NEWS-G
Light dark matter search with a Spherical Proportional Counter

First results and Future prospects

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Les Rencontres de Moriond - EW , March 14, 2018

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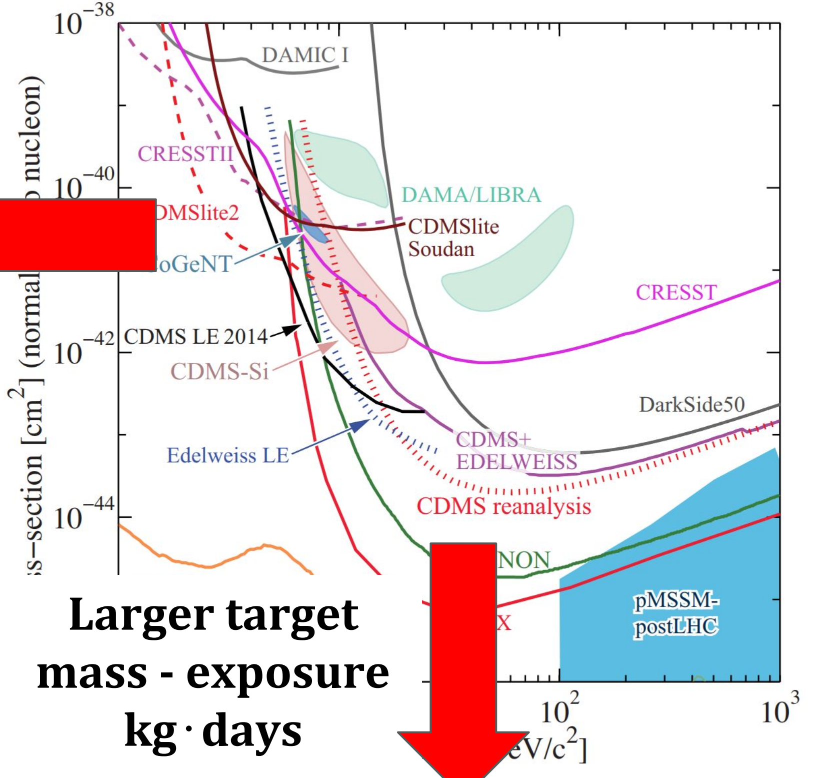
The Dark Matter conundrum

Status as of early-2017

Detectors with a lower threshold



Larger target mass - exposure kg · days

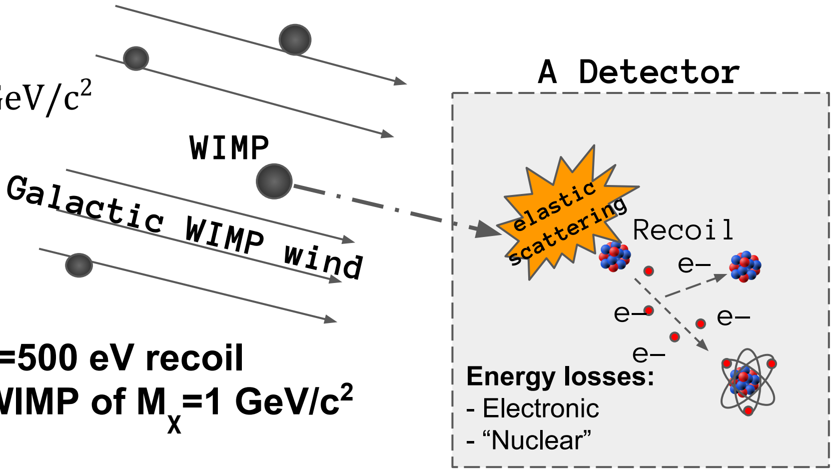
Motivation

1. Non-findings
2. Plethora of DM models

Direct detection of light dark matter

Detection through ionization - An example

Mass range
$0.1 GeV/c^2$- few GeV/c^2



- If we have E_R=500 eV recoil induced by a WIMP of M_χ=1 GeV/c^2

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

Minimum relative WIMP velocity to produce a recoil of E_R

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

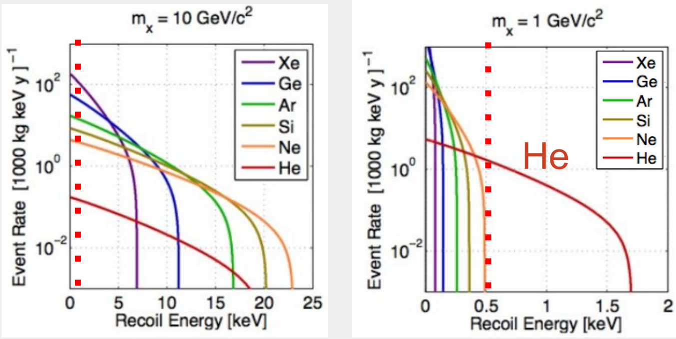
WIMP escape velocity ~540 km/s

- Required Threshold

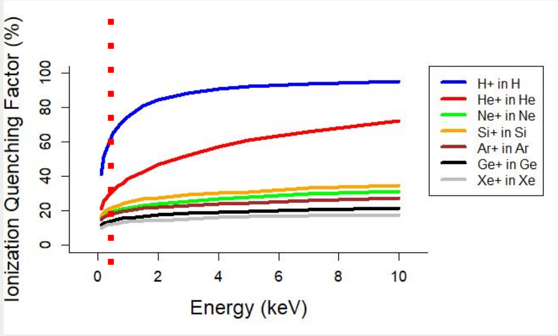
Xe E_i= 50 eV
Ge E_i= 58eV
Ar E_i= 74 eV
He E_i=105 eV

due to quenching $E_i = E_R \cdot q_F$

Kinematic issue



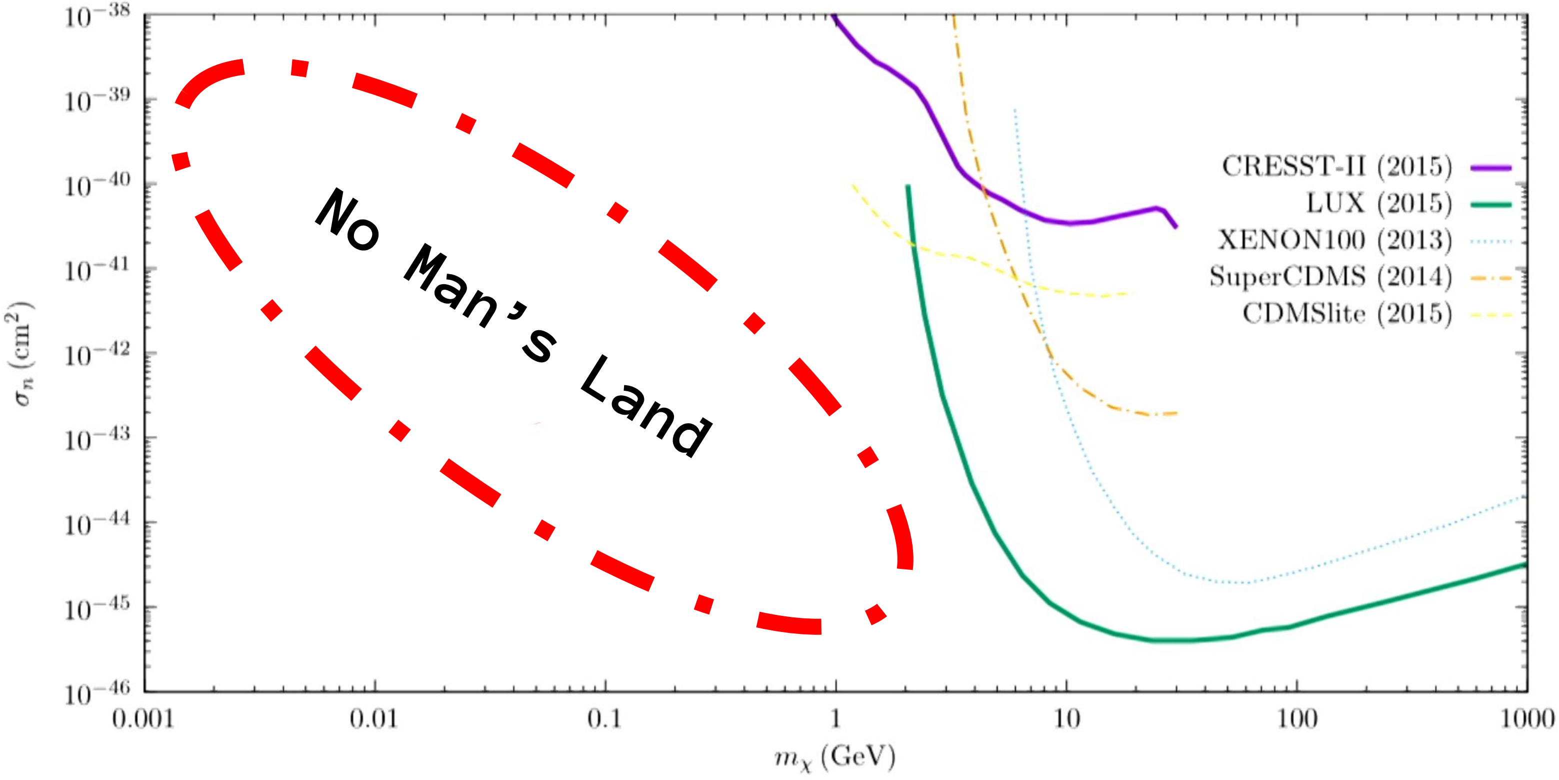
Ionization issue



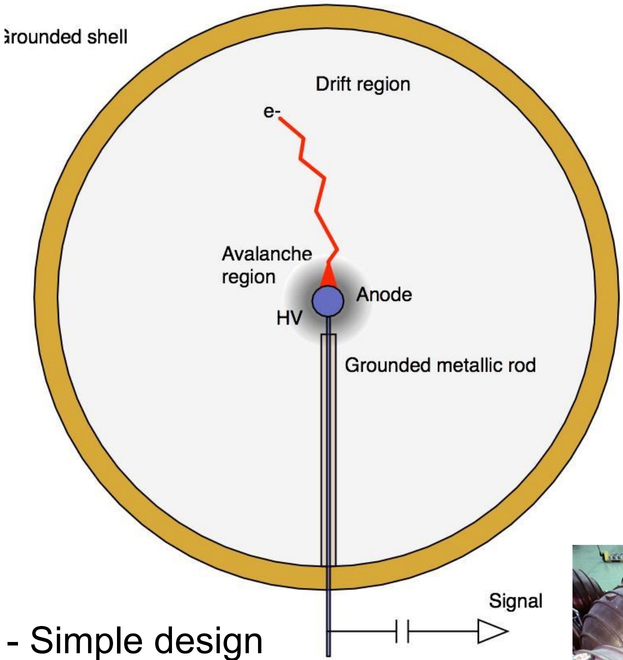
500 eV ....

Direct detection of light dark matter

No searches available in this region



The Spherical Proportional Counter



- Simple design
- Single readout

I.Giomataris et al ,JINST,2008, P09007

Electric field

Strong dependence with the radius

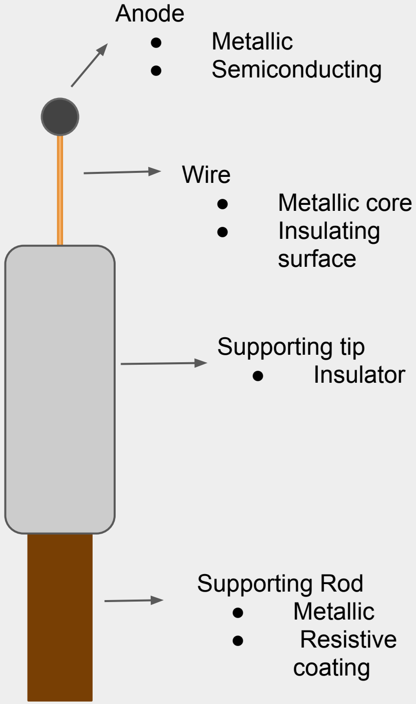
$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$

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**

The Sensor



In the picture:
I.Giomataris, G.Charpak

Why a spherical detector?

Building large volume detectors

[Advantages of the spherical geometry]()

- Lowest surface to volume ratio
- Sustains higher pressure

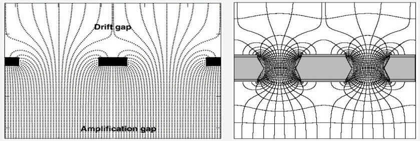
- Low capacitance → Low noise
- High gain

- 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

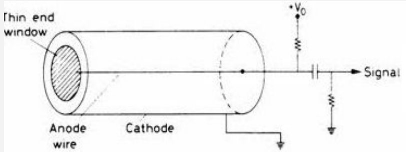
Capacities for a 1 m^3 detector in different geometries

Parallel Plate



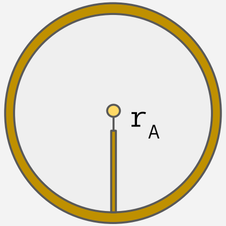
$$C = \varepsilon_0 \frac{S}{d}$$ ≈3.5 nF

Cylindrical counter



$$C = 2\pi\varepsilon_0 \frac{L}{ln(b/a)}$$ ≈115 pF

Spherical counter



$$C \approx 4\pi\varepsilon r_A$$ ≈ 1.5 pF

Why a spherical detector?

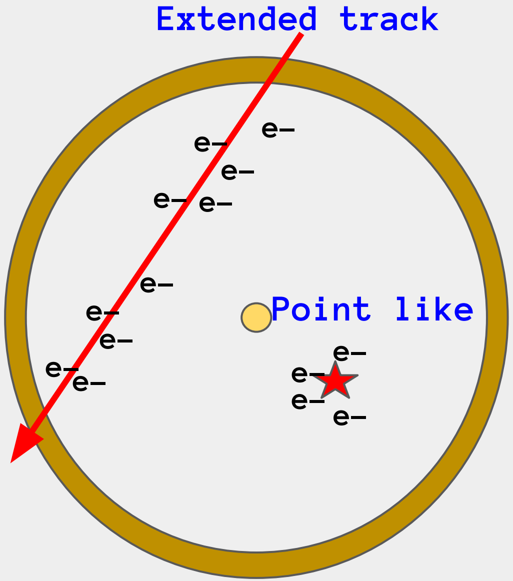
Background rejection capabilities-A

Primary e- drift time dispersion

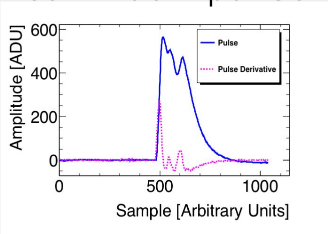
$$\sigma(r) \propto (r/r_{sphere})^3$$

Rise time → Δt between 90% - 10% of pulse height

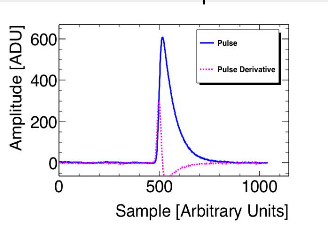
Event discrimination



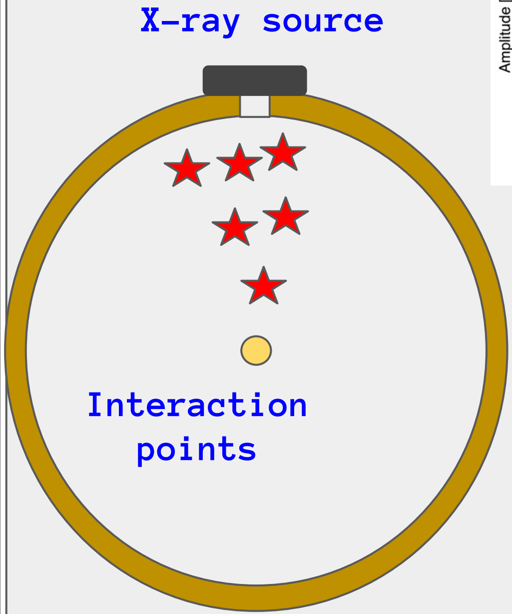
Real muon pulse

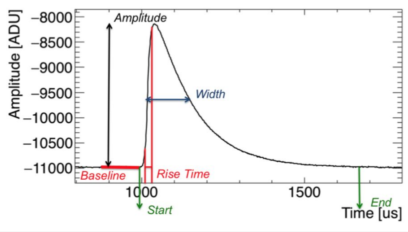


Real $^{+}$Ar pulse

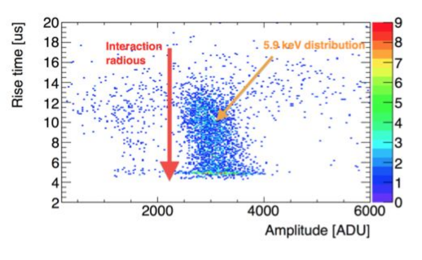


Fiducialization





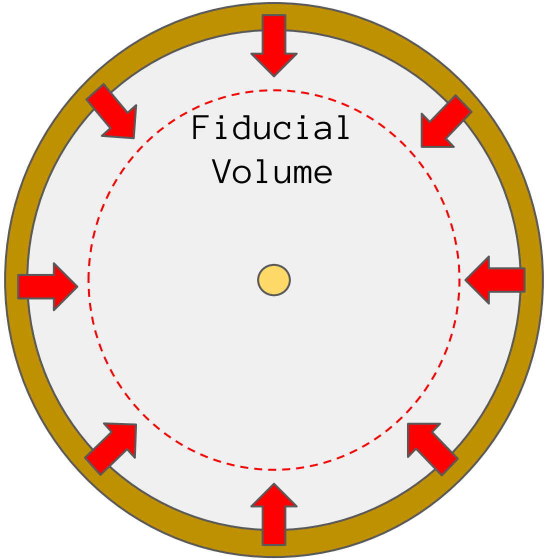
5.9 keV X-rays line

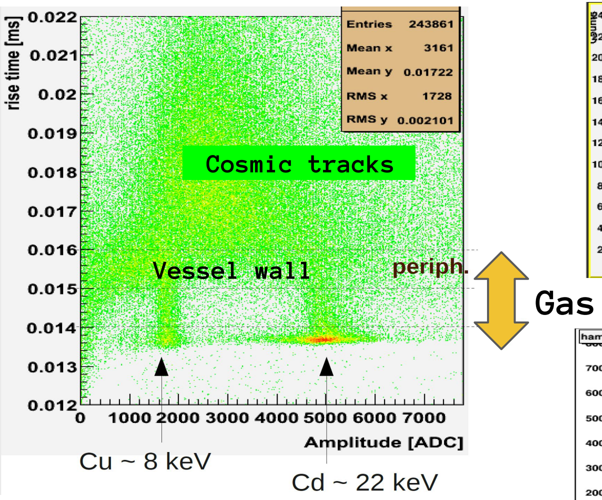


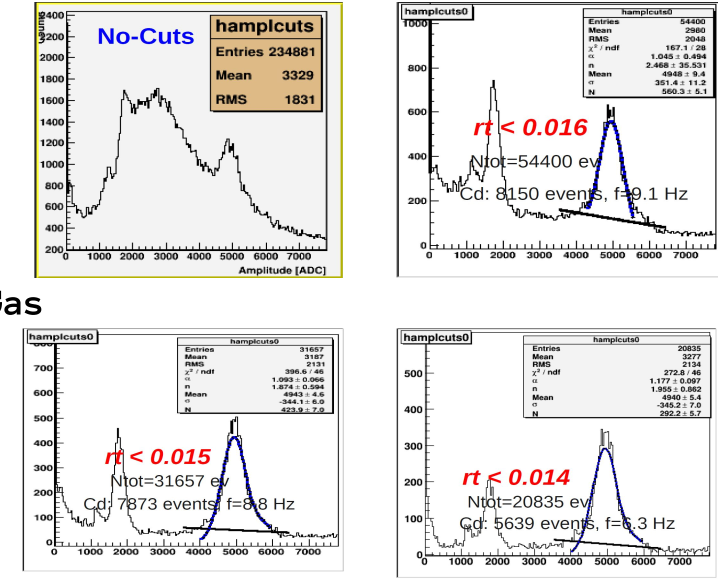
Why a spherical detector?

Background rejection capabilities-B

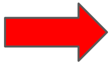
^{109}Cd source
Irradiation through 200μm Al window
P = 100 mb, Ar–CH4 (2%)







Background comes from the materials of the vessel

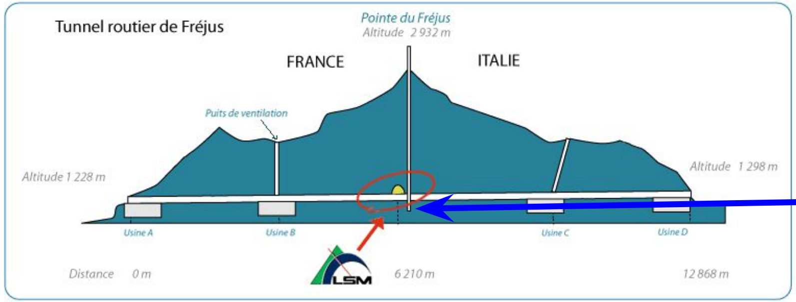
 **Surface**

Efficiency of the cut in rt → ~ 70% signal (Cd line)
Significant background reduction

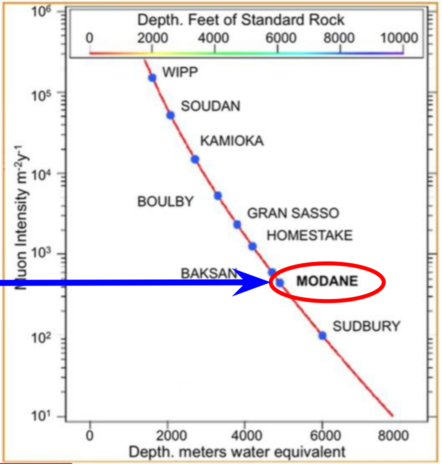
The SEDINE detector at LSM

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

Laboratoire Souterrain de Modane

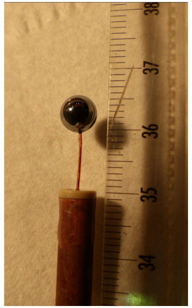


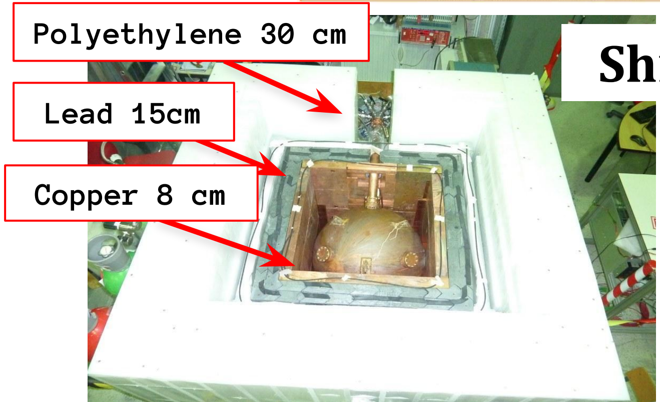
4800 wme
5 μ/m²/day



Vessel
Ø 60cm copper

Sensor
Ø 6.4mm Si





Shielding

WIMP search run data

Target: Ne+0.7%CH_4 at 3.1 bar
→ 280 gr target mass

Duration: 42 days in sealed mode

Dead time: 20.1%

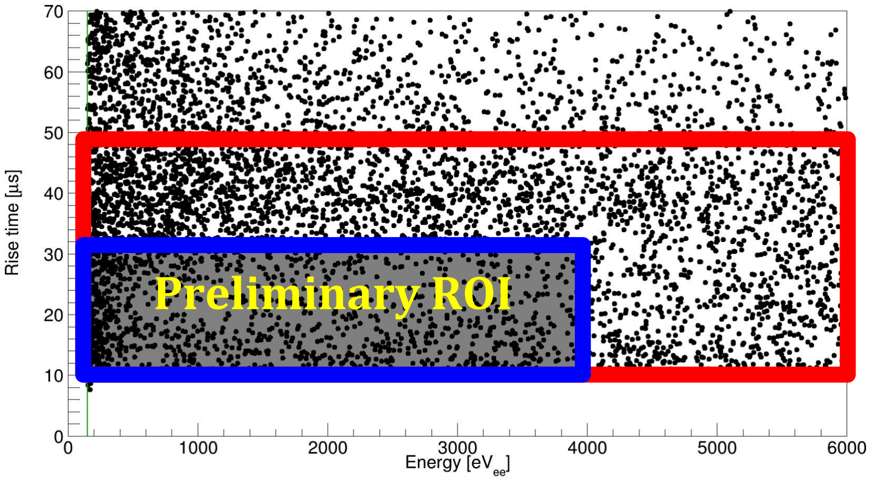
Exposure: 9.6 kg*days (34.1 live-days x 0.28 kg)

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

Analysis threshold: 150 eVee(~720 eVnr)

Calibration: ^{37}Ar gaseous source, 8 keV Cu fluorescence, AmBe neutron source

Rise time vs Energy



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++

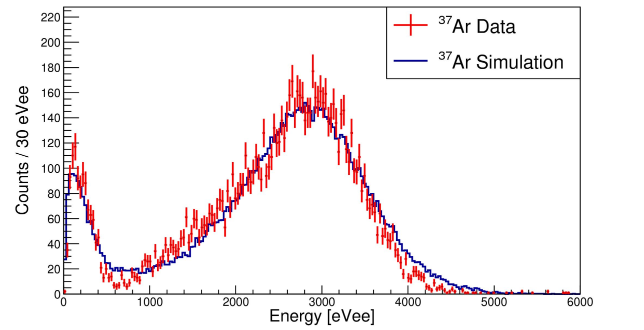
Simulated pulses
- Ion Induced current preamplifier response
- Noise templates taken from the pretraces of real pulses

Same trigger algorithm and processing as used for real pulses

Validation

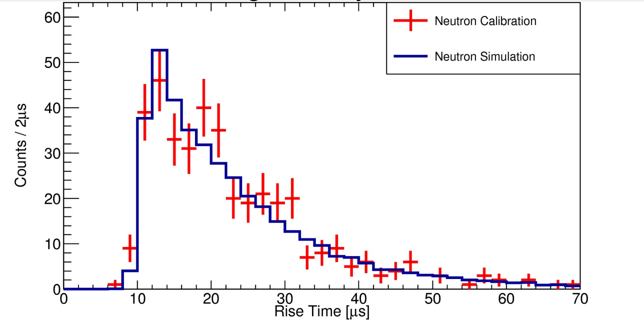
^{37}Ar gaseous source

2.82 keV and 270 eV X-rays (K and L shells)



^{241}Am–^{9}Be neutron source

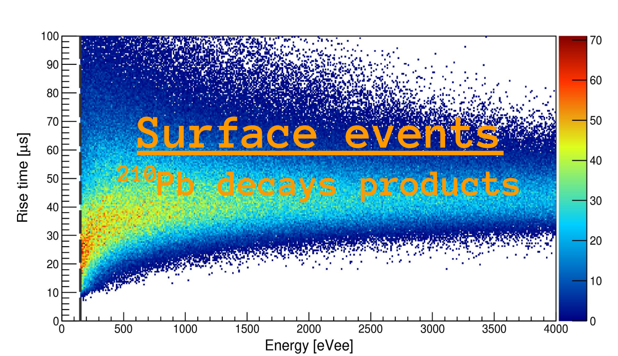
Nuclear recoils homogeneously distributed in the volume

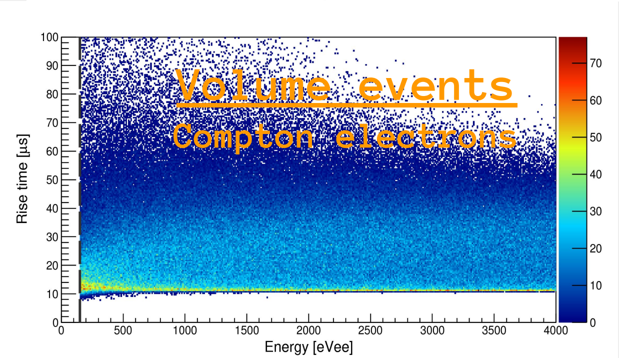


Analysis of the WIMP run data

Analysis methodology - BDT

Background modeling

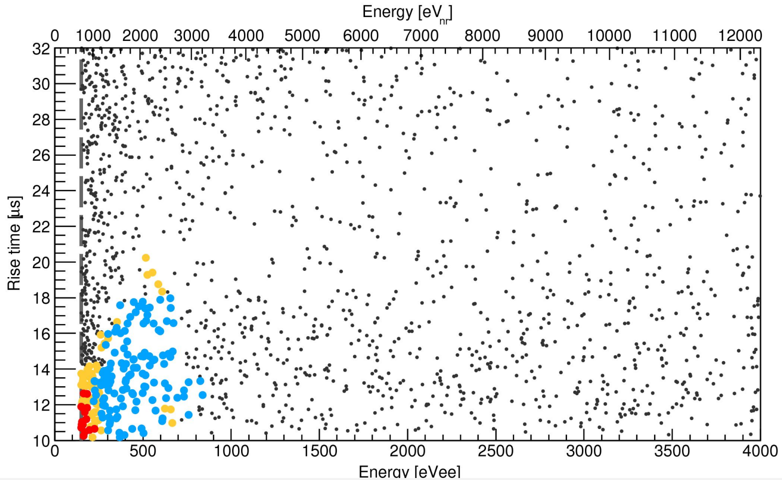




Trained with simulated WIMP and background events

BDT

Mass dependent selection for 8 WIMP masses

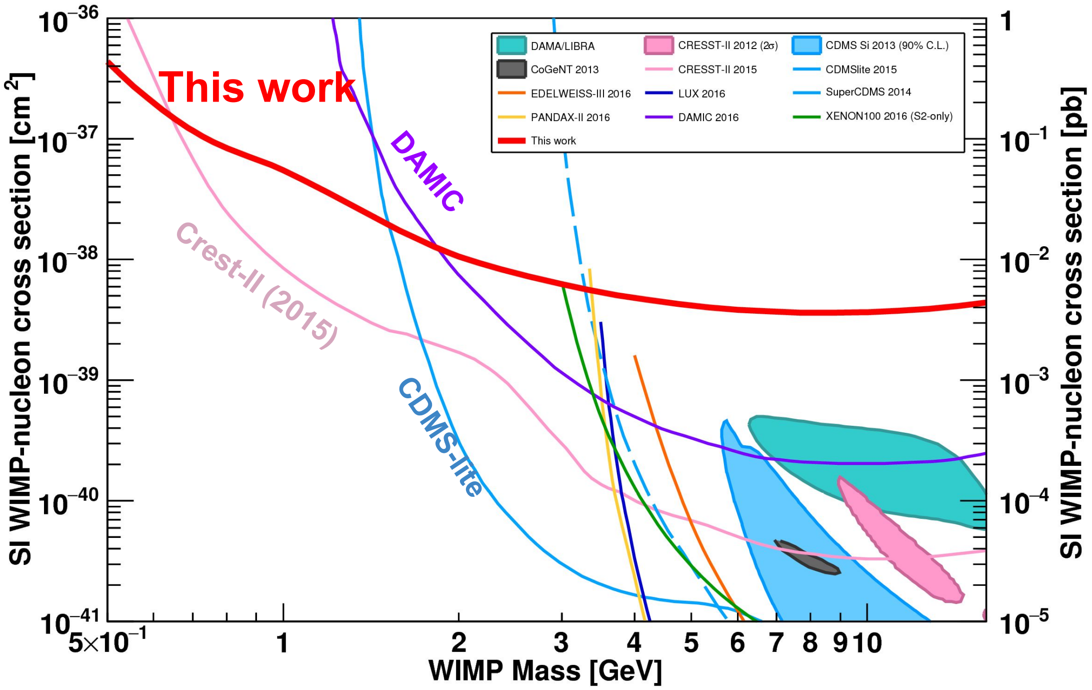


1620 events recorded in the preliminary ROI

- 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

NEWS-G collaboration, Astropart. Phys. 97, 54 (2018), doi: 10.1016/j.astropartphys.2017.10.009



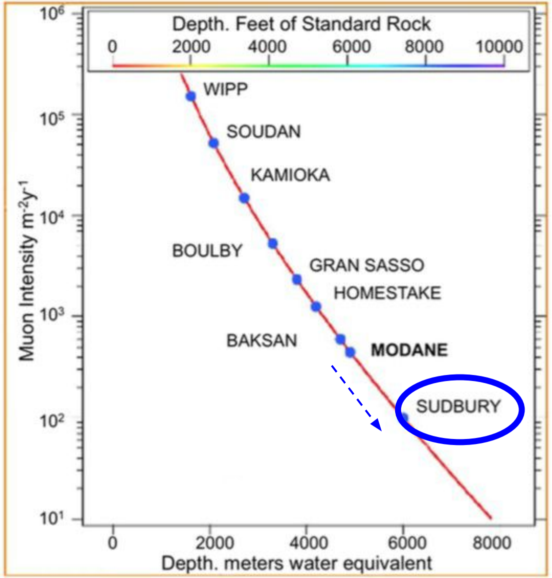
Exclusion at 90% confidence level (C.L.) of cross-sections above $4.4 \cdot 10^{-37}$ cm^2 for a 0.5 GeV/c^2 WIMP

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

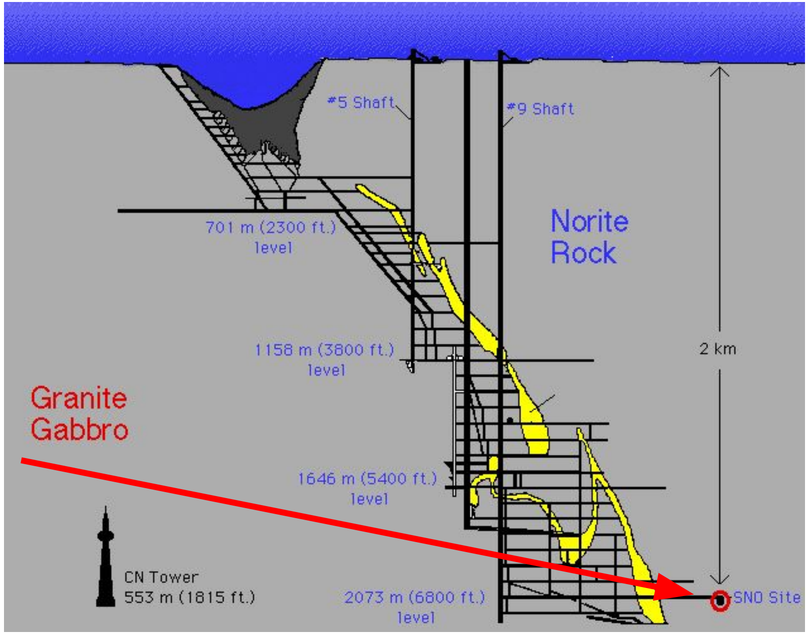
NEWS-G at SNOLAB

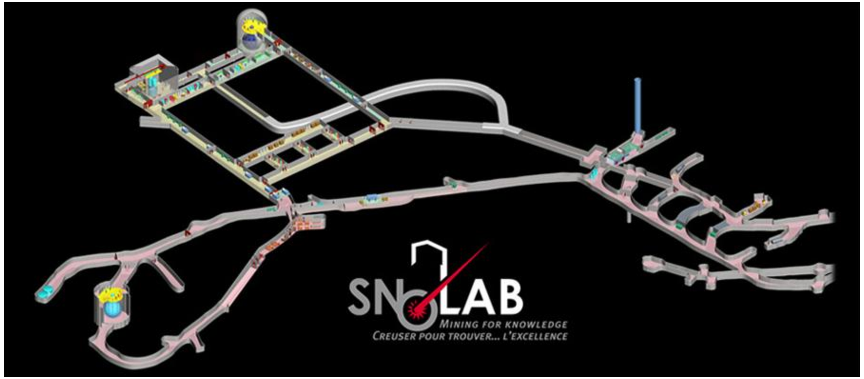
The underground laboratory in the Sudbury, Canada

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

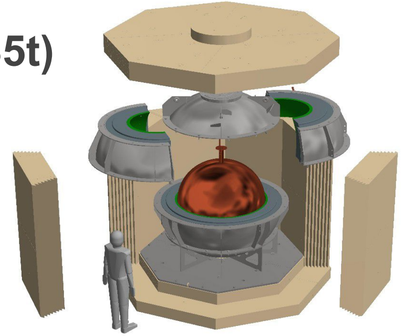
The new and improved setup

Copper vessel (140 cm ⌀, 12 mm thick)

- Low activity copper (C10100)
  - 7 to 25 μBq/kg Th
  - 1 to 5 μBq/kg of U
- Electropolishing & Electroplating

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)



Hemispheres built in France, stored at LSM before welding

Glove box for Radon free rod installation

NEWS-G current status & developments

Preparing the He physics run

Gas quality

Testing gas mixtures of He/CH_4

- *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)*

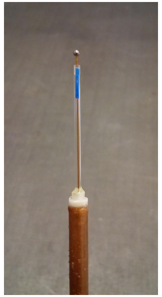
Study of the detector response

Solid state laser (213 nm)

- *monitoring of the gain over time*
- *drift time measurements*
- *parametrization of the avalanche process*

Single anode sensors

“Glass” sensor



“Bakelite” sensor

Multi-anode sensors (ACHINOS)

33-ball bakelite

11-ball 3D printed

Sensor developments

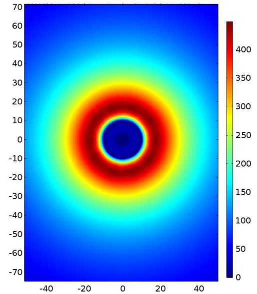
Aims

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

Techniques

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

Studying the effect of ACHINOS with FEM simulations



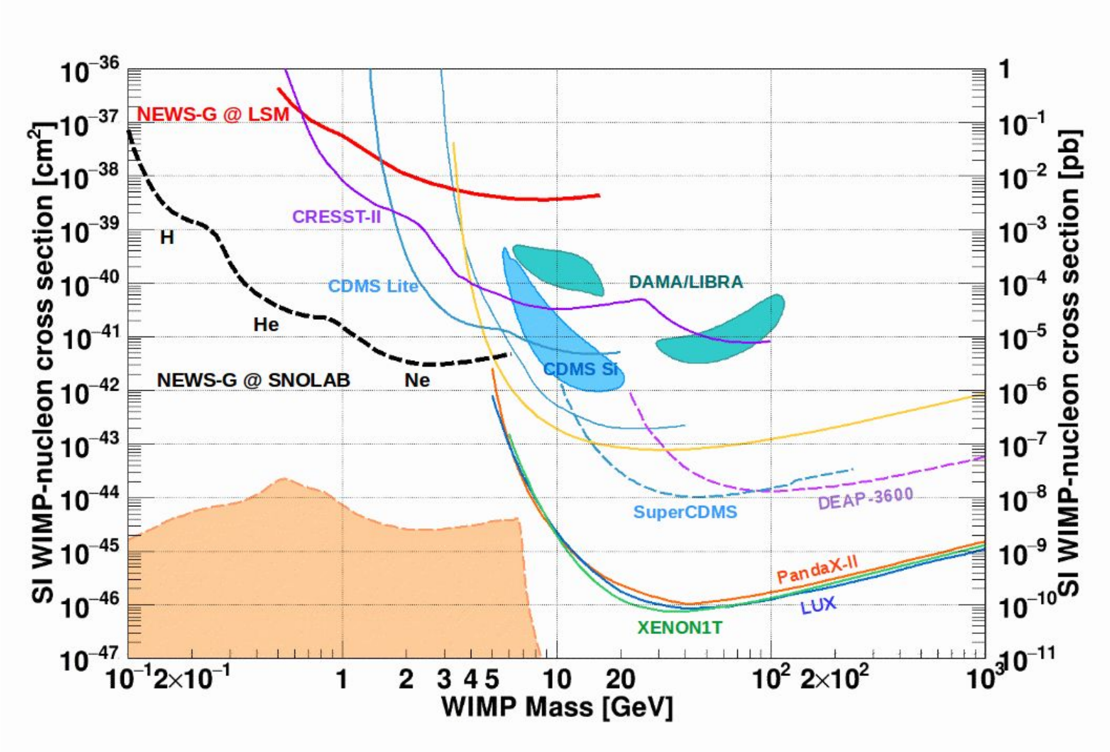
NEWS-G at SNOLAB

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
- **IRFU** (Institut de Recherches sur les Lois fondamentales de l'Univers)**/CEA Saclay** -I Giomataris, M Gros, C Nones, 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, 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 Gorel
  - 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