Background discrimination for low quanta events with NEWS-G

Francisco Vazquez de Sola, on behalf of the NEWS-G collaboration

EXCESS@IDM, July 2022

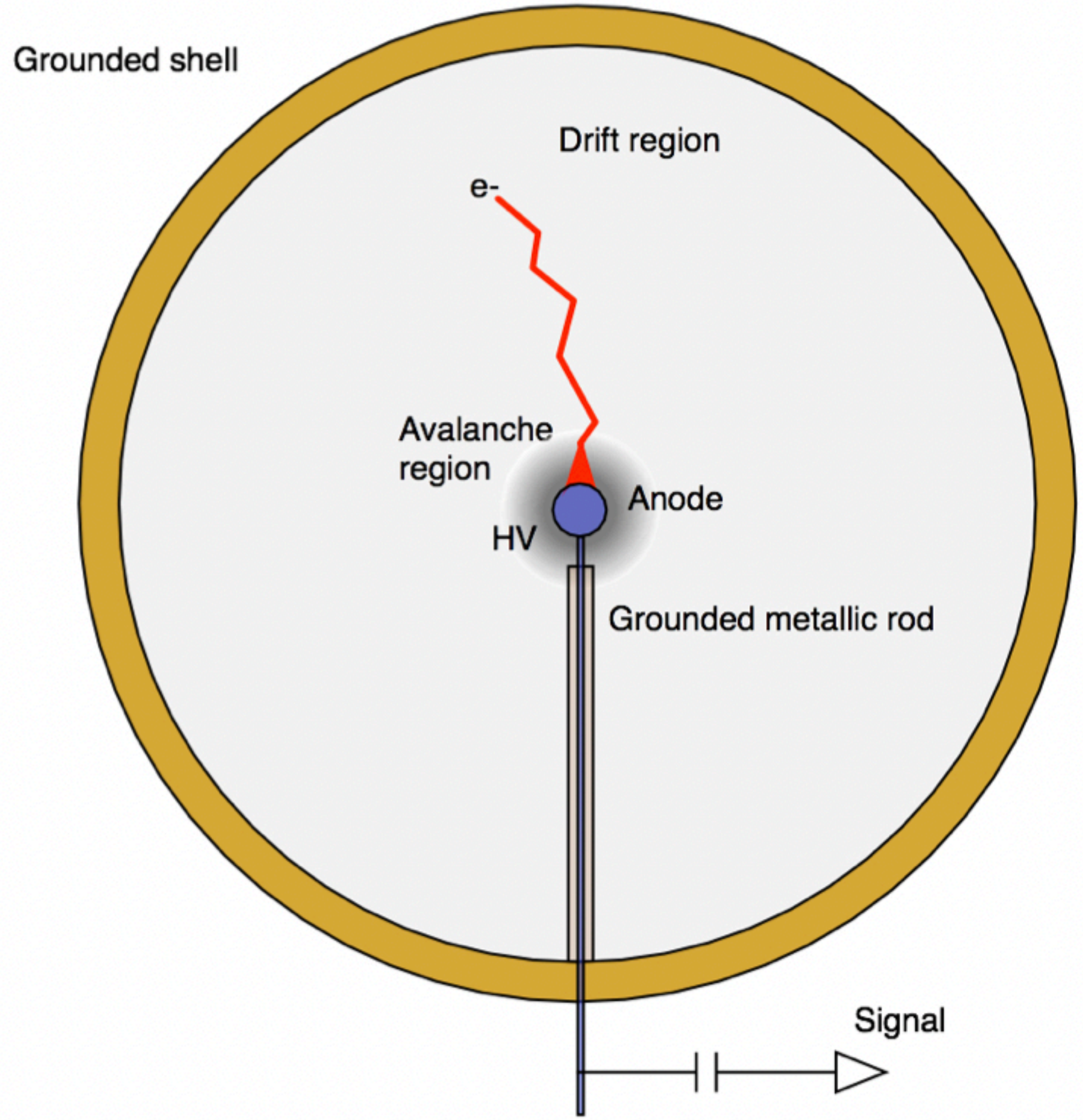
Subatech
CNRS IN2P3 Les deux infinis
IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom
UNIVERSITÉ DE NANTES

NEWS-G : Spherical Proportional Counter

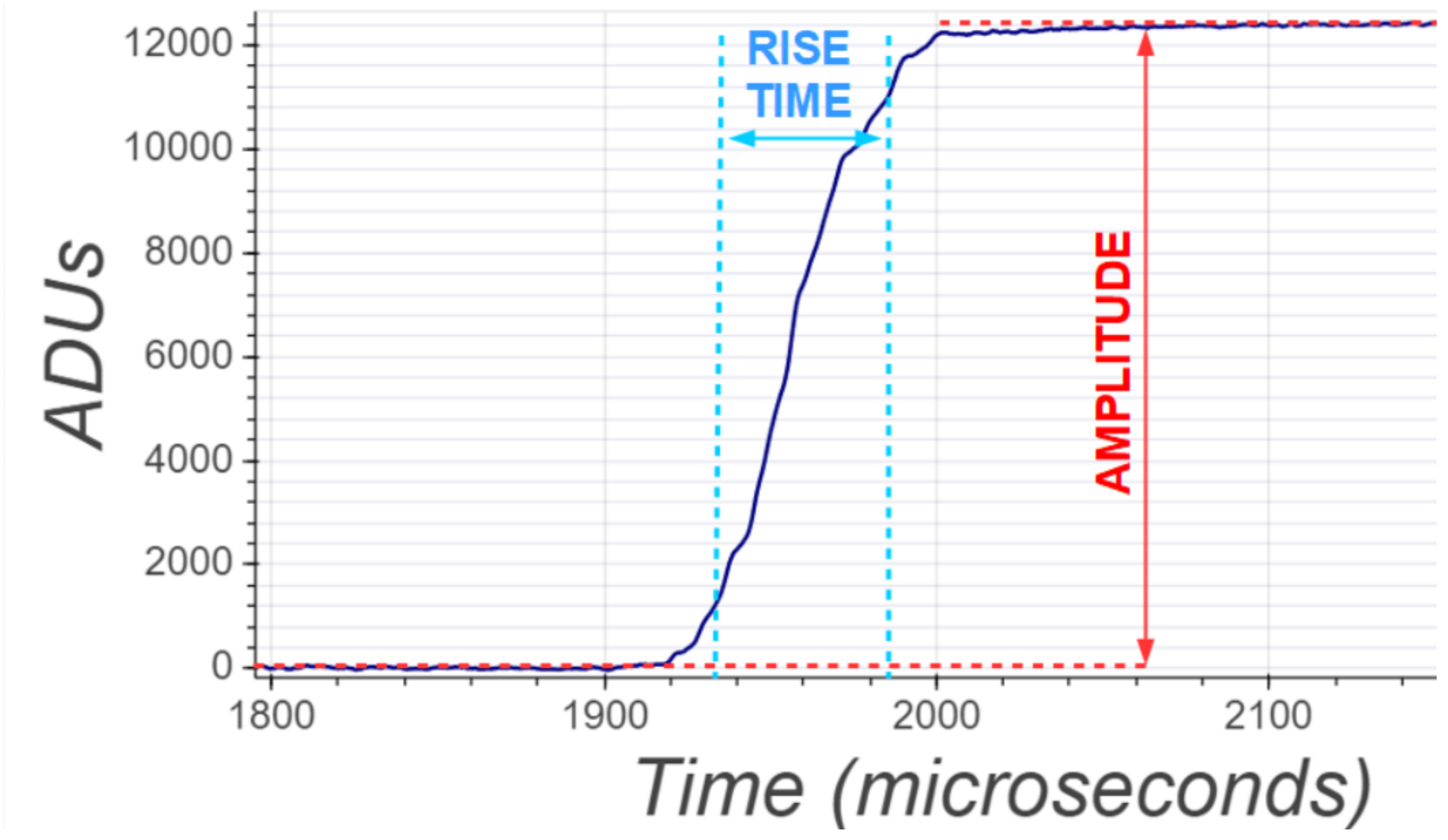
Working Principle

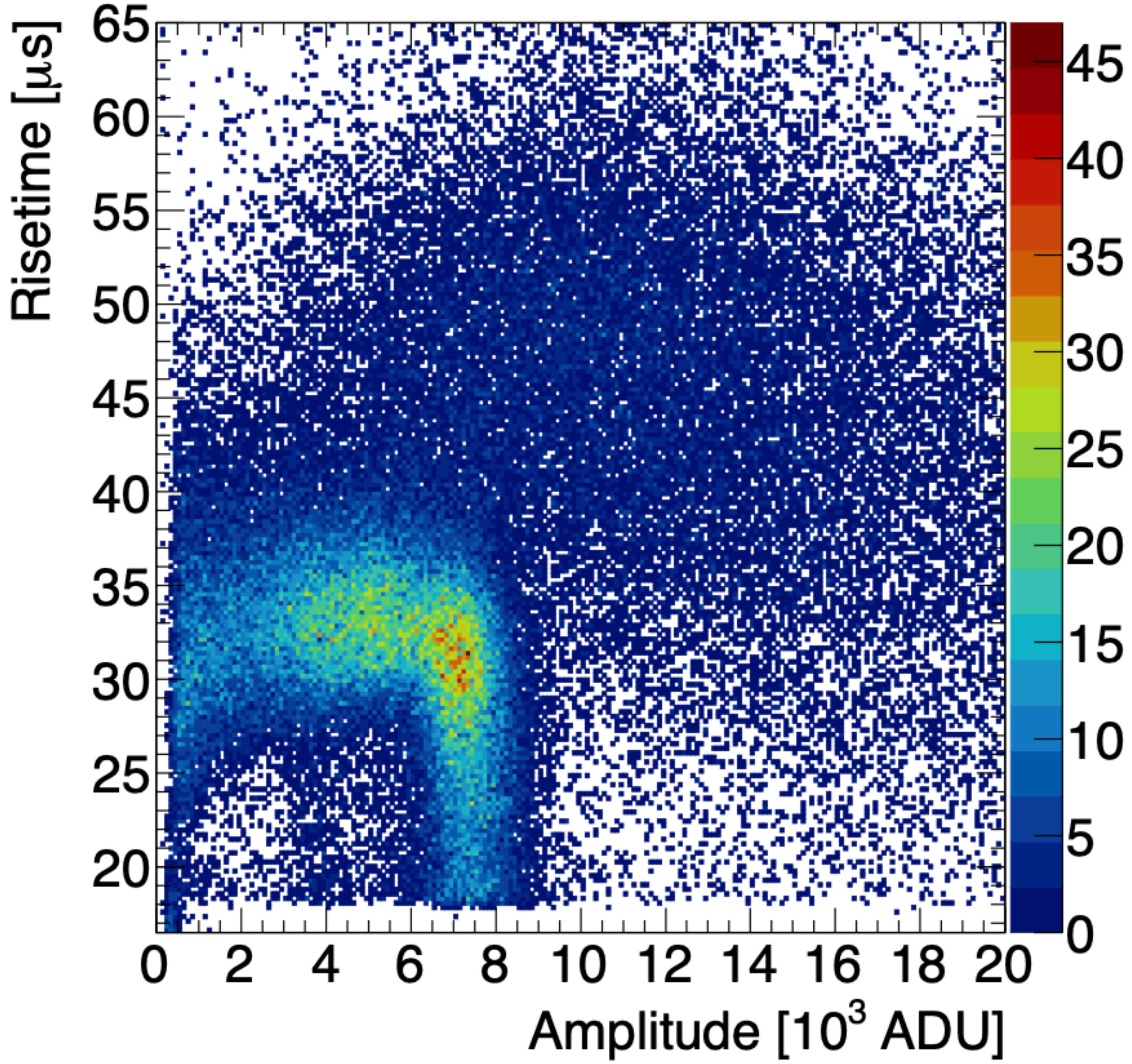
Ionisation detector

- Incident particle induces recoil, releasing ionisation energy
- Primary electrons drift and diffuse towards central anode
- High field in $1/r^2$ at anode produces $\sim 10^3$-10^4 avalanche multiplication
- Drifting ions induce current on anode



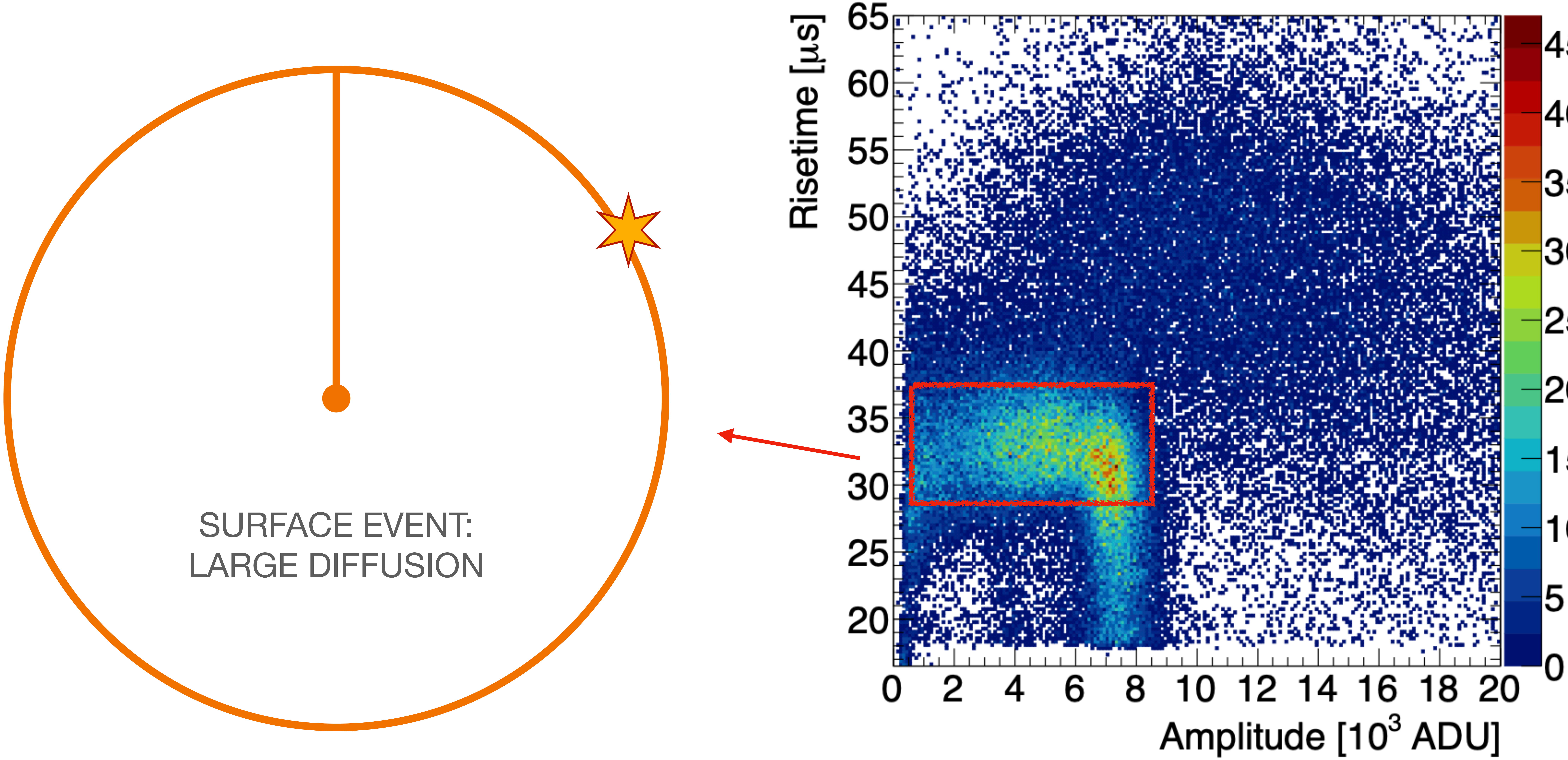
Pulse Shape Discrimination



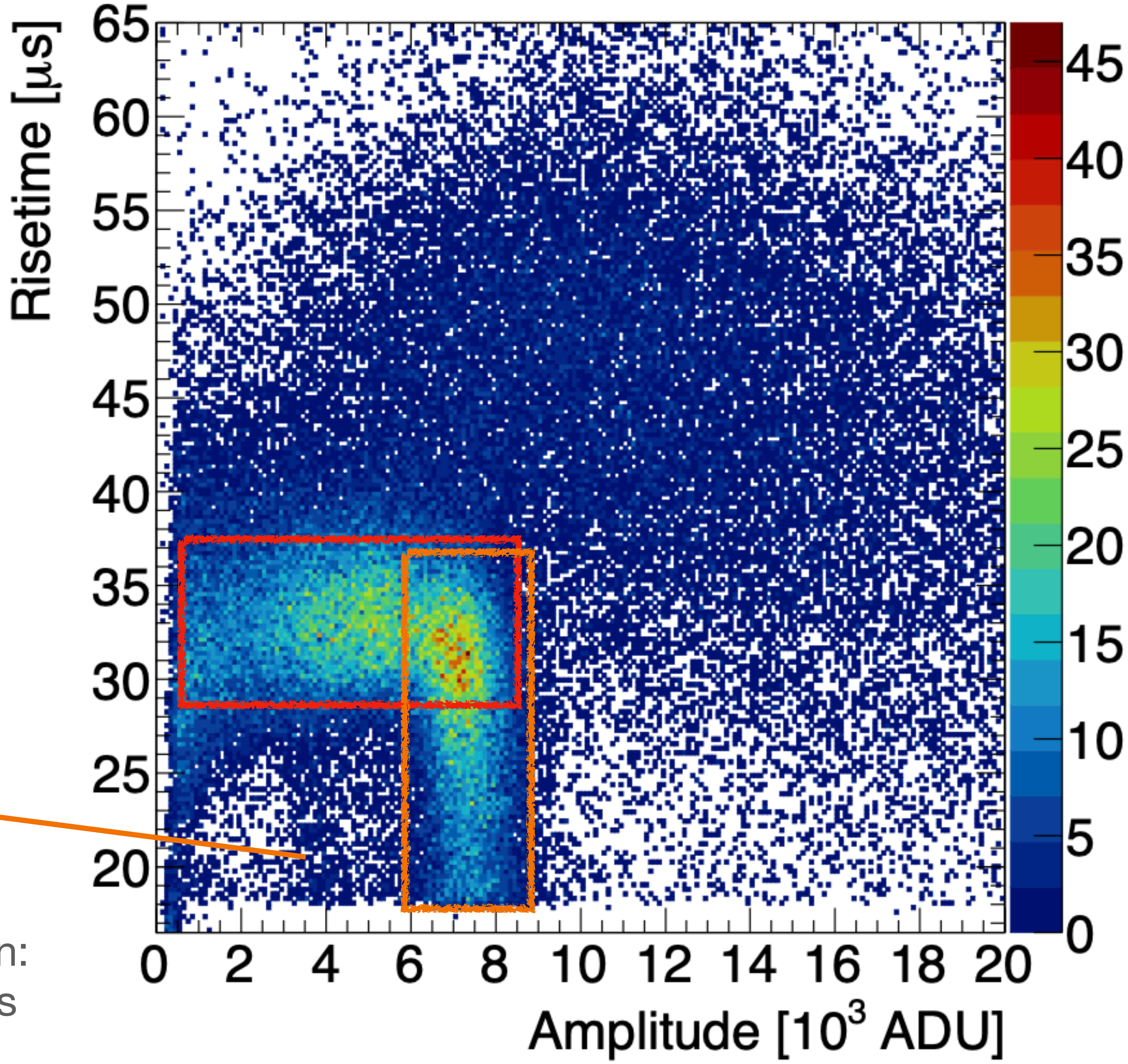


Amplitude: Energy of event
Risetime: Determine type of interaction

Pulse Shape Discrimination

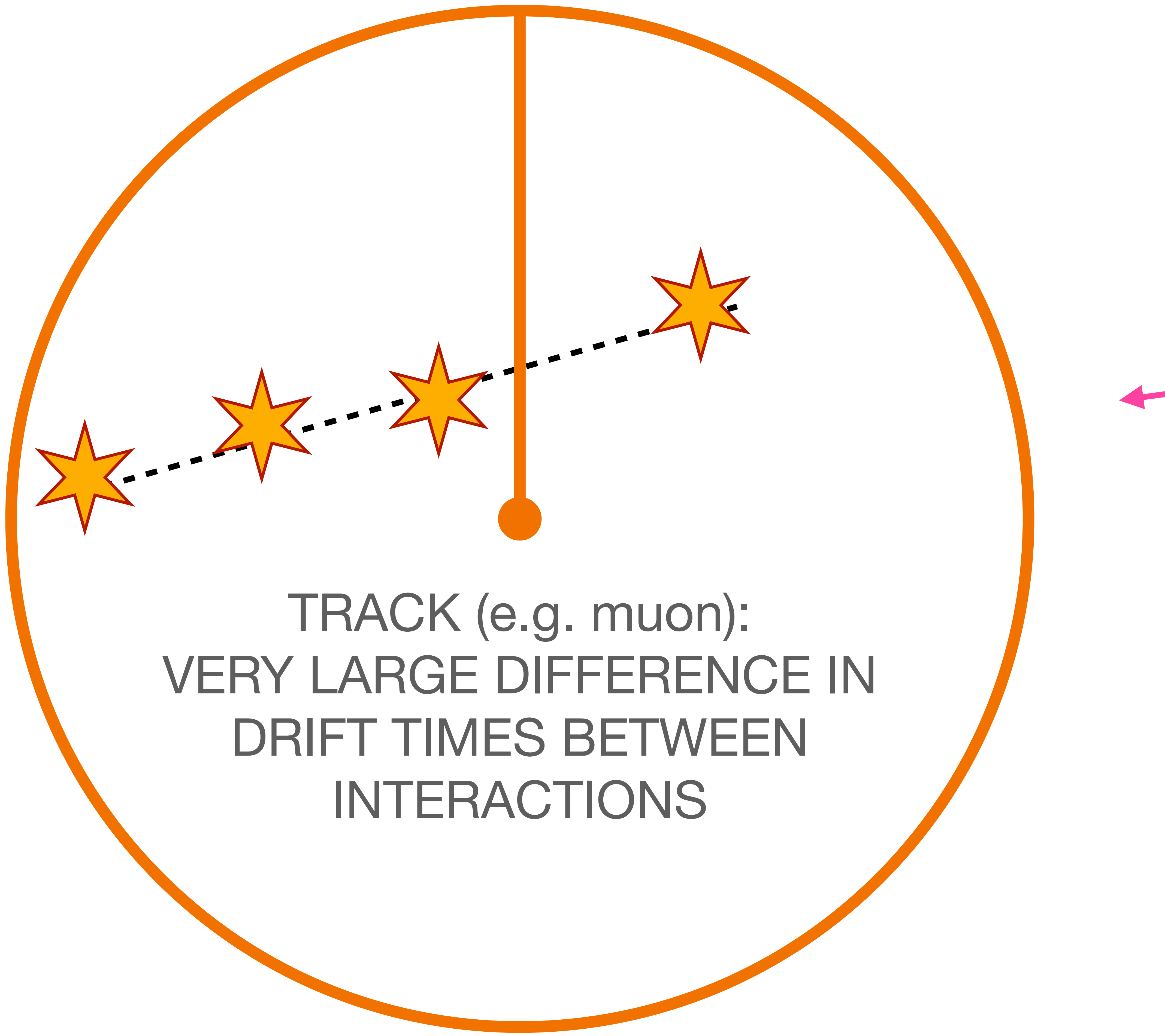


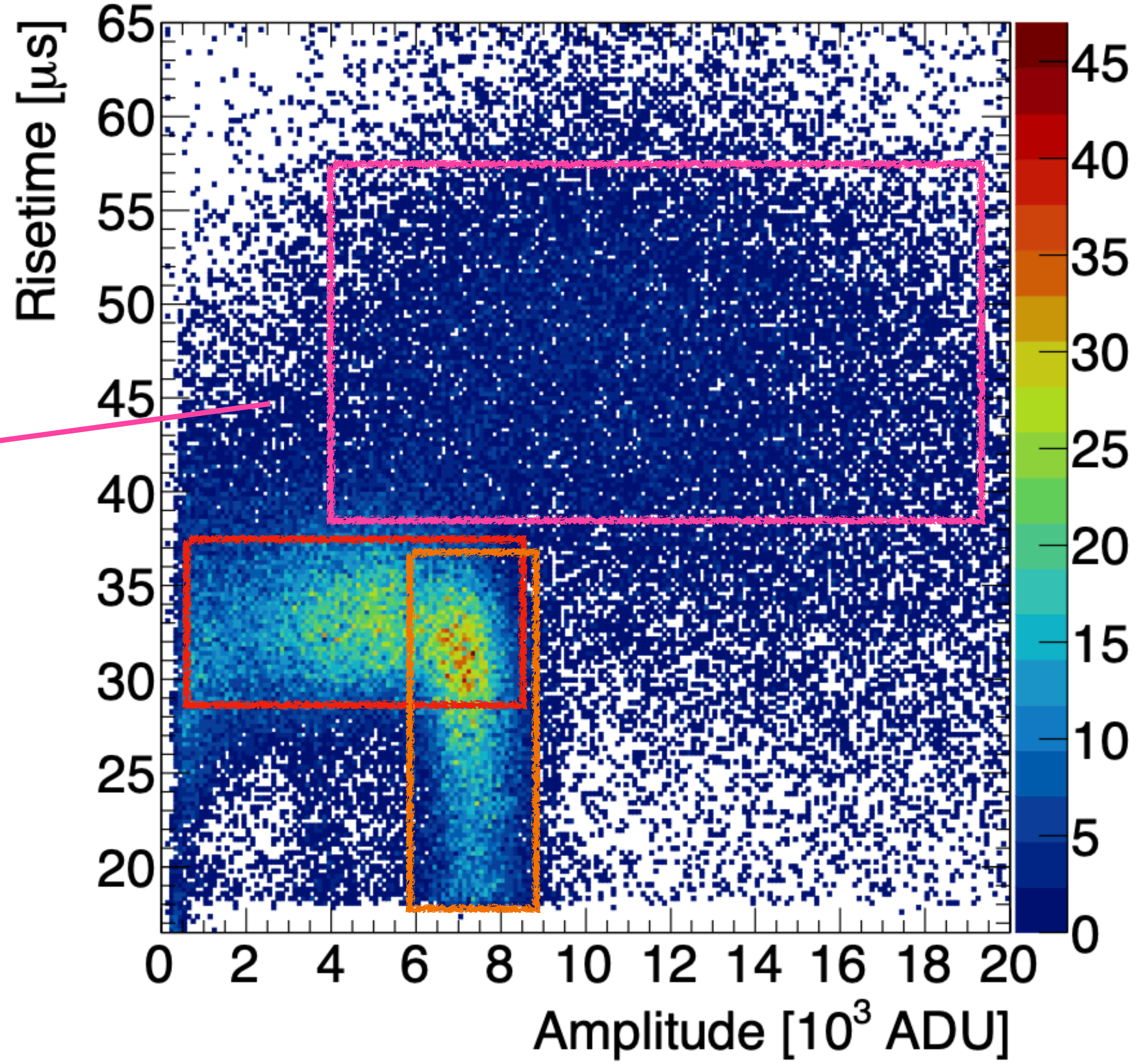
Pulse Shape Discrimination



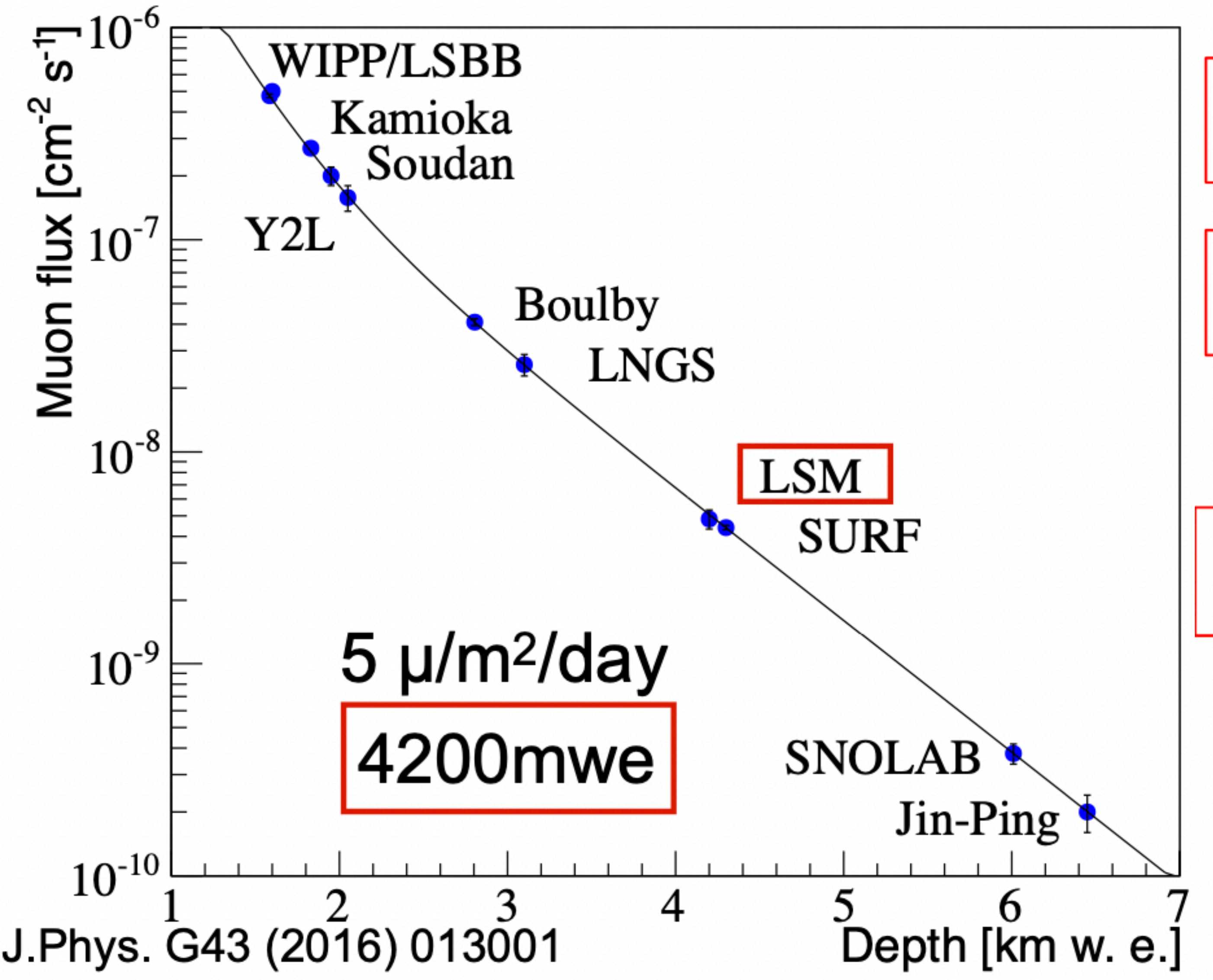
^{55}Fe calibration:
5.9 keV X-rays

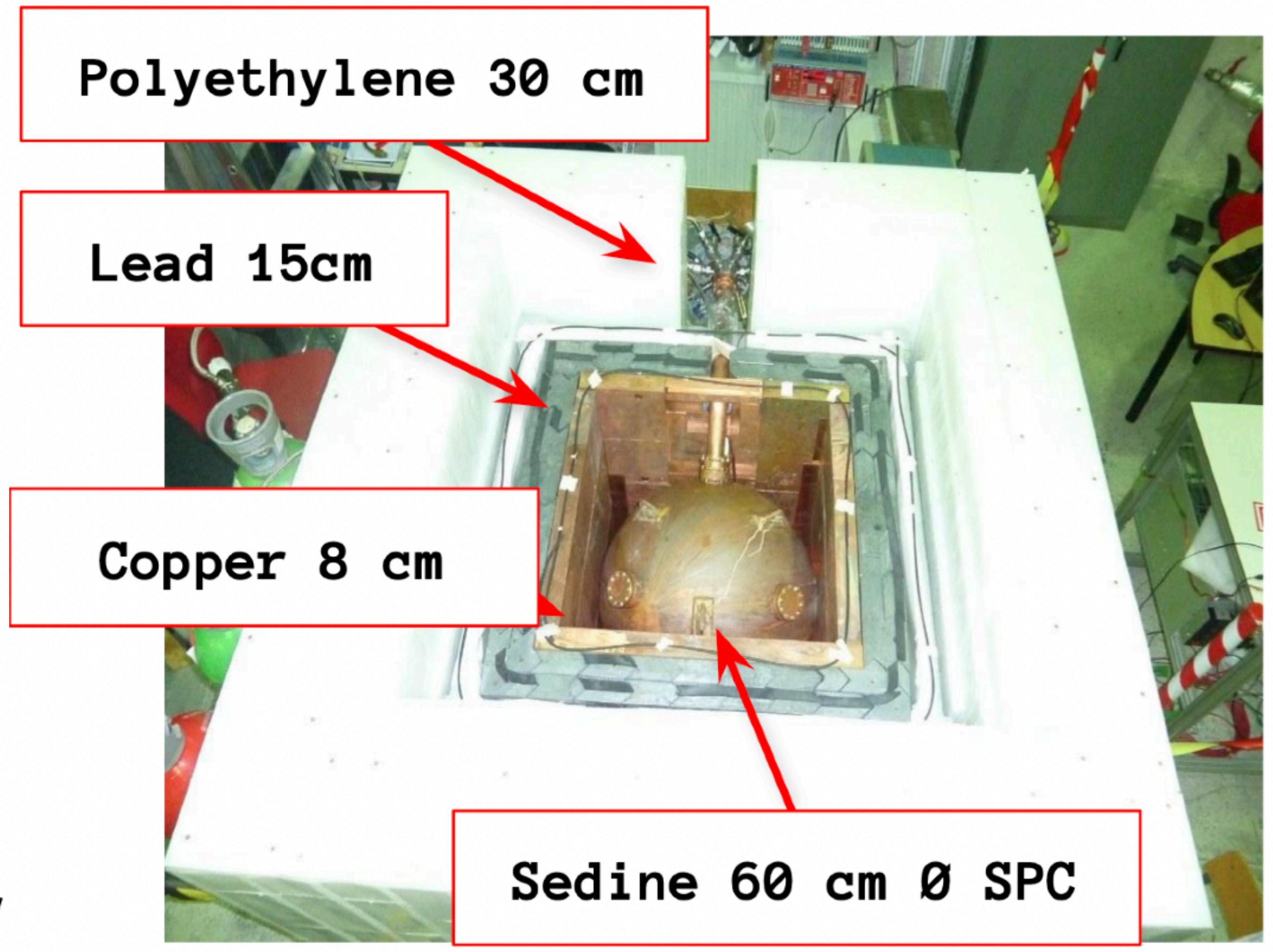
Pulse Shape Discrimination





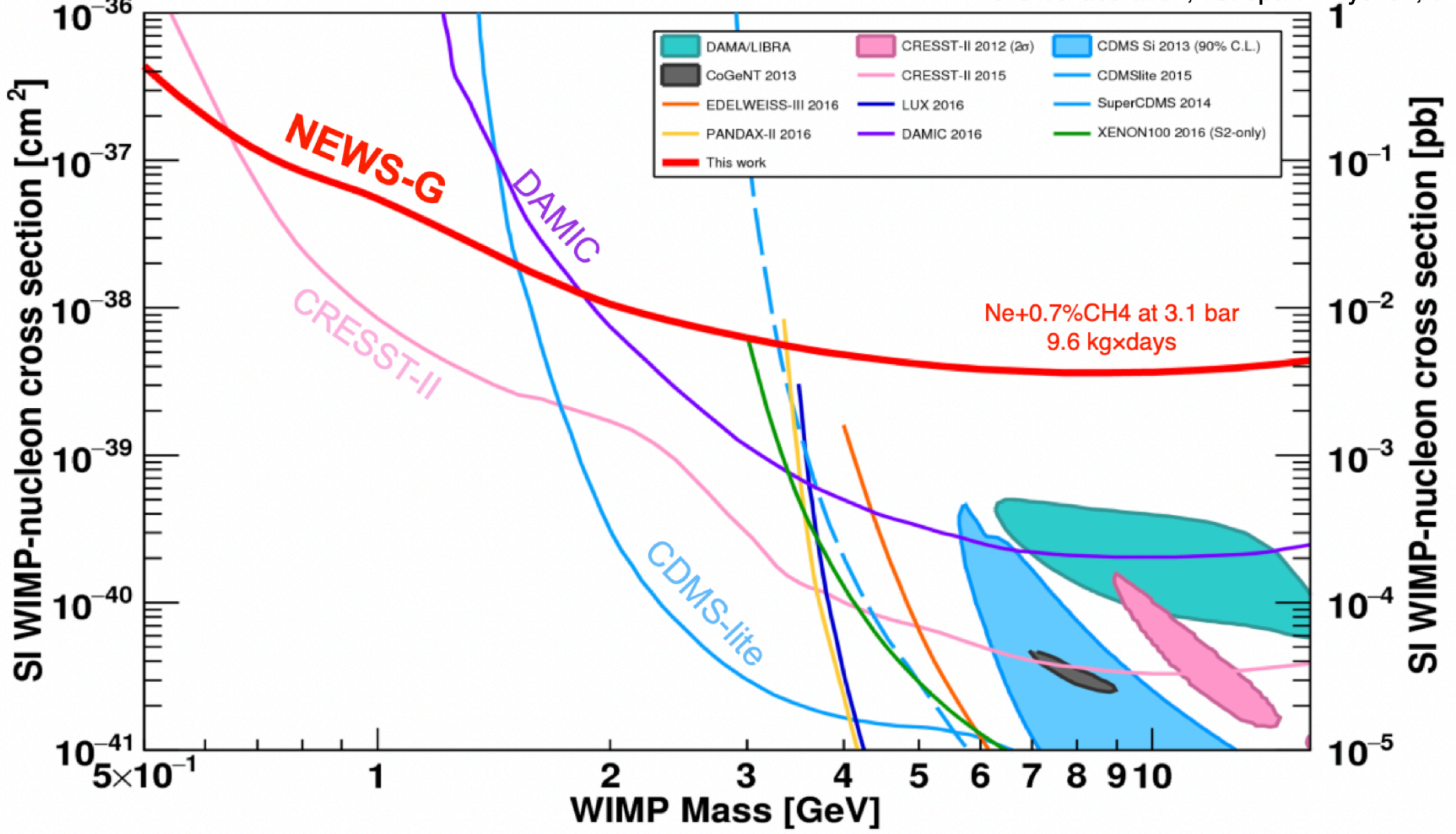
Results with SEDINE prototype at LSM

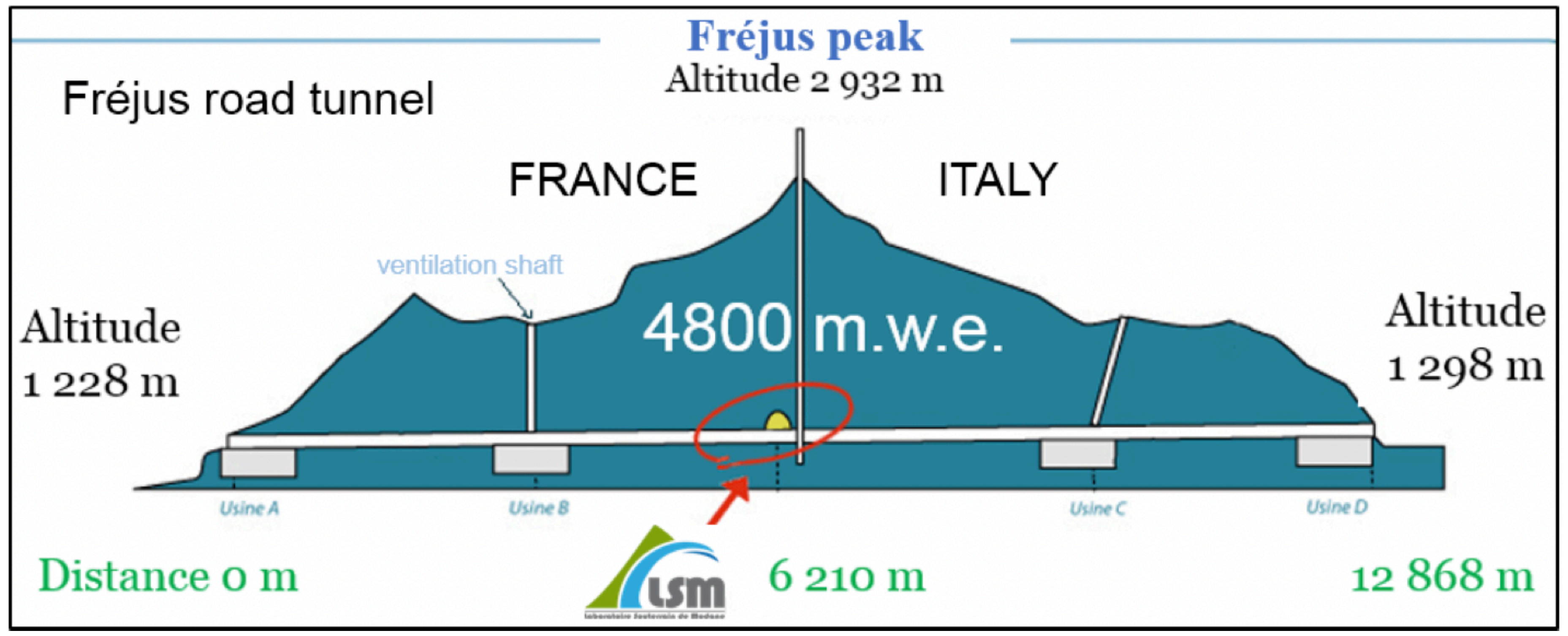


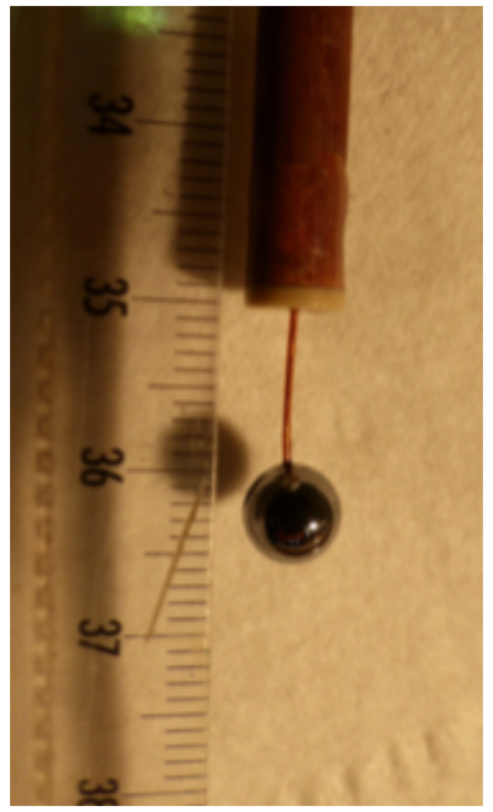


- ⌀60cm NOSV copper vessel, ⌀6.3 mm single-anode sensor
- Physics: 42-day run with 3.1bar of Neon + 0.7% CH_4 (280g, total 9.7 kg·day)
- Main backgrounds:
  - Radon daughters on inner surface of vessel
  - ^{210}Pb in copper bulk

NEWS-G collaboration, Astropart. Phys. 97, 54 (2018)

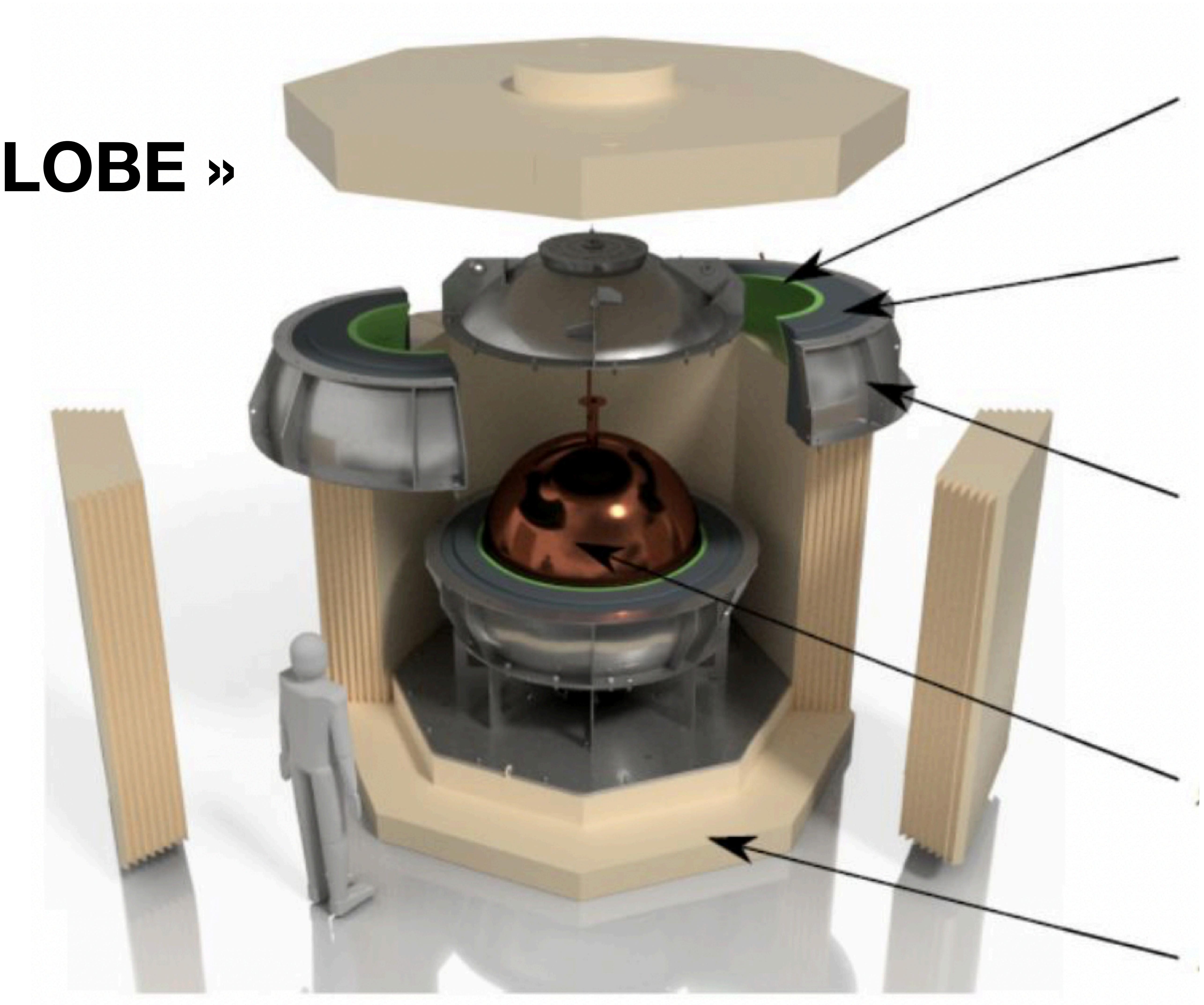






S140

« SNOGLOBE »



Detector paper: https://arxiv.org/abs/2205.15433, pending publication in JINST

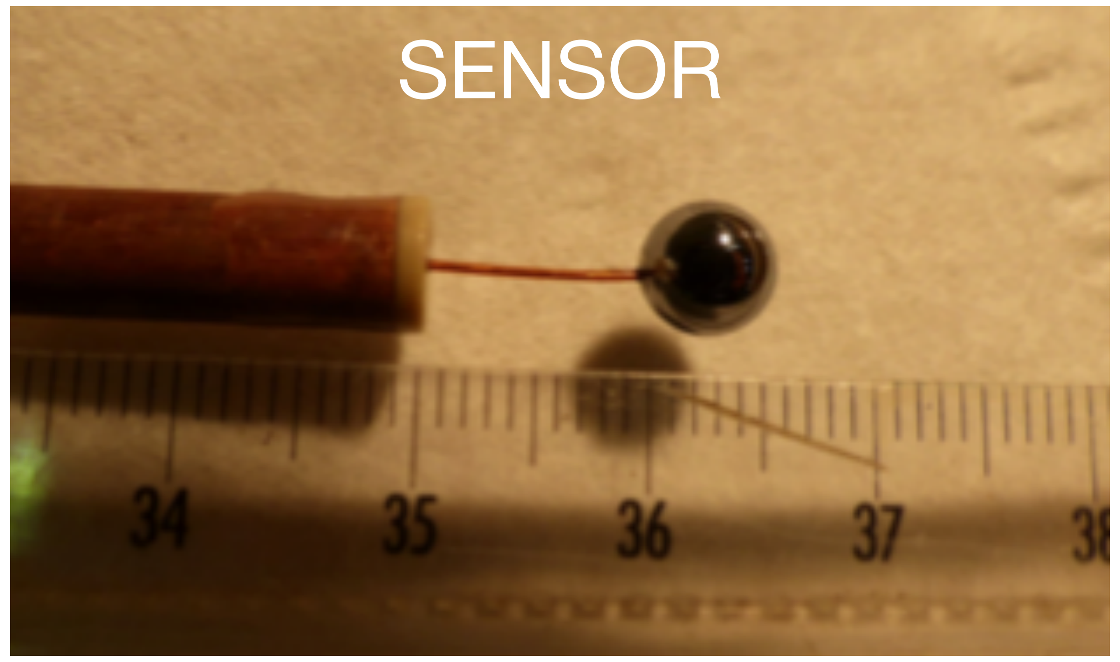
Sensor development

From single to multi-anode

- Single anode sensor field:

$$E \approx r_A \frac{V}{r^2}$$

- Contradictory constraints:
  - High gain requires small radius anode
  - Field far from anode requires large radius anode



Sensor development

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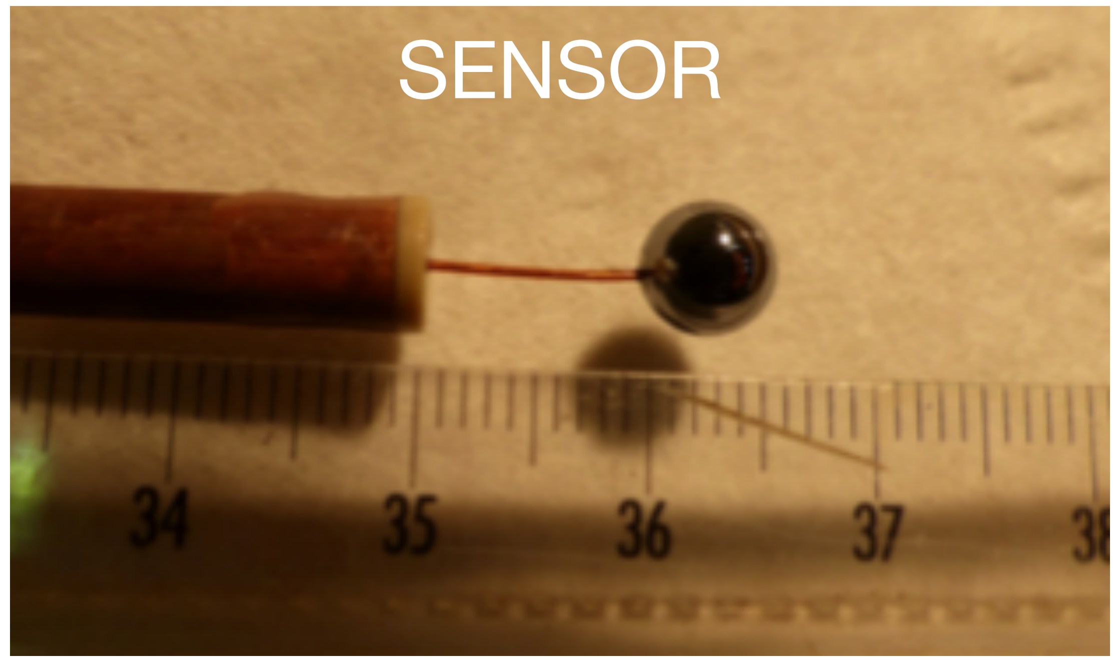
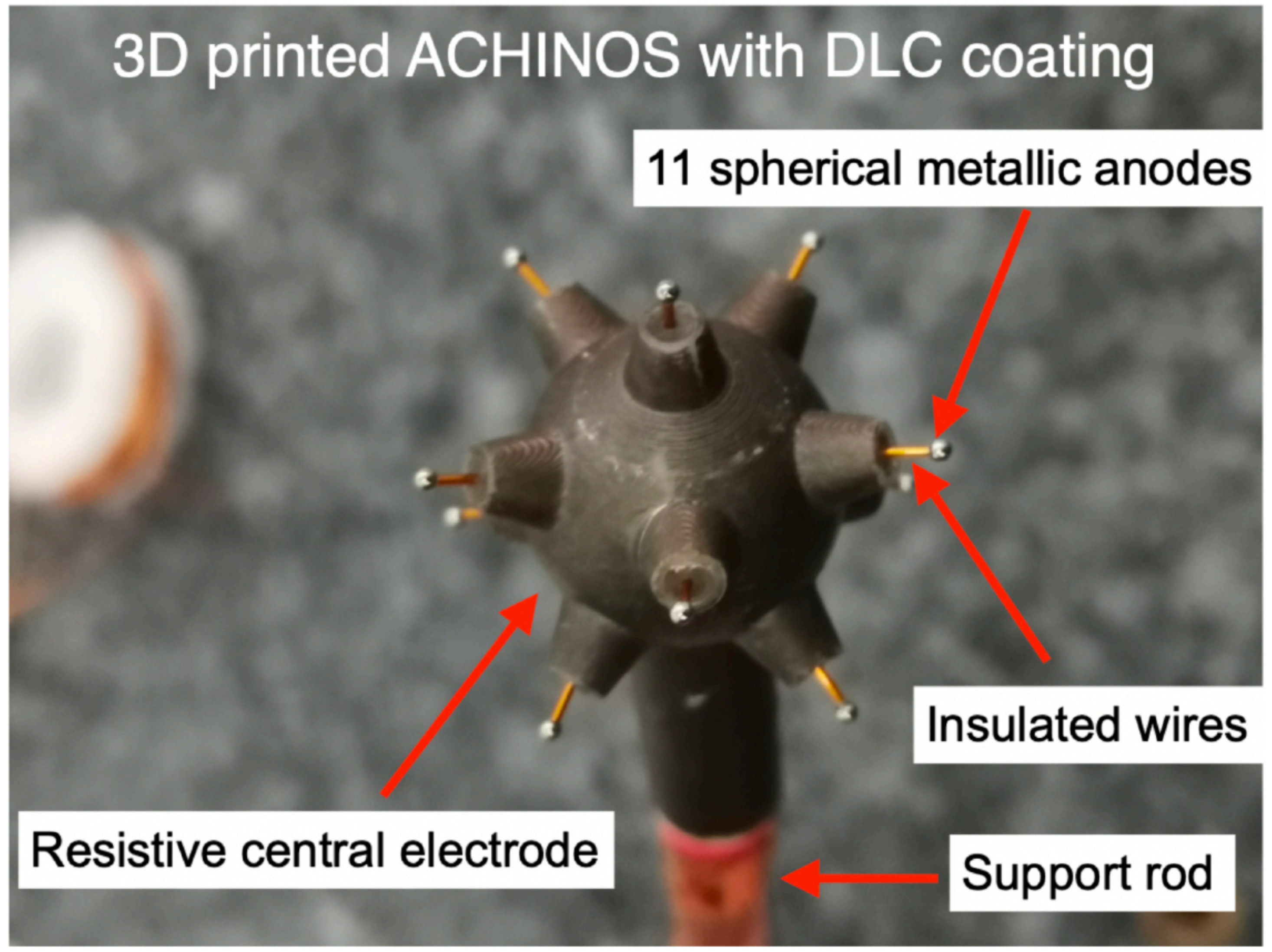
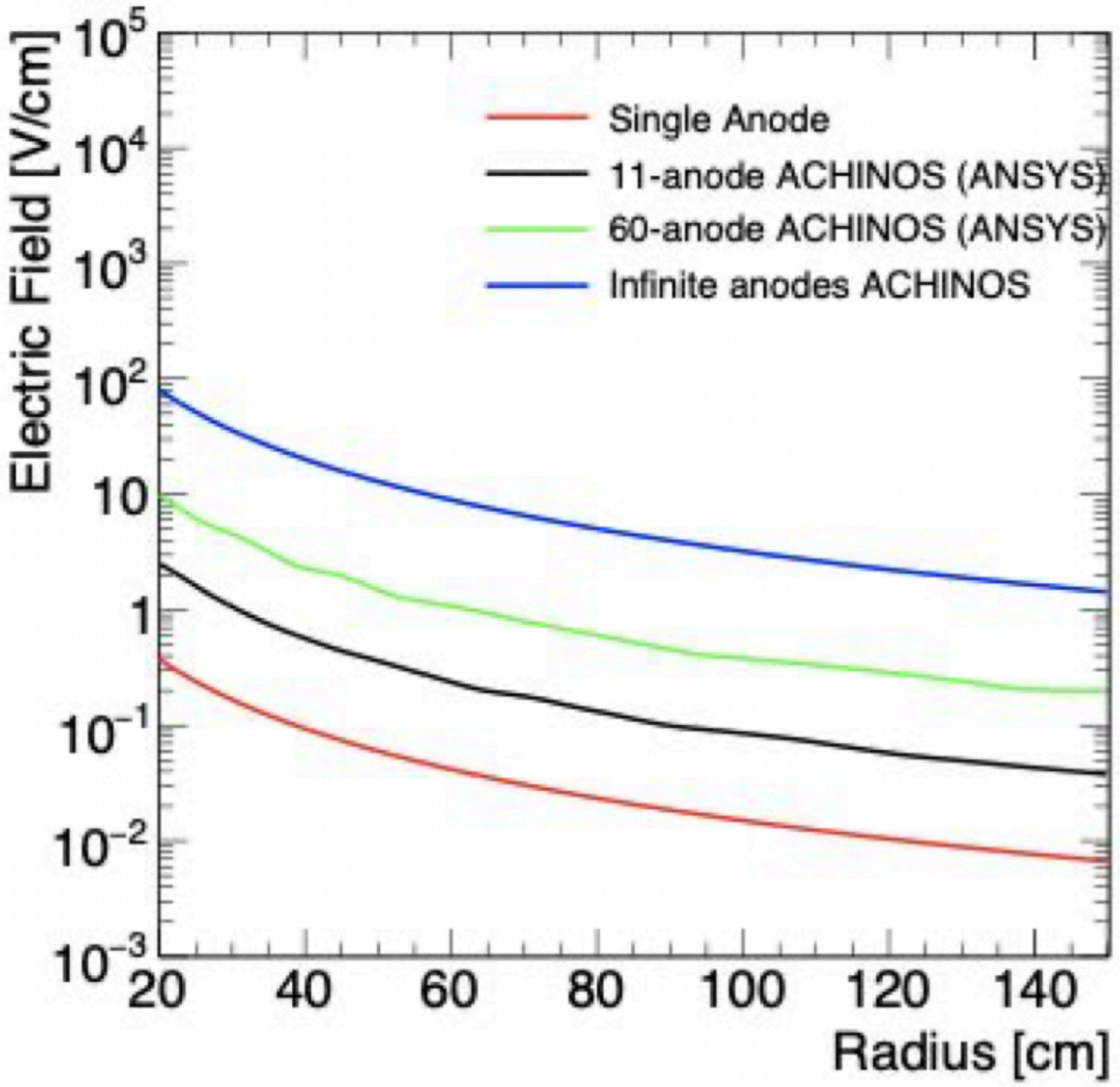


Αχινός (greek. sea urchin)



Enter ACHINOS

- Multiple anodes placed at equal radii
- Boosted field far from anodes, without changing avalanche field: can scale detector up!



JINST 12 (2017) 12, P12031

S140

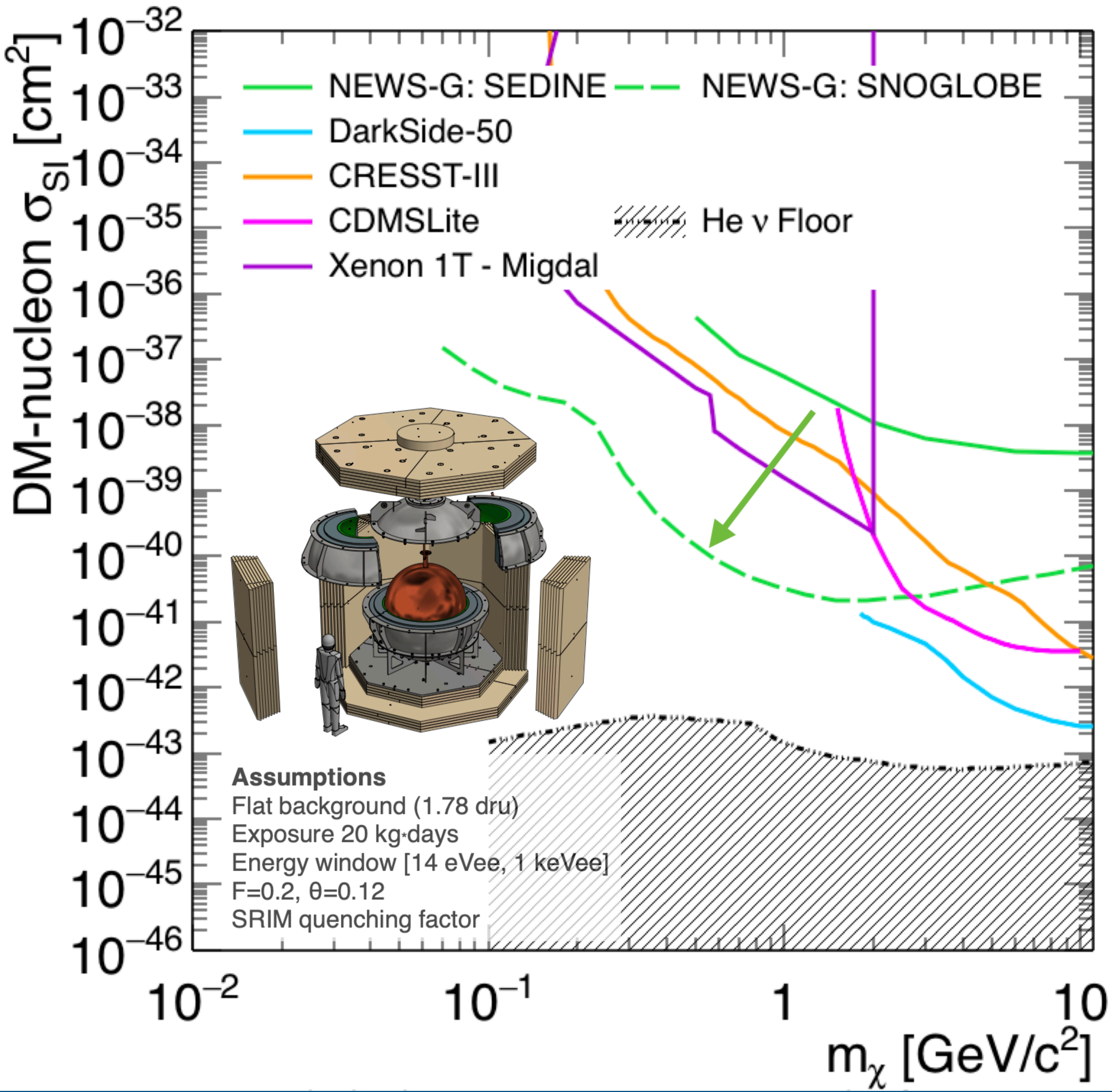
Projections

See IDM talk by P. Knights

S140 improvements:

- Larger volume
- Increased radiopurity of materials
- ~0.5 mm of electroplated copper on inner surface of copper shell
- Radon and oxygen filtering
- Laser calibrations (gain, drift…)
- Multi-anode sensor

~10 days of physics data with <u>135 mbar of CH4</u> taken during commissioning at LSM in 2019



Ionization statistics

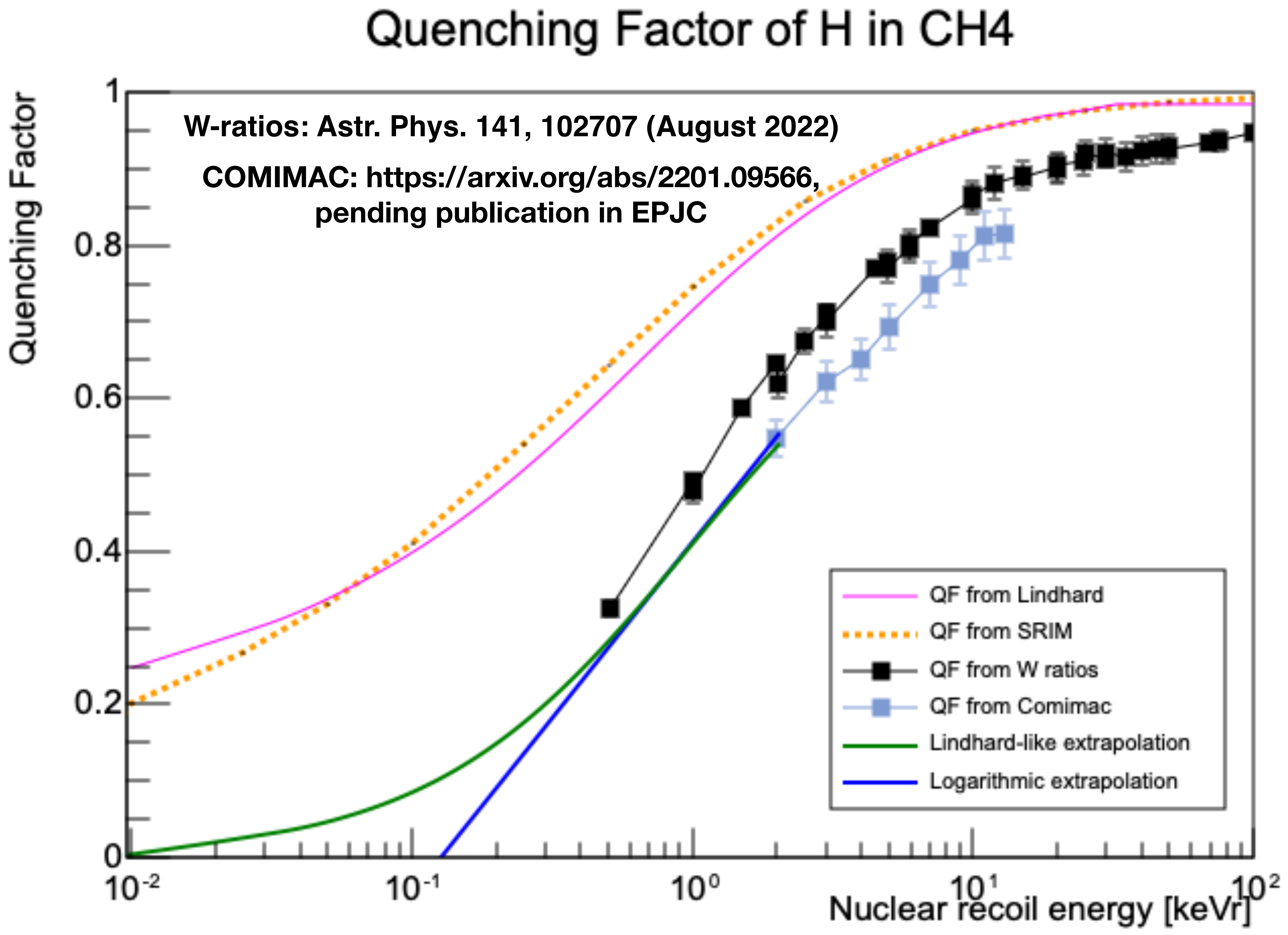
Quenching Factor

- Quenching factor values from existing W-value measurements for ions and measurements from COMIMAC
- The (more conservative) logarithmic extrapolation was used to derive the expected WIMP signal
  - Lindhard-like

$$QF(Er) = m*(\alpha E_r^{\beta})/(1+\alpha E_r^{\beta})$$

  - Logarithmic

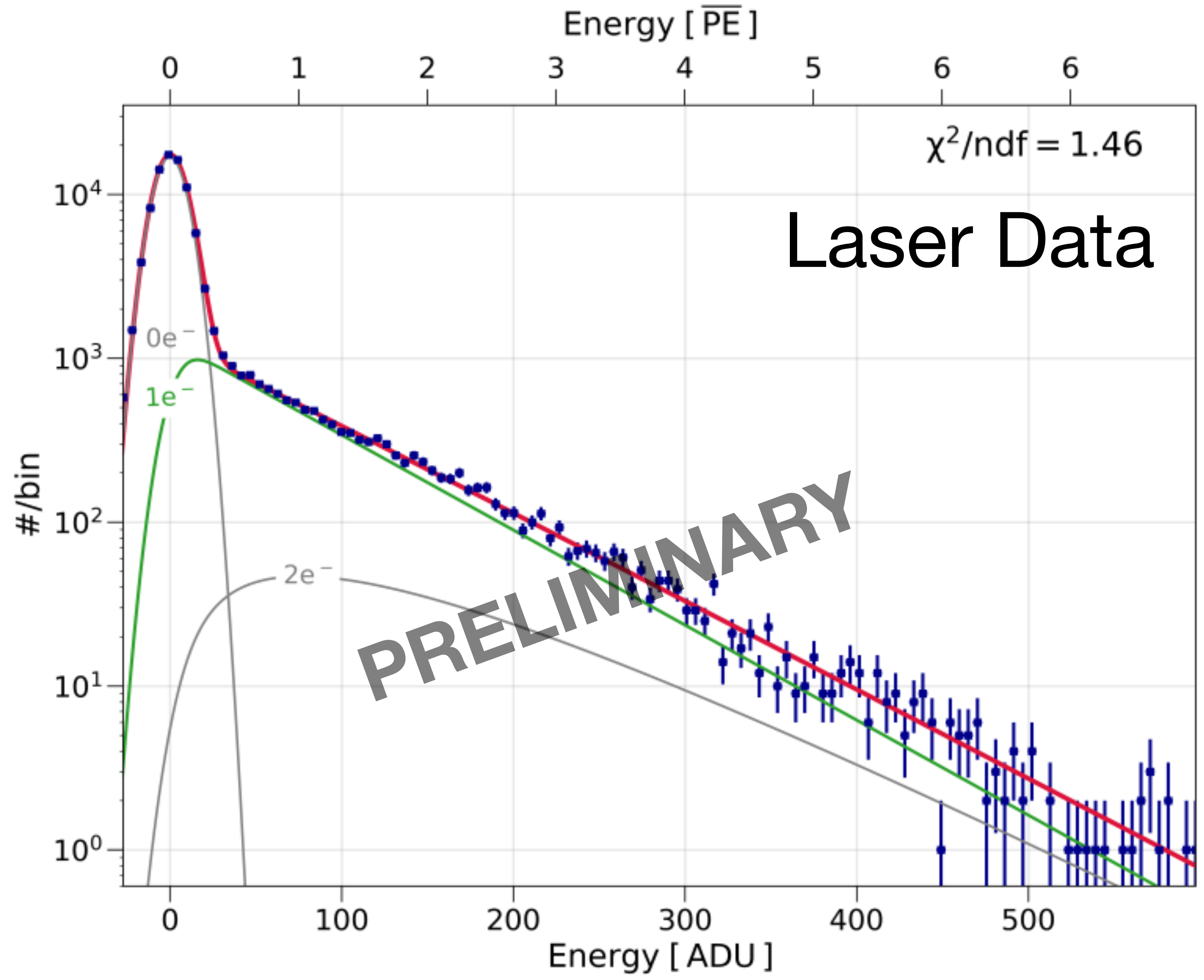
$$QF(Er) = a + b*\log(E_r)$$



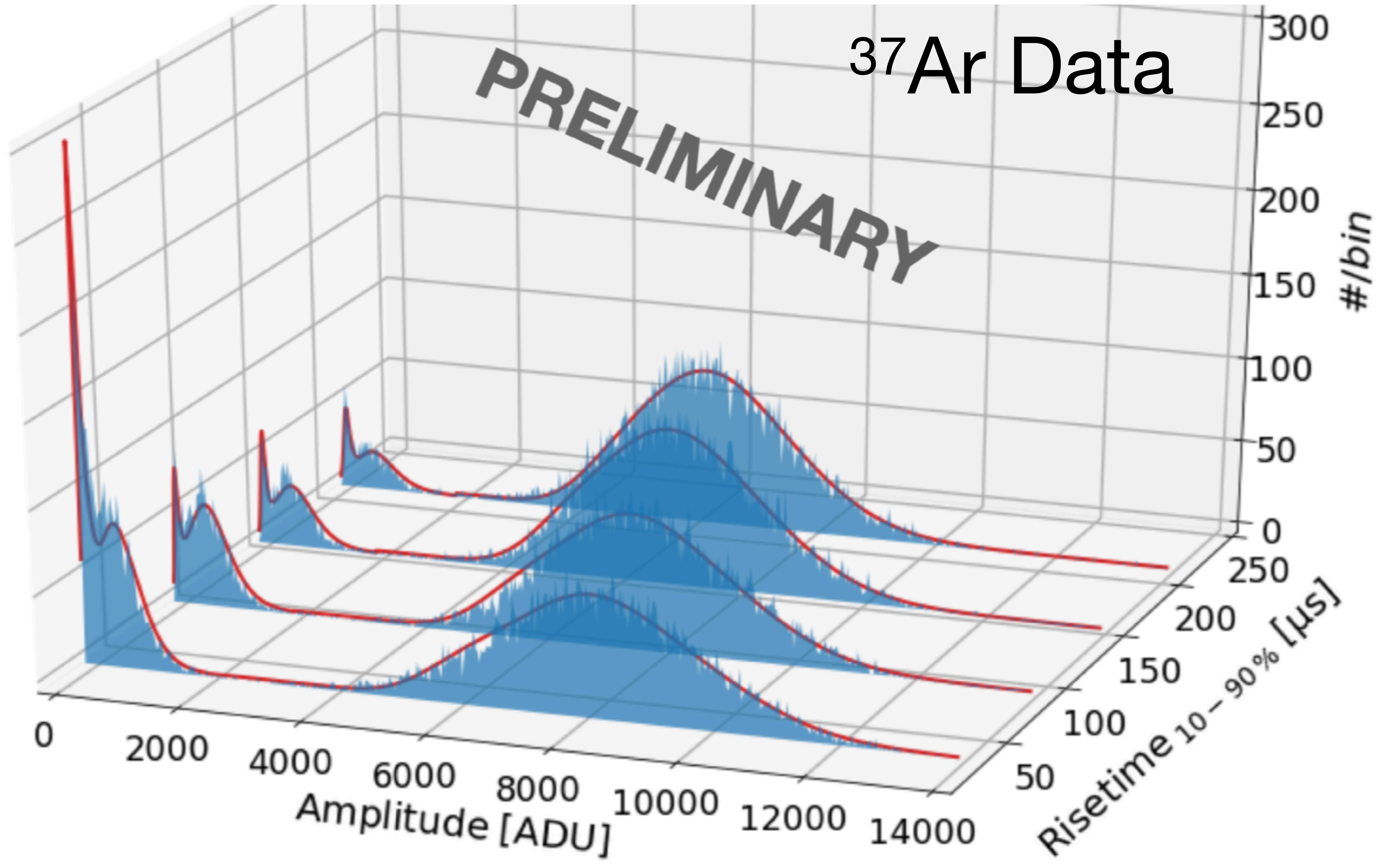
Ionization statistics

Mean Ionization energy

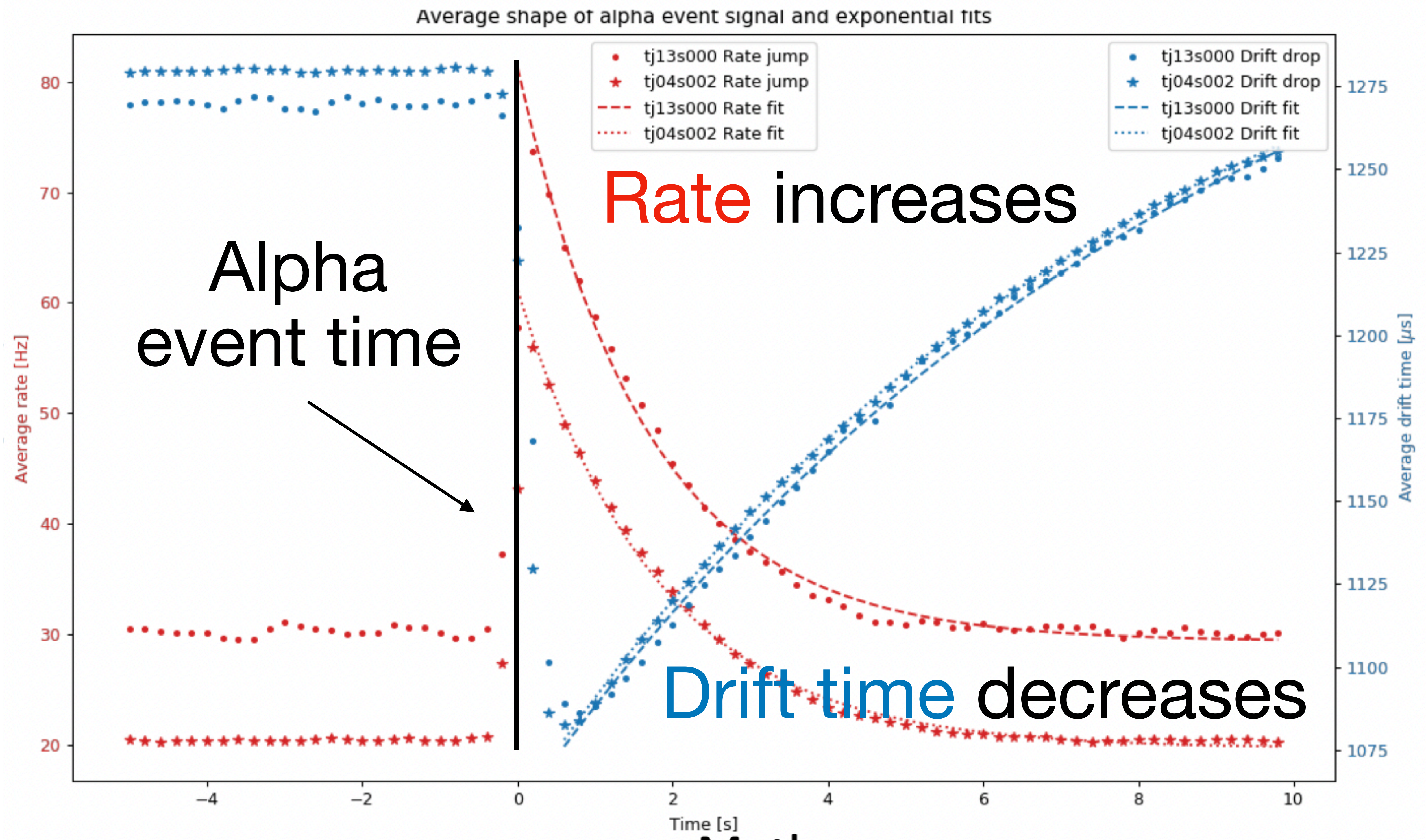
- 213 nm LASER calibration used to obtain single-electron response of detector
- Combine with 2.8 keV, 270 and 200 eV lines from ^{37}Ar (gas, probing whole volume):
  - Confirmation of linearity
  - Measurement of gain of south-channel anodes
  - Parametrization of electron attachment
  - In-situ measurement of W and Fano factor



$$W_0 = 30.0^{+0.14}_{-0.15}\,\text{eV}, \quad U = 15.70^{+0.52}_{-0.34}\,\text{eV}, \quad F = 0.43 \pm 0.05$$



Alpha-correlated electrons

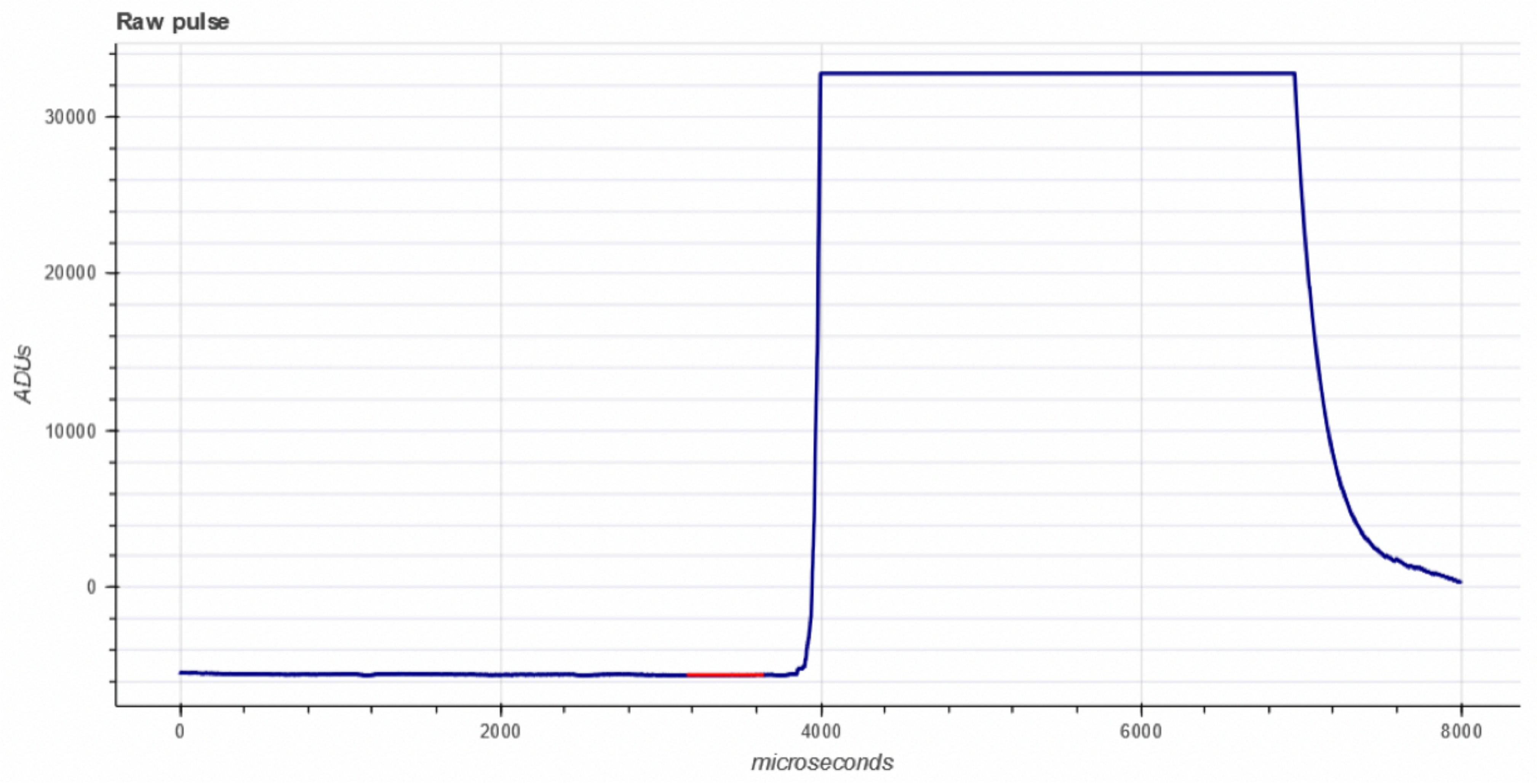


Methane

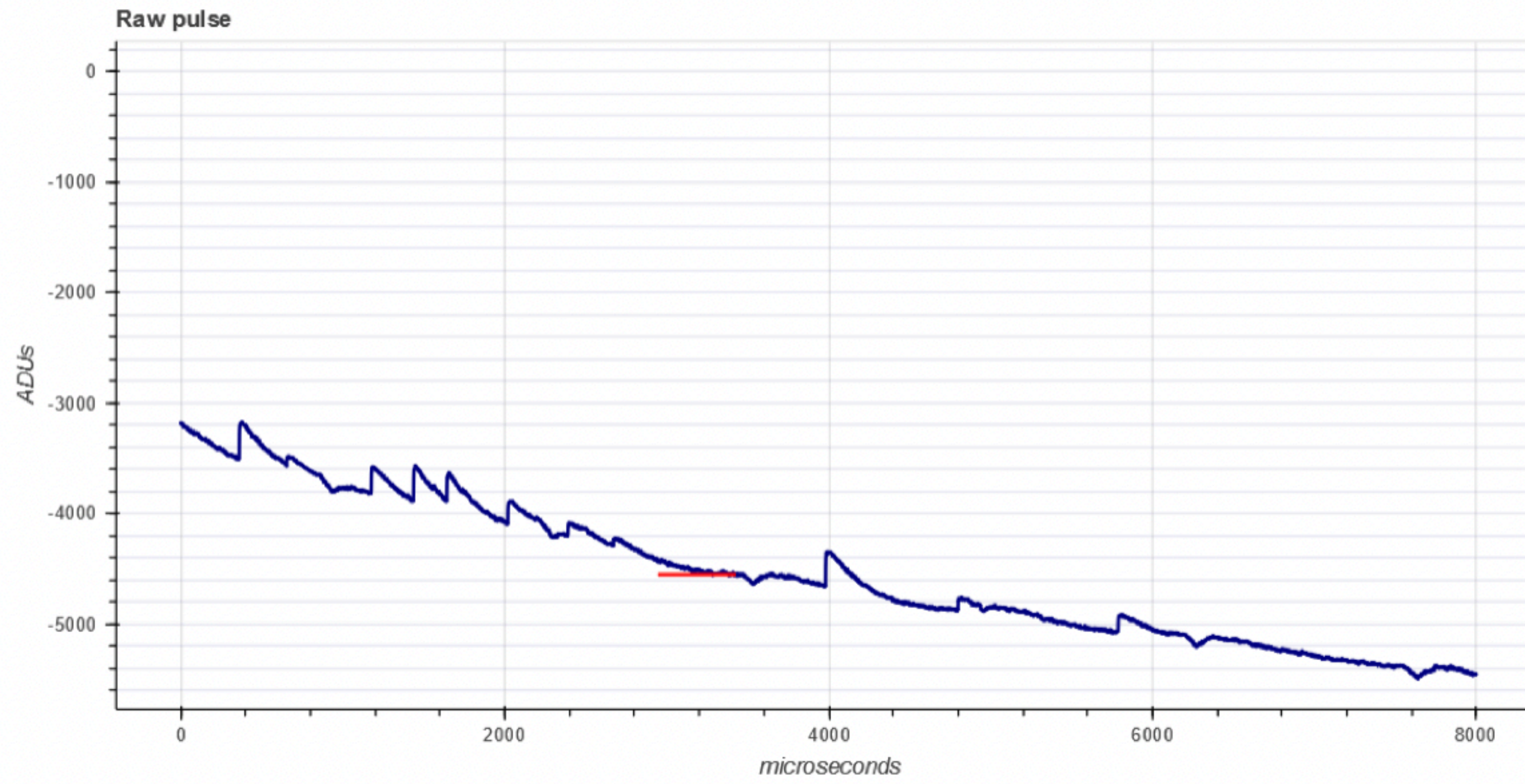
For CH4 data, removing 5s after each alpha reduces exposure by 12%, but reduces background rate by ~70%

Alpha event

J.M. Coquillat



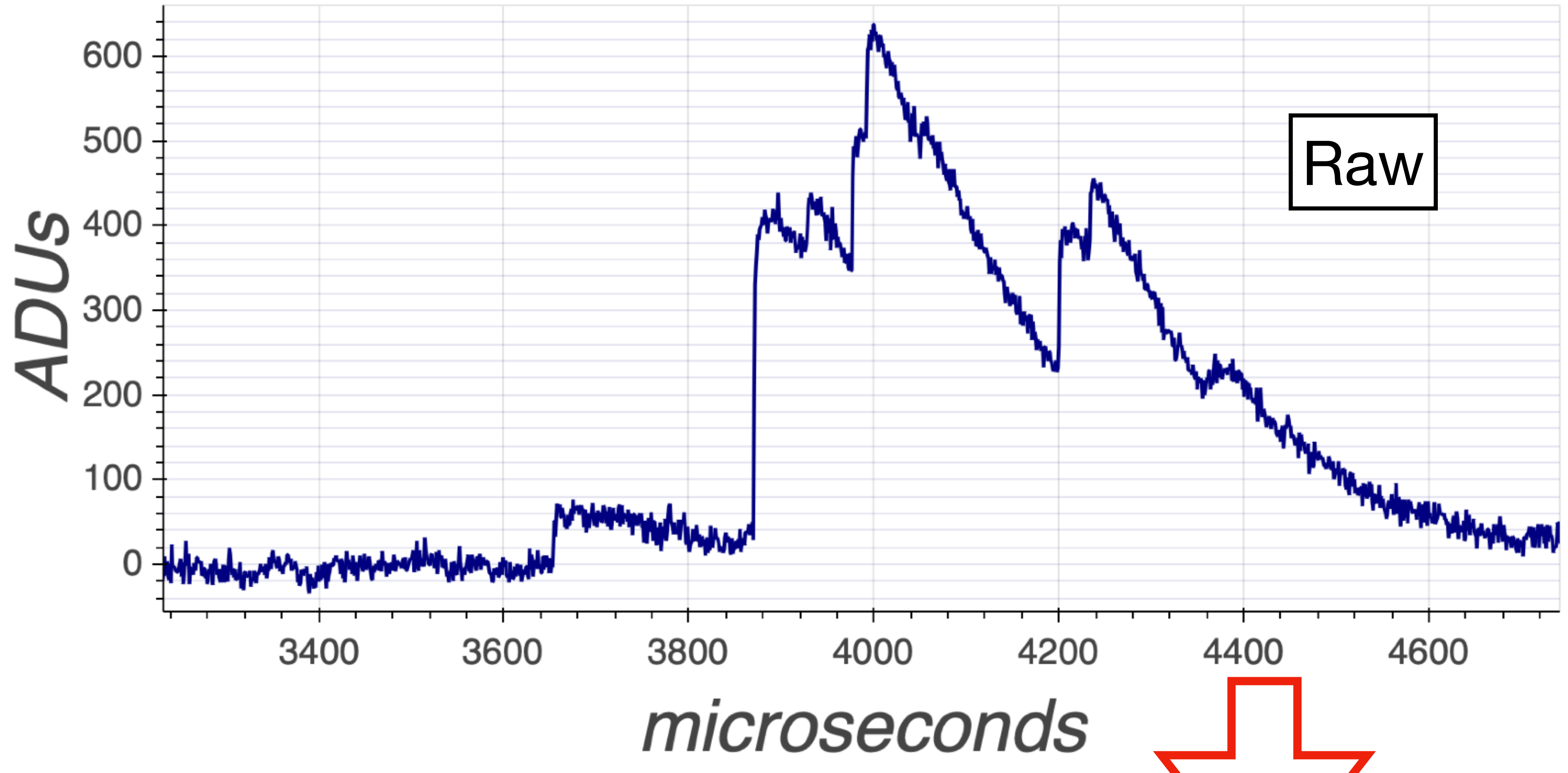
Long tail on following detected event

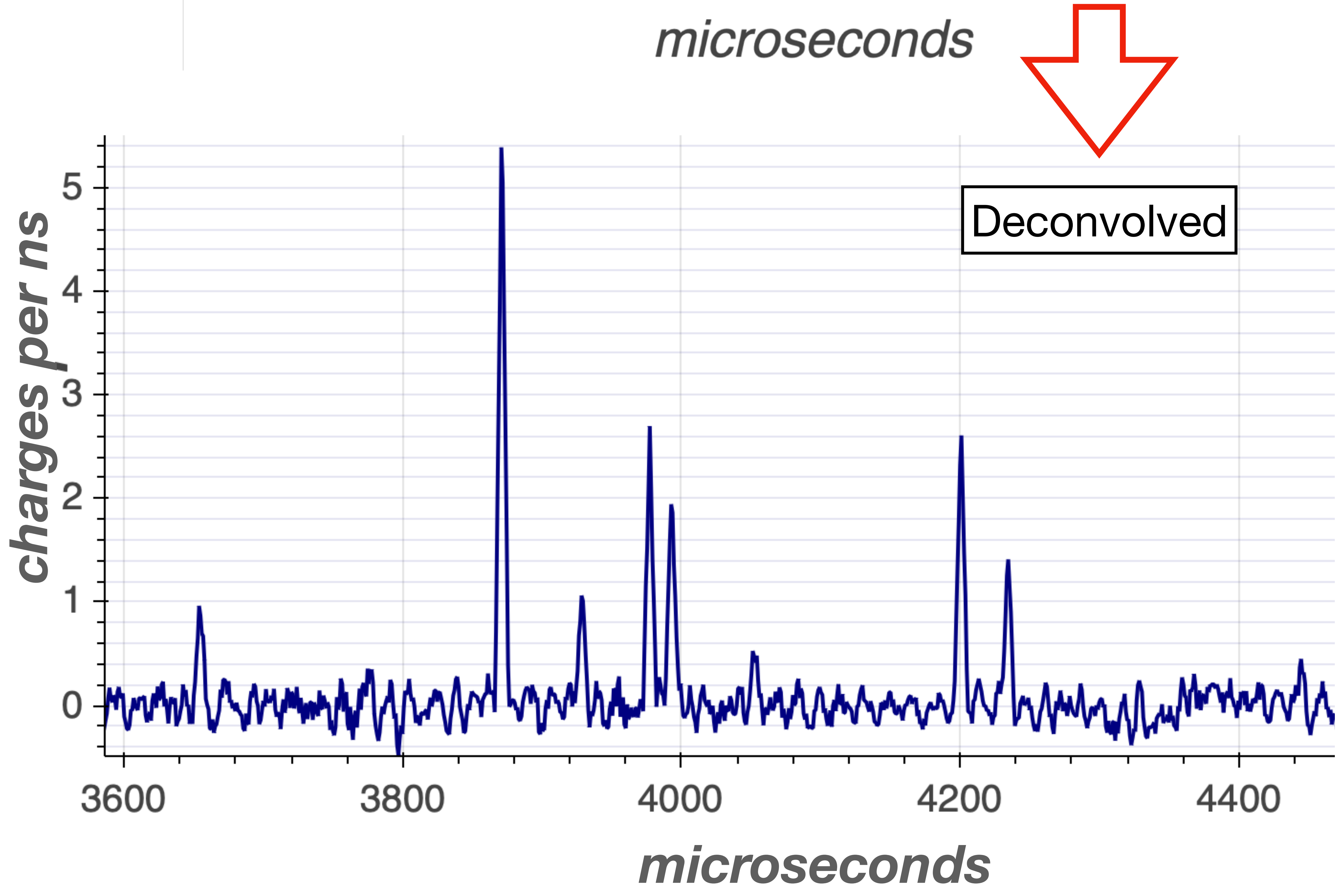


Peak counting algorithm

Commissioning run at LSM with 135 mbar CH4 revealed >100 μs diffusion, >5 times larger than SEDINE's Neon data

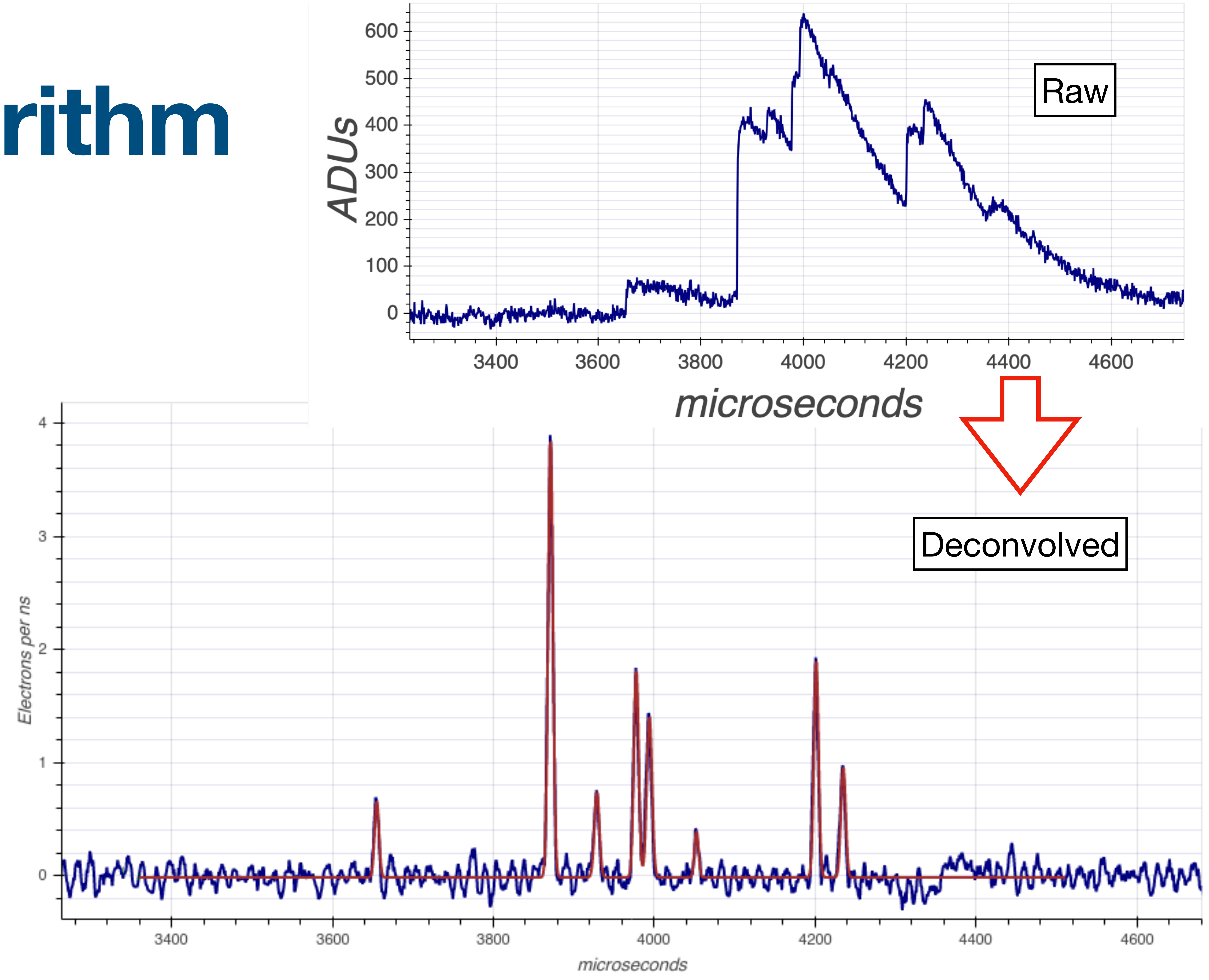
- After deconvolution, can see individual electrons reach the anode.
- Want to keep only >1 e- events, to reject large Single Electron background
- Need to implement algorithm to count number of peaks in signal





Peak counting algorithm

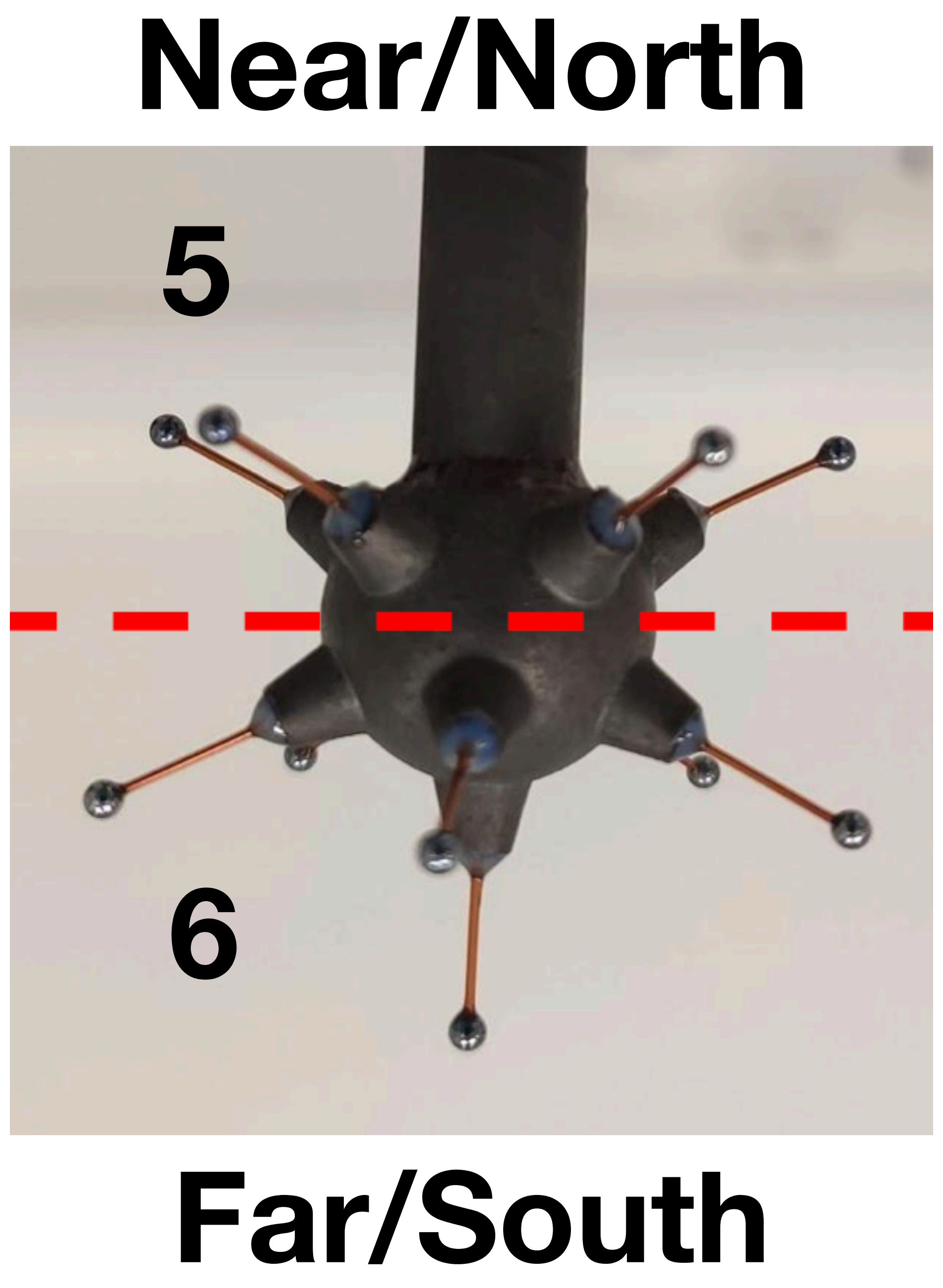
- Deconvolve both preamplifier and ion current response from signal, do running average over 5 bins twice, then use ROOT's TSpectrum::Search() + gaussian fits
- ROOT TSpectrum offers best performance (efficiency vs false positives) compared to simple threshold searches on deconvolution or derivative of pulse
- Neural Network approaches currently being tested

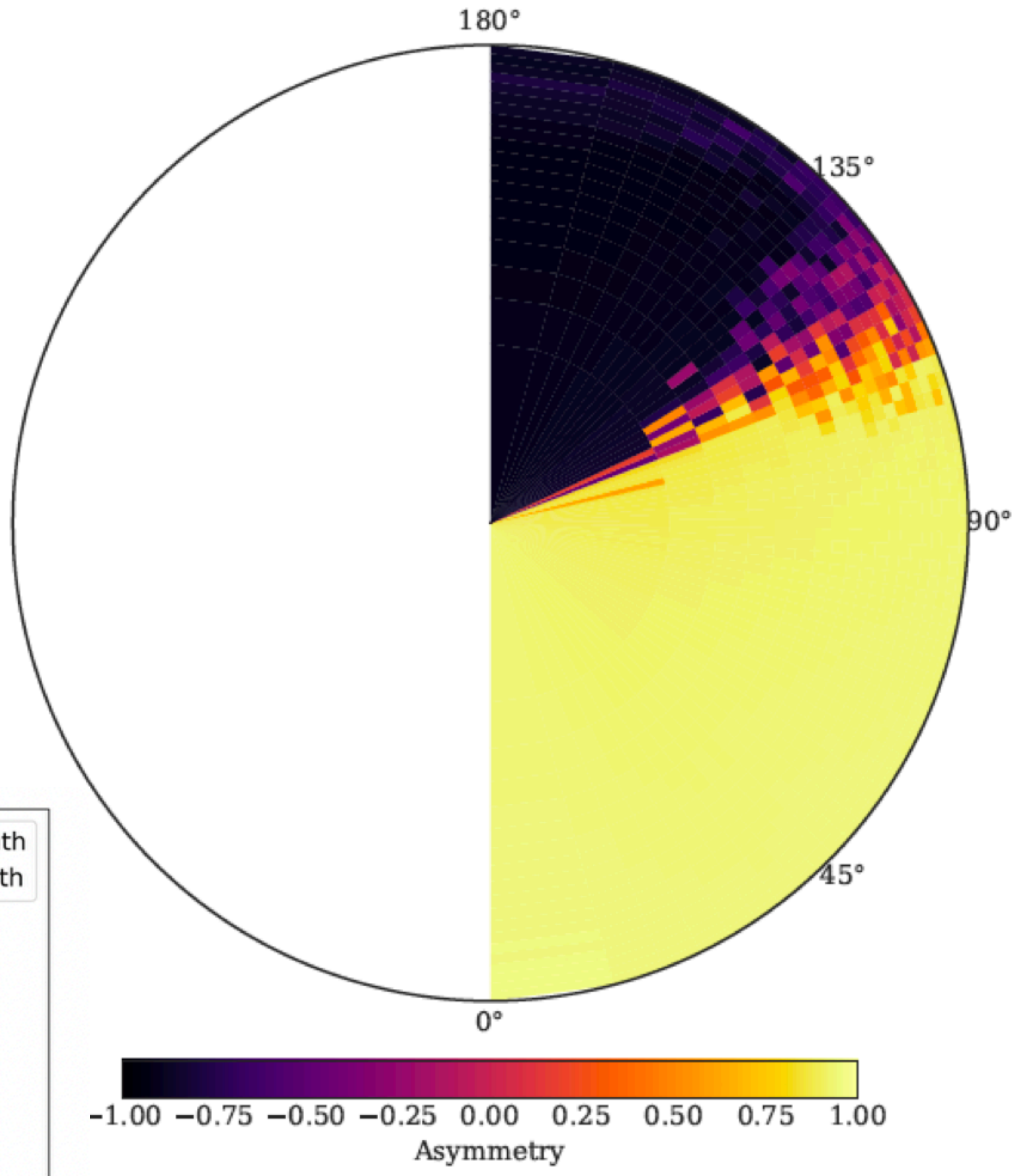


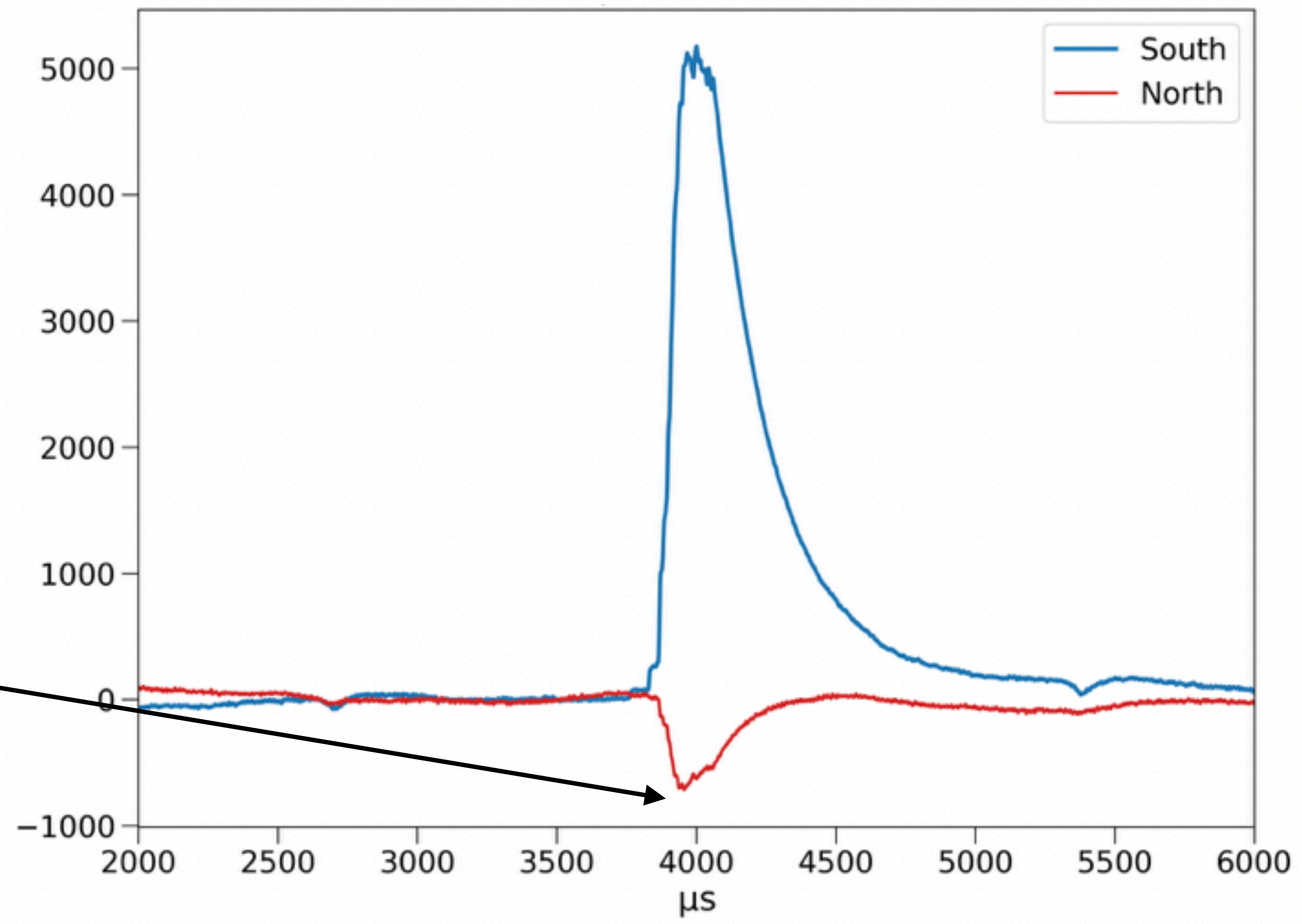
Detector simulation

ACHINOS : 5-6 configuration

- For commissioning run, achinos split into two channels
- Detector simulation performed with Geant4, Garfield++, ANSYS
- Used to estimate fiducial volume of each channel, effect of the support structure, gas choice, etc., verified with ^{37}Ar calibrations
- ***Predicted negative cross-channel induction for «physical» events due to ion movement***





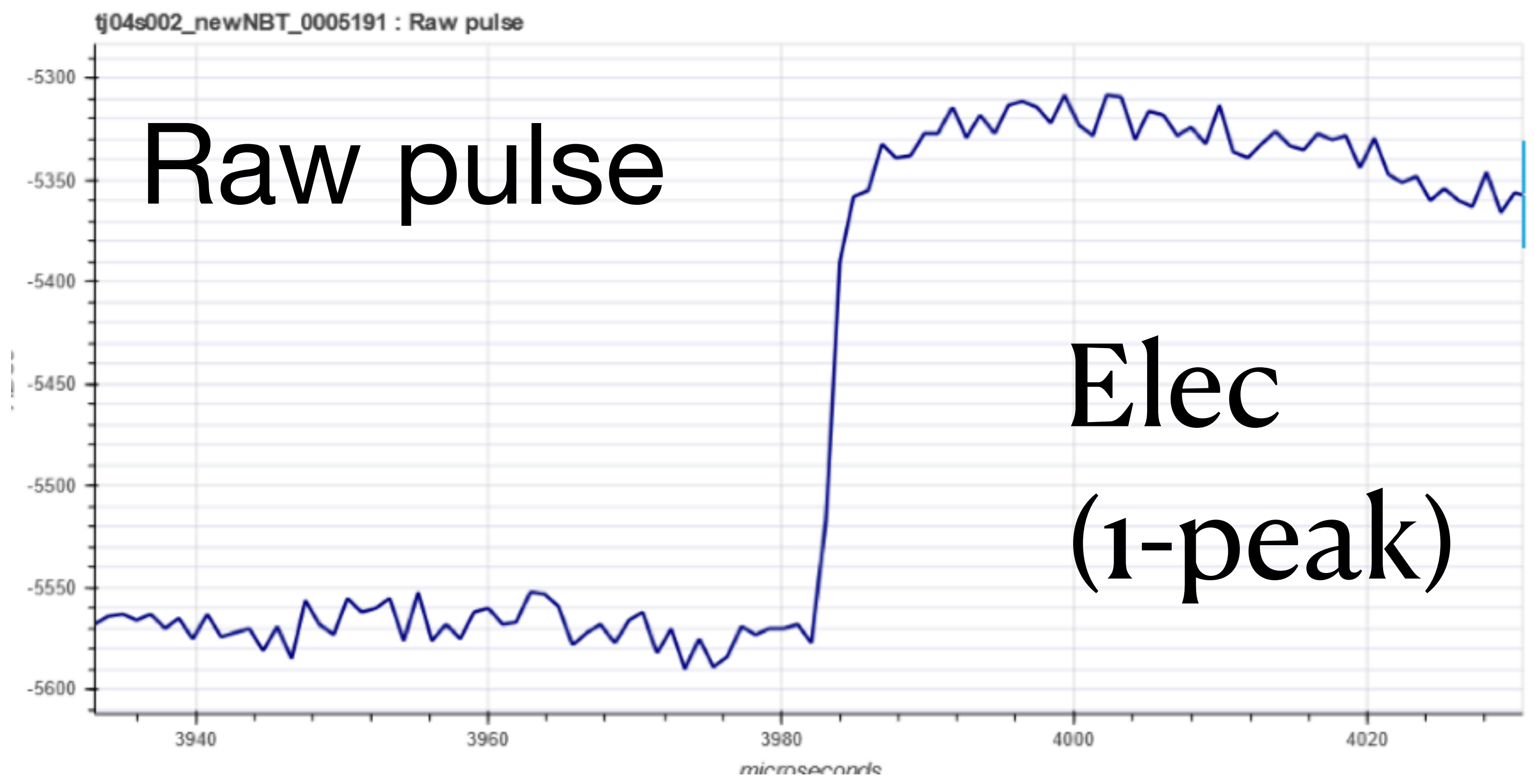


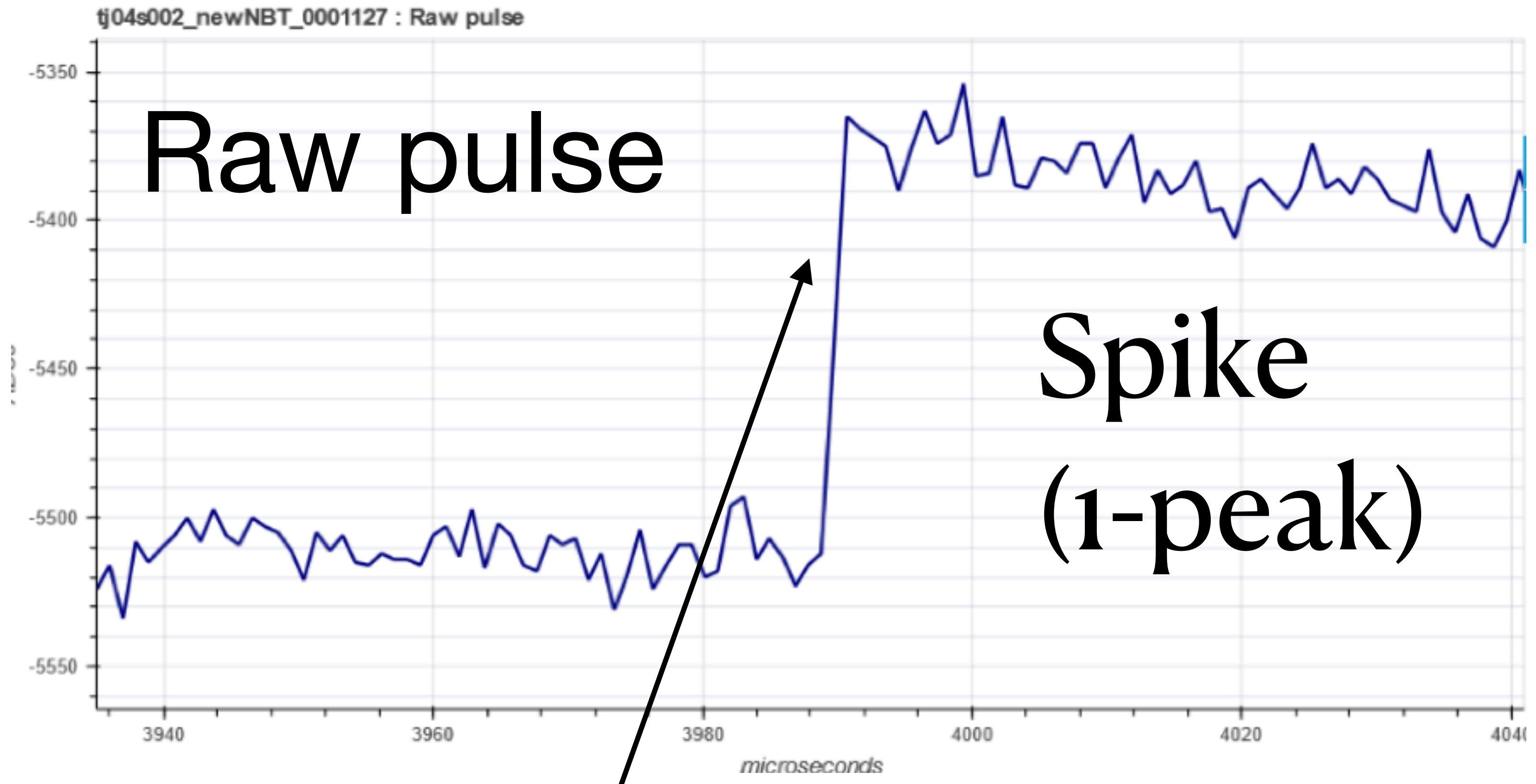
R. Ward et al 2020 JINST 15 C06013

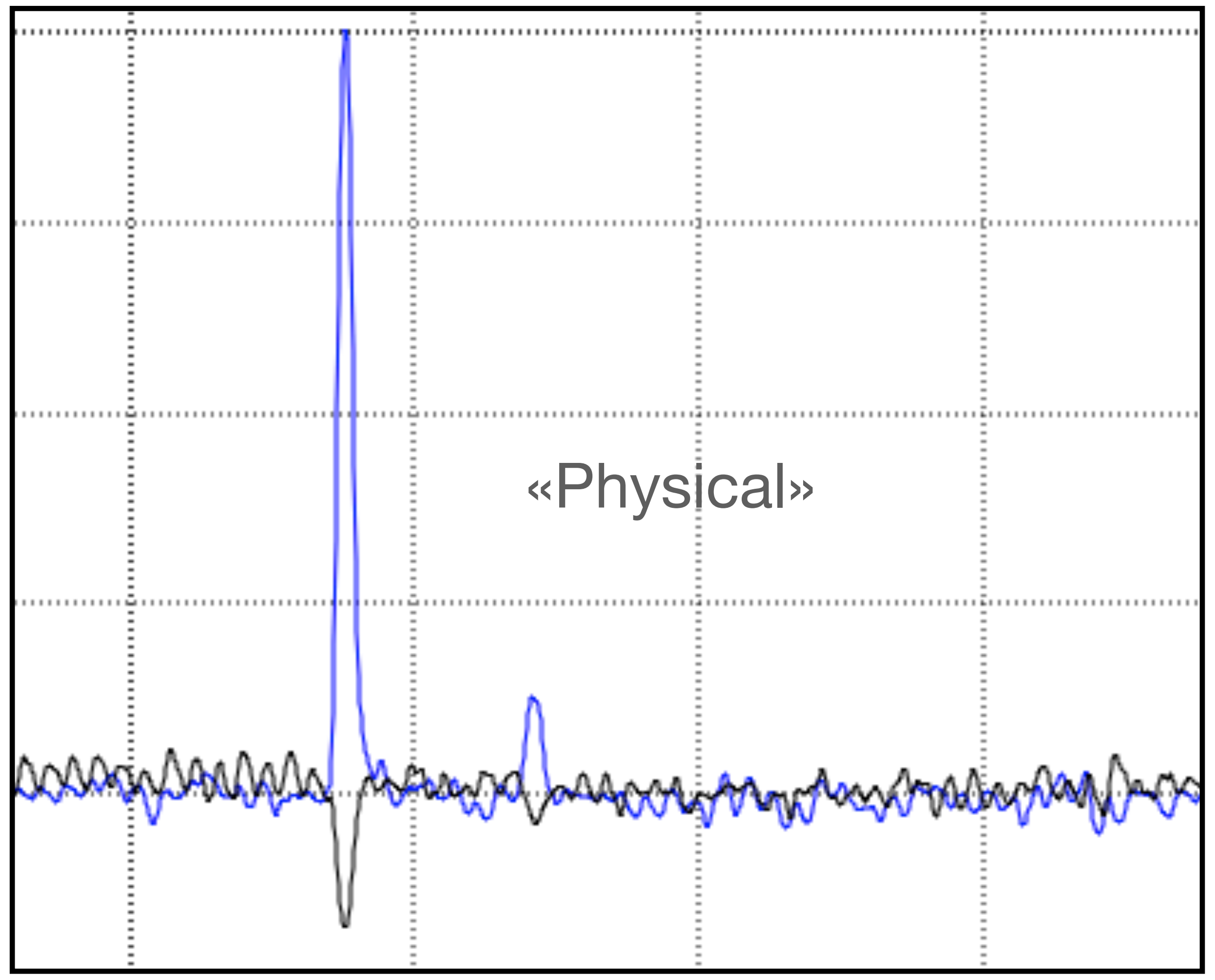
I. Giomataris et al 2020 JINST 15 P11023

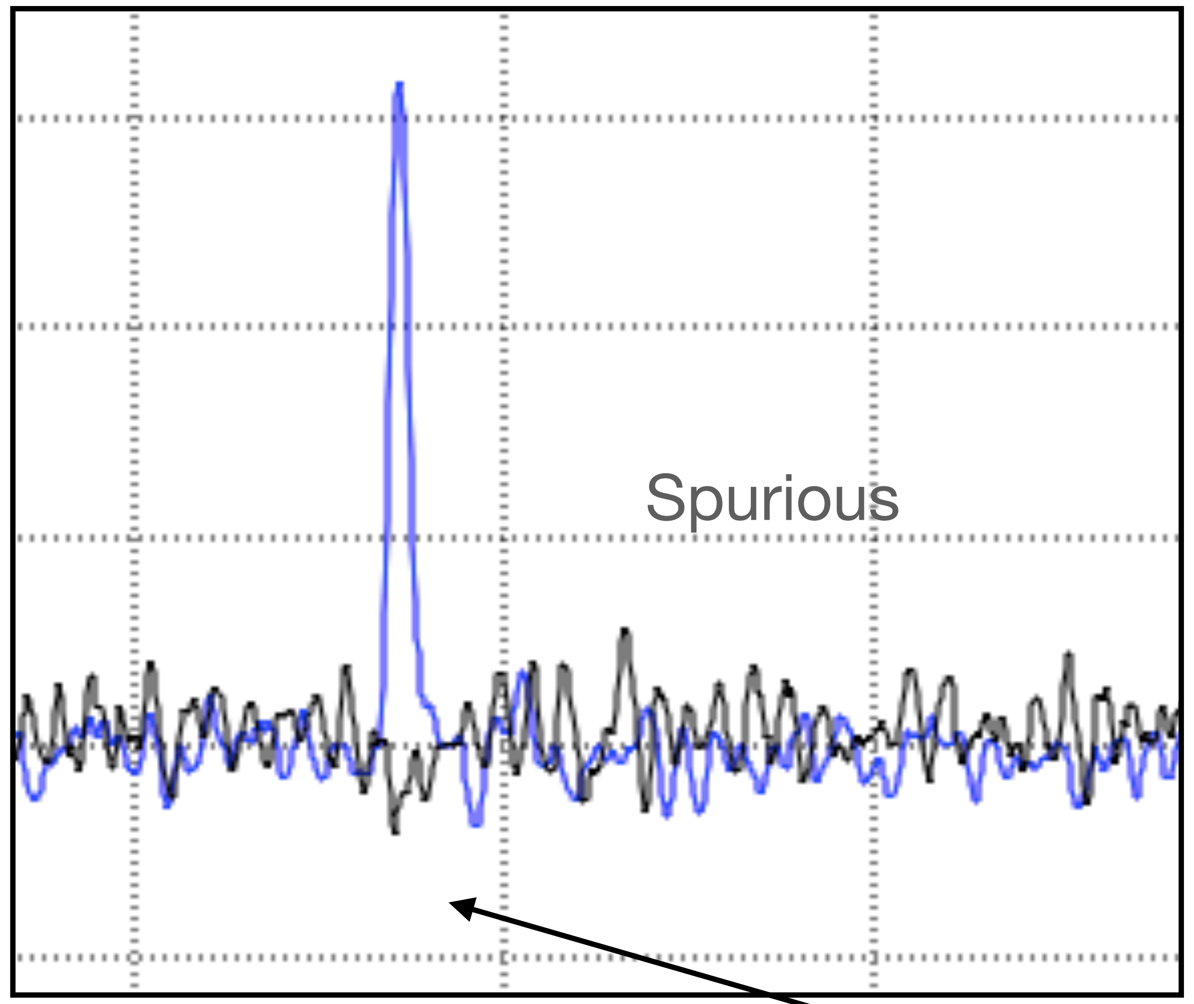
Pulse Shape Discrimination

- Spurious pulses generated in the electronics do not have characteristic shape of physical pulses









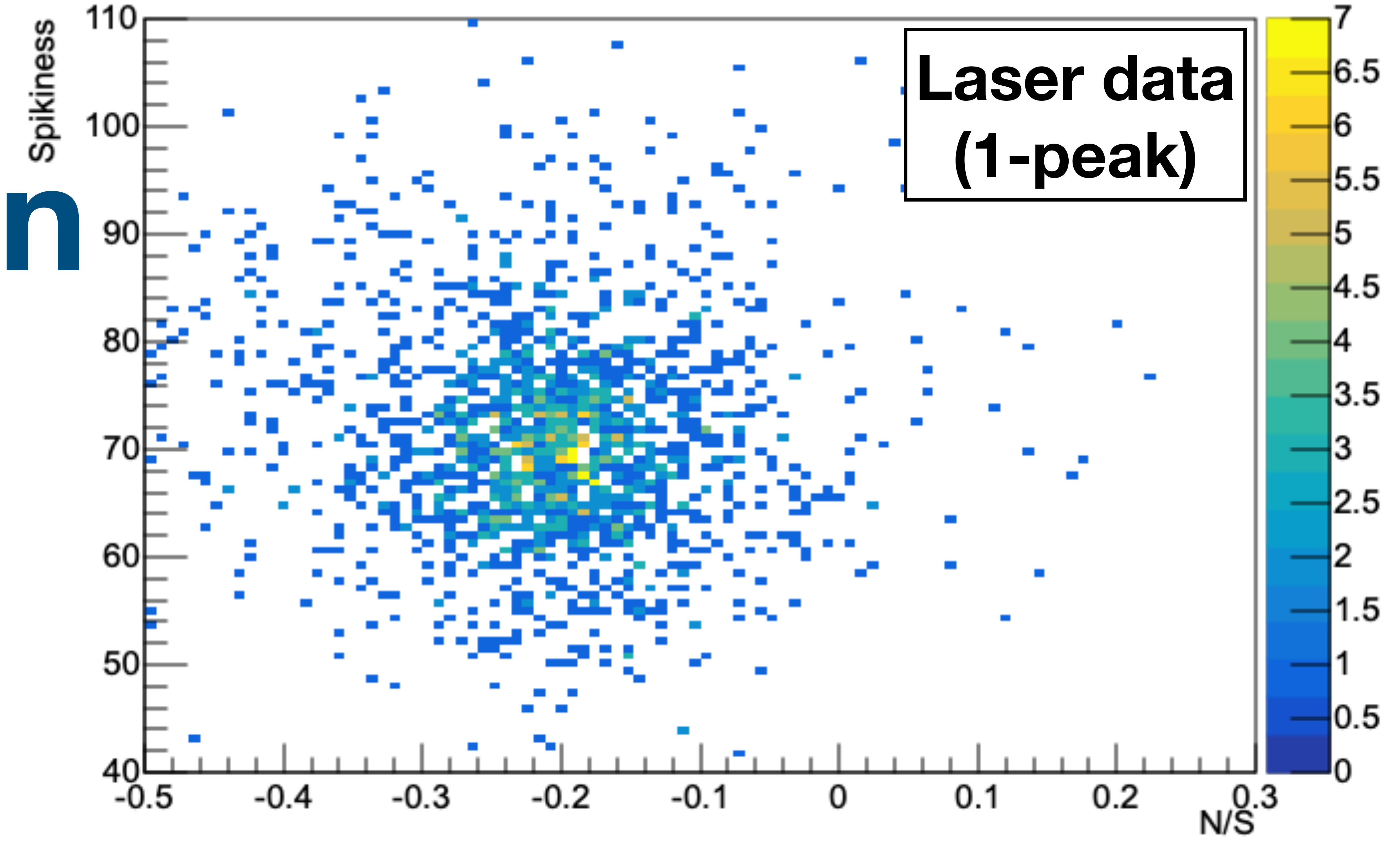
- sharp rise of raw signal
- lack of negative signal on opposite channel (observed for « physical » events)

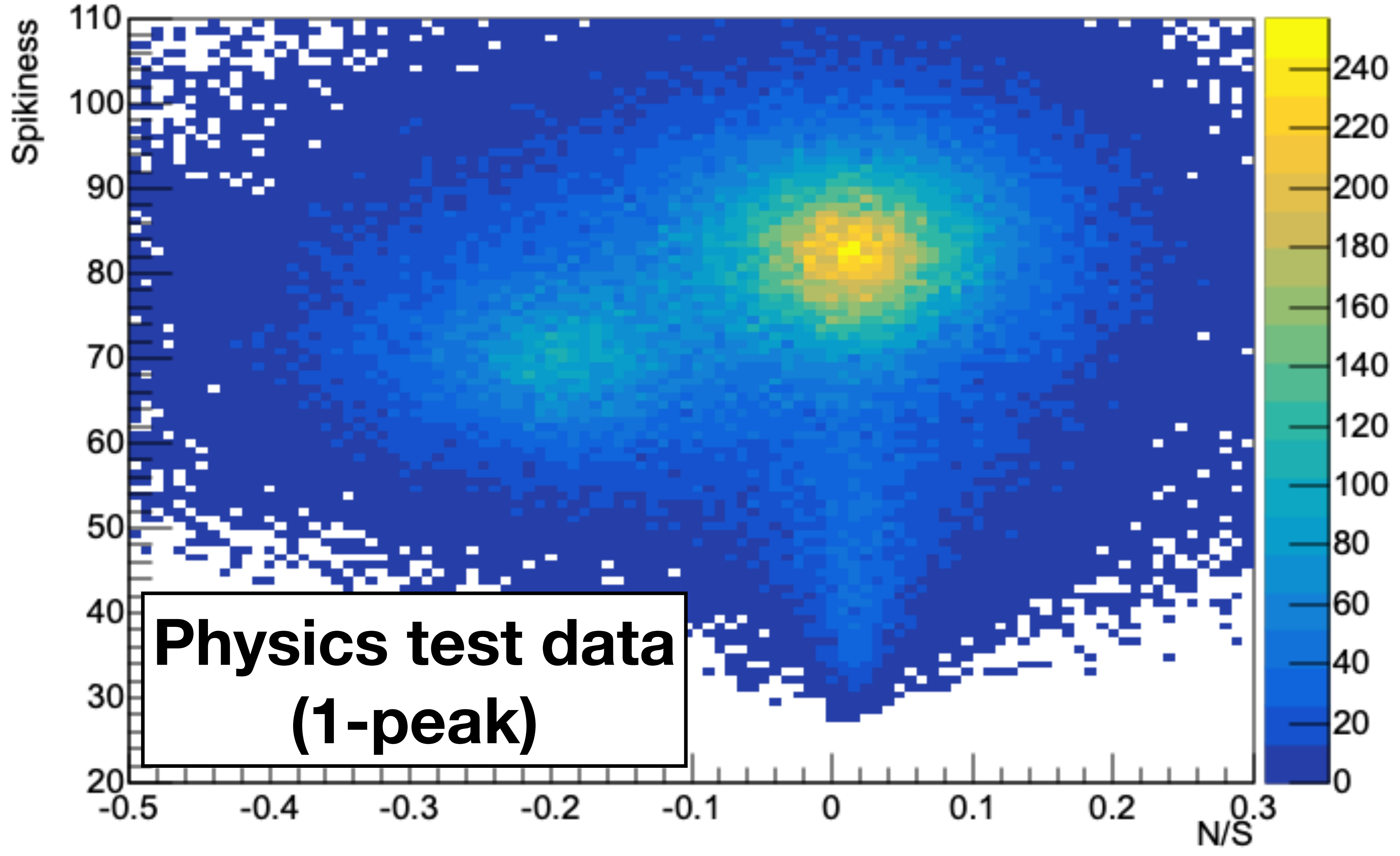
Pulse Shape Discrimination

- Spurious pulses generated in the electronics do not have characteristic shape of physical pulses

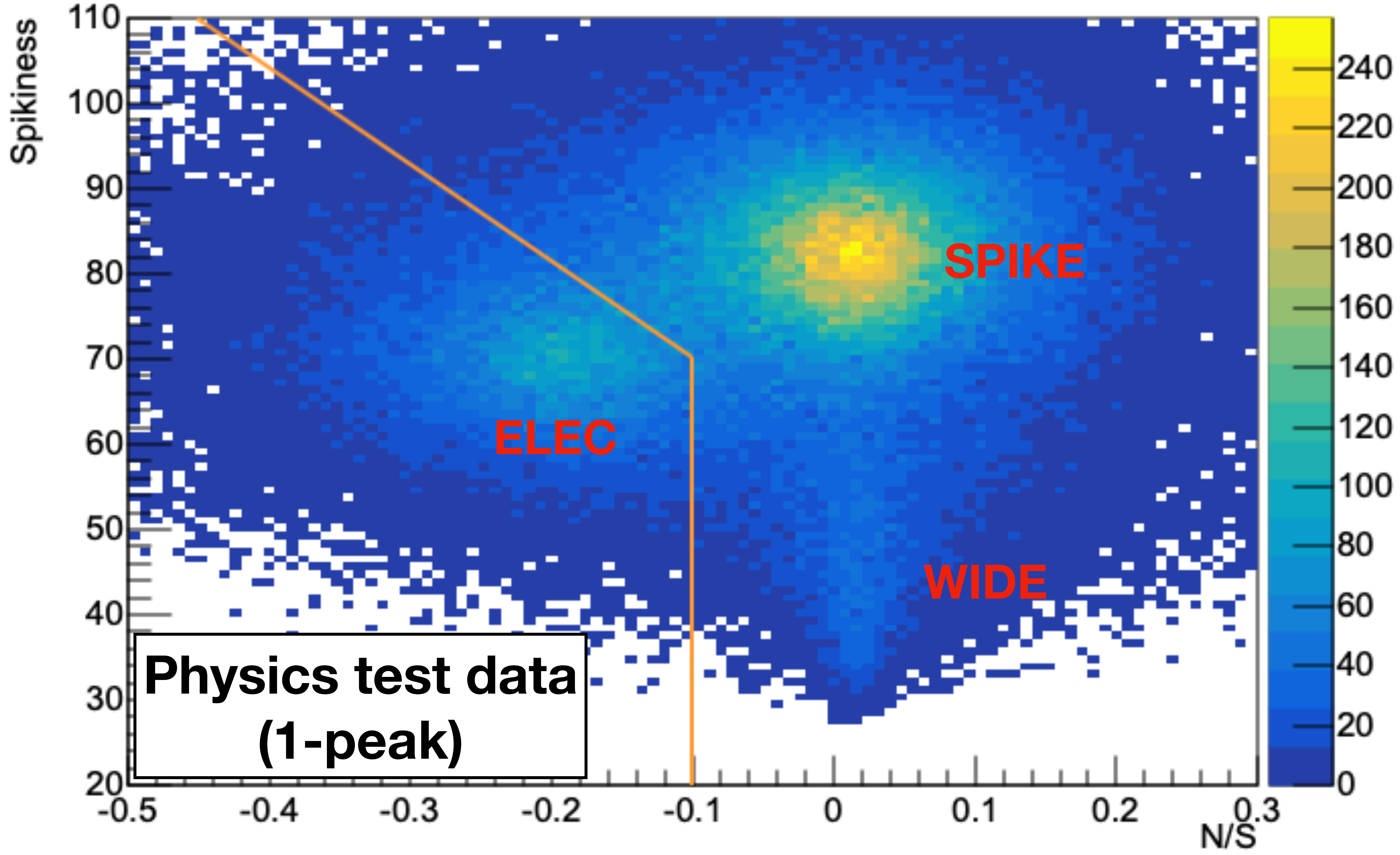
- Use «Crosstalk» (Ampl_North/Ampl_South) and «Spikiness» (MaxDerivative/Ampl) as variables to discriminate both populations

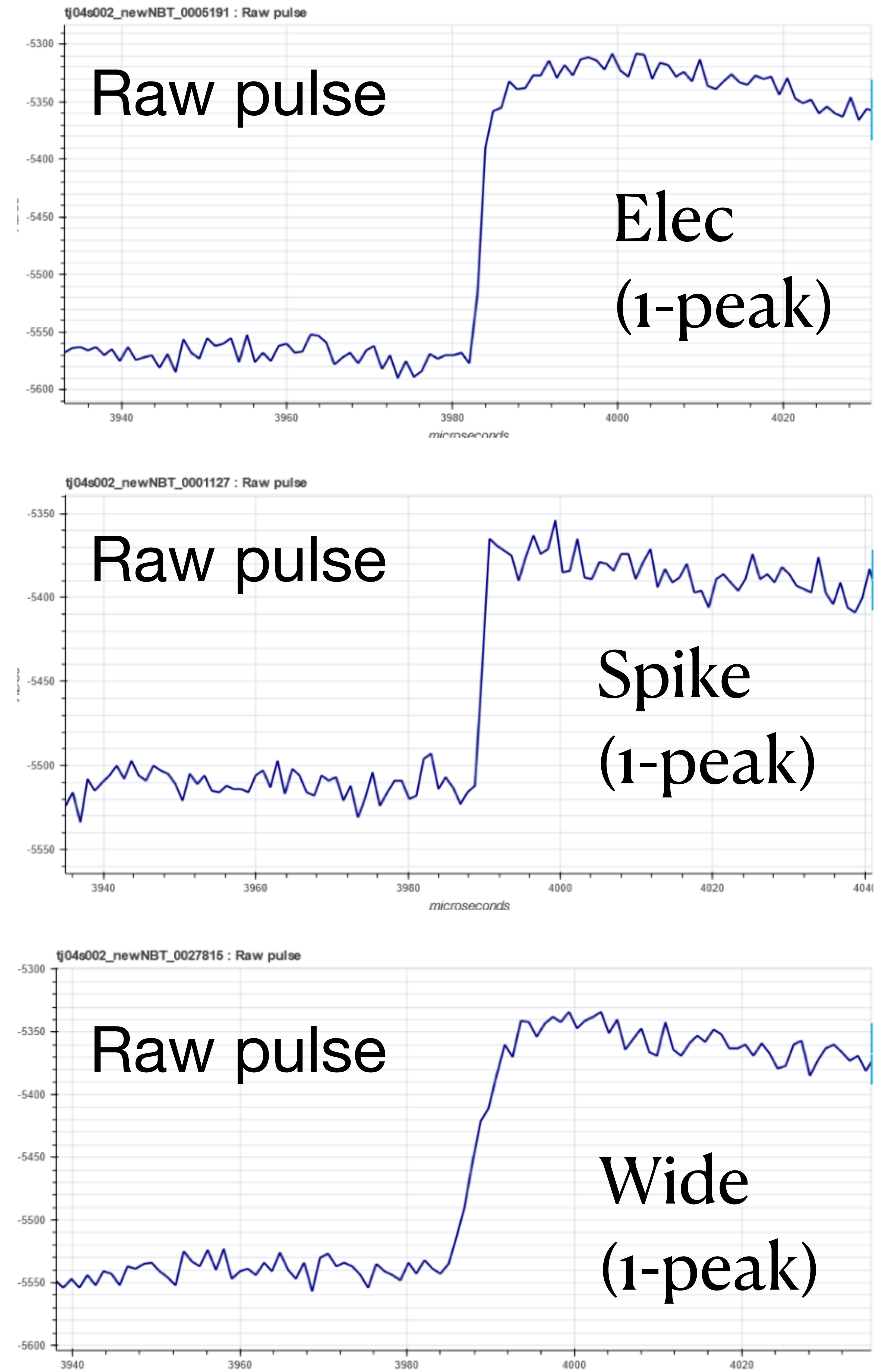
- Cuts are chosen by comparing single-peak events from laser calibrations with those from test physics data





Pulse Shape Discrimination



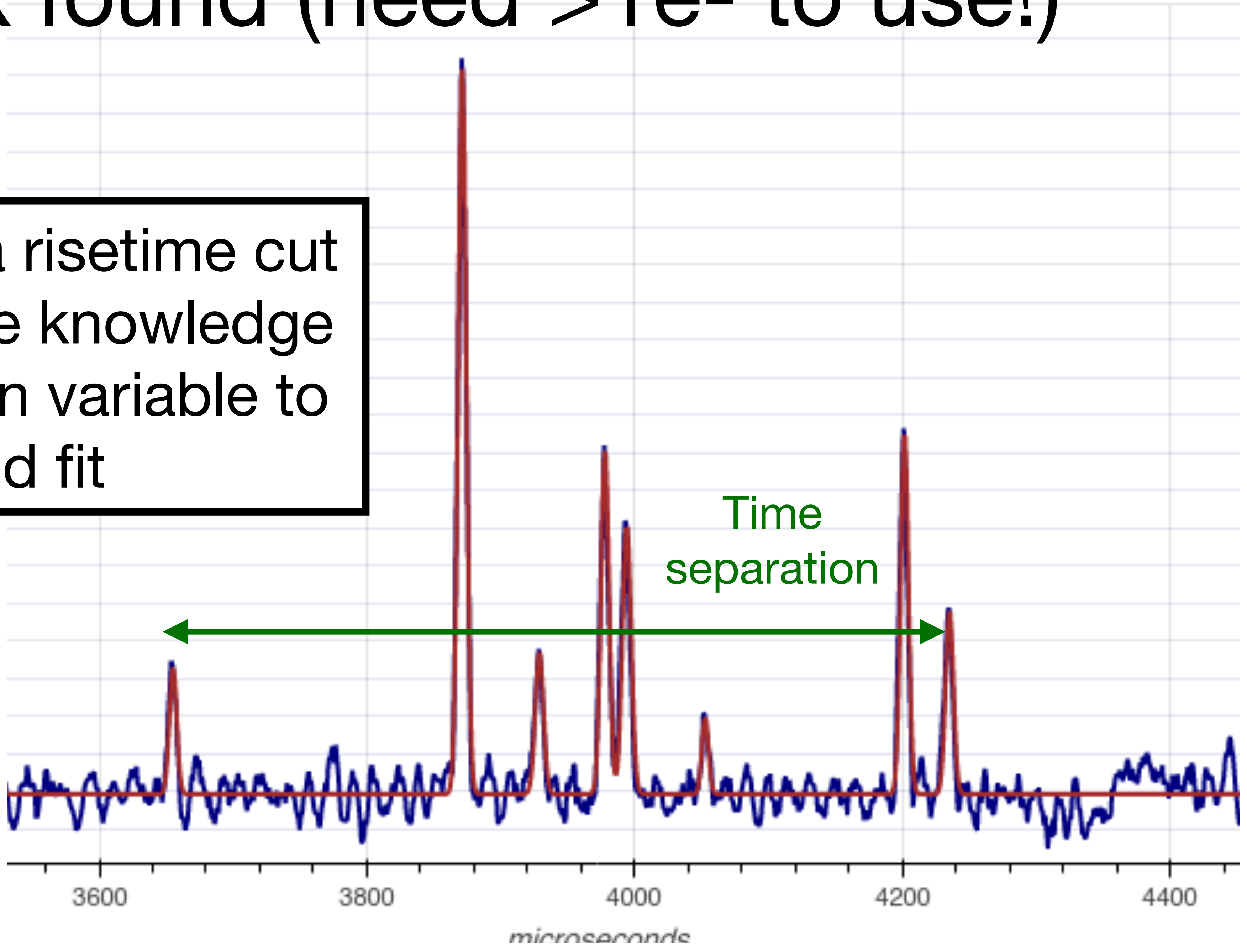


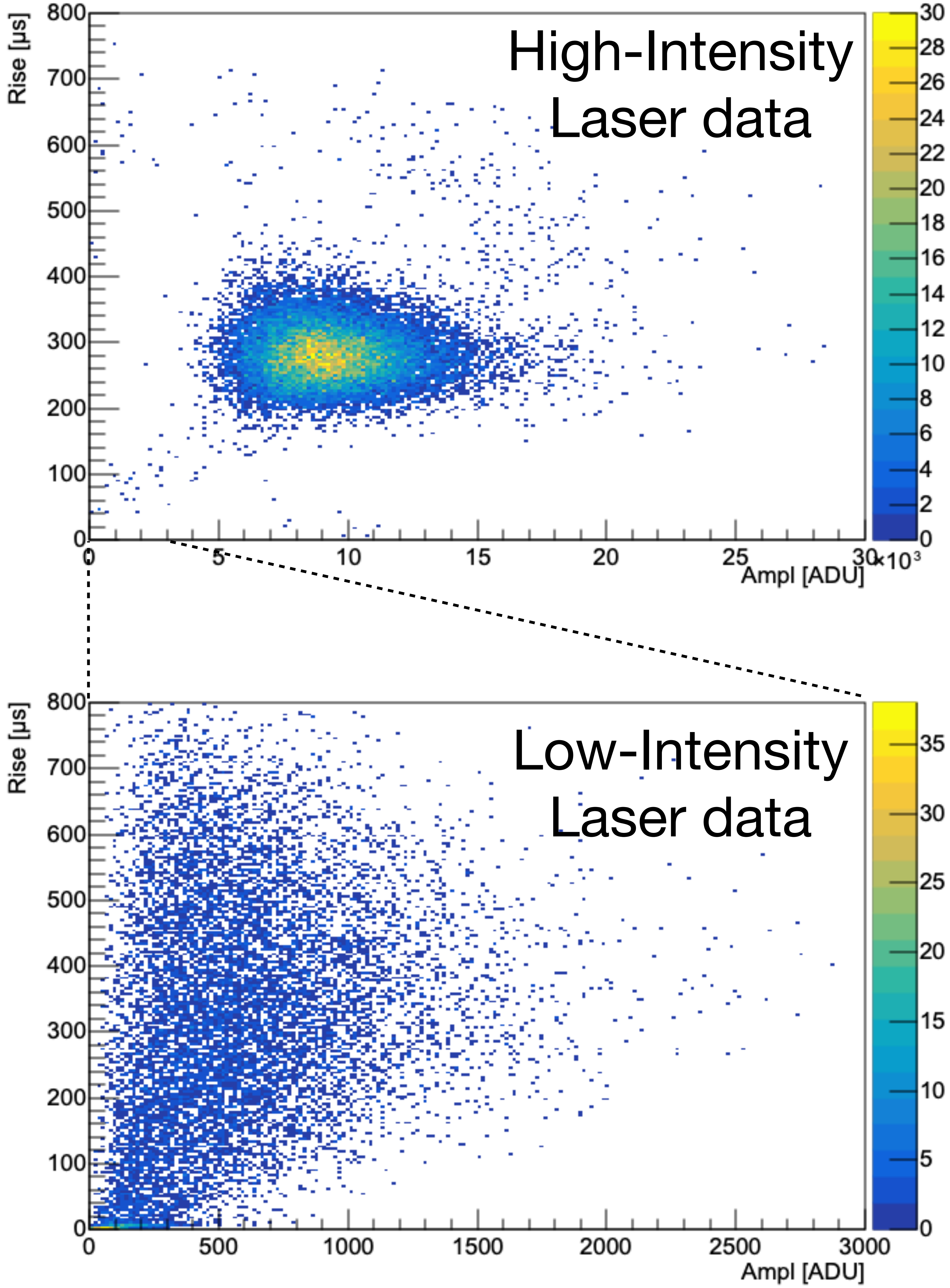
- Fisher discriminant cut is used against « spikes », simple crosstalk cut is used against « wide pulses »
- Keeps 77% of physical events, and rejects ~95% of spurious pulses

New diffusion variable

- As we go to lower amplitudes / fewer primary electrons, risetime becomes « poorly defined », and worse at separating surface and volume events
- New variable tested: time separation between first and last peak found (need >1e- to use!)

CONTEXT: instead of doing a risetime cut to remove surface events, use knowledge of distribution of new diffusion variable to perform a background fit





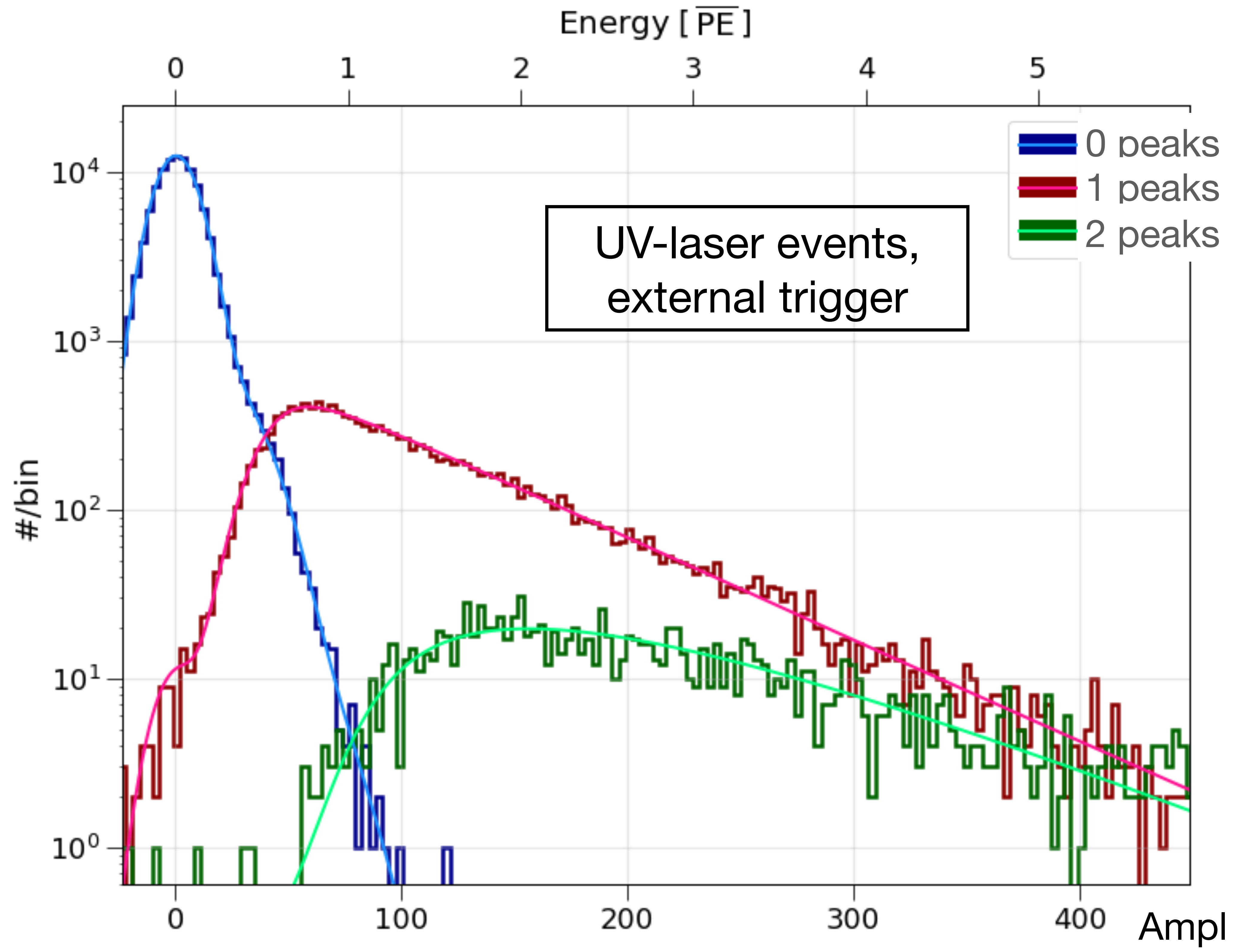
Electron counting

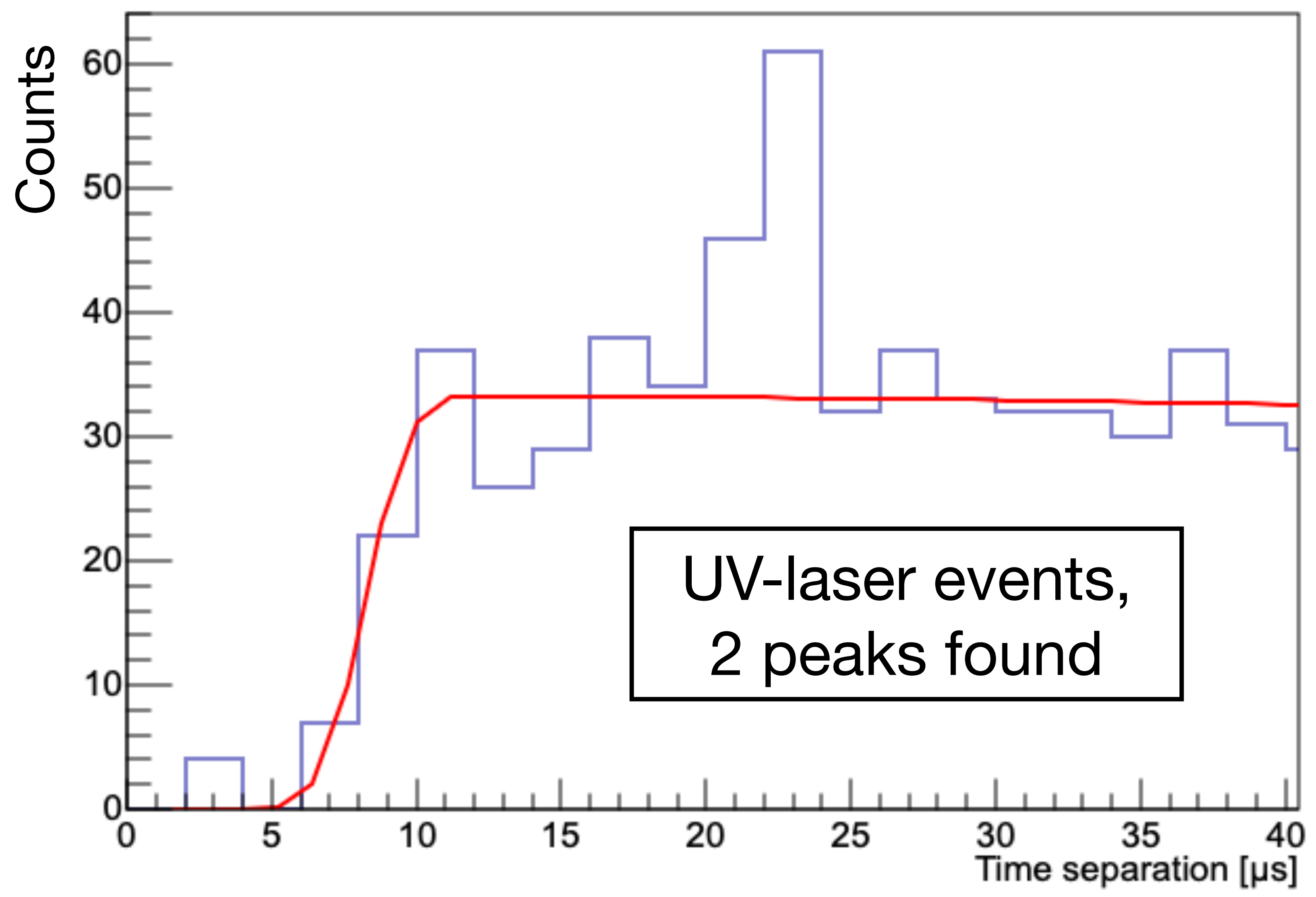
Characterisation

Low-intensity, 213nm UV-laser extracts electrons from copper surface. Applying peak-counting algorithm on this data, we obtain :

- Electron detection efficiency : 60%
- Separation of electron peaks above 8 μs

Full detector simulation did not match shape of observed pulses => use toy model to generate distributions for time separation of surface / volume based on these two values



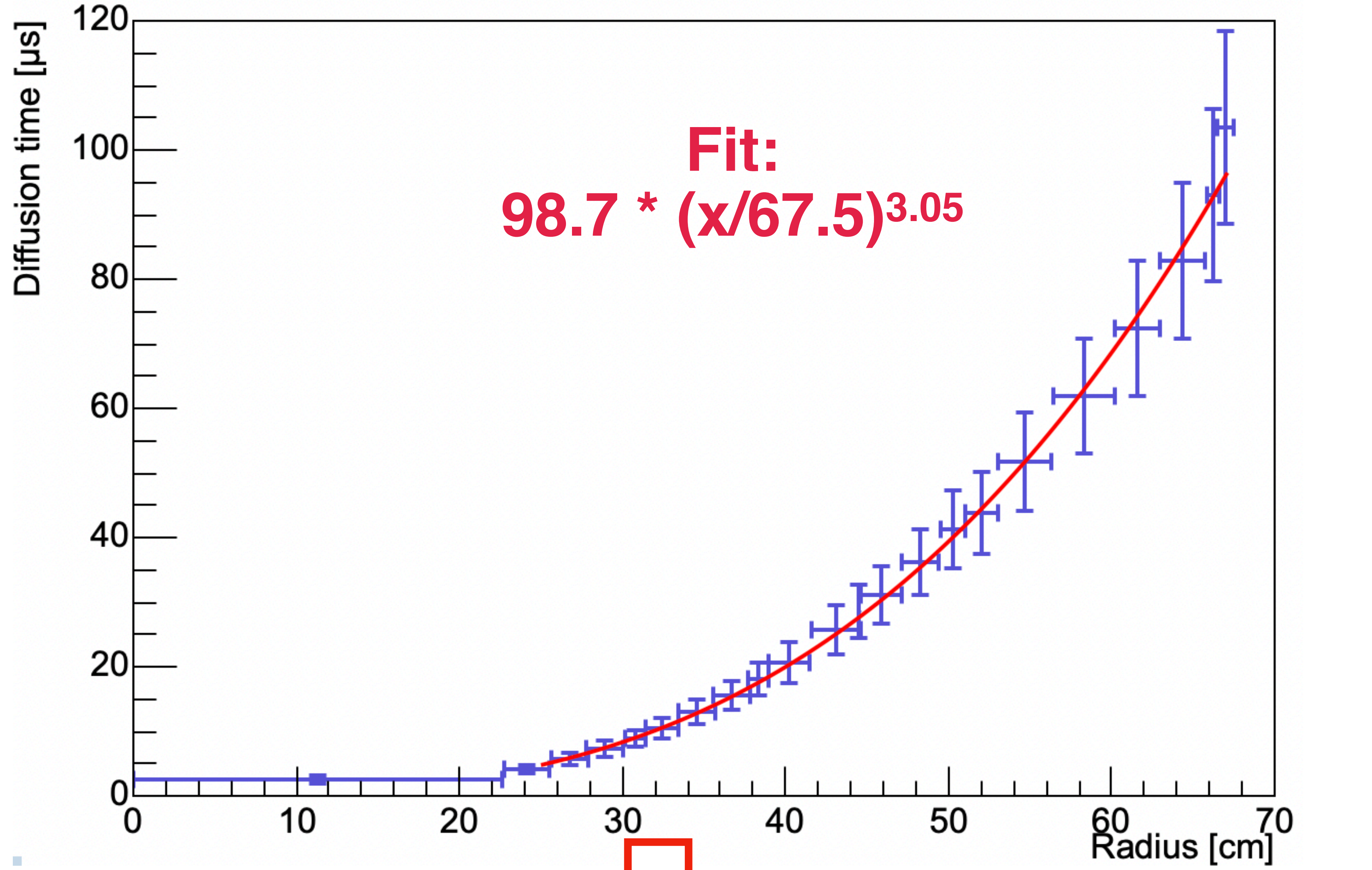


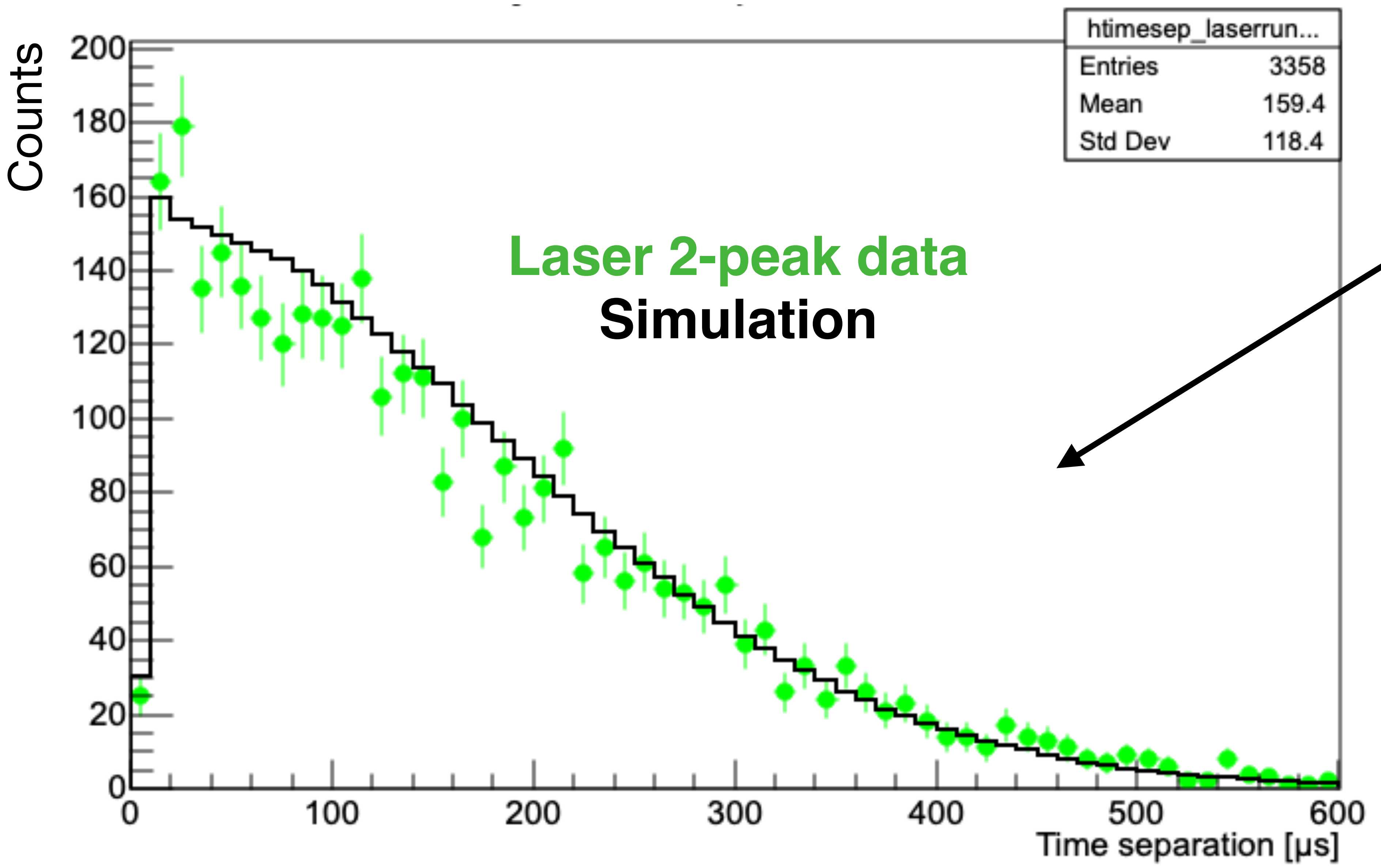
Time separation

Surface / Volume events

- Simulations of surface and volume events in agreement with Laser and ^{37}Ar data respectively
- Low time-separation structure in volume events due to events with high number of electrons but small diffusion reconstructed as much fewer peaks

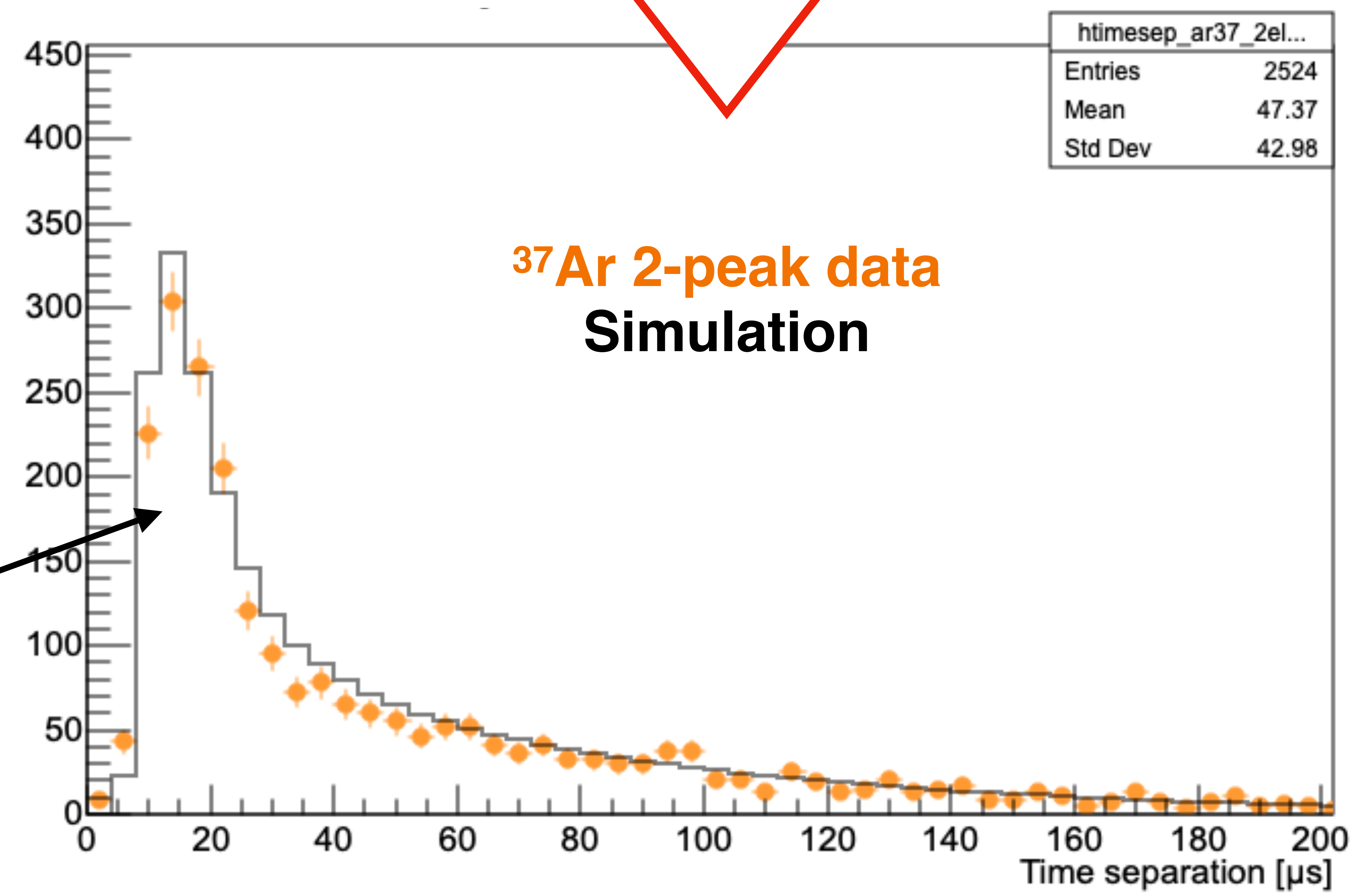
Reconstructed diffusion vs radius from ^{37}Ar calibrations





Surface events:
wide distribution,
large time separations

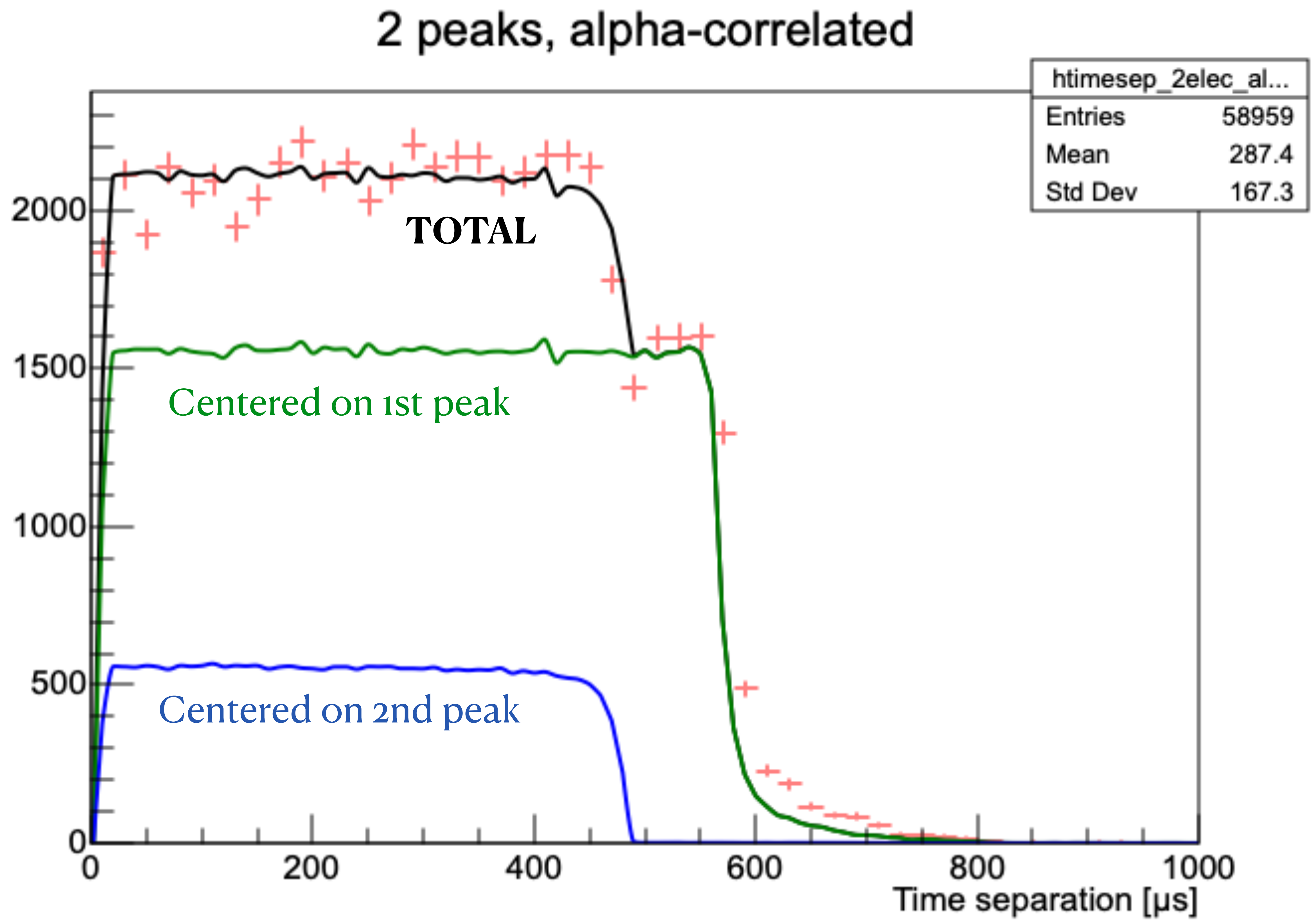
Volume events:
Concentrated at low
time separations



Time separation

Random coincidences

- Calibrate with post-alpha-event periods, when total even rate is much higher
- Match well behaviour of toy model assuming random coincidences, after accounting for peak-search window size and centering effects



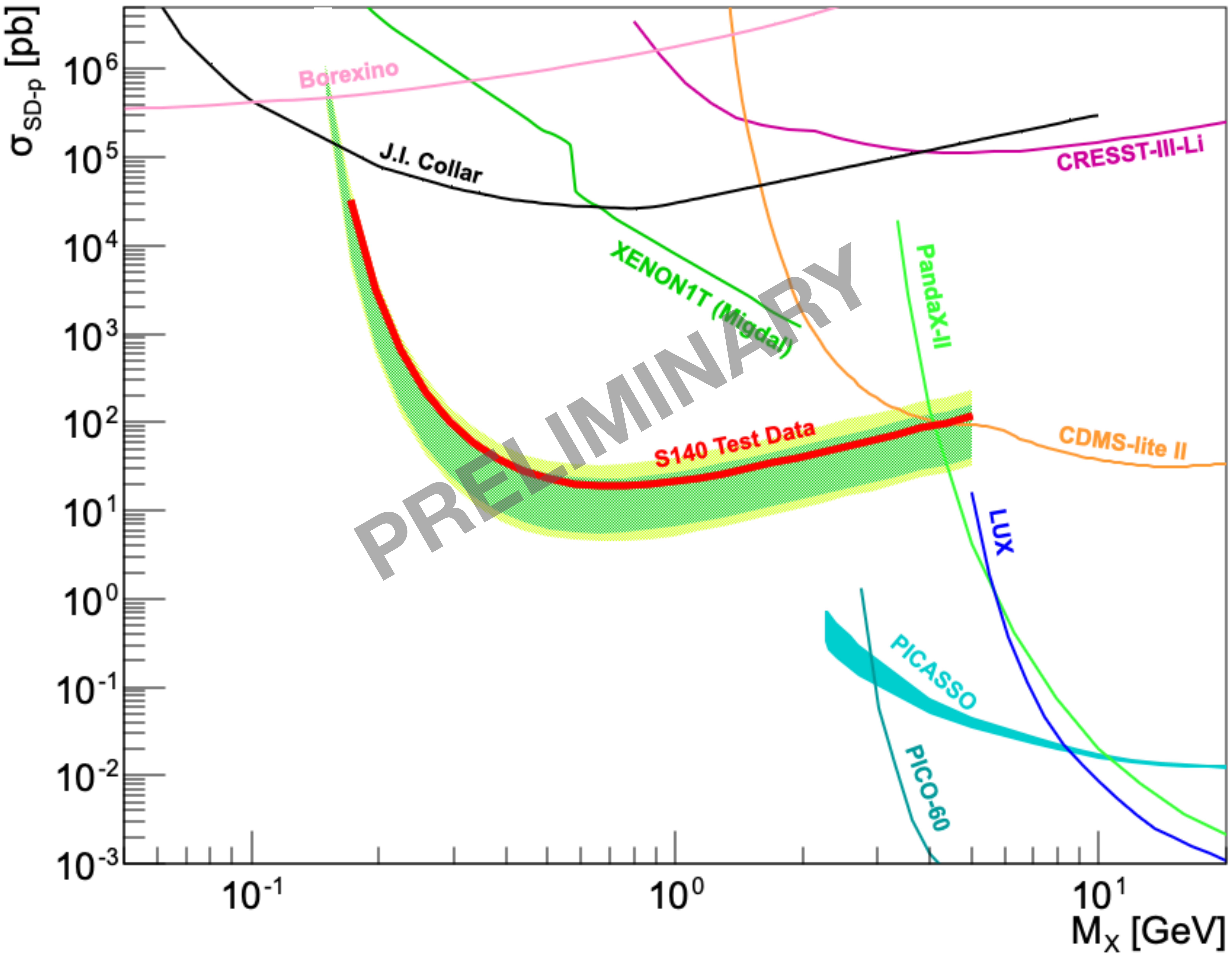
Physics data fit

- Use ~30% of physics data as test data (effective 37h)
- Profile likelihood fit to the 2,3,4-peak data including contributions from WIMP signal, surface, volume and random coincidence backgrounds
- Use modelling derived from simulations and validated with calibration data
- No significant signal observed

New WIMP constraints

- Profile Likelihood used to generate constraints on WIMP cross-section
- Results on test data (effective 0.12 kg·day) : strongest constraint on spin-dependent WIMP-proton cross-section in 0.2-2 GeV range!
  - Final results on blind data in coming weeks

Constraints on Spin-Dependent WIMP-protoncross-section



Summary

- New S140, larger and more radio-pure than SEDINE prototype, tested with new ACHINOS sensor in dual-channel configuration

- Pilot run at LSM :
  - Electron counting for improved low-energy background discrimination and threshold
  - Rejection of « non-physical » events by exploiting multi-channel signal
  - Detailed understanding of detector with Laser, ^{37}Ar calibrations, model backgrounds for fitting data

- First WIMP constraints with proton target in underground lab : 3-4 order of magnitude improvement on constraint on *O*(1) GeV WIMP SD-p cross-section

Thank you for your attention!

NEWS-G collaboration

Queen's University Kingston - G Gerbier, G Giroux, R Martin, S Crawford, G Savvidis, A Brossard, K Dering, V Millious, M Van Ness, M Chapellier, P Gros, JM Coquillat, L Balogh, N Rowe

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Aristotle University of Thessaloníki - I Savvidis, A Leisos, S Tzamarias

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RMCC Kingston - F Kelly, E Corcoran, L Kwon

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University of Alberta - MC Piro, D Durnford, Y Deng, C Garrah

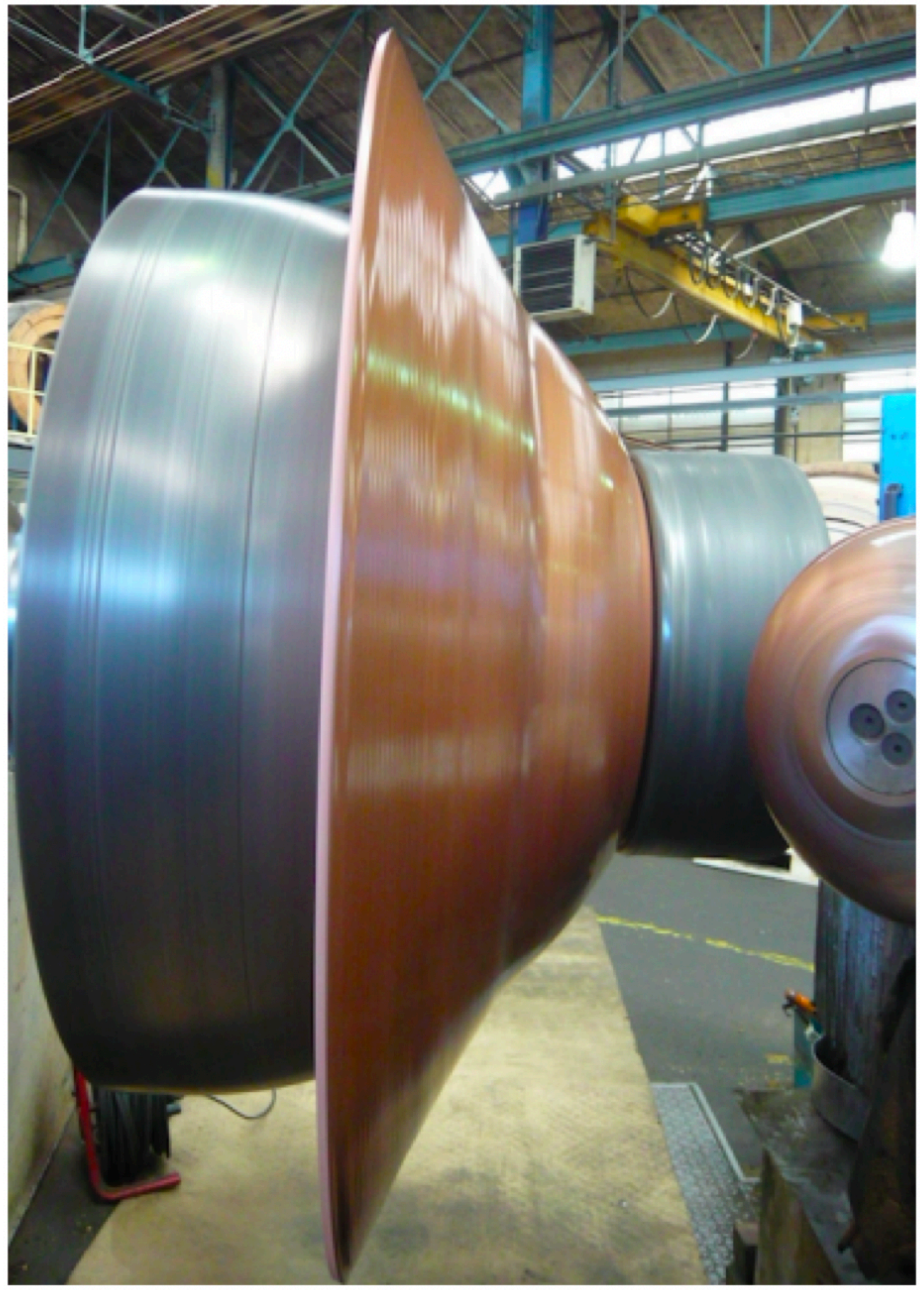
Subatech - P Lautridou, F Vazquez de Sola Fernandez

TRIUMF (associated lab) - F Retiere

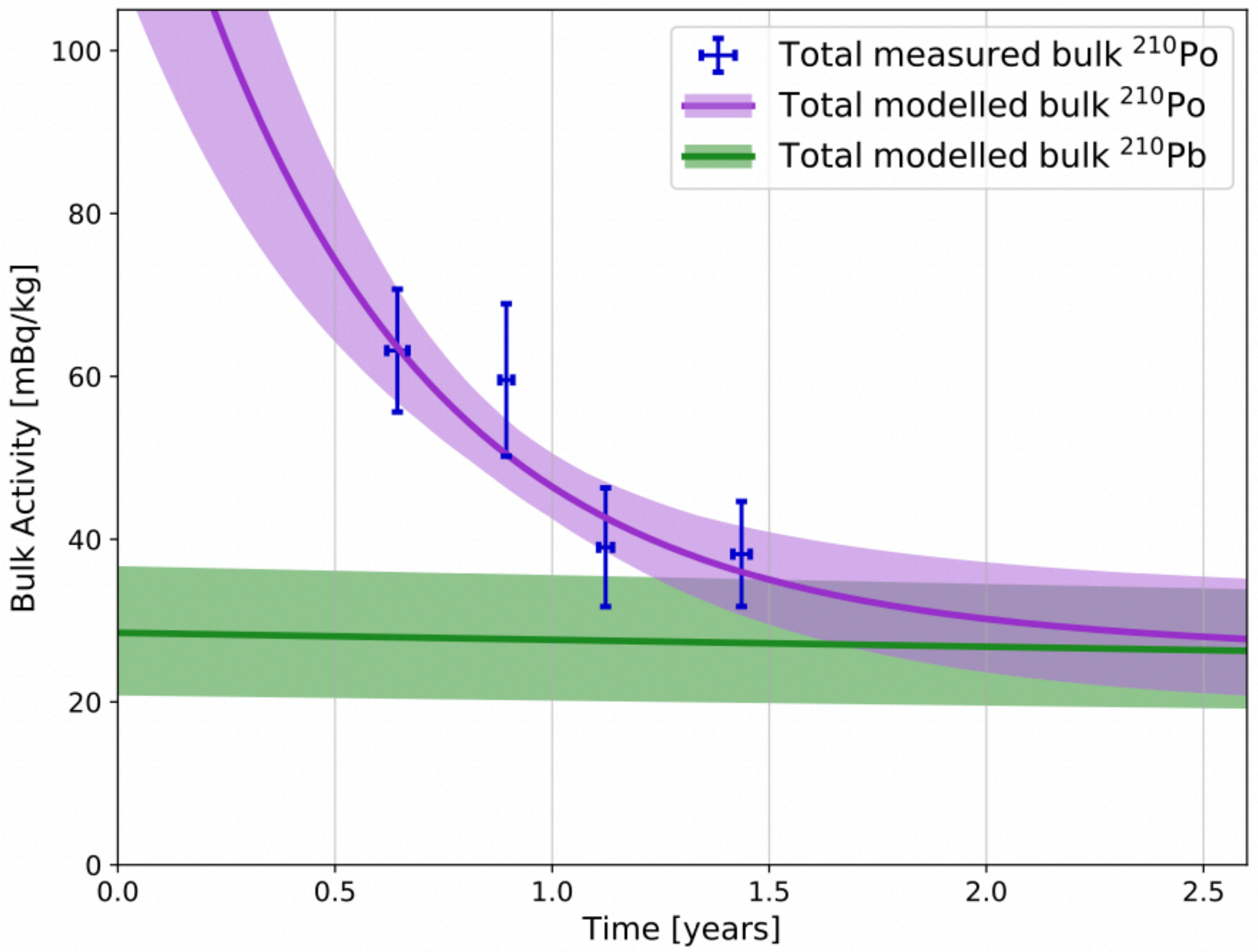
Extra slides

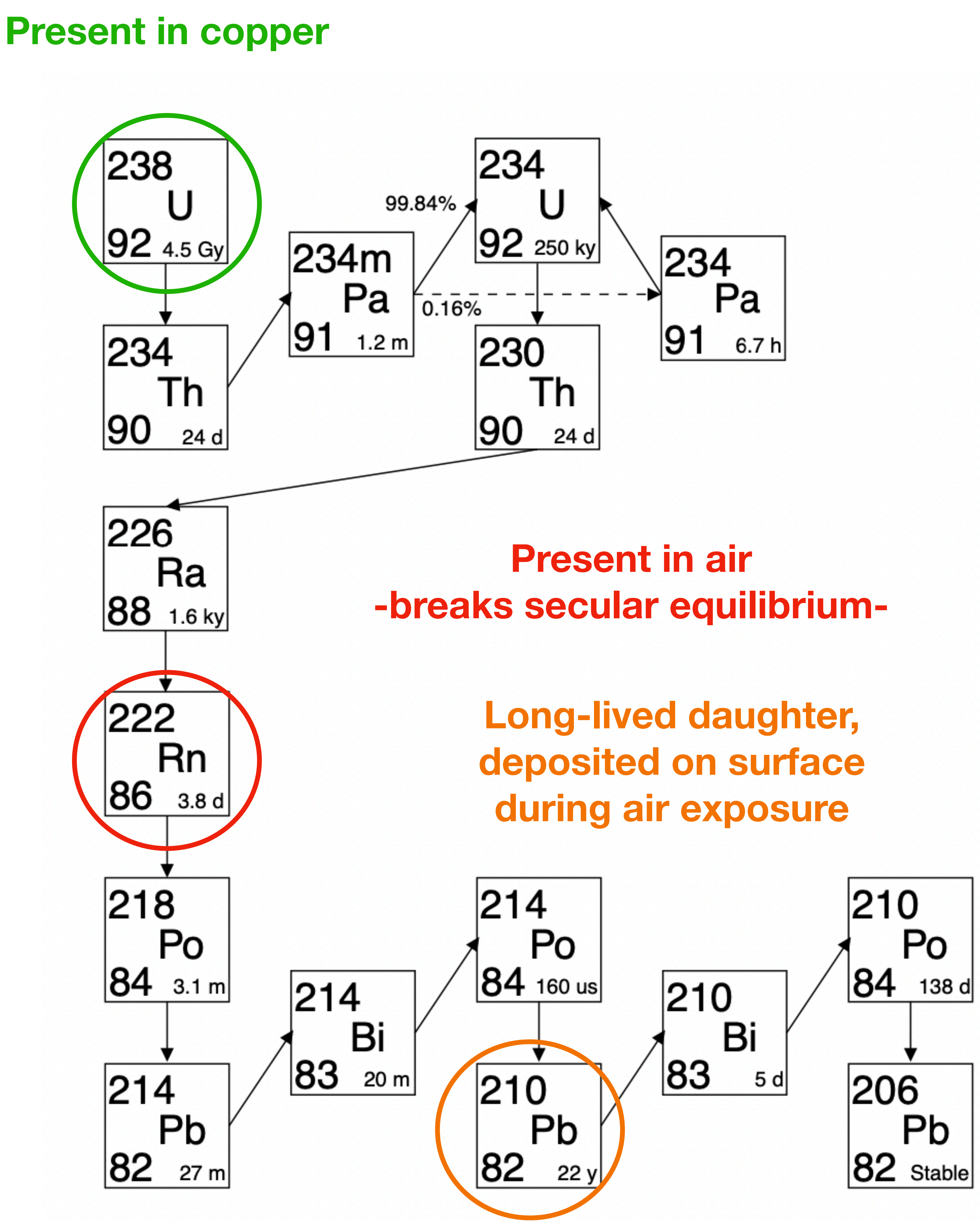
S140: Improvements

Background reduction



- 2 hemispheres of C10100 (4.5N) copper, electron-beam welded together
- XIA alpha counter estimated ~30 mBq/kg ^{210}Pb in copper bulk (collaboration with XMASS)

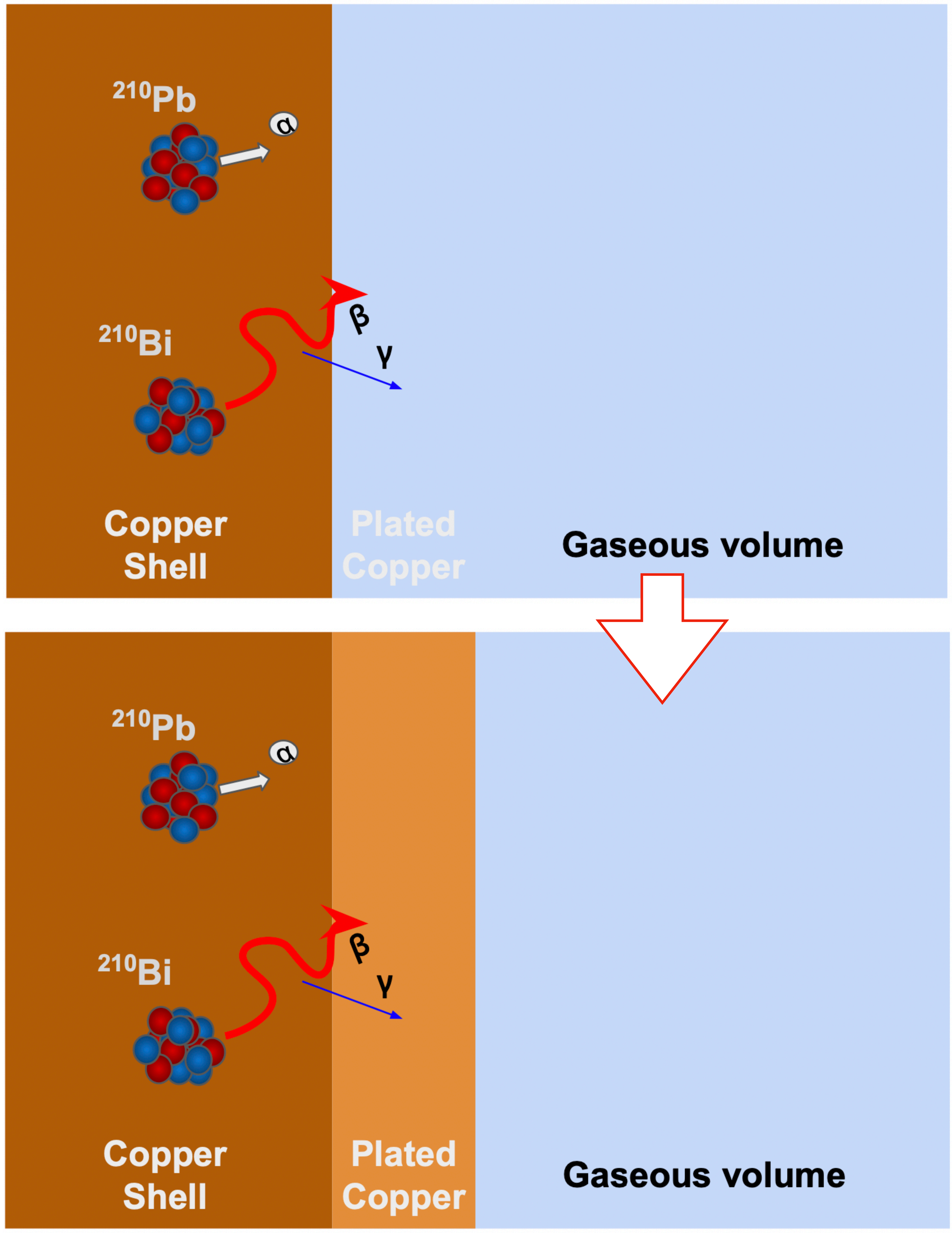




L. Balogh et al, Nucl.Instrum.Meth.A 988 (2021)

S140: Improvements

Background reduction



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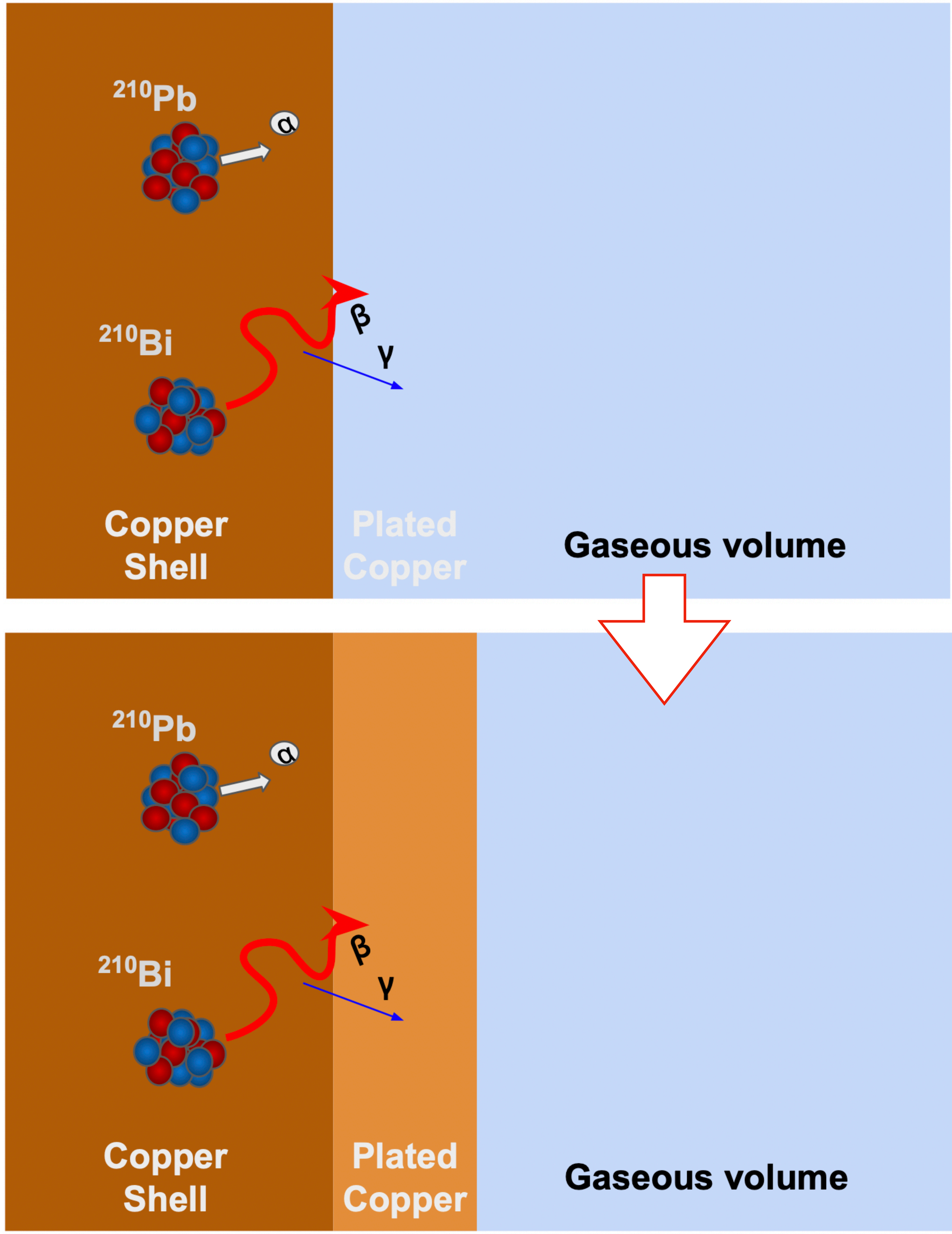
S140: Improvements

Background reduction

- Background: Bremsstrahlung X-rays from ^{210}Pb and ^{210}Bi β-decays in (and on) the copper
- Plating 0.5mm of ultra-pure copper on inner surface of detector expected to reduce background under 1 keV by factor 2.6, and total rate by factor 50

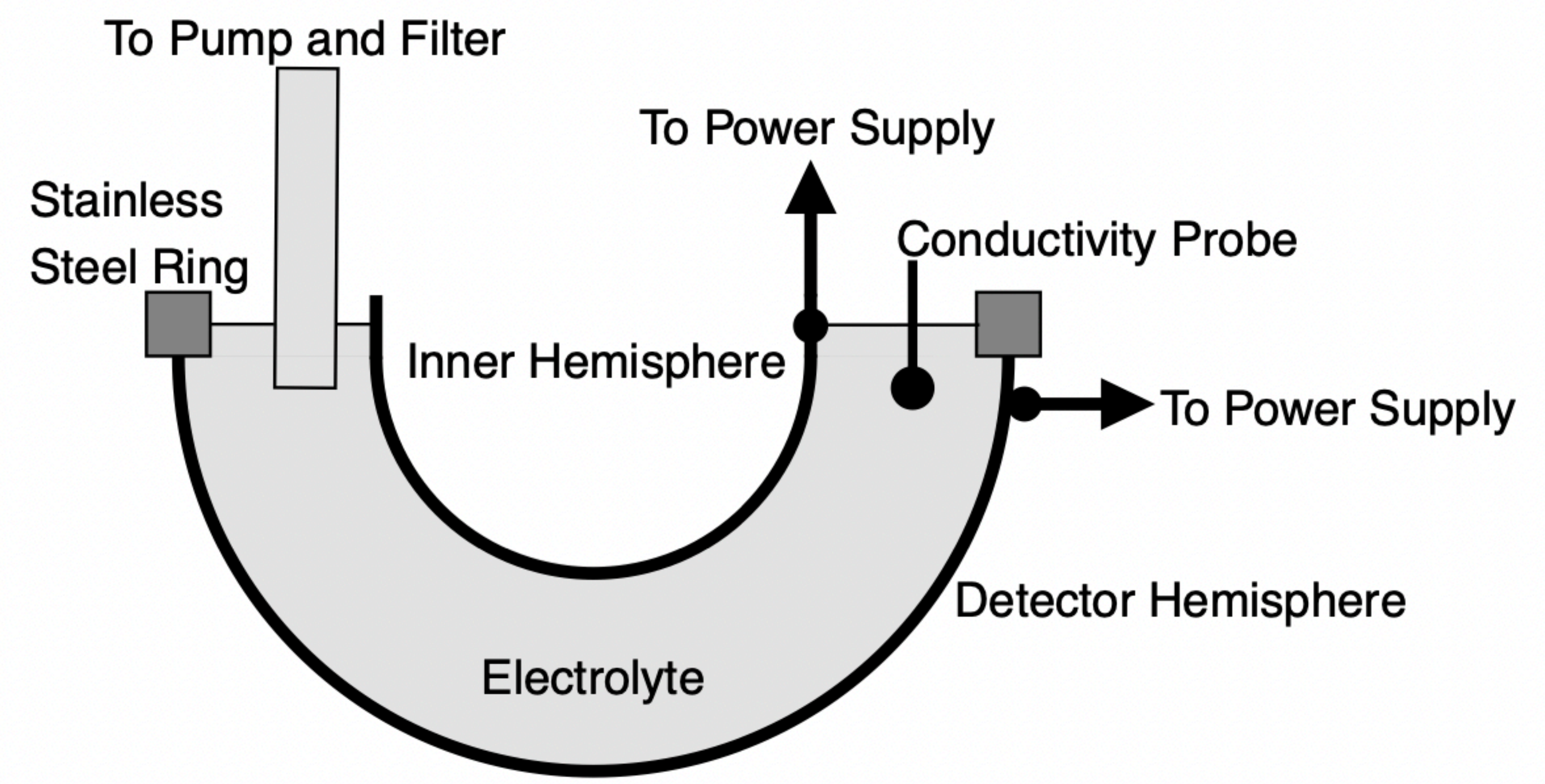
L. Balogh et al, Nucl.Instrum.Meth.A 988 (2021)

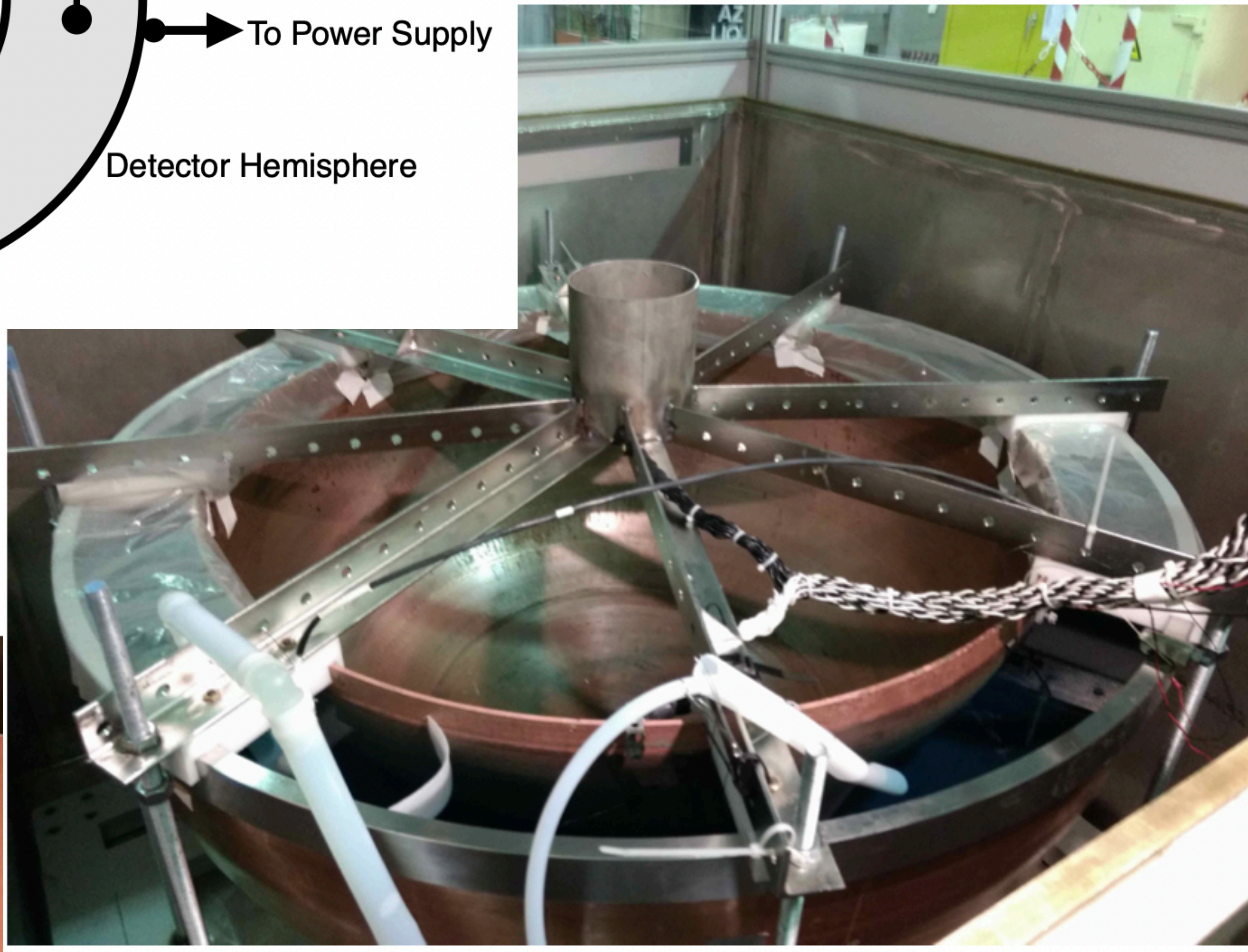


S140: Improvements

Background reduction

- Background: Bremsstrahlung X-rays from ^{210}Pb and ^{210}Bi β-decays in (and on) the copper
- Plating 0.5mm of ultra-pure copper on inner surface of detector expected to reduce background under 1 keV by factor 2.6, and total rate by factor 50
- Intervention successfully carried out at LSM in collaboration with PNNL





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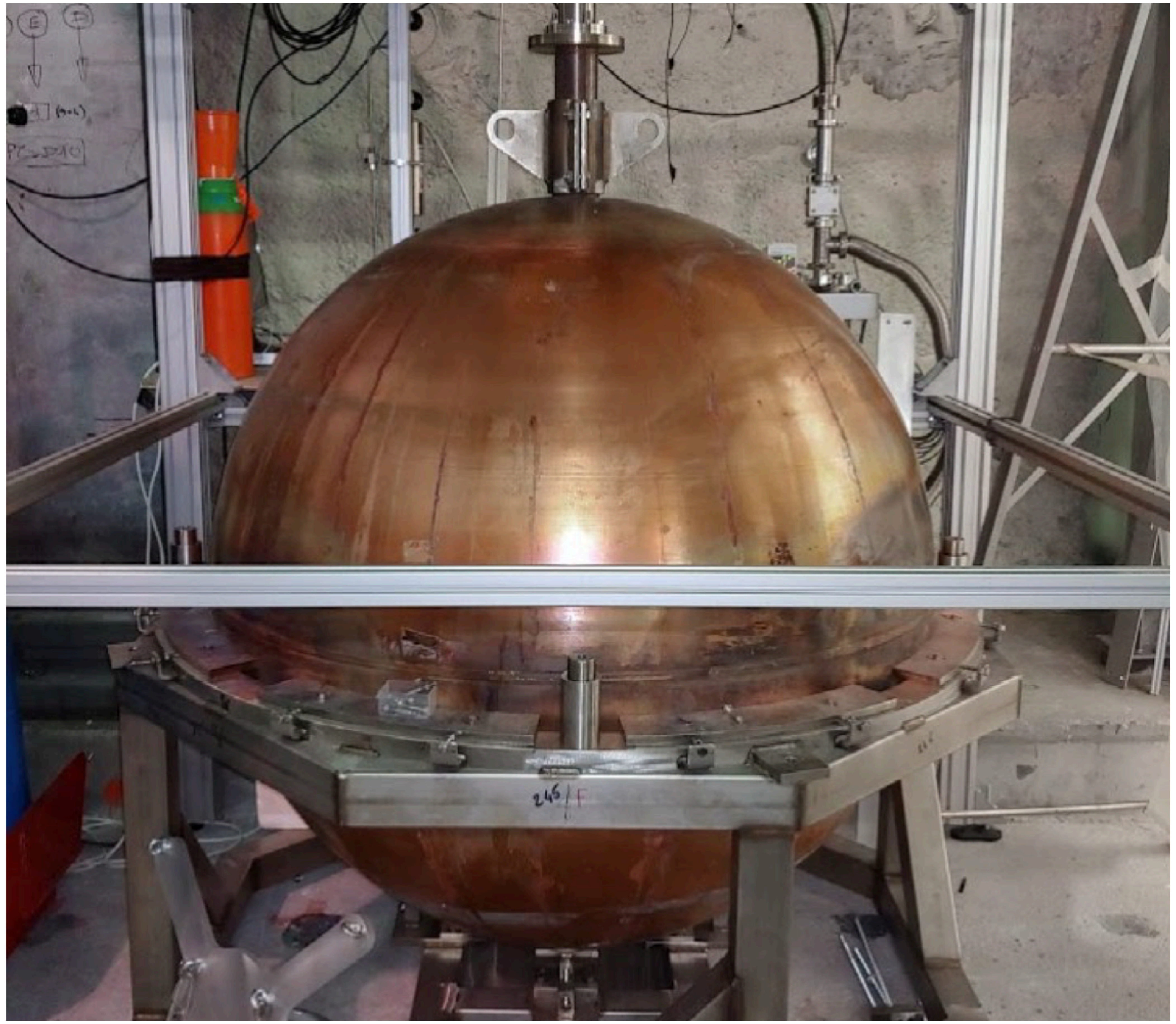
S140: Commissioning at LSM

2019: S140 e-beam welded in France, 3T archeological lead provided by LSM. S140 arrives at LSM in April 2019, starting first commissioning



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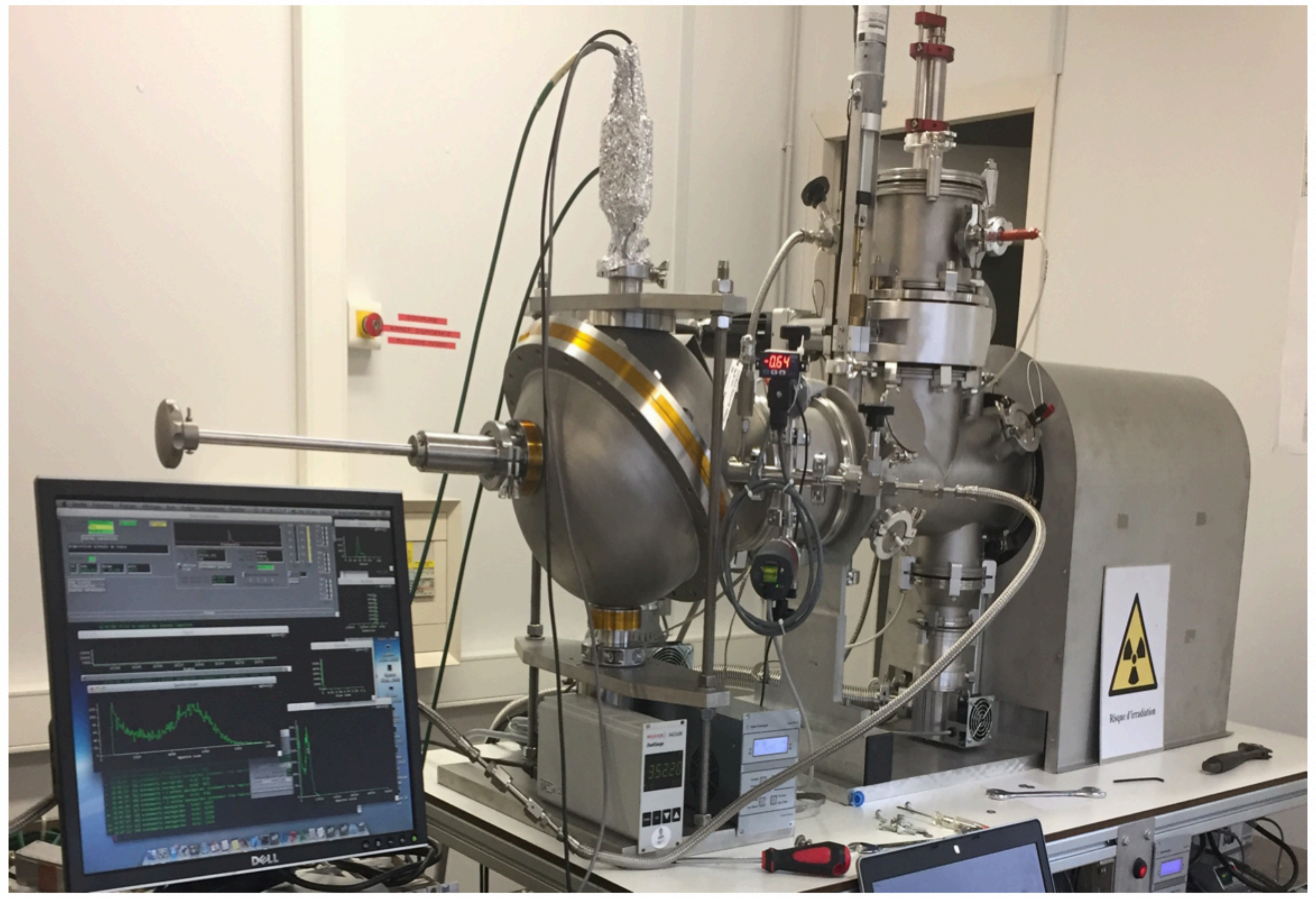
Packed in November 2019 to go to SNOLAB! First signal in summer 2021, currently finishing installation/ commissioning, physics data-taking to restart in coming weeks

Toy model for time separation distribution

- For **n** primary electrons, draw **n** arrival times from a gaussian (standard deviation given by calibrations, and whether we're interested in surface or volume events). Order their arrival times;
- Give each electron a chance to be detected based on attachment and algorithm single-peak finding efficiency;
- Give each set of consecutive electrons a chance to « overlap » and be counted as only one peak based on the calibrated time separation power of the algorithm (plus an ad hoc correction in case of multiple overlaps in a row)

Quenching Factor measurements

COMIMAC, LPSC Grenoble

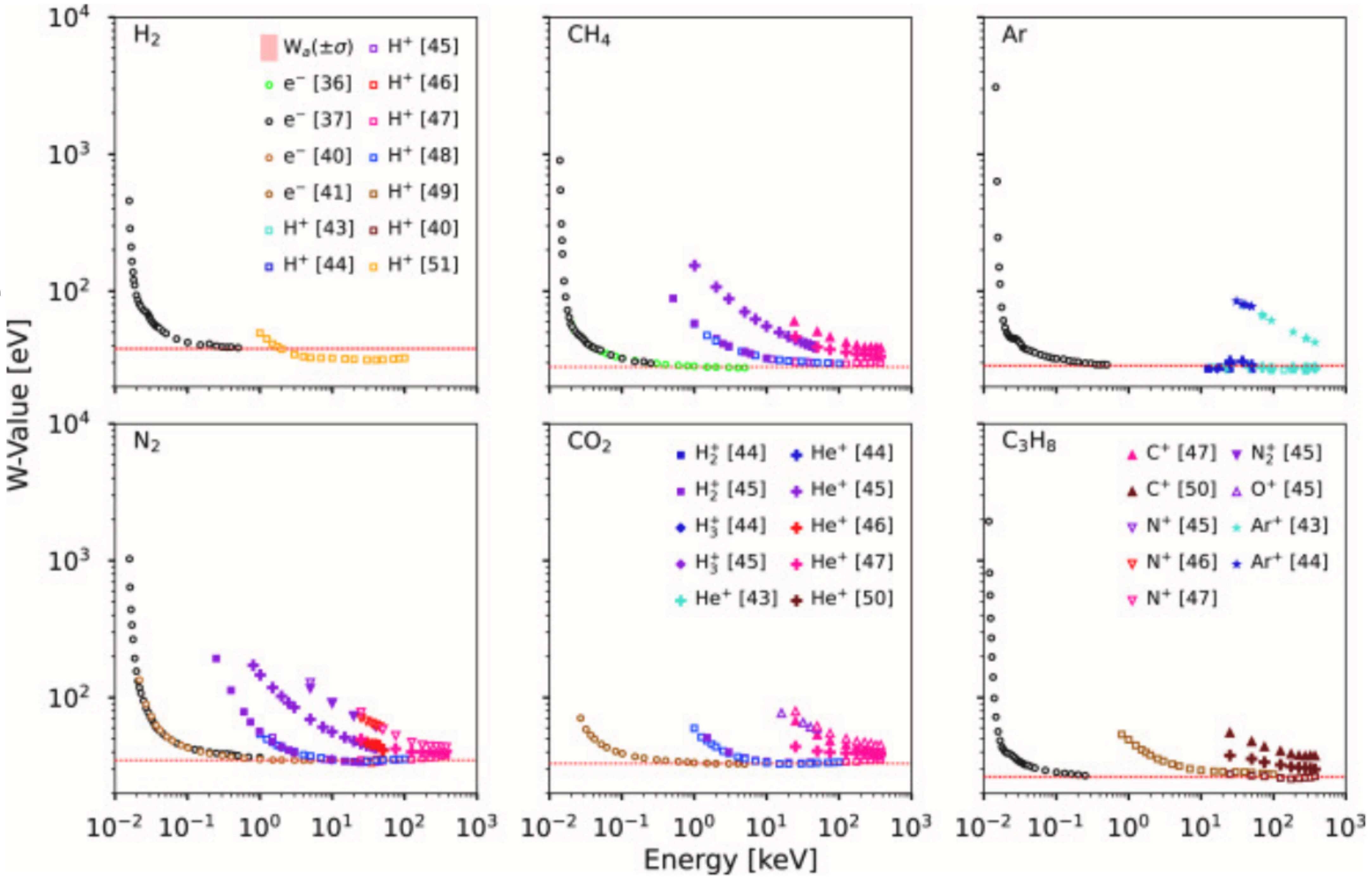


Generates electrons/ions of known energy, accelerated in electric field

https://arxiv.org/abs/2201.09566, pending publication in EPJC

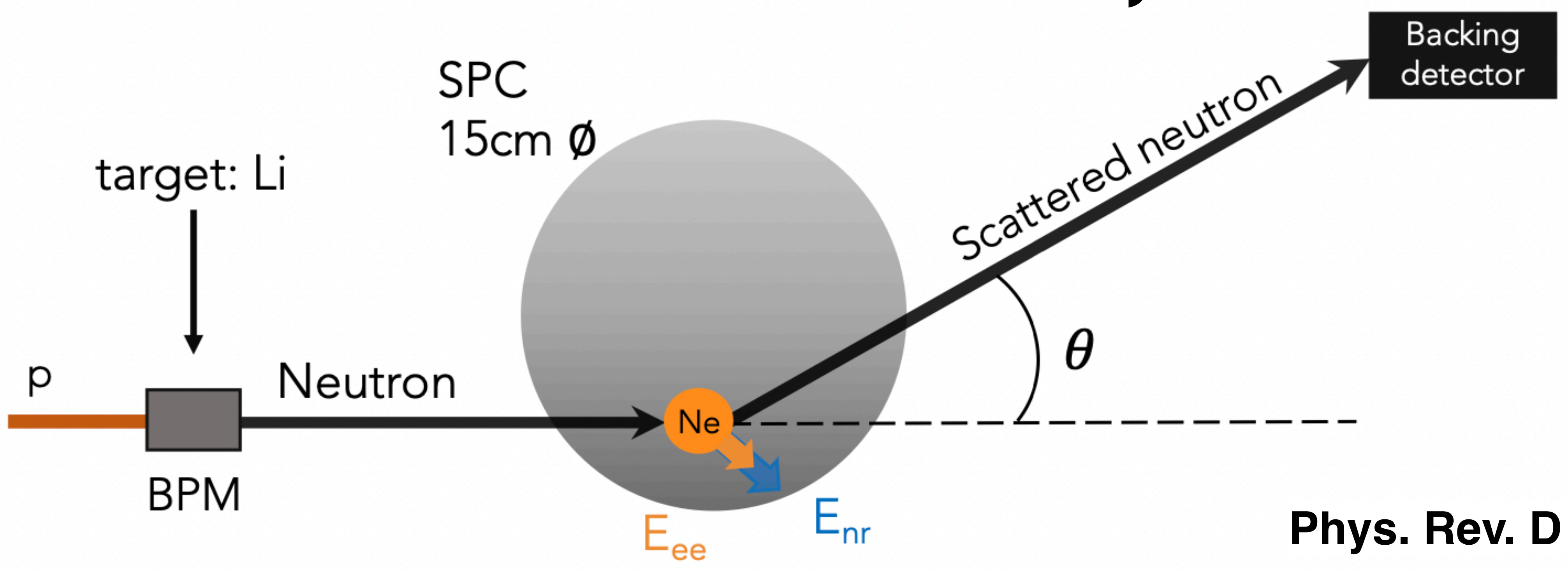
Ratio of literature values for W, Birmingham U.

Exploit literature on mean ionization energy for electrons and ions to produce QF values



Astr. Phys. 141, 102707 (August 2022)

545keV neutron beam, TUNL



Neutron beam generates recoils on target, energy derived from angle of recoil with Backing Detector

Phys. Rev. D 105, 052004 – Published 8 March 2022