Search for light Dark Matter with NEWS-G

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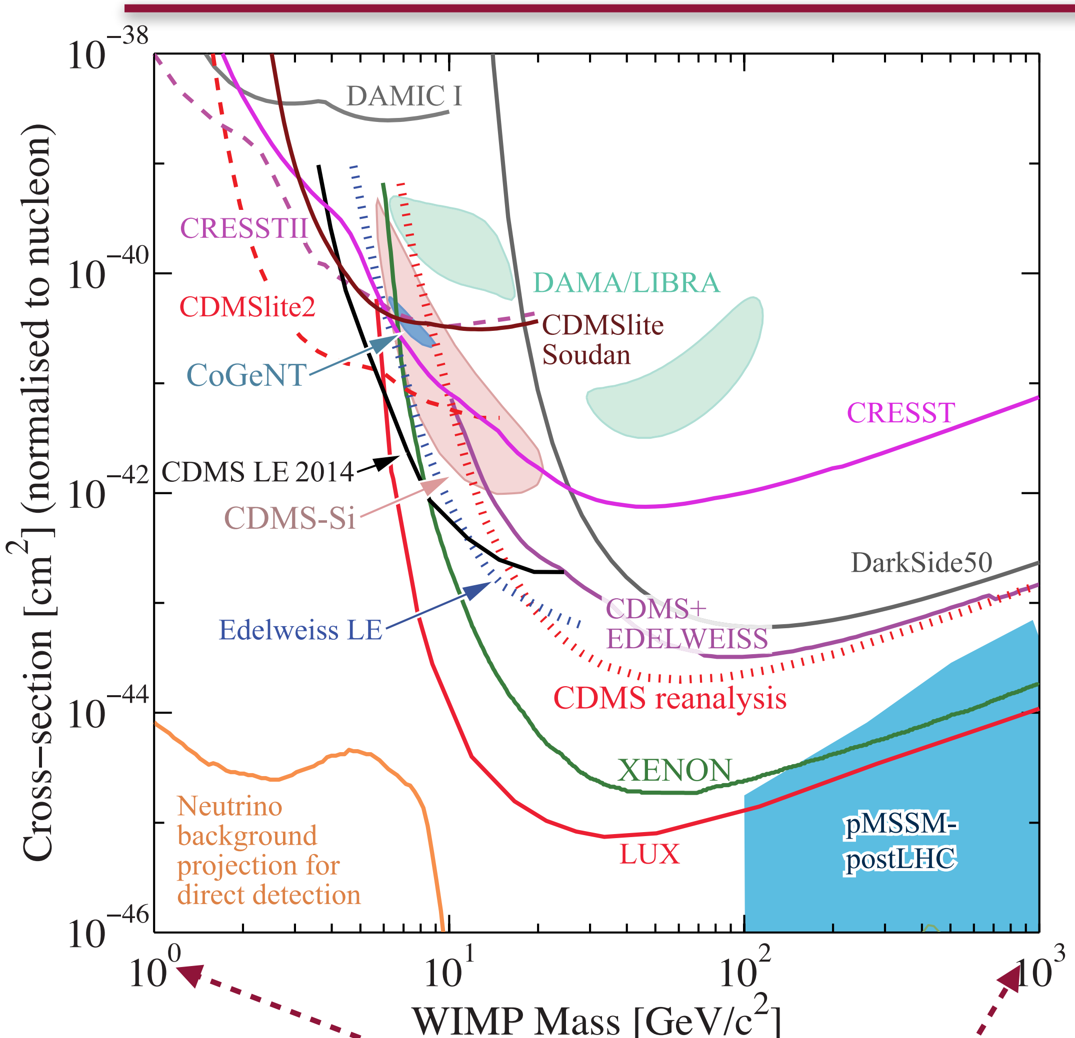
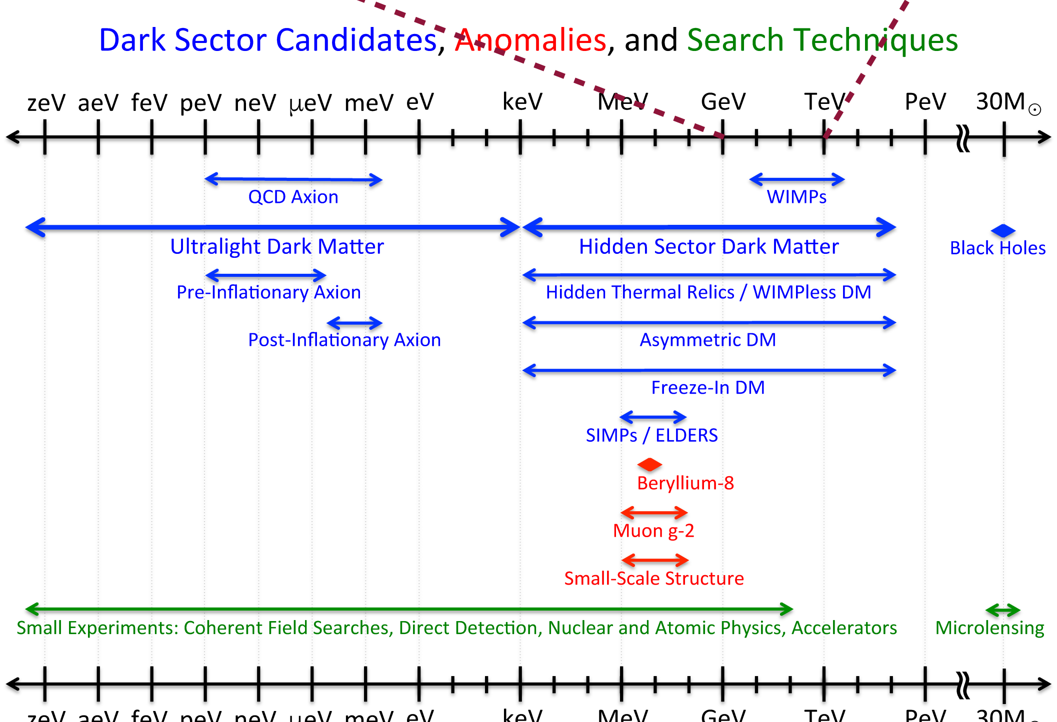
SEDINE prototype at LSM

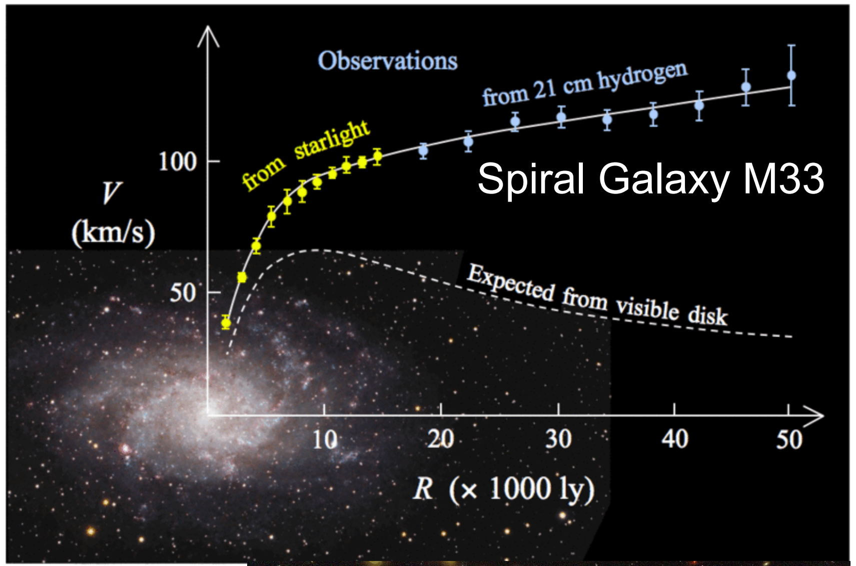
Dark Interactions: Perspectives from Theory and Experiment
October 4th, 2018, Brookhaven National Laboratory, U.S.A.

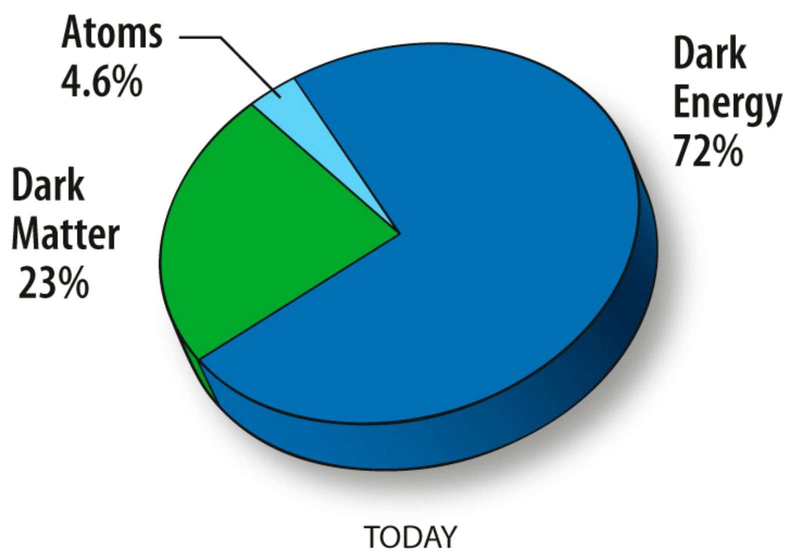
Dark Matter

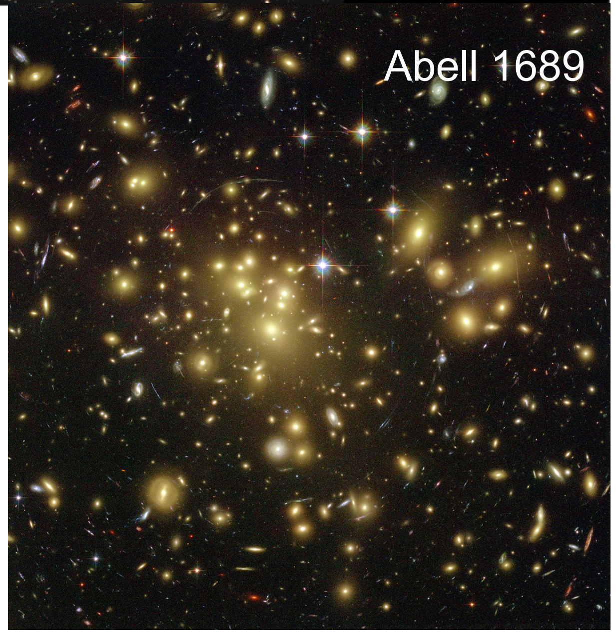




arXiv:1707.04591

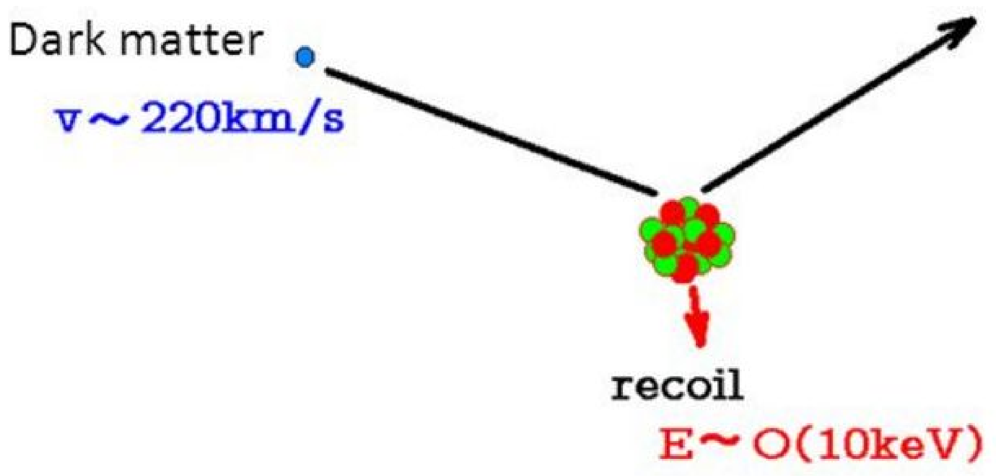






- Current state of affairs:
  - Evidence for existence of Dark Matter
  - Absence of evidence in WIMP-preferred region
- Wide spectrum of possibilities → expand searches
  - DM search: 0.1-10 GeV mass range

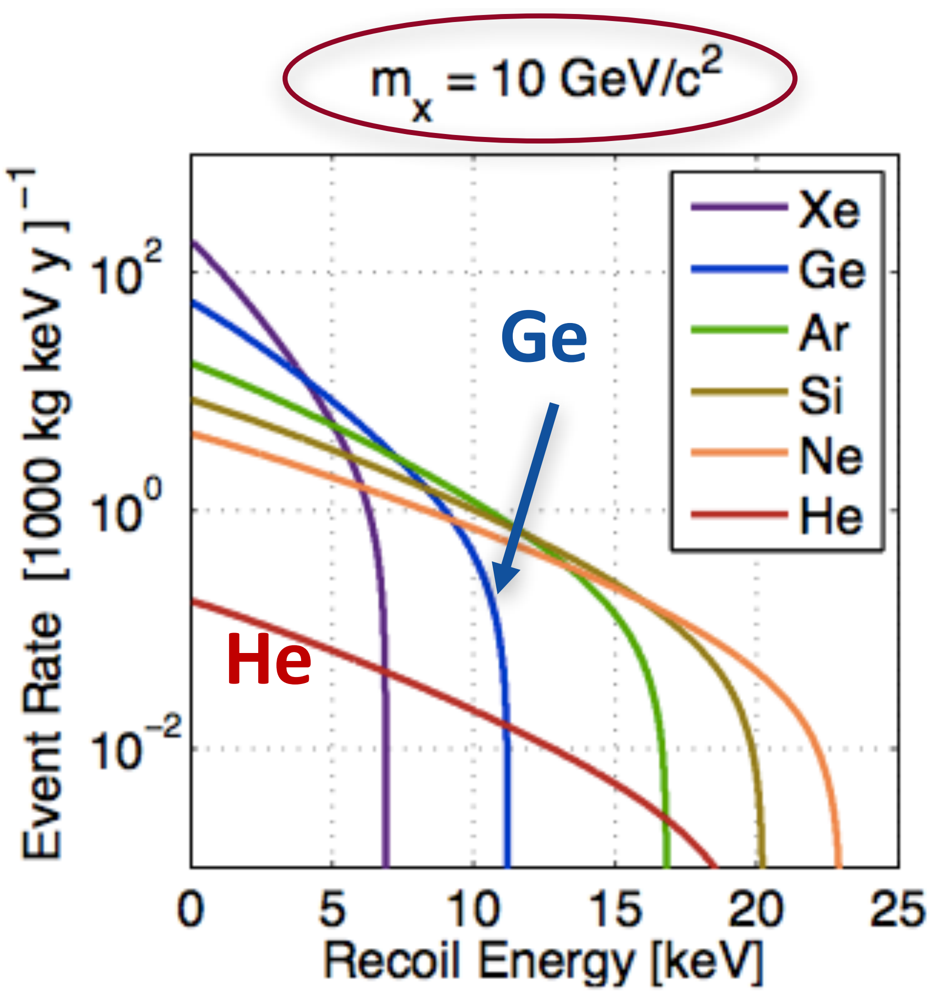
Searching for light DM: Recoil Energy

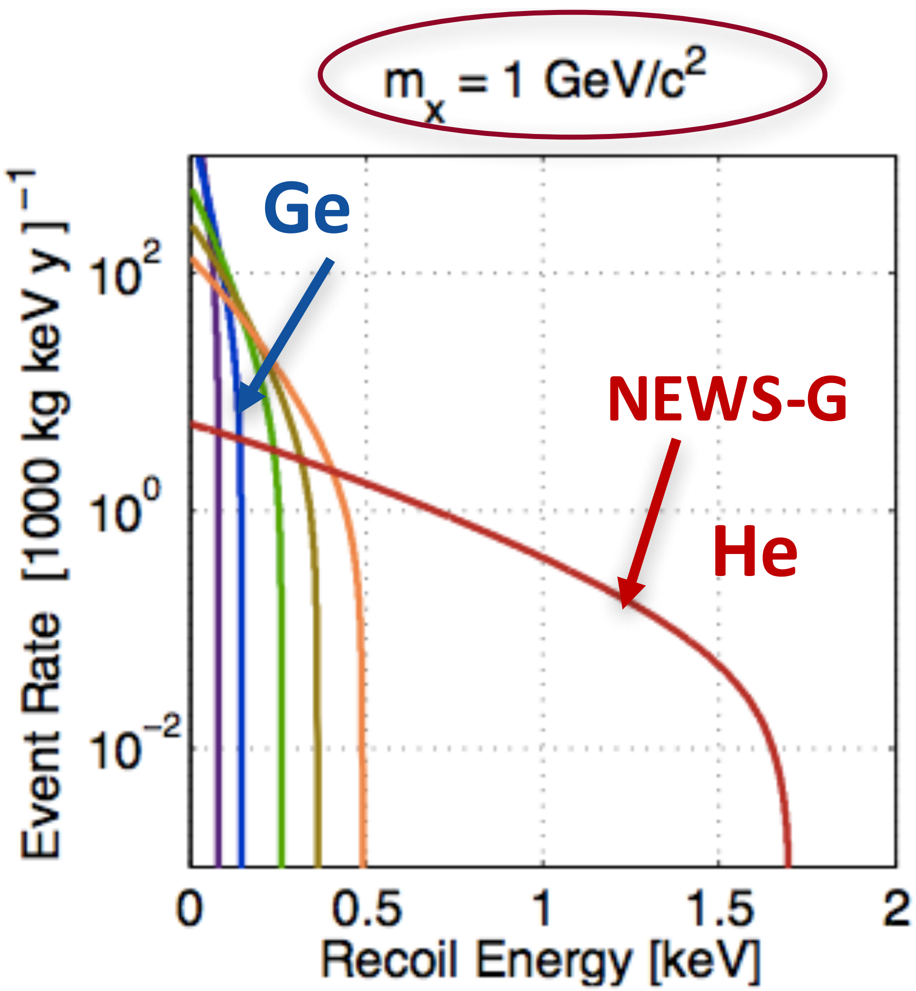


Recoil energy during DM scattering, E_R:

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

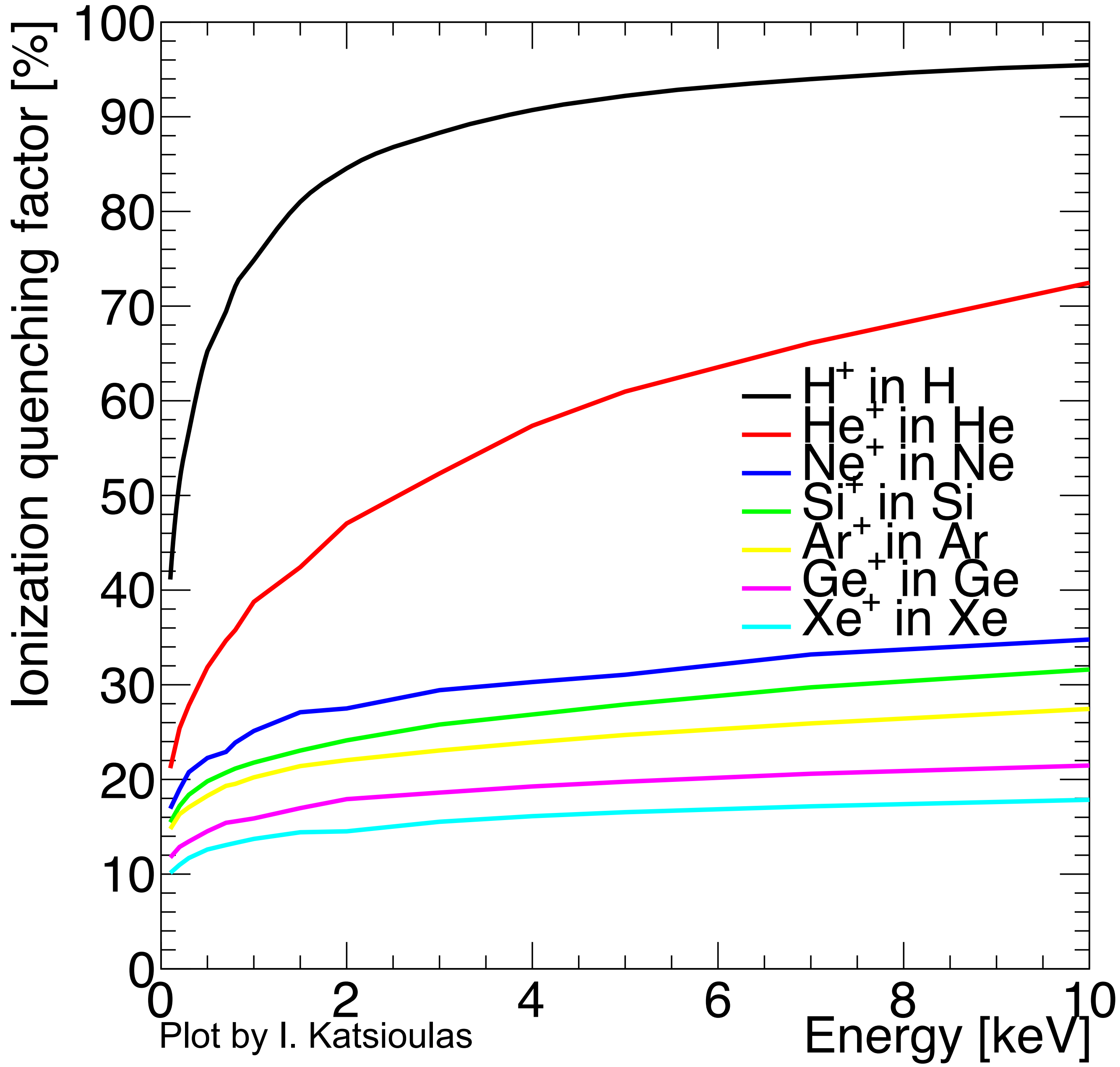
max E_R: head-on-collision and $m_\chi = m_N$





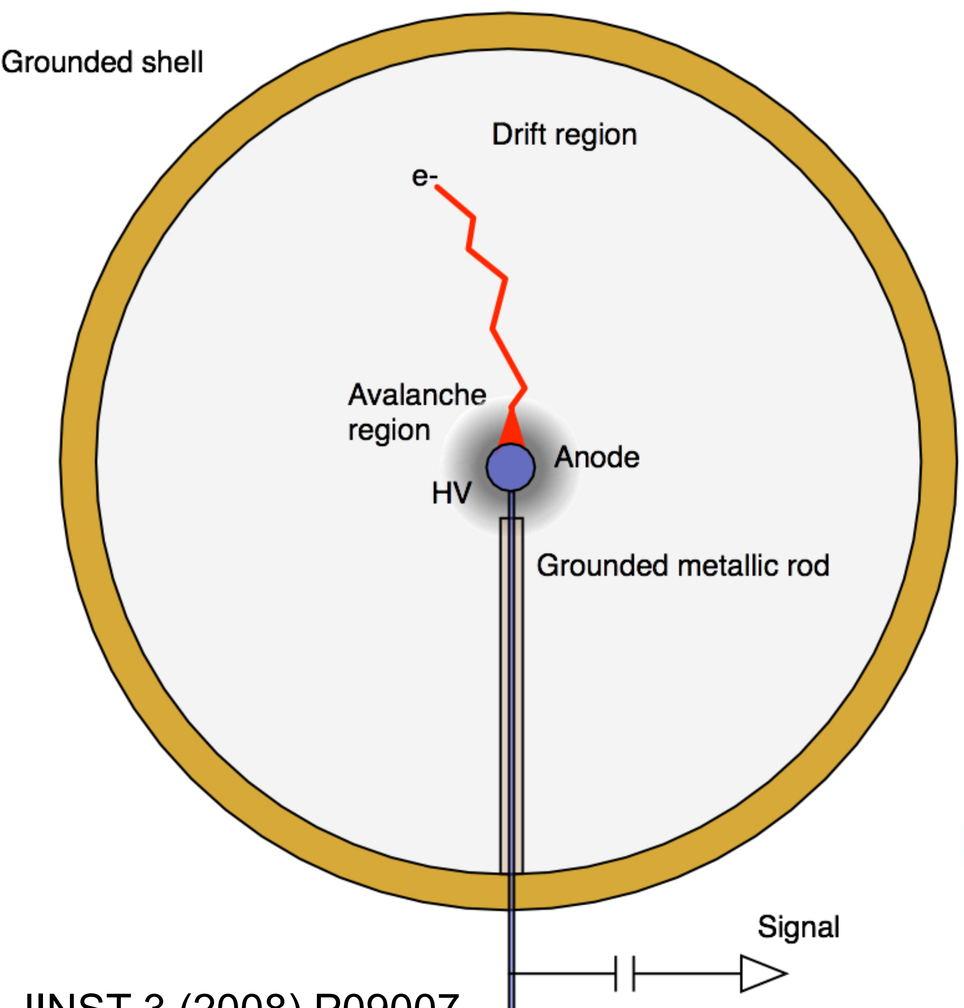
Searching for light DM: Quenching Factor

- 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.

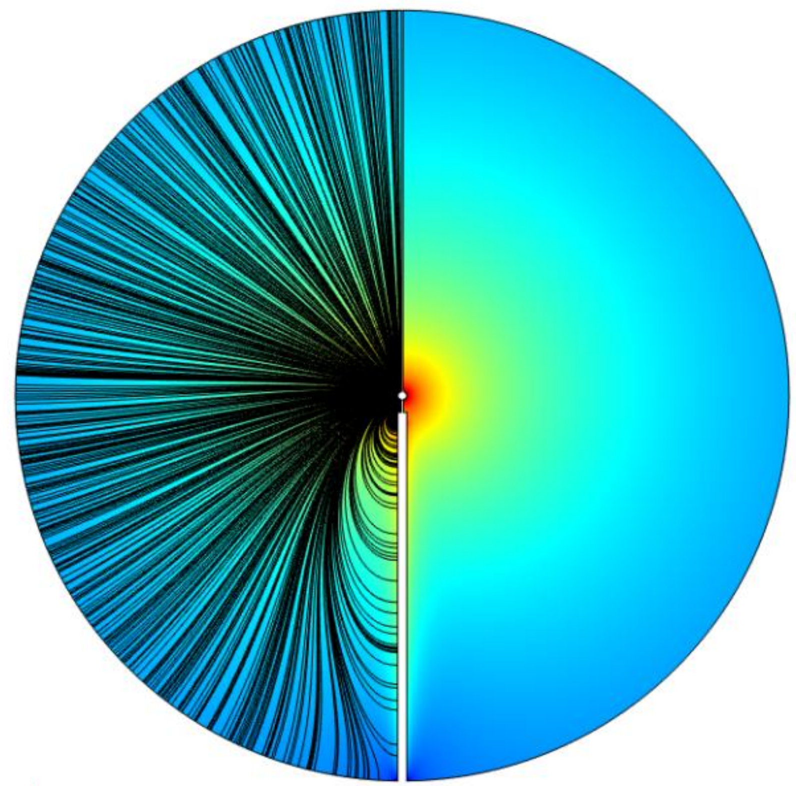


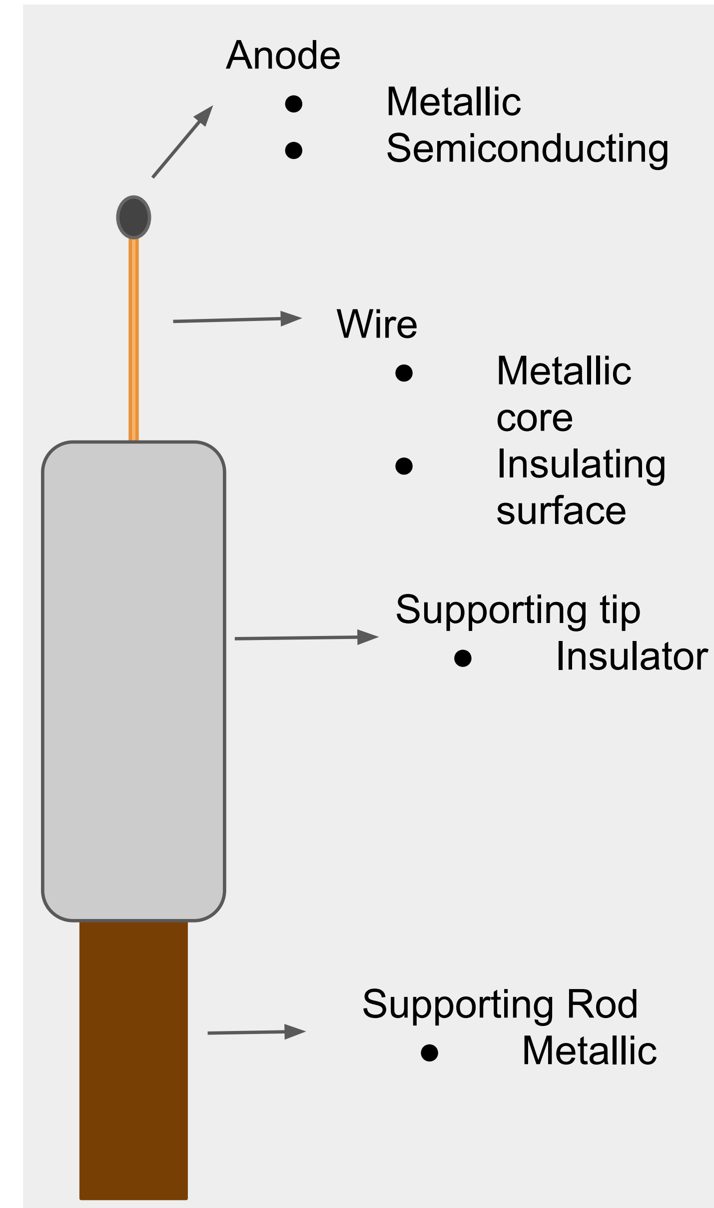
- Direct detection experiment using light gases as target (H, He, Ne)
  - Better projectile-target kinematic match
  - Favourable quenching factor

Spherical Proportional Counter



JINST 3 (2008) P09007





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

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

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

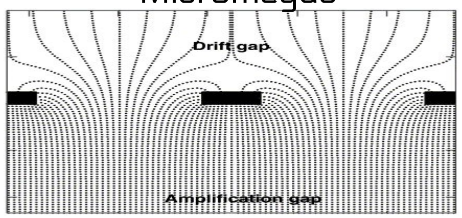
$$r_2 = \text{cathode radius}$$

Detector volume naturally divided in:
"drift" and "amplification" regions.

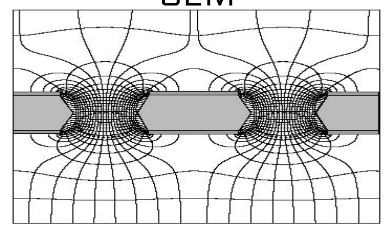
Spherical Proportional Counter

Capacitance dependence on size

Micromegas

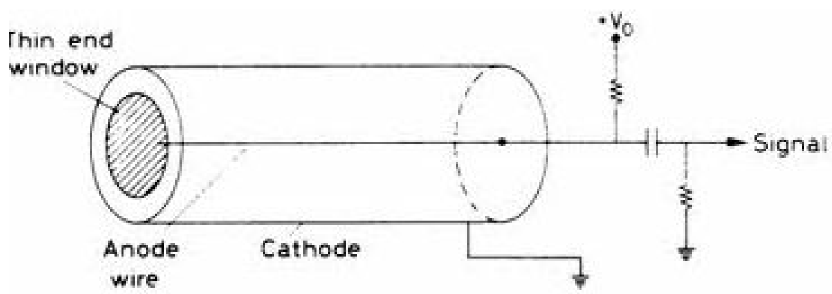


GEM



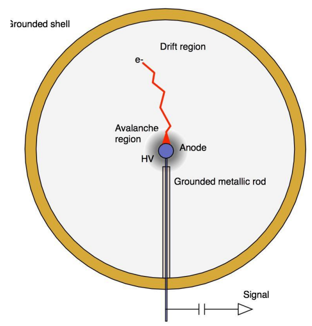
Parallel Plate Detector

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



Cylindrical Proportional Counter

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



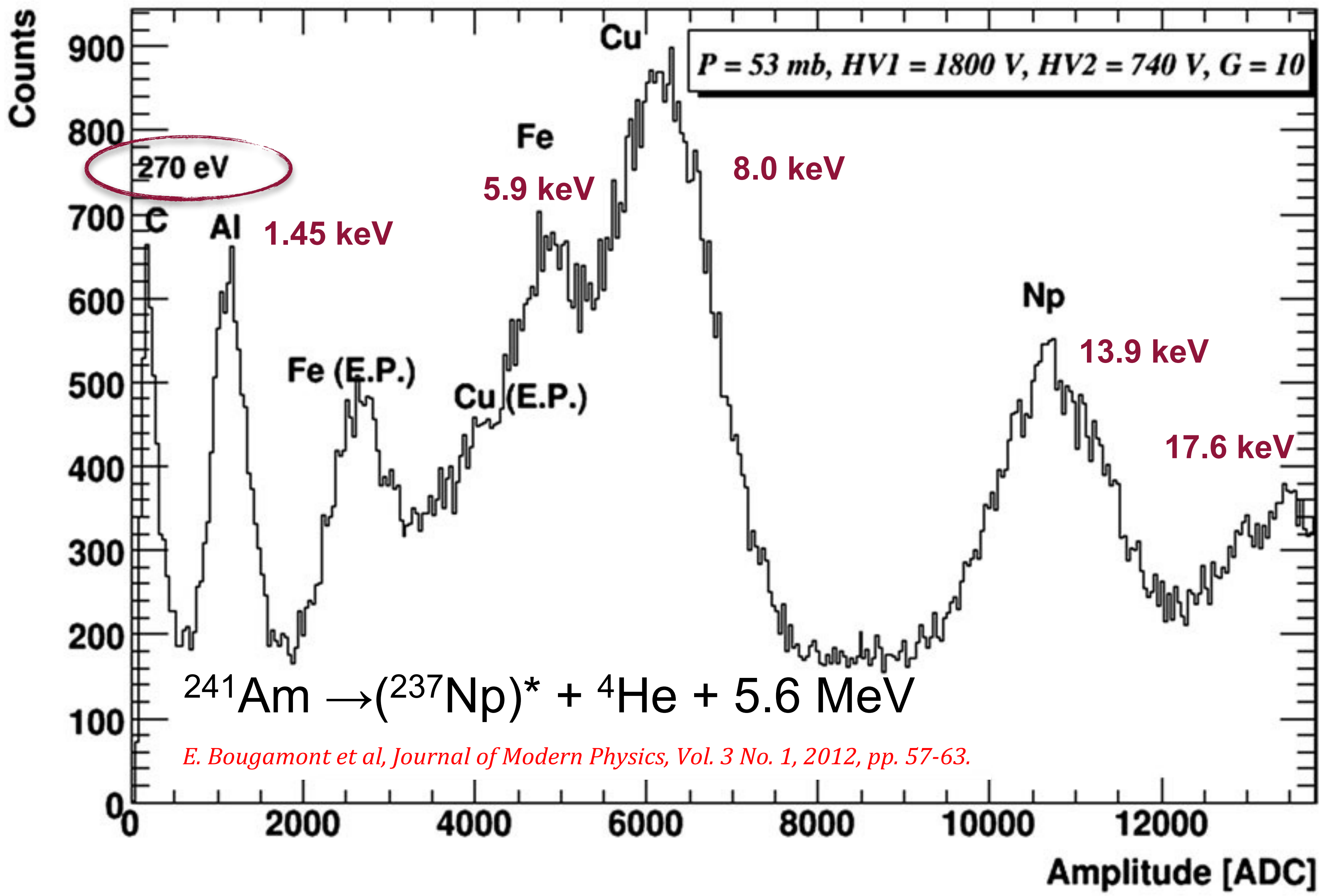
Spherical Proportional Counter

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

Large Size Detector
+
Robust construction

- Low Capacitance → Low electronic noise → Low energy threshold
- Lowest surface area 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



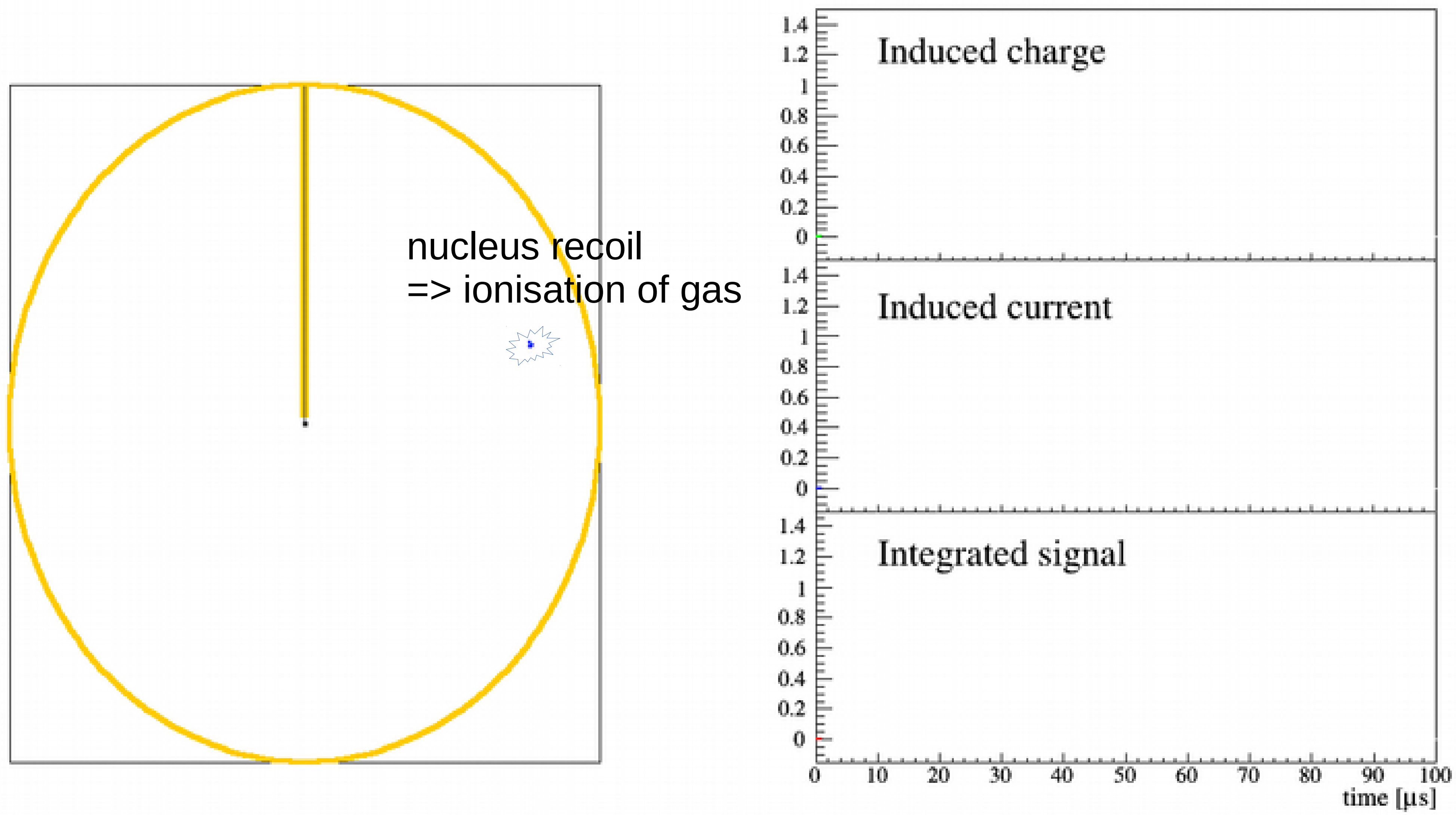
- Spherical Proportional Counter 130 cm diameter
  - Ar + 2% CH_4
- Single Electron detection
- Energy threshold < 50 eV
  - Tested with single electrons extracted from Copper with UV lamp

Spherical Proportional Counter

First Spherical Proportional Chamber made out of LEP RF Cavities

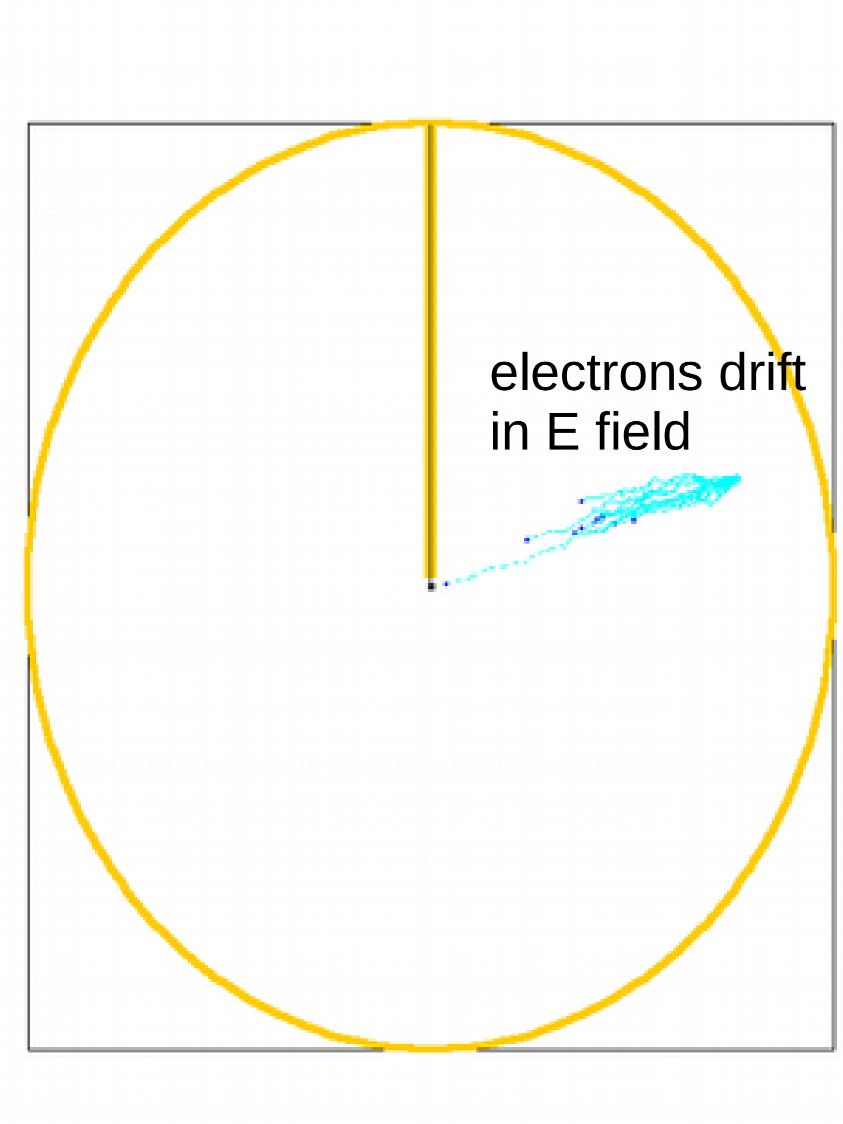
I. Giomataris and G. Charpak

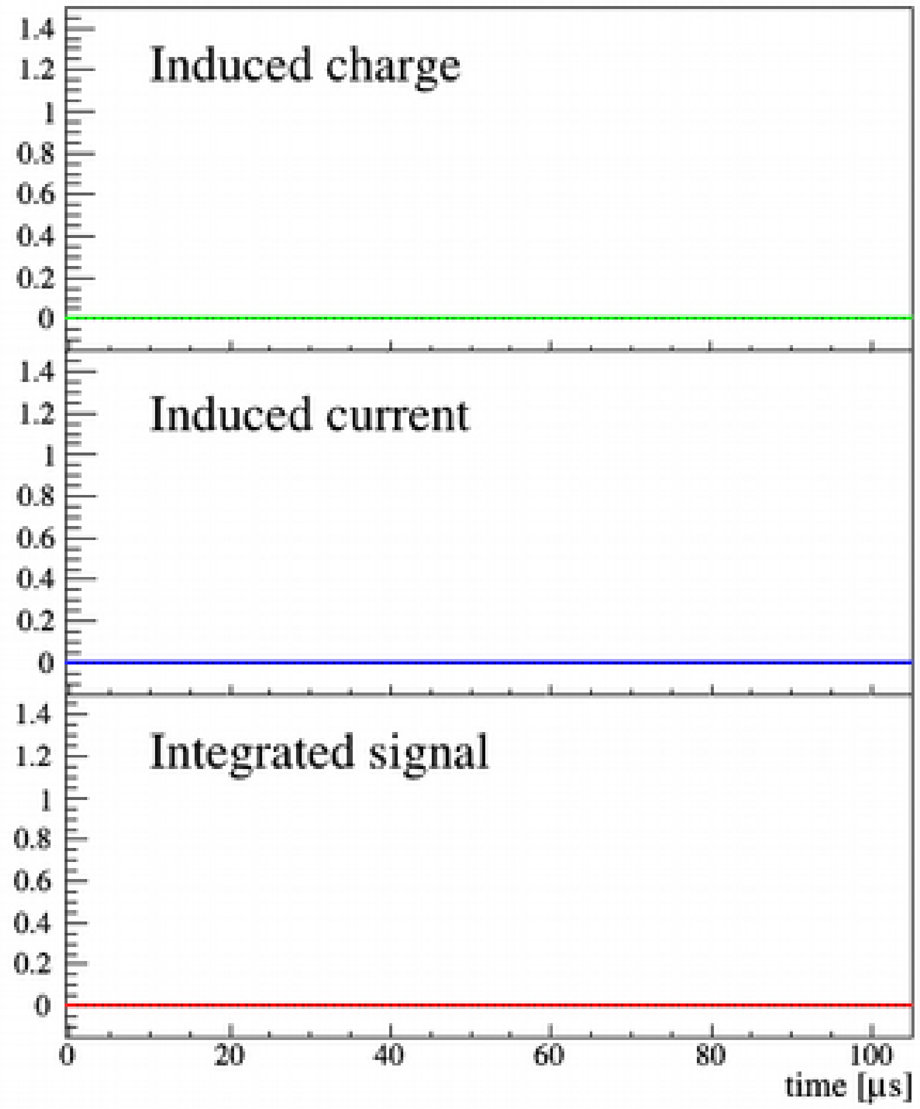
Signal Formation



Plot by P. Gros

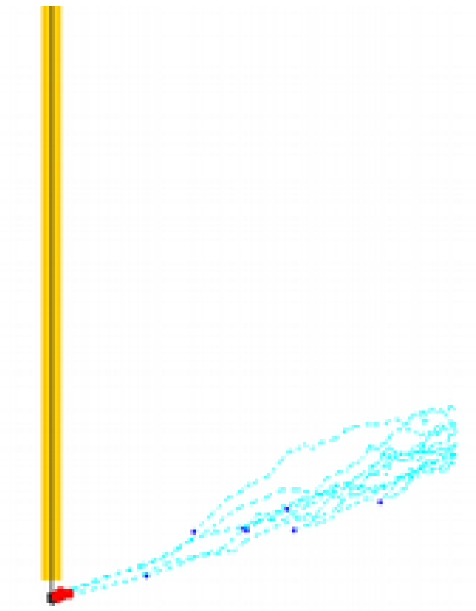
Signal Formation



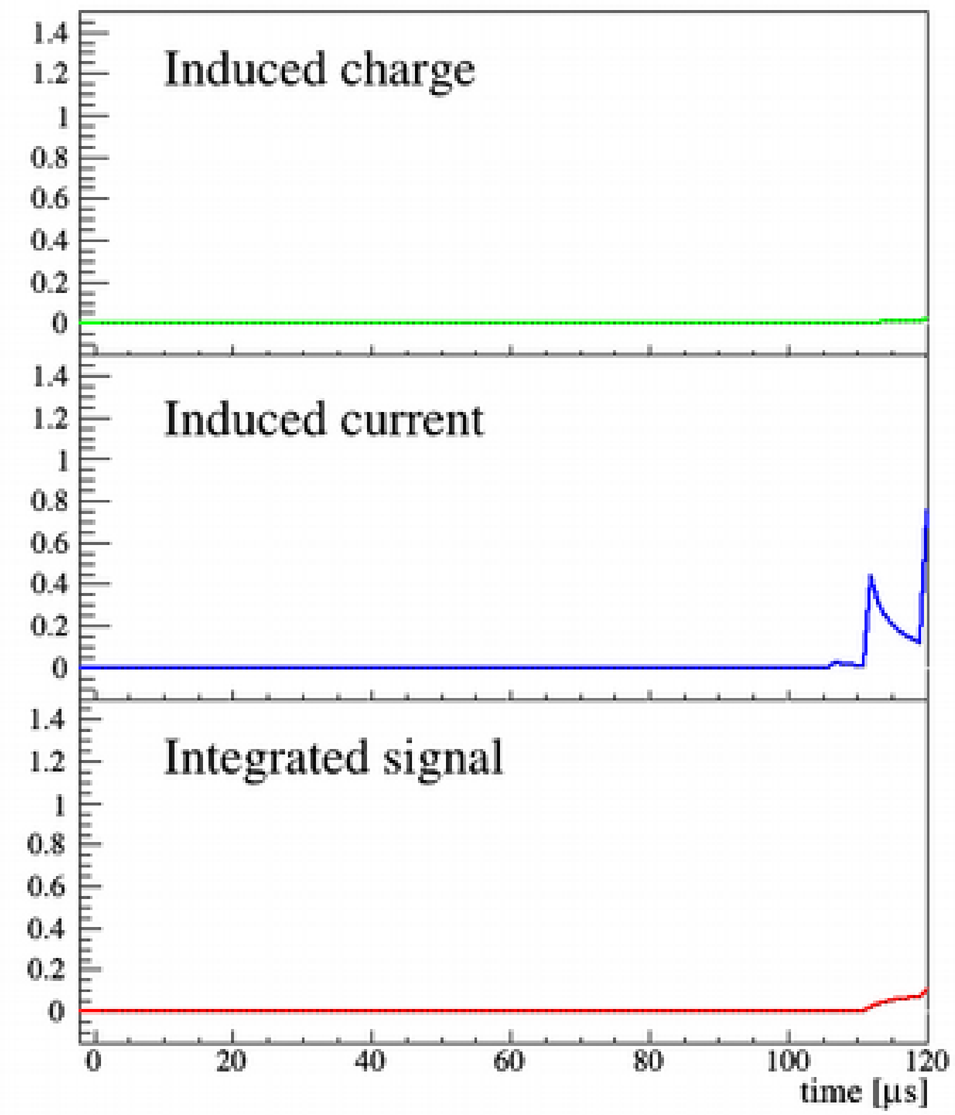


Plot by P. Gros

Signal Formation

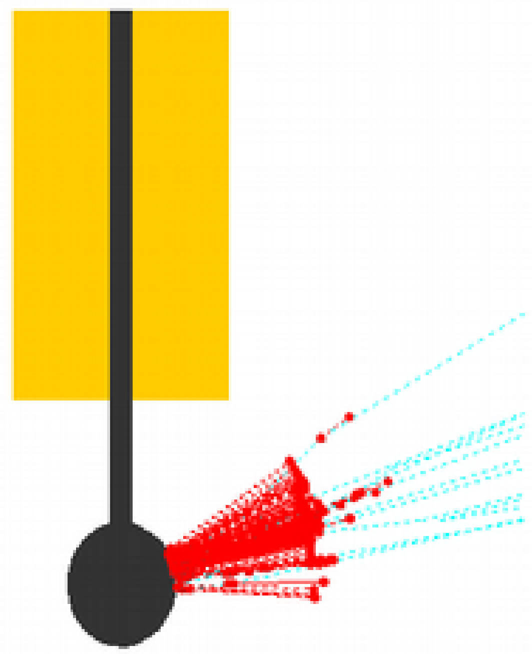


avalanche in high field near sensor

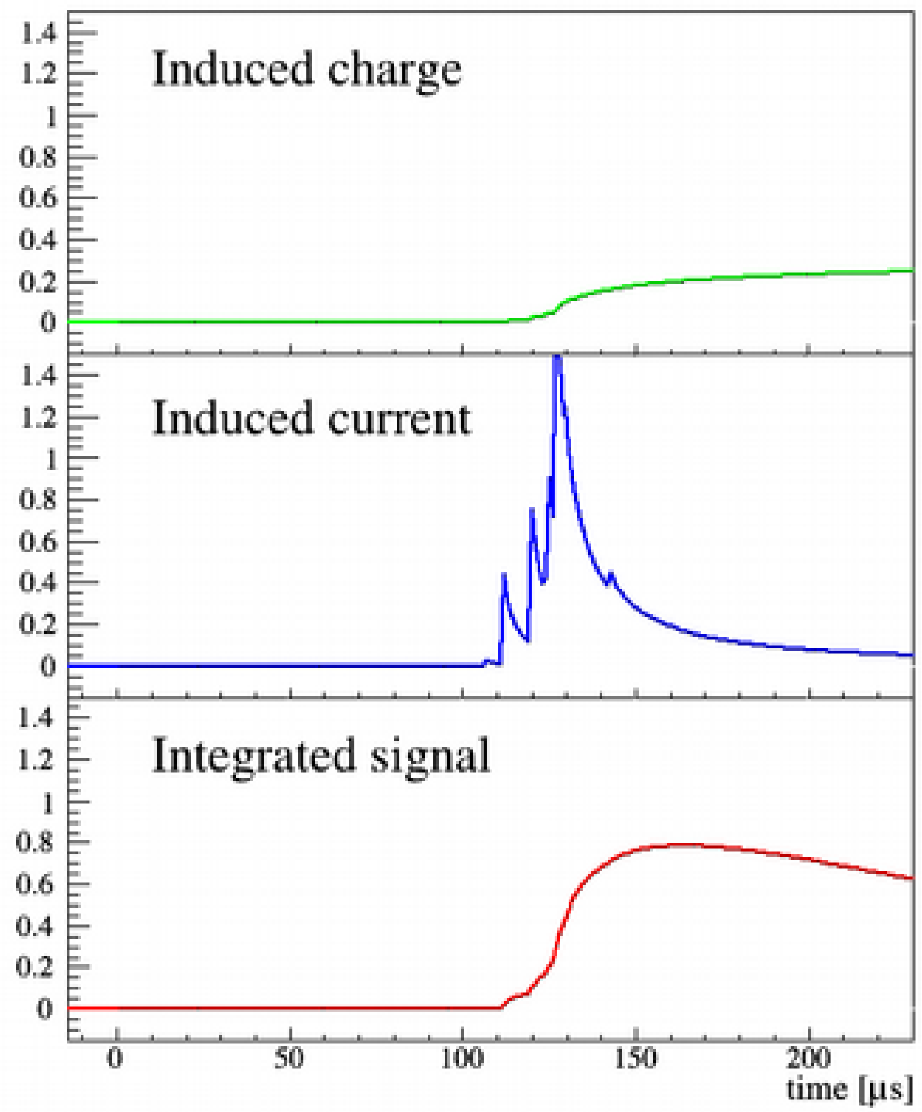


Plot by P. Gros

Signal Formation

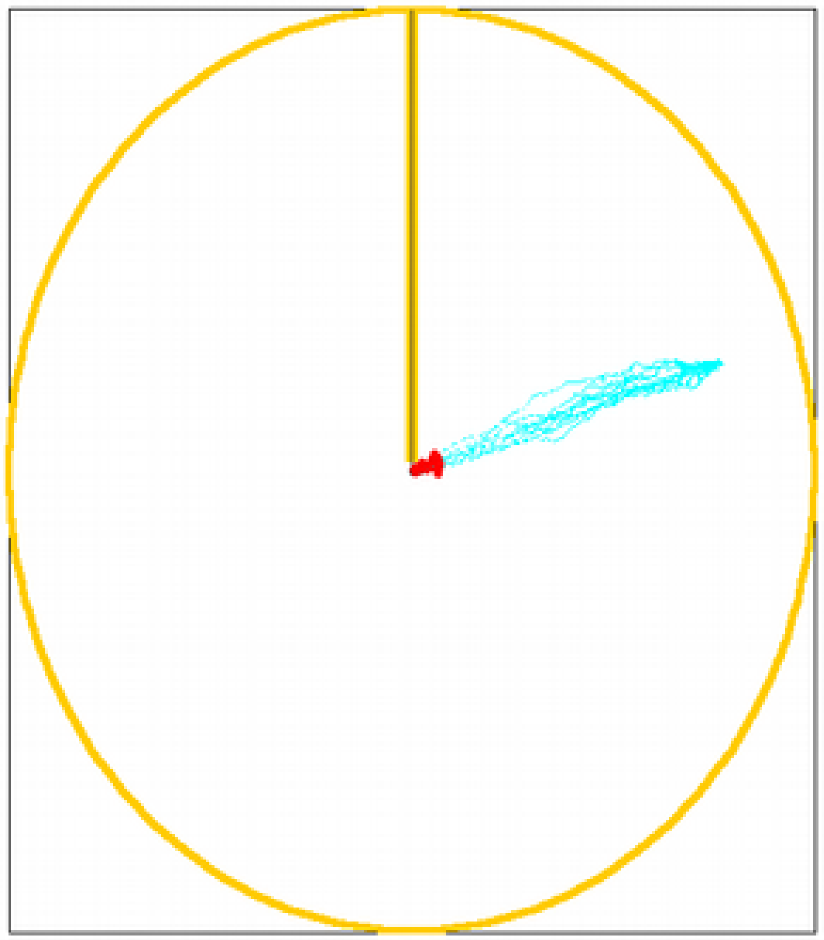


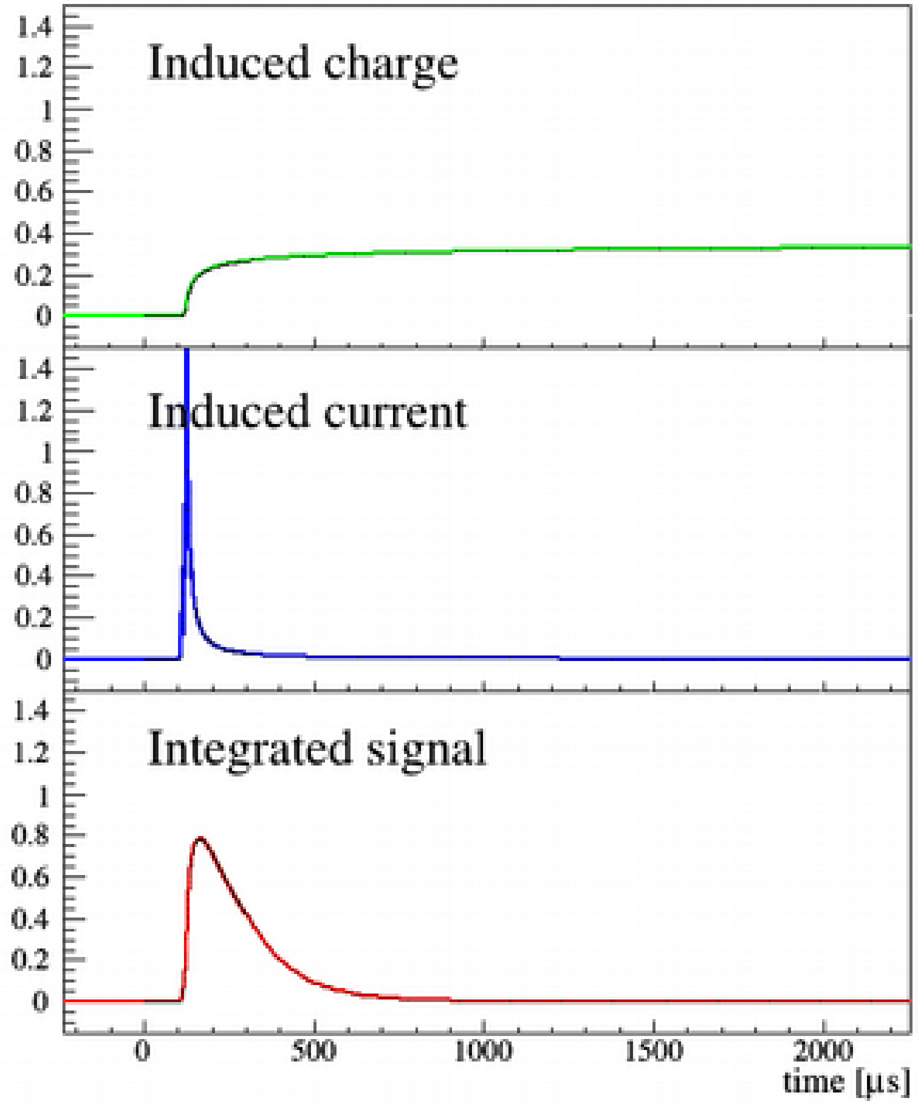
Signal induced by ions drifting back



Plot by P. Gros

Signal Formation

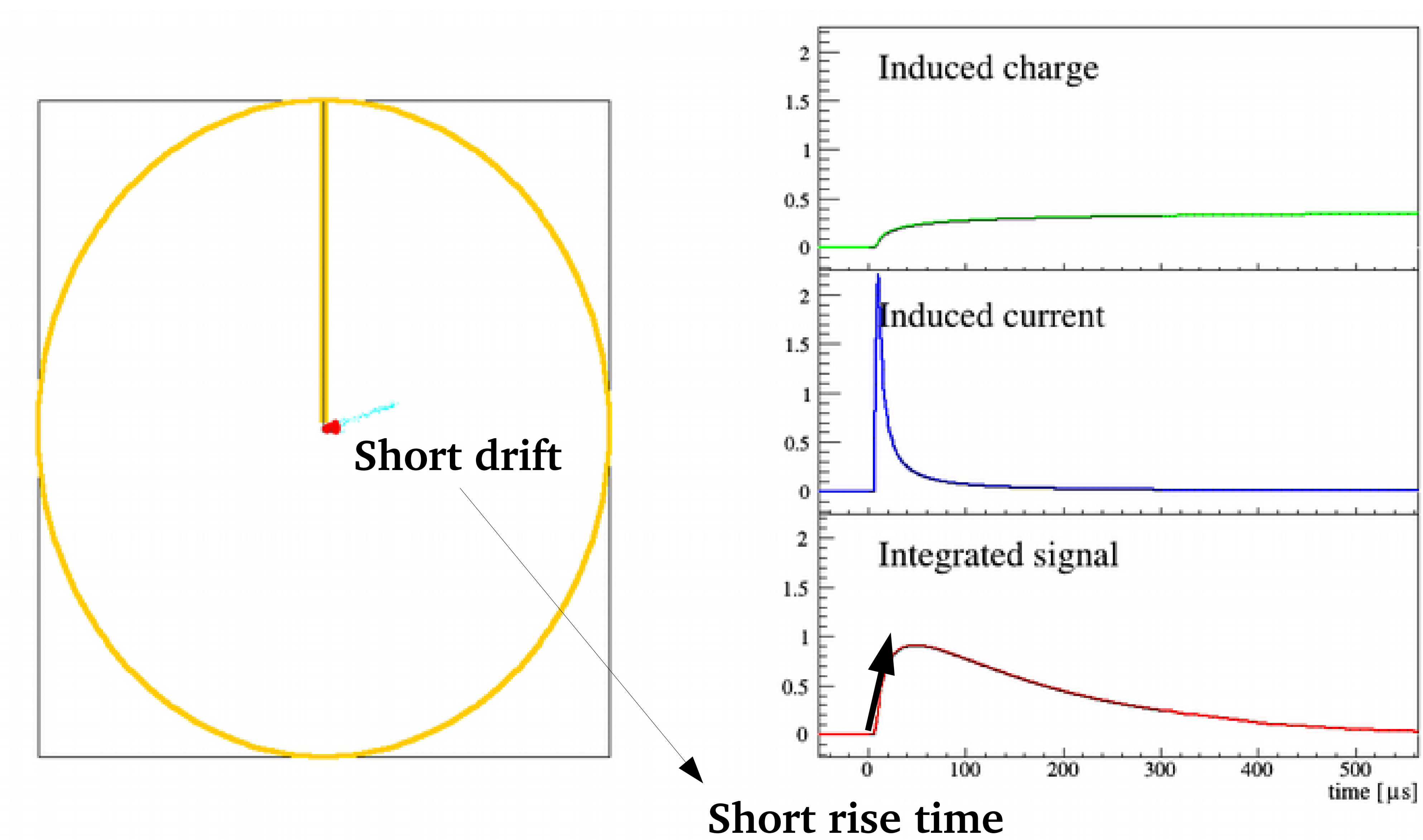




In reality:
Observed Pulse = Induced Current ⊗ Preamplifier Response
Need to deconvolve the preamplifier response

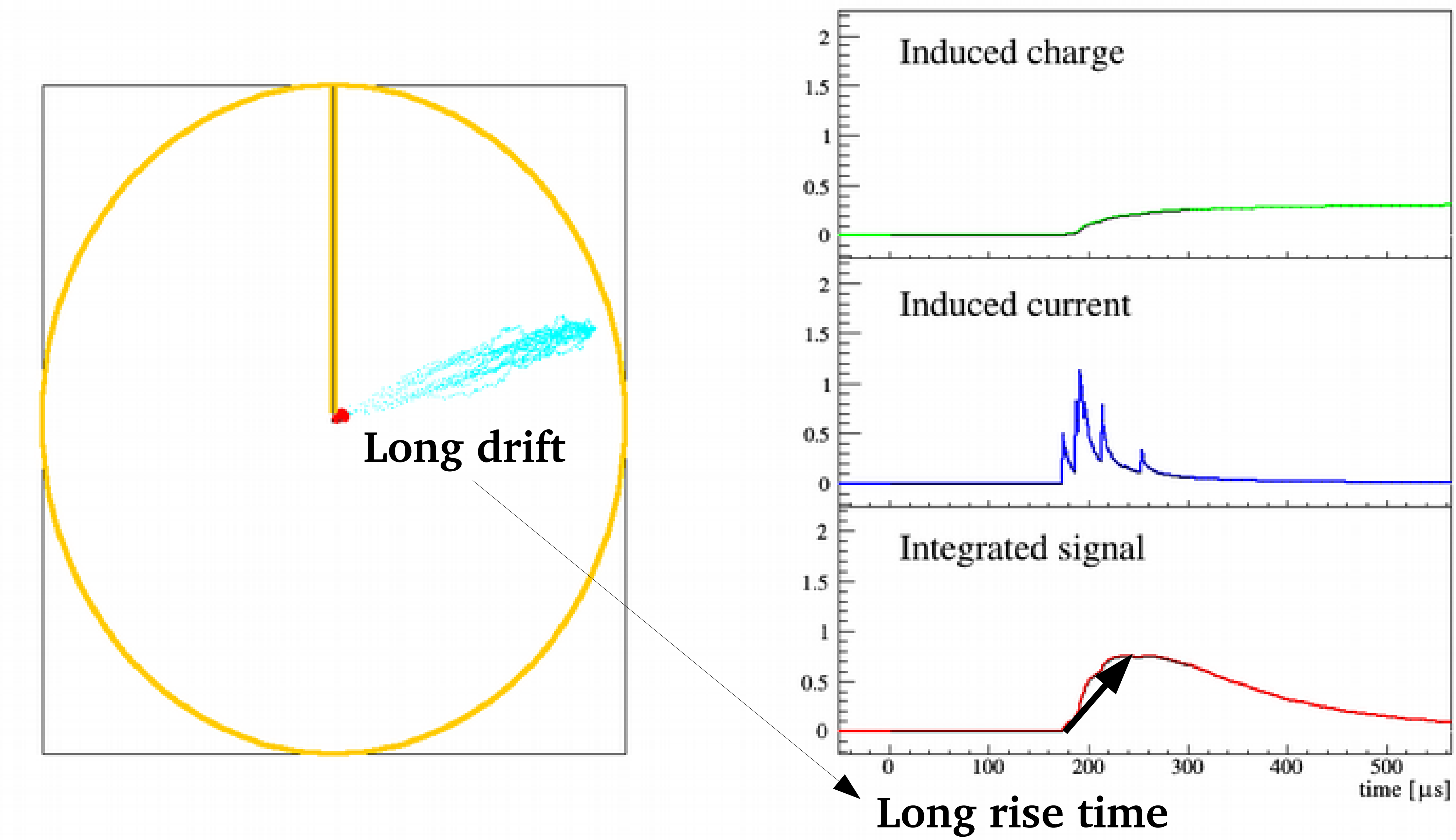
Plot by P. Gros

Background Rejection: Rise Time



Plot by P. Gros

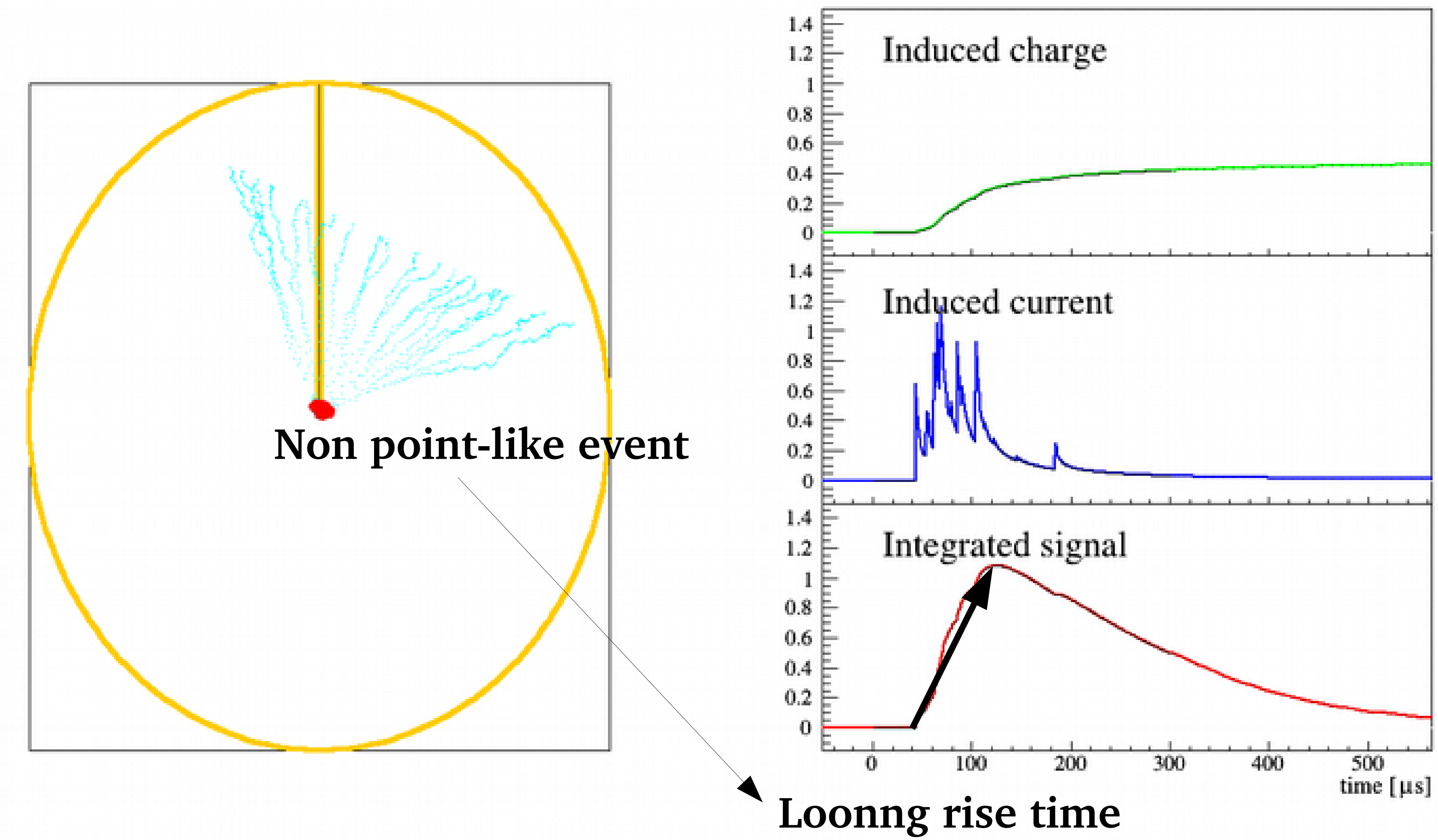
Background Rejection: Rise Time



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

Plot by P. Gros

Background Rejection: Rise Time

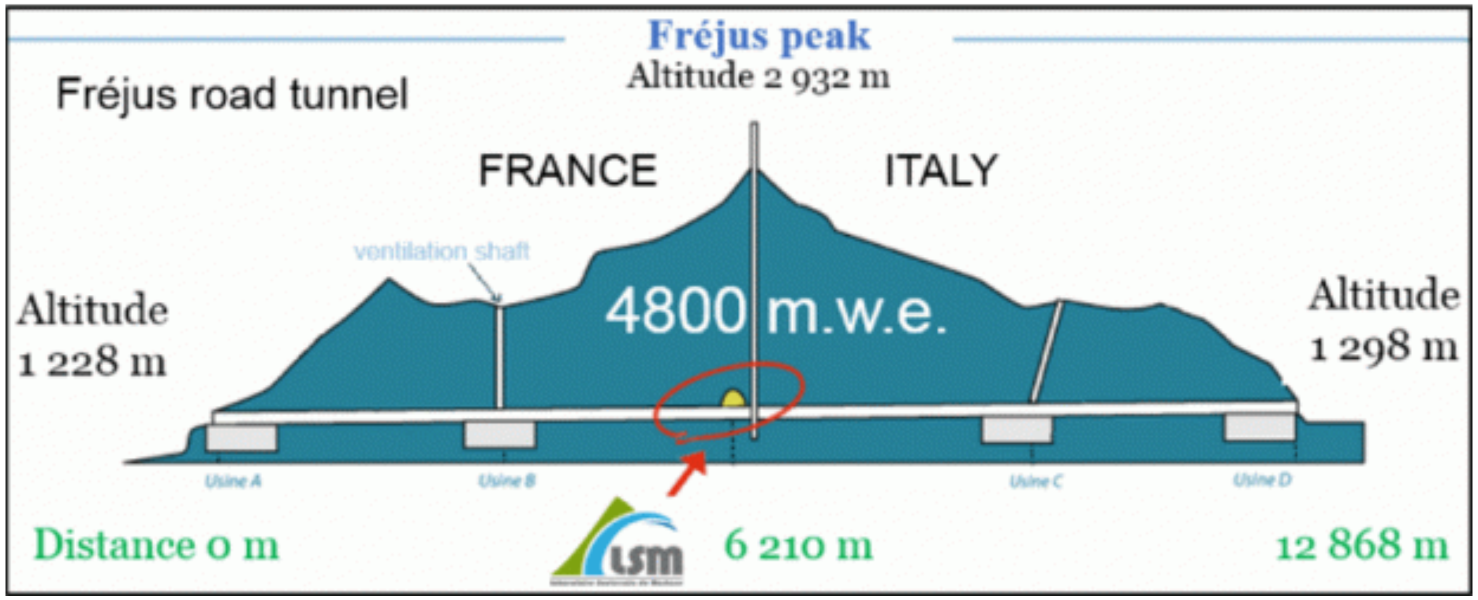


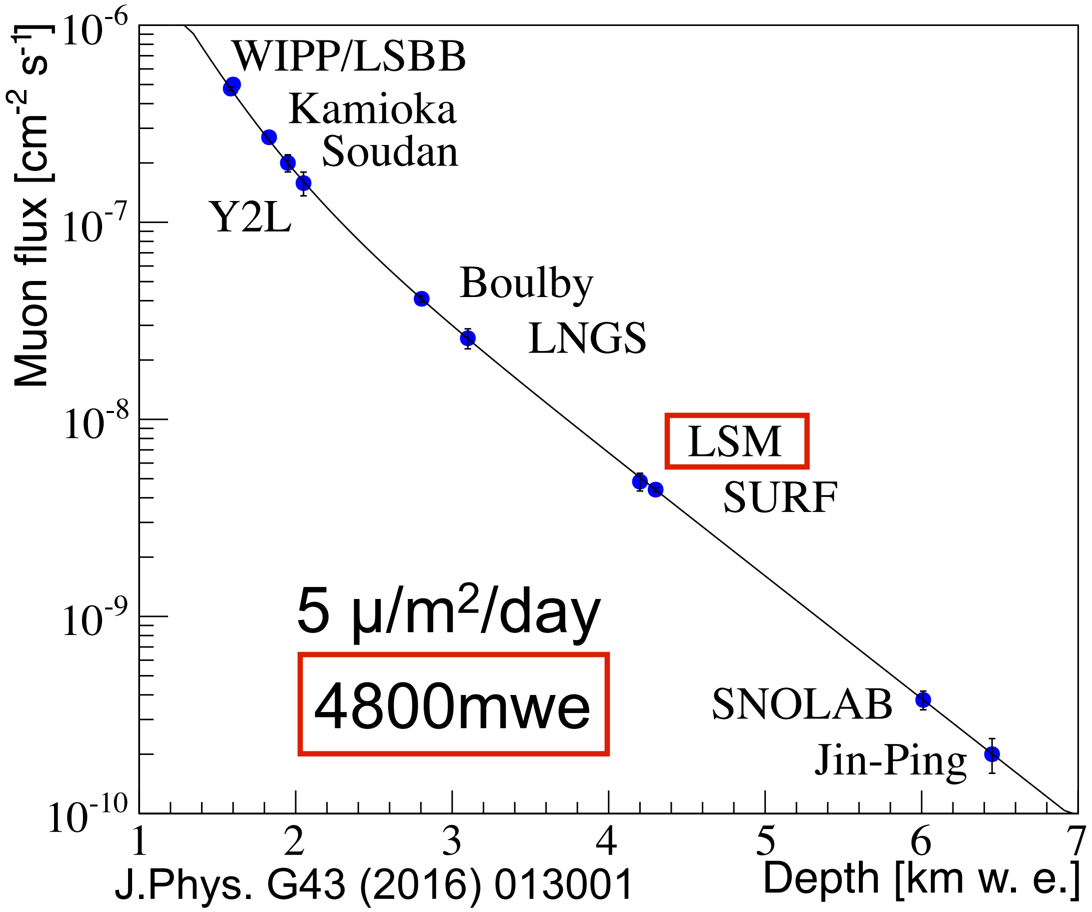
Plot by P. Gros

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





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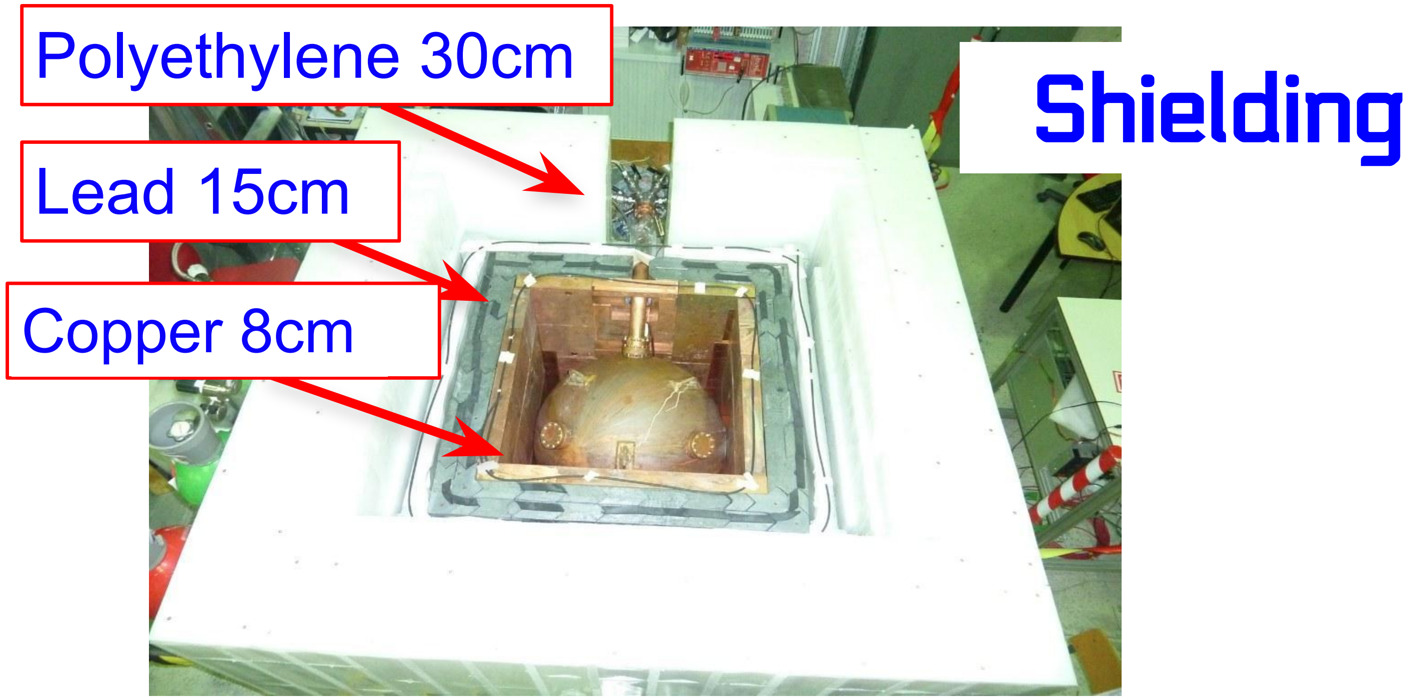
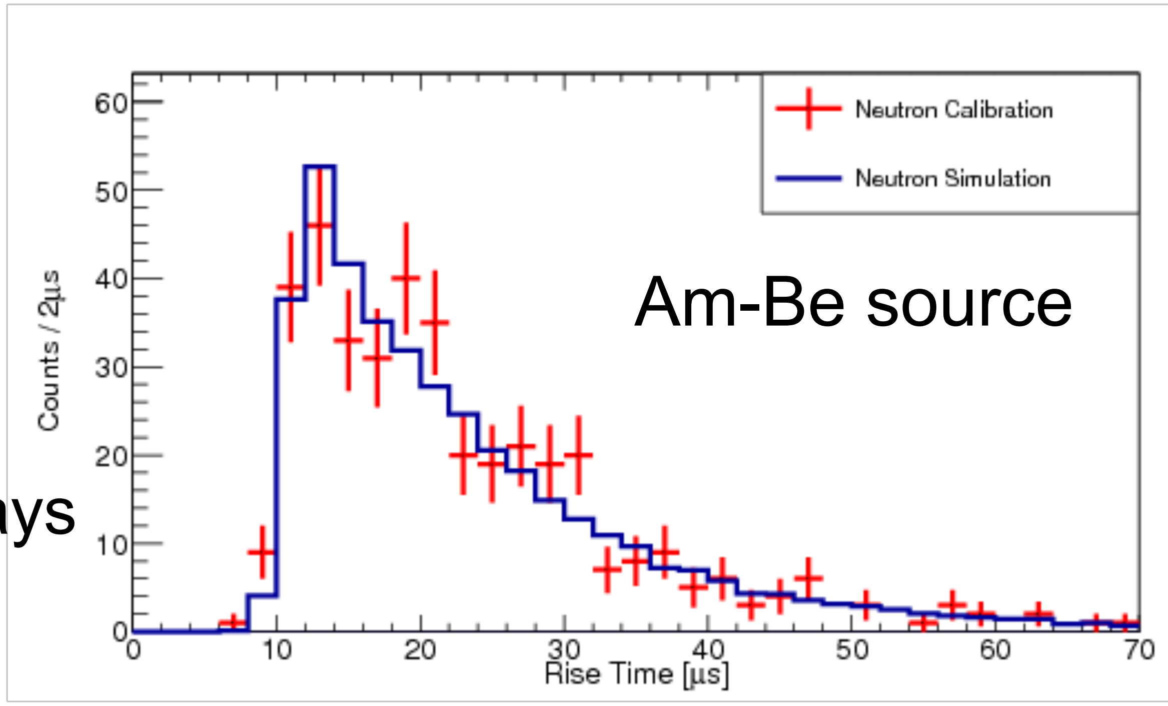
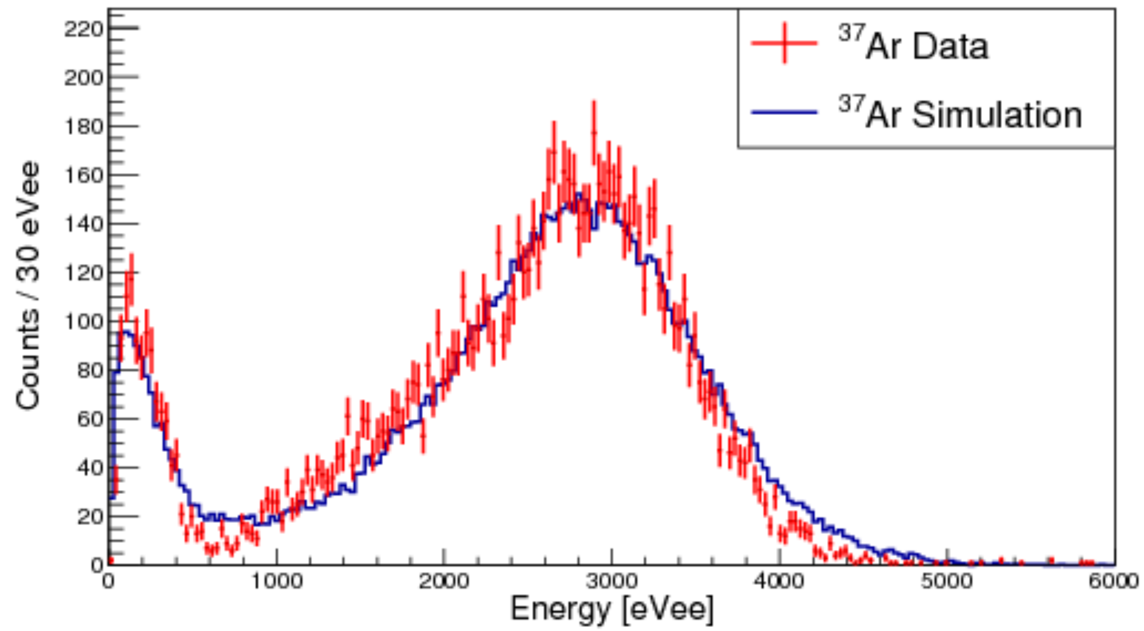
SEDINE sensor



SEDINE: Data taking conditions

- **Target:** Neon + 0.7% CH_4 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:** ^{37}Ar gaseous source,8 keV Cu fluorescence line, AmBe neutron source





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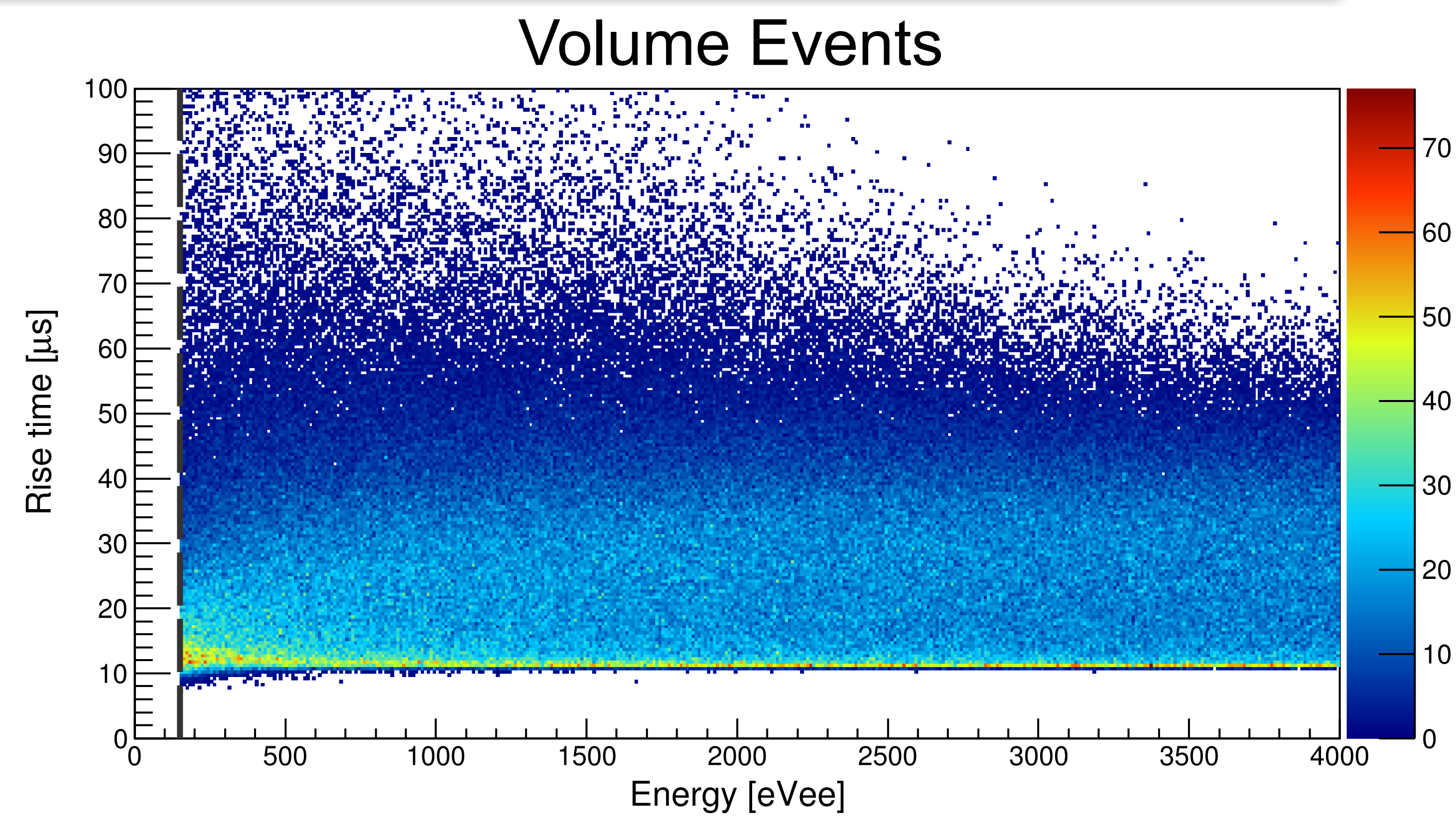
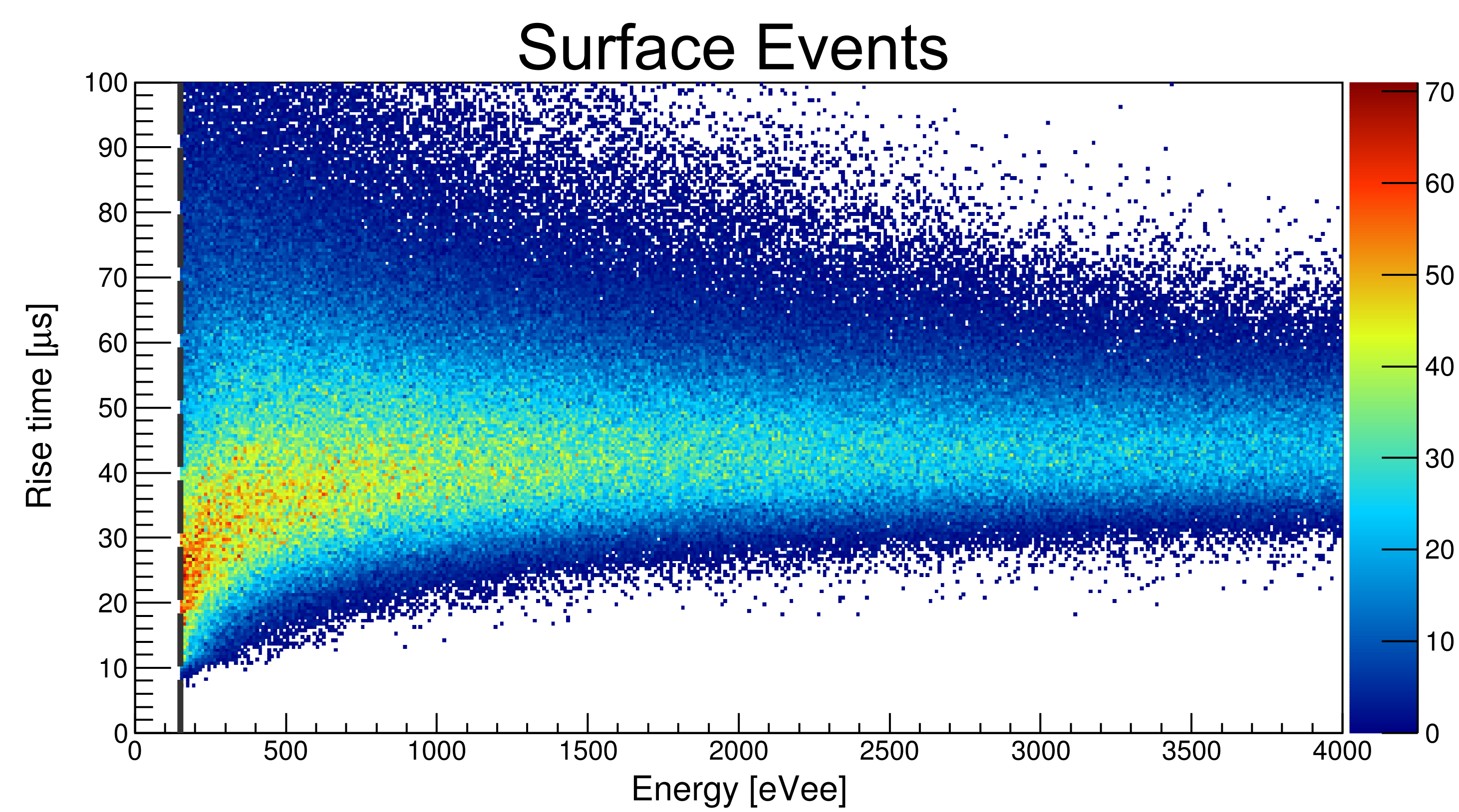
SEDINE: Background simulation

- 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)
    - >200eV: 180 mHz → ~2mHz
    - <200eV: 400 mHz → ~20mHz
- Pulse simulations include:
  - Electric field (FEM)
  - Diffusion (Magboltz)
  - Avalanche process
  - Signal induction
  - Preamplifier response





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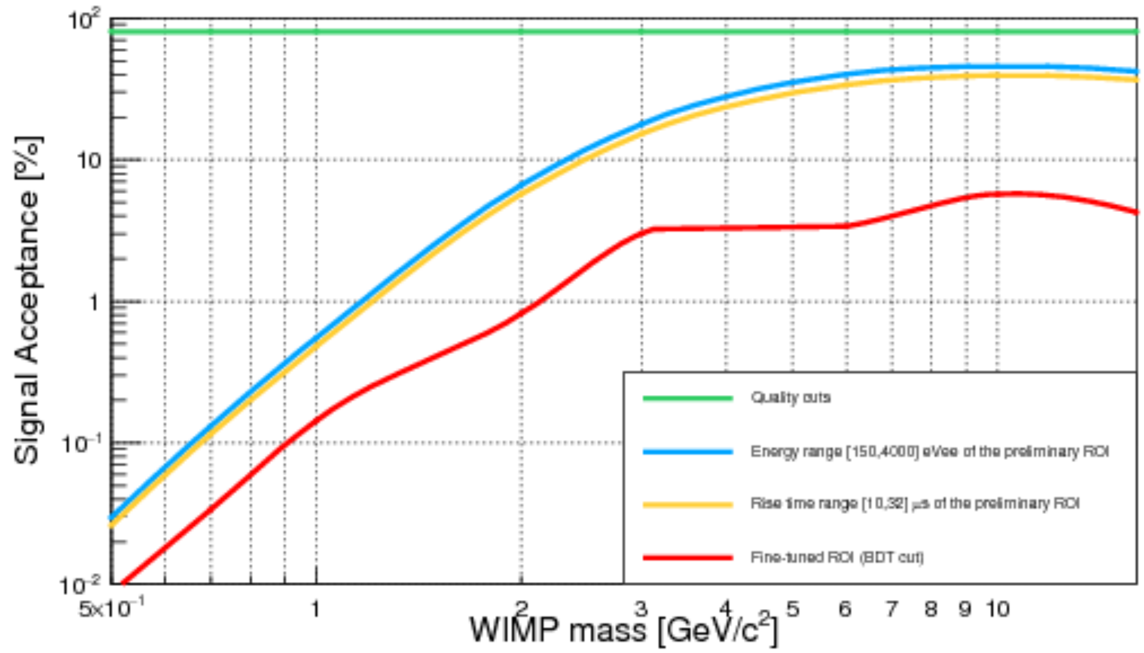
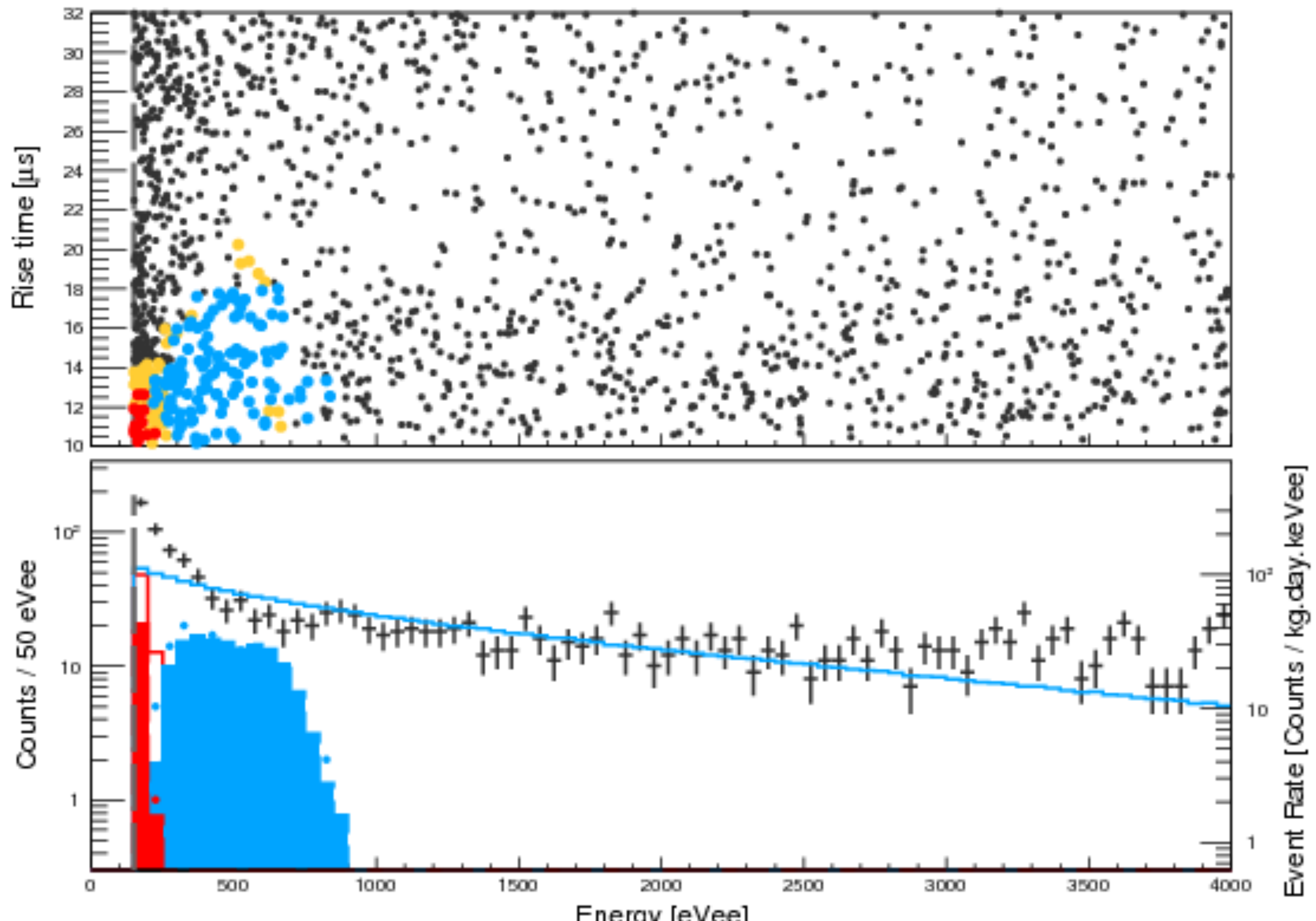
SEDINE: Event Selection

- 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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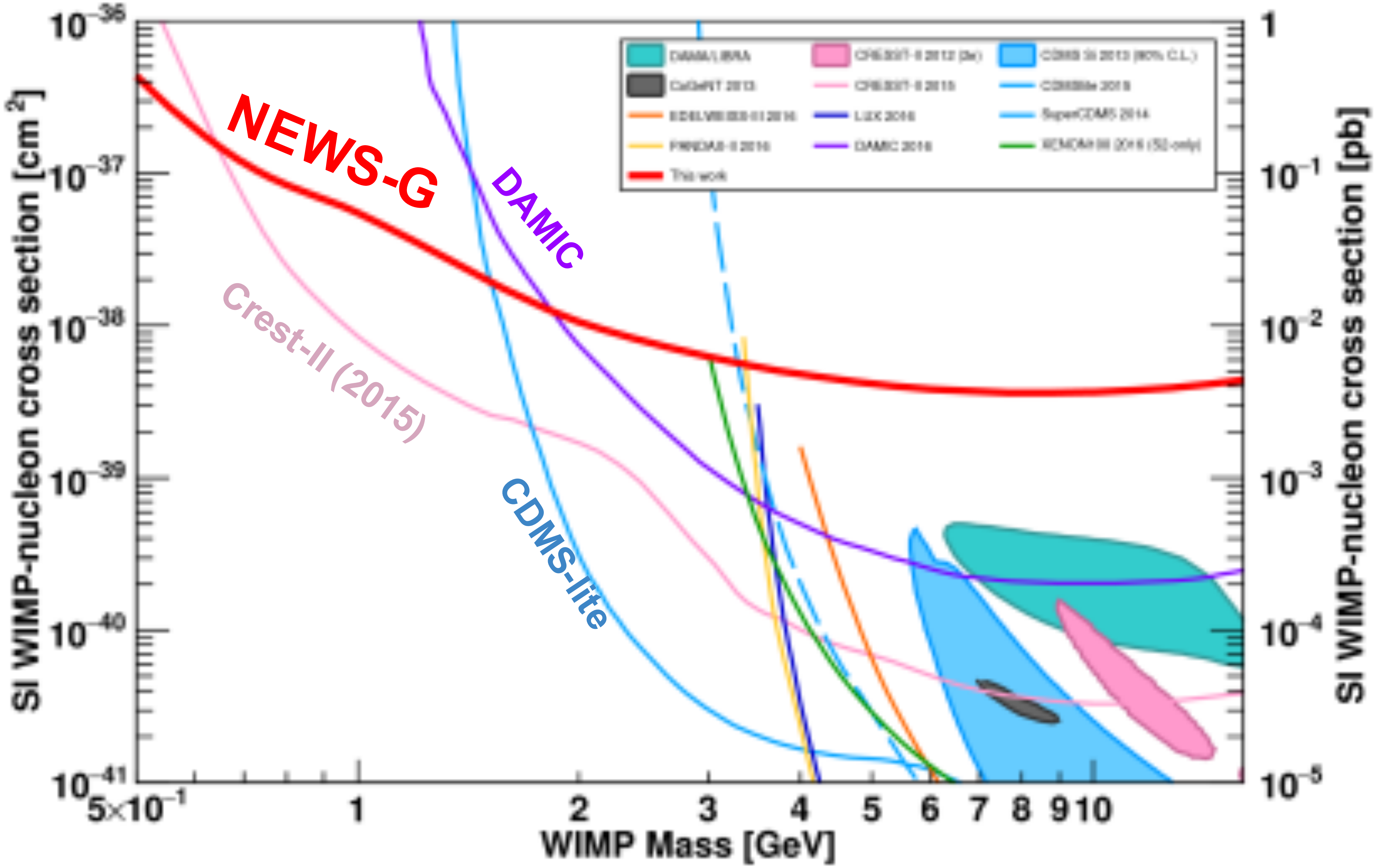


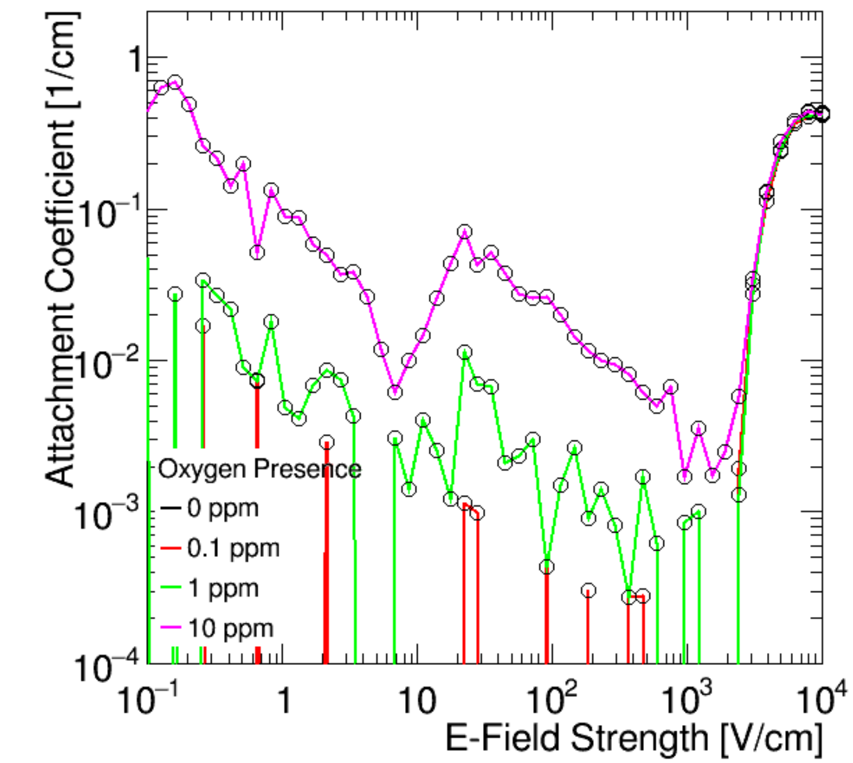
Exclusion at 90% confidence level of cross-sections above 4.4x10^{-37} cm^2 @ mass 0.5 GeV

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

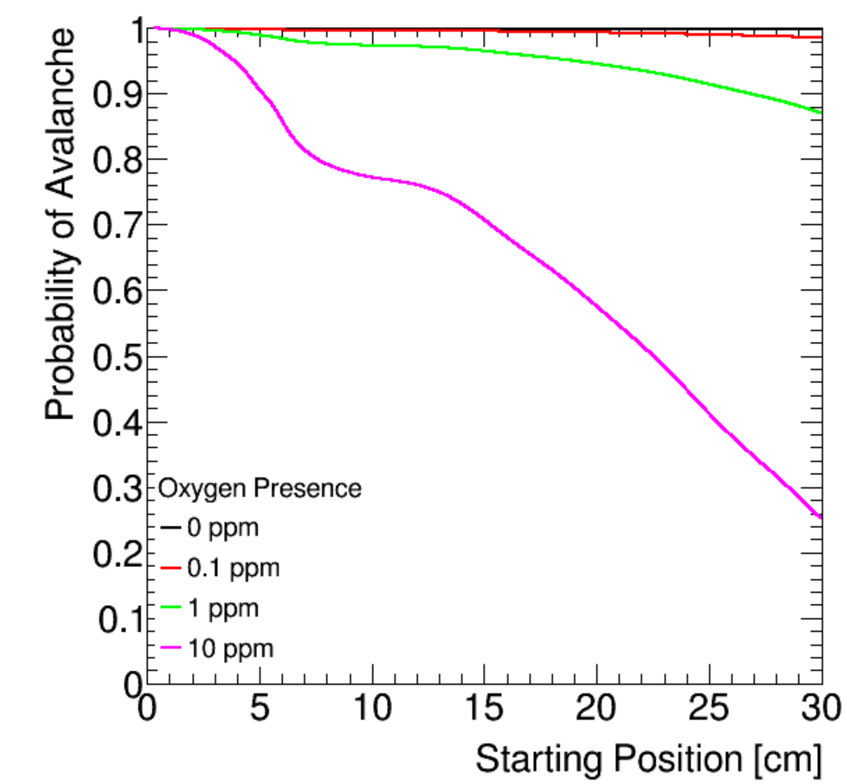
NEWS-G current status & developments

Preparing for the next physics runs

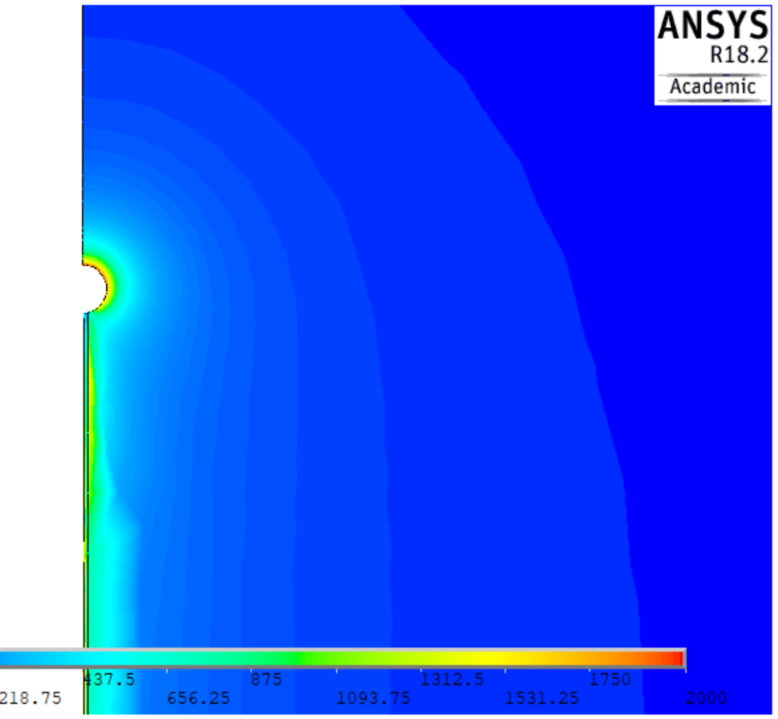
- **Gas quality**
  - Testing gas mixtures of He/CH_4
    - High pressure operation (Penning)
    - Hydrogen rich target
  - Upgrading gas system
    - Tightness
    - Filtering
    - Gas recirculation
    - Monitoring with residual gas analyser
- **Quenching factor measurements**
  - Ion / electron 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



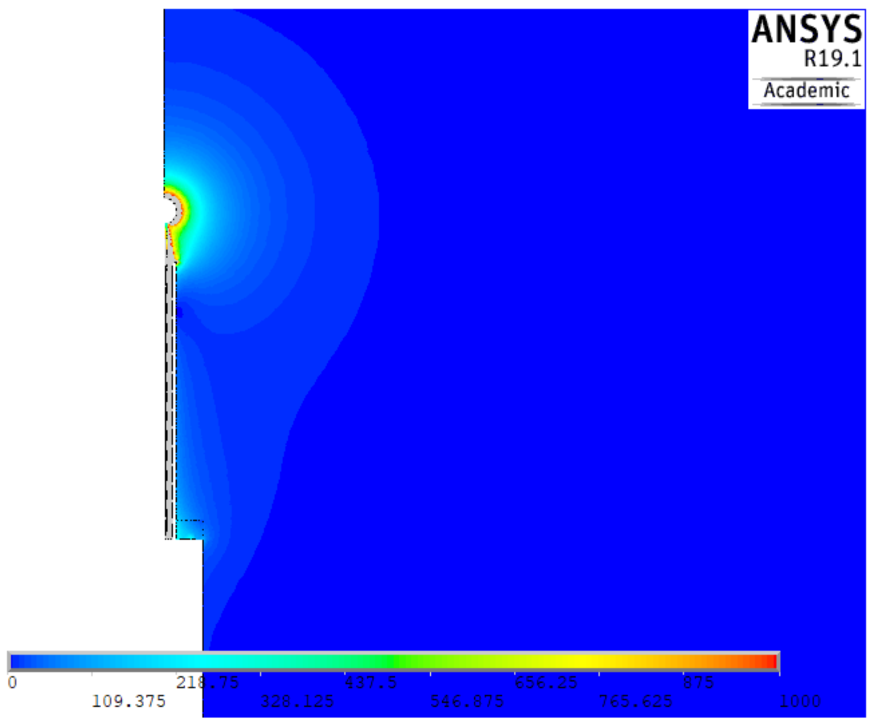
He 90%/CH_4 10% at 1 bar

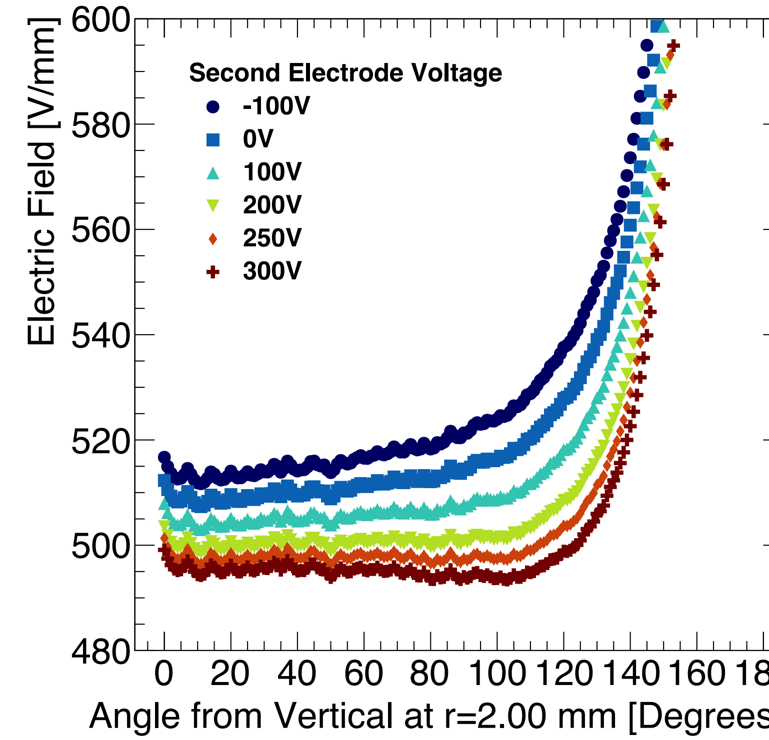


Single-anode Sensors

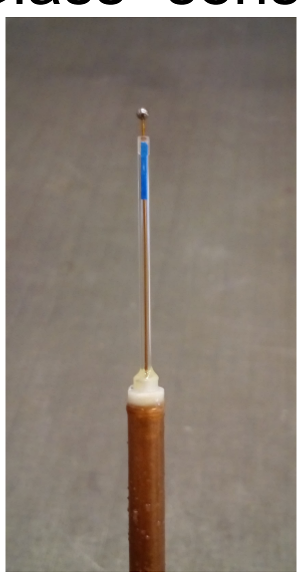


- Aims:
  - High pressure operation
  - Higher gain
  - Larger volumes
  - Increased Stability
  - Low radioactivity
- Techniques
  - Resistive technologies
  - 3D printing technologies
  - FEM simulations

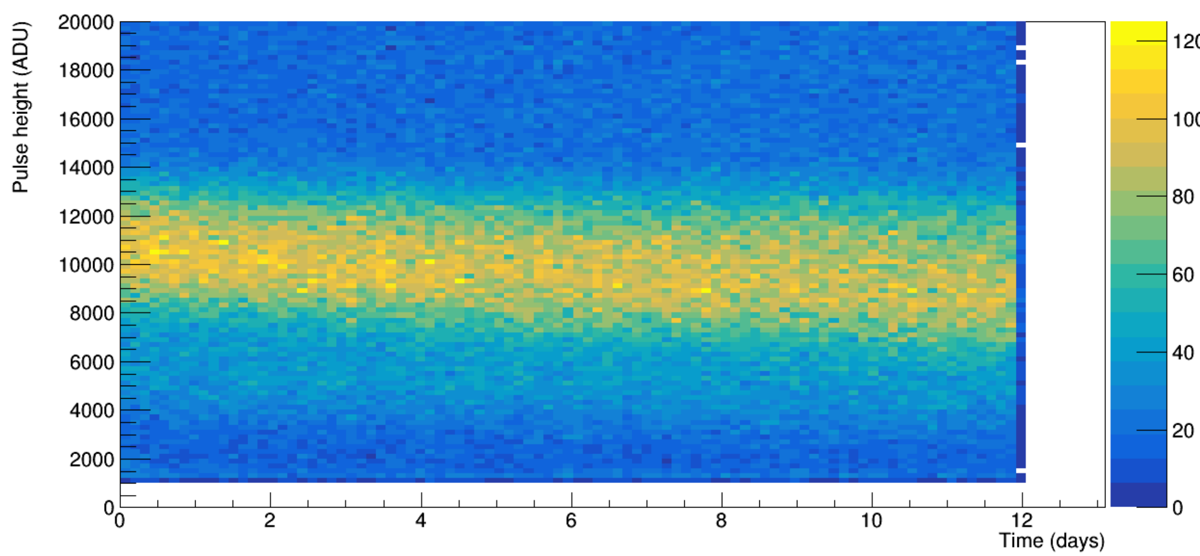




"Glass" sensor



arXiv:1809.03270



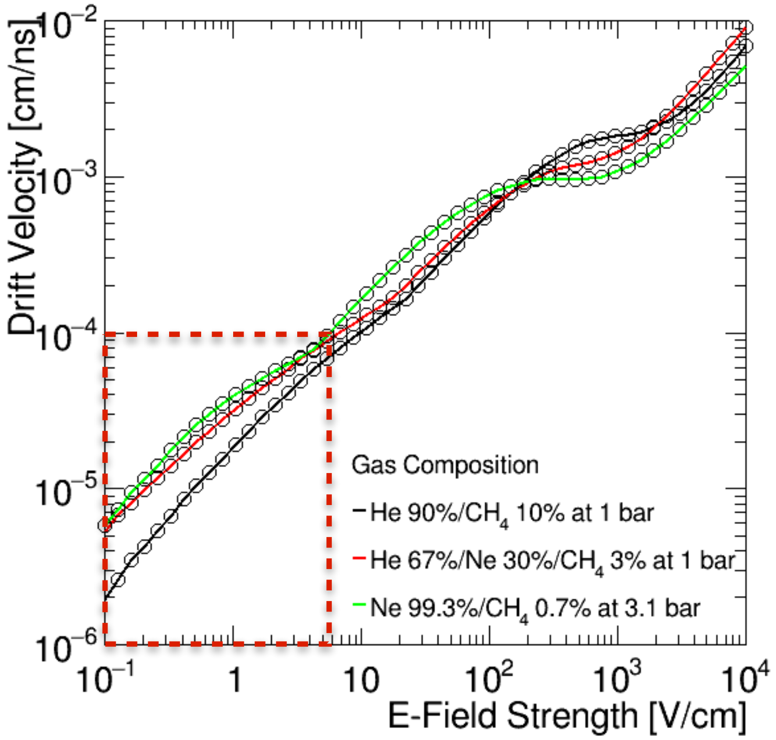
- Operation @2bar
  - He:Ar:CH_4 (87%:10%:3%)
  - Anode at 2350V
  - Correction Electrode 0V

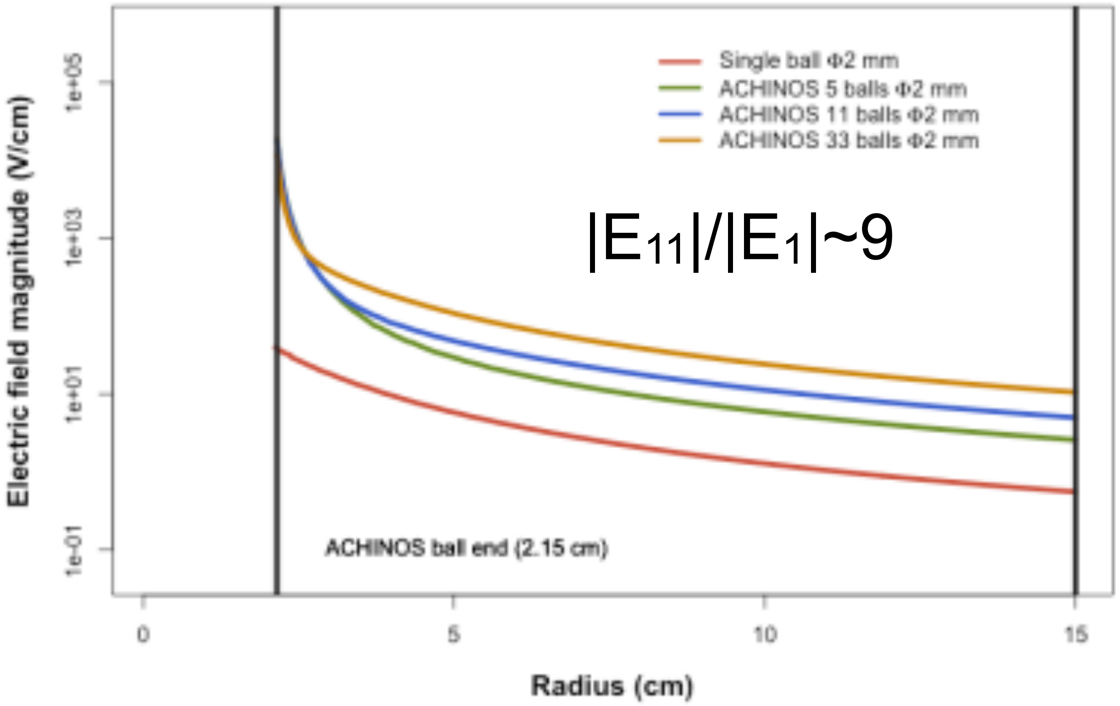
Multi-anode sensors: Achinos

11-ball 3D printed

33-ball bakelite

- Achinos: Multiple anode balls place 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

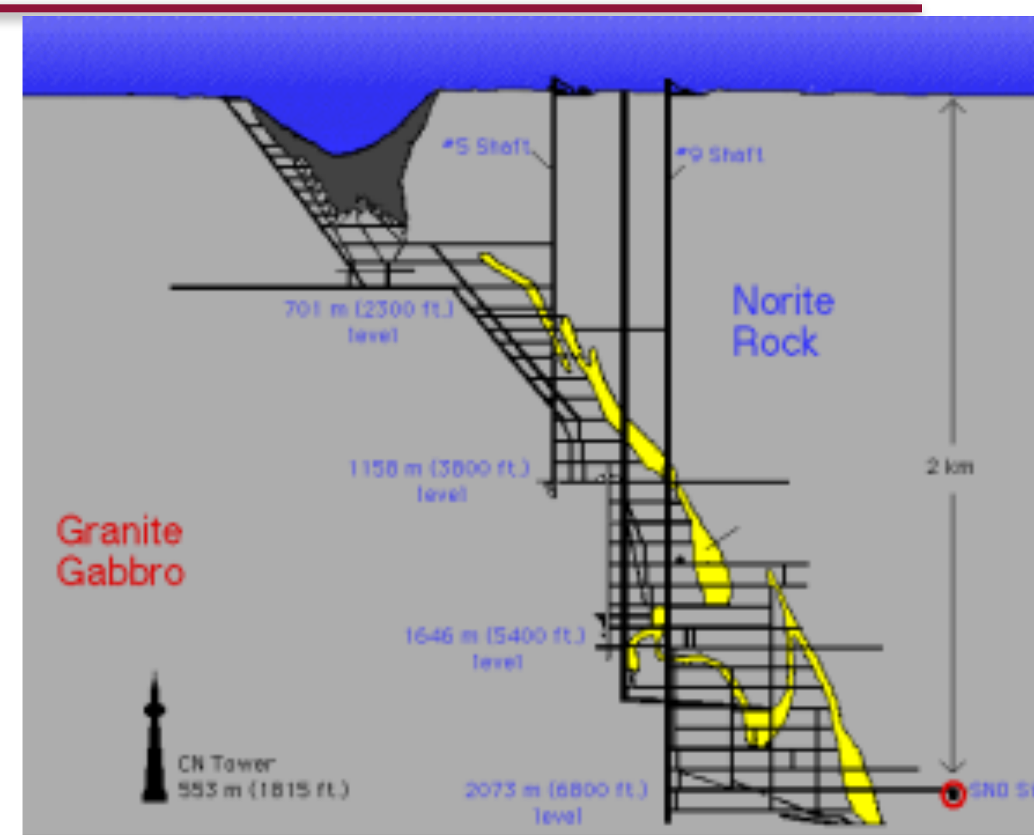


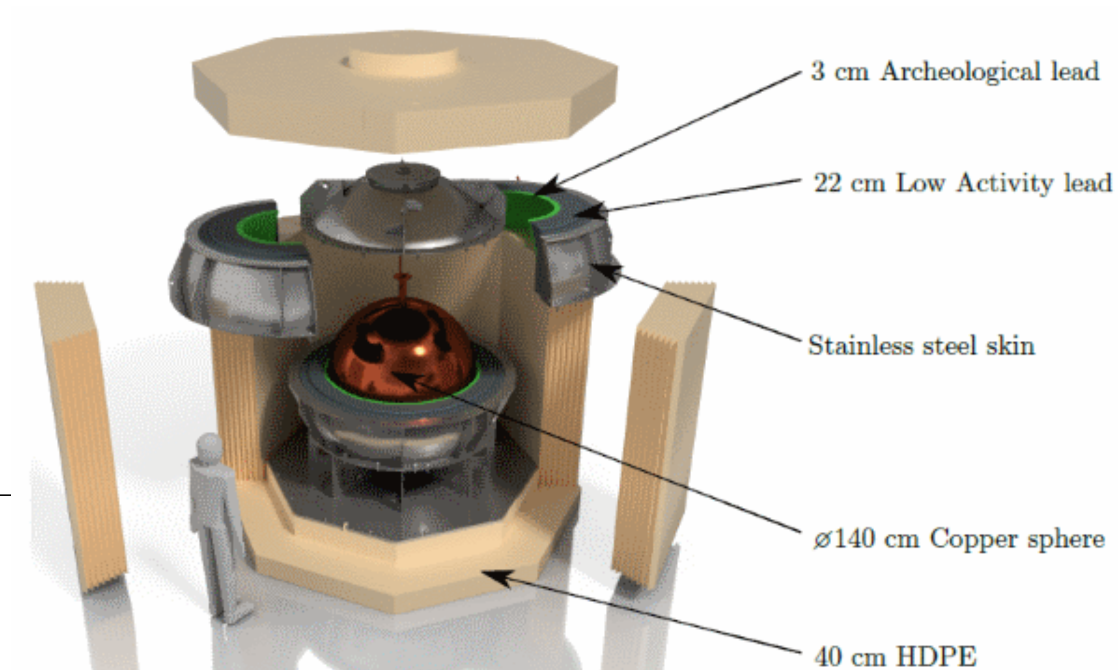


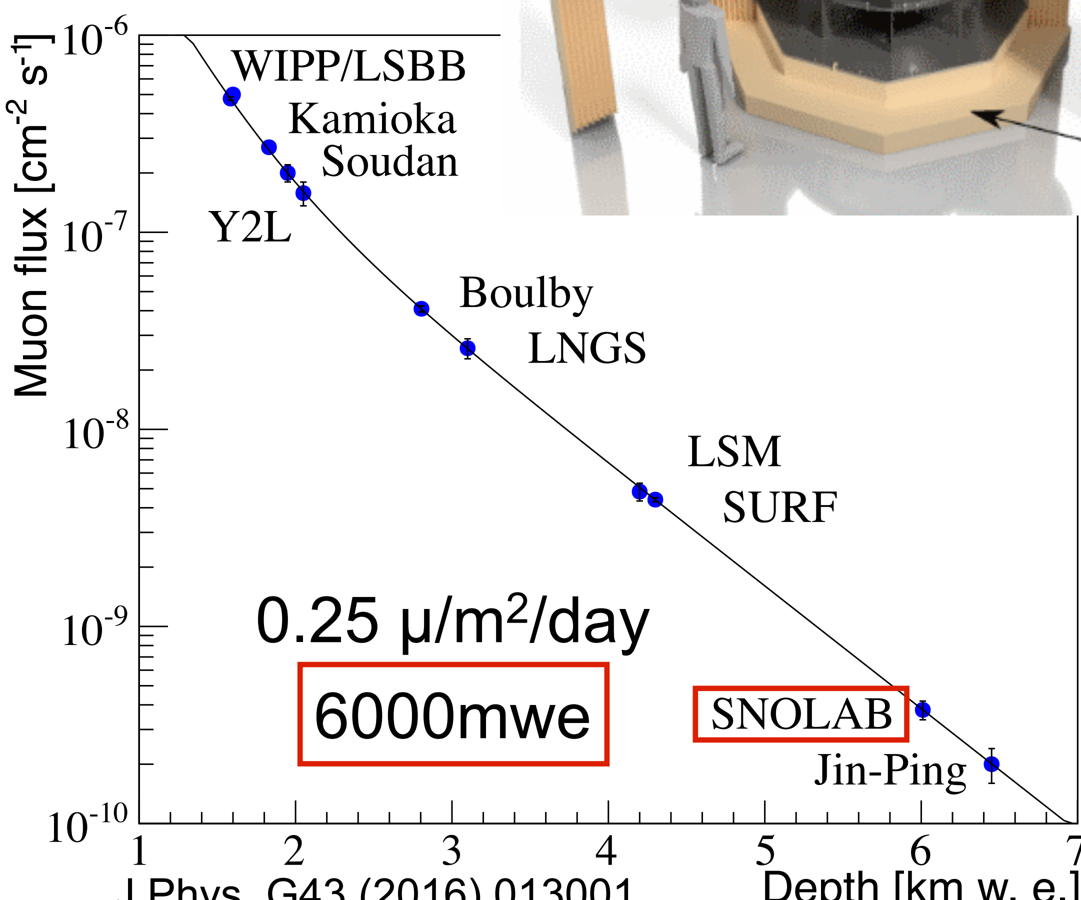
JINST 12 (2017) P12031

NEWS-G at SNOLAB

- Underground laboratory in Sudbury, Canada
  - NEWS-G to be installed in Cube Hall







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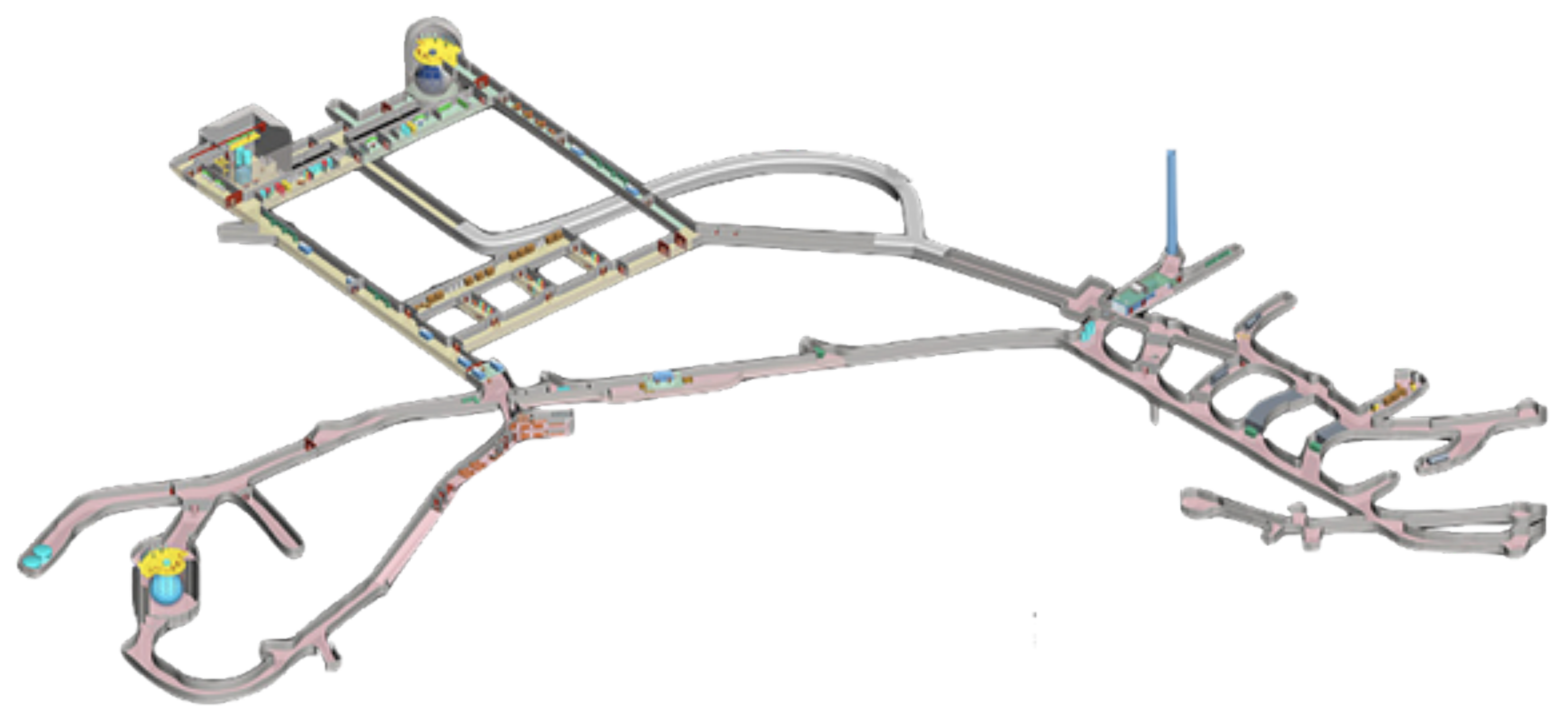
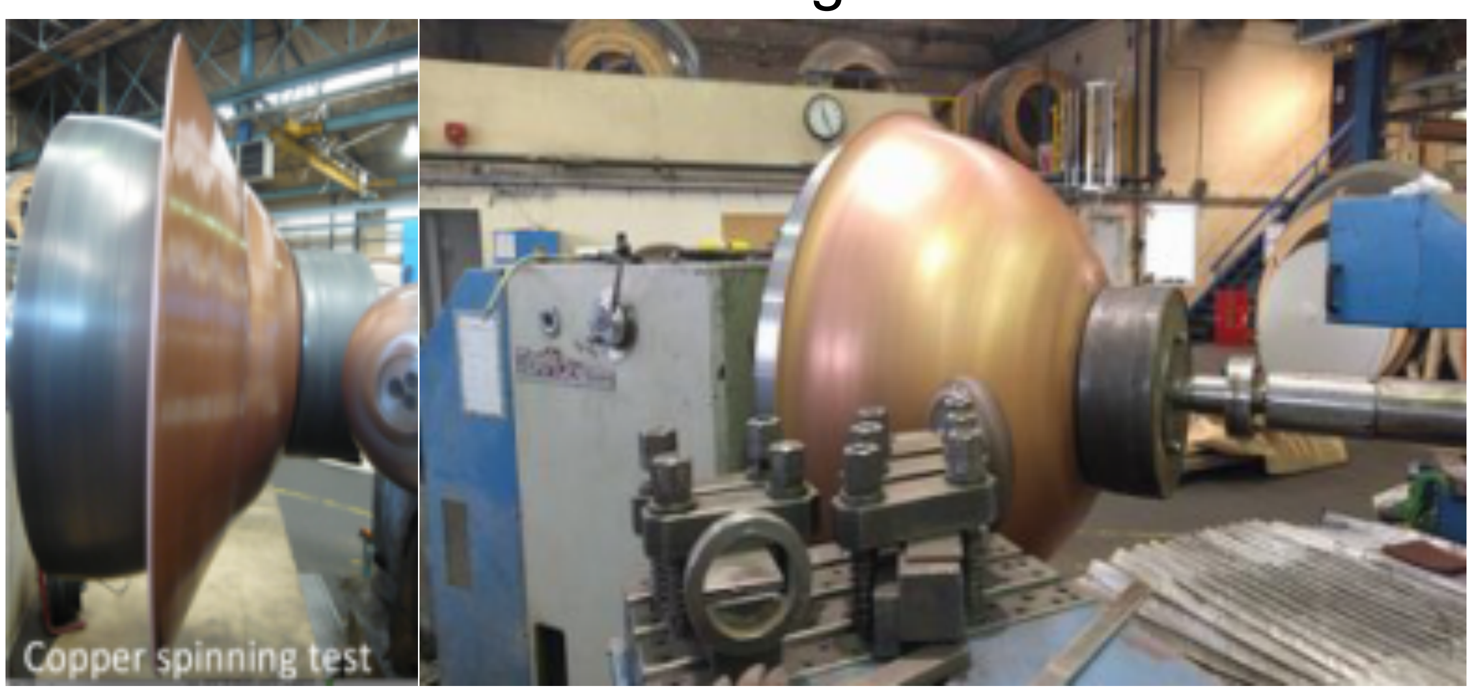


NEWS-G at SNOLab

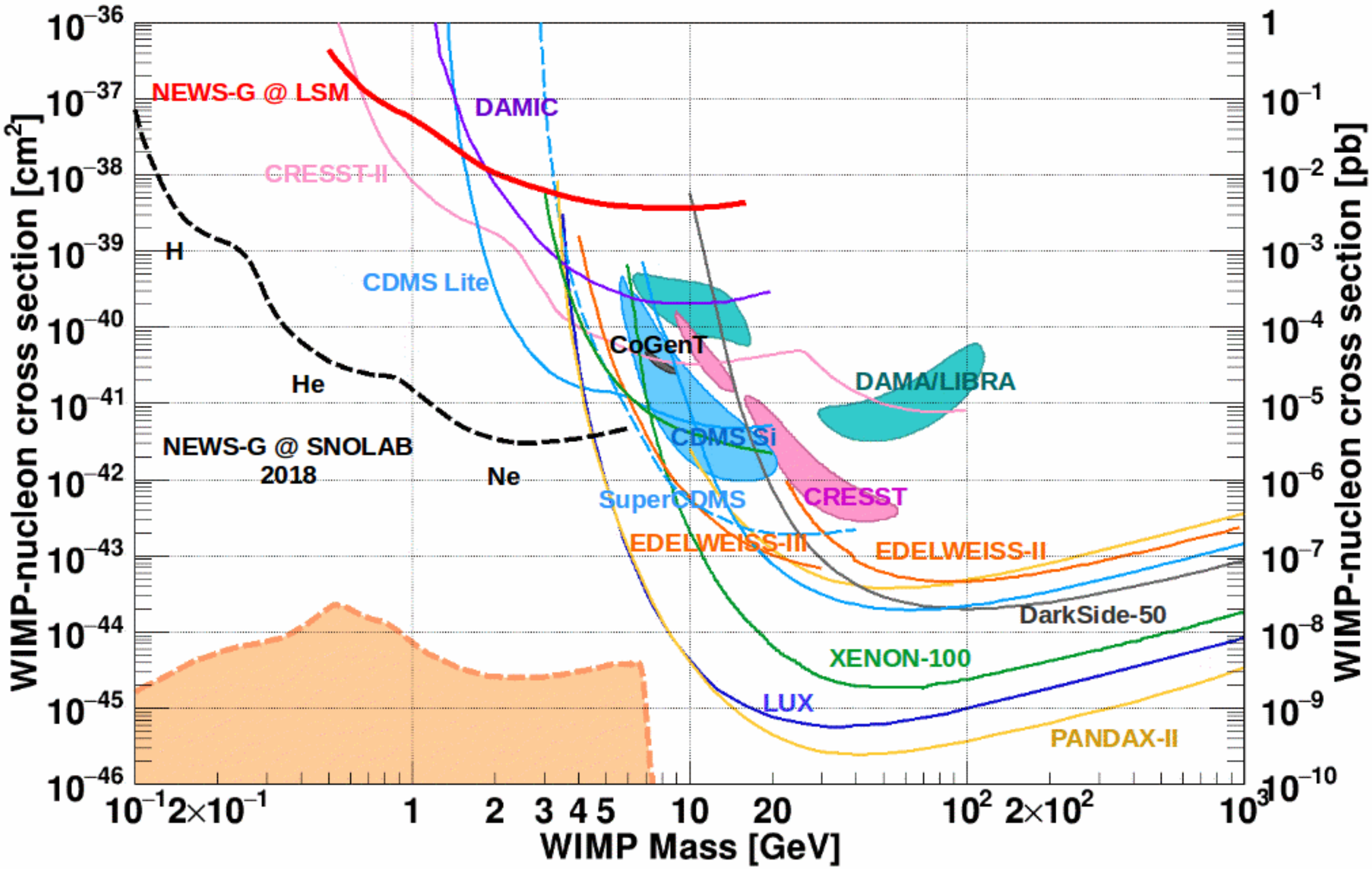
- Copper vessel (∅ 140cm, 12mm thick)
  - Low activity copper (C10100)
  - 7 to 25 μBq/kg Th
  - 1 to 5 μBq/kg of U
  - Electropolishing & Electroplating
  - Gases: Ne, He, CH_4
  - High pressure operation (10 bar)
- Upgraded Shielding (35t):
  - 40cm Polyethylene + Boron sheet
  - 22cm Lead (1 Bq/kg ^{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

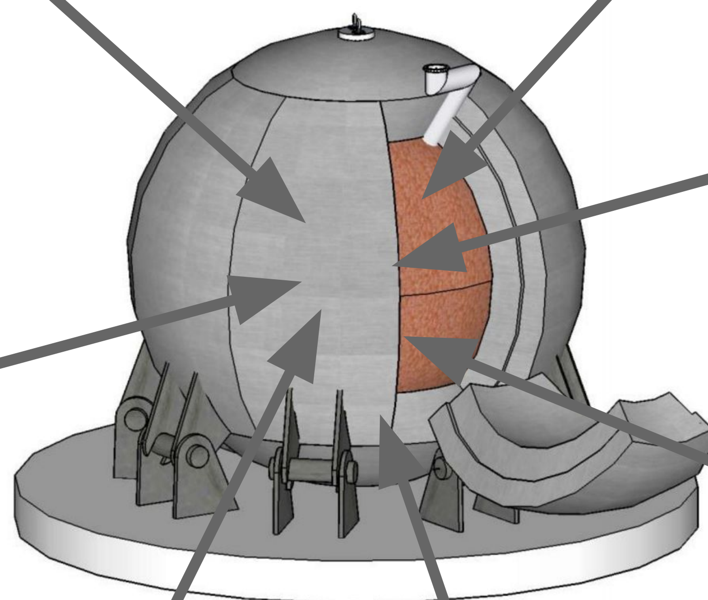
Versatile Detector

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

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

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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
  - 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, …
- Many physics opportunities!

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