Latest results from the NEWS-G experiment

Jean-Marie Coquillat

GUINEAPIG 2023, Montréal

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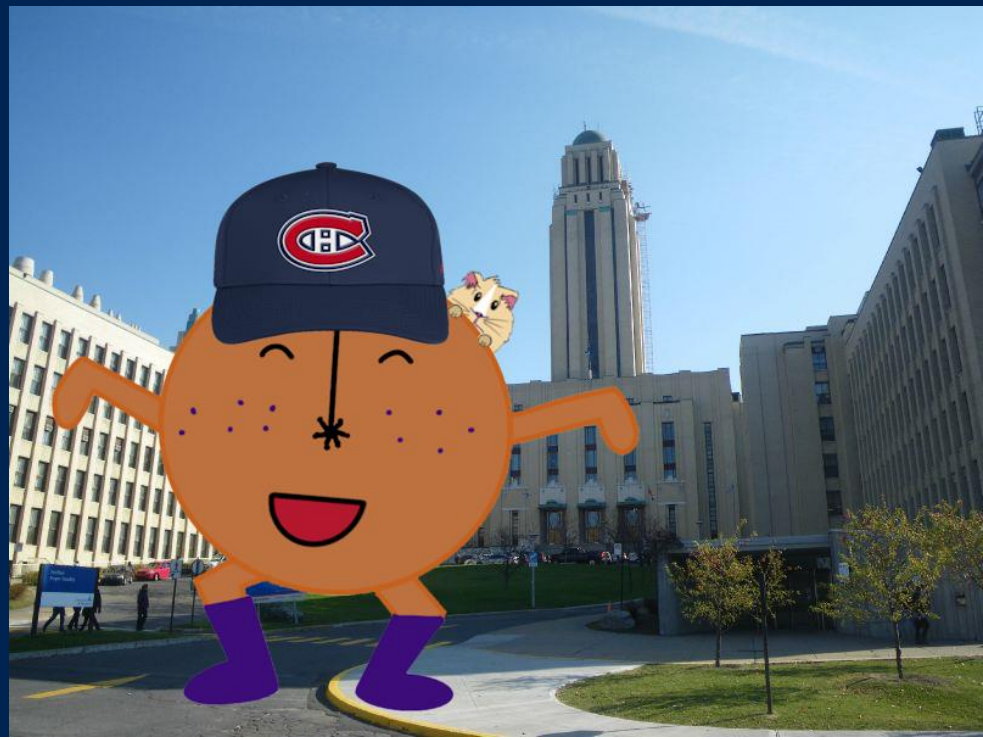
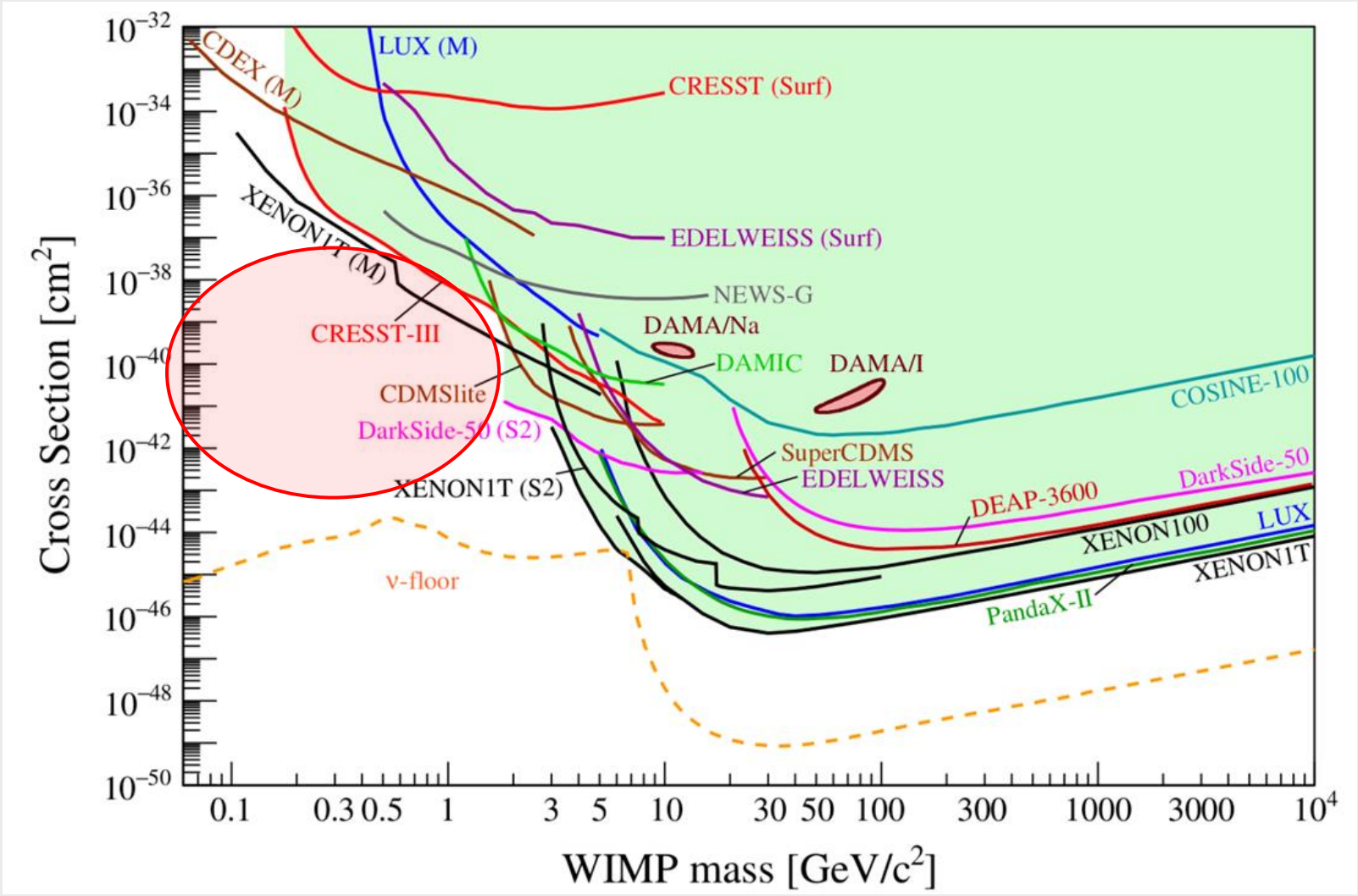


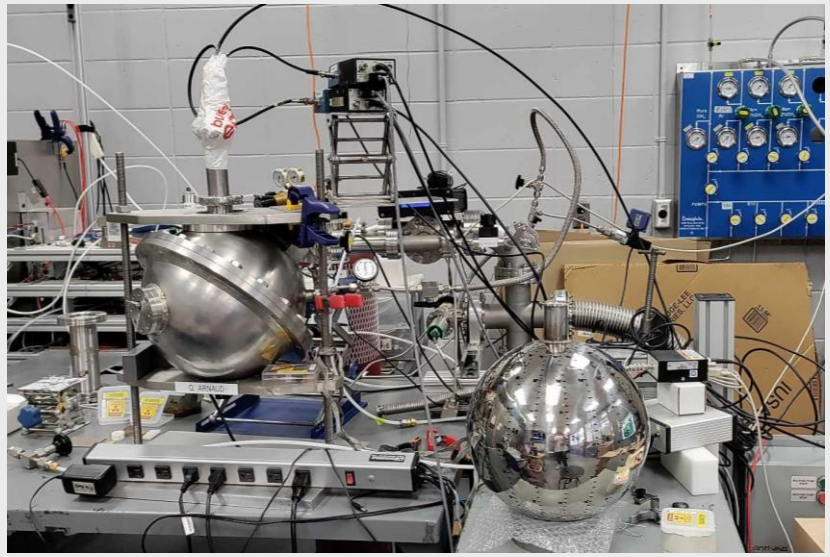
Low mass WIMP search motivation

Given the absence of canonical WIMPs, there is motivation to look at the parameter space left at lower masses (~0.1-1 GeV) for WIMP-like dark matter candidates.



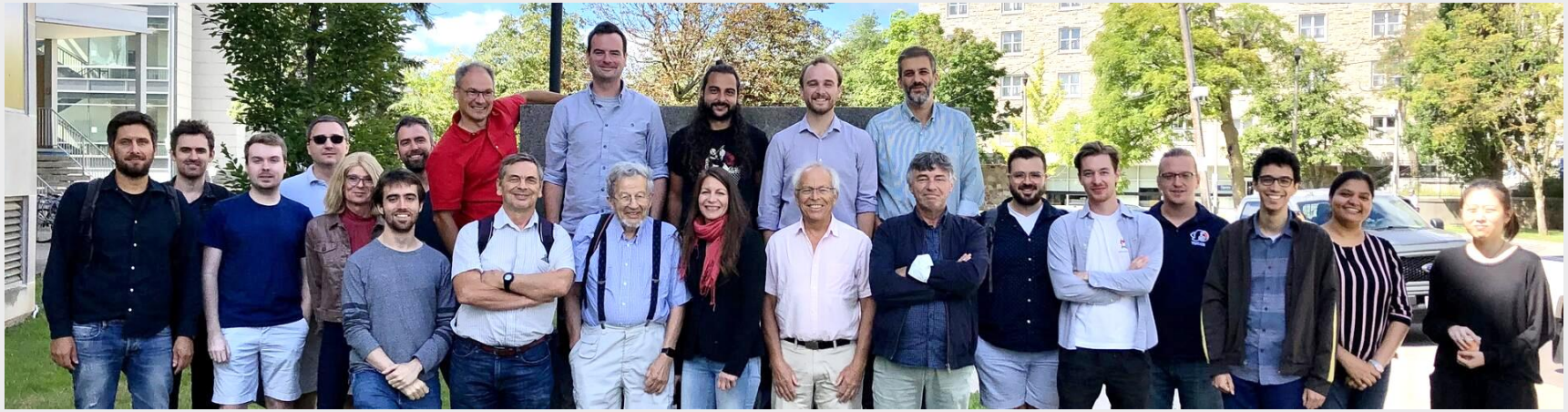
arXiv:2104.07634 [hep-ex]

NEWS-G and SPCs



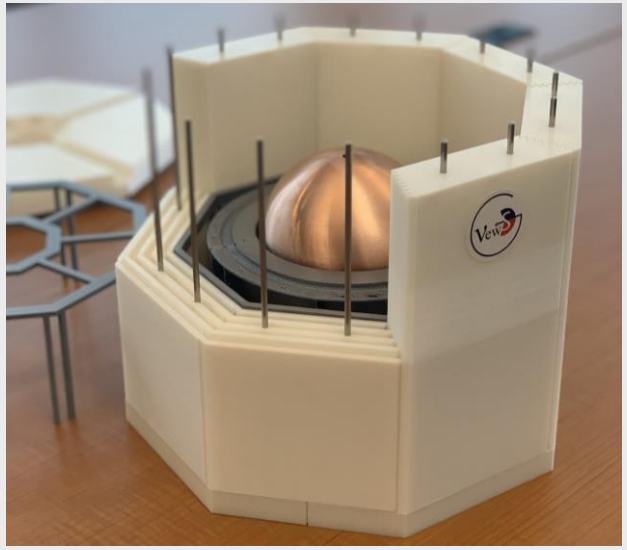
- The NEWS-G experiment uses spherical proportional counters (SPC) to search for low mass dark matter.
- SPCs are metallic spheres filled with gas, with a central anode producing a radial electric field.

- Advantages of SPC:
  - Very low threshold (single-ionization)
  - Can use different gases
  - Sphere provides optimal volume/surface ratio



NEWS-G and SPCs

- The last dark matter limits are from the SEDINE detector (60 cm diameter) at the *Laboratoire Souterrain de Modane* (LSM) in 2017.
- There was 42 days of data with neon + 0.7% of methane at 3.1 bars.
- The latest detector, S140 (or SNOGLOBE), is a 135 cm of diameter copper sphere currently at SNOLAB, after a short commissioning at the LSM in 2019.
- SNOLAB commissioning of S140 started in 2022.



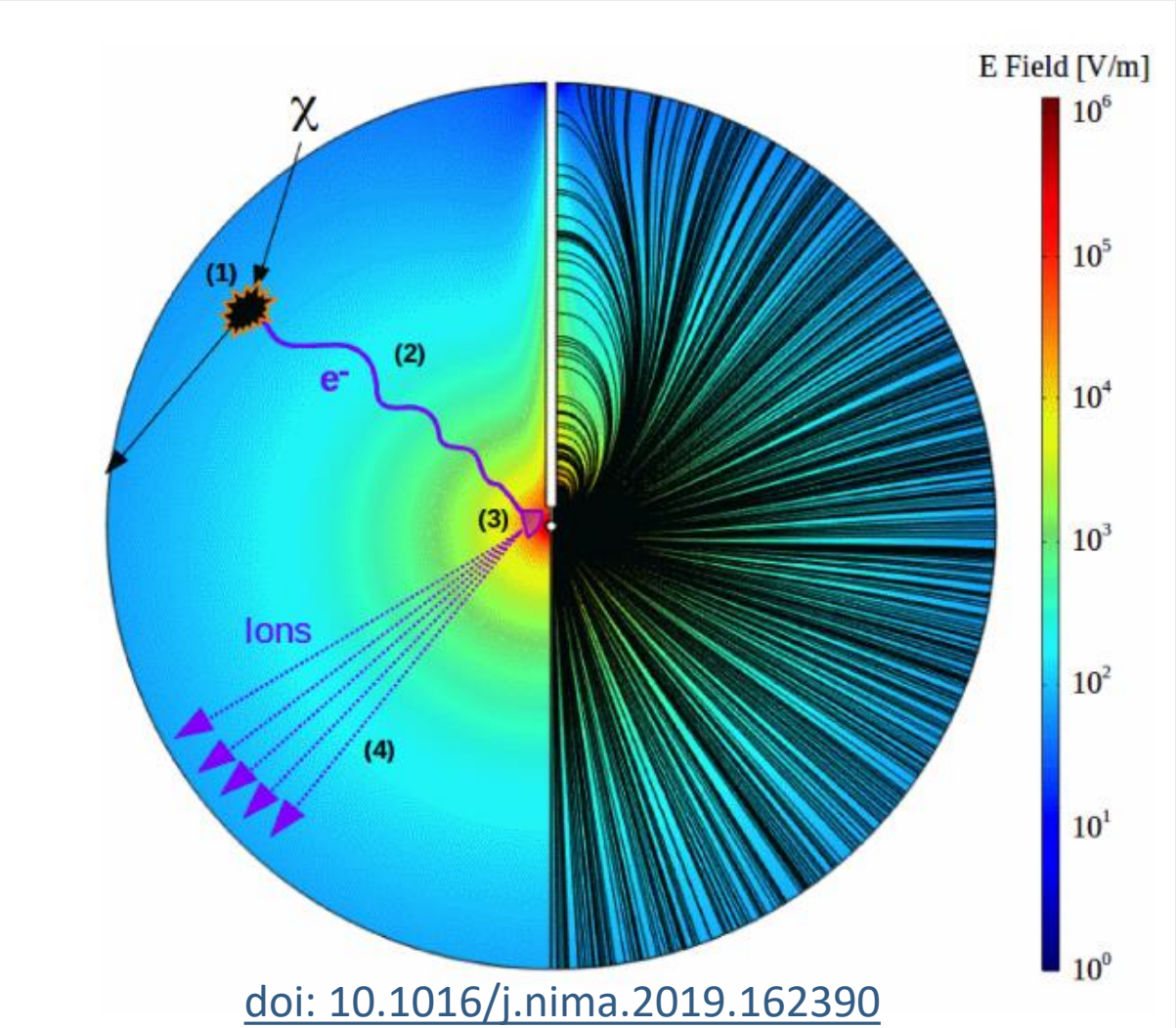
S-140 detector model

The SEDINE detector

doi: 10.1016/j.astropartphys.2017.10.009

How an SPC works:

1. Atomic recoil causes ionization of the gas.
2. Primary electrons drift towards the central anode.
3. Townsend avalanche near the anode amplifies the signal.
4. Drifting secondary ions induce a current on the anode.



doi: 10.1016/j.nima.2019.162390

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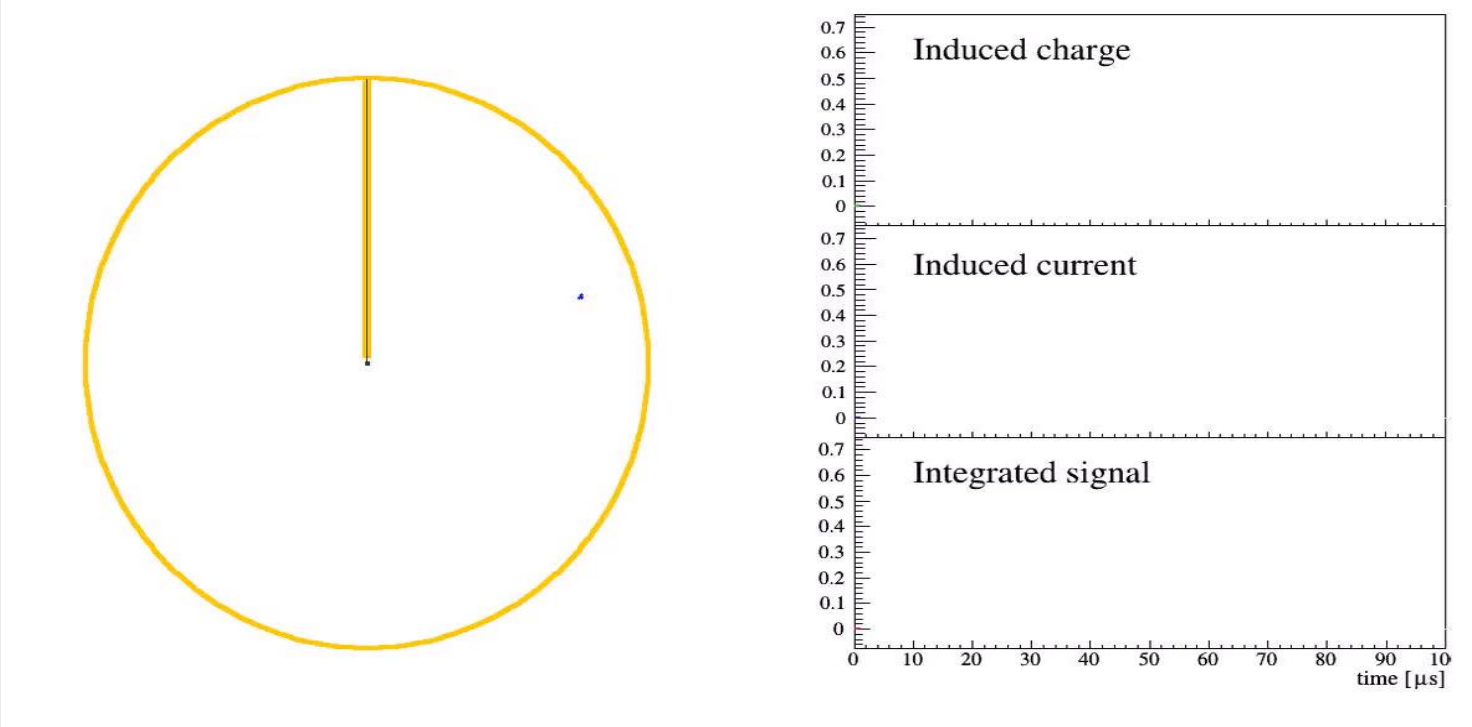
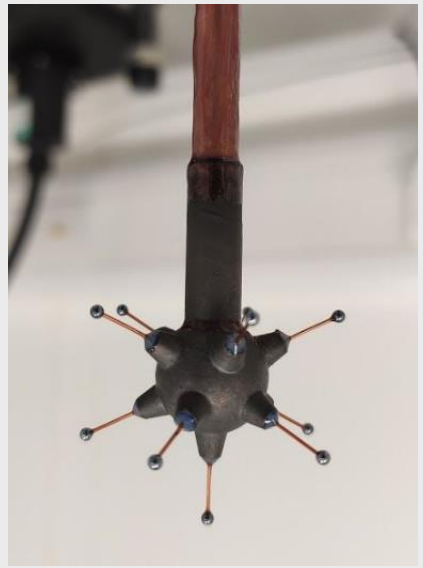


Animation by Philippe Gros

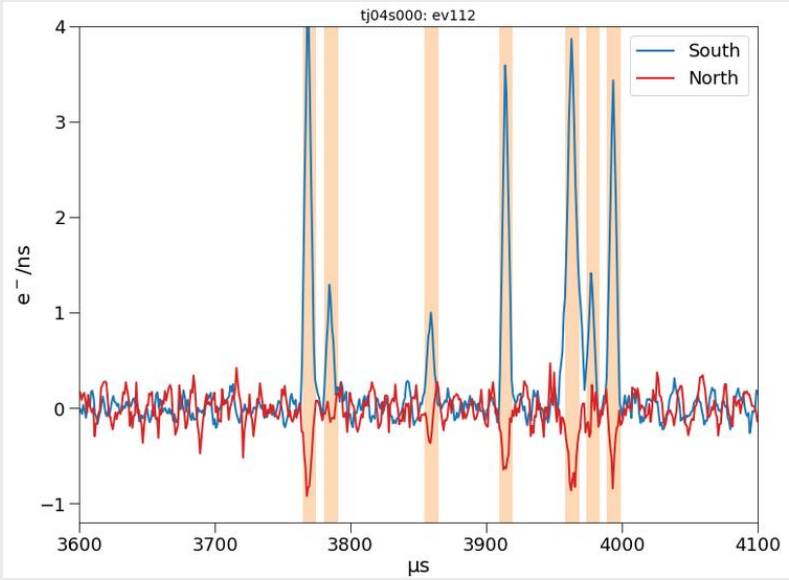
Sensor (achinos)

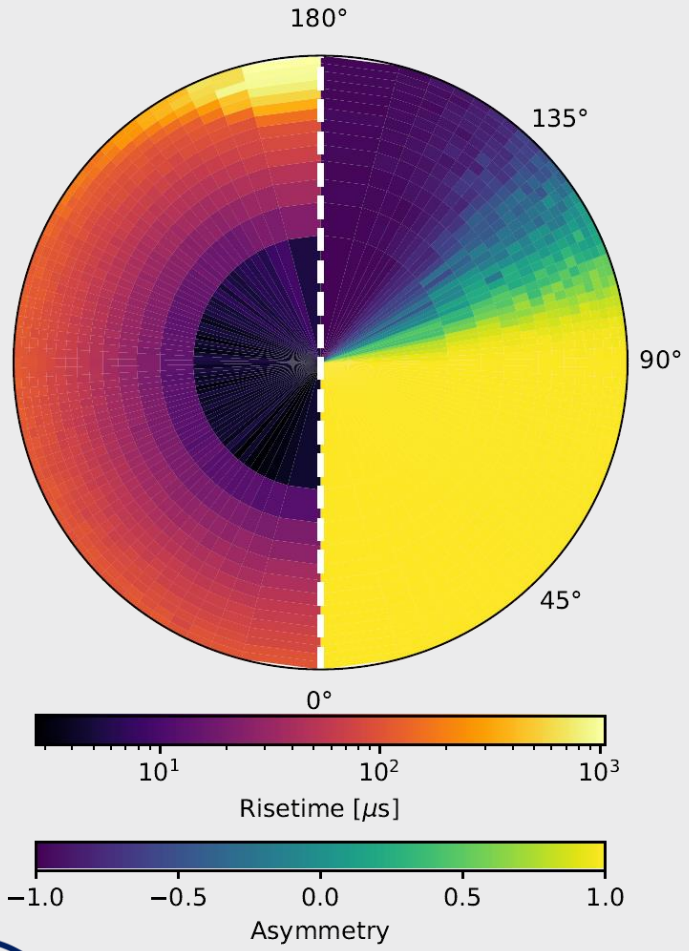
- NEWS-G now uses a multi-anode sensor that can achieve high gain while keeping a strong electric field at a high radius.
- The sensor is divided in two channels connecting the anodes of each hemisphere.
- A signal on one channel induces a negative signal on the other one (Shockley-Ramo effect).
- About 2/3 of the volume leads to the south anodes, due to the effect of the rod on the electric field.

arXiv:2301.05183



doi:10.1088/1742-6596/2156/1/012059





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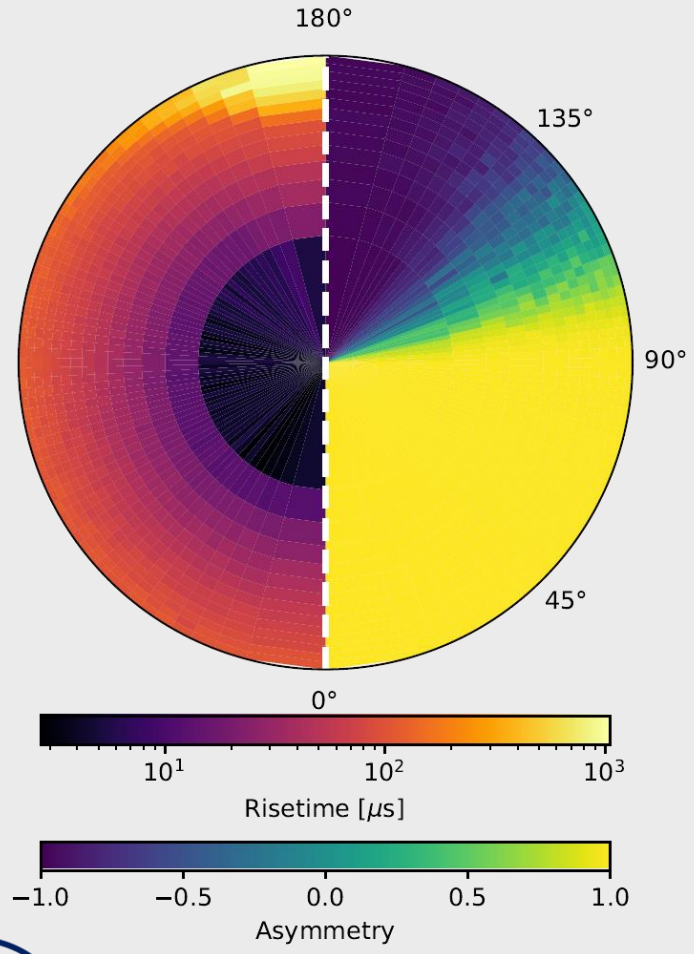

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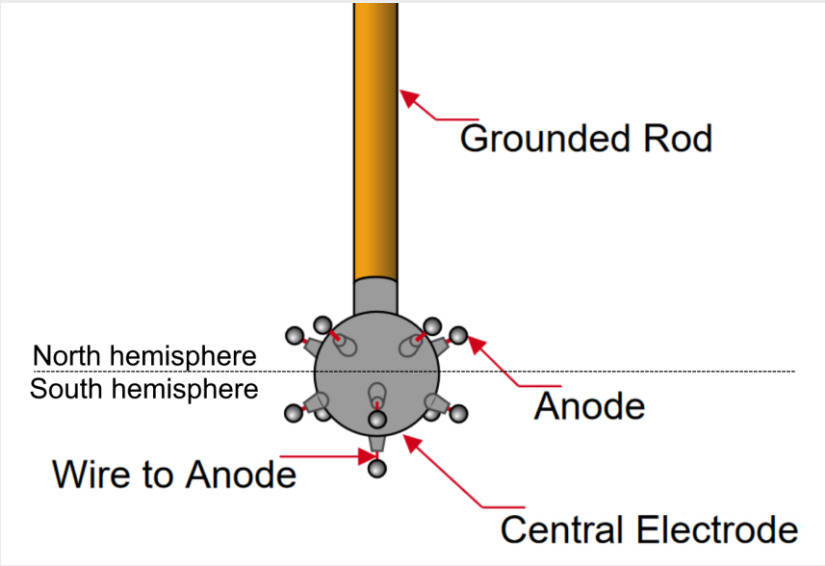

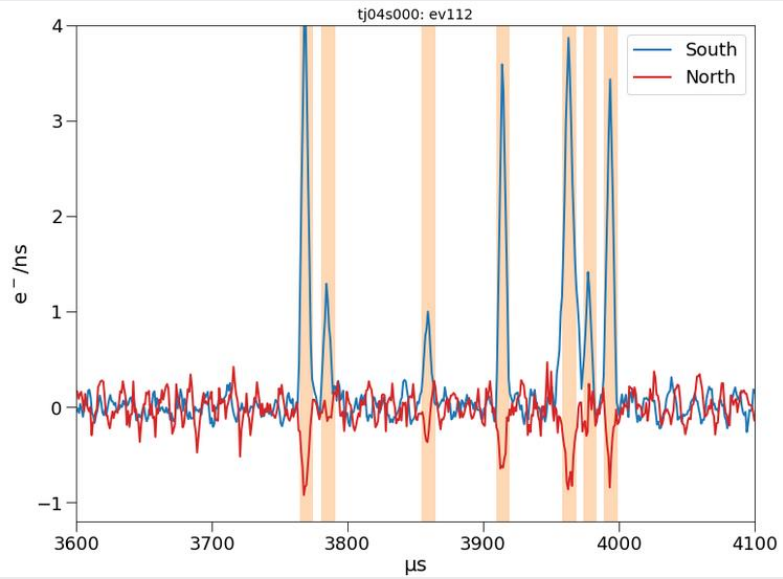

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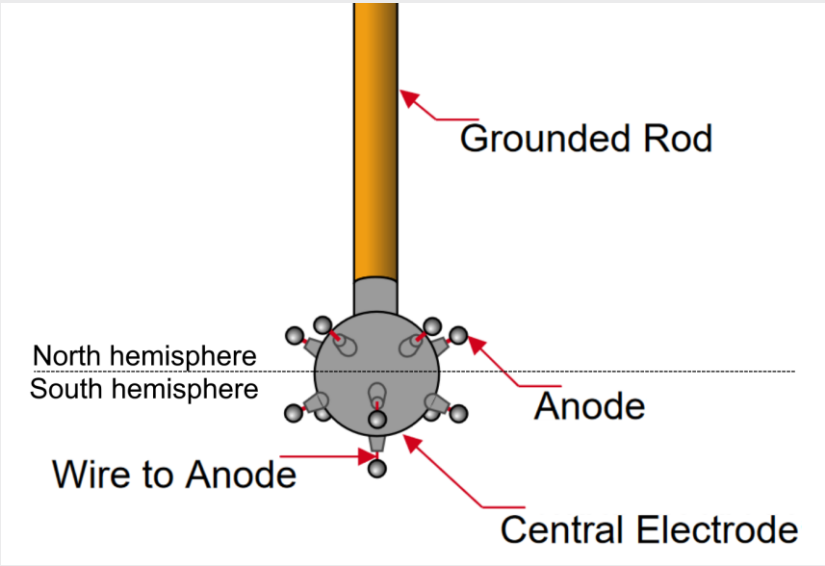
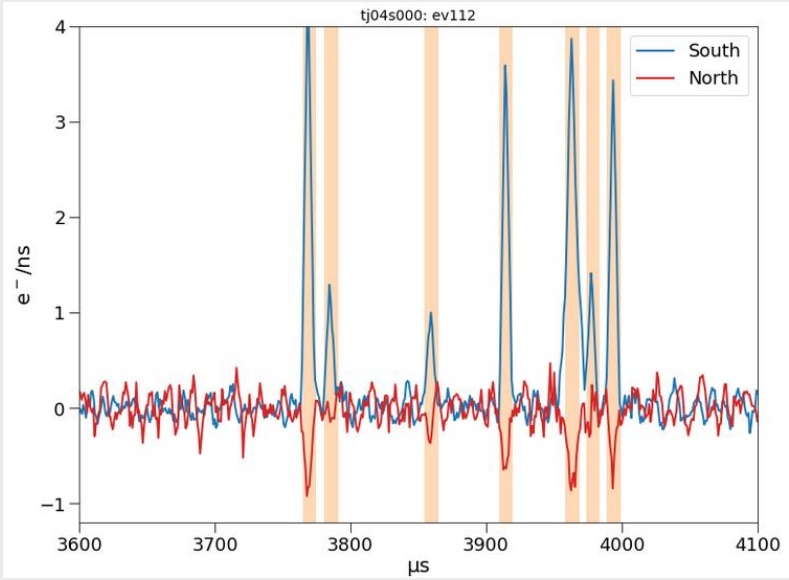
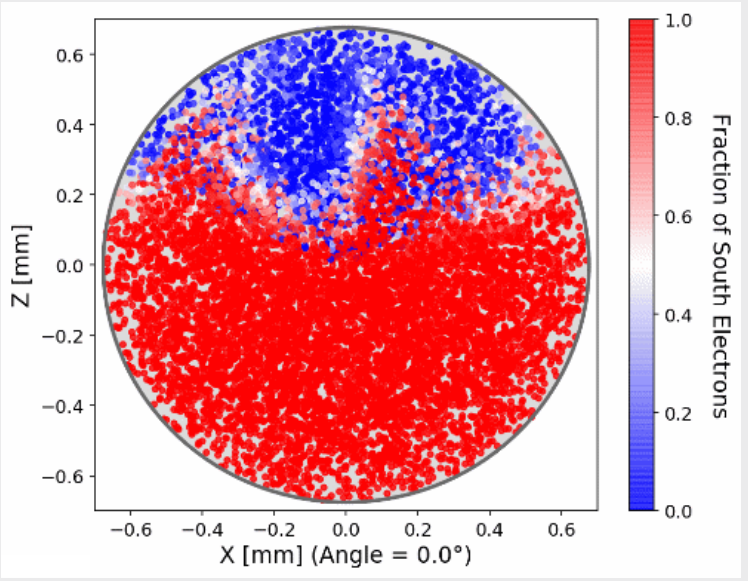


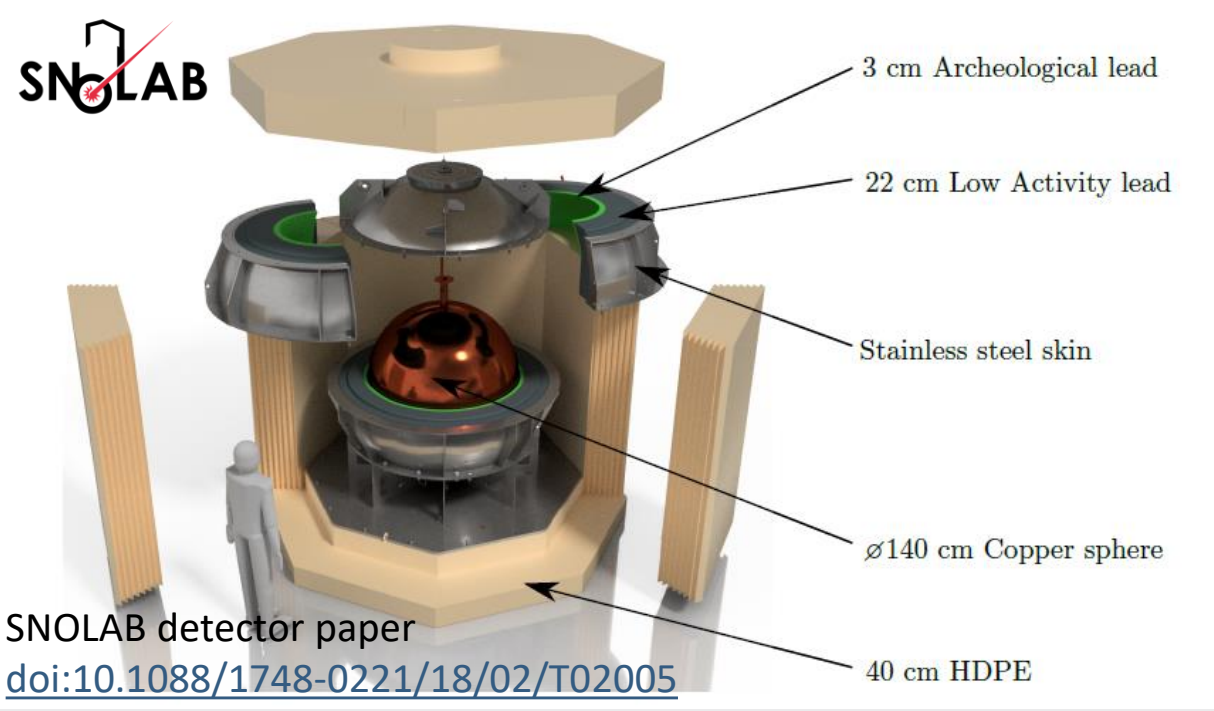




Only pure south events were kept as candidate events.

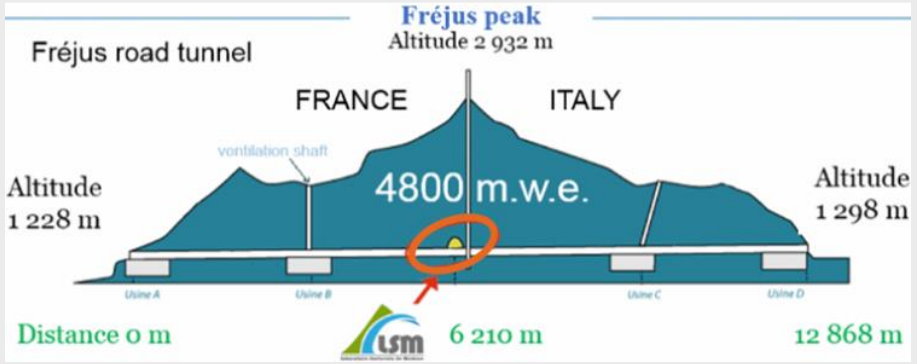
Shielding and data taking with S140

- The sphere is made of C10100 copper, with the inner 0.5 mm being electroformed ultra-pure copper.
- Lead, archeological lead and polyethylene (PE) make the shielding, although water was used at the LSM since the PE shield was unfinished.
- 10 days of physics data taken in 135 mbar of CH_4 at the LSM before the detector was shipped to SNOLAB.



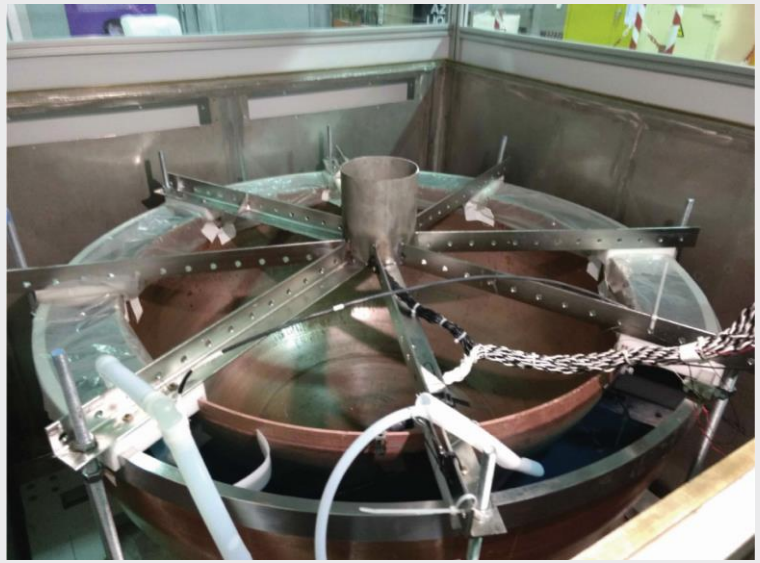
SNOLAB detector paper
doi:10.1088/1748-0221/18/02/T02005

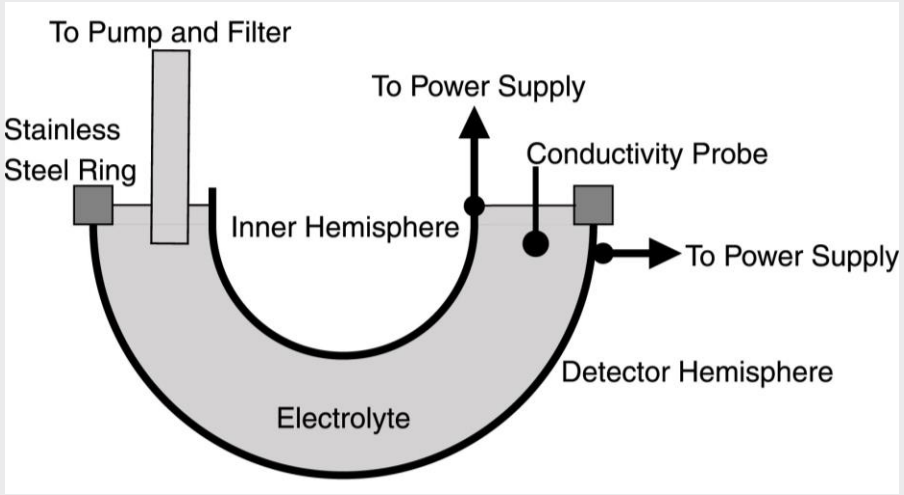
Laboratoire Souterrain de Modane (LSM)



Copper electroforming

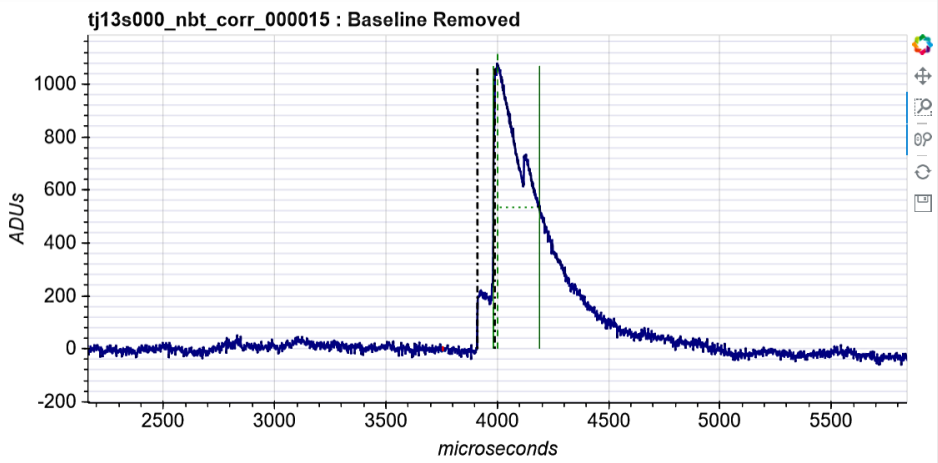
- Even the C10100 copper bulk contains traces of ^{210}Pb, which emits bremsstrahlung X-rays through their beta decay.
- The electroforming of the 0.5mm inner copper surface was done in collaboration with the Pacific Northwest National Lab at the LSM.
- This reduces the overall background by 98%, and the sub-keV background by 70%.





Double deconvolution

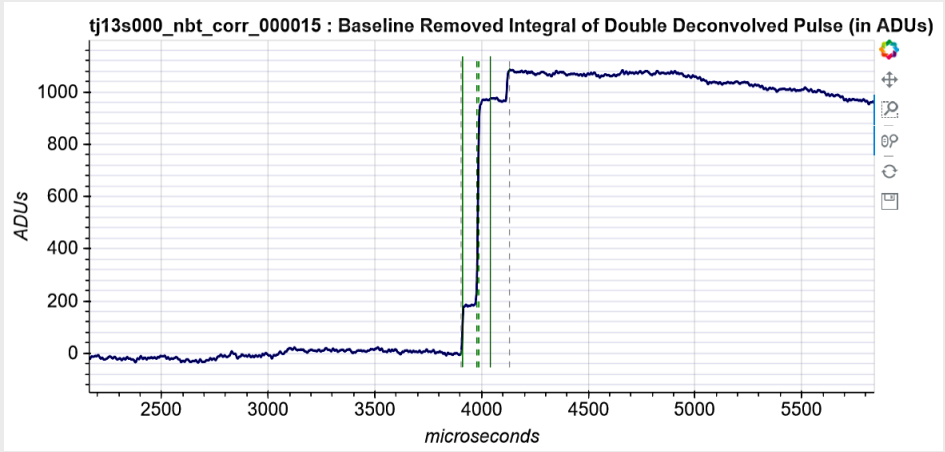
- Ionization equations: $\langle PE \rangle = \frac{E}{W(E)}$; $W_{nr} = \frac{W_\gamma}{QF(E)}$
- Primary ionization follows a COM-Poisson distribution, and the avalanche follows a Polya distribution.
- The exponential decay of the preamplifier and the ion response are deconvolved from the raw signal.
- The integrated double-deconvolved amplitude is proportional to the energy, while the rise time is a measure of the diffusion which relates to the event radial position.



DOUBLE-DECONVOLUTION

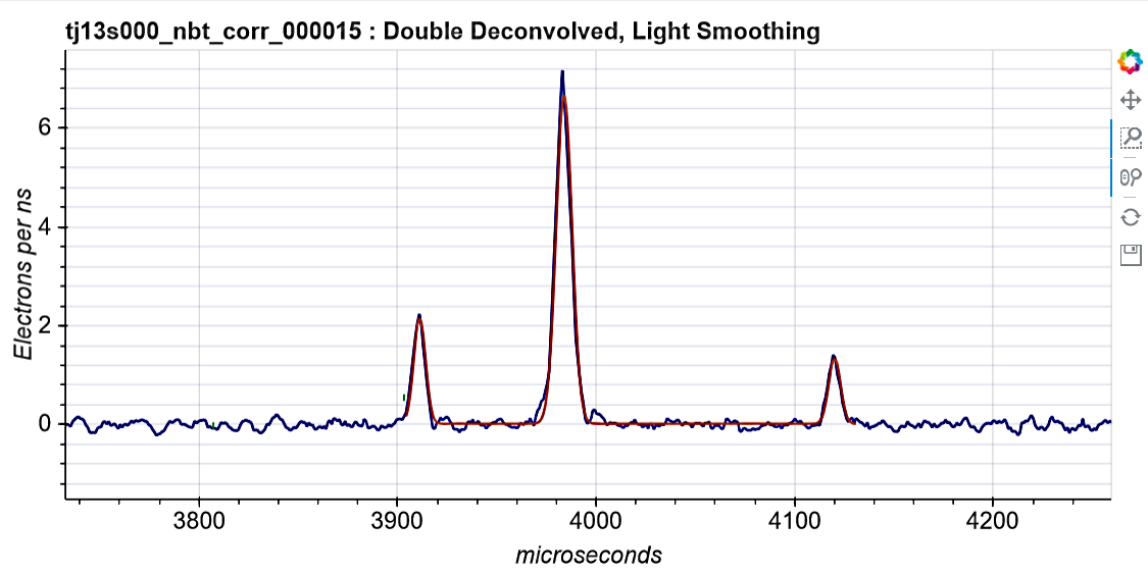
INTEGRATION

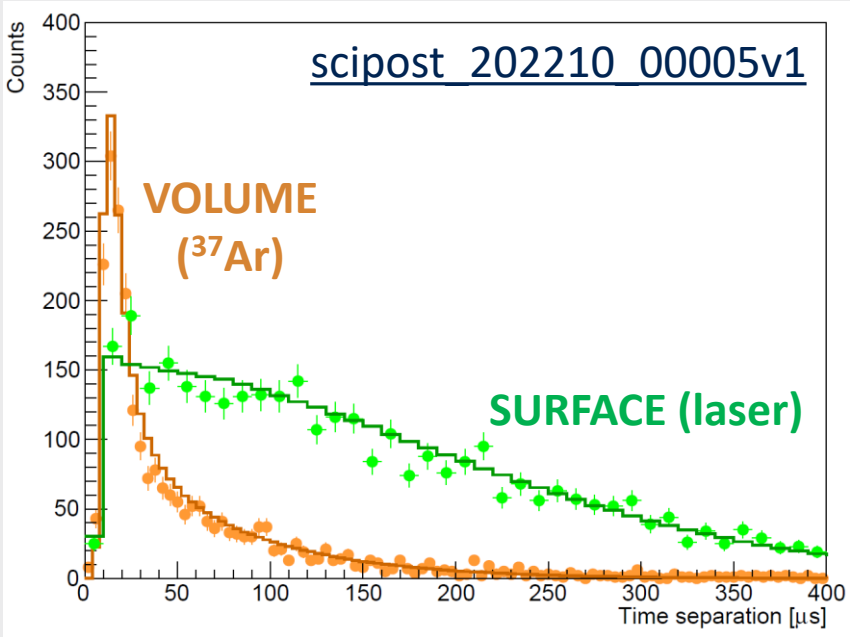
There is work on using machine learning as an alternative



Peak counting and time separation

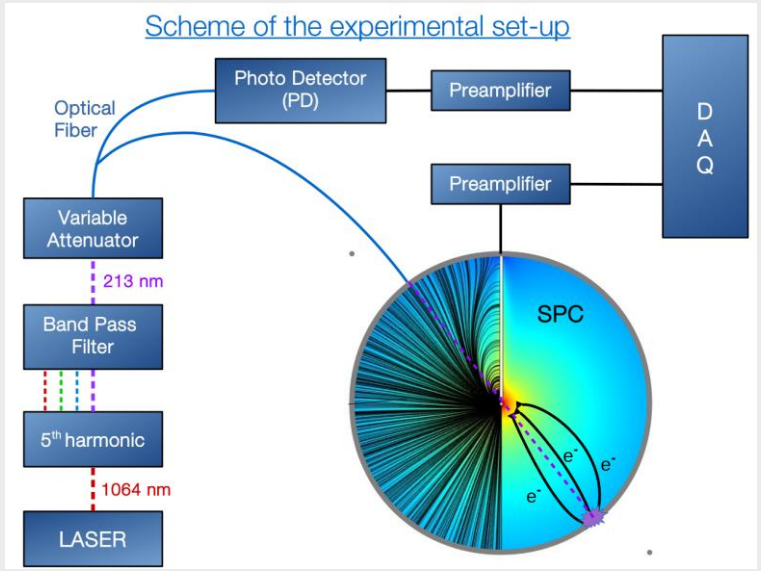
- With the large sphere of S140, it is possible to count individual primary electrons using ROOT TSpectrum.
- The single-electron trigger efficiency is 60%, with a noise trigger proportion around 10^{-4}.
- Surface events experience more diffusion than volume events, which causes the time separation between the first and last peak to be larger.
- Number of electrons is a measure of the energy.

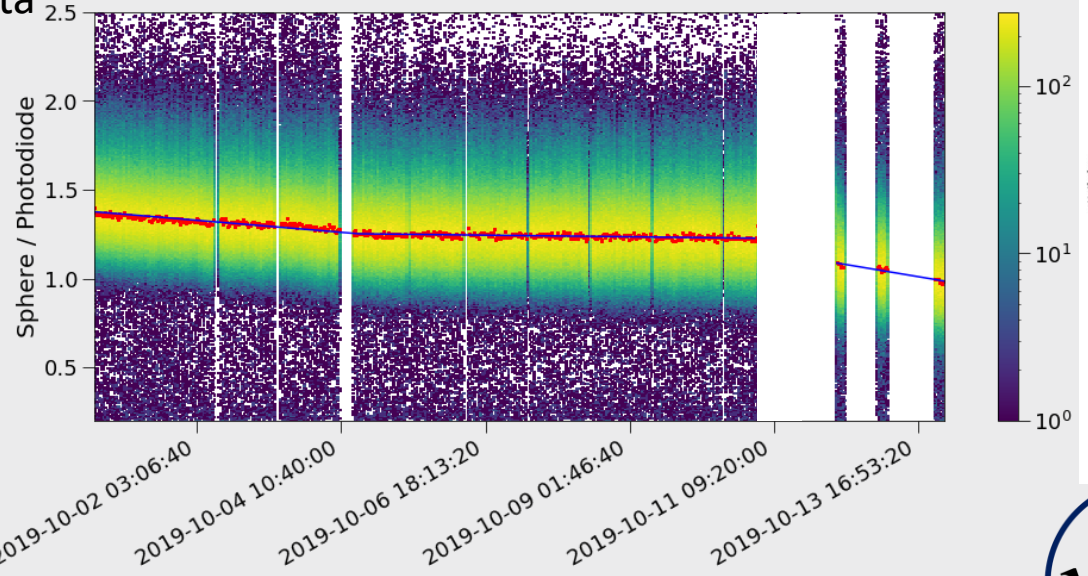


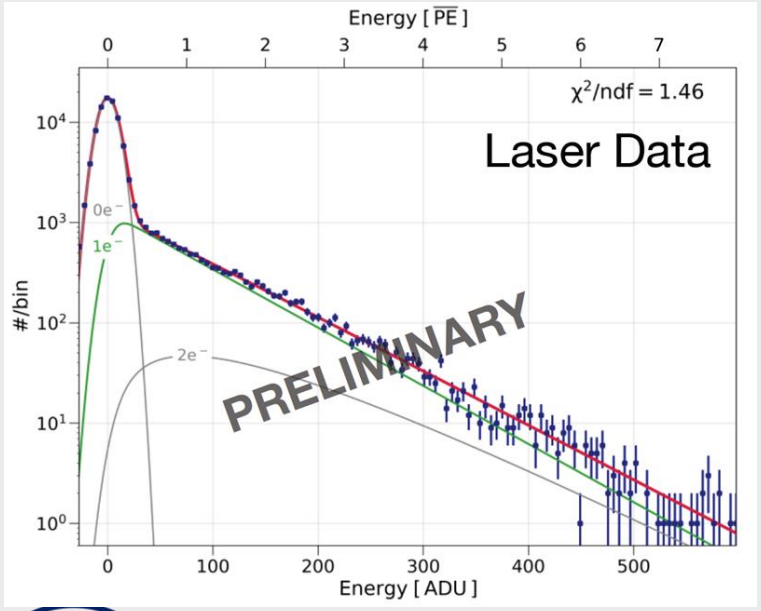


Laser calibration

- A 213nm UV laser is directed at the inner copper surface of the sphere and releases electrons though the photoelectric effect.
- The UV light also goes to a photodetector so the laser events can be tagged.
- Low-intensity laser data enables measurements of the single electron detector response (gain, avalanche statistics, trigger efficiency, peak detection threshold).
- High intensity laser data is used in all runs to enable constant monitoring of the detector.
- Gas degradation inducing a decrease in gain can be seen through laser events.

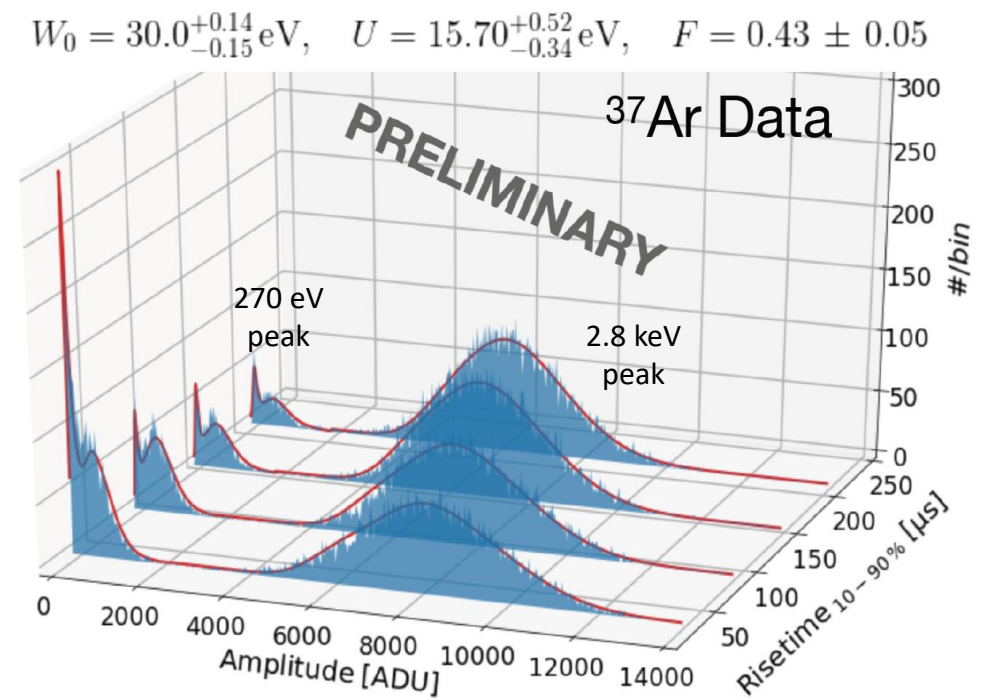


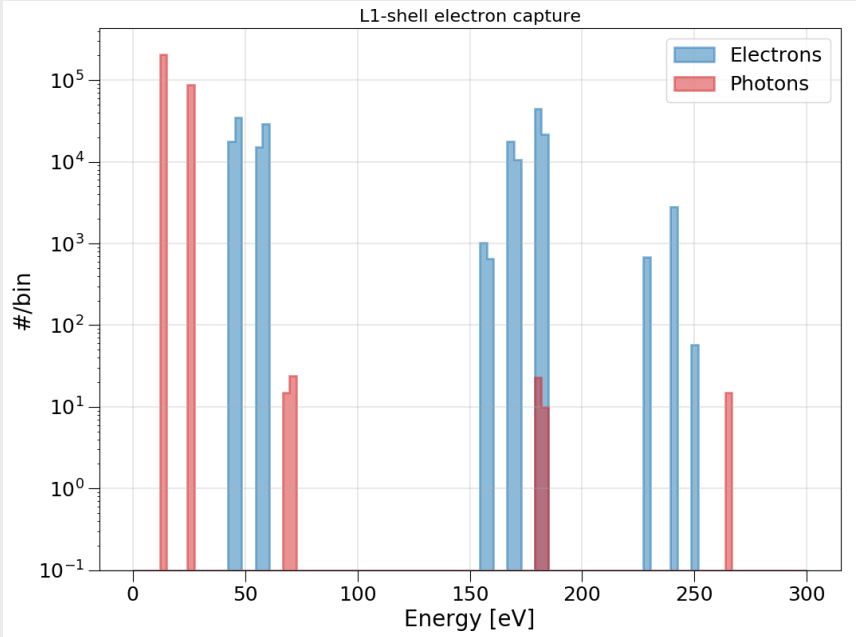




^{37}Ar Calibration

- Some argon-37 is released inside the sphere, and the gas diffuses in the whole volume. ^{37}Ar is produced at the Royal Military College in Kingston, in their SLOWPOKE-II reactor from CaO irradiation.
- This isotope is radioactive and has two main X-ray peaks (270 eV and 2.8 keV). It decays with a half-life of 35 days through electron capture.
- Argon-37 enables:
  - Energy calibration
  - Electron attachment parametrization
  - W-value and Fano factor measurements
  - South-channel anodes gain measurements

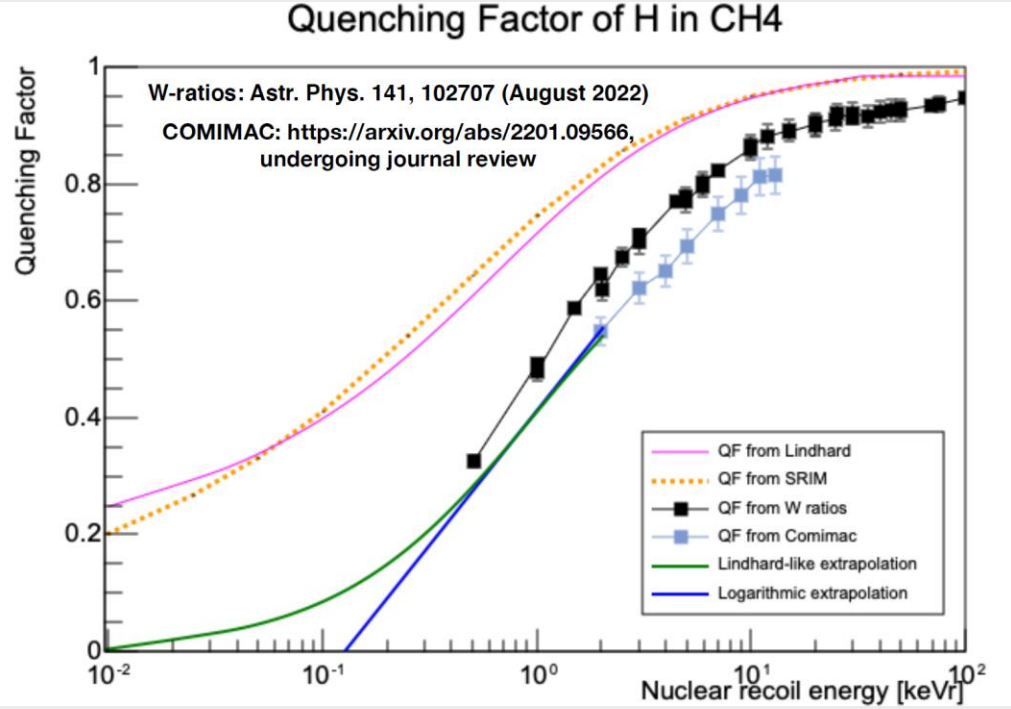


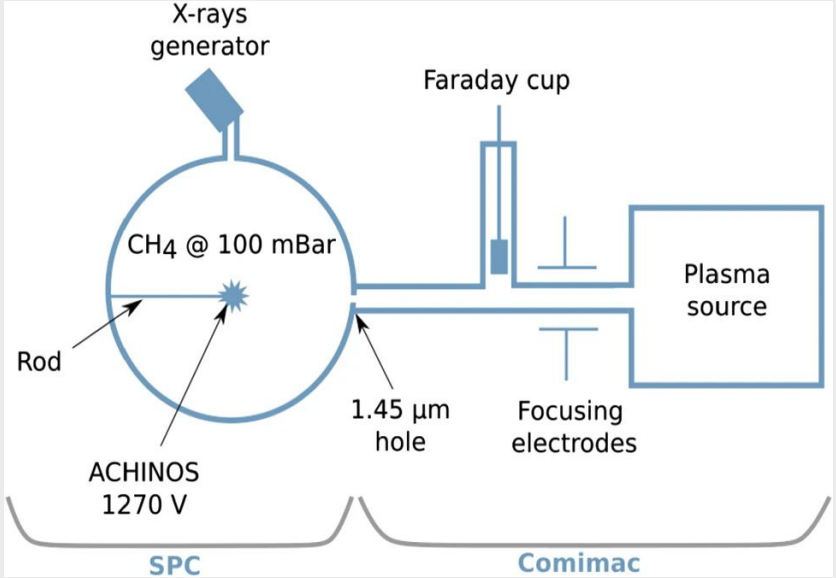


doi:10.1088/1742-6596/2156/1/012059

Quenching factor

- The quenching factor was measured at COMIMAC as well as obtained from literature W-values.
- Lower energy quenching factor were extrapolated logarithmically (more conservative).
- Future quenching factor measurements for lower energies and other gas mixtures in preparation.

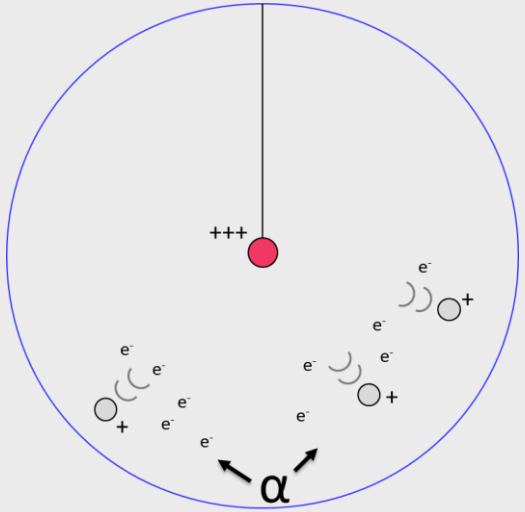


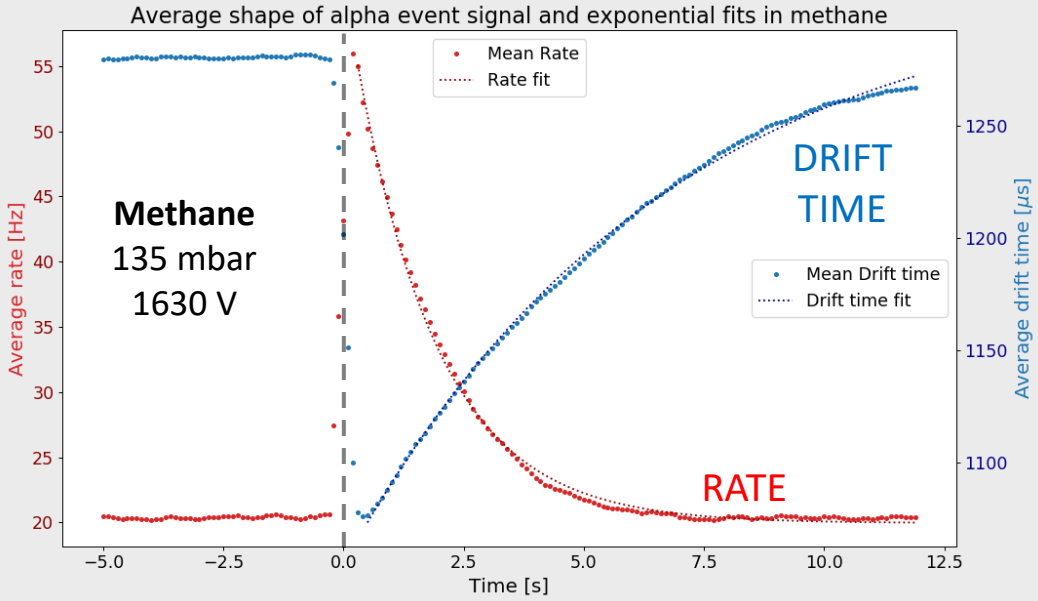


doi:10.1140/epjc/s10052-022-11063-9

Alpha contamination

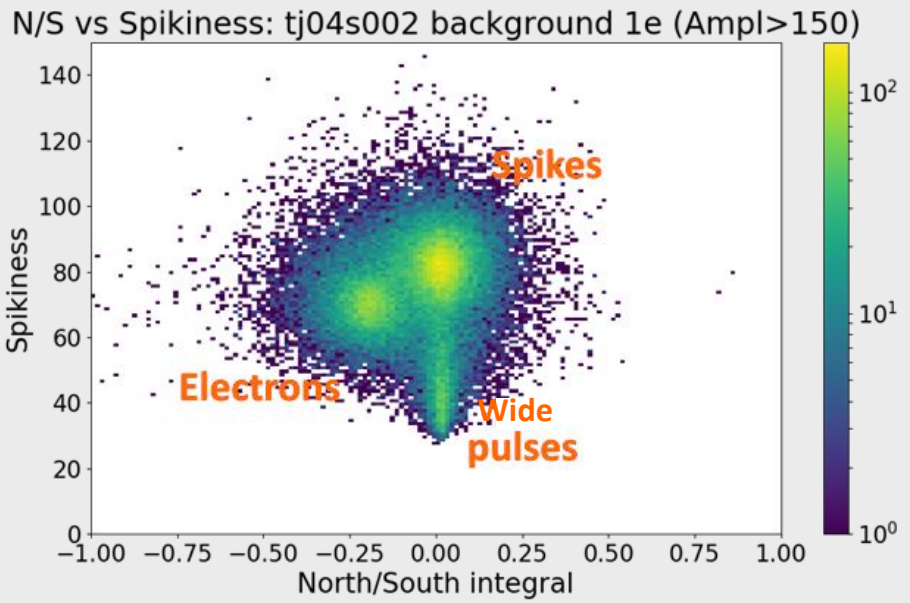
- There is ~25 mHz of alphas from ^{210}Po contamination in the copper surface.
- Alphas ionize a lot of gas and create a space charge that disturbs the electric field, and changes the electron drift time.
- For some still unknown reason, a high rate of low energy events keep happening for around 5s after each alpha.
- We remove 70% of the low-energy background with a 5s cut after each detected alpha, keeping 88% of the total time.

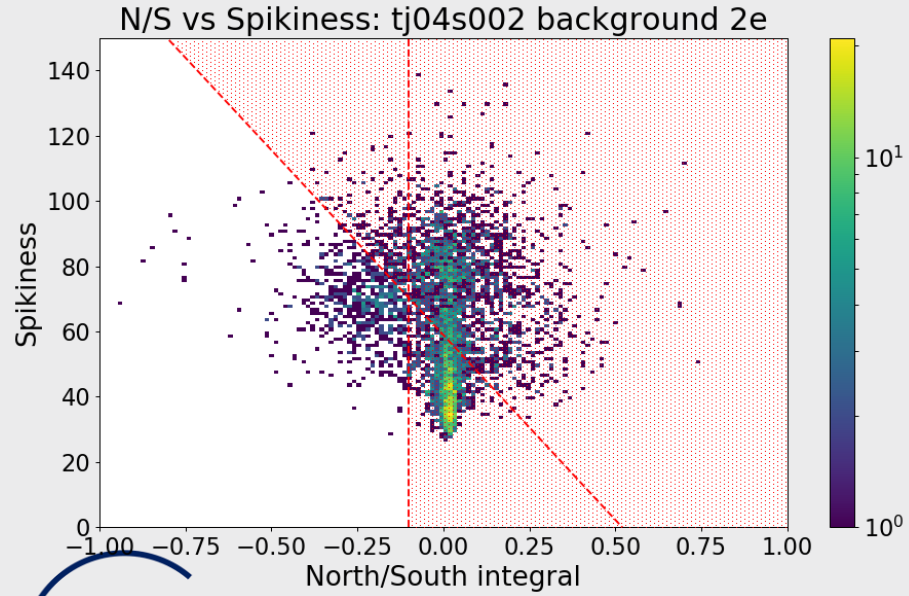




Pulse shape discrimination

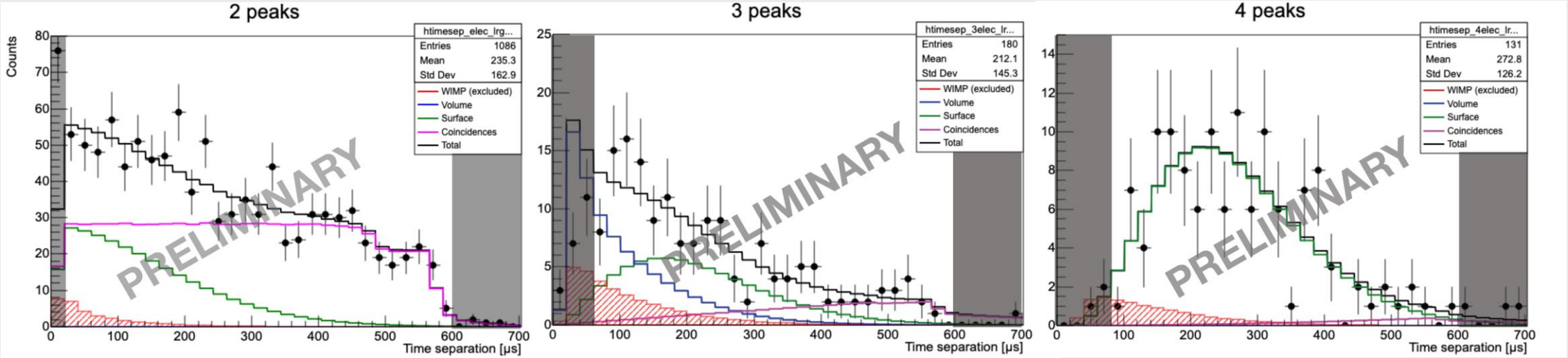
- There are spurious pulses caused by electronic discharges in the data.
- Those can be discriminated from physical events with two different methods:
  - Spurious pulses are either measurably spikier or wider than physical events.
  - Spurious pulses do not cause a negative induced pulse on the opposite channel.
- Around 95% of the spurious pulses are removed with cuts usings theses discriminants, while still keeping 77% of the physical events.





Physics data fits

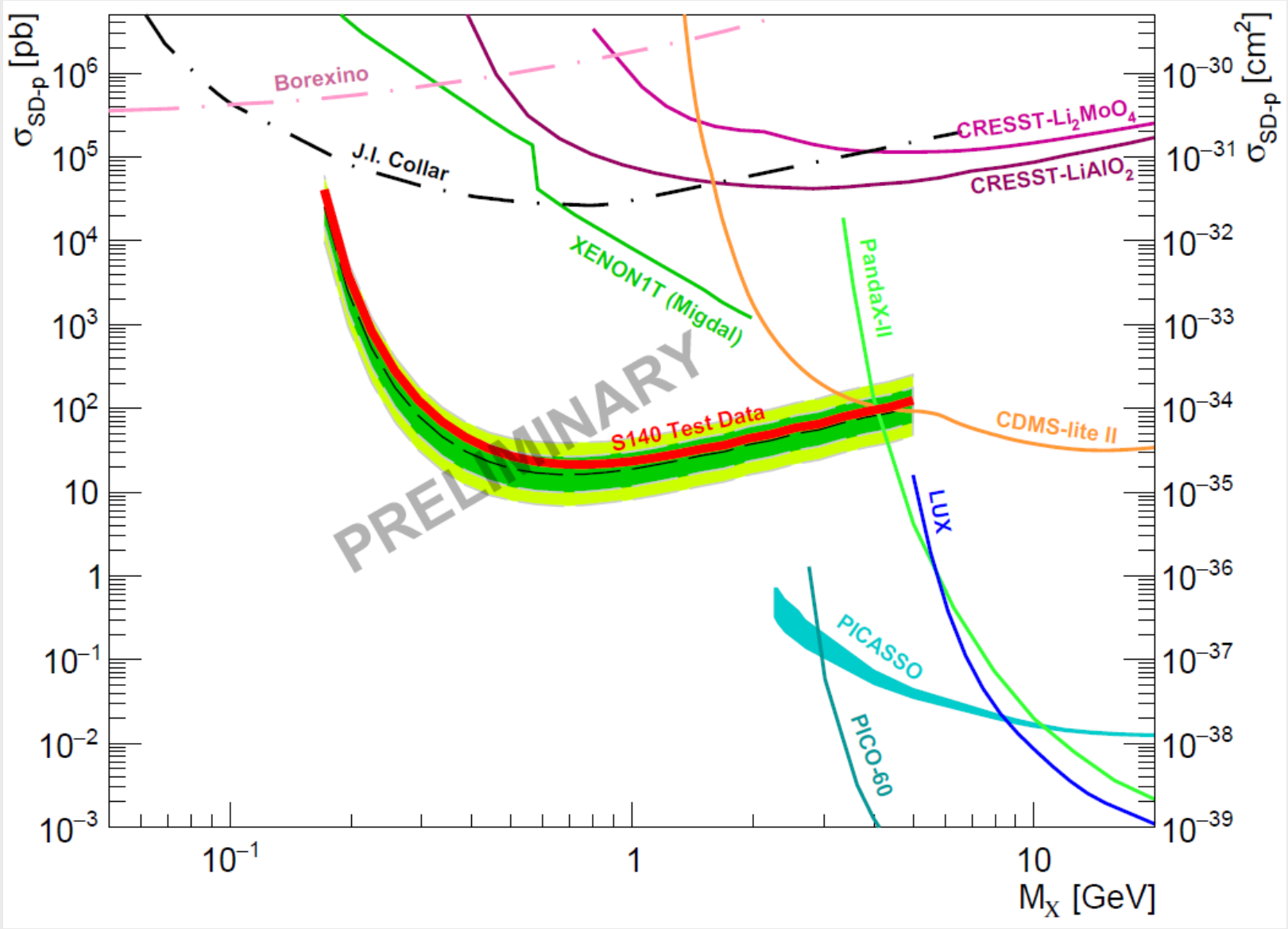
- 30% of the full data was set aside as a test data before the rest is unblinded.
- Profile likelihood fits of the test data were made for 2-3-4 peak data.
- Fits with contributions from volume background, surface background, coincidences and WIMP signal.
- No significant WIMP signal was detected.



scipost_202210_00005v1

Preliminary limits

- WIMP exclusions limits with ~0.12 kg·days of data
- Strongest constraints for the proton spin-dependent interaction in the 0.2 - 1.5 GeV range.
- Final blind data results to come in a few weeks.



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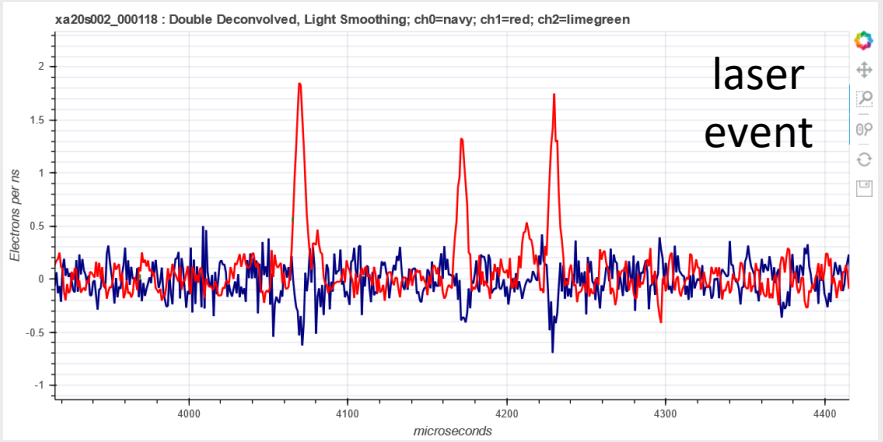
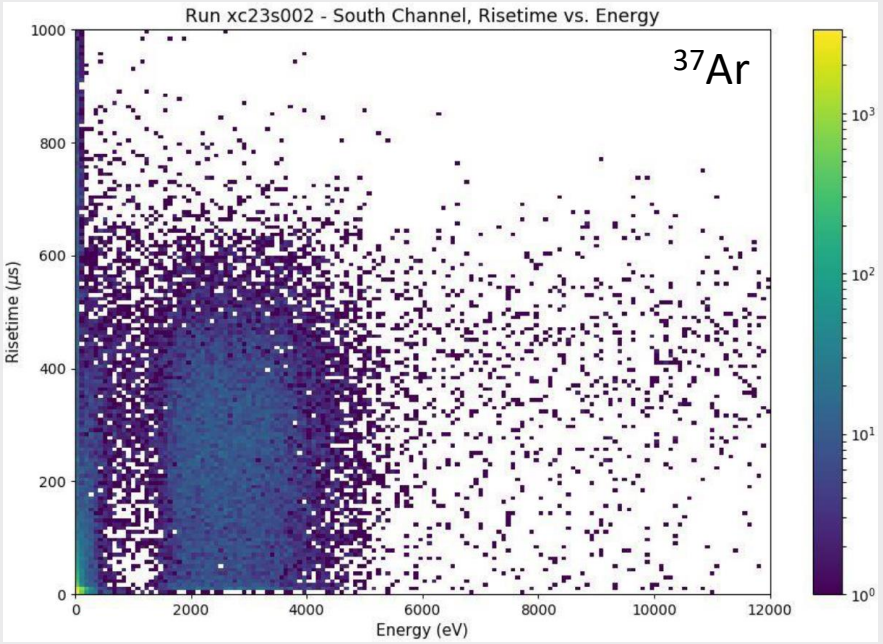
News from SNOLAB

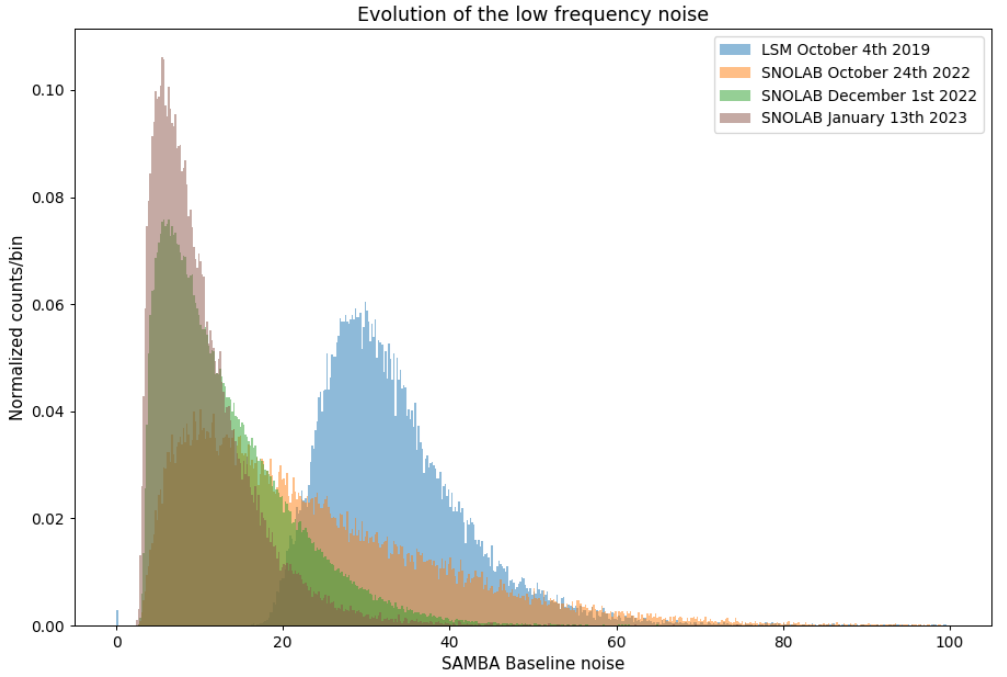
- One physics data campaign taken, preparing the next one
- Still countable electrons
- Improvements from LSM:
  - Trigger on three channels (North, South, PD)
  - Reduced noise
  - No spurious pulses
  - Better gas purity
  - Neon+2%CH_4, CH_4, Ar+CH_4, He+CH_4 etc.

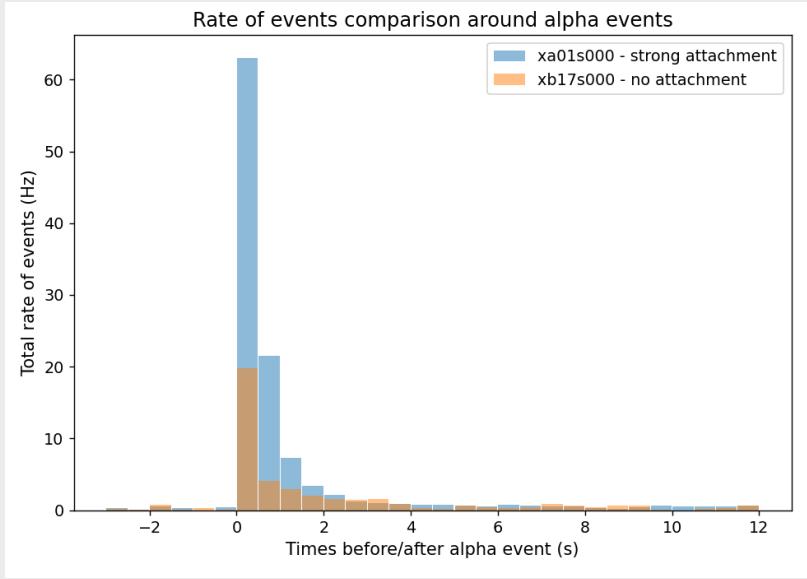




SNOLAB noise

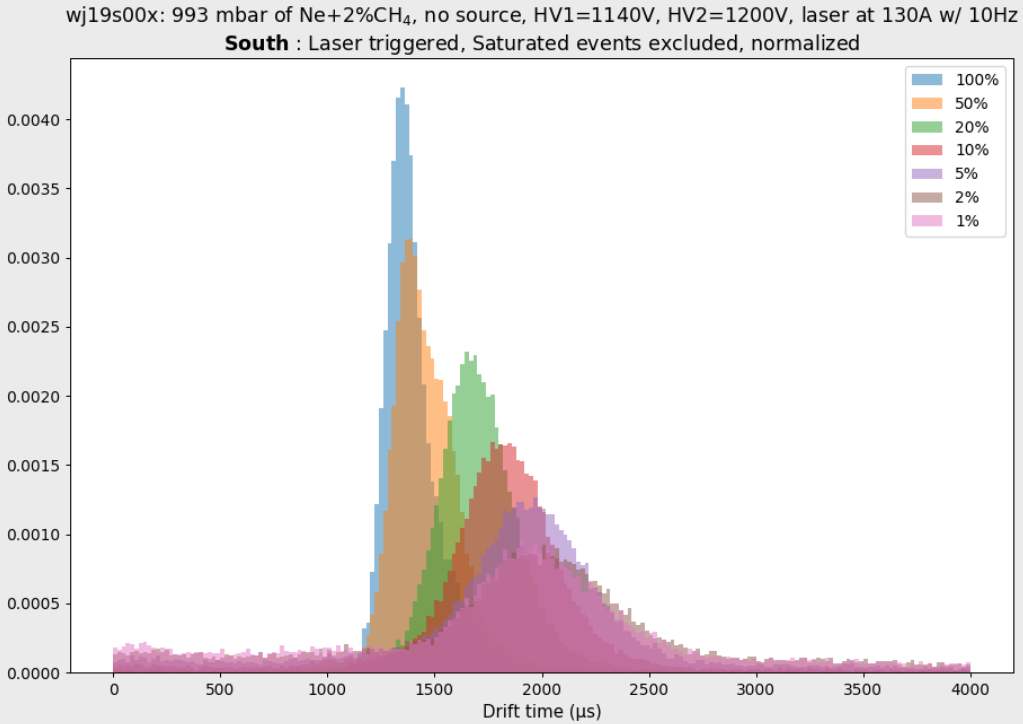
- Multiple improvements (dampening vibrations, better electronic isolation) across months slowly reduced the background noise.
- Better gas quality was shown to reduce the alpha induced background.
- Expected improvements for the rest of the year:
  - Second etching
  - New gas purifier
  - New radon trap
  - New sensors

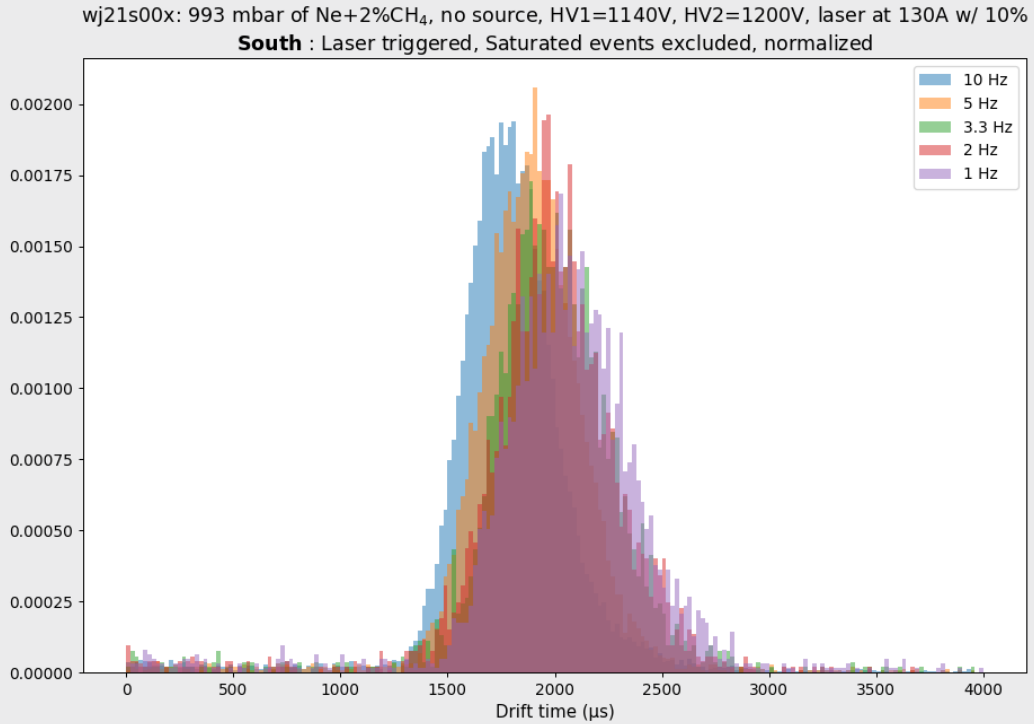




SNOLAB space charge

- Additional studies on the space charge effect show how the electron drift time decreases when the laser intensity or laser rate is increased.





- Also: ongoing analysis on the effects of alphas and space charge on rate and gain. TBC

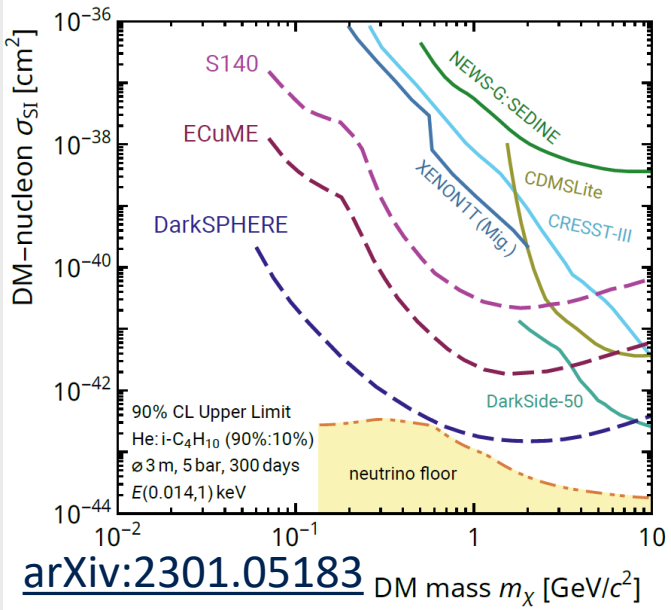
Future DM projects

ECuME

- Fully underground electroformed 140 cm of diameter copper sphere to be made inside SNOLAB.
- Mini-ECUME prototype with 30 cm of diameter to be built during the second half of 2023 at PNNL.
- Last tests before Mini-ECUME currenlty being completed.

DarkSPHERE

- Fully electroformed 3m of diameter sphere in a water shield for the Boulby Underground Laboratory, in England (under consideration).

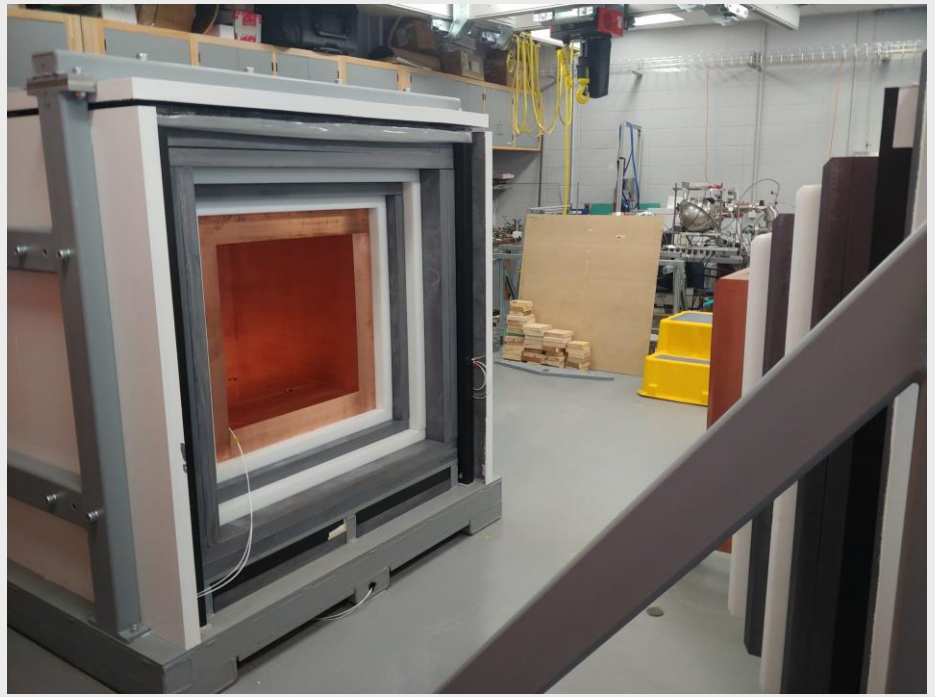


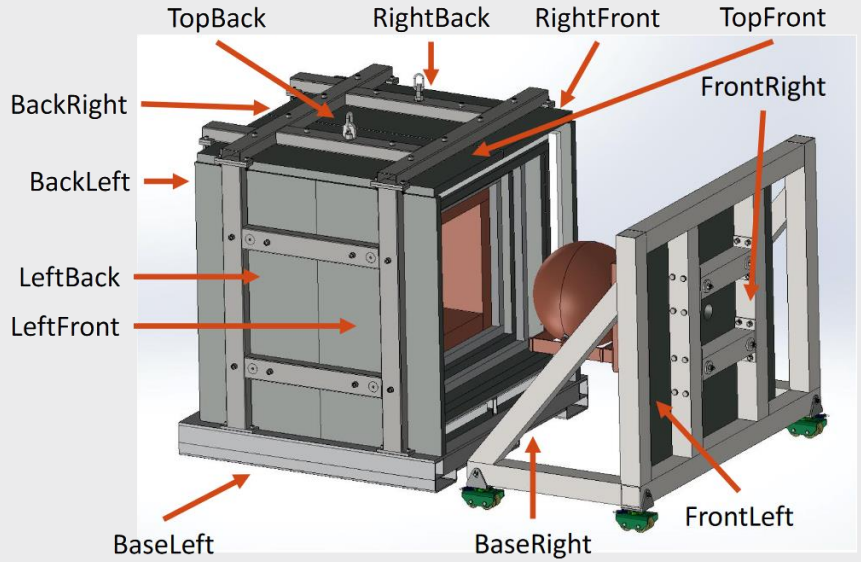
arXiv:2301.05183

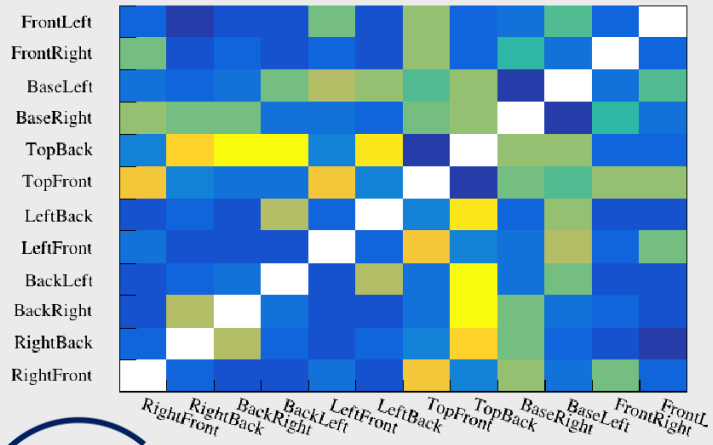
Neutrino research

NEWS-G³ (or G3)

- Shield at Queen's University intended for CEvNS detection at nuclear reactors.
- The shield is comprised of multiple layers of lead, polyethylene, scintillators (muon veto) and copper. It was completed last summer.
- Tests, simulations and calibrations are currently being done at Queen's.







Conclusion

- NEWS-G and SPCs well suited for low mass dark matter search.
- LSM data able to set new SD-p WIMP constraints with CH_4.
- Currently taking physics data at SNOLAB with many improvements.
- Promising future projects in the works.

Merci !!!