In-beam gamma-ray spectroscopy of ^{136}Te within the HiCARI project

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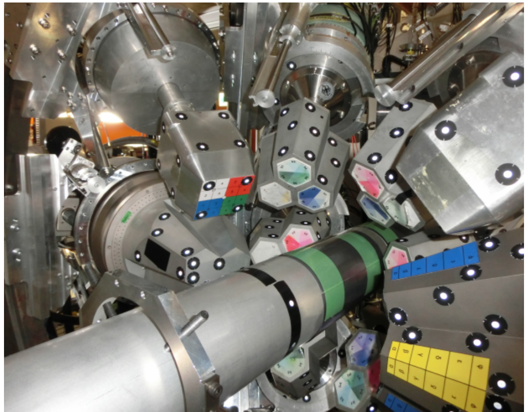
Some context

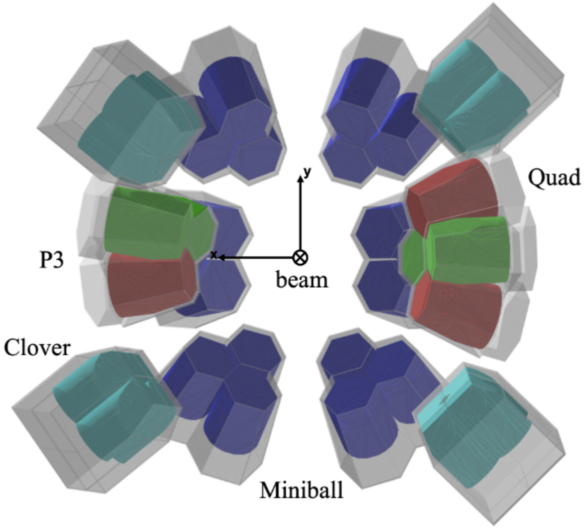
- The HiCARI (High-resolution Cluster Array at the RIBF) campaign consisted on a series of **in-beam** gamma-ray spectroscopy experiments using an **array of Ge detectors**, carried out at RIBF (RIKEN, Japan) in 2020/2021
- HiCARI was a one-time international collaborative array to temporarily substitute the DALI2+ array (NaI(Tl) crystals) → first in-beam spectroscopy using high-resolution detectors at RIBF
- Enhanced energy resolution:
  - new transitions observed
  - lifetimes could be measured with lineshape analysis
- Our work so far: attempt to characterize the array

  and validate the analysis method with **simple**,

  well known reference cases

  ⟹ apply to new physics cases

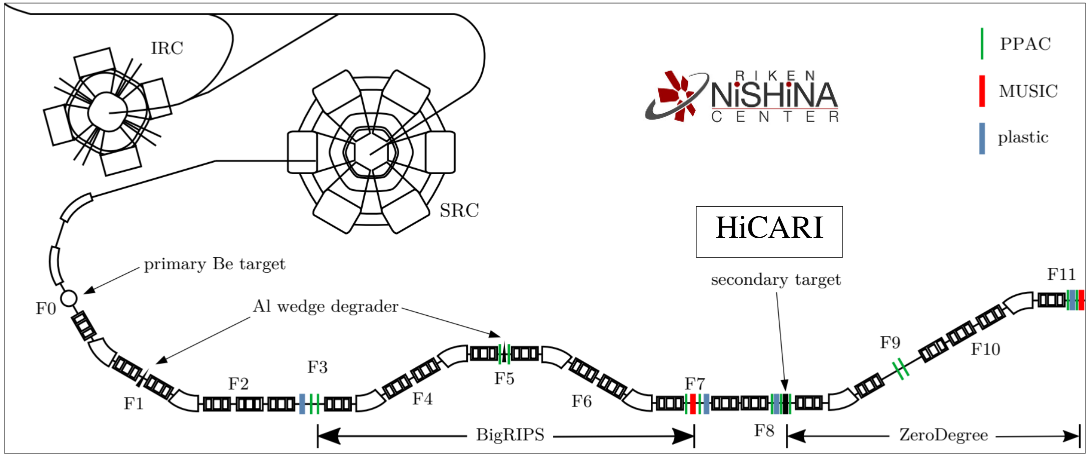




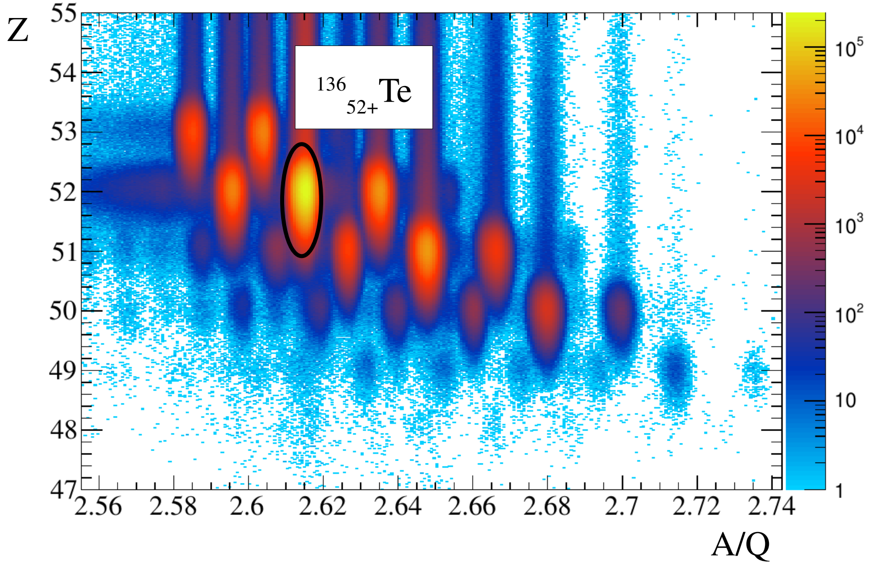
inhomogeneous!

Experimental setup: beam production

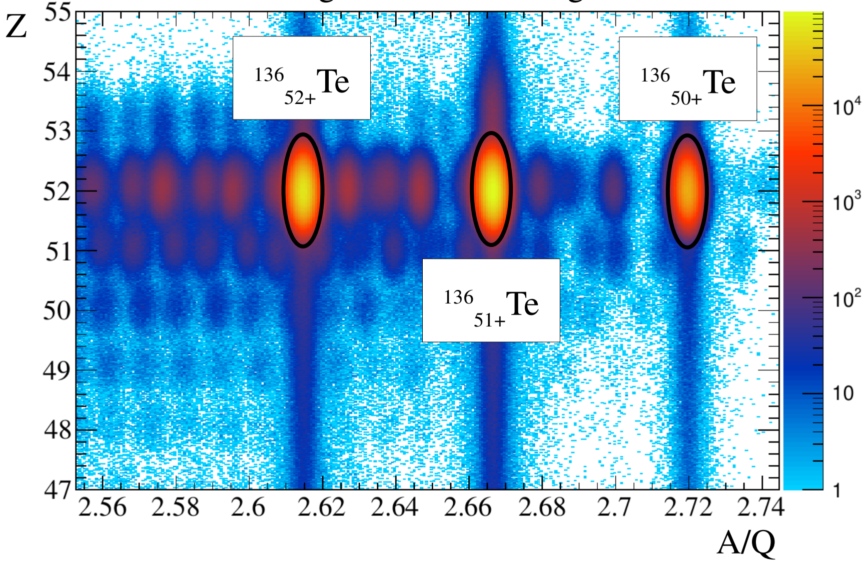
- Identification of particles **event by event**



BigRIPS (before secondary target)



ZeroDegree (after secondary target)
With gate on ^{136}Te in BigRIPS

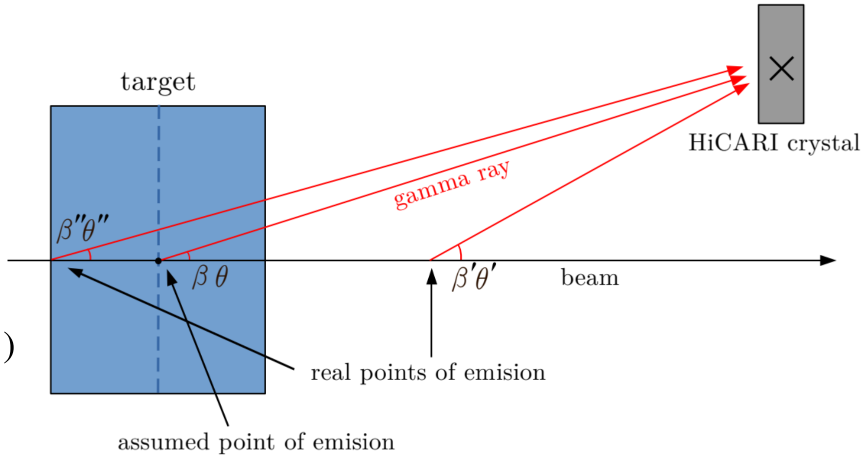


In-beam γ-ray spectroscopy

- Detected gammas are emitted in motion, energies must be Doppler-corrected

$$\boxed{E_{CM} = \gamma(1 - \beta \cos\theta_{lab})E_{lab}}$$

- To perform Doppler correction, β and θ_{lab} are needed



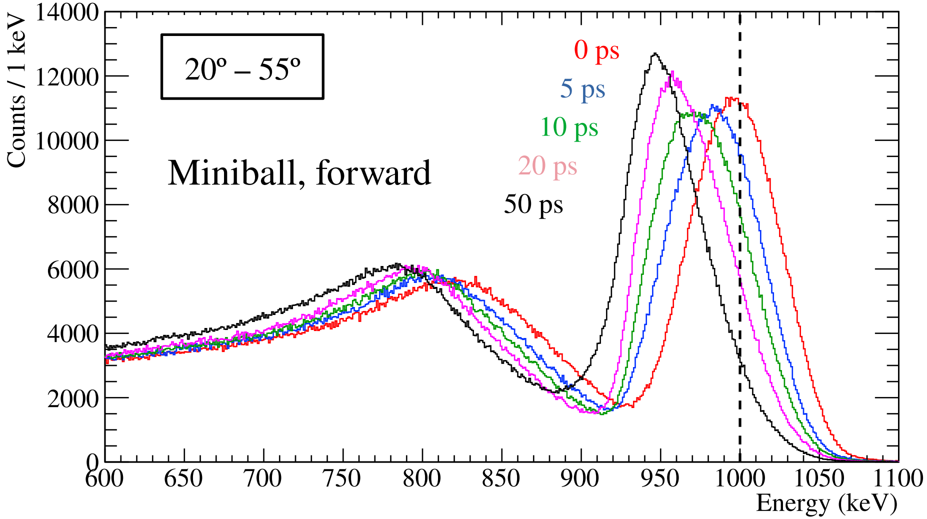
- Some general value is used for all events → imperfect Doppler correction

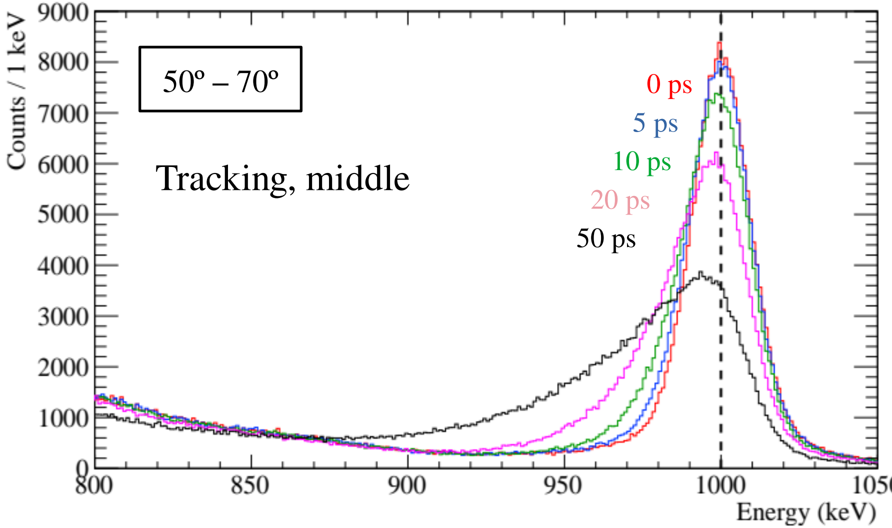
→ wide, shifted and /or assymetric photopeaks (reproduced with simulations!)

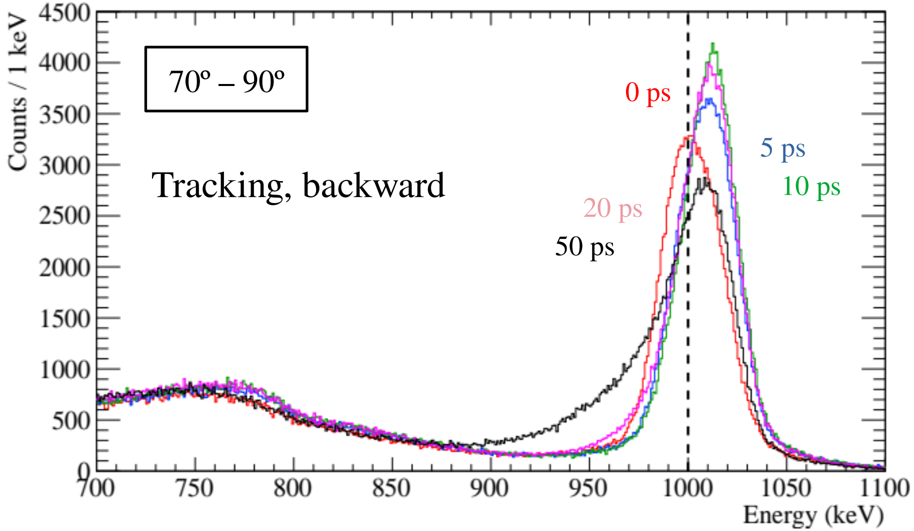
- Gamma emision is spread through the target and after the target
  - Use of wrong β (**velocity effect**): happens at short lifetimes, gamma decays inside target
  - Use of wrong θ_{lab} (**angular effect**): happens at long lifetimes, gamma decays after target

<u>How "imperfect" the DC is depends on excited state lifetime compared to target width</u>

Simulated response functions







Angular effect ⇨ always shifts E_{DC} to smaller values

Velocity effect ⇨ shifts E_{DC} to smaller (larger) values at <60° (>60°)

- Middle detectors are sensitive to θ
- Forward and backward detectors are sensitive to β, θ

<u>Different parts of the array are best suited to study certain lifetime regimes</u>

How to measure lifetimes?

We can simulate different lineshapes corresponding to different lifetimes

⇩

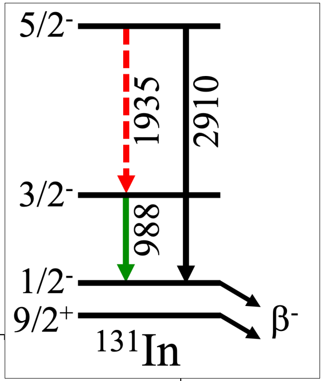
We fit simulations to experimental spectra

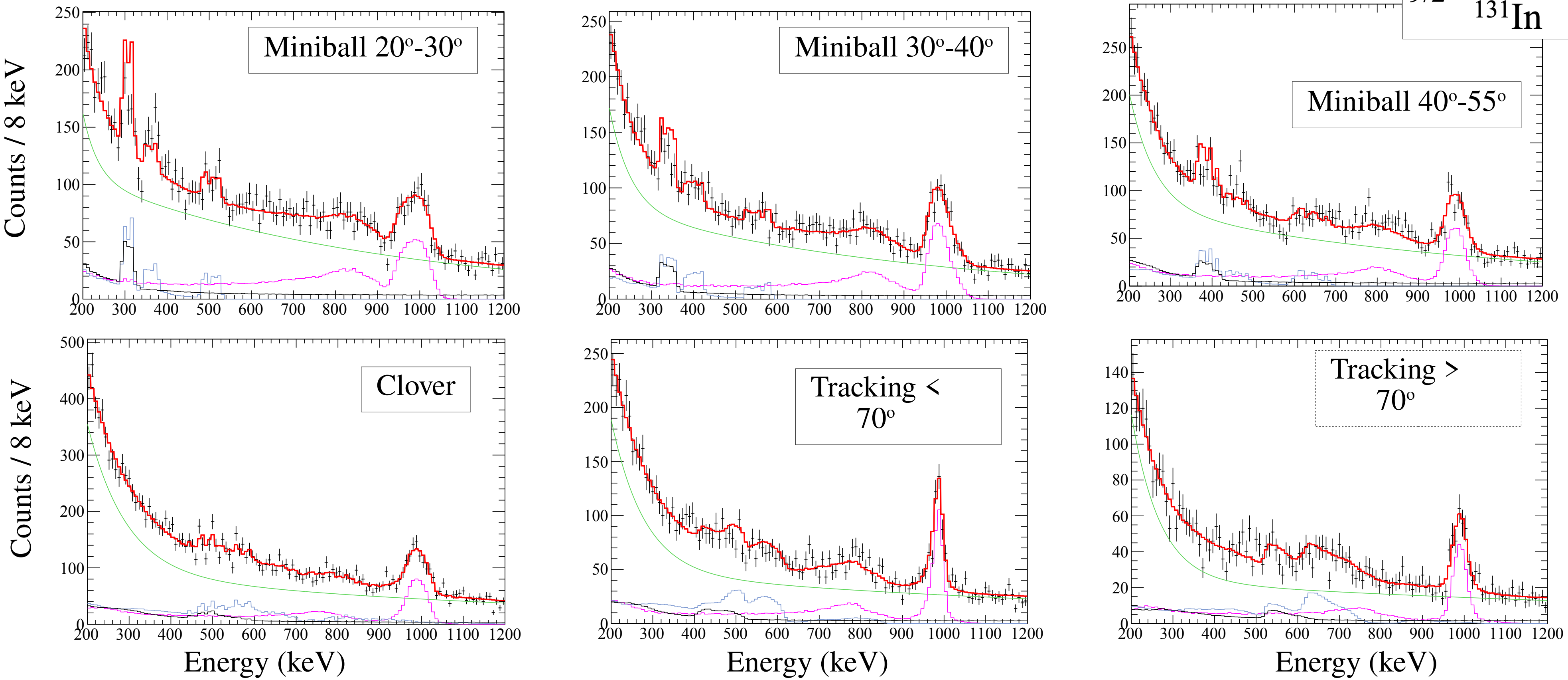
⇩

From the best fit, we obtain experimental $T_{1/2}$, E_{γ} and yields

Reference case: ^{131}In, 988 keV transition (very short lifetime expected)

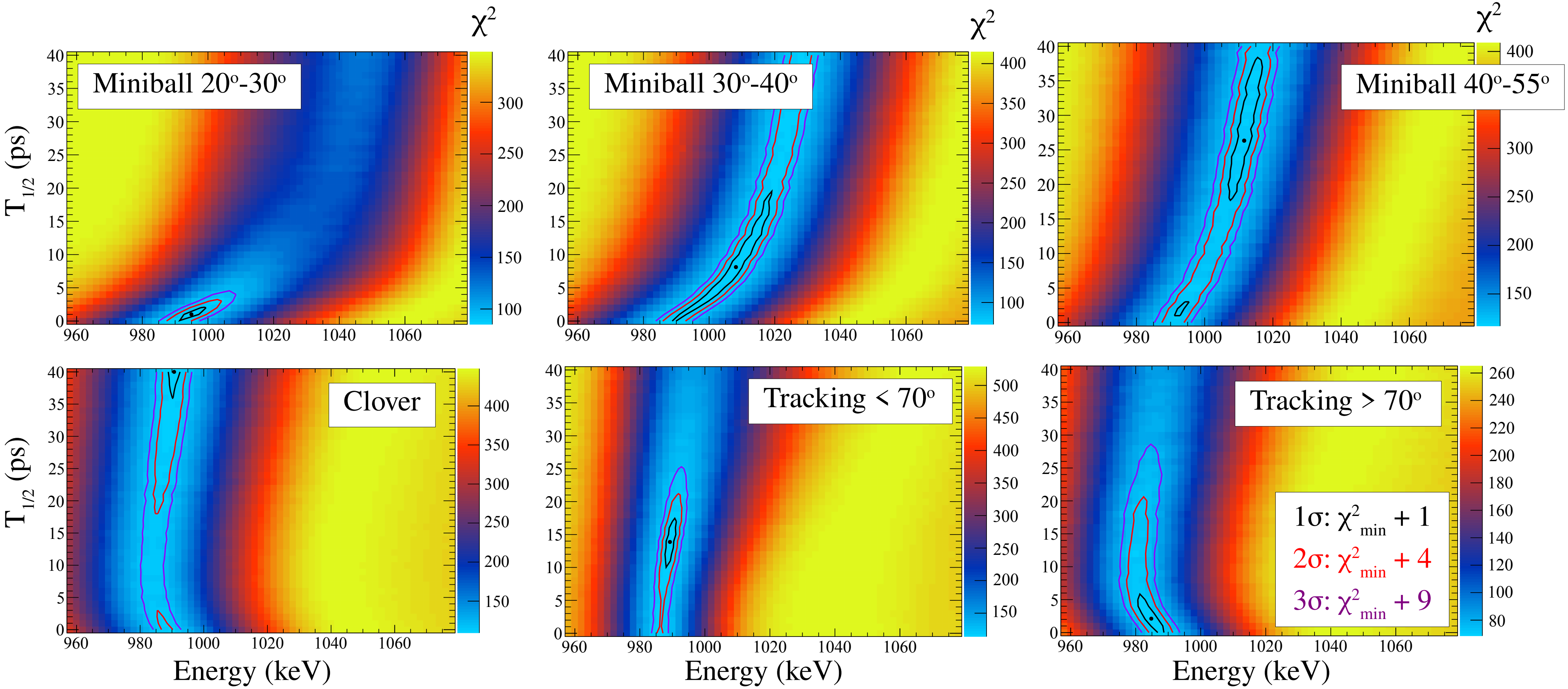
- fit using simulated response functions, for any combination of ($E\gamma$,$T_{1/2}$)





Reference case: ^{131}In, 988 keV transition (very short lifetime expected)

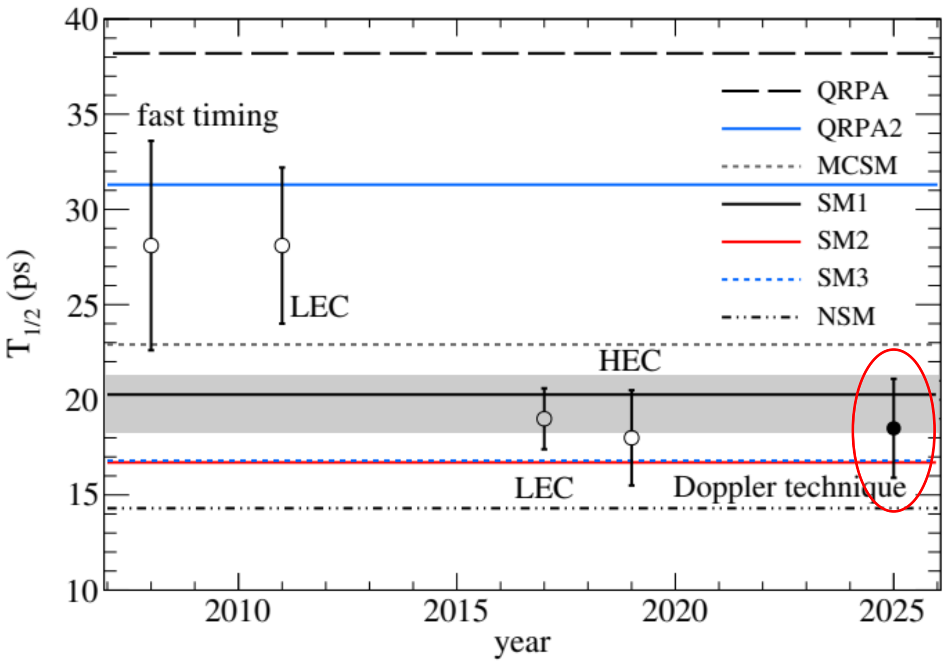
$$\chi^2 = 2\sum_i y_i - n_i + n_i \ln(n_i/y_i)$$



- store the χ^2 of the fits and look for the minimum of the distribution
- final result by combining (summing) all χ^2 distributions

<u>expected sensitivity is well reflected</u>

Measurement of $T_{1/2}$ (2_1^+) and B(E2; $0^+ \rightarrow 2^+$) in ^{136}Te Coulex



LEC: Low Energy Coulex

HEC: High Energy Coulex

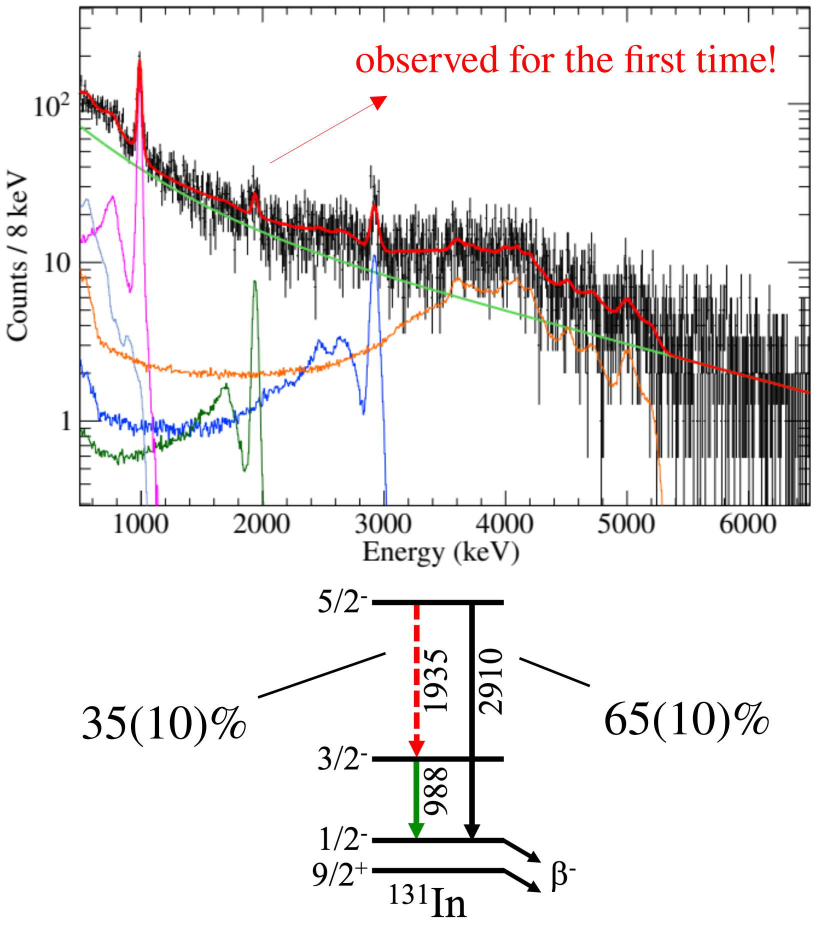
J. Acosta et al, accepted for publication in PRC

$T_{1/2}$ (2^+) = $18.5^{+2.8}_{-2.4}$ ps

Our result is in line with the latest reports

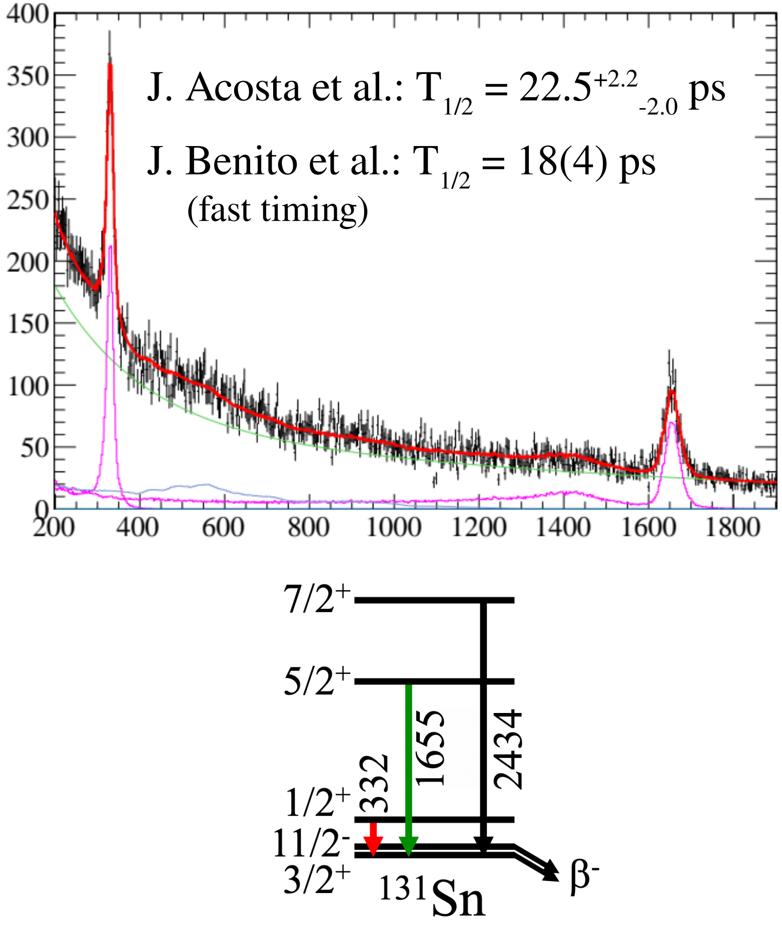
Fraile et al., Proceedings of the 23rd International Nuclear Physics Conference (2008)
Danchev et al., Phys. Rev. C 84, 061306(R) (2011)
Allmond et al., Phys. Rev. Letters, 092503 (2017)
Vaquero et al., Phys. Rev. C 99, 034306 (2019)

New 1934-keV decay branch of the $0f_{5/2}$ state in ^{131}In, correction of S_{exp}



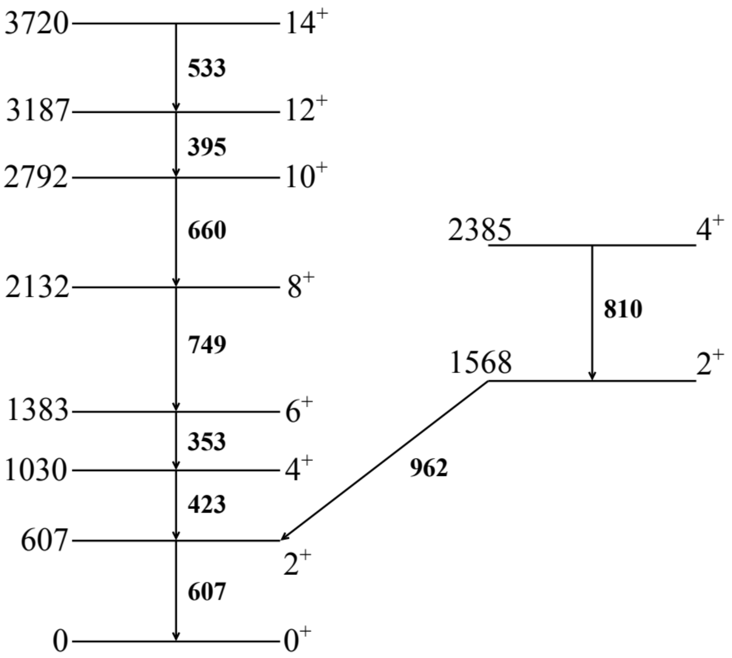
Vaquero et al., Phys. Rev. Lett. 124, 022501 (2020)

The 332-keV, l-forbidden M1 transition in ^{131}Sn



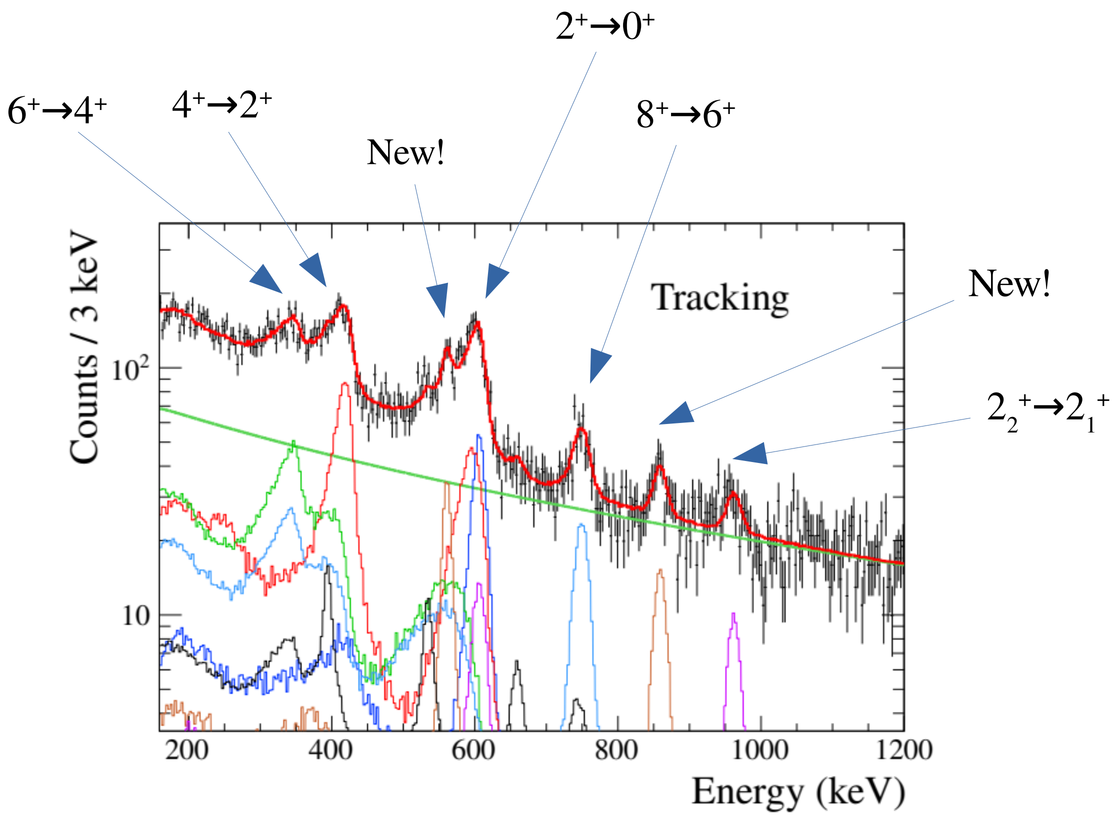
J. Benito et al., Phys. Rev. C 110, 014328 (2024)

Preliminary: ^{136}Te via 1n knockout



G. Häfner et al., Phys. Rev. C 103, p. 034317. (2021)

Vaquero et al., Phys. Rev. C 99, 034306 (2019)



J. Acosta et al., in preparation

- Lifetime measurements
- Exclusive cross sections
- Identification of new transitions

Conclusions and future work

- The HiCARI array was **characterized** and the analysis procedure was **validated** using **simple reference cases**
- **Lifetimes** can be measured via lineshape analysis with relatively **low uncertainty**
- **New transitions** were found thanks to the good **in-beam** energy resolution
- A detailed description of the method can be found in paper just accepted for submission to PRC
- Now we can focus on doing new physics!

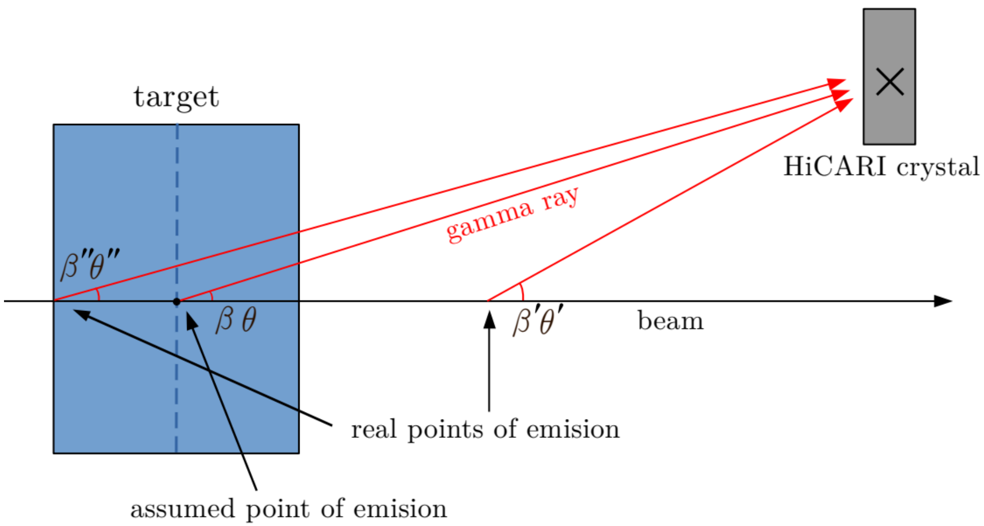
Thank you for your attention!

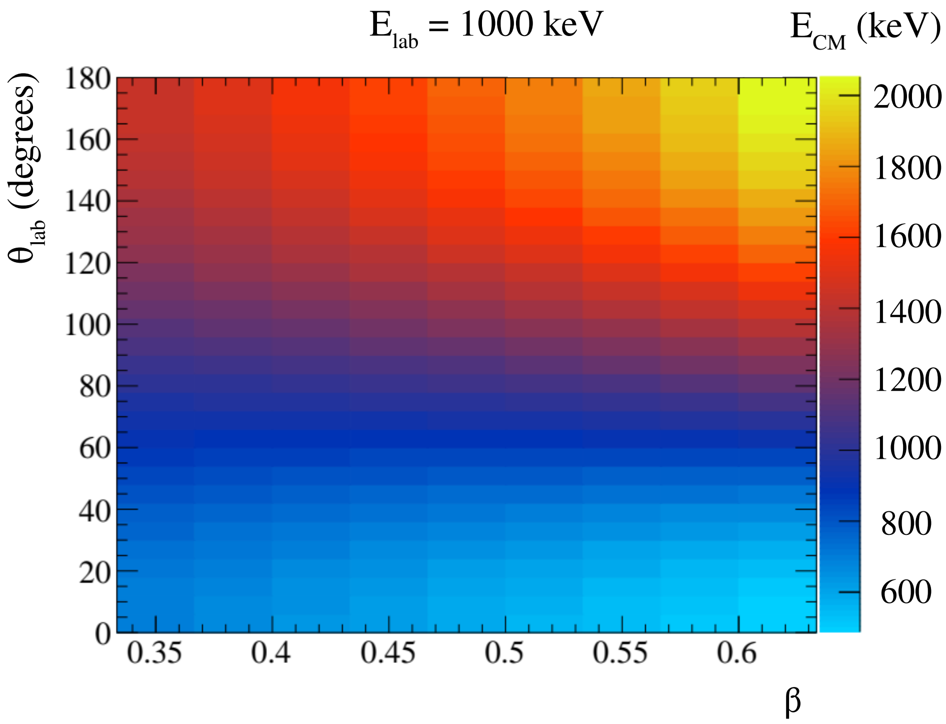
Questions?

References

- S. Baker, R. D. Cousins, *Clarification of the use of chi-square and likelihood functions in fits to histograms.* Nuclear Instruments and Methods in Physics Research 221 (1984) 437-442
- F. James, *Function Minimization and Error analysis.* https://cds.cern.ch/record/2296388/files/minuit.pdf
- R. J. Barlow, *Practical statistics for particle physics.* CERN Yellow Rep.School Proc. 5 (2021) 197, CERN Yellow Rep.School Proc. 5 (2020) 149-197

Backup slides





Two effects in wrong reconstruction:

- Velocity effect: manifests at short times after excitation $\Longrightarrow$ shifts E_{DC} to smaller (larger) values at <60° (>60°)
- Angular effect: manifests at large times after excitation $\Longrightarrow$ always shifts EDC to smaller values

<u>lineshape depends on detector placement and excited state lifetime</u>