New Background Discrimination Methods for the NEWS-G Dark Matter Search Experiment

CAP 2022

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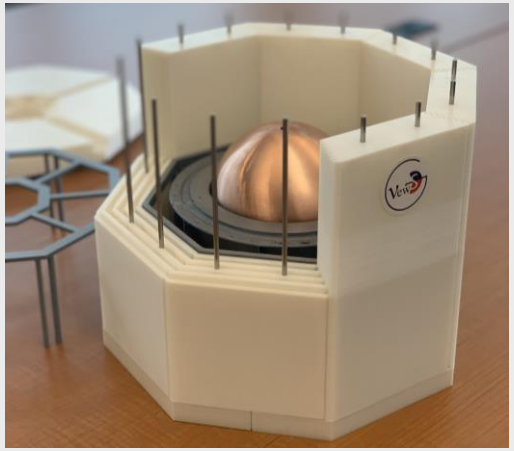
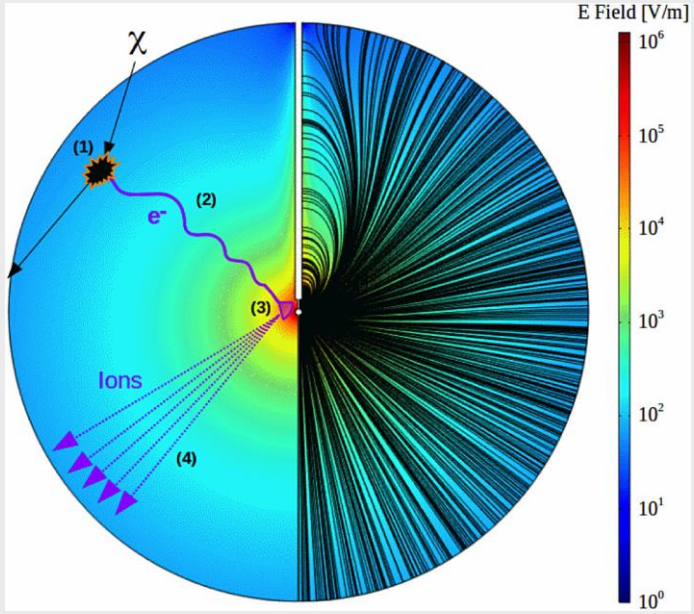
Electric field and calibration

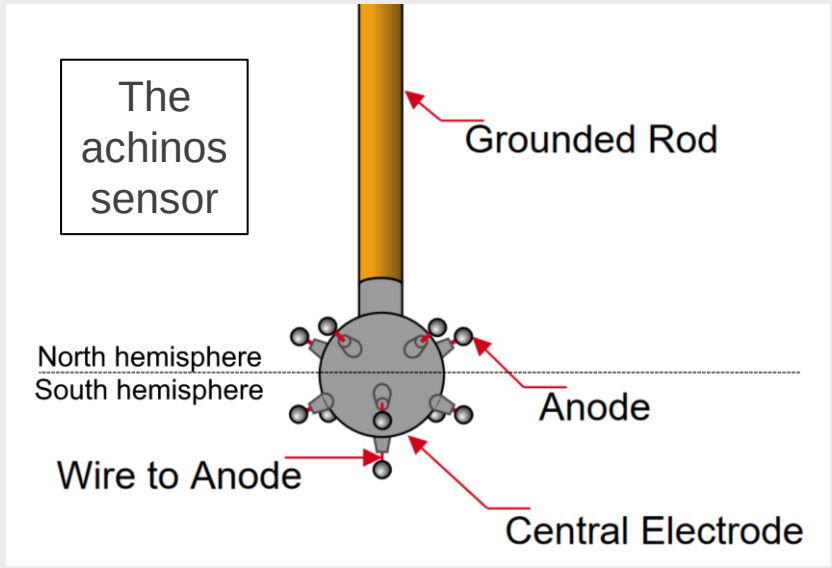
NEWS-G uses a spherical proportional counter in order to search for low mass WIMPs. The latest detector, a 140 cm of diameter sphere, has taken data at the LSM (France) in Fall 2019 and is currently being commissioned at SNOLAB.



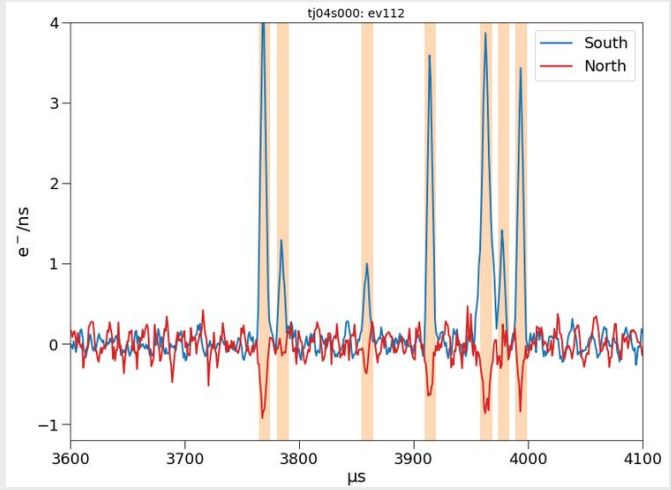
S-140 detector model



WIMP detection principle (left) and electric field inside an SPC (right)

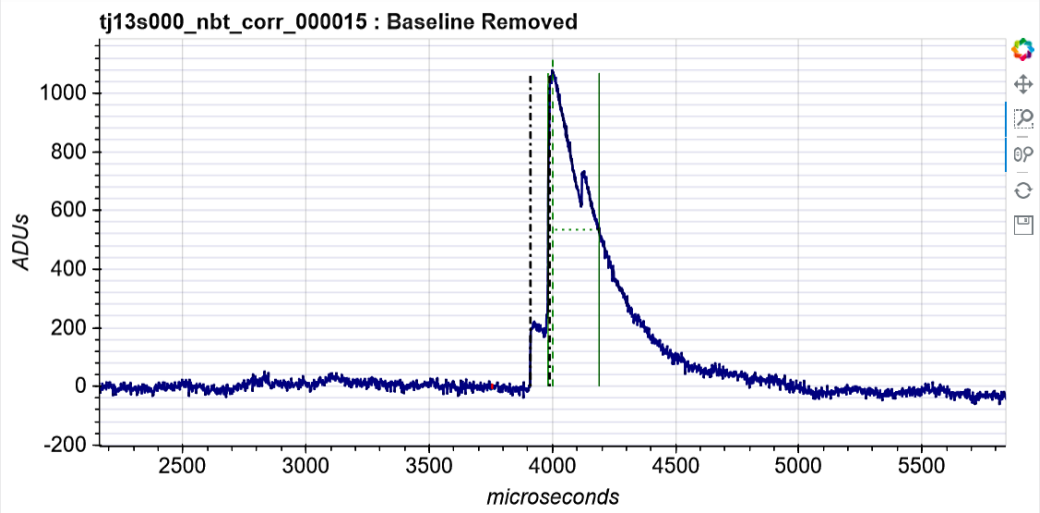


There is a crosstalk between the north and south hemispheres of the achinos. A positive signal in the south anodes creates a smaller negative signal in the north anodes, and vice-versa.

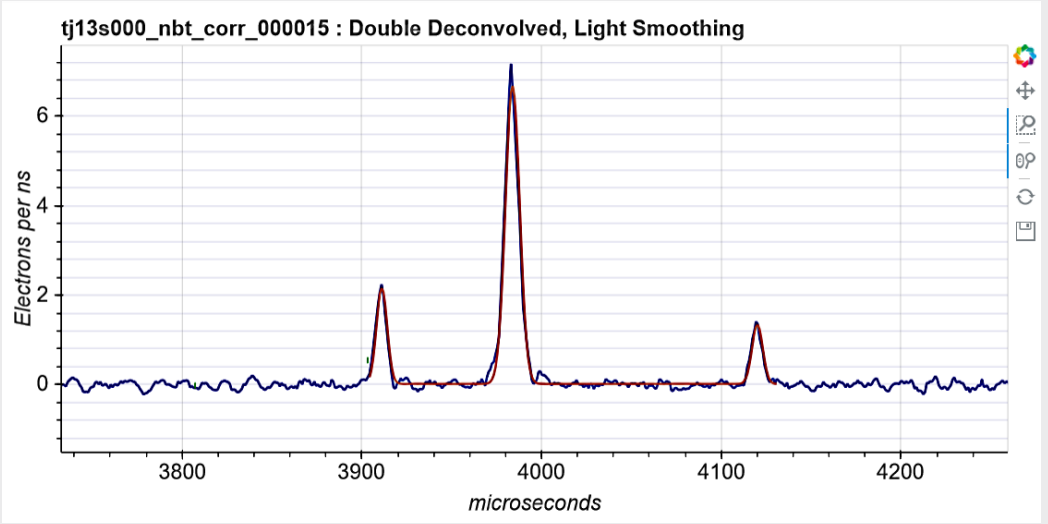


Graph from Daniel Durnford

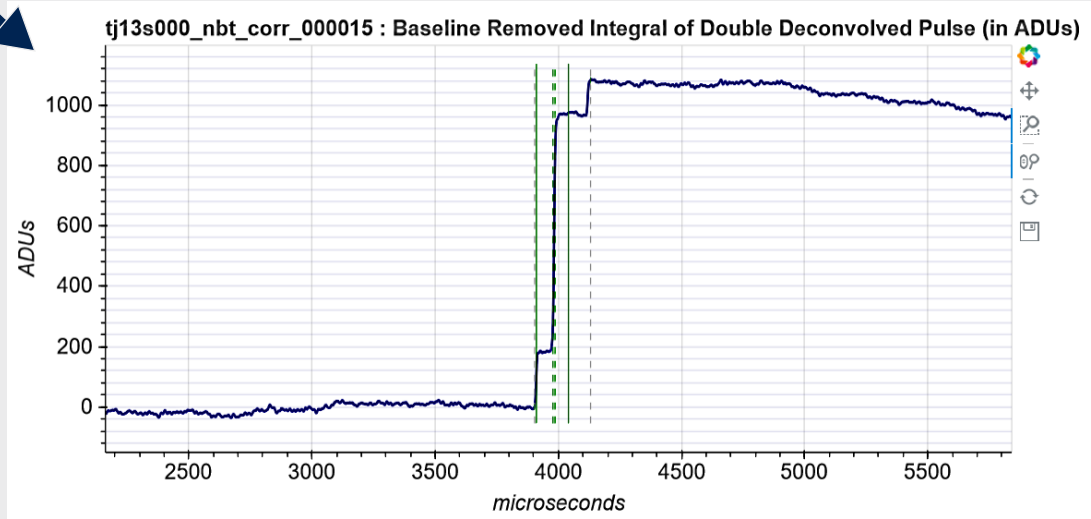
Double deconvolution



Double deconvolution

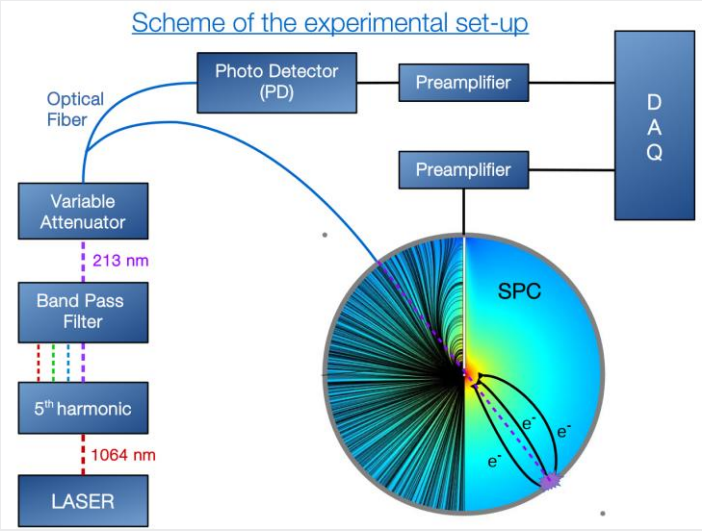


Integration

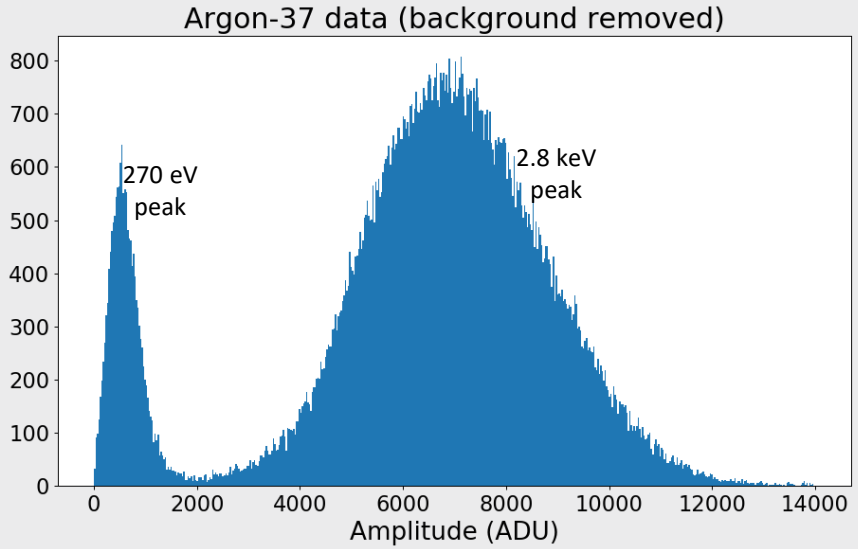


The ballistic deficit is the signal amplitude that gets underestimated due to the exponential decay of the preamplifier.
The full amplitude (energy) is retrieved by doing a double deconvolution of the raw signal, and then integrating the pulses.

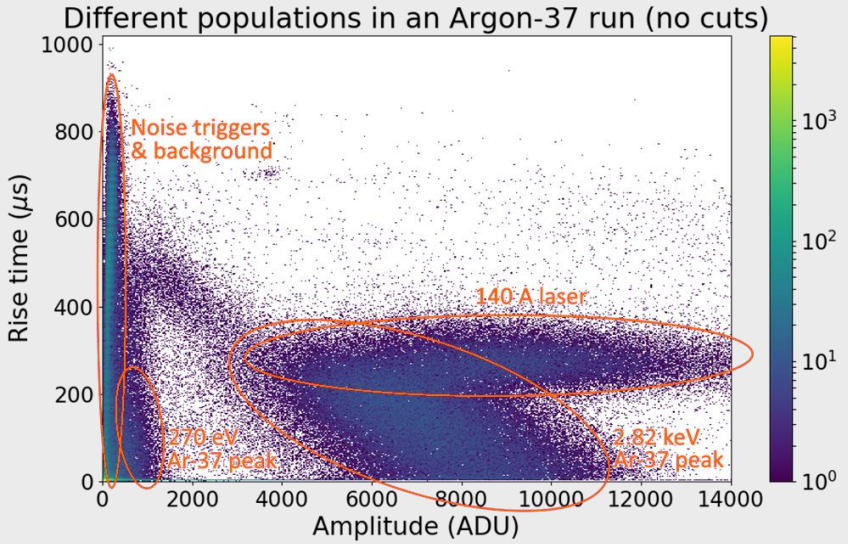
Calibration and background



Laser calibration [10]



^{37}Ar calibration



Selection of different kinds of events

Two troublesome kinds of background:

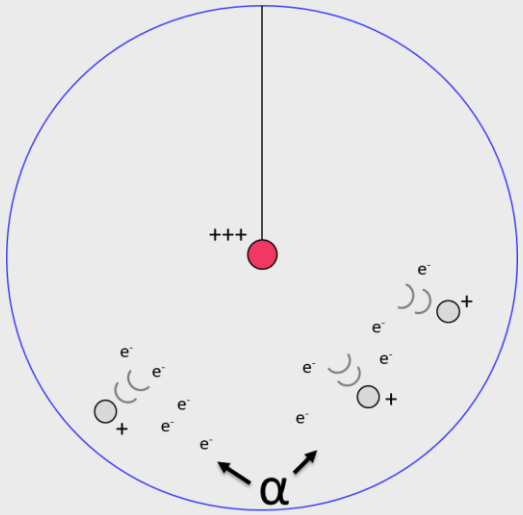
Alphas

- There is ~25 mHz of alpha contamination in the detector.
- Alpha events are easy to remove due to their high energies.
- However, they cause a significant number of low energy events, similar to WIMP signal.

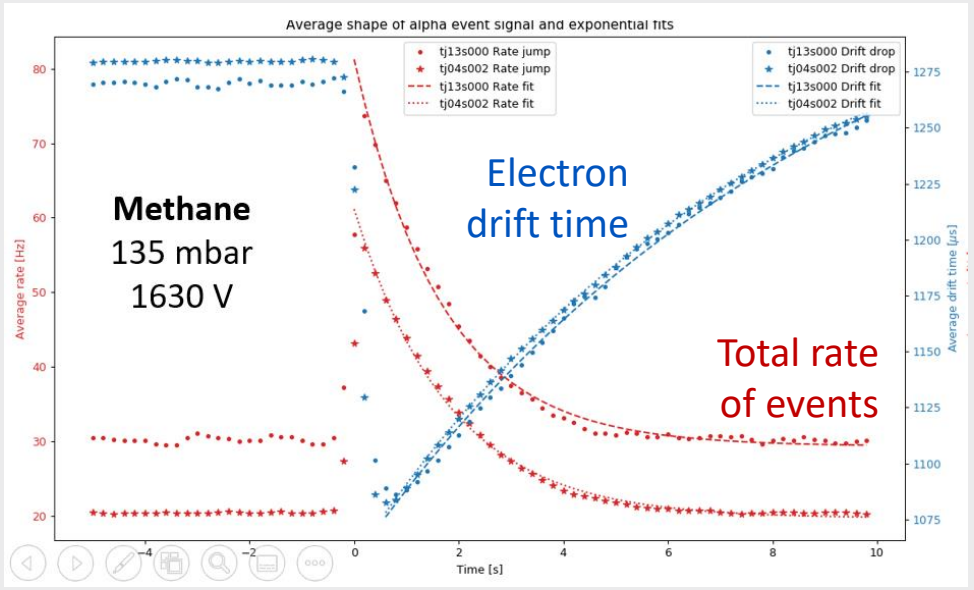
Spikes

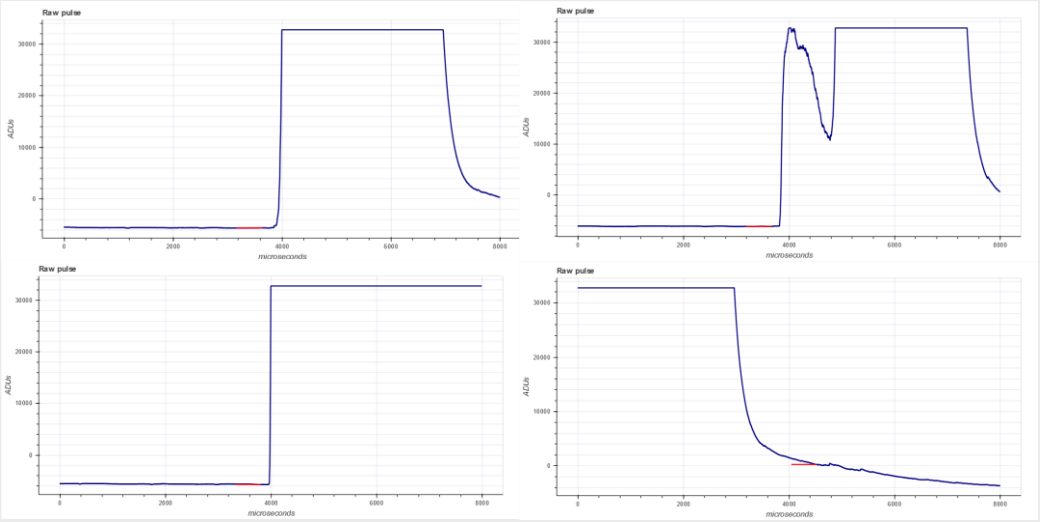
- They are non-physical sudden rises of the signal.
- They do not come from any primary electron, do not create a Townsend avalanche.
- They can be caused by irregularities in the voltage supply or internal discharges.

Alpha background

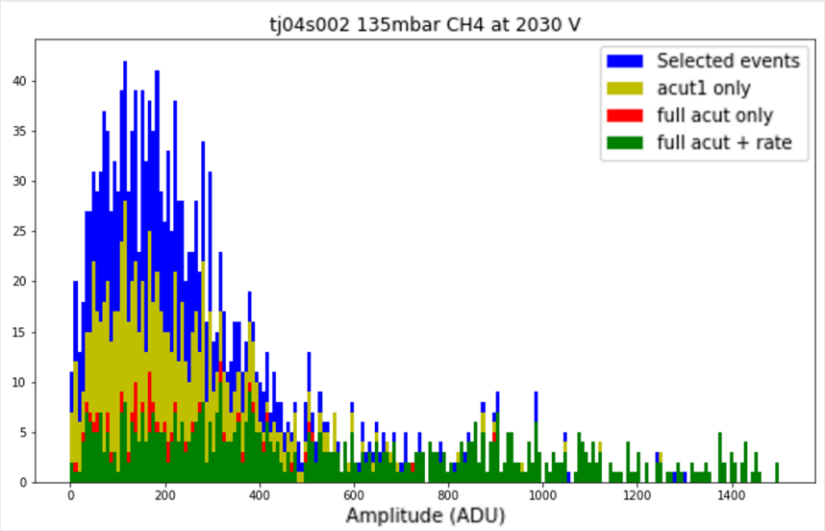


There is ^{210}Po contamination in the copper surface, which causes alphas that ionize a lot of gas. All the ions create a space charge that disturbs the electric field, and changes the electron drift time. For some still unknown reason, a high rate of low energy events keep happening for around 5s after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





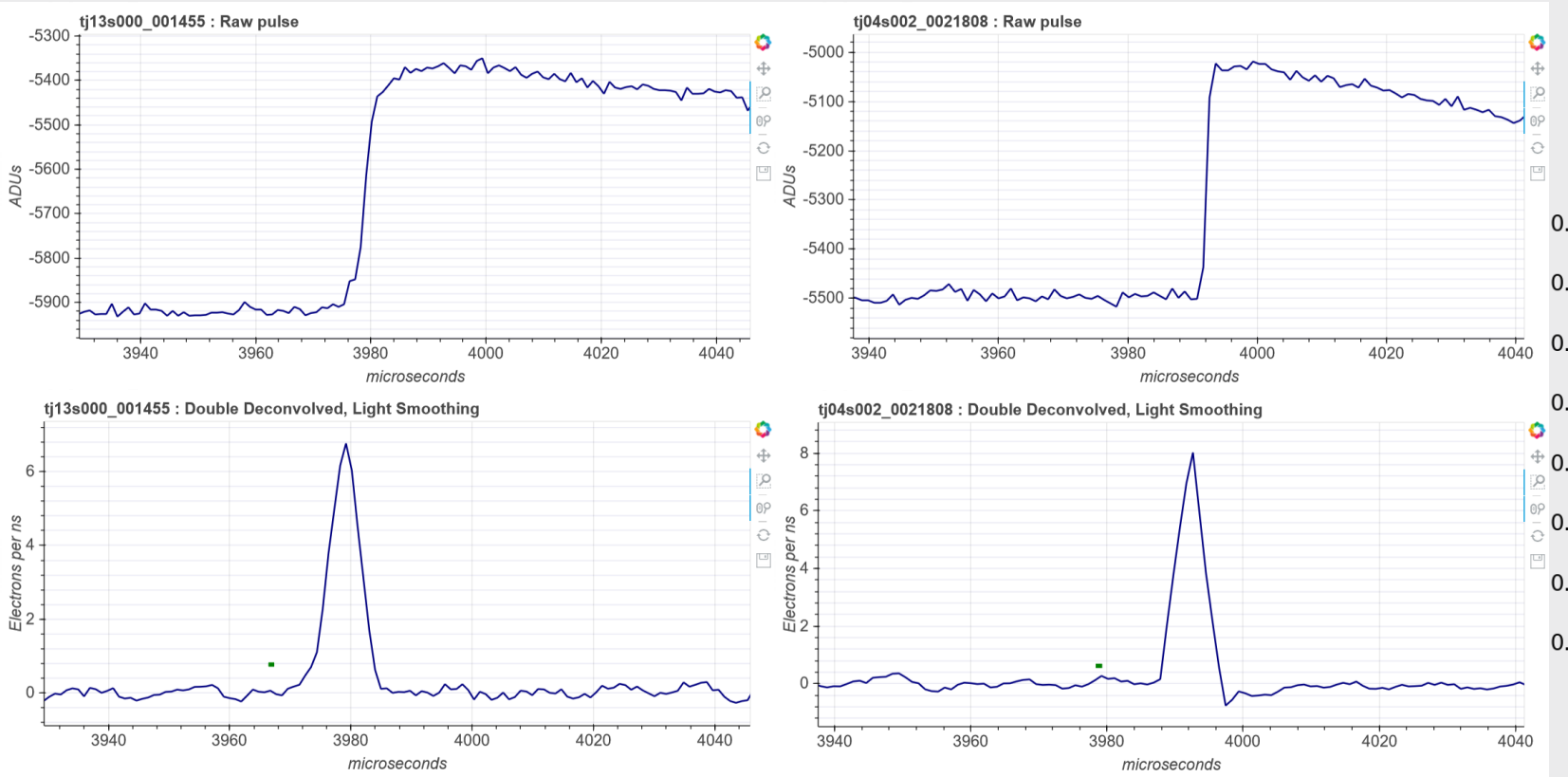
The saturated alpha signals can be broken up and difficult to detect, but using the drift time, rate of events and decreasing baselines, we can identify alphas and remove most of the low-energy background due to them with a 5s cut after each alpha, keeping 85-90% of the total time.

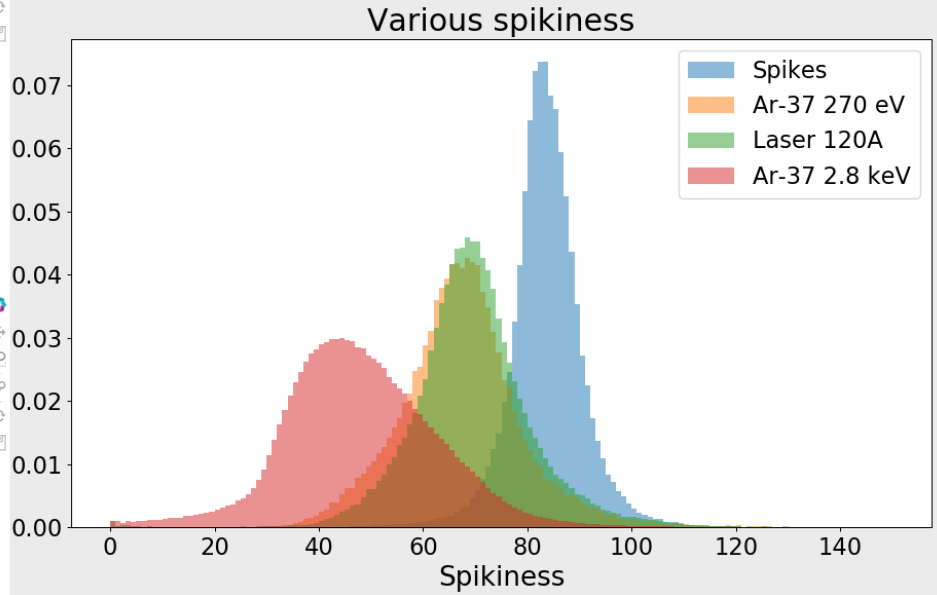


Spikiness

1st comparison method
Spikiness

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



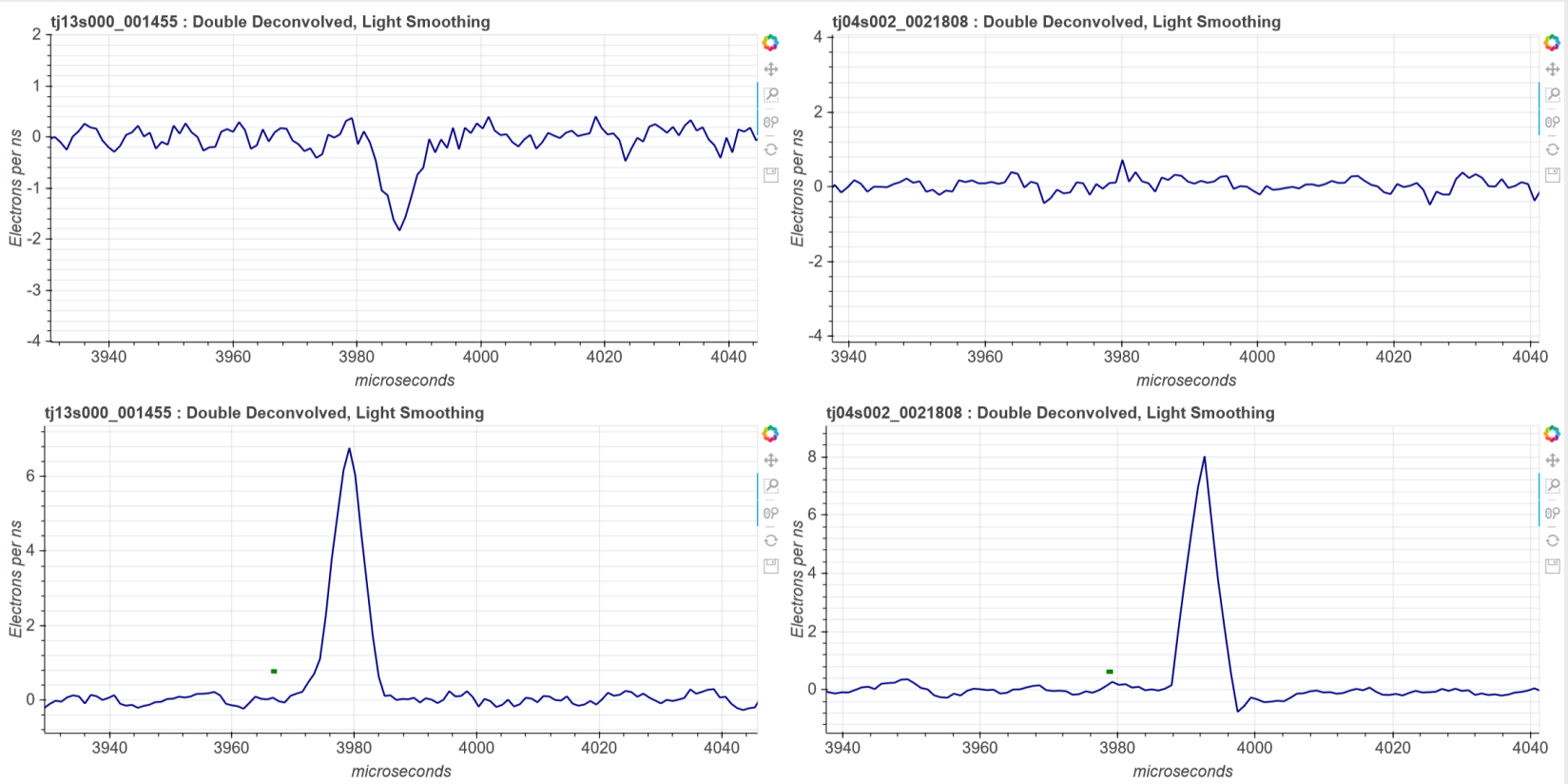


Probable electron event

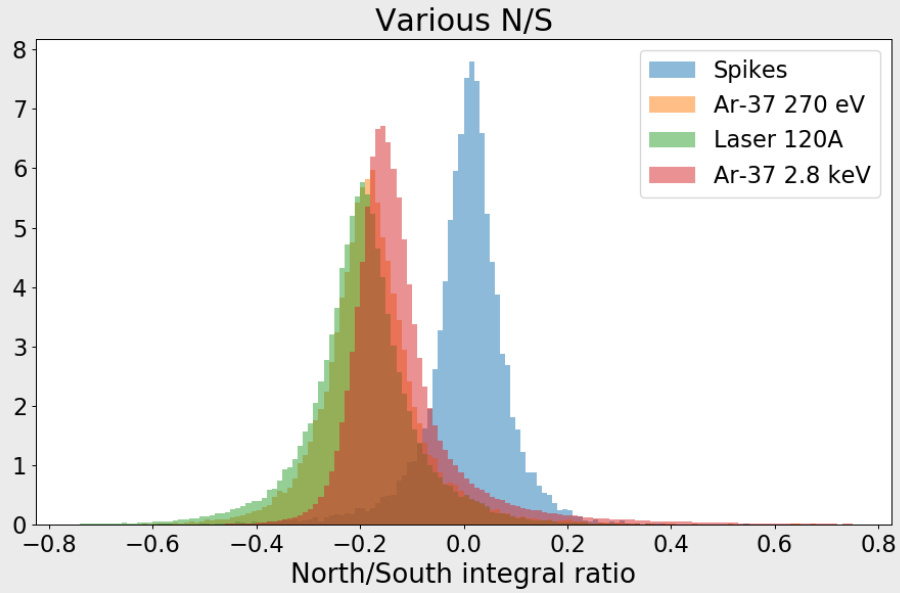
Probable spike event

North/South integral ratio

2nd comparison method
N/S ratio



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

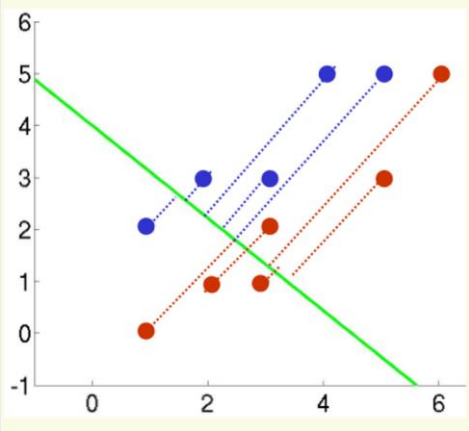


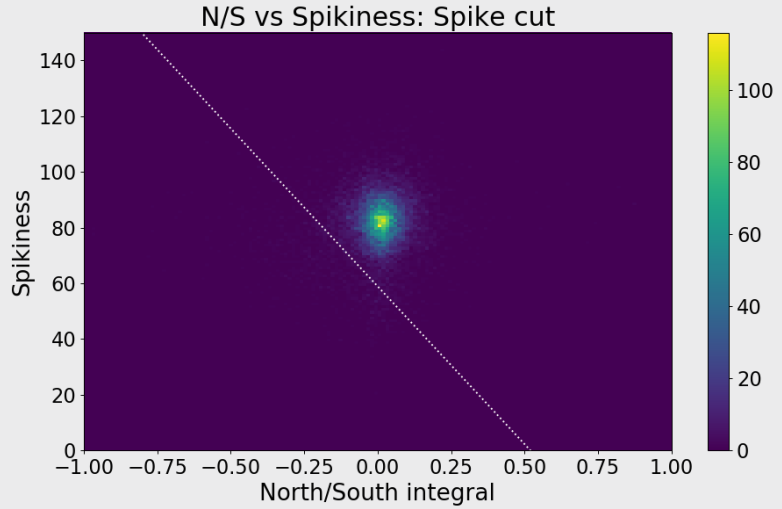
Probable electron event

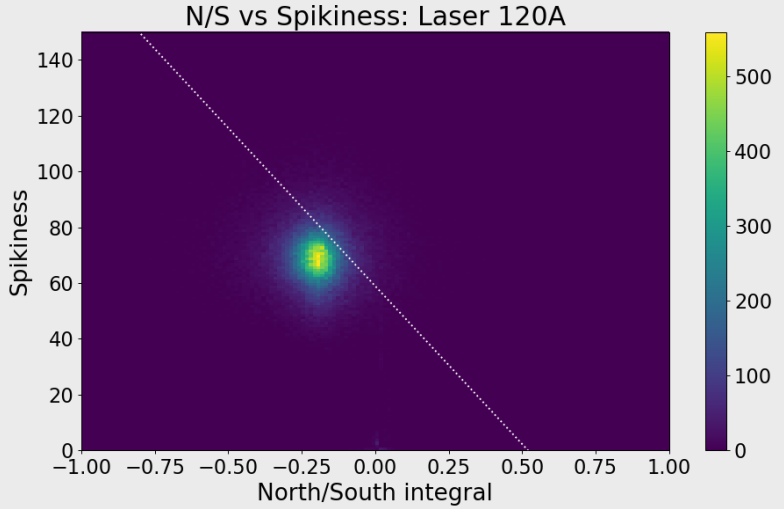
Probable spike event

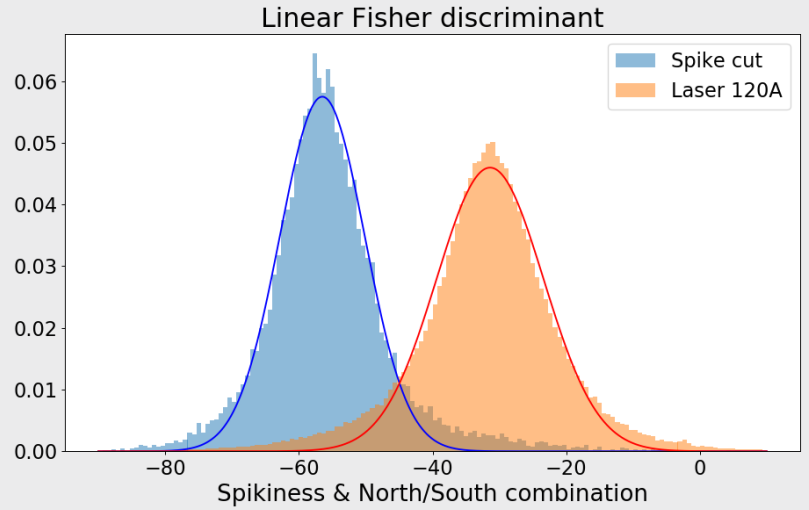
Linear Fisher discriminant

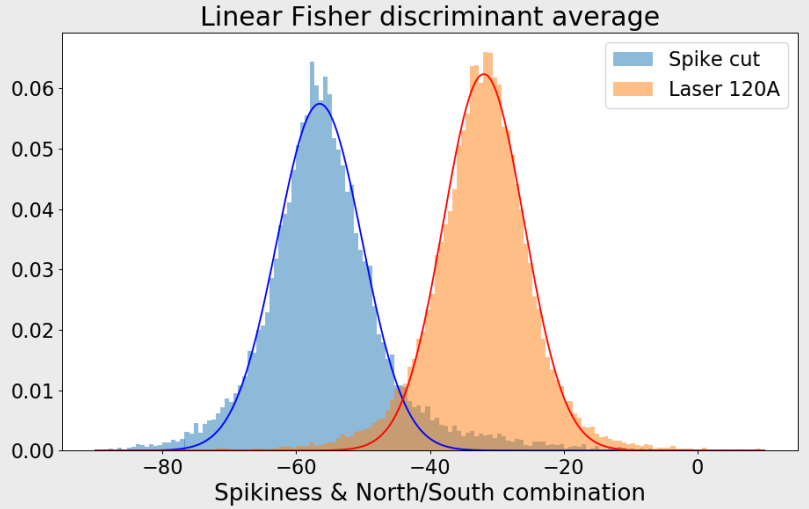
Optimal comparison:
Combining both methods









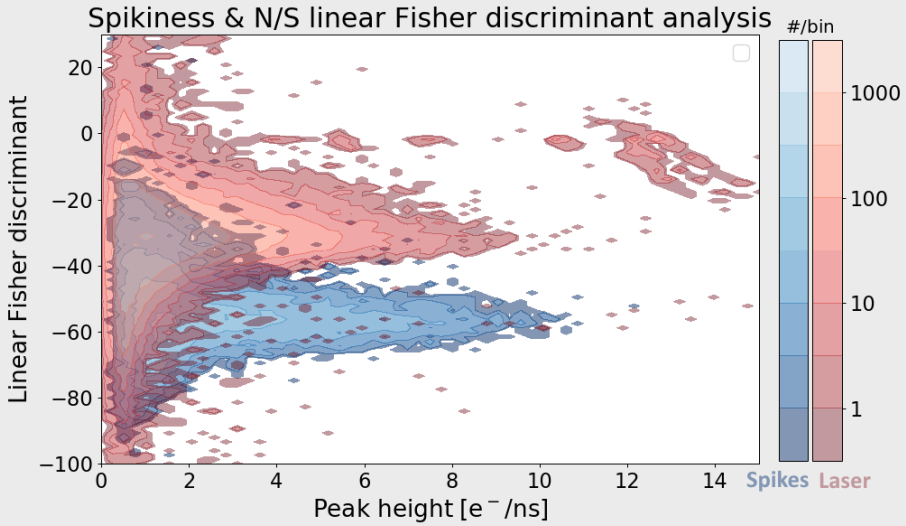


Separation $J(\omega) = \frac{(\mu_1 - \mu_2)^2}{N_1(\sigma_1)^2 + N_2(\sigma_2)^2}$

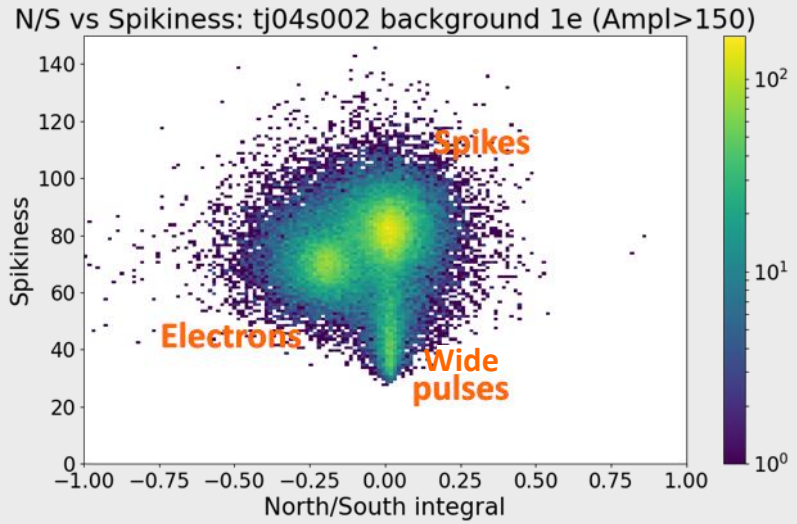
New axis $\tau_i = \omega^t x_i^t$

ω=[−0.678619815,−76.8674863]
Spk NS

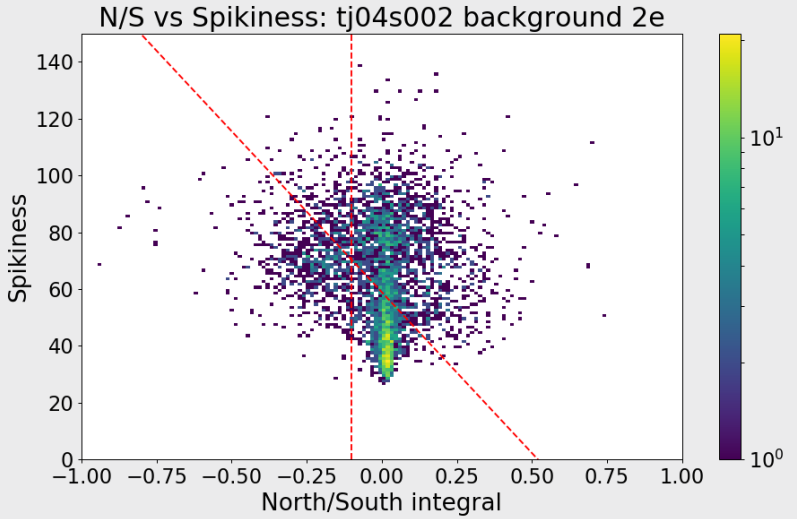
Fits to the physics data



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

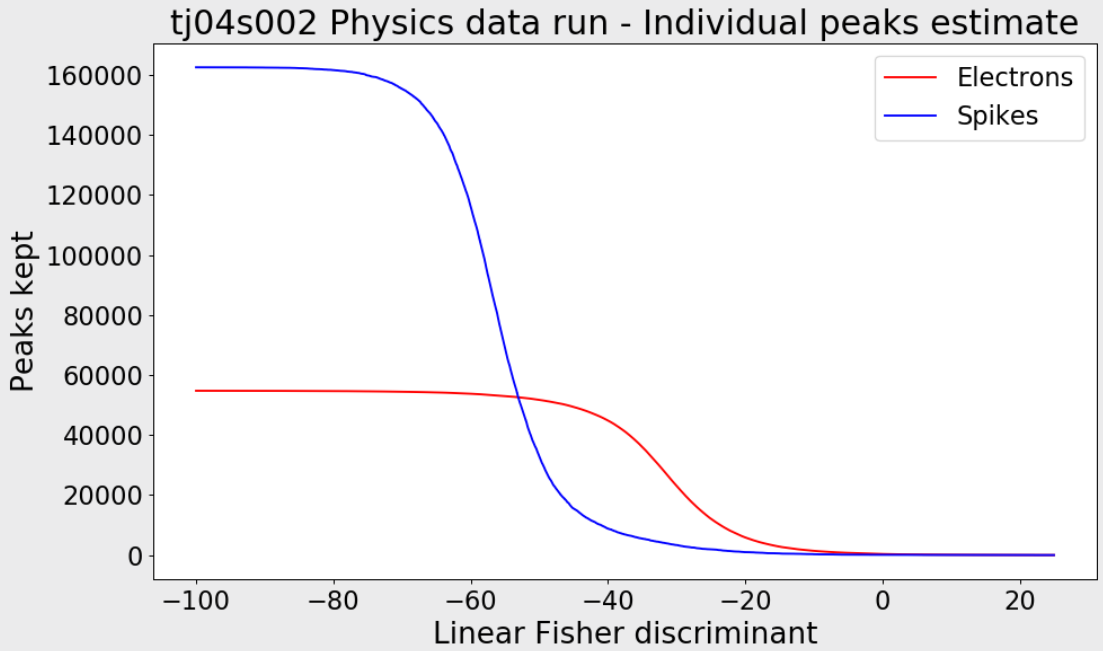


Wide pulses are another dominant background of unknown origin in the data.



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

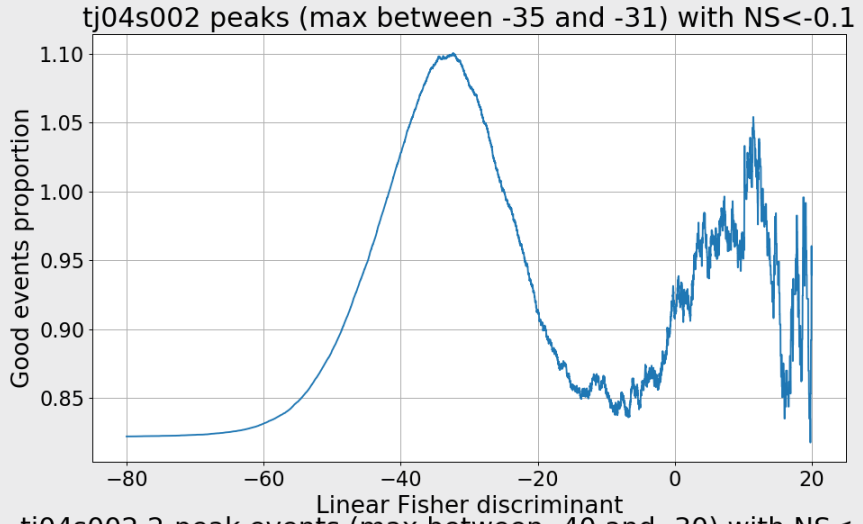
Cut optimization

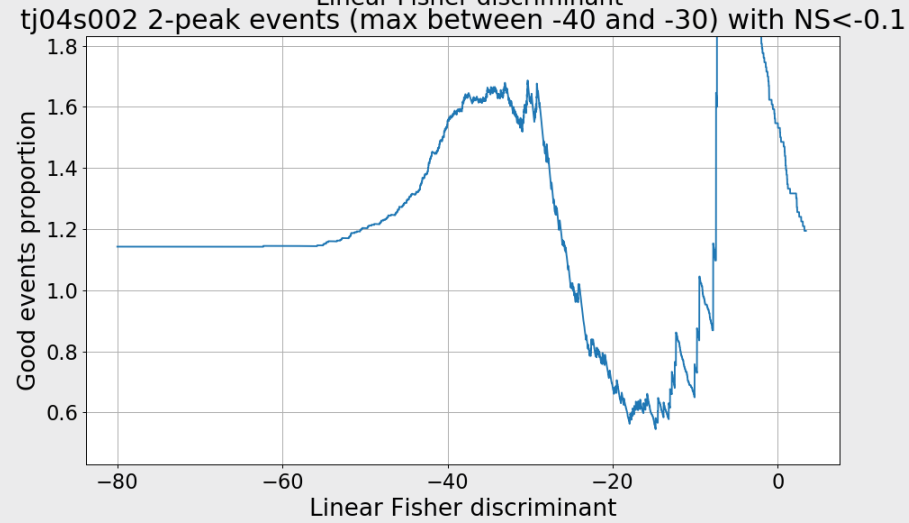


Cut too weak: Not enough spikes are removed

Cut too strong: Too many good electron events are removed

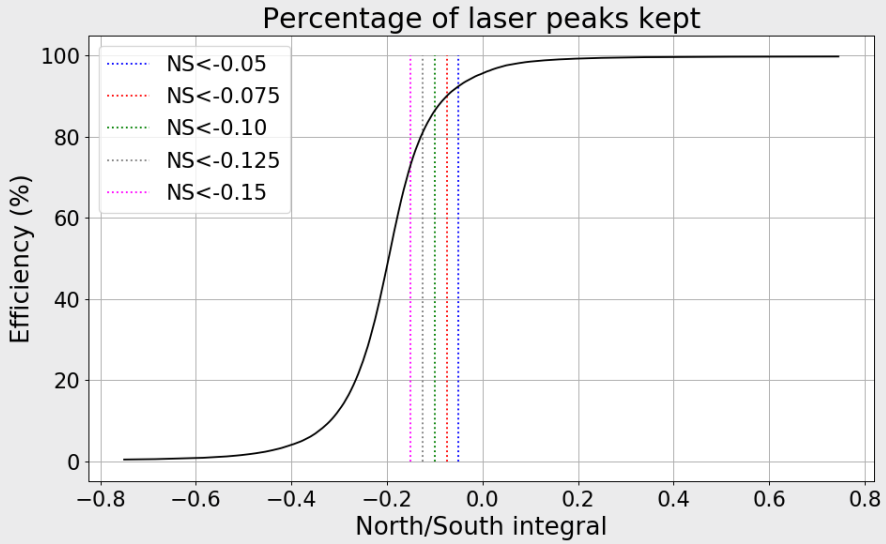
Optimization of cut on the Fisher discriminant

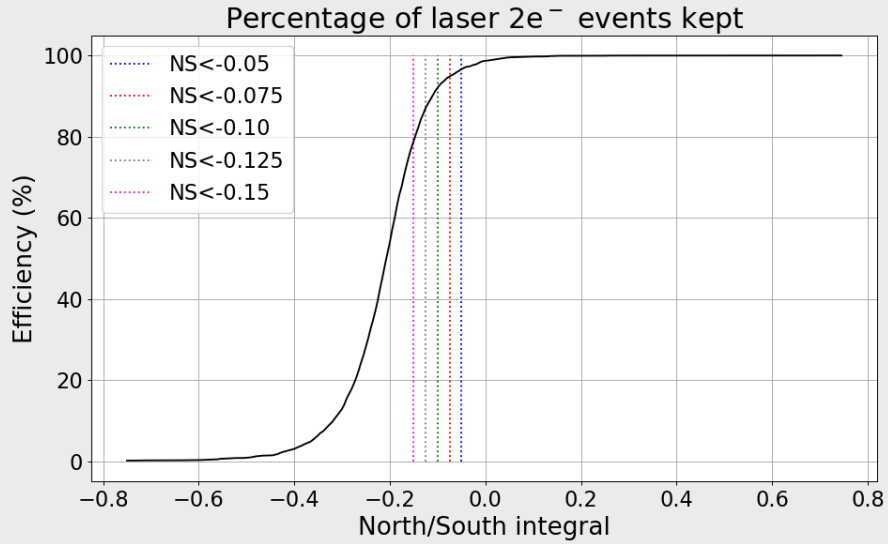




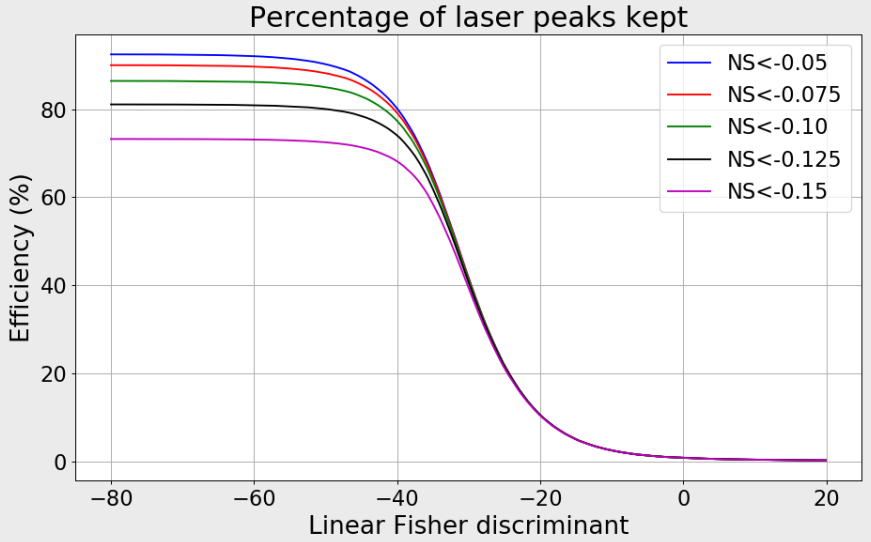
Cut efficiencies

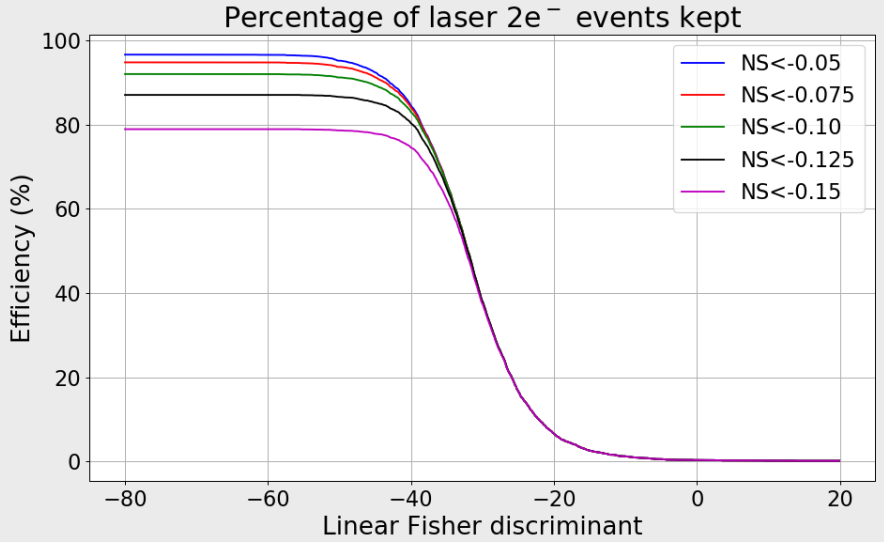
Efficiency of cut on N/S





Efficiency of cut on Fisher discrim.



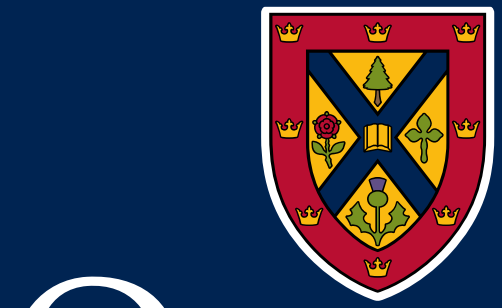


Conclusion

- Events coming from alphas can be removed with 5s cuts after each one.
- Spike events and wide pulses can be discriminated with the combined use of the spikiness and North/South integral ratio variable.
- This event selection will serve in the LSM data paper that should be published in the next weeks, using CH_4 gas.
- This data analysis will continue to be useful in the next WIMP search in SNOLAB and other future SPCs.

Sources

- Main source:
  - Jean-Marie Coquillat. *Calibration and background data analysis in the scope of the NEWS-G dark matter experiment*. Master's thesis, Queen's University, 2021.
- Image sources:
  - Slide 2: A. Giganon, I. Giomataris, M. Gros, I. Katsioulas, and X.F. et al. Navick. *A multiball read-out for the spherical proportional counter*. Journal of Instrumentation, 12(12):P12031–P12031, Dec 2017.
  - Slide 4: Giomataris, I., Gros, M., Katsioulas, I., Knights, P., Mols & et al. (2020). *A resistive ACHINOS multi-anode structure with DLC coating for spherical proportional counters*. Journal of Instrumentation, 15(11), P11023–P11023.
  - Slide 4: Q. Arnaud, J.-P. Bard, A. Brossard, M. Chapellier, and M. et al. Clark. *Precision laser-based measurements of the single electron response of spherical proportional counters for the NEWS-G light dark matter search experiment*. Physical Review D, 99(10), May 2019
  - Slide 7: Olga Veskler. *Cs434a/541a: Pattern recognition*, October 2004.



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Extra slides

Analysis and identification of alpha events for NEWS-G

Introduction: What is NEWS-G

NEWS-G is a dark matter search experiment specialized in low mass WIMPs (0.1 to a few GeV/c²). The detector is a spherical proportional counter filled with gas. If a dark matter particle interacts with a gas particle, the resulting nucleus recoil will ionize the gas. An anode at the center of the sphere produces a radial electric field attracting the primary electrons towards the middle. Near the anode, the electric field becomes so strong that the electrons are accelerated enough to ionize even more gas, in what is called a Townsend avalanche. Thus, all the drifting secondary ions produce a detectable signal. The sensitivity threshold goes as low as ½ an electron, which makes it possible to count individual electrons.

The current analysis being done is on the data taken at the *Laboratoire Souterrain de Modane* in France, with neon and methane.

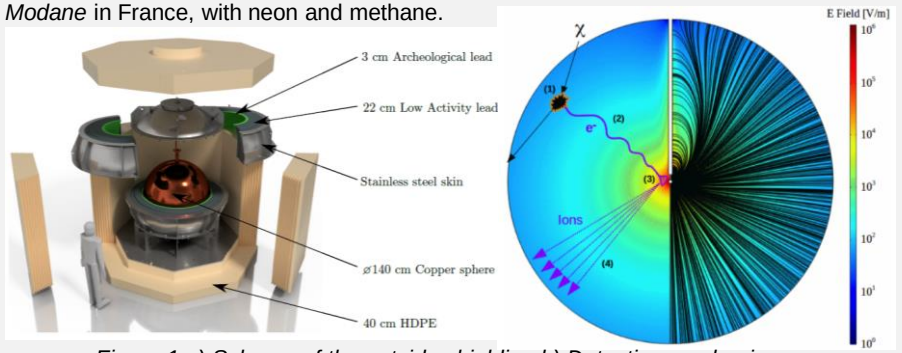


Figure 1 a) Schema of the outside shielding b) Detection mechanism

Fluctuations of the drift time and rate of events

The time it takes for an electron to go from the surface of the sphere to the center is called the drift time, and is measured regularly by sending UV laser pulses on the copper inner surface, which frees electrons through the photoelectric effect.

It was discovered that the drift time fluctuates a lot in a run, dropping suddenly every 30-45 seconds and then slowly rising up again. At the same time as those drops in drift time, the rate of events suddenly increases before coming back to the usual background level in an exponential decline. The related time constant is shorter for rate than drift time, but both depend on the gas composition, pressure and voltage. The jumps in rate are particularly problematic because the influxes of events are at low energy, in the region of interest for dark matter.

Fortunately, the entire phenomenon can be correlated to the presence of alpha events.

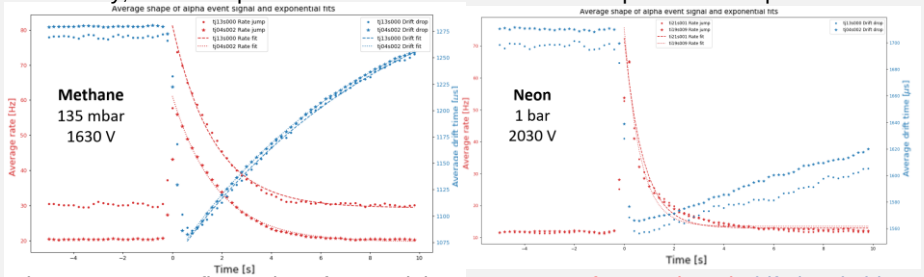


Figure 2: Average fluctuation after an alpha event, Rate of events in red, drift time in blue

Alphas in the detector

The copper surface contains traces of ^{210}Pb which decays towards ^{210}Po, an alpha emitter. The alphas ionize an enormous amount of gas molecules, thus creating a space charge that perturbates the electric field and makes the drift time shorter until the drifting ions reach the inner surface of the sphere. It is still unknown why the rate of events stays high for a few seconds after the alpha. One hypothesis is that it could be related to attachment, i.e. the primary electrons getting caught by gas particles for a few seconds.

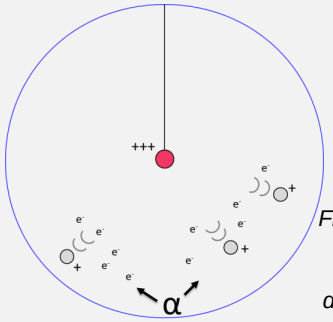


Figure 3: Alpha event diagram

Detection of alpha events

Alpha events are detected as saturated events with a very large width. However, since the processing was not made for events that energetic, the signal is often broken up or cut in half which makes the alphas difficult to detect. To counter that problem, we also use the decreasing baseline in the tail of events following the alpha as an indicator. For the few alphas that still evade that selection, very high rate of events are identified as alpha events as well. The drift time is less stable and hence a weaker indicator, but it is the only usable one in calibration runs that triggered on the laser alone.

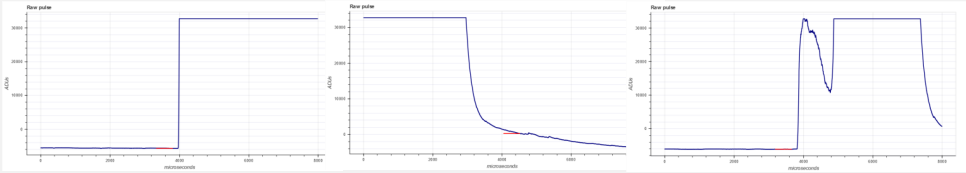


Figure 4 Alpha pulse examples a) Cut at the end b) Cut at the start c) Broken up

Conclusion

Finally, using a cut of 5 seconds after each high width saturated events, strings of decreasing baselines and high rates of events, the low energy background is successively reduced to in the end only 32% of its original amount, while still keeping 88% of the total run time.

The next runs of data taking at SNOLAB will include a low gain channel in order to detect alphas more easily, without saturation of the signal.

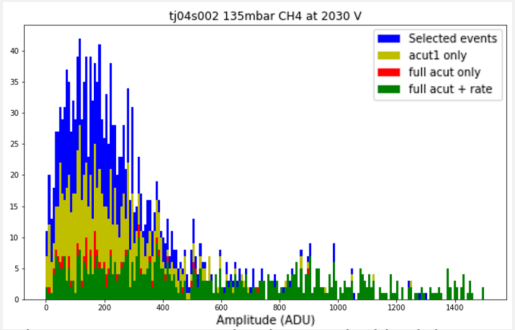
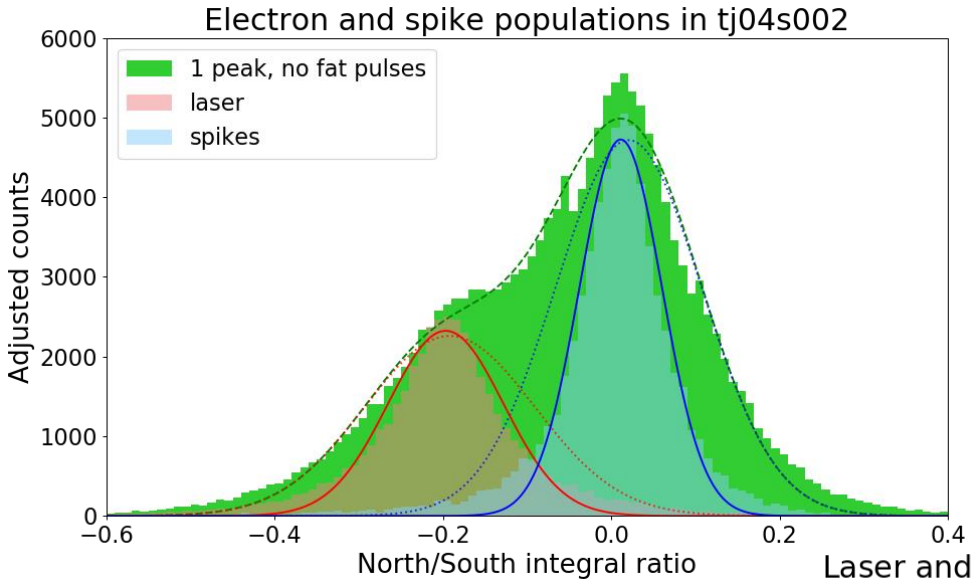


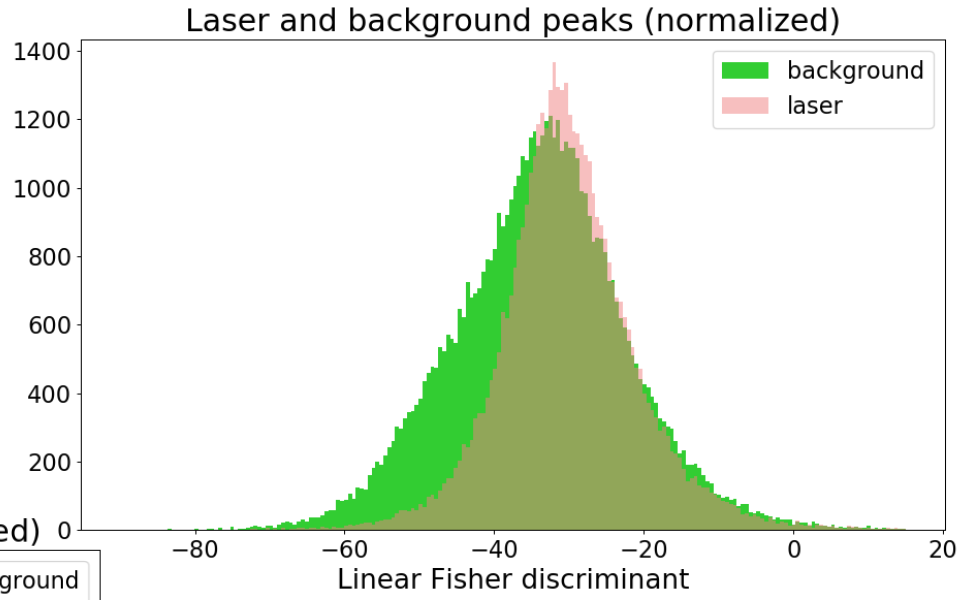
Figure 5: Low energy background with alpha cuts

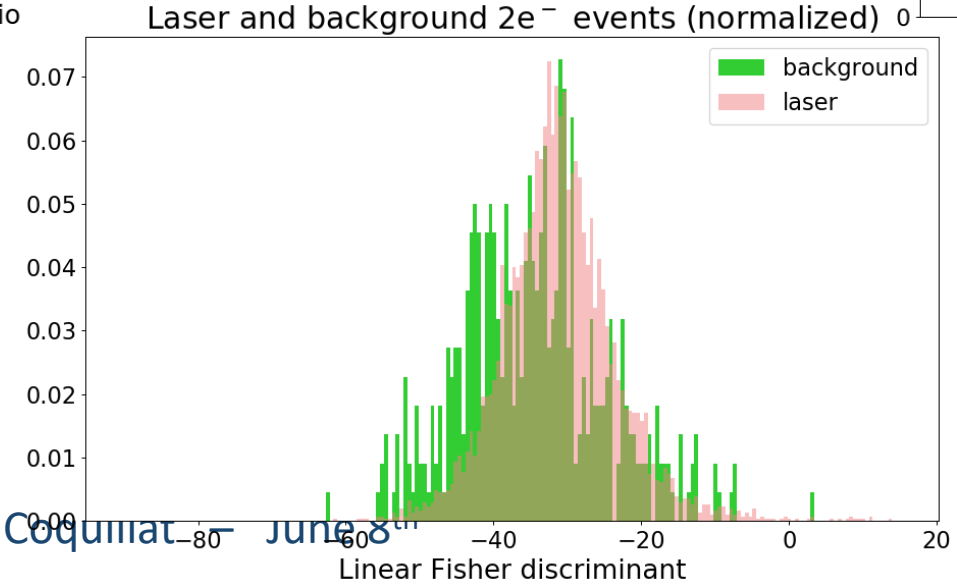
References

- Q. Arnaud et al., First results from the NEWS-G direct dark matter search experiment at the LSM, Astroparticle Physics97(2018) 54-52.
- Q. Arnaud et al., Precision laser-based measurements of the single electron response of SPCs for the NEWS-G light dark matter search experiment, arXiv:1902.08960
- A. Dastgheibi-Fard & G. Gerbier, Development of Spherical Proportional Counter for light WIMP search within NEWS-G collaboration, arXiv:1904.01944

N/S vs Fisher fit to data







$$\frac{\#\text{ of laser event with } \tau > -25}{\#\text{ of total laser events}} = \frac{\#\text{ of physics data events with } \tau > -25}{\#\text{ of total good electron physics data events}}$$

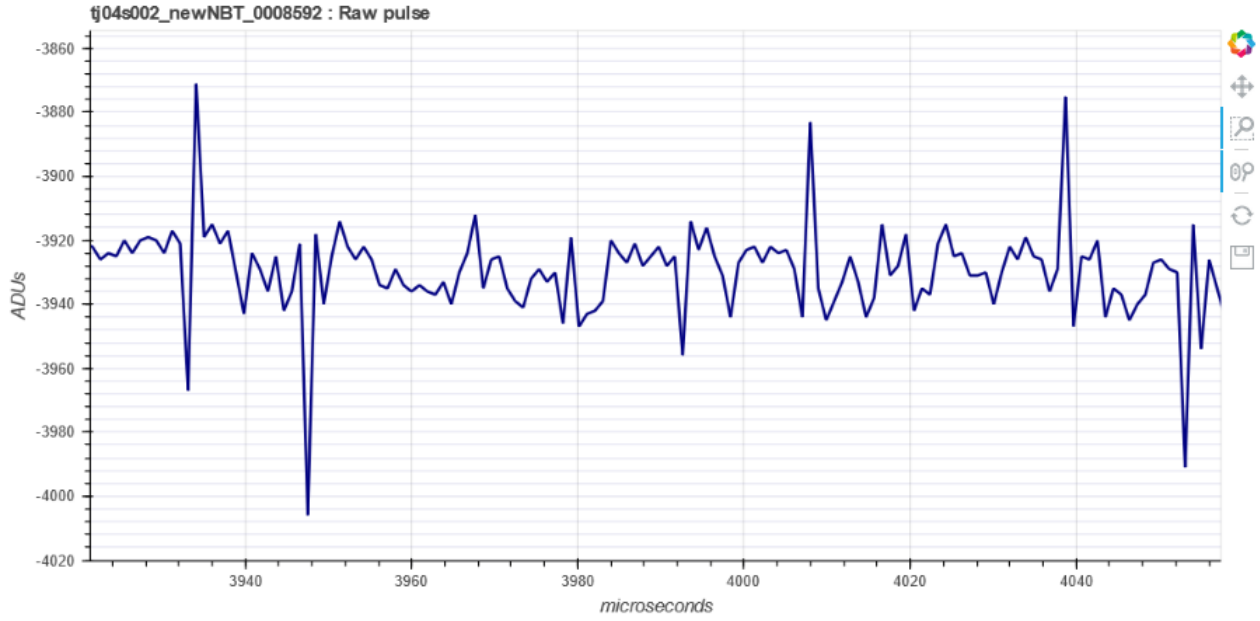
North channel

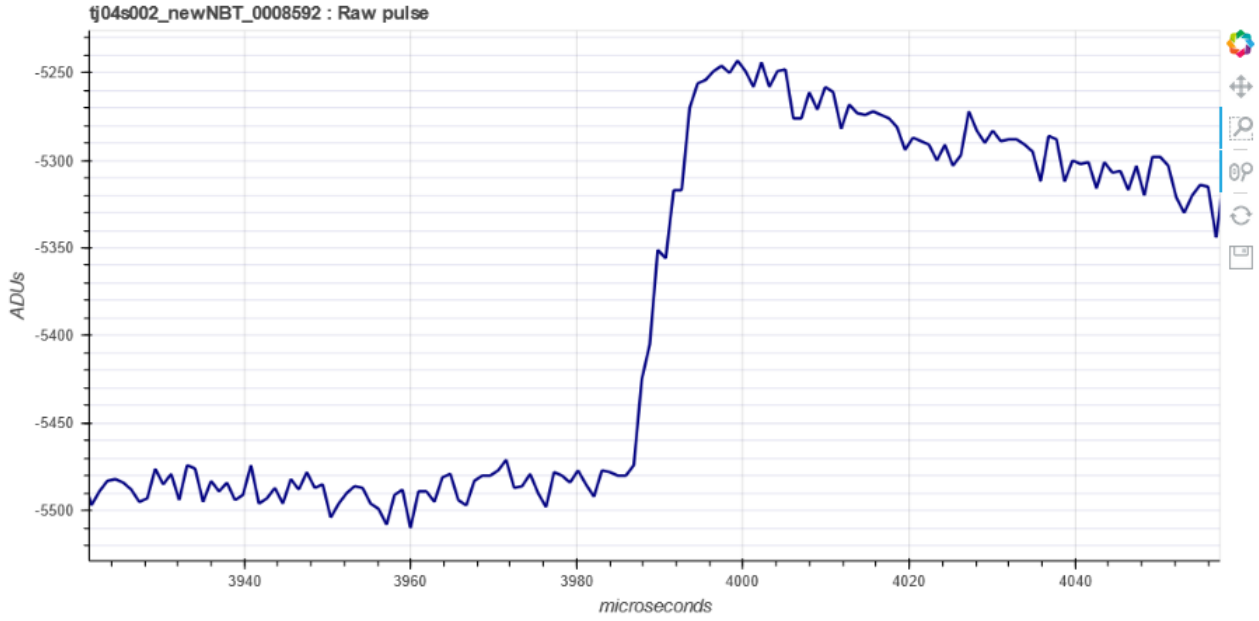
Wide pulse

Spk: 38.5 N/S: 0.036

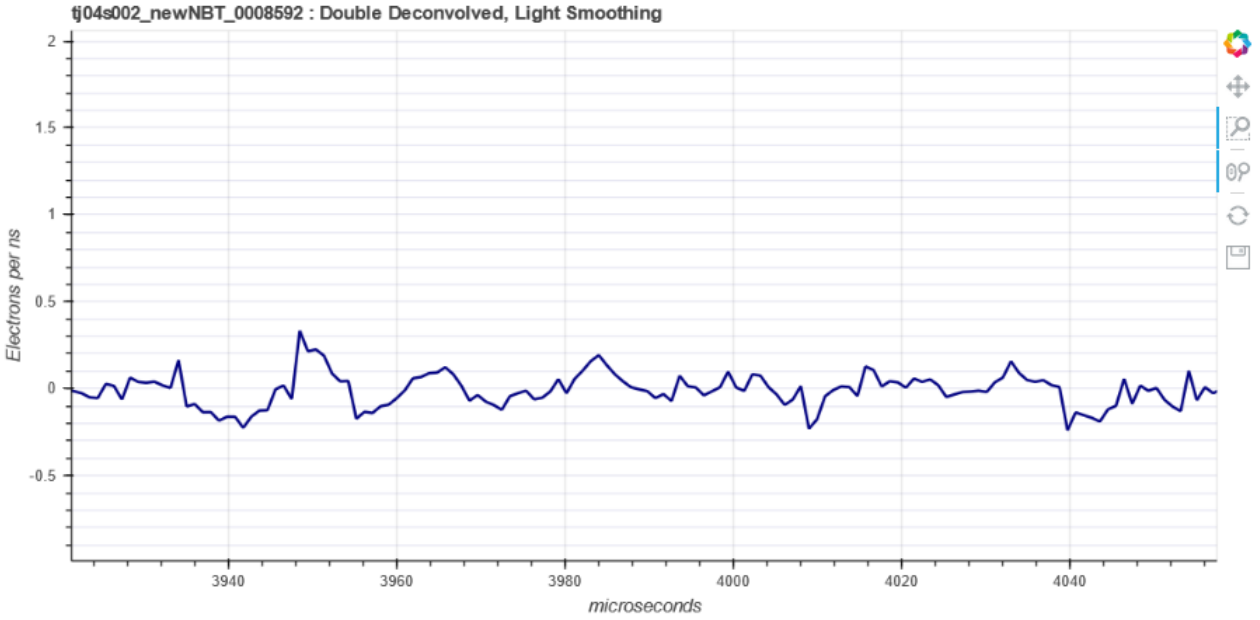
South channel

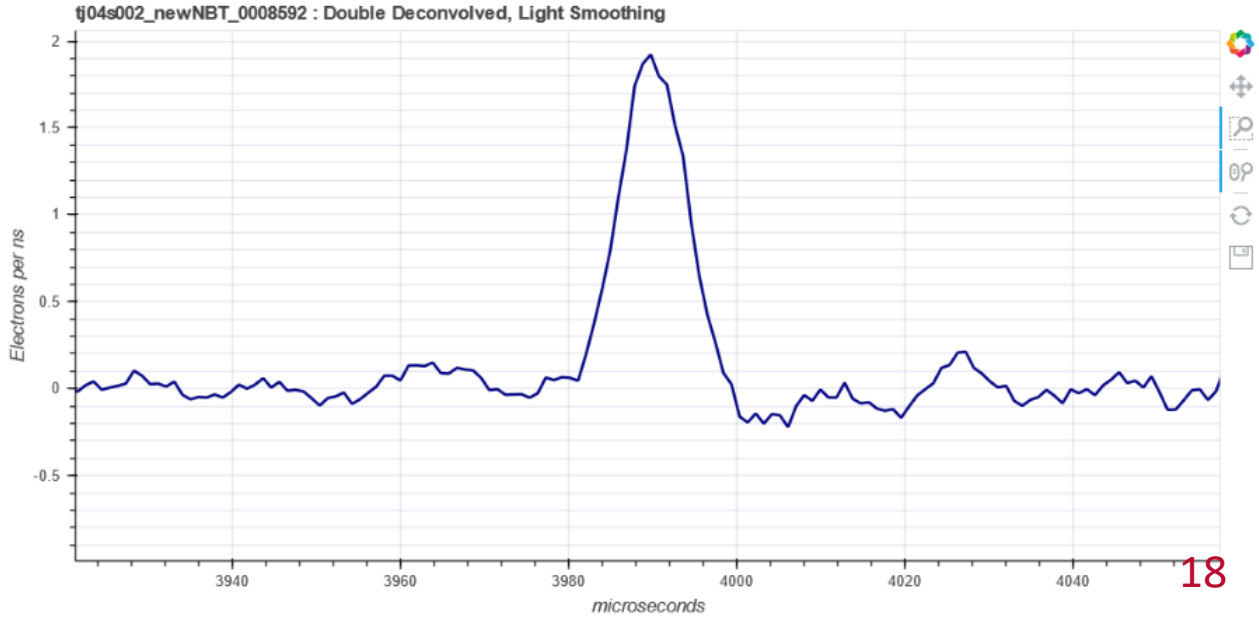
Raw pulse





Double-deconvolved

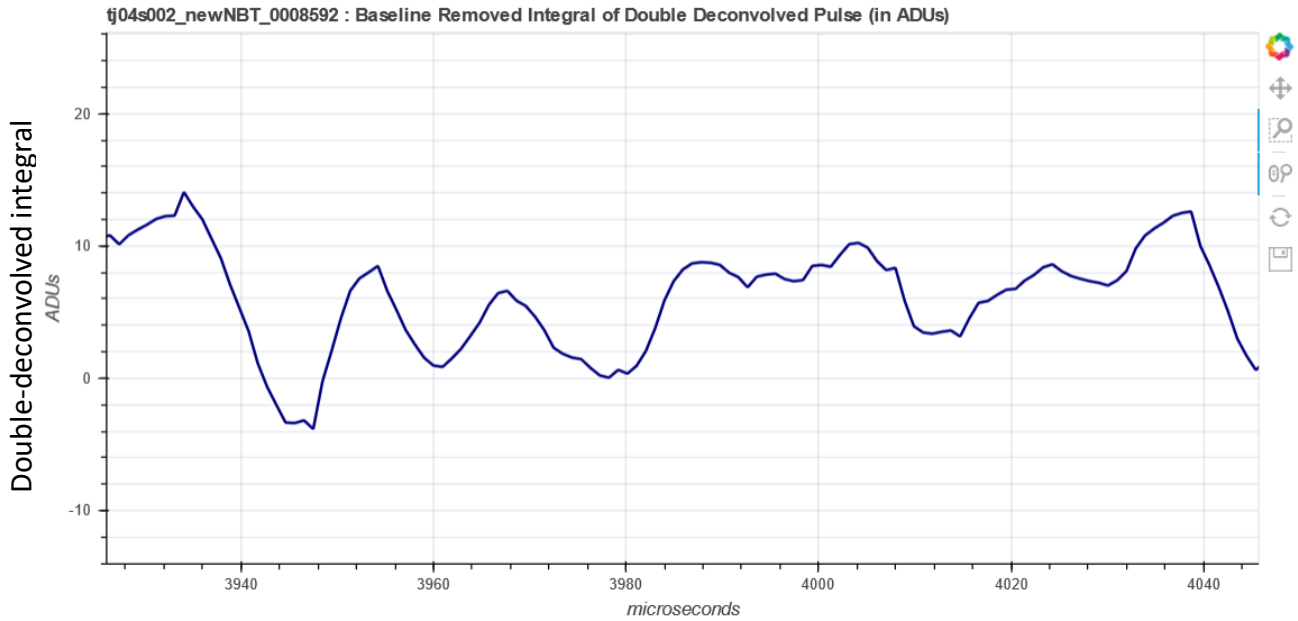




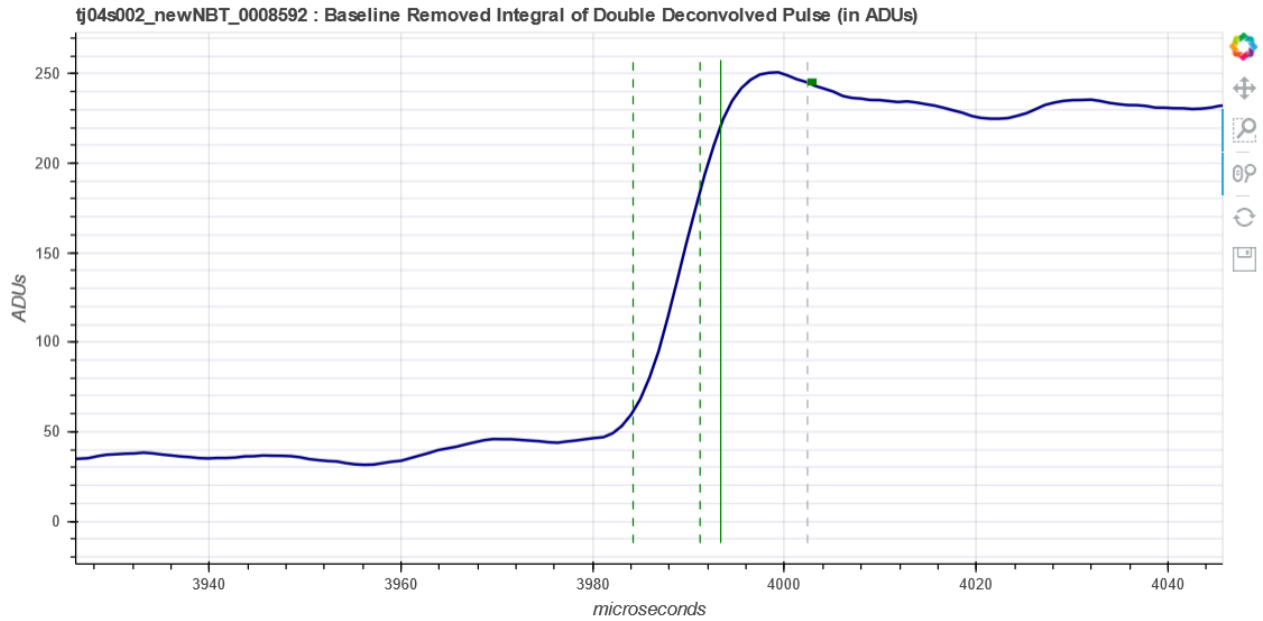
Wide pulse

Spk: 38.5 N/S: 0.036

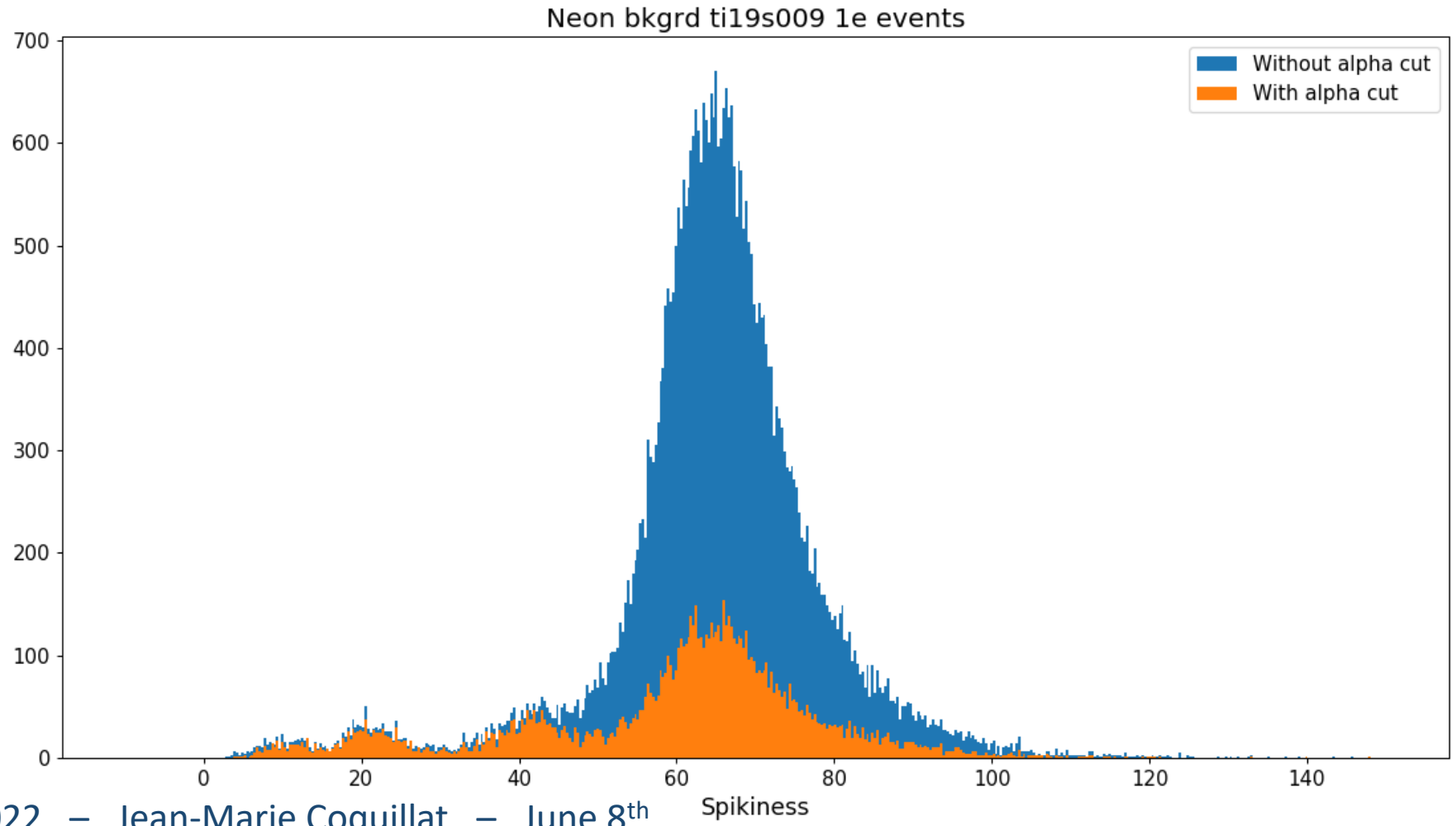
$t_{ch[1]} - t_{ch[0]} = -3\ \mu s$

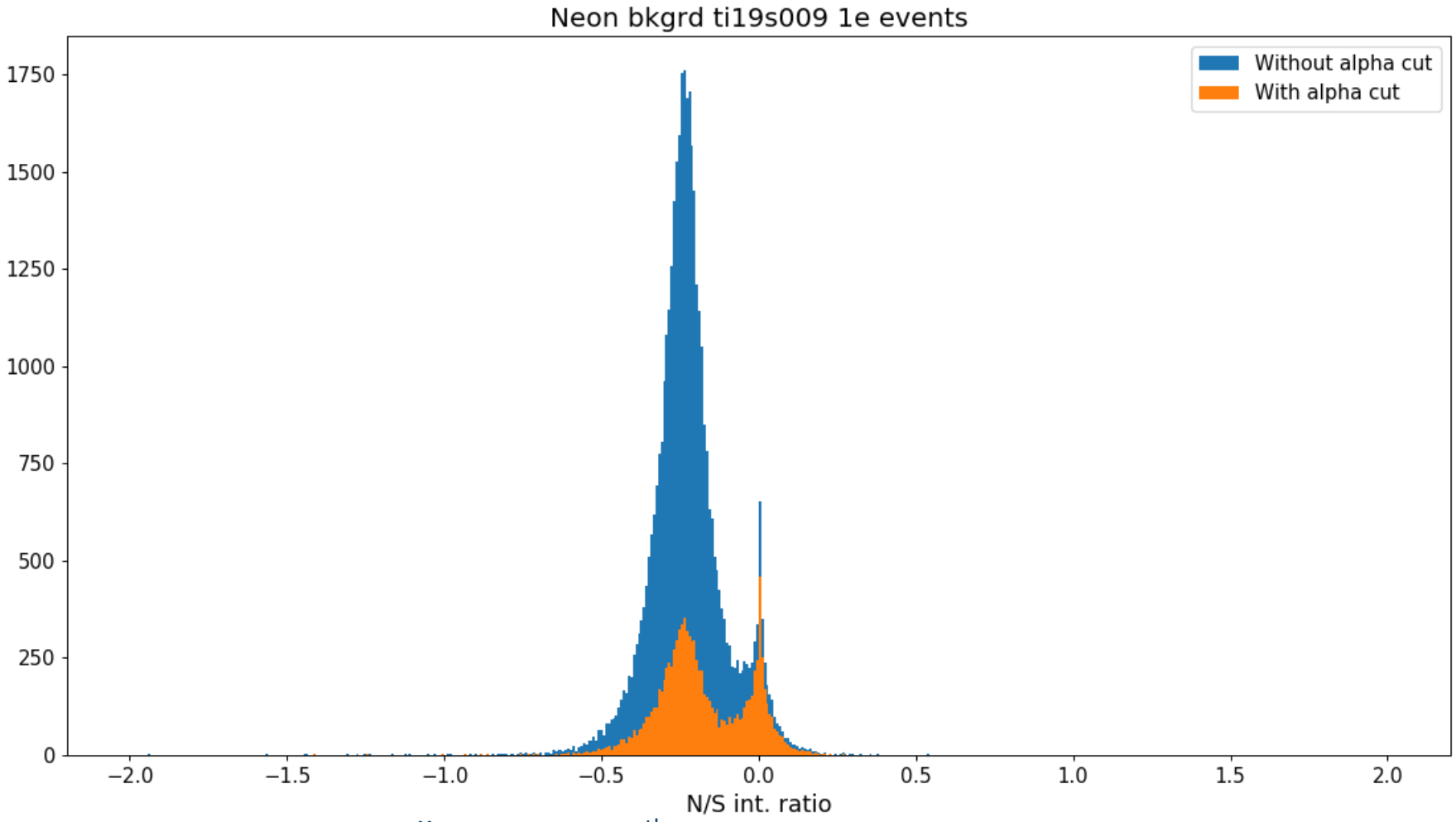


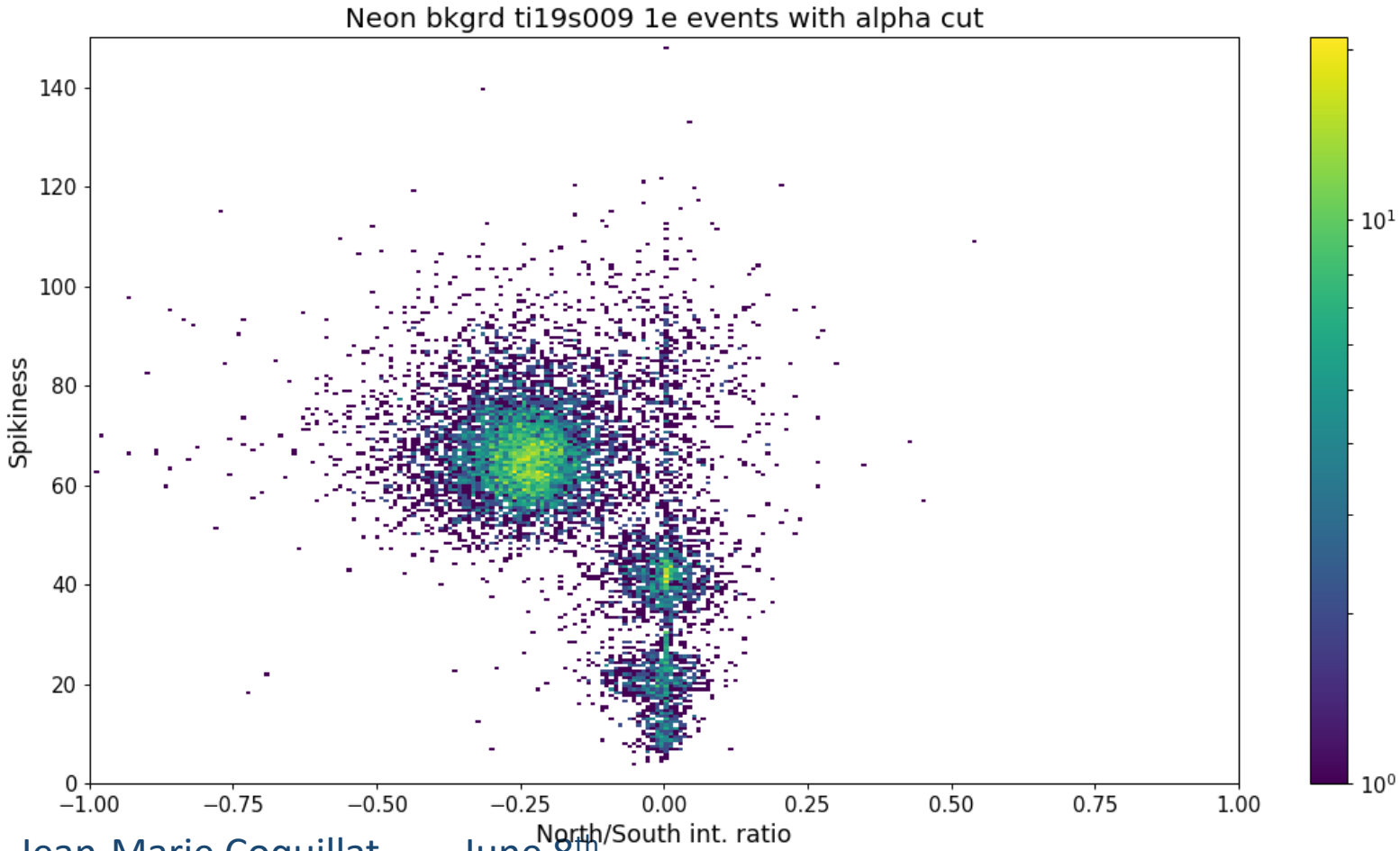
North channel

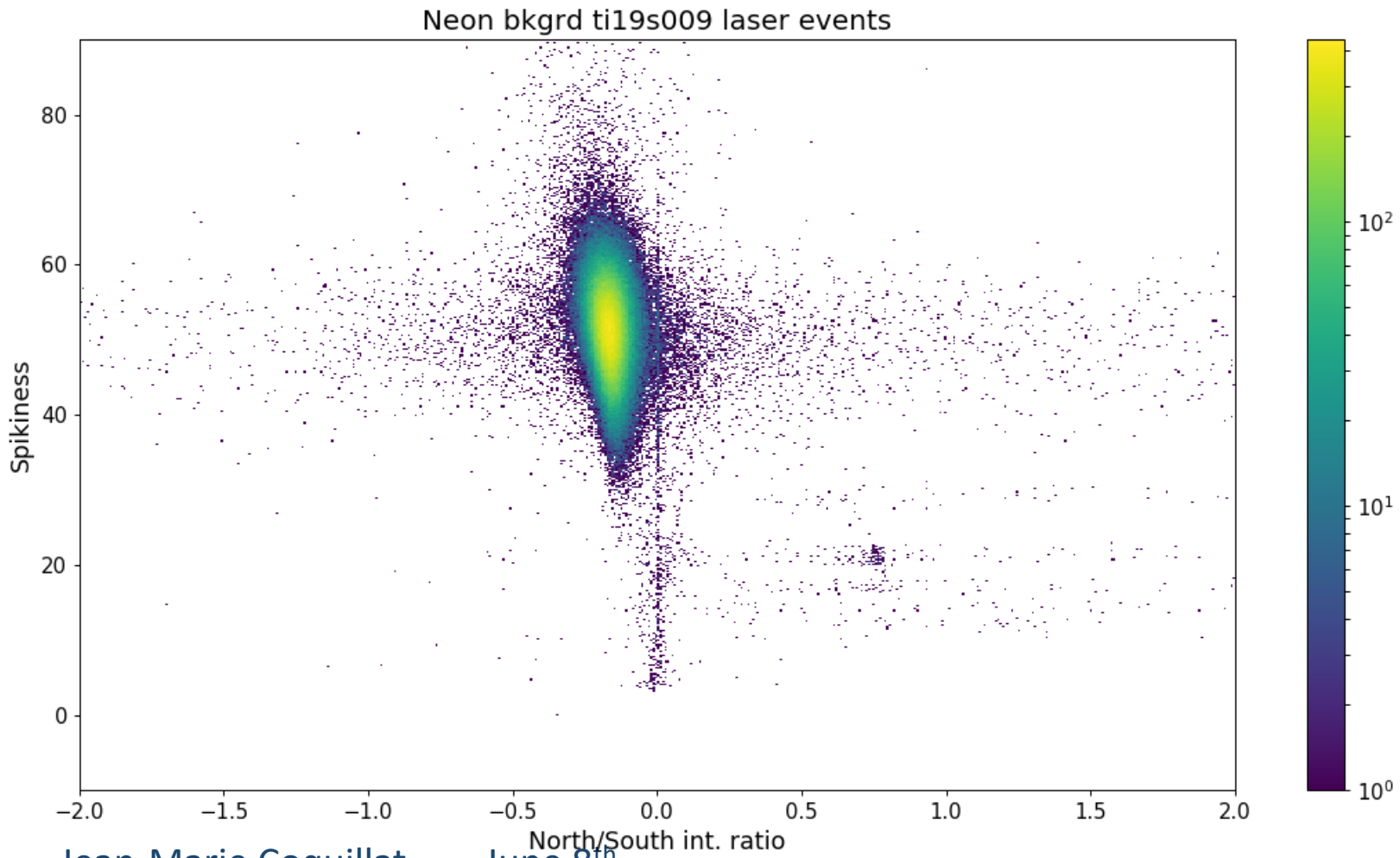


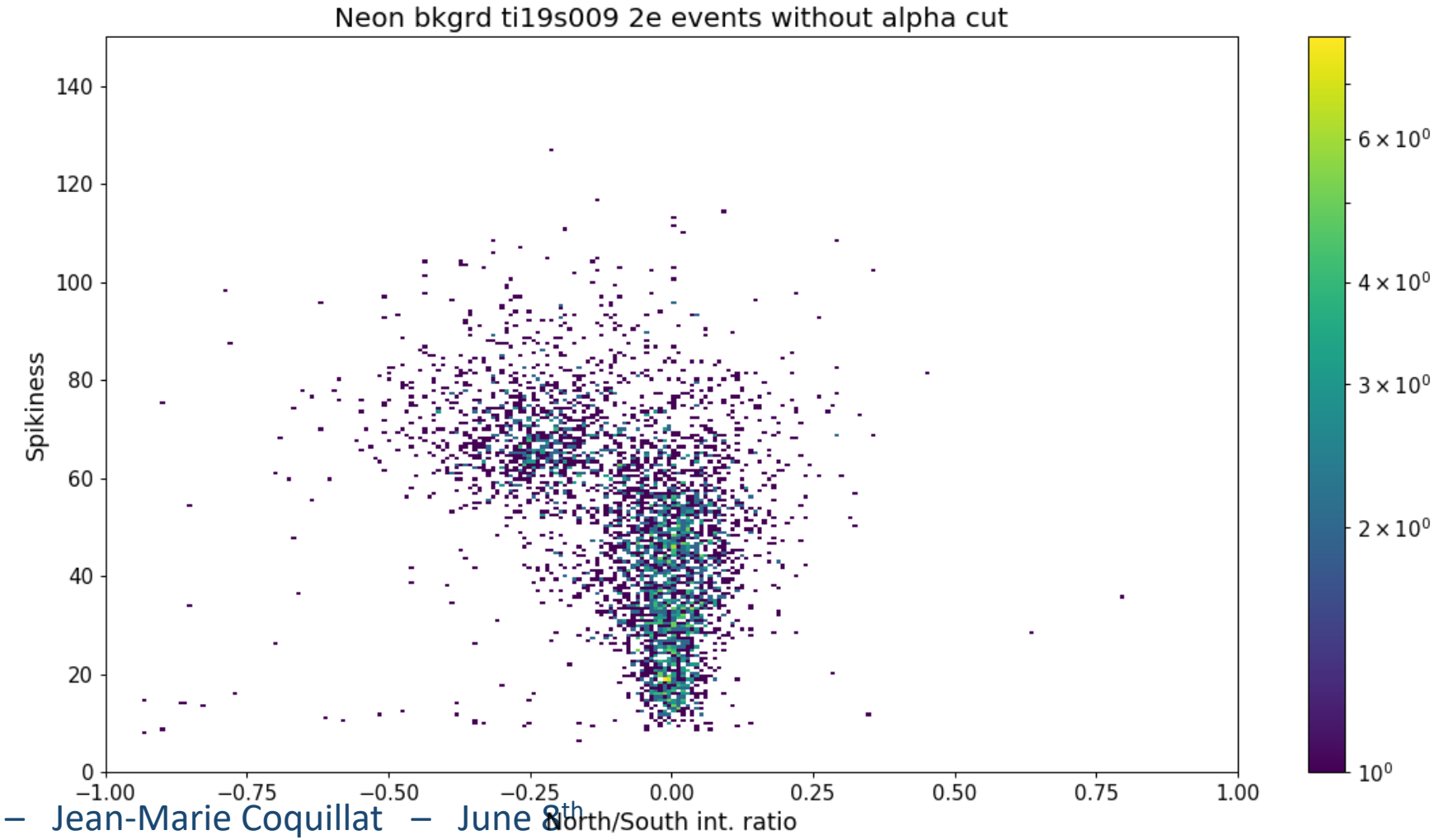
South channel


Neon bkgrd ti19s009 1e events
Without alpha cut
With alpha cut
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Spikiness


Neon bkgrd ti19s009 1e events
Without alpha cut
With alpha cut
1750
1500
1250
1000
750
500
250
0
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
N/S int. ratio


Neon bkgrd ti19s009 1e events with alpha cut
Spikiness
North/South int. ratio
0
20
40
60
80
100
120
140
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
10^1
10^0


Neon bkgrd ti19s009 laser events
Spikiness
North/South int. ratio
80
60
40
20
0
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
10^2
10^1
10^0


Neon bkgrd ti19s009 2e events without alpha cut
Spikiness
North/South int. ratio
140
120
100
80
60
40
20
0
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
6×10^0
4×10^0
3×10^0
2×10^0
10^0