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

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The Search for Light Dark Matter

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

\[ C = \frac{4\pi \varepsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi \varepsilon r_{sensor} \approx 0.35 \text{pF} \]

- 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 Gerbler, P di Stefano, R Martin, G Giroux, D Durnford, S Crawford, M Vidal, G Savvidis, A Brossard, T Vazquez d'S, Q Arnaud, K Dering, J Mc Donald, M Chapollier, A Ronceray, P Gros, A Rolland, C Novon
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis
  - 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 Zampaulo, A DastgheibFard
  - Low activity archaeological lead
  - Coordination for lead/ICE shielding and copper sphere
- Thessaloniki University – I Savvidis, A Leison, 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 Coreoran
  - 37 Ar source production, sample analysis
- SNOLAB – Sudbury – P Gouli
  - 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)CH₄(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 $\times$ preamplifier response
- Noise templates: Taken from the pretraces of real pulses
- Same trigger algorithm and processing than for real pulses

Drift at high theta
Field near sensor
Ideal radial field  AR37 Data Simulation  real field  AR37 Data Simulation
Recent Results from SEDINE at LSM
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:

Fall any of the BDT cuts
pass the BDT cut for 0.5 GeV/c^2: 15 events
pass the BDT cut for 16 GeV/c^2: 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

**37Ar 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

doi: 10.1016/j.astropartphys.2017.10.009
NEWS-G at SNOLAB

- SNOLAB: 6000 mwe (0.27 μm²/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 envelope flushed with pure N (radon mitigation)
Projected sensitivity

Assumptions:
Ne + 10% CH₂, Exposure: 20 kg days, F = 0.2, θ = 0.12,
SRIM quenching factor, Background: 1.78 dru, ROI: 14 eV<sub>ee</sub> - 1 keV<sub>ee</sub>
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

Hemisphere Spinning and Glovebox
Status of NEWS-G at LSM

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

**Electroplating of the Hemisphere inside surface**

![Diagram of electroplating setup](image)
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

“Pulse Reverse Plating”
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 + CH₄), electronic noise hunting, first physical pulses!
Status of NEWS-G at LSM

SPC in lead shielding

LSM neutron shielding water tank

Physics run with pure CH$_4$ in Aug. – Sep.
THANK YOU!
Extra Slides
Roadmap

SPC invention (I. Giomataris 2008)

SEDINE (2015)  NEWS-G 140-cm (Summer 2019)

At LSM  At SNOLAB

NEWS-G 140-cm (Fall 2019)

In the picture:
I. Giomataris, G. Charpak
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

Analysis is underway to extract quenching factors at different energies

Marie Vidal, Queen’s
R&D Activities
Laser Calibration


- 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

37Ar calibration

Measured parameters:
- Mean gain
- Single electron response
- Baseline RMS
Laser Monitoring

Monitoring of detector gain

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

I. Katsioulas, Birmingham
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

**A. Giganon, et al., JINST 12 (2017)**
Copper Backgrounds
Copper backgrounds

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.

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

![Graph showing activity vs time for $^{210}$Po and $^{210}$Pb with measurements and error bars. The graph shows a decay curve with time in years on the x-axis and activity in mBq/kg on the y-axis.]

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 $^{60}\text{Co}$, but also shorter lived $^{58}\text{Co}$, $^{57}\text{Co}$, $^{54}\text{Mn}$.

Events rate < 1 keV after 93 days at sea level

- All ~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 $^{210}\text{Pb}$ 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