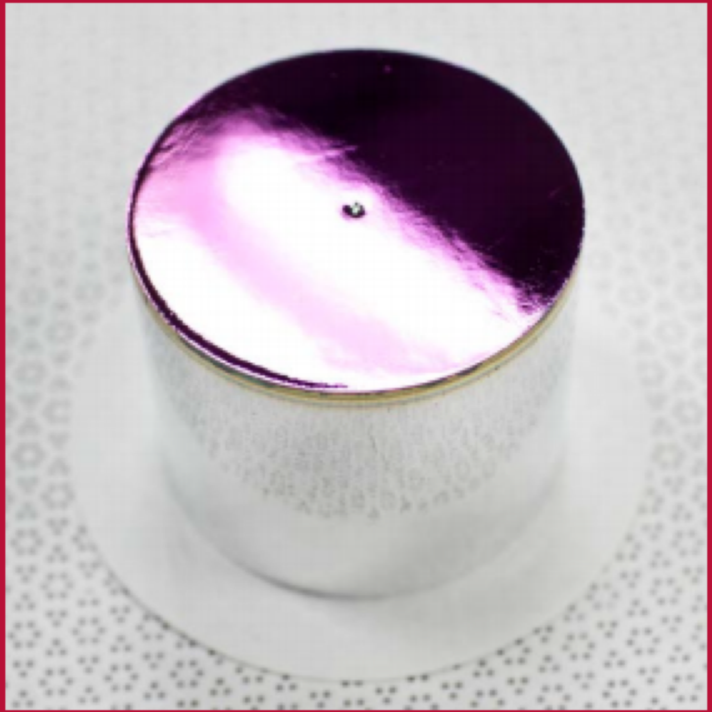
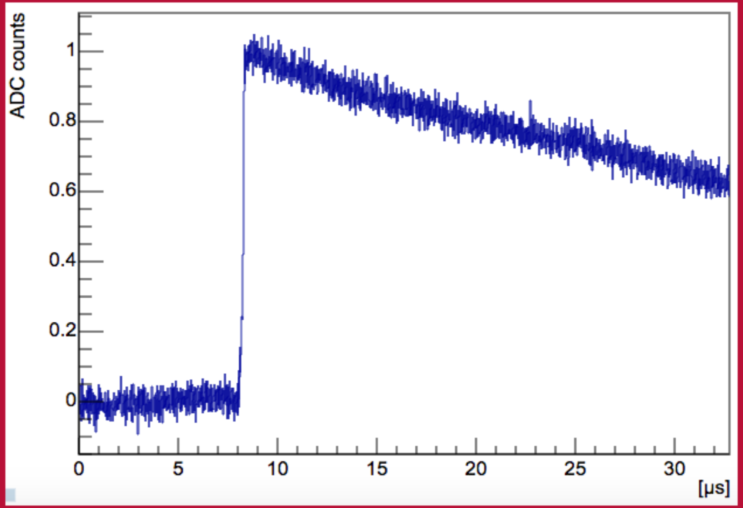
Pulse fitting for event localization in HPGe PPC detectors



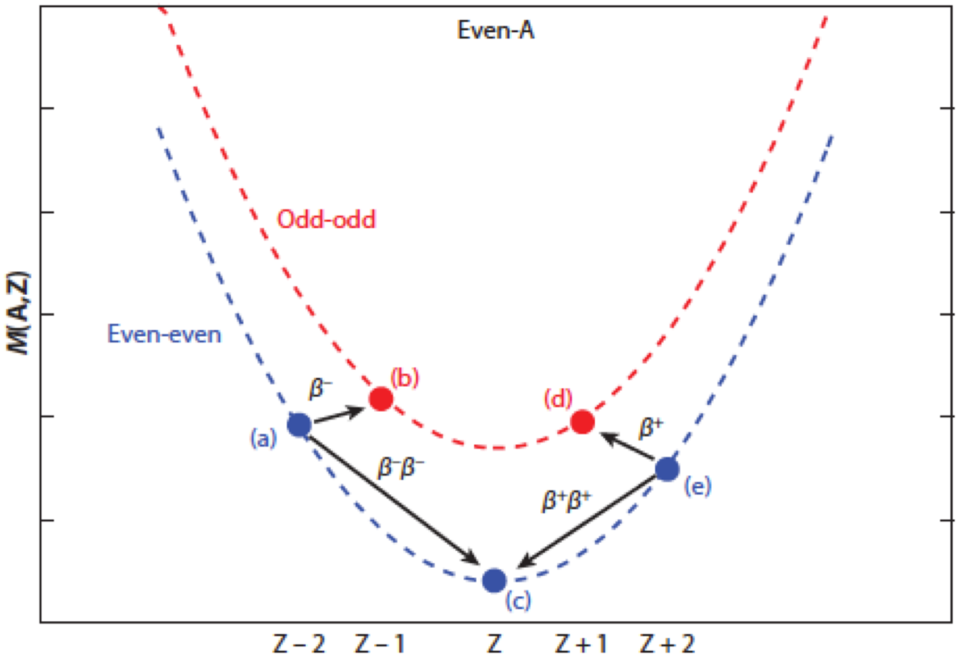


Vasundhara

June 9, 2020

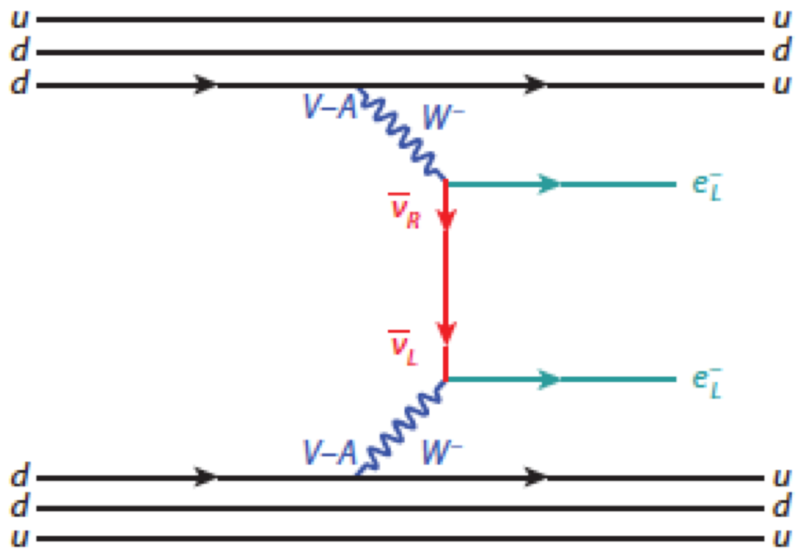
CAP 2020

Neutrinoless double-beta decay



Double beta-decay in even-A isotopes [1]

$$2n \rightarrow 2p + 2e^{-} + 2\bar{\upsilon}$$

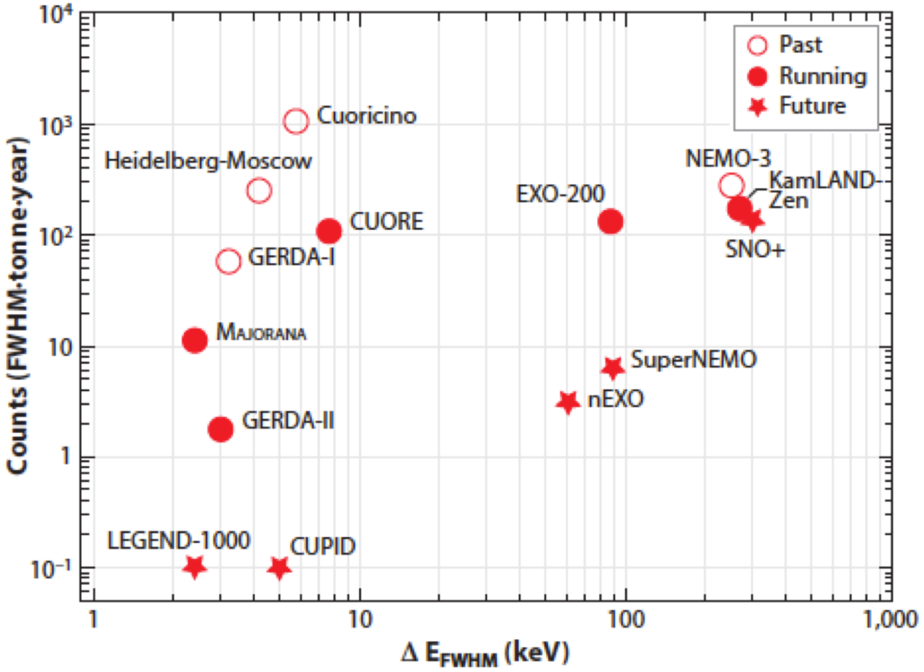


Neutrinoless double-beta decay showing neutrino is a majorana particle [1]

$$2n \rightarrow 2p + 2e^{-}$$

Does not conserve lepton number!

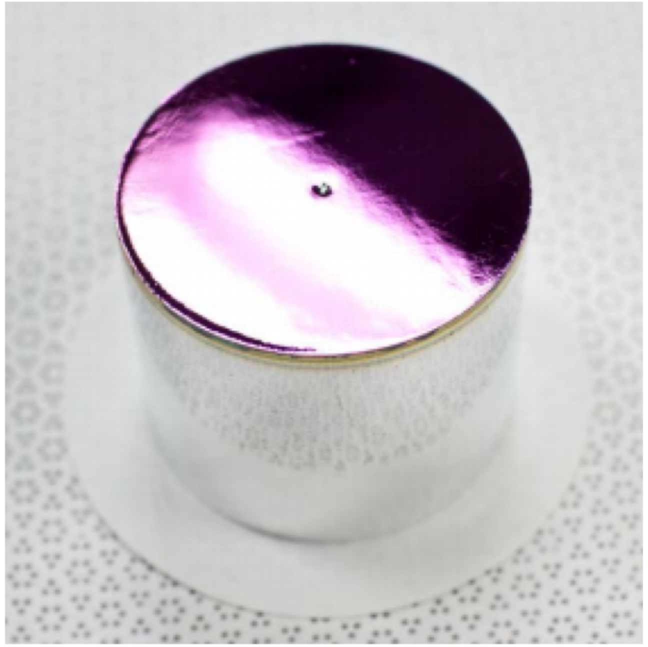
Point contact HPGe detectors for neutrinoless double-beta decay searches

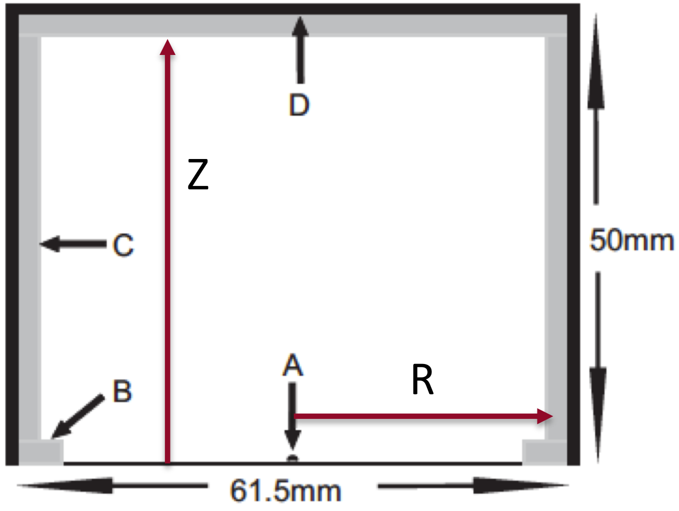


Background index as a function of energy resolution. MAJORANA, GERDA and LEGEND use HPGe detectors. [3]

ADVANTAGES

- Compact dimensions
- Good energy resolution
- High purity Ge → low background [4]





PPC detector showing point contact (A), n+ contact (B and C), ohmic contact for high voltage (D). Not to scale [5]

Why are we localizing events in PPC detectors?

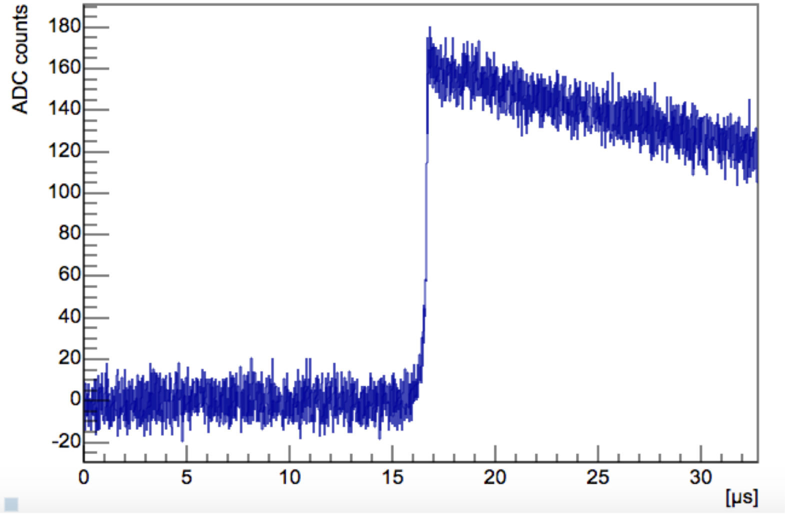
- Can help to identify hot spots (sources of low energy background gamma rays)

- Serves as validation of the pulse shape simulation algorithms

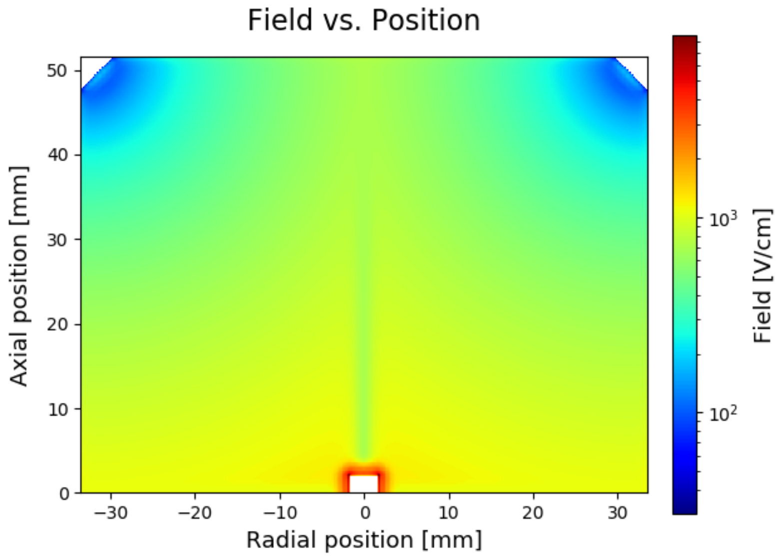
- It will help in modelling and identifying events that occur near the surface of detectors

- It is interesting to localize events with ~1mm accuracy (in some cases) in a detector that has a single readout electrode (normally position reconstruction requires detectors with many electrodes)

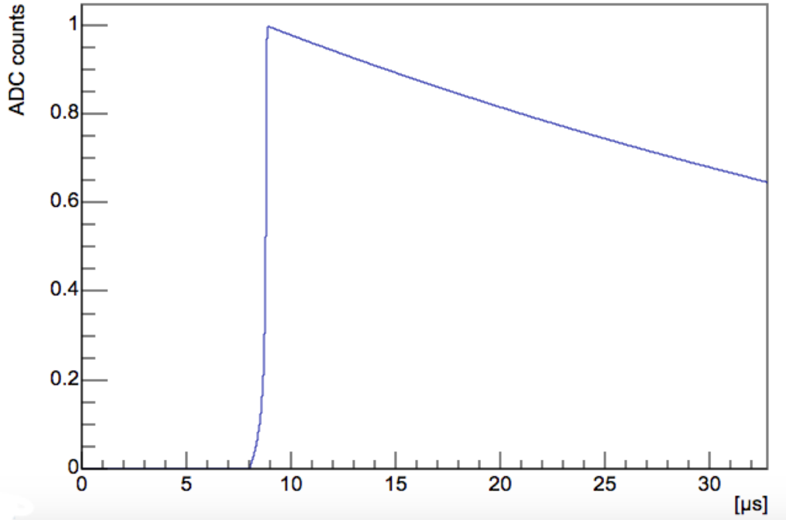
Simulating Pulse shapes



Data pulse obtained from the detector



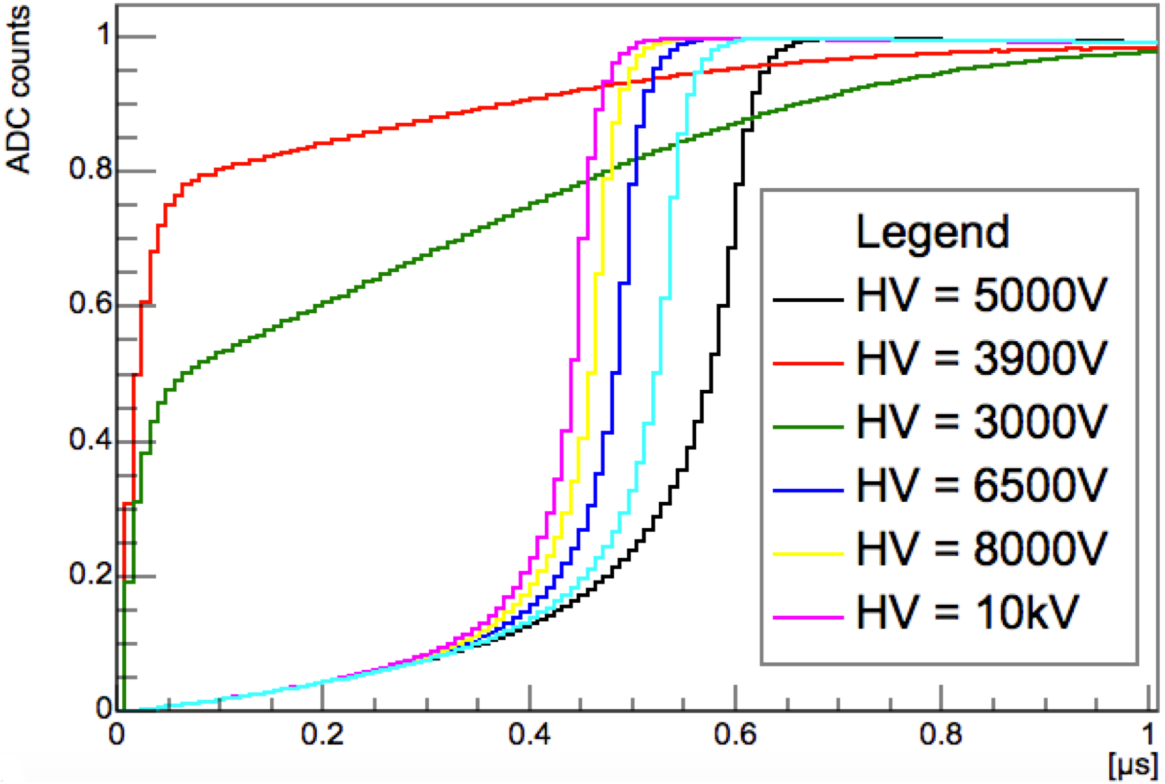
Electric field vs position in log scale



Simulated library pulse obtained after running SigGen. RC decay has been added to these pulses later. [6]

- Signal creation modelled by Shockley – Ramo Theorem [2]
- FieldGen solves Posisson equation using relaxation method to determine the electric field and weighting potential
- Siggen uses the electric field and weighting potential to model the charge signals in germanium detectors
- Simulated pulses on a 1mm grid to create a library of pulses for 1kg detector in our lab[7]

Tuning the simulation

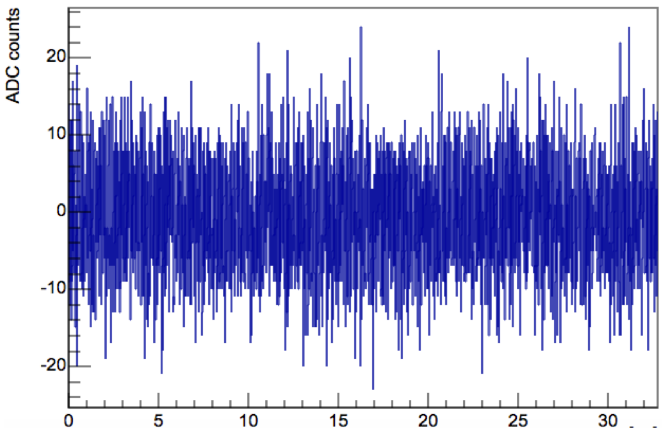


Different curves at different high voltages

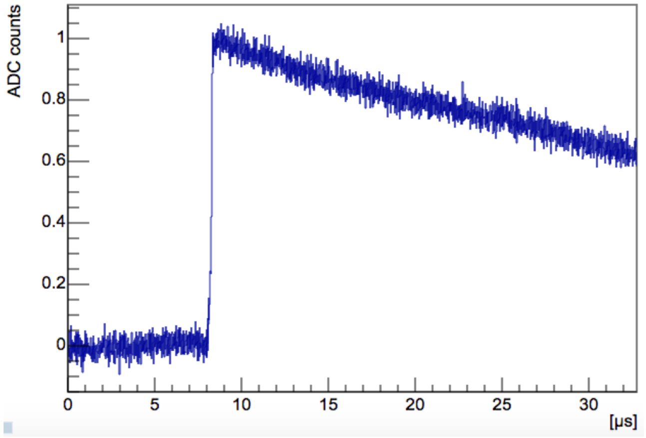
- Several free parameters in the simulation are tuned to reproduce signals from our detector
- Below 3.9kV, the detector is not depleted
- Once the detector is fully depleted, increasing the voltage results in charges drifting faster, leading to faster pulses
- Other parameters include:

- Crystal temperature
- Impurity concentration and gradient
- Preamplifier properties

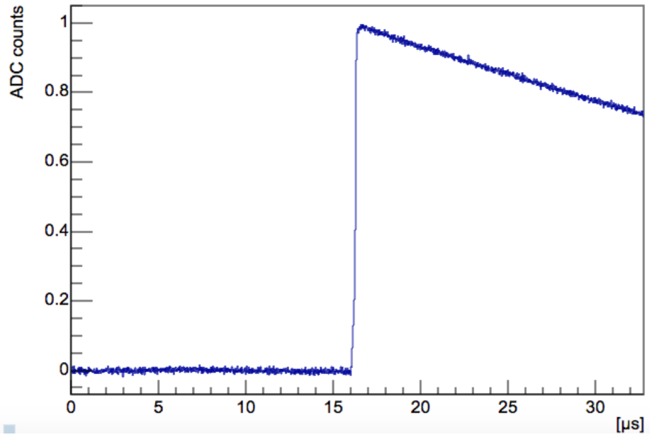
Developing simulated data library



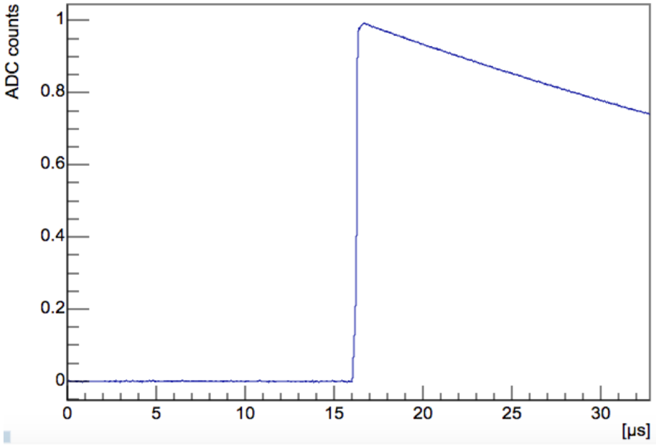
An example of noise pulse noise pulse collected from an actual detector.



60keV simulated pulse



300keV simulated pulse

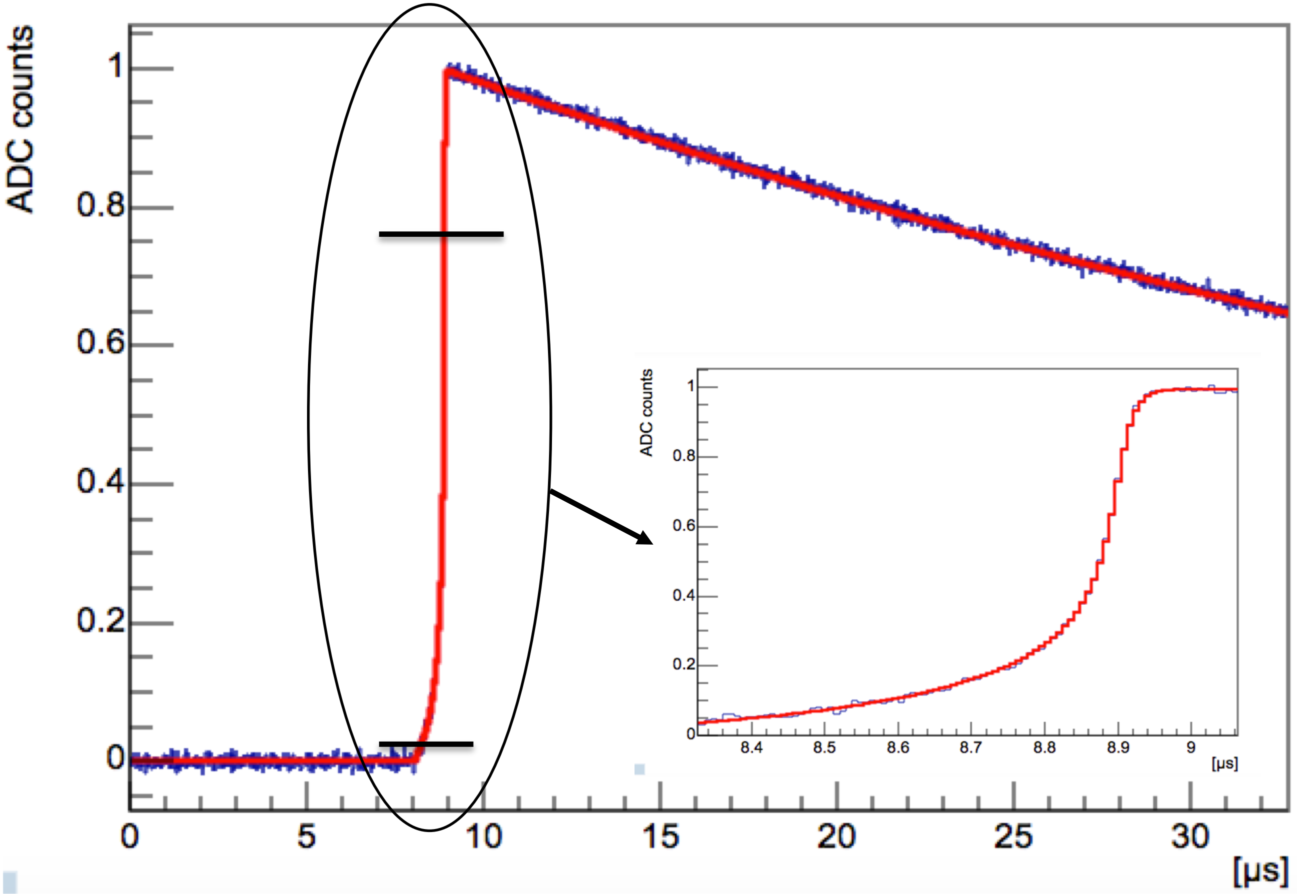


2MeV simulated pulse

- Data was simulated by adding real noise traces to simulated ”library” pulses
- Relative amplitude of the noise determines the effective energy of the pulse

Chi-Square based fitter

- Developed a "fitter" to compare data (simulated and real) pulses and identify the best matching library pulses
- The fitter uses chi-squared comparison
- The fitter can be used to study the set of best matching pulses from the library and determine the position of the data pulse using an average over several best matching library pulses



A simulated data pulse (blue) and the best fitting library pulse (red). The black lines show the max and min threshold between which the chi-square is calculated.

Determining position resolution – Two Methods

METHOD 1

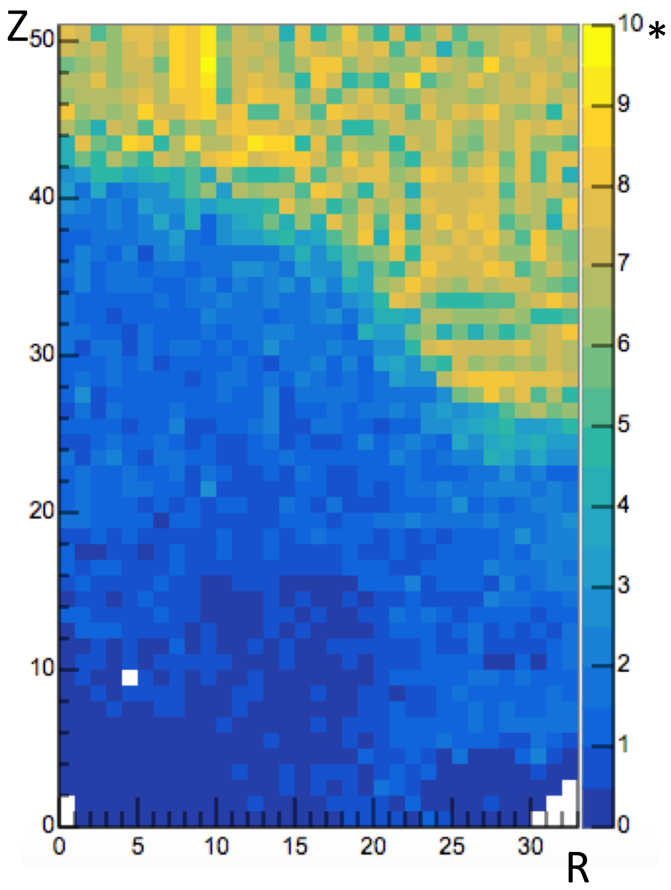
- At each position in the detector 1000 data pulses were simulated with different real noise traces
- Each data pulse was fitted to the library of ~1700 simulated pulses to find the best matching (lowest chi-square) simulated pulse
- The position of the data pulse is inferred based on mean R and Z of the 10 best matching pulses
- The inferred position is then compared to the known position of simulated data pulse

METHOD 2

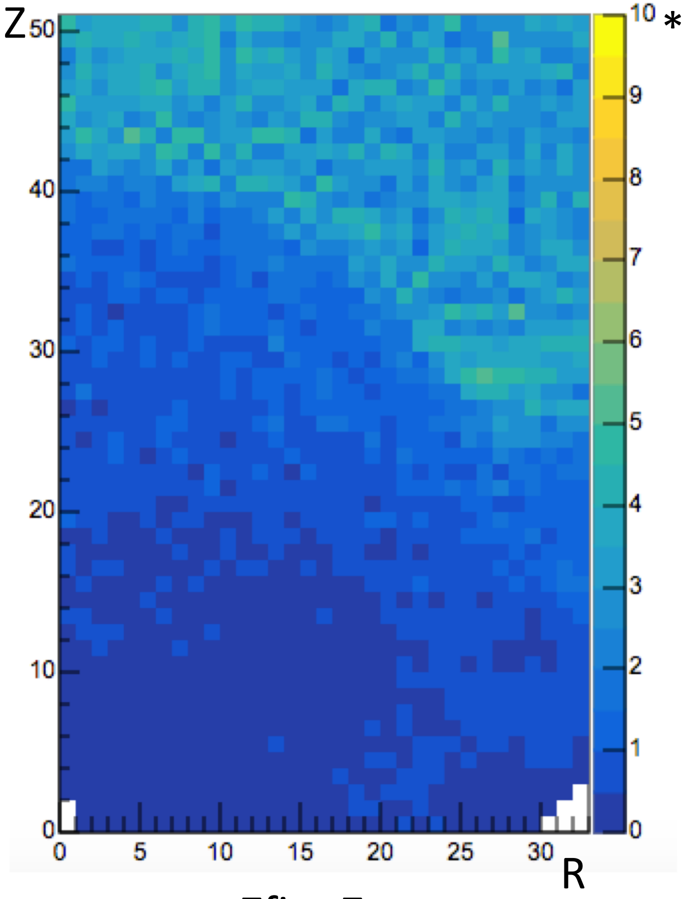
- At each position in the detector 1000 data pulses were simulated with different real noise traces
- Each simulated data pulse found a best fitting library pulse.
- For each library pulse, the position of the simulated data pulses that best fit to that library pulse is recorded.
- The distribution of pulses that fit to one location is analysed

Method 1 – RMS of (Rfit –Rtrue) and RMS of (Zfit –Ztrue)

1MeV



Rfit - Rtrue



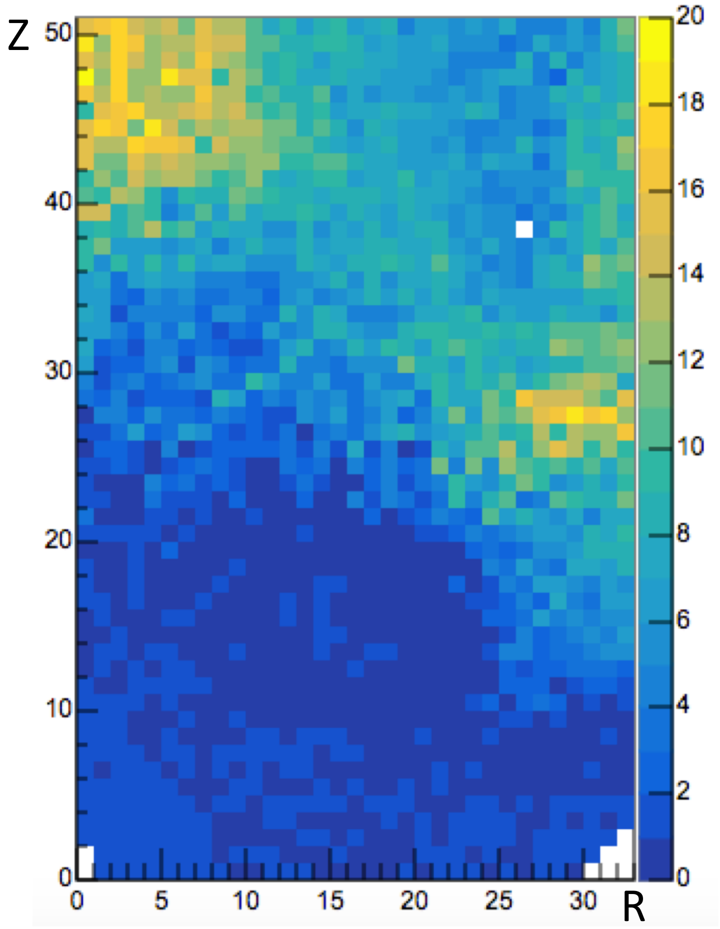
Zfit - Ztrue

- Resolution generally better for Z than R
- Resolution is better near the point contact.

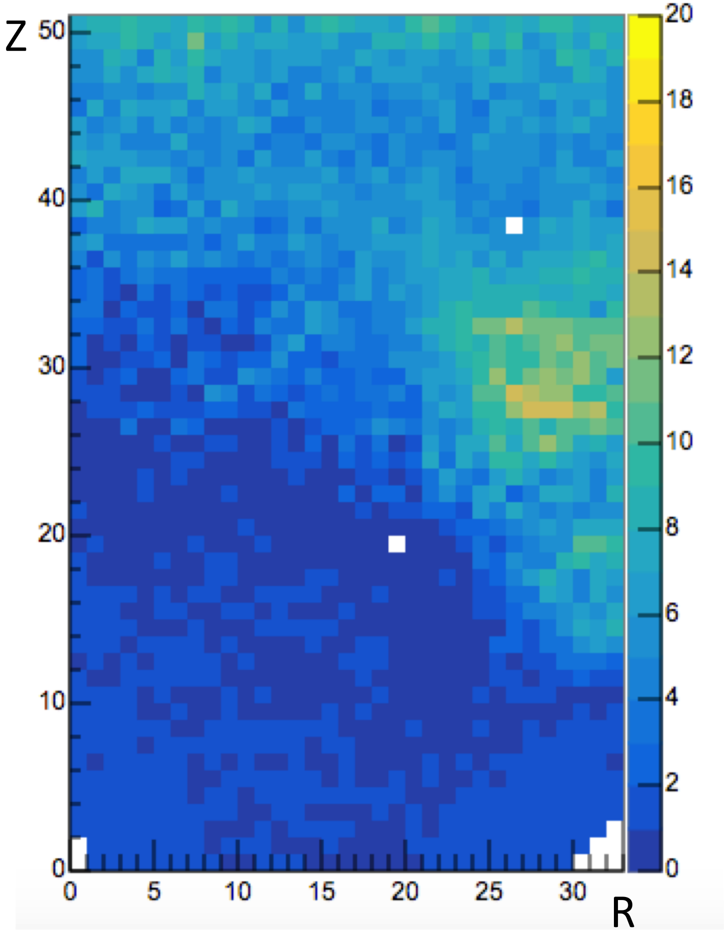
*NOTE: Colour scale in millimetres

Method 2 – RMS of (Rbest – R of all the library pulses which fit) and RMS of (Zbest – Z of all the library pulses which fit)

1MeV



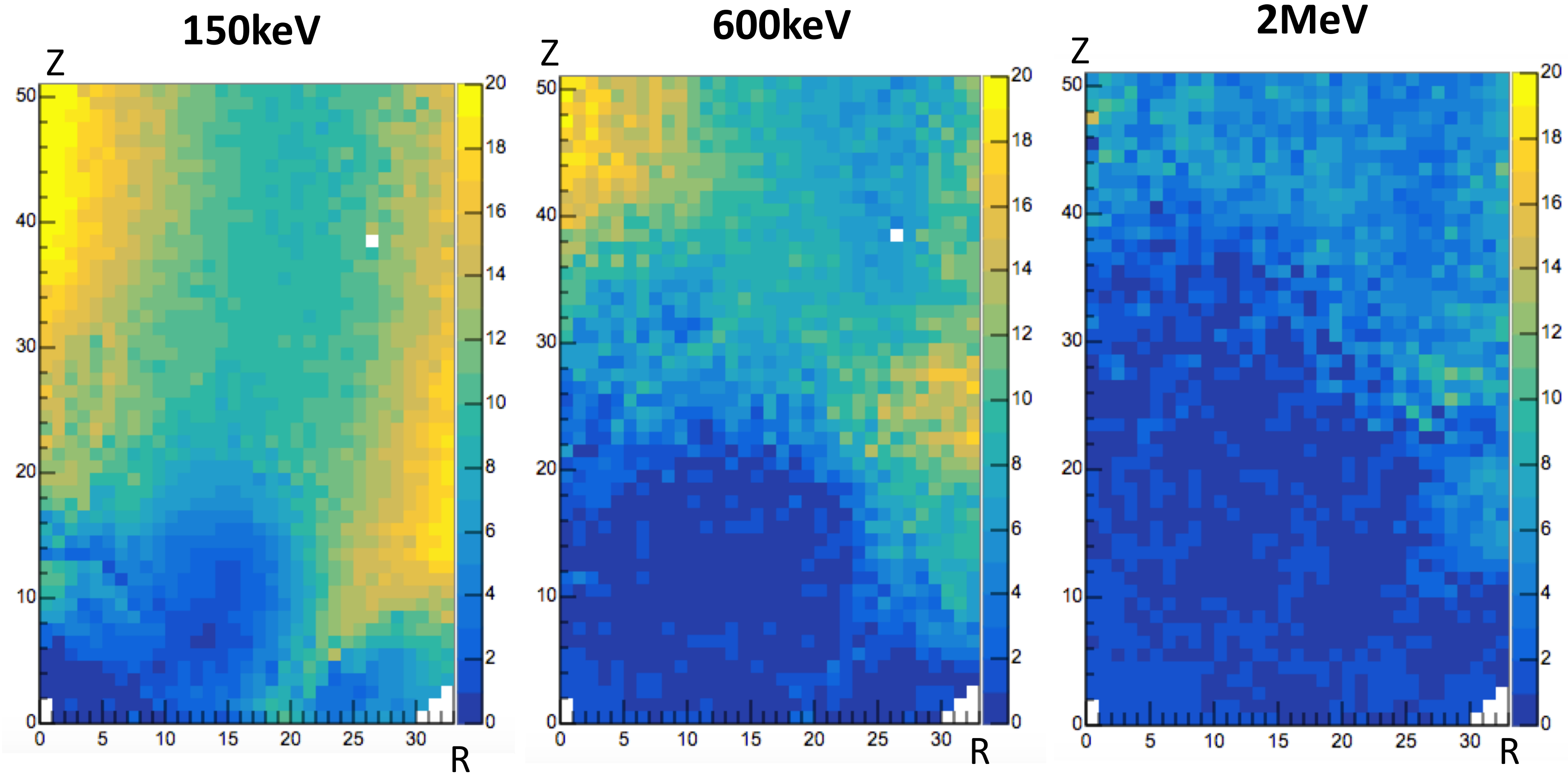
Rbest – R of all the library pulses which fit



Zbest – Z of all the library pulses which fit

- Resolution generally better for Z than R
- Resolution is better near the point contact.

Method 2 – RMS of (Rbest – R of all the library pulses which fit)



Rbest – R of all the library pulses which fit

- the resolution generally improves at higher energy, since the relative amplitude of the noise decreases.

Conclusion

- Presented preliminary results on using simulated pulses for event localization in a PPC detector

- For 1MeV, at locations very near the point contact the typical resolution is sub-millimeter. For Z, the resolution using both methods at any location is less than 7mm. For R, the resolution using method 1 is less than 8mm and using method 2 is less than 8 mm generally, except for at big Z and small R.

- Both the methods are in the process of being validated using data from the collimated beam of Am-241

Conclusion – Why do we do this?

- Can help to identify hot spots (sources of low energy background gamma rays)
- Serves as validation of the pulse shape simulation algorithms
- It will help in modelling and identifying events that occur near the surface of detectors
- It is interesting to localize events with ~1mm accuracy (in some cases) in a detector that has a single readout electrode (normally position reconstruction requires detectors with many electrodes)

References

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