टाटा मूलभूत अनुसंधान संस्थान

TOPTIER CNS Summer School 2026

Development of $LaBr_3$(Ce) Scintillator Fast Timing Setup for Lifetime and Coincidence Measurements

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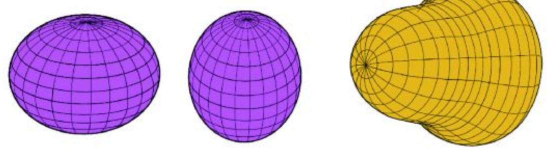
Importance of Nuclear Lifetime Measurements

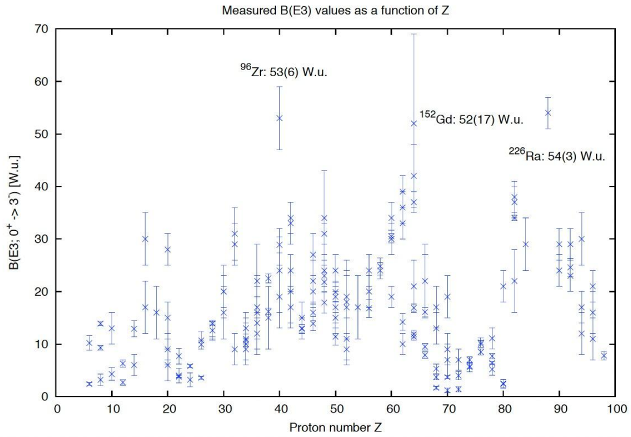
- Excited nuclear states can be broadly described as either single-particle excitations or collective excitation modes.
  - Single-particle excitation: involves the excitation of one or a few nucleons between shell-model orbitals.
  - Collective excitation: arises from the coherent motion of many nucleons.
- Lifetimes of excited nuclear states give information about the transition strengths which help us understand properties of the structure of the nucleus.
- Measured enhanced transitions act as signals of underlying collective phenomenon.



Obertelli, A., Sagawa, H. (2021). Deformation and Rotation

$$T_{fi}^{(\sigma\lambda\mu)} = \frac{2}{\epsilon_0 \hbar} \frac{\lambda+1}{\lambda[(2\lambda+1)!!]^2} \left(\frac{E_\gamma}{\hbar c}\right)^{2\lambda+1} \left|\langle \xi_f\, J_f\, m_f | \mathcal{M}_{\sigma\lambda\mu} | \xi_i\, J_i\, m_i \rangle\right|^2$$

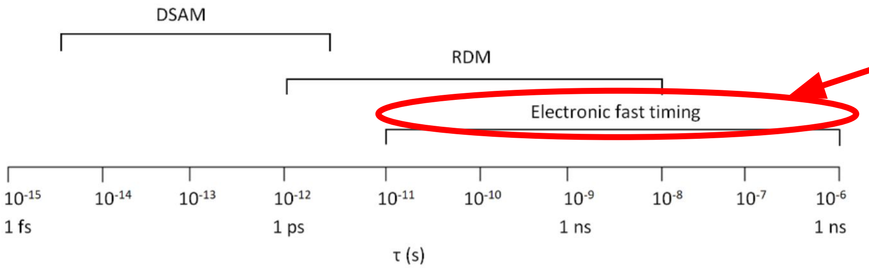
$$\boxed{t_{1/2} = \frac{\ln 2}{T_{fi}}\ .}$$

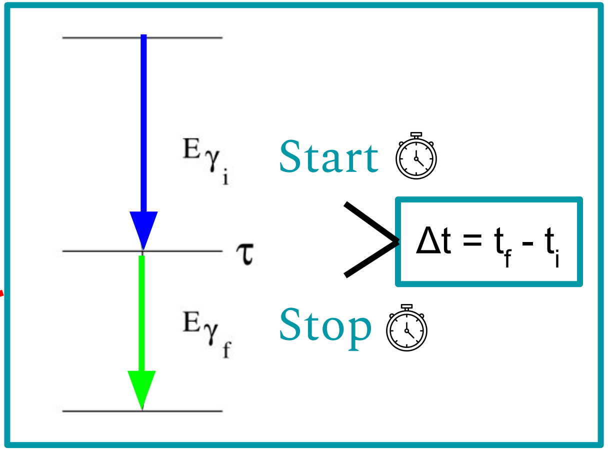


Kibédi and Spear, At. Data Nucl. Data Tables 80, 35 (2002).

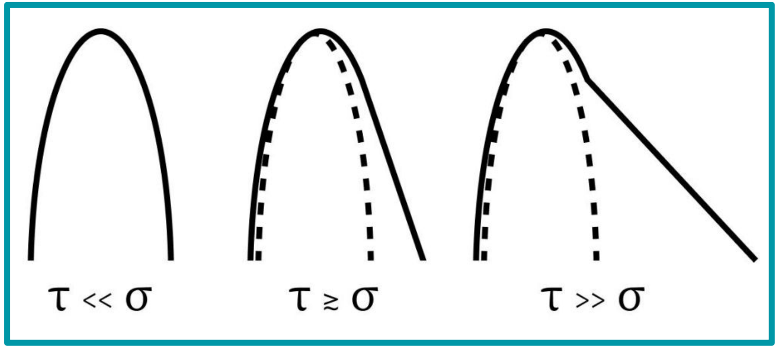
Measurement of the sub ns realm

The measured enhanced transitions correspond to very short lifetimes, hence it is required to have a systematic way of measuring the sub nanosecond realm.





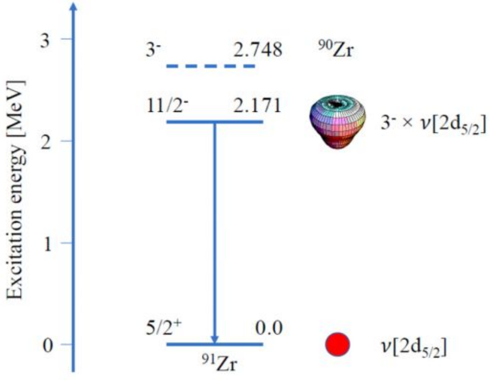
Therefore a detector with a good timing response (FWHM in ps range) is required to probe sub ns lifetimes.

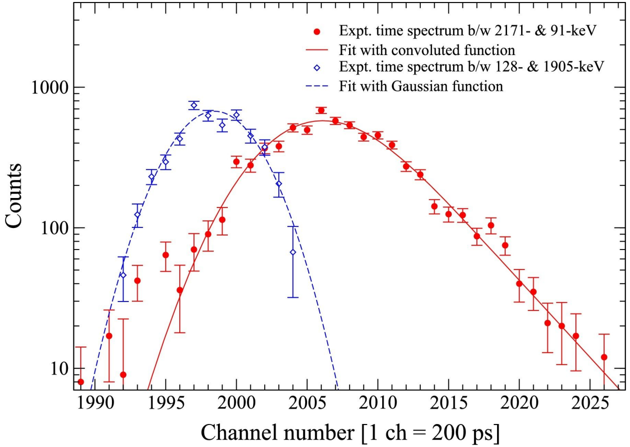


Lifetime Studies using Digital INGA

Equipped with
- HPGe Clover Detectors
- $LaBr_3$(Ce) Scintillators
- CsI(Tl) Charged Particle Detector
- Silicon CD Detector

- R. Palit and R. Raut, AAPPS Bull. 34, 35 (2024).
- P. Dey et al., Phys. Lett. B 140670 (2026).
- P. Dey et al., Nucl. Phys. A 1057, 123035 (2025).
- Md.S.R. Laskar et al., Phys. Rev. C 104, L011301 (2021).

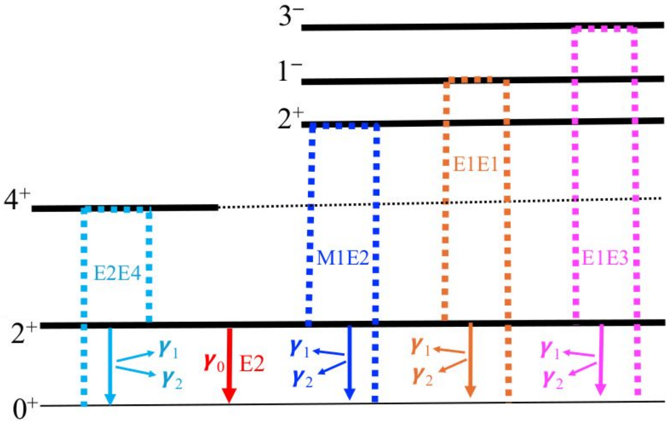


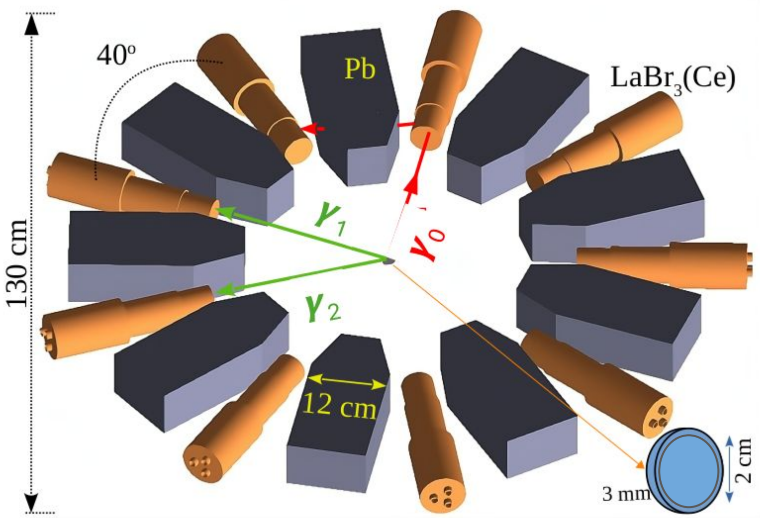


Dey et al., Nucl. Phys. A 1057, 123035 (2025).

Beyond Nuclear Structure: Two Photon Decay

Precision timing helps in reducing SNR. This can help in search for exotic decays

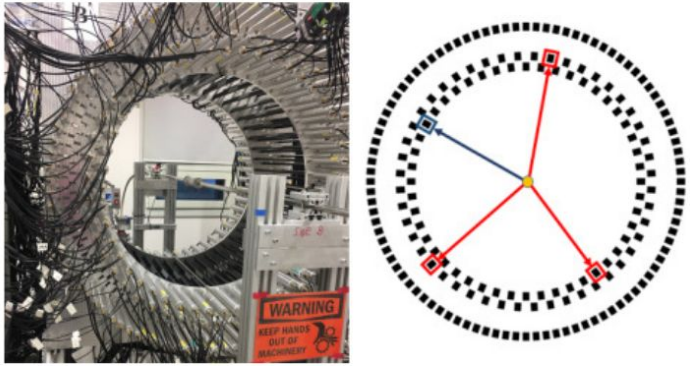




B. Das et al, Under Review

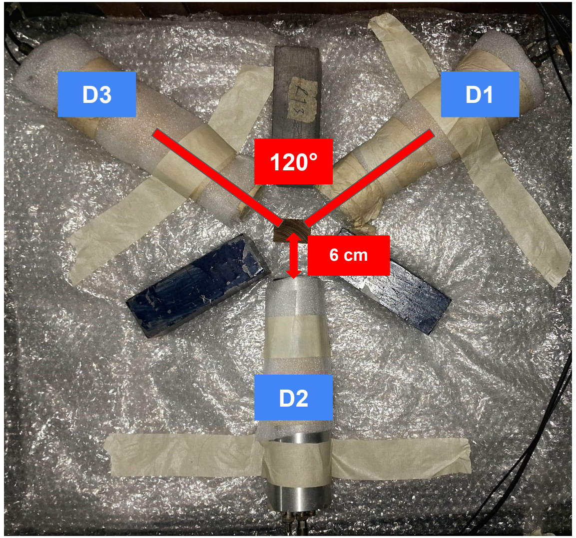
Beyond Nuclear Structure: Orthopositronium Decay

- Ortho-positronium decay serves a test bed for precision measurements and probes of BSM Physics.
- $LaBr_3(Ce)$ detectors with their good energy resolution (~2.7%) can be used to measure energy and angular distribution of the three photons.
- Coupling a position sensitive fast timing detector will enable studies of polarization and entanglement.



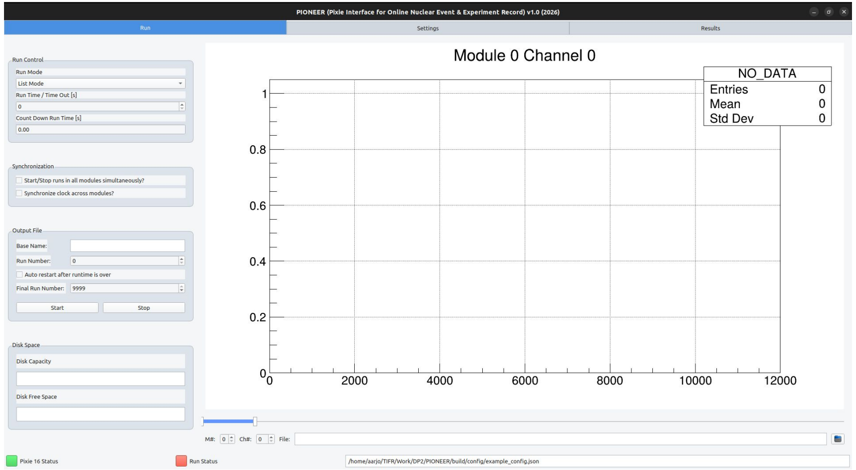
Dulski et al., Nucl. Instrum. Methods Phys. Res. A 1008, 165452 (2021).

Developing the Fast Timing Setup



Setup Details:

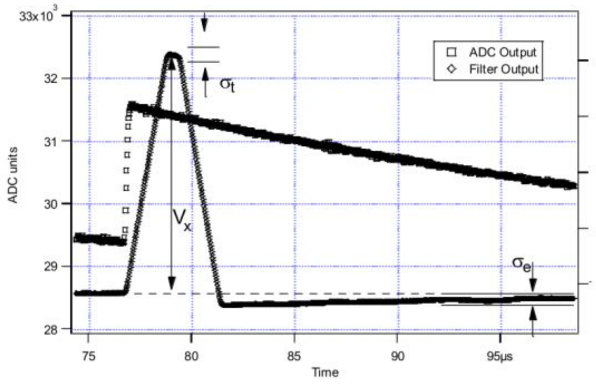
- 2″x2″ $LaBr_3$(Ce) Crystals Saint Gobain
- Hamamatsu R6231 PMTs
- XIA PIXIE 500 MHz Digitizers

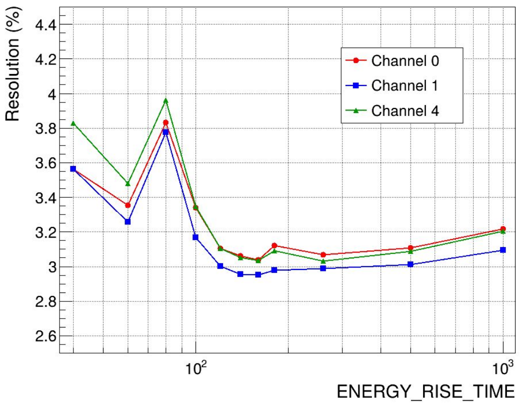


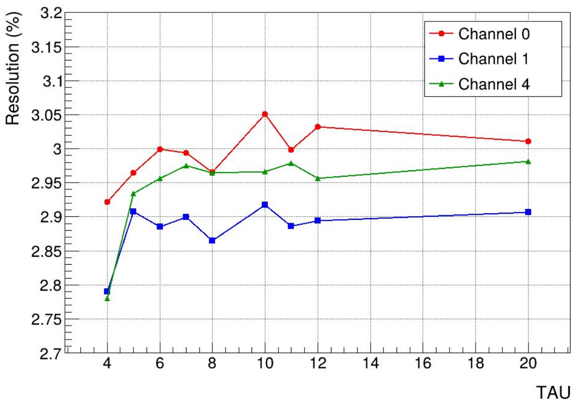
Tasks:

- Development of a GUI for the new SDK
- Optimization of Digital Parameters for Energy and Timing

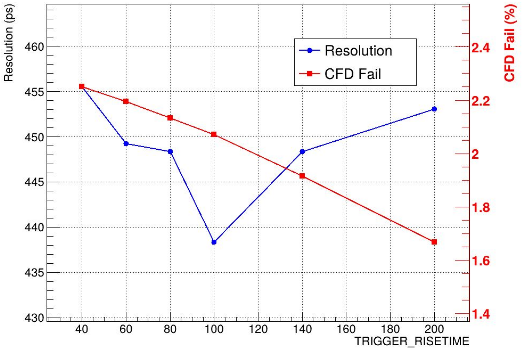
Optimization of DDAQ Setup

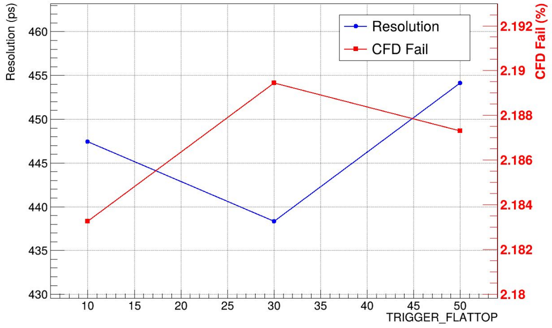




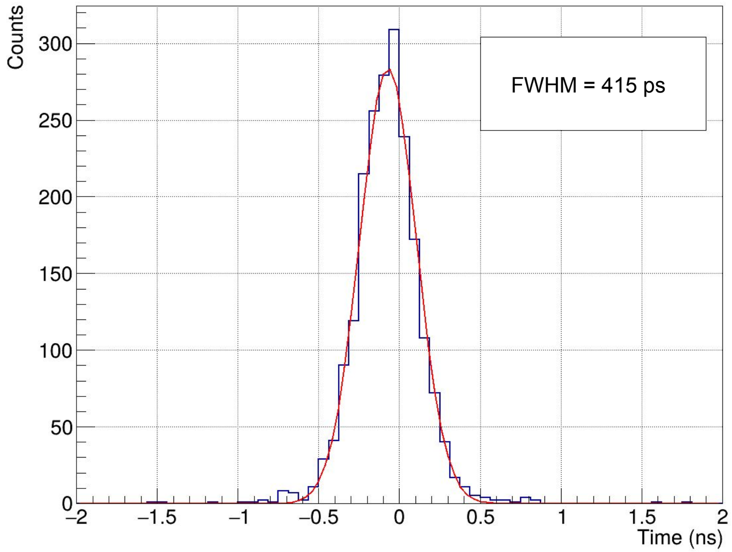


- PIXIE16 Utilizes Trapezoidal Filter for its Energy Estimation and Fast Filter Output.
- Digital CFD is used for time calculation, however the CFD Parameters for the 500MHz are fixed and thus could not be optimized.





Extending the dynamic range of Fast Timing



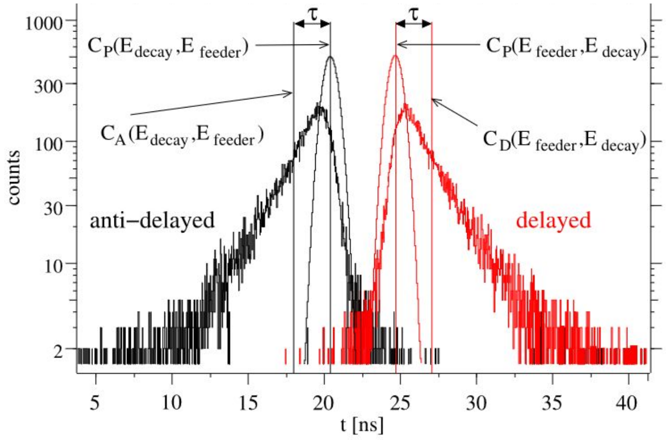
The setup reached an FWHM of 415 ps after optimization.

This allows us to probe a lot of lifetimes by direct slope fit/convolution fit.

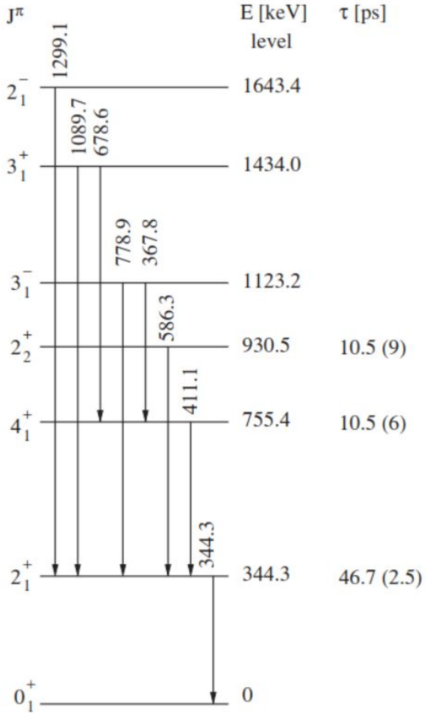
Can we probe lifetimes smaller than 415 ps?

Mirror Symmetric Centroid Shift Method

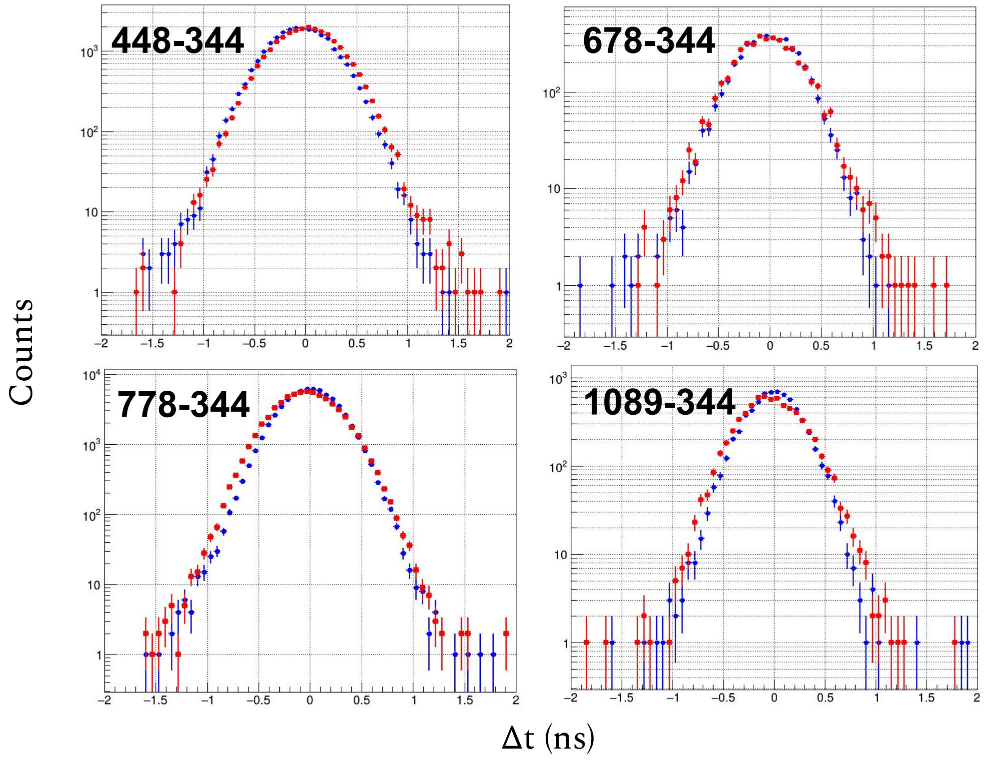
- If order of lifetime is comparable to FWHM of the timing difference spectrum, the information of lifetime is still encoded in the value of the centroid of the distribution.
- $C_D = C_P + \tau$
- The time difference spectrum can correspond to either start branch or stop branch of the detector.
- Since timing characteristics of each branch differ in a real setup, the prompt curve needs to be calibrated independent of the asymmetry.
- This is achieved by defining the centroid shift as $\Delta C = C_D - C_A$.
- This helps us define $\Delta C = PRD + 2\tau$.
- Thus to measure τ, the energy dependent walk ($PRD(\Delta E_\gamma)$) of the system needs to be calibrated.



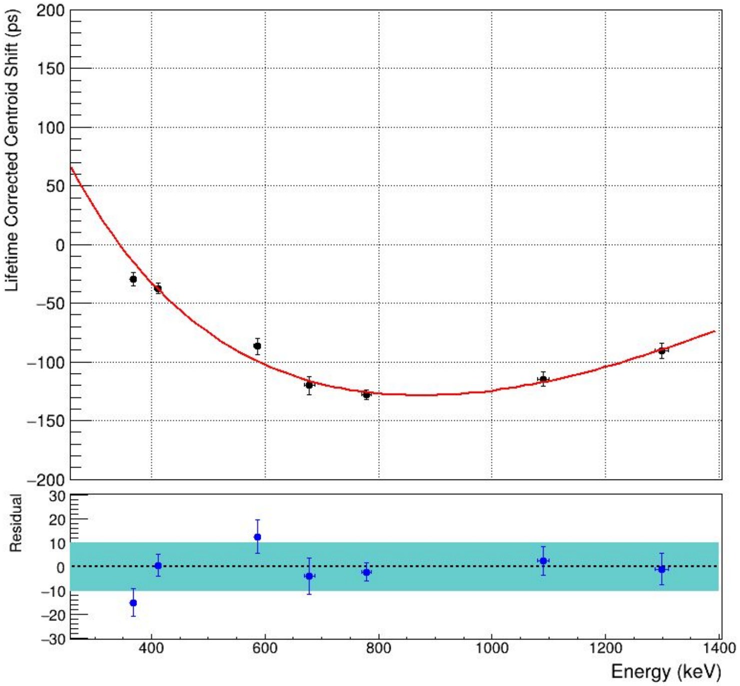
Calibration of the PRD



Partial decay scheme of ^{152}Gd



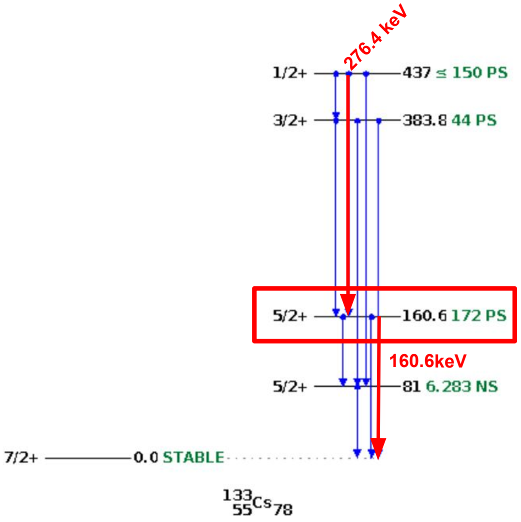
Calibration of the PRD

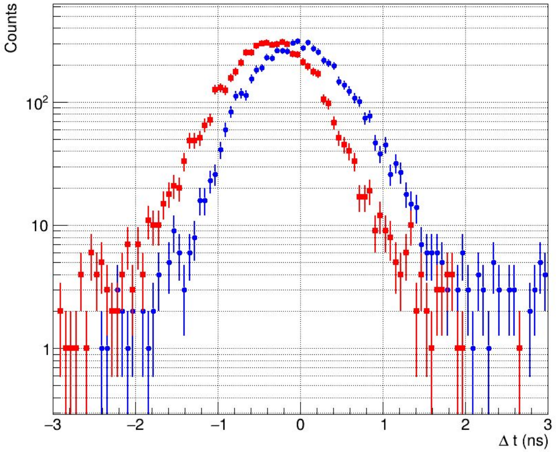


$$PRD(E_\gamma - 344.3) = \frac{a}{\sqrt{E_\gamma + b}} + cE_\gamma + d$$

- Fit was constrained to be 0 at E_γ = 344.3 keV.
- RMS of residuals = 10.1 ps. Error of PRD.
- Optimized setup gives us a minima at around 873 keV. Time walk of the setup has been constrained.

Validation: Lifetime of 5/2$^+$ state in ^{133}Cs

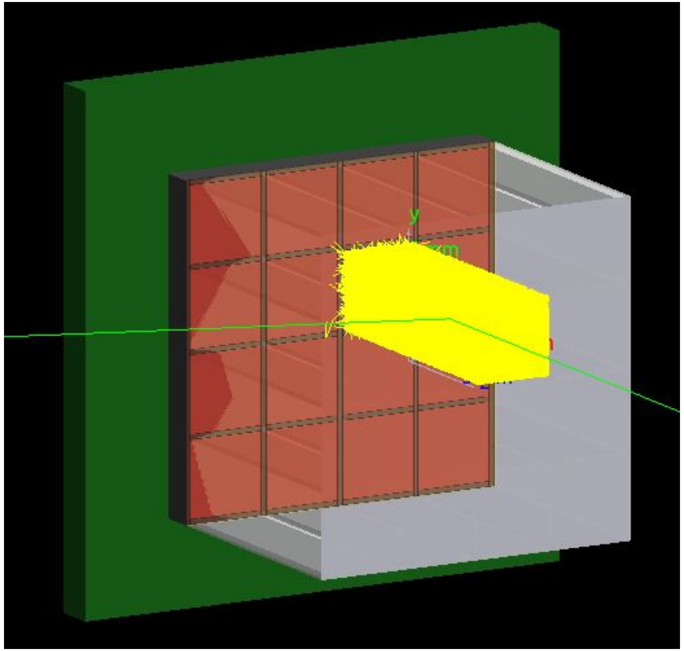


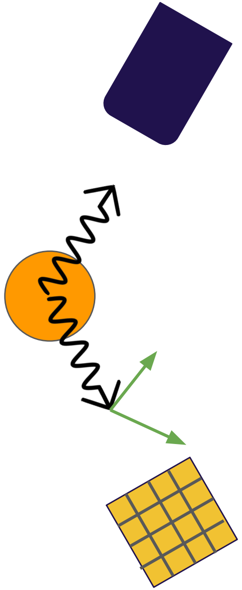


Mean Life extracted:
244.5(14.5) ps

Literature Mean life:
248(6) ps

Towards Position Sensitive Fast Timing





- Future work includes development of a Scintillator Array to enable sensitivity to polarization and position sensitive measurements.
- Making use of good light yield of GAGG(Ce) crystals for good energy resolution

Summary

- Measurement of Nuclear Lifetimes allow us to probe the structure of the nucleus
- There is current ongoing interest in search of octupole collectivity.
- Many such campaigns were done using the Digital INGA equipped with $LaBr_3$(Ce) detectors.
- A more optimized test setup was developed to increase the dynamic range of the detectors.
- New setup was validated using the Mirror Symmetric Centroid shift on a known nucleus.
- Simulation work for future scintillator array is ongoing as well as development of the detector system

— THANK YOU —