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

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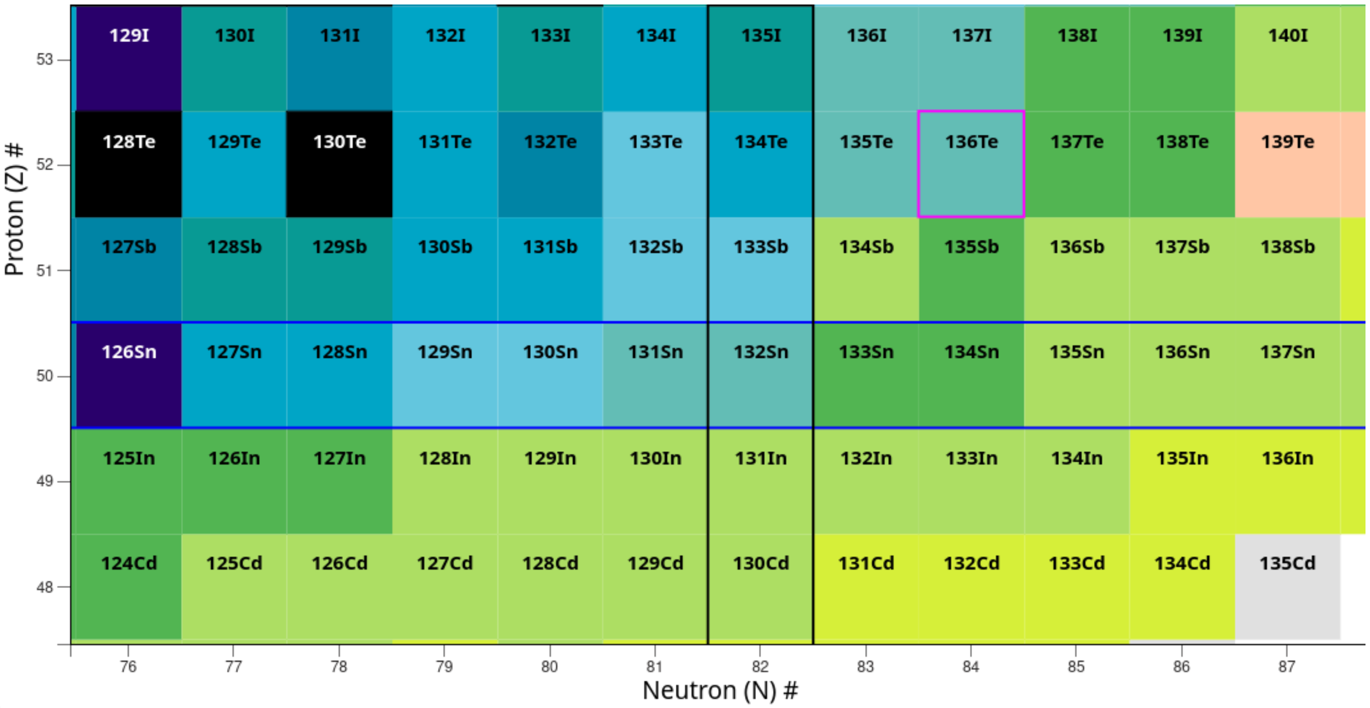
Introduction

The HiCARI campaign consisted on a series of in-beam gamma-ray spectroscopy experiments carried out at RIBF (RIKEN, Japan) using an array of Ge detectors



- Neutron-rich exotic nuclei of intermediate mass, namely in the doubly-magic ^{132}Sn region (Z=50, N=82)
- Nuclear shell model: few nucleons outside core
- Similarities with the ^{208}Pb region can be established

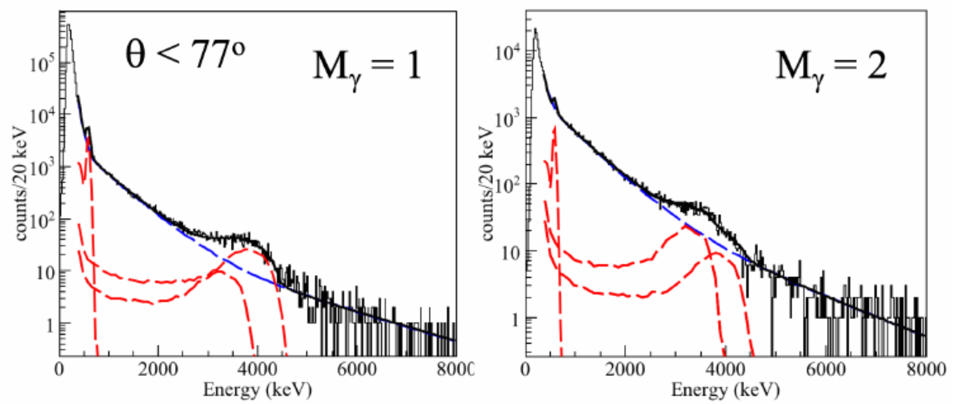
Why ^{136}Te?

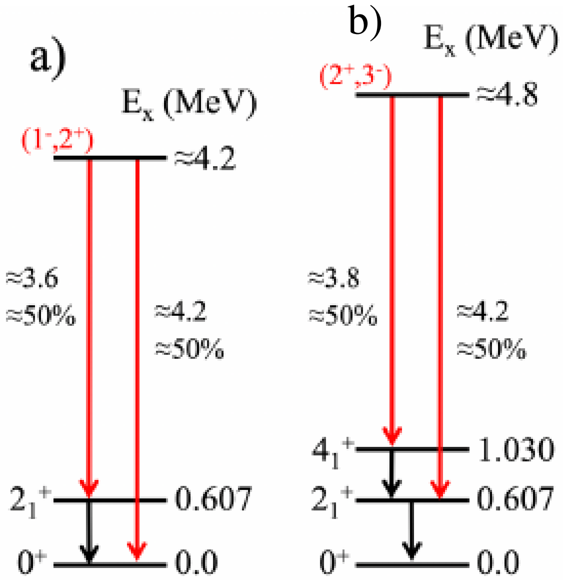
- Conflicting B(E2; $0^+ \rightarrow 2^+$) values were reported from Coulex experiments and direct lifetime measurements with fast-timing technique for the first 2+ excited state

  Half-lives reported are $T_{1/2}$= 19.0(16)[a], 18.0(25)[b], 28.1(55)[c], 28.1(41)[d] ps

- In 2015 a first Coulex experiment was performed using DALI2+ (NaI(Tl) scintillators) @ RIBF

  Two gamma rays at ~4 MeV are believed to be seen, possibly coming from the excitation of the first 3- excited state, but the limited energy resolution available at that moment made impossible to extract further information





a: Allmond et al., *Electromagnetic Moments of Radioactive ^{136}Te and the Emergence of Collectivity 2p (+) 2n Outside of Doubly-Magic ^{132}Sn*, Phys. Rev. Letters, 092503 (2017)

b: Vaquero et al., *In-beam γ-ray spectroscopy of ^{136}Te at relativistic energies*, Phys. Rev. C 99, 034306 (2019)

c: Fraile et al., *In Proceedings of the 23rd International Nuclear Physics Conference (2008)*, p.218

d: Danchev et al., *One-phonon isovector $2^+_{1,MS}$ state in the neutron-rich nucleus ^{132}Te*, Phys. Rev. C 84, 061306(R) (2011)

Arrival of HiCARI (High-resolution Cluster Array at RIBF) to RIKEN in 2020

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Higher energy resolution + tracking detectors

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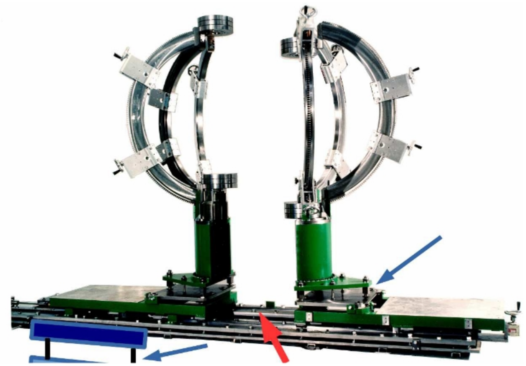
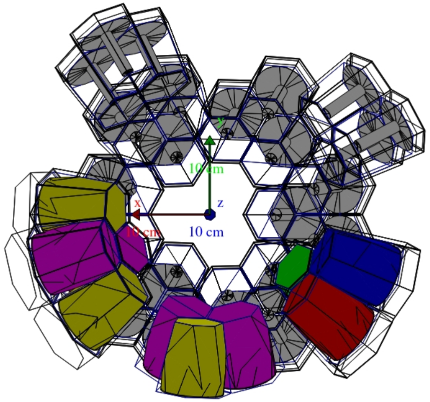
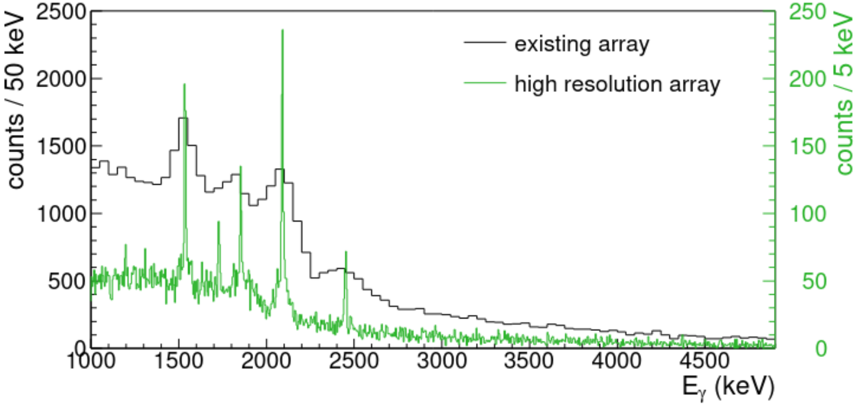
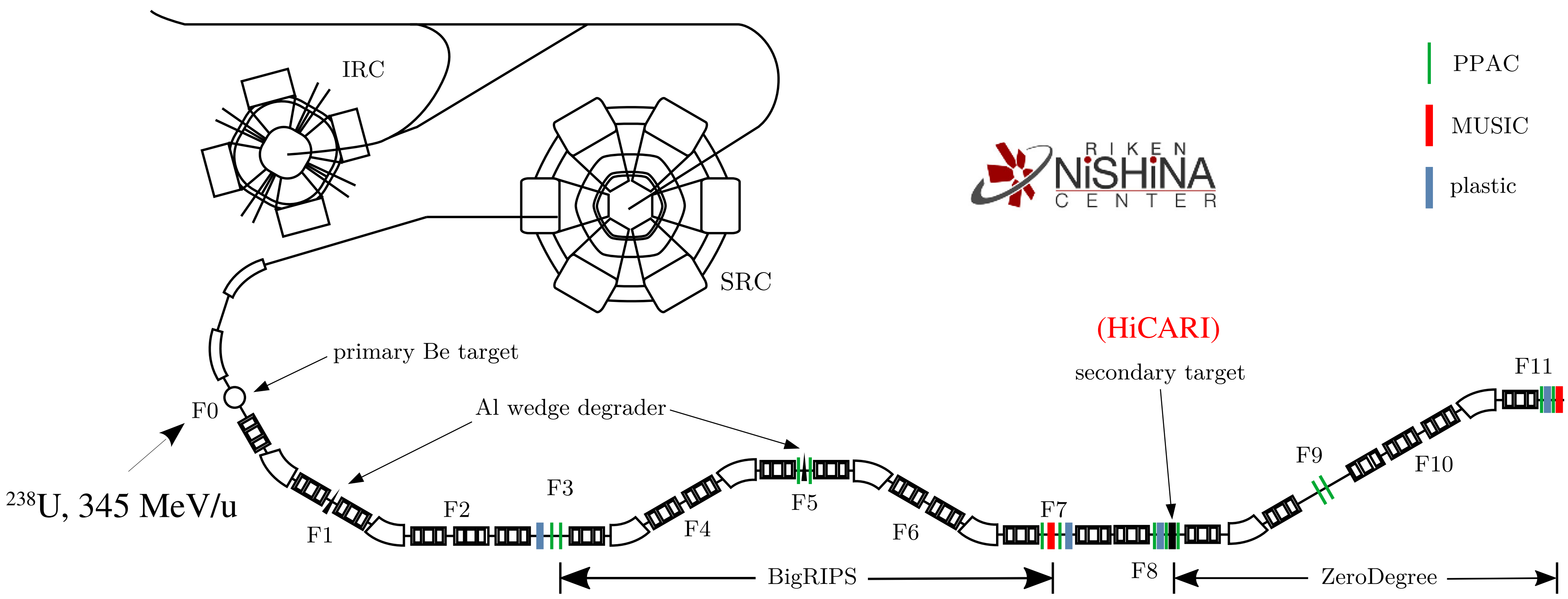
- Resolve gamma-ray transitions and discover new ones
- Obtain lifetimes via lineshape analysis







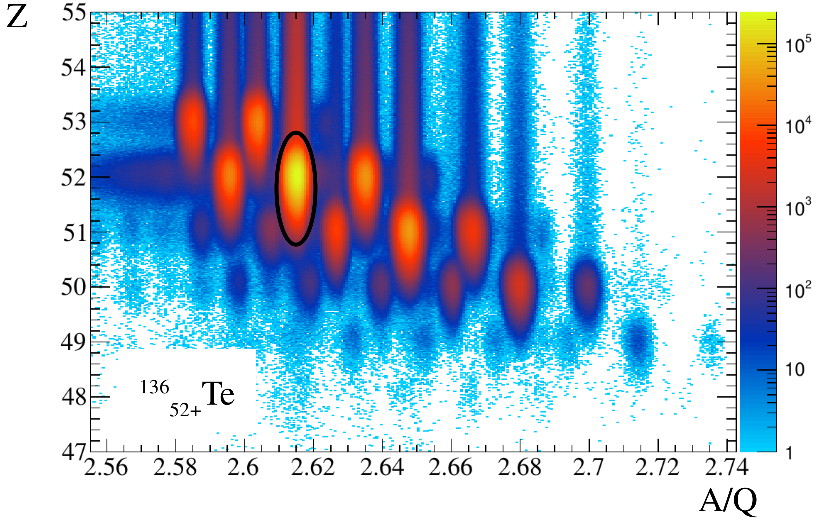
Experimental setup: beam production



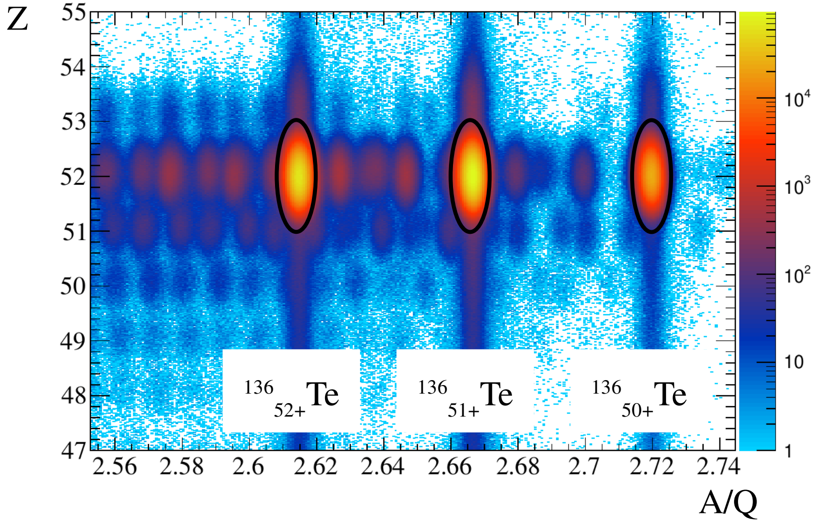
^{136}Te is produced with an energy of 165 MeV/u (relativistic)

- Beam is produced in-flight
- Two spectrometers: BigRIPS and ZeroDegree
- Large acceptance
- Excellent separation and event-by-event identification with TOF-Bρ-ΔE method

Particle identification plots



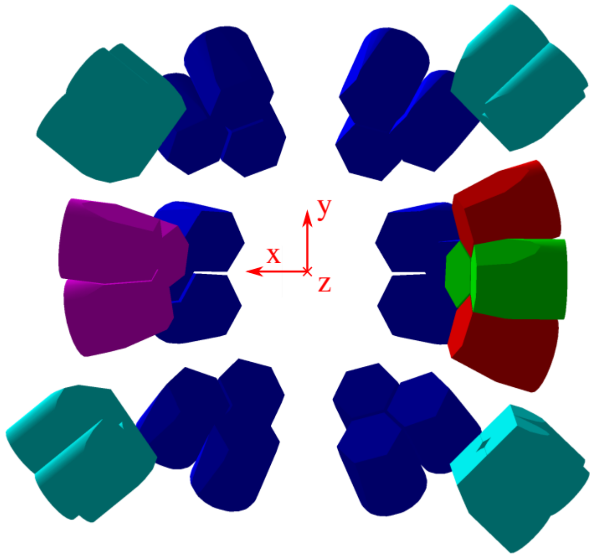
BigRIPS (before secondary target)



ZeroDegree (after secondary target)

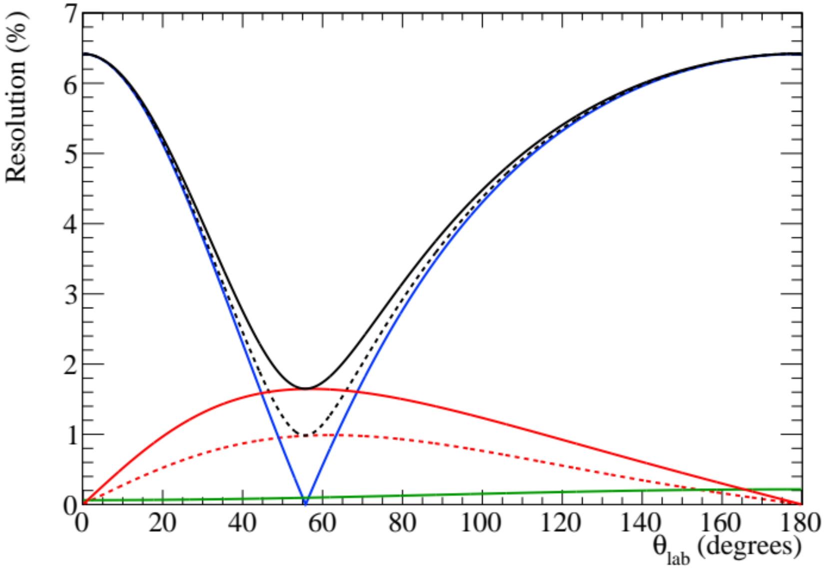
With gate on ^{136}Te in BigRIPS

Experimental setup: gamma-ray detection



Miniball
Clover
RCNP Quad
LBNL P3

- HiCARI consists on 6 Miniballs, 4 Clovers, 2 tracking detectors (LBNL P3 and RCNP Quad)
- Energy resolution (after Doppler correction) between 1% and 6% (depends on the angle), DALI2+ was closer to 10%



Intrinsic energy resolution
Angular component
Velocity component
Total energy resolution

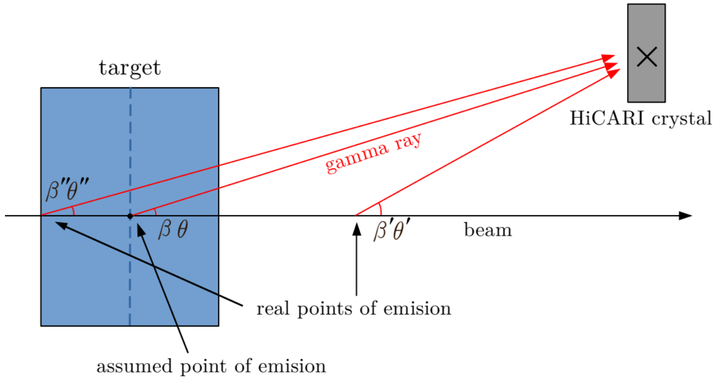
- - - - tracking
——— non-tracking

Analysis method

The gamma-rays are emitted in motion (inverse kinematics) at relativistic energies

The energy spectrum must be Doppler-corrected!

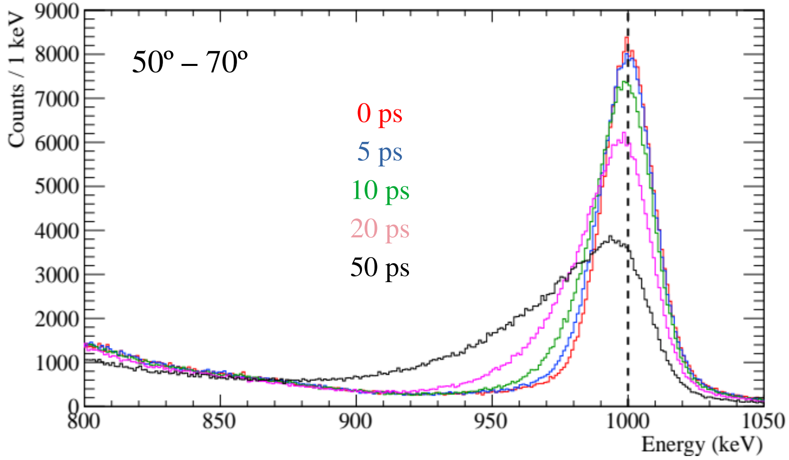
$E_{CM} = \gamma(1 - \beta \cos\theta_{lab})E_{lab} \longrightarrow$ a certain velocity and angle of emision must be assumed (center of the target)

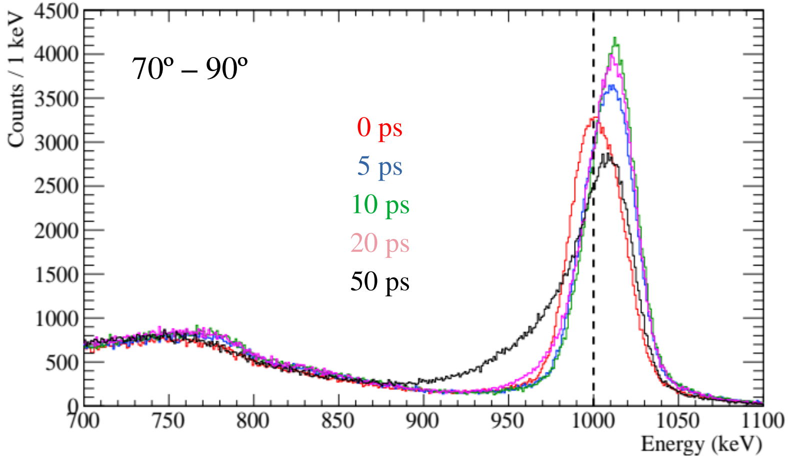


The Doppler reconstruction is not perfect since lifetimes and target thickness extend the range of points of emision and changes the velocity at emision too.

This leads to wrongly corrected energies = different lineshapes in energy spectrum

Different lifetimes yield different lineshapes, depending on the angle of detection!

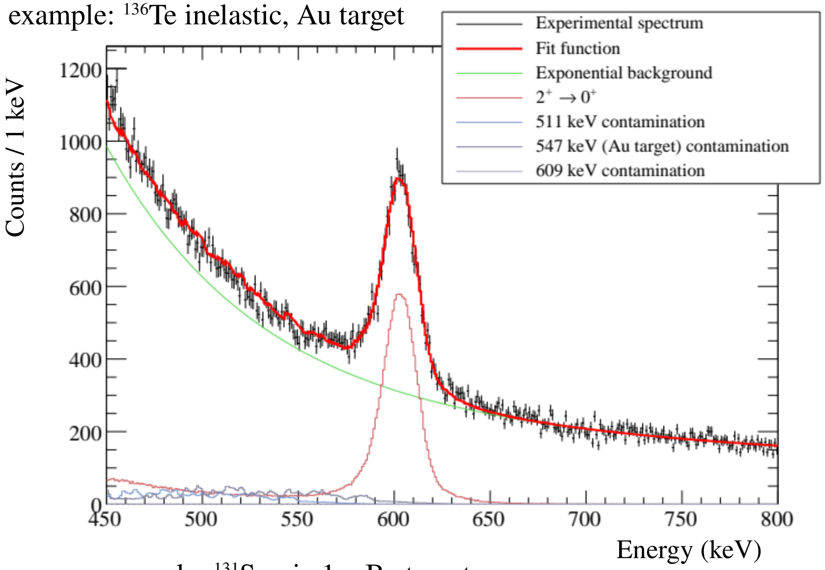




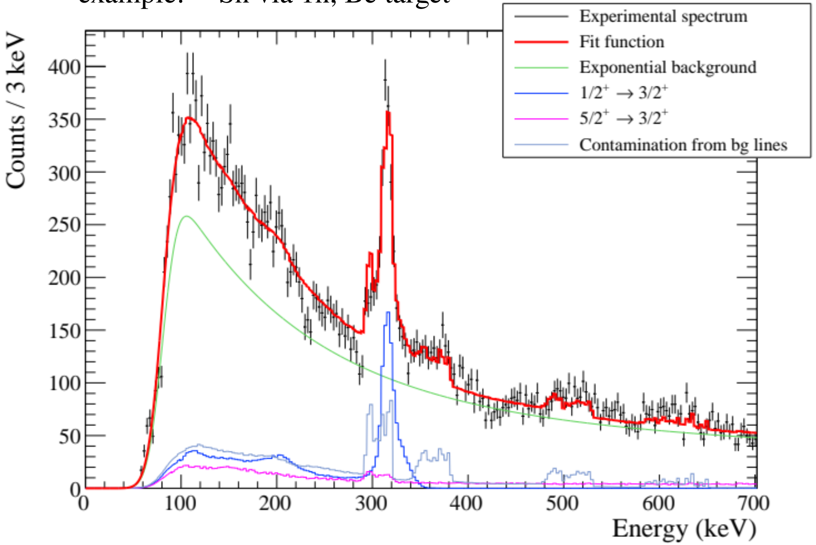
Approach: we perform simulations that describe the experimental conditions using **different half-lives and energies for the level scheme, and compare to the experimental data**

From the best fit, we extract energy and half-life values

Example from simulations: 1 MeV line detected with the tracking detectors example: ^{136}Te inelastic, Au target

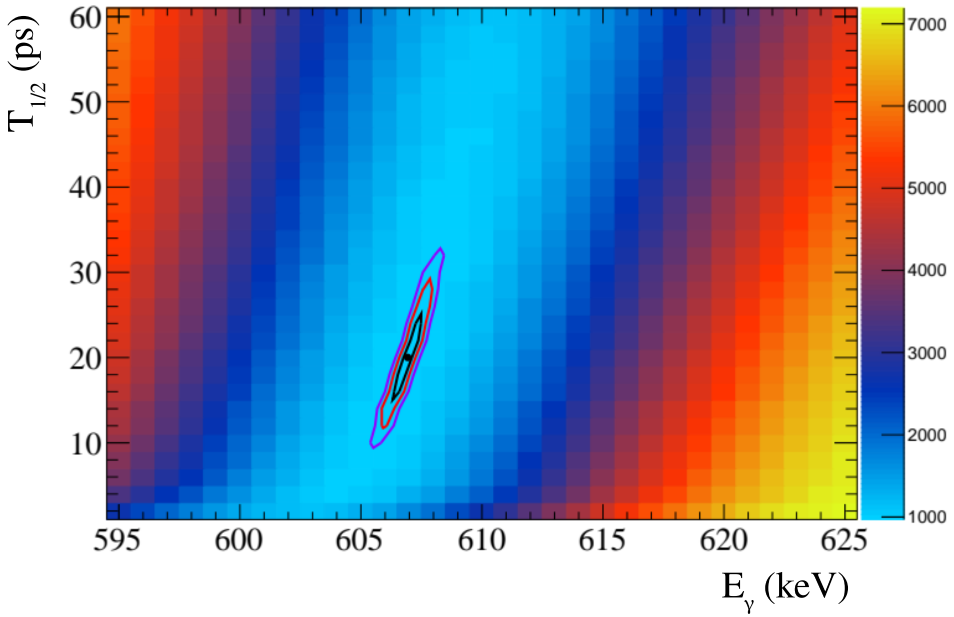


example: ^{131}Sn via 1n, Be target



A N-dimensional χ^2 matrix is created and the minimum is found

example: ^{136}Te inelastic, Au target, $2^+ \rightarrow 0^+$



The x-σ errors are located at ($\chi^2_{min} + x^2$)

1σ: $\chi^2_{min} + 1$

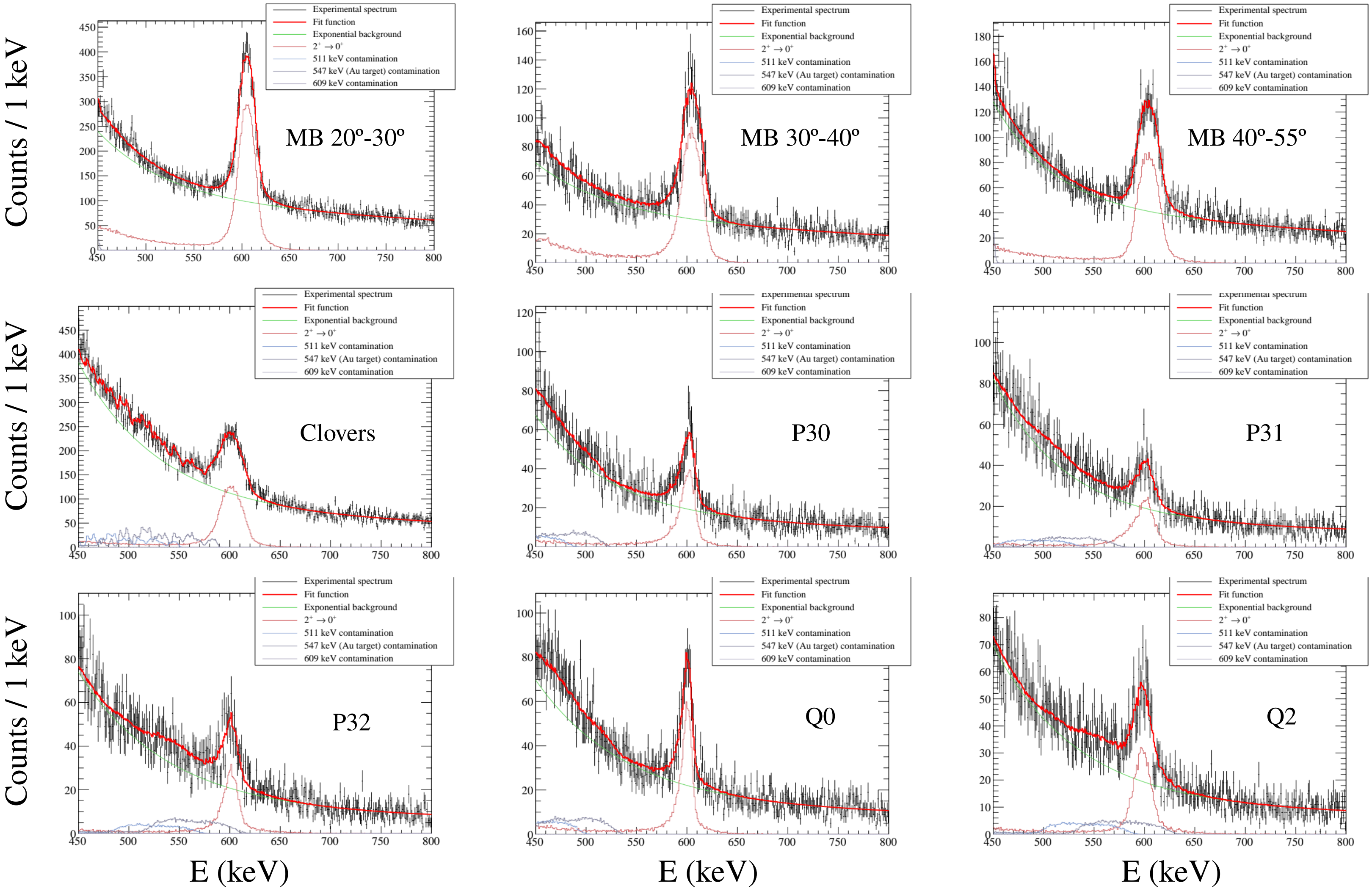
2σ: $\chi^2_{min} + 4$

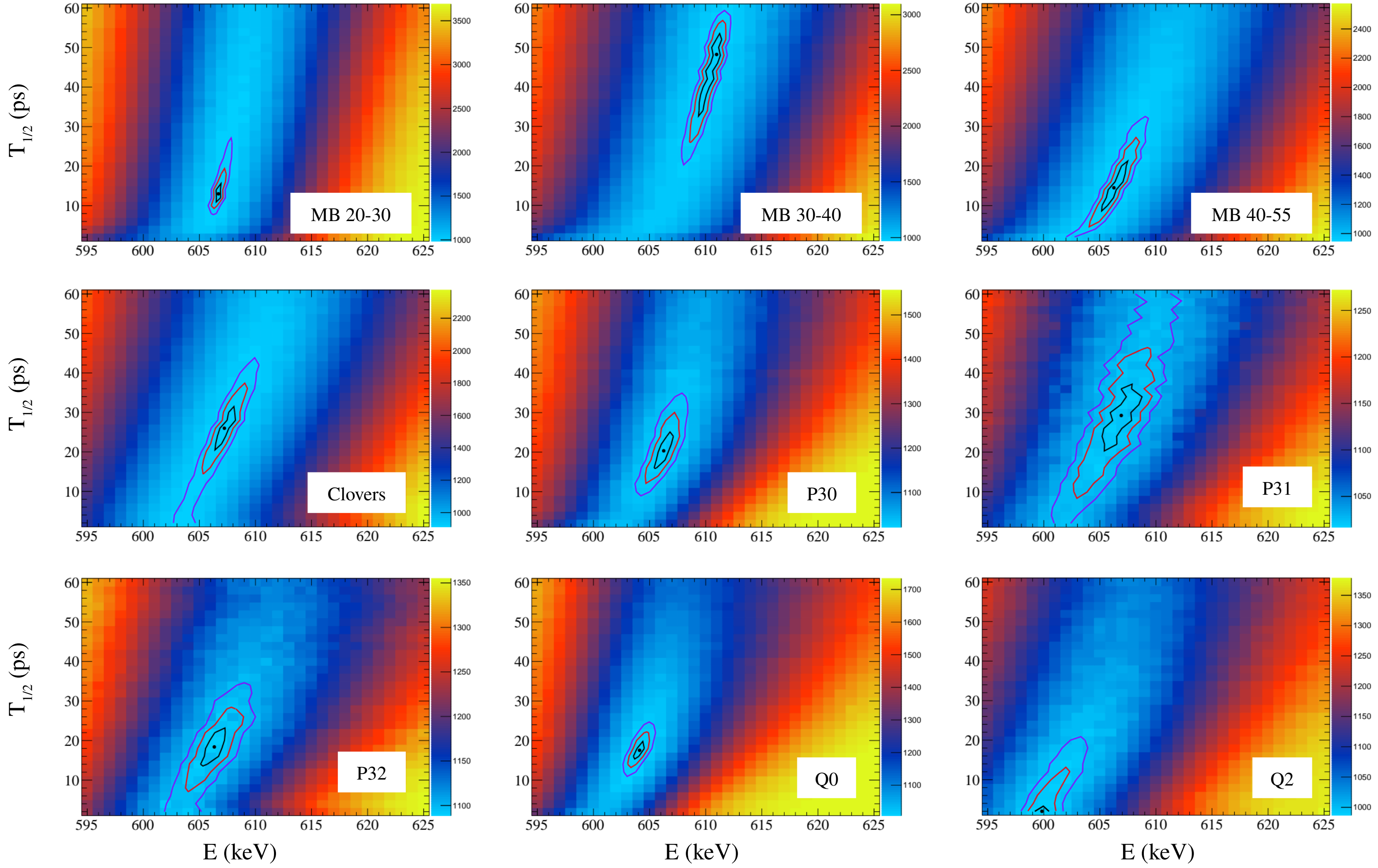
3σ: $\chi^2_{min} + 9$

Results

^{136}Te inelastic on Au

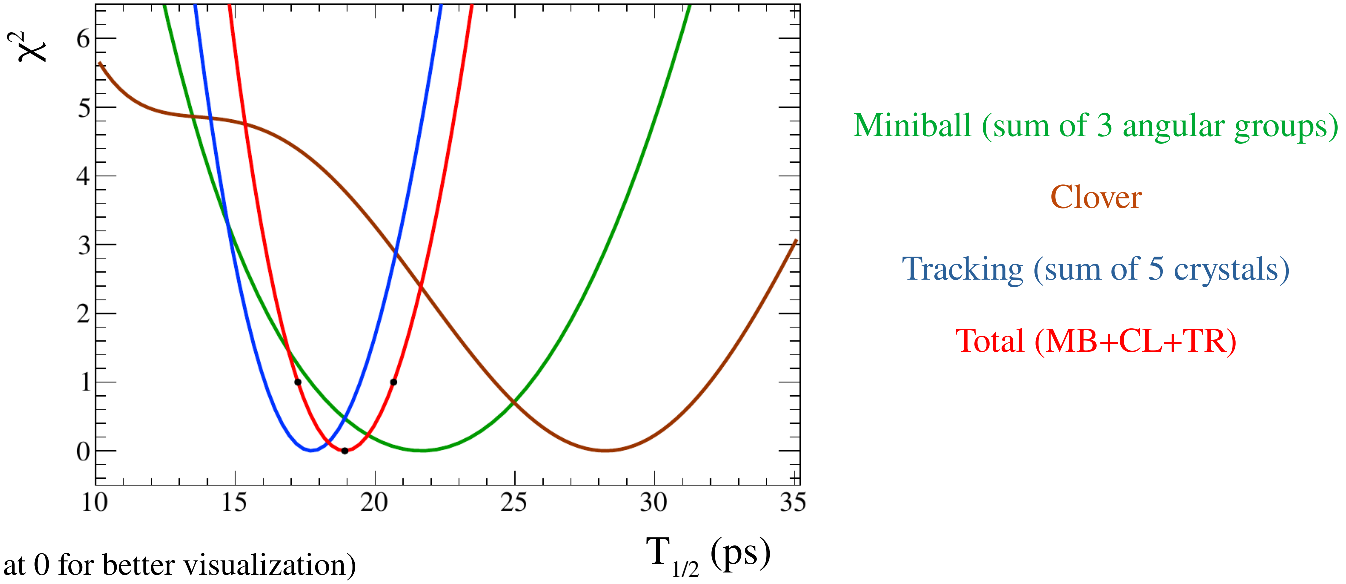
The statistics are high enough so that independent detector groups can be looked at separately




MB 20-30
MB 30-40
MB 40-55
Clovers
P30
P31
P32
Q0
Q2
$T_{1/2}$ (ps)
E (keV)

Results can be combined by summing the $\chi 2$ distributions (= multiplying likelihoods)

For obtaining a final $T_{1/2}$, we can sum the 1-dimensional χ^2 vs. $T_{1/2}$ distributions resulting from minimizing all the other fit parameters (including Eγ) for a given $T_{1/2}$



(The χ^2 curves are drawn with the minimum at 0 for better visualization)

E_γ^{lit} (keV)	E_γ (keV)	$T_{1/2}$ (ps)
606.64(5)	607.6(11)	19(4)

Conclusions and future work

- Lifetimes can be measured via lineshape analysis with reasonable uncertainty
- A 19(4) ps half-life was measured for the first 2^+ state in ^{136}Te in this work
- Other channels in different lifetime regimes were also analyzed in order to characterize the whole HiCARI array and method (paper on the way!)

Half-lives reported are $T_{1/2}$= 19.0(16)[a], 18.0(25)[b], 28.1(55)[c], 28.1(41)[d] ps

Future:

- The Coulex analysis must be done in order to extract the B(E2; $0^+ \rightarrow 2^+$) of ^{136}Te and compare to the lifetime measurement of the 2^+
- The high-energy excited states in ^{136}Te still need to be studied
- There are plenty of other channels in the HiCARI data that can be analyzed...

a: Allmond et al., *Electromagnetic Moments of Radioactive ^{136}Te and the Emergence of Collectivity 2p (+) 2n Outside of Doubly-Magic ^{132}Sn*, Phys. Rev. Letters, 092503 (2017)
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Thank you for your attention!

Questions?

References

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- 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