NEWS-G
Light dark matter search with a Spherical Proportional Counter
First results and Future prospects

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The Dark Matter conundrum

Status as of early-2017

Motivation
1. Non-findings
2. Plethora of DM models

Detectors with a lower threshold

Larger target mass - exposure kg·days
Direct detection of light dark matter

Detection through ionization - An example

Mass range
0.1GeV/c² - few GeV/c²

Galactic WIMP wind

- If we have $E_R = 500$ eV recoil induced by a WIMP of $M_\chi = 1$ GeV/c²

$$u_{\text{min}} = \sqrt{\frac{2 \cdot E_R}{r \cdot M_\chi}}$$

Minimum relative WIMP velocity to produce a recoil of $E_R$

$E_R \rightarrow u_{\text{min}}$
- 1790 km/s for Xe target
- 1340 km/s for Ge target
- 1000 km/s for Ar target

WIMP escape velocity ~540 km/s

- Required Threshold
  - Xe $E_i = 50$ eV
  - Ge $E_i = 58$ eV
  - Ar $E_i = 74$ eV
  - He $E_i = 105$ eV

due to quenching $E_i = E_R \cdot q_F$

Energy losses:
- Electronic
- “Nuclear”

Ionization issue

Kinematic issue
Direct detection of light dark matter

No searches available in this region
**The Spherical Proportional Counter**

**Electric field**

*Strong dependence with the radius*

\[ E(r) = \frac{V_0}{r^2} \frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A \]

- \( r_A \) = anode radius
- \( r_C \) = cathode radius

**Built solely by radiopure materials**

- Vessel made of Cu (~tens of kg)
- Rod made of Cu (~hundreds of gr)
- All the rest less than weigh < 1 g

**In the picture:**

I. Giomataris, G. Charpak

I. Giomataris et al, JINST, 2008, P09007
Why a spherical detector?

Building large volume detectors

**Advantages of the spherical geometry**

- Lowest surface to volume ratio
- Sustains higher pressure
- Low capacitance → Low noise
- High gain
- Robustness (anode Ø 1 mm-6.3 mm)

Large volume - large mass detector with very low noise, thus threshold, designed to increase signal to background ratio

**Capacities for a 1 m³ detector in different geometries**

- **Parallel Plate**
  \[ C = \varepsilon_0 \frac{S}{d} \approx 3.5 \text{ nF} \]

- **Cylindrical counter**
  \[ C = 2\pi \varepsilon_0 \frac{L}{\ln(b/a)} \approx 115 \text{ pF} \]

- **Spherical counter**
  \[ C \approx 4\pi \varepsilon r_A \approx 1.5 \text{ pF} \]
Why a spherical detector?

Background rejection capabilities-A

Event discrimination

Extended track

Point like

Real muon pulse

Real $^+$Ar pulse

Fiducialization

X-ray source

Interaction points

Primary $e^-$ drift time dispersion

$$\sigma(r) \propto \left(\frac{r}{r_{\text{sphere}}}\right)^3$$

Rise time $\rightarrow$ $\Delta t$ between 90% - 10% of pulse height

5.9 keV X-rays line
Why a spherical detector?

Background rejection capabilities-B

$^{109}$Cd source

Irradiation through 200μm Al window

$P = 100$ mb, Ar–CH$_4$ (2%)

Background comes from the materials of the vessel

Efficiency of the cut in $rt \rightarrow ~70\%$ signal (Cd line)

Significant background reduction
The SEDINE detector at LSM

The main detector currently and a testing ground for NEWS-G

Laboratoire Souterrain de Modane

Vessel
Ø 60cm copper

Sensor
Ø 6.4mm Si

Shielding
Polyethylene 30 cm
Lead 15cm
Copper 8 cm

4800 wme
5 μ/m²/day
**Target:** Ne+0.7%CH\(_4\) at 3.1 bar
→ 280 gr target mass

**Duration:** 42 days in sealed mode

**Dead time:** 20.1%

**Exposure:** 9.6 kg*days (34.1 live-days x 0.28 kg)

**Trigger threshold:** 35 eVee (~100% efficient at 150 eVee)

**Analysis threshold:** 150 eVee (~720 eVnr)

**Calibration:** \(^{37}\text{Ar}\) gaseous source, 8 keV Cu fluorescence, AmBe neutron source

Sideband region used together with simulations to determine the number and distribution of expected events in preliminary ROI.
Simulating the detector response

Modeling the rise time vs energy response

**Electric field**
- Field map from COMSOL

**Drift of primary electrons**
- Magboltz drift parameters

**Quenching factor**
- Parametrization derived from SRIM

**Avalanche**
- Polya distribution estimation using Garfield++

**Simulated pulses**
- Ion Induced current preamplifier response
- Noise templates taken from the pretraces of real pulses

Same trigger algorithm and processing as used for real pulses

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**Validation**

**37Ar gaseous source**
2.82 keV and 270 eV X-rays (K and L shells)

**241Am–9Be neutron source**
Nuclear recoils homogeneously distributed in the volume
Analysis of the WIMP run data

Analysis methodology - BDT

Background modeling

Trained with simulated WIMP and background events

1620 events recorded in the preliminary ROI
- Failed 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
First results of NEWS-G with SEDINE


Exclusion at 90% confidence level (C.L.) of cross-sections above $4.4 \times 10^{-37}$ cm$^2$ for a 0.5 GeV/c$^2$ WIMP

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 at SNOLAB

The underground laboratory in the Sudbury, Canada

**Deeper underground**
0.25 μ/m²/day
~8x lower μ flux than LSM

Practically, at 2 km is the deepest clean room in the world.
NEWS-G at SNOLAB

The new and improved setup

Copper vessel (140 cm \(\varnothing\), 12 mm thick)
- Low activity copper (C10100)
  - 7 to 25 \(\mu\)Bq/kg Th
  - 1 to 5 \(\mu\)Bq/kg of U
- Electropolishing & Electroplating

Hemispheres built in France, stored at LSM before welding

Upgraded compact shielding (35t)
- 40 cm PE + Boron sheet
- 22 cm VLA Pb (1 Bq/kg \(^{210}\)Pb)
- 3 cm archaeological lead
- Airtight envelope to flush pure N (against Rn)

Glove box for Radon free rod installation
NEWS-G current status & developments

Preparation of the He physics run

**Gas quality**
- Testing gas mixtures of He/CH₄
- High pressure operation (Penning)
- Hydrogen rich target

**Upgrading gas system**
- Tightness
- Filtering
- Gas recirculation
- Residual Gas Analyzer monitoring

**Quenching factor measurements**
- Ion / electron beam (LPSC, France)
- Neutron beam (TUNL, USA)

**Study of the detector response**
- Solid state laser (213 nm)
  - Monitoring of the gain over time
  - Drift time measurements
  - Parametrization of the avalanche process

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**Sensor developments**

**Aims**
- High pressure operation
- High gain
- Increased stability
- Low radioactivity

**Techniques**
- Resistive technologies
- 3D printing technologies
- FEM simulations

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**Single anode sensors**
- "Glass" sensor
- "Bakelite" sensor

**Multi-anode sensors (ACHINOS)**
- 33-ball Bakelite
- 11-ball 3D printed

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**Studying the effect of ACHINOS with FEM simulations**
NEWS-G at SNOLAB

Projected sensitivity

1) Bigger
2) Cleaner
3) Deeper

100 kg.days, 200eVee ROI above threshold at 1 electron.
(Not accounting for sensitivity improvement from resolution effects and RT cuts)
The NEWS-G collaboration

- Queen’s University Kingston – G Gerbier, P di Stefano, R Martin, G Giroux, T Noble, D Durnford, S Crawford, M Vidal, A Brossard, F Vazquez de Sola, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier, A Ronceray, P Gros, J Morrison, C Neyron
  - 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 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, DM Asner
  - Low activity measurements, Copper electroforming
- RMCC (Royal Military College Canada) Kingston – D Kelly, E Corcoran
  - 37 Ar source production, sample analysis
- SNOLAB – Sudbury – P Goree
  - Calibration system/slow control
- University of Birmingham – K Nikolopoulos, P Knight
  - Simulations, analysis, R&D

Associated lab: TRIUMF – F Retiere
- Future R&D on light detection, sensor
Thanks very much for your attention
Additional material