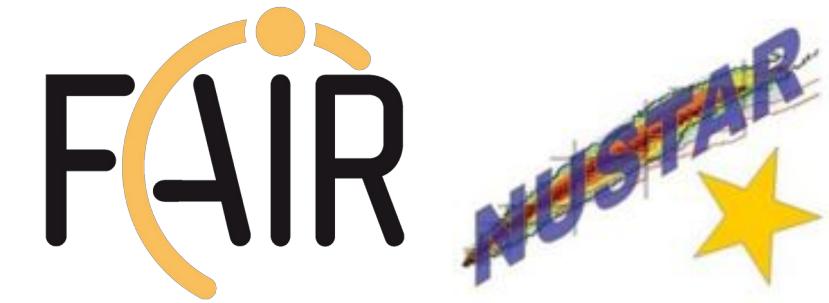




# Core-breaking in the most neutron-deficient Sn isotopes



Guangxin Zhang, Daniele Mengoni

University and INFN, Padova, Italy

and DESPEC collaboration



UNIVERSITÀ  
DEGLI STUDI  
DI PADOVA



GSI Helmholtzzentrum für Schwerionenforschung GmbH

INPC, Santiago de Compostela, Oct 24-28, 2022

1222-2022  
**800** ANNI



# Outlook

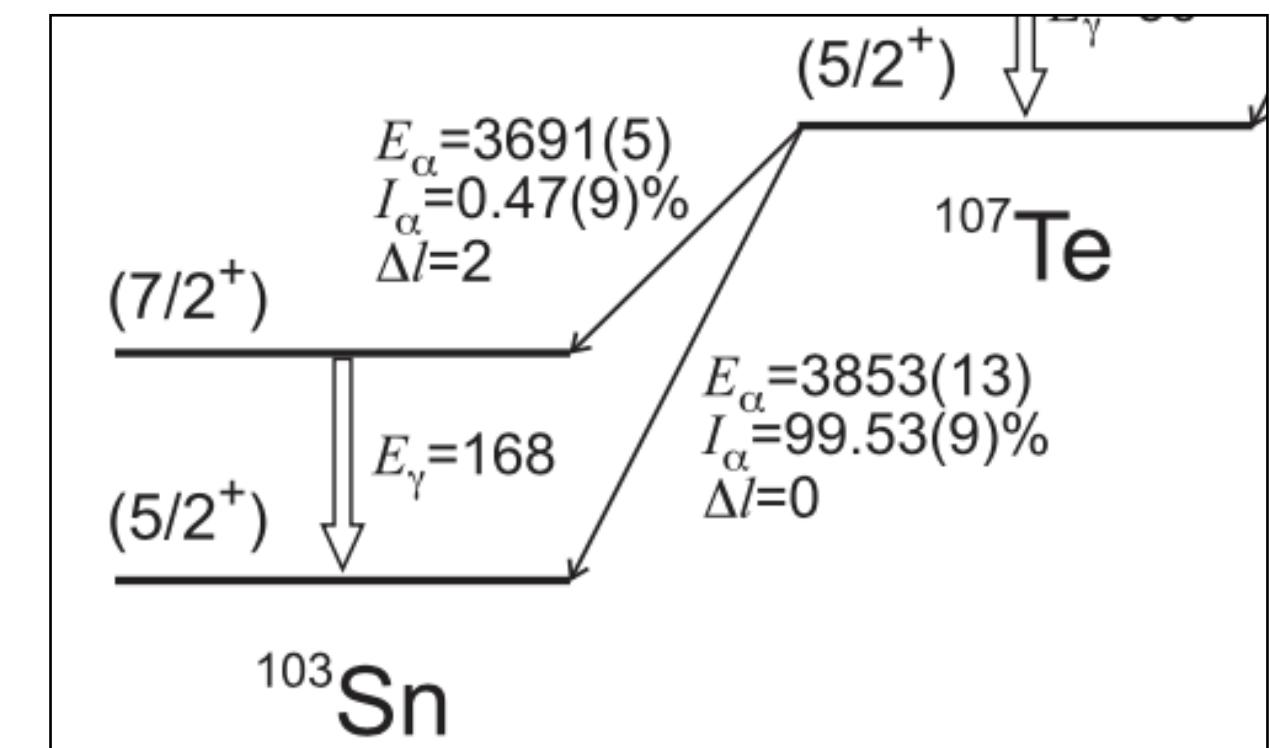
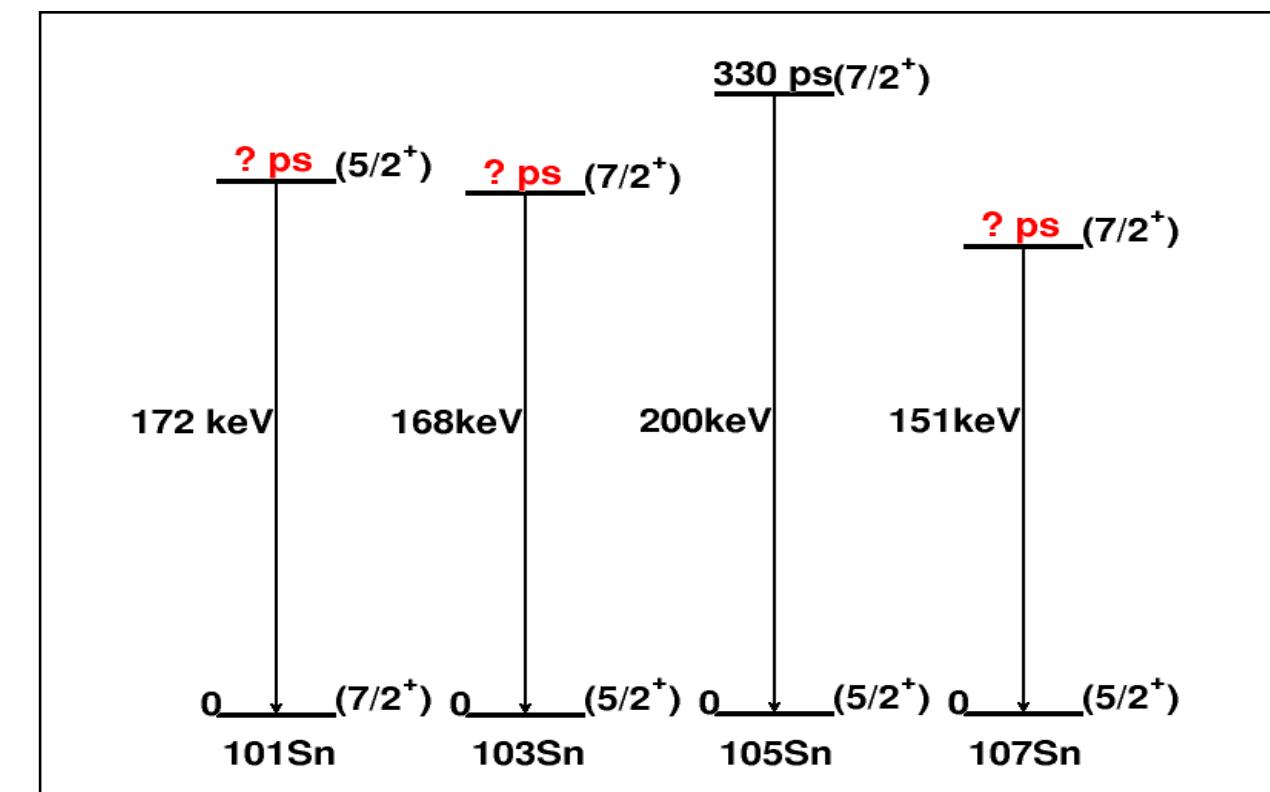
- Motivations
- Facility and experimental setup
- Isomer consistency check
- Lifetime results
- Summary and perspectives

# Nuclear Structure: BM1 in odd-even Sn

## Motivation on $B(M1, 7/2^+ \rightarrow 5/2^+)$ measurement in $^{103}\text{Sn}$

- No lifetime measurement beyond  $^{105}\text{Sn}$  [rel. Coulex in  $^{104}\text{Sn}$  (.. and  $^{102}\text{Sn}$ )].
- Excitation energies can be reproduced in the d5/2 and g7/2 neutron-space, it is *not sufficient* to justify the experimental lifetime value.
- $^{105}\text{Sn}$ : core-breaking effects seems the key
- $^{103}\text{Sn}$ :  $B(M1 : 7/2^+ \rightarrow 5/2^+)$  essential *on the core-breaking contribution* towards  $^{101,100}\text{Sn}$ .
- Experimentally,  $\alpha$  decay from  $^{107}\text{Te}$

	Pure neutron space		Core breaking (gds)		experiment	
	$B(\text{M1}) [\text{W.u.}]$	$\tau [\text{ns}]$	$B(\text{M1}) [\text{W.u.}]$	$\tau [\text{ns}]$	$B(\text{M1}) [\text{W.u.}]$	$\tau [\text{ns}]$
$^{103}\text{Sn}$	$3 \times 10^{-5}$	160	$1 \times 10^{-3}$	6	?	?
$^{105}\text{Sn}$	$1 \times 10^{-4}$	33	$1 \times 10^{-3}$	3	$7.7(19) \times 10^{-3}$	0.5(1)

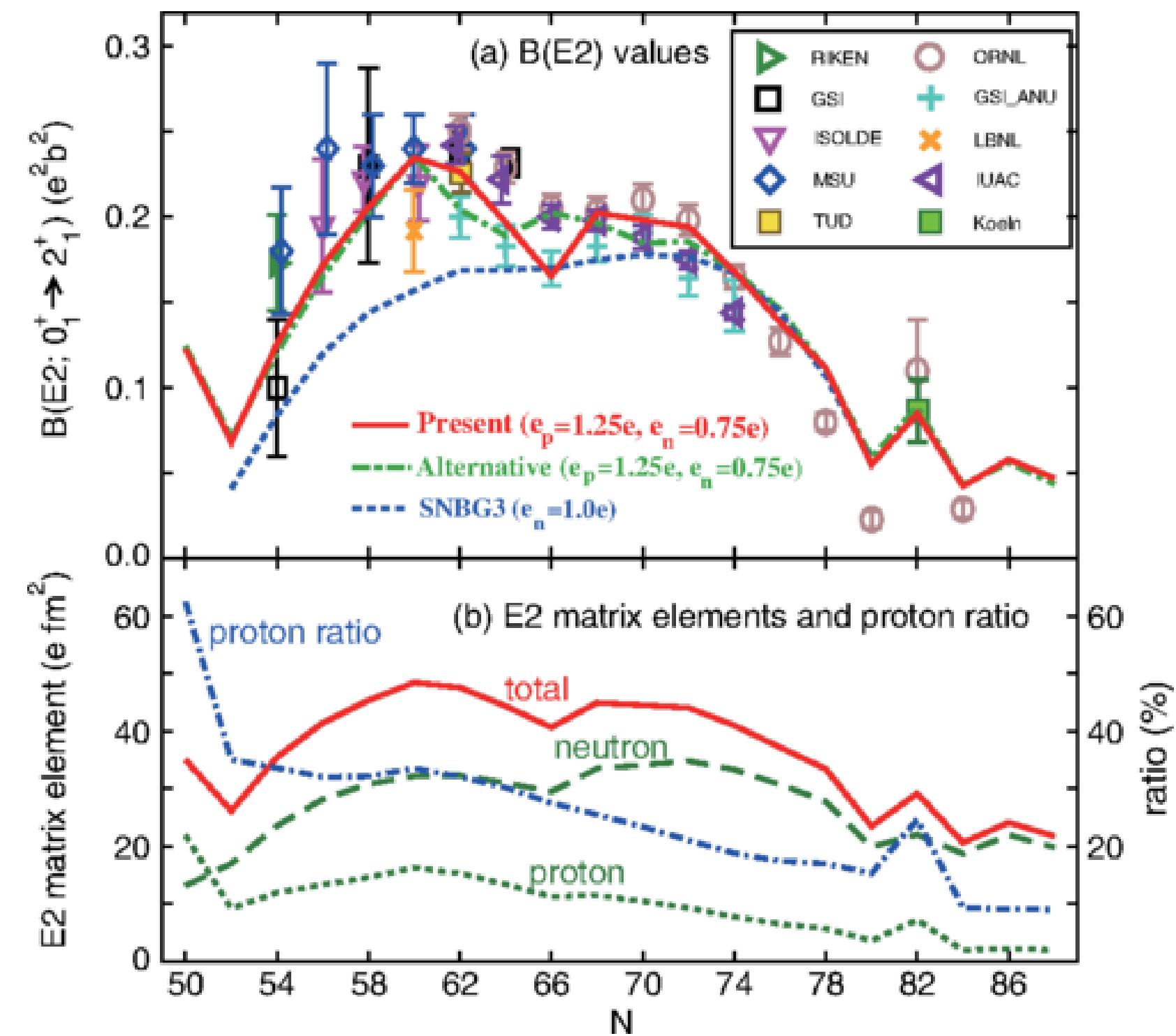


I. G. Darby PRL 105, 162502 (2010)

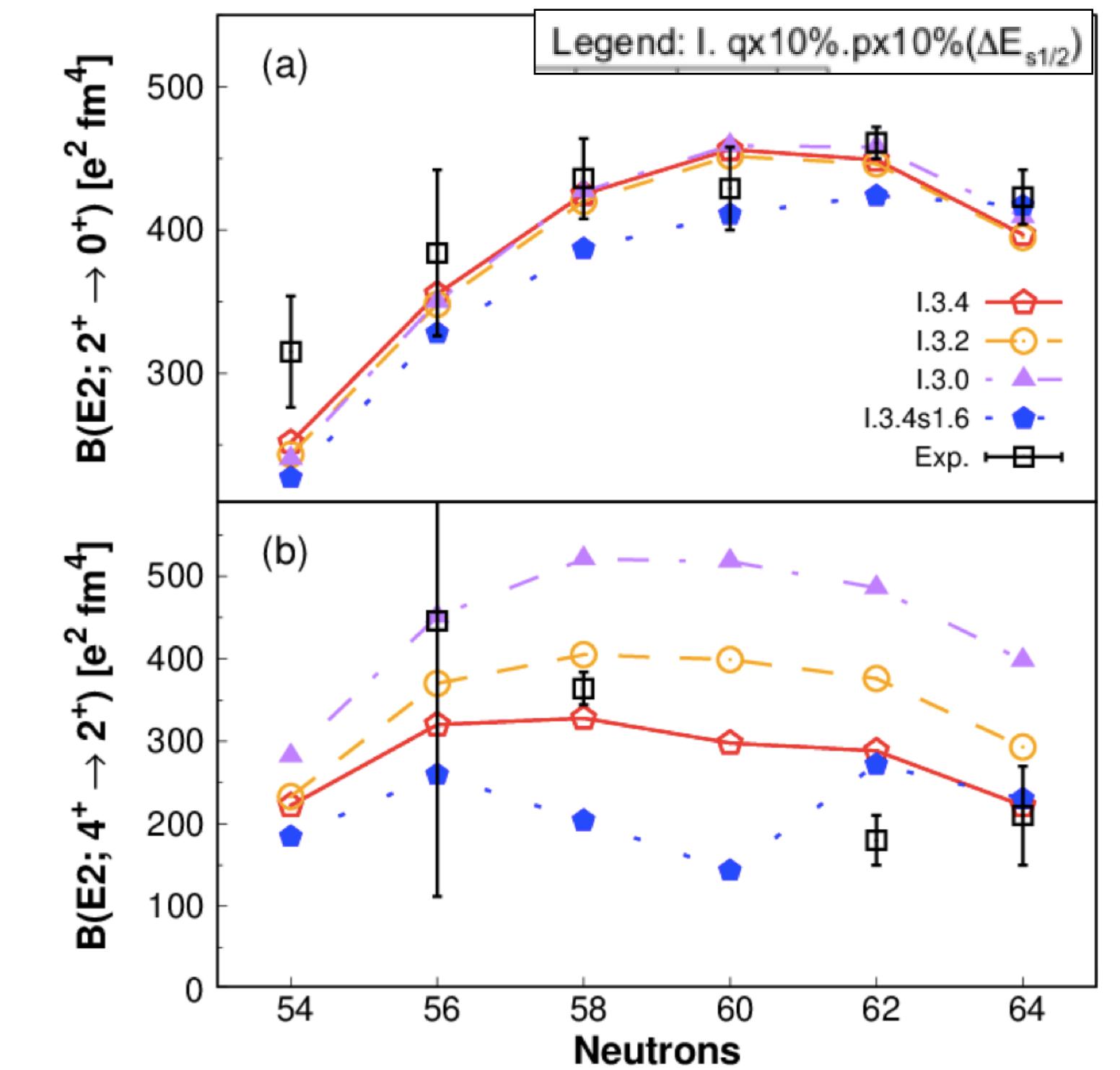
# Nuclear Structure: B(E2) in even-even Sn

## Motivation on $B(E2, 4^+ \rightarrow 2^{++})$ measurement in $^{102}\text{Sn}$

- LSSM explained the  $B(E2 : 0^+ \rightarrow 2^+)$  trend by activating ***protons*** and ***neutrons*** from the  **$g9/2$**  orbital (Togashi et al.) or by polarization mechanism (Zuker).
- Relative ***proton contribution larger*** towards  $^{100}\text{Sn}$  ( $g9/2 \rightarrow d5/2$  excitation is most important, ***quadrupole*** interaction)
- Interplay of pairing and quadrupole interactions called by Zuker, especially evident in the  $4^+$  state
- $B(E2 : 4^+ \rightarrow 2^+)$  value in  $^{102}\text{Sn}$  can probe the nature of first  $4^+$  and  $2^+$  states through the the interplay of pairing and quadrupole interactions.



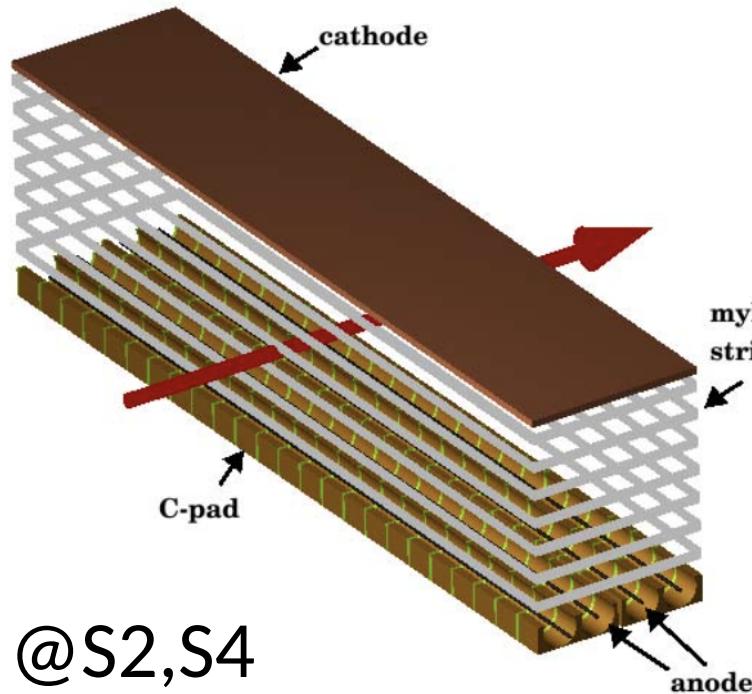
T. Togashi et al., Phys. Rev. Lett. 121, 062501 (2018)



M. Siciliano et al., Phys. Lett. B 806, 135474 (2020)  
A. P. Zuker et al., PRC 103, 024322 (2021)

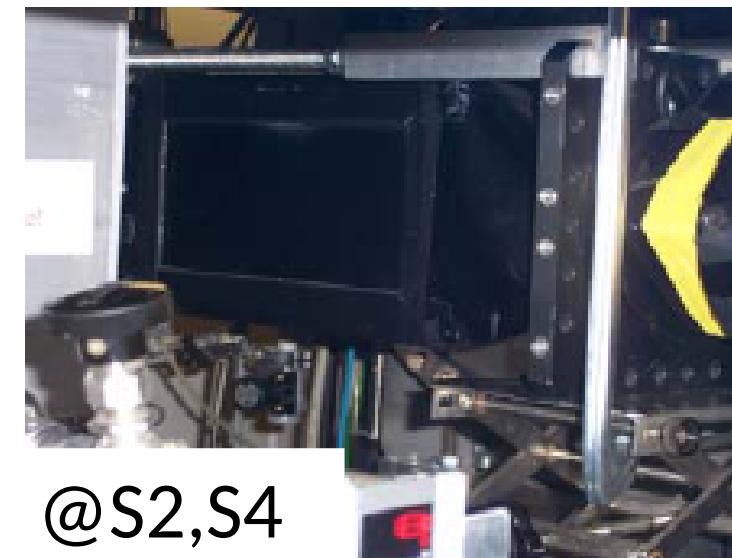
# FRagment Separator (FRS)

TPC: time projection chamber



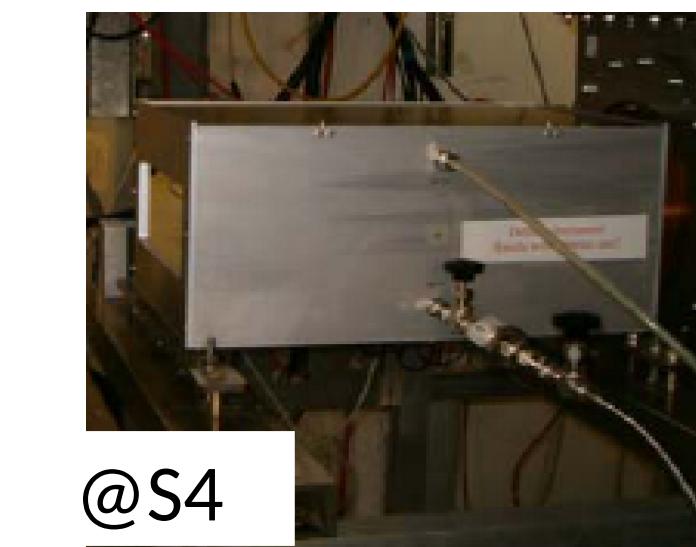
@S2,S4

Plastic scintillators



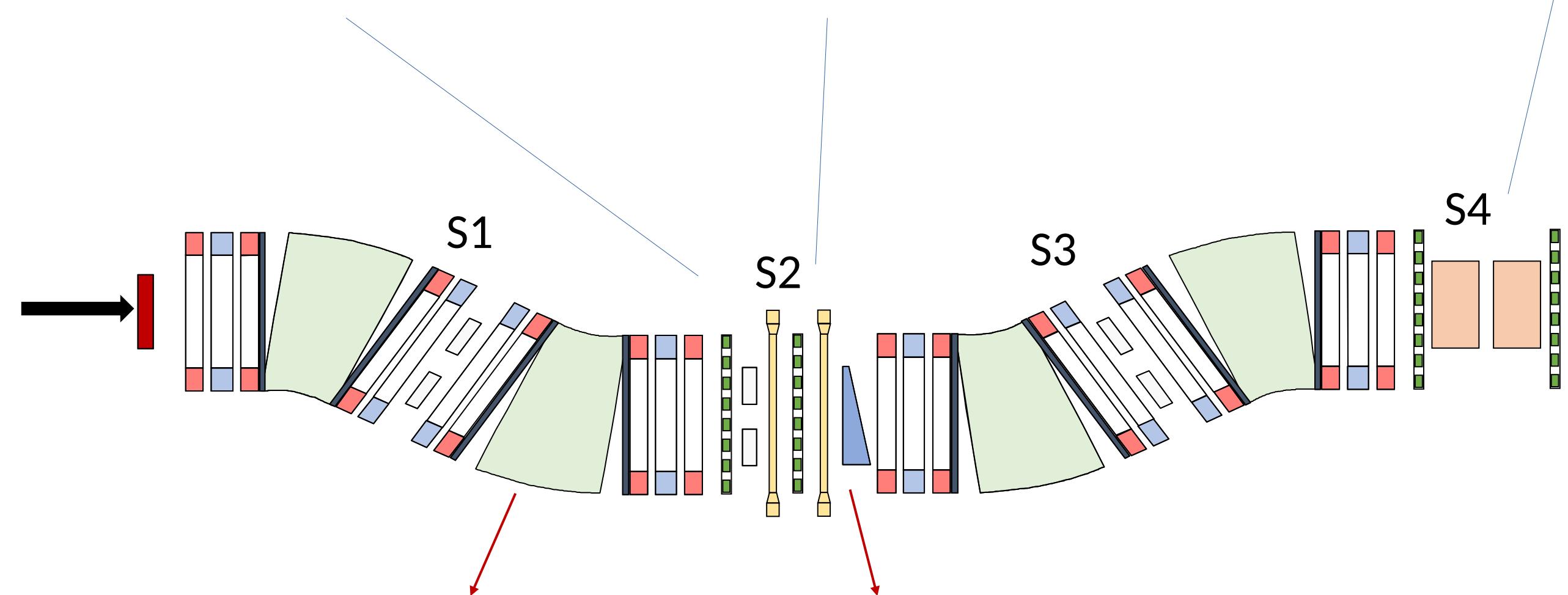
@S2,S4

Multi Sampling  
Ionisation Chambers



$$\Delta E \propto Z^2 f(\beta)$$

Selection and transport:  
 **$B\rho - \Delta E - B\rho$**



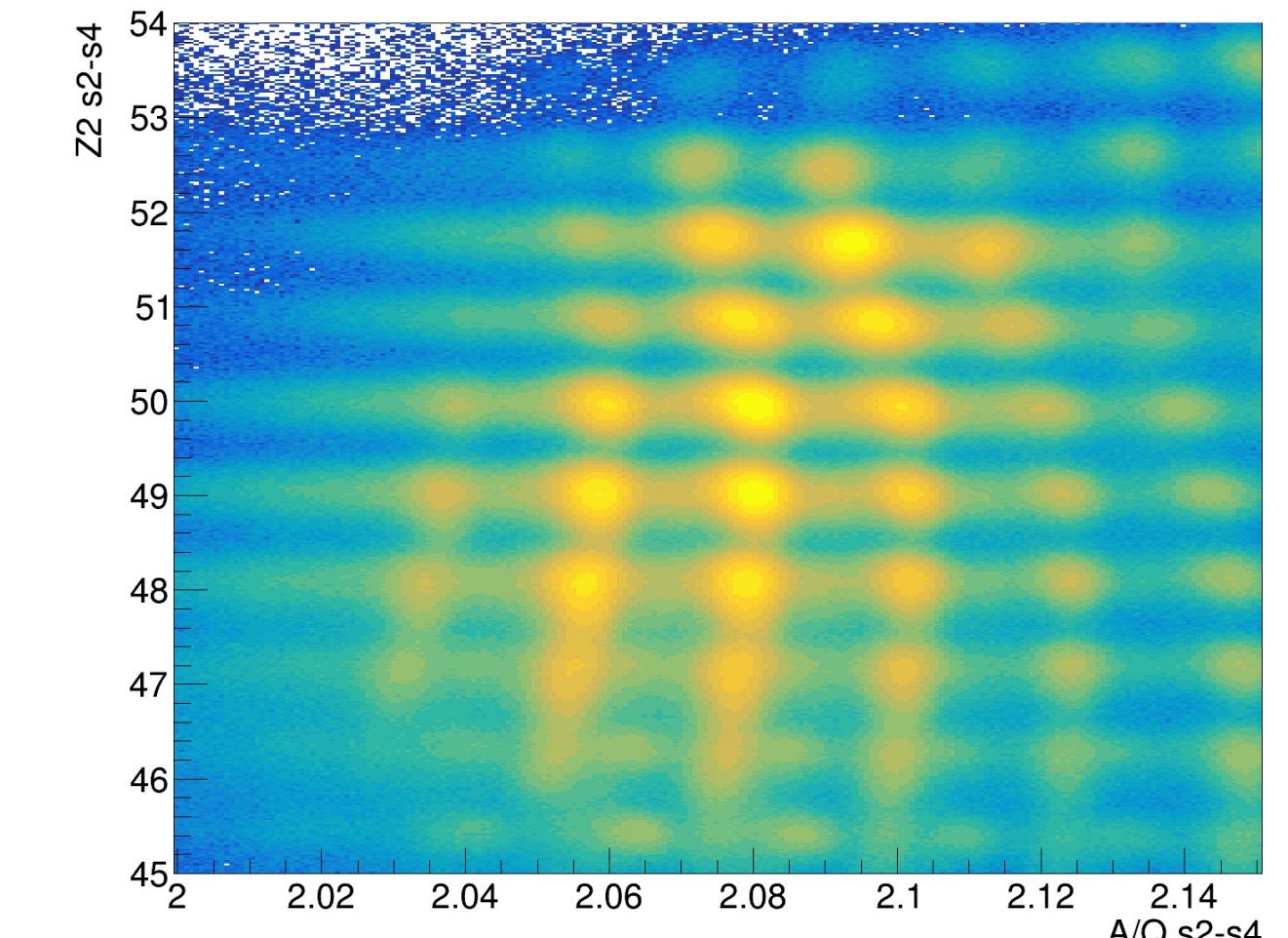
Dipole magnets

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

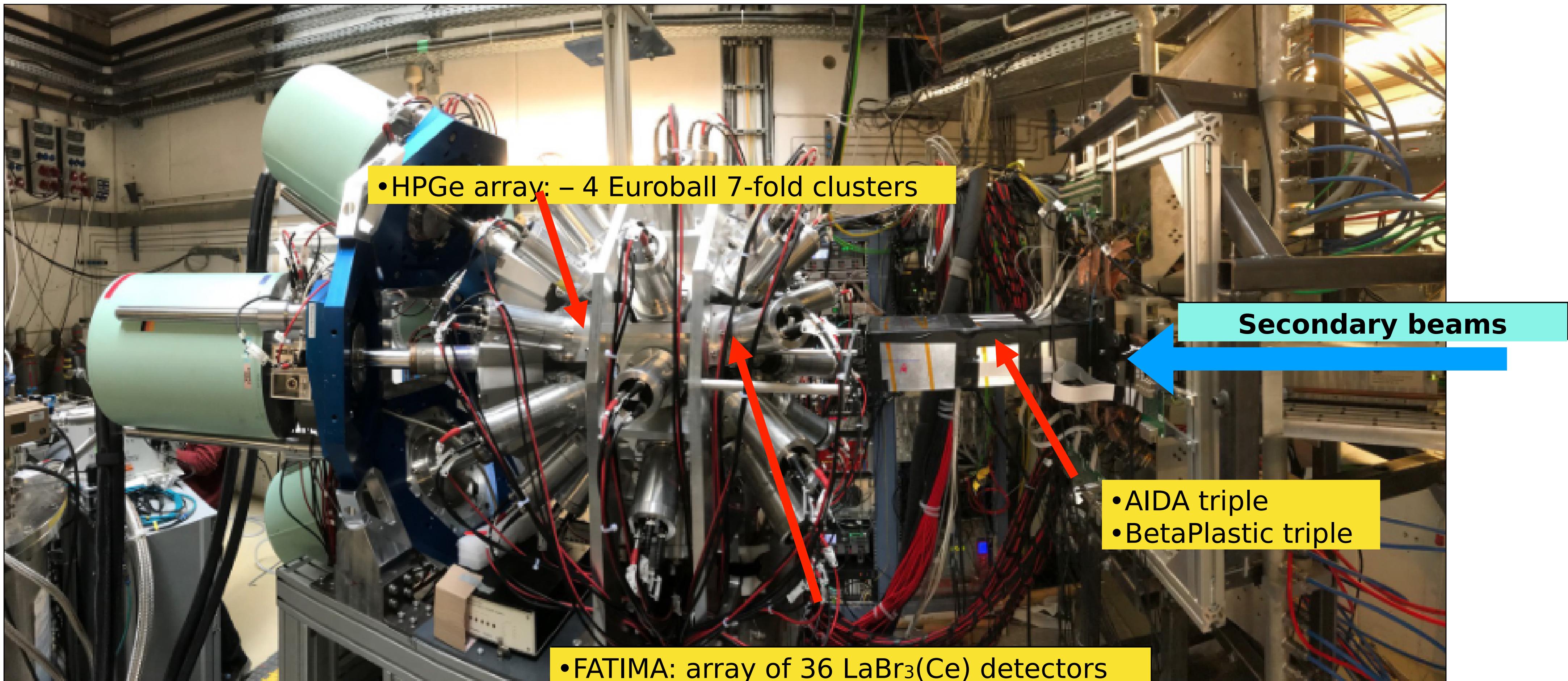
Degrader

$$\Delta E \propto Z^2 f(\beta)$$

Identification:  
**ToF –  $B\rho$  –  $\Delta E$**

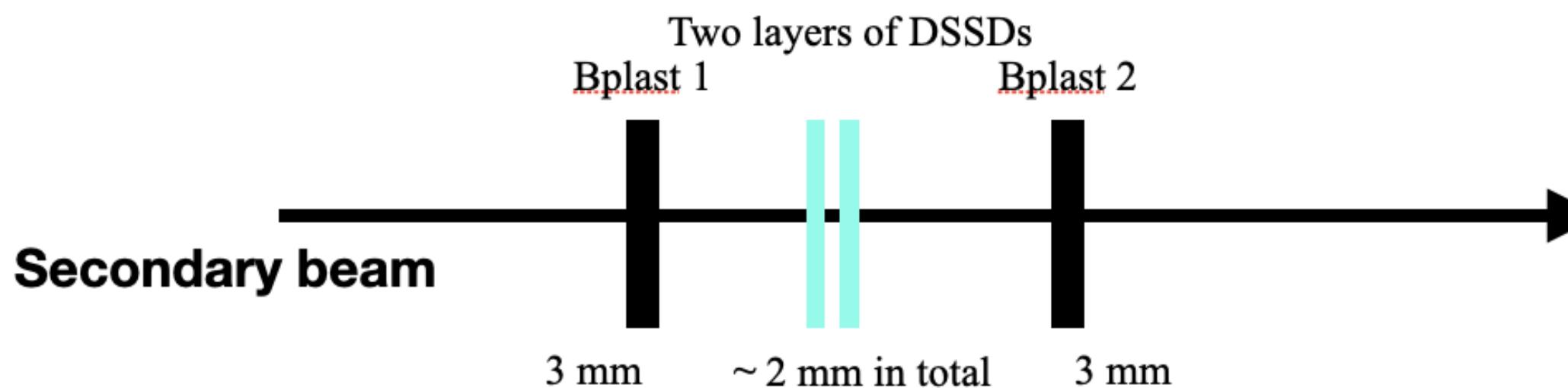


# Decay SPECtroscopy station (S496 exp)

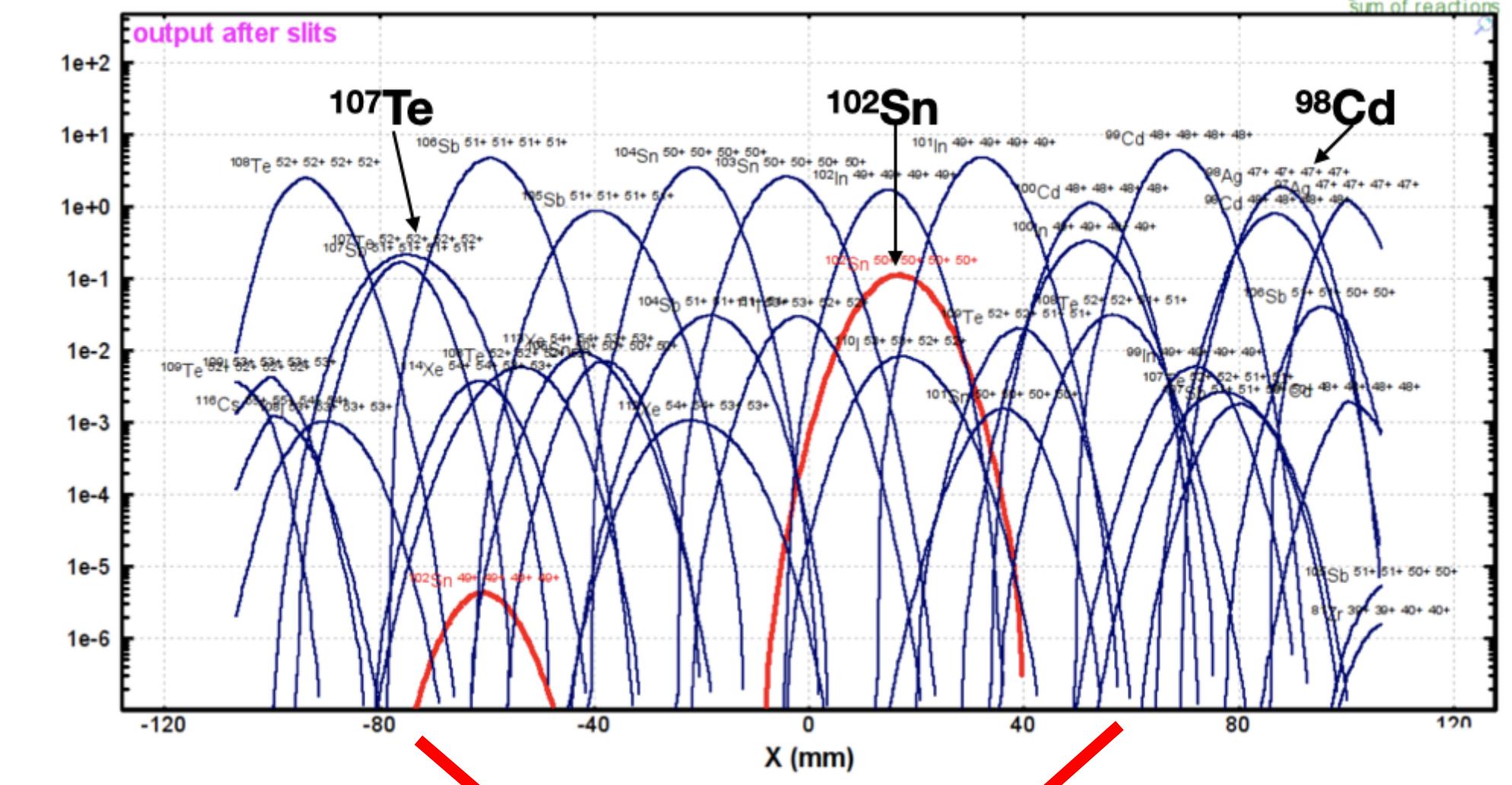


# Triple-AIDA active stopper

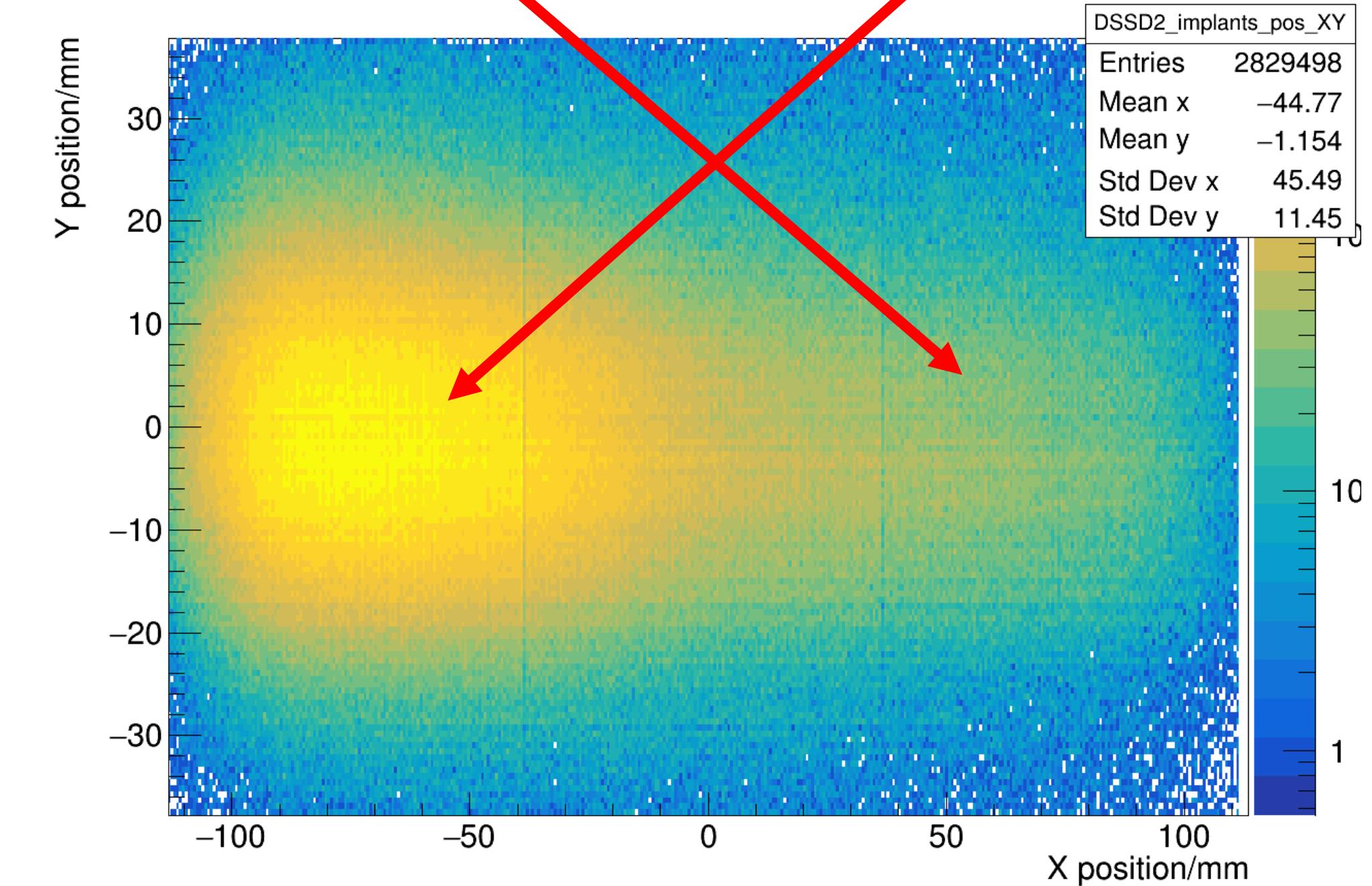
- 24\*8 cm<sup>2</sup>, 384×128 strips (49152 pixels),
- 0.560 mm inter-strip pitch,
- ion-beta correlation,



X-position distribution after S4 slit



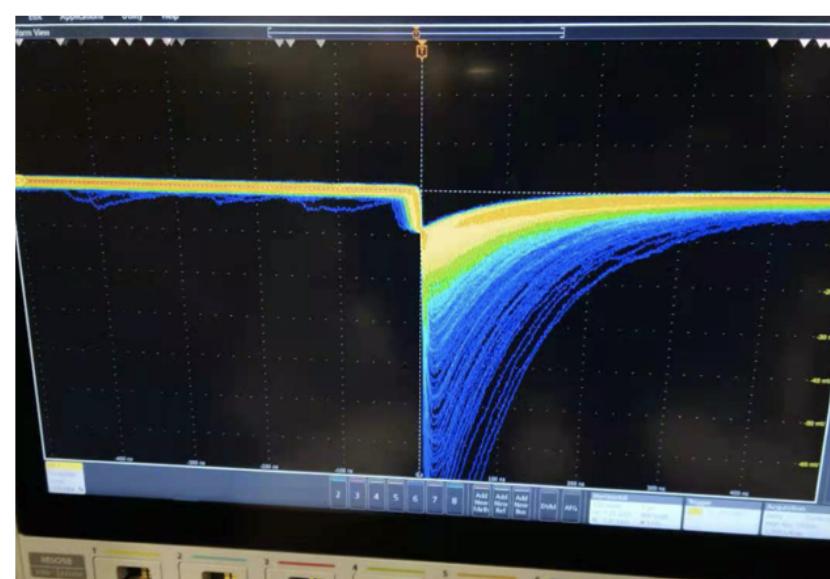
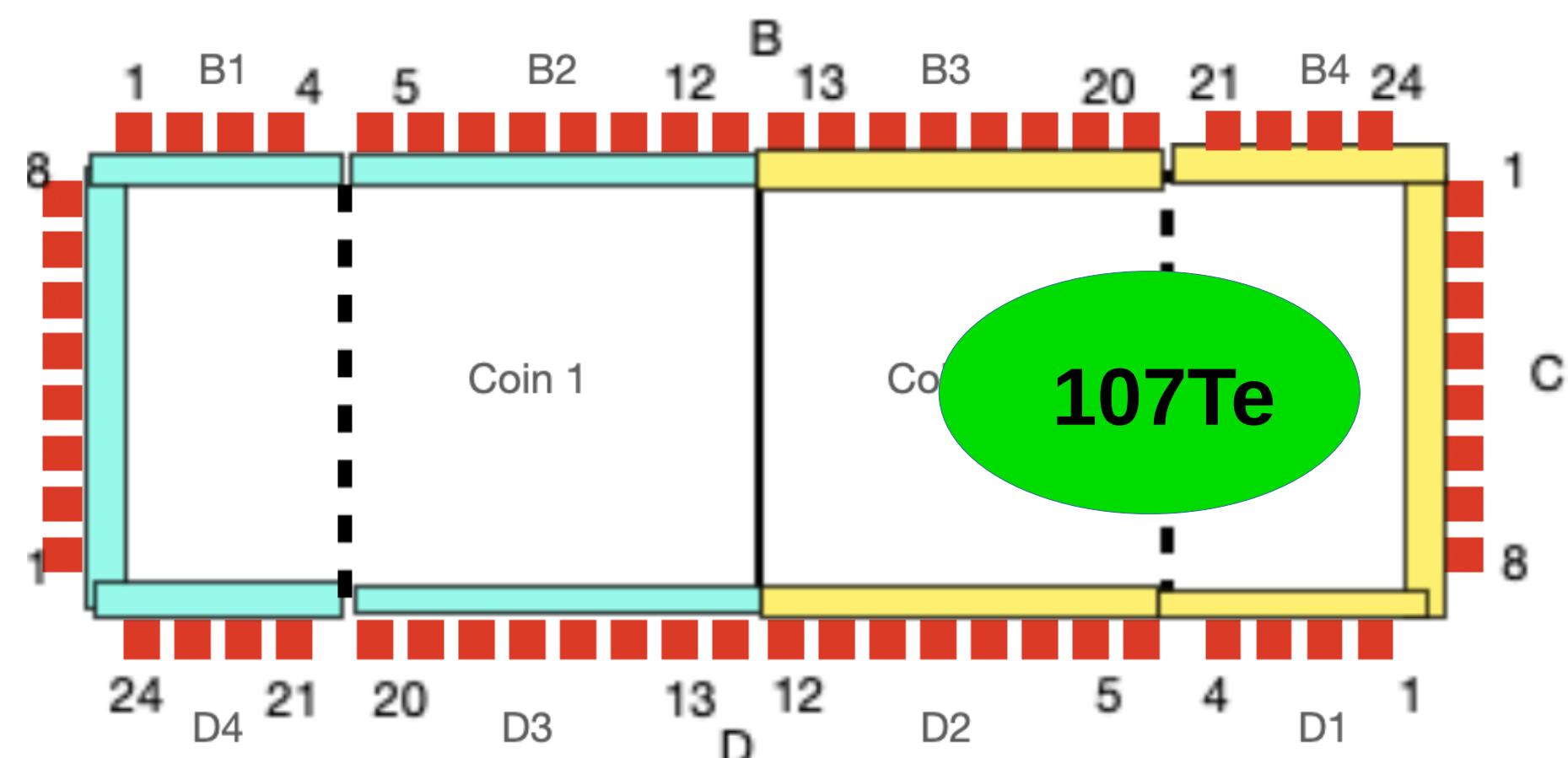
DSSD 2 implant position



24cm\*8cm

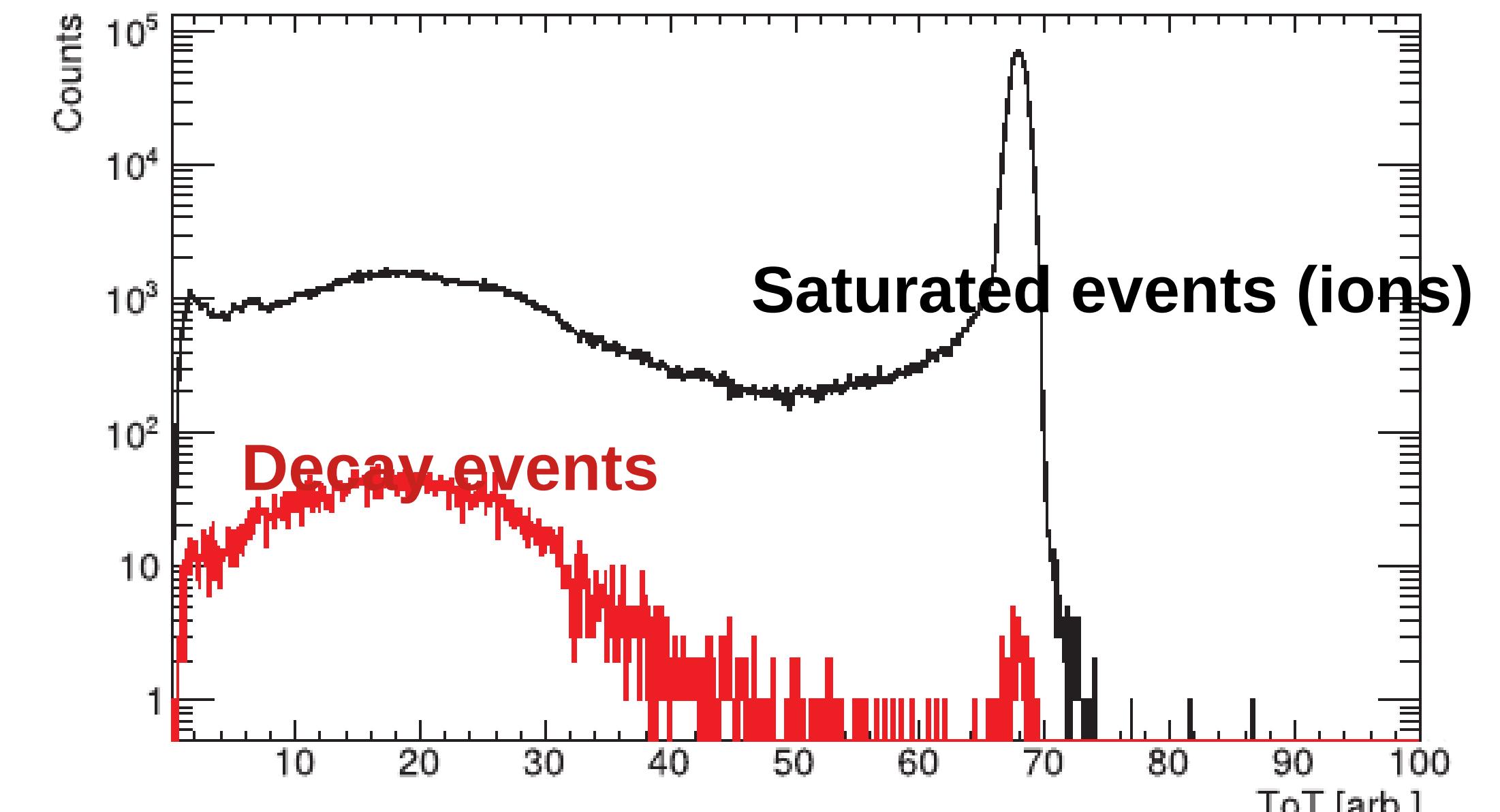
# Triple-BetaPlastic

- $\beta$  particles from  $\sim 80$  keV – 8 MeV
- Extended configuration  $24 \times 8 \text{ cm}^2$ ,
- Good time resolution  $\sim 450$  ps
- (source)

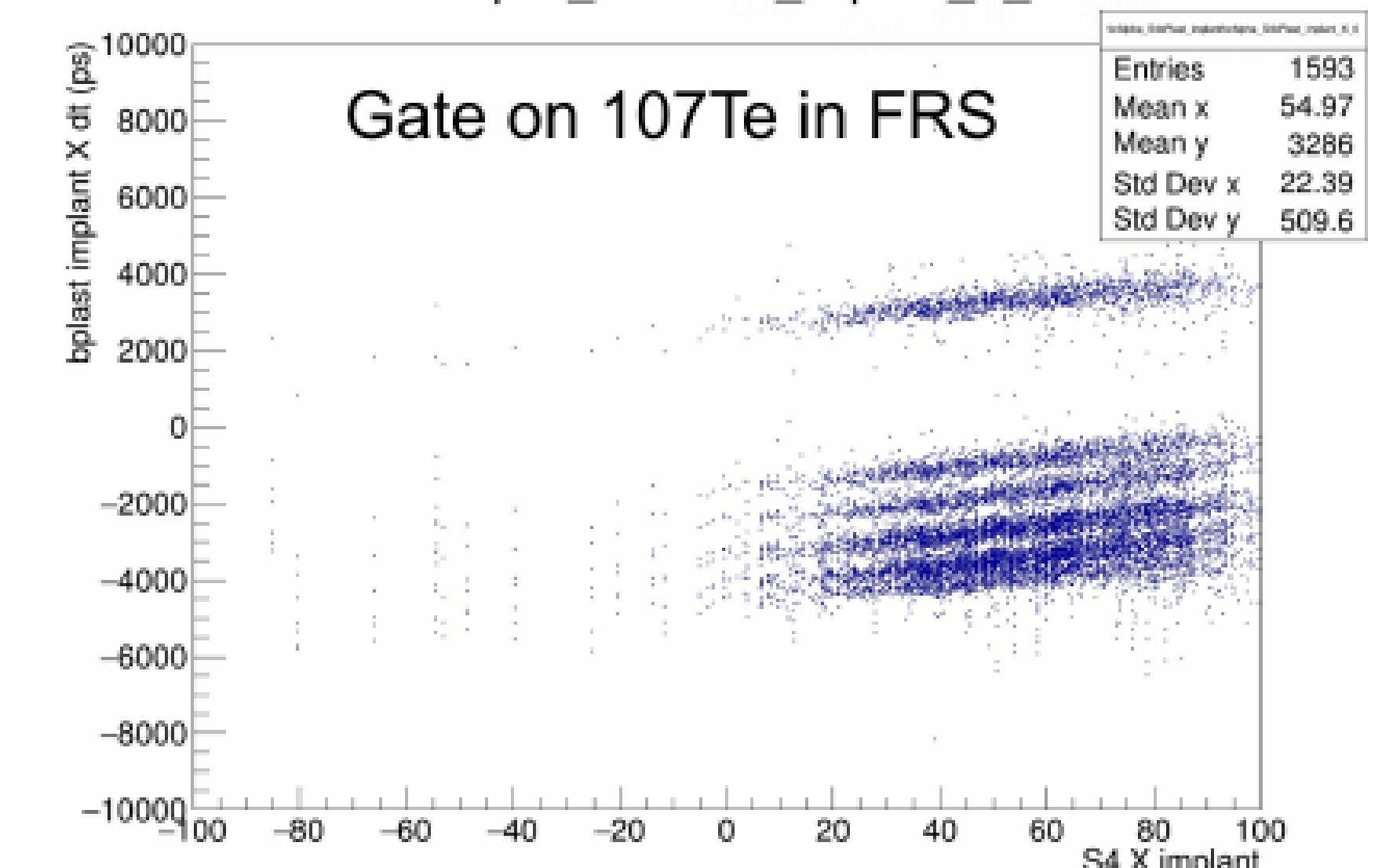


Twin peak: fast and slow signals

~ Energy spectrum

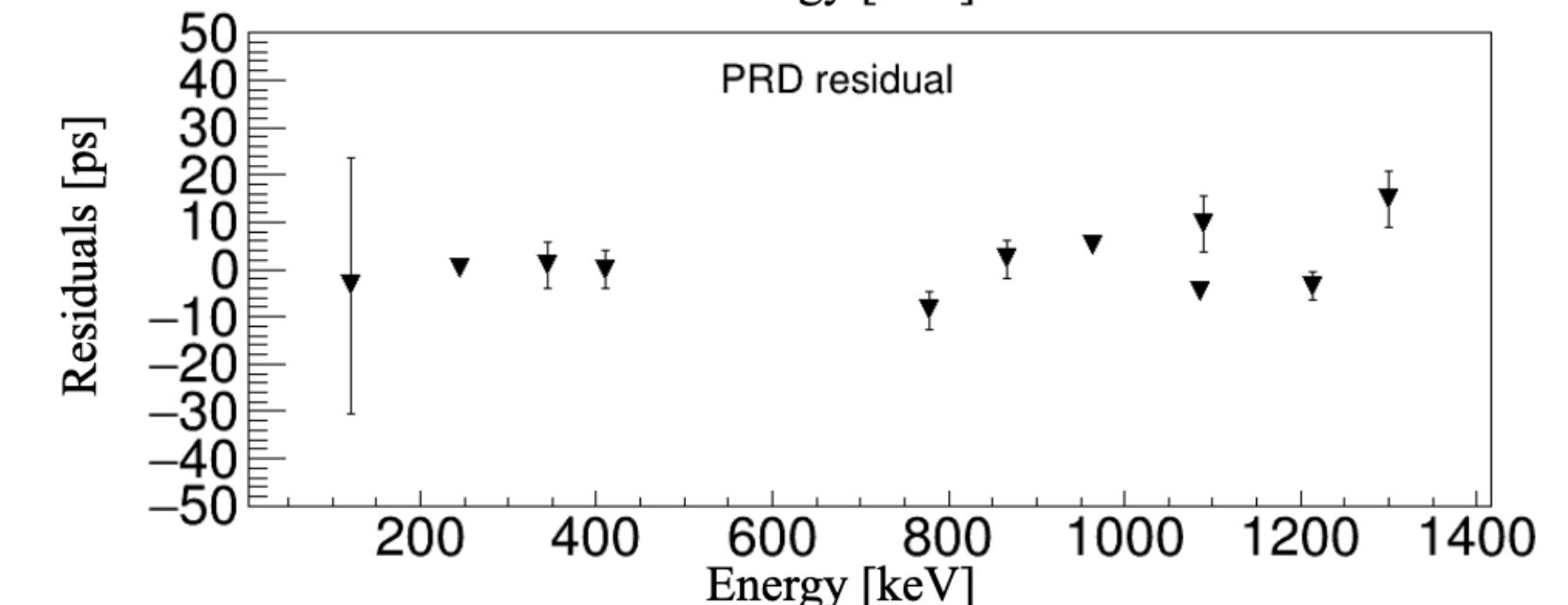
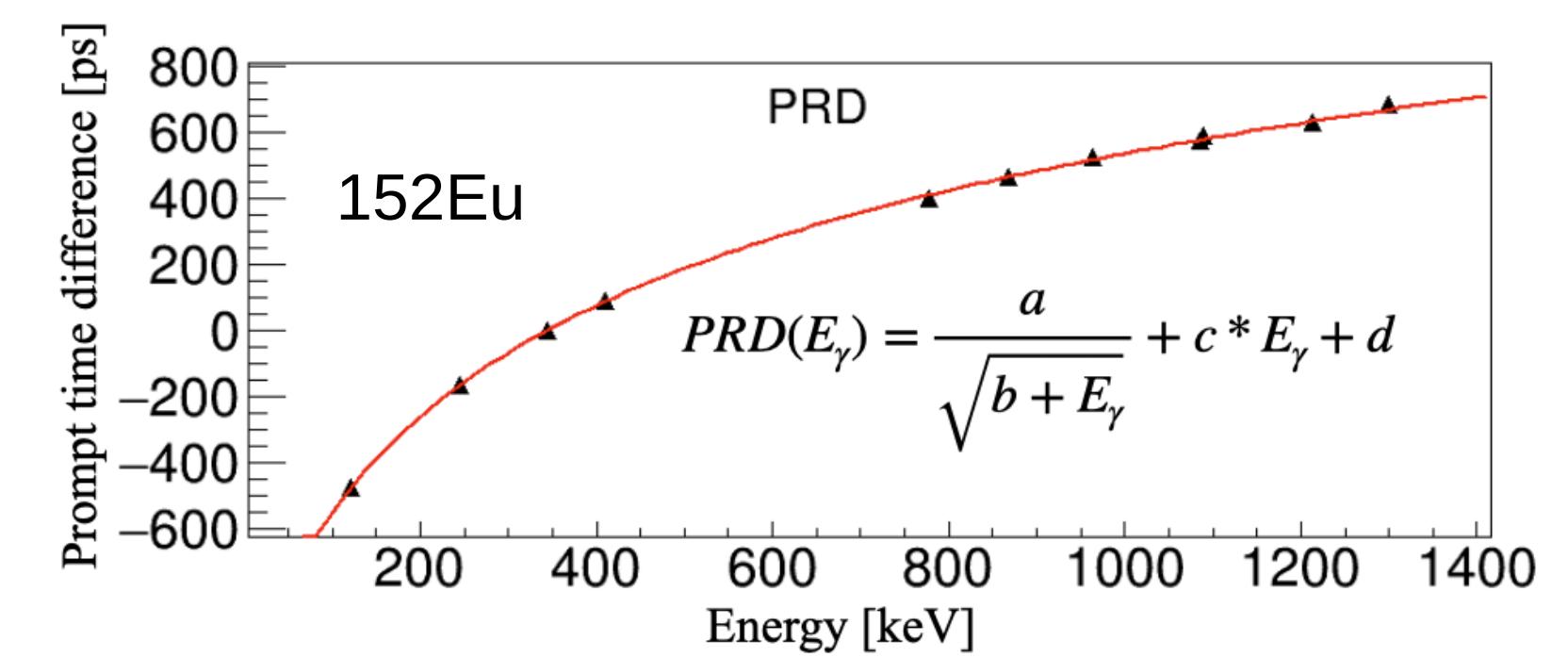
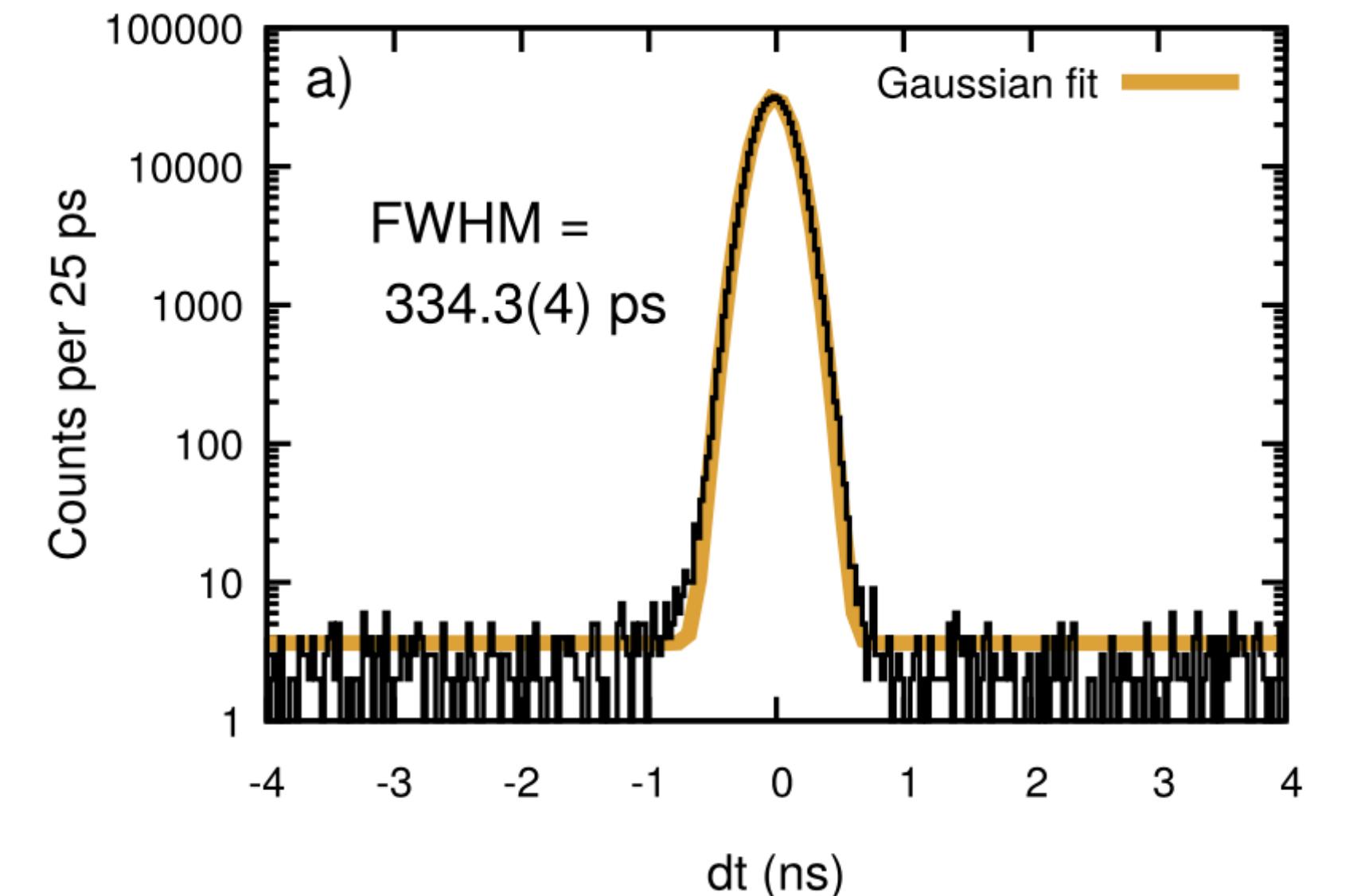
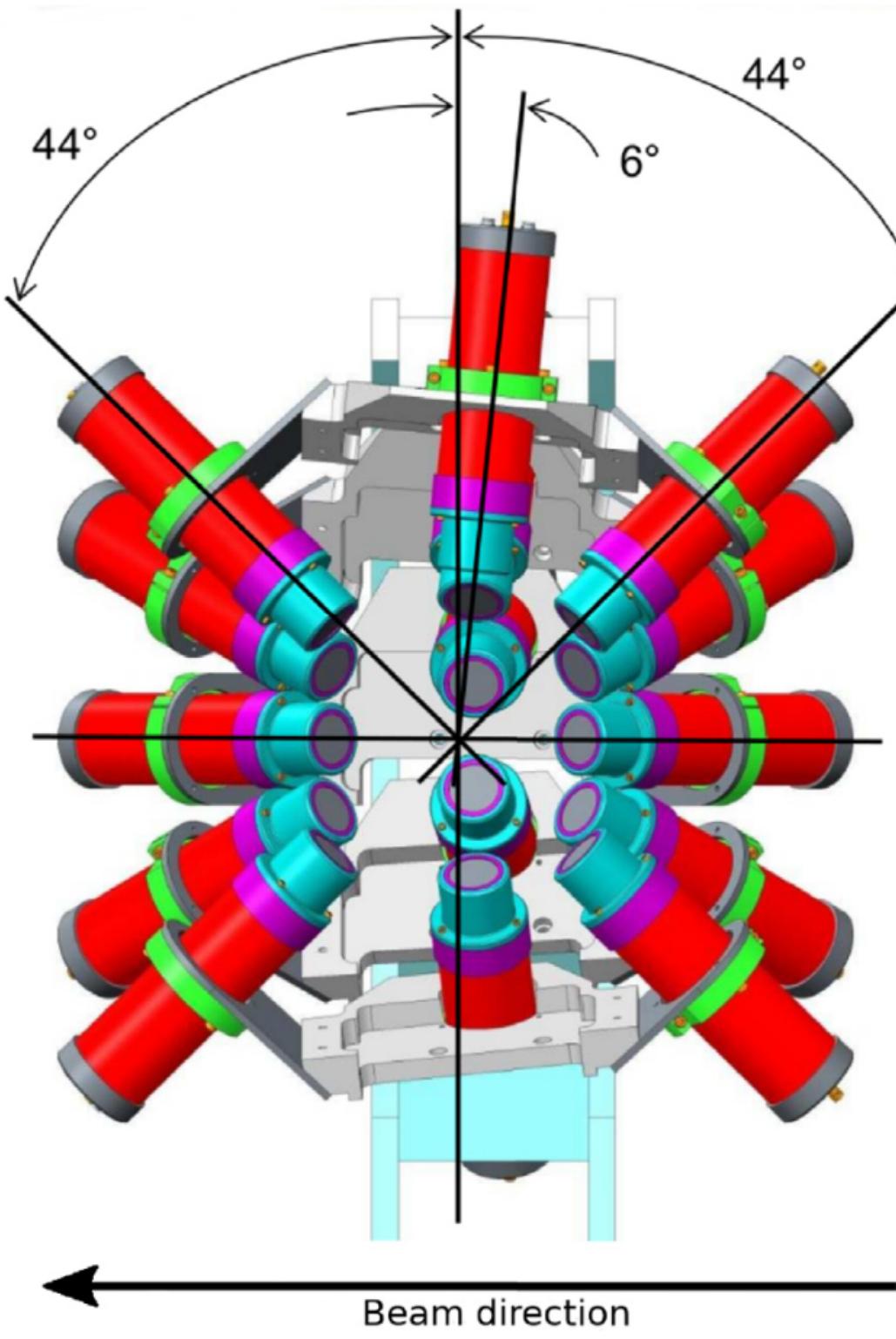


(Investigation of) Position resolution  
forAlpha\_S4bPlast\_Implant\_X\_0



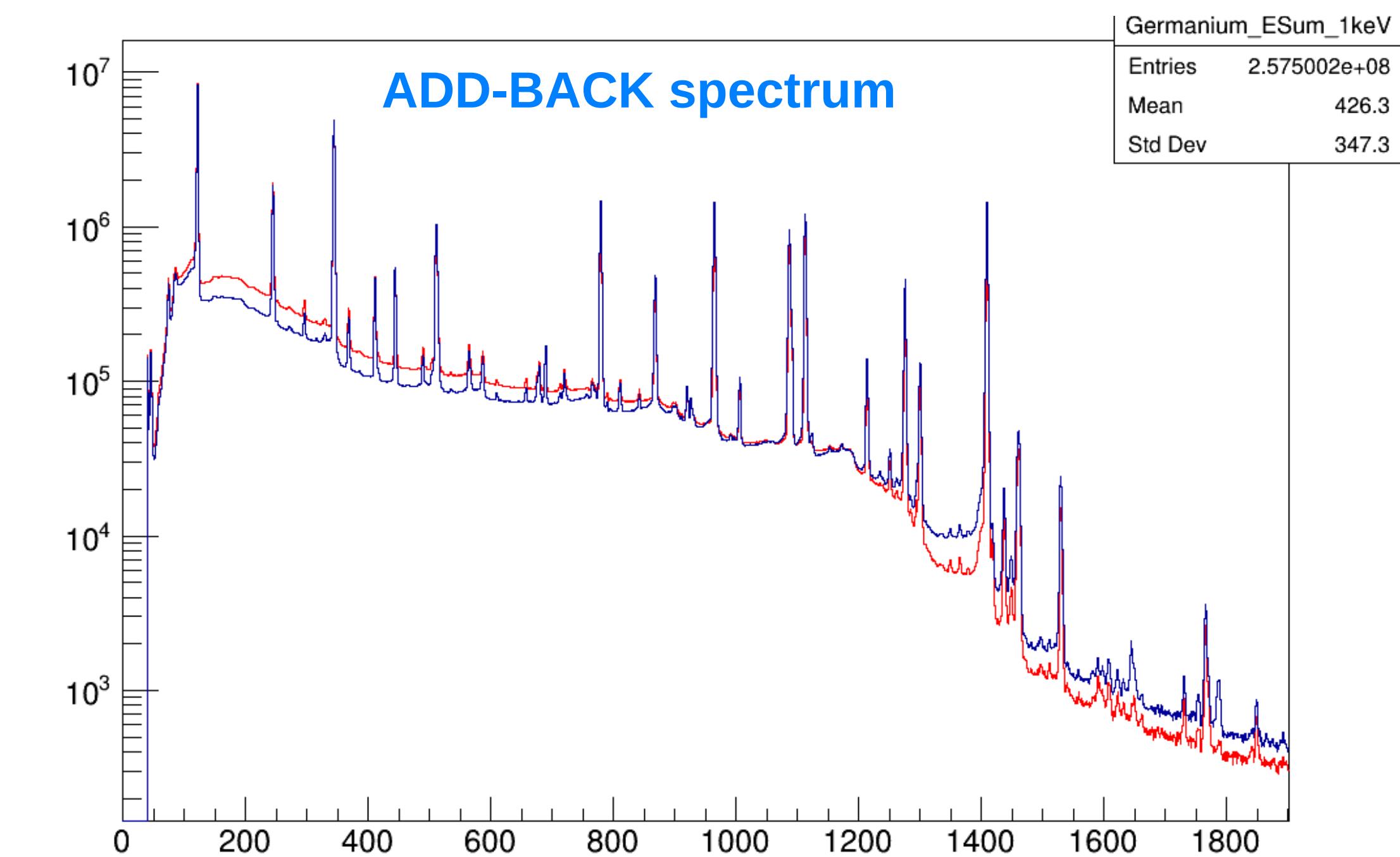
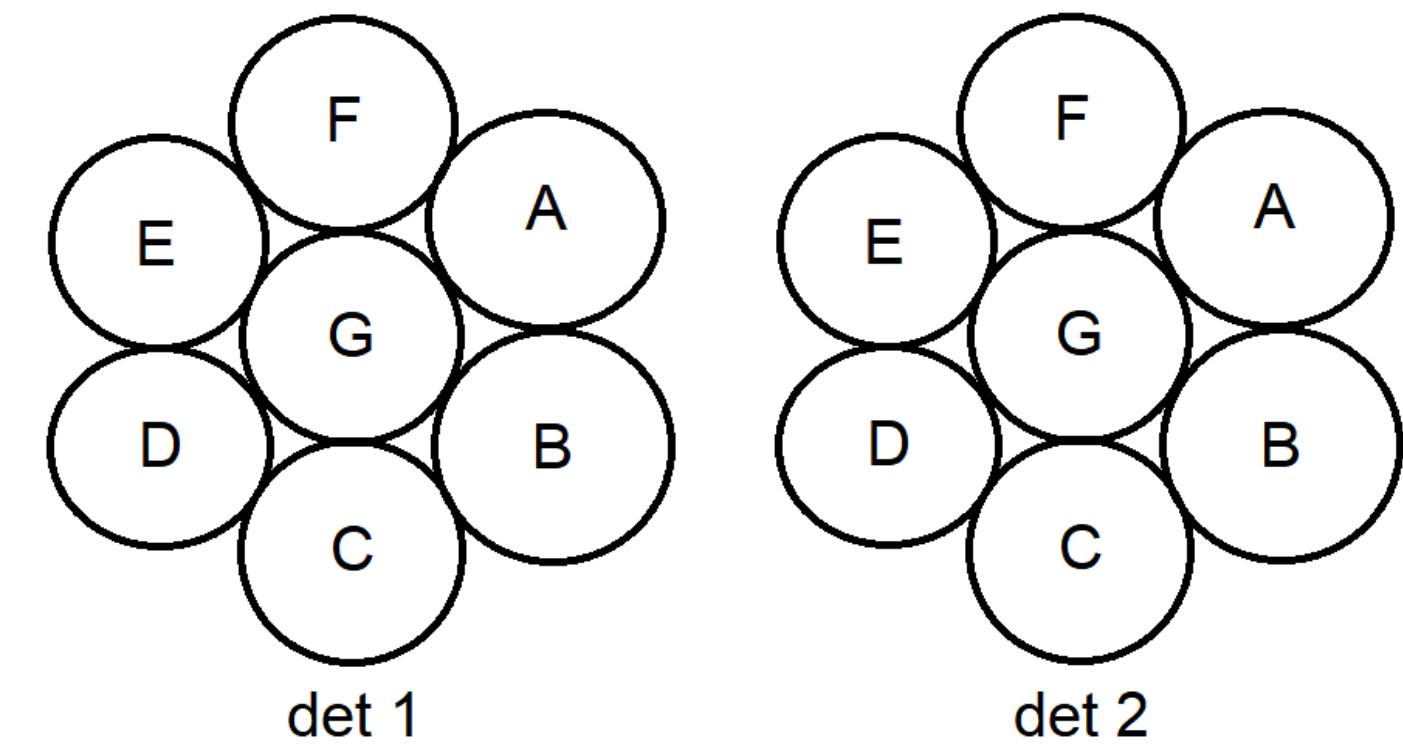
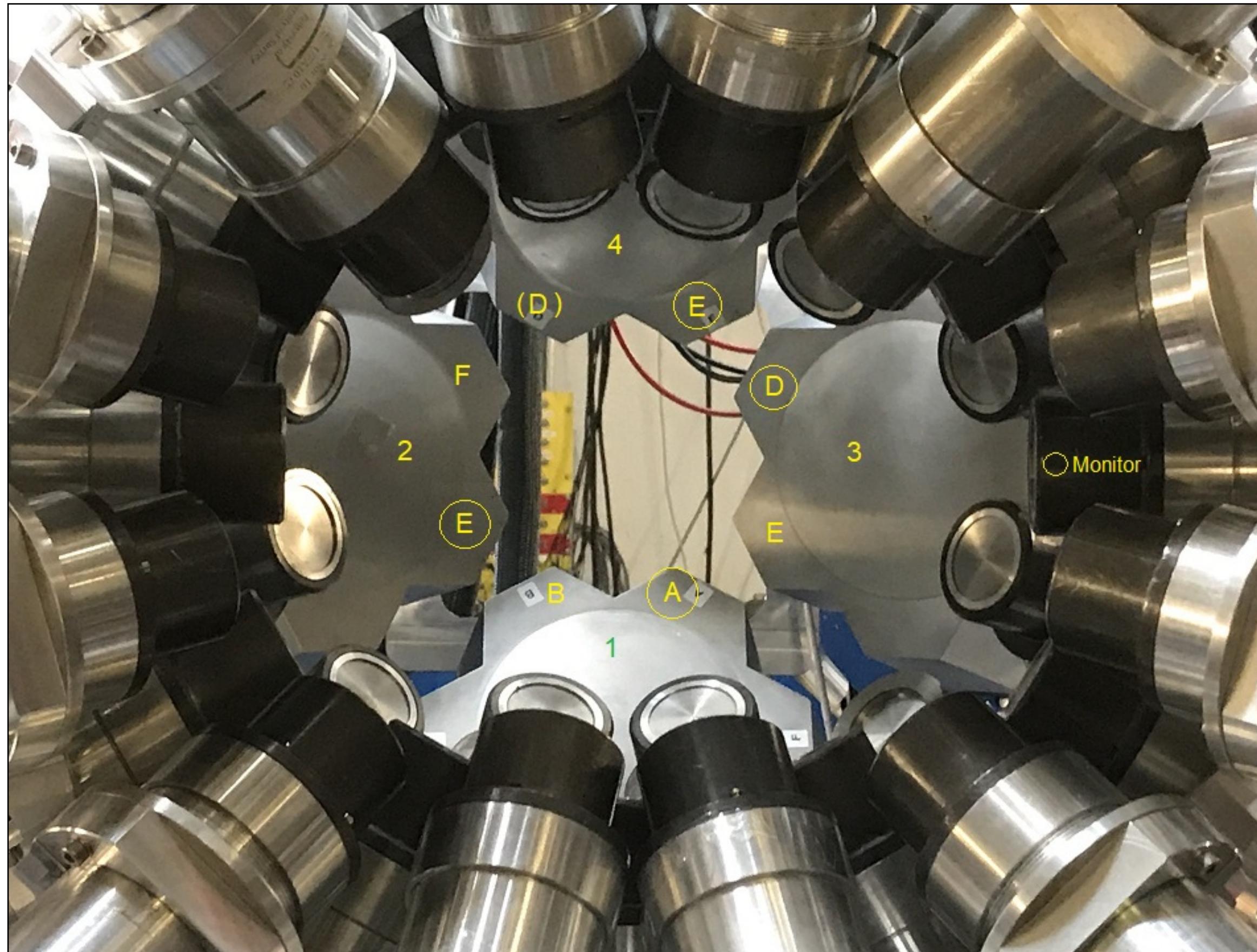
# FATIMA fast timing $\gamma$ -ray array

- 36 LaBr<sub>3</sub>(Ce) cylindrical crystals, 1.5" x 2"
- Efficiency ~5 % @ 511 keV
- Time resolution ~ 330 ps, achievable lifetime down to ~10 ps using  $\gamma$ - $\gamma$  and fast- $\beta$ - $\gamma$  coinc.

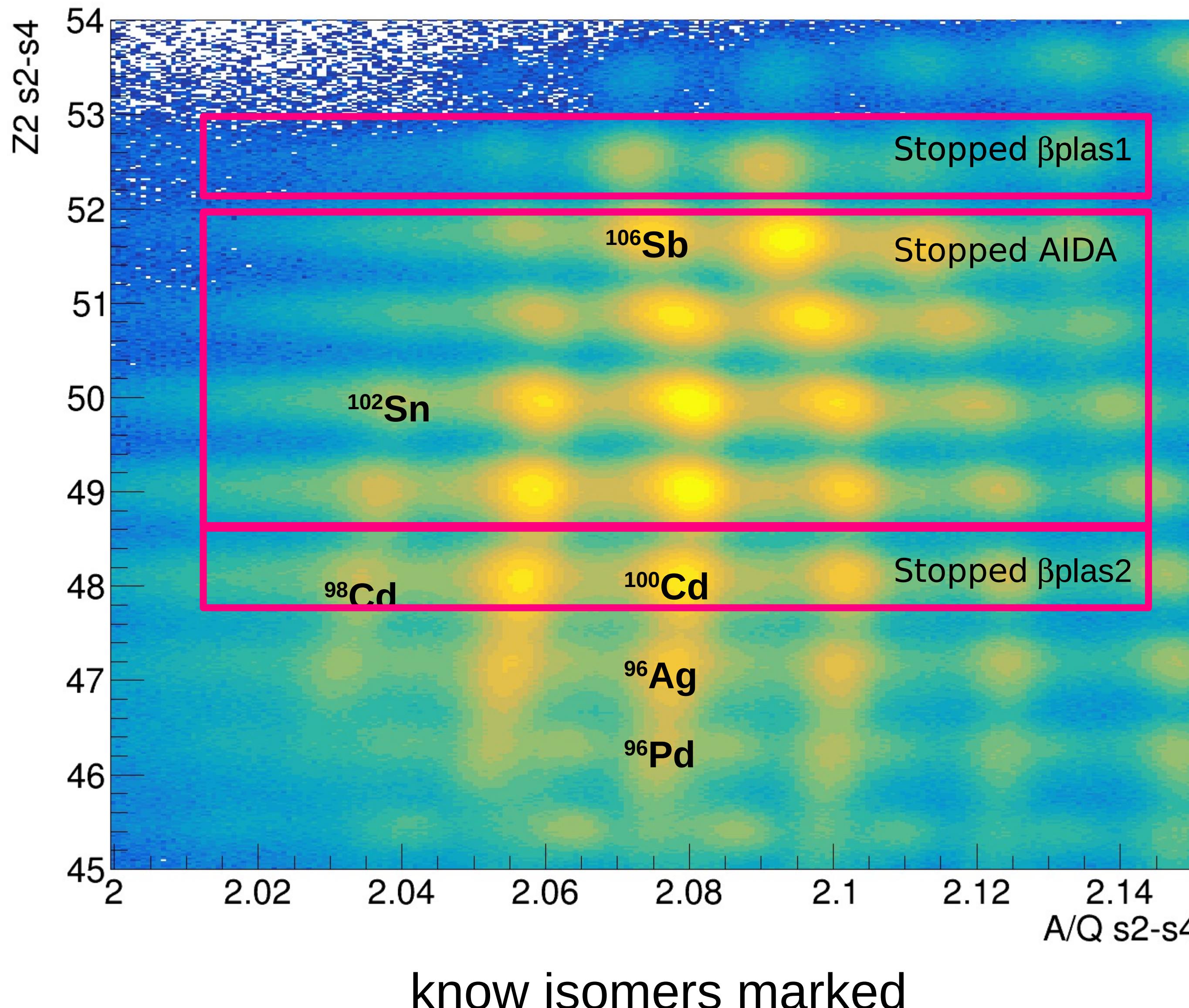


# High-resolution $\gamma$ -ray array

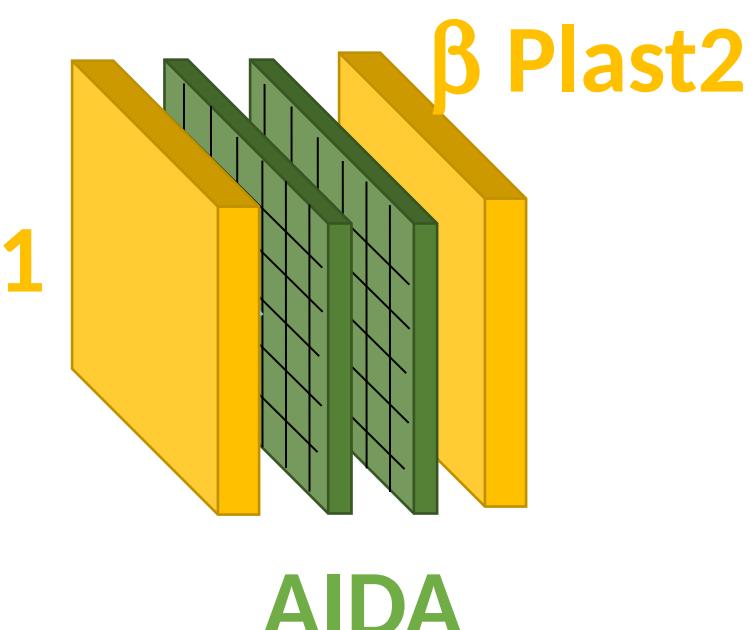
- 4 Euroball 7-folded clusters
- Efficiency: 29 cm, 1.1 % for 1.5-MeV transition
- Time resolution  $\sim$ 10 ns
- Add-back among neighbouring dets



# Particle IDentification matrix (PID)

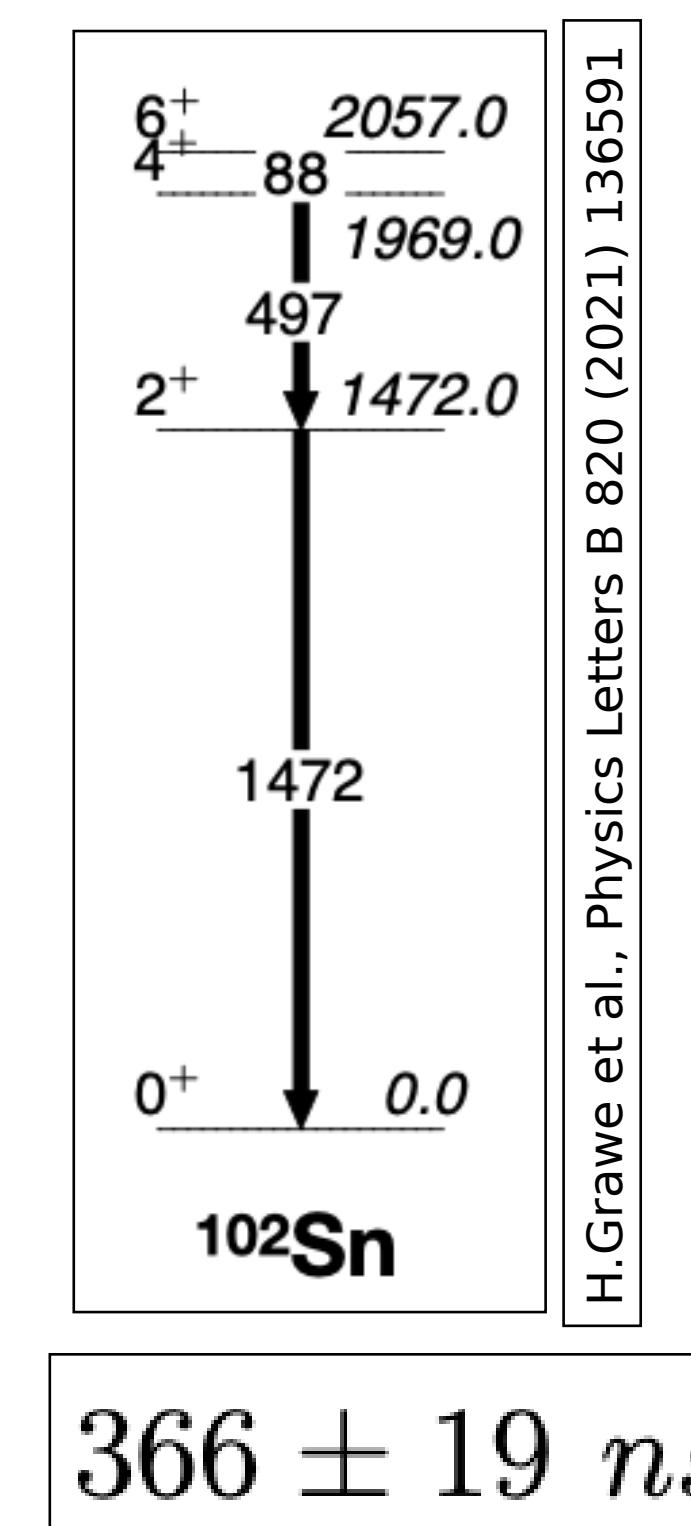
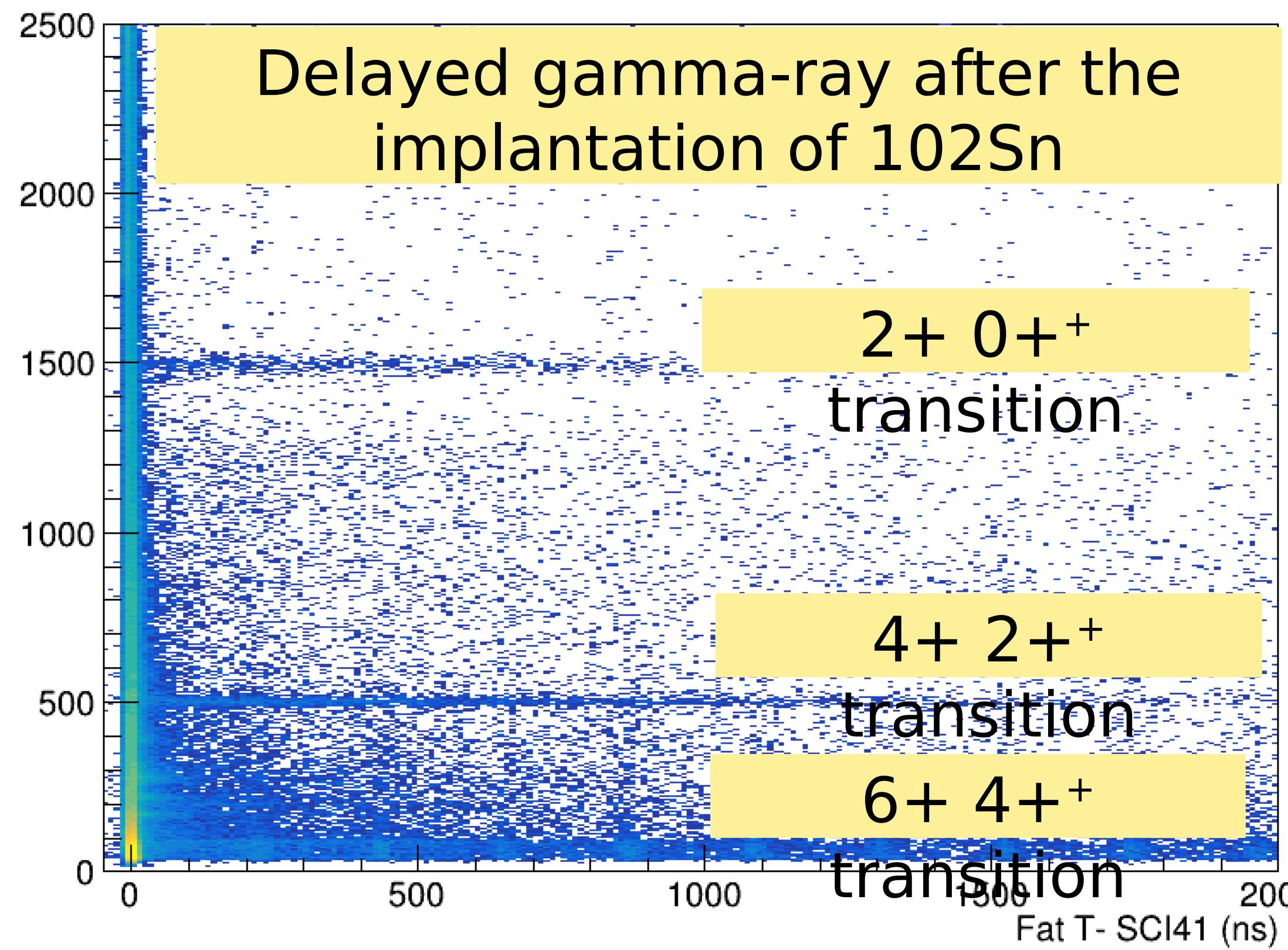


- After presorting each subsystems
- Z from MUSIC2@S4
- Position (S2-S4) either from TPC (this picture) or Scintillator (~similar stat but worst resolution);
- $B\beta$  correction: angle at S4 via TPC  $\rightarrow$  approximate trajectory
- Time ToFS2-S4 (scintillator);
- Implantation at different depth of the active catcher or  $\beta$  plastic 2, except for Te fragments

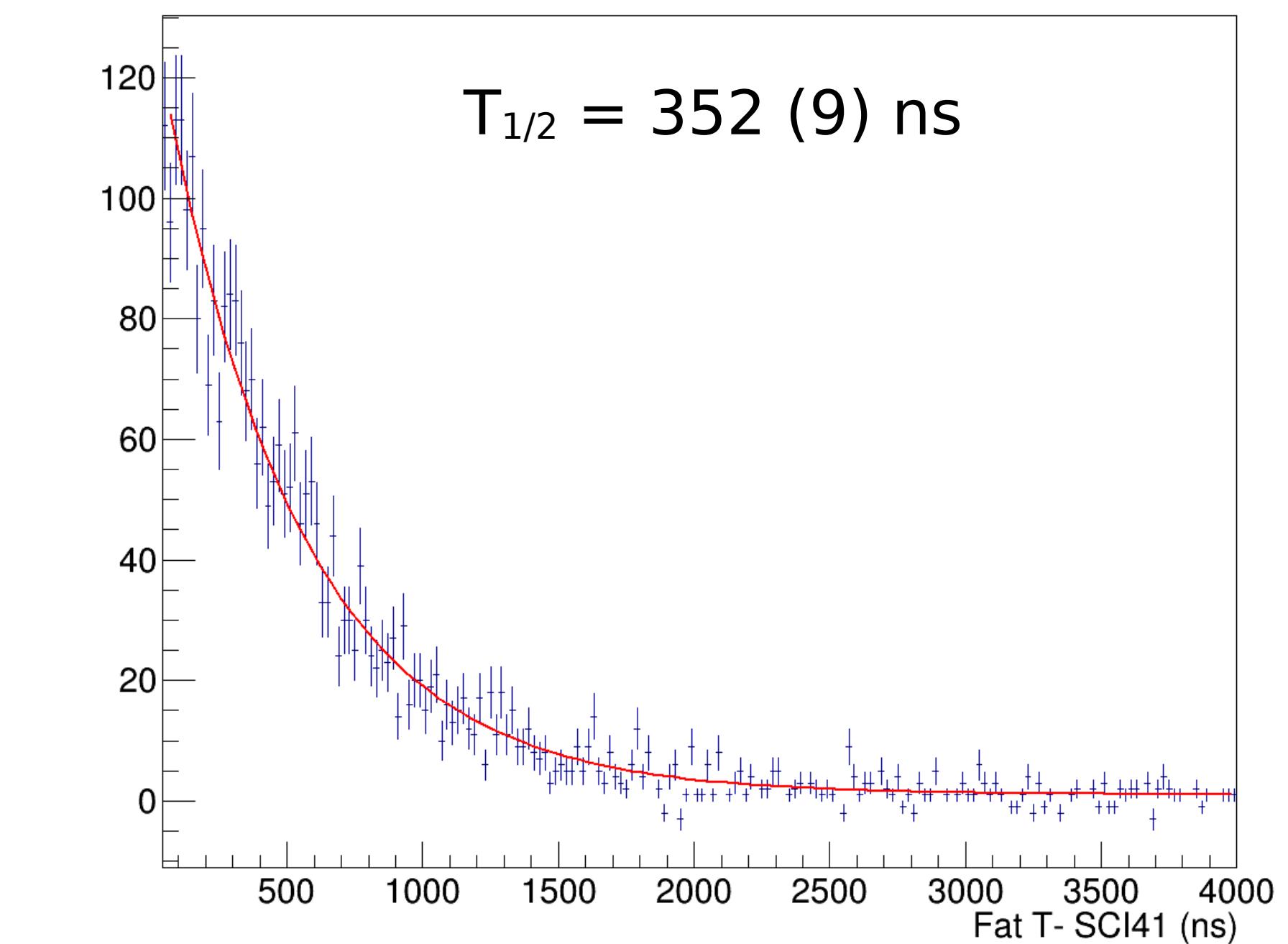


# Isomer benchmark: $^{98,100}\text{Cd}$ , $^{102}\text{Sn}$ , $^{106}\text{Sb}$

- Lifetime measured by  $\beta-\gamma$ ,  $\gamma-\gamma$ ,  $\alpha-\gamma$  time difference,
- Ions produced in the isomeric states (with lifetime comparable or longer than the ToF in FRS): ion-implantation delayed time difference

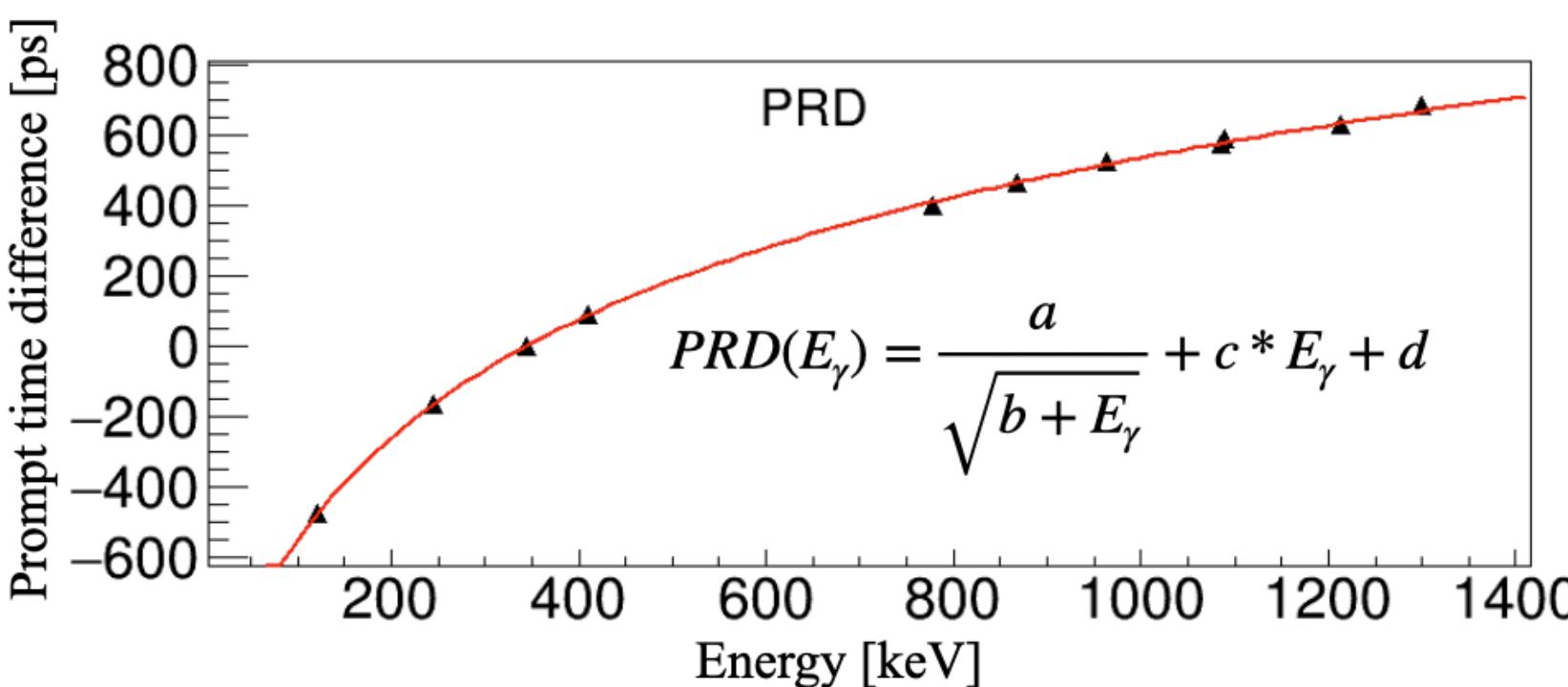
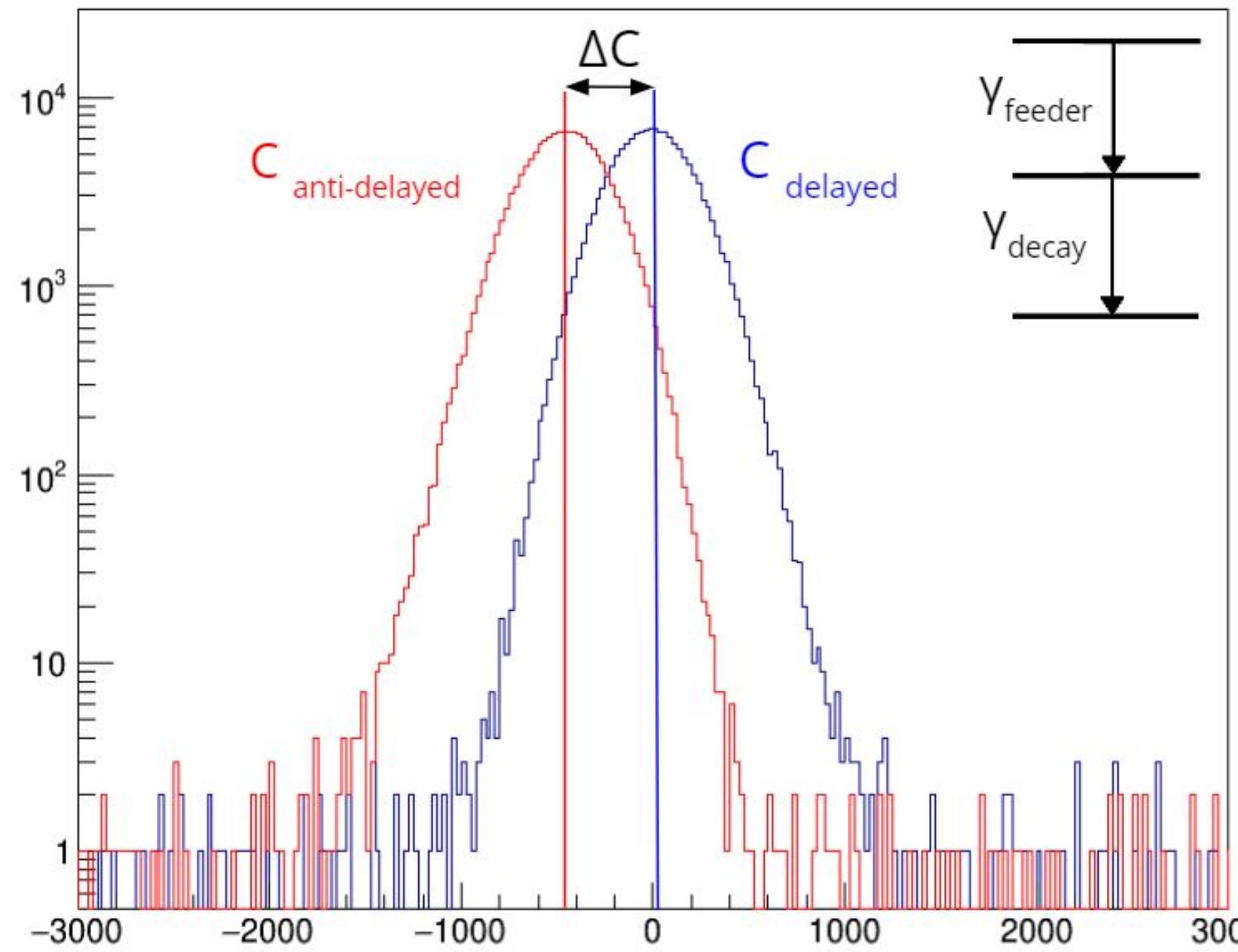


$366 \pm 19 \text{ ns}$



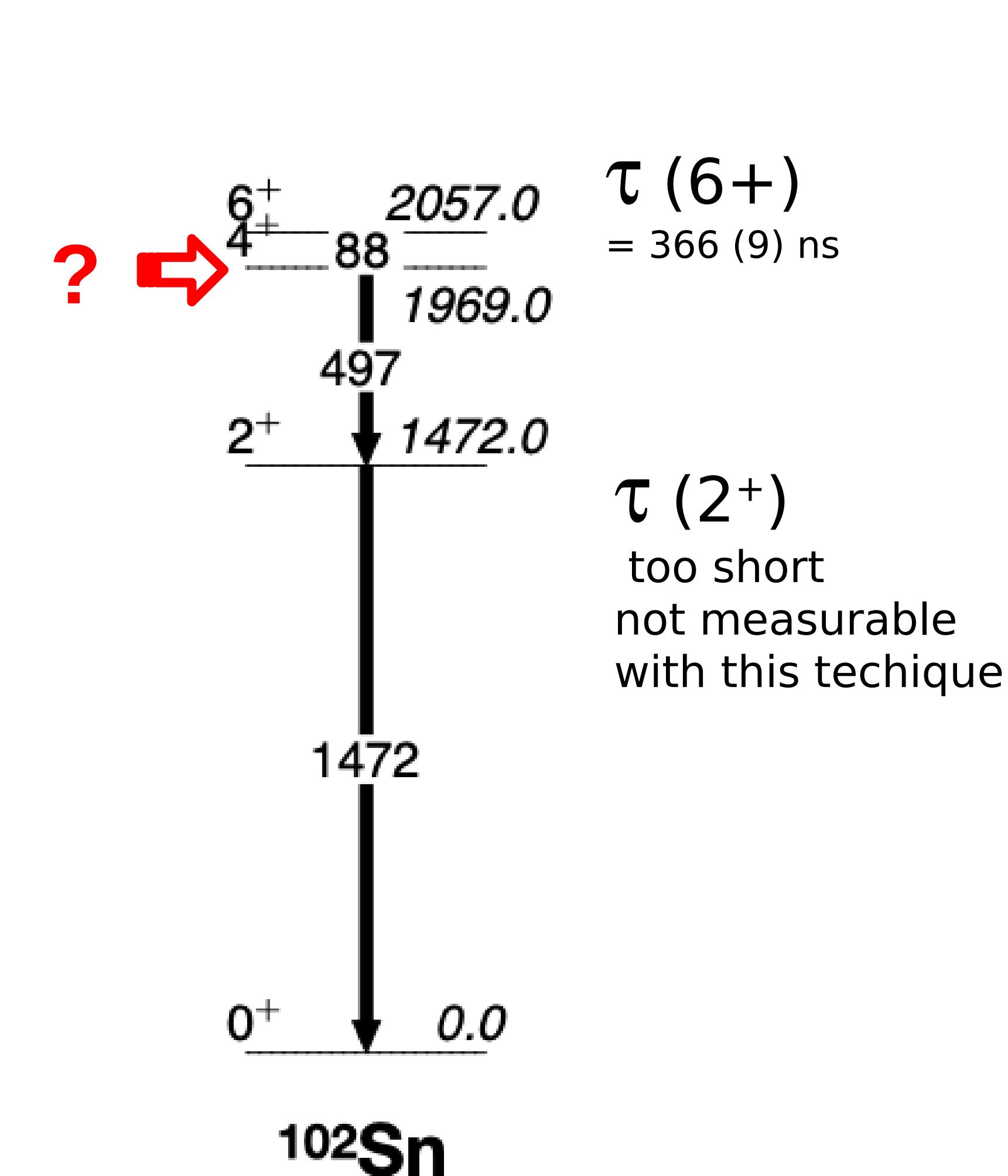
MSc S.Langelund – Univ. of Padova 2021

# Mirror-symmetry centroid difference method

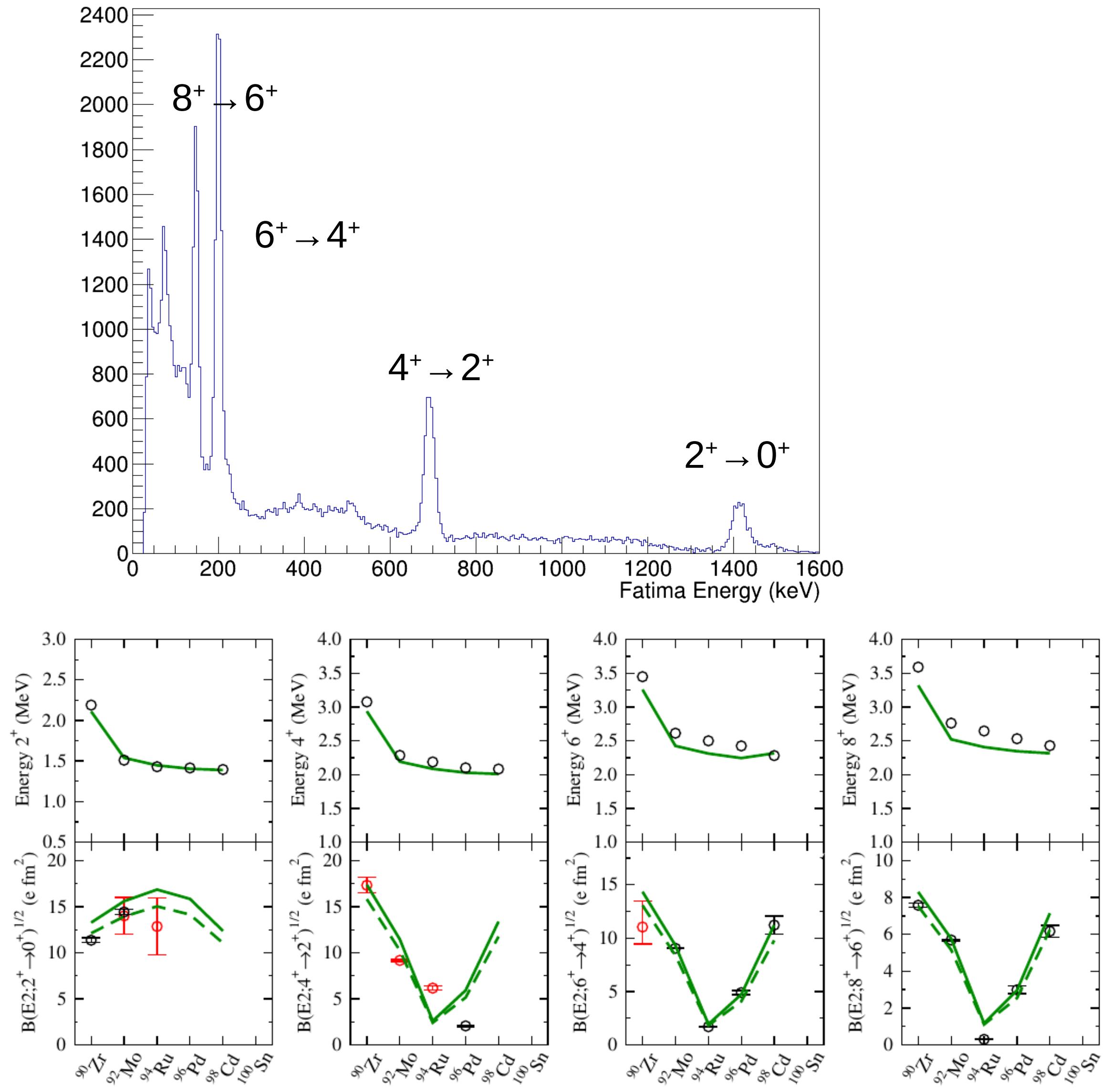


Centroid difference  
between delayed  
and “antidelayed”  
time coincidence  
distribution:  
 $\Delta C = C_{\text{del}} - C_{\text{antidel}}$

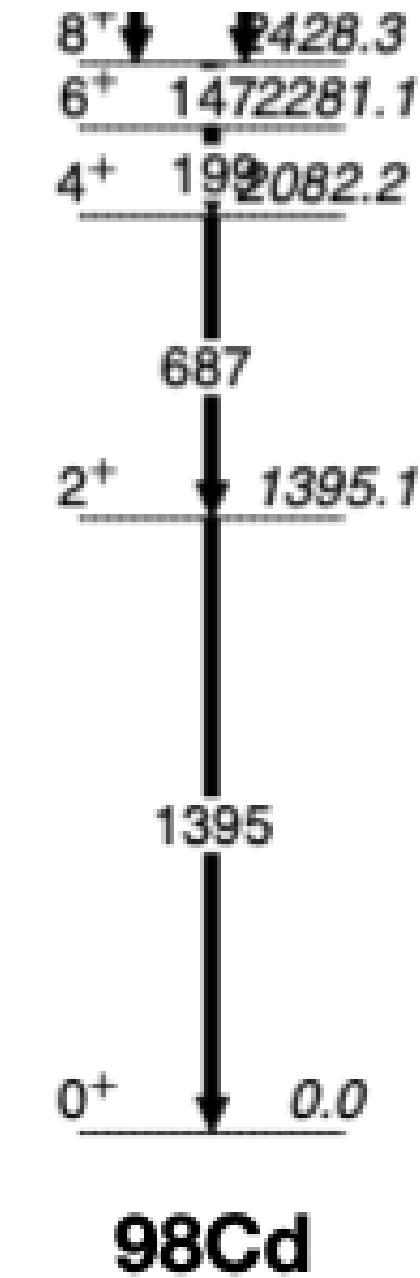
Correction for the  
“prompt” response  
difference (decay  
transition reference):  
 $\Delta C = 2\tau + \text{PRD}$



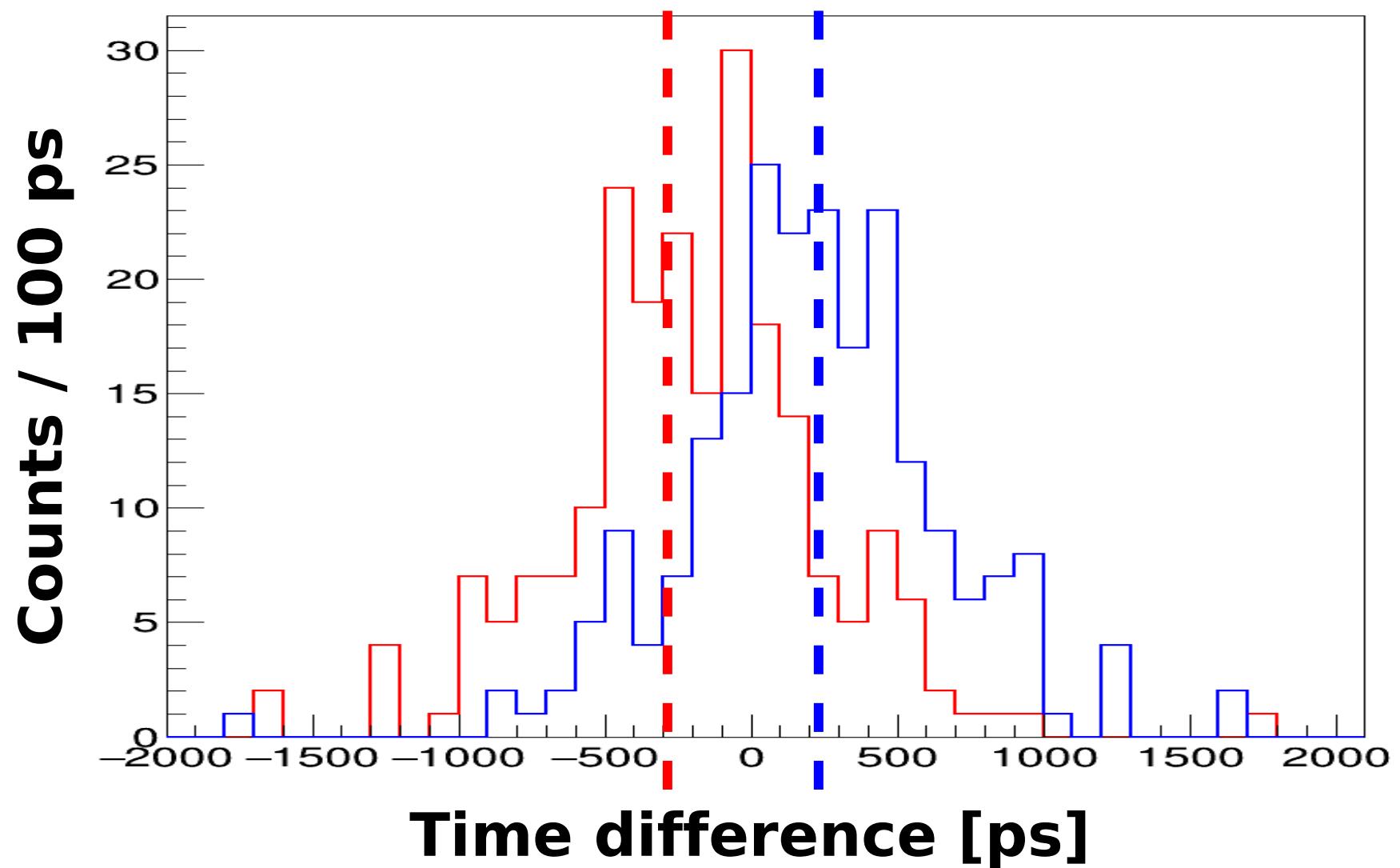
# Experimental results: $^{98}\text{Cd}$



M. Gorska, et al., Z. Physik A 350, 181-182 (1994).



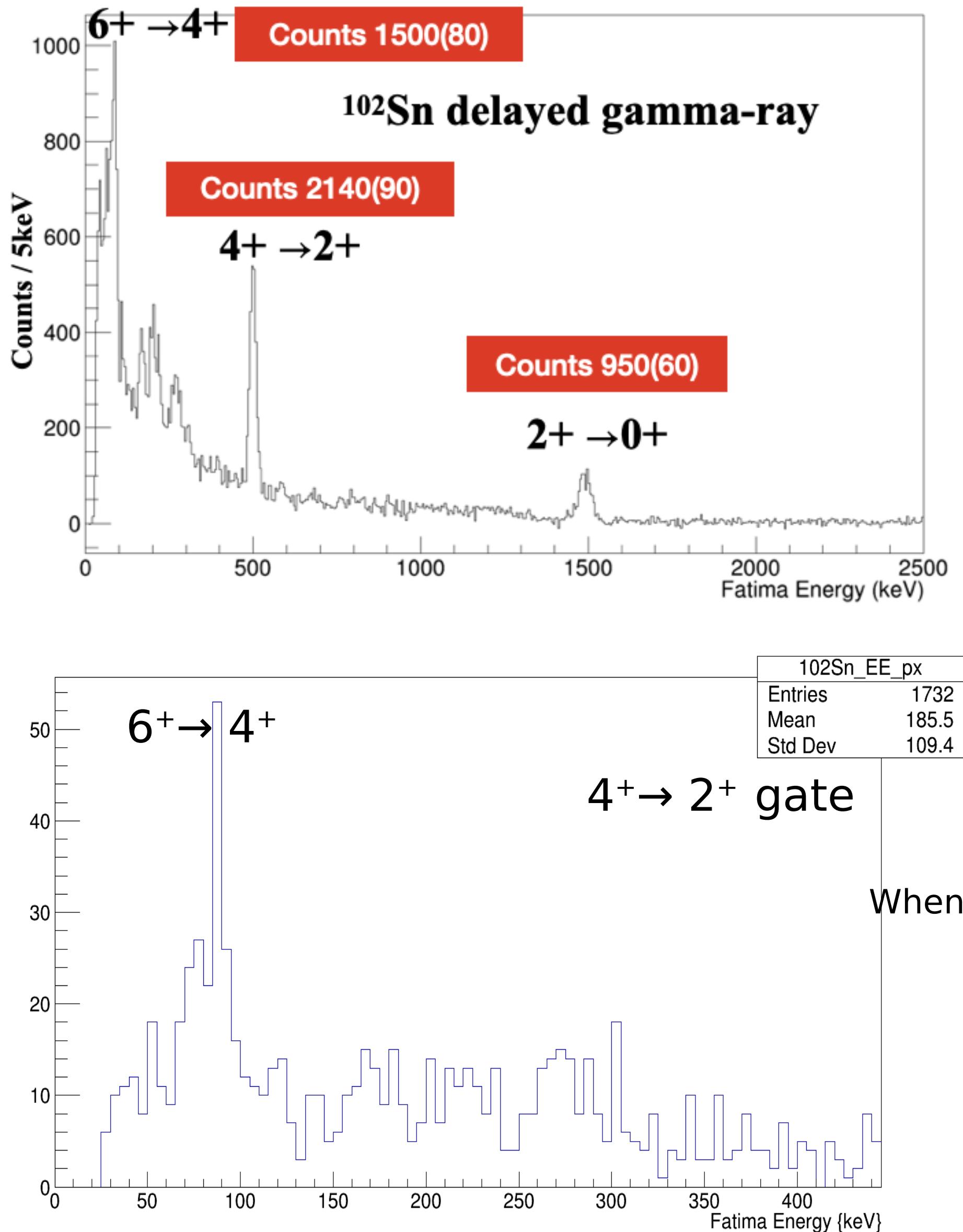
Preliminary result on  $B(E2; 4^+ \rightarrow 2^+)$  measurement in  $^{98}\text{Cd}$



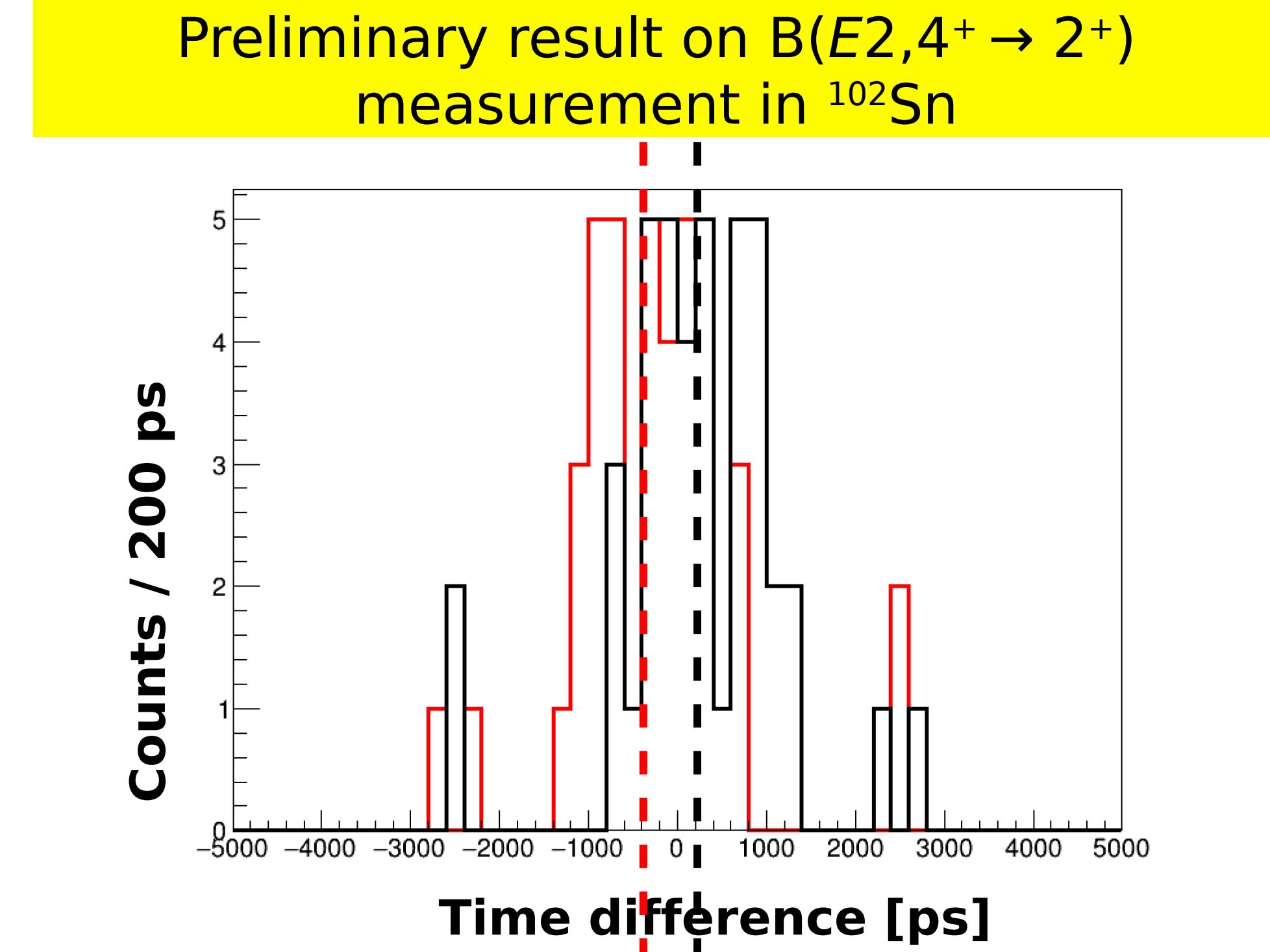
C = -418 (43) ps  
 $\text{PRD}(687\text{-keV-ref}, 199\text{-keV}) = -610(10)$  ps  
 $\rightarrow \tau(4^+) = 96 (22)$  ps  
 $\rightarrow B(E2; 4^+ \rightarrow 2^+) = (55^{+17}_{-10}) e^2 \text{fm}^4$

Partial seniority breaking approaching  $^{100}\text{Sn}$ ?

# Experimental results: $^{102}\text{Sn}$

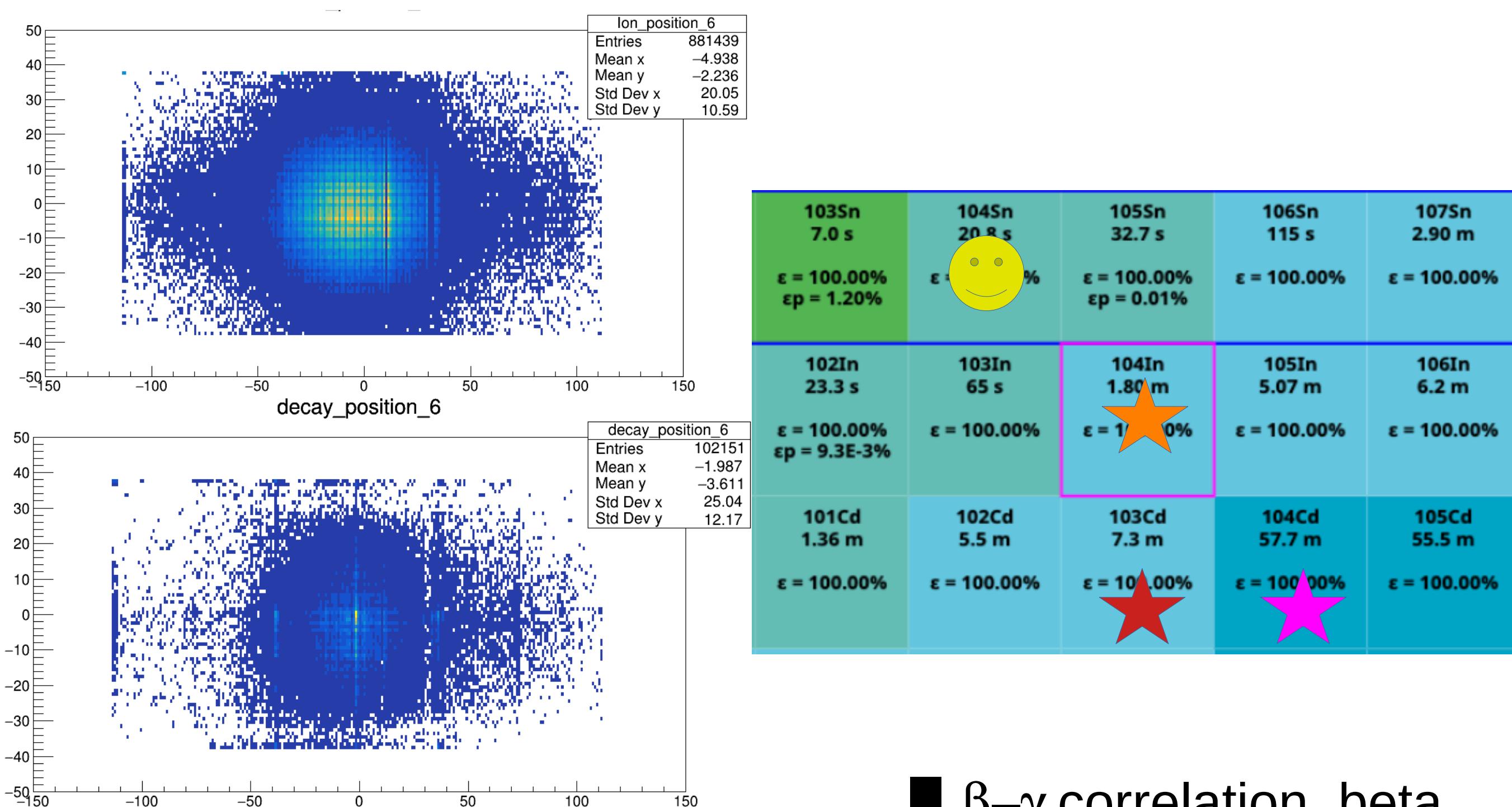


FATIMA spectrum in  
delayed time  
coincidence wrt ion  
implantation



$\Delta C = -291(128) \text{ ps}$   
 $\text{PRD}(497\text{-keV}, 88\text{-keV}) = -776(20) \text{ ps}$   
 $\rightarrow \tau(4^+) = 243(65) \text{ ps}$  [weighted average between different energy gates from background]  
 $\rightarrow B(E2) = 110(29) \text{ e}^2 \text{ fm}^4$

# $\beta$ decay results (in progress): $^{104}\text{Sn}$

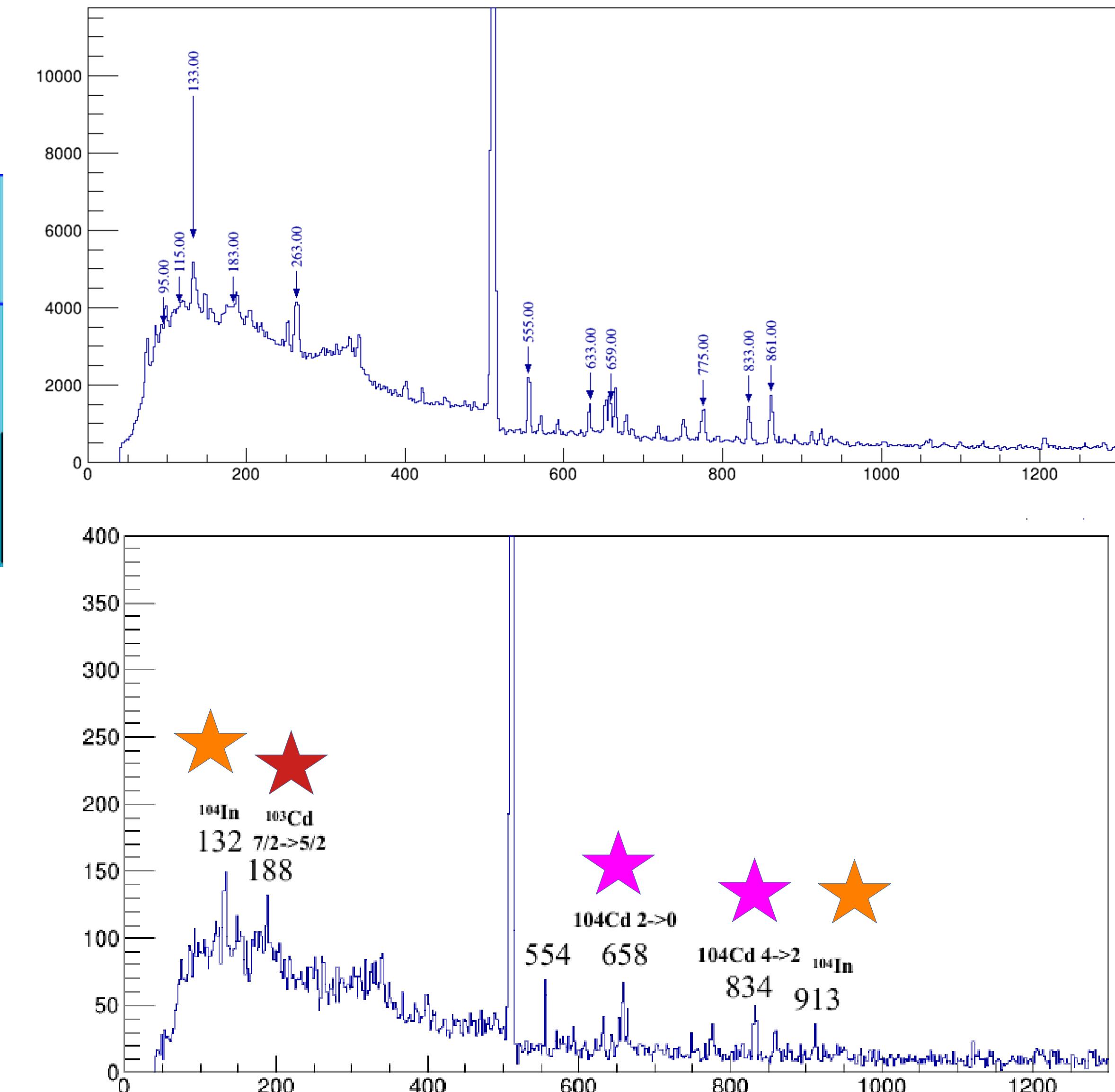


Efficiency estimates:

- ion- $\beta$  correlation:  
 $>10\%$
- ion- $\beta$ - $\gamma$   $\sim 0.15\%$

But  $\beta$ - $\gamma$  correlation  
(no ion) is much larger ..

- $\beta$ - $\gamma$  correlation, beta measured in Bblast and AIDA
- $^{104}\text{Sn}$  ion- $\beta$  correlation ( $\sim 2$  mm), beta measured in Bblast and AIDA, 0~200 s

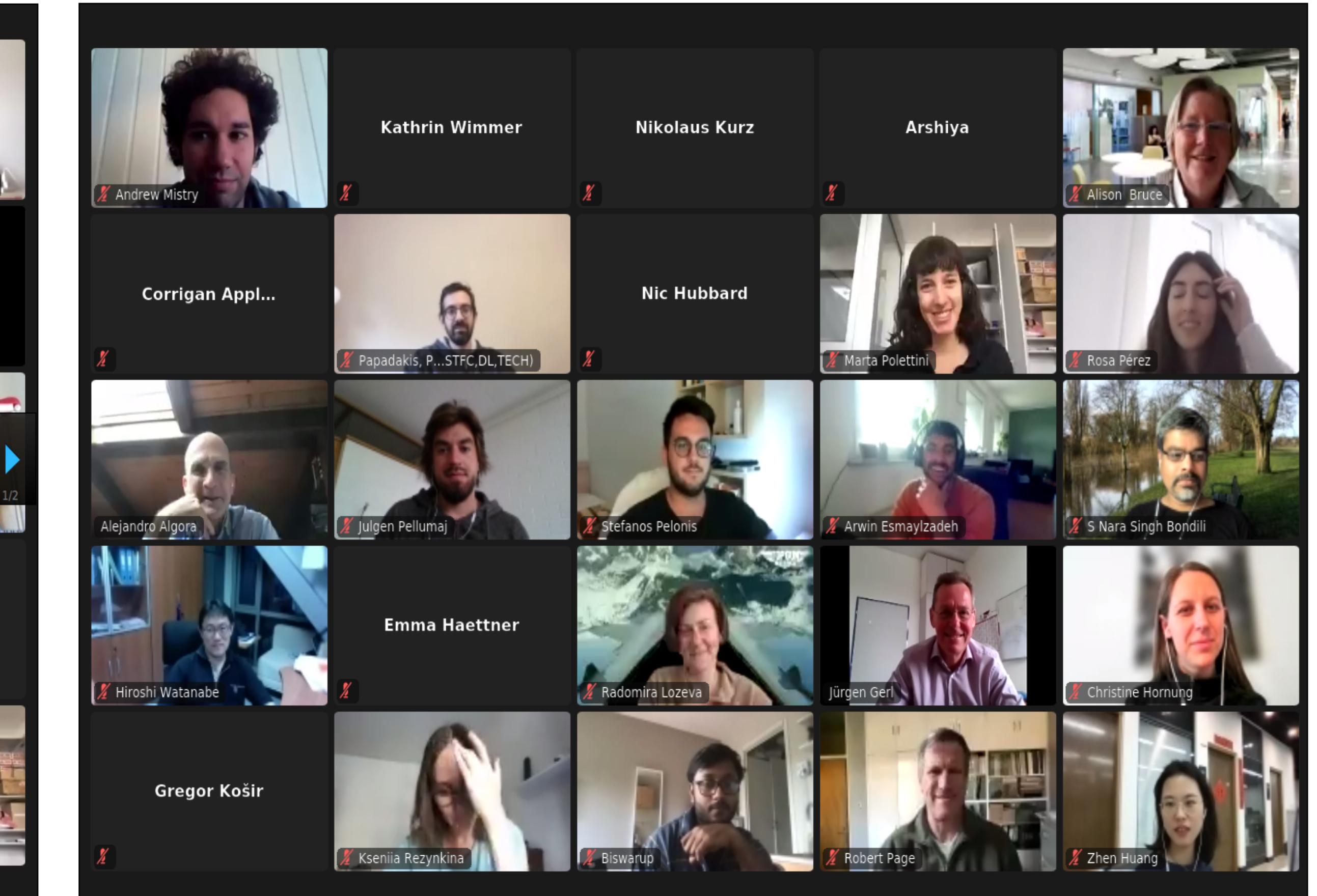
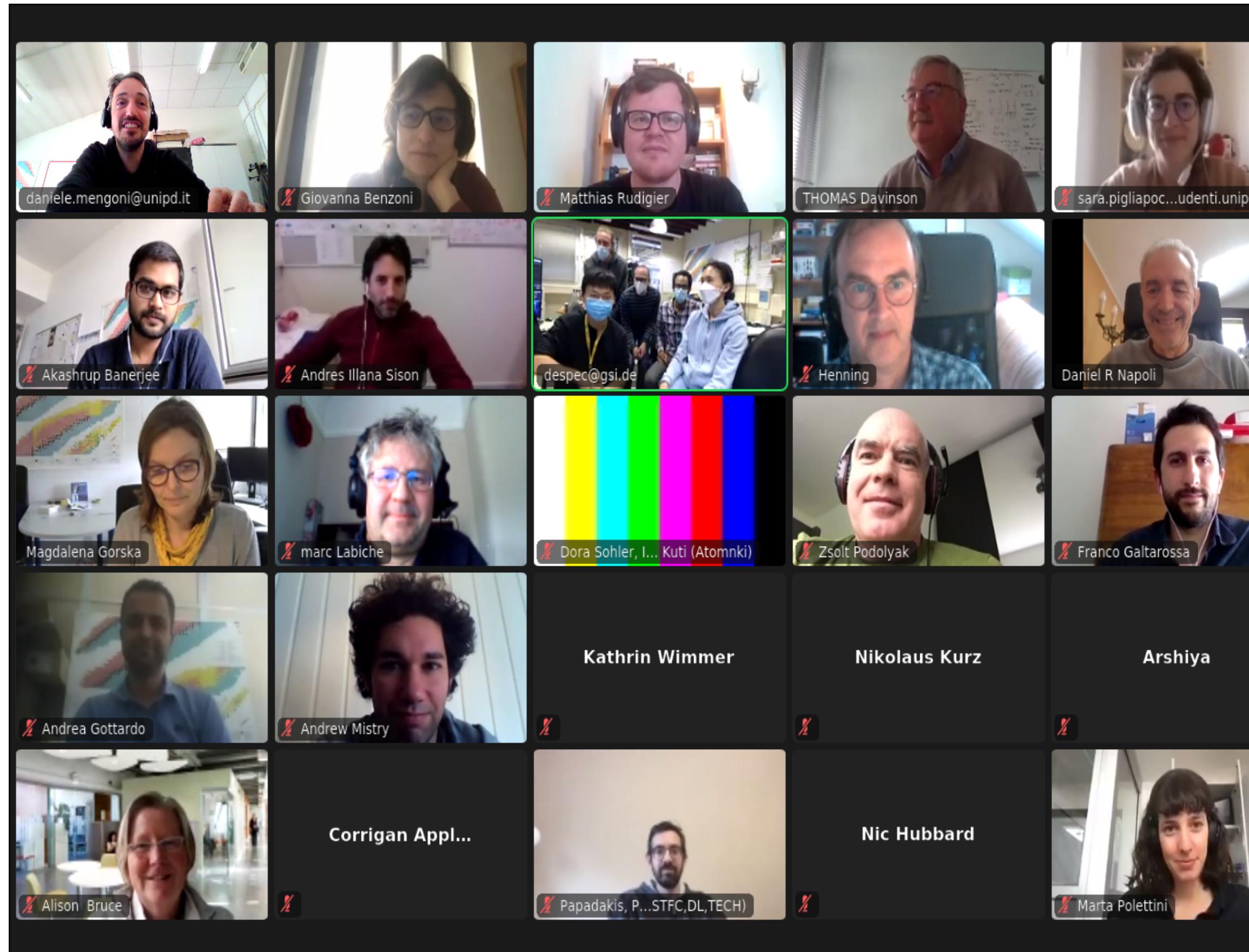


# Summary and Conclusions

- Successful S496 run has been made by the local GSI group as well as a large remote group of participants during Covid-19 time
- Data analysis shows promising lifetime results by fast-timing measurement ( $^{102}\text{Sn}$ ,  $^{98,100}\text{Cd}$ , and more)
- Engaging theoreticians for the extracted  $B(E2)$  values in light Cd and Sn region
- Coming results on  $\beta$ -decay and daughter lifetime spectroscopy
- More efforts for further results on  $\alpha$ -decay delayed- $\gamma$  ray spectroscopy for  $^{103}\text{Sn}$



# S496 collaboration



especially to the locals@GSI

Strong exchange with EFS team

- Preparation
- Data taking
- Data analysis

# Thanks for the attention!

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Backup slide