News from the NEWS-G experiment

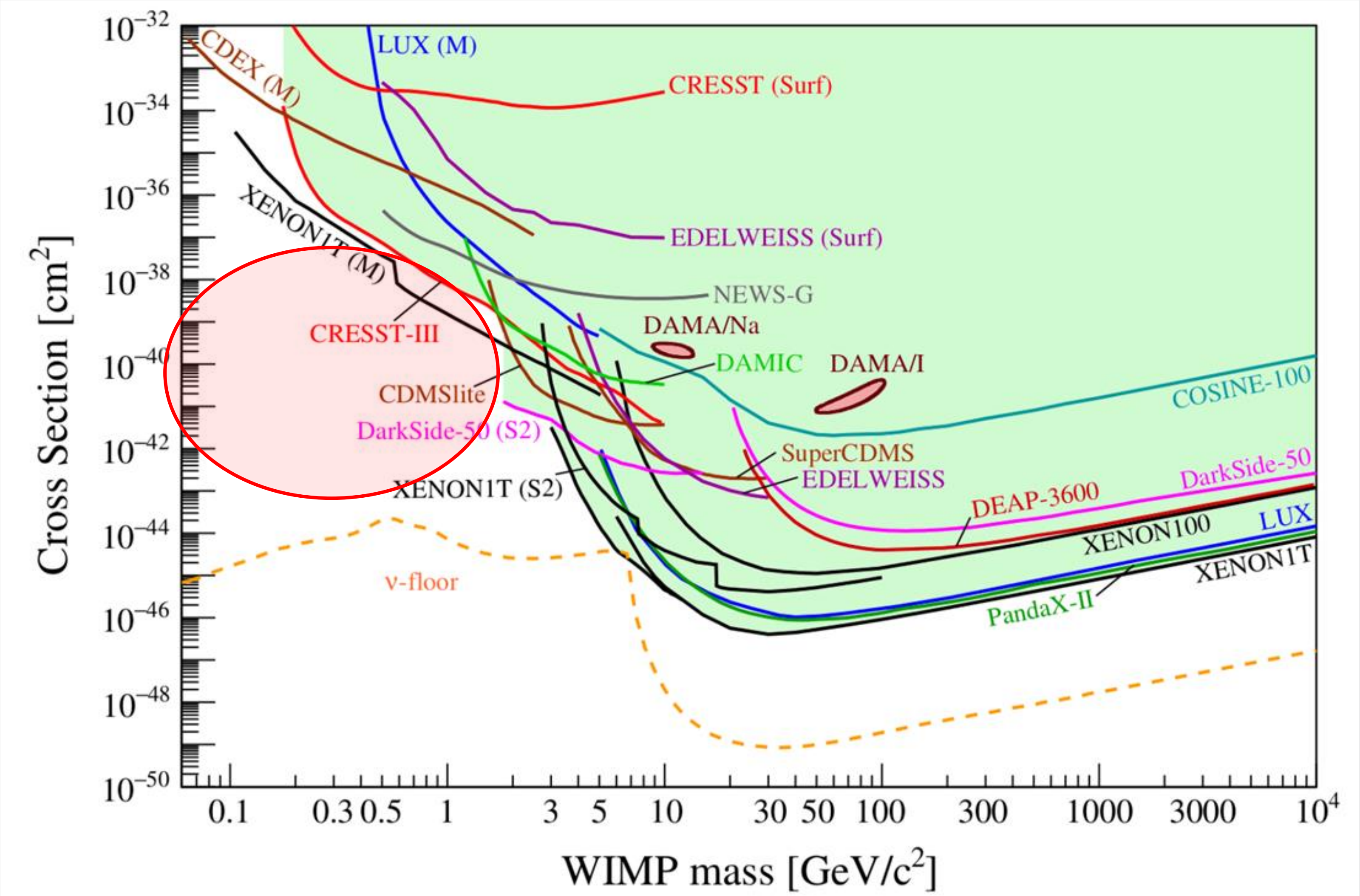
Jean-Marie Coquillat

Lake Louise Winter Institute

February 21st, 2023

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

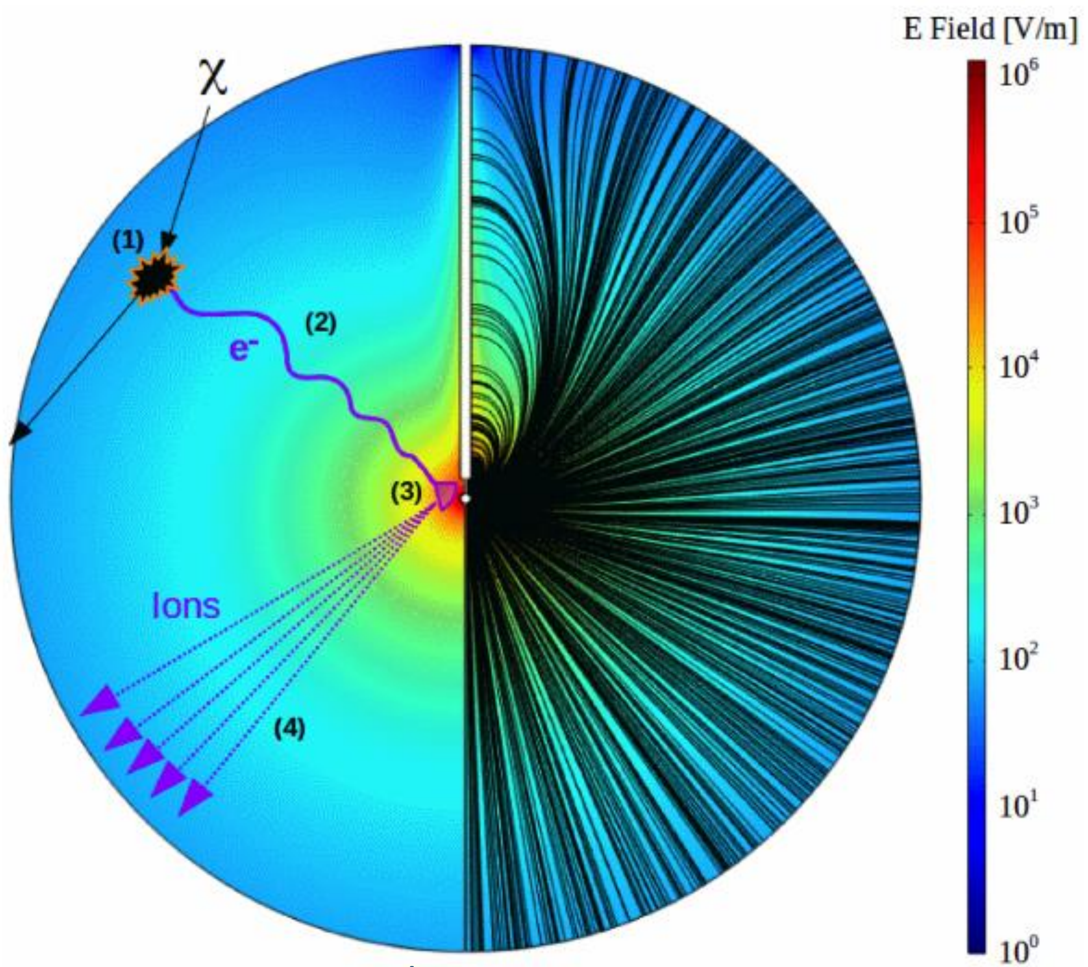
- The NEWS-G experiment uses spherical proportional counters (SPC) to search for low mass dark matter.
- SPCs are metallic spheres filled with gas, with a central anode producing a radial electric field.
- The last dark matter limits are from the SEDINE detector (60 cm diameter) at the *Laboratoire Souterrain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

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.

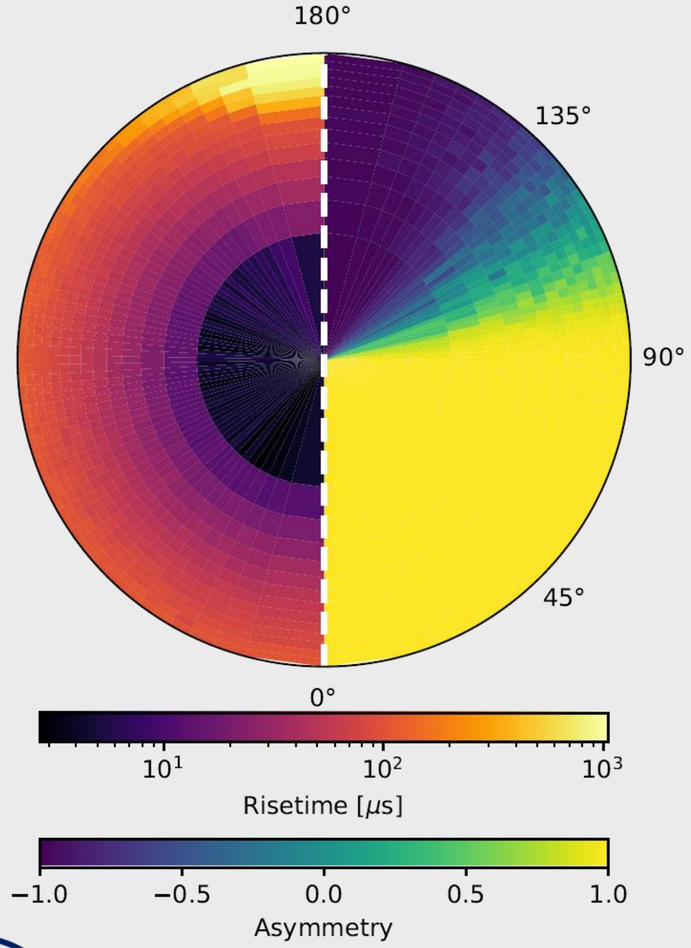


doi: 10.1016/j.nima.2019.162390

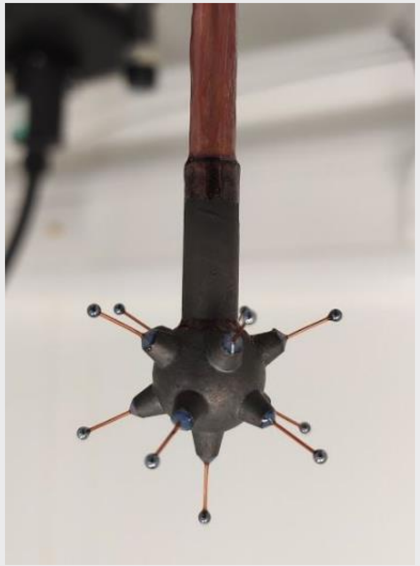
Sensor (achinos)

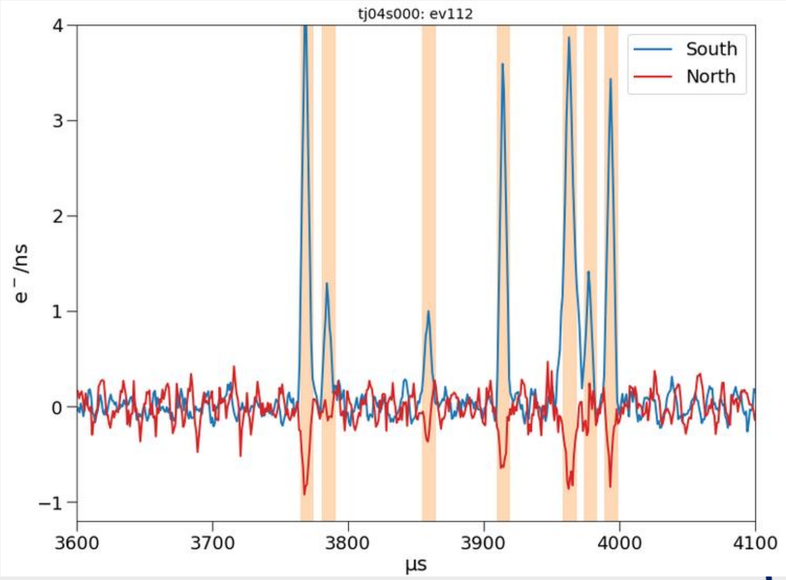
- NEWS-G now uses a multi-anode sensor that can achieve high gain while keeping a strong electric field at a high radius.
- The sensor is divided in two channels connecting the anodes of each hemisphere.
- A signal on one channel induces a negative signal on the other one (Shockley-Ramo effect).
- About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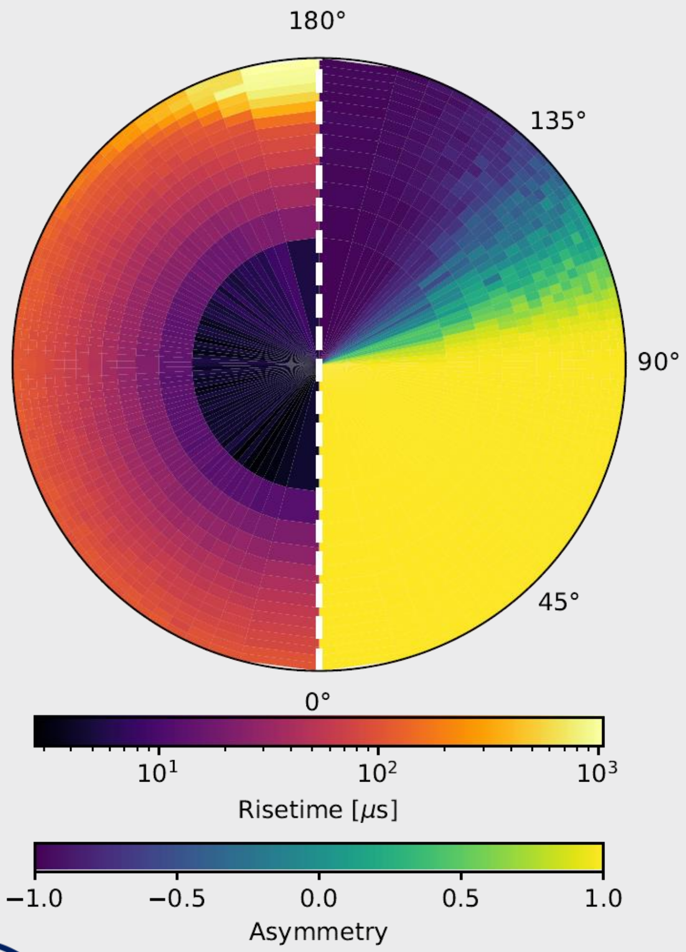

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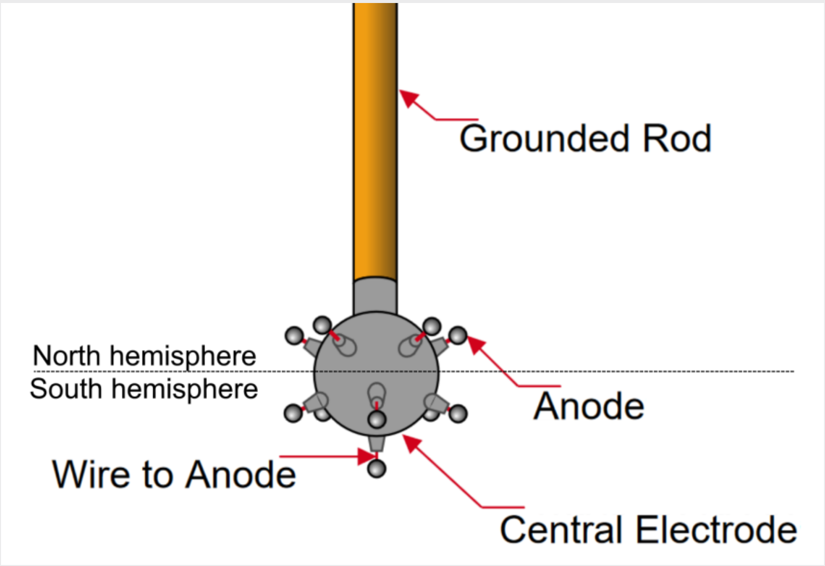
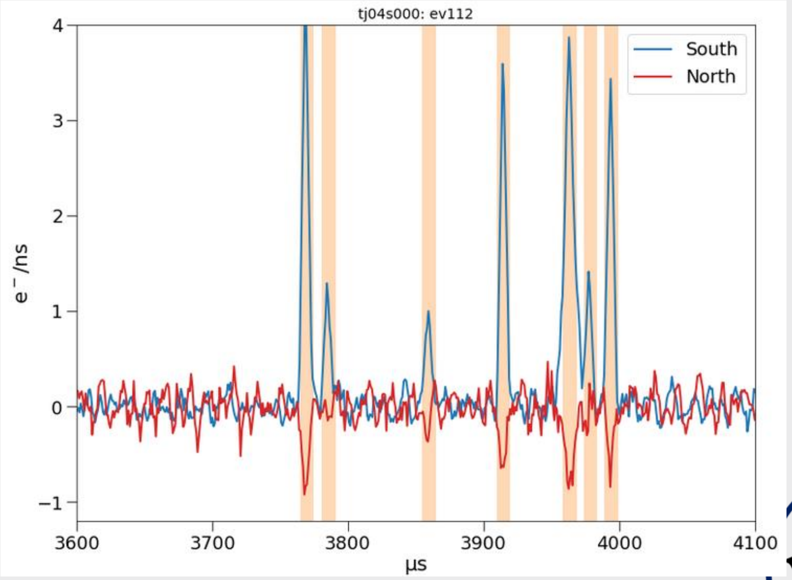
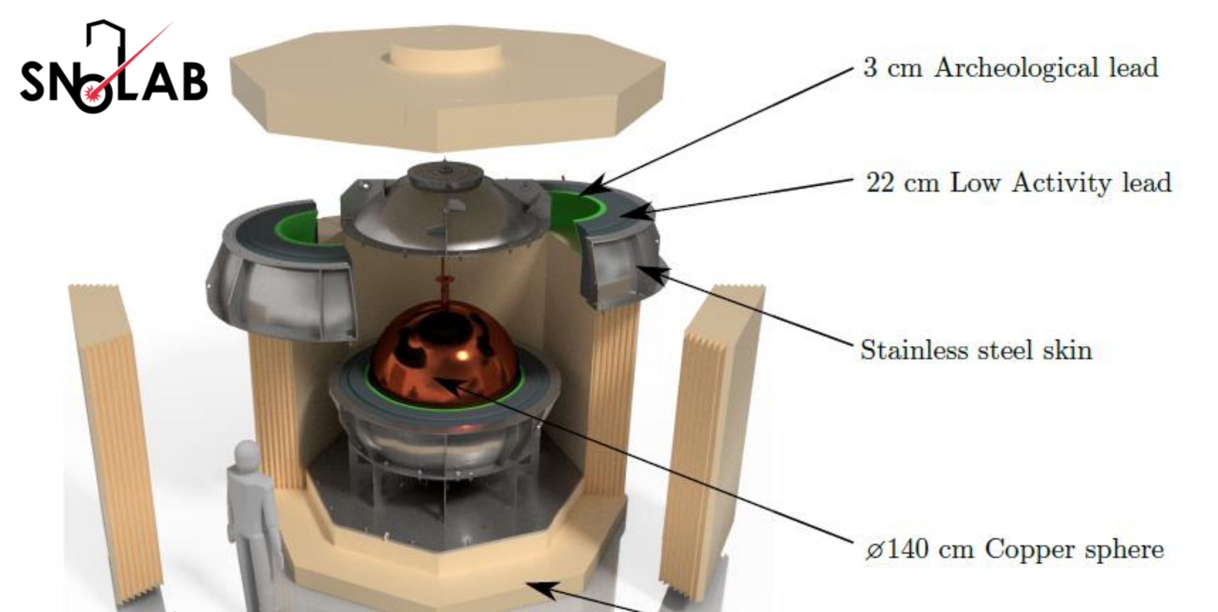




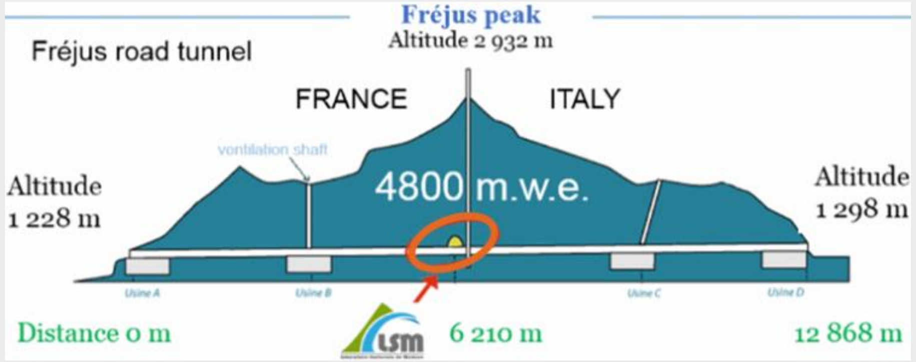
Shielding and data taking with S140

- 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.



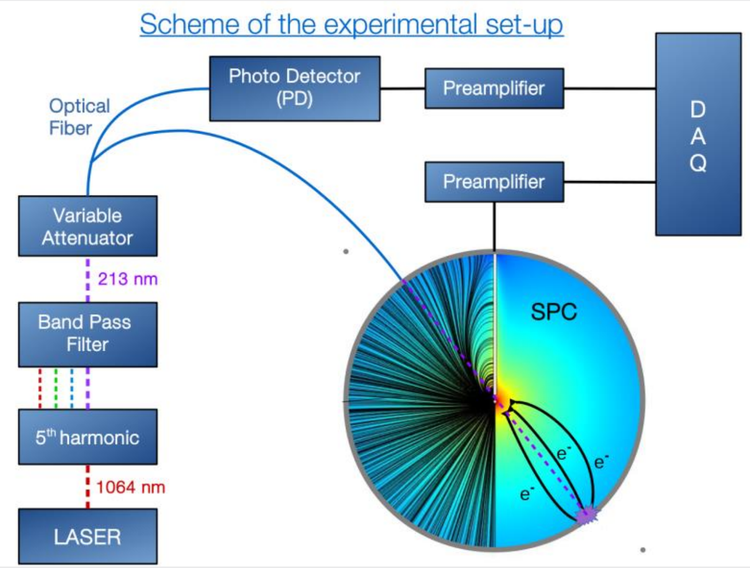
SNOLAB detector paper
doi:10.1088/1748-0221/18/02/T02005

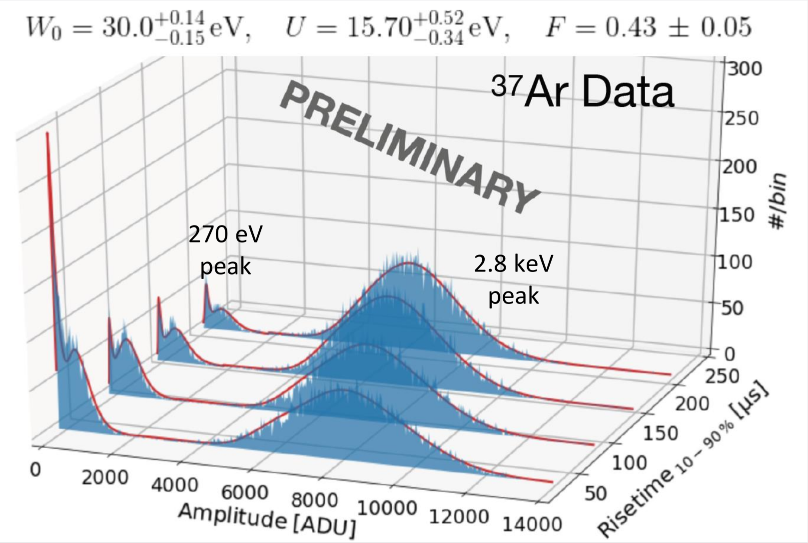
Laboratoire Souterrain de Modane (LSM)

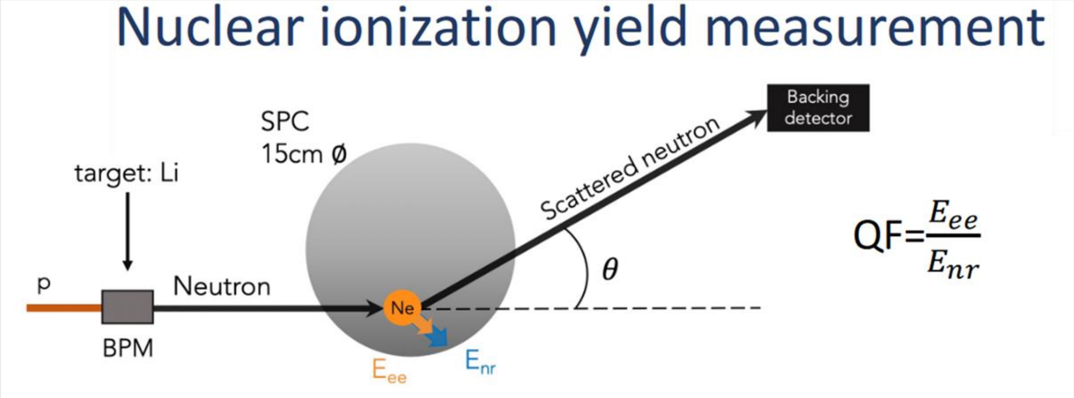


Calibration

- 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.
- The quenching factor was measured at COMIMAC.
- W-value measured at Queen's University.







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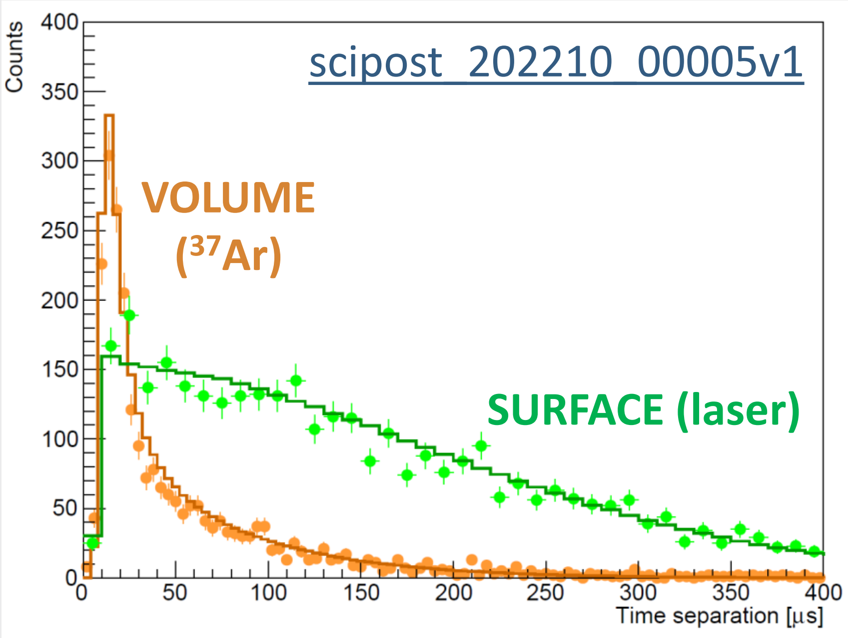
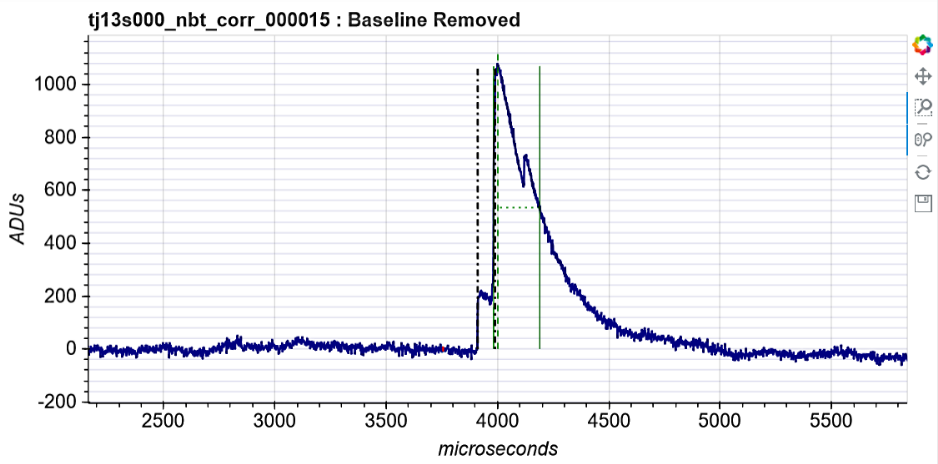
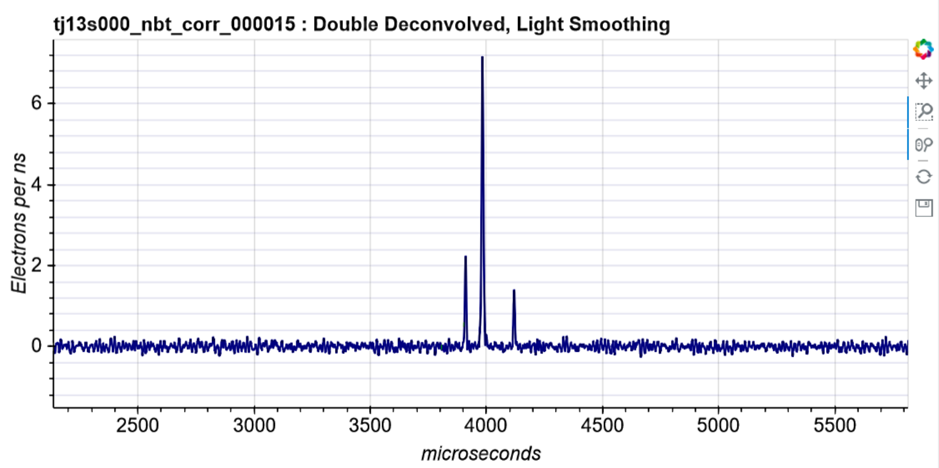
Peak counting and time separation



- 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



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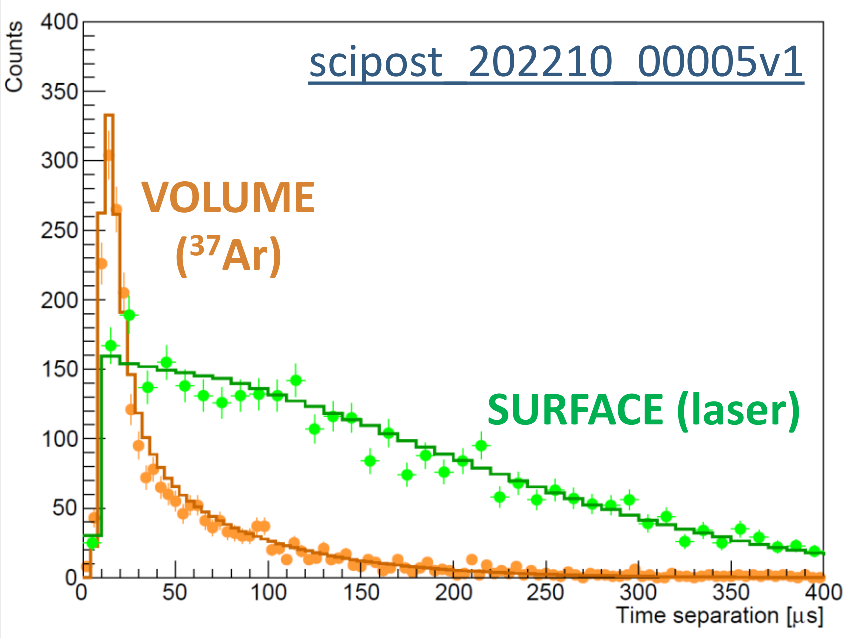

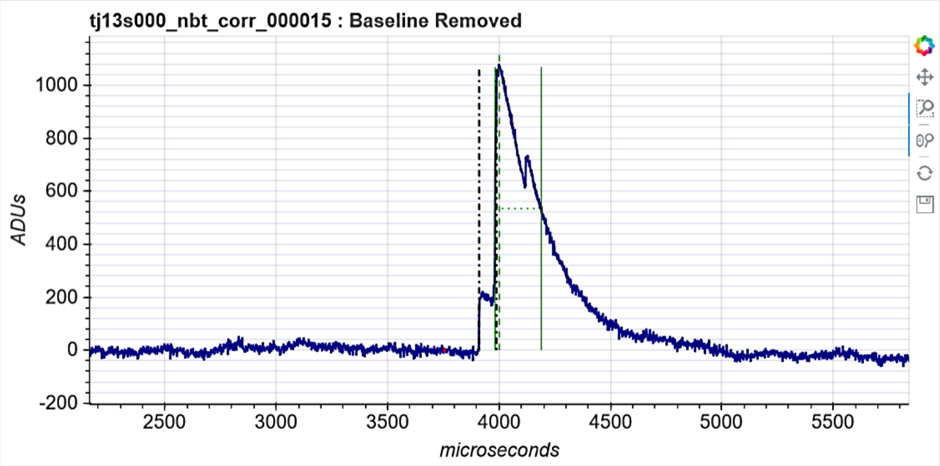

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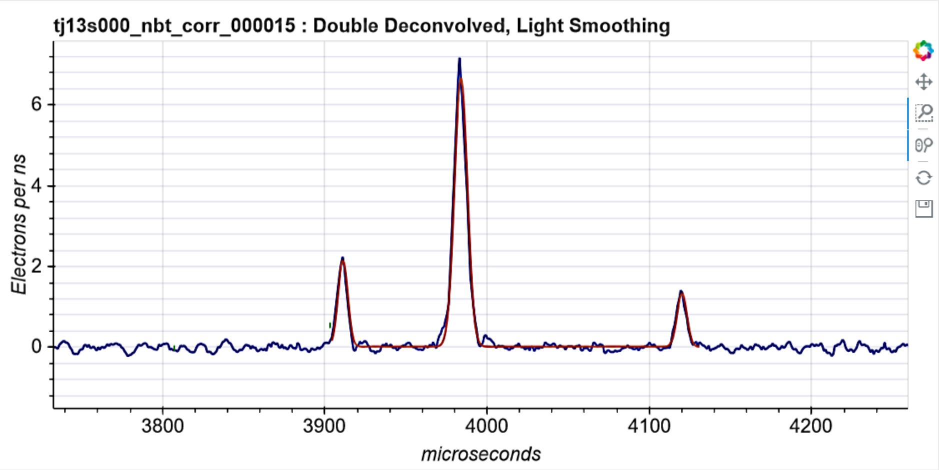
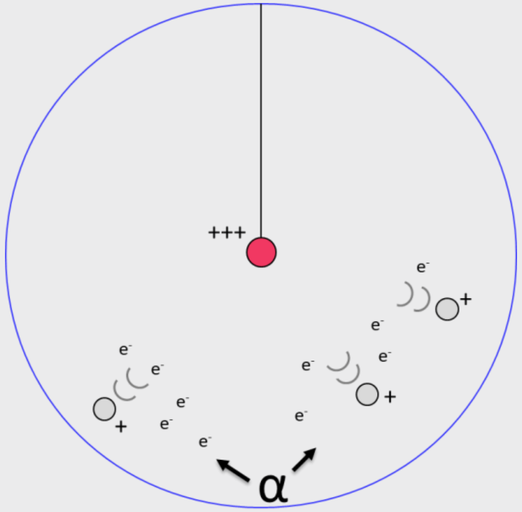
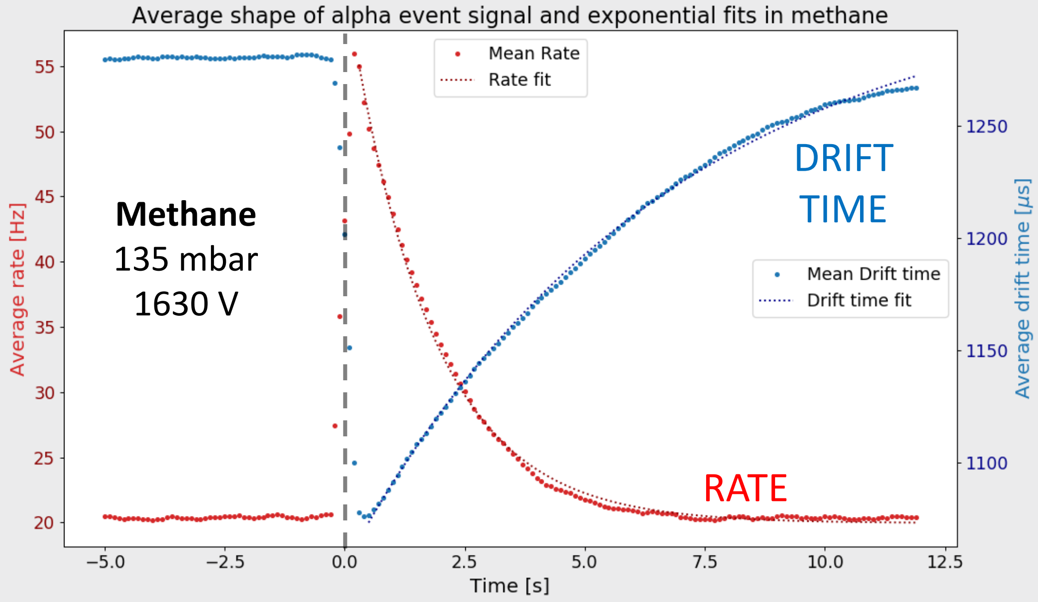


Alpha contamination

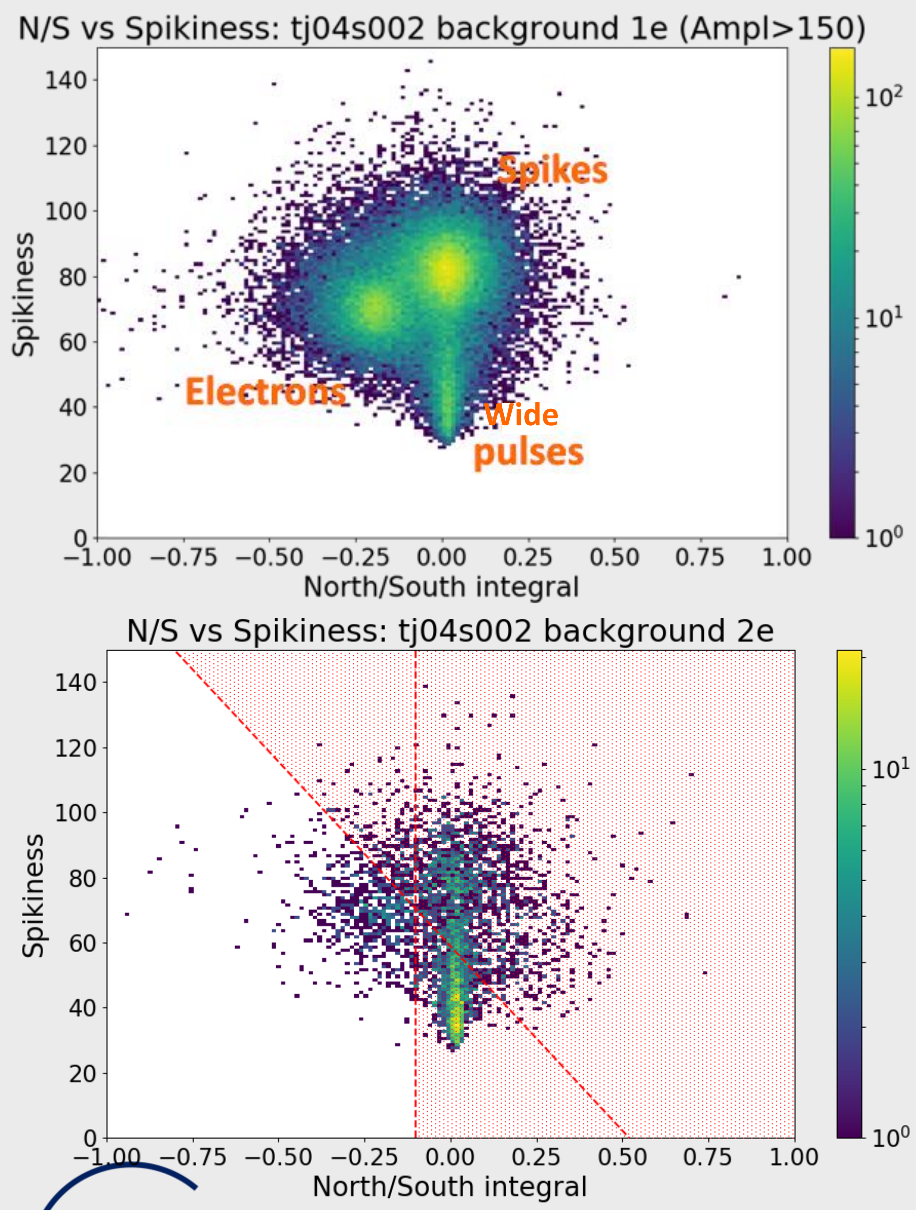
- There is ~25 mHz of alphas from ^{210}Po contamination in the copper surface.
- Alphas ionize a lot of gas and create a space charge that disturbs the electric field, and changes the electron drift time.
- For some still unknown reason, a high rate of low energy events keep happening for around 5s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





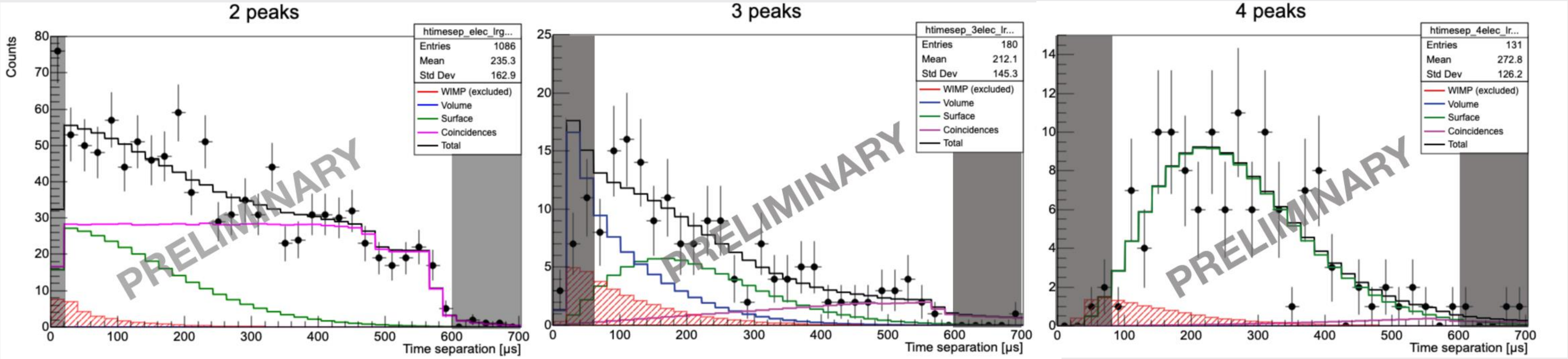
Pulse shape discrimination

- 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

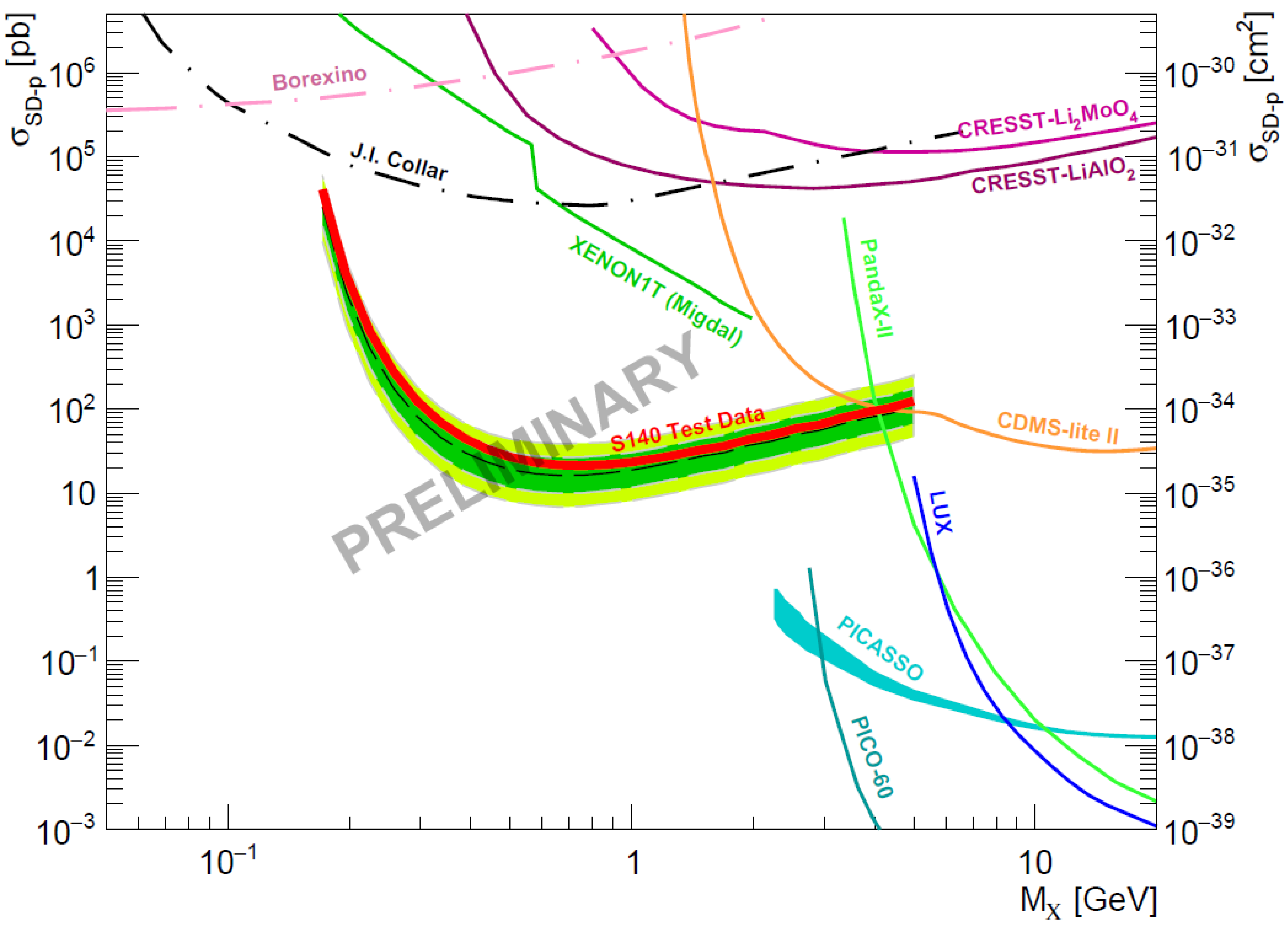
- 30% of the full data was set aside as a test data before the rest is unblinded.
- Profile likelihood fits of the test data were made for 2-3-4 peak data
- Fits with contributions from volume background, surface background, coincidences and WIMP signal.
- No significant WIMP signal was detected.



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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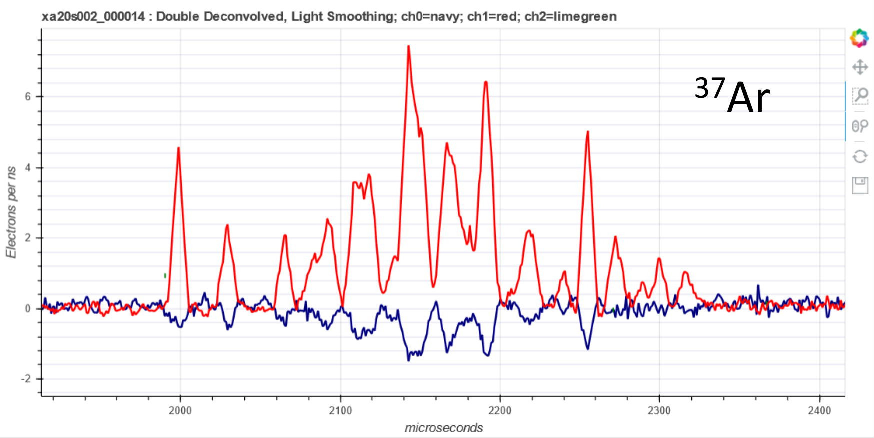
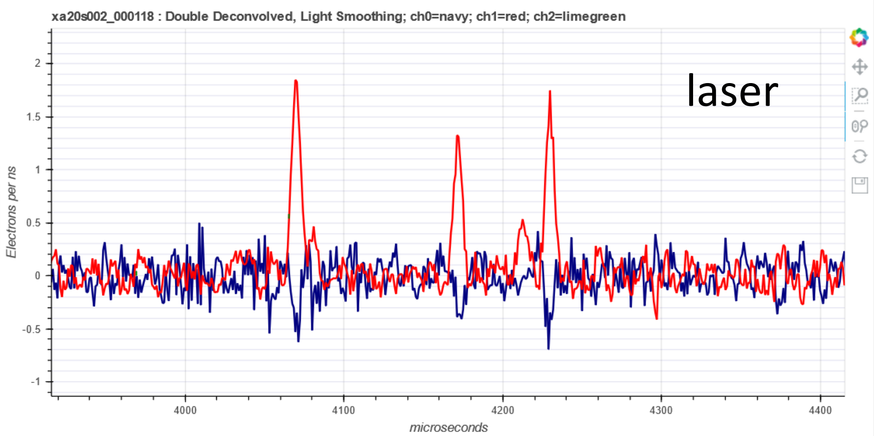
News from SNOLAB

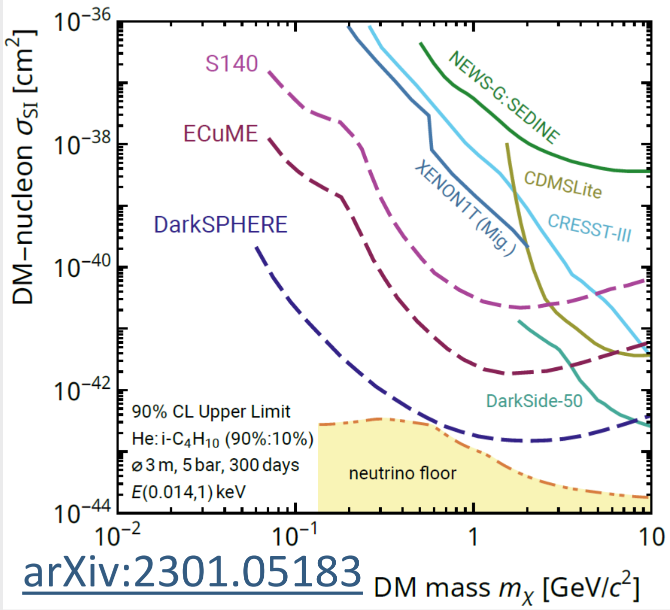
- Currently taking physics data
- Still countable electrons
- Improvements from LSM:
  - Trigger on three channels (North, South, PD)
  - Reduced noise
  - No spurious pulses
  - Neon+2%CH_4, CH_4, He+CH_4 etc.



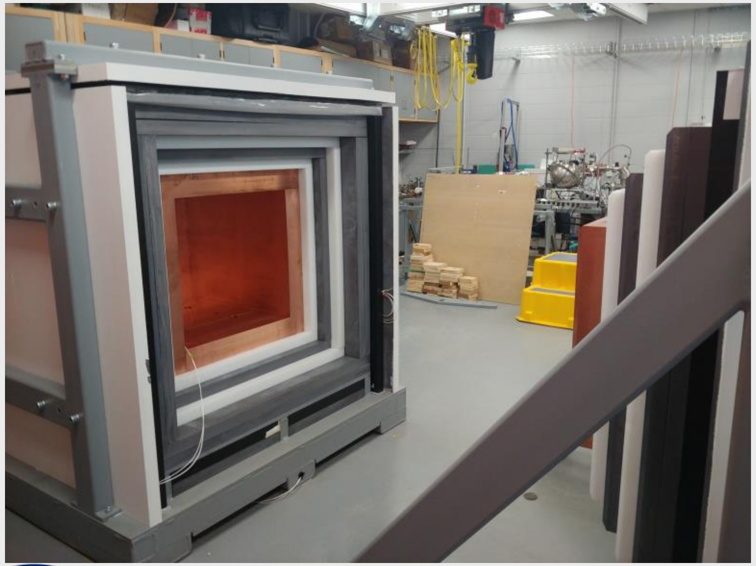


Future projects

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



arXiv:2301.05183



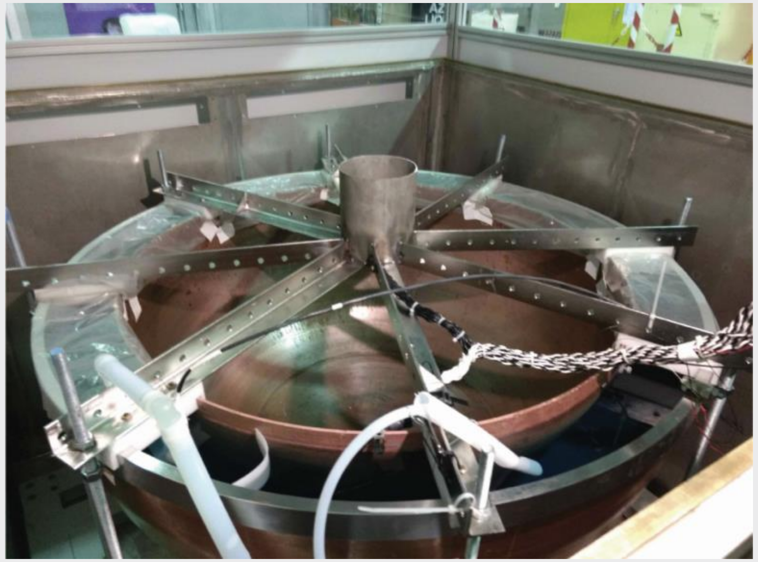
Conclusion

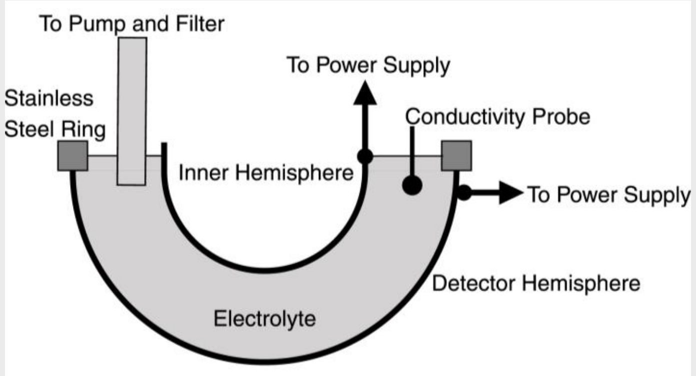
- NEWS-G and SPCs well suited for low mass dark matter search.
- LSM data able to set new SD-p WIMP constraints with CH_4.
- Currently taking physics data at SNOLAB with many improvements.
- Promising future projects in the works.

Thank you!

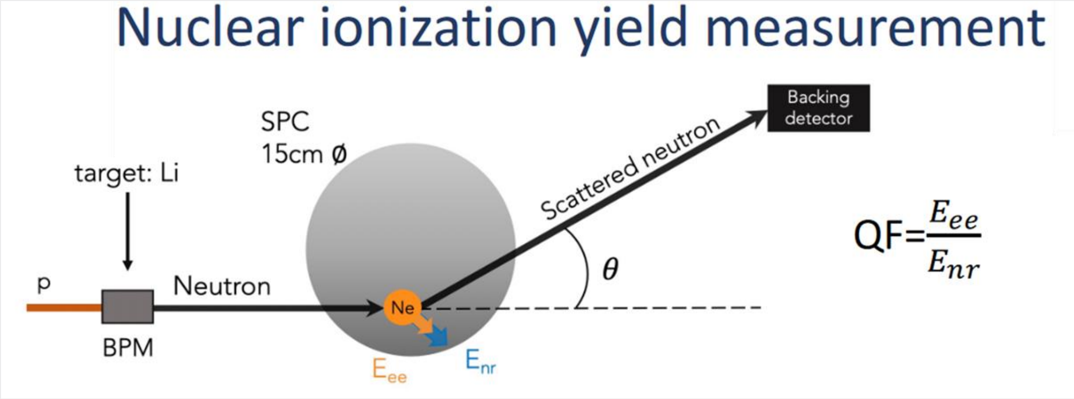
Extra slides

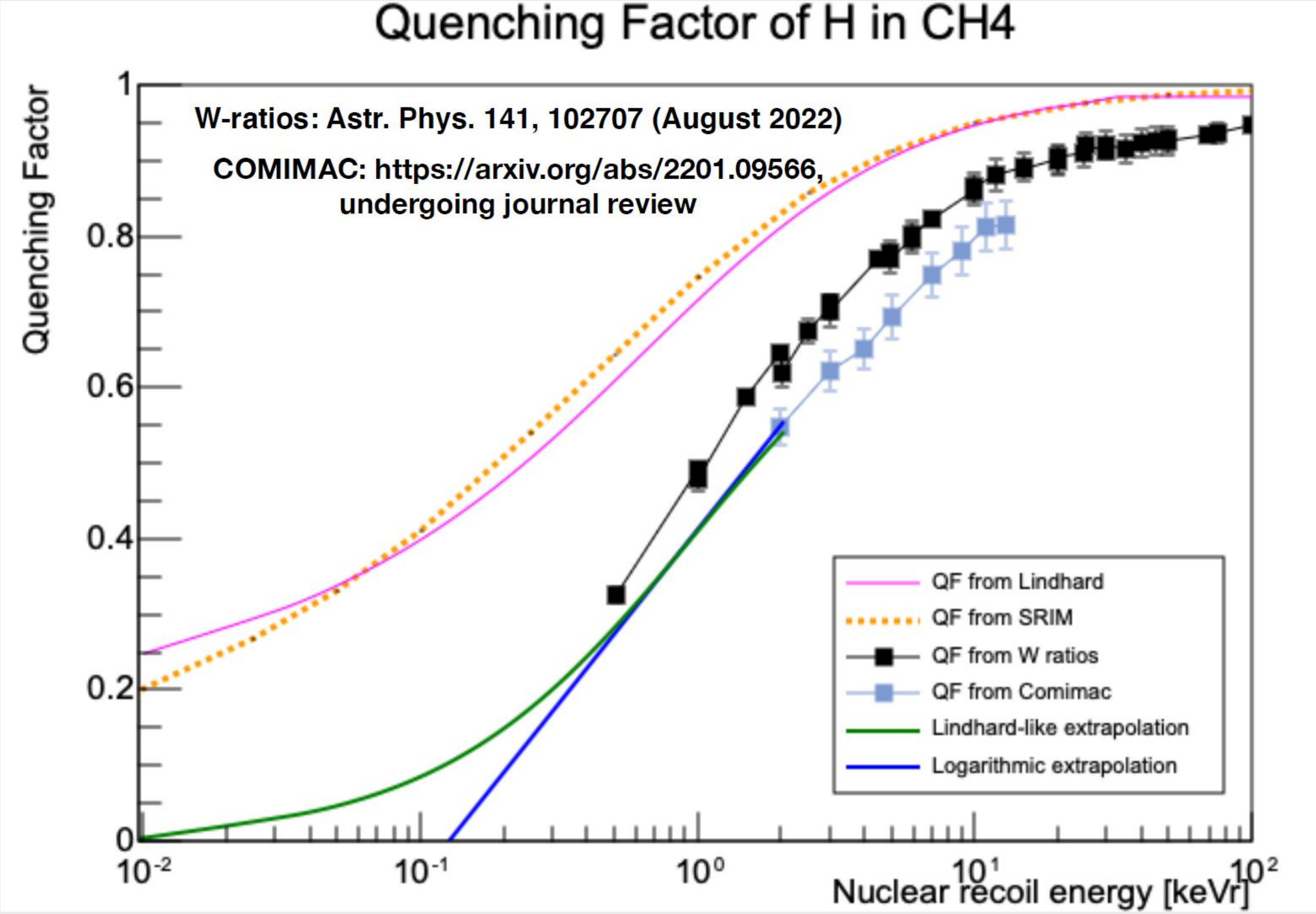
Making the sphere, electroforming, etching



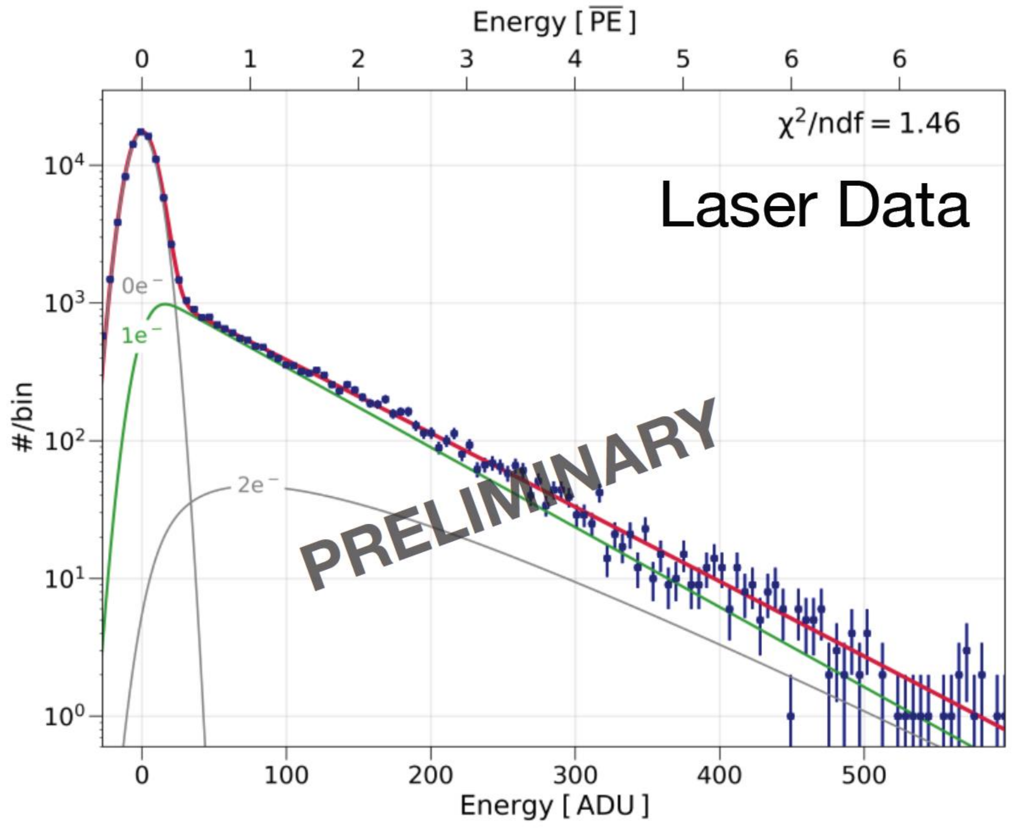


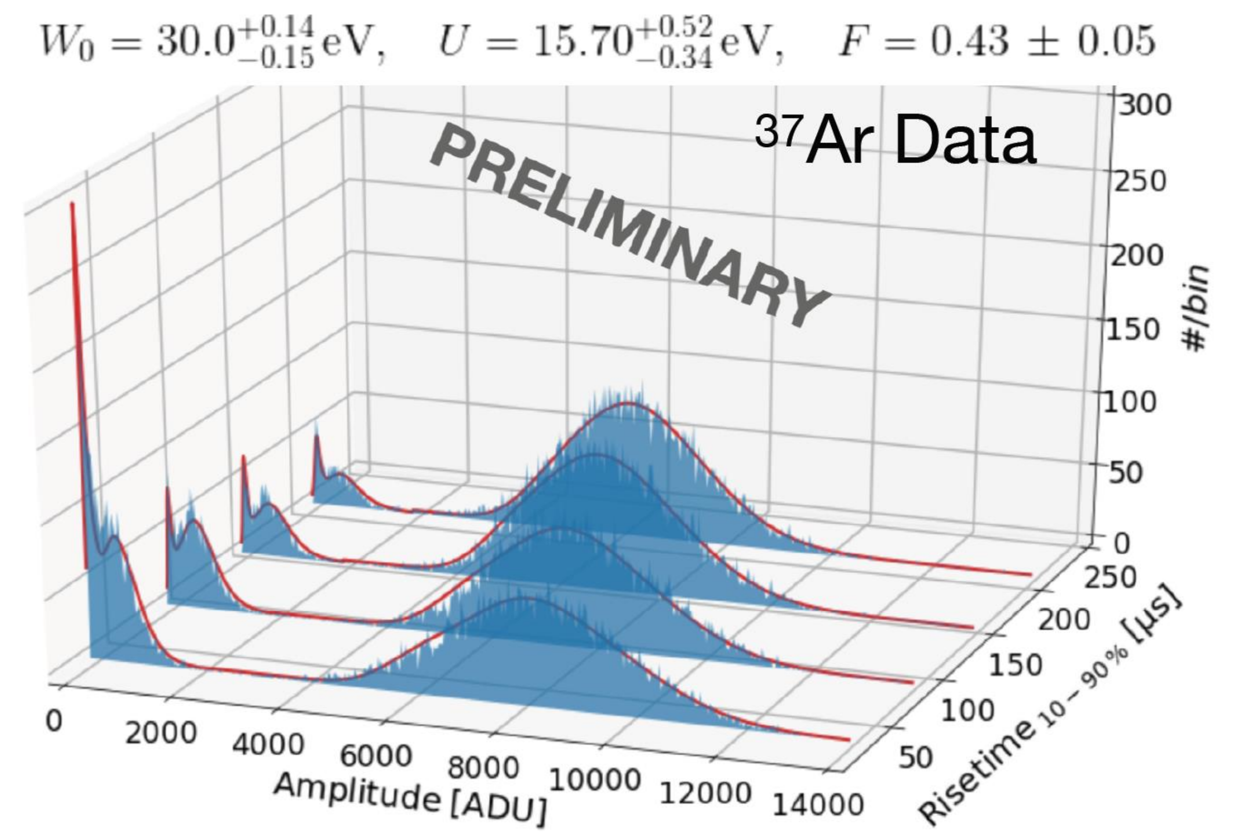
Quenching factor





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





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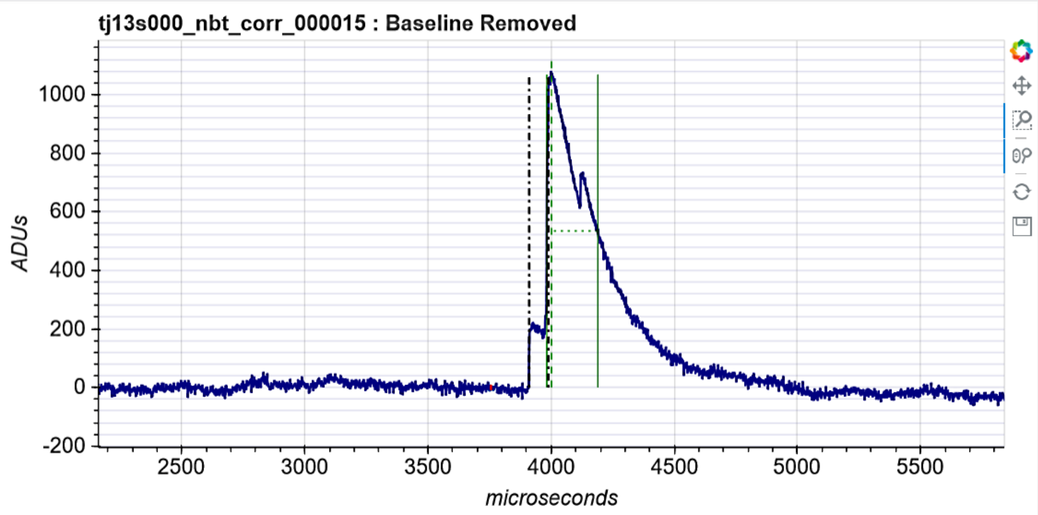
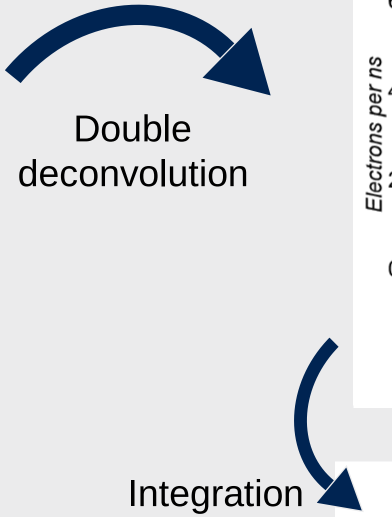
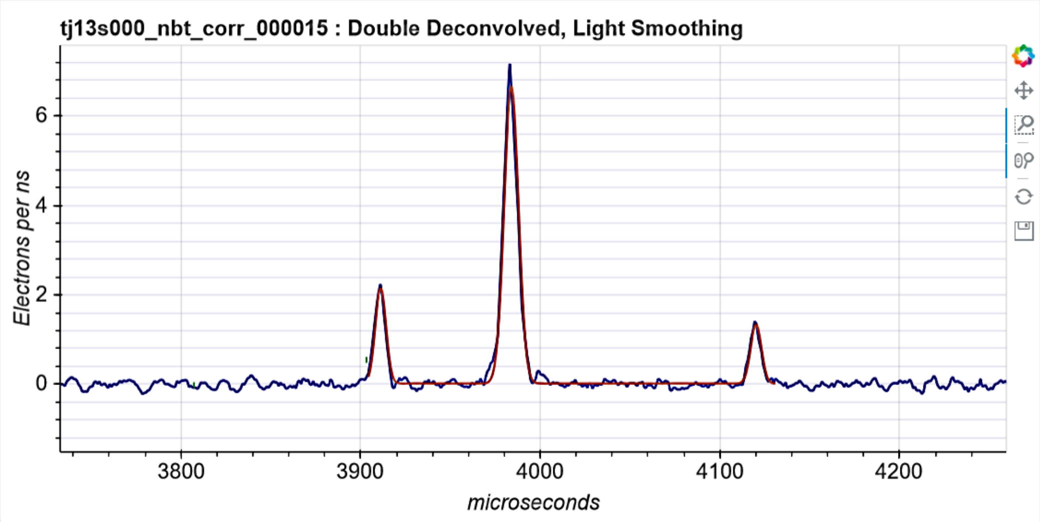
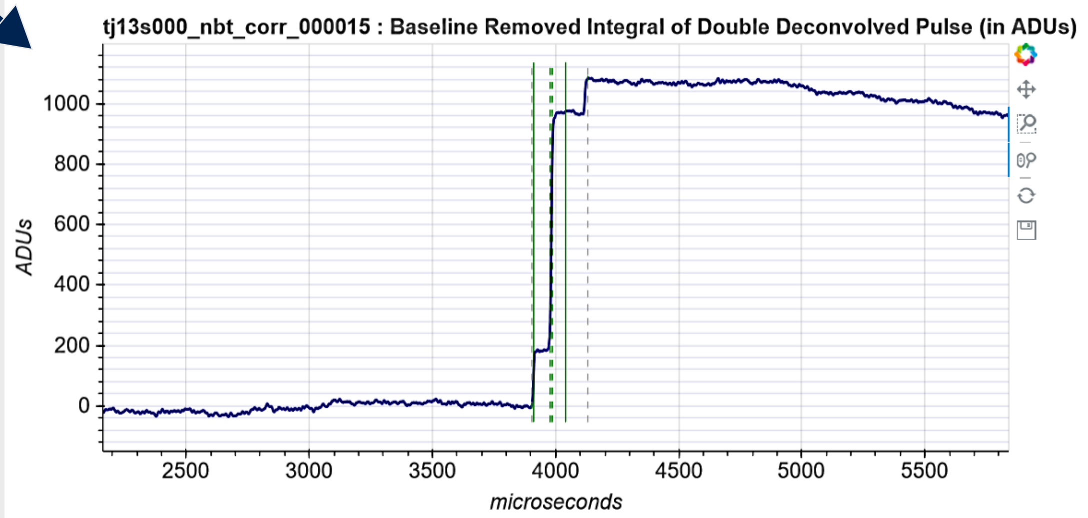
Double deconvolution





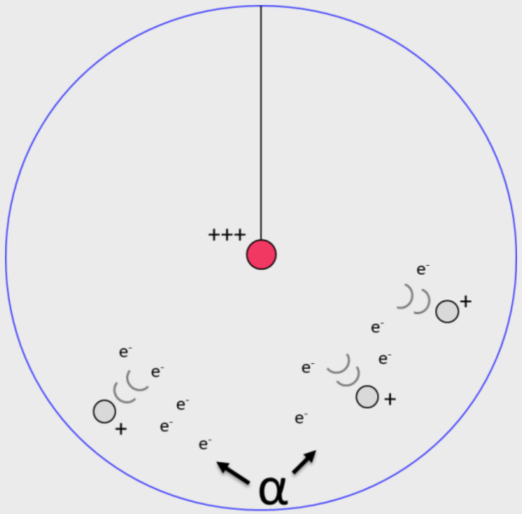




The ballistic deficit is the signal amplitude that gets underestimated due to the exponential decay of the preamplifier.

The full amplitude (energy) is retrieved by doing a double deconvolution of the raw signal, and then integrating the pulses.

Alpha background



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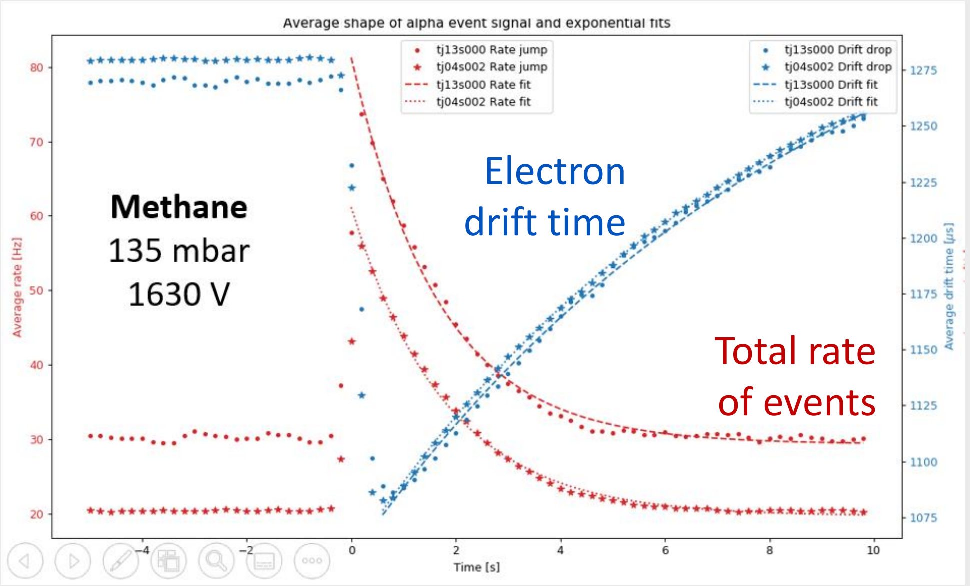
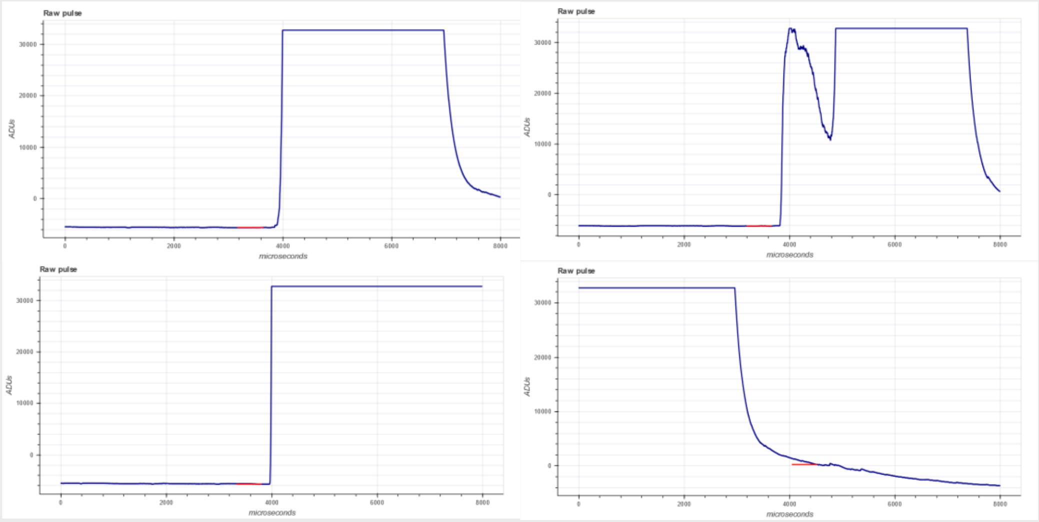
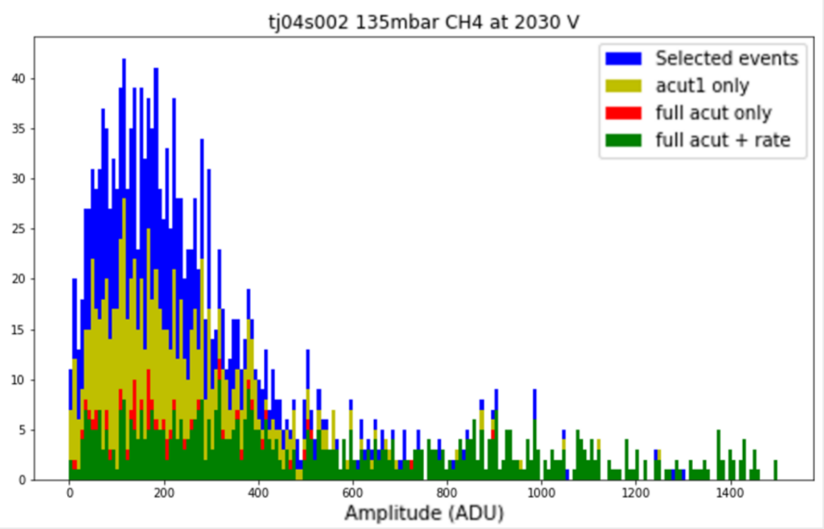




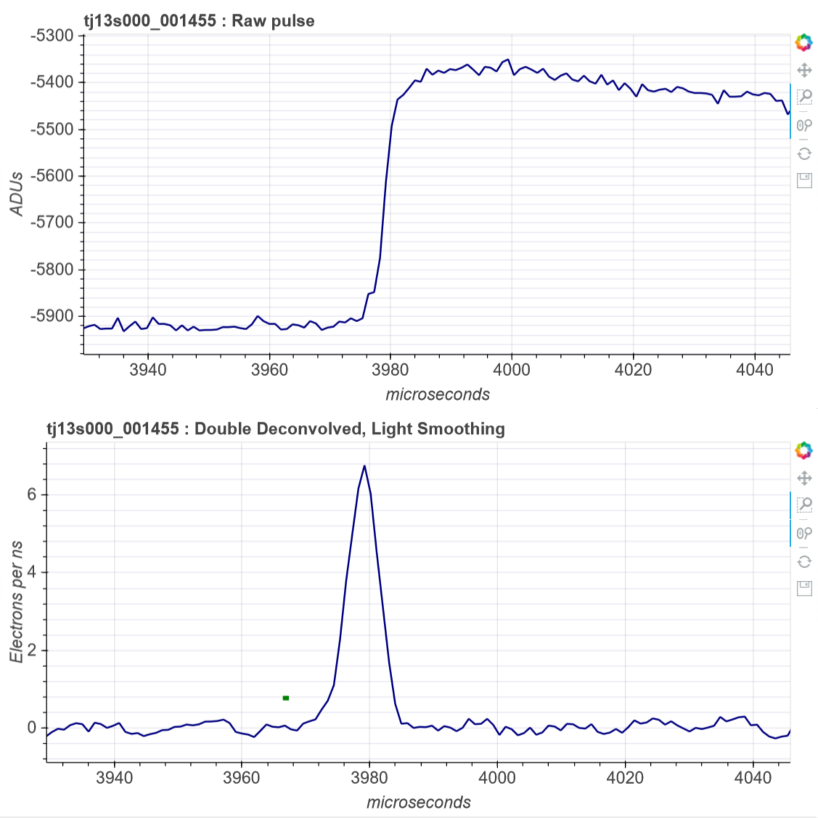
The saturated alpha signals can be broken up and difficult to detect, but using the drift time, rate of events and decreasing baselines, we can identify alphas and remove most of the low-energy background due to them with a 5s cut after each alpha, keeping 85-90% of the total time.

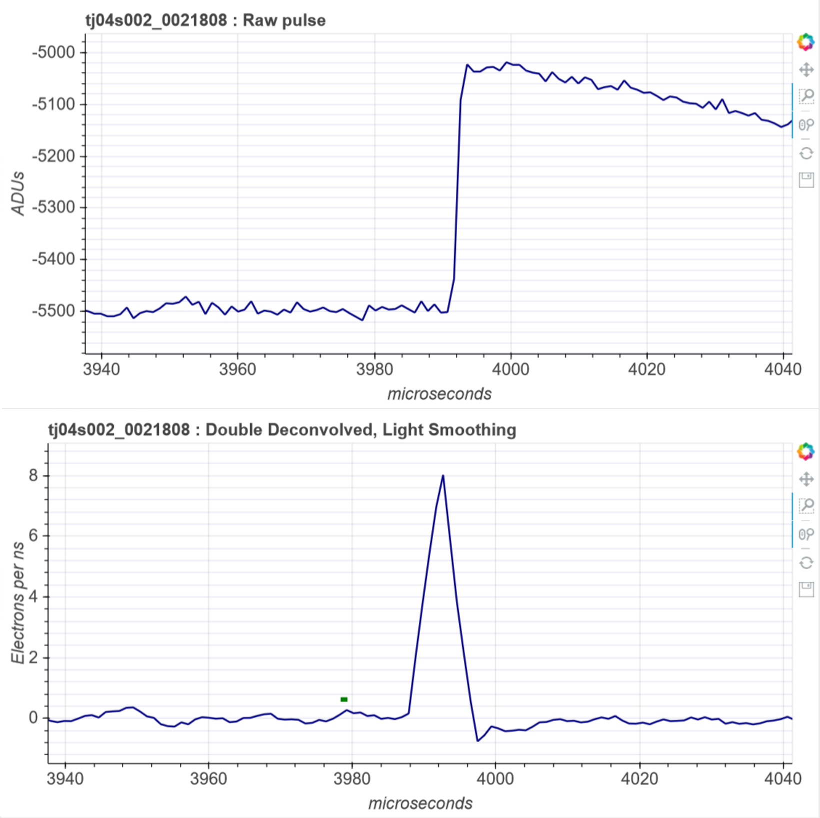


Spikiness

1st comparison method
Spikiness

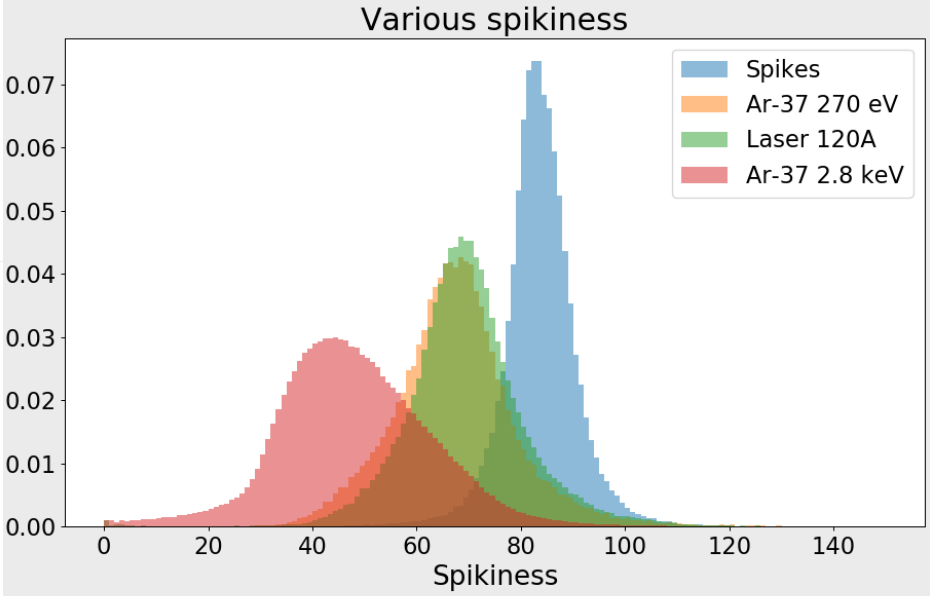
$$\text{Spk} = \frac{\text{Max signal derivative}}{\text{Peak height}}$$





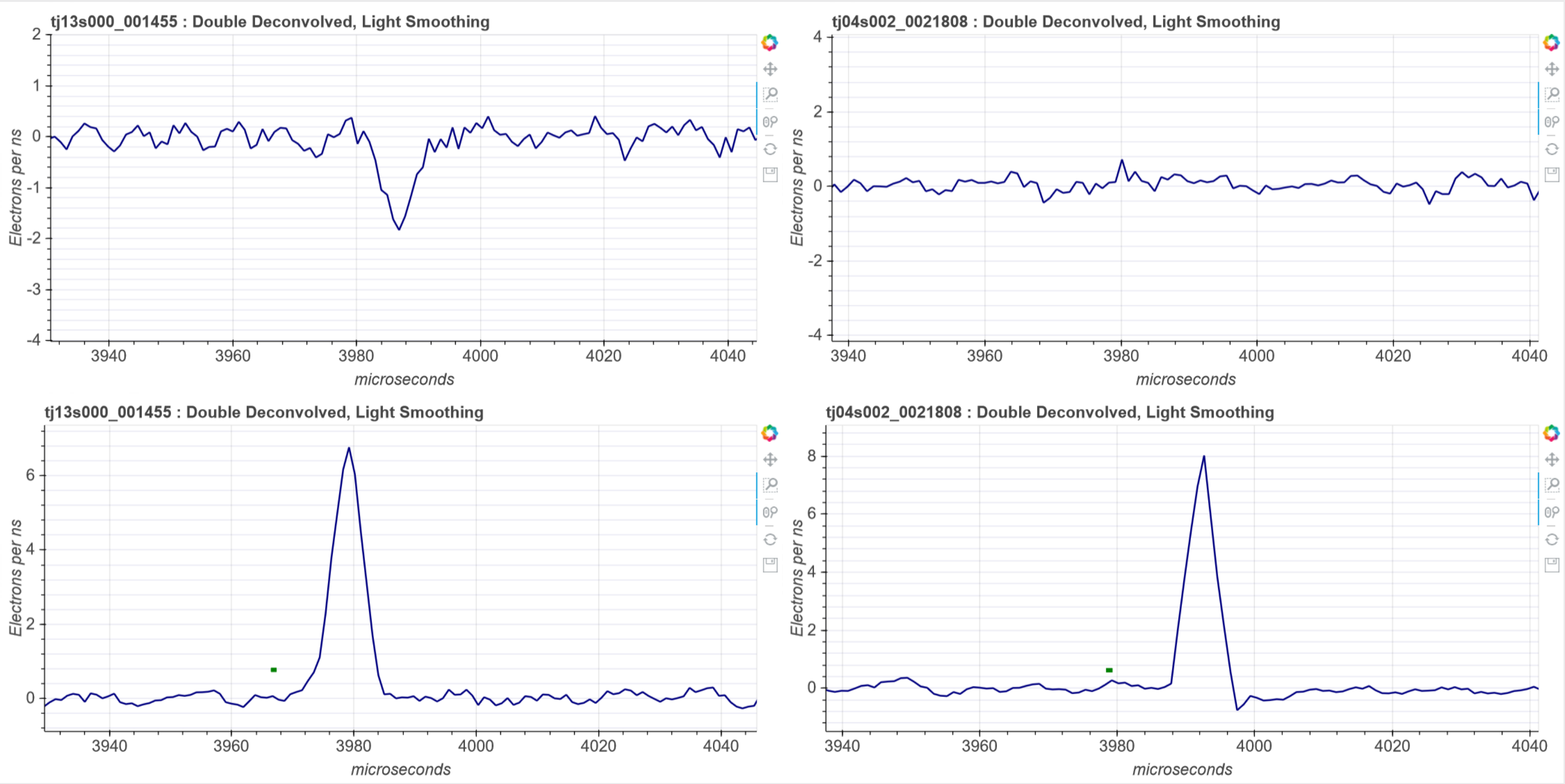
Probable electron event

Probable spike event

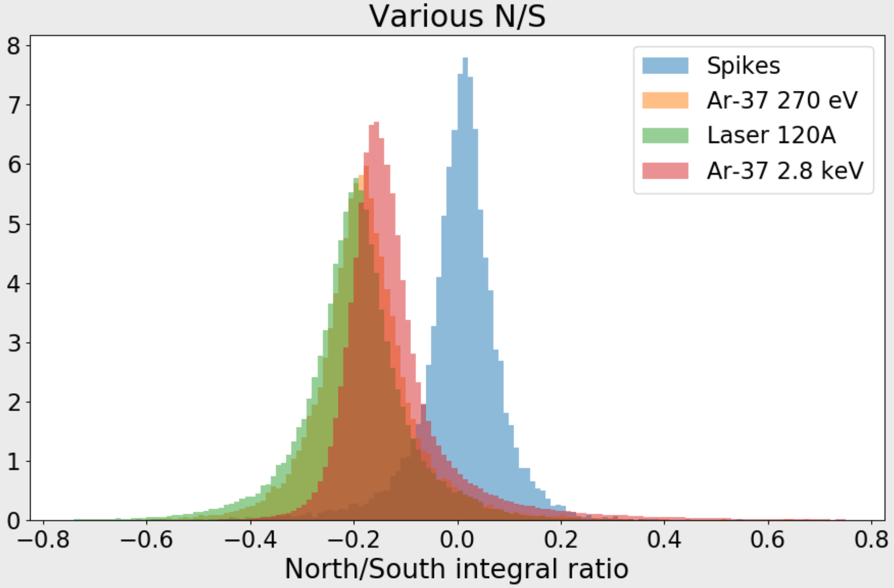


North/South integral ratio

2nd comparison method
N/S ratio



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

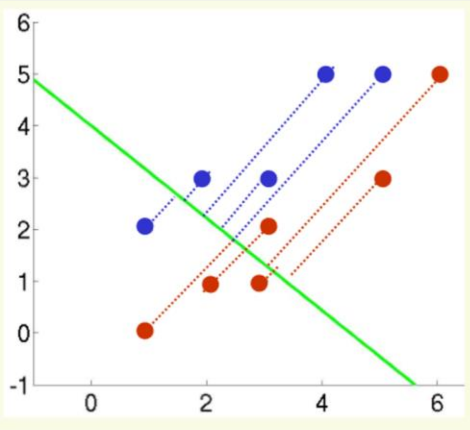


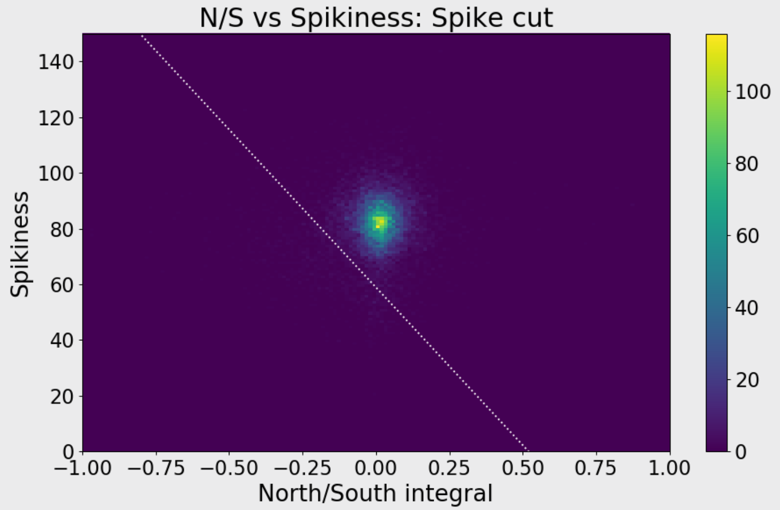
Probable electron event

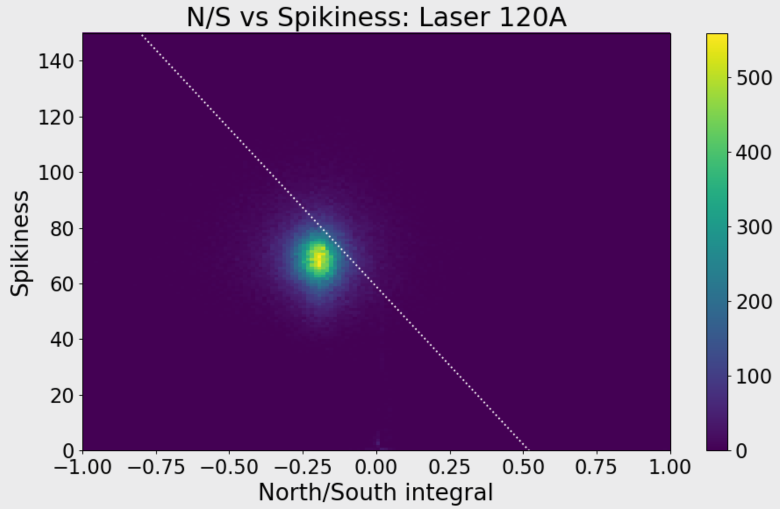
Probable spike event

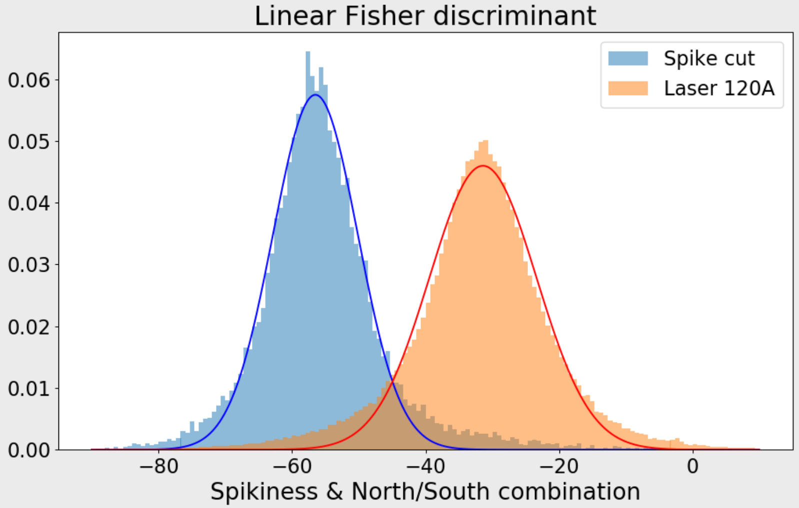
Linear Fisher discriminant

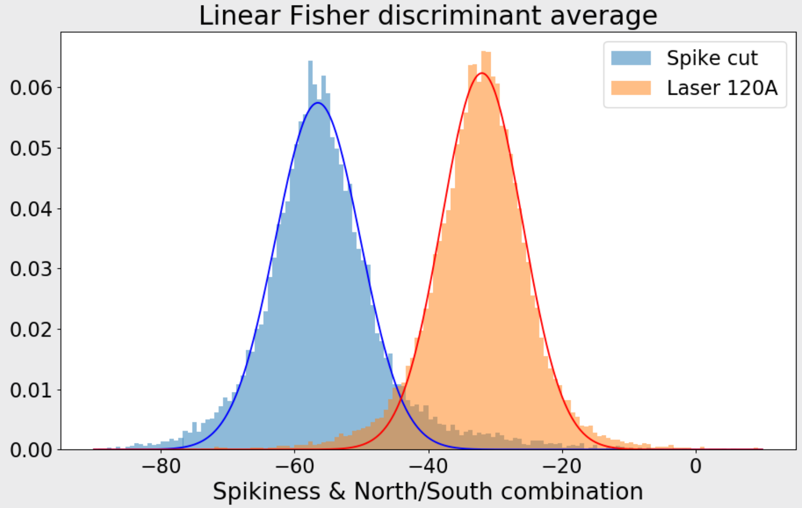
Optimal comparison:
Combining both methods









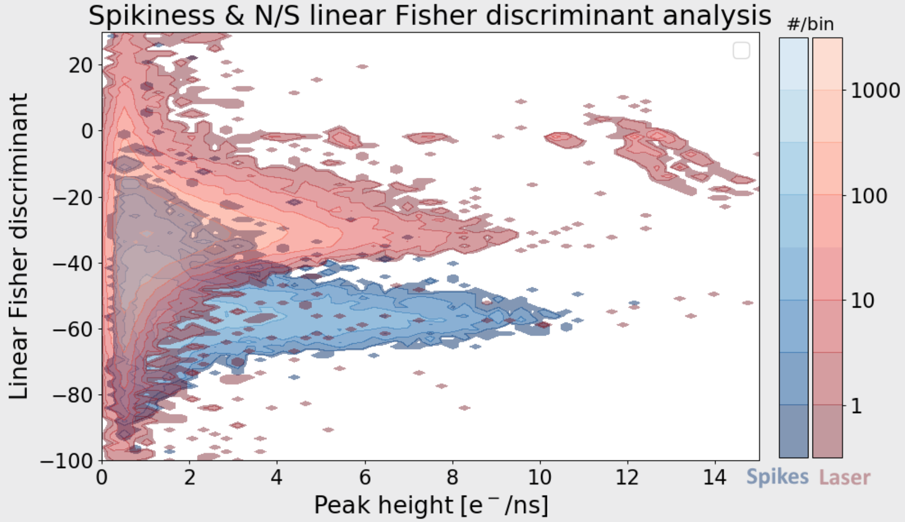


Separation $J(\omega) = \frac{(\mu_1 - \mu_2)^2}{N_1(\sigma_1)^2 + N_2(\sigma_2)^2}$

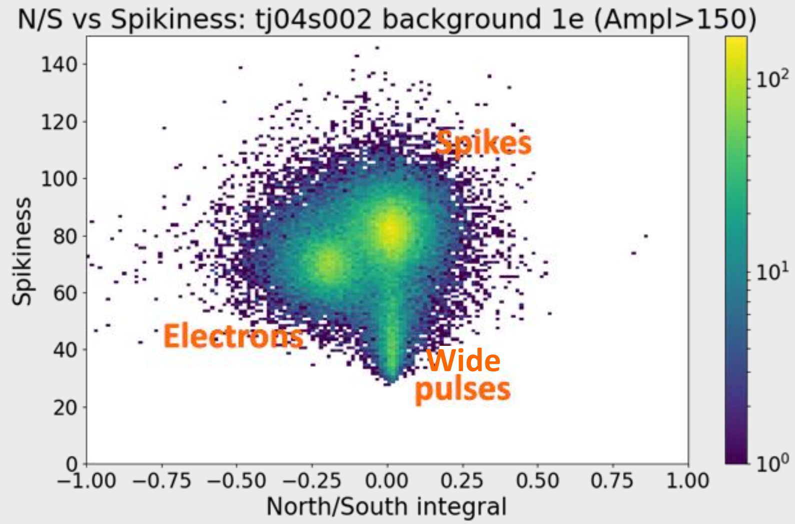
New axis $\tau_i = \omega^t x_i^t$

ω=[−0.678619815,−76.8674863]
Spk NS

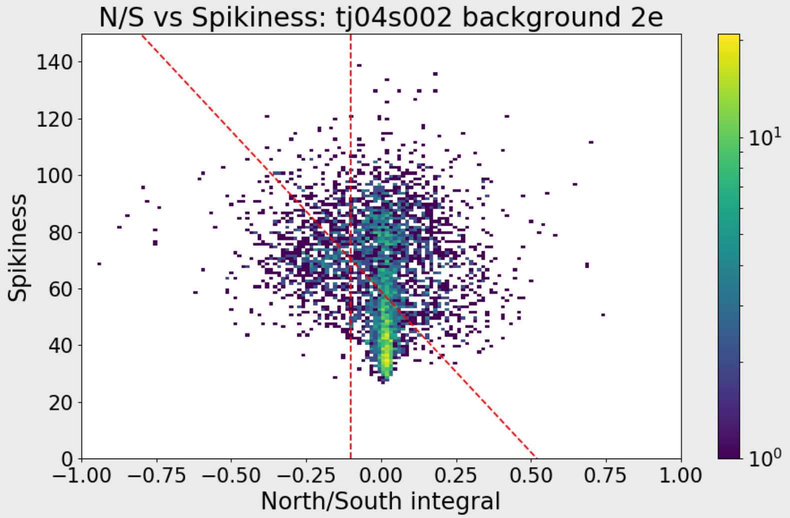
Fits to the physics data



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.