Search for light Dark Matter with NEWS-G

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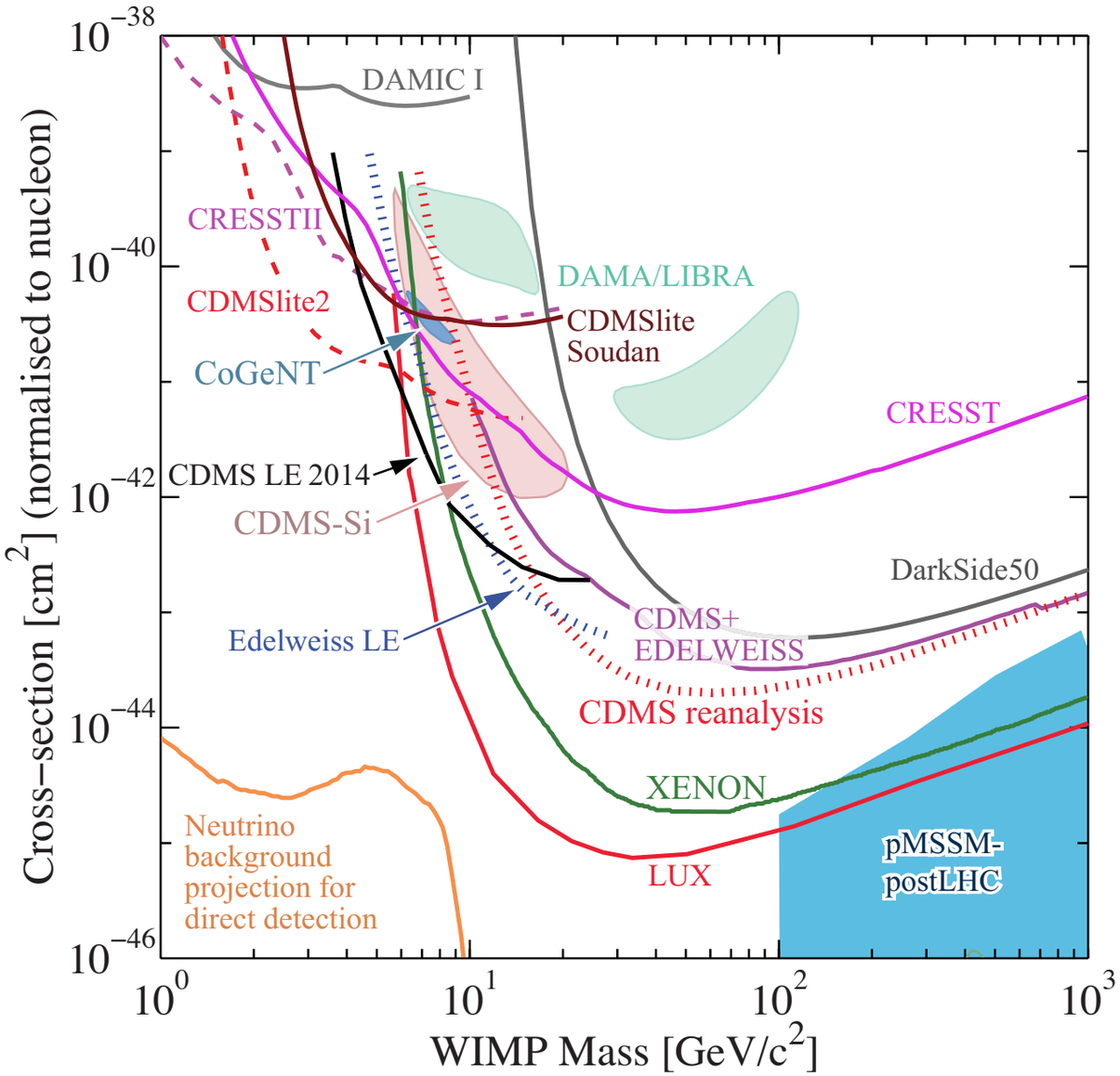
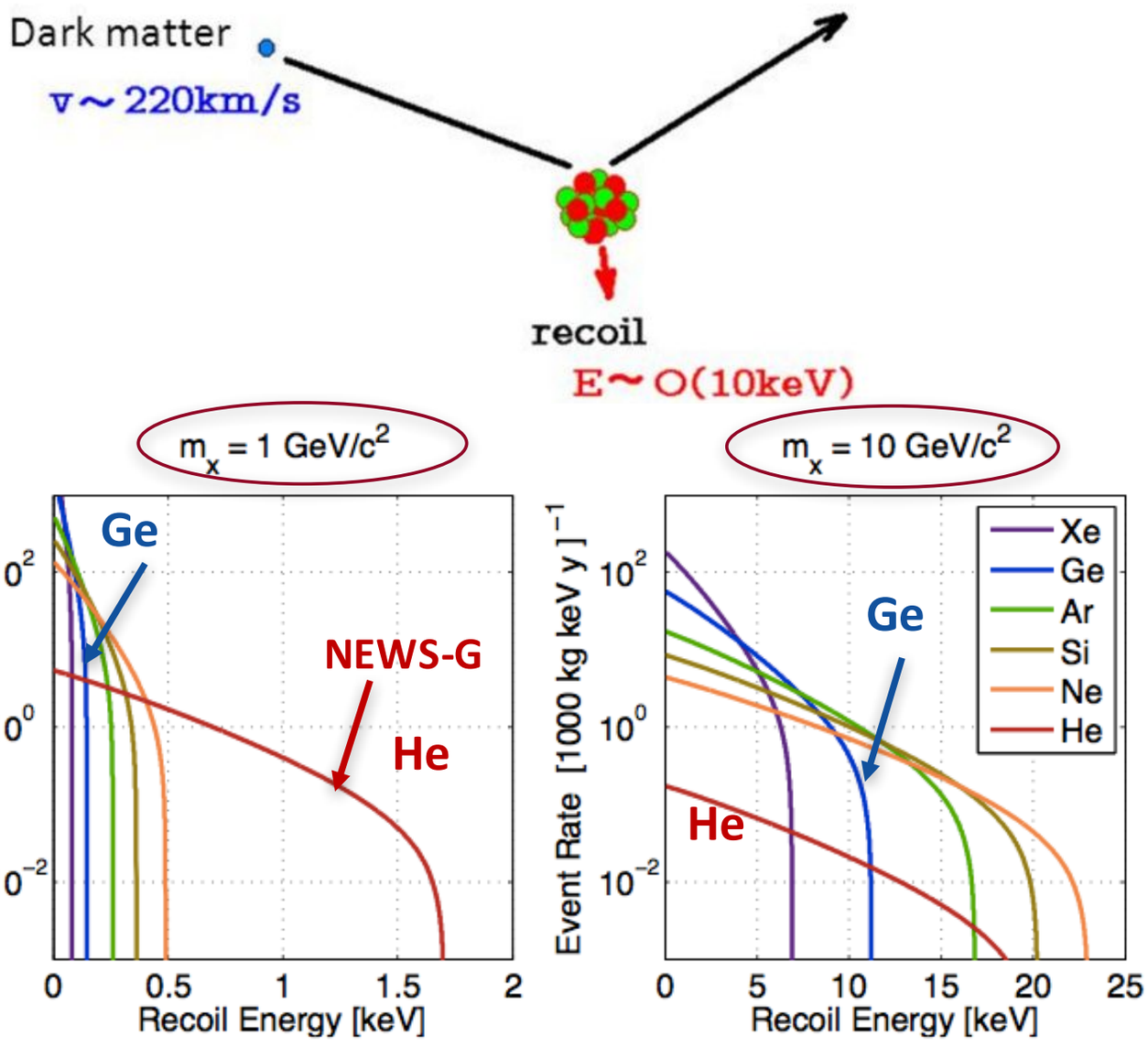
SEDINE prototype at LSM

Open UK meeting on Dark Matter
January 17, 2018, University of Bristol, UK

New Experiments With Spheres - Gas

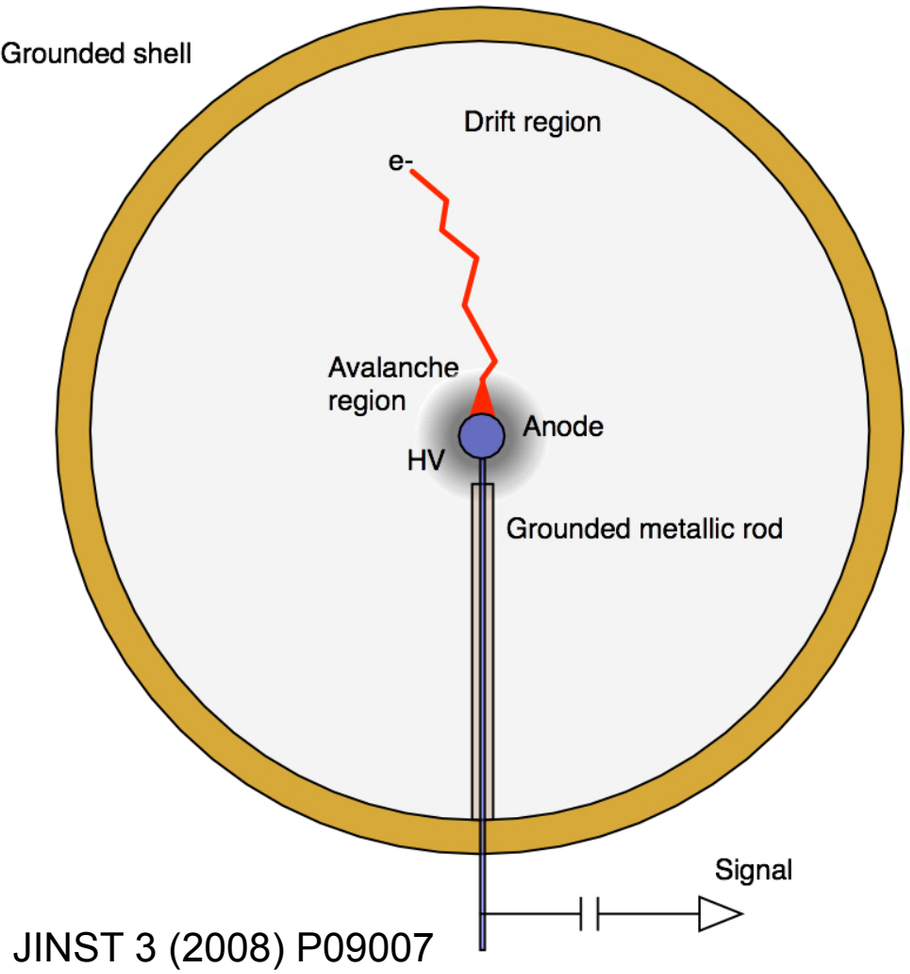




Recoil distributions with various targets

- Search for DM candidates in the 100 MeV – 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

Spherical Proportional Counter



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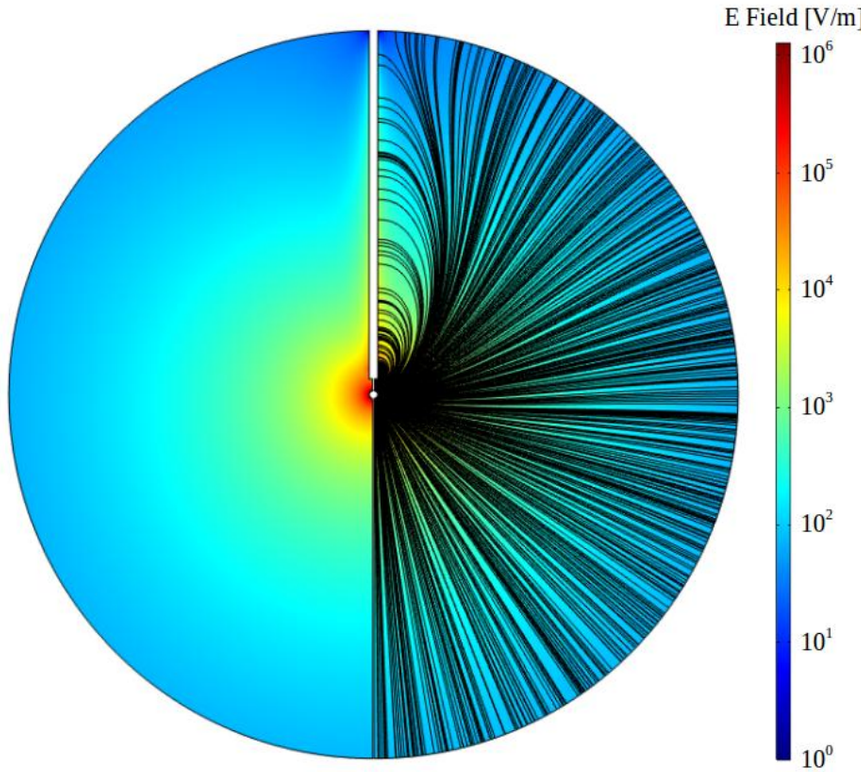
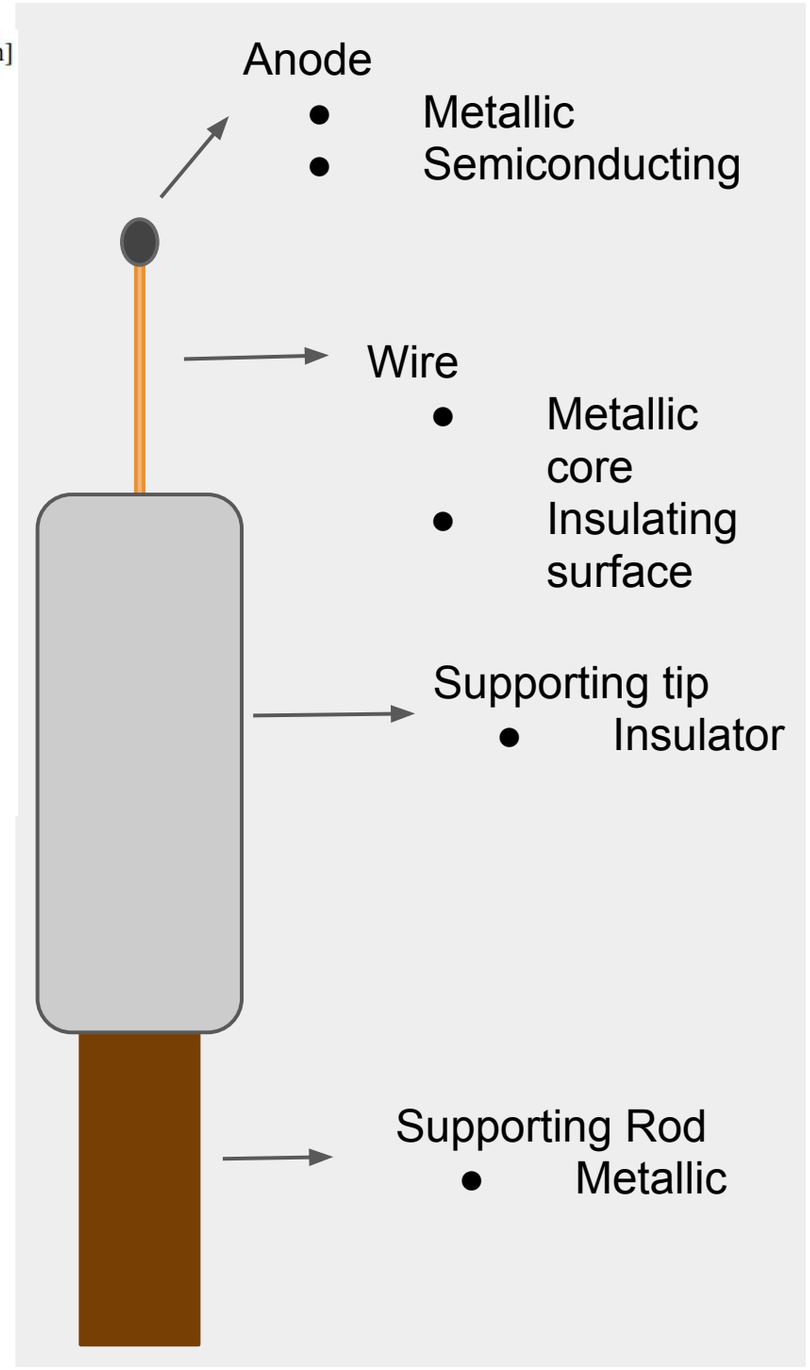




$$E = \frac{V_0}{r^2}\frac{r_1 r_2}{r_2 - r_1} \approx \frac{V_0 r_1}{r^2}$$

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

$r_1 = \text{anode radius}$

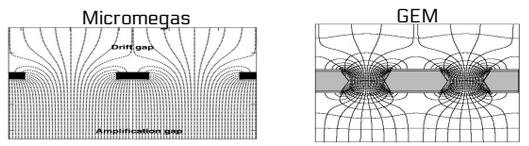
$r_2 = \text{cathode radius}$

The volume of the detector is naturally divided in a “drift” and an “amplification” volume.

Spherical Proportional Counter

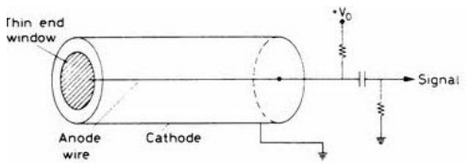
- Low Capacitance
  - Low noise → Low energy threshold
- Fiducial volume selection
  - Through pulse shape analysis
- Flexible (pressure, gas)
- Large mass/volume with one readout channel
- Simple sealed mode

Capacitance dependence on size



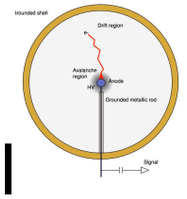
Parallel Plate Detector

C ≈ S > 1nF



Cylindrical Proportional Counter

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



Spherical Proportional Counter

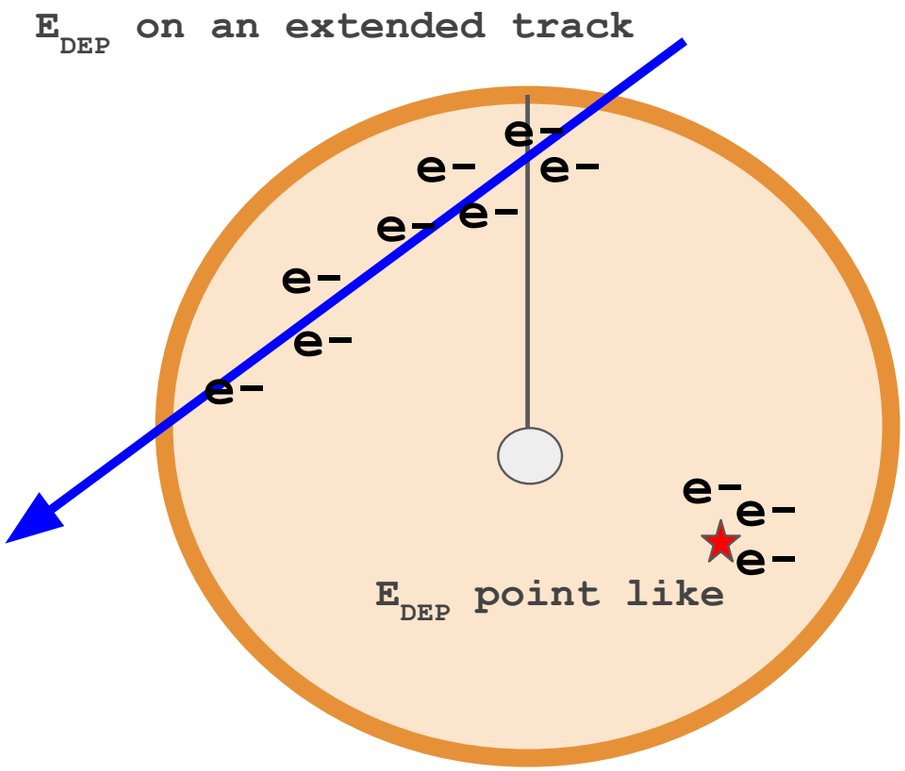
C ≈ r_1 < 1pF

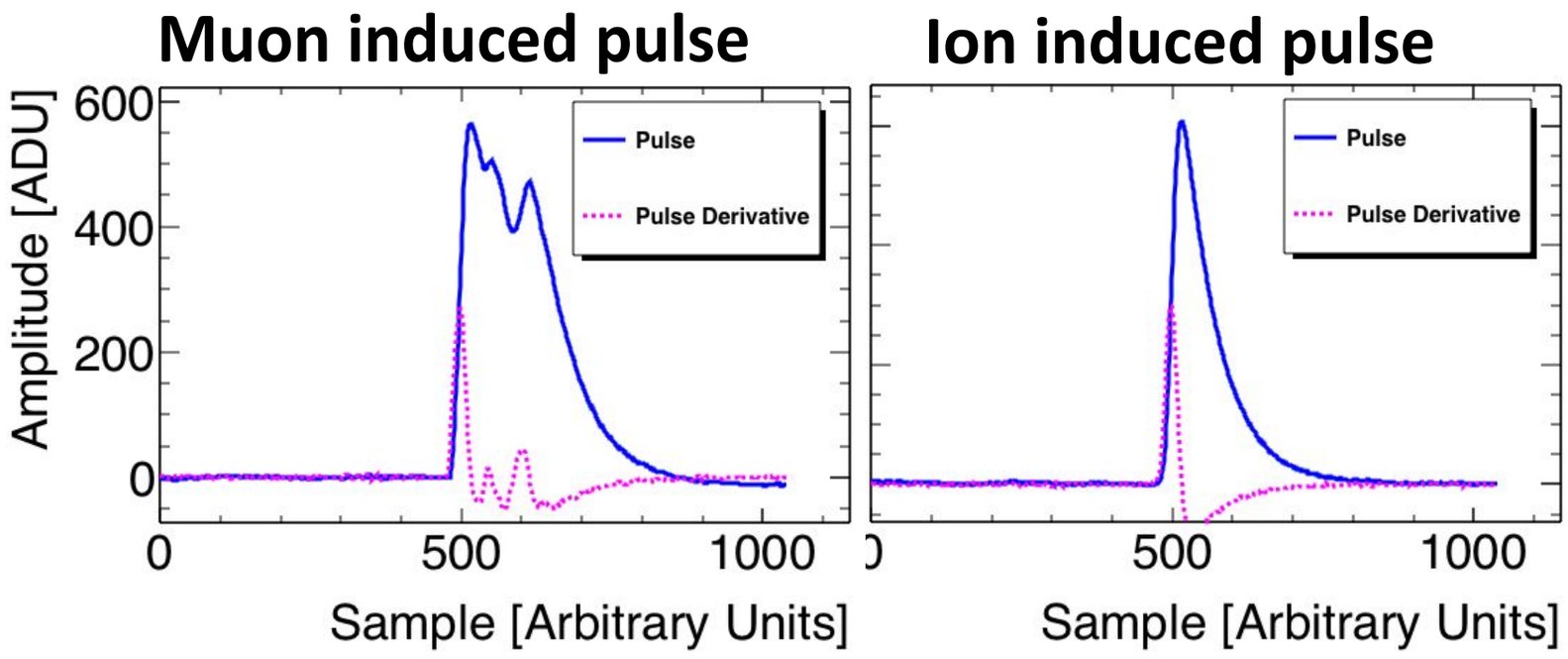
Large Size Detector + Robust construction

First Spherical Proportional Chamber made out of LEP RF Cavities

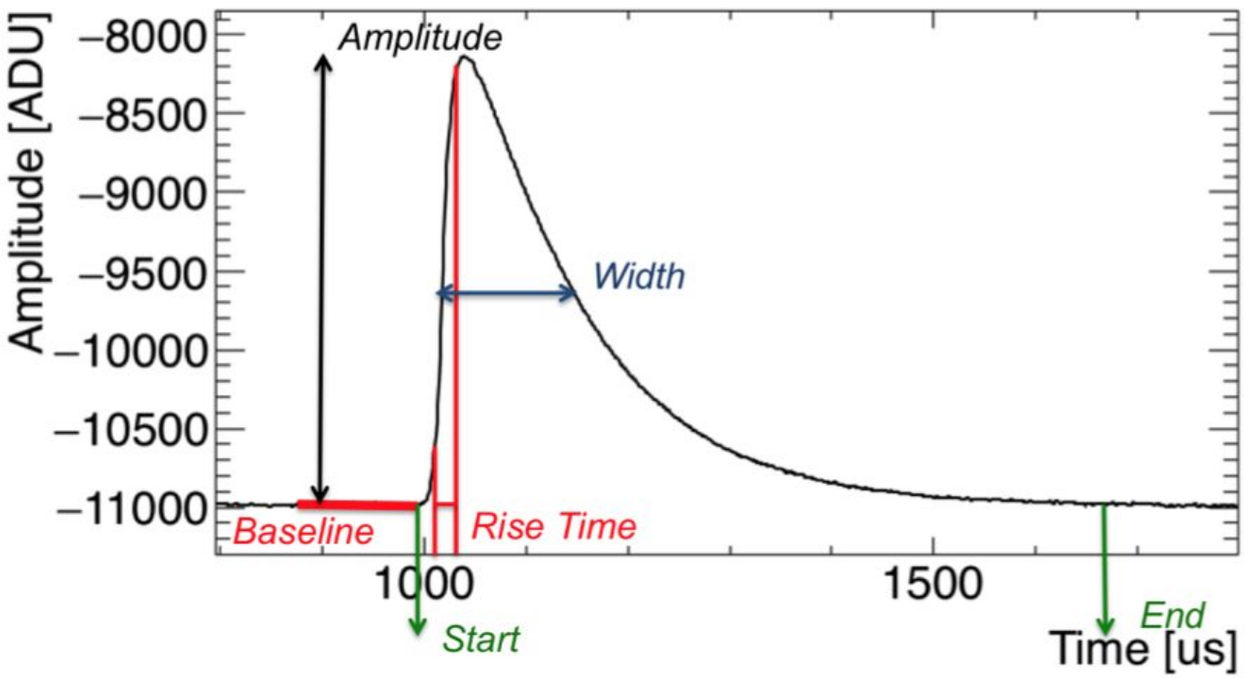
I. Giomataris and G. Charpak

Extended versus point like energy deposition





$\sigma(r) \propto (r/r_{sphere})^3$, e- drift time dispersion



Pulse Shape analysis Parameters

- Baseline
- Noise
- Peak Height
- Rise Time
- Width
- Integral
- Number of Peaks

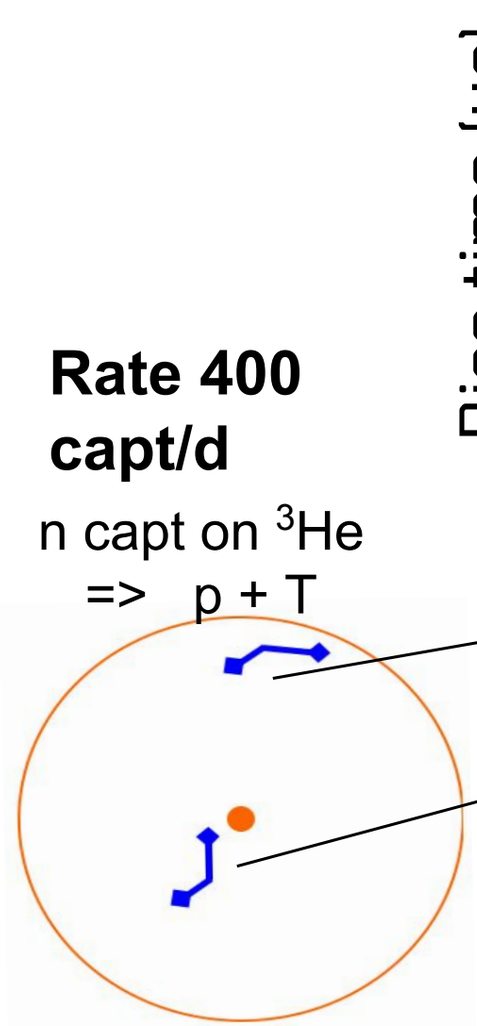
Pulse Rise time & Width ∝ Drift time dispersion

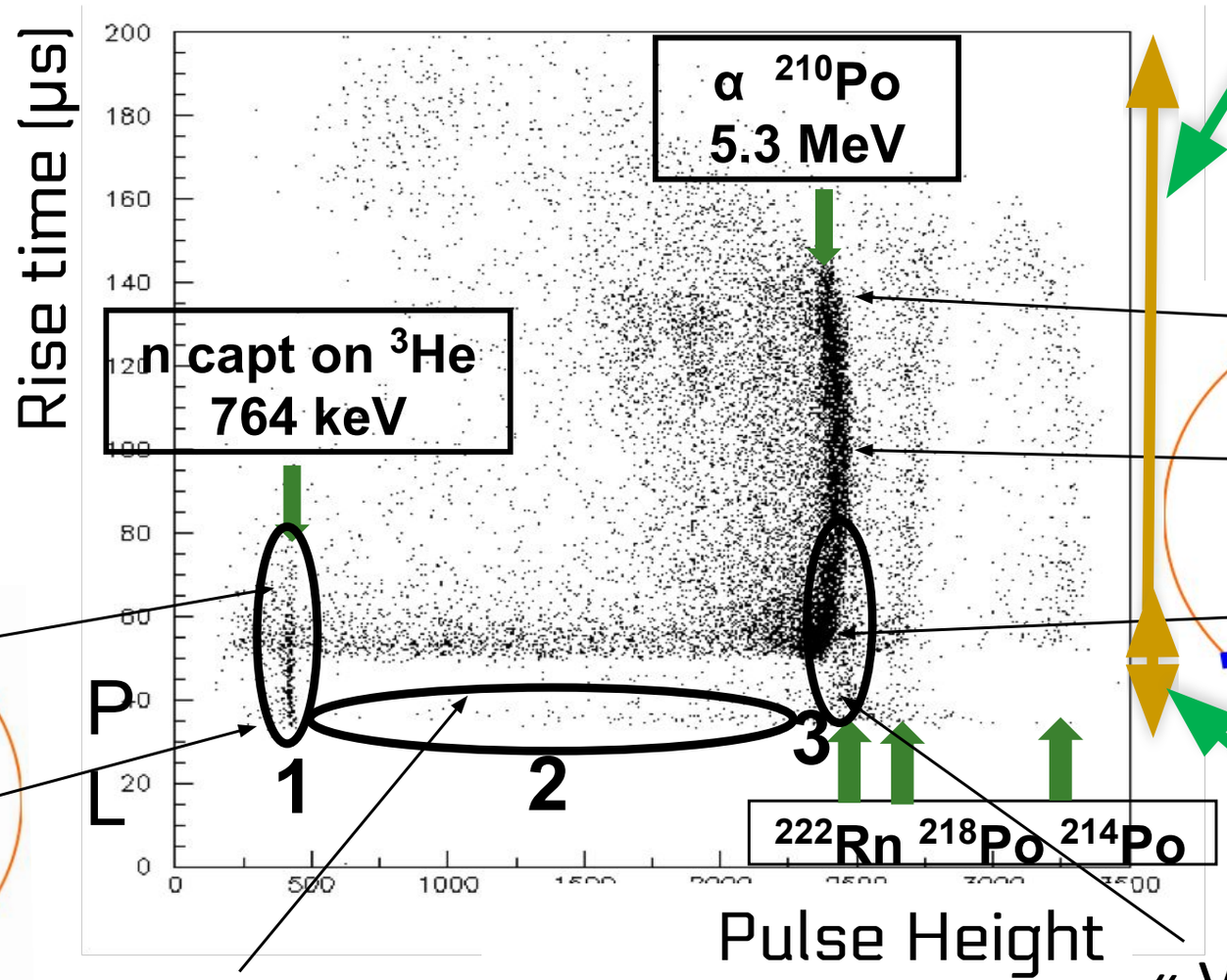
Background Rejection

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

Rate 400 capt/d

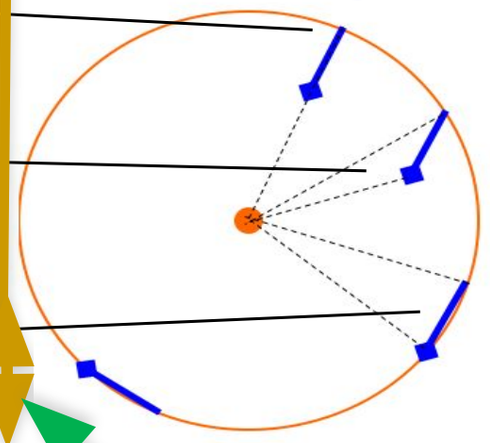
n capt on ^3He
=> p + T





Tracks

α ^{210}Po
5.3 MeV
from ^{210}Pb
@ Cu surface
Range = 15 cm

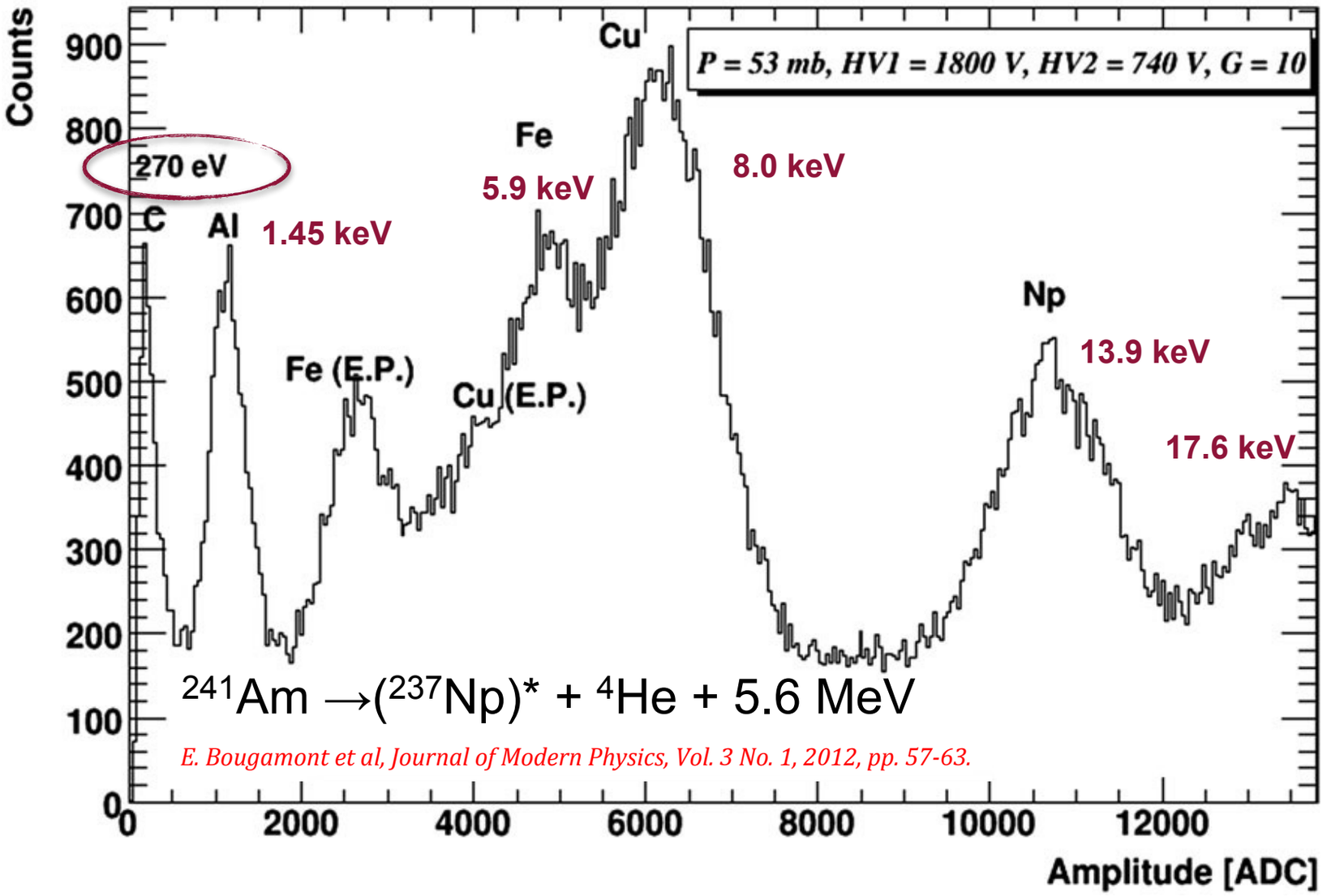


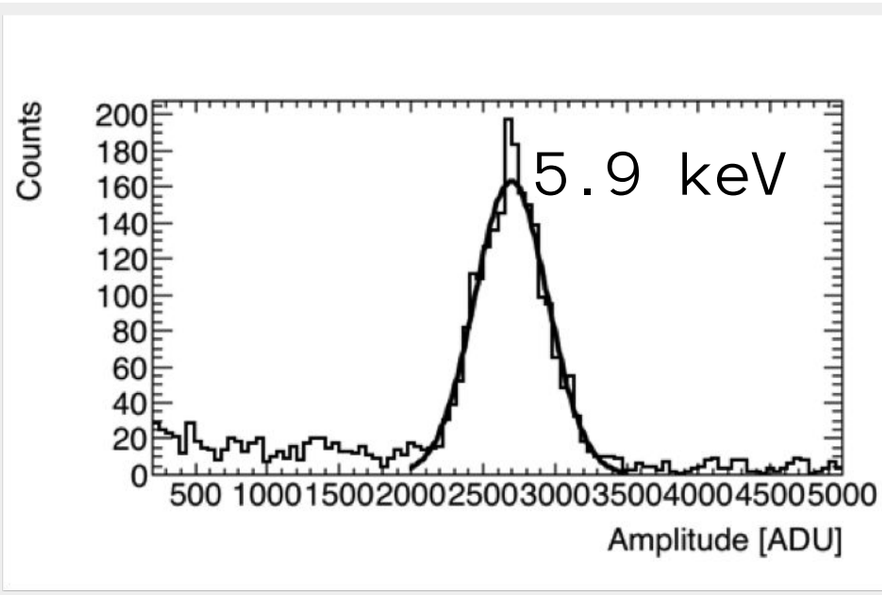
Point like

« Volume »
alpha

Recoils from fast neutrons expected here

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

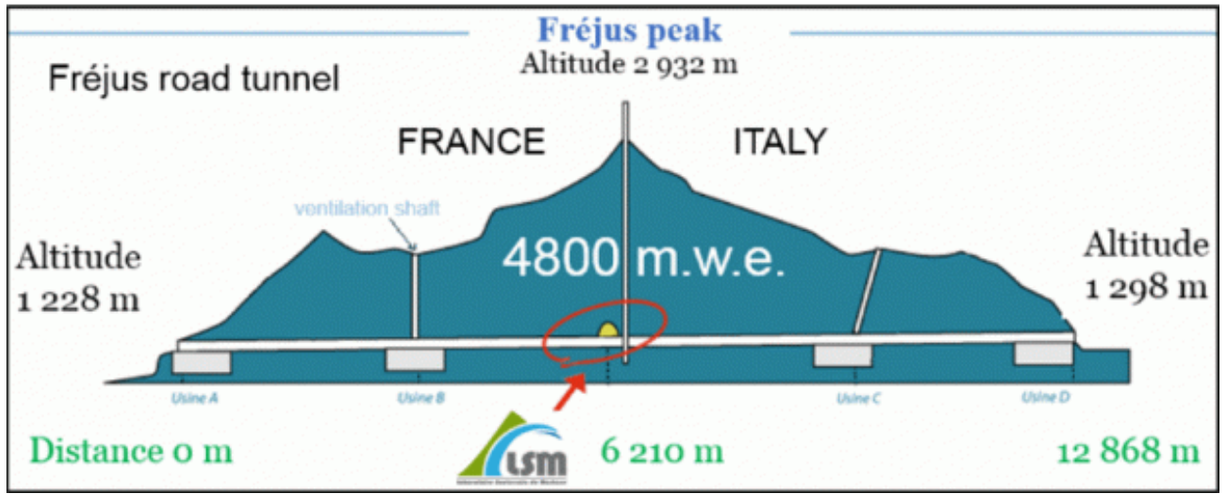
SPC Φ 30 cm

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

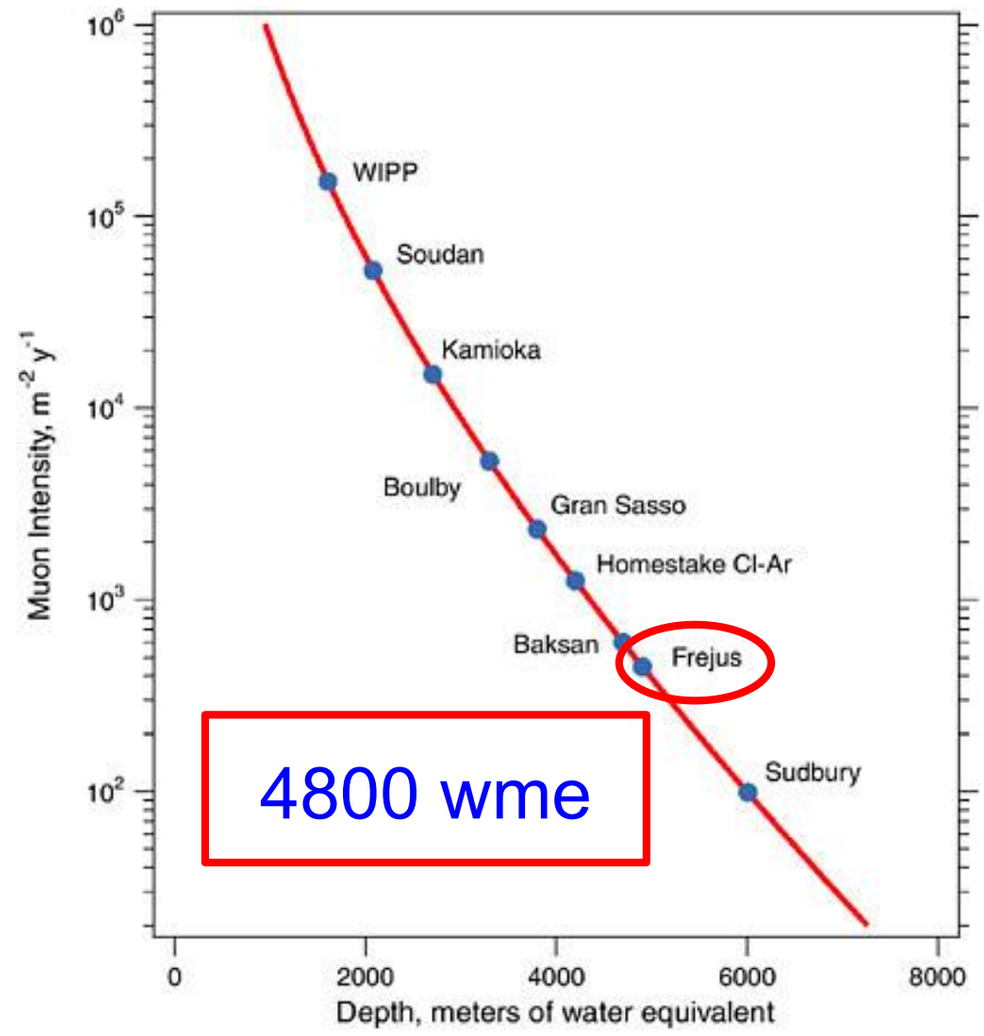
Resolution (σ) <9%

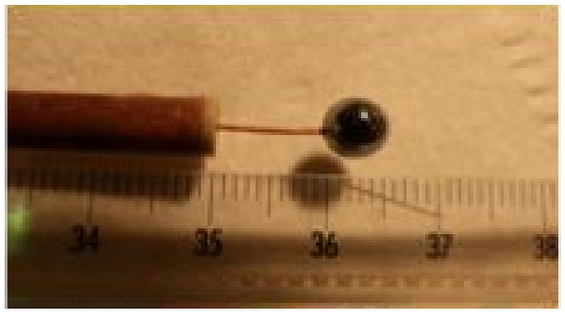
SEDINE: Low background SPC at LSM

- 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

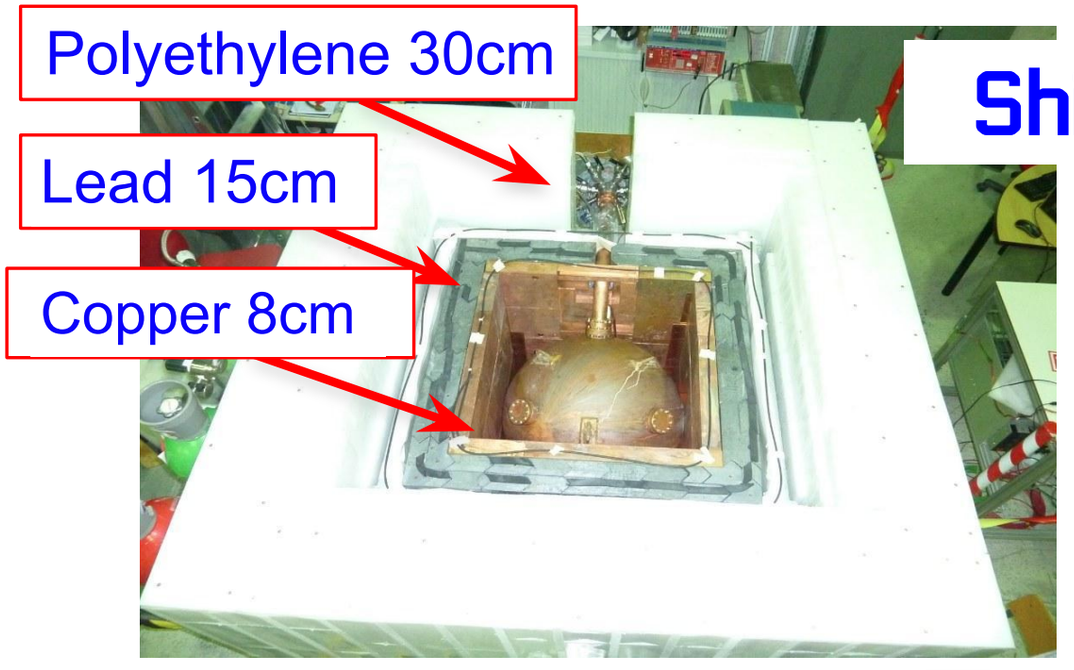


Laboratoire Souterrain de Modane





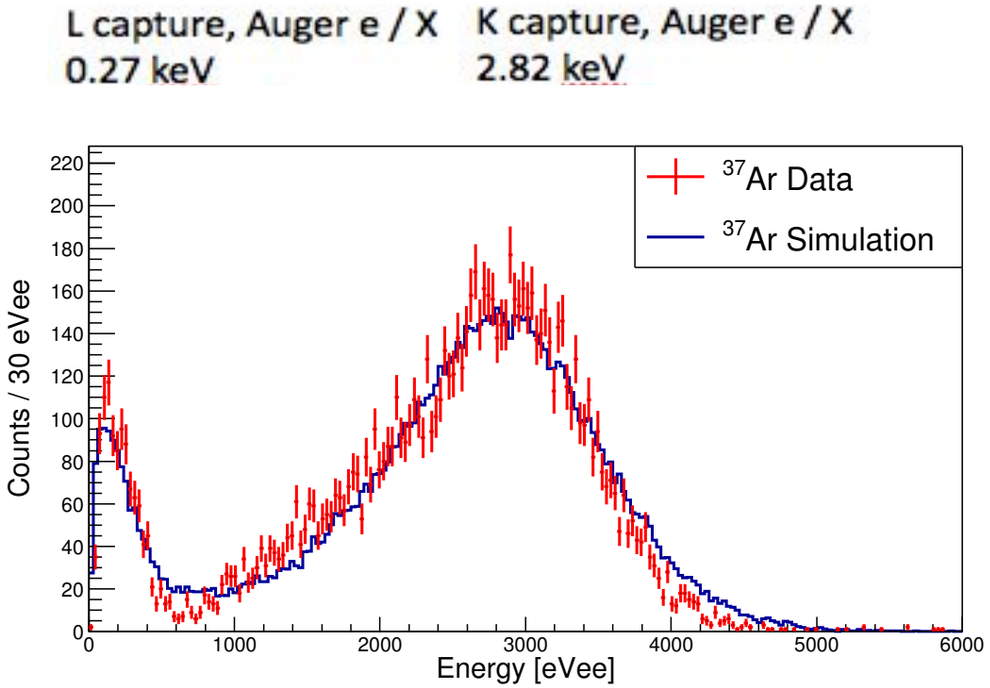
SEDINE sensor

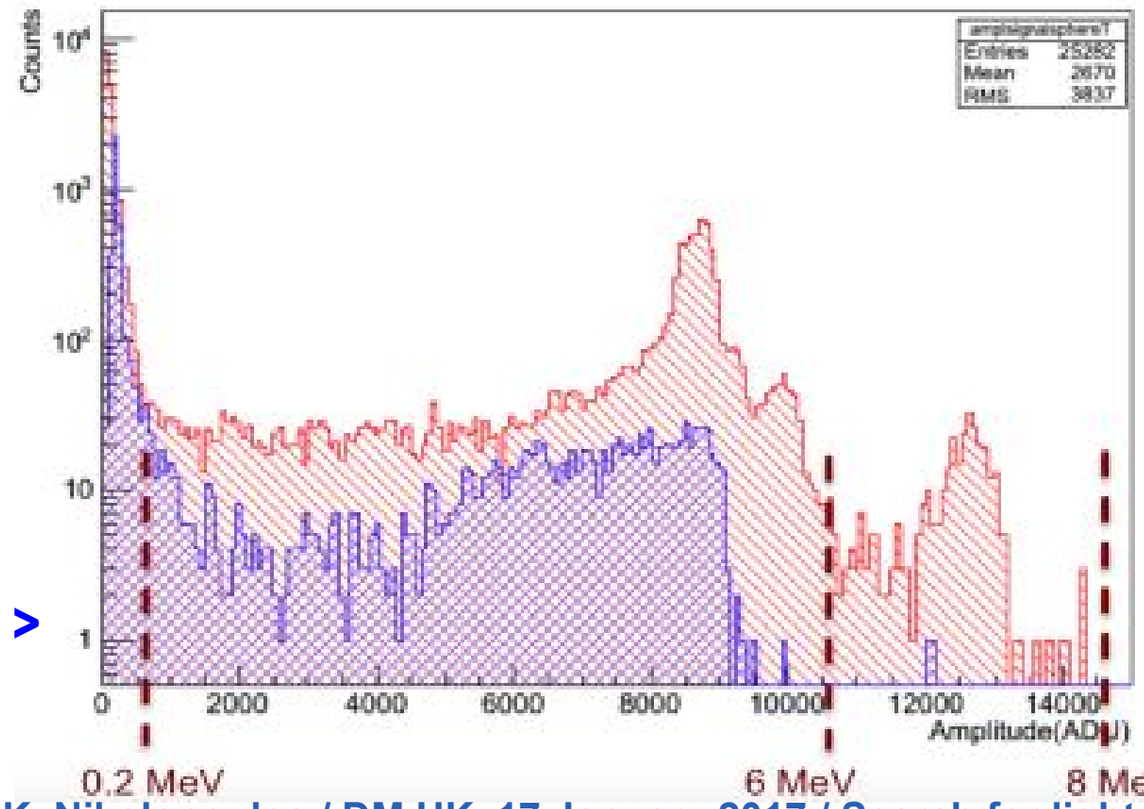


Shielding

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 9.7kg.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 with ^{37}Ar gaseous source and the 8 keV fluorescence line of Copper

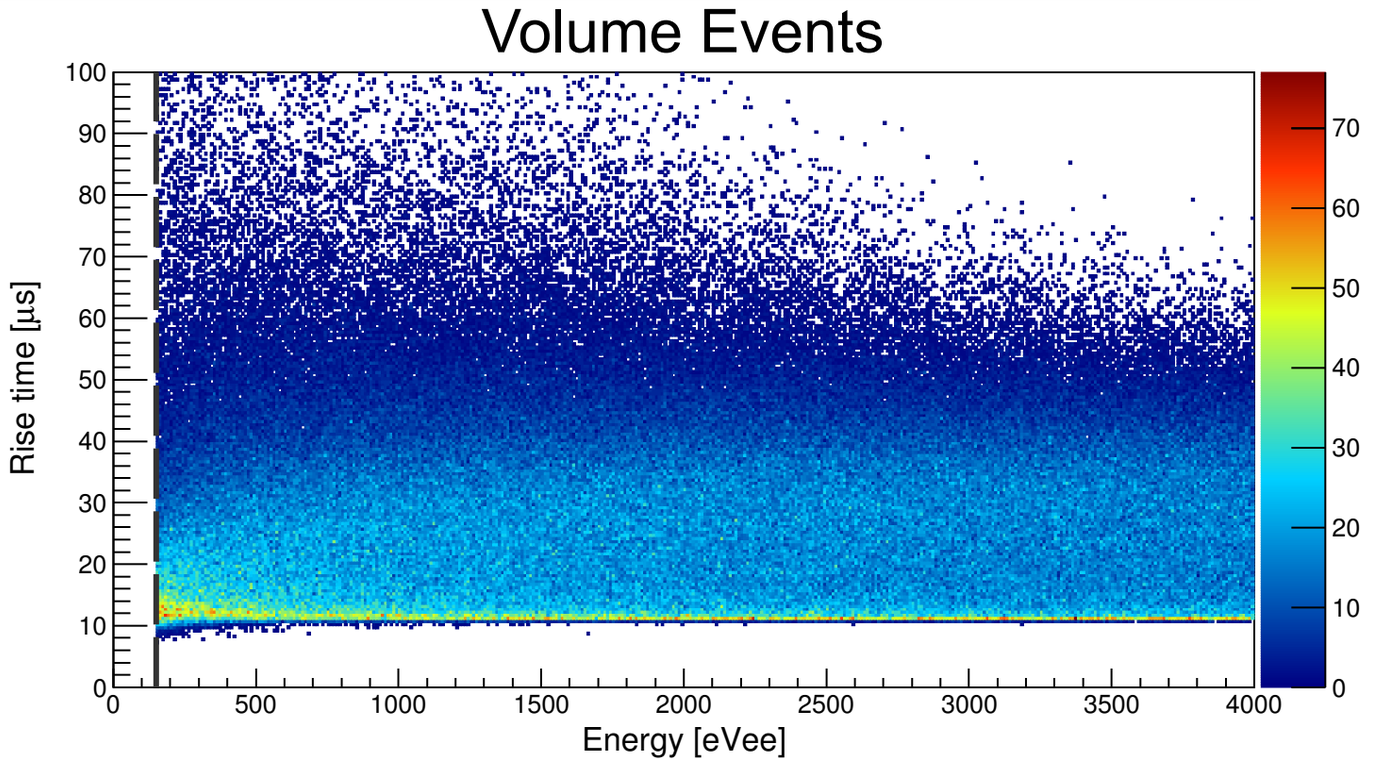


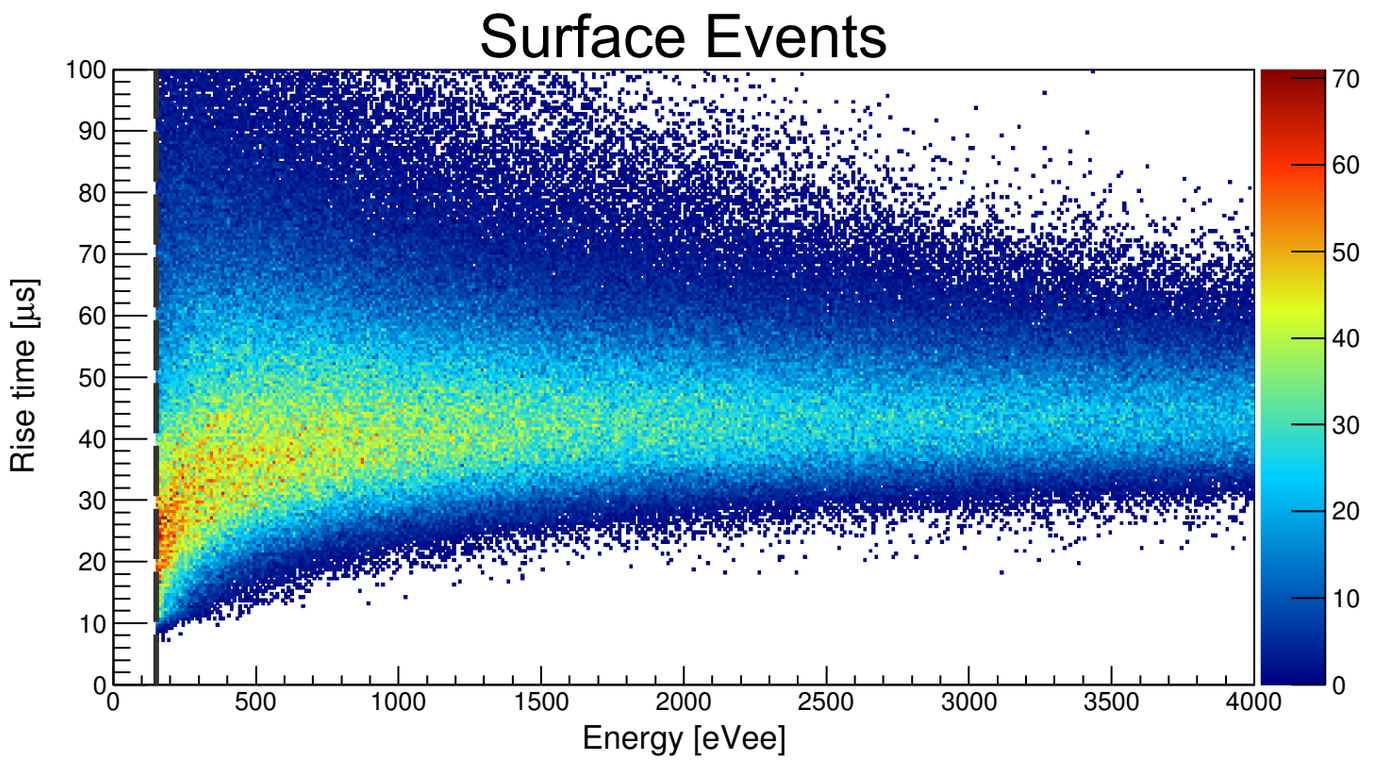


- ^{60}Co contamination of 1mBq/kg
- Background rate = 0.3-0.5 event/keV/kg/day
  - Limit surface exposure for pure copper
- ^{210}Pb, ^{210}Bi contamination of 1nBq/kg
- Background rate = 0.1 event/keV/kg/day
  - Chemical Cleaning
  - Effect of Cleaning
    - High energy events 180 mHz → ~2mHz
    - 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
- Simulation input to a Boosted Decision Tree to determine the optimised signal region for various candidate masses





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NEWS-G / LSM Exclusion Limits

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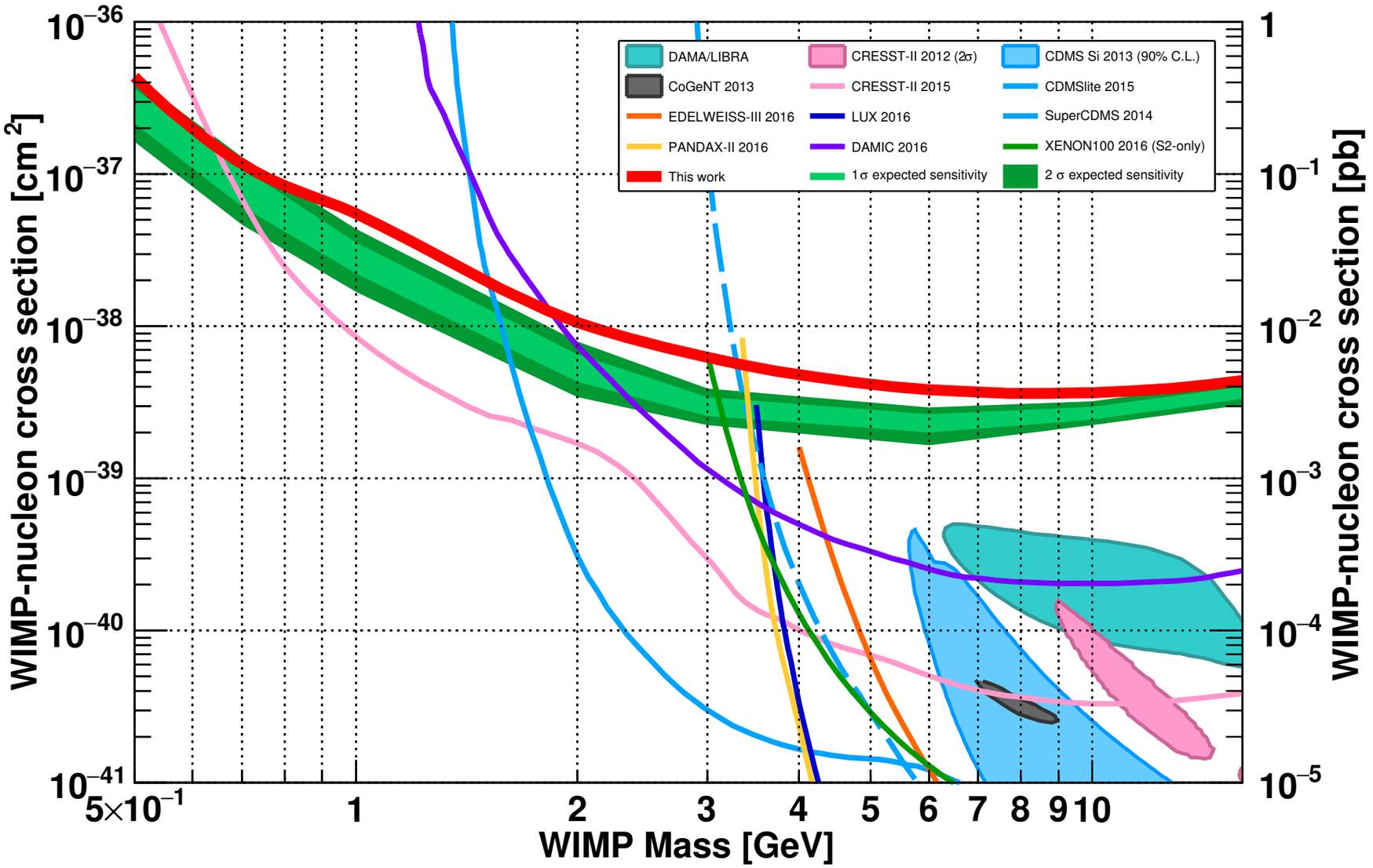
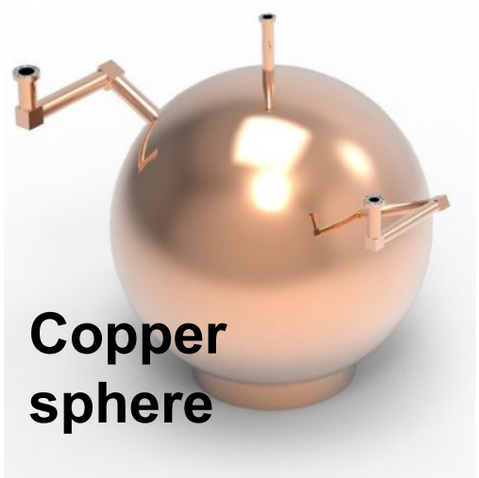
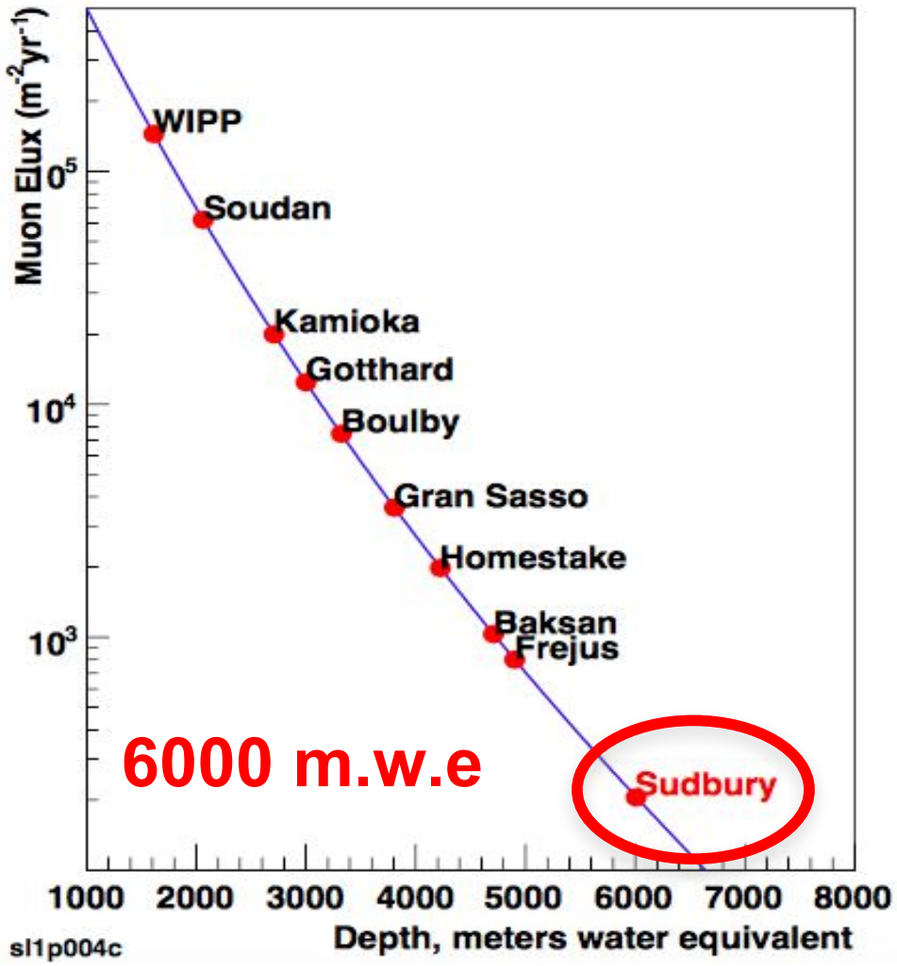


Limit set on spin independent WIMP coupling with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

Installation in SNOLab: Fall 2018

- Detector
  - Gases: Ne, He, CH_4
  - Operation in high pressure (10 bar)
  - Large volume detector (140cm diameter)
- Low background Copper Shell (12mm thick)
- Shielding:
  - 40cm Polyethylene
  - Boron sheet
  - 25cm Lead
  - 3cm archaeological Lead





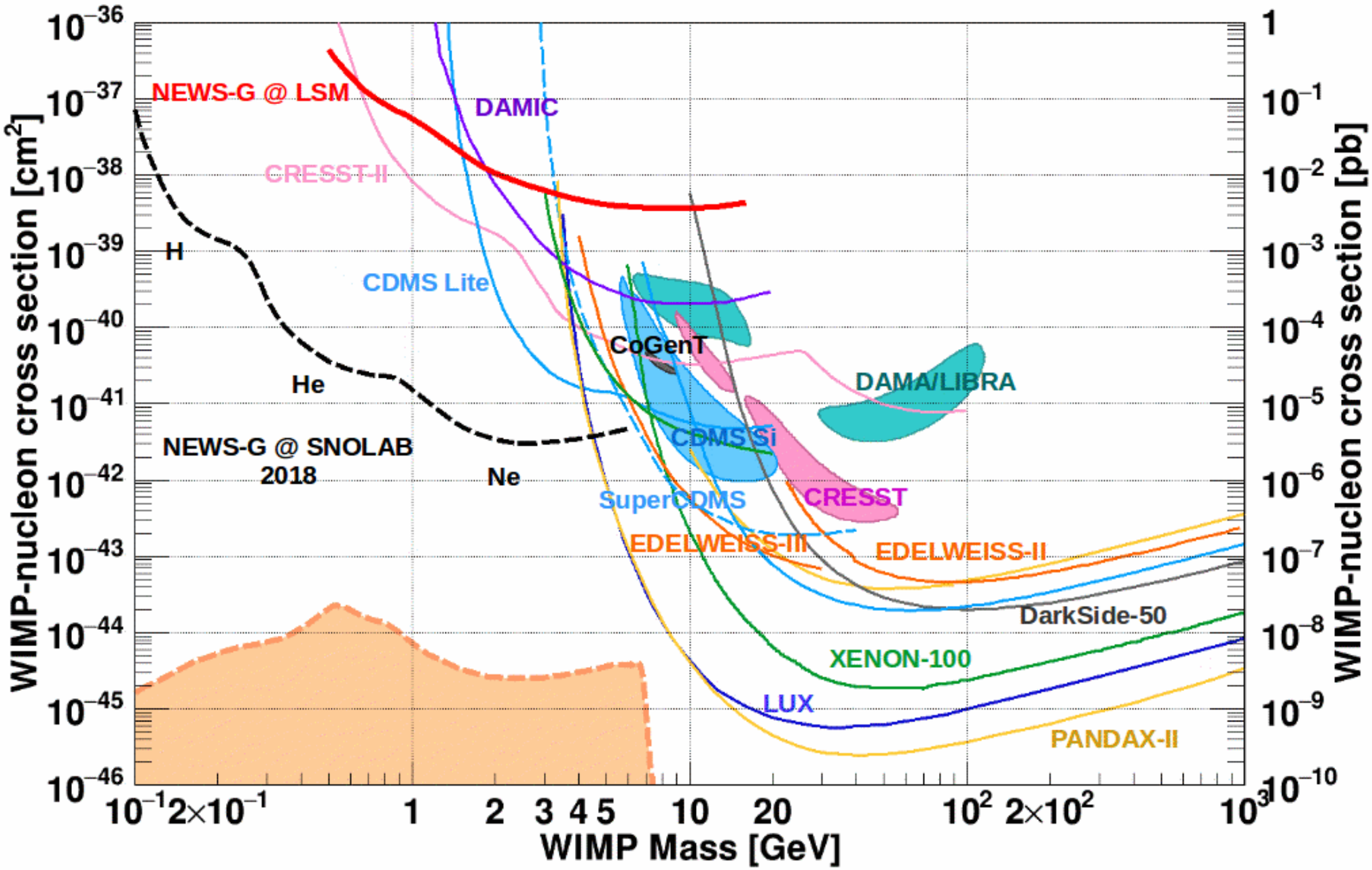
Simulation done with 12mm thick 140cm diam copper sphere full with 99% Ne 1%CH4, 11.43 kg of gas

Source Position	Mass (kg) or Surface (cn		Source	evts/kg/day/[(μBq/kg) or (nBq/cm2)]	contamination	units	evts/kg/day < 1ke
CopperSphere	627.83 kg		Co60	0.0018	30	μBq/kg	0.054
CopperSphere	627.83 kg		U238	0.0036	3	μBq/kg	0.011
CopperSphere	627.83 kg		Th232	0.0049	12.9	μBq/kg	0.063
InnerSurface	57255 cm^2		Pb210	0.012	0.16	nBq/cm2	0.002
ArchLead	2108.95 kg		U238	0.001	61.8	μBq/kg	0.062
ArchLead	2108.95 kg		Th232	0.0011	9.13	μBq/kg	0.010
Rod	0.0931721 kg		Co60	2.95E-007	30	μBq/kg	0.000
Rod	0.0931721 kg		U238	1.81E-006	3	μBq/kg	0.000
Rod	0.0931721 kg		Th232	2.11E-006	12.9	μBq/kg	0.000
Wire	2.66005e-05	kg	Co60	1.48E-010	31000	μBq/kg	0.000
Wire	2.66005e-05	kg	U238	2.12E-009	300000	μBq/kg	0.001
Wire	2.66005e-05	kg	Th232	1.42E-009	50000	μBq/kg	0.000
Wire	2.66005e-05	kg	K40	5.41E-010	1660000	μBq/kg	0.001
LabArea			Tl208/K40				0.076
						Total	0.279

Copper
Internal surface
Lead shield

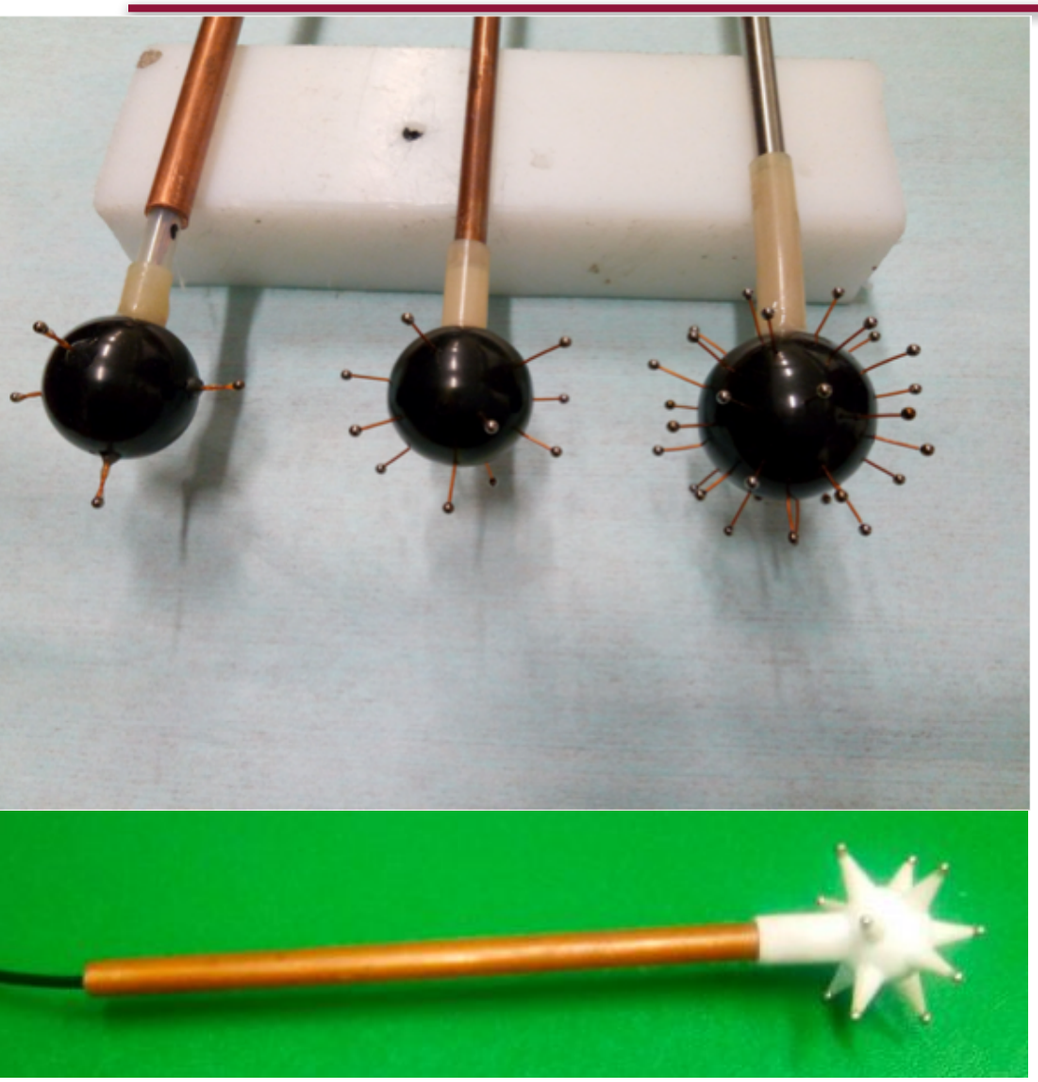
External BG with SNO Flux

Predicted exclusion limits for NEWS-G / SNO

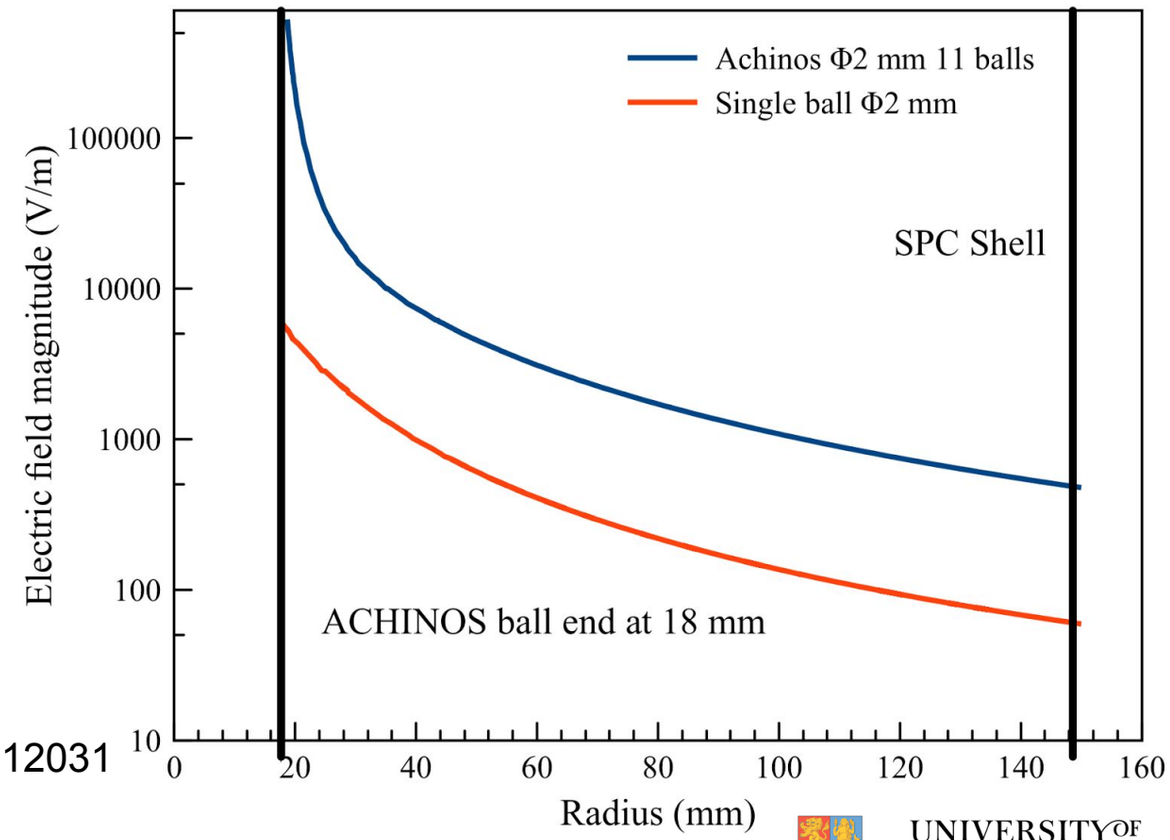


Hypothesis for NEWS-SNO expected sensitivity:
100 kg.days exposure @ 10 bar, threshold 1 electron (~40 eV), 200eV window

Going further: Achinos



- Need for high pressure operation and larger volumes!
- But both gain and drift time function of E/P …
- Achinos: Use multiple balls placed at equal distances on a sphere
  - Same gain but increased field at large radii
  - Decoupling Gain -Drift
  - Tunes Volume electric field
  - Anodes can be read out individually
- Prototypes with 5, 11 and 33 metallic balls of 2 mm in diameter successfully operated
- 3D printed Achinos sensors built and operated



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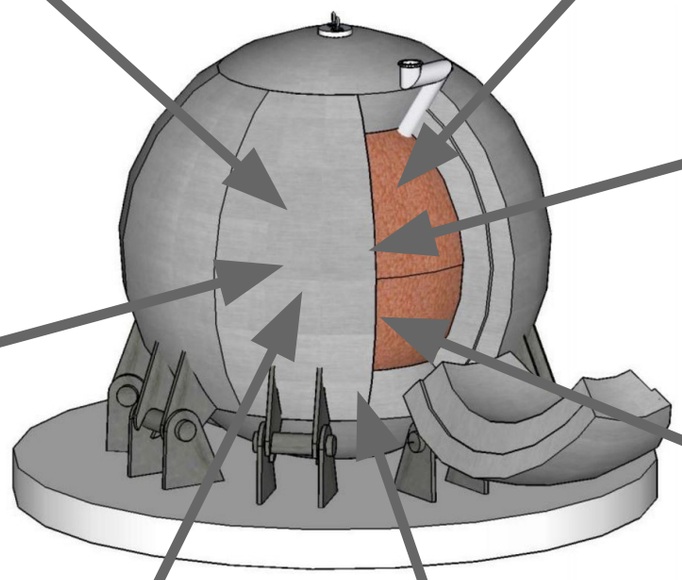
Versatile Detector

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

Queen's University Kingston – G Gerbier, P di Stefano, R Martin, T Noble, D Dunrford, S Crawford, A Brossard, A Kamaha, P Vasquez dS, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier, A Ronceray
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, C Elefteriadis, A Liolios
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

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
  - SEDINE essential for @SNOLAB optimisation

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- 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!