# The NEWS-G dark matter experiment: Shifting from LSM to SNOLAB data

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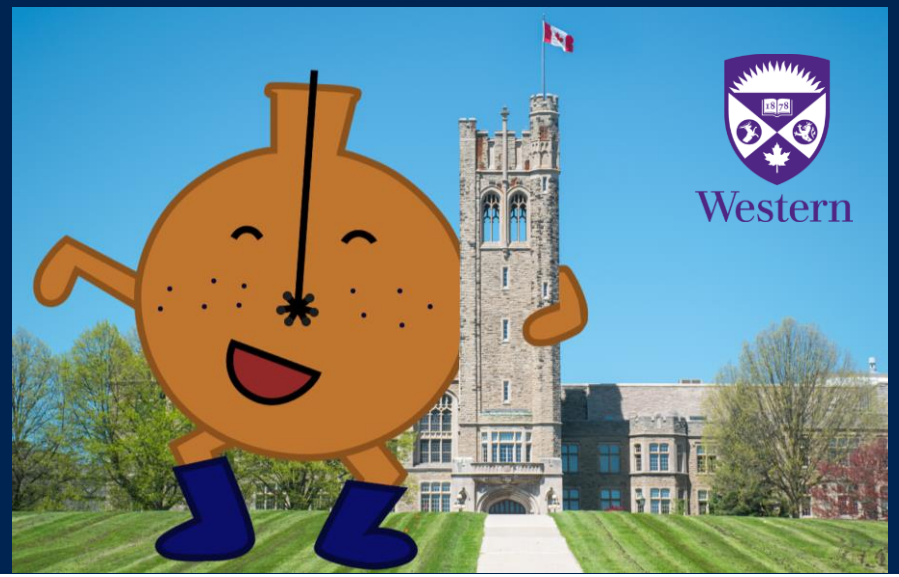
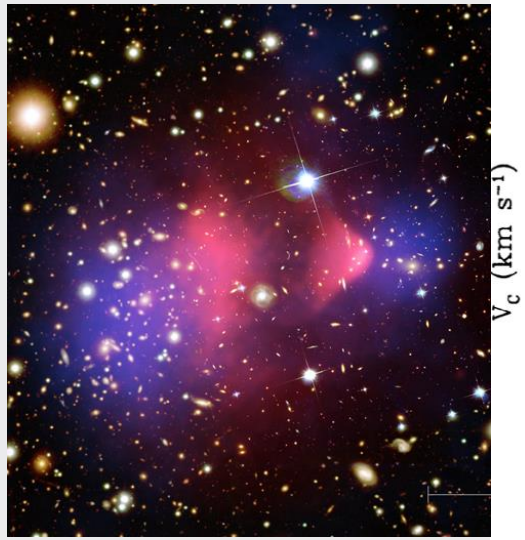
CAP conference, London ON

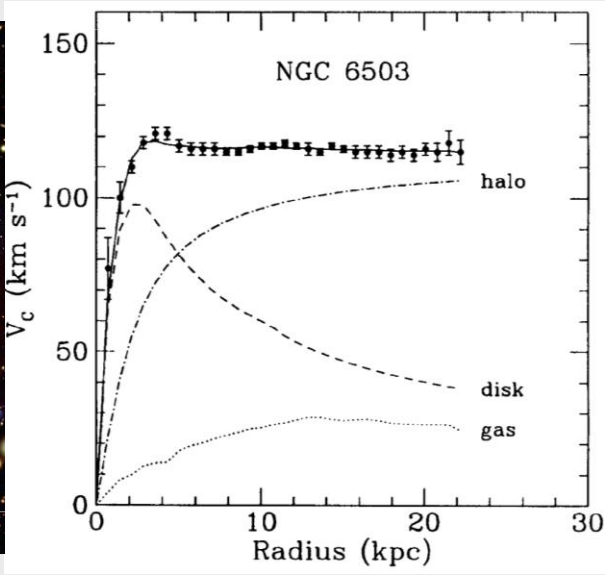
May 27th, 2024

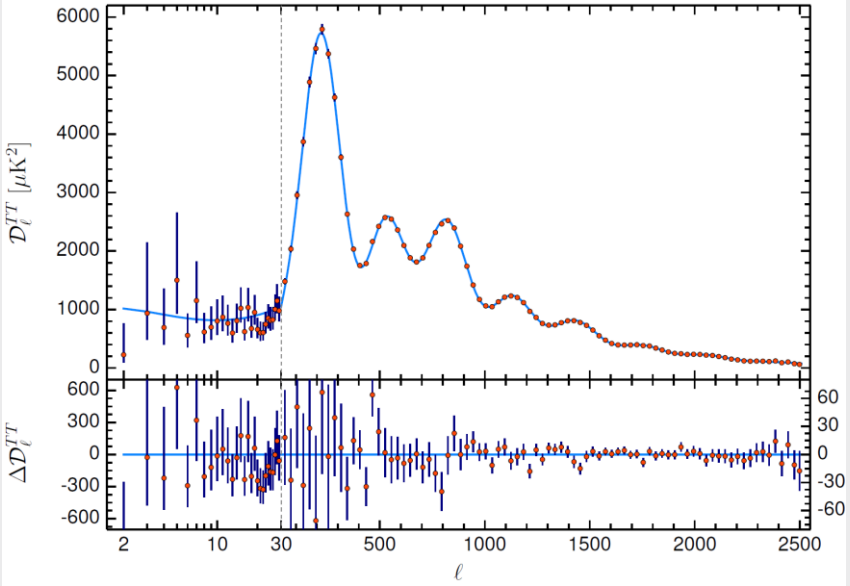


# Dark matter theory

- Dark matter (DM) evidence:
  - First Zwicky (1933): Visible mass of galaxies much lower than expectation from virial theorem.
  - Rotation curves have velocities stay higher than expected from Kepler's 3rd law.
  - Fits on the CMB show 85% of the Universe's mass as non-baryonic matter
  - Gravitational lensing shows the actual mass distribution of galaxies. Most of the Bullet cluster's mass is invisible and less interacting.

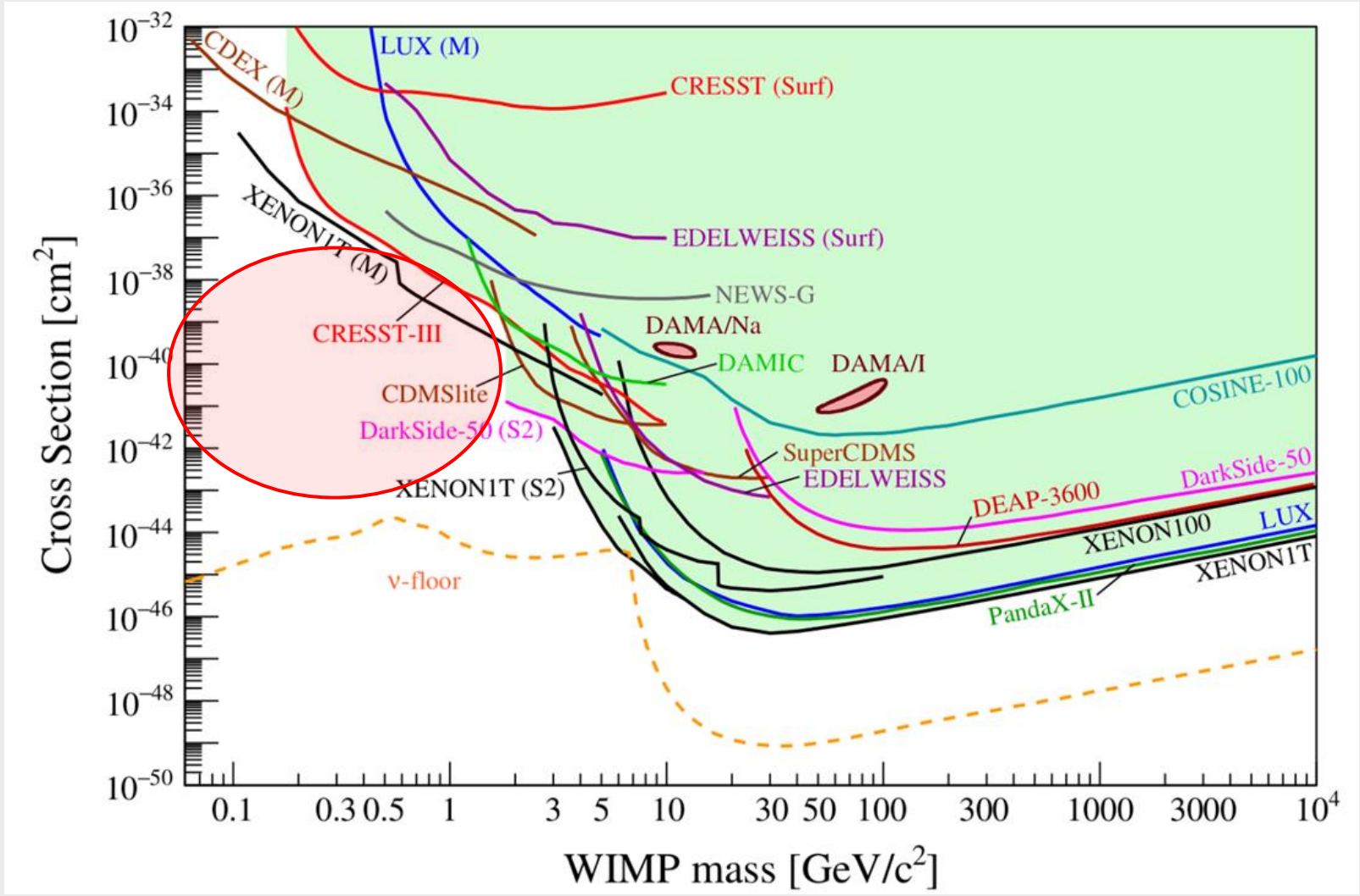




# Low mass WIMP search motivation

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

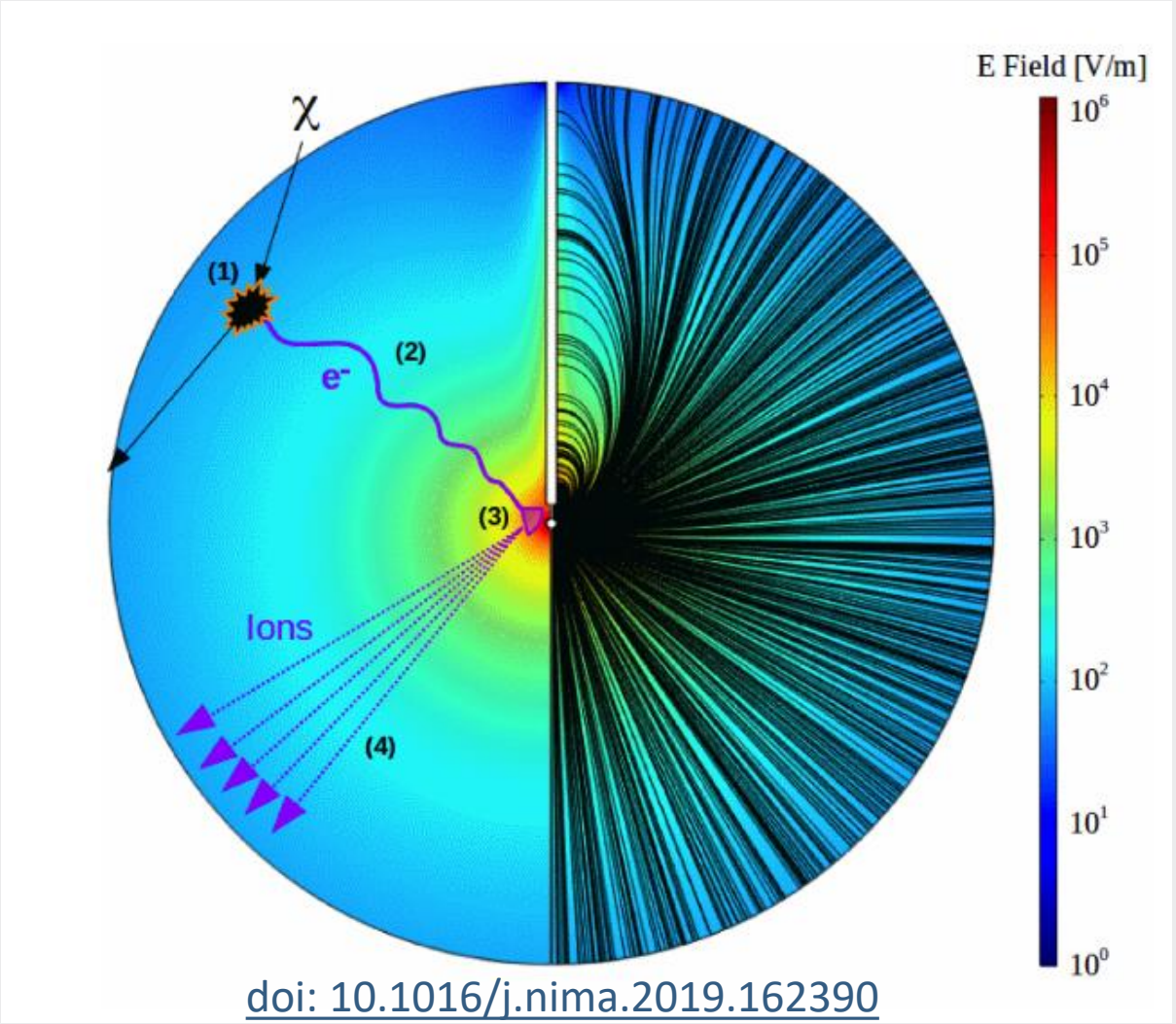
- The NEWS-G experiment uses spherical proportional counters (SPC) to search for low mass dark matter.
- SPCs are metallic spheres filled with gas, with a central anode producing a radial electric field.
- The last dark matter limits are from the SEDINE detector (60 cm diameter) at the *Laboratoire Souterrain de Modane* (LSM) in 2017.
- The latest detector, S140, is a 140 cm of diameter copper sphere which took data at the LSM in 2019, before being shipped to SNOLAB where it is currently taking data since 2022.

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.

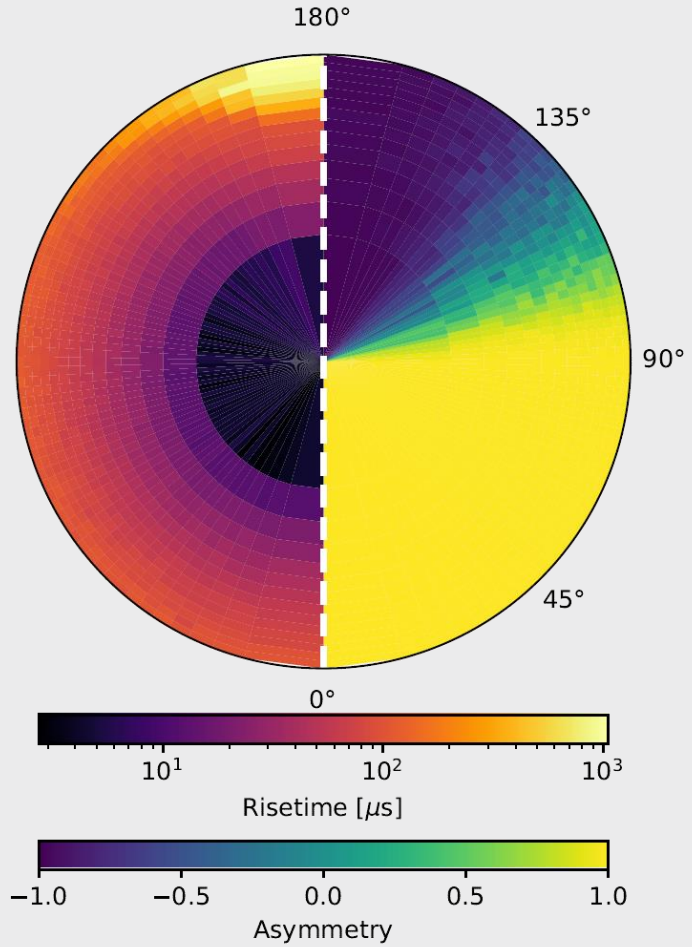



doi: 10.1016/j.nima.2019.162390

# Sensor (achinos)

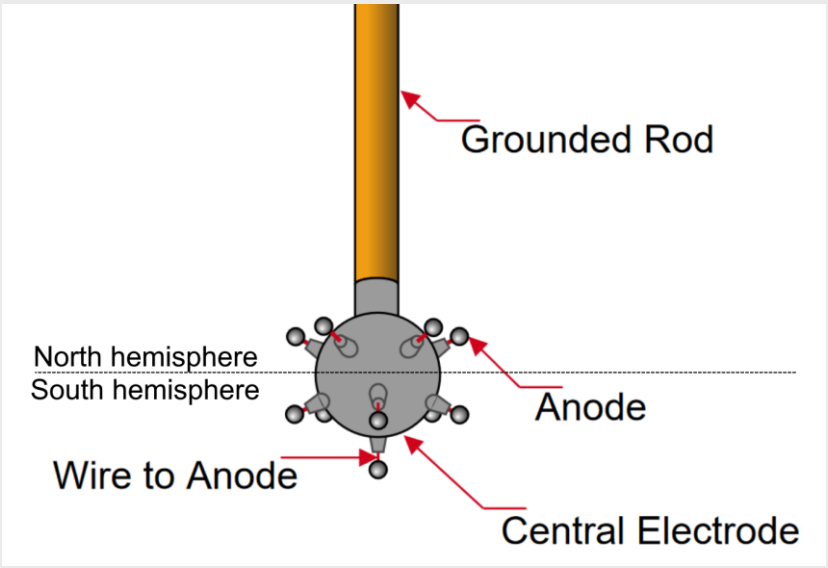
arXiv:2301.05183

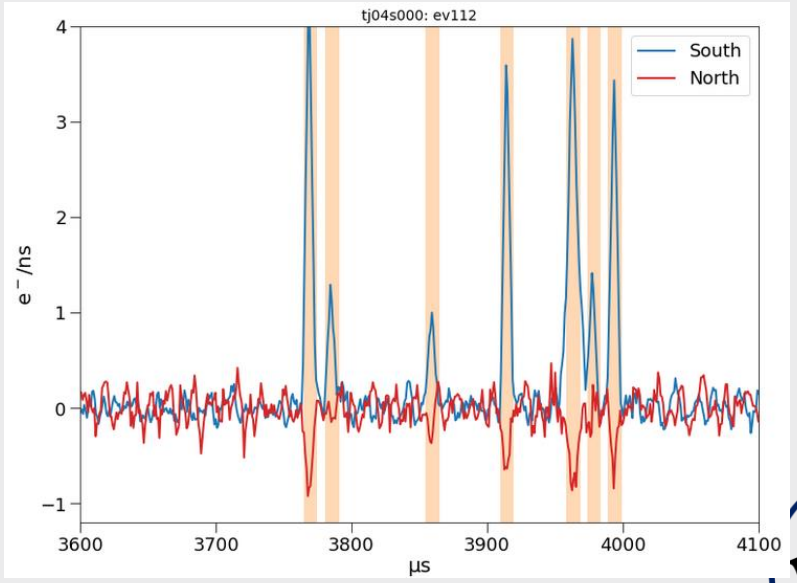
- NEWS-G now uses a multi-anode sensor that can achieve high gain while keeping a strong electric field at a high radius.
- The sensor is divided in two channels connecting the anodes of each hemisphere.
- A signal on one channel induces a negative signal on the other one (Shockley-Ramo effect).
- About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




Only pure south events are kept as candidate events.

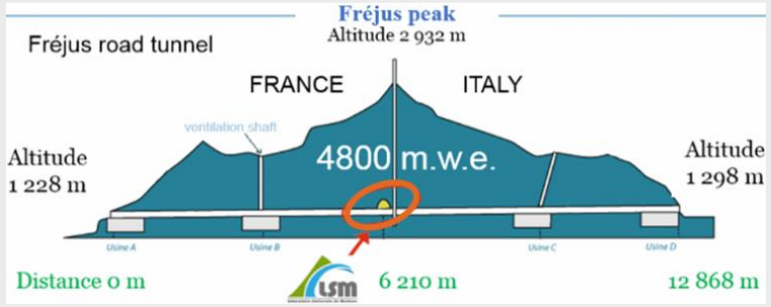
doi:10.1088/1742-6596/2156/1/012059

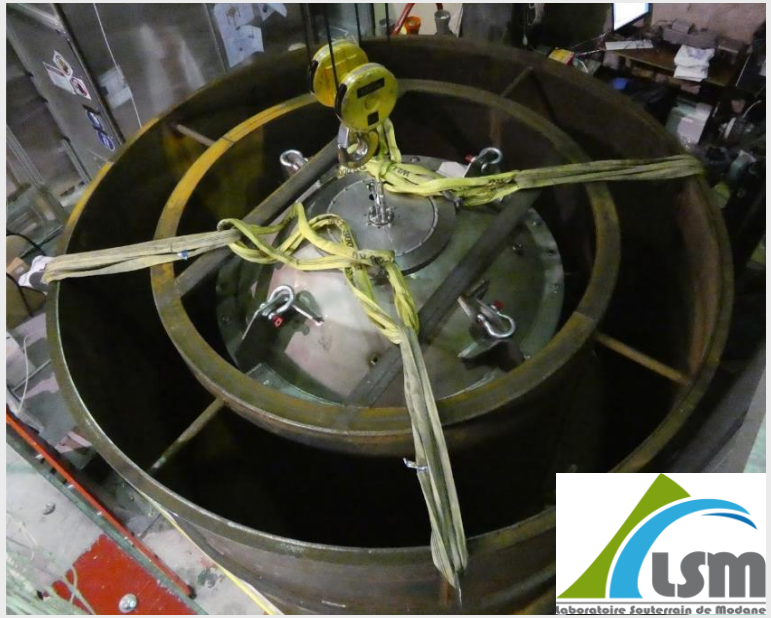


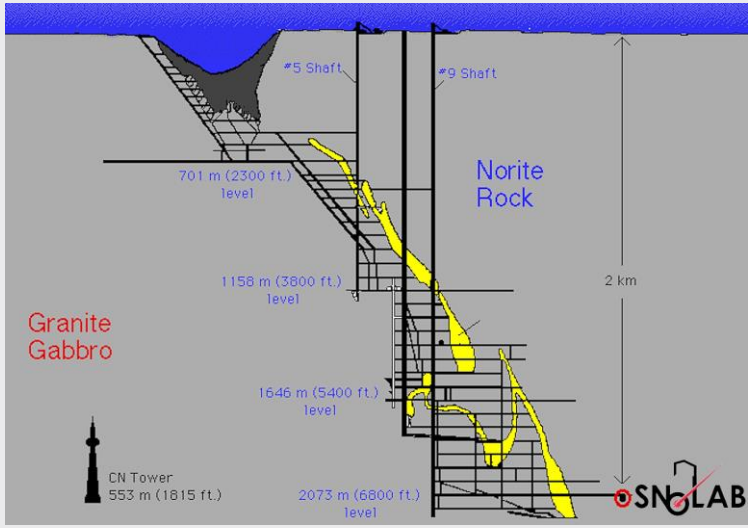
# Shielding and data taking with S140

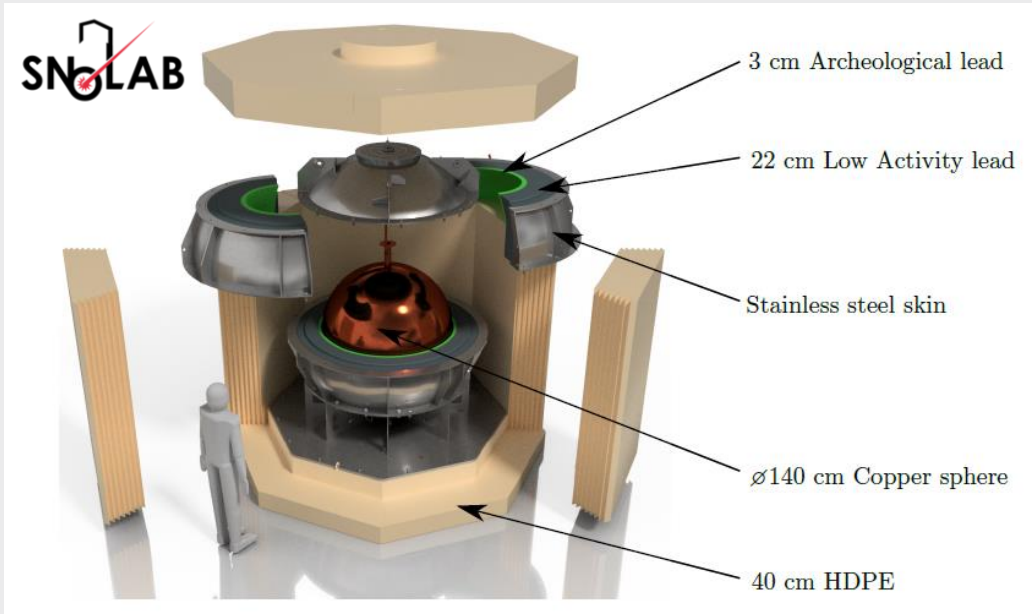
Laboratoire Souterrain de Modane (LSM)



- 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.
- More time in SNOLAB to try more gas mixtures. Already 2 weeks with 1 bar of Ne + 2%$CH_4$. Now taking Ar + 5% $CH_4$ data.



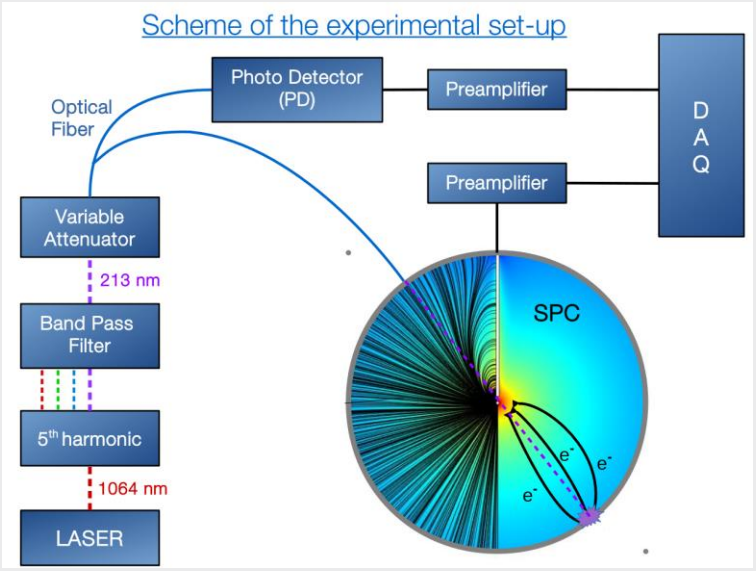



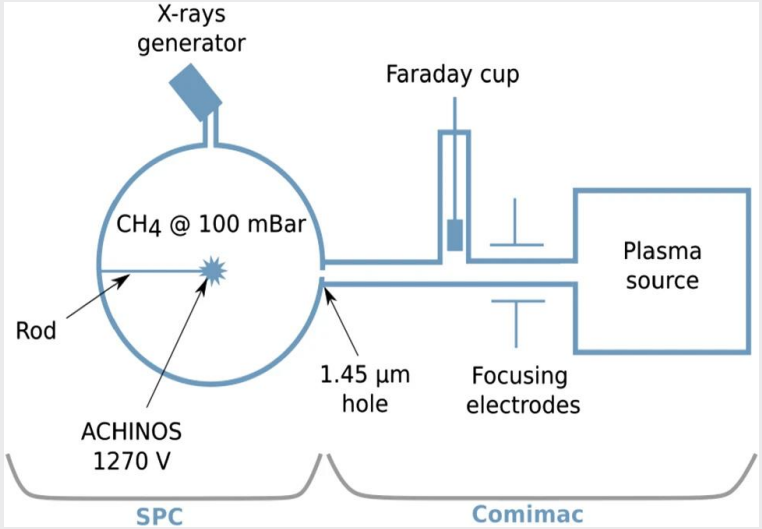

SNOLAB detector paper
doi:10.1088/1748-0221/18/02/T02005

# Calibration

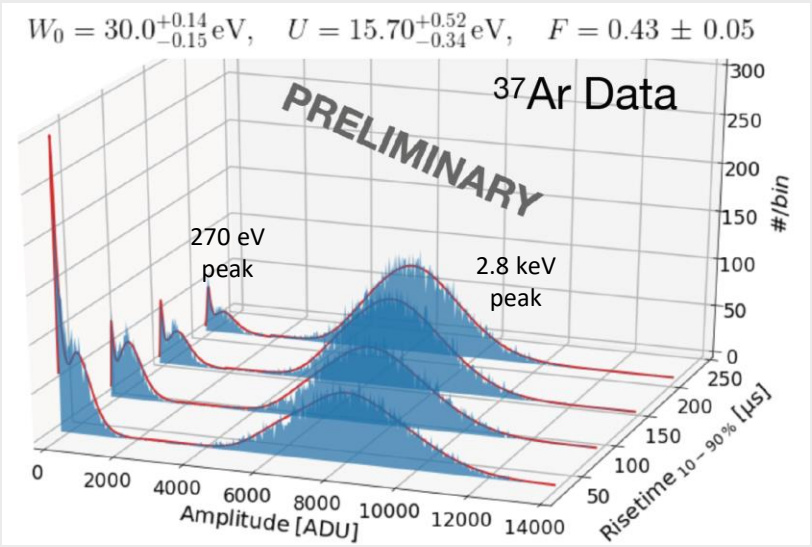
- A UV laser is directed at the inner copper surface of the sphere and releases electrons though the photoelectric effect. The UV light also goes to a photodetector so the laser events can be tagged.
- Some argon-37 is released inside the sphere, and the gas diffuses in the whole volume. This isotope is radioactive and has two peaks that enable energy calibration.
- Ionization yield (W-value) for $CH_4$ measured at Queen's University.
- The nuclear quenching factor was measured at COMIMAC as well as obtained from literature W-values.
- New lower energy quenching factor measurements are planned at UdeM and RMTL, with the backing detector currently being built.

*Poster on QF from Neha Panchal*
*Talk from Mayank Arora tomorrow*



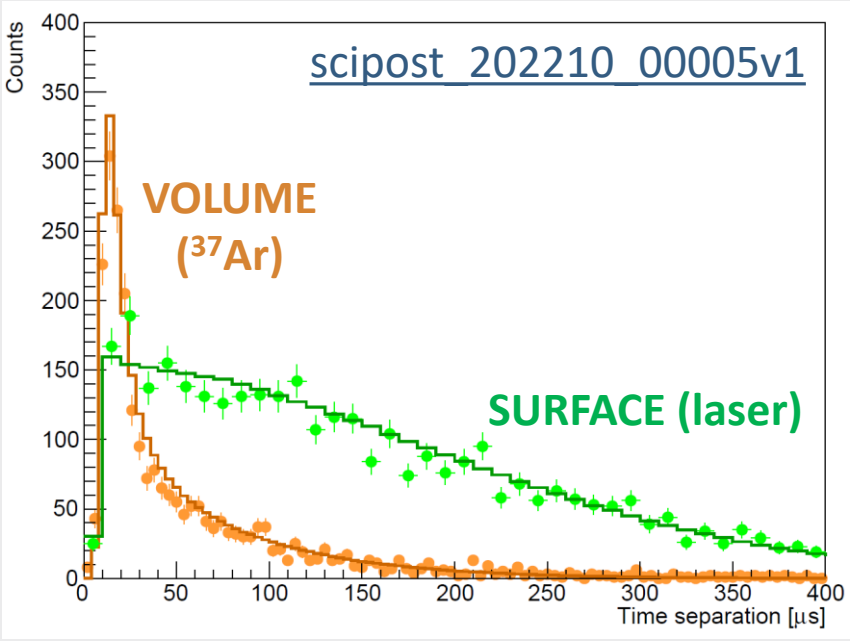

doi:10.1140/epjc/s10052-022-11063-9

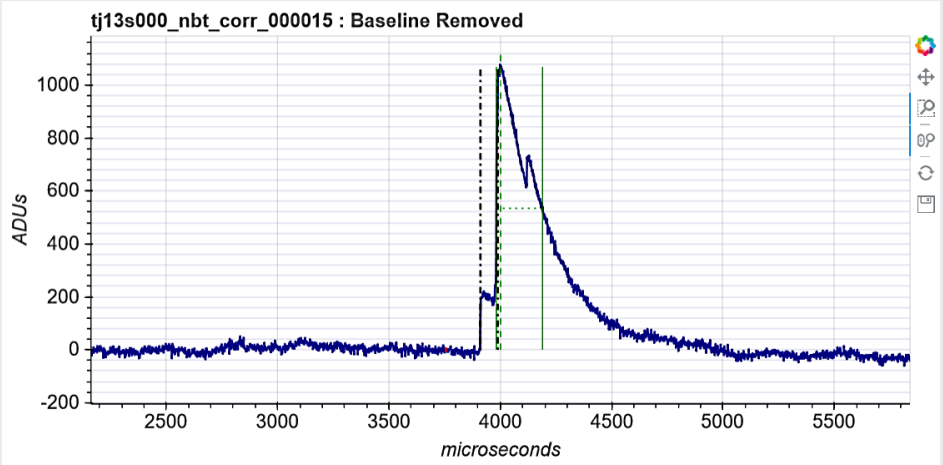



doi:10.1088/1742-6596/2156/1/012059

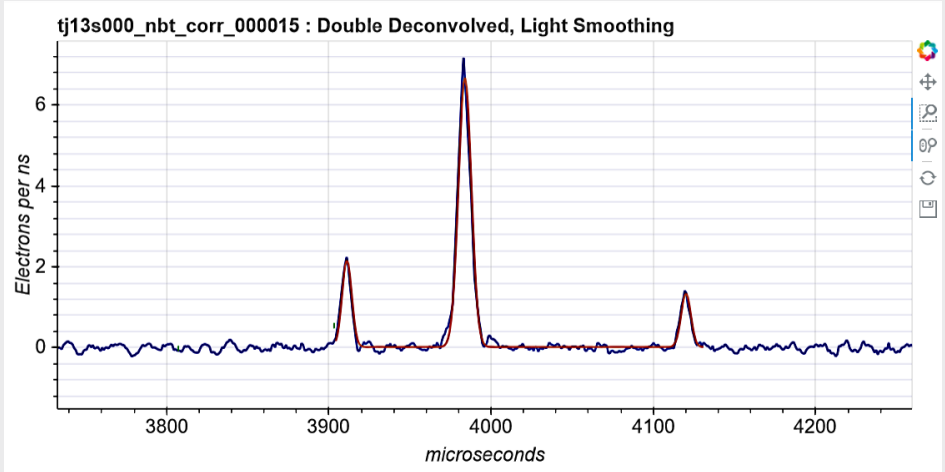
# Peak counting and time separation

- The exponential decay of the preamplifier and the ion response are deconvolved from the raw signal.
- It is possible to count individual primary electrons.
- Surface events experience more diffusion than volume events, which causes the time separation between the first and last peak to be larger.



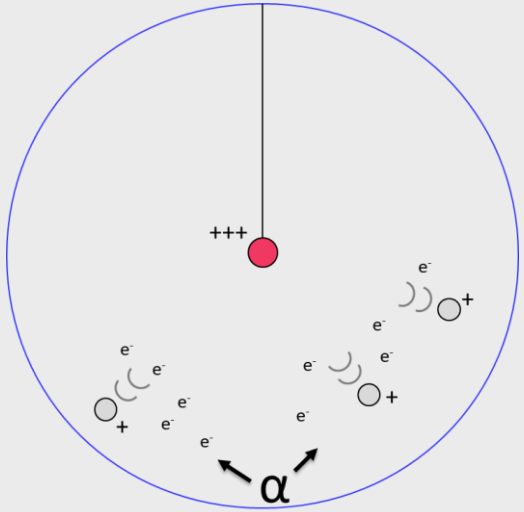

**DOUBLE-DECONVOLUTION**

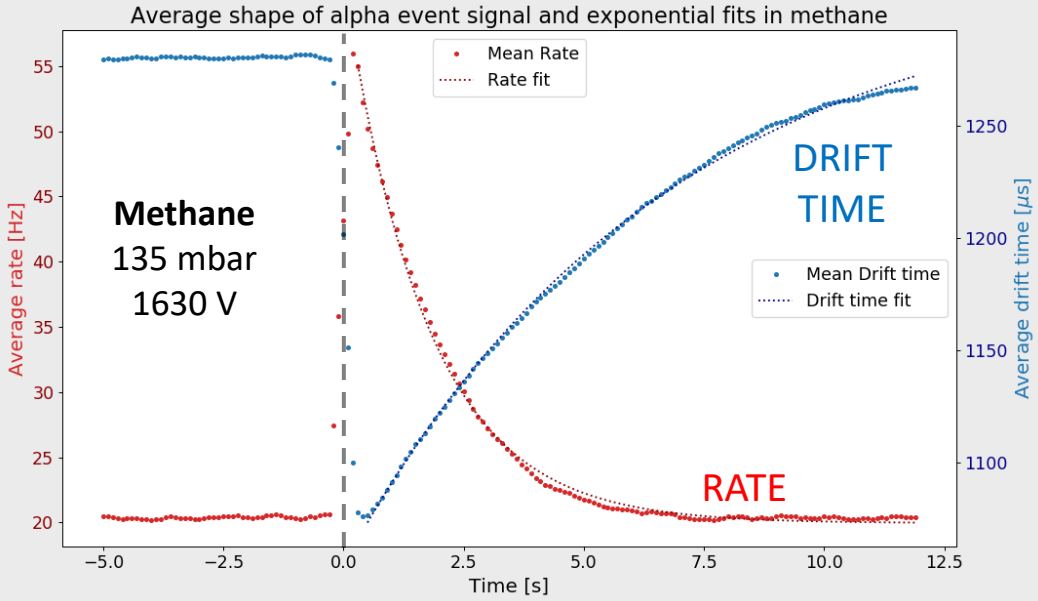



*Talk on denoising from Annabelle Makowski in ~10min*

# Alpha contamination

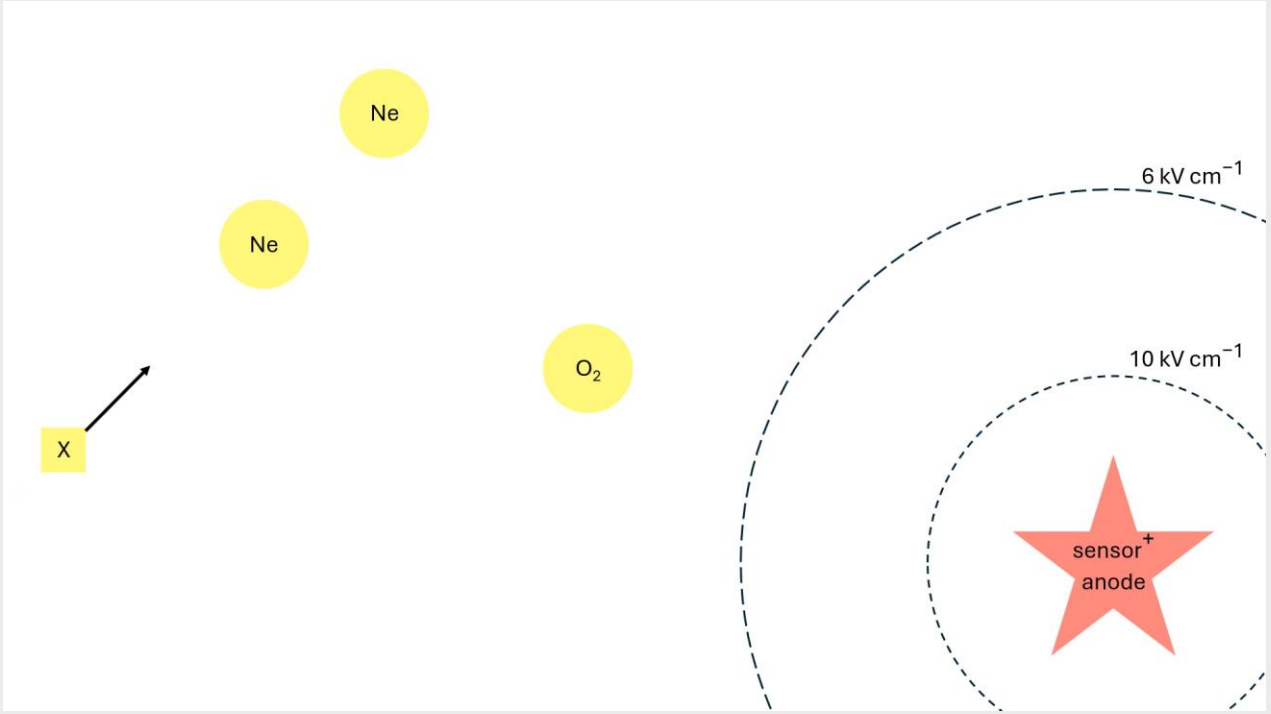
- There is ~25 mHz  of alphas from either $^{222}$Rn or $^{210}$Po contamination in the copper surface.
- Alphas ionize a lot of gas and create a space charge that disturbs the electric field, and changes the electron drift time.
- Probably due to attachment, a high rate of low energy events keep happening for around 5s after each alpha.
- We remove most of the low-energy background due to alphas with a 5s cut after each one, keeping 85-90% of the total time.

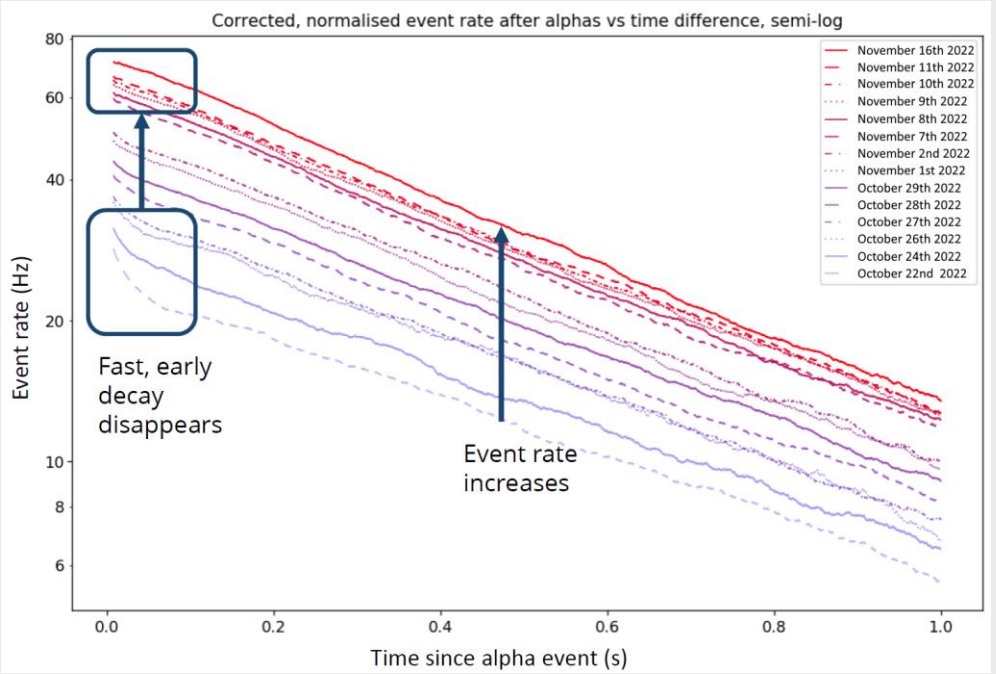


# Alphas in SNOLAB

- SNOLAB still has an alpha background with a similar rate. Etching of the inner surface has not removed the alphas.
- The increased rate of events after alphas is correlated with the impurity of the gas.
- The leading theory is that negative ions cause the delayed signals in the seconds after alpha events.

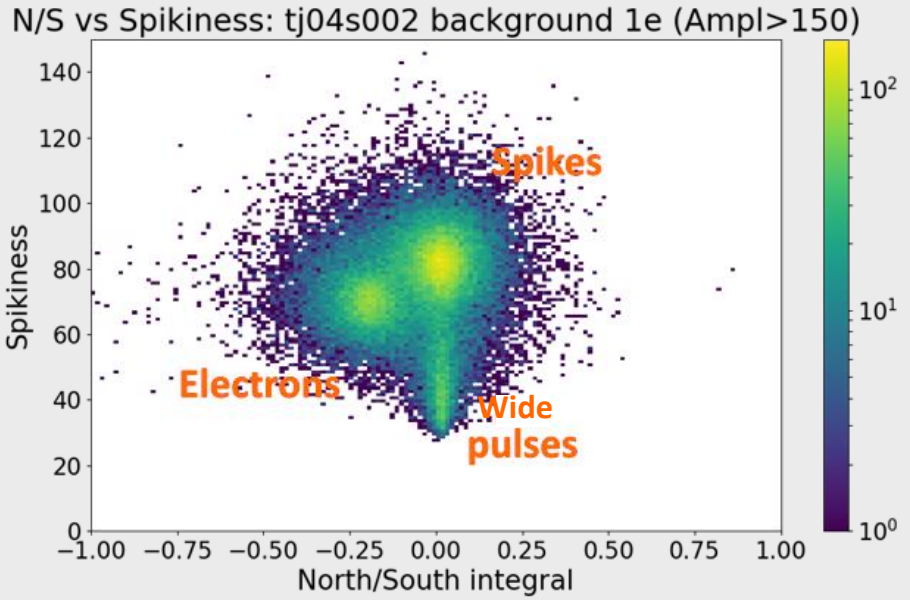


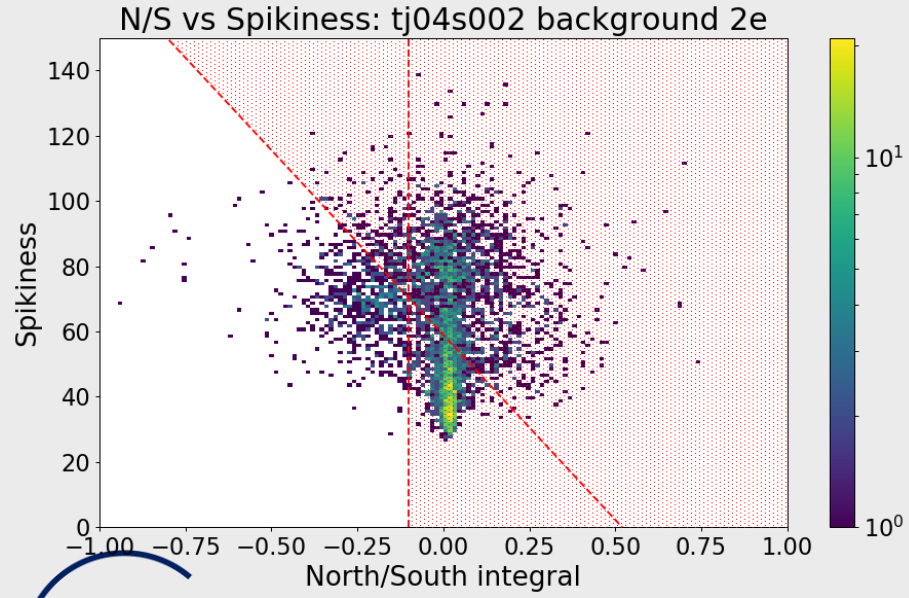




J. Clarke

# Pulse shape discrimination

- In the LSM, there were 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.
- In SNOLAB, spurious pulses have been less numerous due to having more time to fix the electronics and remove them from the source.

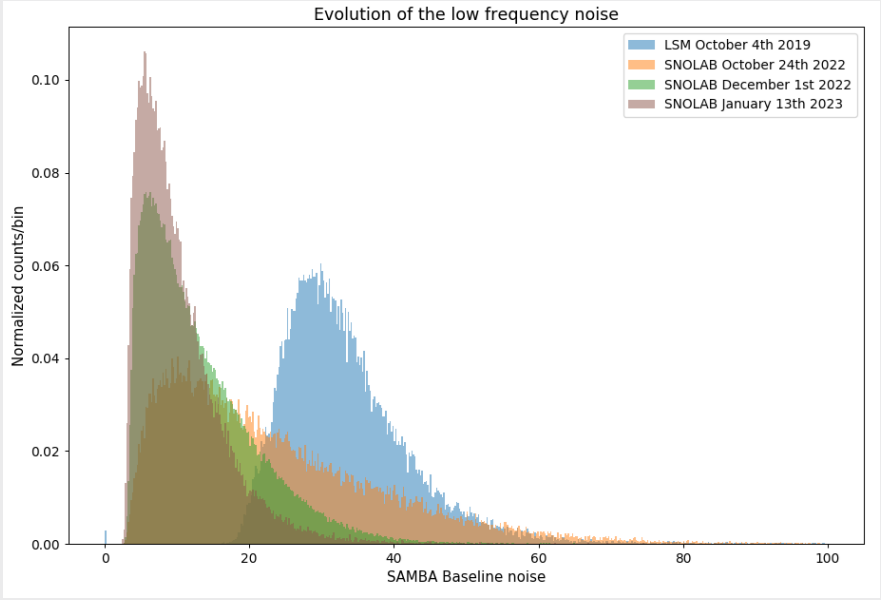


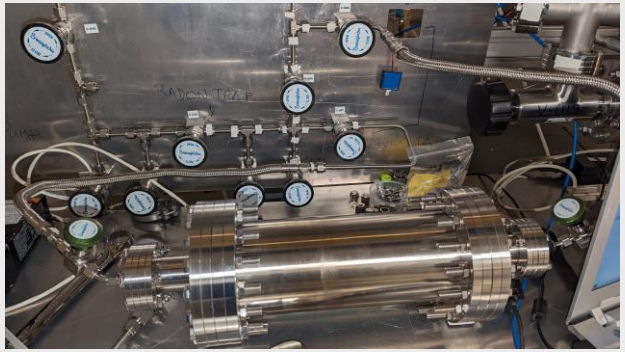
# Noise and data taking

Improvements from LSM:

- Trigger on three channels (North, South, PD) instead of only one at a time
- Reduced noise
- Better gas purity
- Gas purifier from University of Birmingham
  - Oxygen removal from copper balls and molecular sieve
- Silver zeolite radon trap from University of Alberta
  - New installation this week after adjustments
- Time to try multiple gas mixtures:
  Ne+2%$CH_4$, Ar+$CH_4$, Ne+7%$CH_4$, $CH_4$, He+$CH_4$ etc.



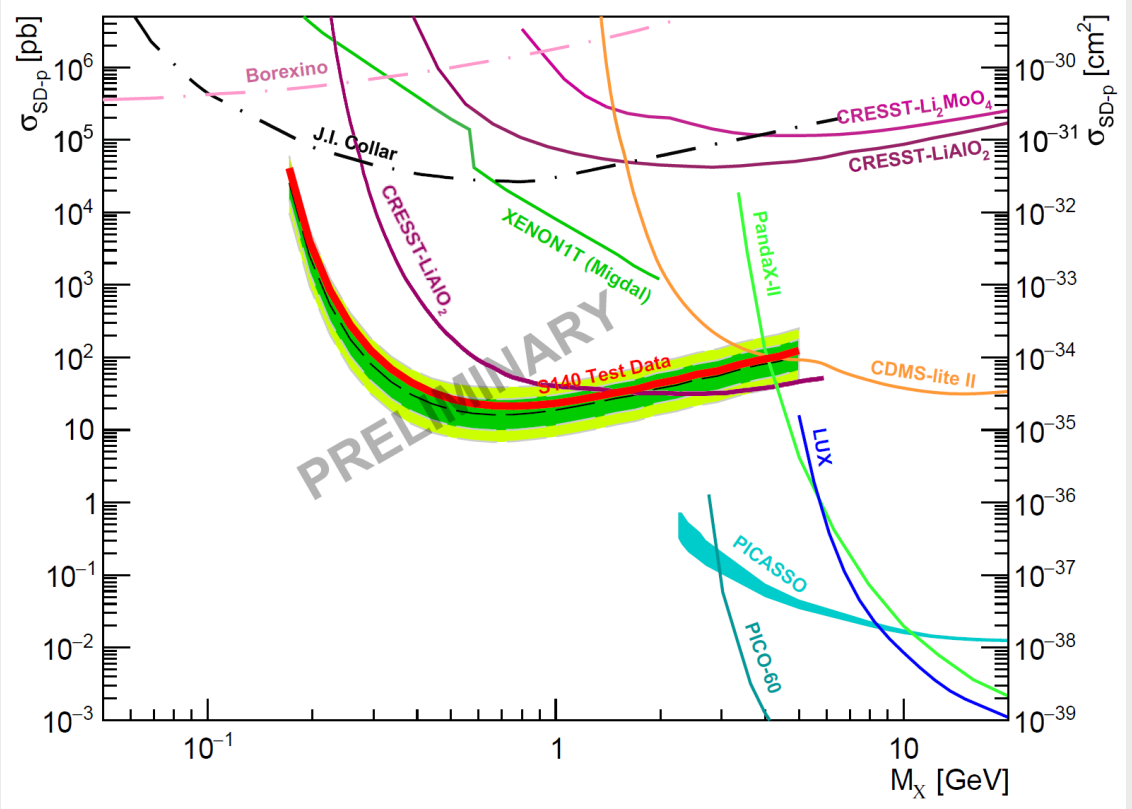
Radon trap

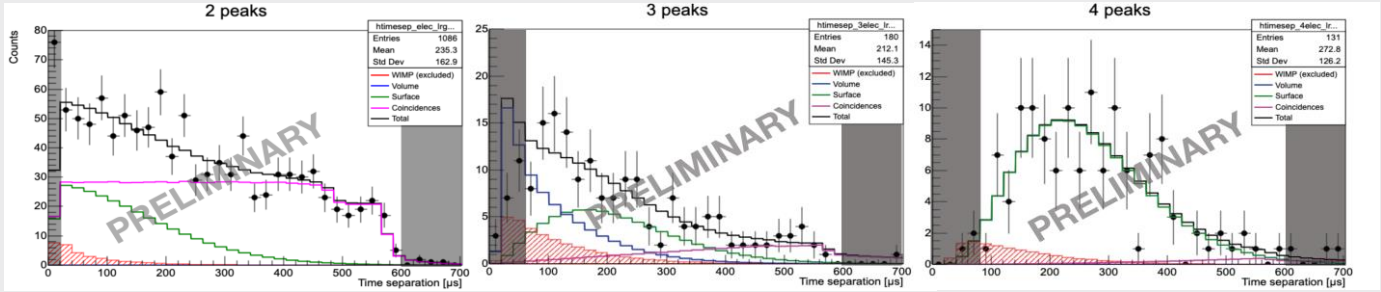


Gas purifier

# LSM preliminary limits

- 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 surface background, coincidences and WIMP signal.
- No significant WIMP signal was detected. 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 soon: paper currently in internal review.



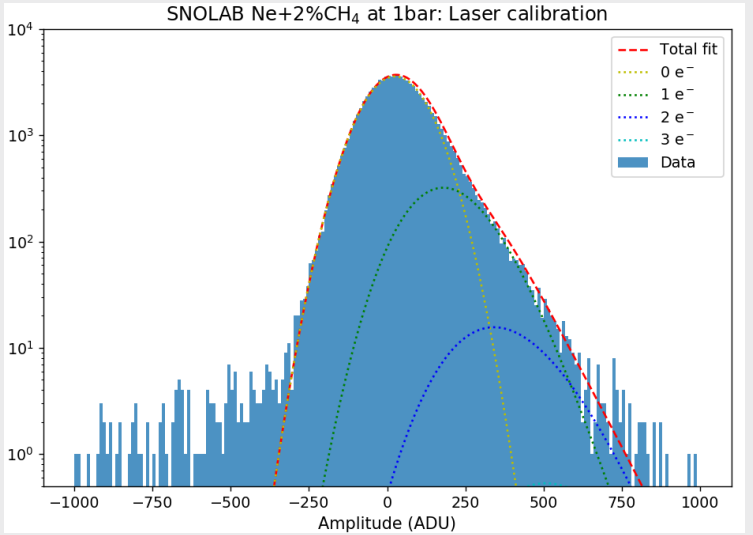



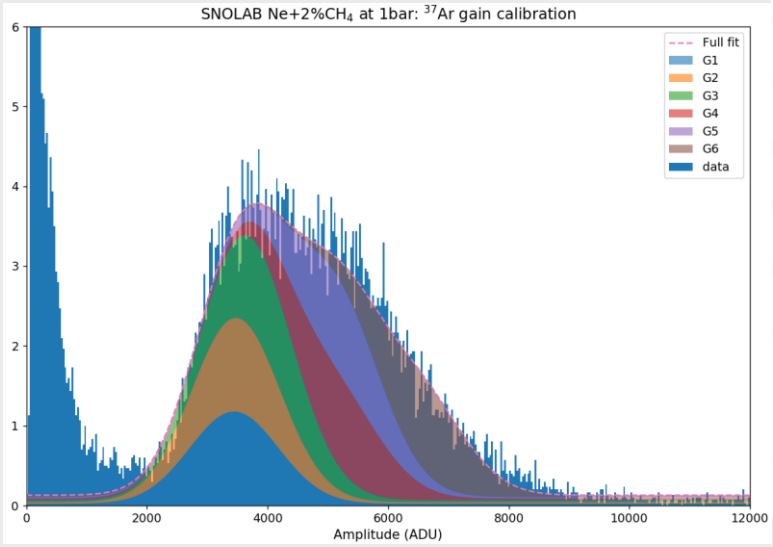

scipost_202210_00005v1

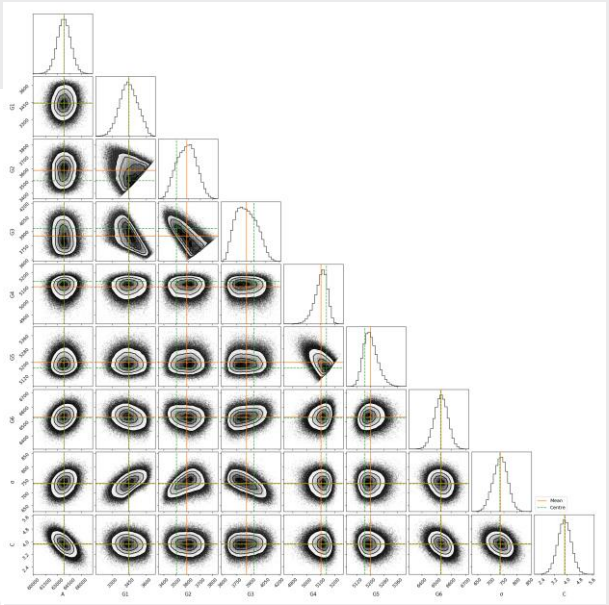
# SNOLAB data analysis

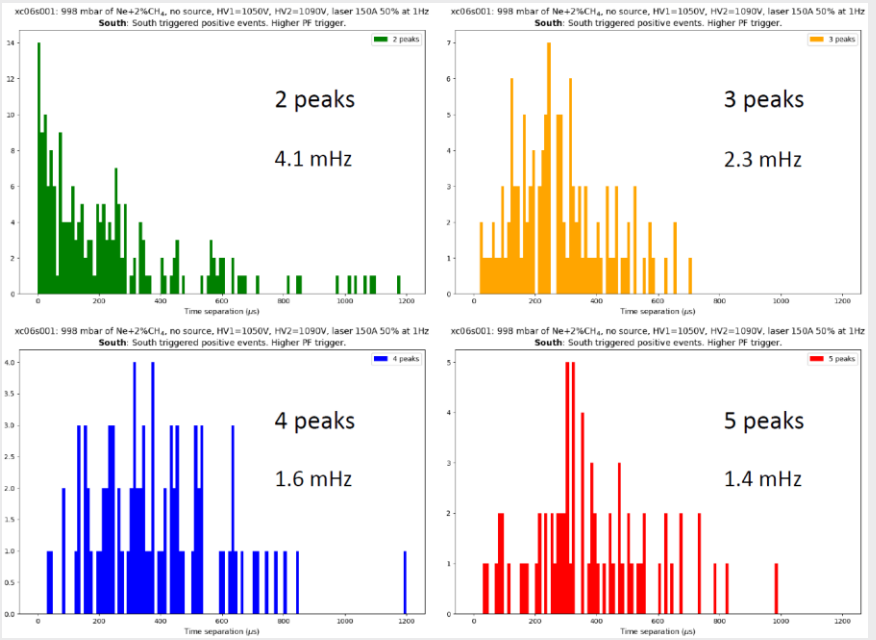
Here are some preliminary results from the neon data taken in Winter 2023:

- Laser calibration fits show the contributions from all numbers of primary electrons.
- MCMC fits of $^{37}$Ar data show the different gains of each southern anode of the sensor.
- Physics test data hints at a lesser contribution from the single-electron background compared to the LSM.





# Conclusion

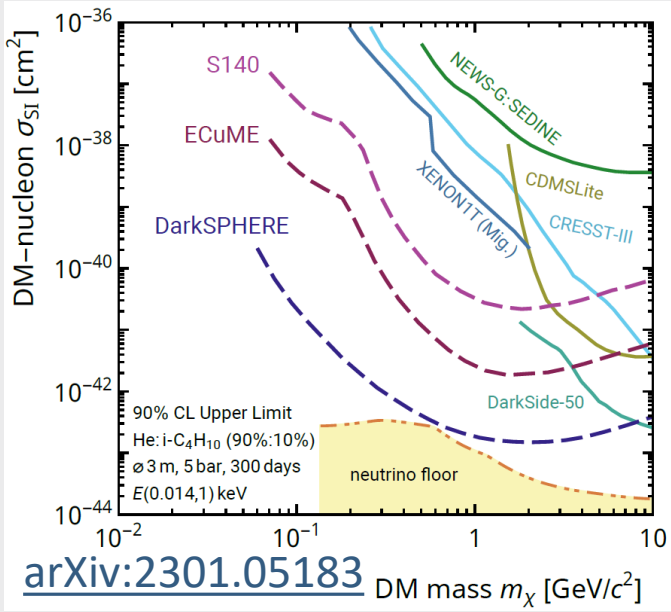
- NEWS-G and SPCs well suited for low mass dark matter search.
- LSM data able to set new SD-p WIMP constraints with $CH_4$.
- Currently taking improved physics data at SNOLAB.
- Expecting even better results from the SNOLAB data.

# Thank you!

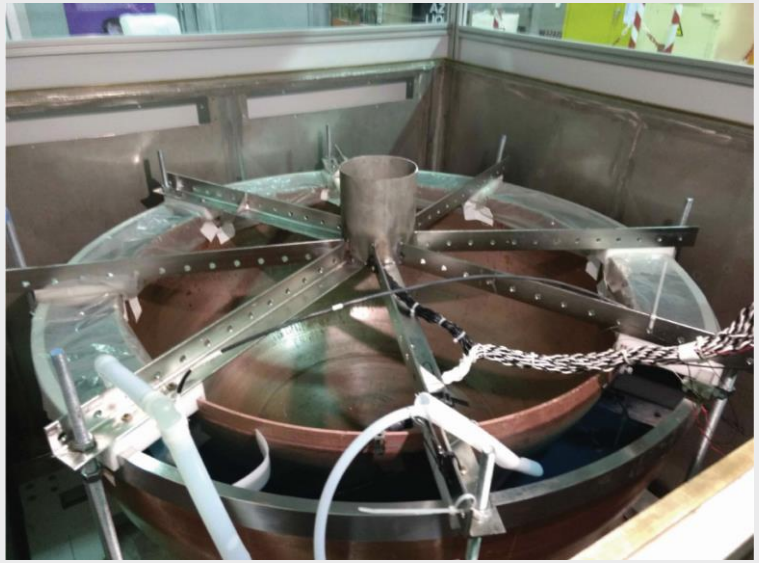
# Extra slides

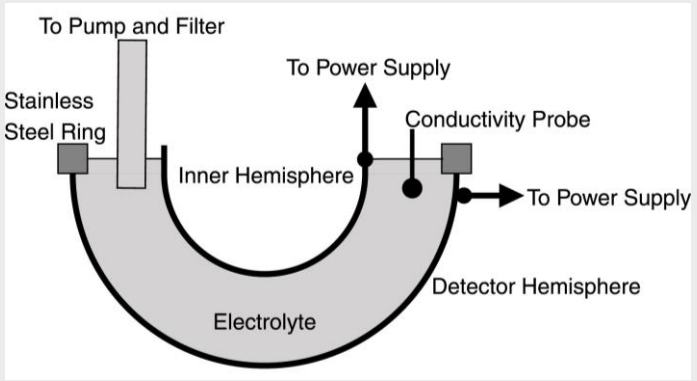
# Future projects

- ECuME (& miniECuME):
  - Fully underground electroformed 140 cm of diameter copper sphere in SNOLAB.
    (tests ongoing at PNNL)
- DarkSPHERE:
  - Fully electroformed 3m of diameter sphere in a water shield.
    (under consideration)
- NEWS-G3:
  - Shield at Queen's University intended for CEvNS detection at nuclear reactors.
    (shield completed, started testing)



# Making the sphere, electroforming, etching





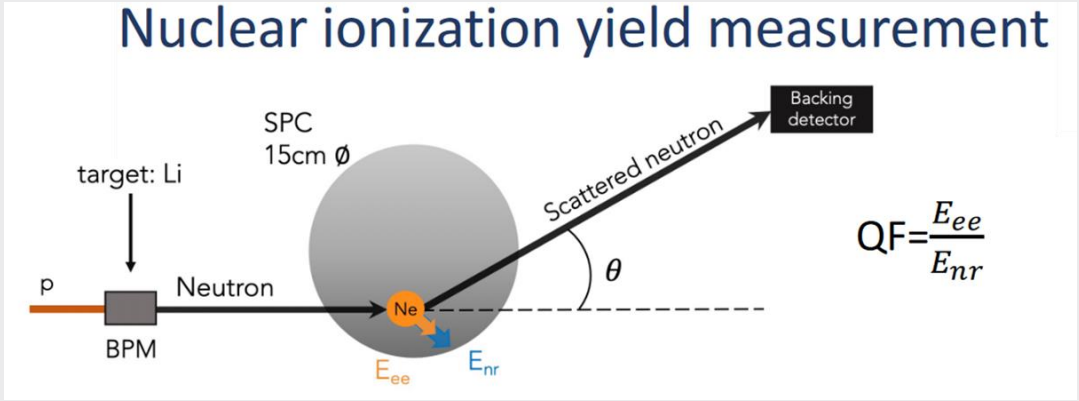
Birmingham Purifier

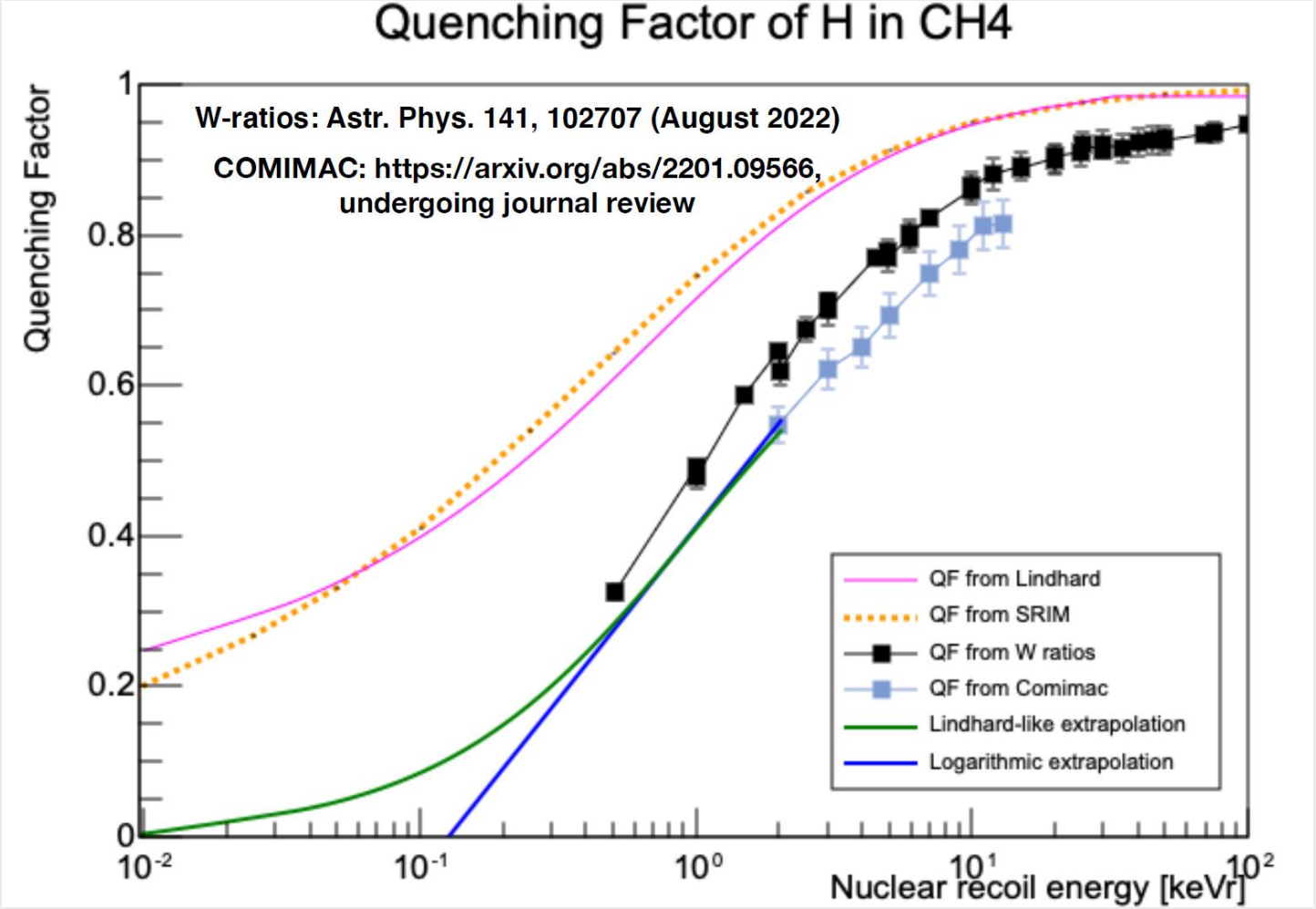
- oxygen removal
- copper balls + molecular sieve
- installed at SNOLAB
- few 10mBq radon

Radon trap

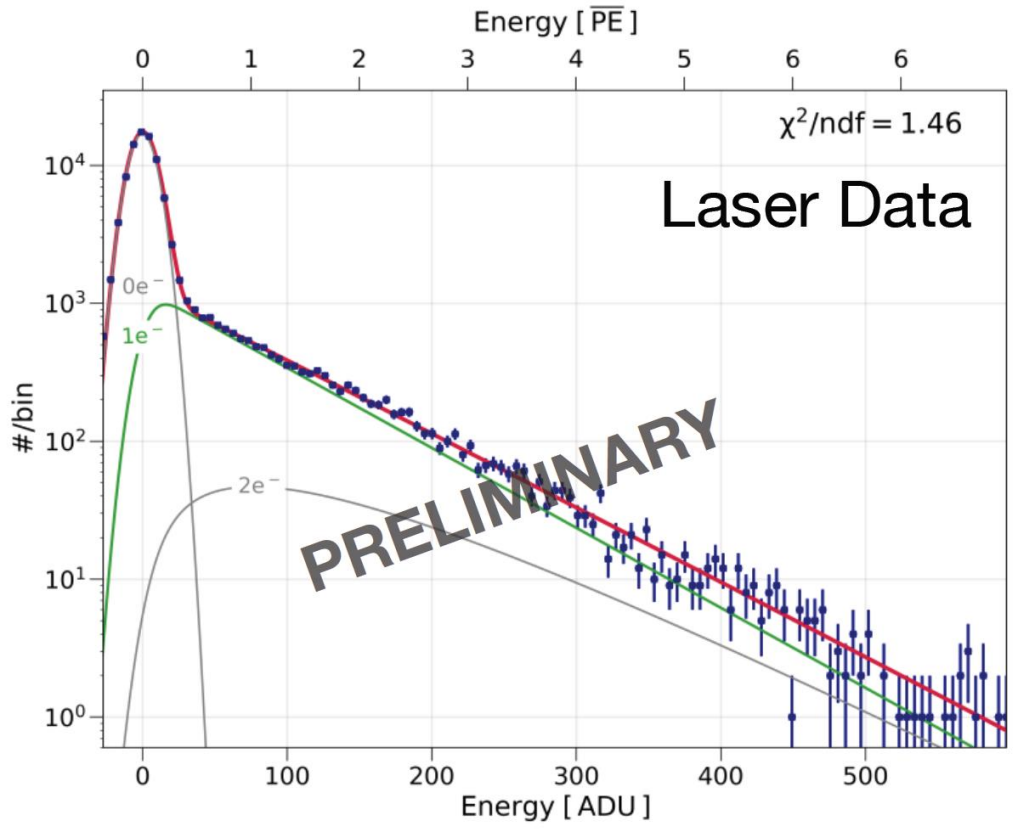
- silver zeolite
- tested at UoA
- in 10cm long, 10mm diameter SS pipe
- installed at SNOLAB
  - too much resistance for circulation
  - wider and 5x larger trap under construction (in CF40 pipe (34mm diameter))

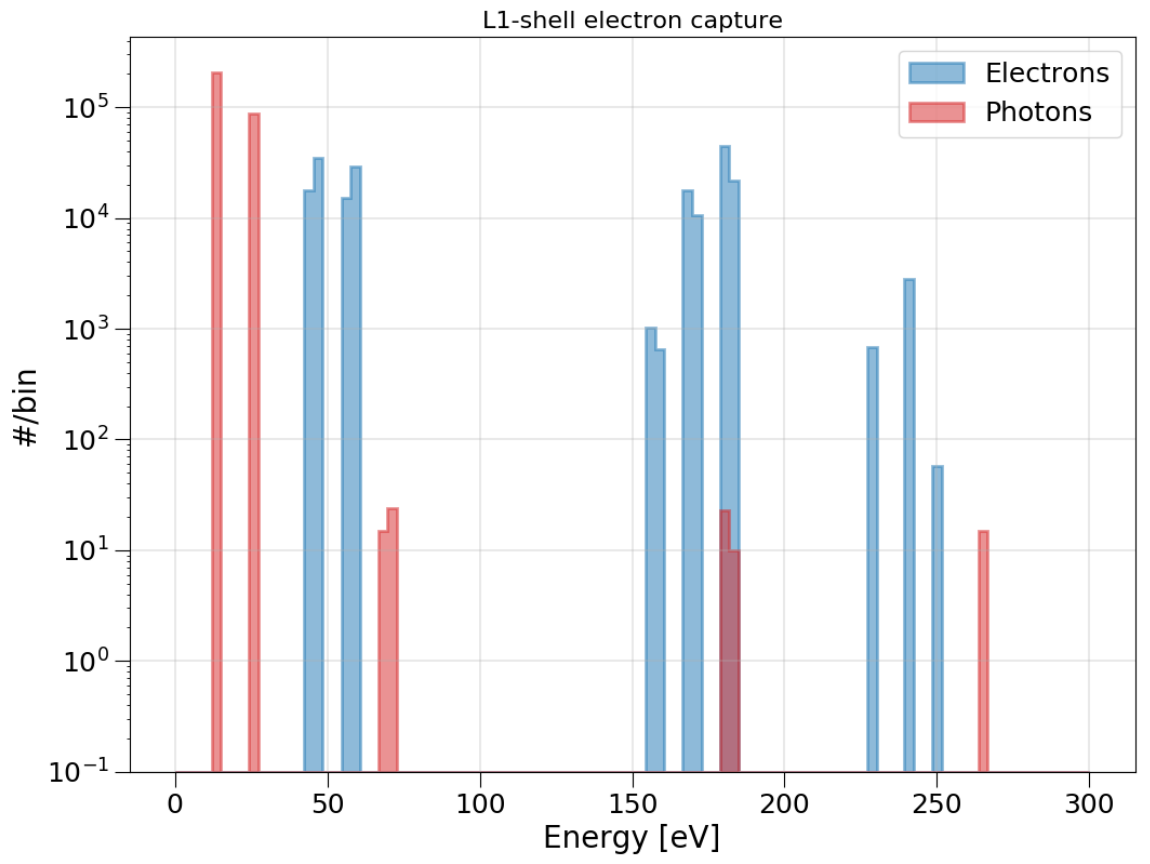
# Quenching factor



# Gas mixture and calibration (laser and $^{37}$Ar)

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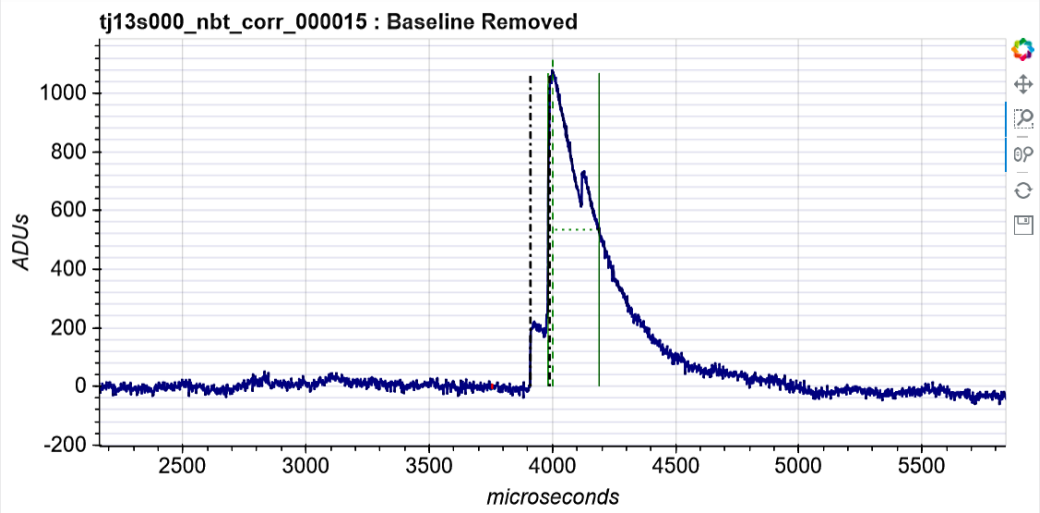
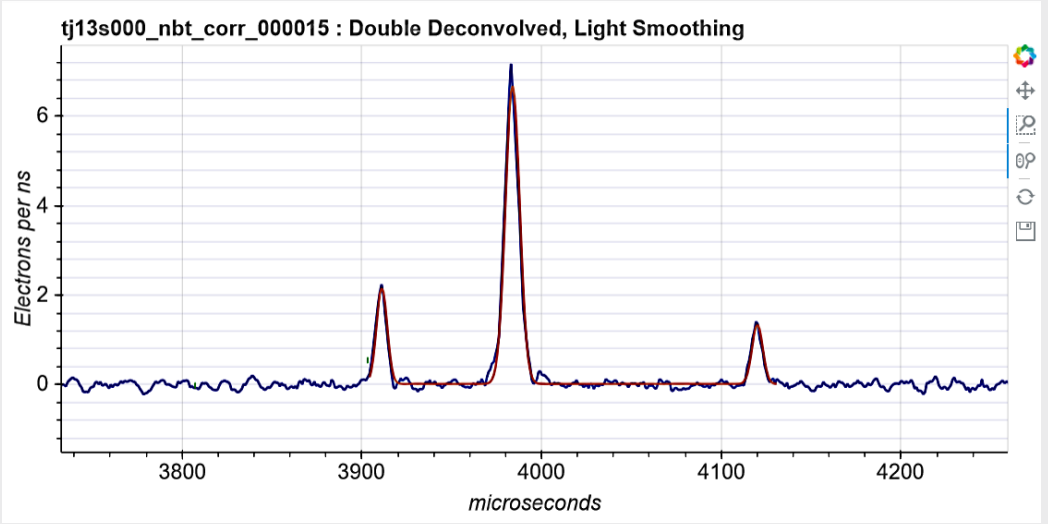
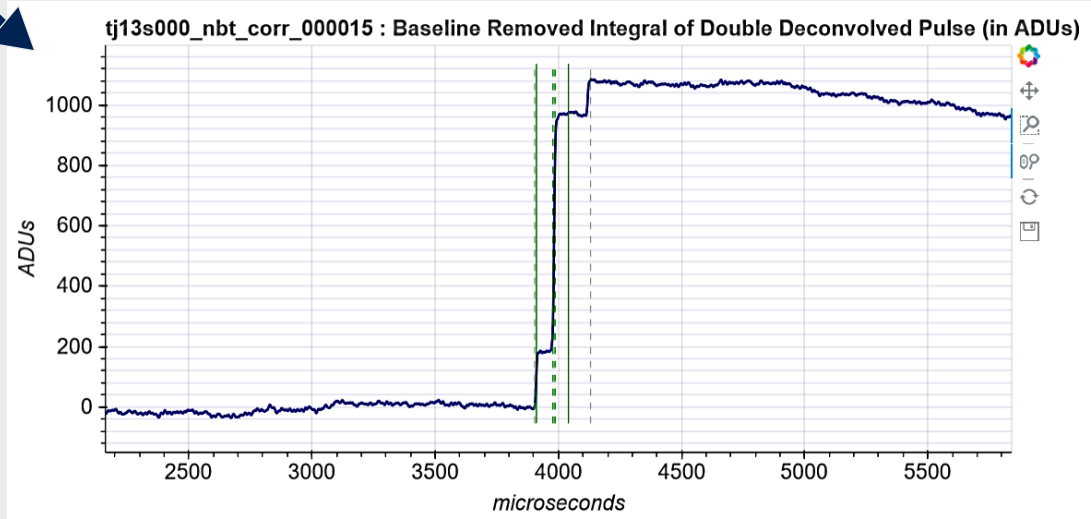
# Double deconvolution




Double deconvolution

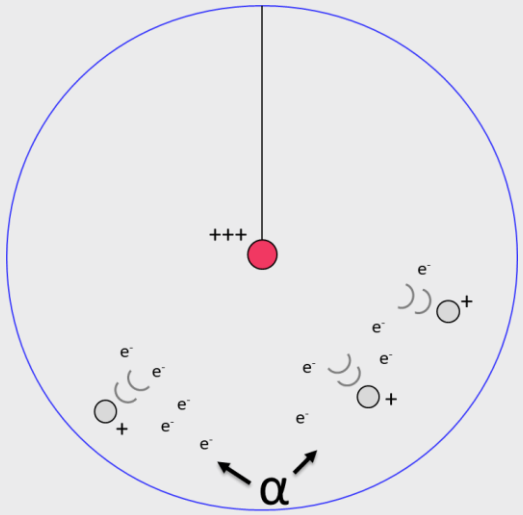



Integration

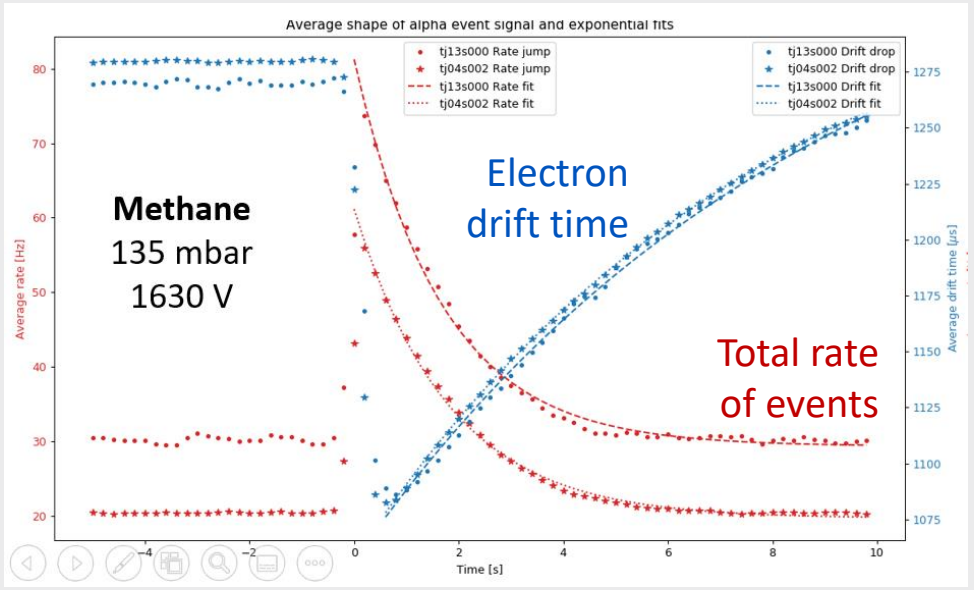


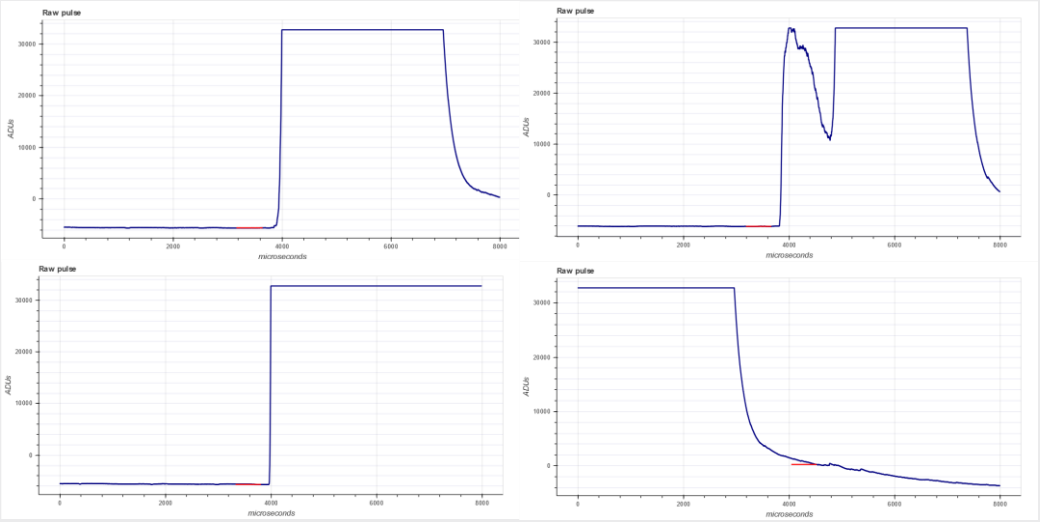

The ballistic deficit is the signal amplitude that gets underestimated due to the exponential decay of the preamplifier.
The full amplitude (energy) is retrieved by doing a double deconvolution of the raw signal, and then integrating the pulses.

# Alpha background

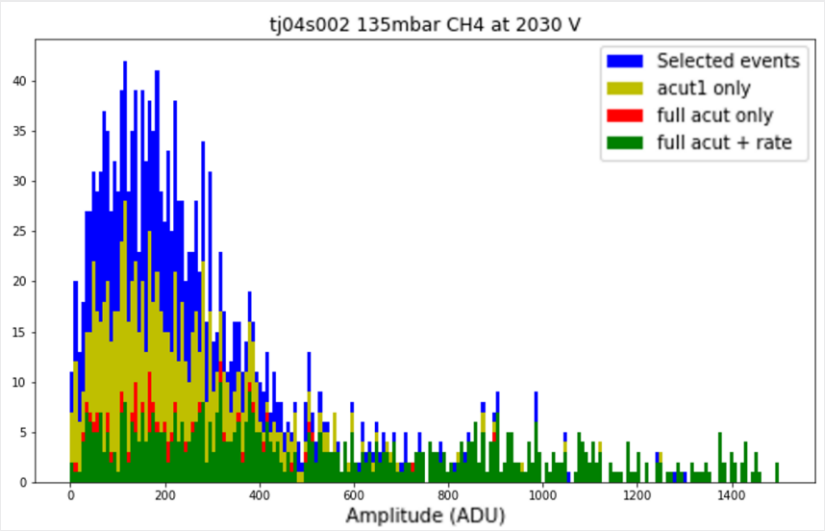



There is $^{210}$Po contamination in the copper surface, which causes alphas that ionize a lot of gas. All the ions create a space charge that disturbs the electric field, and changes the electron drift time. For some still unknown reason, a high rate of low energy events keep happening for around 5s after each alpha.



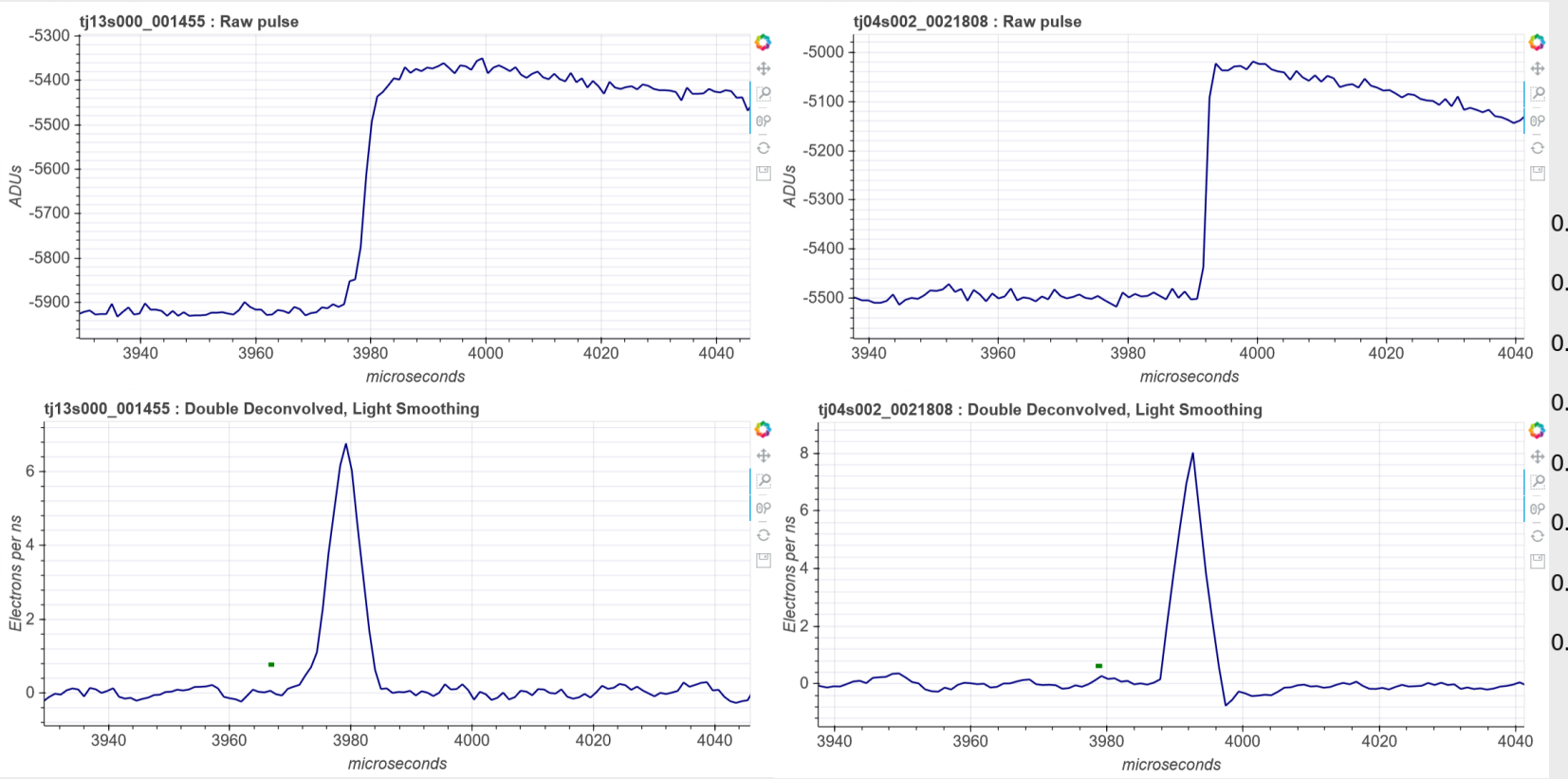

The saturated alpha signals can be broken up and difficult to detect, but using the drift time, rate of events and decreasing baselines, we can identify alphas and remove most of the low-energy background due to them with a 5s cut after each alpha, keeping 85-90% of the total time.

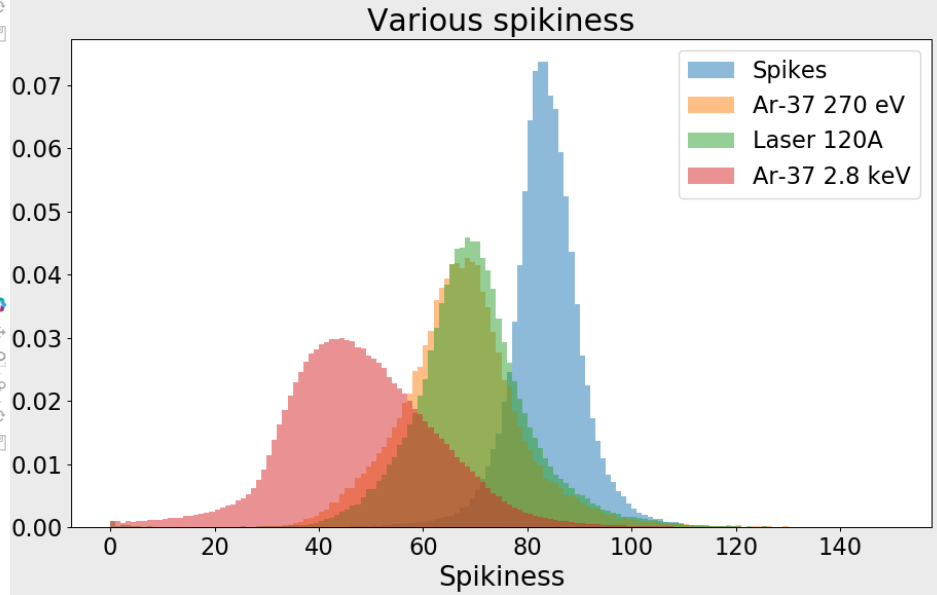


# Spikiness

1st comparison method
Spikiness

$$\text{Spk} = \frac{\text{Max signal derivative}}{\text{Peak height}}$$



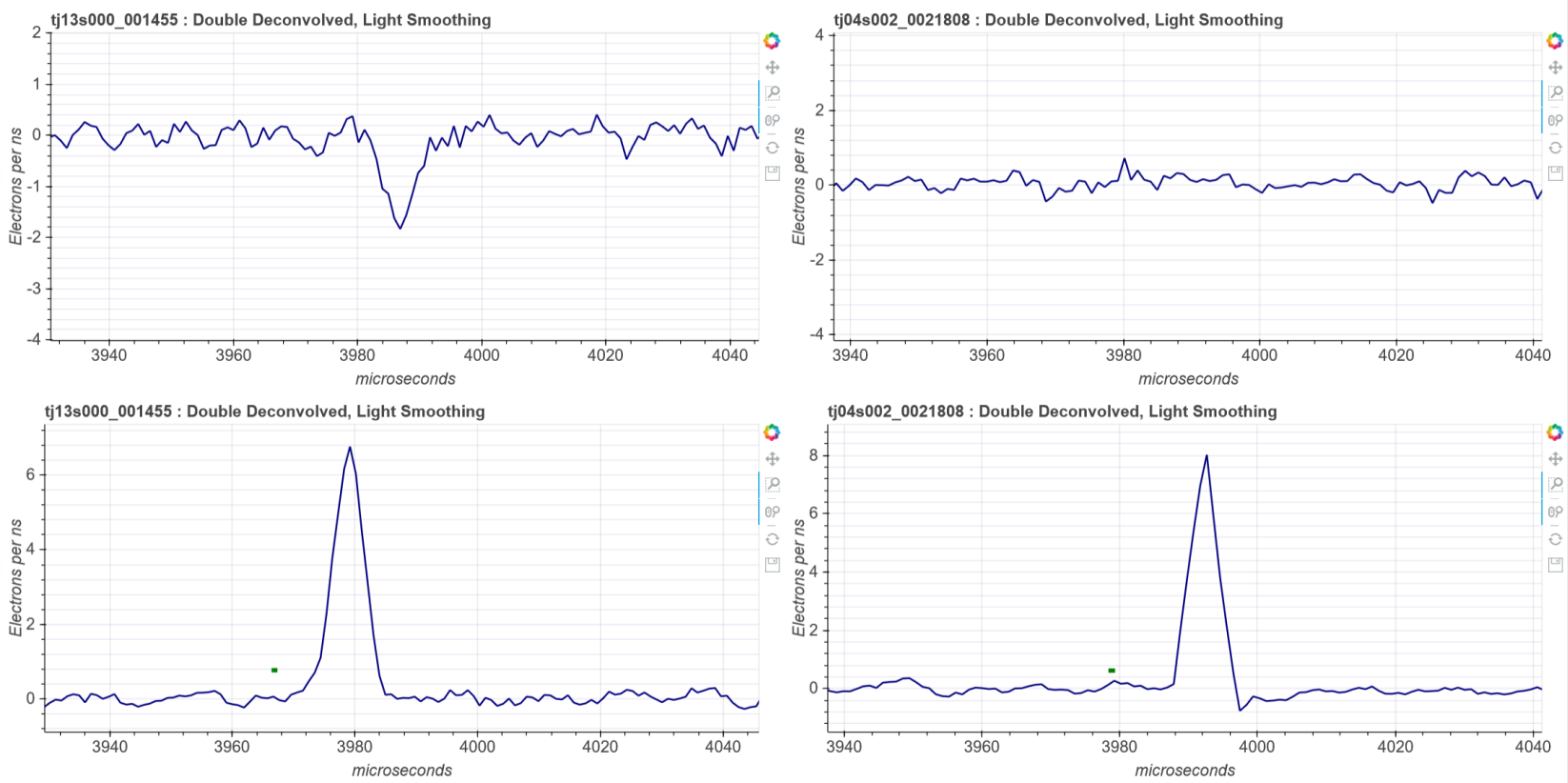




Probable electron event

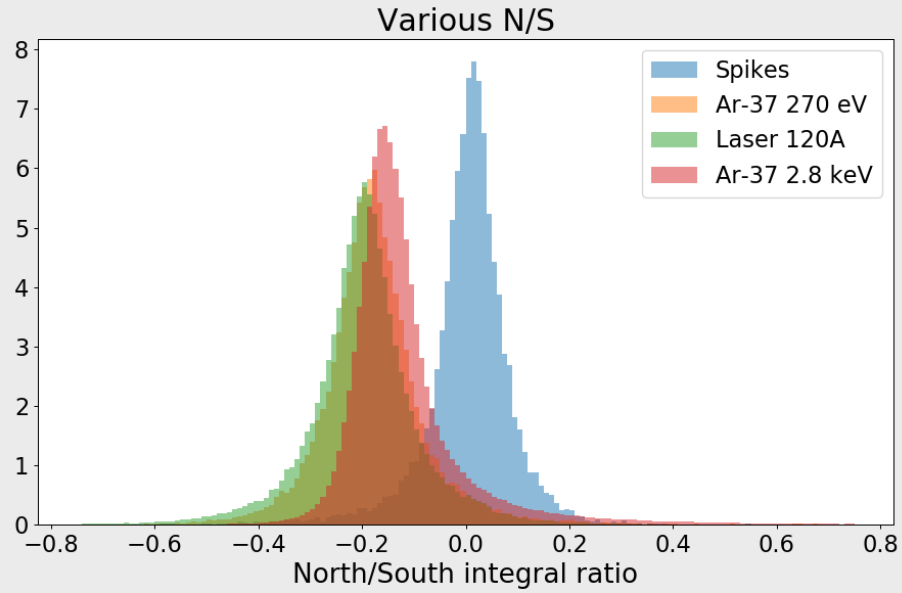
Probable spike event

# North/South integral ratio

2nd comparison method
N/S ratio




$$N/S = \frac{\text{North DD2 integral}}{\text{South DD2 integral}}$$

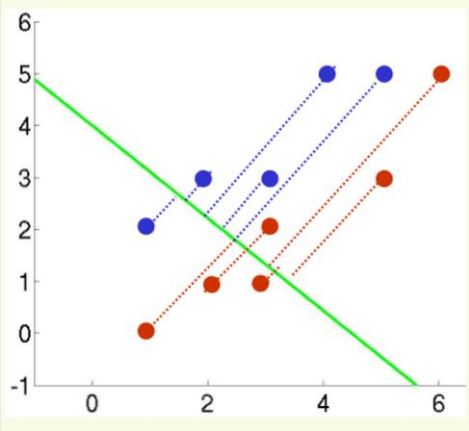


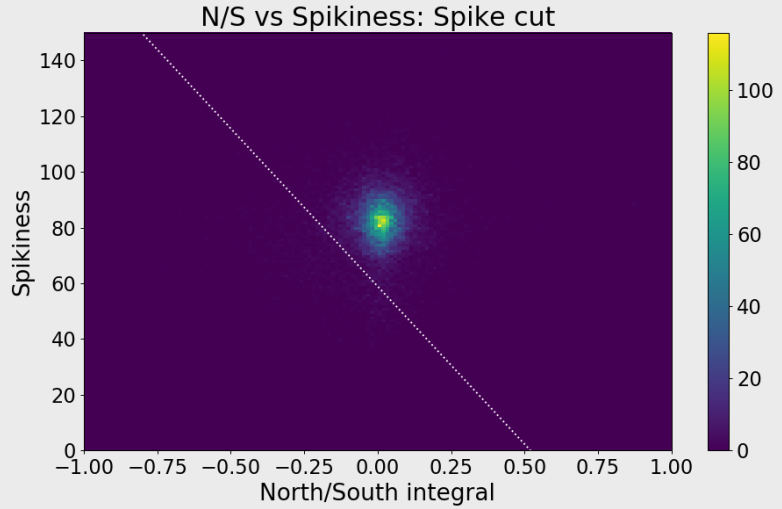

Probable electron event

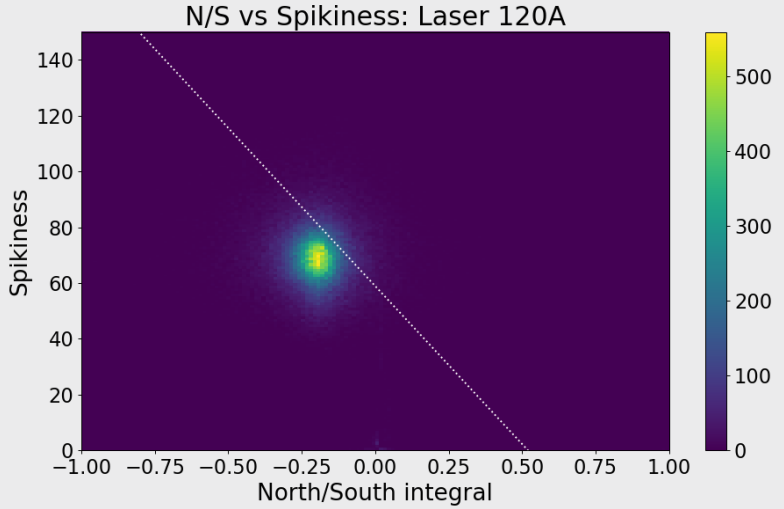
Probable spike event

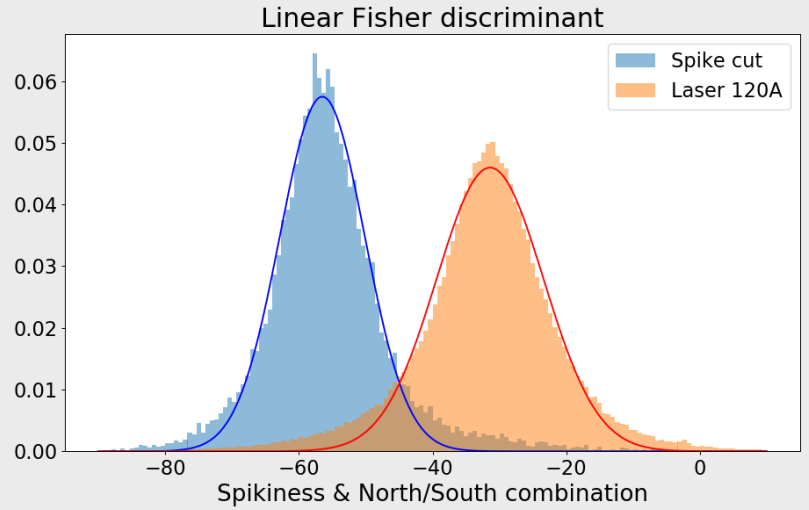
# Linear Fisher discriminant

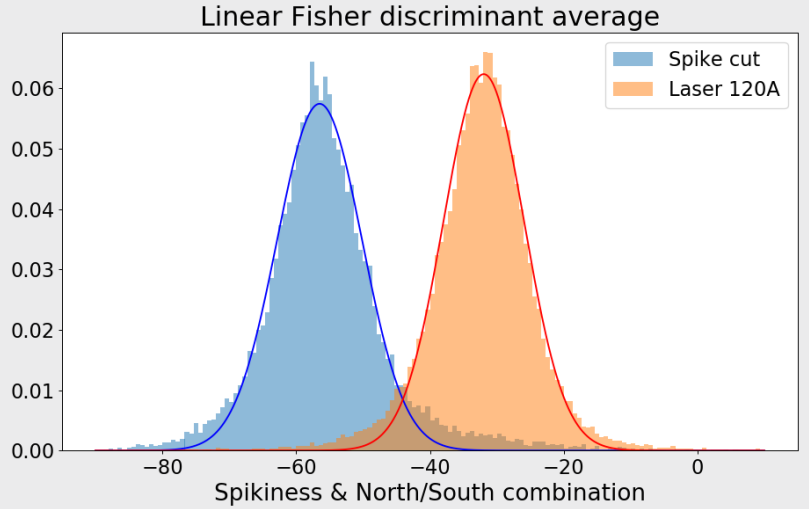
Optimal comparison:
Combining both methods





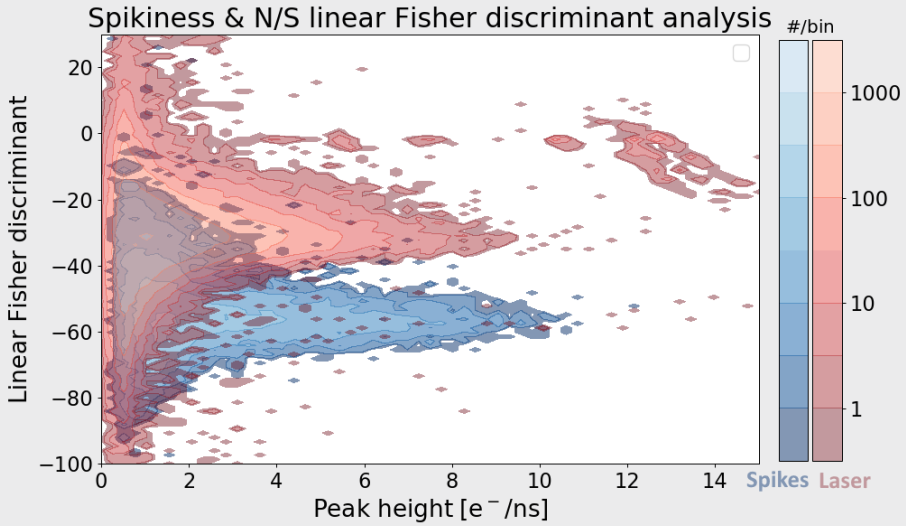




Separation $J(\omega) = \frac{(\mu_1 - \mu_2)^2}{N_1(\sigma_1)^2 + N_2(\sigma_2)^2}$

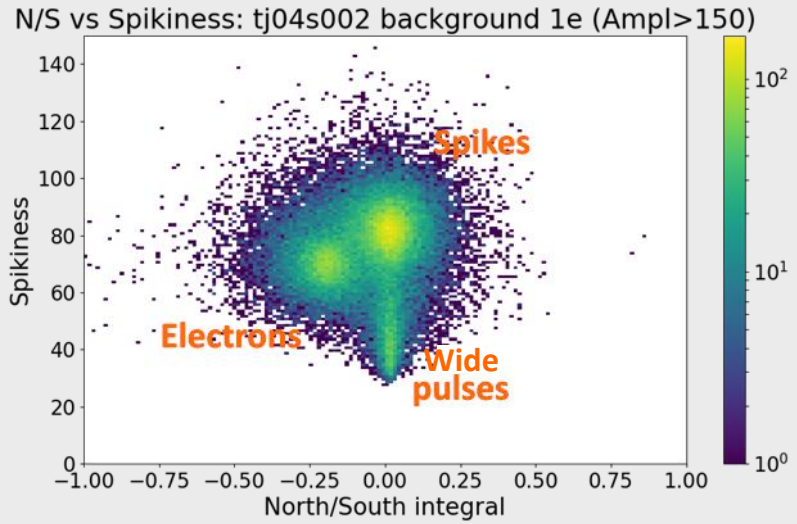
New axis $\tau_i = \omega^t x_i^t$

ω=[−0.678619815,−76.8674863]
Spk NS

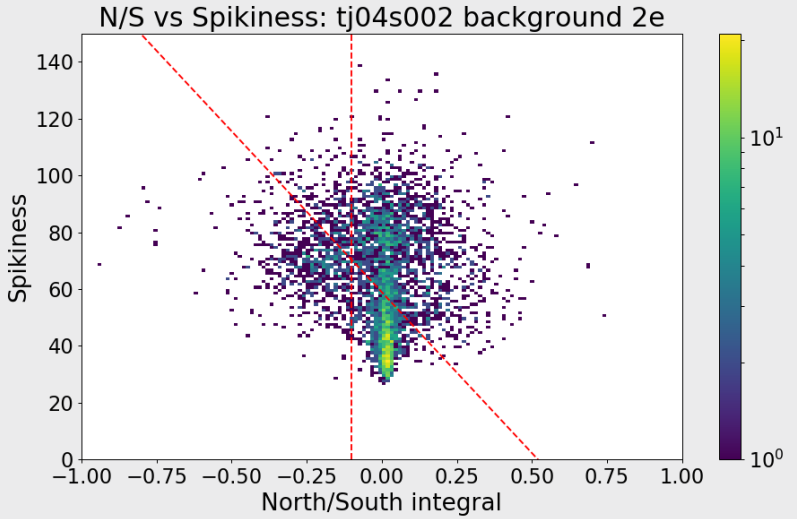
# Fits to the physics data




The separation between electron and spike events is weaker at lower energies.

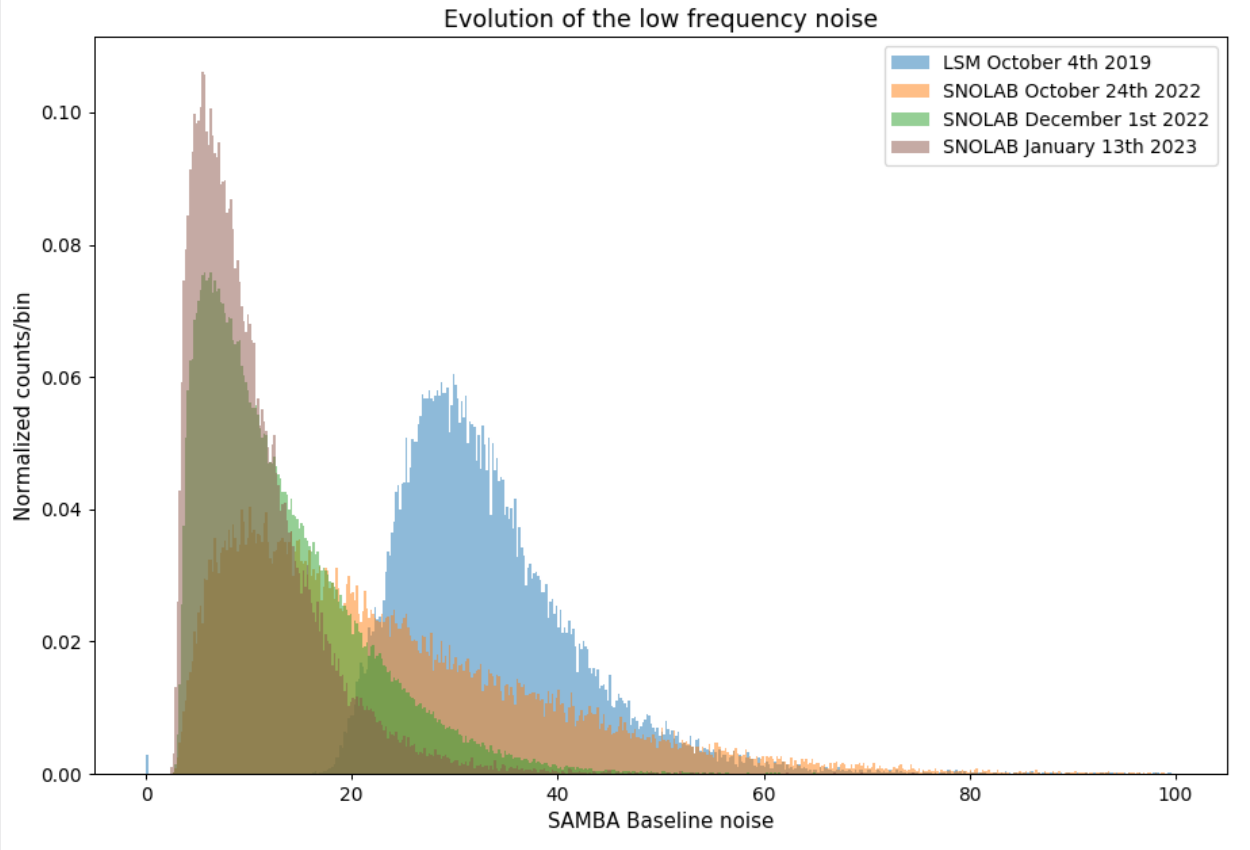


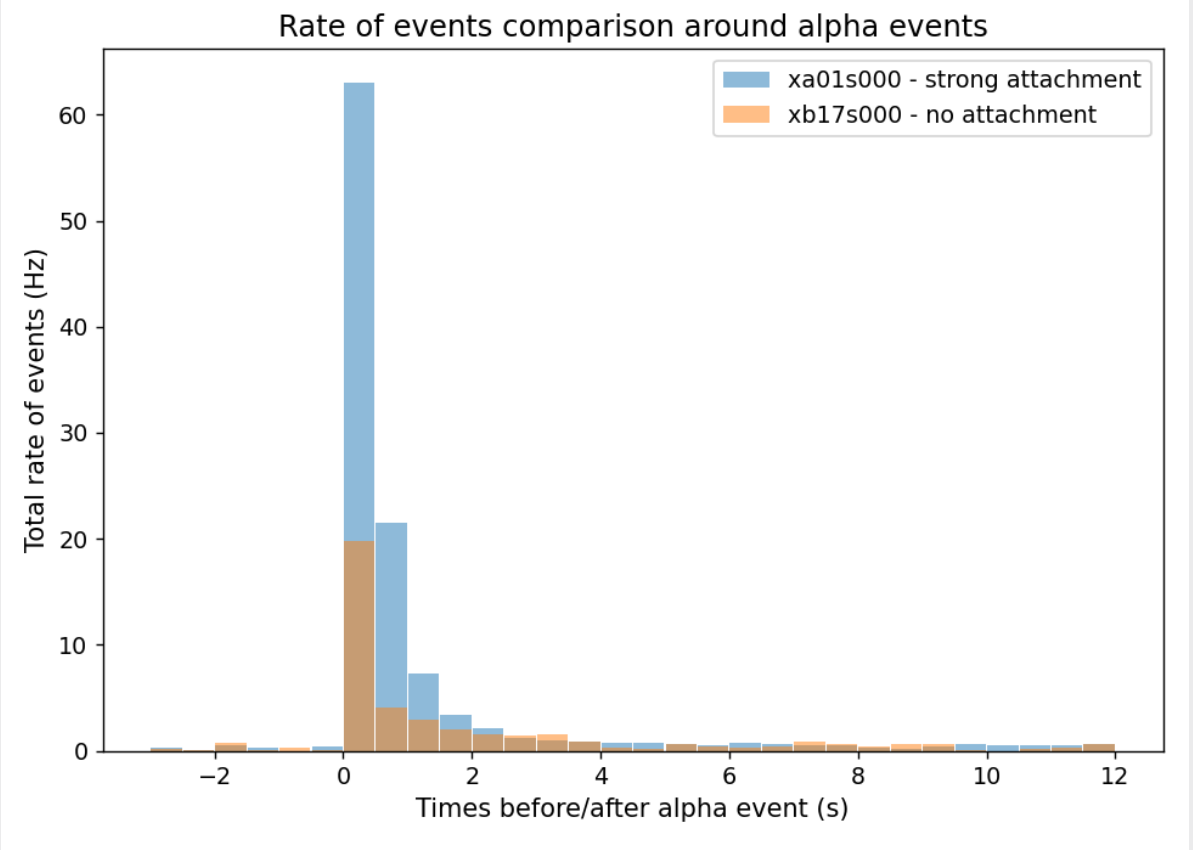

Wide pulses are another dominant background of unknown origin in the data.



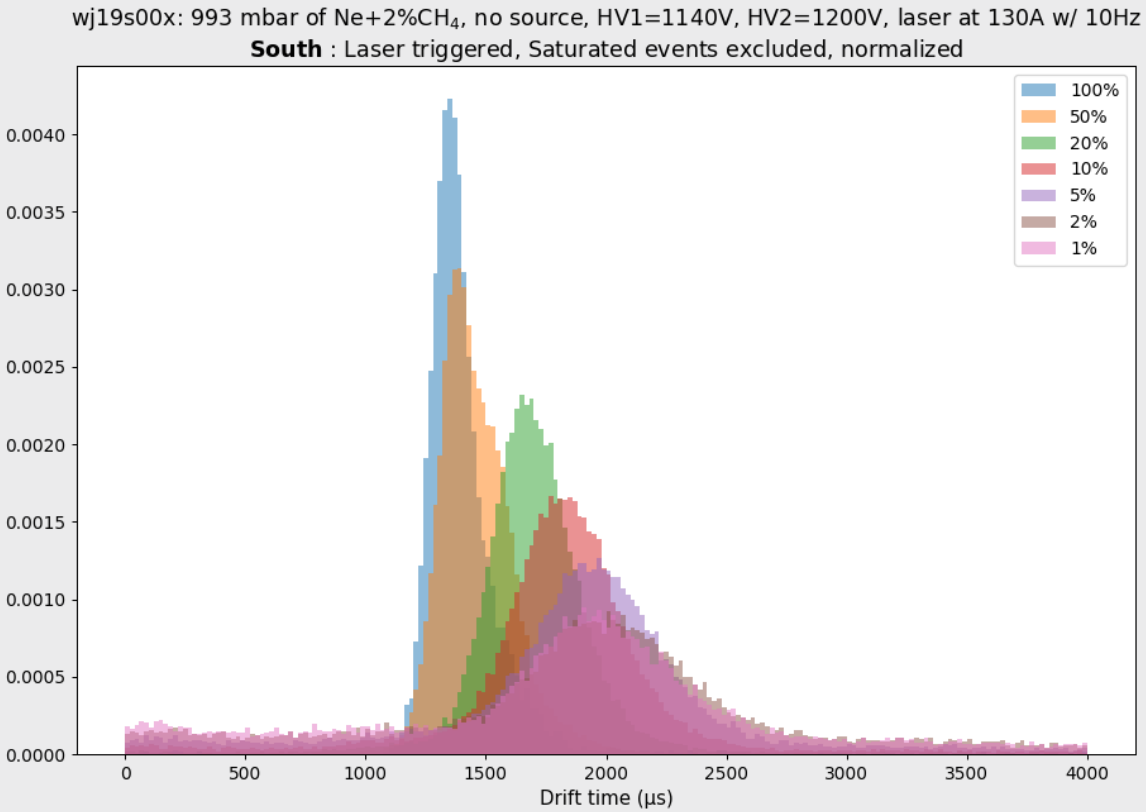

A cut on N/S removes fat pulses (dominant in 2-peak data) and a Fisher discrim. cut removes spikes.

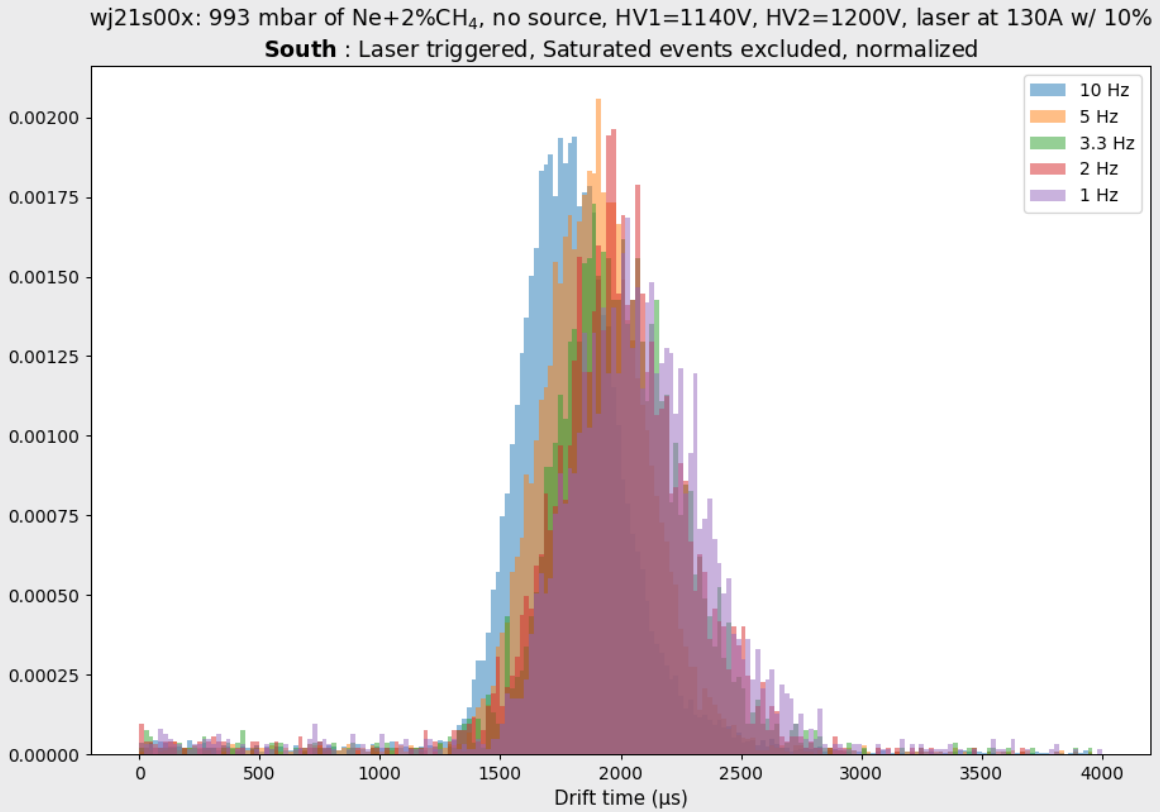
# SNOLAB noise

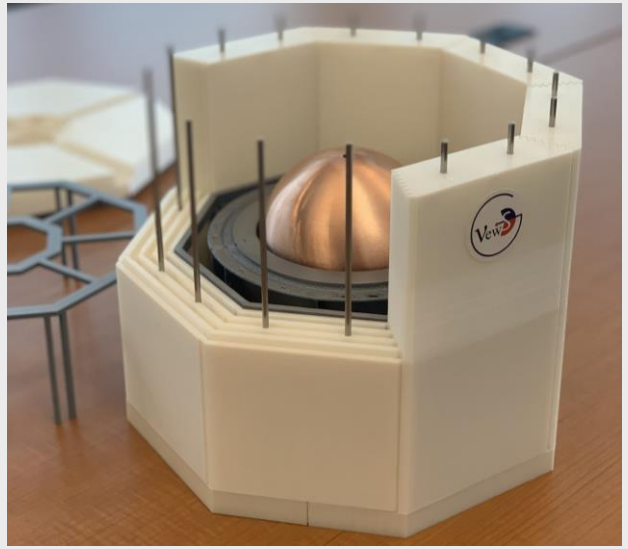


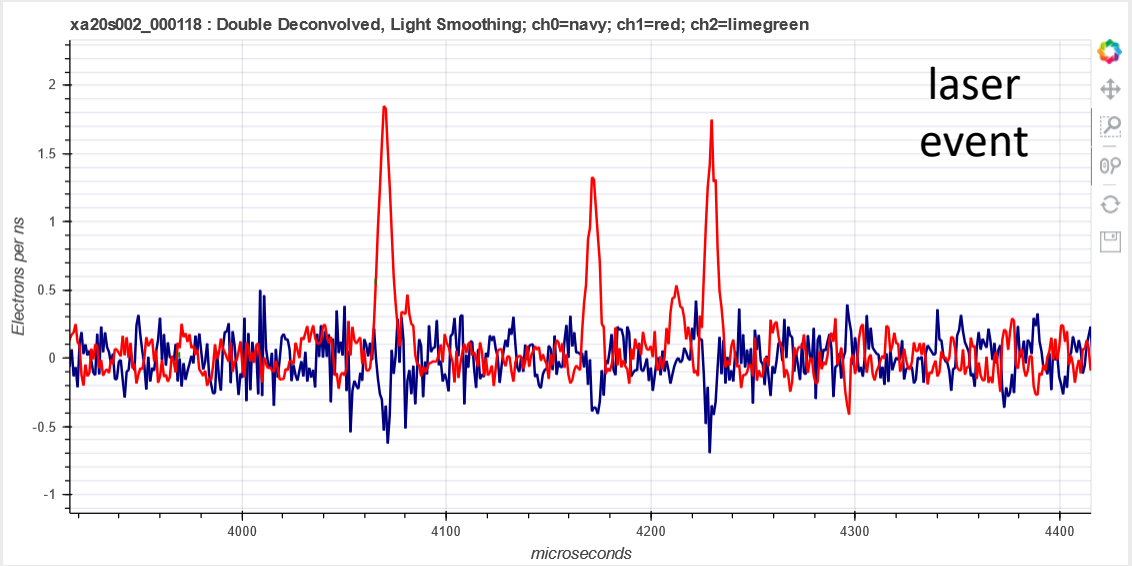



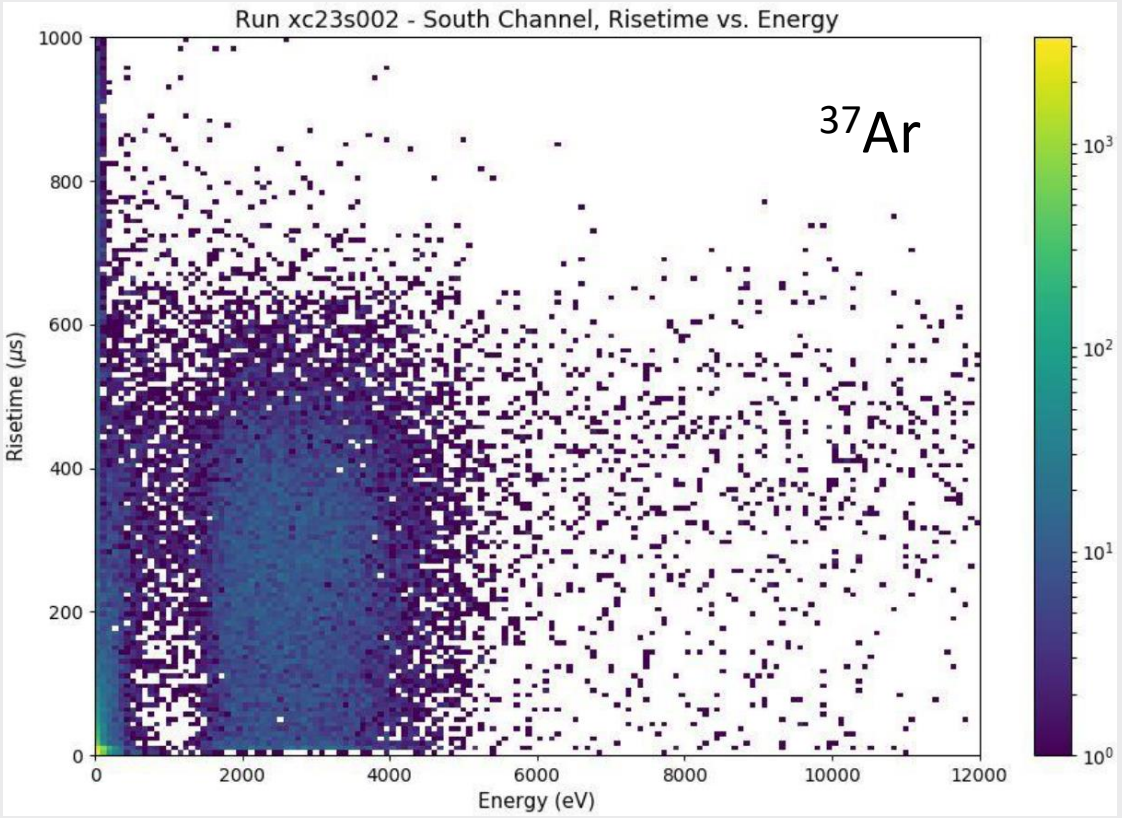
# SNOLAB space charge

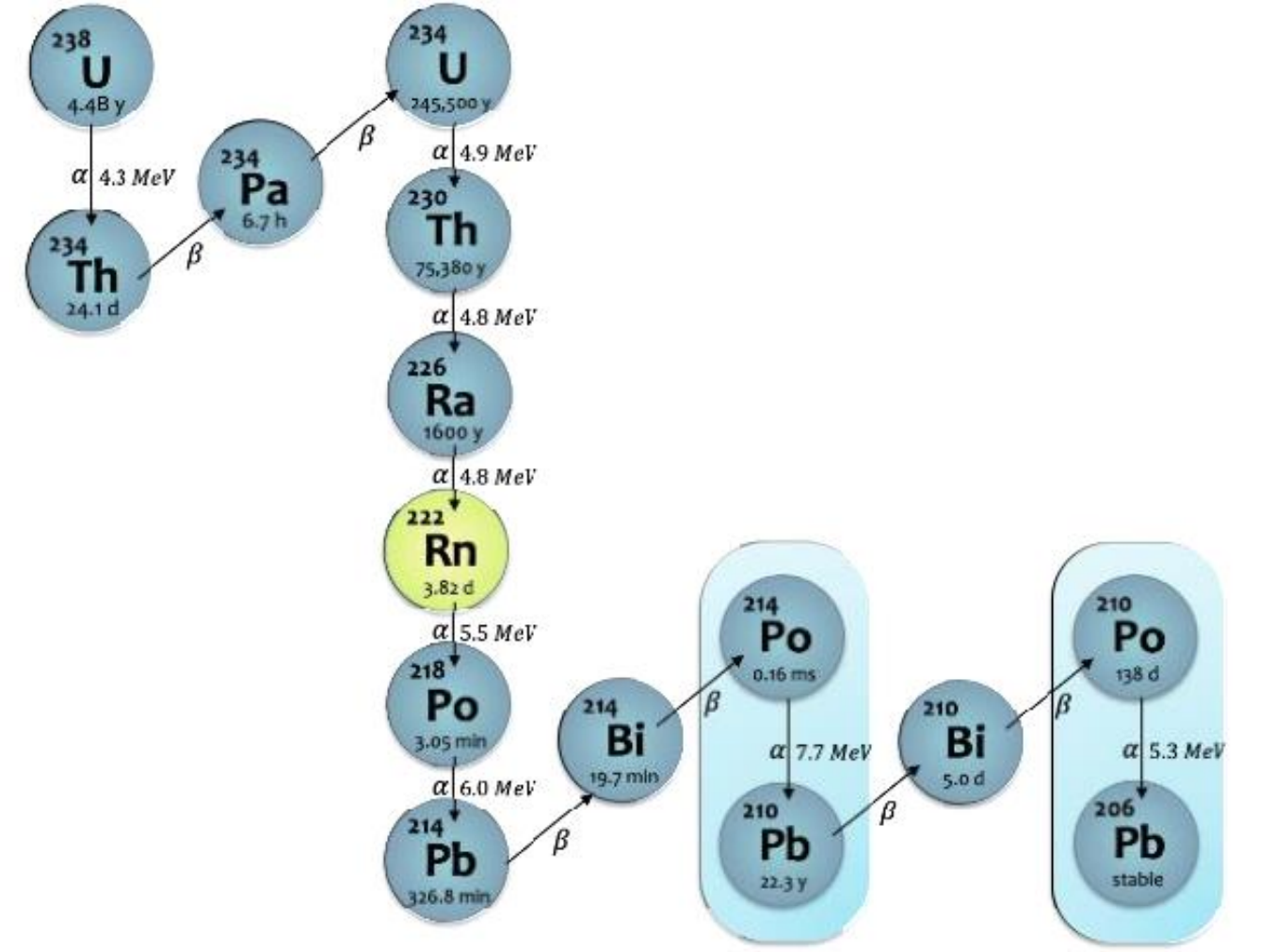


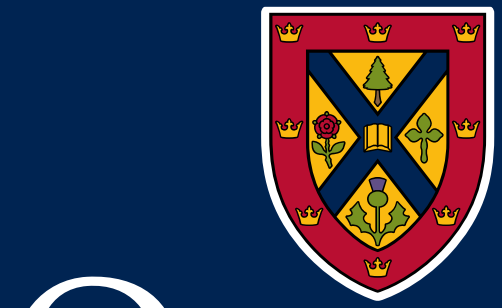



xa20s002_000118 : Double Deconvolved, Light Smoothing; ch0=navy; ch1=red; ch2=limegreen
laser
event
Electrons per ns
microseconds


Run xc23s002 - South Channel, Risetime vs. Energy
$^{37}$Ar
Risetime (μs)
Energy (eV)




Radon Plate-out and the Effects of Airflow and Electric Charge for Dark Matter Experiments - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Uranium-238-decay-chain-As-shown-in-Figure-2-the-decay-chain-of-238-U-involves-the_fig2_377611580 [accessed 23 May, 2024]



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