Rare decays with gamma-ray detectors

Rudrajyoti Palit
TIFR

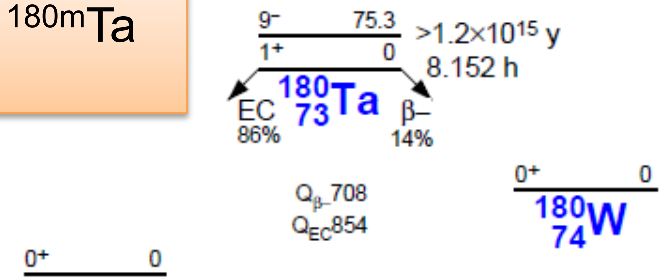
Collaboration
TIFR, BARC, SINP, VECC, IITs, Universities, …

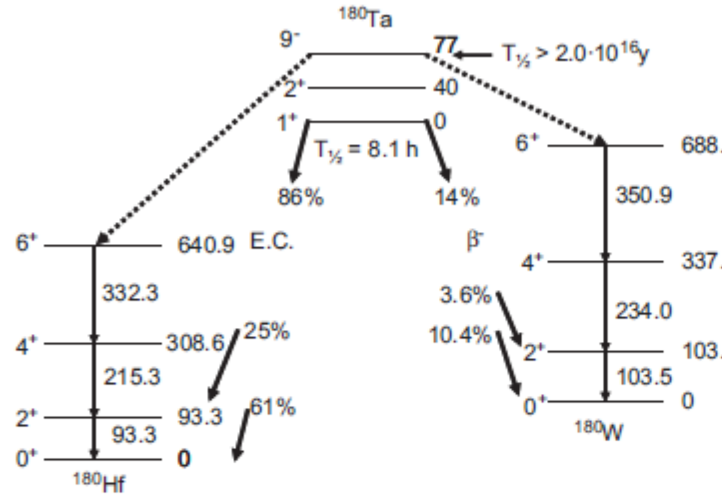
Rare decays

- Two-photon decay in atomic nuclei
- Long-lived isomers and its application
- Charge changing decays
- Applications

Search for the decay of natures rarest isotope ^{180m}Ta

Extremely interesting case:
g.s. state quickly decays ($T_{1/2}$~8 h);
isomeric state (E_{exc}=77 keV) has very big $T_{1/2}$>2e16 y
δ(^{180m}Ta)=0.012%





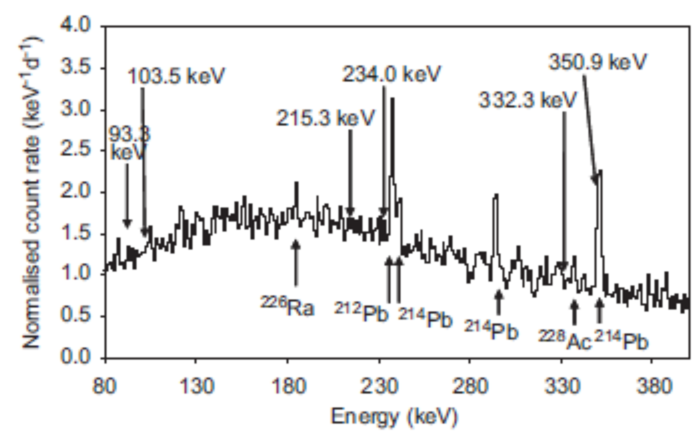


Fig. 3. The part of the γ-ray spectrum collected for 68 days that encompasses the energy regions with the γ-rays expected from the decay of ^{180m}Ta. The spectrum has been re-binned to enhance visibility. The peaks are all from background of the naturally occurring decay chains and the radionuclides being the major contributors to those peaks are indicated.

Search for the decay of natures rarest isotope ^{180m}Ta

Reference	Year	Technique	Lower half-life limit		
			EC	β^-	total
Eberhardt et al.[5]	1955	Mass Spec.	—	$9.9 \cdot 10^{11}$ yr	—
Eberhardt and Signer[6]	1958	Mass Spec.	$4.6 \cdot 10^{9}$ yr	—	$4.5 \cdot 10^{9}$ yr
Bauminger and Cohen[7]	1958	γ-spec. NaI	$2.3 \cdot 10^{13}$ yr	$1.7 \cdot 10^{13}$ yr	$9.7 \cdot 10^{12}$ yr
Sakamoto[8]	1967	γ-spec. NaI	$1.5 \cdot 10^{13}$ yr [a]	—	—
Ardisson[9]	1977	γ-spec. Ge(Li)	$2.1 \cdot 10^{13}$ yr	—	—
Norman[10]	1981	γ-spec. Ge(Li) enr. Ta	$5.6 \cdot 10^{13}$ yr	$5.6 \cdot 10^{13}$ yr	$2.8 \cdot 10^{13}$ yr
Cumming and Alburger[11]	1985	γ-spec. HPGe enr. Ta	$3.0 \cdot 10^{15}$ yr	$1.9 \cdot 10^{15}$ yr	$1.2 \cdot 10^{15}$ yr
Hult et al.[12]	2006	γ-spec. HPGe	$1.7 \cdot 10^{16}$ yr	$1.2 \cdot 10^{16}$ yr	$7.2 \cdot 10^{15}$ yr
Hult et al.[13]	2009	γ-spec. Sandwich HPGe	$4.45 \cdot 10^{16}$ yr	$3.65 \cdot 10^{16}$ yr	$2.0 \cdot 10^{16}$ yr

New result 4.5×10^{16} years — B. Lehnert et al., Phys. Rev. C 95(4), 796 (2017).

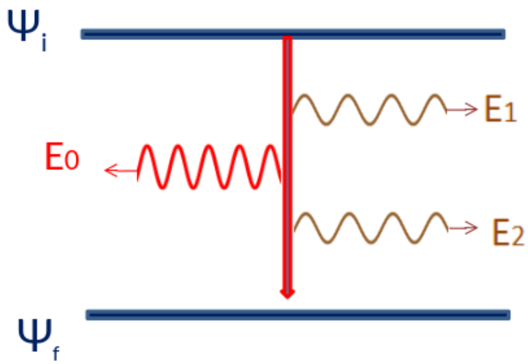
Now with better experimental techniques and better theoretical understanding:

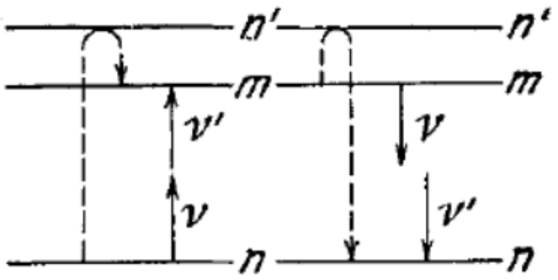
Searches for (and investigations of) rare β decays and isomers are very active and interesting field of researches

Searches for new, previously undiscovered, alpha decays are also active during last years

Two-photon decay in atomic nuclei

- The two-photon decay is a second order process of quantum electrodynamics
- The excited nuclear state can emits two-gamma quanta in a single quantum transition with very small probability.





On the probability of a collaboration of two light quanta in an elementary process
M. Goppert. Natureweiss 17 932 (1929)

Opportunity in two-photon decay

Two-photon M.E. similar to E1 polarizability / 0νββ − NME

Related to Symmetry Parameter of Nuclear EoS

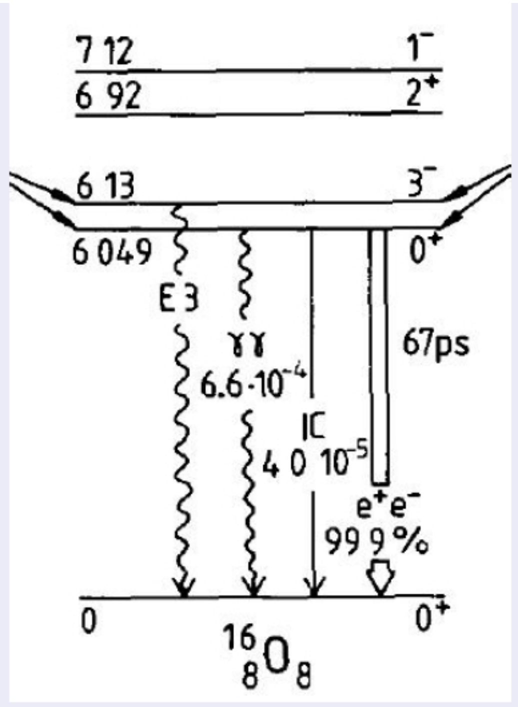
Access to aspects of NME for 0νββ − decay

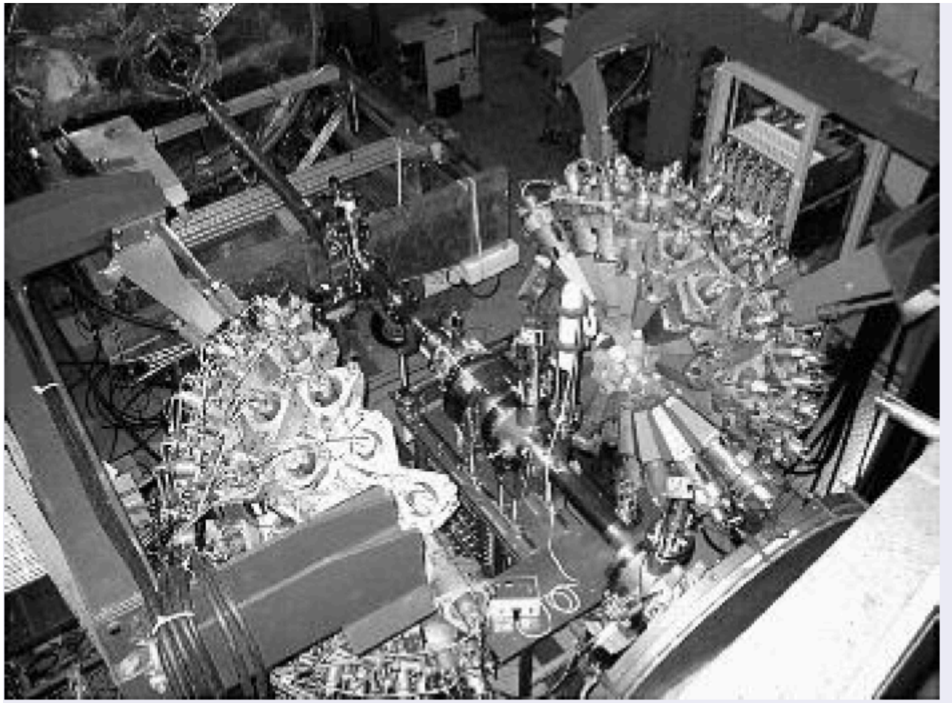
^{48}Ca (2+ -> 0+)   B.R. 3×10^{-8}

A. P. Severyukhin, N. N. Arsenyev and N. Pietralla PRC 104, 024310 (2020)

Classic Nuclear Physics Experiment with Crystal Ball

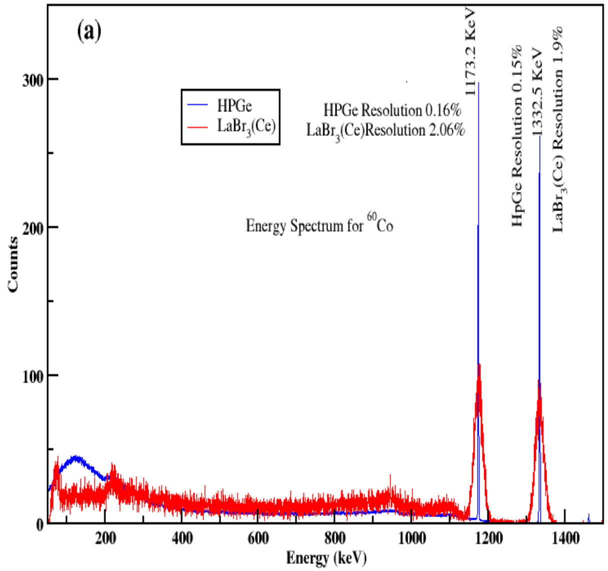
Studied $0^+ \rightarrow 0^+$ decay in ^{16}O, ^{40}Ca, ^{90}Zr

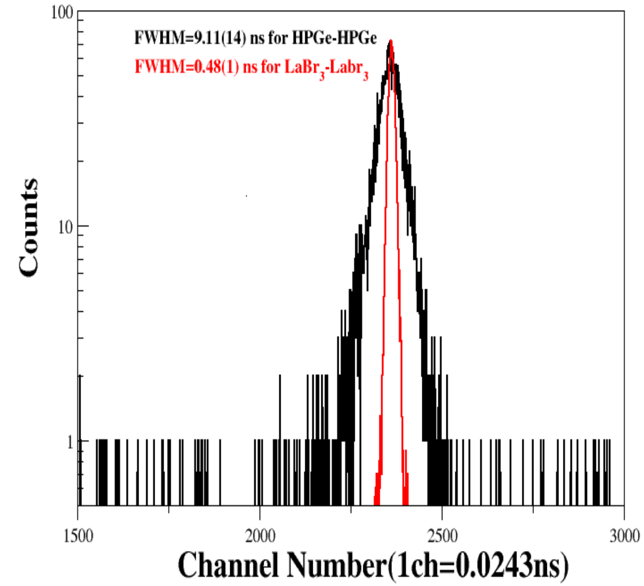




J Kramp et al. Nucl. Phys. A474 (1987) 412

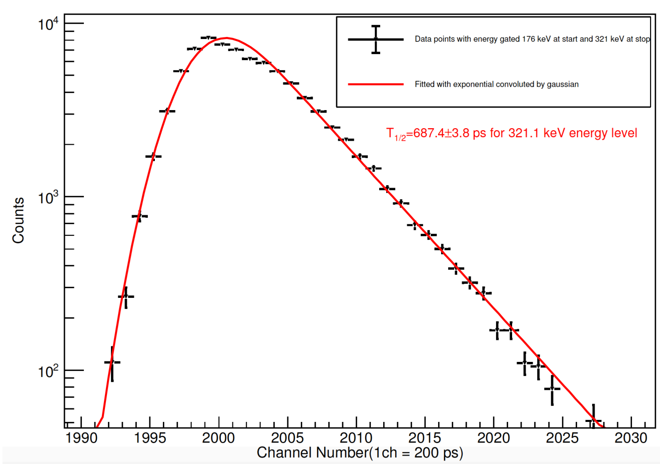
Energy and Time resolution comparison between HPGe and $LaBr_3(Ce)$



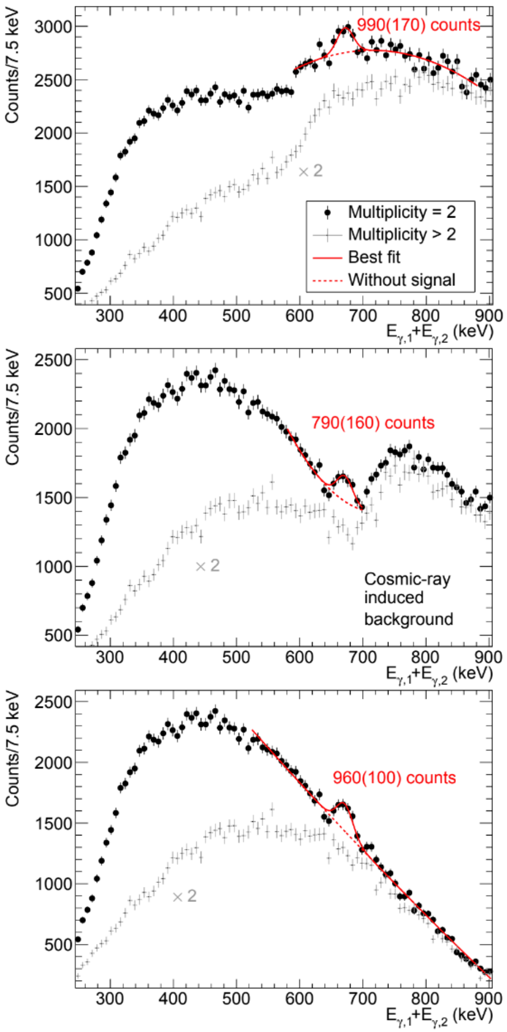


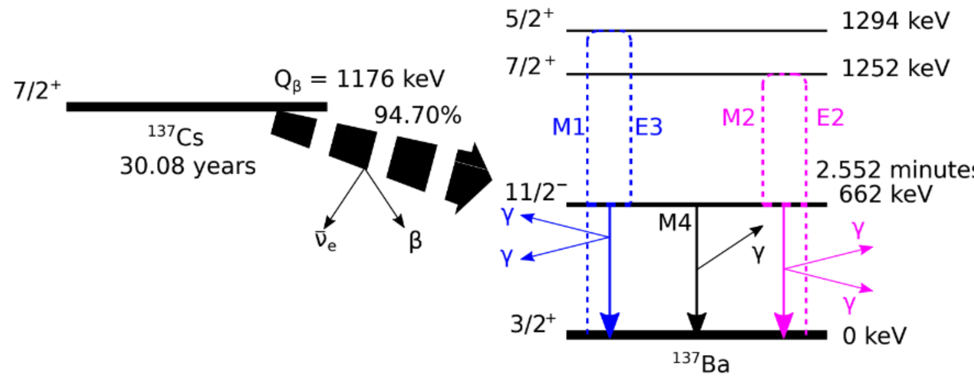
- Energy resolution of HPGe is better than $LaBr_3(Ce)$.
- Time resolution of $LaBr_3(Ce)$ is better that HPGe.

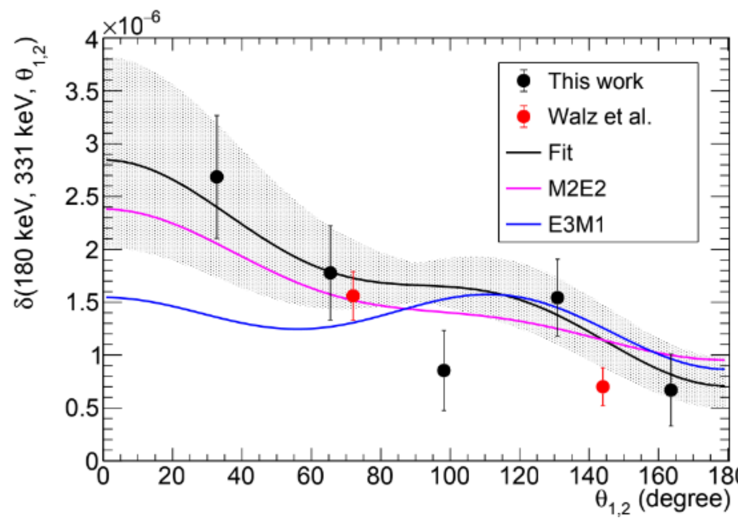
Test case: $T_{1/2}$ measurement for $9/2^-$ state in ^{125}Te



Two-photon decay in ^{137m}Ba





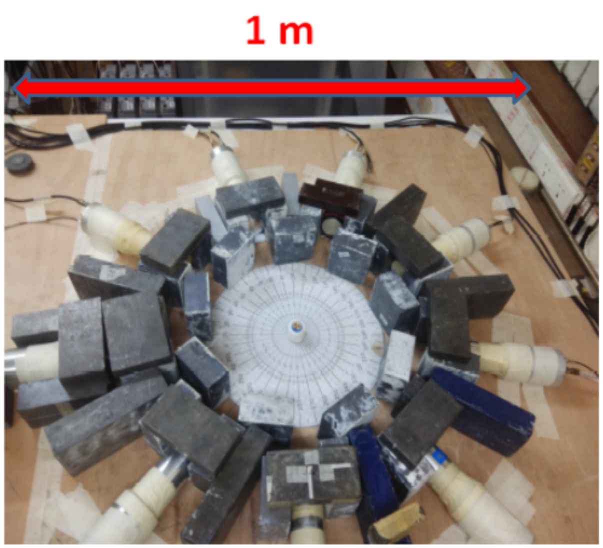


C.Walz et al., Nature 526, 406 (2015)

P.-A. Soderstrom et al., Nature Communications 11, 3242 (2020)

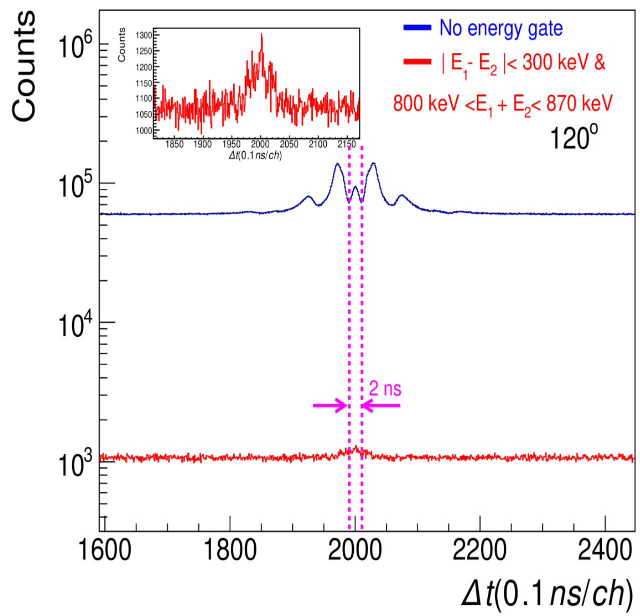
Experimental set-up at TIFR

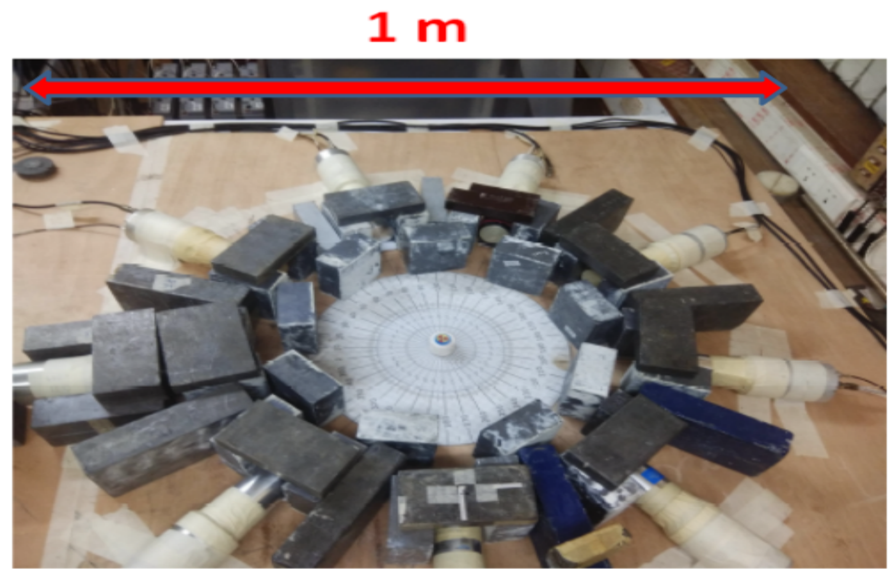
- Nine detectors were kept at 30 cm(front face) from the source on horizontal plane.
- Relative angle is 40° between two adjacent detector.
- Total solid angle covered by nine detectors is 0.2026 sr (1.61%) .
- 14 cm wide lead brick was put between two adjacent detectors.
- Detector pairs: 40°, 80°, 120°, and 160°

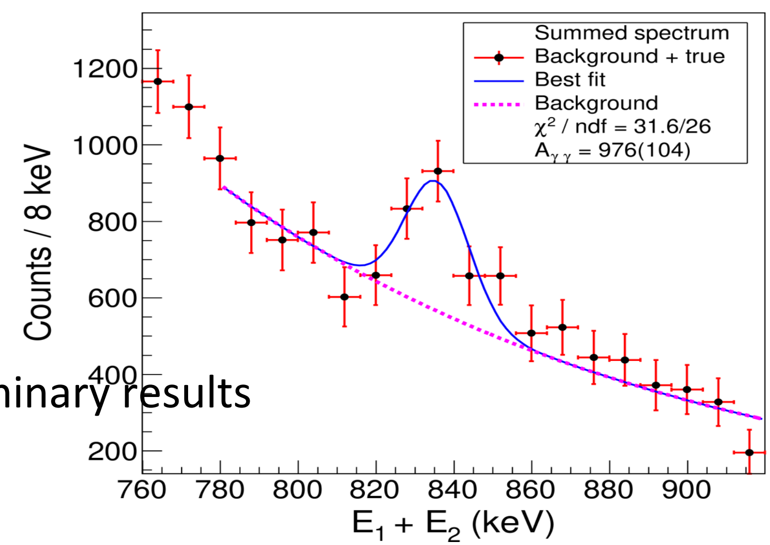


Two-photon decay from 2^+ to 0^+

Measurement time source ~ 87 days
background ~ 40 days







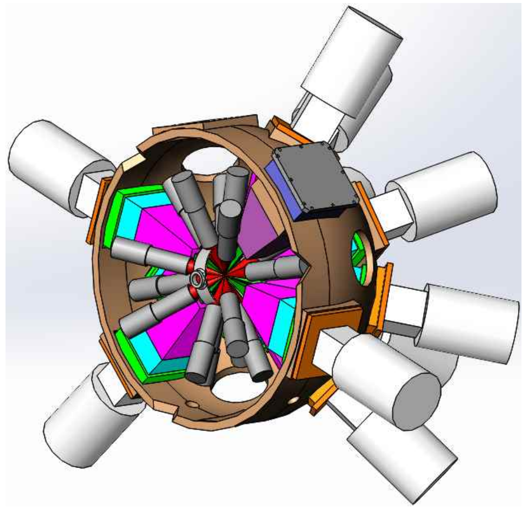
Preliminary results

Biswajit Das et al

Nuclear structure studies and advance detectors

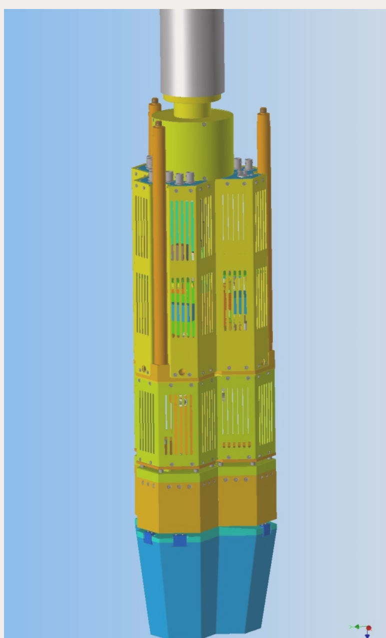
1. Hybrid array of Clover HPGe and LaBr3(Ce) for nuclear structure
i) Octupole correlations near N=50 and 82

2. Two-photon decay

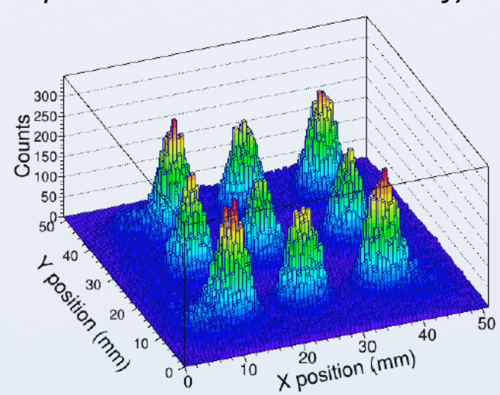


1 m

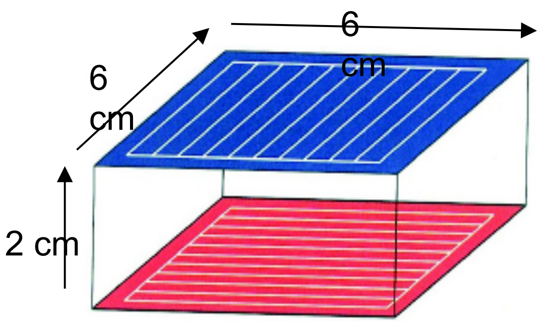
Detector at FAIR
Formation of heavy elements in the Universe

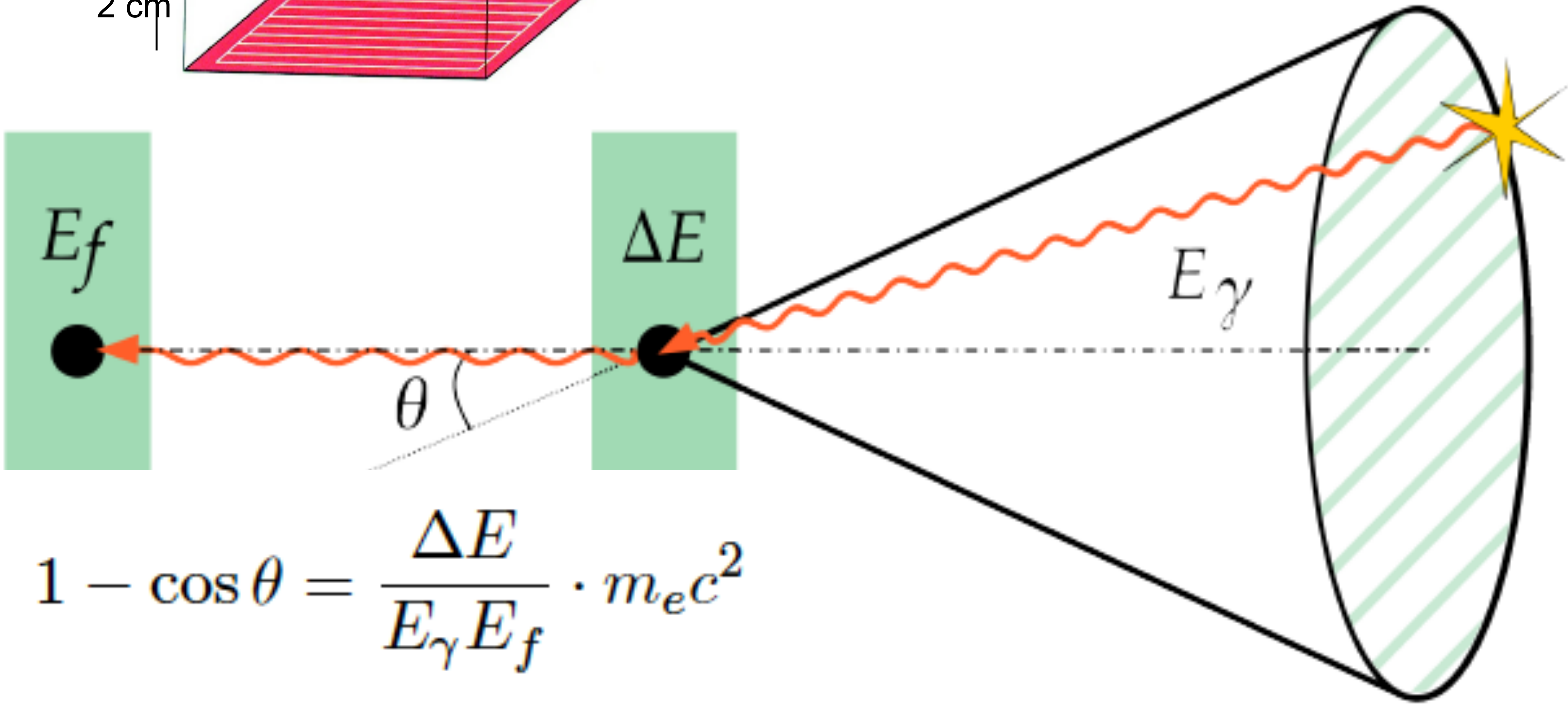


Applications in Basic and Applied Science
B. Das et al. EPJ Conf Series (2021)
(First prize in ANNIMA 2021 Conf)



R&D towards Compton Imaging using Planar HPGe detectors

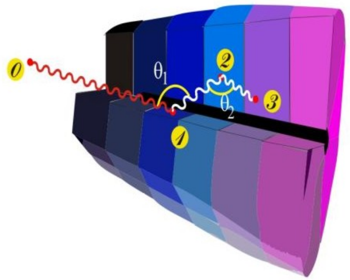


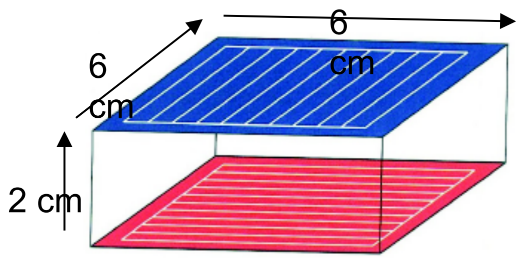


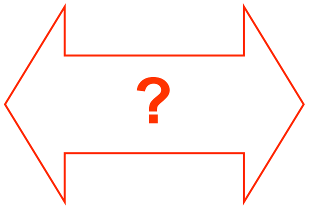
$$1 - \cos\theta = \frac{\Delta E}{E_\gamma E_f} \cdot m_e c^2$$

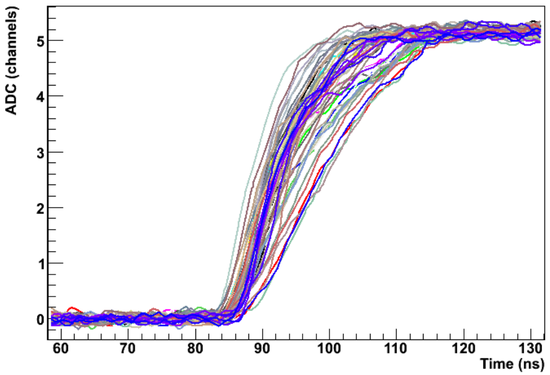
Method to characterize the pulse shape of HPGe detectors

Determine a **data-base of pulse shapes** S(x,y,z) which allows one to correlate an arbitrarily measured pulse, with an interaction position inside the detector.







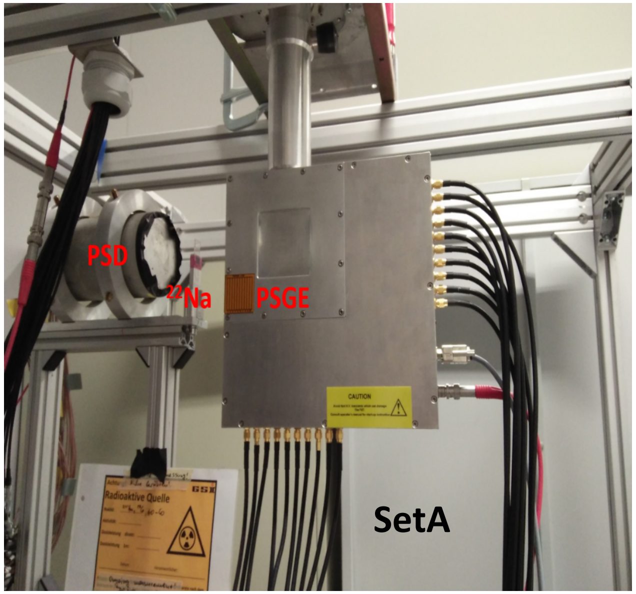


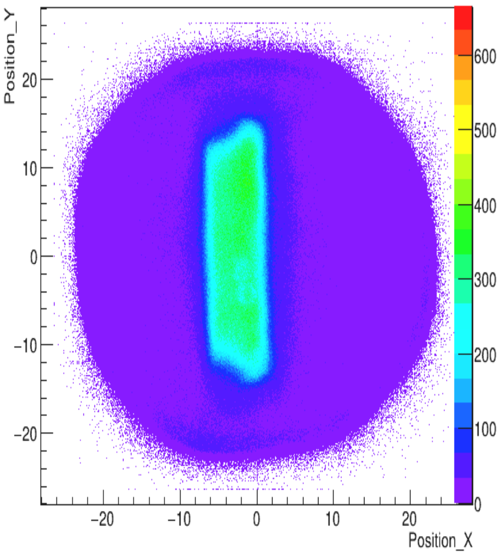
How to do this?

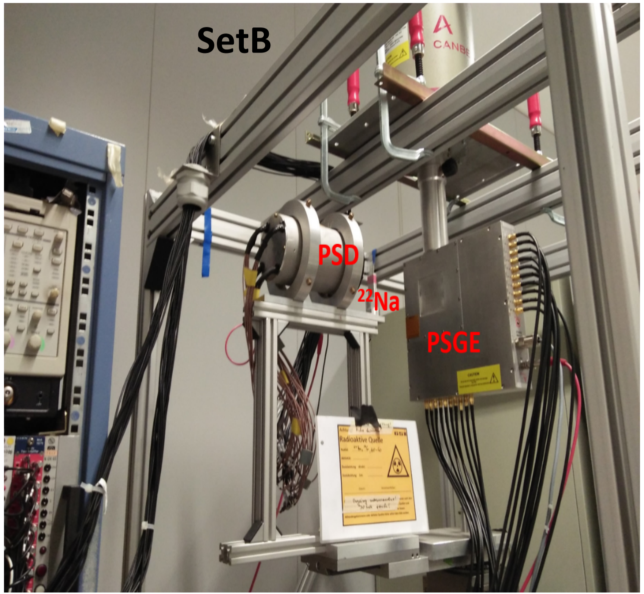
Using PET principle in combination with γ-ray imaging techniques !

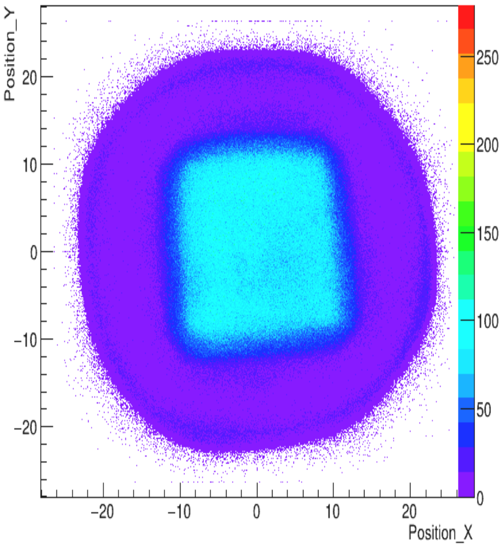
Scanning of DSGeSD

- Scanner consists of PSD and ^{22}Na source mounted on an Aluminium frame.
- Measurements performed at GSI.
- PSD is LYSO scintillator detector coupled to PSPMT.
- Two set of measurements taken: SetA and SetB.
- SetA : PSD at 0 degrees.
- SetB : PSD at 90 degrees.
- Construction of the 2-D image from the PSD using the centroid fitting approach.



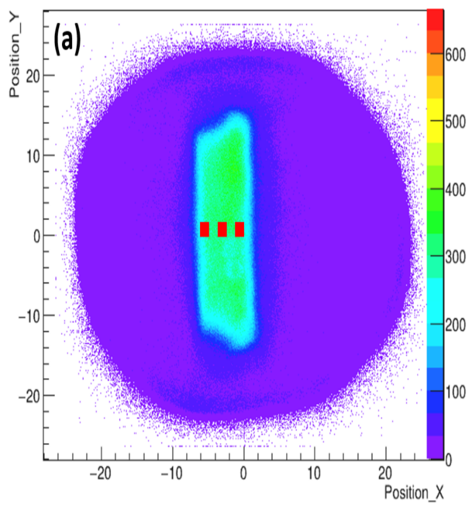






A. Sharma et al. EPJ Conf Series (2021)

Rise-time of pulses for Depth of Gamma-ray Interaction



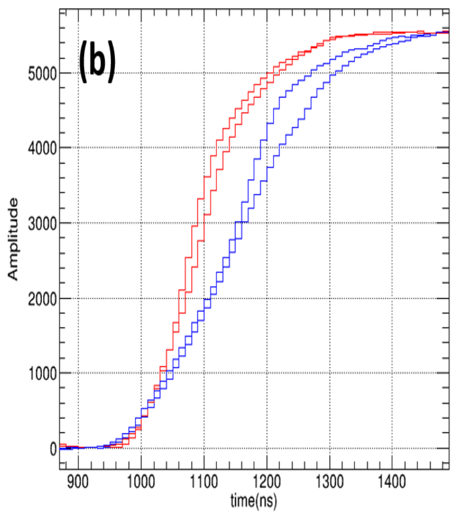
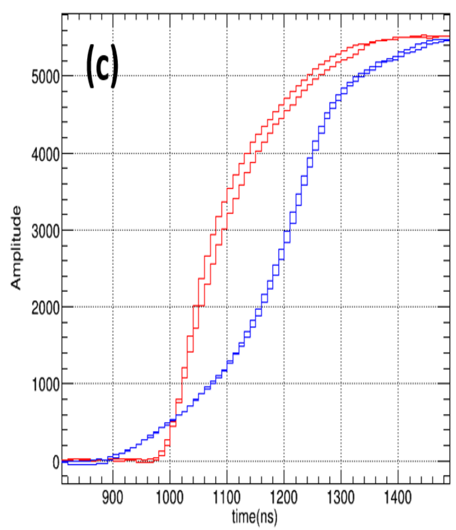
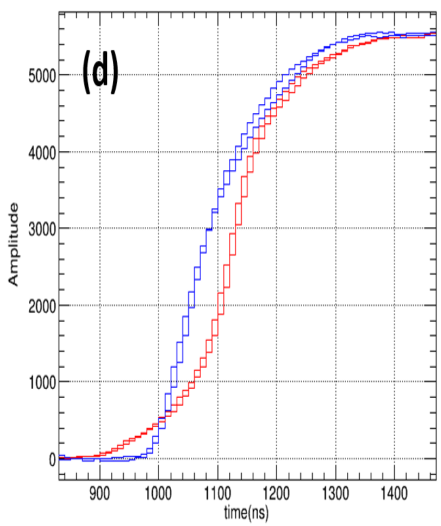


Fig: (a) 2-D image with 3 cuts in white squares, i.e., Cut 1 (left), Cut 0 (middle), and Cut 2 (right). The corresponding behavior of both the strip is shown using T10 aligned traces for (b) Cut 0 (c) Cut 1 (d) Cut 2. The red, and blue traces correspond to DC4, and AC20 electrodes, respectively.





Cut No.	T50_DC4 (ns)	T50_AC20 (ns)
Cut 1	51	189
Cut 0	61	111
Cut 2	105	57

Position sensitive scintillator detectors

- Position Sensitive Photo Multiplier Tubes(PSPMT) coupled with a scintillator
- crystal converts the scintillation light into a current signal in the localized
- photo-cathode.

- The current signal distribution contains important information regarding
- energy, timing and the interaction position of the γ-ray in the detector crystal.
- The detector can be used in:

i) Pulse shape analysis and scanning of a segmented HPGe detector

ii) Medical imaging

iii) Back scattering imaging

iv) Compton camera

v) Study of nuclear rare decay

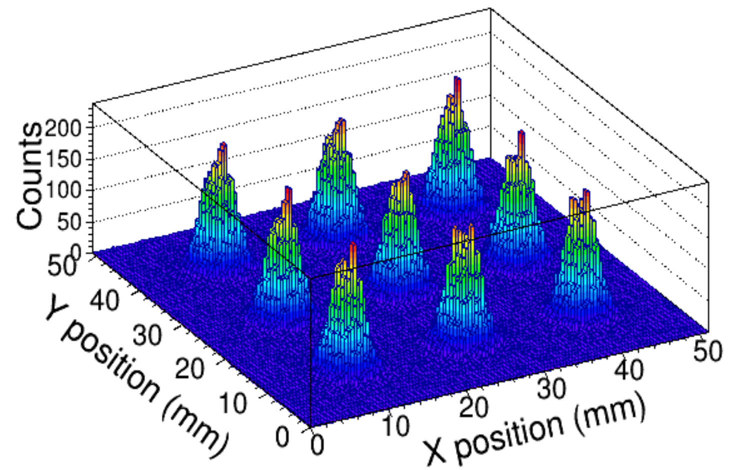
Development of a position-sensitive fast scintillator ($LaBr_3$(Ce)) detector setup for gamma-ray imaging application

Biswajit Das[1], R. Palit[1], R. Donthi[1], A. Kundu[1], Md. S. R. Laskar[1], P. Dey[1], D. Negi[1], F. S. Babra[1], S. Jadhav[1], B. S. Naidu[1], and A. T. Vazhappilly[1]

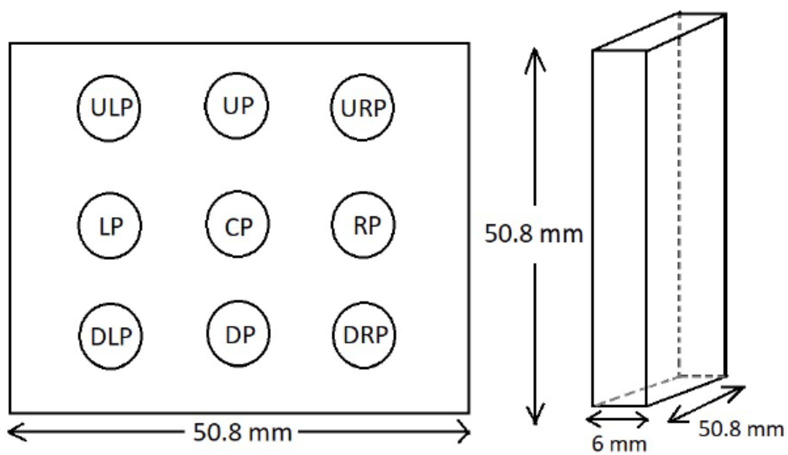
Experiment and simulation results

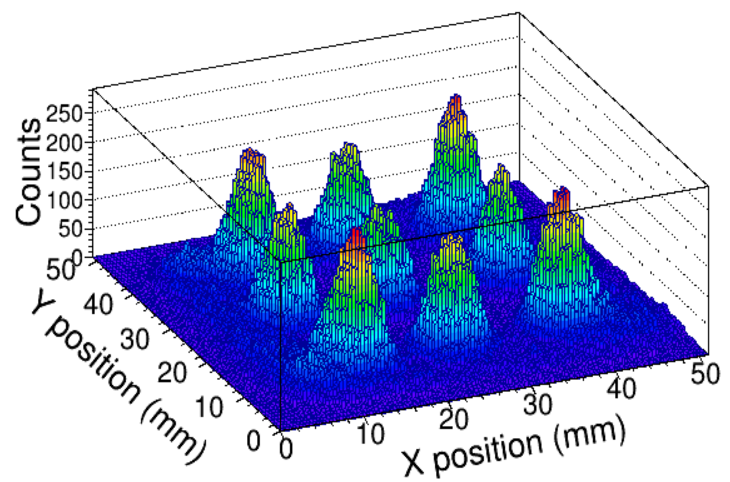
- Irradiation spot is obtain by energy gate condition (at 122 keV).
- The FWHM is found to be 3.0 - 3.5 mm with 2.0 mm collimated gamma rays.

- Thin crystal → better position resolution.
- Position resolution is slightly poor near the edges.



G4 simulation



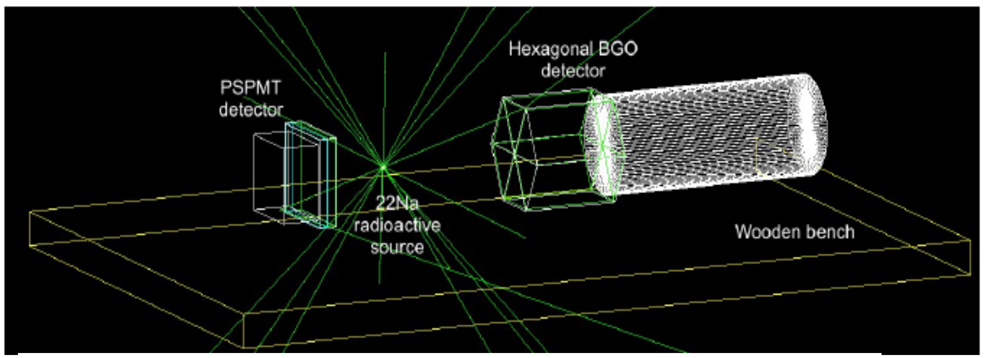


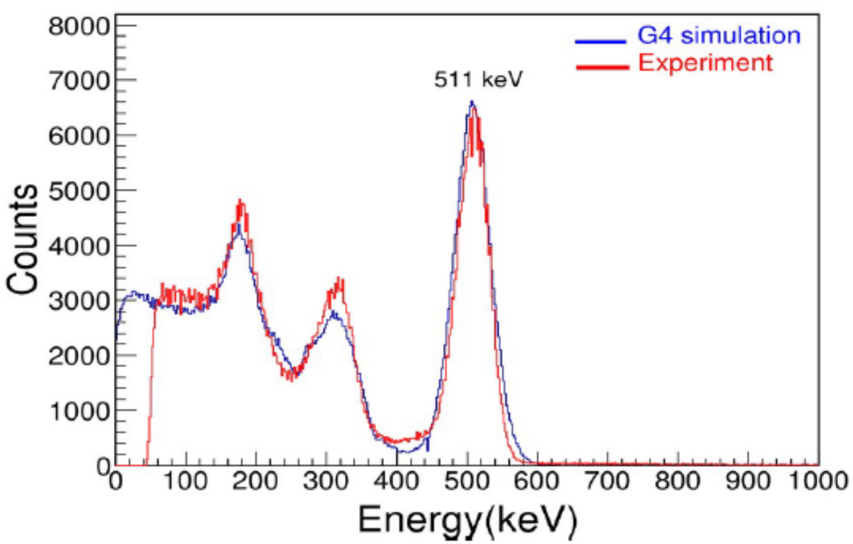
Experiment

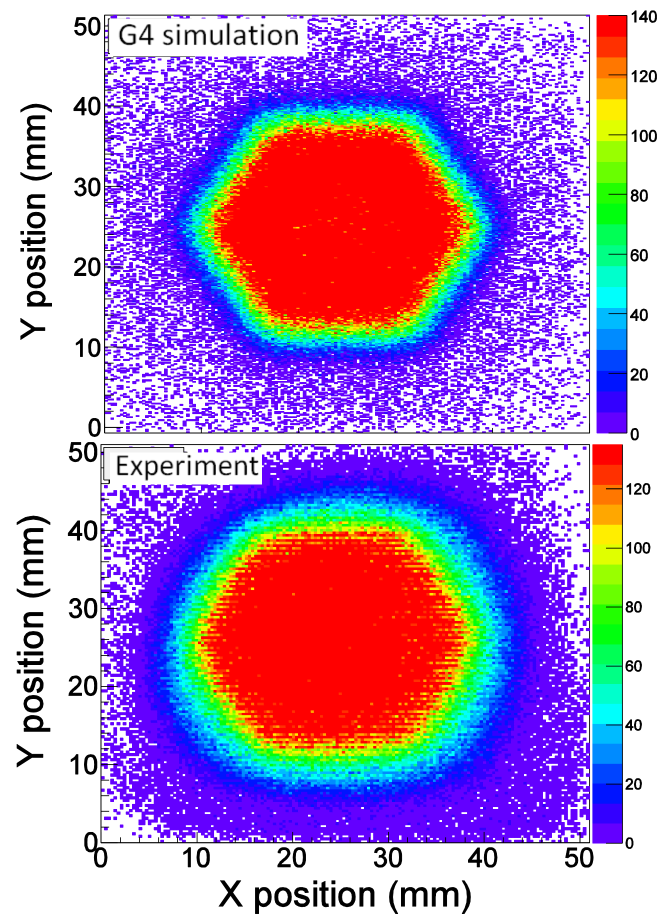
B. Das et al. EPJ Conf Series (2021)

Imaging in coincidence

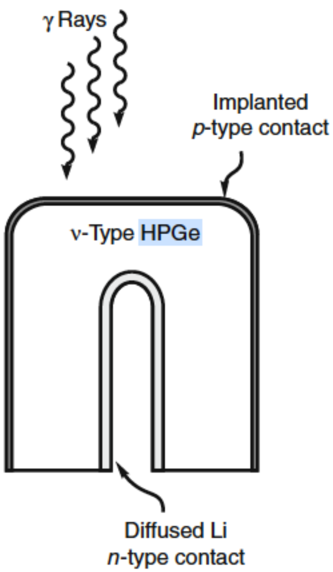
- ➢Coincidence between position sensitive detector and a hexagonal BGO detector.
- ➢Image reconstructed → Energy gate on 511 keV.

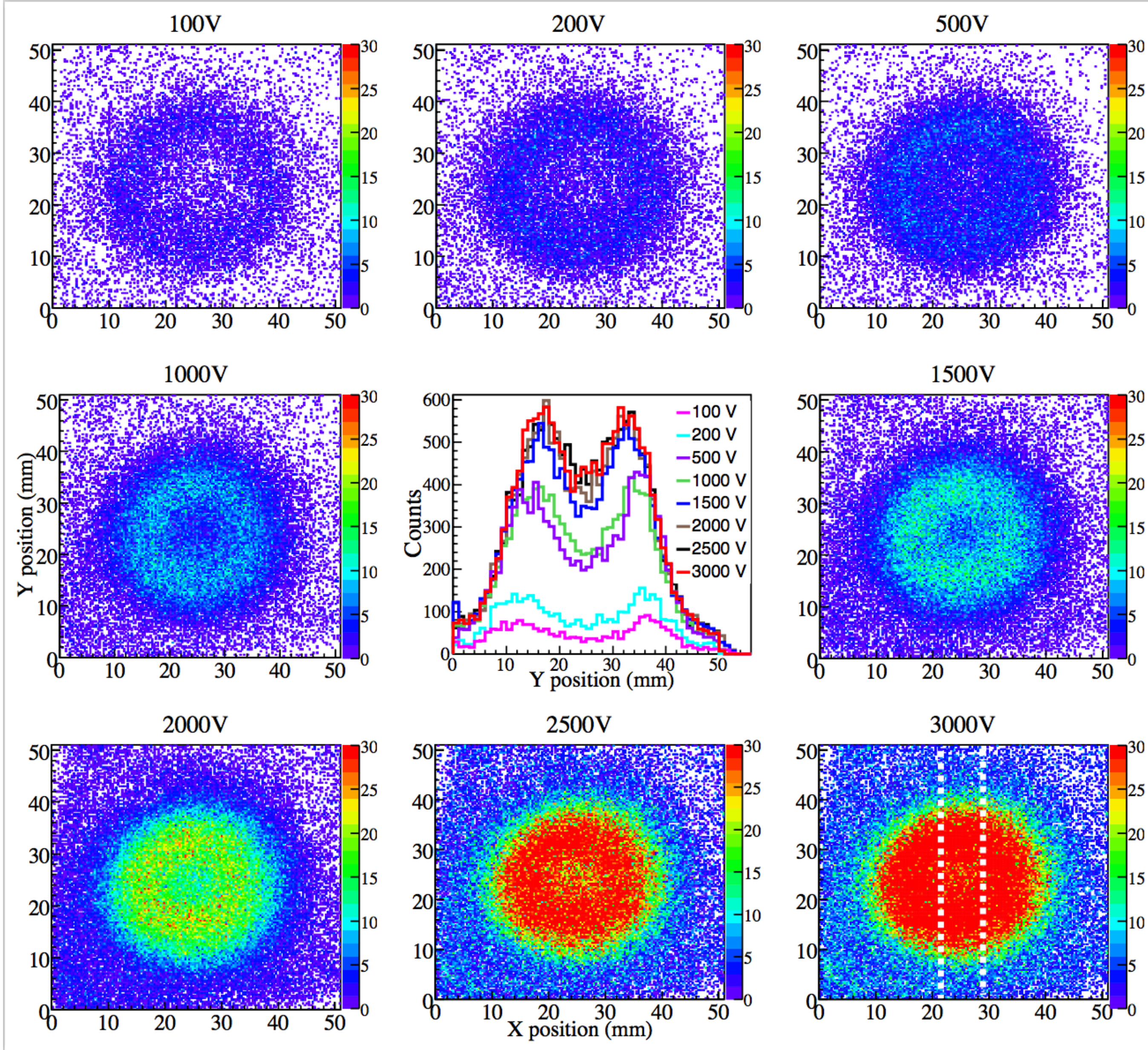






Imaging of the front face of single HPGe





B. Das et al.

Summary

Requirement:
High efficiency, High granular Energy and time resolution
polarization, Imaging capability, *Low background material*

Position sensitive detectors and combination of fast scintillators and HPGe detectors
Development of SiPM readout technology with minimum dead-layer in scintillator

Study of rare decay processes in nuclei
Underground measurement of two-photon decay in
^{54}Mn, ^{60}Co, ^{137}Cs
Formally similar to E1 polarizability
Related to Symmetry Parameter of Nuclear EoS ?
Access to aspects of NME for $0\nu\beta\beta$ − decay?
^{48}Ca (2+ -> 0+)   B.R. 3×10^{-8}

Thank you for your kind attention