Scintillating Materials and SiPM Readout for an Electromagnetic Calorimeter at the EIC

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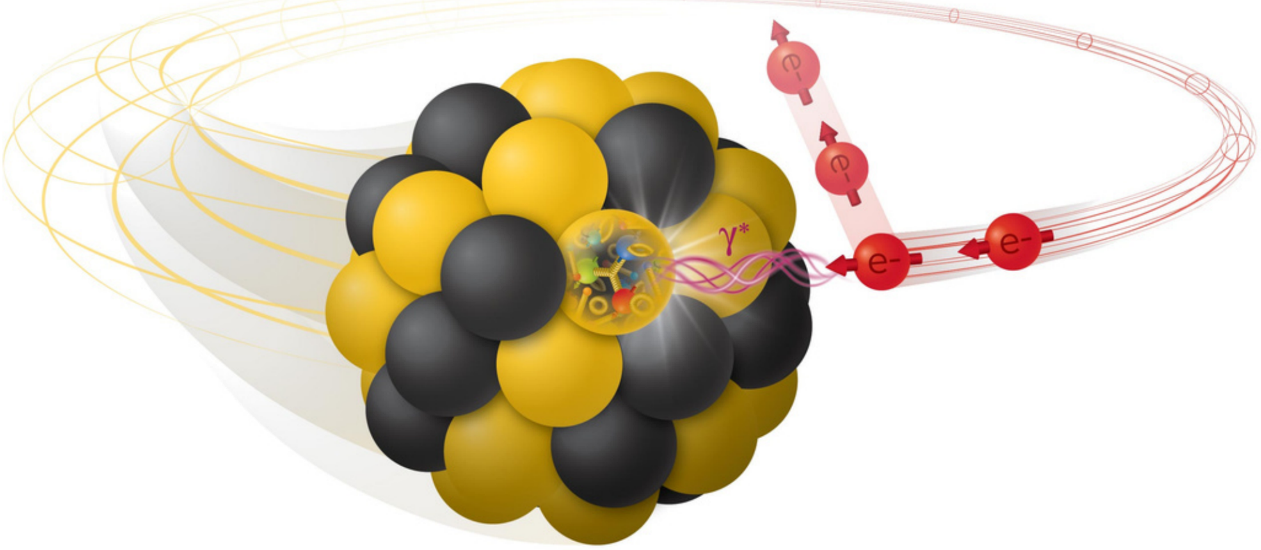
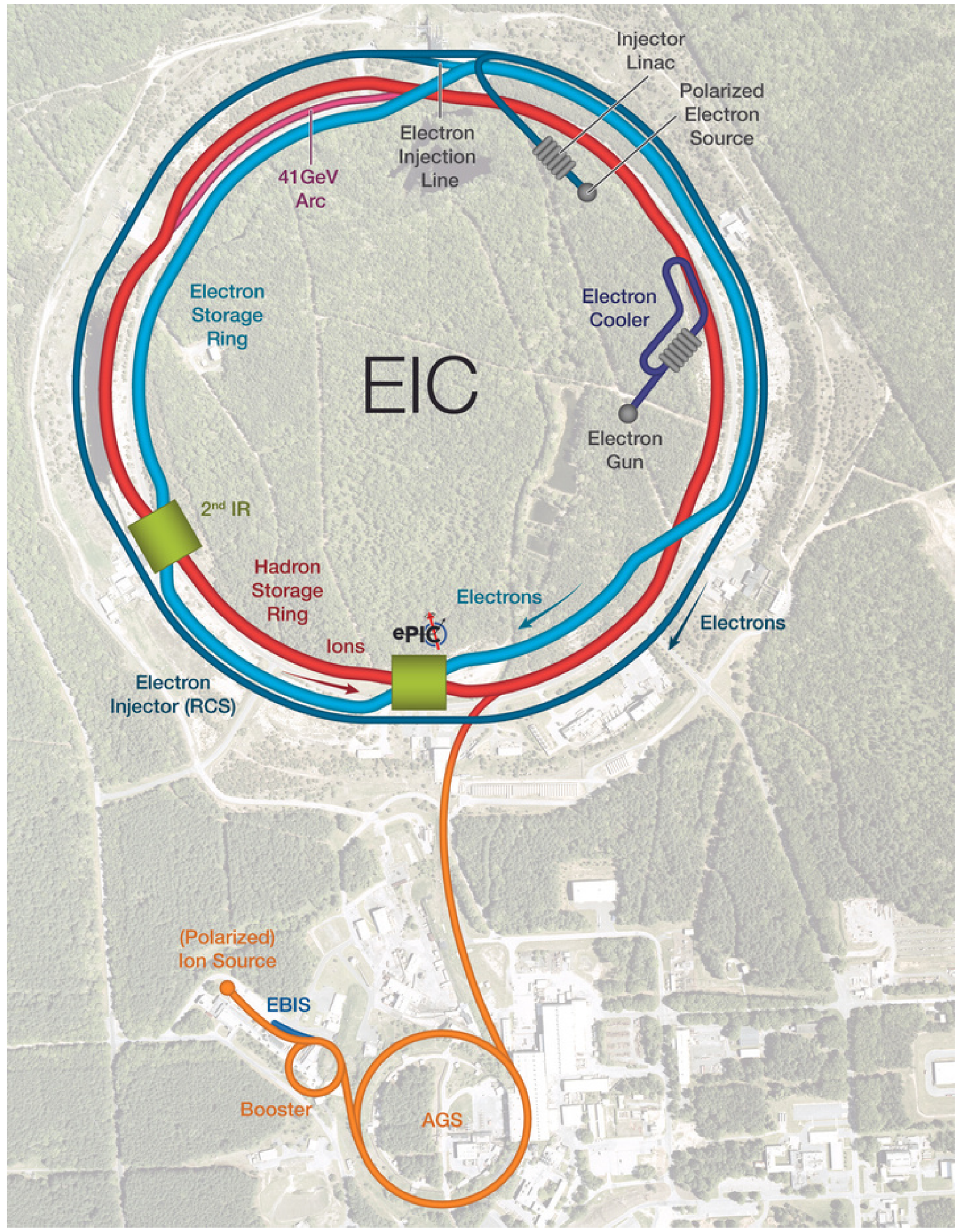
Assemblée Générale 2024 du GDR QCD - 29th May 2024

The Electron Ion Collider and the ePIC detector

Electron-Ion Collider (EIC) at Brookhaven National Lab in the 2030s

- Polarized electron and proton beams.
- Ions from deuterium to heavy nuclei.
- 29–140 GeV e+p center-of-mass energies.
- High luminosity 10^{33}–10^{34} $cm^{-2}.s^{-1}$



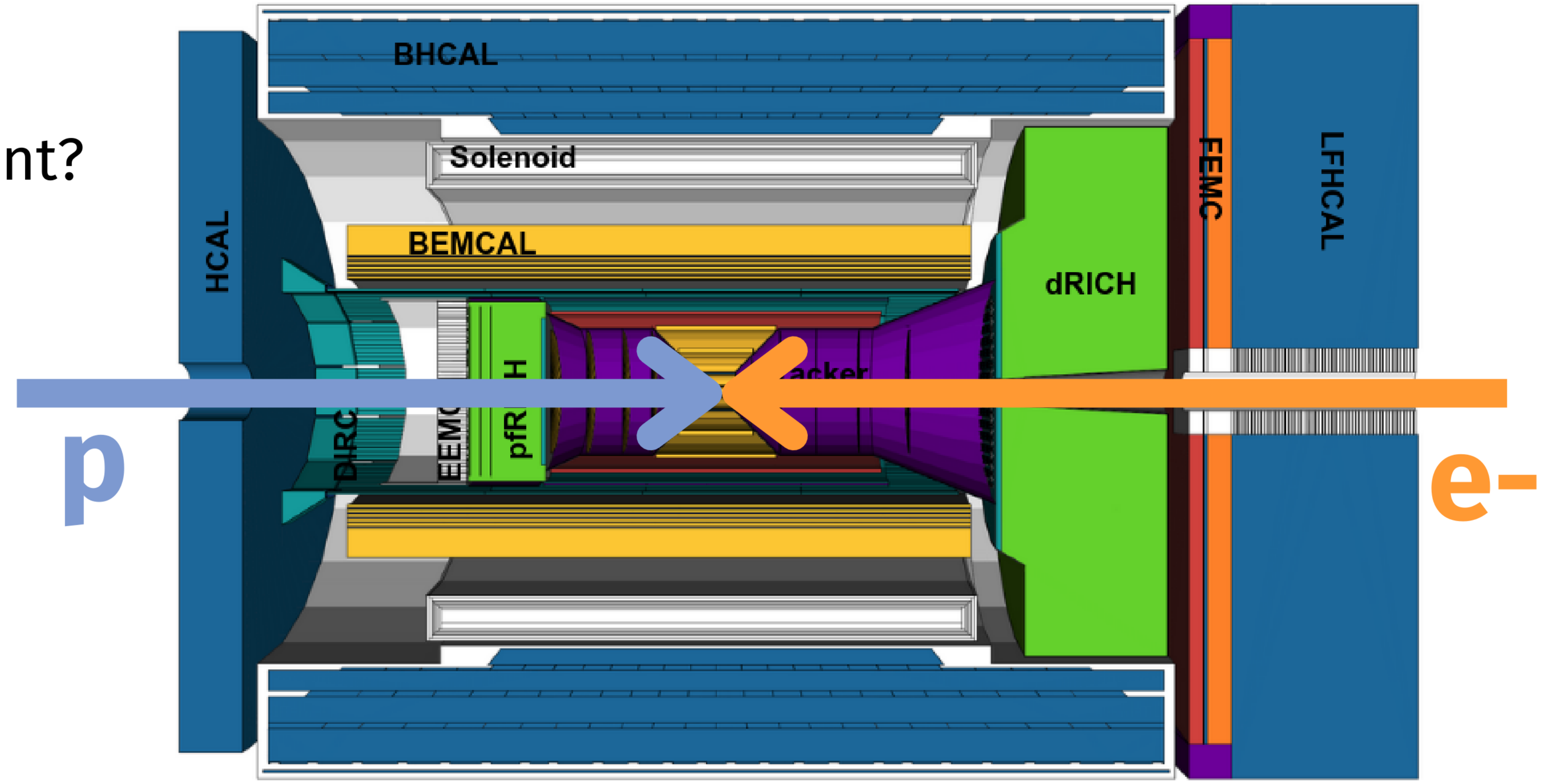


Broad scientific program bringing together medium energy hadronic and high-energy heavy ion communities

- Properties and structure of nucleons?
- Gluon saturation?
- Confinement?
- Nuclear environment?

The ePIC detector:

- Calorimetry
- Tracking
- PID (TOF, RICH,...)

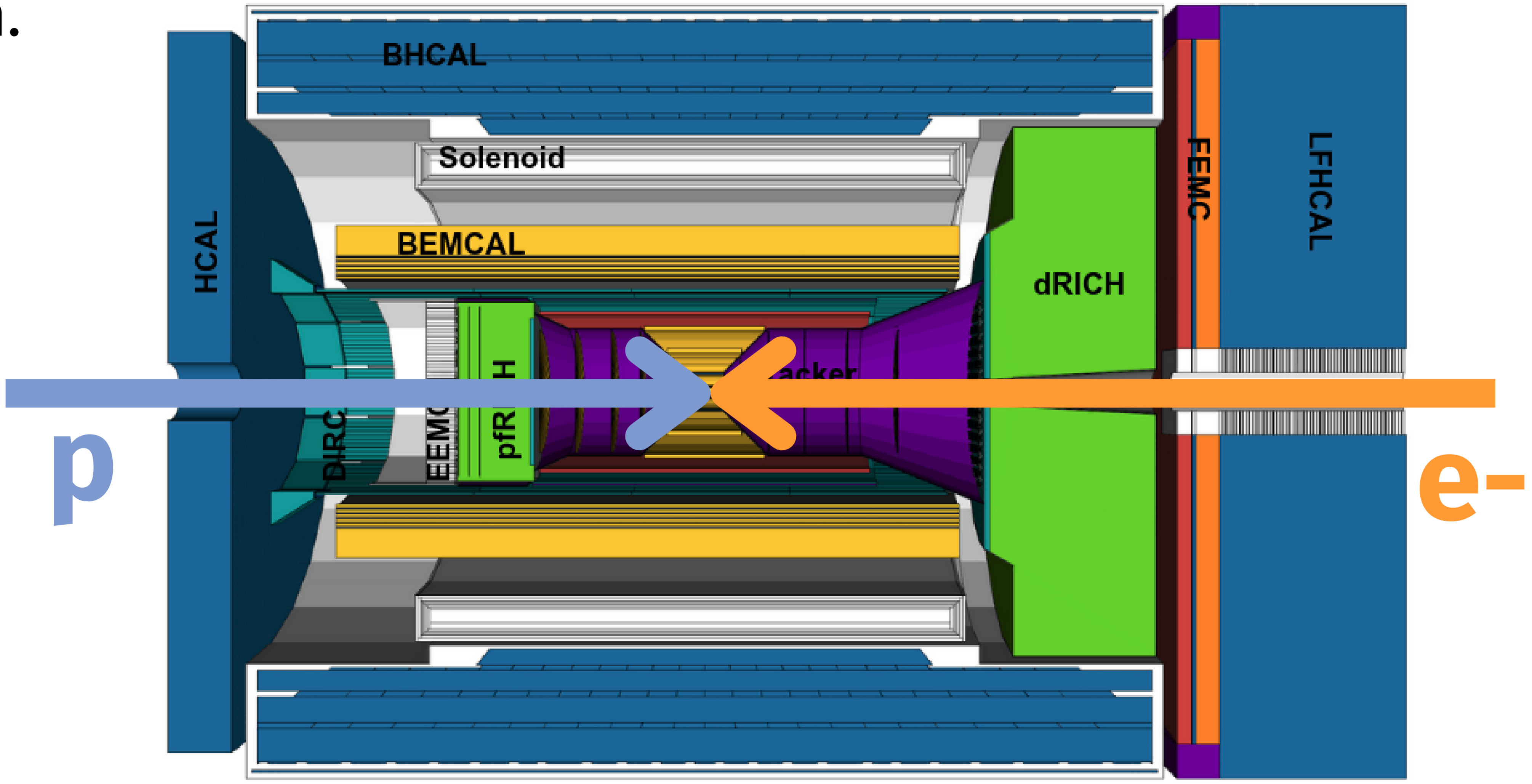


The Electron Endcap Electromagnetic Calorimeter

Nearly all processes require detection of the scattered e^- at the EIC.

Physics goals set the requirements for the Electron-Endcap Electromagnetic Calorimeter (EEMC).

- Momentum and energy reconstruction.
- Particle ID.
- π / e− separation.
- Detection of neutral particles.
- Separation of 2 γ in π_0 decay …



η	-4 to -2	-2 to -1	-1 to 1	1 to 4
$\sigma_E/E \cdot \sqrt{E/1\,\text{GeV}}$	2%	7%	10-12%	10-12%

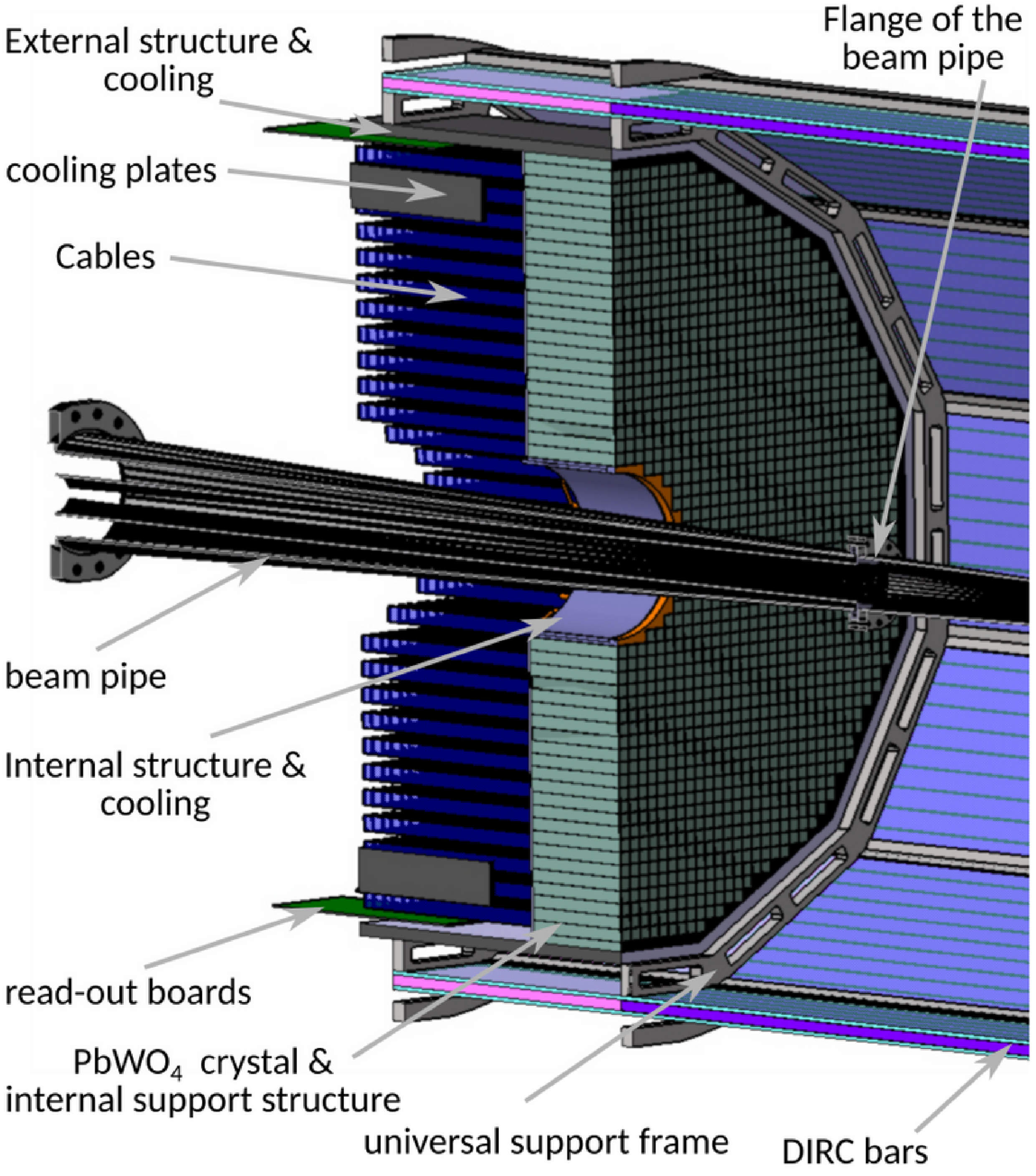
- Excellent energy resolution
- Large dynamic range : ~5 MeV to ~15 GeV

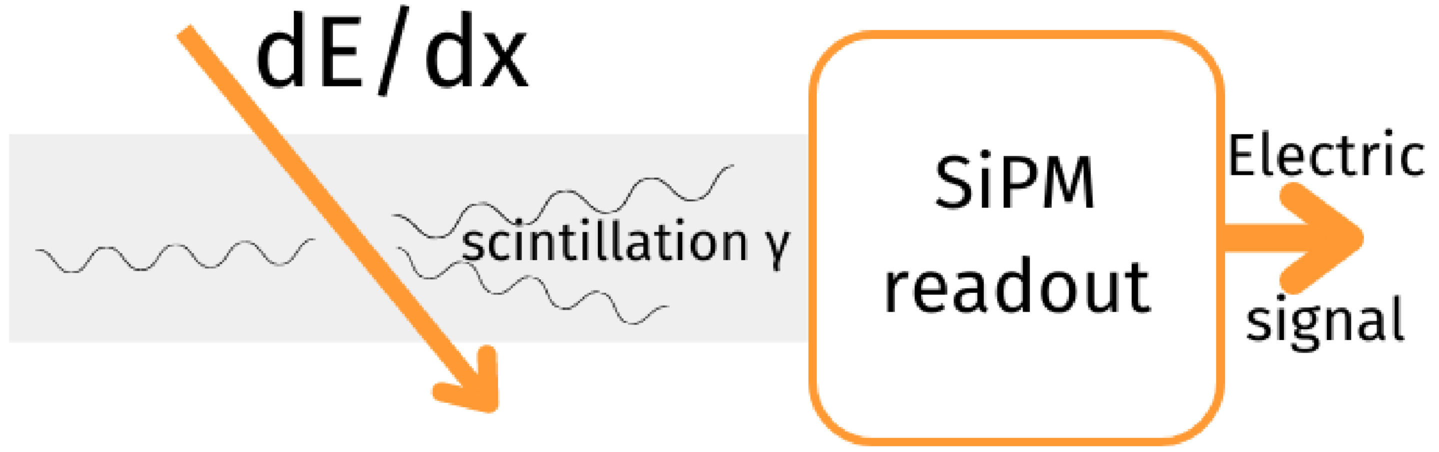
Environment constraints:

- Limited space : compact detector
- Radiation hardness : 30 Gy/year
- Intense magnetic field

The EEMC

3000 PbWO4 crystals readout by Silicon Photomultipliers (SiPMs).





Scintillating material requirements:

- High energy resolution: high light yield, high transmittance.
- Limited space : short radiation length X0.
- Radiation hard.

Readout + electronics :

- Intense magnetic fields: SiPMs.
- Need to collect light on the surface of the crystal : matrix of SiPMs.
- Large dynamic range.

Scintillating Material

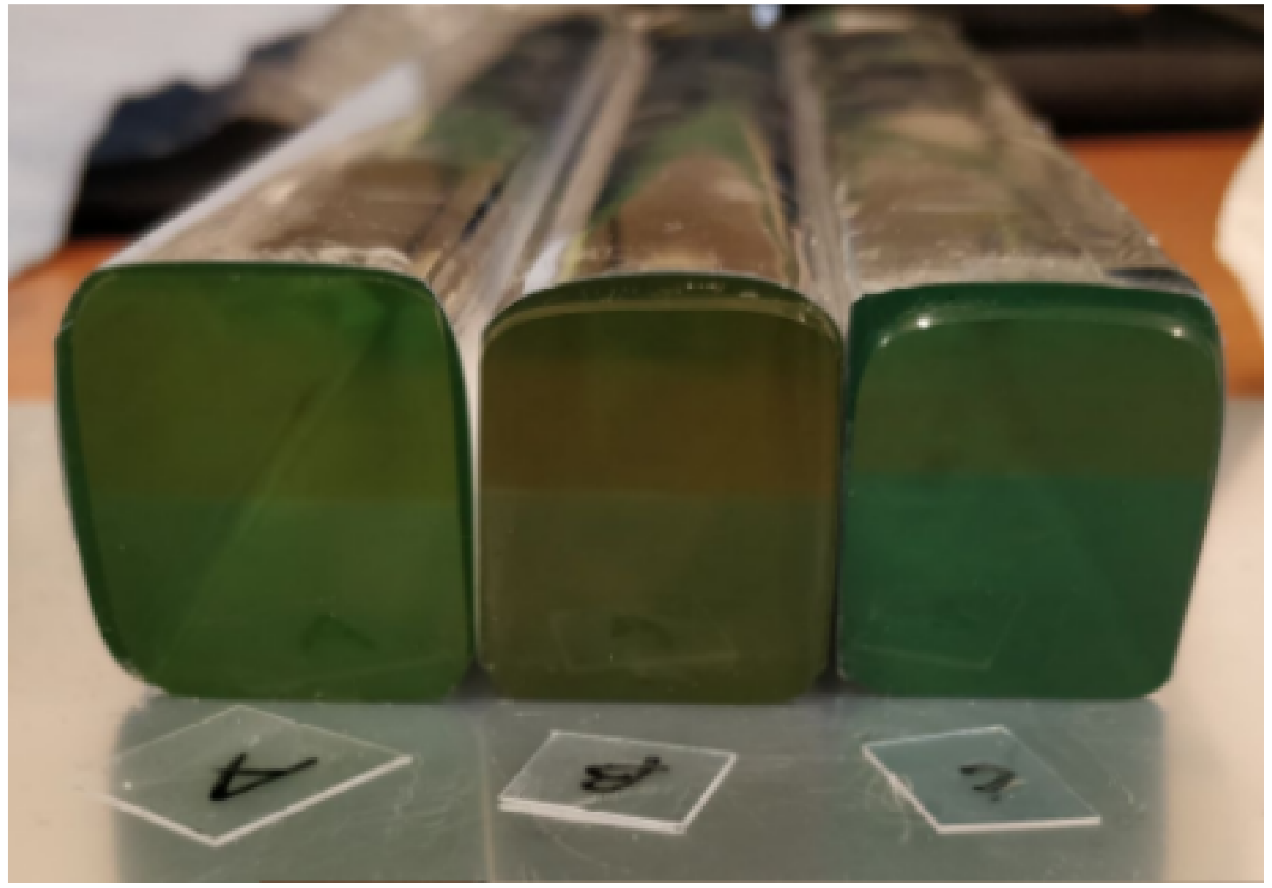
Choice of a scintillating material

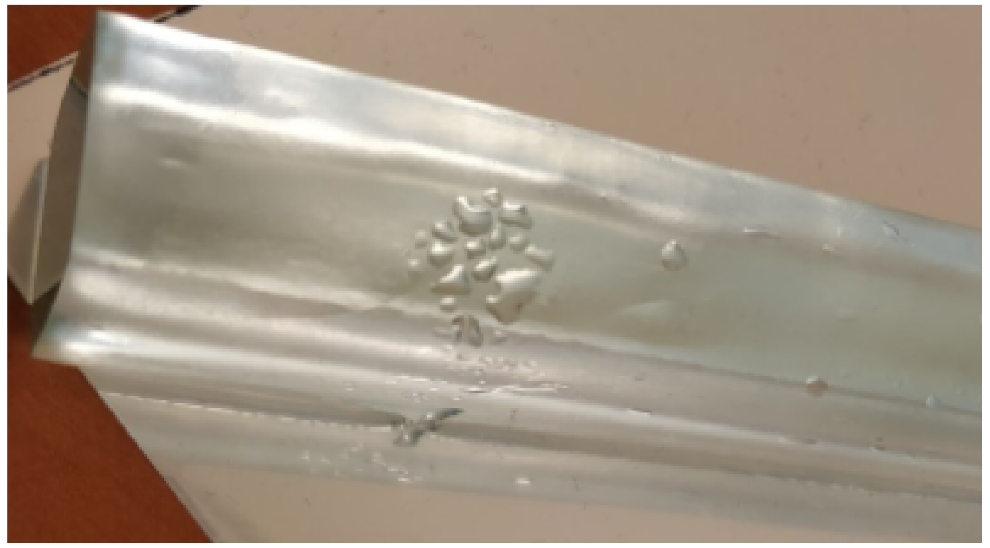
Best candidate to meet the requirements: $PbWO_4$ crystals.

- X_0 = 8.9 mm
- Can detect energies as low as 20 MeV photons
- Tested to be radiation hard

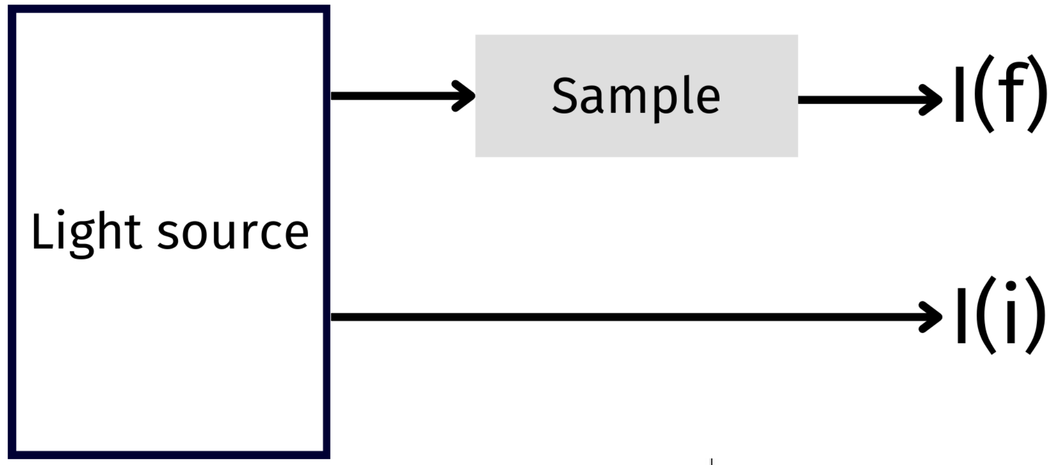
Alternative : SciGlass, a new cheaper material.

- Cost effective
- X_0 = 22 – 28 mm
- Tests of a few samples: 200 mm long, 20x20 mm^2

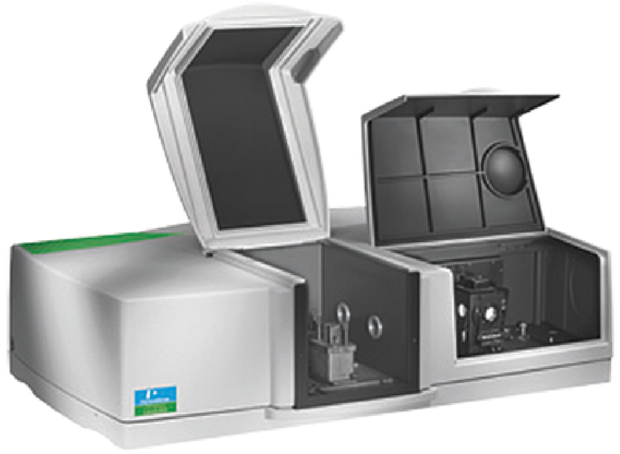


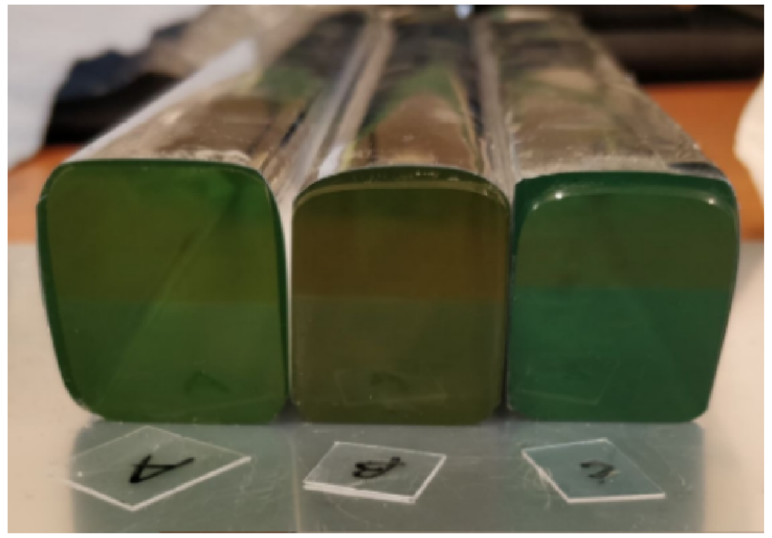


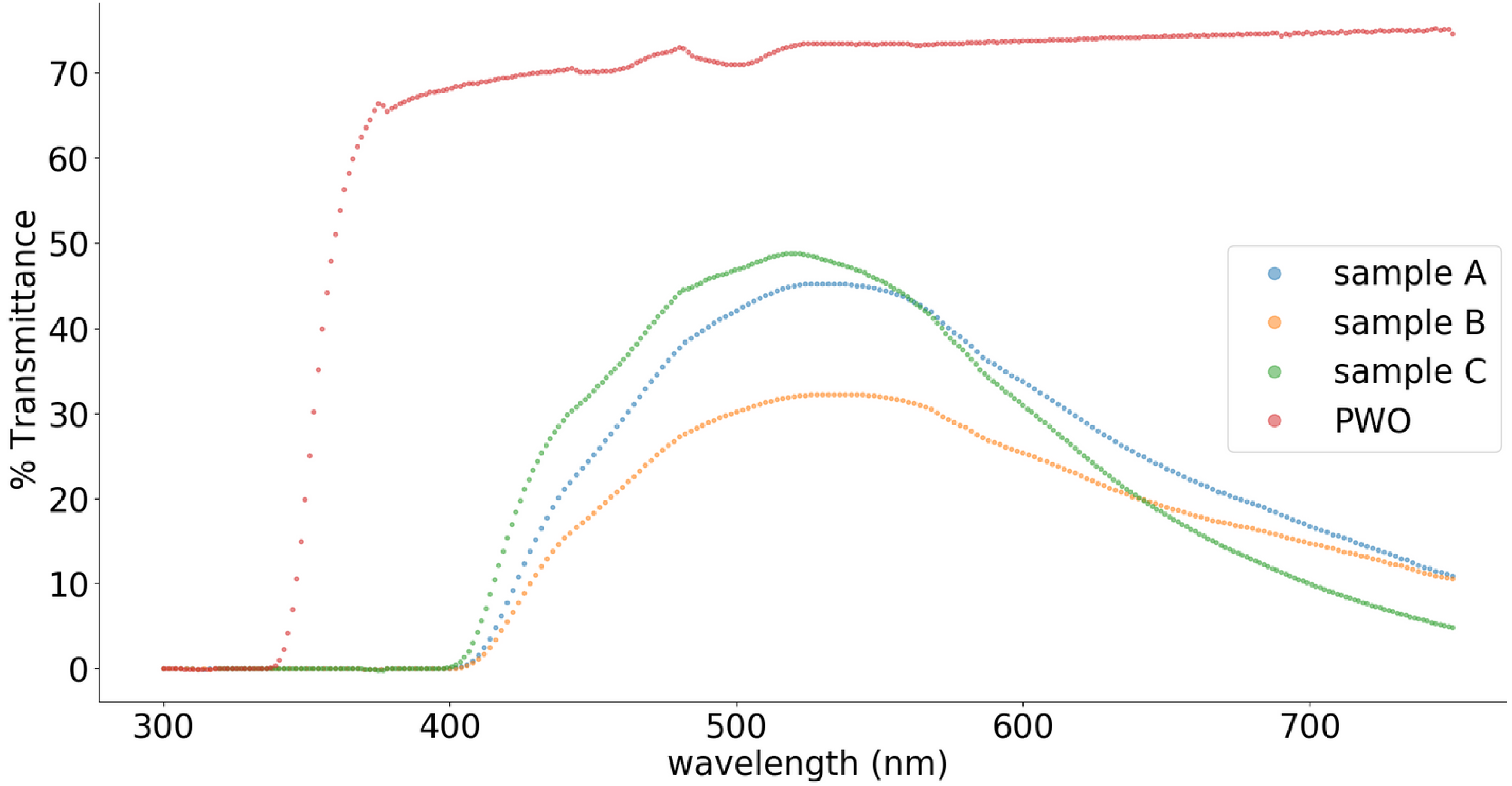
Transmittance Measurement



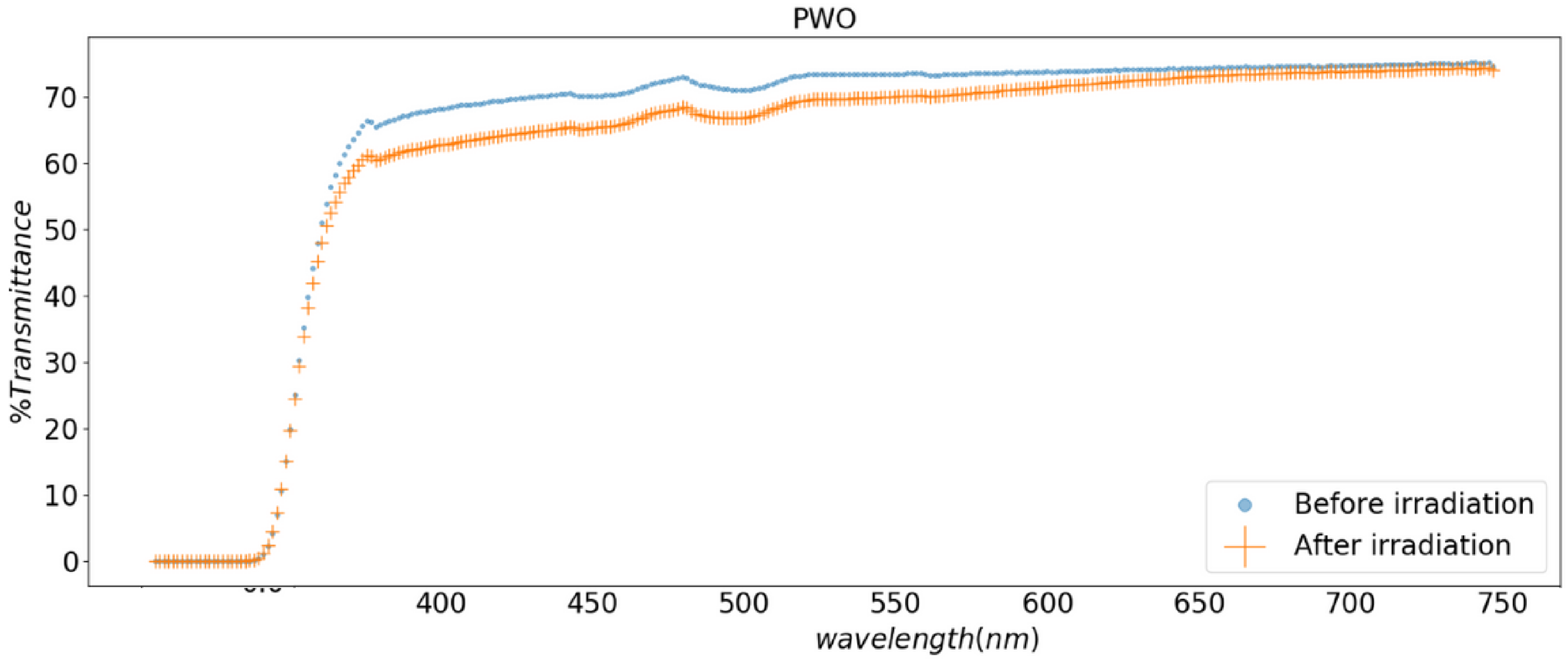
$$T = I(f)/I(i)$$

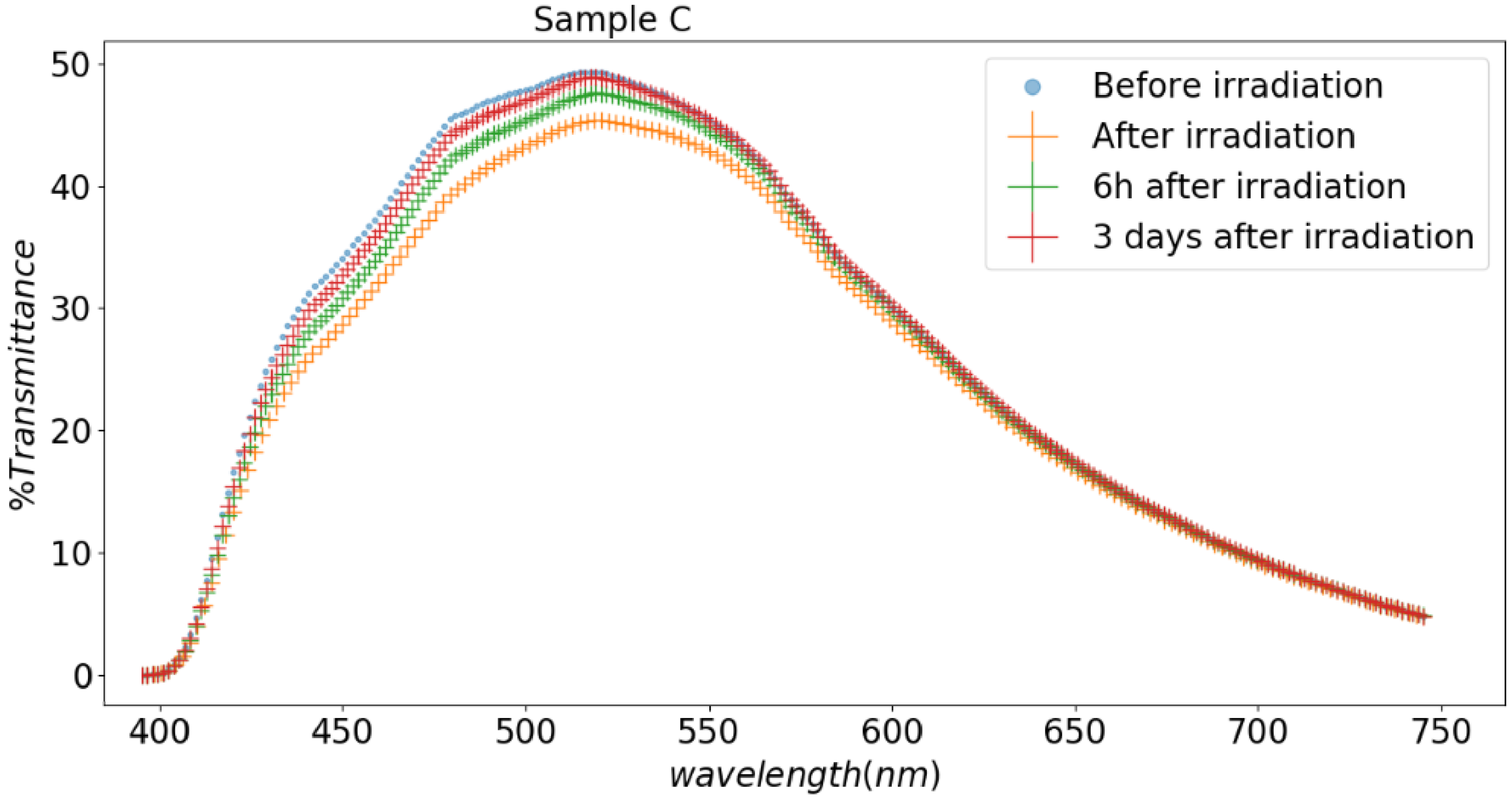






Radiation Hardness



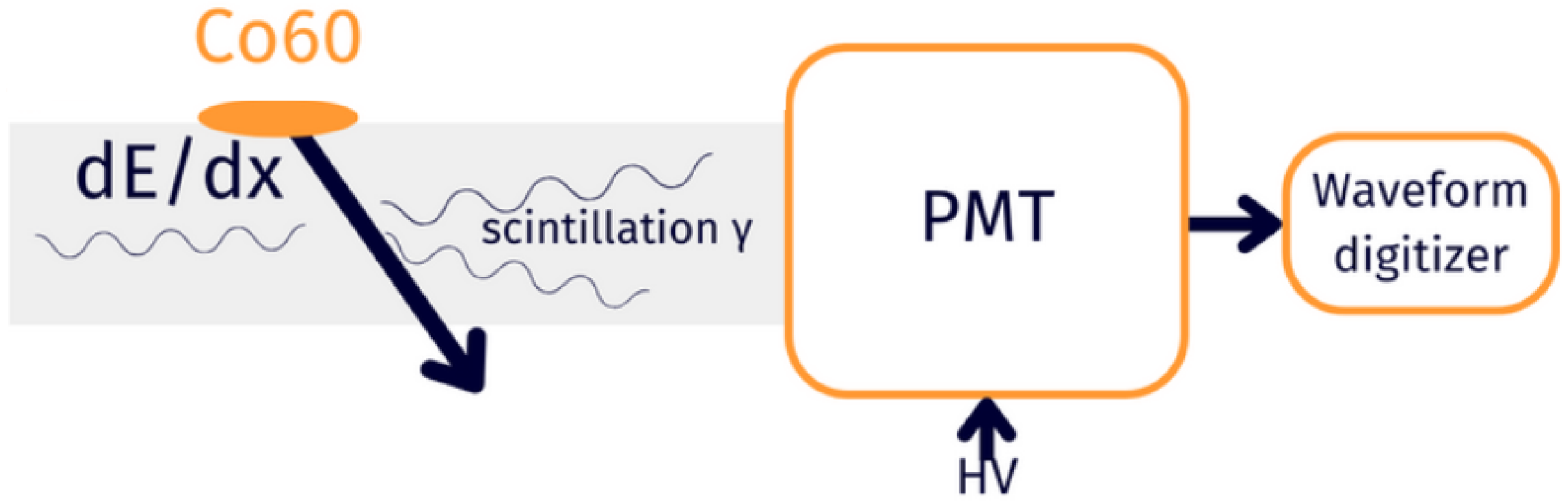


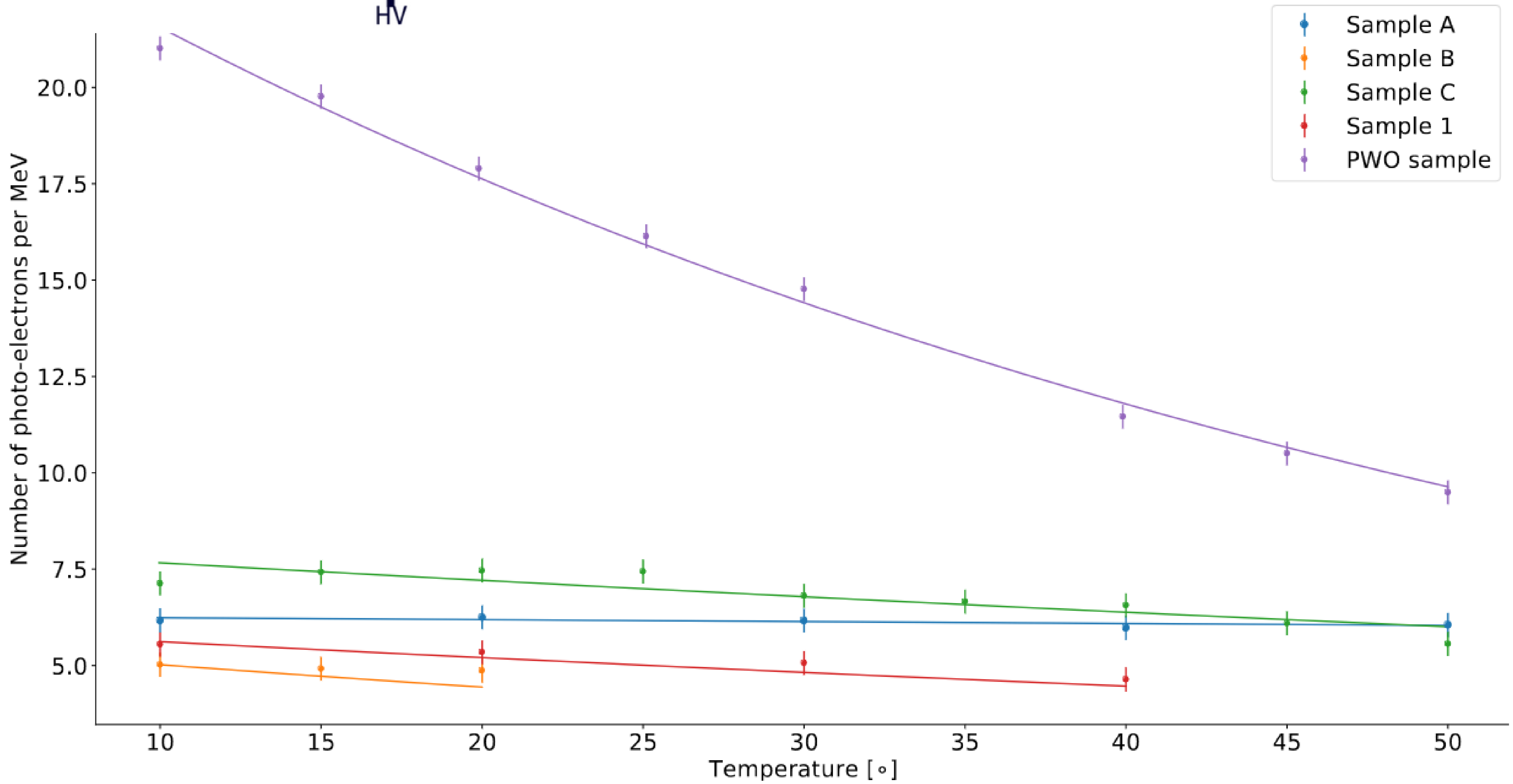
Transmittance measurement to assess the creation of light-absorbing centers with radiation damage.

Samples received a dose of 30Gy
(1 year at the EIC) in 30 minutes.

- Both PWO and SciGlass resist well to radiation damage.
- Curing PWO crystals to recover from radiation damage is well-mastered.
- Most SciGlass samples were not damaged, and almost entirely recovered at room temperature, in the dark.
- Further tests were made with high doses, tests of annealing procedures showing excellent capabilities under radiation.

Light Yield

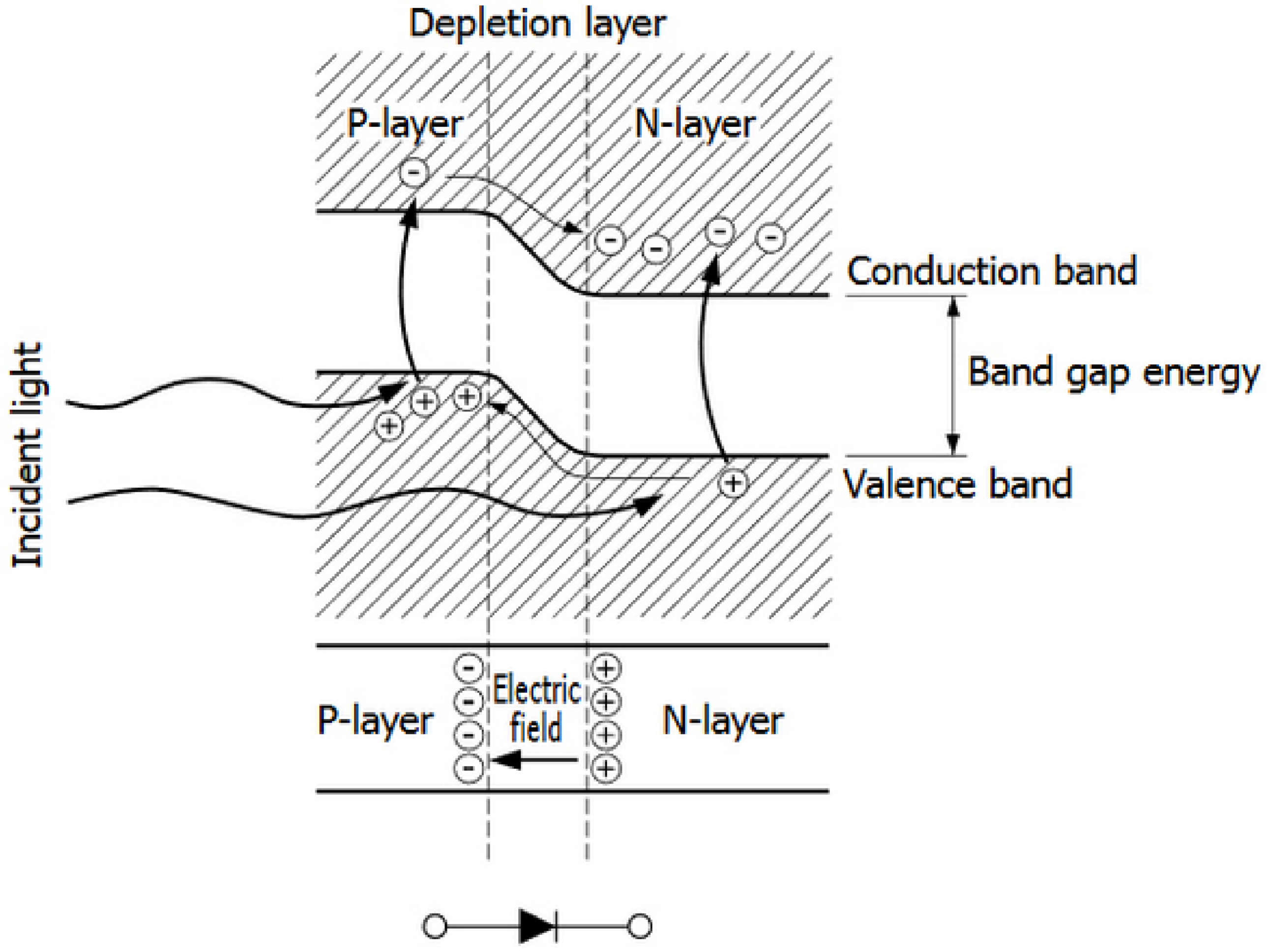

Co60
dE/dx
scintillation γ
PMT
Waveform digitizer
HV


Sample A
Sample B
Sample C
Sample 1
PWO sample
Number of photo-electrons per MeV
20.0
17.5
15.0
12.5
10.0
7.5
5.0
10
15
20
25
30
35
40
45
50
Temperature [∘]

SiPM Readout

SiPMs

PN junction for photodetection



- Avalanche photodiode (APD):

External voltage → avalanche phenomenon → higher signal

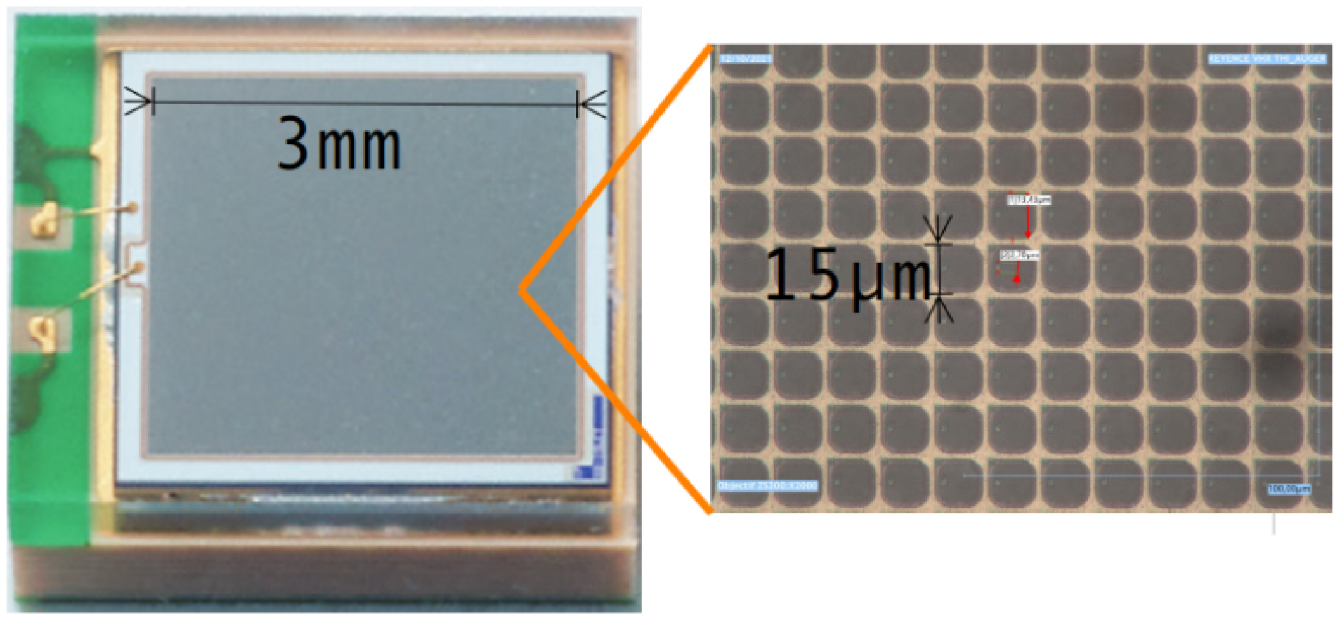
- GAPD (Geiger mode):

Increasing V → e−/h+ multiply faster than they can be extracted → digital photodetector

- SiPM: a matrix of GAPDs !

All pixels are read in parallel → analog detector

signal   number of fired pixels "   " incident number of γ



Main challenge for the SiPM readout is the dynamic range.

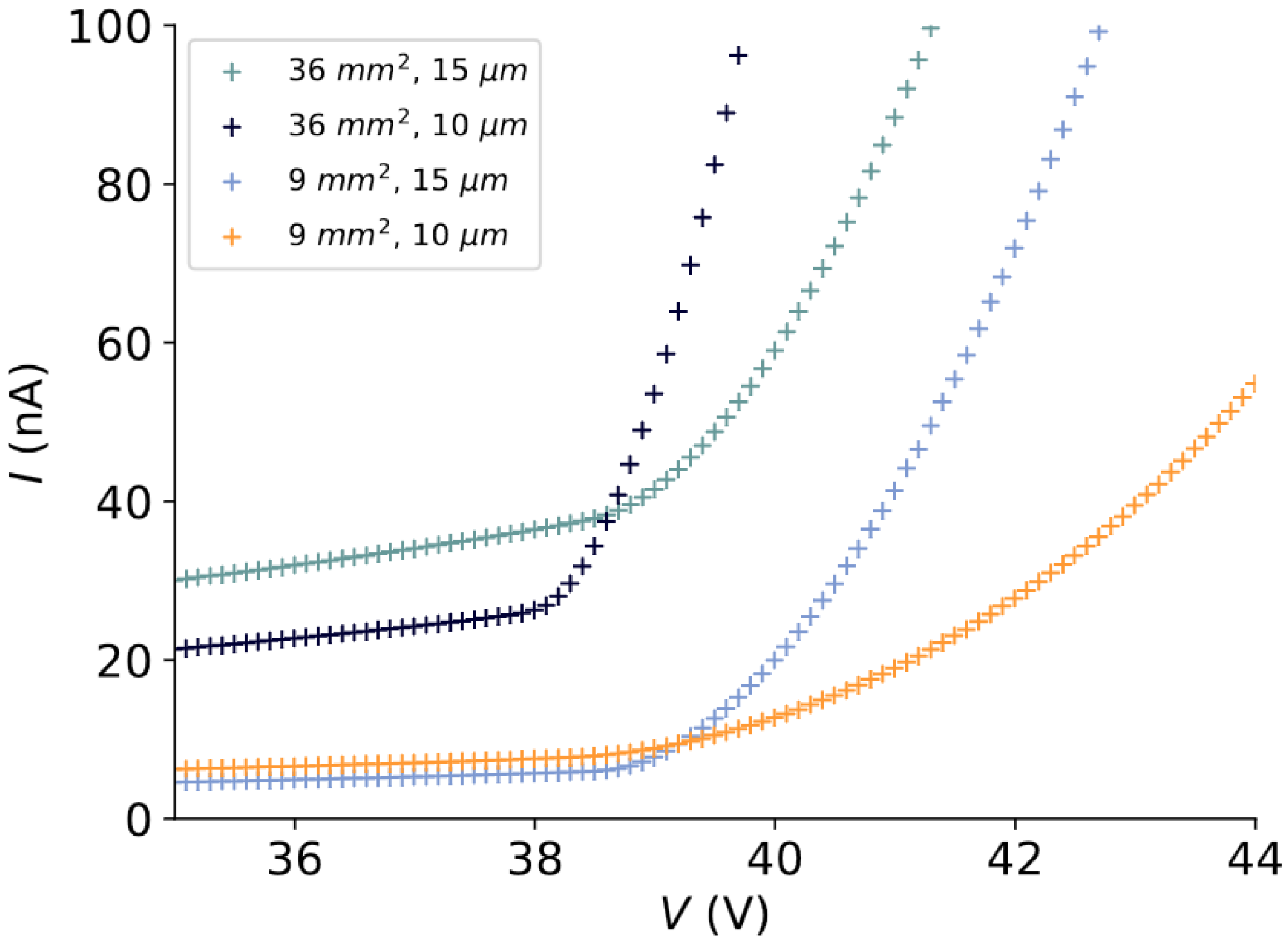
- Minimal detectable energy? Intrinsic noise in the SiPMs
- Non linearities at high energies?

Surface [mm^2]	Pixel size [µm]	Number of pixels
36	10	359011
36	15	159565
9	10	89984
9	15	39984

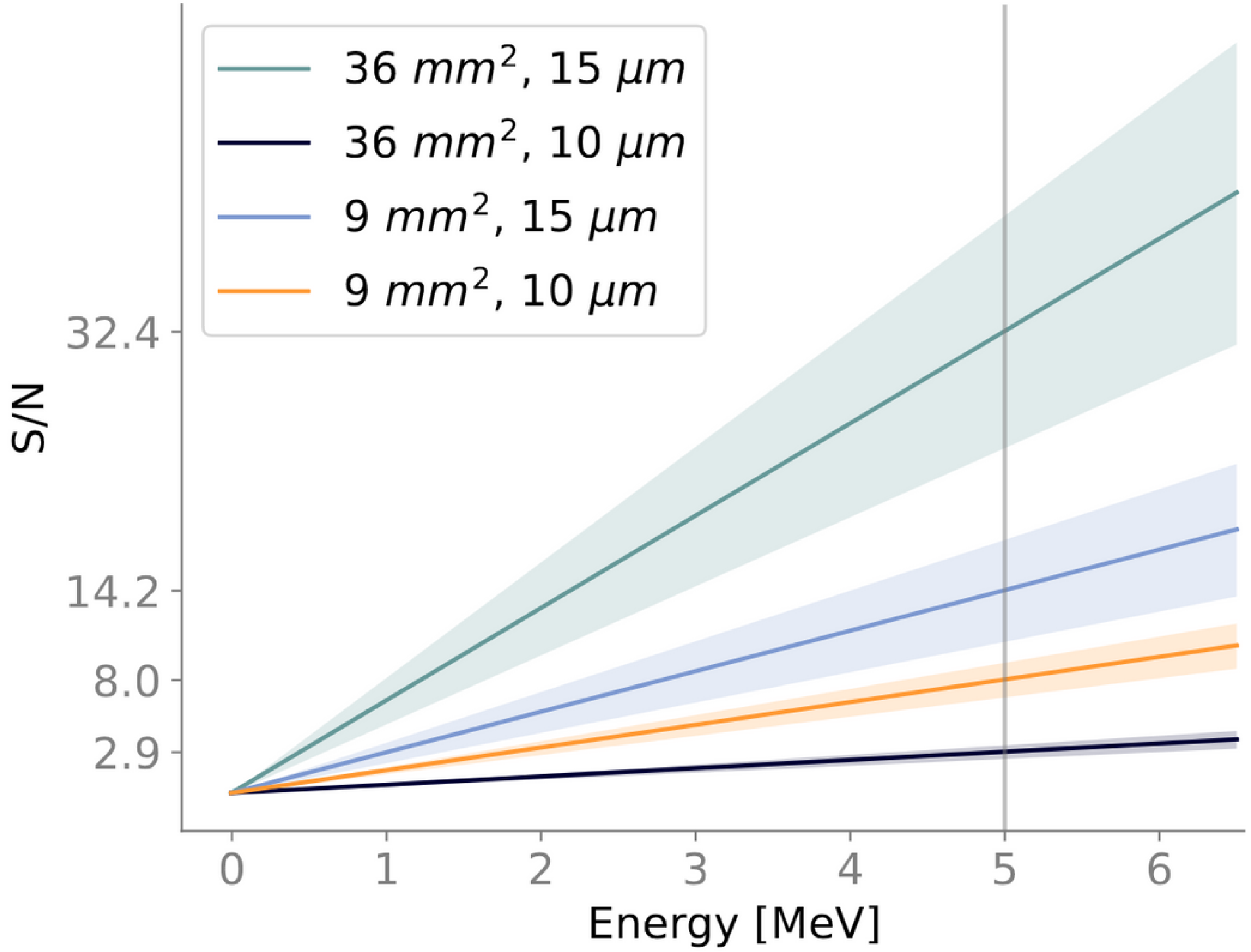
Dark Noise Measurement

Limitation for low energy measurements: Dark Noise.

Reading output current for SiPMs in the dark



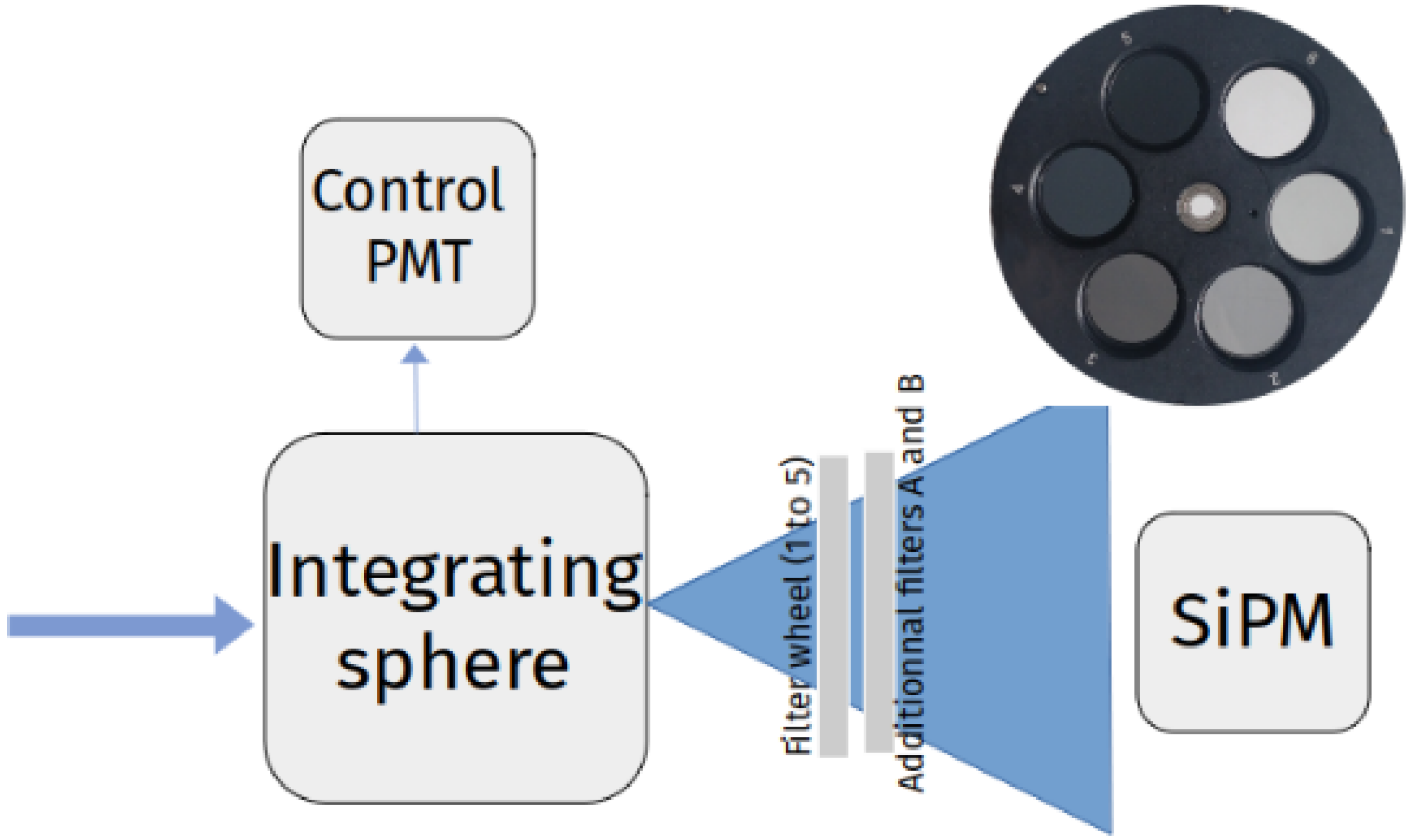
Comparing it to expected signal.
PWO's LY: 17 pe/MeV over the crystal surface



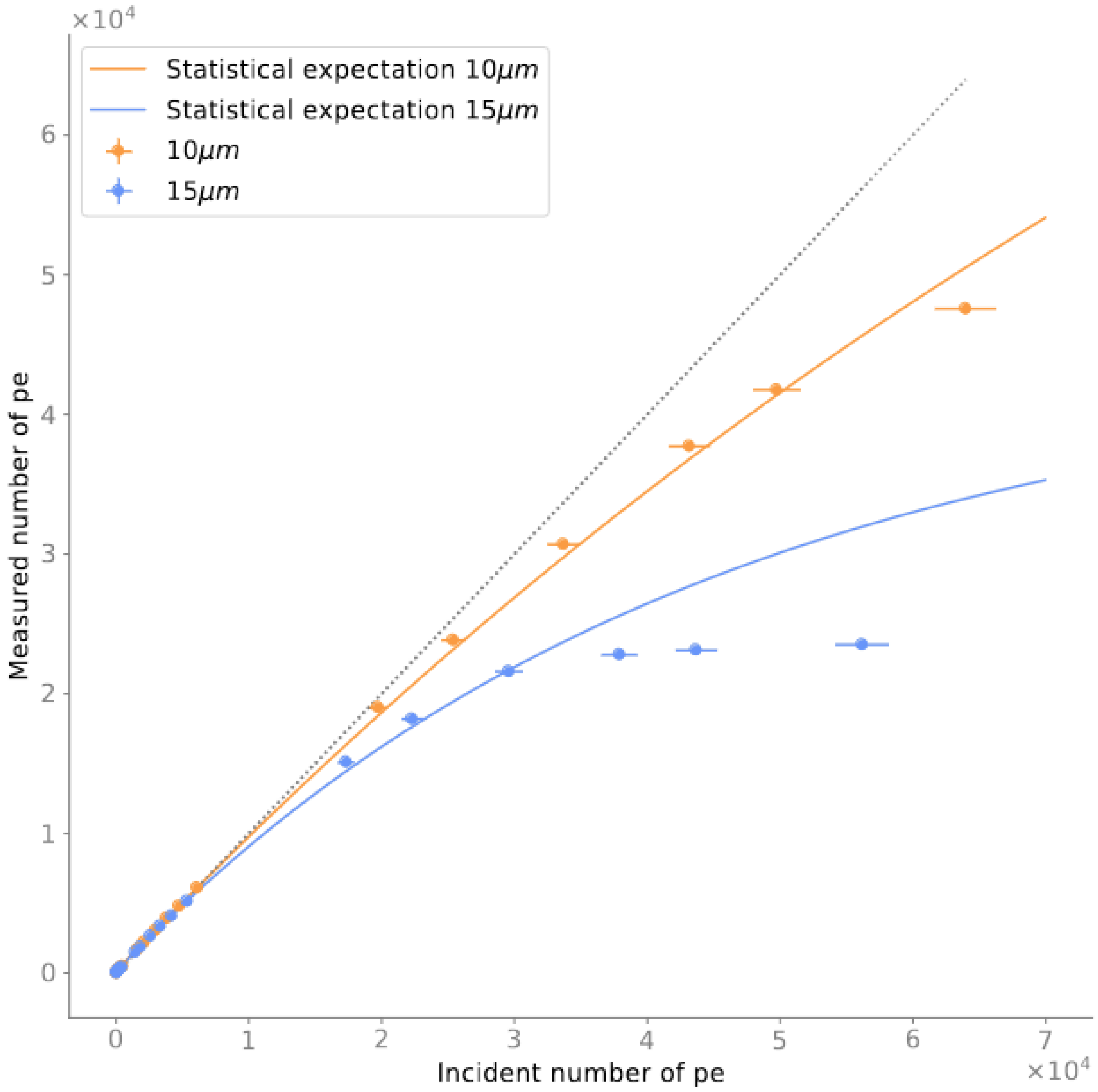
Linearity Measurement

Limitation for high energies: non linearities

For a high number of incident photons, there is a probability that more than one enters the same pixel



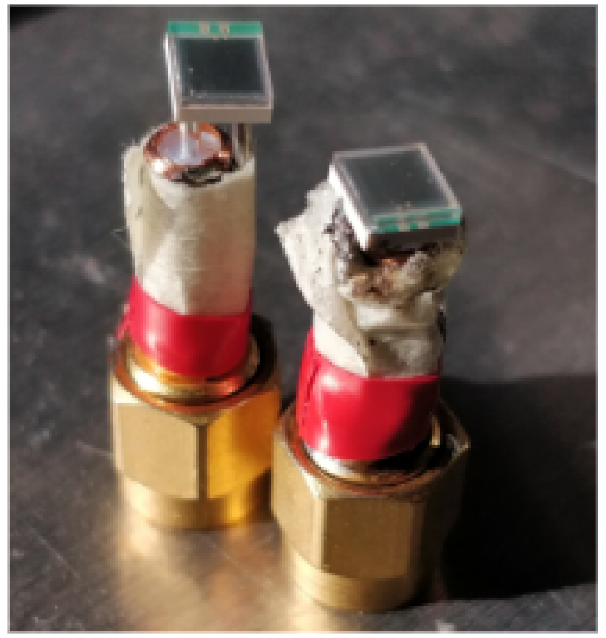
“ $N_{detected} = N_{pixel}\left(1 - e^{-\frac{incident}{N_{pixel}}}\right)$ “

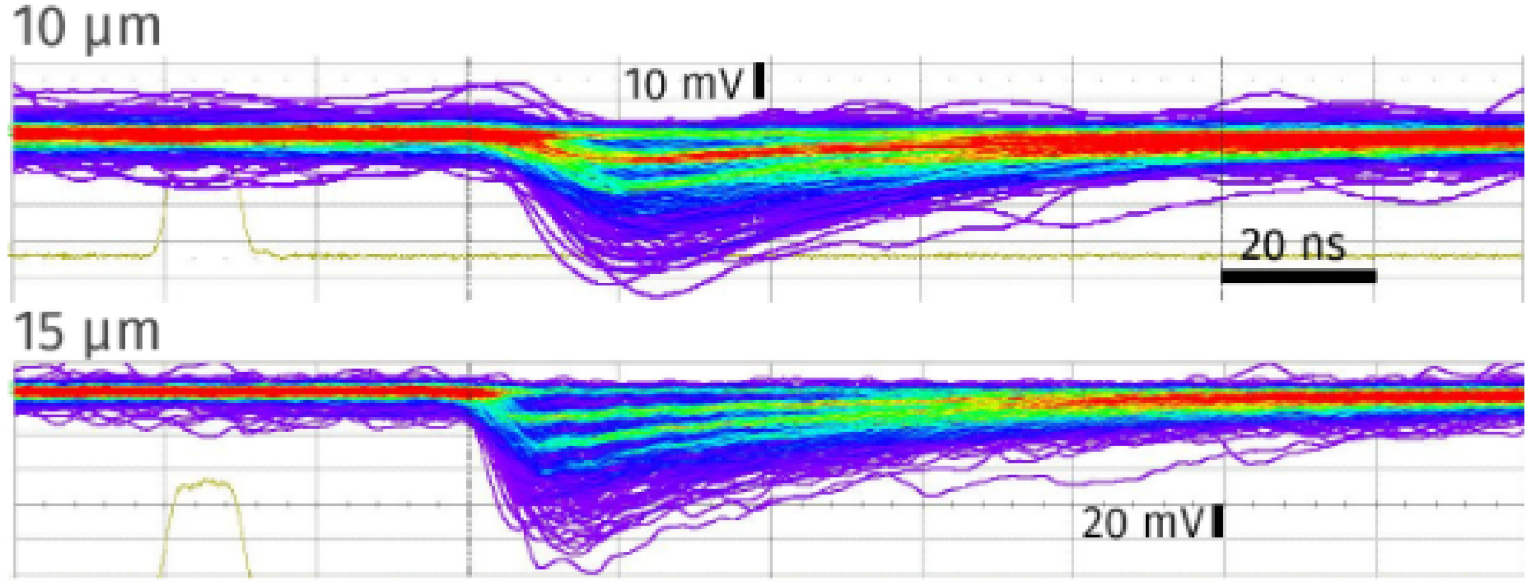


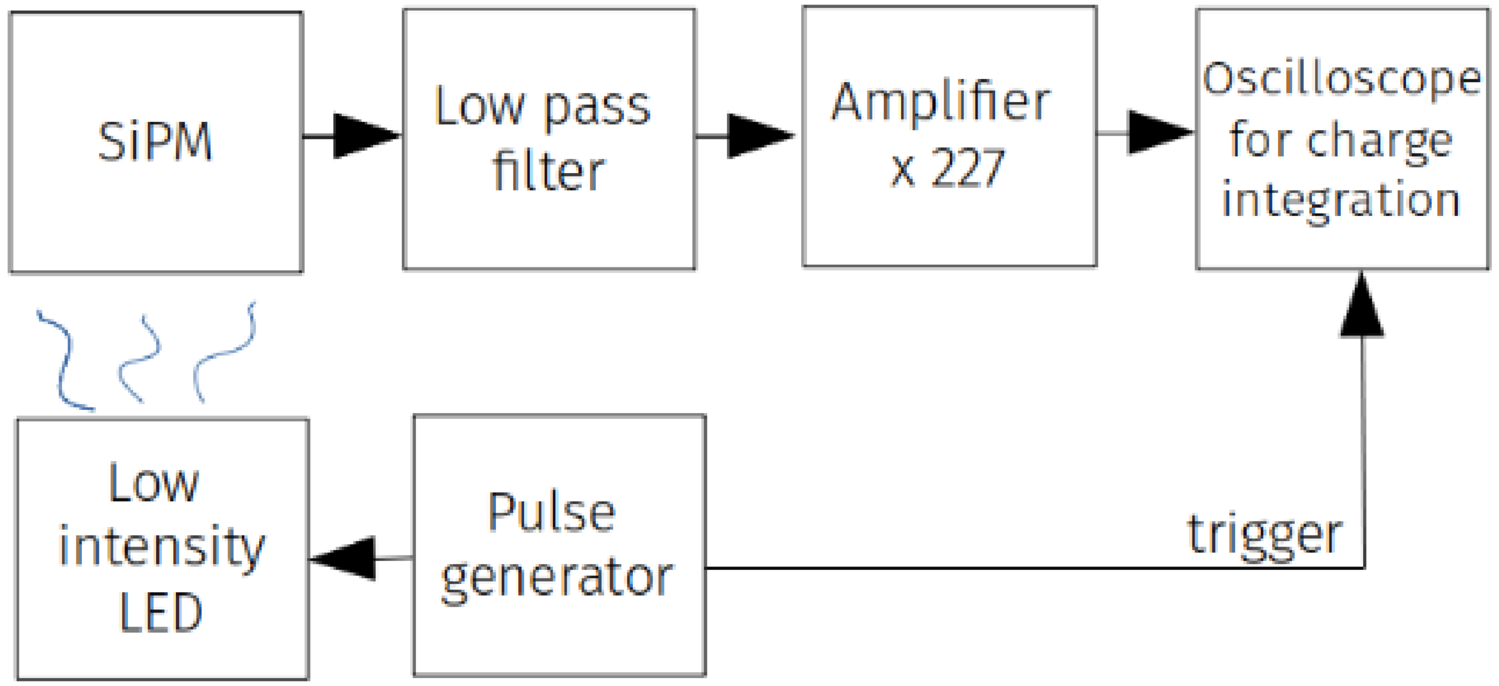
Summary, Outlooks

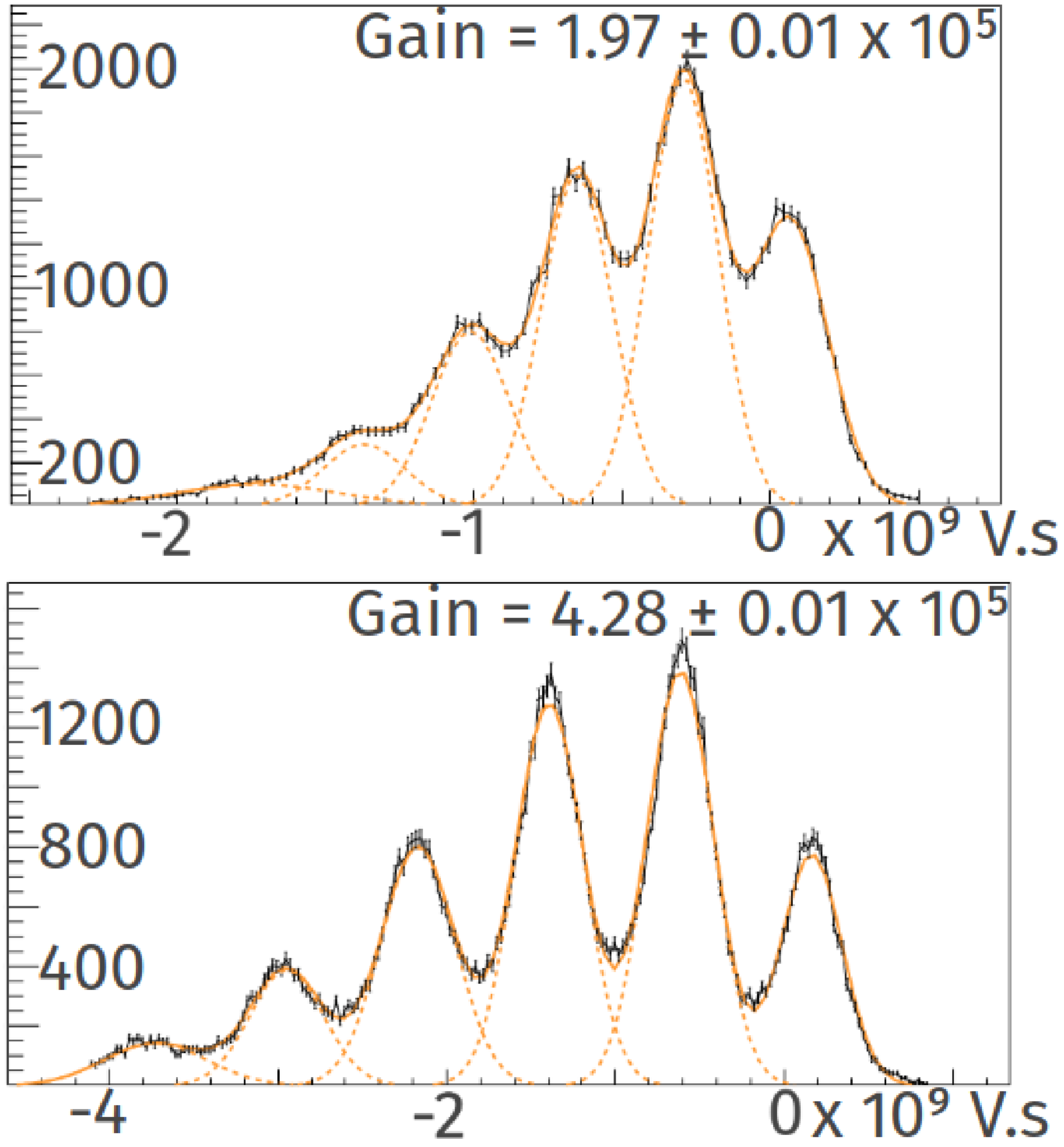
- Scattered electrons at the EIC will be detected in the EEMC with very good energy resolution and over a wide dynamic range.
- The EEMC will be comprised by bars of PWO crystals readout by SiPMs to measure scattered electrons at the EIC.
- PWO meets the requirements for energy resolution and radiation hardness.
- SciGlass was tested as an alternative, its development is ongoing and hold promises for future electromagnetic calorimeters.
- Testing of SiPMs validated this solution for the light readout of the EEMC.
- Choice between the different models is a compromise to be made between low and high energies capabilities.
- Tests with matrices of SiPMs are ongoing and will set the requirements for the electronics to be developed and the structure of the detector.
- Ongoing work at IJCLab and LLR/Omega: development of a specific ASIIC for the readout, mechanical structure of the EEMC.

Gain Measurement



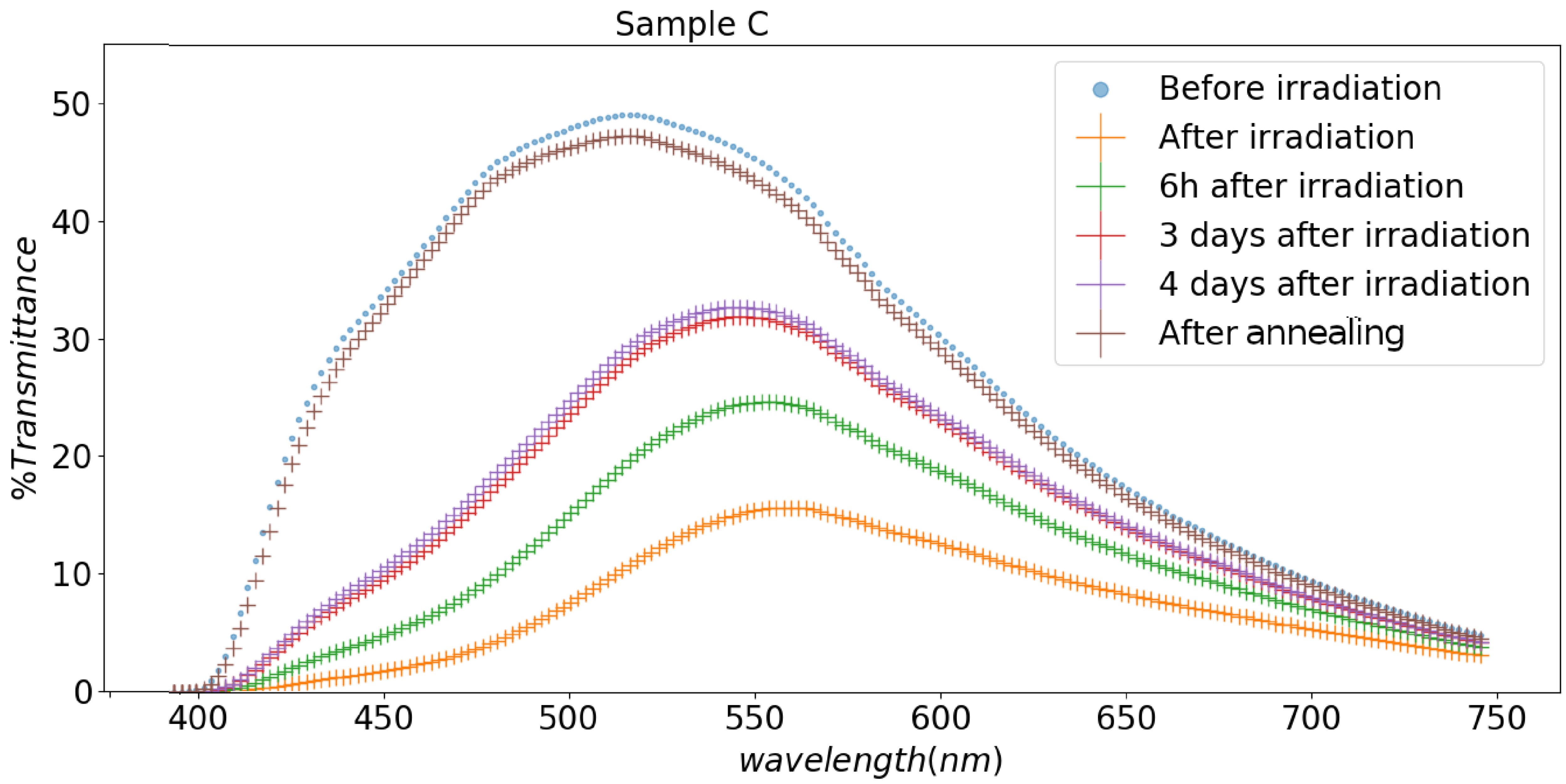






Radiation Hardness

- Further tests were made with high doses (180 Gy).
- Tests of annealing procedures.



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