NEWS-G

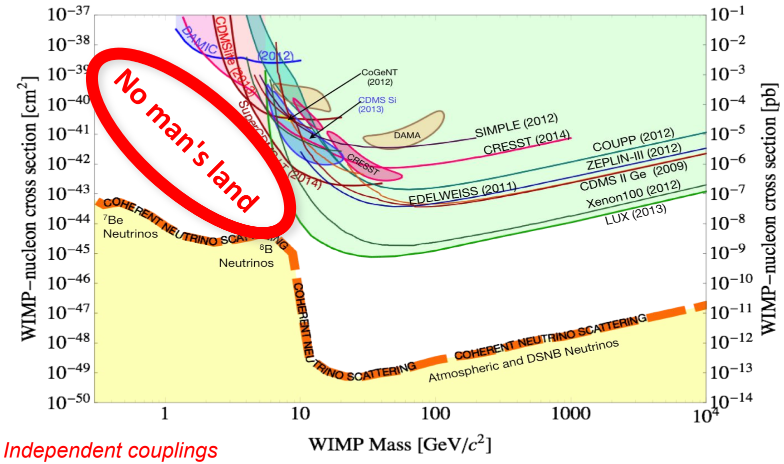
Ultra-Light Dark Matter searches with a Spherical Gaseous Detector

Ioannis KATSIOULAS
CEA, Saclay

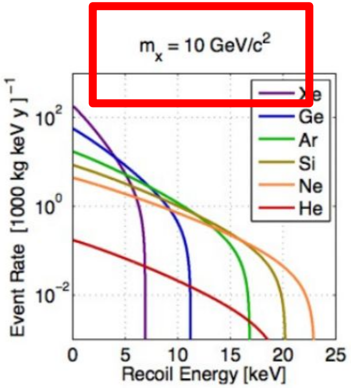
ioannis.katsioulas@cea.fr

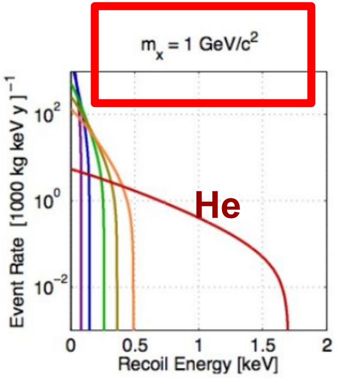
New Experiments With Spheres

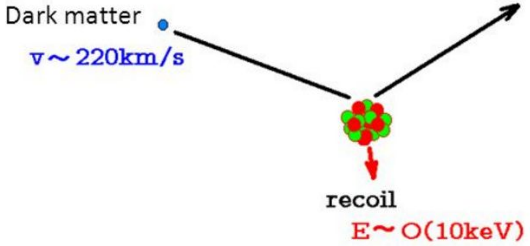
Search for WIMPs in the 100 MeV – 10 GeV mass range



Spin Independent couplings







Motivation:

Non findings at:

- Passive experiments
- LHC

Method:

Direct detection using:

- A Novel spherical gaseous proportional counter

- Light gases as target (H, He, Ne) for a better projectile – target kinematical match

Spherical Proportional Counter - Spherical TPC

Fun facts

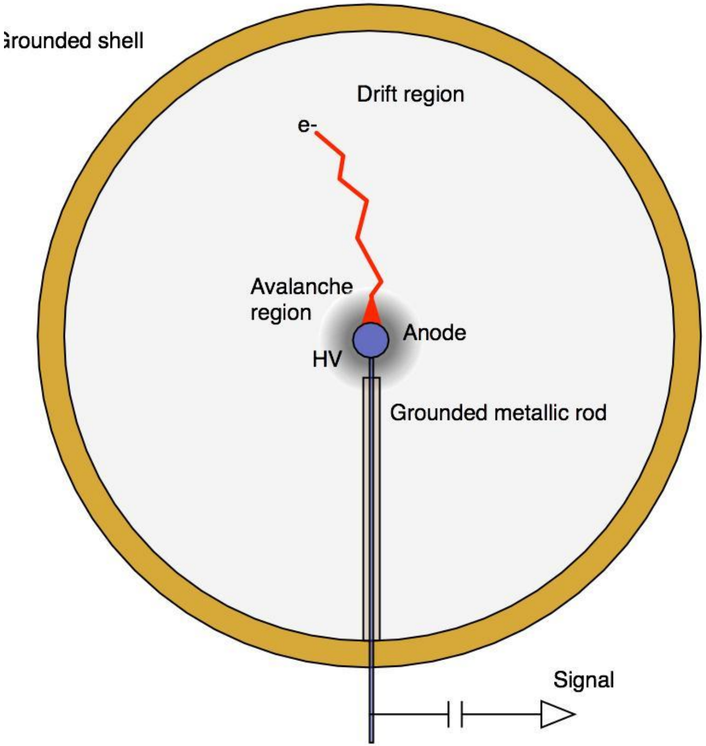
Old LEP RF cavities

Spherical gaseous detectors

In the picture:
I.Giomataris, G.Charpak

Spherical Proportional Counter

Principal of operation



I.Giomataris et al ,JINST,2008, P09007

Greatly varying field along the radius

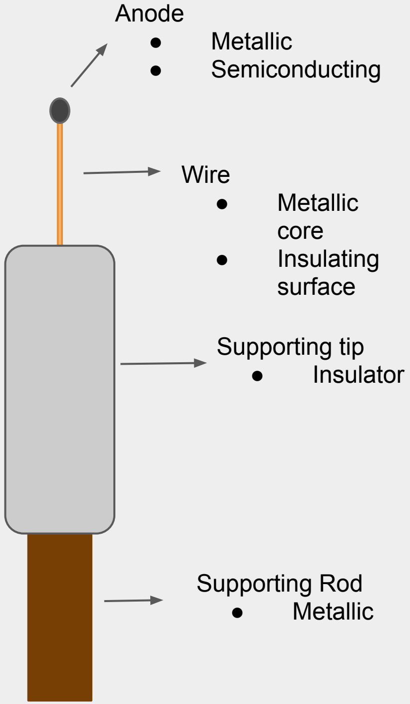
$$E = \frac{V_0}{r^2}\frac{r_1 r_2}{r_2 - r_1} \approx \frac{V_0}{r^2} r_1$$

r_1 = *anode radius*
r_2 = *cathode radius*

Natural division of the volume in two

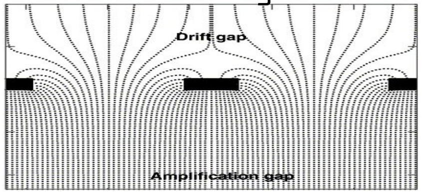
- Drift volume
- Multiplication volume

The Sensor

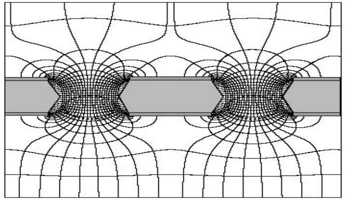


Capacitance dependence on size

Micromegas

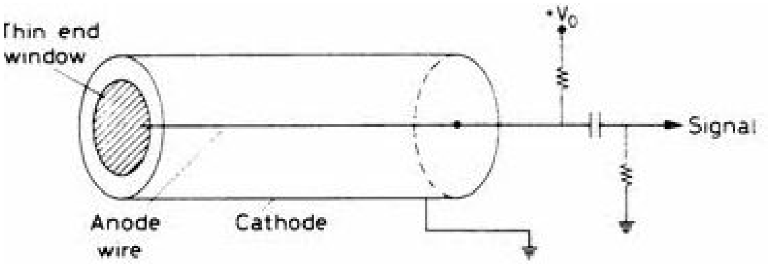


GEM



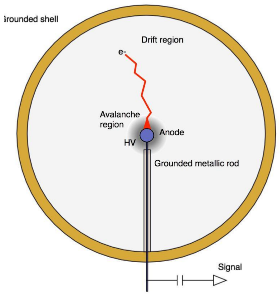
Parallel Plate Detector

$$C \approx S > 1nF$$



Cylindrical Proportional Counter

$$C = 2pL/\ln(b/a) >> 10\ pF$$

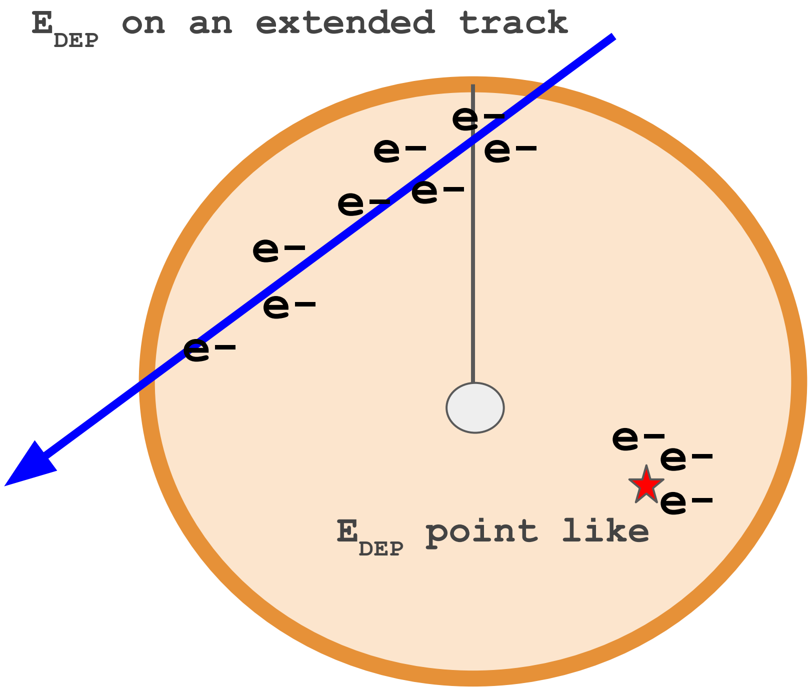


Spherical Proportional Counter

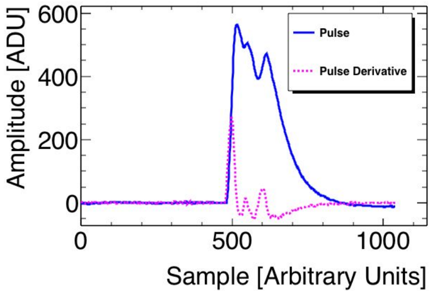
$$C \approx r_1 < 1pF$$

Large Size Detector
+
Robust construction

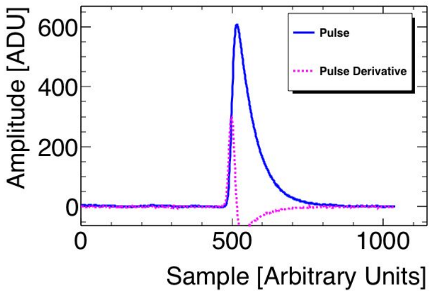
Extended versus point like energy deposition



Muon induced pulse



Ion induced pulse

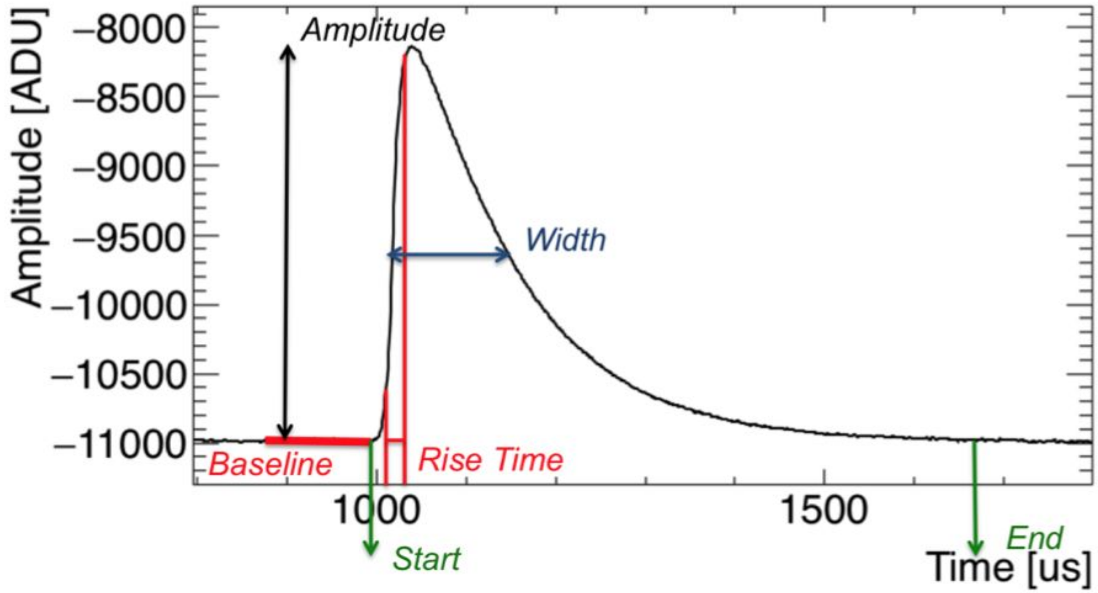


$\sigma(r) \propto (r/r_{sphere})^3$, e− drift time dispersion

Induced Pulses

Pulse Shape Analysis (PSA) parameters

Long Tail Pulse



Pulse Rise time & Width ∝ Drift time dispersion

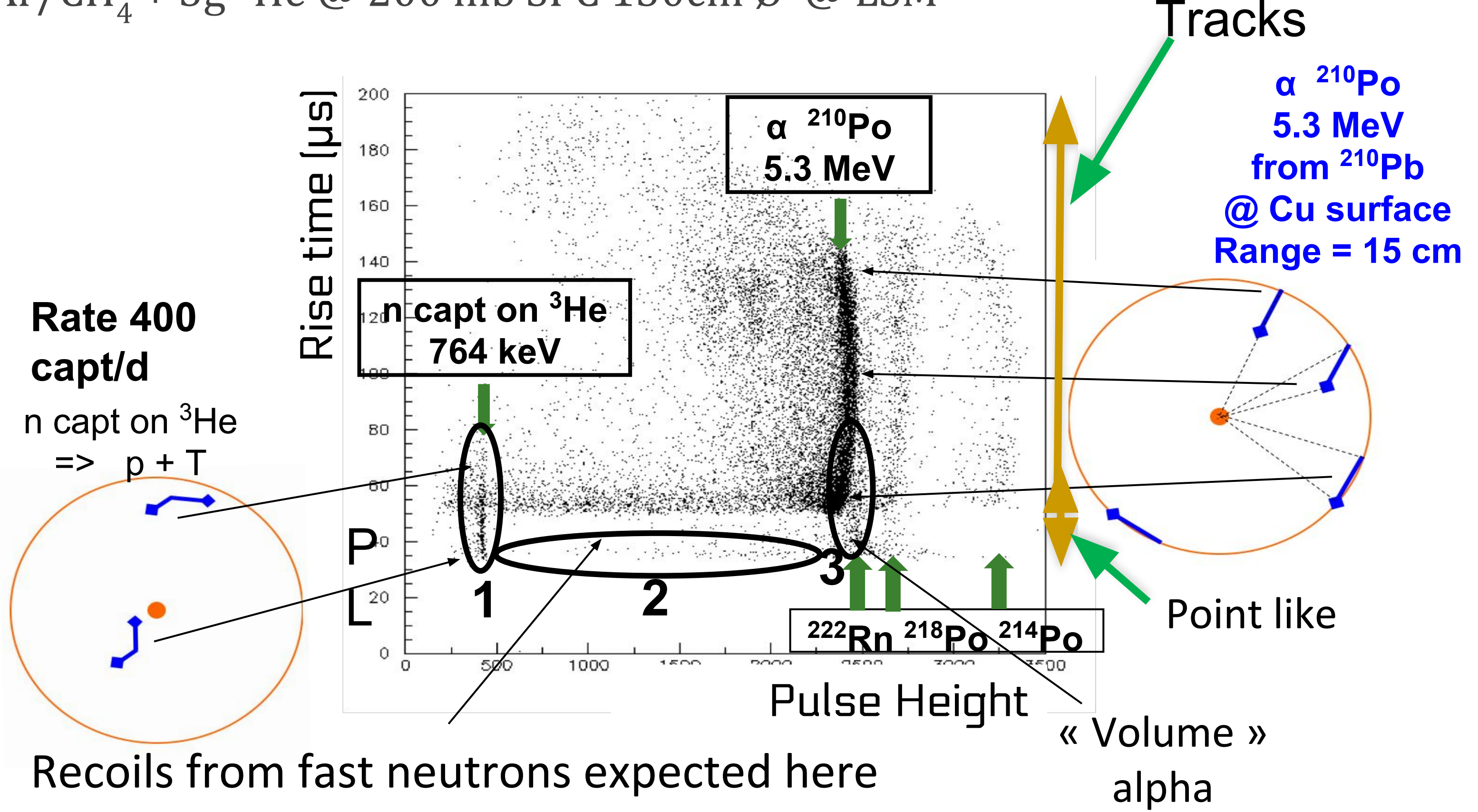
<u>Parameters</u>

- Baseline
- Noise
- Peak height
- <u>Rise time</u>
- <u>Width</u>
- Integral
- Number of peaks

A lot of information hiding in the pulse shape

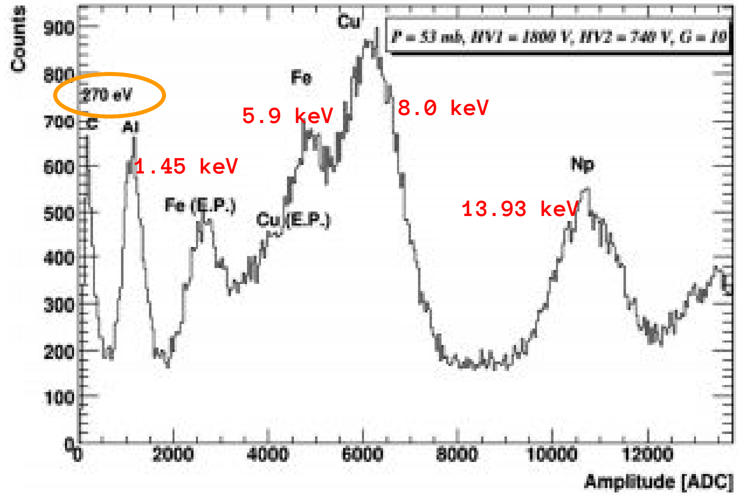
Illustration of particle identification – Background rejection

Run with Ar/CH_4 + 3g ^3He @ 200 mb SPC 130cm Ø @ LSM



Low energy capabilities

E. Bougamont et al, Journal of Modern Physics, Vol. 3 No. 1, 2012, pp. 57-63.



SPC Φ 130 cm

Gas: Ar+2% CH_4

Detection of fluorescence X-rays

^{241}Am -> ^{237}Np+^{4}He+ 5.6 MeV

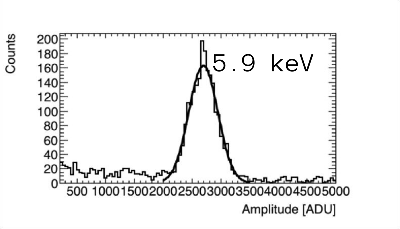
Lines

Al -> 1.45 keV

Cu -> 13.93 keV

^{237}Np -> 13.93 keV(L_α)

17.60 keV(L_β)



SPC Φ 30 cm

Irradiation by an ^{55}Fe source (5.9 keV)

Resolution (σ) <9%

- **Single electron detection**
- **Energy threshold < 50 eV**

Structure of the experiment

Ground Labs → **LSM Underground Lab** → **SNO Underground Lab**

Ground Labs

- R&D
- Electronics
- Gas studies
- Simulations
- Data analysis methods
- ...

LSM Underground Lab

- SEDINE detector in operation
- Competitive - will also act as the testbench for SNO detector

SNO Underground Lab

- The NEWS-G leading actor

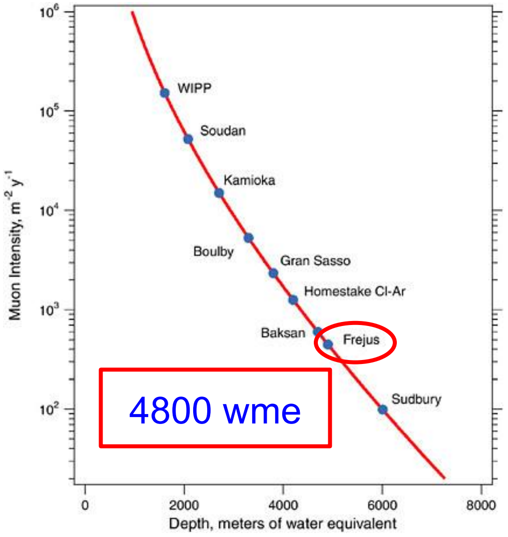
LPSC Grenoble

Ionization Quenching Factor measurements using a low energy ion accelerator

Prototype low background SPC at LSM, Modane (SEDINE)

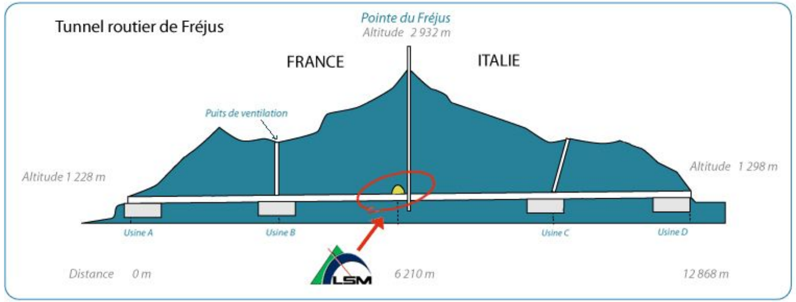
A competitive detector and a testing ground for NEWS-G / SNO

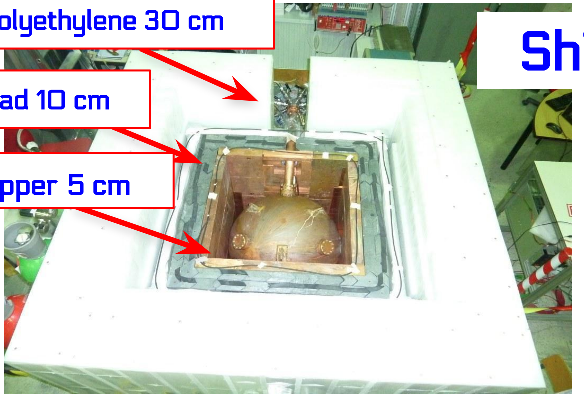
- Copper vessel (Ø 60 cm)
- Equipped with a 6.3mm Ø sensor
- Chemically cleaned several times for Radon deposit removal



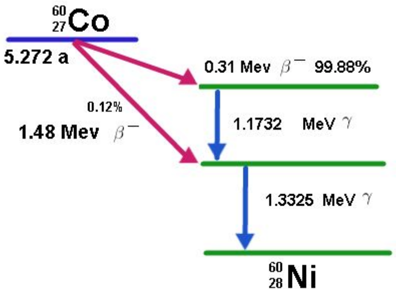
The SEDINE sensor

Laboratoire Souterrain de Modane





Main background sources for LSM detector



^{60}Co Contamination of 1 mBq/kg

BG Rate = 0.3-0.5 evnt/keV/kg/day

Solution: Limit time exposure on ground for pure copper.

^{210}Pb, ^{210}Bi Contamination of 1 nBq/kg

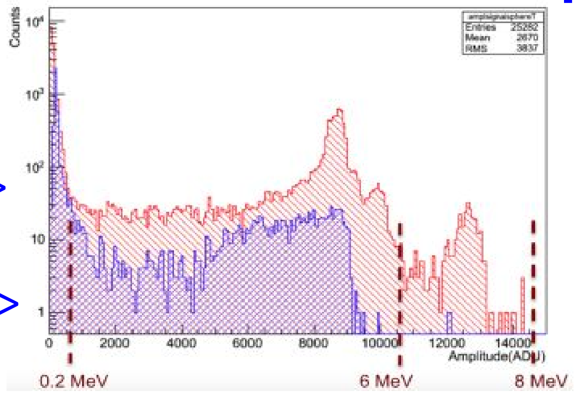
BG Rate = 0.1 evnt/keV/kg/day

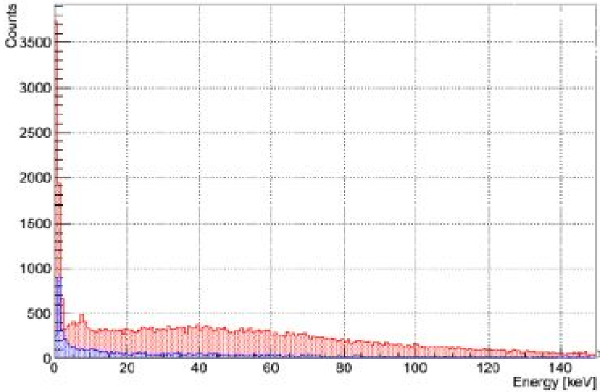
Competitive BG levels

Solution: Chemical cleaning

Effect of cleaning:

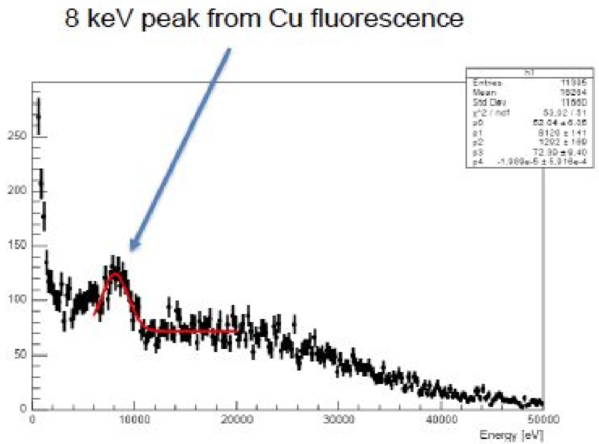
- High energy events 180 mHz => ~2 mHz
- Low energy events 400 mHz => ~20 mHz

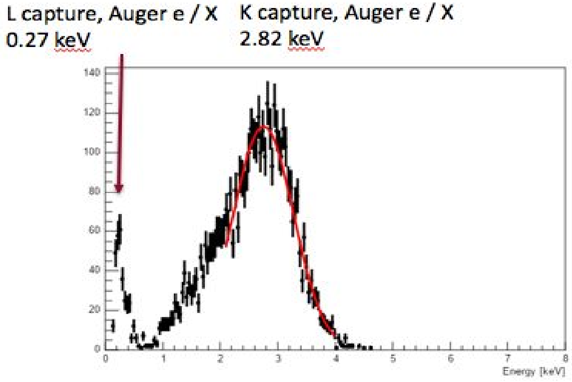




Operation and data taking conditions

- Data taking continuously during 42 days
- 99.3% Neon + 0.7 % CH_4 at 3.1 bar (310 gr)
- High voltage on anode set to 2520 V, no sparks
- Absolute Gain around 3000.
- Seal mode, no recirculation.
- Loss of gain 4% along 42 days
- Canberra charge sensitive preamplifier 2006 (RC=50 μs)
- Calibration with an ^{37}Ar gaseous source (from (n, α) reaction of ^{40}Ca) and the 8 keV fluorescence line of Copper

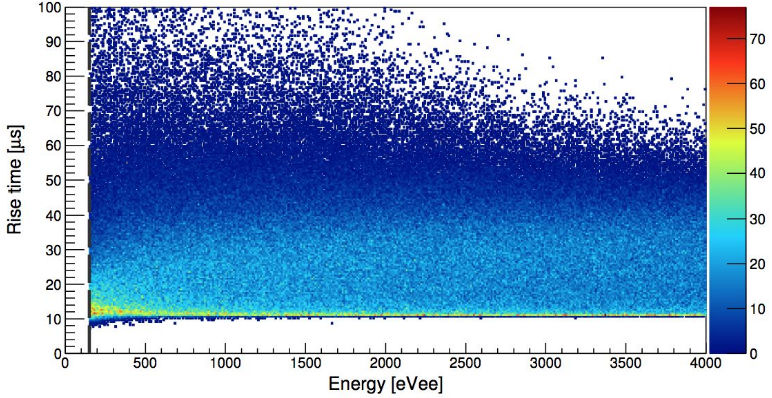




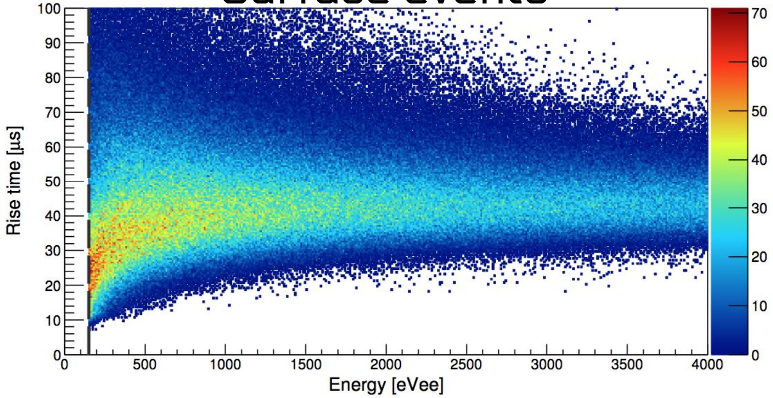
^{37}Ar X rays calibration

Simulation of volume and surface events

Volume events



Surface events



Anticipated main backgrounds:

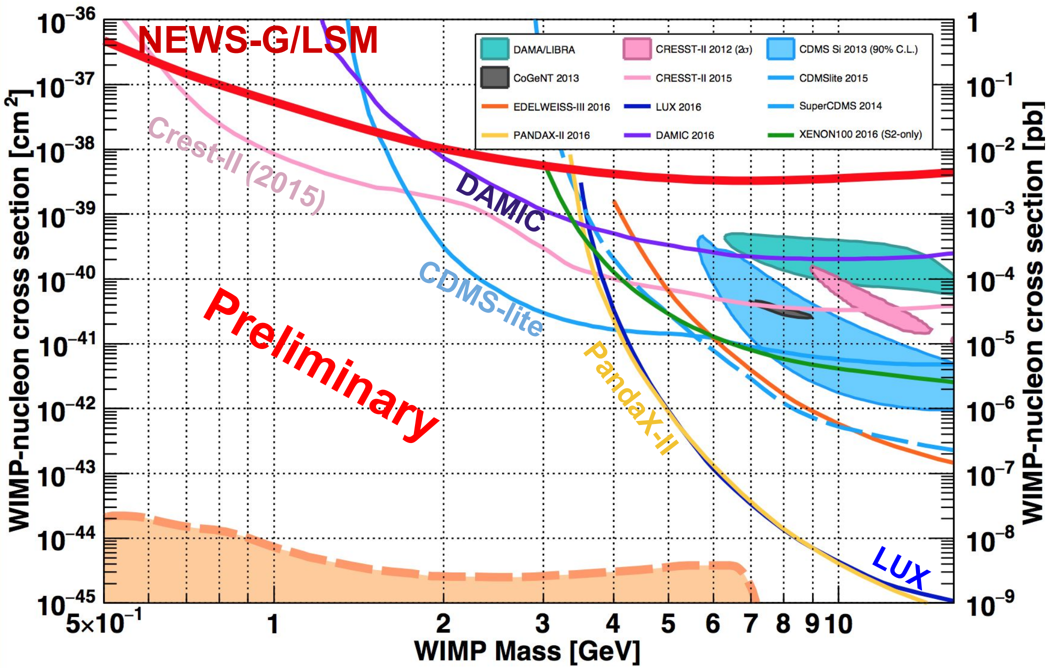
- Compton electrons (volume)
- ^{210}Pb decay products (surface)

Pulse simulations include:

- Electric field (FEM)
- Diffusion (Magboltz)
- Avalanche process
- Signal induction
- Preamplifier delta response

The Simulation results were used at input to a Boosted Decision Tree (BDT) algorithm to determine a fine tuned ROI optimized for Signal/Background discrimination

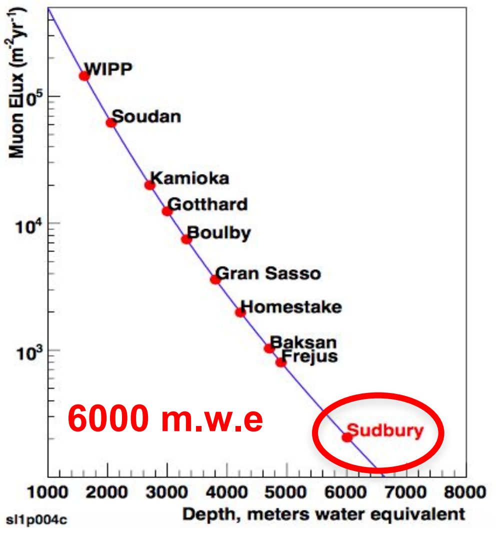
Exclusion limit of NEWS-G / LSM for Spin Independent Wimp couplings

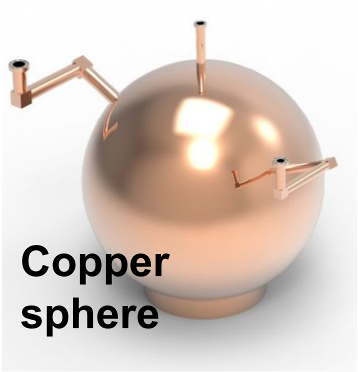


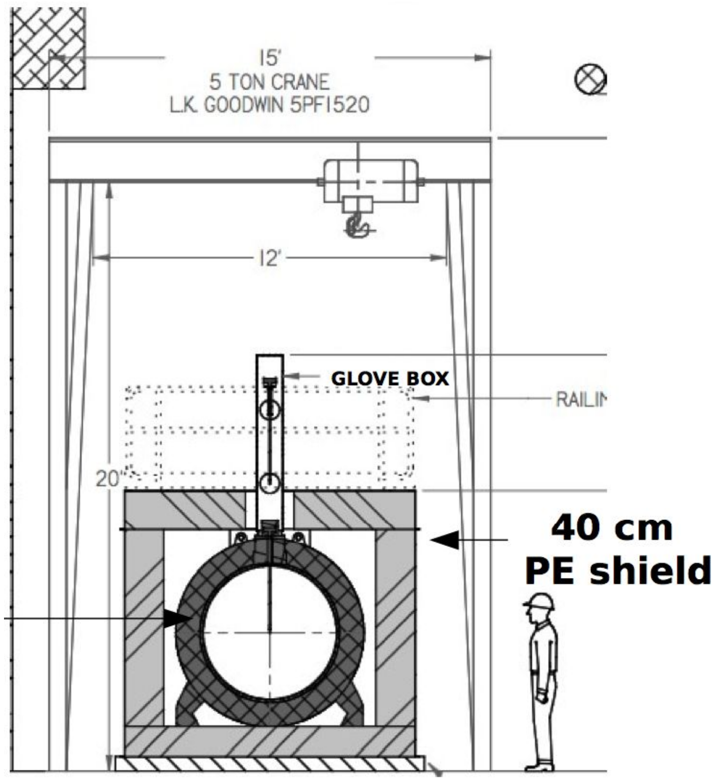
Limit set on spin independent WIMP coupling with standard assumptions on WIMP velocities, escape velocity and with quenching factor of Neon nuclear recoils in Neon calculated from SRIM

Implementation at SNOLAB by fall 2018

- 140 cm Ø detector, 10 bars, Ne, He, CH_4
- Low BG Copper Shell (12 cm thick)
- Shield: 40cm PE +Boron sheet + 25cm Lead + 3cm Ancient Lead







35 t shields

Estimated background

Simulation done with 12mm thick 140cm diam copper sphere full with 99% Ne 1%CH4, 11.43 kg of gas

Source Position	Mass (kg) or Surface (cn		Source	evts/kg/day/[(µBq/kg) or (nBq/cm2)]	contamination	units	evts/kg/day < 1ke
CopperSphere	627.83 kg		Co60	0.0018	30	µBq/kg	0.054
CopperSphere	627.83 kg		U238	0.0036	3	µBq/kg	0.011
CopperSphere	627.83 kg		Th232	0.0049	12.9	µBq/kg	0.063
InnerSurface	57255 cm^2		Pb210	0.012	0.16	nBq/cm2	0.002
ArchLead	2108.95 kg		U238	0.001	61.8	µBq/kg	0.062
ArchLead	2108.95 kg		Th232	0.0011	9.13	µBq/kg	0.010
Rod	0.0931721 kg		Co60	2.95E-007	30	µBq/kg	0.000
Rod	0.0931721 kg		U238	1.81E-006	3	µBq/kg	0.000
Rod	0.0931721 kg		Th232	2.11E-006	12.9	µBq/kg	0.000
Wire	2.66005e-05	kg	Co60	1.48E-010	31000	µBq/kg	0.000
Wire	2.66005e-05	kg	U238	2.12E-009	300000	µBq/kg	0.001
Wire	2.66005e-05	kg	Th232	1.42E-009	50000	µBq/kg	0.000
Wire	2.66005e-05	kg	K40	5.41E-010	1660000	µBq/kg	0.001
LabArea			Tl208/K40				0.076
						Total	0.279

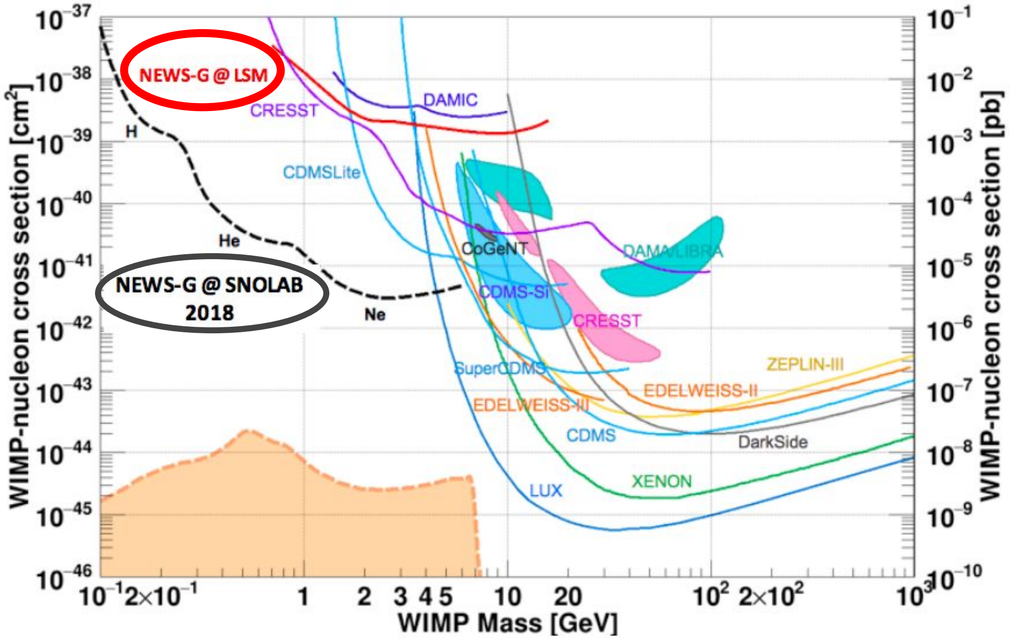
Copper

Internal surface

Lead shield

External BG with SNO Flux

Predicted exclusion limits for NEWS-G / SNO



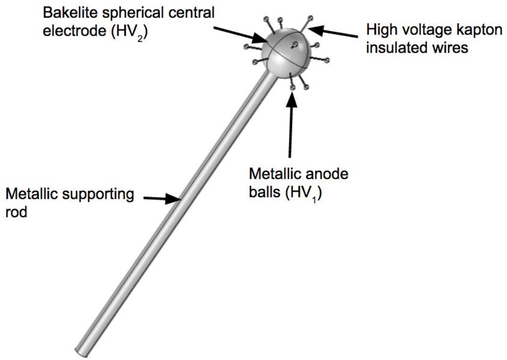
Hypothesis for NEWS-SNO expected sensitivity:

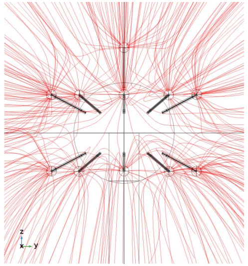
100 kg.days exposure @ 10 bar, Threshold 1 electron (~40 eV), 200eV window

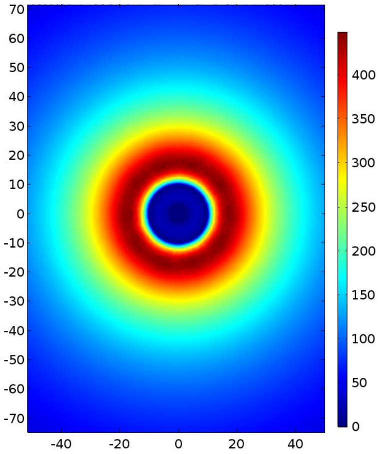
A sensor upgrade

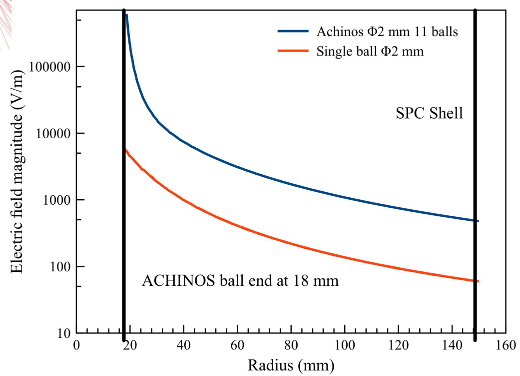
Sensor development - ACHINOS

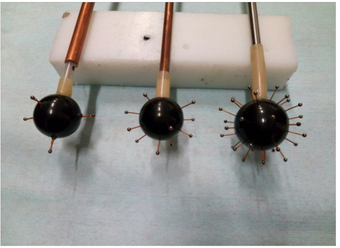
If instead of one ball we use a number of them placed at equal distance on a sphere you can have the same gain but increased field at the outer region of the detector











AIM:

1. Operation in high pressure
2. Build larger volume detectors

Conundrum:
Both Gain and Drift time are a function of E/P

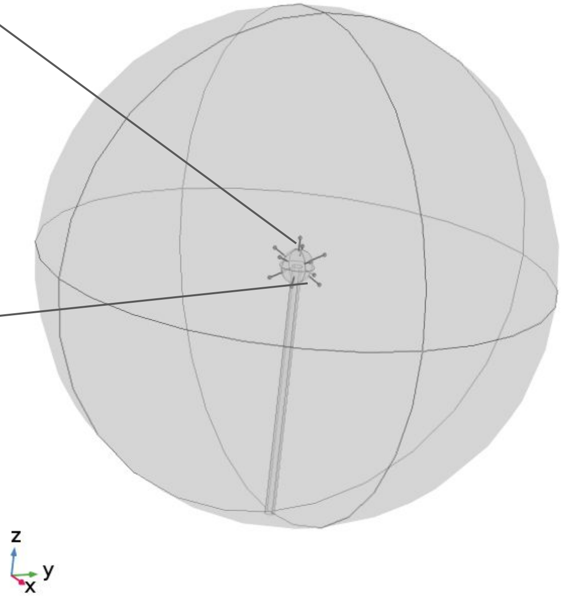
$$\ln M = \int_{E(r1)}^{E(r2)} a(E/P)\frac{dr}{dE}\,dE$$

$$v_{drift} = \mu \frac{E}{P}$$

The elegant solution – ACHINOS

- Decoupling Gain -Drift
- Tunes Volume electric field
- Anodes can be read out individually

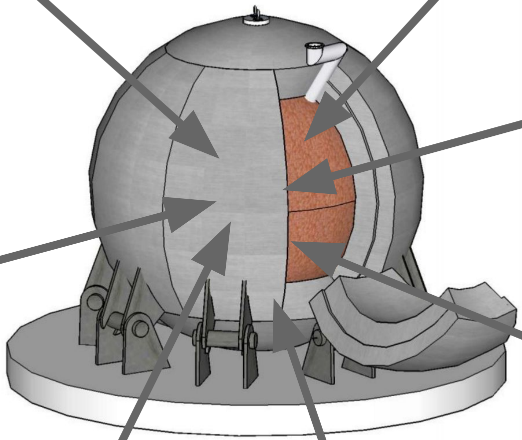
And just in case you wondered about the name …



ACHINOS = Sea urchin = Riccio di mare

Detector versatility

NEWS-G
SNO



Operation with different targets:
Ne, He, H

Operation with different pressures:
Tenths mbar - 10 bar

Operation with High Z medium (Xenon) to better determine the background

Resistive sensors:
High Gain

ACHINOS sensor:
Tuning volume electric field - High gain- Multichannel readout

"Penning" Mixtures
Ne/CH_4 or He/CH_4 (99.3/0.7):
High pressure - High Gain - Minimized voltages applied

Regular Mixtures
Ne/CH_4 or He/CH_4 (90/10):
Hydrogen rich gases

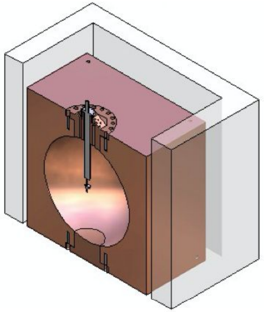
Conclusions and Outlook

- The SPC is a simple, robust detector, providing background rejection capabilities

- The first very competitive gaseous detector in DM searches
- First runs with He/CH4 mixtures have already started in LSM, Modane
- The Sedine detector is an excellent testing ground for NEWS-G/SNO

- The NEWS-G/SNO will have better Shield-Materials-Installation Procedure
- Construction is expected to start by fall 2017 and the installation by 2018

- R&D for the detector development
  - Underground electroformed sphere (PNNL)
  - Cubic sphere



- Some extra investigations with our detector
  - KK solar axions through 2 photon decay
  - Coherent neutrino nucleus elastic scattering (Reactor/Supernova neutrinos)

NEWS-G collaboration

- **Queen's University Kingston** – G Gerbier, P di Stefano, R Martin, T Noble, D Dunrford A Brossard, A Kamaha, P Vasquez dS, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier
  - 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 Dastgheibi Fard
  - Low activity archeological lead
  - Coordination for lead/PE shielding and copper sphere
- **Thessaloniki University** – I Savvidis, A Leisos, S Tzamarias, C Elefteriadis, L Anastasios
  - 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
- **Technical University Munich** – A Ulrich, T Dandl
  - Gas properties, ionization and scintillation process in gaz
- **Pacific National Northwest Lab** – E Hoppe, D 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** – Kostas Nicolopoulos
  - Simulations, analysis, R&D
- **Associated lab : TRIUMF** - F Retiere
  - Future R&D on light detection, sensor


Thanks for your attention !