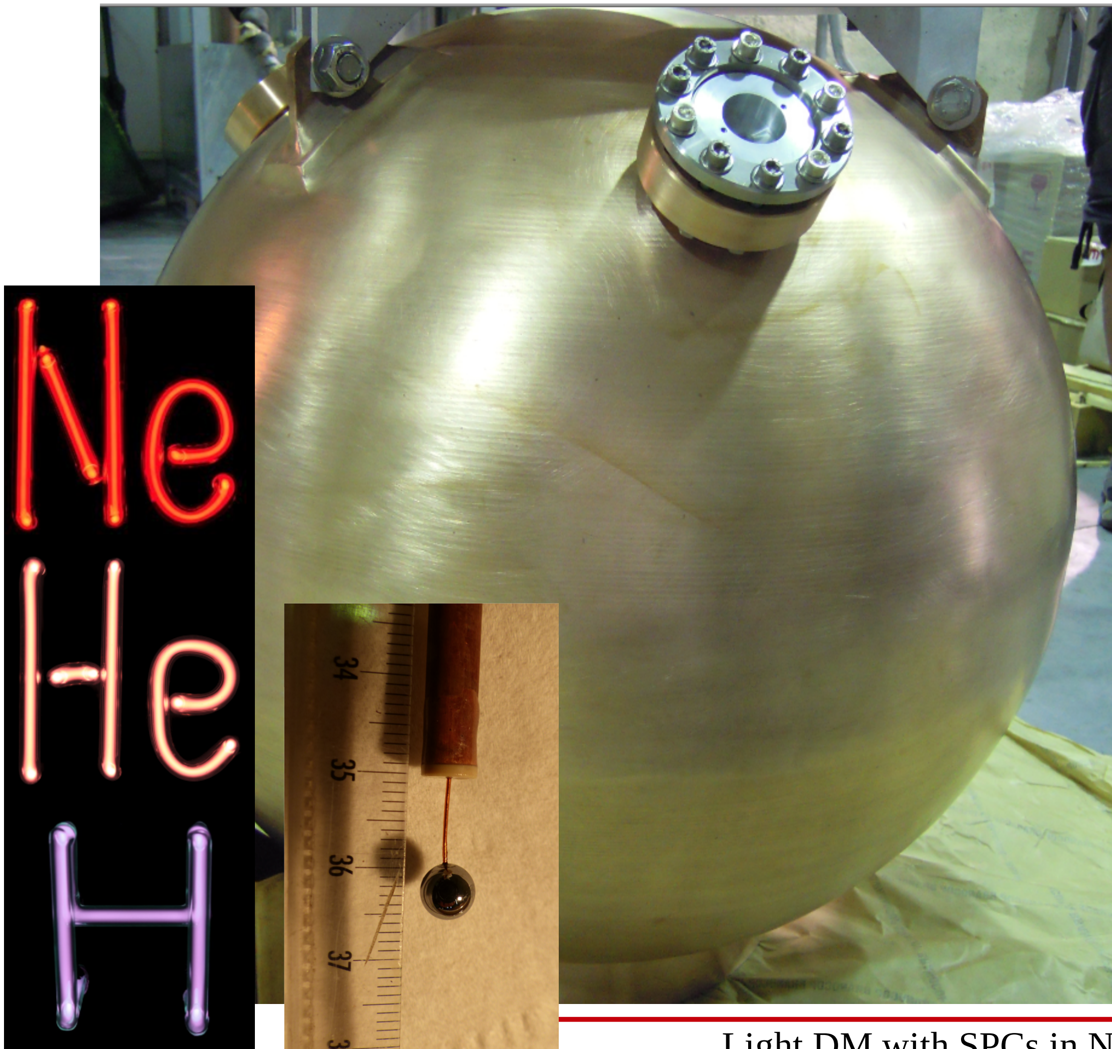
The search for Light Dark Matter with SPCs in NEWS-G

Philippe Gros
On behalf of the NEWS-G Collaboration

September 8th 2022

Spherical Proportional Counters (SPCs)



Metallic vessel filled with a noble gas mixture, with a single high voltage anode/sensor

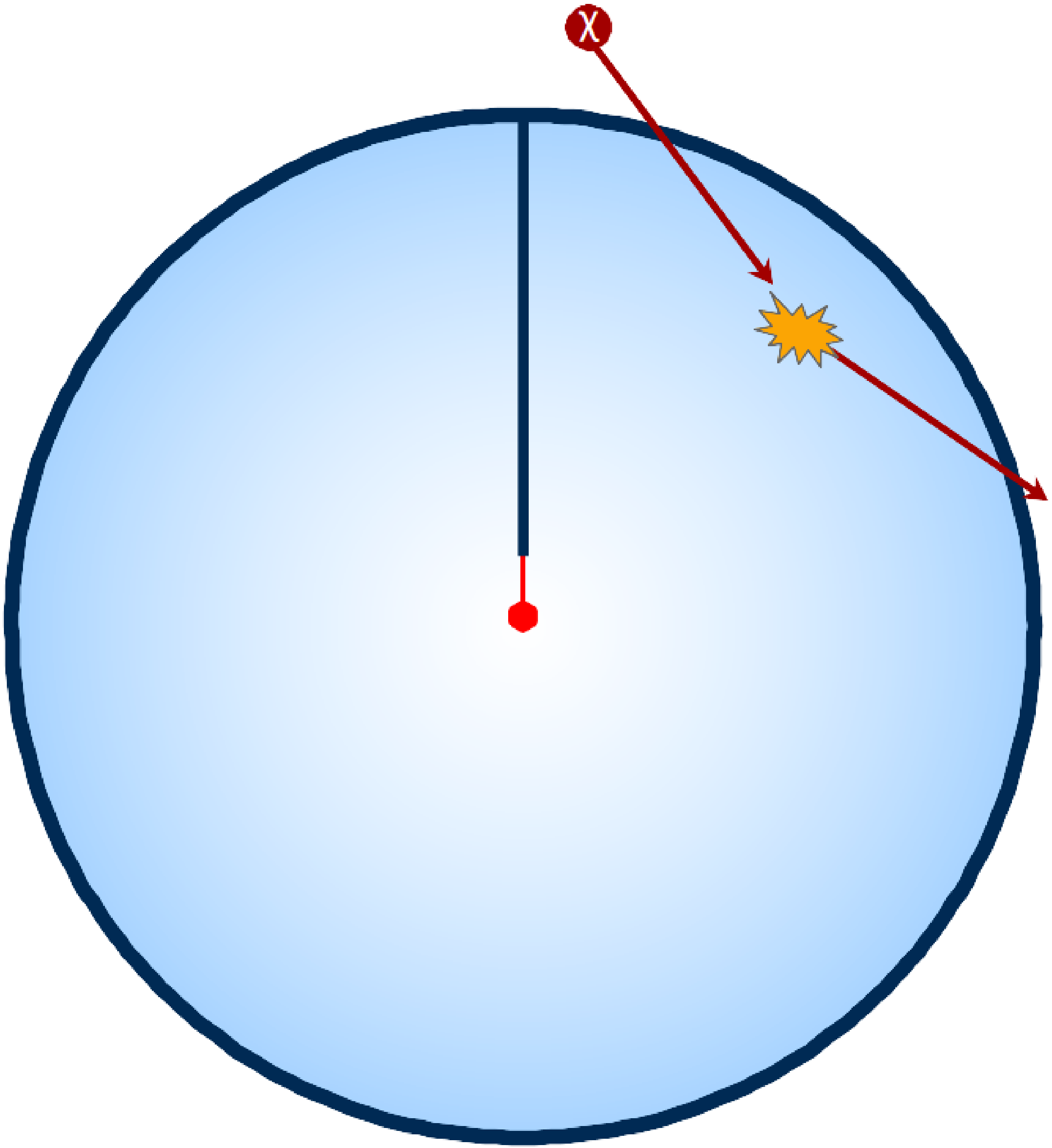
Low-A target atoms increases sensitivity to low-mass WIMPs

Low capacitance (~0.4 pF) decreases electronic baseline noise

Townsend avalanche provides large gain

Single ionization detection threshold!

Principle of operation



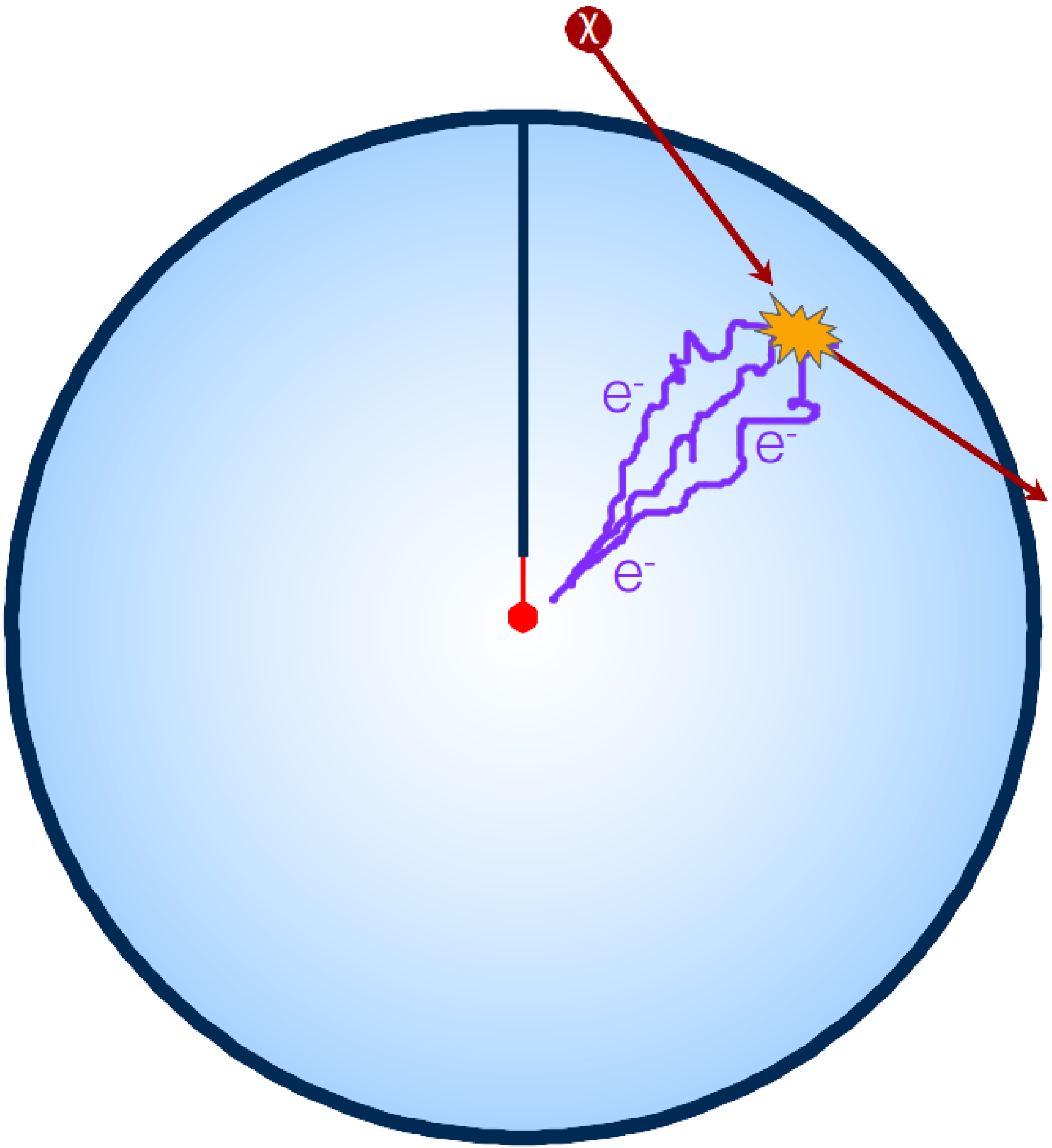
(1) Primary Ionization

$$\langle \#PE \rangle = \frac{E}{W(E)}$$

$$W_{\rm nr} = W_\gamma / Q(E)$$

Neon: W_γ ~ 36 eV/pair
Q ~ 0.2

Principle of operation



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Radially-dependent diffusion allows for fiducialization

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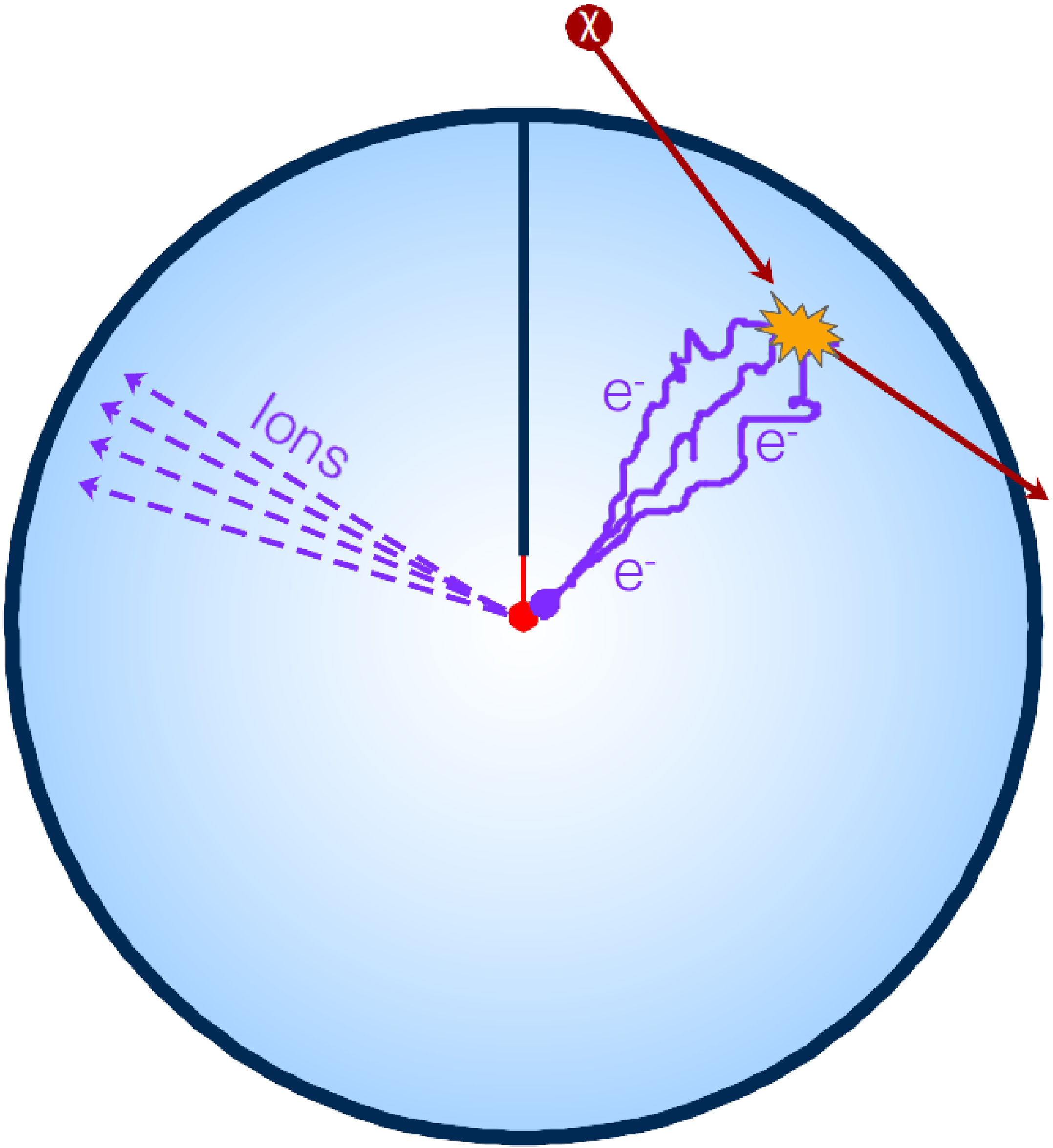

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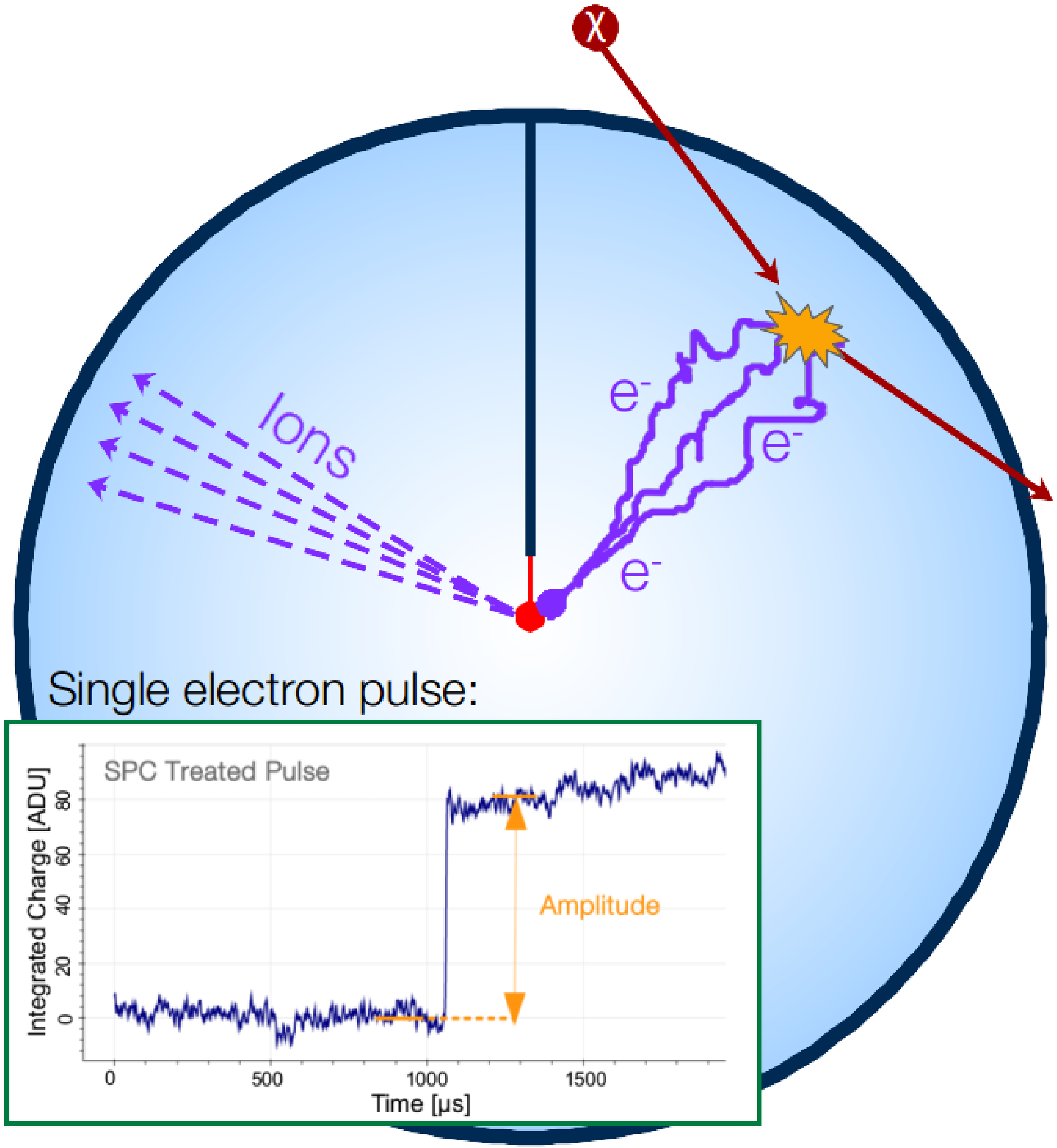
(3) Avalanche of secondary e⁻/ion pairs

Amplification of signal through Townsend avalanche (tunable with V)

(~10^3 - 10^4 secondary pairs)

Principle of operation



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Radially-dependent diffusion allows for fiducialization

(3) Avalanche of secondary e^-/ion pairs

Amplification of signal through Townsend avalanche (tunable with V)

(4) Signal formation

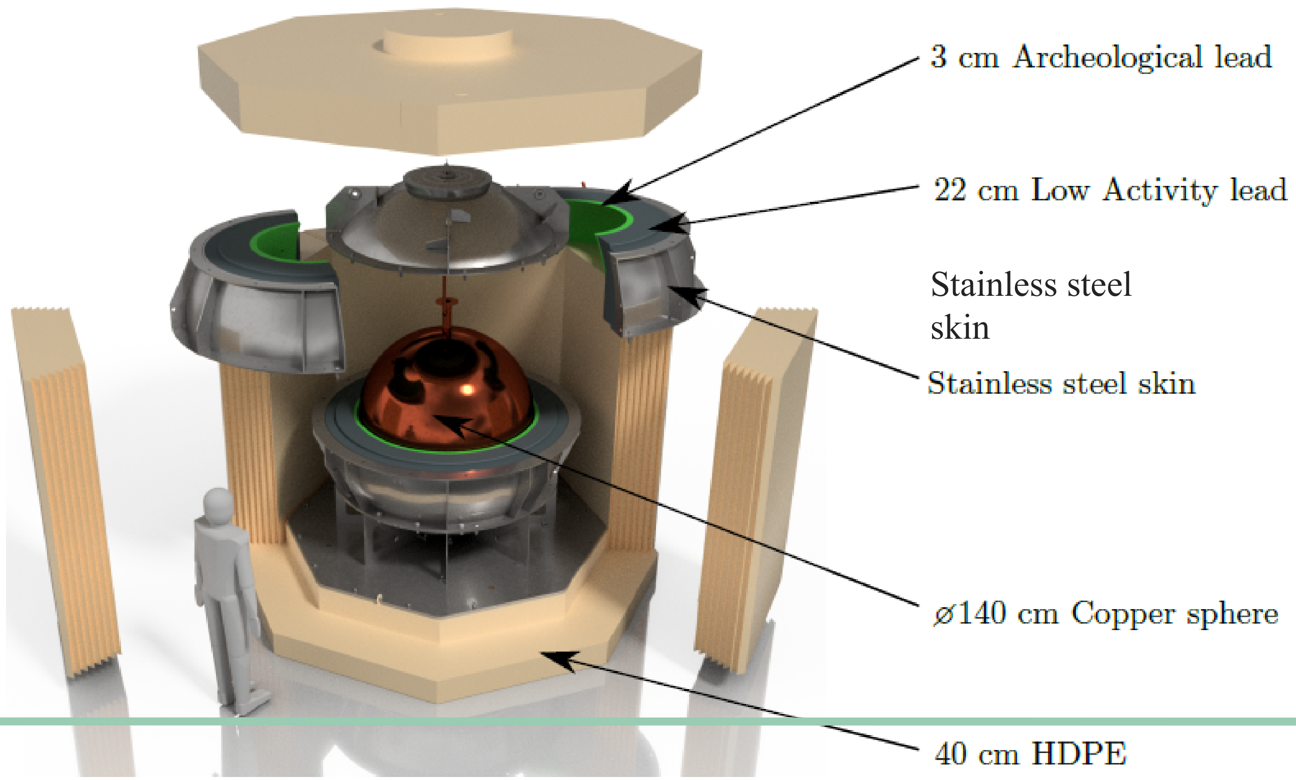
Current induced by the secondary ions drifting away from anode

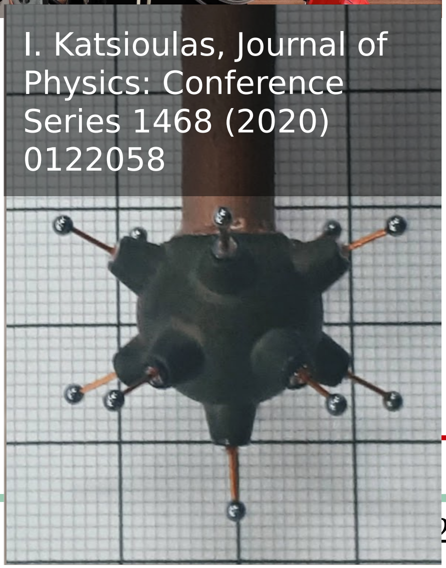
(5) Signal readout

Current integrated and digitized

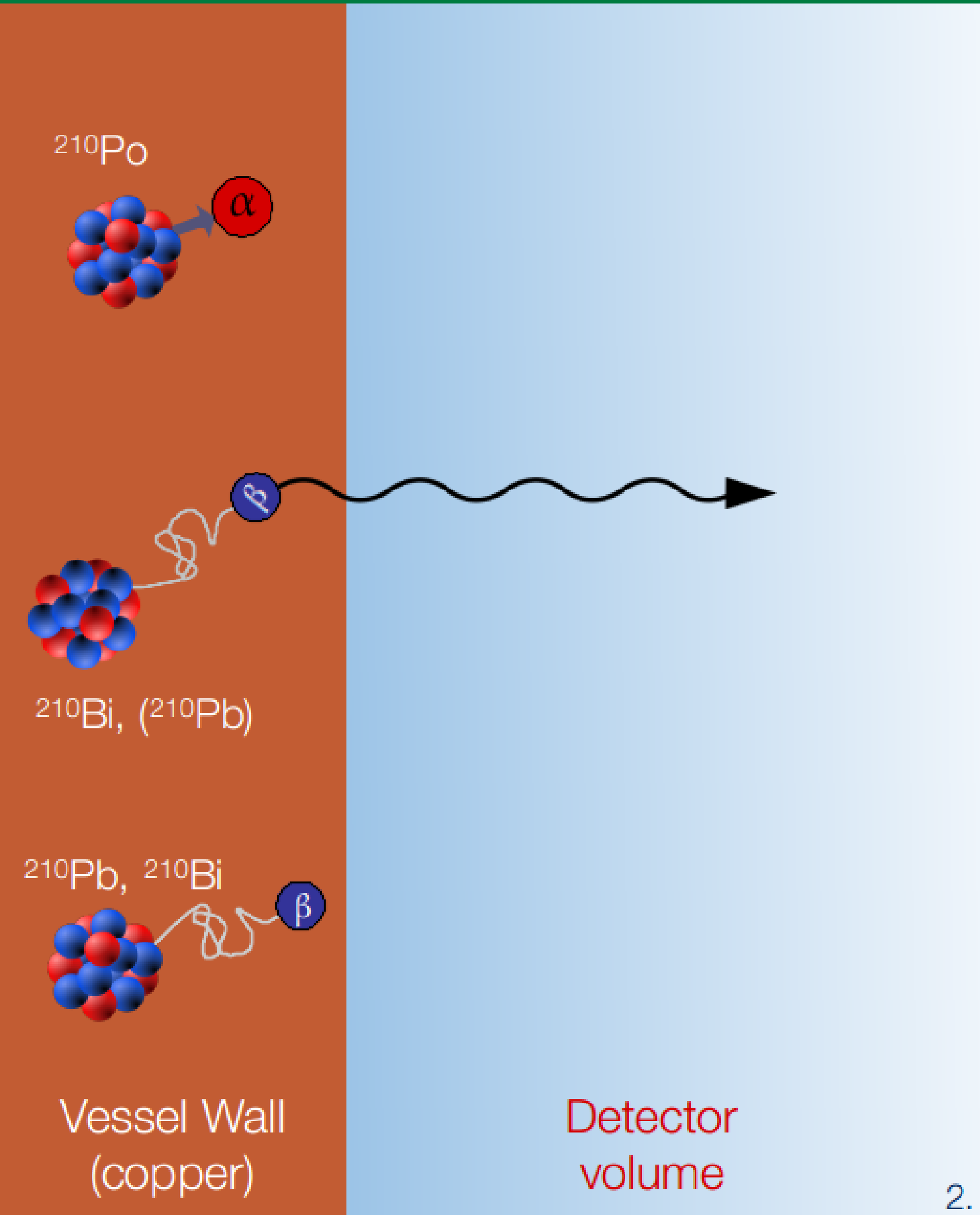
SNOGLOBE at SNOLAB

- Radio-pure construction, multi-layered compact shield system
- Gas quality: contamination filter and radon removal, precise measurement of methane
- Multi-anode sensor for more isotropic response





The SNOGLOBE detector



^{210}Pb can be incorporated into copper during the manufacturing process

Bremsstrahlung x-rays (~keV) from ^{210}Pb and ^{210}Bi β^- decay in the copper escape, travel through whole gas volume

XIA measurements in collaboration with XMASS [1] yields 29±8 mBq/kg bulk ^{210}Pb in our copper [2]

1. K. Abe et al, Nucl. Instrumen. Methods A, 884 (2018)
2. L. Balogh et al, Nucl. Instrumen. Methods A, 988 (2021)

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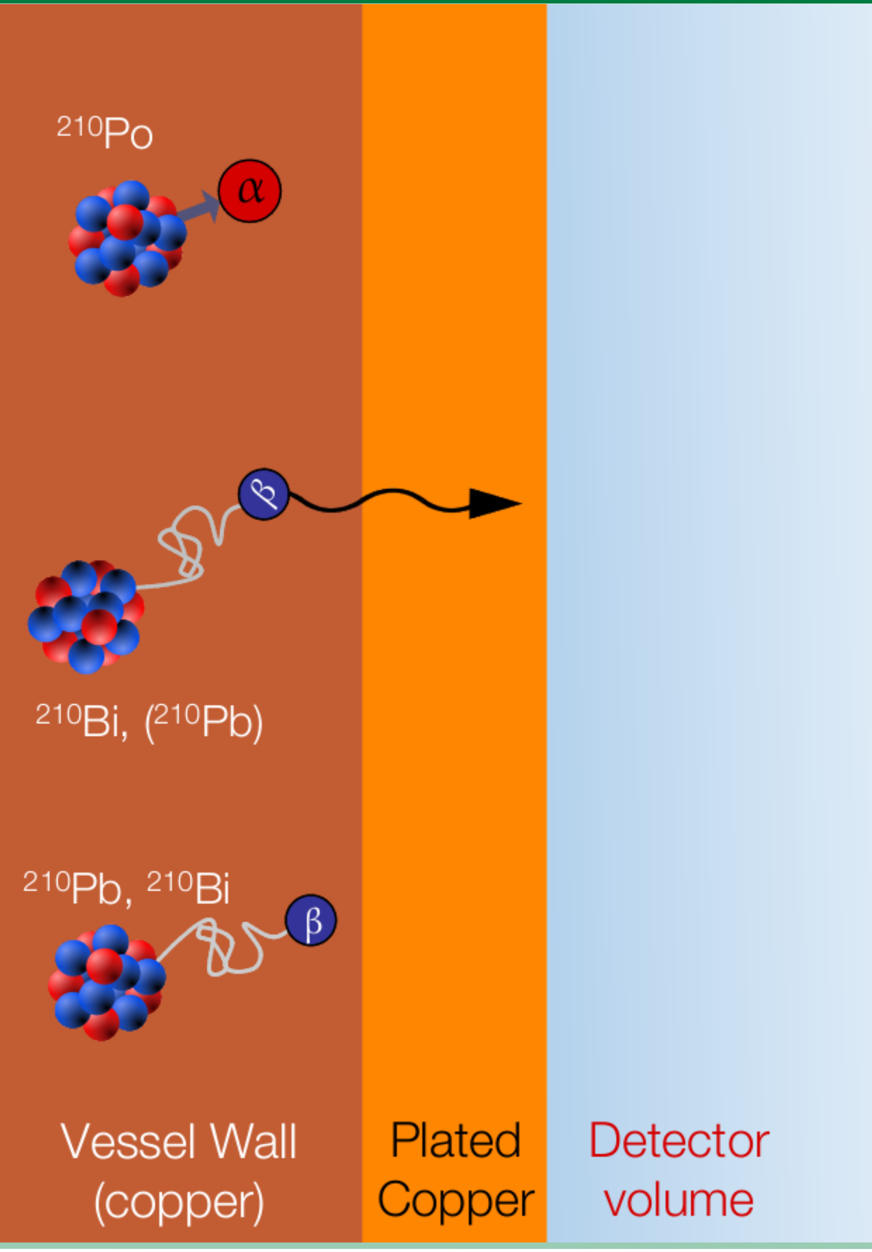
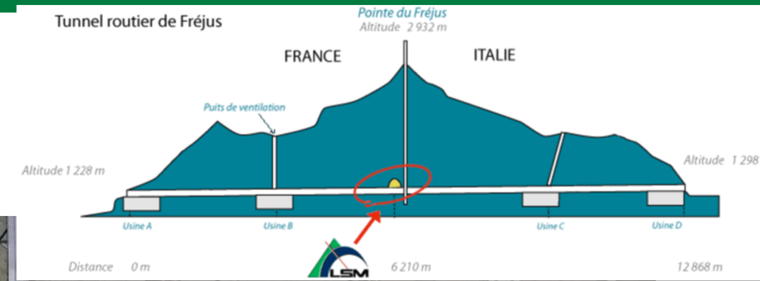


Plating ~0.5mm of pure copper will reduce this background by ~70% below 1 keV and the total rate by ~98%

Plating successfully carried out at the LSM in collaboration with PNNL

SNOGLOBE @ the LSM



Commissioning data was taken at the LSM:

A water tank was used instead of the PE shield. First test of sensor deployment system, electronics

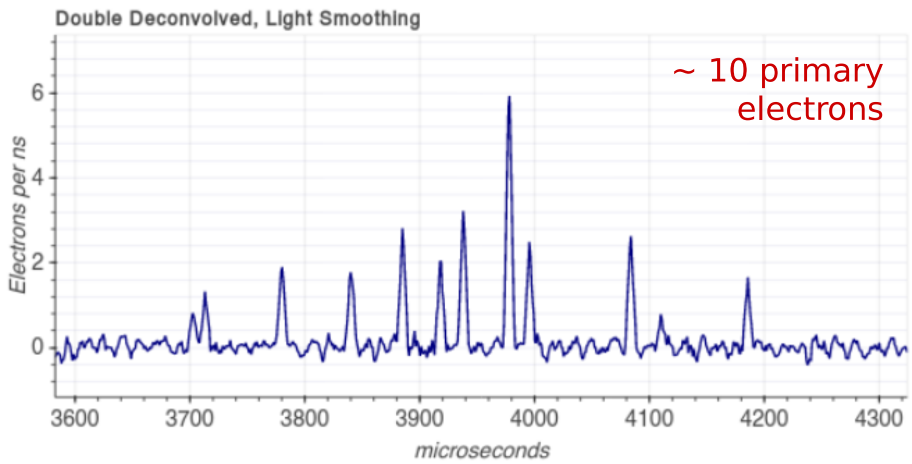
~10 days of data taken with 135 mbar of pure CH_4 (110 g):

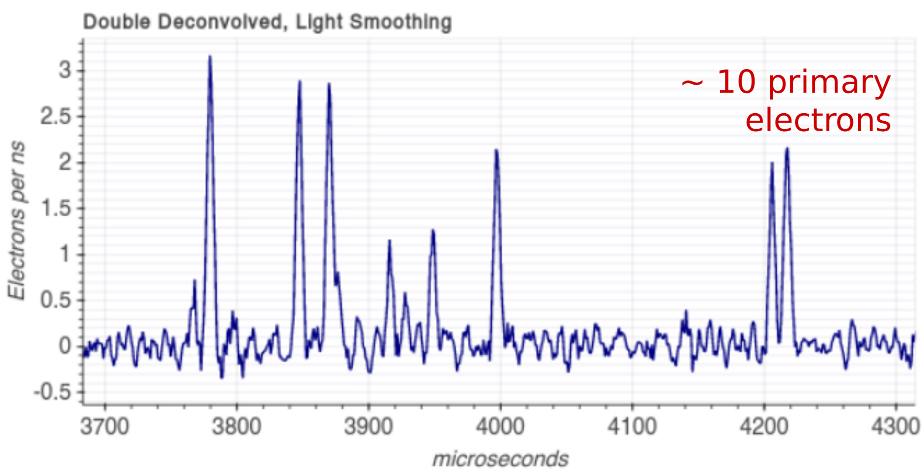
- Larger fraction of hydrogen for low-mass DM sensitivity
- More transparent to high energy γ's, lower background rate/unit mass than Ne/CH_4 mixture

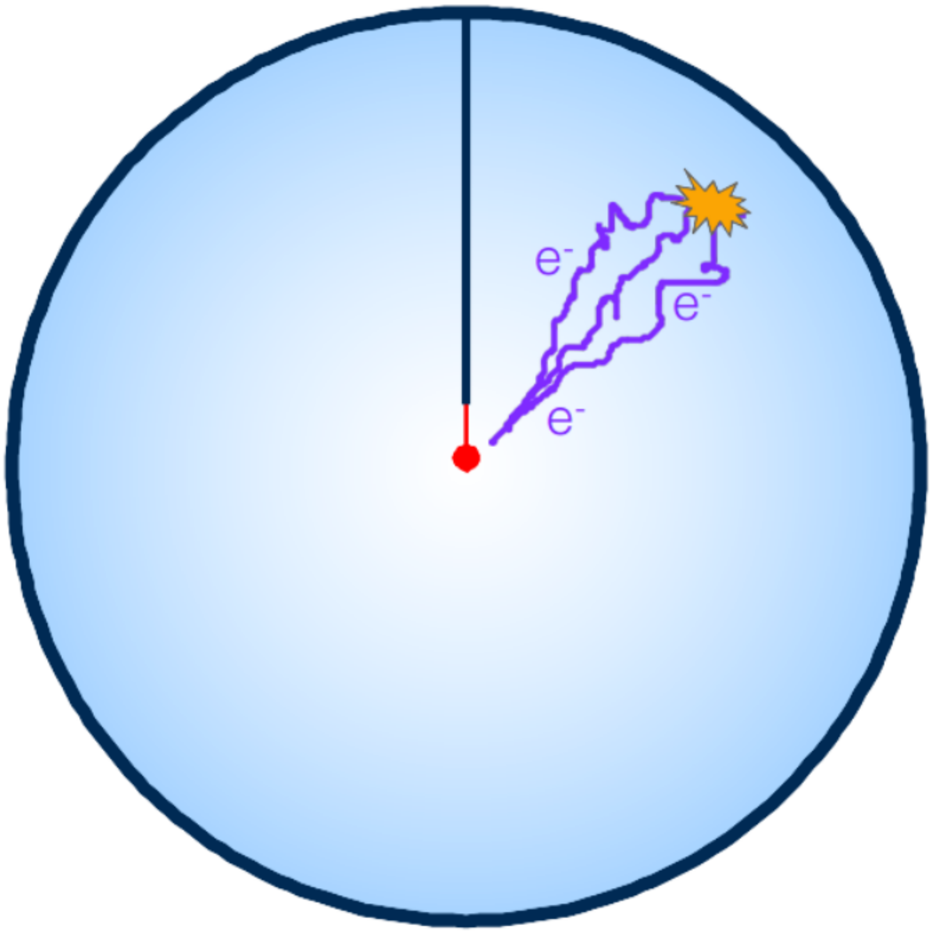
Electron peak finding

The large drift volume allows us to resolve individual primary electrons in time!

UV Laser events from new 140cm SPC:







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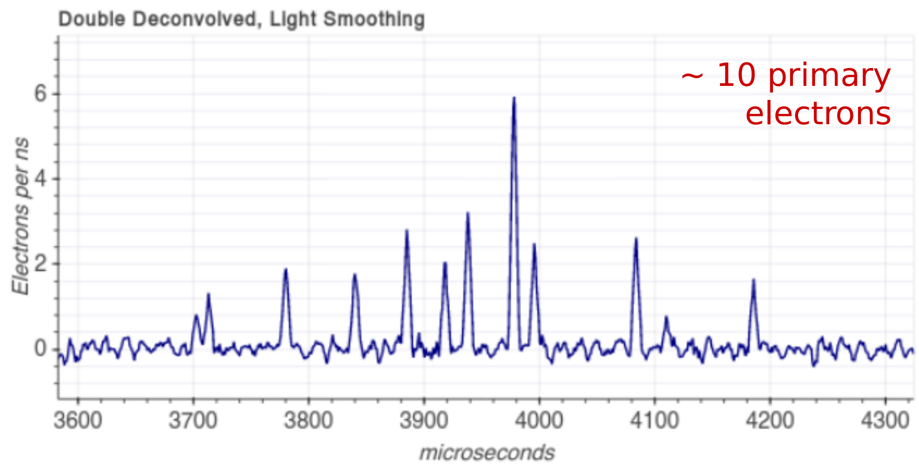
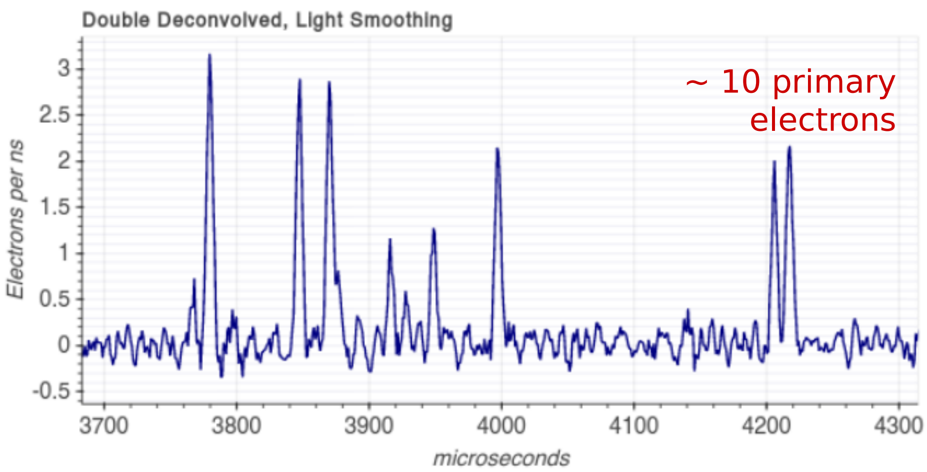
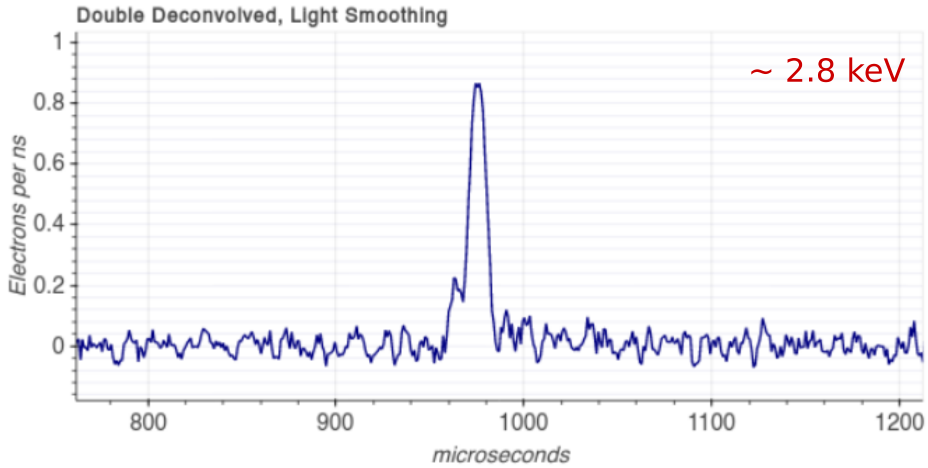
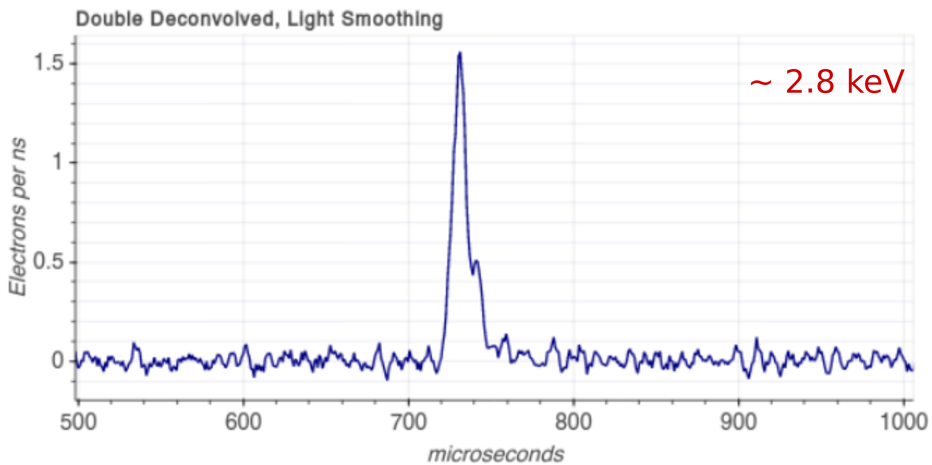




^{37}Ar events from 30cm prototype SPC:

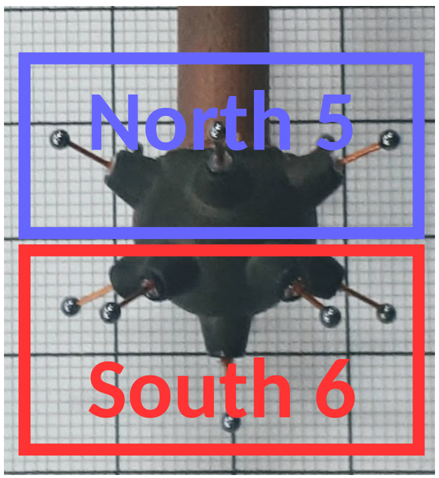




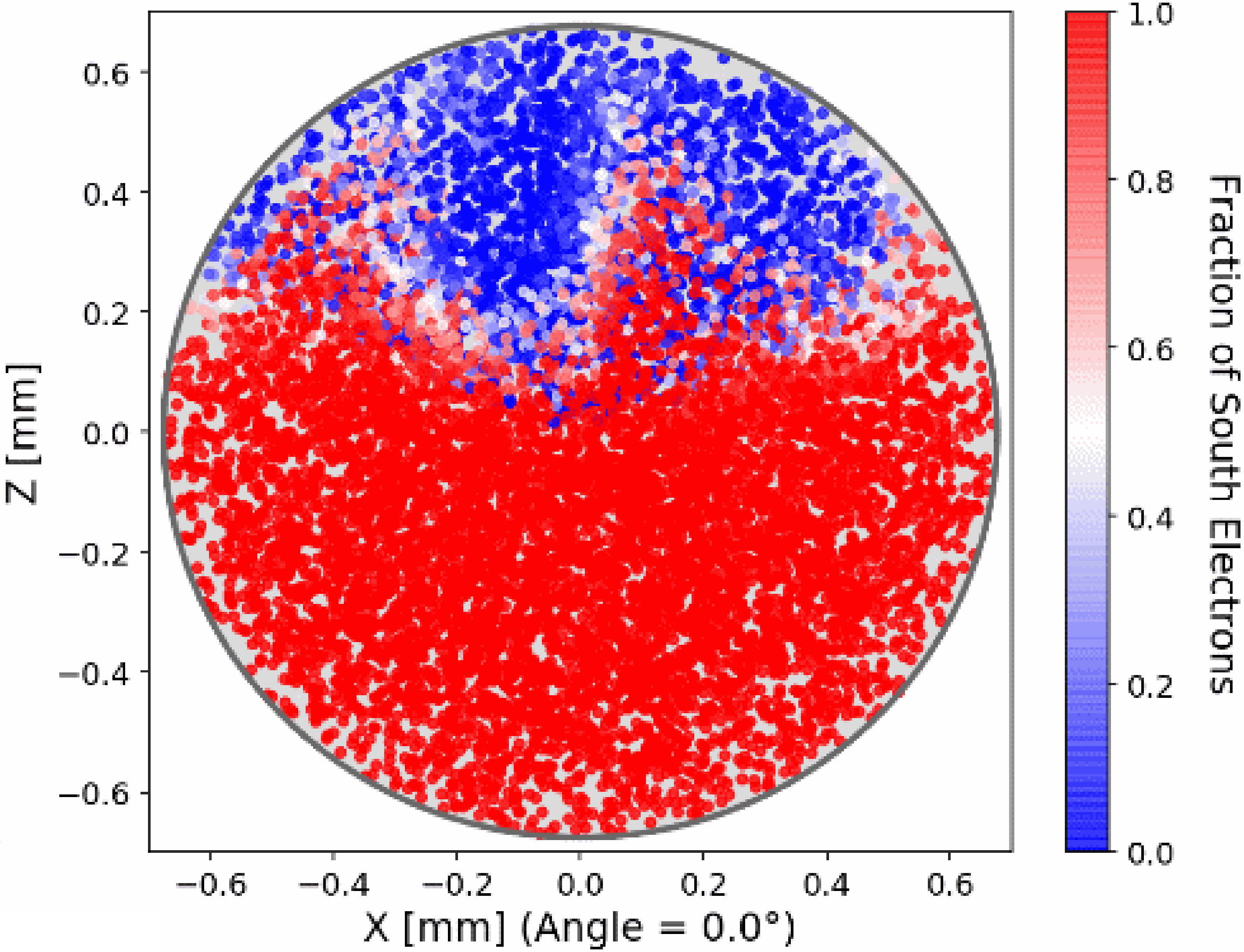
Sensor readout

The 11-anode sensor is read out in two channels (north and south)

In this analysis, only pure south-channel events are kept as candidate events (more isotropic field structure)



The fiducial volume covered by the southern 6 anodes is approximately 70%



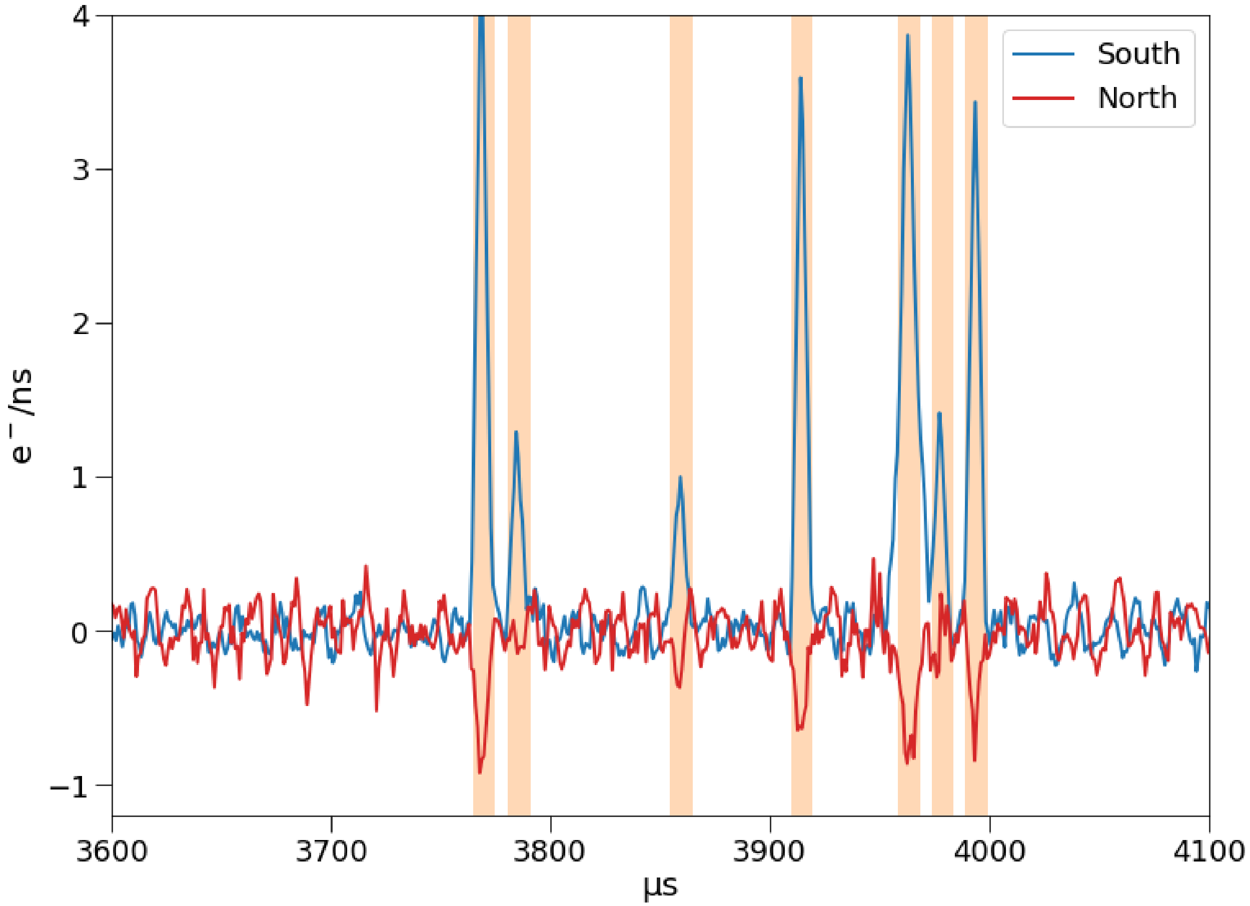
Pulse shape discrimination

Physical events induce mirror, smaller pulses in the opposite sensor channel with a characteristic scale

Spurious pulses (electronic artifacts) do not exhibit this behaviour, and tend to be sharper

PSD possible using combination of North/South peak amplitudes and pulse derivative (“spikiness”)

Approximately 77% of physical events kept, 95% of spurious pulses rejected



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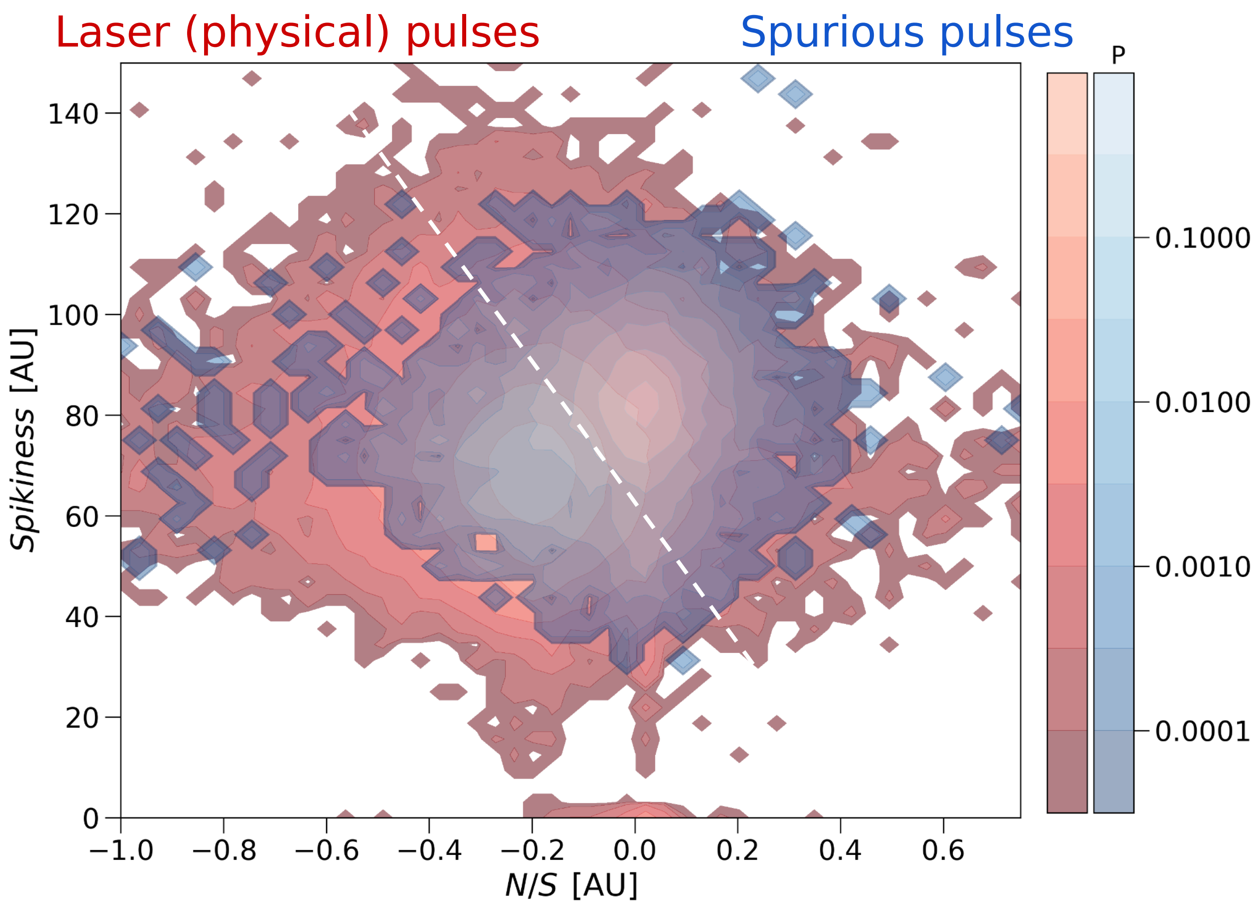
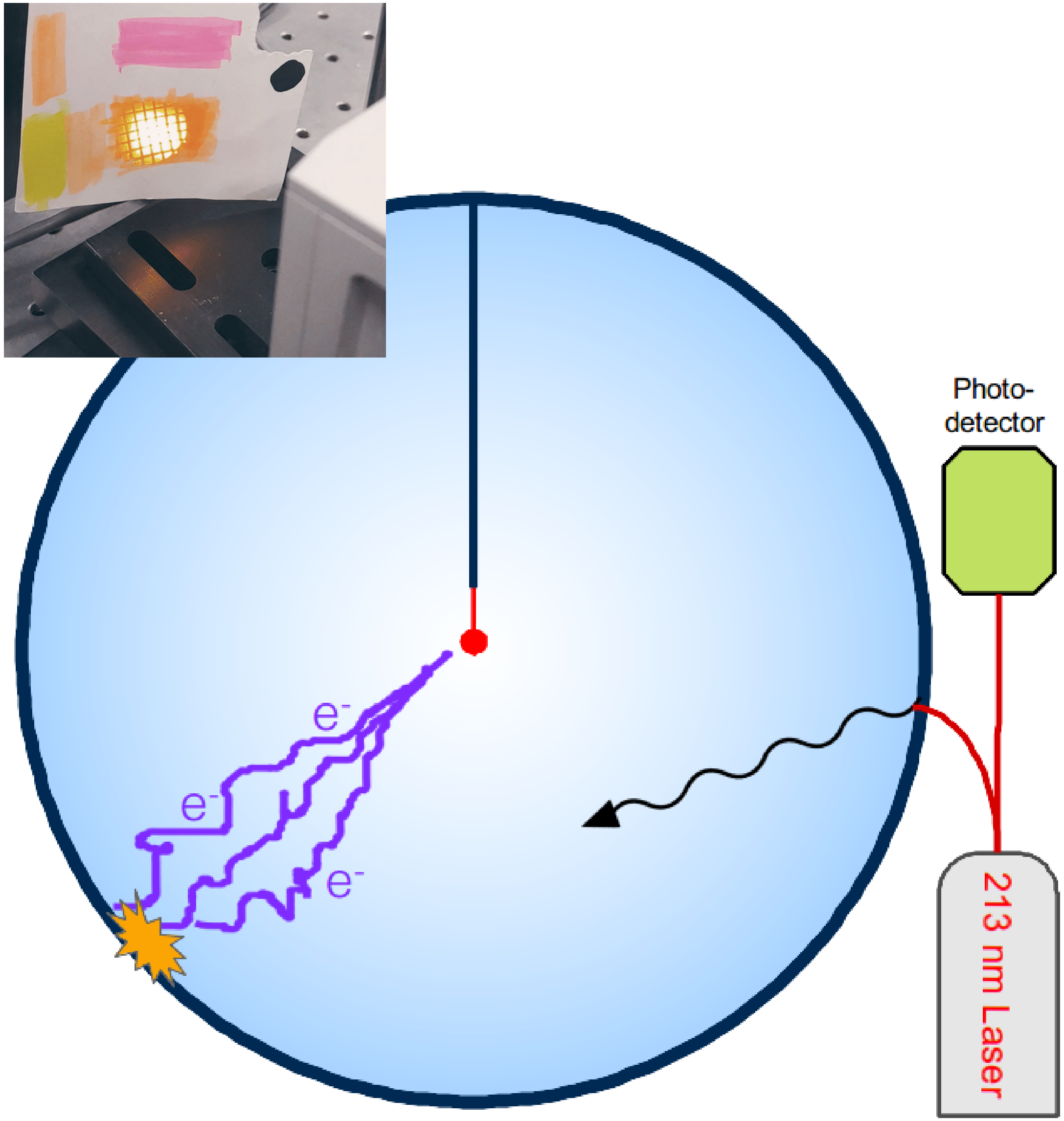


UV laser calibration



A 213 nm laser shone into the sphere extracts photo-electrons from the inner surface of the vessel [1]:

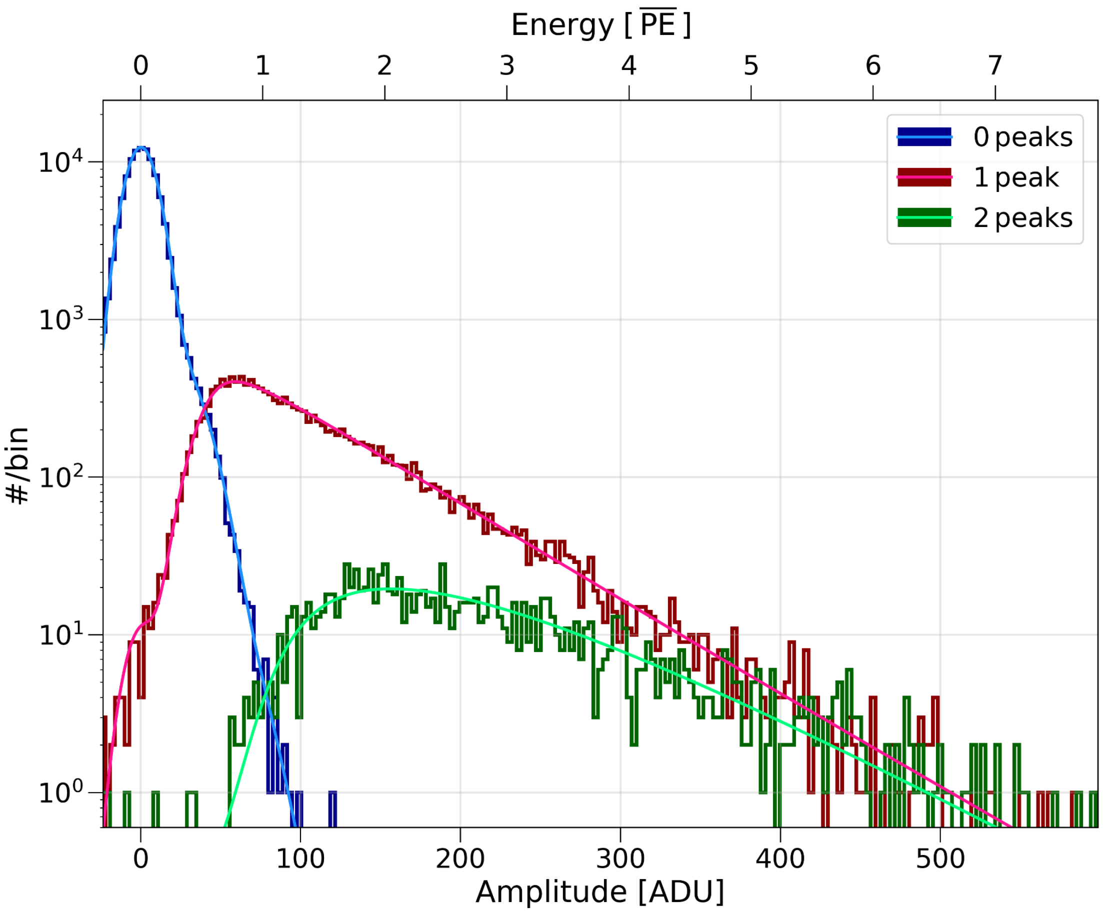
Laser-induced calibration events are tagged with a photodiode

Continuous operation during physics runs allows for monitoring of the detector response, changes in detector gain over time

Low intensity laser data also allows for measurement of the hardware trigger efficiency

[1] Q. Arnaud et al, Phys. Rev. D 99, 102003 (2019)

UV laser calibration



A 213 nm laser shone into the sphere extracts photo-electrons from the inner surface of the vessel [1]:

Data with 0 or a few electrons is used to measure the single electron response of the detector (gain and avalanche statistics)

Also used to quantify the performance of the peak-finding algorithm (peak detection threshold and noise trigger probability)

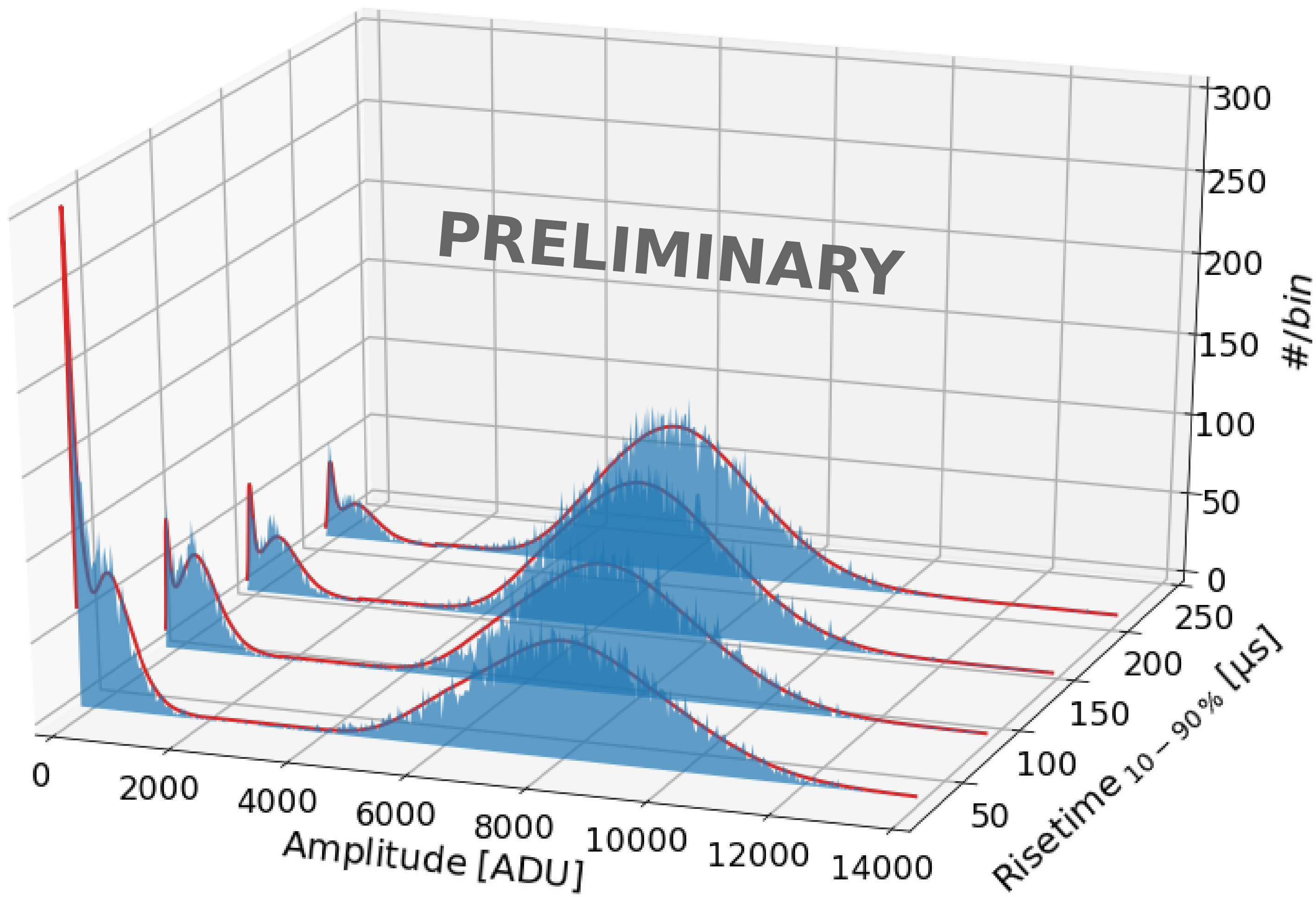
[1] Q. Arnaud et al, Phys. Rev. D 99, 102003 (2019)

Detector response

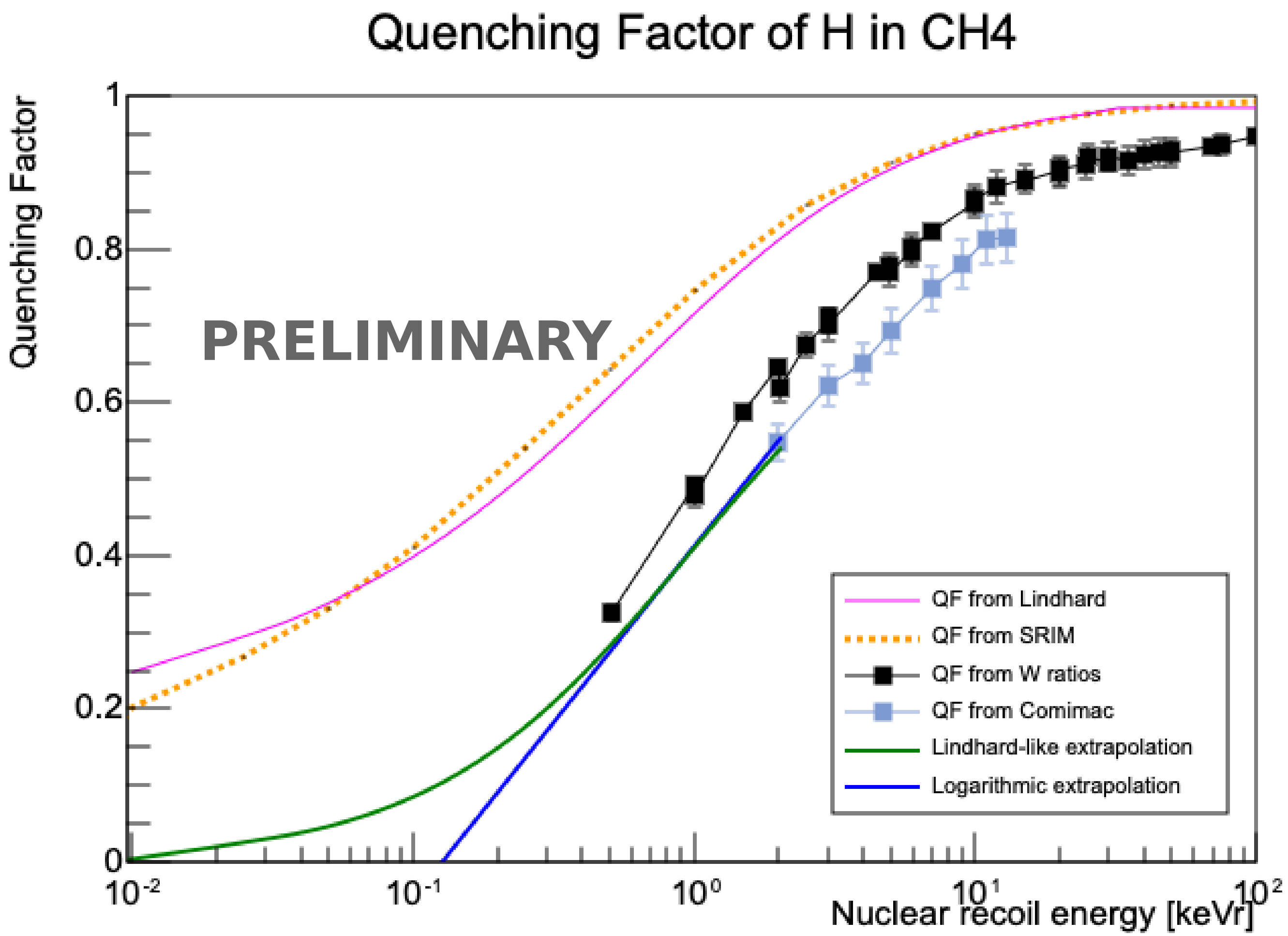
^{37}Ar gas was injected in the SPC after the physics campaign, producing (almost) monoenergetic lines at 200 ev, 270 eV, and 2.8 keV

$$W_0 = 30.0^{+0.14}_{-0.15}\,\mathrm{eV}, \quad U = 15.70^{+0.52}_{-0.34}\,\mathrm{eV}, \quad F = 0.43 \pm 0.05$$

- Confirmation of energy linearity
- Measurement of the gain of all south-channel anodes
- In situ measurements of the W-value and Fano factor
- Parameterization of electron attachment



Detector response



Quenching factor values from existing W-value measurements for ions [1] and measurements from COMIMAC [2]

The (more conservative) logarithmic extrapolation was used

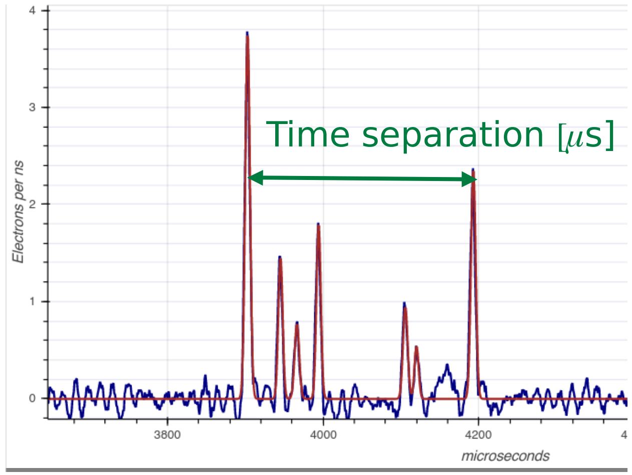
[1] Katsioulas et al, Astropart. Phys. 141, 102707 (2022)
[2] L. Balogh et al, arXiv:2201.09566

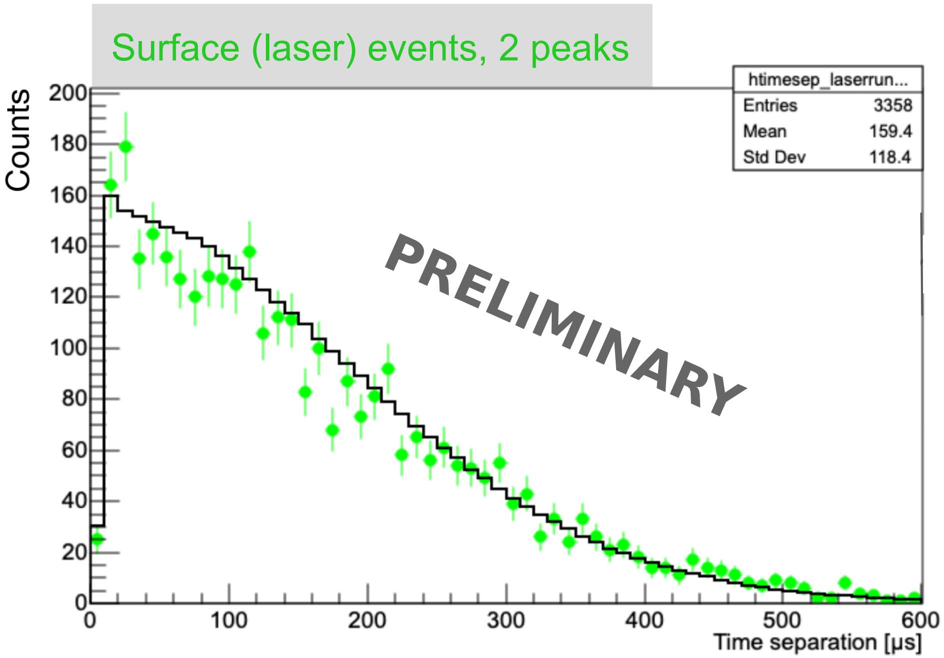
Time separation

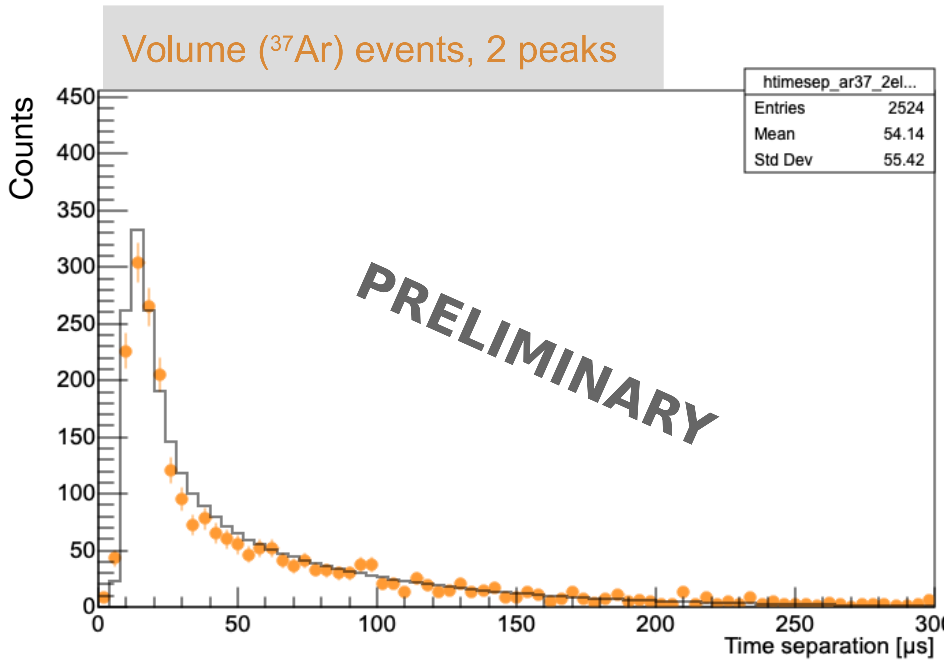
Time separation between the first and last peak is used as the primary analysis variable

Allows for discrimination between surface, volume, and pile-up events

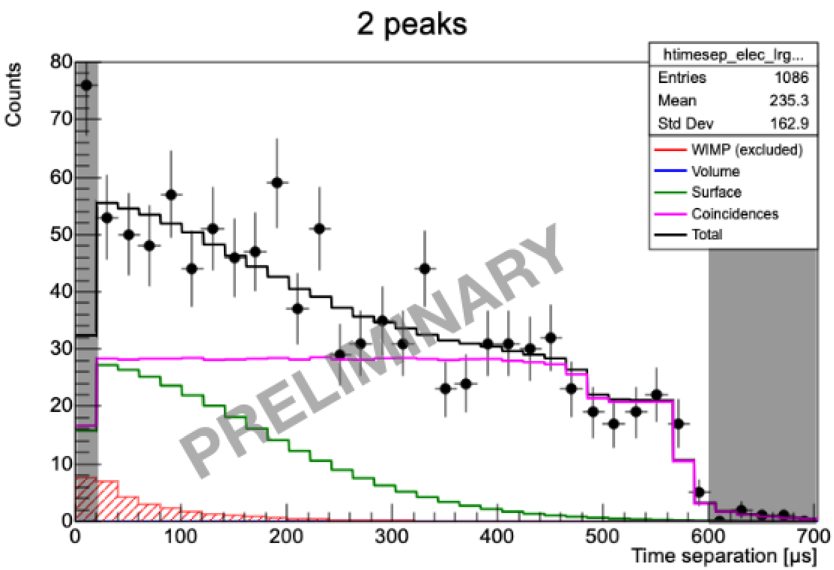
Calibrated with laser (surface) and ^{37}Ar (volume) data

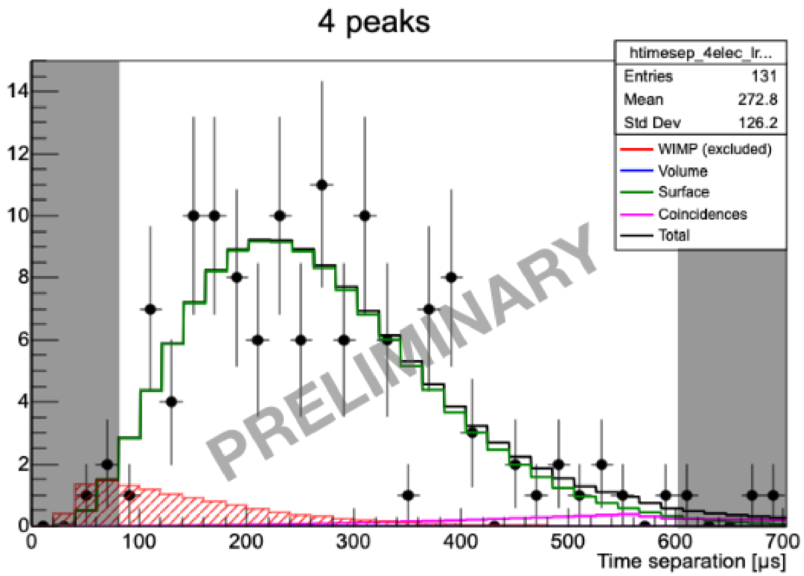






LSM Physics results





Data divided into subsets with 2/3/4 peaks found (not electrons). The 1 peak signal was overwhelmed by secondary/induced electron events

Time separation (time between first and last peak) is used for surface/volume event discrimination, address coincident event background

The physics data was split into test and blind data (~30/70%); here the fit of the test data is shown, including a WIMP signal component for demonstration (760 MeV/c^2)

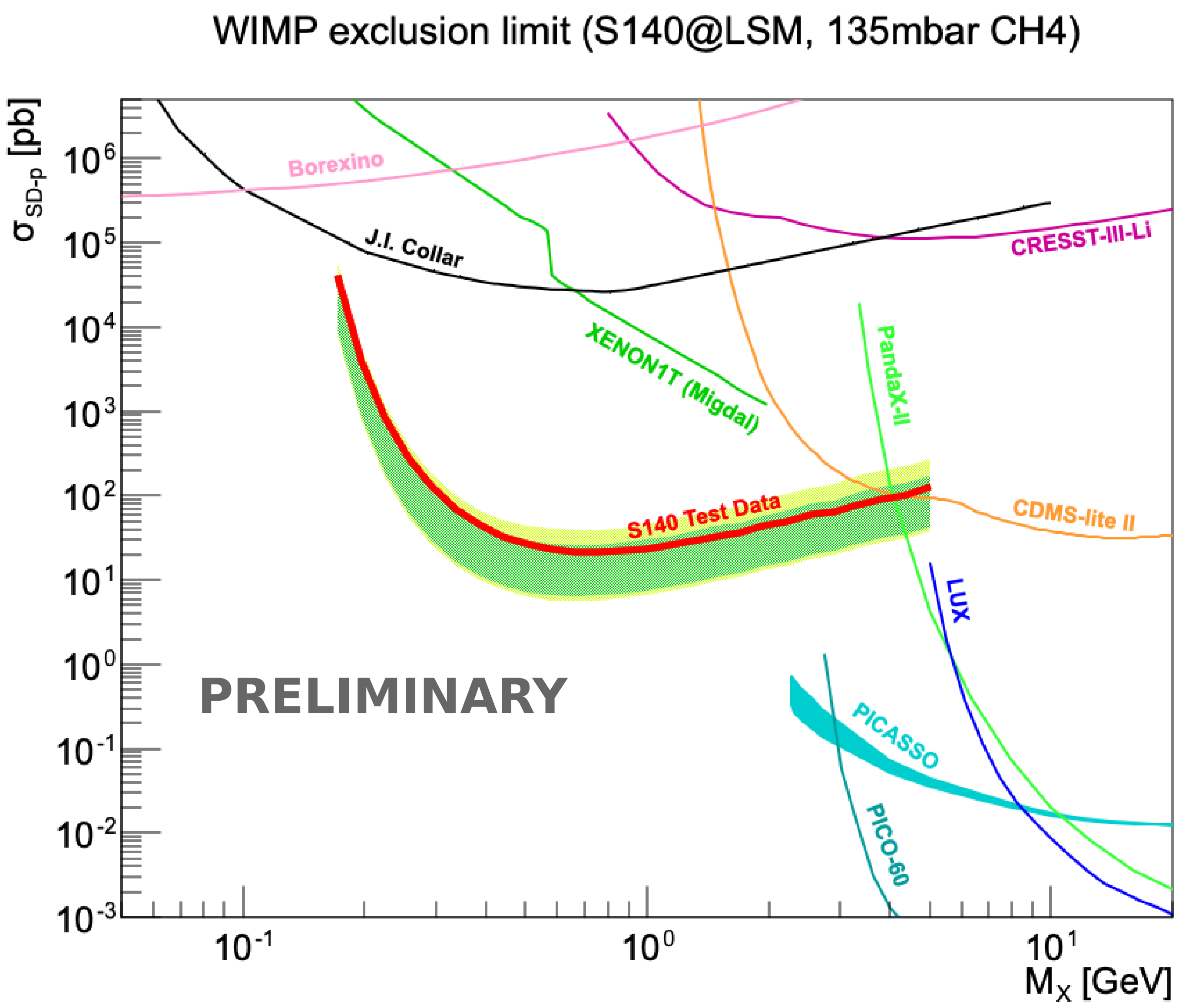
No significant WIMP signal is observed

LSM Physics results

[Results with test data (~0.12 kg.days)](#)

Profile likelihood ratio method used to calculate 90% exclusion limit on the existence of WIMPs

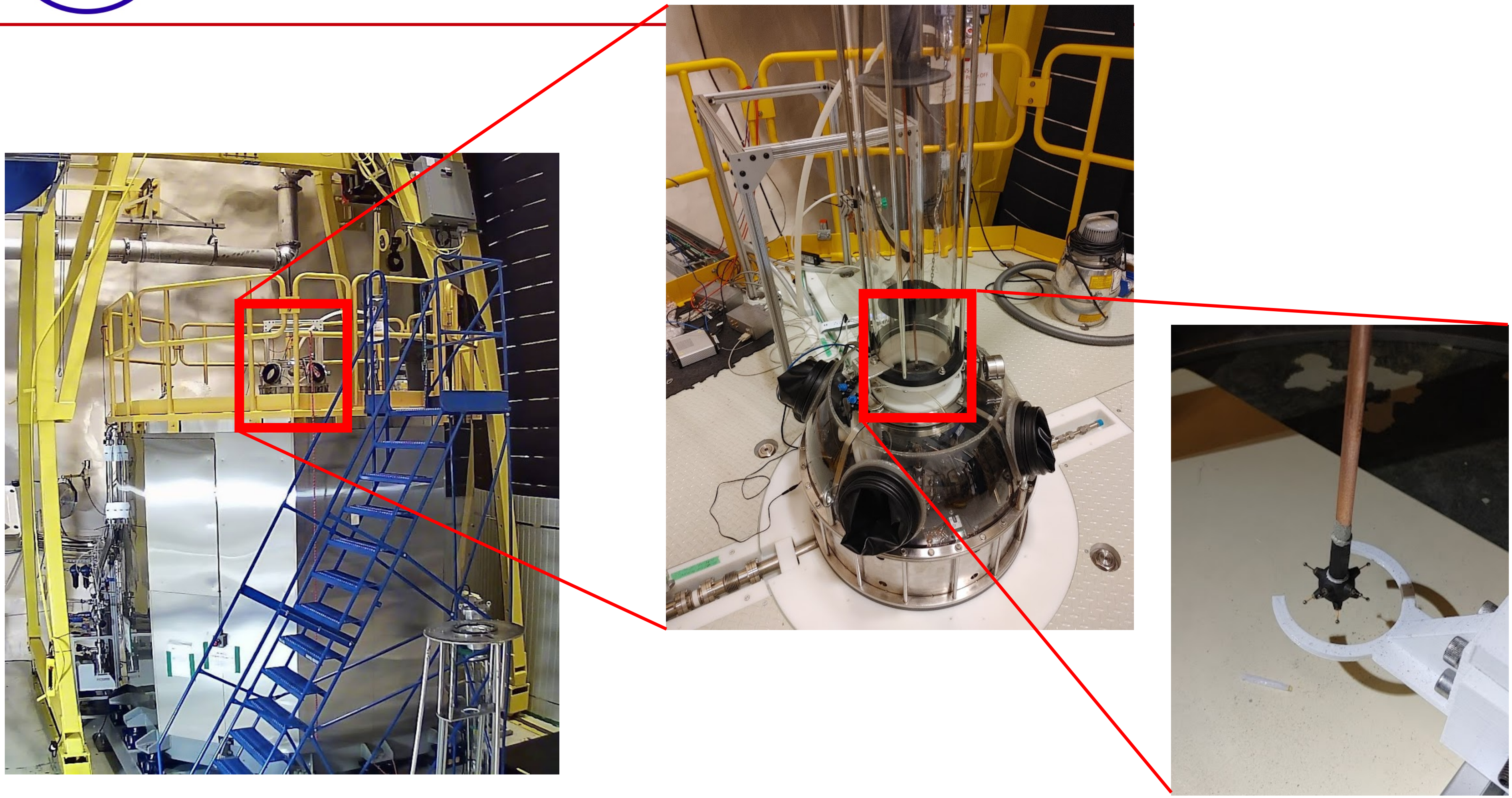
Full results with blind data expected within weeks - possibly best constraints on SD-p WIMP interactions below 1 GeV!



NEWS-G at SNOLAB

- Installation completed in summer 2021
- Long commissioning 2021-2022
  - leaks, electronics noise, …
- Improved sensor installation June 2022
  - lower electronics noise (better wire configuration)
  - extensive characterisation at Queen's
- First high gain data in August 2022
  - calibration laser missing
  - evaluation ongoing

Some Pictures



Plans 2022-23

- Complete and assess current physics run
- Fix laser issue
- Upgrade for use of pure methane
- Extra internal etching
  - if deemed necessary from BG data
- Physics runs in pure CH_4, He:CH_4, Ne:CH_4
- Quenching factor measurement
  - neutron scattering at TUNL and UdM
  - low neutron energy (<100keV) for sub-keV recoils
  - pure CH_4, He:CH_4, Ne:CH_4

Longer term

- Improve BG
  - need better understanding of existing BGs
  - fully electroformed copper sphere?
- More exotic gases
  - Odd neutrons for spin dependent (F, ^{19}Ne, ..?)
  - higher masses to characterise BG (depleted Ar?, Xe?)
- Larger size
  - DarkSphere project at Boulby
  - 3m diameter, water shield
  - very early stages...

Conclusion

- NEWS-G will soon publish new DM limits from data taken at LSM in 2019
- The detector is installed at SNOLAB and taking physics data will reduced calibration capability
- Good hope for high quality data in neon and methane this year
  - surface background might still be an issue
- Main challenge: Quenching Factor at low energy
  - plans of neutron scattering at TUNL and UdM
- Lots of ideas for the future...

Thank you for your attention!

SNOLAB

UNIVERSITY OF ALBERTA

Subatech

BOULBY UNDERGROUND LABORATORY

NEWS-G Collaboration

RMC CMR

LPSC Grenoble

cea Irfu

UNIVERSITY OF BIRMINGHAM

PER ARDUA AD ALTA

LSM

Laboratoire Souterrain de Modane

Special thanks to Daniel Durnford

Queen's UNIVERSITY

ARISTOTLE UNIVERSITY OF THESSALONIKI

Pacific Northwest NATIONAL LABORATORY

Thank you for your attention!

NEWS-G Collaboration

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