Review of the NEWS-G Dark Matter Searches and Related Projects

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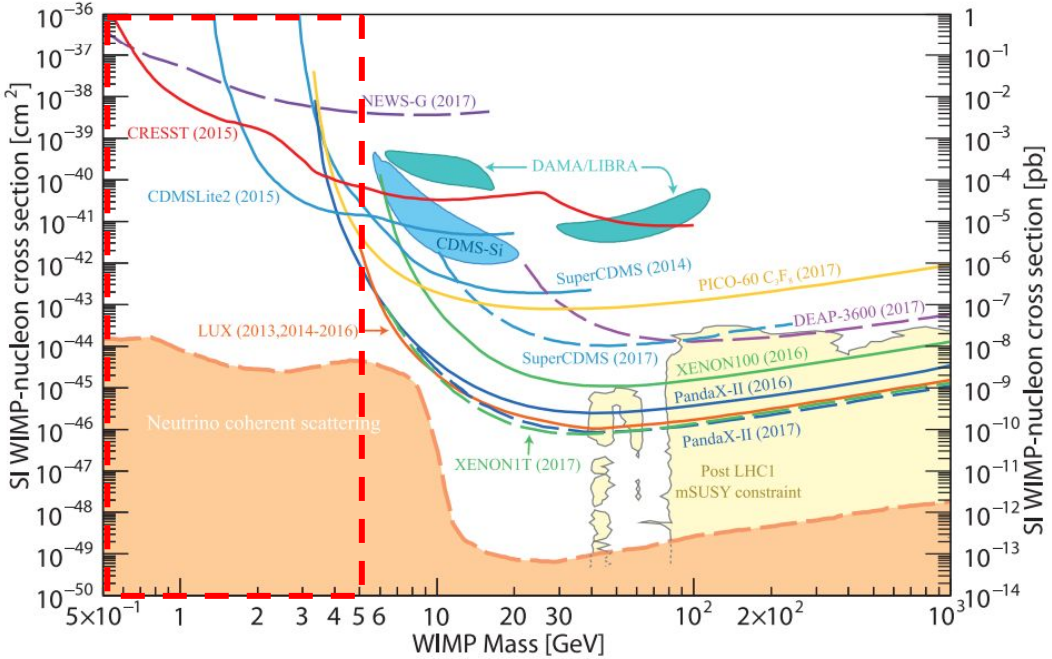
Arthur B. McDonald Canadian Astroparticle Physics Research Institute
Queen's University, Canada

9th Symposium on Large TPCs for Low-Energy Rare Event Detection
Paris, France

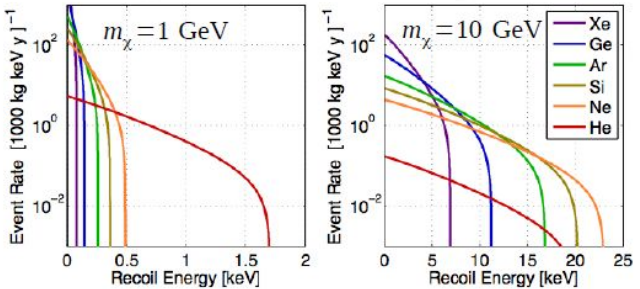
The Search for Low-Mass Dark Matter



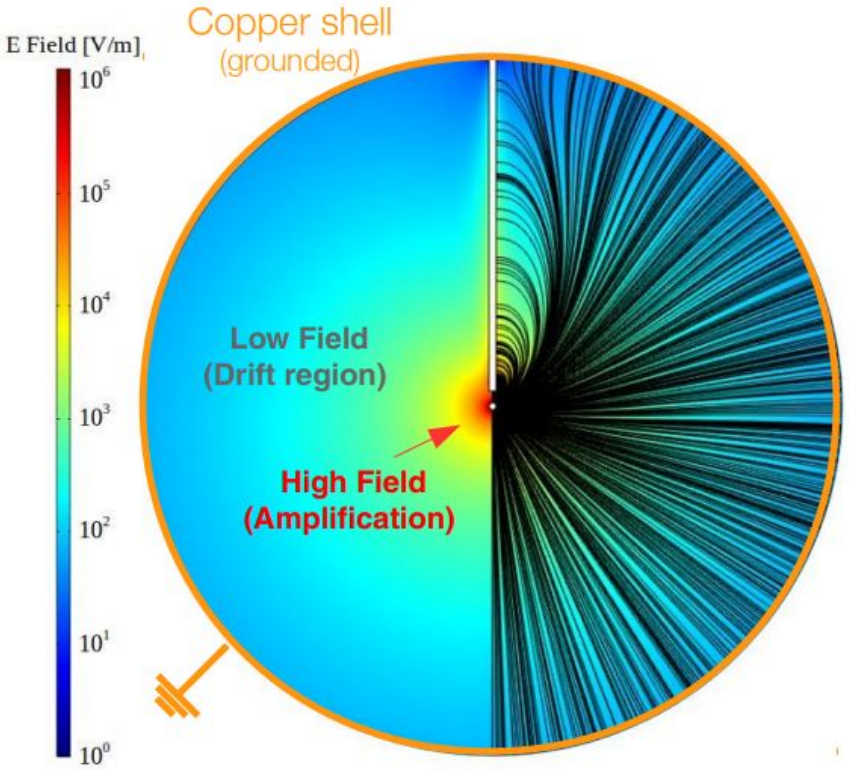
Requirements:

- 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

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

Pulse shape discrimination

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

Light Targets (H,He,Ne)

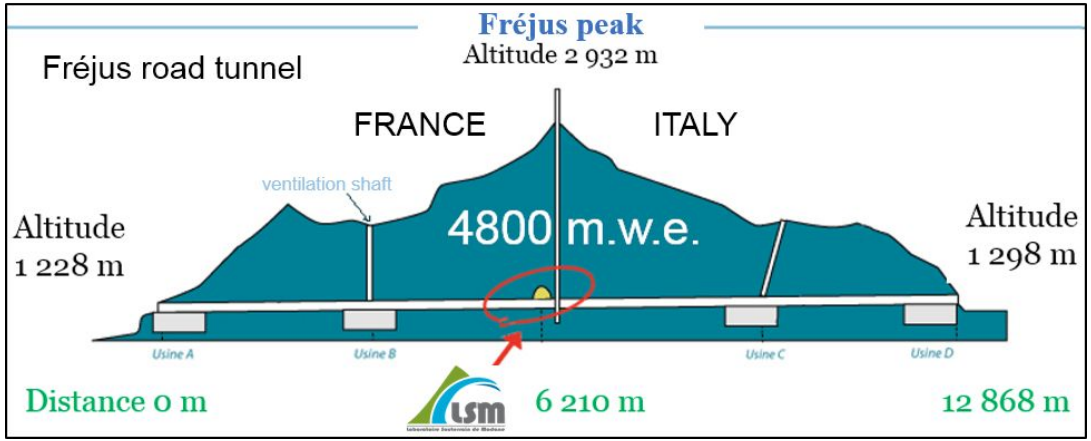
The NEWS-G Collaboration

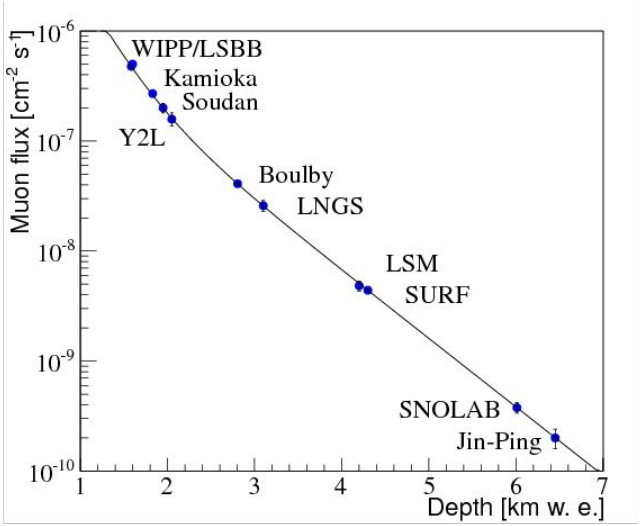
- **Queen's University Kingston – G Gerbier,** P di Stefano, R Martin, G Giroux, D Dunrford, S Crawford, M Vidal, G Savvidis, A Brossard, P Vazquez dS, Q Arnaud, K Dering, J Mc Donald, M Chapellier, A Ronceray, P Gros, A Rolland, , C Neyron
  - Copper vessel and gas set-up specifications, calibration, 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

The SEDINE Detector at Modane

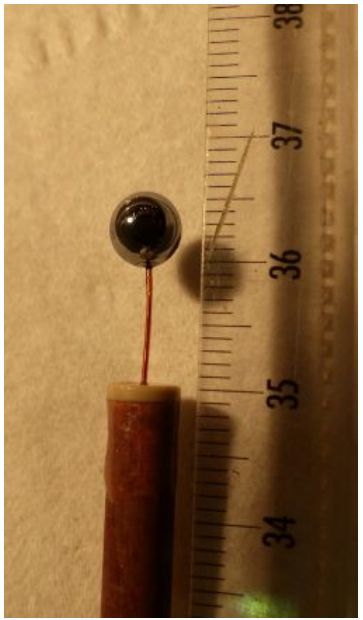




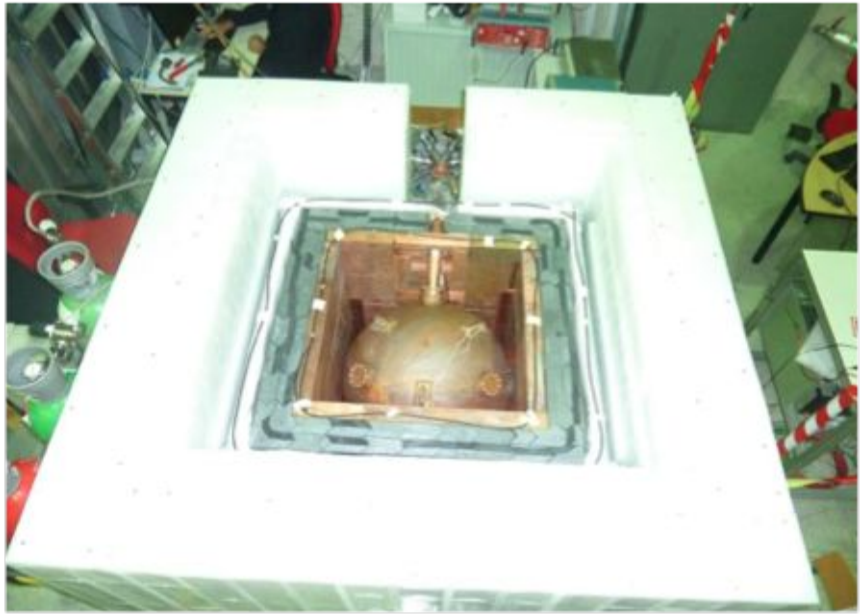
- Prototype SPC at the Laboratoire Souterrain de Modane (LSM): SEDINE
- 60-cm SPC filled with Ne(99.3)CH_4(0.7) at 3.1 bar (310 g active mass)
- 42 live day WIMP search run (9.7 kg-day) at 50 eV acquisition threshold

The SEDINE Detector at MODANE

60-cm NOSV Copper SPC

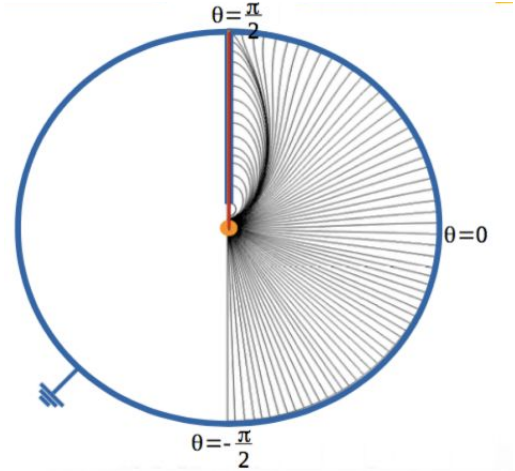


6.3 mm sensor

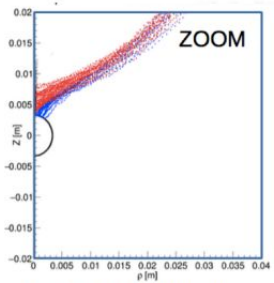


Shield: 2 - 7 cm Cu, 10 cm Pb, 30 cm PE

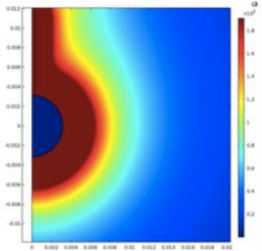
Recent Results from SEDINE



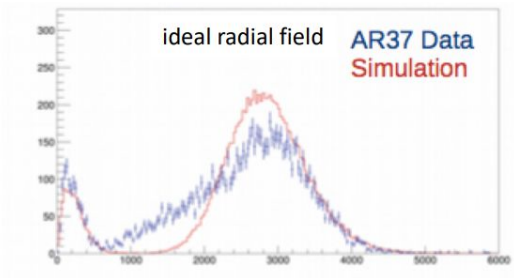
- **Drift of individual electrons** : Field map from COMSOL, drift parameters from Magboltz
- **Quenching** $Q(E_R)=0.216\,E_R^{0.163}$ parametrization derived from SRIM (Stopping and Range of Ions in Matter)
- **Avalanche** : Number of secondary ionizations drawn from the Polya distribution (parametrized 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**

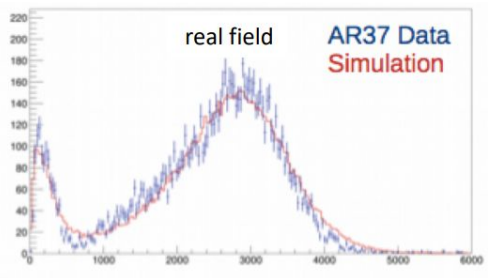


Drift at high teta



Field near sensor

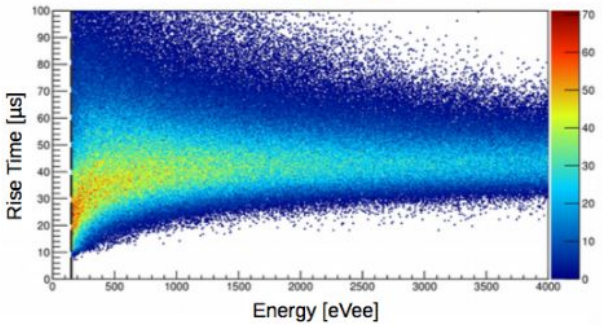




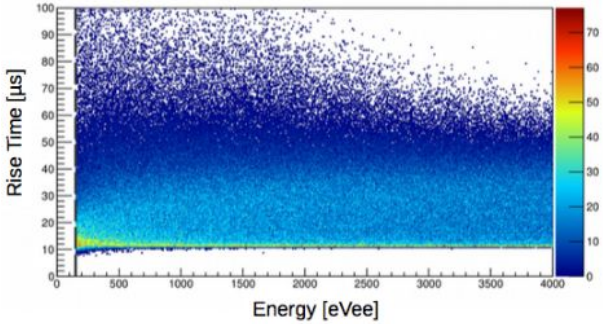
Recent Results from SEDINE

Simulations

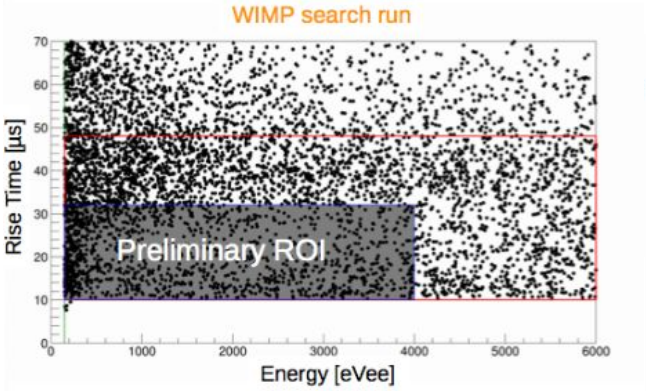
Surface events



Volume events



WIMP search run



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)

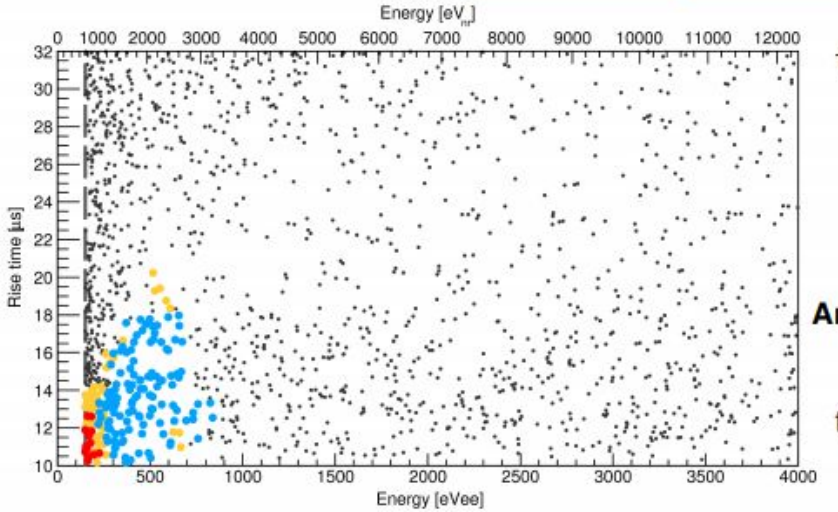
Q. Arnaud, Queen's

Recent Results from SEDINE

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

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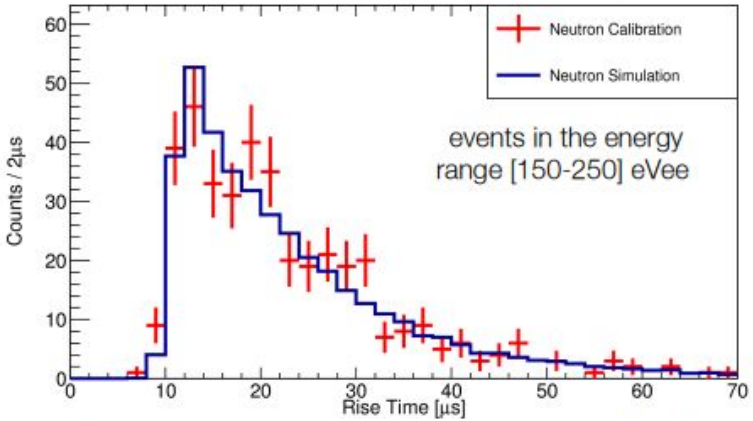
Recent Results from SEDINE

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

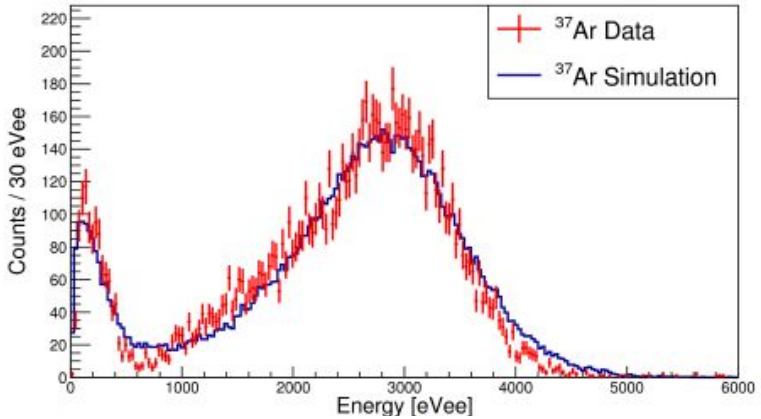
Am-Be neutron source

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

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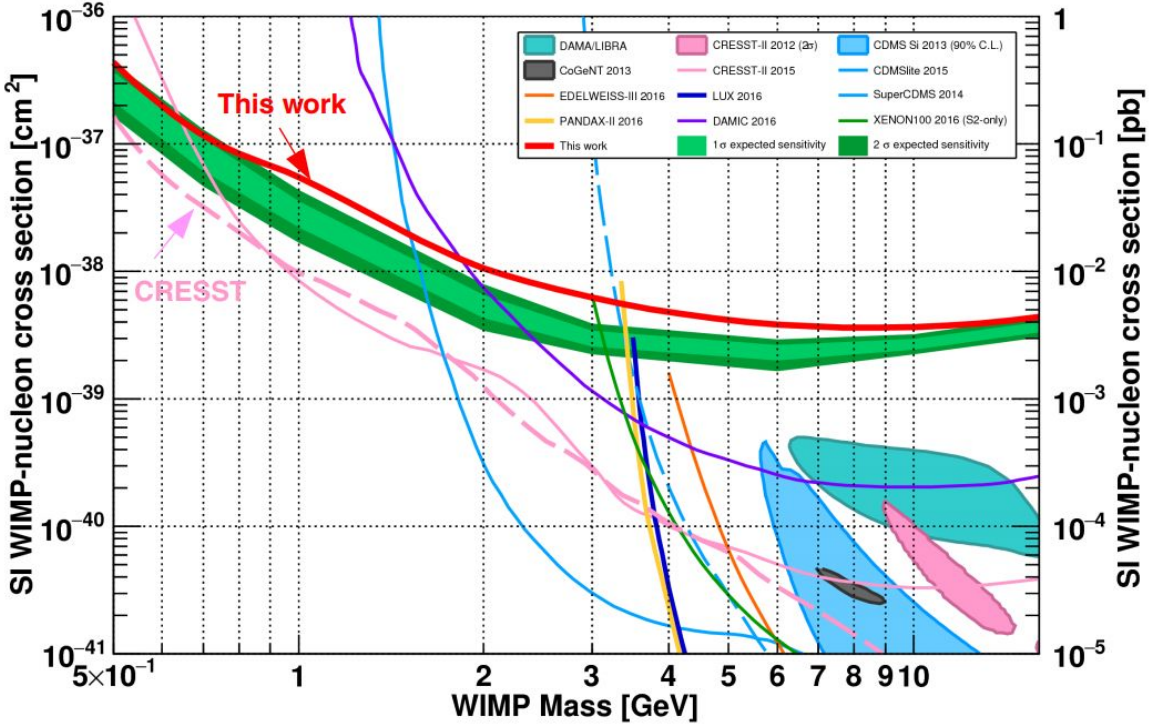
Recent Results from SEDINE

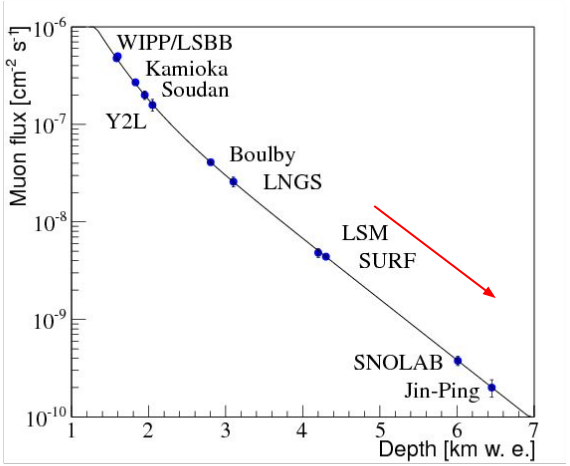


Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018) doi: 10.1016/j.astropartphys.2017.10.009

Q. Arnaud, Queen's

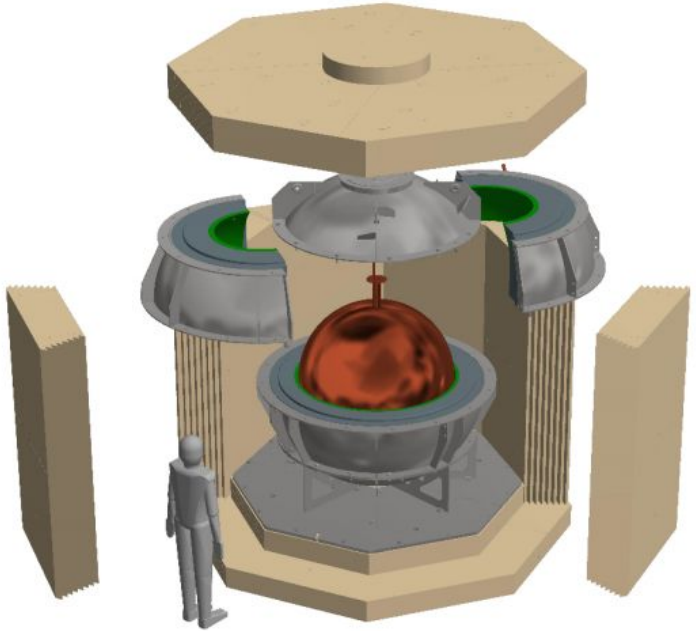
Status of NEWS-G at SNOLAB

Status of NEWS-G SNOLAB



SNOLAB: 6000 mwe (0.27 μ/m^2 /day)

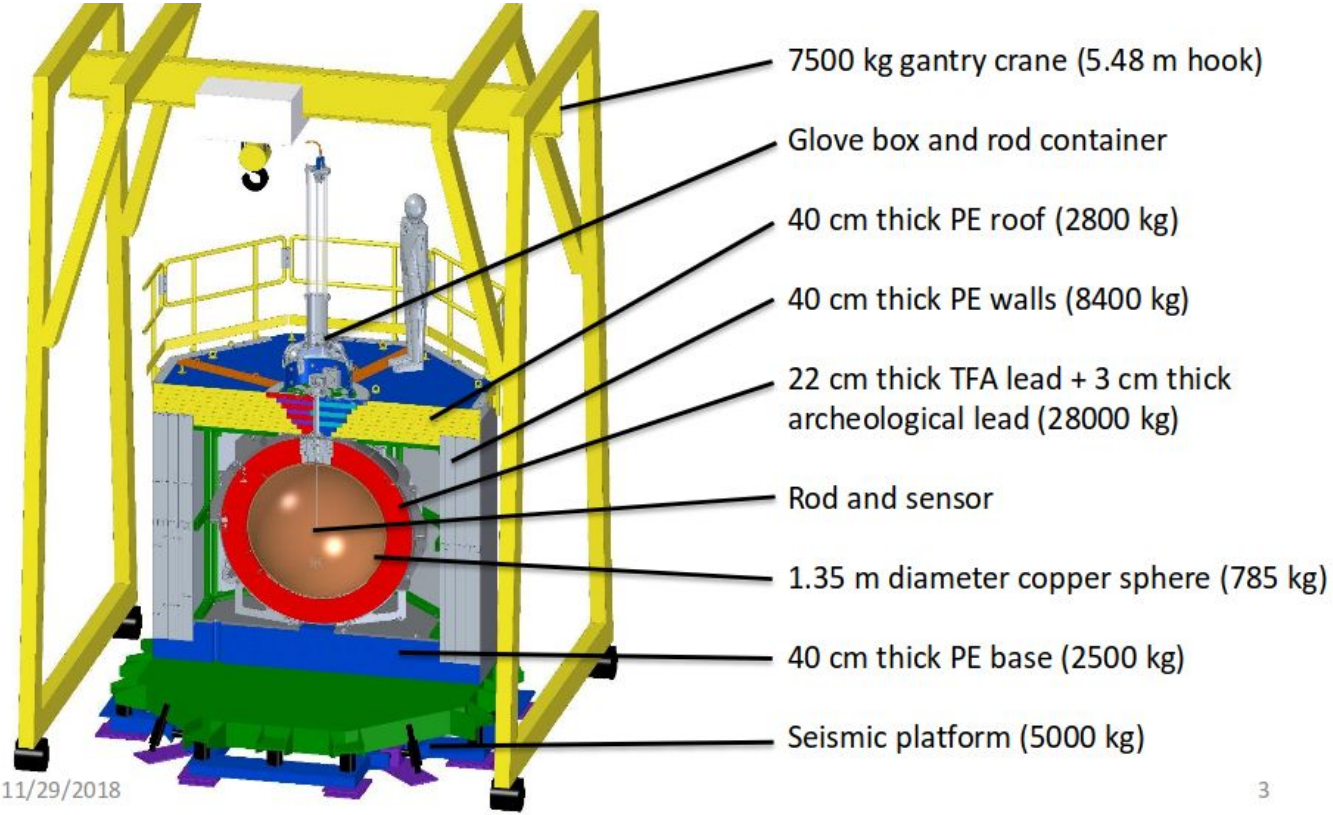
140 cm diameter low activity copper (C10100) SPC
7 - 25 µBq/kg ^{232}Th
1 - 5 µBq/kg ^{238}U
Electropolishing and electroplating



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)

Status of NEWS-G SNOLAB

Installation in SNOLAB "Cube Hall" in Spring 2019



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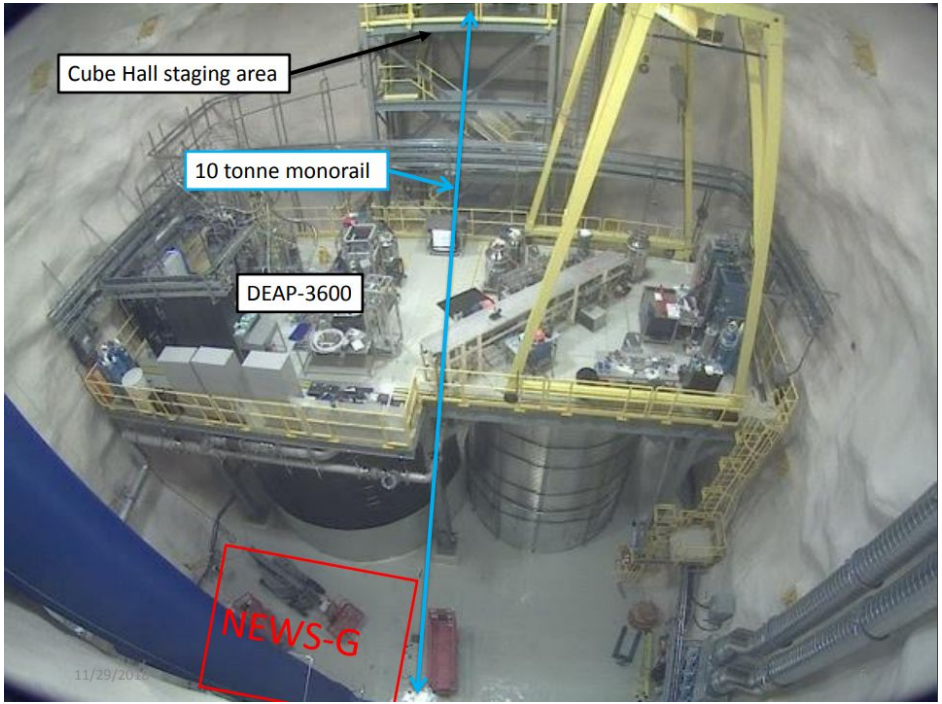
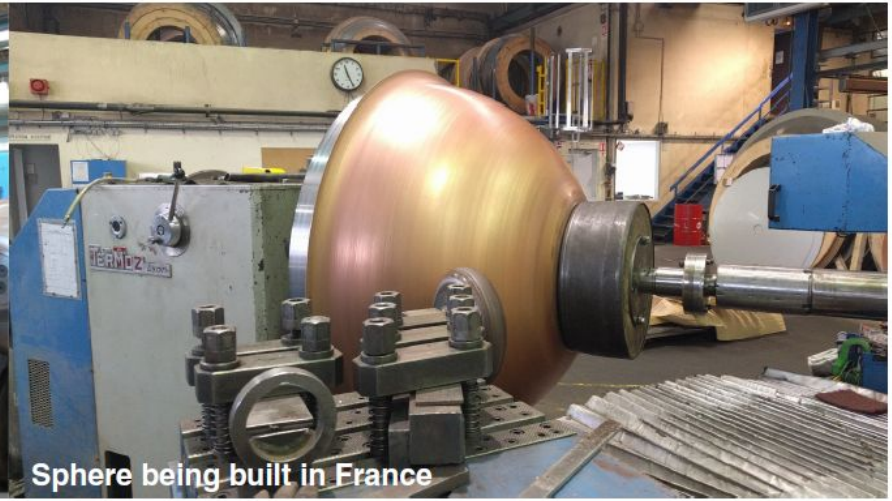


Status of NEWS-G SNOLAB

Recent progress:



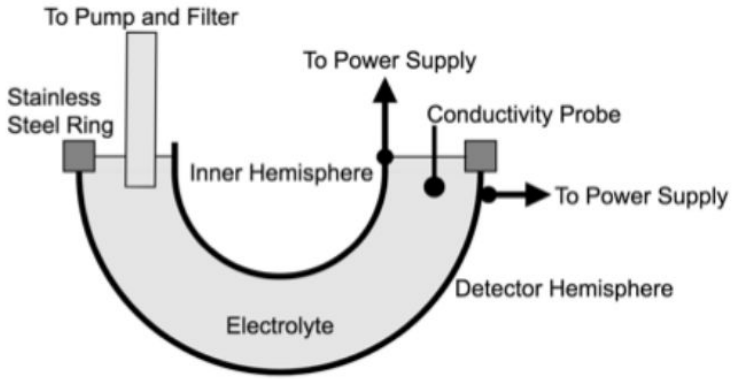
Copper hemisphere “spinning” completed in France

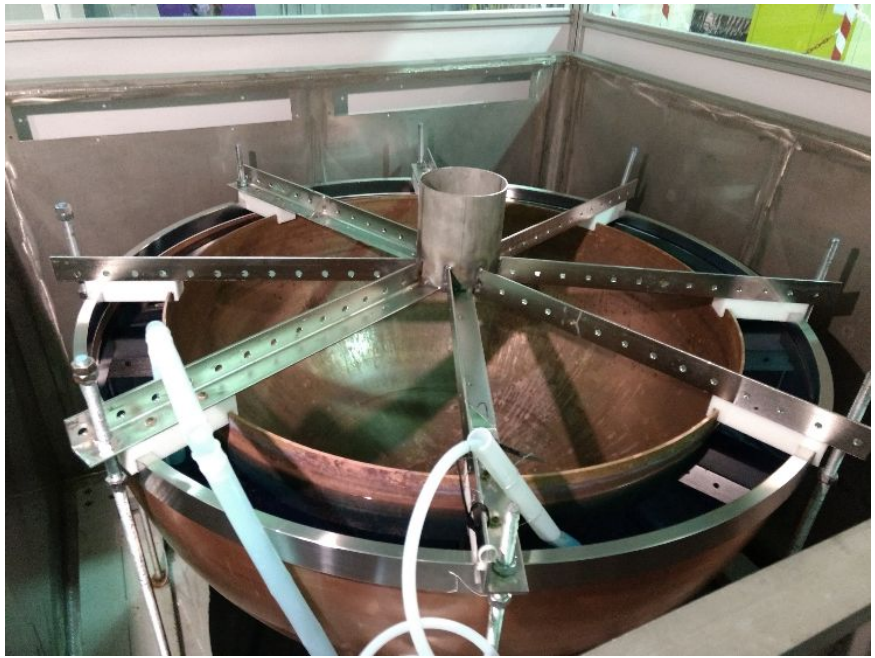
Glovebox ready

Status of NEWS-G SNOLAB

Mitigation of the ^{210}Pb bulk copper background:
(P. Knights, Fri. 11:40a)

Electroplating of the Hemisphere inside surface

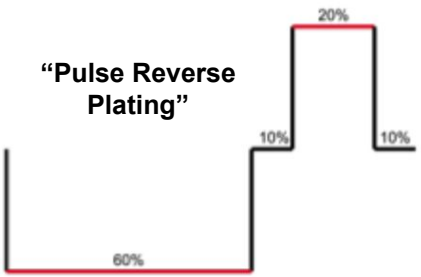


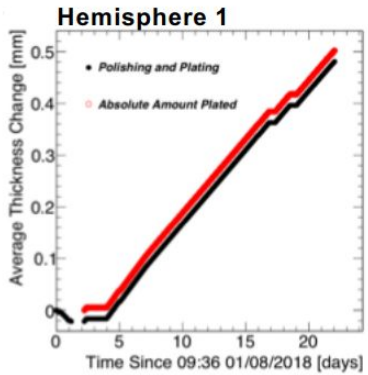


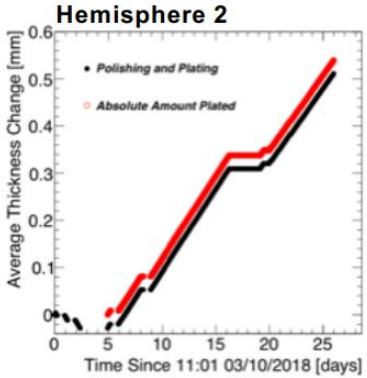
Status of NEWS-G SNOLAB

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

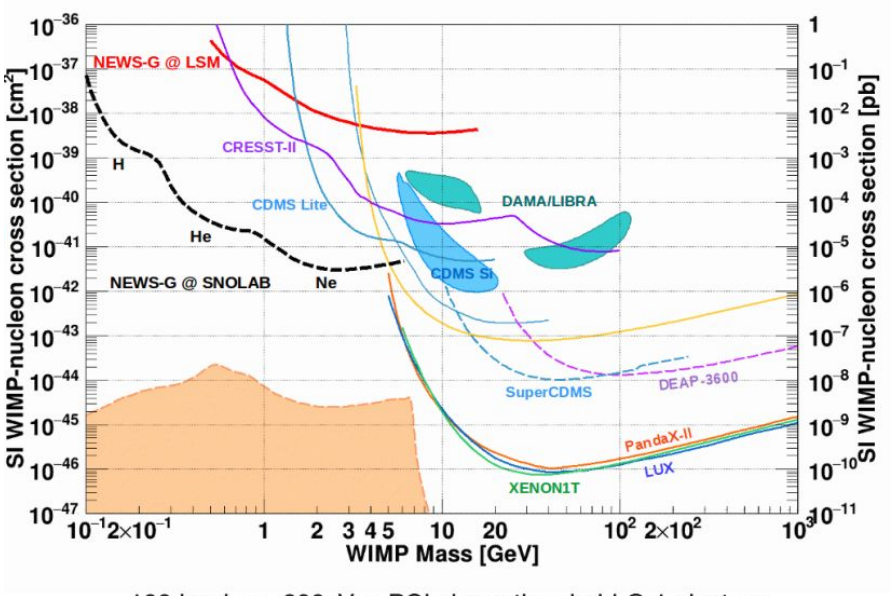






Status of NEWS-G at SNOLAB

- **Improved sensitivity to low-mass WIMPs**
  - Lighter targets (H,He)
  - Lower background
  - Lower threshold
- **Improved gas quality and monitoring** **(P. Knights, Fri 11:40a)**
  - Recirculation
  - Getter
  - RGA
- **Improved calibration and monitoring** **(P. Gros, Fri 11:20a)**
  - Laser
  - ^{37}Ar
- **Quenching factor measurements**
  - Neutron Beam (TUNL, Duke)
  - Ion/electron beam (LPSC, Grenoble)
- **Sensor development** **(I. Katsioulas, Thu. 4:20p)**
  - Better field uniformity
  - Electron extraction near walls



100 kg.days, 200eVee ROI above threshold @ 1 electron

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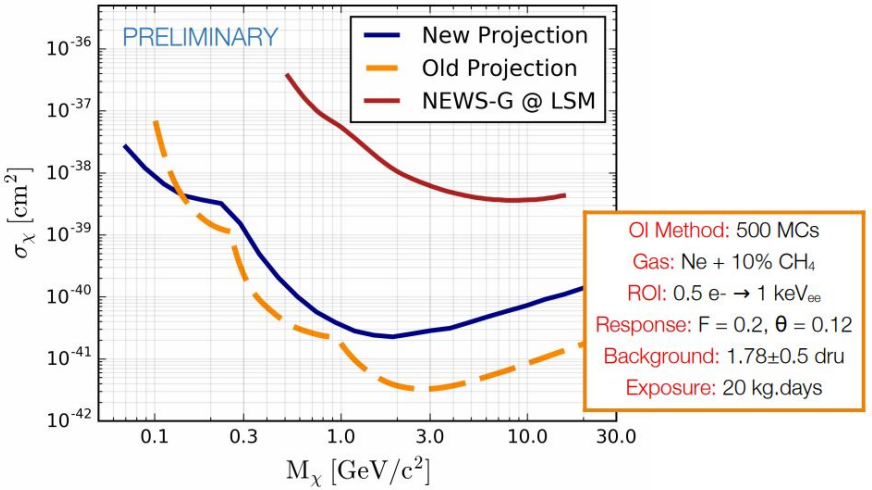
Updated sensitivity projection using current background model and Ne(90)CH4(10)



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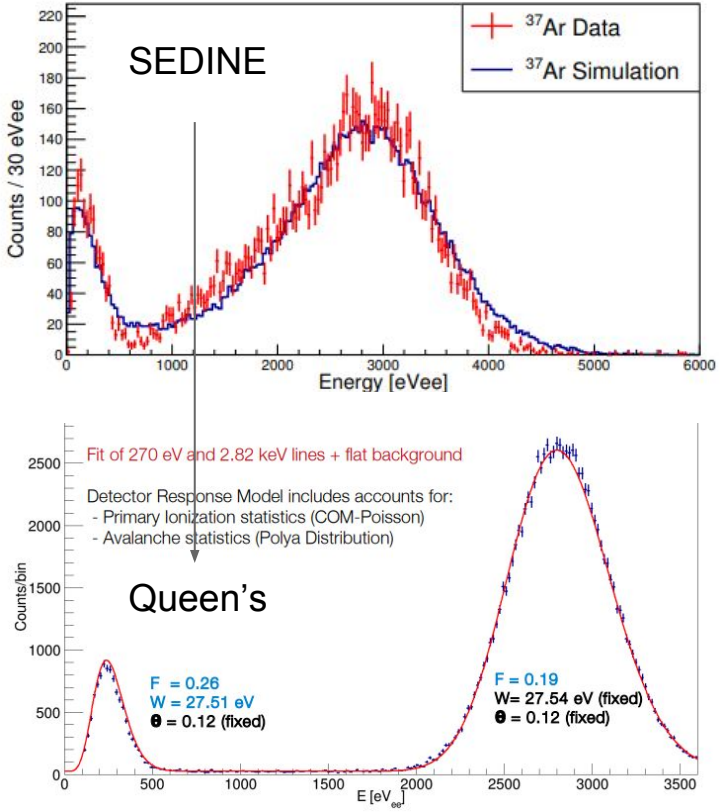


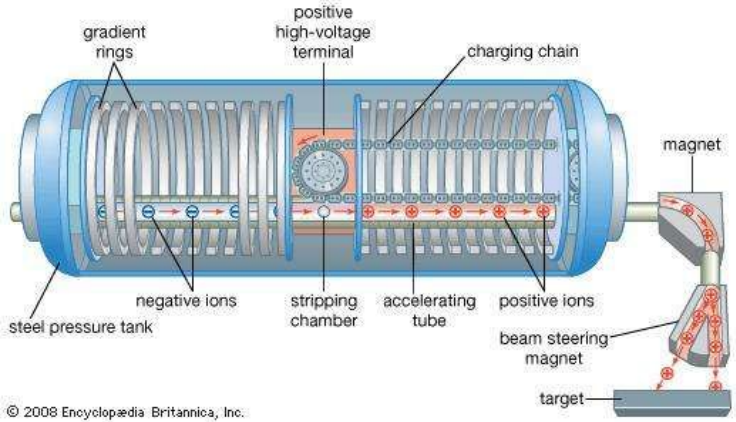
Quenching Factor Measurements at TUNL

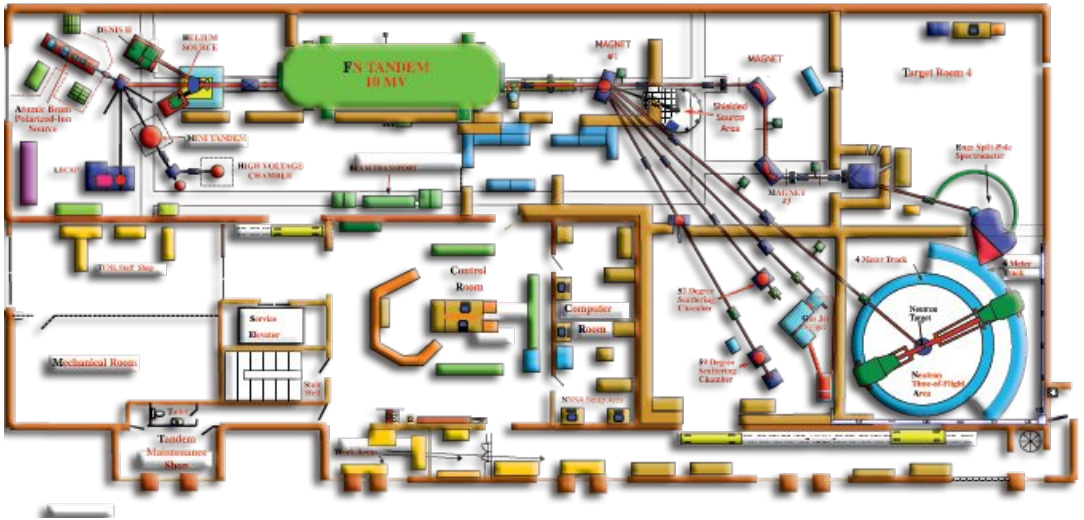
Quenching Factor Measurement at TUNL

TUNL: Triangle Universities Nuclear Laboratories (Duke University, Durham, North Carolina, USA)

Tandem Van de Graaf Accelerator:

- E_{max} (p,d) = 20 MeV
- Pulsed: DC to 1 ns
- I_{max} = 5 μA





Quenching Factor Measurement at TUNL

Reaction: D+D→ n+^{3}He+2.5MeV
Neutron beam 3.85 MeV

Detector: 15 cm diameter sphere made of stainless steel

Gas: Neon:CH_4 (98:2)

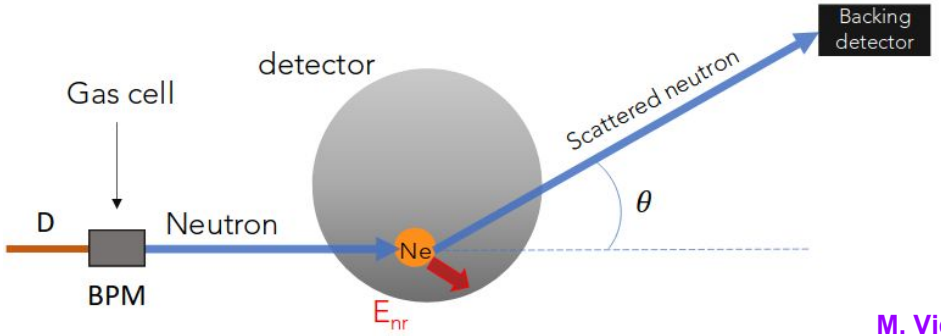
Pressure: ~500mbar

HV: 800V

Energy calibration: Fe55 peak at 5.9keV

Backing detectors: Liquid scintillator + PMTs, allow for neutron/gamma identification by pulse shape discrimination
→ Data taking: trigger on backing detectors

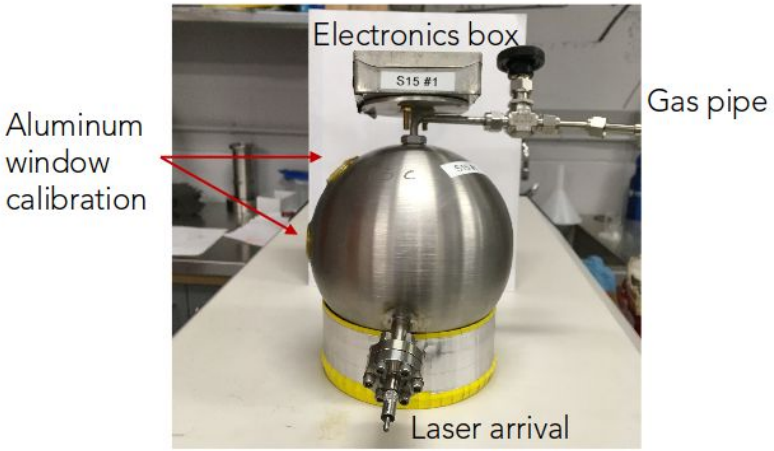
Beam Pick-off Monitor (BPM): Induction based signal triggered when beam crosses D gas cell



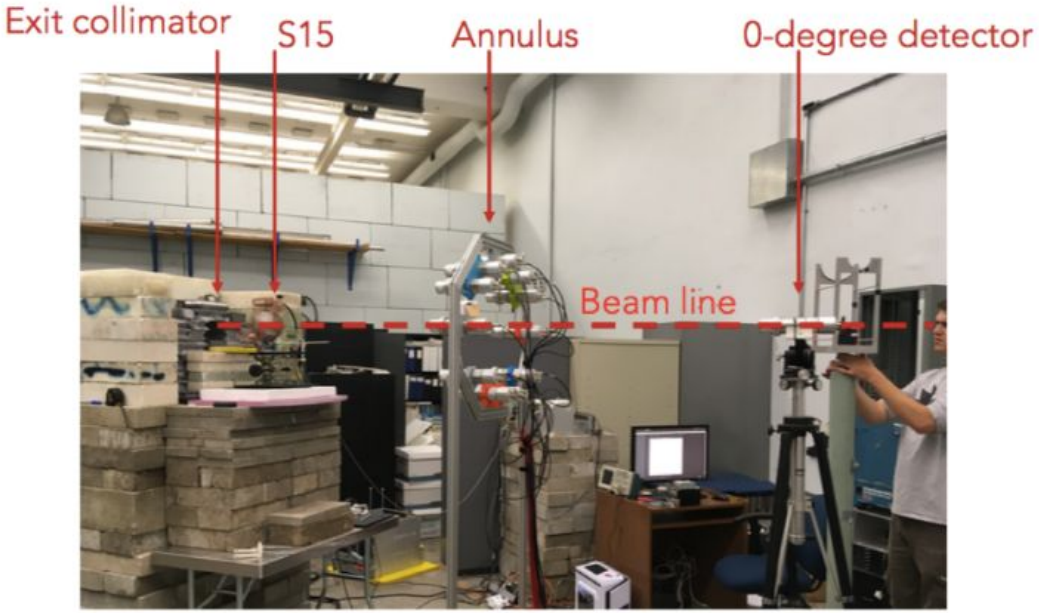
M. Vidal, Queen's

Quenching Factor Measurement at TUNL

Stainless steel 15 cm Ø sphere



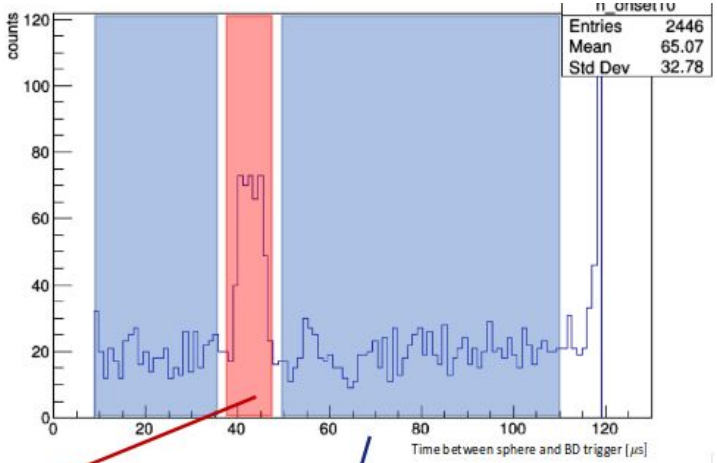
Angles Solid angle of the backing detectors + uncertainty from laser	Recoil energies (keVnr)	Exposure (h)
9.2 ± 0.8 °	4.95	16
12.4 ± 1.1/1.0 °	9	8
16.2 ± 1.4/1.3 °	15.3	12
22.4 ± 1.8/1.7 °	28.96	8

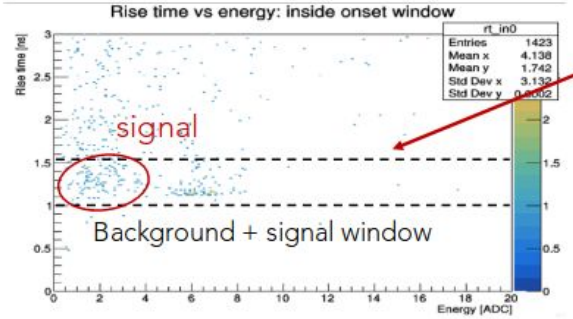


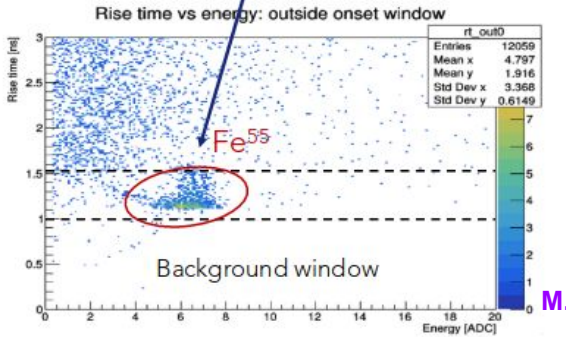
M. Vidal, Queen's

Quenching Factor Measurement at TUNL

- TOF cut and backing detector PSD cut
- Clear nuclear recoil signal found
- Energy scale (gain drift) set by ^{55}Fe calibration

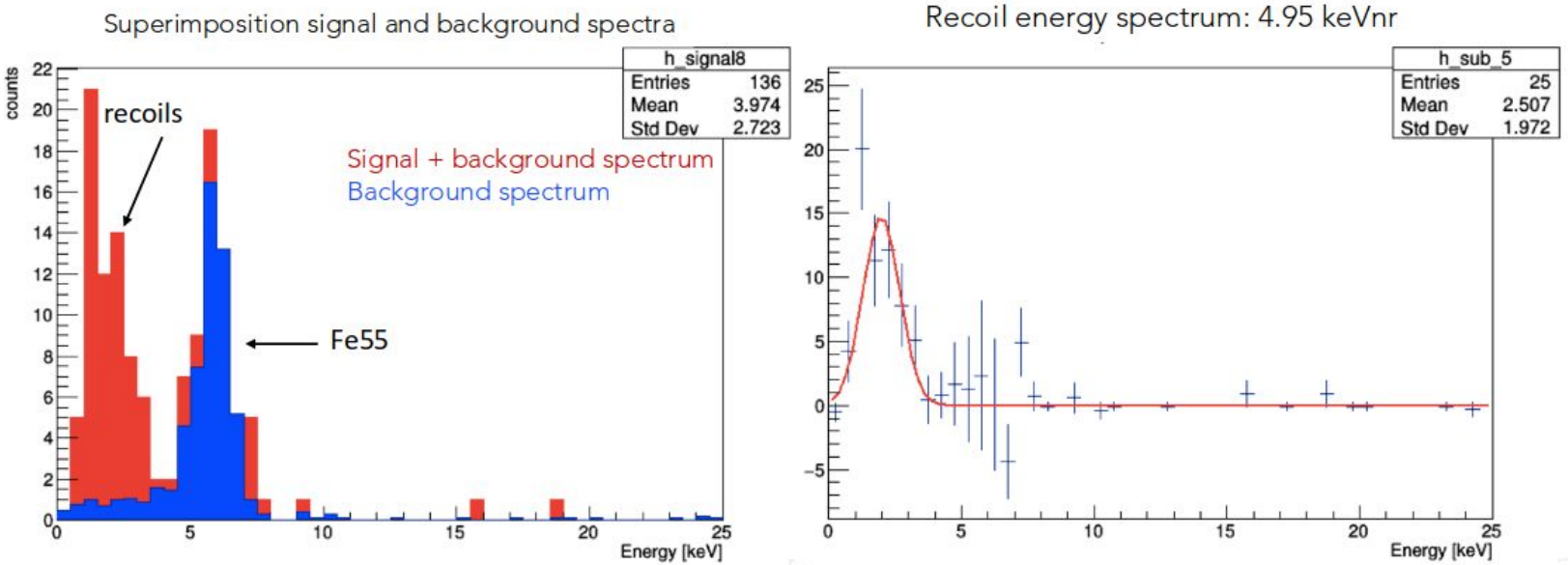






M. Vidal, Queen's

Quenching Factor Measurement at TUNL



Background Subtraction

M. Vidal, Queen's

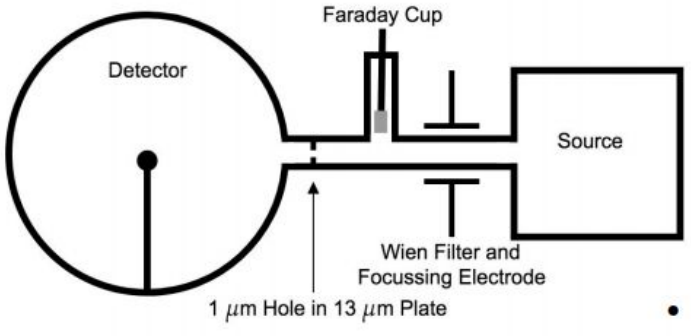
Quenching Factor Measurement: outlook

Outlook:

- Data analysis ongoing (^{55}Fe calibration, systematics, neutron energy spectra)

- Second run at TUNL (Winter 2019):
  - Lower energies (down to 150 eVnr)
  - Pressure, gas mixture
  - Updated S15 sensor (better gain stability)
  - Second calibration point (1.4 keV aluminum fluorescence using aluminum sphere)

- Quenching factor measurements in parallel at CoMicmac facility in Grenoble
  - Electron cyclotron resonance source 1 - 40 keV electrons and ions
  - Injected in SPC through 1 µm hole in 12 µm stainless steel plate



Summary

Summary and Outlook

- NEWS-G
  - SPC advances: sensors, background, calibration and monitoring
- SEDINE at LSM
  - Recent results: published 9.7 kg-day Ne(99.3)CH_4(0.7) dark matter search run
  - Current plans: Test Ne(90)CH_4(10) gas, Helium, sensors, etc.
- NEWS-G at SNOLAB
  - Plans at LSM: Full implementation of 140 cm SPC + dark matter search run (spring-summer 2018)
  - Plans at SNOLAB: Seismic base construction, neutron shield (spring 2018), 140 cm SPC (summer 2018)
- Quenching factor measurements
  - Data analysis ongoing
  - Data taking at TUNL
  - Complementary measurements with electrons/ions at CoMimac
  - Queen's University neutron beam

Thank you.