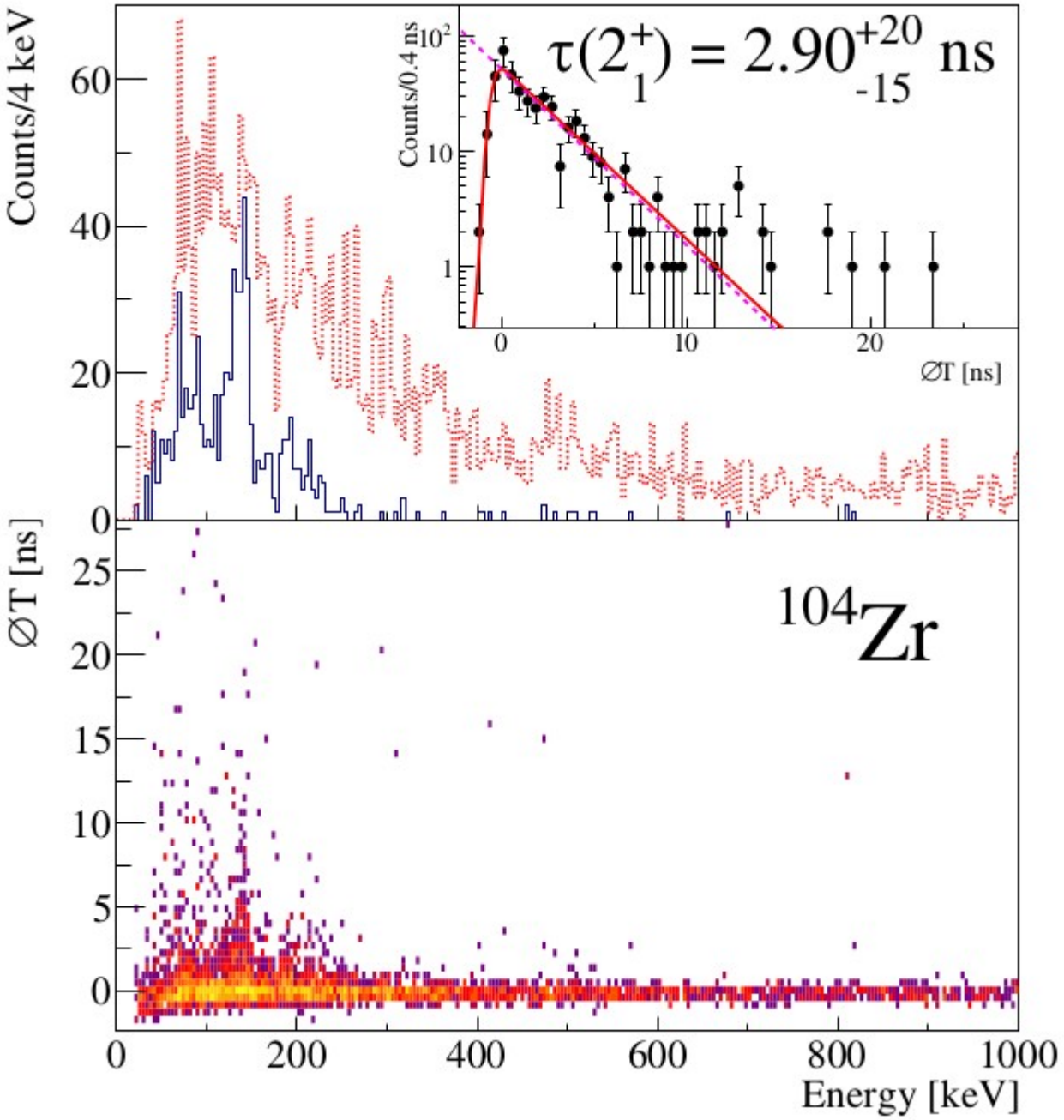
Prompt transition

- Use 160 keV transition in ^{102}Zr
  - Gate on 152 keV $2^+ \rightarrow 0^+$ in EURICA





Results - ^{104}Zr

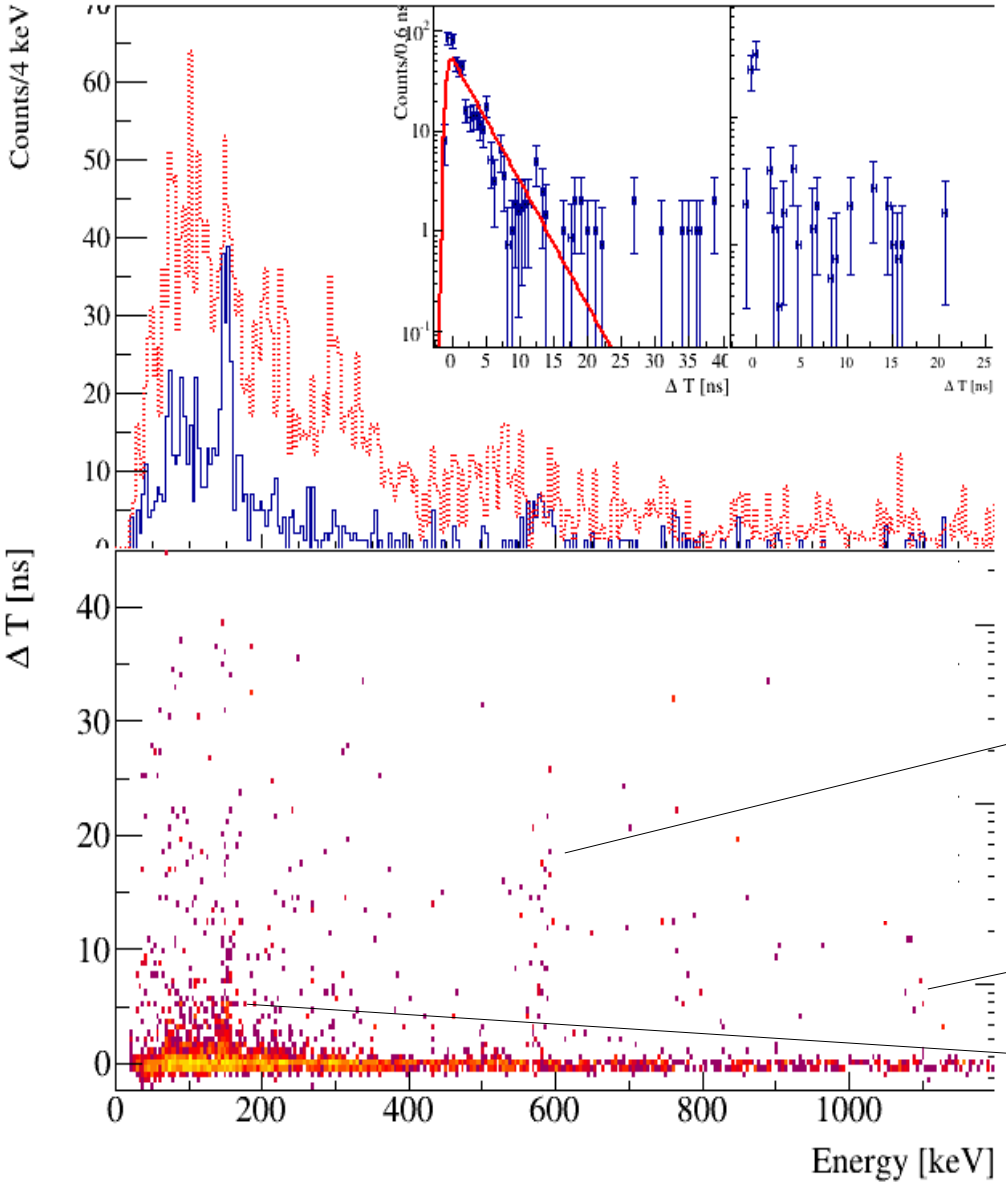


Adopted: 2.9(4) ns[1]

50 ps added to upper uncertainty, higher lying states Predicted from others in the region

[1] J. K. Hwang, A. V. Ramayya, J. H. Hamilton, Y. X. Luo, A. V. Daniel, G. M. Ter-Akopian, J. D. Cole, and S. J. Zhu, Phys. Rev. C. 73, 044316 (2006).

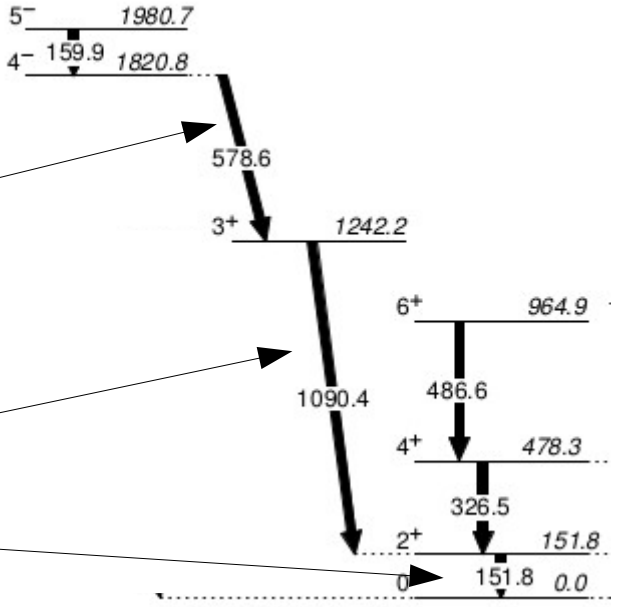
Results ^{102}Zr



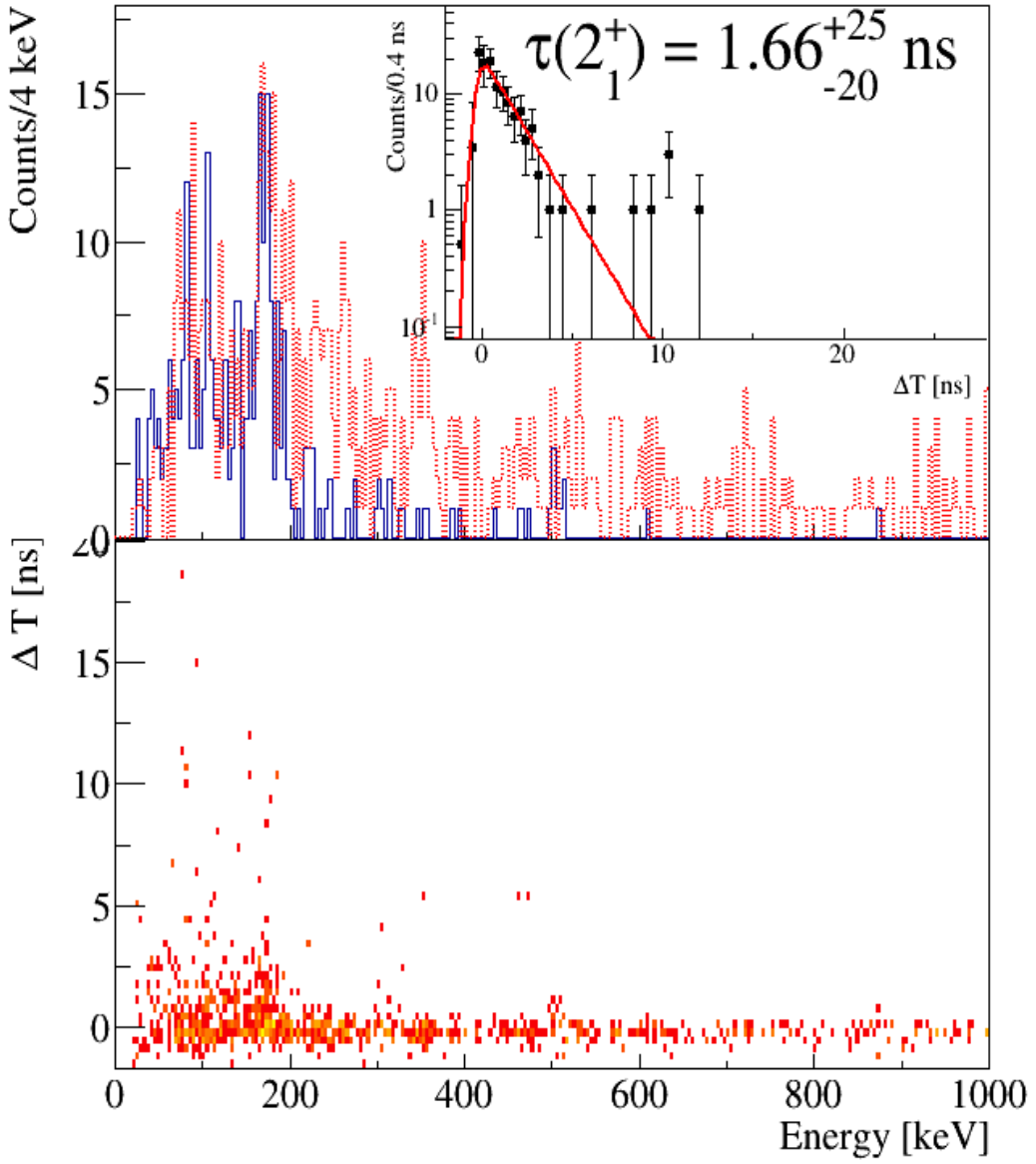
Beta-decay populates up to 5^- in ^{102}Zr.

Very long, τ~6 ns, state observed at least from 4^-

Strong feeding from this transition affects the measured lifetime of the 2^+



Results ^{106}Mo



Adopted: 1.80(4) ns[1]

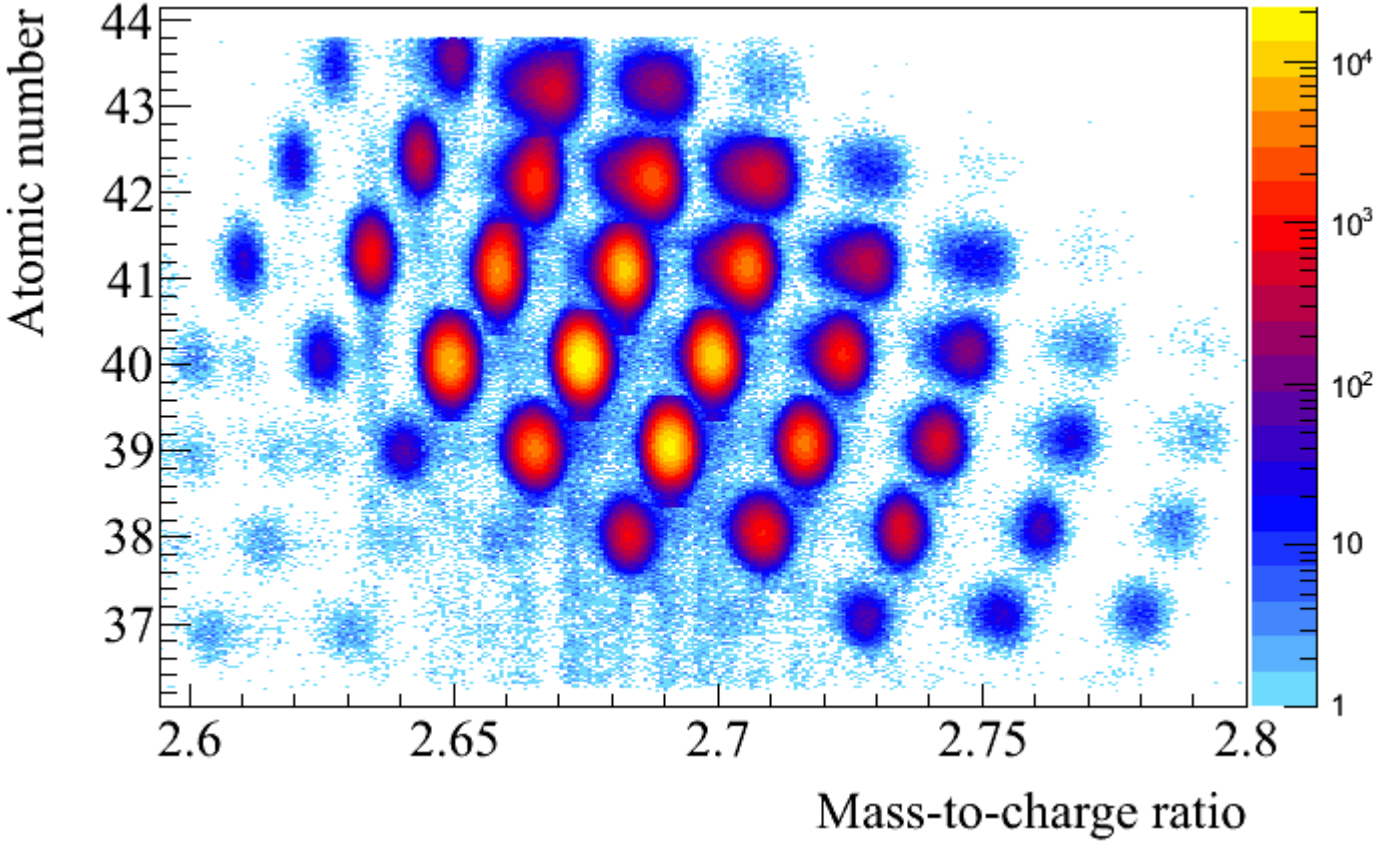
[1] R.C.Jared, H.Nifenecker, S.G.Thompson, LBL-2366, p.38 (1974)

Where have we been?

- Description of fast beta-gamma timing at RIKEN
- The considerations for using a large beam spot
- Efficacy of array used confirmed with lifetimes of known states in the nanosecond regime
  - In case of ^{104}Zr the precision has been increased
  - Long-lived components from rotational bands in ^{102}Zr identified

Where next?

With a full LaBr array...
Gamma-gamma from beta-decay
Or even from isomer decay?
AIDA is at RIKEN...



Thanks for collaborating...

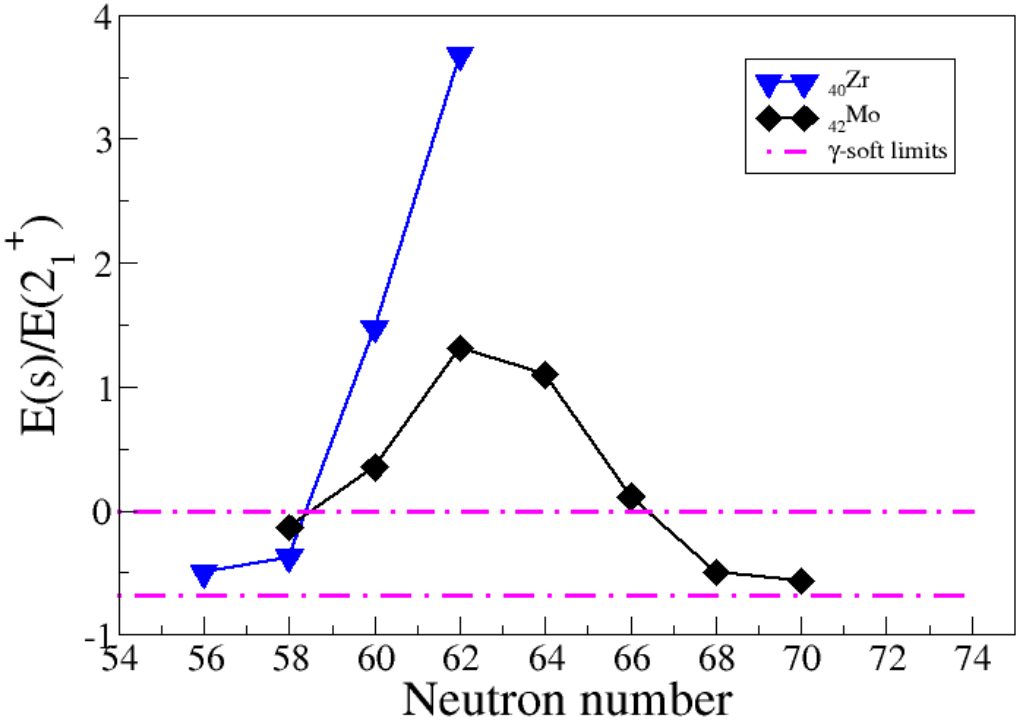
F. Browne[1,3], A. M. Bruce[1], T. Sumikama[2], S. Nishimura[3], P. Doornenbal[3], G. Lorusso[3], Z. Patel[3,4], S. Rice[3,4], L. Sinclair[3,5], P.-A. Söderström[3], H. Watanabe[3,6], J. Wu[3,7], Z. Y. Xu[8], H. Baba[3], N. Chiga[2], R. Carroll[4], R. Daido[9], F. Didierjean[13], Y. Fang[9], G. Gey[10,11,3], E. Ideguchi[9], N. Inabe[3], T. Isobe[3], D. Kameda[3], I. Kojouharov[12], N. Kurz[12], T. Kubo[3], S. Lalkovski[14], Z. Li[7], R. Lozeva[13], N. Naoki[3], I. Nishizuka[2], H. Nishibata[9], A. Odahara[9], Zs. Podolyák[4], P. H. Regan[4,15], O. J. Roberts[1], H. Sakurai[3], H. Schaffner[12], G. S. Simpson[10], H. Suzuki[3], H. Takeda[3], M. Tanaka[9], J. Taprogge[16,17,3], V. Werner[18,19], O. Wieland[20], and A. Yagi[9]

[1] *School of Computing, Engineering and Mathematics, University of Brighton, Brighton BN2 4JG, United Kingdom*
[2] *Department of Physics, Tohoku University, Aoba, Sendai, Miyagi 980-8578, Japan*
[3] *RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan*
[4] *Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*
[5] *Department of Physics, University of York, Heslington, York YO10 5DD, United Kingdom*
[6] *Department of Physics, Beihang University, Beijing 100191, China*
[7] *Department of Physics, Peking University, Beijing 100871, China*
[8] *Department of Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[9] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[10] *LPSC, Université Grenoble-Alpes, CNRS/IN2P3, F-38026 Grenoble Cedex, France*
[11] *ILL, 38042 Grenoble Cedex, France*
[12] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*
[13] *IPHC, CNRS/IN2P3 and Université de Strasbourg, Strasbourg, France*
[14] *Department of Physics, University of Sofia, 1164 Sofia, Bulgaria*
[15] *National Physical Laboratory, Teddington, Middlesex, TW11 0LW, United Kingdom*
[16] *Departamento de Física Teórica, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
[17] *Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain*
[18] *A. W. Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520, USA*
[19] *Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany*
[20] *INFN Sezione di Milano, I-20133 Milano, Italy*

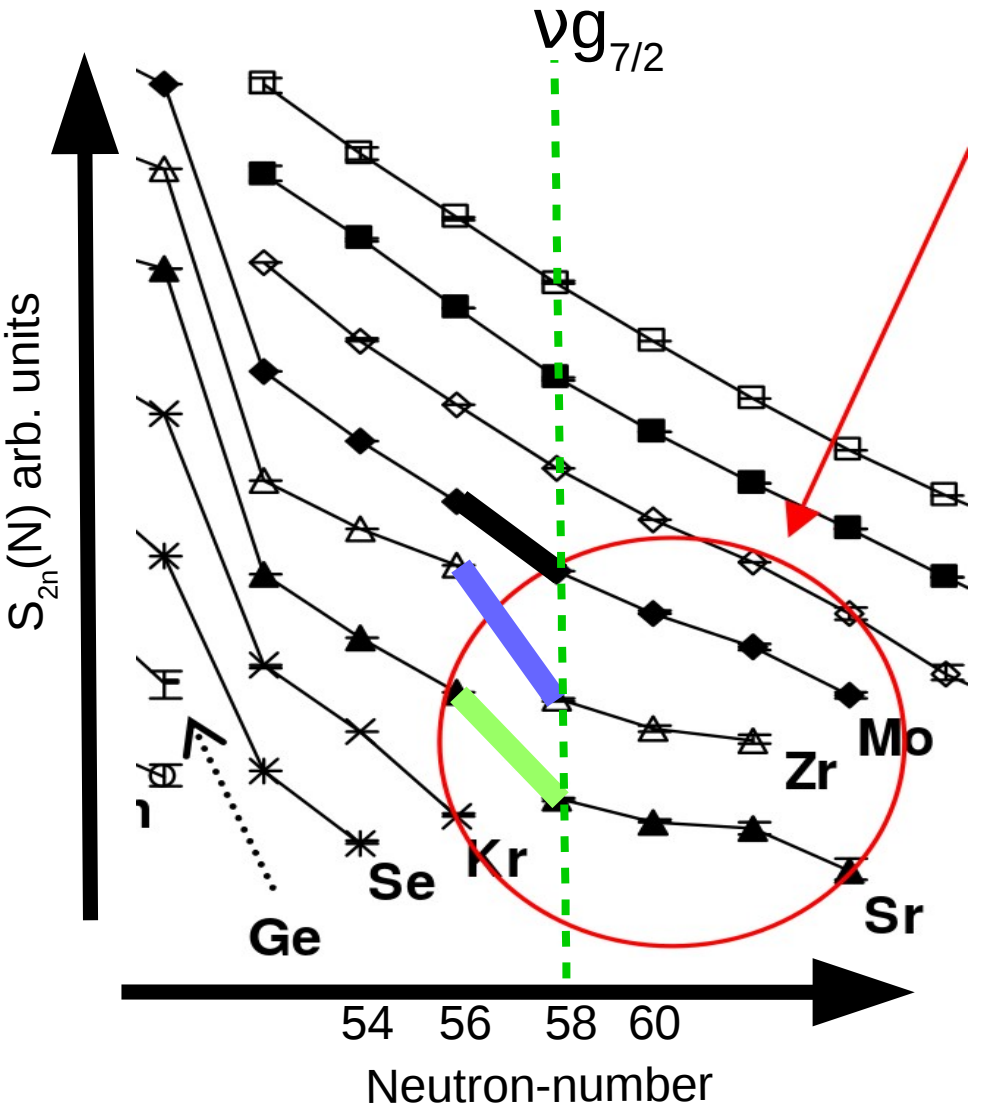
… and thank you for listening!

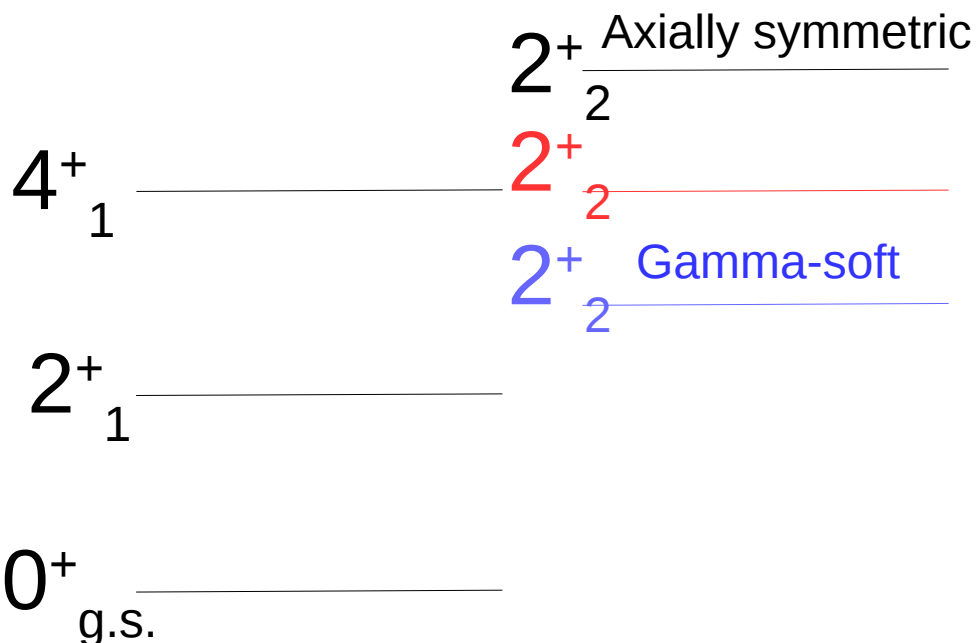
Axial symmetry?

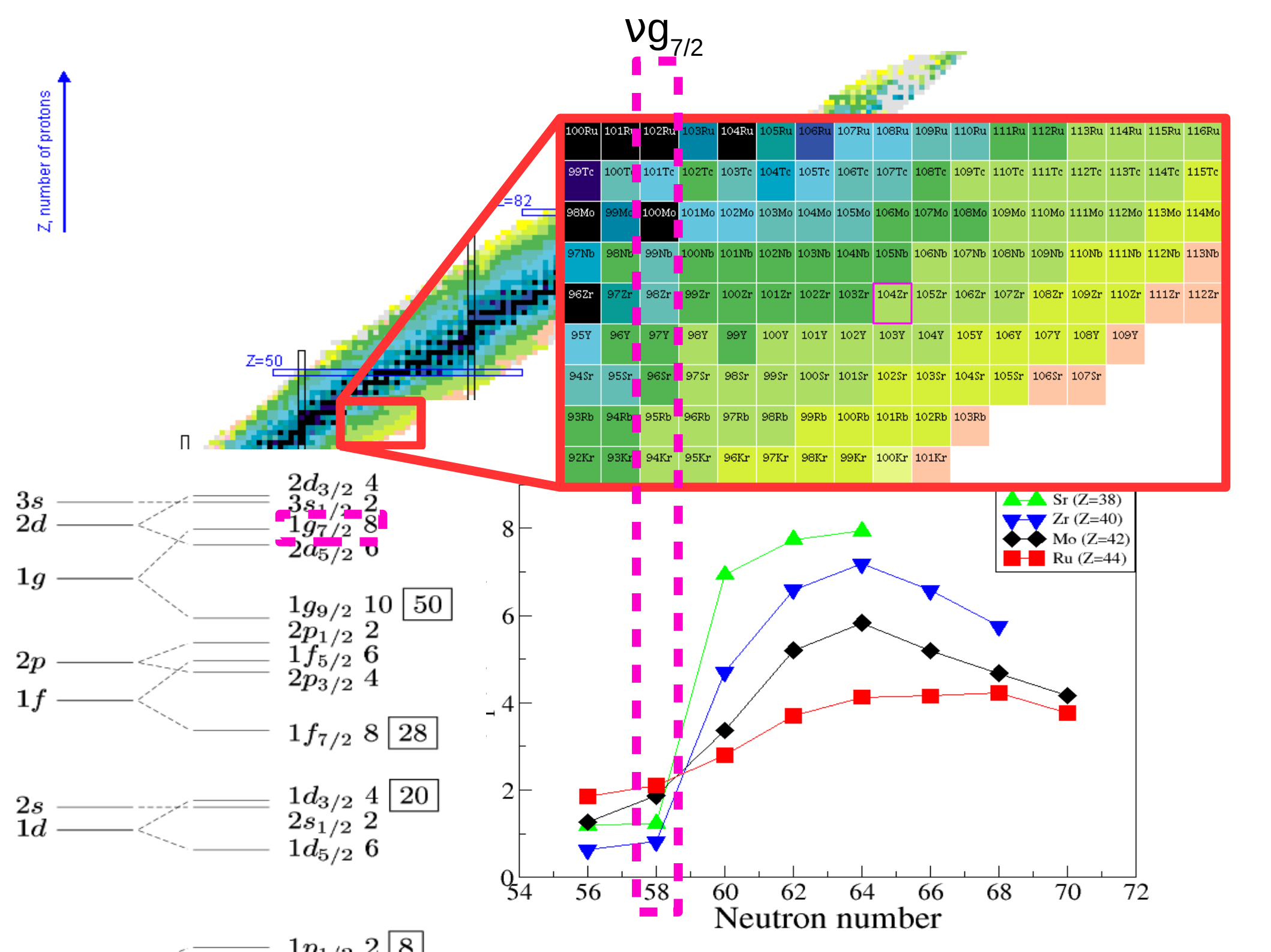
$E(2^+_2\text{-}4^+_1)/E(2^+_1)$



$S_{2n}(N)=E_B(N+1)-E_B(N)$
(phase change)






νg7/2
Z, number of protons
Z=82
Z=50
100Ru 101Ru 102Ru 103Ru 104Ru 105Ru 106Ru 107Ru 108Ru 109Ru 110Ru 111Ru 112Ru 113Ru 114Ru 115Ru 116Ru
99Tc 100Tc 101Tc 102Tc 103Tc 104Tc 105Tc 106Tc 107Tc 108Tc 109Tc 110Tc 111Tc 112Tc 113Tc 114Tc 115Tc
98Mo 99Mo 100Mo 101Mo 102Mo 103Mo 104Mo 105Mo 106Mo 107Mo 108Mo 109Mo 110Mo 111Mo 112Mo 113Mo 114Mo
97Nb 98Nb 99Nb 100Nb 101Nb 102Nb 103Nb 104Nb 105Nb 106Nb 107Nb 108Nb 109Nb 110Nb 111Nb 112Nb 113Nb
96Zr 97Zr 98Zr 99Zr 100Zr 101Zr 102Zr 103Zr 104Zr 105Zr 106Zr 107Zr 108Zr 109Zr 110Zr 111Zr 112Zr
95Y 96Y 97Y 98Y 99Y 100Y 101Y 102Y 103Y 104Y 105Y 106Y 107Y 108Y 109Y
94Sr 95Sr 96Sr 97Sr 98Sr 99Sr 100Sr 101Sr 102Sr 103Sr 104Sr 105Sr 106Sr 107Sr
93Rb 94Rb 95Rb 96Rb 97Rb 98Rb 99Rb 100Rb 101Rb 102Rb 103Rb
92Kr 93Kr 94Kr 95Kr 96Kr 97Kr 98Kr 99Kr 100Kr 101Kr
3s
2d
1g
2p
1f
2s
1d
2d3/2 4
3s1/2 2
1g7/2 8
2d5/2 6
1g9/2 10 50
2p1/2 2
1f5/2 6
2p3/2 4
1f7/2 8 28
1d3/2 4 20
2s1/2 2
1d5/2 6
Sr (Z=38)
Zr (Z=40)
Mo (Z=42)
Ru (Z=44)
Neutron number