Measurement of Detector Properties in a Spherical Proportional Counter

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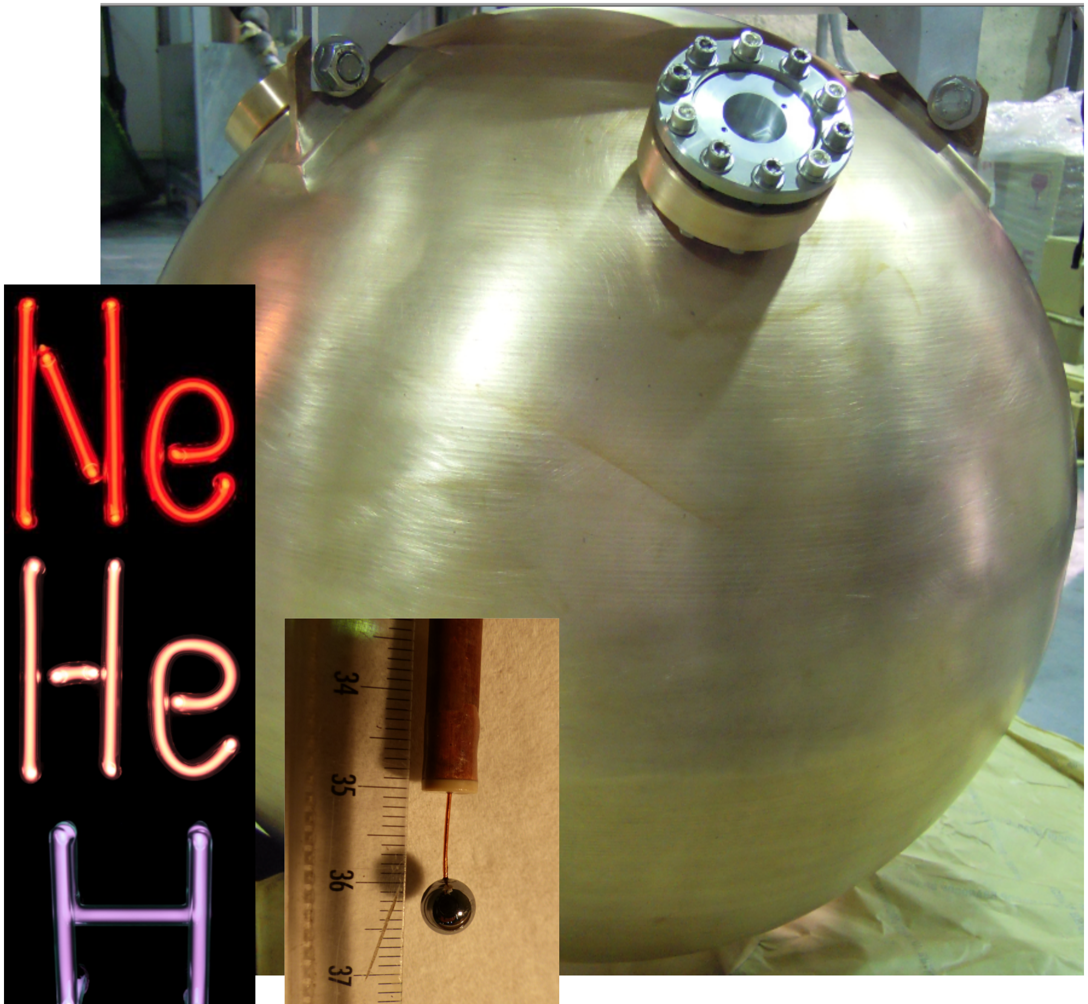
On behalf of the NEWS-G Collaboration

December 15th 2022

Outline

- SPCs and NEWS-G
- Calibration tools
- Measured detector properties

Spherical Proportional Counters (SPCs)



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

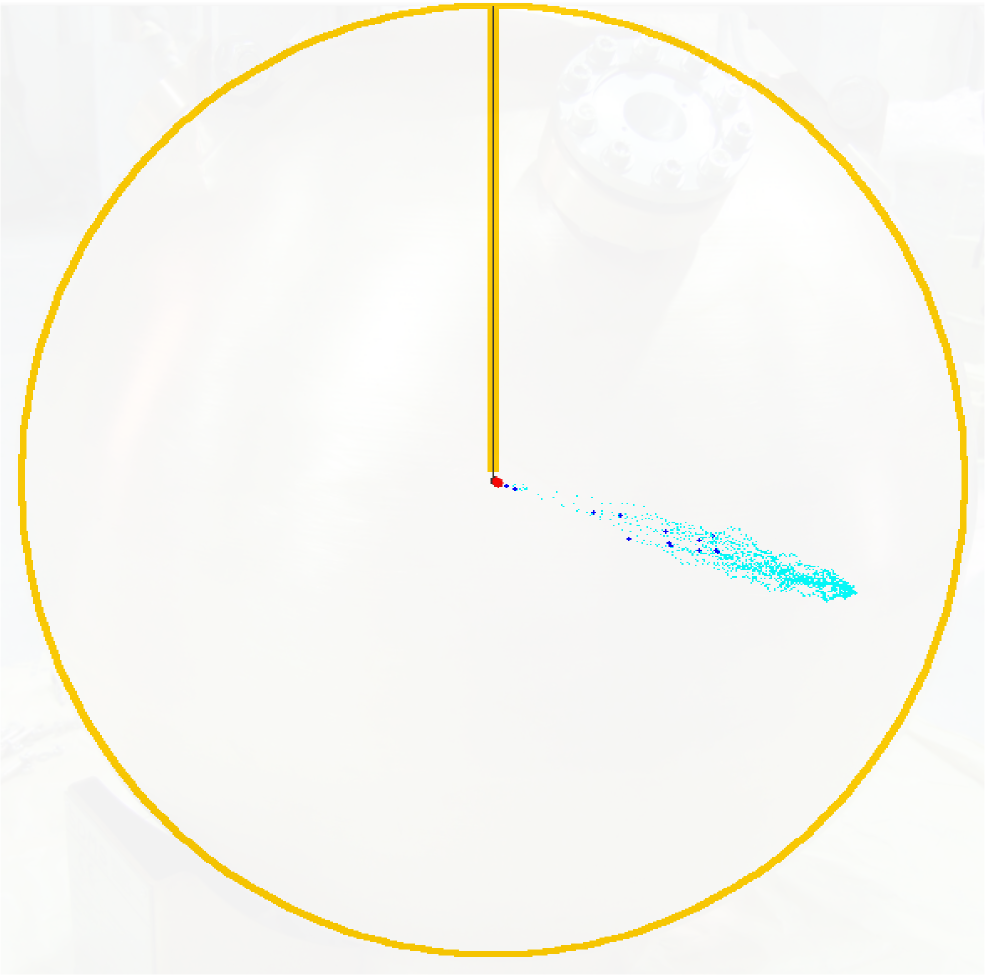
Low-A target atoms increases sensitivity to low-mass WIMPs

Easily exchanged target gas allows BG characterisation

Low capacitance and high gain provide excellent signal/noise

Single ionization detection threshold!

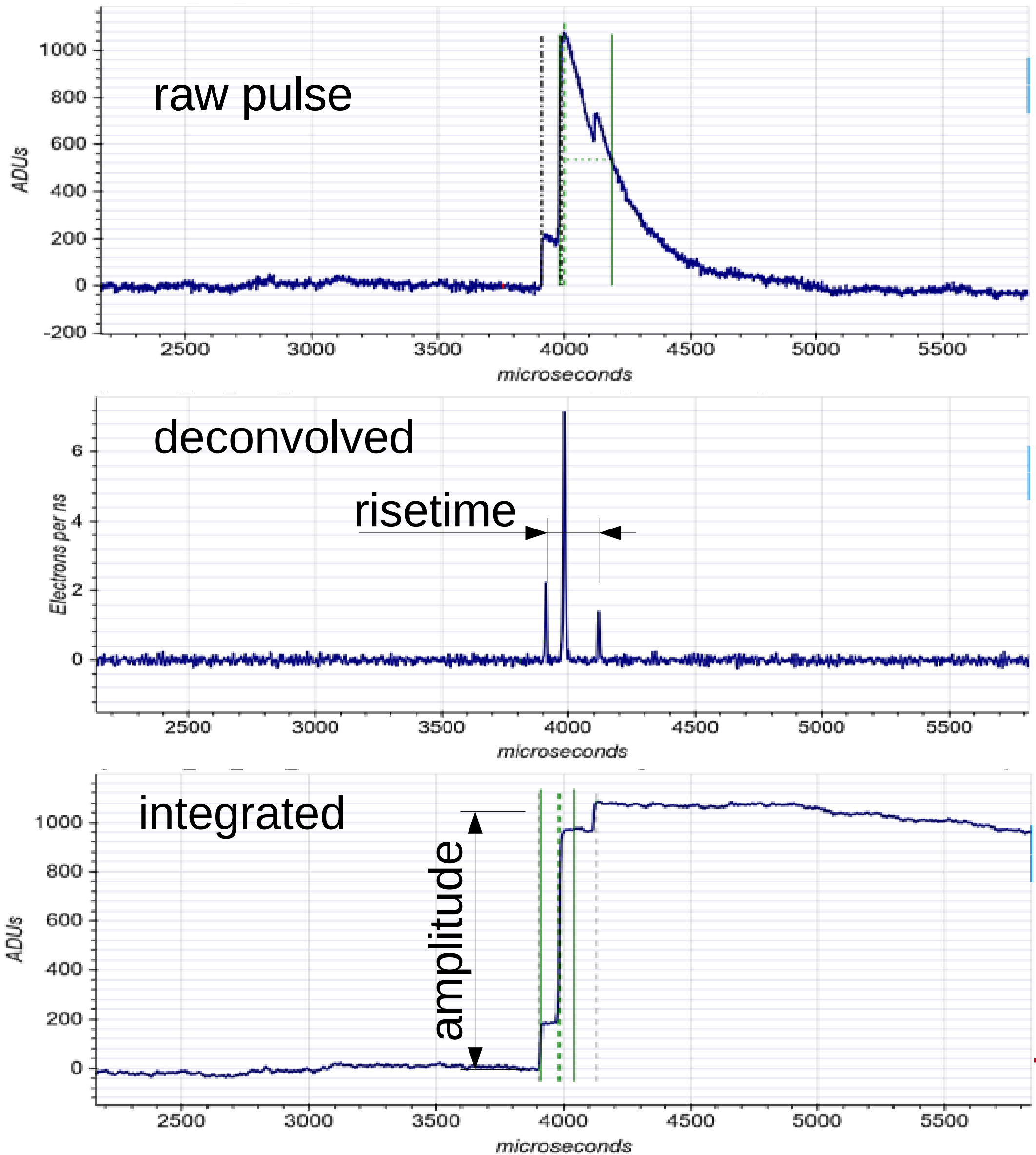
Principle of Operation



- *Primary ionisation*:
  - nuclear recoils, point-like
- *Drift*:
  - E ∝V/r^2
  - r calculated "globally"
- *Avalanche*:
  - E ∝V/r^2
  - r calculated "locally"
- *Signal from positive ion drift*
  - time response related to field
- *Signal readout*:
  - charge amplifier
  - digitizer

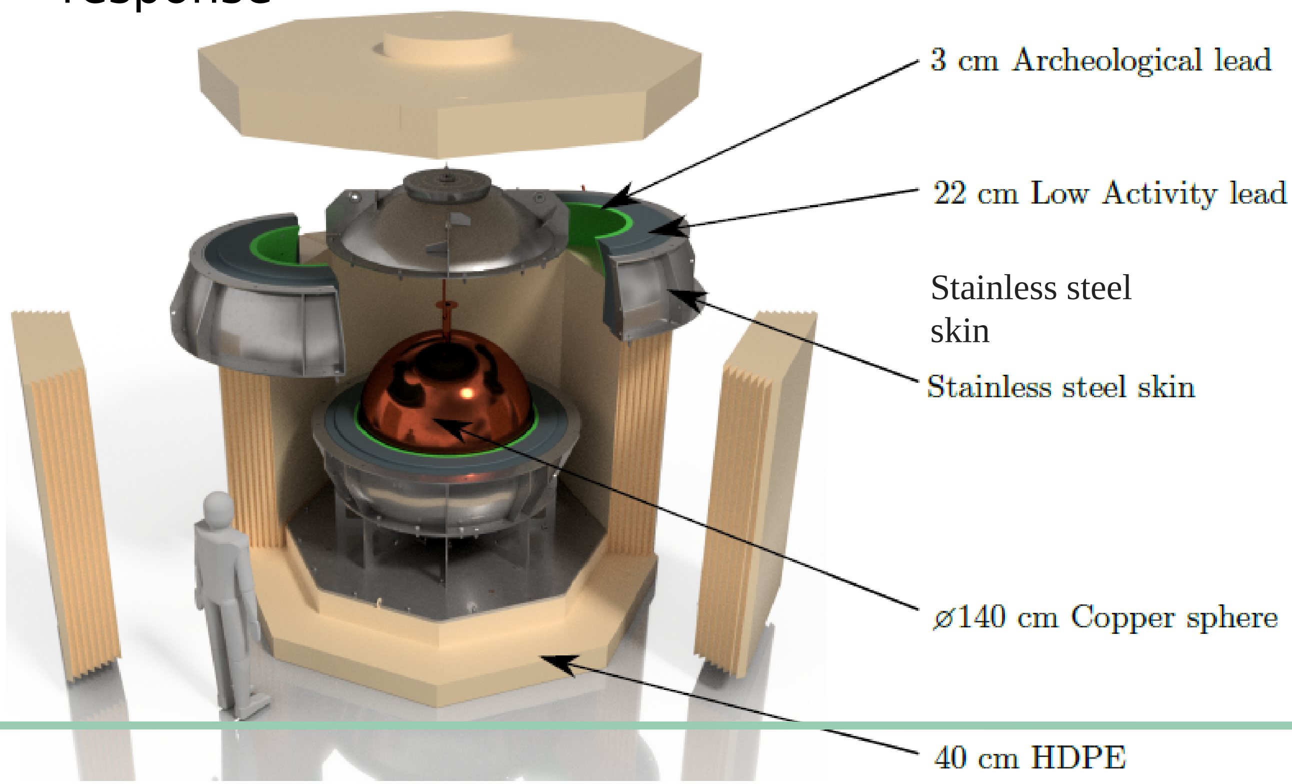
Signal processing

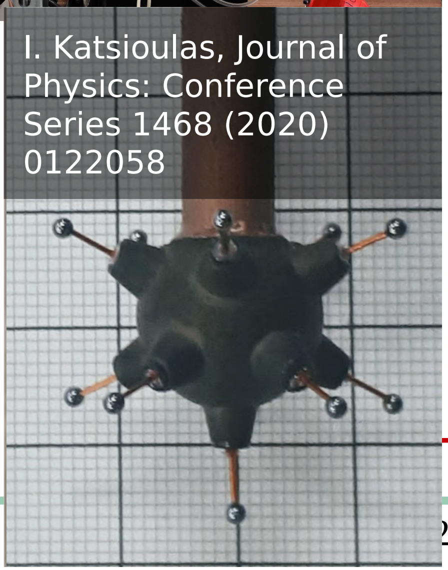
- Double deconvolution
  - amplifier response
  - ion drift
- Measurements
  - amplitude → Energy
  - risetime → diffusion/space distribution
  - electron counting (possible if high diffusion)



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 improved field more isotropic response





I. Katsioulas, Journal of Physics: Conference Series 1468 (2020) 0122058

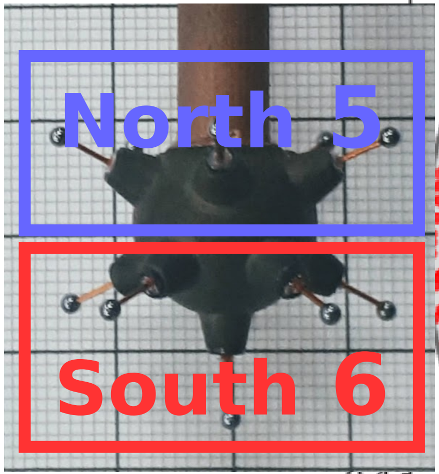
Sensor readout

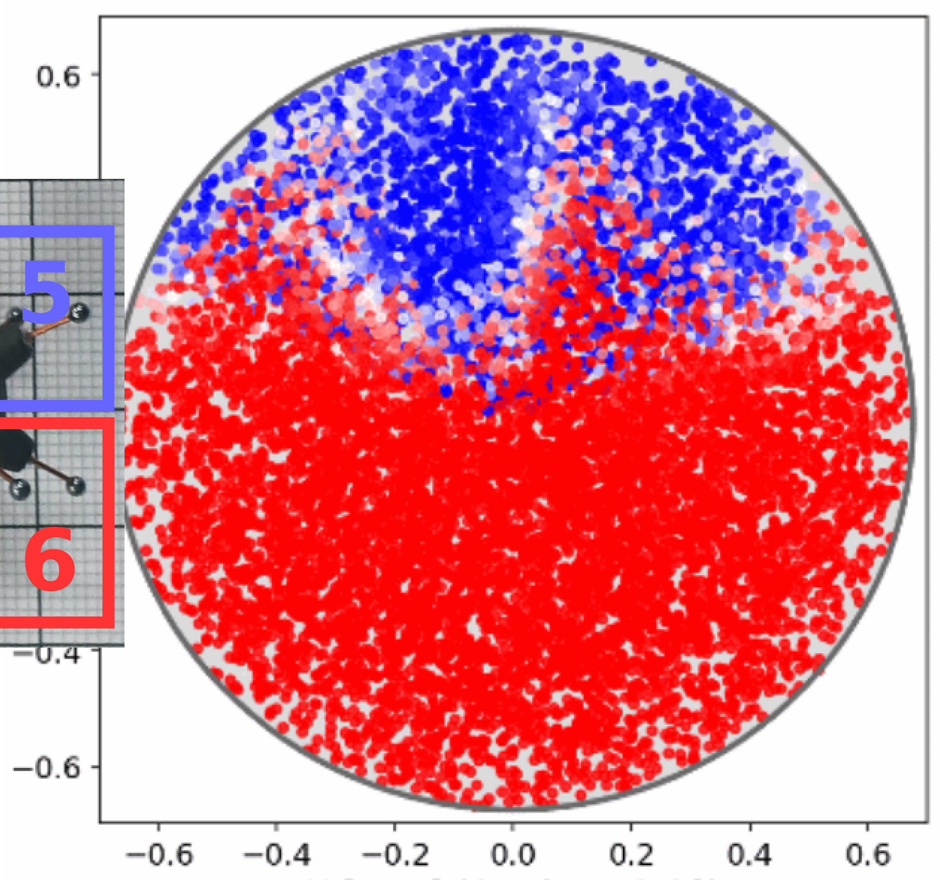
The 11-anode sensor is read out in two channels (north and south)

11-anode “achinos” structure allows better drift field at large radius, with similar gain (high field near anode)

The 11 anodes are bundled into 2 channels:
- “North” (rod side)
- “South” (away side)

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



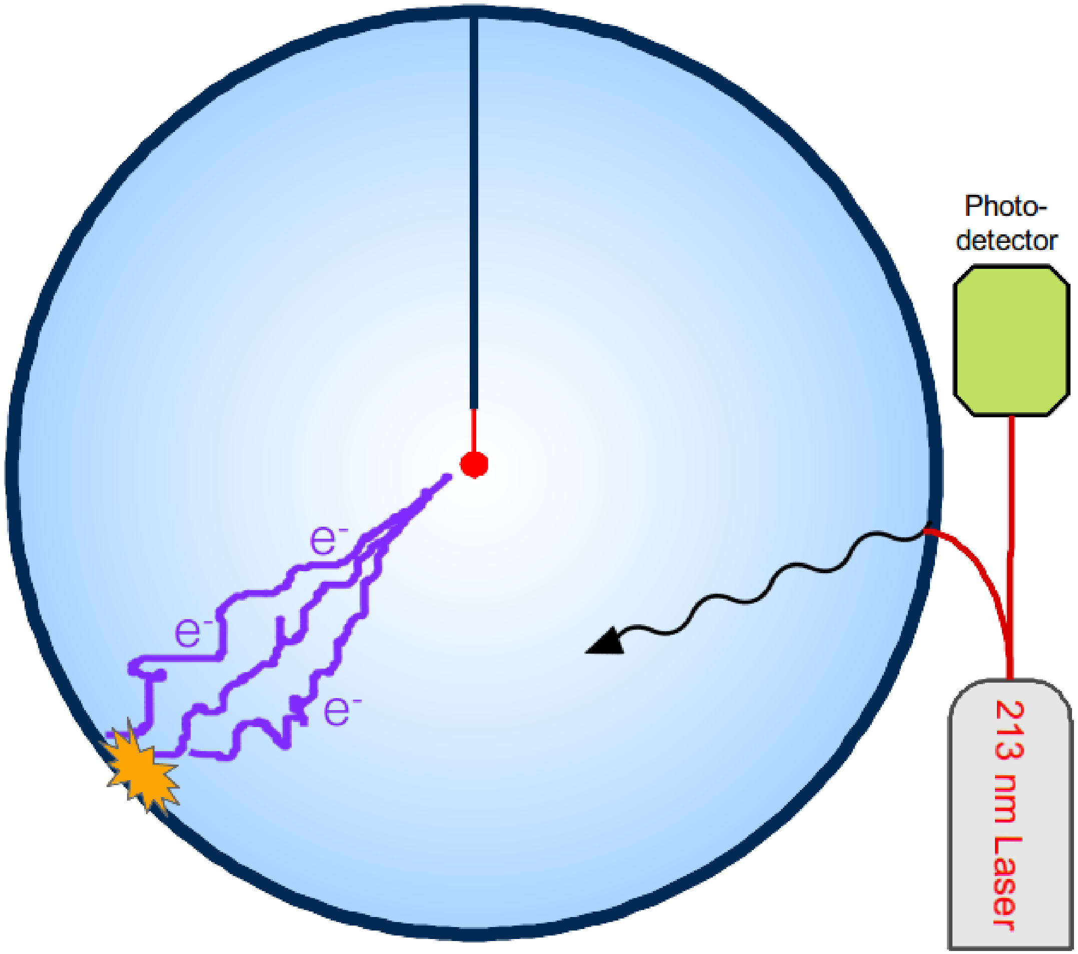


Calibration tools

Radioactive sources

- Fe55
  - 5.9keV peak
  - source windows on prototype spheres
  - not possible on high purity copper sphere
- Ar37
  - 2.8keV and 270eV
  - gaseous, uniformly distributed
  - cannot be removed/ cannot be used during rare event search
- AmBe
  - MeV neutrons
  - elastic nuclear recoils (same as WIMP)
  - possible tagging with liquid scintillator

UV laser calibration



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

Laser-induced calibration events are tagged with a photodiode
Does not create BG (only minor dead time)

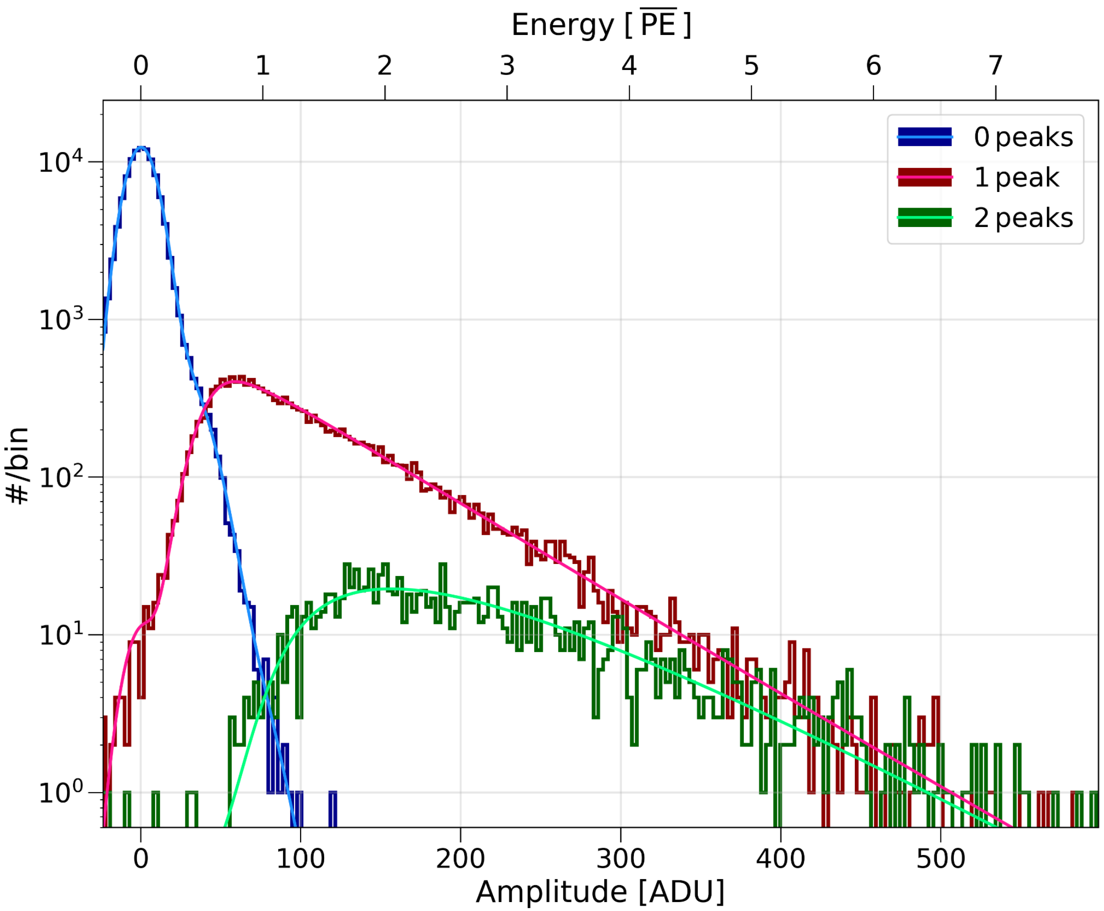
Continuous operation during physics runs allows for monitoring of the detector response, changes in detector gain over time

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

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

Various results

Single electron spectrum



Tagged events associated to laser

Low intensity to get only a few electrons

Single photon ionisation allows to assume Poisson statistics

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

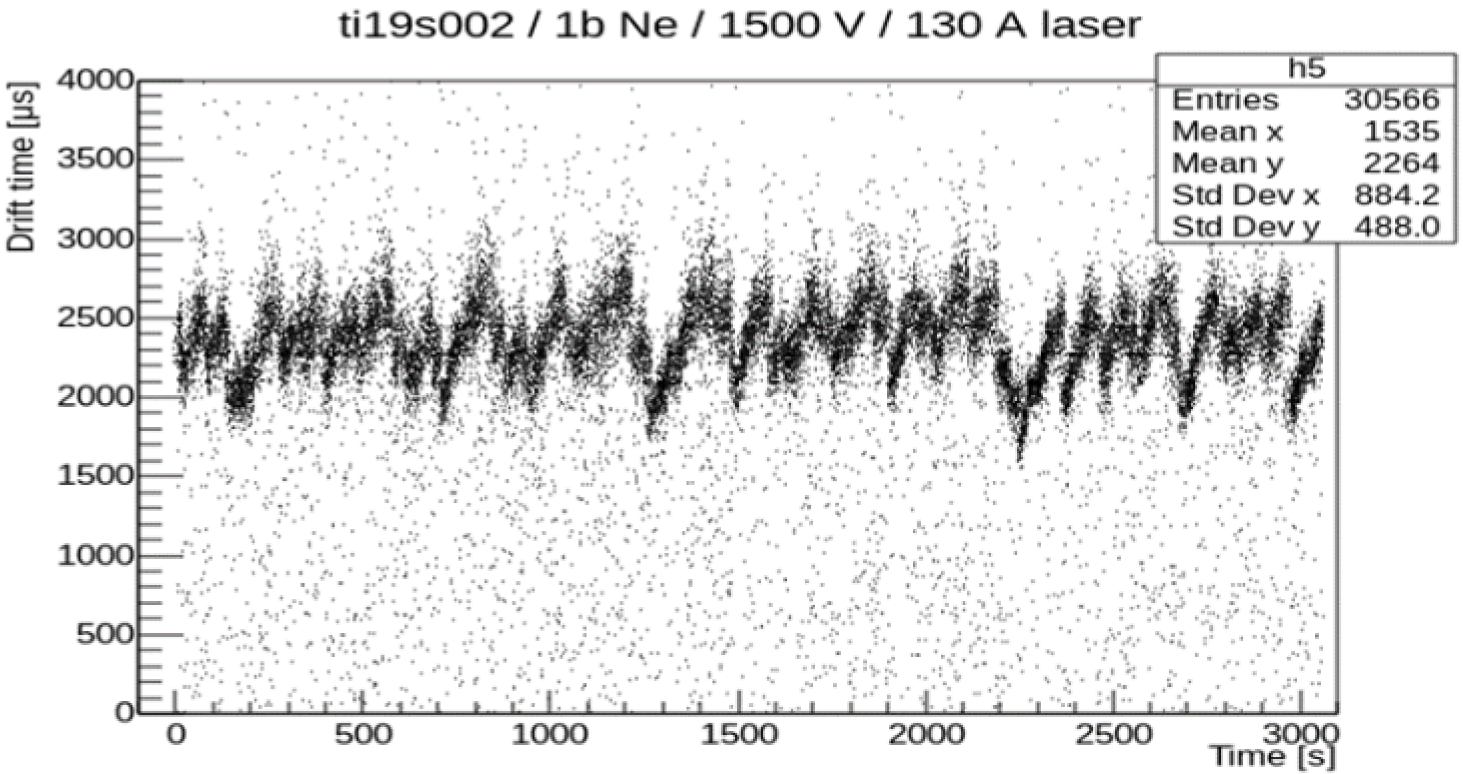
Also used to quantify the performance of the peak-finding algorithm and trigger efficiency

Combined with 37Ar source → mean ionisation W

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

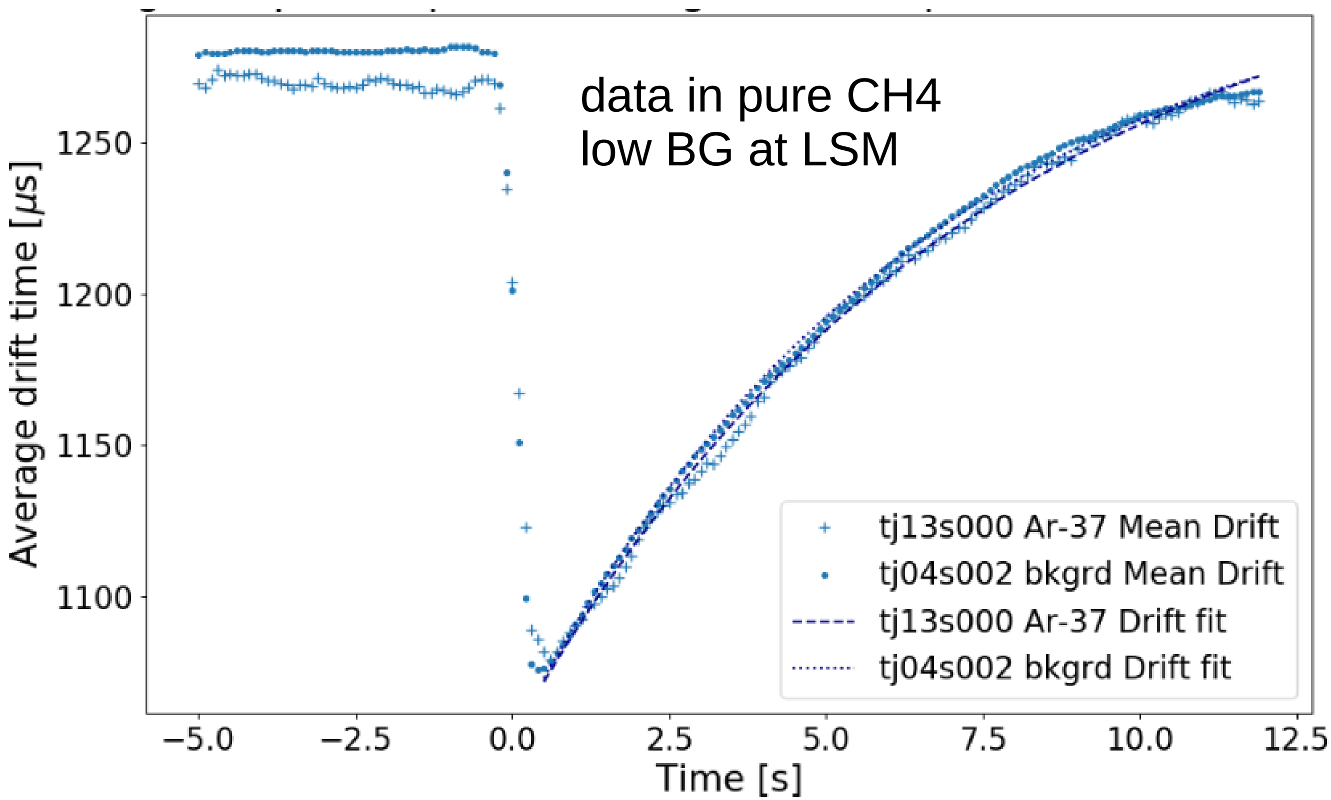
Drift velocity

- Laser tagging allows to easily monitor the total drift time in the SPC
  - The drift time fluctuates due to variations of temperature and pressure, and the positive ions density in the sphere



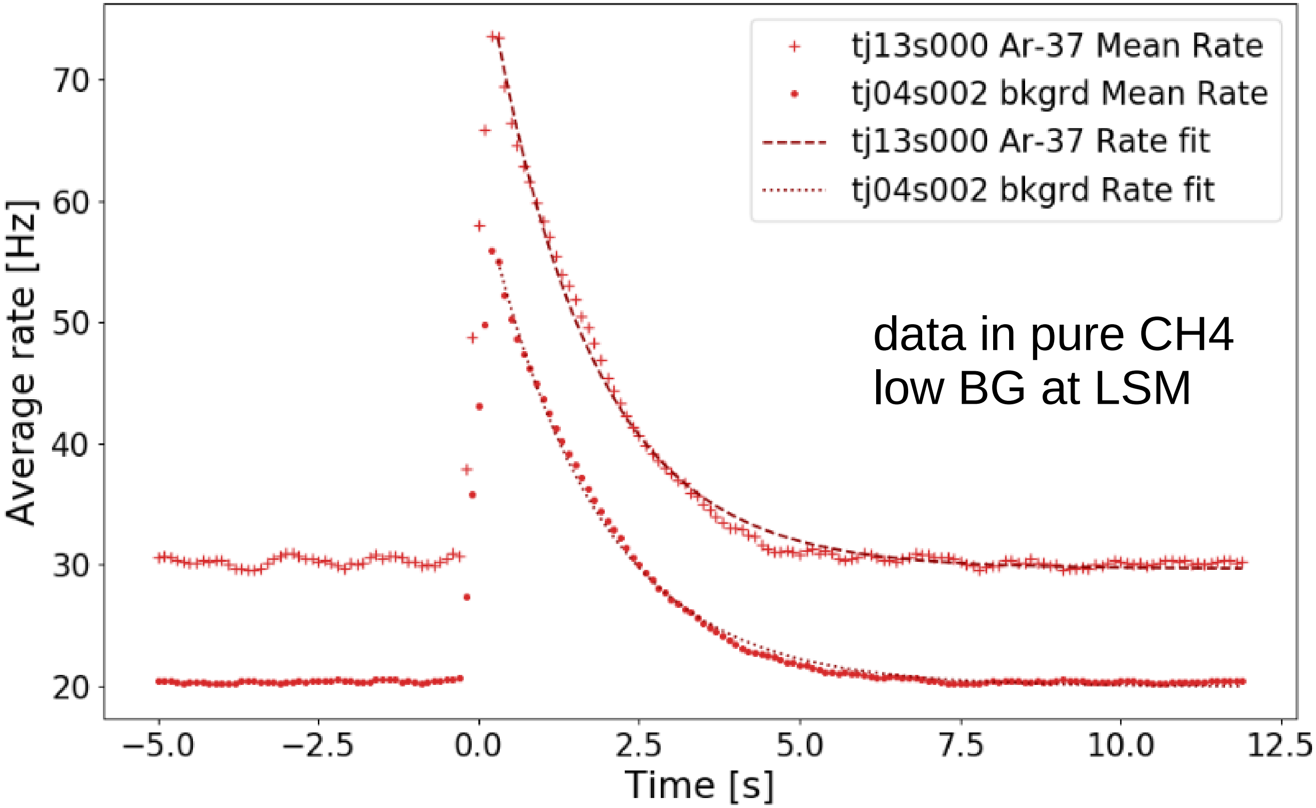
Drift velocity vs space charge

- The drift time is strongly correlated to the time since the last alpha event (high energy)



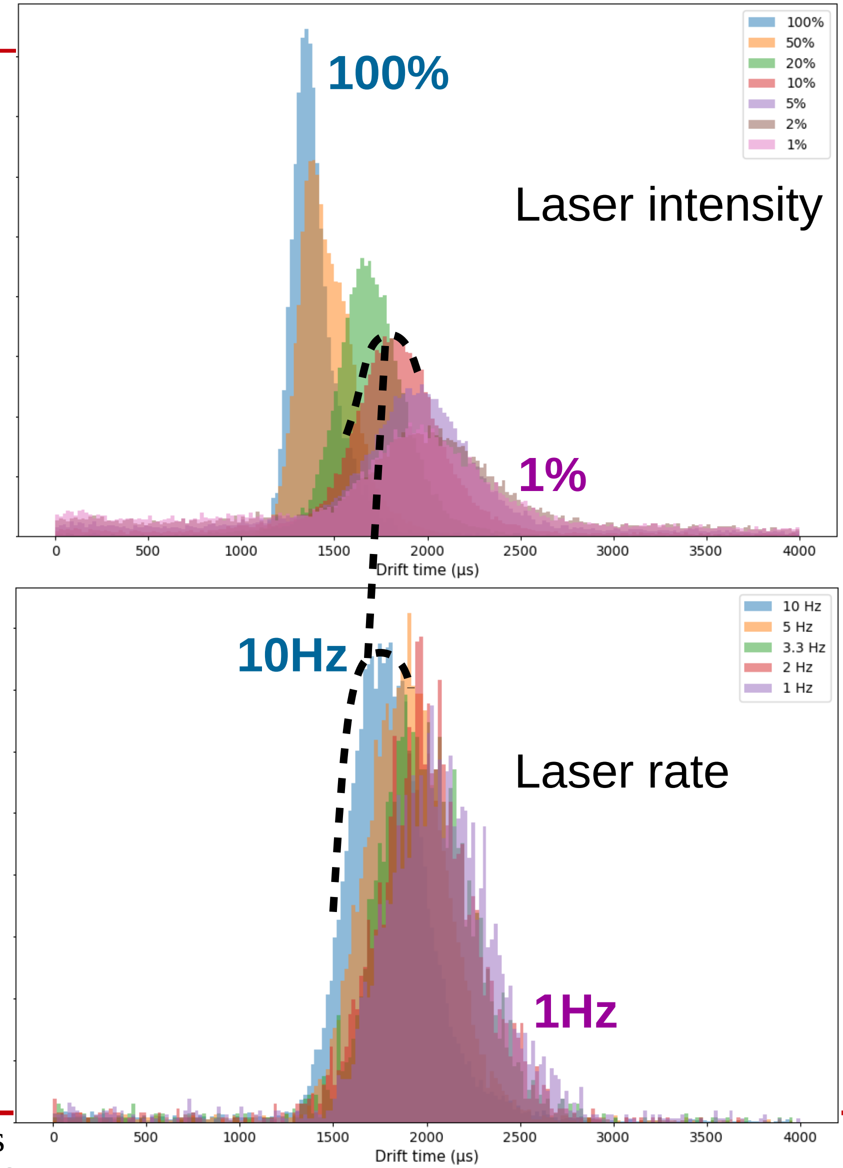
“Alpha tail”

- Alpha events are also followed by a trail of low amplitude (~1electron) events



Small charge dependence

- Drift velocity sensitive to small space charge
- Effect visible with changing laser intensity or repetition rate
- Number of primary electrons O(1-100)



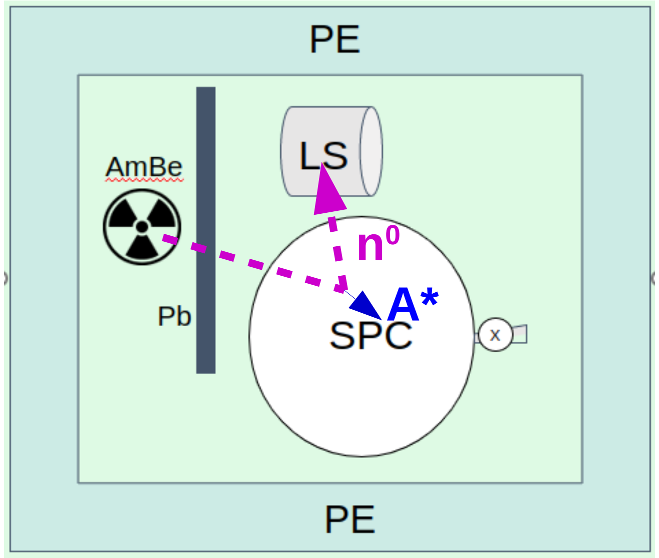
Nuclear recoils from neutrons

- Nuclear recoils are important calibration
  - WIMP like signal
  - different ionisation yield from gamma & electrons

    critical calibration for WIMP search
  - point-like, even at higher energies
- Hard to calibrate
  - neutron scattering
  - low cross-section
  - wide energy distributions
  - tagging difficult at low energy

Table top neutron scattering experiment

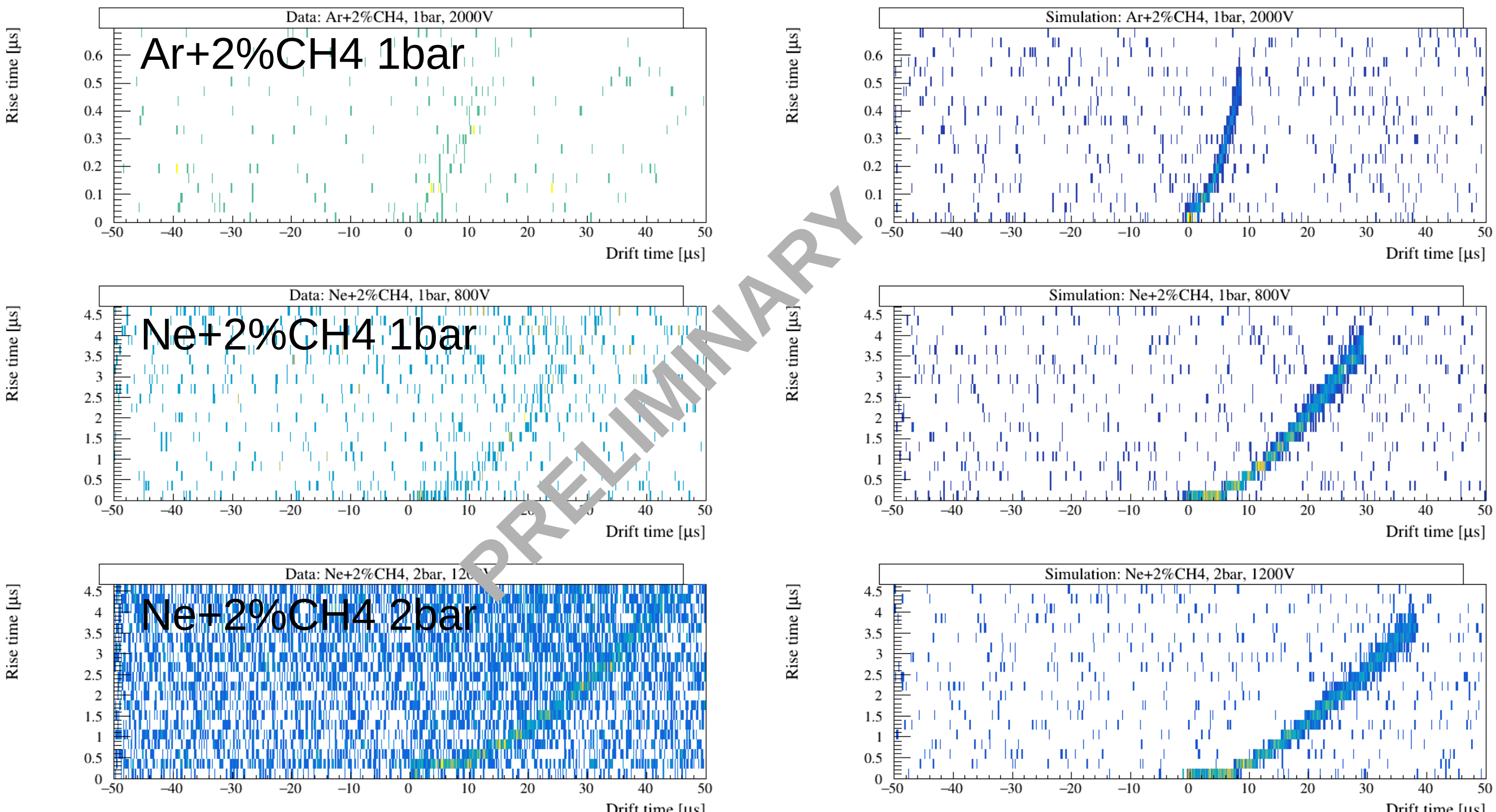
- AmBe neutron source O(MeV)
- Liquid scintillator neutron detector
  - PSD to select neutrons
  - trigger from neutron signal
- Read SPC signal with prompt neutron trigger
- Compare with simple simulation of SPC
  - ideal field (V/r^2)
  - drift and diffusion from Magboltz
  - amplifier + digitizer response



Results

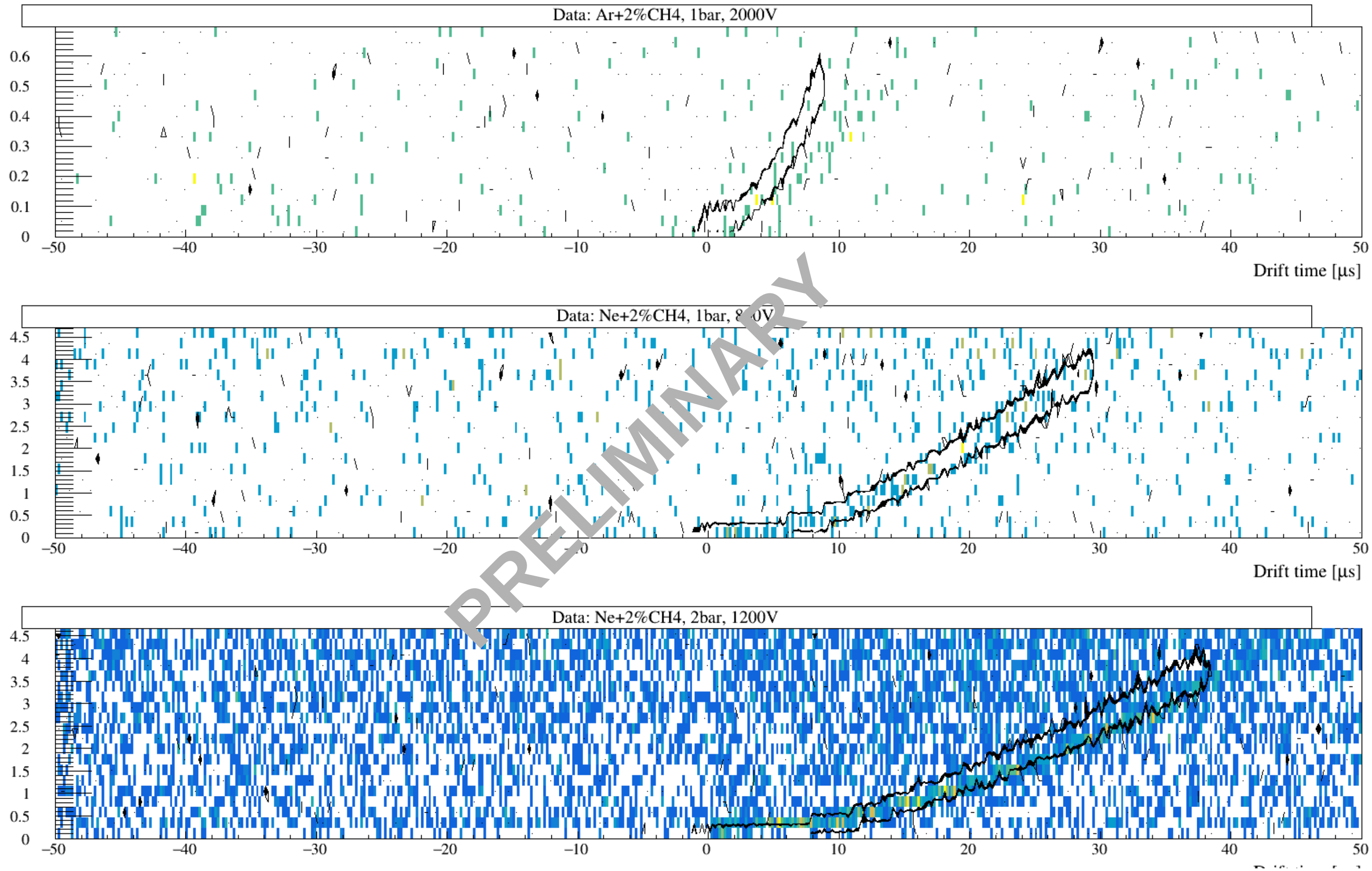
DATA SIMULATION

Risetime [µs] ~ Diffusion



T(sphere)-T(scintillator) [µs] = drift time

Results



Data: Ar+2%CH4, 1bar, 2000V
Drift time [µs]
Data: Ne+2%CH4, 1bar, 8?0V
Drift time [µs]
Data: Ne+2%CH4, 2bar, 1200V
PRELIMINARY

Neutron scattering

- Excellent agreement with simulation from very simple detector
- Preliminary test for beam experiments with monoenergetic neutron beams
- measurement of ionisation yield from nuclear recoil
  - Ne recoil in Ne:CH4 mixture down to ~300eV (done 2019, 250keV neutron beam at TUNL) *Phys.Rev.D 105 (2022) 5, 052004*
  - proton recoil in pure CH4 planned 2023 using 45keV neutron beam at UdeMontreal

Conclusion

- NEWS-G is operating an SPC at SNOLAB to search for light WIMPs
- Very simple detector, but careful characterisation is needed
- Combination of UV laser, X-ray sources allow monitoring and calibration in situ
- Extra experiments with smaller prototypes and various sources and accelerators give further information
- The detector is well described by simulations

Thank you for your attention

SNOLAB

UNIVERSITY OF ALBERTA

Subatech

BOULBY UNDERGROUND LABORATORY

NEWS-G Collaboration

RMC CMR

UNIVERSITY OF BIRMINGHAM

LPSC Grenoble

cea Irfu

LSM Laboratoire Souterrain de Modane

Queen's UNIVERSITY

ARISTOTLE UNIVERSITY OF THESSALONIKI

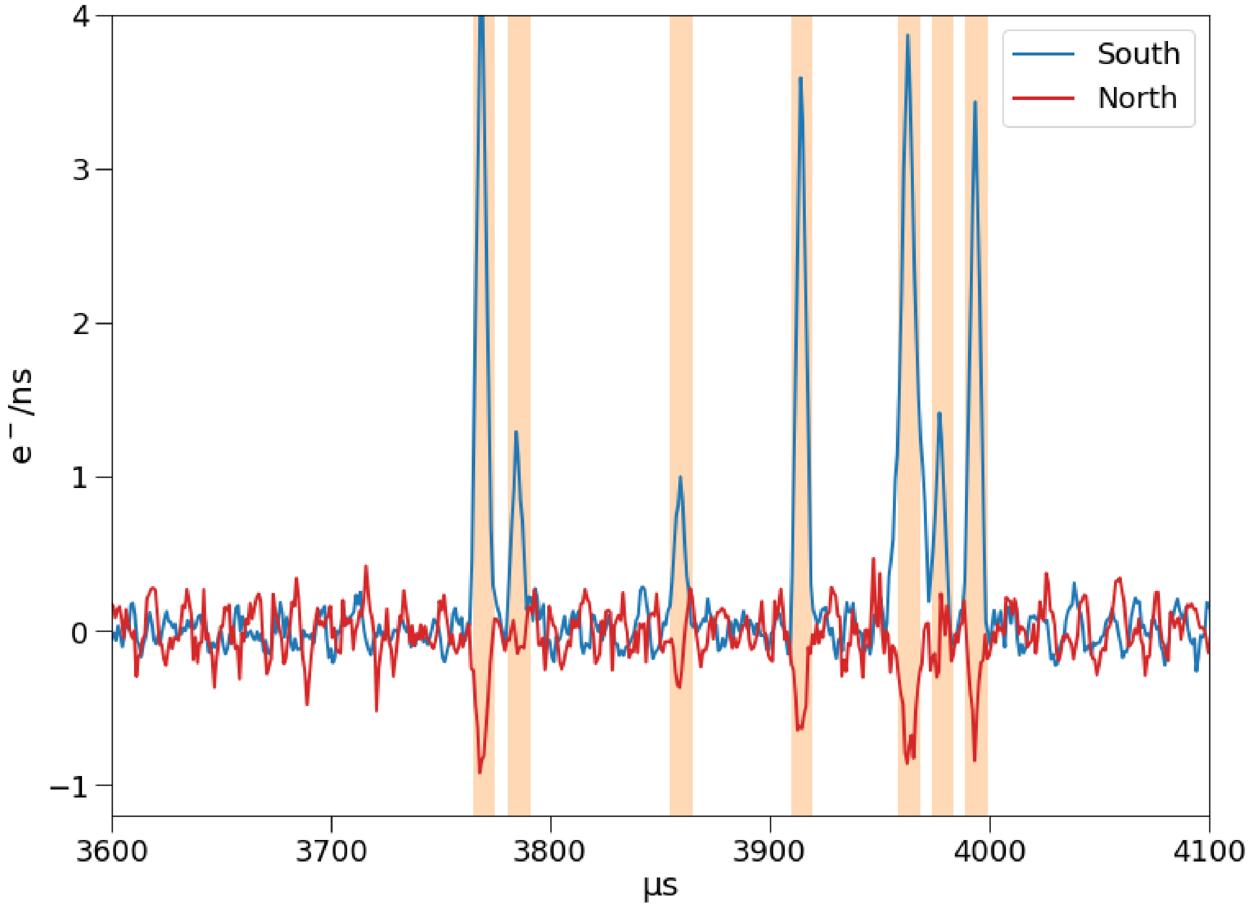
Pacific Northwest NATIONAL LABORATORY

Pulse shape

Pulses are processed with a double deconvolution for the amplifier response, and the ion drift

In the achinos, physical events induce mirror, smaller pulses in the opposite sensor channel with a characteristic scale

These negative pulses are induced by the ion movements and reproduced in simulations. They have a slightly different shape.

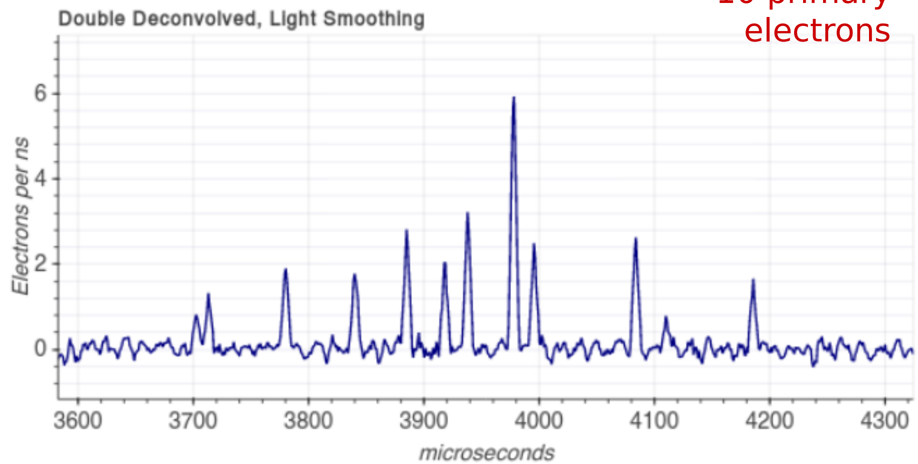


Electron peak finding

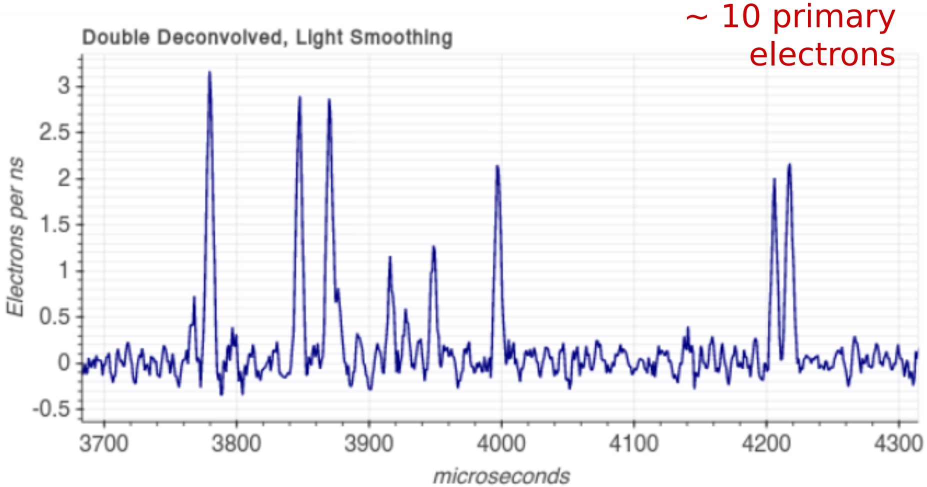
The large drift volume allows us to resolve individual primary electrons in time!

UV Laser events from new 140cm SPC:

~ 10 primary electrons

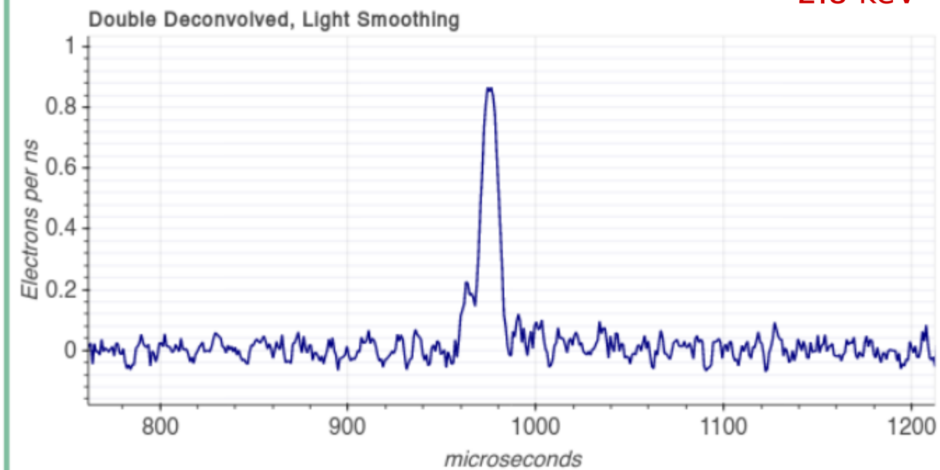


~ 10 primary electrons

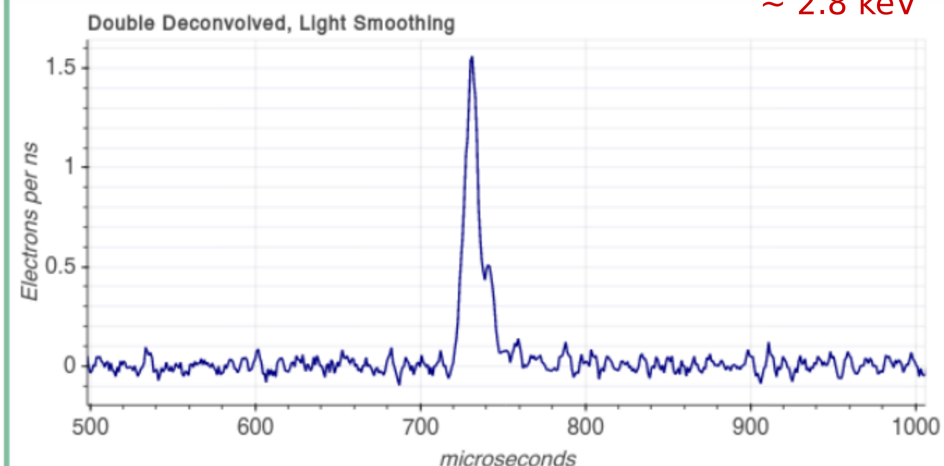


^{37}Ar events from 30cm prototype SPC:

~ 2.8 keV



~ 2.8 keV

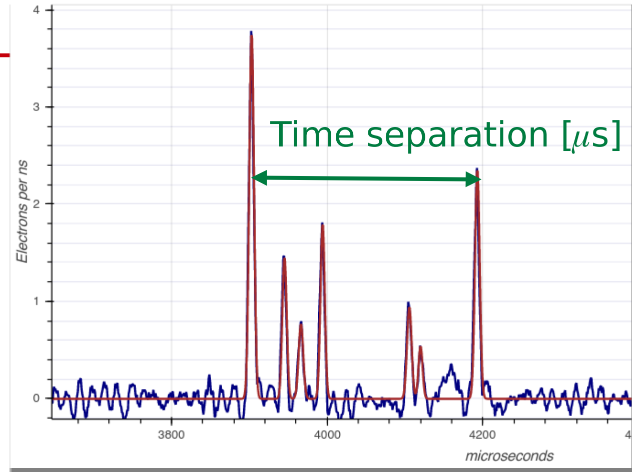


Time separation

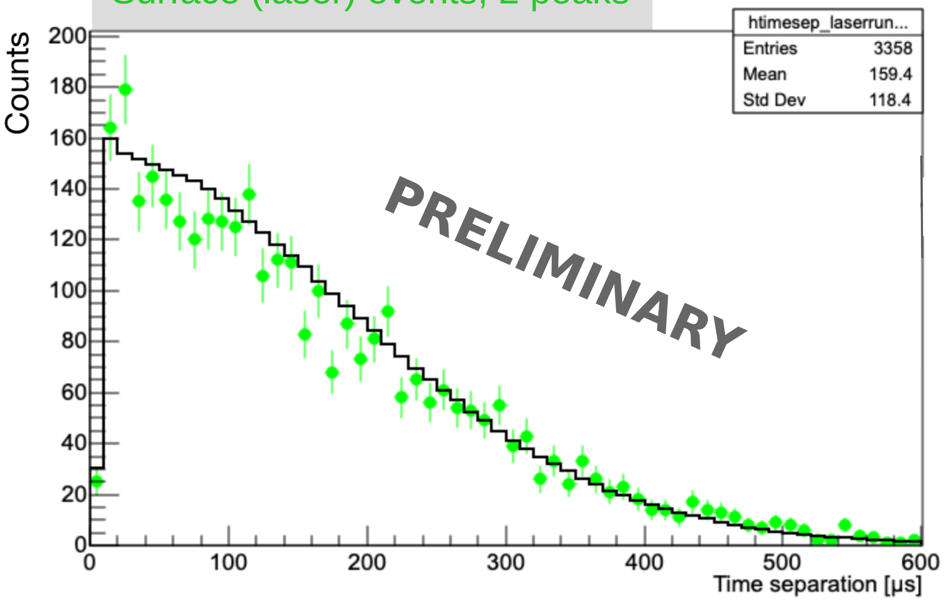
Time separation between the first and last peak is used as the primary analysis variable

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

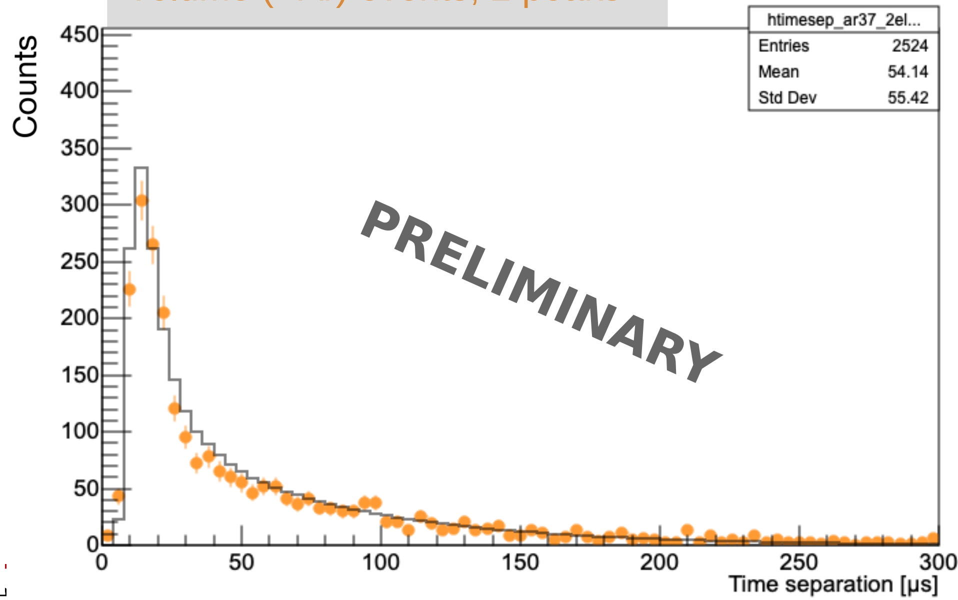
Calibrated with laser (surface) and ^{37}Ar (volume) data



Surface (laser) events, 2 peaks



Volume (^{37}Ar) events, 2 peaks

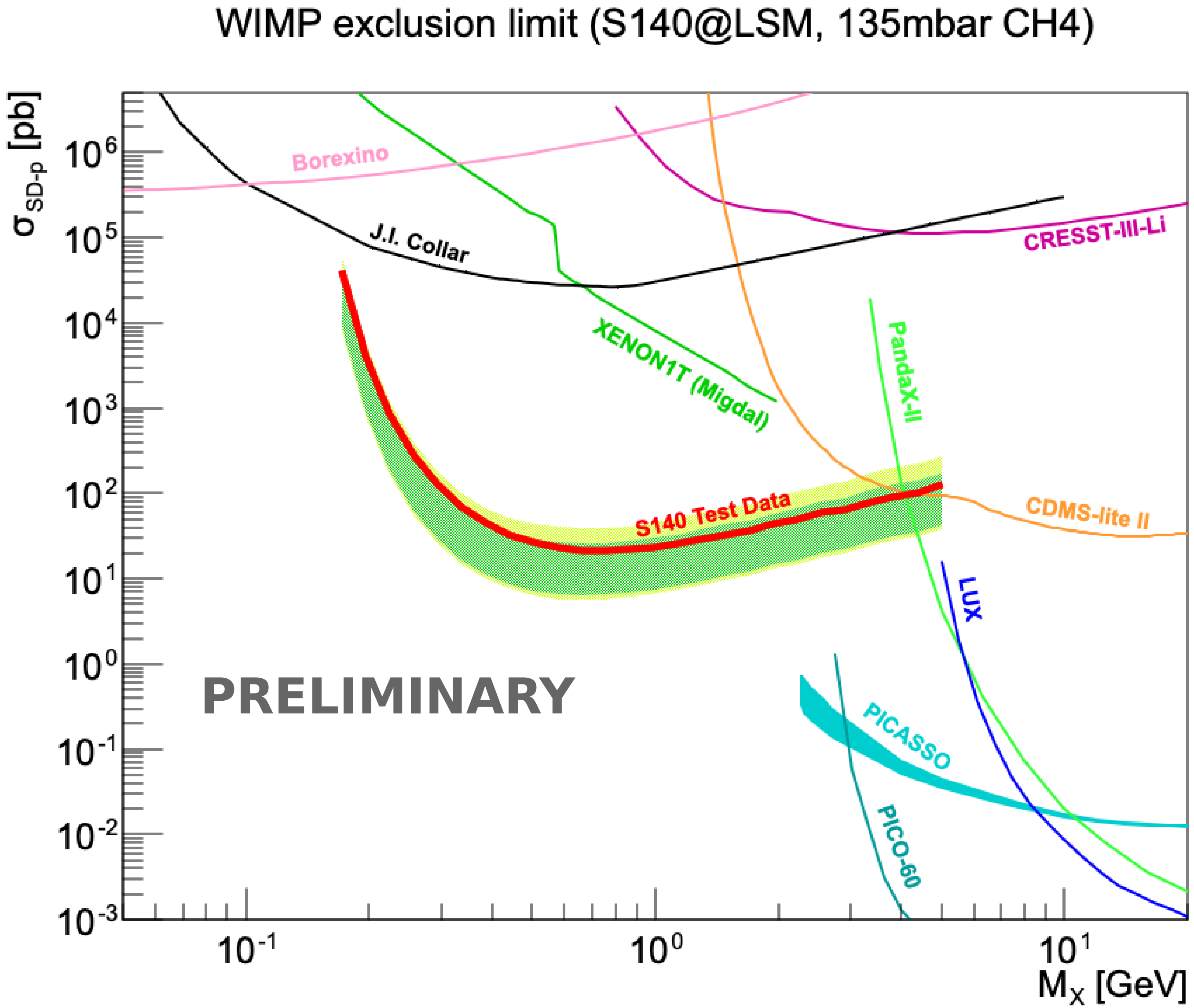


LSM Physics results

[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!

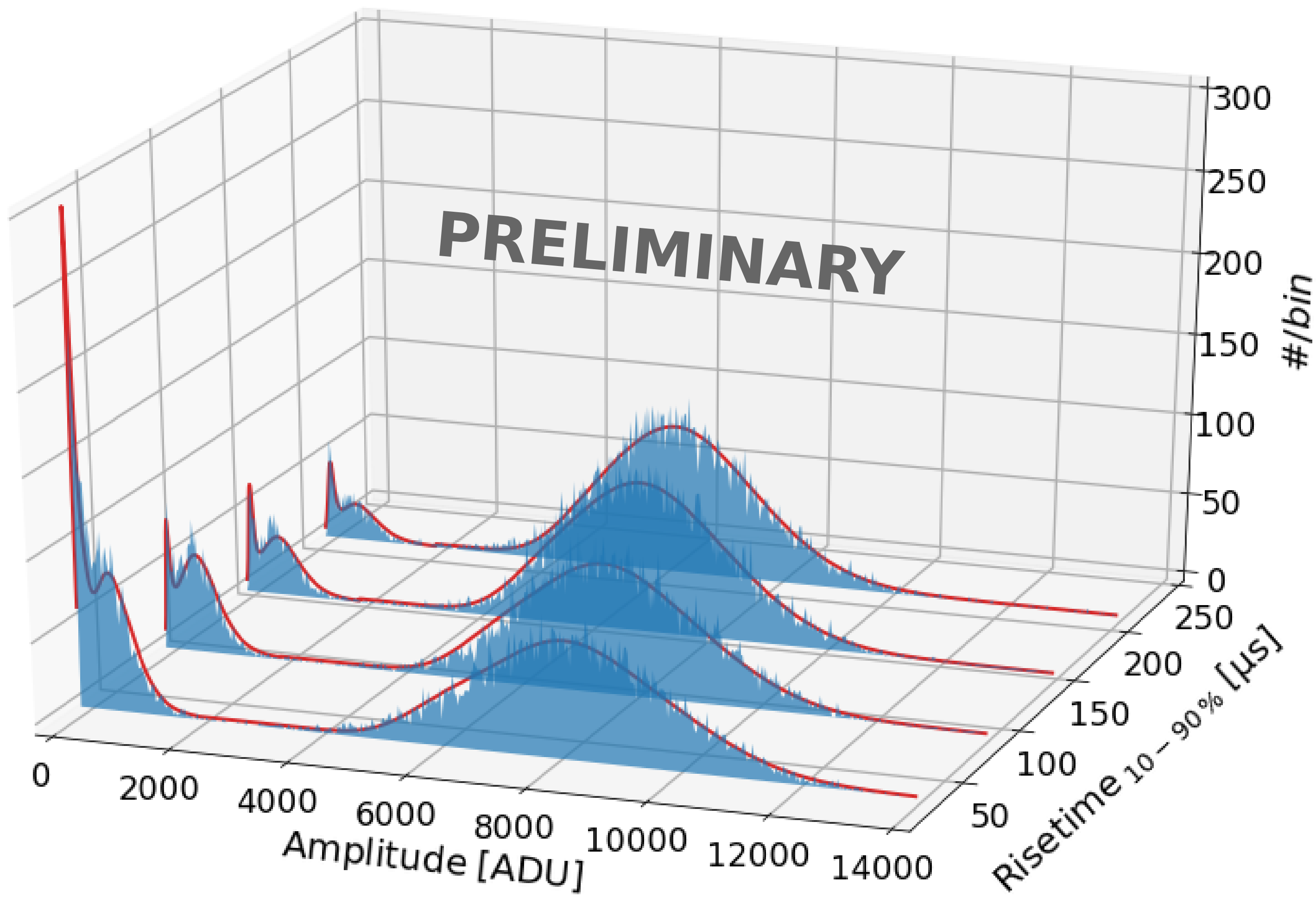


Detector response

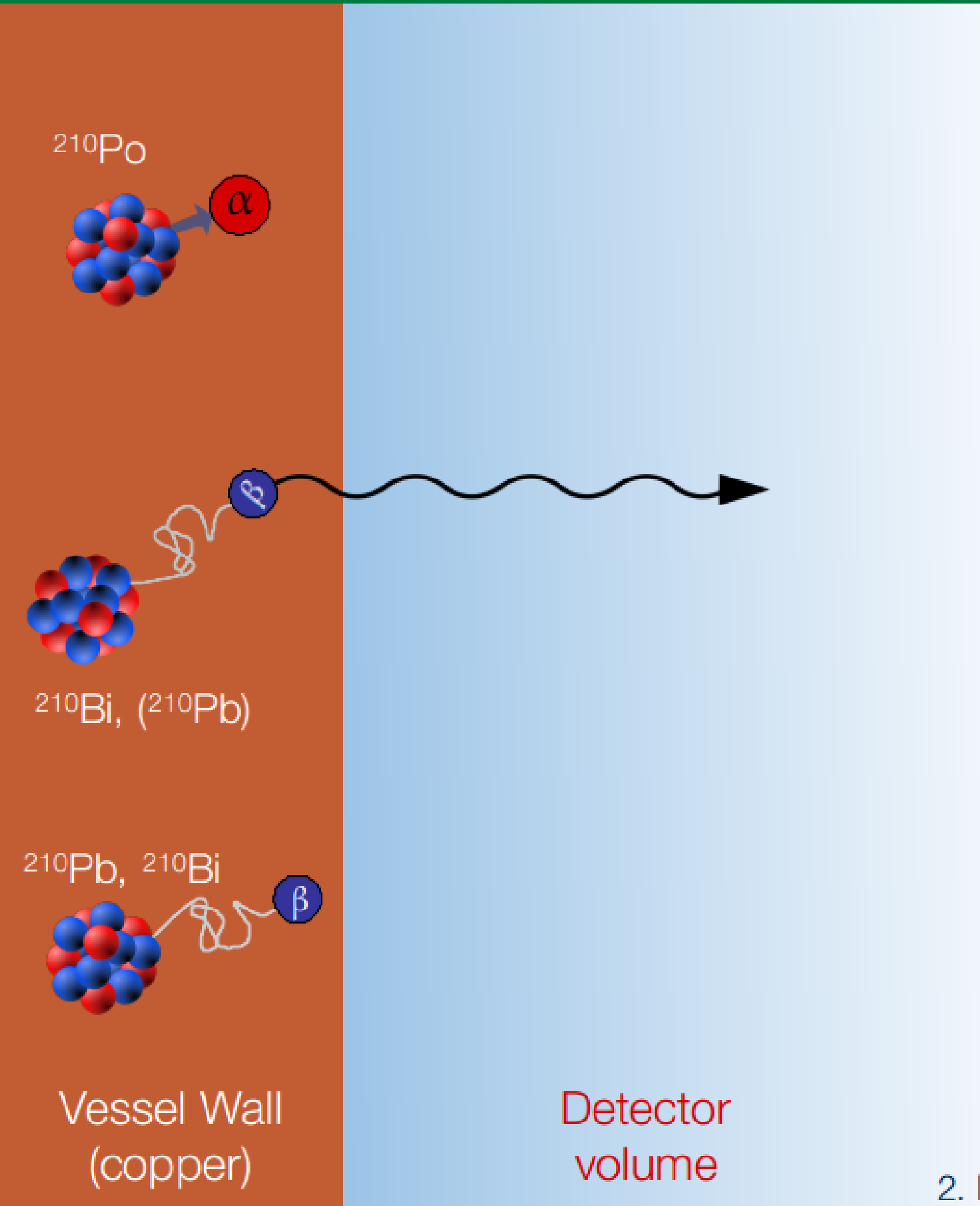
^{37}Ar gas was injected in the SPC after the physics campaign, producing (almost) monoenergetic lines at 200 ev, 270 eV, and 2.8 keV

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

- 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



The SNOGLOBE detector



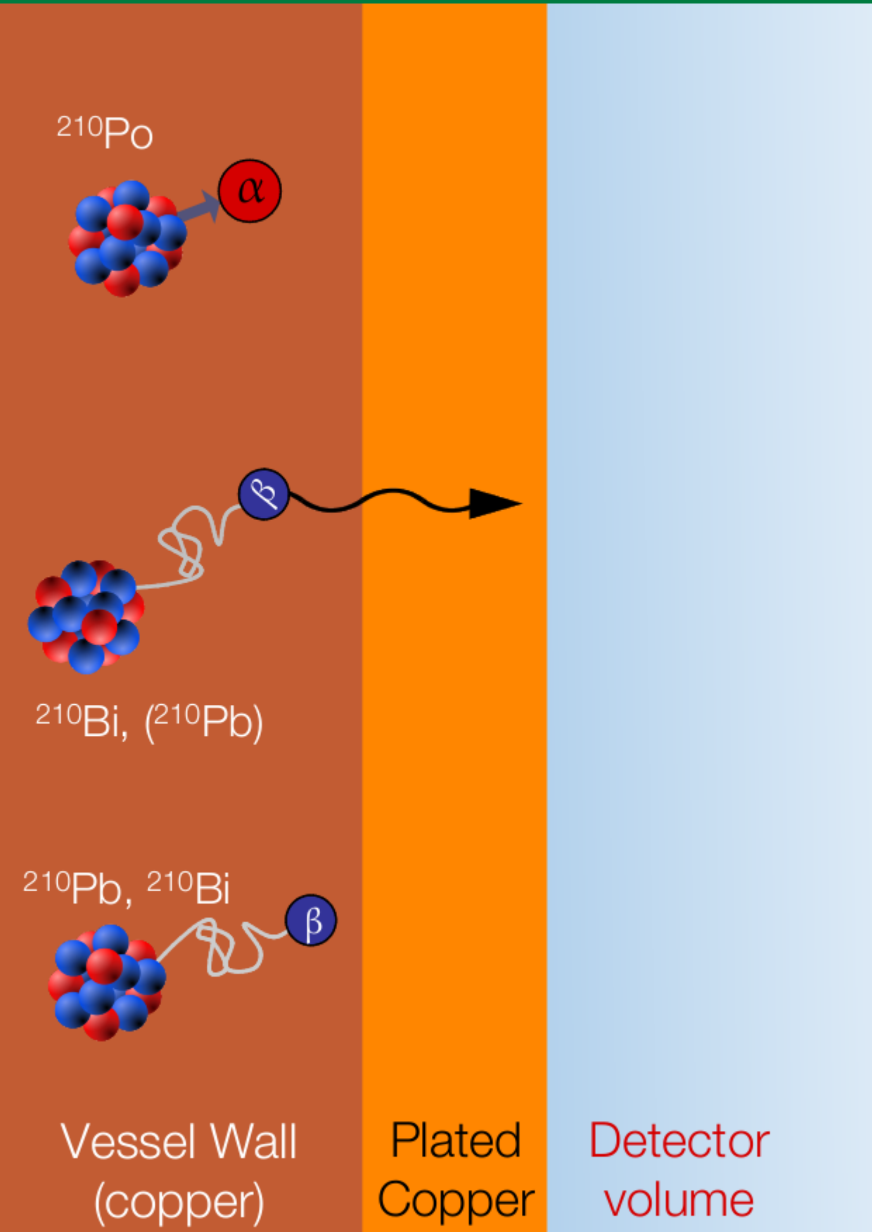
^{210}Pb can be incorporated into copper during the manufacturing process

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)

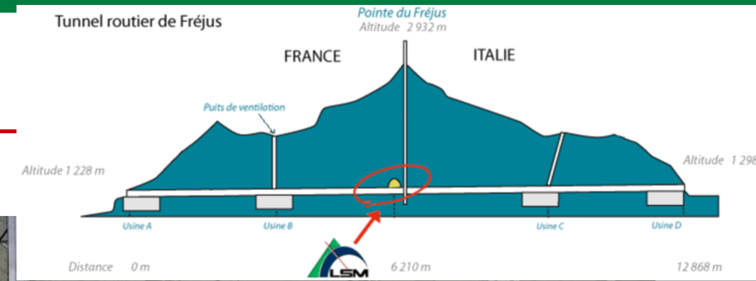
The SNOGLOBE detector



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

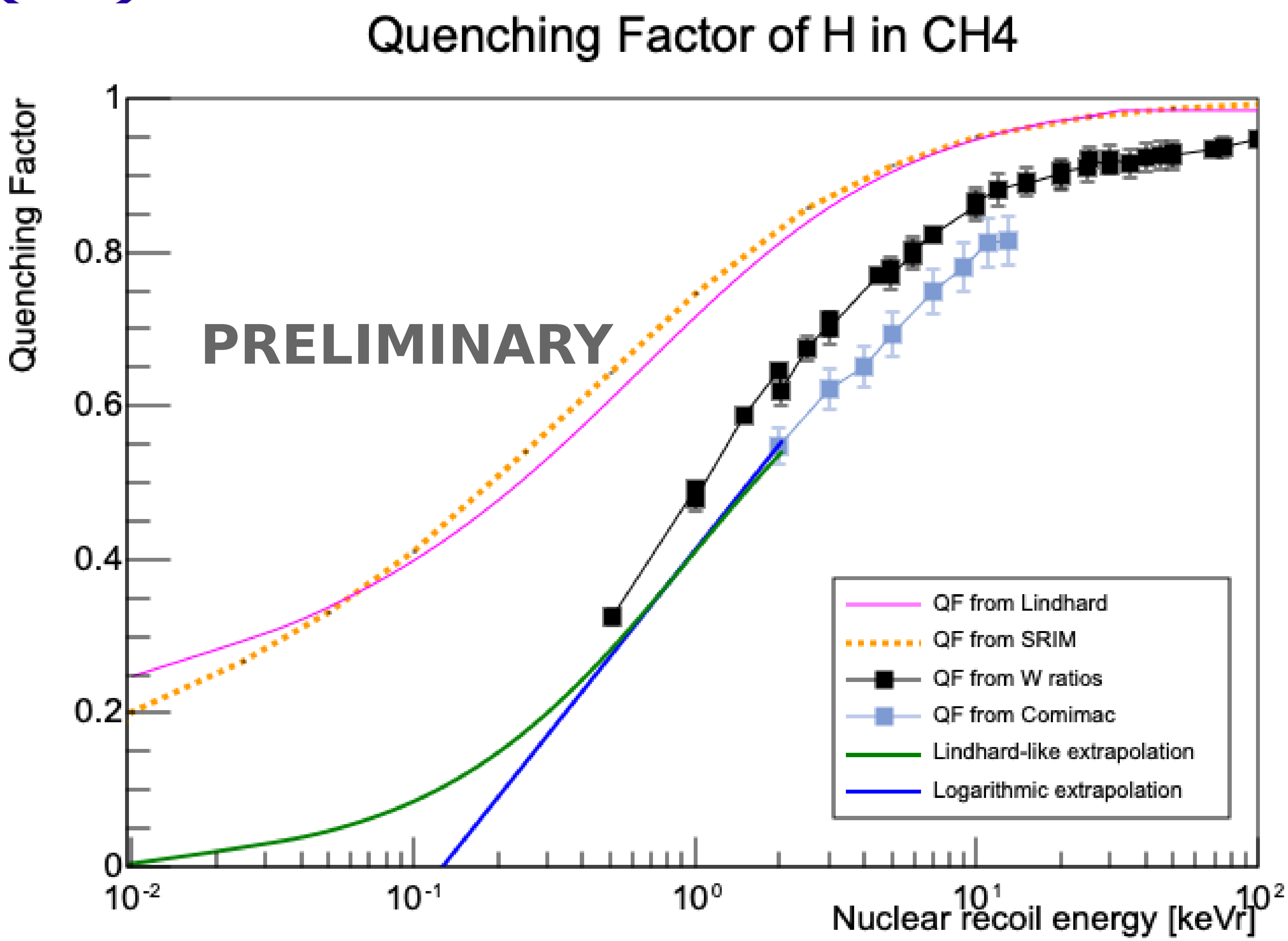


Commissioning data was taken at the LSM:

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



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

Some Pictures