Pulse Shape Analysis with a Ultra-Low Background Frisch-Grid Ionisation Chamber

Workshop on Gas-filled Detectors and Systems

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23/01/2019

Detector Design and Setup

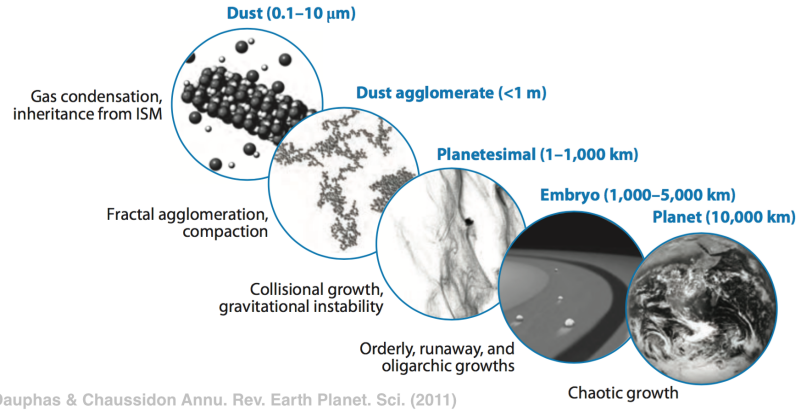
Pulse Shape and Simulations

Cuts and Calibration

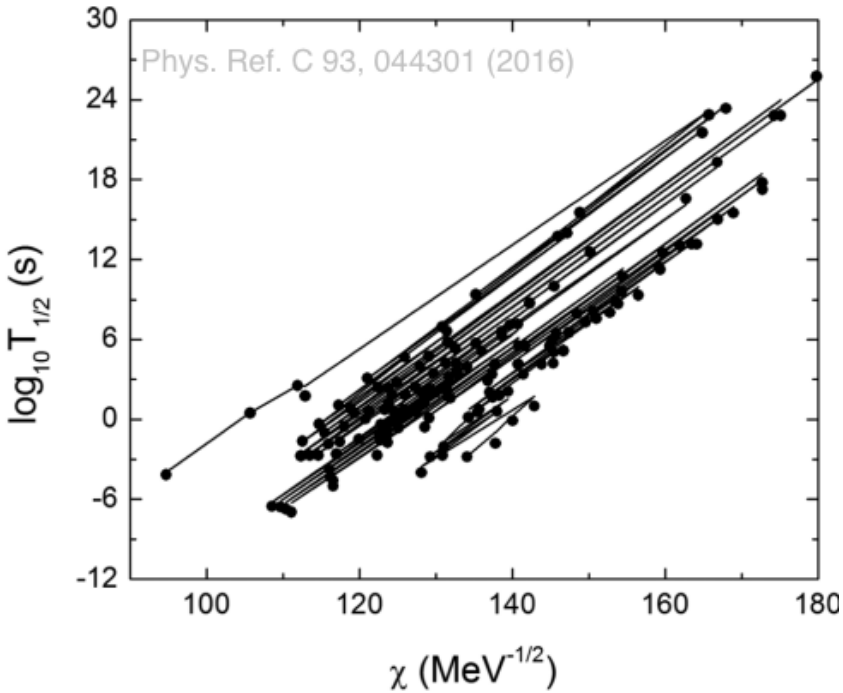
Results of Samarium and Platinum Half-lives

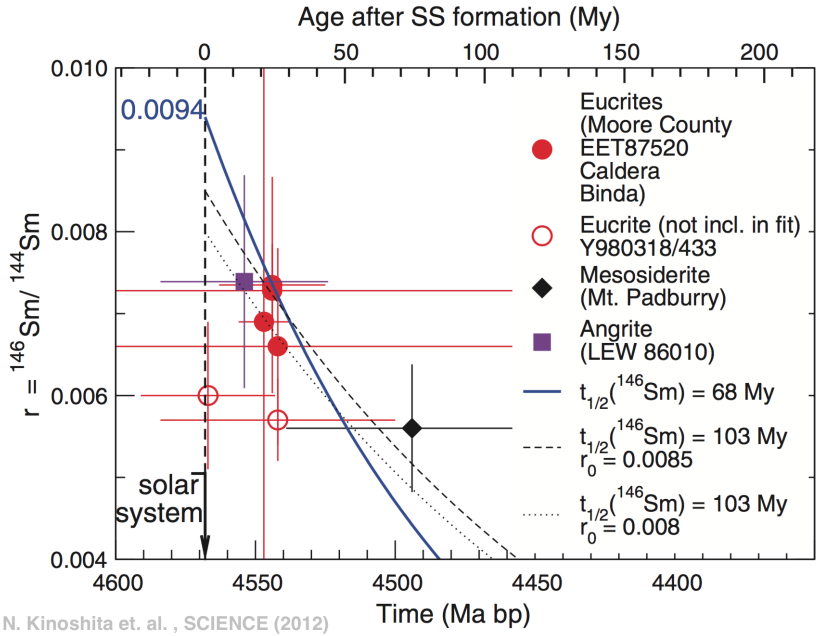
Summery

Motivation

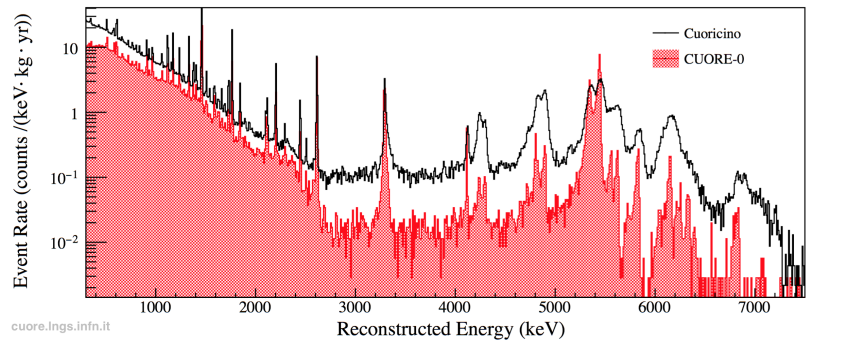


Dauphas & Chaussidon Annu. Rev. Earth Planet. Sci. (2011)

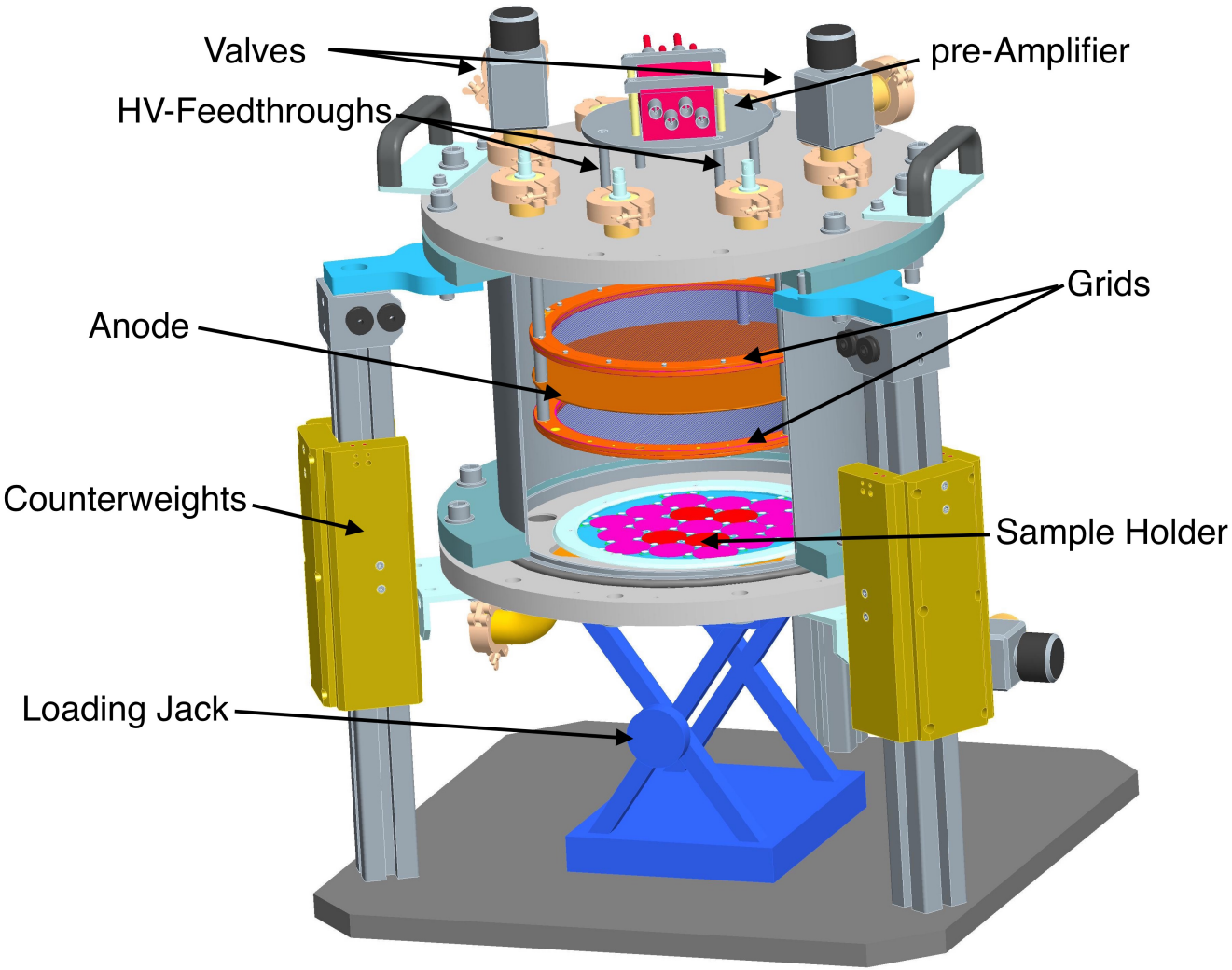




N. Kinoshita et. al. , SCIENCE (2012)

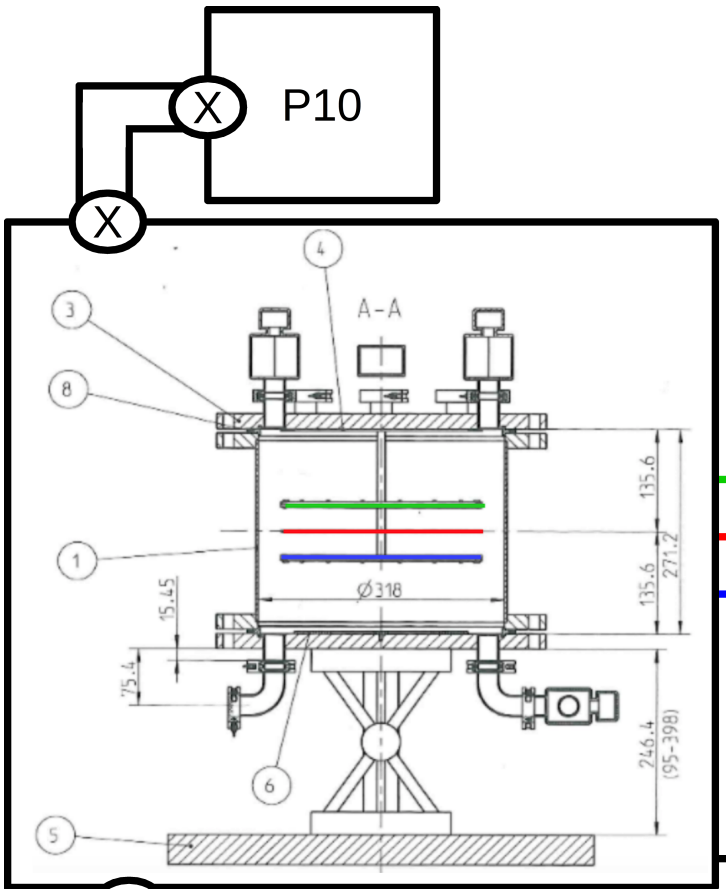


Twin Frisch-grid Ionisation Chamber (TFGIC)



- Radio pure materials for **low intrinsic background**
- **Fast signal** times ($\sim \mu$s)
- Signal is amplified with a low noise Pre-Amp (CAEN:*A1422*)
- Pulse shapes digitised (CAEN FADC:*N6724*) stored in **ROOT** files

Well Monitored Experimental Setup



P10

High Voltage

3
2
1

ADC

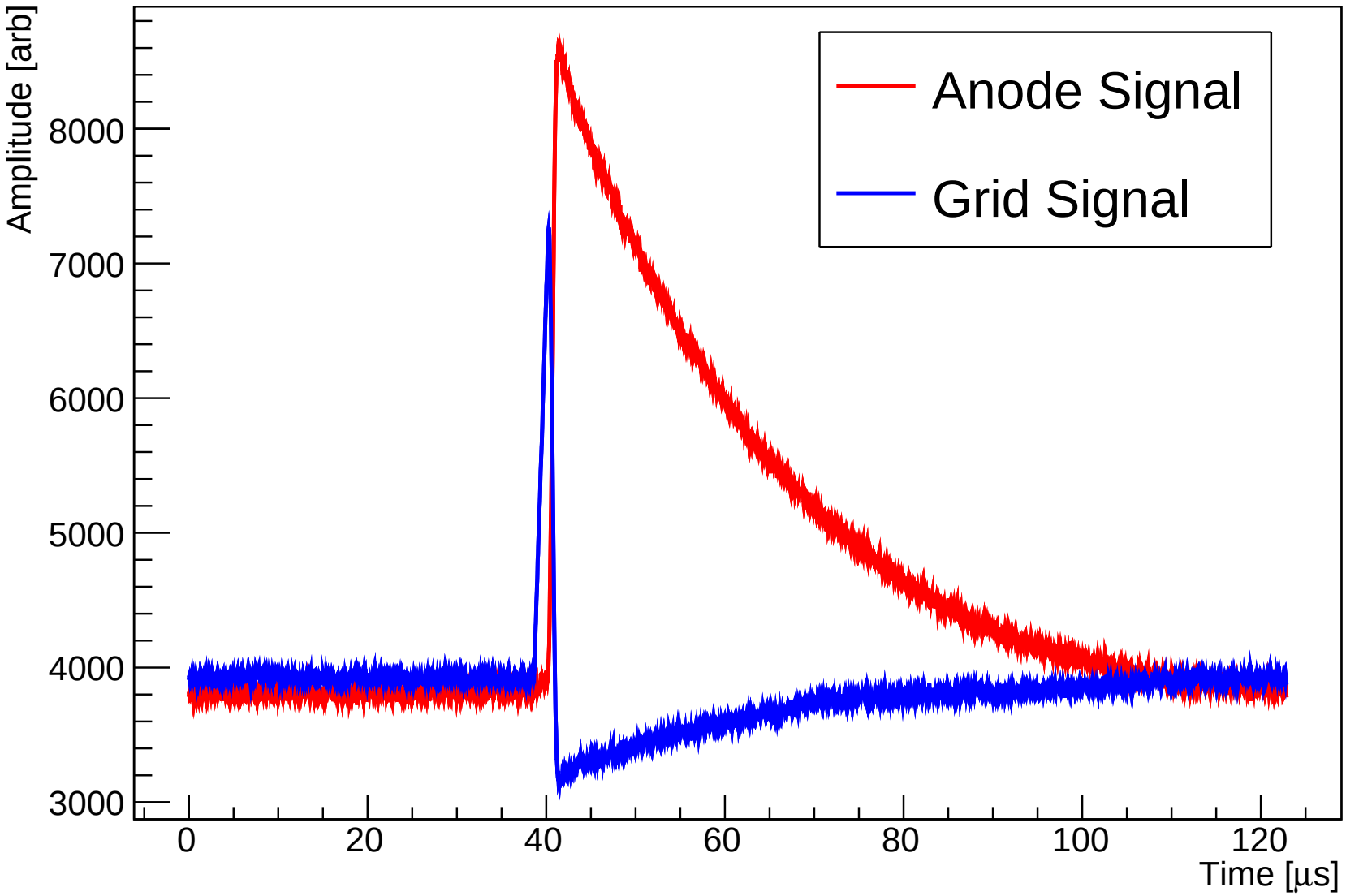
Pre Amp

ROOT

Pressure and Temperature

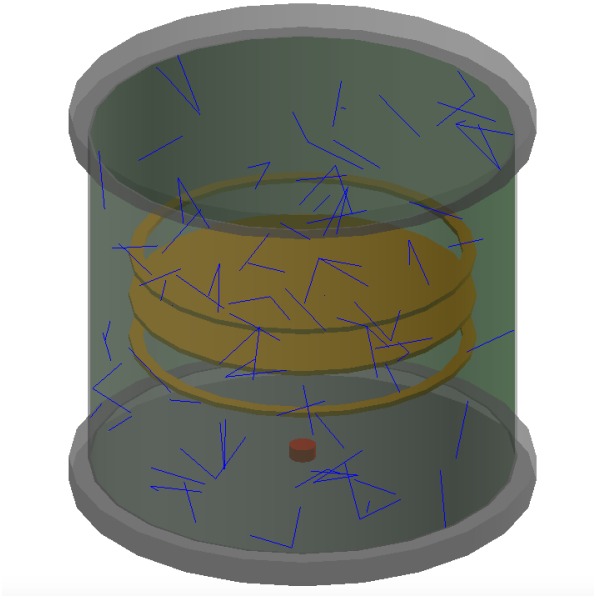
Vacuum Pump

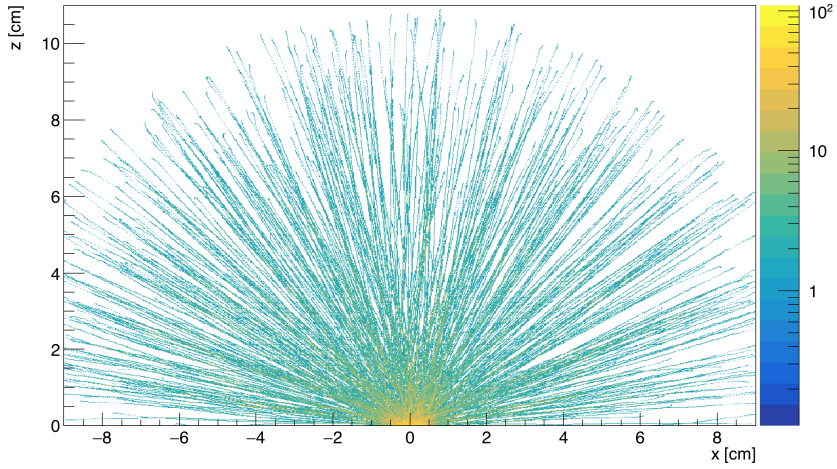
Raw Alpha Signal

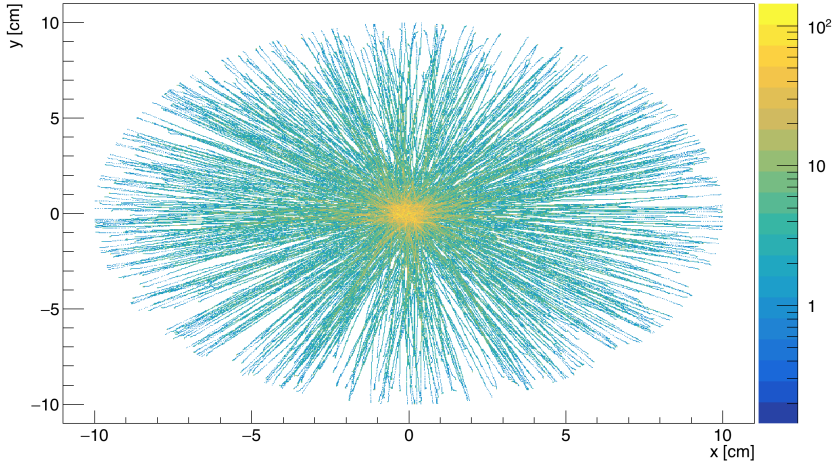


GEANT4 Simulation of Alpha Ionisation

- GEANT4 simulation **simulates energy spectra and tracks**
- Monte Carlo describes **self absorption** and **geometric efficiency**







Calculating Pulse Shape with Shockley-Ramo Theorem

$$Q = \oint_S \varepsilon \, \mathbf{E} \cdot d\mathbf{S}$$

$$\mathbf{E} = \mathbf{E}_0 + \mathbf{E}_s + \mathbf{E}_q$$

The charge Q and current i on an electrode induced by a moving point charge q are given by:

$$Q = -\, q\, \varphi_0(\mathbf{x})$$

$$i = q\, \mathbf{v} \cdot \mathbf{E}_0(\mathbf{x})$$

$$\mathbf{E}_0(\mathbf{x}) = -\, \nabla \varphi_0(\mathbf{x})$$

NIM A **463**, 250 - 267 (2001)

Pulse shape calculation method:

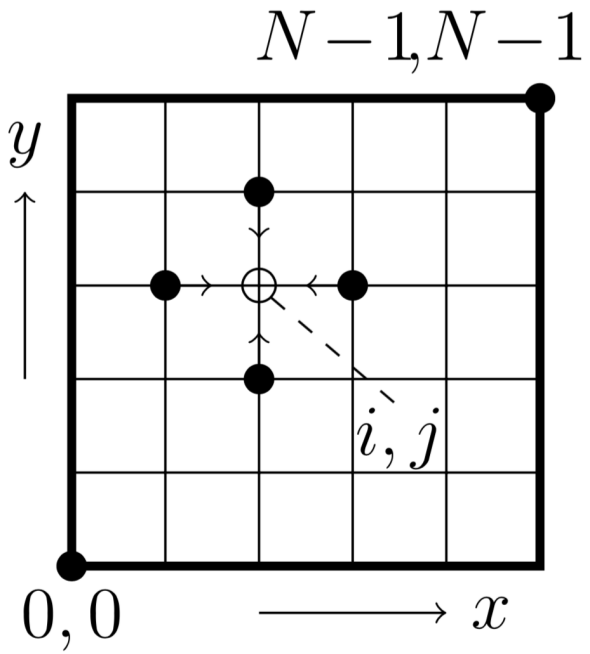
Classical: Electromagnetism using change in flux

Problem: Computationally difficult

Solution: Weighted potential

Calculating Electric Fields - Solving Laplace Equation (2D)

"**Weighted Potential** (WP) is created by setting the electrode potential to **1** and all others to **0**."



$$\nabla^2 U = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) U = 0\,,$$

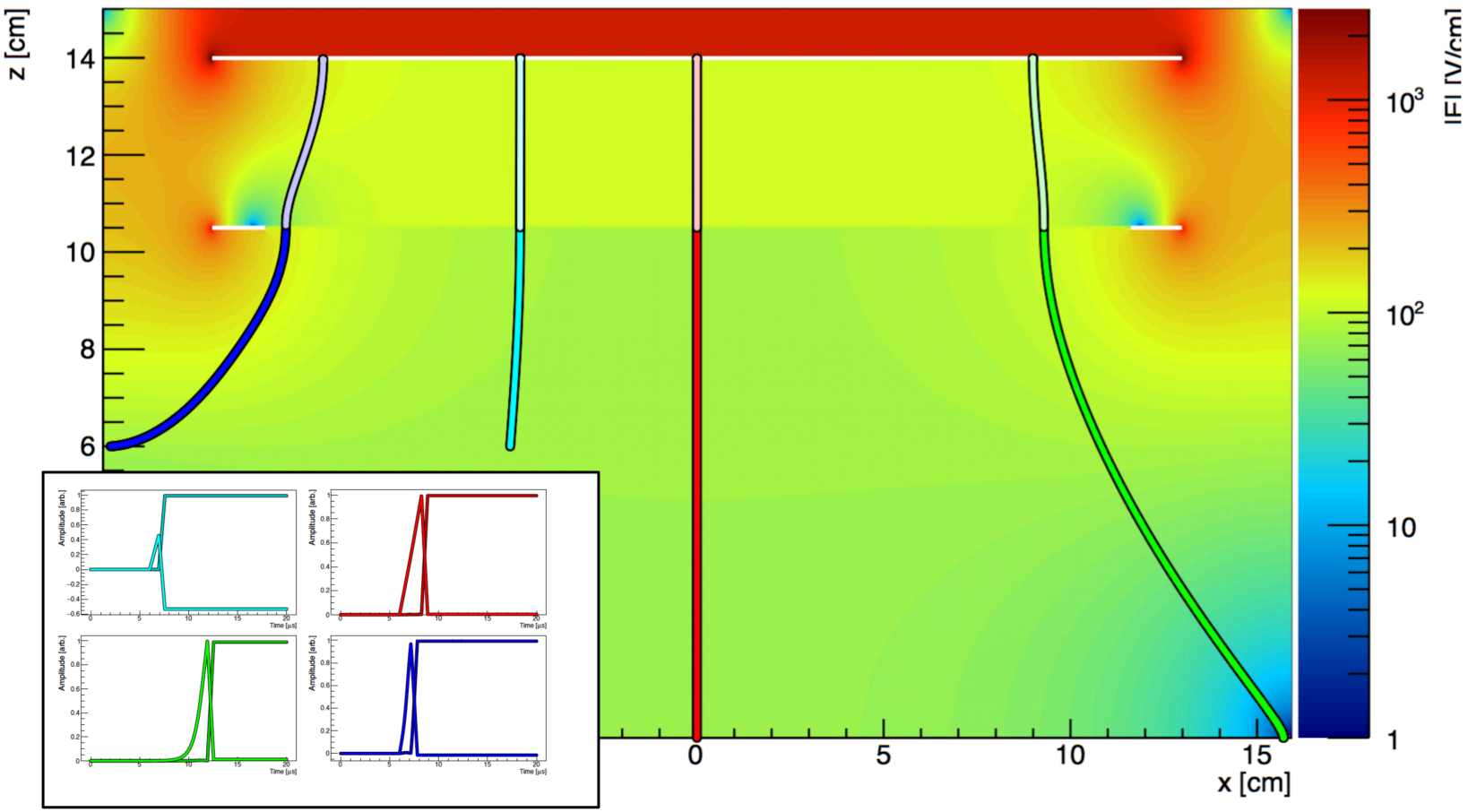
$$U \simeq U^{(m+1)} = U^{(m)} + \frac{s \cdot r}{4}\,,$$

$$r = U_{i-1,j} + U_{i+1,j} + U_{i,j-1} + U_{i,j+1} - 4U_{i,j}\,,$$

$$s \simeq \frac{2}{\left(1 + \frac{\pi}{L}\right)}\,.$$

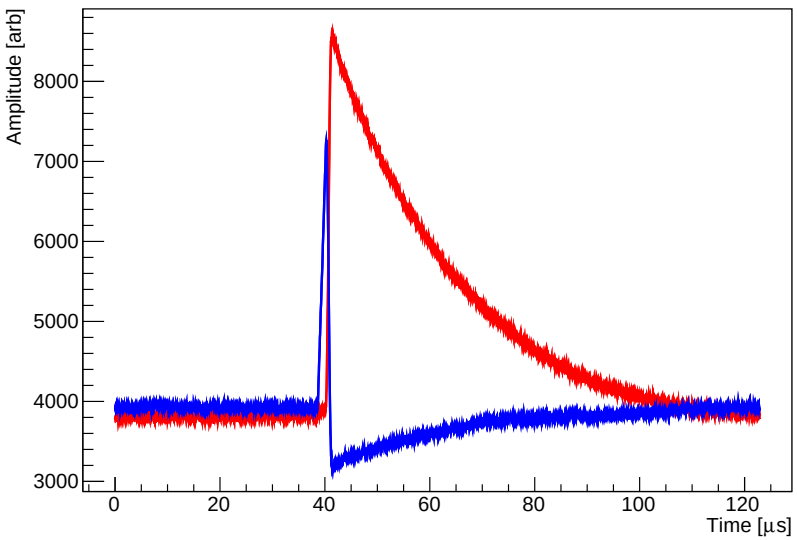
Used Successive Over Relaxation (SOR) to speed up computation

Pulse Shapes for Different Event Locations

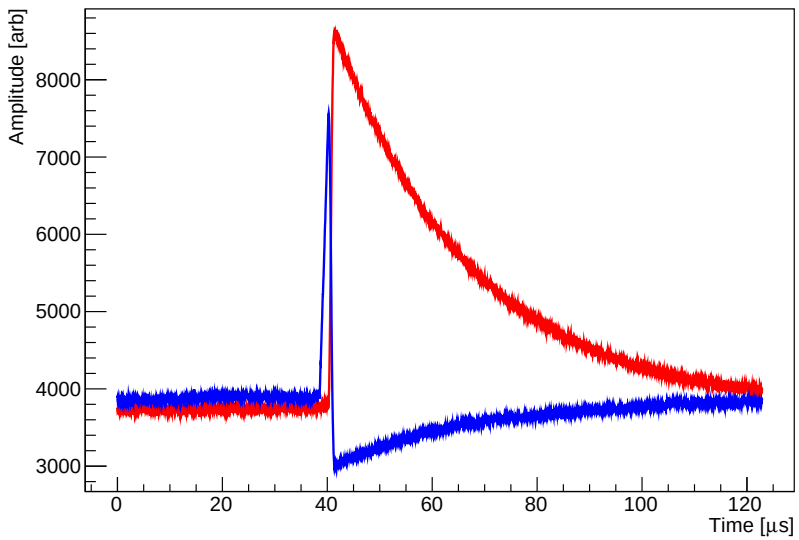


Full Simulation of Pulse Shape

Real Pulse Shape

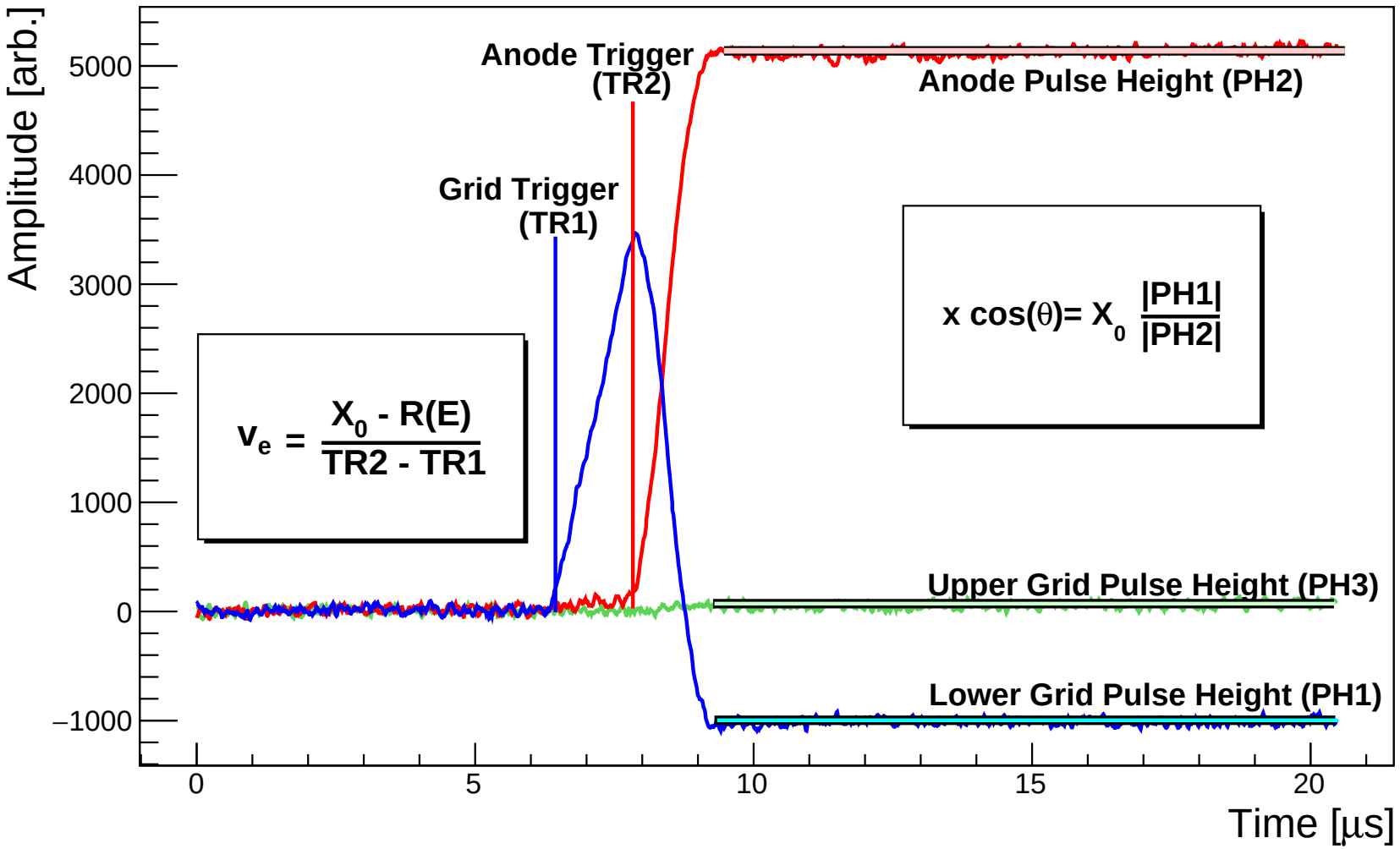


Simulated Pulse Shape



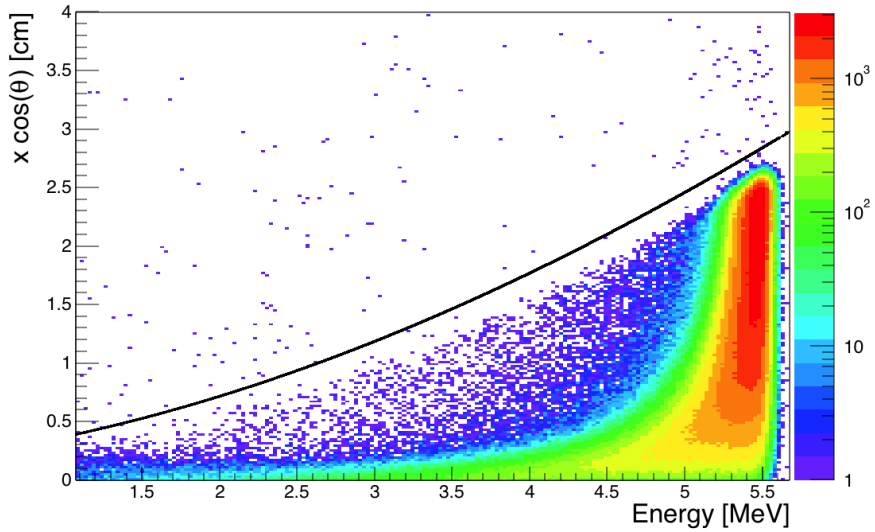
Real pulse shape same as simulated pulse shape!

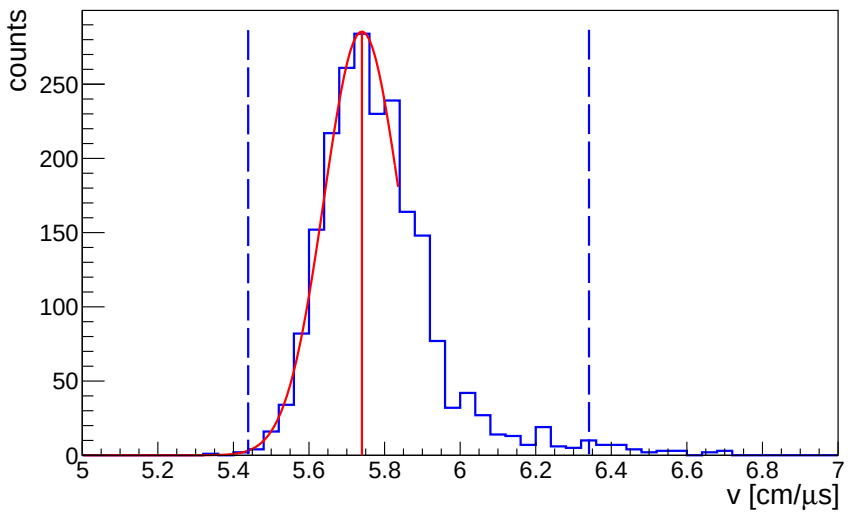
Pulse Shape Analysis Parameters



Data Cuts and Efficiancy

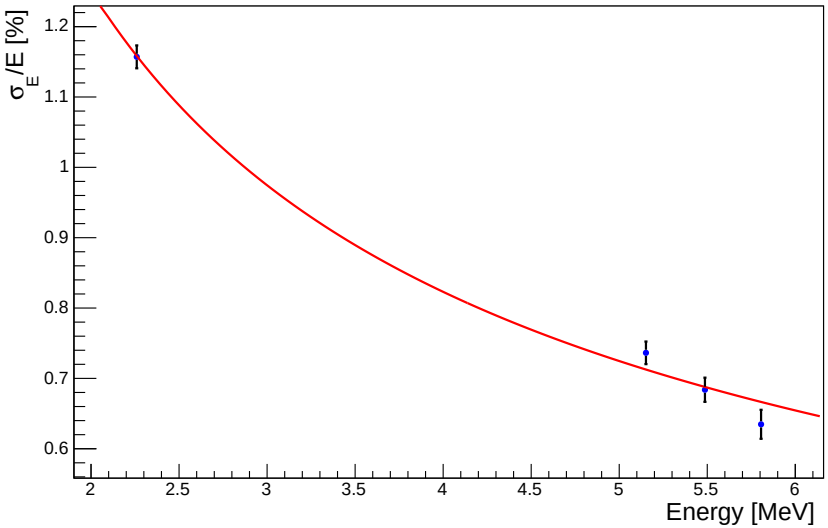
- v_e cuts are based on literature values for P10 gas
- **TRIM and GEANT4** simulations are used to define the maximum and minimum of the $x \cdot \cos(\theta)$
- Cuts are based on the electron velocity v_e in the gas and the centre of charge $x \cdot \cos(\theta)$
- $\varepsilon = \varepsilon_{\text{det}} \cdot \varepsilon_{\text{cut}} = \underline{98.6(22)\%}$



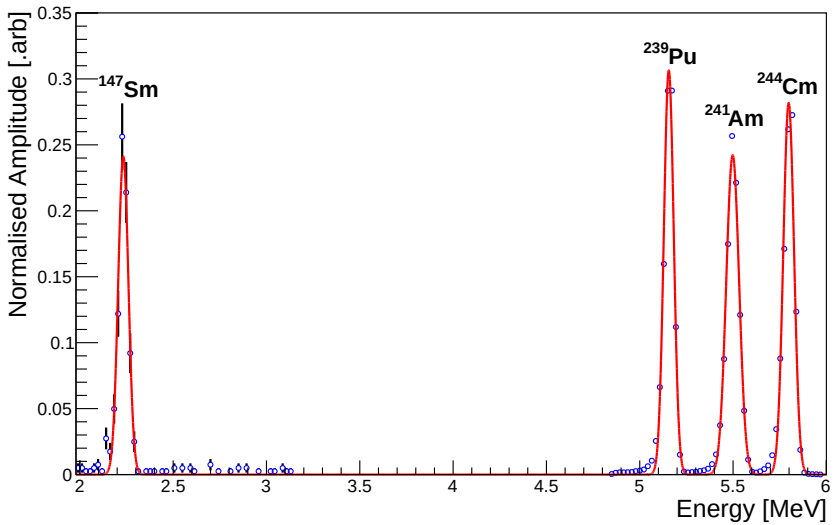


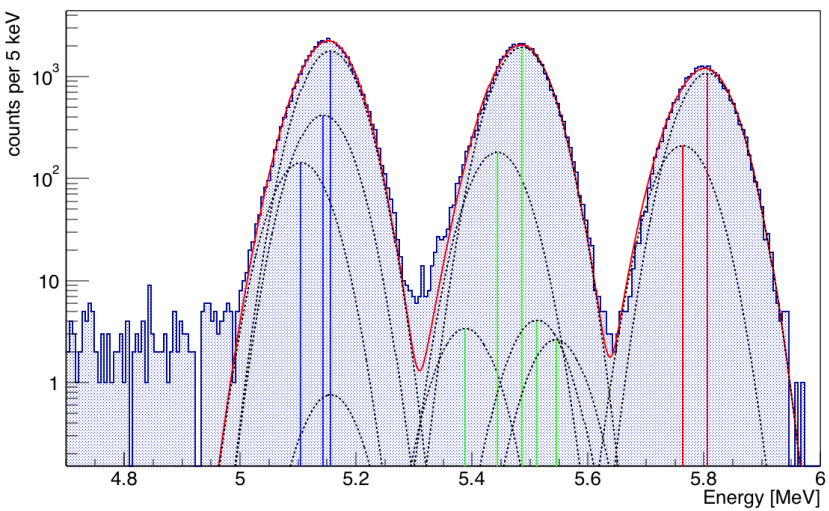
H. Wilsenach et al., *Nucl. Instrum. Methods A* **814**, 12 (2016)

Energy and Resolution Response

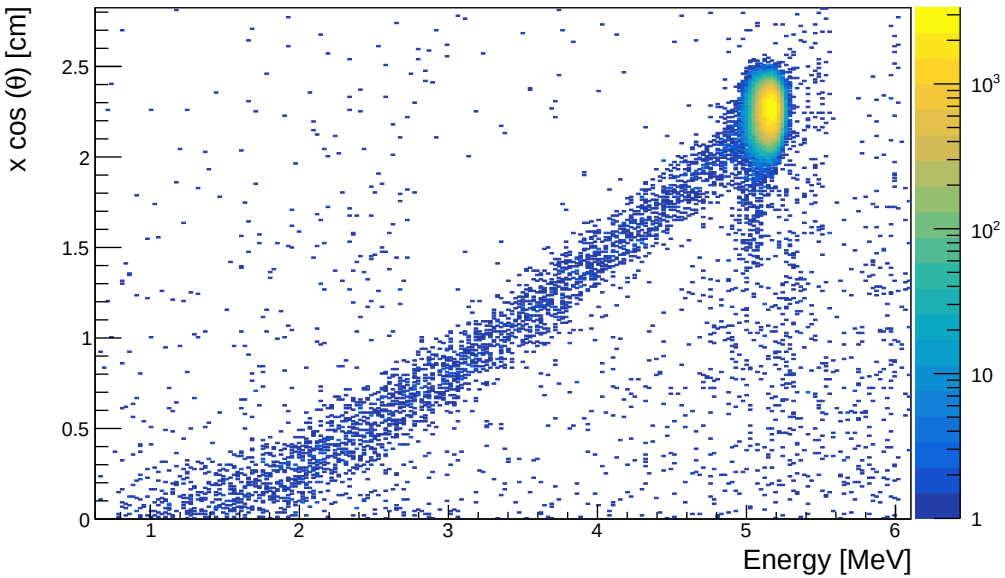


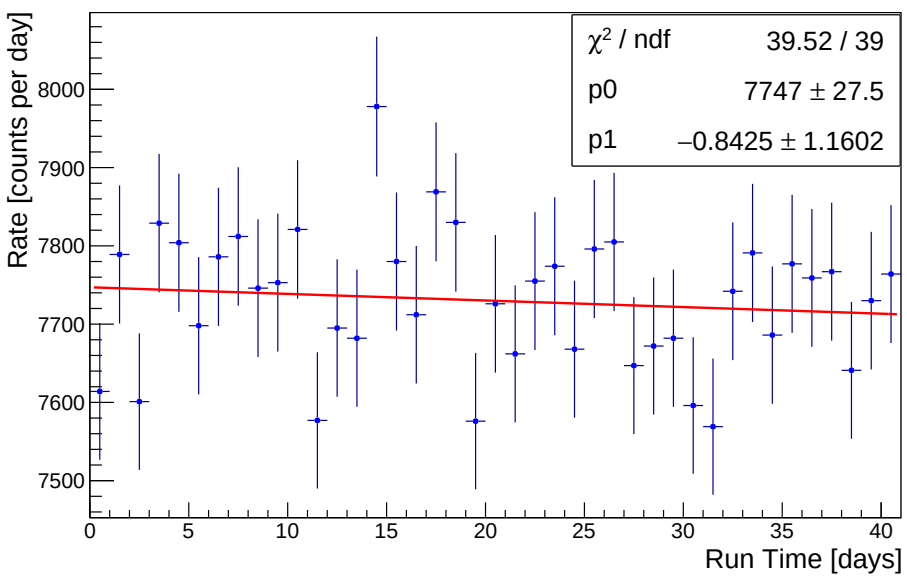
- Energy scale is calibrated using a mixed source of ^{241}**Am** ^{239}**Pu**, ^{244}**Cu**
- Lower energy is calibrated using ^{147}**Sm**
- For thin samples the peak is described with a gaussian



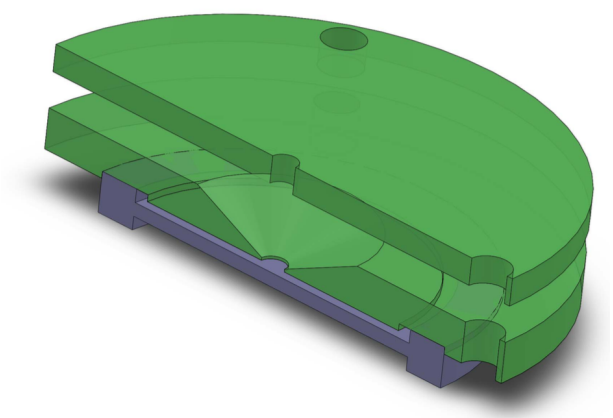


Longterm Counting Stability

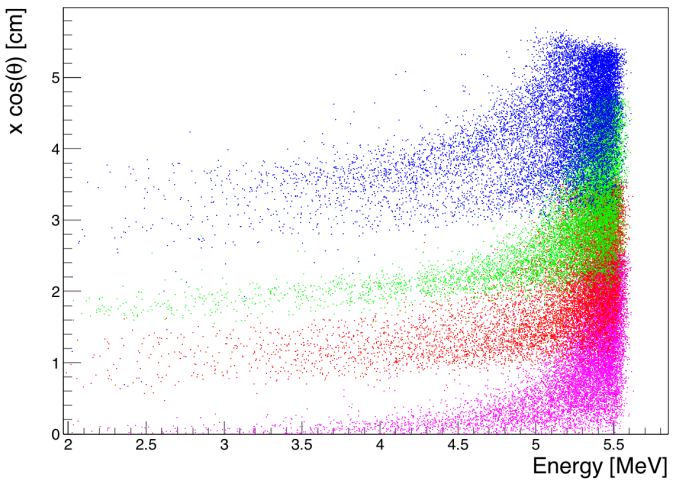




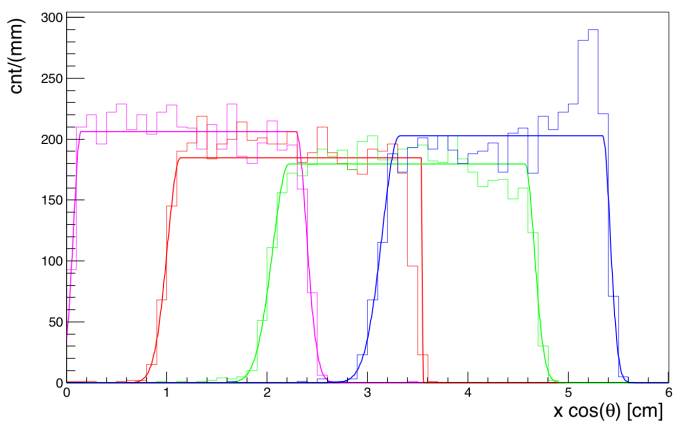
- A collimated ^{241}Am source was run for a duration of **40 days**
- The deviation away from zero of the gradient has a 46% statistical probability (0.73 σ)

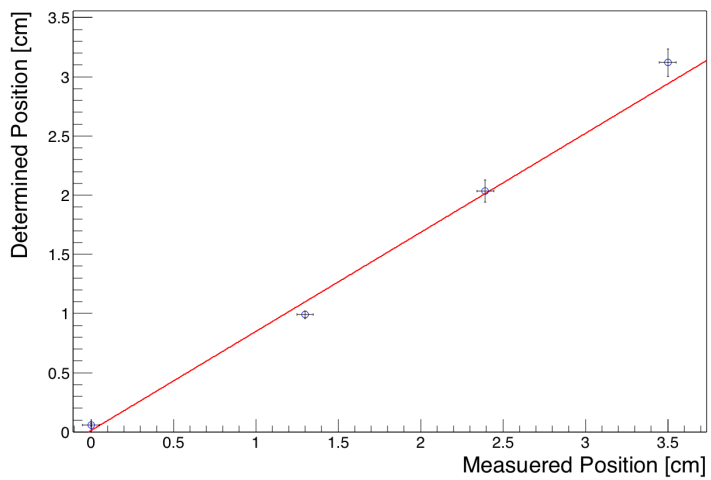


Position Calibration



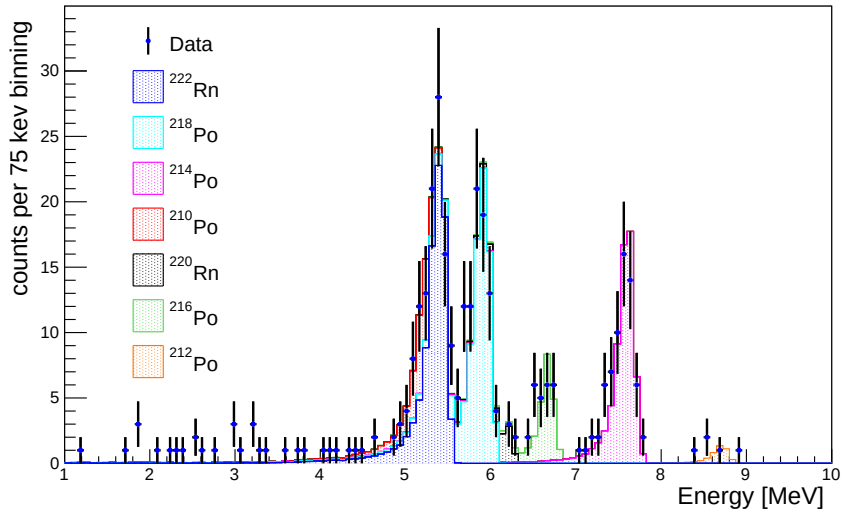
- Centre of charge resolution was calibrated by placing ^{241}Am sample on **different acrylic discs**
- Lowest point was measured and determined from the data
- Position resolution σ_z of 4.2(3) mm was measured



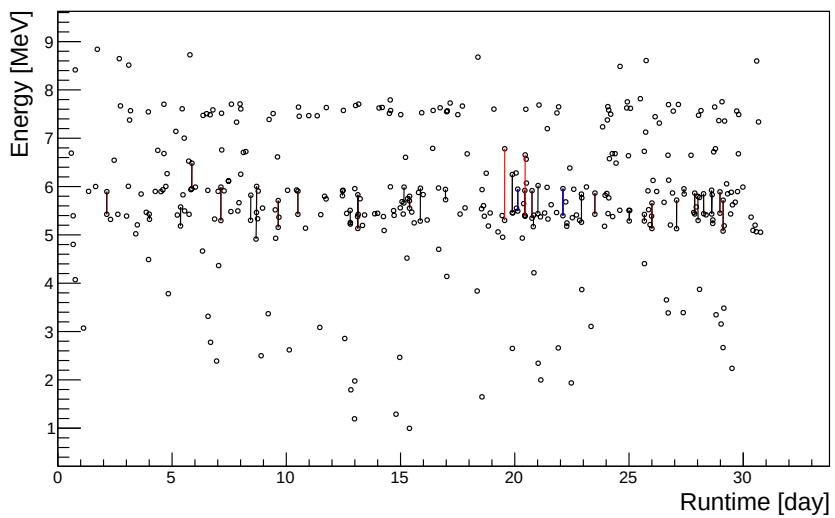


Background Spectrum and Time Profile

- Background run of **30.8 days** was performed, the total rate was 10.9(6) c.p.d.
- MC spectra were used to determine the source of each background

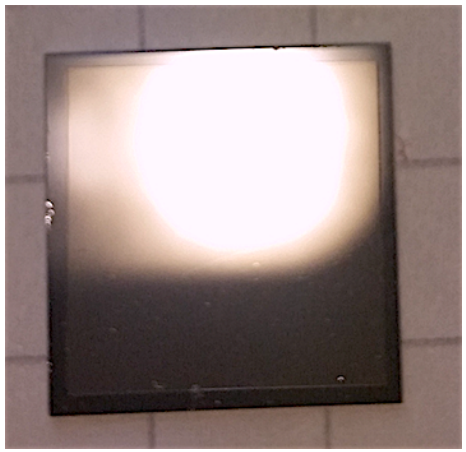


Element	Rate [c.p.d.]
^{222}Rn	2.89(41)
^{218}Po	2.77(32)
^{214}Po	2.12(27)
^{210}Po	0.85(31)
^{220}Rn	0.27(16)
^{216}Po	0.79(18)
^{212}Po	0.16(11)

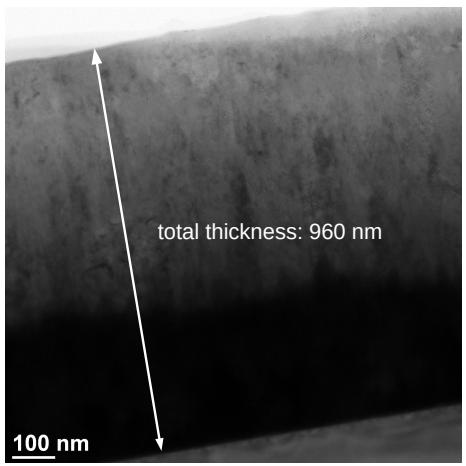


Samarium Half-life Measurement and Self Absorption

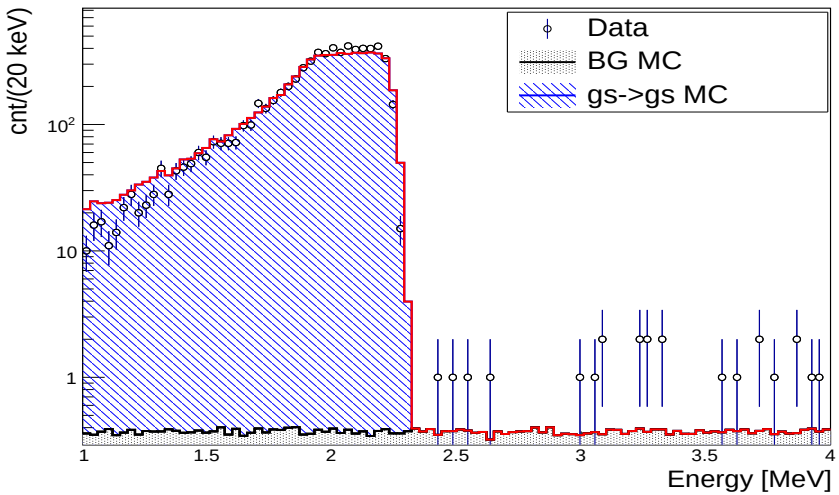
- $4 \times 1 \times 1$ cm^2 silicon wafers were coated in **natural samarium**($^{147}\mathrm{Sm} = 14.99(18)$ % abundance)
- Deposited amount of $^{147}\mathrm{Sm}$ was determined using **RBS** and checked with **EDX** and **AFM**

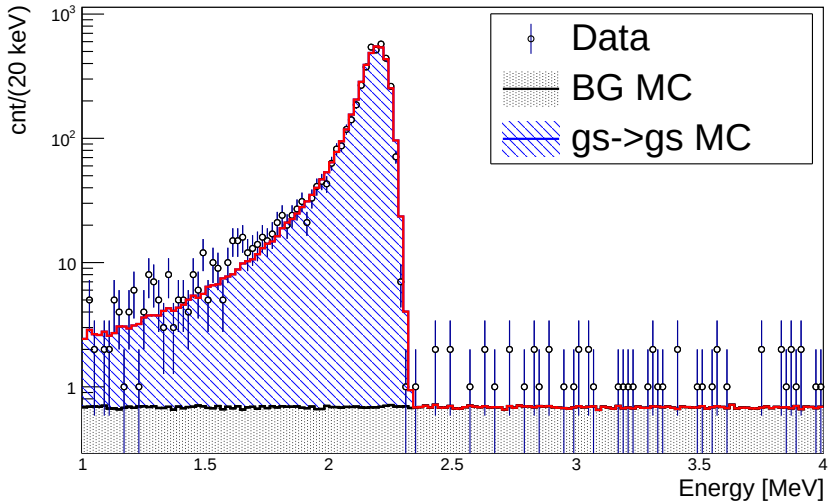


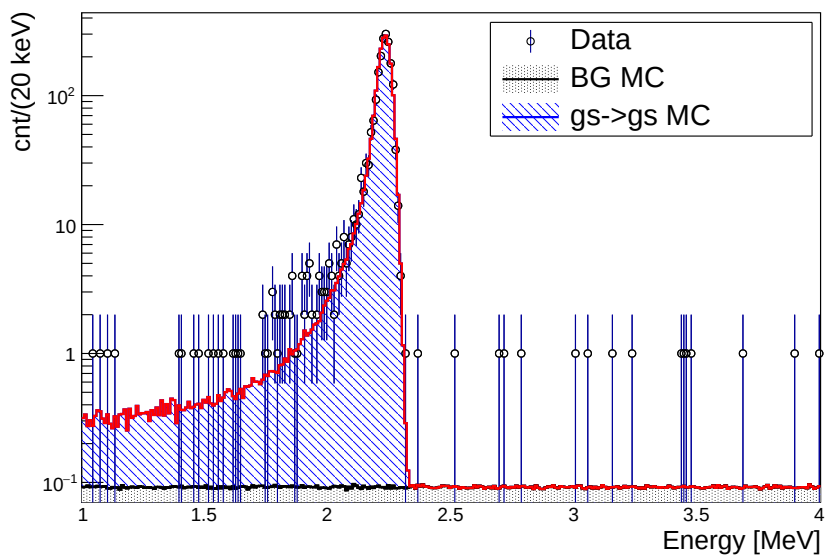
Sample	Area [mm^2]	RBS [nm]	Cr [nm]
SM001	80.6(4)	35.2(7)	5
SM002	80.6(4)	41(1)	4
SM003	76.4(4)	226(2)	10
SM004	80.1(4)	904(7)	10

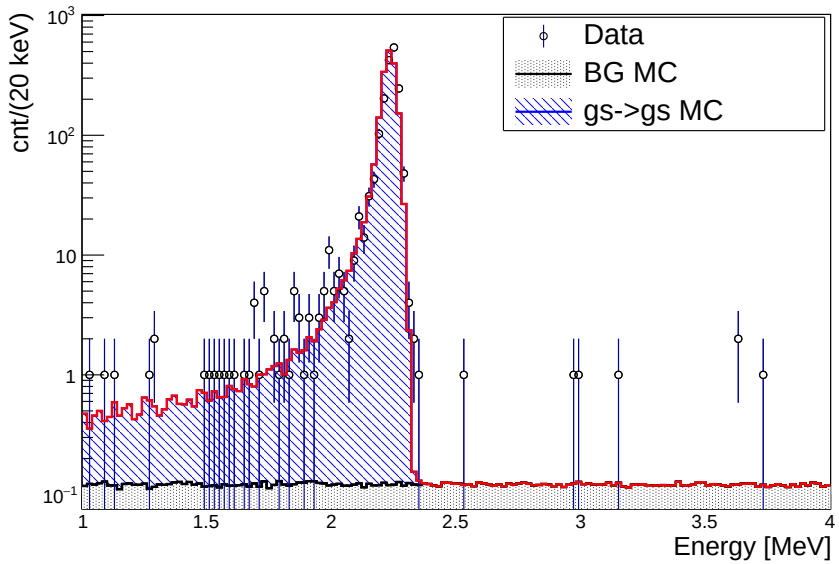


MC in Agreement with Data





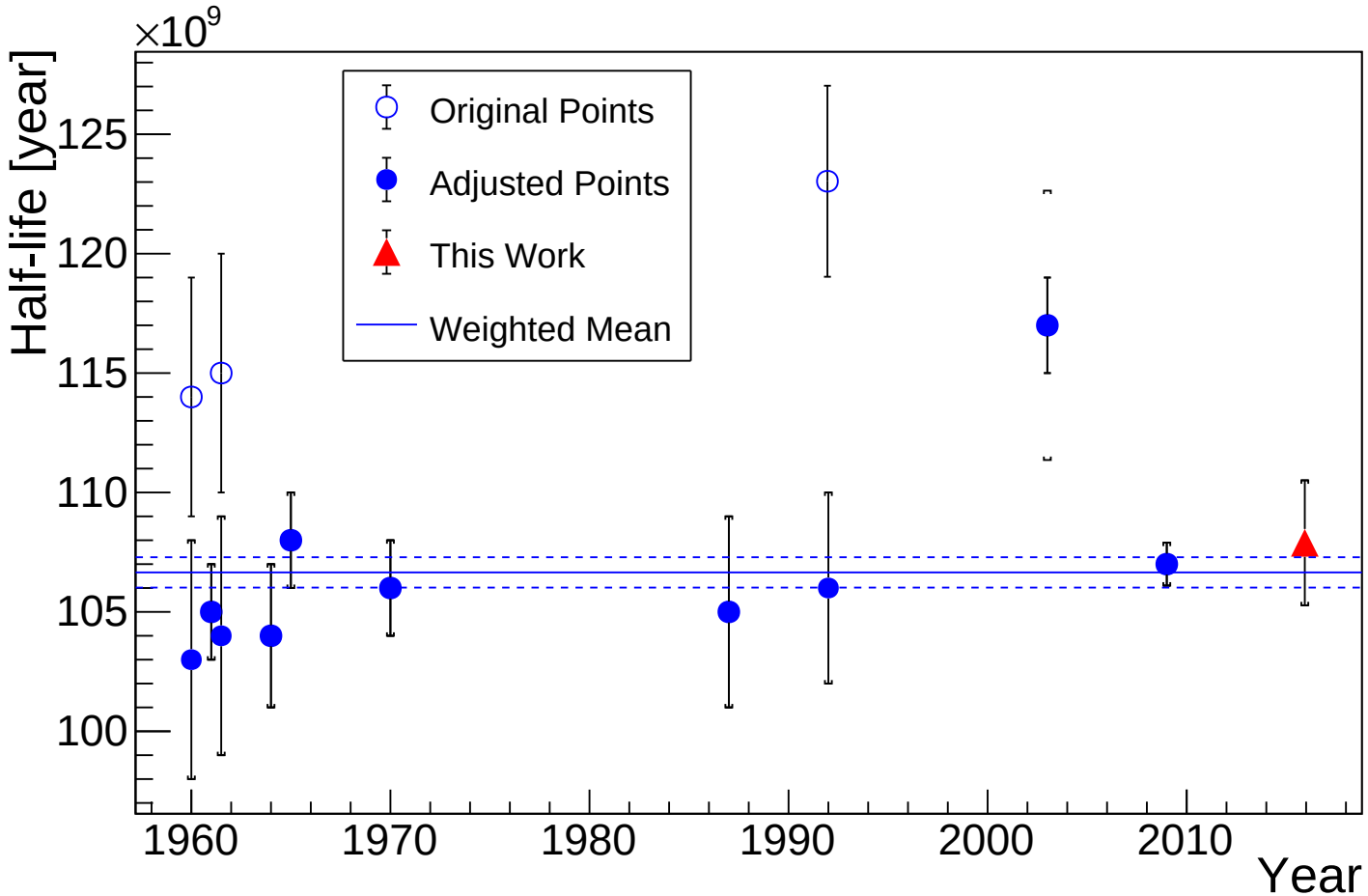




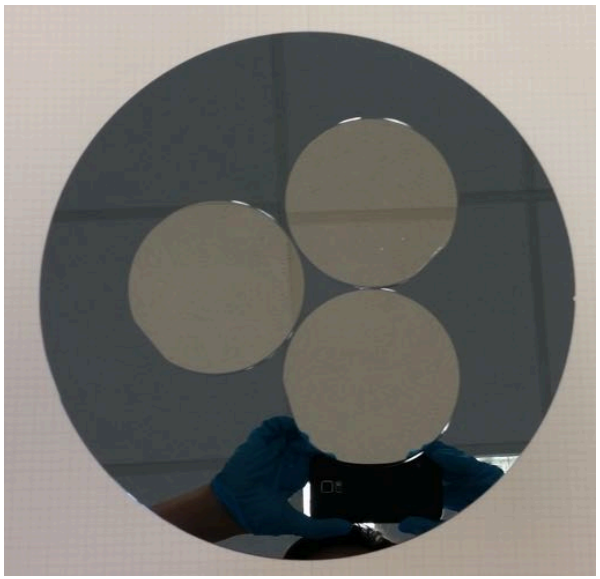
^{147}Sm Half-life Result Comparison

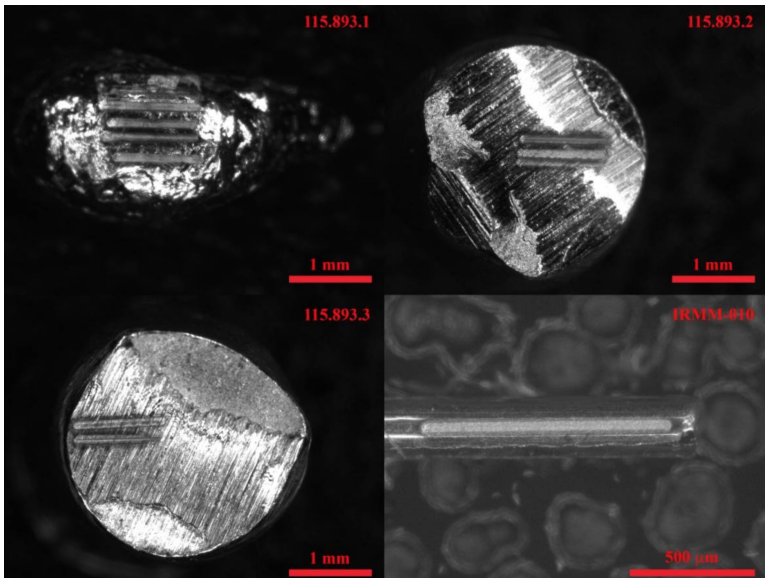
$$T_{1/2} = (1.0787 \pm 0.0095(\text{stat.}) \pm 0.0244(\text{sys.})) \times 10^{11} \text{ years}$$

$$T_{1/2}^{\text{group}} = (1.067 \pm 0.006) \times 10^{11} \text{ years}$$



Platinum Half-life Measurement





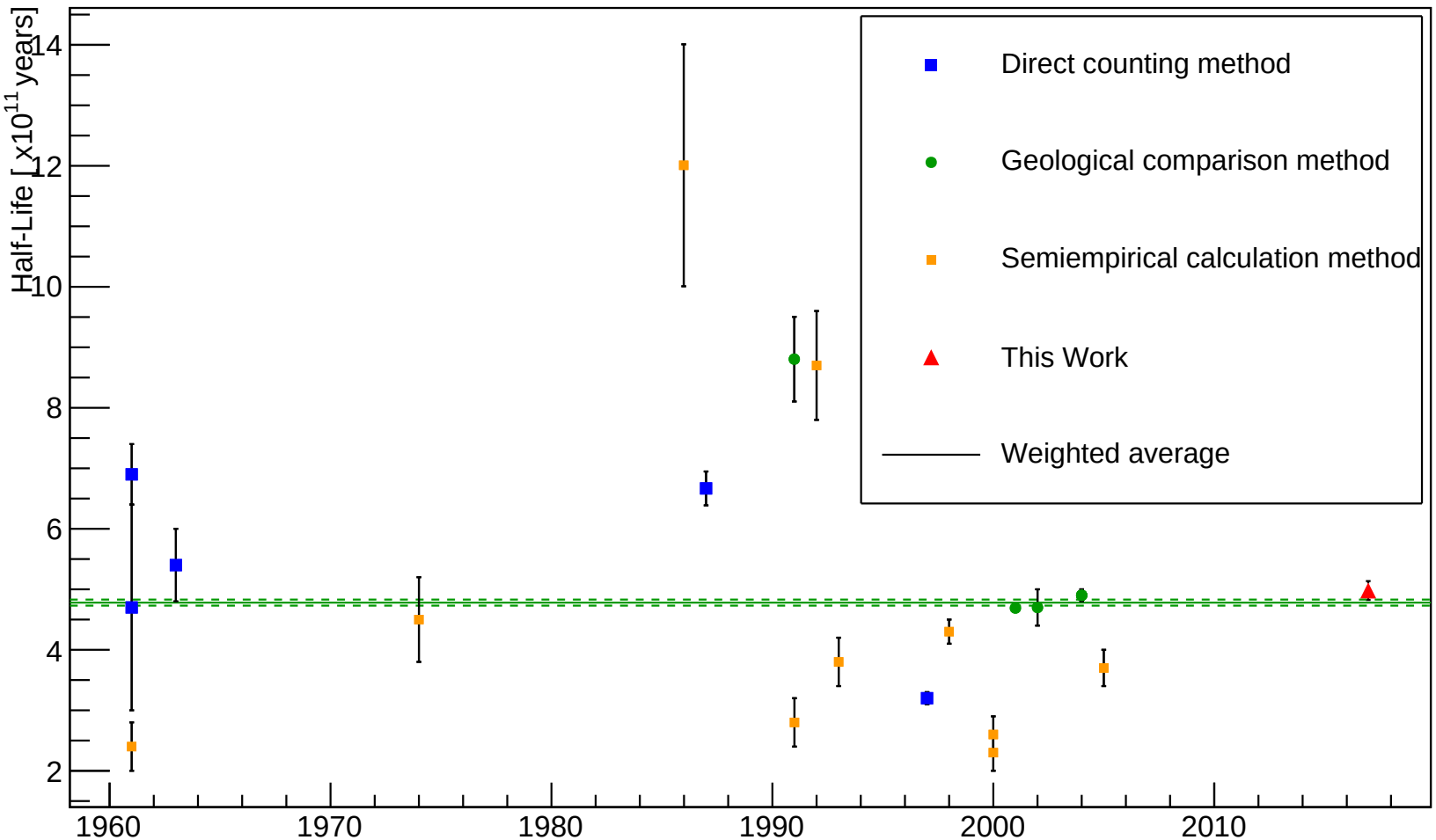
- 3×4" silicon wafers were coated in **natural platinum**. ($^{190}\mathrm{Pt} = 0.01125(21)$ % abundance)
- Deposition was weighed to **0.1% accuracy**

Target Name	Mass [mg]	Thickness [nm]
Pt01	75.2(1)	441(4)
Pt02	73.1(1)	429(4)
Pt03	68.3(1)	401(4)

(M. Braun et. al. *P*LB, 2017)

^{190}Pt Half-life Result Comparison

$$T_{1/2} = (4.97 \pm 0.16) \times 10^{11} \text{ years} .$$
$$T_{1/2}^{\text{group}} = (4.759 \pm 0.031) \times 10^{11} \text{ years}$$



Summary

- The chamber has been calibrated and the efficiencies have been determined and **published**.
- Cuts have been developed to increase the signal to background ratio.
- A MC simulation has been validated and used to fit spectra.
- Experience has been gained in the manufacturing and characterisation of samples.
- The measurement of $^{190}\mathrm{Pt}$ and $^{147}\mathrm{Sm}$ has been completed and **published**.
- Next stage is to measure the extinct isotope $^{146}\mathrm{Sm}$.