NEWS-G: status and quenching factor measurement

Marie Vidal on behalf of the NEWS-G collaboration

Magnificent CEνNS workshop: The PIT

November 10th 2019

NEWS-G

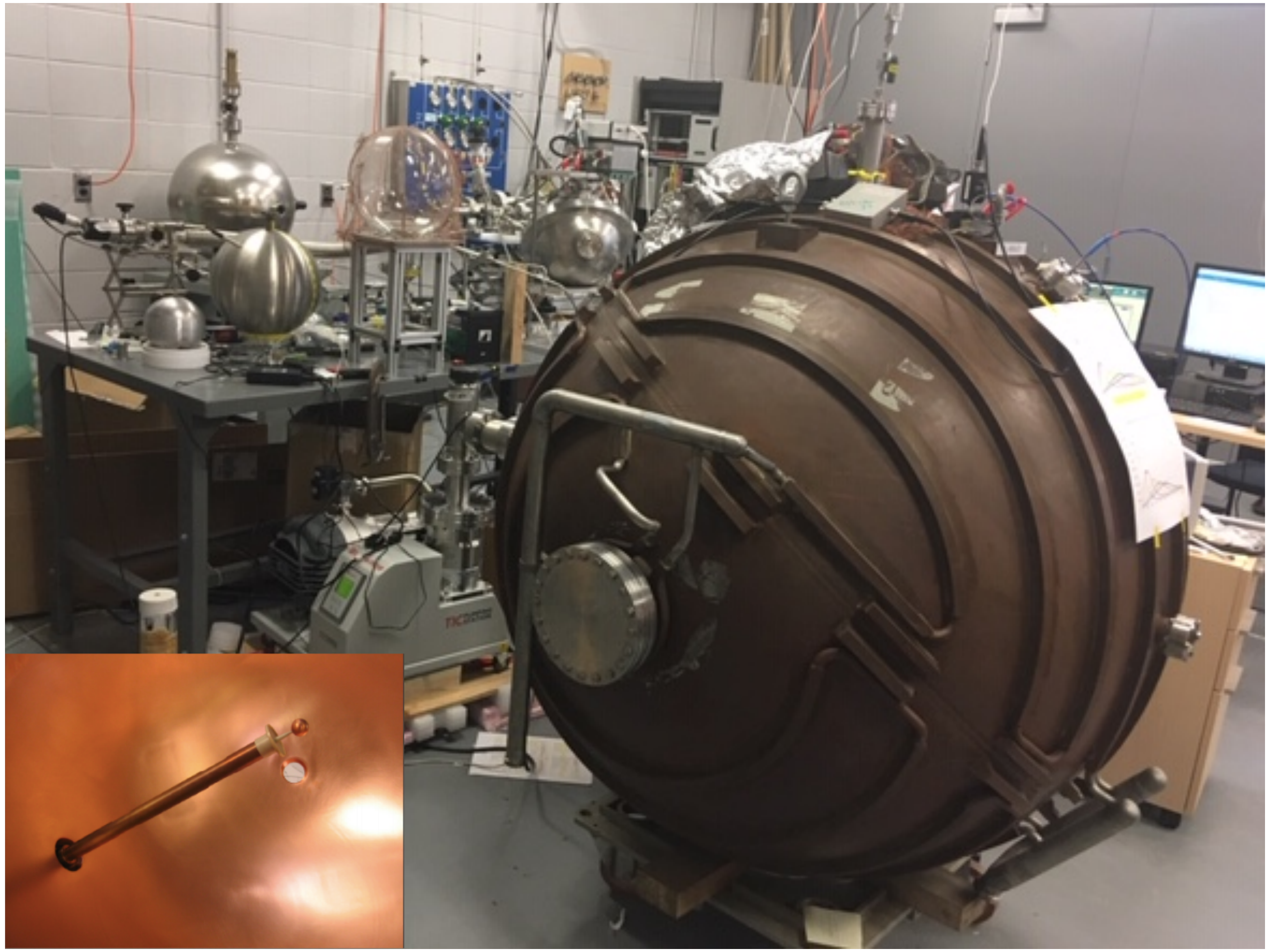
6th collaboration meeting in Grenoble, June 2019 (France, UK, Canada, US, Greece)

- Spherical metallic vessel filled with noble gas, HV on central anode: Spherical Proportional Counter.
- Main goal: search for low mass Dark Matter
- Other applications: CEνNS detection, $0\nu\beta\beta$ search

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 lab

NEWS-G: pulse formation

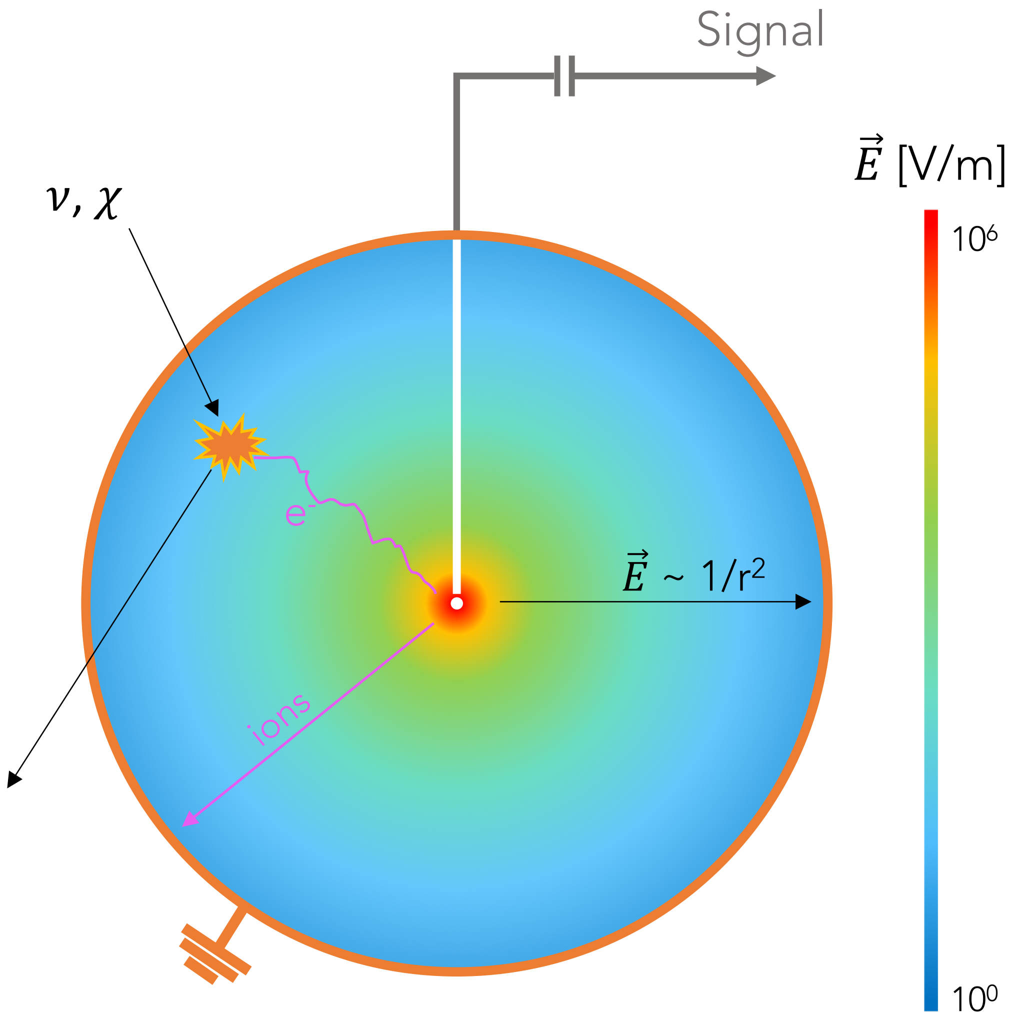
1. Primary ionization
   Mean energy necessary to generate 1 e^-/ion pair:
   W = 27.6 eV [1] in Neon + CH_4

2. Drift of primary e^- towards sensor
   Typical drift times: ~ 2 ms,
   diffusion: ~100 μs for 140 Ø SPC

3. Avalanche in the vicinity of the anode
   Generation of thousands of secondary e^-/ion pairs
   Governed by G (gain) and θ_{Polya}

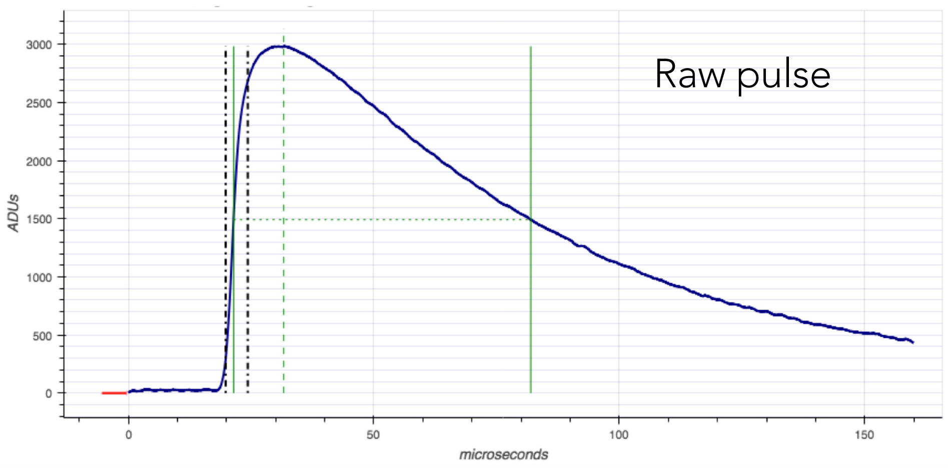
4. Signal formation
   Current induced by ions → sphere surface

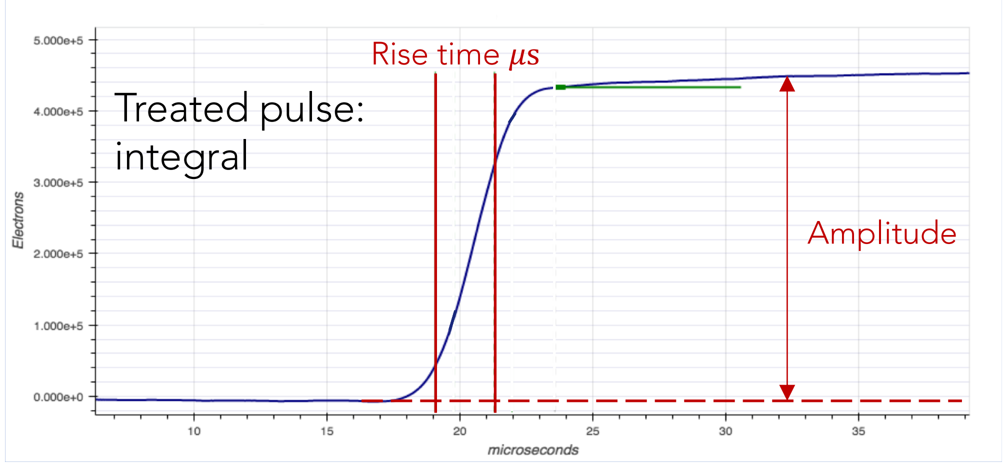
5. Read out: preamplifier



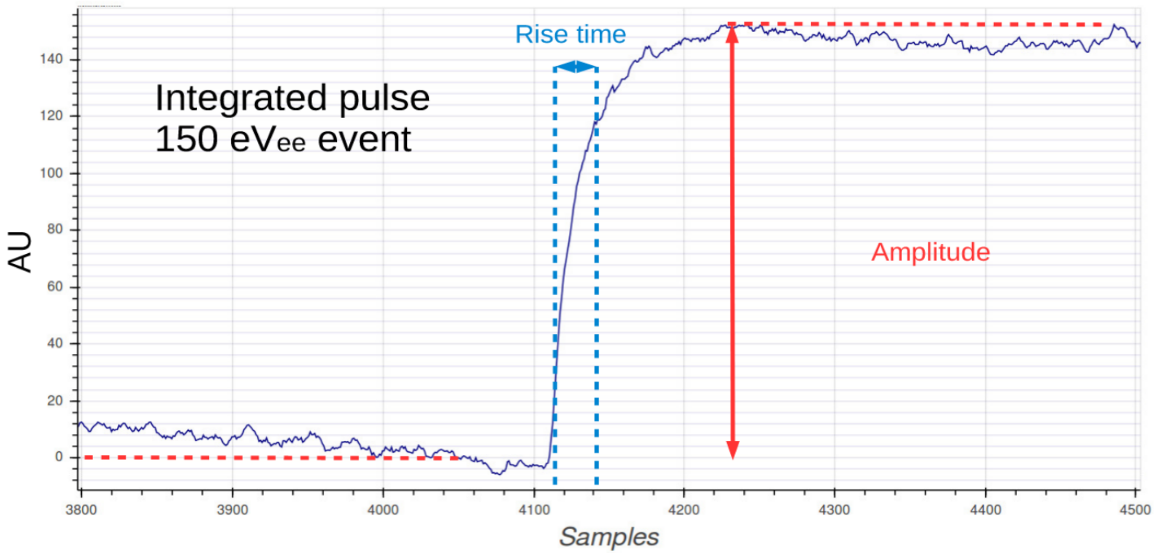
[1] Q. Arnaud et al. (NEWS-G Collaboration), Phys. Rev. D 99, 102003 (2019)

Example pulse





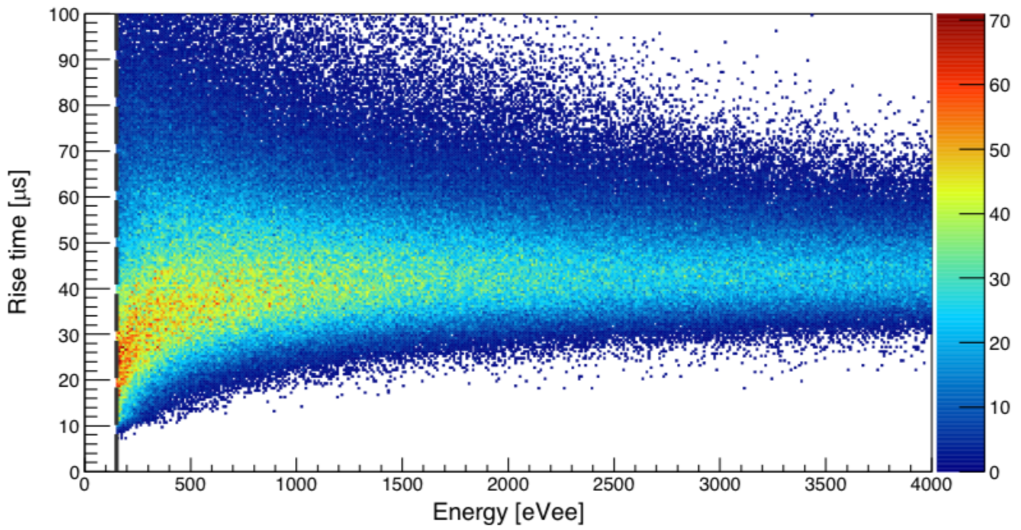
Amplitude provides estimation of the energy of the event.
Rise time provides an estimation of the radial distance of the event.



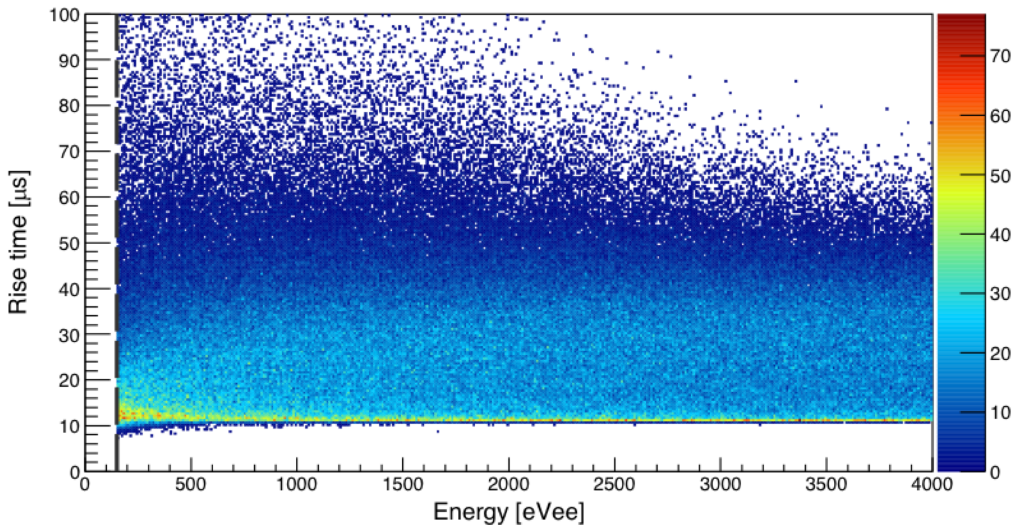
Data analysis: rise time versus energy

Rise time vs energy:

Surface events



Volume events



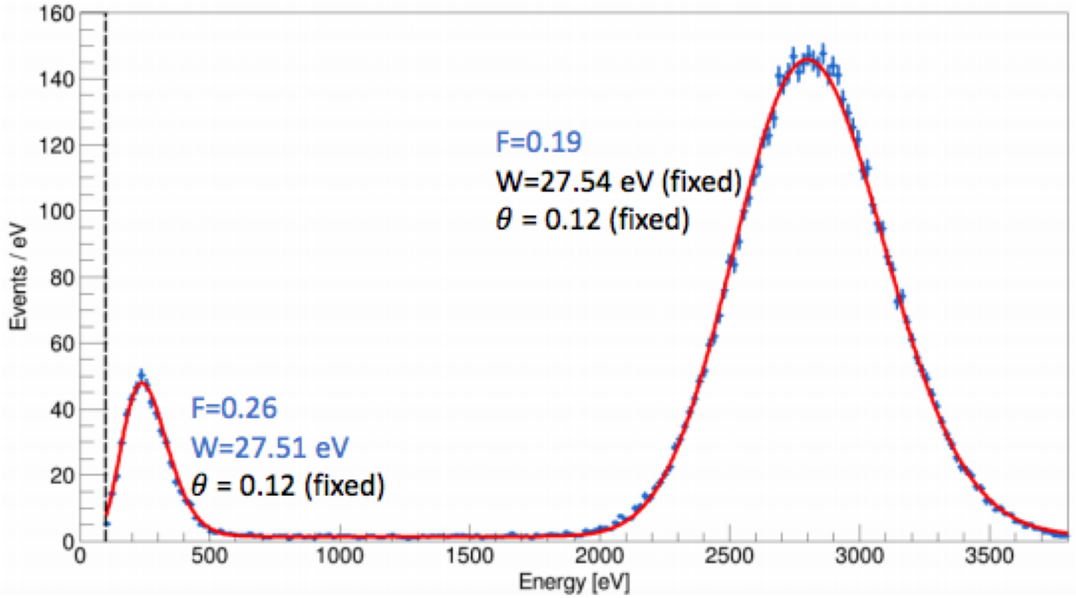
Simulations of the surface and volume events are used to determine the background in the region of interest → volume events

[2] Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018)

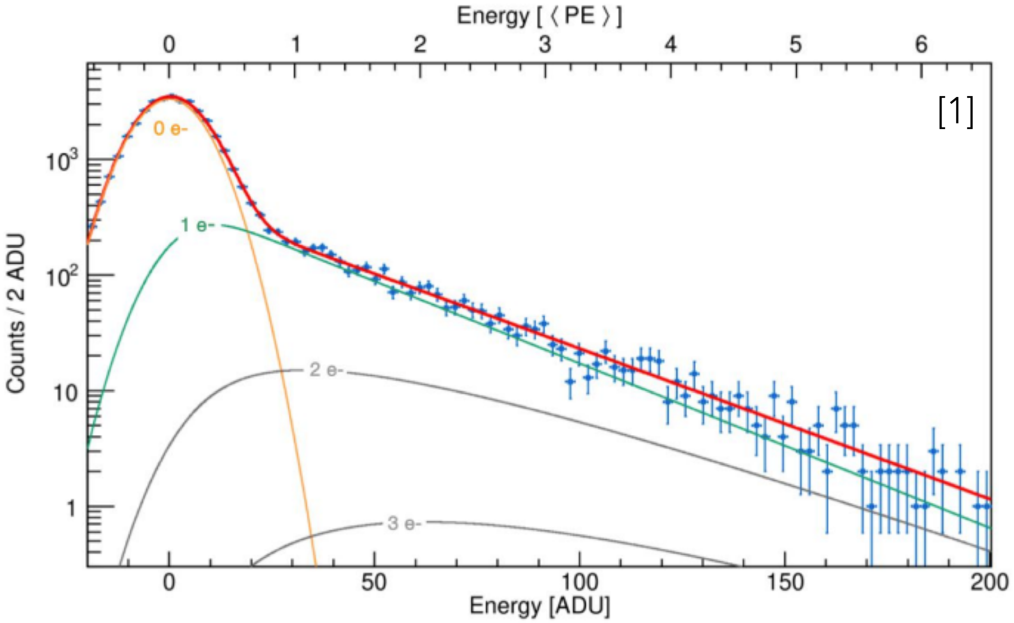
Sensitivity to sub keV

Calibration measurements with a 30 cm SPC using bakelite sensor:
Ar (2% CH_4), pressure = 500 mbar

^{37}Ar radioactive gas source



Single electron calibration with laser (213 nm)



[1] Q. Arnaud et al. (NEWS-G Collaboration), Phys. Rev. D 99, 102003 (2019)

NEWS-G first results: SEDINE detector

The NEWS-G collaboration has an experimental set up at LSM (Laboratoire Souterrain de Modane in France).

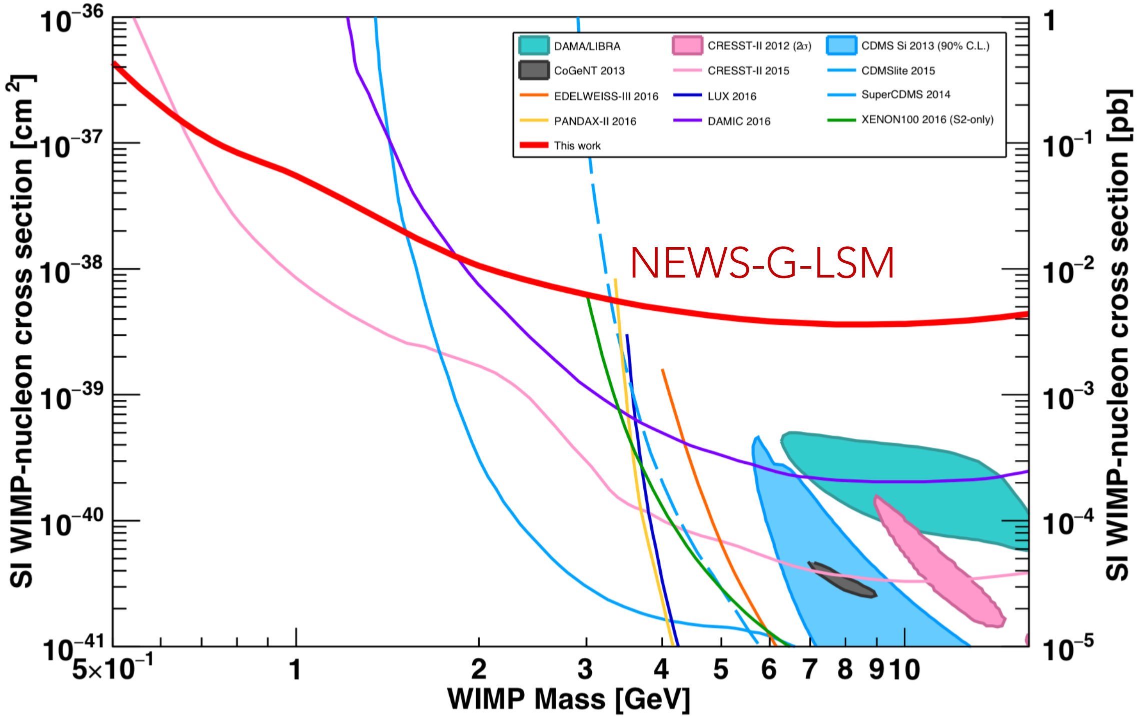
Data taking conditions:

9.6 kg days of exposure with Neon (+0.7% CH_4), pressure = 3.1 bar → 42.7 days of data

Shielding: 30 cm PE, 15 cm Pb, 8 cm Cu

60 cm Ø copper sphere

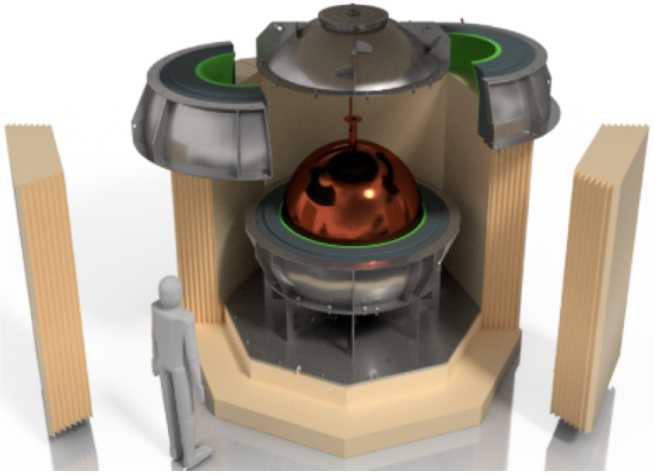
WIMP-nucleon cross section vs WIMP mass

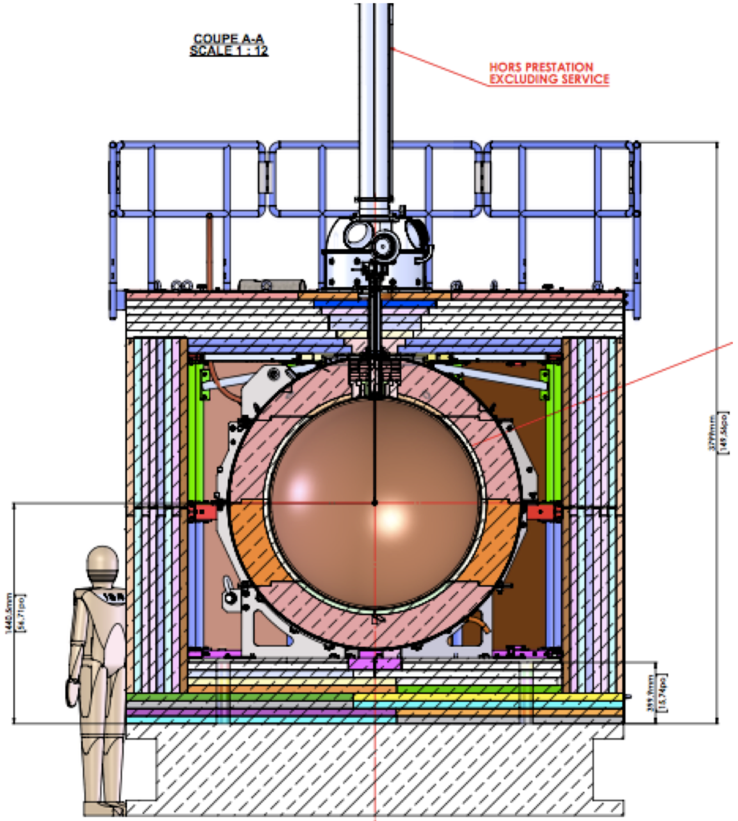


[2] Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018)

NEWS-G at SNOLAB

- Larger sphere: 140 cm Ø copper vessel, 12 mm thick low activity copper, electroplating of 500 μm of pure copper.
- New sensor: better $\vec{E}$ isotropy, better threshold
- Better shielding: archeological lead 3 cm, very low activity lead 22cm, 40 cm HDPE.
- Allow sensitivity down to ~ 10^{-41} cm^2, use of He and H targets to reach WIMP mass sensitivity down to 0.1 GeV.
- Commissioning of the detector at the LSM in summer before installation at SNOLAB beginning of 2020.



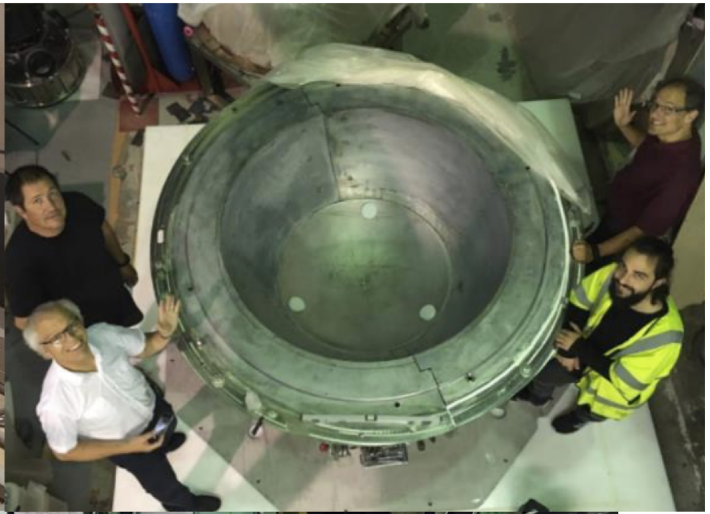


LSM commissioning

- Assembly of the detector at LSM
- Dedicated water tank for neutron shield
- Gas mixture: Neon 1bar (+2%CH_4) and CH_4 135 mb

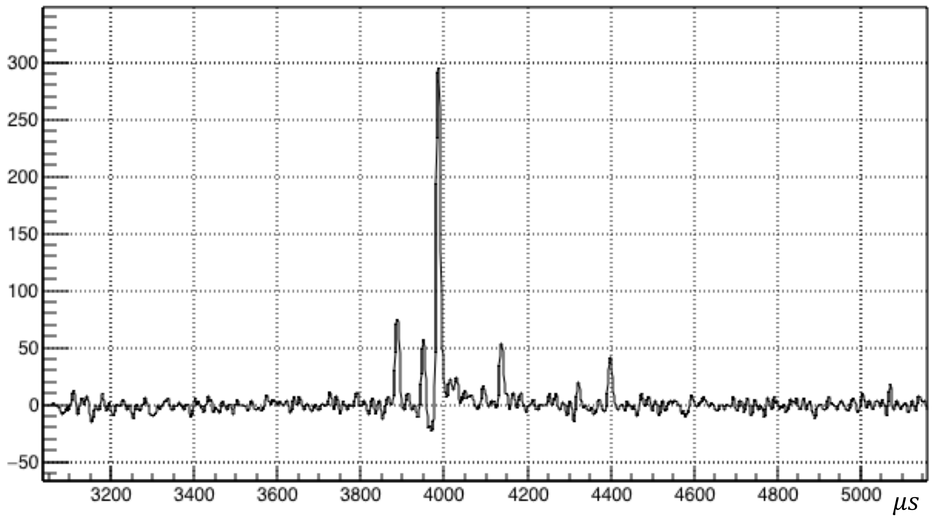
- Validation of:
  - Operation of 2 channels (``achinos" sensor) with south/north hemisphere
  - Laser and ^{37}Ar calibrations
  - ½ ionization/electron threshold

- Data under analysis for background/noise rejection.

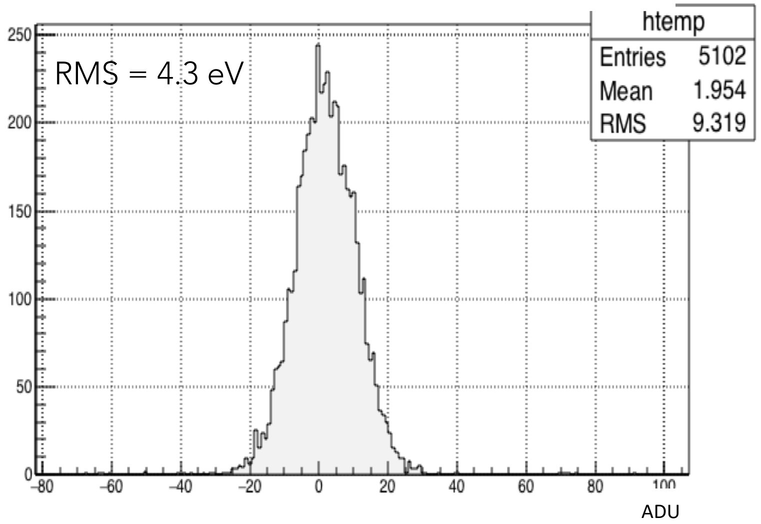
LSM commissioning: first results on performance

Deconvolved pulse

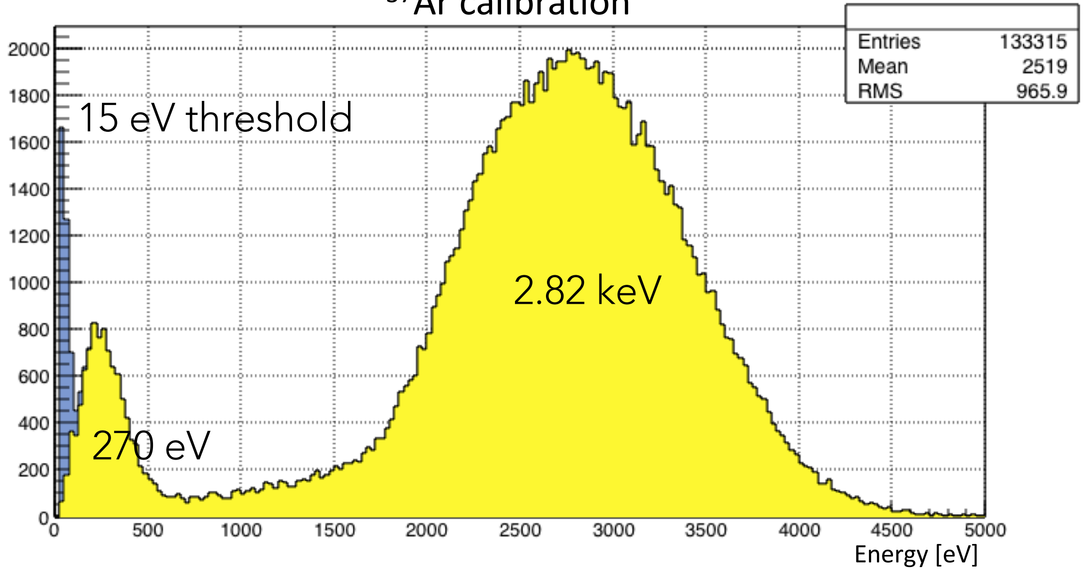


Preliminary

Deconvolved pulse baseline



^{37}Ar calibration

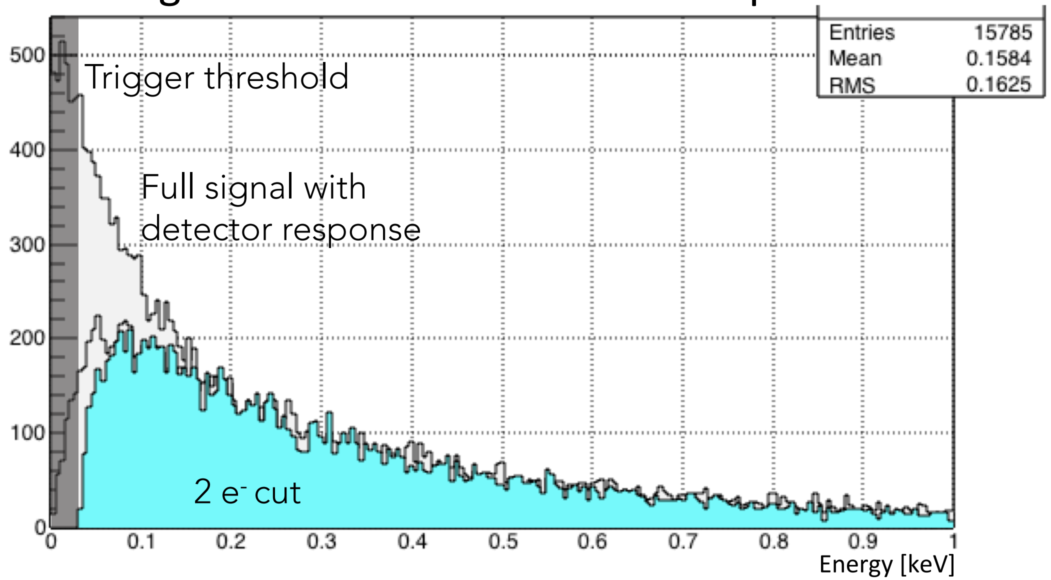


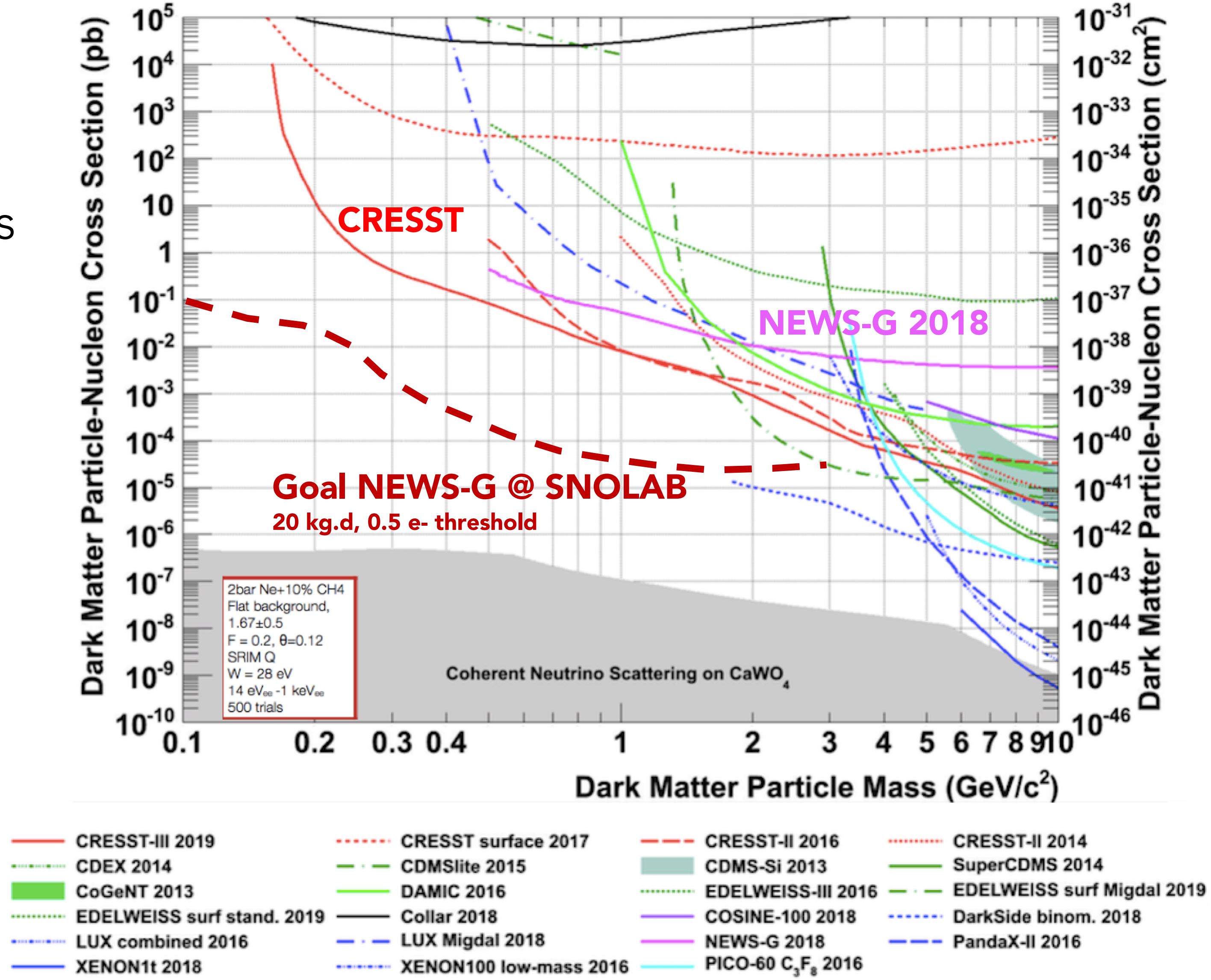
G. Gerbier

NEWS-G: Goals

- Low atomic mass targets (He, CH_4, Ne) to match mass of light WIMPs
- What signal to expect from low mass WIMPs

Signal from a 0.5 GeV WIMP on proton

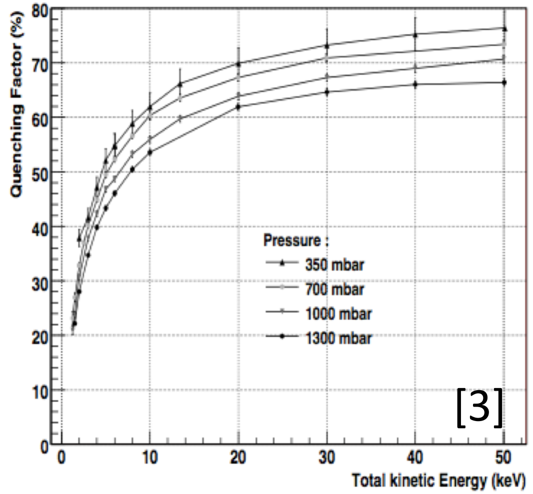




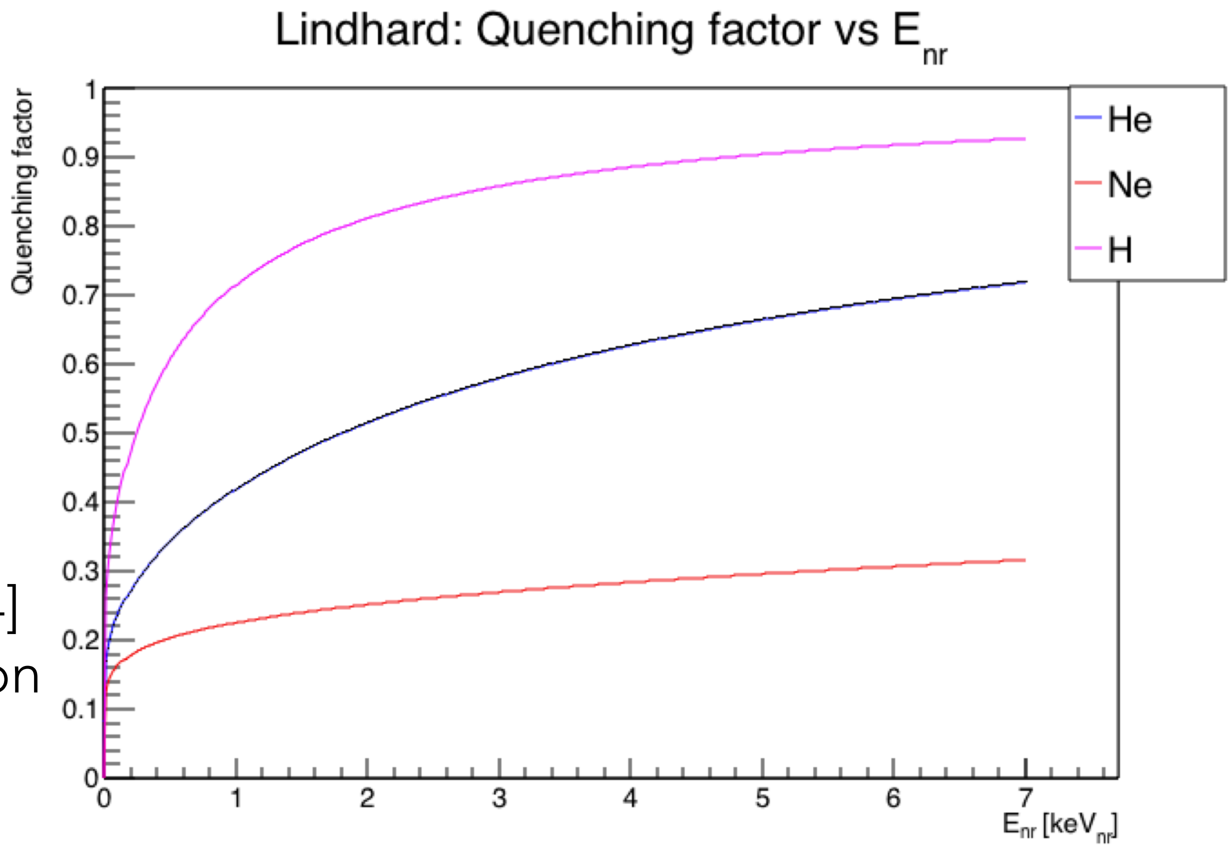
G. Gerbier, D. Durnford

Quenching factor

- ^{4}He: data available using MIMAC.



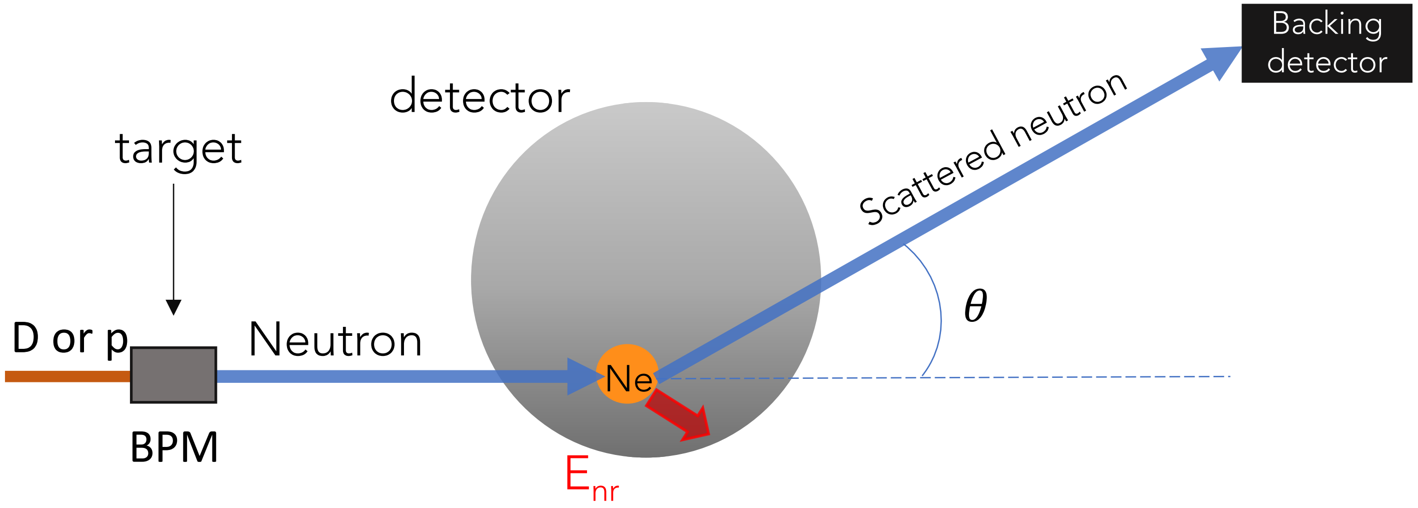
- H: investigation on isobutane by MIMAC [4]
- H: project to develop a high intensity proton and low energy (~30 keV) neutron beam at Queen's.



- ^{20}Ne: need to get measurements, experiment at the TUNL facility.

[3] D. Santos, F. Mayet, O. Guillaudin et al.: arXiv:08101137v1
[4] B.Tampon, D. Santos, O. Guillaudin, J-F. Muraz, L. Lebreton, T. Vinchon and P. Querre: DOI: 10.1051/epjconf/201715301014

Quenching factor measurements



- E_n: known
- θ: chosen
- E_{nr}: calculated
- E_{ee}: extracted energy mean from energy spectrum (ideally)

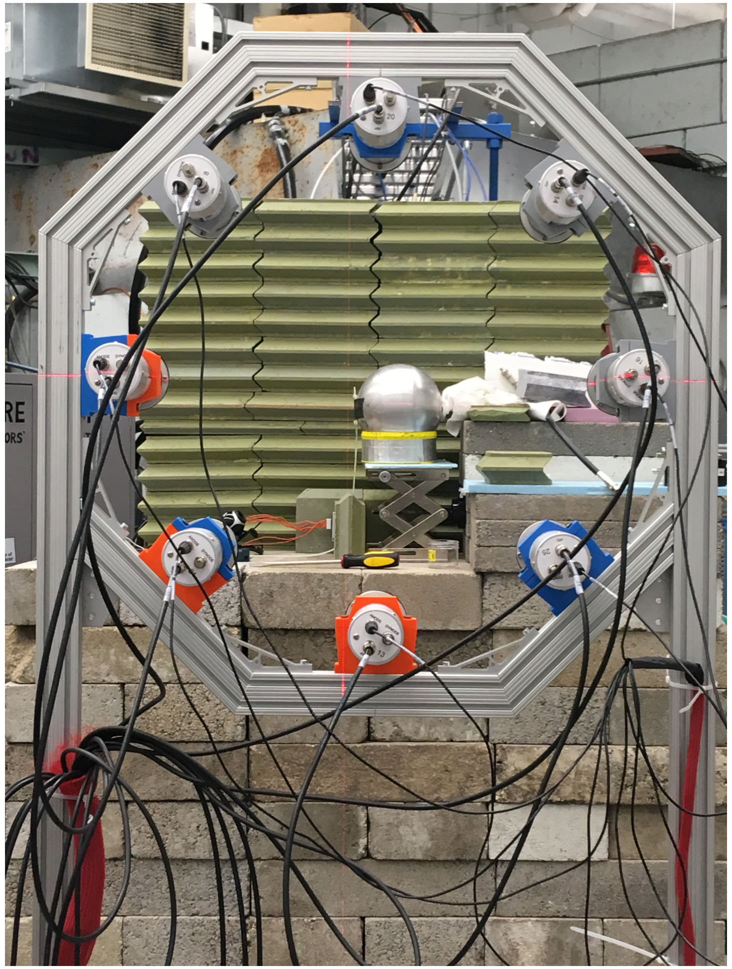
- Backing detectors (BD)
- Beam Pick-off Monitor (BPM)

Quenching factor measurements

- Organization of 2 measurements campaign at the TUNL facility in May 2018 and in February 2019.
  - 2018 campaign: D+D→ n+^{3}He+γ: Neutron beam 3.68 MeV, 4energy points: 4.95-28 keV_{nr}
  - 2019 campaign: p + ^{7}Li → n + ^{7}Be+ γ: Neutron beam 545keV, 8 energy points: 0.34-6.5 keV_{nr}

- Gas: Neon:CH_4 (97:3)
- Pressure (2018/2019): 500mbar/2bar
- Energy calibration: Fe55 peak at 5.9keV

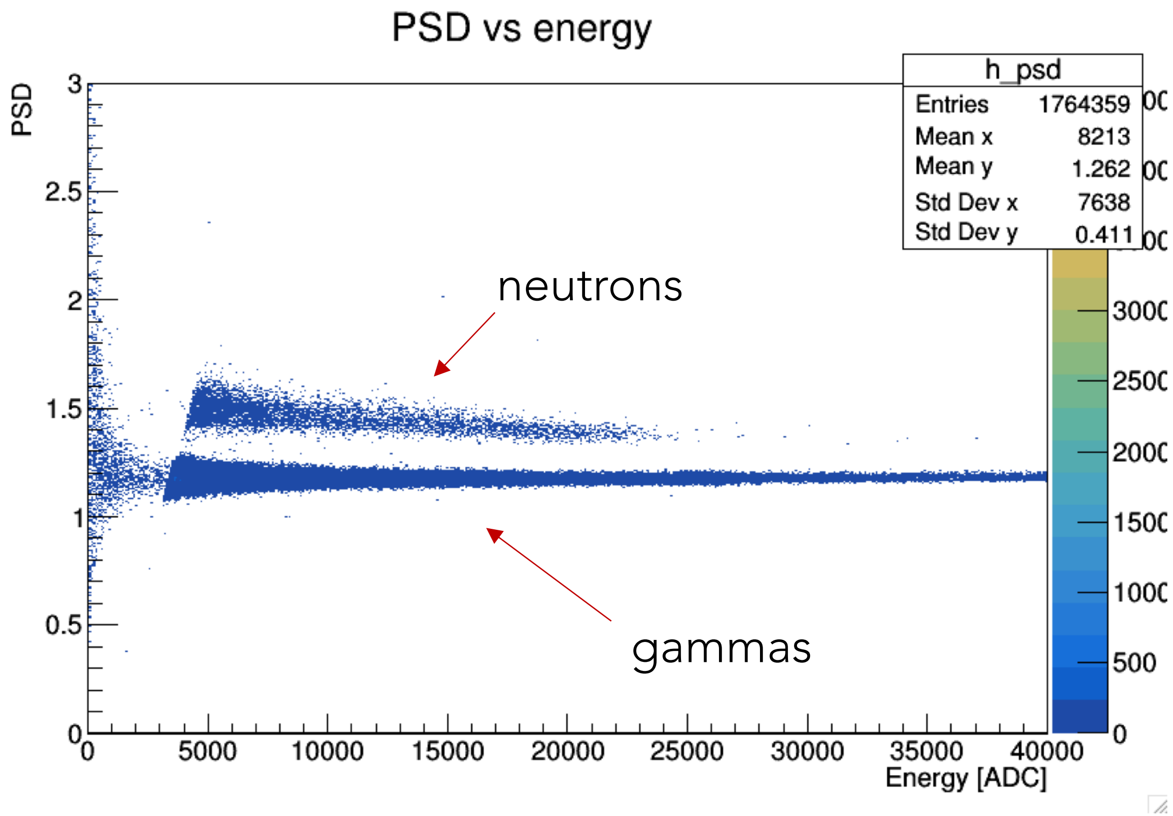
Quenching factor: 2 Experimental Set Ups

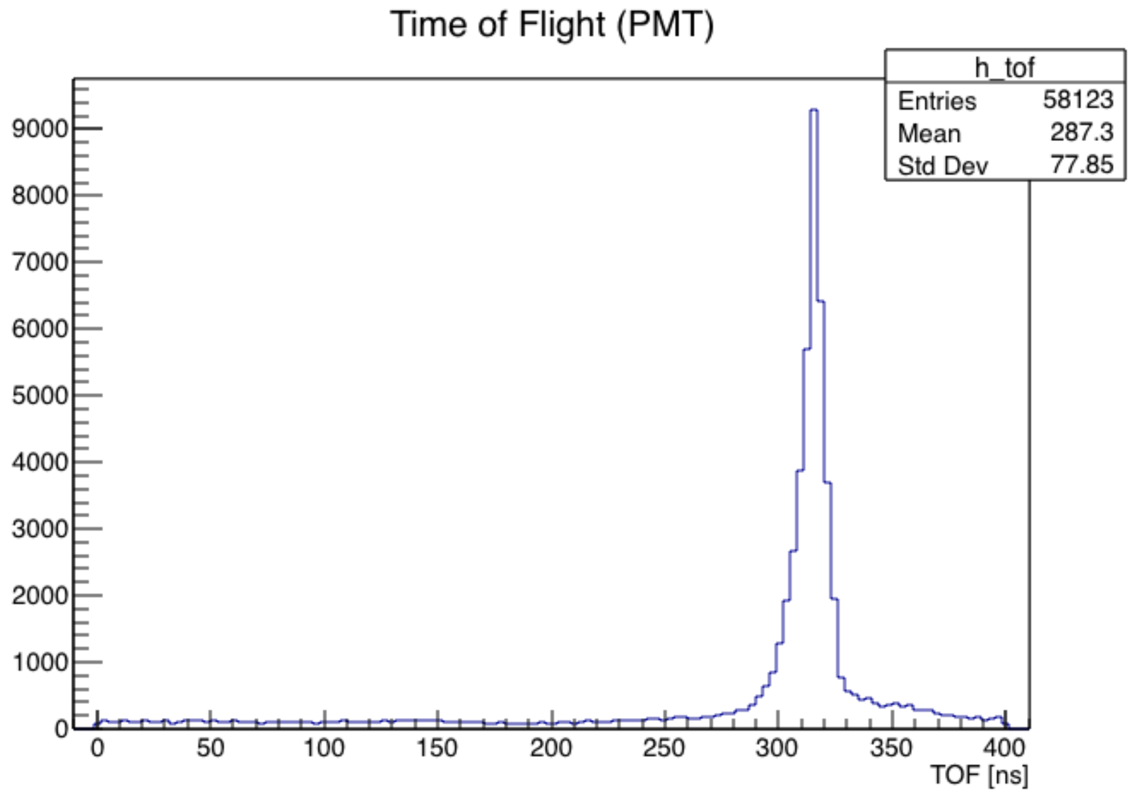


Annulus configuration

Multiple energies configuration

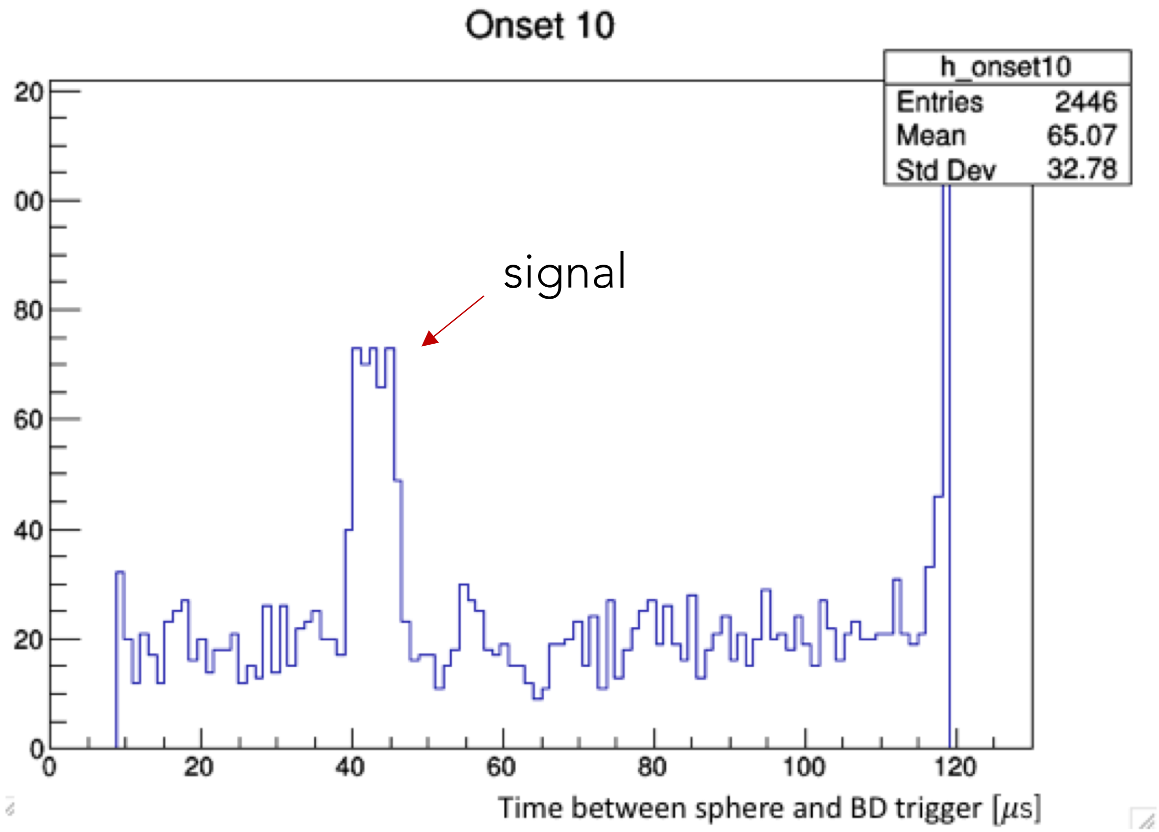
Analysis: recoil event selection by BDs





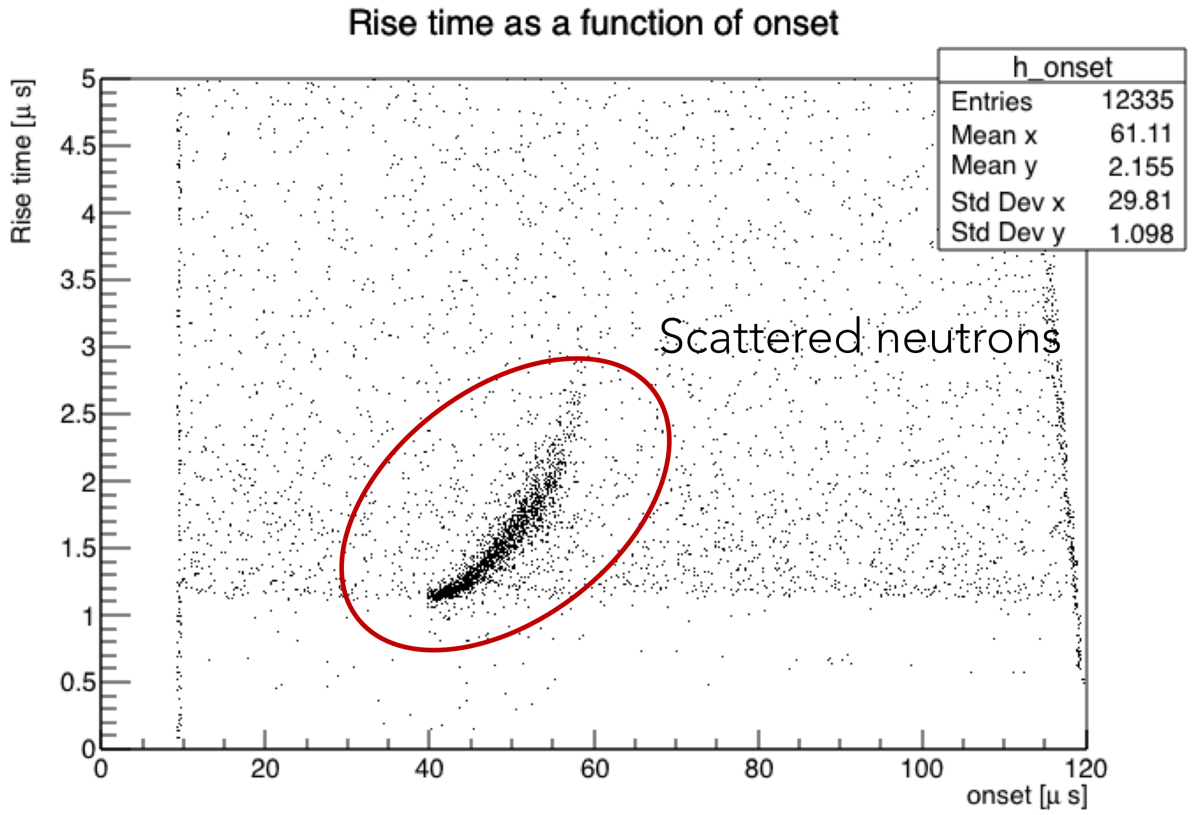
Time of flight: time of the neutron event at backing detector – time of the neutron event at BPM

Analysis: recoil event selection



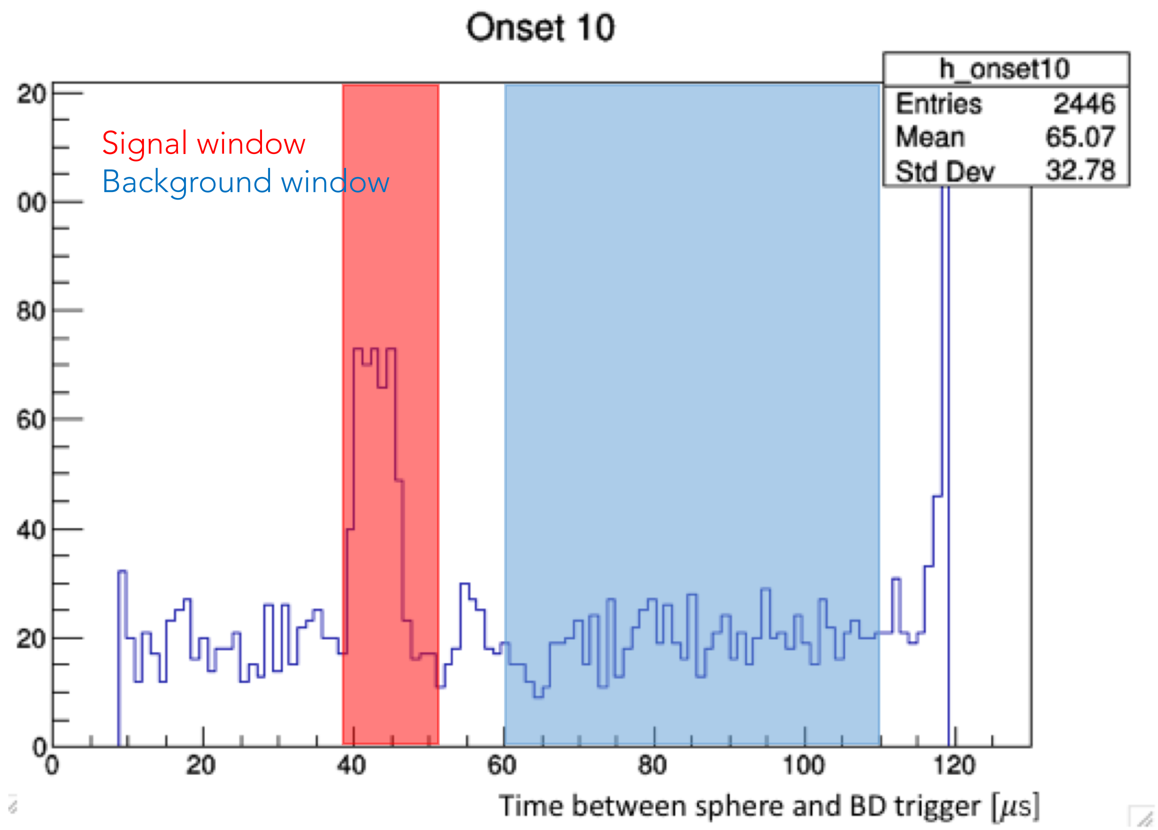
Location of SPC events in time relative to the DAQ trigger (/BD trigger)

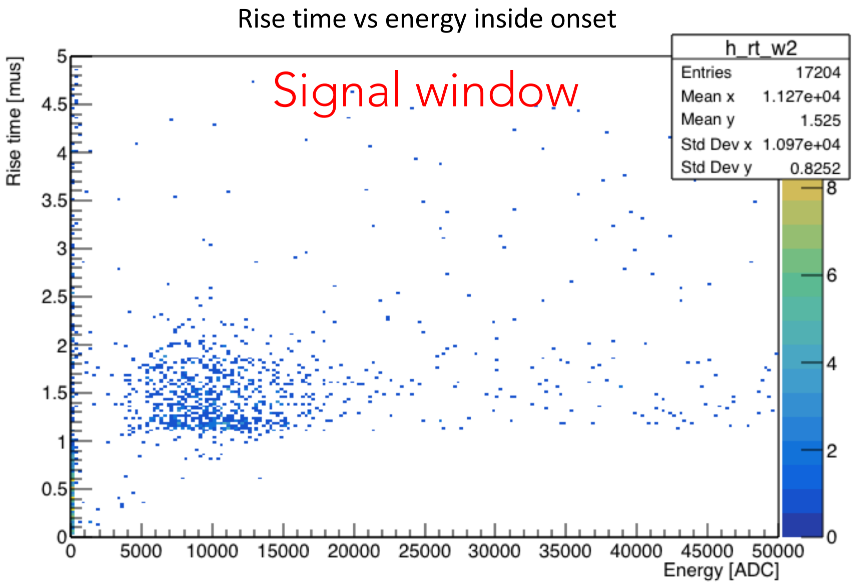
- Excess between 40 μs and 55 μs

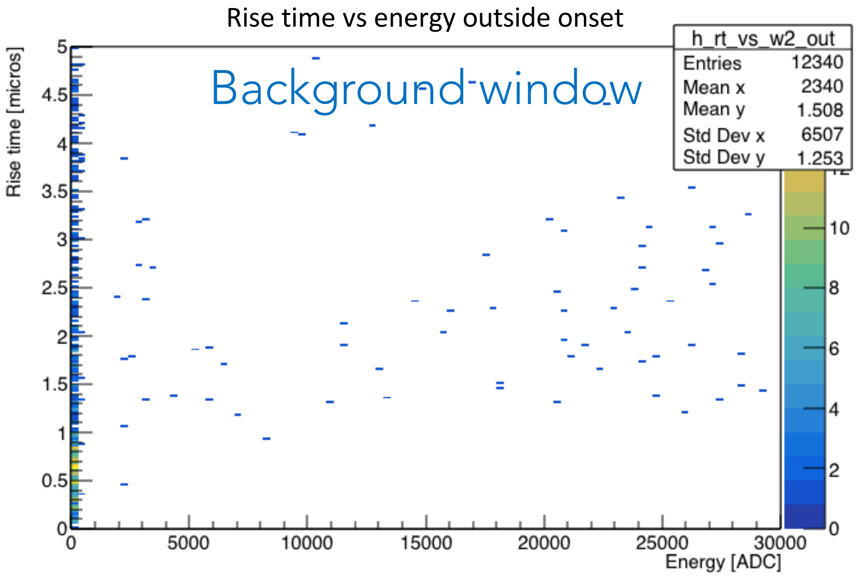


Dependence on rise time and onset time

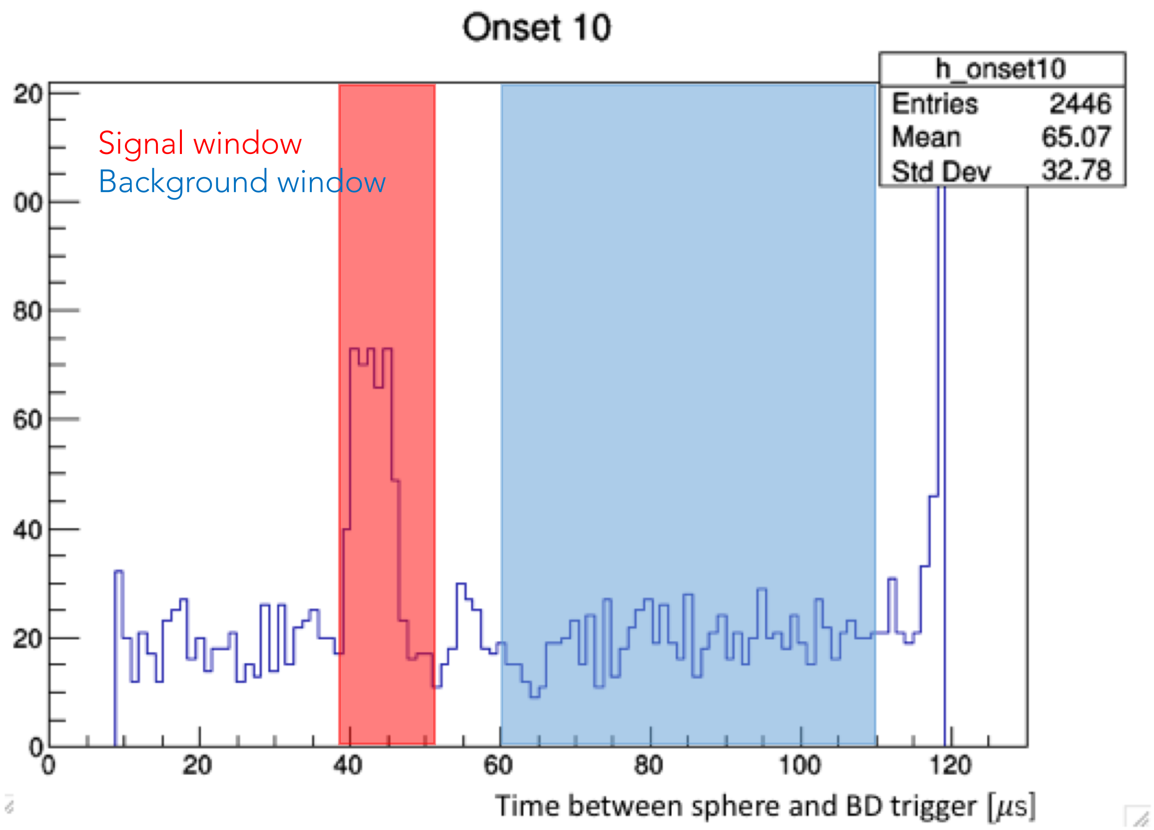
Analysis: recoil event selection

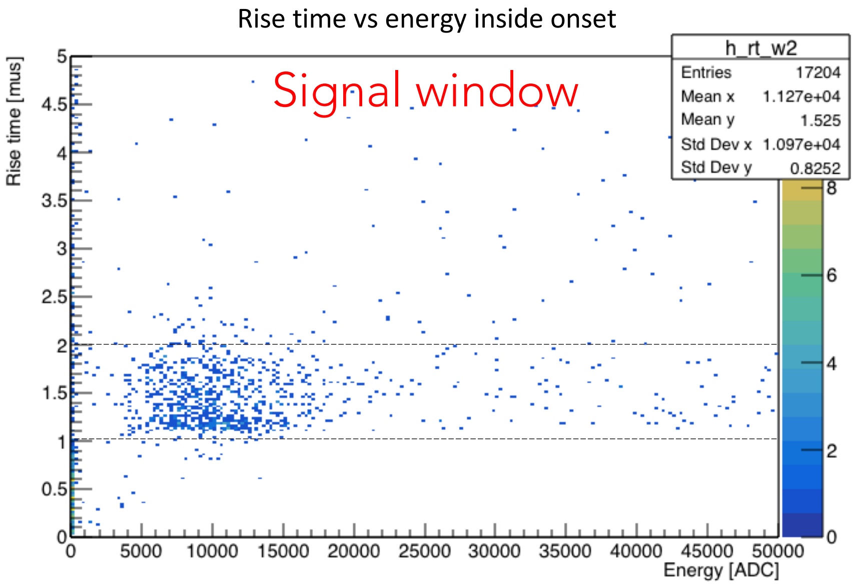


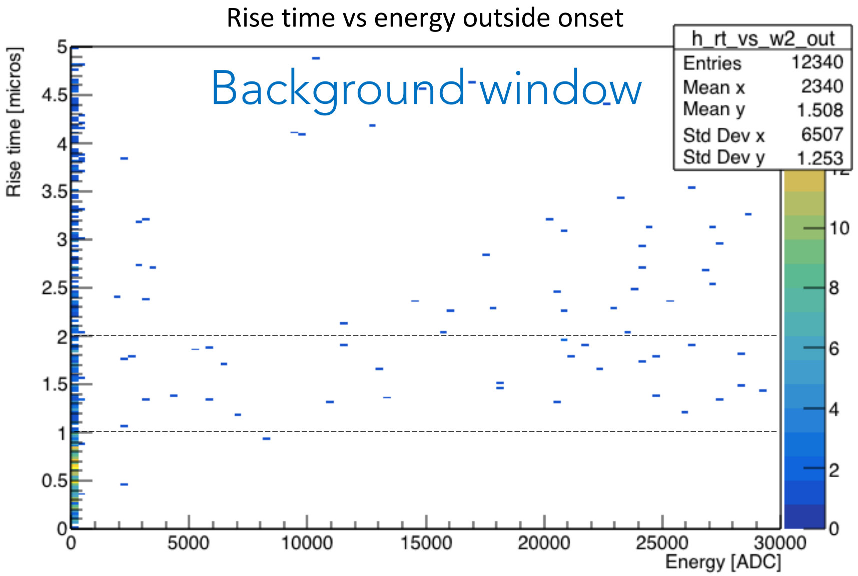




Analysis: recoil event selection

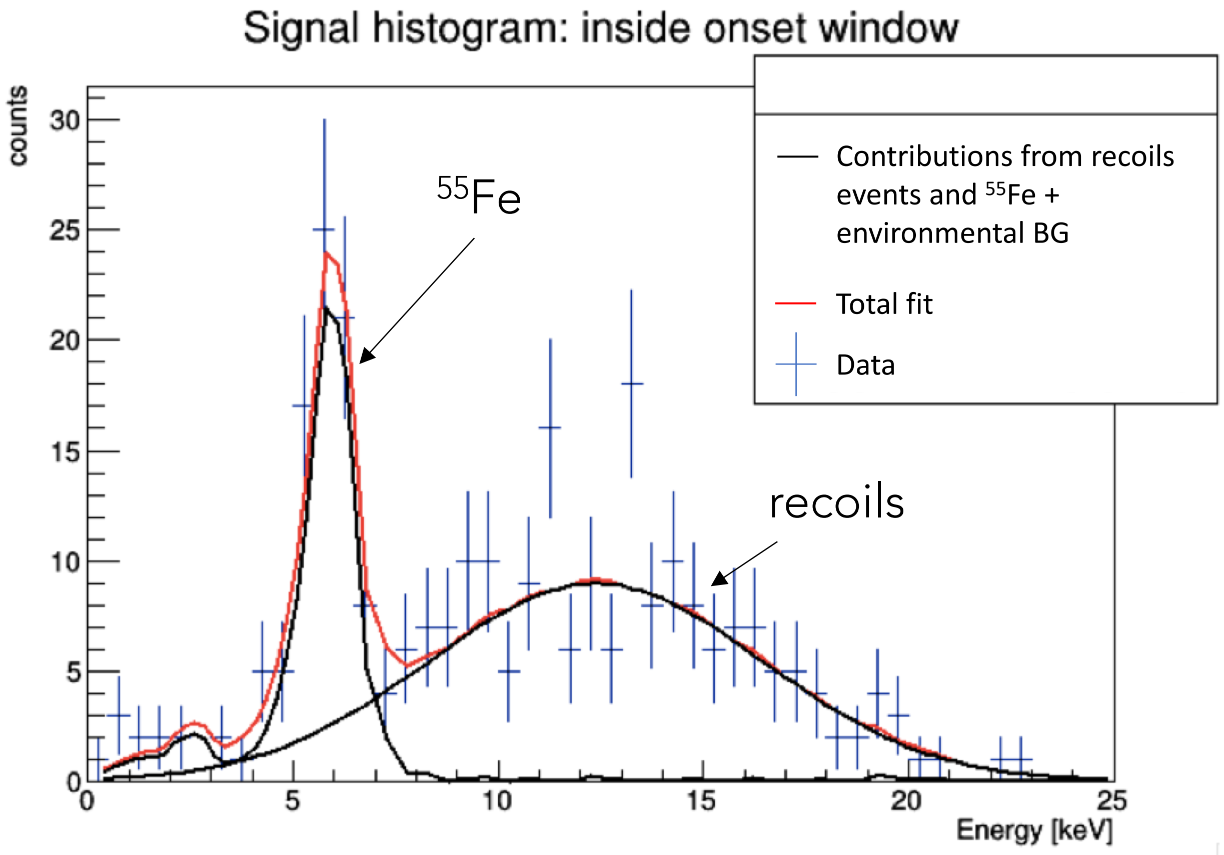






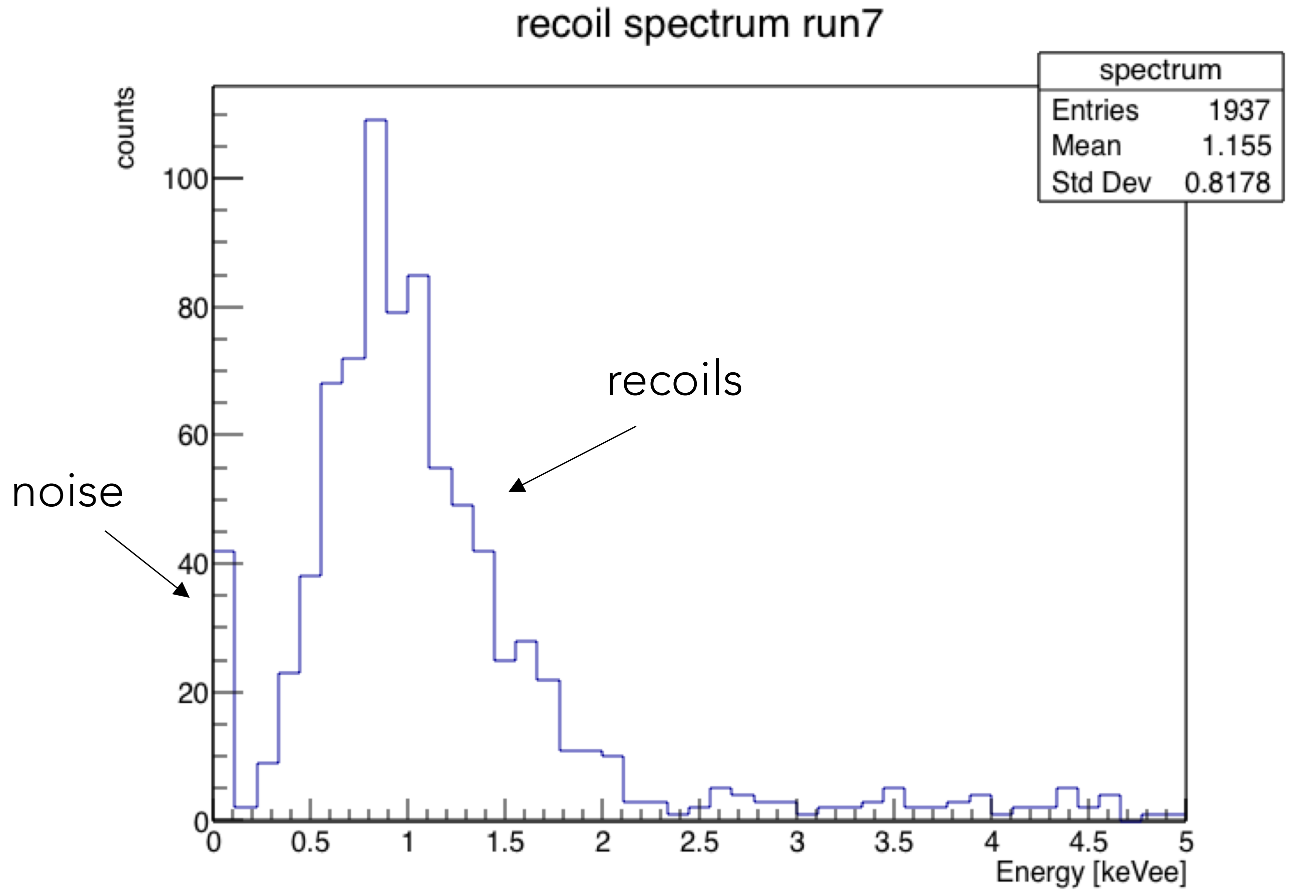
Rise time cuts to build energy spectra.

Energy spectrum for 2018 campaign



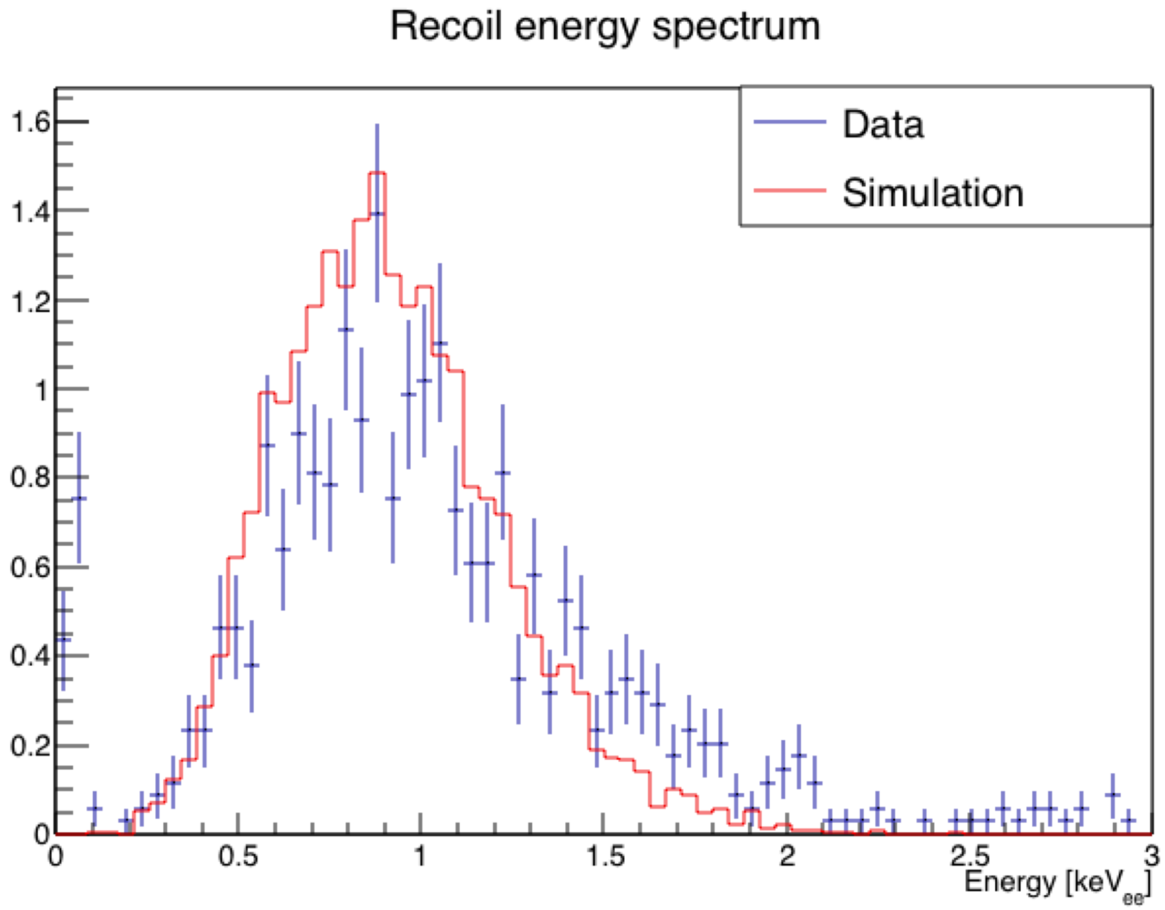
- During data taking the ^{55}Fe source was still in front the window.
- Fit of the recoils peak with a gaussian
- Fit of the background with interpolation of the background energy spectrum (from outside onset window).
- E_{ee} mean returned by fitter: estimation of QF for the 4 data points investigated in 2018.

Energy spectrum for 2019 campaign



- No calibration during data taking.
- The recoil peak can no longer be modelled by a gaussian.
- Background flat and noise peak.
- Can no longer extract the energy mean E_{ee} from fit.
- Need to come up with a model of the recoil peak
- Unbinned log likelihood of the data.

Study of the peak shape



- Take into account the geometry of the experiment: impact on scattering angle
- Take into account the response of the detector:
  - Primary ionization: Poisson
  - Second ionization (avalanche): Polya
- Include quenching factor: constant
- Simulation and data don't match at higher energy.

QF(E_{nr})

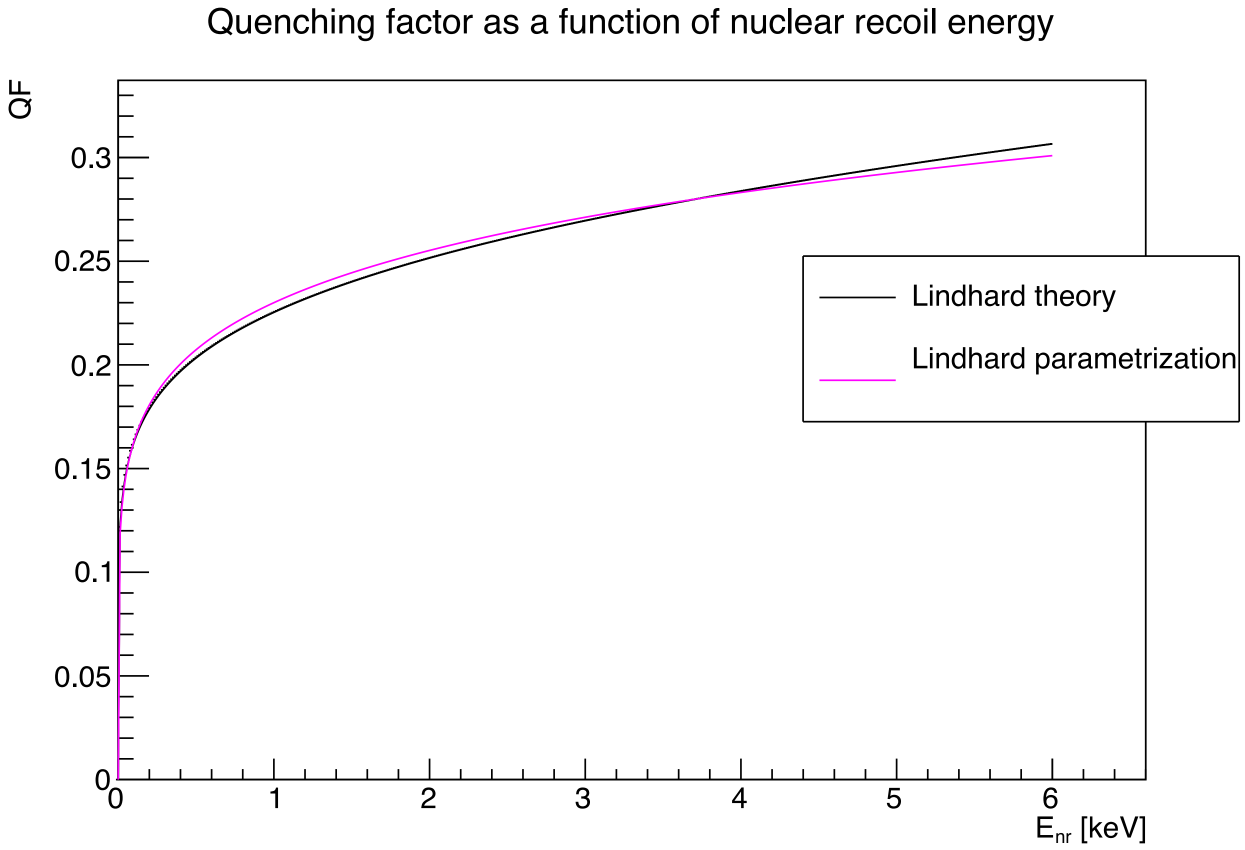
- Lindhard: $$f_n = \frac{kg(\epsilon)}{1+kg(\epsilon)}$$

$$k = 0.133 Z^{2/3} A^{-1/2}$$

$$\epsilon = 11.5 E_r Z^{7/3}$$

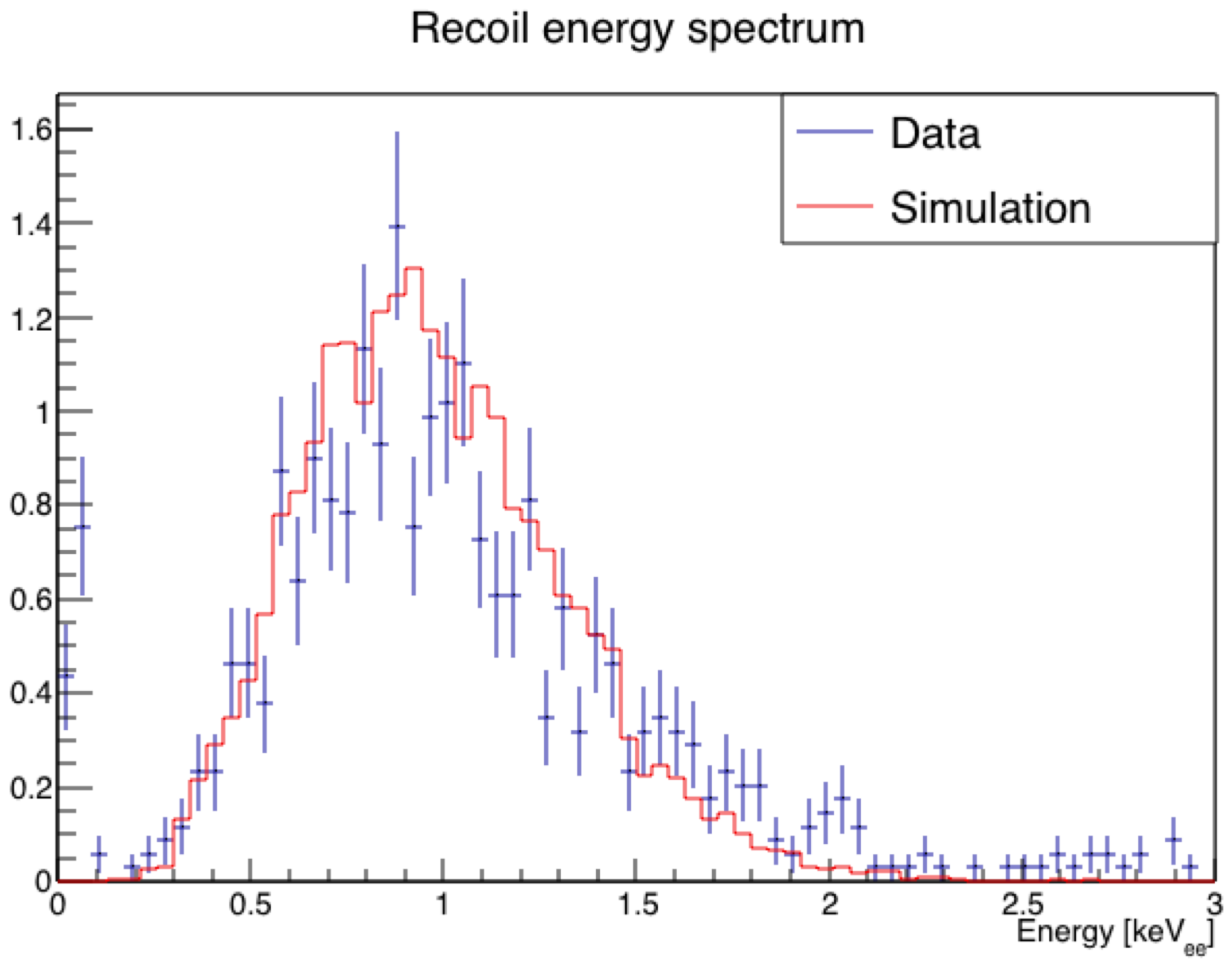
$$g(\epsilon) = 3\epsilon^{0.15} + 0.7\epsilon^{0.6} + \epsilon$$

- Parametrization of Lindhard, already used by DM experiments (e.g. Edelweiss): $$QF(E_{nr}) = \alpha E_{nr}^{\beta}$$



Study of the peak shape

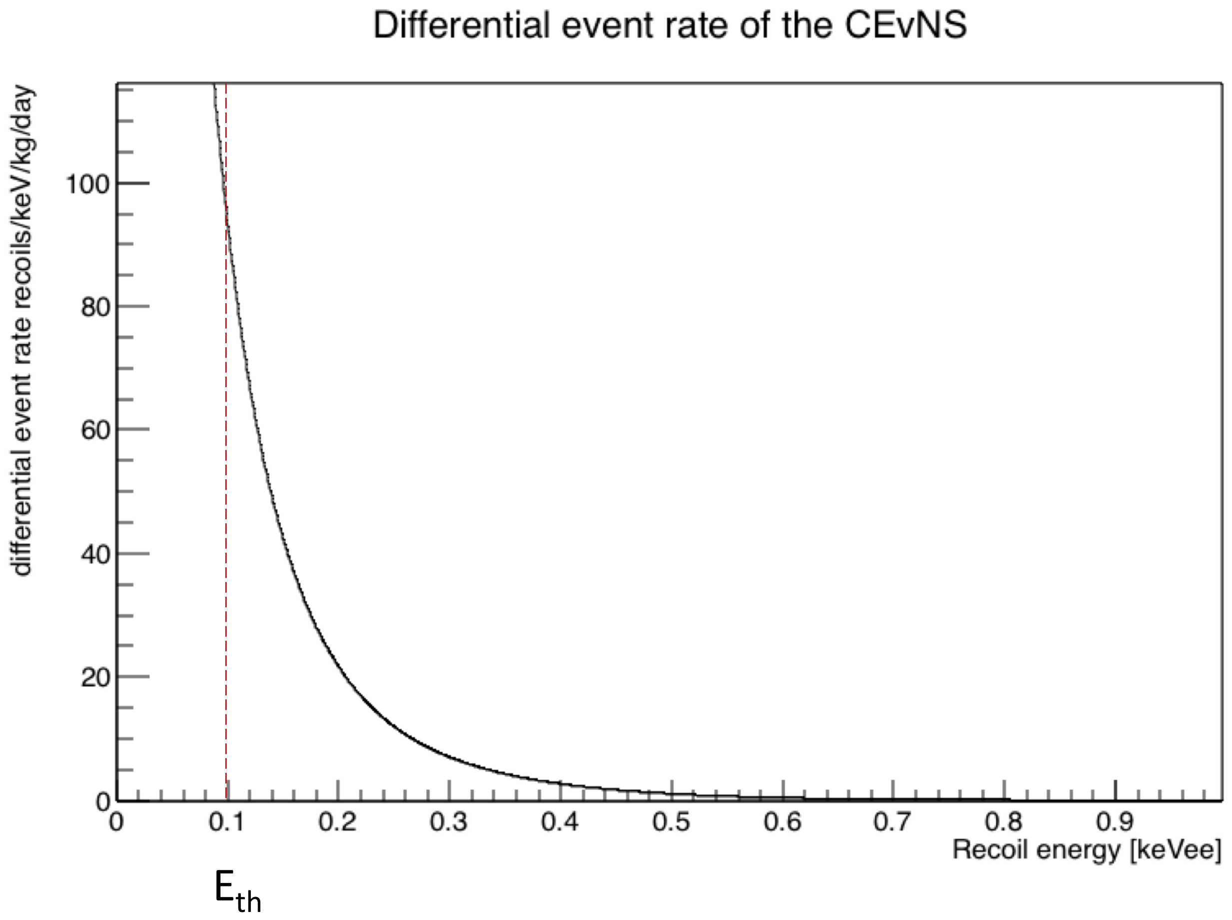
- Higher energies described better.
- Fit the data using QF(E_{nr}): Lindhard parametrization.
- Work on the ULLH is on going: paper to come out soon.



Preliminary calculation: CEvNS

First estimation of the event rate:

- Target: ^{40}Ar
- Source nuclear reactor: Baldoncini's model, neutrino flux of ~ 2 x 10^{20} ν/s/GW
- 1 GW thermal power
- Detector 10m from core
- Lindhard: quenching factor (*arXiv:0712.2470v2 [nucl-ex]*)
- Considering E_{th} = 100 eV_{ee}: ~ 7 CEνNS events/kg/day



CEνNS future work

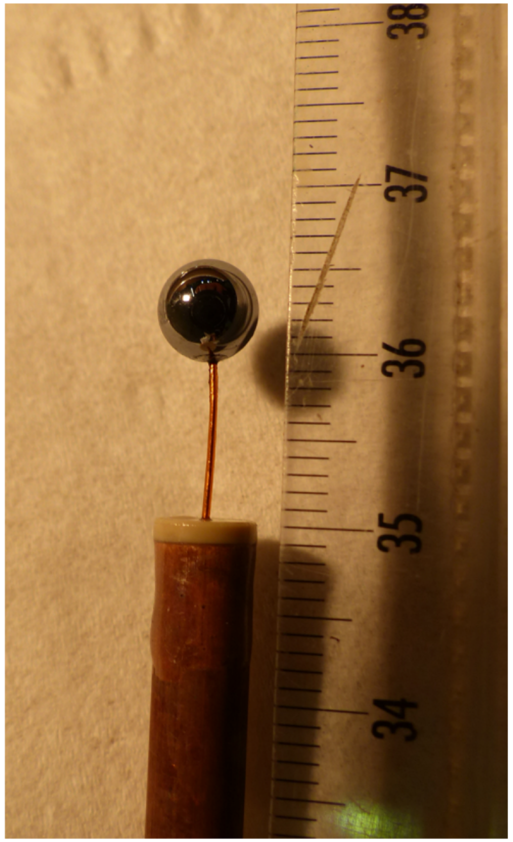
- Include complete response of the detector
- Study of the background, develop appropriate shielding
  - shielding expected size: 1.4 x 1.4 x 1.4 m^3
- Find nuclear power plant site
- Develop a complete simulation (Geant4): size SPC (its response), gas, pressure, shielding
  - constrained by the detectable rate of neutrino interactions

Conclusion

- The NEWS-G collaboration is competitive in light dark matter searches.
  - Promising first results
  - New experiment development NEWS@SNO
- Quenching factor measurements
  - Neon down to 0.34 keV_{nr}: paper soon to be published.
  - Challenge on proton: developing a low energy neutron beam project at RMTL.
- Use technology developed by NEWS-G collaboration to detect CEνNS.
- Develop a project to use SPCs to detect CEνNS using reactor neutrinos. Collaborations are welcome!

Thank you

R&D sensor



"old sensor"

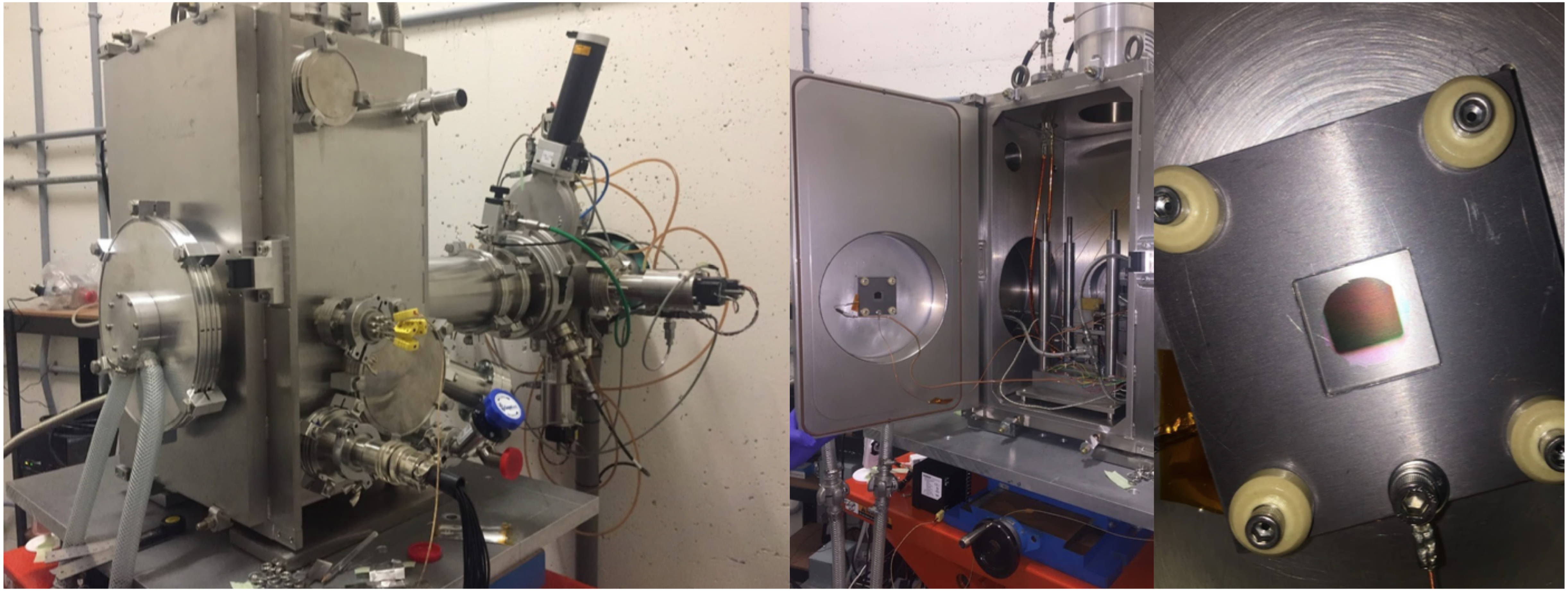
"new sensor"
Rod + umbrella
(bakelite) + ball

achinos

QF experiments at Queen’s: RMTL

- The Reactor Materials Testing Laboratory tests materials and devices for radiation damages.
- 1-8 MeV proton beam
- High beam current: 0.05-45 μA
- Target: LiF from Université de Montréal
- First tests:
  - target can handle 20 μA without elaborate cooling system.
  - proton beam profile is offset or broadened by 30 keV.
  - neutron energy spectrum very broad: due to proton beam profile, but also reflections r moderation?

QF experiments at Queen's: RMTL



J-F. Caron

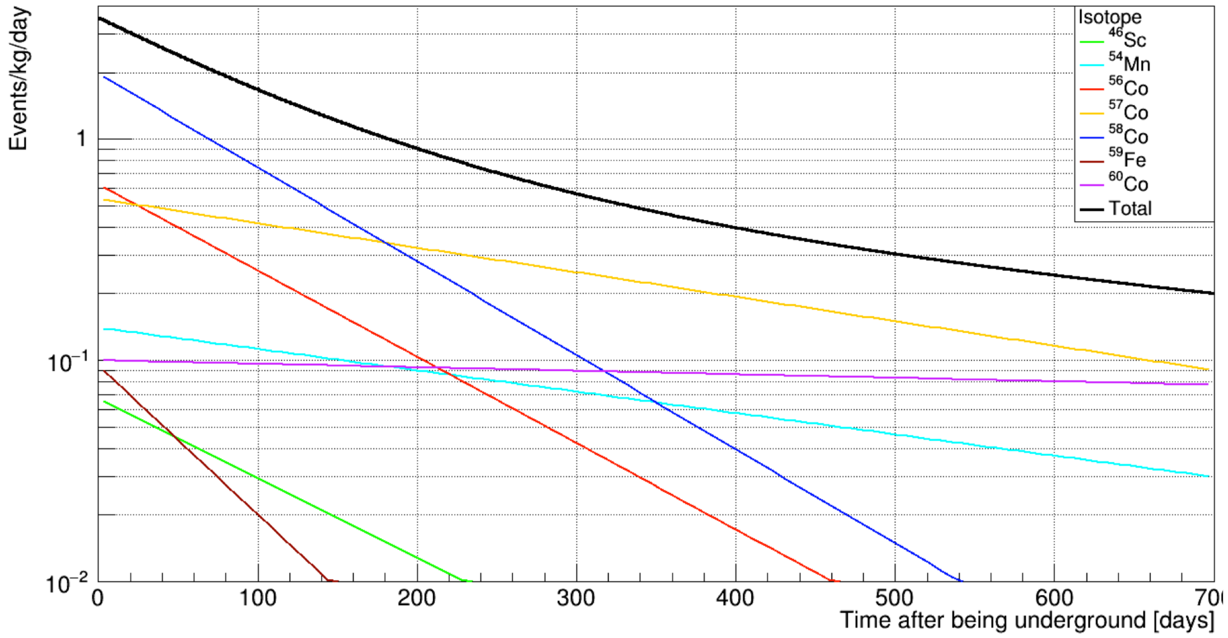
Background summary: Ne + 2%CH_4 at 2 bar

	Source	Contamination / flux		dru <1 keV
Copper Sphere 500 µm of electrolyte	^{210}Pb	28.5	mBq/kg	1.04
	^{238}U	3	µBq/kg	0.0117
	^{232}Th	13	µBq/kg	0.0754
Archeological Lead	^{210}Pb	<50	mBq/kg	0.28
	^{238}U	44.5	µBq/kg	0.142
	^{232}Th	9.1	µBq/kg	0.0256
Modern Lead	^{210}Pb	4.6	Bq/kg	0.053
	^{238}U	79	µBq/kg	0.17
	^{232}Th	9	µBq/kg	0.0251
Cavern	Gamma	2.11E+00	γ/cm2/s	0.00837
	Neutron	4000	n/m2/day	0.00438
	Muon	0.27	µ/m2/day	6.20E-04
Total without upper limit				1.56

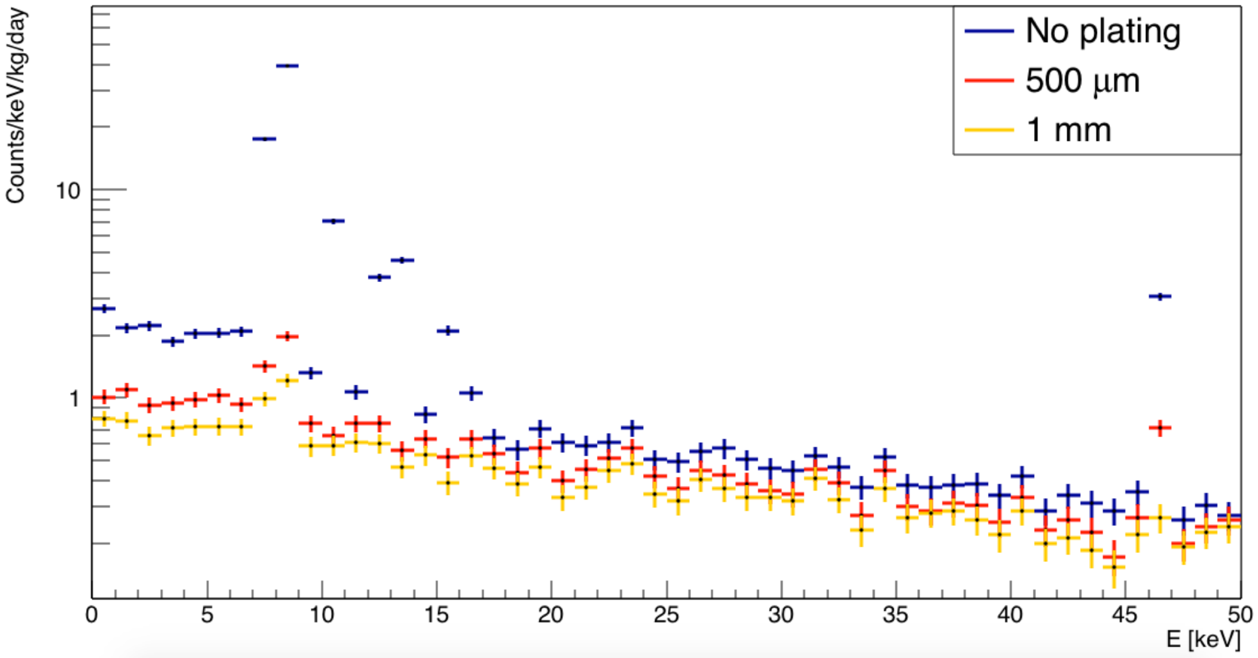
A. Brossard

Background summary: Ne + 2%CH_4 at 2 bar

Background induced by 3 months of cosmogenic activation of the copper sphere



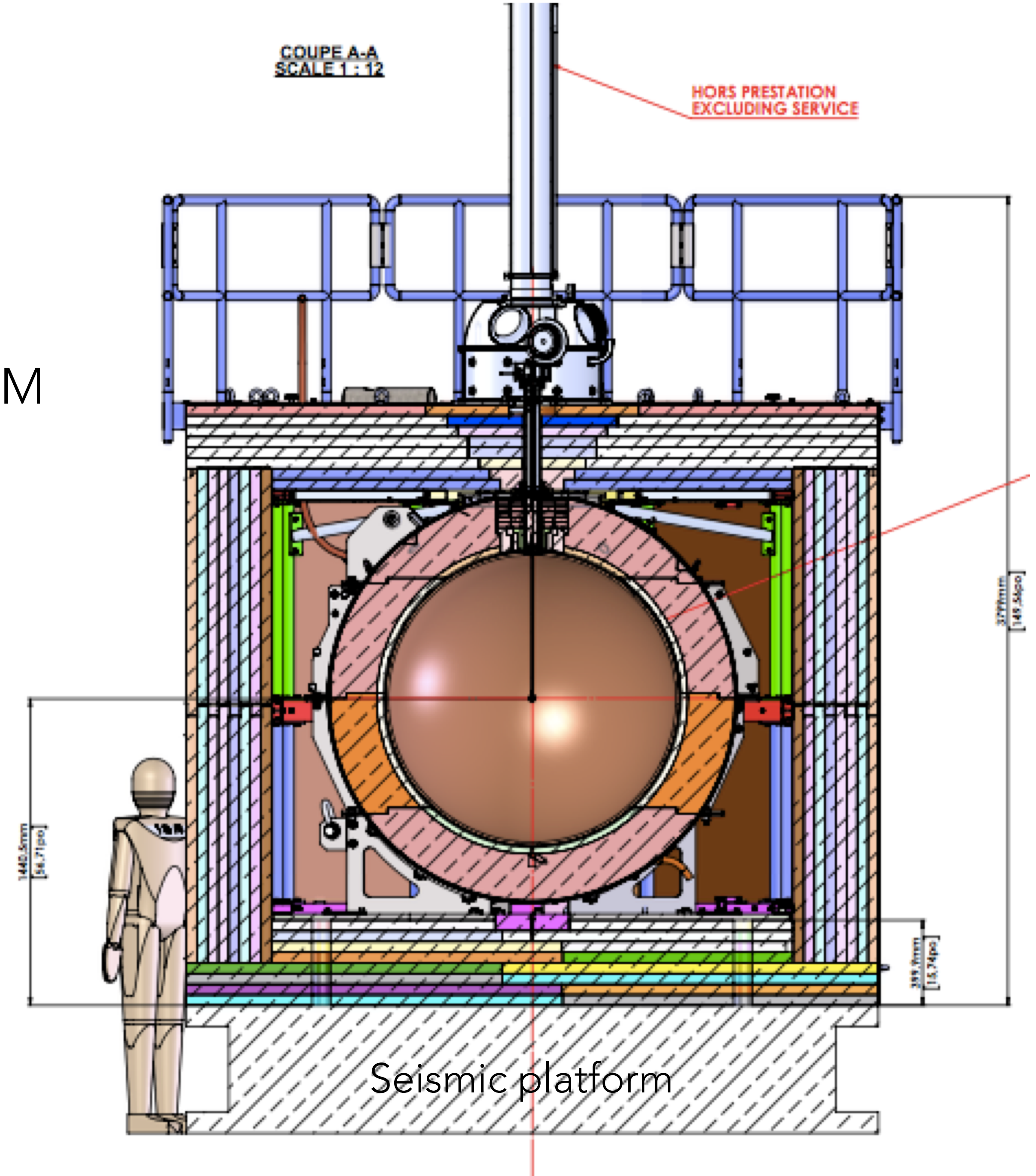
Effect of the electroplating on ^{210}Pb in the copper sphere



A. Brossard.

Details of the SNOLAB project

- Glovebox system: Saclay (CEA) and LSM
- Copper sphere + lead shield: France
- Seismic platform: SNOLAB



Detector pictures