



Search for light Dark Matter with NEWS-G

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University of Birmingham



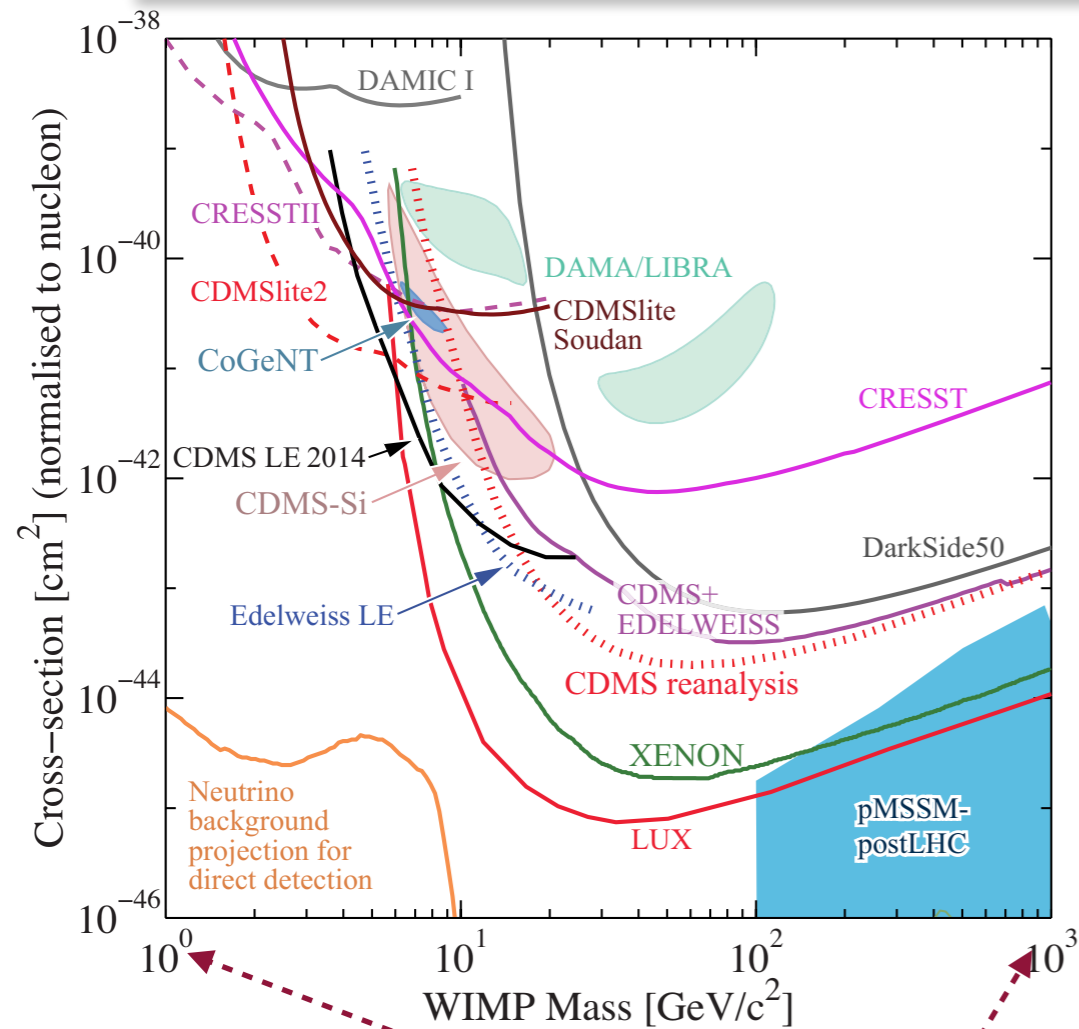
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Workshop on the Standard Model and Beyond
September 8th, 2018, Corfu Summer Institute, Greece

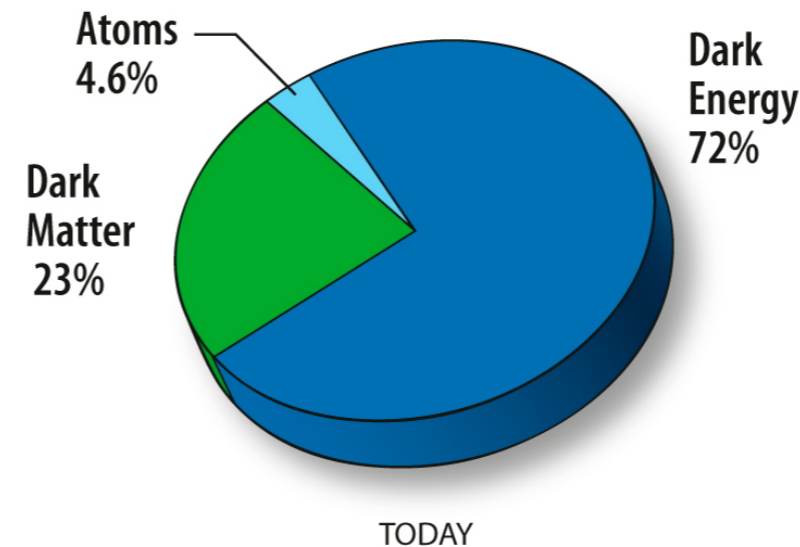
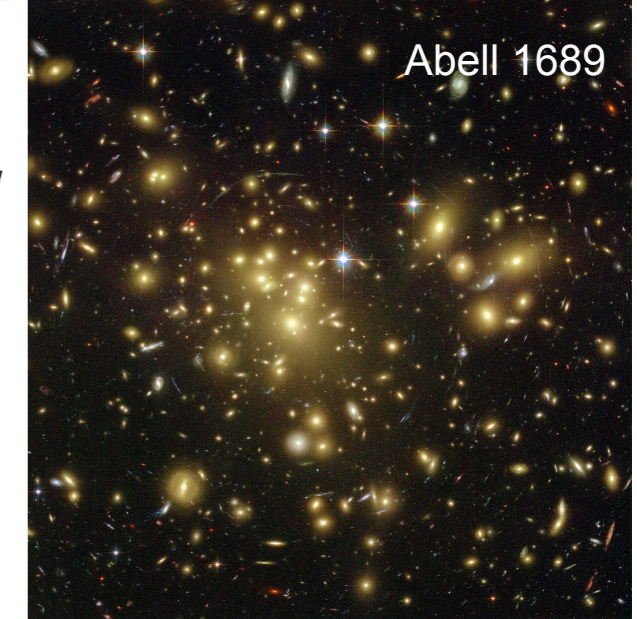
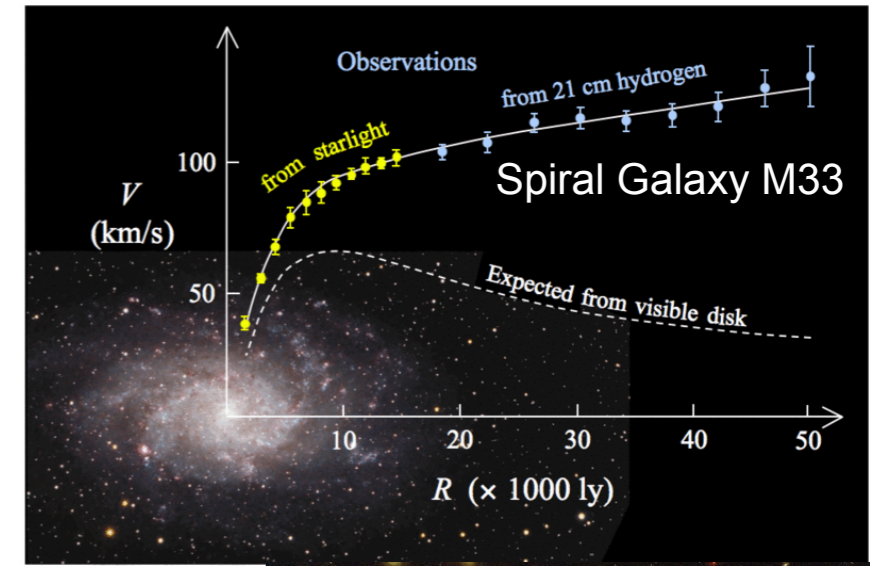
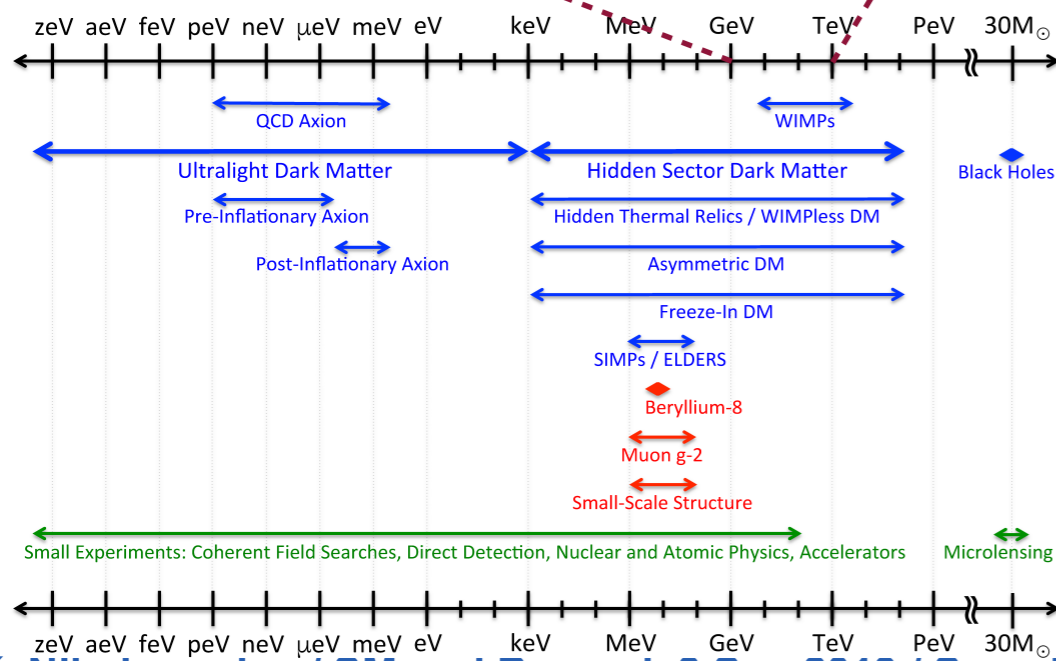


SEDINE prototype at LSM

Dark Matter



Dark Sector Candidates, Anomalies, and Search Techniques



- Current state of affairs:
 - ▶ Evidence for existence of Dark Matter
 - ▶ Absence of evidence in WIMP-preferred region
- Wide spectrum of possibilities → expand searches
 - ▶ DM search: 0.1-10 GeV mass range

arXiv:1707.04591

K. Nikolopoulos / SM and Beyond, 8 Sep 2019 / Search for light Dark Matter with NEWS-G



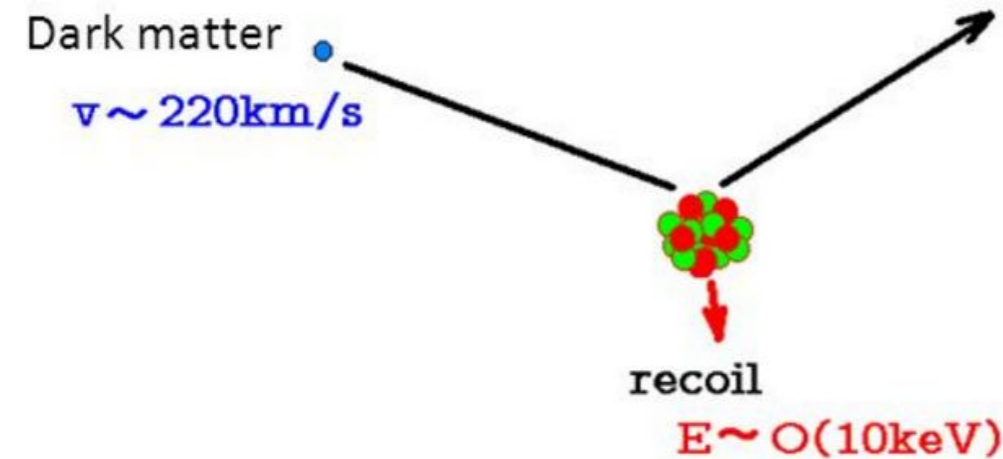
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Searching for light DM: Recoil Energy

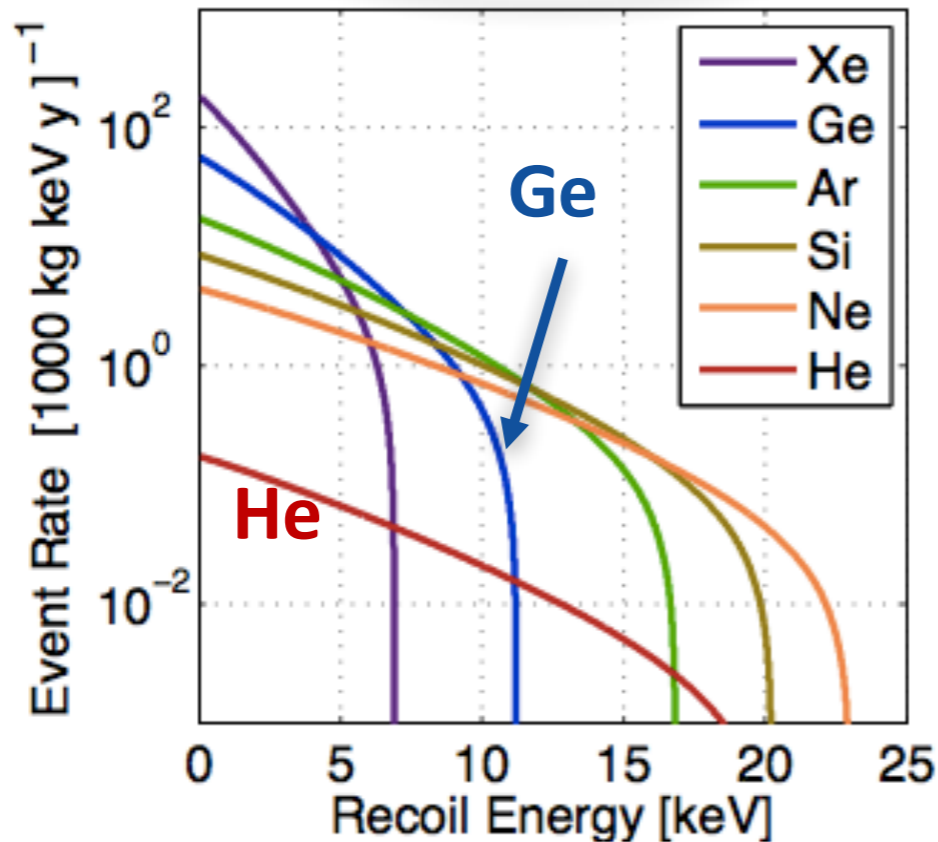
Recoil energy during DM scattering, E_R :

$$E_R = \frac{1}{2} m_\chi u^2 \frac{4m_\chi m_N}{(m_\chi + m_N)^2} \frac{1 + \cos \theta}{2}$$

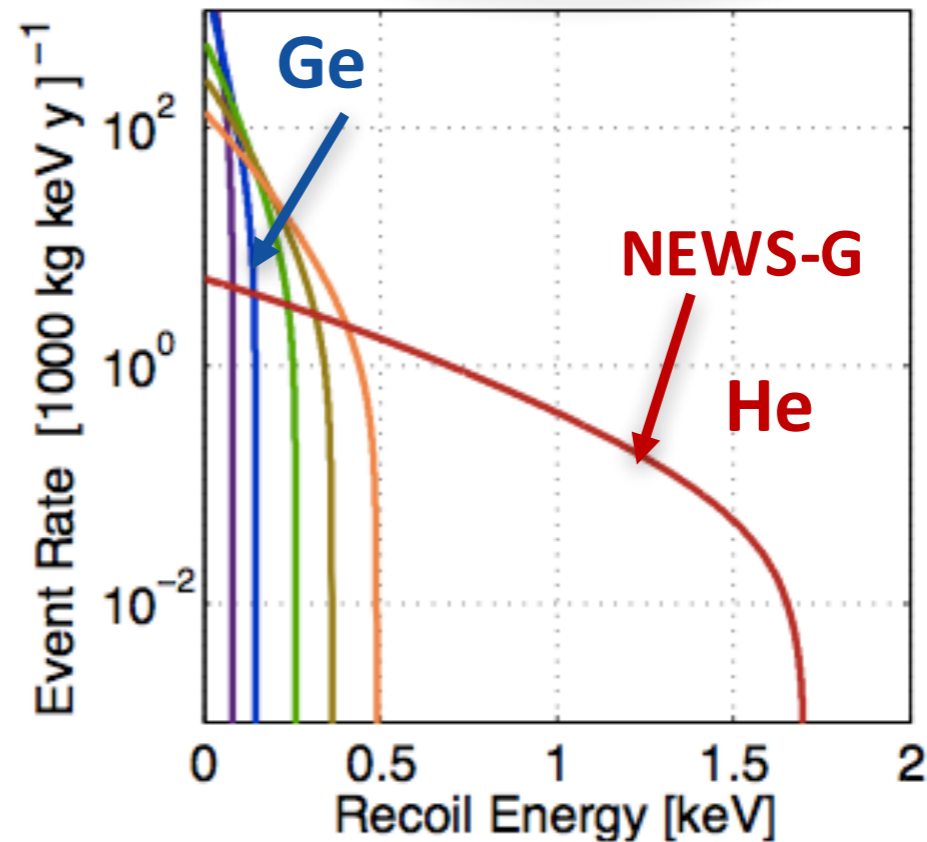
max E_R : head-on-collision and $m_\chi = m_N$



$m_\chi = 10 \text{ GeV}/c^2$

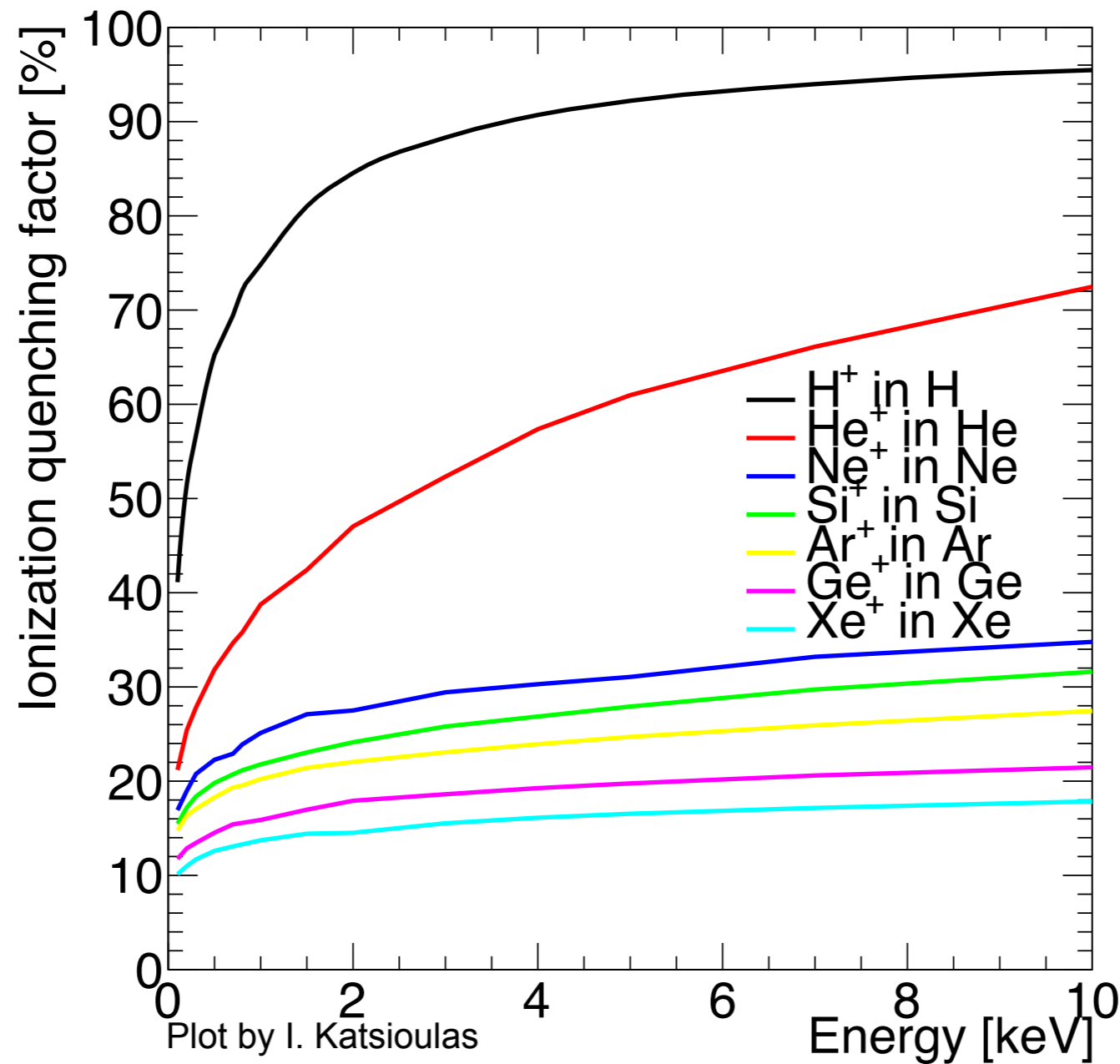


$m_\chi = 1 \text{ GeV}/c^2$



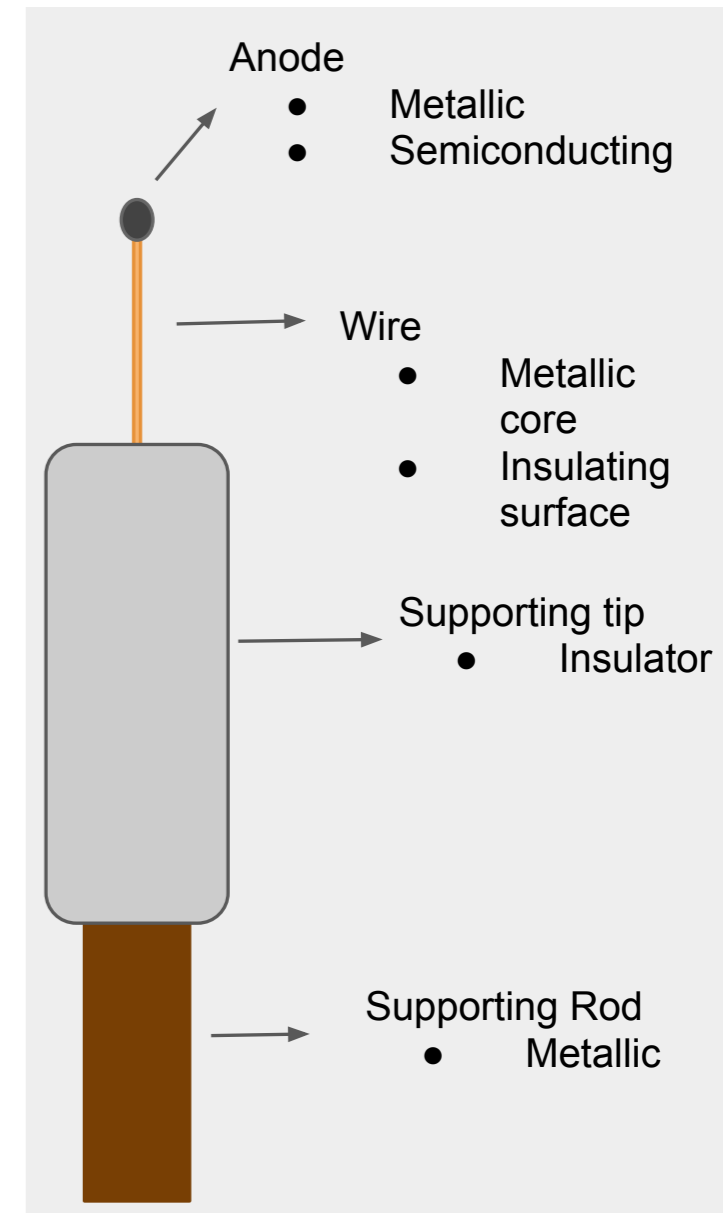
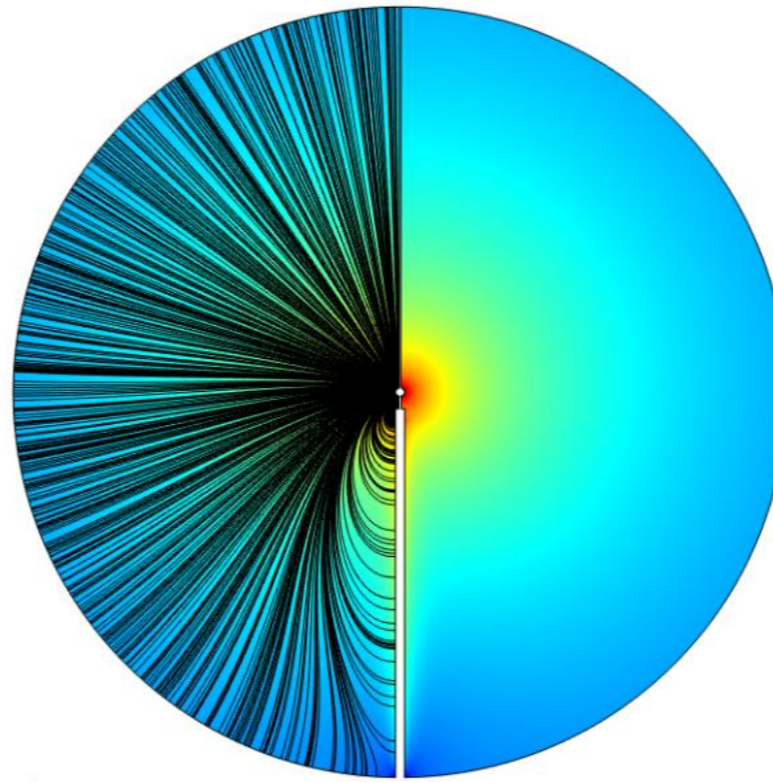
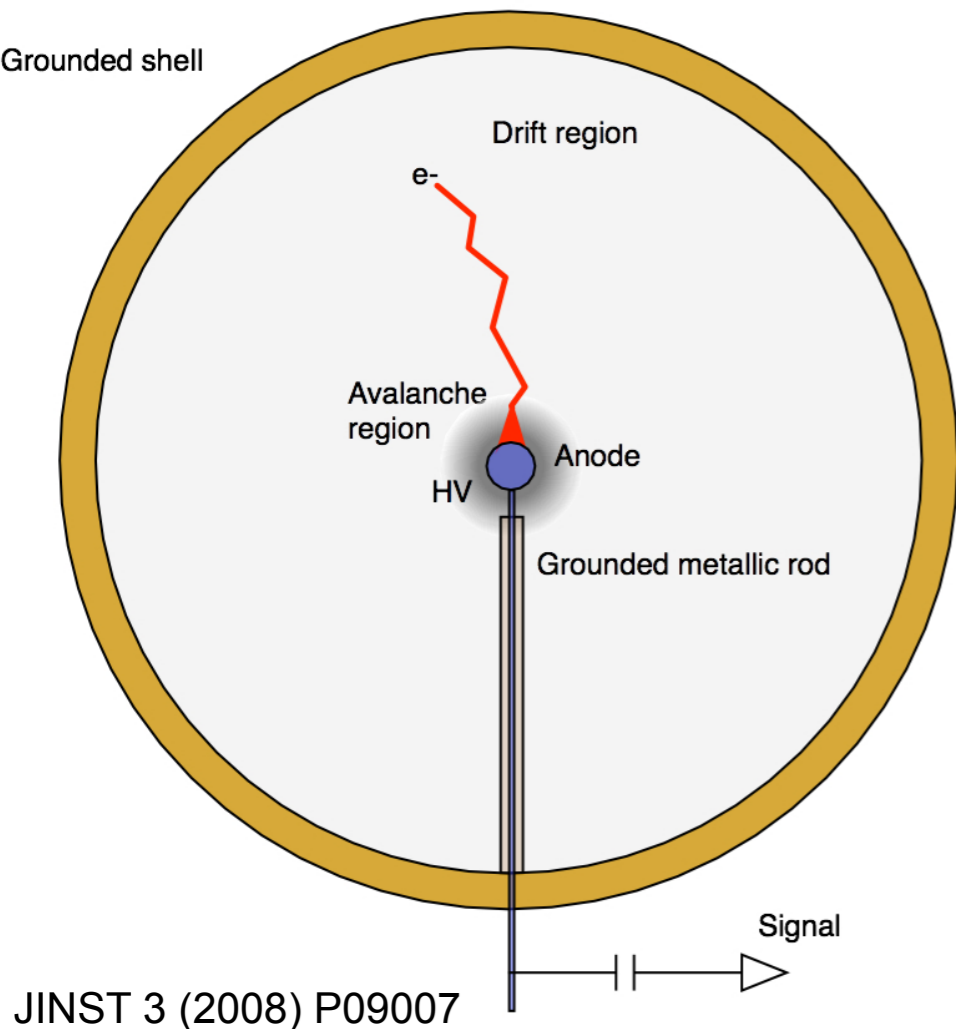
Searching for light DM: Quenching Factor

- ▶ Quenching factor: fraction of ion kinetic energy dissipated in a medium in the form of ionization electrons and excitation of the atomic and quasi-molecular states.



- Direct detection experiment using light gases as target (H, He, Ne)
 - ▶ Better projectile-target kinematic match
 - ▶ Favourable quenching factor

Spherical Proportional Counter



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

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

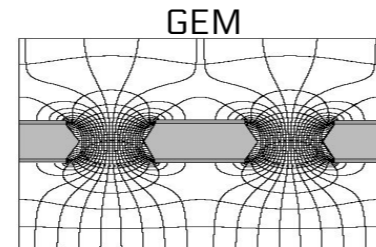
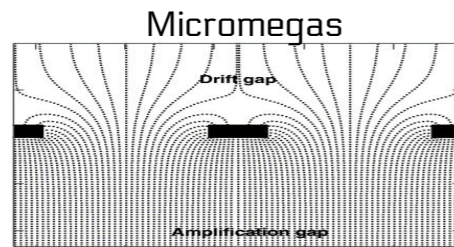
r_1 = anode radius

r_2 = cathode radius

Detector volume naturally divided in:
“drift” and “amplification” regions.

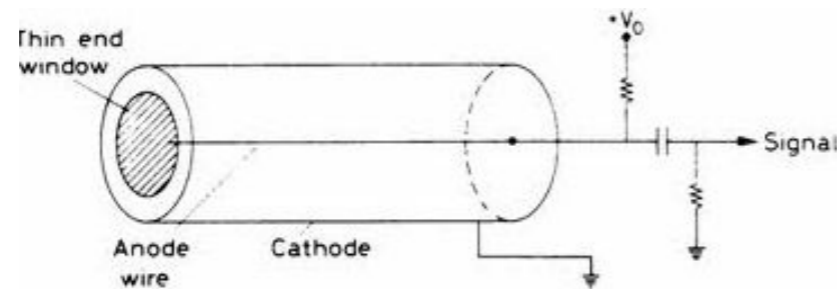
Spherical Proportional Counter

Capacitance dependence on size



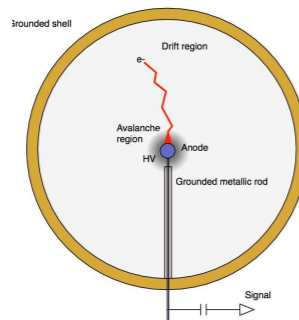
Parallel Plate Detector

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



Cylindrical Proportional Counter

$$C = 2\pi L / \ln(b/a) \gg 10 \text{ pF}$$



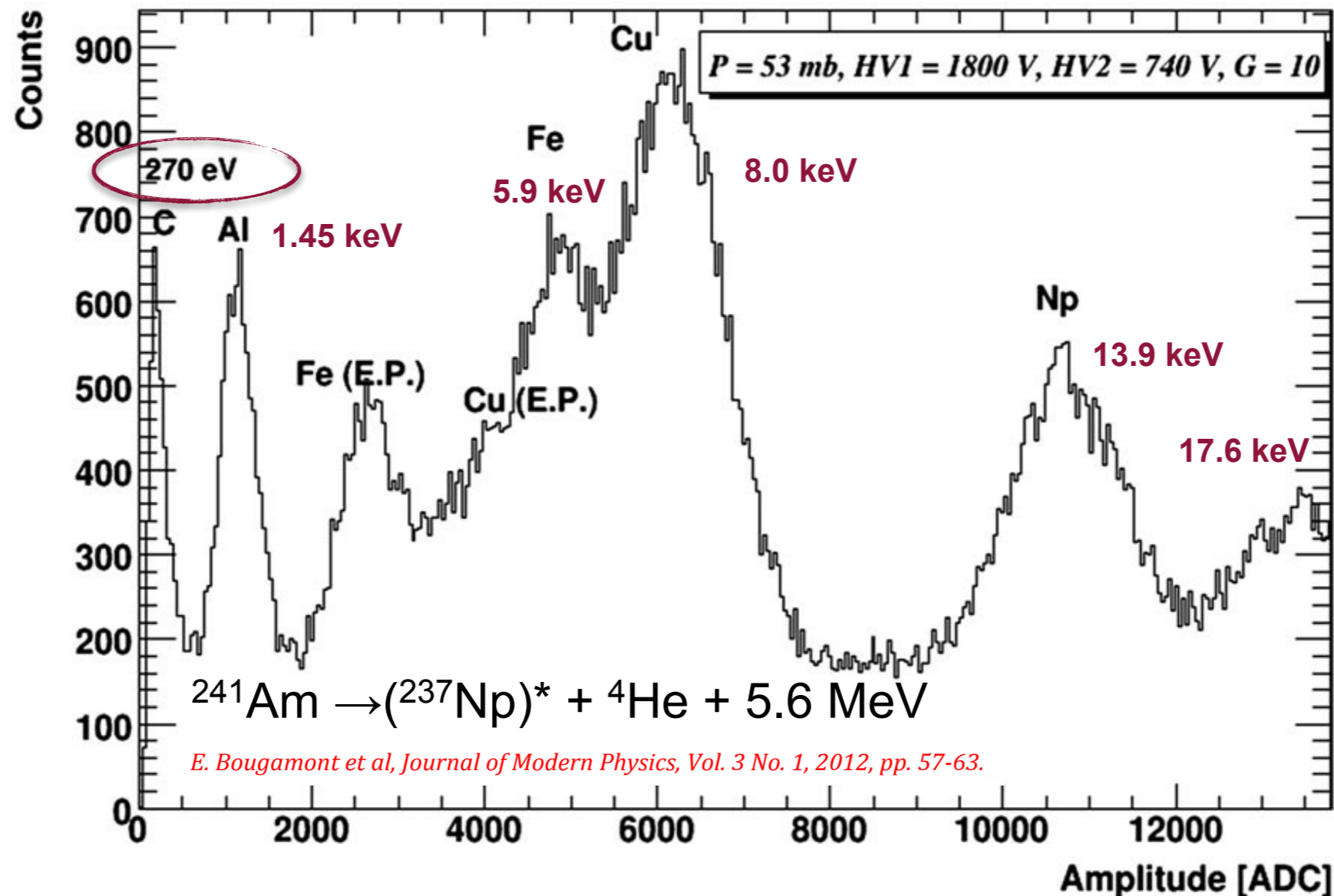
Spherical Proportional Counter

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

Large Size Detector
+
Robust construction

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

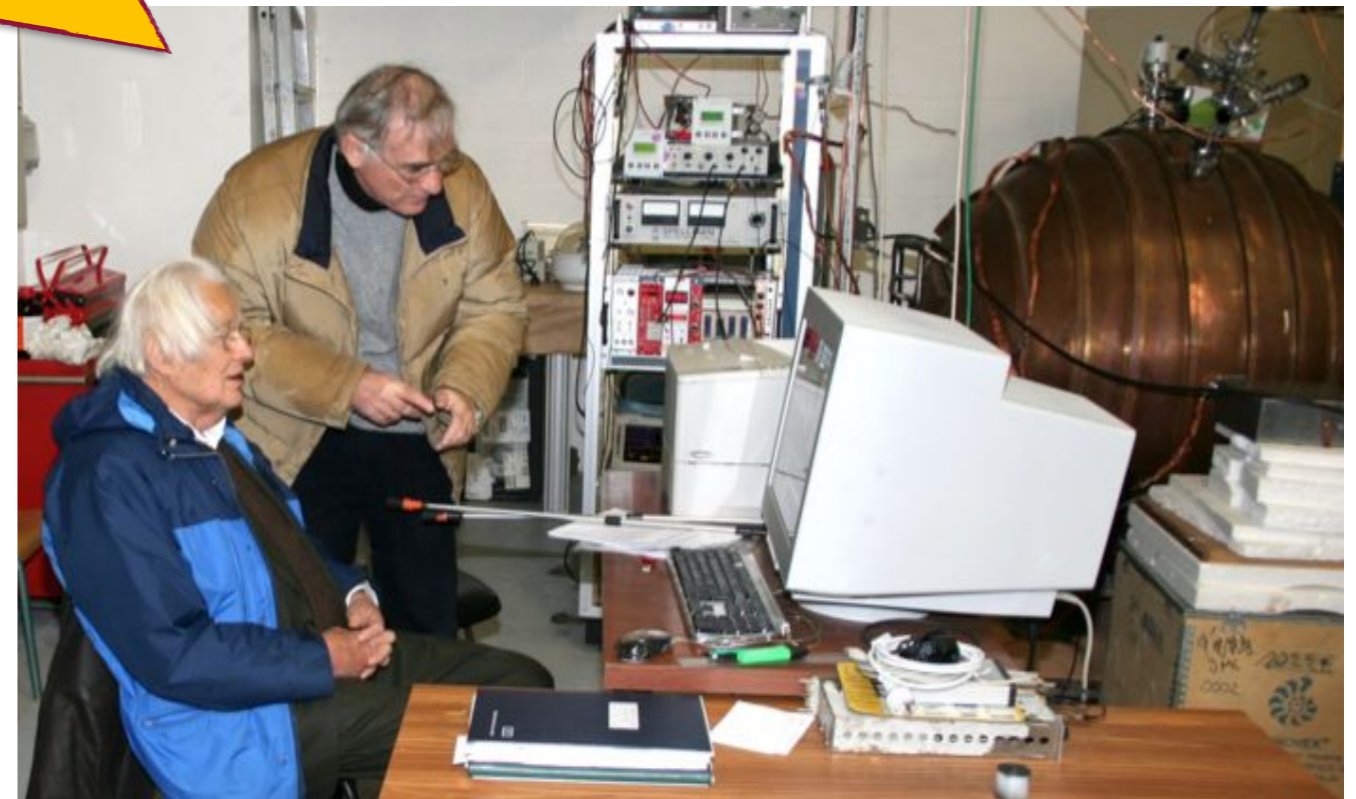
Low Energy Capabilities



- Spherical Proportional Counter 130cm diameter
 - ▶ Ar + 2% CH₄
- Single Electron detection
- Energy threshold < 50 eV
 - ▶ Tested with single electrons extracted from Copper with UV lamp

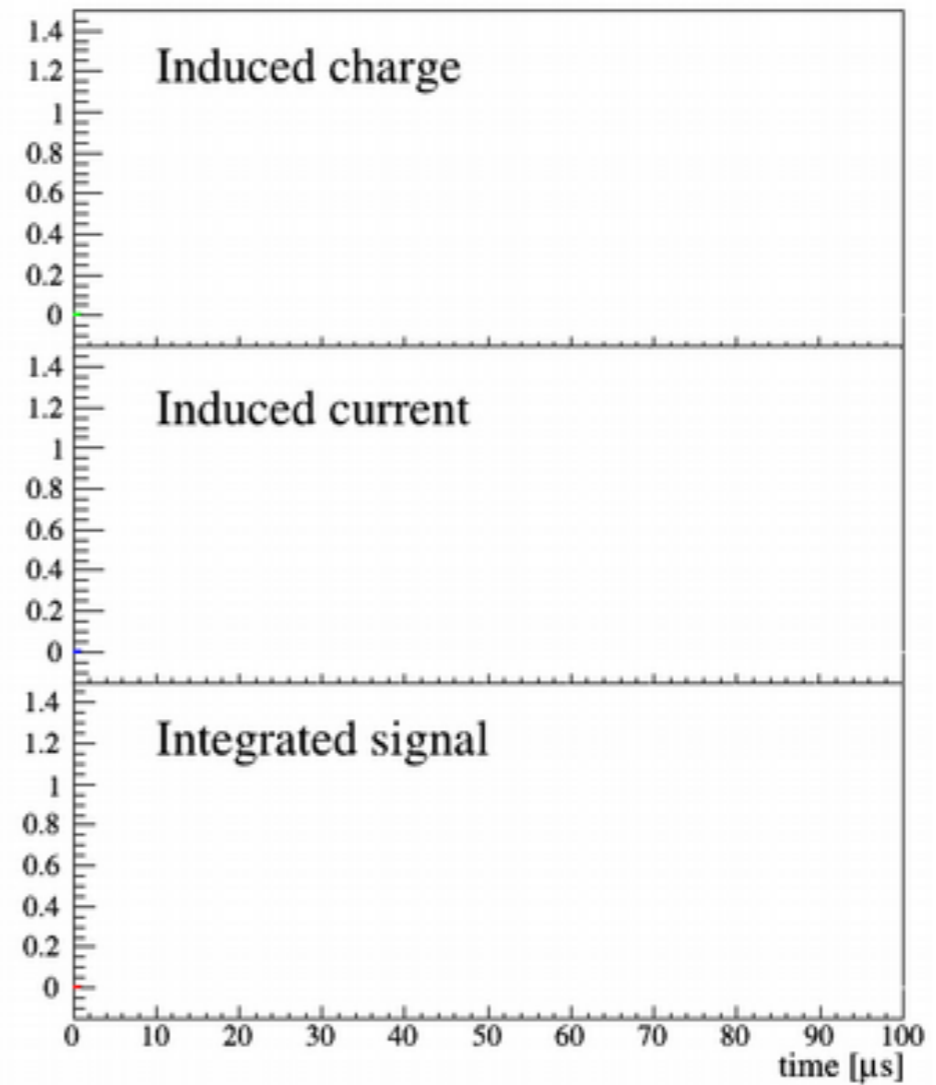
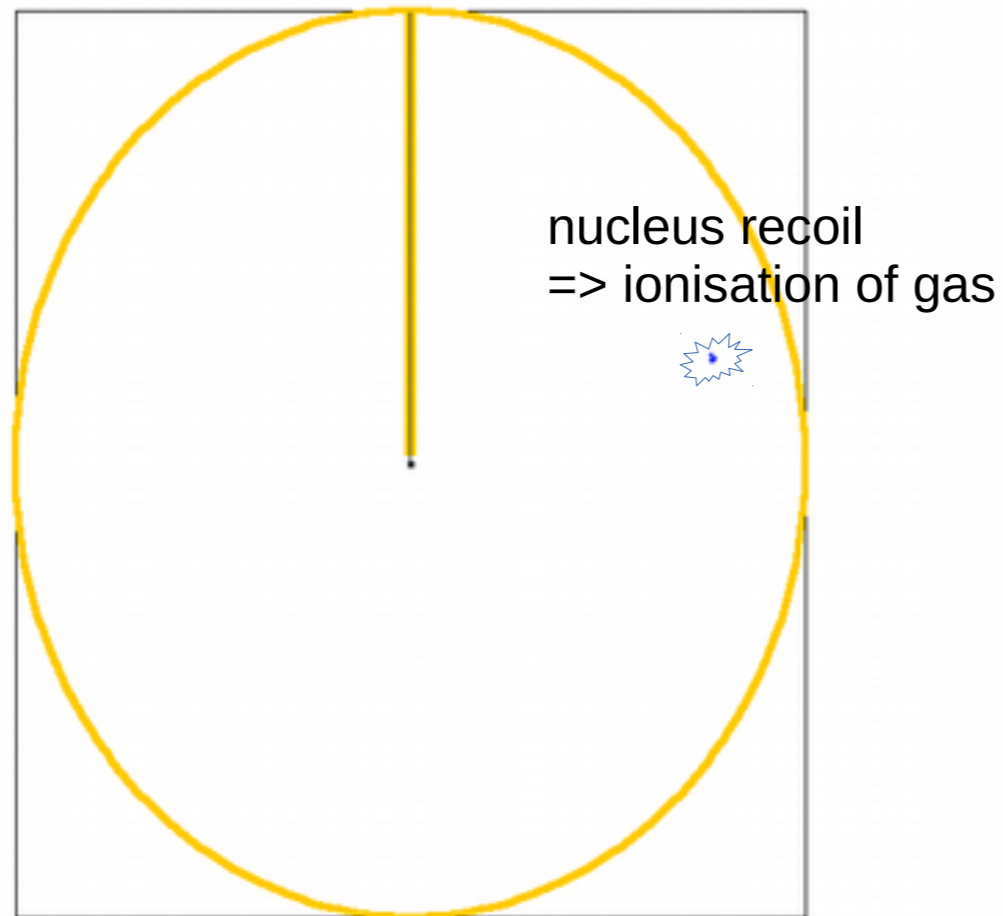
Spherical Proportional Counter

First Spherical Proportional Chamber made out of LEP RF Cavities



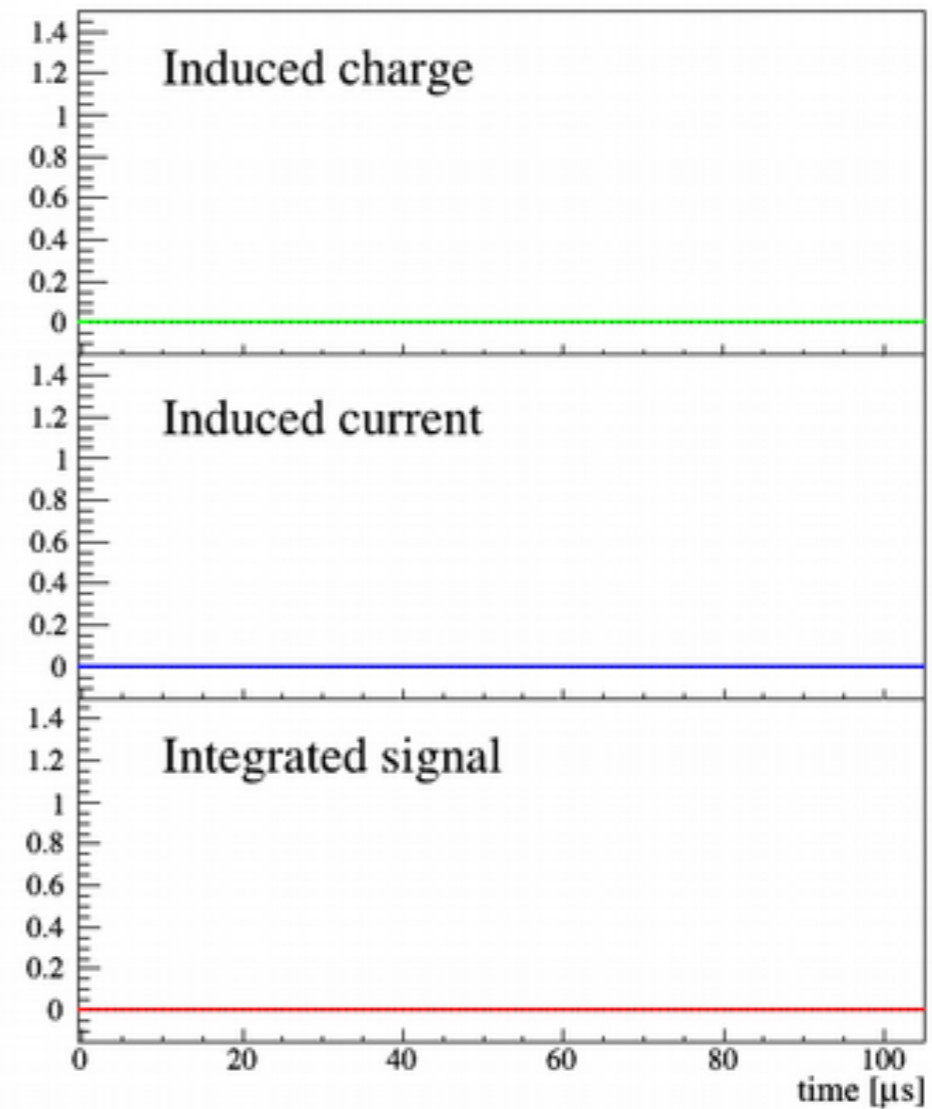
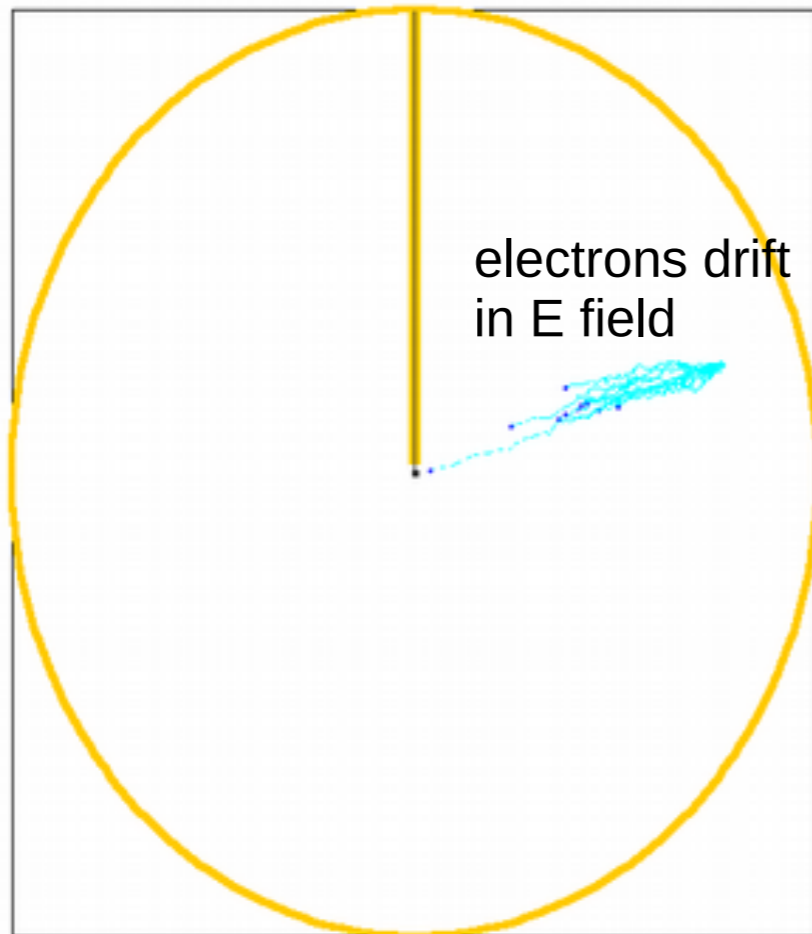
I. Giomataris and G. Charpak

Signal Formation



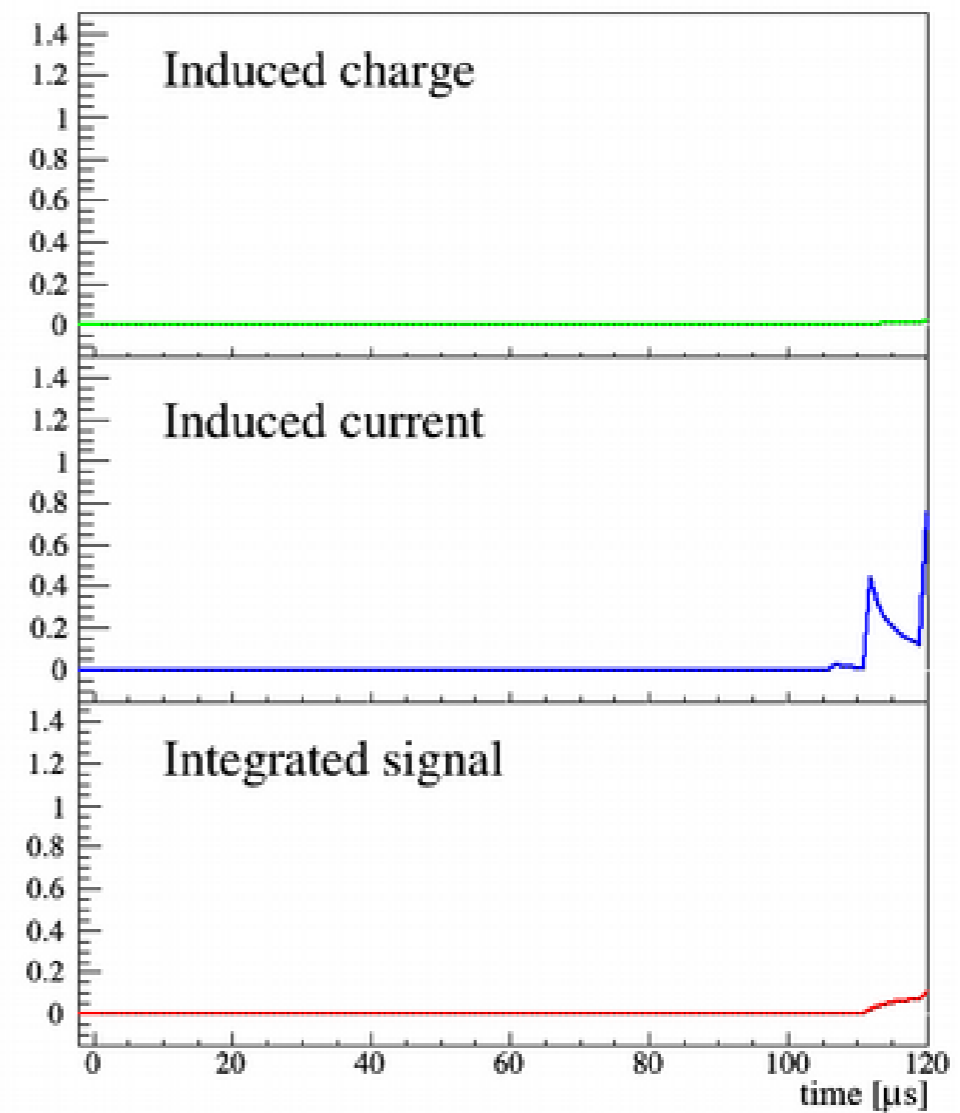
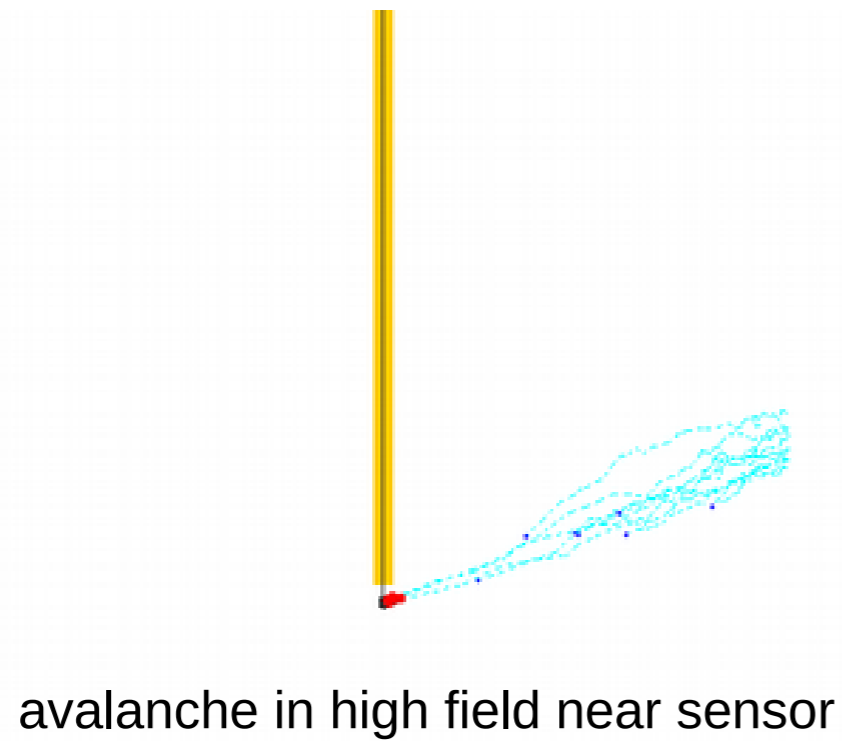
Plot by P. Gros

Signal Formation



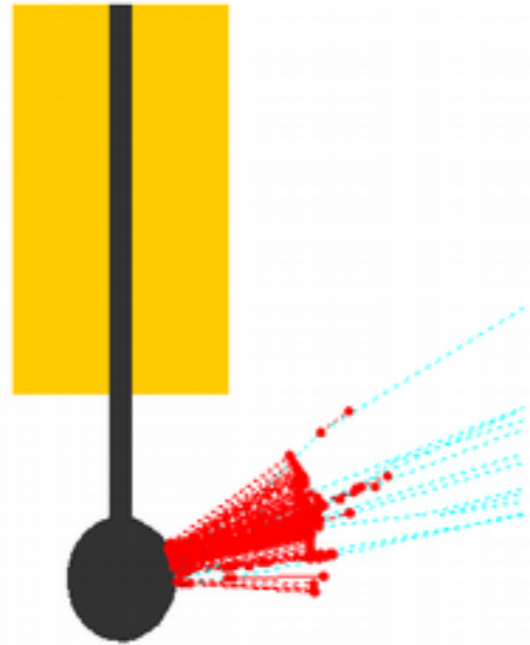
Plot by P. Gros

Signal Formation

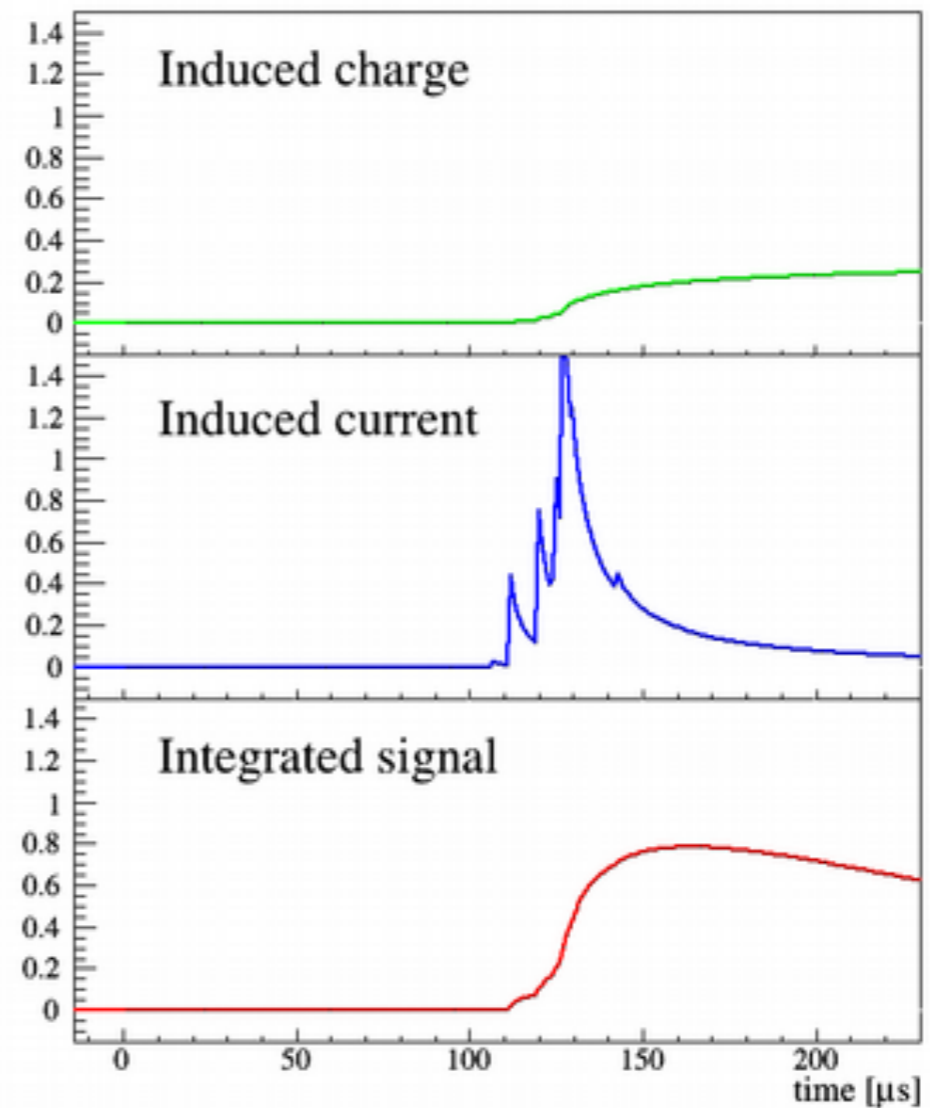


Plot by P. Gros

Signal Formation

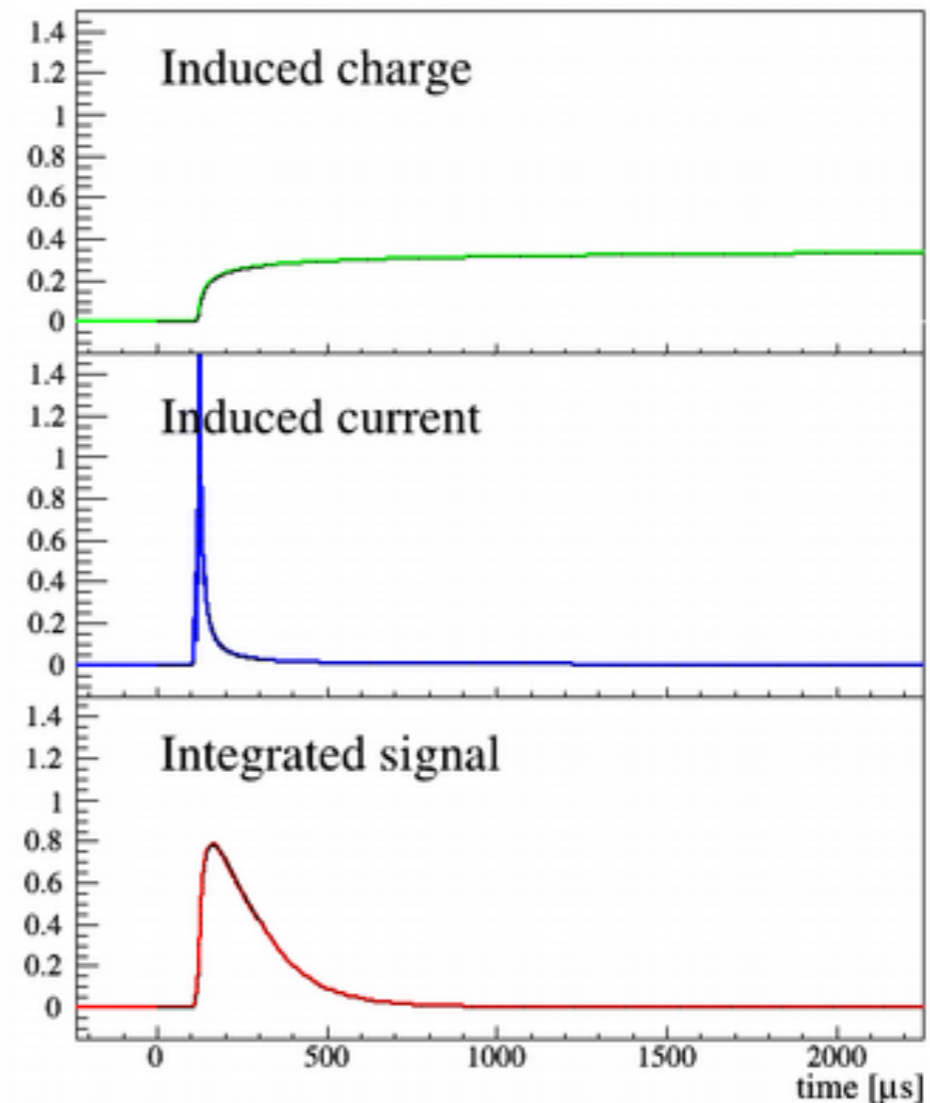
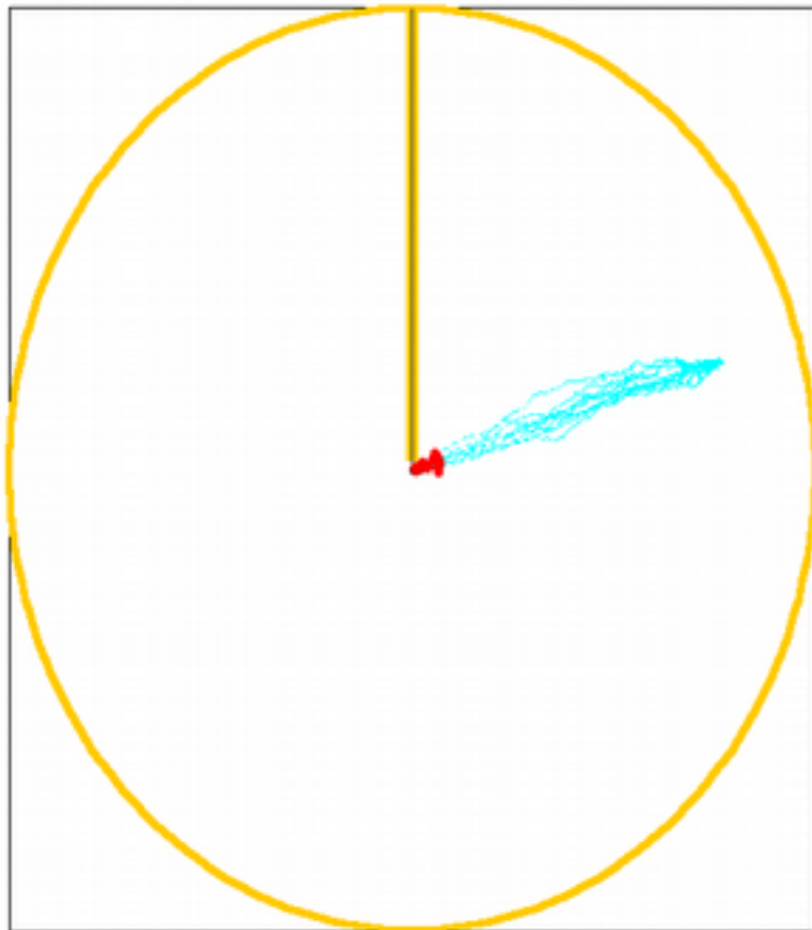


Signal induced by ions drifting back



Plot by P. Gros

Signal Formation



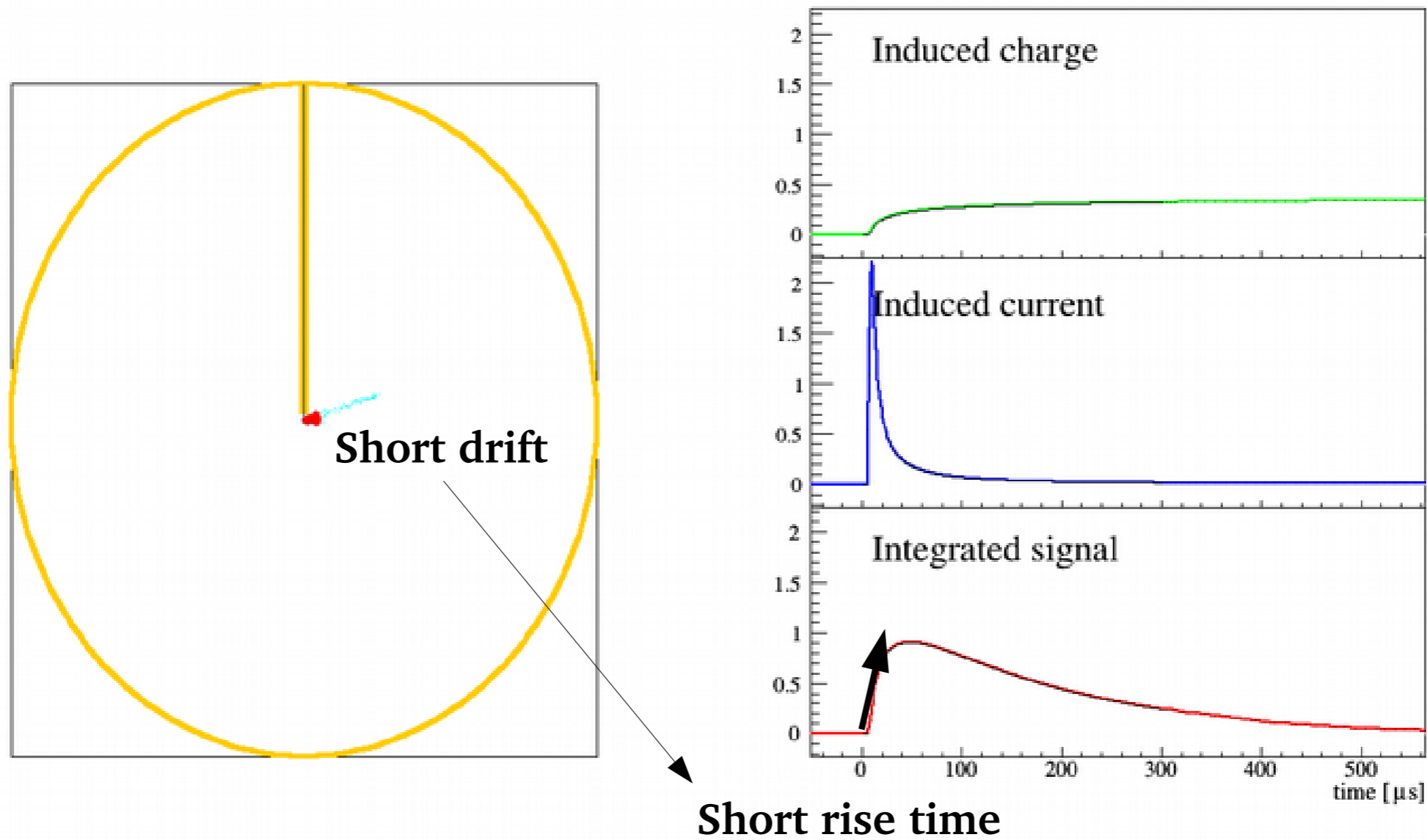
In reality:

Observed Pulse = Induced Current \otimes Preamplifier Response

Need to deconvolve the preamplifier response

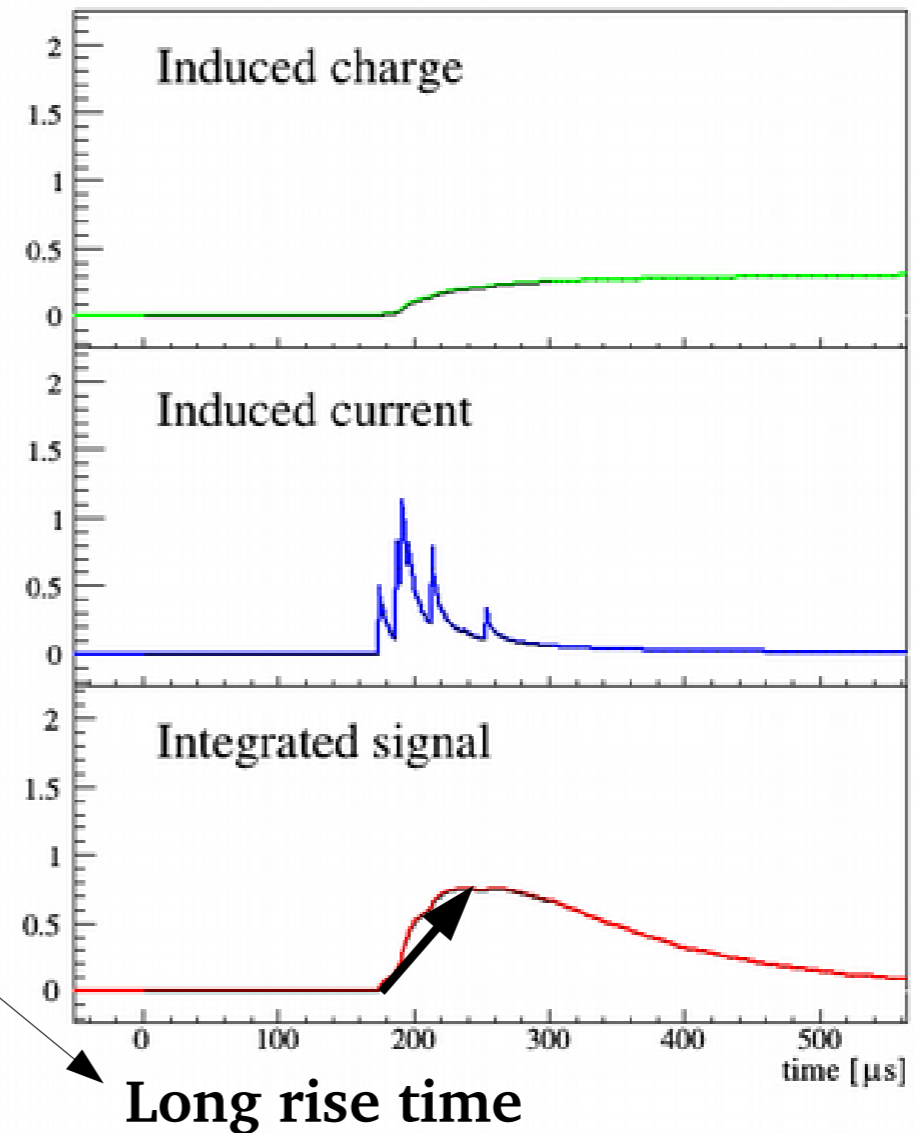
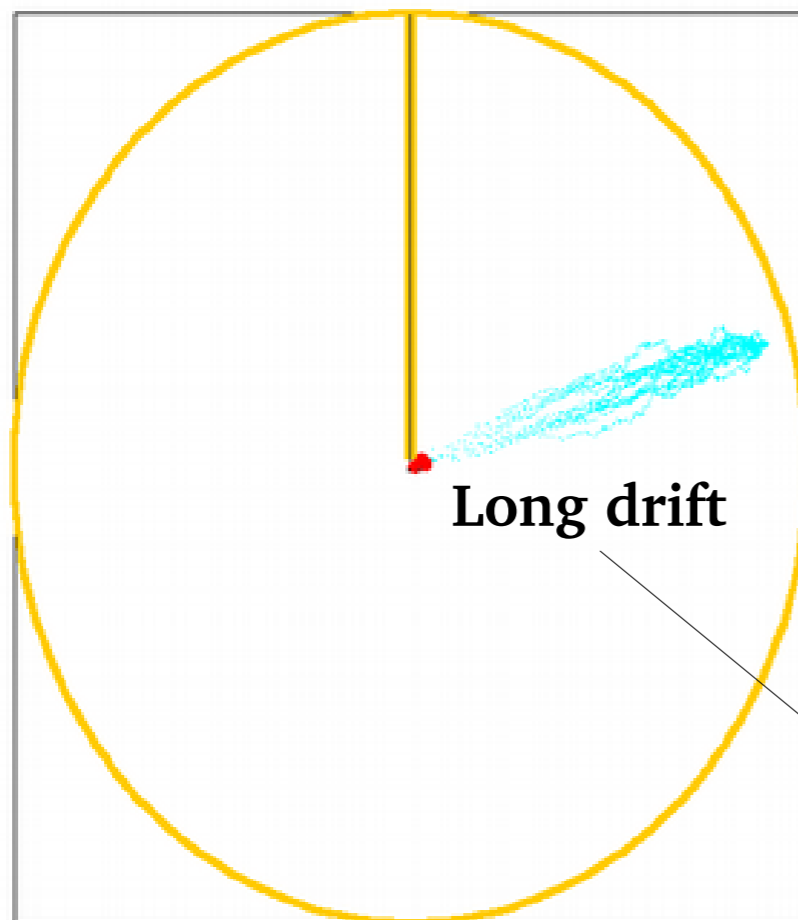
Plot by P. Gros

Background Rejection: Rise Time



Plot by P. Gros

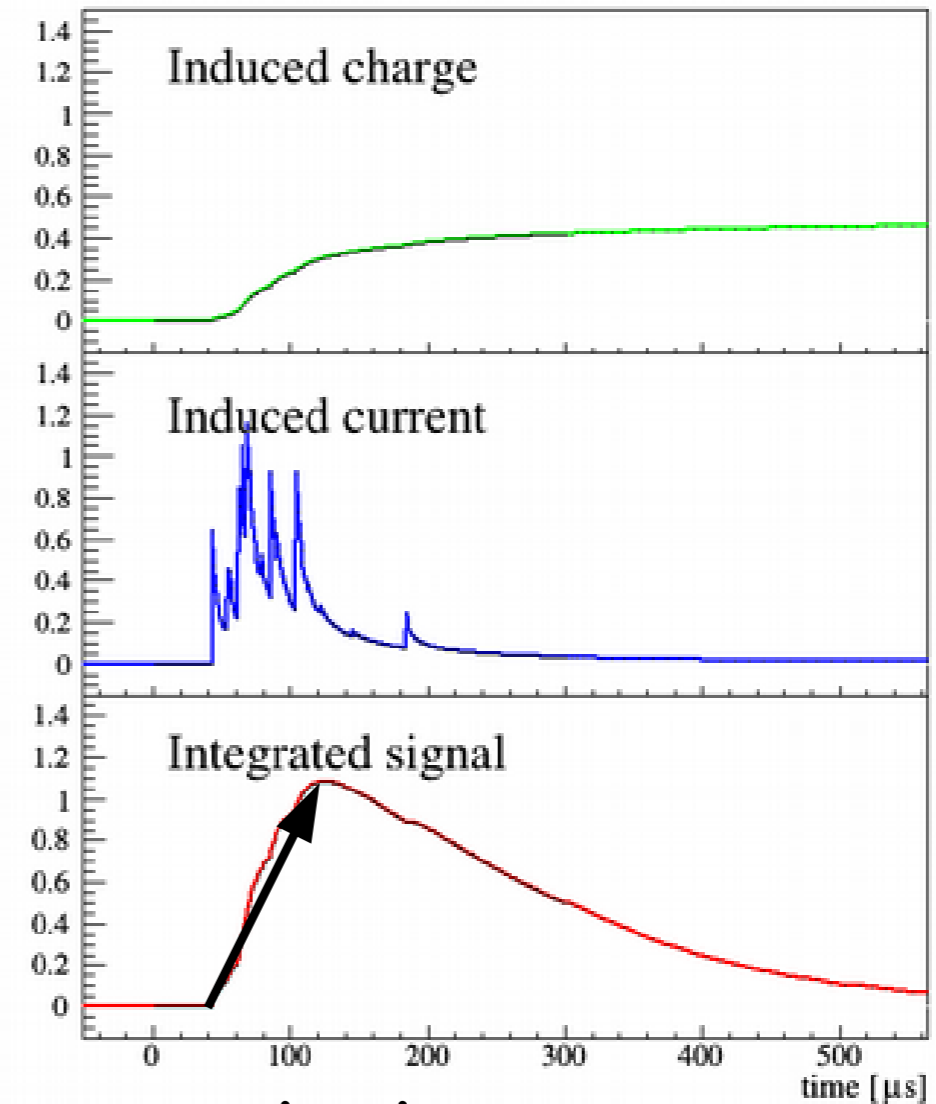
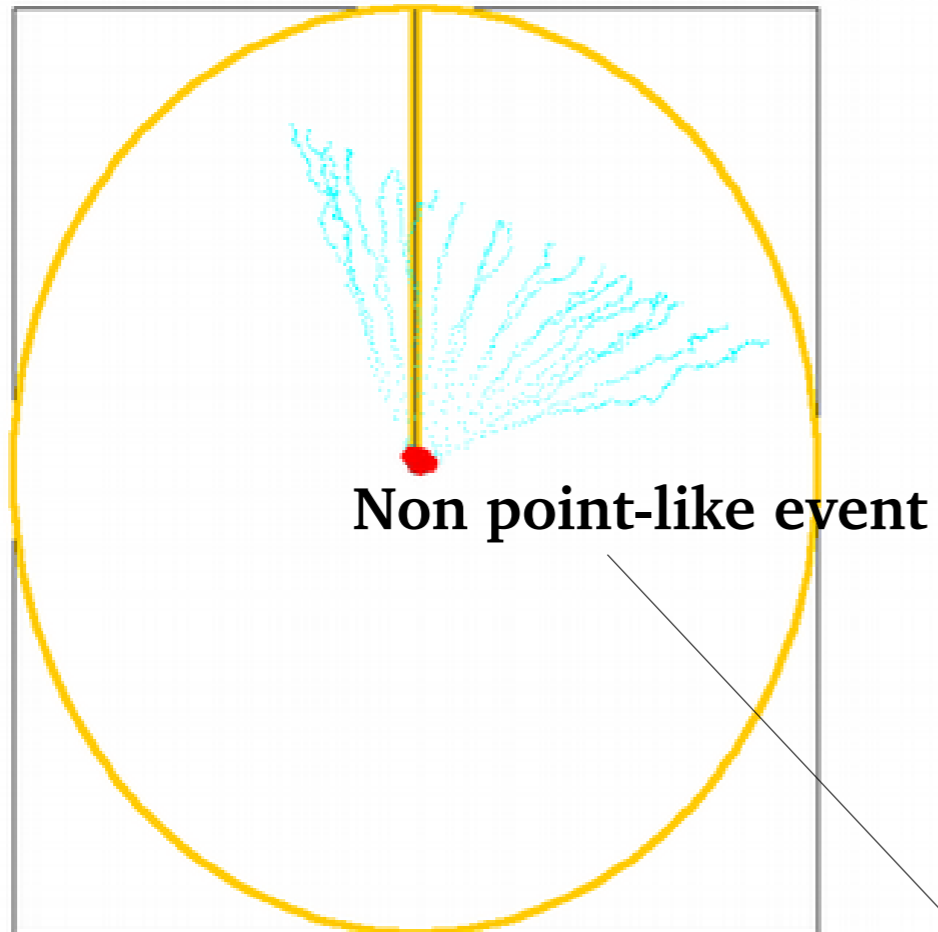
Background Rejection: Rise Time



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

Plot by P. Gros

Background Rejection: Rise Time



Loonng rise time

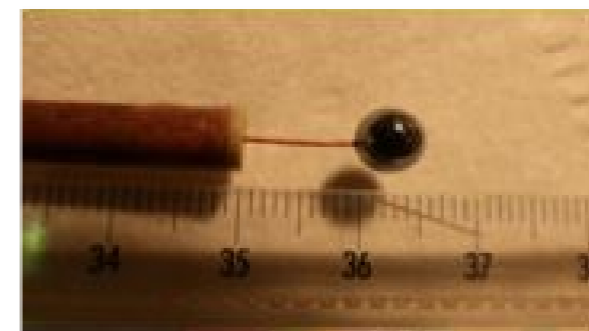
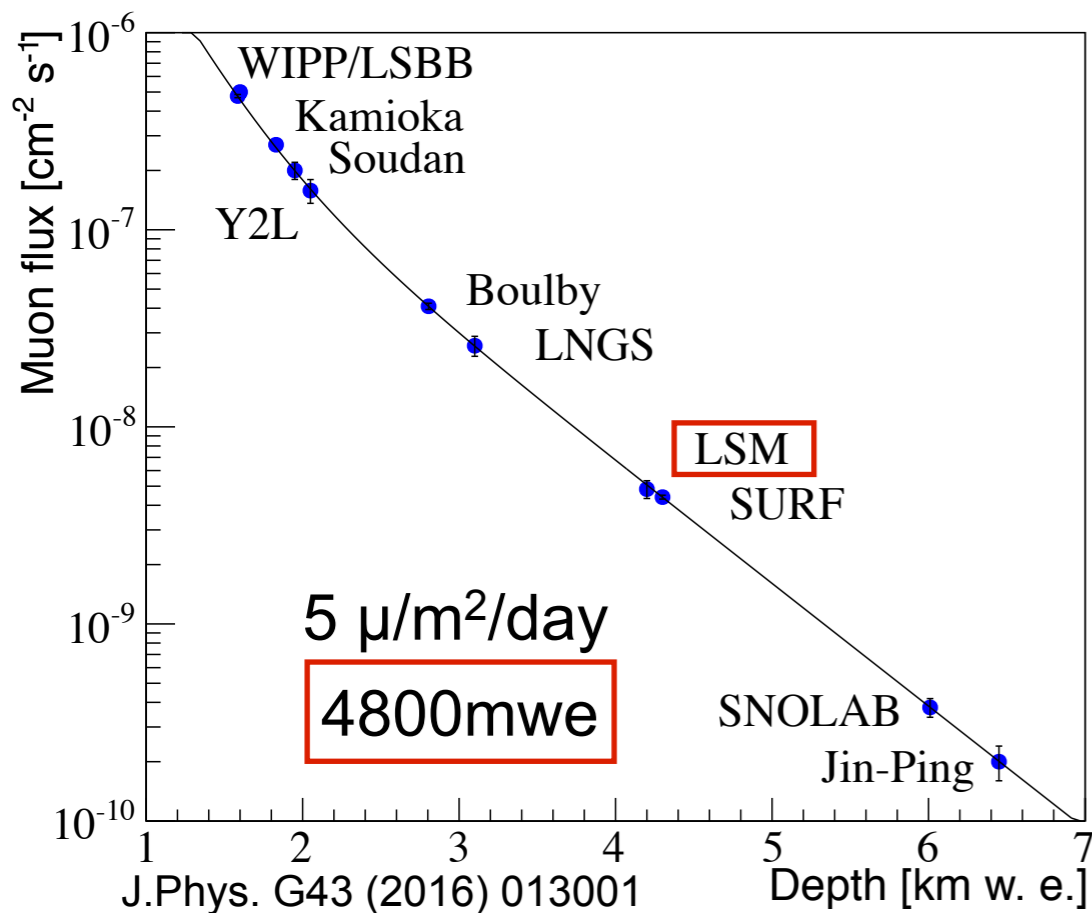
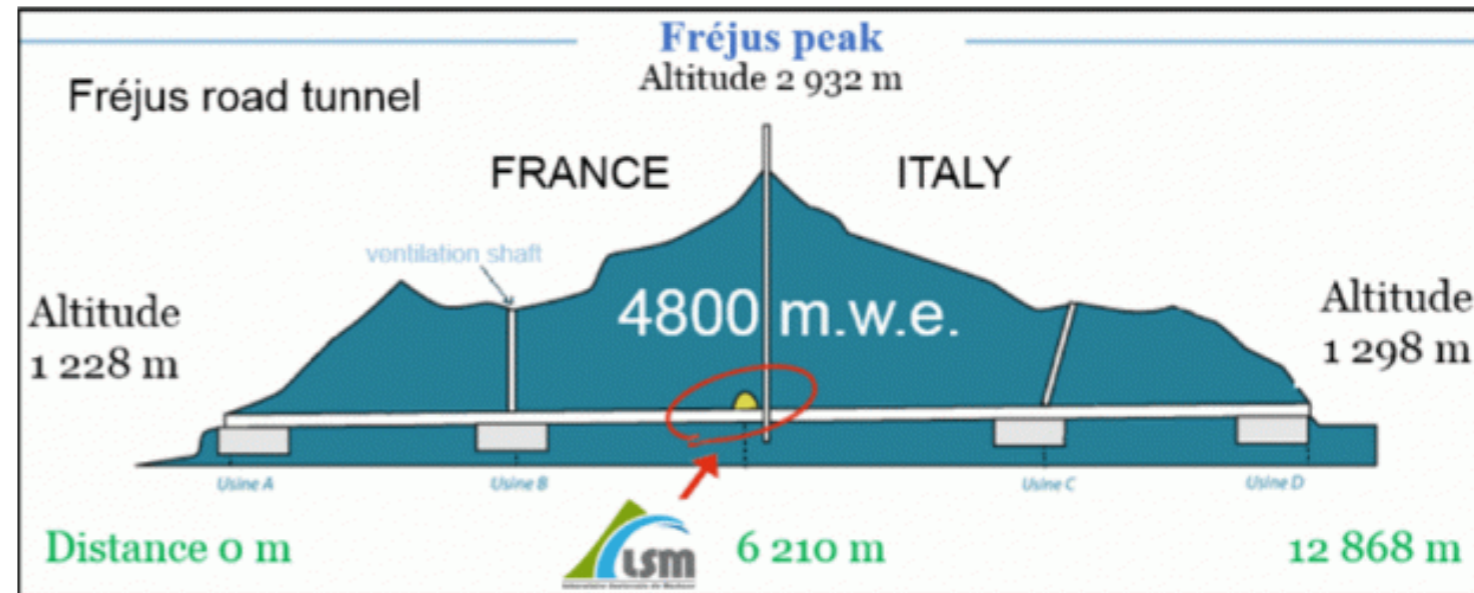
Plot by P. Gros

NEWS-G/LSM: SEDINE low background SPC

■ 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

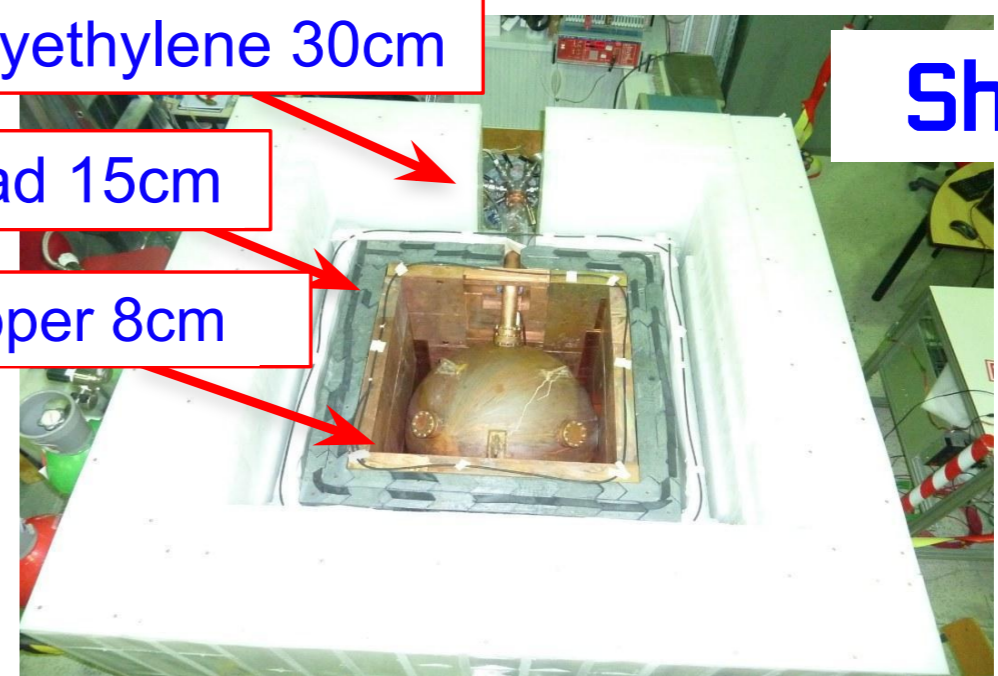


SEDINE sensor

Polyethylene 30cm

Lead 15cm

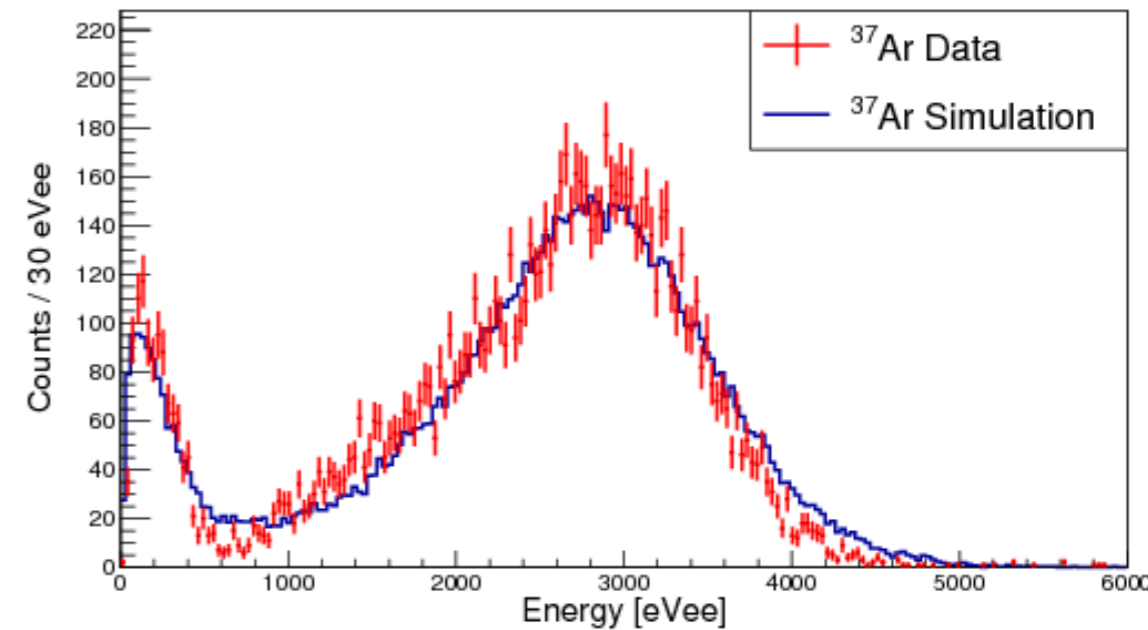
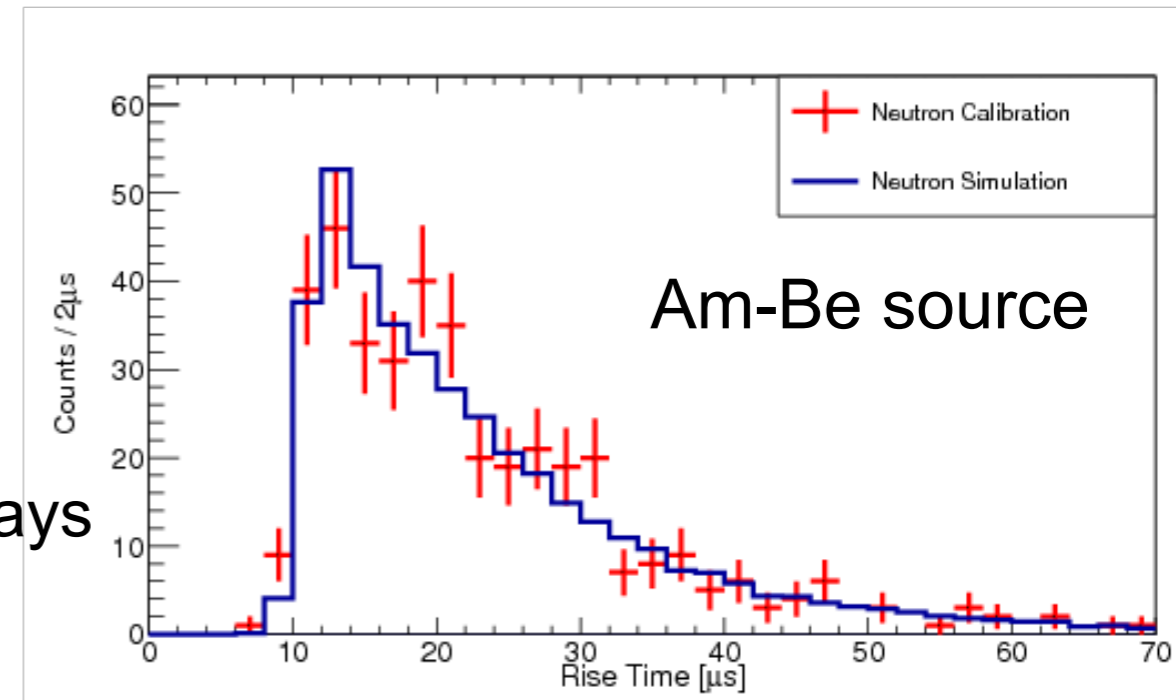
Copper 8cm



Shielding

SEDINE: Data taking conditions

- **Target:** Neon + 0.7% CH₄ at 3.1 bar (282 gr)
- **Run time:** Continuous data taking for 42.7 days
 - ▶ **Exposure:** 34.1 live-days x 0.282 kg = 9.6 kg.days
- Anode high voltage 2520 V, no sparks
 - ▶ Absolute Gain ~3000.
 - ▶ Loss of gain 4% throughout the period
- Sealed mode, no recirculation.
- **Read-out:** Canberra charge sensitive preamplifier (τ_{RC}=50 μs)
- **Calibration:** ³⁷Ar gaseous source, 8 keV Cu fluorescence line, AmBe neutron source



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SEDINE: Background 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

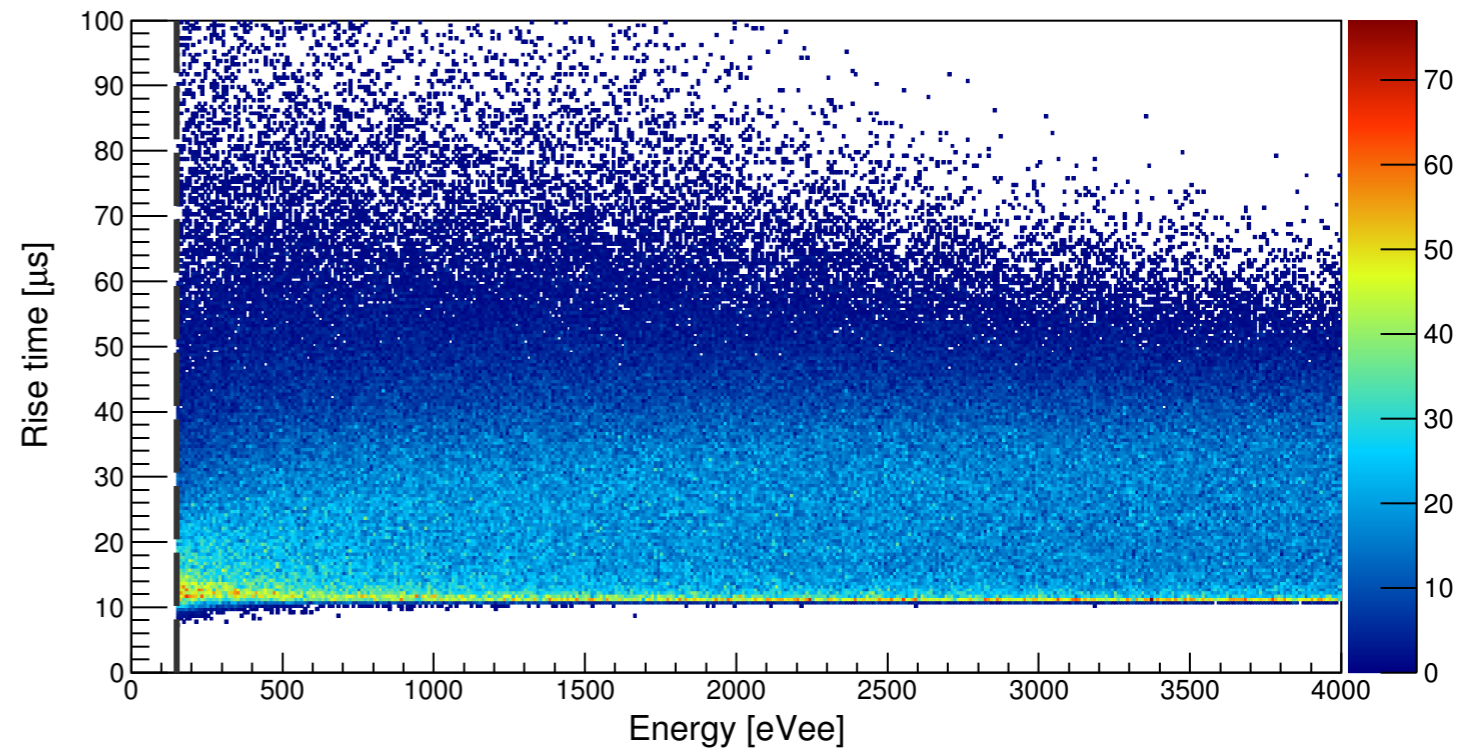
▶ Chemical Cleaning (nitric acid)

- ▶ $>200\text{eV}$: 180 mHz \rightarrow $\sim 2\text{mHz}$
- ▶ $<200\text{eV}$: 400 mHz \rightarrow $\sim 20\text{mHz}$

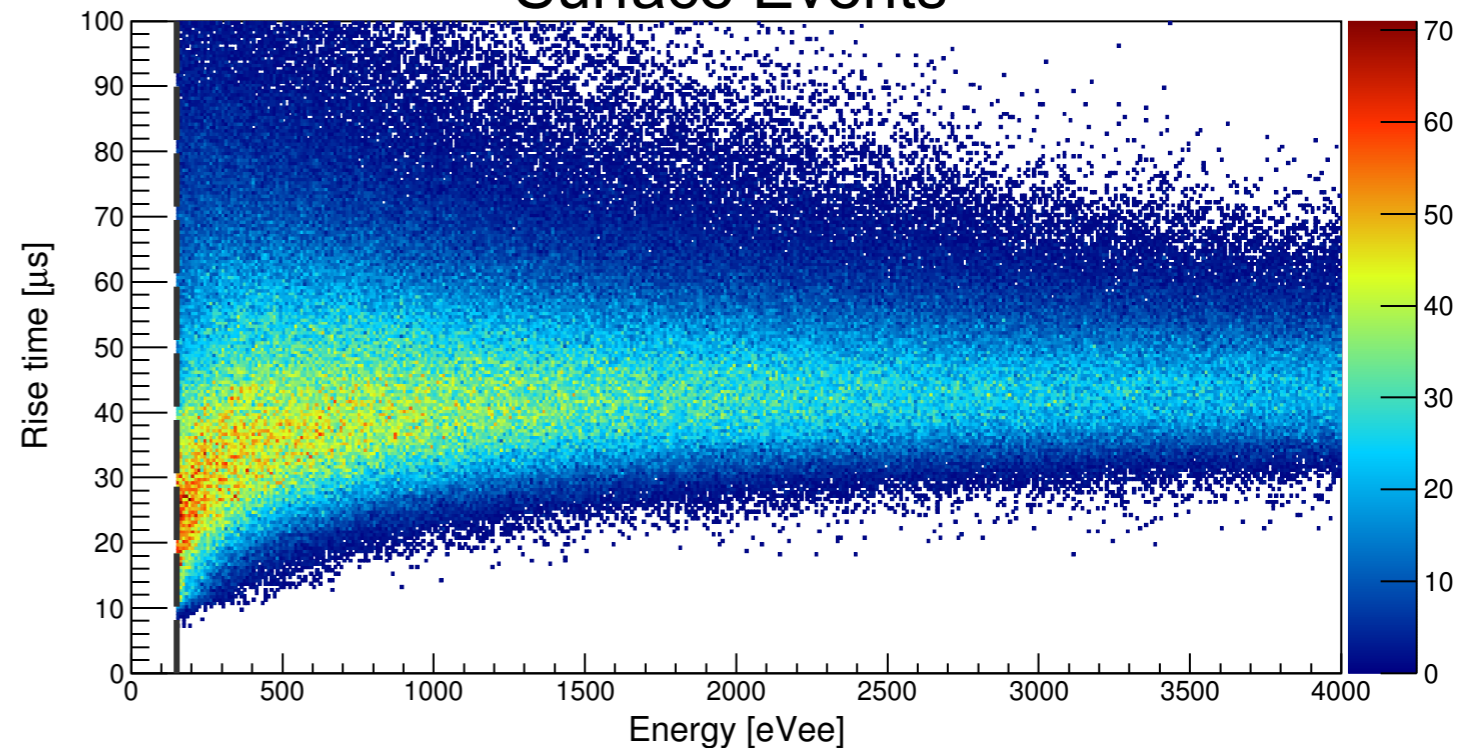
Pulse simulations include:

- ▶ Electric field (FEM)
- ▶ Diffusion (Magboltz)
- ▶ Avalanche process
- ▶ Signal induction
- ▶ Preamplifier response

Volume Events



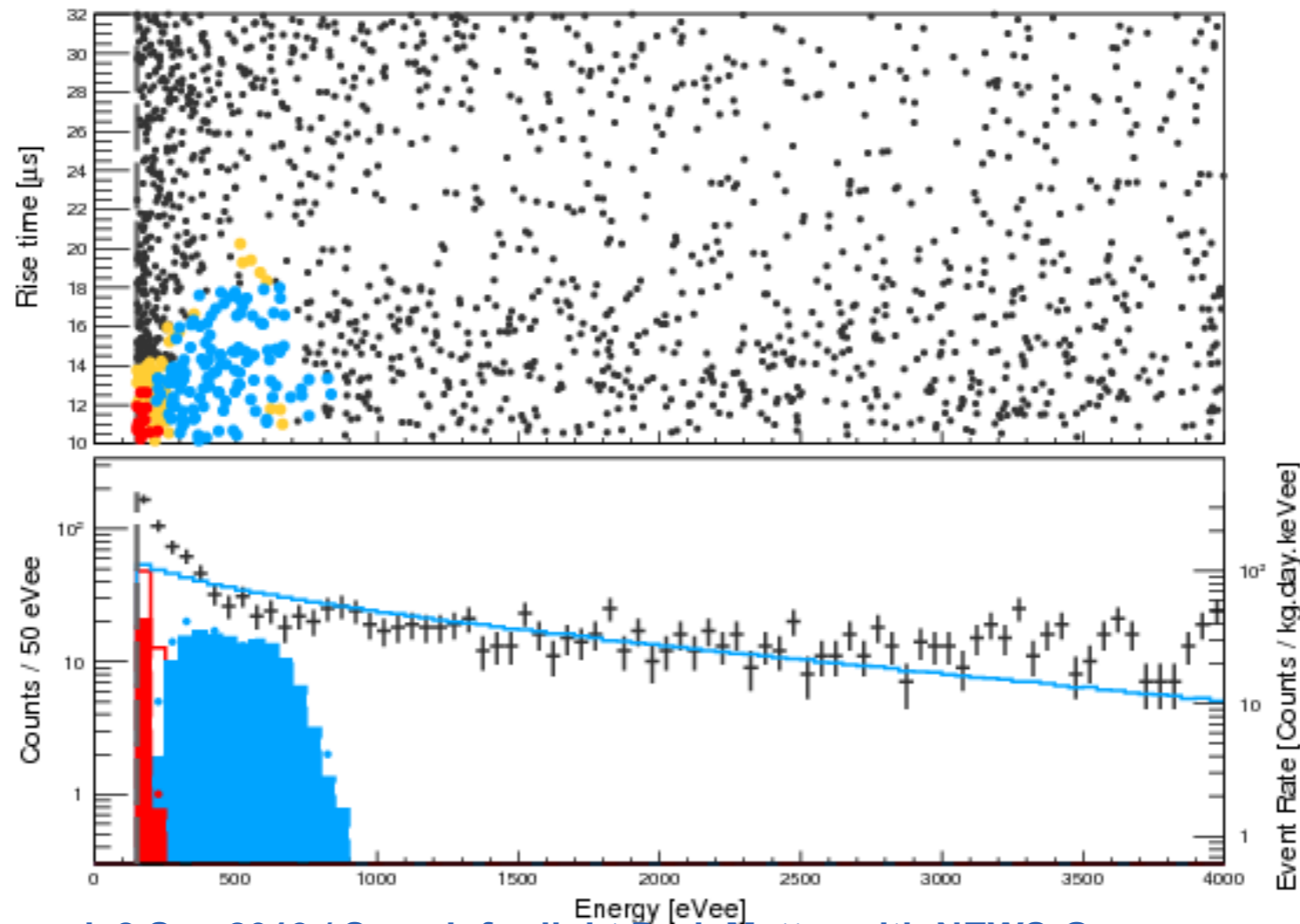
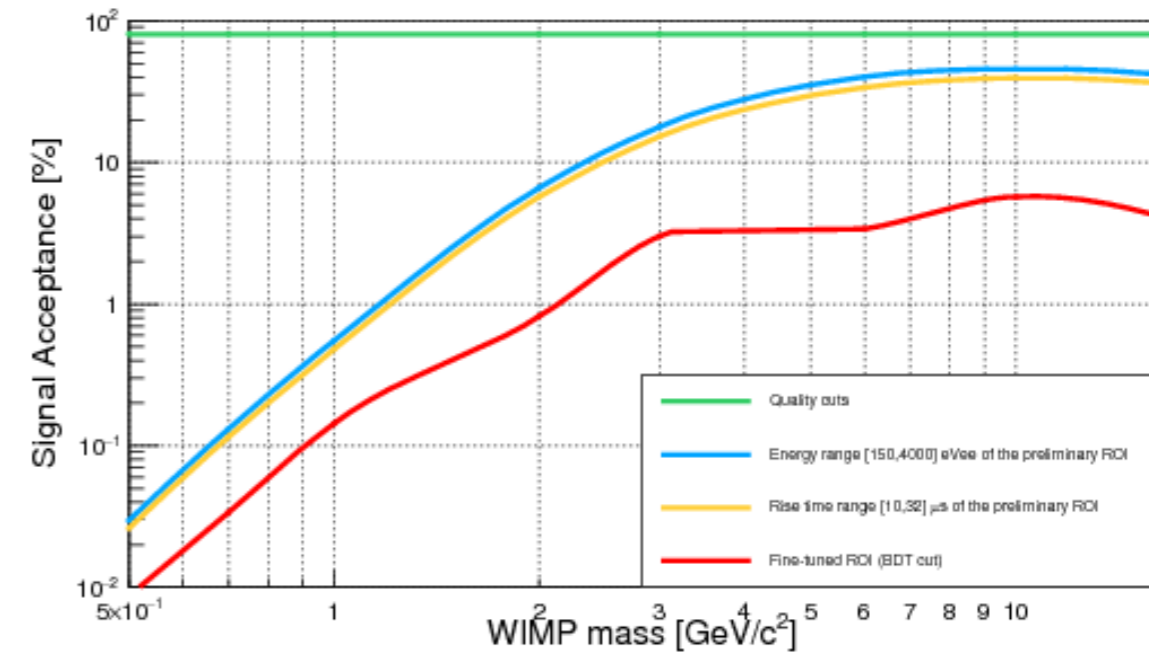
Surface Events



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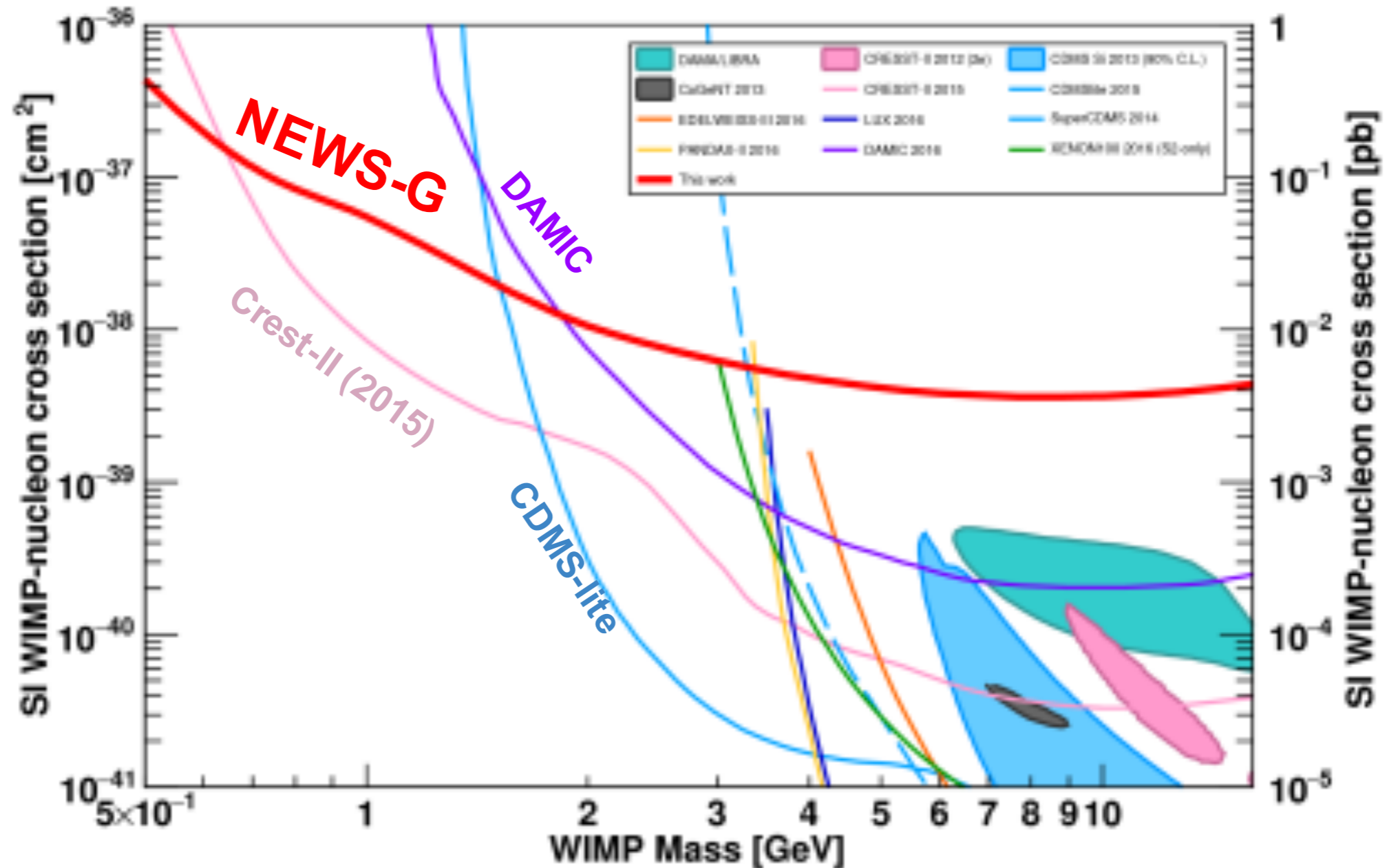
SEDINE: Event Selection

- Analysis threshold: 150 eVee (~ 720 eVnr)
- 100% trigger efficiency (threshold @ ~ 35 eVee)
- Optimised Signal Region determined with Boosted Decision Tree (8 candidate masses)
- 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 $4.4 \times 10^{-37} \text{ cm}^2$ @ 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

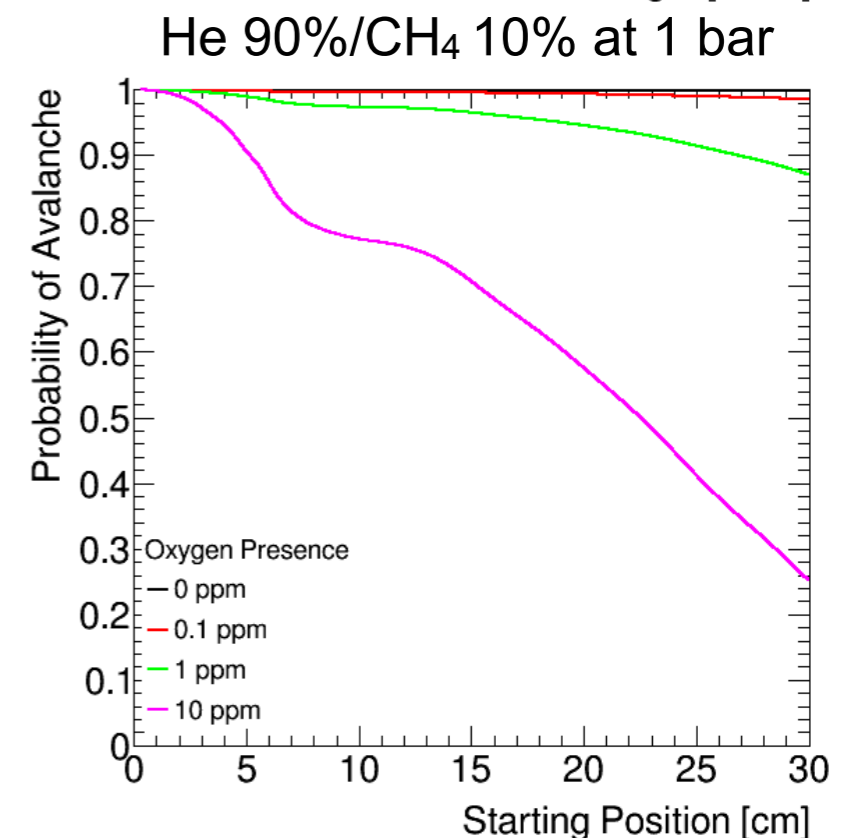
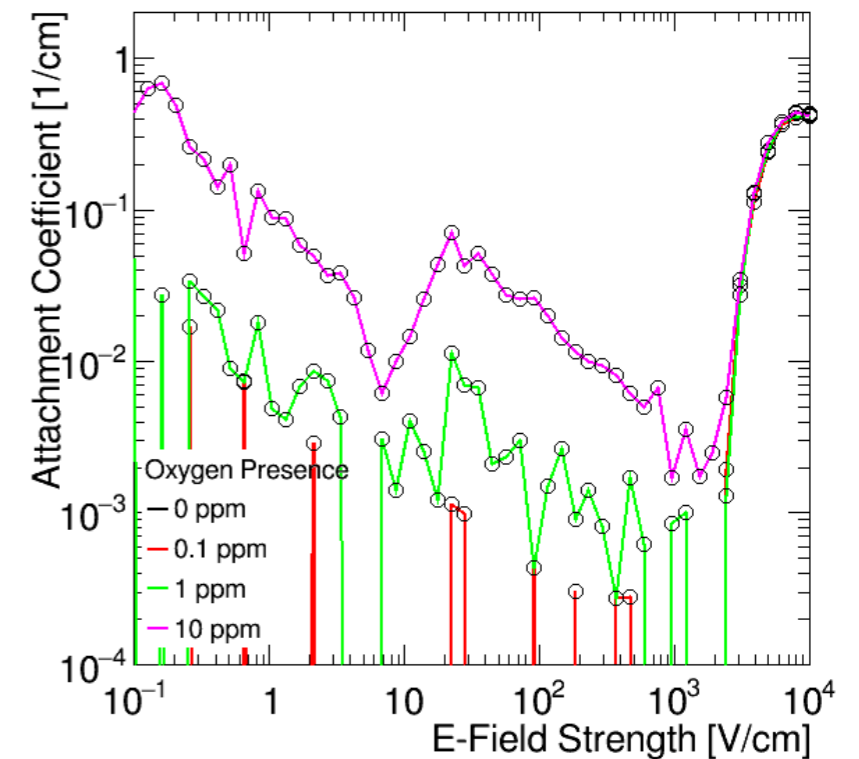
- ▶ Testing gas mixtures of He/CH₄
 - ▶ High pressure operation (Penning)
 - ▶ Hydrogen rich target
- ▶ Upgrading gas system
 - ▶ Tightness
 - ▶ Filtering
 - ▶ Gas recirculation
 - ▶ Monitoring with residual gas analyser

■ 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



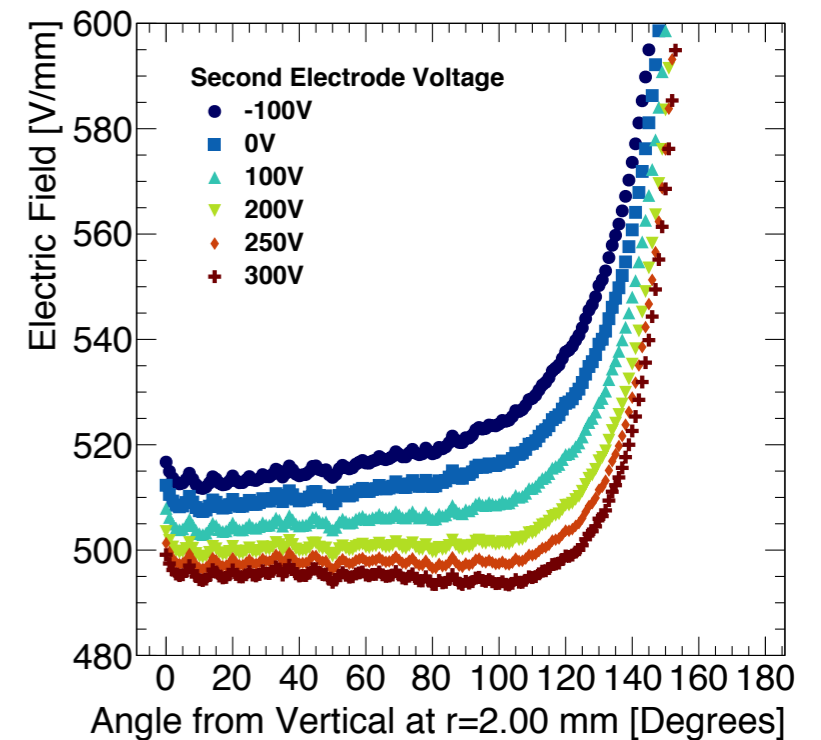
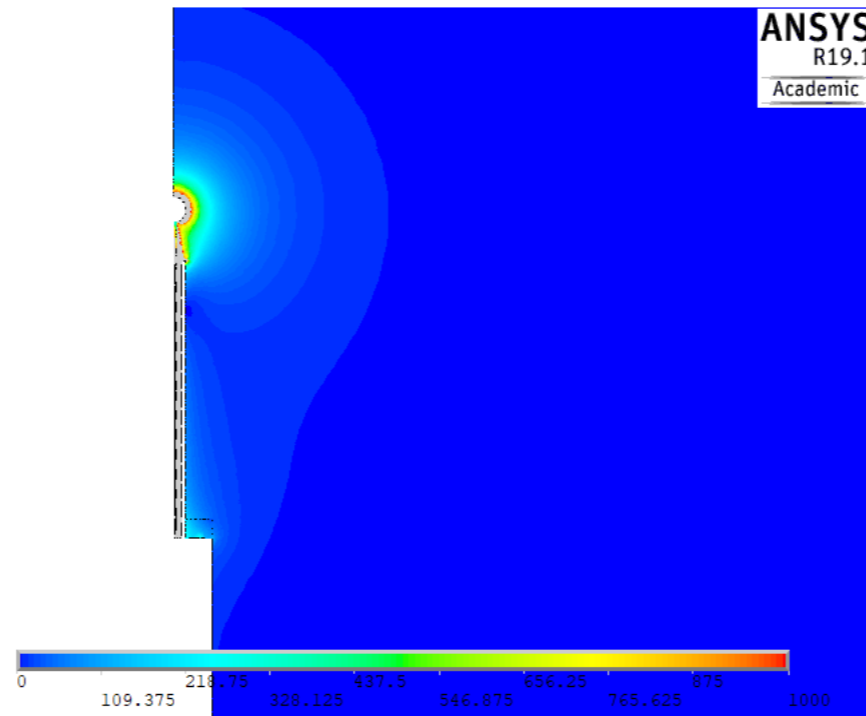
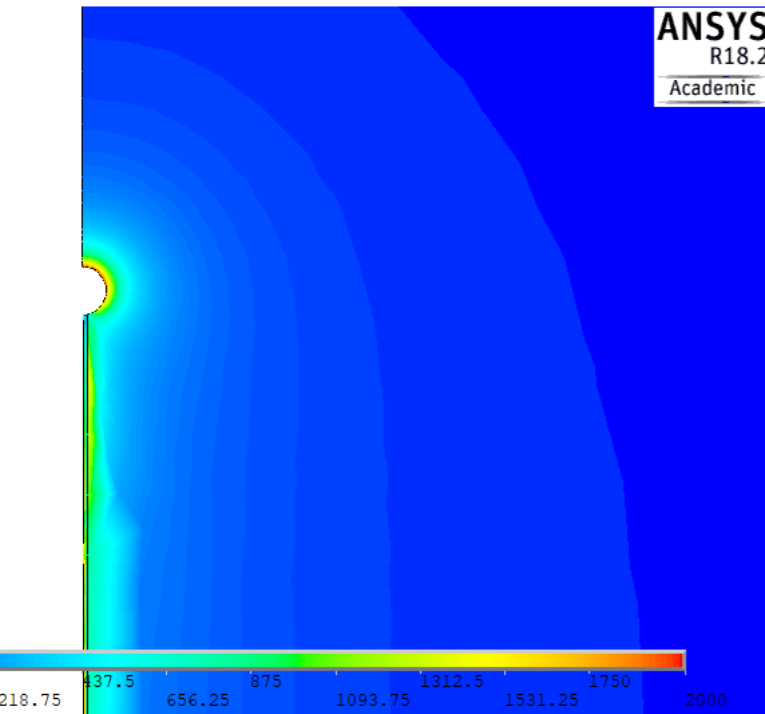
Single-anode Sensors

Aims:

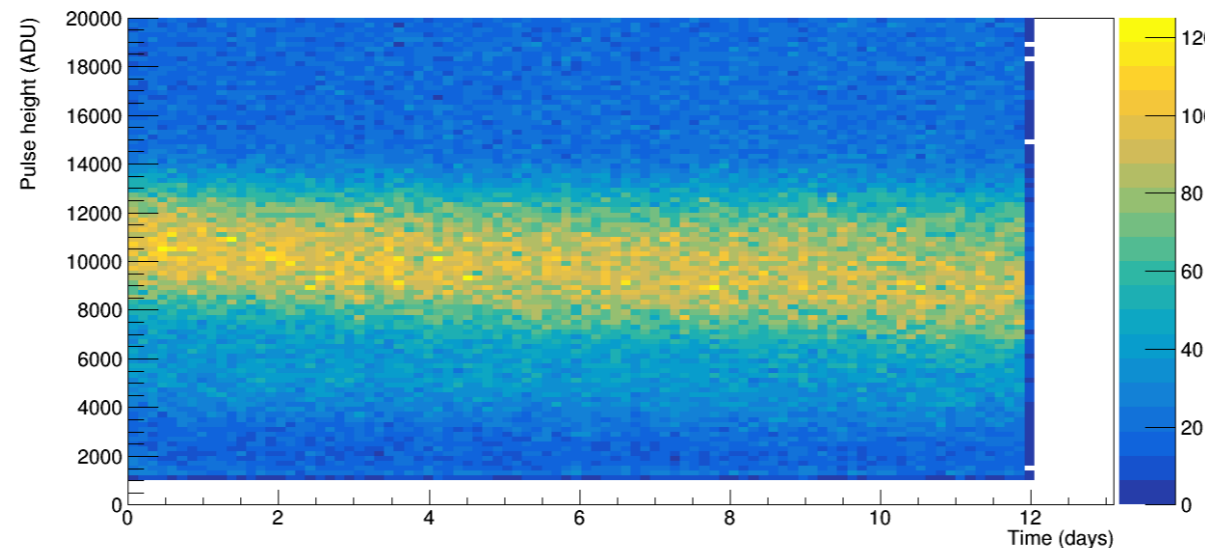
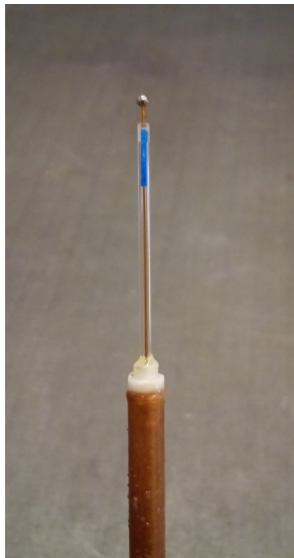
- ▶ High pressure operation
- ▶ Higher gain
- ▶ Larger volumes
- ▶ Increased Stability
- ▶ Low radioactivity

Techniques

- ▶ Resistive technologies
- ▶ 3D printing technologies
- ▶ FEM simulations



“Glass” sensor



Operation @2bar

- ▶ He:Ar:CH₄ (87%:10%:3%)
- ▶ Anode at 2350V
- ▶ Correction Electrode 0V

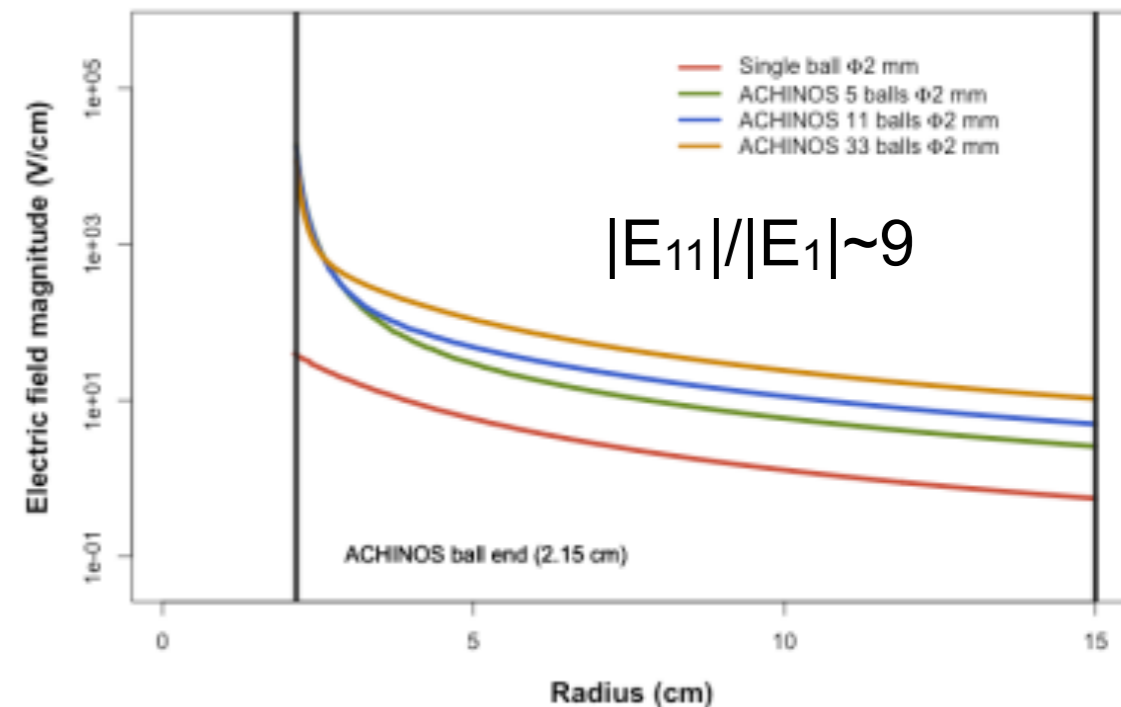
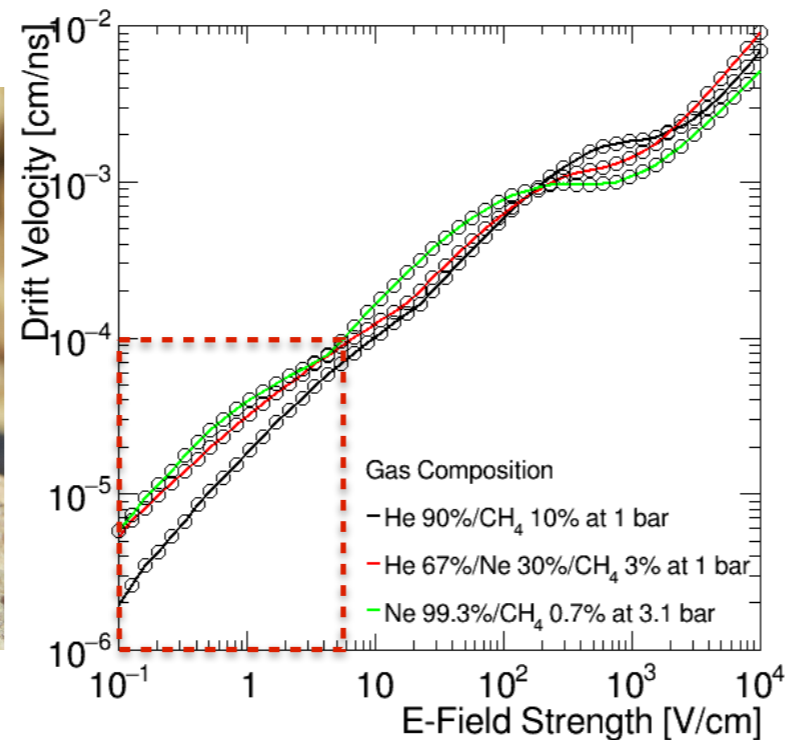
Multi-anode sensors: Achinos

11-ball 3D printed

33-ball bakelite



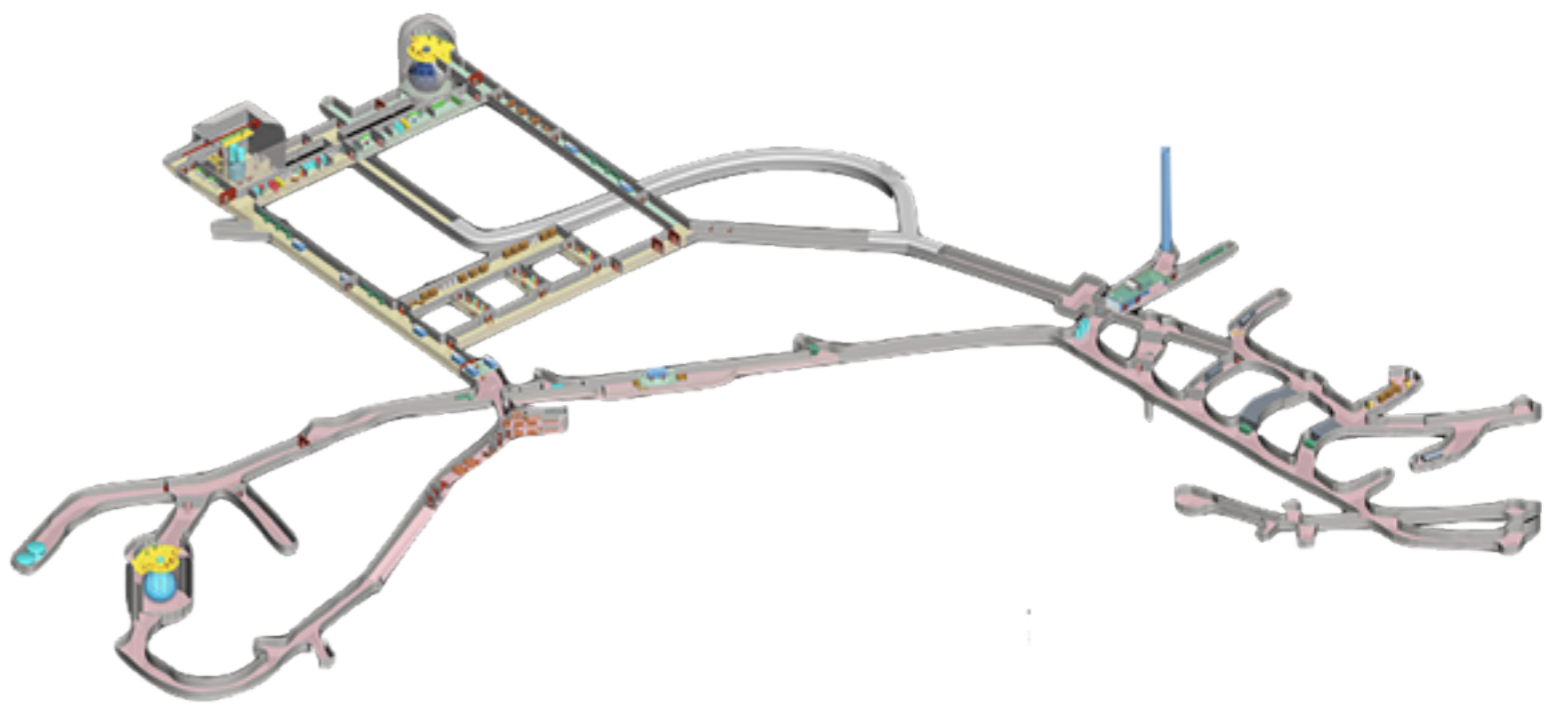
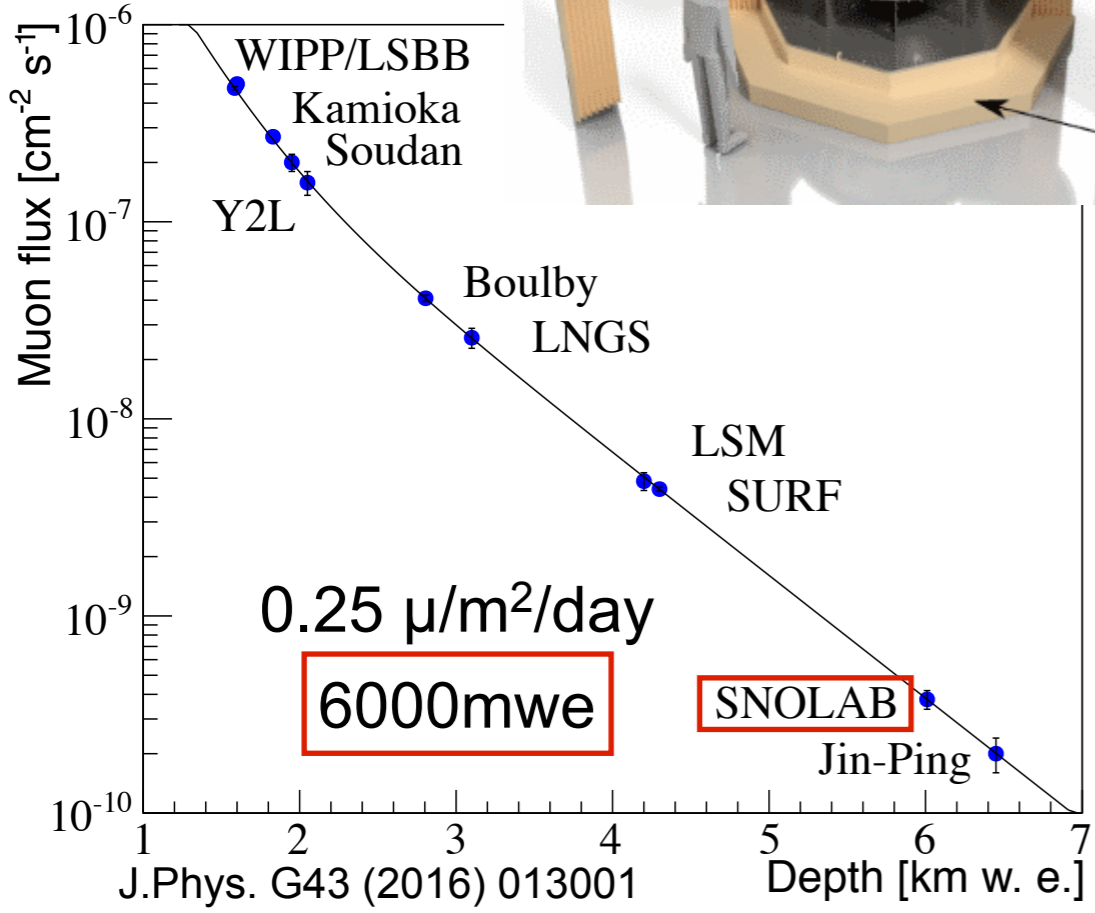
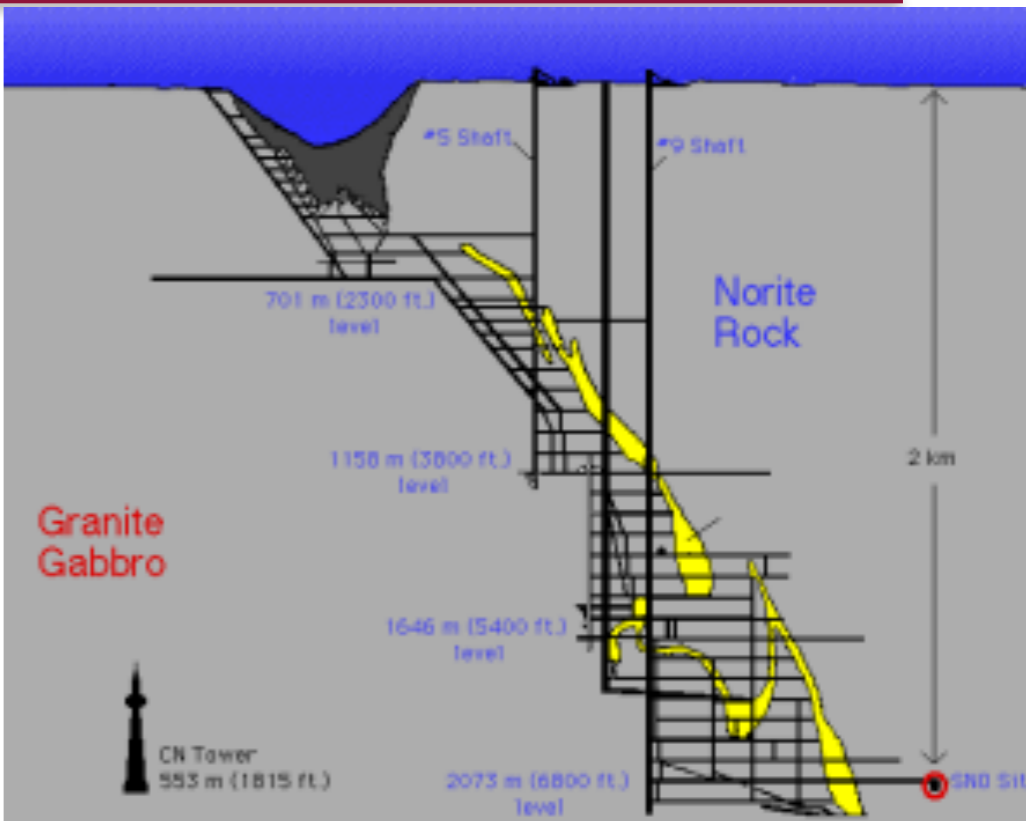
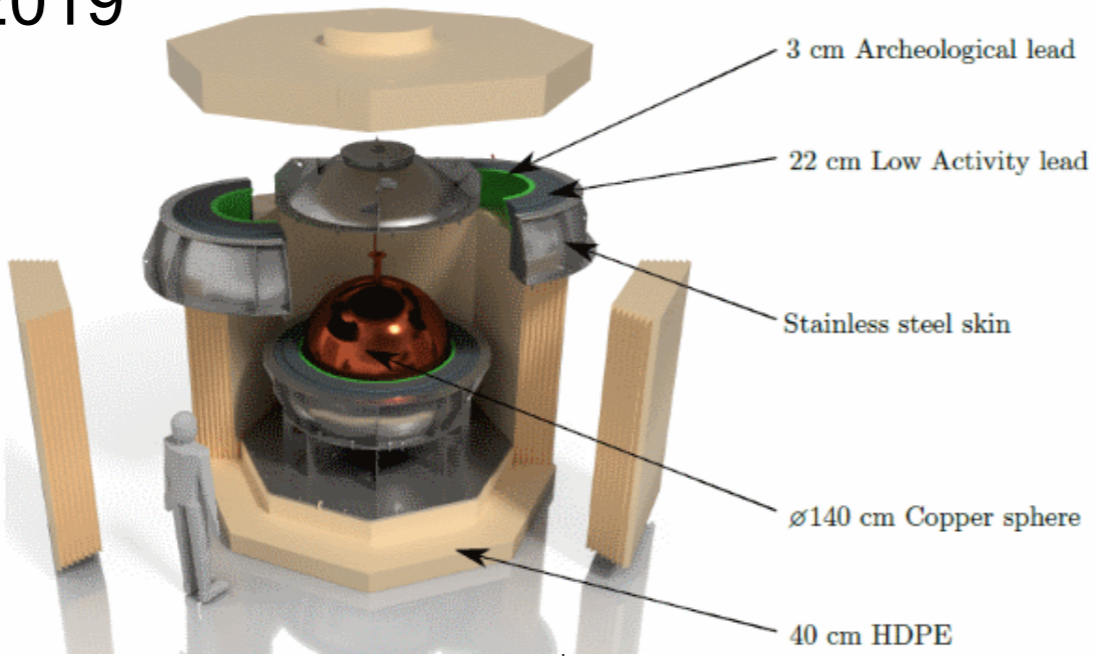
- Achinos: Multiple anode balls placed at equal distances on a sphere
 - ▶ Same gain but increased field at large radii
 - ▶ Decoupling Gain and Drift
 - ▶ Anodes can be read out individually
- Prototypes: 5, 11, 33 metal balls \varnothing 2mm successfully operated
- 3D printed Achinos sensors built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



JINST 12 (2017) P12031

NEWS-G at SNOLAB

- Underground laboratory in Sudbury, Canada
- ▶ NEWS-G to be installed in Cube Hall
- ▶ Installation in 2018
- ▶ Data-taking 2019



- Copper vessel (\varnothing 140cm, 12mm thick)
 - ▶ Low activity copper (C10100)
 - ▶ 7 to 25 $\mu\text{Bq/kg}$ Th
 - ▶ 1 to 5 $\mu\text{Bq/kg}$ 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)

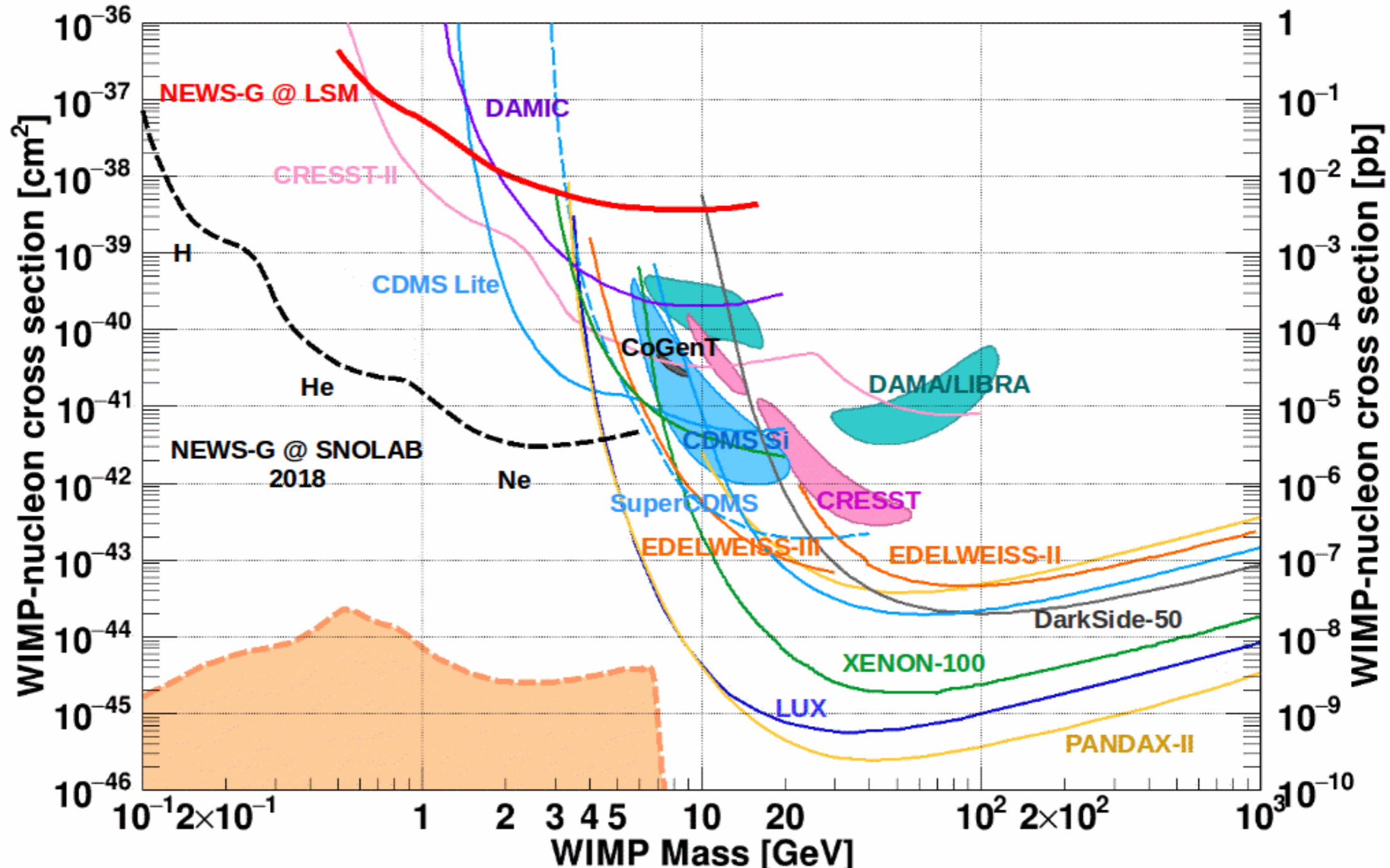
Hemispheres built in France,
stored at LSM before welding



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

NEWS-G SNO

Operation with different targets:
Ne, He, H

Operation with different pressures:
Tenths mbar - 10 bar

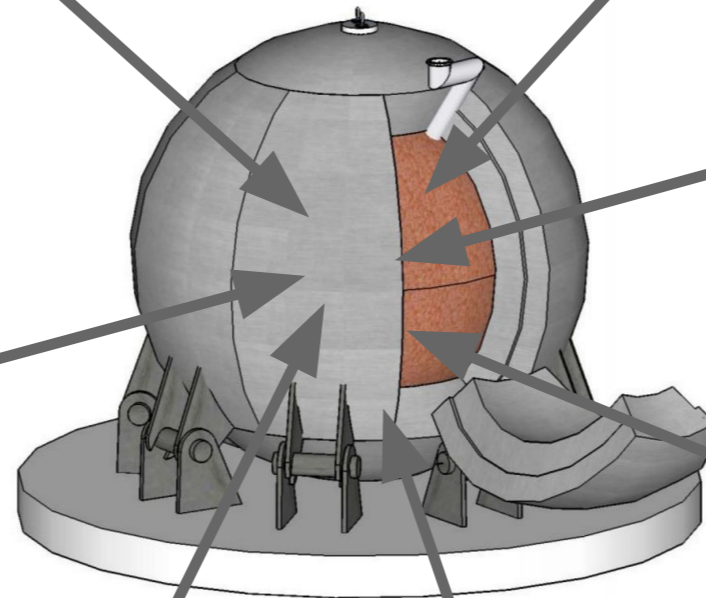
Operation with High Z medium (Xenon) to better determine the background

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



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
IRFU/CEA Saclay – I Giomataris, M Gros, C Nones, I Katsioulas, T Papaevangelou, JP Bard, JP Mols, XF Navick,
Laboratoire Souterrain de Modane, IN2P3, U of Chambéry – F Piquemal, M Zampaolo, A Dastgheibi-Fard
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, R Ward
University of Alberta – M. Piro
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 NEWS-G/LSM

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▶ SEDINE essential for @SNOLAB optimisation

■ NEWS-G/SNOLAB

▶ Larger detector and target mass

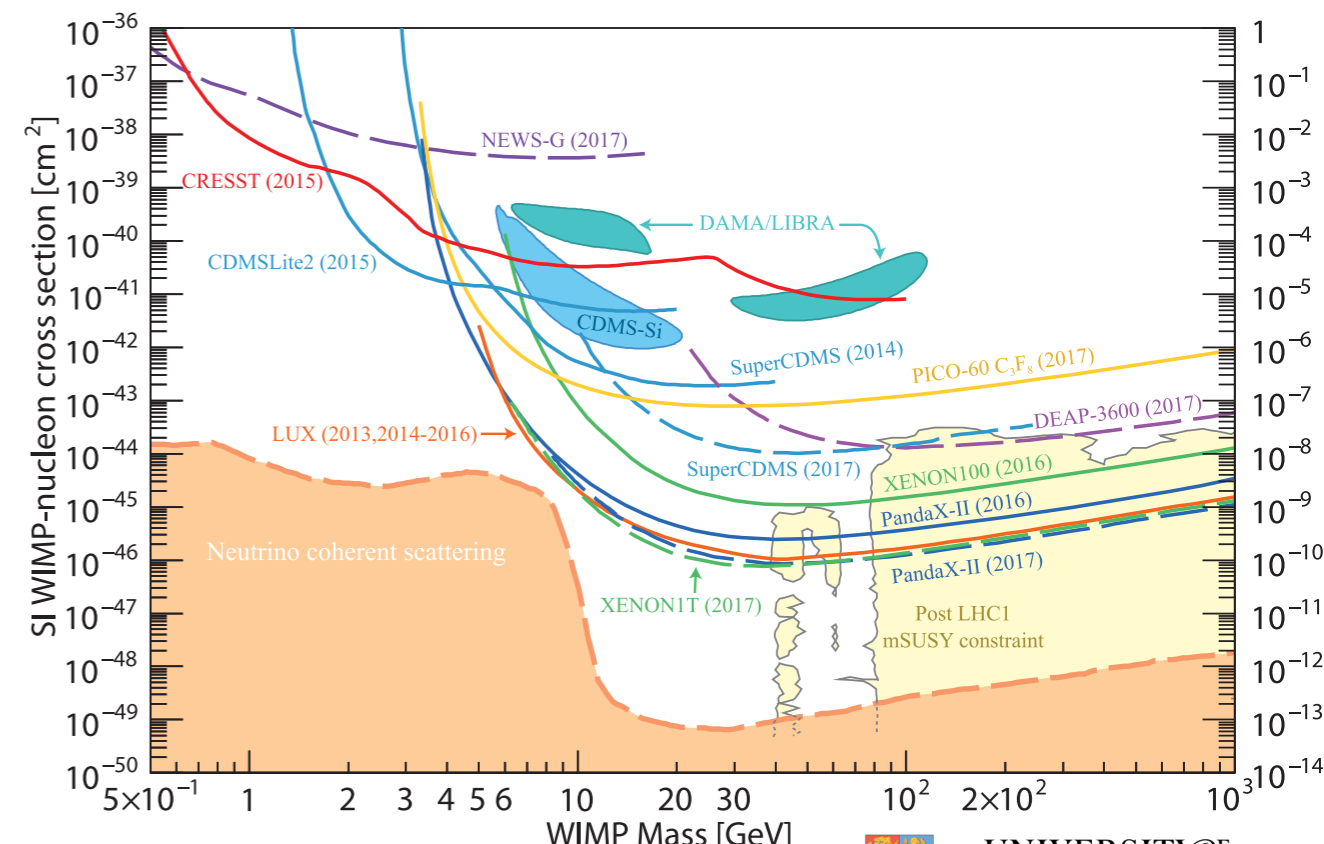
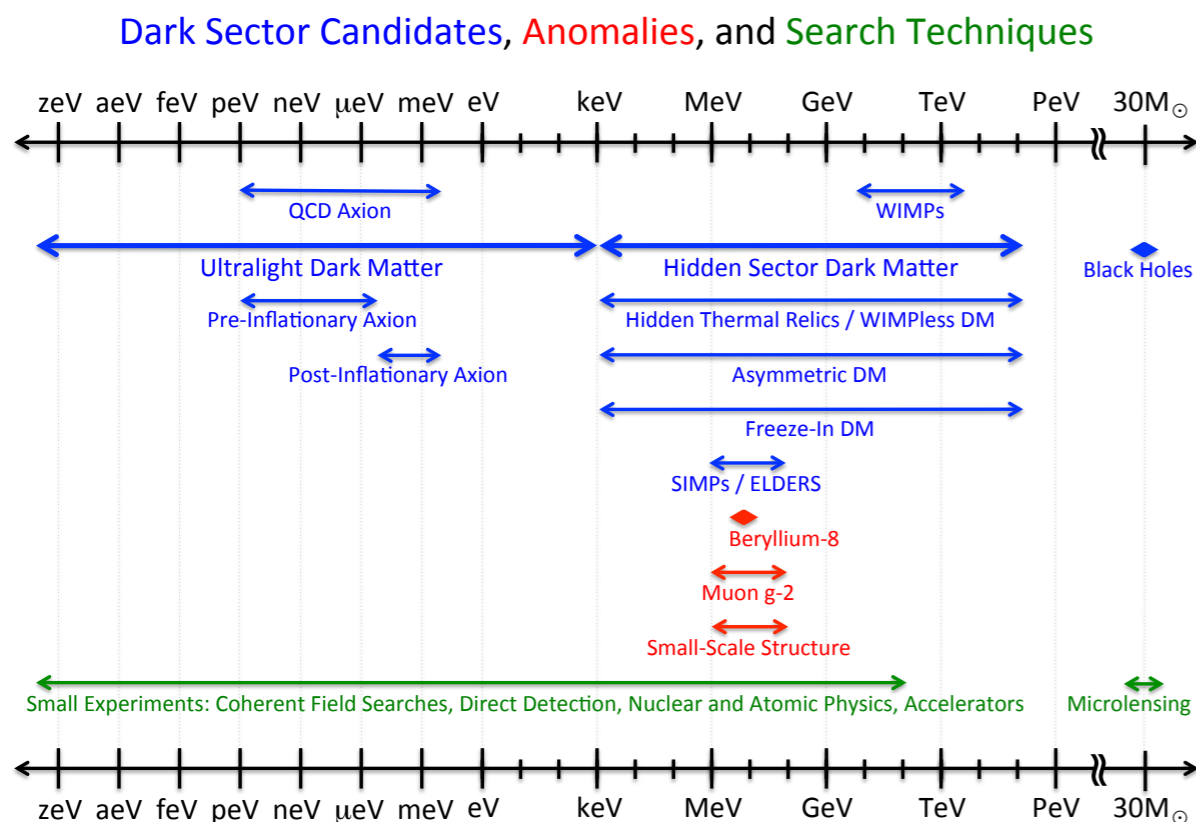
▶ Improved shield /materials/procedure

▶ Installation at SNOLAB in 2018

■ R&D on-going: cleaning methods, underground electroformed sphere, “achinos” type sensor, multi channels sensor, low pressure operation, ...

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■ Many physics opportunities!



Additional Slides

Pulse Treatment

Observed Pulse = Induced Current \otimes Preamplifier Response

