Research and Development for the NEWS-G Dark Matter experiment

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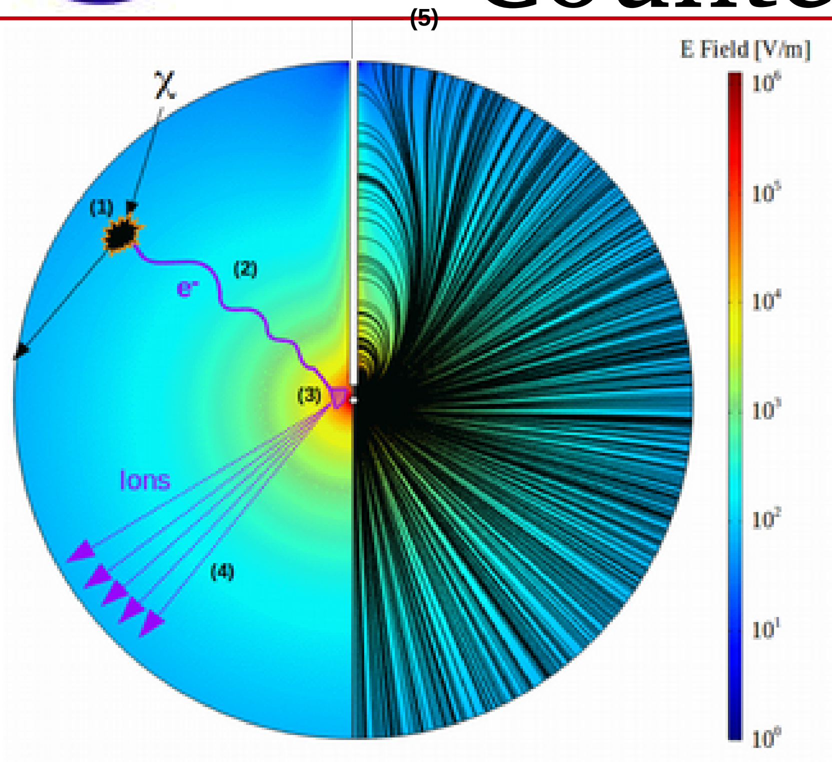
CAP Congress
2018-06-11 Halifax

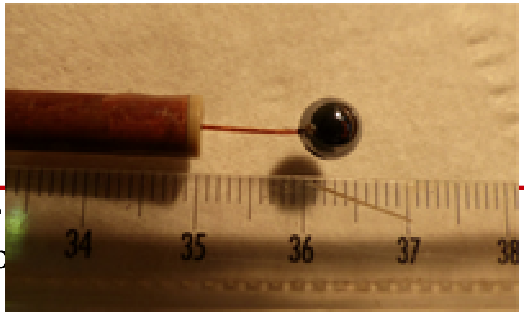
Spherical Proportional Counters (SPCs)



(1) Particle ionizes gas.
(2) Primary electrons drift toward the sensor.
(3) Close to the sensor, secondary ion/electron pairs are produced.
(4) Signal is induced by the motion of secondary ions.
(5) The signal is processed by a pre-amplifier and digitized.

-Possibility to use large range of target mass.
-Sub-keV energy threshold down to single electron.
-Identification of point like energy deposition.

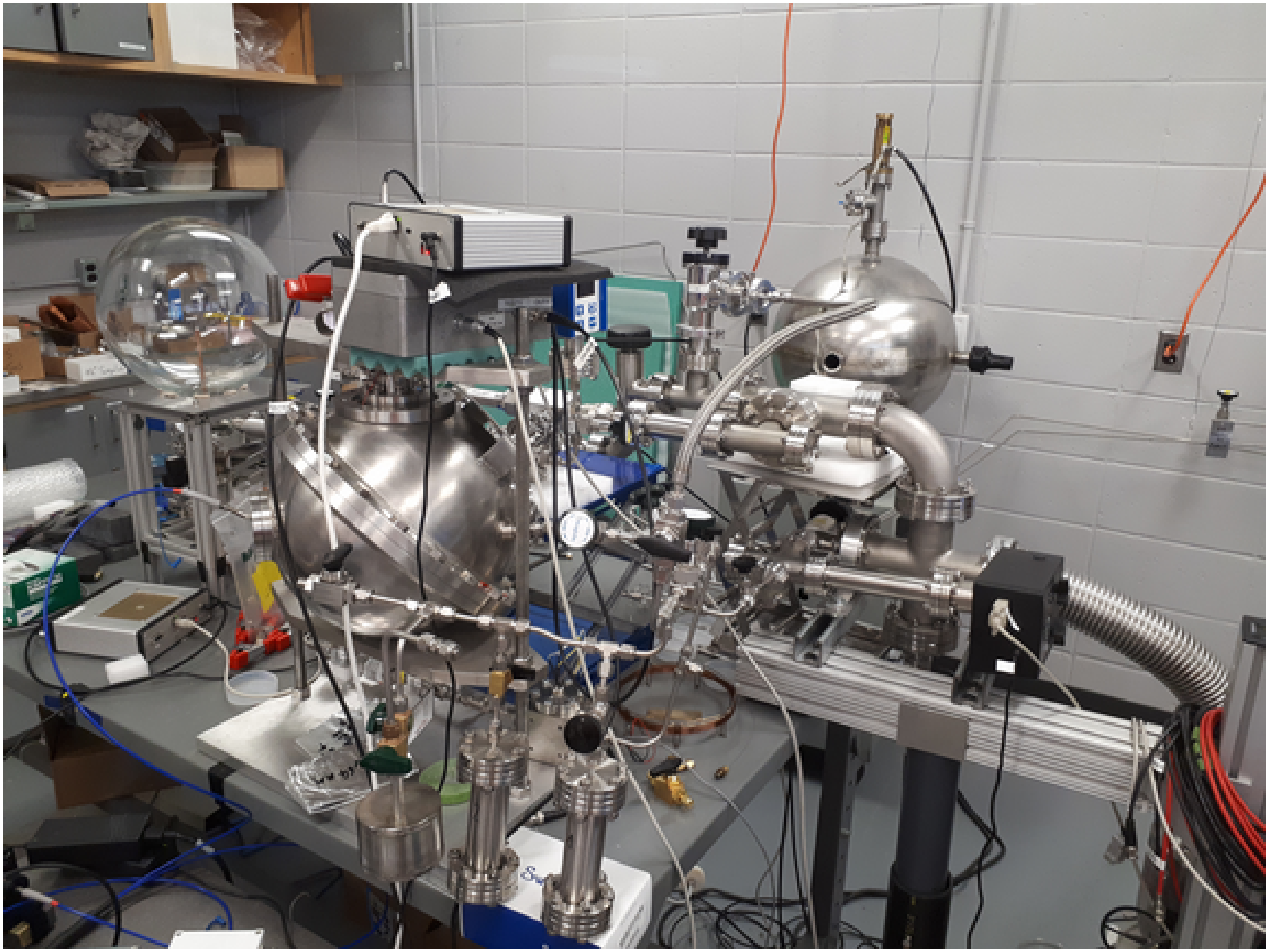
-Dark matter search
-Neutrino physics



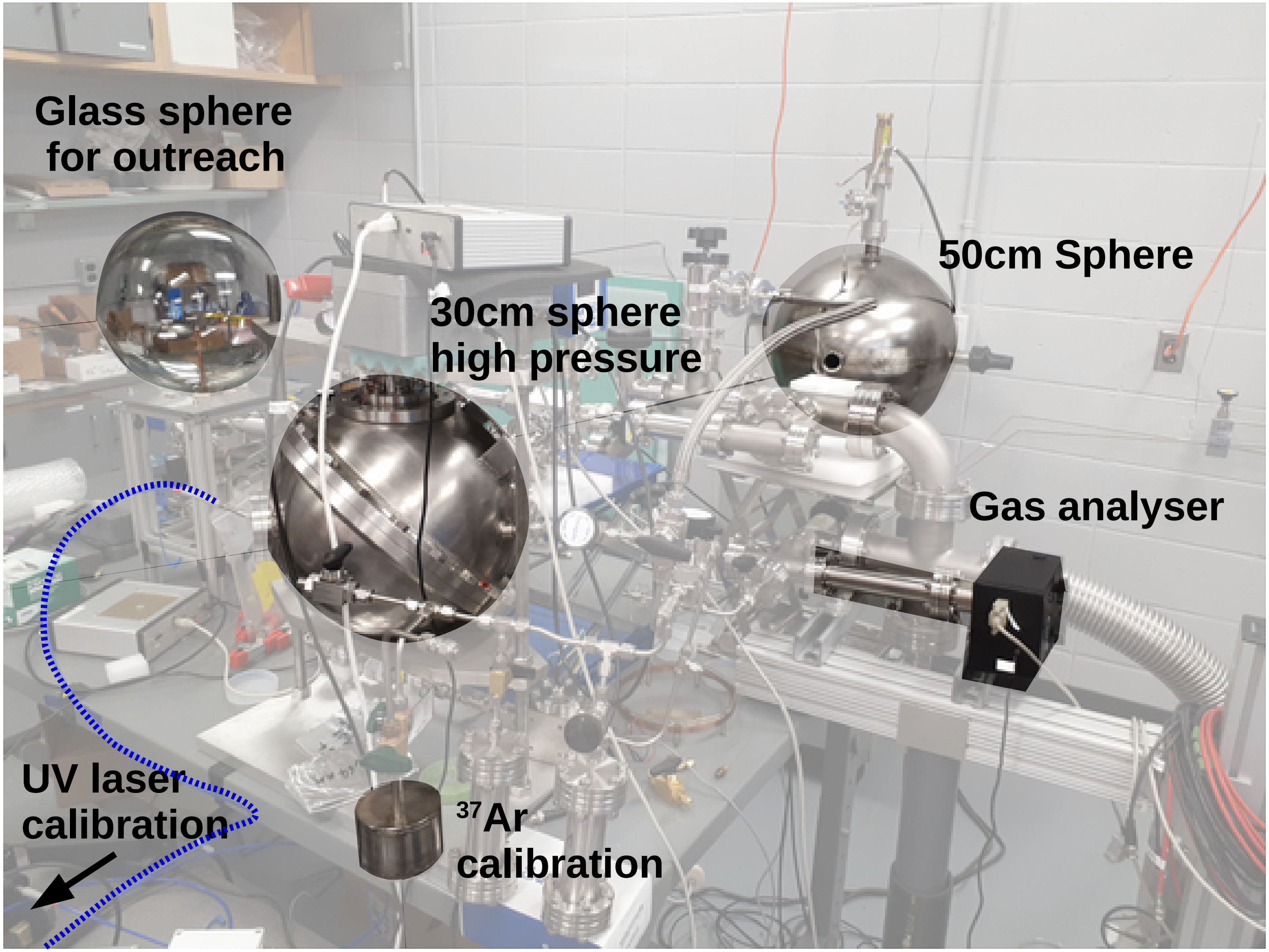
Motivation, outline

- Proof of concept validated with SEDINE
  - competitive limits
- Bigger and better at SNOLAB
  - improve material purity (improved manufacturing)
  - improve electric field
  - improve gas quality
  - improve calibration and understanding

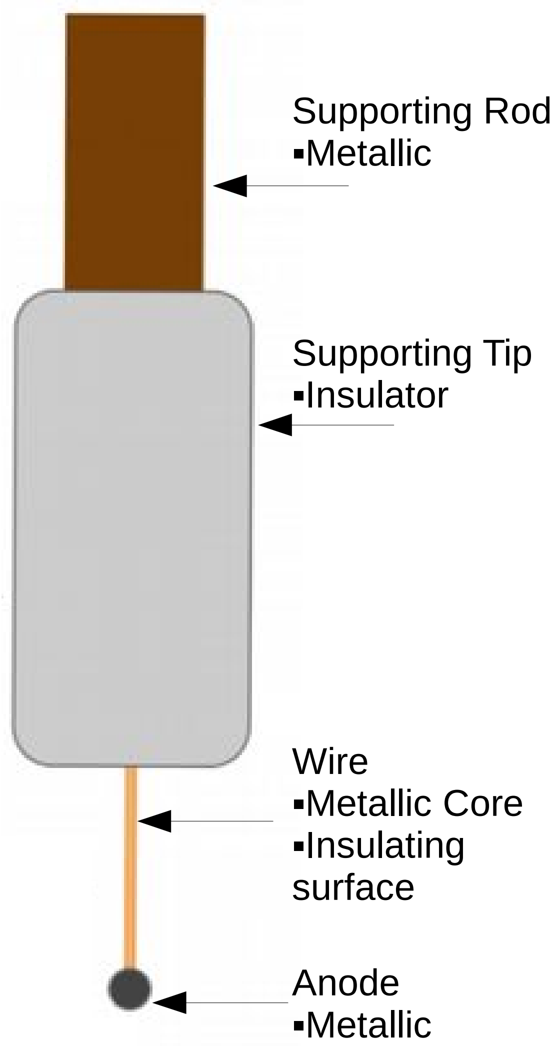
R&D lab at Queen's U

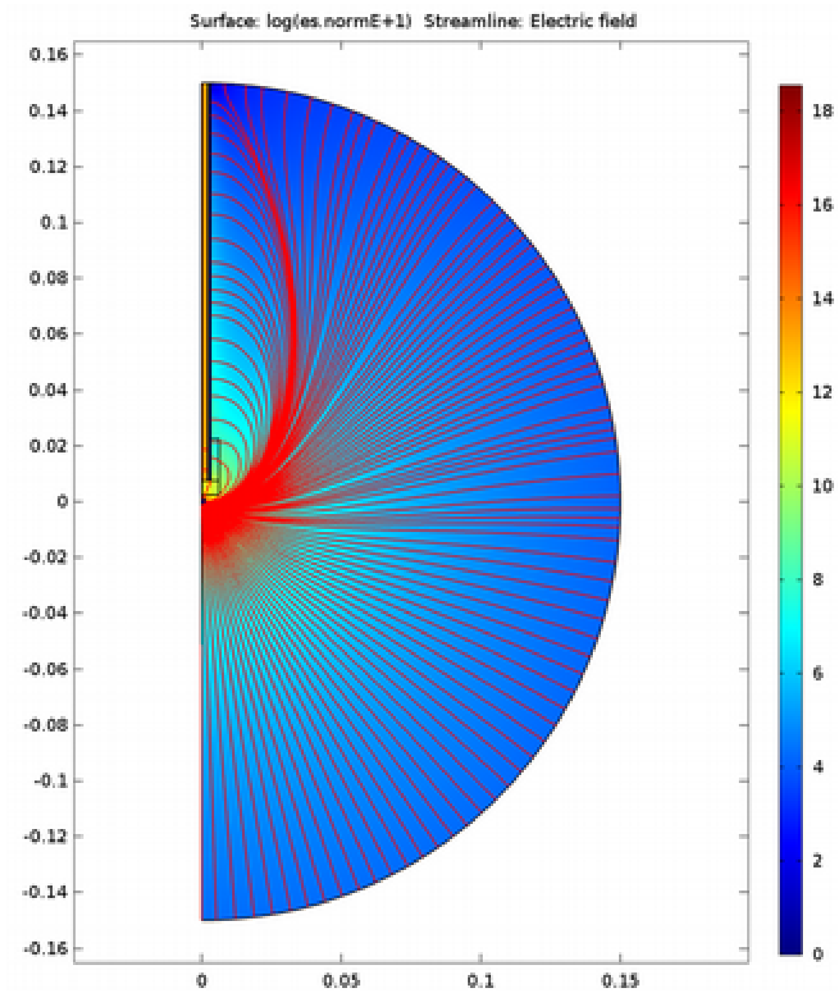


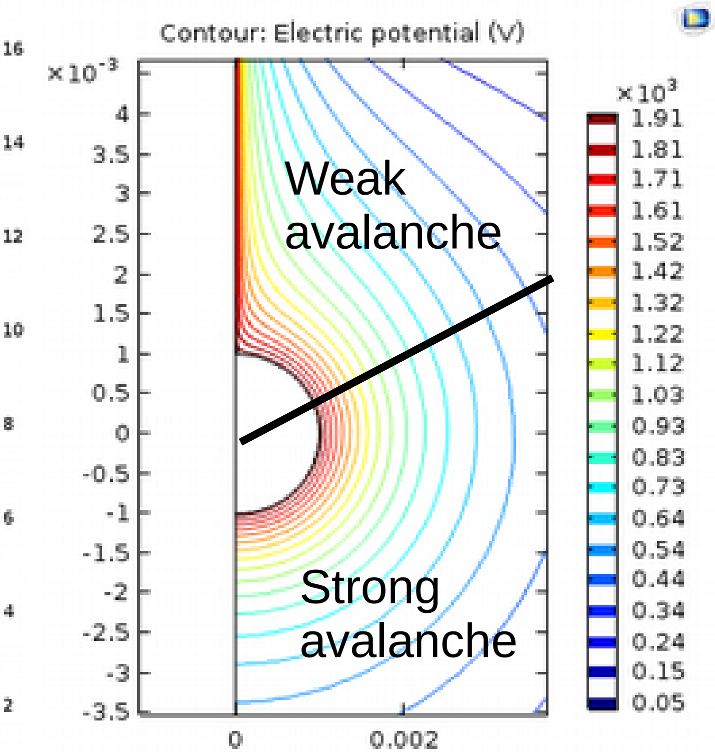
R&D lab at Queen's U



Electric field: sensor development





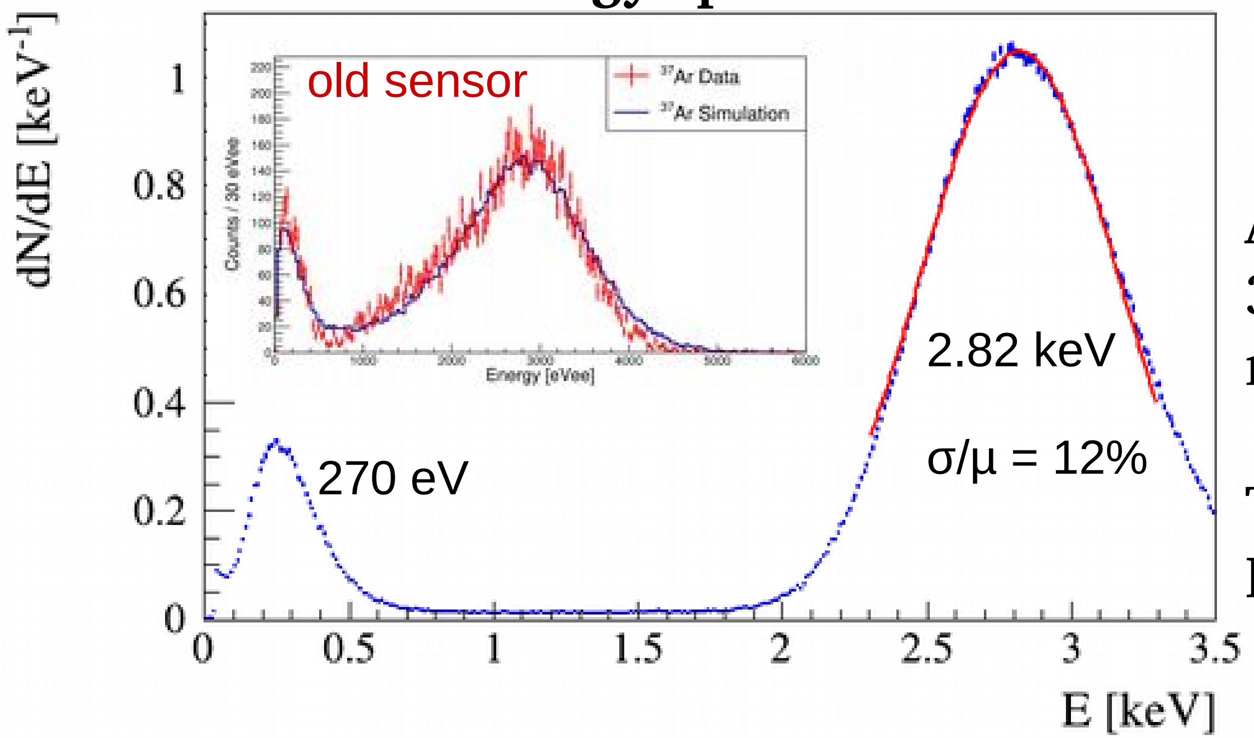


A simple sensor gives a non-uniform field, and gain depending on the location of the avalanche:
→ Poor resolution!

Electric field: Second electrode

"Umbrella" on top of sensor ball
Corrects the field and improves gain uniformity
Made of resistive material (bakelite, glass) to prevent discharges

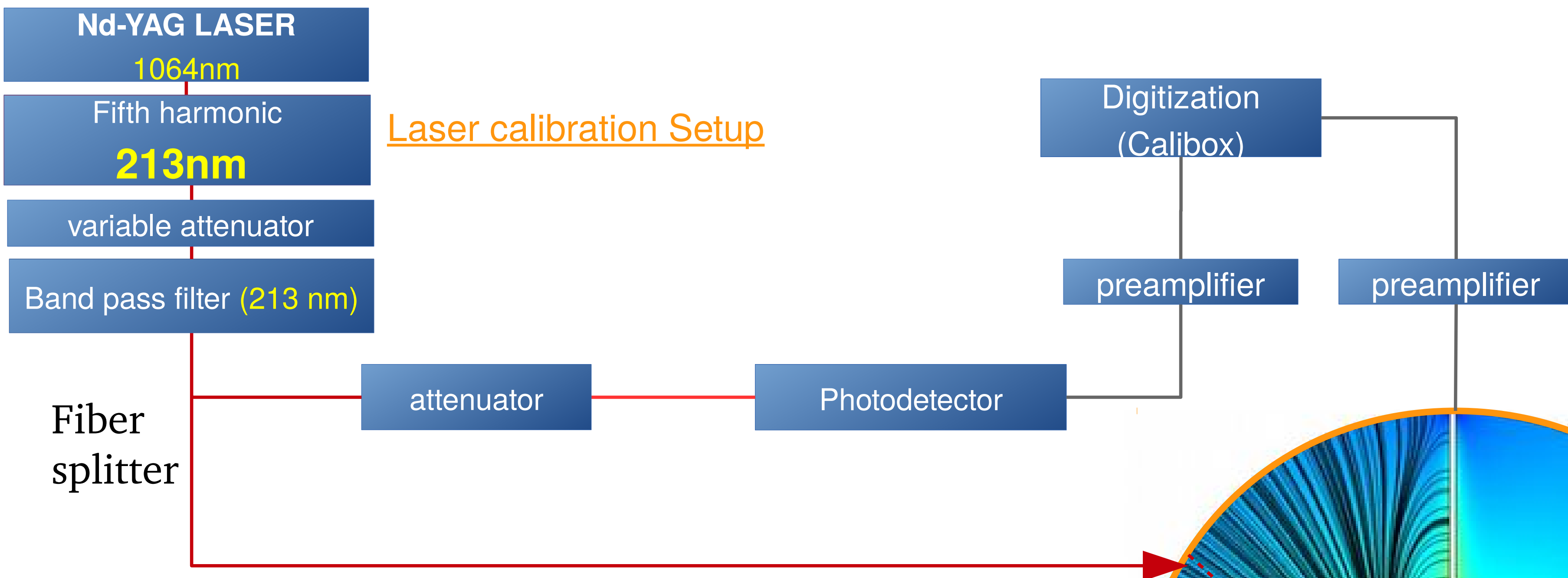
^{37}Ar energy spectrum

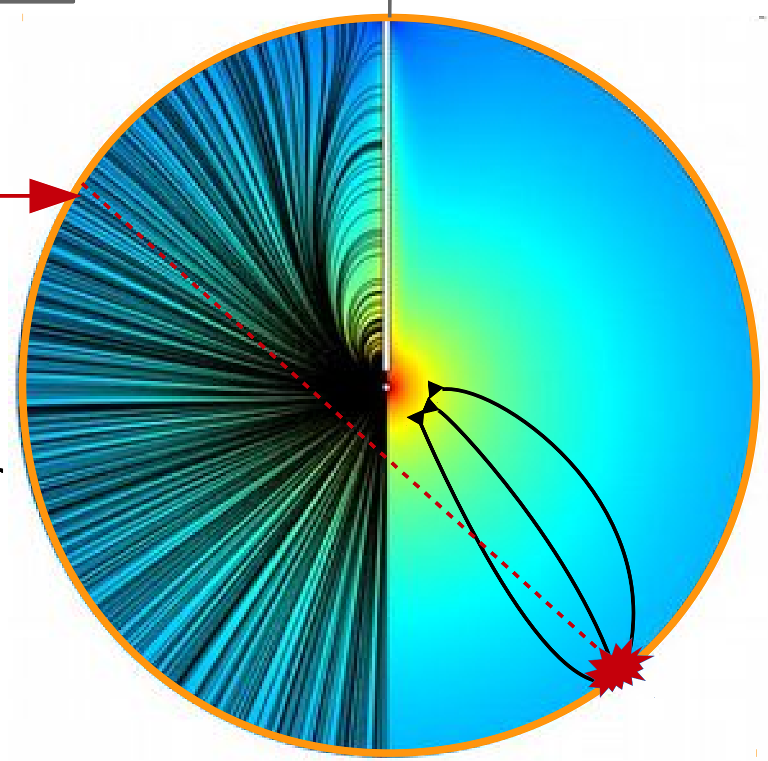


Ar-37 events recorded with a 30-cm SPC filled with 500 mbar of Ar + 2 % CH_4.

Two millimetre ball with HV1 = 2020 V, HV2 = -120 V

Laser calibration





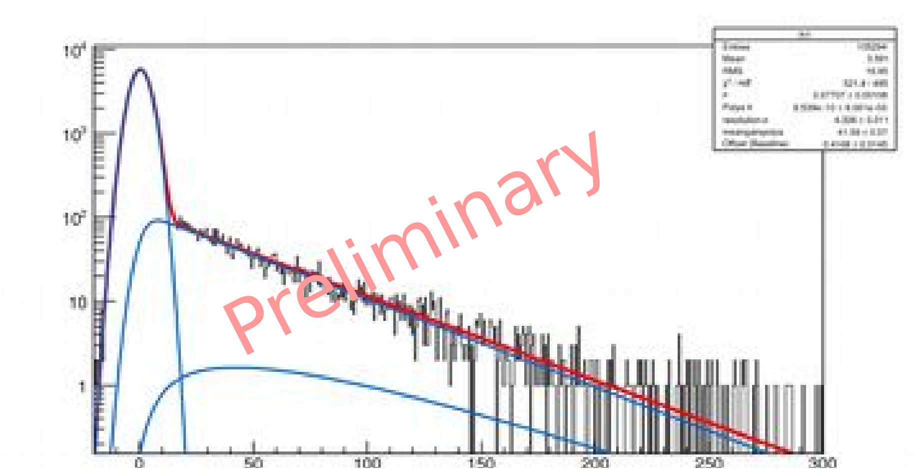
<u>Laser Data</u>

- Single electron response parametrization (θ of Polya)
- Energy calibration / W-value measurements
- Monitoring of the stability of the detector response over time
- Drift and Diffusion time measurements

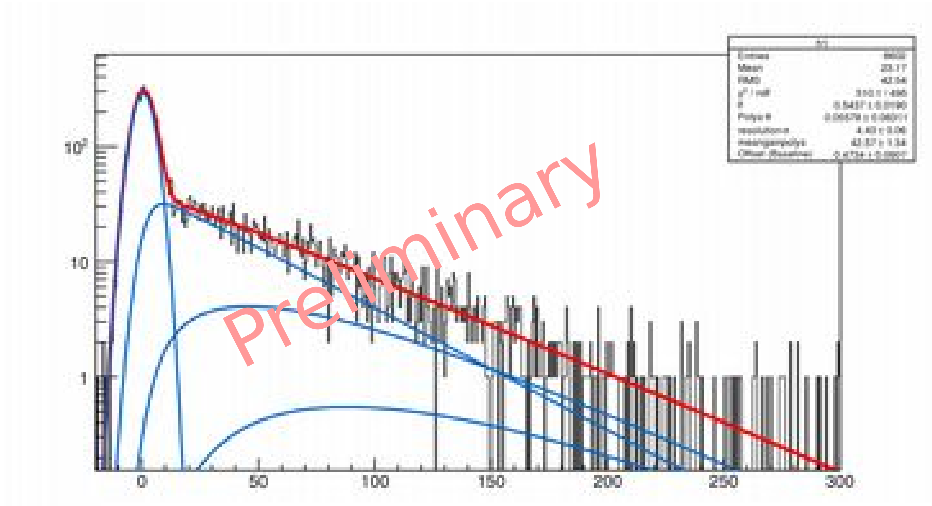
<u>Photodetector (PD)</u>

- Monitoring of the stability of laser
- Start Time (in drift time measurements)

Single electron spectra



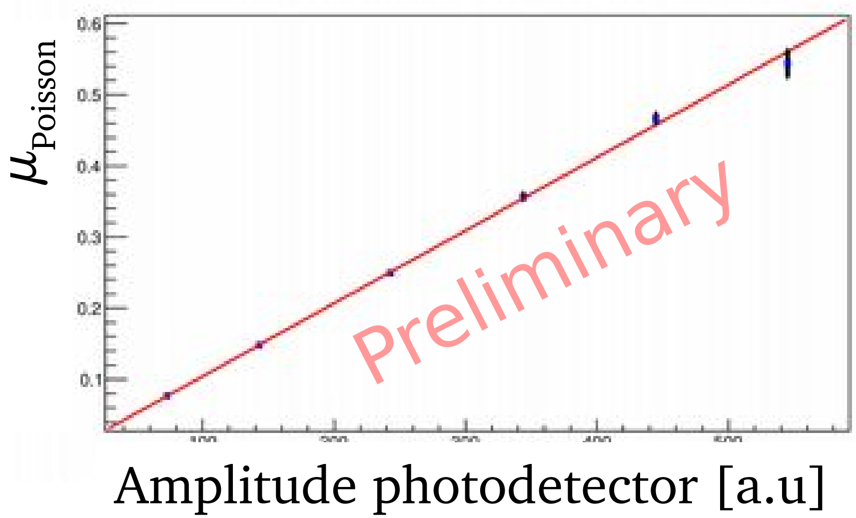
Amplitude sphere [a.u]

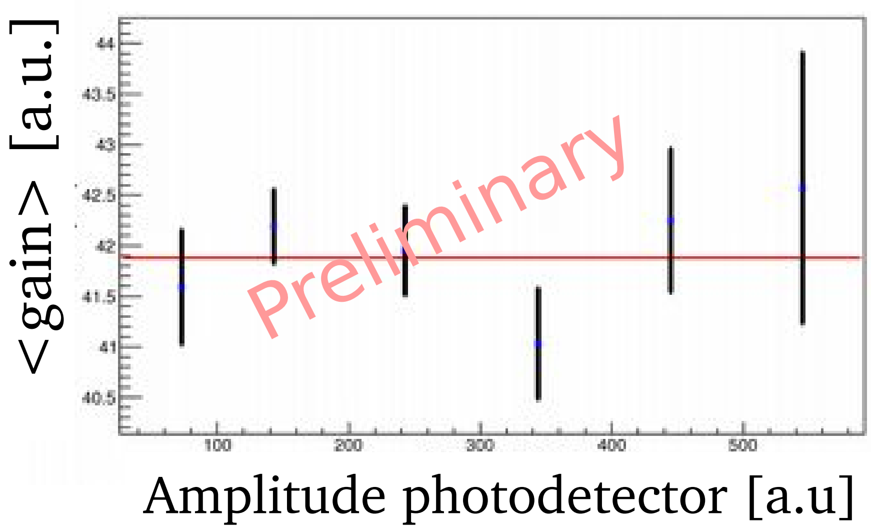


Amplitude sphere [a.u]

- Fitted with full model of the detector (4 parameters)
  - Poisson fluctuations: μ_{Poisson}
  - gain fluctuation: <gain>, θ
  - noise σ_{noise}
- <u>Fit valid for multiple electrons (Poisson)</u>
- only μ_{Poisson} depends on laser intensity

Extraction of detector parameters

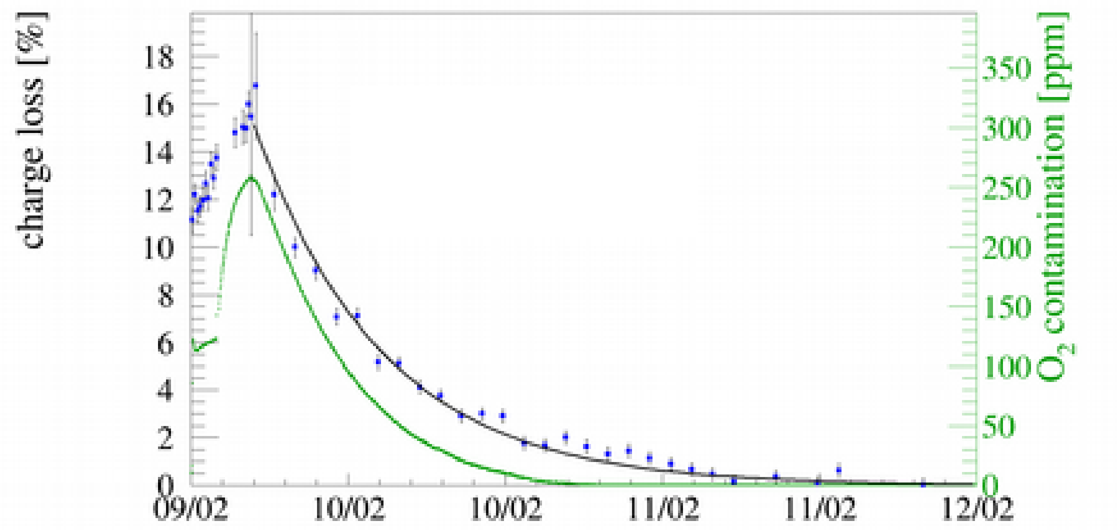


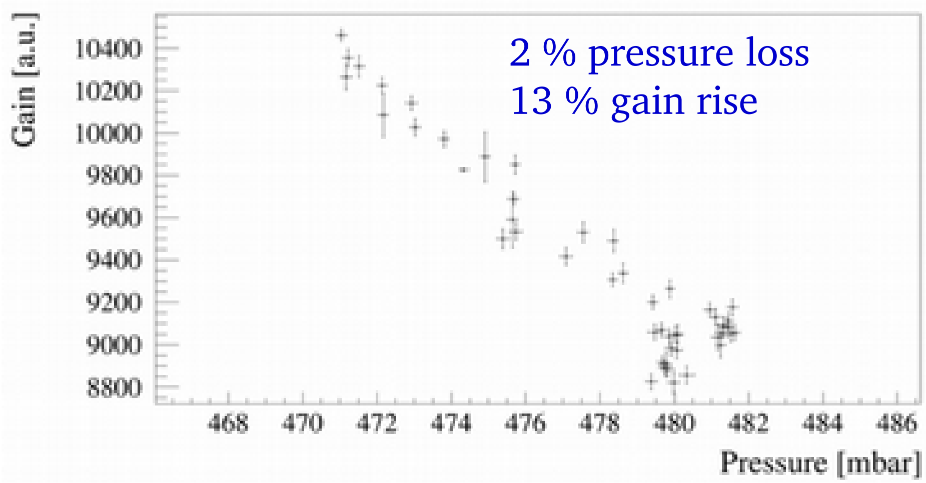


- Mean number of electrons measured is proportional to laser intensity
  - single photon photoelectric process
- Mean gain and θ consistent for all intensities
  - robust fit
- Simultaneous measurement of 37Ar
  - measurement of mean number of ionisation electrons for the gas mixture (first results in argon consistent with literature)

Gas quality

- Oxygen captures drifting electrons → signal loss
- RGA monitors oxygen contamination
- Gas purifier removes oxygen from gas mixture





- Gain very sensitive to gas pressure
- Continuous monitoring of pressure
- measurement of dependence

Conclusions and outlook

- NEWS-G has an ambitious program of WIMP detection with SPCs
- Intensive work provided great improvement in detector performance and understanding
  - improved electric field and gas purity
  - detailed measurement of amplification and drift parameters

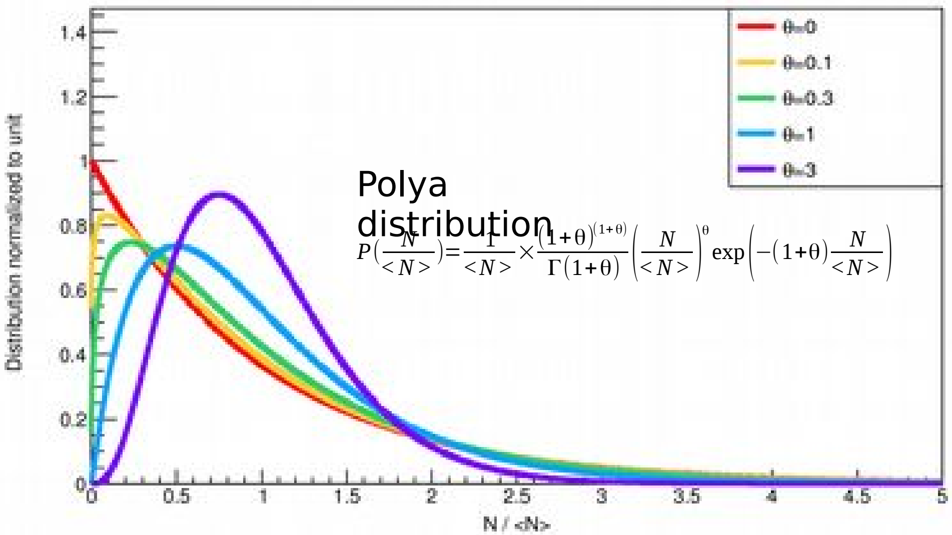
NEWS-G collaboration 2018

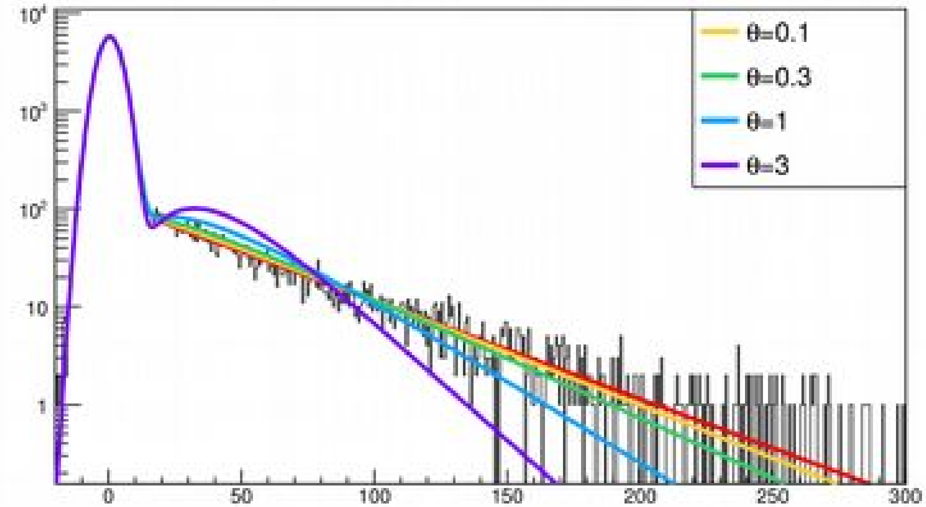
- **Queen's** University Kingston – **G Gerbier,** P di Stefano, R Martin, G Giroux, T Noble, D Dunrford, S Crawford, M Vidal, A Brossard, P Vazquez dS, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier, A Ronceray, P Gros, J Morrison, C Neyron
  - Copper vessel and gas set-up specifications, calibration, 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
  - 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
- **Pacific National Northwest Lab**– E Hoppe, R Bunker
  - 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
- **University of Birmingham**– K Nikolopoulos, P Knights
  - Simulations, analysis, R&D
- **Associated labs : TRIUMF** - F Retiere,

Apr 2018

Laser calibration measurements

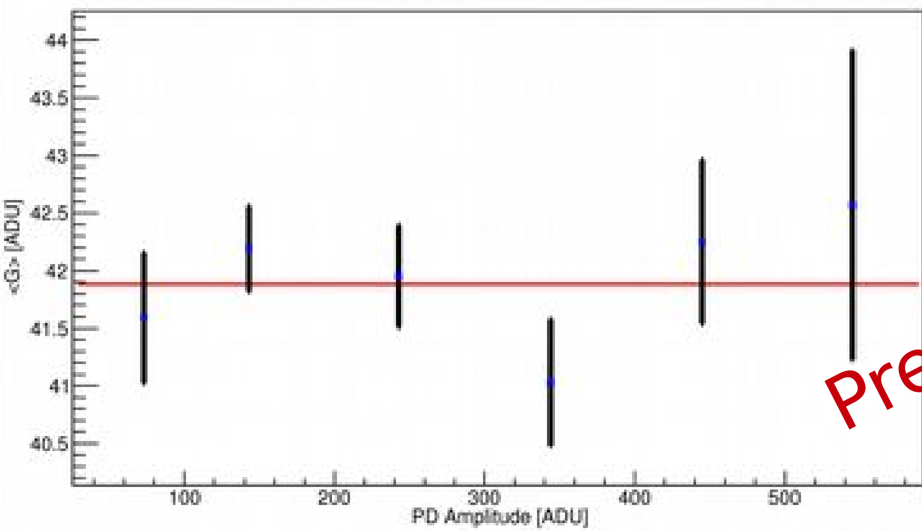
Parametrization of the Single Electron Response (SER)

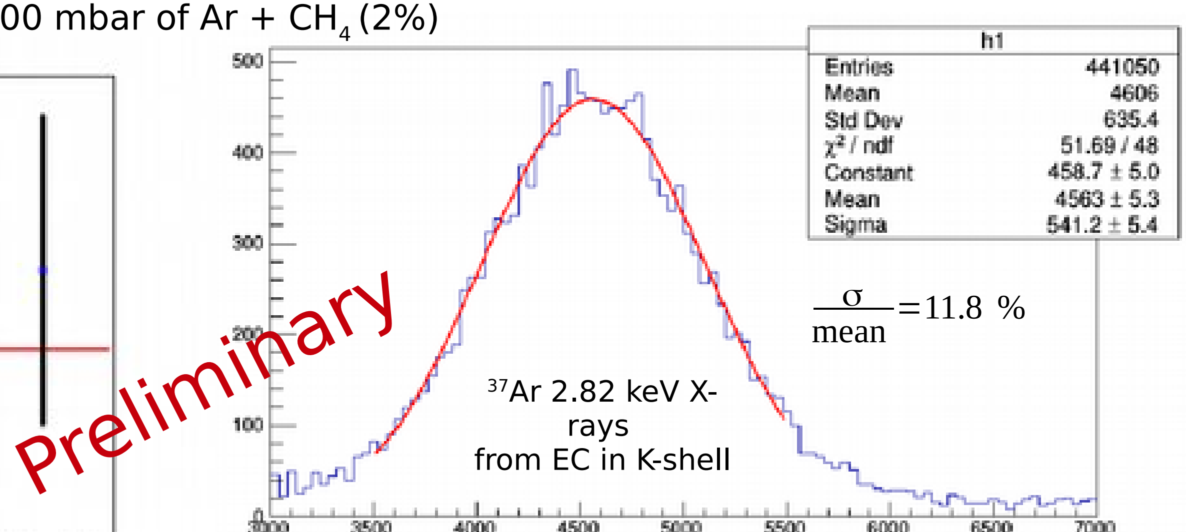




W-value measurement and upper limit on the Fano factor

in 500 mbar of Ar + CH_4 (2%)





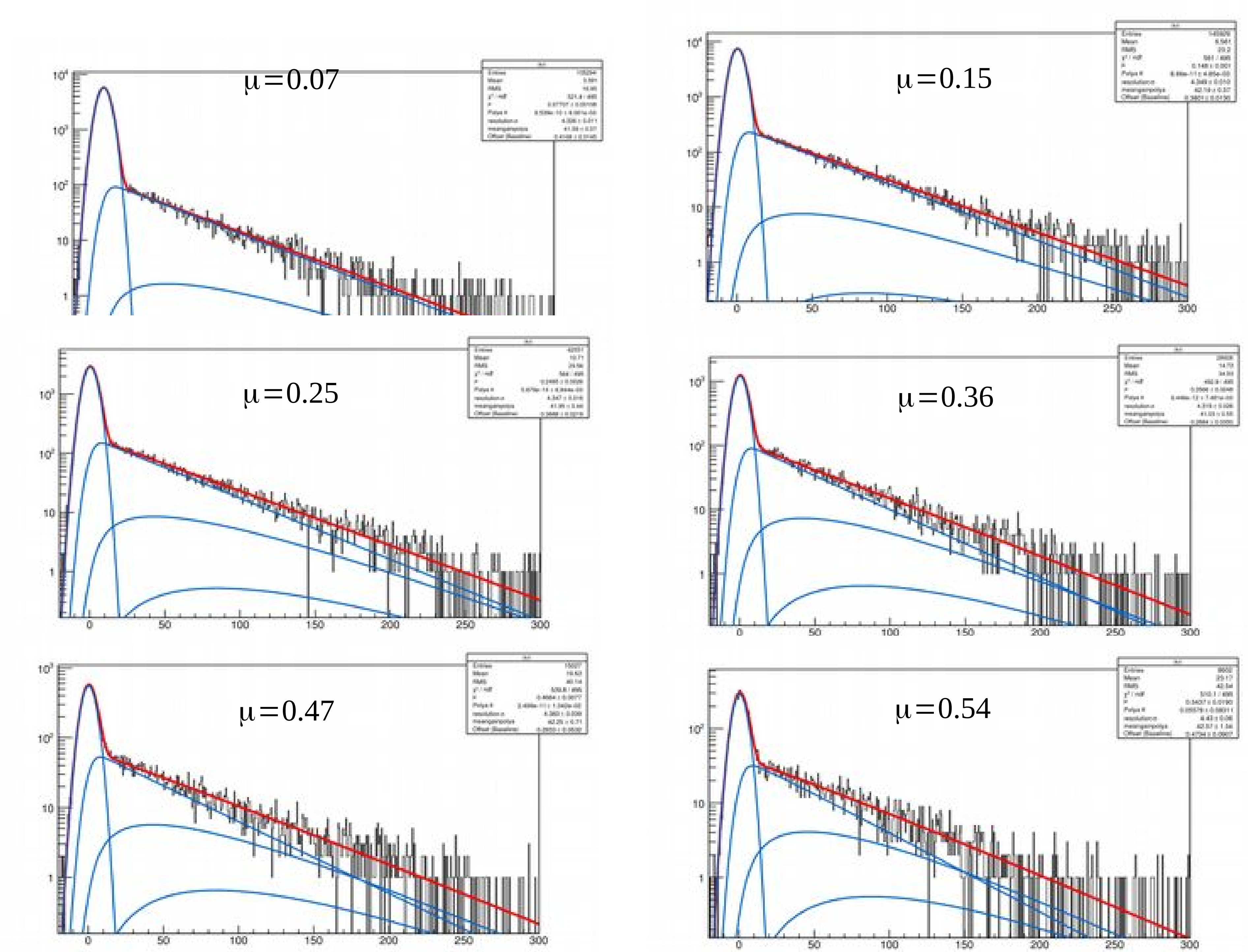
⟨Gain⟩ ~ 41.9 ADU
&
2820 keV peak @ 4563 ADU

W ~ 25.9 eV

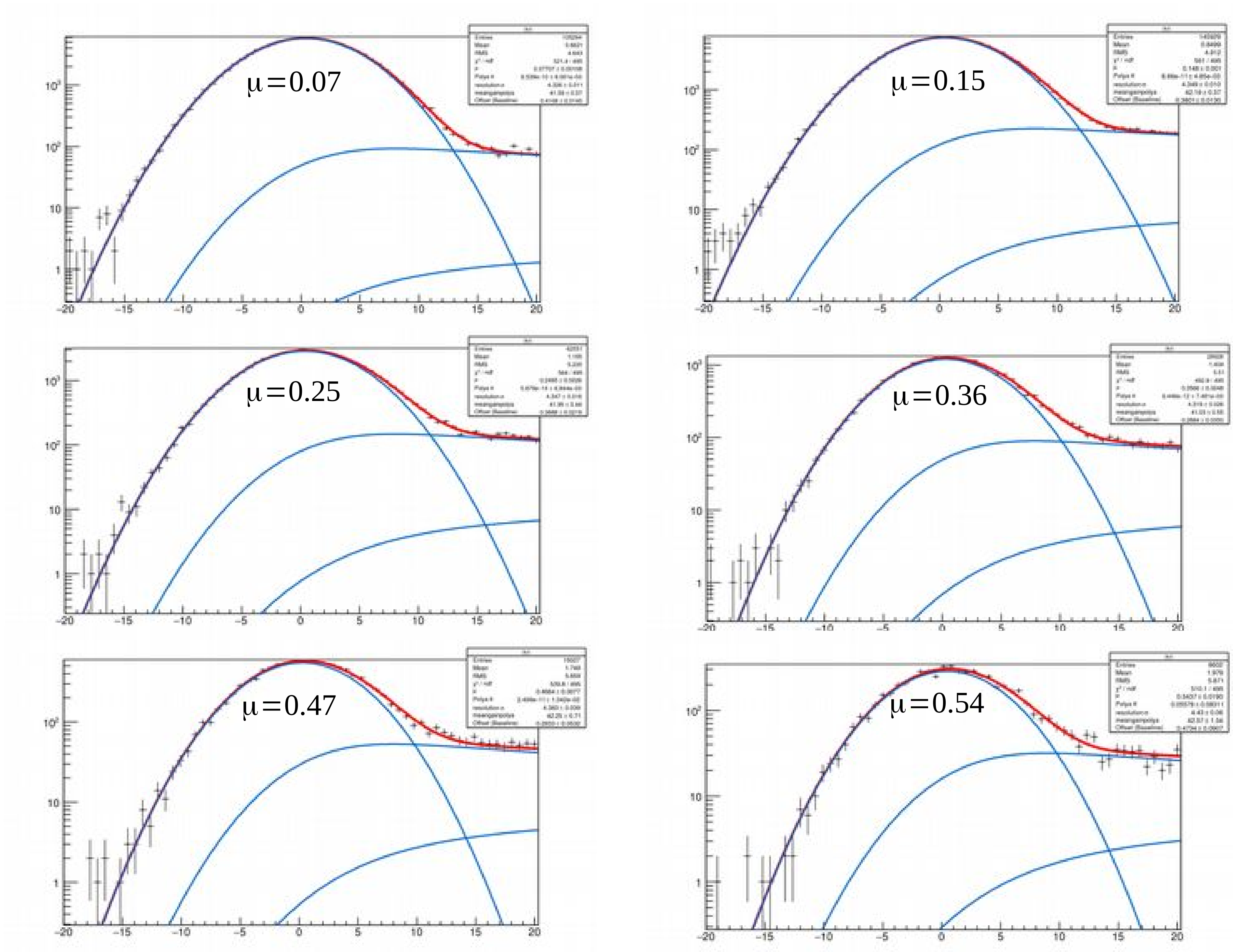
$$\left(\frac{\sigma}{\text{mean}}\right)^2\times\frac{E_R}{W}=\left(F+\frac{1}{1+\theta}\right)$$

F < 0.53

Fit of our model to Real data



Fit of our model to Real data (zoom in the low energy region)

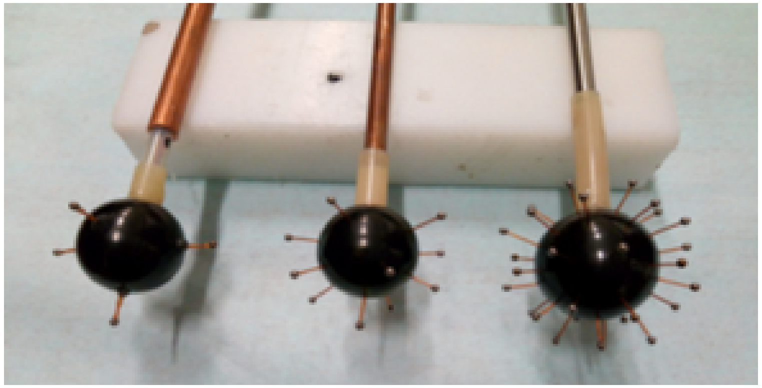


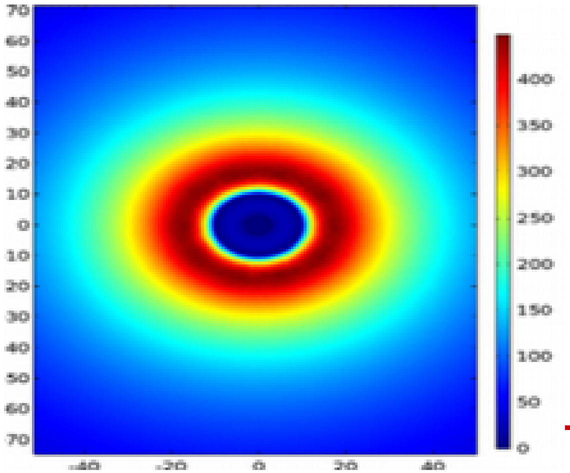
-Amplification is driven by the ball size. Smaller ball gives higher amplification.

-Electric field far from the sensor is proportional to sensor radius. In large diameter sphere, a too small sensor gives a too weak electric field at large distance, then electron attachment induce a loss of signal.

Achinos sensor

$$E(r) \approx \frac{V}{r^2} r_{anode}$$

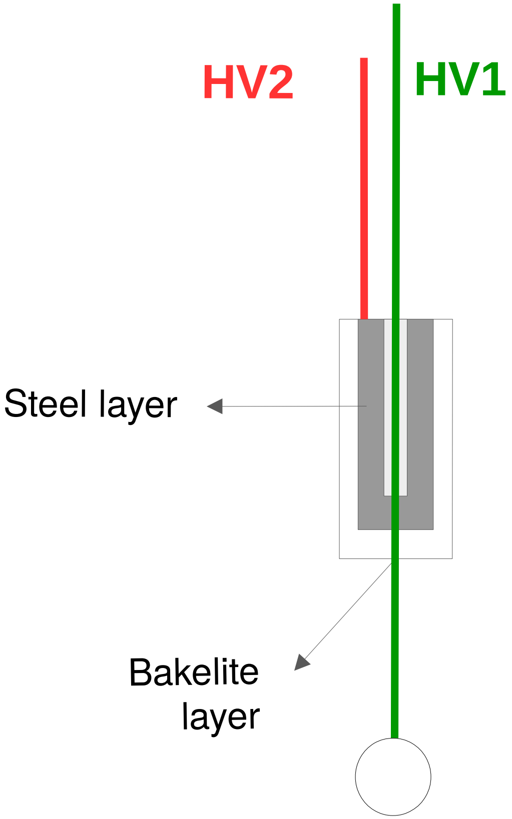


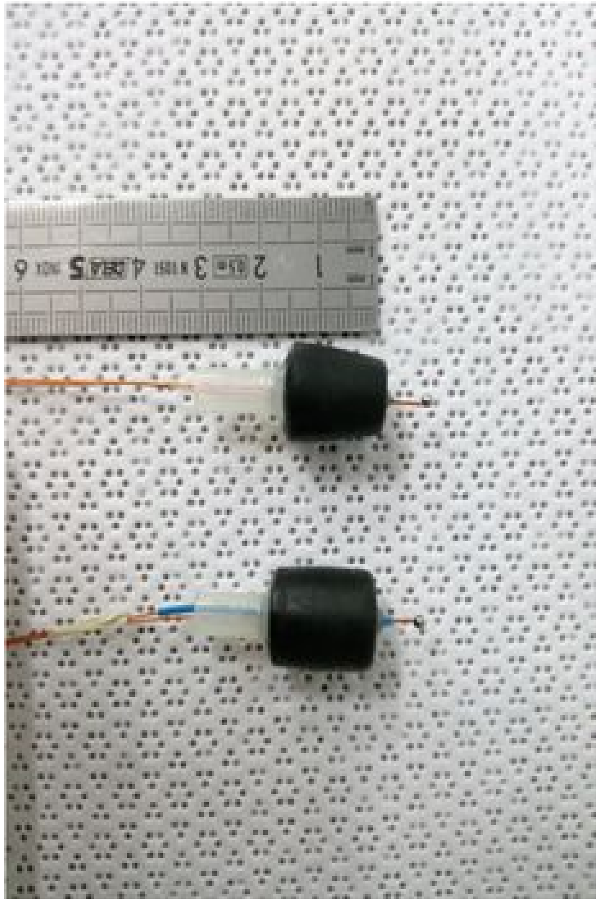


-Amplification is driven by size of each small ball.

-Volume electric field is driven by Achinos structure

The bakelite resistive umbrella





Bakelite
Chemical Formula:
(C6-H6-O.C-H2-O)x

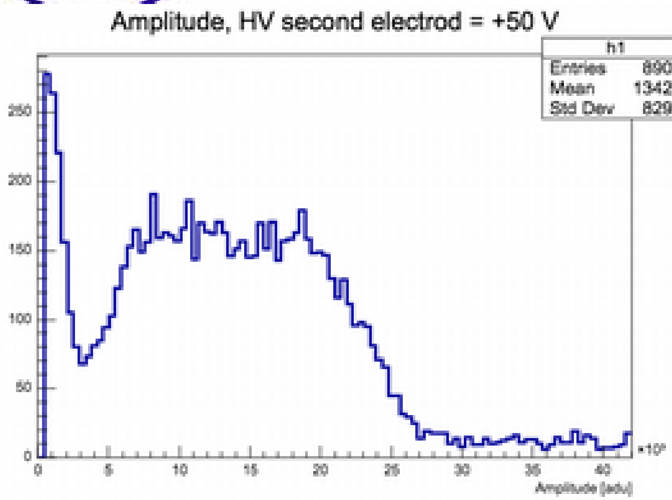
Thermosetting phenol formaldehyde resin, formed from a condensation reaction of phenol with formaldehyde.

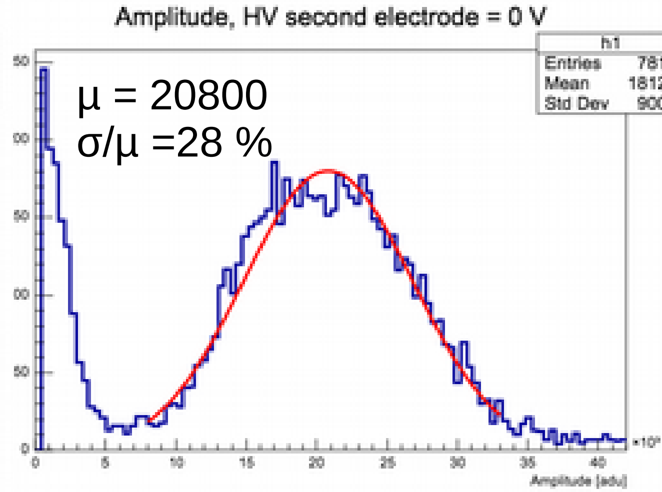
Advantages:

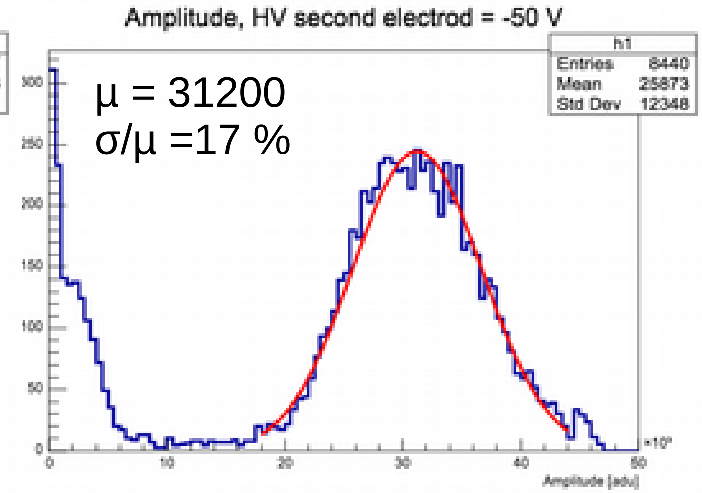
- Bakelite resistivity up to ~ 10^12 Ω.cm
- Compact and homogenous material

30 cm diameter sphere / Gas mixture: Ar + 2% CH_4 @ 500 mbar

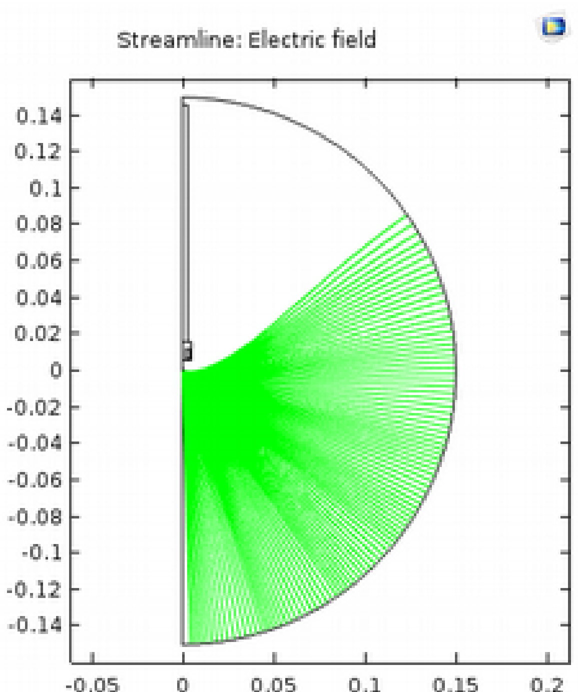
Source: ^{37}Ar Electronic capture released 0.27 or 2.8 keV



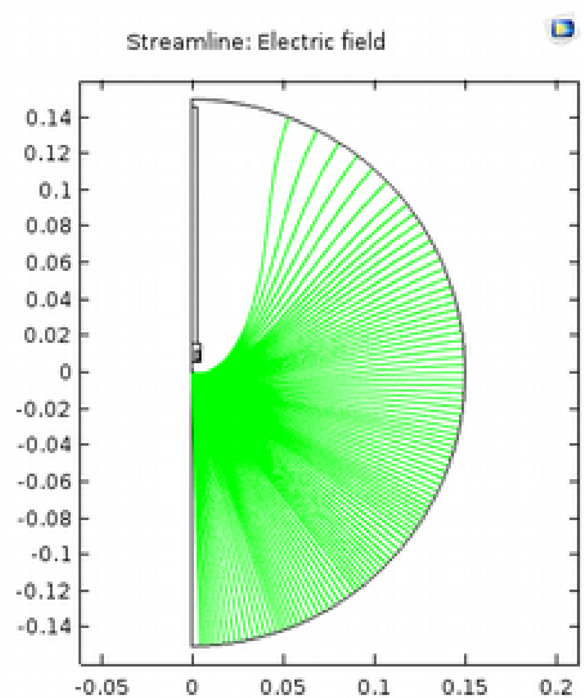




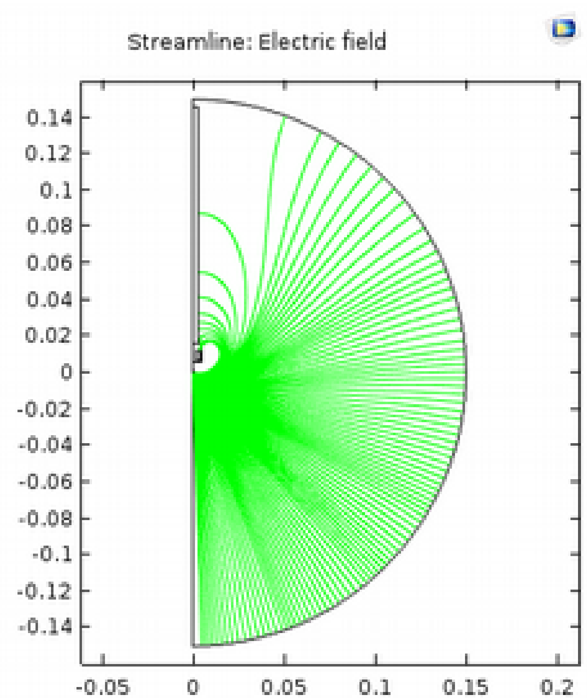
Electric filed lines reaching the lower half of the sensor



HV2 = +50 V



HV2 = 0 V



HV2 = -50 V