Detection of low mass WIMPs with Spherical Proportional Counters

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On behalf of the NEWS-G collaboration

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Low-Mass Dark Matter detection with NEWS-G
Low-Mass Dark Matter detection with NEWS-G

Direct Detection: WIMP interacts with the gas nuclei through elastic scattering

Measure the recoil energy of the scattered nuclei
The Spherical Proportional Counter
Spherical Proportional Counter: Principle of Operation

Ideal Spherical Capacitor Field

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

\[ C \approx 4\pi \varepsilon r_A \approx 1.5 \text{ pF} \]
Spherical Proportional Counter: Principle of Operation

- Incoming particle ionizes the gas
  - Primary Ionization

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Ideal Spherical Capacitor Field

\[ C \approx 4\pi \varepsilon r_A \approx 1.5 \, pF \]

\[ r_A = \text{anode radius} \]
\[ r_C = \text{cathode radius} \]
Spherical Proportional Counter: Principle of Operation

- Incoming particle ionizes the gas – Primary Ionization
- e- drift towards the anode at the center along the $E$ field lines

Ideal Spherical Capacitor Field

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

Incoming particle

Cathode

Grounded shell

Drift region

Anode

HV

Grounded metallic rod

Signal

C=\text{Rin}= 0.085 \text{ mm} < .1\text{pF}
Spherical Proportional Counter: Principle of Operation

- Incoming particle ionizes the gas  
  – Primary Ionization

- e- drift towards the anode at the center along the $\vec{E}$ field lines

- Avalanche occurs  
  – Secondary Ionization

**Ideal Spherical Capacitor Field**

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

\[ r_A = \text{anode radius} \]
\[ r_C = \text{cathode radius} \]

\[ C \approx 4\pi \varepsilon r_A \approx 1.5 \text{ pF} \]
Spherical Proportional Counter: Principle of Operation

- Incoming particle ionizes the gas  
  – Primary Ionization
- $e^-$ drifts towards the anode at the center along the $\vec{E}$ field lines
- Avalanche occurs  
  – Secondary Ionization
- Signal is produced and measured

Goal: WIMP detection at SNOLAB!

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

Ideal Spherical Capacitor Field

$C \approx 4\pi \varepsilon r_A \approx 1.5 \, pF$
Pulse Shape Discrimination

- Amplitude $\propto$ Particle Energy
- Risetime $\propto$ Spatial Distribution of Energy Deposition
Pulse Shape Discrimination

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Pulse Shape Discrimination

Counting the electrons at very low energies

5.9 keV X-rays from $^{55}$Fe decays

"Surface"-like events

"Muon"-like events

"Signal"-like events

K. Nikolopoulos / 18 March 2021 / NEWS-G: Search for light DM with SPCs
The problem: $\vec{E}$ field vs Gain

Electric Field of an ideal Spherical Capacitor

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

Gain $\approx \frac{1}{r_A}$

The solution: Multi-anode sensor


Original achinos paper: [https://inspirehep.net/literature/1613557](https://inspirehep.net/literature/1613557)

\[ E_{eachinos} \approx 11 E_{single} \]

Gain $\approx \frac{1}{r_A}$
Background
Background and Shielding

7-25 μBq/kg $^{232}$Th / 1-5 μBq/kg $^{238}$U (measured by PNNL using mass spectrometer)

$^{210}$Pb activity is about 28.5 mBq/kg (measured by the XMASS collaboration using XIA)

Electroplating at LSM to suppress $Pb^{210}$ background

Commissioning results at LSM
Commissioning results at LSM

1 bar Neon+5%CH4

135 mbar pure CH4
(Exploitation of proton recoil energies)

Full scale test
• Multi-anode Achinos sensor with 2-readout channels
• Compact Shielding
• Ar37 calibration
• Single Electron calibration with Laser
Background reduction with alpha cuts

Cut on such high energy events leads to ~70% background events reduction with a 12% exposure reduction.

Fiducialization study

North events=24%
South events=68%
Shared events=8%

Ar37 Calibration

Also see talk by Philippe Gros in the ”Gaseous Detector Session”
Single Electron calibration in Pure CH4

• 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

See talk by Philippe Gros in "Gaseous Detector Session"

37Ar decays 100% by electron capture to 37Cl

• K-Shell: 2.8 keV
• L-Shell: 270 eV

Publication on pure CH4 results soon

Daniel Durnford, PhD candidate, University of Alberta
The NEWS-G experiment at SNOLAB
The NEWS-G experiment at SNOLAB

Projected Sensitivity at SNOLAB

$\phi 1.7mm Si balls$

Phases of the Detector Installation at SNOLAB
NEWS-G Timeline and Future Projects

**ECuME**

ECuME Projected Sensitivity

**DarkSPHERE Projected Sensitivity**

Operation with 5 bar He$_2$C$_4$H$_6$ (90%:10%) (27 kg)

K. Nikolopoulos / 18 March 2021 / NEWS-G: Search for light DM with SPCs
Thank you for your attention
Detection of low mass WIMPs with Spherical Proportional Counters

Queen's University Kingston - G Gerbier, G Giroux, R Martin, S Crawford, M Vidal, G Savvidis, A Brossard, F Vazquez de Sola, K Dering, V Milious, J McDonald, M Van Ness, M Chapellier, P Gros, JM Coquillet, JF Caron, L Balogh
- Copper vessel and gas set up specifications, calibration, project management
- Gas characterization, laser calibration on smaller scale prototypes
- Simulations/Data analysis

IRFU (Institut de Recherches sur les Lois fondamentales de l'Univers)/CEA Saclay - I Giomataris, M Gros, JP Mols
- Sensor/rod (low activity, optimization with 2 electrodes)
- Electronics (low noise preamps, digitization, stream mode)
- DAO/soft

Aristotle University of Thessaloniki - I Savvidis, A Leisos, S Tzamarias
- Simulations, neutron calibration
- Studies on sensor

LPSC/LSM Laboratoire de Physique Subatomique et Cosmologie, Laboratoire Souterrain de Modane) Grenoble - D Santos, M Zampaolo, A DastghheibiFard JF Muraz, O Guillaudin
- Quenching factor measurements at low energy with ion beams
- Low activity archaeological lead
- Coordination for lead/PE shielding and copper sphere

Pacific Northwest National Laboratory - E Hoppe, R Bunker
- Low activity measurements, copper electro-forming

RMCC Kingston - D Kelly, E Corcoran, L Kwon
- 37Ar source production, sample analysis

SNOLAB Sudbury - P Gorel, S Langrock
- Calibration system/slow control

University of Birmingham - K Nikolopoulos, P Knights, I Katsioulas, R Ward
- Simulations, analysis, R&D

University of Alberta - MC Piro, D Durnford, Y Deng, P O'Brien, C Garrah
- Gas purification, data analysis, simulation

Associated labs: TRIUMF - F Retiere

Subatech, Nantes – P. Lautridou, F. Vazquez de Sola
Back up
Results from SEDINE 60cm prototype


SEDINE: First Prototype
3.1 bars of Ne + 0.7% CH4 42 days of data
Low-Mass Dark Matter detection with NEWS-G

Light targets: Favourable recoil energies

Light targets: Lower Quenching Factor

Recoil Energy Distribution

$m_{DM}=1$ GeV

ionisation Quenching Factor
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