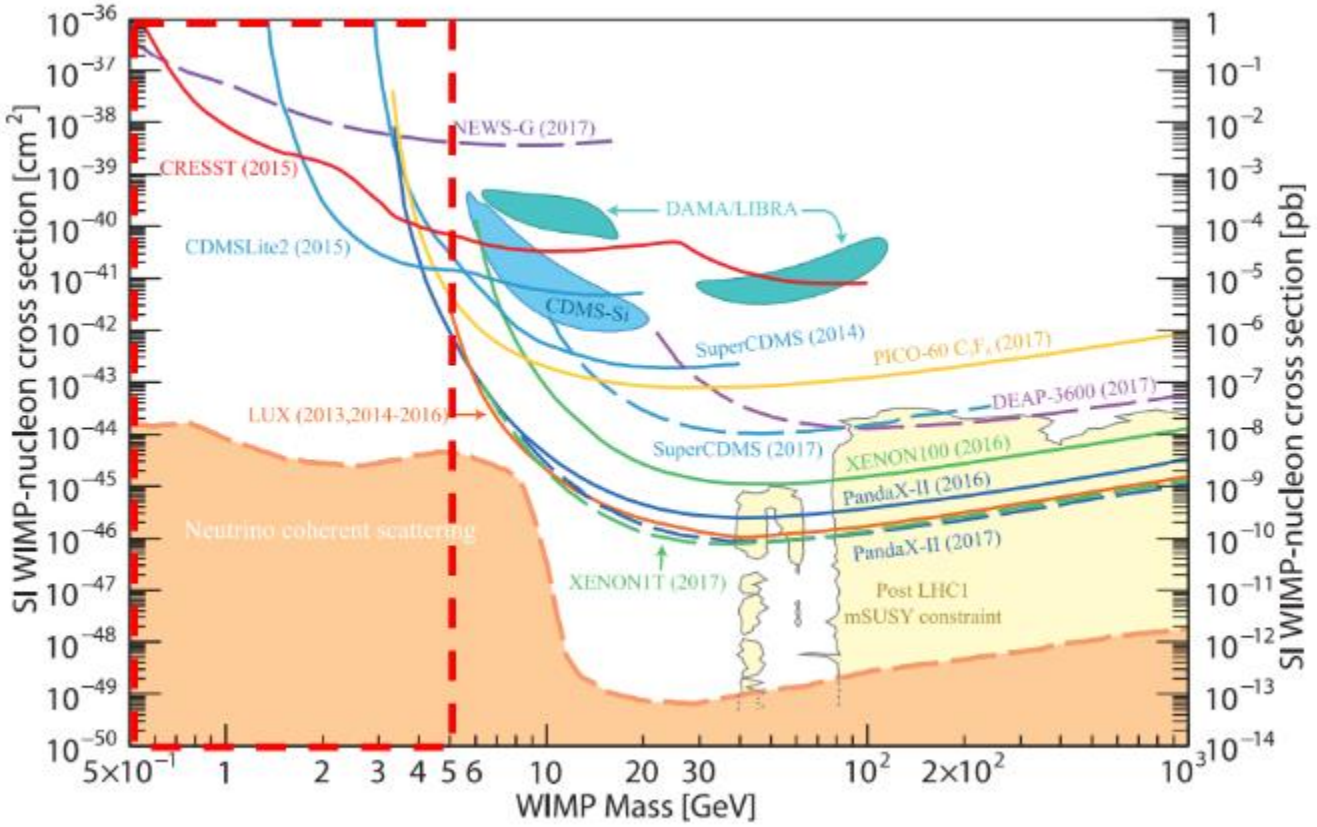
The Search for Light Dark Matter with the NEWS-G Detector

GUILLAUME GIROUX

29TH INTERNATIONAL SYMPOSIUM ON LEPTON PHOTON INTERACTIONS AT HIGH ENERGIES

TORONTO, AUGUST 2019

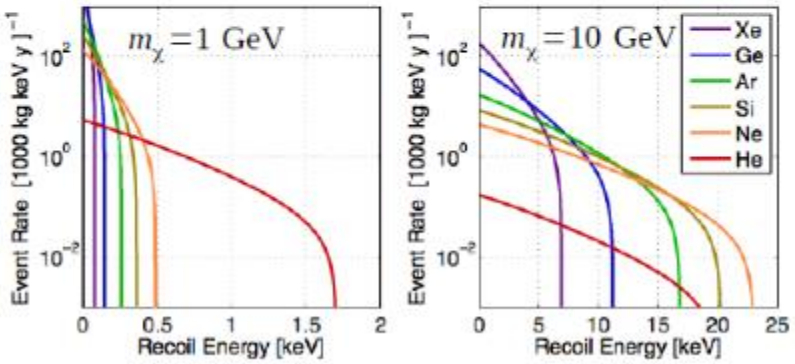
The Search for Light Dark Matter



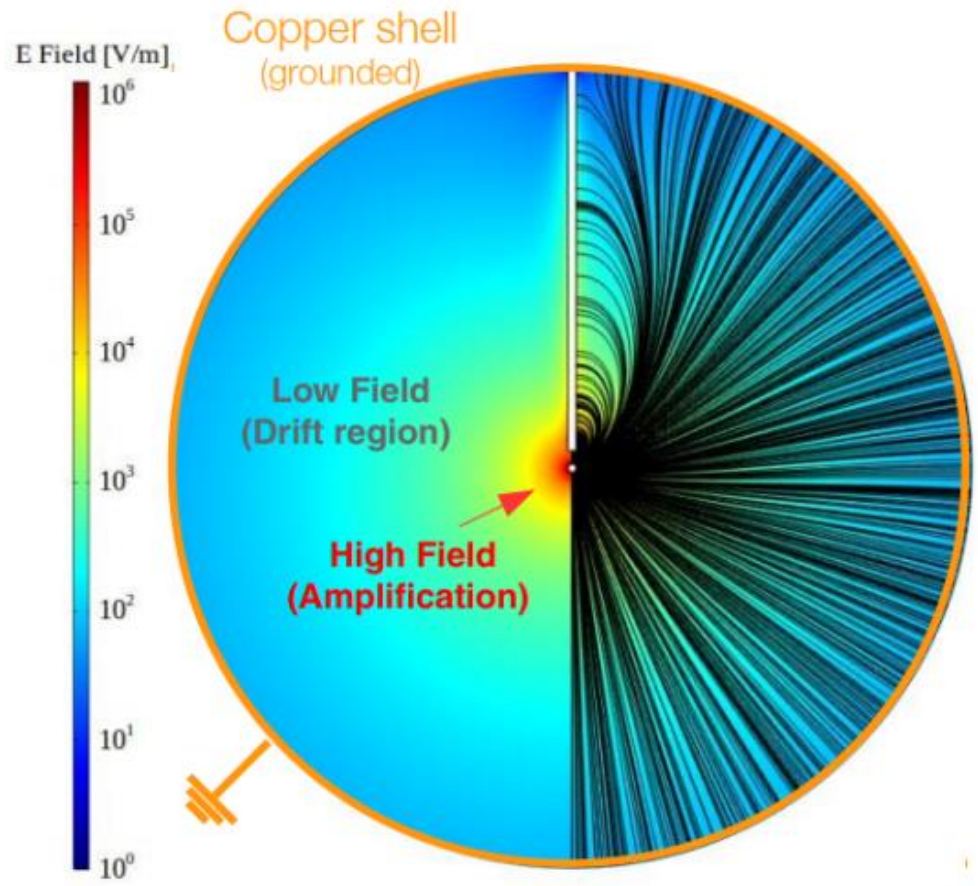
Requirements:

- Light targets (kinematics)
- Low energy threshold
- Low backgrounds

Optimization of momentum transfers for low-mass particles



The Spherical Proportional Counter (SPC)



Sensitivity to single electrons

Low energy thresholds of 10 - 40 eVee

High amplification gain arising from $E(r) \propto \frac{1}{r^2}$

Low intrinsic capacitance (independent on the size of the sphere)

Easily scalable

$$C = \frac{4\pi\epsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi\epsilon r_{sensor} \approx 0.35\,\mathrm{pF}$$

Pulse shape discrimination

The rise time of pulses allows for a statistical discrimination against sub-keV surface events

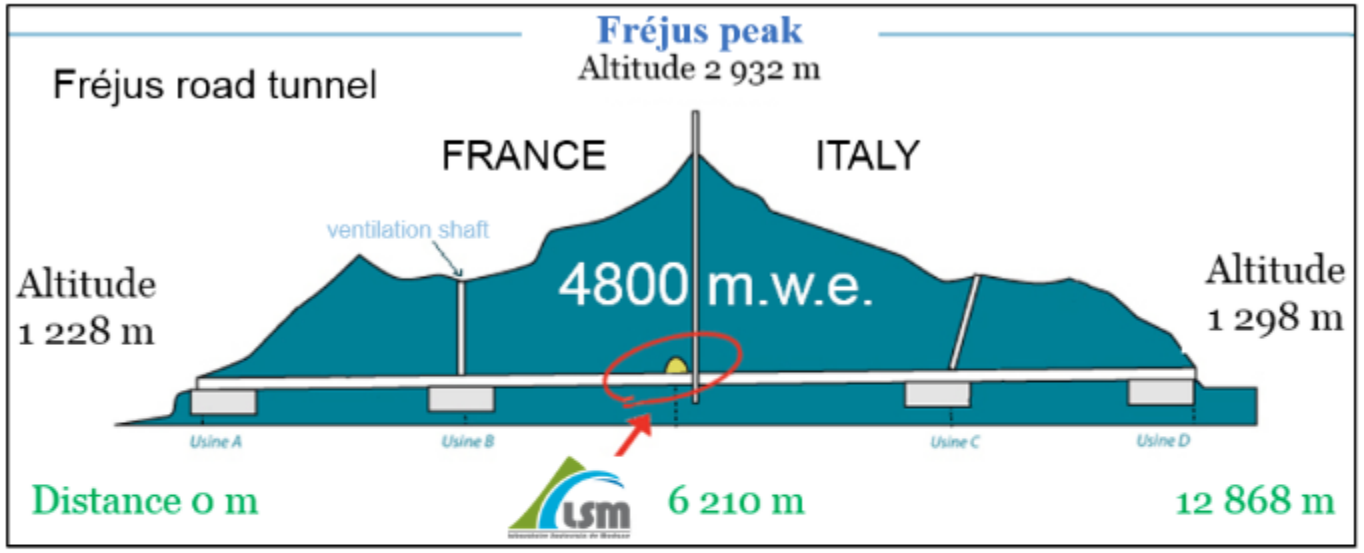
Light Targets (H,He,Ne)

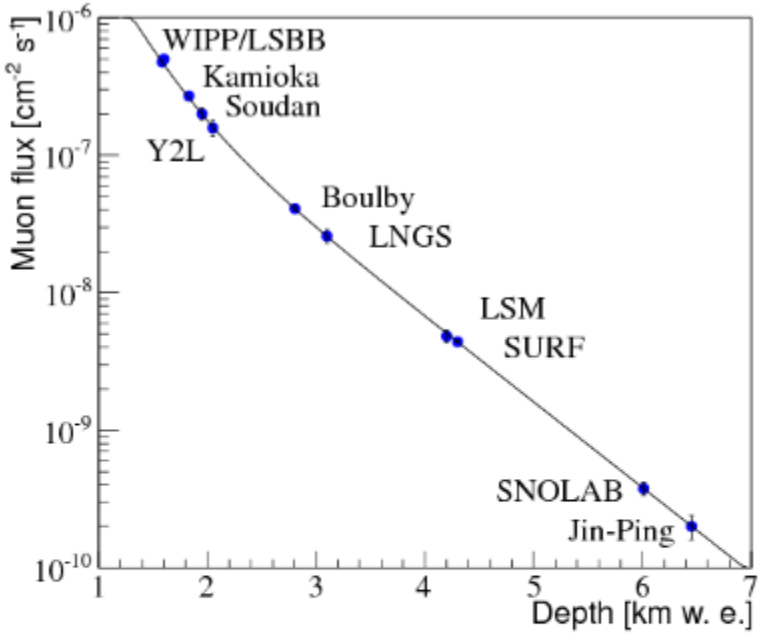
The NEWS-G Collaboration

- **Queen's University Kingston – G Gerbier,** P di Stefano, R Martin, G Giroux, D Dunrford, S Crawford, M Vidal, G Savvidis, A Brossard, P Vazquez dS, Q Arnaud, K Dering, J Mc Donald, M Chapellier, A Ronceray, P Gros, A Rolland, , C Neyron
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis
- **IRFU** (Institut de Recherches sur les Lois fondamentales de l'Univers)**/CEA Saclay -I Giomataris**, M Gros,, I Katsioulas, T Papaevangelou, JP Bard, JP Mols, XF Navick
  - Sensor/rod (low activity, optimization with 2 electrodes)
  - Electronics (low noise preamps, digitization, stream mode)
  - DAQ/soft
- **LSM** (Laboratoire Souterrain de **Modane**), IN2P3, U of Chambéry **-** F Piquemal, M Zampaolo, A DastgheibiFard
  - Low activity archeological lead
  - Coordination for lead/PE shielding and copper sphere
- **Thessaloniki University** – I Savvidis, A Leisos, S Tzamarias
  - Simulations, neutron calibration
  - Studies on sensor
- **LPSC (**Laboratoire de Physique Subatomique et Cosmologie) **Grenoble** - D Santos, JF Muraz, O Guillaudin
  - Quenching factor measurements at low energy with ion beams
- **Pacific National Northwest Lab**– E Hoppe, R Bunker
  - Low activity measurements, Copper electroforming
- **RMCC (**Royal Military College Canada**) Kingston** – D Kelly, E Corcoran
  - 37 Ar source production, sample analysis
- **SNOLAB –Sudbury** – P Gorel
  - Calibration system/slow control
- **University of Birmingham**– K Nikolopoulos, P Knights
  - Simulations, analysis, R&D
- **University of Alberta :** MC Piro, D Durnford, S Ogmen
  - Gas purification, data analysis
- **Associated labs : TRIUMF** - F Retiere

Sep 2018

Recent Results from SEDINE at LSM



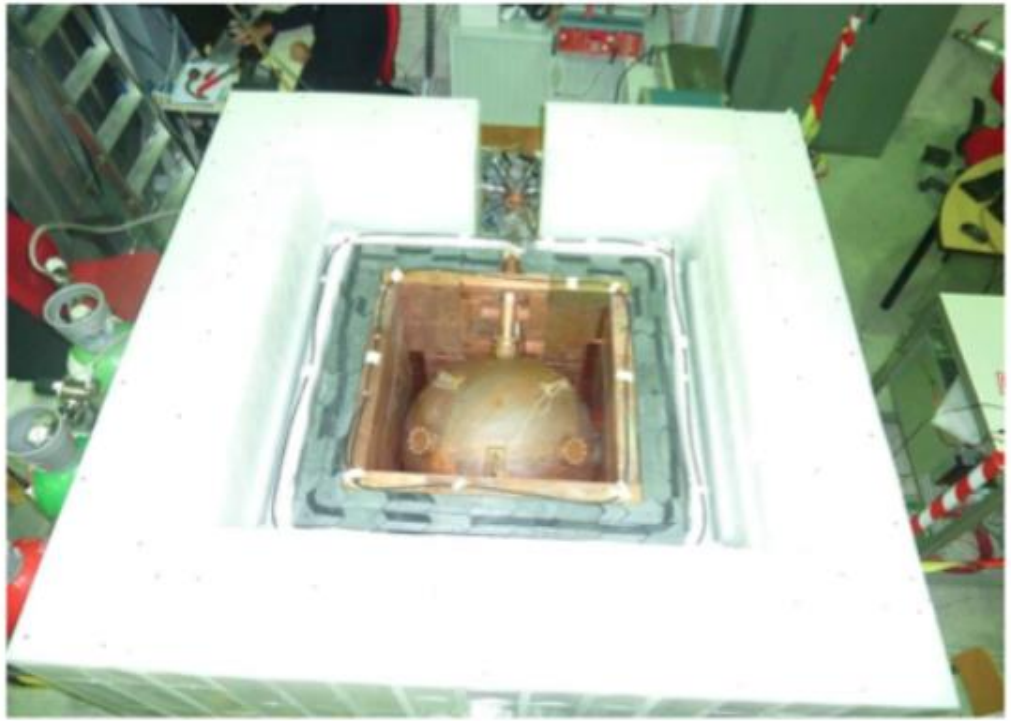


- Prototype SPC at the Laboratoire Souterrain de Modane (LSM): SEDINE
- 60-cm SPC filled with Ne(99.3)CH_4(0.7) at 3.1 bar (310 g active mass)
- 42 live day WIMP search run (9.7 kg-day) at 50 eV acquisition threshold

Recent Results from SEDINE at LSM

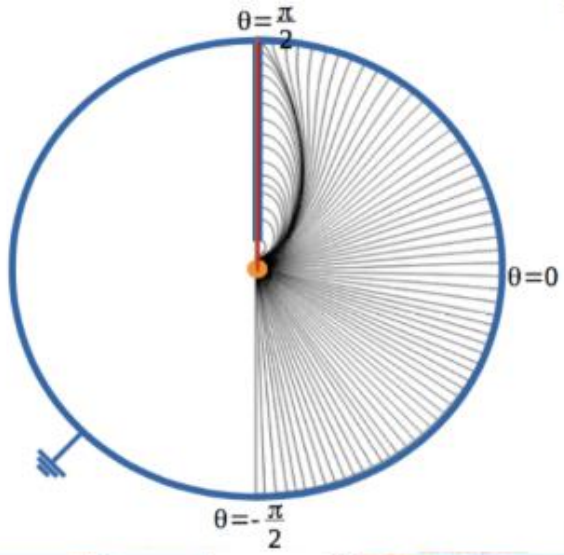
60-cm NOSV Copper SPC

6.3 mm sensor

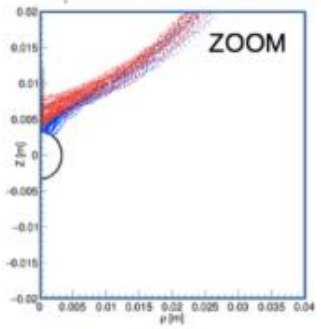


Shield: 2 - 7 cm Cu, 10 cm Pb, 30 cm PE

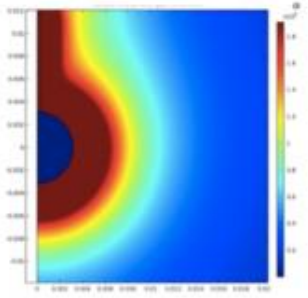
Recent Results from SEDINE at LSM



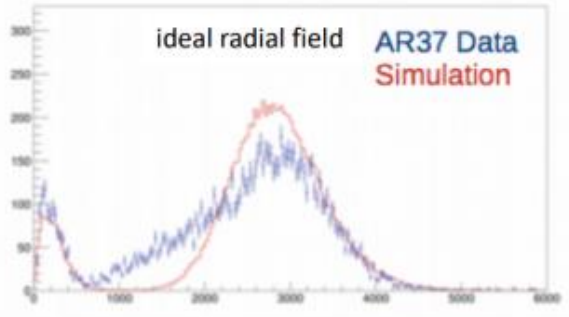
- **Drift of individual electrons** : Field map from COMSOL, drift parameters from Magboltz
- **Quenching** $Q(E_R)=0.216\,E_R^{\,0.163}$ parametrization derived from SRIM (Stopping and Range of Ions in Matter)
- **Avalanche** : Number of secondary ionizations drawn from the Polya distribution (parametrized with Garfield)
- **Simulated pulses** : (Ion Induced current **X** preamplifier response)
- **Noise templates** taken from the pretraces of real pulses
- **Same trigger algorithm and processing than for real pulses**

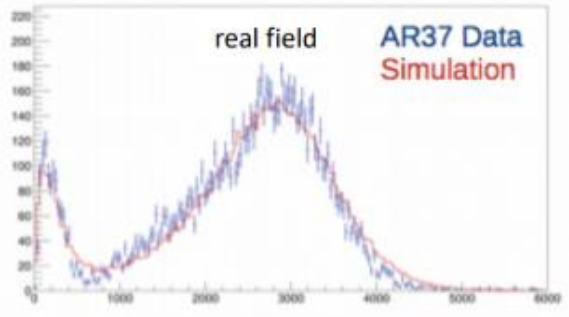


Drift at high teta

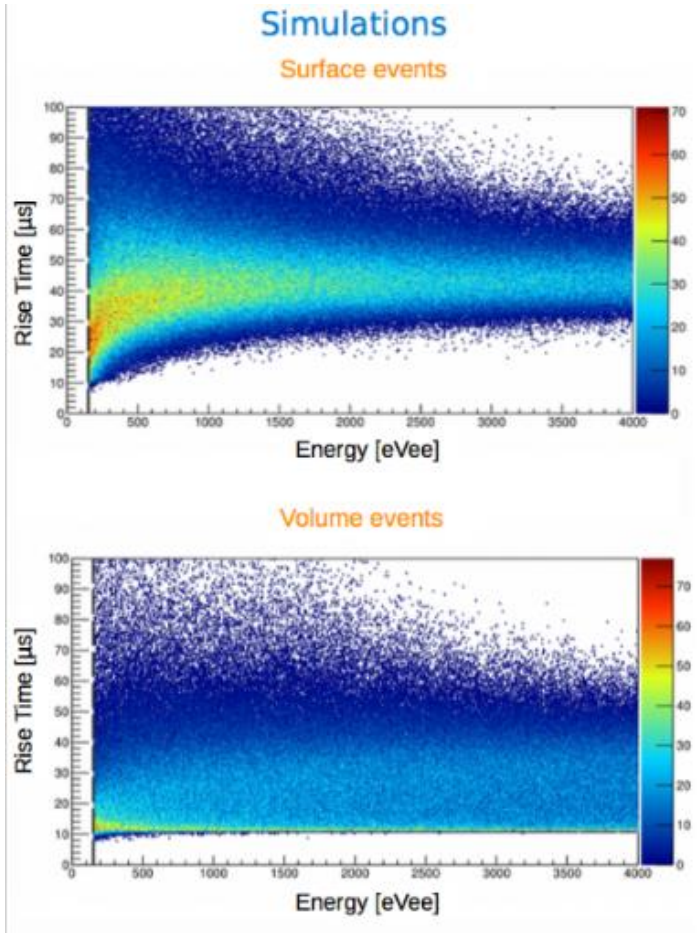


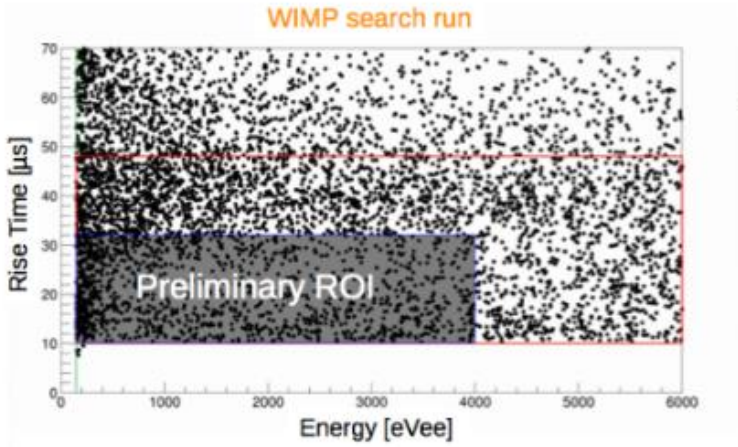
Field near sensor





Recent Results from SEDINE at LSM





Physics-run Data

Quality cuts responsible for 20.1 % dead time

Total exposure = 34.1 live-days x 0.28 kg = **9.7 kg.days**

Analysis threshold : 150 eVee (~720 eVnr)

100% trigger efficiency (trigger threshold @ ~35 eVee)

Side Band region used together with simulations to determine the number and distribution of background events expected in the **preliminary ROI**

Further tuning of the ROI performed with a Boosted Decision Tree (BDT)

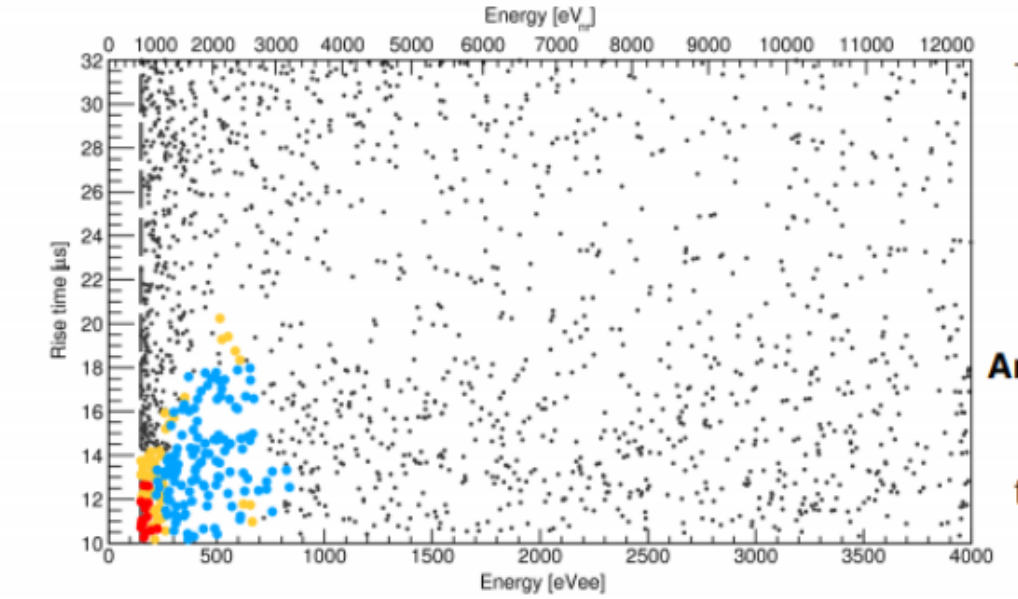
Q. Arnaud, Queen's

Recent Results from SEDINE at LSM

ROI optimization with Boosted Decision Tree (BDT)

Physics-run data analysis

WIMP mass dependent ROI for 8 WIMP masses



1620 events recorded in the preliminary ROI :

Fail any of the BDT cuts
pass the BDT cut for 0.5 GeV/c2 : 15 events
pass the BDT cut fot 16 GeV/c2 : 123 events
pass the BDT cut for other masses

Analysis methodology robust against background mis-modeling

If the BDT were to be trained with inaccurate bkg models,
the ROI would simply not be optimized for signal/bkg discrimination

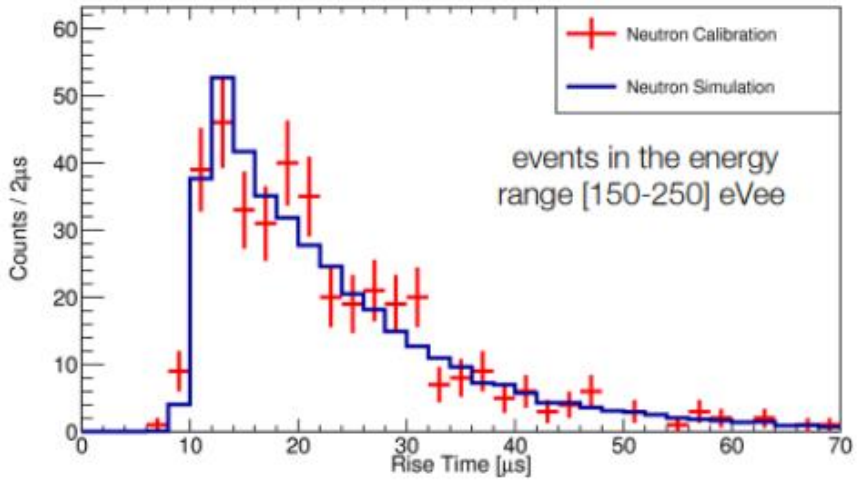
Q. Arnaud, Queen's

Recent Results from SEDINE at LSM

Validation of the modeling of the detector response in energy and rise time

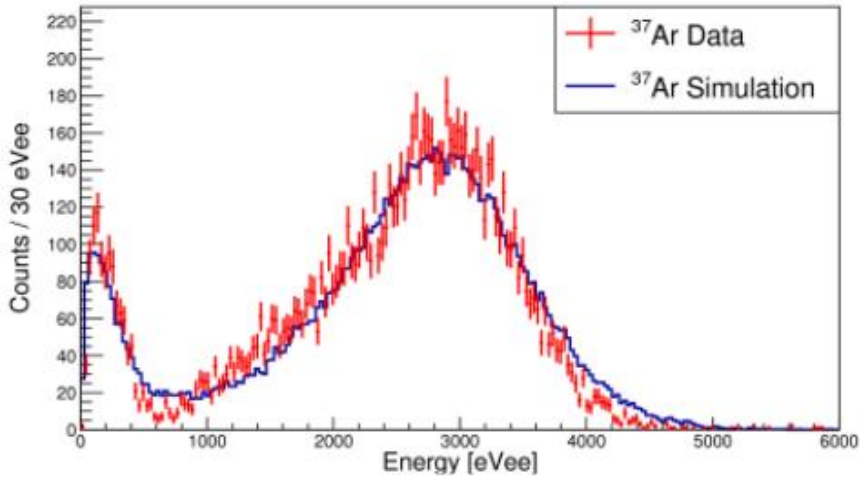
Am-Be neutron source

Nuclear recoils
homogeneously distributed in the volume



^{37}Ar gas added to the mixture

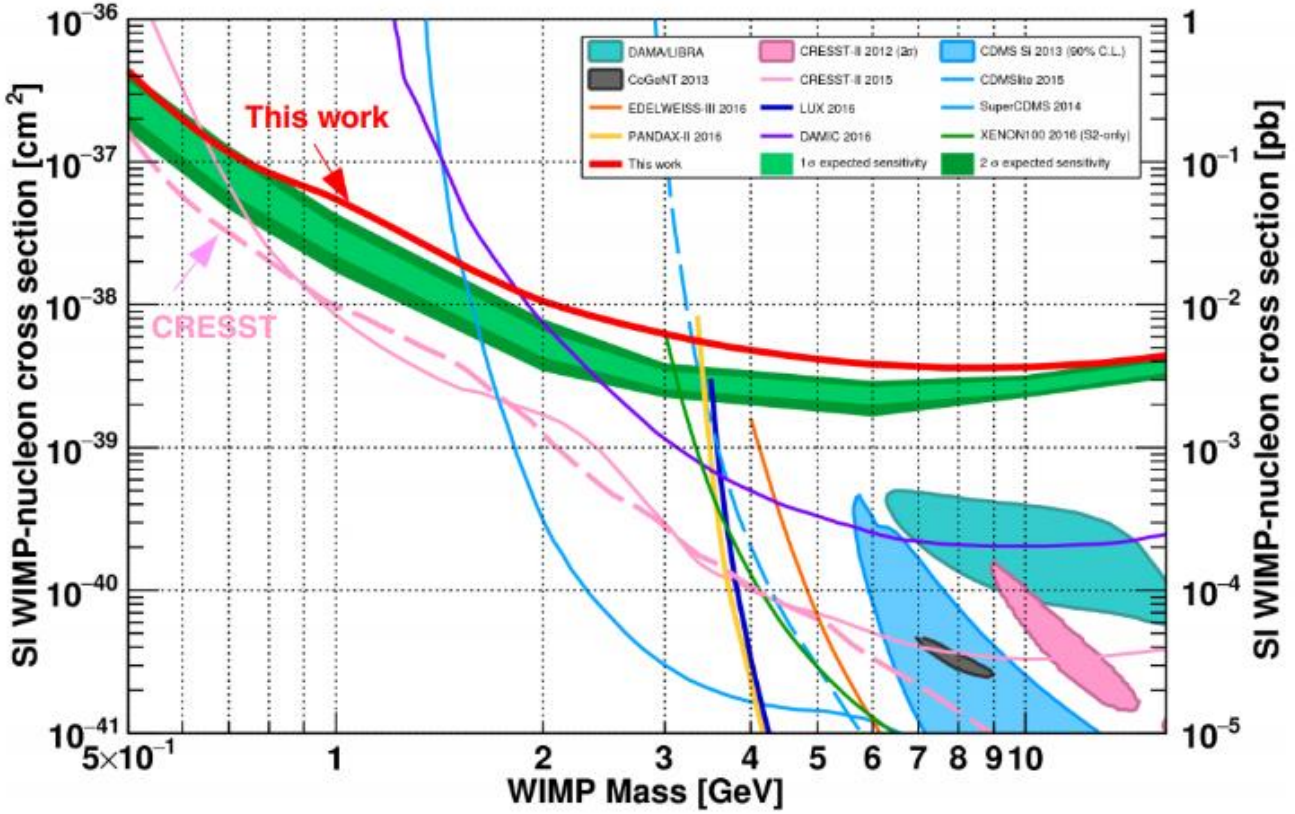
2.82 keV and 270 eV X-rays from
the electron capture in the K- and L-shells respectively



Good agreement between data and simulation:
Confidently derive the signal efficiency of cuts in rise time and energy from simulated WIMP events

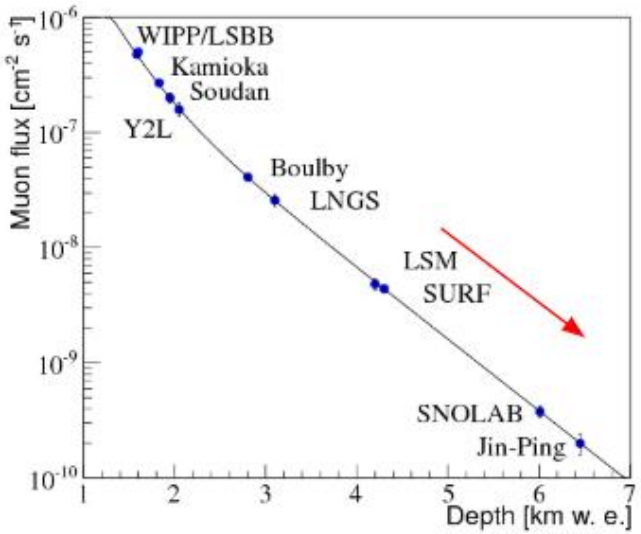
Q. Arnaud, Queen's

Recent Results from SEDINE at LSM



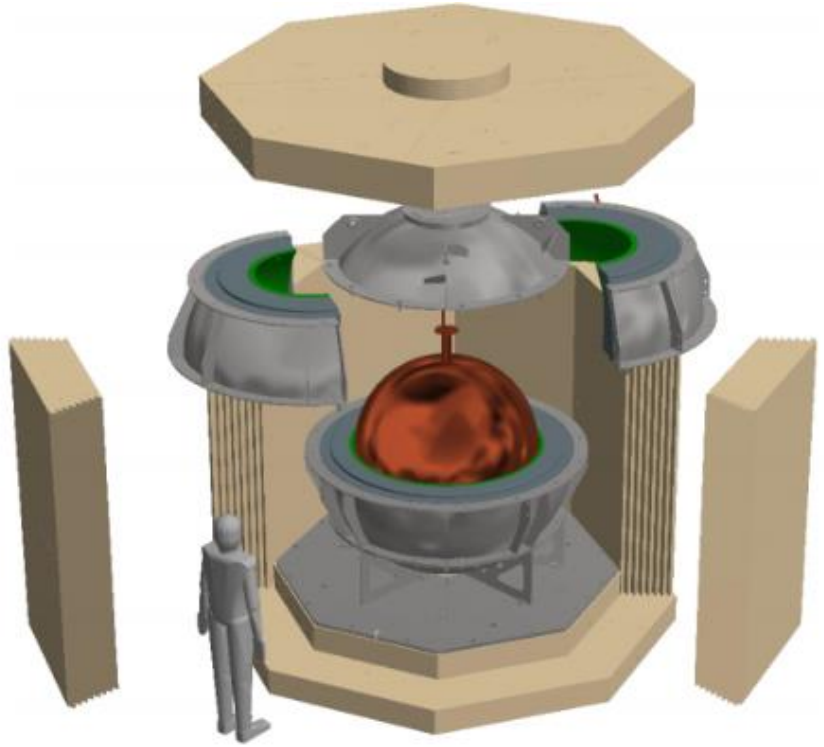
Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018) doi: 10.1016/j.astropartphys.2017.10.009

NEWS-G at SNOLAB



SNOLAB: 6000 mwe (0.27 μ/m^2 /day)

140 cm diameter low activity copper (C10100) SPC
7 - 25 µBq/kg ^{232}Th
1 - 5 µBq/kg ^{238}U
Electropolishing and electroplating

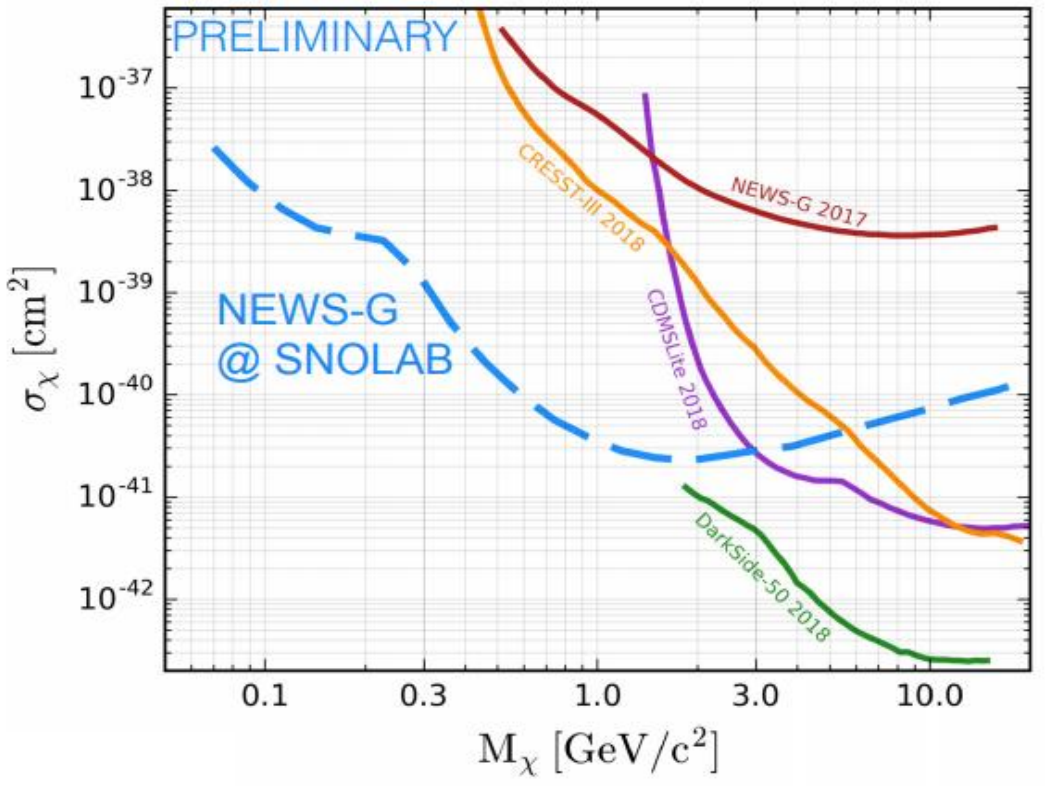


Compact Shielding (35 t)
40 cm borated PE
22 cm low activity Pb (3 cm archeological Pb)
SS enveloppe flushed with pure N (radon mitigation)

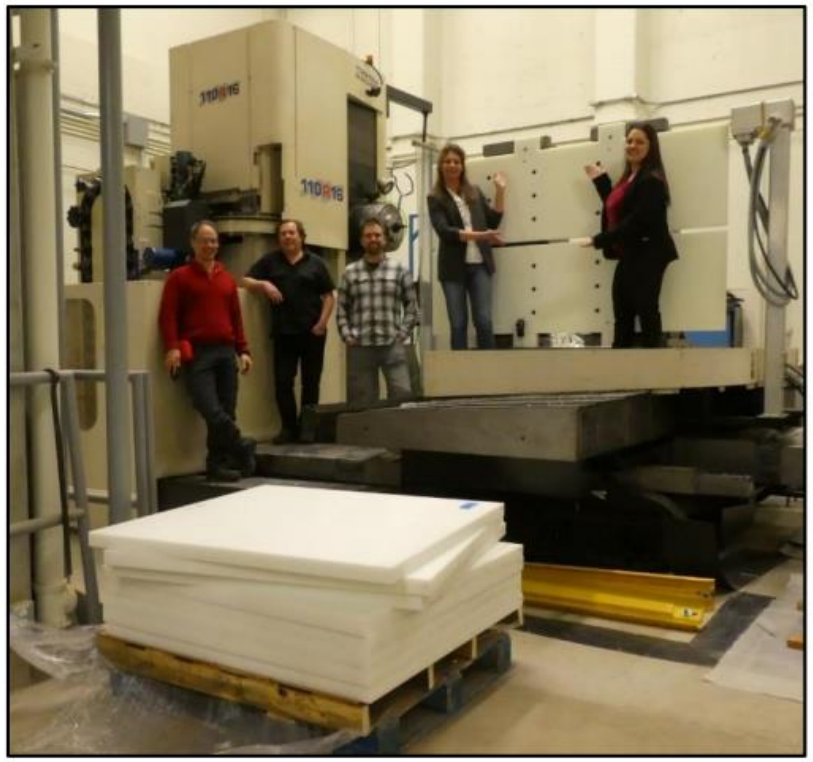
NEWS-G at SNOLAB

Projected sensitivity

Assumptions:
Ne + 10% CH_4, Exposure: 20 kg days, F = 0.2, θ = 0.12,
SRIM quenching factor, Background: 1.78 dru, ROI: 14 eV_{ee} - 1 keV_{ee}
Median of 500 MCs, Optimum Interval Method

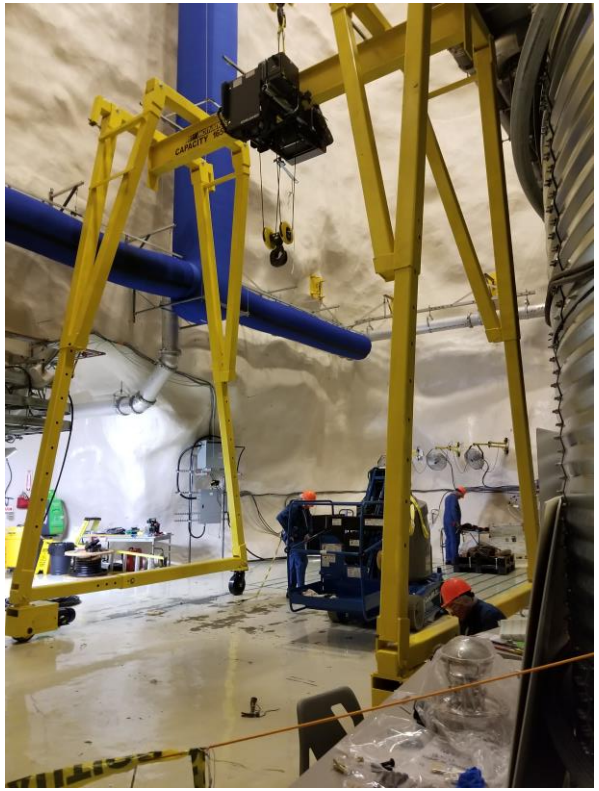


Status of SNOLAB PE shield



Polyethylene shielding components are being machined at the University of Alberta.
Shipping to SNOLAB is expected for November

Status of NEWS-G at SNOLAB

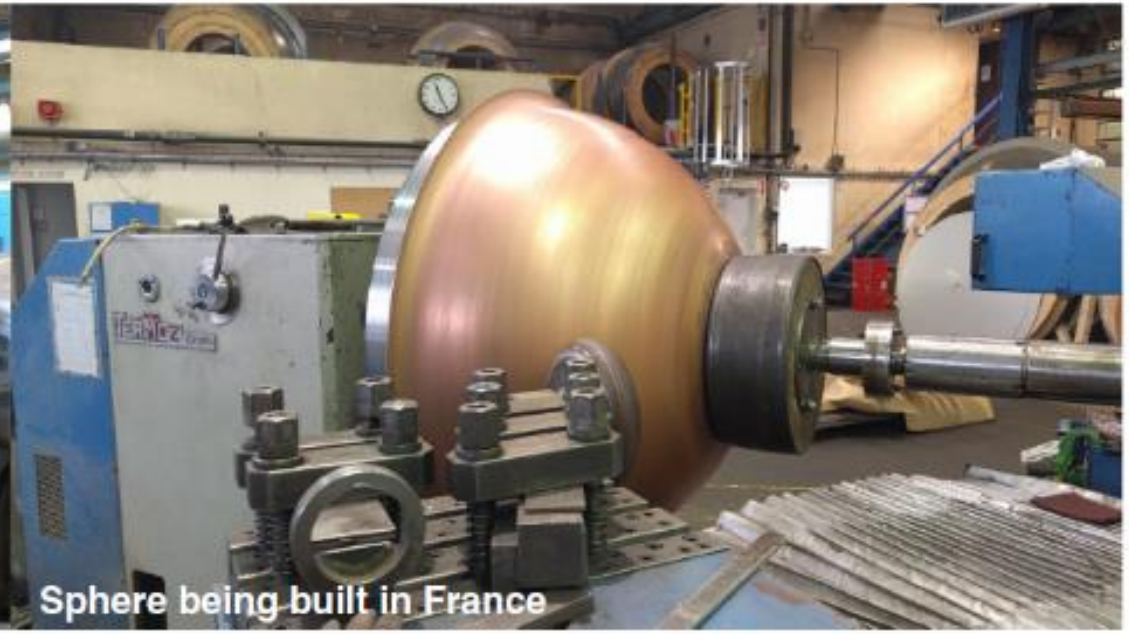


17-ton gantry crane constructed.
Commissioning in July

Seismic platform fabricated, shipping to SNOLAB in September

Status of NEWS-G at LSM


Copper spinning test

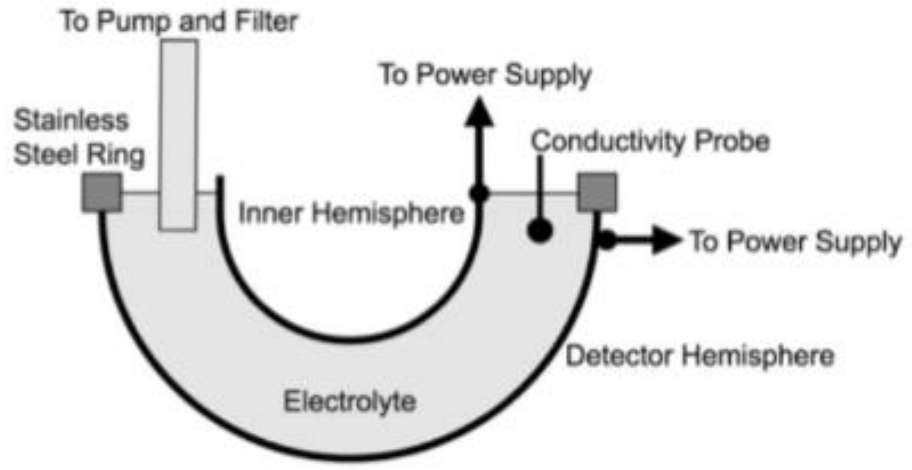

Sphere being built in France

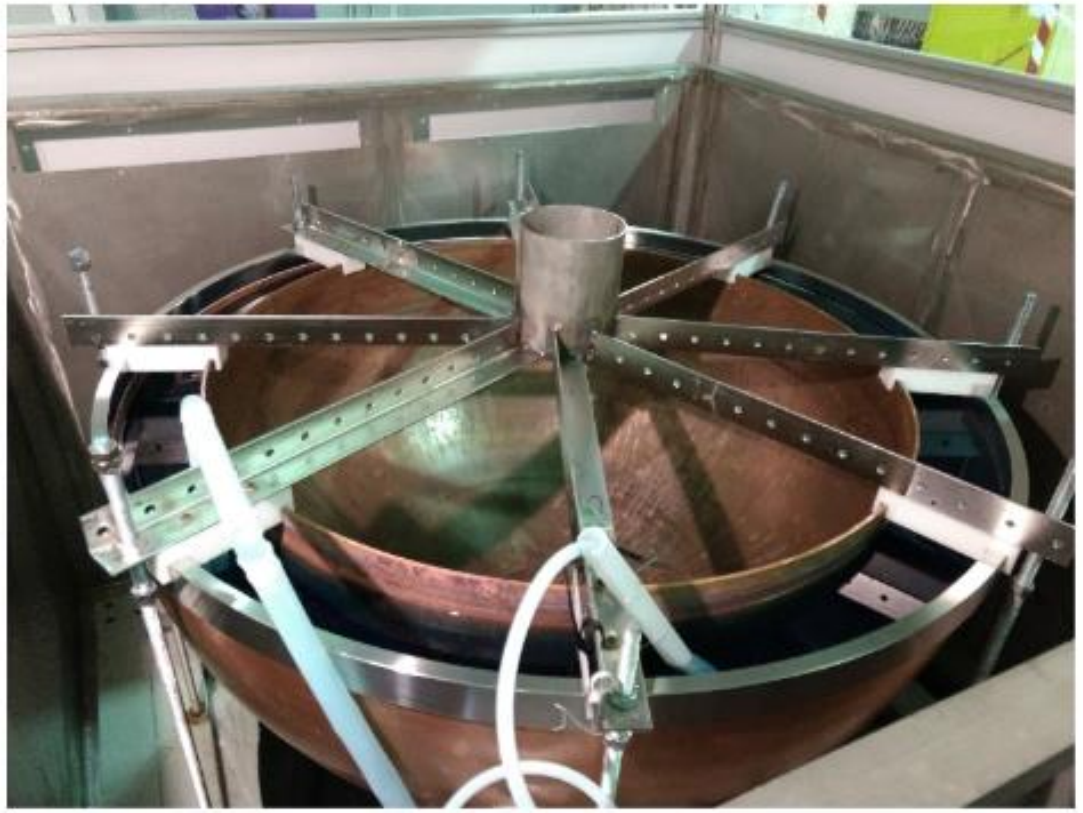
Hemisphere Spinning and Glovebox

Status of NEWS-G at LSM

Mitigation of the ^{210}Pb bulk copper background:

Electroplating of the Hemisphere inside surface

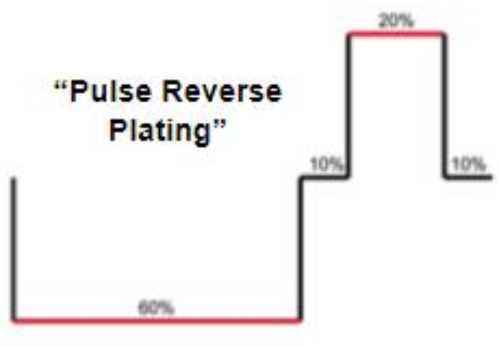


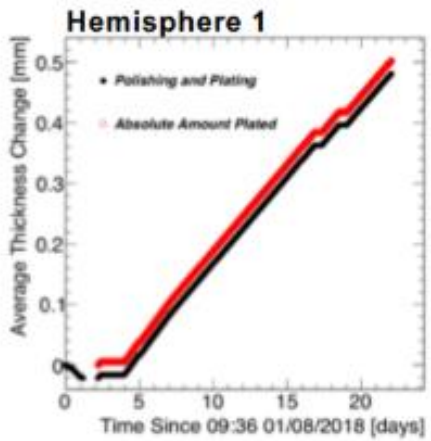


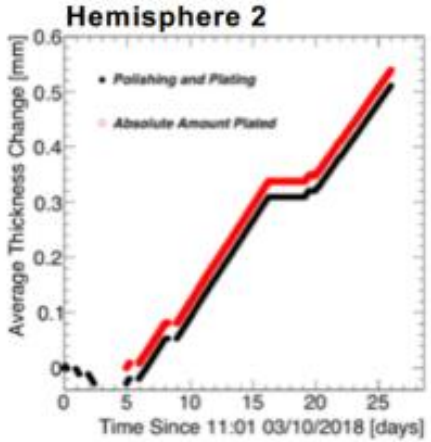
Status of NEWS-G at LSM

Status:

- 0.5 mm plated on the 2 hemispheres underground at LSM
- Surfaces cleaned and passivated
- Stored in radon tight plastic and ready to electron-beam welding





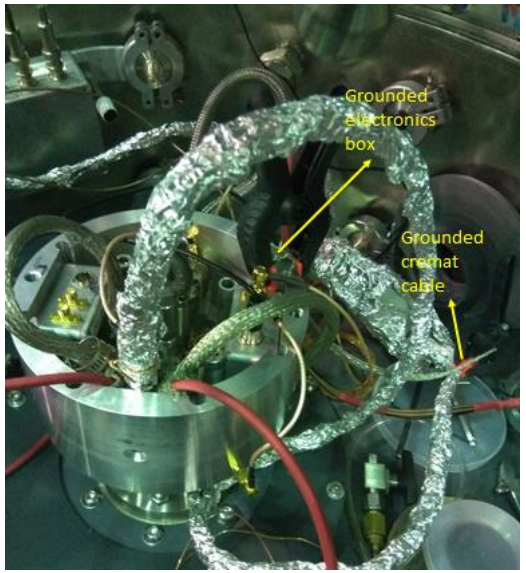


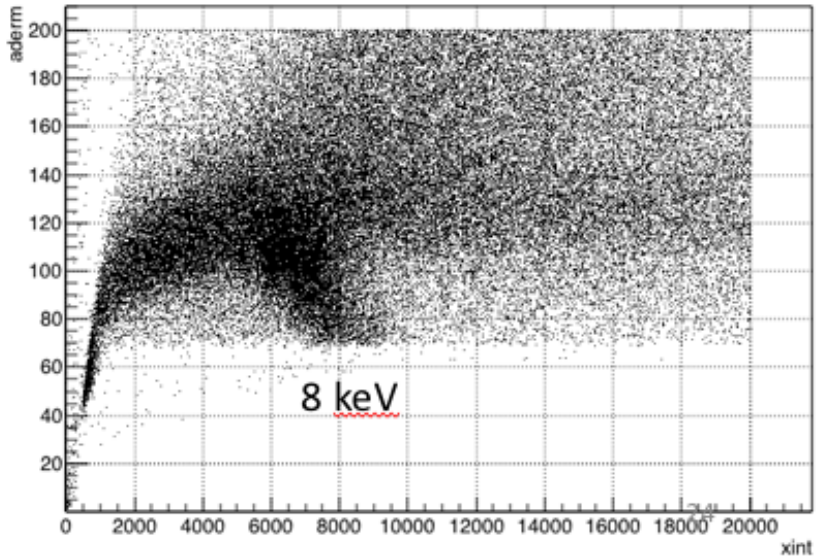
Status of NEWS-G at LSM

Sphere's interior and exterior etched with H2O2 and sulfuric acid

Status of NEWS-G at LSM

"First Commissioning" (no lead shield) in early summer





Glovebox installation, sensor rod insertion, gas fill (Ar + CH_4), electronic noise hunting, first physical pulses!

Physics run with pure CH_4 in Aug. – Sep.

Status of NEWS-G at LSM

SPC in lead shielding

LSM neutron shielding water tank

THANK YOU!

Extra Slides

Roadmap

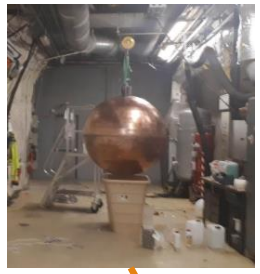
SPC invention (I. Giomataris 2008)

In the picture:
I.Giomataris, G.Charpak

SEDINE (2015)

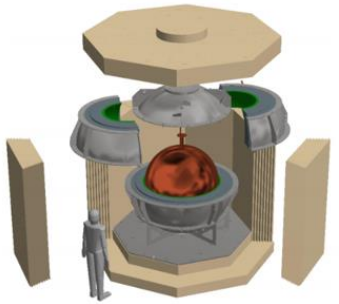
At LSM

NEWS-G 140-cm (Summer 2019)

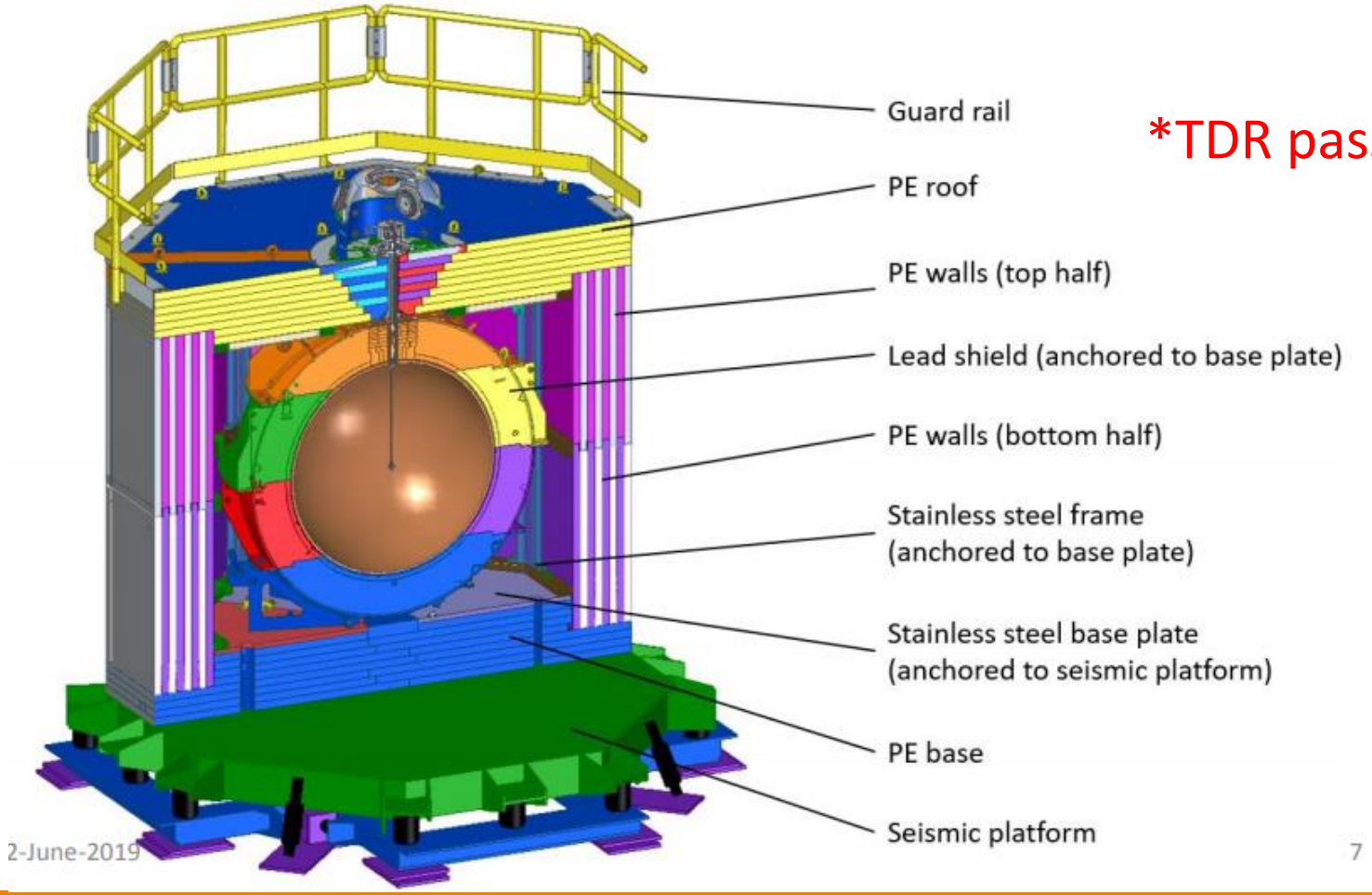


NEWS-G 140-cm (Fall 2019)

At SNOLAB

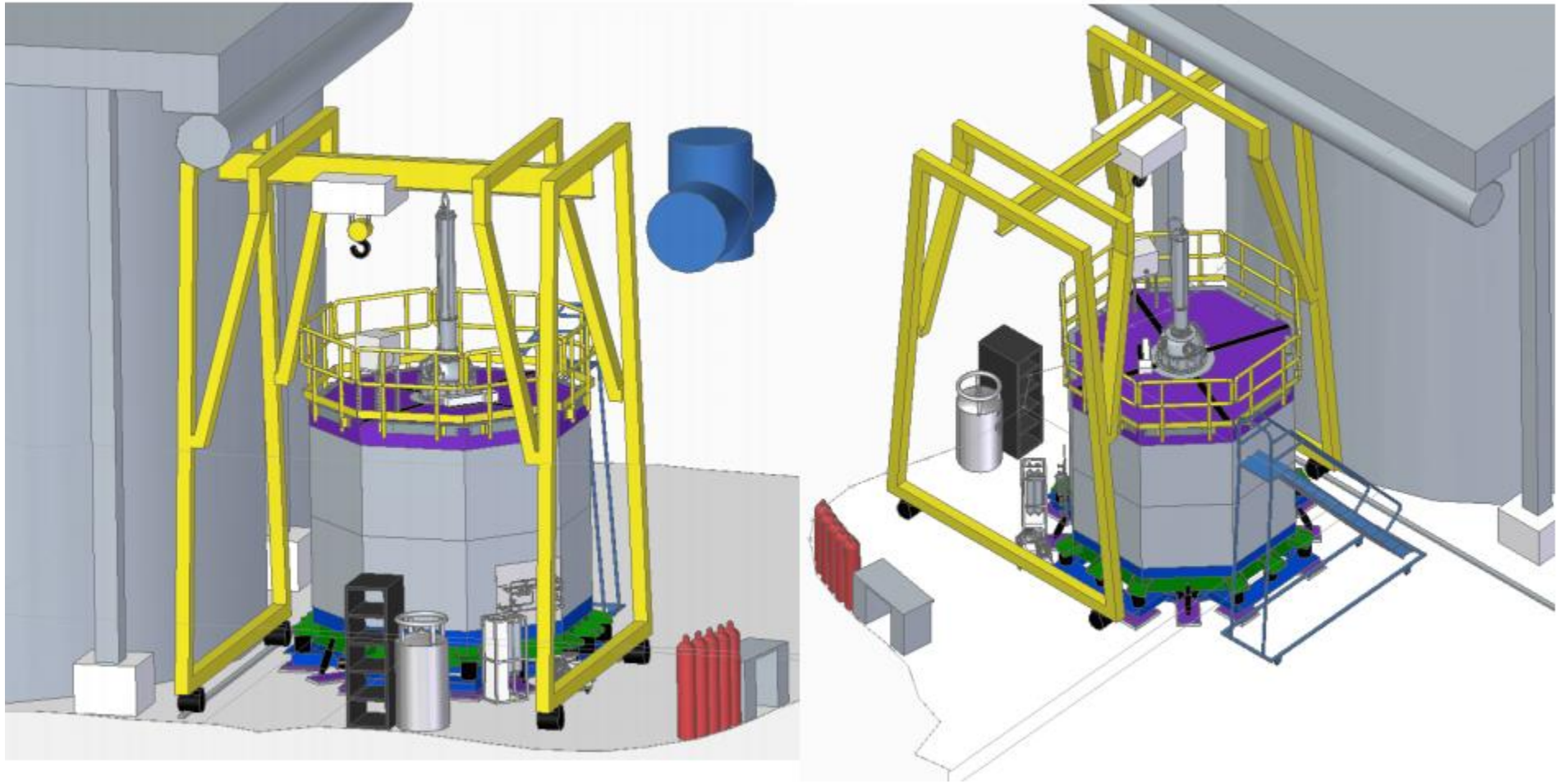


Status of NEWS-G at SNOLAB



TDR passed April 2019

Layout of NEWS-G at SNOLAB

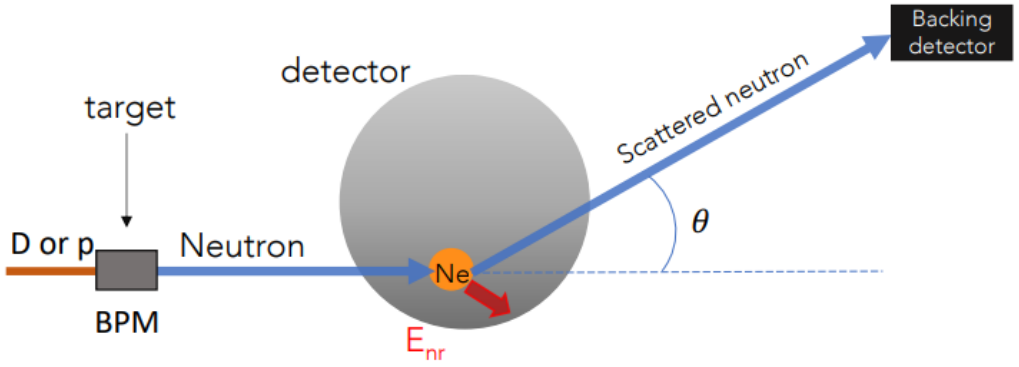


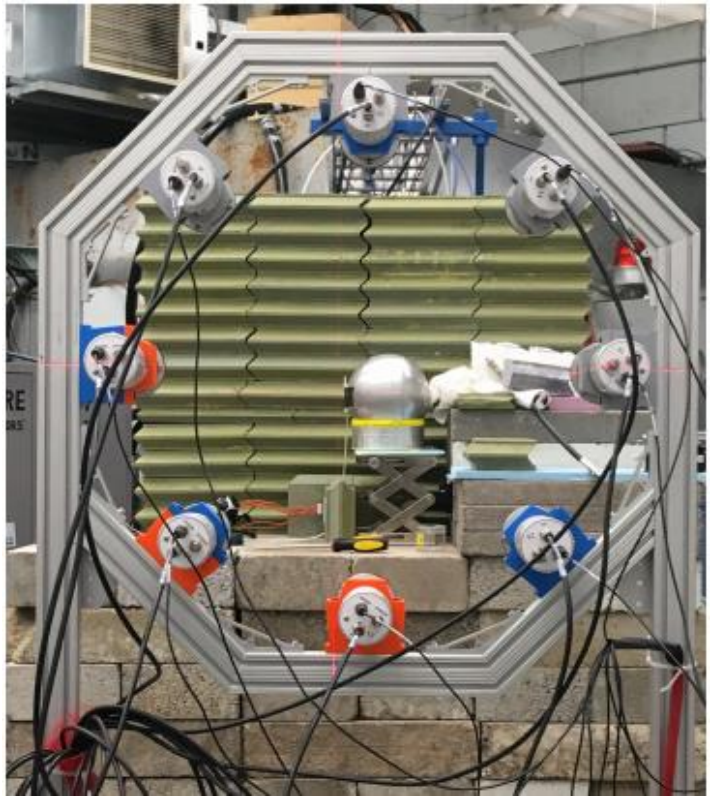
Quenching Factor Measurements

Quenching Factor Measurements

Quenching factor measurements at TUNL (Duke) Tandem facility.

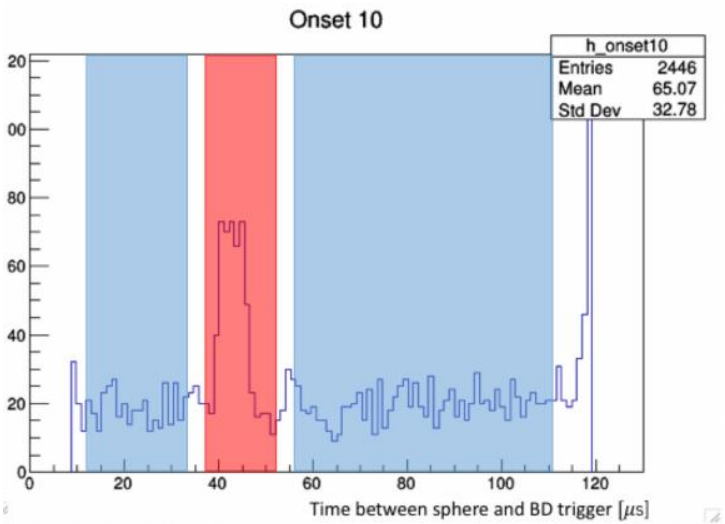
Probing nuclear recoil energy points between 0.34 and 27 keVnr



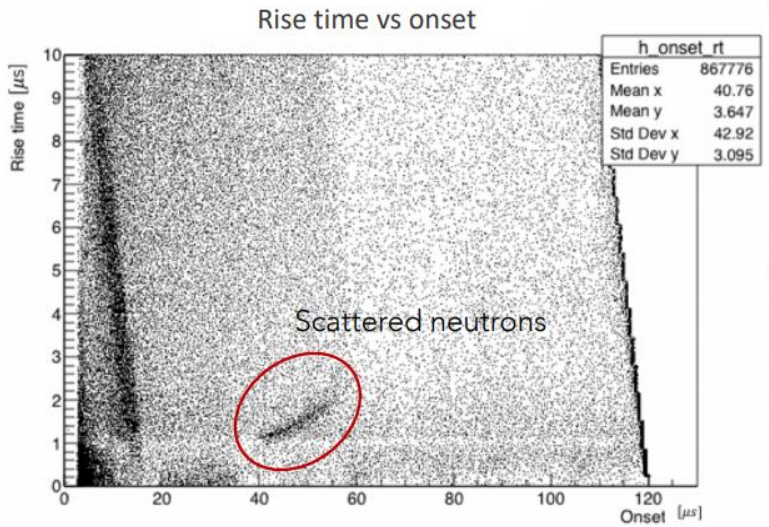


Marie Vidal, Queen's

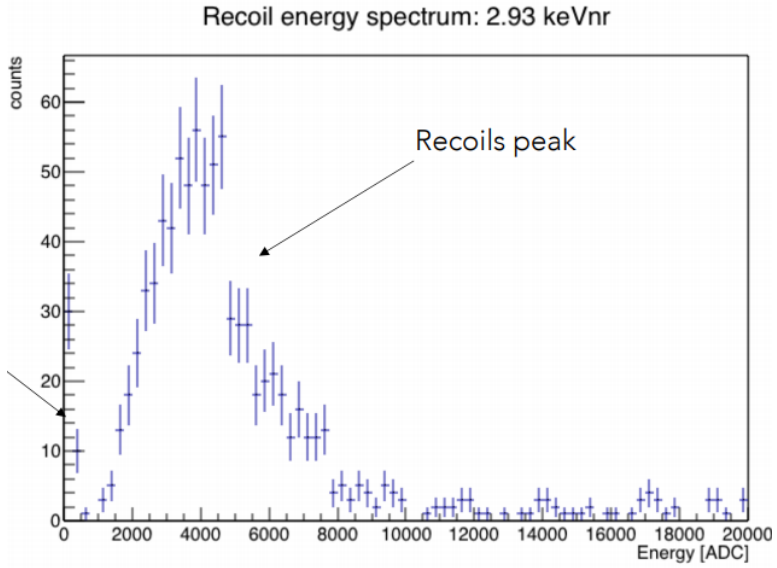
Quenching Factor Measurements



Location of SPC events in time relative to the DAQ trigger (/BD trigger)
→ Excess ~ 40 μs
→ Signal of interest!



Dependence in rise time and onset time



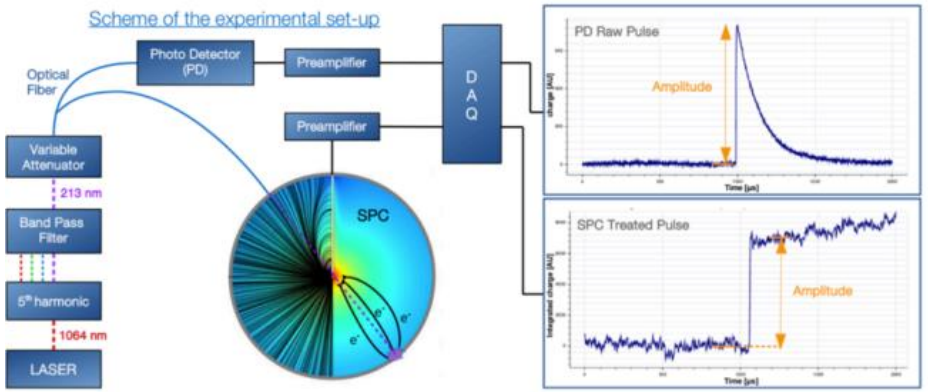
Analysis is underway to extract quenching factors at different energies

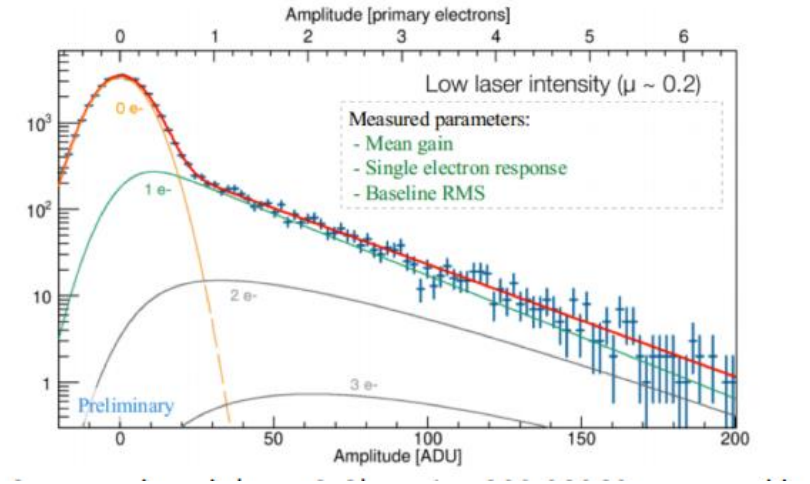
Marie Vidal, Queen's

R&D Activities

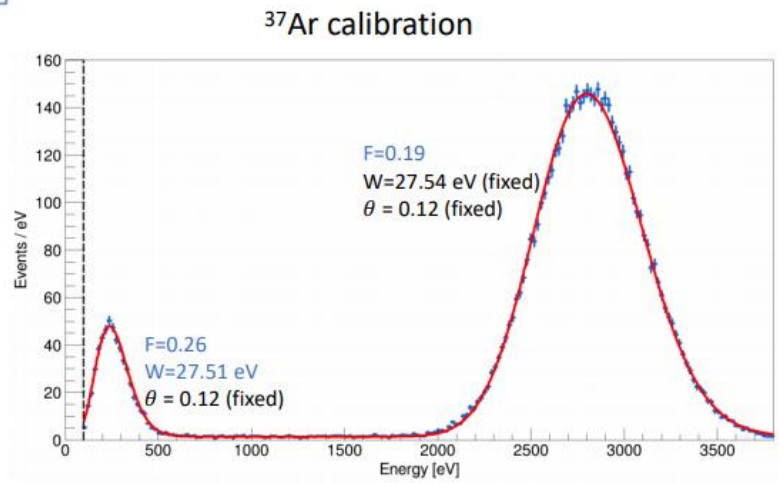
Laser Calibration

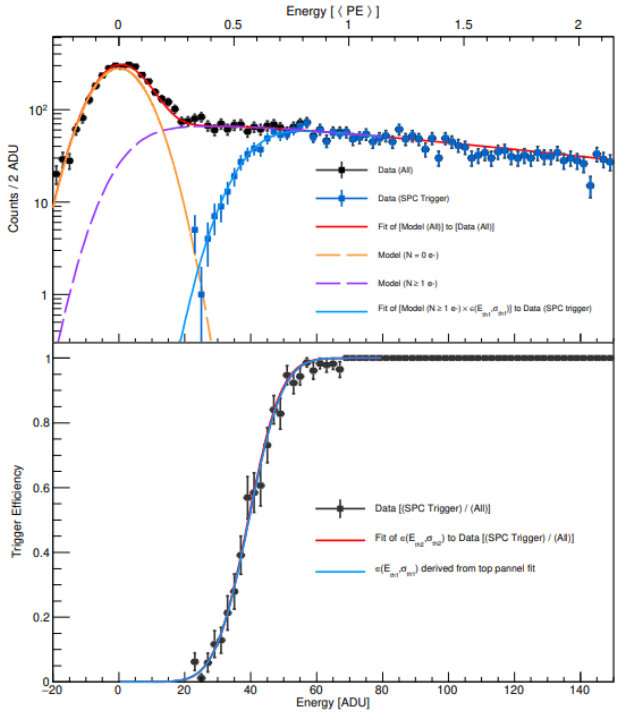
Q. Arnaud, et al., Phys. Rev. D 99, 102003 (2019)





- Measure mean gain to 1% precision
- Measure drift and diffusion time
- Monitor stability of detector within 1%
- Measure trigger threshold efficiency
- Measure of W-value to 1% precision and constraint on the Fano factor

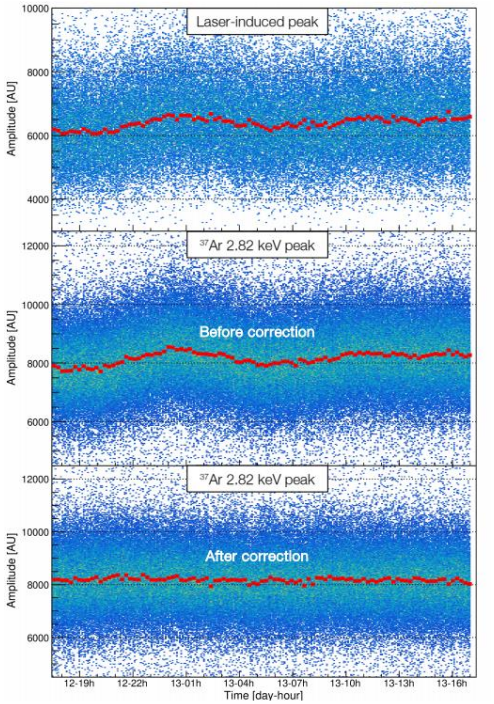




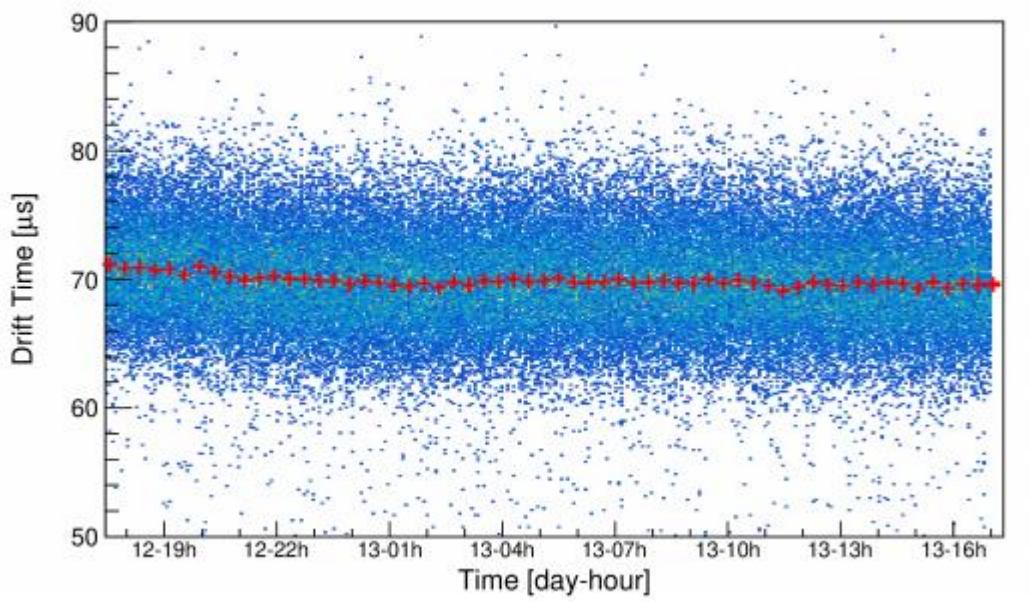
Laser Monitoring

Q. Arnaud, et al., Phys. Rev. D 99, 102003 (2019)

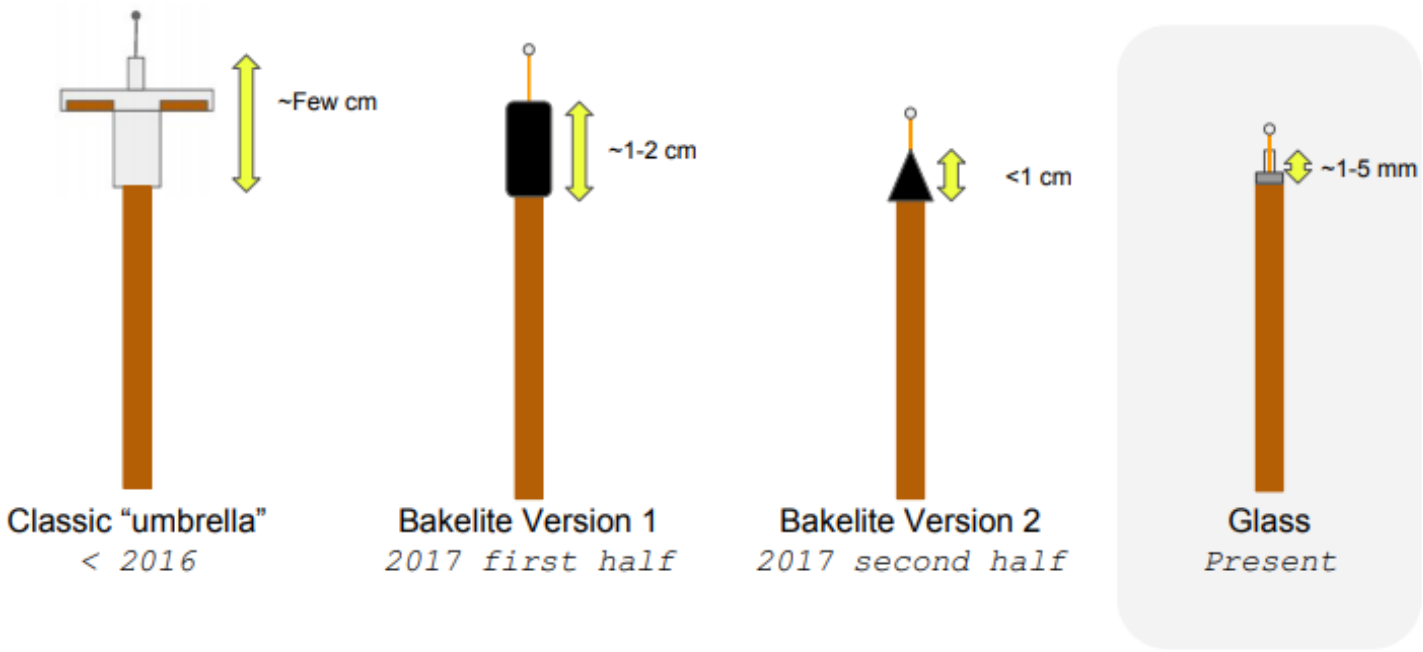
Monitoring of detector gain



Monitoring of drift time



Sensor Development

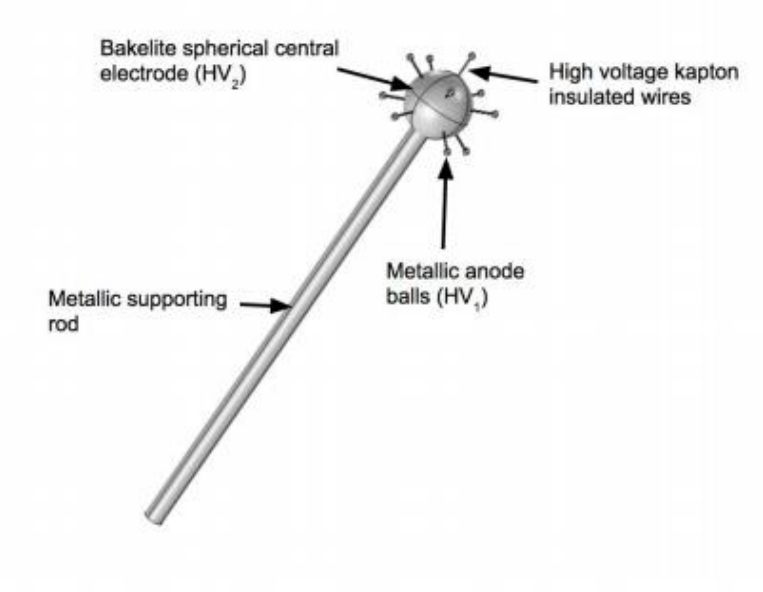


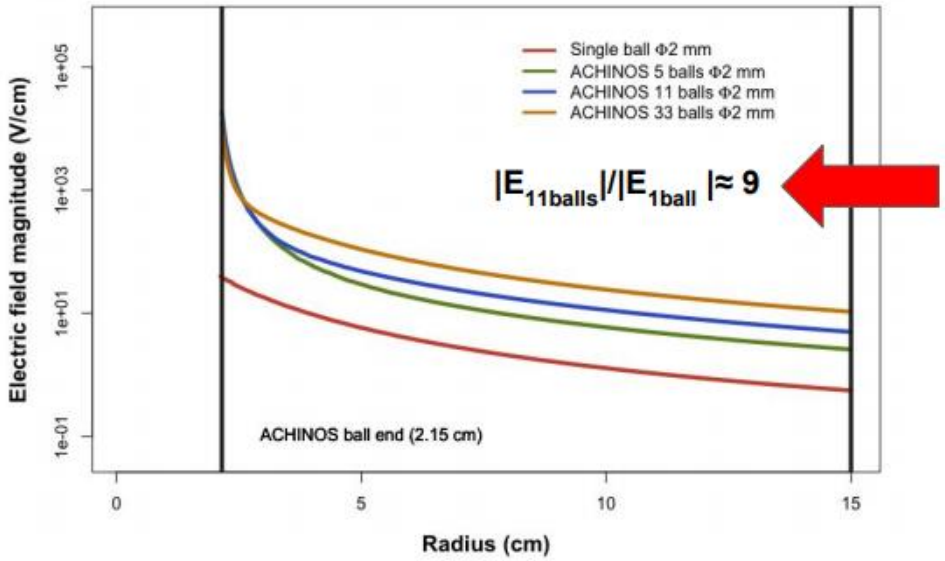
Various electrode configuration have been tested to improve field uniformity, detector stability, sparking, etc.

I. Katsioulas, Birmingham

Sensor Development

A. Giganon, et al., JINST 12 (2017)





New multi-ball sensors allow for higher E field at long range, while keeping the amplification field on each small ball: **ACHINOS sensors** (Greek for Sea-Urchin)

Multichannel readout

- North/South: Field uniformity
- Dark Matter Directionality

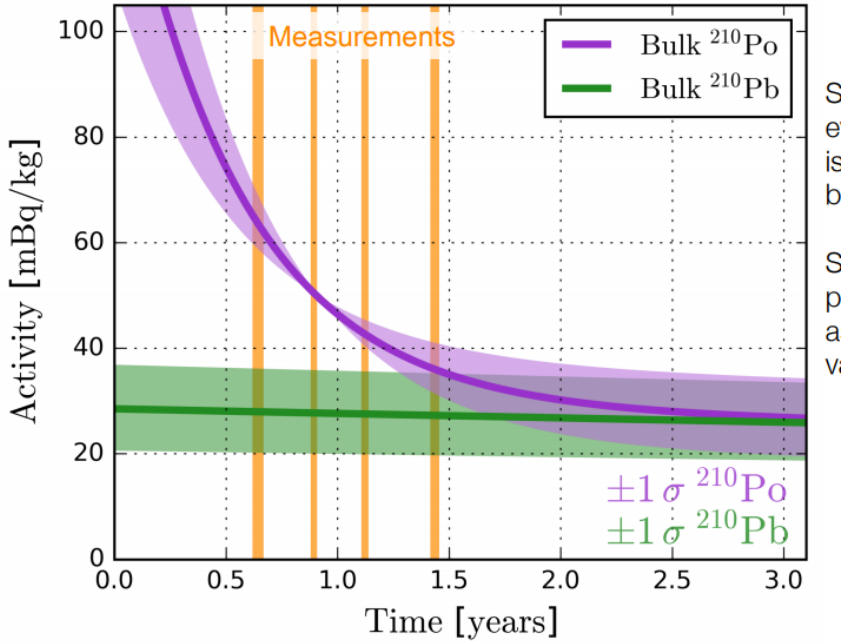
Copper Backgrounds

Copper backgrounds

See A. Brossard talk on Wednesday at the Low Background Workshop for details

Current status: 140-cm sphere (C10100 Cu)

- Commercial copper, leading source of background is ^{210}Pb from the bulk copper. Recently measured with XIA by XMASS collaboration at 29 +/- 8 Bq/kg, ~5 times as much as all other backgrounds combined



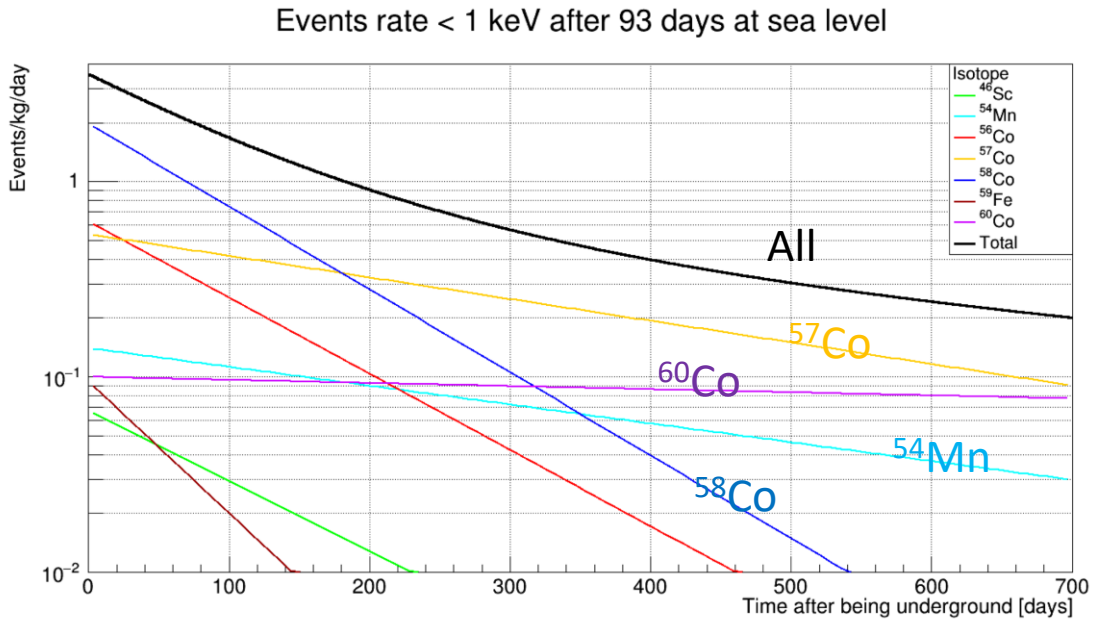
1.5 DRU

[Dan Durnford]

Copper backgrounds

Current status: 140-cm sphere (C10100 Cu)

- Spinning, welding, weld repair: ~93 days at the sea-level
- Cosmogenic activation: long lived ^{60}Co, but also shorter lived ^{58}Co, ^{57}Co, ^{54}Mn.



~4 DRU at t = 0

~0.4 DRU at t = 1 yr

[Alexis Brossard]

Future Mitigation of Copper Backgrounds

Ultimate solution:

- Electroforming of a monolithic copper shell in an underground environment (PNNL, or in situ at SNOLAB or LSM)
  - Perfect control on cosmogenic activation
  - Removes machining steps that may add backgrounds
  - No measurable ^{210}Po with XIA, < 4.1 mBq/kg, but expected to be << 4.1 mBq/kg
- Currently prohibited by costs
  - Mostly costs of manpower at PNNL
- There is a need to establish a new underground facility for this art
  - LSM is starting on this, which would mean physics run at LSM (cosmogenics)
  - Canfranc, Jinping are on it…
  - SNOLAB?

Future Mitigation of Copper Backgrounds

Intermediate solution:

- Cleanest commercially available copper sphere: Mitsubishi Material Corporation (MMC) 6N copper
  - 99.9999% Purity
  - No measurable ^{210}Pb with XIA (<4.1 mBq/kg)
- A 60-cm SPC to be certified for 10-bar pressure
  - Production of disks limit SPC size to 70 cm.
  - 60-cm chosen to leave option open to host in SEDINE shielding at LSM
  - Design piping to be able to fit in NEWS-G SNOLAB shielding
- Mitigation of cosmogenic activation
  - Dedication of a production line at MMC
    - Delivery 3 months after order
    - 1.5 months to prepare production line
    - 1.5 months to production from electrolization to disk form
  - Learning from previous experience and manage better shipping, machining, and transport between machining sites and LSM/SNOLAB