Search for Light Dark Matter with Spherical Proportional Counters

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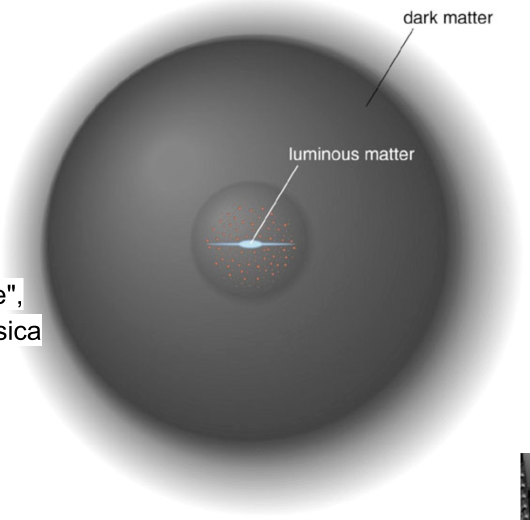
The dark matter conundrum



Observations of F.Zwicky 87 years ago

"The Redshift of Extragalactic Nebulae", published in German in Helvetica Physica Acta in 1933

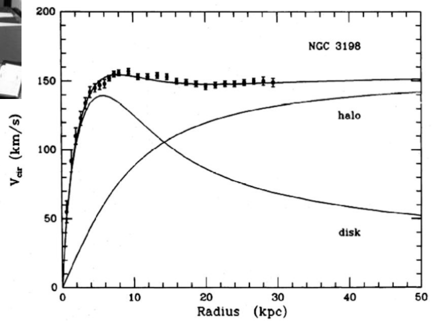
“In a spiral galaxy, the ratio of dark-to-light matter is about a factor of ten. That's probably a good number for the ratio of our ignorance-to-knowledge. We're out of kindergarten, but only in about third grade.”

Vera Rubin

What should it be from astrophysical constraints:

- Mostly “Cold”
- Non-Baryonic
- “Weakly” interacting
- $\Omega_{DM} = 0.265$
- Stable or $\tau_X >> \tau_U$

No Standard Model particle matches the criteria



Dark matter detection

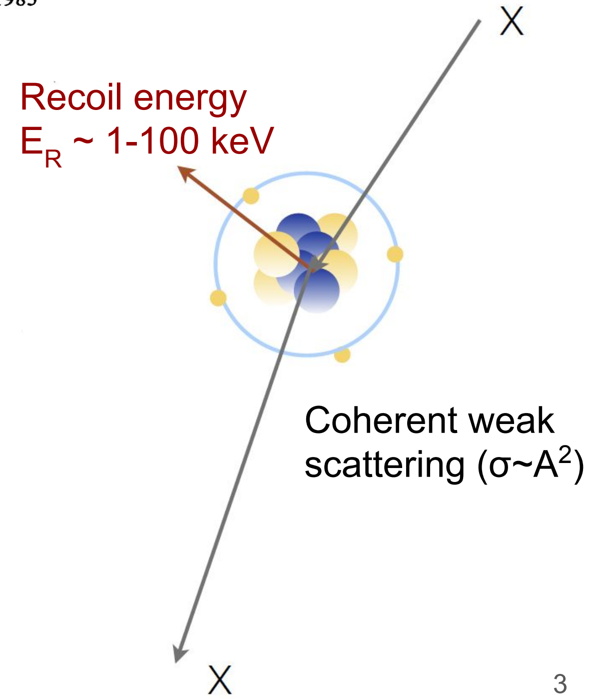
PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544

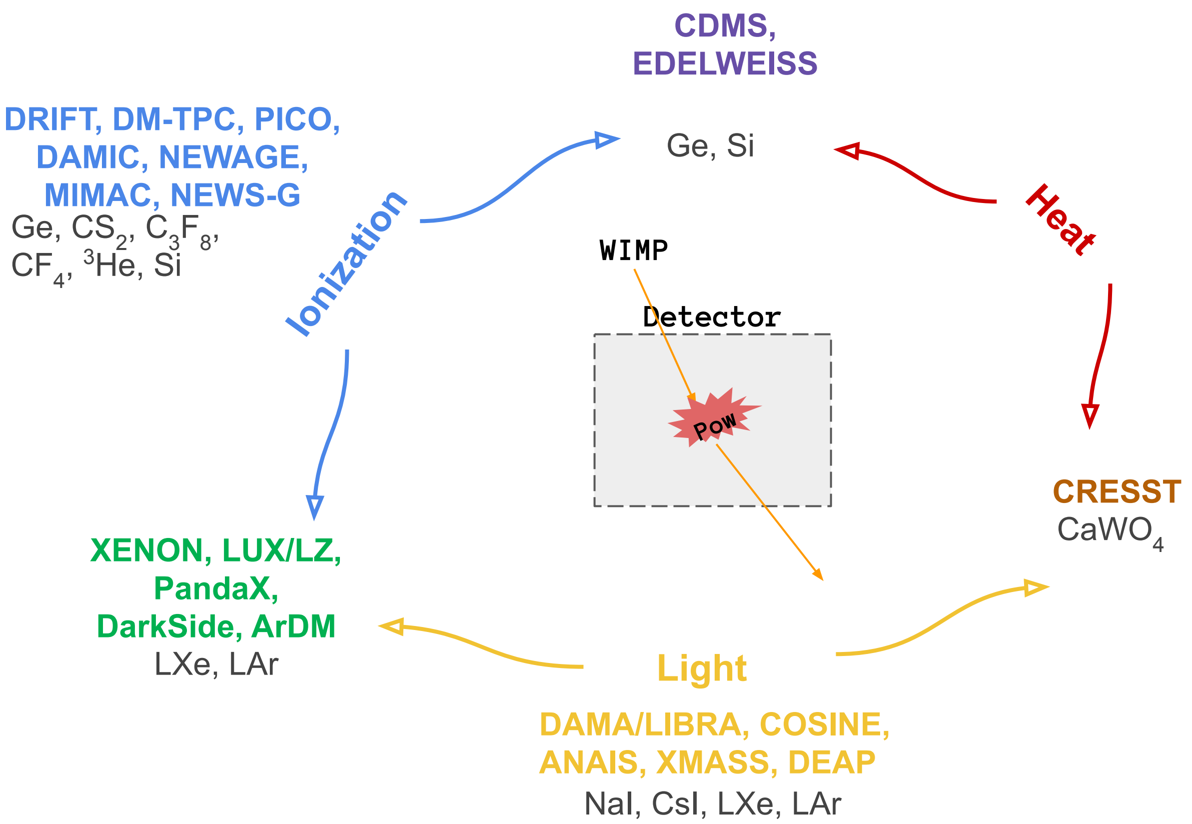
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

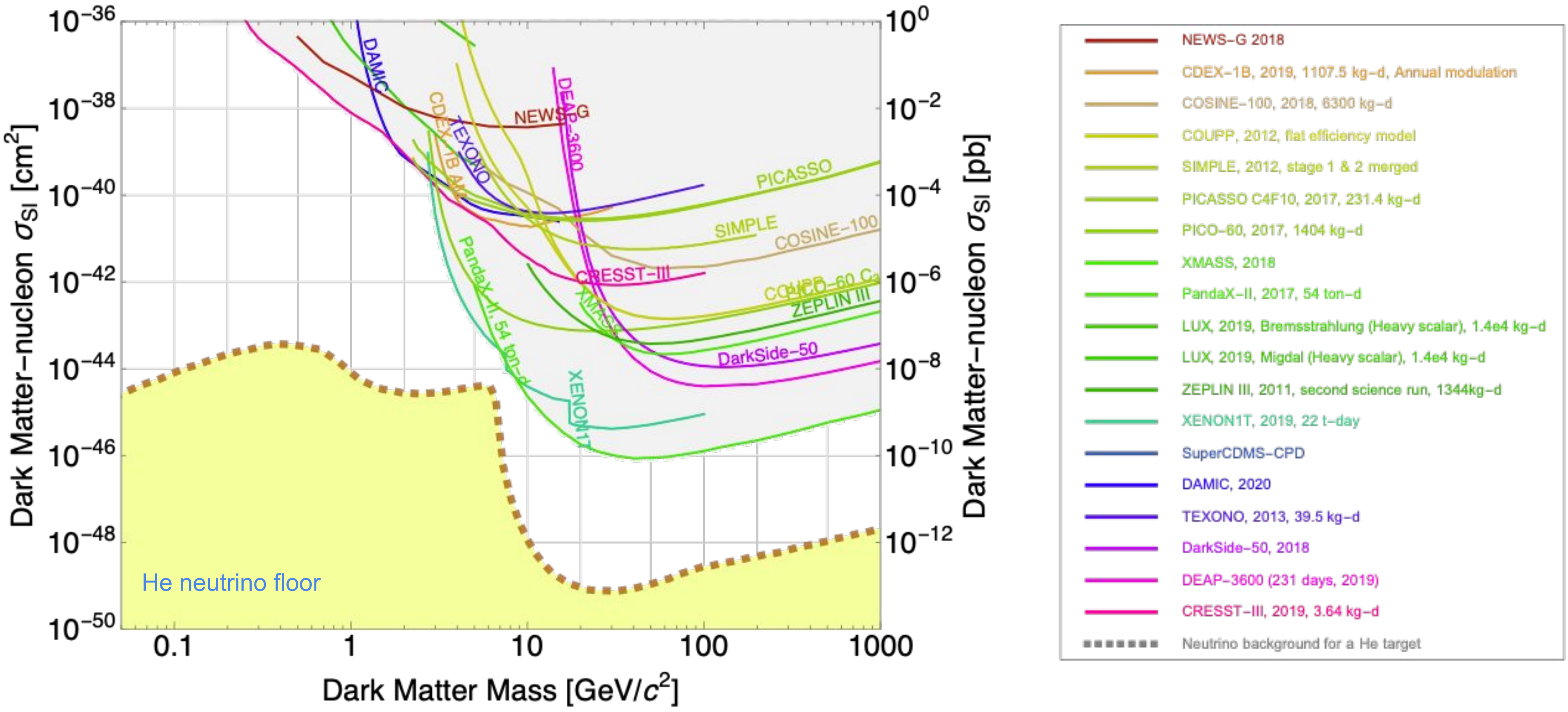


“WIMP miracle” ⇒ Relic abundance explained by a massive particle (5 GeV/c^2 - few TeV/c^2) interacting through weak scale interaction with baryonic matter

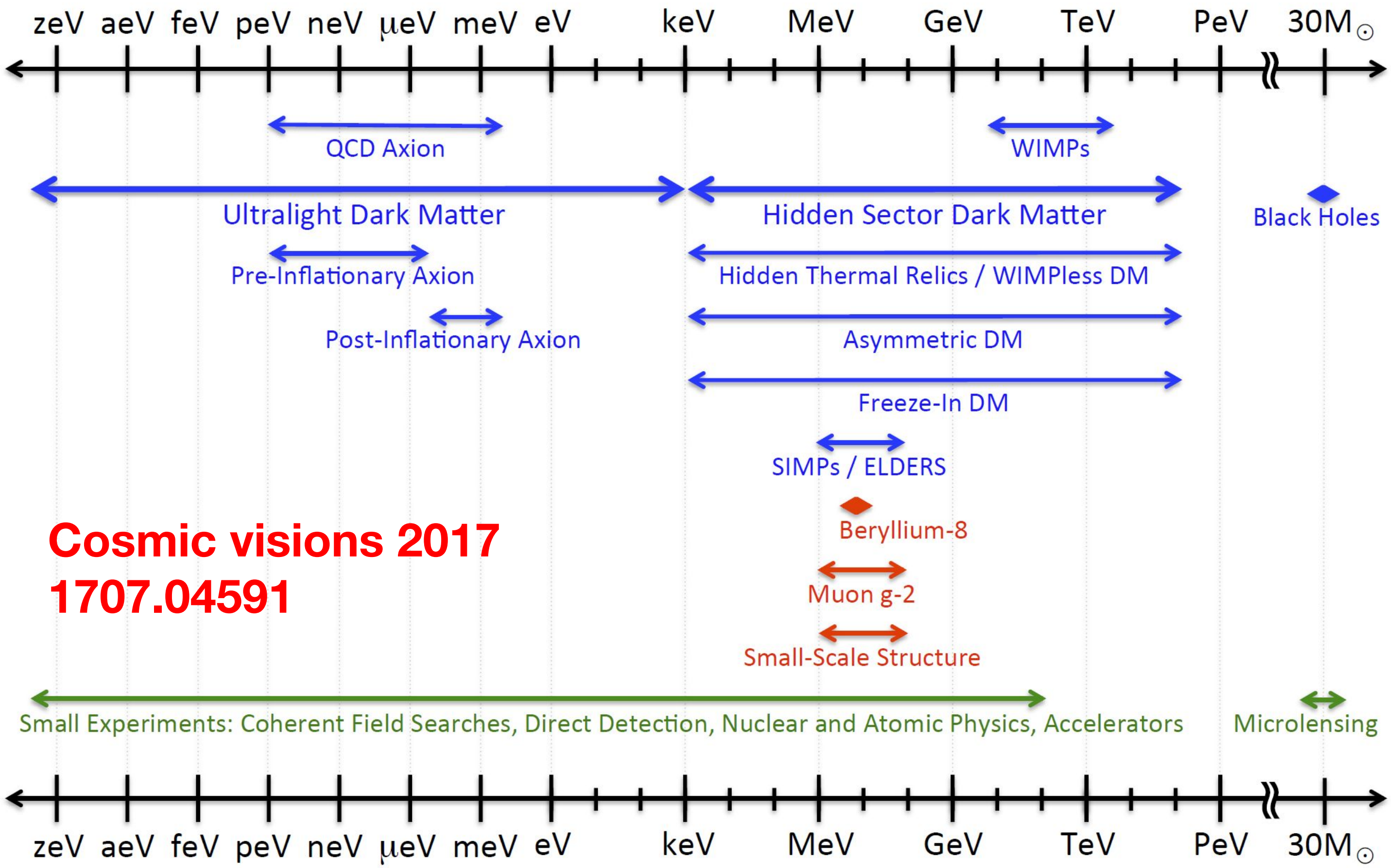
State of the art for dark matter detectors



Direct detection landscape

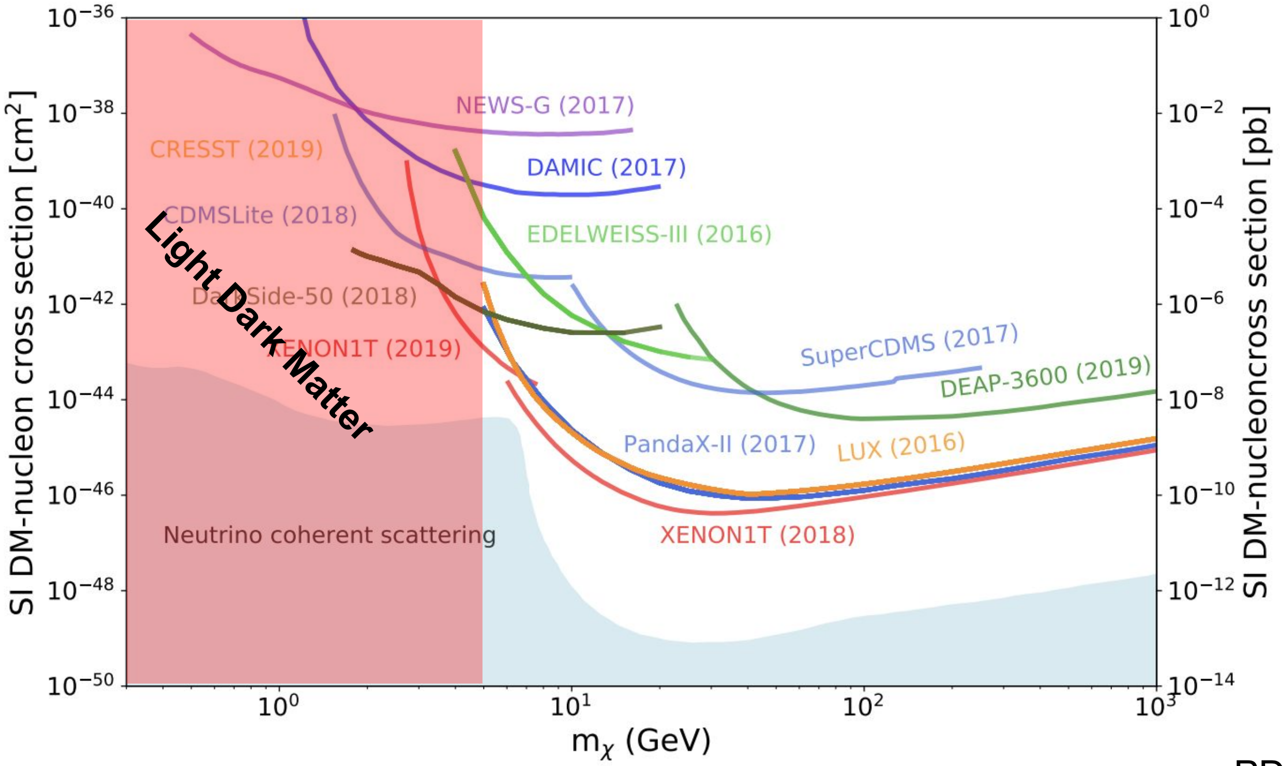


Dark Sector Candidates, Anomalies, and Search Techniques



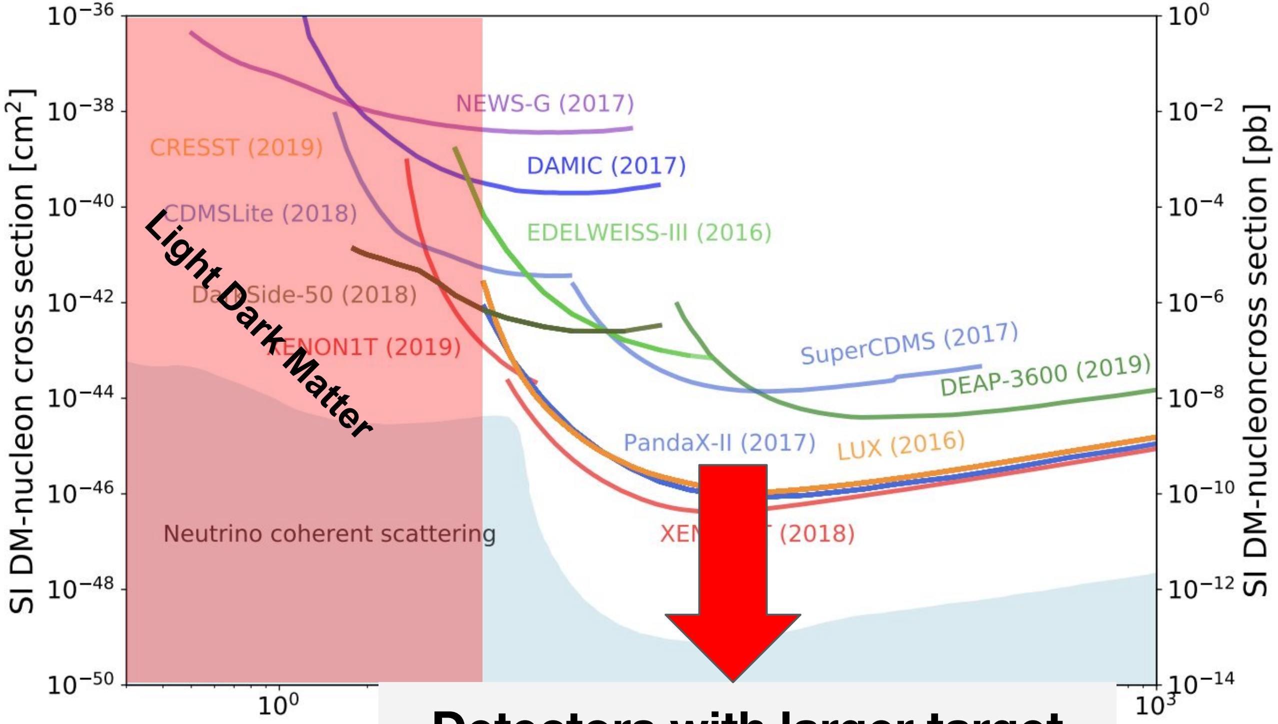
Cosmic visions 2017
1707.04591

Light Dark Matter (LDM) mass region



PDG 2019

How does one search the LDM region?



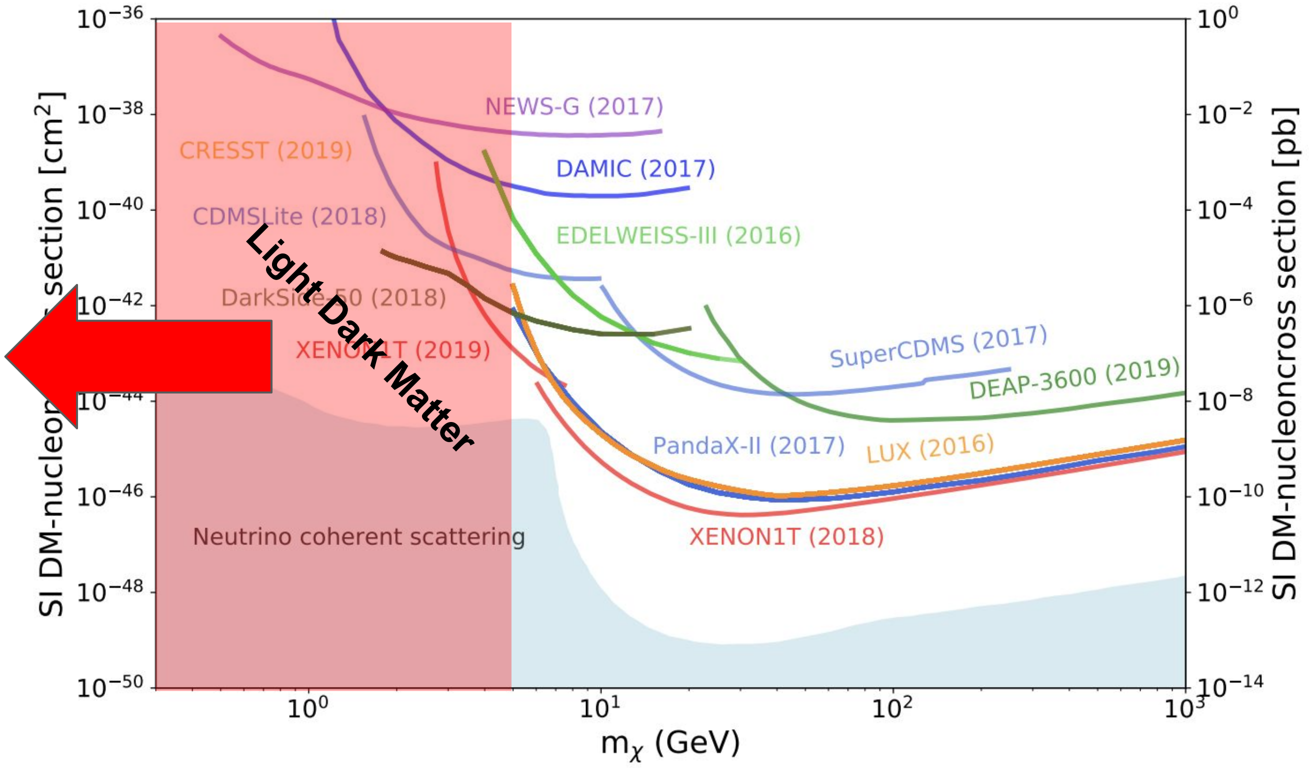
Detectors with larger target mass - exposure kg·days

PDG 2019

Direct detection landscape

New detector technologies:

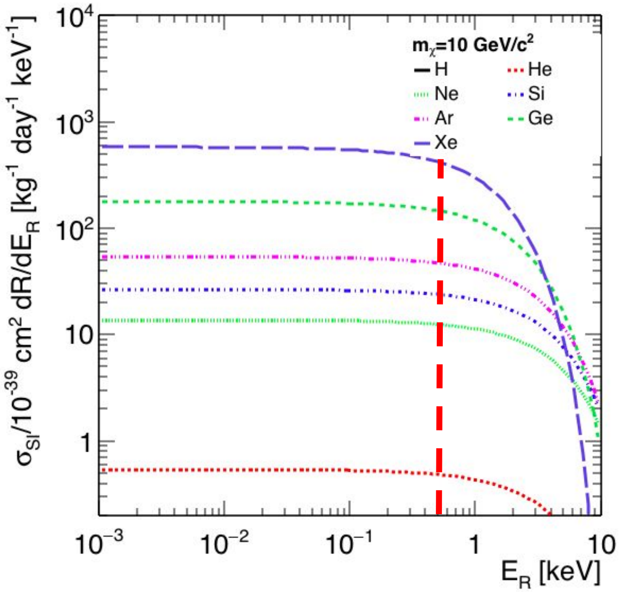
- **Lower threshold**
- **Lighter targets**

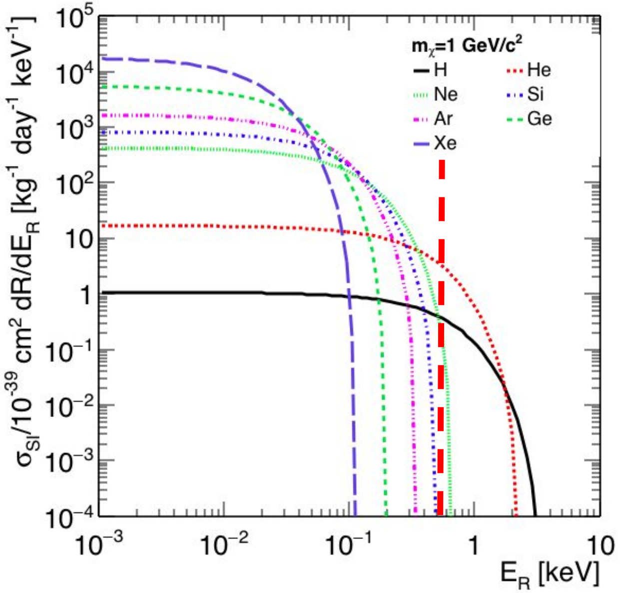


PDG 2019

Light-DM detection particularities - A

Target kinematics





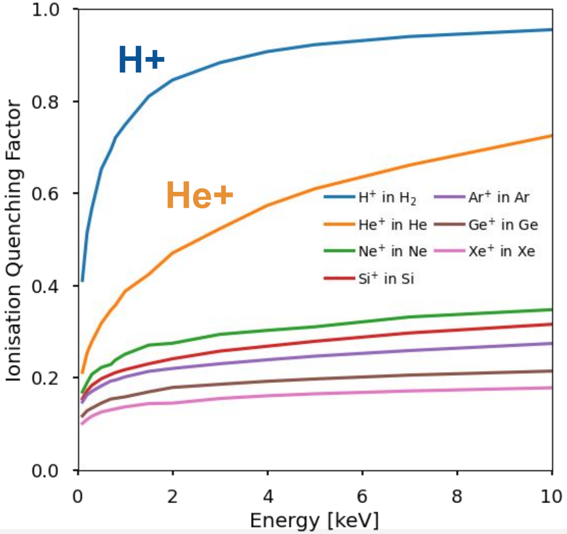
500 eV

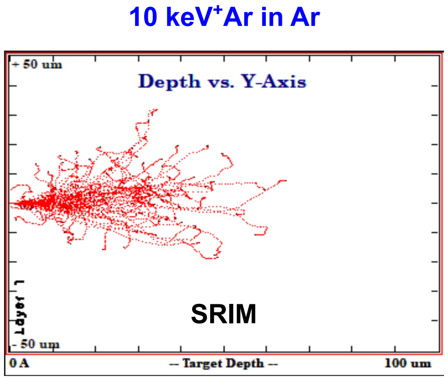
Light Projectile + Light target ⇒ Better kinematic match

Light-DM detection particularities - B

Ionization quenching

Quenching factor: fraction of ion kinetic energy dissipated in a medium in the form of ionization electrons and excitation of the atomic and quasi-molecular states.





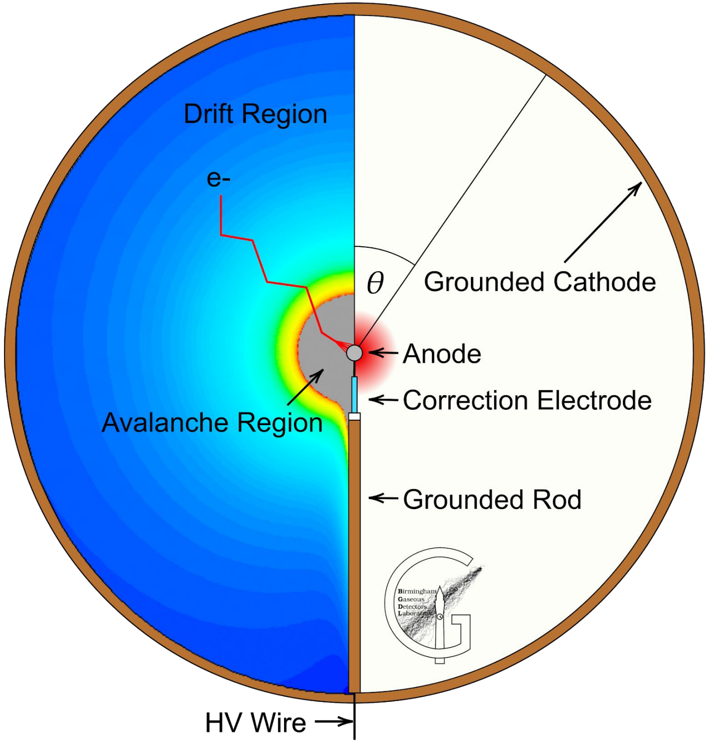
Light Projectile + Light target ⇒ Less demanding detector threshold

NEWS-G collaboration
UK, France, Greece, Canada, US

Light Dark Matter searches with an innovative gaseous detector the Spherical Proportional Counter

The Spherical Proportional Counter (SPC)

I.Giomataris et al ,JINST,2008, P09007



Electric field

Strong radial dependence

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

r_A = anode radius
r_C = cathode radius

Detector volume naturally divided in:

- **Drift region**
- **Amplification region**

- Simple design
- Single readout

Spherical Proportional Counter (SPC)

The "birth" of a detector

Old LEP RF cavities

Spherical gaseous detectors

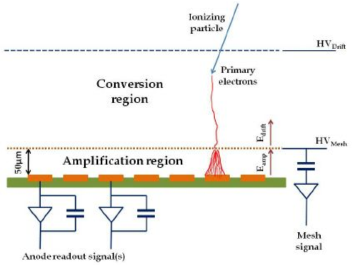
In the picture:
I.Giomataris, G.Charpak

Advantage of spherical geometry

Large detectors - Low threshold

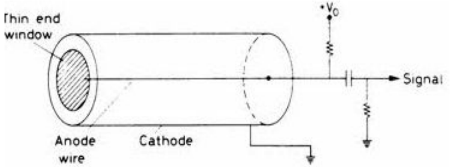
Capacities for a 1 m^3 detector in different geometries

Parallel Plate



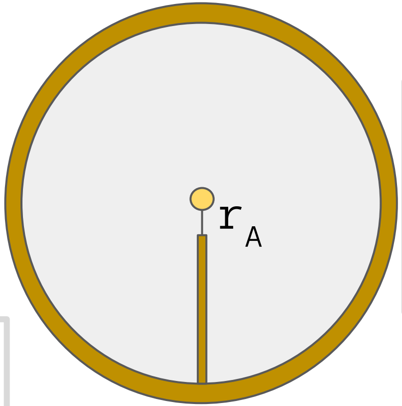
$$C = \varepsilon_0 \frac{S}{d} \approx 3500 \text{ pF}$$

Cylindrical



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

Spherical



$$C \approx 4\pi\varepsilon r_A \approx 1.5 \text{ pF}$$

Lower Capacitance ⇢ Lower Electronic Noise ⇢ Lower Threshold

Advantage of spherical geometry

Construction with radiopure materials

Advantages of the spherical geometry

- Lowest surface to volume ratio
- Sustains higher pressure
- Robustness (anode Ø 1 mm - 6.3 mm)

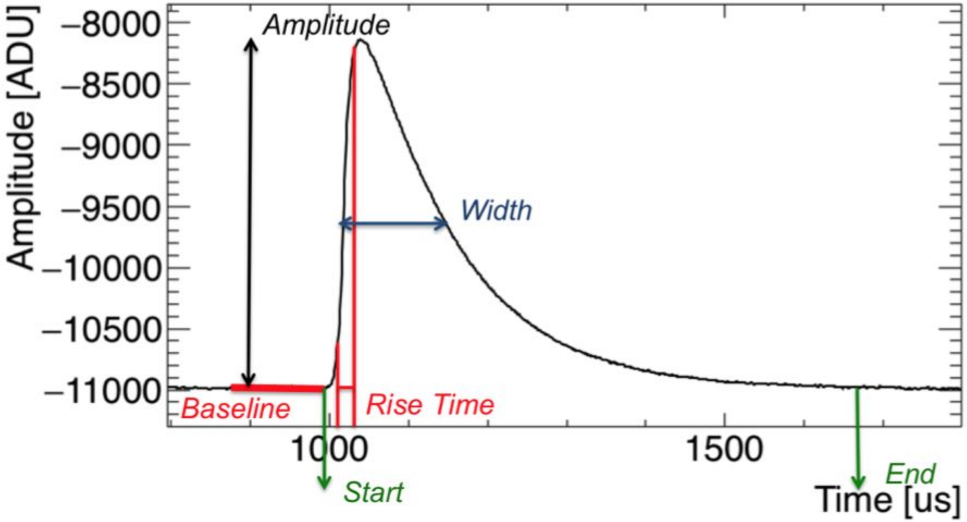
Built solely by radiopure materials

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

Induced Pulses

Pulse Shape Analysis (PSA) parameters

Long Tail Pulse



Rise time & Width ∝ Drift time dispersion

Basic Parameters

- Baseline
- Noise
- Amplitude (Pulse Height)
- Rise time
- Width
- Integral
- Number of peaks

A lot of information in the pulse shape

Pulse-Shape Discrimination

(1) X-rays in volume,

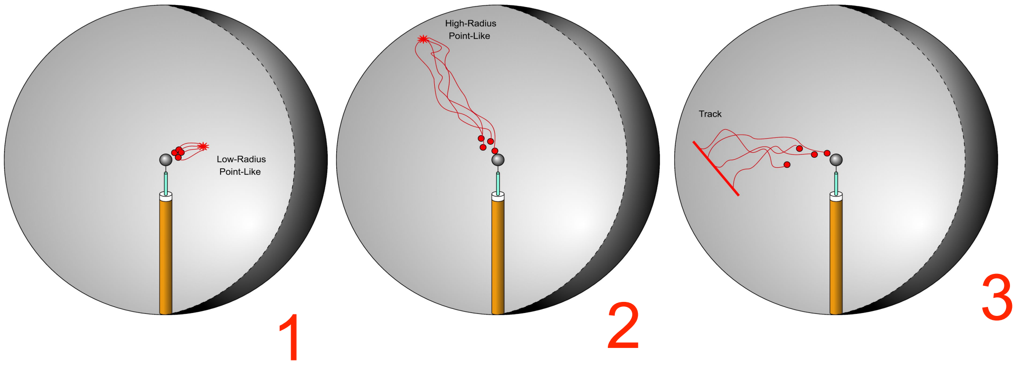
(2) X-rays near cathode

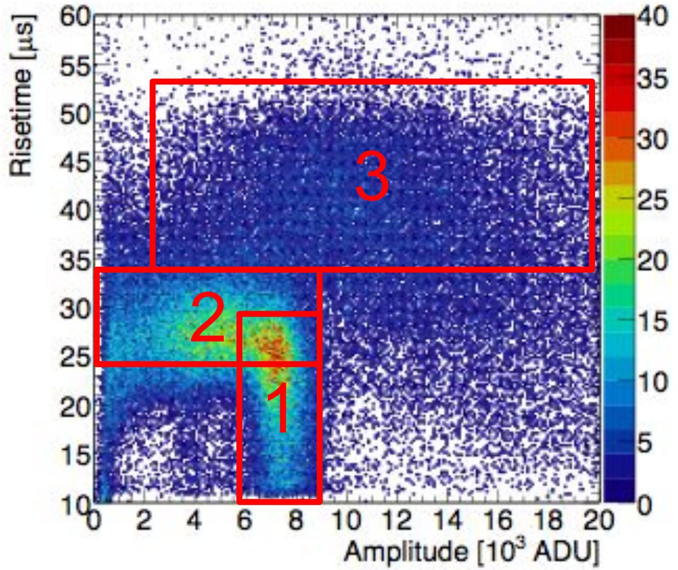
(3) Cosmic Muons

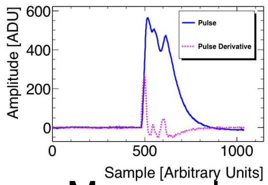
⌀30 cm detector
1.3 bar
He:Ar:CH4
(51.7:46:2.3)
Fe-55 Source
Inside

Rise time (~charge collection time) selections to:

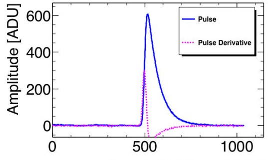
- Distinguish point-like versus extended ionisations
- Fiducialise detector
  - Majority of background from cathode material
  - Can select against near-cathode events
- Reliant on homogeneous electric field and high electric field at large radii (for charge collection)







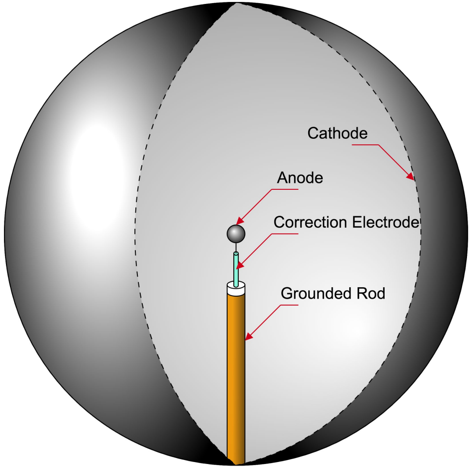
Muon pulse



$^+$Ar pulse

Detector features

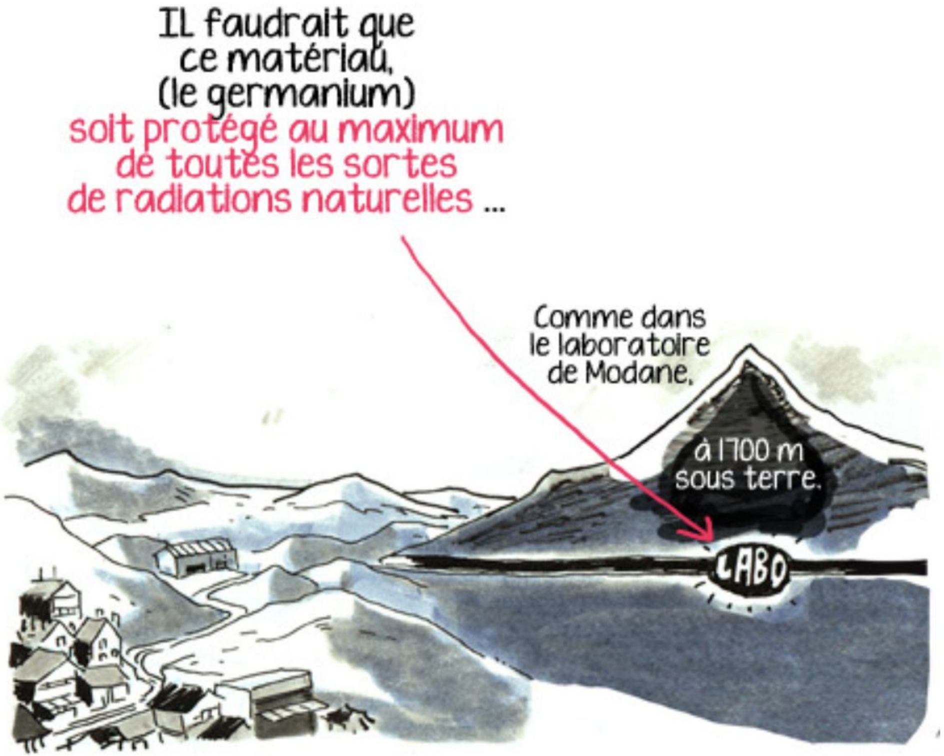
- **Large volume read out with a small number of channels**
- **Single electron threshold due to:**
  - **Low capacitance**
  - **High gain**
- **Radio-pure construction**
- **Background rejection handles**
- **Flexible operation**
  - **Swappable gases-targets**
  - **Variable pressure choice**

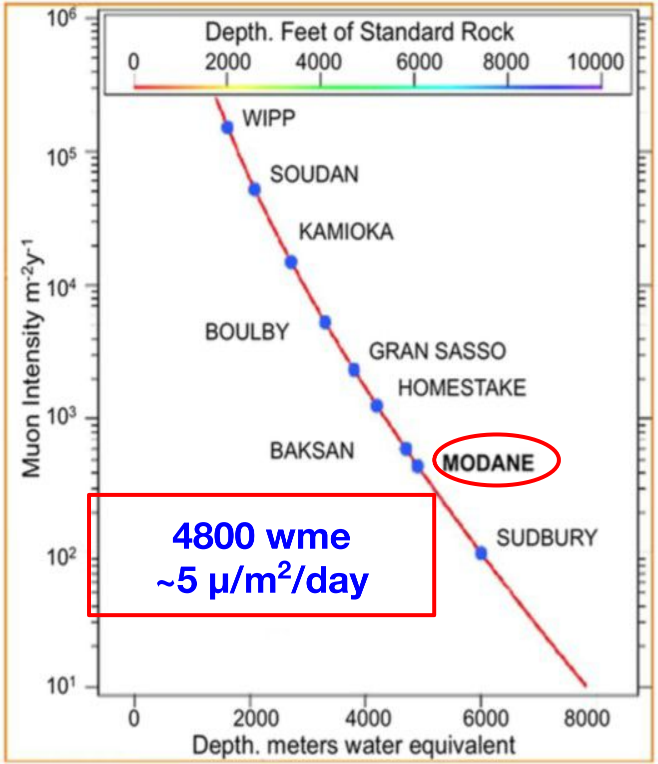


Applications include:

- Dark matter searches
- 2β0ν decay searches
- CEνNS physics
- Neutron spectroscopy (potentially useful for proton therapy)

NEWS-G at Modane



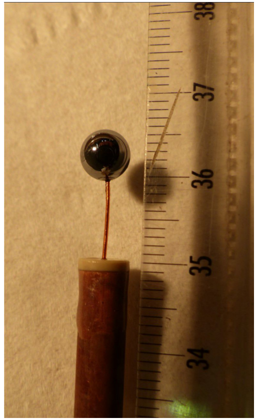


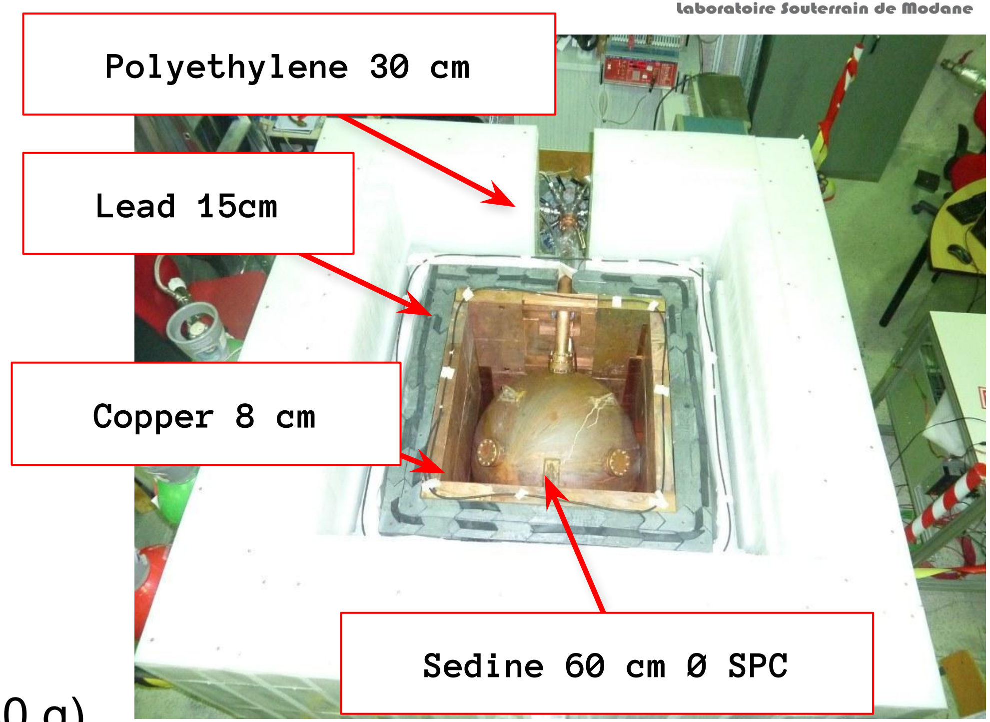
NEWS-G at Modane

SEDINE detector

Vessel
Ø 60cm copper

Sensor
Ø 6.3mm Si

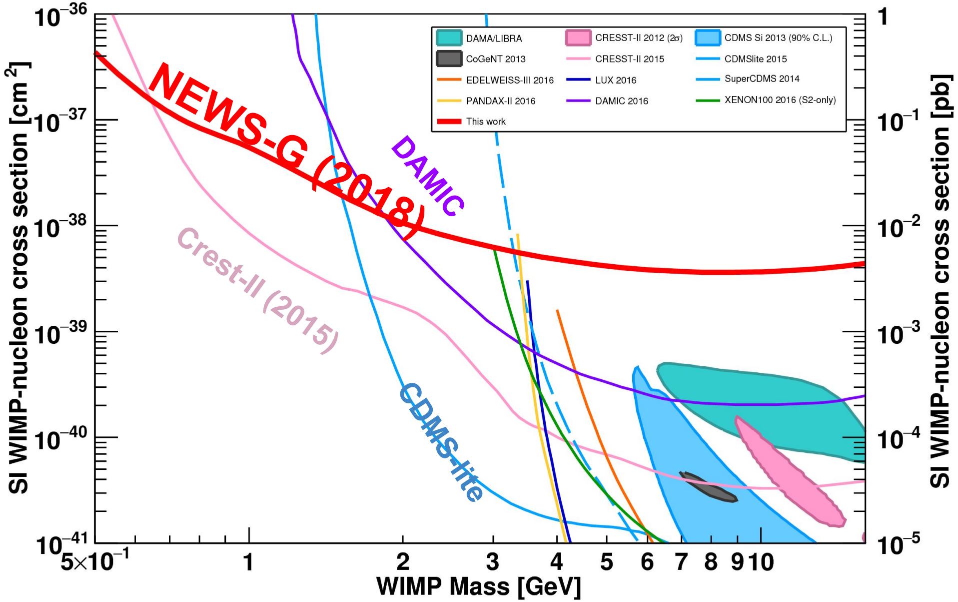




Gas Mixture: Ne+0.7%CH_4 at 3.1 bar (280 g)
Exposure: 9.6 kg*days (34.1 live-days x 0.28 kg)

First results of NEWS-G with SEDINE (2018)

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



Astroparticle Physics 97 (2018) 54–62

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journal homepage: www.elsevier.com/locate/astropartphys

ELSEVIER

First results from the NEWS-G direct dark matter search experiment at the LSM

Q. Arnaud[a,*], D. Asner[b], J.-P. Bard[c], A. Brossard[a,c], B. Cai[a], M. Chapellier[a], M. Clark[a], E.C. Corcoran[d], T. Dandl[e], A. Dastgheibi-Fard[f], K. Dering[a], P. Di Stefano[a], D. Durnford[a], G. Gerbier[a], I. Giomataris[c], P. Gorel[g], M. Gros[c], O. Guillaudin[h], E.W. Hoppe[b], A. Kamaha[a], I. Katsioulas[c], D.G. Kelly[d], R.D. Martin[a], J. McDonald[a], J.-F. Muraz[h], J.-P. Mols[c], X.-F. Navick[c], T. Papaevangelou[c], F. Piquemal[f], S. Roth[a,1], D. Santos[h], I. Savvidis[i], A. Ulrich[e], F. Vazquez de Sola Fernandez[a], M. Zampaolo[f]

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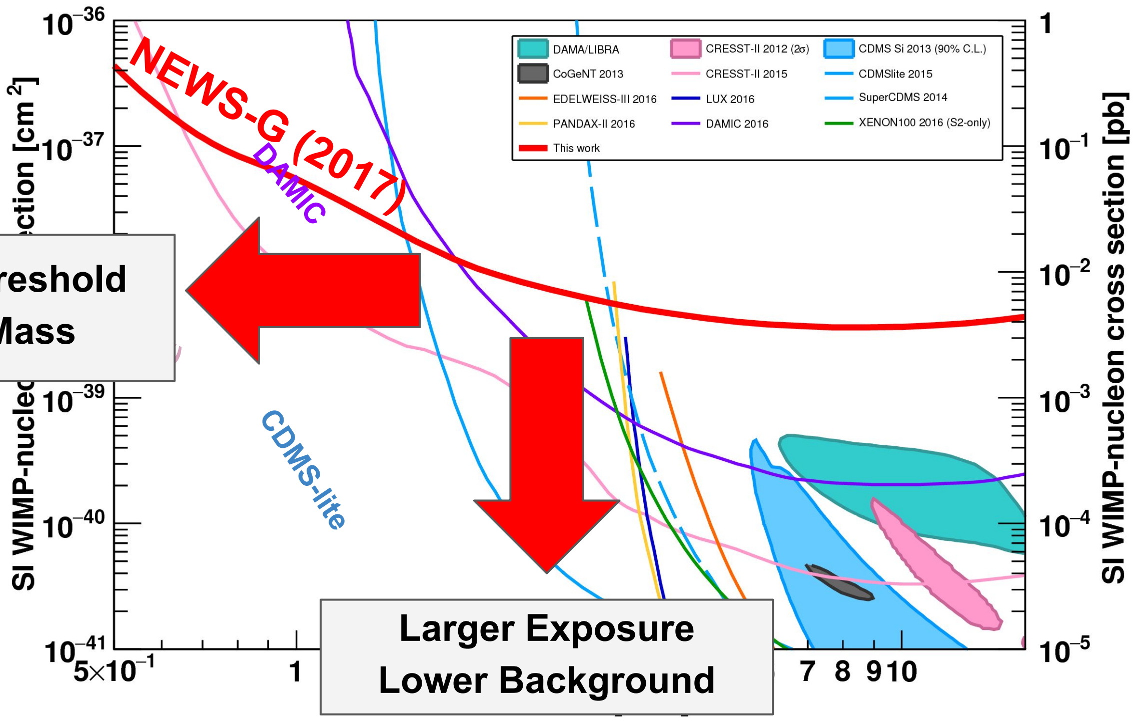
[h] LPSC, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
[i] Department of Physics, Aristotle University of Thessaloniki, GR-52124 Thessaloniki, Greece

Exclusion at 90% confidence level (C.L.) of cross-sections above $4.4 \cdot 10^{-37}$ cm^2 for a **500 MeV/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

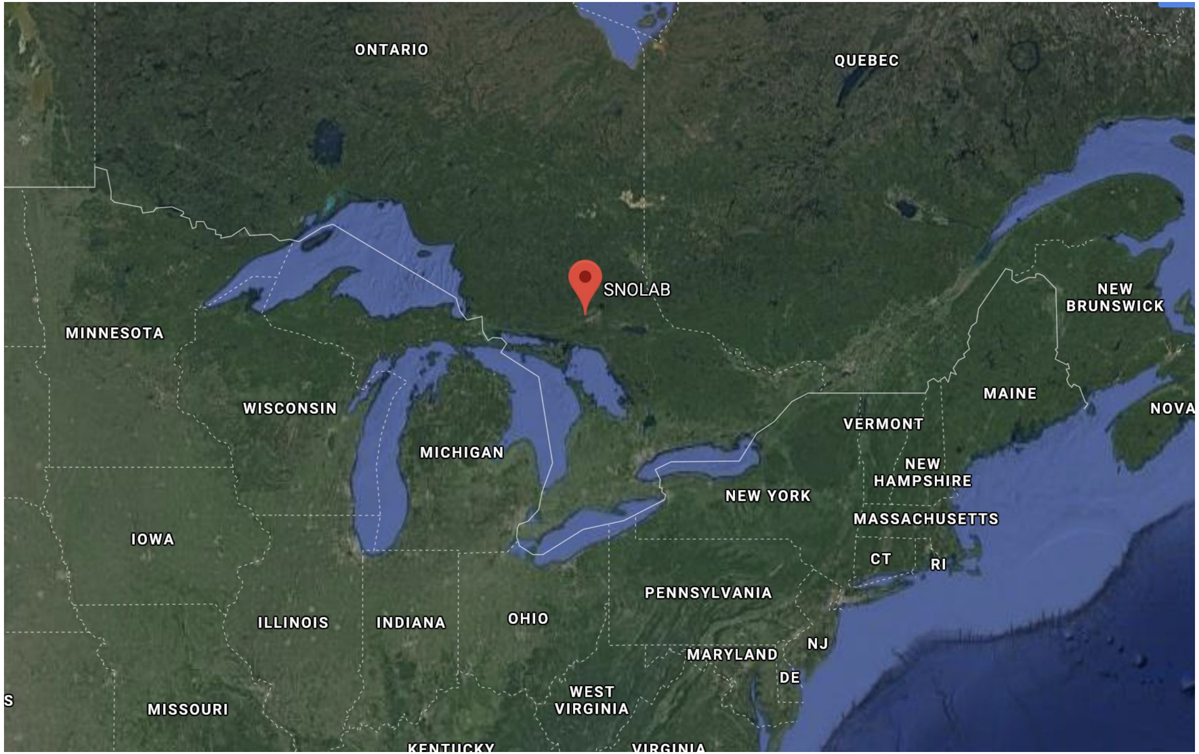
NEWS-G moving forward



Lower Energy Threshold
Lower Target Mass

Larger Exposure
Lower Background

NEWS-G at SNOLAB

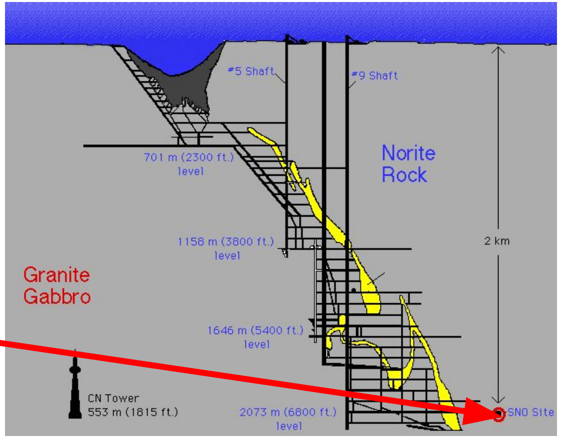


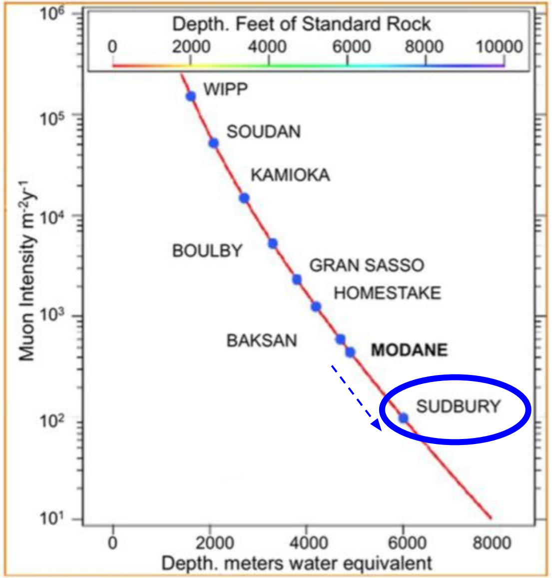
NEWS-G at SNOLAB

The underground laboratory in the Sudbury, Canada

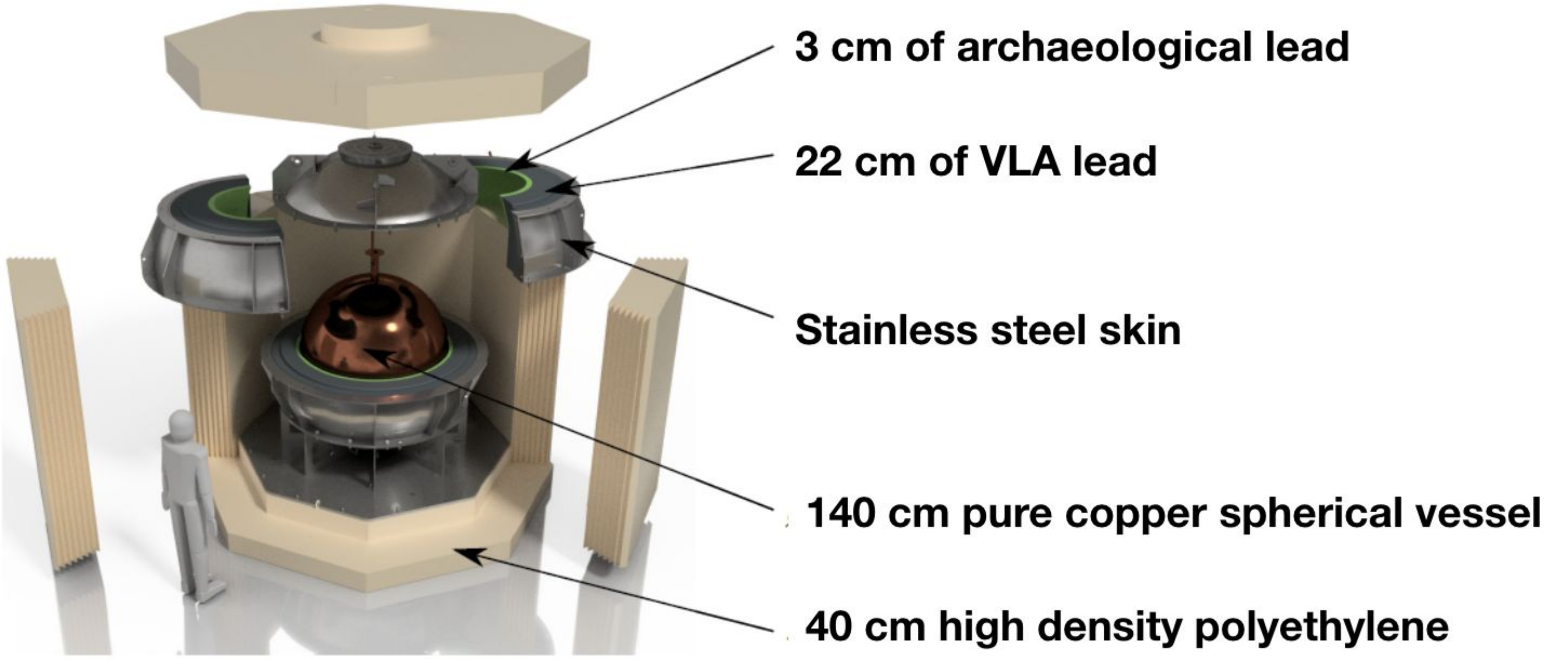
Deeper underground
0.25 μ/m²/day
~8x lower μ flux than LSM

Practically, at 2 km is the deepest clean room in the world





The NEWS-G detector - SNOGLOBE



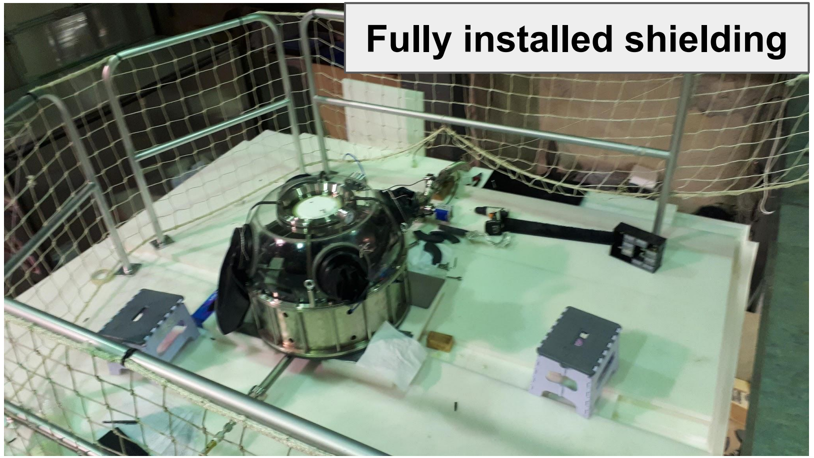
SNOGlobe at LSM

- Detector already commissioned at LSM
  - Assembled and operated for a month
  - Gases used Ne/CH_4 (1 bar), CH_4 (135 mbar)
  - Sensor and electronics performance tested
  - Backgrounds under study

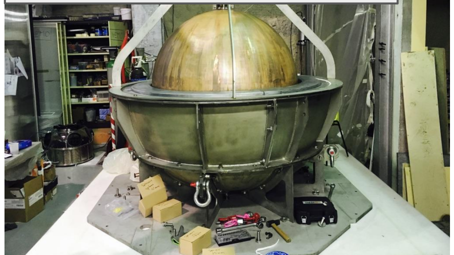
Temporary neutron shielding

Glove-box

Fully installed shielding



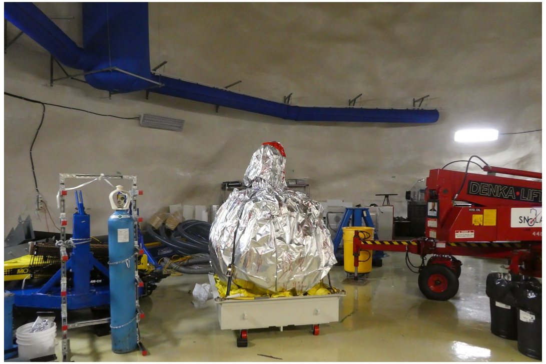
Half installed lead shielding



Status of installation at SNOLAB

Shipment December 2019

Moving underground



Placement

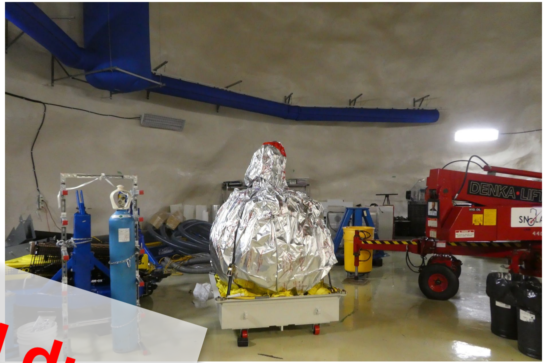
Flushed with N_2

Status of installation at SNOLAB

Installation work halted due to COVID-19 lockdown
Restarted in Sep 2020

Shipment December 2019

Moving underground



Placement

Flushing with N_2

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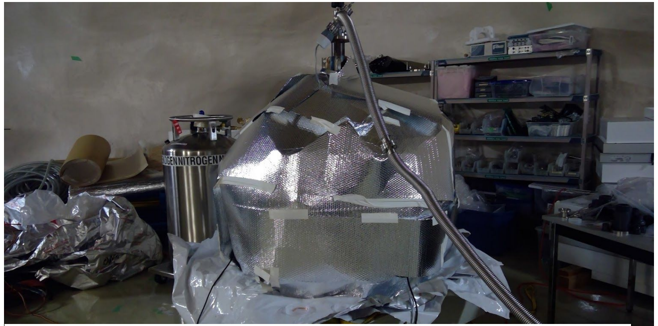
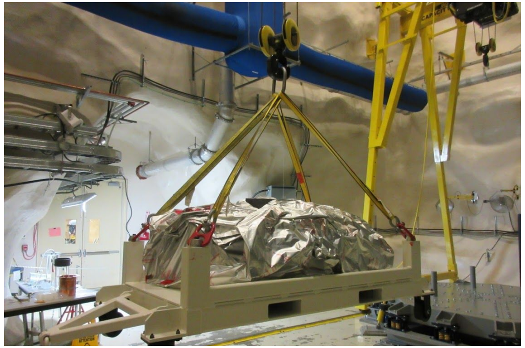
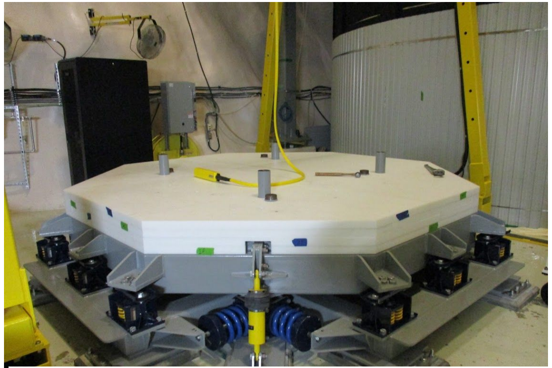


Unwrapped and baked Sep 2020

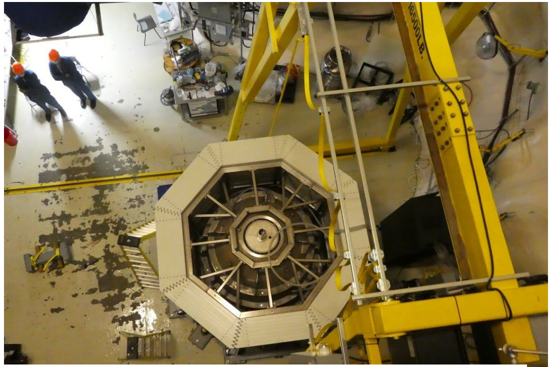


Lead pieces arrival

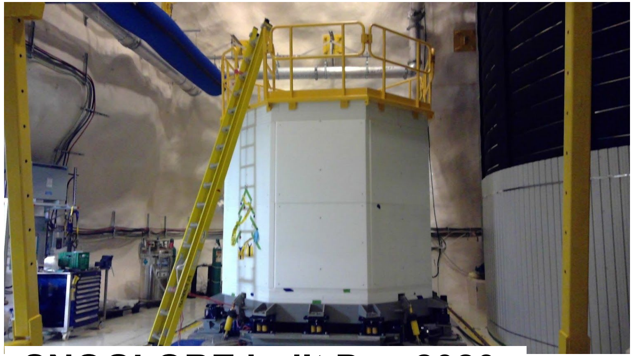


Seismic platform installation

SPC inserted in Lead shield



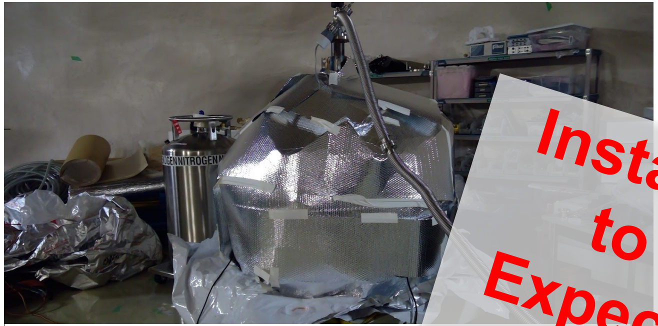
PE shielding installation



SNOGLOBE built Dec 2020

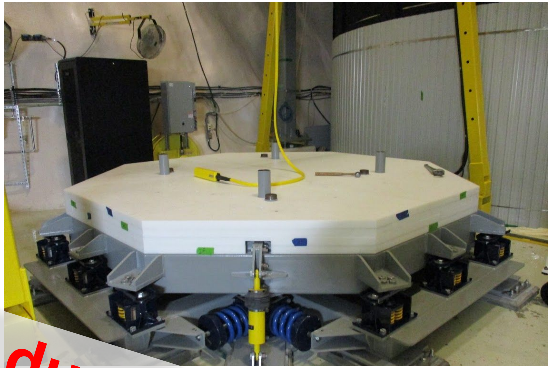
https://www.youtube.com/watch?v=NMjhzkLJP6M

Status of installation at SNOLAB



Unwrapped and baked Sep 2020

Lead pieces arriv

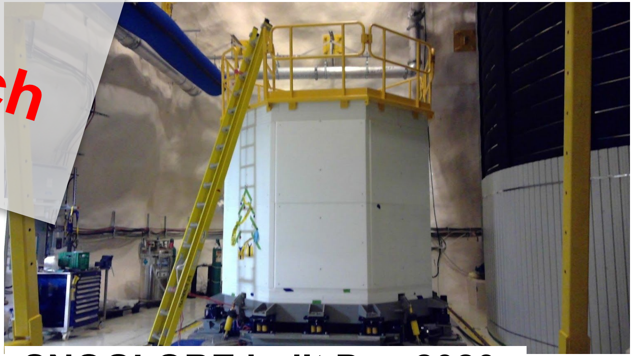


Seismic platform installation

Installation work halted due to COVID-19 lockdown
Expected to restart in March 2021

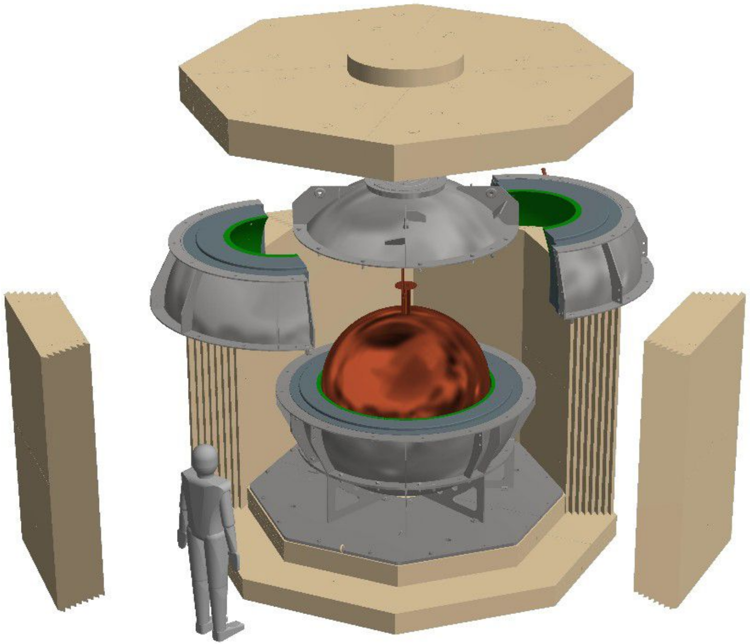
SPC inserted in Lead shield

PE shielding installation



SNOGLOBE built Dec 2020

Challenges with the NEWS-G detector



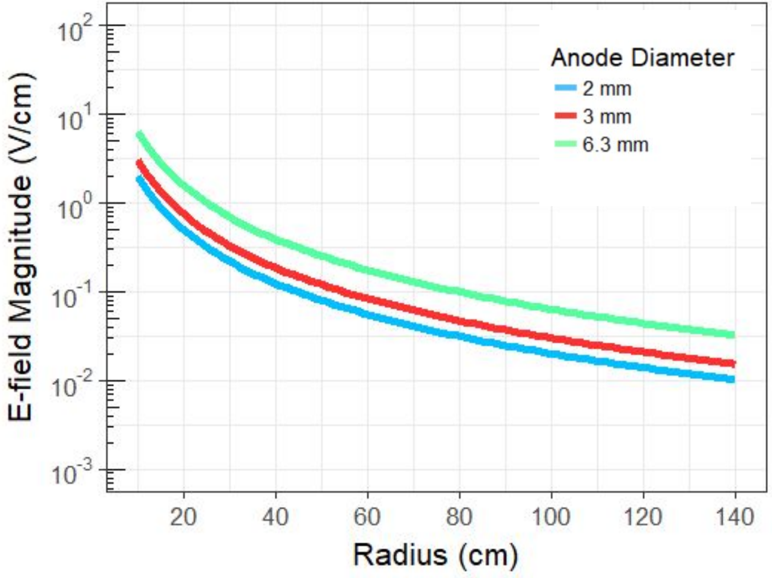
- Charge collection at large radii and high pressure operation
  - Electric field strength
  - Contaminants
- Detector response uniformity
- Background
  - Material purity
- Monitoring and calibration
- Detector simulation/response

Electric field strength in large volume SPCs

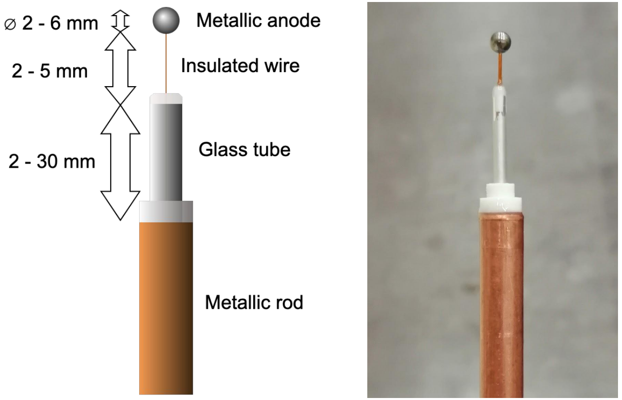
Scaling-up

$$v(r), E(r) \sim r_A/r^2$$

Comparison of E-field magnitude for different anode diameters



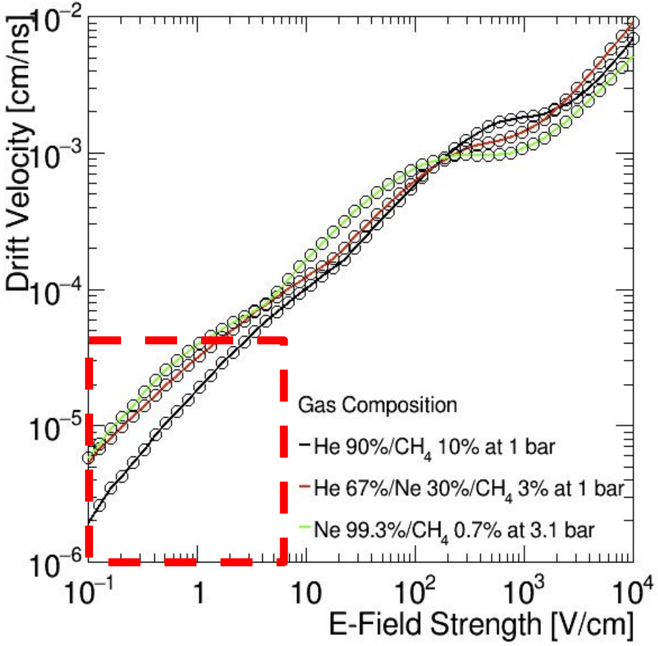
Single anode glass sensors

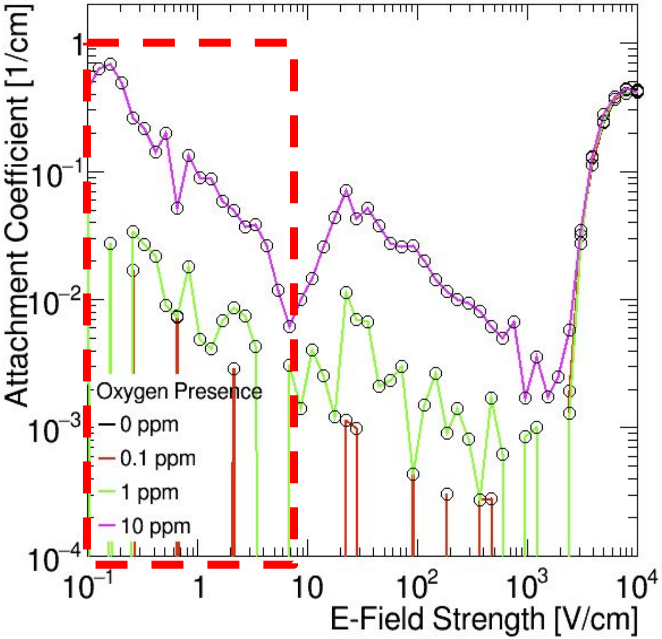


[I. Katsioulas et al, JINST, 13, 11, P11006, 2018
10.1088/1748-0221/13/11/P11006]

Charge collection in low electric field

Magboltz study on the sensitivity to contaminants

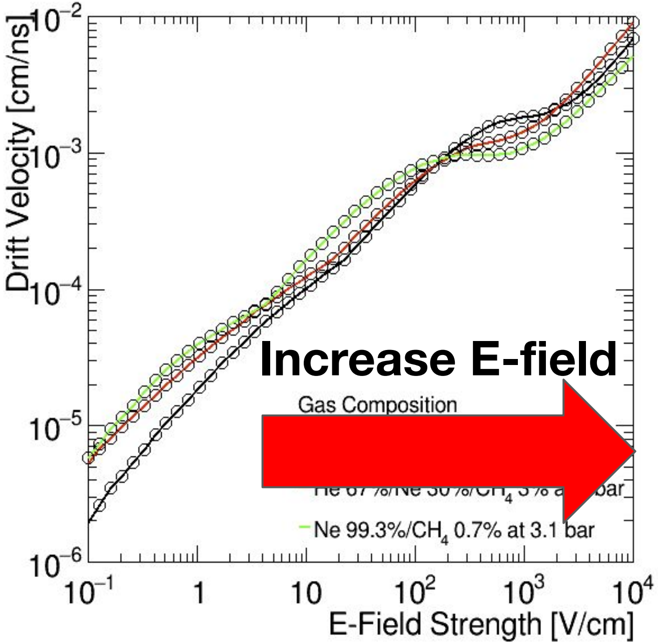


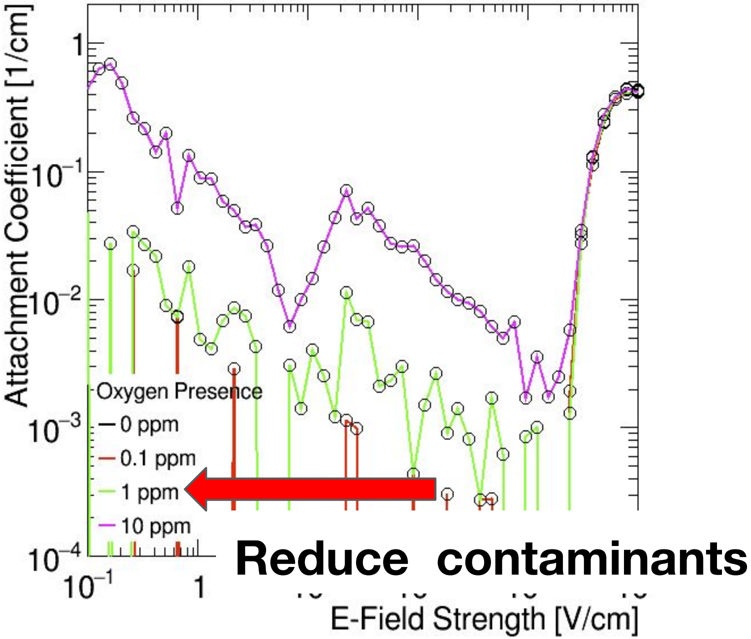


Low E-field region

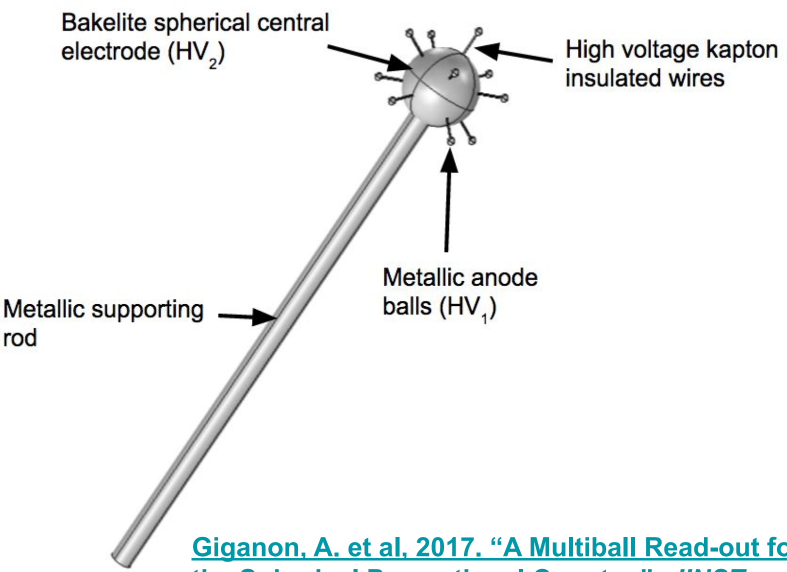
Charge collection in low electric field

Magboltz study on the sensitivity to contaminants

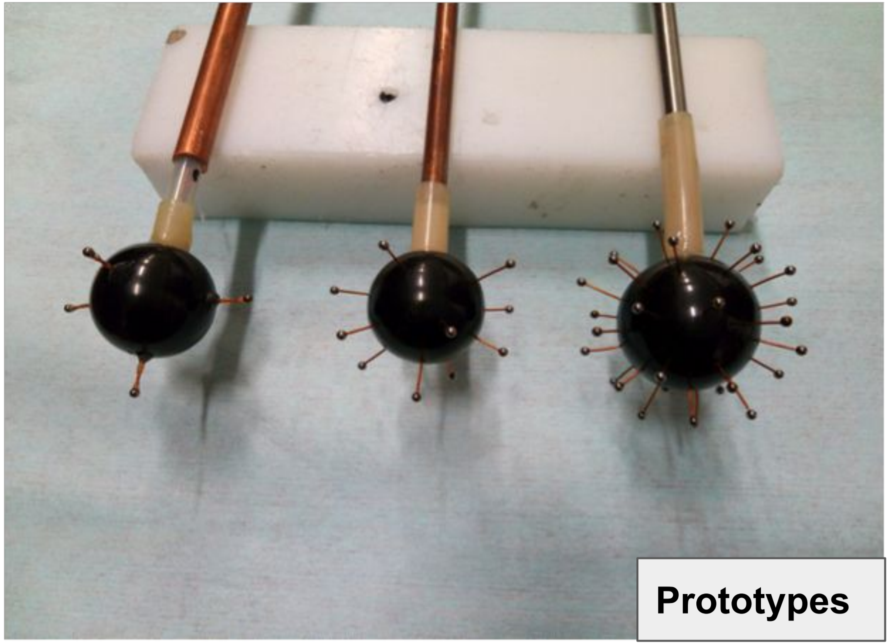




The multi-anode sensor - ACHINOS



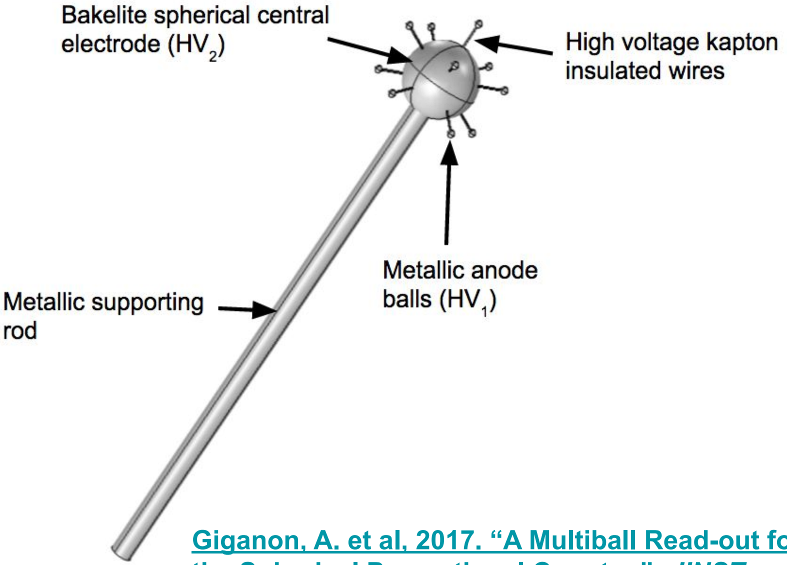
[Giganon, A. et al, 2017. "A Multiball Read-out for the Spherical Proportional Counter.", *JINST*]



Prototypes

Instead of one => Use multiple anodes set to the same potential !!!

The multi-anode sensor - ACHINOS

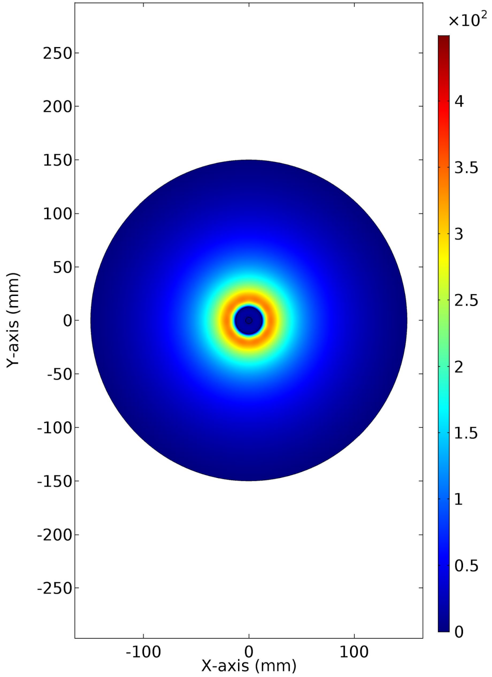


[Giganon, A. et al, 2017. "A Multiball Read-out for the Spherical Proportional Counter.", *JINST*]

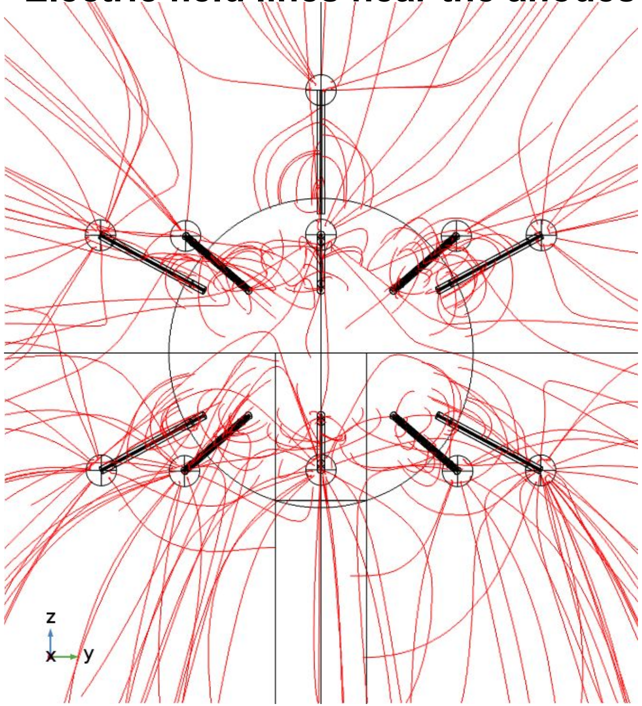
Instead of one => Use multiple anodes set to the same potential !!!

Electric field configuration with an ACHINOS

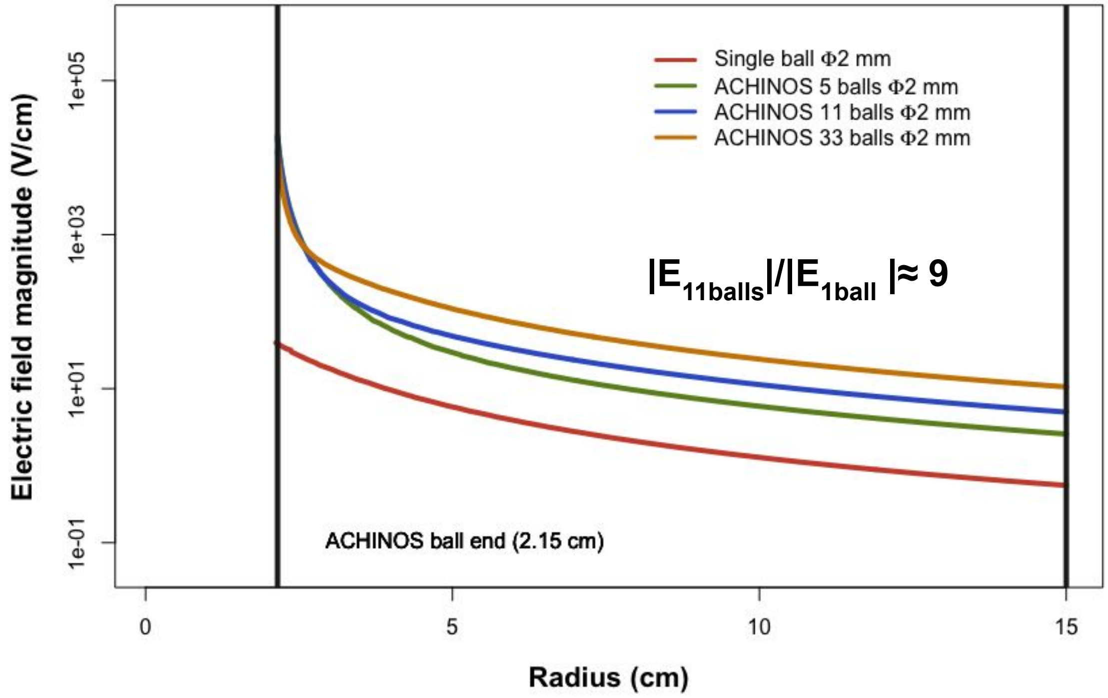
Collective iso-potentials



Electric field lines near the anodes



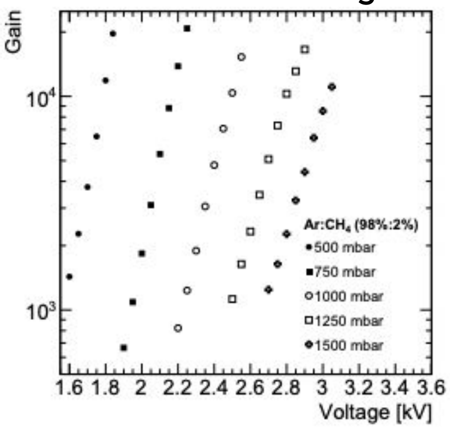
Advantages of the ACHINOS sensor

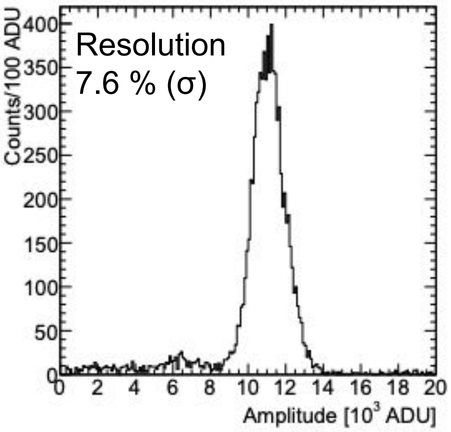


- **Decouples electron drift and multiplication**
  - **Small anode size → high gain**
  - **More anodes → Efficient charge collection**
- **Allows for increased target mass**
  - **Larger volume**
  - **Higher pressure**
- **Individual readout TPC-like capabilities to the SPC**

Performance of ACHINOS with DLC coating

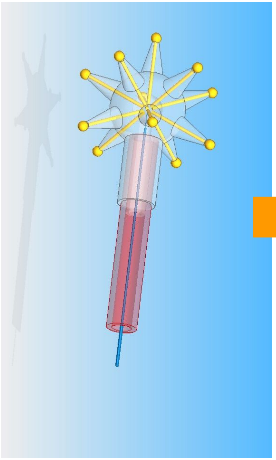
Gain vs Voltage



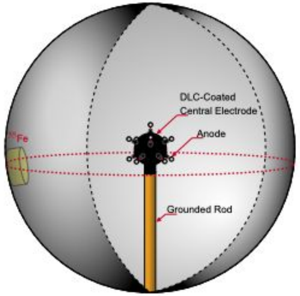


Measurement of the 5.9 keV ^{55}Fe X-ray line

3D design



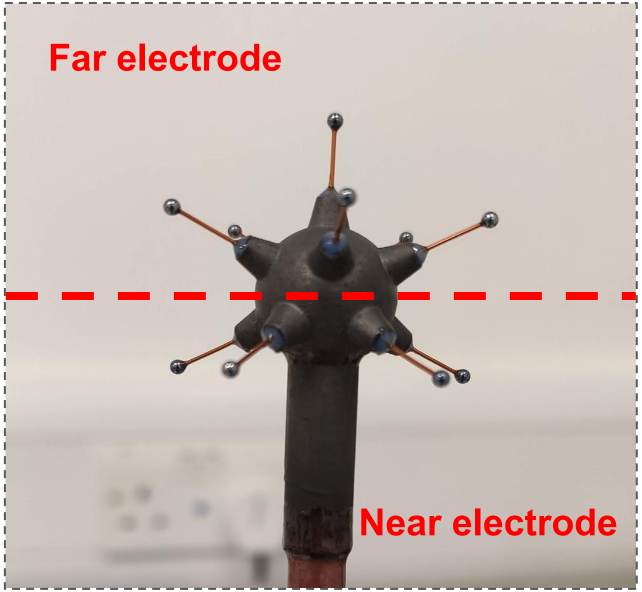
Modules using 3D printing



- **Good energy resolution**
- **High pressure operation (> 2 bar)**
- **High gain**
- **Stability**
- **Multi-anode readout**

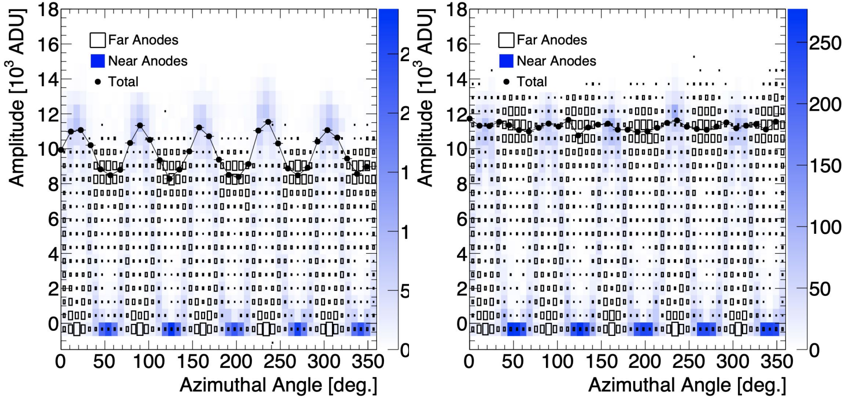
I. Giomataris *et al* 2020 *JINST* 15 P11023

Performance of ACHINOS with DLC coating



I. Giomataris *et al* 2020 *JINST* 15 P11023

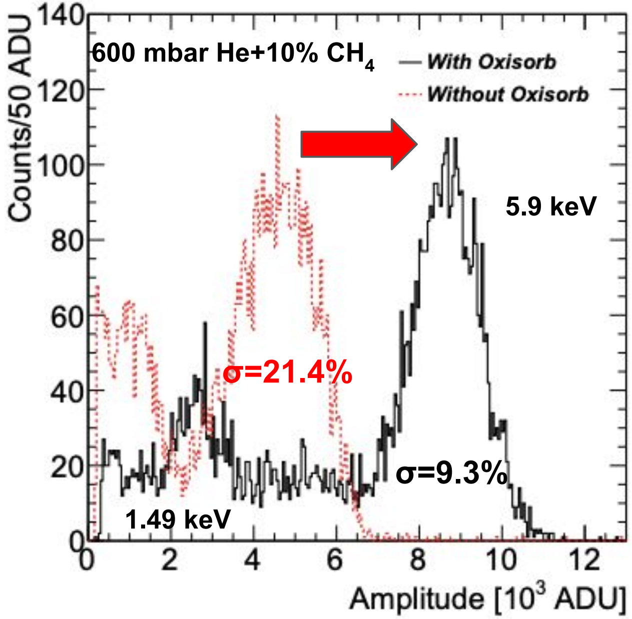
Simulations

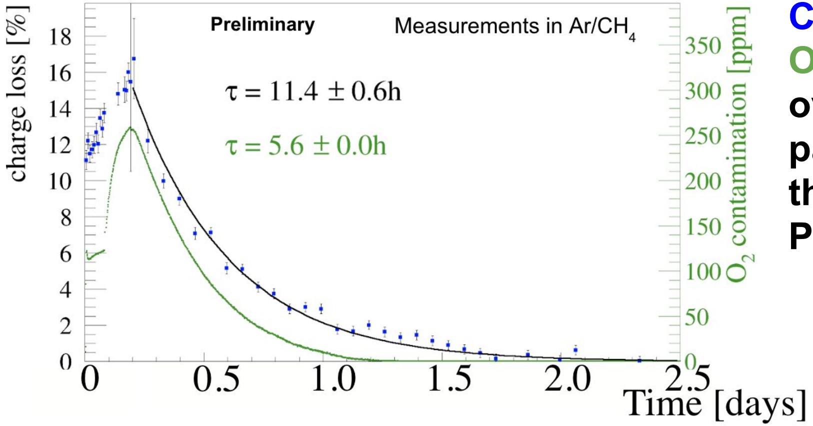


- Good energy resolution
- High pressure operation (> 2 bar)
- High gain
- Stability
- **2 channel readout**

Gas Purification

- Contaminants: O_2, H_2O, electronegative gases
- Filtering with: Getter, Oxysorb, Custom filter
- Filtering in a gas recirculation system
  - SAES MicroTorr Purifier (MC700 902-F)
  - Incorporated with Residual Gas Analyser
- Improved filtering efficiency in large sphere





Charge Loss and Oxygen Concentration over Time while gas passes circulated through MicroTorr Purifier

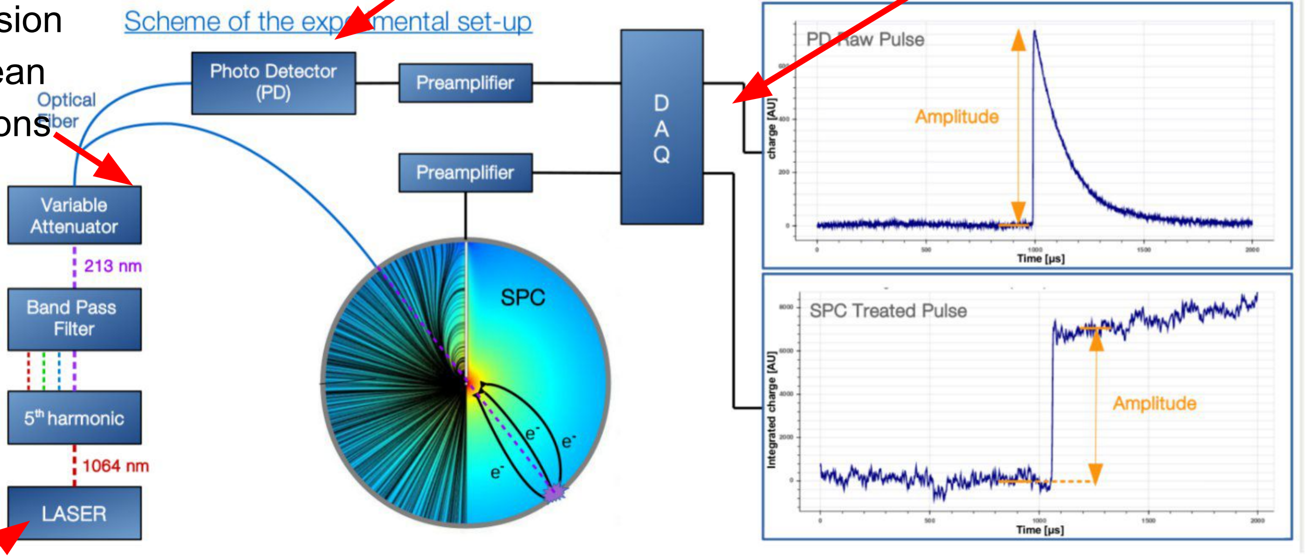
NEWS-G Collaboration, Phys. Rev. D 99, 102003 (2019)

Laser calibrations

Parallel photodetector to tag laser events

Common DAQ for timing analysis between two channels

Tunable transmission to control the mean number of electrons



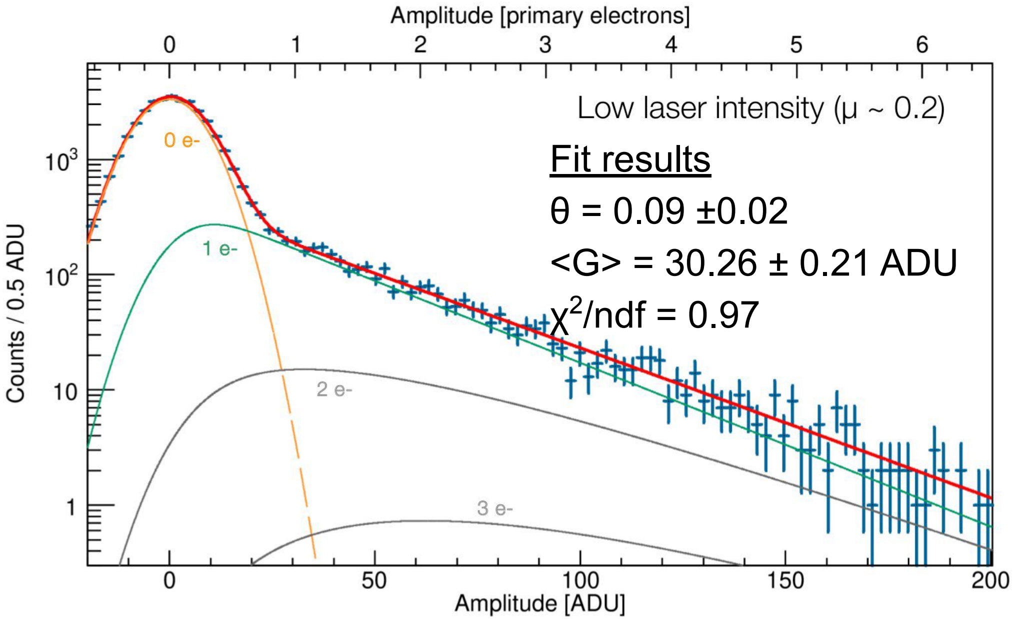
A powerful UV laser capable of extracting 100s of electrons

- **213 nm laser used to extract primary electrons from wall of SPC**
- **Photo detector in parallel tags events and monitors laser power**
- **Laser intensity can be tuned to extract 1 to 100 photo electrons**

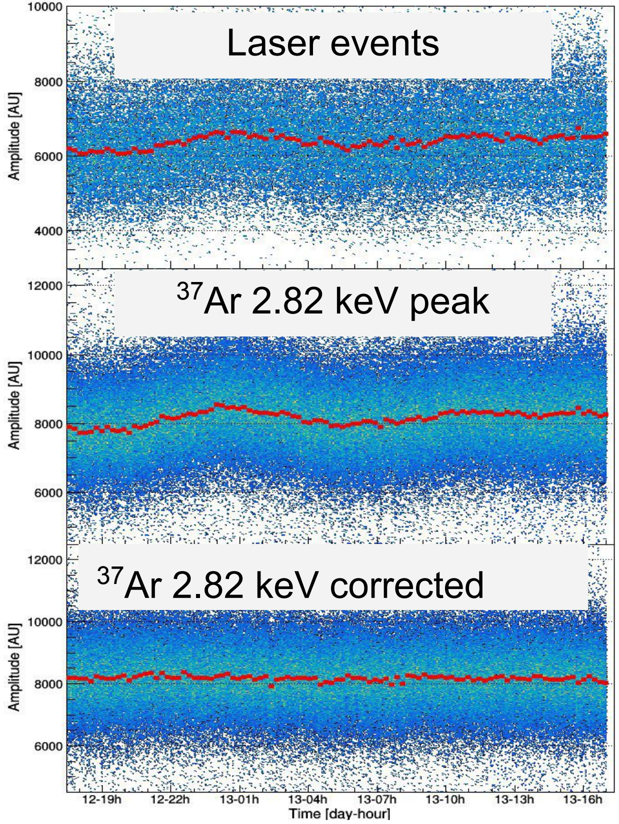
NEWS-G Collaboration, Phys. Rev. D 99, 102003 (2019)

Laser calibrations

Single electron response modeling

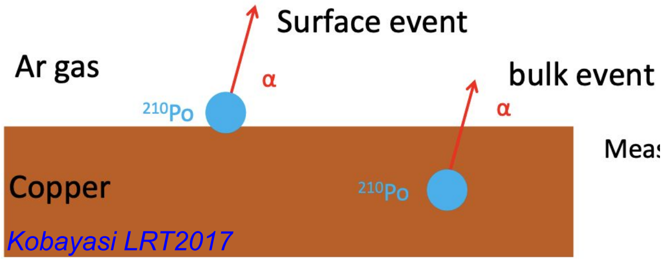


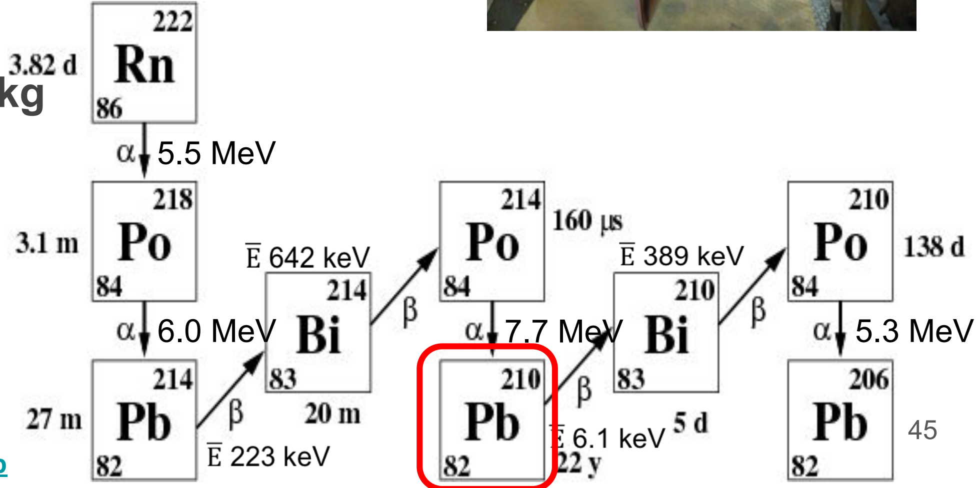
Detector monitoring



Background in NEWS-G copper

- 4N Aurubis Oxygen Free Copper C10100 (99.99% pure)
  - Spun into two hemispheres
- Copper has no long-lived isotopes
- $^{63}Cu(n,\alpha)^{60}Co$ from fast neutrons – mostly cosmic muon spallation
- Contaminants : U and Th decay chain traces
  - Measured for NEWS-G ~10 µBq/kg
  - ^{210}Pb out of equilibrium - 28.5 mBq/kg





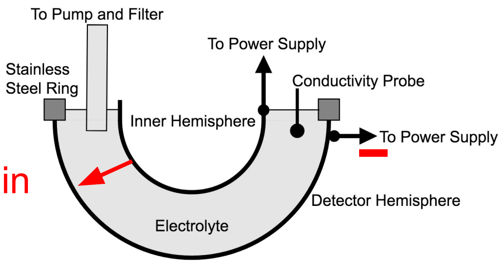
Electroplating Copper

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 988, 1 February 2021, 164844

Copper electroplating for background suppression in the NEWS-G experiment

L. Balogh [a], C. Beaufort [b], A. Brossard [a], R. Bunker [c], J.-F. Caron [a], M. Chapellier [a], J.-M. Coquillat [a], E.C. Corcoran [d], S. Crawford [a], A. Dastgheibi Fard [b], Y. Deng [e], K. Dering [a], D. Durnford [e], G. Gerbier [a], I. Giomataris [f], G. Giroux [a], P. Gorel [g, h, i], M. Gros [f], P. Gros [a], O. Guillaudin [b], E.W. Hoppe [c], I. Katsioulas [j], F. Kelly [d], P. Knights [f, j], L. Kwon [d], S. Langrock [h], P. Lautridou [k], R.D. Martin [a], J.-P. Mols [f], J.-F. Muraz [b], X.-F. Navick [f], T. Neep [j], K. Nikolopoulos [j], P. O'Brien [e], R. Owen [j], M.-C. Piro [e], D. Santos [b], G. Savvidis [a], I. Savvidis [l], F. Vazquez de Sola Fernandez [a], M. Vidal [a], R. Ward [j], M. Zampaolo [b], NEWS-G Collaboration, S. Alcantar Anguiano [c], I.J. Arnquist [c], M.L. di Vacri [c], K. Harouaka [c], K. Kobayashi [m, n, 1], K.S. Thommasson [c]

The setup during electroplating at LSM

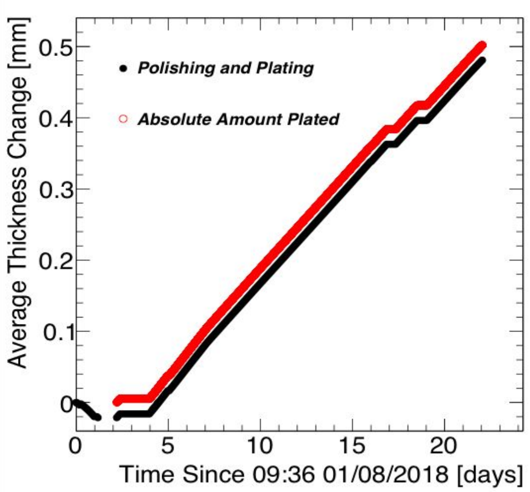


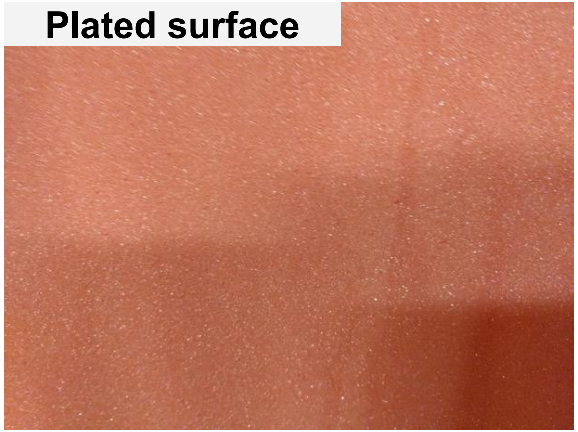
Cu Movement in Electroplating

- Using PNNL expertise - Strong participation from UoB in electroforming copper
- The inner surface of the detector was electroplated to stop Bremsstrahlung X-rays from ^{210}Pb and ^{210}Bi β-decays in copper
- 0.5 mm pure copper plated on inner surface at LSM: expected background from ^{210}Pb and ^{210}Bi under 1 keV reduced by a factor 2.6
- Total background in the experiment expected to be 1.96 dru

P.Knights
UoB - Paris-Saclay

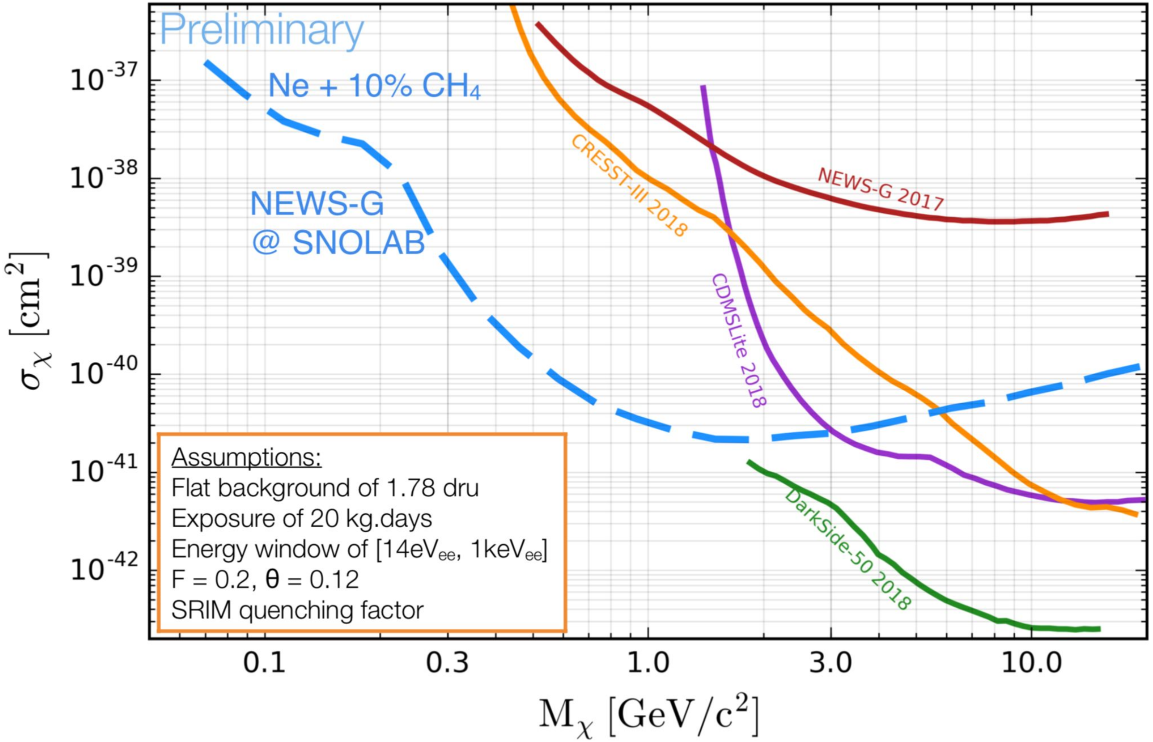
Result after plating





- **Good surface quality achieved**
- **Hemispheres electron-beam welded together**
- **Detector already operating at LSM**
- **Copper was deposited at a rate of ~36 μm/day**
  - **Result is promising for possibly a whole detector electroformed underground**

Projected sensitivity for SNOGLOBE

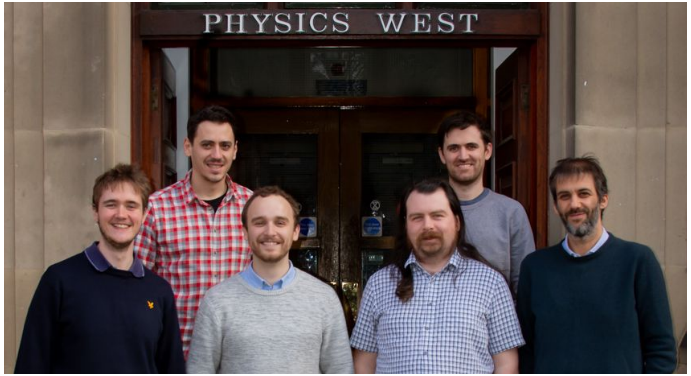


- **Low threshold**
- **Strong background rejection handles**
- **Hydrogen-rich mixtures**
- **Lower backgrounds**

NEWS-G @ Birmingham

I. Katsioulas, P. Knights, J. Mathews I. Manthos, T. Neep, K. Nikolopoulos, R. Ward

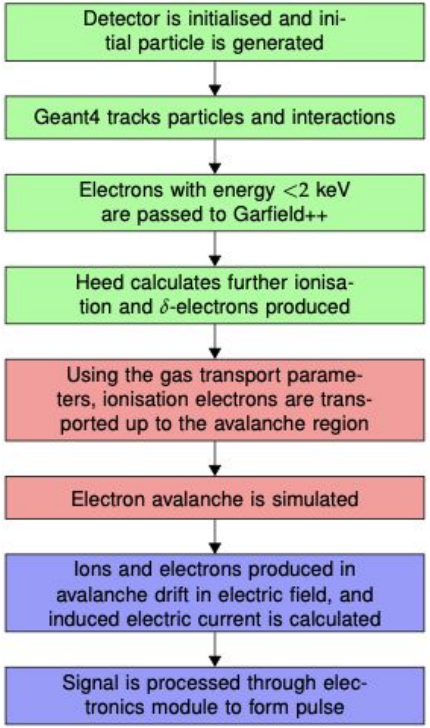
- Co-spokesperson (April 2021)
- Physics Run coordination
- Detector instrumentation
- Background suppression techniques
- Detector physics simulations
- Multivariate analysis techniques
- Ionisation quenching studies
- Neutron background studies



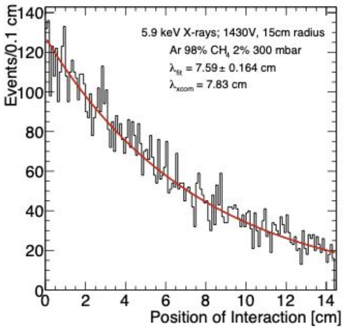
Newest additions!

Inspired by: Pfeifer, D. et al, Nucl. Instrum. Methods Phys. Res., A 935 (2019) 121-134

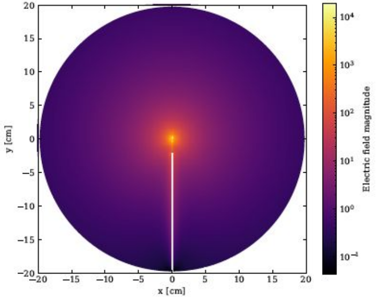
Simulating the detector response



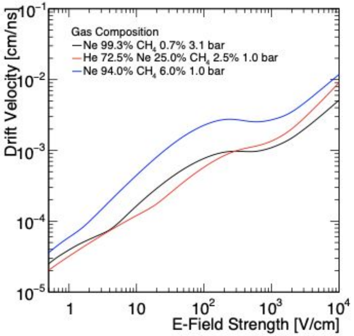
Primary interaction



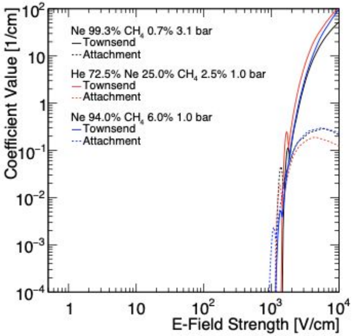
Electric field



Electron Drift



Electron Multiplication

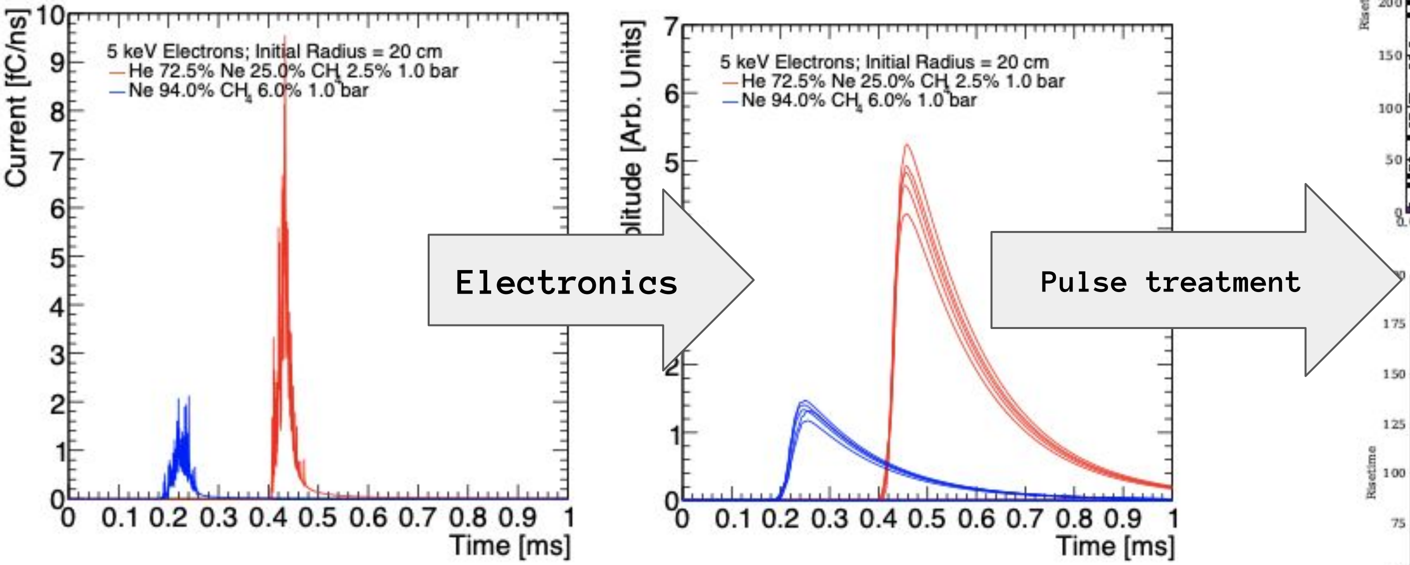


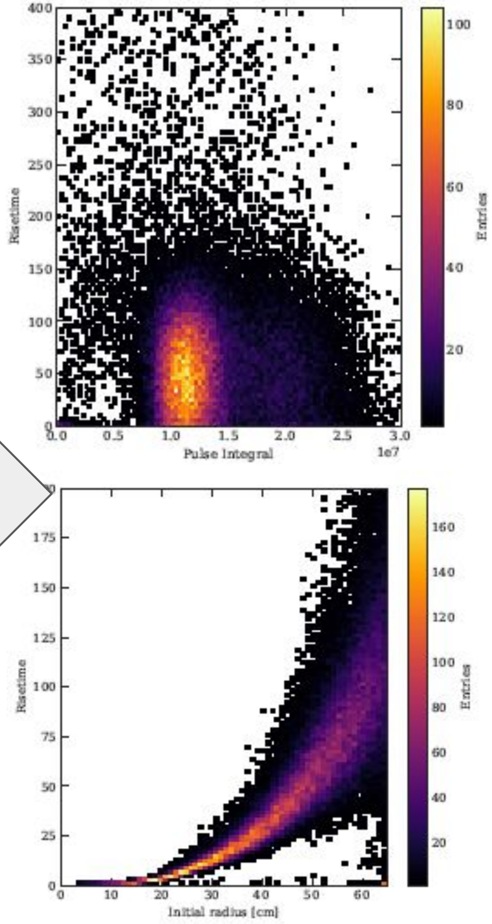
Garfield++

Katsioulas, I. et al, 2017. "Development of a Simulation Framework for Spherical Proportional Counters", arXiv:2002.02718

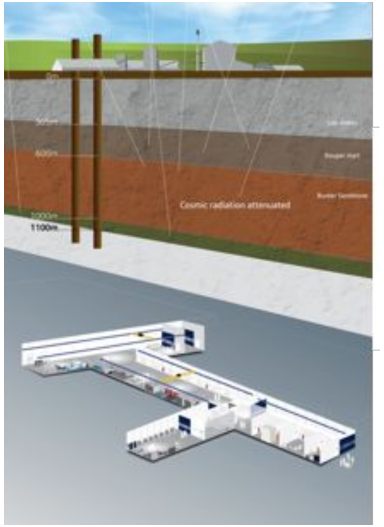
[Katsioulas, I. et al, 2017. “Development of a Simulation Framework for Spherical Proportional Counters”,arXiv:2002.02718]

Simulating the detector response

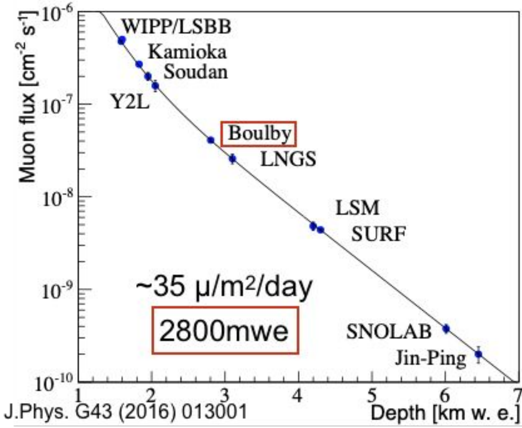




Collaboration with Boulby underground laboratory



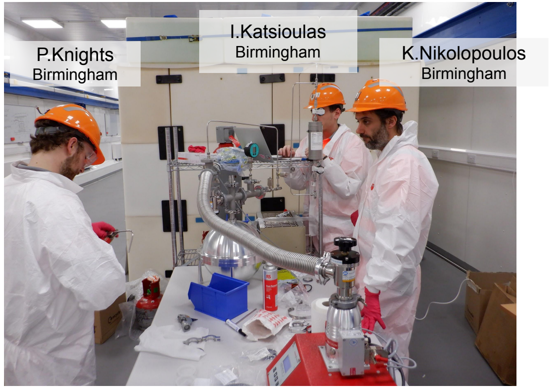
Lowest Radon Levels 3 Bq/m^3

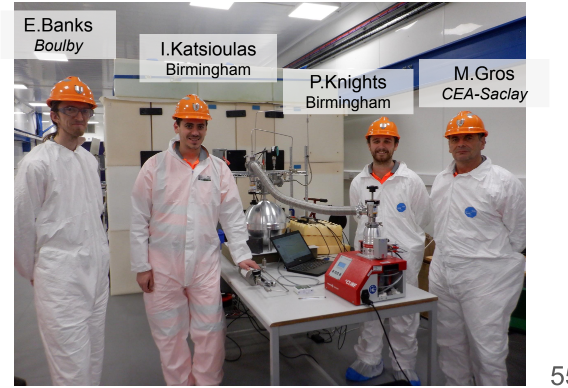


Background measurements at Boulby

- Instrumentation R&D at controlled environment
- Neutron flux measurement
  - Thermal neutron
  - Fast neutron
- Including energy information
- Method applicable to all other underground laboratories

Aluminium S30

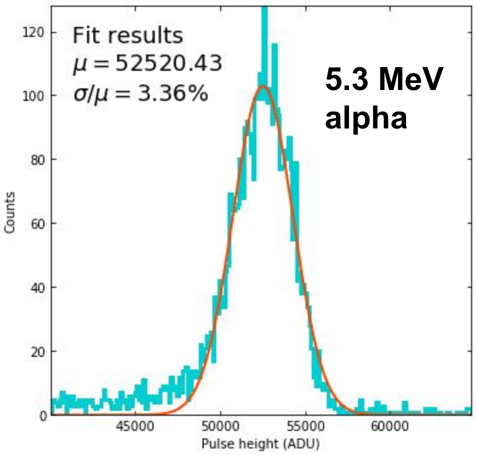


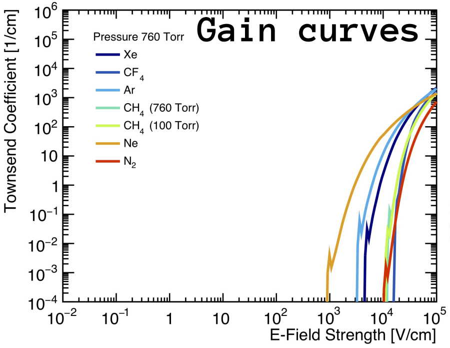


Neutron detection with SPCs

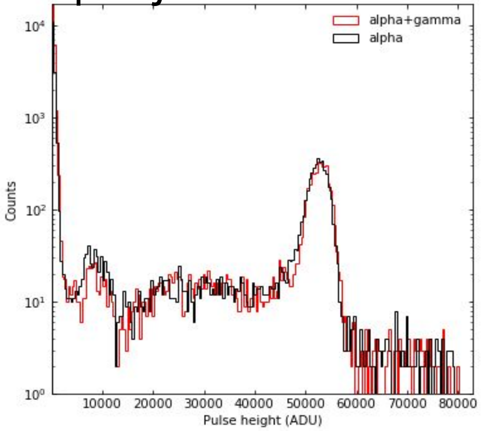
- Neutron spectroscopy with Spherical Proportional Counter
  - Using Nitrogen as gas
  - $^{14}N+n \rightarrow ^{14}C+p$ + 625 keV
  - $^{14}N+n \rightarrow ^{11}B+\alpha$ - 159 keV
- Initially demonstrated: *Bougamont, E et al (2017). NIM A, 847, 10–1*
  - ^{252}Cf, $^{241}Am^{9}Be$, ambient fast neutrons
  - Thermal neutrons
  - Operation at 0.2-0.5 bar
  - HV reached 6 kV

Resolution





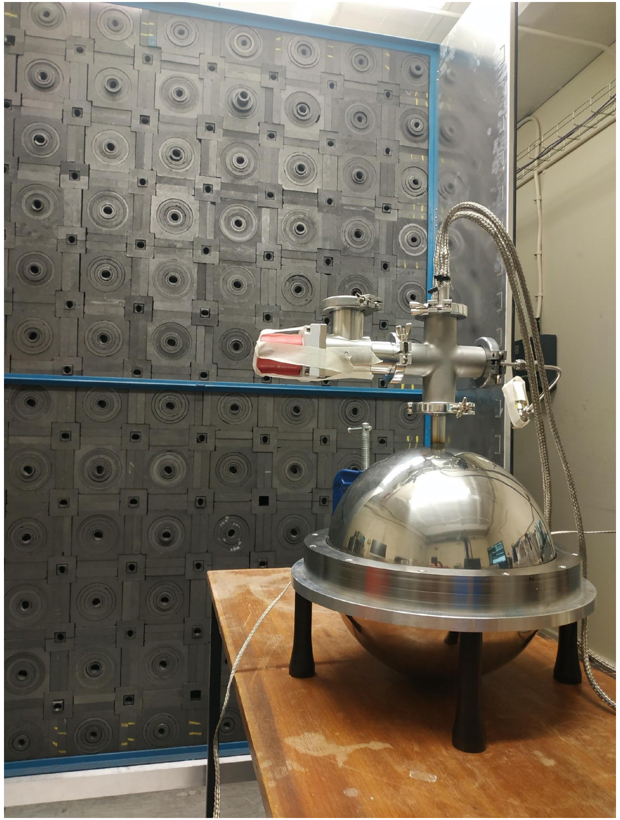
γ-ray discrimination



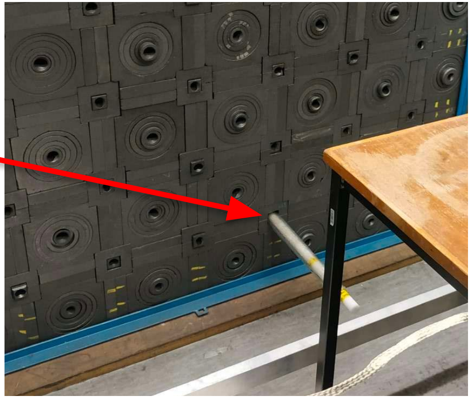
Goals:

- Operation in high pressure (~5 bar)
  - Minimisation of wall effect
  - Larger target mass - Sensitivity
- Calibration with mono-energetic neutrons
- Measurements with thermal and fast neutrons

Neutrons measurements at UoB



$^{241}Am^{9}Be$ neutron source
A = ~10^{10} Bq



<u>SPC</u>
- 30 cm ∅
- N_2 gas filling

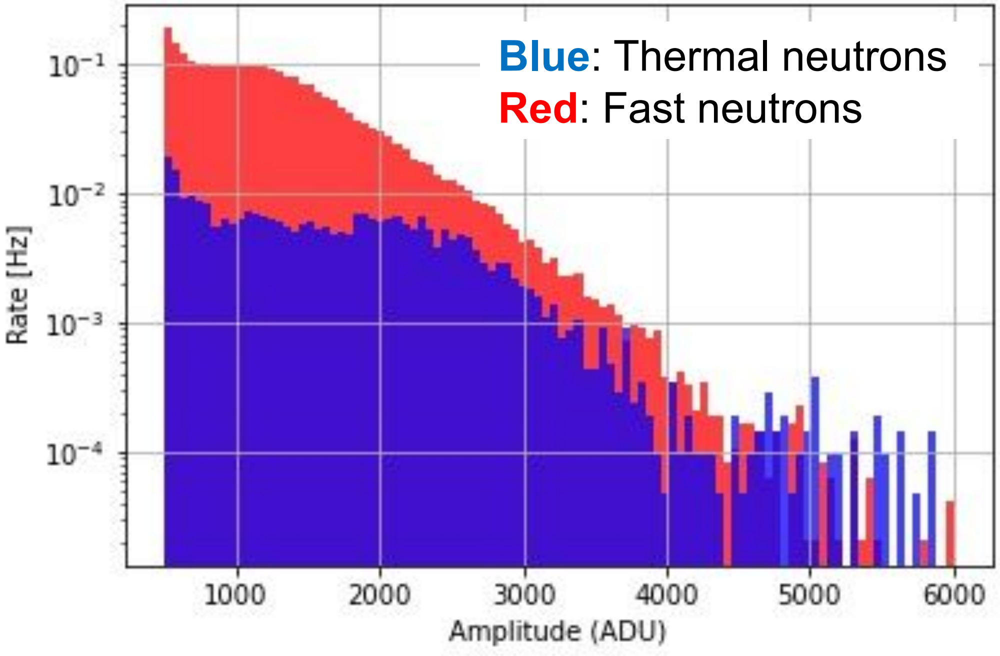
<u>Multi-anode sensor</u>
- 11 anodes
- 1mm ∅
- Reading in 2 channels

Investigate the capability of the SPC to detect fast neutrons and neutrons thermalized by the graphite.

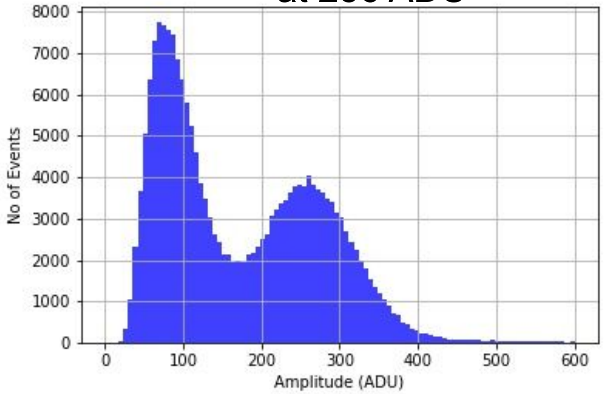
Neutron measurements with the SPC

$^{241}Am^{9}Be$ neutron source
1 bar N_2, 3.8 kV

Preliminary results (ongoing analysis)



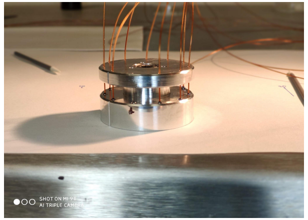
Thermal neutrons
at 256 ADU

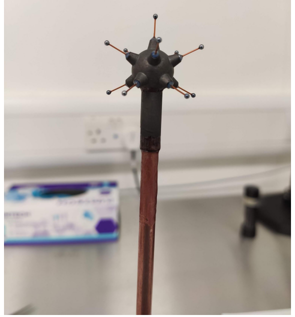


Instrumentation developments at UoB

ACHINOS - Achievements

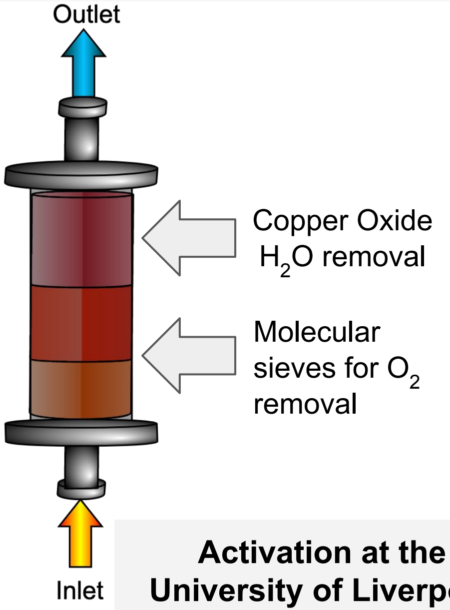
- Fully coated with DLC
- Improved accuracy on anode placement
- Improved spacing





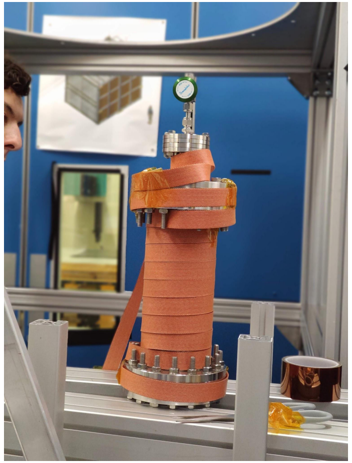
Gas Filter - Aims

- Replace commercial filters
- Reduce Rn emanation
- Maintain efficiency
- Known ingredients
- Cost effective



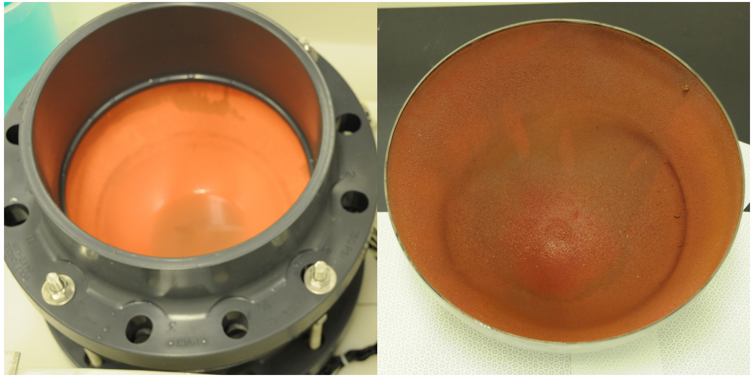
Activation at the University of Liverpool

Collaboration with Dr. K.Mavrokoridis Team



ECUME - Electroformed CUprum Manufacturing Experiment

- Underground electroformed ∅140 cm sphere
  - Minimised cosmogenic activation - Electroformed in SNOLAB
  - No machining or welding - grow sphere directly
- Based on what was achieved for current NEWS-G sphere
  - 36 μm/day → ~1 mm/month



Scale hemi-spherical model (PNNL) used for previous electroplating of detector

Current Status:

- R&D bath for prototype at PNNL - underway
- ∅30 cm prototype will then be produced
- Full-scale scheduled for late 2021

ECUME - Electroformed CUprum Manufacturing Experiment

	Source	Contamination / flux	Unit	Events rate <1 keV [dru]	Events rate in [1;5] keV [dru]	Total rate [mHz]
Gas mixture	^{3}H	13	μBq/kg	0.05	0.06	0.005
	^{222}Rn	111	μBq/kg	0.05	0.04	0.2
Copper sphere 500 μm electrolyte	~~^{210}Pb~~	~~28.5~~	~~mBq/kg~~	~~1.04~~	~~1.01~~	~~0.86~~
	~~^{238}U~~	~~3~~	~~μBq/kg~~	~~0.0117~~	~~0.115~~	~~0.028~~
	~~^{232}Th~~	~~12~~	~~μBq/kg~~	~~0.0754~~	~~0.0692~~	~~0.162~~
	~~^{40}K~~	~~0.1~~	~~mBq/kg~~	~~0.0157~~	~~0.0186~~	~~0.0622~~
Roman lead	^{210}Pb	<25	mBq/kg	<0.14	<0.12	0.057
	^{238}U	44.5	μBq/kg	0.142	0.094	0.277
	^{232}Th	9.1	μBq/kg	0.0256	0.0161	0.0577
	^{40}K	<1.3	mBq/kg	<0.28	0.23	0.65
Low activity lead	^{210}Pb	4.6	Bq/kg	0.053	0.055	0.17
	^{238}U	79	μBq/kg	0.17	0.132	0.5
	^{232}Th	9	μBq/kg	0.0251	0.0201	0.075
	^{40}K	<1.46	mBq/kg	<0.35	0.26	0.67
Cavern	Gamma	4.87×10^{-8}	γ/cm^2/s	0.0084	0.0095	0.00464
	Neutron	4000	neutron/m^2/day	0.0044	0.0004	3.54×10^{-11}
	Muon	0.27	muon/m^2/day	0.00062	0.00044	5.04×10^{-8}
Total				1.67	1.54	2.4
Total ~~+ cosmogenic activation of the copper sphere~~				~~5.29~~	~~5.29~~	~~5.4~~
Total + cosmogenic ~~activation of the copper sphere and 6 months of cooling~~				~~2.8~~	~~2.5~~	~~3.4~~
Total + cosmogenic ~~activation of the copper sphere and 1 years of cooling~~				~~2.1~~	~~1.9~~	~~3.0~~
Total + cosmogenic ~~activation of the copper sphere and 2 years of cooling~~				~~1.9~~	~~1.7~~	~~2.9~~

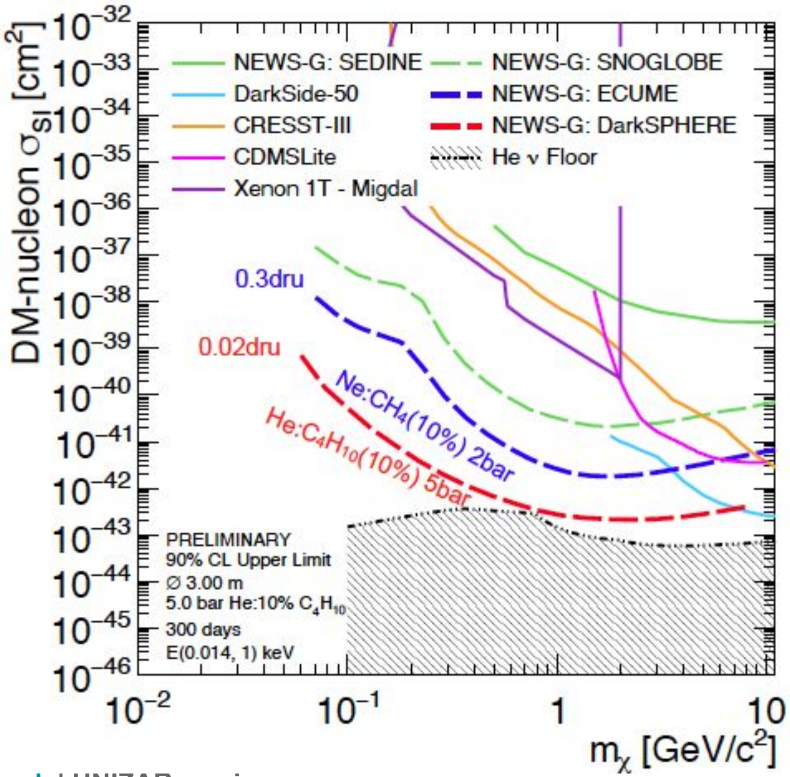
Removing contributions from copper, lead shielding becomes dominant background

PhD Thesis, Alexis Brossard, 2020

DarkSPHERE: Exploring light Dark Matter with Spherical Proportional Counters electroformed underground

Conceptual parameters:

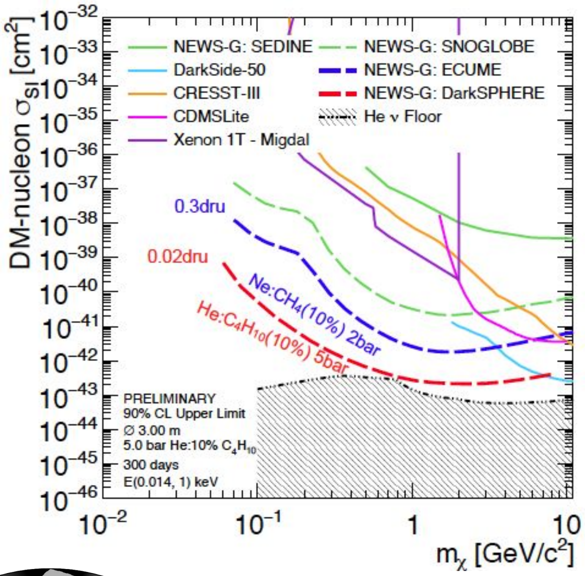
- **Installation at Boubly**
- **3 m ⌀ SPC**
- **Fully electroformed underground**
- **Operation with He/iC_4H_{12} and possibly Xe**
- **Pressure up to 5 bar**
- **Large target mass *O(100kg)***
- **Sensitivity down to the *ν*-floor**
- **Multiphysics platform**

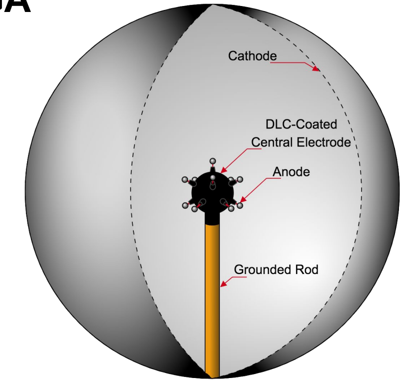


Dimensions in mm

Summary

- **NEWS-G searches for light DM candidates**
  - **Lighter targets**
  - **Improved shielding/materials/procedure**
  - **Lower energy threshold**
- **Sensor Development**
  - **Improved electric field uniformity**
  - **ACHINOS: electric field in large detectors**
- **Improved gas quality: Filtering, Recirculation,**
- **Improved calibration/monitoring: ^{37}Ar, Laser, RGA**
- **Simulation framework development**
- **On going work at Boulby!**
- **Paving the way for future NEWS-G!**
- **Many physics opportunities!**





Summary

- **NEWS-G searches for light DM candidates**
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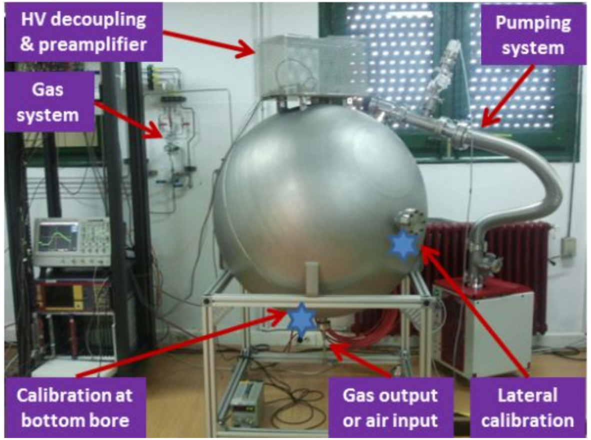
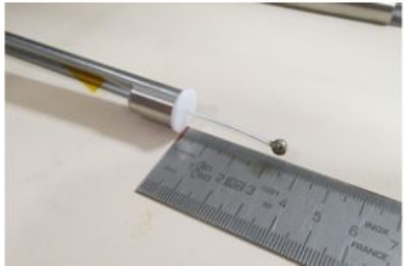
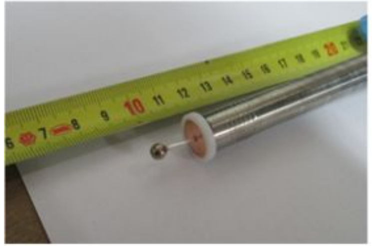
The SPC in UNIZAR!



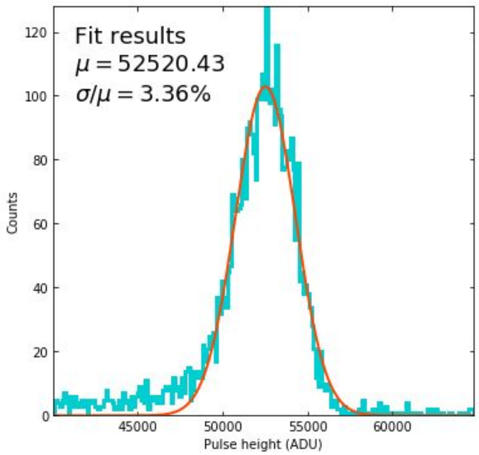




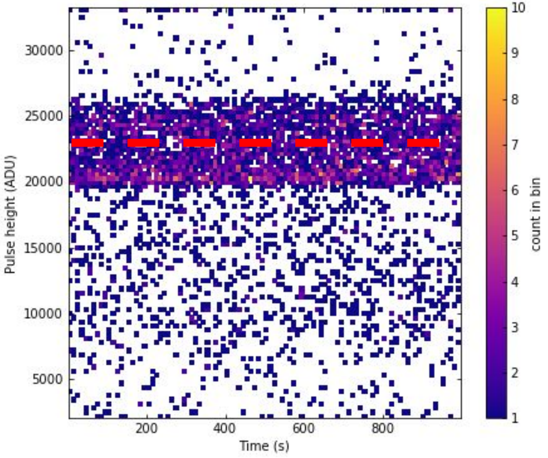
BACKUP SLIDES

Detector characterisation - In progress

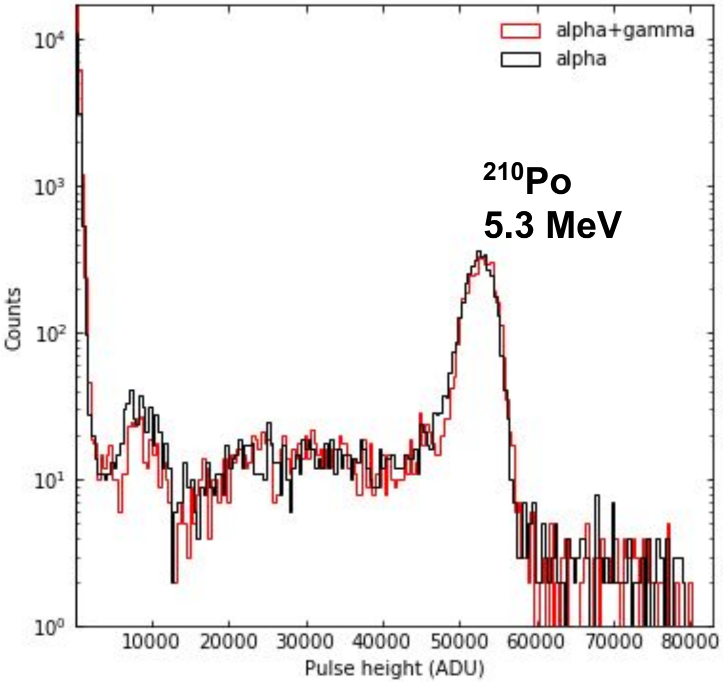
Resolution



Stability



γ-ray discrimination



Planning:

- **Operation at up to 2 bar**
  - **Minimisation of wall effect**
  - **Larger target mass - Sensitivity**
- **Calibration with mono-energetic neutrons**
- **Measurements with thermal and fast neutrons**

BG budget

	Source	Contamination / flux	Unit	Events rate <1 keV [dru]	Events rate in [1;5] keV [dru]	Total rate [mHz]
Gas mixture	^{3}H	13	μBq/kg	0.05	0.06	0.005
	^{222}Rn	111	μBq/kg	0.05	0.04	0.2
Copper sphere 500 μm electrolyte	^{210}Pb	28.5	mBq/kg	1.04	1.01	0.86
	^{238}U	3	μBq/kg	0.0117	0.115	0.028
	^{232}Th	13	μBq/kg	0.0754	0.0692	0.163
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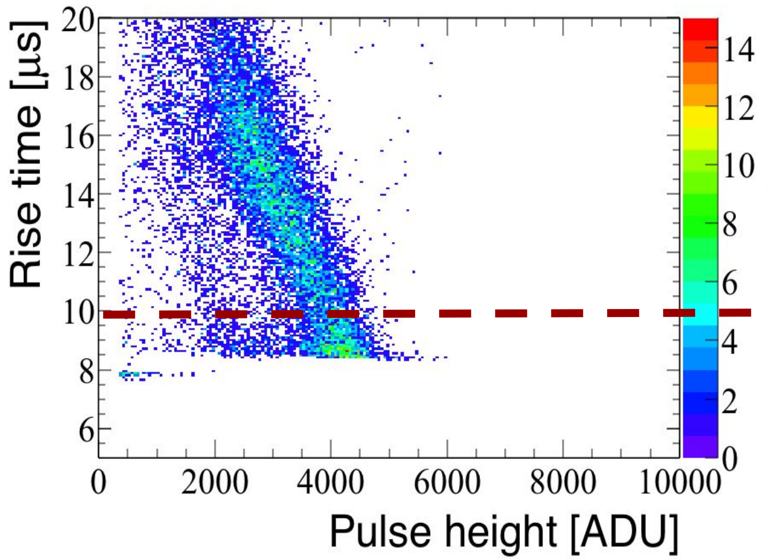
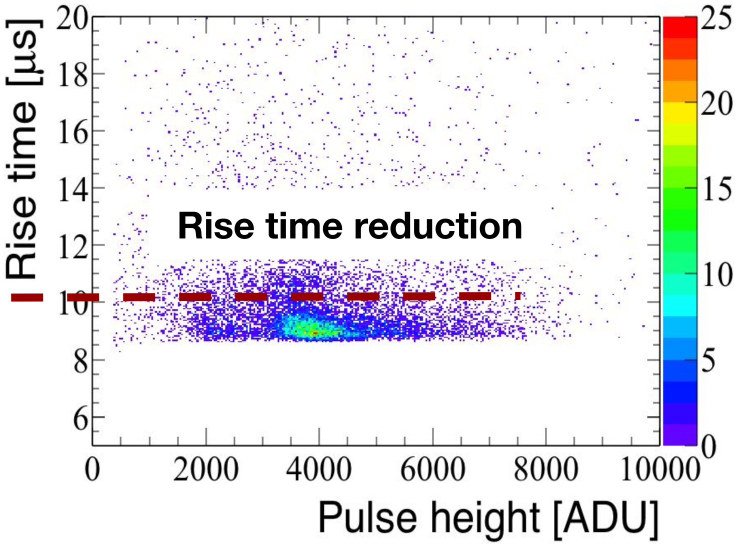
Total + cosmogenic activation of the copper sphere and 2 years of cooling				1.9	1.7	2.9

Results with the prototypes

Giganon, A. et al, 2017. "A Multiball Read-out for the Spherical Proportional Counter.", *JINST*

Rise time reduction

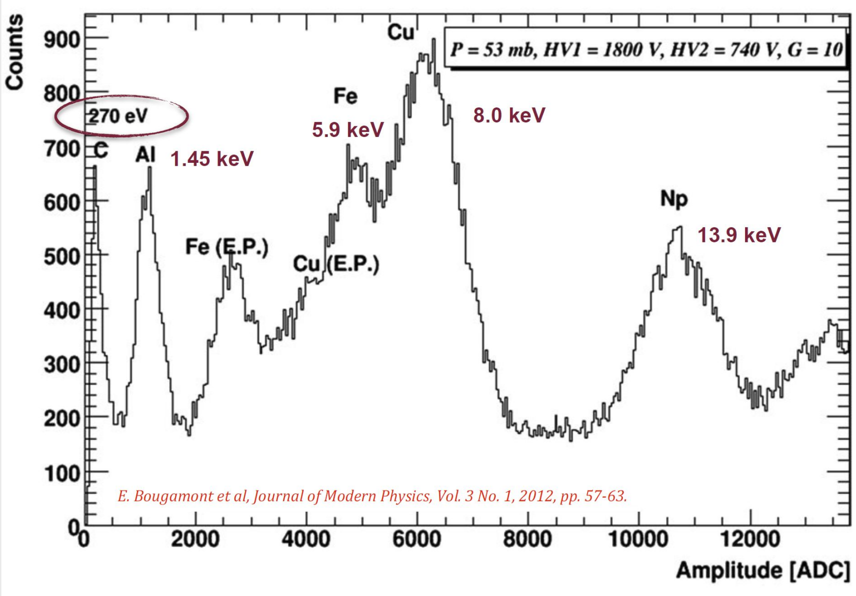




Maximum rise time

$He:Ar:CH_4(80:11:9)$
640 mbar
HV_1 = 2015 V
HV_2 = −200 V
2 mm Ø anodes

Low energy detection capabilities of a large volume SPC



SPC Ø 130 cm

Gas: Ar+2%CH$_4$

Detection of fluorescence X-rays

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

Lines

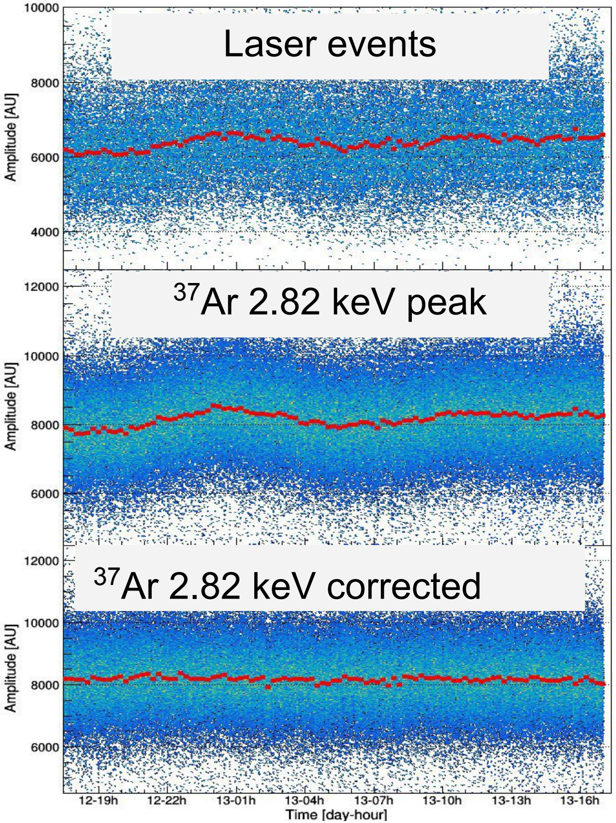
Al -> 1.45 keV

Cu -> 13.93 keV

^{237}Np -> 13.93 keV(L$_\alpha$ 17.60 keV(L$_\beta$)

-Energy threshold at the single electron level

Detector monitoring



The laser can be used to monitor the detector response during physics runs

Long-term fluctuations in gain can be caused by temperature changes, O_2 contamination, sensor damage...

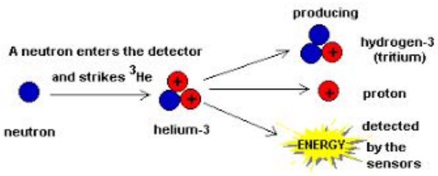
Laser monitoring data could even be used to correct for long-term fluctuations

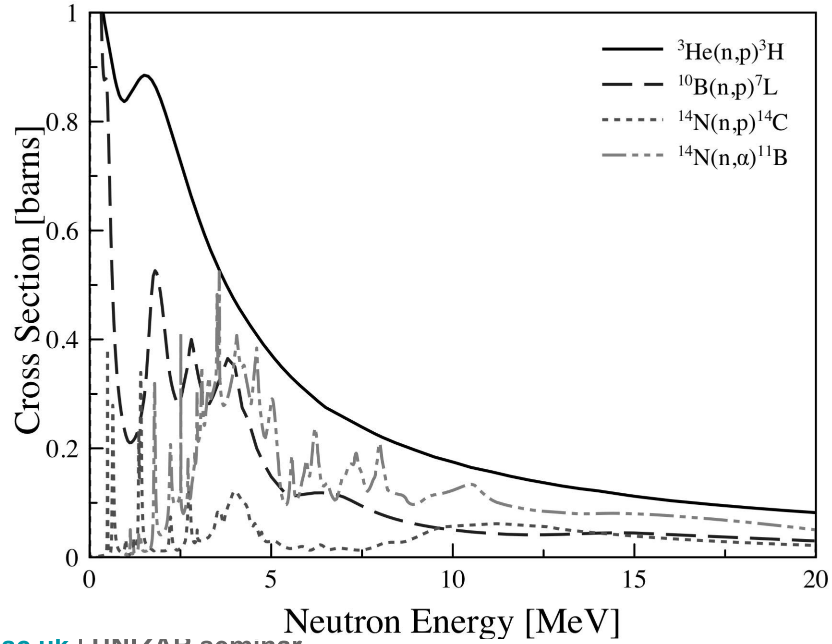
Neutron spectroscopy

Common targets:
$^{3}He + n \rightarrow {}^{3}H + p + 765$ keV, $\sigma_{th} = 5330$ b

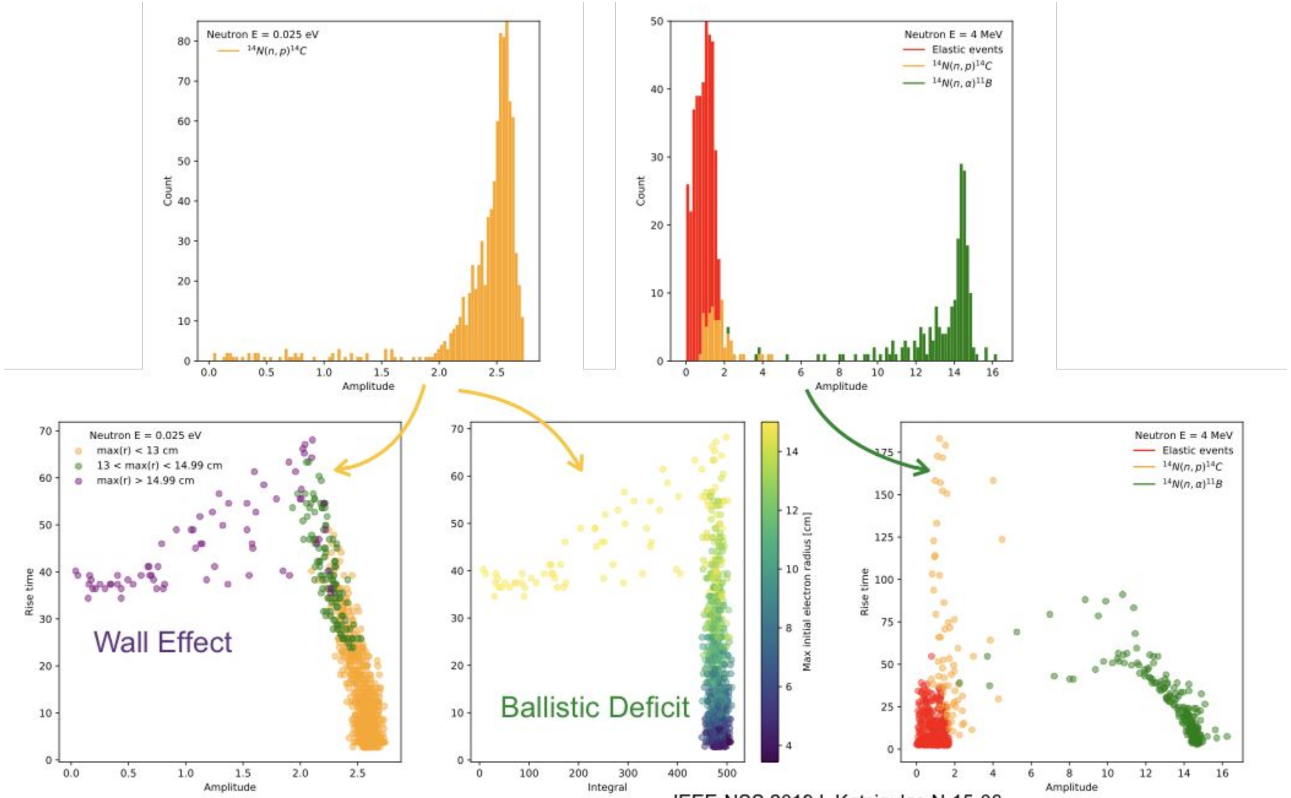
$^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He + 2310$ keV, $\sigma_{th} = 3840$ b
($^{7}Li^{*} \rightarrow {}^{7}Li + 480$ keV)

- **Neutrons: important background in DM searches**
  - **Identical signature to signal events**
  - **Stored material activation**
- **Few measurements at underground laboratories**
  - **^{3}He-based detectors extremely expensive**





Simulation of neutron transport



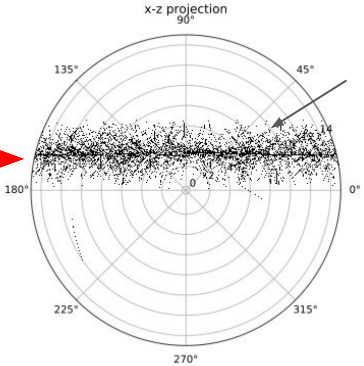
IEEE-NSS 2019 I. Katsioulas N-15-06

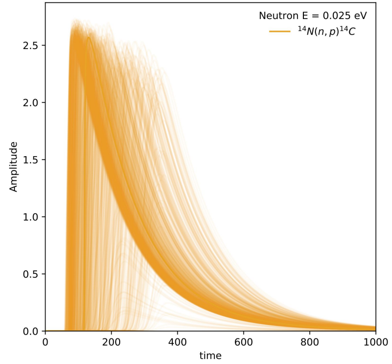
Simulation of neutron transport

Simulation Parameters:
Ø vessel 30 cm
Nitrogen at 300 mbar
Anode Ø 2 mm

Neutron Beam

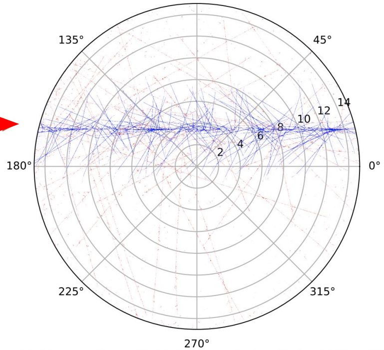
0.025 eV

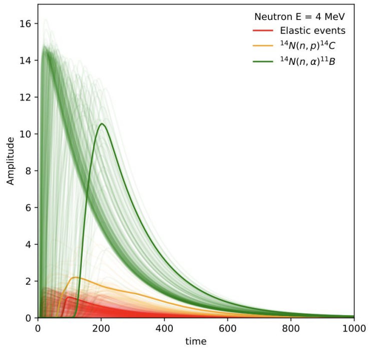




Neutron Beam

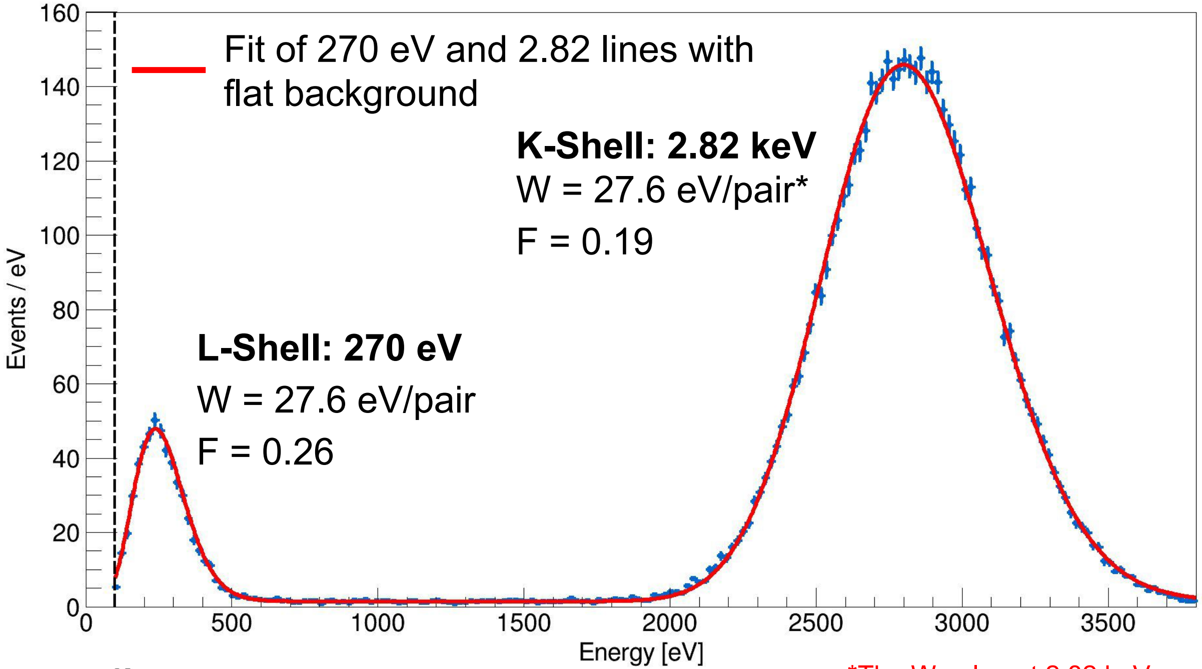
4 MeV





Q. Arnaud et al. (NEWS-G Collaboration), Phys. Rev. D 99, 102003 (2019)

Ar37 calibrations and gas fundamentals properties measurement



$$f\left(E'\right)=\sum_{N=1}^{N_{\max}} P_{\mathrm{CMP}}\left(N|\mu,F\right)\times P_{\mathrm{Polya}}^{(\mathrm{N})}\left(E'|\left\langle G\right\rangle,\theta\right)$$

*The W-value at 2.82 keV was calculated directly from <G> and fixed for this fit

- **Ar37 produced by irradiating Ca power with a high flux of fast neutrons**
- **Together with laser calibrations, can find W (mean Ionization energy) with 1% precision for target gas, and set upper limits on F (Fano factor)**

Detector response modeled:

- **Primary ionisation (COM-Poisson)**

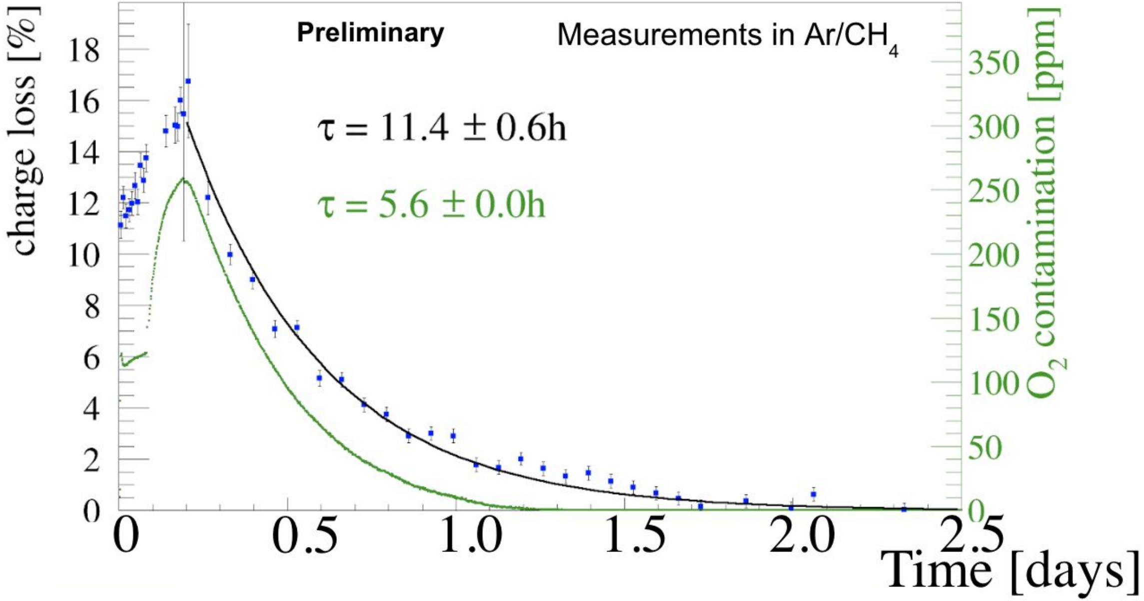
D. Durnford et al, Phys. Rev. D 98, 103013 (2018)

- **Avalanche (Polya)**

Filtering within a recirculation system

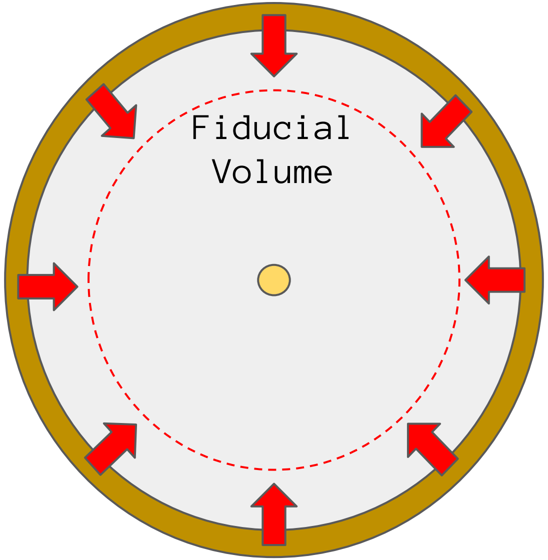
- SAES MicroTorr Purifier (MC700 902-F) then used
- Improved filtering efficiency in large sphere – **attachment problem 'solved'**
- Incorporated into recirculation system with RGA

Charge Loss and Oxygen Concentration over Time while gas passes circulated through MicroTorr Purifier



Background rejection capabilities-A

Fiducialisation



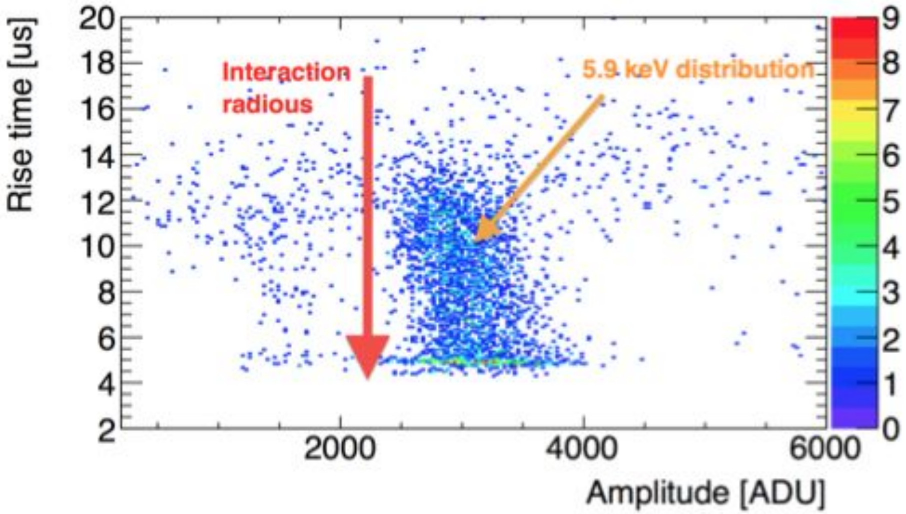
Background comes from the materials of the vessel

→ **Surface**

Primary e- drift time dispersion

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

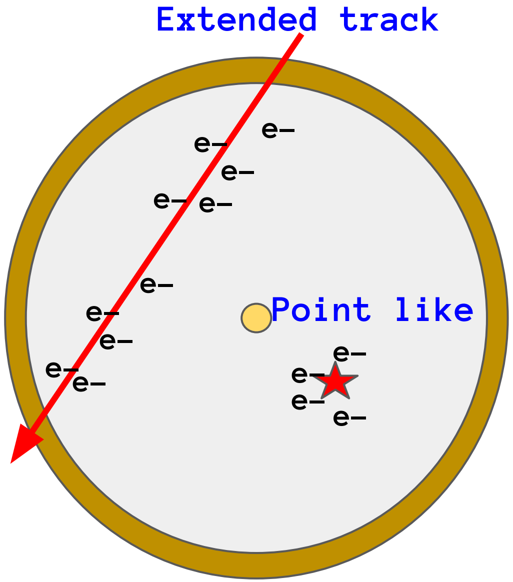
5.9 keV X-rays line

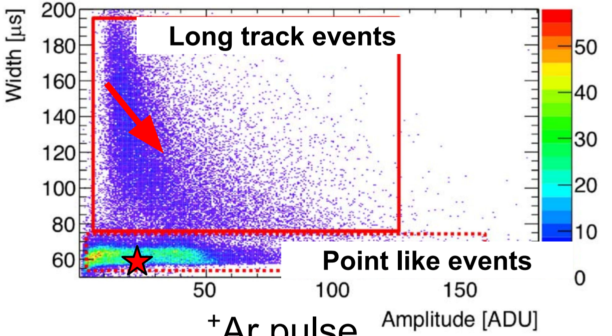


Rise time → Δt between 90% - 10% of pulse height

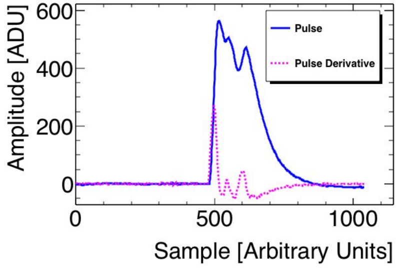
Background rejection capabilities-B

Event discrimination



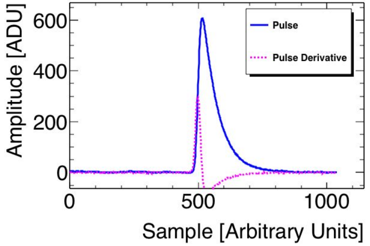


Muon pulse



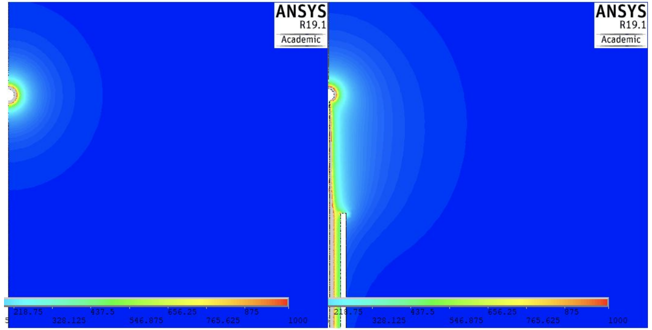

```
Amplitude     = 575 ADU
Width (FWHM) = 155.5 µs
Rise time     = 18.2 µs
```

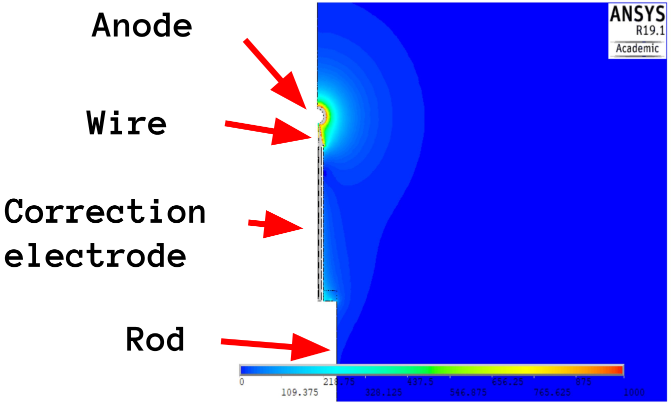
$^{+}$Ar pulse

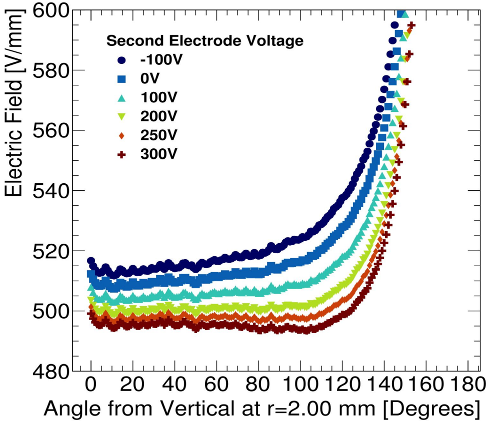



```
Amplitude     = 606 ADU
Width (FWHM) = 63.4 µs
Rise time     = 16.3 µs
```

Electric field homogeneity



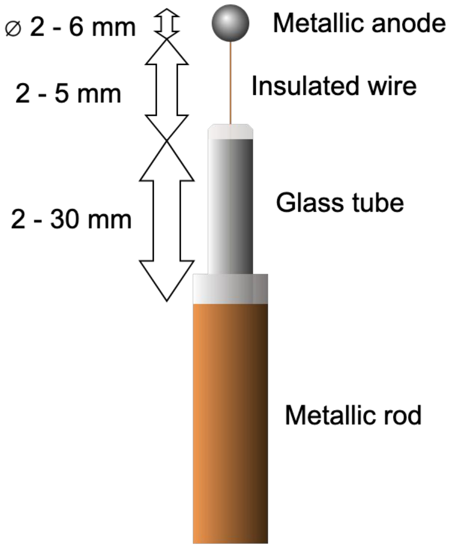




- **Ideally, electric field:**
  - **Purely radial**
  - **Strength $1/r^2$**
- **Reality more complex, as support structure needed for sensor**
  - **$E=E(r,\theta)$**
  - **Non-uniform detector**
  - **Response**
- **Improved field uniformity by adding correction electrode**

The resistive glass electrode

Design



Implementation

Provides

- Spark quenching
- Charge evacuation

Advantages

- Simple
- Symmetric
- Robust
- Low material budget

Material properties

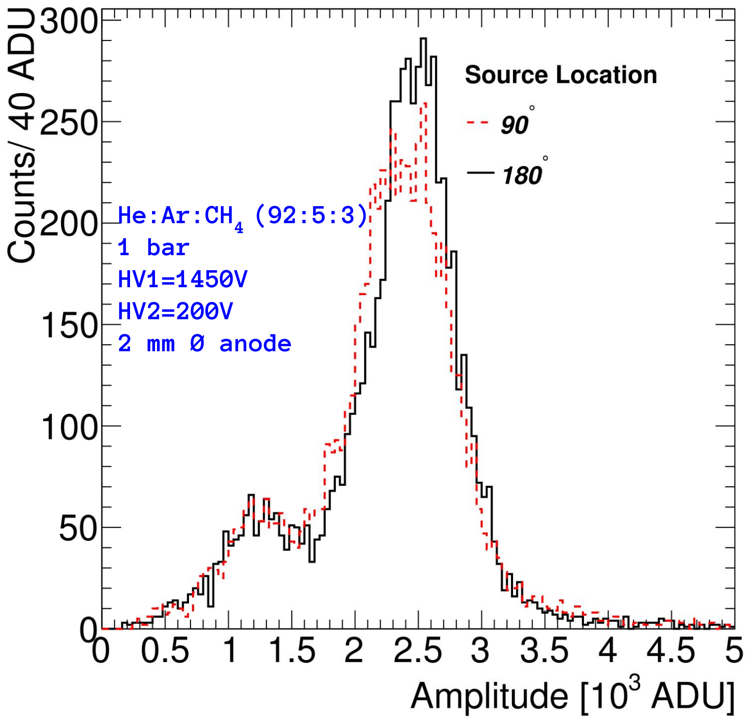
- Soda-lime glass
- $\rho = 5.05\times10^{10}\ \Omega\cdot\mathrm{cm}$
- d = 2.1-2.25 g/cm3
- A = 14.48 mBq/g

[I. Katsioulas et al, JINST, 13, 11, P11006, 2018
10.1088/1748-0221/13/11/P11006](10.1088/1748-0221/13/11/P11006)

[I. Katsioulas et al, JINST, 13, 11, P11006, 2018](https://doi.org/10.1088/1748-0221/13/11/P11006)
[10.1088/1748-0221/13/11/P11006](https://doi.org/10.1088/1748-0221/13/11/P11006)

Performance

Measurements with the SPC in the two positions



Detector stability