Development of the electron detectors and readout electronics for BRAND experiment

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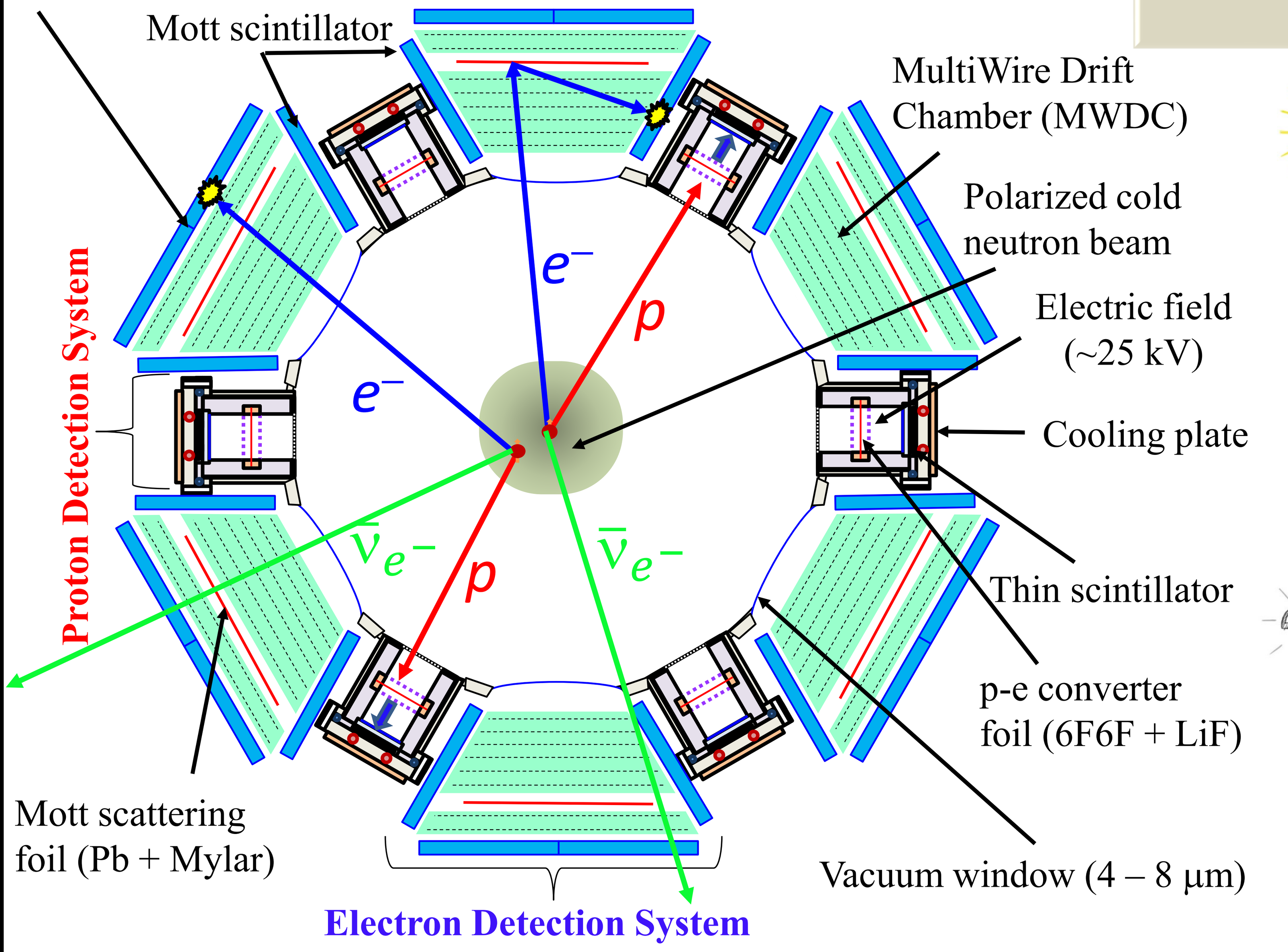


Conceptual BRAND Experimental Setup (Cross Section)

Introduction

- Beta decay is one of the tools to investigate deviation from the Standard Model (SM) indicating new physics
- Uniqueness of BRAND: Attempt to measure 11 correlation coefficients simultaneously
- Differential decay rate:

$$d\Gamma \sim 1 + a\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + b\frac{m_e}{E_e} + \frac{\langle \mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + D\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\right] +$$
$$\hat{\sigma}\cdot\left[H\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + L\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + N\frac{\langle \mathbf{J}\rangle}{J} + R\frac{\langle \mathbf{J}\rangle}{J}\times\frac{\mathbf{p}_e}{E_e} + S\frac{\langle \mathbf{J}\rangle}{J}\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + U\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\frac{\langle \mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_e}{E_e} + V\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\times\frac{\langle \mathbf{J}\rangle}{J}\right]$$

$\mathbf{p}_e$ – electron momentum
$\mathbf{p}_\nu$ – neutrino momentum
σ – electron spin projection direction
J – neutron spin

Electron transverse polarization | Never Attempted Before

- The transverse electron polarization is an ideal observable for the Physics Beyond the SM
- All correlation coefficients are combinations of real and imaginary parts of the exotic (scalar and tensor) couplings ($X = H, L, N, R, S, U, V$)

$$X = X_{SM} + X_{EM} + c_{\mathrm{Re}\,S}\,\mathrm{Re}\,S + c_{\mathrm{Re}\,T}\,\mathrm{Re}\,T + c_{\mathrm{Im}\,S}\,\mathrm{Im}\,S + c_{\mathrm{Im}\,T}\,\mathrm{Im}\,T$$

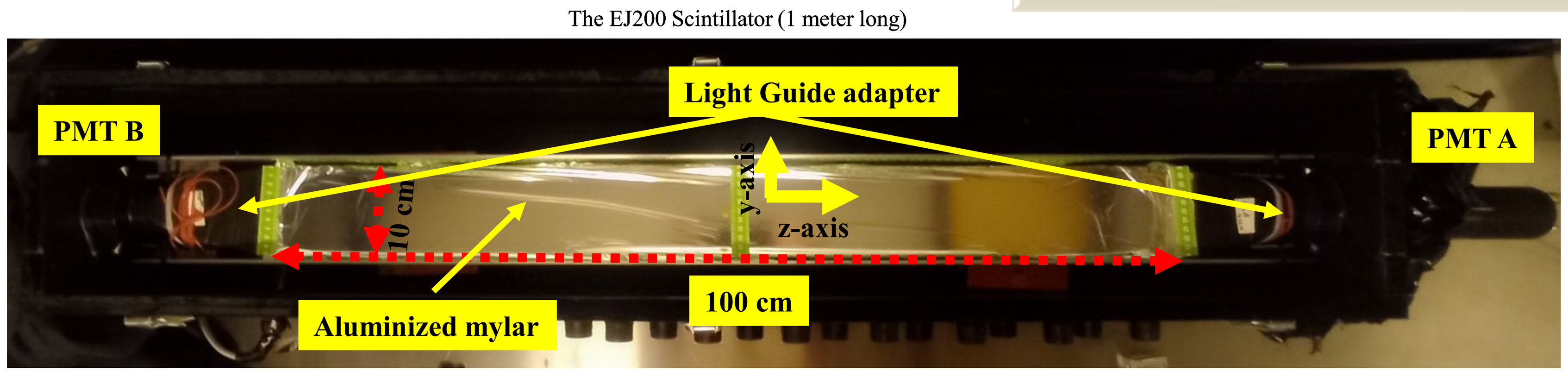
- **Measurement of correlation coefficients H, L, N, R, S, U and V with 5 x 10^{-4} accuracy will put significant limit on scalar and tensor couplings**

Observable quantities:

- Incoming electron momentum (electron track + energy deposition in scintillator)
- Scattered electron momentum (electron track + energy deposition in scintillator)
- Recoil proton momentum (proton hit position + time of flight (TOF))
- Neutron polarization vector

Electron Detector & Readout Electronics

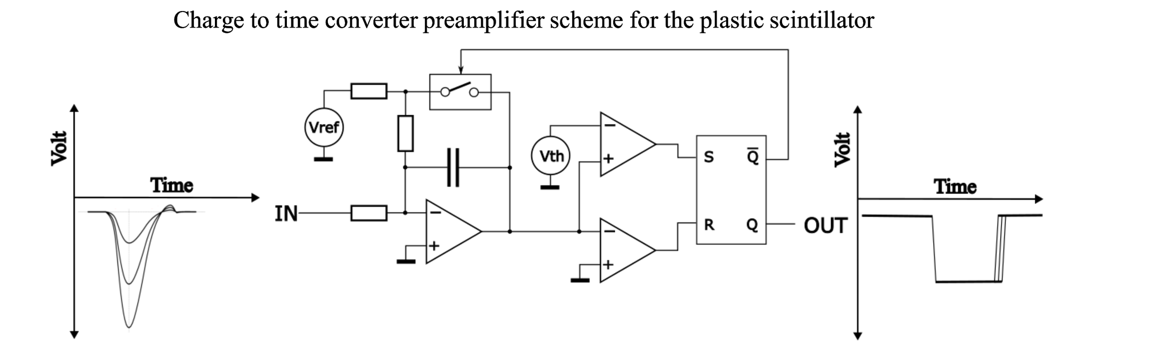
The EJ200 Scintillator (1 meter long)



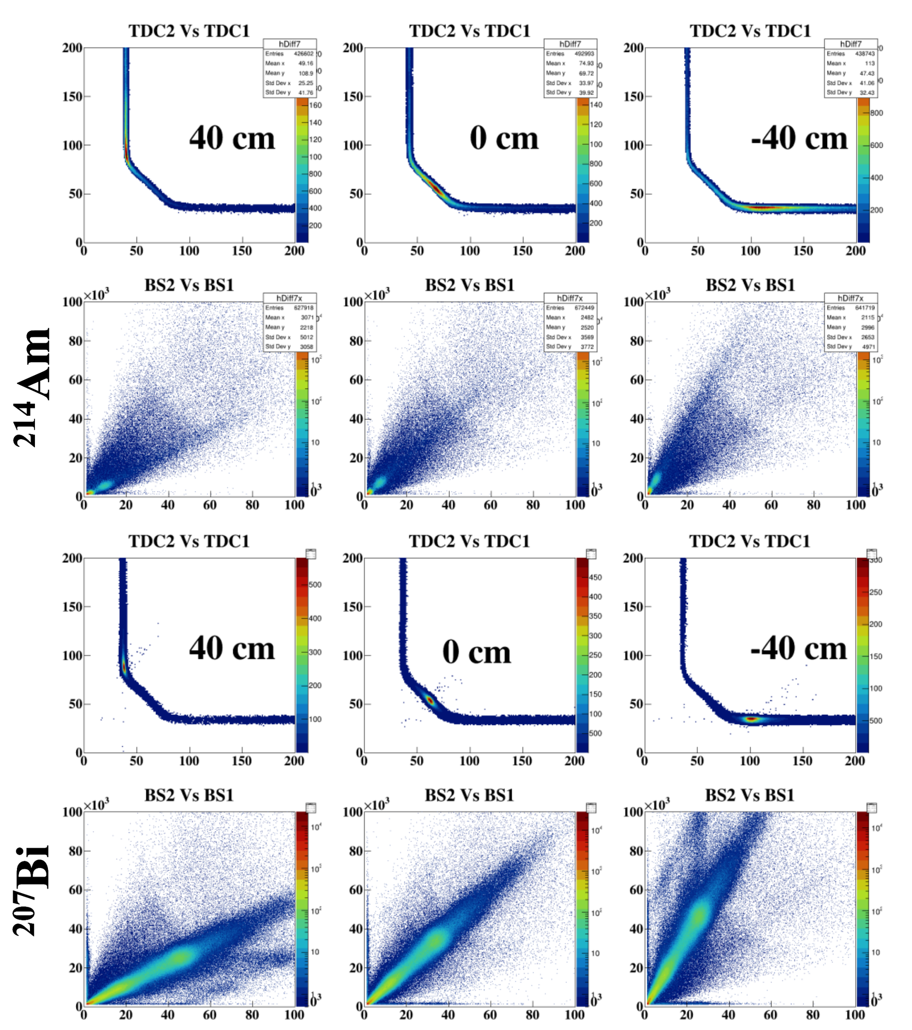
- The R&D for the scintillator (100 cm x 10 cm x 1 cm) for the ultimate version of BRAND is ongoing, aiming to use it as the detector for direct and Mott scattered electrons.
- The scintillator is coupled to two Hamamatsu PMTs (R1828-01) through a light guide adapter.
- To enhance light collection, the light guide adapter and three faces of the scintillator are wrapped with a 98% reflective film (3M ESR). The front face is wrapped with reflective mylar (6 μm).

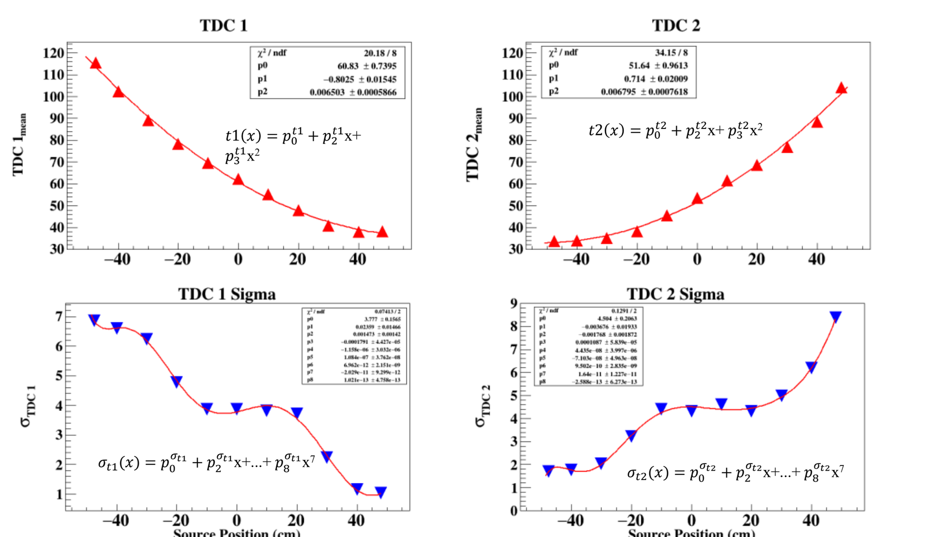
- BRAND will employ energy and time information to achieve kinematics reconstruction.
- Traditionally, Analog-to-Digital Converter (ADC) and Time-to-Digital Converter (TDC) modules are required to measure the energy and timing of corresponding channels.
- However, if the charge integration information is encoded as time width, the use of ADC modules becomes unnecessary.

Charge to time converter preamplifier scheme for the plastic scintillator



- The charge-to-time conversion-based preamplifier is a powerful solution for measuring both the timing and the energy deposited in the detector.
- Considering the situation and cost-effectiveness, the ideal choice for the Data Acquisition (DAQ) system is a multihit TDC (CAEN VX1190) with a resolution of 100 ps.

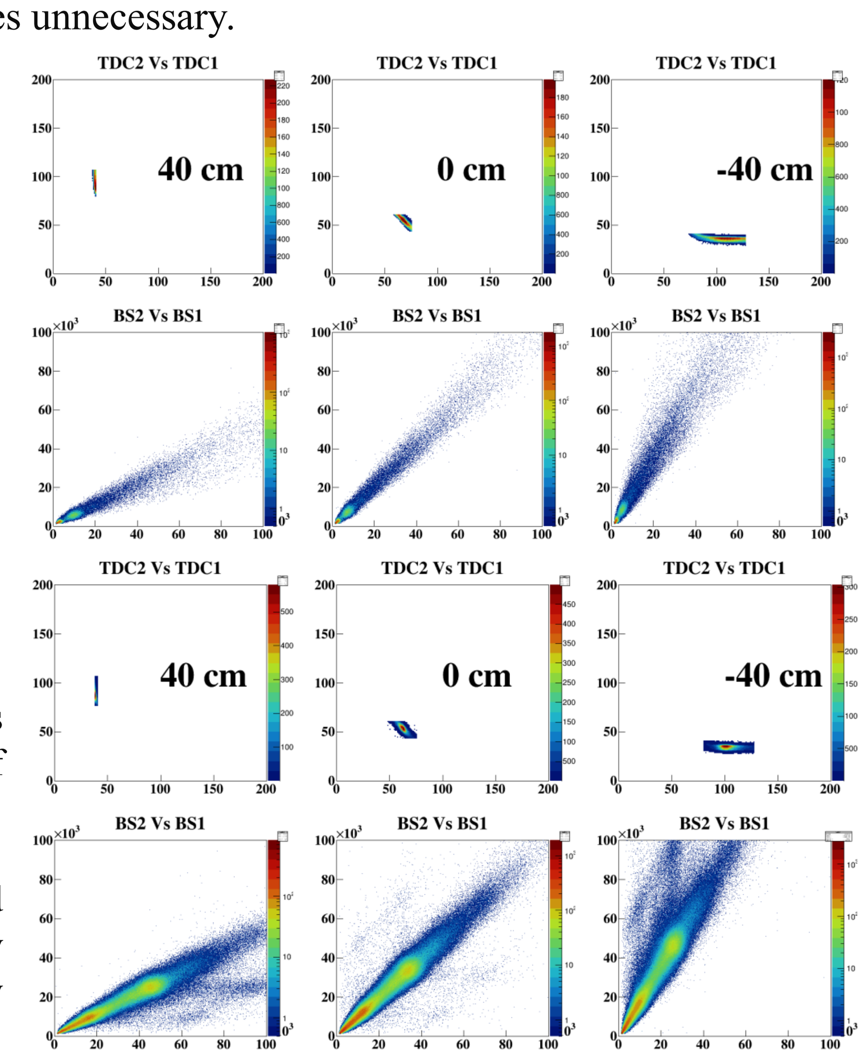


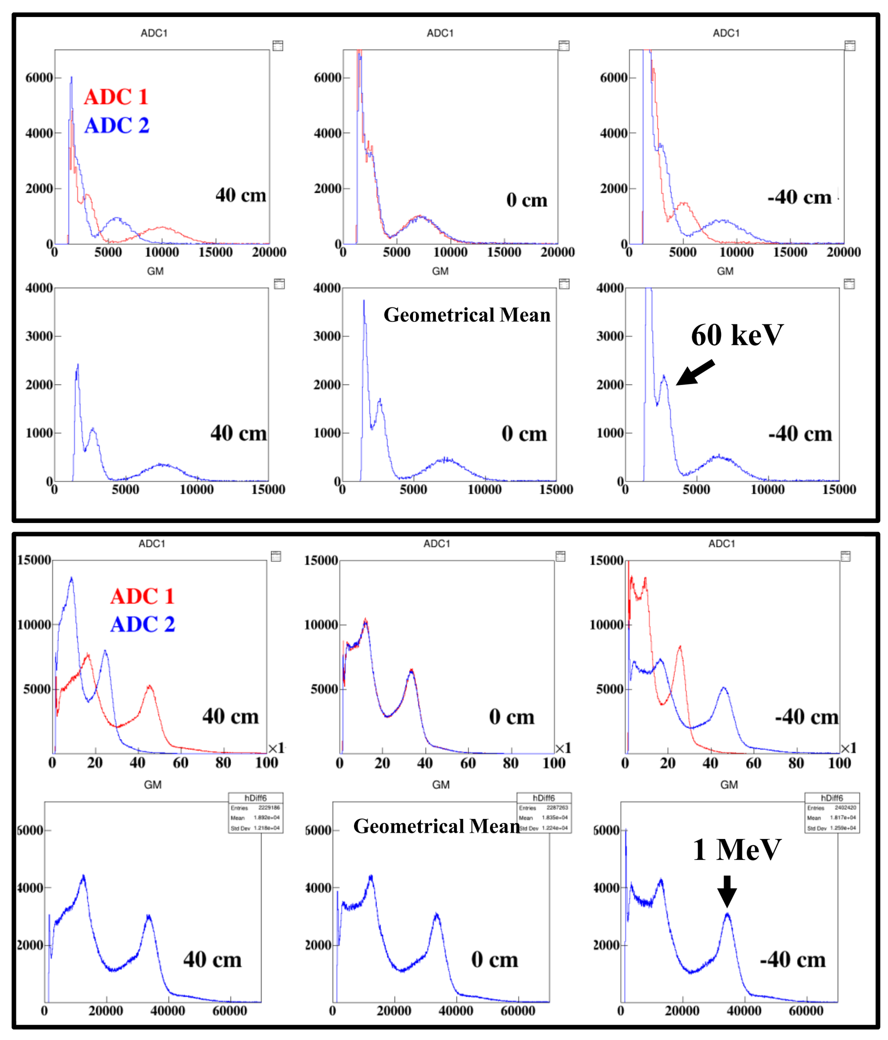


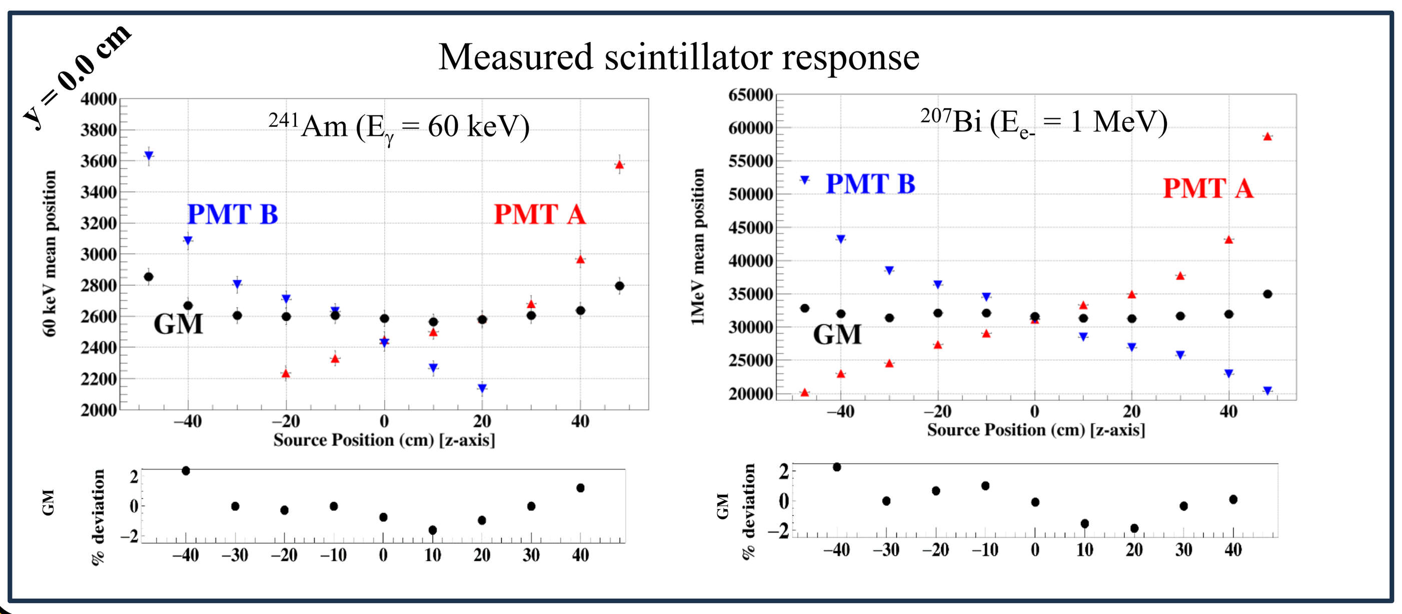
$t^1_{min} = \mathrm{t1(x)} - S^*\sigma_{t1}(x)$
$t^1_{max} = \mathrm{t1(x)} + S^*\sigma_{t1}(x)$

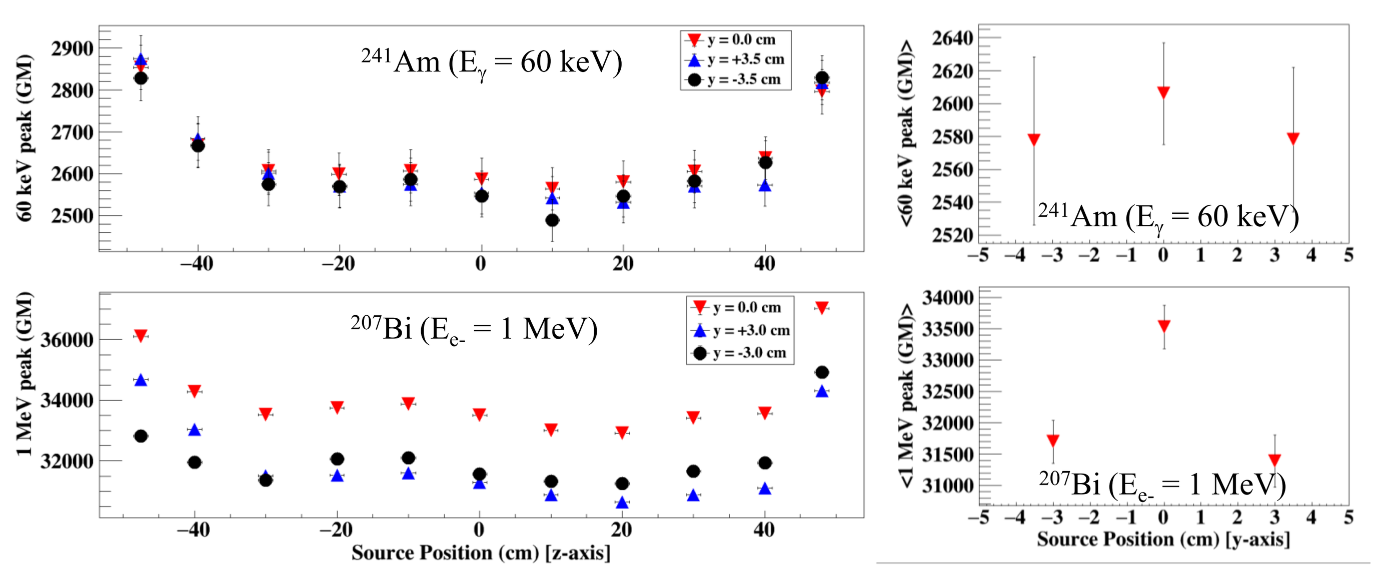
$t^2_{min} = \mathrm{t2(x)} - S^*\sigma_{t2}(x)$
$t^2_{max} = \mathrm{t2(x)} + S^*\sigma_{t2}(x)$

- Parametrizing time is a useful technique for selecting events at a specific hit position, ensuring precise identification of relevant data points.
- The parameter "S" represents the sigma spread factor.
- Parametrization-assisted event selection cuts, the background noise, primarily consisting of Compton electrons induced by gamma radiation from radioactive sources, is significantly reduced.









- The measured response using ^{241}Am (60 keV gamma) and ^{207}Bi (1 MeV conversion electron) demonstrates an almost uniform distribution, with a deviation of approximately 2% along the z-axis within a range of ±40 cm.
- However, along the y-axis, the deviation in response is around 2% for the 60 keV gamma rays and approximately 6% for the 1 MeV conversion electrons.
- Consequently, it is crucial to perform gain mapping throughout the experiment to account for these variations and ensure accurate measurements.

Summary

- The scan show significantly uniform response, over scintillator.
- The performance of the electron detectors will be validated using the radioactive source ^{207}Bi with suppressed gamma counts by coincidence with signals from MWDC.
- The charge-to-time converter-based electronics is excellent for this application and significant reduction of the cost.

Acknowledgment

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References

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