Search for light Dark Matter with NEWS-G

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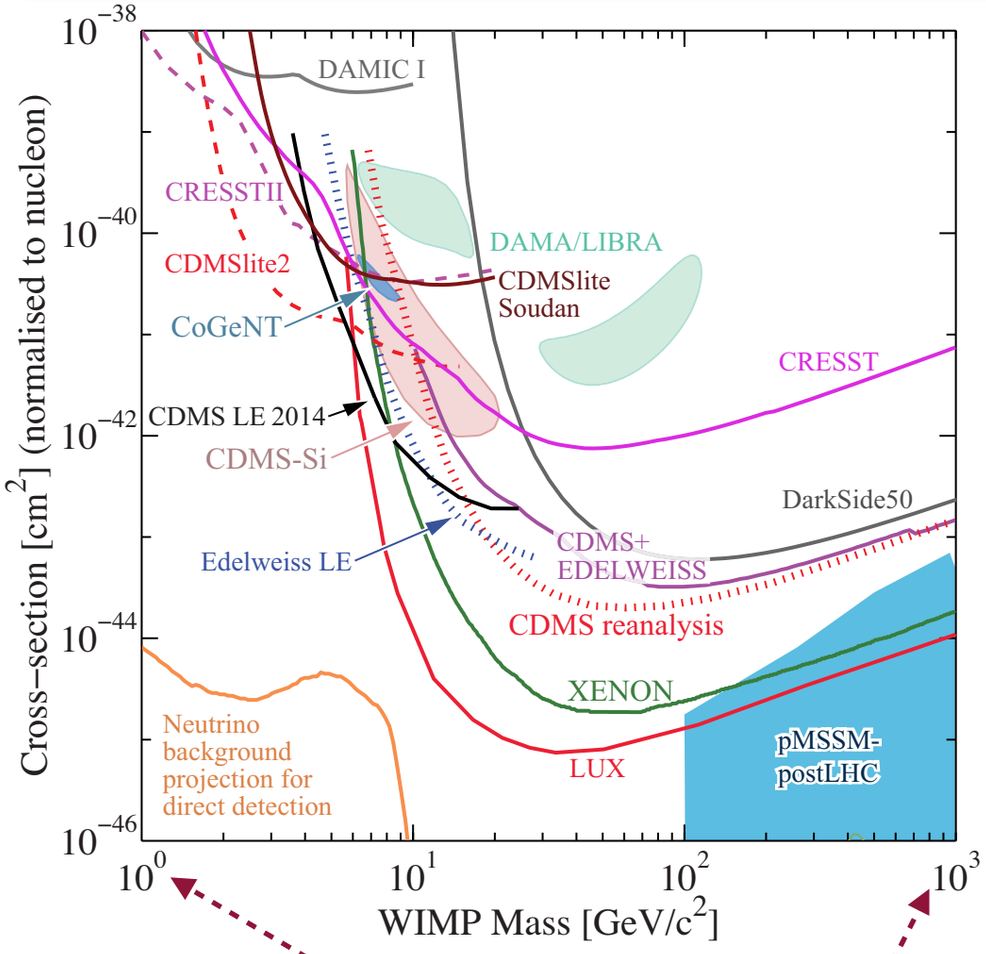
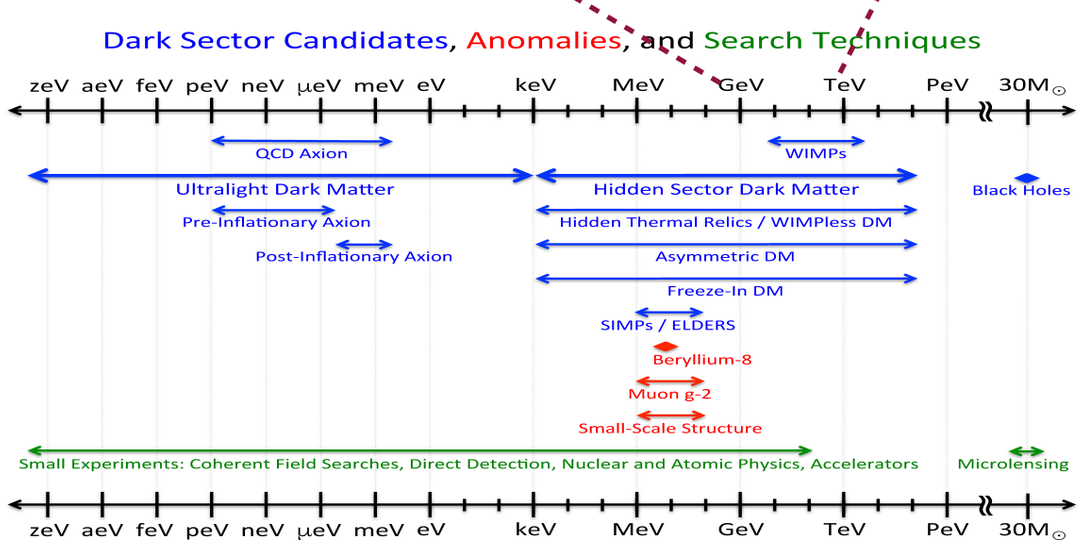
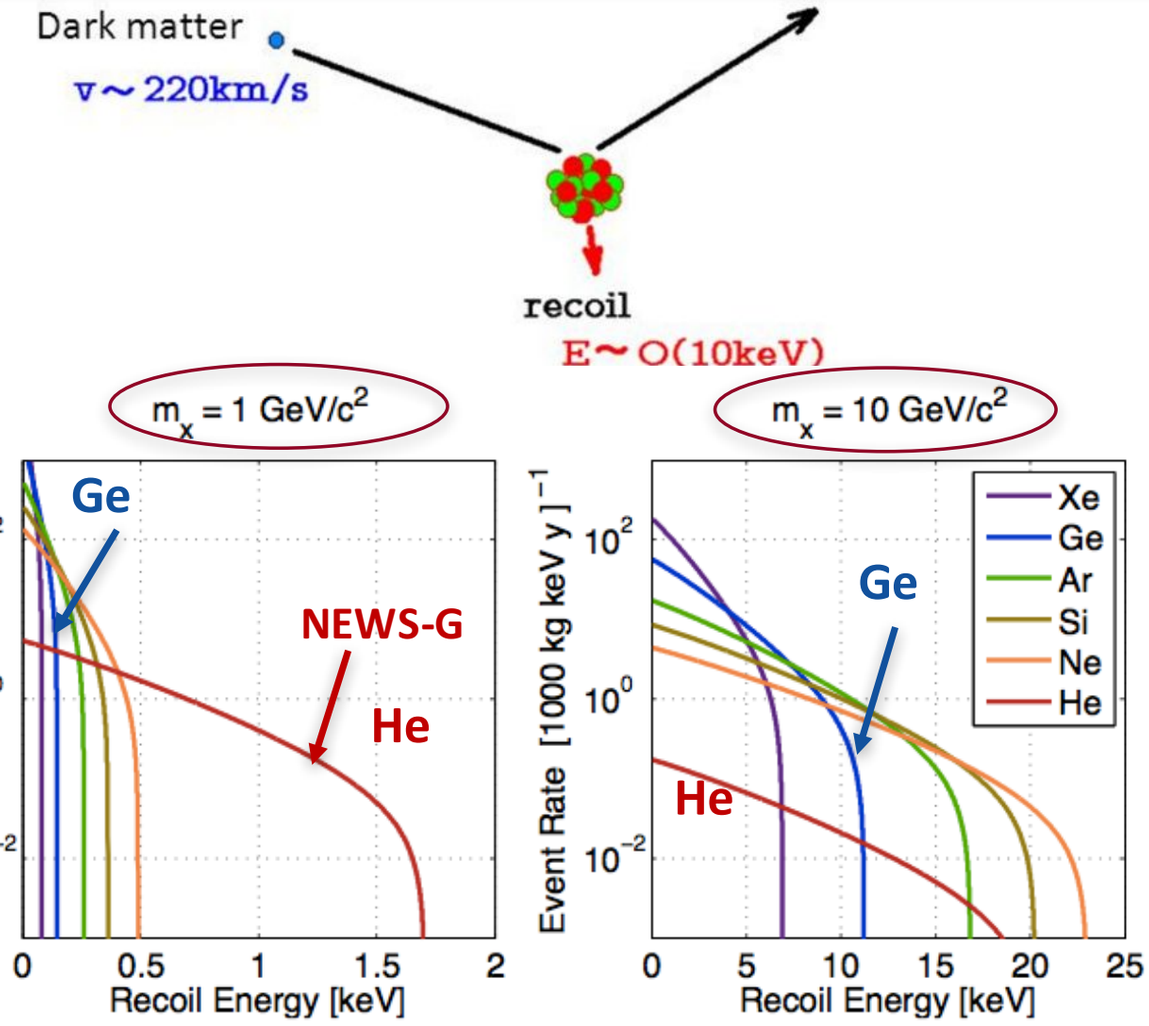
SEDINE prototype at LSM

IoP Joint APP and HEPP Annual Conference
March 27, 2018, University of Bristol, UK

New Experiments With Spheres - Gas





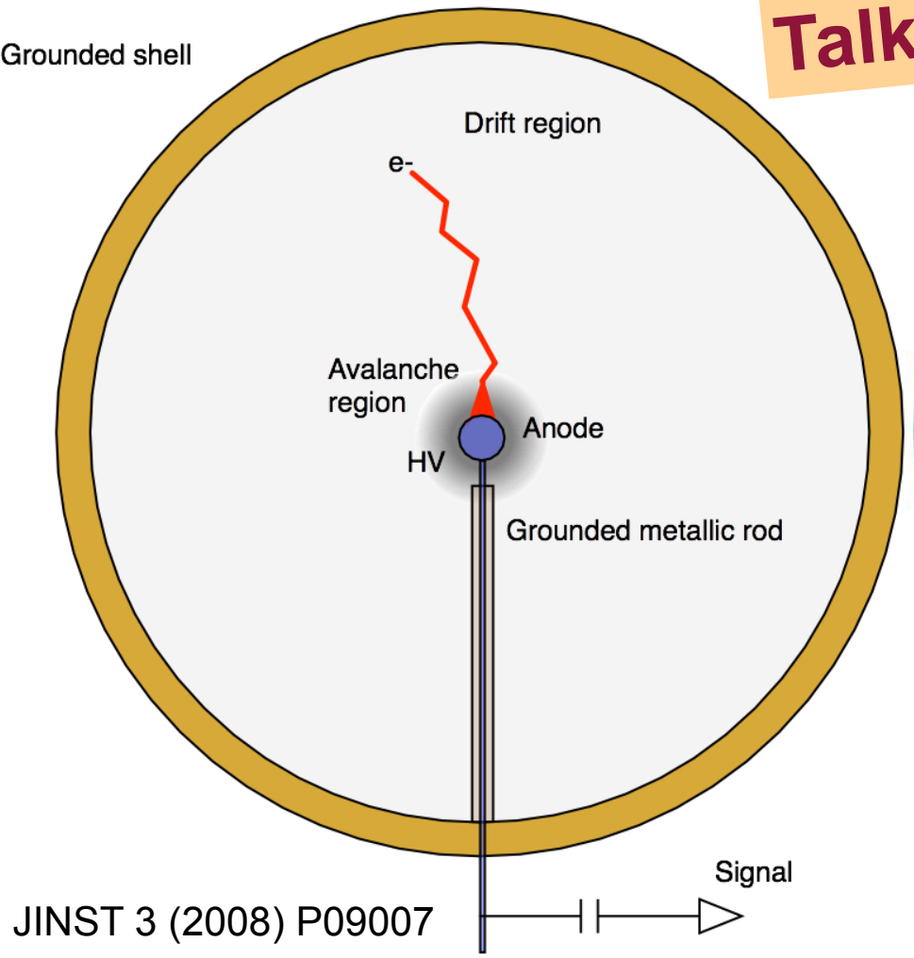


Recoil distributions with various targets

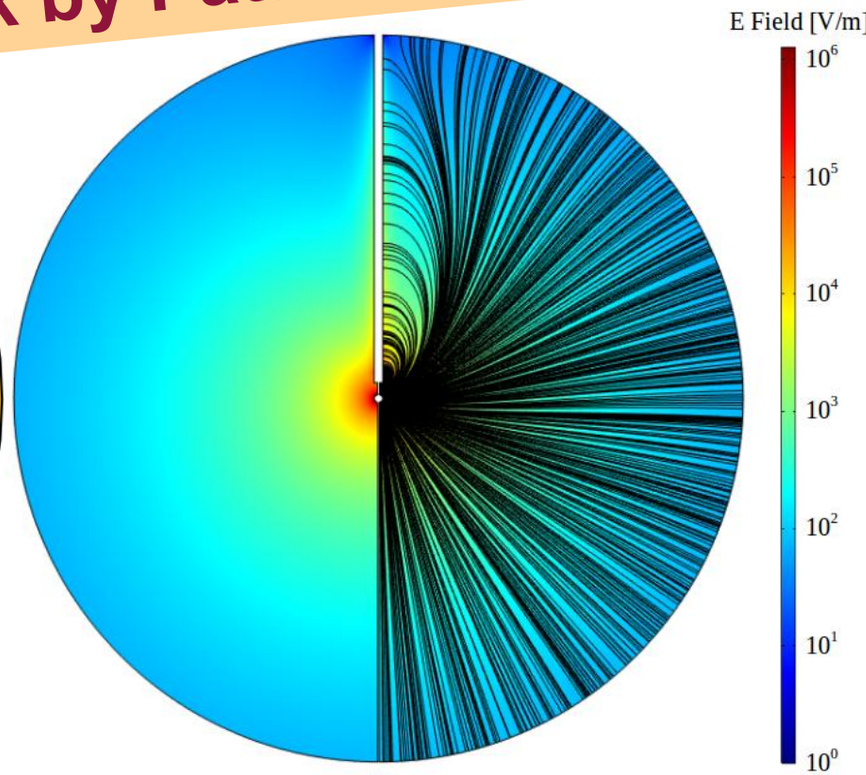
- Search for DM candidates in 0.1 - 10 GeV range
- Direct Detection experiment
  - Novel Spherical Gaseous Proportional Chamber
  - Light Gases as target (H, He, Ne)
    - Better projectile - target kinematic match
  - Low energy threshold
  - Favourable quenching factor

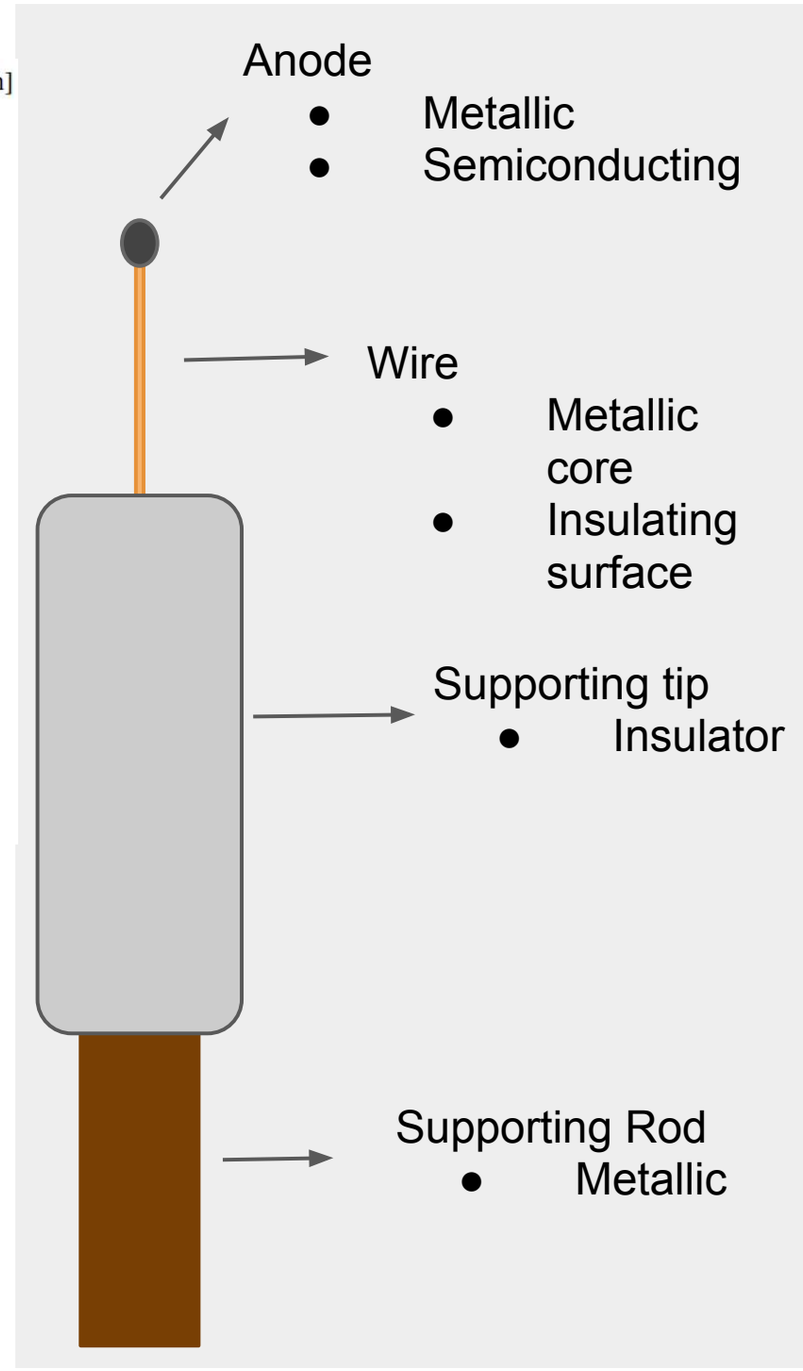
Spherical Proportional Counter

Talk by Patrick Knights



JINST 3 (2008) P09007





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

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

$r_1 = \text{anode radius}$

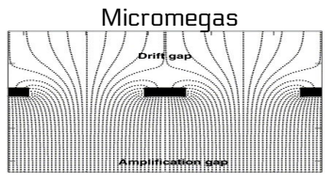
$r_2 = \text{cathode radius}$

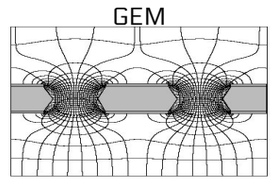
Detector volume naturally divided in a “drift” and an “amplification” volume.

Spherical Proportional Counter

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

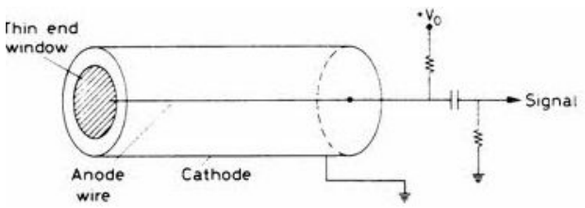
Capacitance dependence on size





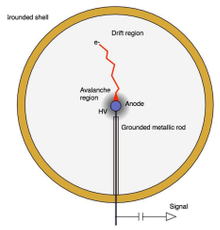
Parallel Plate Detector

C ≈ S > 1nF



Cylindrical Proportional Counter

C =2pL/ln(b/a)>> 10 pF



Spherical Proportional Counter

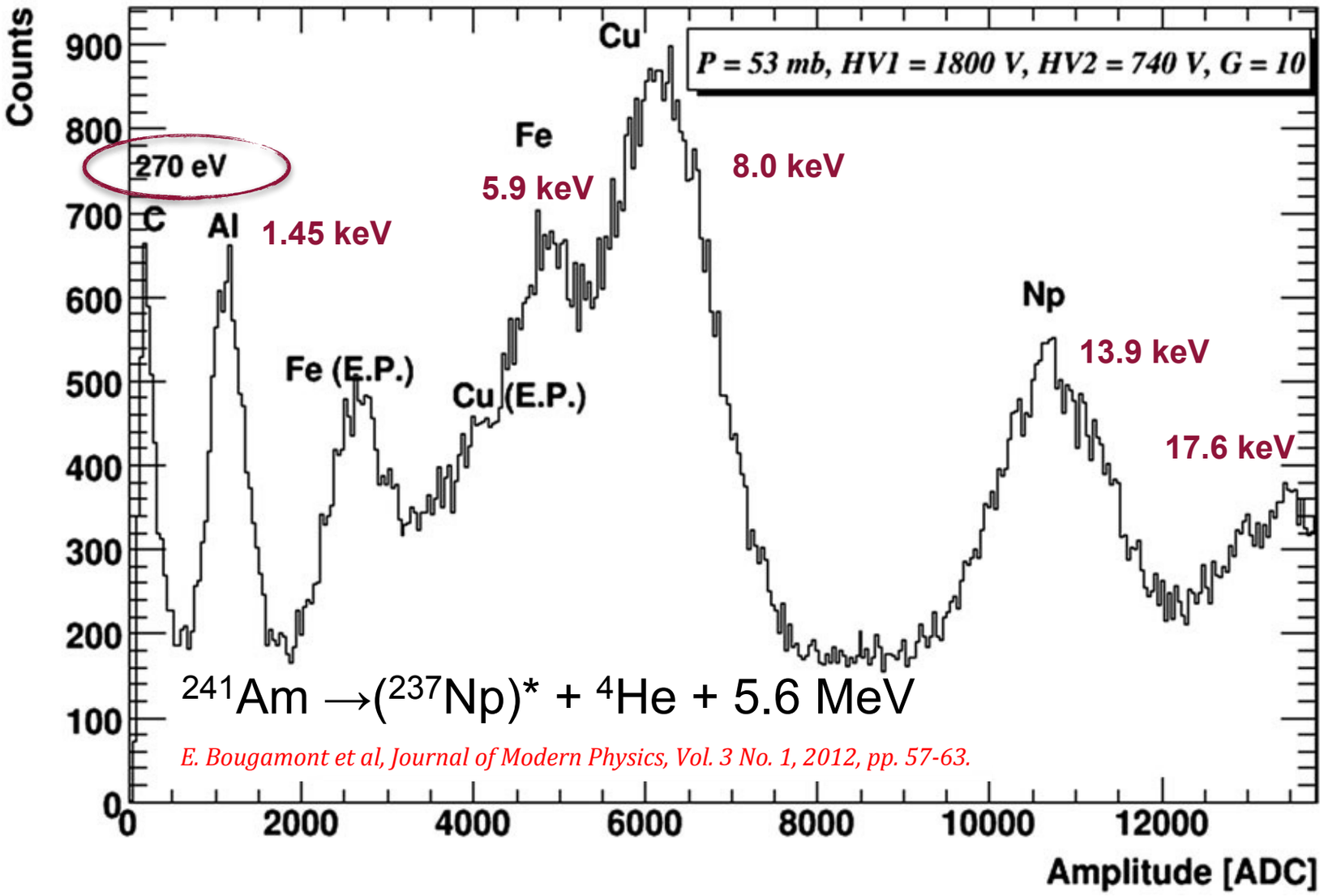
C ≈ r_1 < 1pF

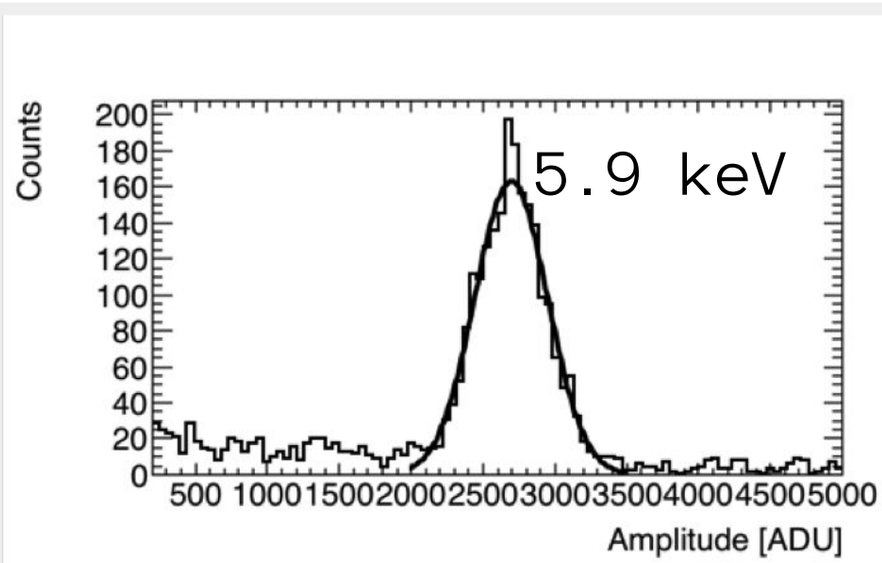
Large Size Detector + Robust construction

First Spherical Proportional Chamber made out of LEP RF Cavities

I. Giomataris and G. Charpak

Low Energy Capabilities





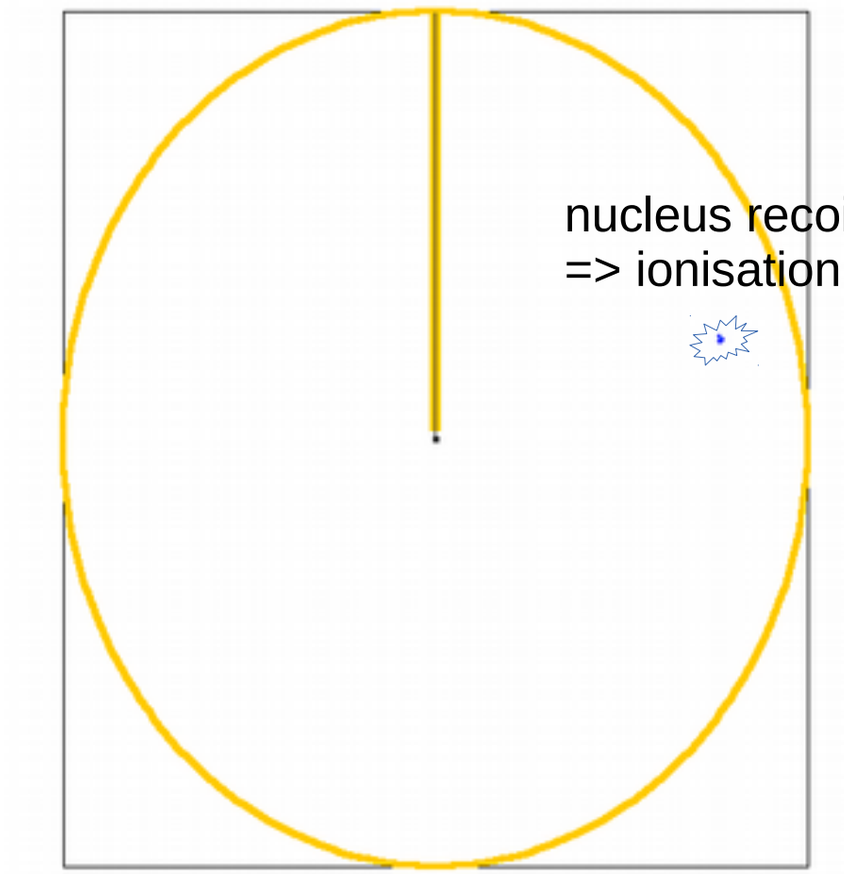
- SPC 130cm diameter
  - Ar + 2% CH_4
- Single Electron detection
- Energy threshold < 50 eV
  - Tested with single electrons extracted from Copper with UV lamp

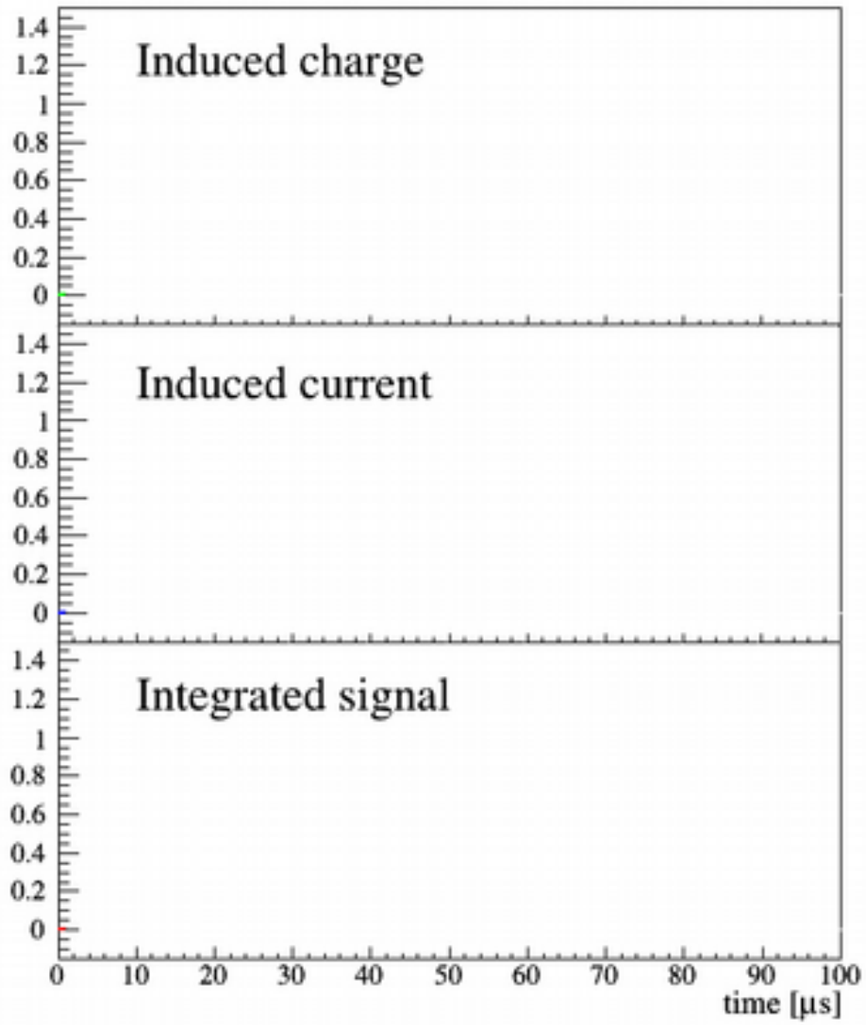
SPC Φ 30 cm

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

Resolution (σ) <9%

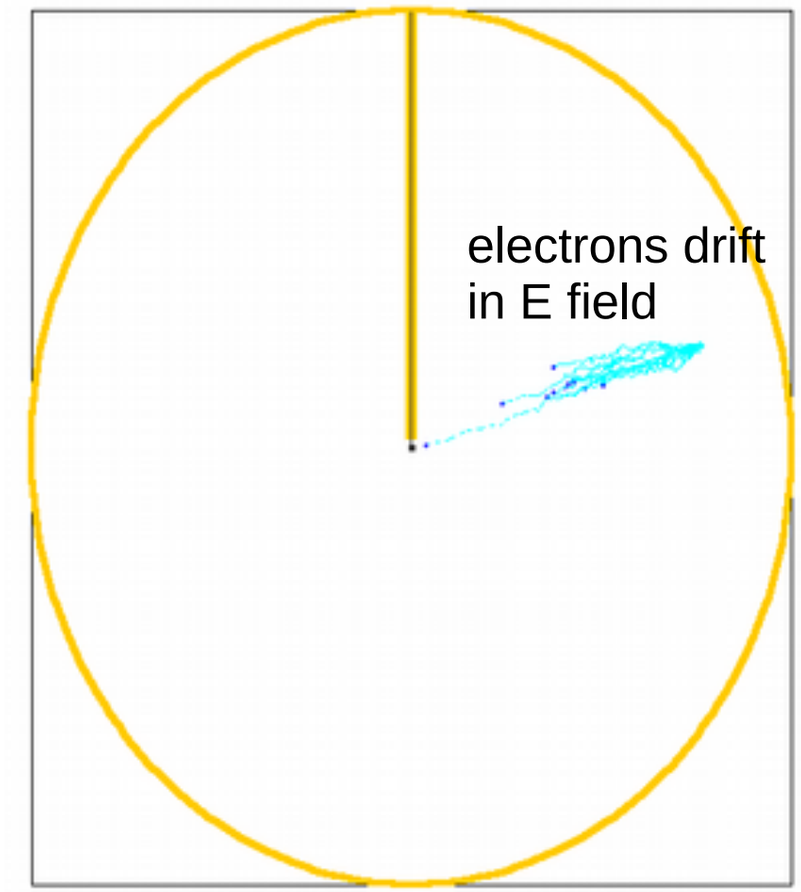
Signal Formation

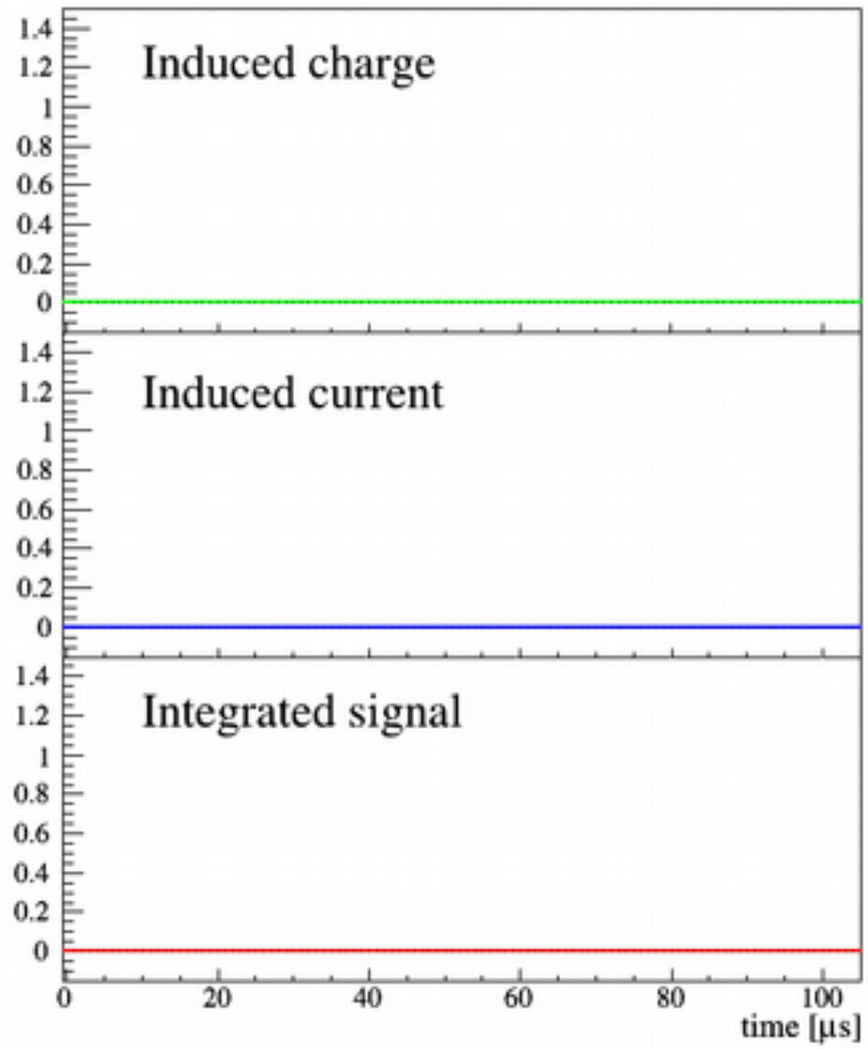




Plot by P. Gros

Signal Formation





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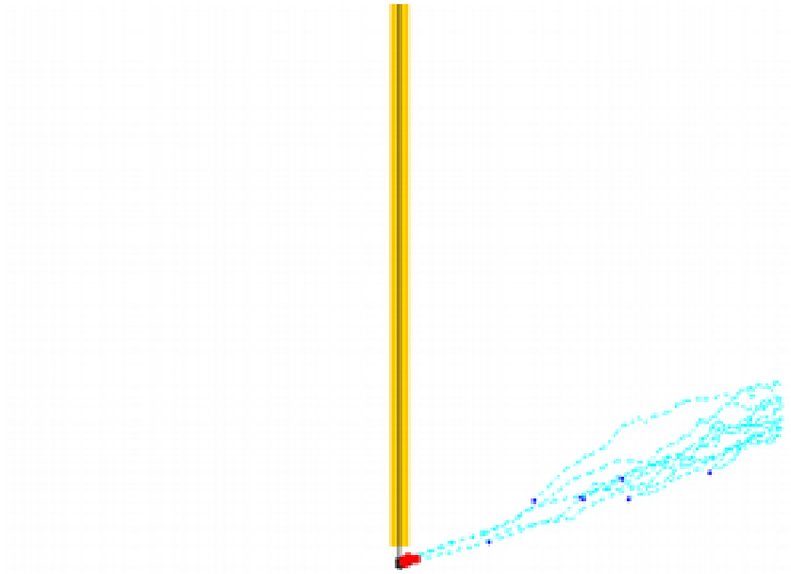
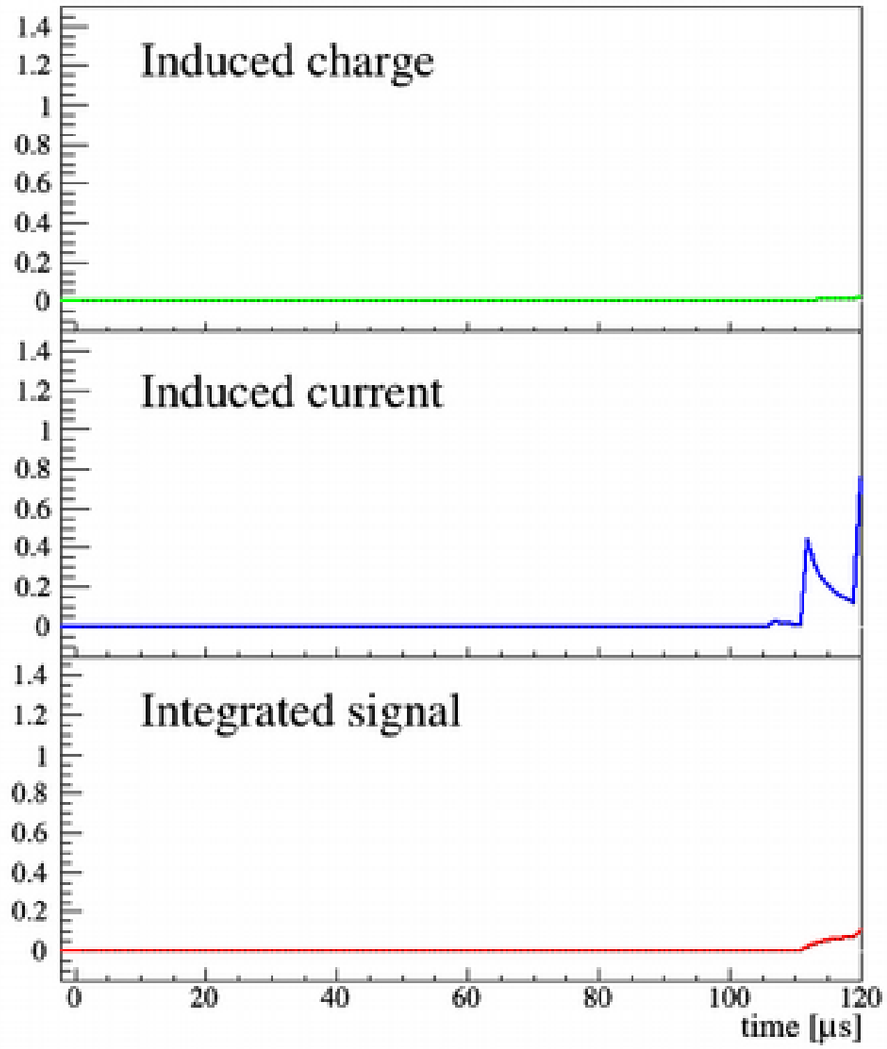
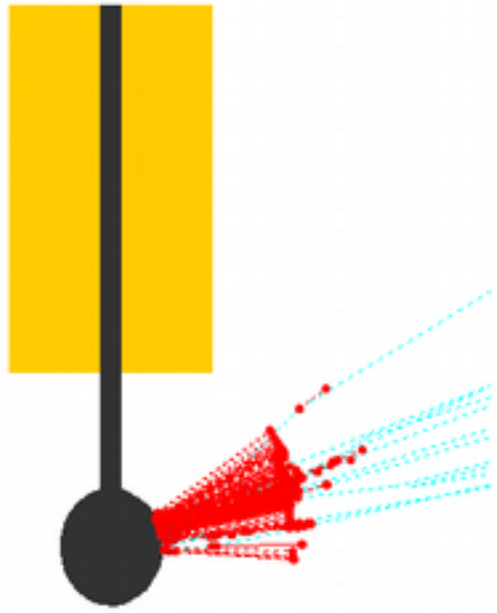


avalanche in high field near sensor

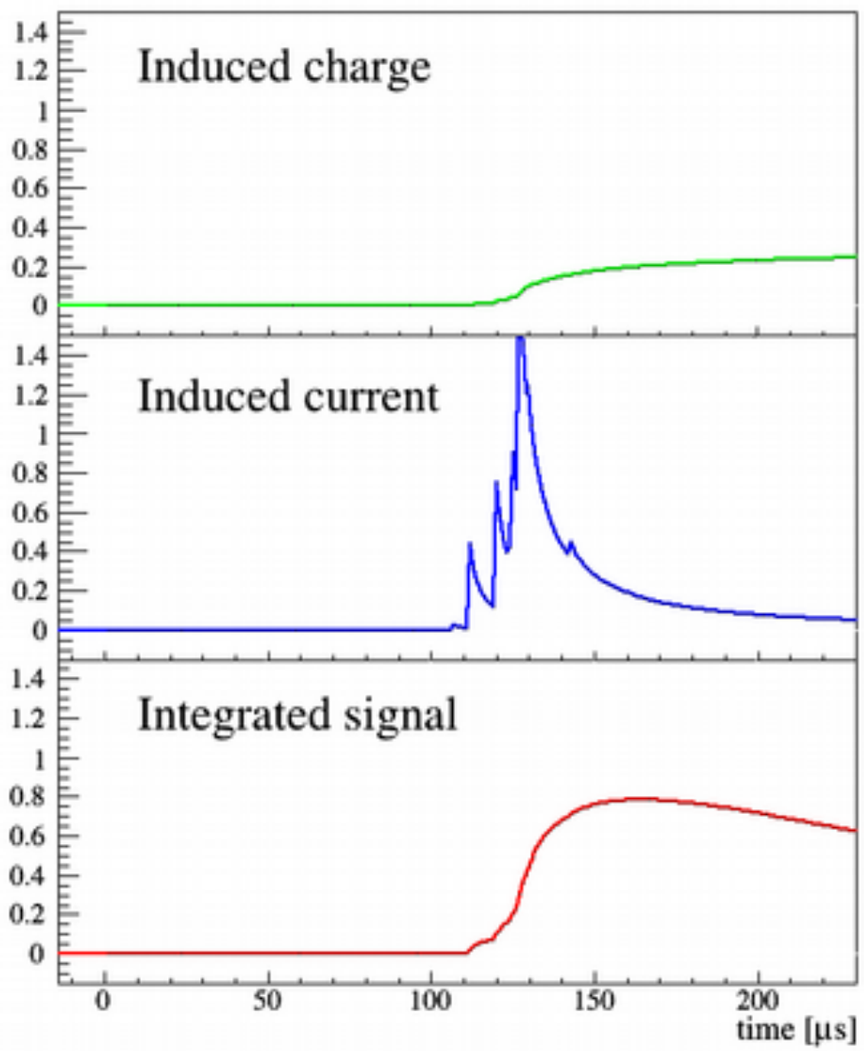


Plot by P. Gros

Signal Formation

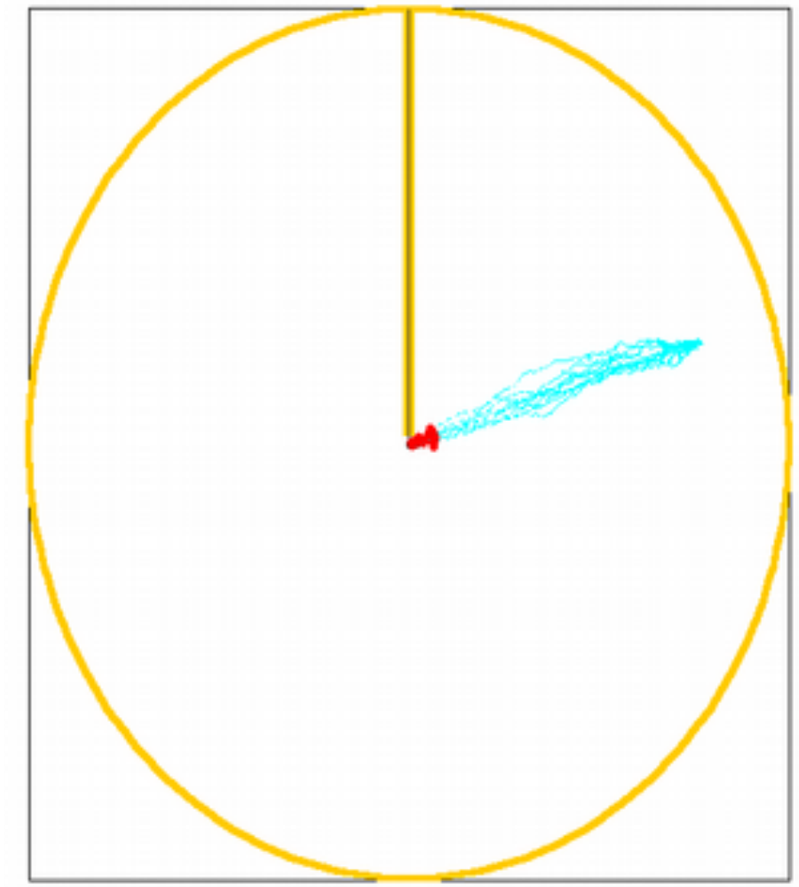


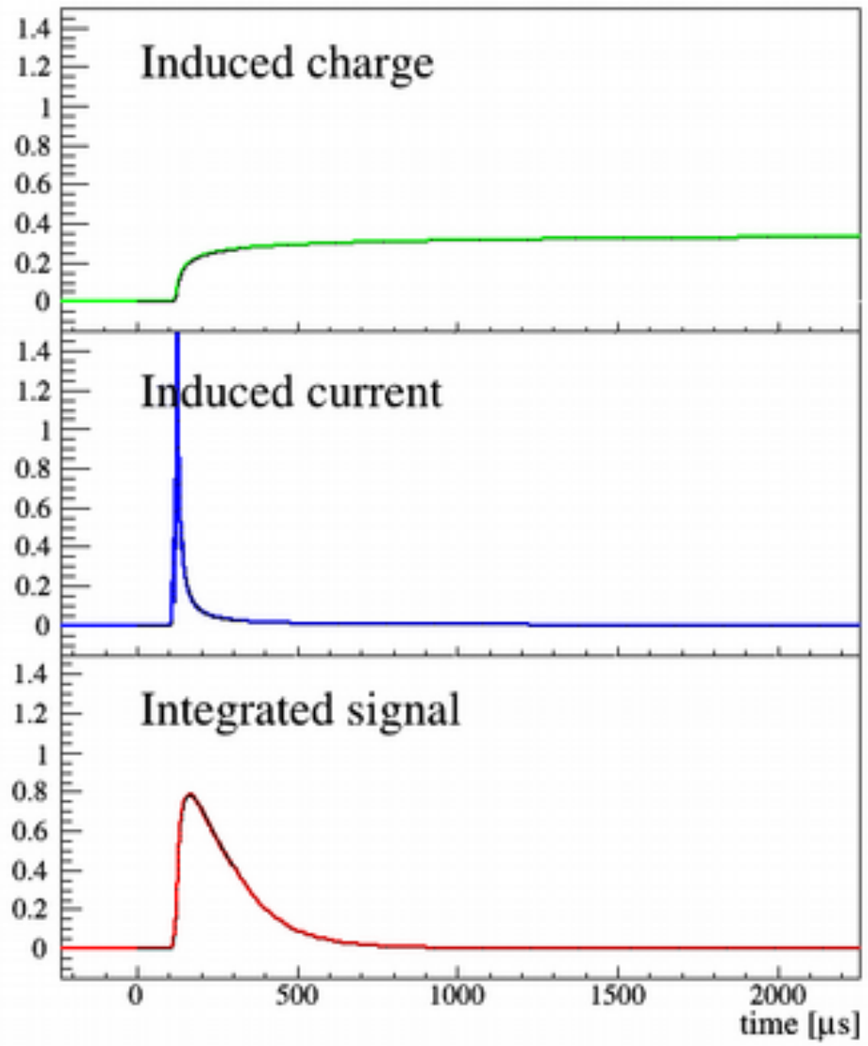
Signal induced by ions drifting back



Plot by P. Gros

Signal Formation

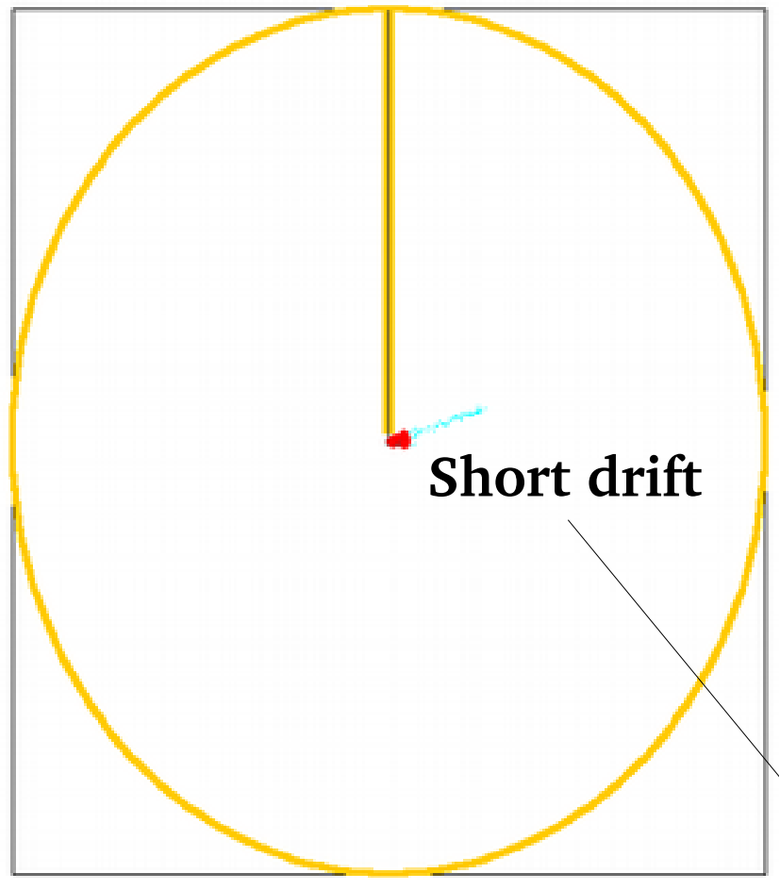


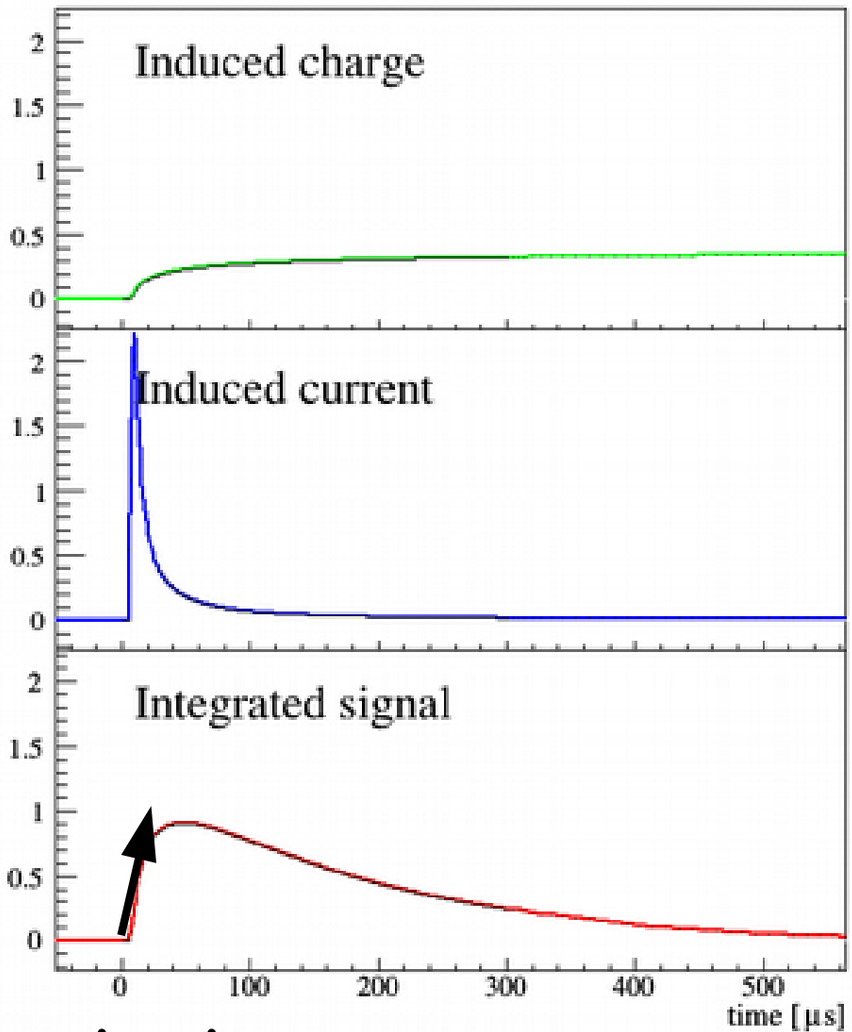


In reality:
Observed Pulse = Induced Current ⊗ Preamplifier Response
Need to deconvolve the preamplifier response

Plot by P. Gros

Background Rejection: Rise Time

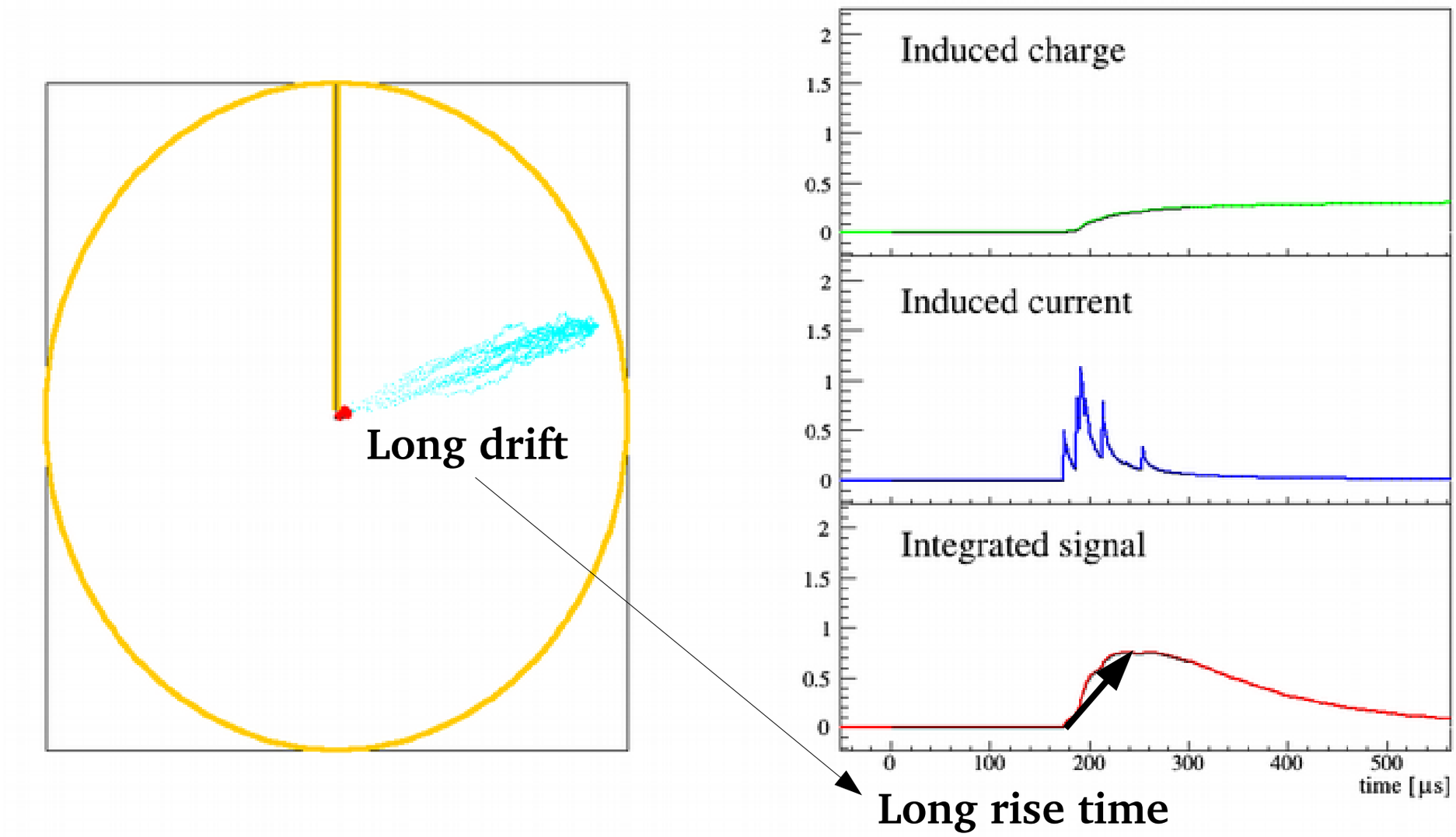




Short rise time

Plot by P. Gros

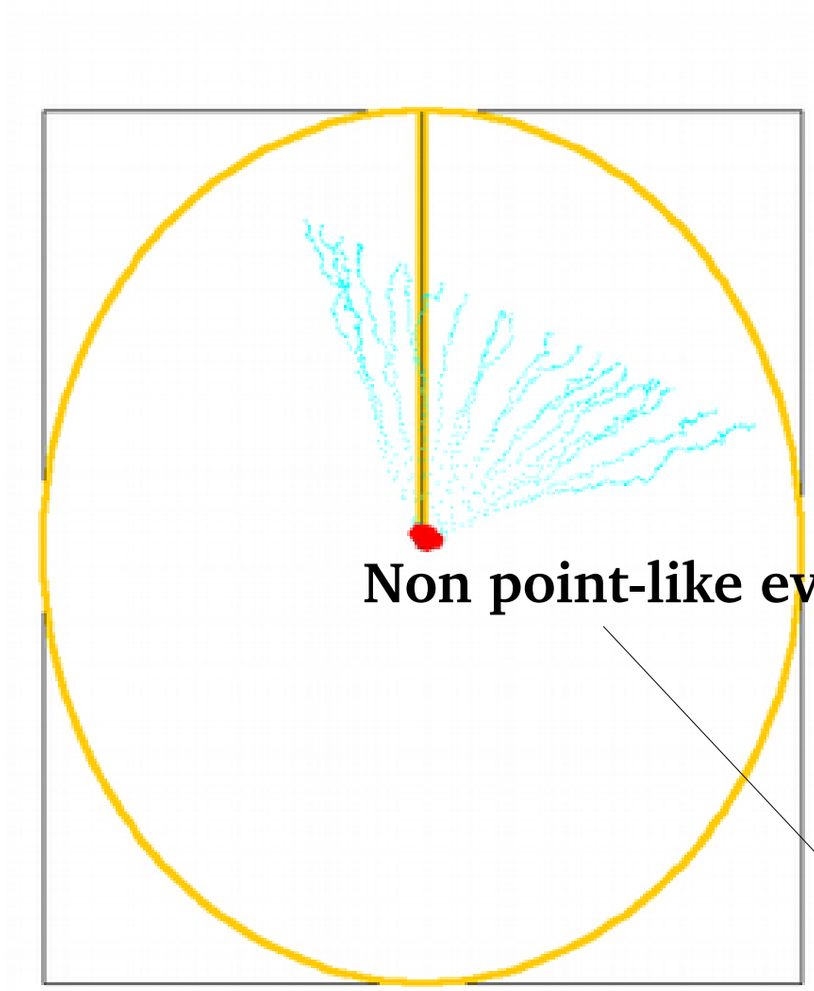
Background Rejection: Rise Time

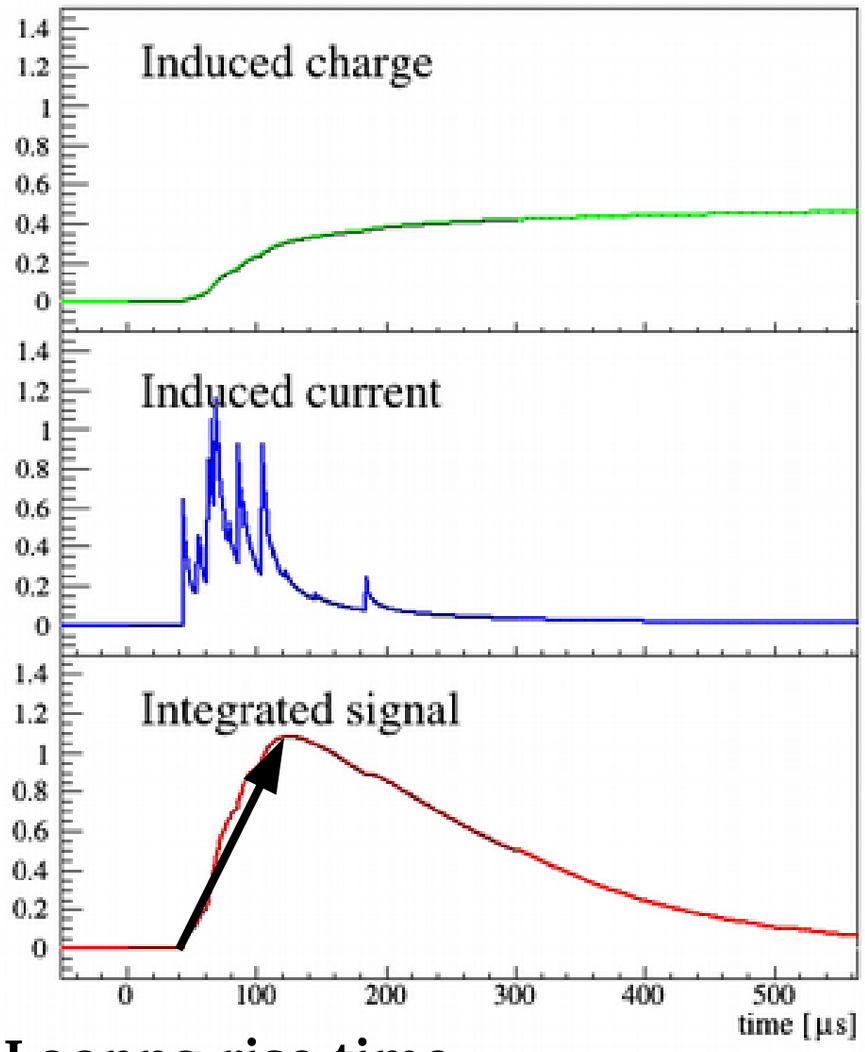


$\sigma(r) \sim 20\ \mu s \times (r/r_{sphere})^3$, e- drift time dispersion

Plot by P. Gros

Background Rejection: Rise Time



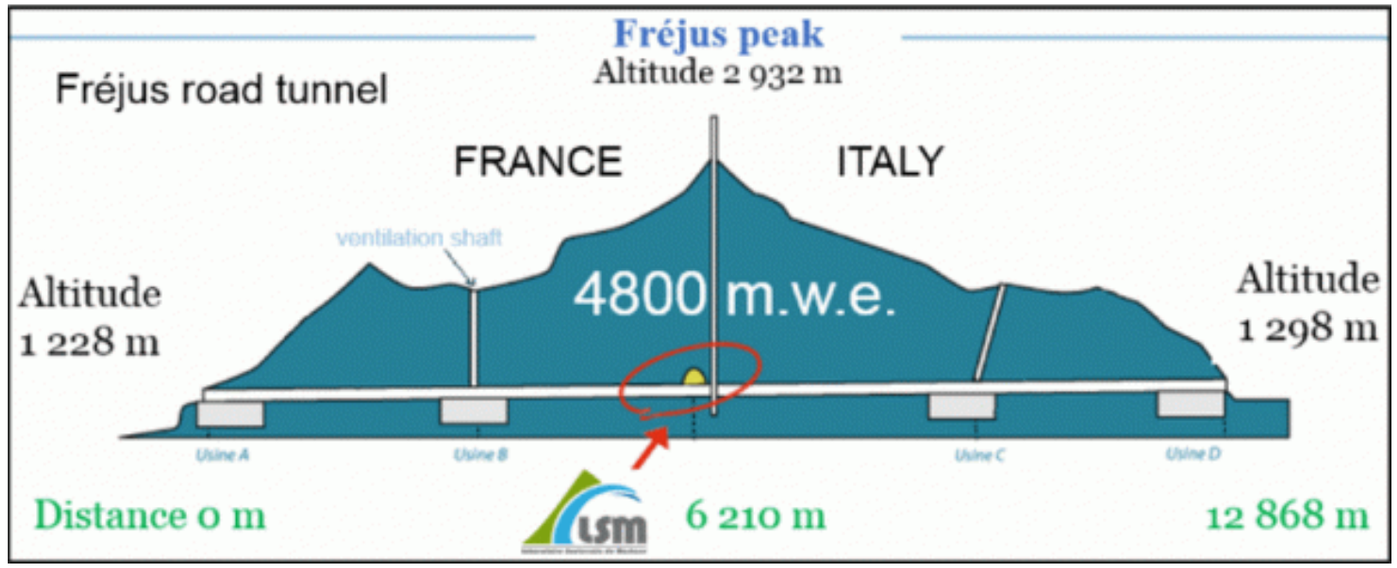


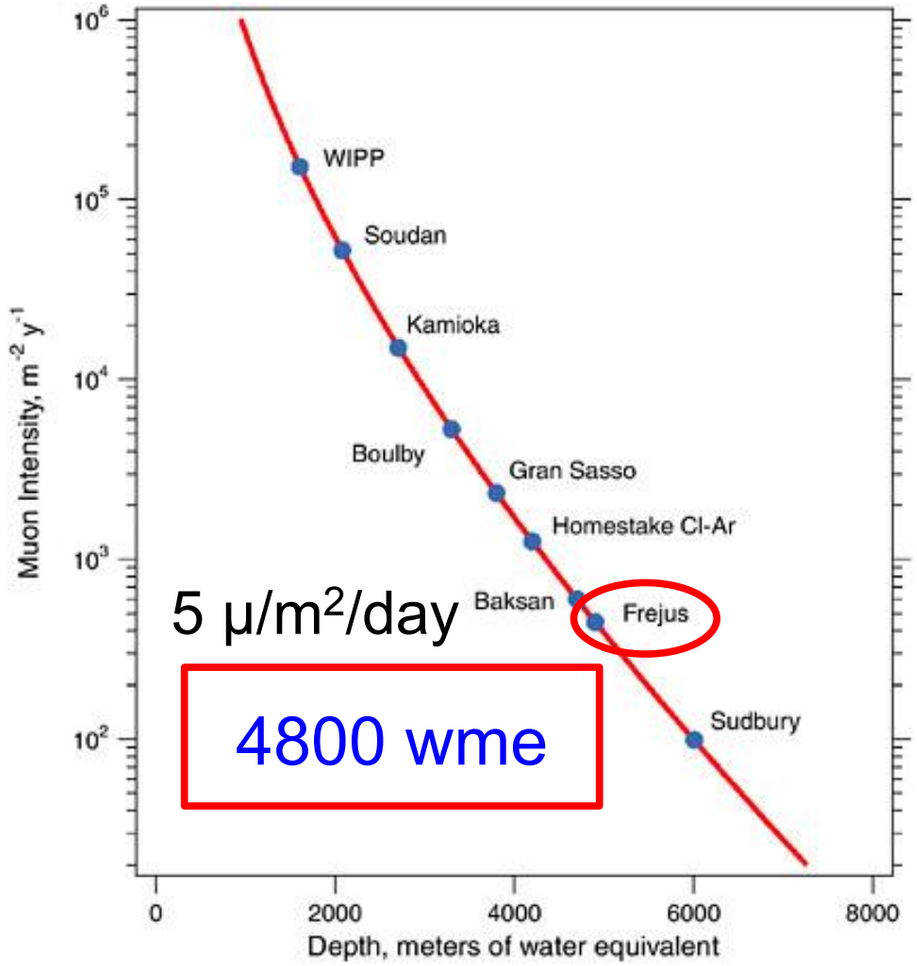
Plot by P. Gros

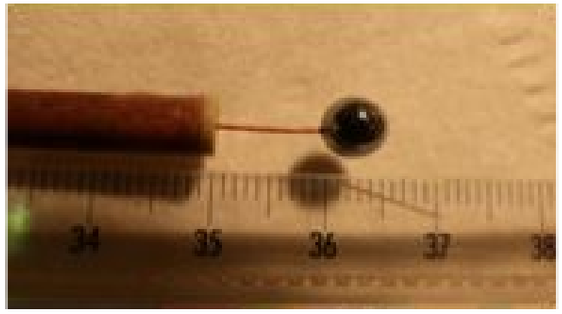
SEDINE: Low background SPC at LSM

- 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

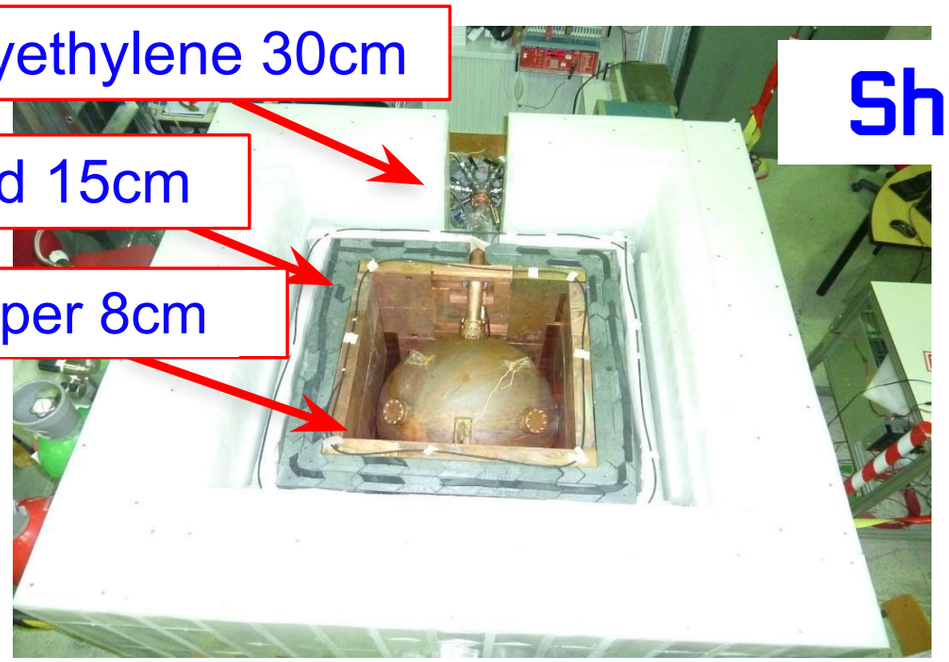
Laboratoire **S**outerrain de **M**odane







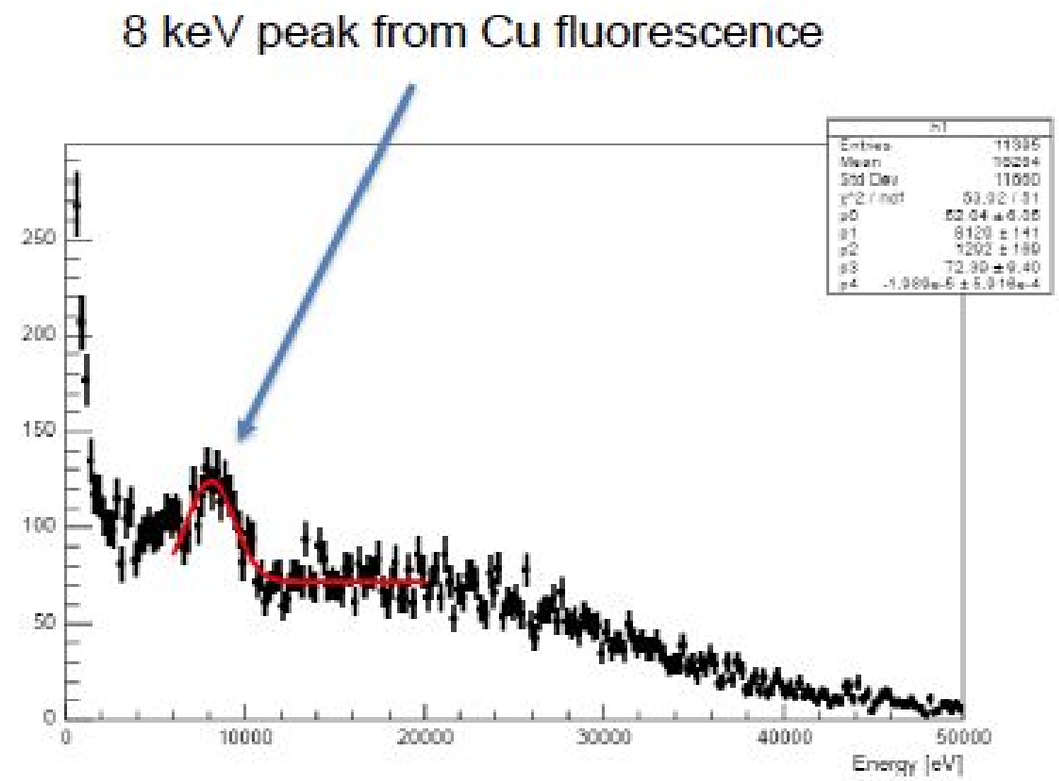
SEDINE sensor

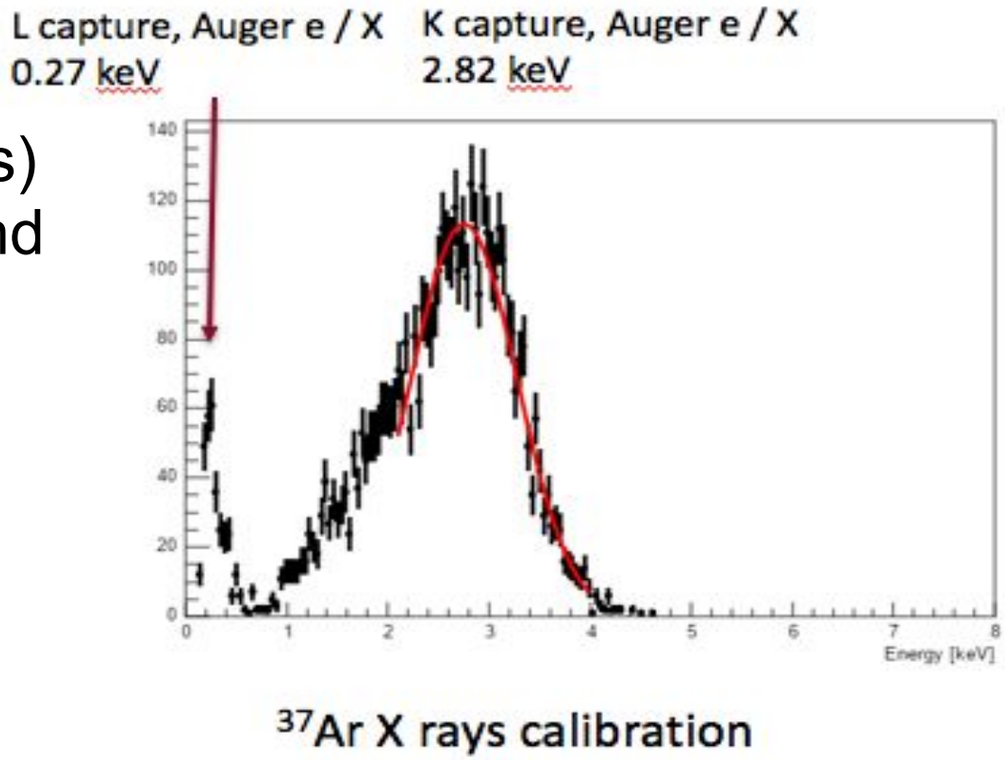


Shielding

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

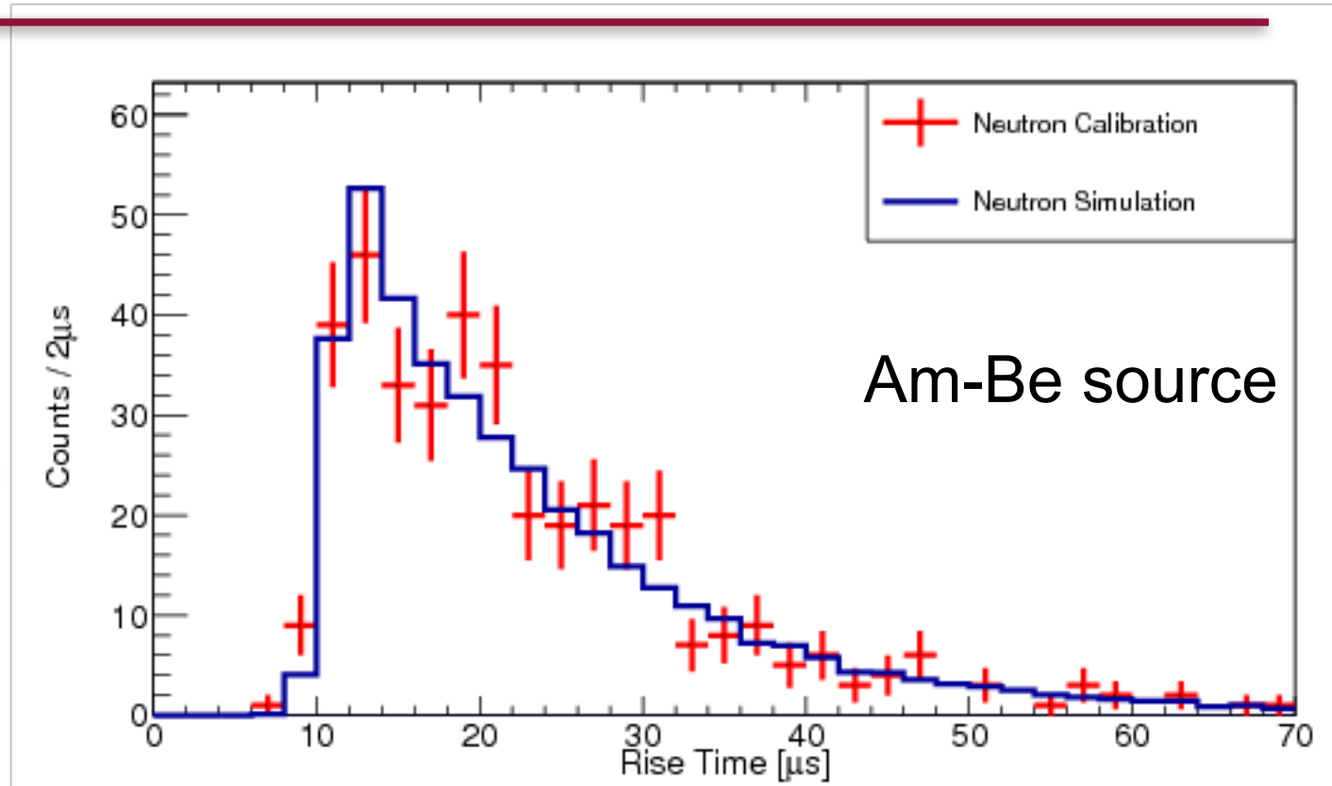




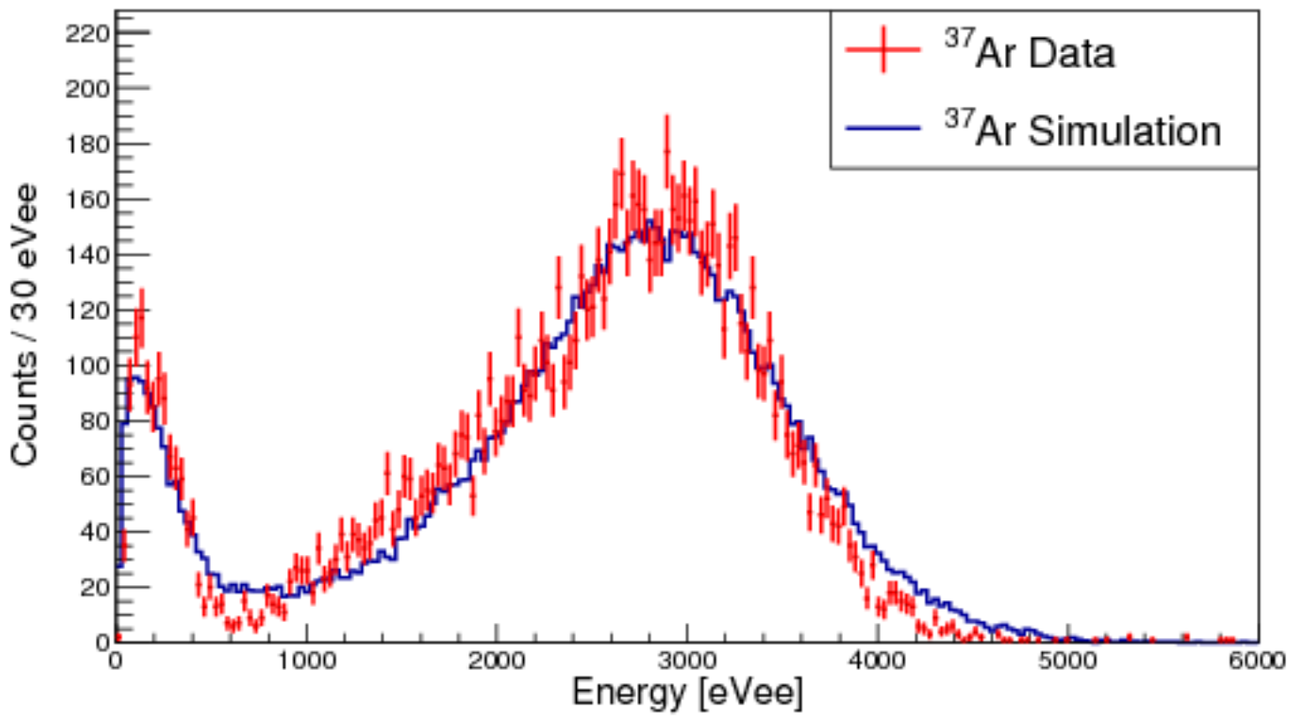
^{37}Ar X rays calibration

SEDINE:Volume and surface events simulation

- Anticipated main backgrounds:
  - Volume: Compton electrons
    - ^{208}Tl and ^{40}K in the rock
    - ^{238}U, ^{232}Th, and ^{60}Co copper shell/shielding
  - Surface: Radon decay products
  - Chemical Cleaning (nitric acid)
    - >200eV: 180 mHz → ~2mHz
    - <200eV: 400 mHz → ~20mHz



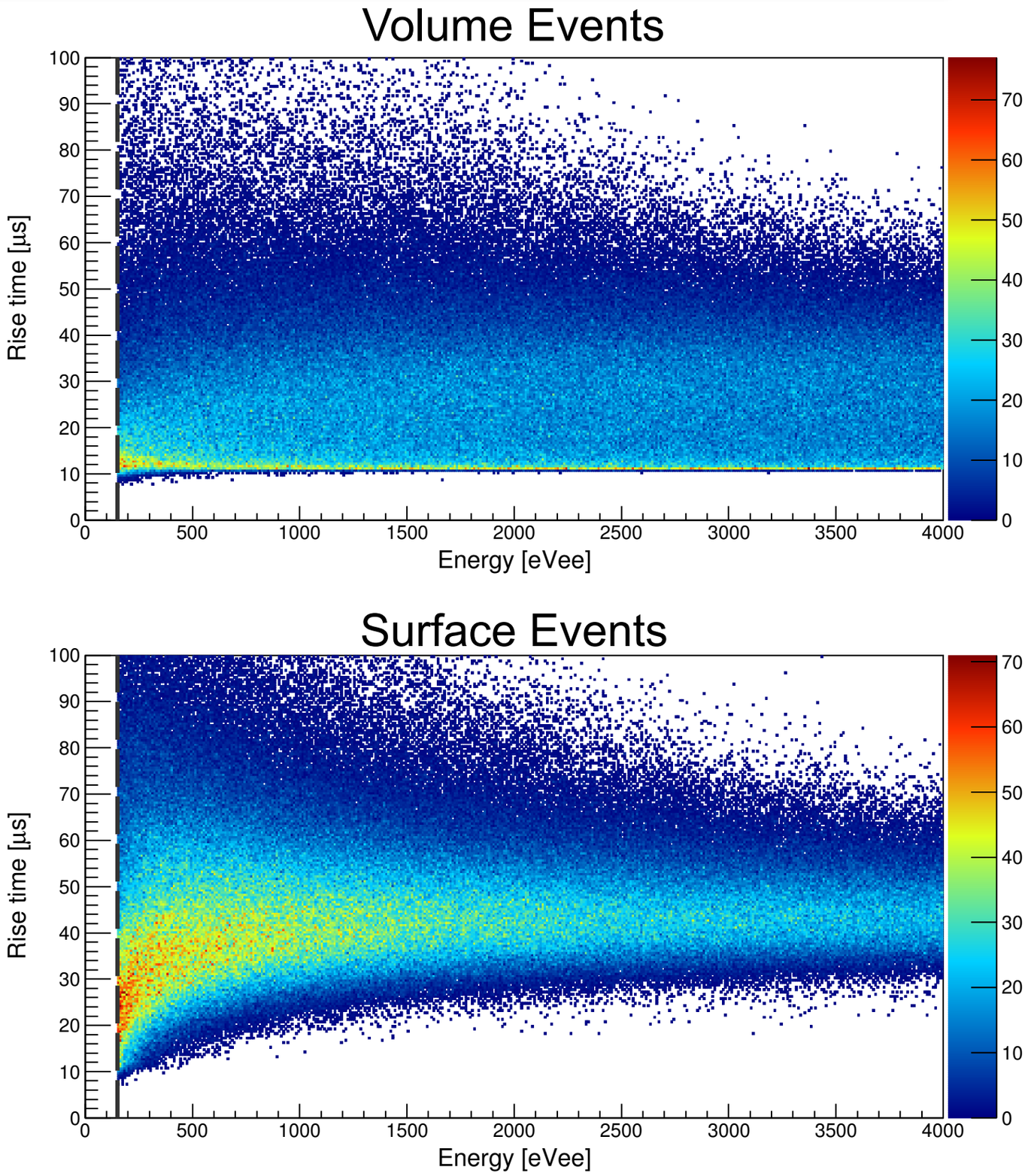
- Pulse simulations include:
  - Electric field (FEM)
  - Diffusion (Magboltz)
  - Avalanche process
  - Signal induction
  - Preamplifier delta response



Astropart.Phys. 97 (2018) 54-62

SEDINE:Volume and surface events simulation

- Data in side-bands used together with simulations to obtain number/ 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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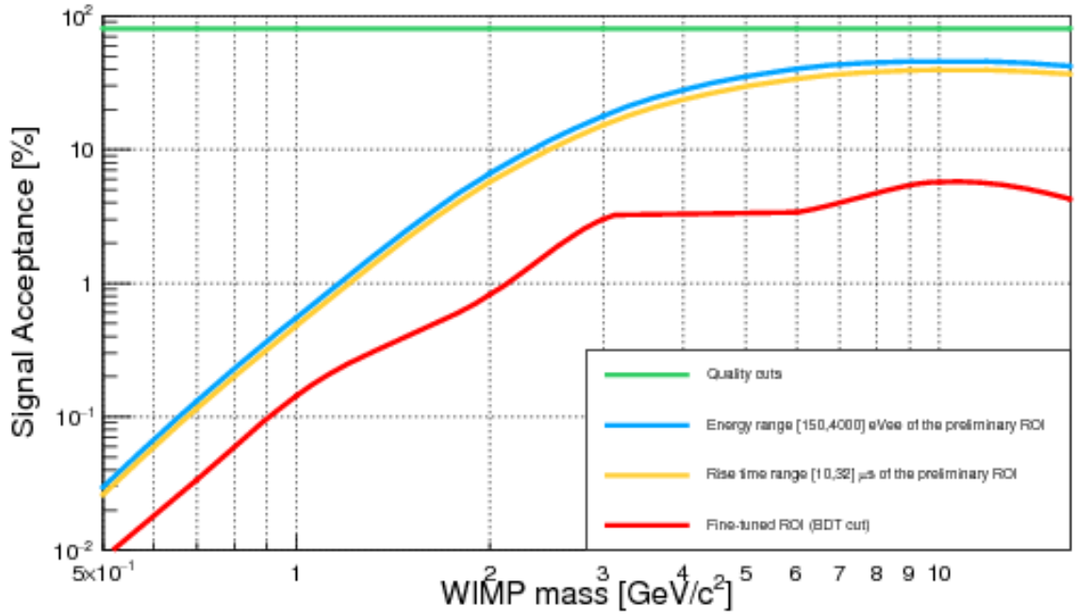
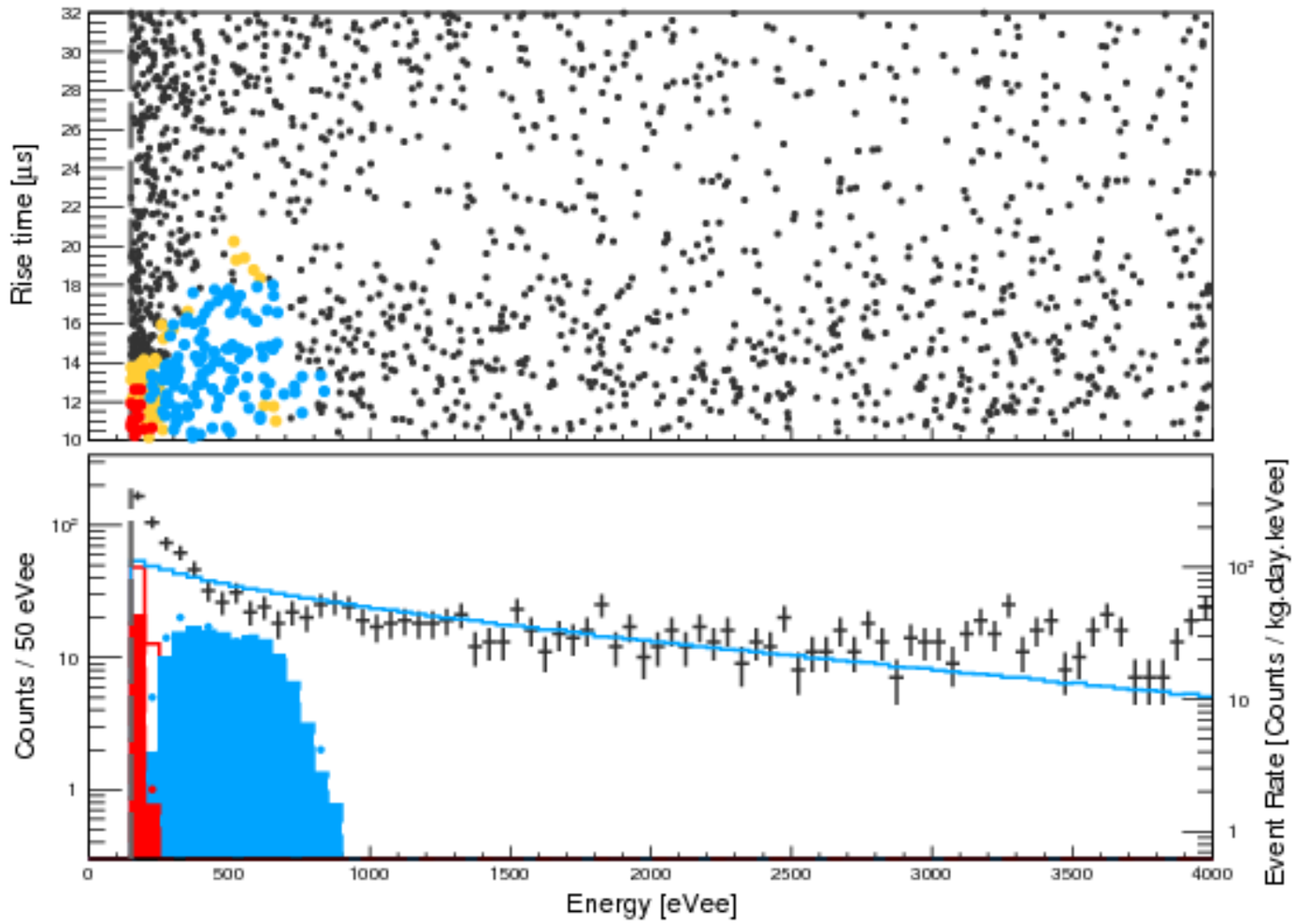
Event Selection

- 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





NEWS-G / LSM Exclusion Limits

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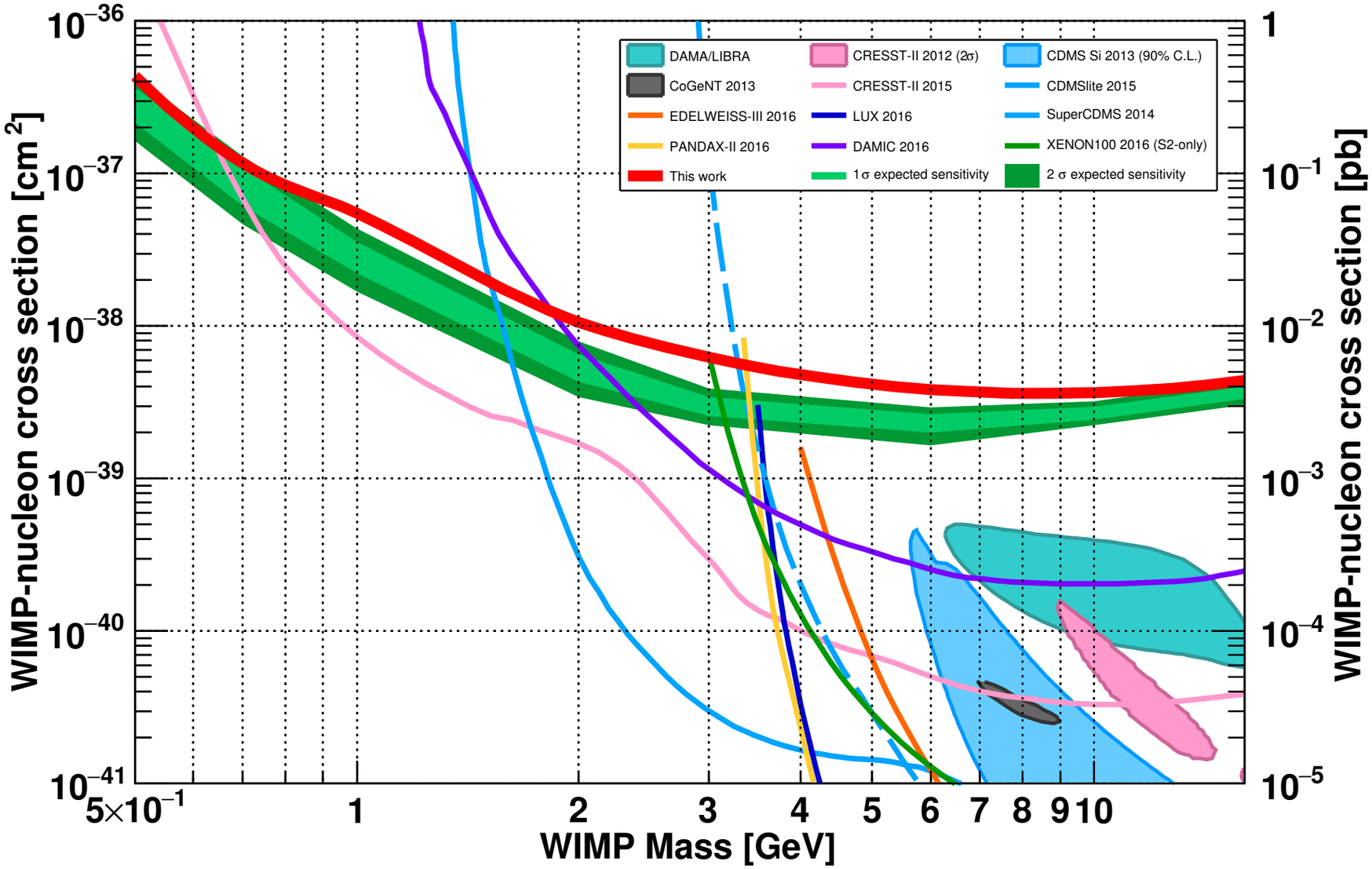


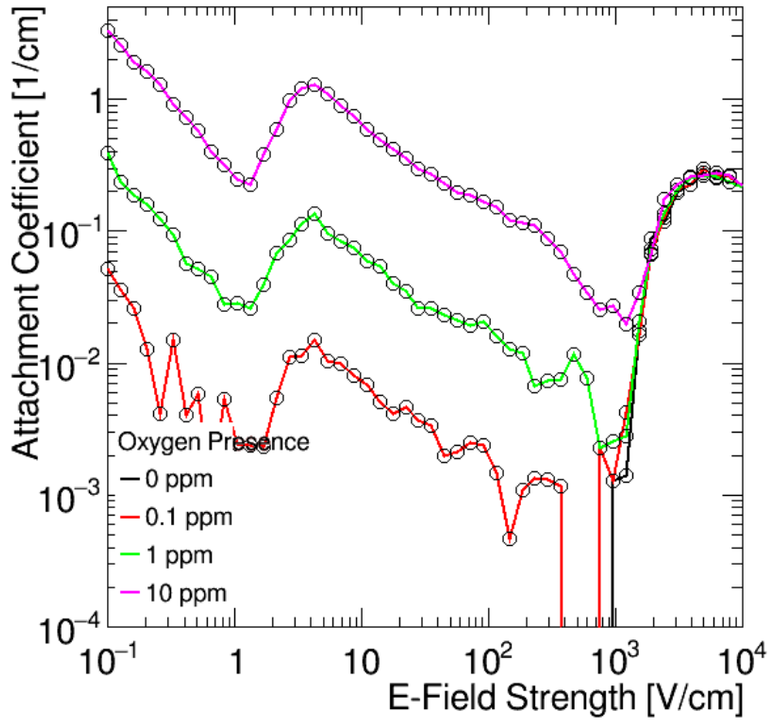
Exclusion at 90% confidence level of cross-sections above 4.4×10^{-37} cm^2 @ mass 0.5 GeV

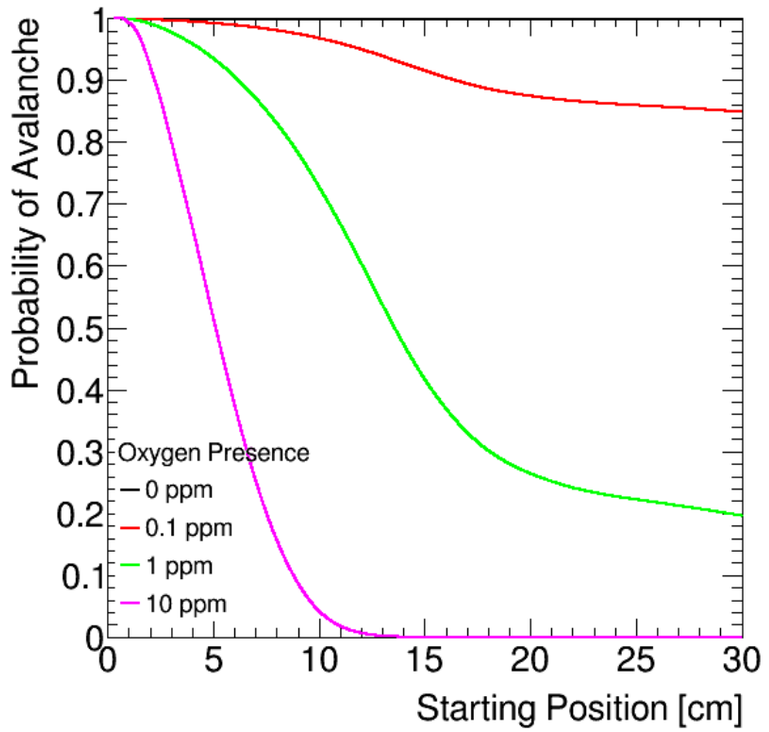
Limit set on spin independent WIMP coupling with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

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

Talk by Patrick Knights

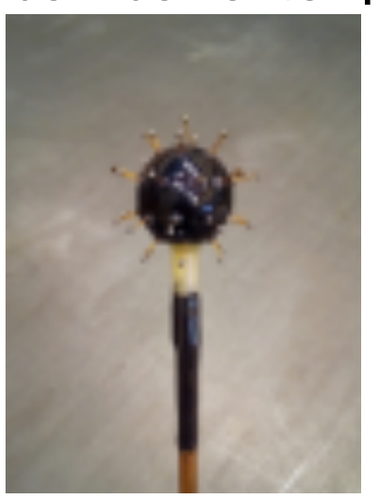
Single-anode Sensors

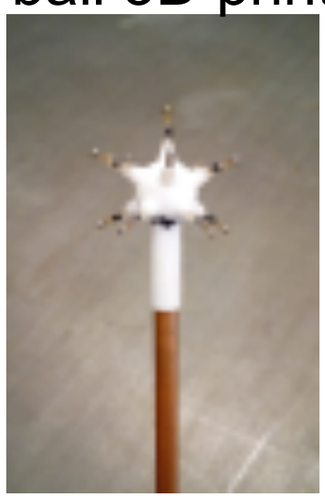
"Glass" sensor "Bakelite" sensor

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

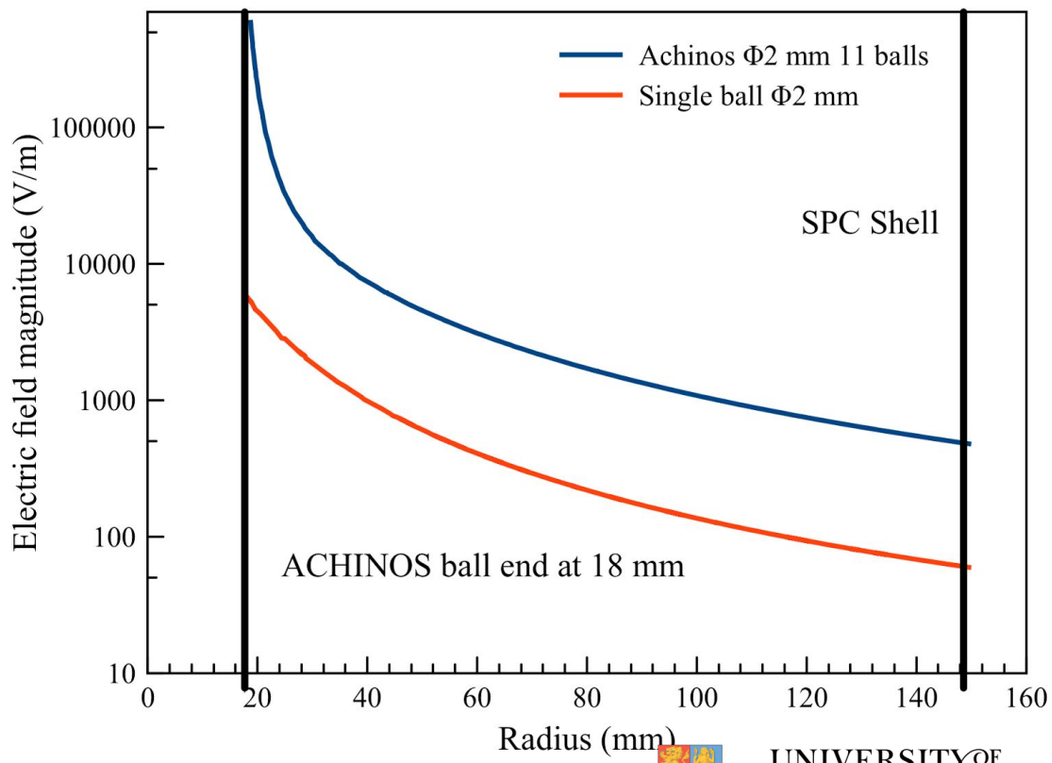
Multi-anode Sensors (Achinos)

33-ball bakelite 11-ball 3D printed



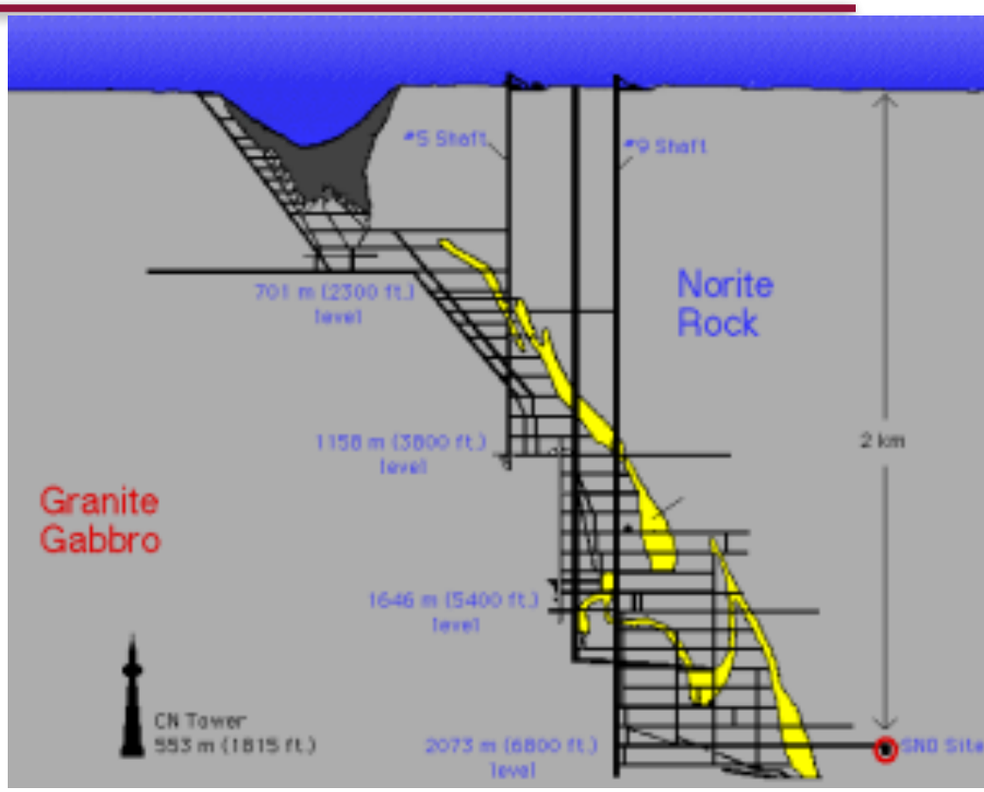


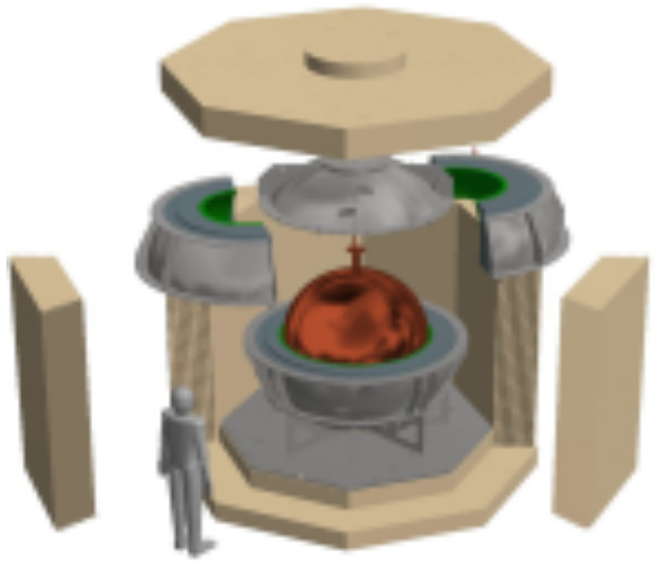
JINST 12 (2017) P12031

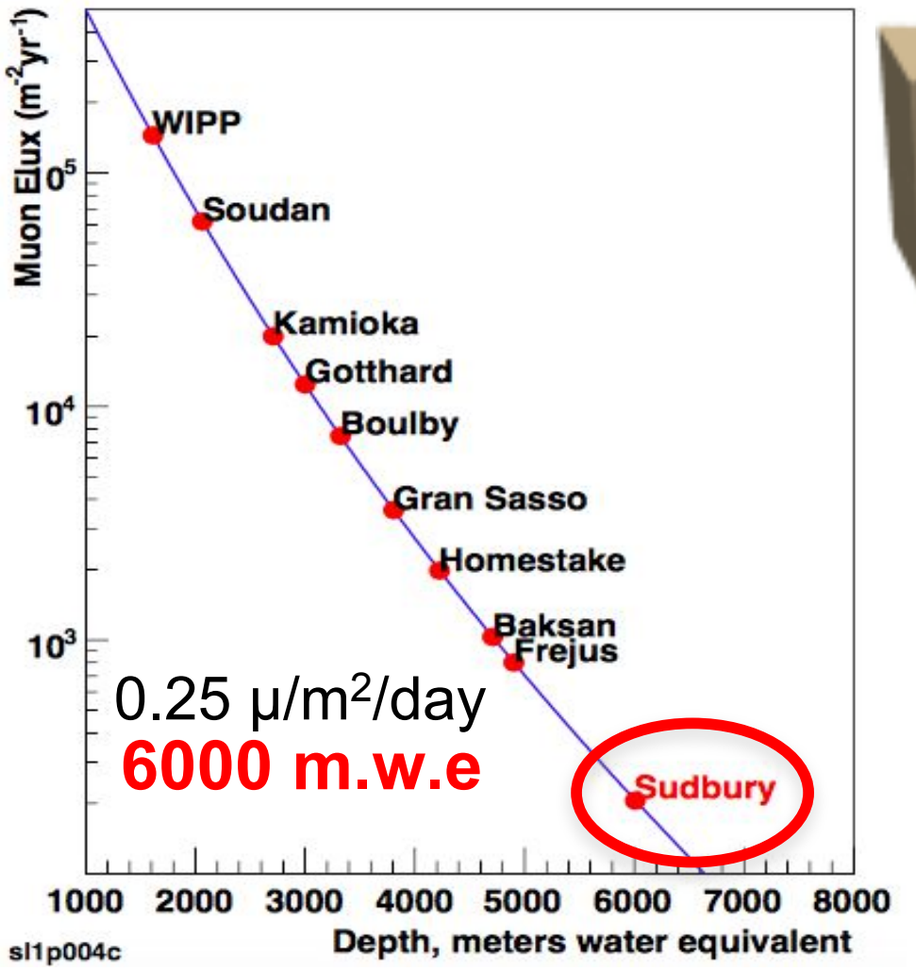


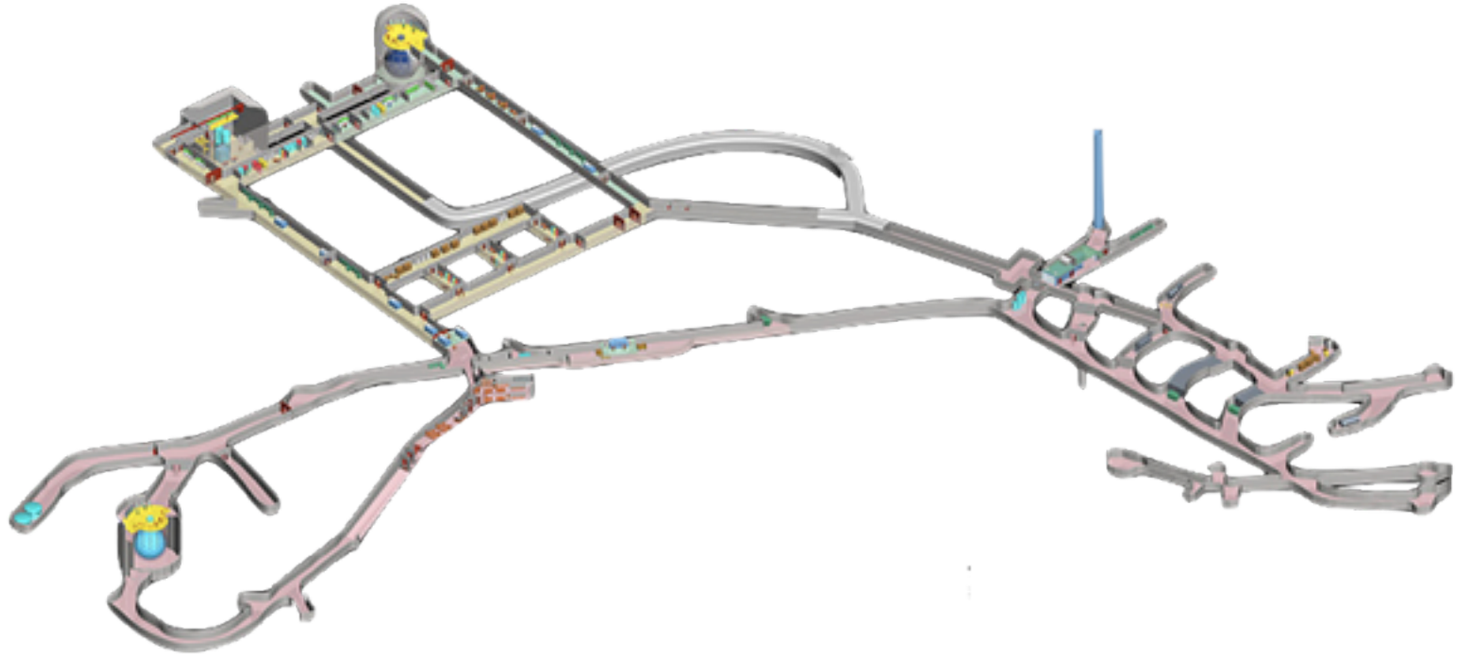
NEWS-G at SNOLAB

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









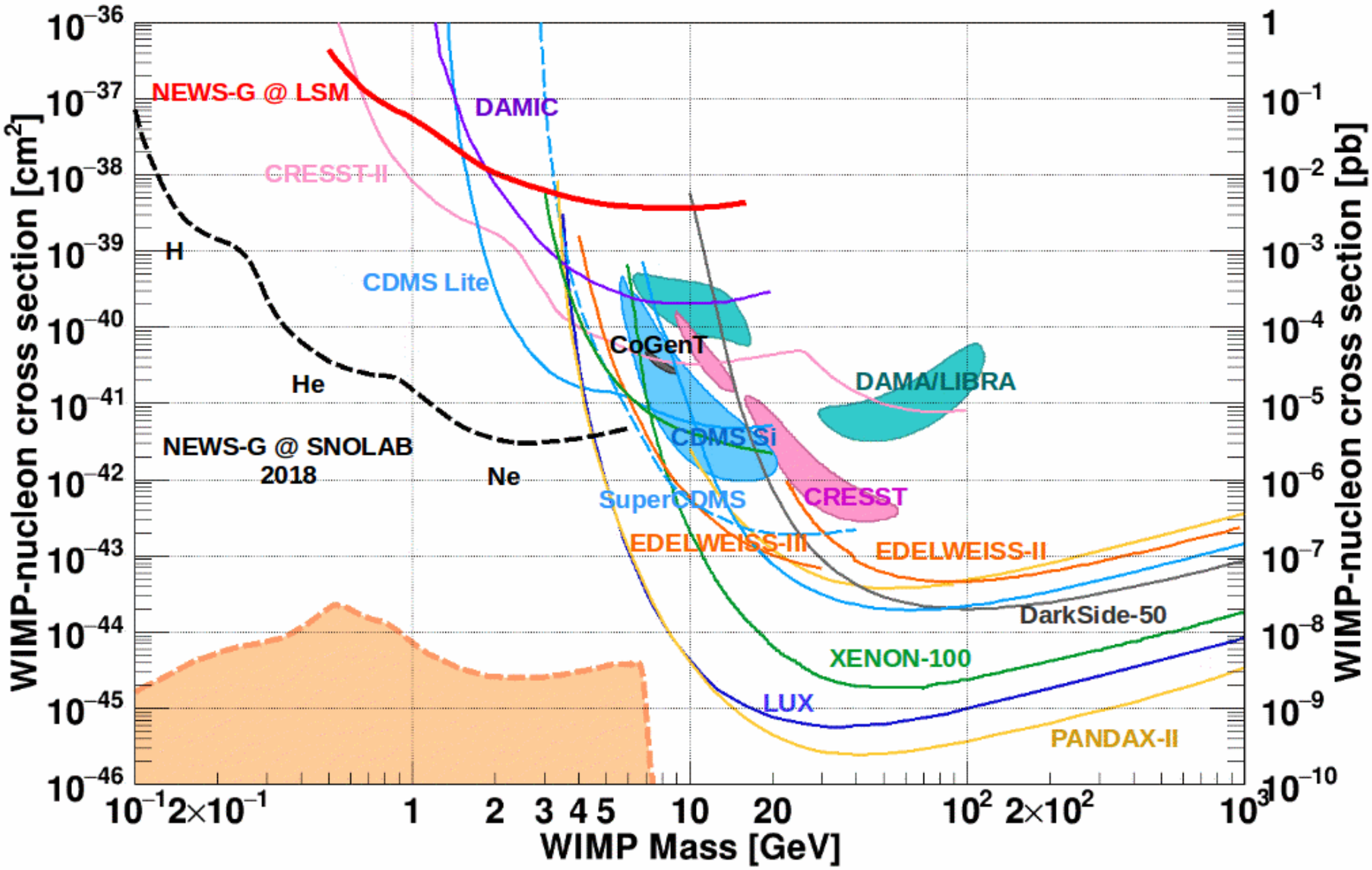
NEWS-G at SNOLab

- 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



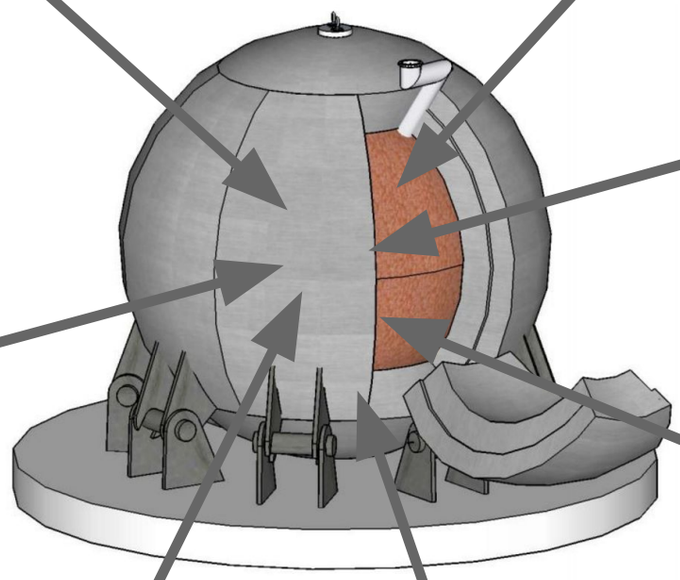
NEWS-SNO expected sensitivity assuming:
100 kg.days exposure @ 10 bar, threshold 1 electron (~40 eV), 200eVee ROI window

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



Resistive sensors:
High Gain

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

“Penning” Mixtures
Ne/CH4 or He/CH4 (99.3/0.7):
High pressure - High Gain - Minimized voltages applied

Regular Mixtures
Ne/CH4 or He/CH4 (90/10):
Hydrogen rich gases

The NEWS-G Collaboration

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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

Summary

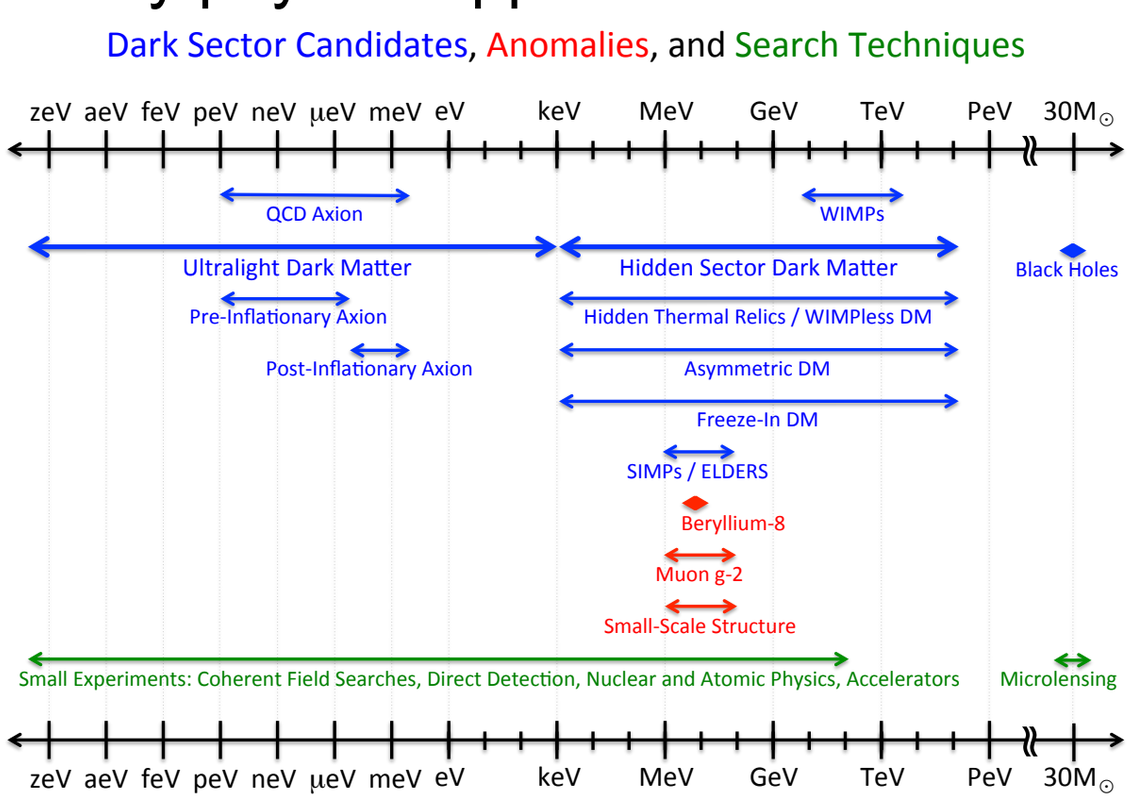
- NEWS-G aims to search for DM candidates the 0.1 – 10 GeV mass range
  - First competitive results with gas detector in Dark Matter search
  - Further He and H runs planned with SEDINE @LSM
  - SEDINE essential for @SNOLAB optimisation

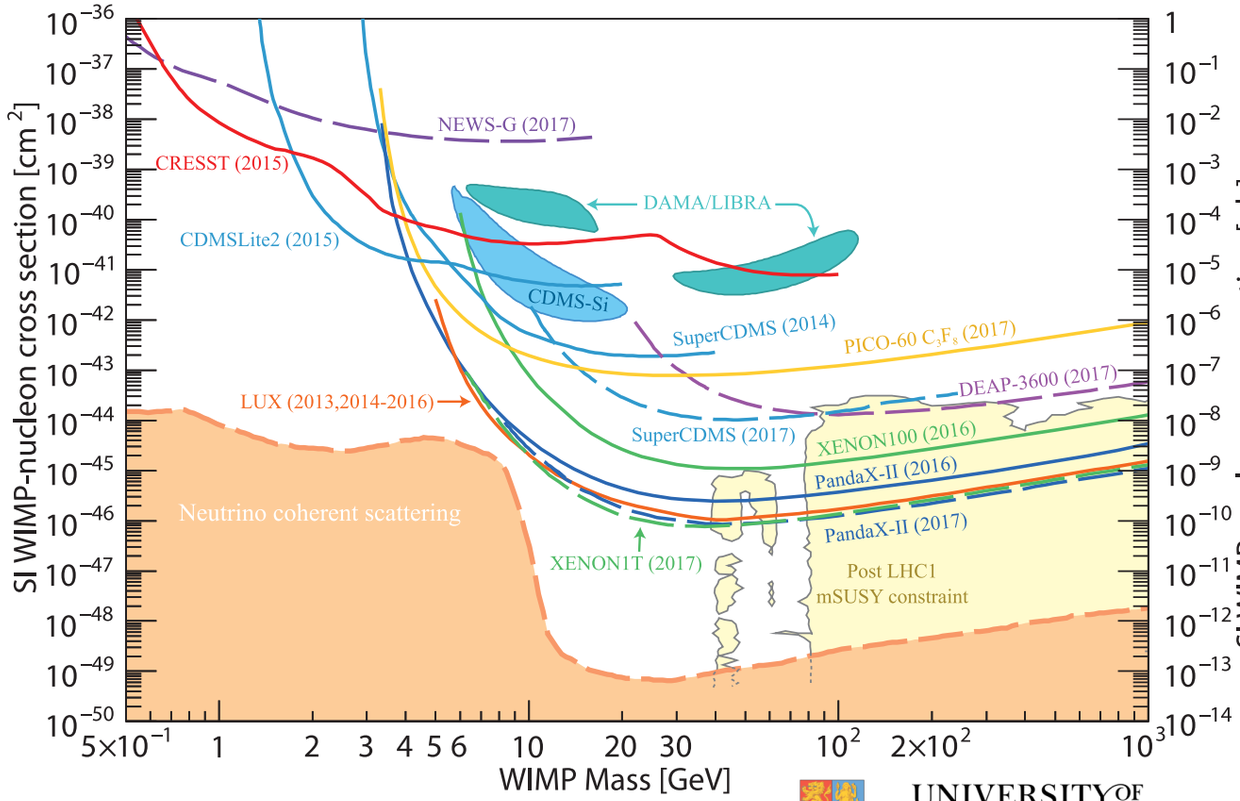
Astropart.Phys. 97 (2018) 54-62

- 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!





Additional Slides

Pulse Treatment

Observed Pulse = Induced Current ⊗ Preamplifier Response