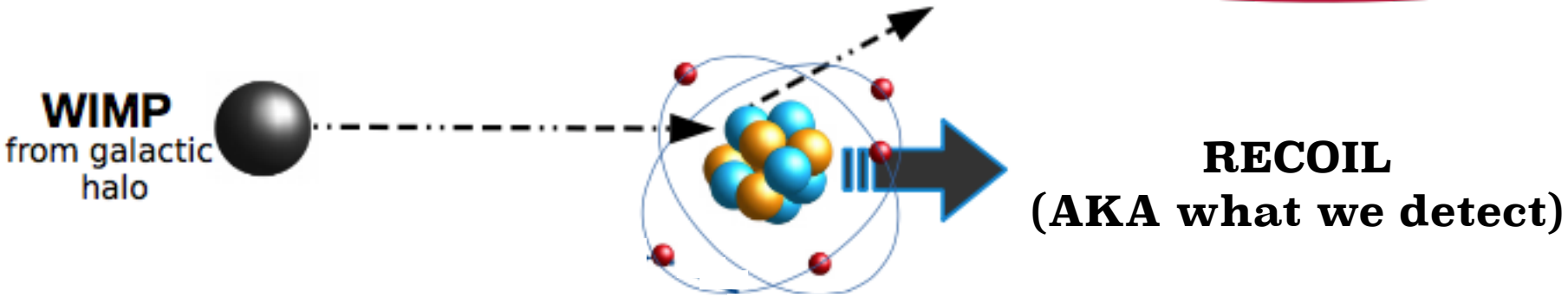
Dark Matter direct detection with NEWS-G

Francisco Andres Vázquez de Sola Fernández
NEWS-G collaboration at Queen's University
WNPPC, February 2017

Summary

- Intro: Dark Matter direct detection
- NEWS-G
  - the Detector
  - the Working Principle
- Pulses
  - Parameter estimation
  - Shape discrimination
- Future detector: NEWS-SNO
- Outro: Work at Queen's

Dark Matter Direct Detection

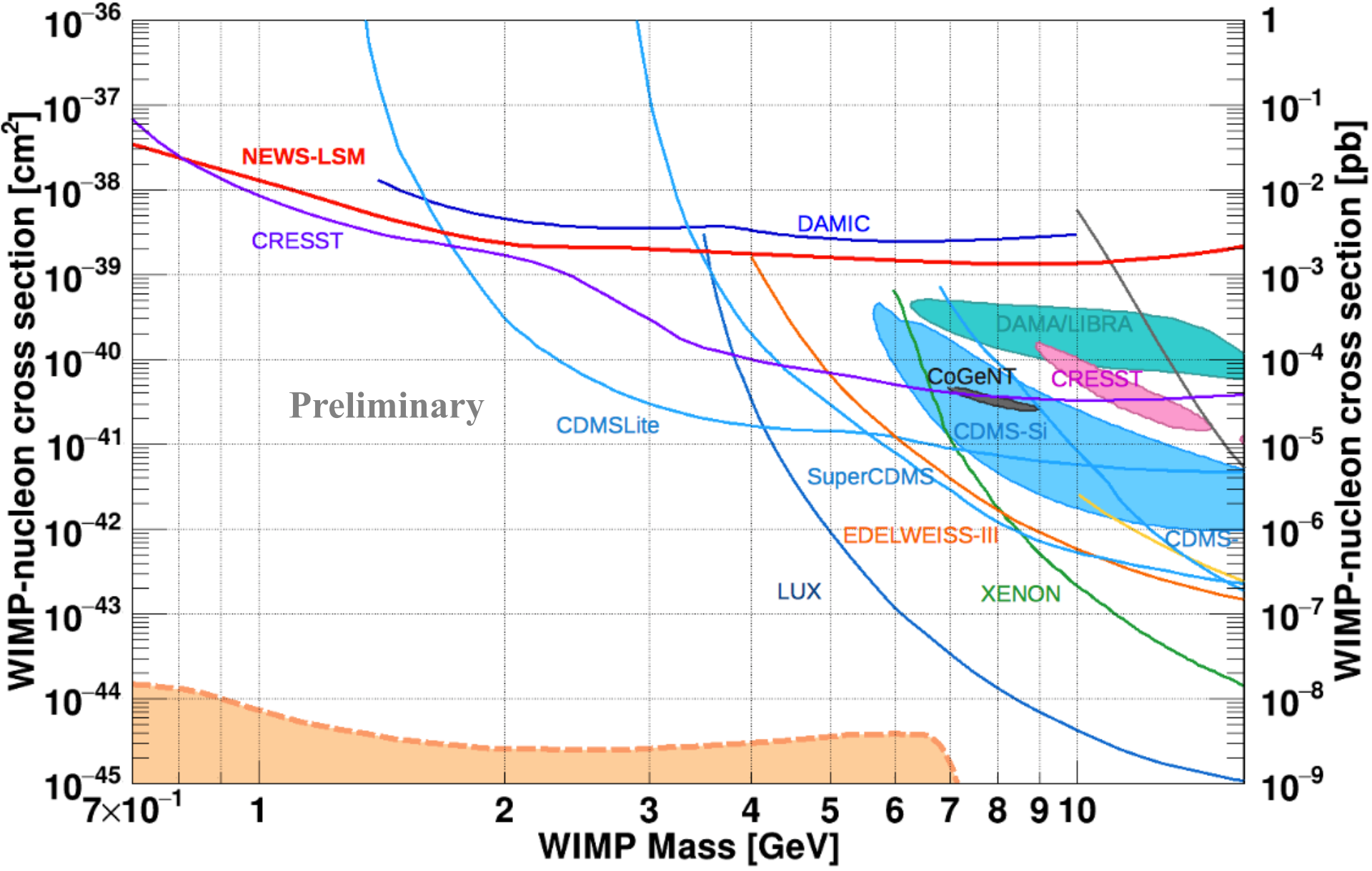


- Rare < 1 evt/kg/year
- Small recoils < 1 keV (depends)

Need:

- large exposures: large target mass, long data taking
- background reduction: underground lab, shielding, clean materials, event discrimination

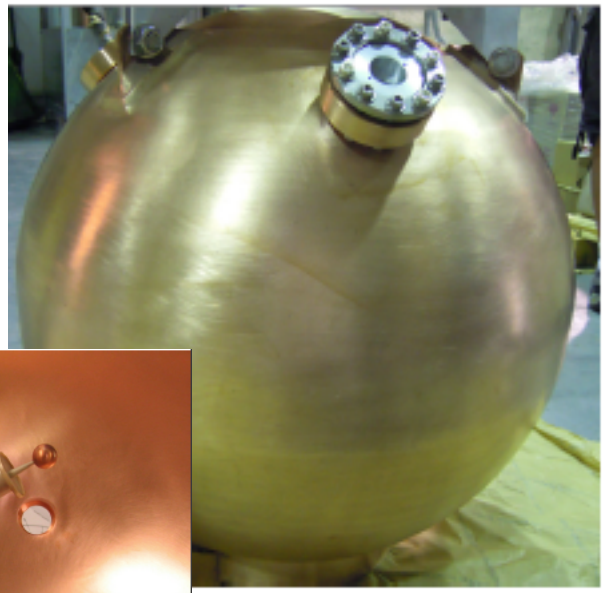
NEWS-G : Exclusion Limit

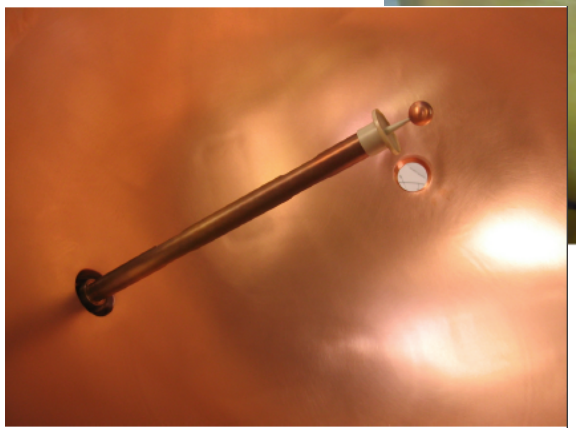


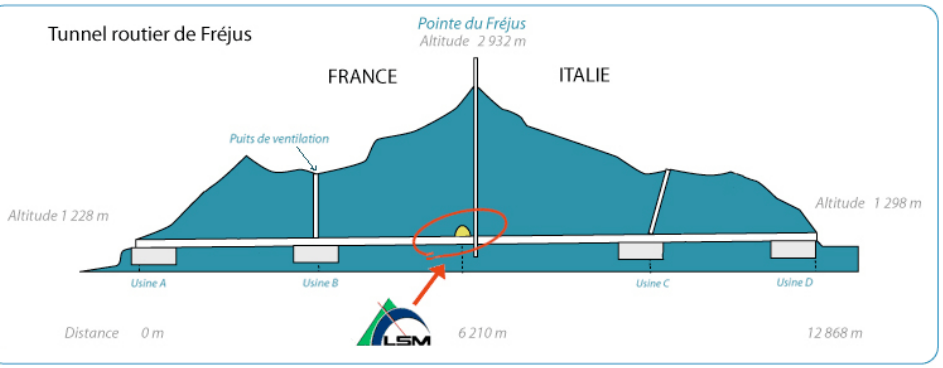
- 42 days of data, with Neon + 0.7% CH4 at 3.1 bar

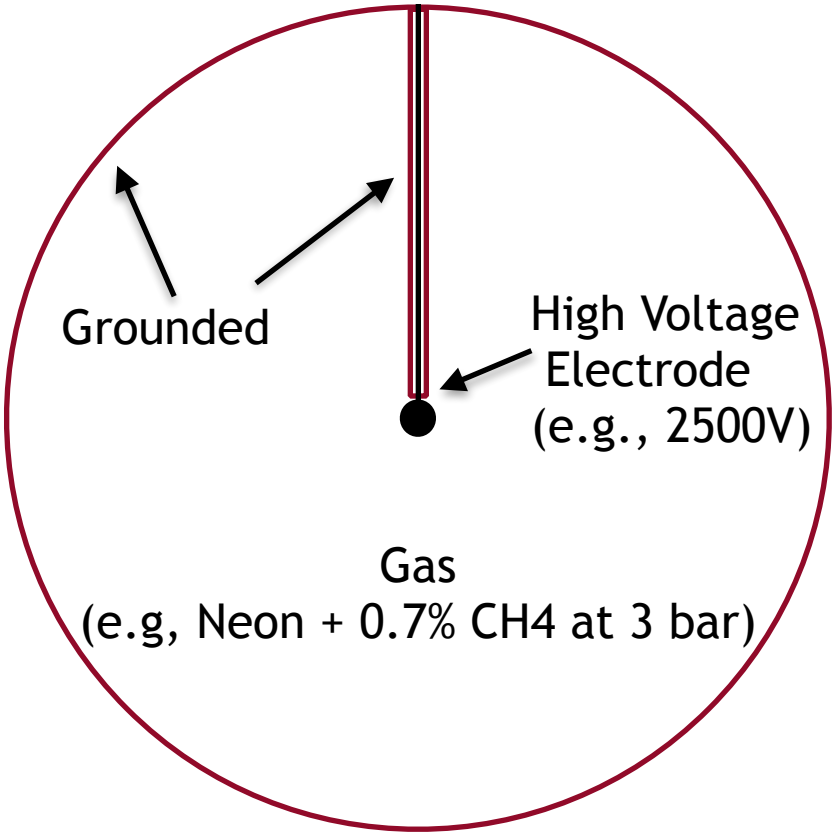
NEWS-G : the Detector

SEDINE
60 cm copper vessel detector at LSM



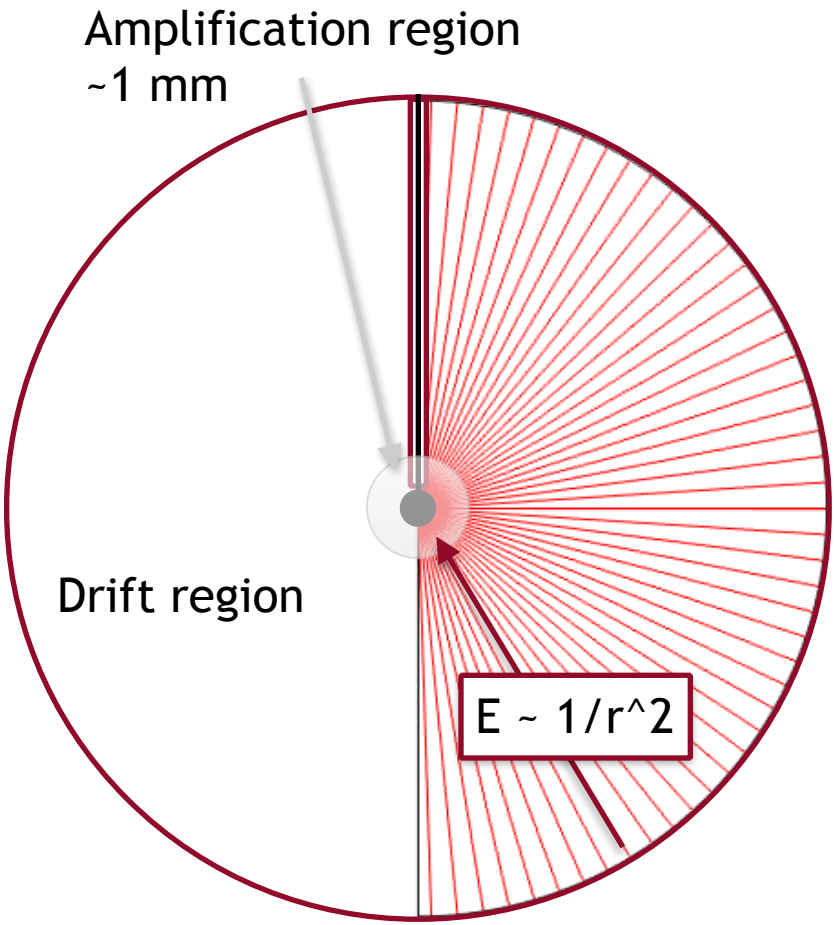






Spherical Proportional Counter

NEWS-G : the Detector



Spherical Proportional Counter

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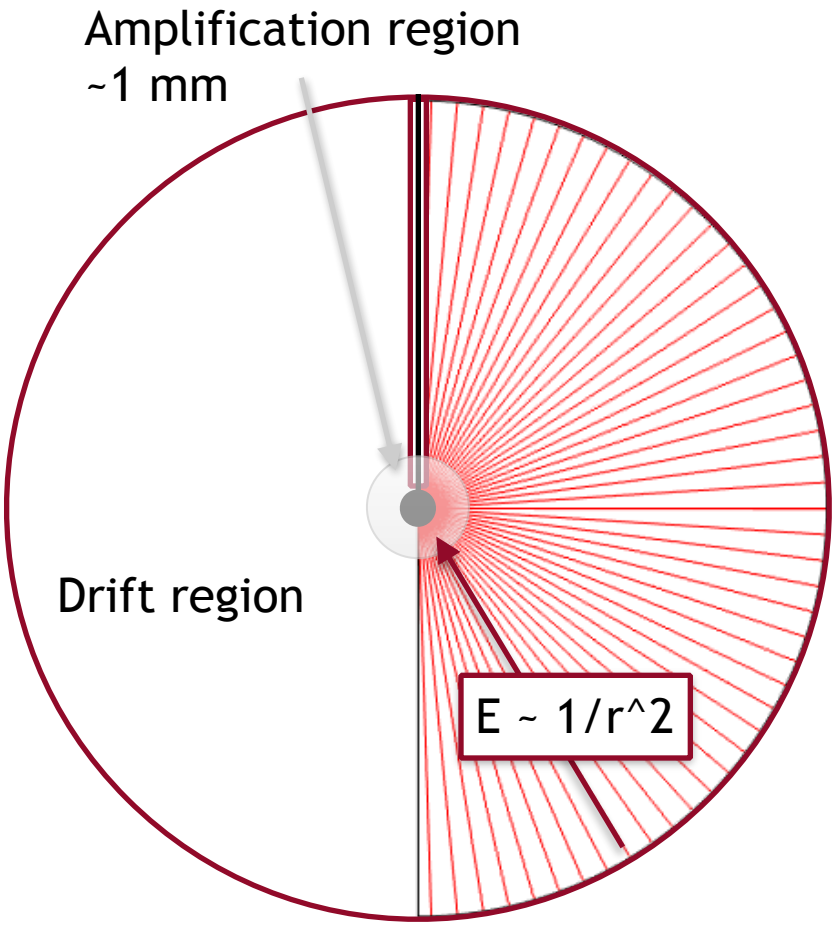
- Particles colliding with the gas release energy inside the detector as ionization. The resulting electrons drift towards the electrode, where they are amplified and detected. This is an “event”.



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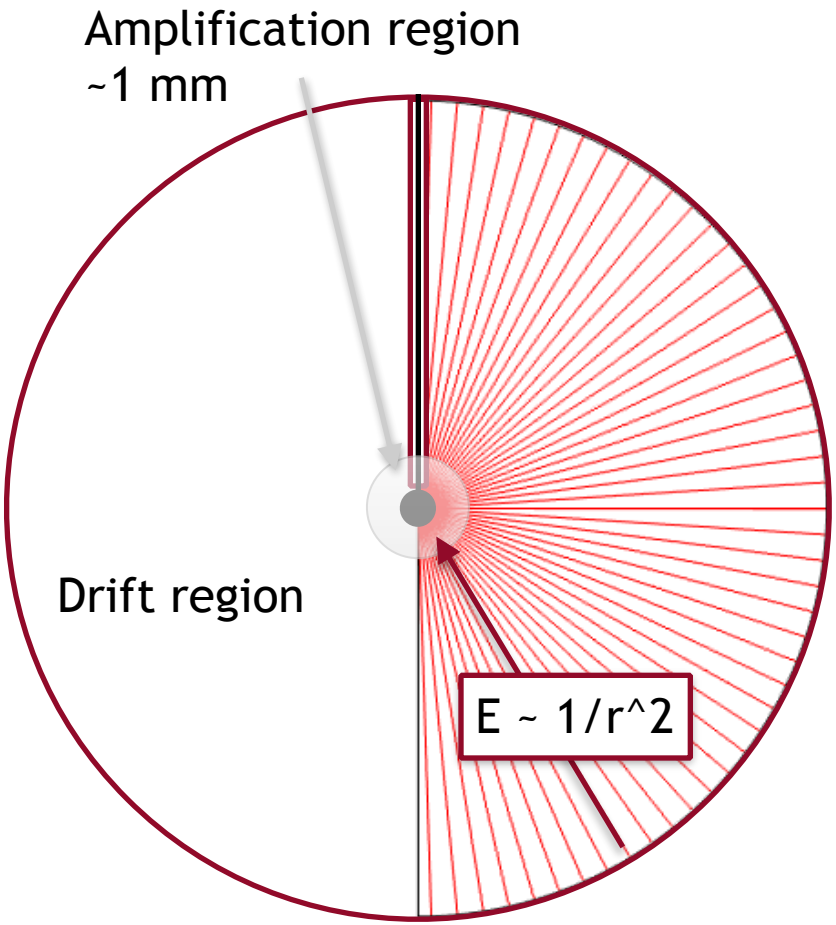
- An excess of events compared to the expected background would be indicative of new physics. Dark Matter?
  - Need very good background reduction!



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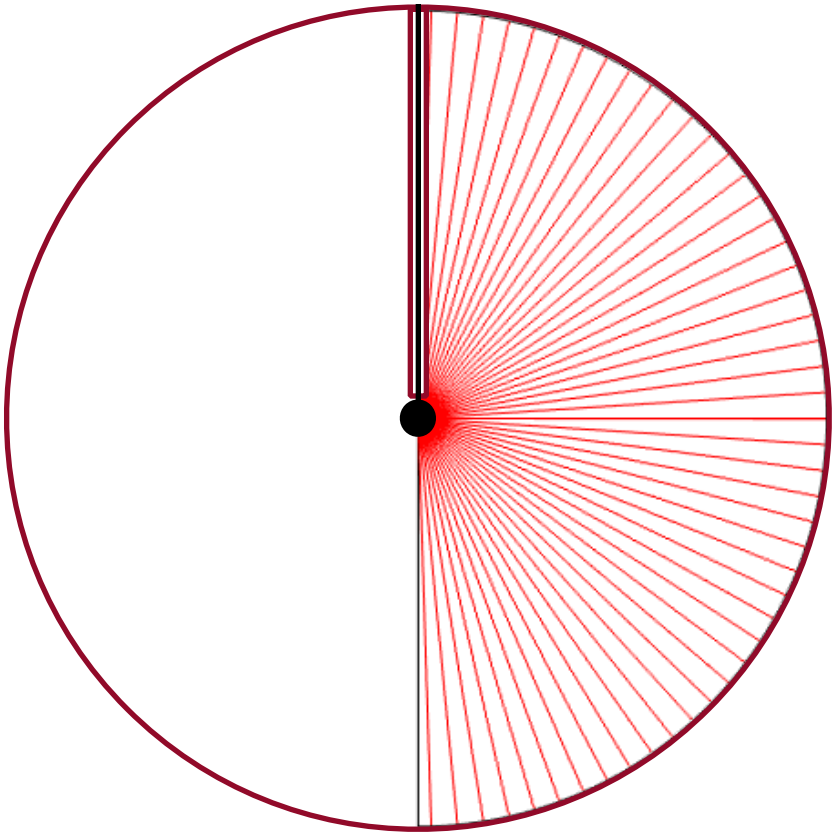
NEWS-G : Working principle



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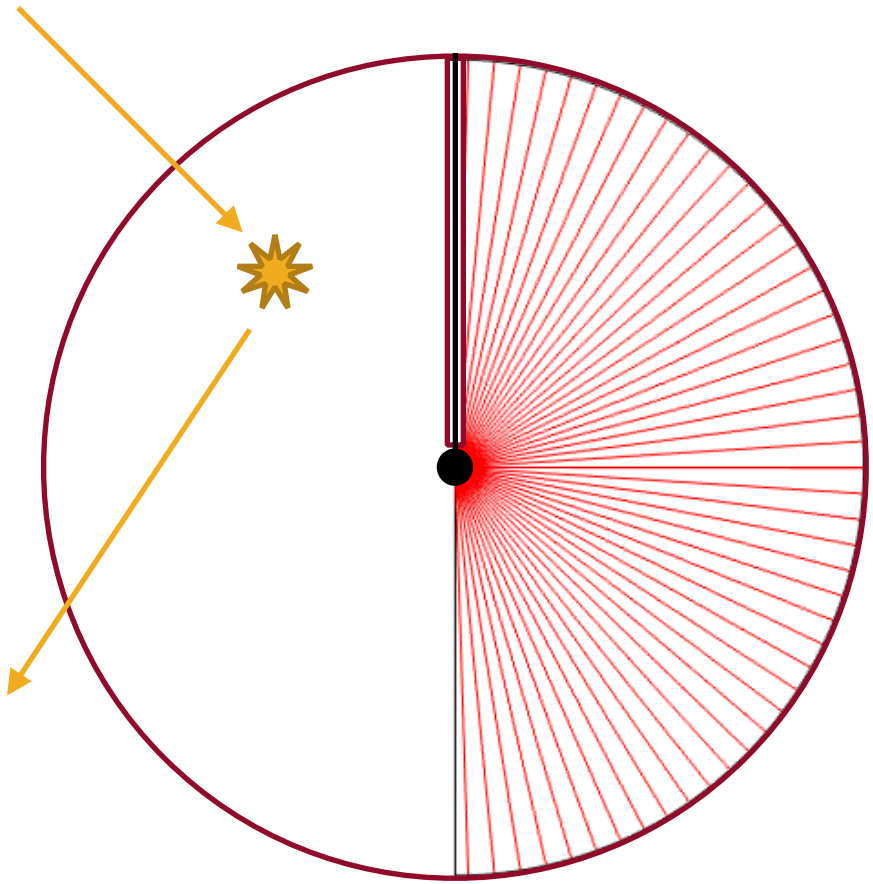
  - for Neon, average of 1 electron per 36eV



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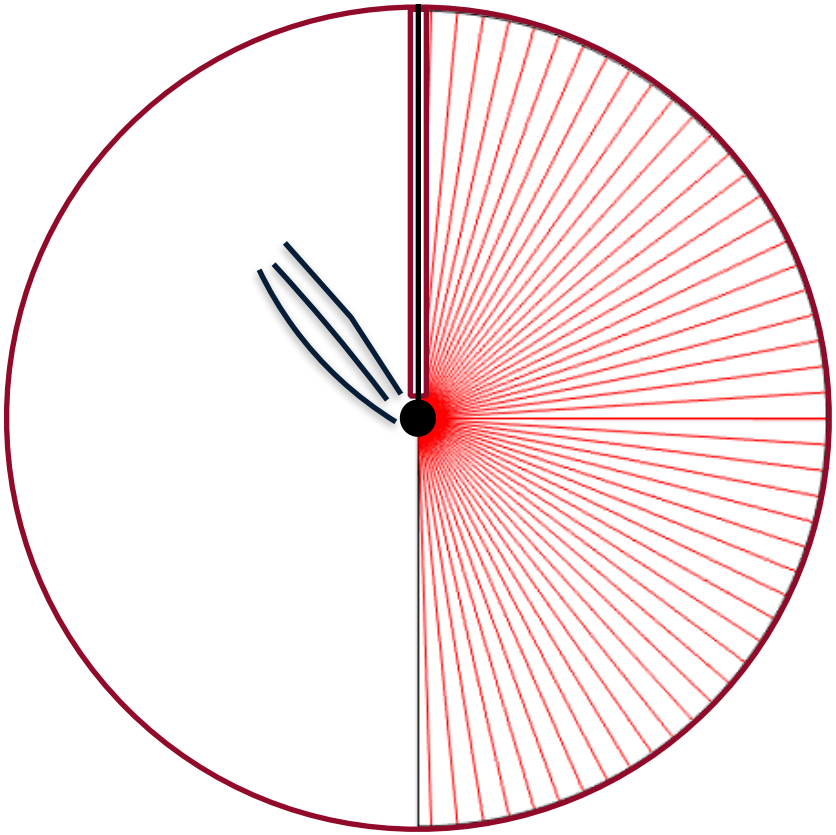

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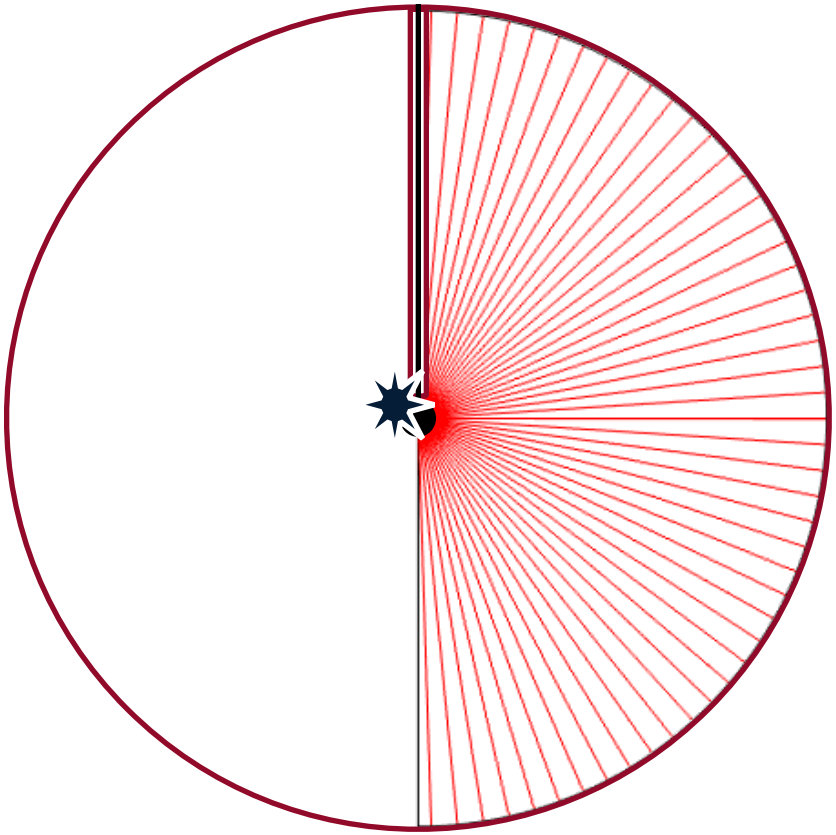

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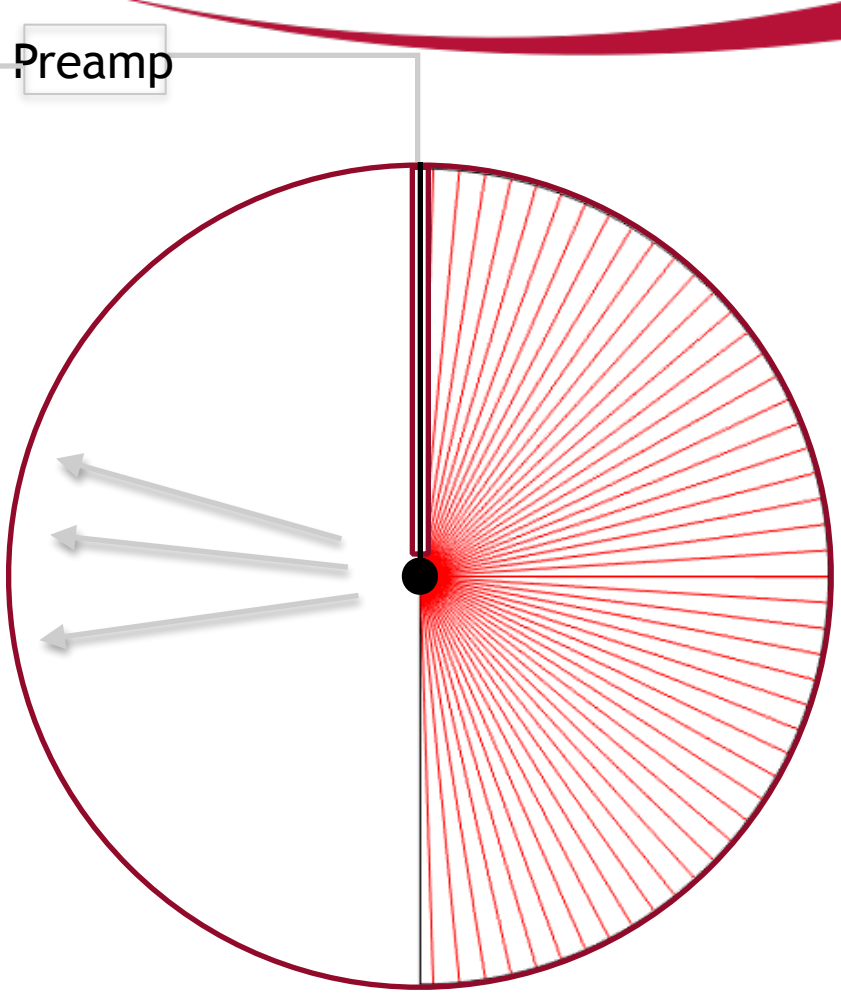
- Signal Formation
  - Current induced on electrode by ions
  - Current integrated with preamp, with ~ 50 μs decay



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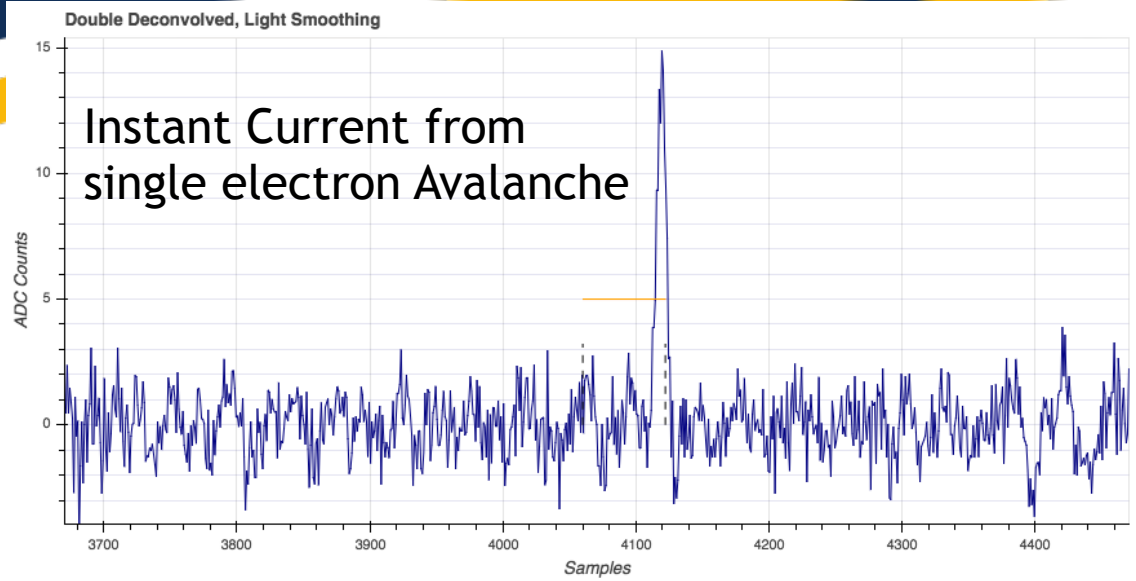

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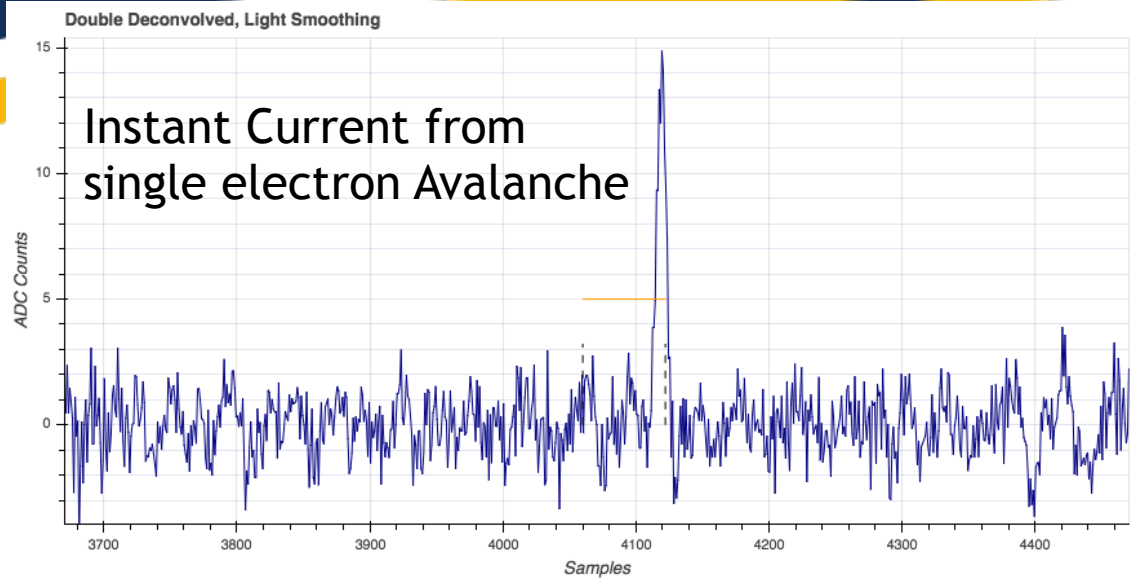
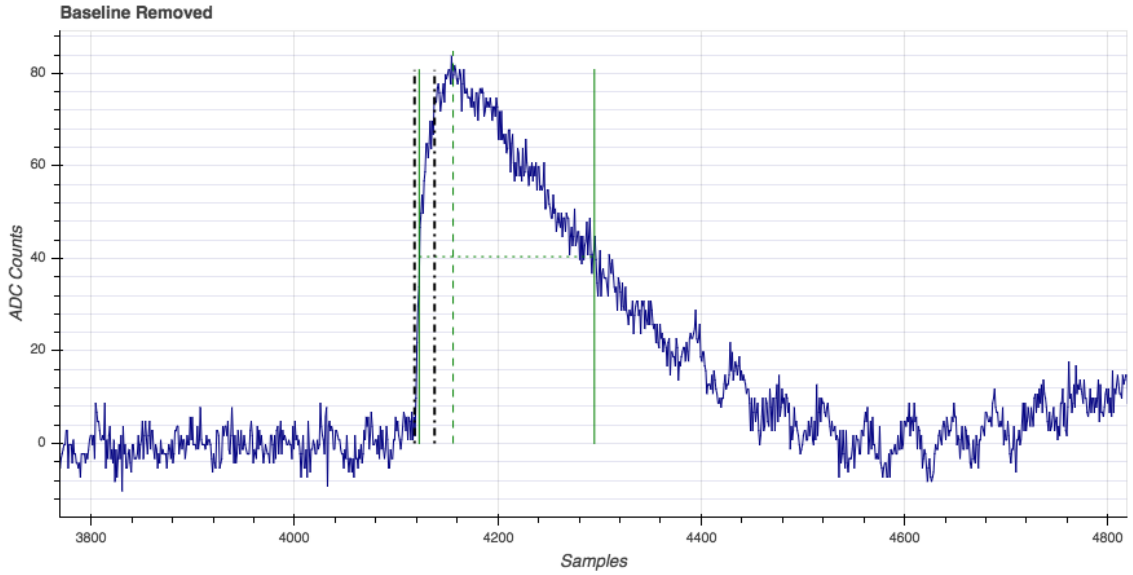


- Response function of detector gives the recorded pulse.



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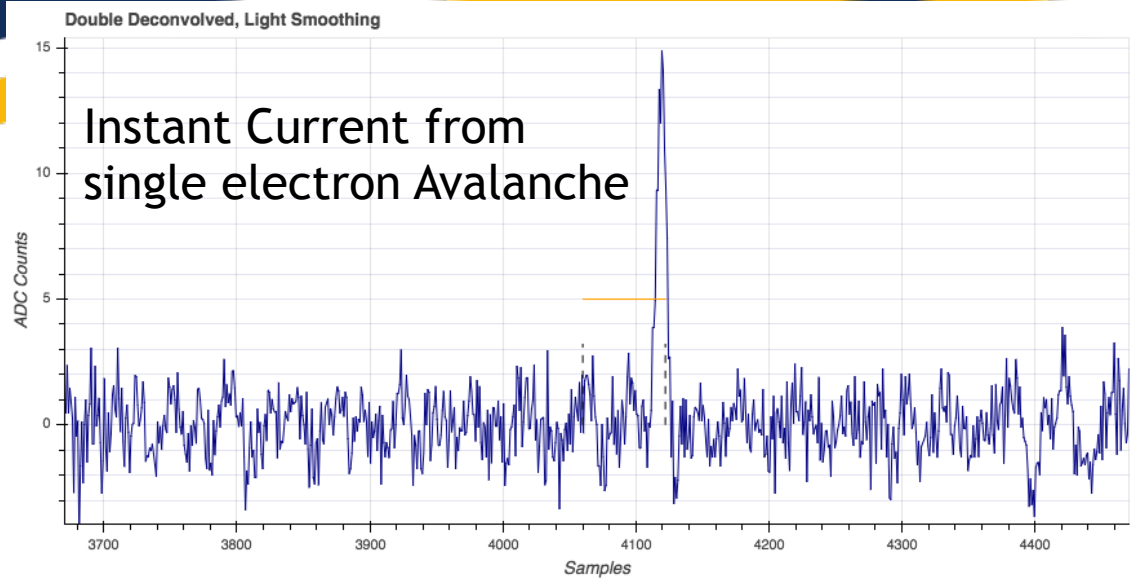

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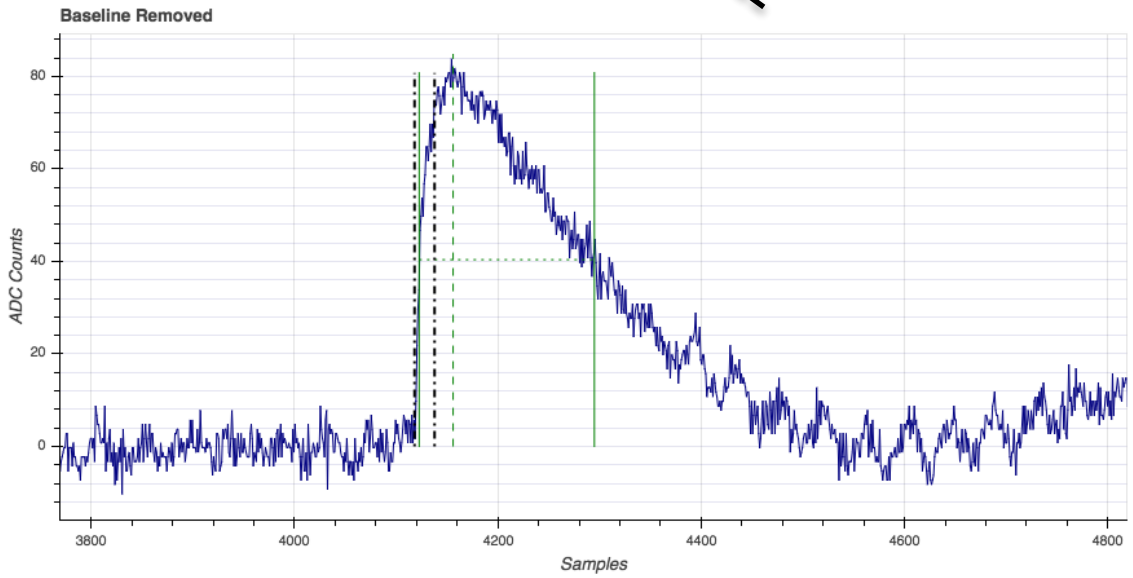

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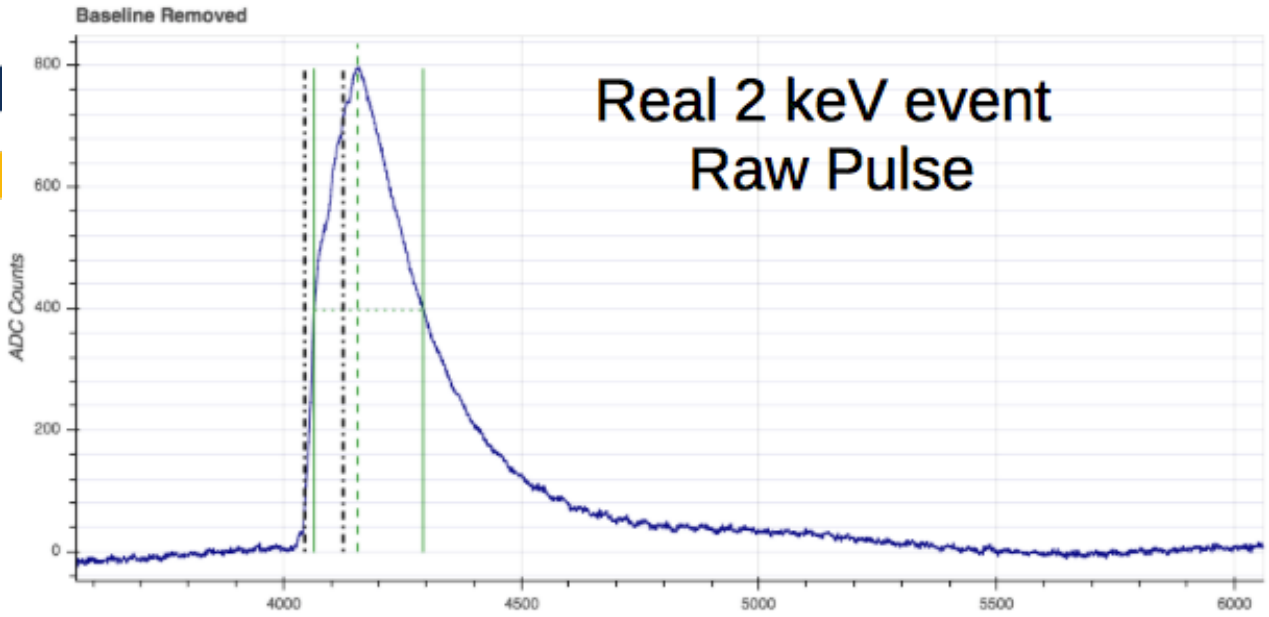

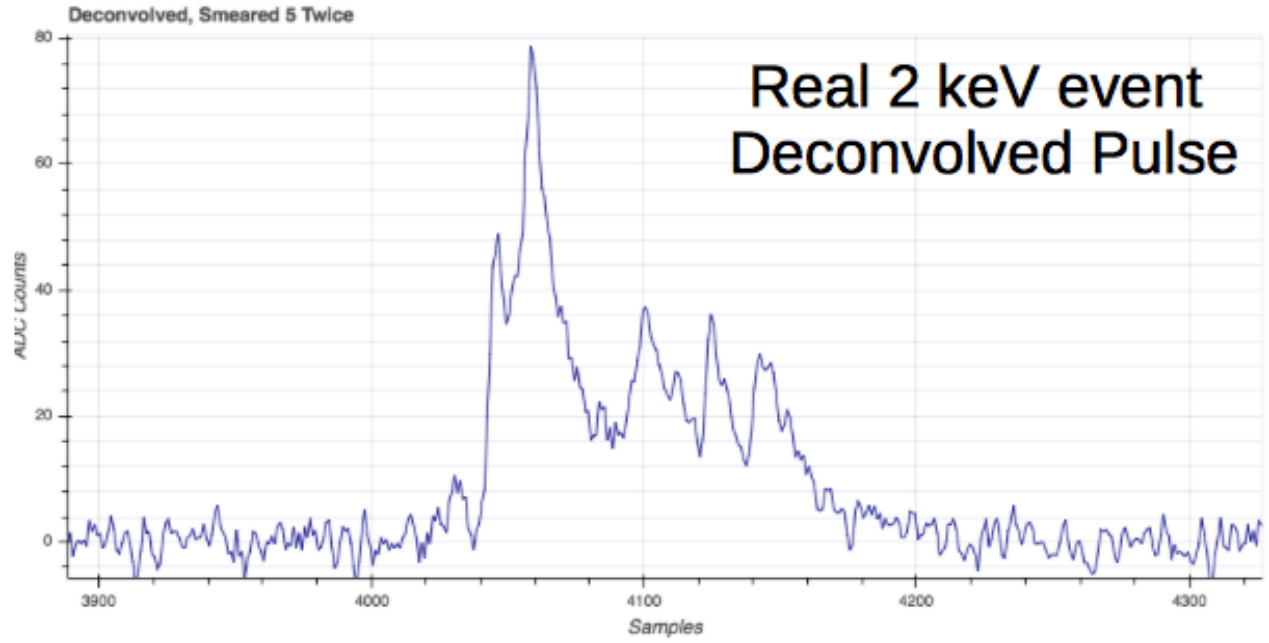

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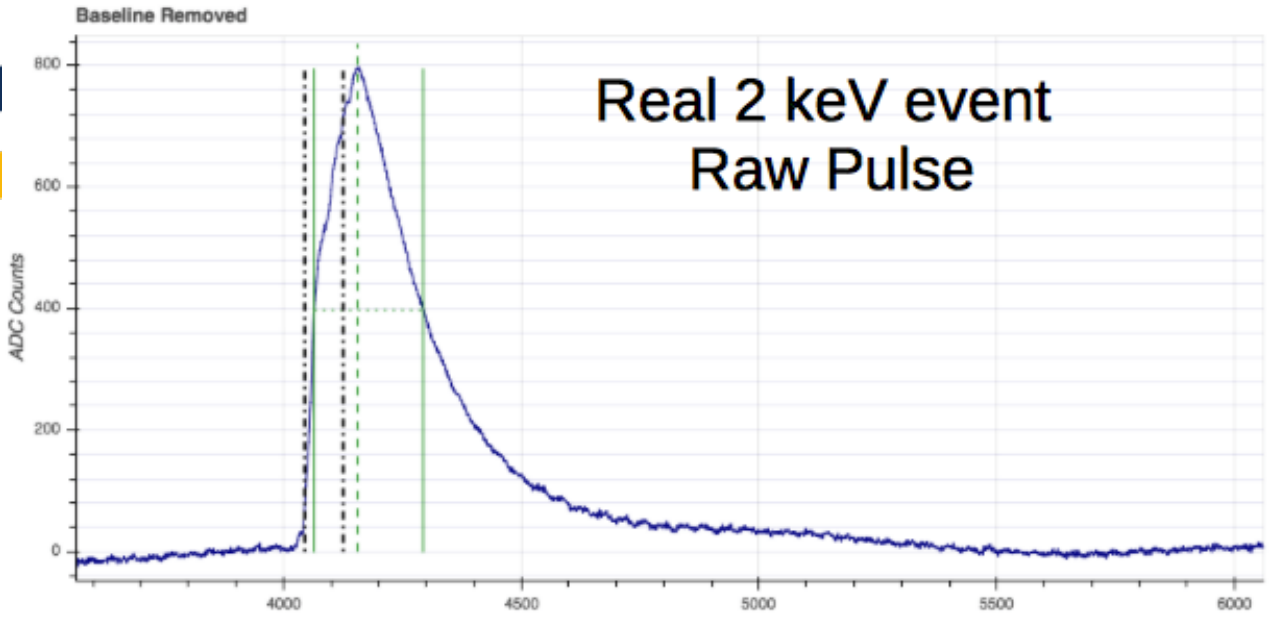
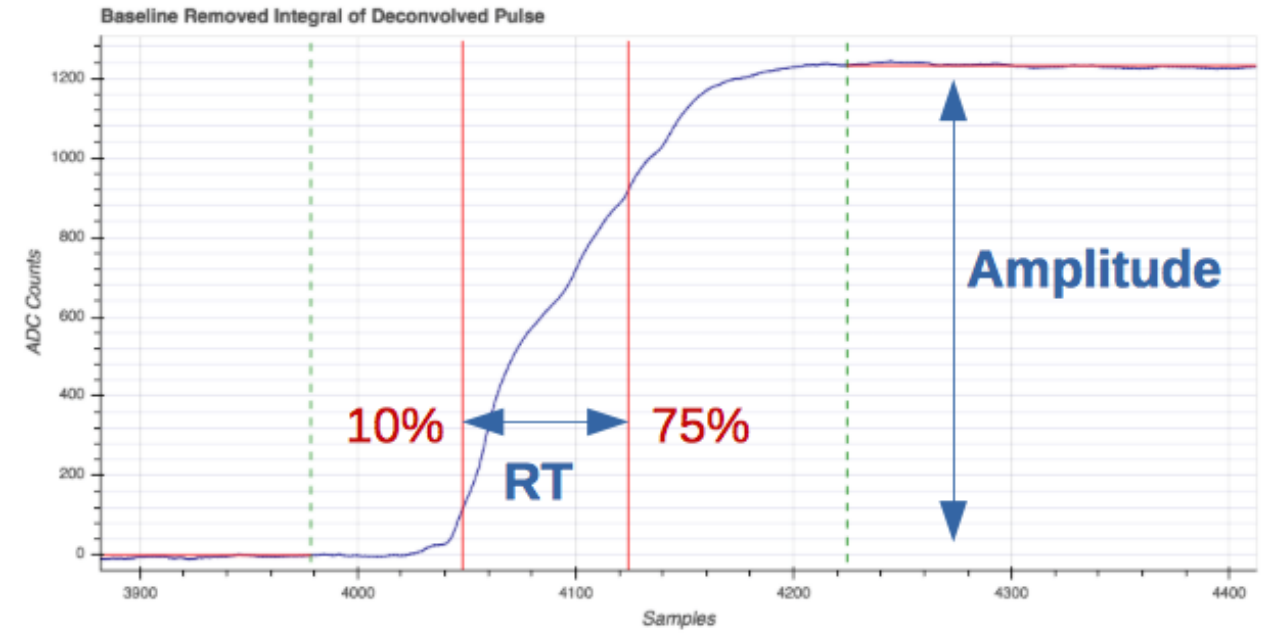
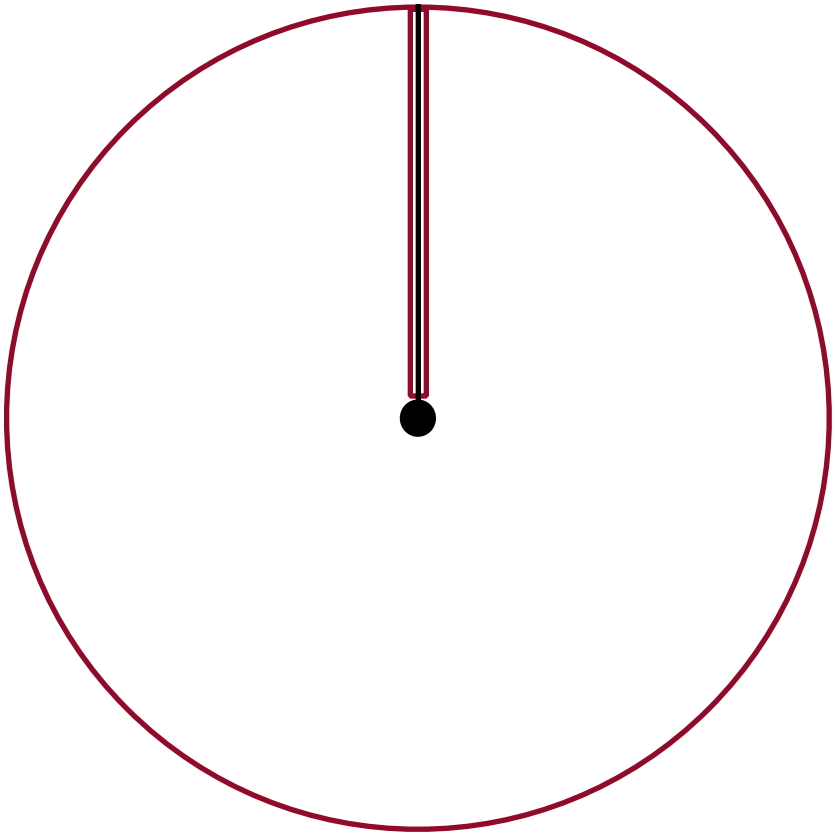




- Integrate deconvolved pulse to get final signal.
- Amplitude of final signal is estimator of event energy.
- Risetime of final signal is estimator of event position/type.

NEWS-G : Pulse Shape Discrimination



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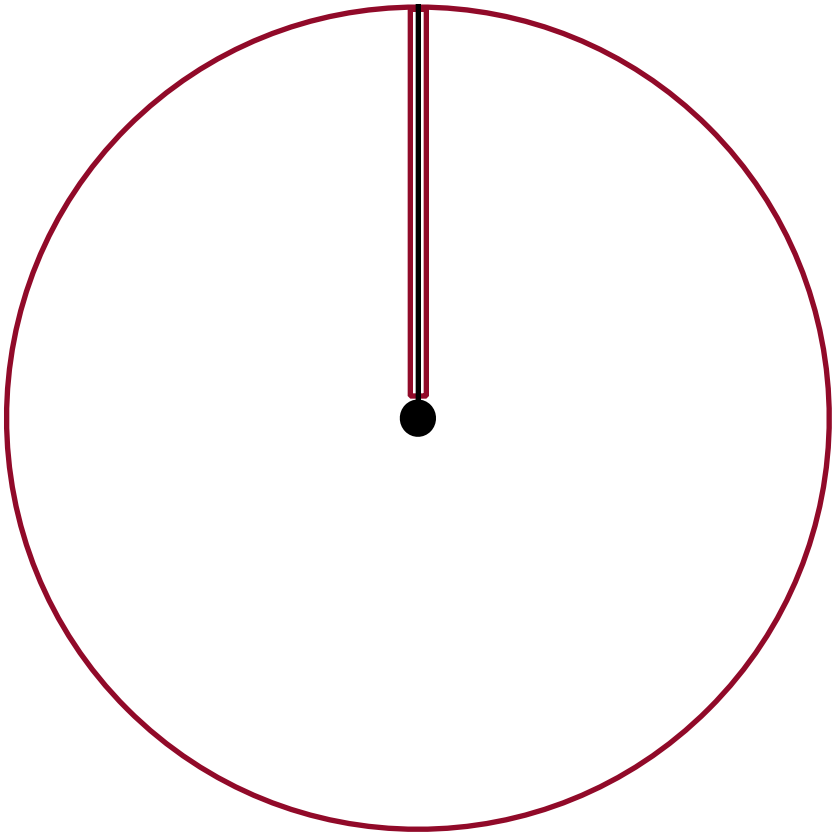
- Both drift and diffusion time increase with distance to the electrode.



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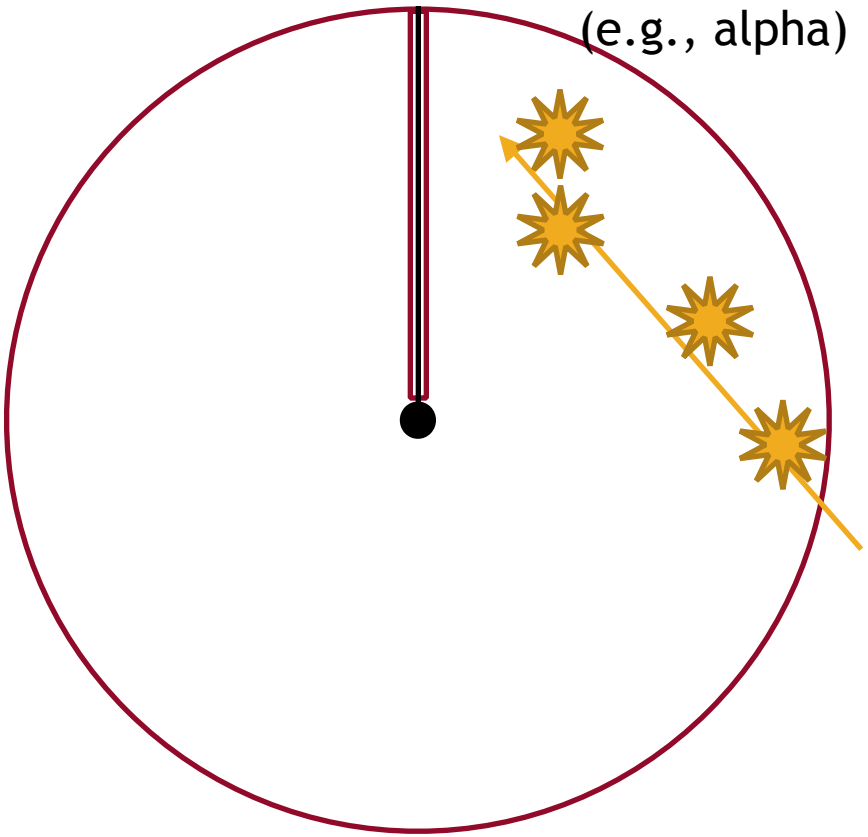

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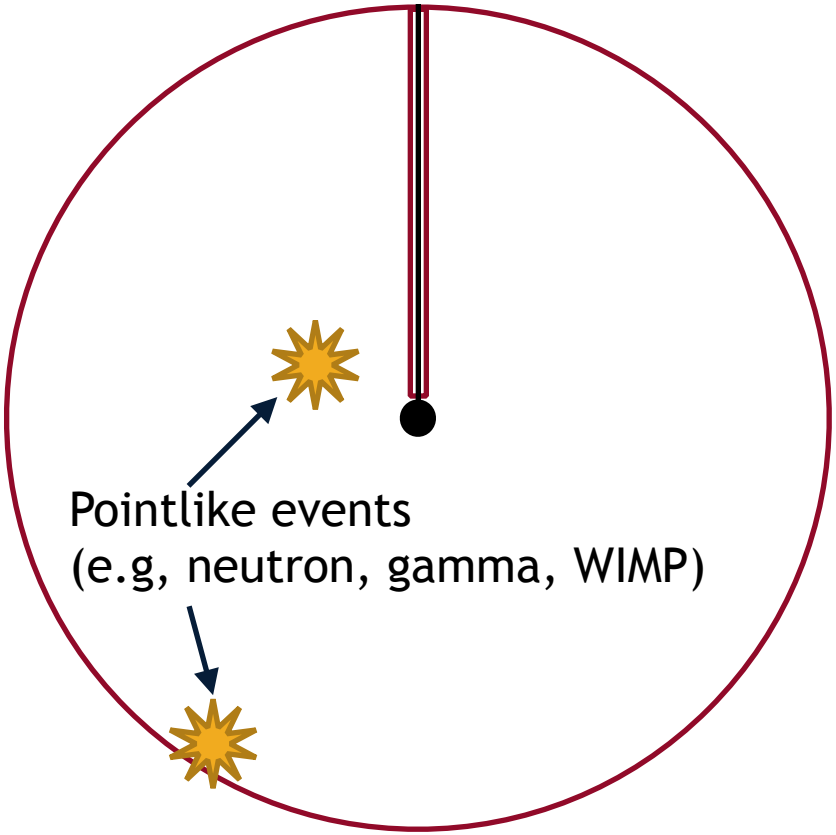

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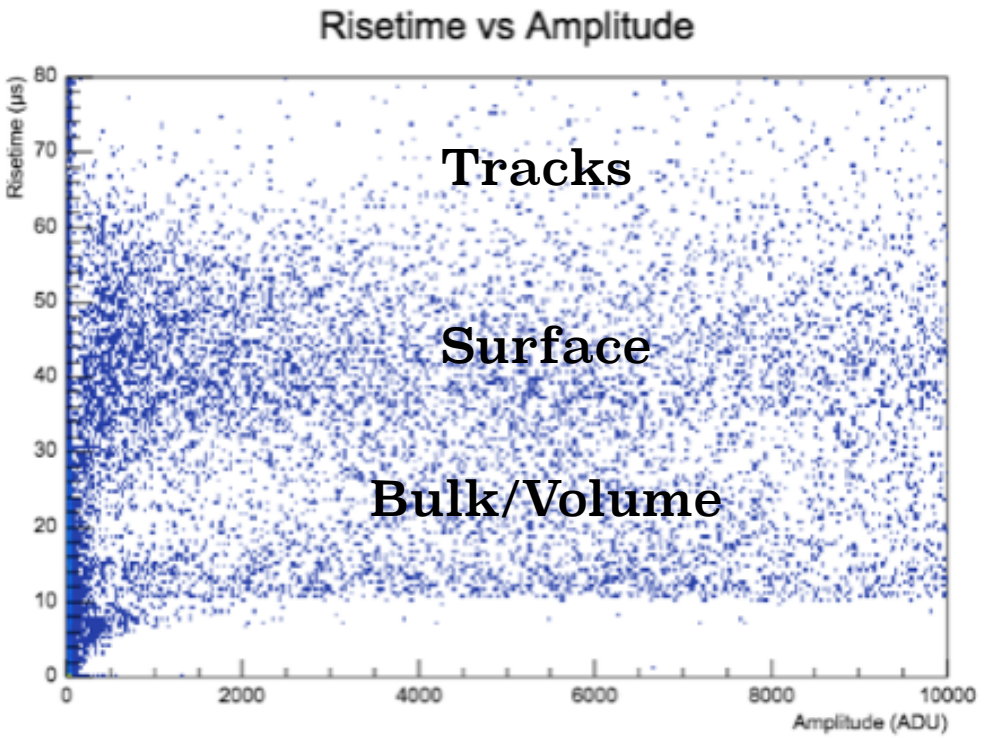
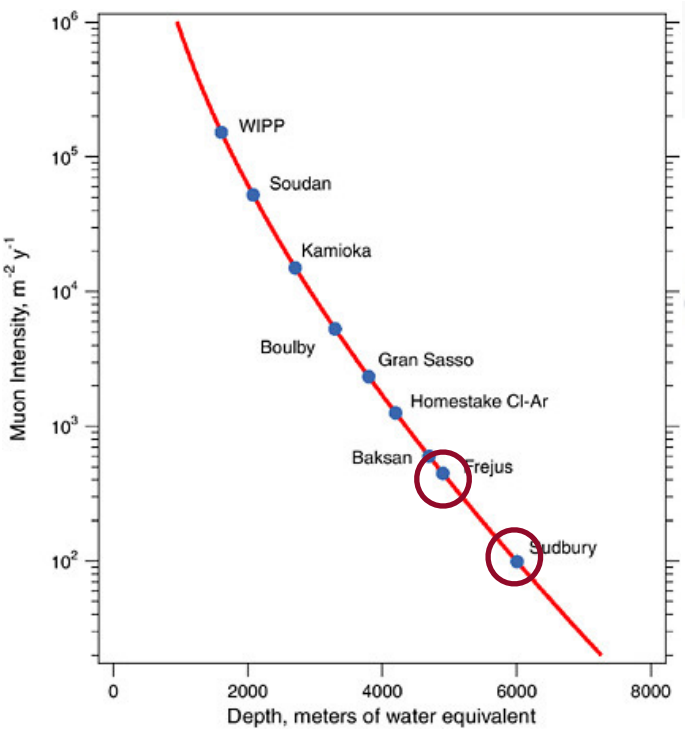
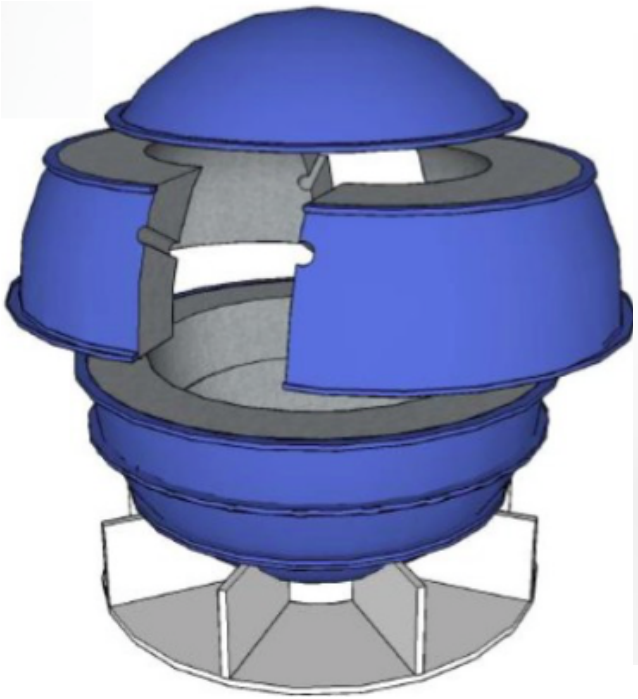


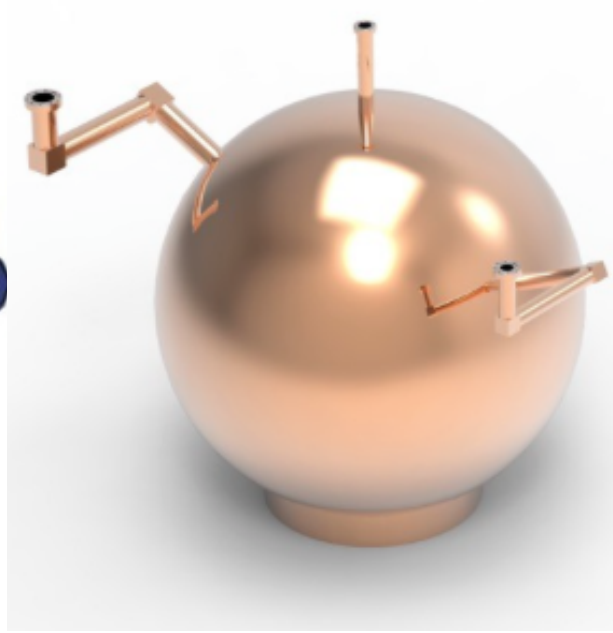
NEWS-G : Future at SNOLAB

Specifications for NEWS-SNO (compared to SEDINE, detector in LSM)

- 140 cm diameter (60cm), 10 bar of pressure (3bar).
- 25 cm of lead shielding (15cm), 34 cm of polyethylene shielding (28 cm), spherical shield (cubic shield).
- Cleaning of inside of sphere in de-radonized air (normal air), then isolate from outside (not isolated).
- Detector in SNOLab (in LSM, with ~ 4 times the muon flux of SNOLab).

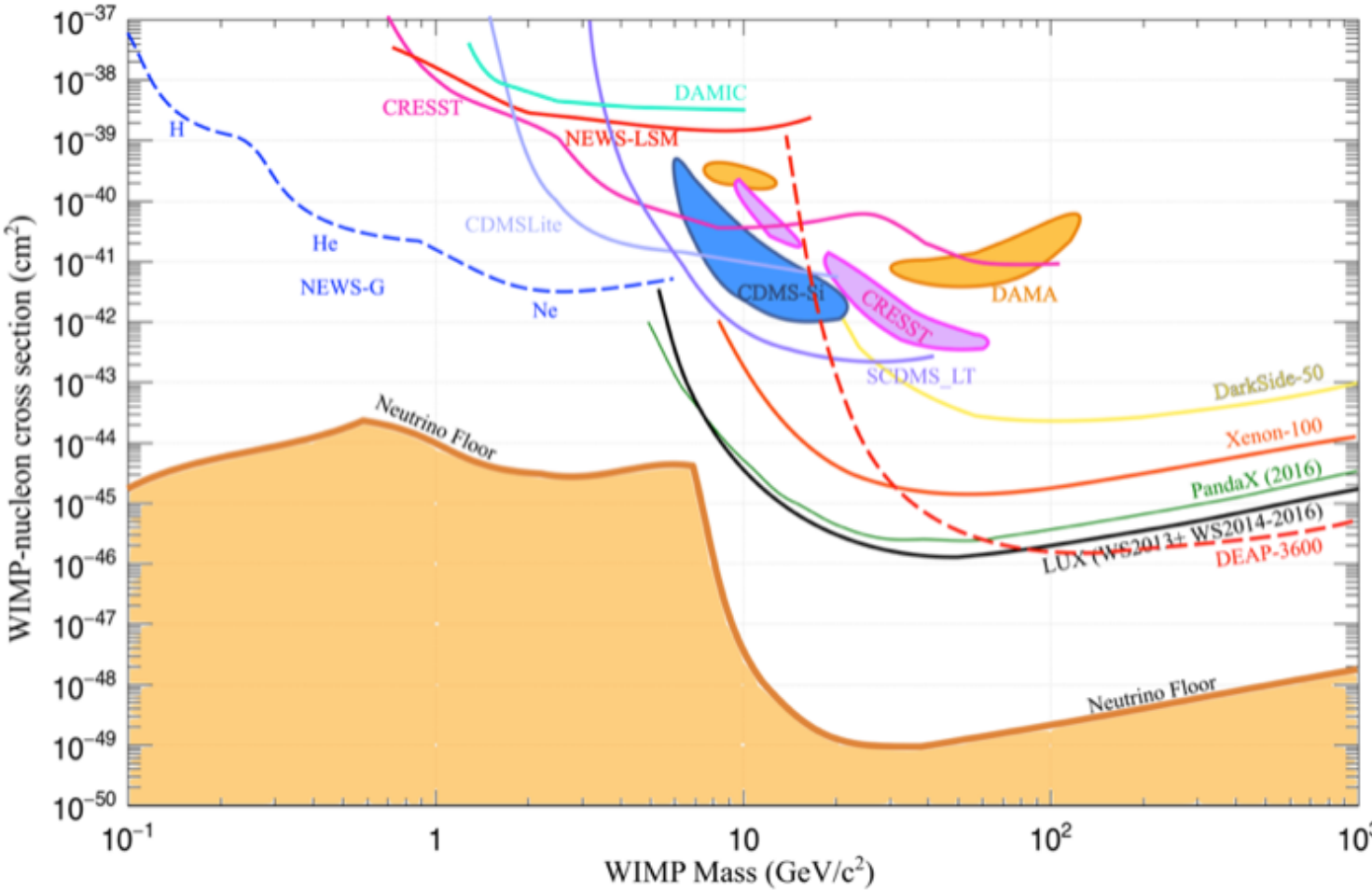




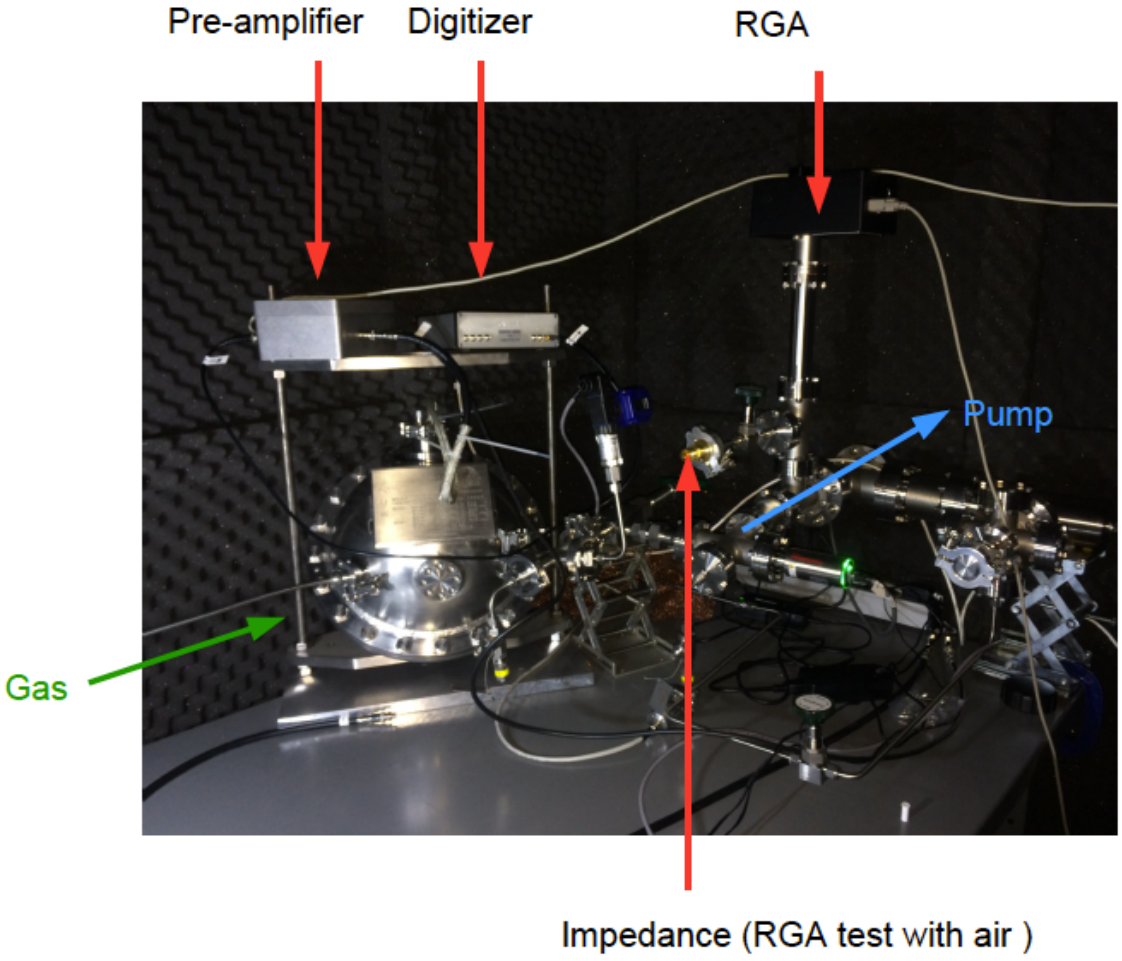


NEWS-G : Projected sensitivity

100 kg-day, 1 electron threshold



NEWS-G : Work at Queen's



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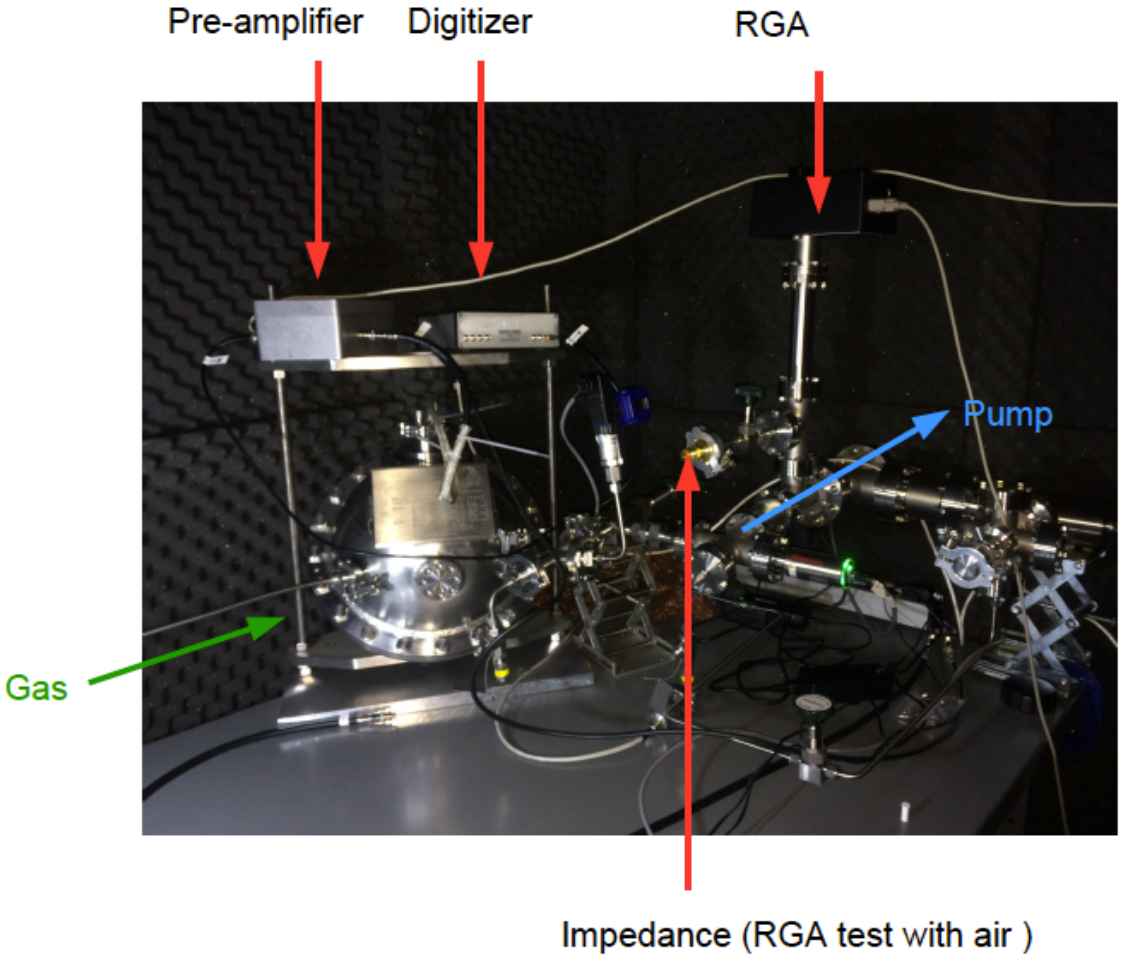
- Prototype spheres with 15, 30 and 50 cm in diameter (pictured: S30) :



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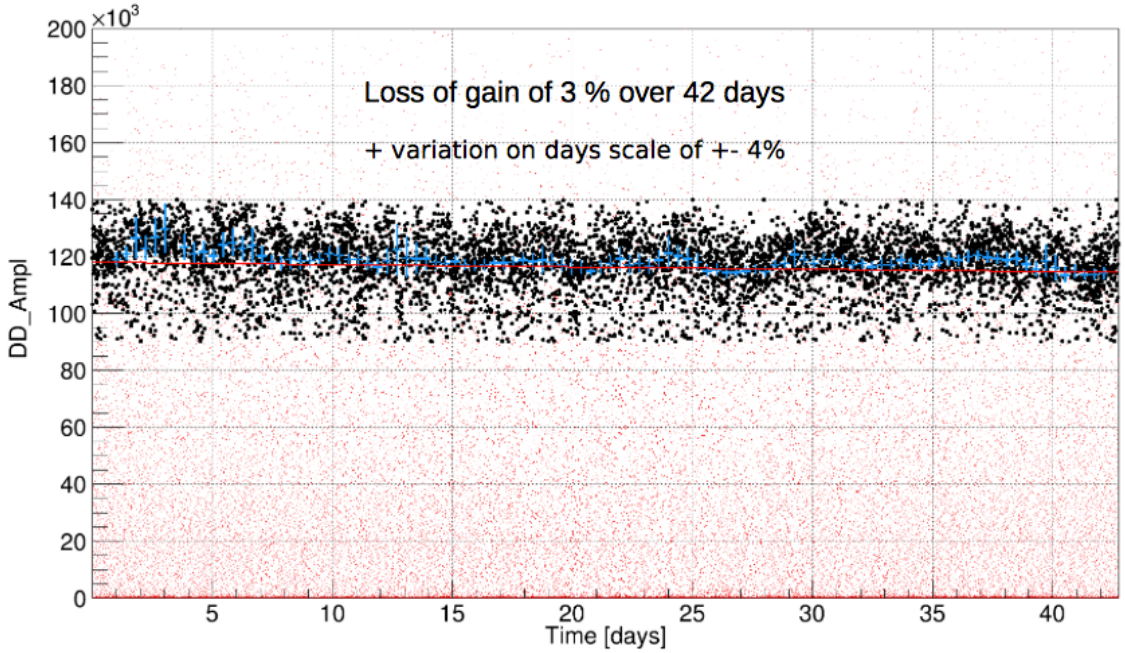

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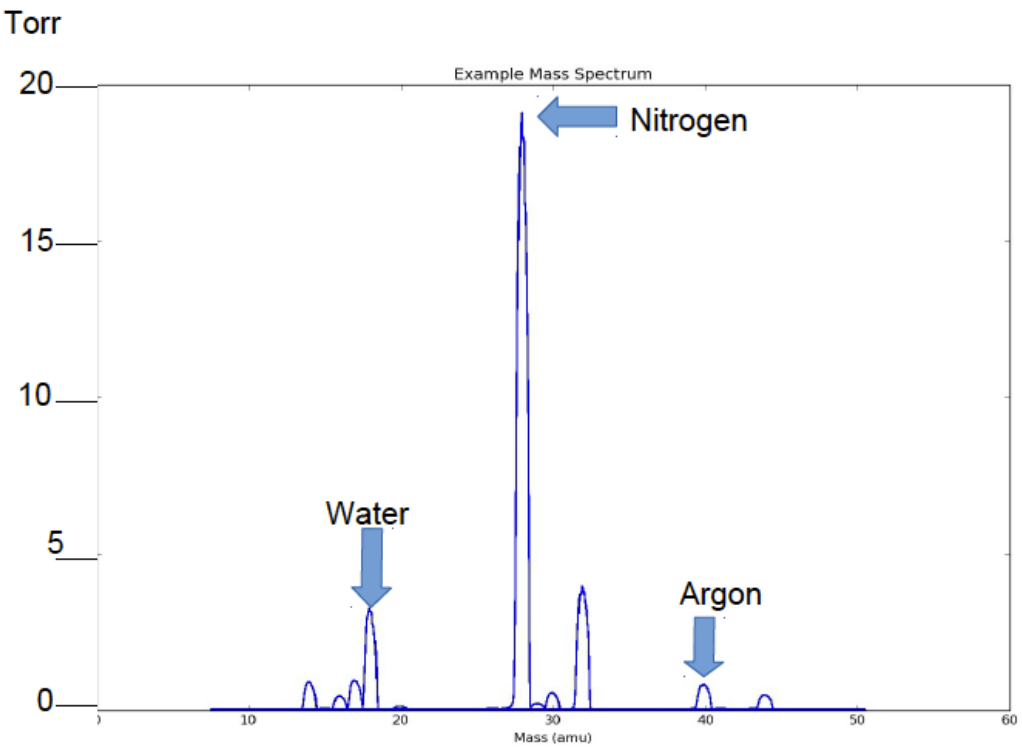

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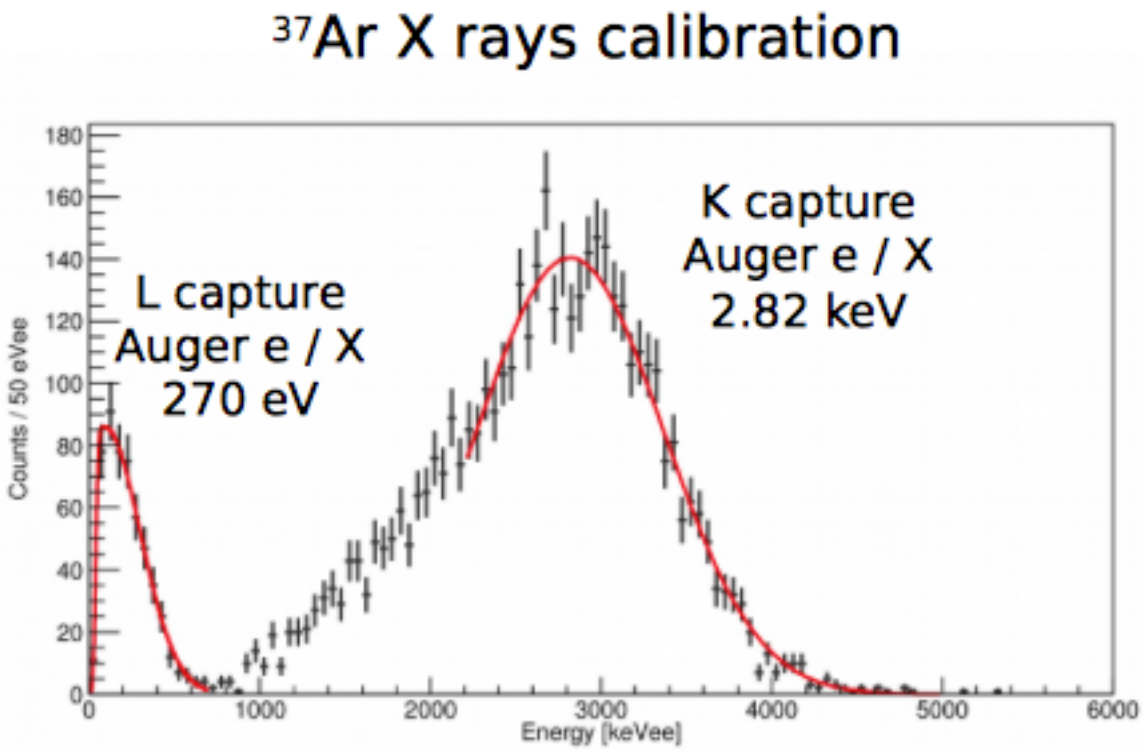

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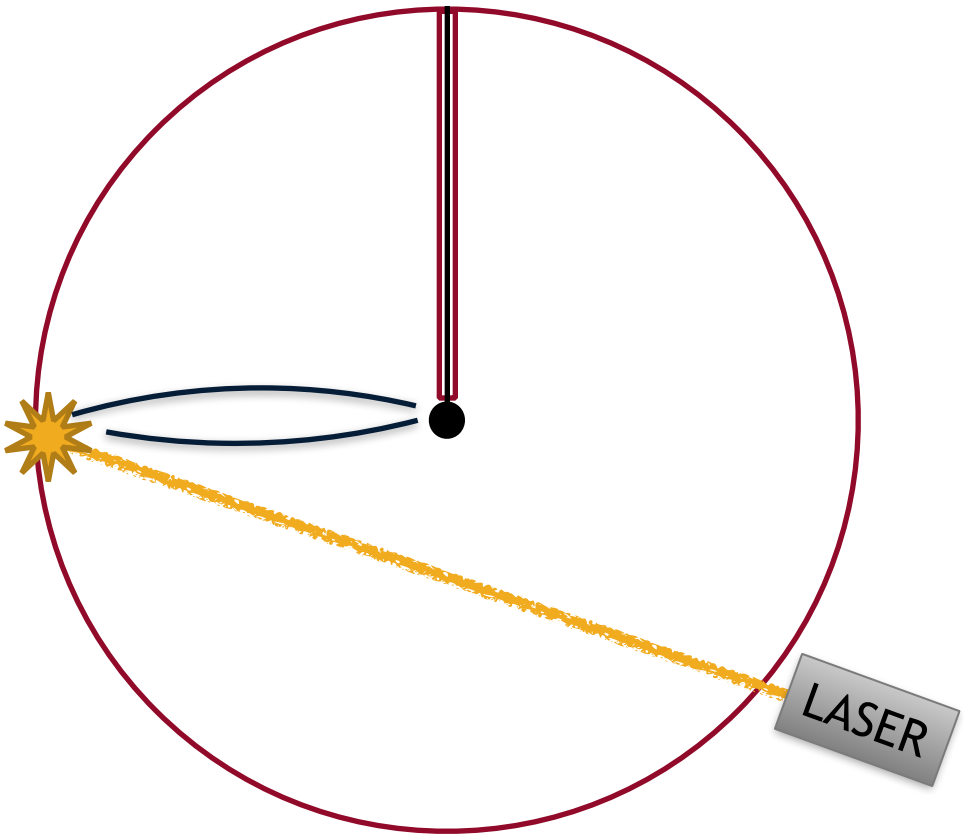

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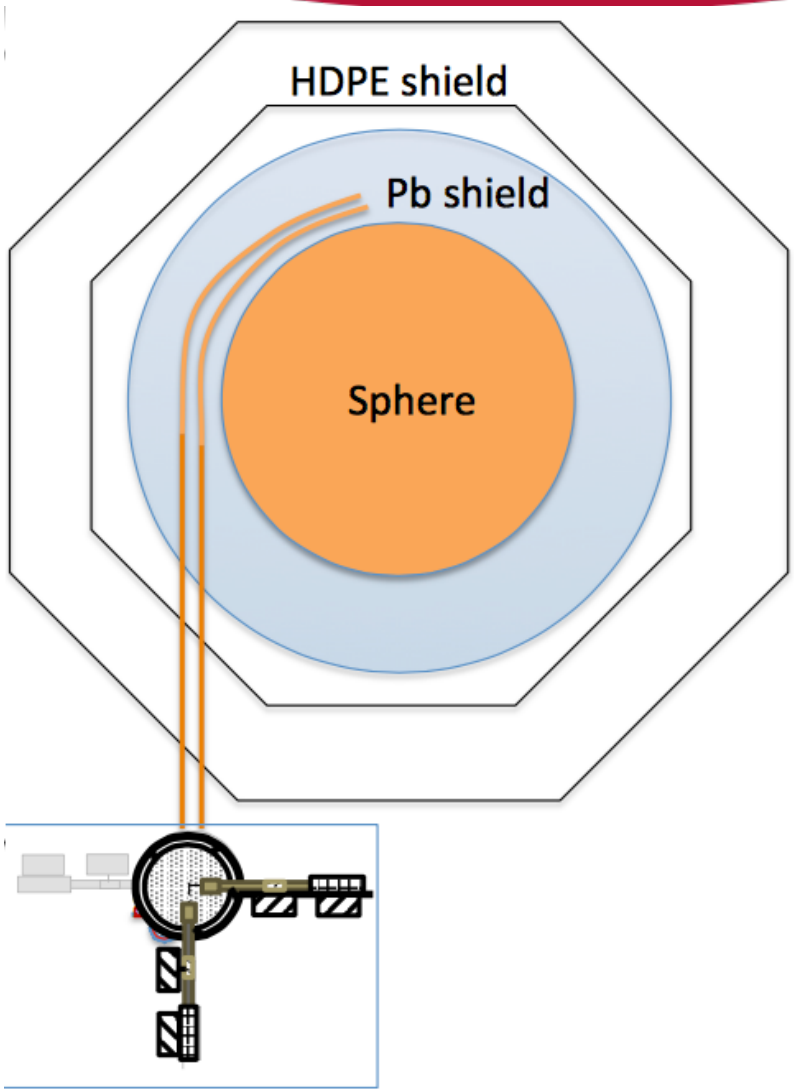

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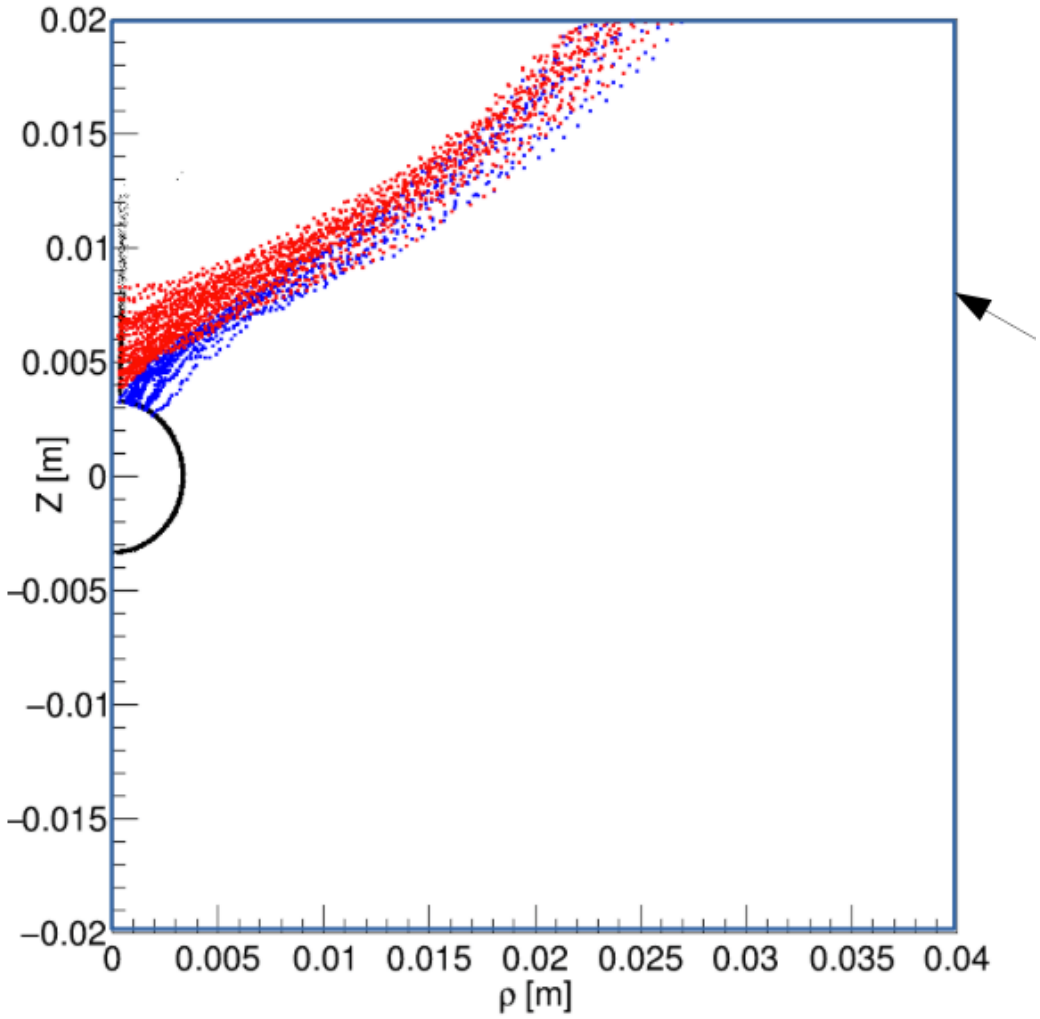

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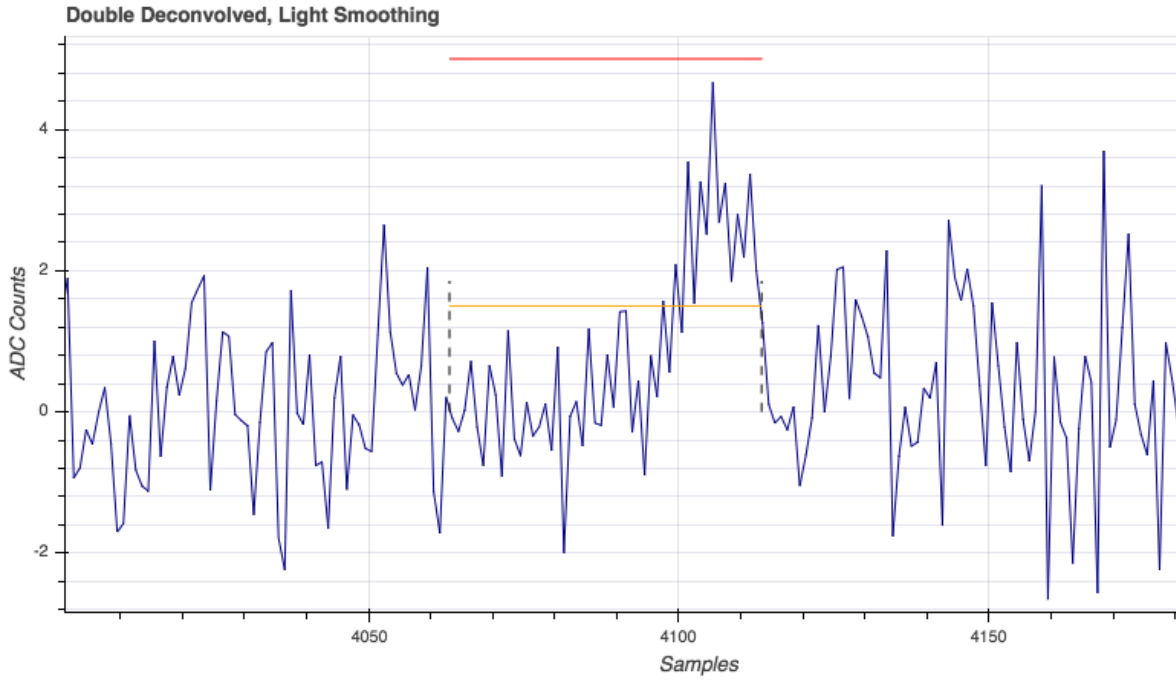

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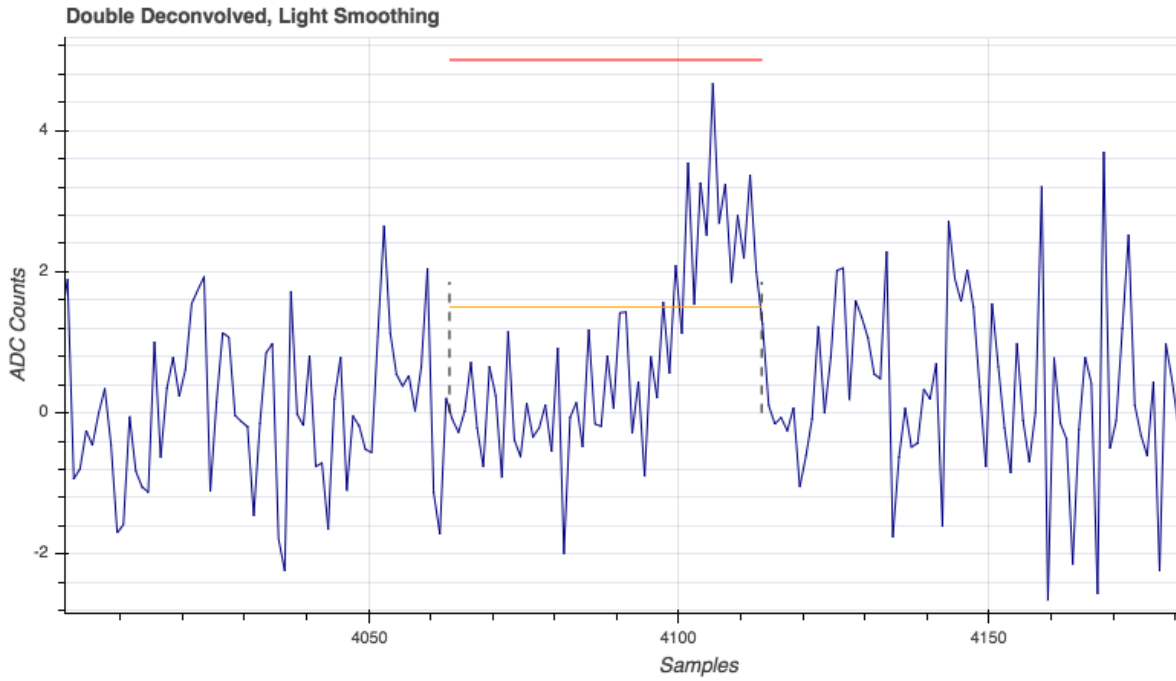
  - Etc



Summary

- NEWS-G detects particle interactions via their ionization signal.
- The detector can discriminate events based on their position and length.
- Already competitive for low-mass WIMP search.
- Leading results expected for incoming NEWS-SNO.

- Lots of work remain to be done!

Thank you for your attention!

Collaboration as of nov 10th

- **Queen's University Kingston –** G Gerbier, P di Stefano, R Martin, T Noble, A Brossard, A Kamaha, P Vasquez dS, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis
- **IRFU** (Institut de Recherches sur les Lois fondamentales de l'Univers)**/CEA Saclay** -I Giomataris, M Gros, C Nones, I Katsioulas, T Papaevangelou, JP Bard, JP Mols, XF Navick,
  - Sensor/rod (low activity, optimization with 2 electrodes)
  - Electronics (low noise preamps, digitization, stream mode)
  - DAQ/soft
- **LSM** (Laboratoire Souterrain de **Modane**), IN2P3, U of Chambéry - F Piquemal, M Zampaolo, A DastgheibiFard
  - Low activity archeological lead
  - Coordination for lead/PE shielding and copper sphere
- **Thessaloniki University –** I Savvidis, A Leisos, S Tzamarias, C Elefteriadis, L Anastasios
  - Simulations, neutron calibration
  - Studies on sensor
- **LPSC** (Laboratoire de Physique Subatomique et Cosmologie) **Grenoble** - D Santos, JF Muraz, O Guillaudin
  - Quenching factor measurements at low energy with ion beams
- **Technical University Munich –** A Ulrich, T Dandl
  - Gas properties, ionization and scintillation process in gaz
- **Pacific National Northwest Lab–** E Hoppe, D Asner
  - Low activity measurements, Copper electroforming
- **RMCC** (Royal Military College Canada) **Kingston –** D Kelly, E Corcoran
  - 37 Ar source production, sample analysis
- **SNOLAB –Sudbury –** P Gorel
  - Calibration system/slow control
- **Associated lab : TRIUMF** - F Retiere
  - Future R&D on light detection, sensor

Nov 2016

Backup slides

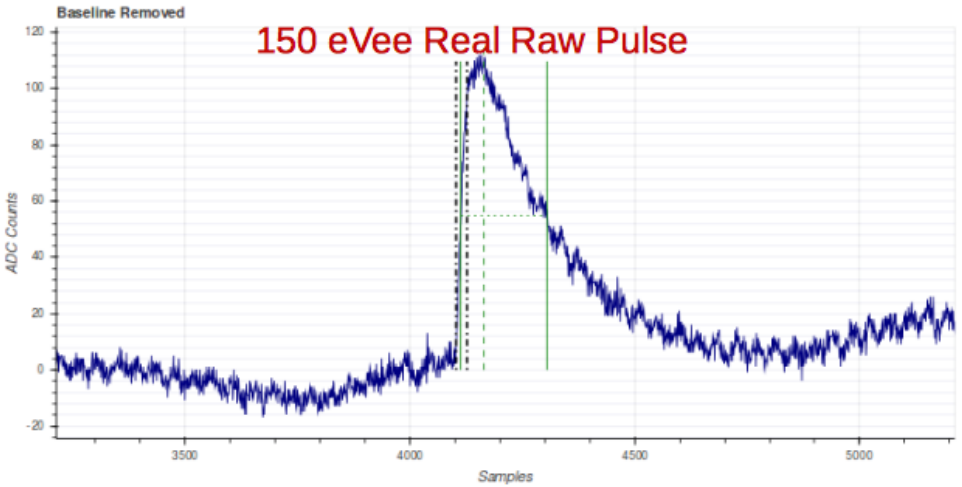
NEWS-G : Simulations

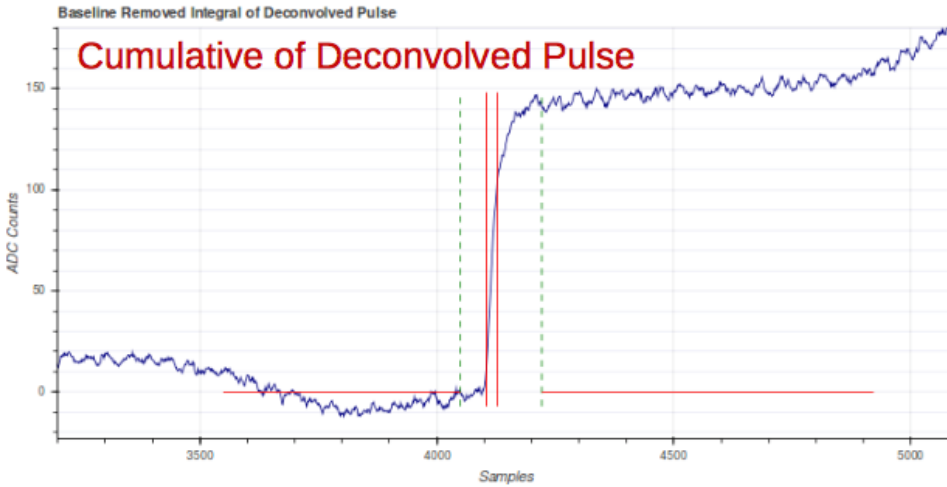
- Through understanding of physics of detector, can simulate pulses (starting from an energy and a position) and apply same analysis on them.

- Comparison of simulations with data allows optimal choice of Region of Interest and further understanding of data and results.
  - e.g., compare simulated neutron events with neutron calibration run, or apply Boosted Decision Tree method to select conservative optimized RoI.

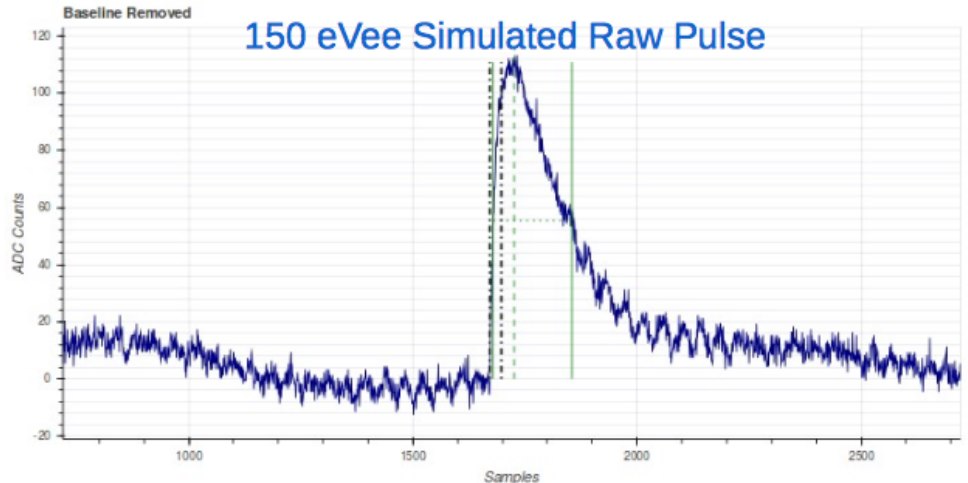
NEWS-G : Simulations (event)

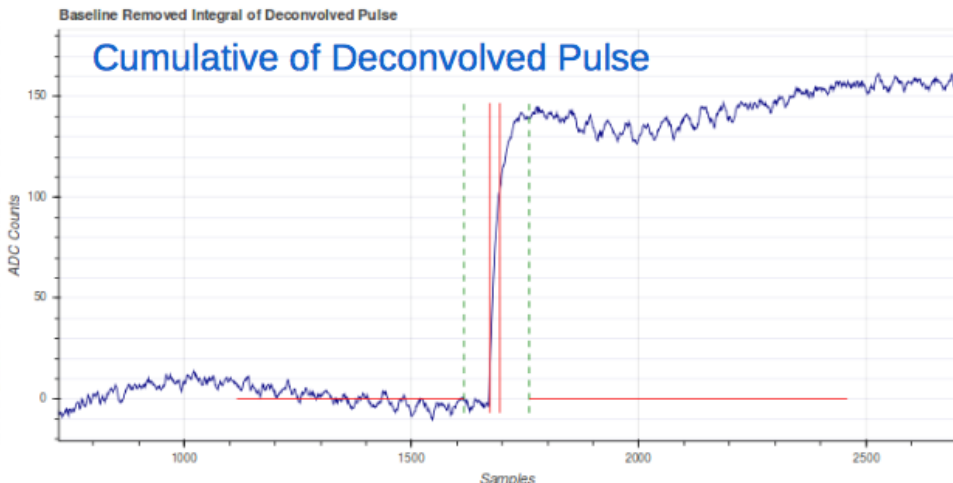
Data



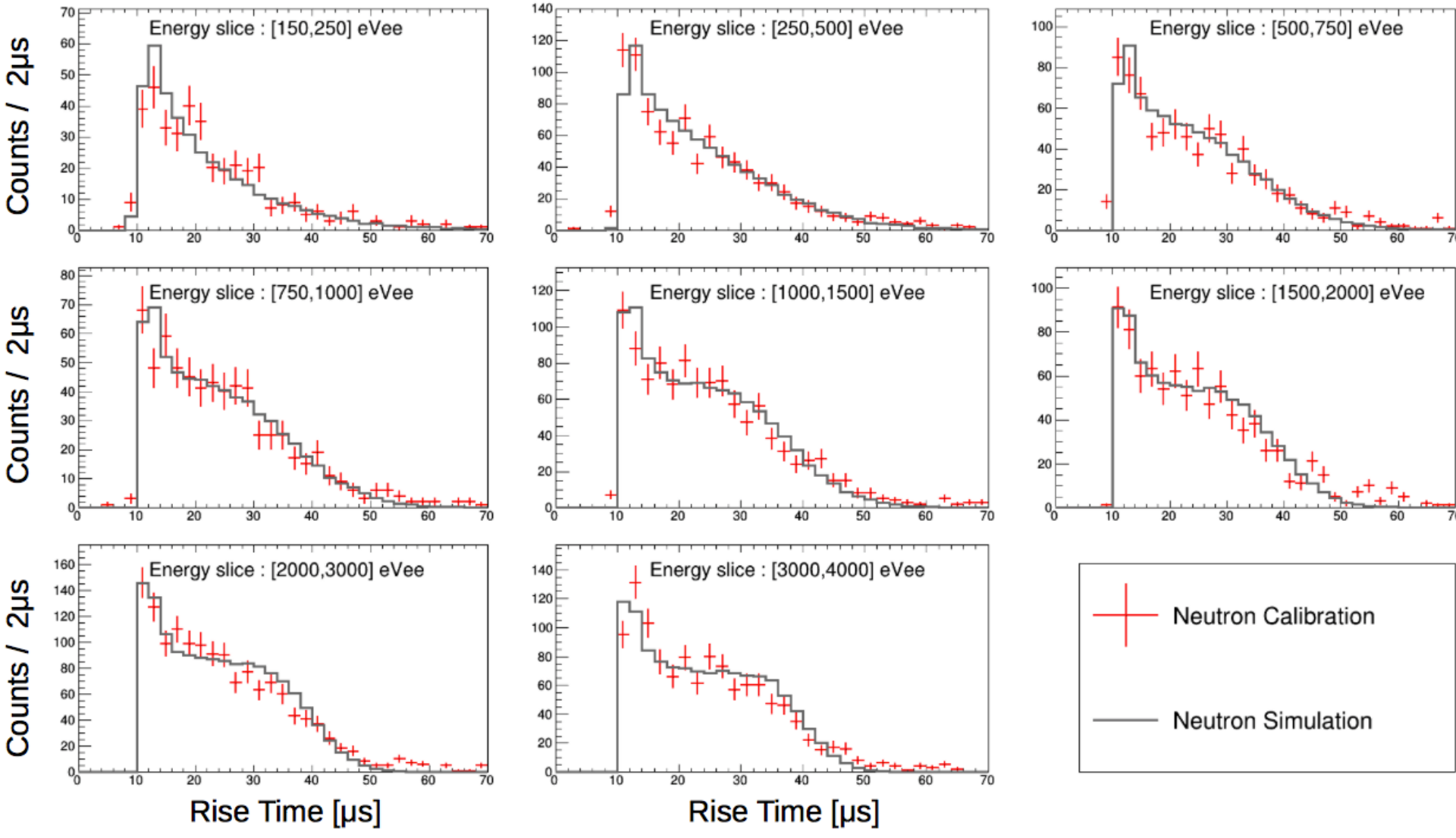


Simulation



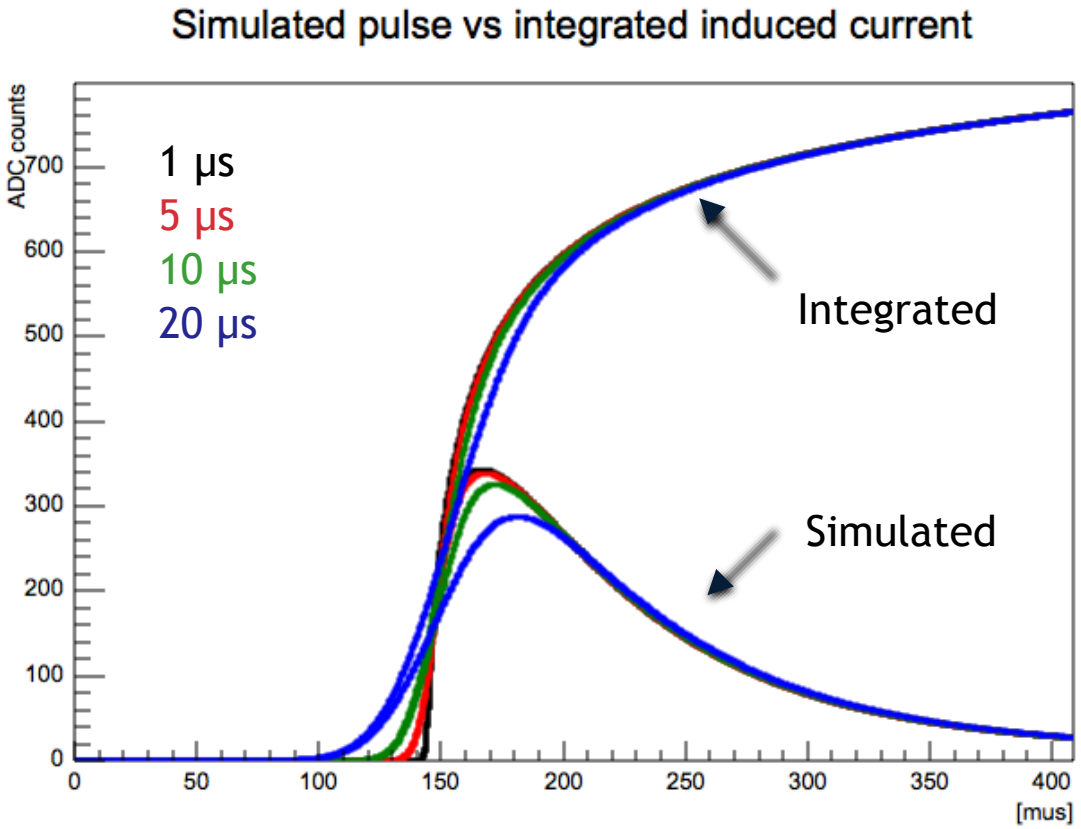


NEWS-G : Simulations (run)



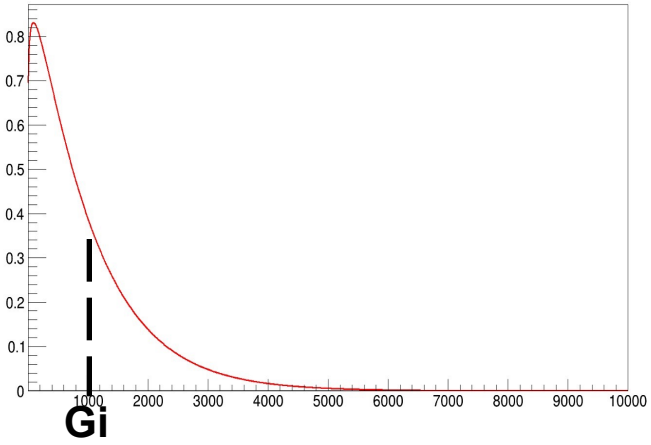
Pulse Formation : Ballistic Deficit

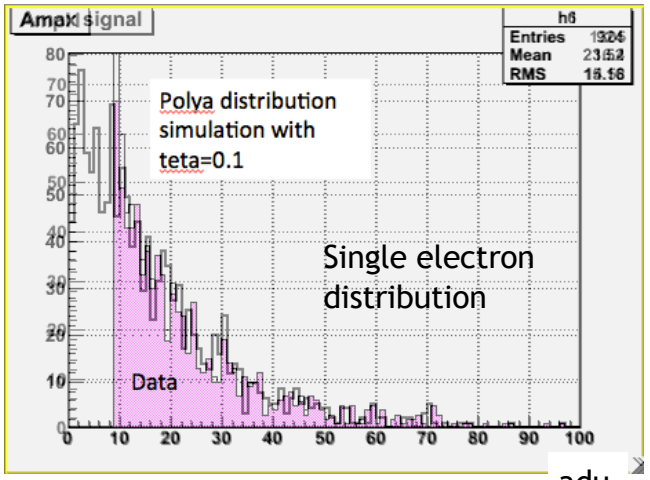
- Characteristic shape of all volume events
- Ballistic deficit: at fixed energy, the longer the diffusion time, the smaller the height of the pulse



Polya distribution

Polya distribution: $\theta = 0.1$ & $\overline{G}$





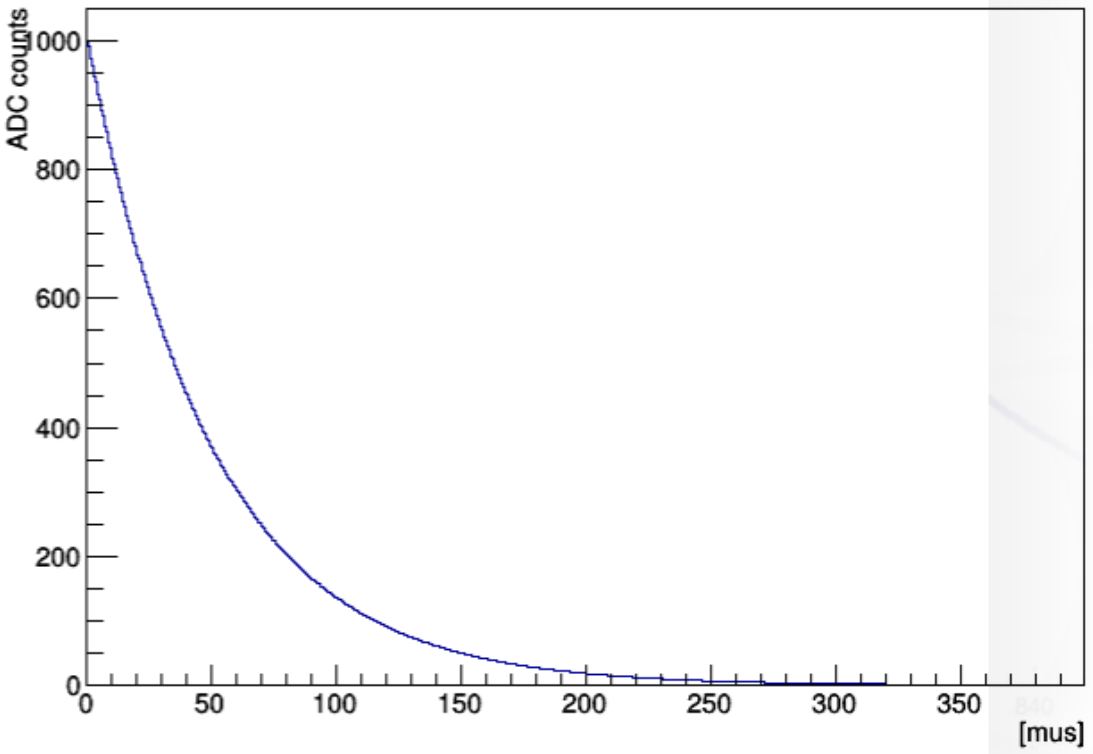
$$P\left(\frac{G}{\overline{G}}\right) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)}\left(\frac{G}{\overline{G}}\right)^{\theta} \exp(-(1+\theta)\frac{G}{\overline{G}})$$

Laser calibration

Pulse Formation : Proportional Counter

- Proportional counter "integrates" current to get total charge
- Response function of the preamplifier is a decaying exponential with decay time of ~ 50 μs for Modane's

Response function of preamplifier

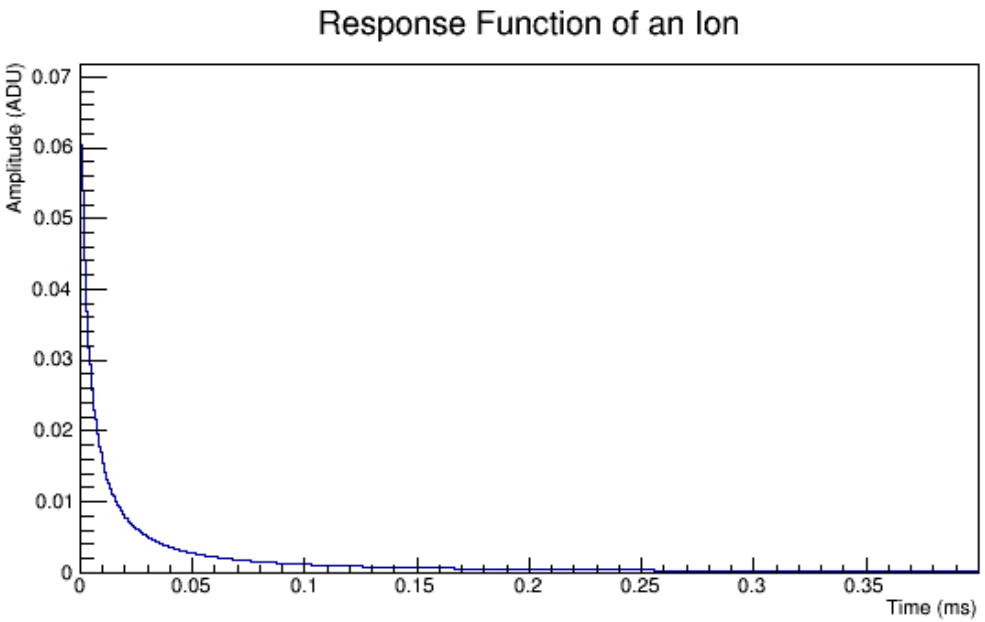


Pulse Formation : Ion Induced Current

- From Shockley-Ramo theorem, the current induced by a unit charge is:

$$i(t) = \frac{\alpha\rho}{(r^3 + 3\alpha t)^{\frac{4}{3}}}$$

- r is the radius of the electrode
- α is directly proportional to voltage, ρ, and the mobility of the charge in the gaz, and inversely proportional to pressure
- ρ is a parameter that depends mostly on the dimensions of the electrode



Parameter extraction : DDec

- We can deconvolve the amplifier response and the ion induced current to get the electron signal back (without ballistic deficit, and with structure)
- The amplifier response can be deconvolved via:

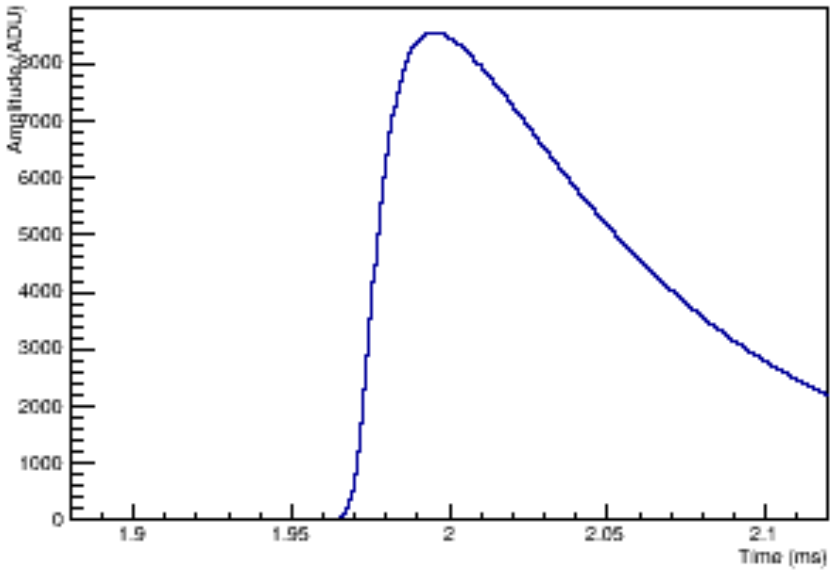
Deconvolved pulse

Original pulse

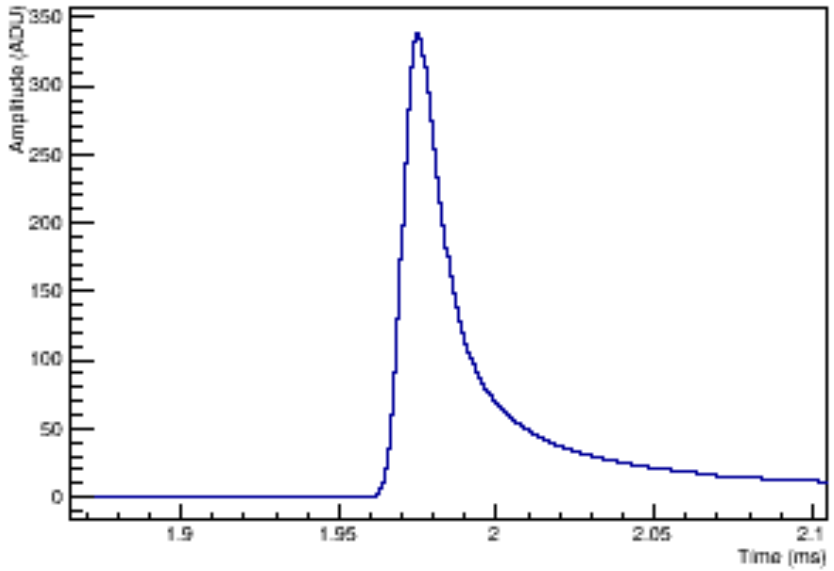
$$b(t) = \frac{da}{dt}(t) + \frac{a(t)}{RC}$$

- For the ion induced current, we need to go into Fourier space:
  - Get the Fourier transform of both pulse and ion induced current
  - Divide pulse's transform by induced current's transform
  - Do the inverse Fourier transform

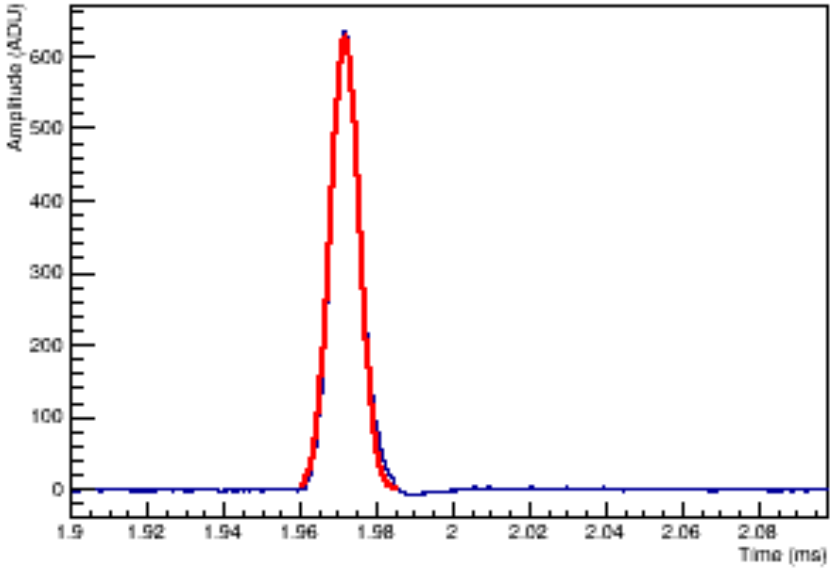
Original Pulse (RunAv)



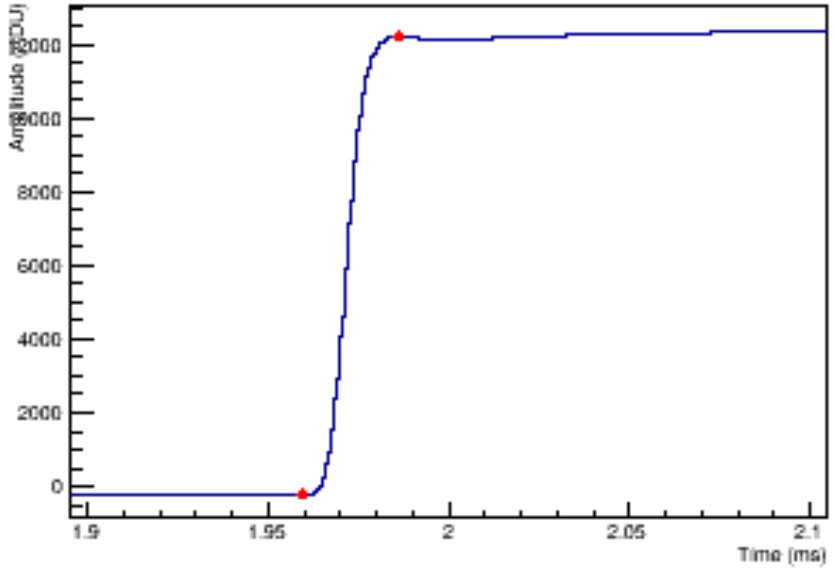
Pulse deconvolved from Amplifier (RunAv)



Double Deconvolved Pulse

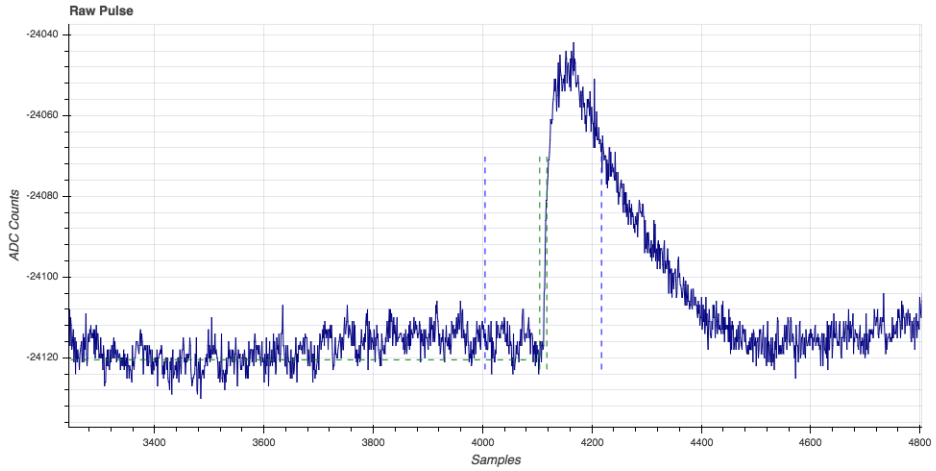


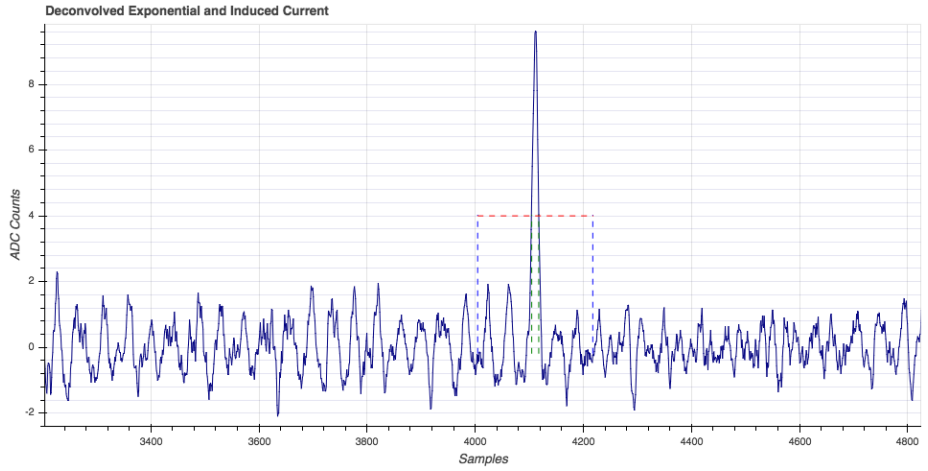
Double Deconvolved Pulse (Integral)



Parameter extraction : DDec

- After DDec, we recover a signal that goes back to (flat) baseline in a few tens of μs at most: model consistent with data!
- Integral of deconvolved pulse gives amplitude and risetime of event
- Applying the DDec method to data also corrects the ballistic deficit
- Problem: DDec method greatly amplifies noise





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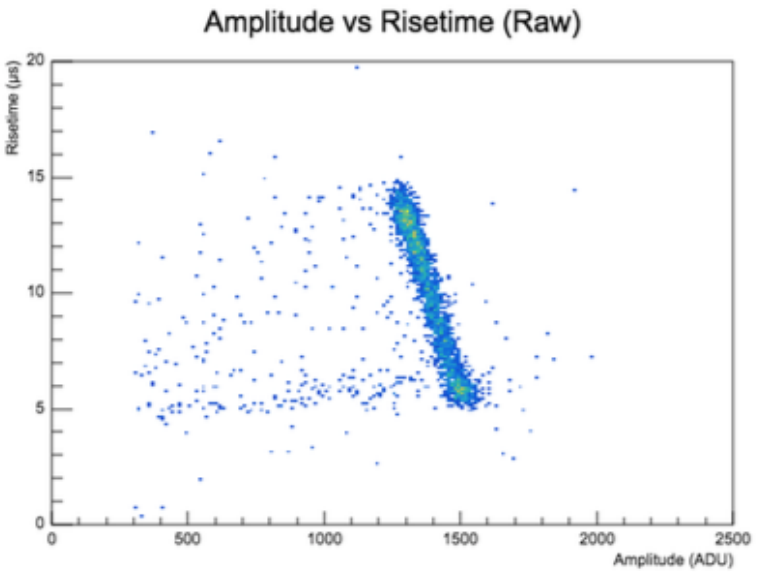
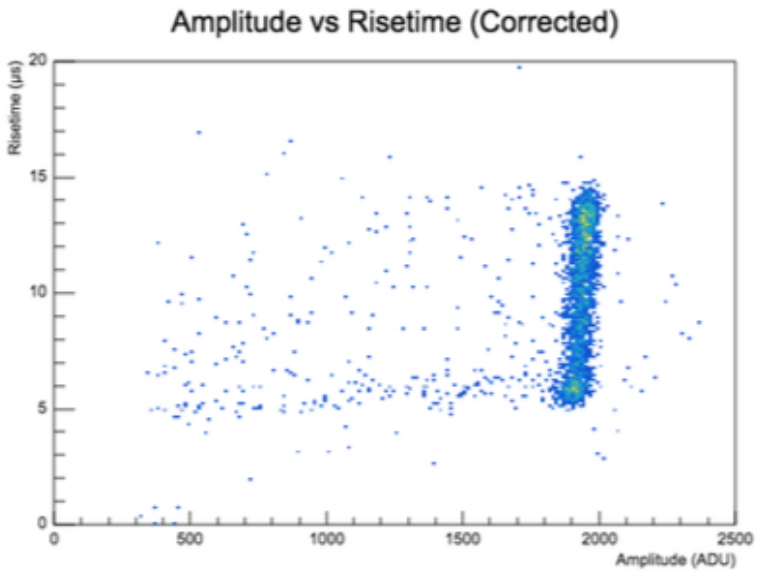
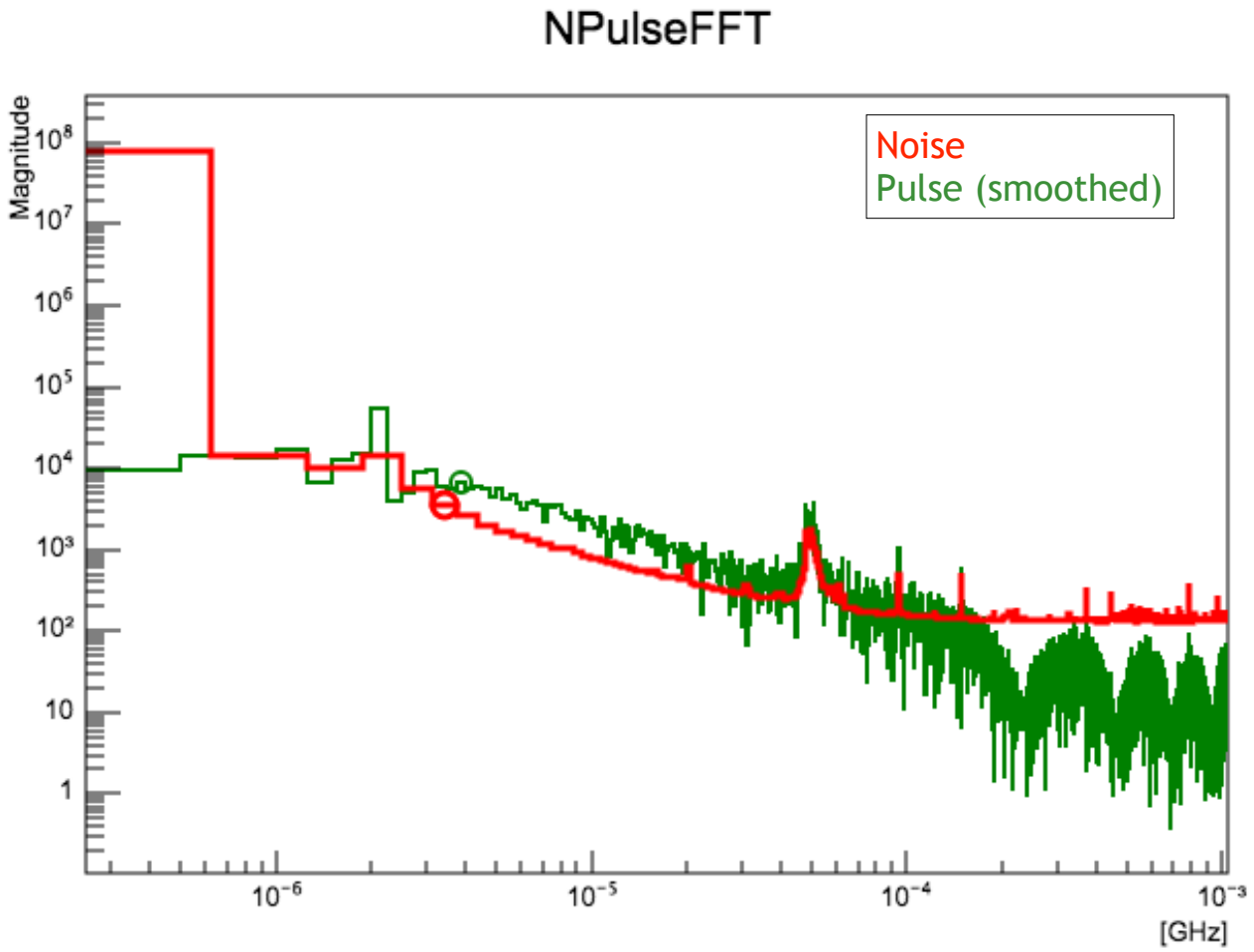




Parameter extraction : DDec



- Noise source at 50kHz sets limit to shape analysis of deconvolved pulses

NEWS-G : Background

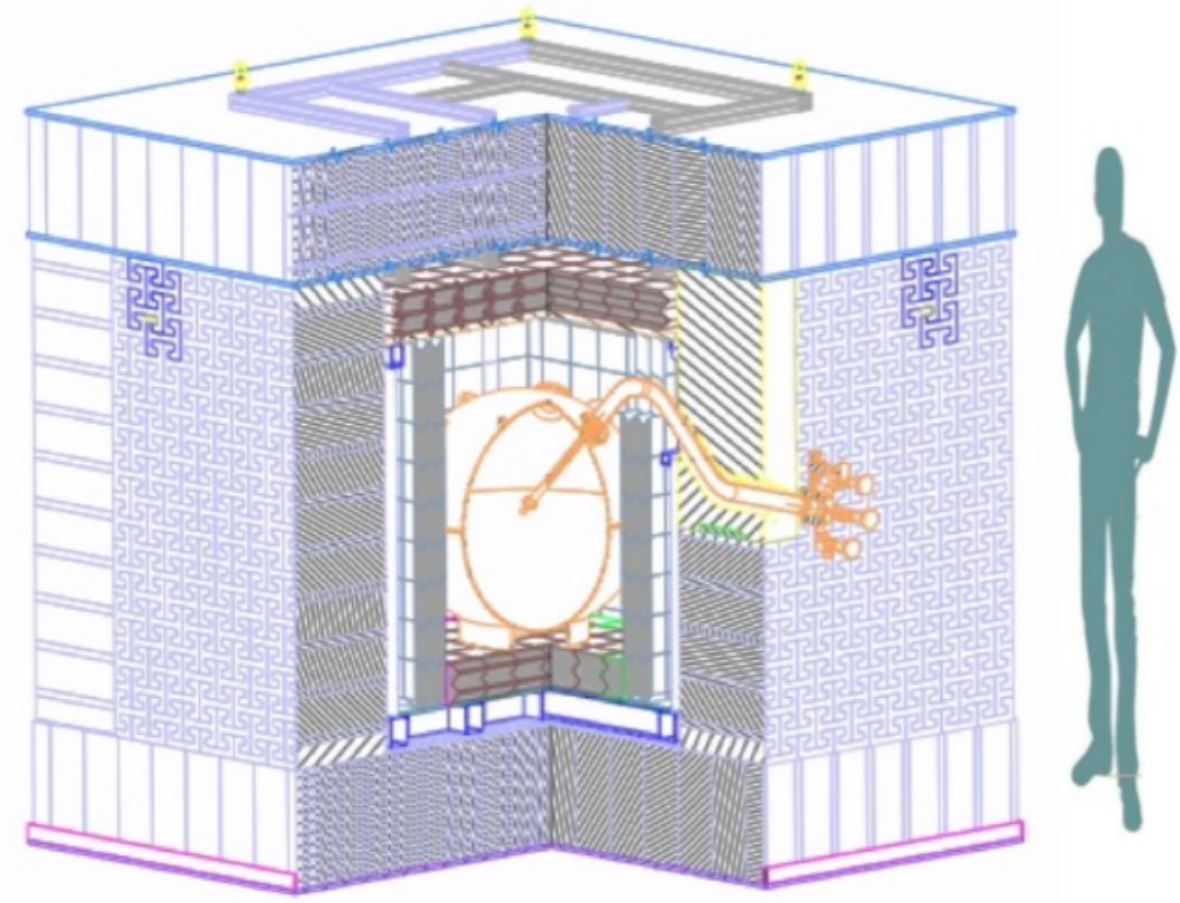
Sources:

- Cosmic radiation
- Cosmic-activated copper
- Uranium and Thorium decay chains

Generate alphas, gammas, neutrons and electrons

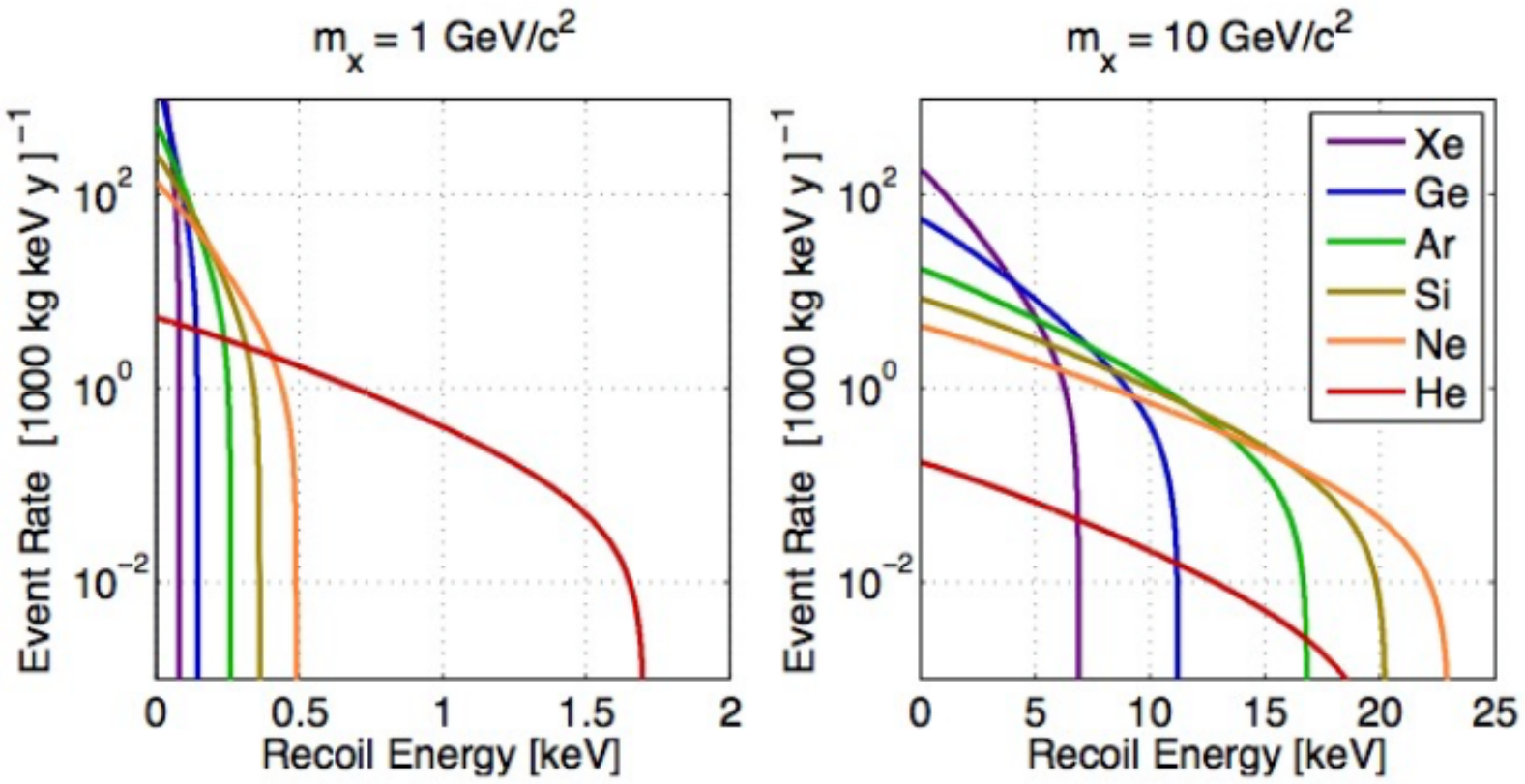
Shielding:

- Polyethylene (n)
- Lead (gammas)
- Copper (radiation from lead)



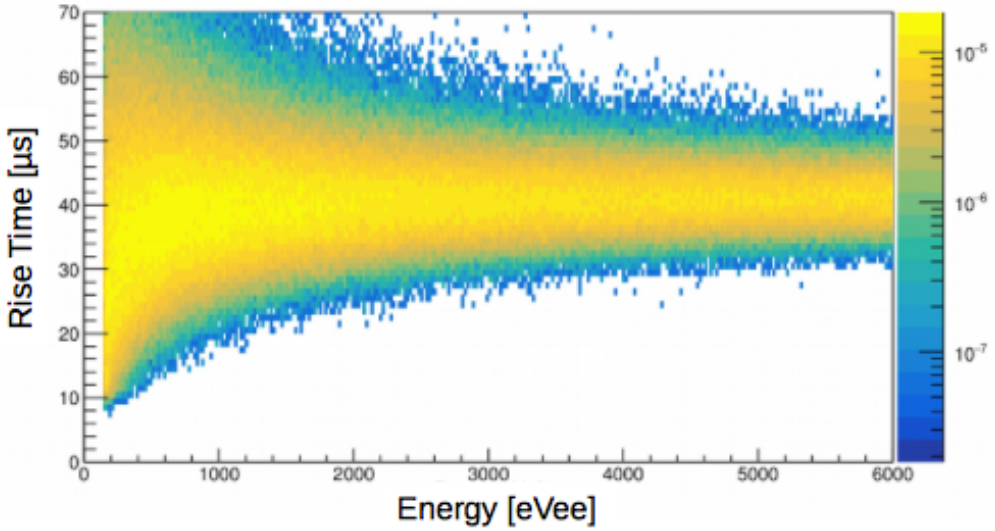
Recoil spectrum

Light Target

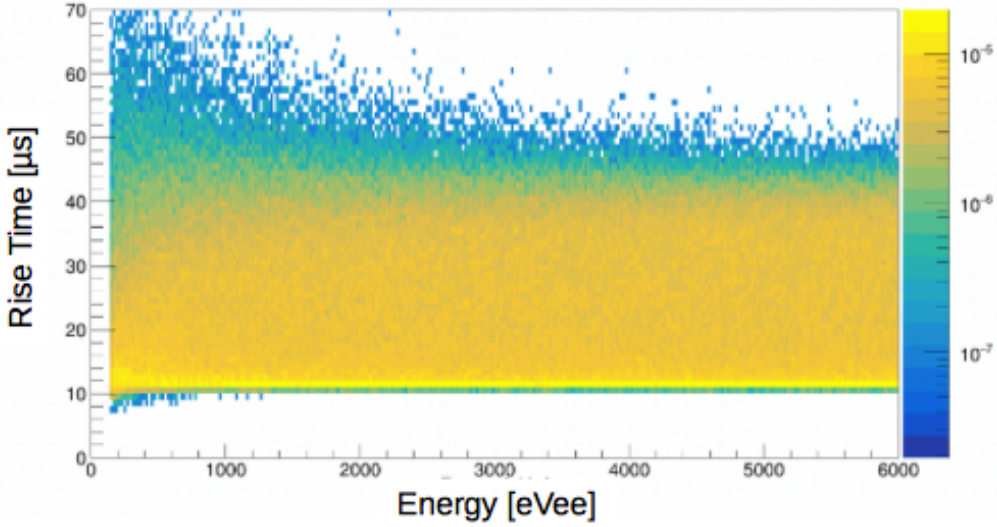


Background PDFs

Surface events

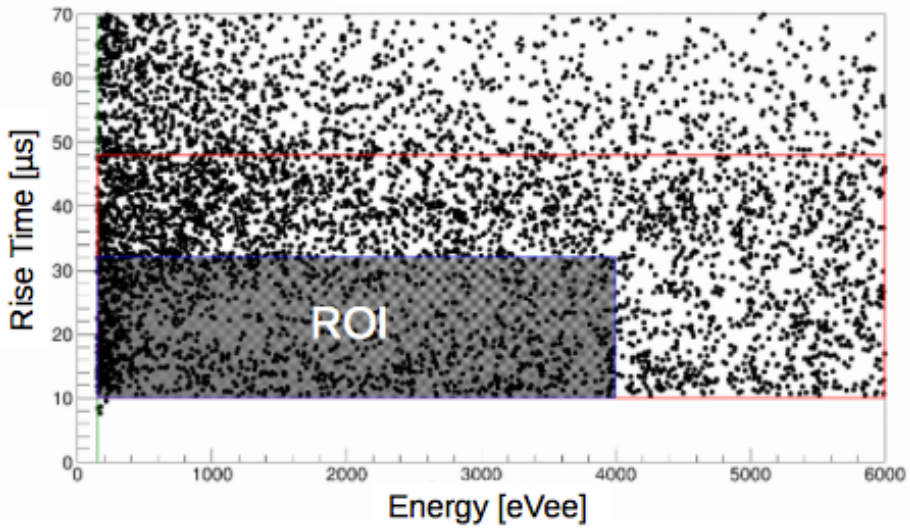


Volume events



Sedine data

WIMP search run



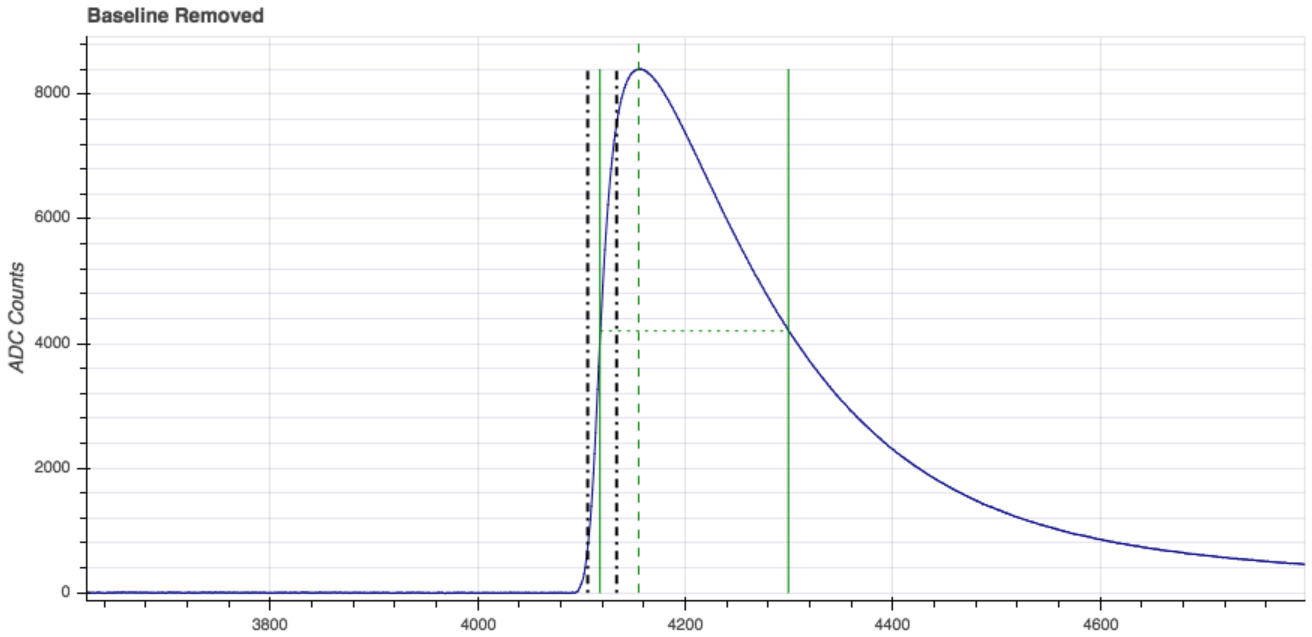
Analysis threshold set at **150 eVee**
(100% trigger efficiency)

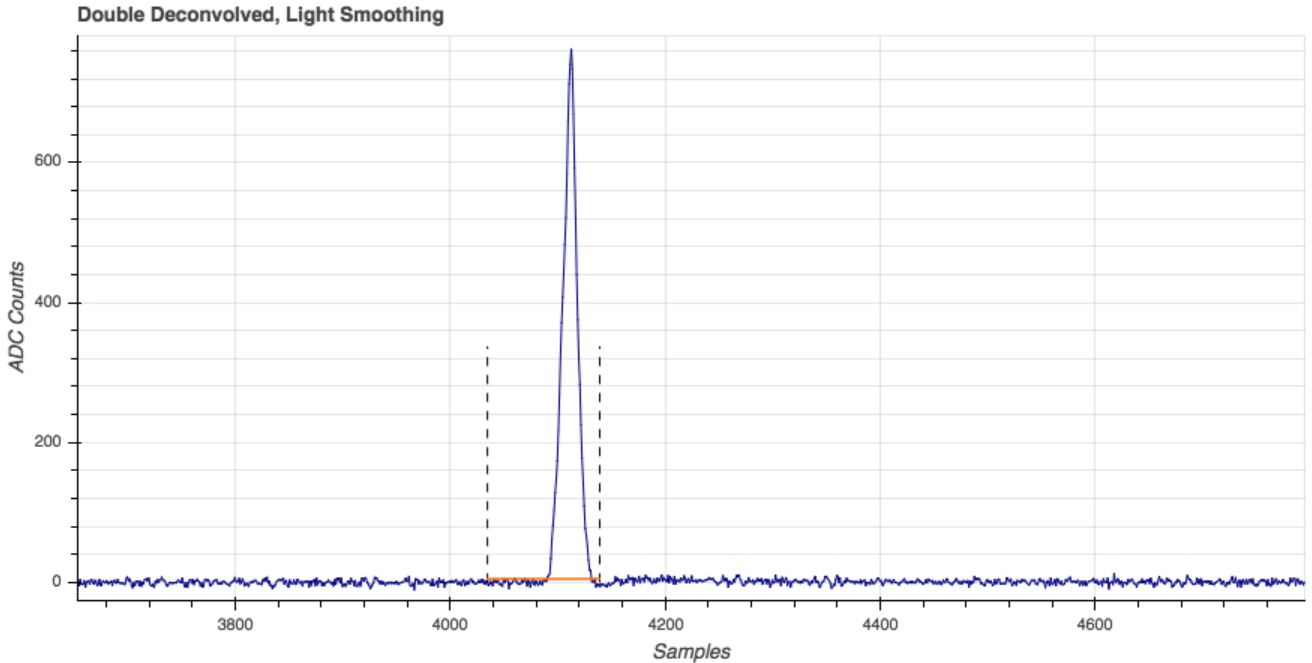
Side Band region used to determine
The number of background events
expected in the **ROI**

~1600 events expected in the ROI ...

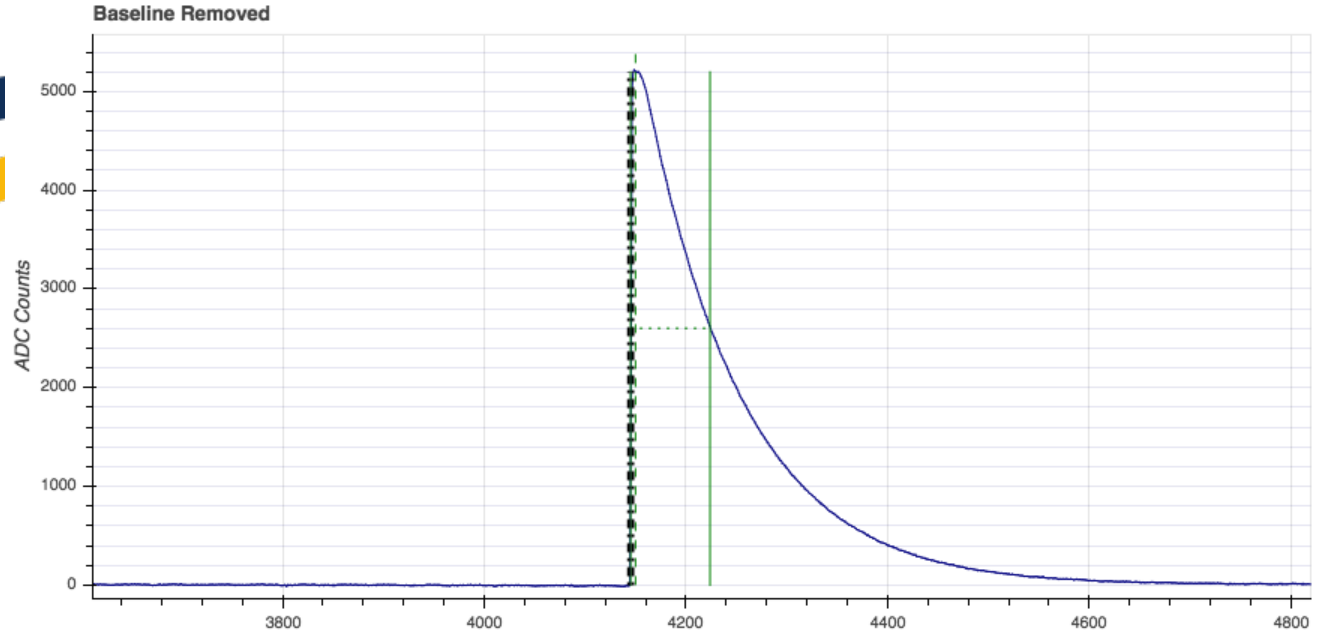
Need to determine a fine-tuned ROI optimized for signal/background discrimination

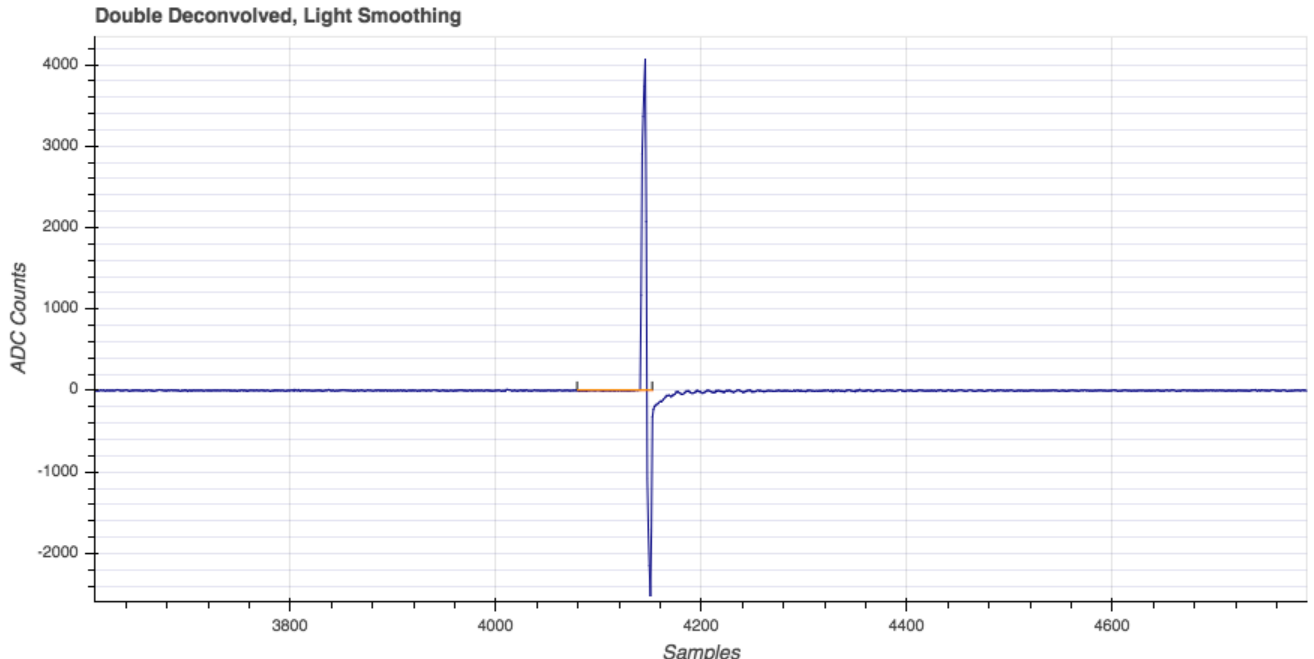
Pulse type: pointlike



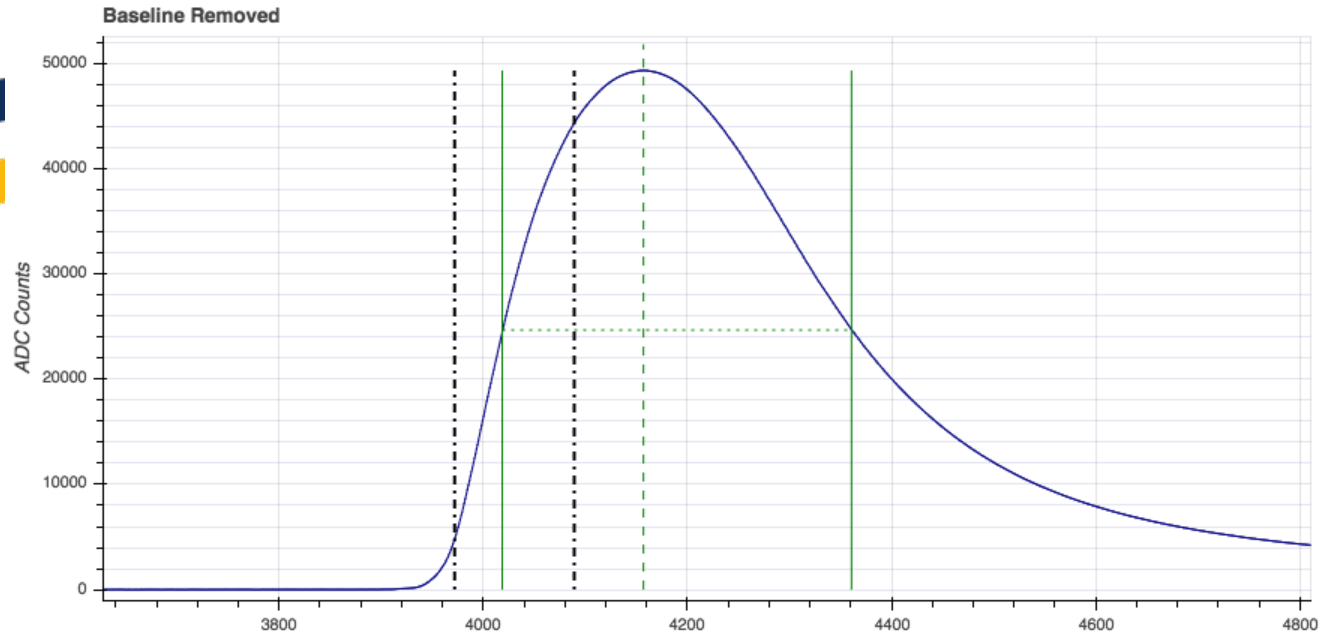


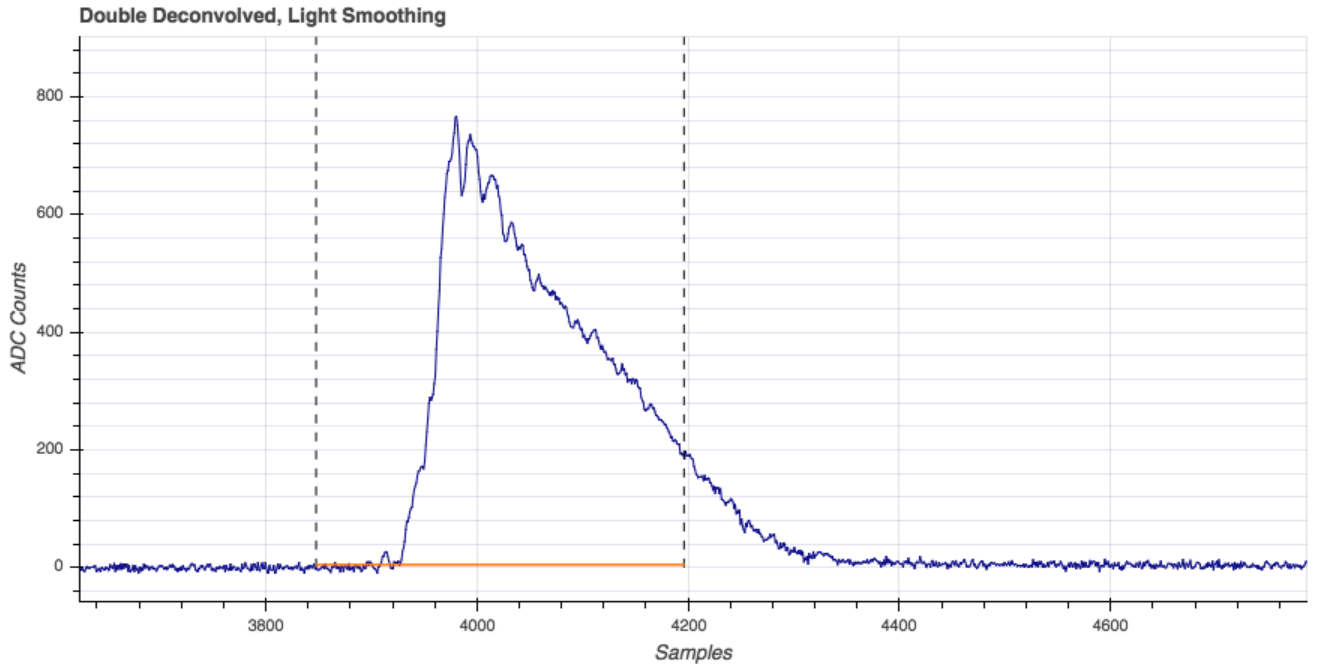
Pulse type: “electronic” events





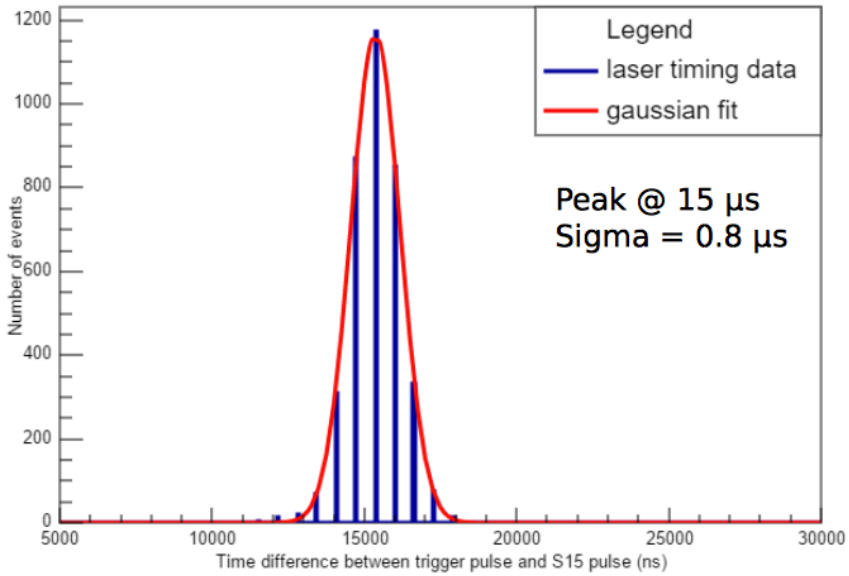
Pulse type: track

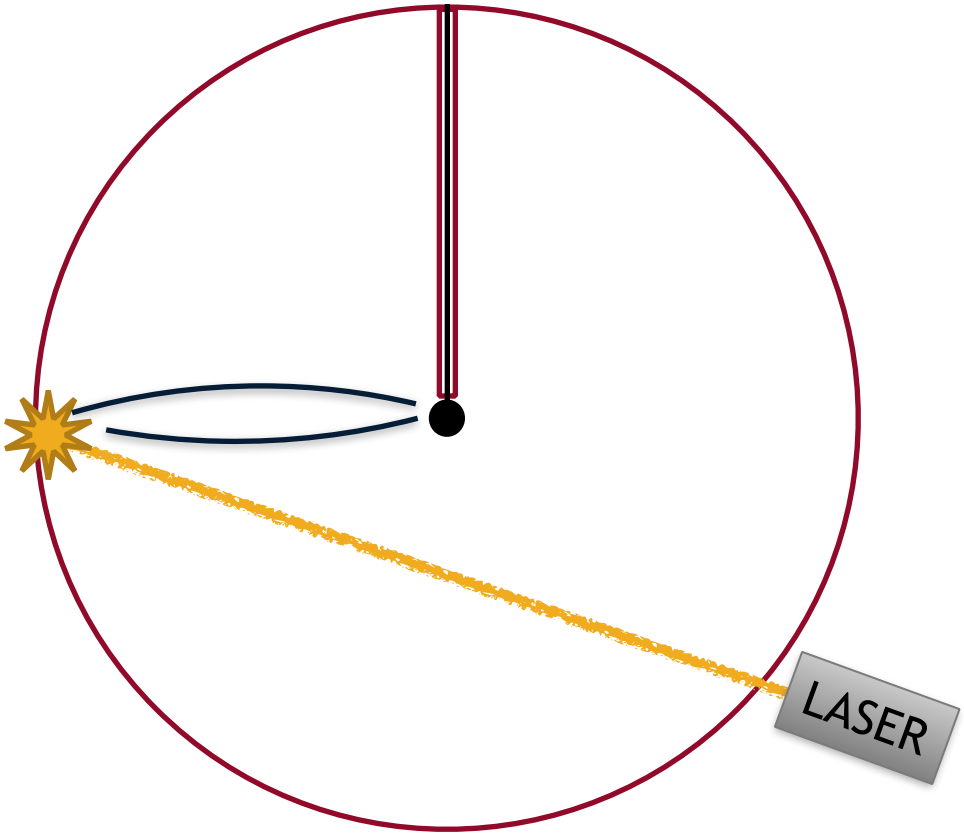




NEWS-G : Work at Queen's

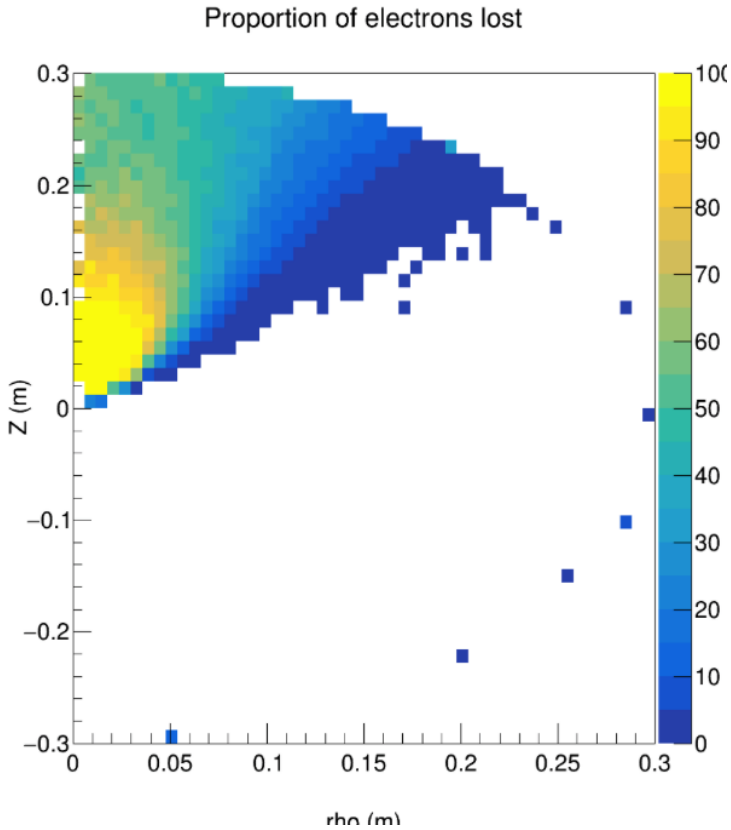
- Laser induced photo-excitation of electrons.
- On demand events, can study drift time or avalanche process.

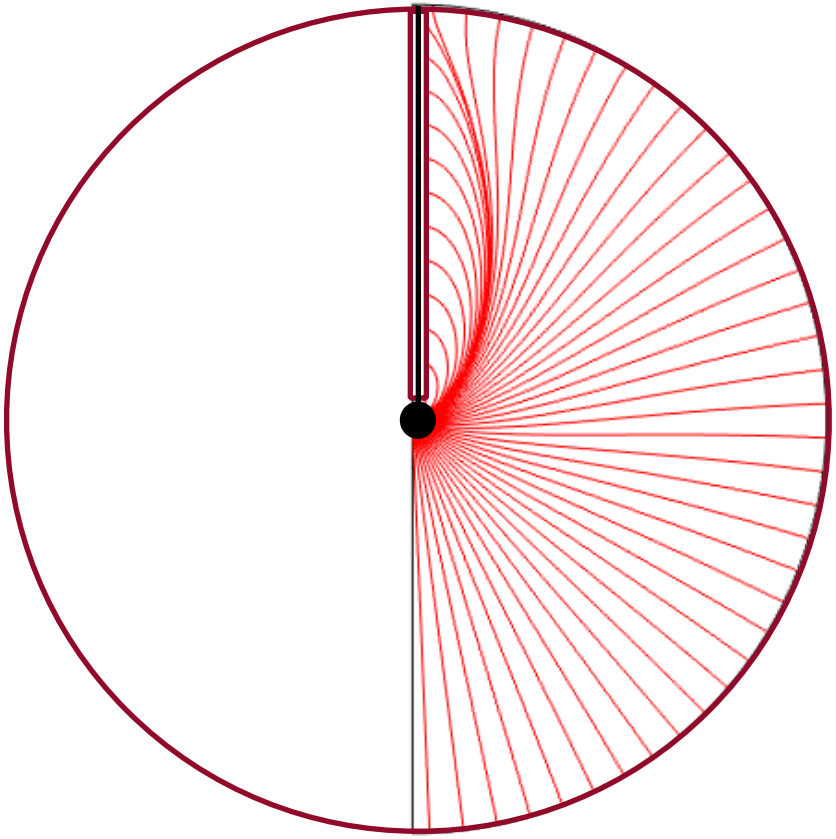




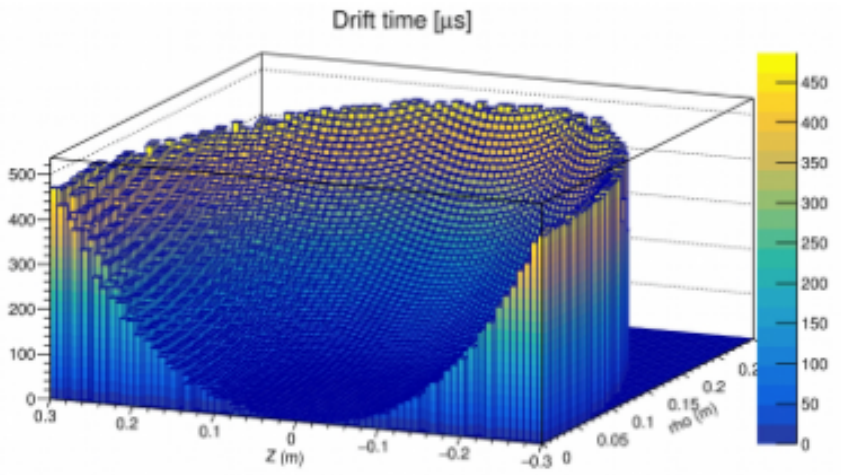
NEWS-G : Work at Queen's

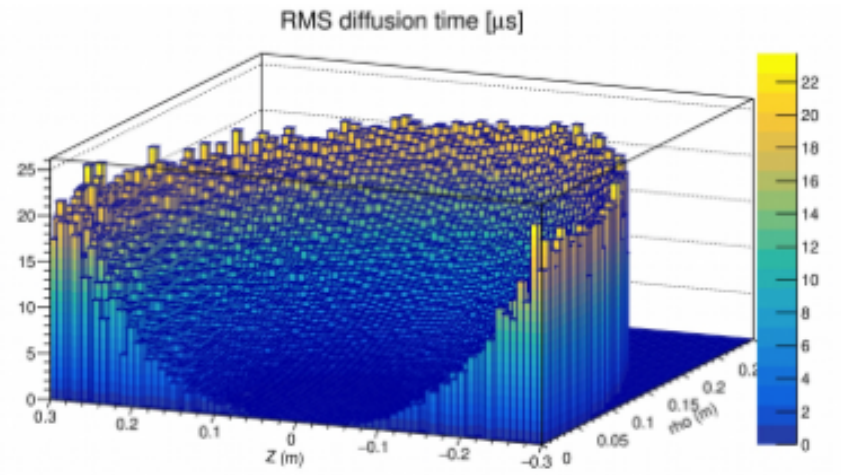
- Distortion of field due to presence of rod (real geometry)
- Affects ~10% of volume, can be neglected on approximation.



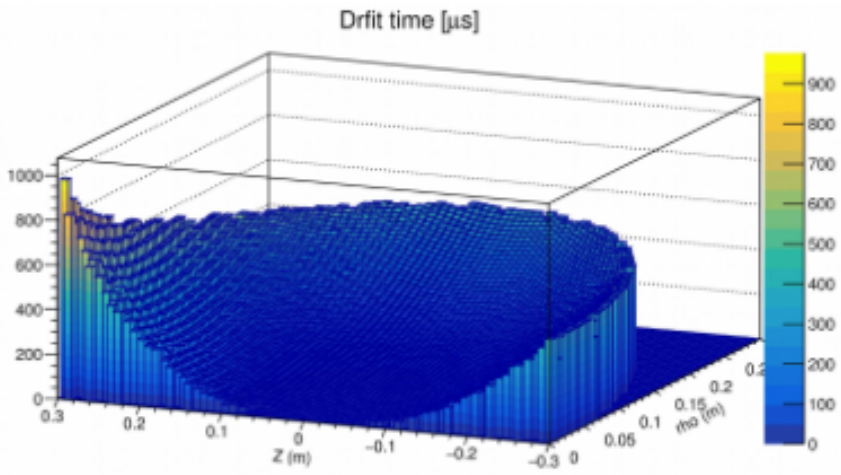


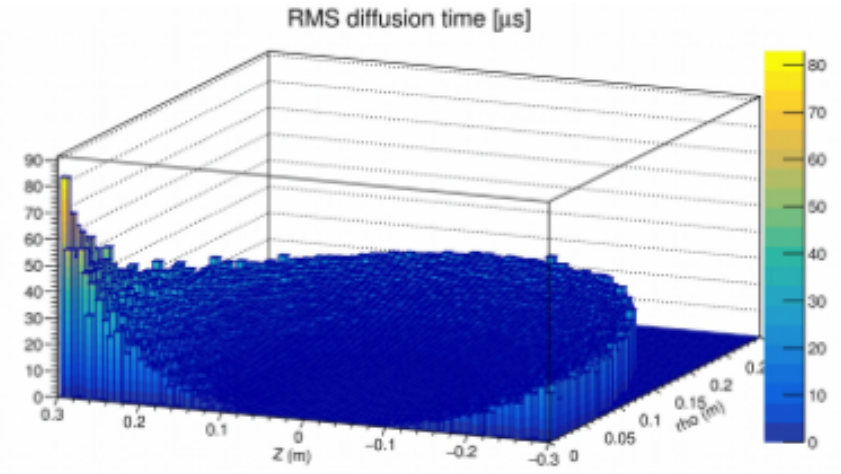
Ideal Geometry



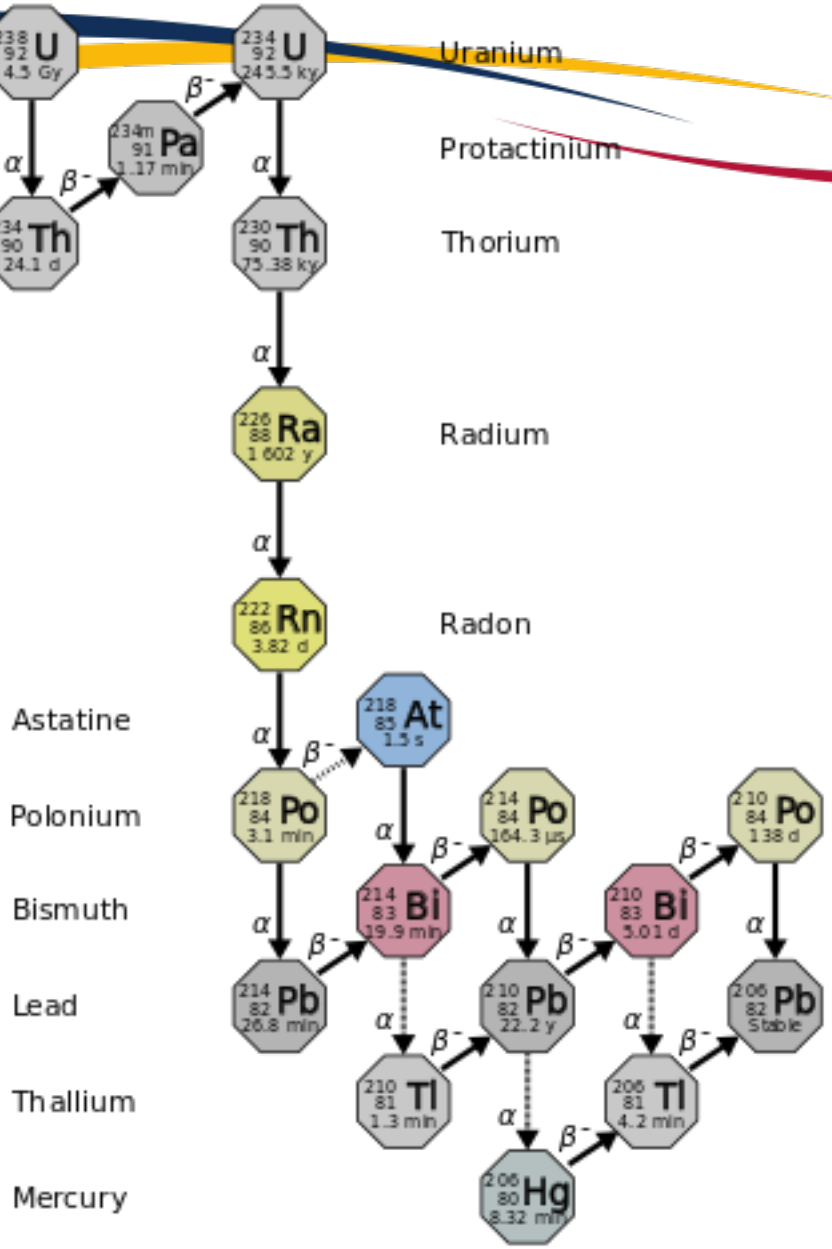


Real Geometry

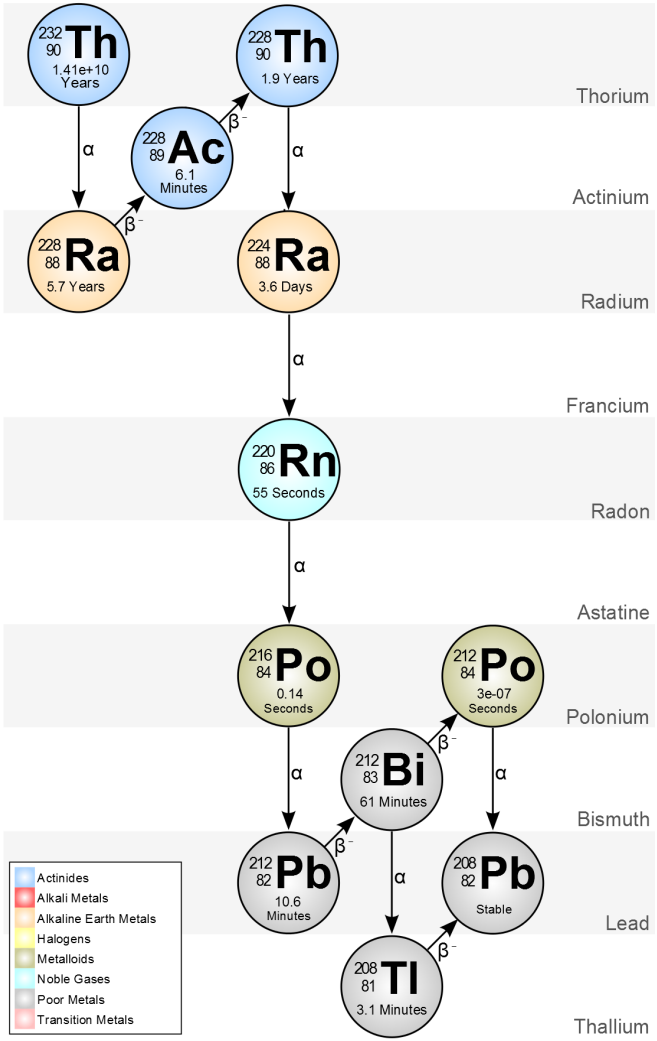




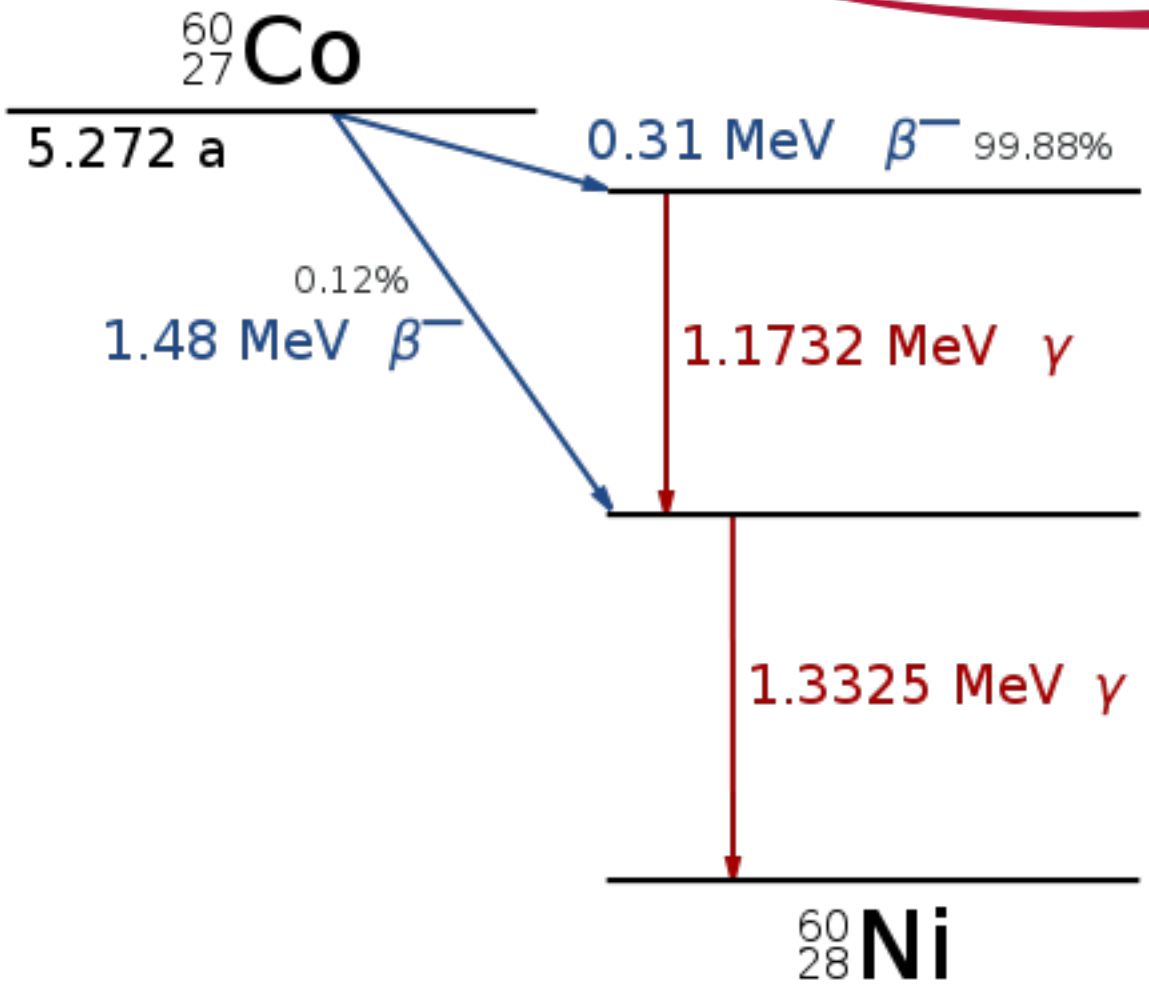
Background radiation



Background radiation



Background radiation



Ar37 Calibration