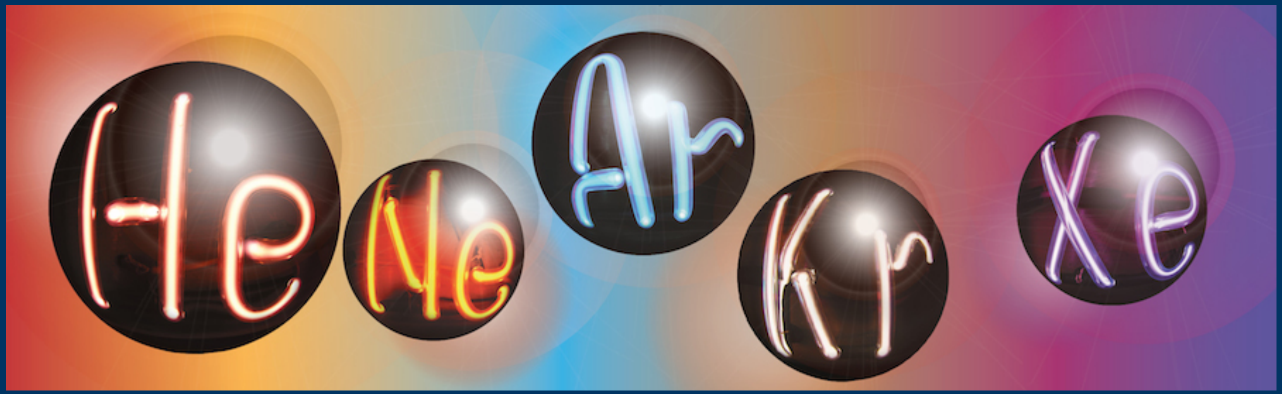
The PETALO project

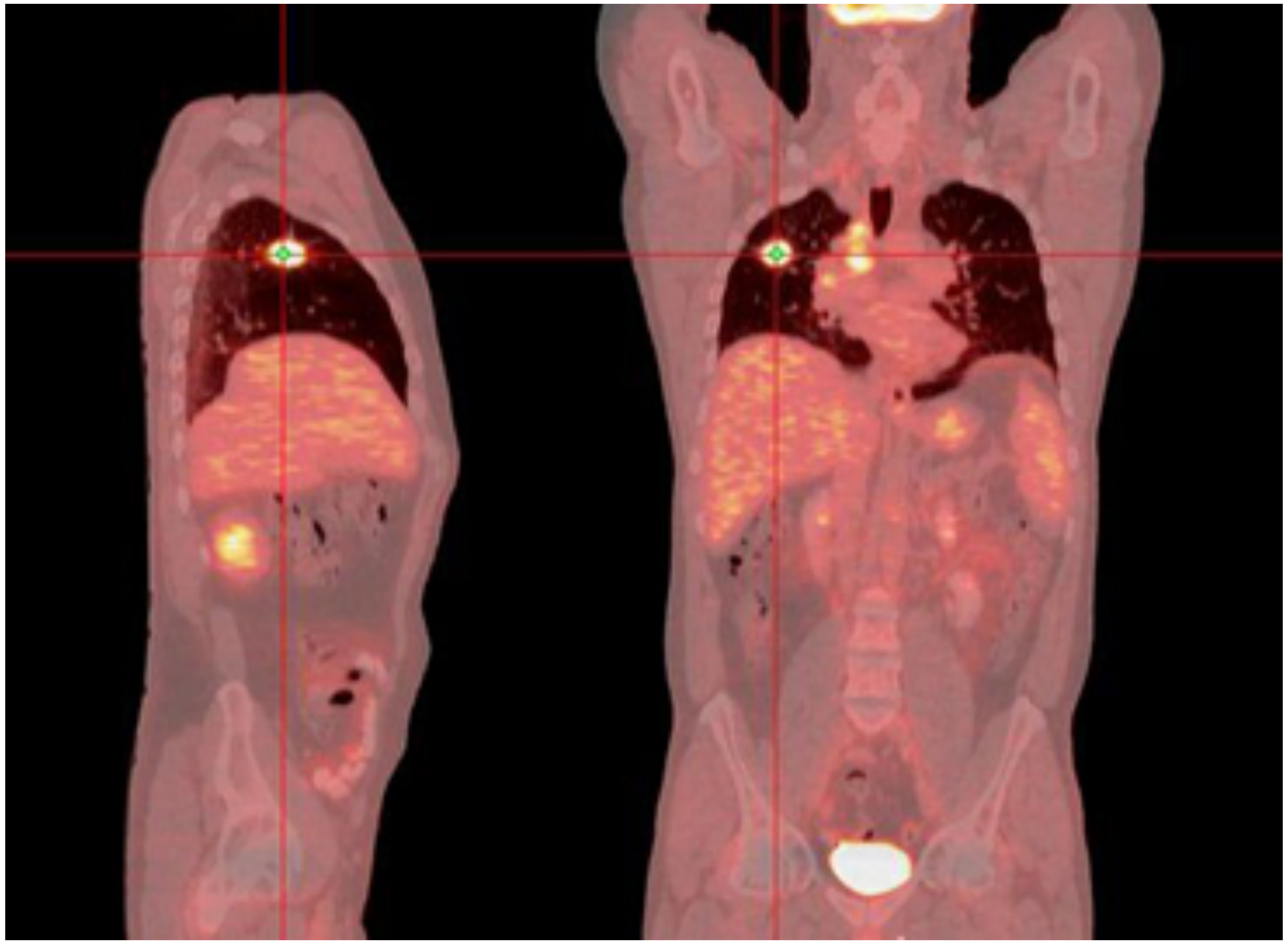
Positron Emission Tomography Apparatus based on Liquid xenOn



Paola Ferrario, DIPC&Ikerbasque, LIDINE 2022: LIght Detection In Noble Elements, 22/09/22, Warsaw

Positron emission tomography

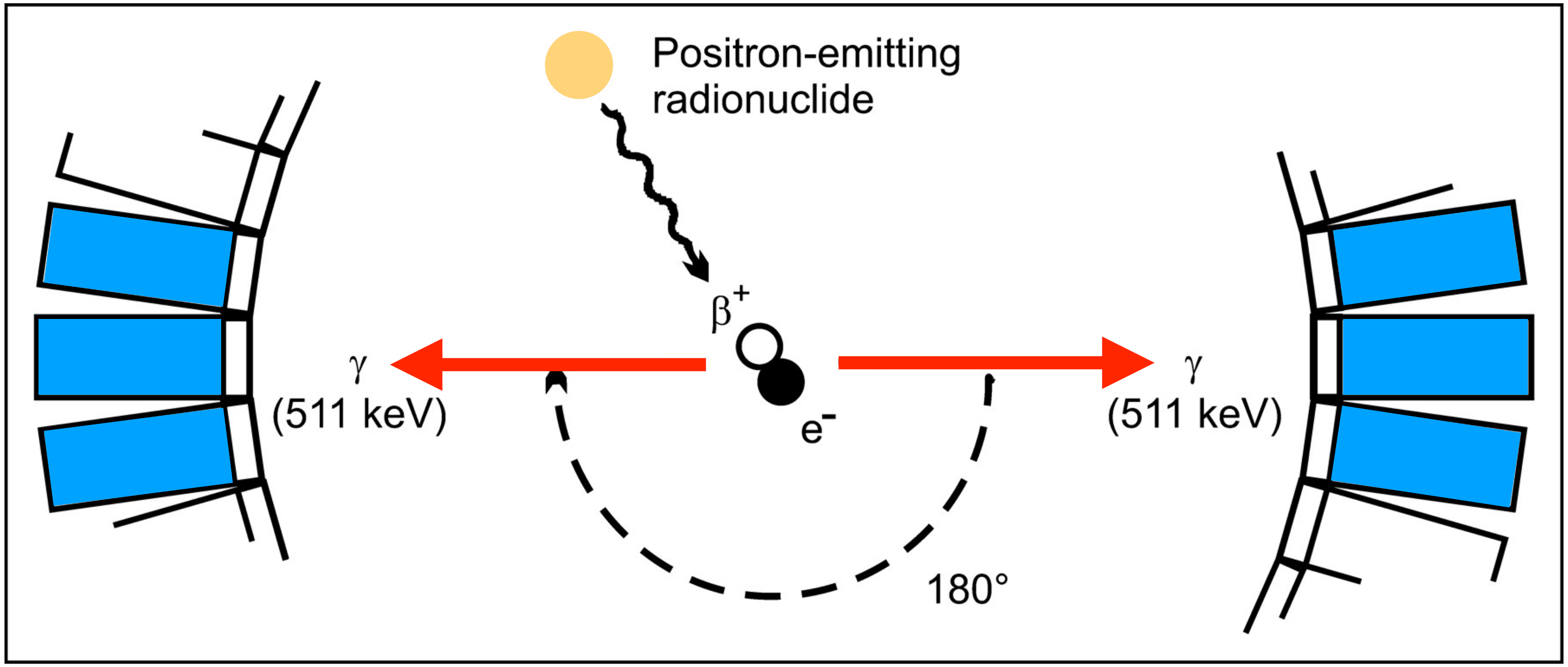
What



- PET scans shows the metabolic activity in an organ or tissue.
- High metabolism areas appear as bright spot.
- Used to detect and monitor cancer, central nervous system disorders (Alzheimer, Parkinson, epilepsy…) and cardiovascular diseases (i.e., revealing decrease of blood flow).

Positron emission tomography

How

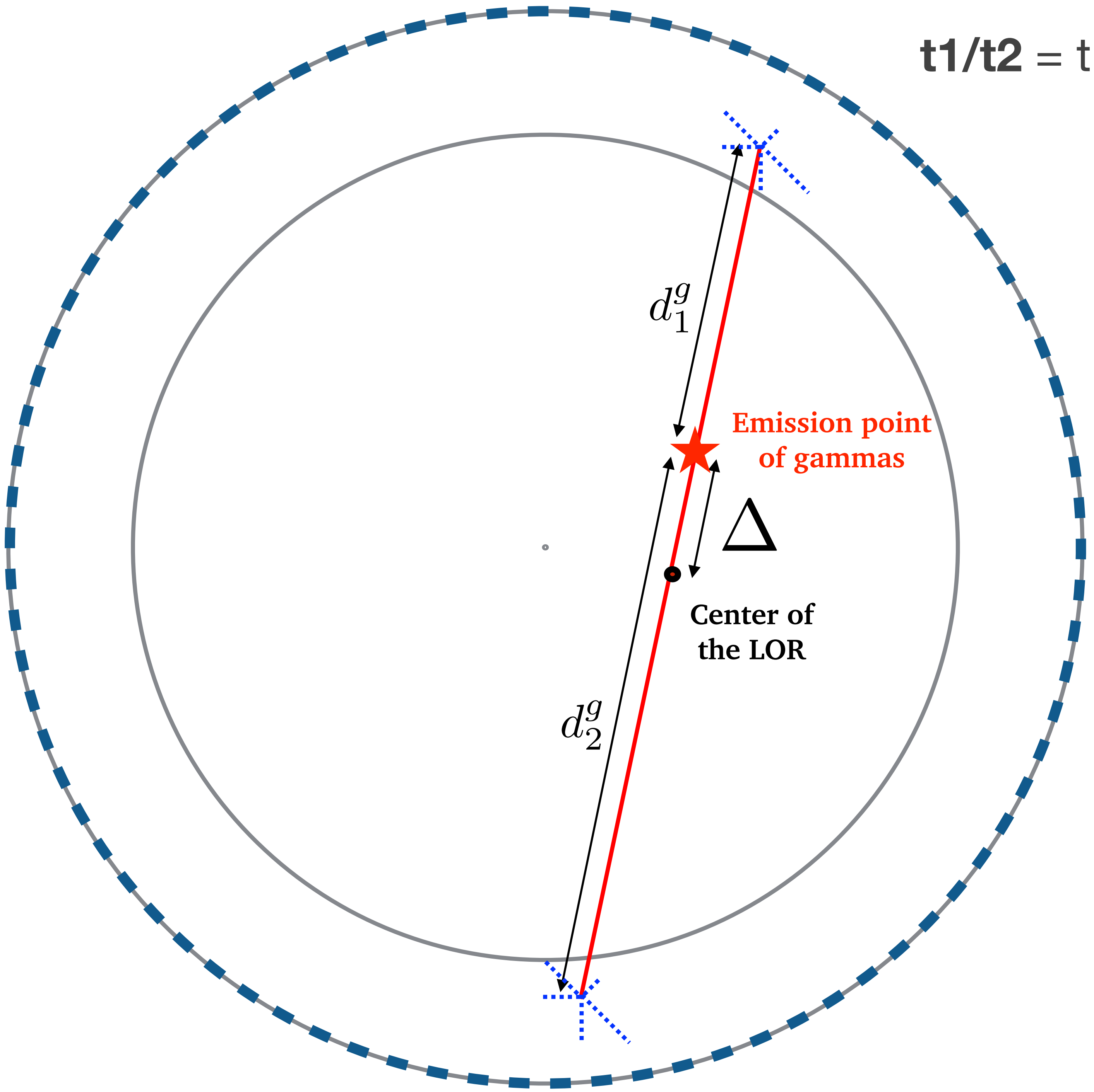


- Glucose analogue doped with β-emitter radioactive isotope.
- Positron annihilation produces two 511-keV gammas almost back-to-back.
- Gammas are detected by a ring of scintillators.
- A line of response (LOR) is identified through time coincidence of two detectors.
- Image is reconstructed crossing many LORs.

Time of Flight

Constraining the emission point

t1/t2 = time in which gamma1/gamma2 interacts



$$t_i = \frac{d_i^g}{c}$$

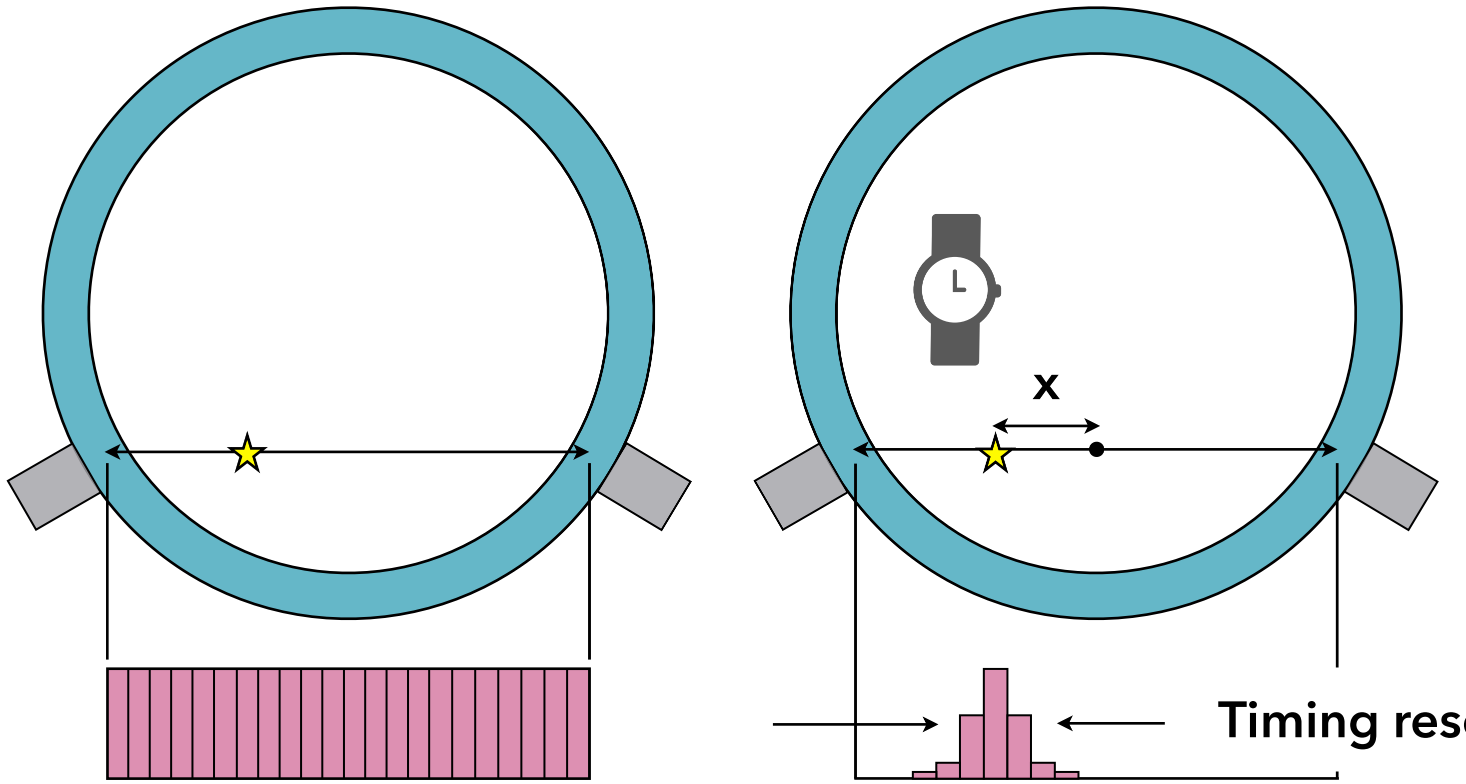
$$t_1 - t_2 = \frac{d_1^g}{c} - \frac{d_2^g}{c}$$

$$t_1 - t_2 = -2\frac{\Delta}{c}$$

$$\Delta = \frac{c}{2}(t_2 - t_1)$$

Time of Flight

Image improvement

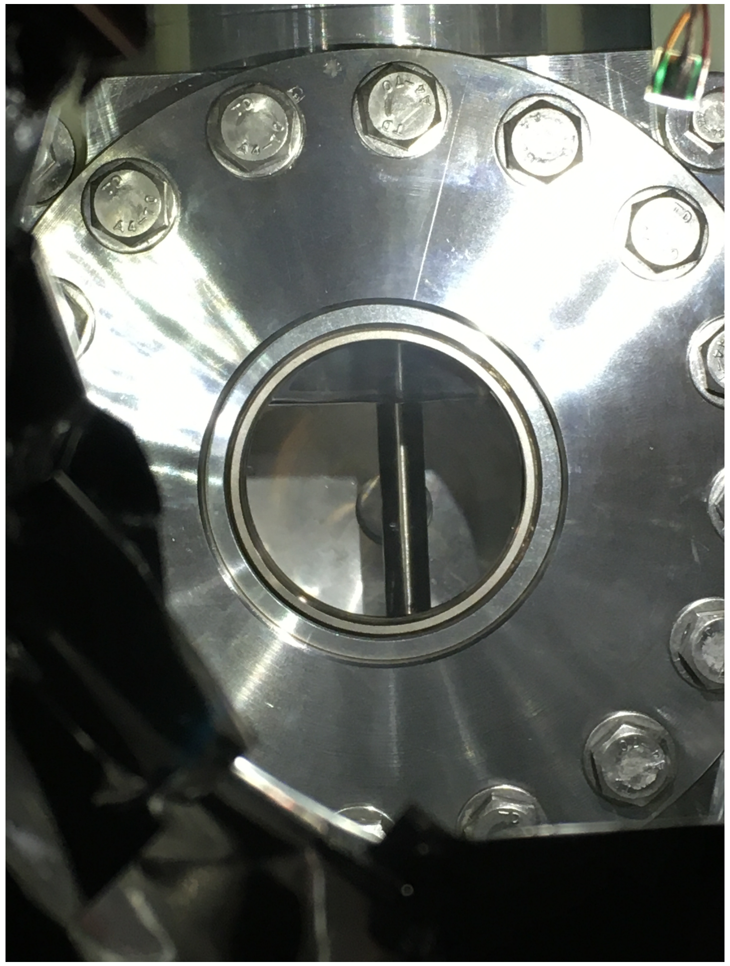


- **Time resolution**: scintillation time, propagation of photons in the material, jitter of photosensors and electronics.
- Noise is reduced.
- Results improve at low statistics or bad quality data.
- Sensitivity increases, exposure time and/or dosis can be reduced.

The PETALO concept

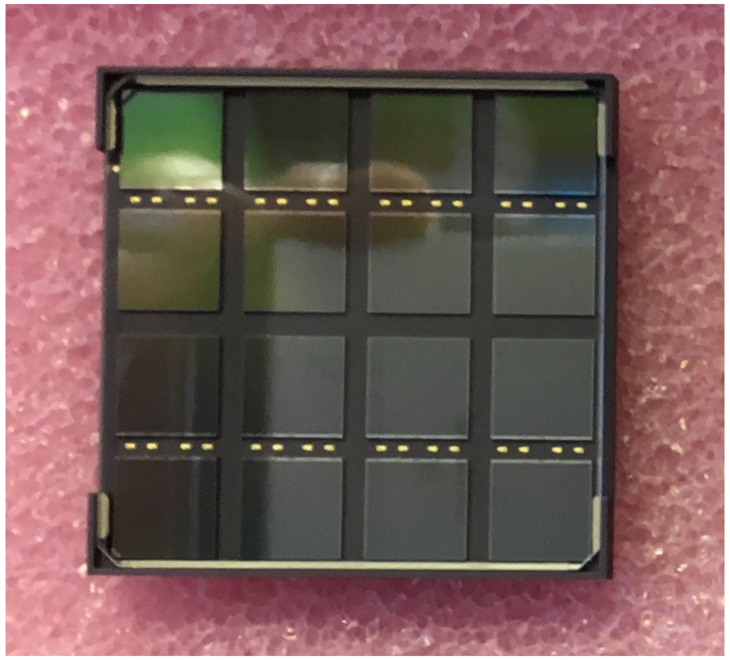
LXe

- Liquid xenon as scintillation medium.
- High yield (~30k ph/511 keV), fast time (2 ns in the fast component).
- Transparent to its own scintillation light.
- One volume compared to thousands of modules (crystals).

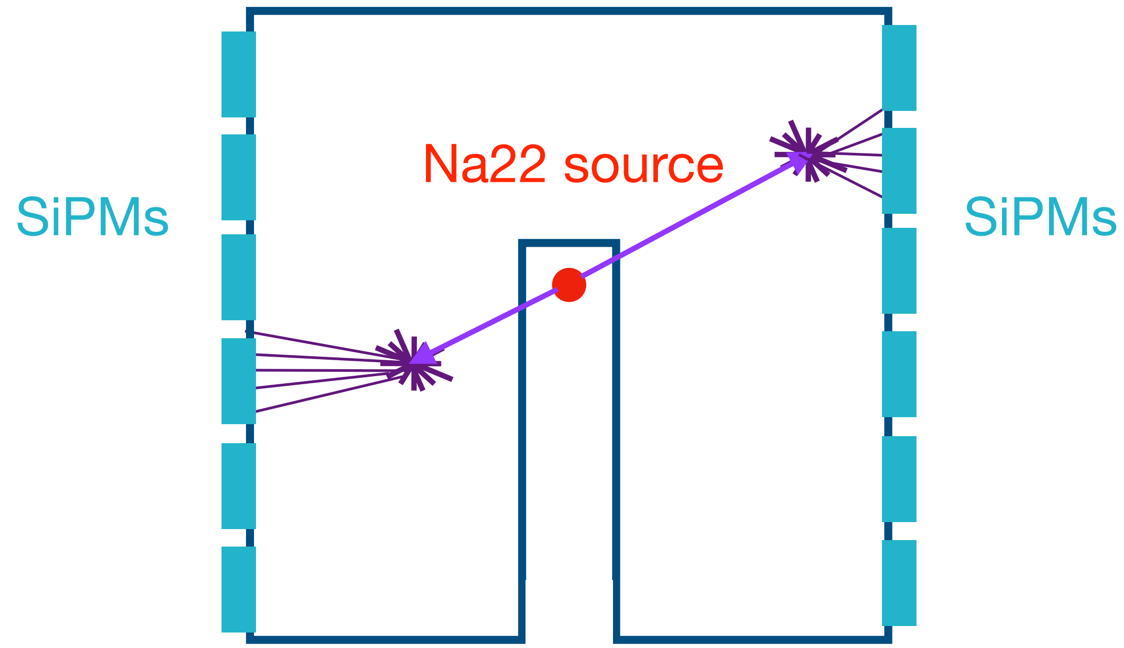


SiPMs

- Fast response, high gain.
- Almost no dark count at cryogenic temperatures.
- Compatibility with magnetic fields (NMR).

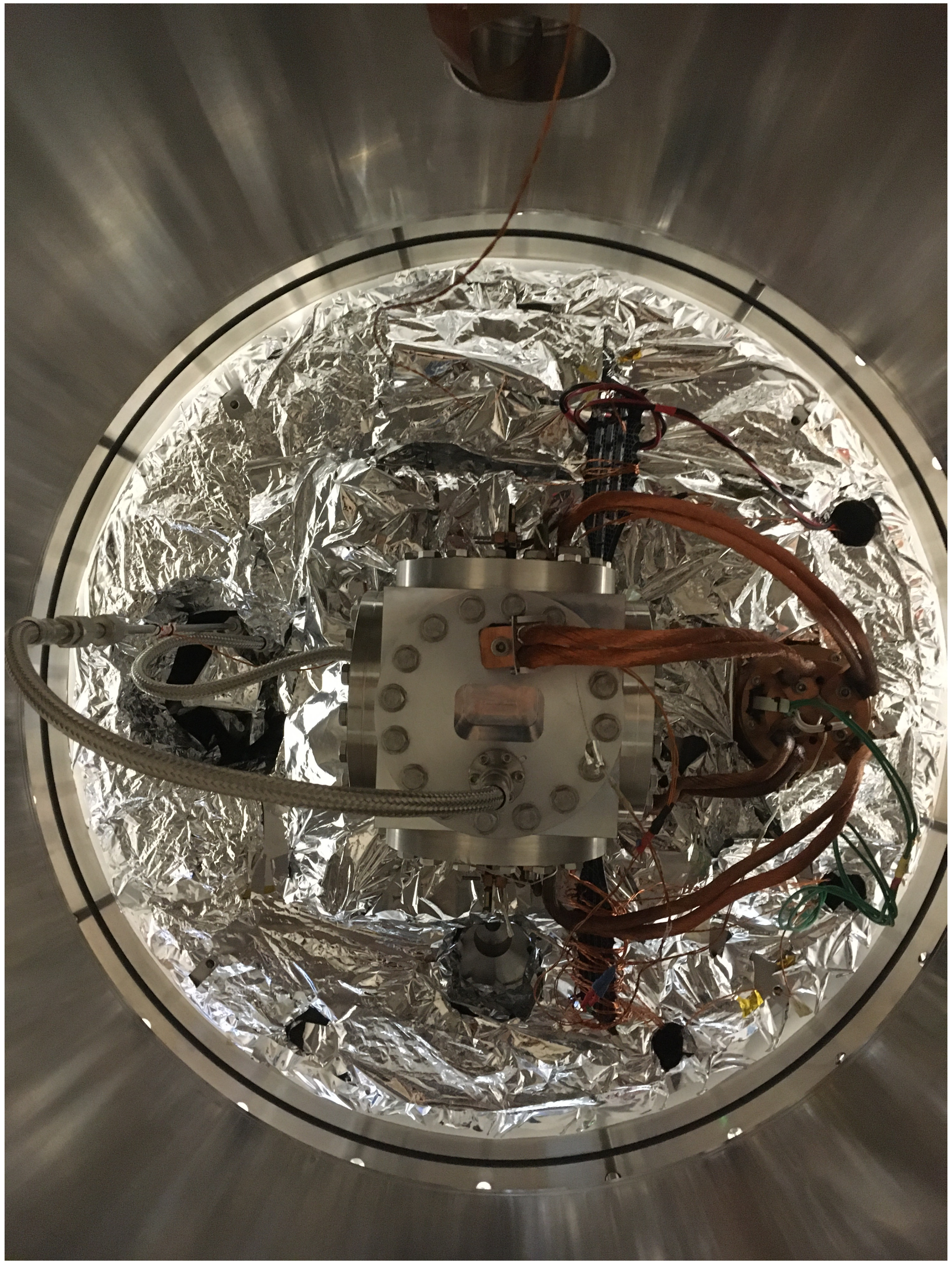


First prototype: PETit



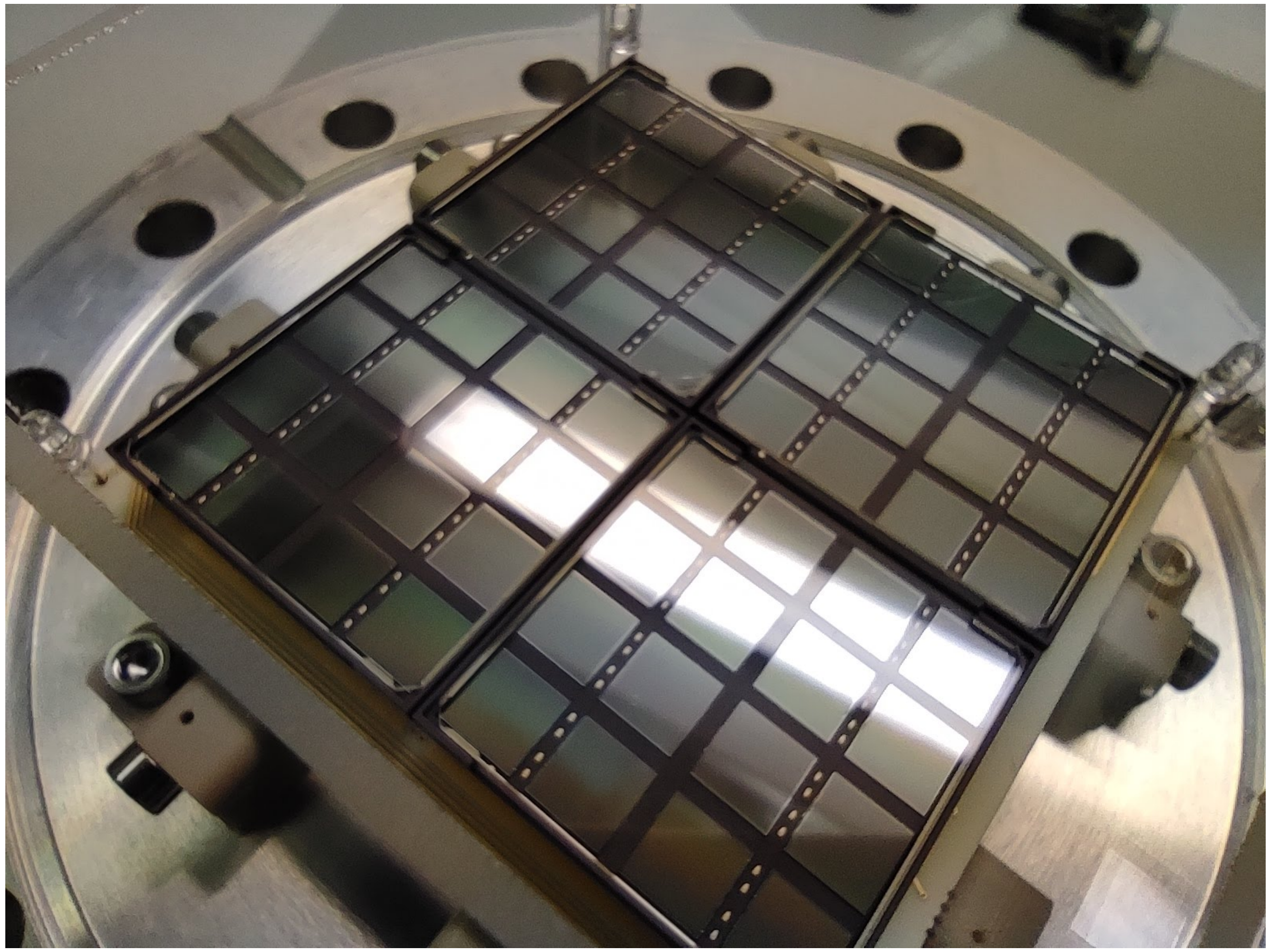
- Aluminum box, CF-100 size.
- Port for calibration source, inserted in a carbon-fiber tube.
- 3 cm of liquid xenon in each side.
- Measure energy and time resolution.

First prototype: PETit



First prototype: PETit

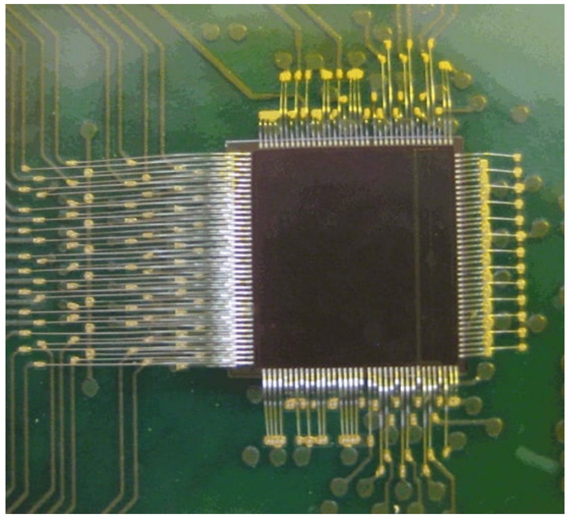
Photosensors



- Hamamatsu VUV-sensitive S15779, 6x6 mm2 area.
- 4 arrays of 4x4 SiPMs per side.
- Protection window made of VUV-transparent quartz.

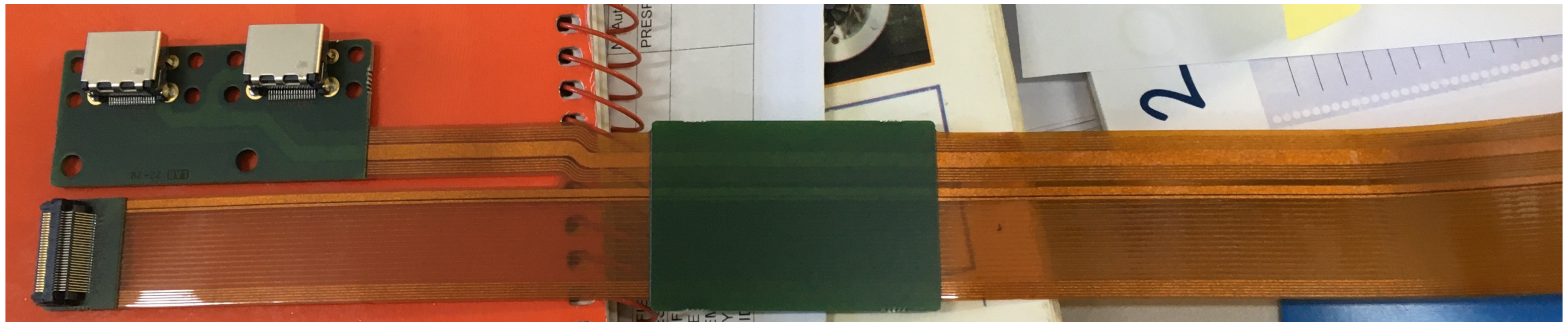
First prototype: PETit

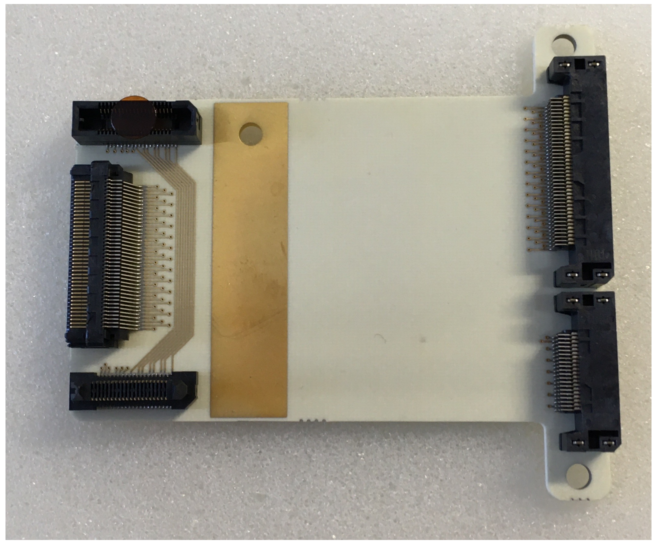
Electronics



- 2 TOFPET2 asics from PETsys.
- Two thresholds: low for timestamp, high for charge integration.
- Fast time and high rate applications.

External feedthrough



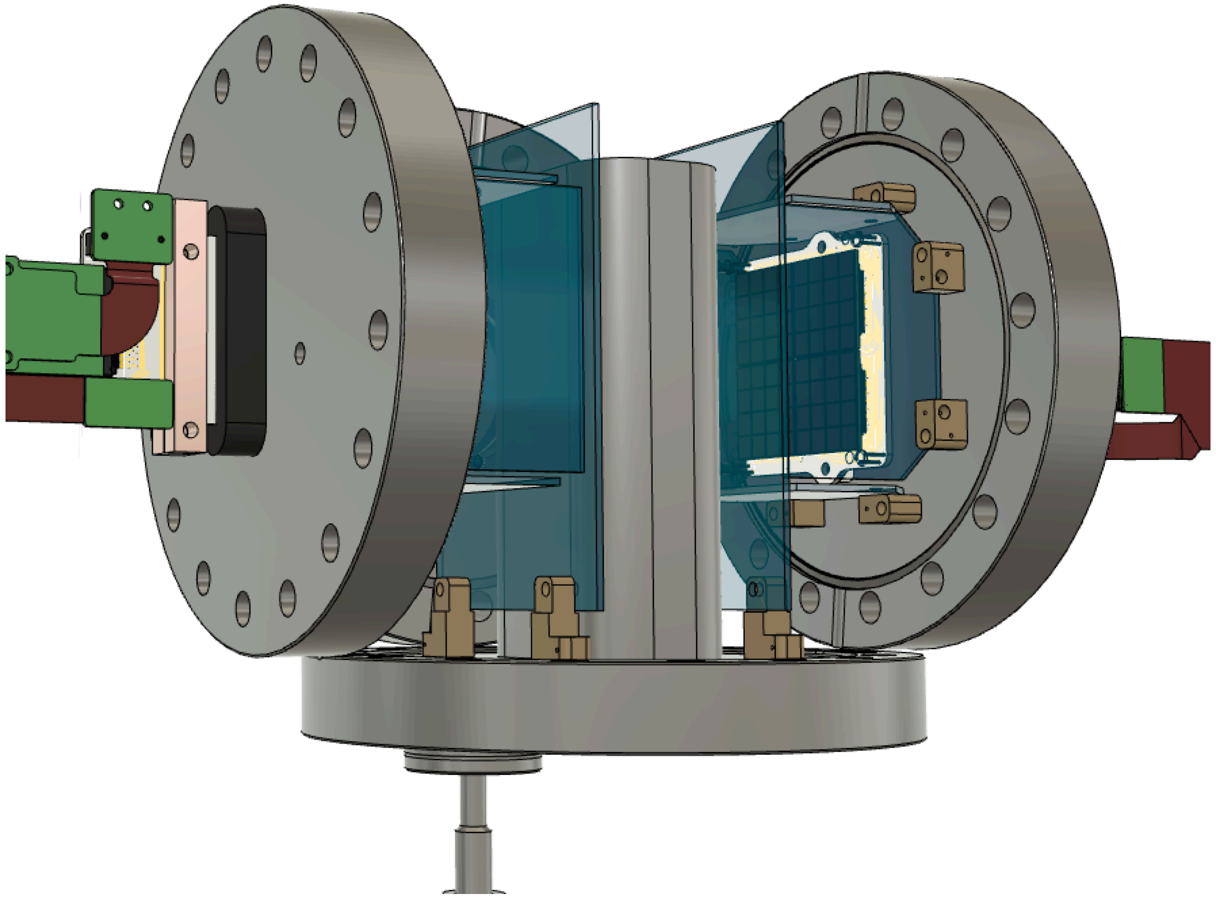


Internal feedthrough

Measurements

First run

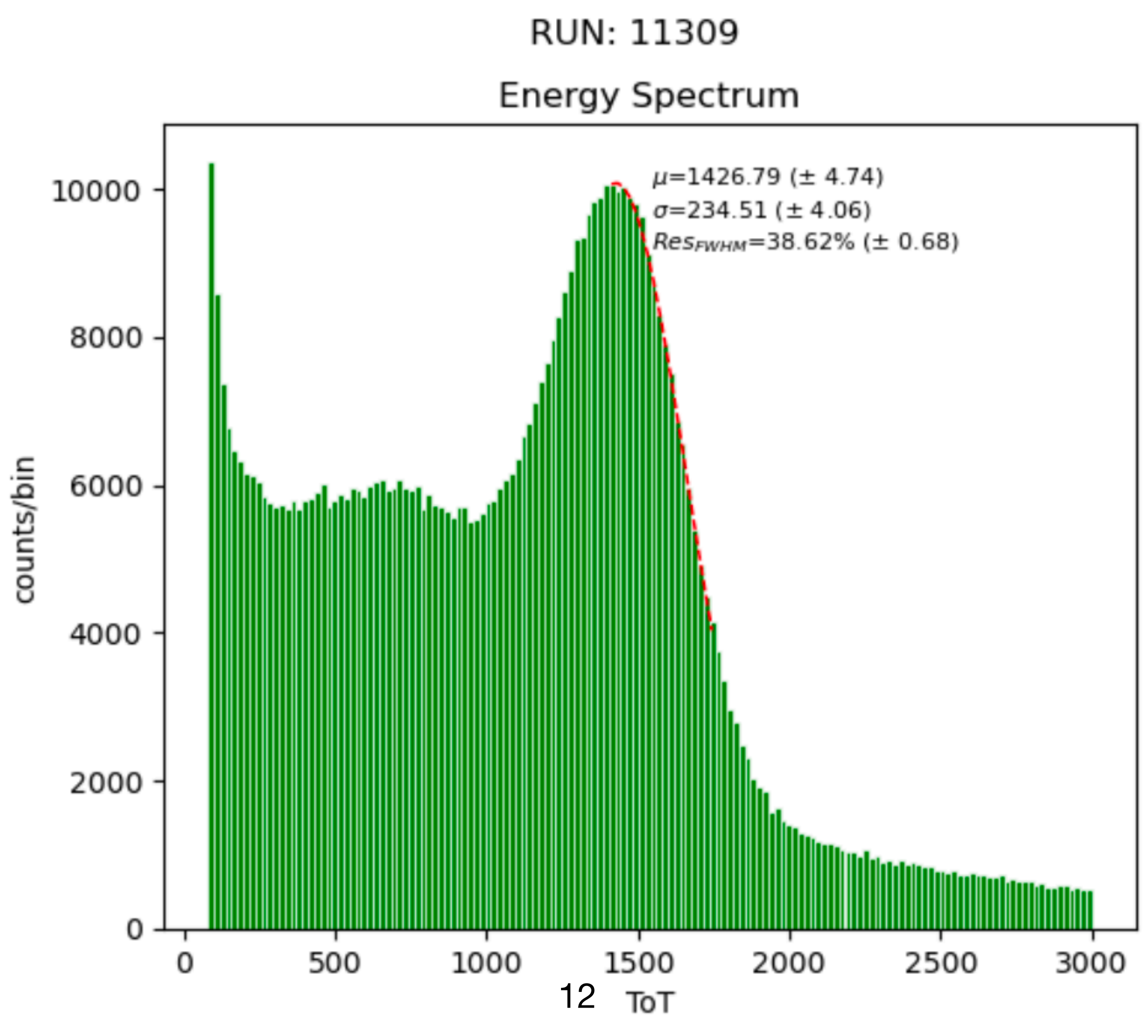
- Only energy measurements, with a Na22 source.
- Pyrex panels to absorb VUV light for better reconstruction of position.



Measurements

First run

- Very low level of charge per SiPM using the integration mode of TOFPET, very bad charge resolution.
- Tried Time Over Threshold (TOT) mode and convert to charge using Monte Carlo and assuming the shaping introduced by TOFPET.
- Poor resolution.



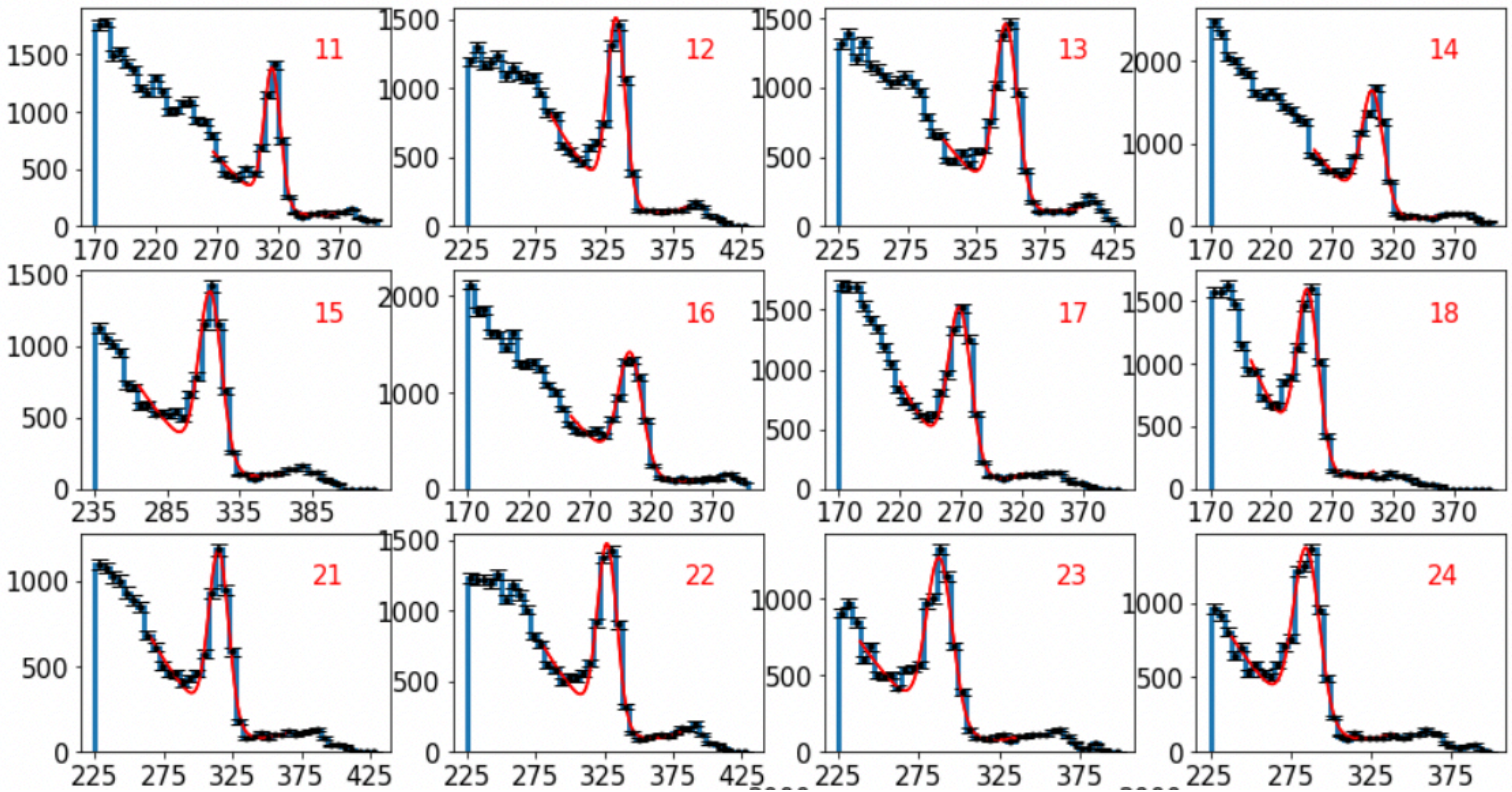
Measurements

Second run

- Try to maximize light collection.
- Reduce Depth of Interaction to measure the intrinsic Time of Flight.
- Teflon block to fill all xenon volume except for 5mm-deep holes in front of SiPMs.
- The light produced in each gamma interaction is collected mostly by the sensor in front.

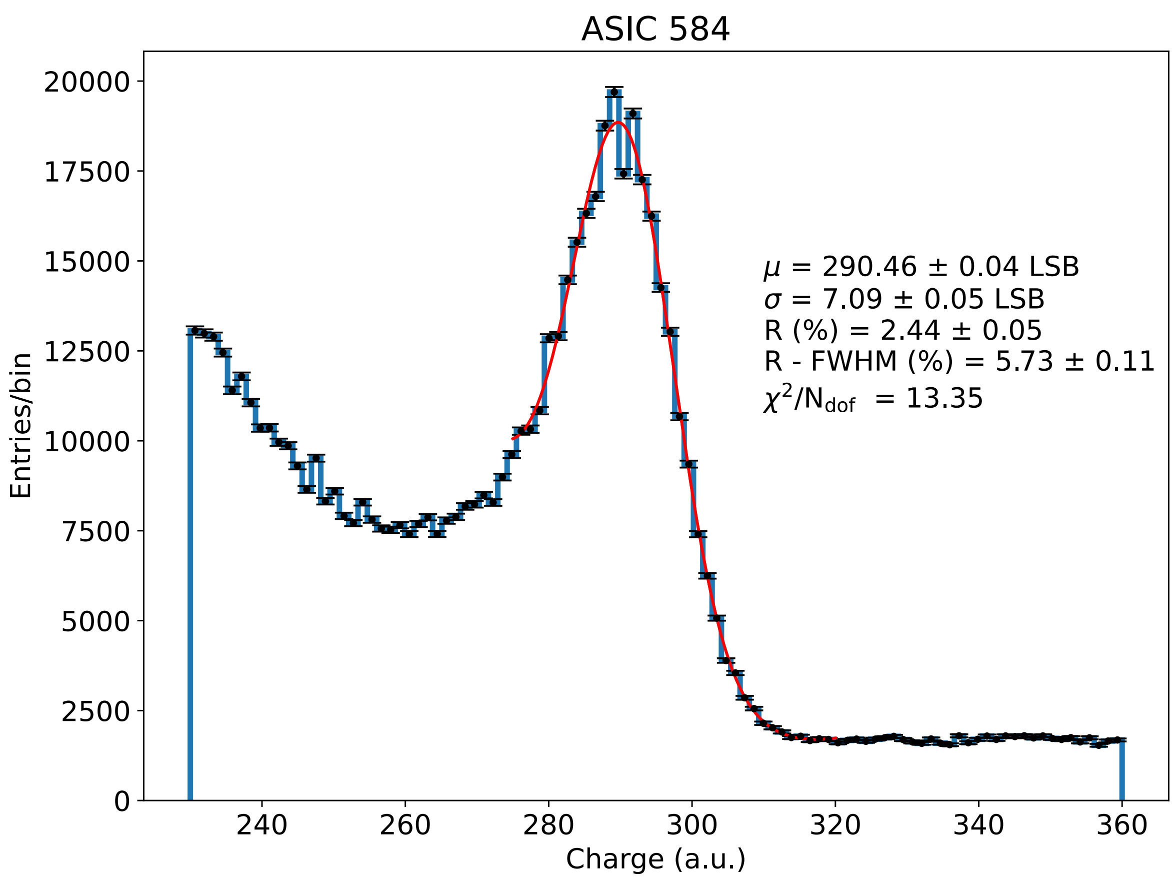
Measurements

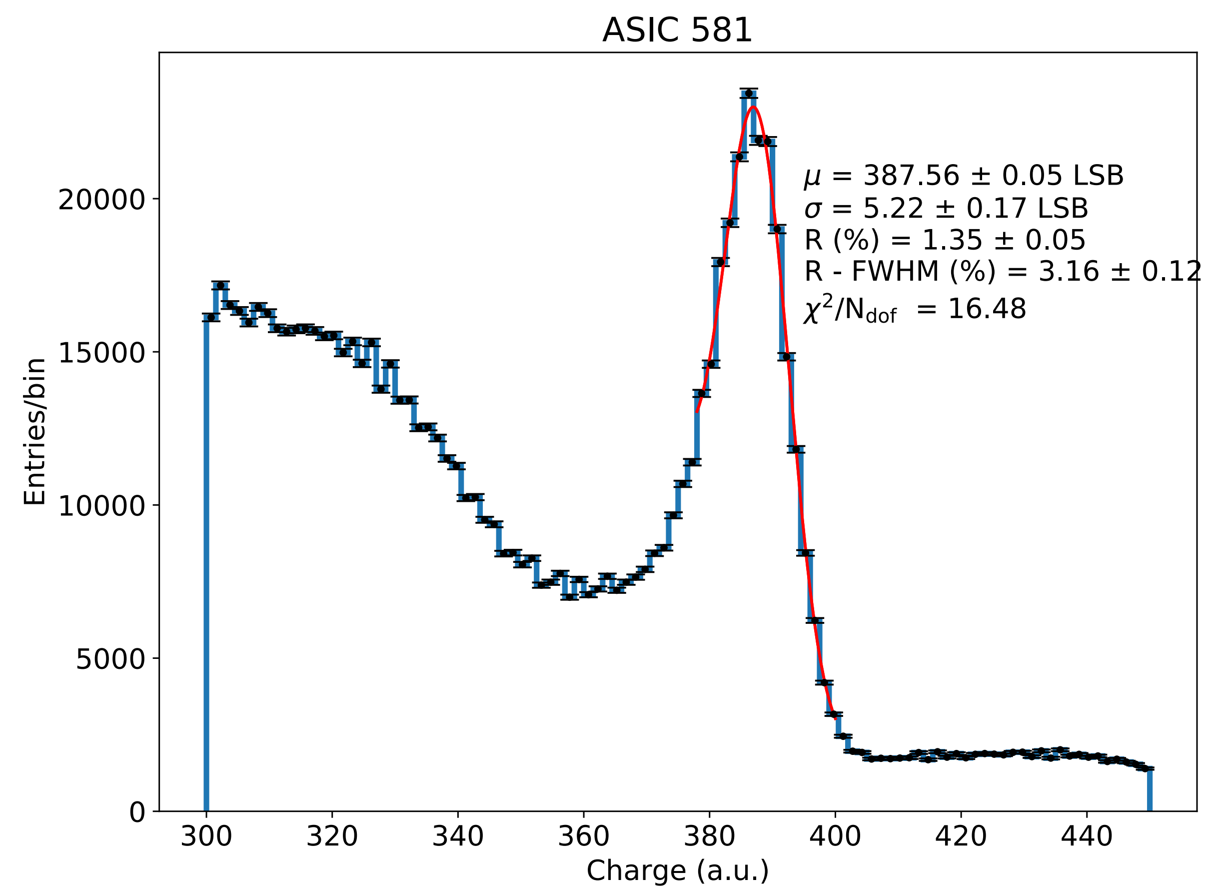
Energy resolution



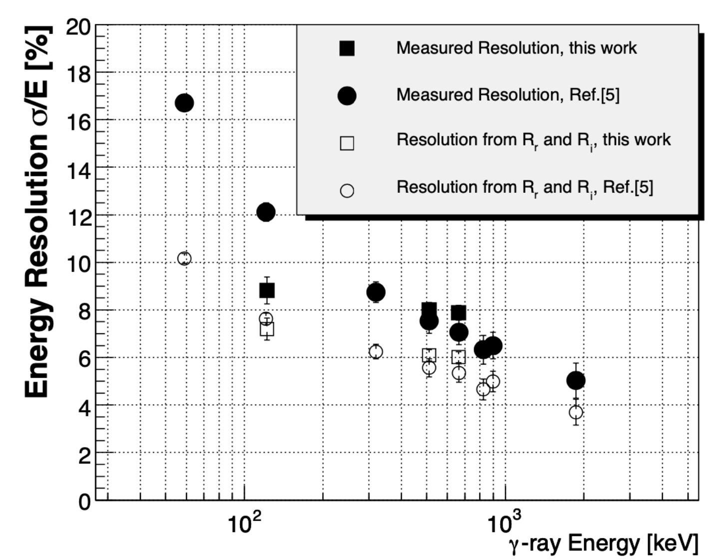
Measurements

Energy resolution





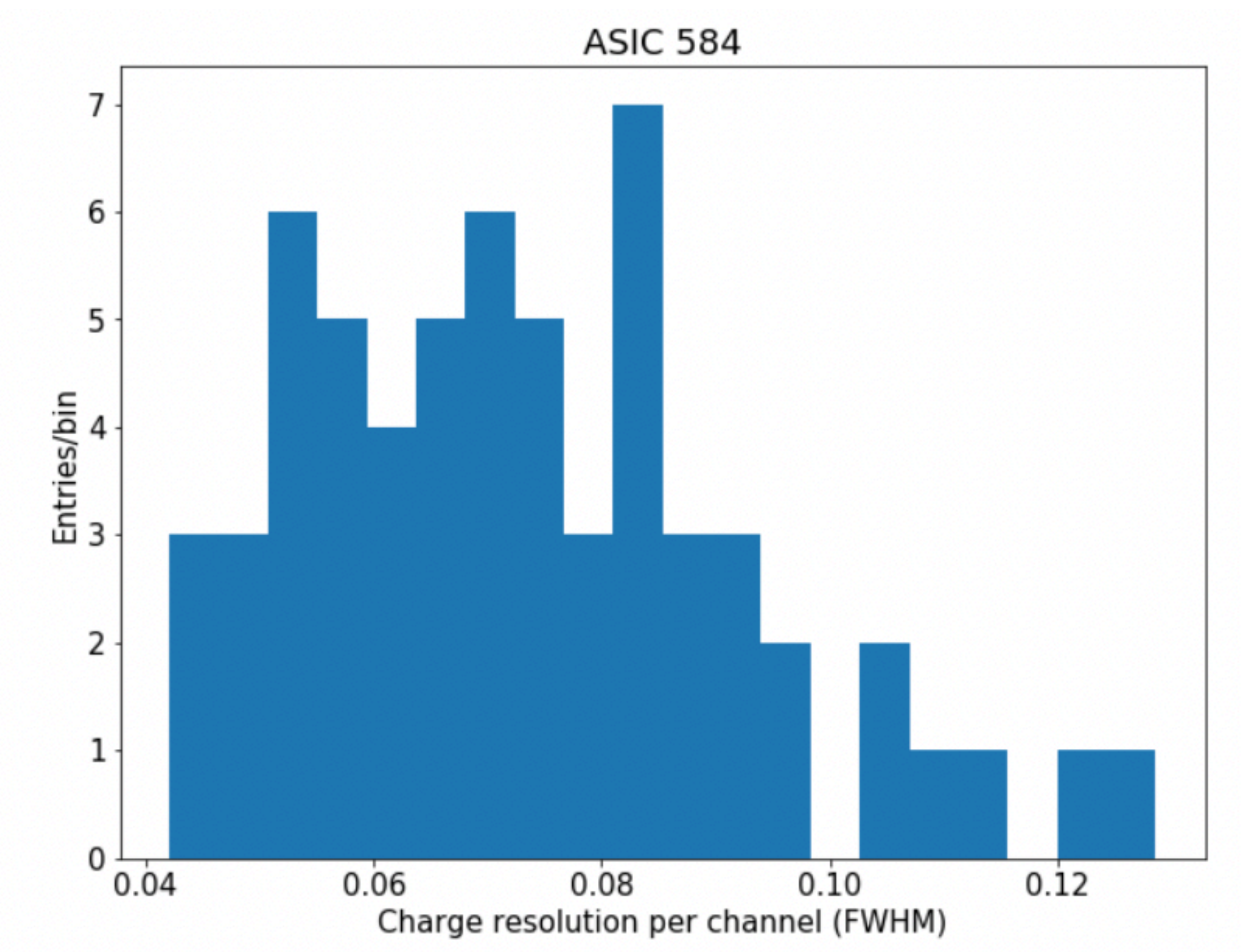
- Intrinsic resolution in LXe @511keV should be 14% FWHM (but much larger volume).
- Can teflon affect recombination?
- Difference between planes (SiPM degradation?).

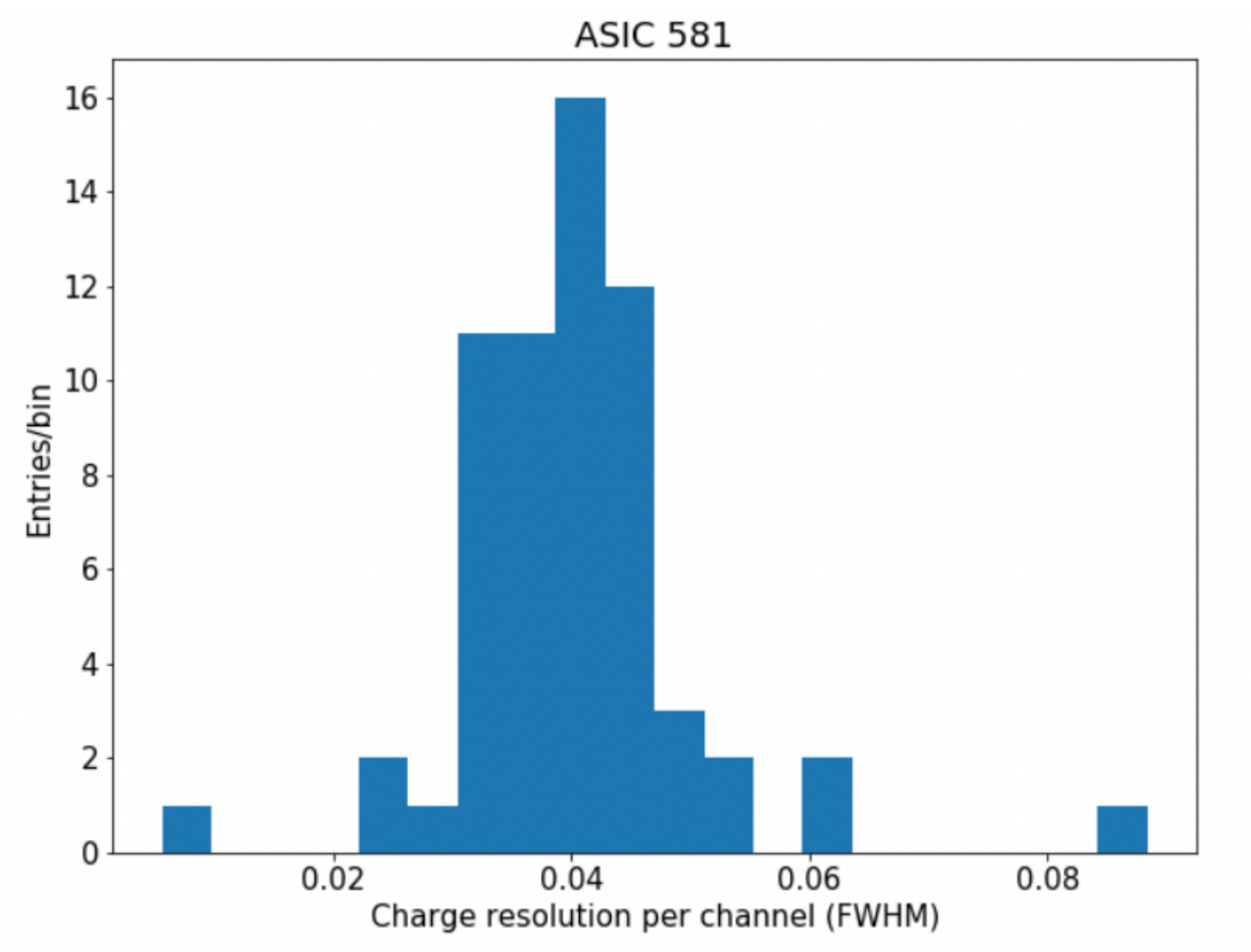


[K.Ni, et al, JINST, vol. 1, p. P09004, 2006]

Energy resolution

Second run

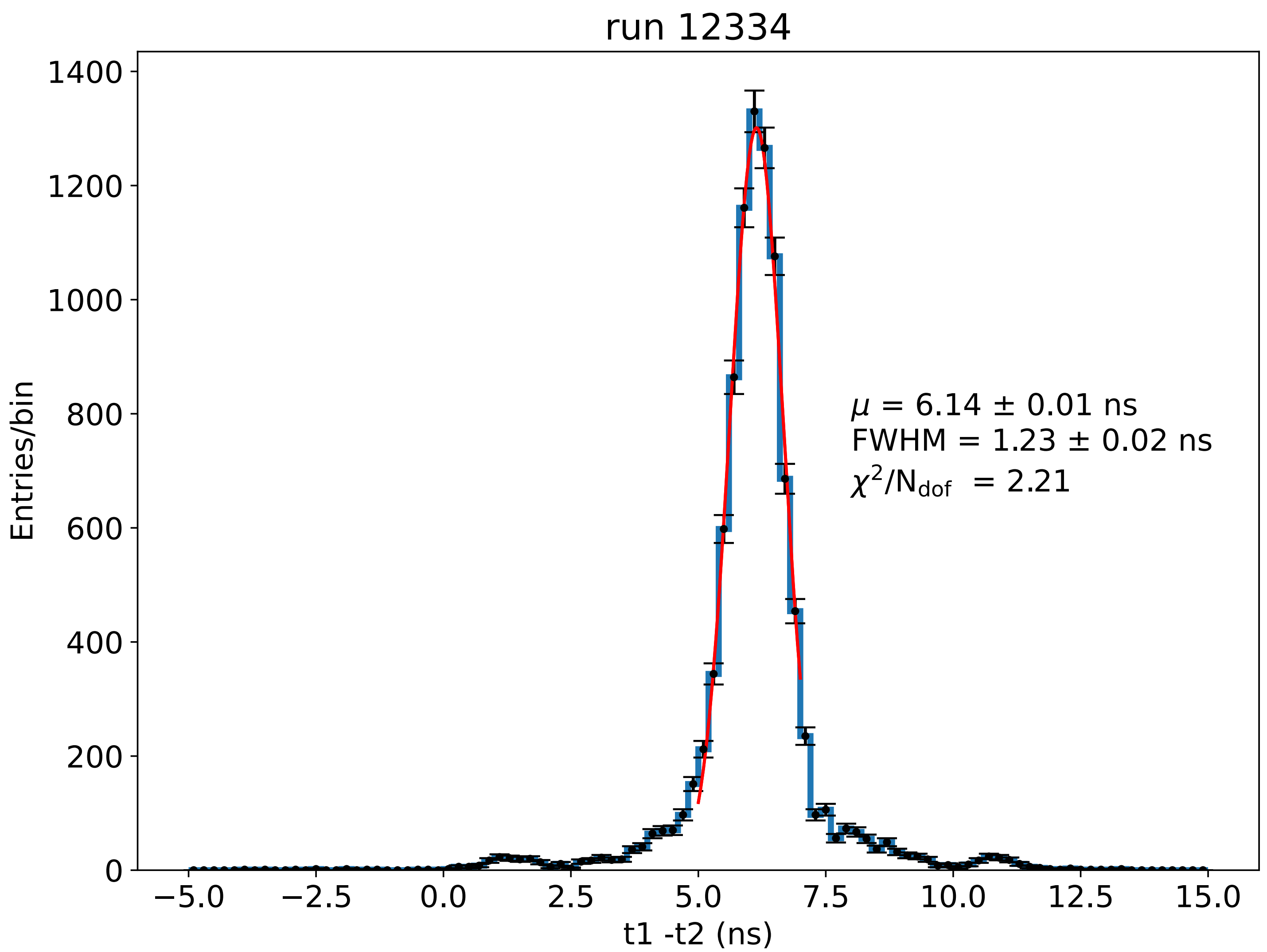




- Different resolutions (due to SiPM arrays? ASICs?).

Measurements

Time resolution



- Shift from zero, probably due to problem with clock synchronization, under study.
- Poor time resolution: degradation of signal because of connectors, cables?

Conclusions and outlook

- First measurements of PETit shows some issues and things to understand.
- Any comments, suggestions and ideas are welcome!
- We’ve had a hard time figuring out how TOFPET works (still not sure we get it completely).

- Thinking about adding wires to collect charge to improve energy resolution.
- Using G4+NEST to simulate i-electrons and photon yields in LXe (thanks to Matthew Szydagis and Jason Brodsky for their continuous help!).
- Testing simulation with the image reconstruction algorithm to see the performance.
- Upgrade of PETit once we understand the basics.

List of publications

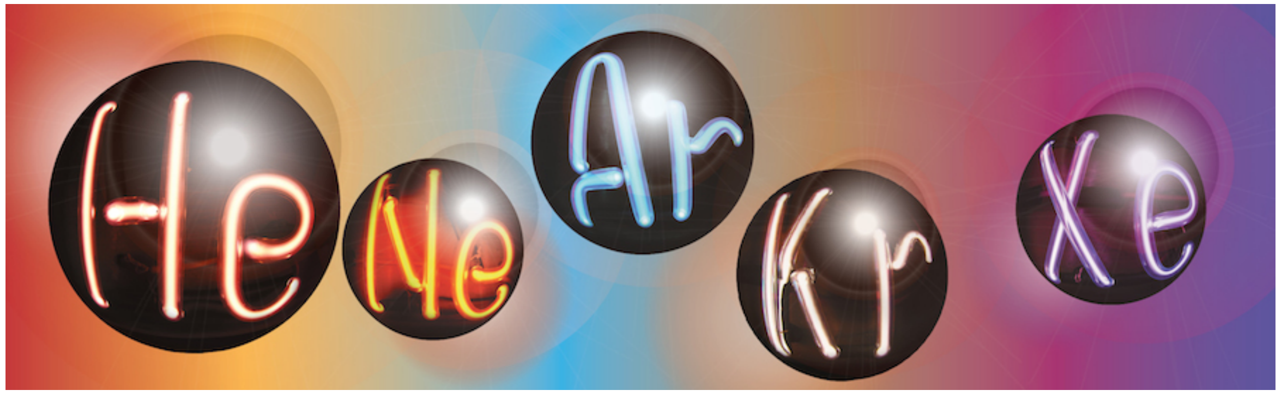
Papers

JINST 17 (2022) 05, P05044
JINST 12 (2017) 08, P08023
JINST 11 (2016) 09, P09011

Proceedings

JINST 17 (2022) 01, C01057
JINST 13 (2018) 01, C01044
Contribution to: NSS/MIC 2019, e-Print: 2001.04724
Contribution to: NSS/MIC 2018, e-Print: 2101.10055
Contribution to: NSS/MIC 2018, e-Print: 1911.10994

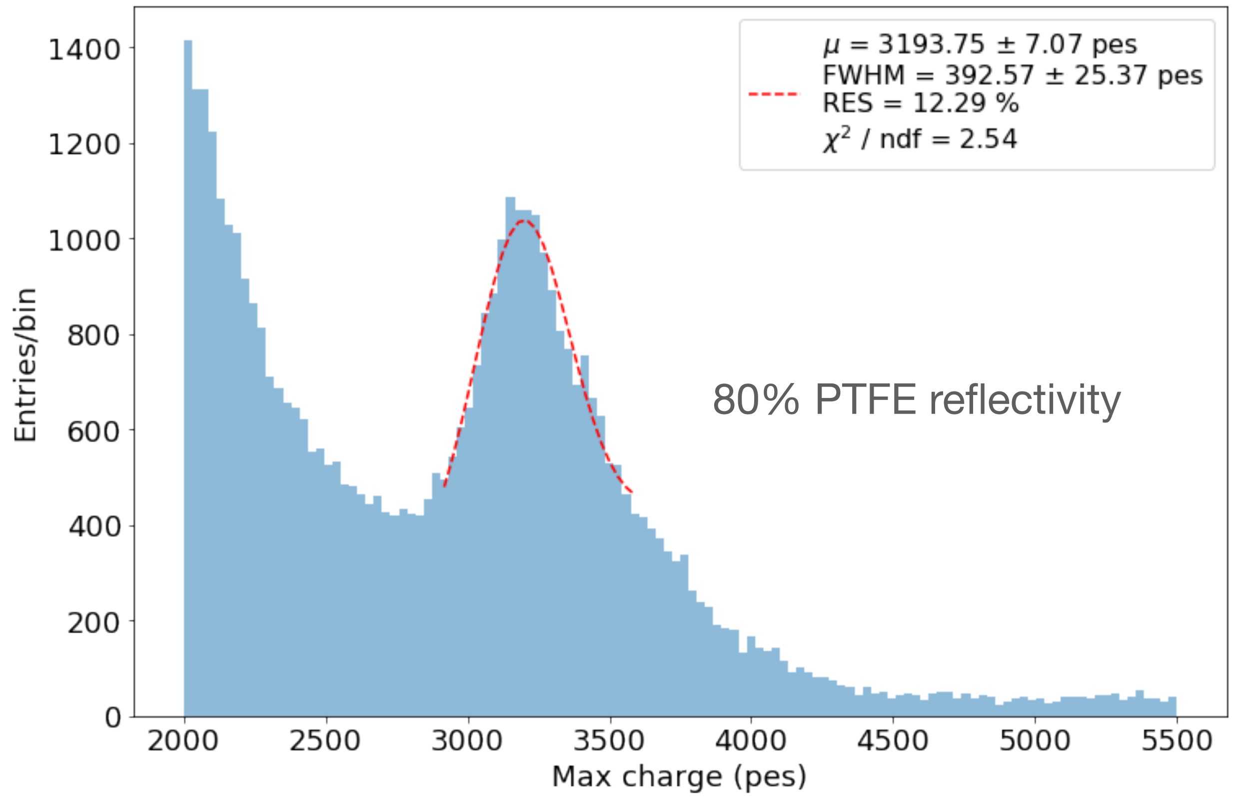
Dziękuję Ci



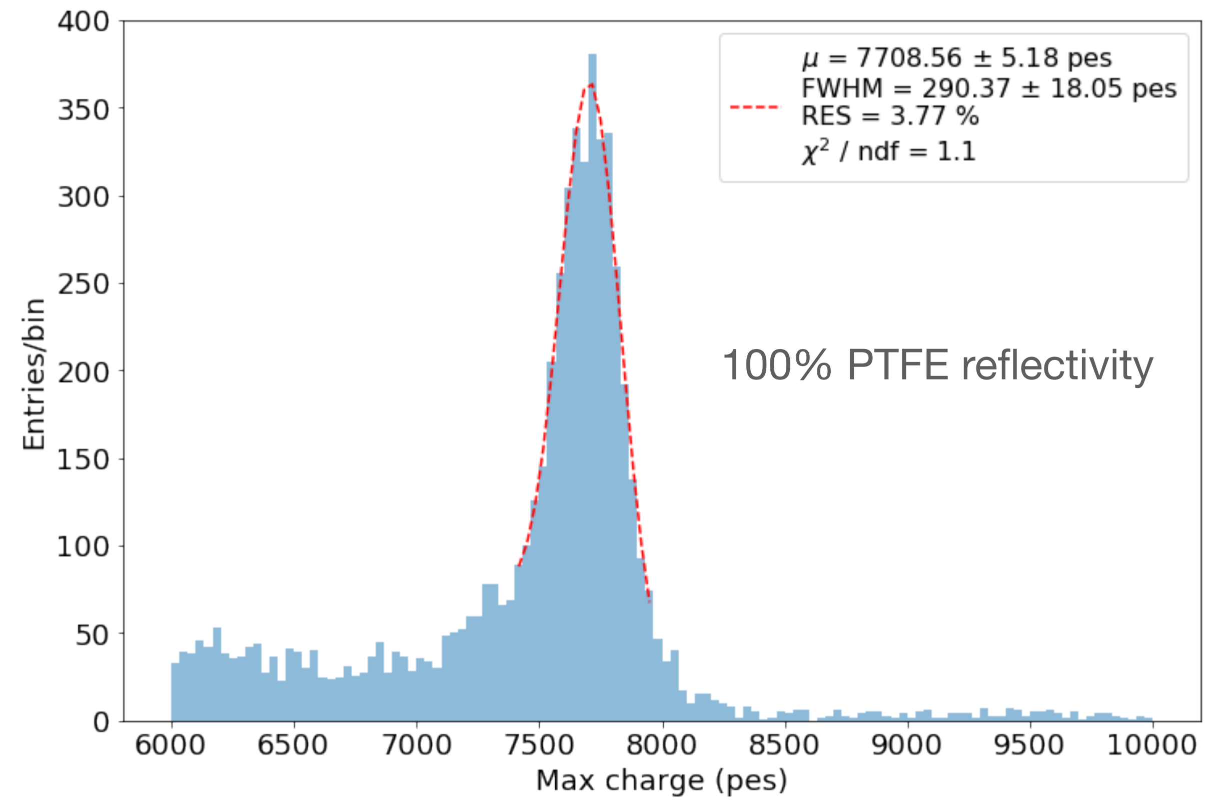
backup

slides

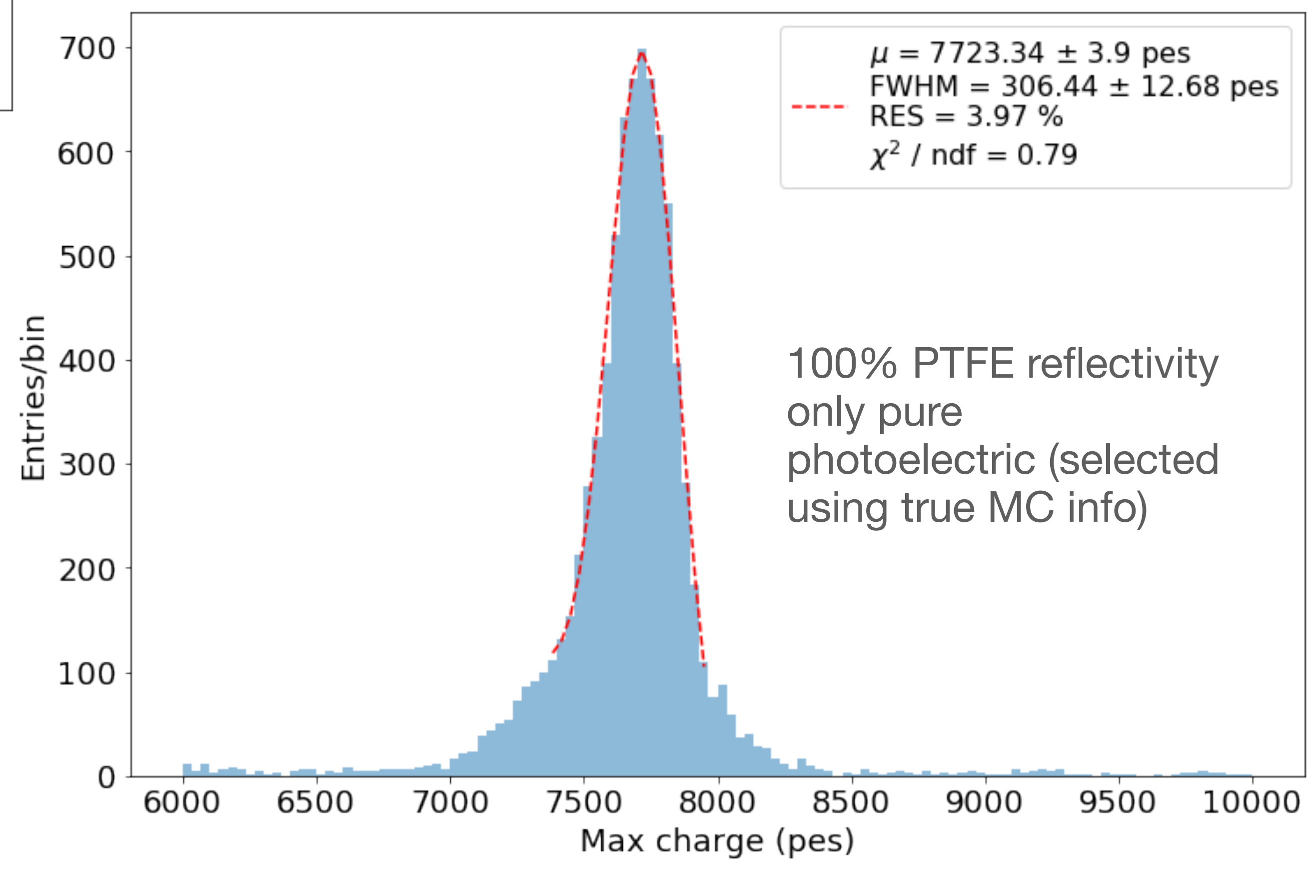
Monte Carlo



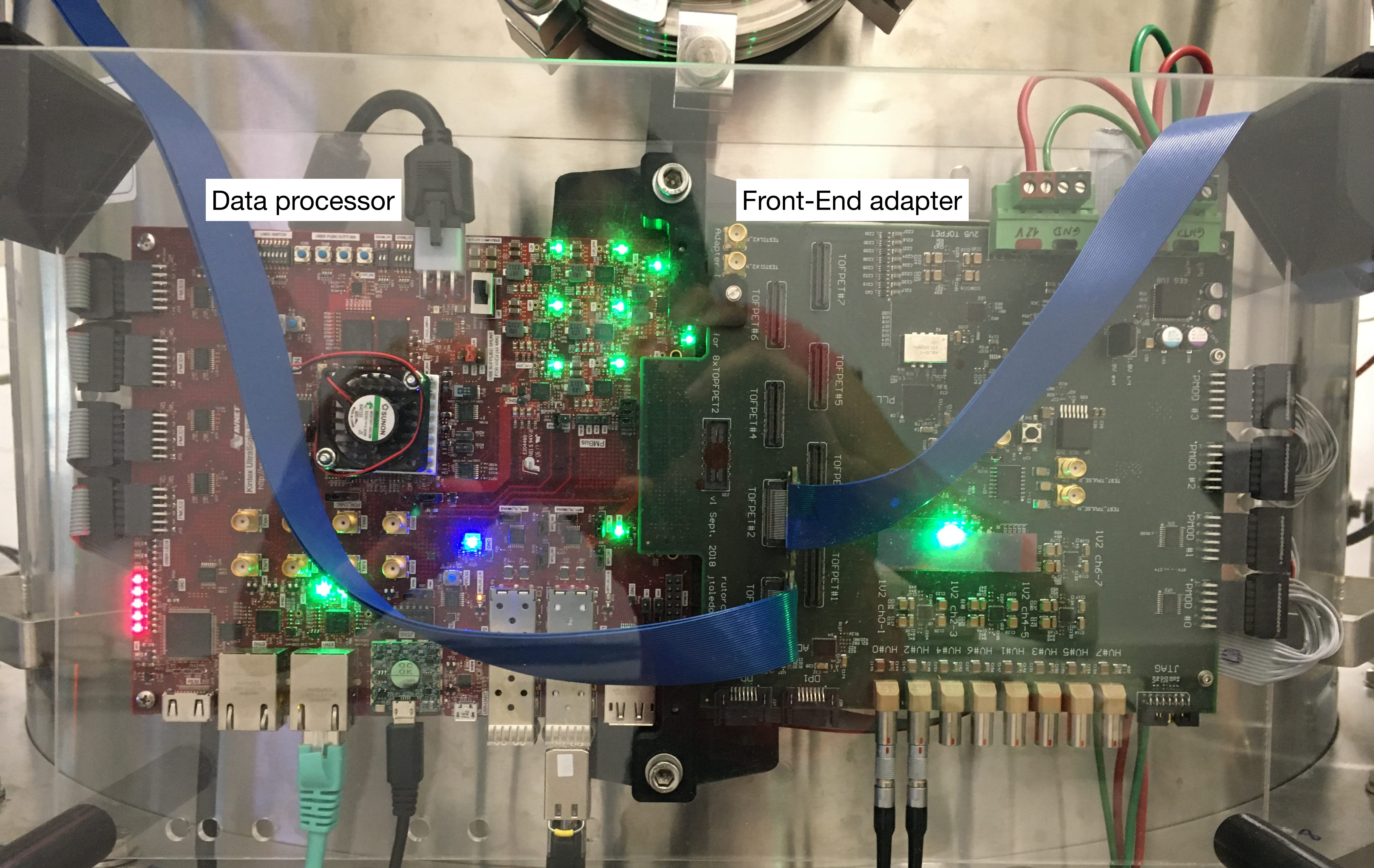
μ = 3193.75 ± 7.07 pes
FWHM = 392.57 ± 25.37 pes
RES = 12.29 %
χ^2 / ndf = 2.54
80% PTFE reflectivity
Entries/bin
Max charge (pes)



μ = 7708.56 ± 5.18 pes
FWHM = 290.37 ± 18.05 pes
RES = 3.77 %
χ^2 / ndf = 1.1
100% PTFE reflectivity
Entries/bin
Max charge (pes)



μ = 7723.34 ± 3.9 pes
FWHM = 306.44 ± 12.68 pes
RES = 3.97 %
χ^2 / ndf = 0.79
100% PTFE reflectivity
only pure
photoelectric (selected
using true MC info)
Entries/bin
Max charge (pes)



- Front-end adapter: controls T sensors, SiPMs, clock system and clock distribution among chips.
- Data processor: receives data and sends them to computer, receives TOFPET configuration and sends it to chips, manages clock synchronization.