# Progress with crystal testing and selection

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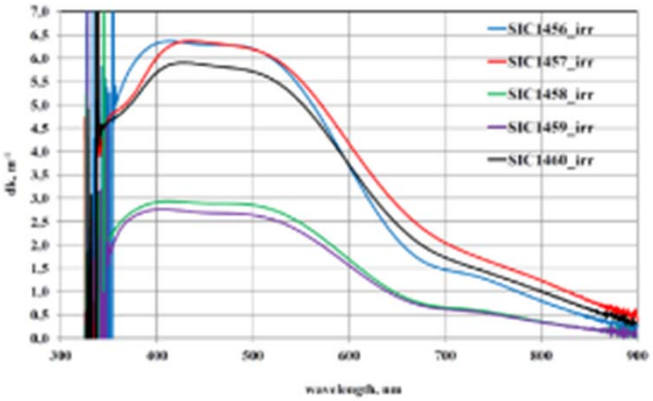
**Thanks to Tanja Horn, Marco Carmignotto, Frédéric Georges and Gabriel Charles for slides/plots…**

# Studies of PbWO4 Crystal Quality: synergy with EIC R&D

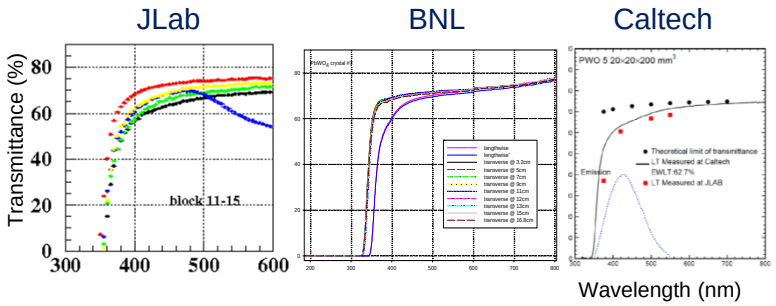
- Two PbWO4 manufacturers: SICCAS/China and CRYTUR/Czech Republic – the company that produced crystals for CMS is out of business

- Our studies show significant crystal-to-crystal variations for crystals manufactured at SICCAS after 2012 – consistent with findings at PANDA

  - Evaluation of this variation and possibly determining the origin of it is one of the main goals of this R&D project




Example of radiation hardness studies from PANDA. Only 3 out of 10 crystals would pass the specifications



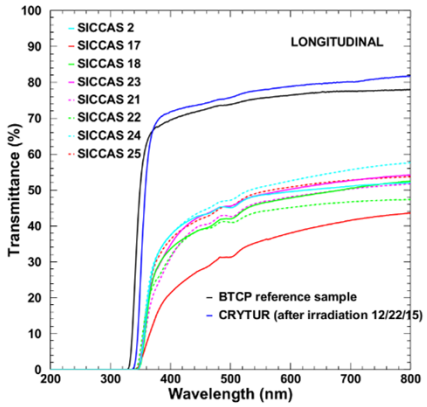

Systematic differences between setups

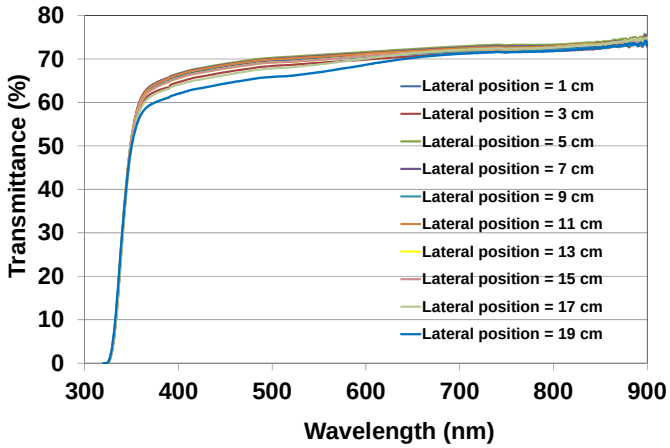
- There are differences in crystal characterization results at different institutions

  - Understanding the effect of this is important for interpretation of crystal quality and setting up specifications for EIC

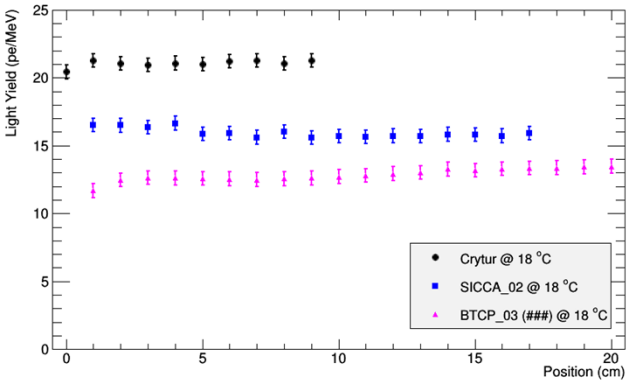
# 2014/2015 PbWO4 Crystals

- Optical transmittance of 2015 SICCAS and CRYTUR produced crystals
  - Chemical analysis to further understand variations




- Light output of Crytur crystals outperforms that of SICCAS and BTCP samples



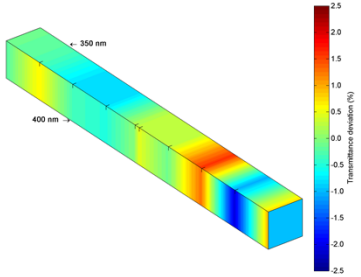

- Crystals produced in 2014 at SICCAS are radiation hard
  - Irradiation with electron beam at Idaho
  - Result confirmed with radioactive sources

# Crystal Testing Facility Setup at CUA

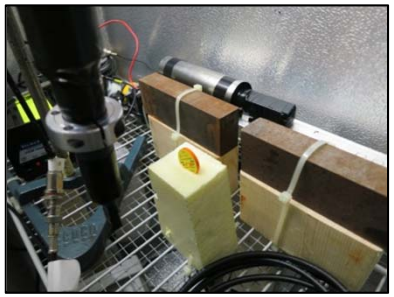
THE CATHOLIC UNIVERSITY of AMERICA

- Close proximity to JLab (synergy with the $PbWO_4$-based NPS project) and The Vitreous State Laboratory (state-of-the-art crystal testing instrumentation and expertise)

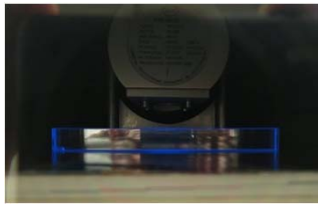
- Optical Transmittance (LT/TT)
  - Perkin-Elmer Lambda 750 spectrometer
  - Setup was commissioned for LT and TT with reproducibility ~0.2%

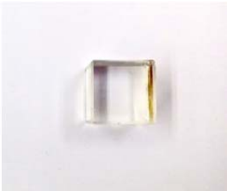



- Crystal light yield and timing
  - Na-22 source and 2-inch PMT (XP2262)
  - Temperature control with accuracy and stability better than 1 ˚C
  - Anode signals digitized with charge sensitive ADC (LeCroy 2249W)



- Radiation hardness and recovery
  - X-ray irradiation system and radioactive sources

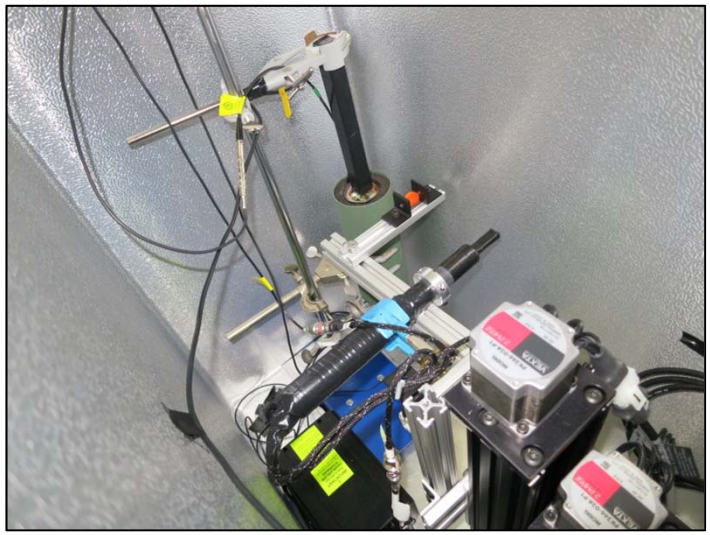




- Chemical analysis (XRF, SEM, TEM, Raman, etc.)

# Light Yield setup

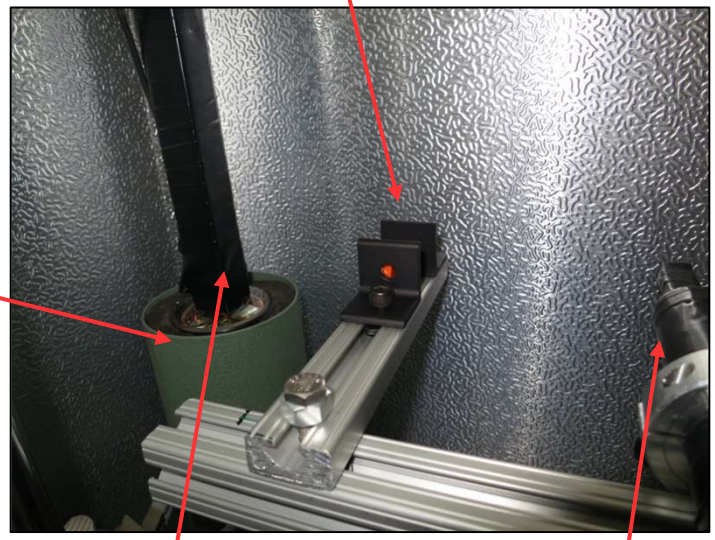
Temperature controlled dark box



Stepper motor based setup used to scan the light yield along the crystal.

Source of Na-22 (two 0.511 keV photons back-to-back)

PMT

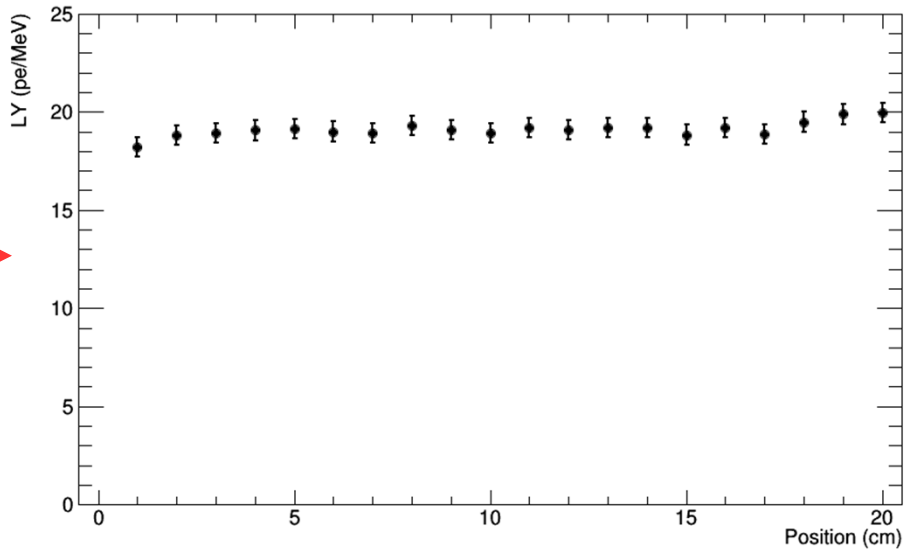


Wrapped crystal

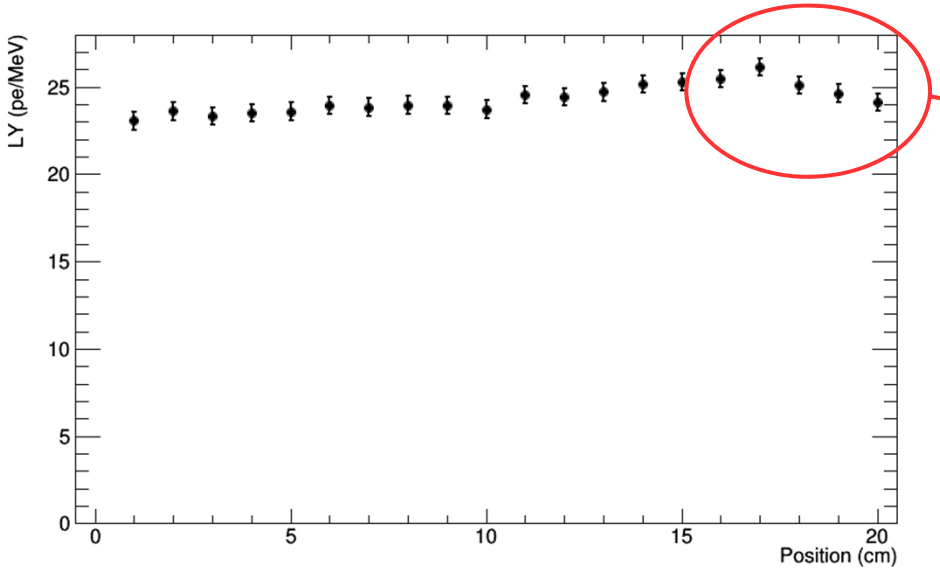
Trigger PMT

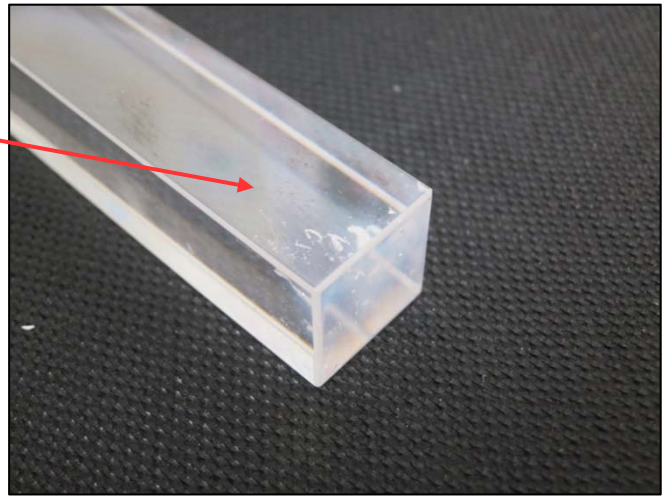
# Light Yield measurements

Typical measurement of Light Yield:




Light yield along crystal SICCA J17

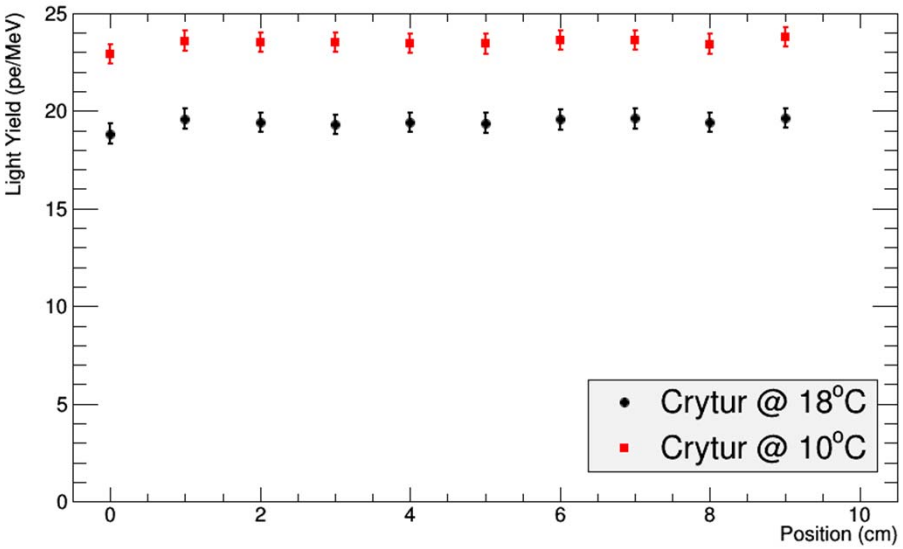


Crystal with internal defects (bubbles)

# Light yield results

Temperature dependence



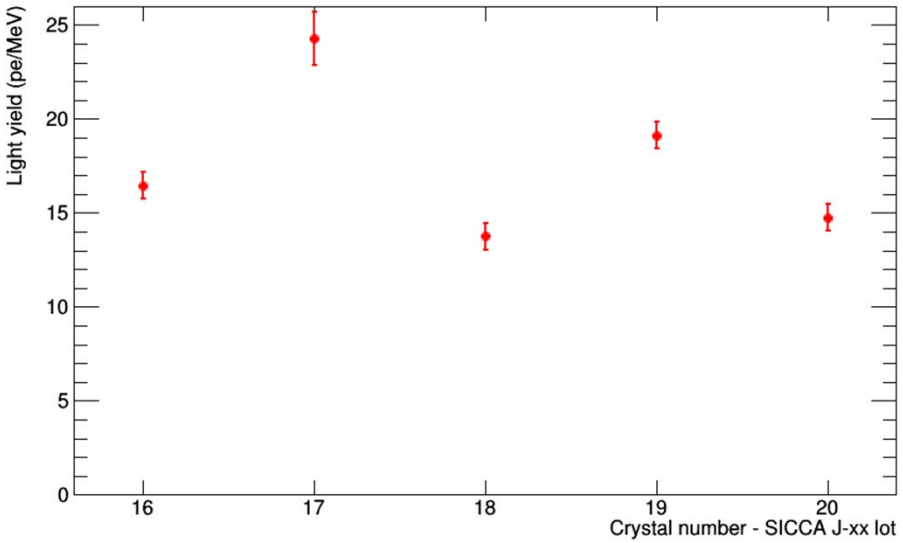

Comparison with Gissen measurement:

LY @ 18 oC

CUA: 19.4 +/- 0.7 pe/MeV
Gissen: 19.2 pe/MeV

Important: PMTs quantum efficiencies are similar, but probably different.

JLab sample of SICCA's crystals



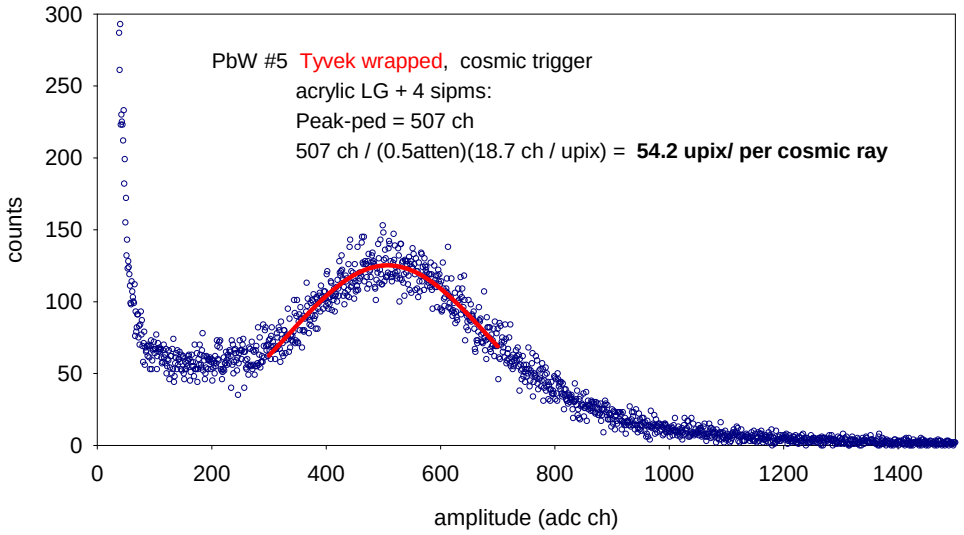

**High variability within the same lot of crystals**

(work in progress to measure more crystals)

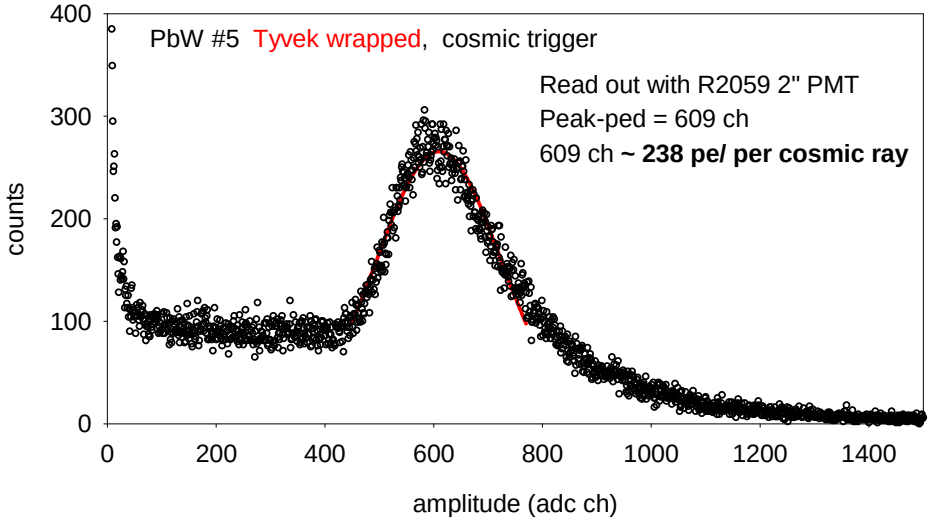
# Towards a SiPM-based readout

- Light output of one 2014 SICCAS produced crystal was measured with a PMT and four SiPMs (Hamamatsu S-12572-015P)

**PMT**



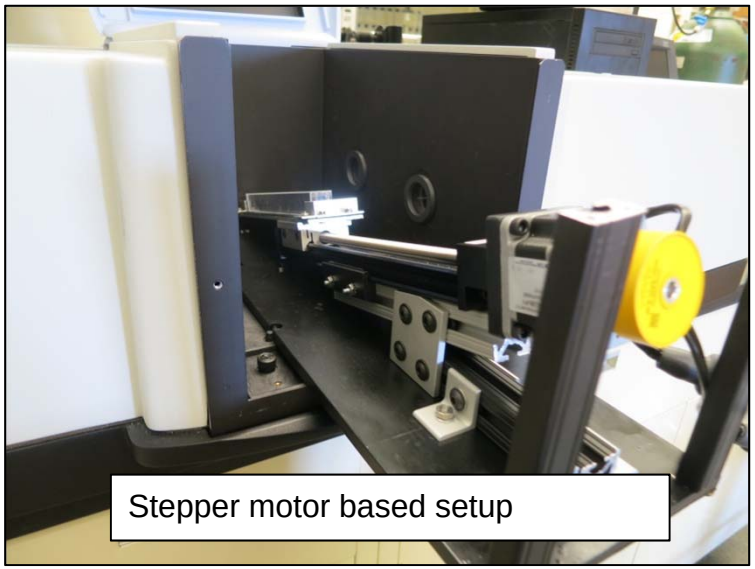

**SiPM**




- Based on this measurement the level of light yield of PWO with SiPMs is sufficient to provide better than 2%/√E of energy resolution
  - Significant optimizations of this measurement are expected and are currently explored

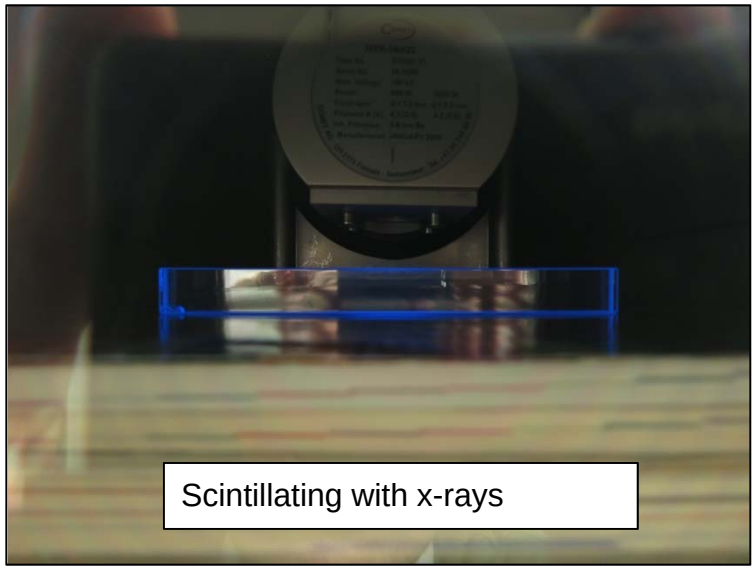
# Other activities in progress

**Position dependent light transmittance of the crystals**



Stepper motor based setup

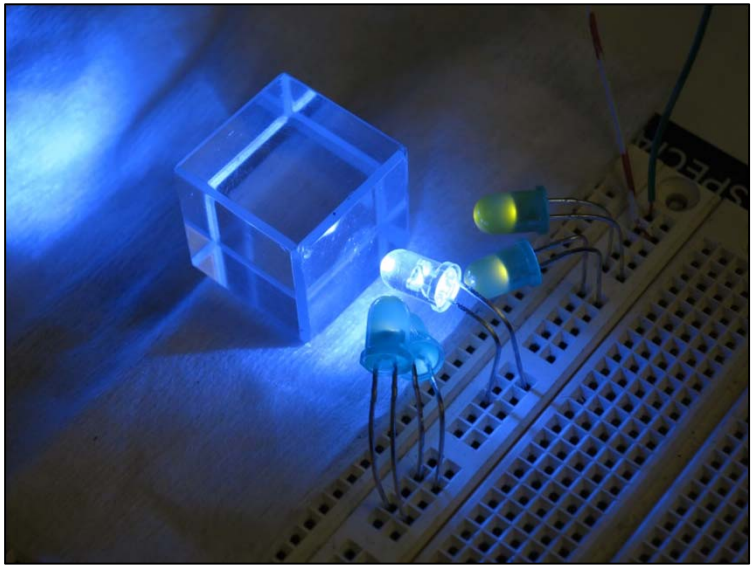
**X-ray machine for radiation hardness characterization**



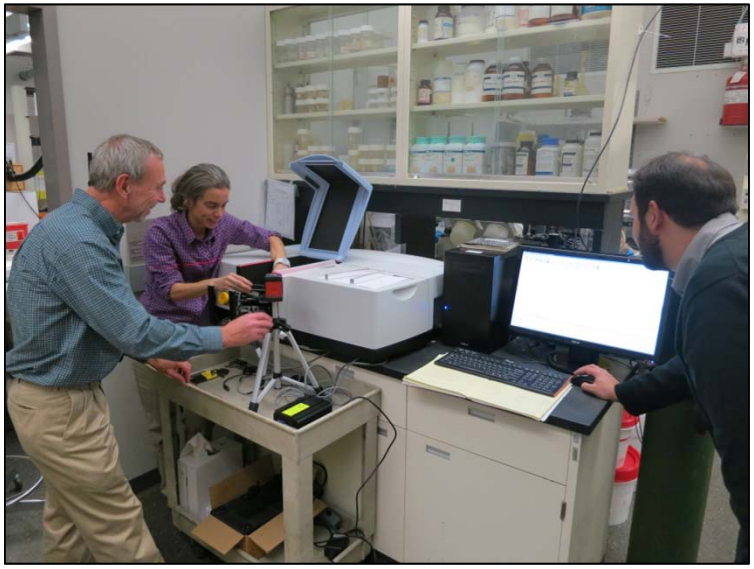
Scintillating with x-rays

# Other activities

**Light annealing (LED)**



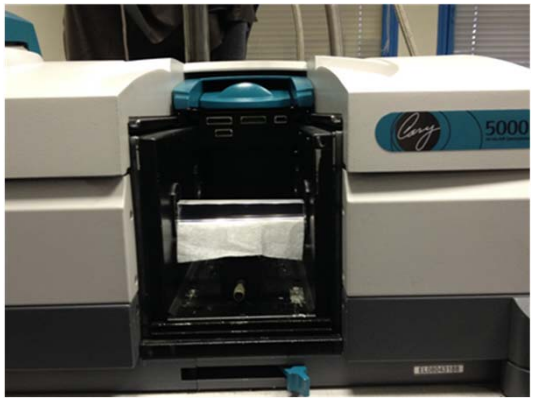
**Thermal annealing (oven)**

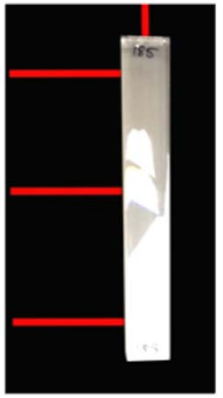


Joining forces with VSL at CUA to characterize PbWO4 crystals!

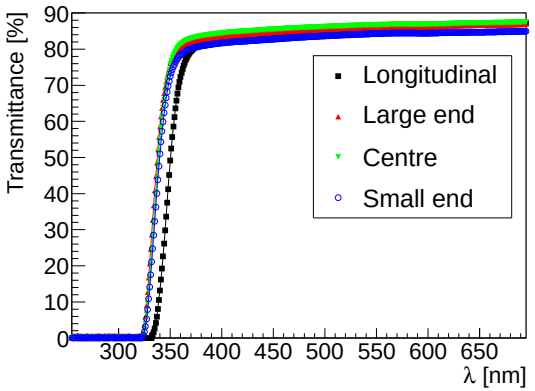
# Crystal Testing Facility Setup at IPN-Orsay

- Close proximity to Giessen University (cross calibration of setup and expertise)
- Optical Transmittance (L/T)
  - Varian Cary 5000 spectrometer
  - Setup was commissioned with BTCP crystals on loan from Giessen
  - To accommodate crystals of lengths greater than 15 cm a more versatile configuration with a fiber-based spectrometer is being built



Laboratoire de Chimie Physique (Orsay)




- Crystal light yield and timing
  - A setup is currently being tested with cosmic rays
- Radiation Hardness
  - Panoramic irradiation facility available ($^{60}$Co sources):
    - 5000 Gy/h at 10 cm
    - 300 Gy/h at 35 cm
    - 6 Gy/h at 260 cm

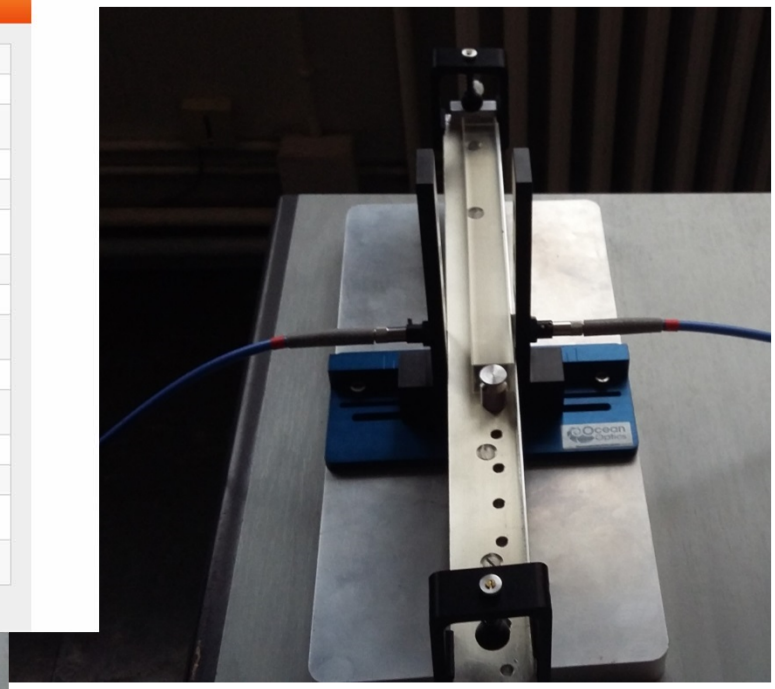
At ~1m 30 Gy in ~30 min

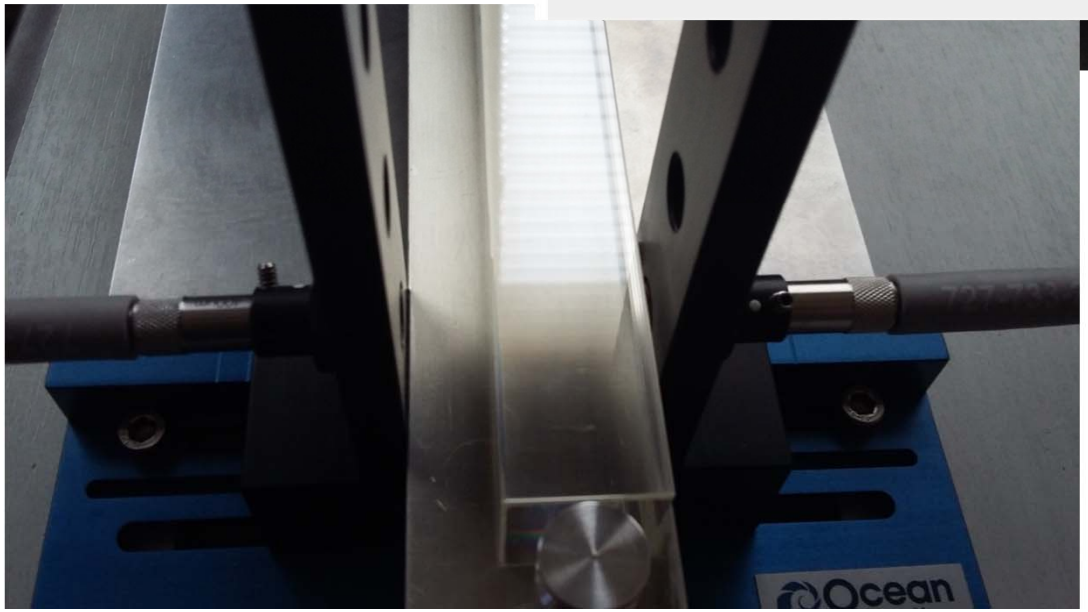
# Transmittance measurements at IPN-Orsay

+ Deuterium Tungsten Halogen UV-Vis-NIR Light Source (stable spectral output from 215-2500 nm)

SPECIFICATIONS

| | |
|---|---|
| Dimensions: | 89.1 mm x 63.3 mm x 34.4 mm |
| Weight: | 190 g |
| Detector: | Sony ILX511B (2048-element linear silicon CCD array) |
| Wavelength range: | 200-850 nm |
| Integration time: | 1 ms – 65 seconds (20 seconds typical) |
| Dynamic range: | 8.5 x 10^7 (system); 1300:1 for a single acquisition |
| Signal-to-noise ratio: | 250:1 (full signal) |
| Dark noise: | 50 RMS counts |
| Grating: | 600 lines/mm, set to 200-850 nm (blazed at 300 nm) |
| Slit: | 25 µm |
| Detector collection lens: | L2 |
| Order-sorting: | OFLV-200-850 |
| Optical resolution: | 1.5 nm FWHM |
| Stray light: | <0.05% at 600 nm; <0.10% at 435 nm; <10% at 250 nm |
| Fiber optic connector: | SMA 905 to 0.22 numerical aperture single-strand fiber |



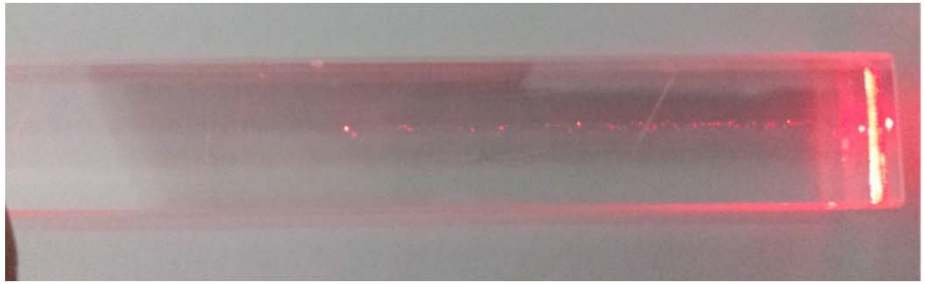



- Accurate block position and alignment
- Transmission measurements reproducible

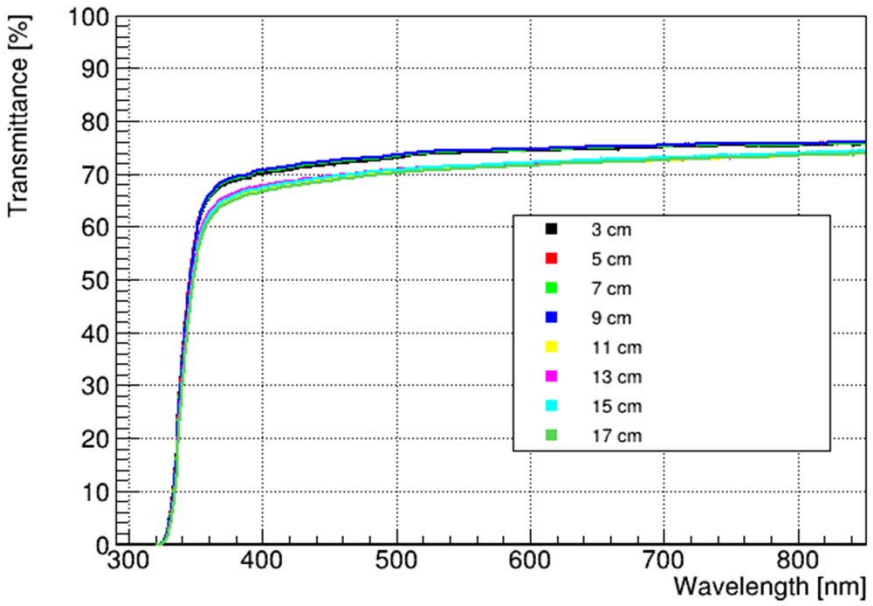
- Absolute results dependent on collimation of light
- But stable and reproducible for a given position of collimating lenses.

# CRYTUR block 39

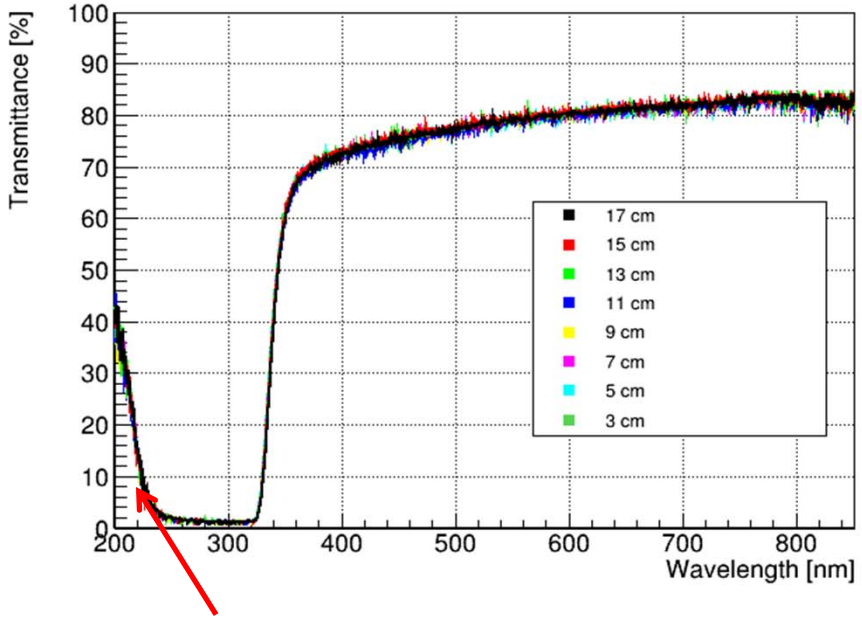
Grown in Ar atmosphere & doped with La+Y
2x2x20 cm3 – CRYTUR, October 2015



Giessen: CRYTUR 39



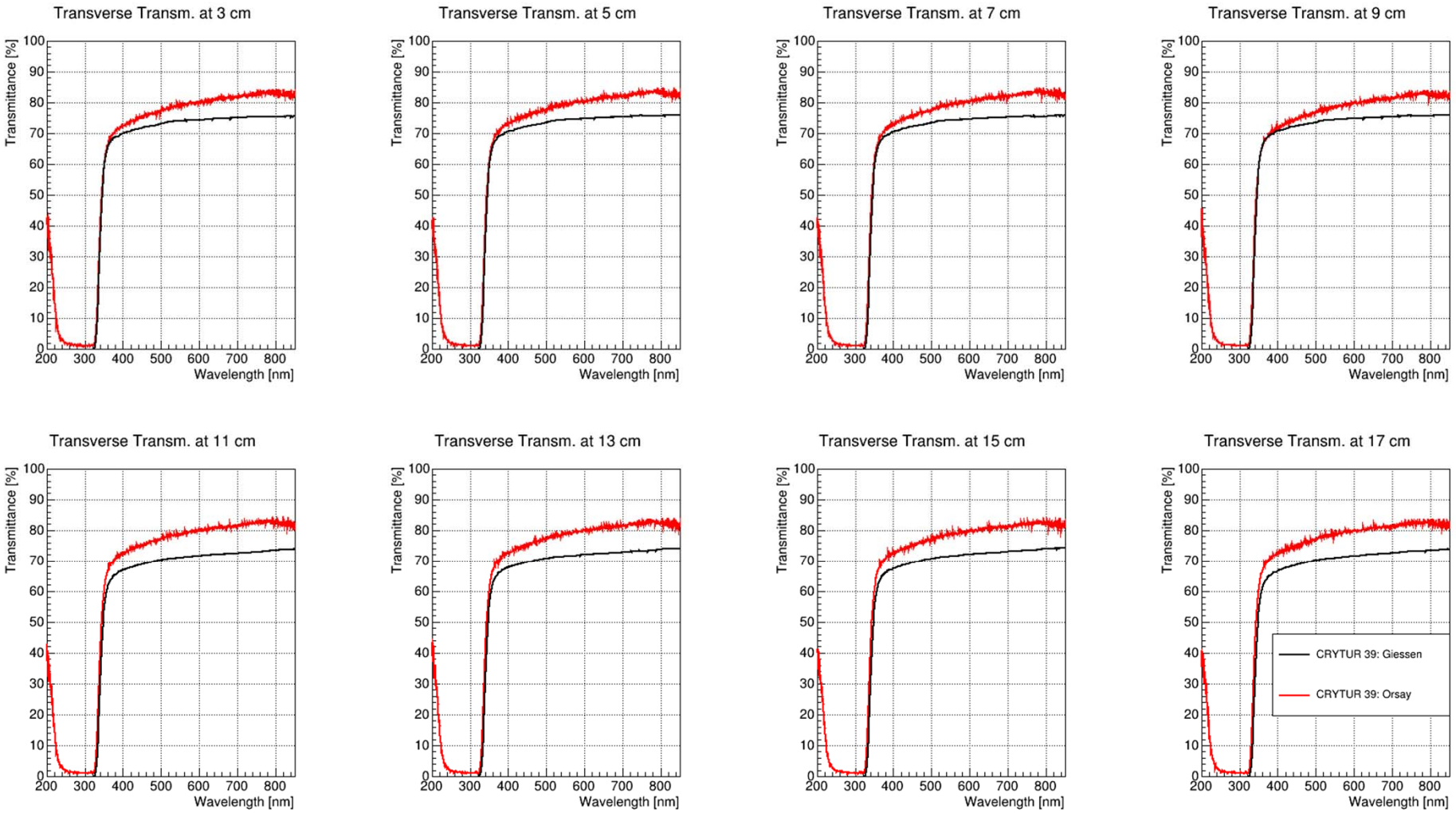

Orsay: CRYTUR 39




Non-physical transmission
measured at low wavelength

F. Georges
G. Charles

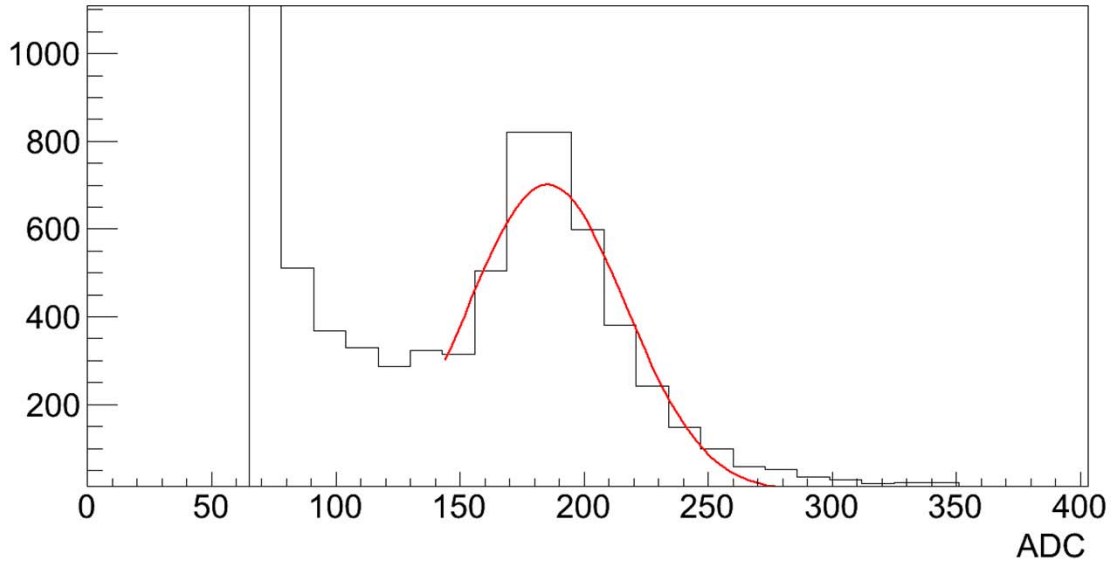
# CRYTUR block 39: Giessen/Orsay comparison




F. Georges
G. Charles

# Light yield measurements in Orsay

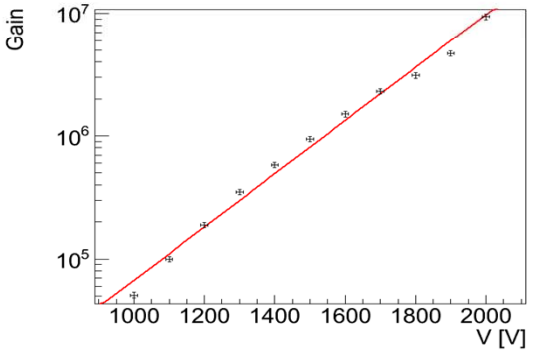
**Vertical cosmics through a PWO crystal**




- Cosmic setup to measure light yield at room temperature
- Results so far on a old BTCP crystal

Mean value at 182 ADC ch with a pedestal at 72.
This yields **117 photons per MeV at room temperature**,
very close to values measured for these crystals by other groups.

Average thickness of the crystal: 2.1 cm
ADC sensitivity: 0.25 pC/channel
PMT gain: 4.1 $10^5$
PMT QE: 25%
Light collection efficiency: ~70%




PMT calibration using 1-pe peak

# CRYTUR: 3 new blocks ordered by IPN (Nov'15)

"Unfortunately, the batch of the crystals for you did crack and we have to produce new ones.
Now we can offer you a product with missing material in the corners of the prism and cracks on the edge – as you can see on the attached picture of the prism after cutting. Or we can offer you regular prisms, but shorter." (18.5 cm)

- First 2 blocks expected end of January, 3rd one end of February
- Giessen will characterize the blocks first (1-2 days) and send them to IPN-Orsay right after

# Orsay: irradiation plans

**Photons:**

- Panoramic irradiation facility available ($^{60}$Co sources):
  - 5000 Gy/h at 10 cm
  - 300 Gy/h at 35 cm
  - 6 Gy/h at 260 cm

At ~1m 30 Gy in ~30 min

Laboratoire de Chimie Physique (Orsay)

**Electron/protons:**

- ALTO facility in Orsay:

- 50 MeV electrons up to 1 uA
- 10-20 MeV protons/ions

Plan to to irradiation studies in the next 1-2 months

# Outlook

- **Finalize the crystal testing facilities at IPN-Orsay and CUA** – allows for testing the optical properties and homogeneity of crystals produced at SICCAS and procured through synergy with the NPS project at JLab
  - Results are an essential aspect required to quantify crystal-to-crystal variations and possibly understand their origin - would thus provide a measure of the quality that can be achieved by that vendor
- **Procure 10 full-sized crystals from CRYTUR** – allows for reliable evaluation of crystal-to-crystal variation
- **Construct a prototype to study the crystals in test beam** and measure the actual energy and position resolution – also allows for testing a SiPM-based readout
- Optimization of geometry, cooling and choices of readout system of the inner crystal calorimeter

Neutral Particle Spectrometer prototype produced with 3D printing technology