QA Testing of $PbWO_4$ Crystals for EEEMCal

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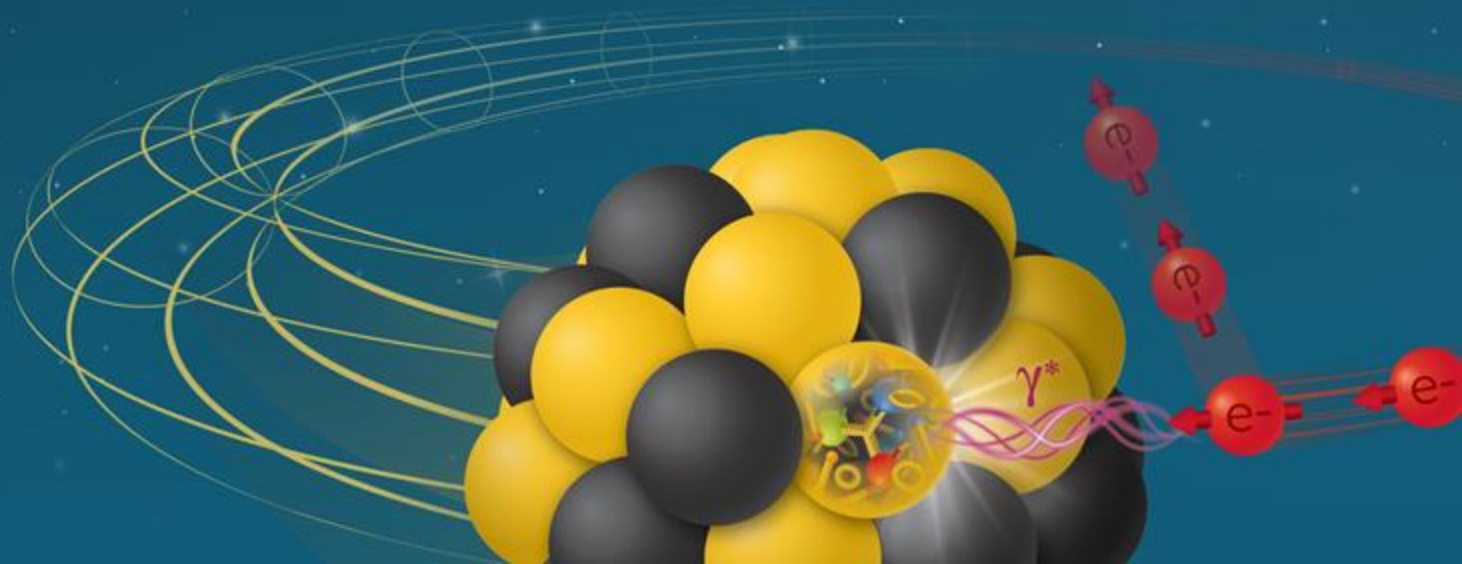


TIC Meeting
July 28th, 2025

Electron-Ion Collider

Detector Background

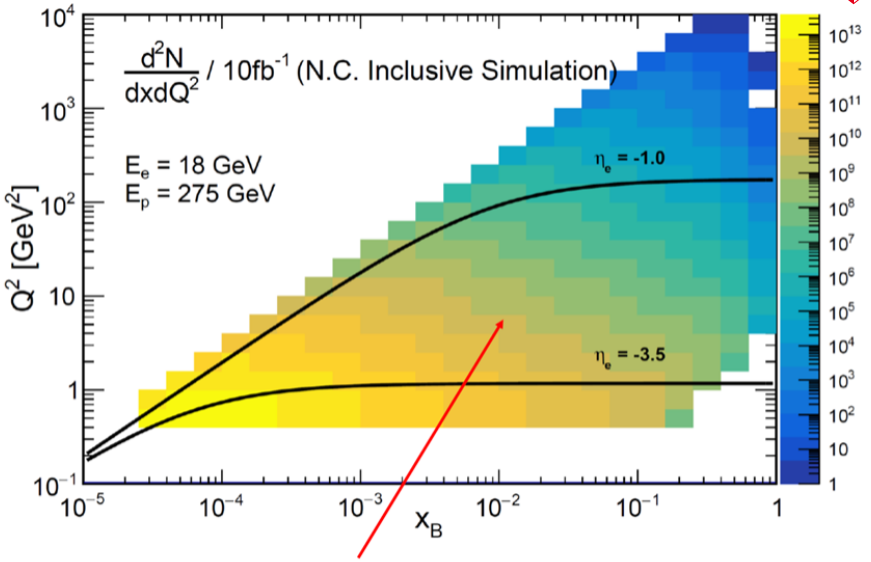
Goals:

- ❑ Electron/pion separation
- ❑ Improve electron resolution at large |η|
- ❑ Measure photons with good resolution
- ❑ Separate 2-γ from the π^0 at high energy

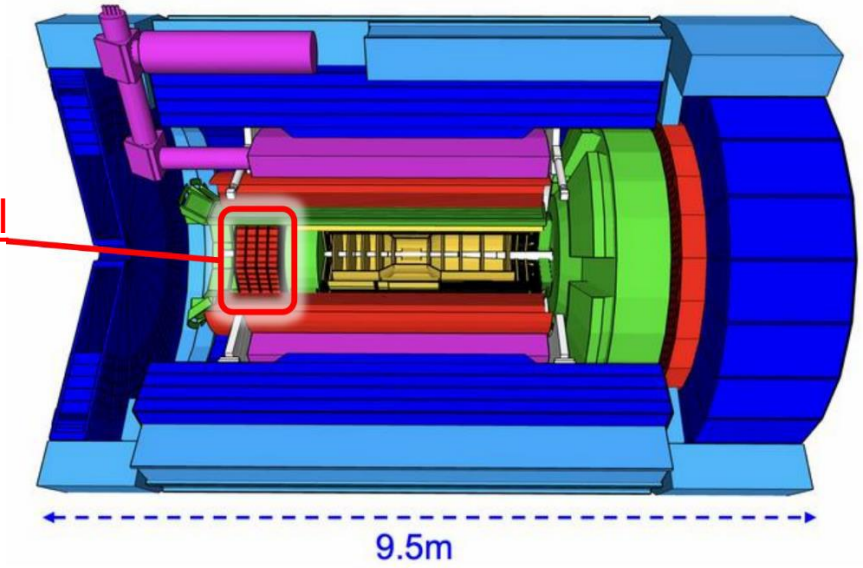
Requirements:

- ❑ Energy resolution: 2%/$\sqrt{E}$ + (1-3%)
- ❑ Pion suppression: 1:10^4
- ❑ Minimum detection energy: >50MeV

Electromagnetic calorimetry is key to any EIC detector concept



Region of physics enabled by the EEEMCal

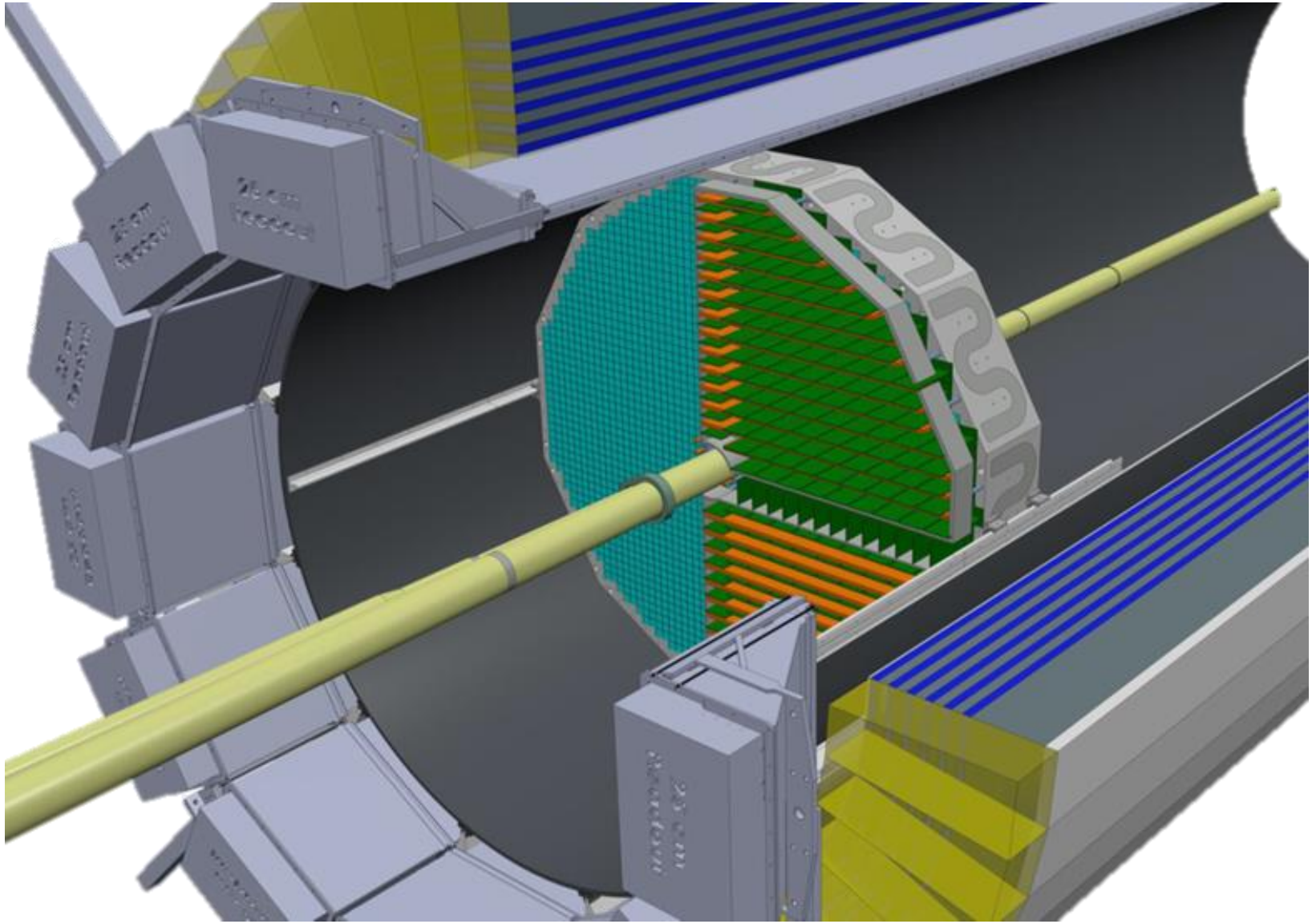


High resolution in the forward region (endcap) can only be achieved with homogenous materials, such as crystals

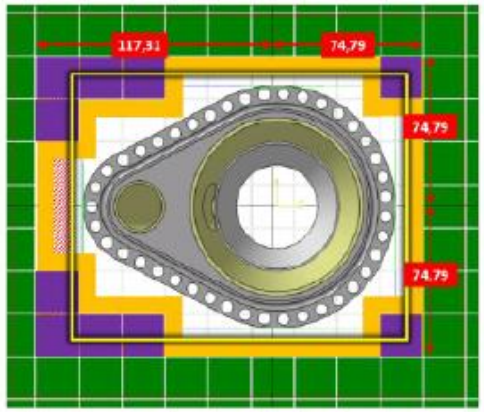
Technology choice: PWO crystals (2x2 cm^2) with high density SiPM (16 3x3 mm^2 or 4 6x6 mm^2 per crystal)

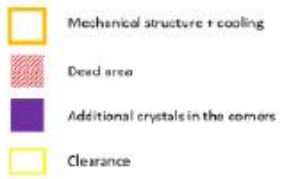
Detector Overview

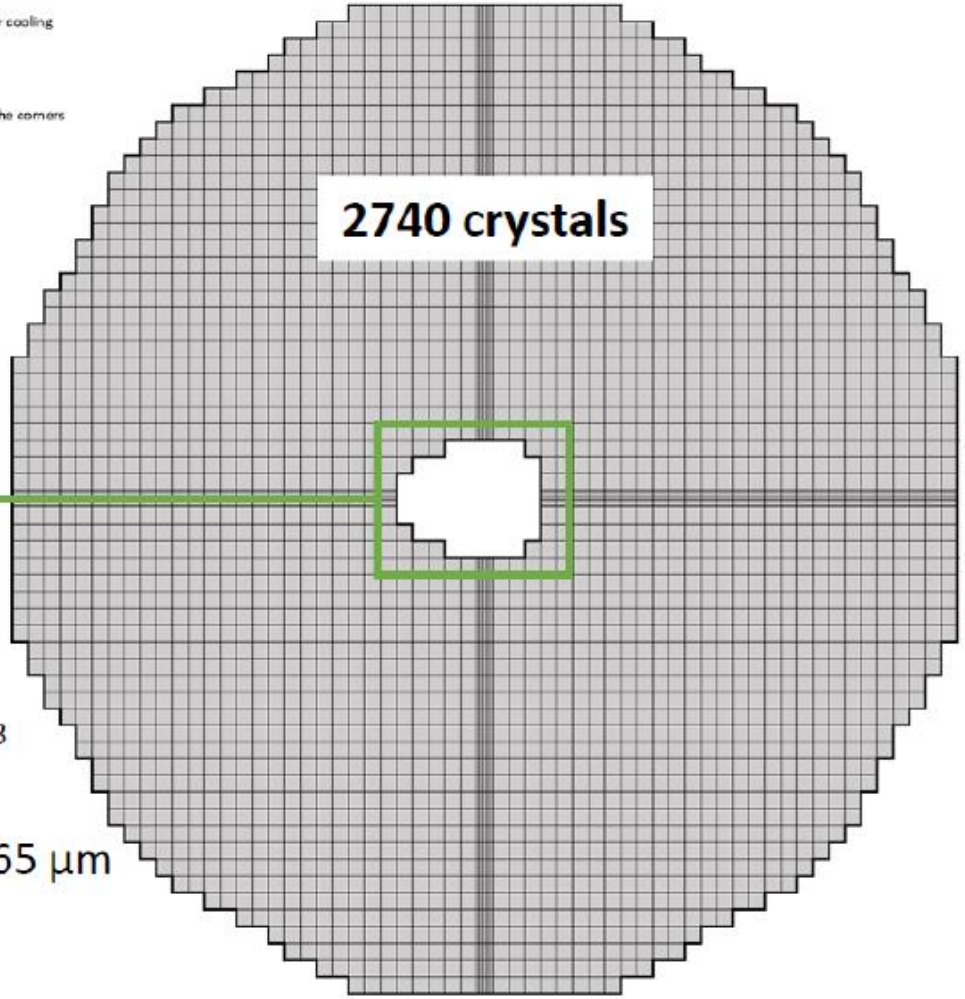
- Radiator consisting of scintillating lead tungstate (PWO) crystals and a thin reflector wrapping.
  - Physics requirements for electron identification and detection dictate the main requirements for the radiator.
- Photosensors consisting of SiPMs grouped into an array to maximize the surface coverage of the PWO blocks.
- Mechanical structure, including installation fixtures and a cooling system providing thermal stabilization.
  - Important for crystal performance.
- Signal Processing/DAQ providing the front-end electronics to transmit the signals to the data analysis modules.

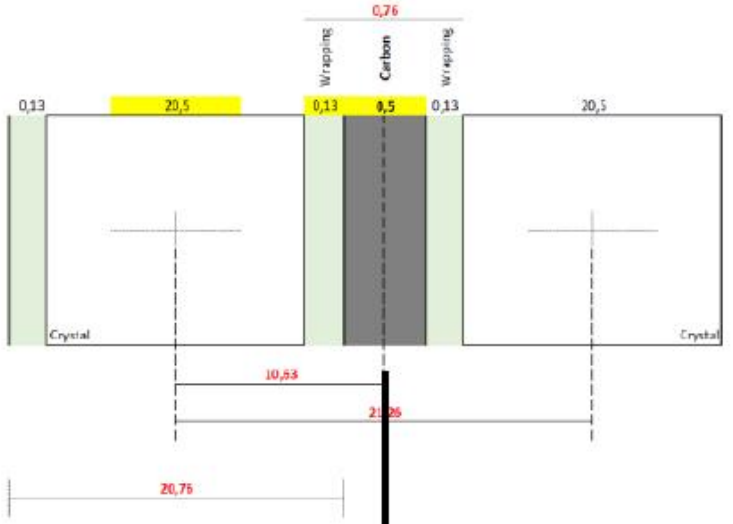


Internal Structure



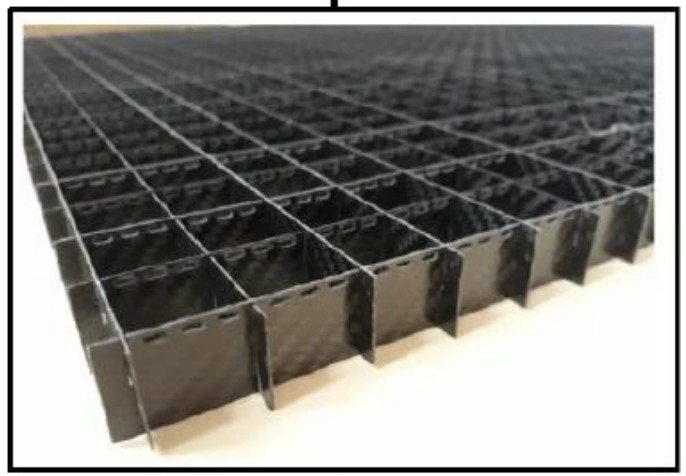






Crystals:

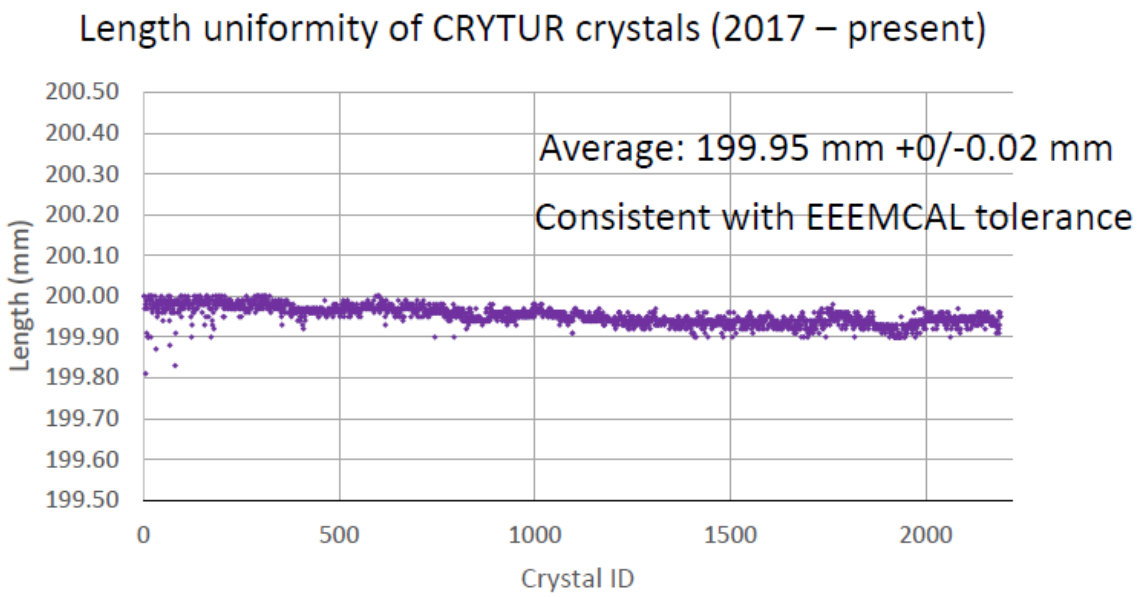
- Material: PWO ($PbWO_4$)
- Size= $20.5^{+0-0.5}$x$20.5^{+0-0.5}$x200 mm^3
- Mass= 0,7 Kg (8,28 $g.cm^{-3}$)
- Reflector: ESR® (3M) VM2000 = 0.65 µm
- Light insulation: Tedlar® = 0.65 µm
- Carbon plate= 0.5 mm



Carbon plate (NPS calorimeter)

QA Background

- Our group has a long history of working with these crystals
  - CRYTUR has delivered ~2190 PWO crystals continuously for projects at JLab since 2017.
  - Crystals used for both NPS in Hall C and FCal-2 upgrade (ECAL) in Hall D.
  - All 1100 crystals for NPS passed the quality assurance tests (similar for ECAL)
- We are capable of ingesting CRYTUR's deliveries (110/per month) at the current rate with our existing level of QA onsite.



QA Motivations

- The crystal's optical properties are susceptible to issues in the mechanical features.
  - Physical defects, scratches, chips, and others depending on their locations can have a large impact on properties like transmission and light yield.
- We have observed physical defects that were serious considerations when working with other vendors in the past and are aware of the potential impacts as well as their visual cues.
- Mechanical dimensions can have impact on the stacking tolerances in the full detector assembly.
  - These can be mitigated by design considerations in most cases.
- Each of these crystals cost ~$3k per article which is a significant investment and they are processed at a rapid rate thanks to CRYTUR's efficiency.
  - This means we are receiving large batches of up to 110 articles (~$330k/per lot).
  - We have an efficient process in place for ingesting at this rate to track the overall quality.

Strategy/Goals

- Efficient & safe processing of the crystals in a timely manner.
  - Acceptance sampling for the monthly batches after baselines determined from the 1st article.
  - ANSI/ASQ Z1.4, AQL of 0.25% with expected sampling size of 20 per lot.
- Good communication with all the parties involved in the process, CRYTUR, BNL, JLab, EEEMCal Consortium, and others.
  - Direct email communications as well as persistent digital inspection spreadsheet on a google drive for ease of access and cross-checking.
- Accurate tracking and recording of pertinent metrics.
  - Digital spreadsheet in use for all crystals accepted currently comprised of data from CRYTUR and JLab inspections and measurements.
- Safe long term storage and testing of the crystals throughout the handling process, minimizing contact is crucial.
  - Experimental Equipment Lab (EEL) room 126 selected for storage.
- Staging for the eventual next steps of the detector assembly.

Routing Path

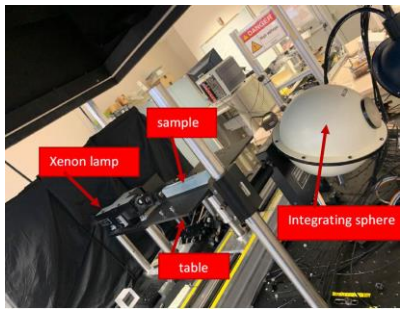
Lot arrives at the shipping and receiving bay in the EEL Building

Transport to Cleanroom

Visual inspection process & Initial acceptance against the manifest

Updating the spreadsheet record of the crystals, backups maintained

Measure the mechanical dimensions of the crystals, also recorded in the spreadsheet



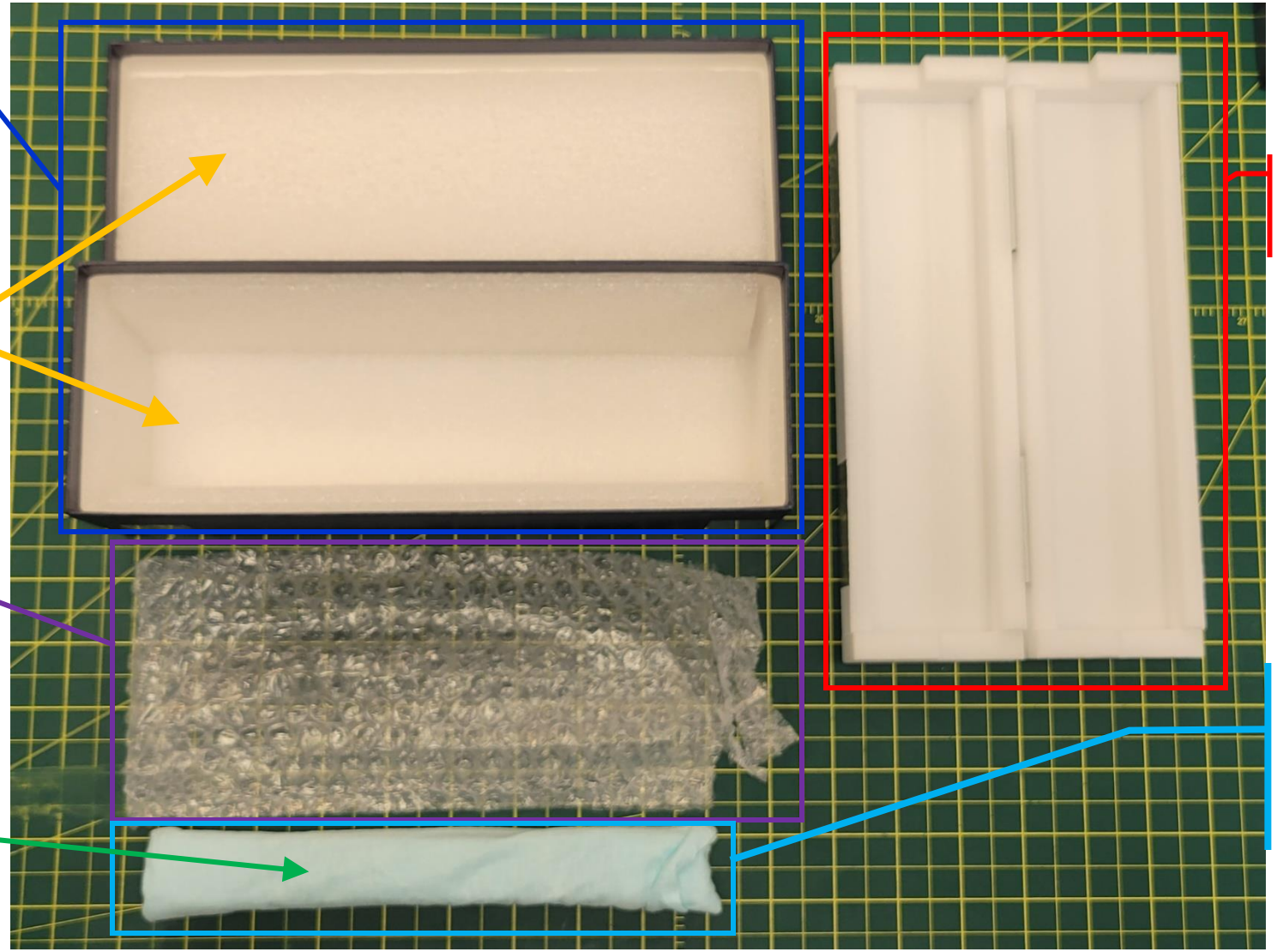
Transmission measurements made in the ARC building in DSG monochrometer setup

Long term storage at JLab in EEL 126

Next

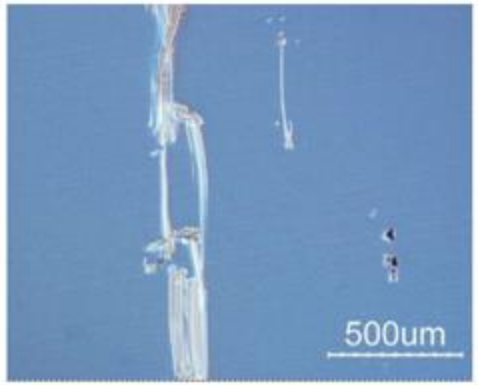
Packaging

❑ CRYTUR Shipping Packaging

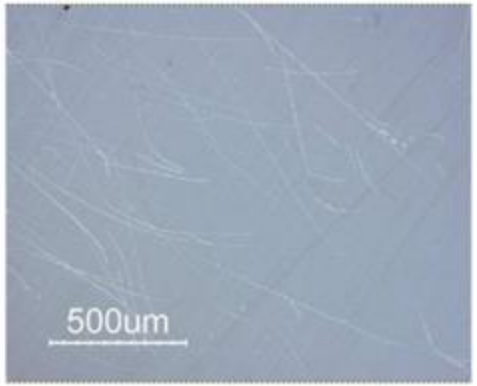


Visual Inspection Methods

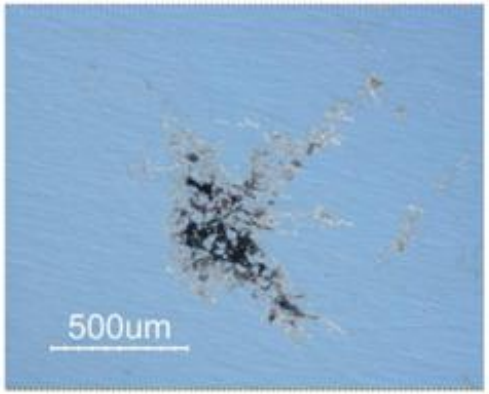
- Our visual inspection processes is keyed to looking for physical defects
  - Chips
  - Scratches
  - Bubbles
  - Chamfer geometry



Deep Scratches

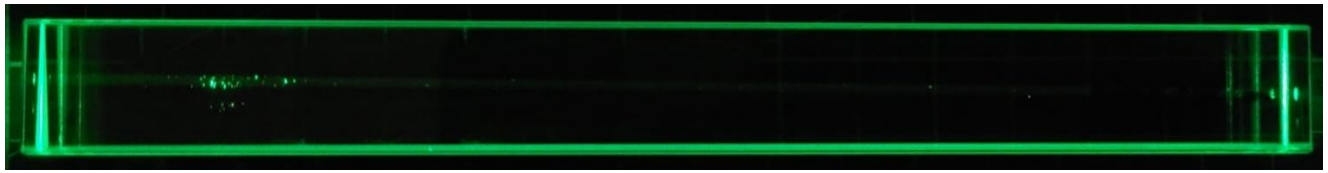


Large region Scratches



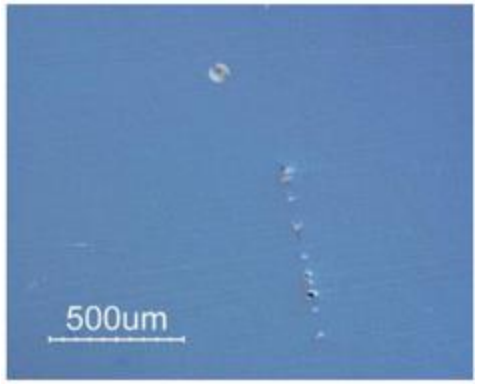
Surface Pitting

- We have experienced issues with other previous vendors.

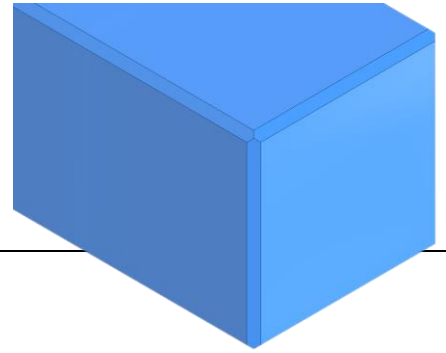


- Small bubbles are evaluated by use of a green laser which illuminates them.
  - We look for large regions of high density
- Each crystal has a picture taken of it and saved to an online storage location.

M. Lajos inspecting crystals

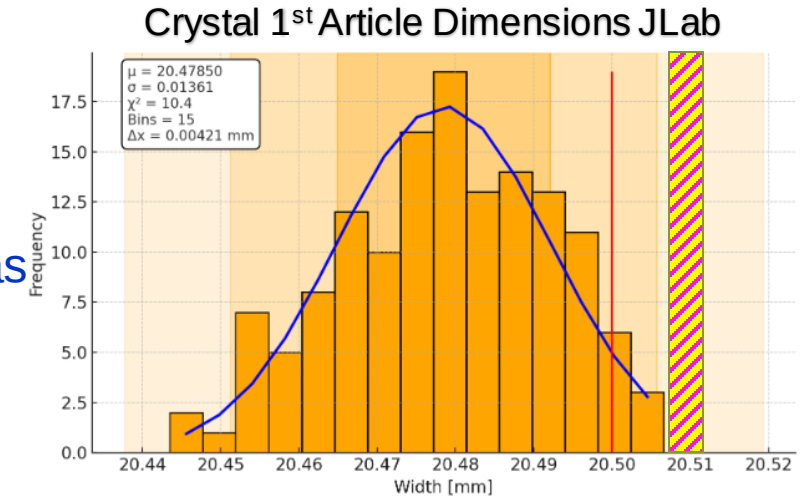


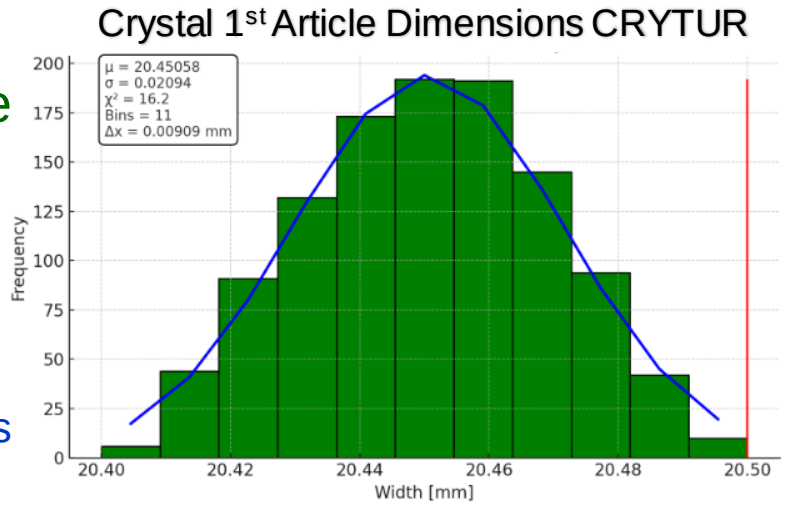
Large Bubbles



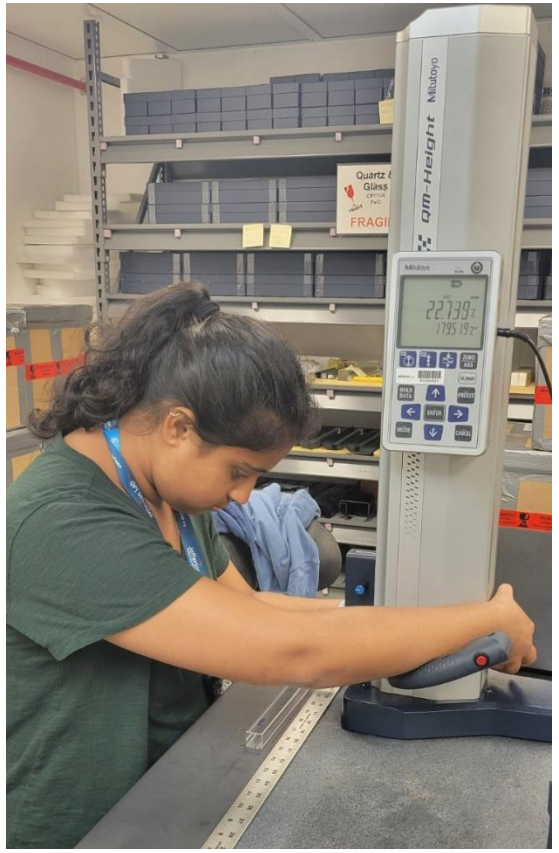
Mechanical Dimension Checks

- We measure the dimensions of the crystals, both the short and long dimensions and record them in the spreadsheet.
  - Our hardware setup is different from theirs as well as the techniques.
  - The numbers we measure are compared to the numbers that CRYTUR obtained for the batch in order to understand the systematic differences and cross-calibrate.
- Our technique determines the height of the crystals against a flat slab in all dimensions whereas CRYTUR profiles the crystal geometry digitally in 3D using surface planes.
  - Using both methods we determined that all crystals from the first article pass the mechanical dimensions.





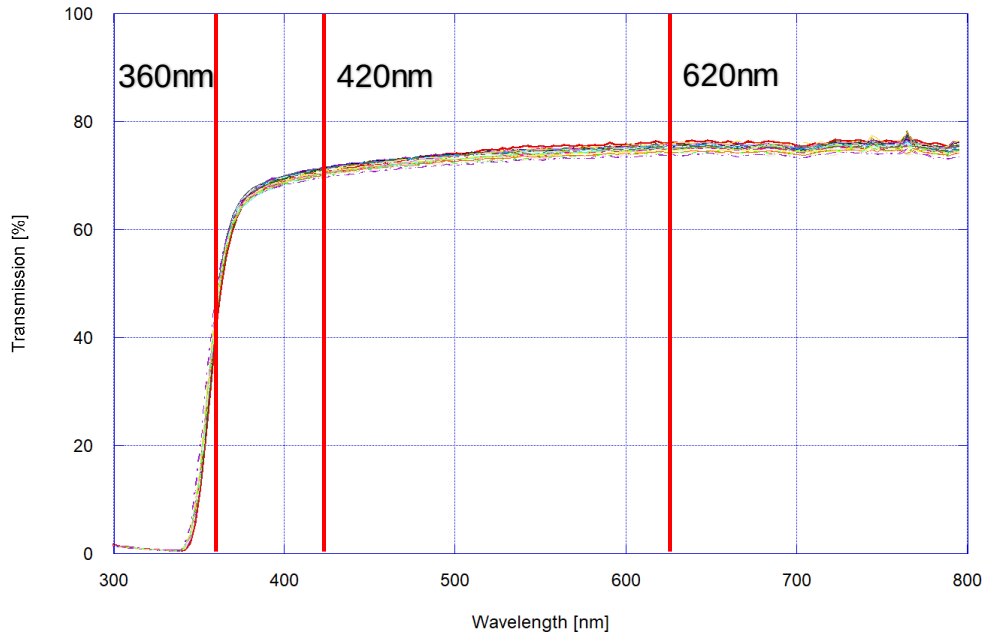
Specification: $20.5^{+0.0mm}_{-0.1mm}$ width

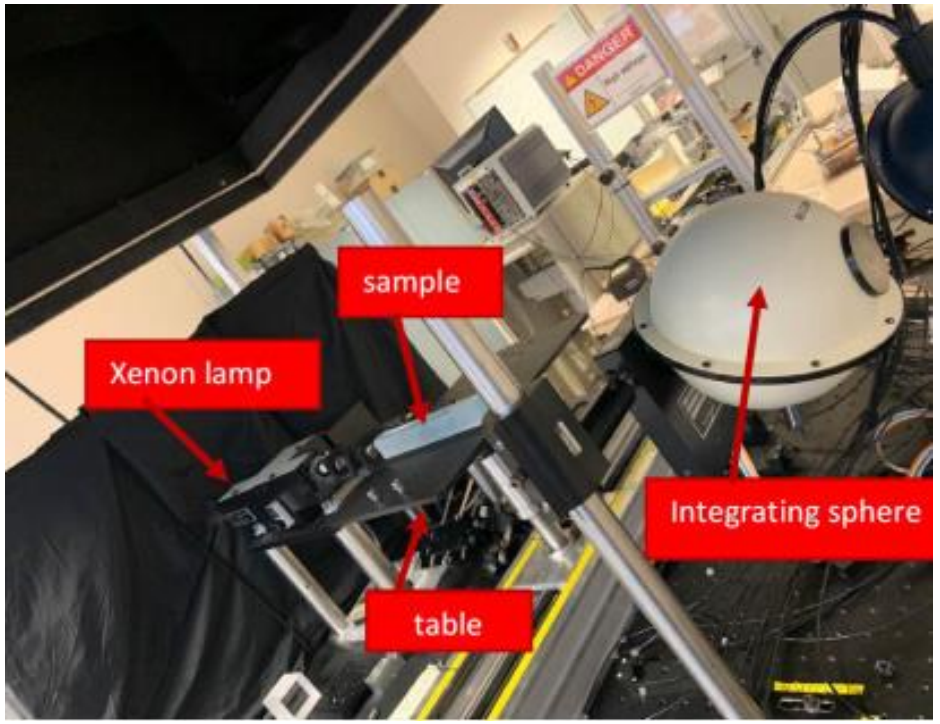


A. Parameswaran measuring crystal dimensions

Transmission Measurements

- At JLab we have access to a transmission measurement setup in the ARC building which is in the Detector Support Group (DSG) lab spaces.
  - Each crystal's transmission profile is measured individually.
  - The detector setup utilizes a collimated light source which is delivered from a monochrometer though the sample into an integrating sphere coupled to a photomultiplier.
  - This setup has a resolution of 1% and is monitored for repeatability via calibration samples.
- There are three wavelengths of interest that we use as indicators of the crystal's overall quality
  - 360nm corresponds to the midpoint of the cutoff wavelength.
  - 420nm is the point after the shoulder where the profile begins to flatten out.
  - 620 is within the plateau region of the transmission curve
- All articles that have been checked to date passed.





Passing Requirements:

%T @ 360 nm >35%

%T @ 420 nm >60%

%T @ 620 nm >70%

Long Term Storage Solution

- Long term storage of the crystals will take place at JLab in the Experimental Equipment Lab (EEL) in room 126.
- Shelving was selected specifically for this project and has been approved for the JLab EIC group use.
  - Shelving unit is large enough to hold the entire detector supply
- Previously the shelving was being utilized for the storage of Lead Glass blocks which we cleared and consolidated into another shelving unit in the same room.
- Front and side screens are on order from the manufacturer.

Status

- 1st article of 140 crystals arrived in JLab on April 2nd 2025 and have passed QA visual inspections as well as dimension measurements.
  - 20 crystals have been processed for transmission values and show expected good values across the board.
- Three more lots of 110 each have also arrived.
  - Lots two and three have all passed visual inspection.
  - Lot four is in process for visual inspection, with all passing so far.
- In our current sampling plan we are going to have a sample size of 20 crystals per lot to be tested with the full procedure, including mechanical dimensions and transmission. We have an escalation plan in place if issues are observed.
  - This number has been arrived at in the spirit of ANSI/ASQ Z1.4.
  - All crystals will be given visual inspection as well.
- We are working with the QA group here at JLab to facilitate the Umbrella QC plan (see section 2.7).
  - Keeping in mind that we have limited resources/time to develop these procedures with no FTE designated.

Summary/Outlook

- We have a long history of working with these crystals across several different experiments and detectors.
  - CRYTUR has a excellent record of providing good product.
- Our testing methods are well established and have been used on previous shipments shipments from the same vendor.
  - Mechanical dimensions check of 1st article shows reasonable agreement considering the different methods used, and pass spec.
  - Transmission measurements reported from the 1st article are in agreement with our measurements, all measured passing spec.
- Long term storage location is designated and prepared.
- Total of 470 crystals of the initial order of 1000 have arrived on site and are being processed.
  - Working to incorporate into the Umbrella QC plan.
- Looking towards the next steps there are two paths being considered:
  1. Complete/partial detector assembly at JLab with the resulting detector being shipped to BNL.
  2. Individual wrapping of the crystals at JLab then shipping to BNL and the detector will be assembled there.

Questions?