Spherical Proportional Counters for low mass rare events detection

Philippe Gros
On behalf of the NEWS-G Collaboration

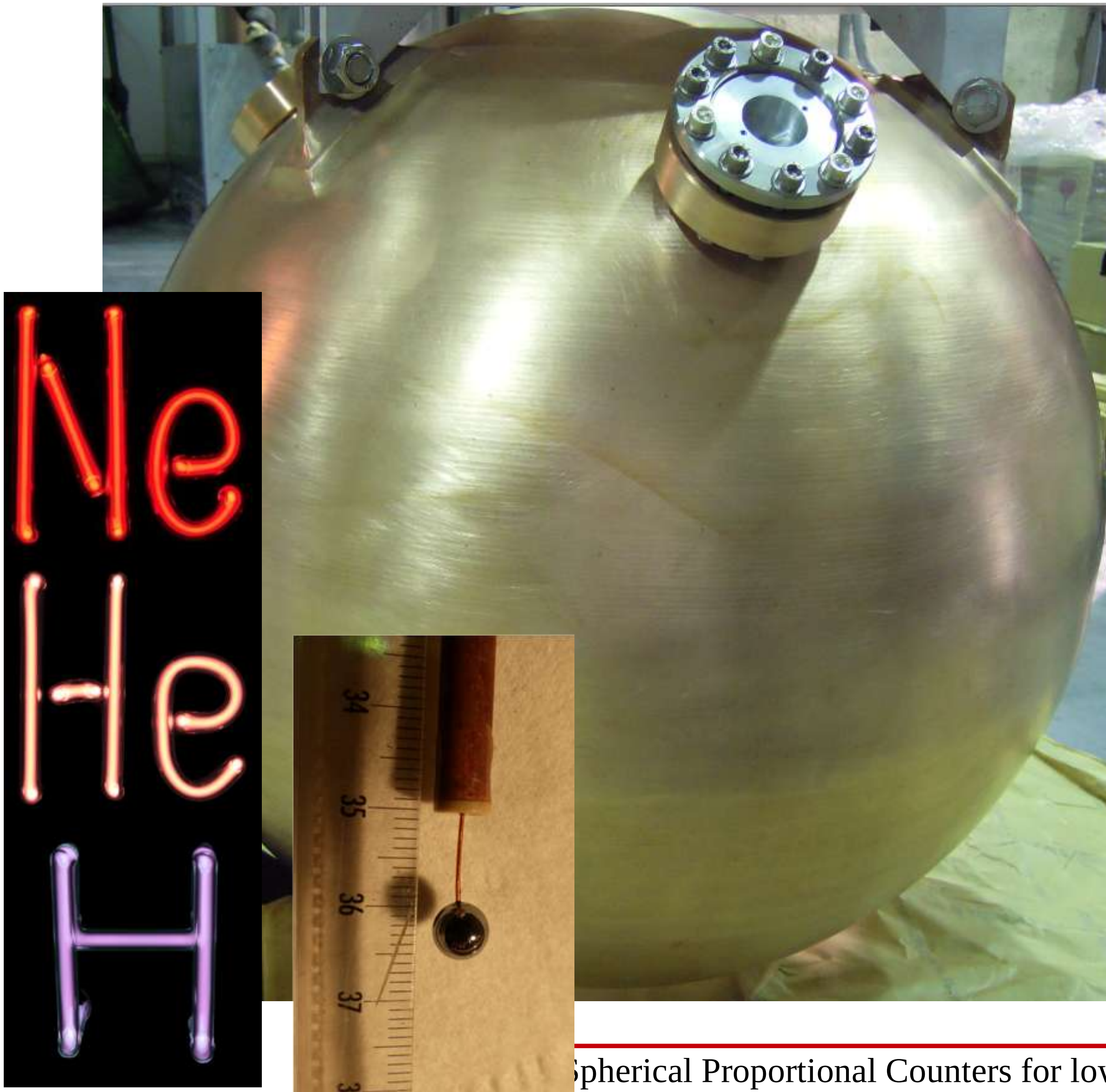
May 6th 2026

Outline

- SPCs and NEWS-G
- Characterisation of the detector underground
- Gases characteristics and purification

Spherical Proportional Counters

Spherical Proportional Counters (SPCs)



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

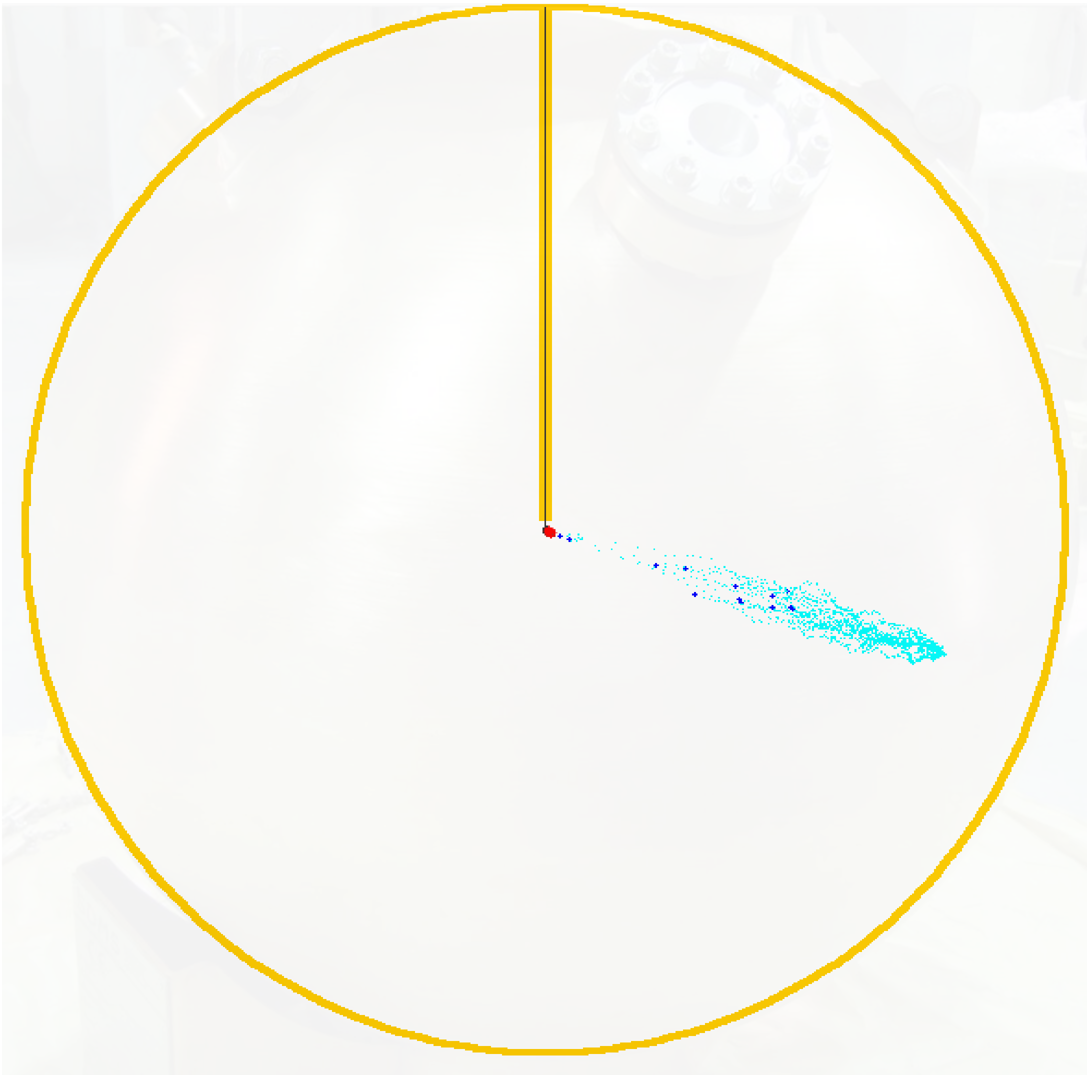
Low-A target atoms increases sensitivity to low-mass WIMPs

Easily exchanged target gas allows BG characterisation

Low capacitance and high gain provide excellent signal/noise

Single ionization detection threshold!

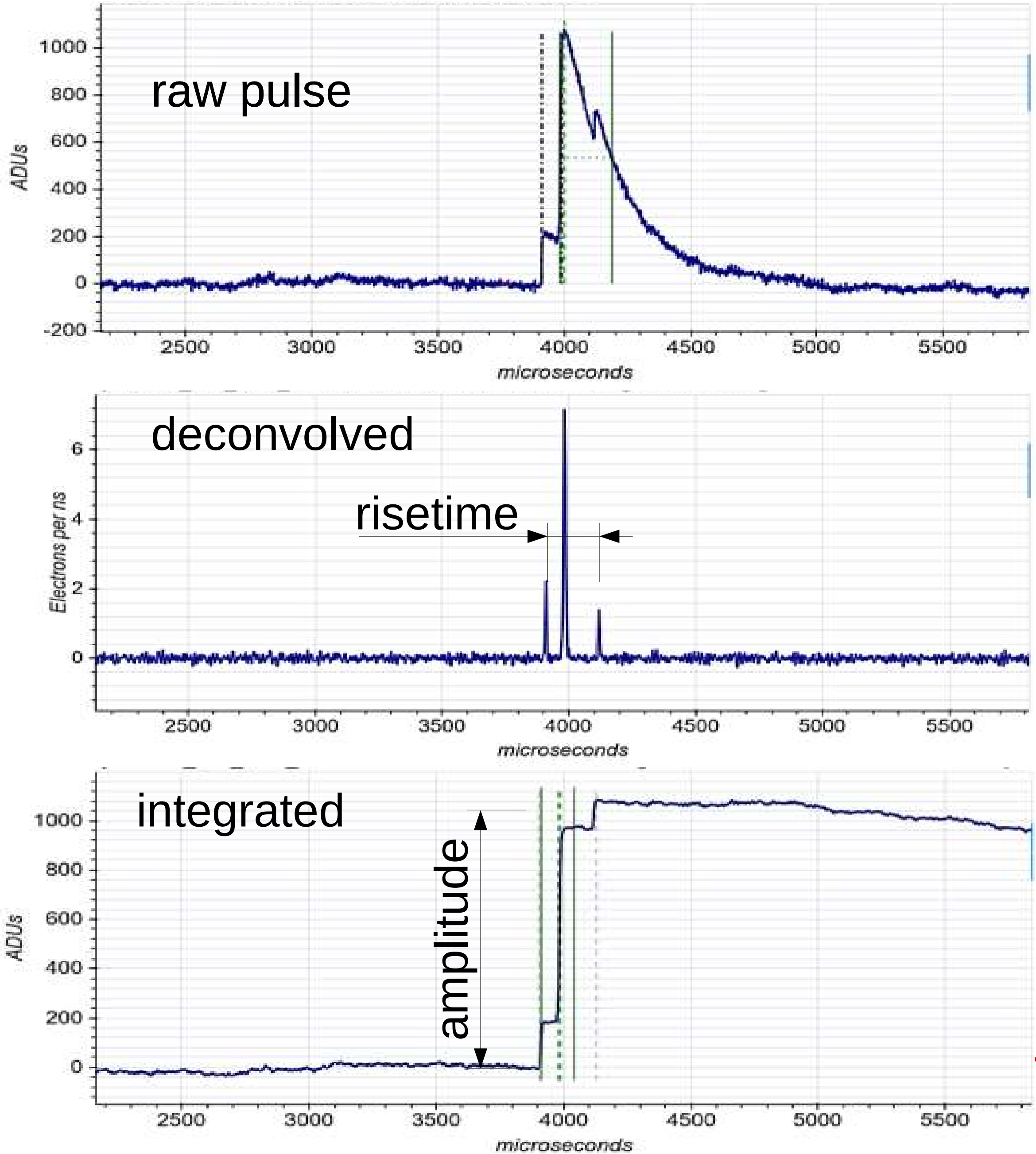
Principle of Operation



- *Primary ionisation*:
  - nuclear recoils, point-like
- *Drift*:
  - E ∝V/r^2
  - r calculated “globally”
  - <1V/cm at large R
- *Avalanche*:
  - E ∝V/r^2
  - r calculated “locally”
- *Signal from positive ion drift*
  - time response related to field
- *Signal readout*:
  - charge amplifier
  - digitizer

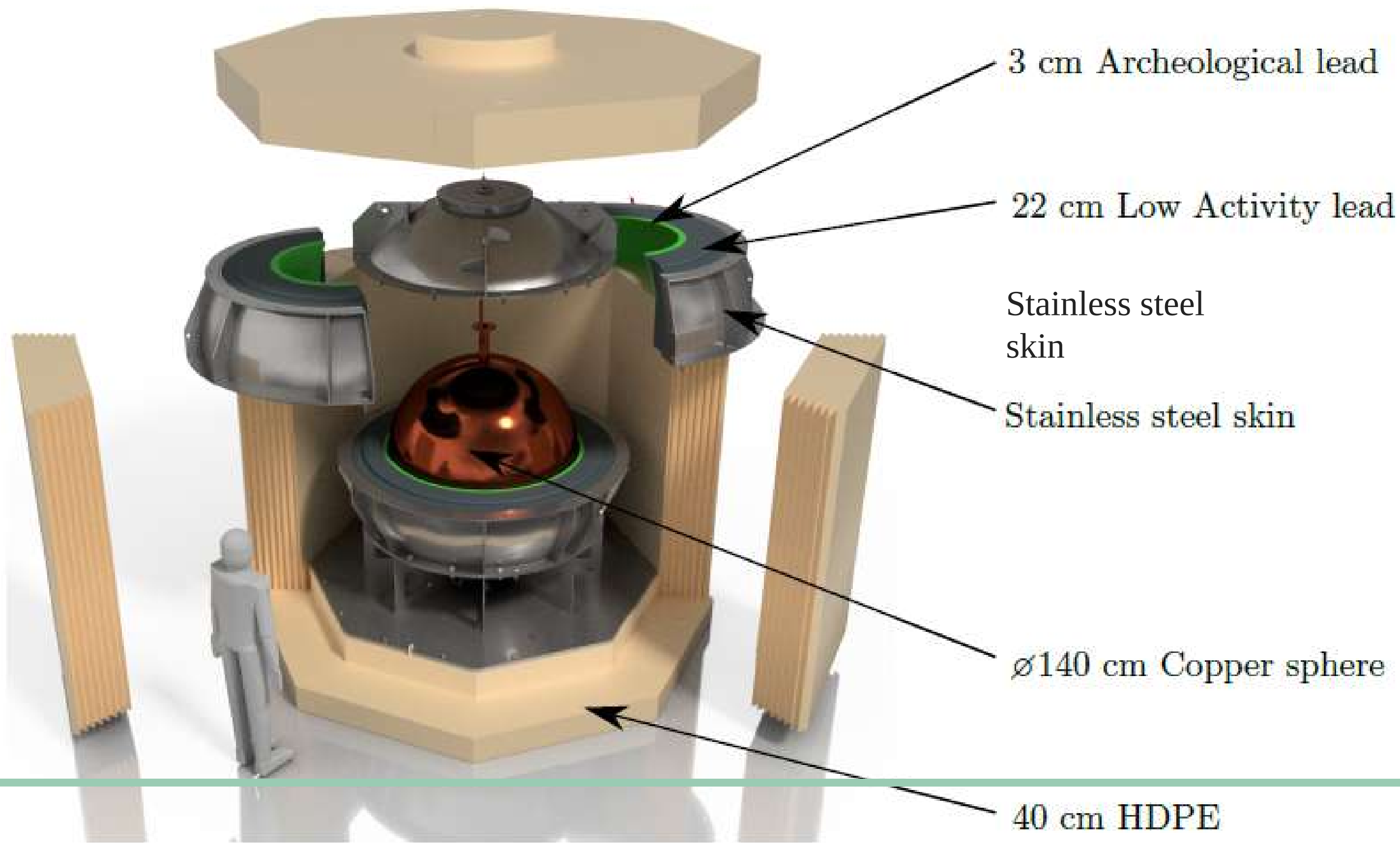
Signal

- 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

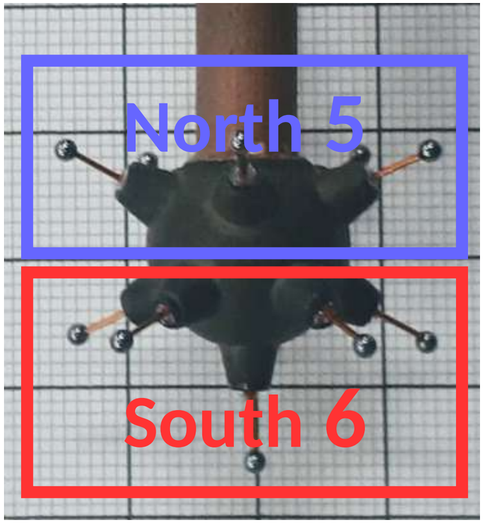
Sensor readout

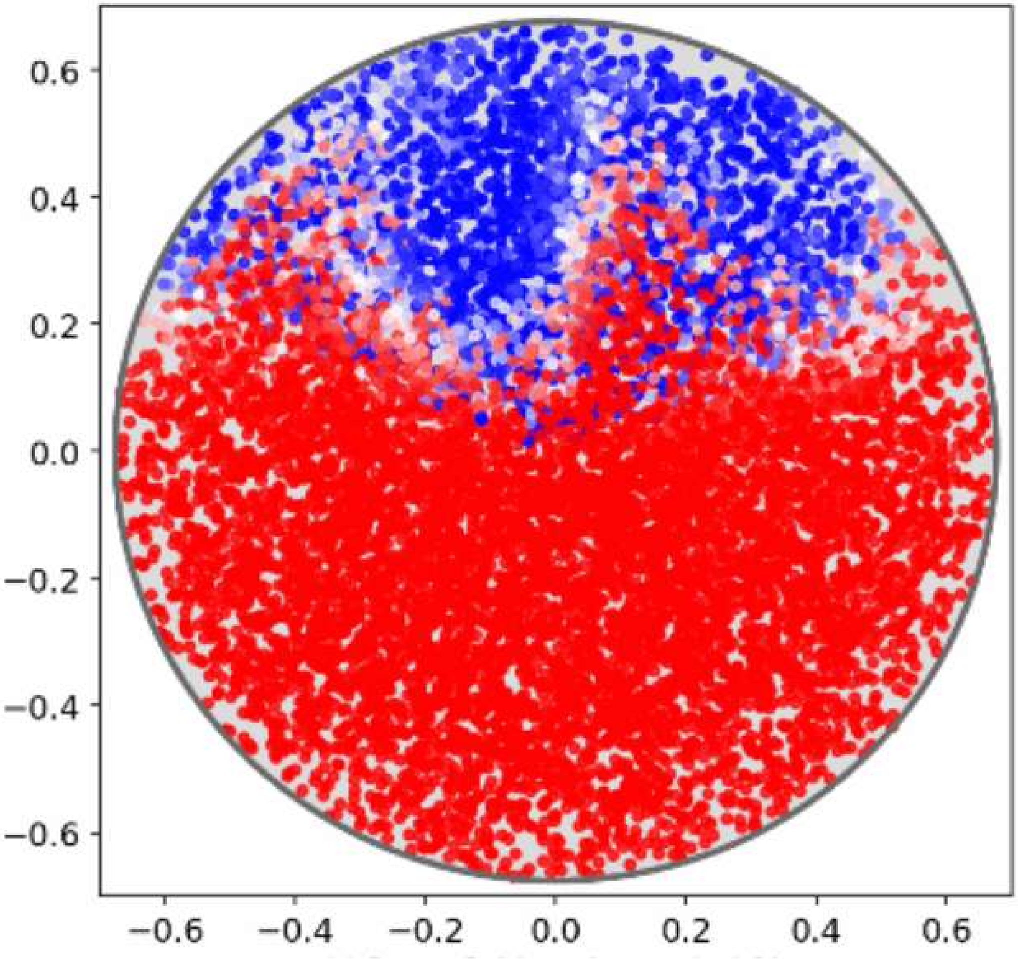
The 11-anode sensor is read out in two channels (north and south)

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)

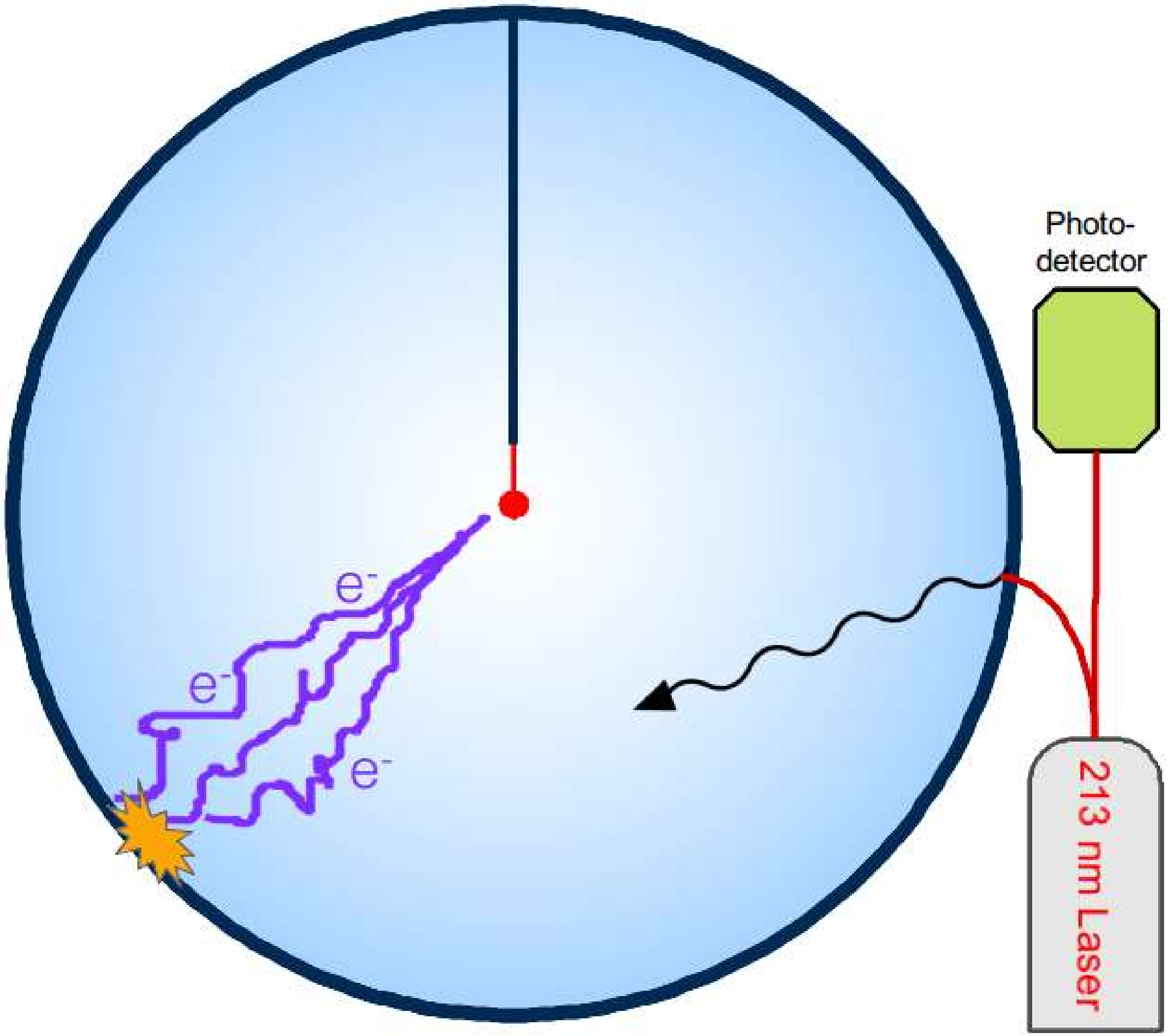
The fiducial volume covered by the southern 6 anodes is approximately 70%





Characterisation underground

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)

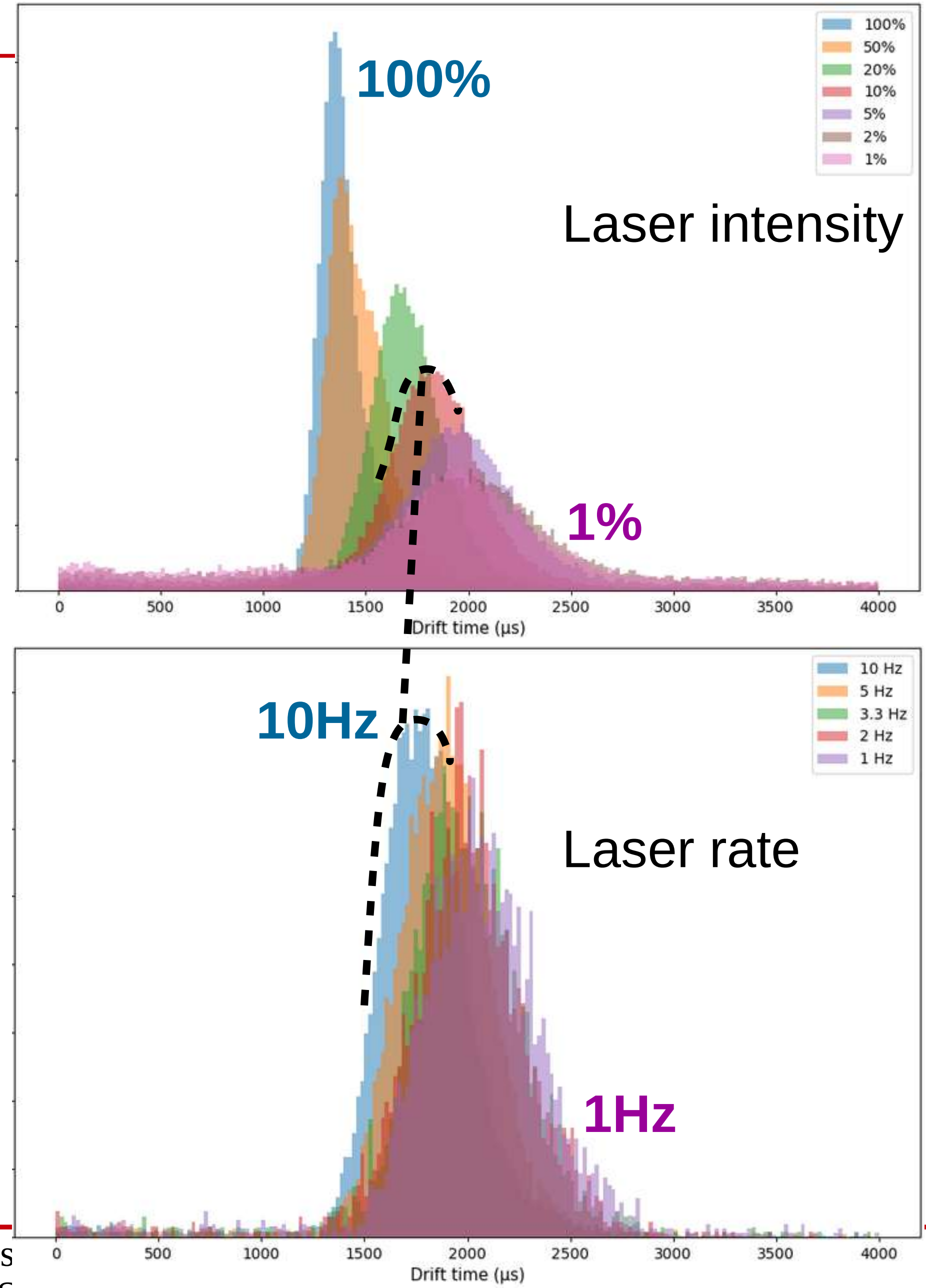
Continuous operation during physics runs allows for monitoring of the detector response, changes in detector **gain** and **drift velocity** over time

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

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

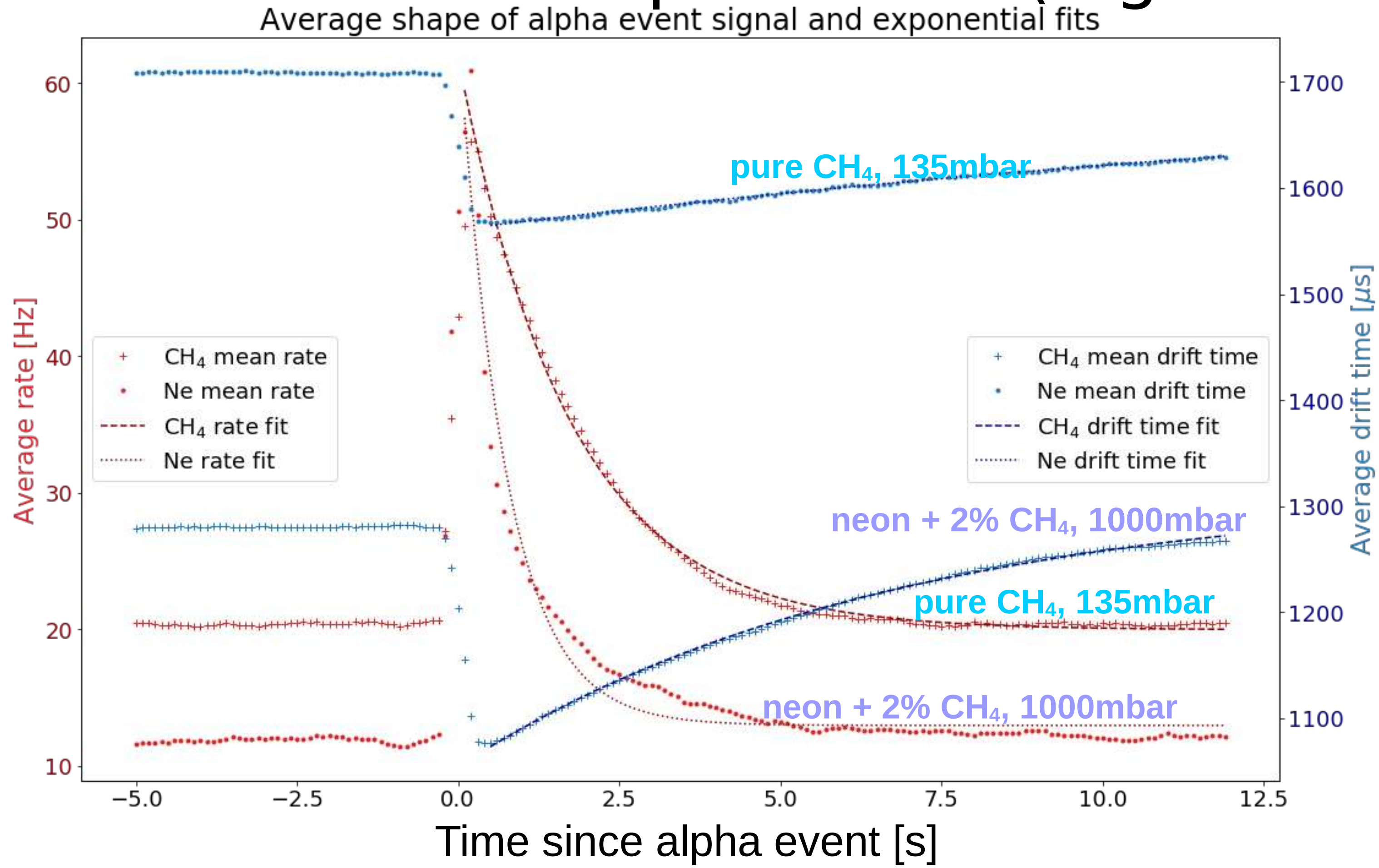
Small charge dependence

- Drift velocity sensitive to small space charge in the low field (<1V/cm) region
- Effect visible with changing laser intensity or repetition rate
- Number of primary electrons O(1-100)



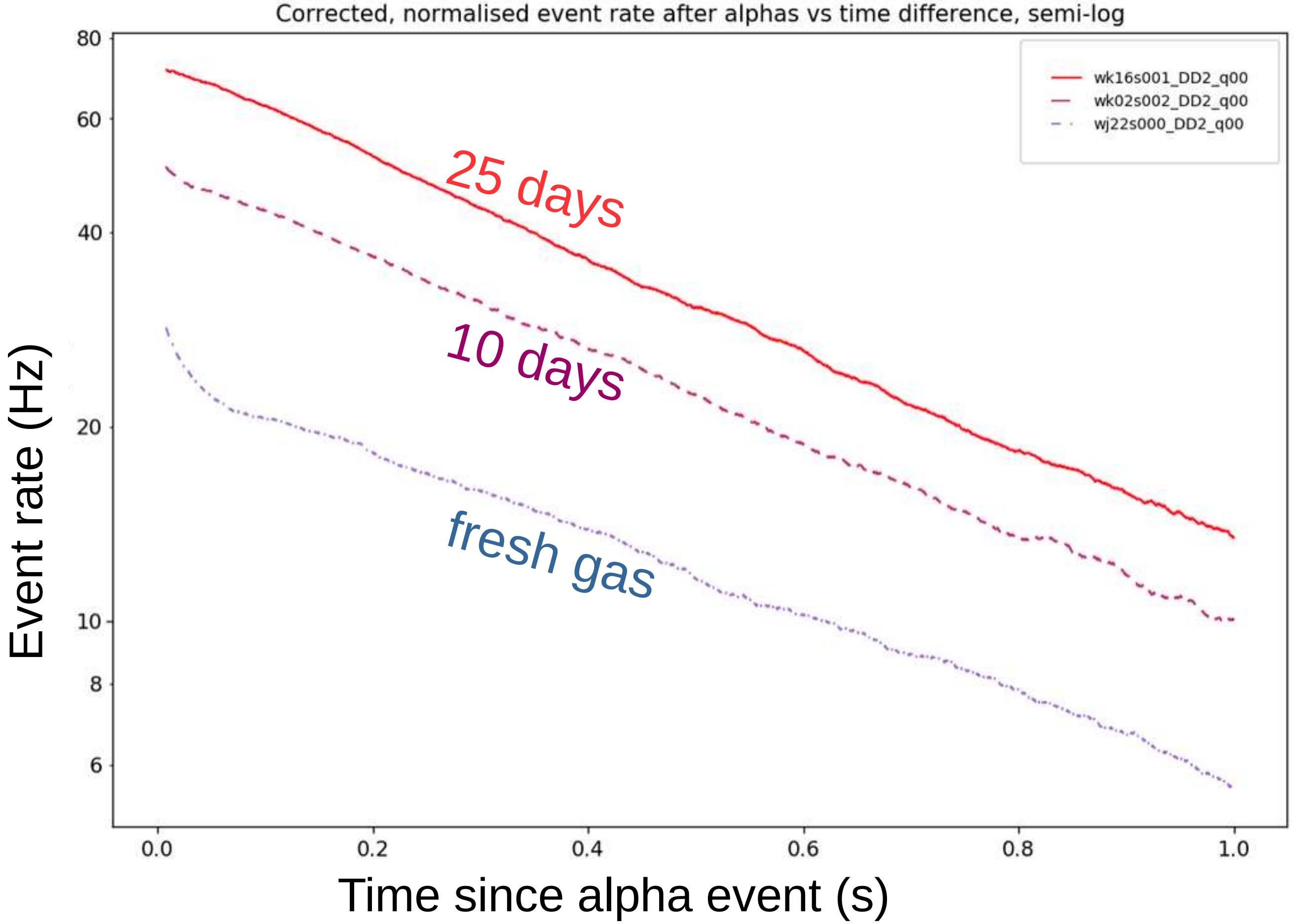
Drift velocity vs space charge

- 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



<u>Likely explanation:</u>
Negative ions from electron capture

- rate of event increases with gas degradation.
- time scale consistent with ion drift time
- Exact process under investigation. Detachment process poorly described

Gas quality requirements

- “Alpha tail” probably main BG source
- Alpha BG
  - 10s of mBq observed
  - Most of it radon (volume events)
- Oxygen contamination
  - O(0.1ppm) estimated
  - BG depends on gas mixture (through drift velocity)

Gases and their challenges

Sensor constraints

- Drift and amplifications fields are entangled
  - Drift field fixed by amplification voltage
- Amplification/drift constraint only changes with changed sensor geometry
- Development and testing of new geometries ongoing
    - More smaller anodes
    - Additional electrode for drift control
    - ...

Gas mixtures tested

Gas	Typical voltage at 1bar, 1.7mm anodes	Drift time in S140	Advantages	Downsides	Use
Argon+ 2% CH_4	>2500V	~1ms	Cheap, fast	39Ar BG	testing
Neon+ 2% CH_4	~1200V	~3ms	Low BG, good compromise	expensive	Physics
Helium+ 10% CH_4	~1200V	~10ms	Low BG, light target, single electron separation	Hard to calibrate, needs high purity, LF noise	Physics
Pure CH_4	>5000V ~2000V at 150mbar	~3ms	Low BG, light target	Flammability, high voltage/low pressure	Physics

Nuclear recoils

- Calibration is only possible with electron recoils (X rays, gammas)
- Quenching factor for nuclear recoils needed
  - Preliminary measurements with neutron scattering in 2bar neon down to 400eV published
  - Measurements with nucleus beam in CH4 down to 2keV
  - New neutron scattering campaign planned at lower energy for neon, helium and CH4 later this year

Conclusion

- NEWS-G is operating an SPC at SNOLAB to search for light WIMPs
  - Limits published in pure CH4 at LSM
  - New data at SNOLAB, challenging analysis
- Very simple detector, characterisation is tricky
  - Combination of UV laser and X-ray source
  - 2 channels help, more might be better...
- Multiple gas mixtures tested
  - Multiples gases and pressures useful for BG studies
  - Changes in amplification/drift fields creates analysis challenges

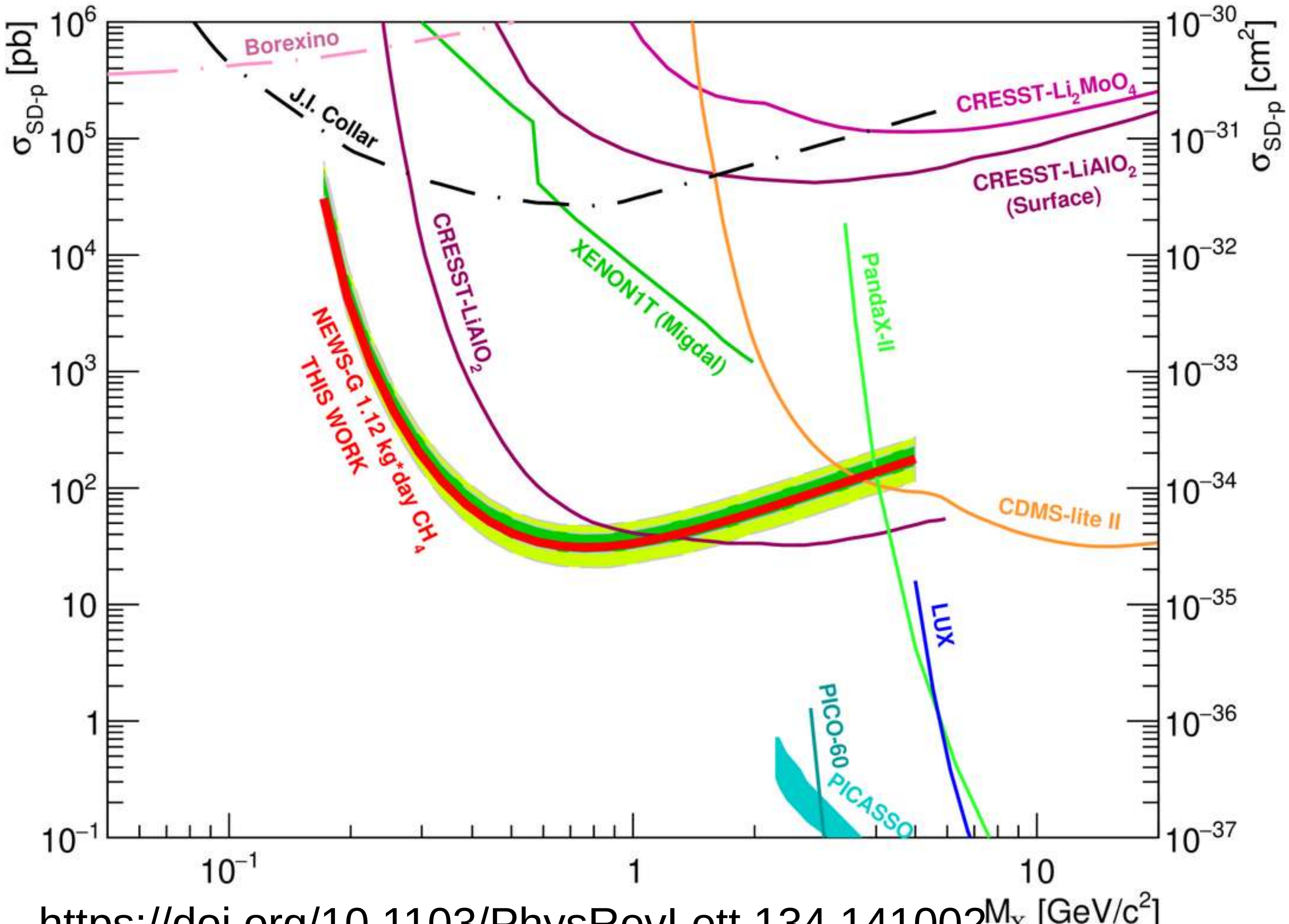
Thank you for your attention

NEWS-G Collaboration

Results in pure CH4

From data taken in 2019 at LSM

Analysis for neon and helium mixtures at SNOLAB ongoing



https://doi.org/10.1103/PhysRevLett.134.141002

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

Nuclear recoils from neutrons

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

    critical calibration for WIMP search ("Quenching Factor")
  - point-like, even at higher energies
- Hard to calibrate
  - neutron scattering
  - low cross-section
  - wide energy distributions
  - tagging difficult at low energy
- **See following presentation by Neha Panchal**