Exclusive reactions and the PbWO4-based Inner Calorimeter for the Electron-Ion Collider

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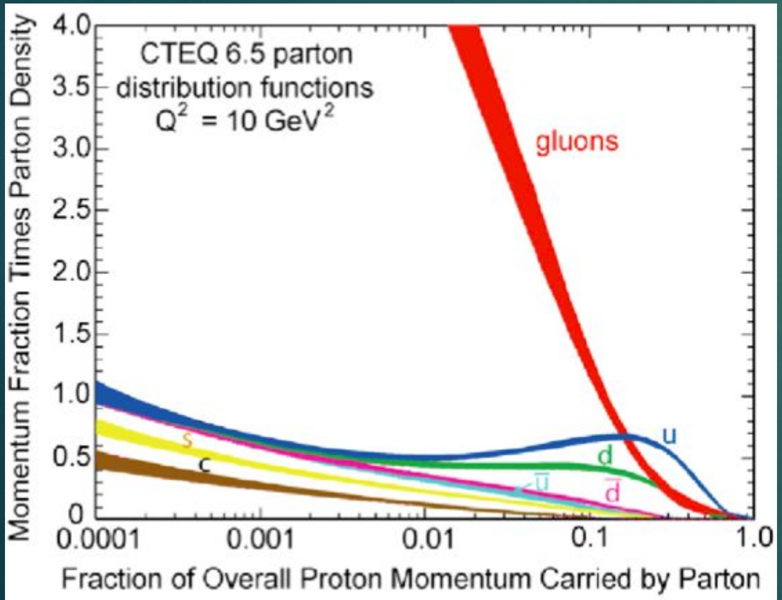
Nucleon Structure

- How do hadronic properties arise from its constituents?
  - A nucleon structure is more than just quarks
  - The dynamics of gluons place a significant role in the spin of a nucleon
  - The ability to probe a 3D structure of a nucleon enables a better understanding of it's hadronic properties



Electron-Ion Collider (EIC)

- The EIC will provide 3D imaging of the nuclei, to reveal the role of angular motion of the sea quarks and gluons in forming nucleon spin
- This is obtained through a new framework that uses the Generalized Parton Distributions (GPDs) and Transverse Momentum-Dependent Parton Distributions (TMDs)

Crystal Calorimeter

- A general calorimeter has two purposes
  - PID (through DVCS)
  - Particle reconstruction (to provide accurate reconstruction of the four-momentum scattering of electrons at small angles)
- Calorimeters have a critical angle for particle reconstruction
  - Below this critical angle the resolution will be better
- The PbWO4 crystal has a better resolution compared to silicon tracking, for all reasonably high energies

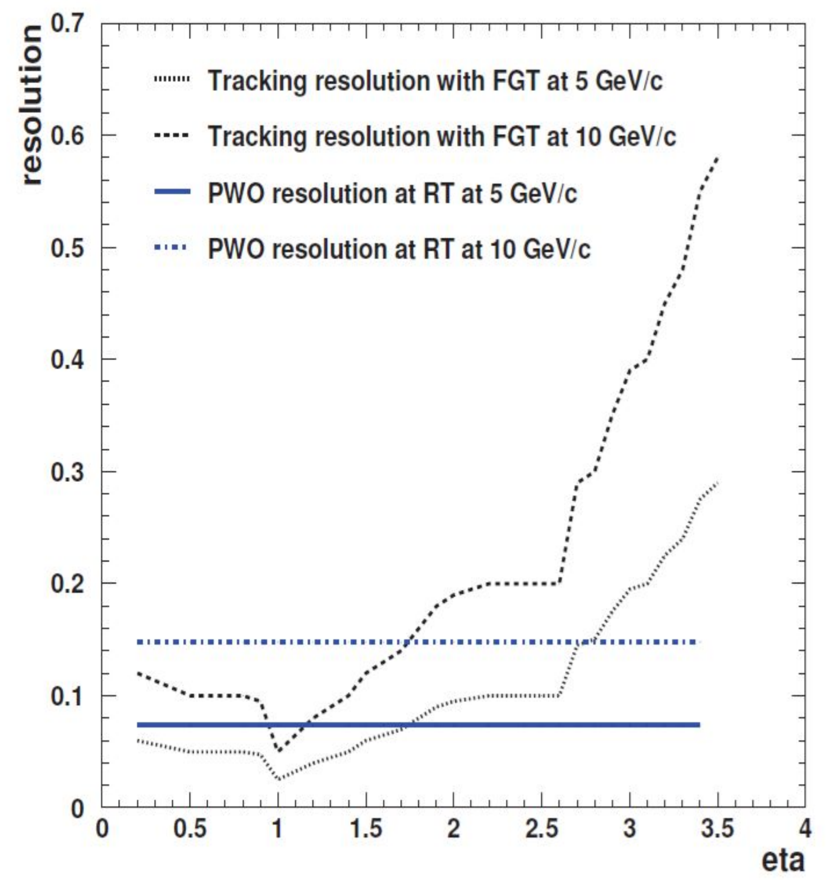
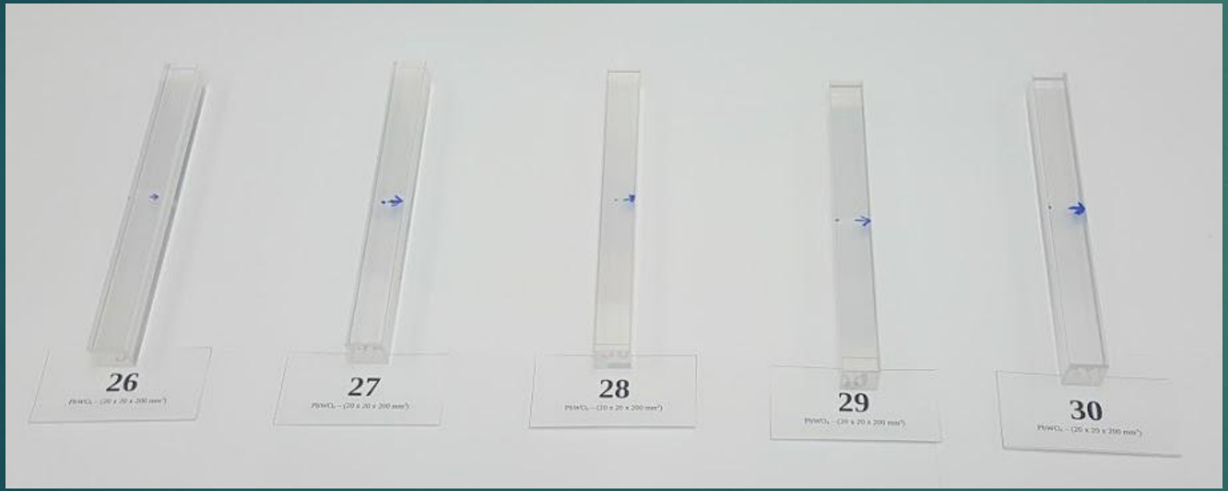


Fig. 1. (color online) The resolution as a function of rapidity (eta) for tracker and PbWO4 crystals at representative particle momenta of 5 GeV/c and 10 GeV/c of the experiments. The tracking resolution at large values of eta is relatively poor and can be compensated by that of high resolution crystals.

PbWO4-Based Calorimeter

- Crystal calorimeters provide high resolution and detection efficiency which make them ideal for the EIC
- PbWO4-based calorimeters, in particular, because of their small Moliere radius and radiation hardness.



- Crystal production by BTCP (Russia) and SIC (China) were used in previous calorimeters (CMS, Jlab, PANDA, etc.)
- BTCP used the Czochralsky method, which showed a significant improvement in light output and radiation hardness (manufacturing processes). Sadly they closed production.
- Maintaining good crystal quality is troublesome with the SIC crystals.
- Possible solution in Crytur (Czech Republic), will discuss later

Crystal Specifications

Parameter	Unit	NPS Required	NPS Acceptable	CMS Limit	PANDA Limit	Inform. Source
Light Yield (LY) at RT (for all sides polished crystals)	pe/MeV	≥15	≥10	≥8	≥16	Test with γ-source
LY uniformity between blocks	%	10%	20%			Test
LY(100ns)/LY(1μs)	%	>95	>90	>90	>90	Test
Longitudinal Transmission at λ=360 nm at λ=420 nm at λ=620 nm	 % % %			 ≥25 ≥55 ≥65	 ≥35 ≥60 ≥70	Optic. Measure.
Transverse Transmission and LY uniformity along crystal	%	10	15			Optic. Measure.
Inhomogeneity of Transverse Transmission Δλ at T=50%	nm	≤5	≤10	≤3	≤3	Optic. Measure.
Induced radiation absorption coefficient Δk at λ=420 nm and RT, for integral dose >100 Gy	m^{-1}	<1.0	<1.5	≤1.6	≤1.1	Test
Mean value of dk	m^{-1}	≤0.75	≤1.0	≤1.5	≤0.75	Test
Tolerance in Length Tolerance in sides	μm μm	≤±100 - ≤±50	≤±150 ≤±100	+0., -100 ≤ ±50	±50 ±50	Measure.
Surface polished, roughness Ra	μm	≤0.02	≤0.05	≤0.02		Company
Tolerance in Rectangularity (90°)	degree	≤0.1	≤0.2	≤0.12	<0.01	Measure.
Purity specific. (raw material)				5N–6N		Company
Mo contamination	ppm	<10		<10	<1	Company
La, Y, Nb, Lu contamination	ppm	?		≤100	≤40	Company

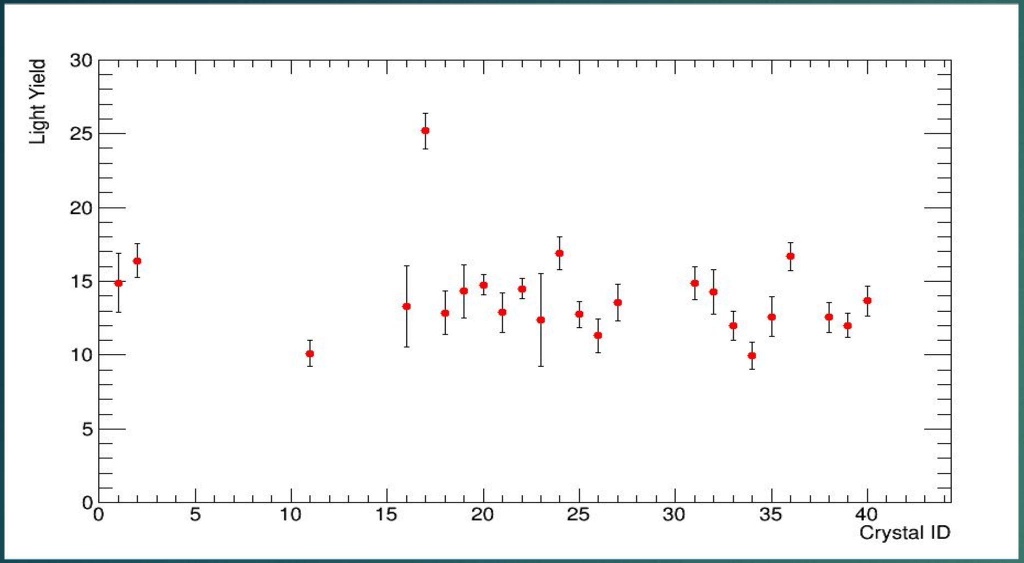
IPN-Orsay Group (France)

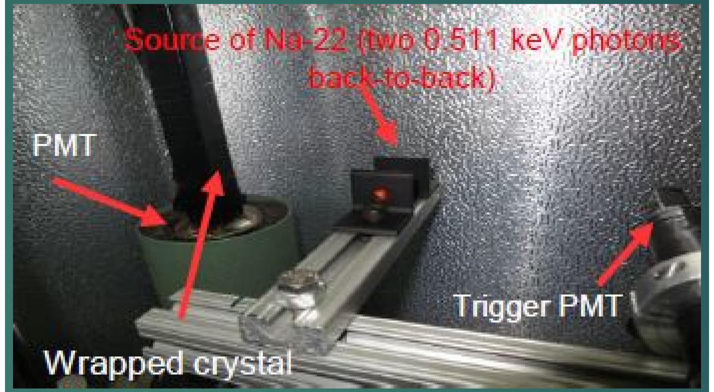
- Gabriel Charles, Carlos Munoz-Camacho
- Optical Transmittance
  - Fiber-based spectrometer
  - Setup was commissioned with BTCP crystals on loan from Giessen
- Light Yield
  - A set up is currently being tested with cosmic rays
- Radiation hardness
  - Strong Colbalt-60 sources available at LCP-Orsay
  - Initial tests performed on June 23
- ALTO at IPN-Orsay
  - 50 MeV electrons up to 1uA
  - Proton beam also available

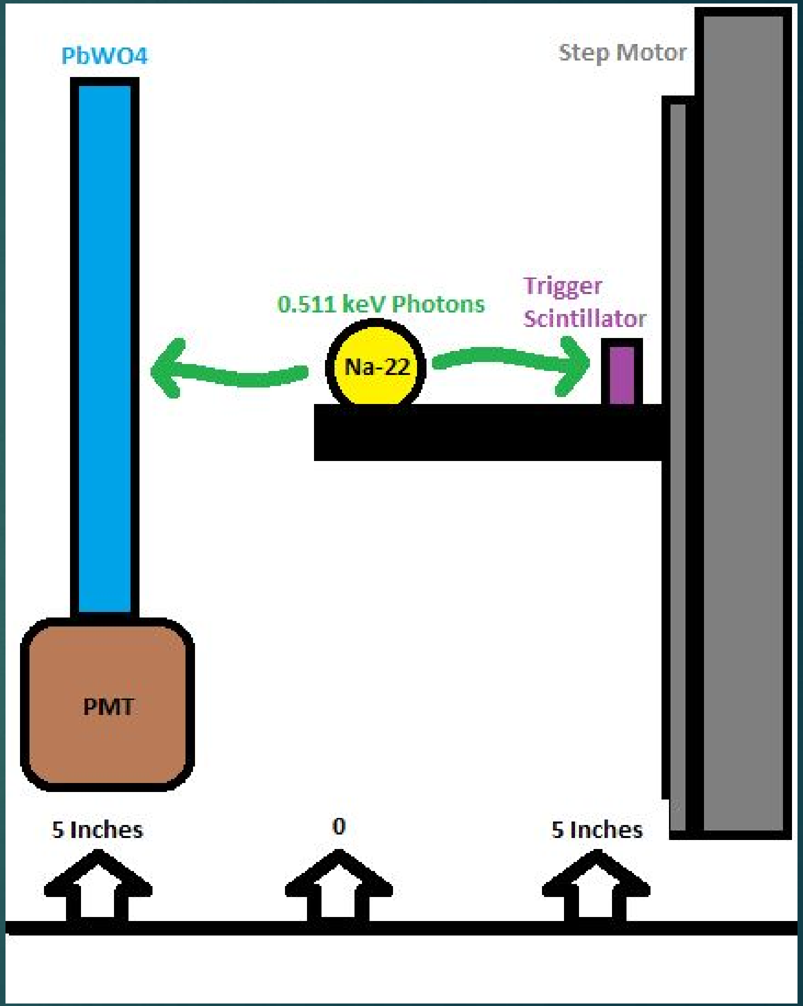
CUA Group (USA)

- Discussed in upcoming slides

Light Yield



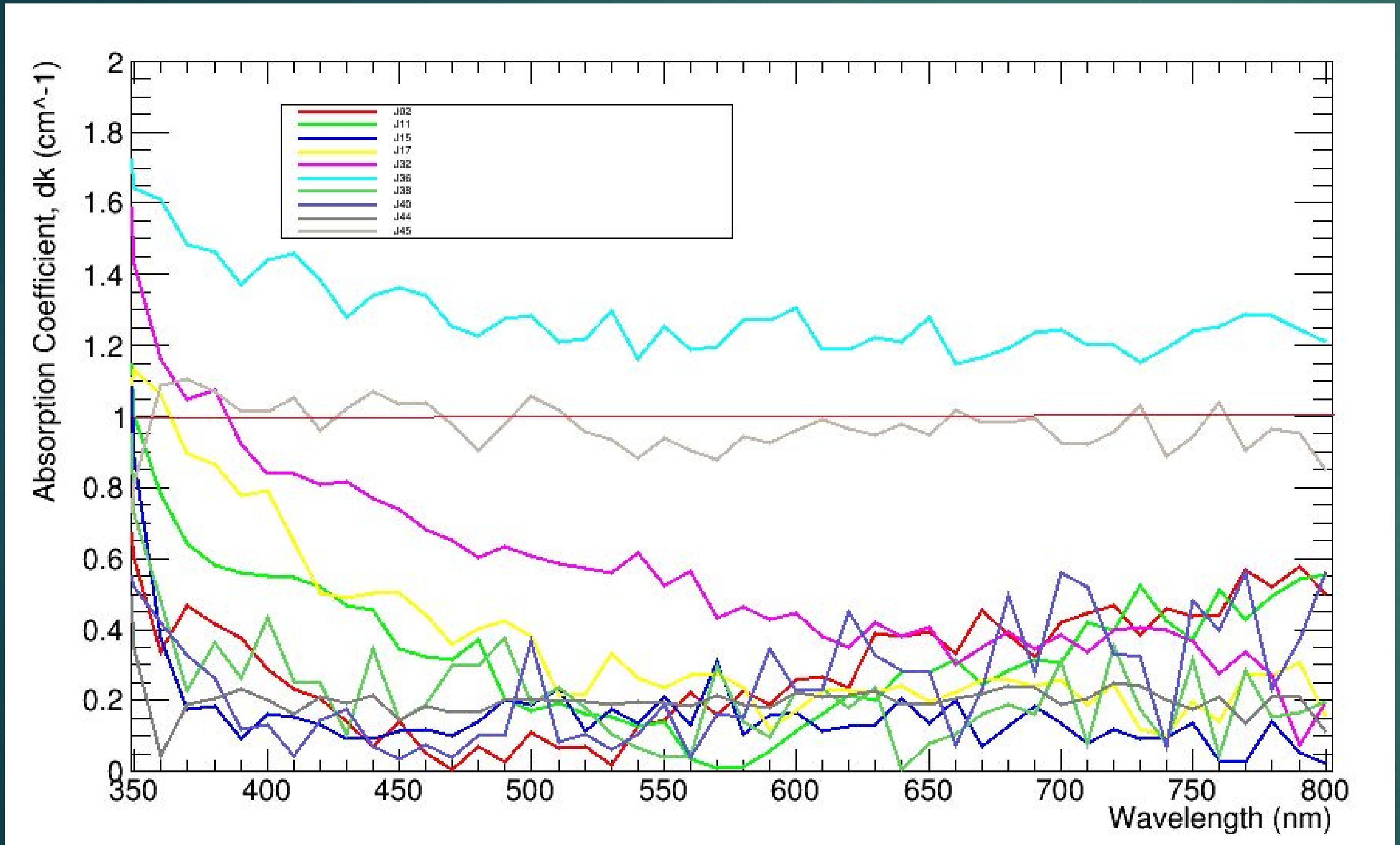


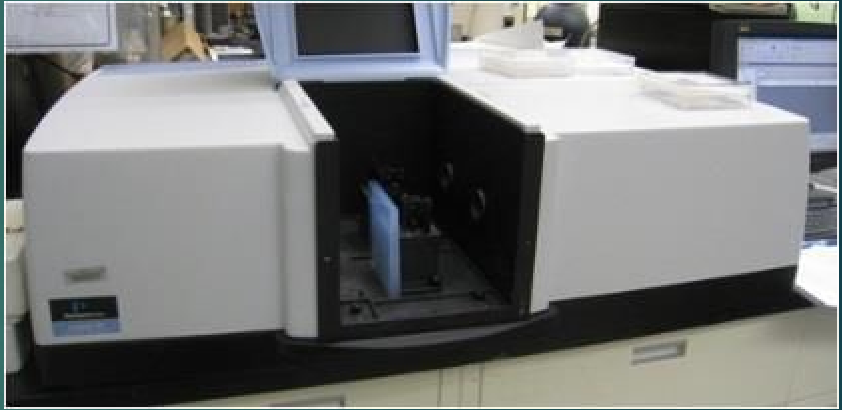


Chemical Analysis

- Collaboration with VSL (Marek Brandys and Ian Pegg)
  - Initial results available (though not fully understood yet)
  - Developing non-destructive methods for testing large number of crystals

Transmittance and Radiation Hardness

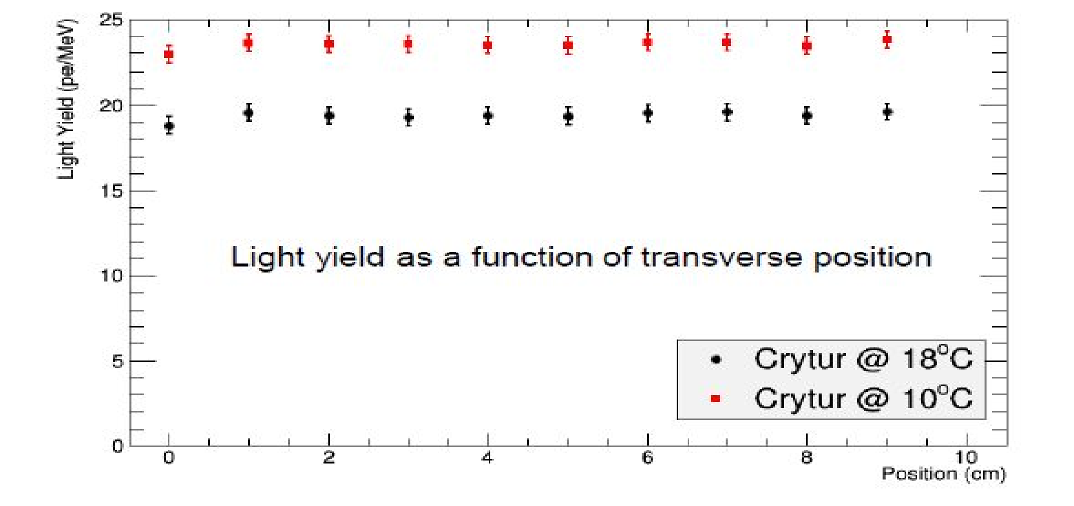


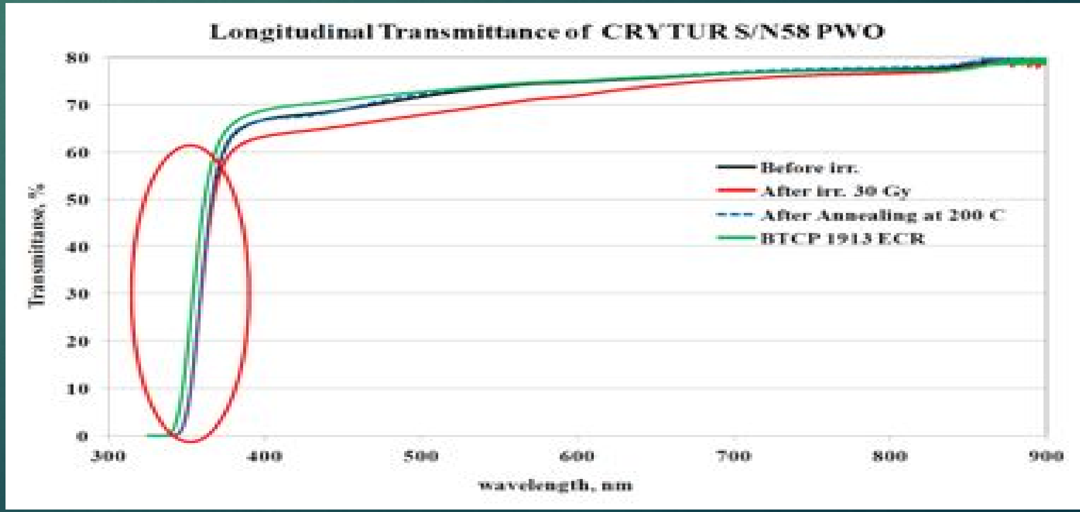


$$dk = \ln\left(\frac{T_{before}}{T_{after}}\right) \cdot \left(\frac{1}{D}\right)$$

Crytur

- 3 new (2016) crystals from CRYTUR with dimensions: 20x20x18.5 mm3 (2 at Giessen and 1 at CUA)
- Grown in Ar atmosphere & doped with La+Y
- First full size (2x2x20 cm3) crystal produced by CRYTUR (Oct 2015)
- Low light yield (12-13 pe at 18°), with tolerable non-uniformity (perhaps due to high doping)
- Acceptable transmittance
- Crystal similar to CMS quality (shift of transmittance edge and low radiation induced coefficient)





Summary and Future

- Finalized setups for crystal testing at CUA (including chemical analysis)
- Acquiring more crystals to test is in the works
- The results of the chemical analysis should provide much needed insight into the composition of the crystals
- Further tests in regards to radiation hardness to confirm possible correlation to light yield loss
- Finalize chemical composition and radiation hardness results to find a possible conclusion
- Investigations into a setup for growing crystals