Status and perspectives of the PETALO project

Positron Emission Tomography Apparatus based on Liquid xenOn

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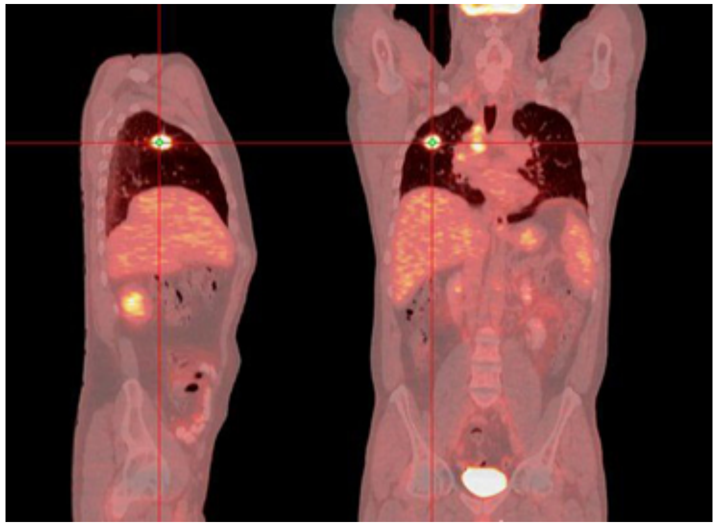
Positron emission tomography

What

- Non-invasive diagnostic technique which scans the metabolic activity of the body.

Why

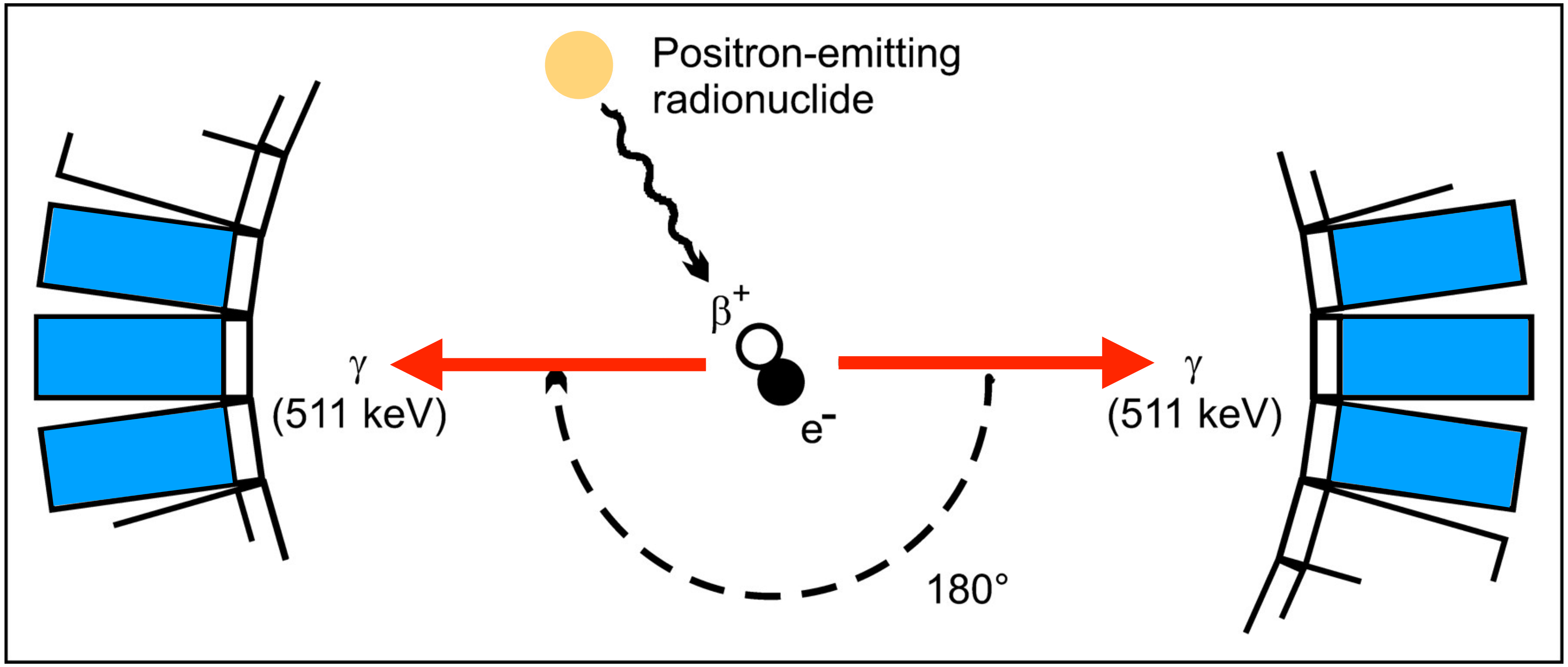
- **Brain imaging** (neurological activity is related to glucose consumption) —> Alzheimer, epilepsy...
- **Cancer detection** (tumoral cells tend to have a higher metabolism, so they're seen as bright spots).
- **Any metabolic process** can be studied with specific radiotracers.



- Complementary to computed tomography or magnetic resonance (anatomic image, shows the shape of organs and structures).
- It can detect abnormal changes before anatomic changes occur.

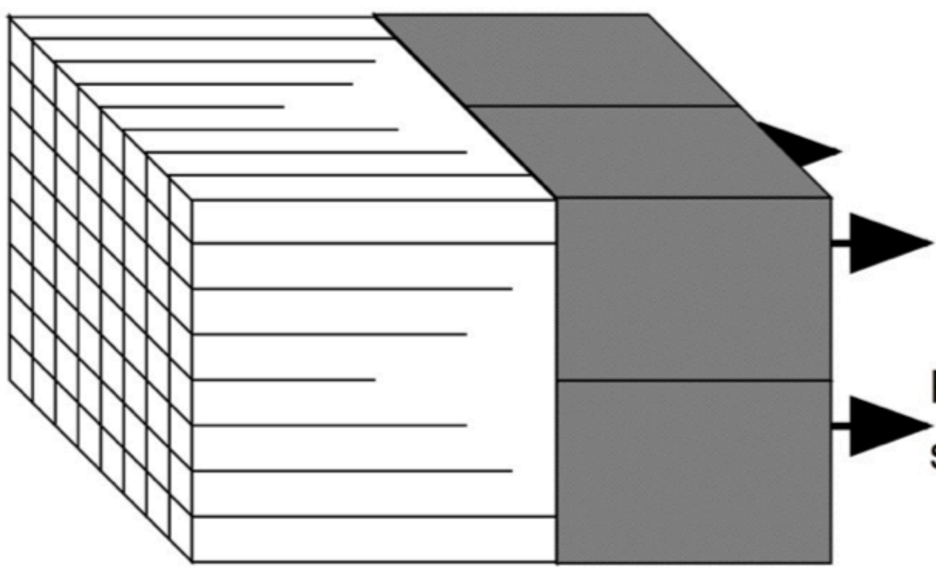
Positron emission tomography

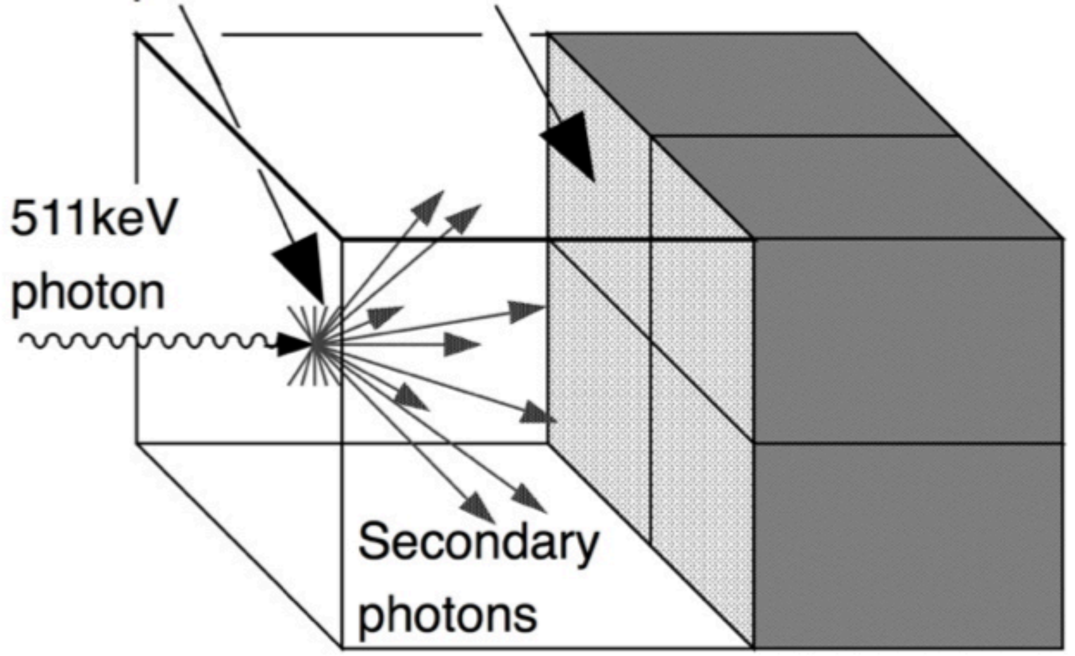
How



- 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.

Current technology





- Crystals, read by PMTs or SiPMs.
- High density materials (BGO, LYSO, LSO).

Energy resolution

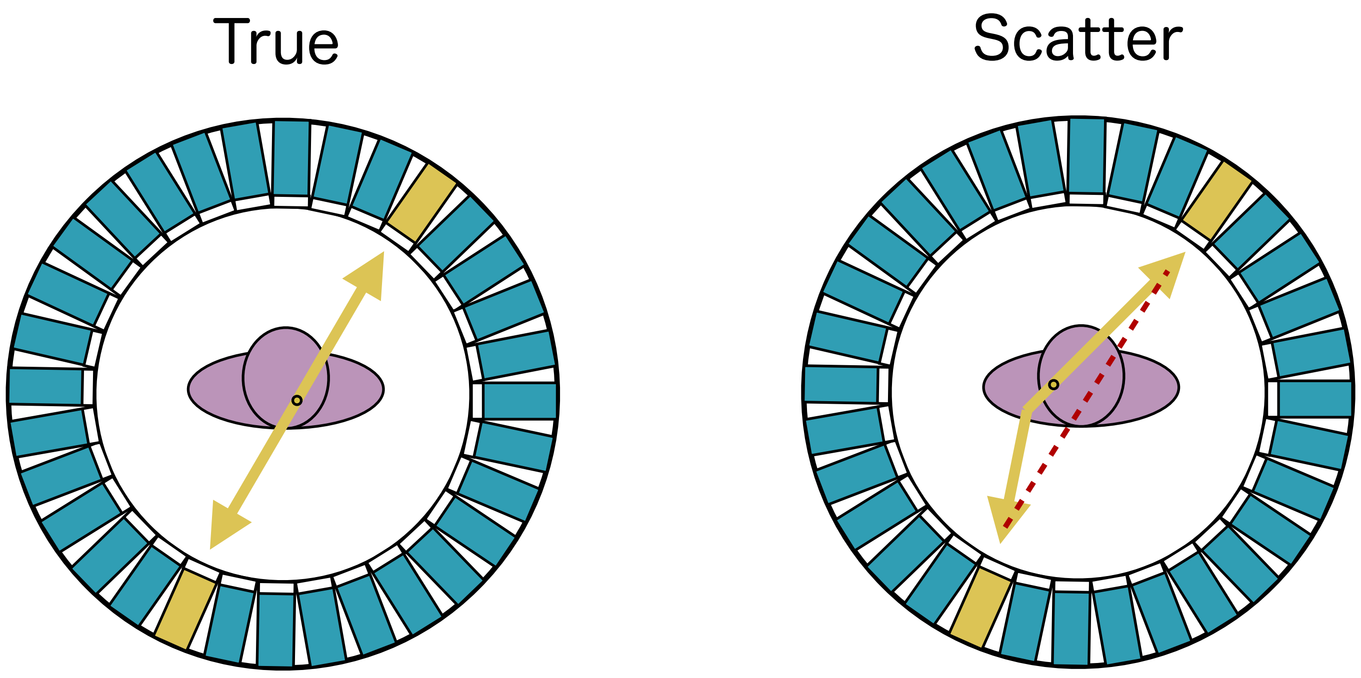
Image improvement

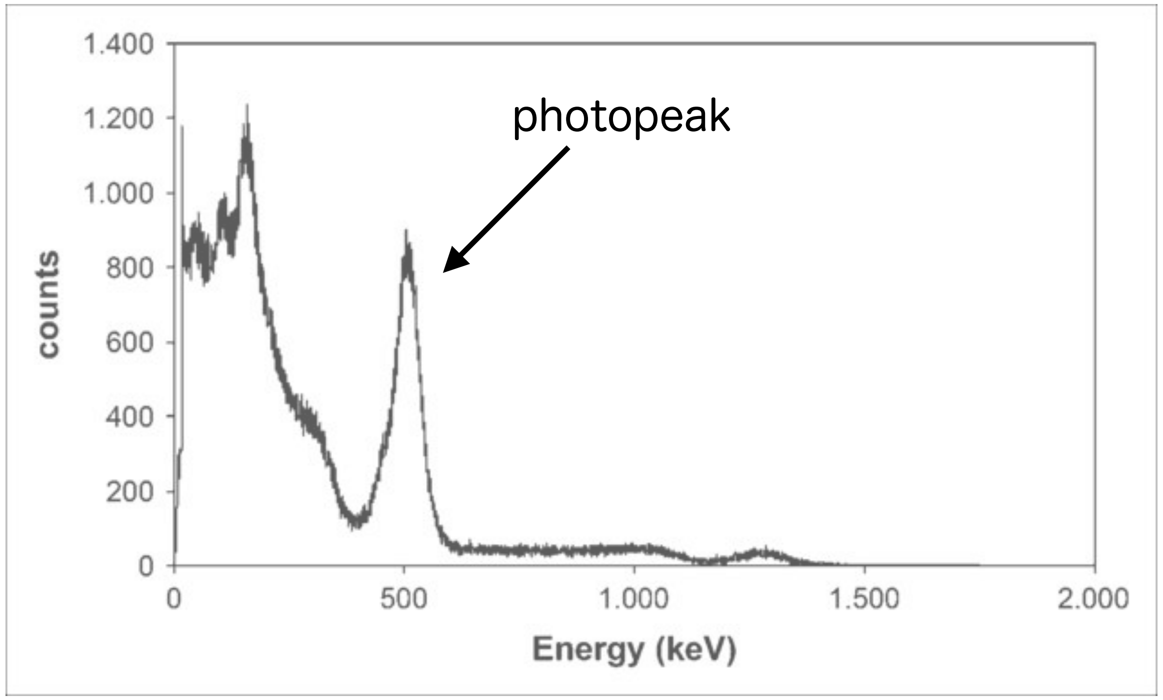
- Energy resolution to reject scatters.

↓

- Less noise in the image.
- Crucial in total-body PET.

- Current PET resolution: 10-20% FWHM



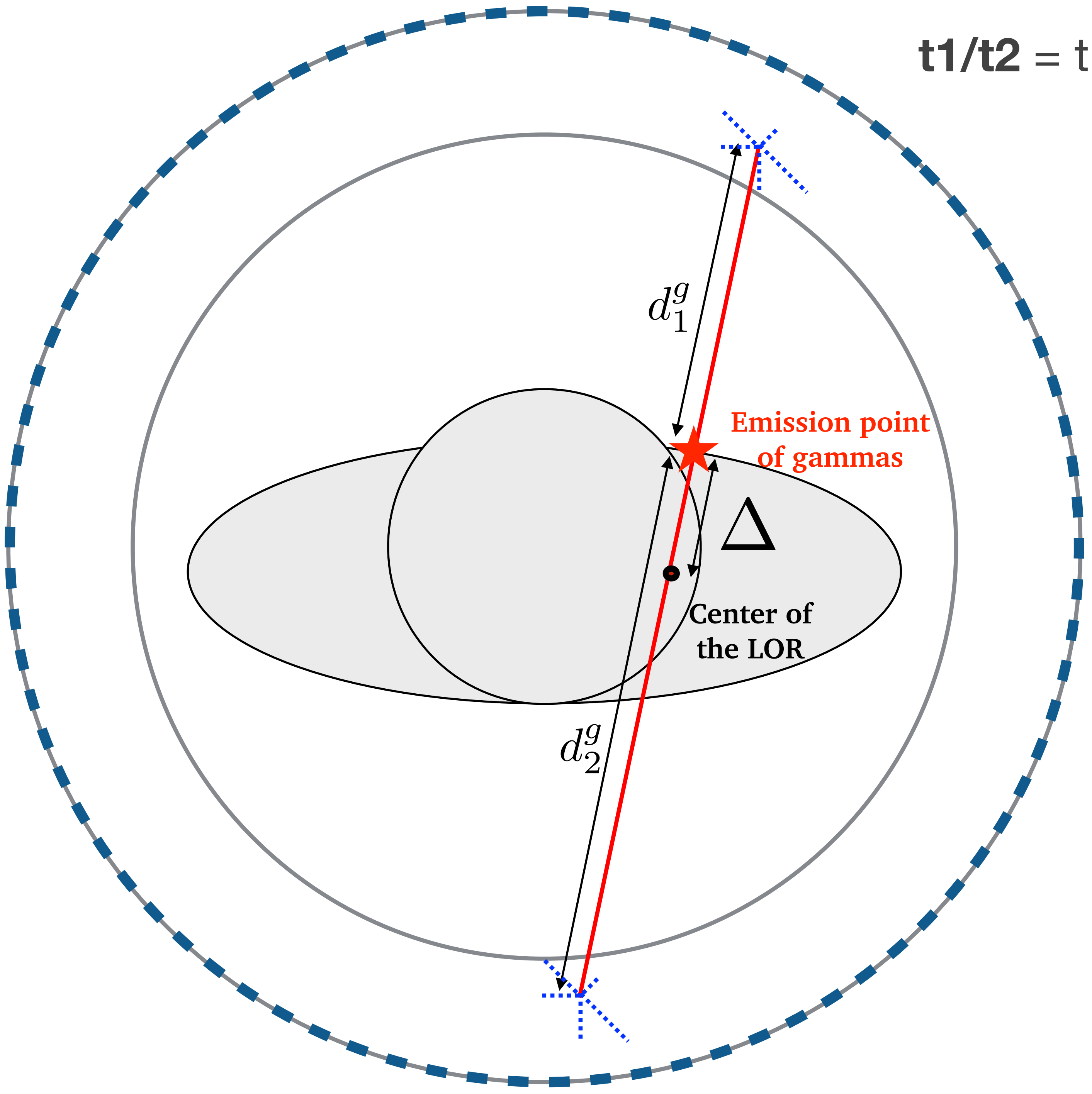


From Journal of Nuclear Medicine 47(4):639-47

Time of Flight

Constraining the emission point

t1/t2 = time in which gamma1/gamma2 interacts



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

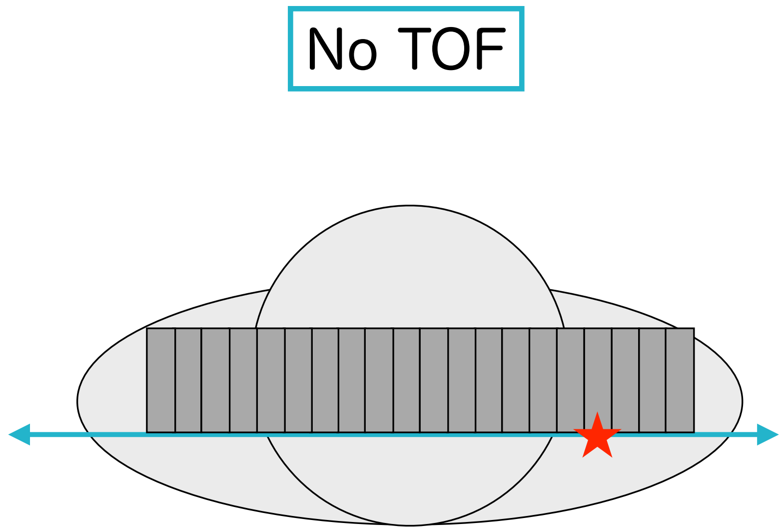
$$t_1 - t_2 = \frac{d_1^g}{c} - \frac{d_2^g}{c}$$

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

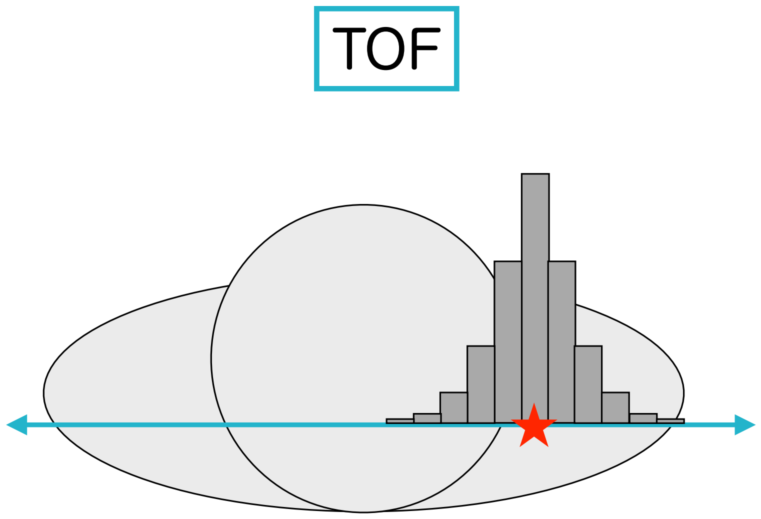
$$\Delta = \frac{c}{2}(t_2 - t_1)$$

Time of Flight

Image improvement



Same probability for every voxel in the line of response



A segment is constrained of width = time resolution of the system

- **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 dose can be reduced.

Why liquid xenon?

- Transparent to its own scintillation light.
- High yield, short characteristic emission time.
- Continuous medium, uniform response.
- Less mechanical complexity.
- Shorter wavelength —> needs dedicated photosensors.
- Needs to be liquefied —> cryostat to reach -110 Celsius degrees.

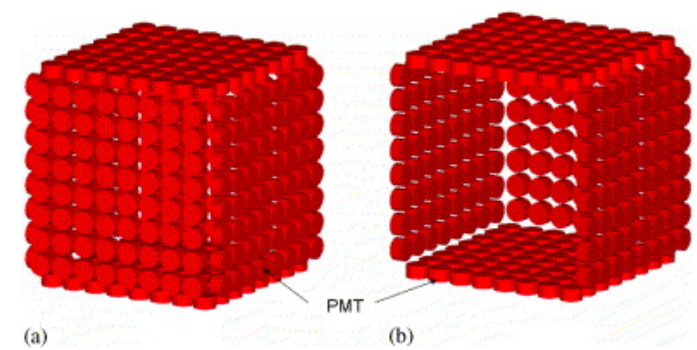
	BGO	LSO	LYSO	LXe
Attenuation length@511 keV (mm)	10	11.5	12	36
Yield (photons/keV)	9	26	33	**68**
Decay time (ns)	300	40	36	**2.2**, 27
Wavelength (nm)	480	420	420	178
Photo-fraction	40%	30%	30%	20%

Liquid xenon in medical imaging

1976 - **Lavoie**, first idea of using LXe in PET

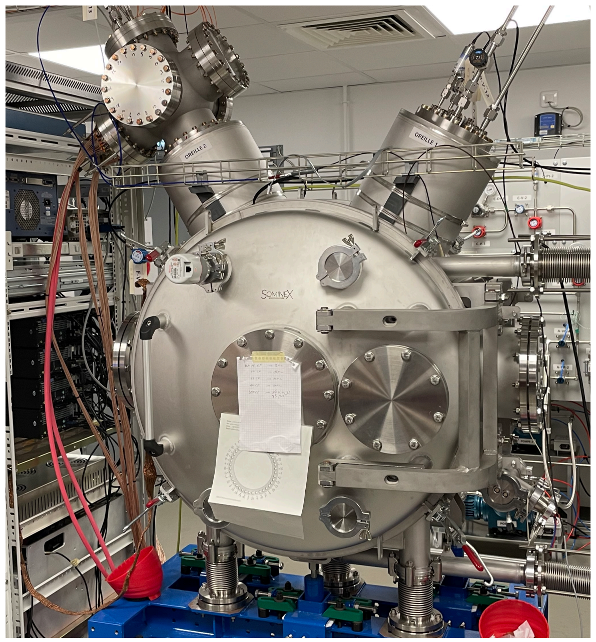
Chepel et al. (1993) and **TRIUMF** (2008): LXe Time Projection Chamber, with light and charge detection - PMTs and APDs.

2004 - **Waseda group**: scintillation only and PMTs

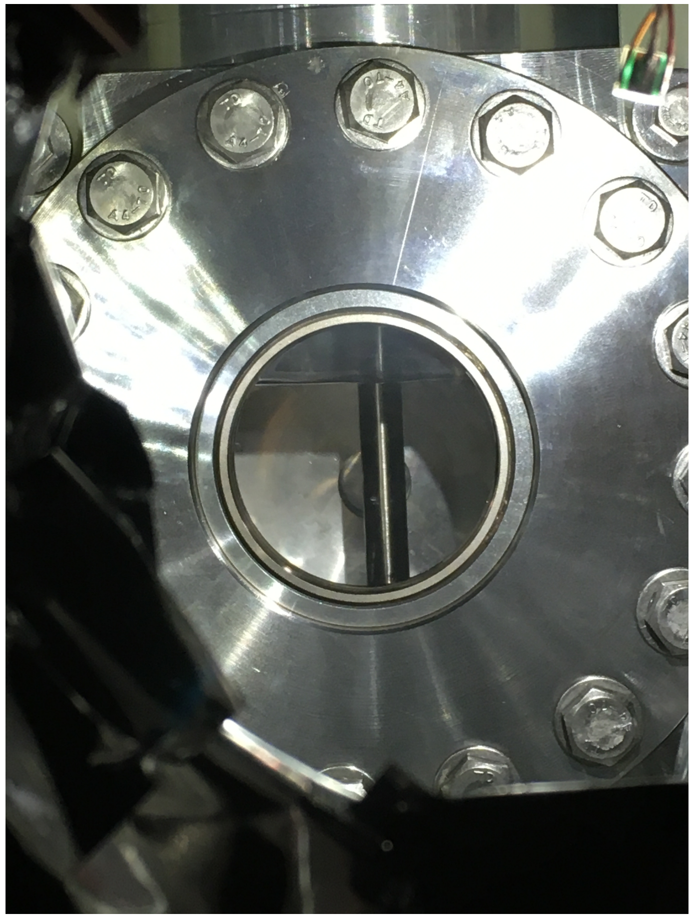


2004-today - **Nantes-Subatech** group, LXe TPC Compton telescope

- β^+ emitter + high energy photon
- Localization of the origin of emission from LOR + Compton cone
- Segmented anode+Frisch grid reads ionization charge



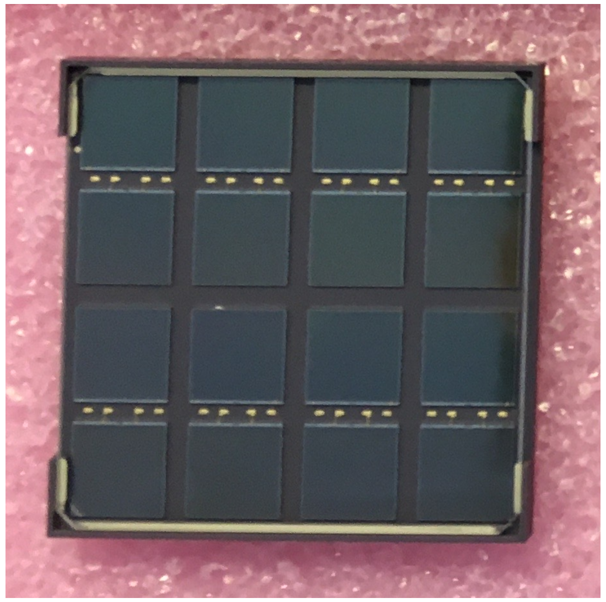
The PETALO concept



LXe with scintillation

- Detect scintillation light only: less complexity, less dead time.

SiPMs

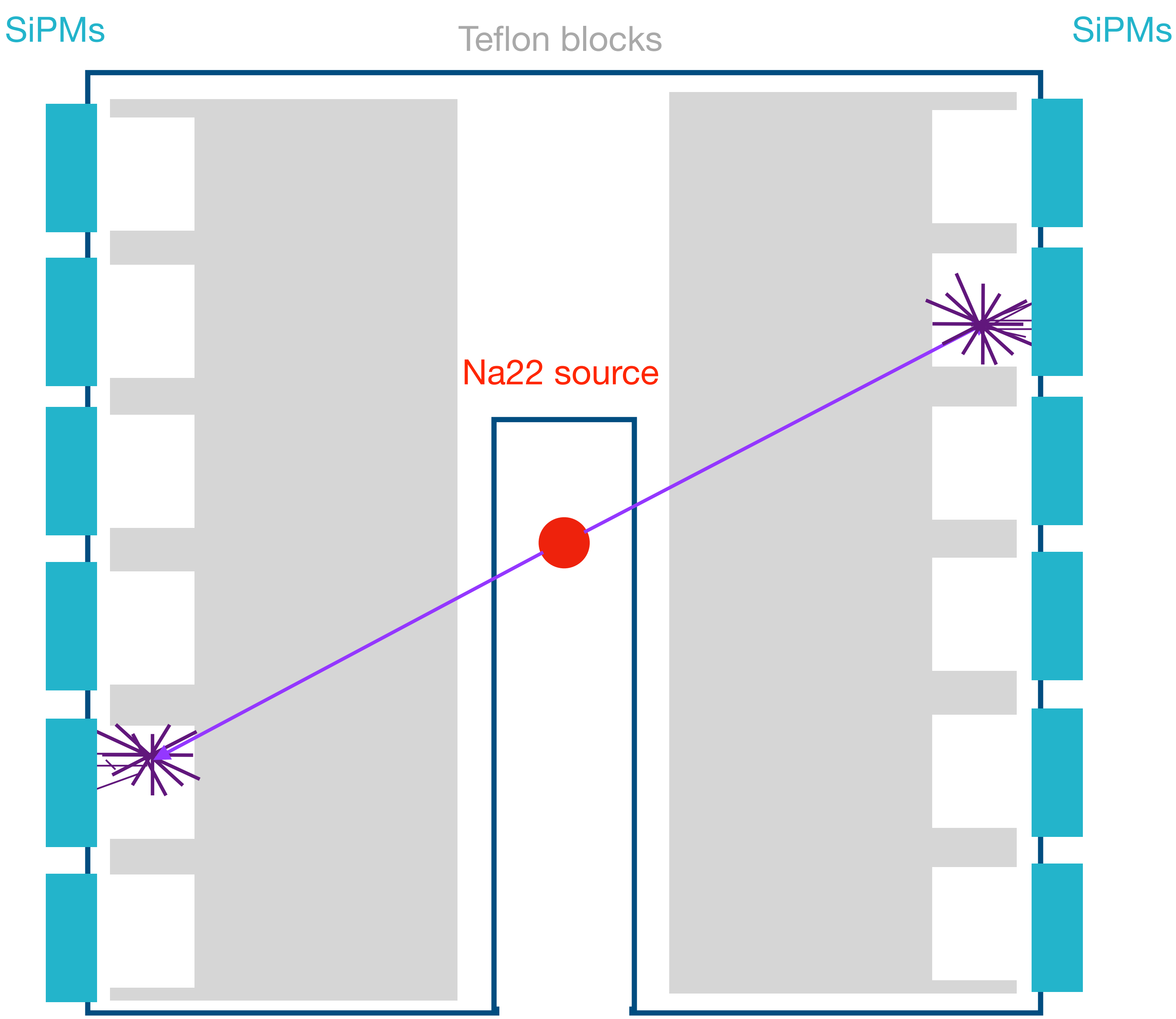


- Fast response, high gain.
- Almost no dark count at cryogenic temperatures.
- Small, high granularity, flexibility of arrangement.
- Compatibility with magnetic fields (NMR).

People and institutions

- 3 senior physicist researchers
- 3 senior engineer researchers
- 2 post-doc
- 4 engineers
- 2 PhD students (one recently defended her PhD)

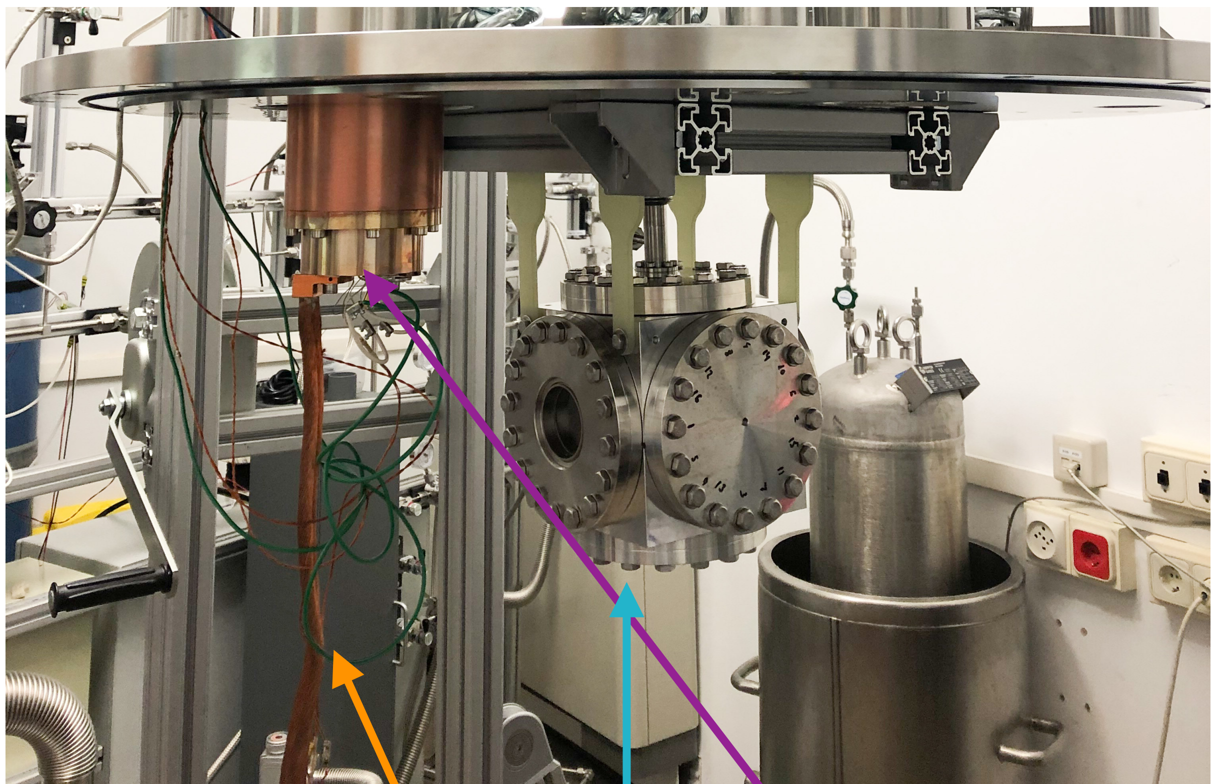
First prototype: PETit



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


Kurt J. Lesker

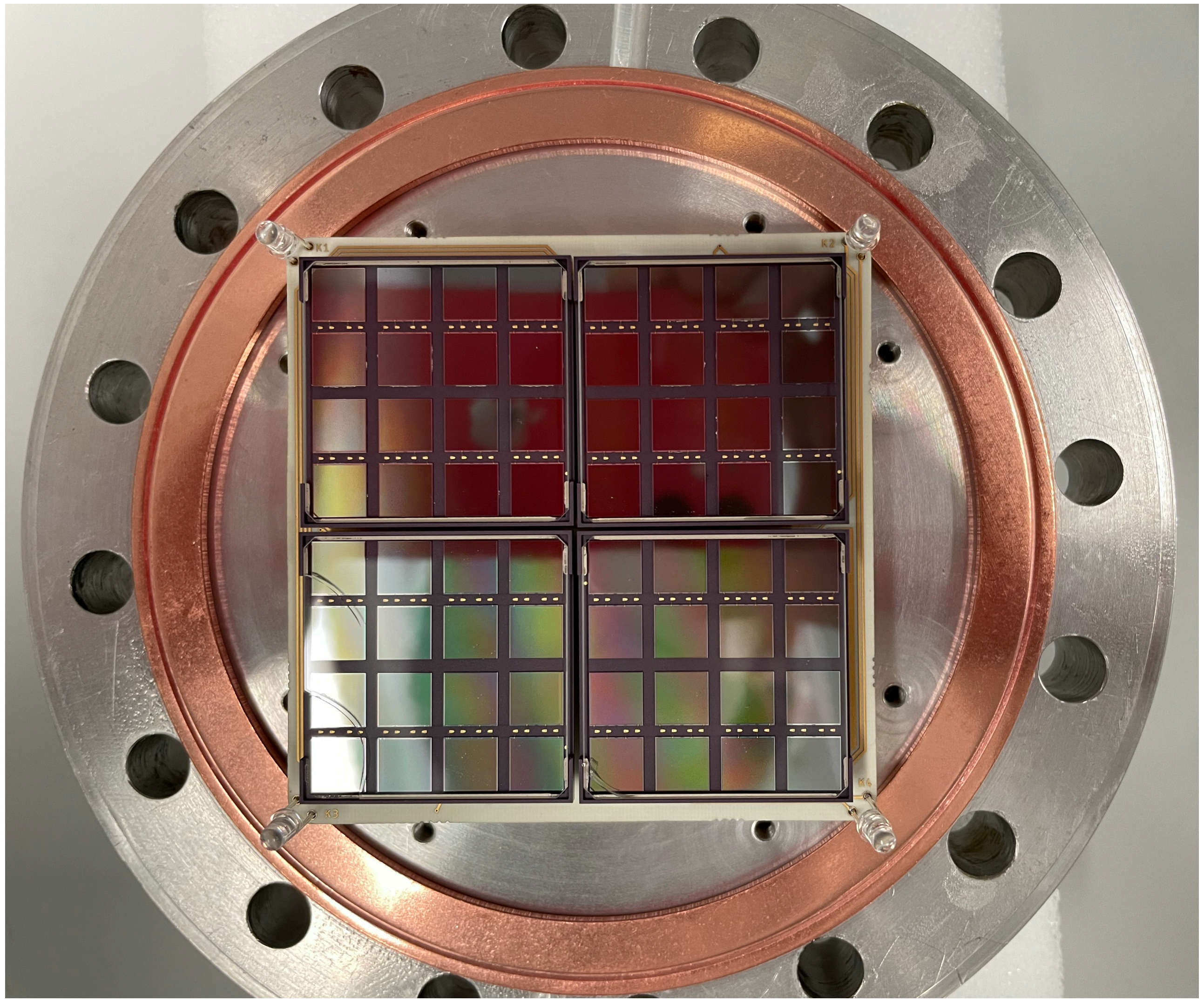
First prototype: PETit



- CF-100 size aluminum cube.
- Cooled by Sumitomo CH-100 cold head, via custom-made thermal links.
- Vacuum vessel for thermal isolation.

First prototype: PETit

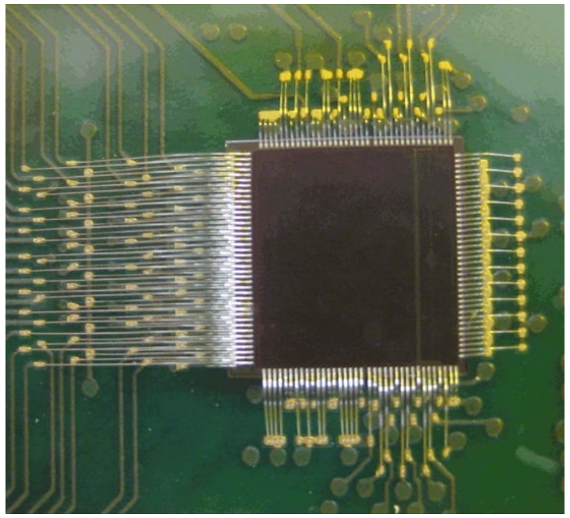
Photosensors



- Hamamatsu VUV-sensitive S15779, 6x6 mm^2 area.
- 4 arrays of 4x4 SiPMs per side.
- Protection window made of VUV-transparent quartz.

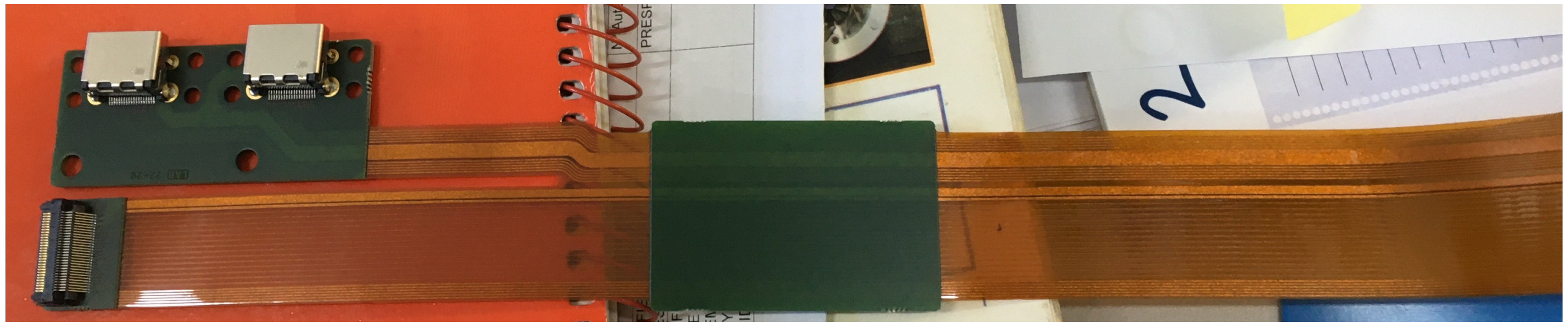
First prototype: PETit

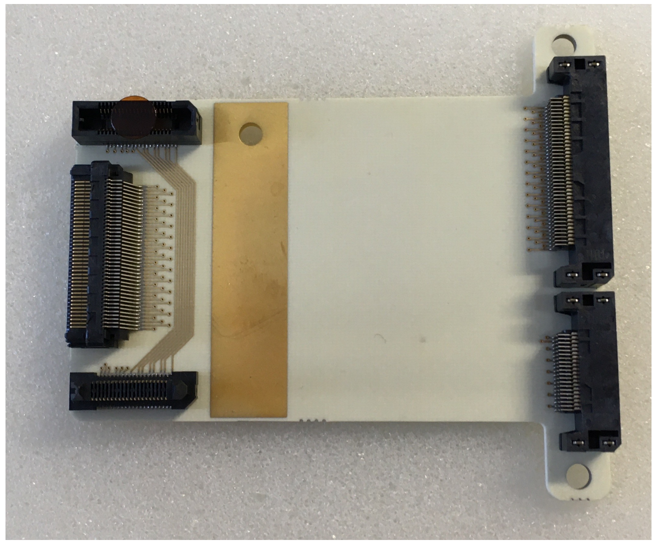
Electronics



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

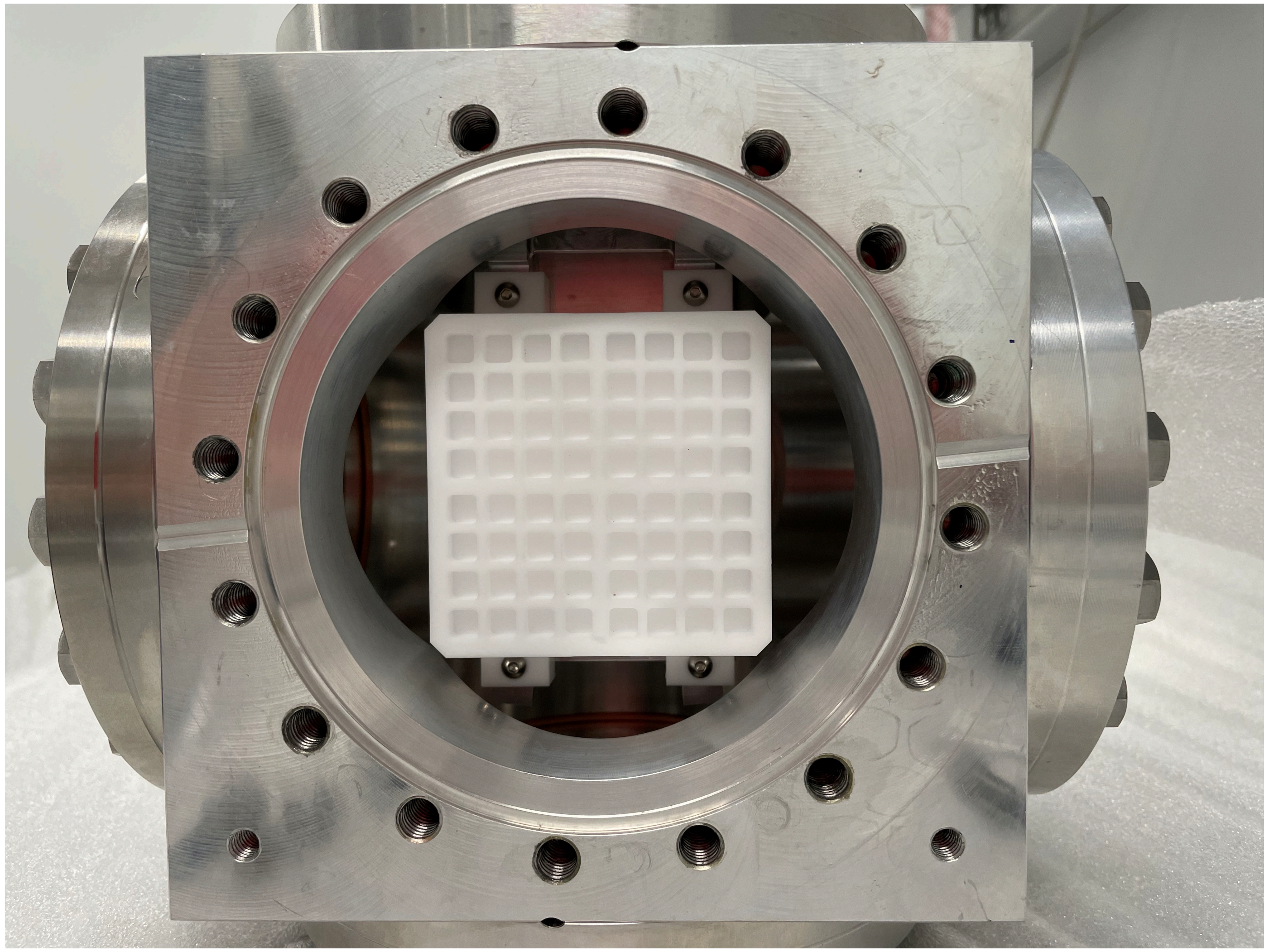
External feedthrough





Internal feedthrough

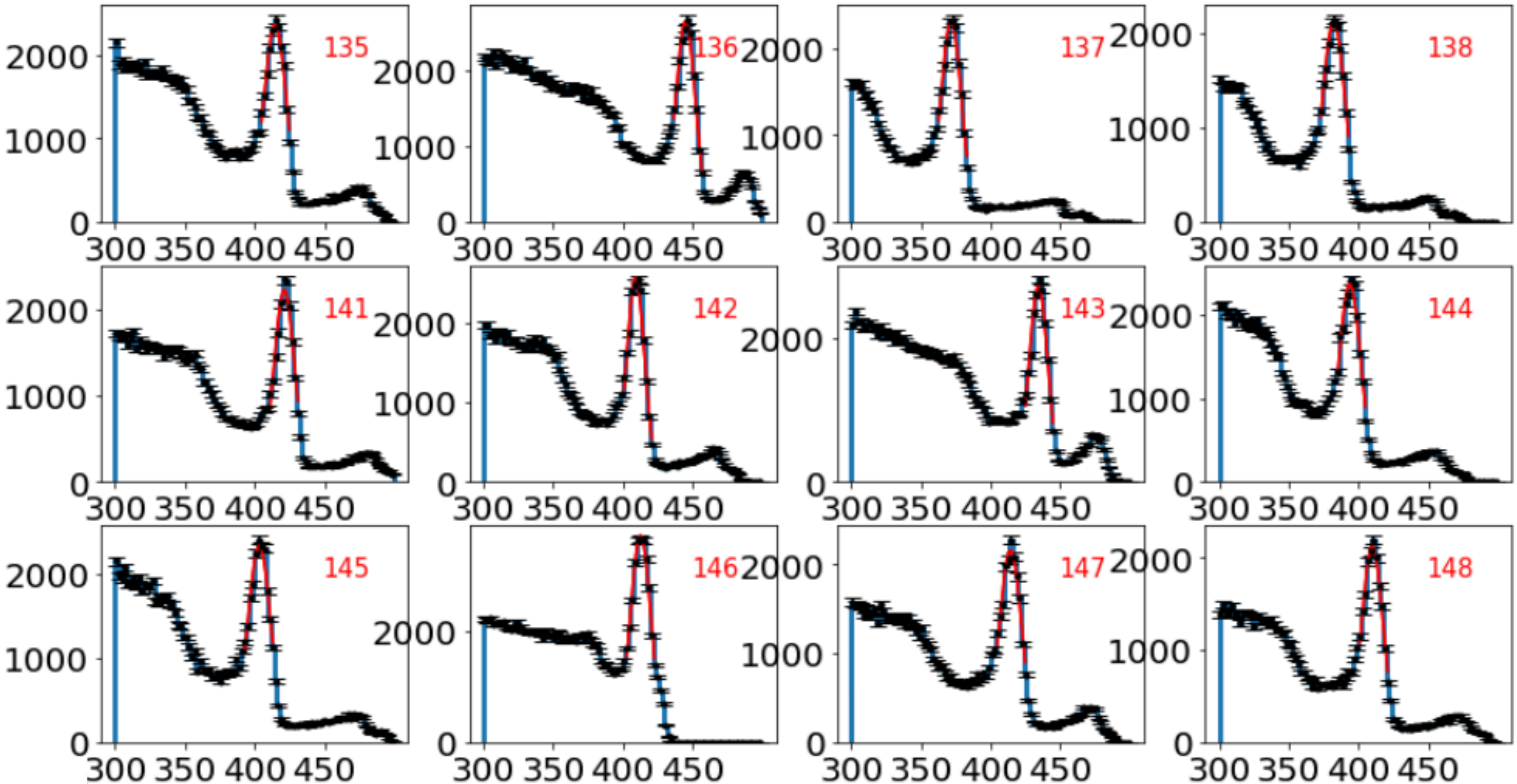
Measurements



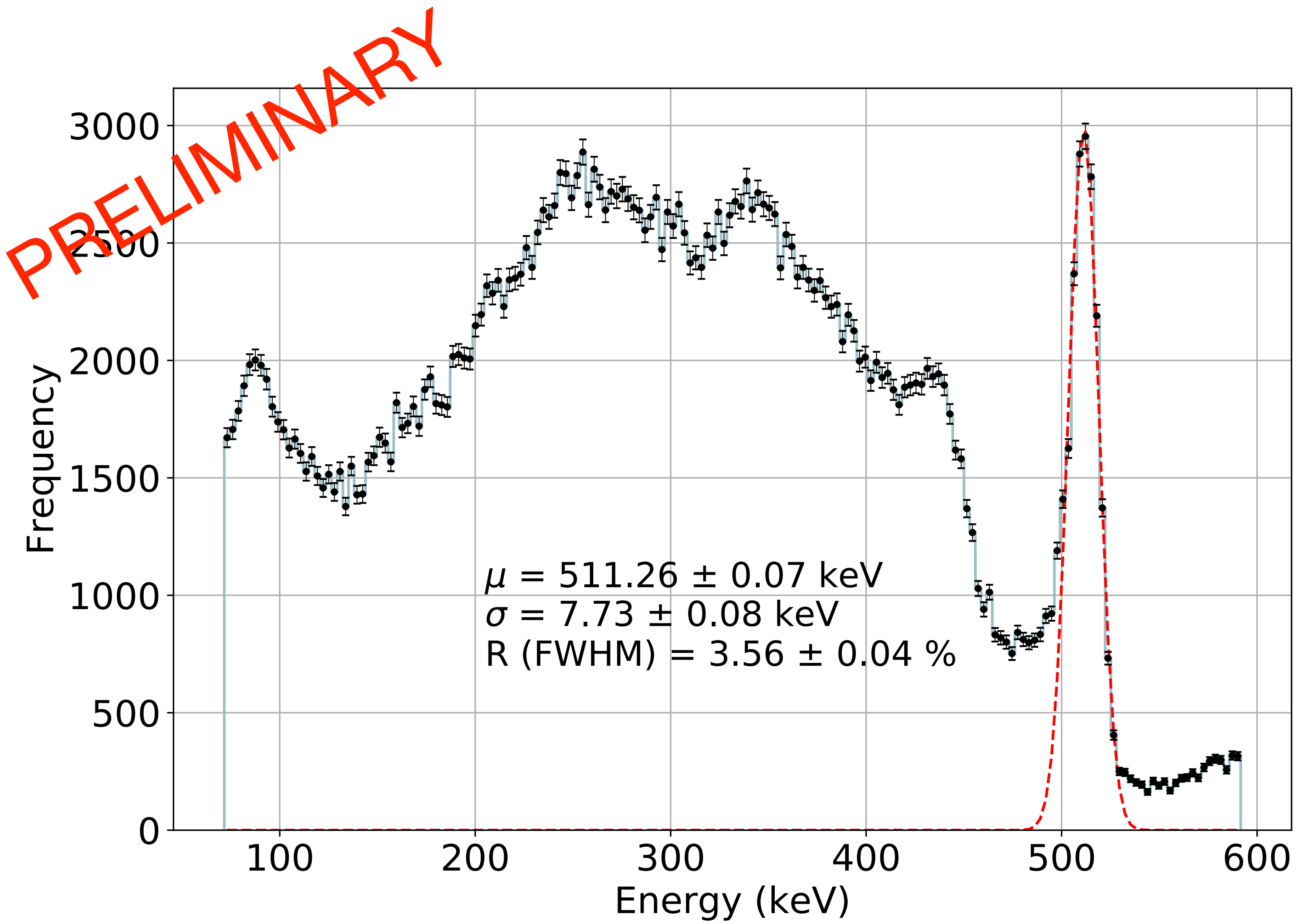
- Segmentation of the volume in $6x6x5\ mm^3$ LXe spaces with teflon.
- One "cell" in front of each SiPM.
- The light produced in each gamma interaction is collected mostly by the sensor in front.
- Light collection optimized.

Measurements

Energy resolution



Energy resolution



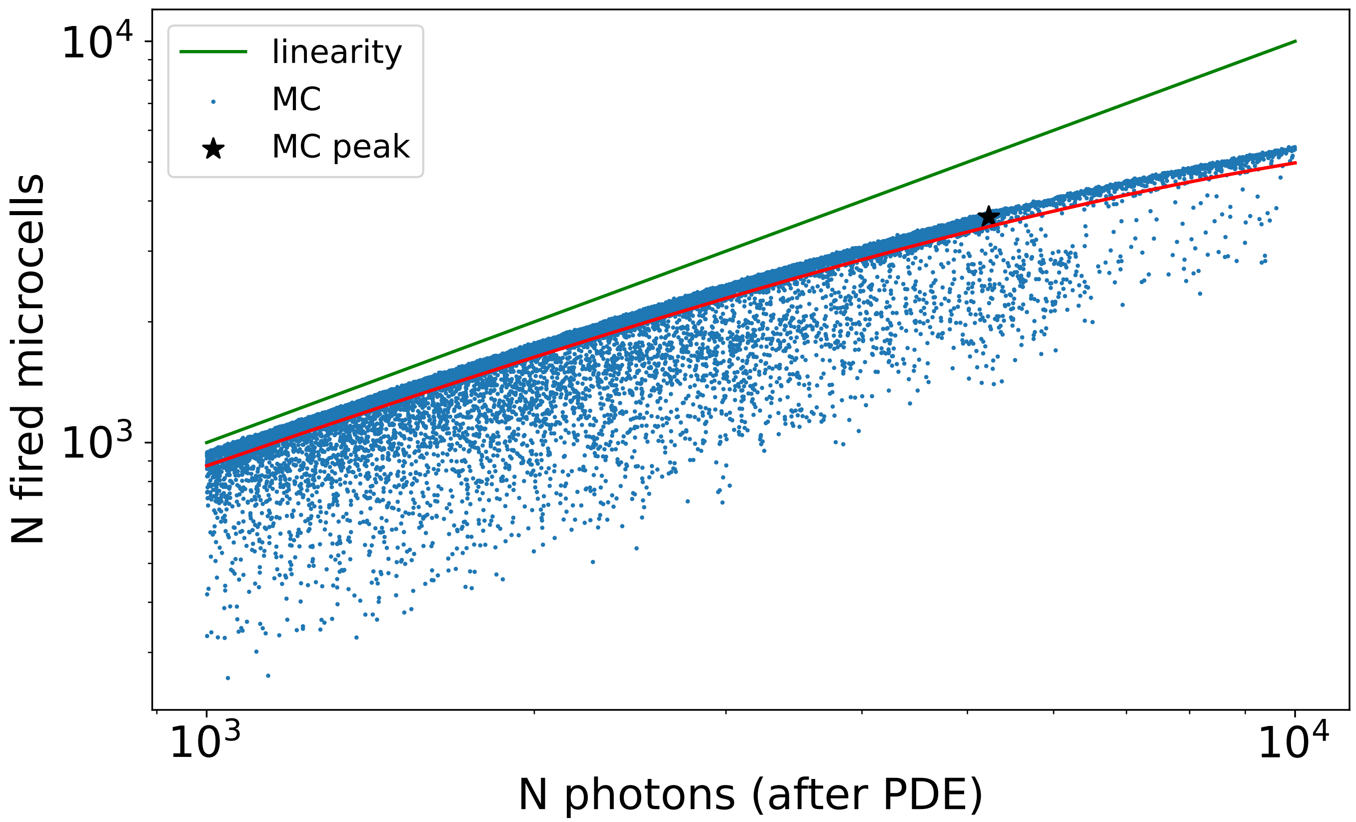
Measurement of 64 channels:
4.2% +- 0.2% FWHM

- Compatible with NEST simulation of 511 keV gammas (~4%).
- Monte Carlo simulation gives 5.4% FWHM, which hints to some problems.

Saturation effects

Correct SiPM charge

- Possible problem of saturation: 6126 microcells per SiPM and MC predicts ~5300 pe.



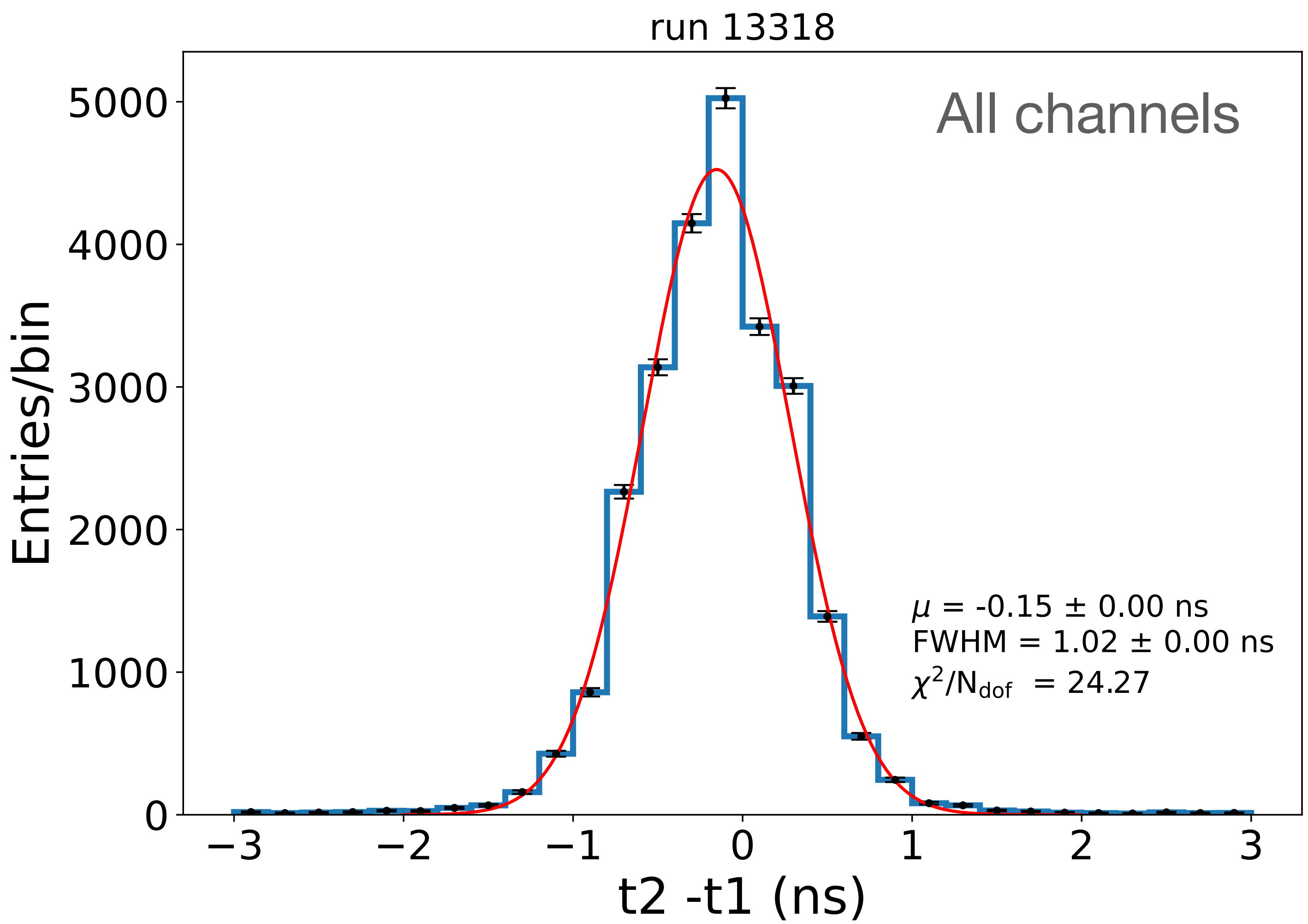
Assuming 250 ns recovery time

PRELIMINARY

- Monte Carlo simulation, **with** saturation effects, gives 4.4% +- 0.8% FWHM.
- Extract saturation function from MC -> correct data —> ~5.3% FWHM.
- Measurement of Ba-133 on-going: 81 and 356 keV.

Measurements

Time resolution



- Time resolution ~1 ns, larger than expected: still not correcting for time skew + other sources of degradation.
- TOFPET2 parameters being studied.

Conclusions and outlook

- PETALO is a technology based on LXe and SiPMs for PET scanners.
- First measurements of PETit shows excellent energy resolution.
- Studying saturation effects and intrinsic resolution.
- Potential for full-body PET.

- Improvement in the time measurement.
- Testing simulation with the image reconstruction algorithm to see the performance.
- Upgrade of PETit with larger volumes.

Thank you!

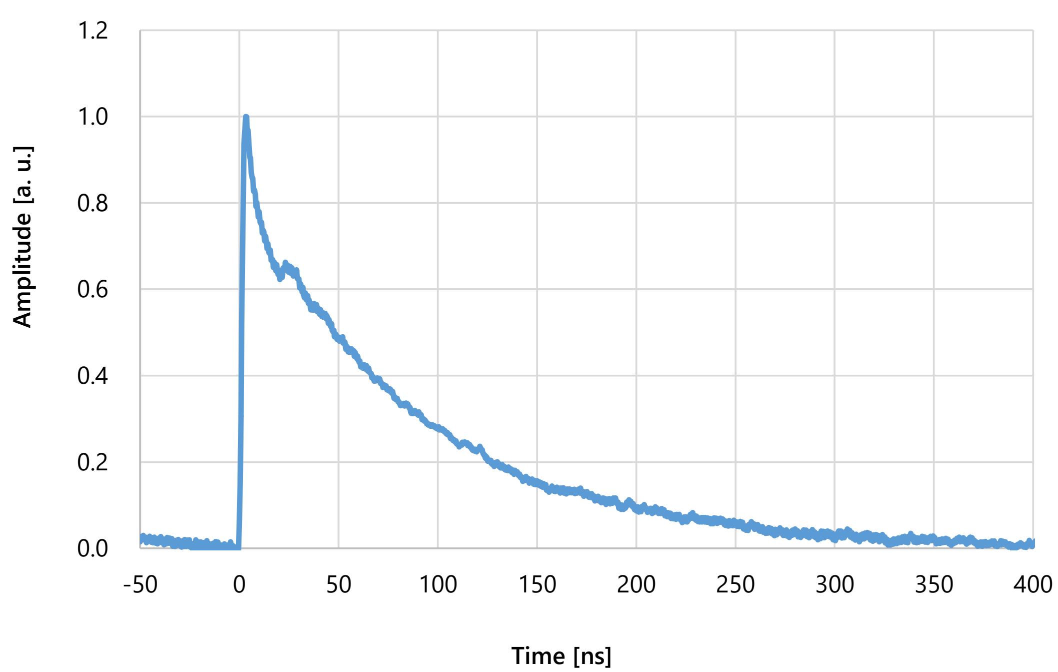
backup

slides

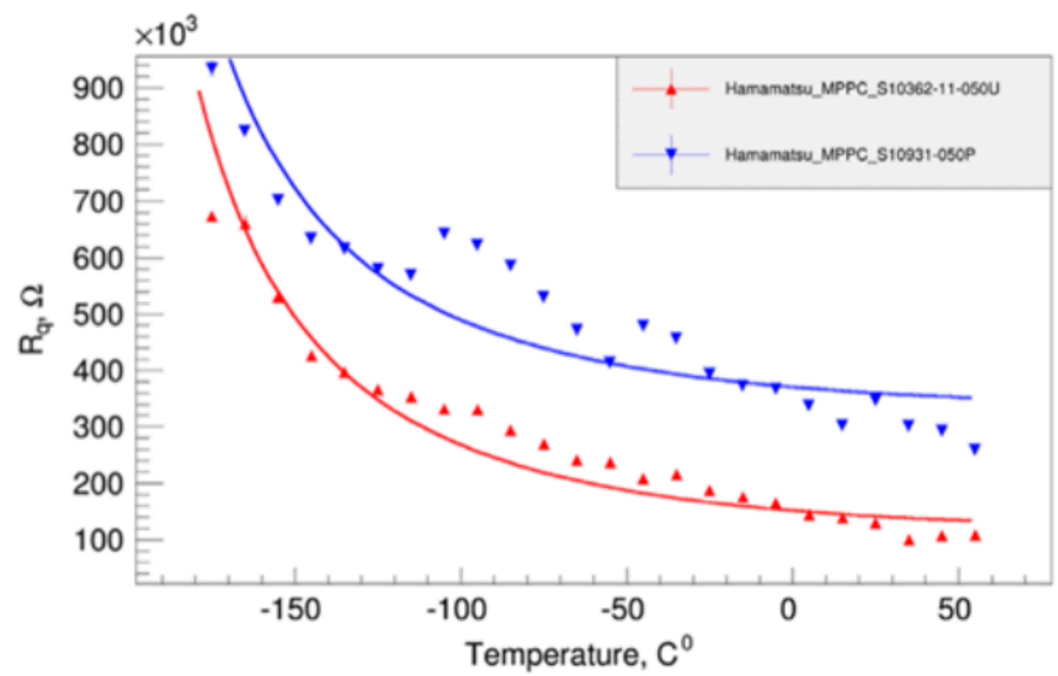
MC studies of saturation

- Recovery time constant: 90 ns
  (90% recovery time: 200 ns)

S15779(ES1) 1 p. e. pulse output (25 °C)

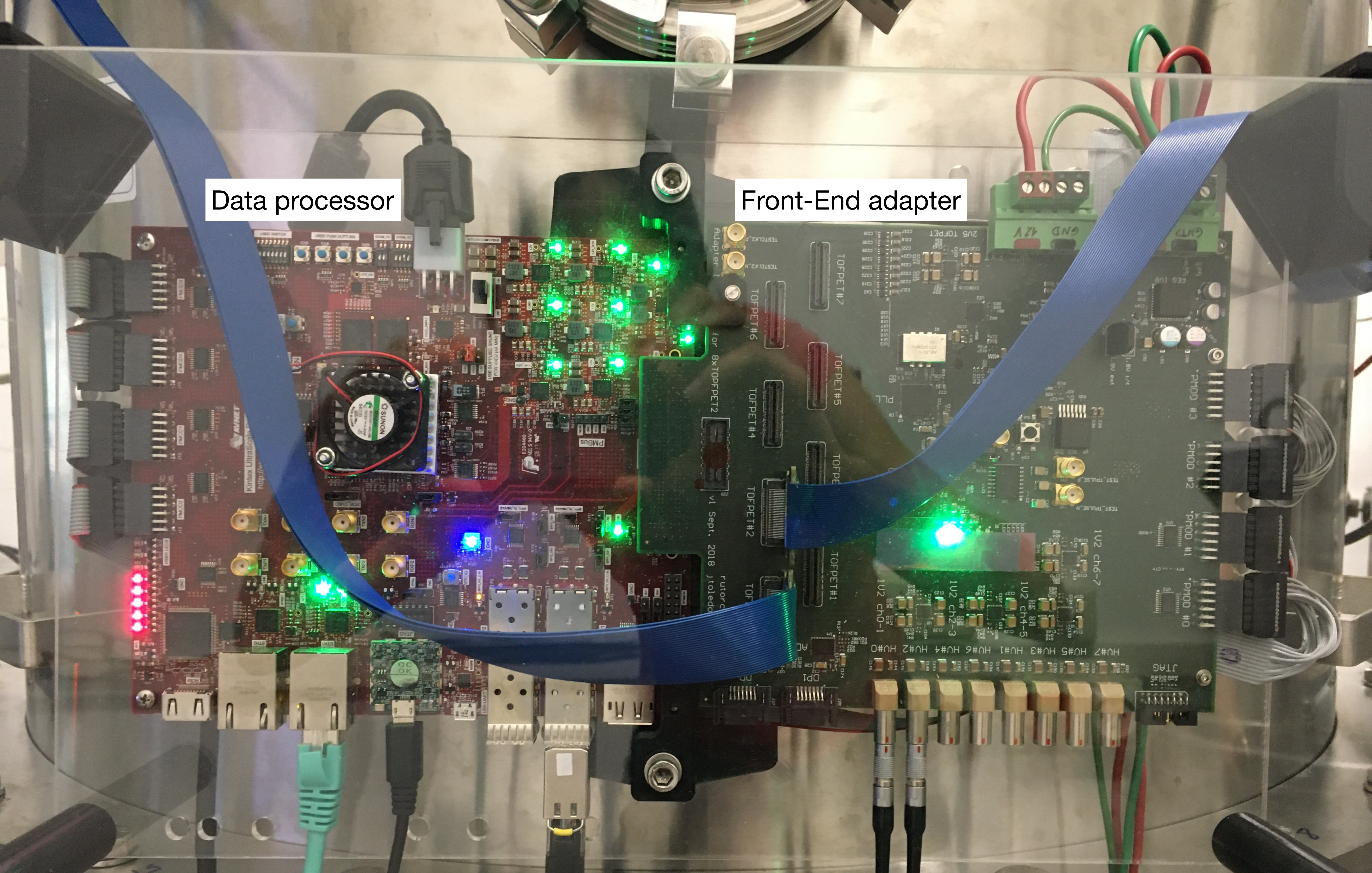


Quenching resistance vs temperature



~+160 kOhm from 25 to -110 C

Estimated recovery time: 250 ns



- 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.