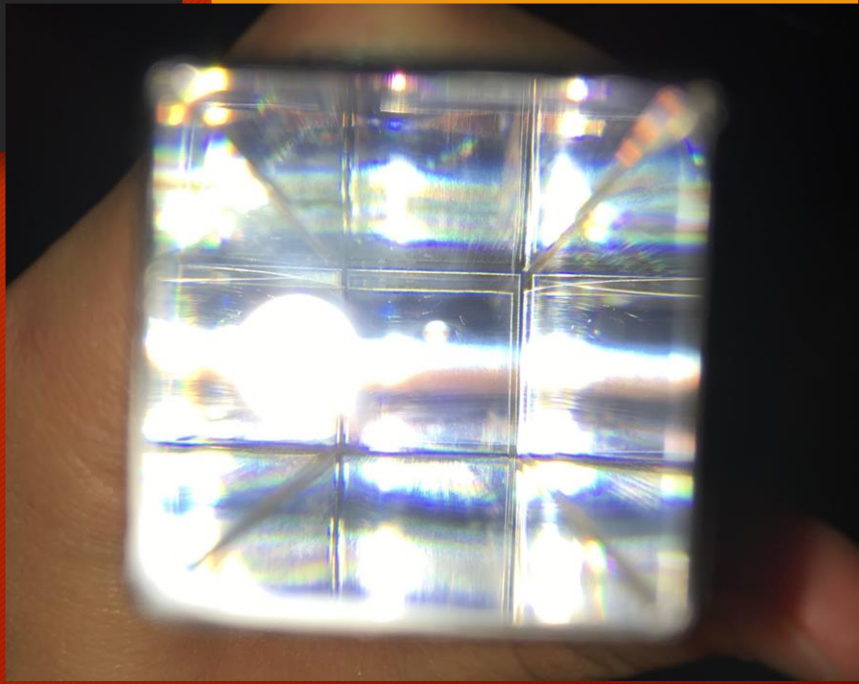
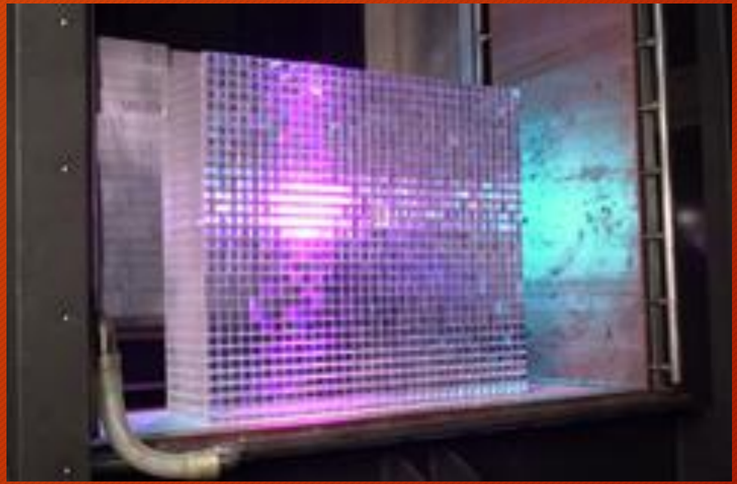
Impact of Crystal Non-uniformities on Electromagnetic Calorimeter Performance

Casey Lauer and Dannie Griggs



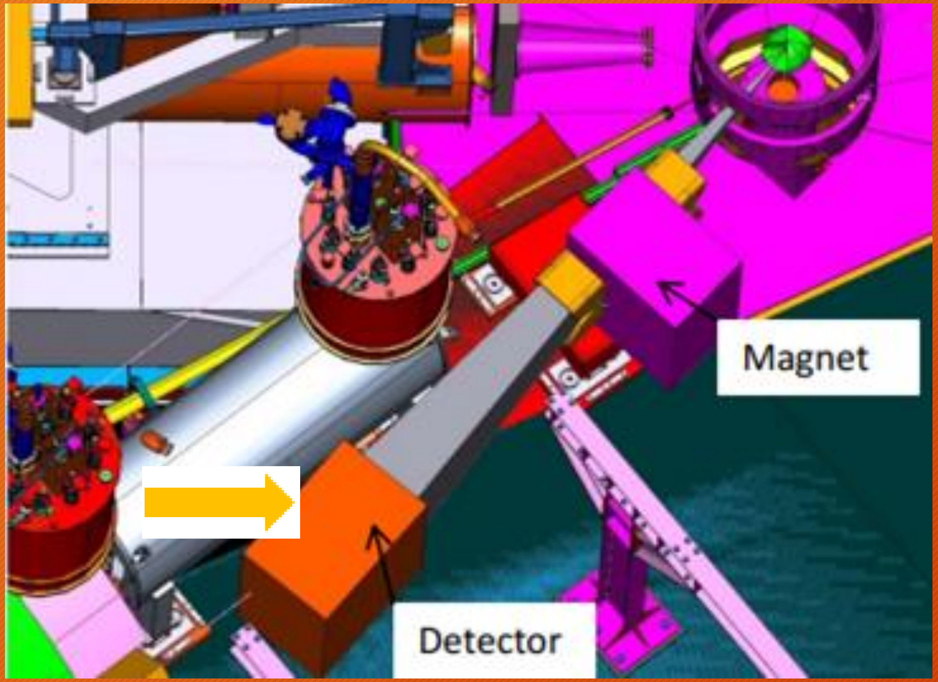
Why is PWO important?

- Lead Tungstate Crystals (PWO) are ideal for use in a compact electromagnetic calorimeter
  - Small Moliére Radius
  - Short Radiation Length = high stopping power
  - Higher light yield than other heavy crystals
    - In part due to high density
  - Radiation hard
- HOWEVER, recent measurements have shown considerable variation of crystal properties
- Necessary to measure and understand the origin of variation

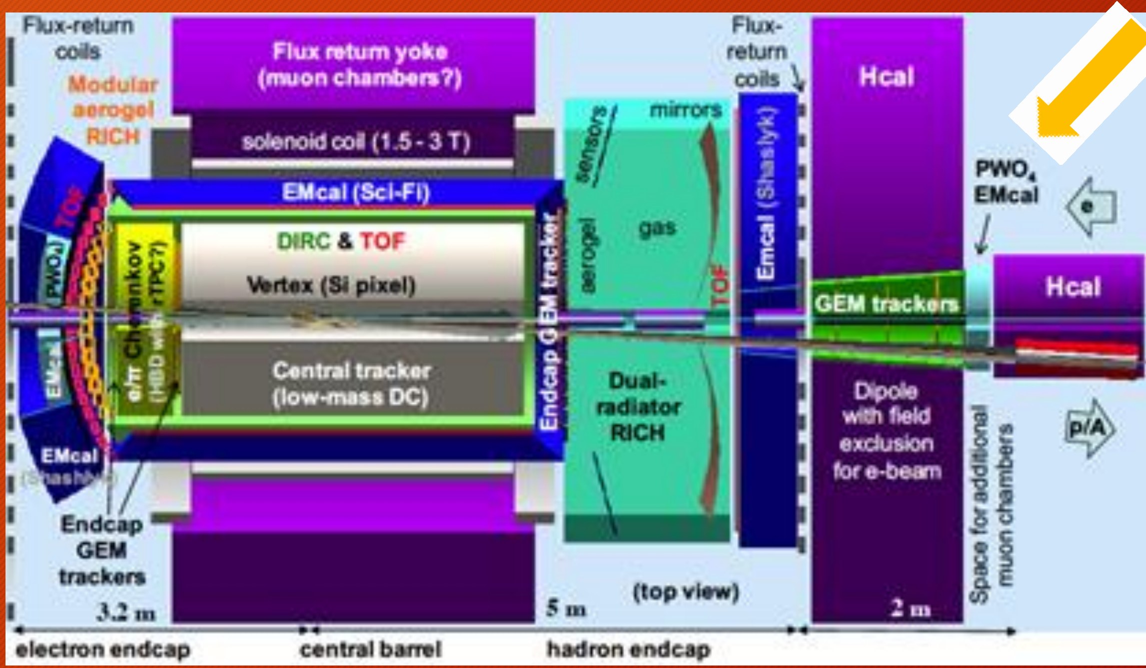


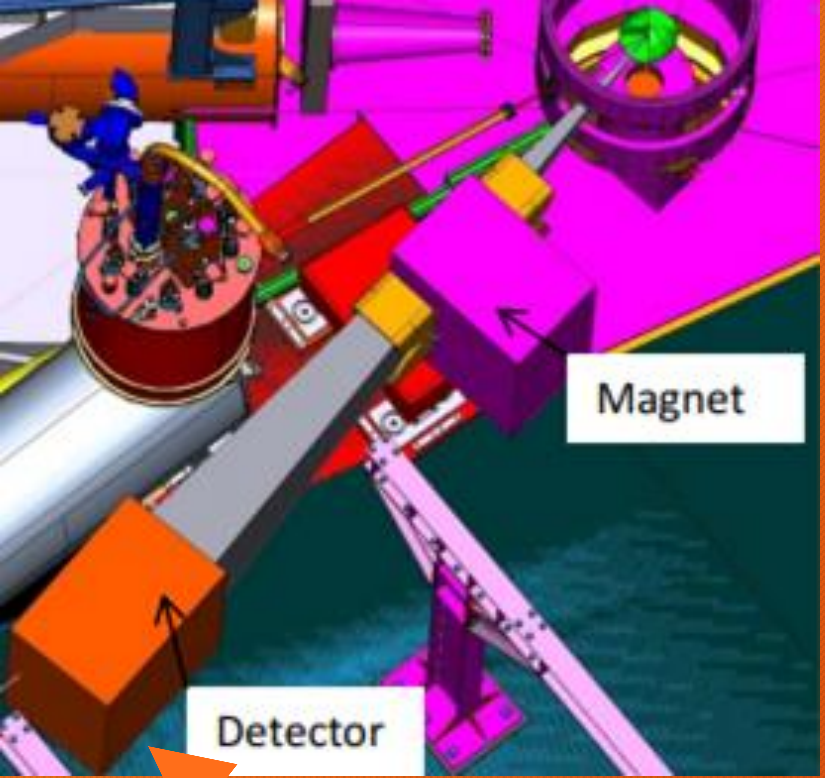
Examples: HyCal and CMS ECAL

Neutral Particle Spectrometer

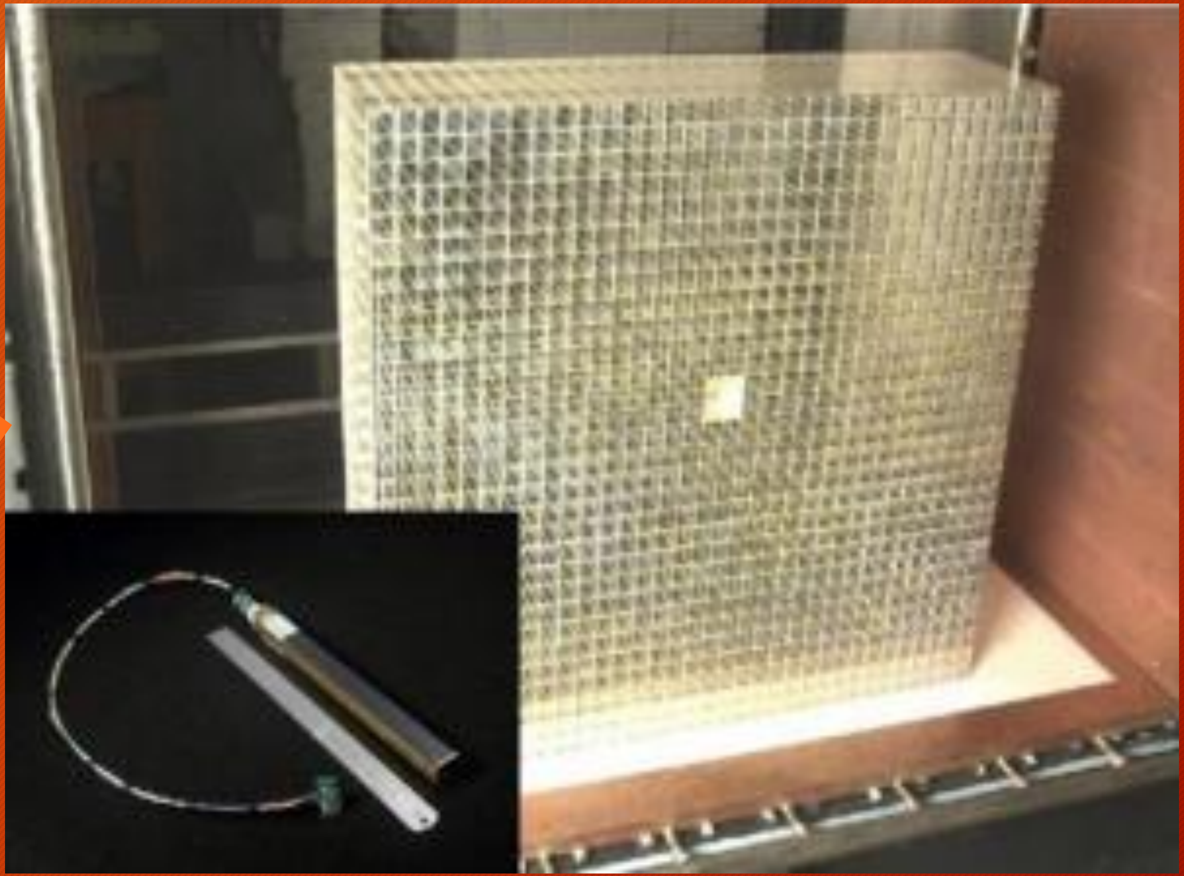


Electron Ion Collider





PbWO4 Crystal
Calorimeter

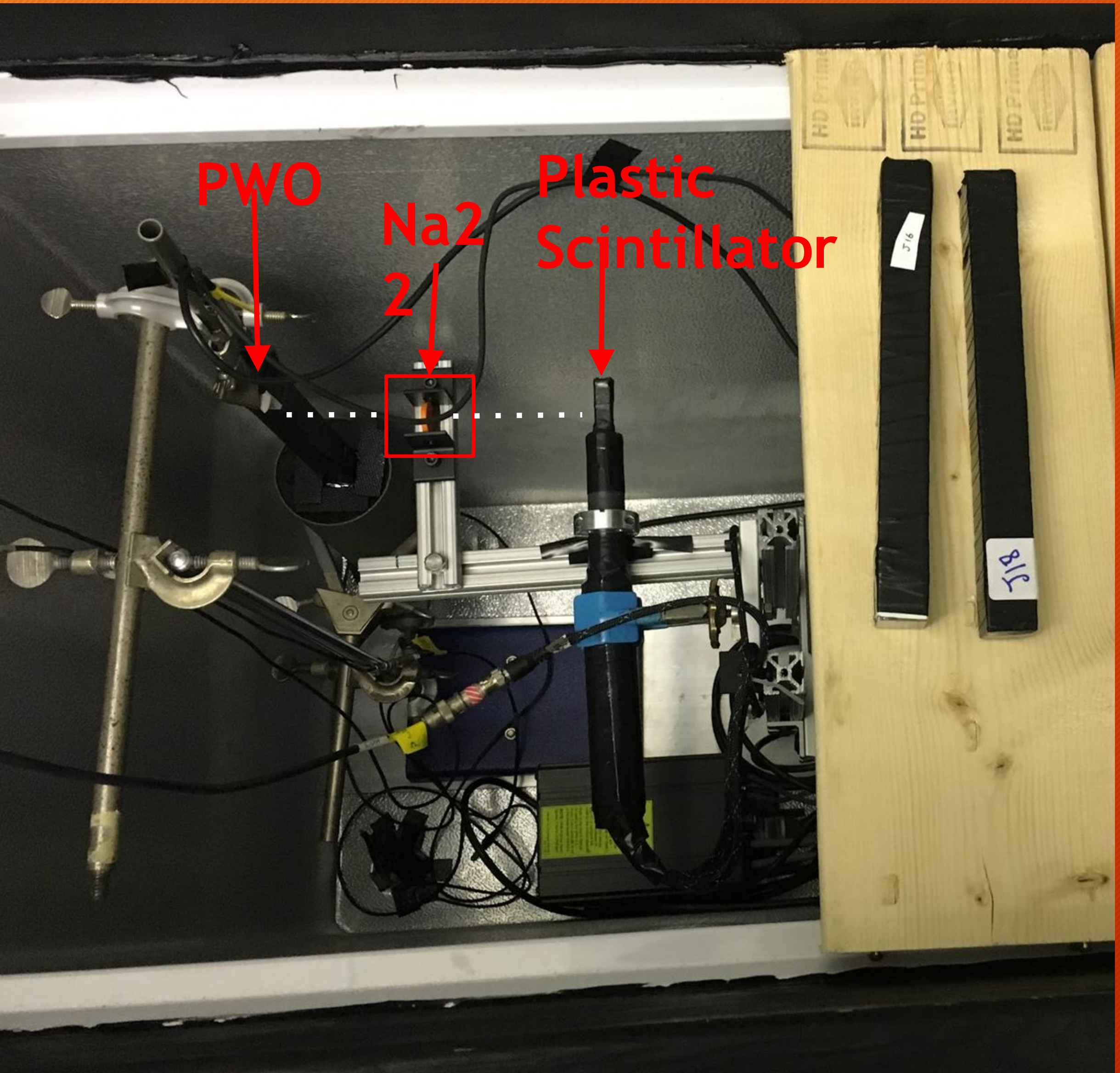


31x36 matrix, 61x74 cm^2 area

Crystal Specifications

Parameter	Unit	EIC	NPS
Light Yield	pe/MeV	15	10-15
Transmittance @420nm	%	>60%	>60%
dk	m^{-1}	<1.5	<1.5

Light Yield Setup: amount of photoelectrons produced per 0.511 MeV



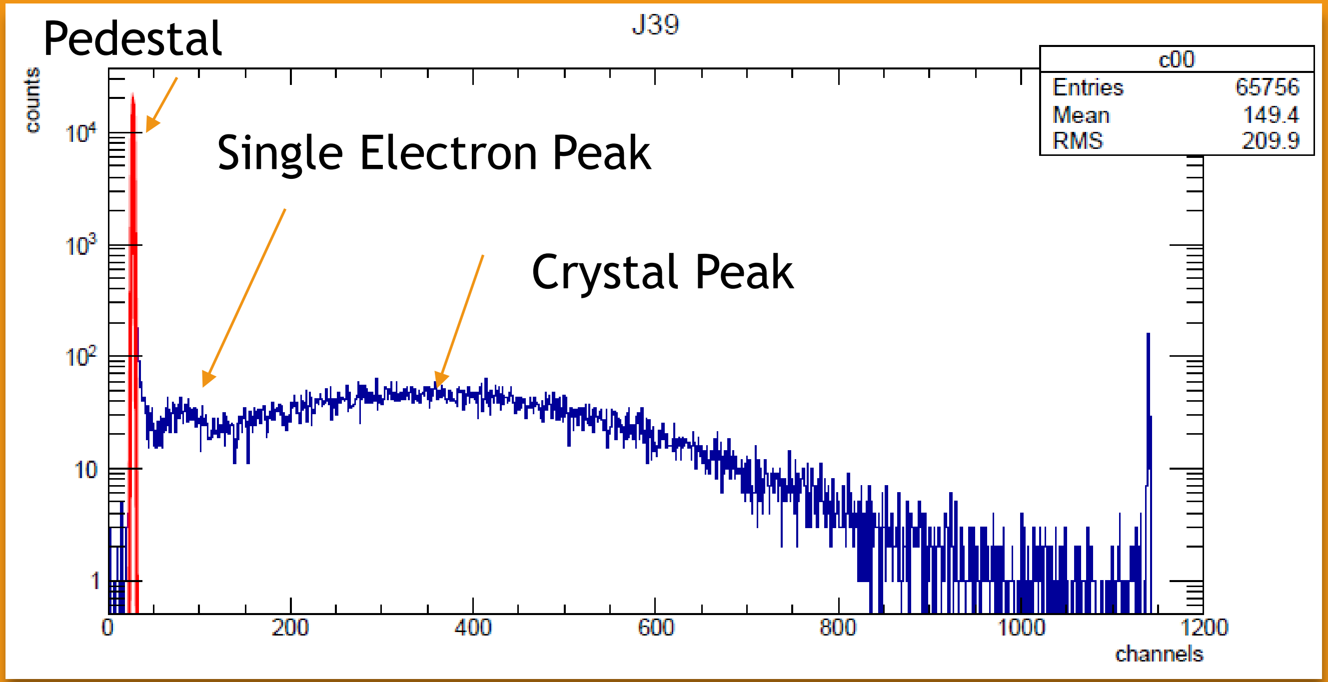
$$^{22}Na \rightarrow {}^{22}Ne + \beta^{+} + \nu + \gamma$$

$$\beta^{+} + \beta^{-} \rightarrow 2\gamma$$

Single Photoelectron Calibration

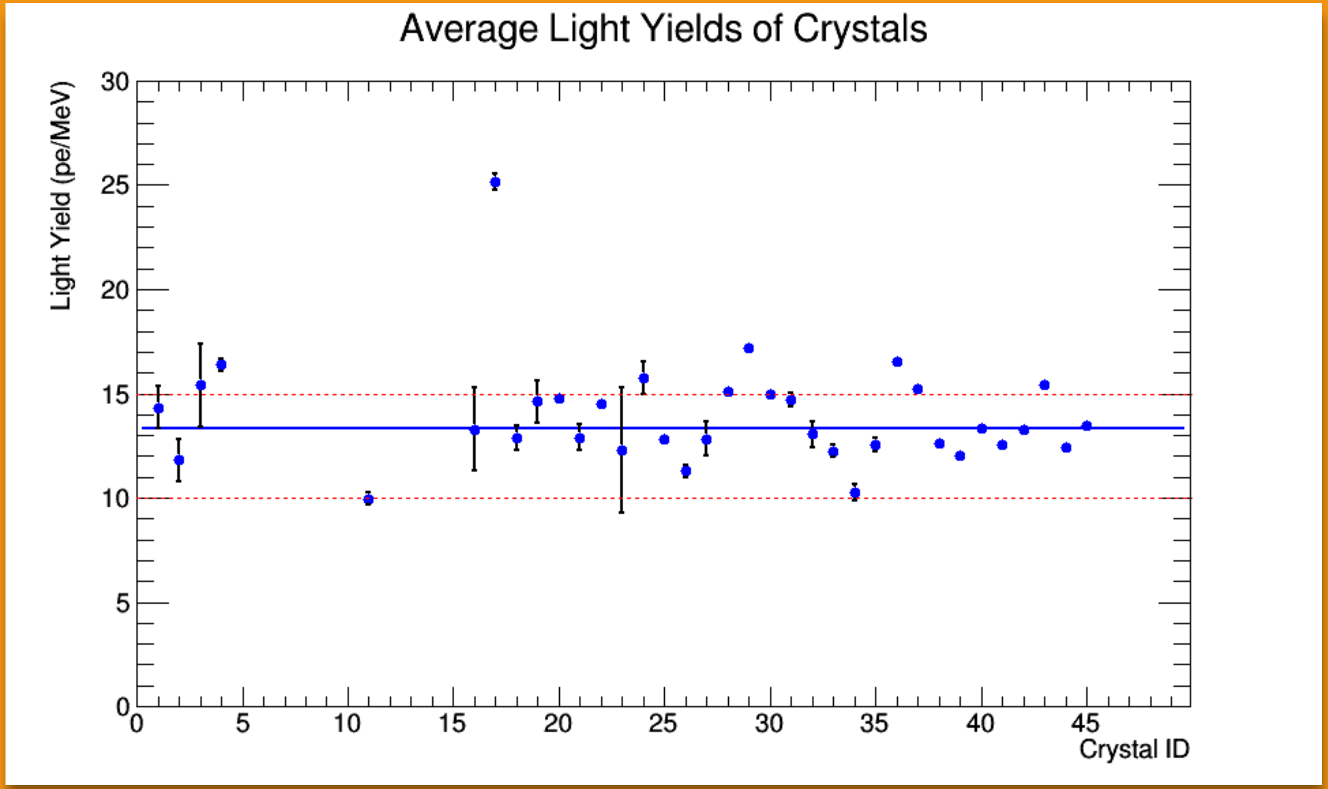
- ((Crystal Peak-Pedestal)/(Single Electron Peak - Pedestal)) = x photoelectrons per photon

- (x electrons)/(.511MeV)= Light Yield



Average Light Yields of All Crystals

- Inconsistencies show that optical grease impacts the light yield
- All crystals should have a light yield > 15 pe/MeV
  - 10 crystals meet this standard
- There appears to be a periodic increase and decrease in light yield for crystals J25 – J4
  - This could indicate a flaw in the process used to create the crystals

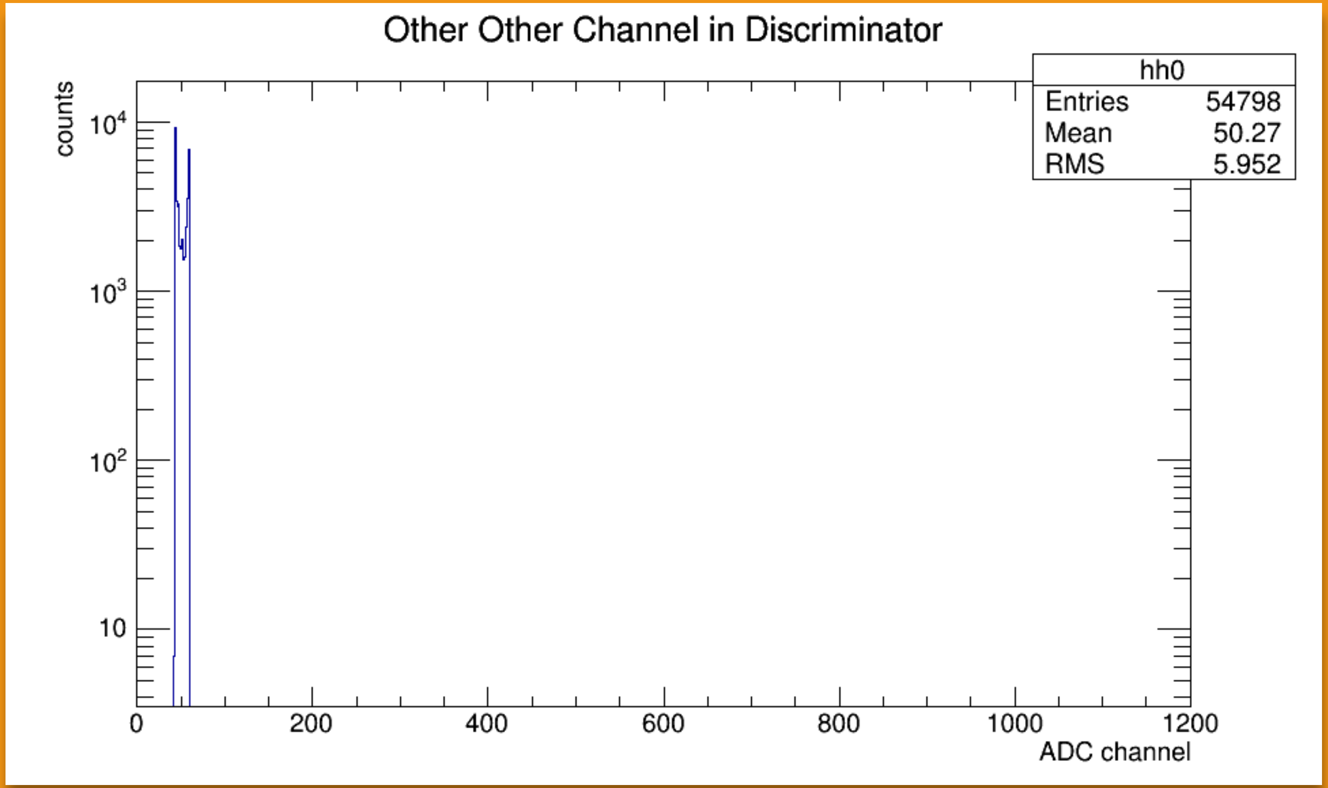


Set Up

- Crystals were wrapped in 3 layers of teflon tape and 2 layers of electrical tape
- The set up pictured was used to apply optical grease so that a consistent amount is used in each trial
  - Once we began to use this set up, the results were more consistent
- The test was run for 20 min (>50,000 events)

Double Peak

- We have been observing a double peak in the light yield graphs
- At the moment, we do not know what is causing this
- The shift between peaks is very small in comparison to the entirety of the graph
  - The data can still be analyzed, and the shift is reflected in the uncertainties



Reflector Studies

This year we started a new investigation into the characteristics of the crystal surface by changing the reflectors used

Mylar Foil

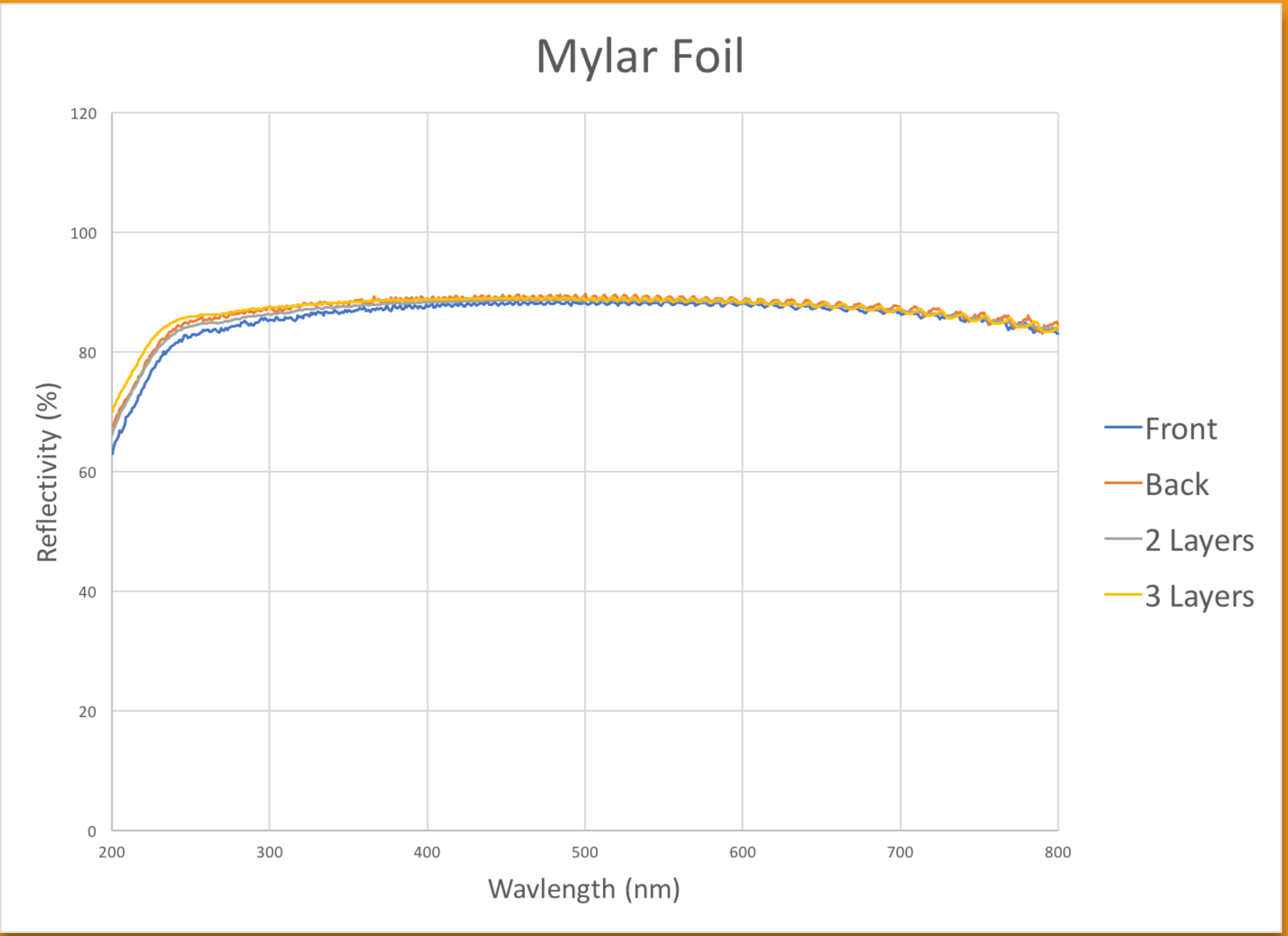
Enhanced Specular Reflector

Tedlar

Teflon Tape

Mylar Foil

- High reflectivity
- Multiple layers has almost no effect
- Specular reflector

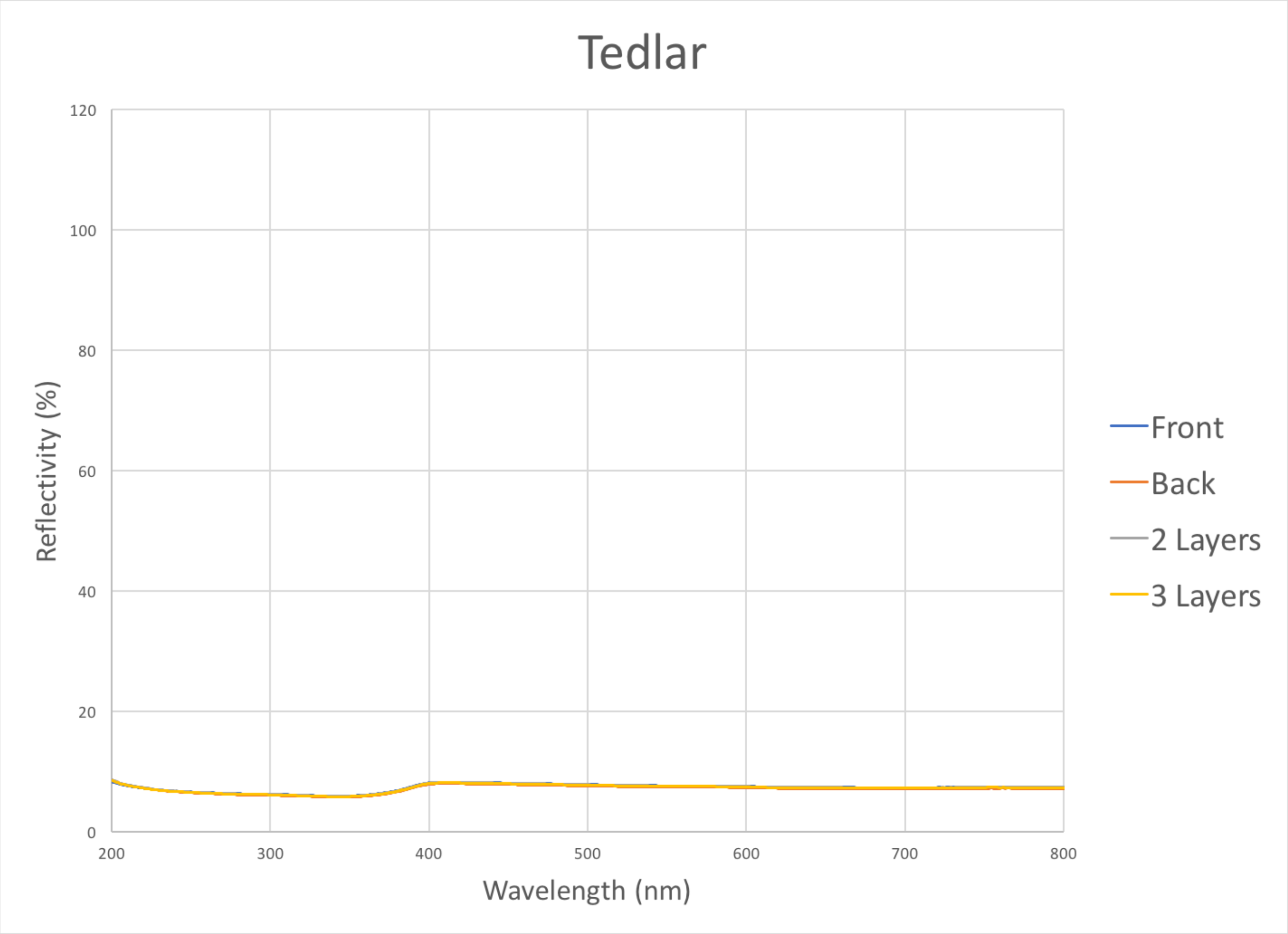


Enhanced Specular Reflector (ESR)

- Very high reflectivity
- Multiple layers has no effect
- The front of the material resulted in a graph with essentially the same shape as the back, but shifted up or down at wavelengths lower than 400nm
  - Does not affect light yield because wavelengths between 400 and 500 nm are important
- Specular reflector

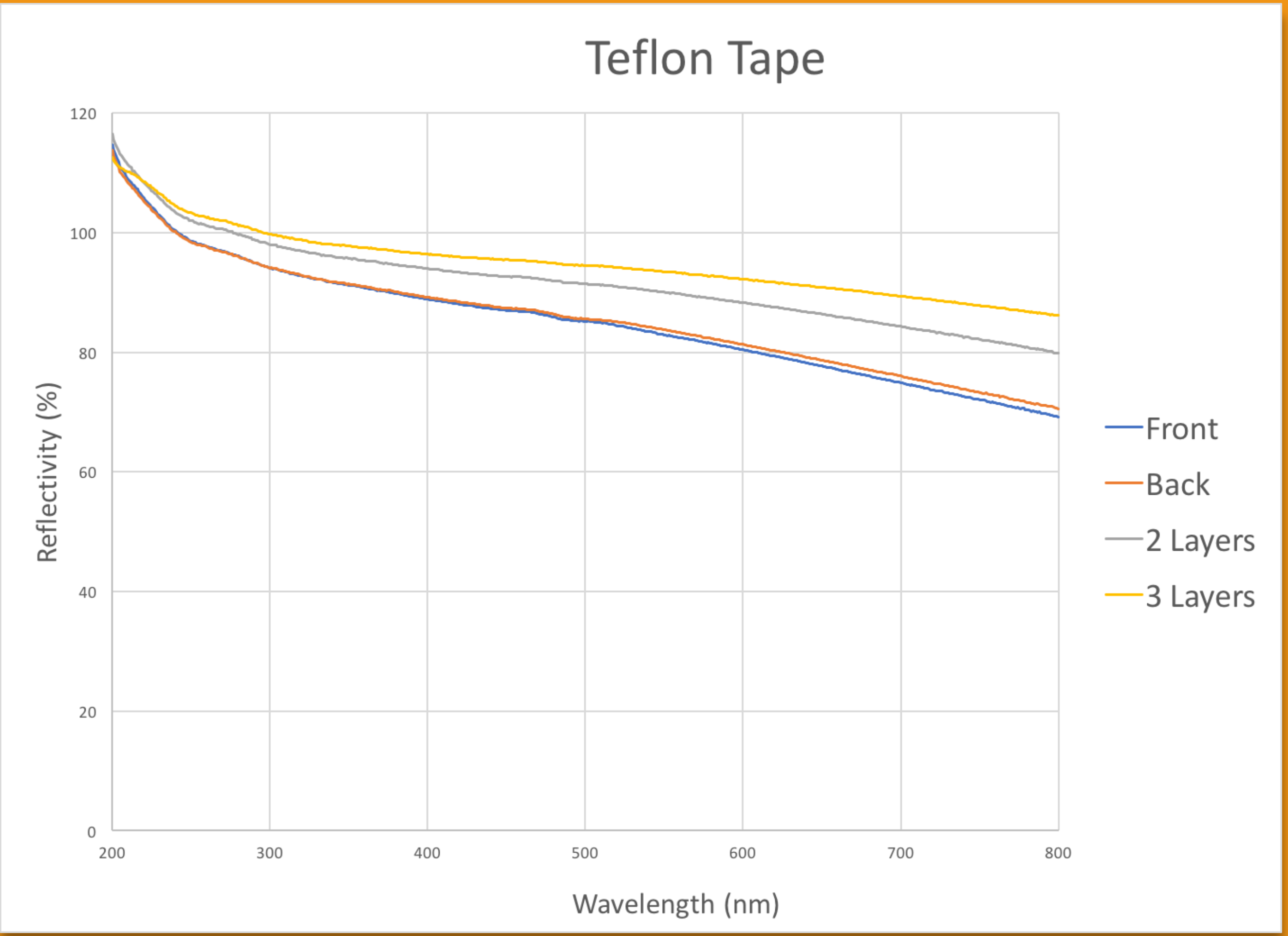
Tedlar

- Very low reflectivity
- Multiple layers has no effect
- Commonly used to block out light
- Tedlar will be used to compare the results from the other reflectors to, and to investigate the importance of different parts of the crystal during light yield tests



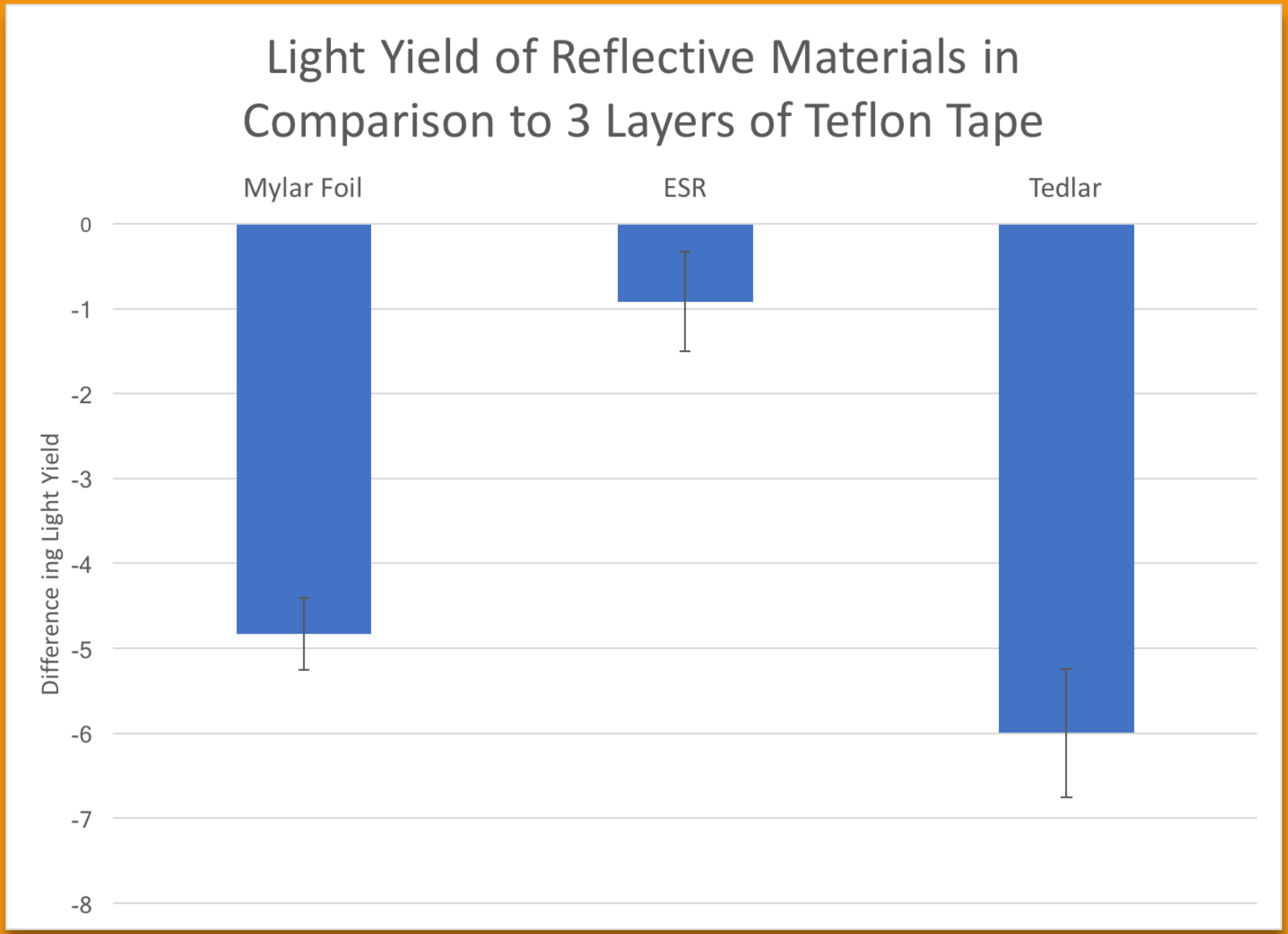
Teflon Tape

- High reflectivity
- Multiple layers have a significant effect
    - Slightly transparent to light, allowing a second and third layer to reflect light
    - I can test the effect of multiple layers on light yield
- Diffuse reflector



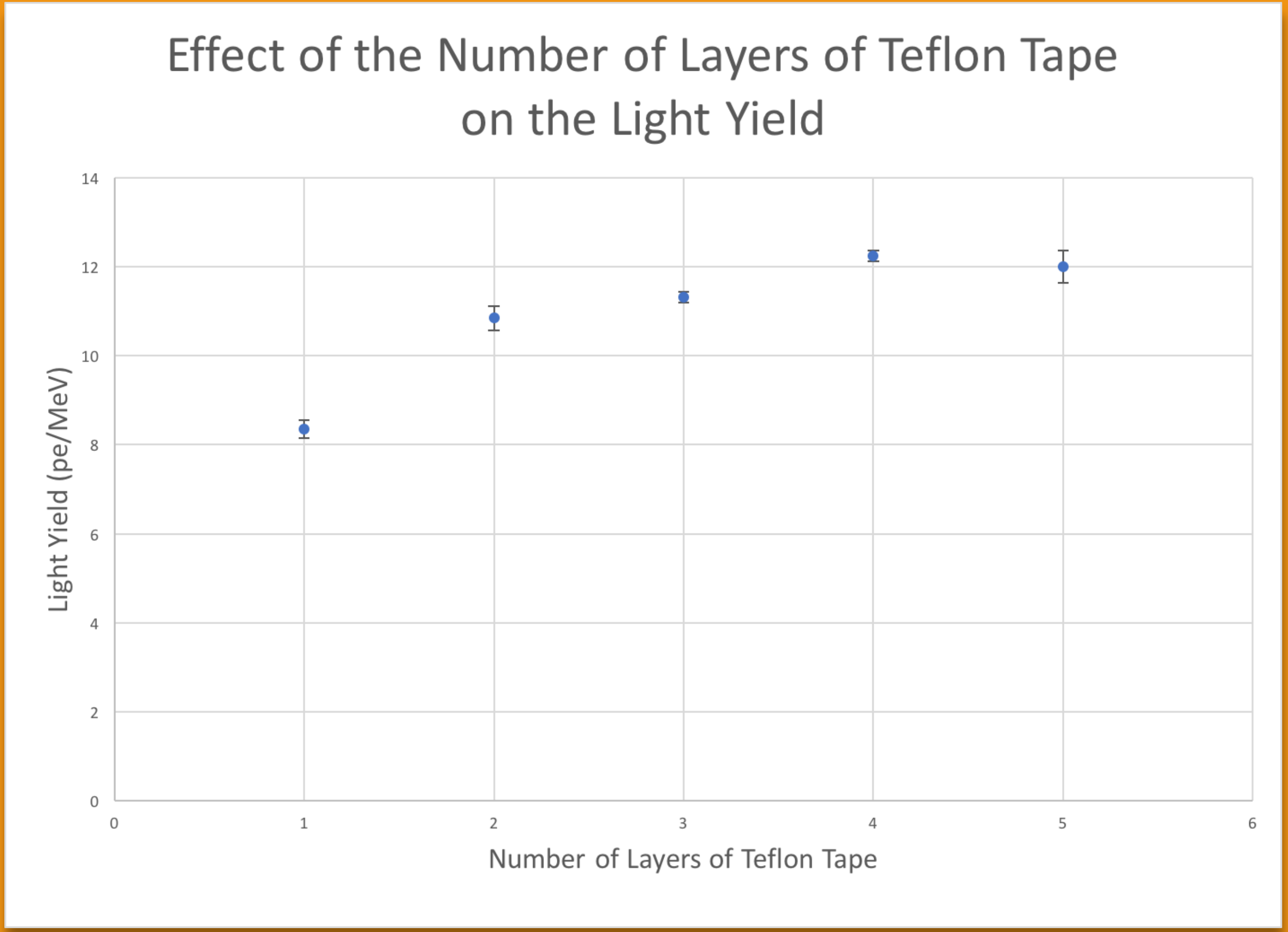
New Reflectors

- Light Yield compared to results when using 3 layers of Teflon Tape
- All reflectors had lower average light yields than when 3 layers of Teflon Tape are used
- Despite Mylar foil's high reflectivity when put in the spectrometer, the light yield results were very low
  - I am currently researching why Mylar Foil is not effective when used with these crystals



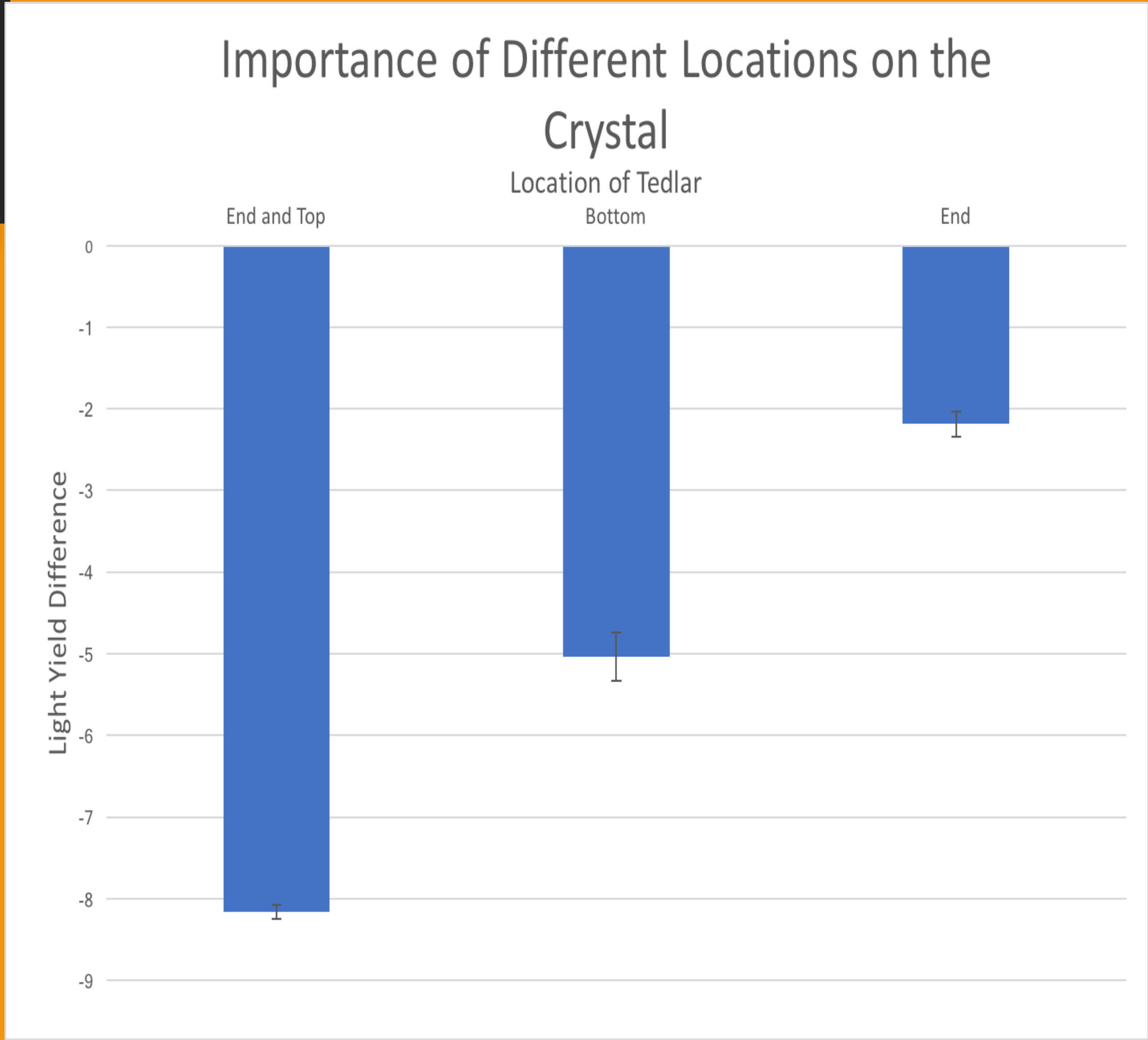
Multiple Layers of Teflon Tape Light Yield

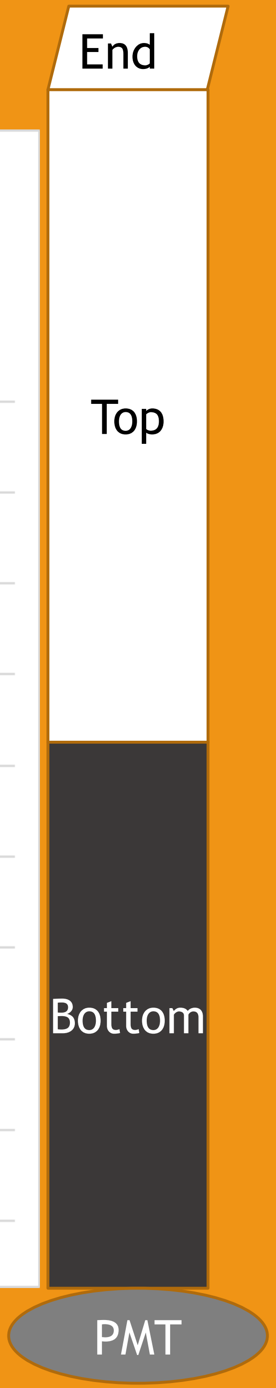
- As the number of layers increases, the light yield also increases
- At higher number of layers, there appears to be a plateau
- 5 layers of teflon tape resulted in a slightly lower light yield than 4 layers
  - Test 6+ layers to see if trend continues



Impact of the Reflector at Different Locations on the Crystal

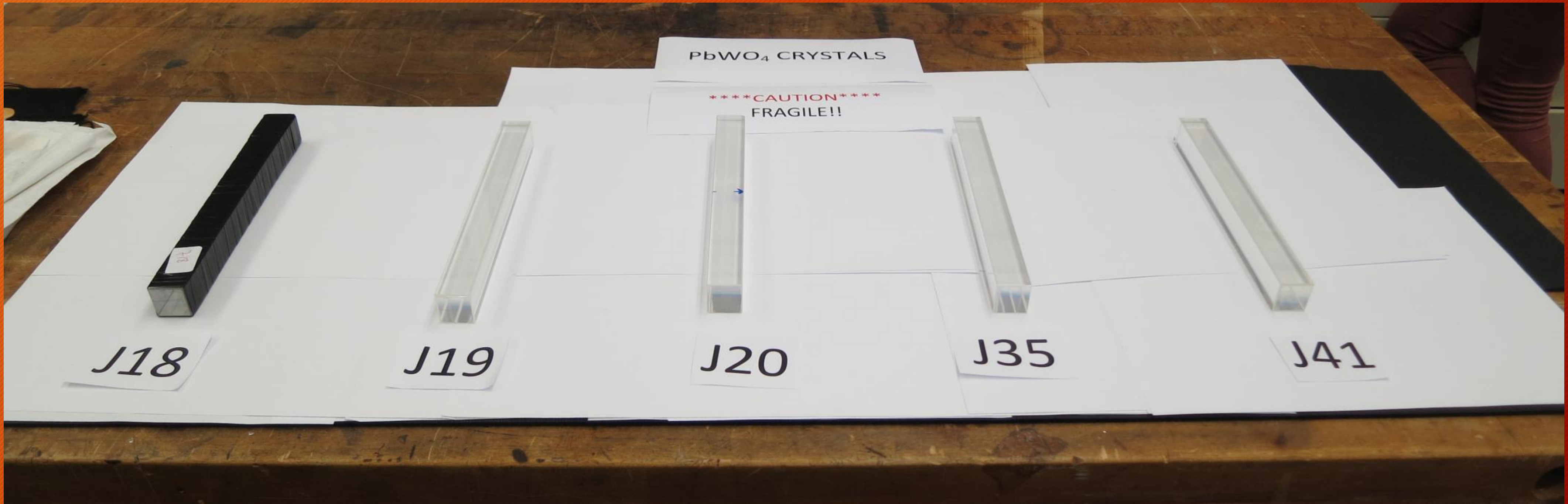
- The tedlar had the greatest negative impact on the light yield results when it was placed on the top half of the crystal
  - The majority of photon multiplication and reflection occurs in the top half of the crystal
- A significant amount of reflection occurs at the covered end of the crystal



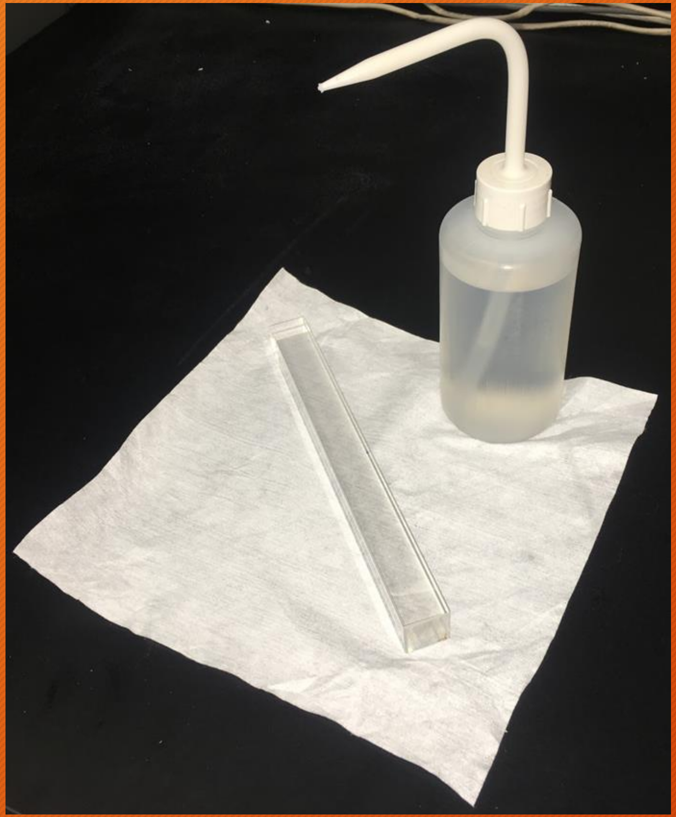


More Tests

- We currently have about 45 crystals, but will be receiving 460 soon
- Next we will review some other tests that we can conduct

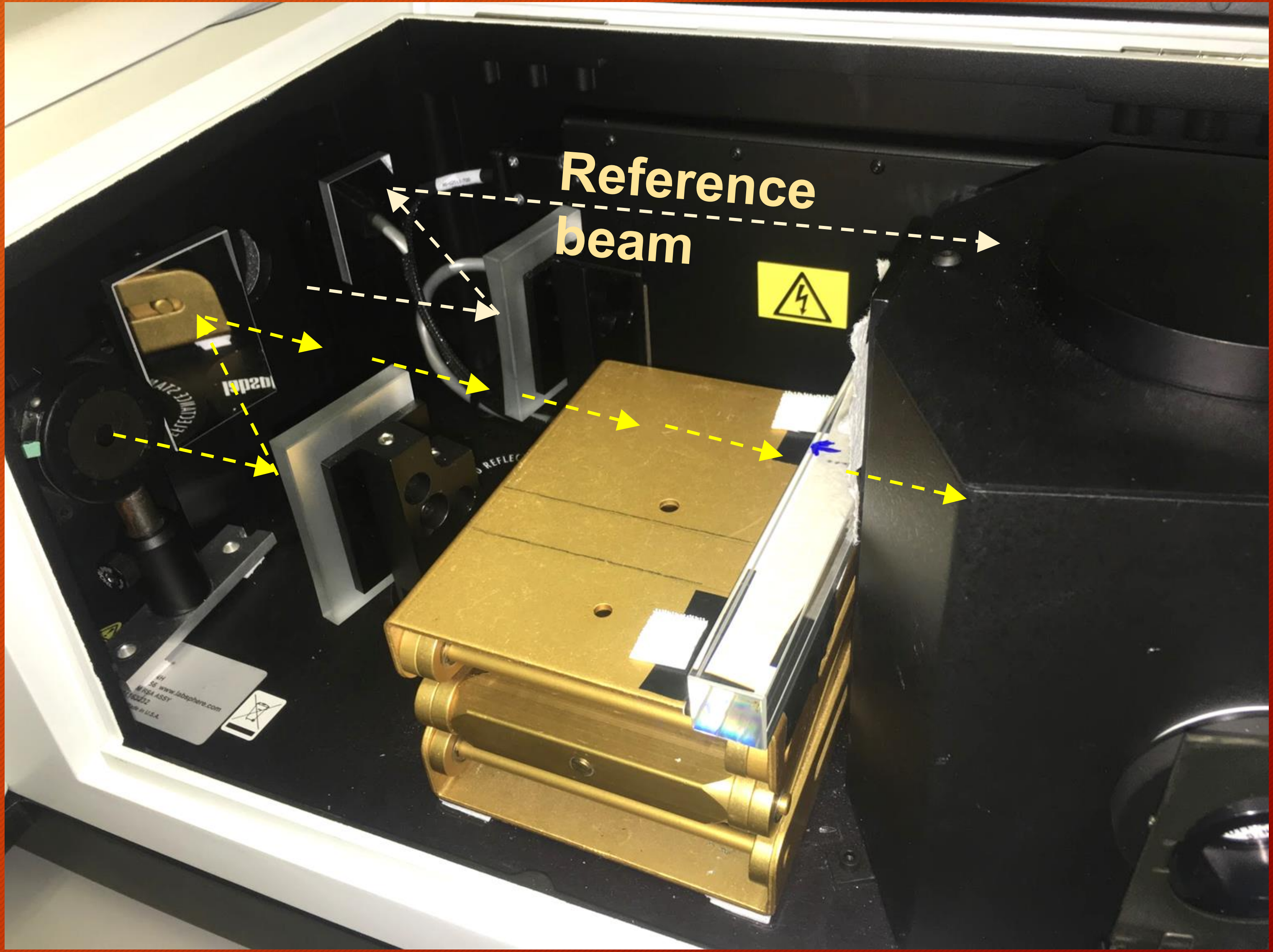


Transverse Light Transmittance



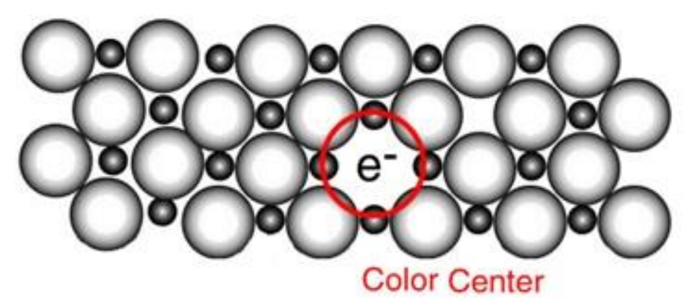
Crystal Preparation:

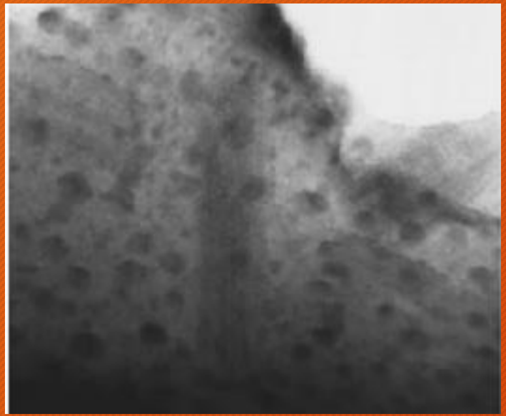
- All tape removed
- Wiped with isopropanol



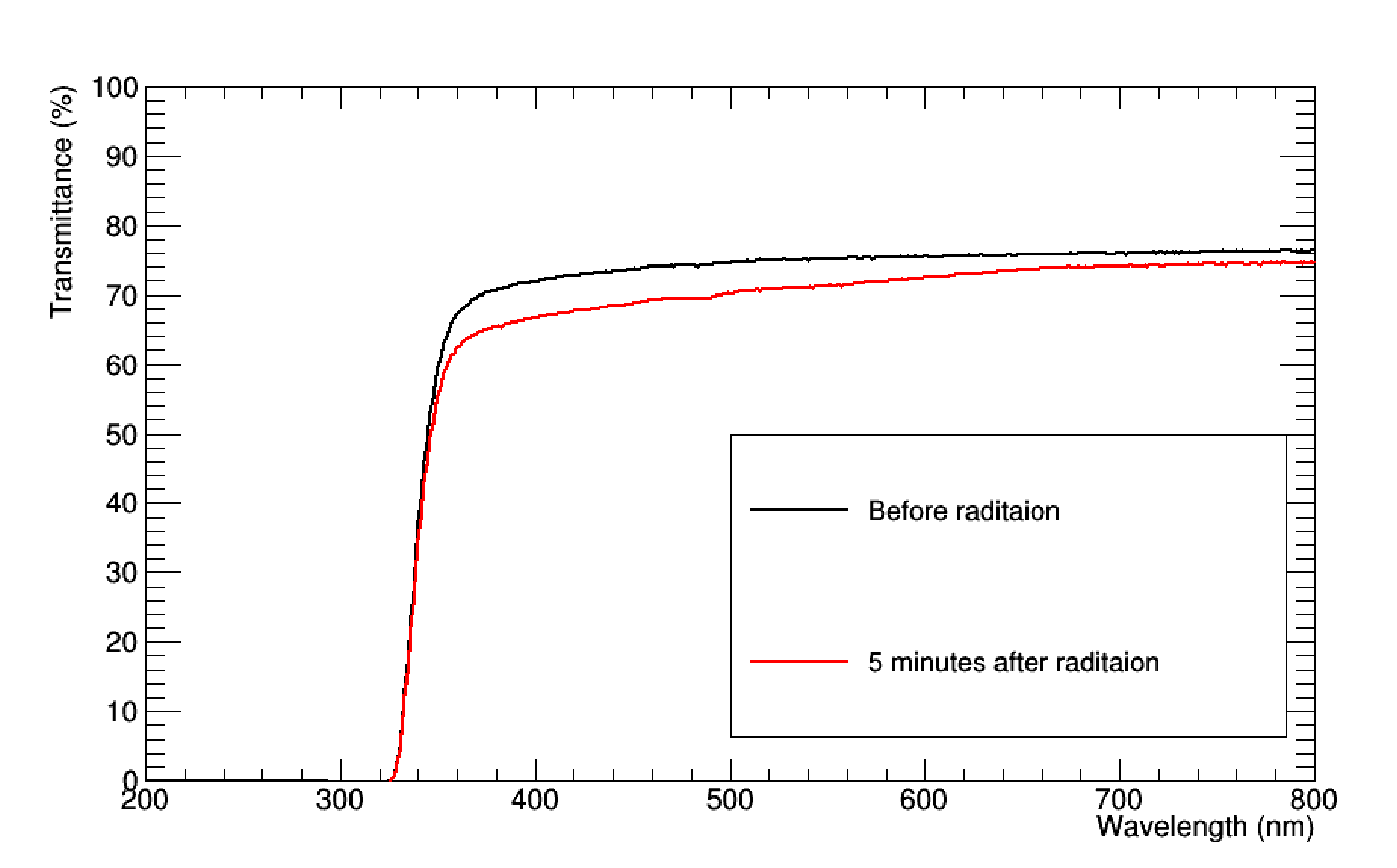
Degradation of Transparency

- Irradiation → point structure defects, electron traps, holes create color centers within crystal lattice that absorb light → reduction in transparency
- Degradation of energy resolution

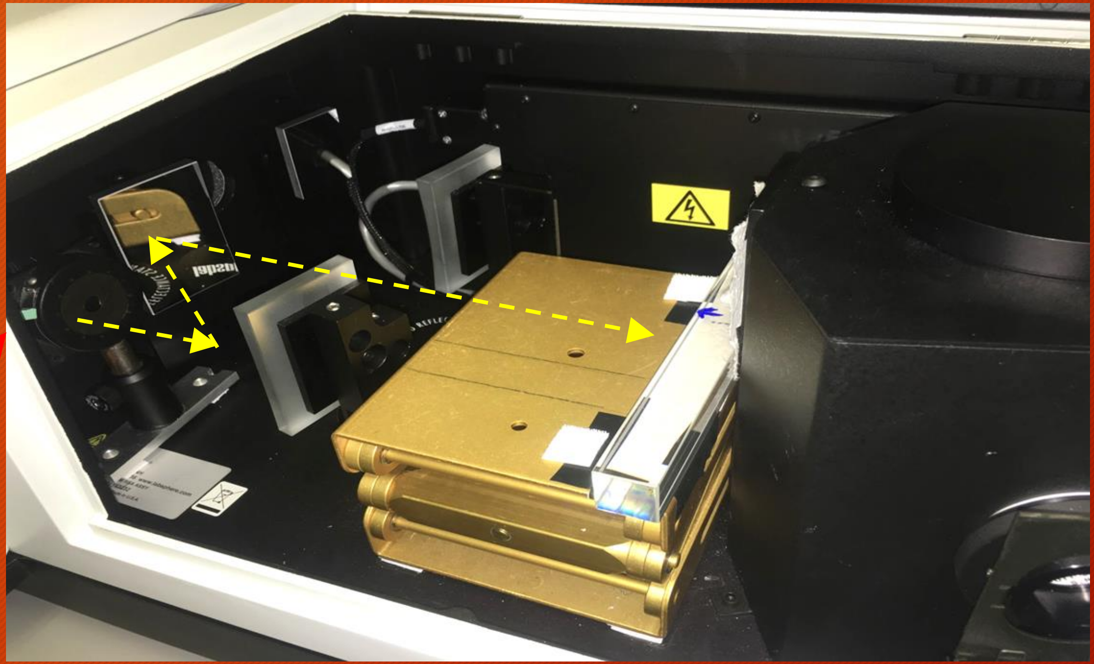


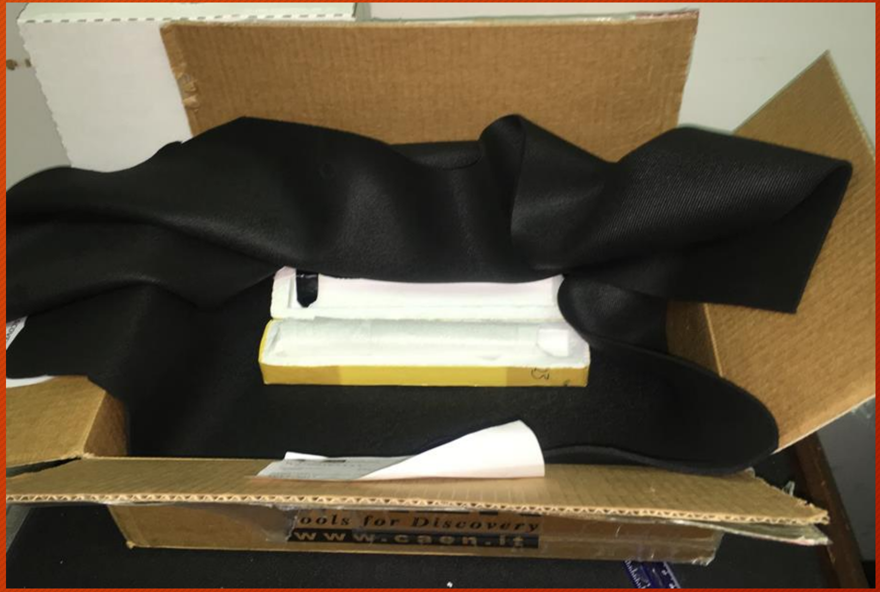


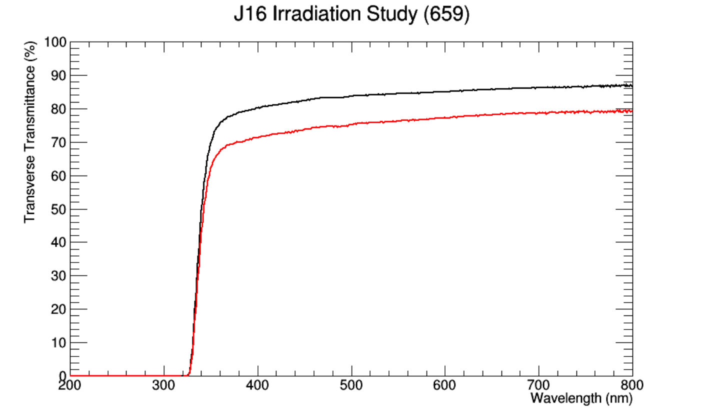
Zhu, Ren-Yuan. "Precision Crystal Calorimeters in High Energy Physics: Past, Present and Future." *AIP Conference Proceedings* (2006): n. pag. Web.

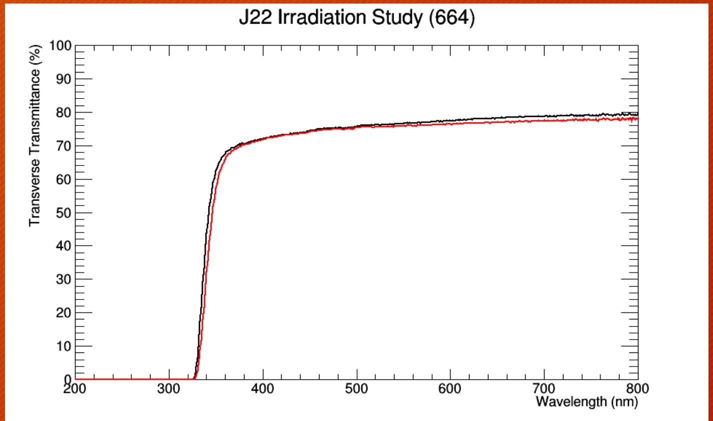


X-ray Irradiation: 6970 R/min



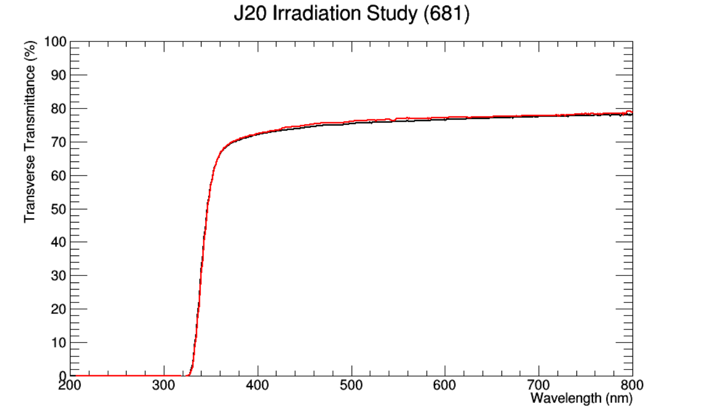


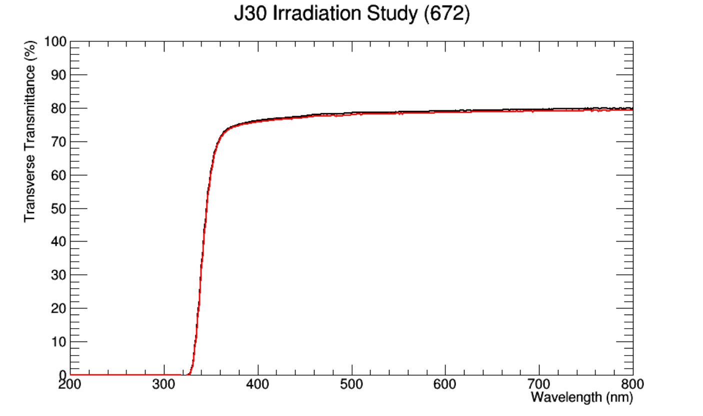


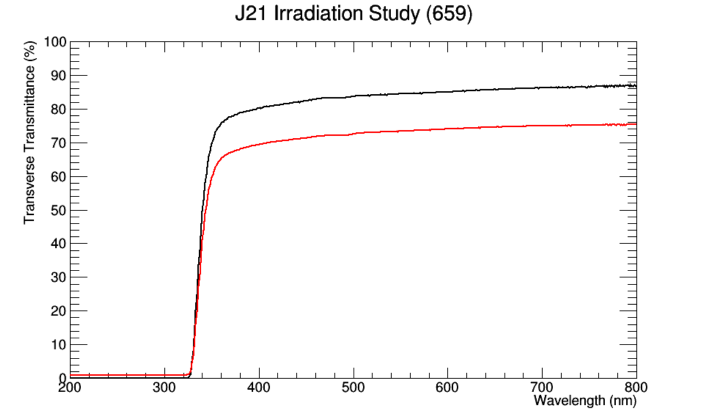


*Black= before radiation

*Red= after radiation





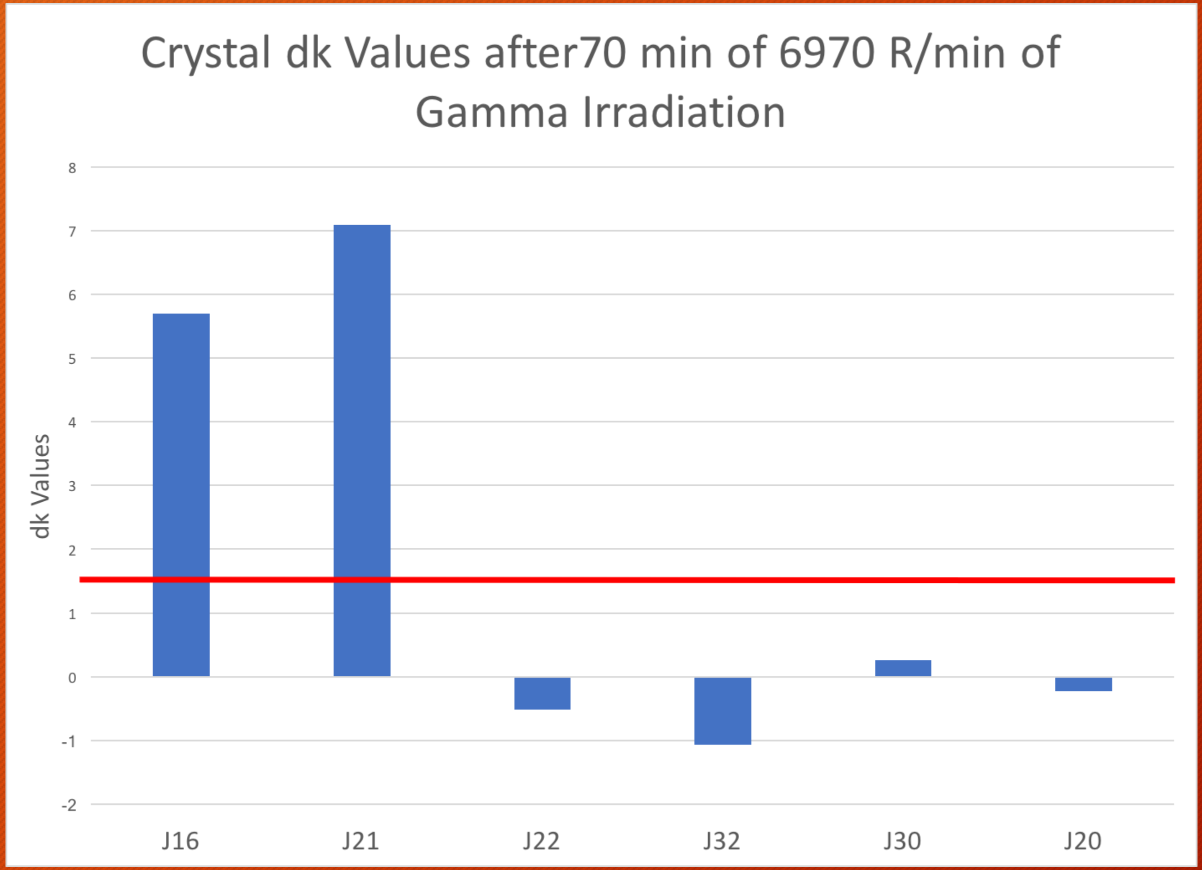


Variation in Radiation Hardness

Quantification of Radiation Hardness: dk at 420 nm

$$dk = \frac{1}{length} \ln\left(\frac{T_{bef}}{T_{irr}}\right)$$

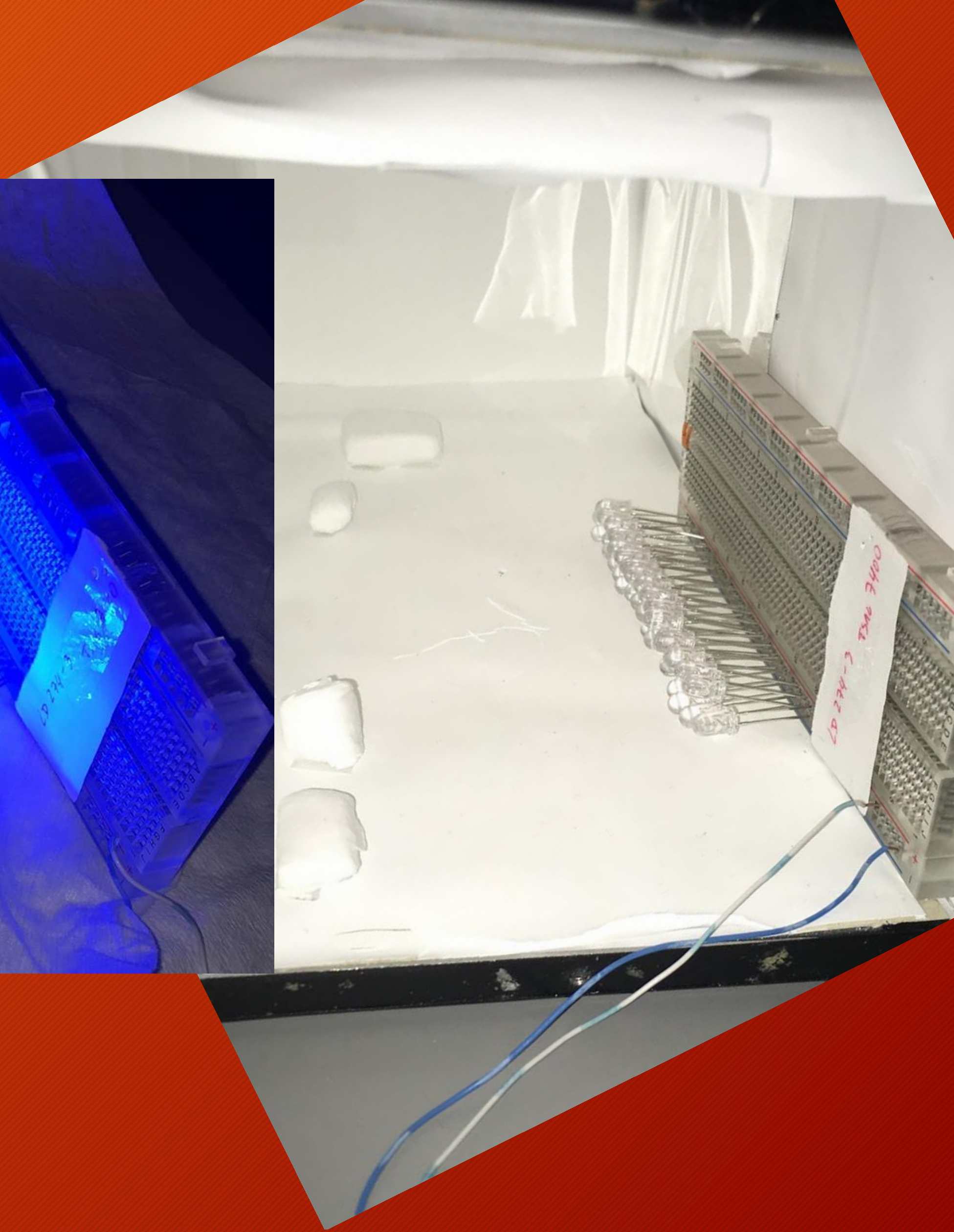
- Closer to 0 = better radiation hardness



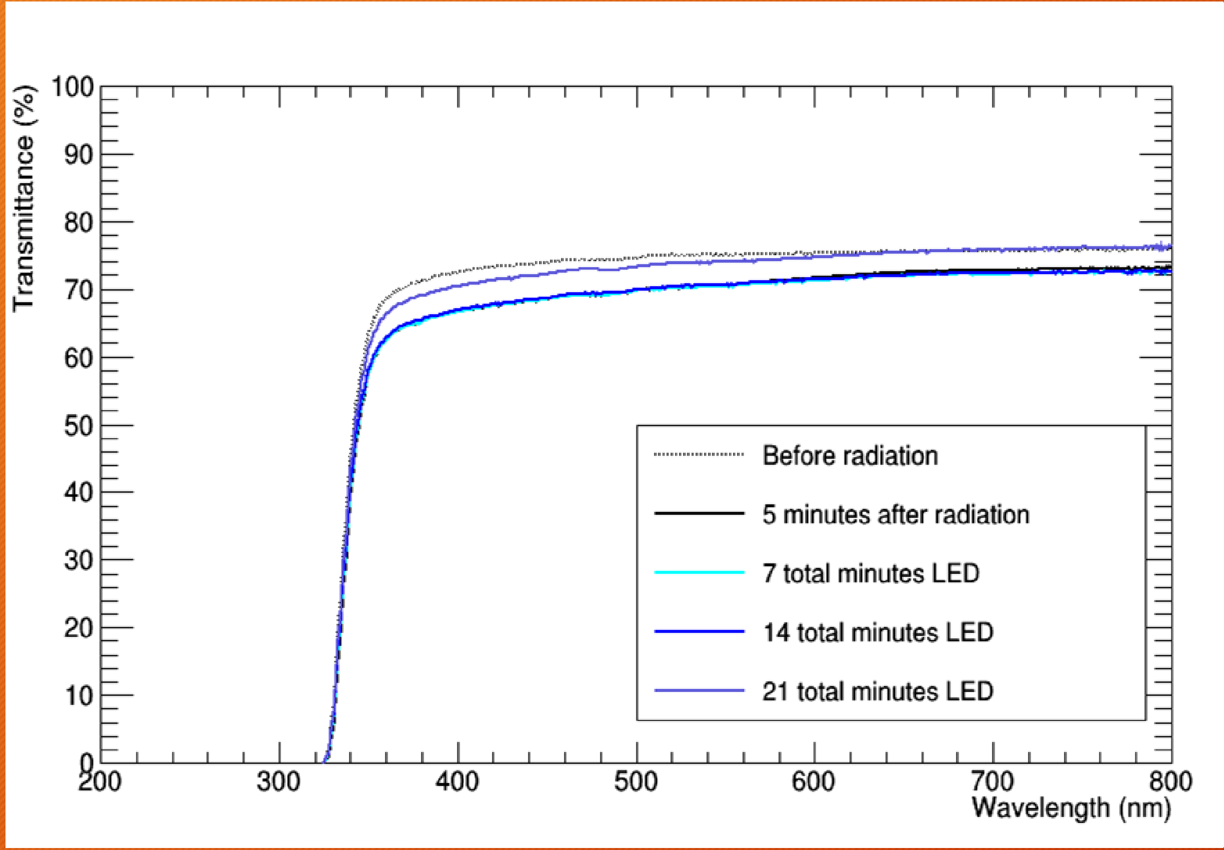
How do we restore optical properties post-irradiation?

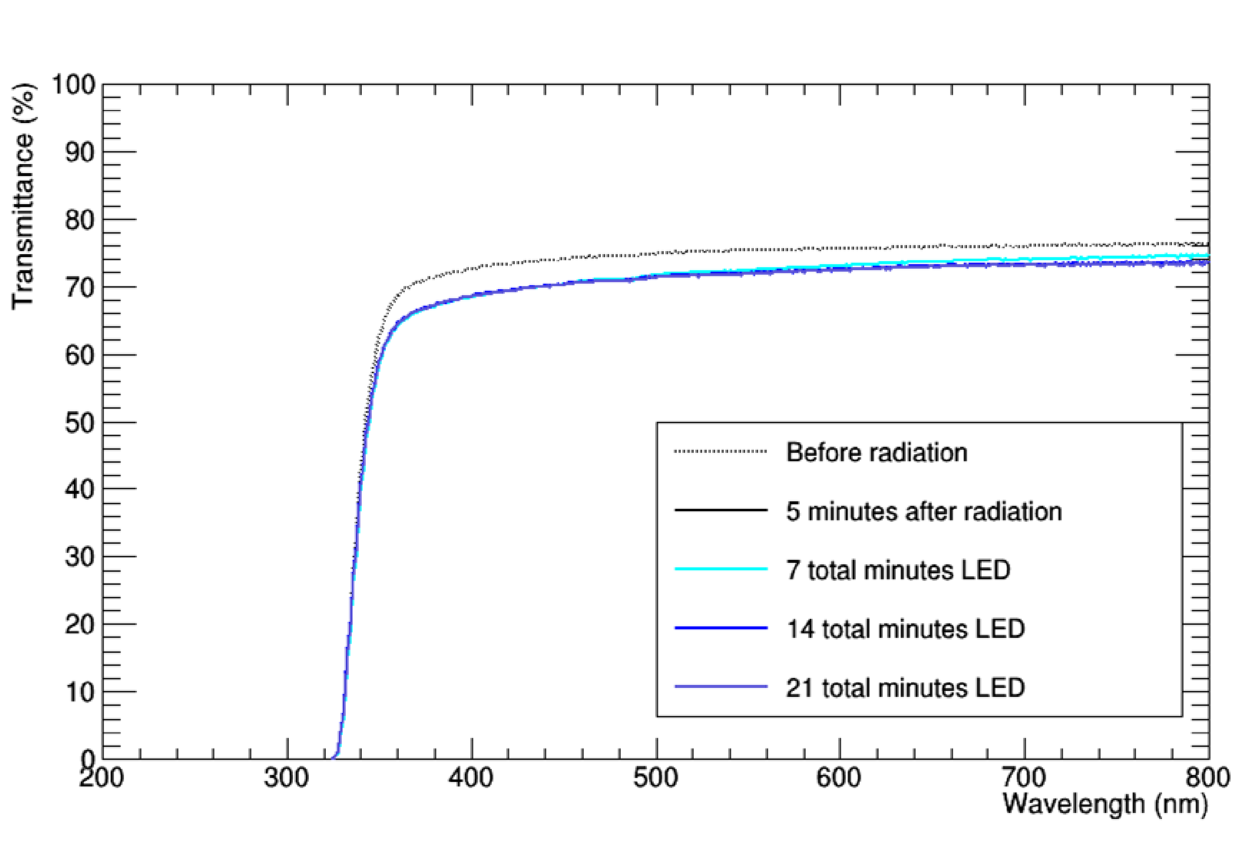
- Thermal annealing
  - Not practical with crystals while they are in the array (heavy, time consuming, requires lots of energy)
- Instead, supplying energy to the crystals through photons from LED lights
  - Blue LED light "optical bleaching" → ionizes color centers by exciting them → frees them from crystal structure
  - Restoration of crystal transparency

LED Curing



LED Curing





- Establishment of procedure
- Inconclusive results- too little data

Conclusion

- The crystals need a consistent amount of optical grease to give a consistent light yield result
- The top half of the crystal is most important for the multiplication and reflection of photons in the crystal
  - I will conduct more studies using different reflectors and number of layers at different locations
- Despite having a lower reflectivity between 400 and 500 nm than ESR, multiple layers of Teflon Tape is the most effective reflector to use out of the reflectors studied
  - This indicates that the crystals are most efficient when used with a diffuse reflector
  - I have recently received more reflective materials and will test them in the next couple of days
  - More studies will allow us to determine the ideal number of layers

Conclusion

- From what we have seen so far, crystals tend to pass transverse transmittance tests prior to irradiation
- Several of the crystals we measured did not have dk values below 1.5, meaning there would need to be a curing system in place to restore optical properties
- We need to do more trials testing the effectiveness of LED curing

Thank You!

- Dr. Horn
- Marco
- Andres
- Richard
- Salina
- Salim
- VSL
- CUA