Nuclear ionization yield measurements in Neon gas for NEWS-G

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CAP Congress 2020

June 8th

NEWS-G

- Main goal: search for low mass Dark Matter

- Other applications: Coherent elastic neutrino-nucleus scattering ,or CEνNS, detection (future project).

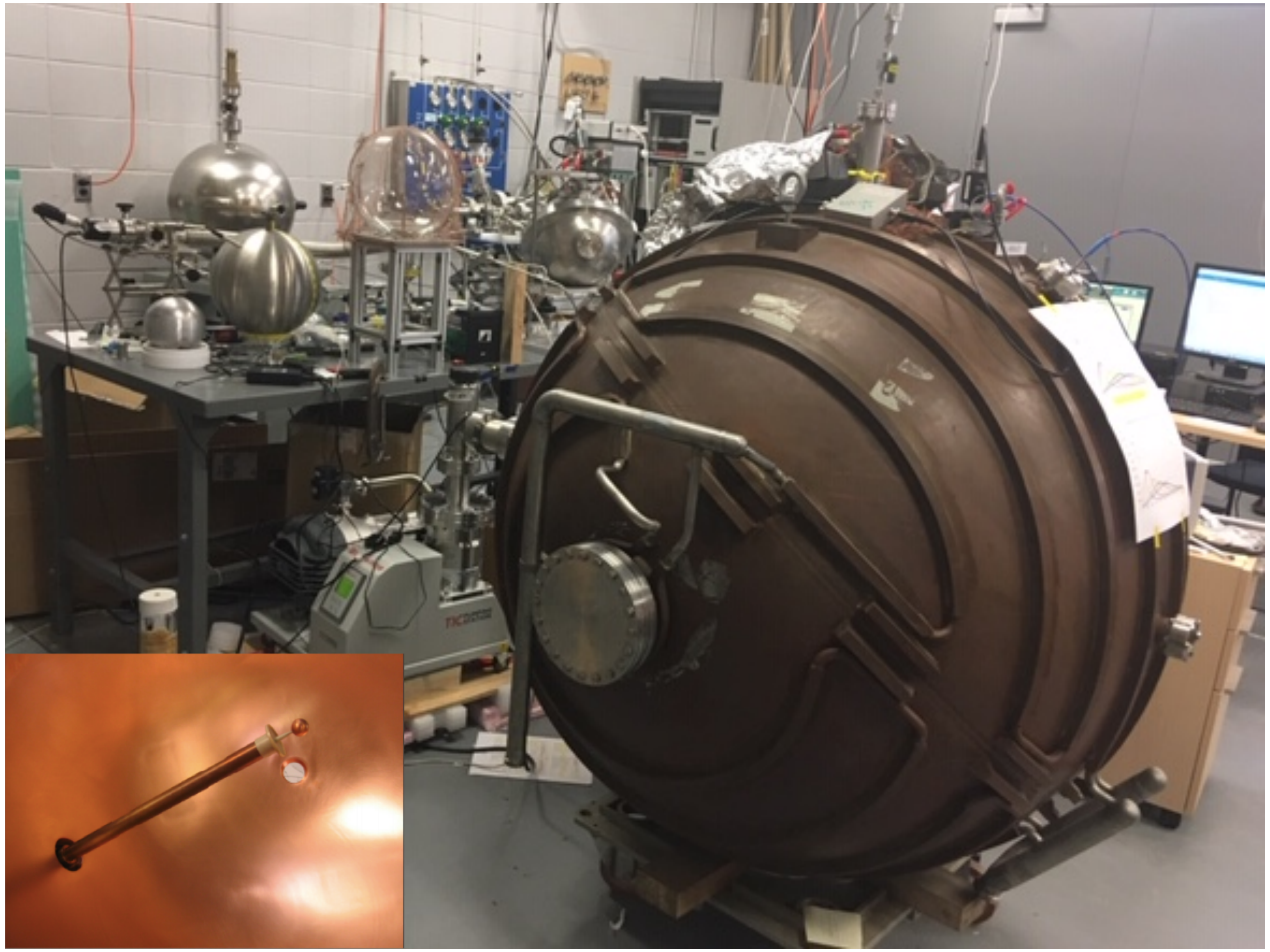
- Spherical metallic vessel filled with noble gas + HV on central anode: Spherical Proportional Counter.

6th collaboration meeting in Grenoble, June 2019

Prototype Sedine: Laboratoire souterrain de Modane

Detectors

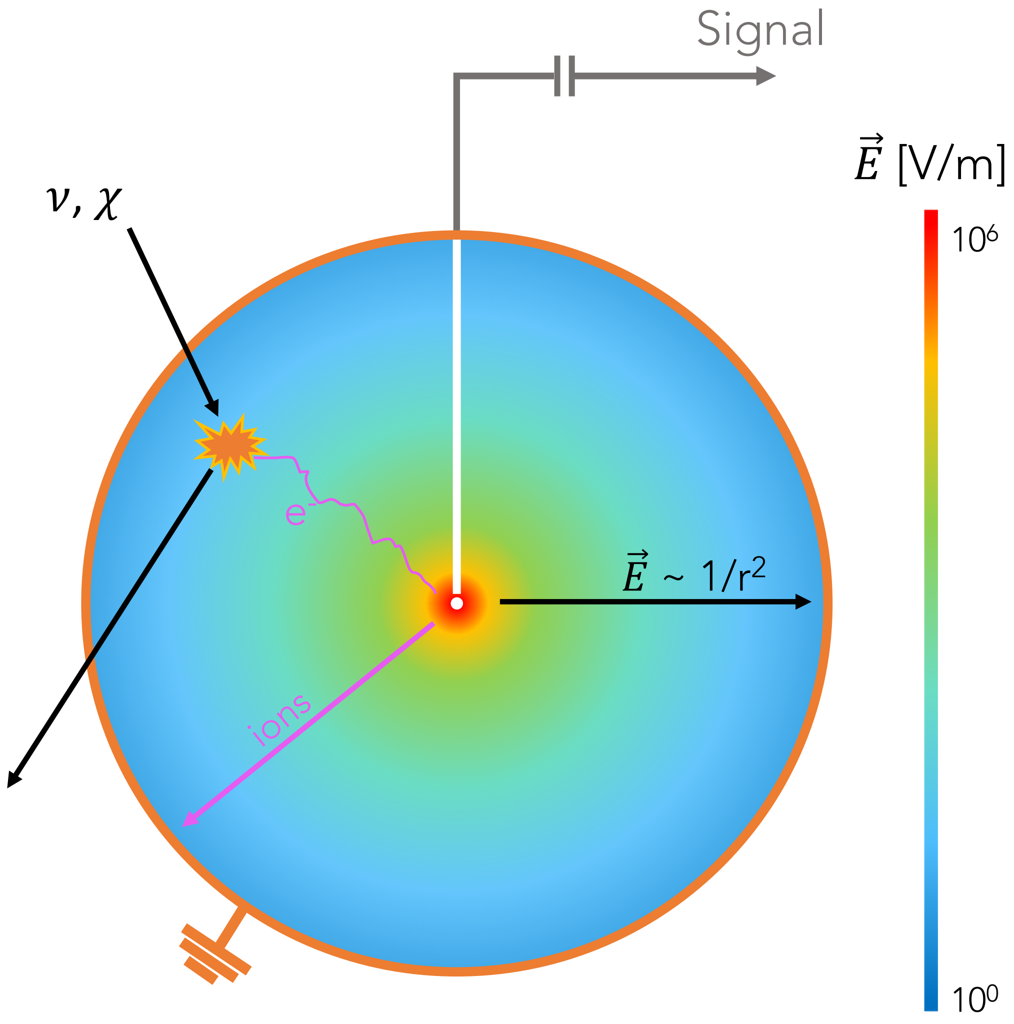
- Diameter: 15, 30, 60, 140 cm
- Sphere: stainless steel, copper, glass, aluminum
- Sensor diameter: 1 – 16 mm
- Gas: Neon, Argon, Helium, CH_4
- High voltage on sensor: $\vec{E} \sim 1/r^2$
- Large gain
- Low energy threshold, independent of the SPC size
- No e^-/nr discrimination for P>200mbar
- Discrimination surface/volume events



Queen's University lab

SPC: principle

1. Primary ionization
   Mean energy necessary to generate 1 e^-/ion pair: ~30eV in Neon
2. Drift of primary e^- towards sensor
   Typical drift times:
   ~ 100 μs for 30cm Ø
3. Avalanche in the vicinity of the anode
   Generation of thousands of secondary e^-/ion pairs
4. Signal formation
   Current induced by ions → sphere surface



Motivation for ionization yield measurements

- Energy calibration of gaseous detector: γ or X sources
  γ or X rays interact with electrons → electronic recoils (E_{ee})
- (ν, χ) interact with nuclei → nuclear recoils (E_{nr})

→ don't ionize the same amount of gas.

- The ionization yield, or quenching factor, is the ratio of the number of charges produced by an electron and a nuclear recoil of the same energy.

$$QF(E_{nr}) = \frac{E_{ee}}{E_{nr}}$$

- It is also the scale to go from the energy observed (E_{ee}) to the total nuclear recoil energy (E_{nr}).

Quenching factor measurements

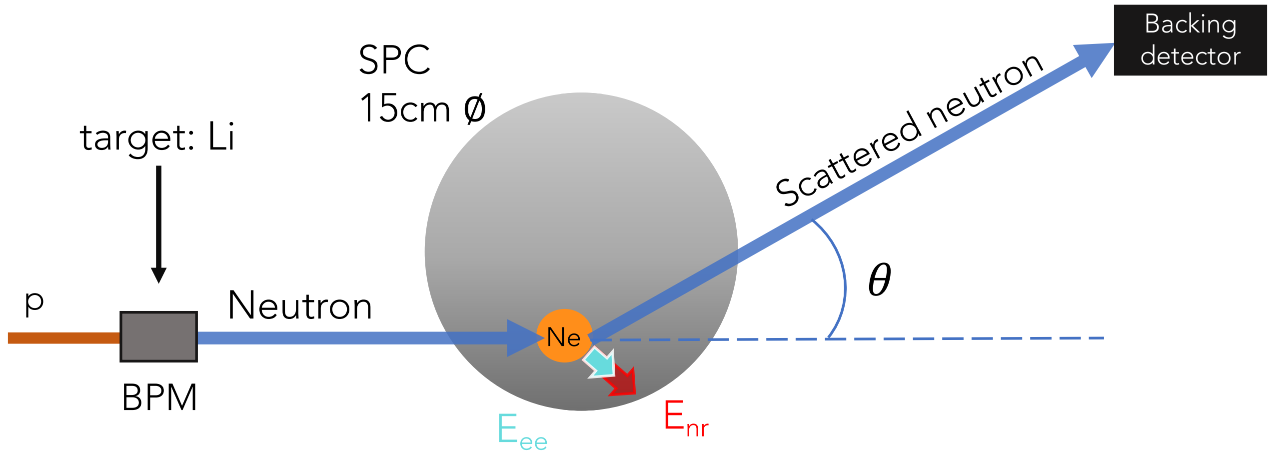
- QF measurements priority for NEWS-G (interpretation of data): low energies
- → 1st QF measurement in Neon gas

- Source of known nuclear recoil energies (E_{nr}):
  - Neutrons scatter off nuclei
  - We know the neutrons energy
  - Monoenergetic neutron beam

- The TUNL (Triangle University National Laboratory) facility has a tandem 10MV accelerator [1].
  - Organization of 2 measurement campaigns.
- Today, I'll be talking about the 2019 measurements.

[1] https://tunl.duke.edu/

2019 QF experiment summary

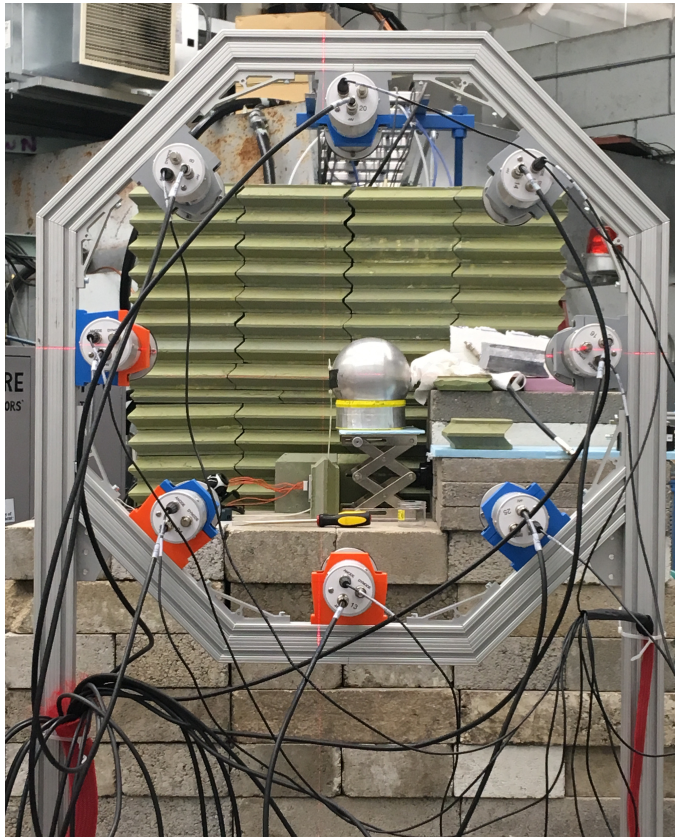


Run	E_{nr} [keV_{nr}]	θ [^{o}]
8	6.8	29.02
7	2.93	18.84
14	2.02	15.63
9	1.7	14.33
10	1.3	12.48
14	1.03	11.13
11	0.74	9.4
14	0.34	6.33

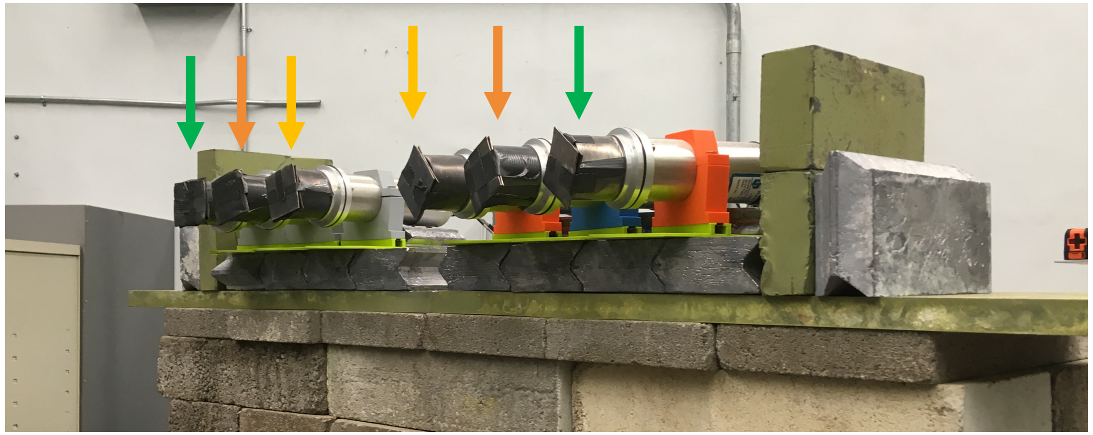
- Gas: Neon + CH_4 (97:3) @ 2 bar
- E_n = 545 ± 20 keV
- calculated nuclear recoil energy (E_{nr})
- scattering angle given by the position of the backing detectors.
- 8 energy points: 0.34 to 6.8 keV_{nr} (see table).
- energy detected (E_{ee})

- Backing detectors (BDs): DAQ trigger on BDs
- Beam Pick-off Monitor (BPM): TOF neutrons
- Energy calibration: ^{55}Fe source

Quenching factor: 2 Experimental Set Ups



Annulus configuration

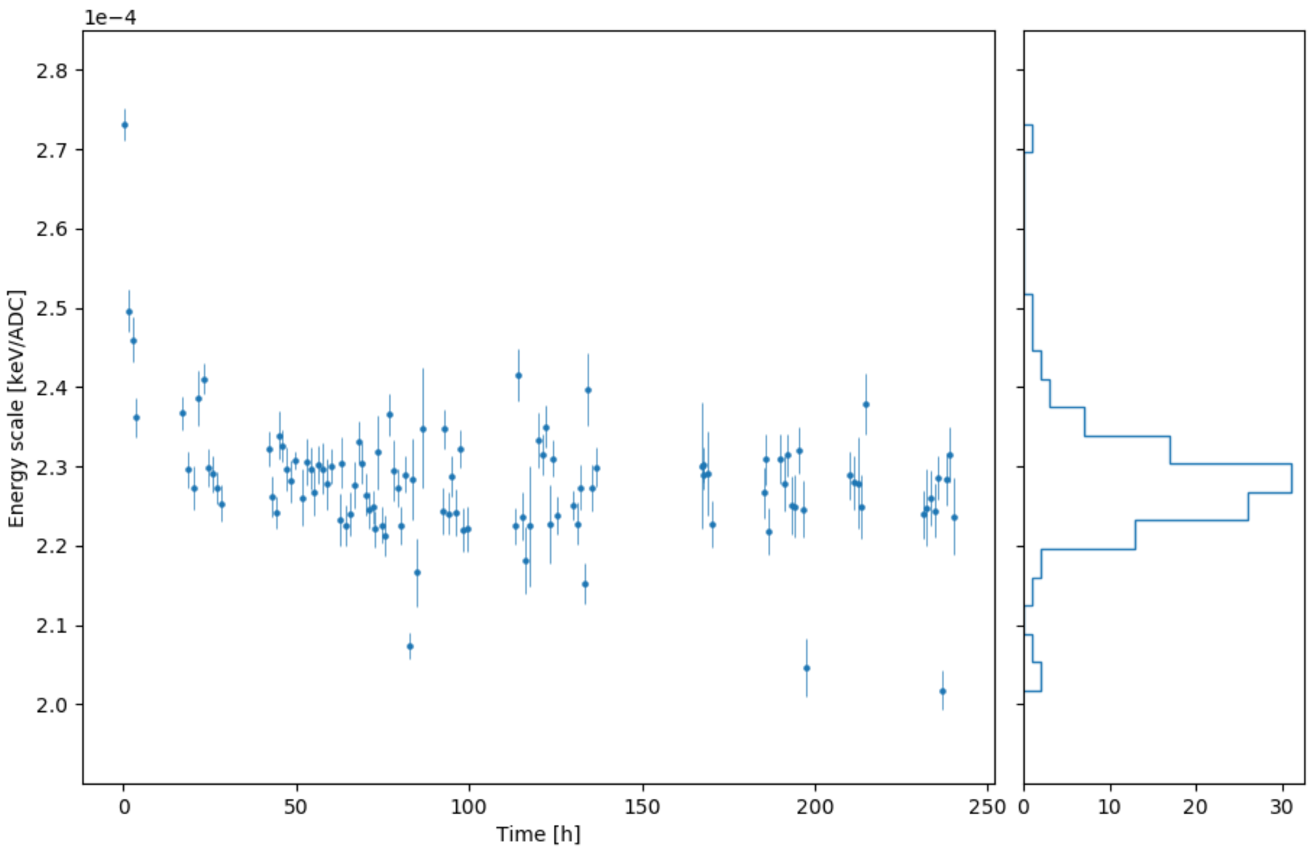


Multiple energy configuration

- Annulus configuration:
  - 8 BDs at the same scattering angle → same E_{nr}
  - 5 energy runs: from 6.8 keV_{nr} down to 0.7 keV_{nr}
- Multiple energies configuration:
  - To reach 0.3 keV_{nr}
  - 3 nuclear recoil energies recorded: 0.3, 1 and 2 keV_{nr}

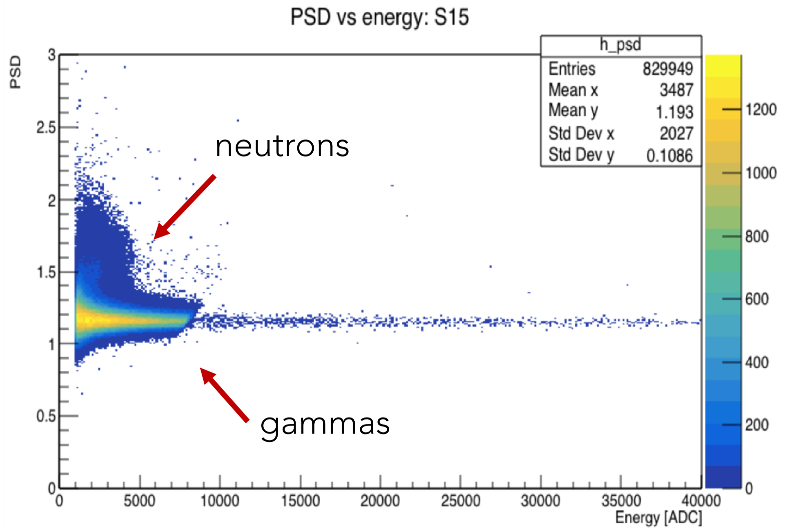
^{55}Fe calibration

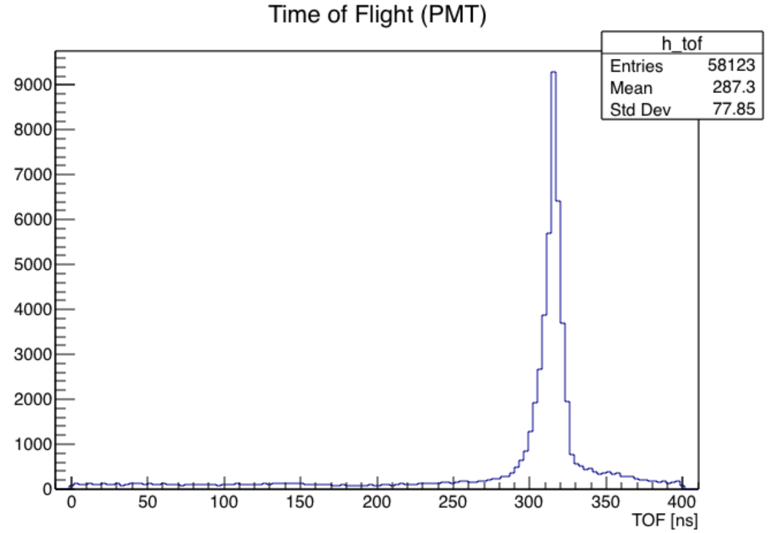
- Monitor the energy scale and eventual gain drift.
  - calibration data taken every 1h for 5 min.
- The energy scale was extracted from the ^{55}Fe calibration data.
  - gaussian to describe ^{55}Fe peak.
- Some fluctuation of the energy scale but mostly constant in time.
- Plot shows the energy scale evolution throughout the experiment.

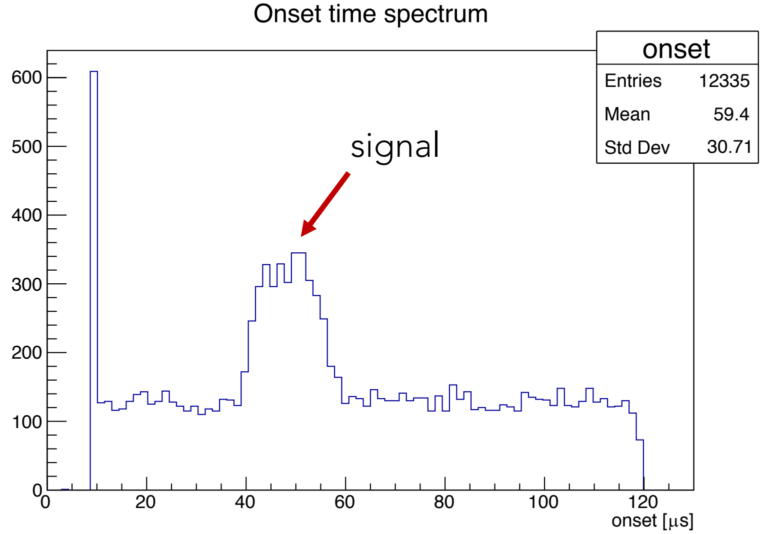


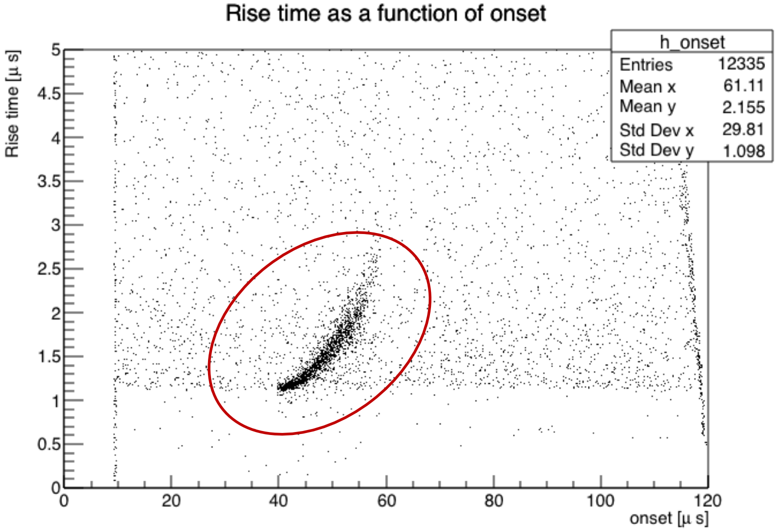
Summary of the cuts

- PSD: discriminate gamma and neutron events, $psd_n > \sim 1.3$
- Time of Flight (TOF): $T_{n,BD} - T_{n,BPM}$, TOF specific to each energy run.
- Onset time:
  - onset = time when the pulse reaches 10% of its amplitude.
  - DAQ: coincidence events between BD and SPC results in a pulse centered at 40 μs.
  - Expect to see excess of events at 40 μs: recoils events.
- Rise time:
  - reject surface events

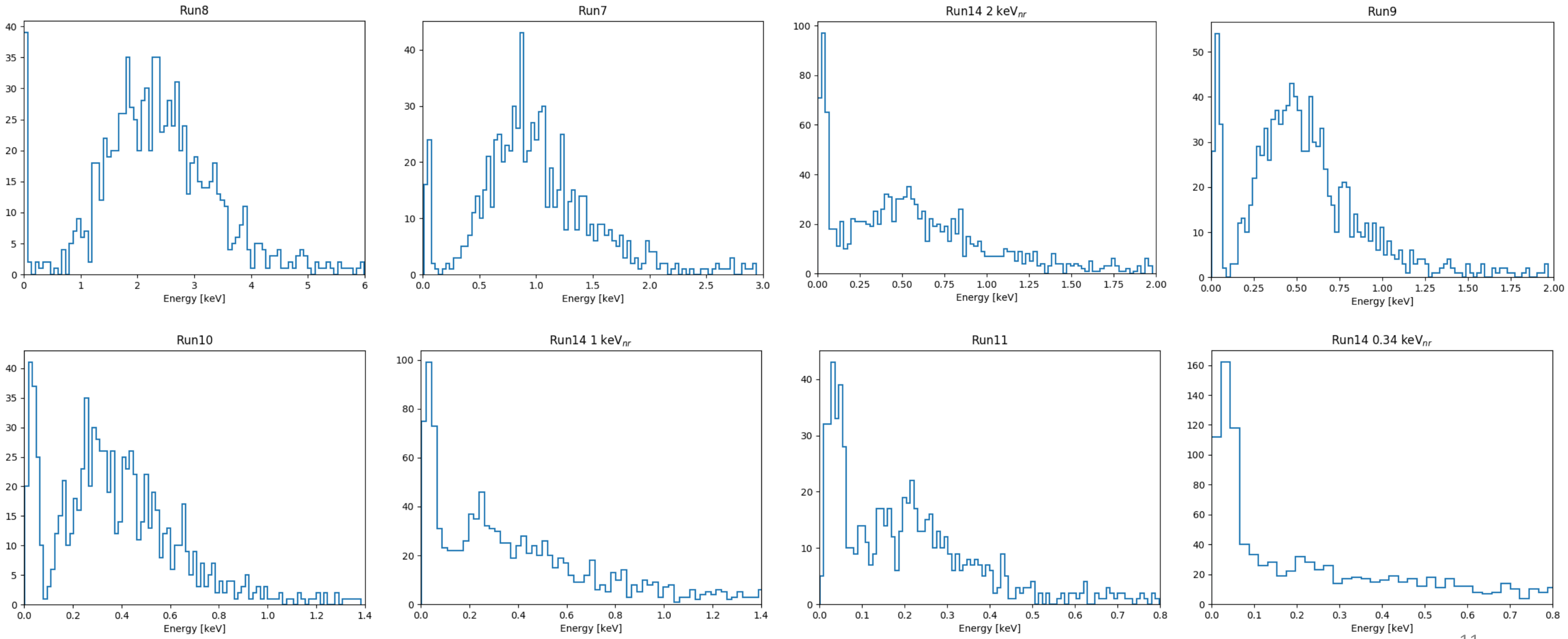








Data: energy spectra



Analysis

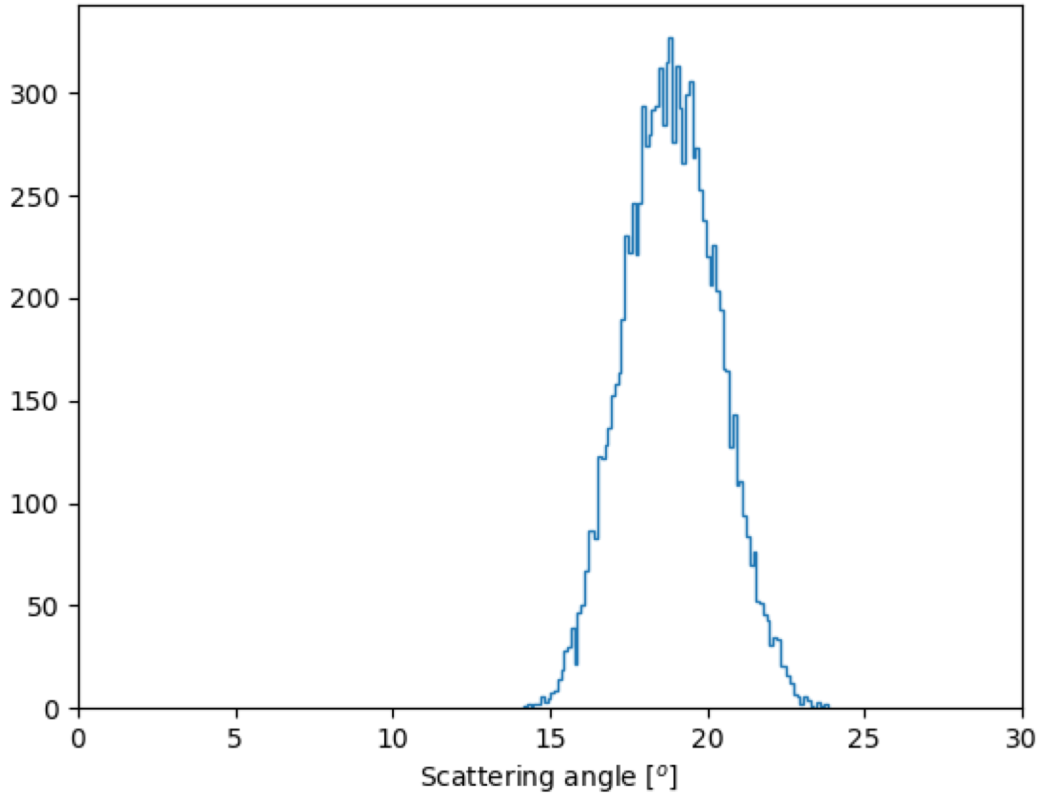
- Recoil peaks can't be modelled by a gaussian.
  - We can't use the mean of the peak to calculate the QF.

  → $QF(E_{nr}) = \mu_{E_{ee}} / \mu_{E_{nr}}$
  - Asymmetric distribution.
- We need to model the signal events to understand the recoils distribution.

- Goal is to do a join likelihood fit and extract the parameters of the quenching factor using all data sets.
- The likelihood is: P(data | parameters)

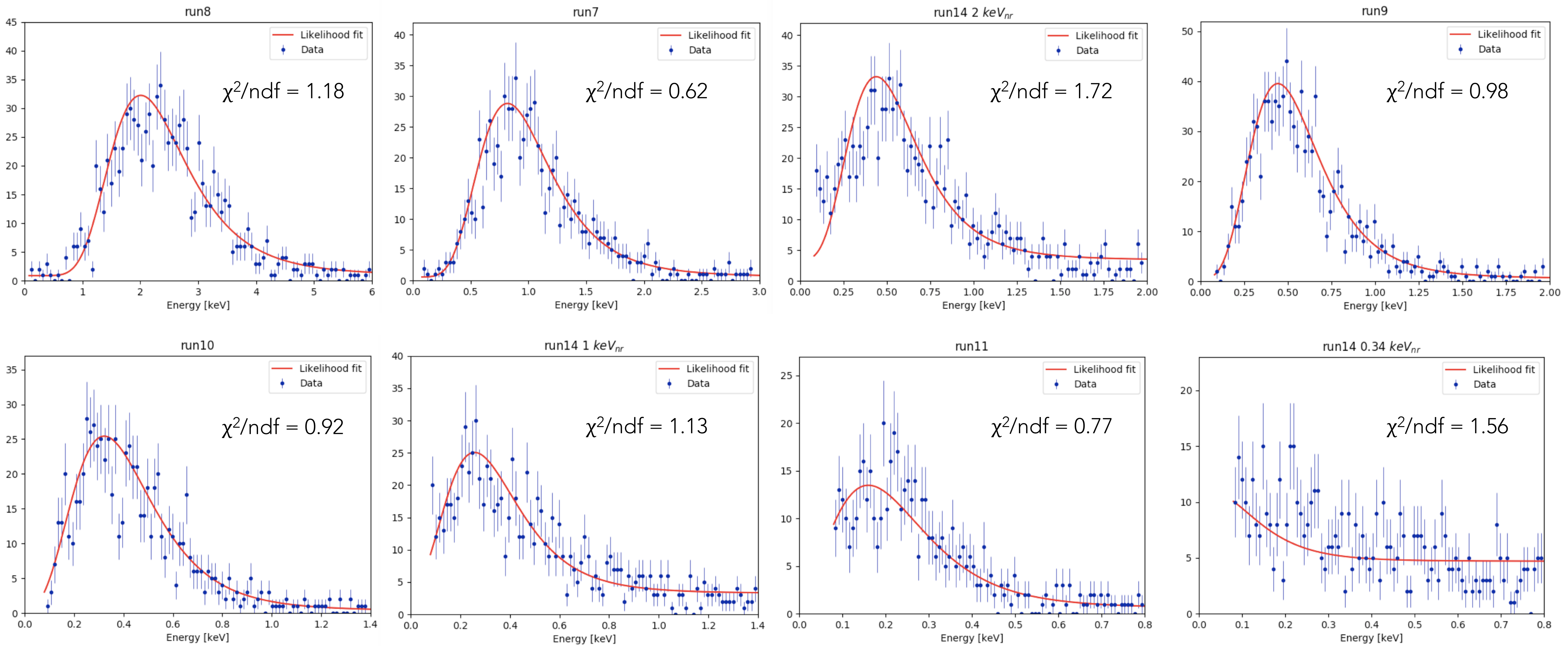
Signal model

- Geometry of the experiment:
  - scattering angle distribution
  - impact E_{nr} spectrum
- Neutron energy distribution
- Response of the detector:
  - Primary ionization: Poisson
  - Secondary ionization (avalanche): Polya
- Include quenching factor:
  - a parametrization of the quenching factor, based on the Lindhard theory [2].
- Distribution of the energy scale throughout the volume.



[2] J. Lindhard, V. Nielsen, M. Scharff and P.V. Thomsen, Mat. Fys. Medd. Dan. Vid. Selsk. 33 10 (1963)

Fit and data


run8
Likelihood fit
Data
χ^2/ndf = 1.18
Energy [keV]
run7
χ^2/ndf = 0.62
run14 2 keV_{nr}
χ^2/ndf = 1.72
run9
χ^2/ndf = 0.98
run10
χ^2/ndf = 0.92
run14 1 keV_{nr}
χ^2/ndf = 1.13
run11
χ^2/ndf = 0.77
run14 0.34 keV_{nr}
χ^2/ndf = 1.56

Conclusion

- We demonstrated the feasibility of QF measurements in gases using a SPC and a neutron beam.
- We successfully took data in Neon gas: first time!
- We reached single electron sensitivity: 80 eV.
- The analysis is almost complete.
- Results will be published soon.

Thank you

Any questions?

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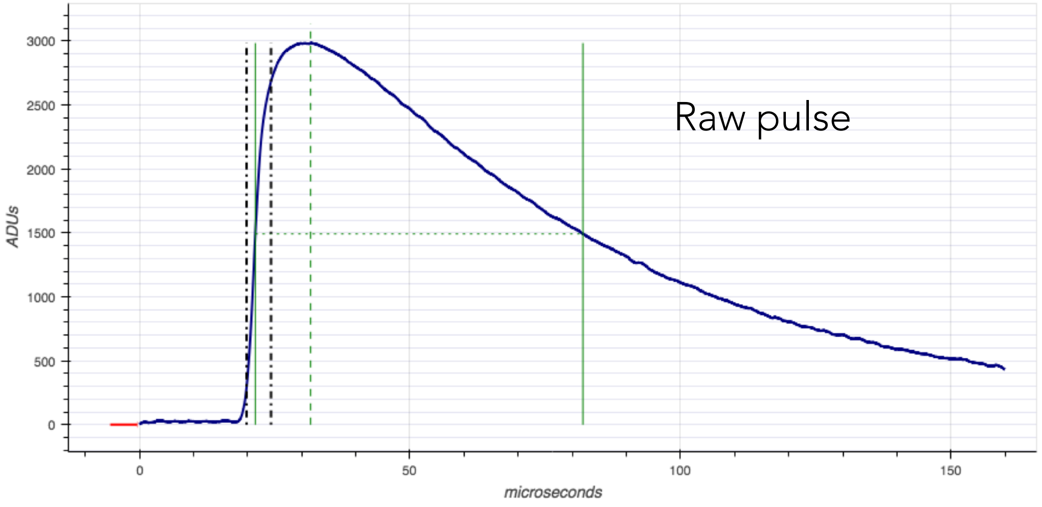
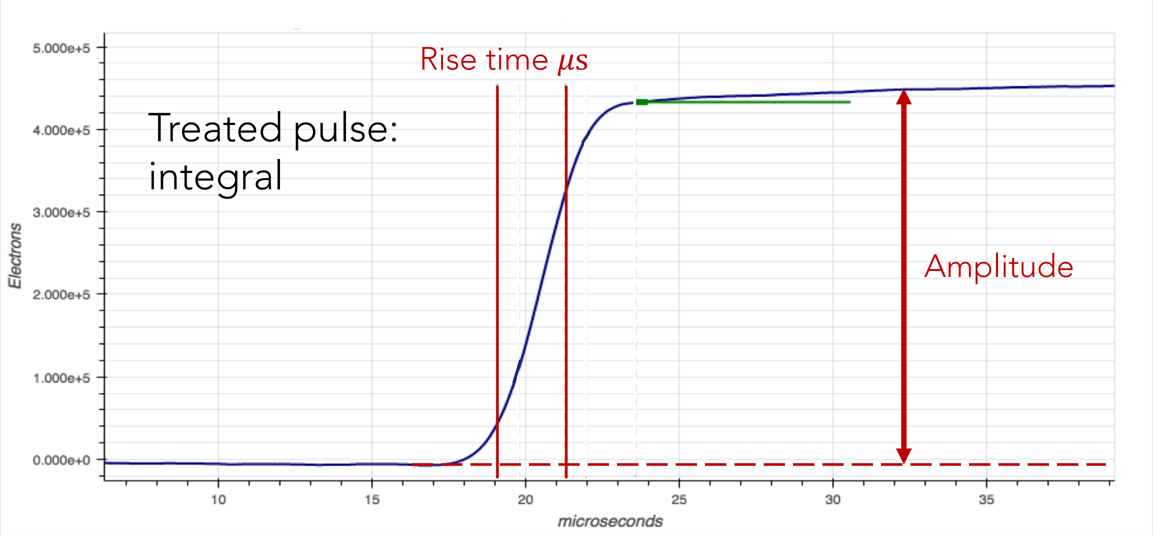
TUNL Triangle Universities Nuclear Laboratory

Backup slides

NEWS-G: Example pulse

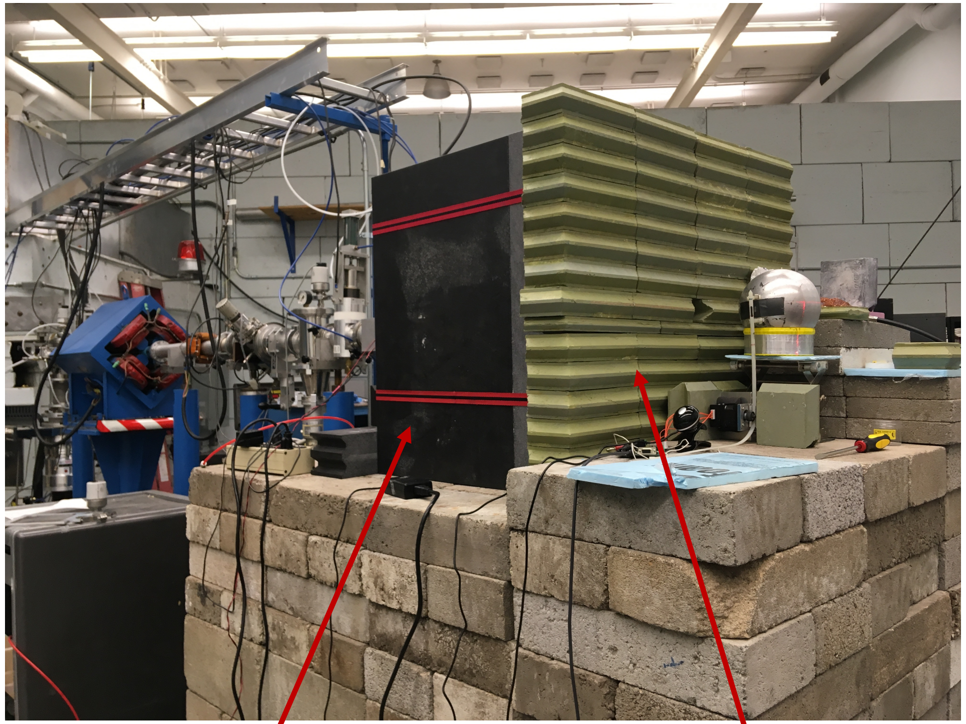




Amplitude provides estimation of the energy of the event.
Rise time provides an estimation of the radial distance of the event → Rise time linked to diffusion of the electrons along their drift toward anode.

Experiment conditions

Shieldings have been added around the beam line.

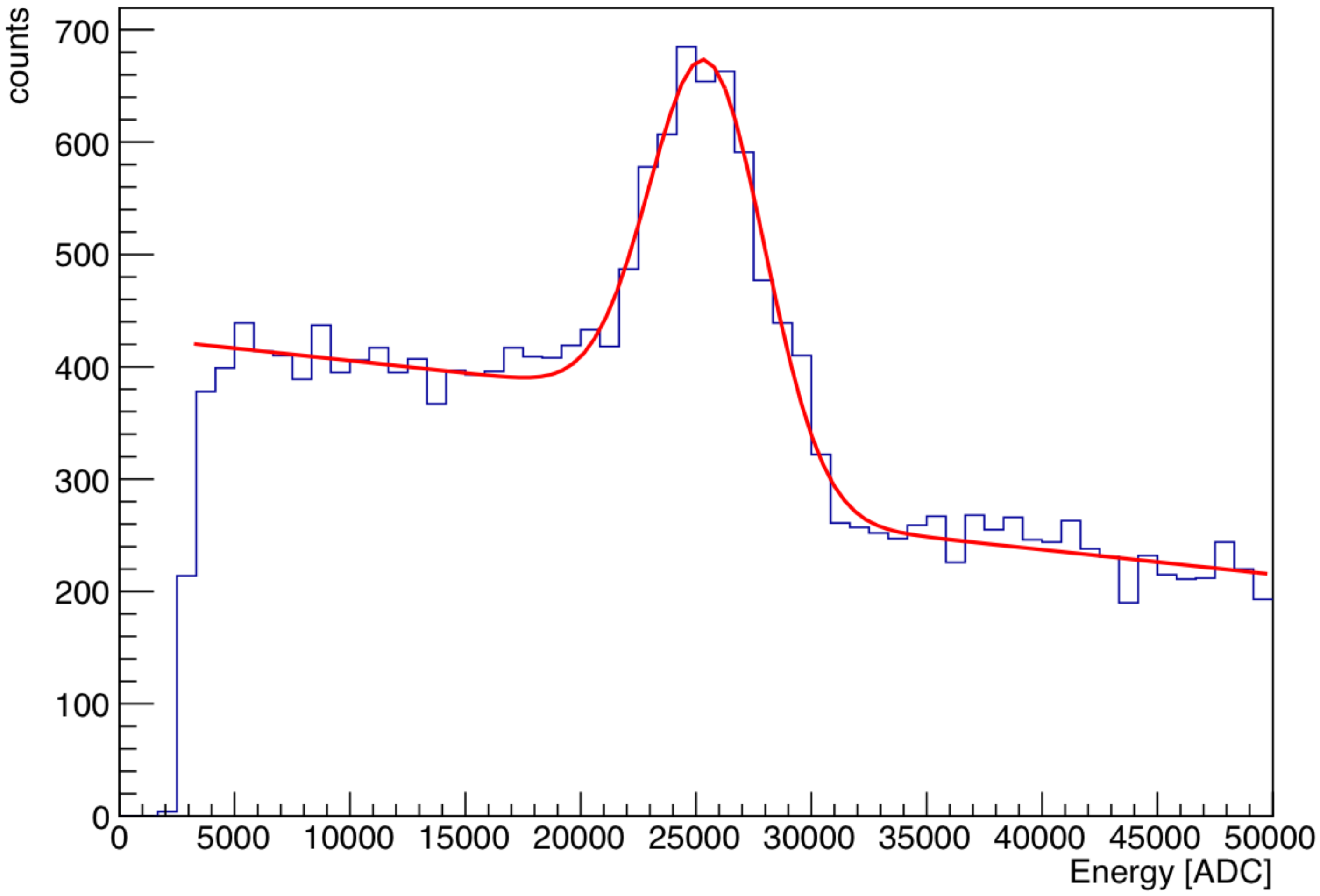


Polyethylene doped with B for neutron capture

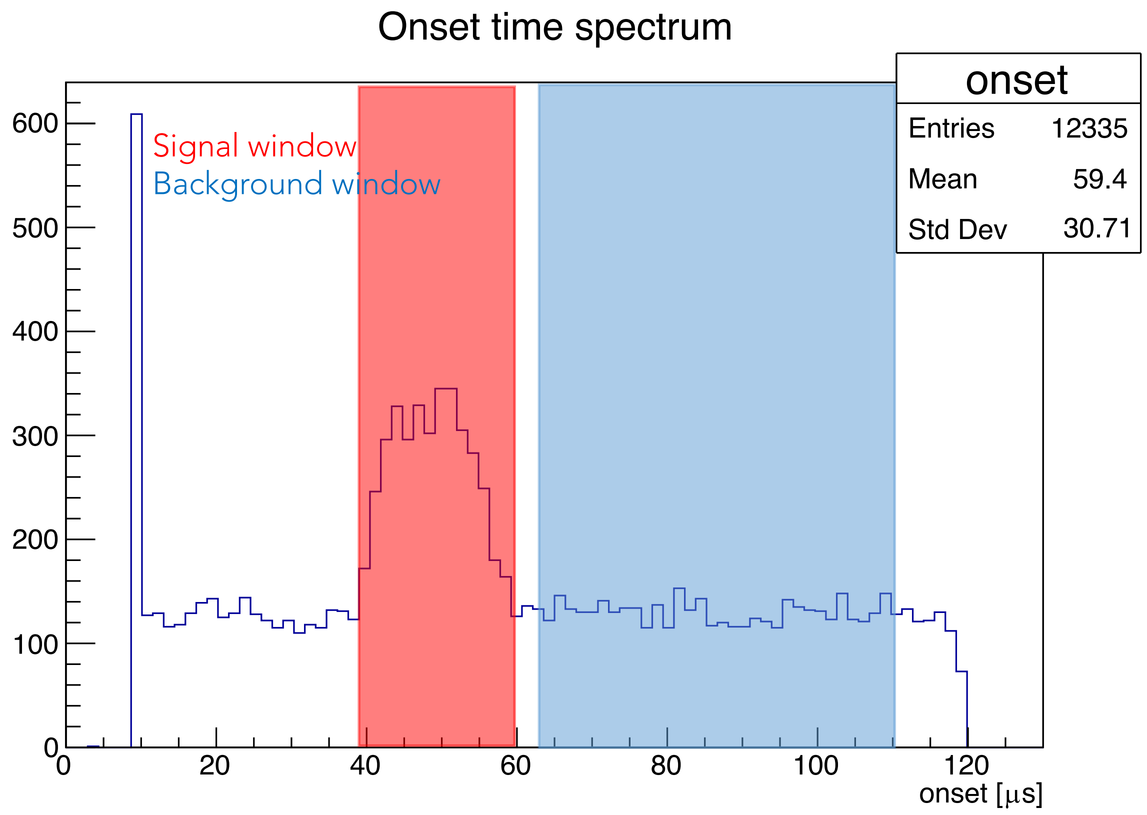
Lead wall for gammas

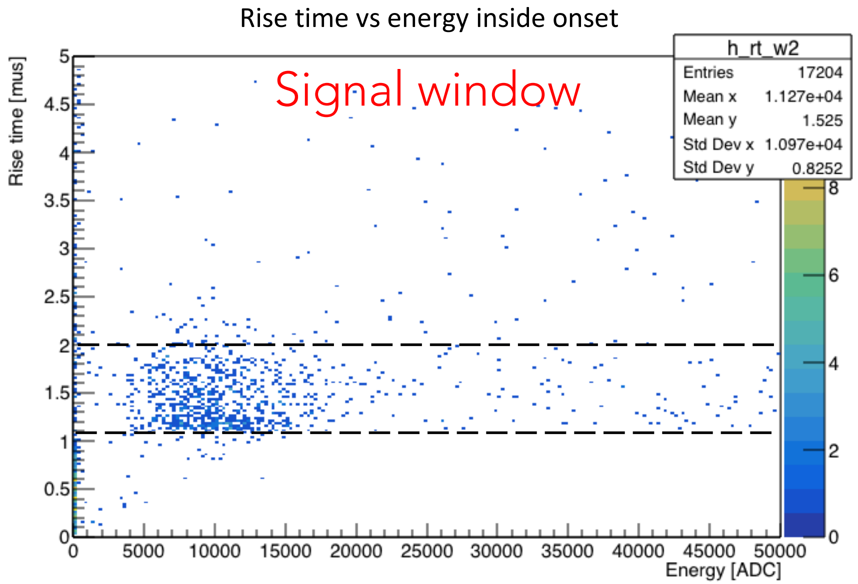
Lead shield on backing detectors to improve gammas background

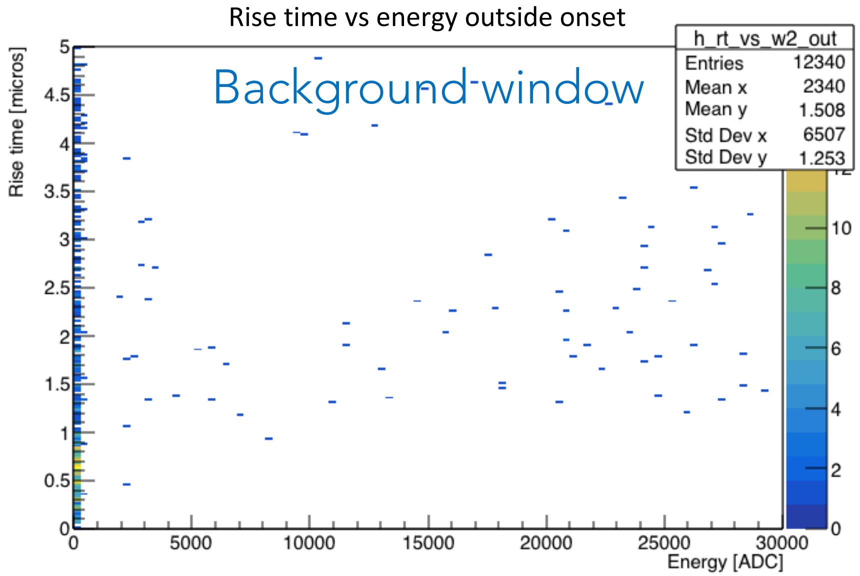
Fe55 energy spectrum



Building the energy spectra







Volume sampling

- Volume sampled by the ^{55}Fe source (left plot).
- Volume sampled by the recoils (right plot).
- Recoil events sample a larger region of the electric field (volume).