GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

European Research Council

petalo

Overview and Current Status of the PETALO project

Carmen Romo Luque, on behalf of the PETALO Collaboration

XeSAT2022 Coimbra

25/05/2022

IFIC INSTITUT DE FÍSICA CORPUSCULAR

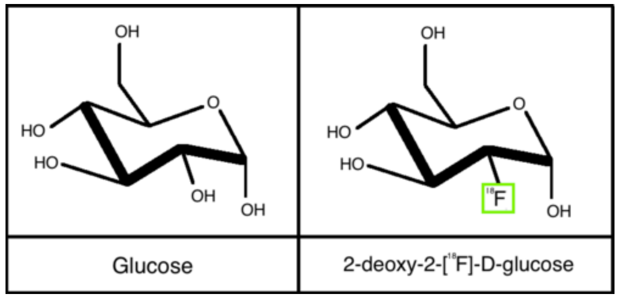
VNIVERSITAT DE VALÈNCIA

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

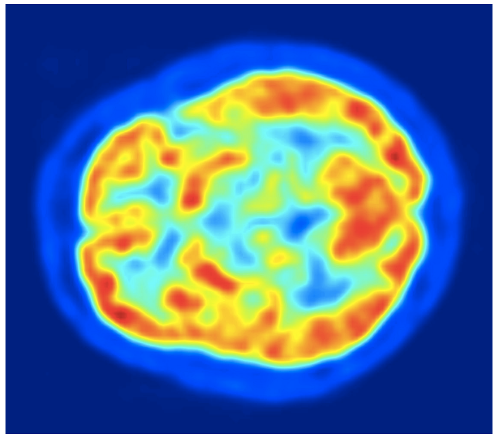
DIPC

Positron Emission Tomography (PET)



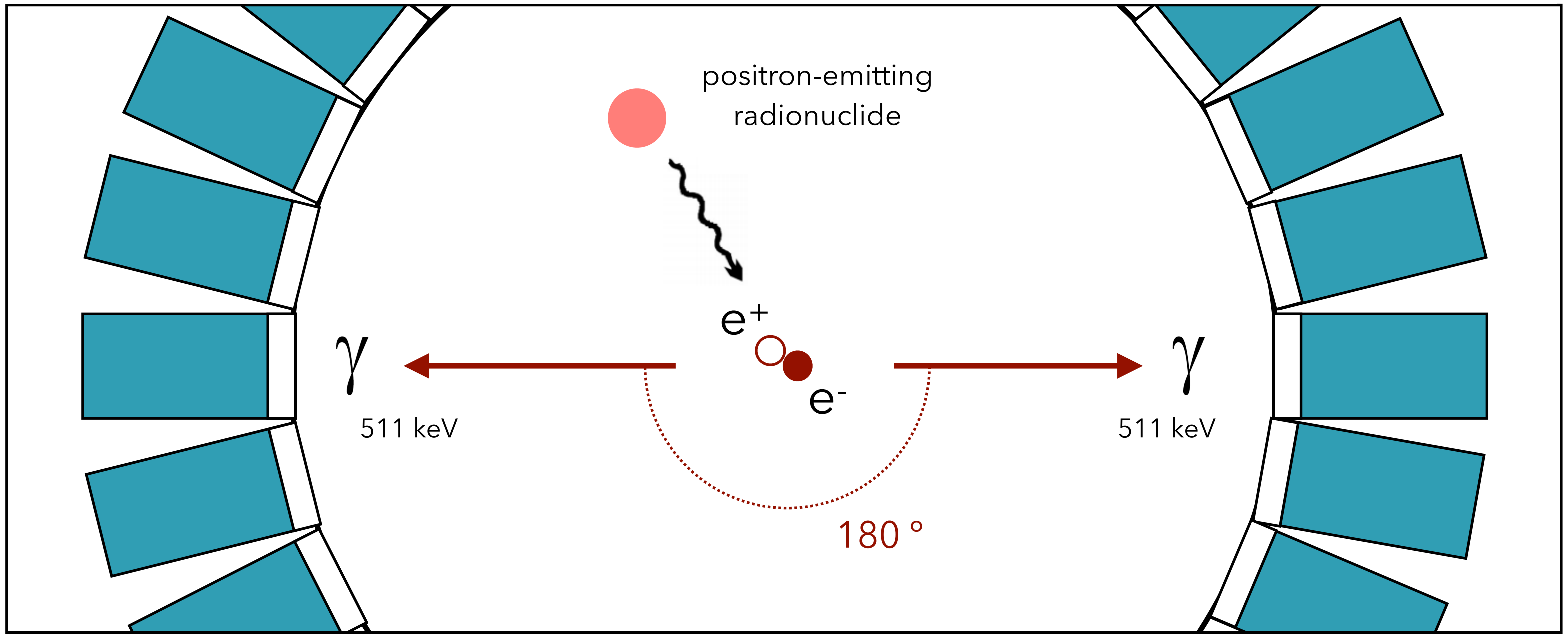
- Non invasive technique that produces a 3D image of metabolic processes in the body.
- Principle of operation: injection into the patient of a biologically active molecule analogue of glucose doped with a radioactive isotope.

- Medical and research tool.
  - **Cancer detection**. High metabolism of tumoral cells.
  - **Brain imaging**: neurological activity - glucose consumption.
  - **Blood flow monitoring** and heart related diseases.
- A **functional image** is obtained.
- Combine PET/CT technologies.



Brain PET scan

Positron Emission Tomography (PET)

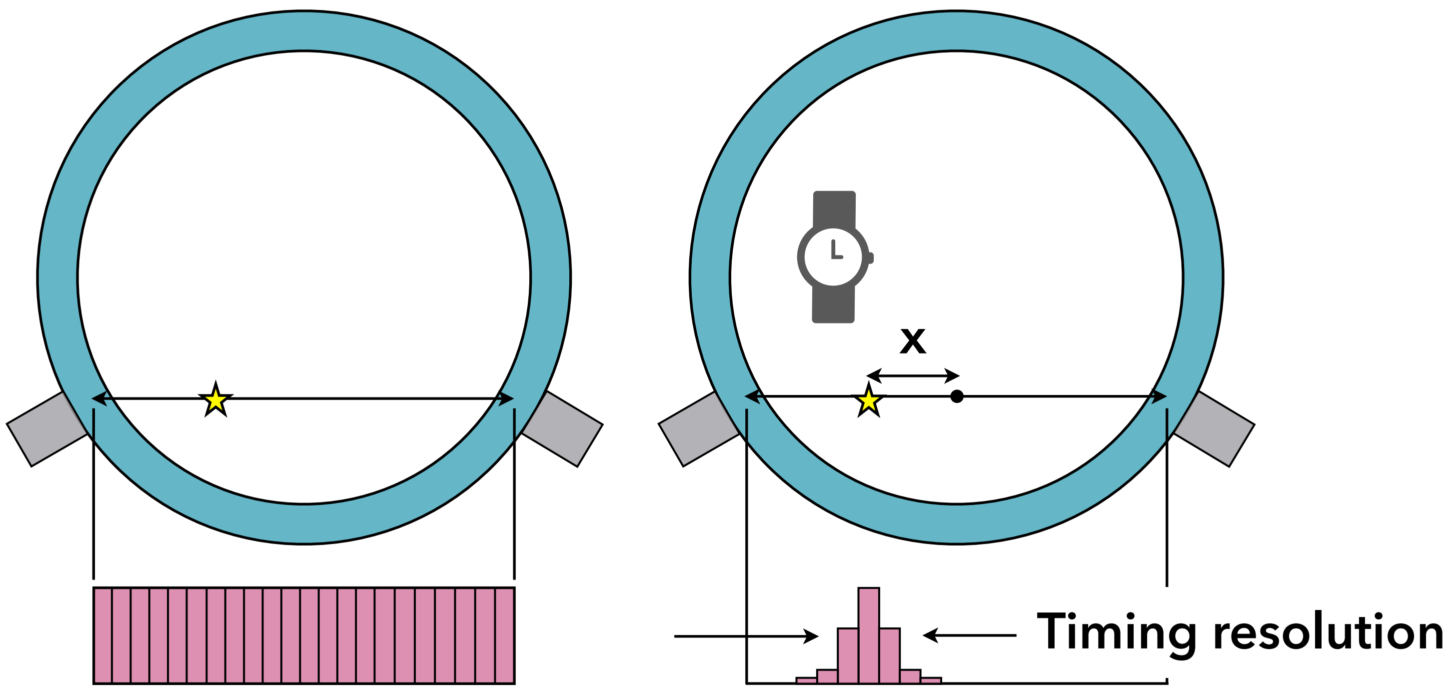


PET operation:

- Glucose analogue is doped with a radioactive isotope (e.g., ^{18}F), which emits positrons.
- Injection of the radiotracer into the patient.
- The positron annihilates with an electron of its environment, giving rise to two back-to-back 511 keV photons.
- These photons are detected in coincidence (LOR) by a ring of detectors: scintillator crystal + photodetector, registered and used to reconstruct an image of the distribution.

Time of Flight

In PET-TOF the **difference in arrival time** of the two photons is measured precisely enough to localize the emission point along the LOR.



no TOF

Same probability
Much noise

TOF

A segment in the line is constrained
The noise is reduced
Improves results at low statistics

$$\Delta x = \frac{\Delta t \cdot c}{2}$$

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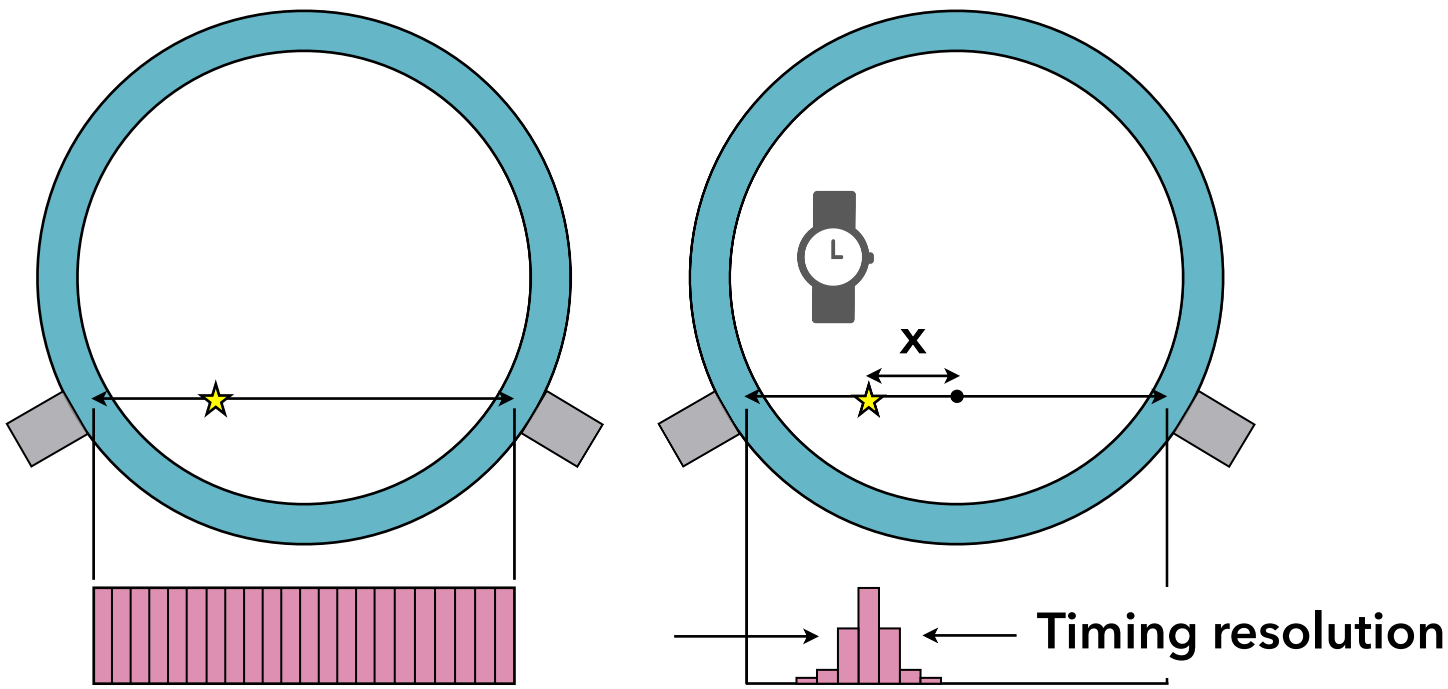

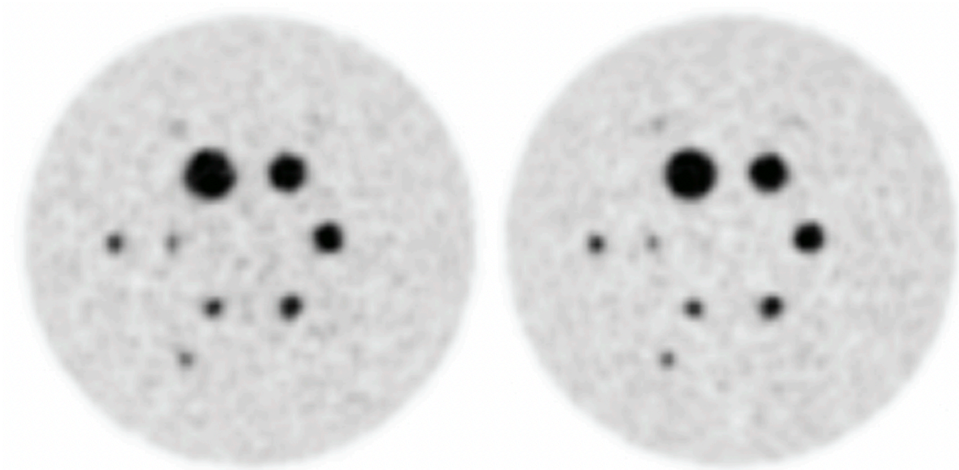

TOF (2′)

no TOF (10′)

Canon Celesteion: Time-of-Flight Technology Medical Review

no TOF

Same probability
Much noise

TOF

A segment in the line is constrained
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Improves results at low statistics

$$\Delta x = \frac{\Delta t \cdot c}{2}$$

The PETALO concept

Positron Emission TOF Apparatus based on Liquid xenOn

- Proposed new type of PET scanner designed to maximize TOF performance.
- Spin-off of the next experiment.
- Uses NEXT technology (Xe, SiPM).
- Uses LXe Scintillation signal only (fast response, avoid electric fields).
- Instrumented faces covered with dense array of SiPMs.

The PETALO concept

Positron Emission TOF Apparatus based on Liquid xenOn

Liquid Xenon as scintillator

- Z = 54. High density: high **stopping power**.
- Large **scintillation yield** and **transparent** to its own scintillation light.
- **Fast scintillation** (2.2 ns): **TOF capability**.
- Uniform continuous medium, **homogeneous detector**, minimized dead regions and border effects.
- At atmospheric pressure xenon liquifies at ~161 K and thus **cryogenics** is relatively simply.
- Emission of **Cherenkov light**.

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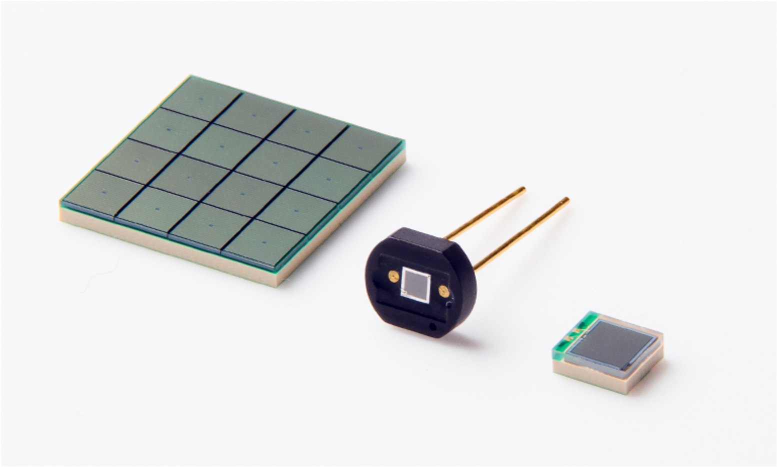
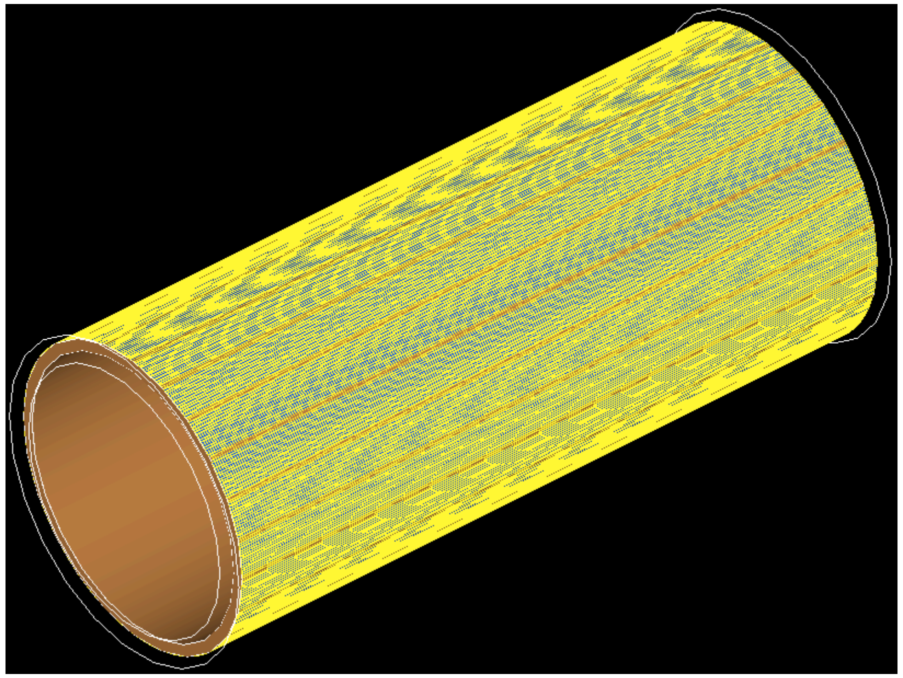
SiPMs as readout

- Solid state detectors working in Geiger mode: **high gain**.
- Size of few mm: fine **granularity** for spatial resolution.
- **Fast response**.
- **Low dark count rate** at cryogenic temperatures.
- Insensitive to magnetic fields.



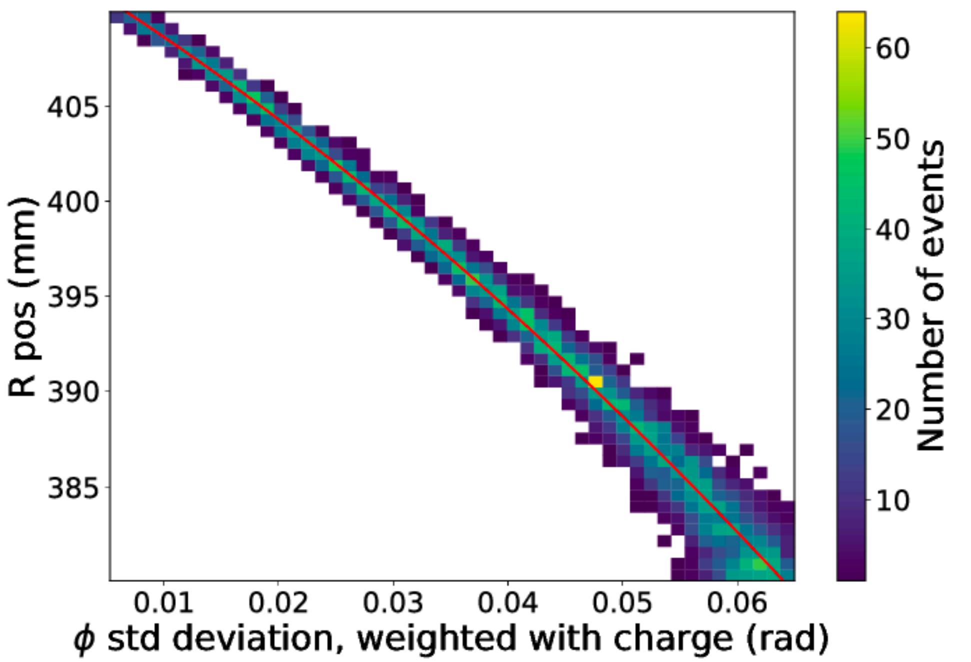
MC: Full Body PET performance

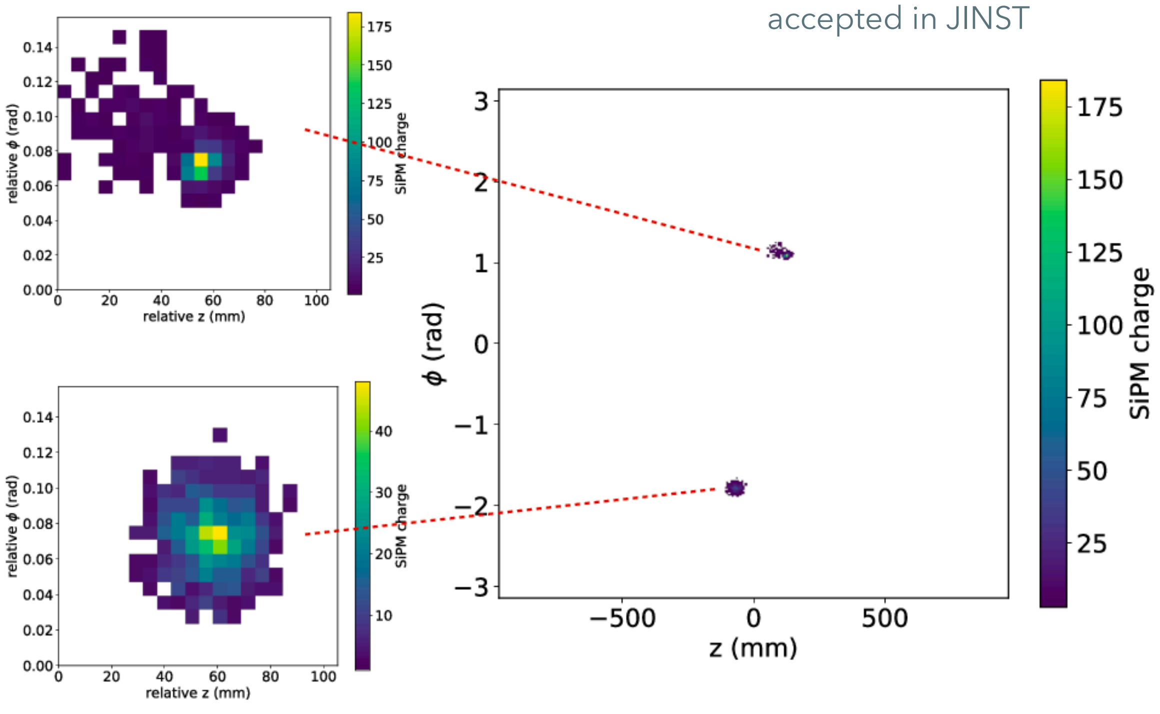
Geant4 used to simulate geometry and propagation of particles.



- 2 m length, 3 cm thickness (trade-off sensitivity-performance).
- 6x6 mm^2 SiPMs only on the external surface to avoid mechanical complexity, ~100 000. 30% PDE.
- Non-reflective internal surface to improve spatial resolution.
- From the scintillation photons detected by the sensors, the 3 spatial coordinates are reconstructed (z, phi barycenter, r map), **~1 - 1.5 mm.**

Characterization of PETALO, a full-body liquid xenon-based PET detector
accepted in JINST





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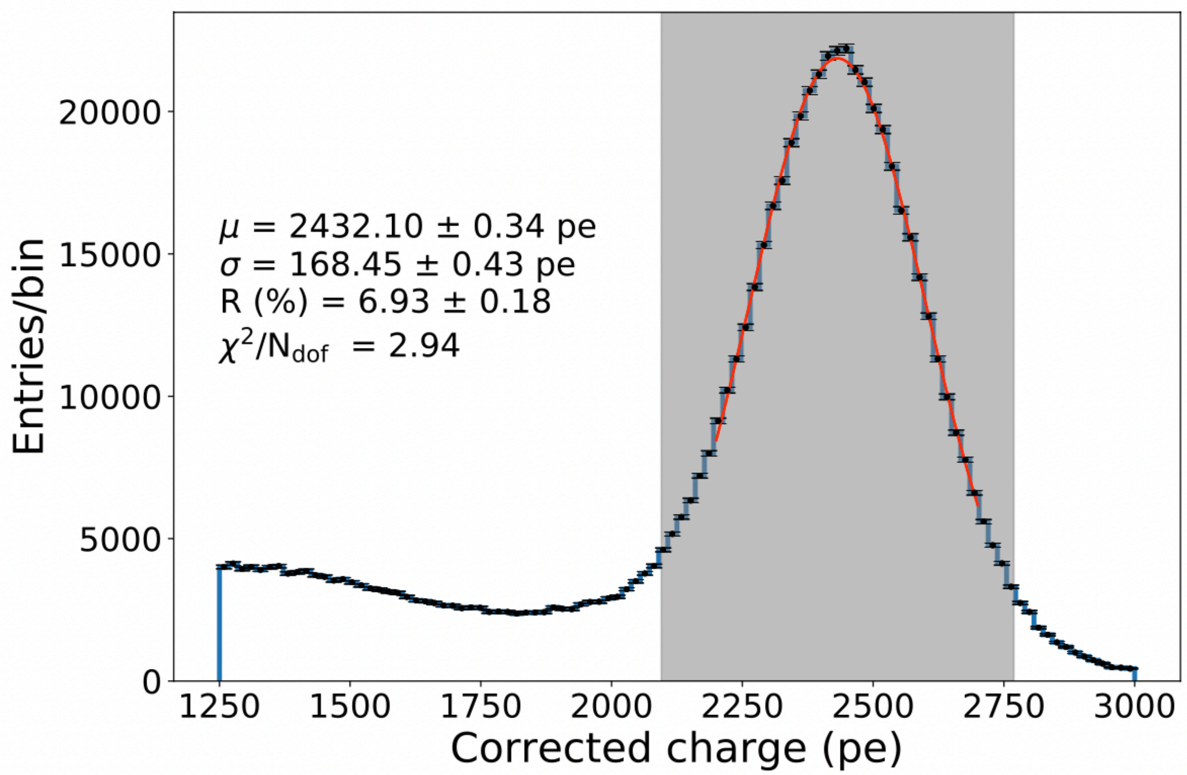


Characterization of PETALO, a full-body liquid xenon-based PET detector accepted in JINST

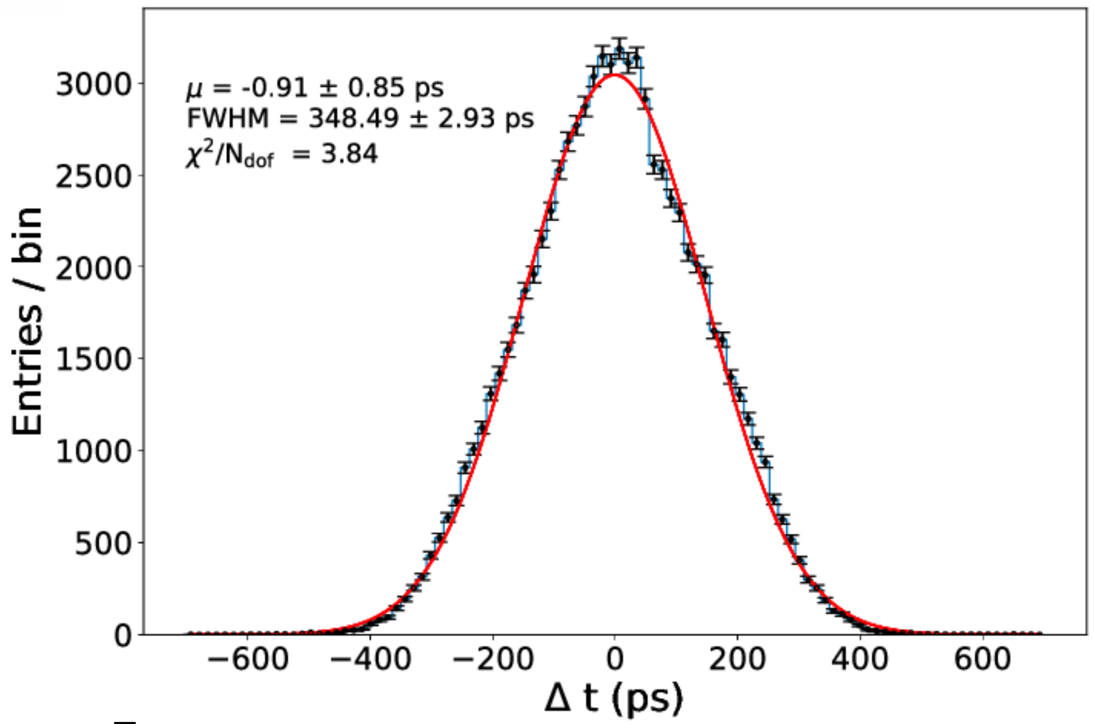
- Energy resolution: **~ 15-16%**

$$R^2 = R^2_{\rm geom} + R^2_{\rm stat} + R^2_{\rm recomb} + R^2_{\rm intr}$$

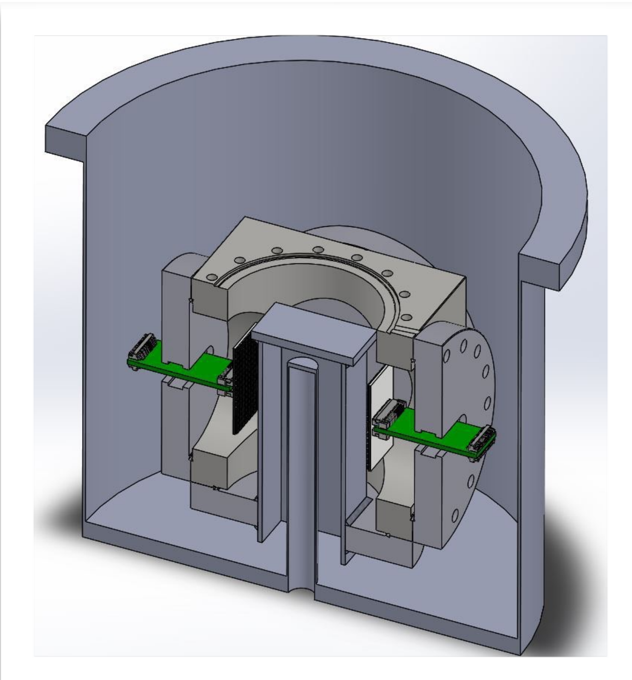
7% FWHM from MC — 14% FWHM @zero E field, 511 keV

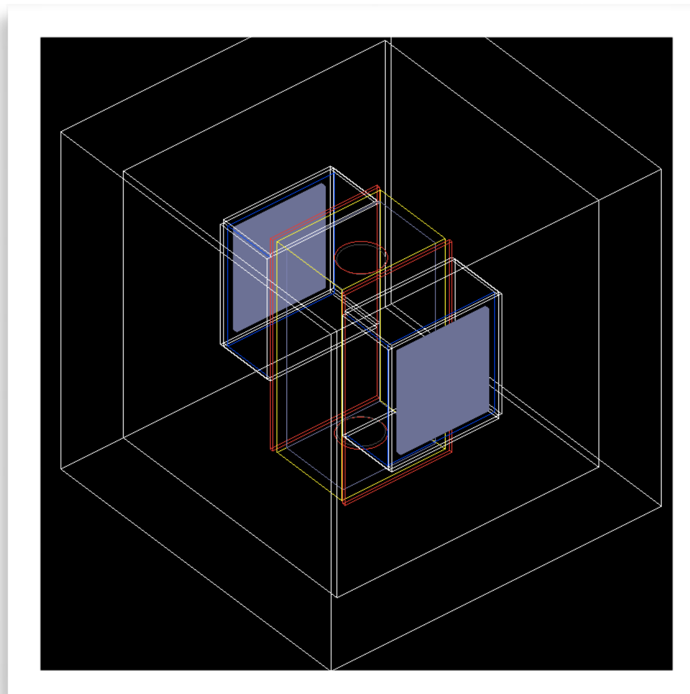
K.Ni, et al, JINST, vol. 1, p. P09004, 2006

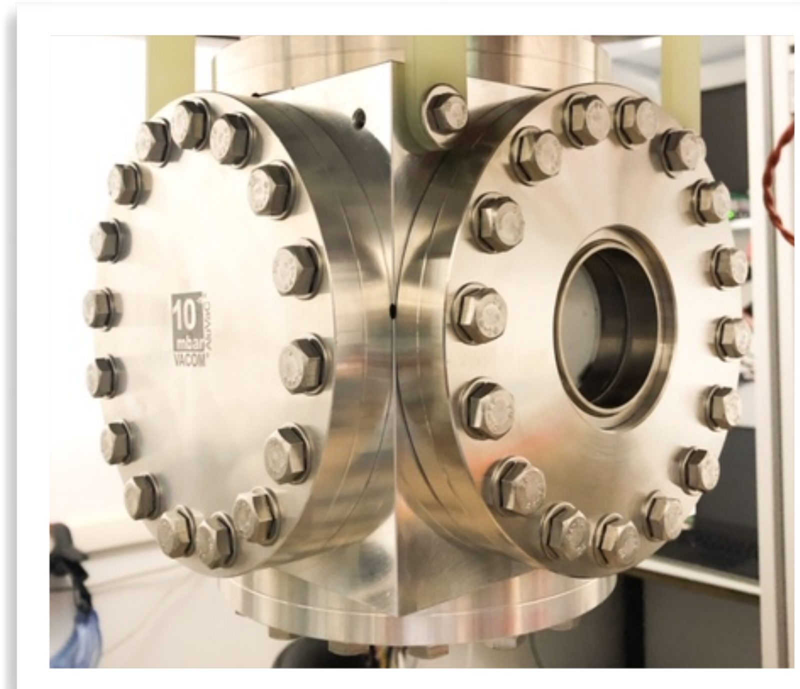
- Coincidence Time Resolution (CTR):



PETit: First Prototype



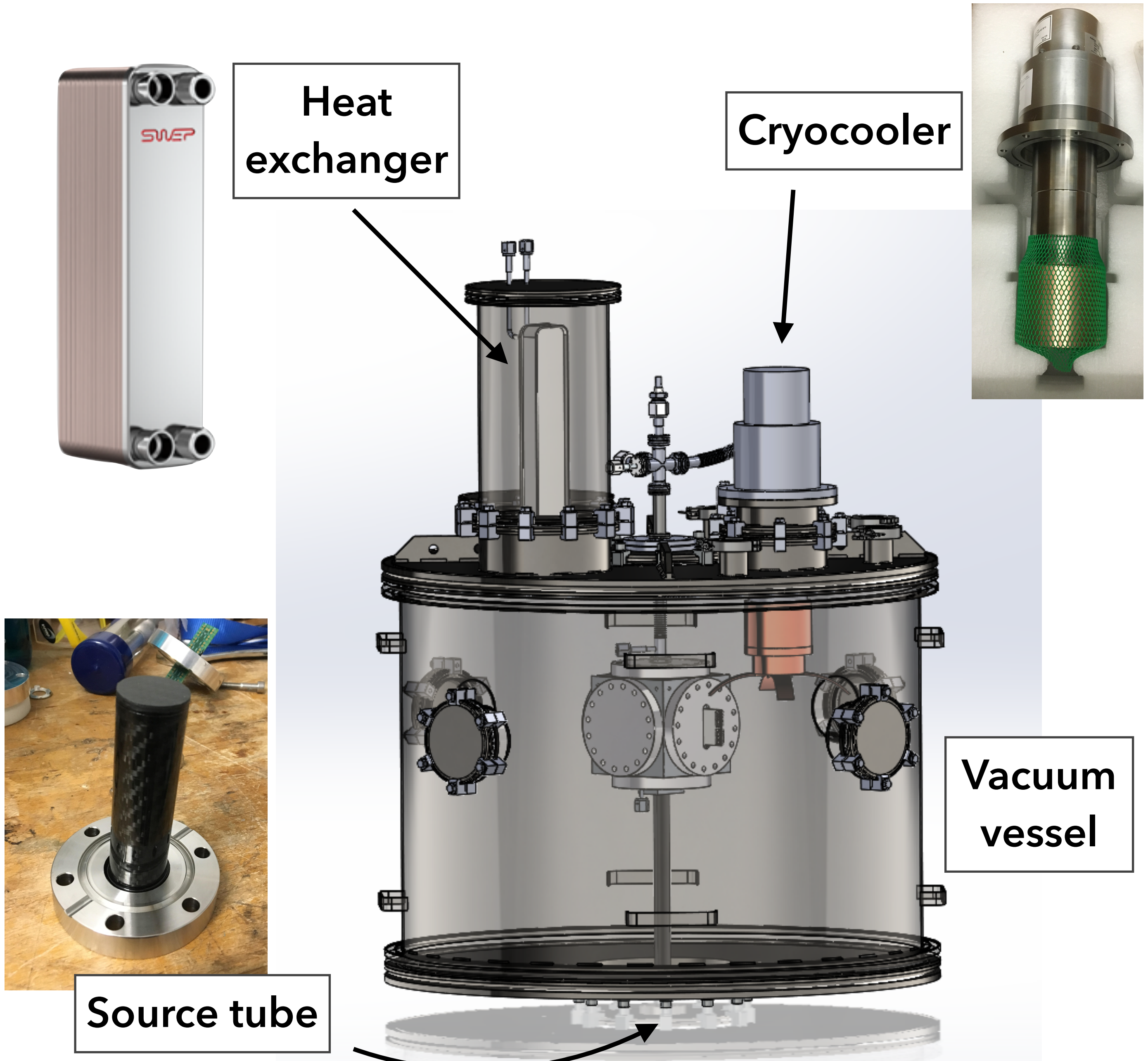




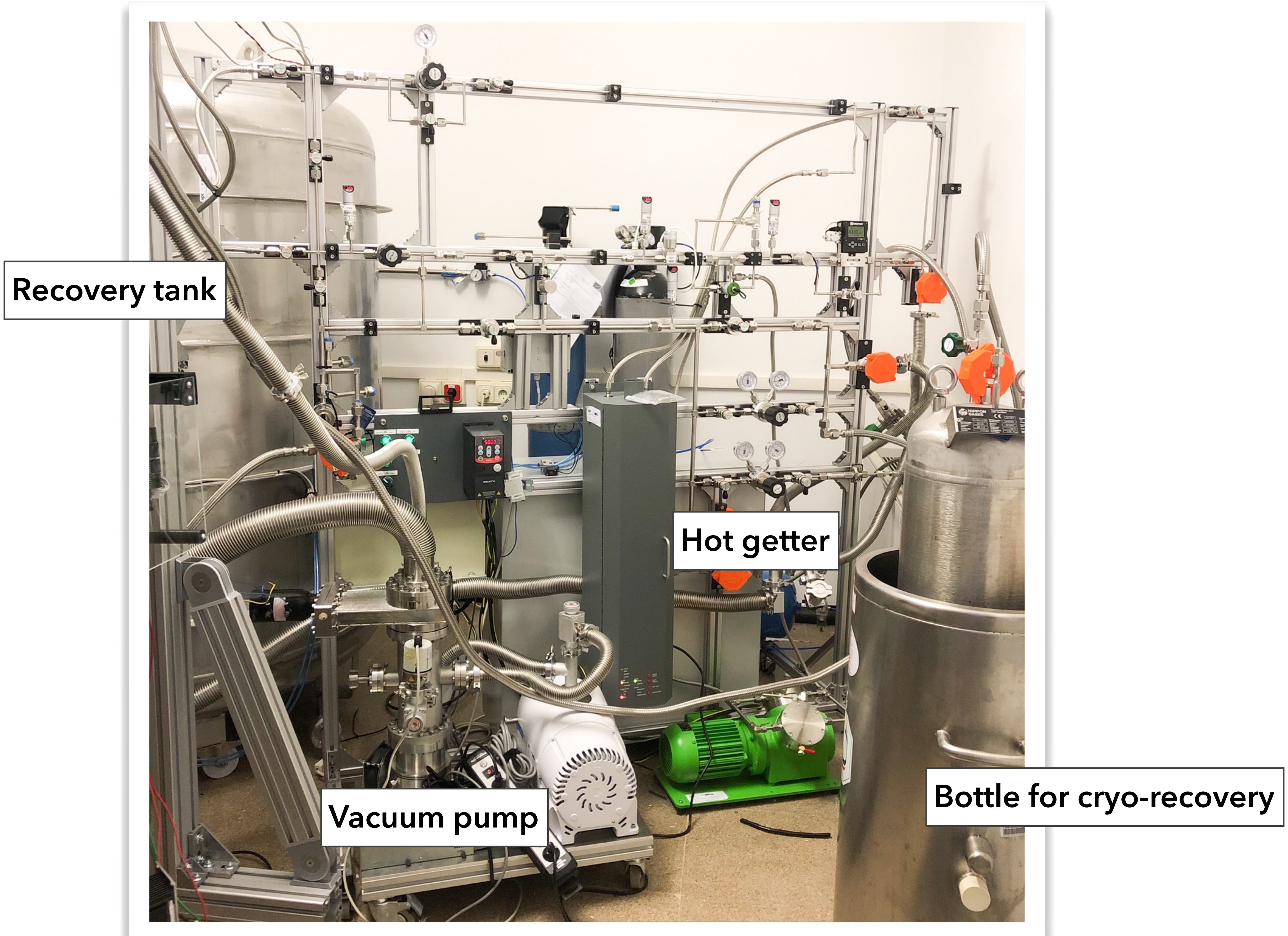
- Operating at IFIC (Valencia, Spain).
- Aluminum CF-100 box filled with liquid xenon.
- Two planes of SiPMs on opposite sides.
- 3 cm of active volume of xenon. With possibility of adjustment.
- Non-reflective pyrex planes surrounding the LXe active volume.
- **Aim:** measuring energy and time resolution with a Na^{22} calibration source.

Cryostat

- Box inside a vacuum vessel to isolate xenon.
- Cryocooler to keep 161 K.

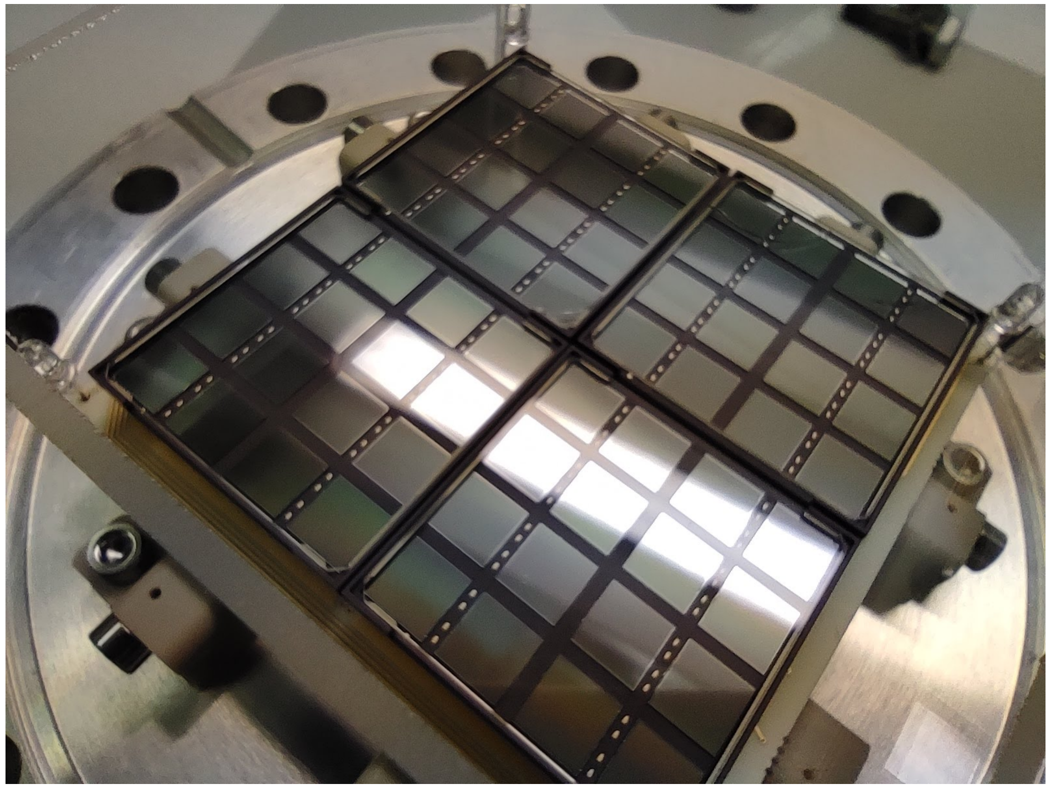


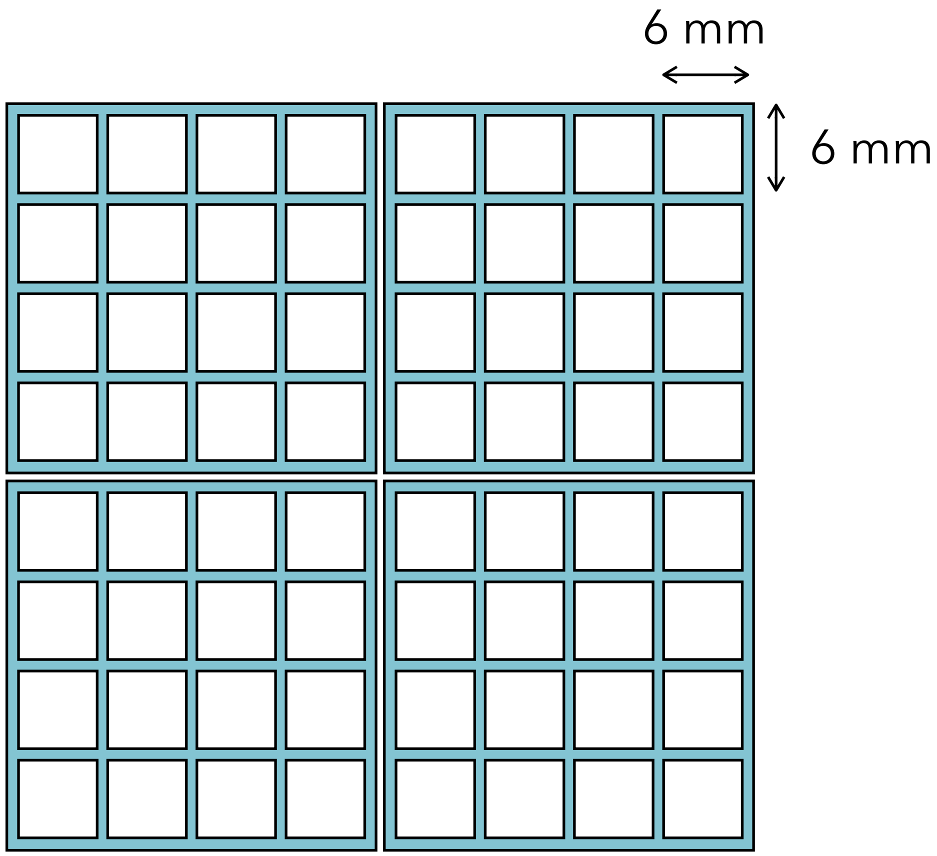
Gas system


Recovery tank
Hot getter
Vacuum pump
Bottle for cryo-recovery

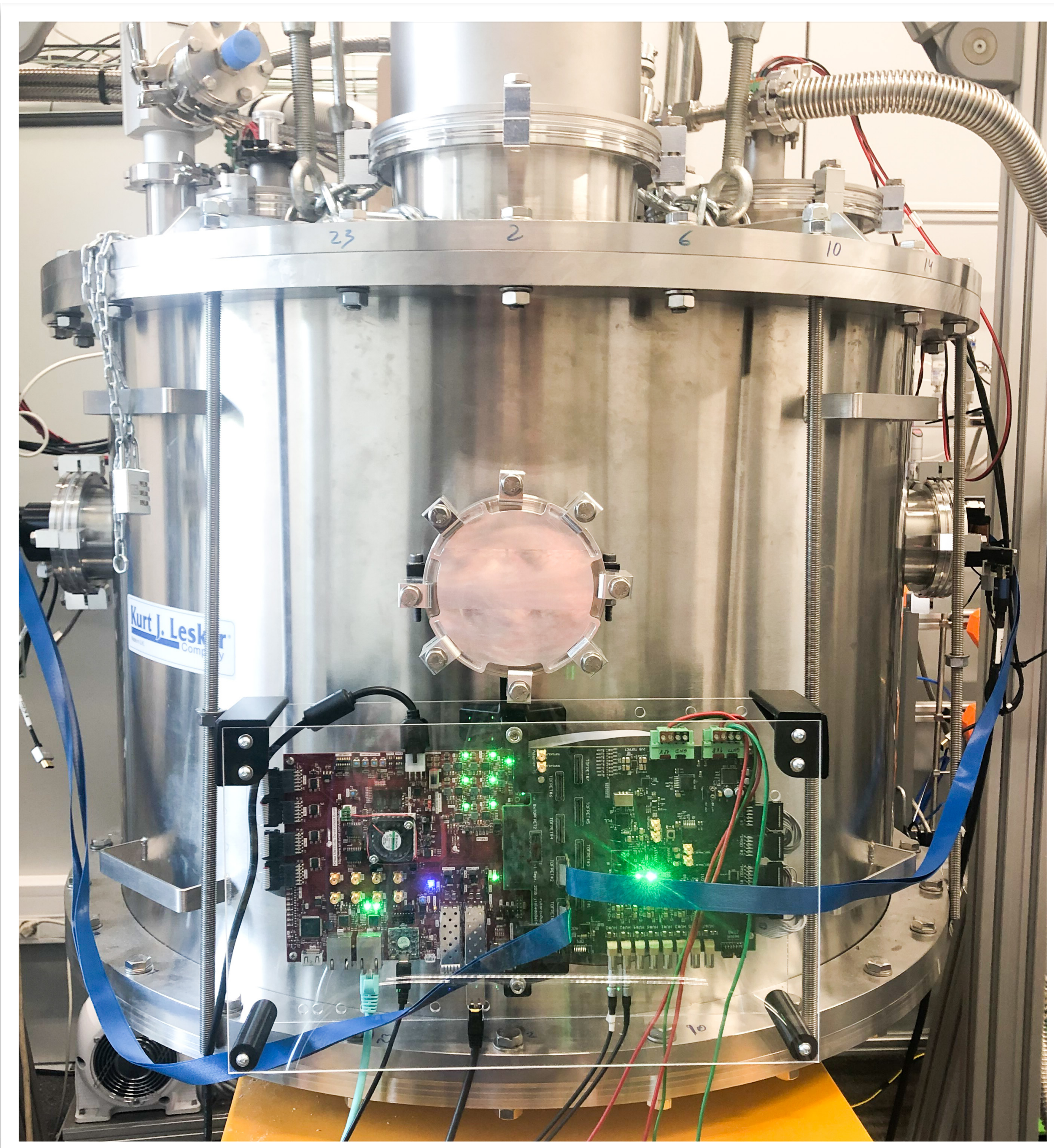
SiPMs

- Two planes of **64 VUV SiPMs**: Hamamatsu VUV-sensitive S15779 6x6 mm^2 (FBK sensors discarded).
- Four arrays of 4x4 sensors, specifically designed to increase fraction of active area, with **protective quartz window** in front (90% transparency to VUV light).
- Larger area: lower cost, better coverage but larger capacitance –> worse TOF.
- Possibility of using **conventional SiPMs** (detecting blue light) using wavelength shifter.





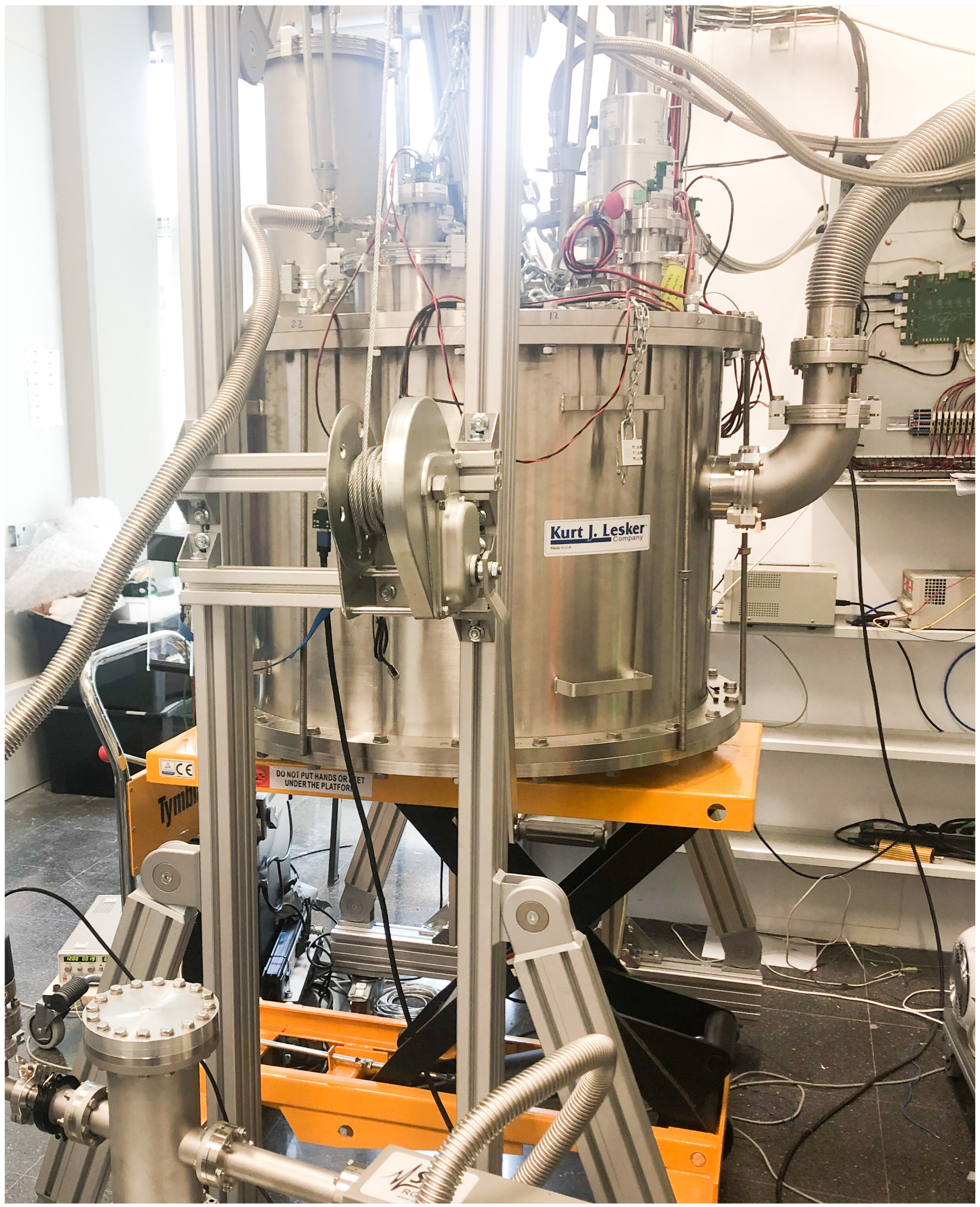
Electronics



Prototype of the acquisition module
of up to 8 TOFPET2 ASICs

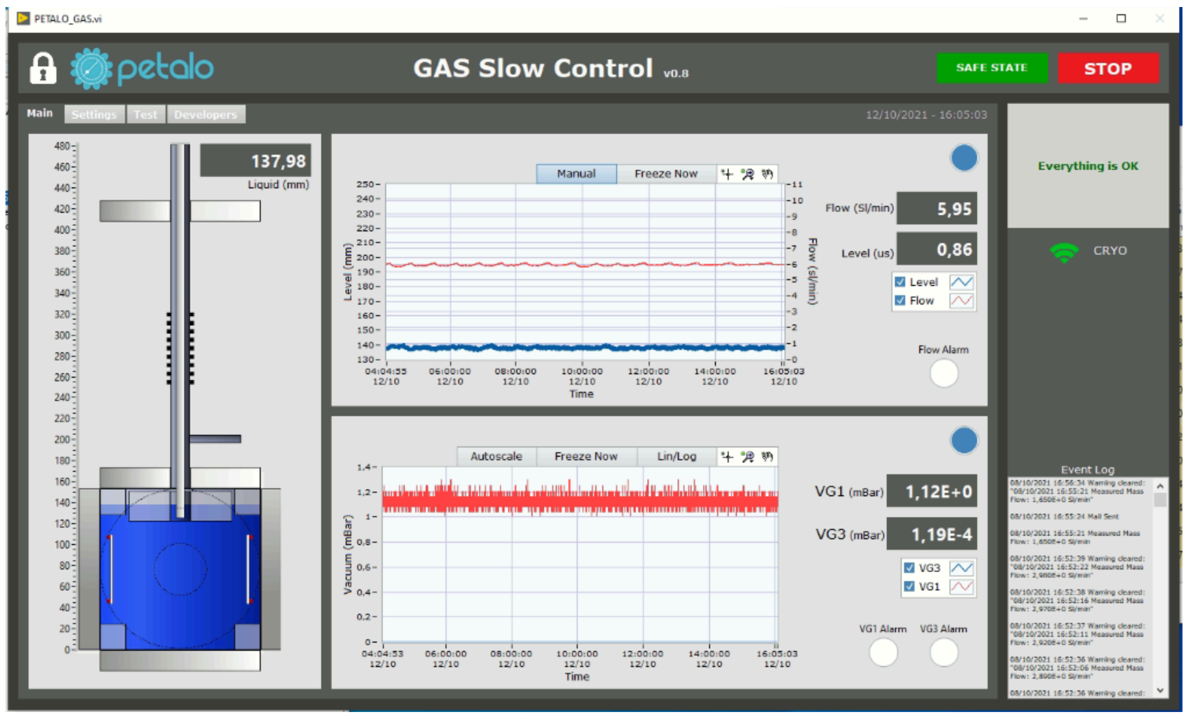
- **2 TOF-PET2 ASICs by PETsys** for signal digitization with 64 channels.
- Specifically designed for **fast timing and high rate applications**.
- Two **thresholds** separately configurable for time (low) and energy (high).
- Custom-made feedthroughs, which also support SiPM boards, optimizing space.
- The structure is modular and **scalable** to larger dimensions.

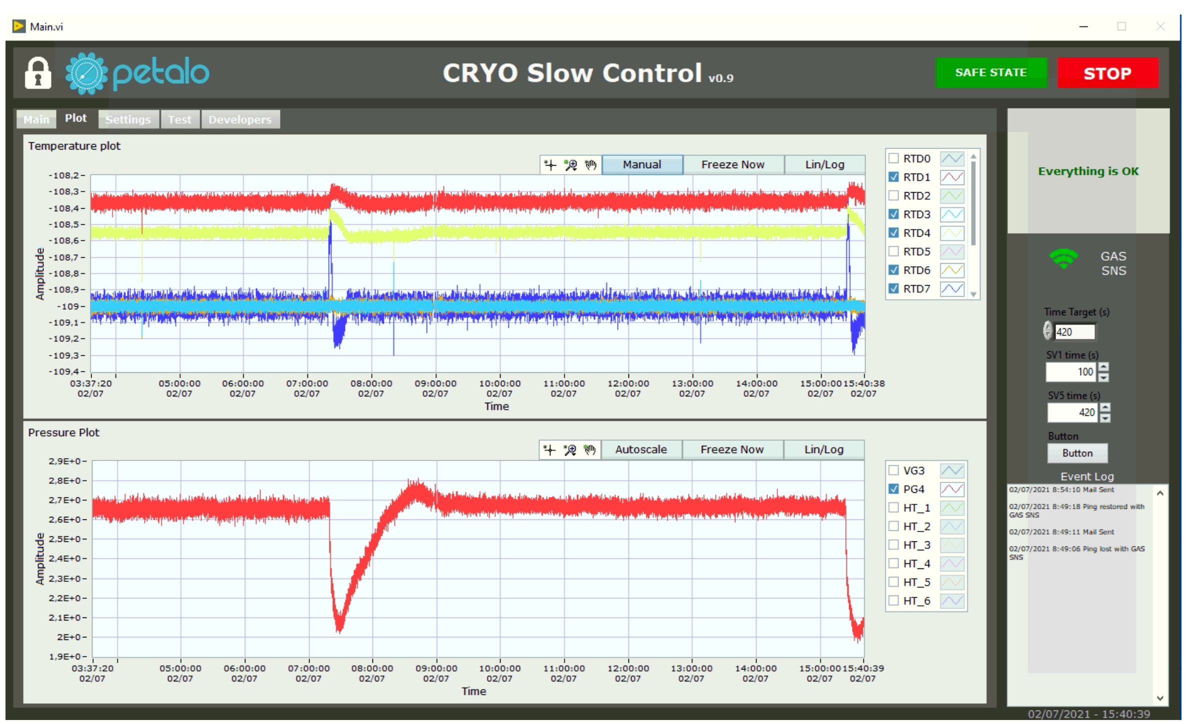
Status of the prototype



- First data taking run: July - December 2021.
- Devoted to understand the **detector and the sensor response**.
- Testing **different sensors**: Hamamatsu and FBK.
- We have debugged our **coincidences reconstruction algorithms**.

Status of the prototype





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- We are about to start the second data taking run. Stay tuned!

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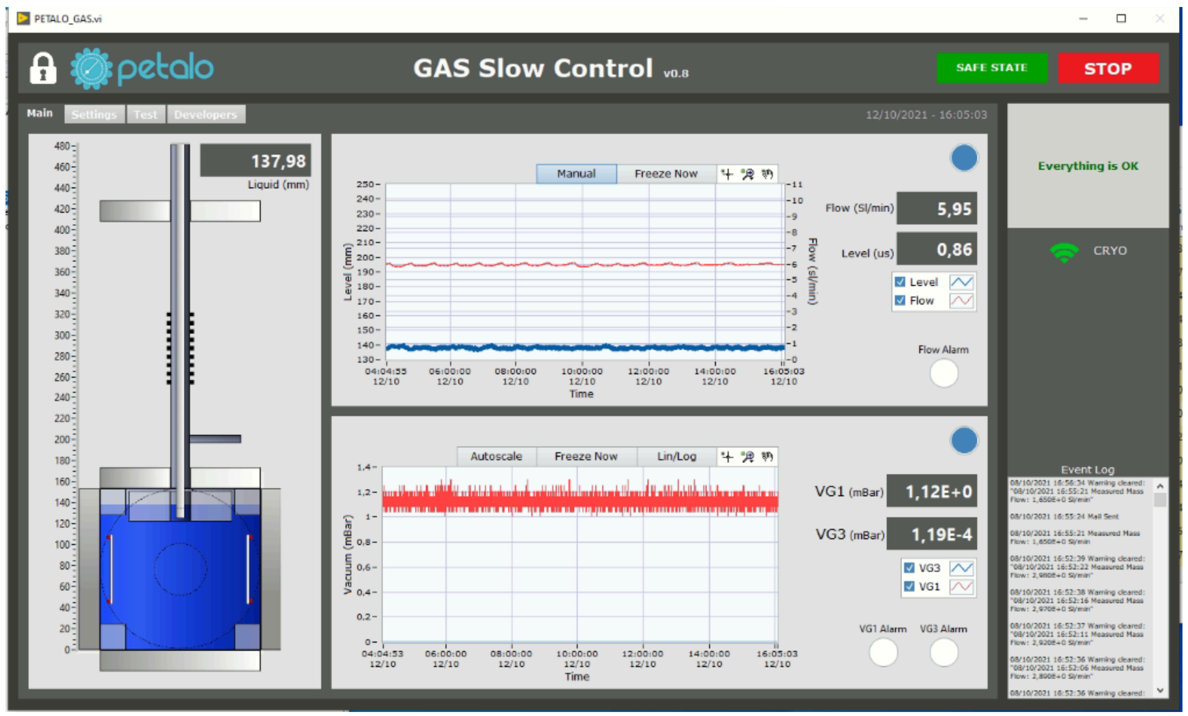

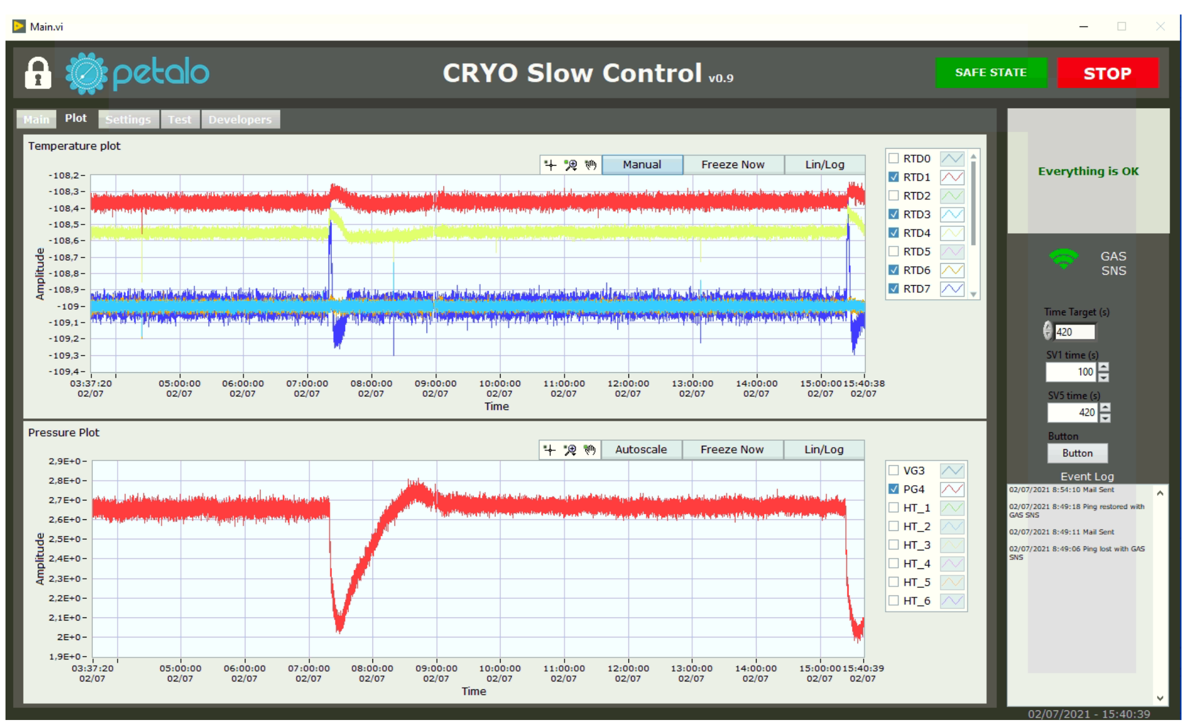

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Thanks!

Backup

MC: Spatial coordinates reconstruction

- From the scintillation photons detected by the sensors, the 3 spatial coordinates are reconstructed (z, phi barycenter, r map), **~1mm.**

Depth coordinate: R

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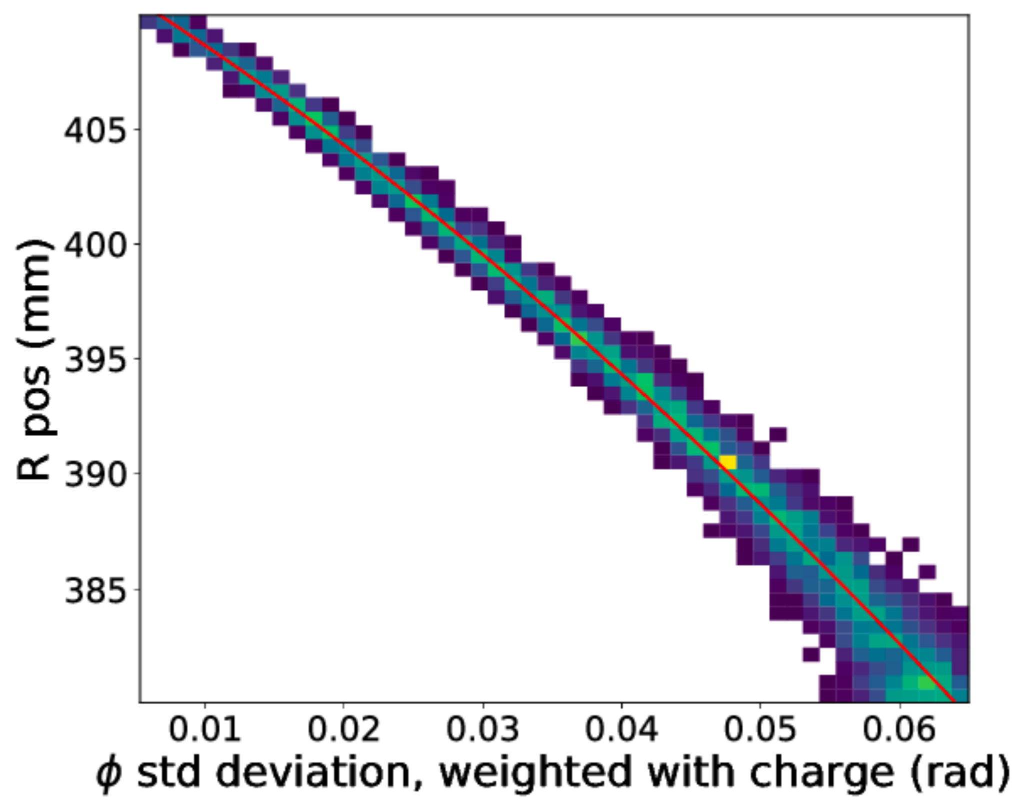

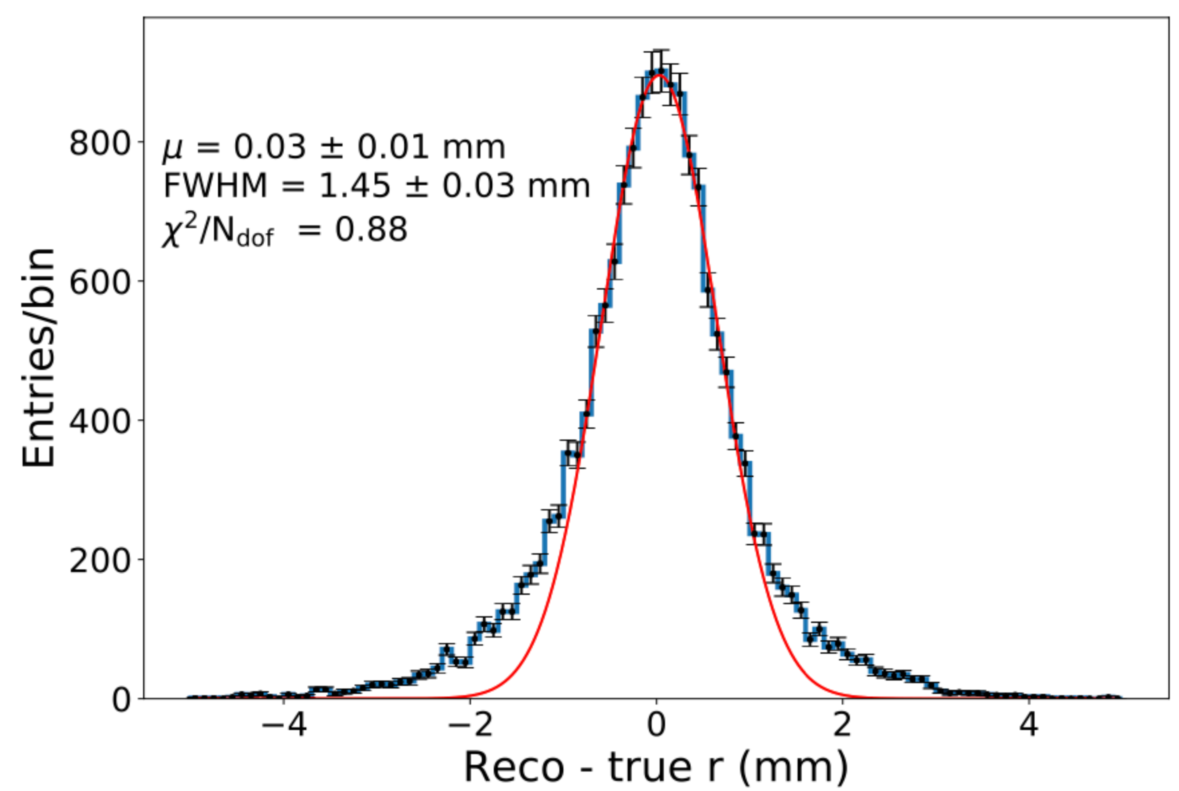

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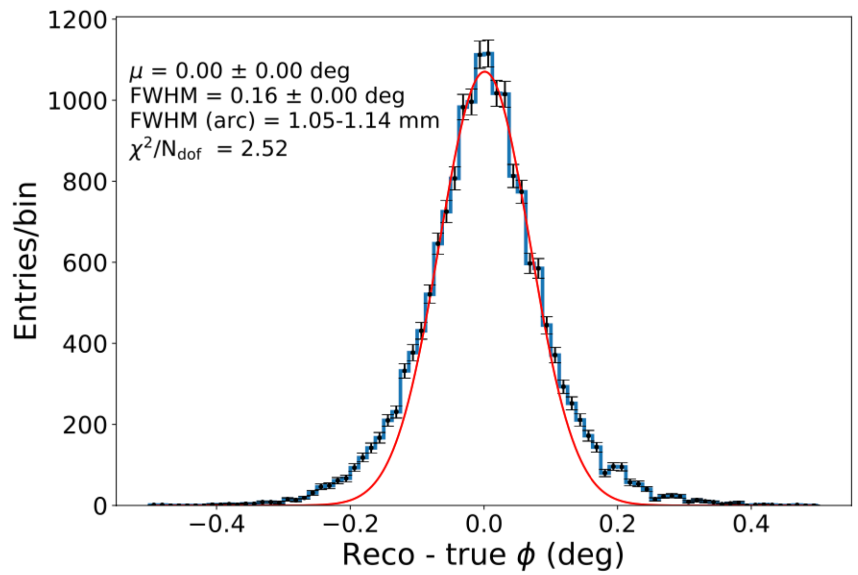
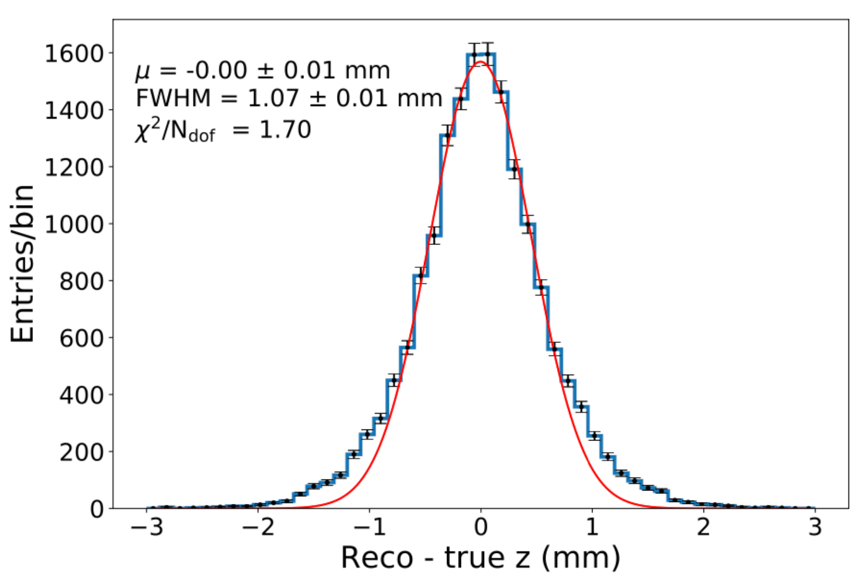
Phi & Z coordinates





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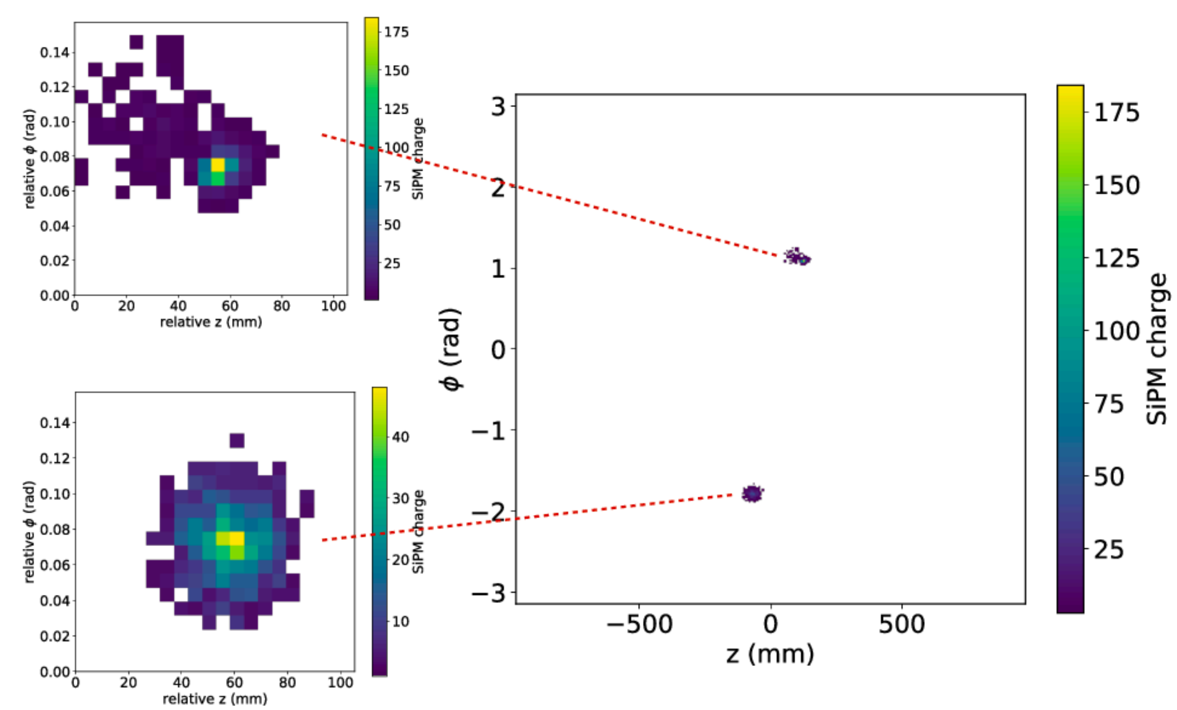

MC: energy resolution

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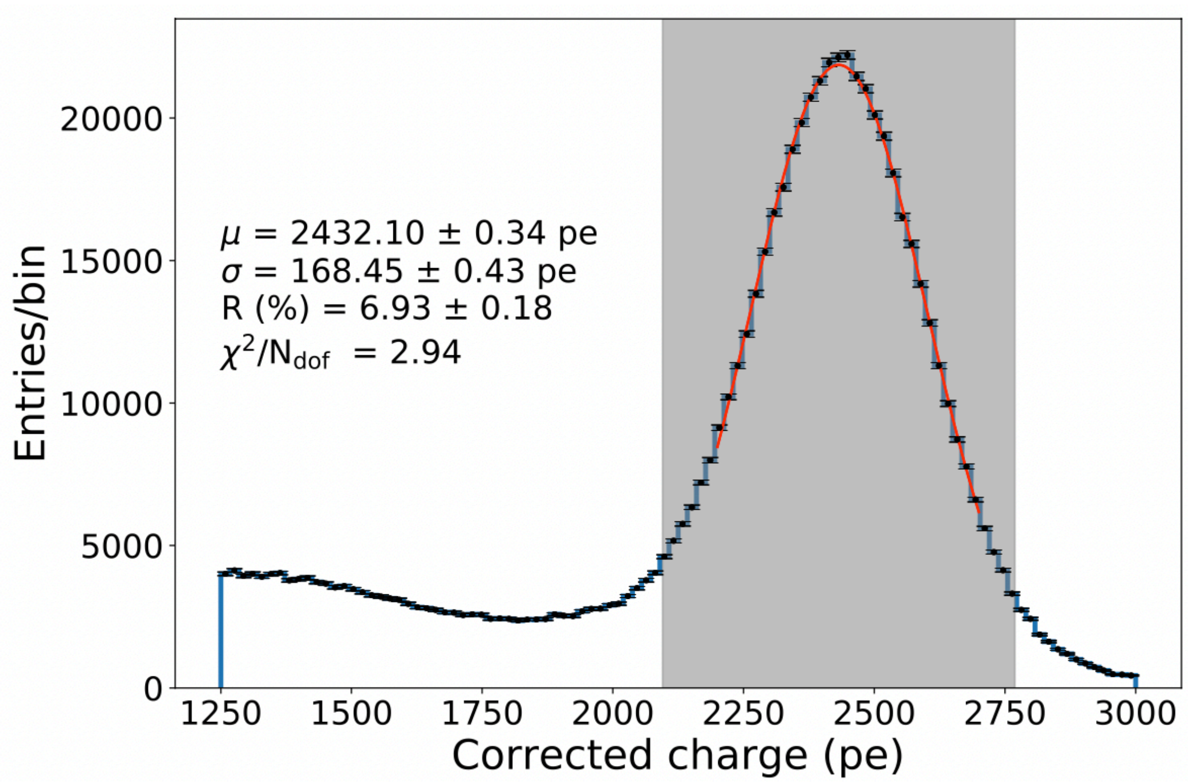

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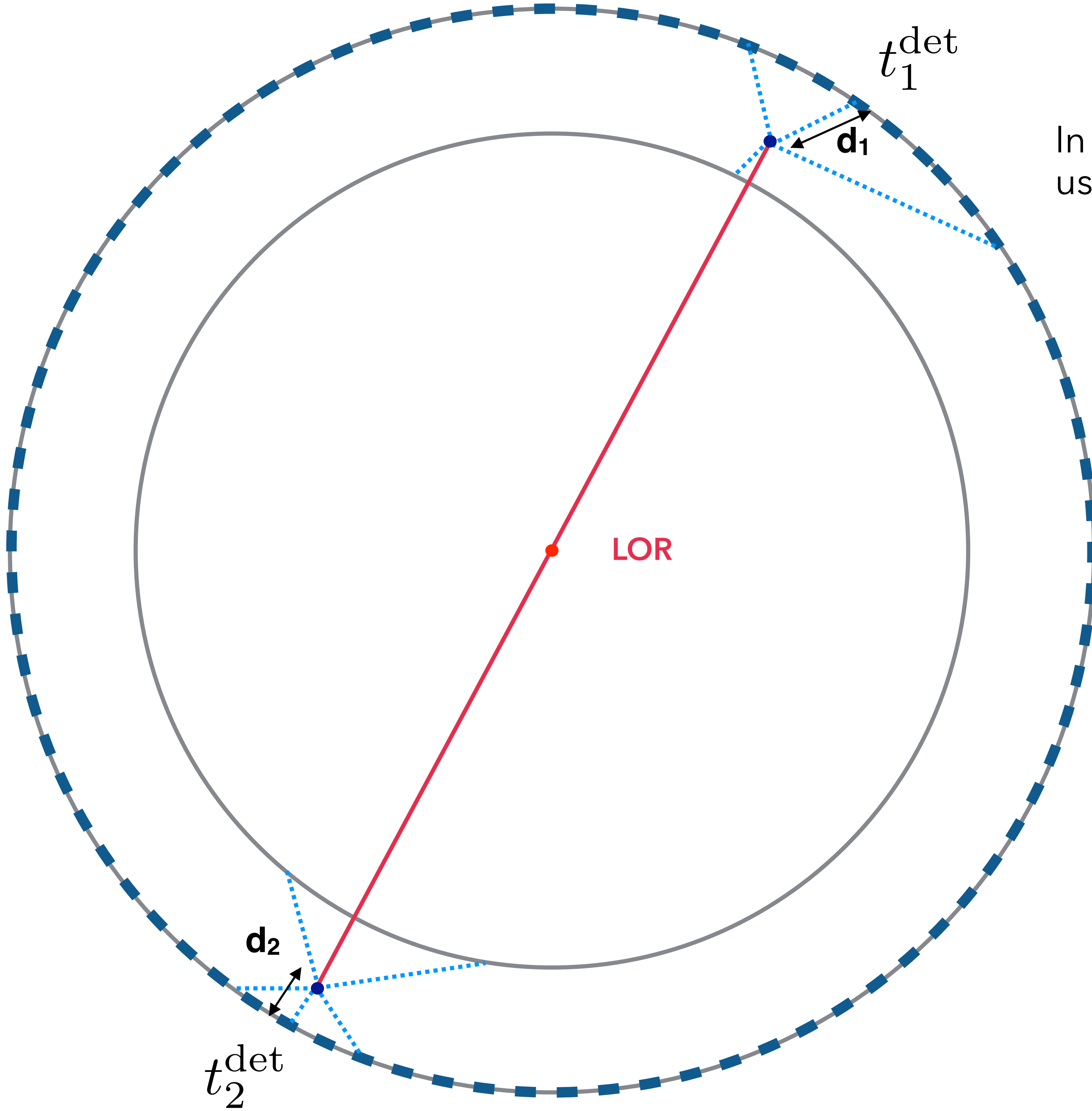
$$R^2 = R^2_{\mathrm{geom}} + R^2_{\mathrm{stat}} + R^2_{\mathrm{recomb}} + R^2_{\mathrm{intr}}$$

7% FWHM from MC 14% FWHM @zero E field, 511 keV

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

LXe intrinsic E resolution ⟶ Non proportionality of the scintillation light in absence of charge collection.

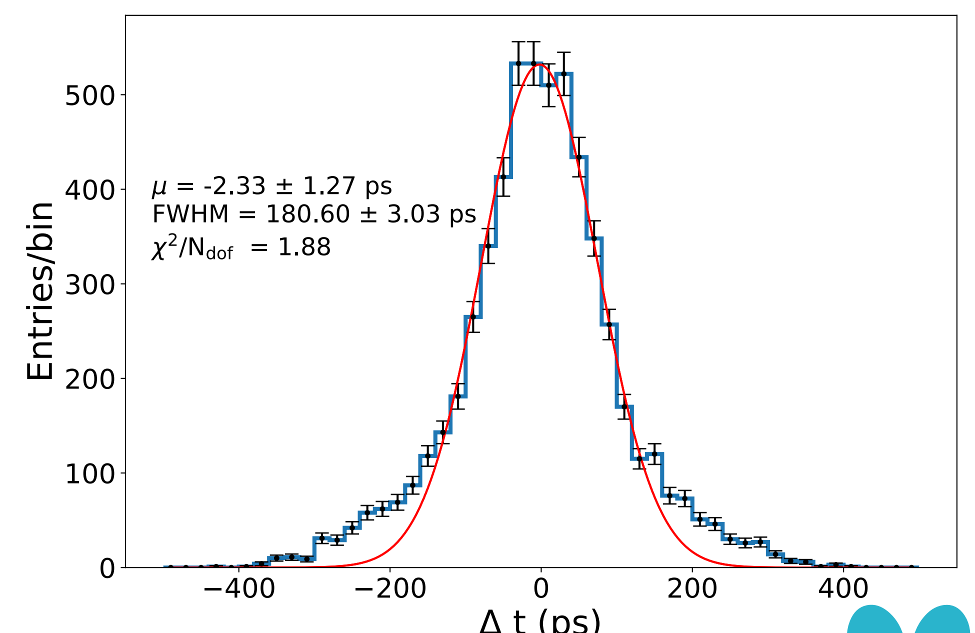
MC: coincidence time resolution (CTR)



In a **continuous LXe-based PET** t^{det} can be corrected using the information on the 3D position.

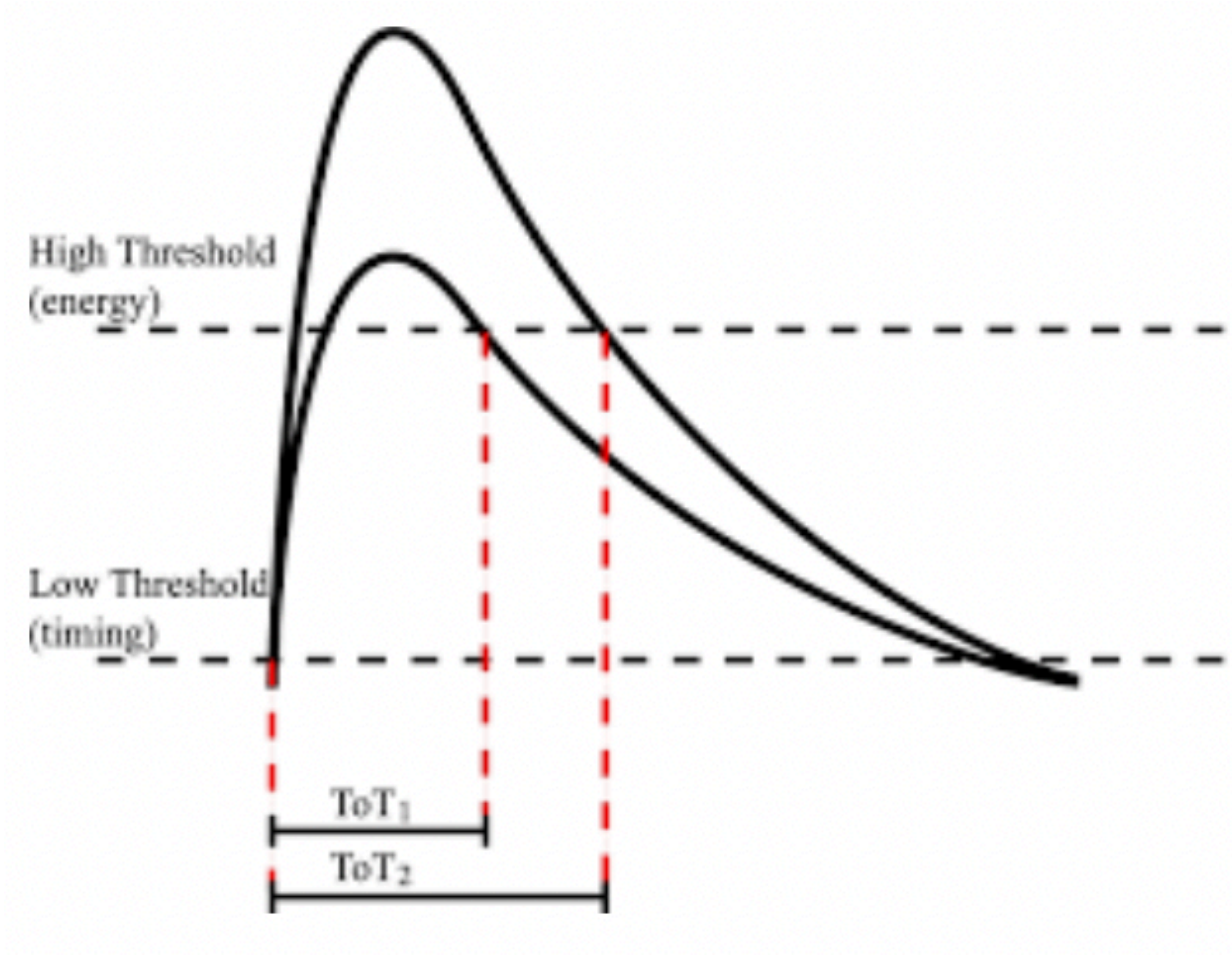
$$\mathrm{CTR} = t^{\mathrm{reco}} - t^{\mathrm{true}}$$

$$= t_1^{\mathrm{det}} - t_2^{\mathrm{det}} - (t_1^{\mathrm{opt}} - t_2^{\mathrm{opt}}) - (t_1^{\mathrm{true}} - t_2^{\mathrm{true}})$$

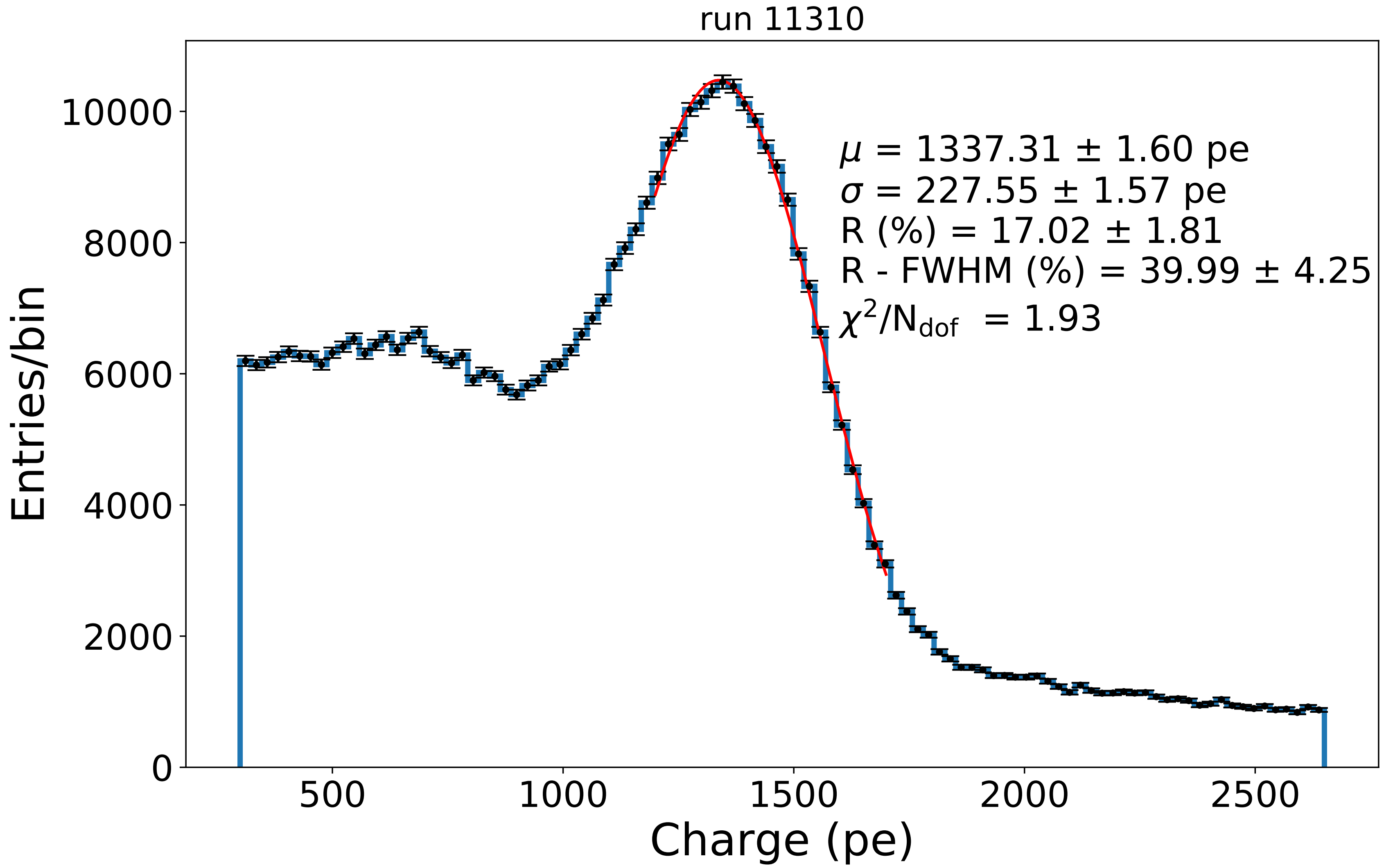


Having into account time fluctuations from SiPMs and electronics

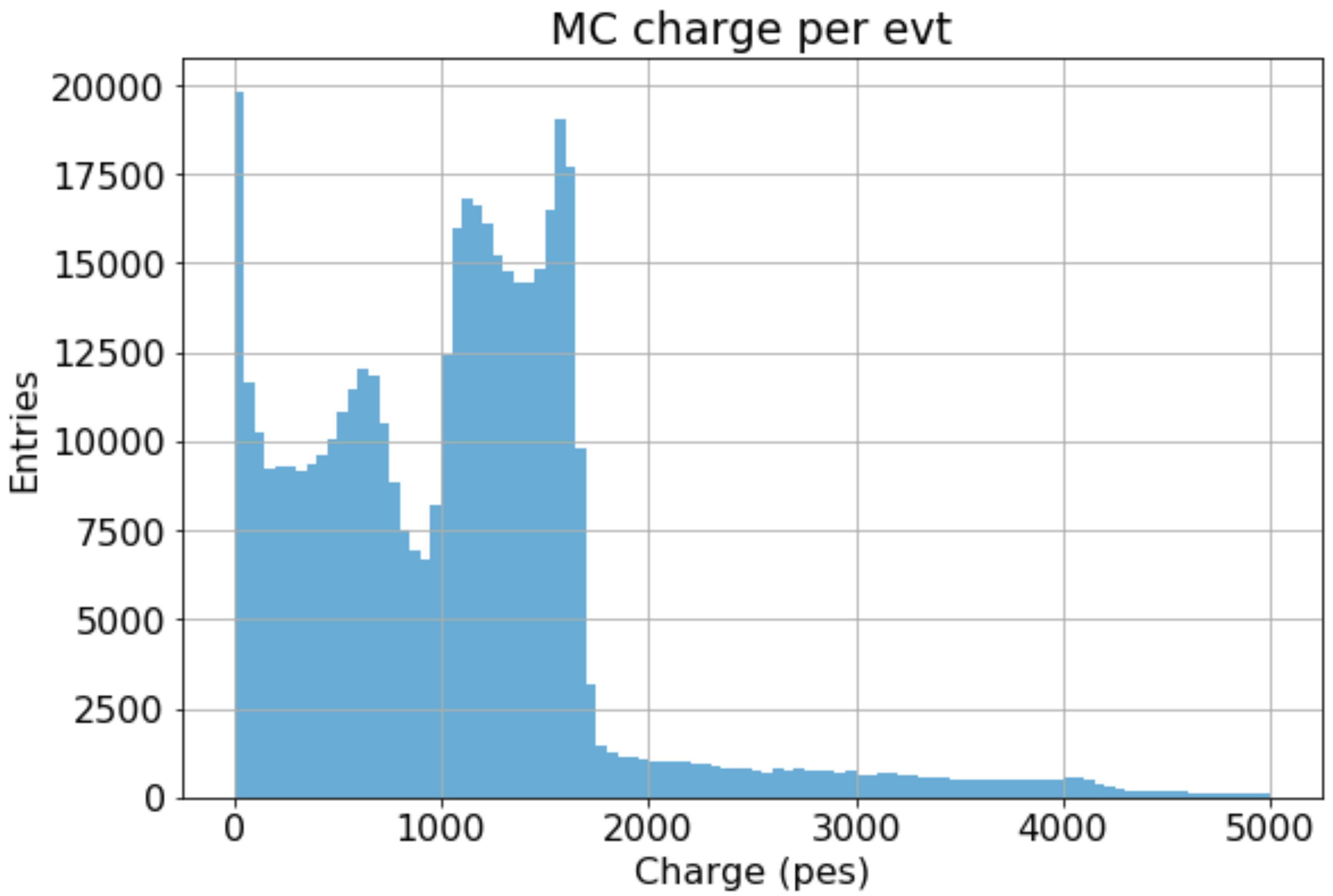
PETit: thresholds in ASICs



PETit: First results



PETit: MC results



PETit: MC results