Search for light Dark Matter with NEWS-G

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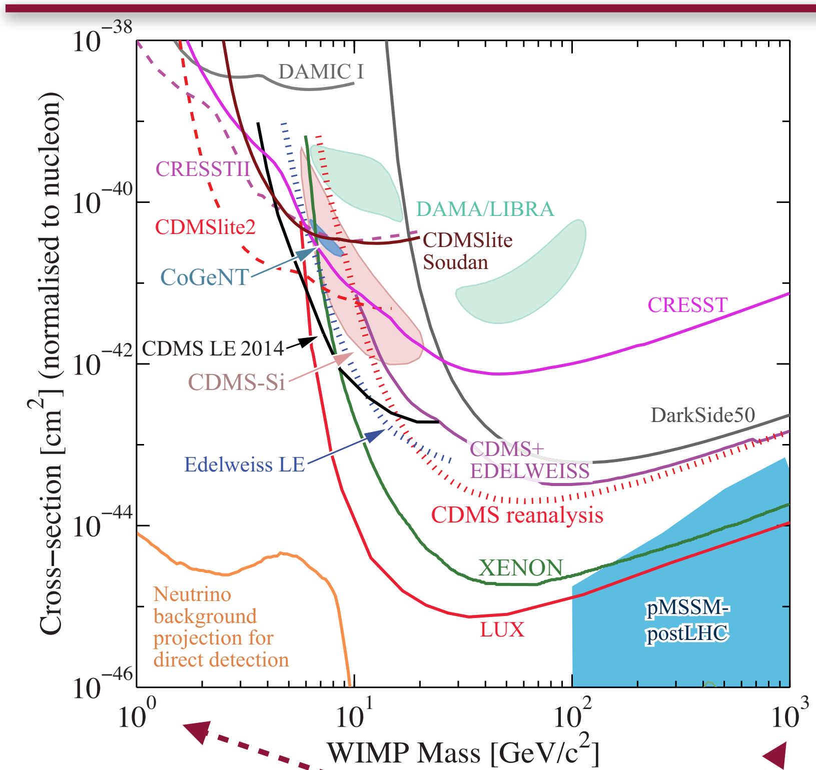
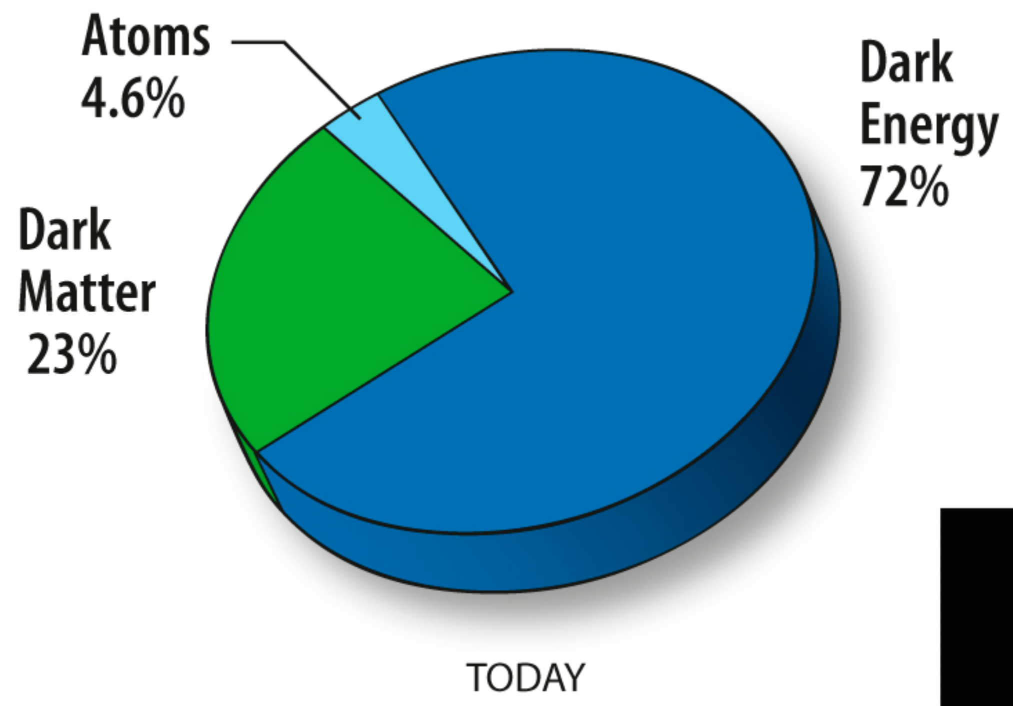
UNIVERSITY OF BIRMINGHAM

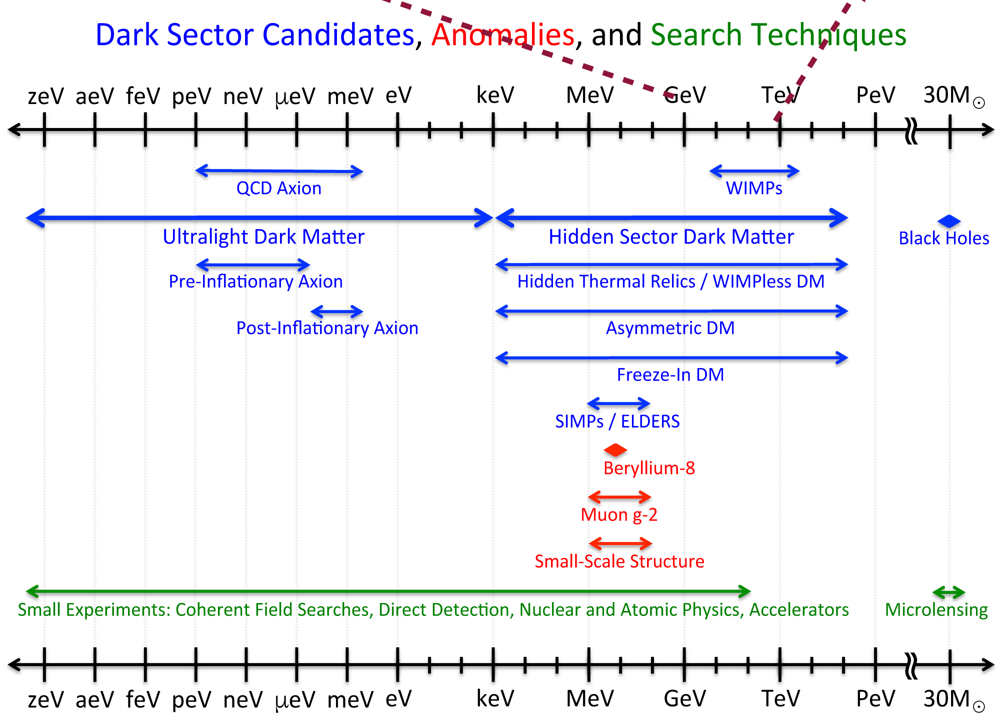
SEDINE prototype at LSM

Unravelling the Dark Matter Mystery
March 15, 2018, Durham University, UK

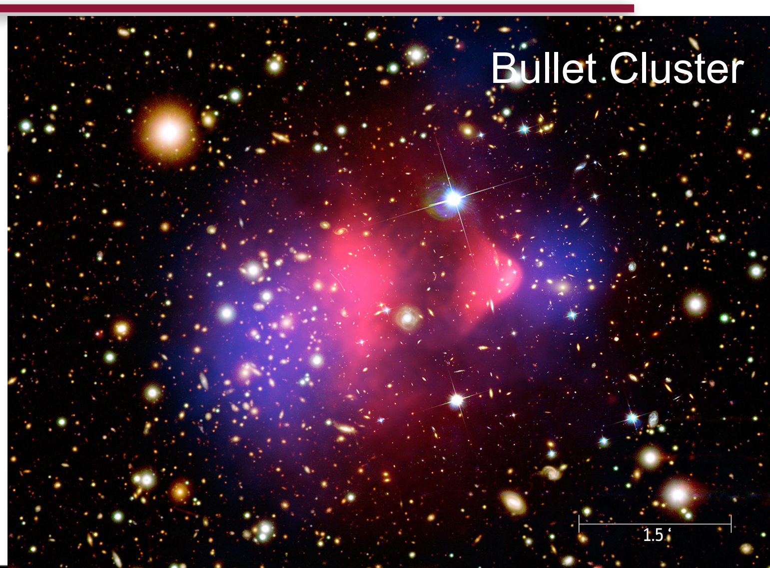
New Experiments With Spheres - Gas

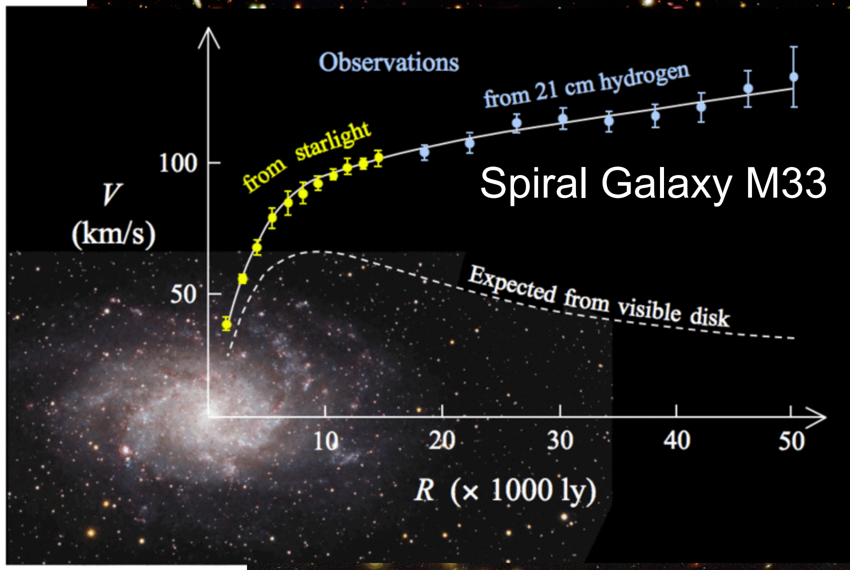


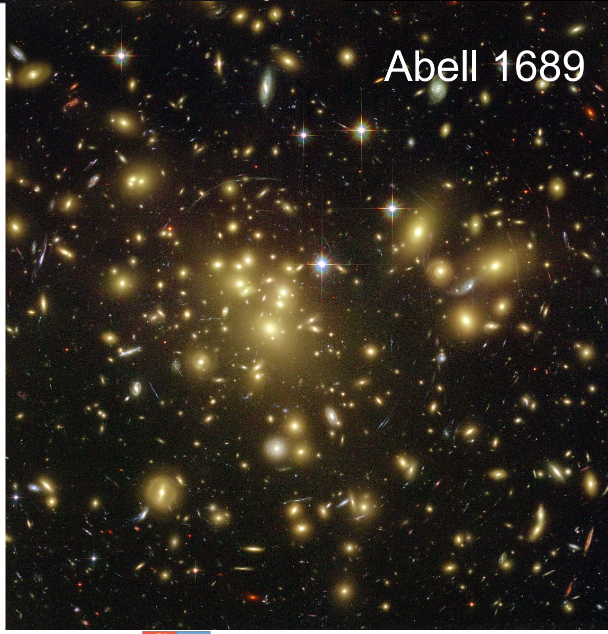




arXiv:1707.04591

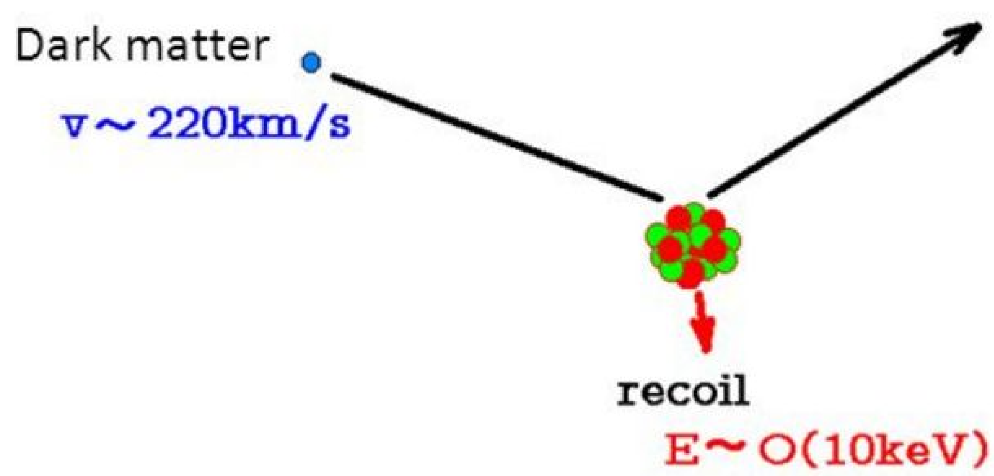


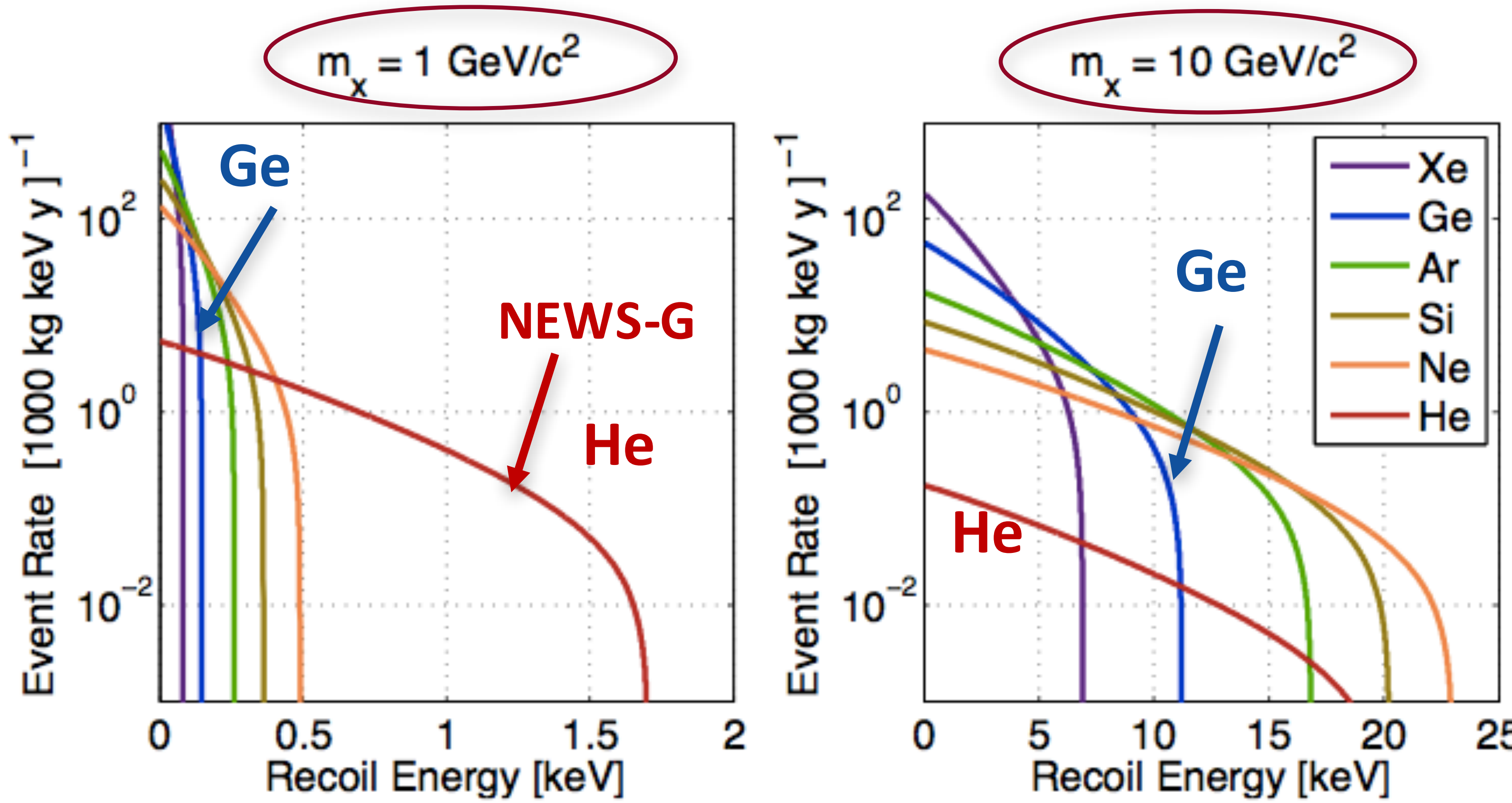




- Current state of affairs:
  - Evidence for the existence of Dark Matter
  - Absence of evidence in the WIMP-preferred region of masses
- Crucial to expand searches beyond this mass region

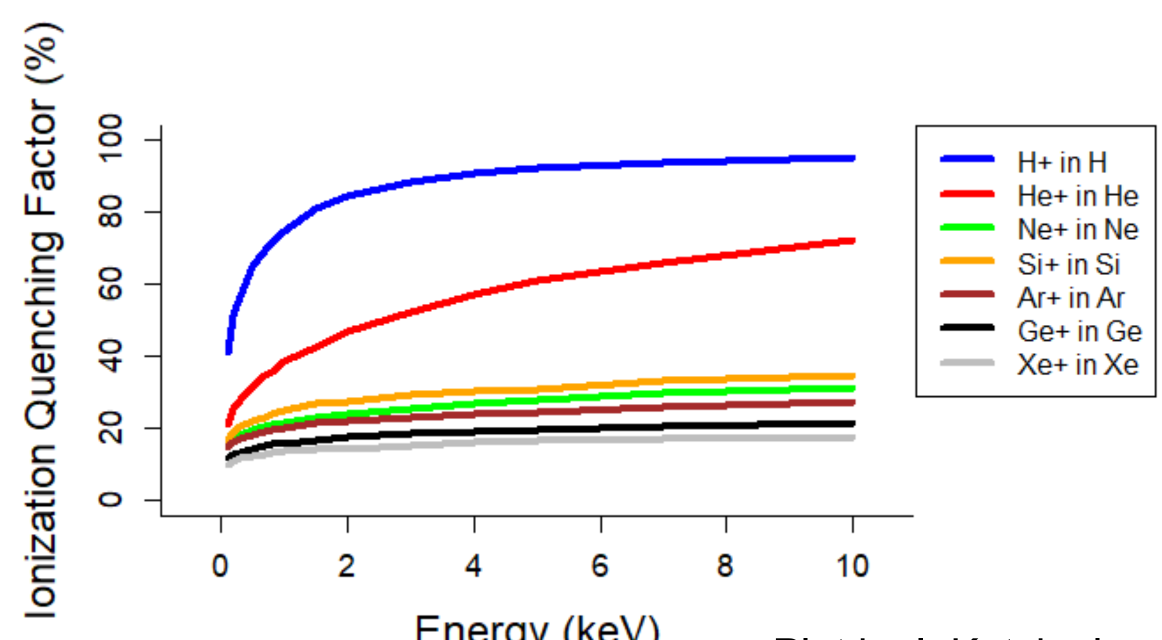
New Experiments With Spheres - Gas





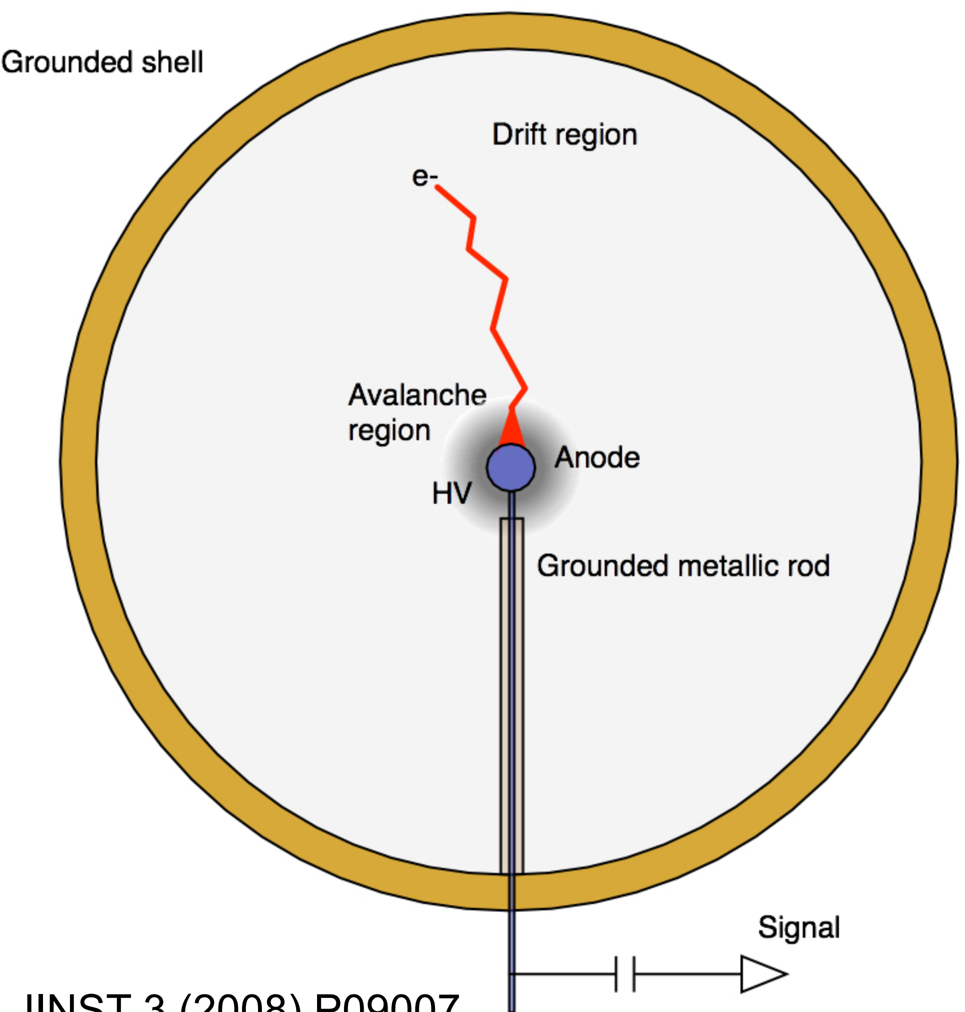
Recoil distributions with various targets

- Search for DM candidates: 0.1-10 GeV mass range
- Direct Detection experiment
  - Novel Spherical Gaseous Proportional Chamber
  - Light gases as target (H, He, Ne) for a better projectile - target kinematic match
  - Need low energy threshold and favourable quenching factor



Plot by I. Katsioulas

Spherical Proportional Counter



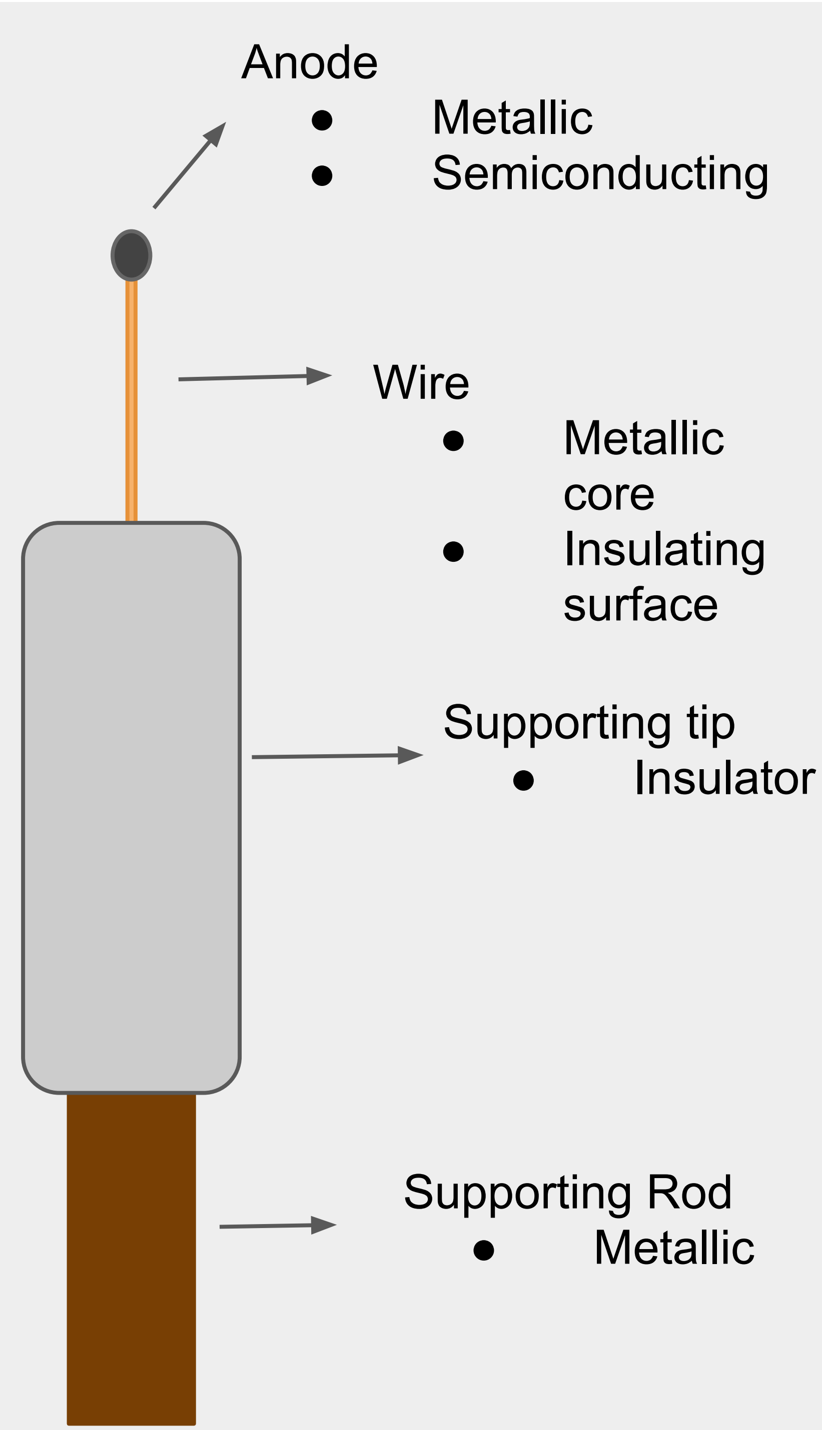
JINST 3 (2008) P09007

$$E = \frac{V_0}{r^2}\frac{r_1 r_2}{r_2 - r_1} \approx \frac{V_0 r_1}{r^2}$$

$$C = \frac{4\pi\epsilon}{r_2 - r_1} r_1 r_2 \approx 4\pi\epsilon r_1$$

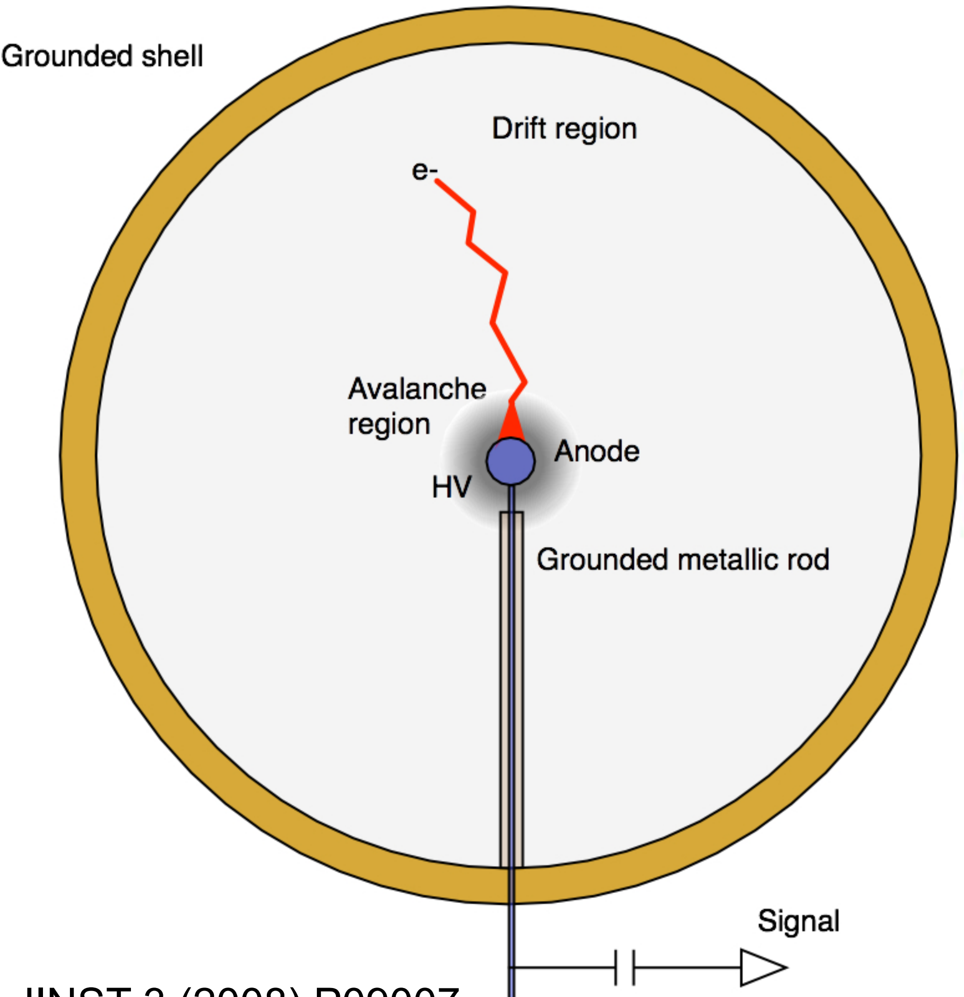
$$r_1 = \text{anode radius}$$

$$r_2 = \text{cathode radius}$$



Detector volume naturally divided in a “drift” and an “amplification” volume.

Spherical Proportional Counter



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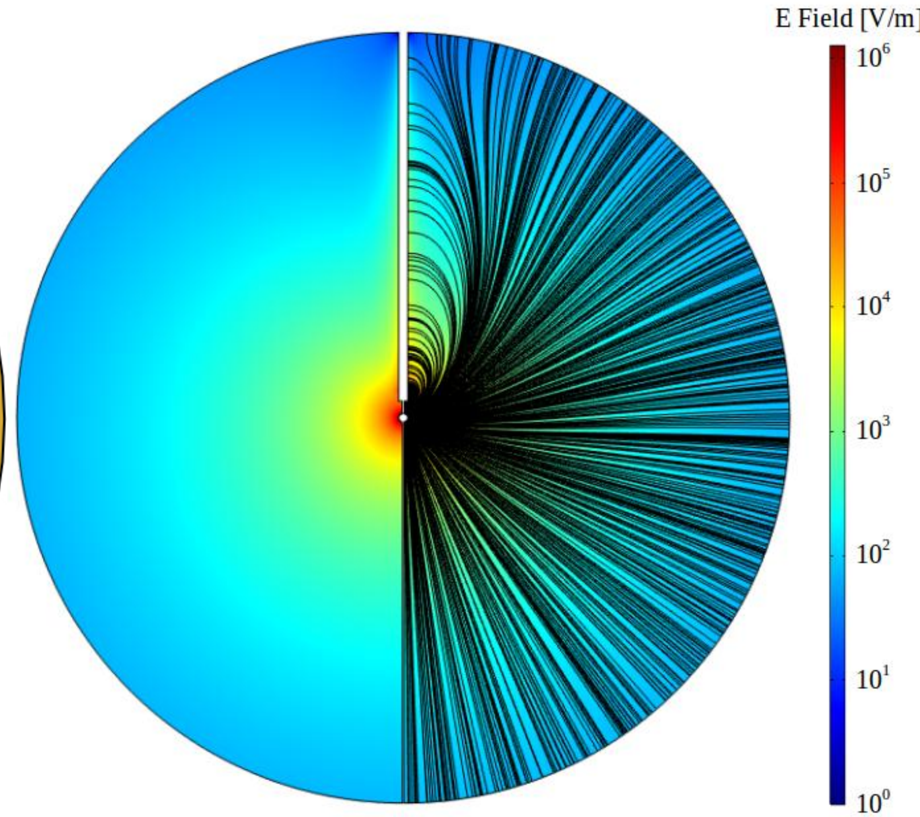
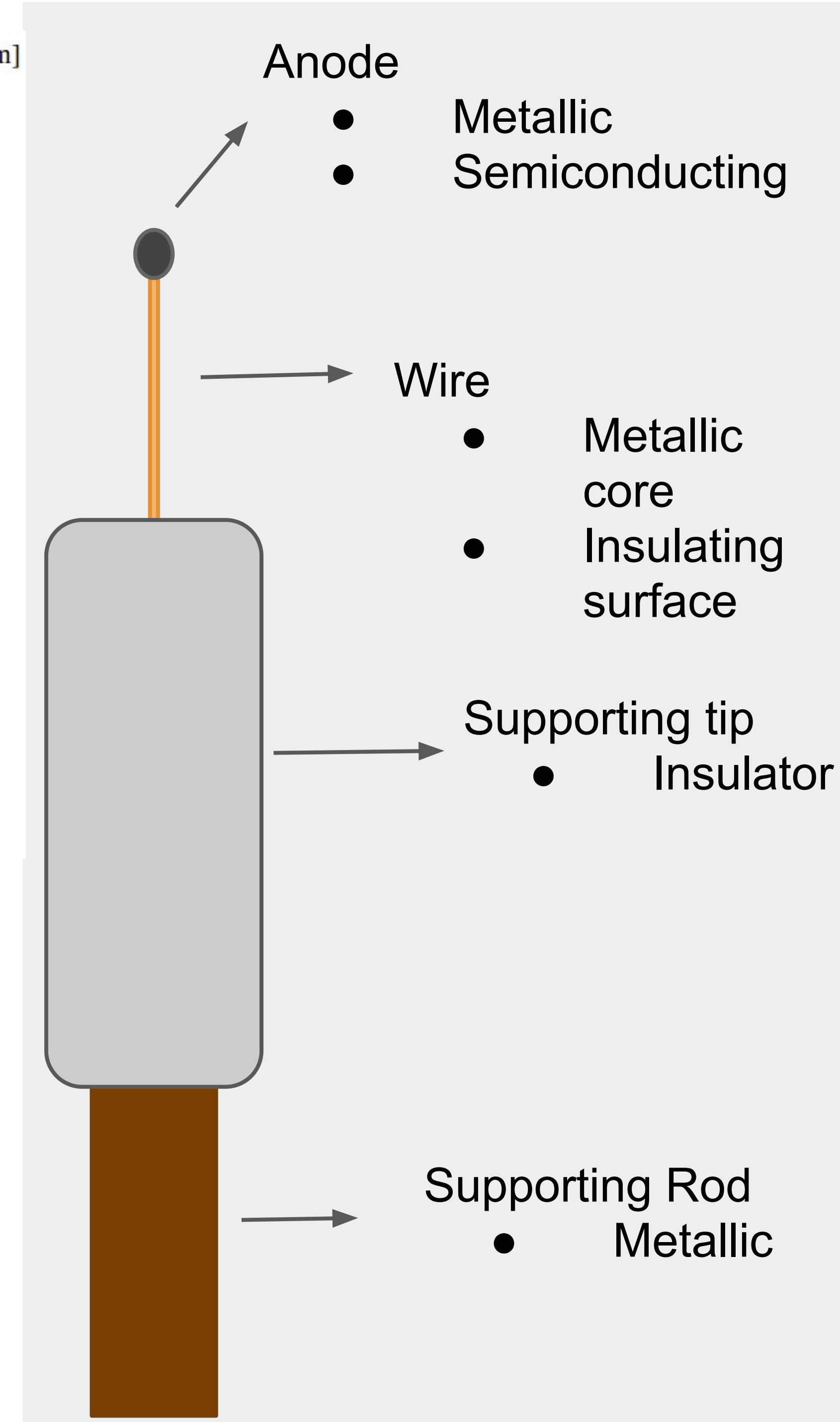


Realistic Electric Field



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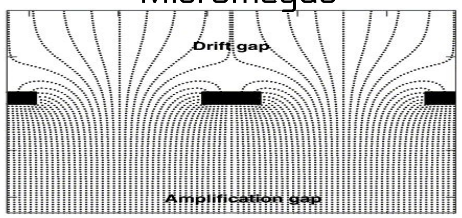
Detector volume naturally divided in a “drift” and an “amplification” volume.

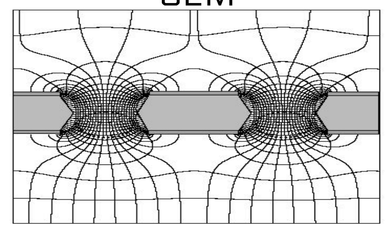
Spherical Proportional Counter

Capacitance dependence on size

Micromegas

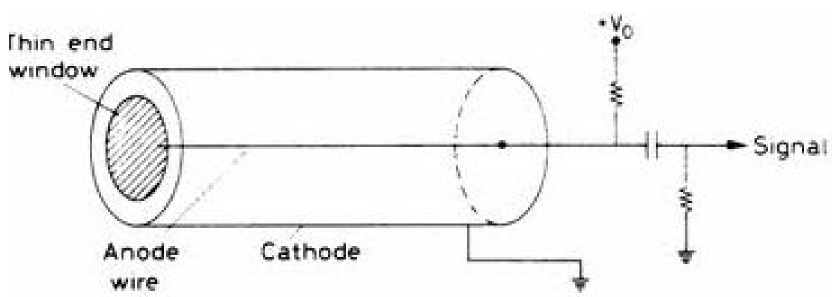


GEM



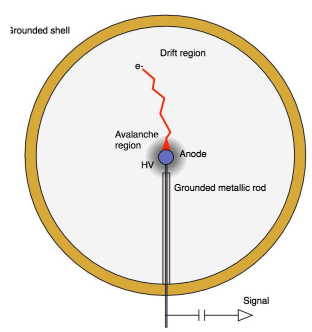
Parallel Plate Detector

$$C \approx S > 1\text{nF}$$



Cylindrical Proportional Counter

$$C = 2pL/\ln(b/a) >> 10\text{ pF}$$



Spherical Proportional Counter

$$C \approx r_1 < 1\text{pF}$$

Large Size Detector
+
Robust construction

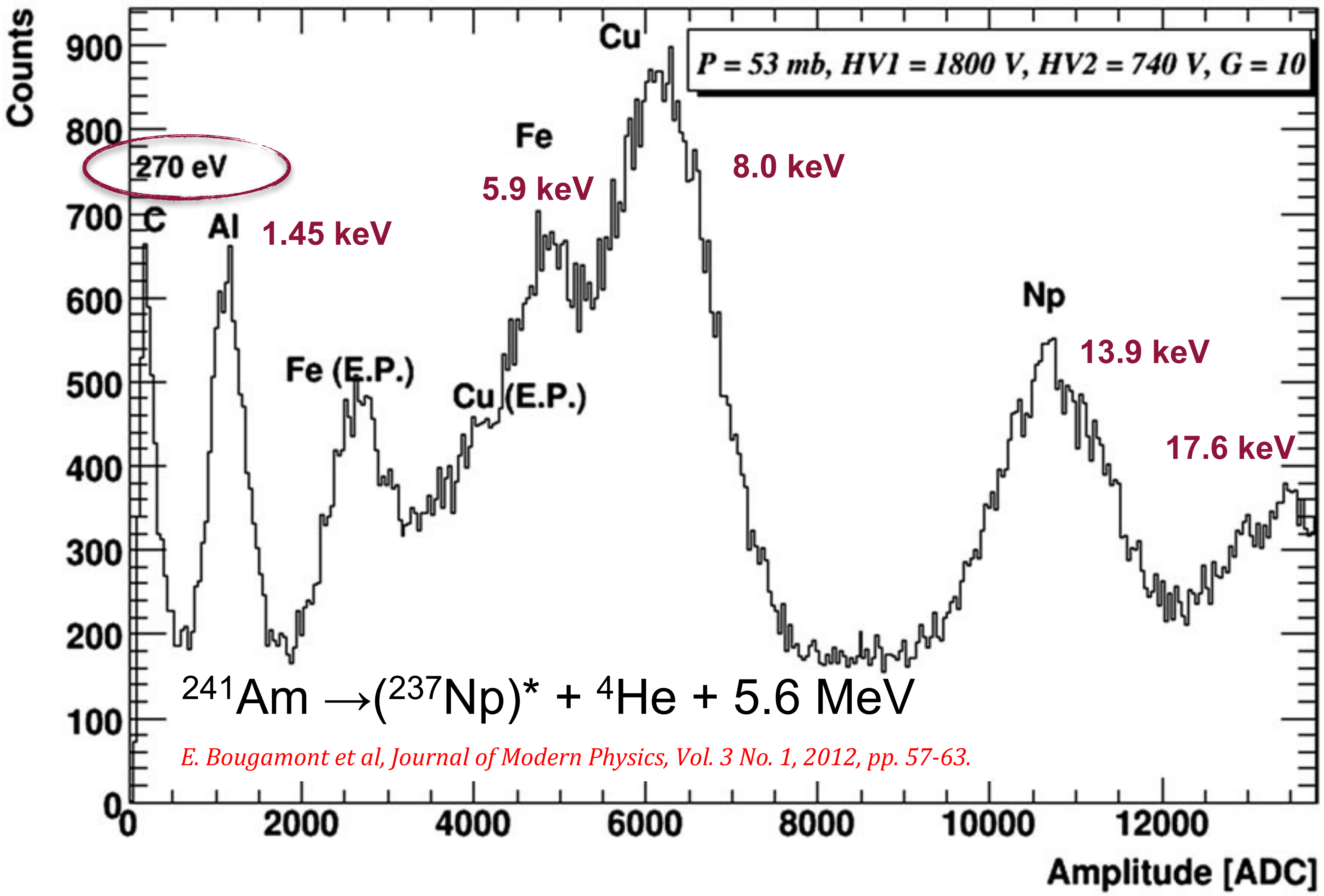
- Low Capacitance
  - Low noise → Low energy threshold
- Fiducial volume selection
  - Through pulse shape analysis
- Flexible (pressure, gas)
- Large mass/volume with one readout channel
- Simple sealed mode

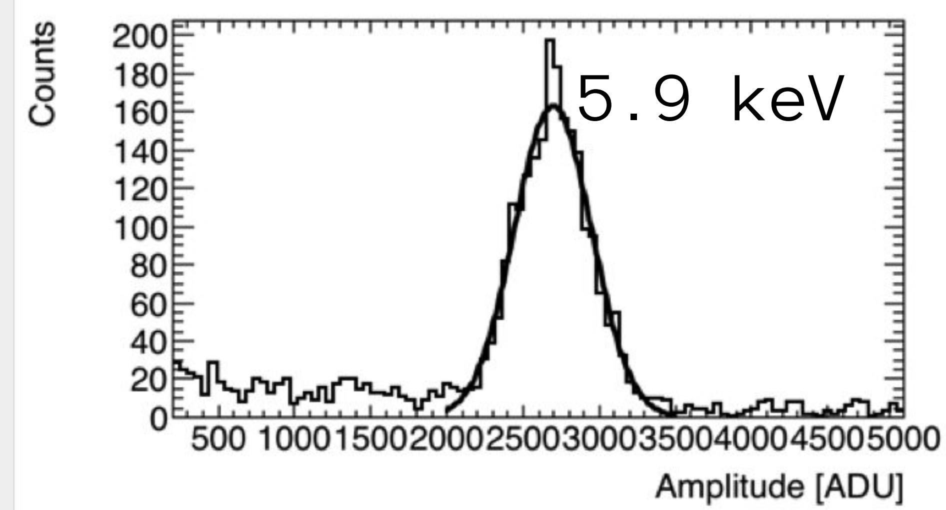
Spherical Proportional Counter

First Spherical Proportional Chamber made out of LEP RF Cavities

I. Giomataris and G. Charpak

Low Energy Capabilities





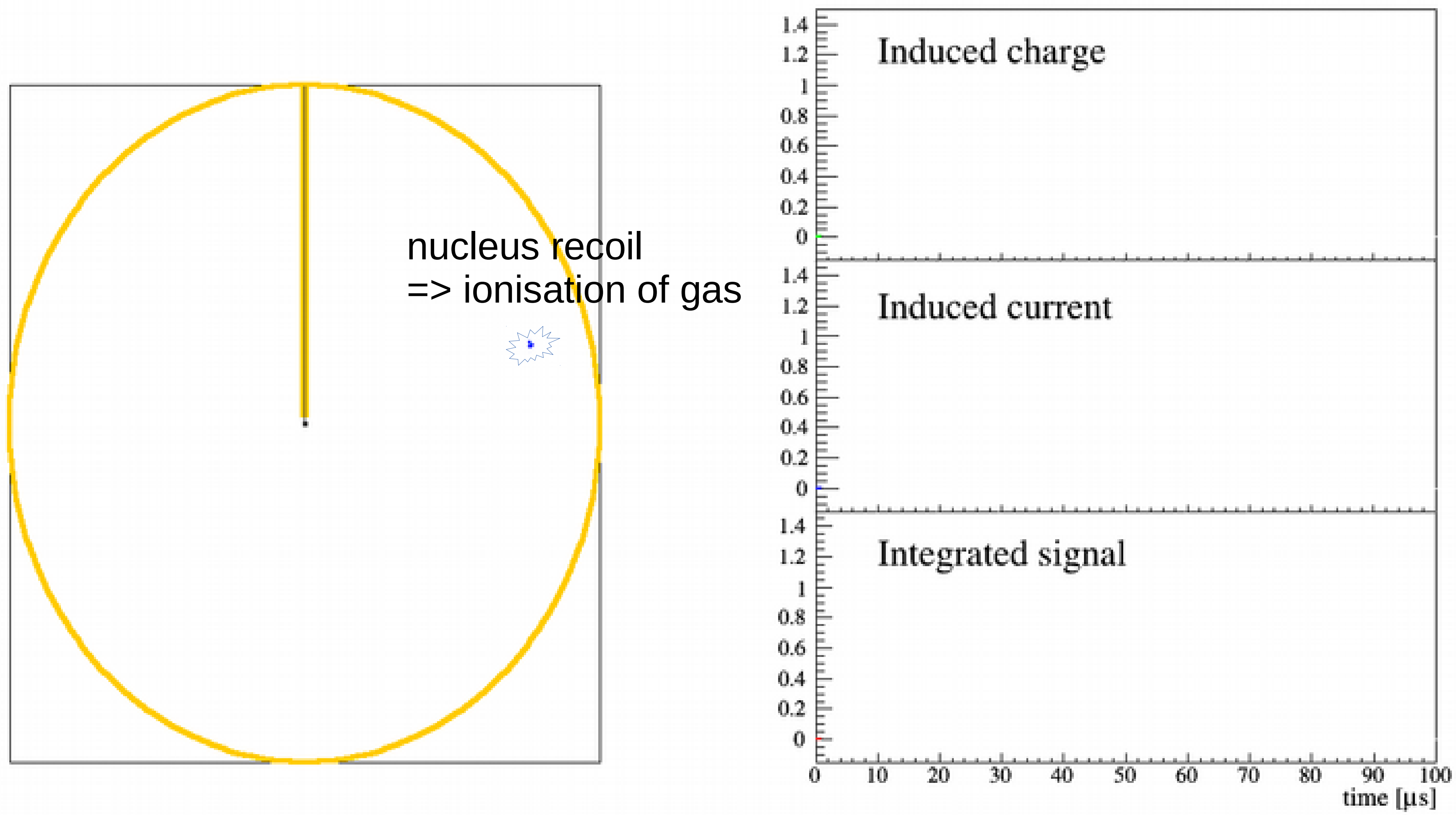
SPC Φ 30 cm

Irradiation by an ^{55}Fe source (5.9 keV)

Resolution (σ) <9%

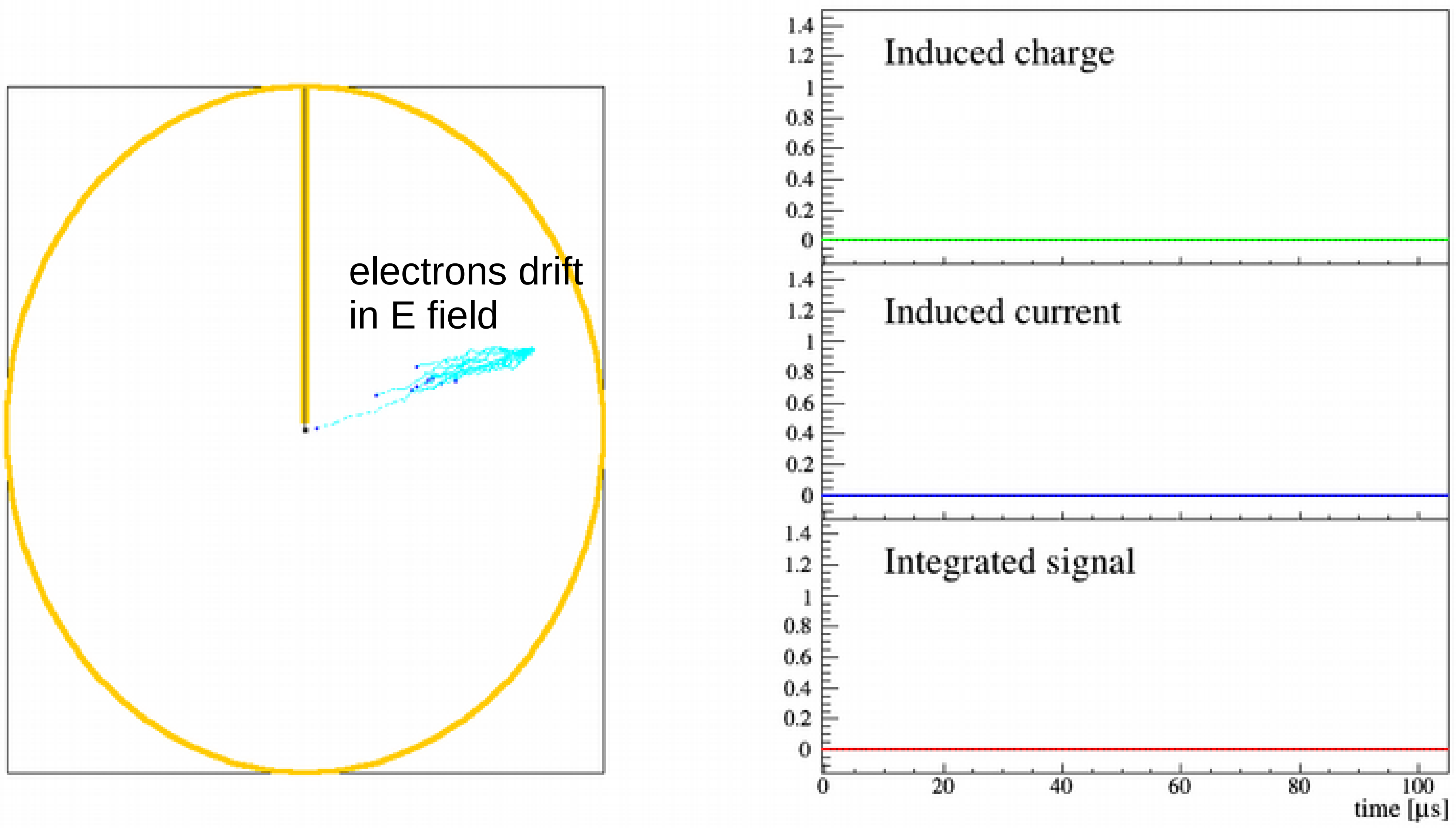
- SPC 130cm diameter
  - Ar + 2% CH_4
- Single Electron detection
- Energy threshold < 50 eV
  - Tested with single electrons extracted from Copper with UV lamp

Signal Formation



Plot by P. Gros

Signal Formation



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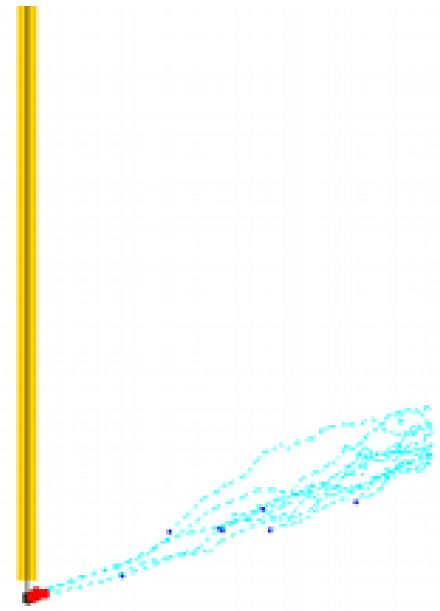
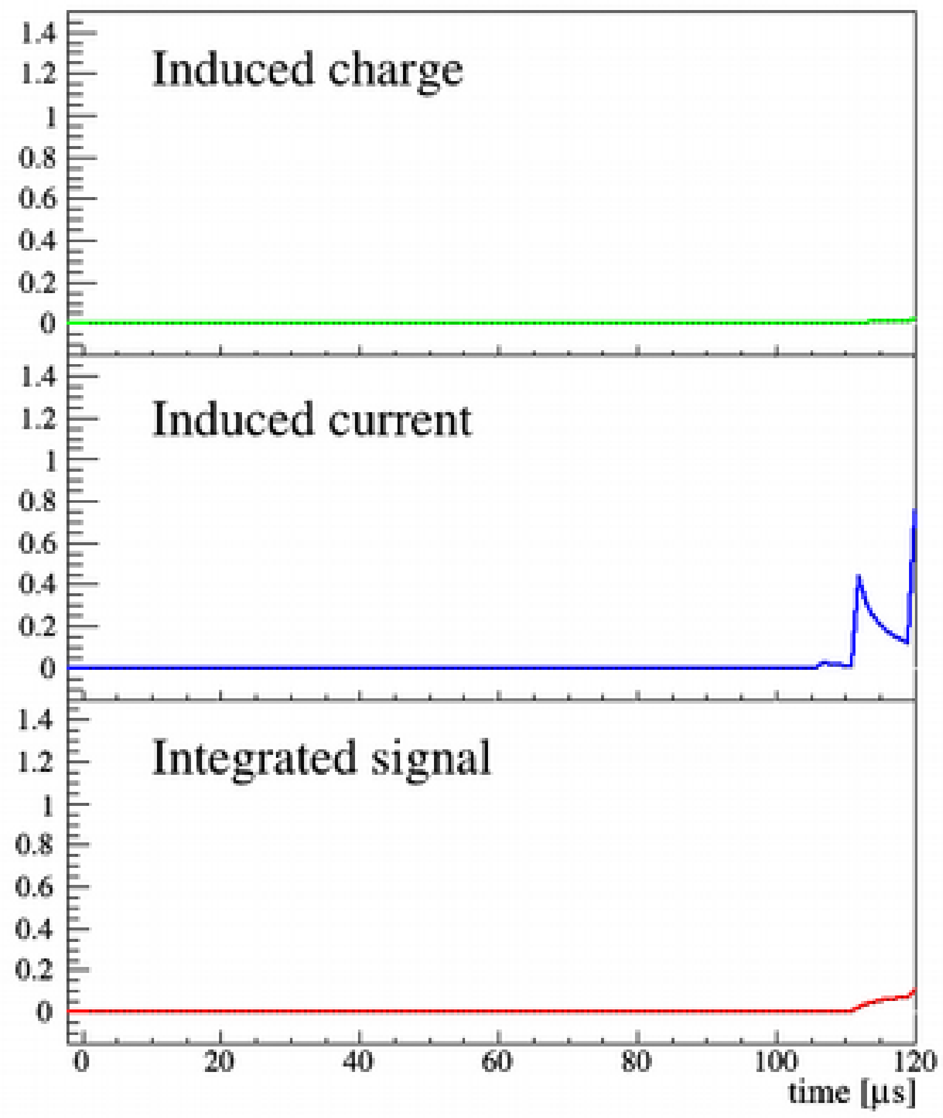


avalanche in high field near sensor



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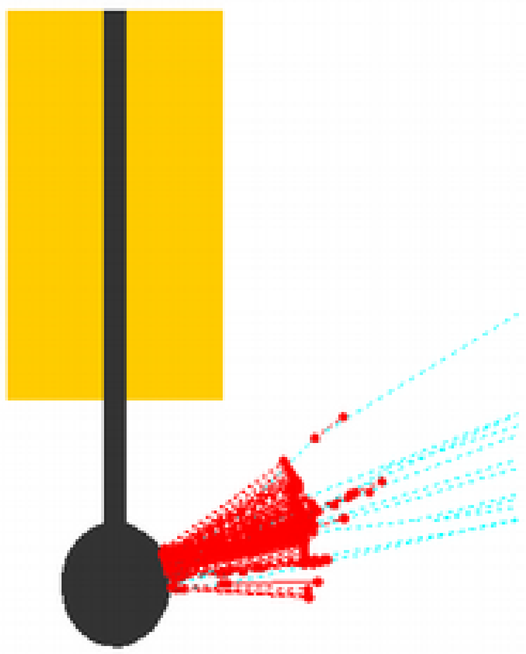
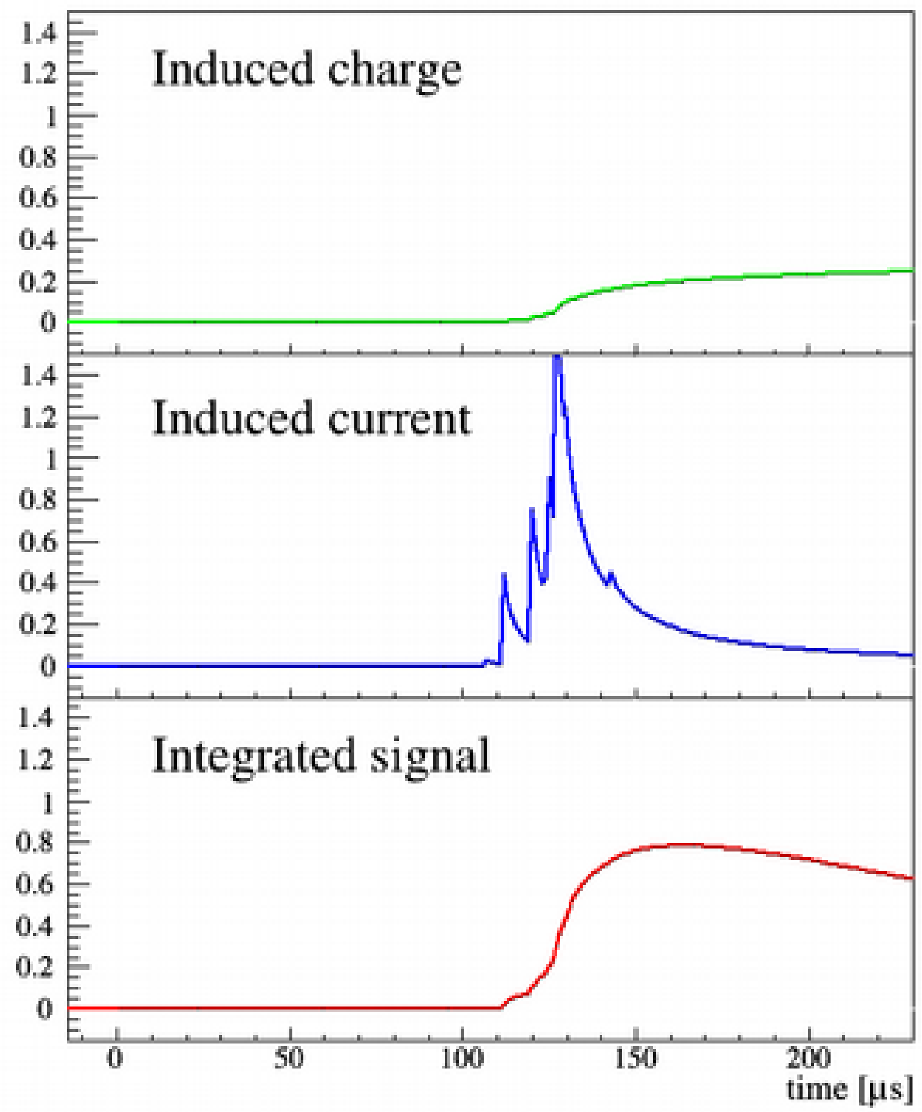


Signal induced by ions drifting back



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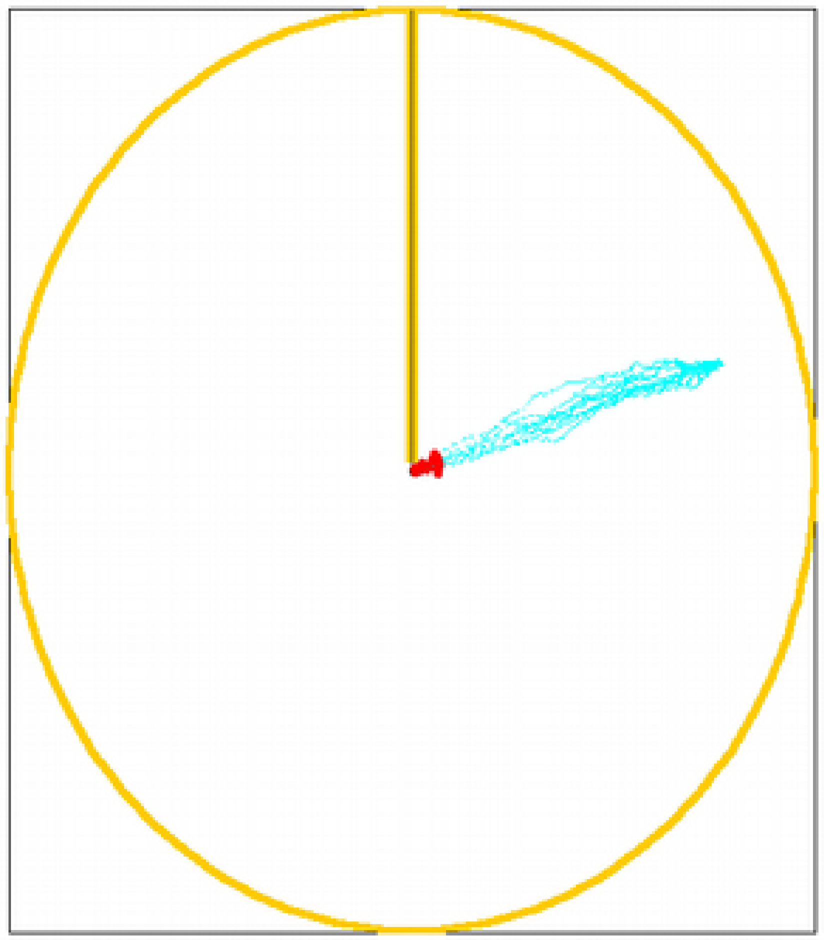
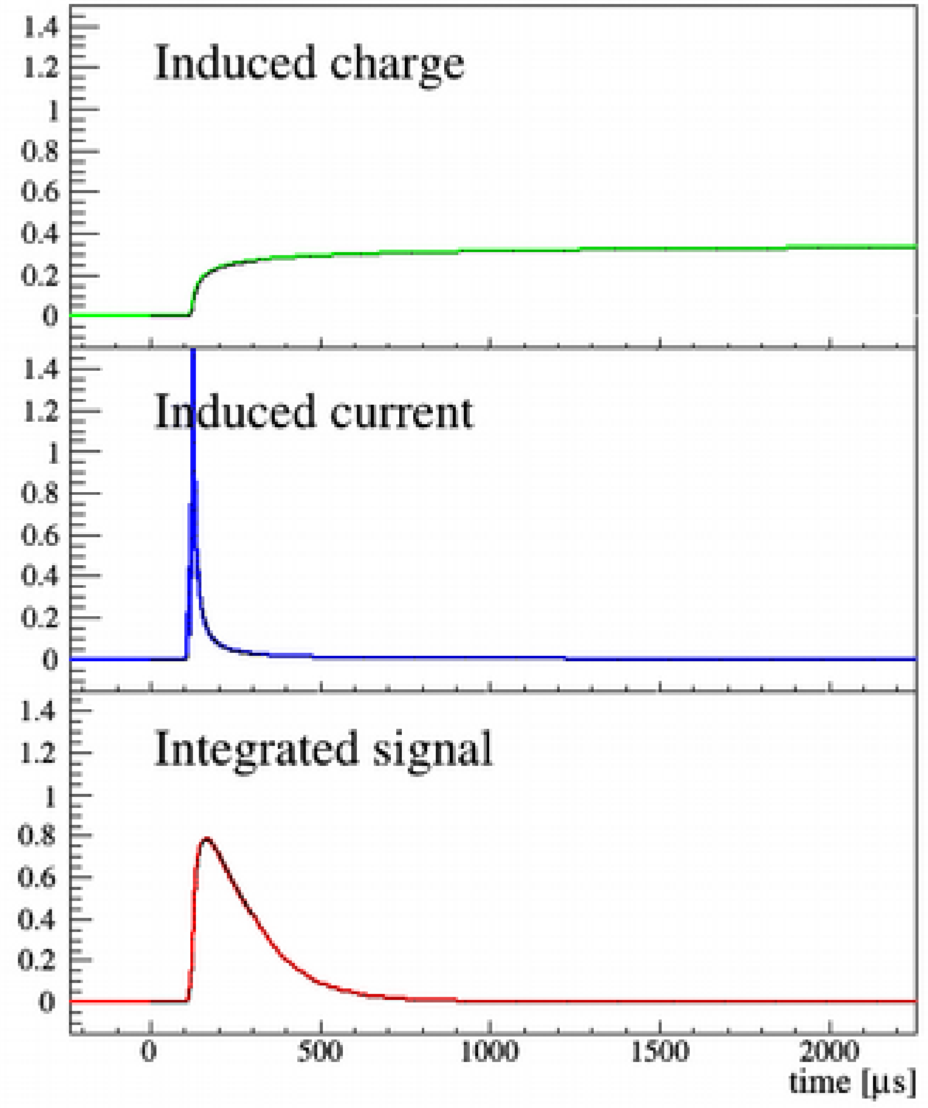
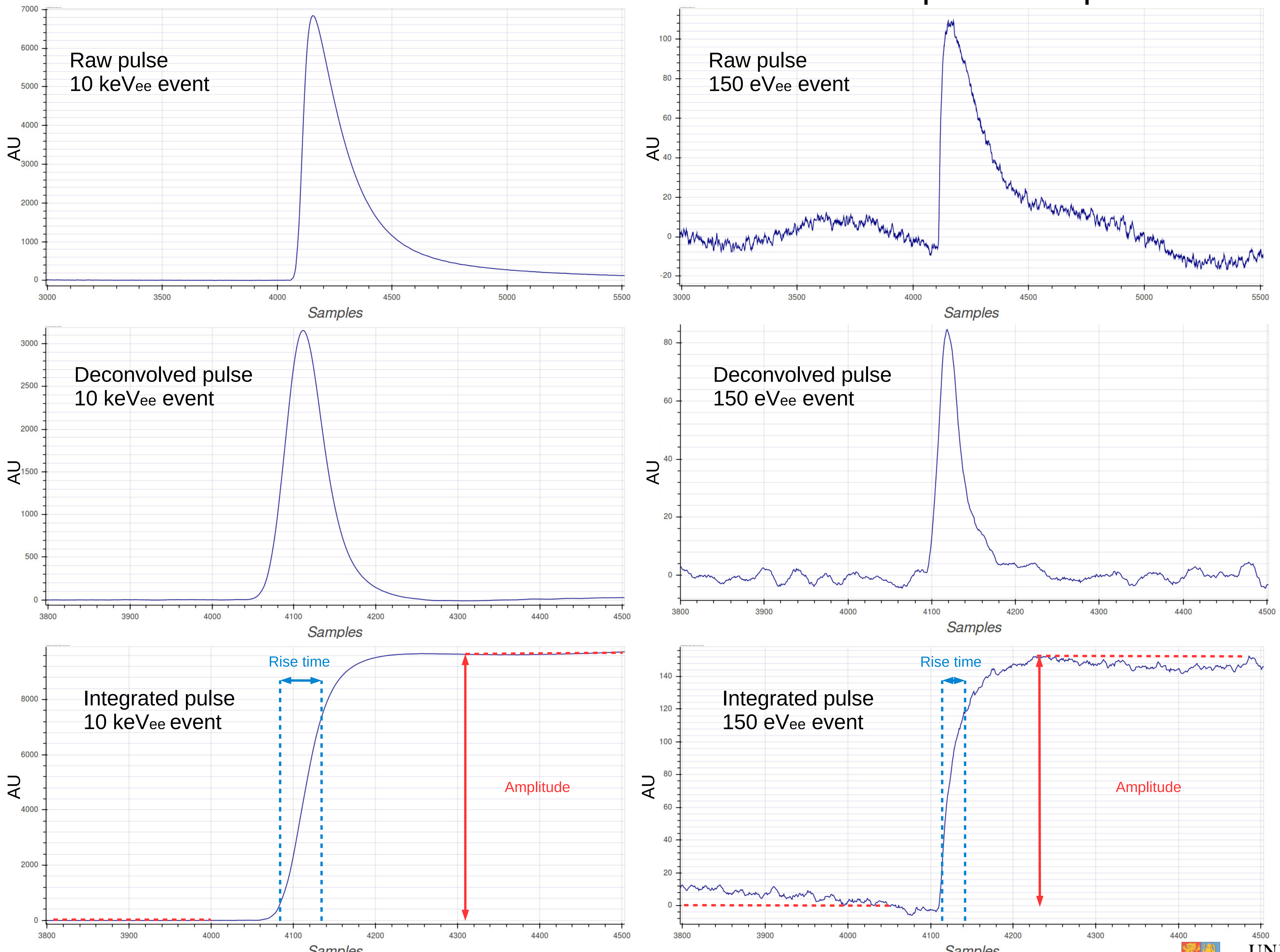




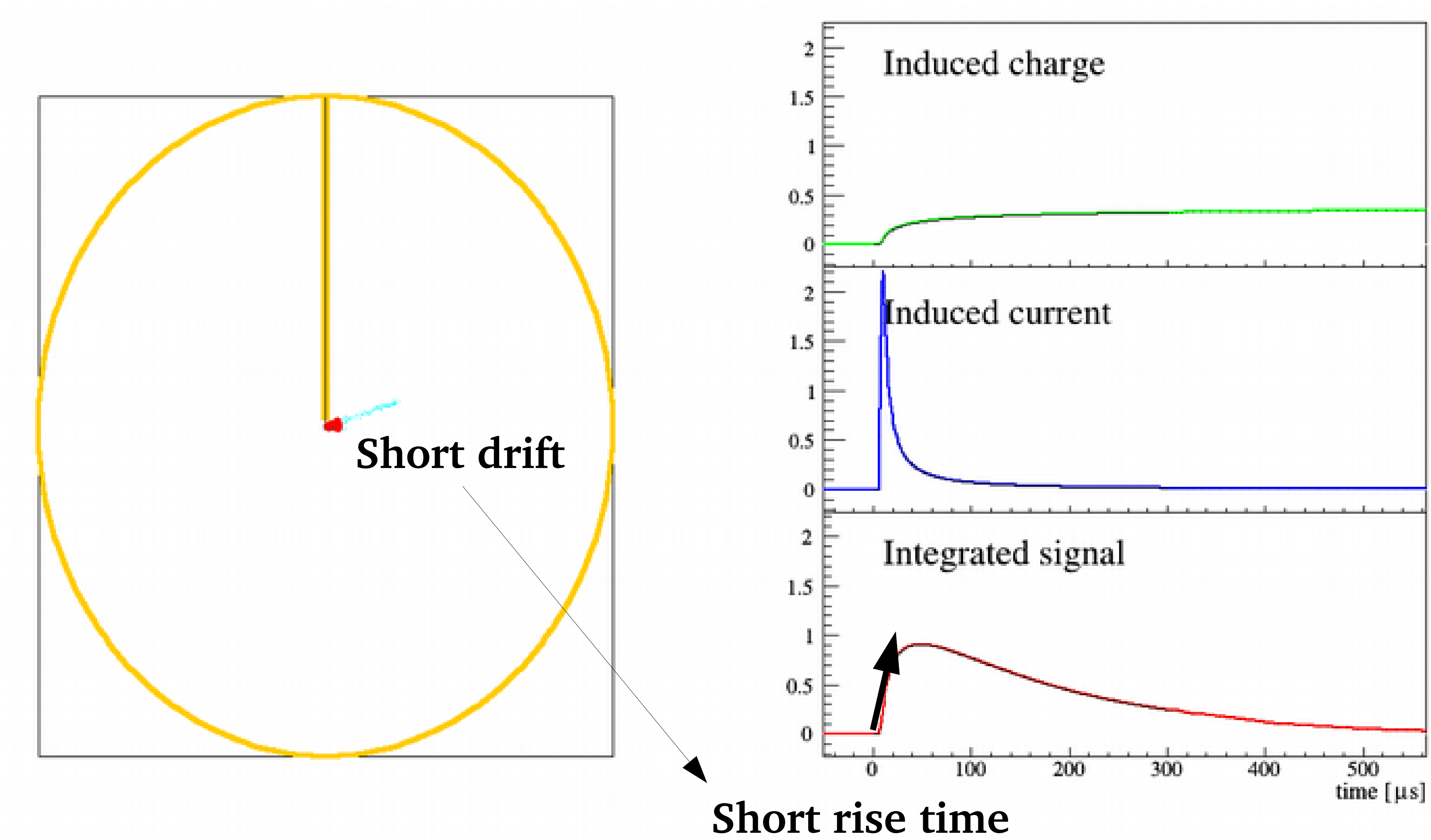
Plot by P. Gros

Pulse Treatment

Observed Pulse = Induced Current ⊗ Preamplifier Response



Background Rejection: Rise Time



Plot by P. Gros

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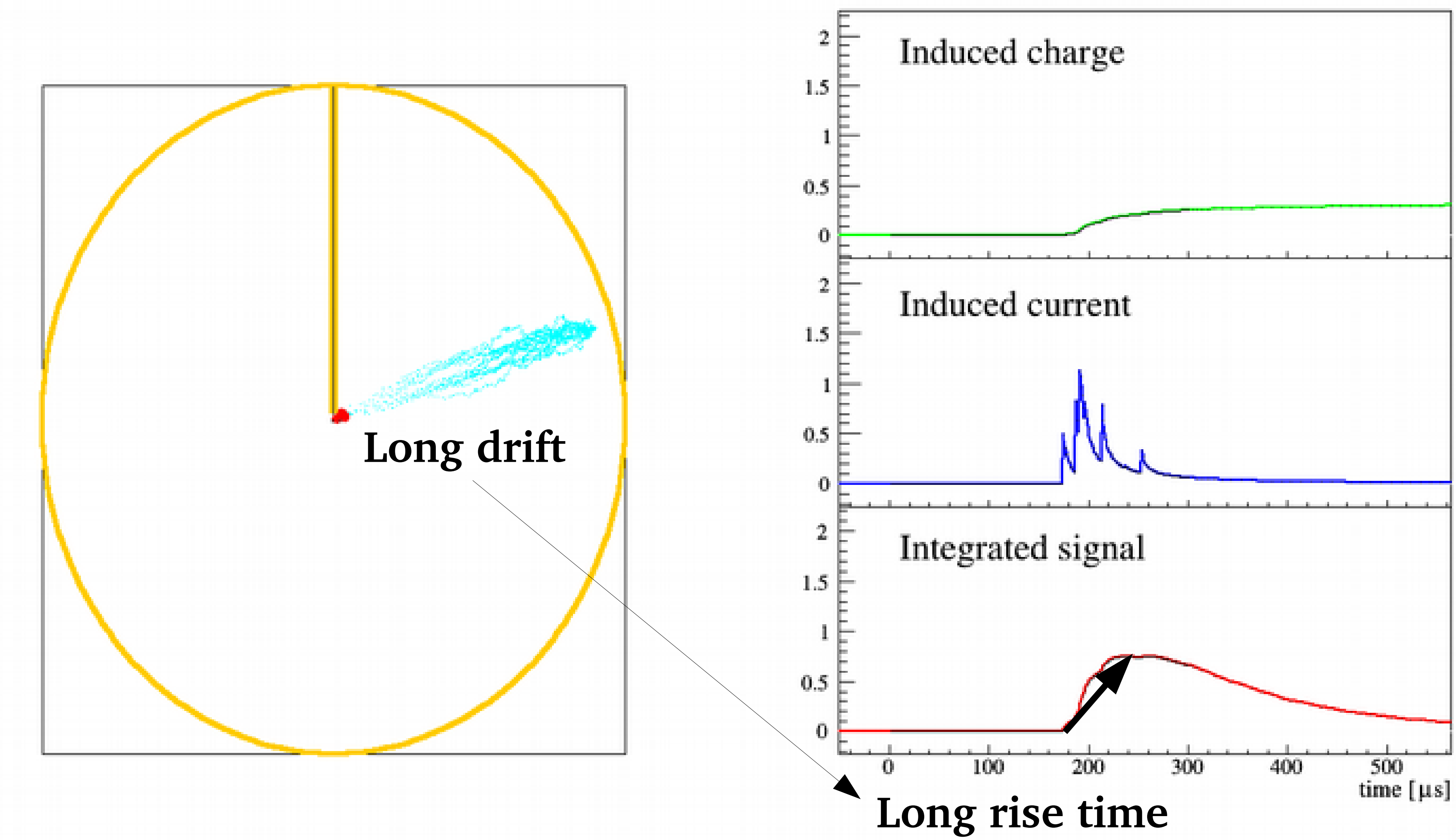
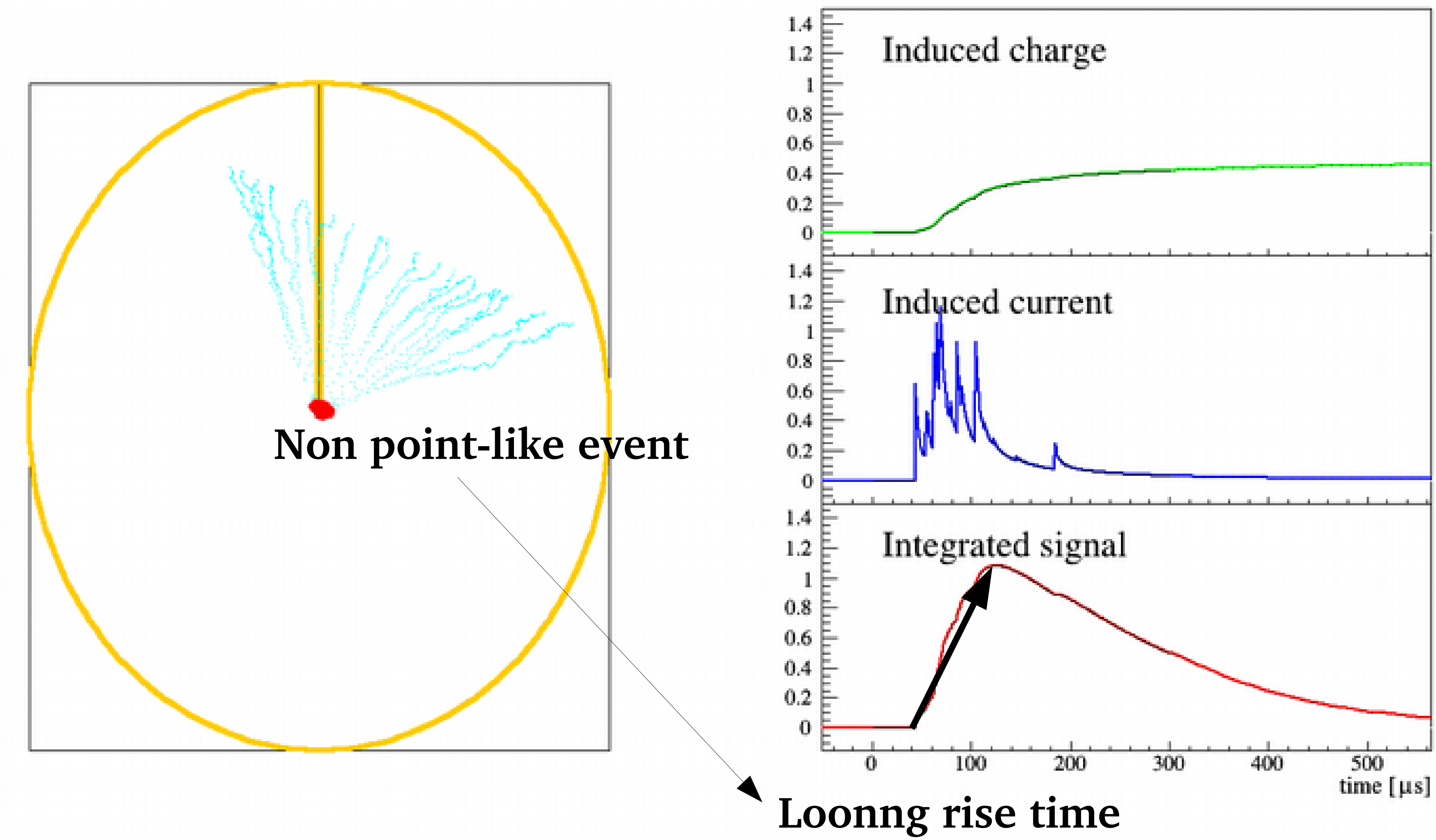


σ(r) ~ 20 µs x $(r/r_{sphere})^3$, e- drift time dispersion

Plot by P. Gros

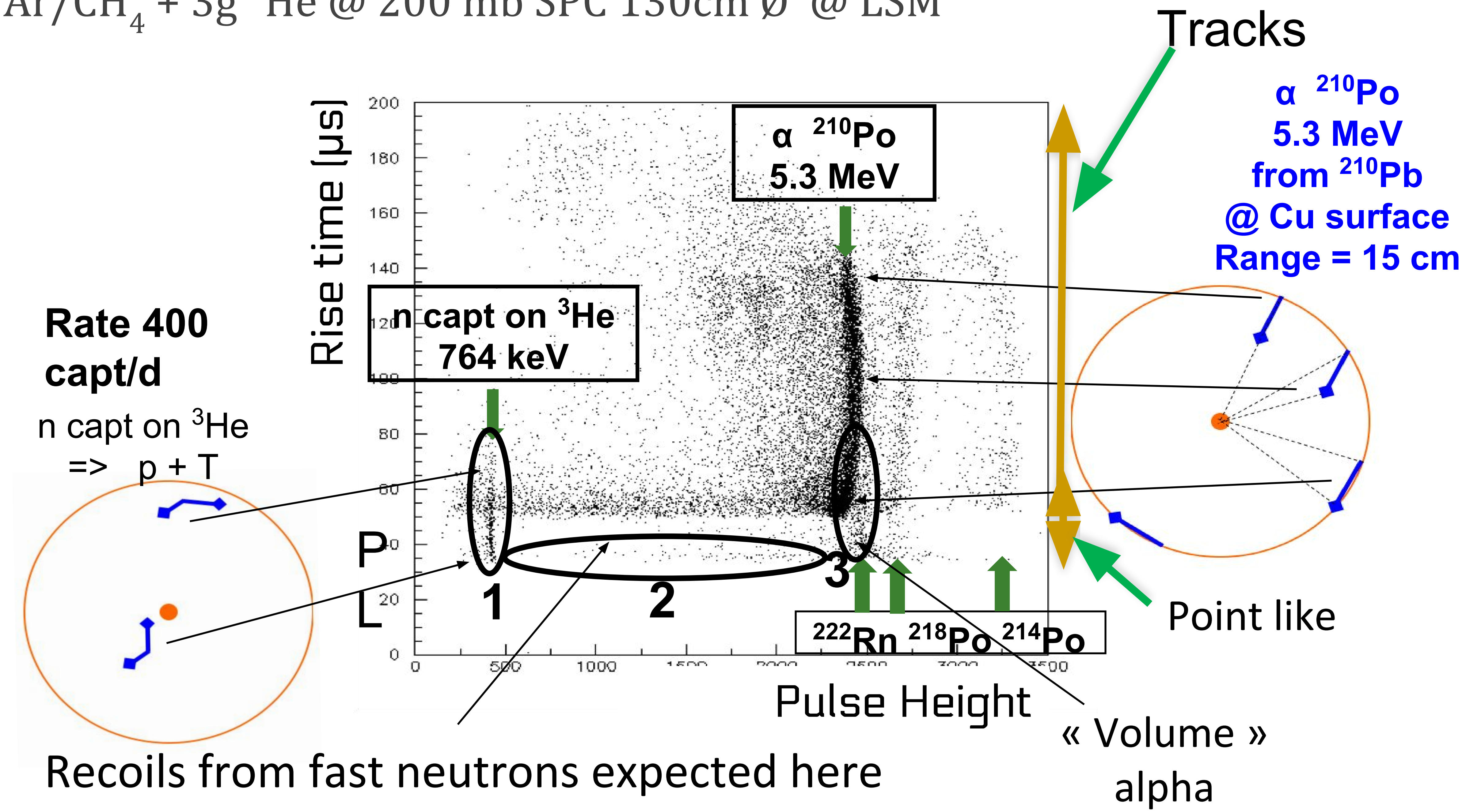
Background Rejection: Rise Time



Plot by P. Gros

Background Rejection

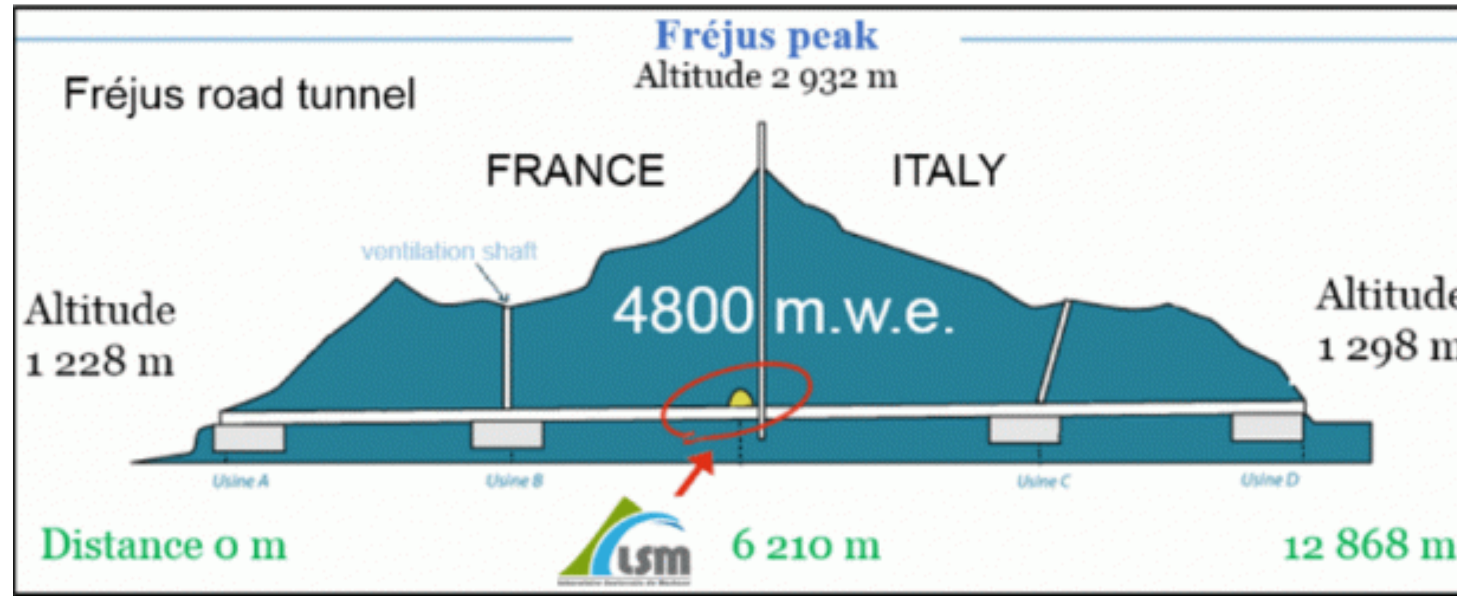
Run with Ar/CH_4 + 3g ^{3}He @ 200 mb SPC 130cm Ø @ LSM

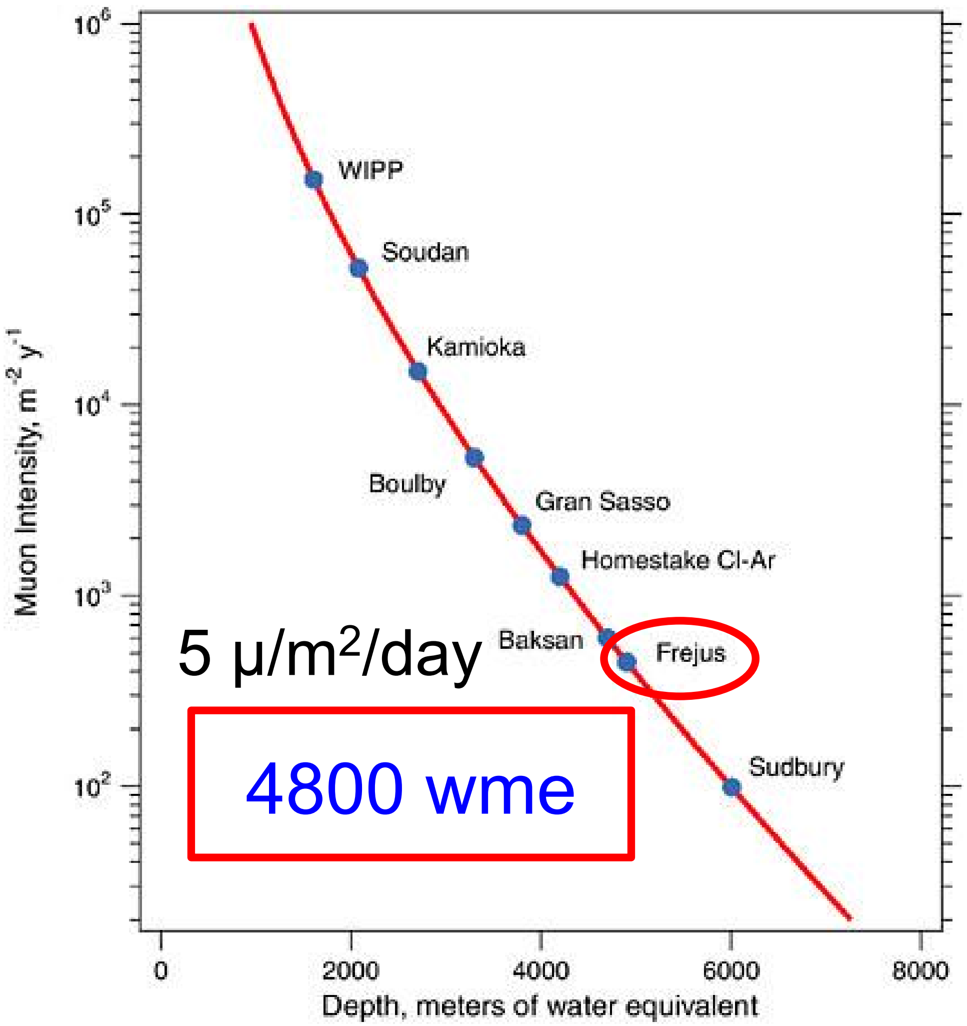


SEDINE: Low background SPC at LSM

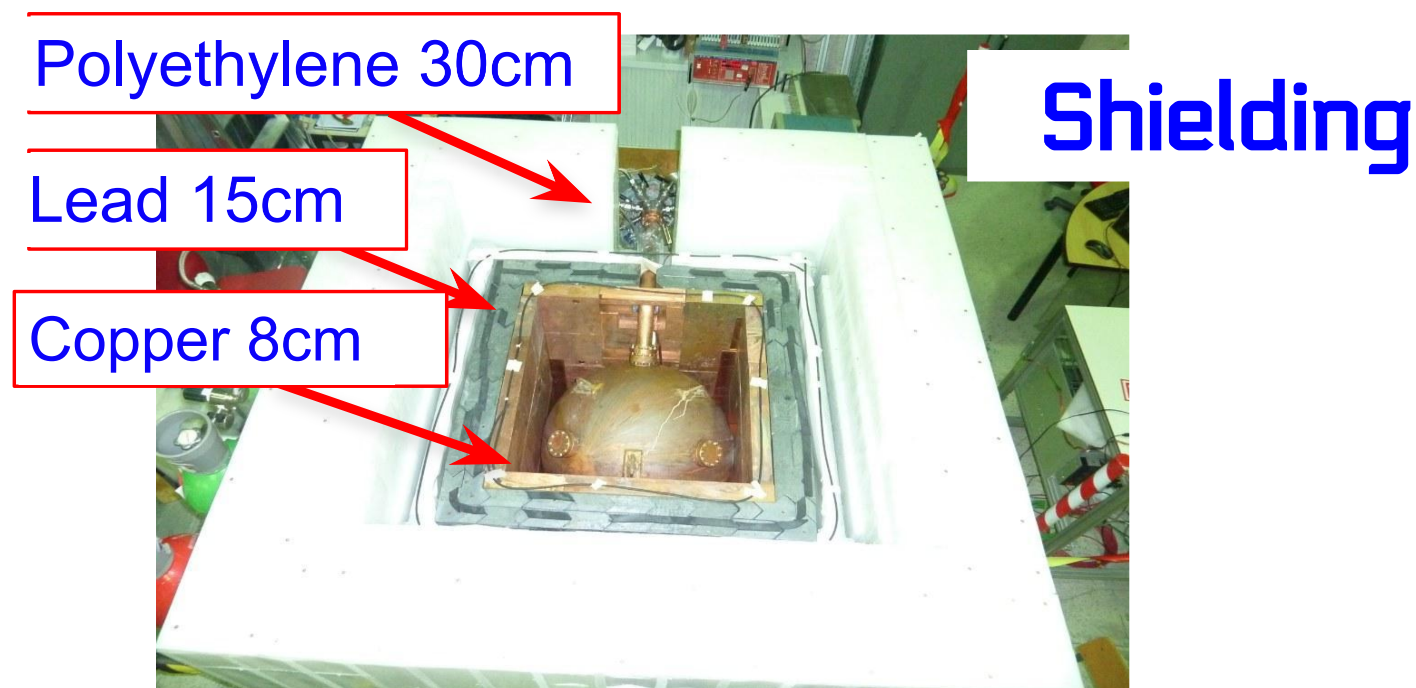
- A competitive detector and a testing ground for NEWS-G/SNO
  - Ultra pure Copper vessel (60cm diameter)
  - 6.3mm diameter sensor
  - Chemically cleaned several times for Radon deposit removal

Laboratoire Souterrain de Modane



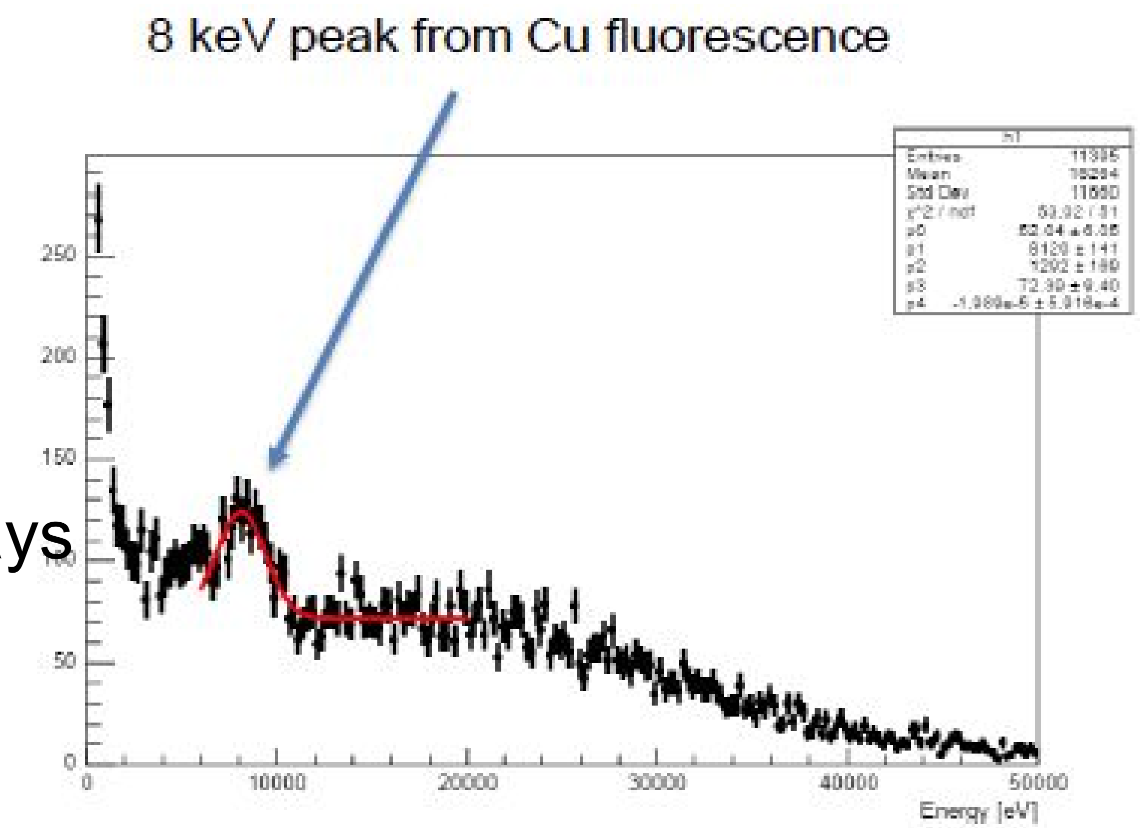


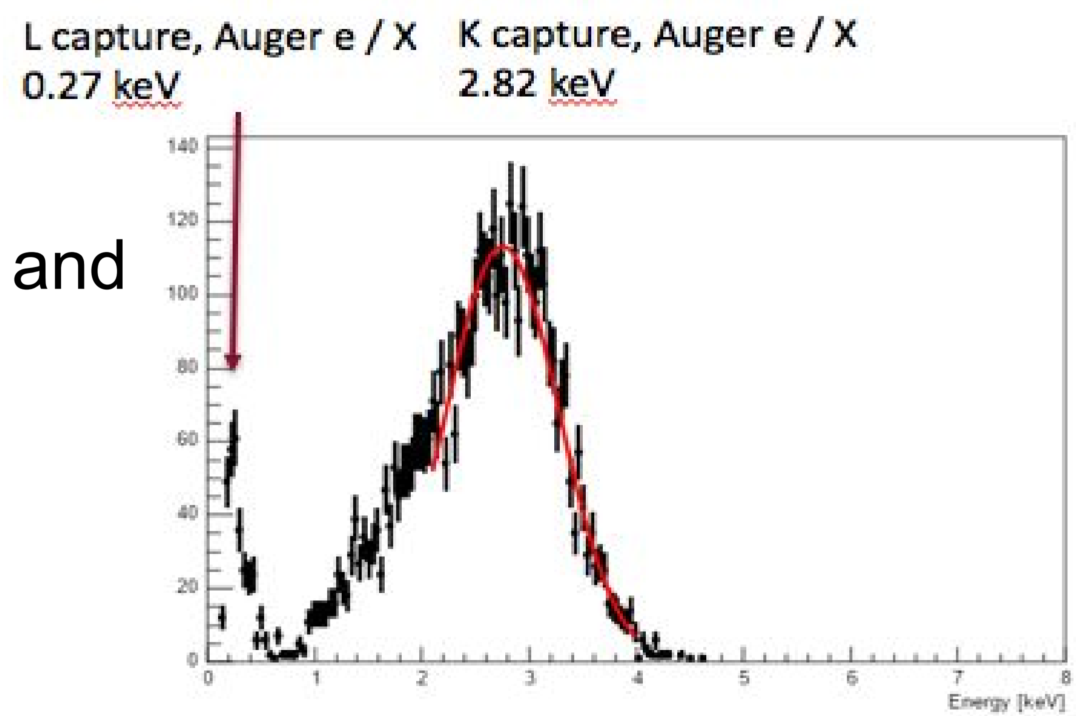
SEDINE sensor



SEDINE: Operation and data taking conditions

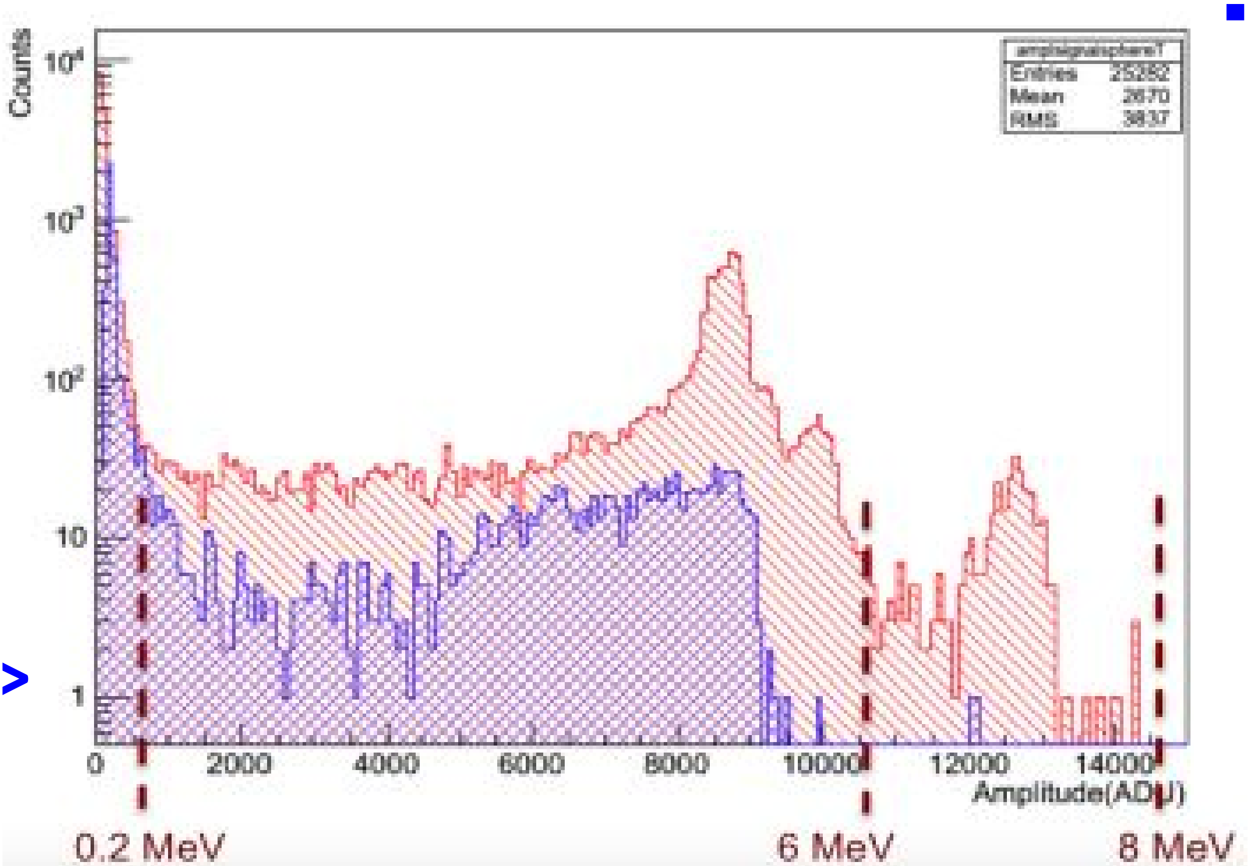
- Continuous data taking for 42.7 days
- 99.3% Neon + 0.7 % CH_4 at 3.1 bar
  - Exposure 34.1 live-days x 0.28 kg =9.7 kg.days
- Anode high voltage 2520 V, no sparks
  - Absolute Gain around 3000.
  - Loss of gain 4% throughout the period
- Sealed mode, no recirculation.
- Canberra charge sensitive preamplifier (RC=50 μs)
- Calibration/Validation with ^{37}Ar gaseous source and 8 keV Cu fluorescence line





^{37}Ar X rays calibration

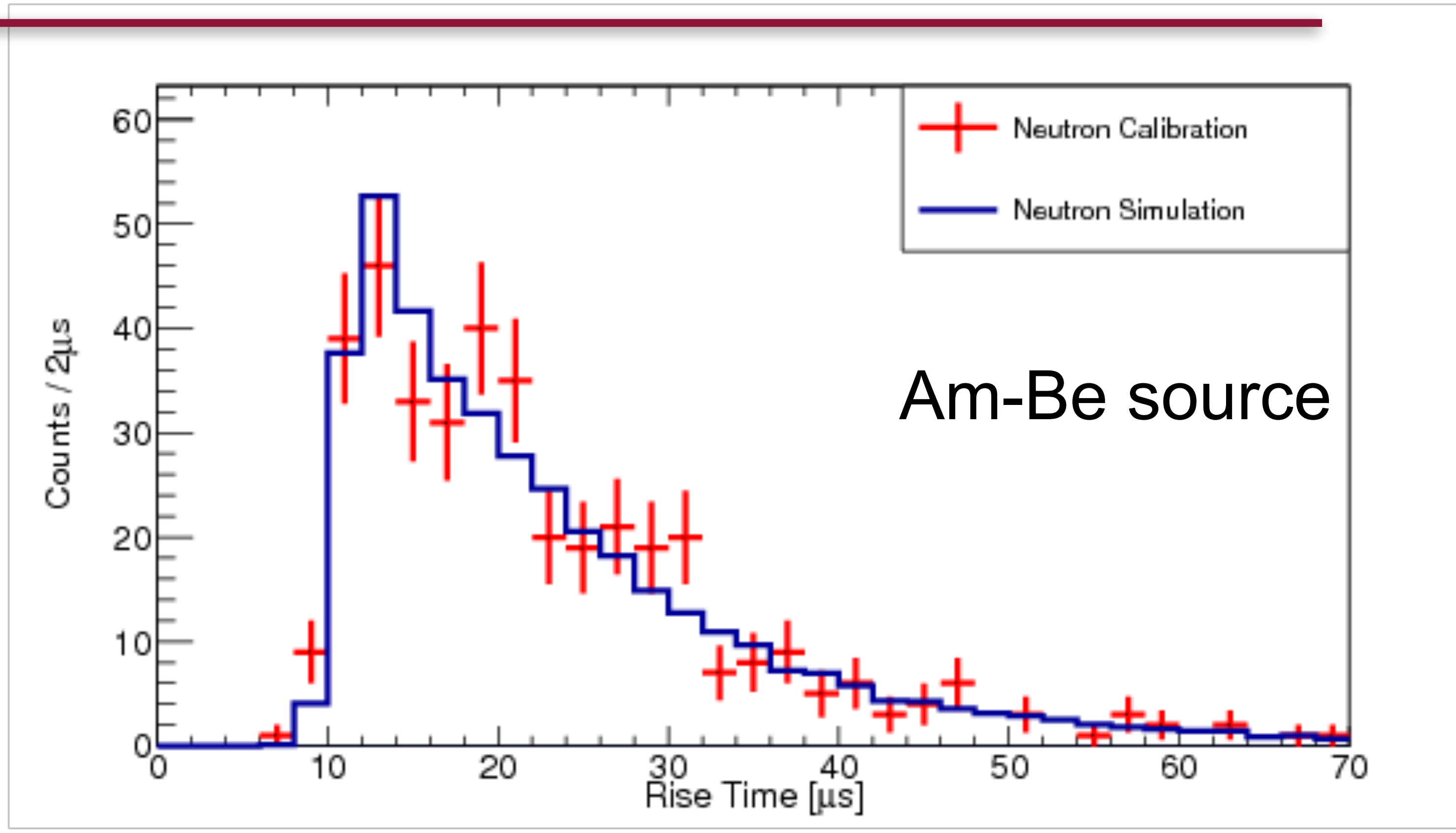
SEDINE: Main Background Sources

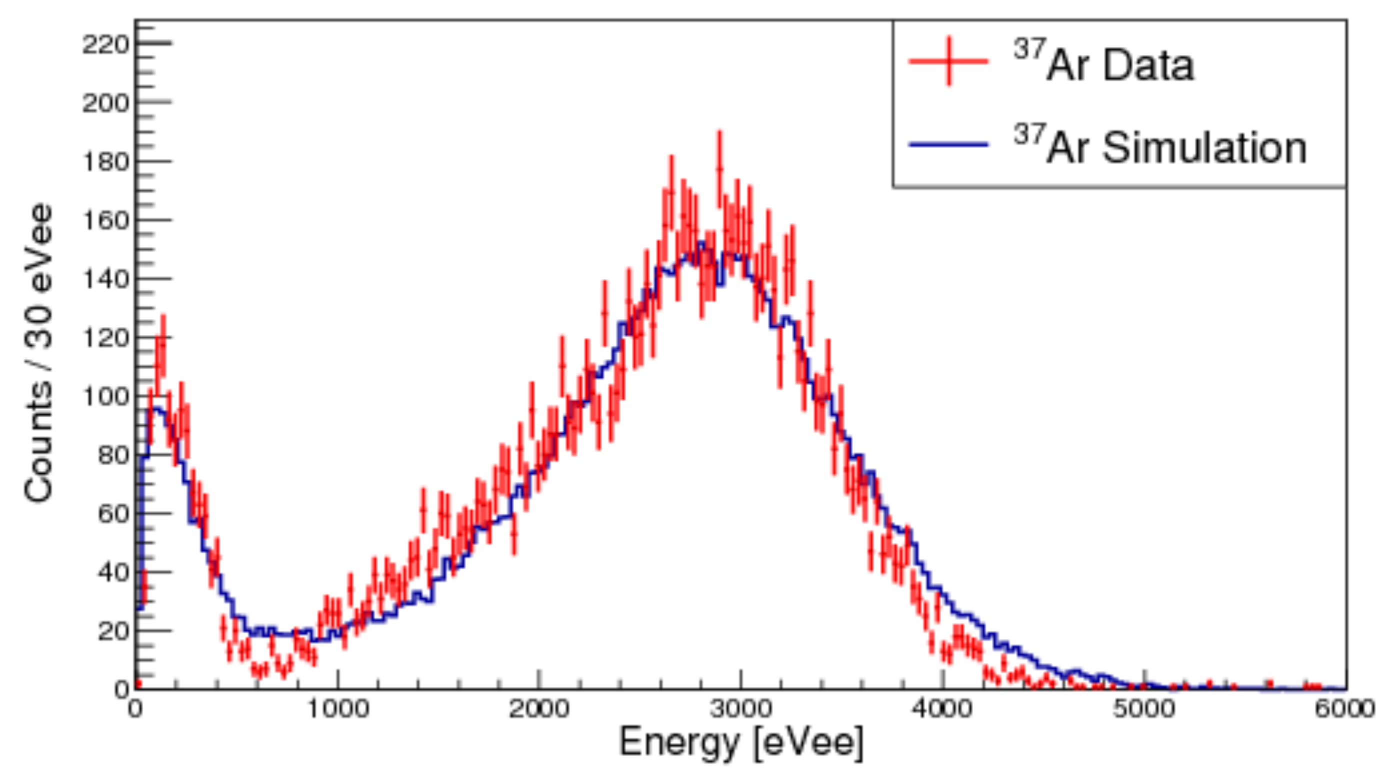


- Compton interactions
  - uniformly distributed in volume
  - γ-rays from:
    - ^{208}Tl and ^{40}K in the rock
    - ^{238}U, ^{232}Th, and ^{60}Co copper shell/ shielding
- Surface Events
  - contamination of sphere's inner surface
  - Radon daughter decays
    - mostly β^- from ^{210}Pb, ^{210}Bi*
    - dominate low energy range
- Chemical Cleaning (nitric acid)
  - High energy events 180 mHz → ~2mHz
  - Low energy events 400 mHz → ~20mHz
- Overall: Competitive Background levels

SEDINE:Volume and surface events simulation

- Anticipated main backgrounds:
  - Compton electrons (volume)
  - ^{210}Pb decay products (surface)
- Pulse simulations include:
  - Electric field (FEM)
  - Diffusion (Magboltz)
  - Avalanche process
  - Signal induction
  - Preamplifier delta response

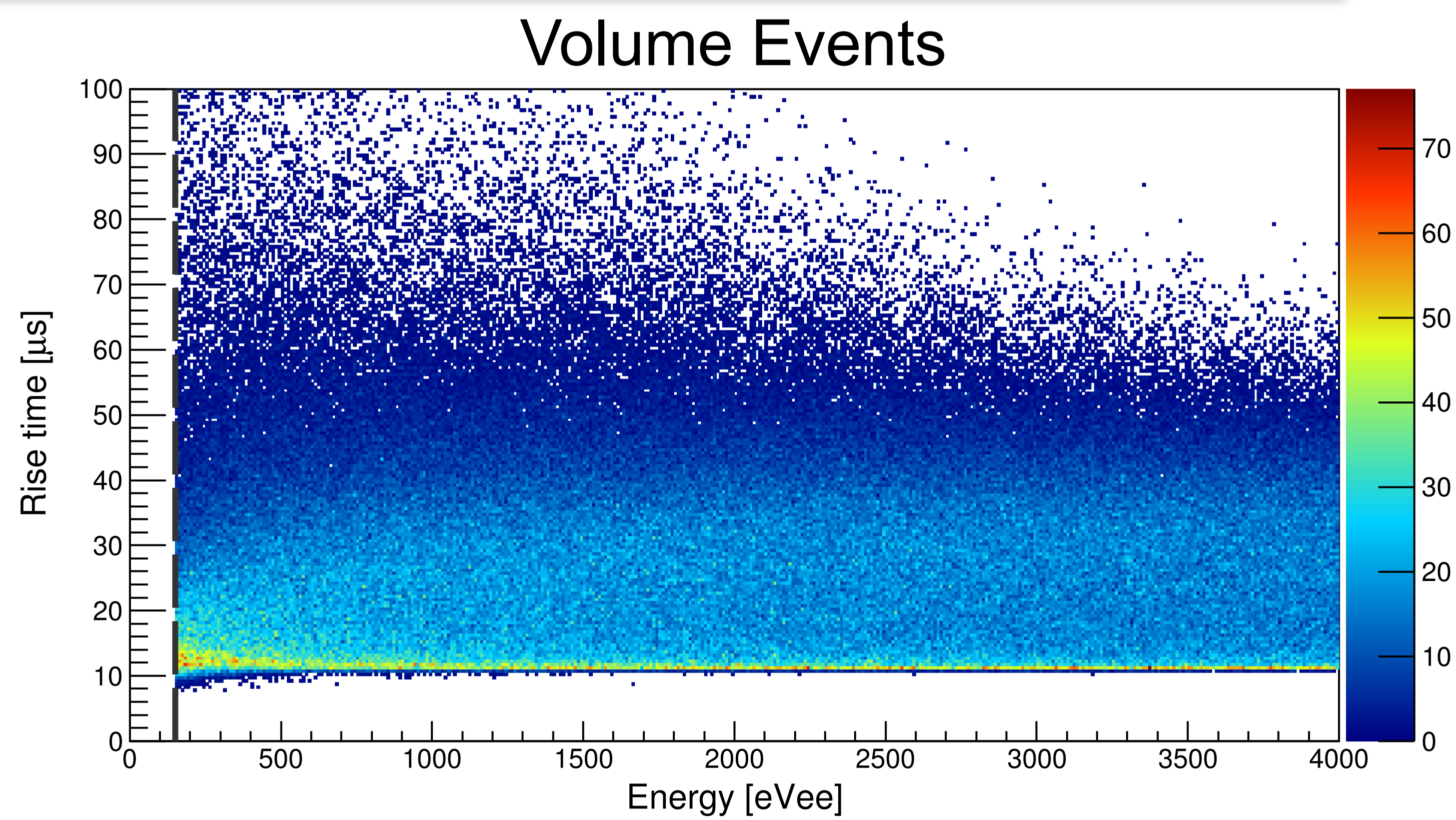


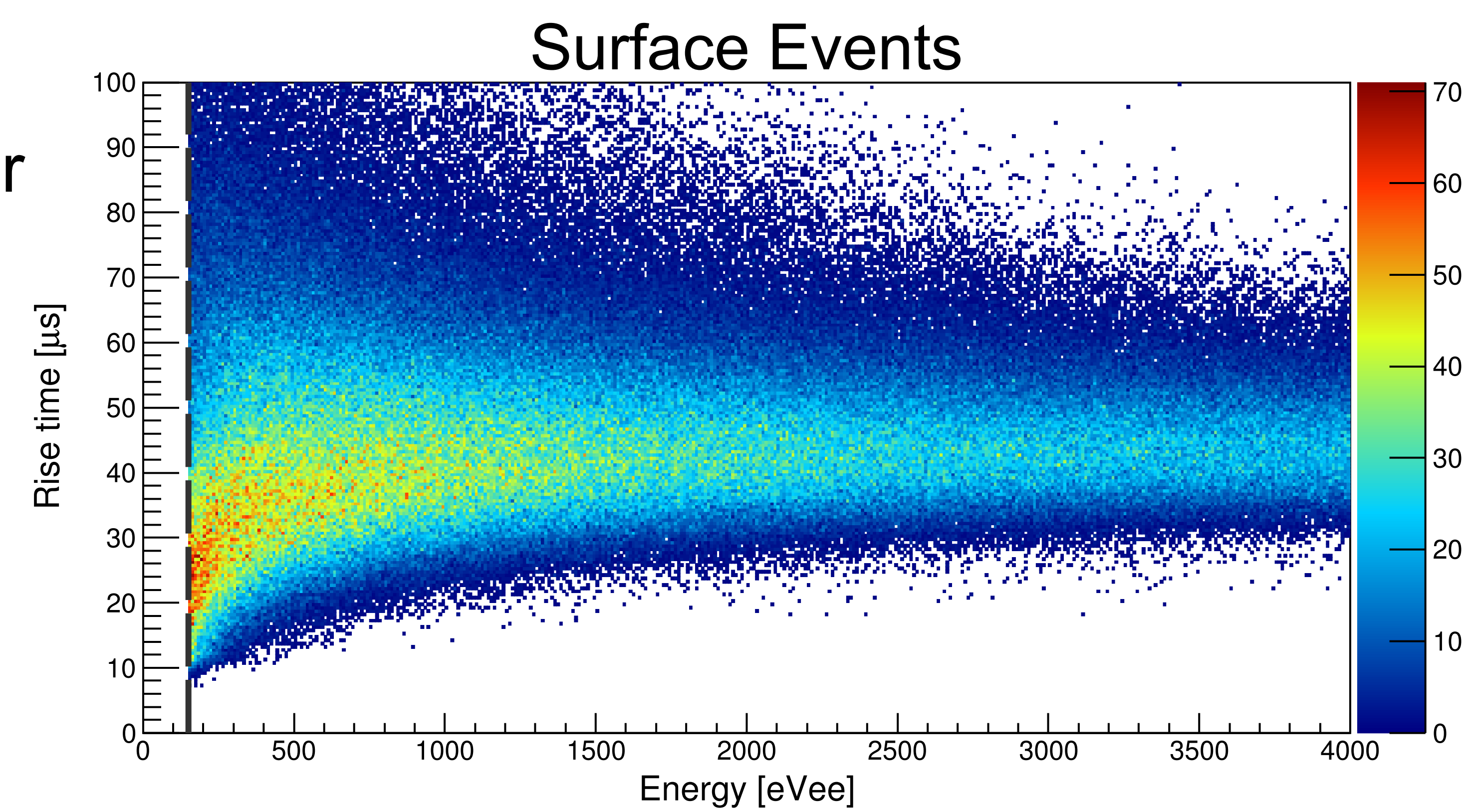


Astropart.Phys. 97 (2018) 54-62

SEDINE:Volume and surface events simulation

- Anticipated main backgrounds:
  - Compton electrons (volume)
  - ^{210}Pb decay products (surface)
- Pulse simulations include:
  - Electric field (FEM)
  - Diffusion (Magboltz)
  - Avalanche process
  - Signal induction
  - Preamplifier delta response
- Data side-band region used together with simulations to determine the number and distribution of background events expected in the preliminary ROI
- Simulation input to a Boosted Decision Tree to determine the optimised signal region for 8 candidate masses





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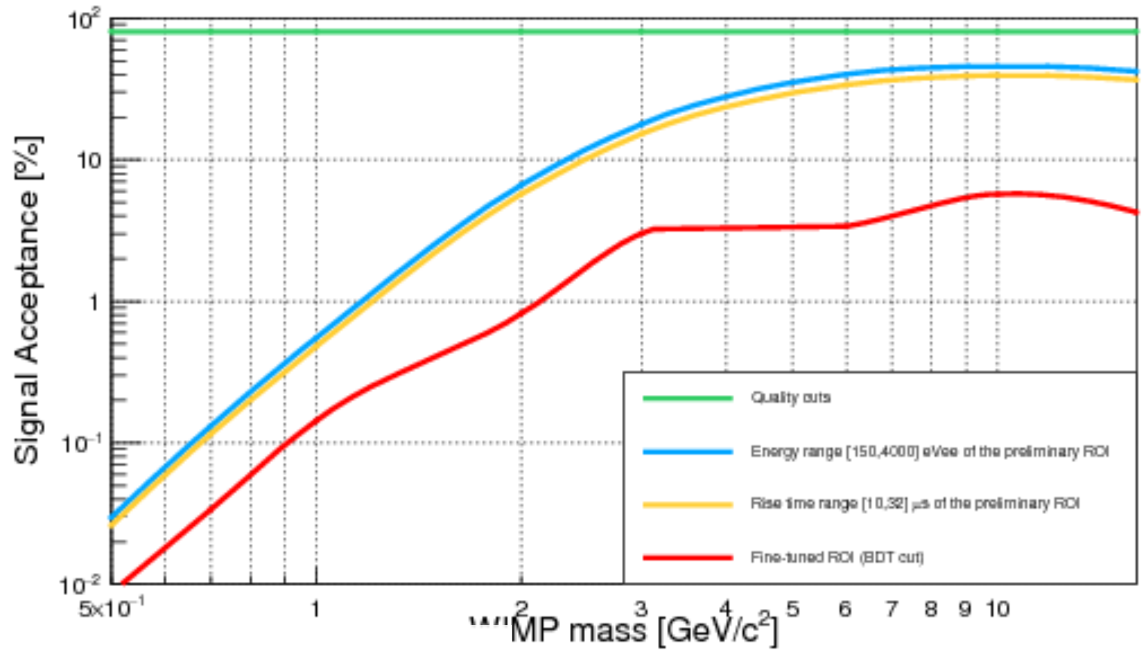
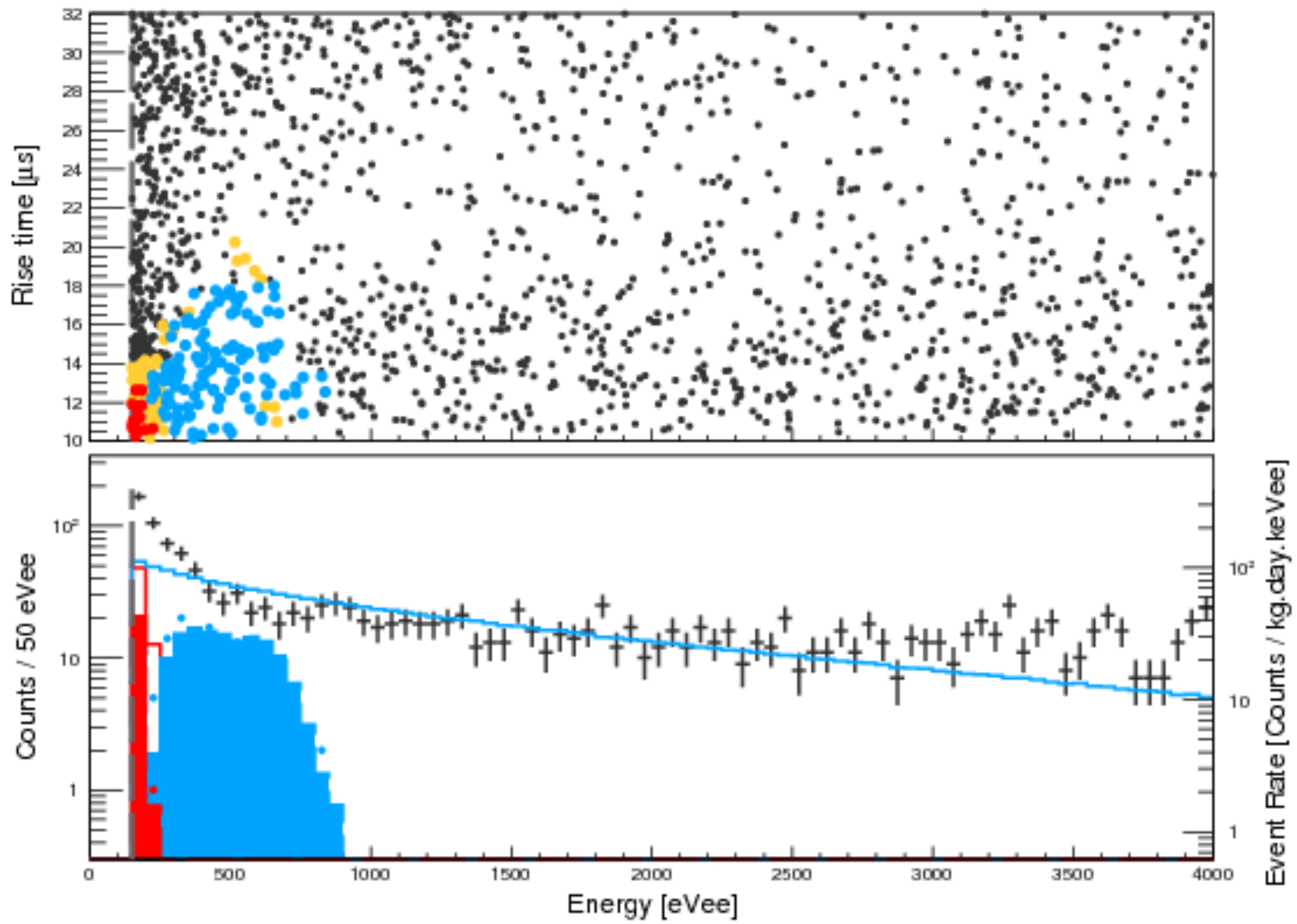
Event Selection

- Analysis threshold : 150 eVee (~720 eVnr)
- 100% trigger efficiency (threshold @ ~35 eVee)
- 1620 events selected in preliminary ROI
  - Failed BDT
  - Pass 0.5 GeV BDT: 15 events
  - Pass 16 GeV BDT: 123 events
  - Pass BDT for other masses





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NEWS-G / LSM Exclusion Limits

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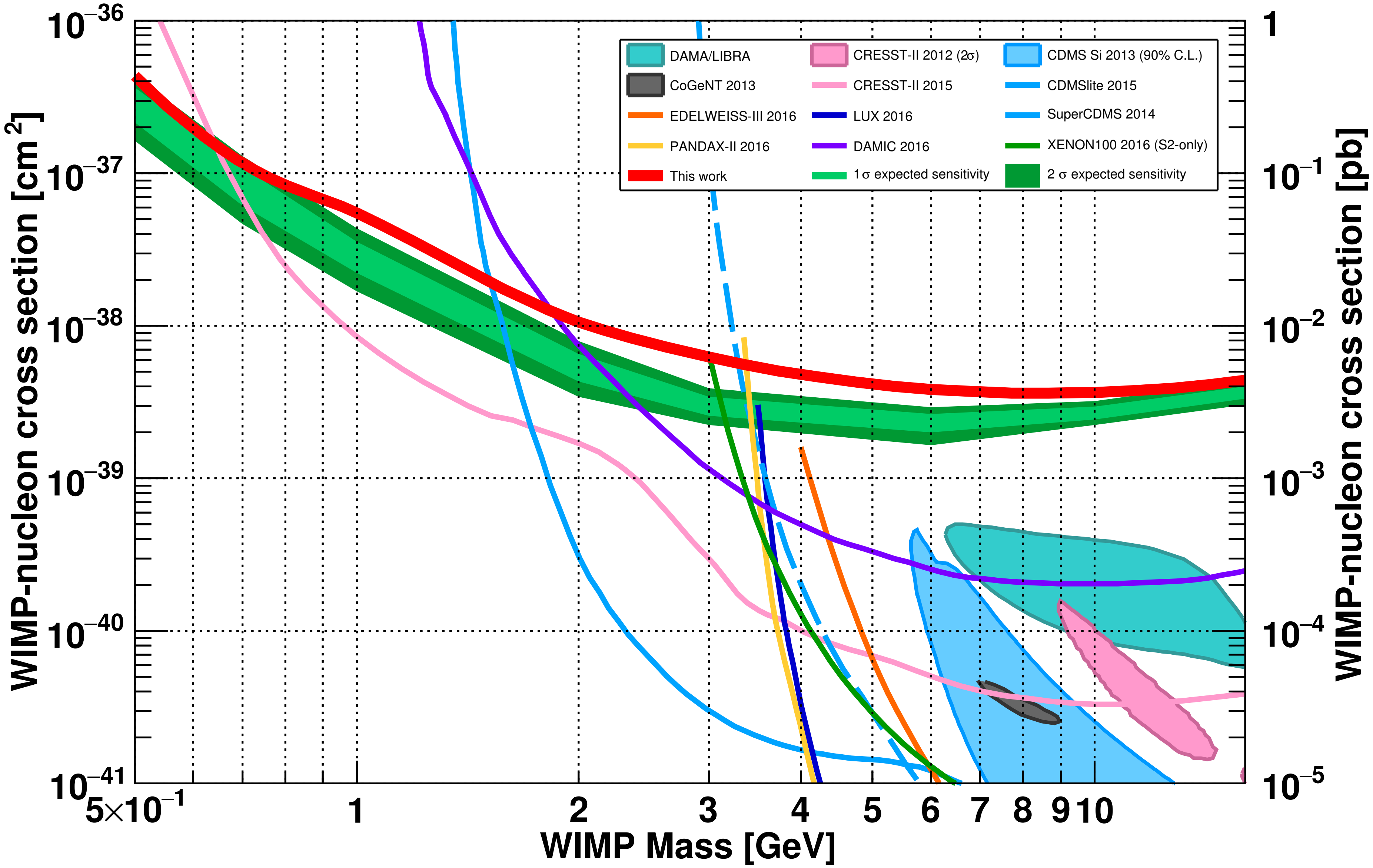


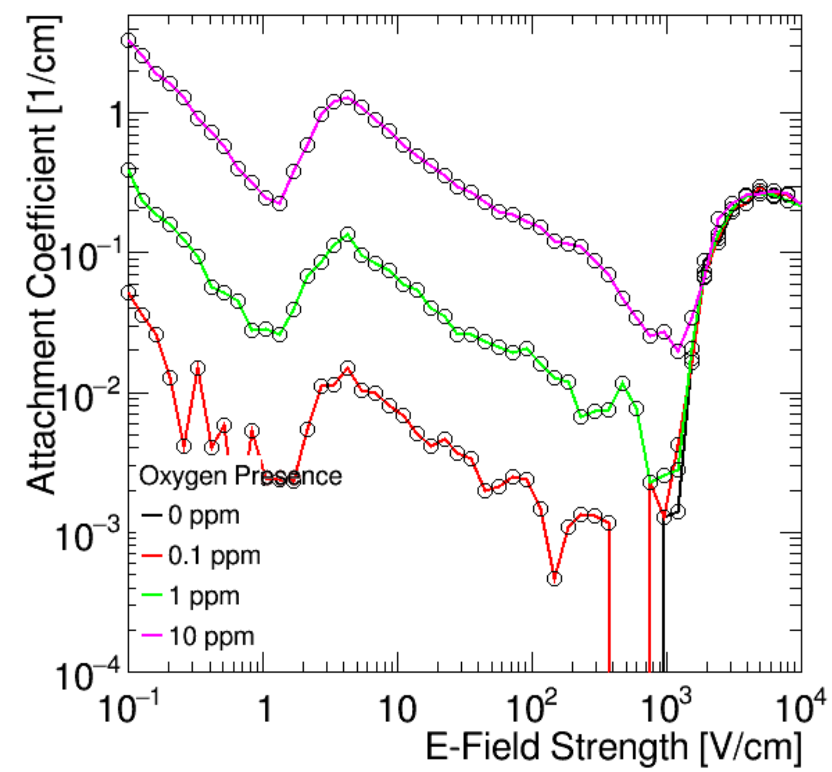
Exclusion at 90% confidence level of cross-sections above $4.4\text{x}10^{-37}$ cm^2 @ mass 0.5 GeV

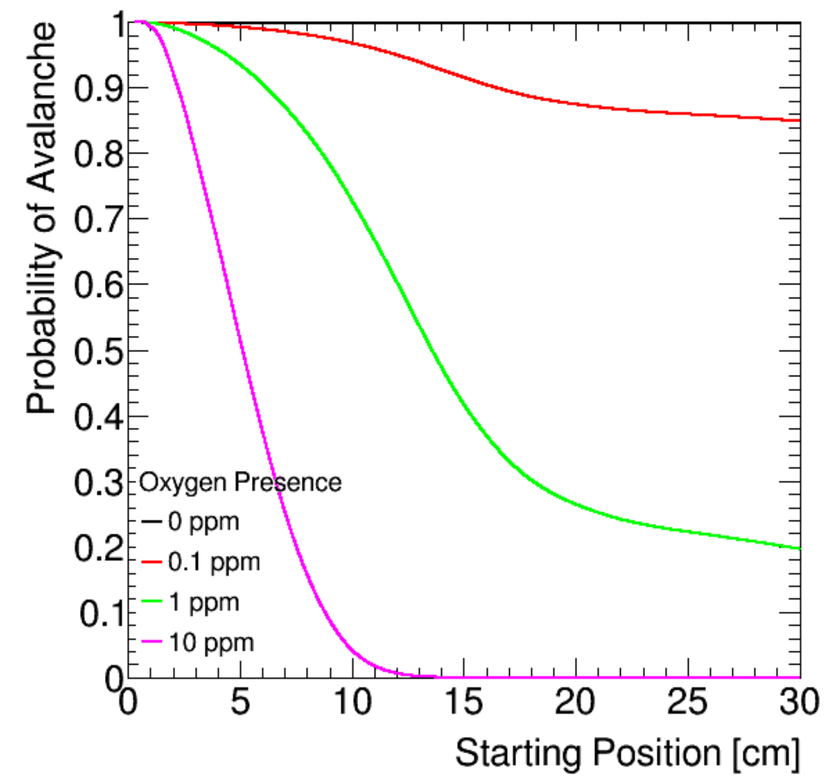
Limit set on spin independent WIMP coupling with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

NEWS-G current status & developments

Preparing for the He physics run at LSM

- Gas quality
  - Testing gas mixtures of He/CH_4
    - High pressure operation (Penning)
    - Hydrogen rich target
  - Upgrading gas system
    - Tightness
    - Filtering
    - Gas recirculation
    - Monitoring with residual gas analyser
- Quenching factor measurements
  - Ion / electron beam (LPSC, France)
  - Neutron beam (TUNL, USA)
- Study of the detector response
  - Solid state laser (213 nm)
    - monitoring of gain with time
    - drift time measurements
    - parametrization of the avalanche process





NEWS-G current status & developments

- Aims:
  - High pressure operation
  - Higher gain
  - Larger volumes
  - Increased Stability
  - Low radioactivity
- Techniques
  - Resistive technologies
  - 3D printing technologies
  - FEM simulations

Single-anode Sensors

“Glass” sensor

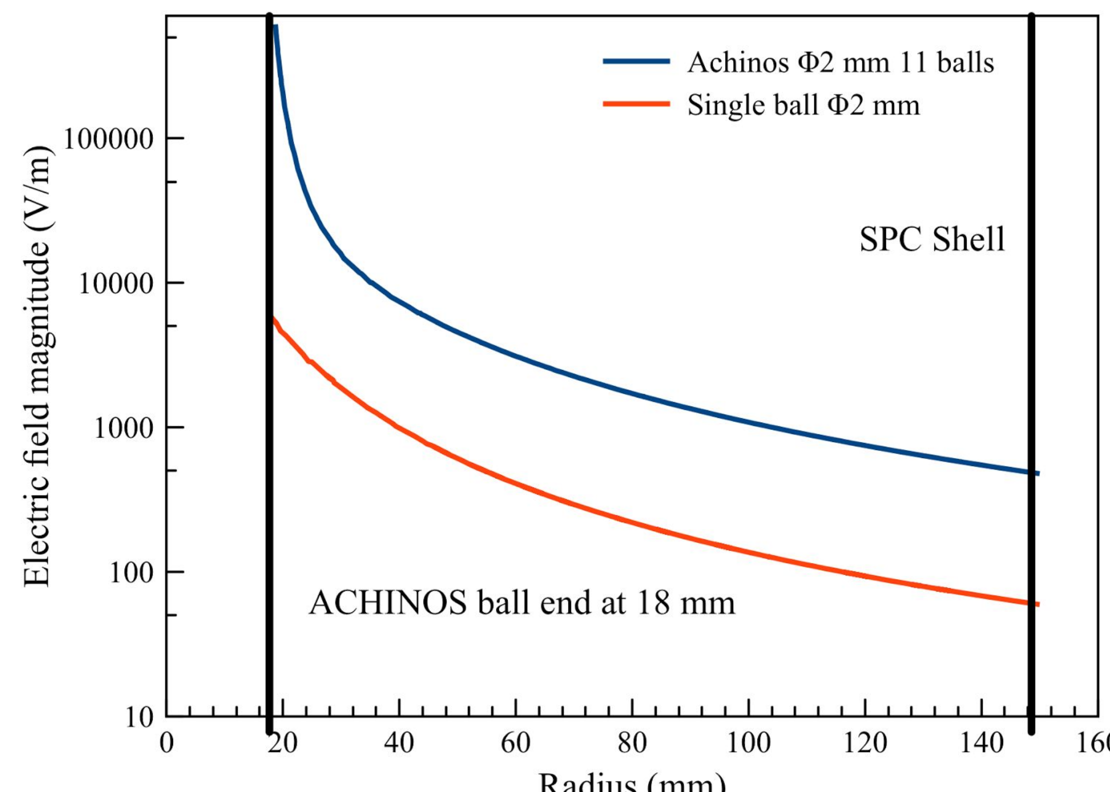
“Bakelite” sensor

- Achinos: Multiple balls placed at equal distances on a sphere
  - Same gain but increased field at large radii
  - Decoupling Gain and Drift
  - Anodes can be read out individually
- Prototypes: 5, 11, 33 metal balls ∅ 2mm successfully operated
- 3D printed Achinos sensors built and operated

Multi-anode Sensors (Achinos)

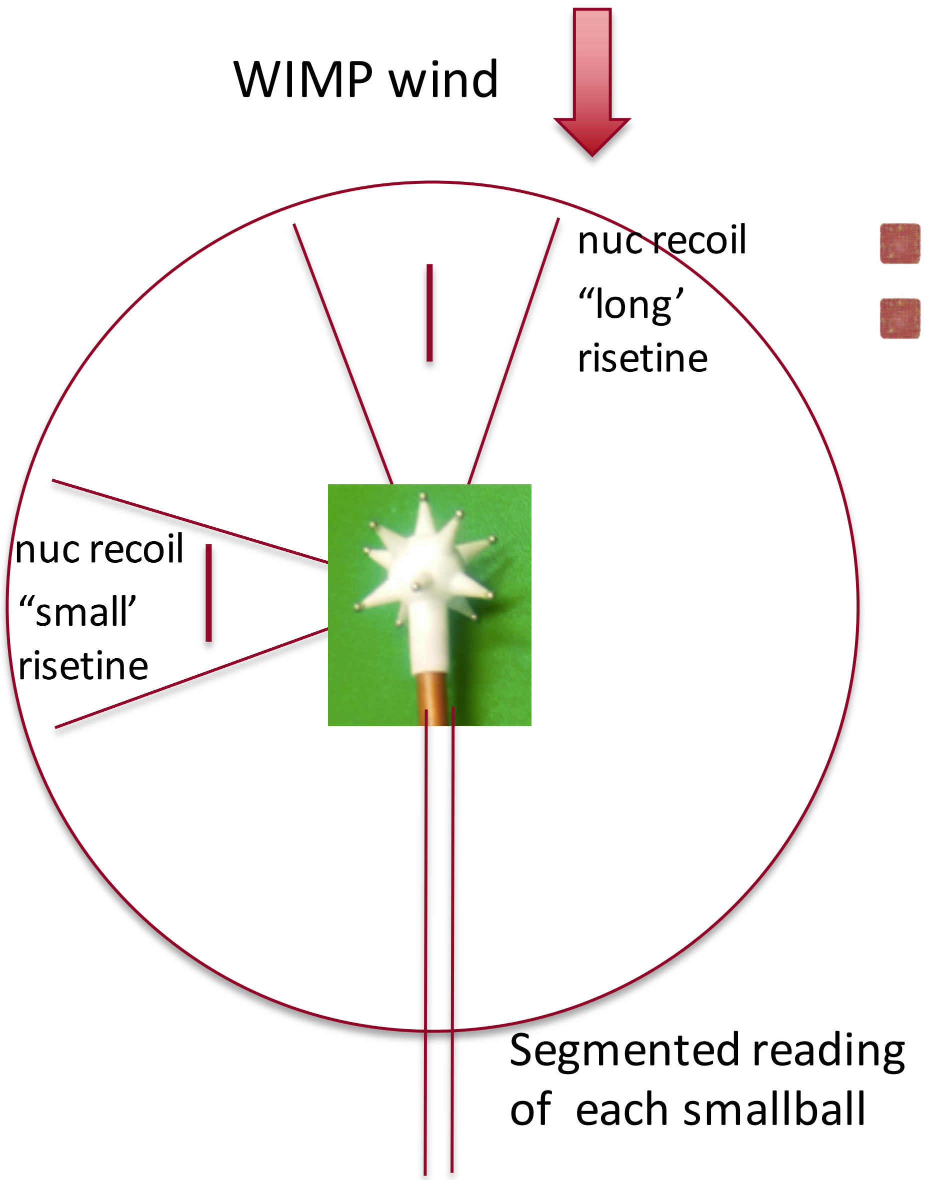
33-ball bakelite

11-ball 3D printed

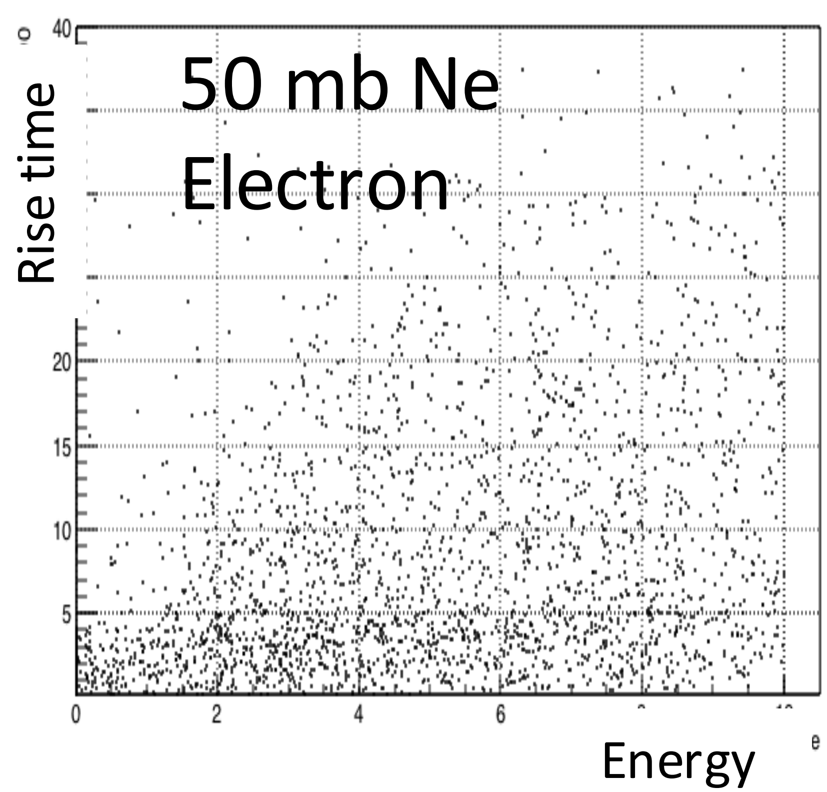


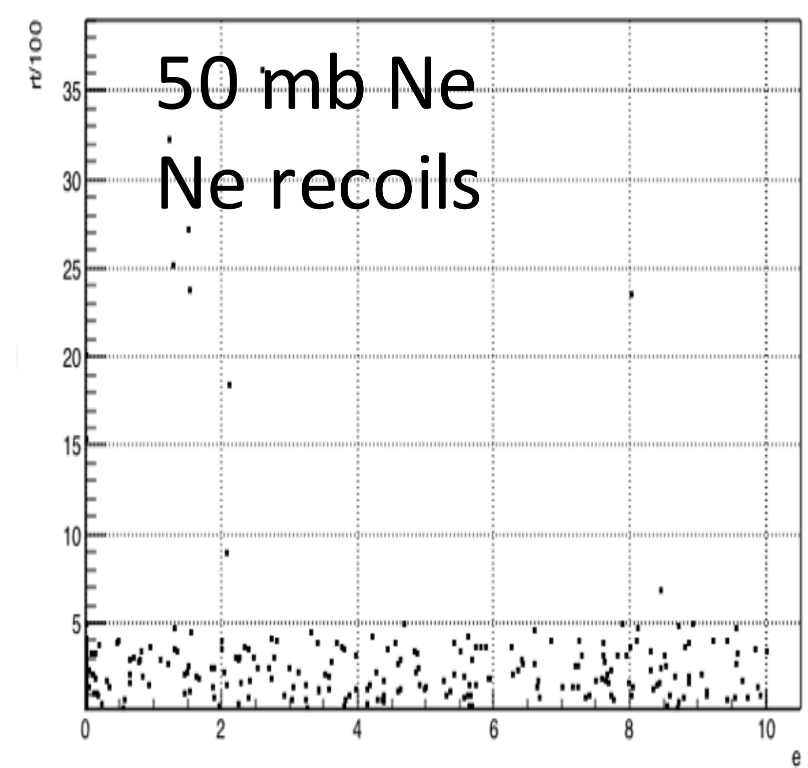
JINST 12 (2017) P12031

NEWS-G current status & developments



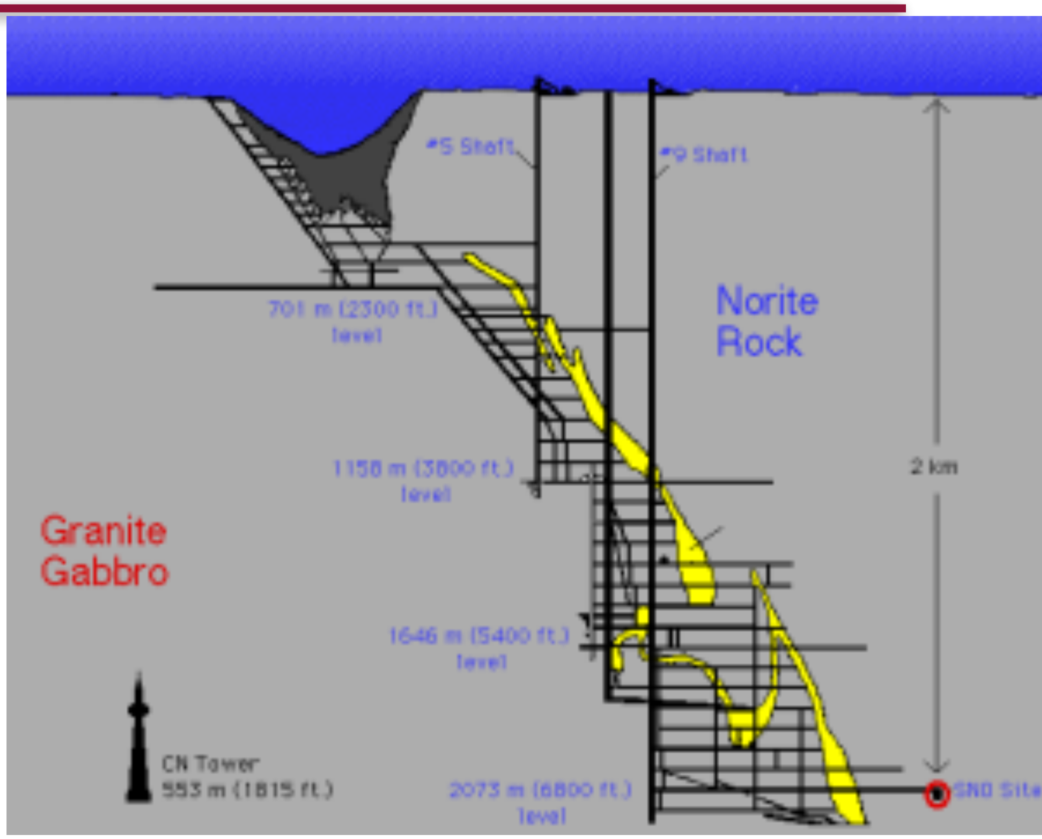
- Further improvements are being considered
- In particular for low-pressure operation
  - Directionality in conjuction with Achinos
  - Electron vs Nuclear Recoil discrimination through rise-time

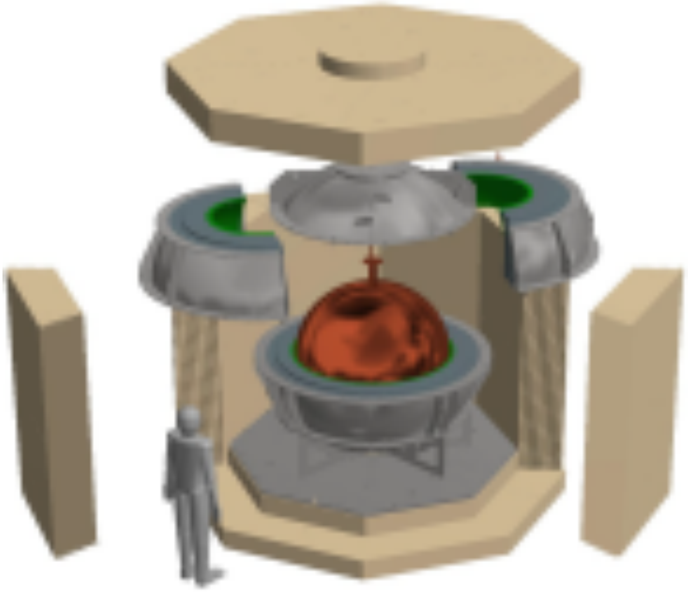


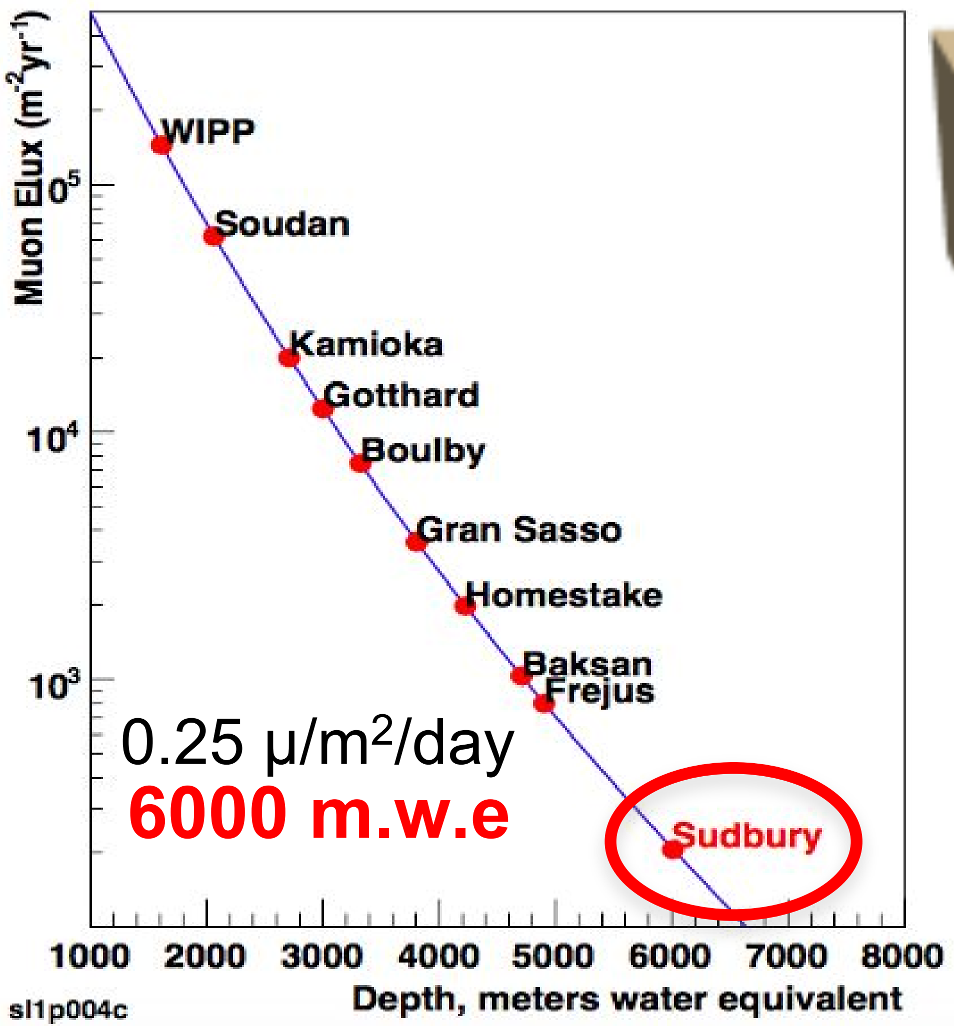


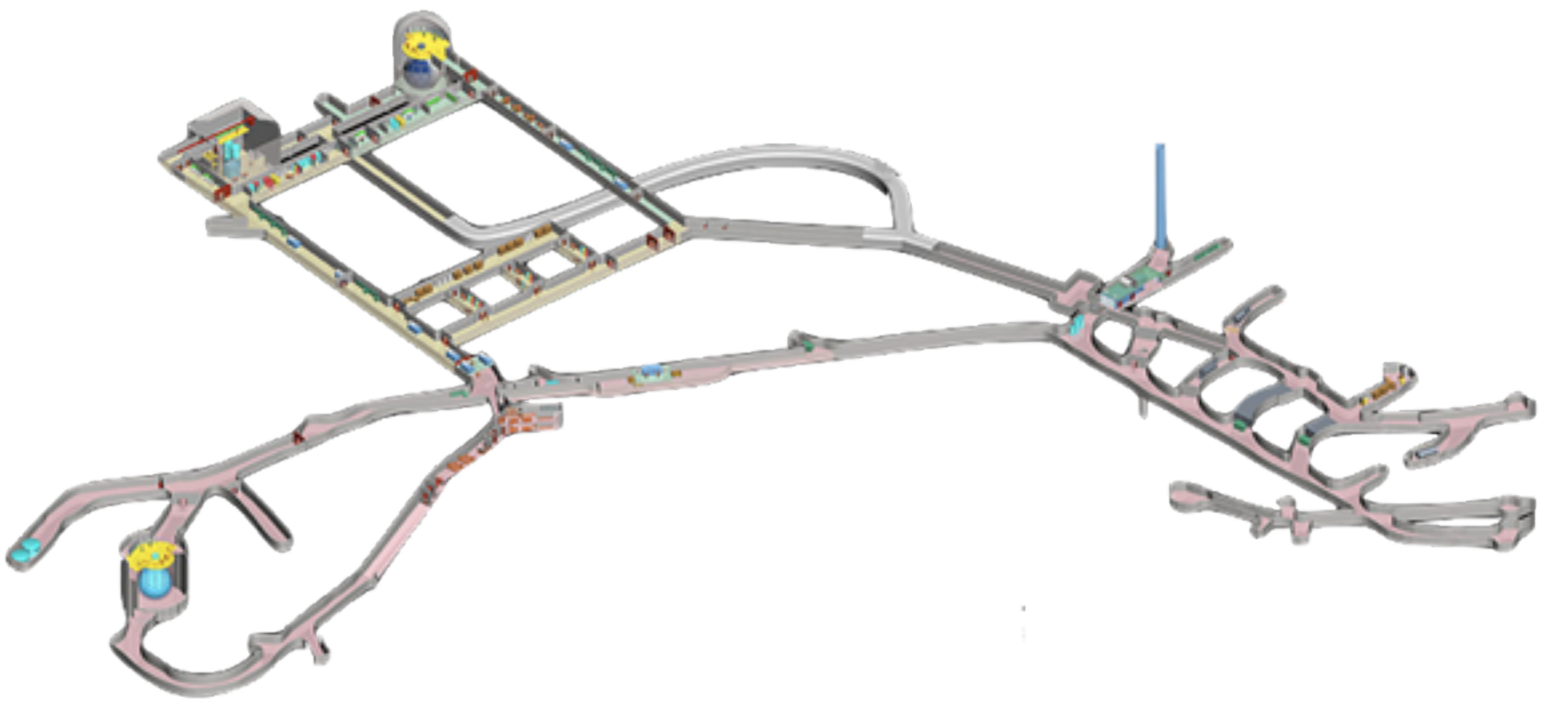
NEWS-G at SNOLAB

- Underground laboratory in Sudbury, Canada
  - World's deepest clean-room
  - NEWS-G to be installed in Cube Hall







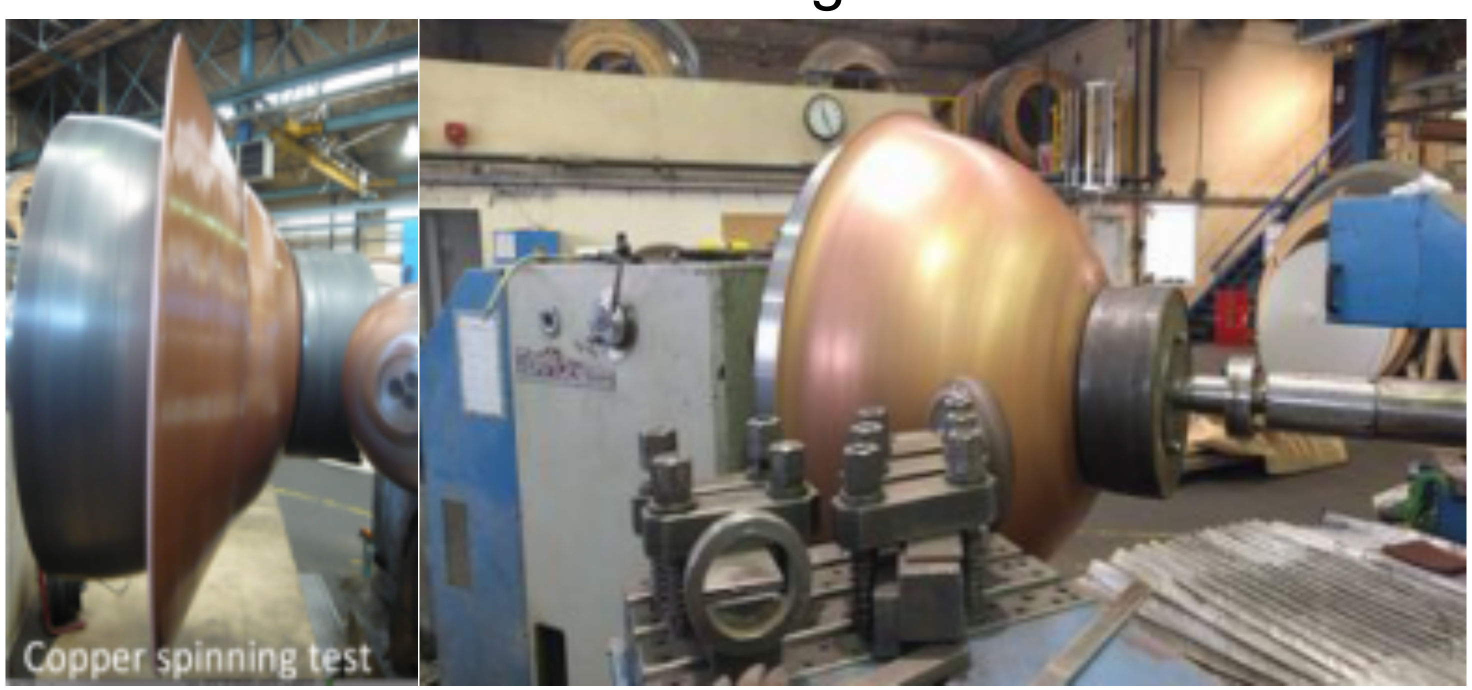


NEWS-G at SNOLab

- Copper vessel (⌀ 140cm, 12mm thick)
  - Low activity copper (C10100)
  - 7 to 25 μBq/kg Th
  - 1 to 5 μBq/kg of U
  - Electropolishing & Electroplating
  - Gases: Ne, He, CH_4
  - High pressure operation (10 bar)

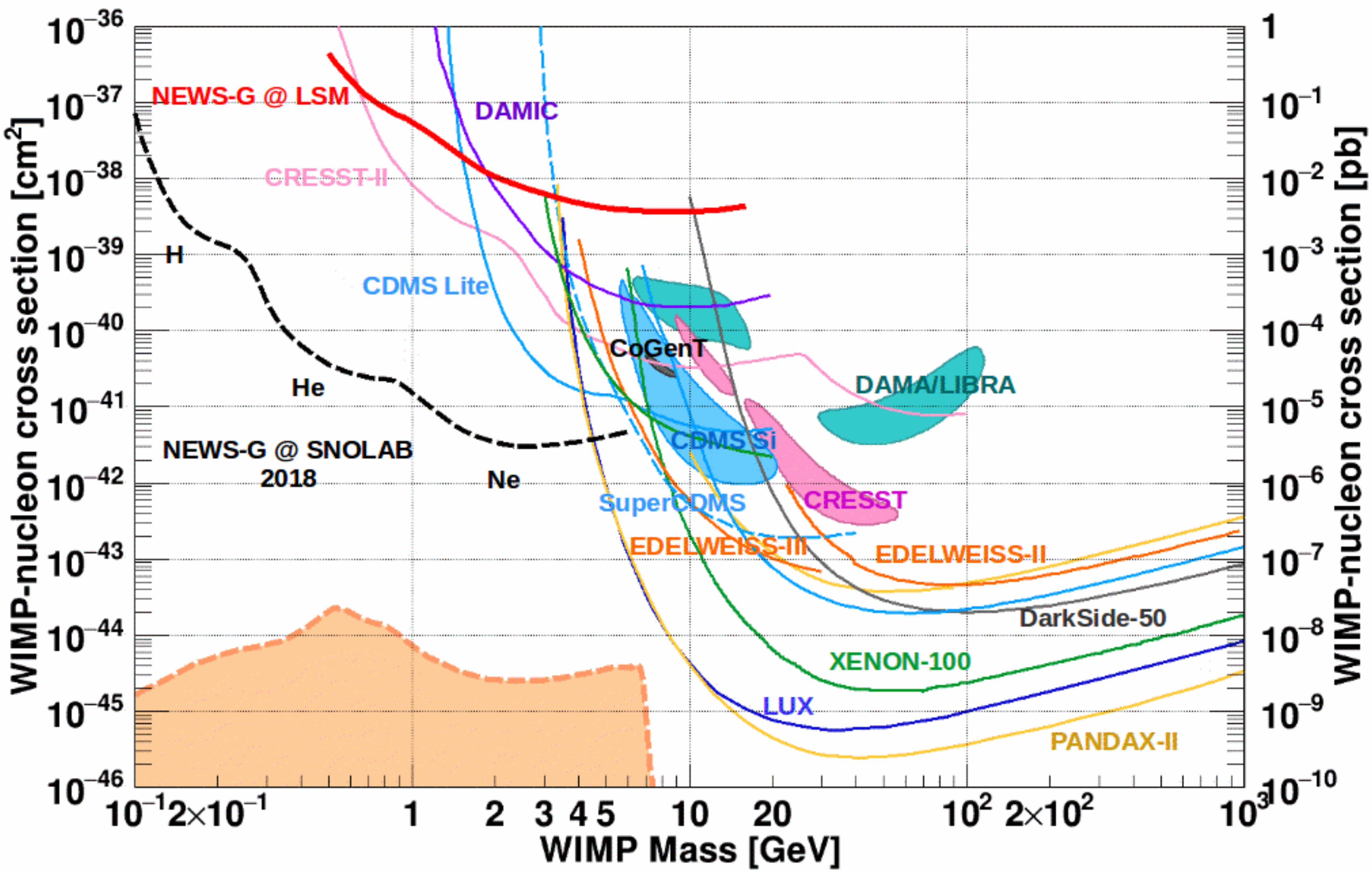
- Upgraded Shielding (35t):
  - 40cm Polyethylene + Boron sheet
  - 22cm Lead (1 Bq/kg ^{210}Pb)
  - 3cm archaeological Lead
  - Air-tight envelope to flush pure N (vs Rn)

Hemispheres built in France, stored at LSM before welding



Glove box for Radon-free rod installation

Predicted exclusion limits for NEWS-G SNOLAB



NEWS-SNO expected sensitivity assuming:
100 kg.days exposure @ 10 bar, threshold 1 electron (~40 eV), 200eVee ROI window
(Not accounting for sensitivity improvement from resolution effects and RT cuts)

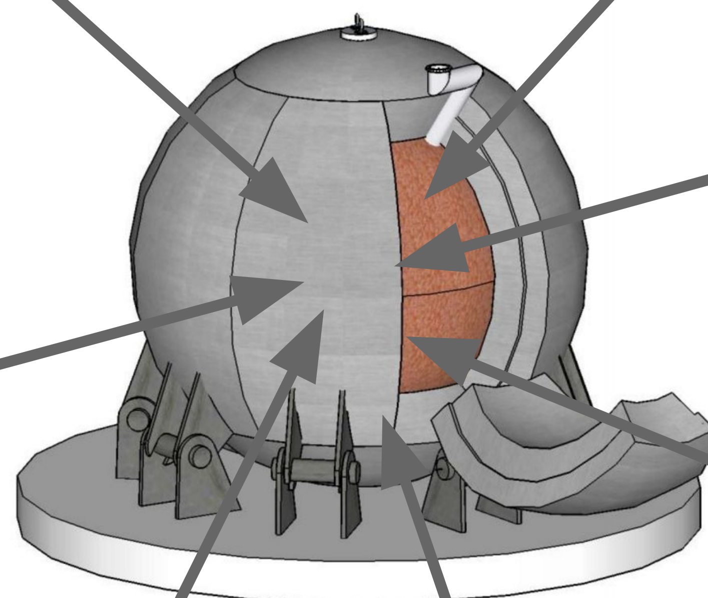
Versatile Detector

Operation with different targets:
Ne, He, H

Operation with different pressures:
Tenths mbar - 10 bar

Operation with High Z medium (Xenon) to better determine the background

NEWS-G
SNO



Resistive sensors:
High Gain

ACHINOS sensor:
Tuning volume electric field - High gain-
Multichannel readout

"Penning" Mixtures
Ne/CH_4 or He/CH_4 (99.3/0.7):
High pressure - High Gain -
Minimized voltages applied

Regular Mixtures
Ne/CH_4 or He/CH_4 (90/10):
Hydrogen rich gases

The NEWS-G Collaboration

Queen's University Kingston – G Gerbier**,** P di Stefano, R Martin, T Noble, D Dunrford, S Crawford, A Brossard, P Vasquez de Sola, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier, A Ronceray, P. Gros, J. Morrison, C Neyron
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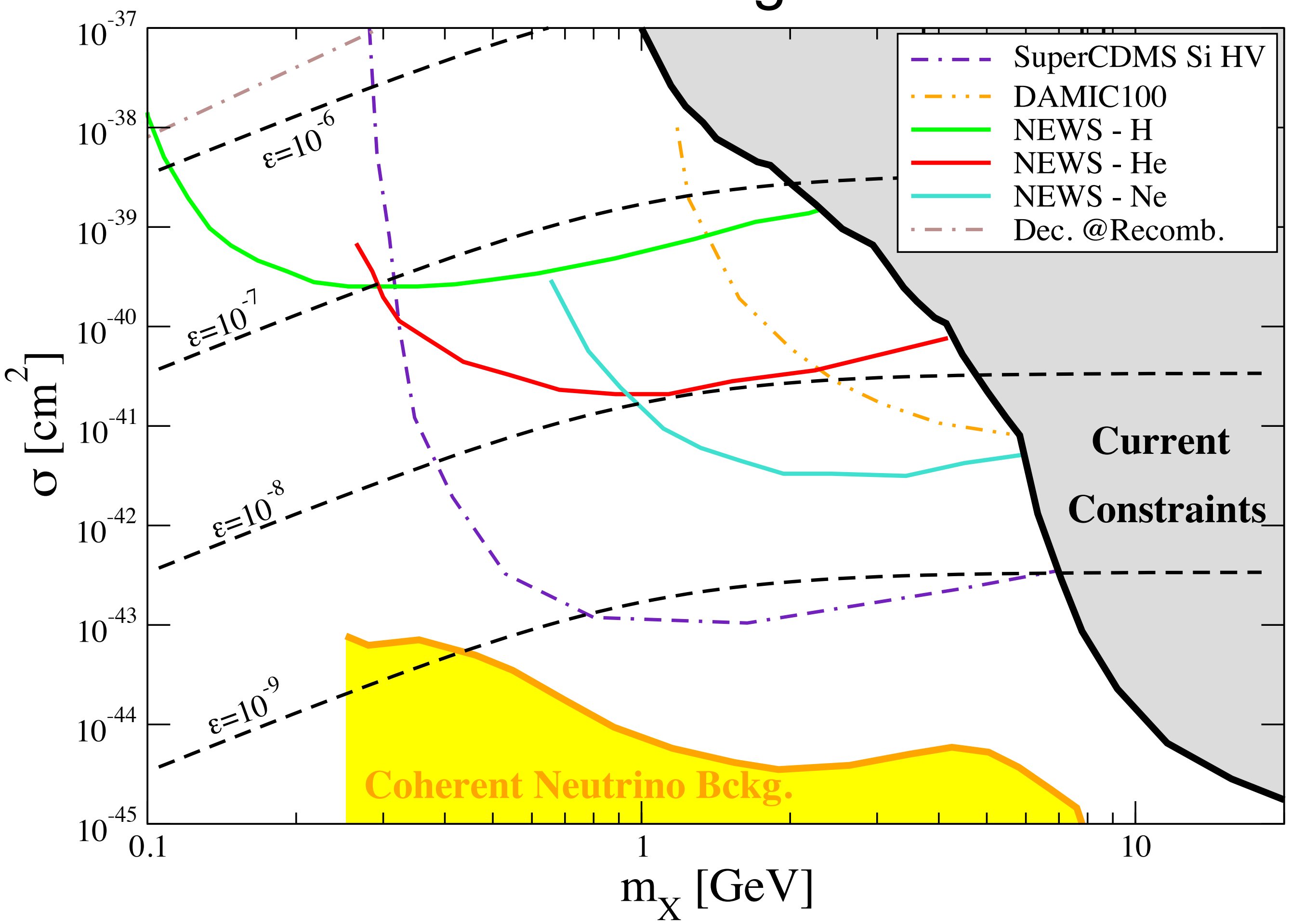
Aristotle University of Thessaloniki – I Savvidis, A Leisos, S Tzamarias,
Laboratoire de Physique Subatomique et Cosmologie Grenoble - D Santos, JF Muraz, O Guillaudin
Pacific National Northwest Lab – E Hoppe, D Asner
Royal Military College Canada, Kingston **–** D Kelly, E Corcoran
SNOLAB - **Sudbury –** P Gorel
University of Birmingham – K. Nikolopoulos, P Knights
Associated lab : TRIUMF - F Retiere

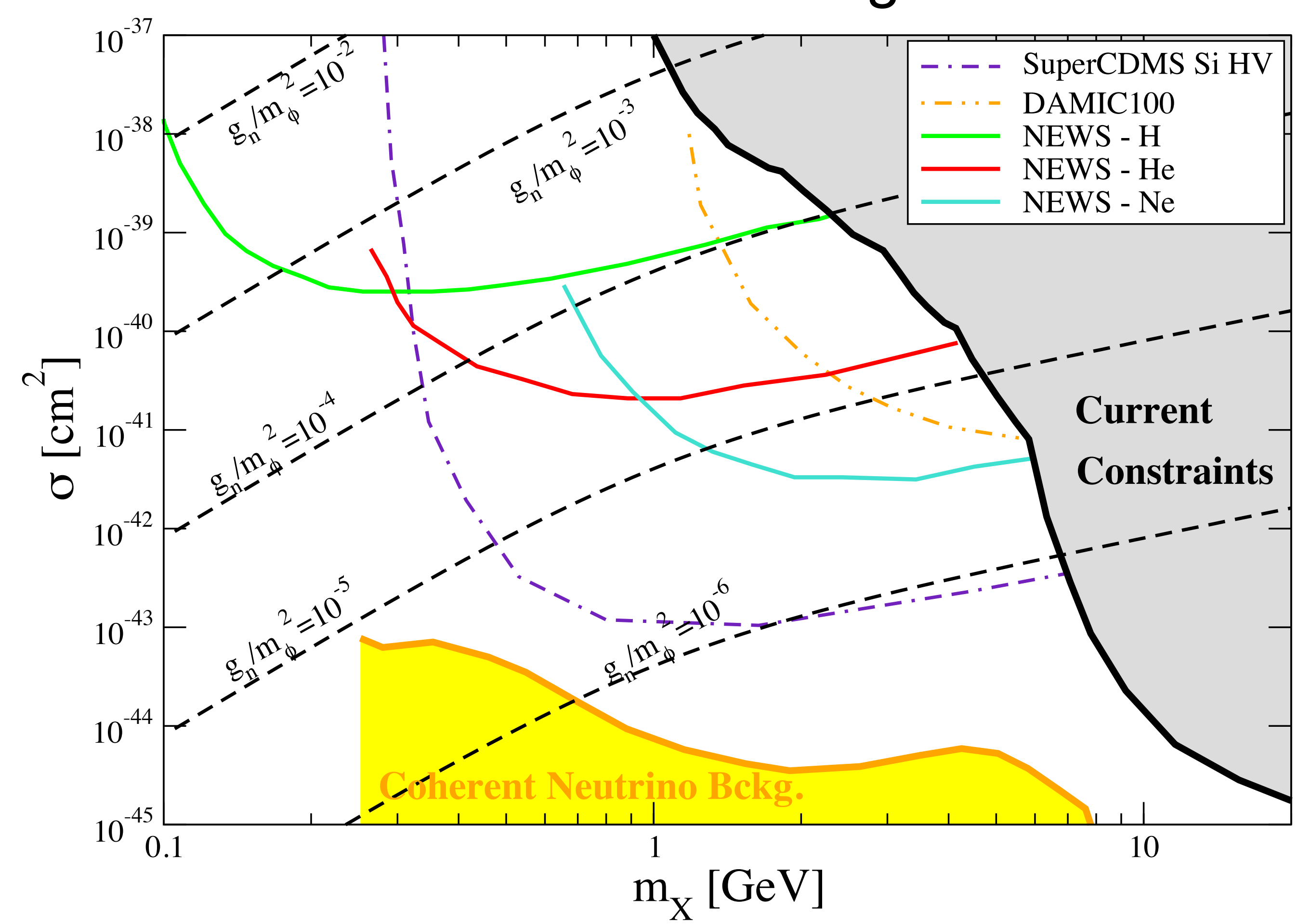
arXiv:1507.07531

milli-charged Dark Matter



for illustration/discussion

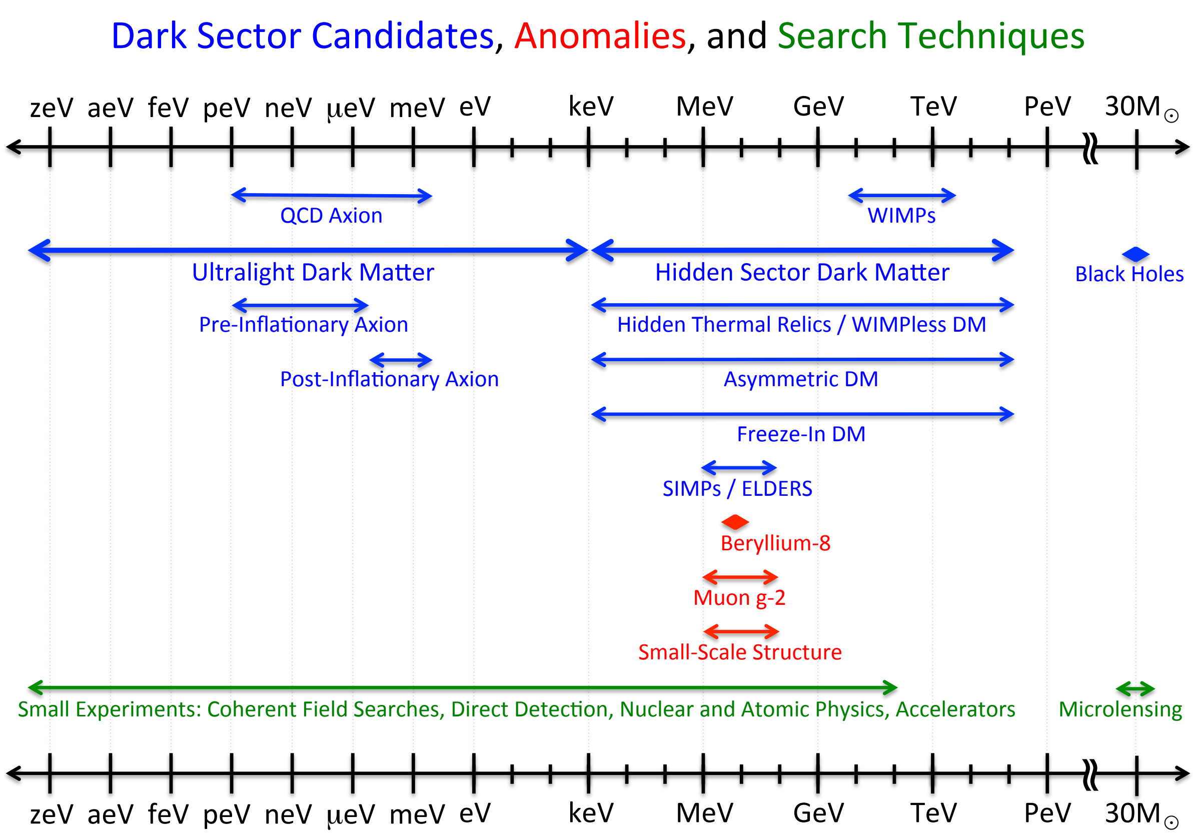
Dark matter with light mediator

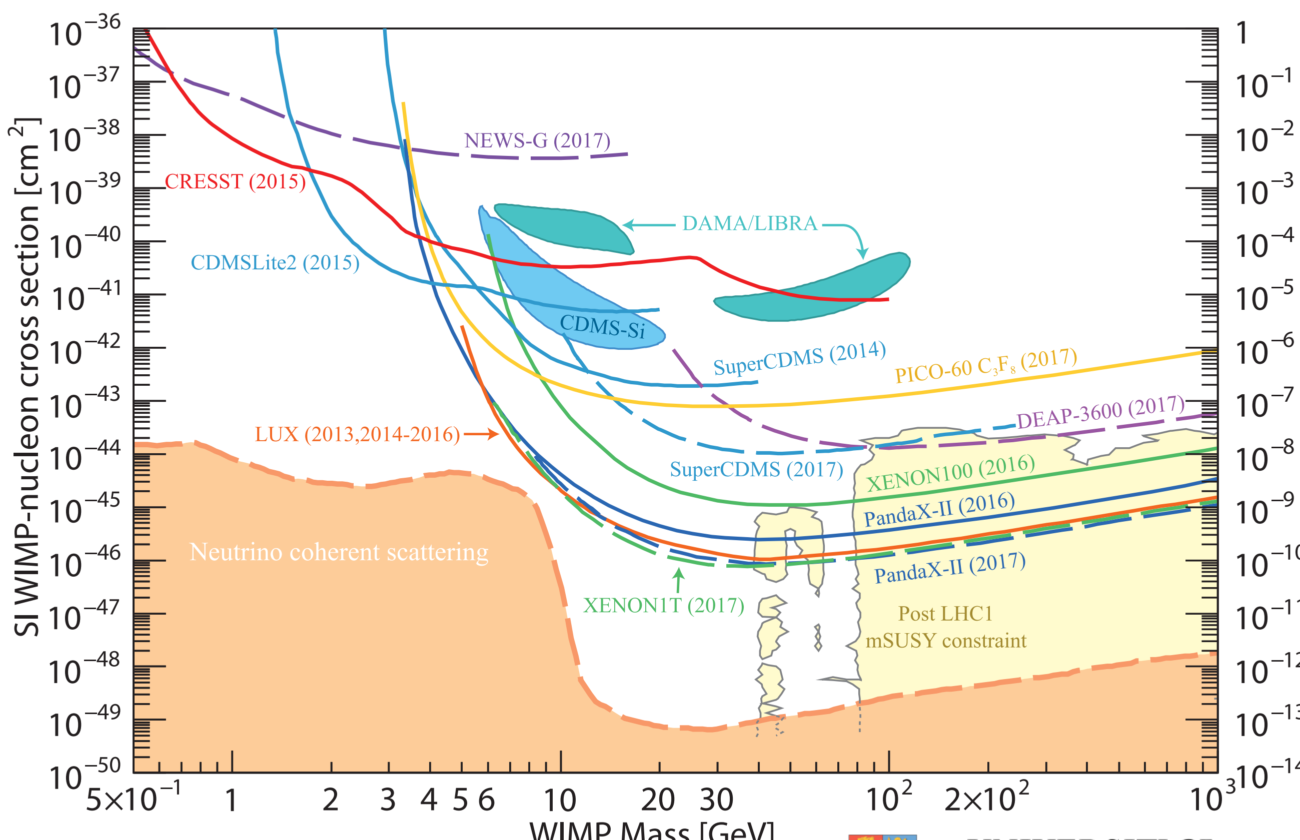


arXiv:1507.07531

Summary

- NEWS-G aims to search for DM candidates the 100 MeV – 10 GeV mass range
  - First competitive results with gas detector in Dark Matter search
  - Further He and H runs planned with SEDINE @LSM — Astropart.Phys. 97 (2018) 54-62
  - SEDINE essential for @SNOLAB optimisation
- NEWS-G @SNOLAB
  - Larger detector and target mass
  - Improved shield /materials/procedure
  - Installation at SNOLAB in 2018
- R&D on-going: cleaning methods, underground electroformed sphere, “achinos” type sensor,multi channels sensor, low pressure operation, … — JINST 12 (2017) P12031
- Many physics opportunities!





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