ePIC Backward EM calorimeter (EEEMCAL) status

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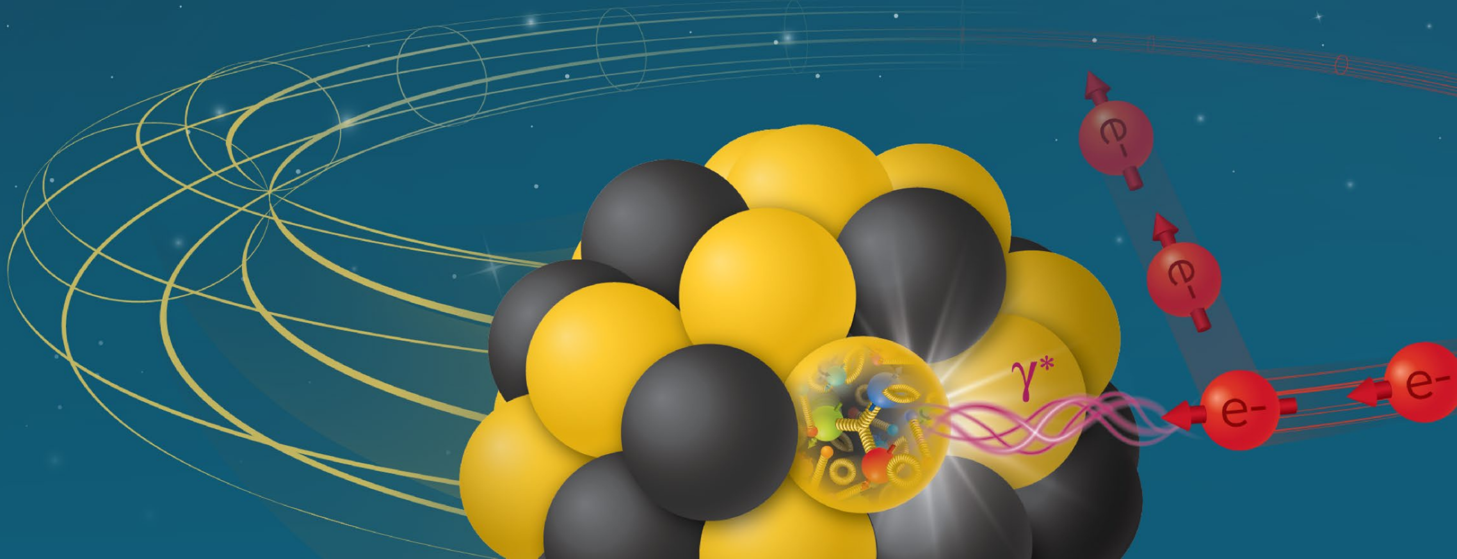
for the EEEMCAL Consortium

10th EIC DAC Review
June 11th – 13th, 2025

Electron-Ion Collider

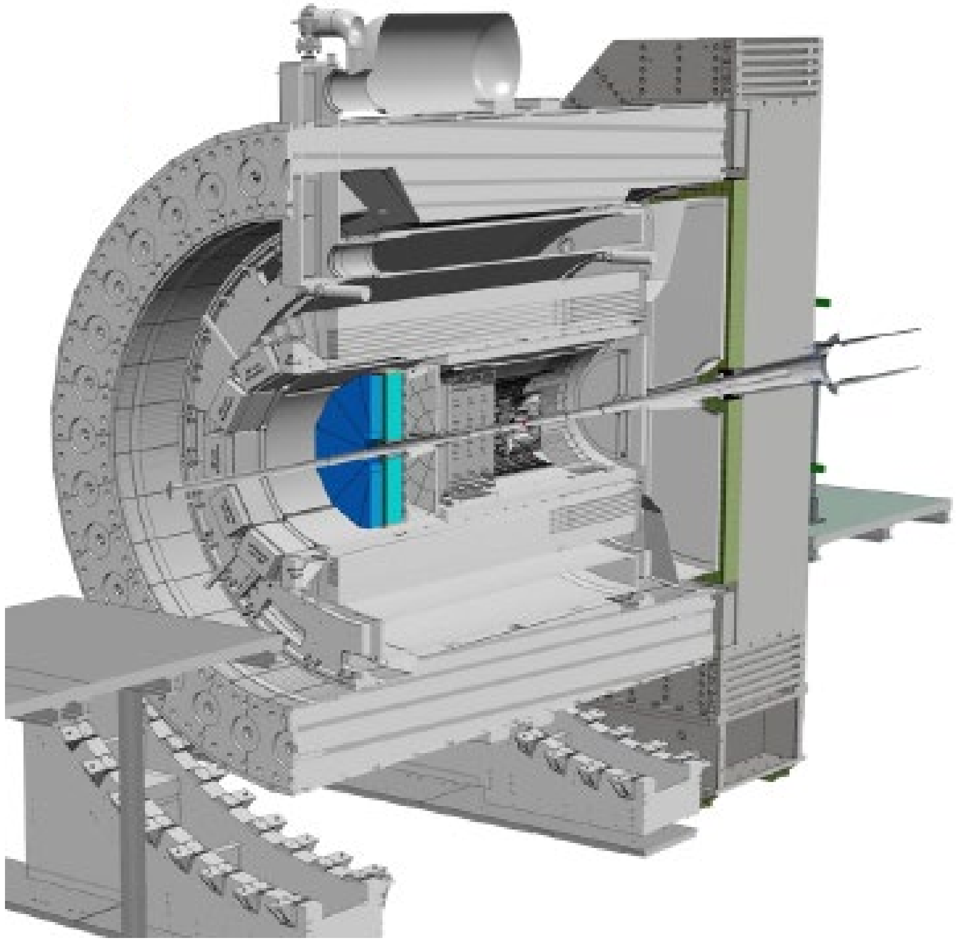


Charge Questions

- Is the design of the ePIC detector and its sub-systems appropriate and progressing well?
- Are the remaining work and technical, cost and schedule risks adequately understood? Are there opportunities?
- Will the detector be technically ready for baselining by late 2025?
- Are the detector integration and planning for installation and maintenance progressing well? Are there areas where further ideas should be pursued?
- Will the detector be ready for start of construction by late 2026?

EEEMCAL Major Components

- **Radiator** consisting of scintillating **lead tungstate (PWO)** crystals and a thin reflector wrapping. The physics requirements for electron identification and detection dictate the main requirements for the radiator.
- **Photosensors** consisting of **multi-pixel photon counters (MPPC)** 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, which is important for crystal performance.
- **Signal Processing/DAQ** providing the front-end electronics to transmit the signals to the data analysis modules.
- Simulations/Software providing the software libraries and infrastructure foundation for extracting the physics from the detector.



EEEMCAL Status Summary

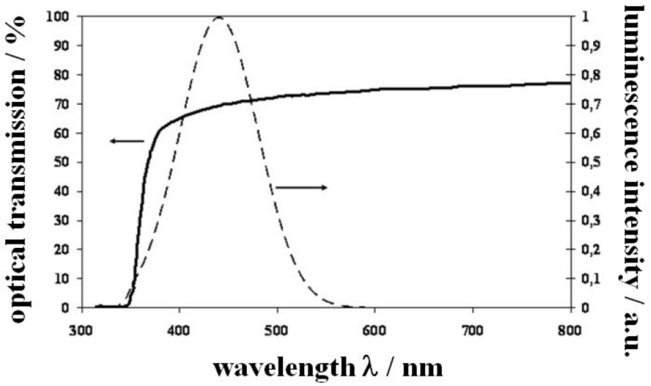
Status

- ❑ FDR PWO crystals – completed
- ❑ FDR MPPC – completed
- ❑ Detailed mechanical design – approaching 80%
- ❑ Front End Readout – at different stages
- ❑ Engineering article test runs – multiple prototype beam tests completed, engineering articles complete and last phase of beam tests ongoing
- ❑ CD3A QA on PWO crystals – first (140) articles passed QA
- ❑ Assembly and Installation planning - ongoing

Items for 2025

- ❑ EEEMCAL FDR – plan for this Fall after completion of further scheduled DESY and JLab beam tests
- ❑ Finalize mechanical design
  - ❑ Finalize front-end electronics (FEE) and associated cooling design
  - ❑ Final cooling implementation depends on final beam tests for FEE readout choice
- ❑ Continue CD3A (and in 2026+ also CD3B) QA on PWO crystals

PWO Specifications



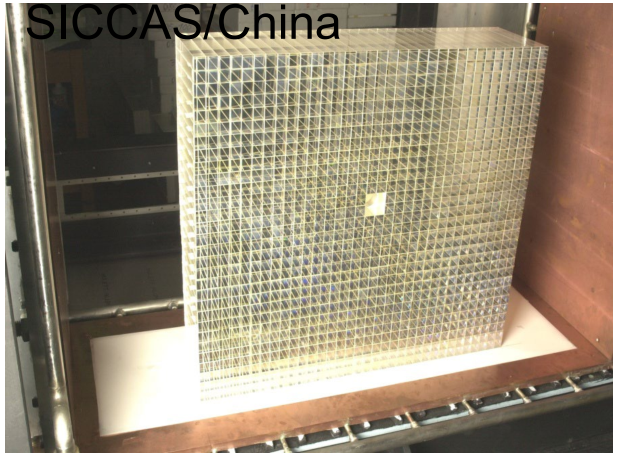
- ❑ Smaller decay time – fast timing
  - ➢ LY (100ns)/LY(1us) specification
- ❑ Optimizing the light yield relies on crystal transmittance in the near UV region
  - ➢ longitudinal transmittance specification
  - ➢ Transmittance spectrum in agreement with photosensor curve
- ❑ Require homogeneous collection of scintillation light along the crystal
  - ➢ specification on transverse transmittance
- ❑ Mechanical specifications important for assembly, e.g., to minimize gaps
- ❑ Raw materials used impact crystal performance – QA with vendor

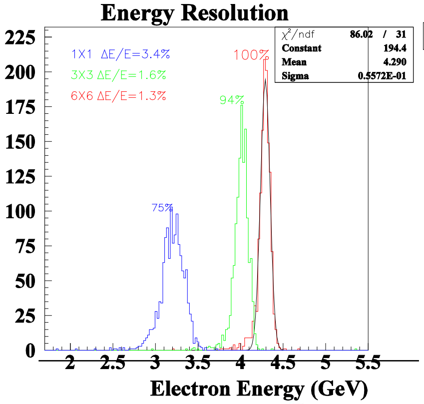
Parameter	Unit	EEEMCAL Required	Q&A Inform. Source
Light Yield (LY) at RT (for all sides polished crystals)	pe/MeV	≥15	Test with γ-source
LY(100ns)/LY(1μs)	%	>90	Test with γ-source
Longitudinal Transmission at λ=360 nm at λ=420 nm at λ=620 nm	% % %	≥35 ≥60 ≥70	Optical Measurement
Transverse Transmission and LY uniformity along crystal	%	10	Optical Measurement
Inhomogeneity of Transverse Transmission Δλ at T=50%	nm	≤5	Optic. Measure.
Induced radiation absorption coefficient Δk at λ=420 nm and RT, for integral dose >100 Gy	m^{-1}	<1.5	Irradiate with different sources
Mean value of dk	m^{-1}	≤1.0	Test
Tolerance in Length Tolerance in sides	μm μm	≤±0,-100 ≤±50	Measure.
Surface polished, roughness Ra	μm	≤0.02	Vendor
Tolerance in Rectangularity (90°)	degree	≤0.1	Measure.
Purity specific. (raw material)			Vendor
Mo contamination	ppm	<10	Vendor
La, Y, Nb, Lu contamination	ppm	?	Vendor

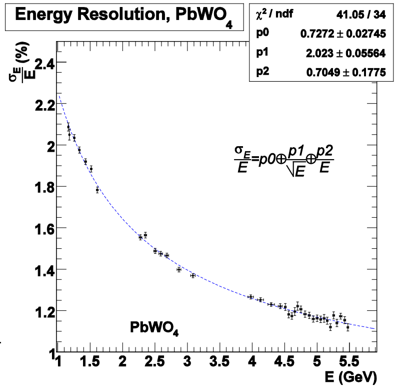
$PbWO_4$ specifications are similar to those achieved for JLab Projects (NPS, FCAL)

Crystal Beam Test Campaigns at JLab

HyCal (pre-2014)
1152 $PbWO_4$ crystals (PWO-I)
SICCAS/China

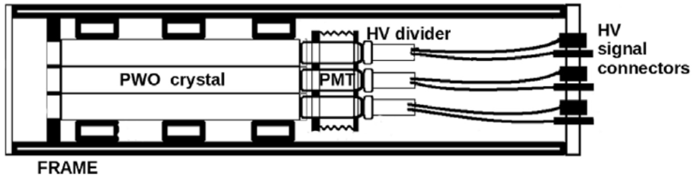


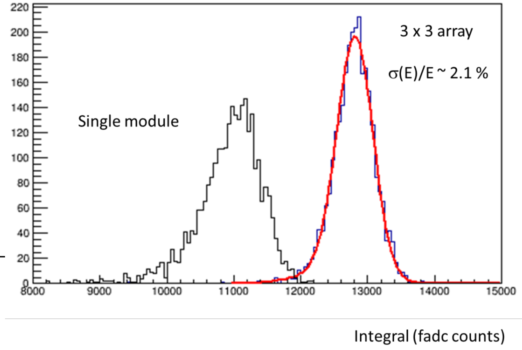




Electron-Ion Collider

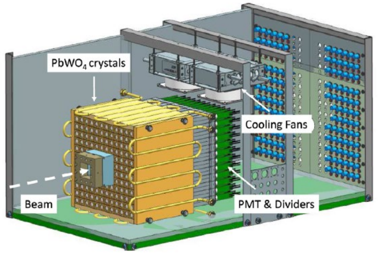
3x3 prototypes (2018/19)
9 $PbWO_4$ (PWO-II) crystals
CRYTUR/Czech Rep.

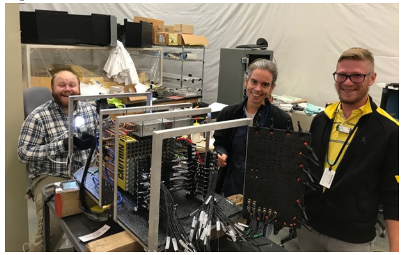


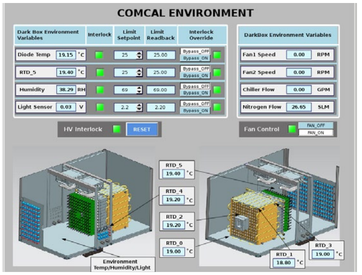


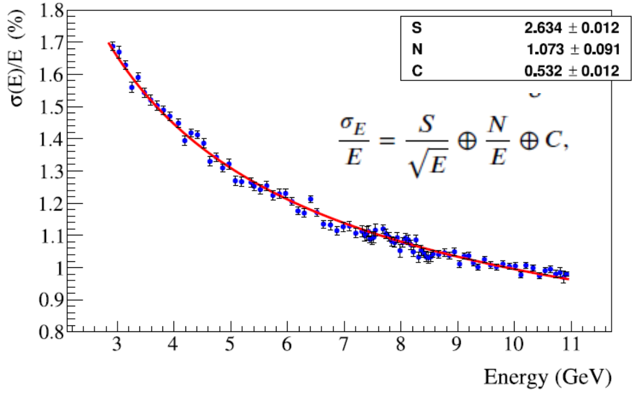
12x12 prototypes (2019)
144 $PbWO_4$ (PWO-II) crystals
CRYTUR/Czech Rep/

ComCal /FCAL



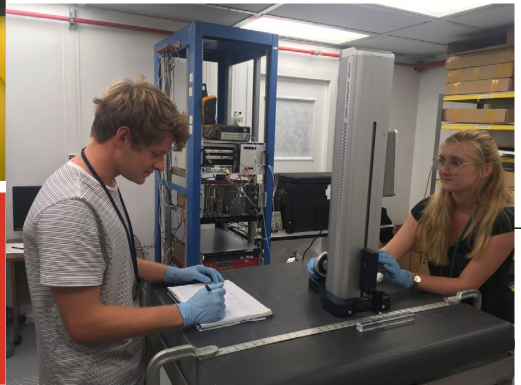






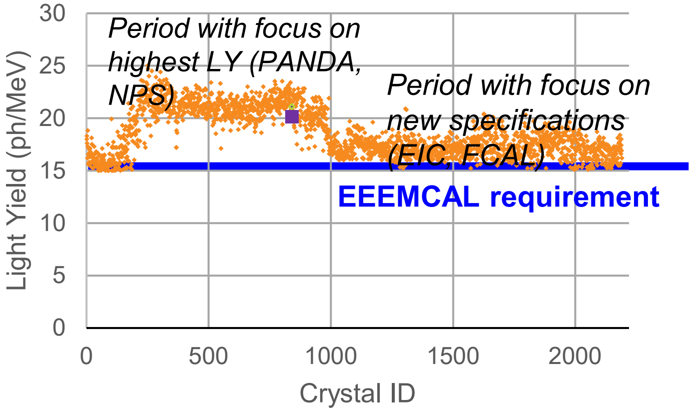
PWO Quality Assurance Protocol

- ❑ PWO crystals are CD3A item
- ❑ **First articles (140 crystals) passed QA**
- ❑ Additional 110 crystals arrived at JLab end of May 2025 awaiting QA
- ❑ The QA builds on the process developed for NPS and consists of:
  - ➢ 2 step visual inspection
  - ➢ mechanical dimension measurement
  - ➢ light yield measurement
  - ➢ Kinetics
  - ➢ transmittance measurement
  - ➢ induced radiation absorption coefficient.

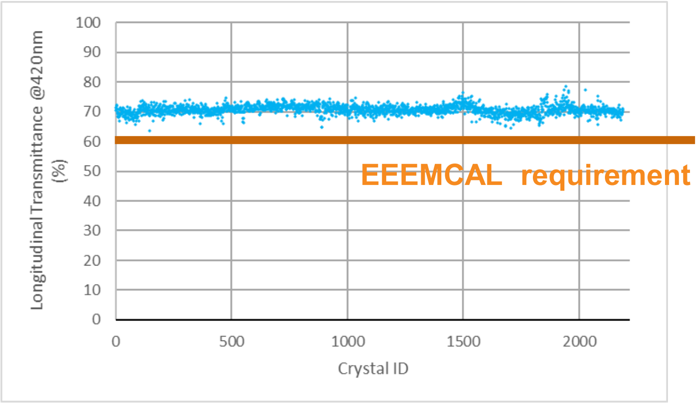


Characterization results of CRYTUR produced crystals (2017 – present)

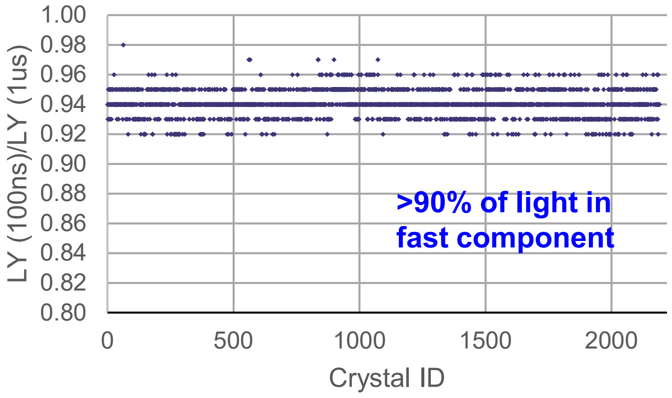
Light Yield (LY)

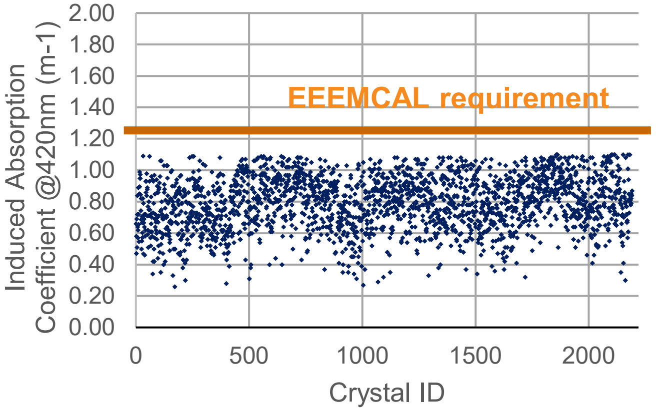


Longitudinal Transmittance



Kinetics



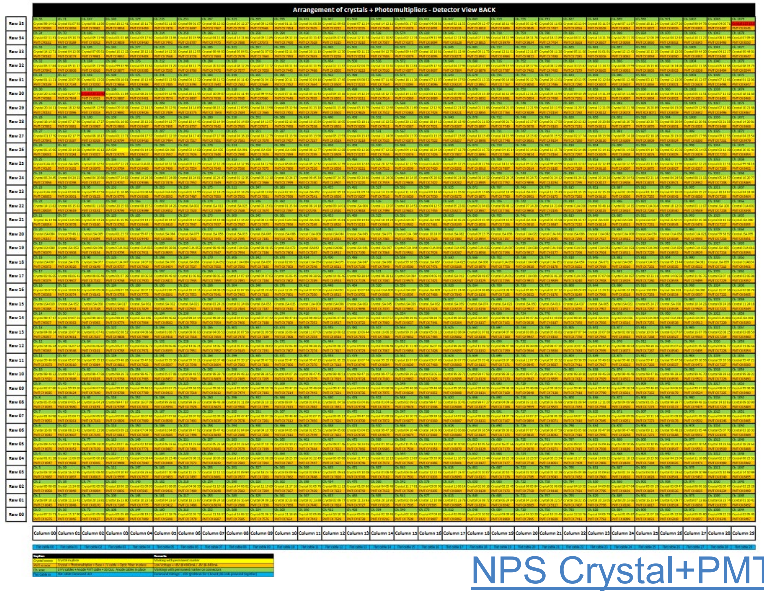


PWO Quality Assurance Documentation

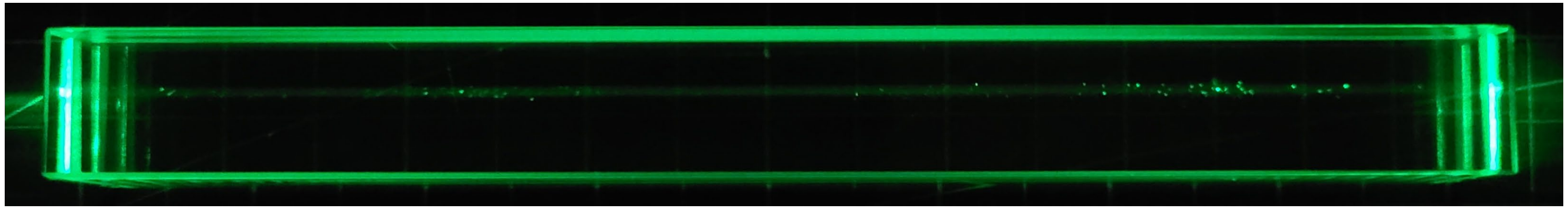
Crystal quality assurance results are documented in a central location with a master spreadsheet

ID #	Receive	Bubble	Scratches/Chips	Chamfer	Visual Inspection Accepte	Box Nur	L	L mea	V1-8	V1 me	V2 me	V3 me	V4 me	V5 me	V6 me	V7 me	V8 me	T 360 nm [%] >35	T 420 nm [%] >6	T 620 nm [%] >7	LY [ph/Me	LY (100 ns)*100/LY (1u	Δk (420 nm)	LY NU	λmin a	Ttrans NUF @360	Ttrans NUF@420 nm	Ttrans NUF@620 nm	Sloupe	Location
163864	TRUE	None	Few	Good	TRUE	1. box	200.00	199.96	20.50	20.47	20.46	20.49	20.48	20.48	20.49	20.49	20.50	43.3	71.3	79.3	19.80	93.50	0.69							NPS Clean Room
203794	TRUE	None	None	Good	TRUE	1. box	200.00	199.95	20.50	20.43	20.41	20.43	20.41	20.44	20.43	20.46	20.45	44.7	70.3	79.0	19.80	92.80	0.78							NPS Clean Room
183816	TRUE	Few	Few	Good	TRUE	1. box	200.00	199.95	20.50	20.45	20.46	20.44	20.46	20.46	20.48	20.46	20.48	44.7	70.5	78.4	18.70	93.80	0.58							NPS Clean Room
163589	TRUE	Few	Few	Good	TRUE	1. box	200.00	199.95	20.50	20.46	20.45	20.45	20.45	20.48	20.47	20.49	20.48	42.6	69.9	78.3	17.90	91.20	0.87							NPS Clean Room
73760	TRUE	Few	None	One End	TRUE	1. box	200.00	199.94	20.50	20.41	20.42	20.42	20.43	20.45	20.45	20.46	20.46	45.8	72.8	79.5	17.70	92.80	0.57							NPS Clean Room
43822	TRUE	None	Few	Good	TRUE	1. box	200.00	199.96	20.50	20.44	20.44	20.44	20.44	20.44	20.48	20.45	20.49	44.5	72.3	75.9	18.80	93.60	0.81							NPS Clean Room
63818	TRUE	None	Few	Good	TRUE	1. box	200.00	199.96	20.50	20.43	20.43	20.41	20.42	20.50	20.46	20.46	20.42	44.5	72.3	78.9	17.10	93.80	0.41							NPS Clean Room
43858	TRUE	Few	Few	Good	TRUE	1. box	200.00	199.96	20.50	20.48	20.49	20.48	20.49	20.48	20.45	20.48	20.46	45.4	71.4	79.0	19.70	93.70	0.52							NPS Clean Room
183836	TRUE	Few	Few	Good	TRUE	1. box	200.00	199.97	20.50	20.48	20.45	20.47	20.43	20.48	20.46	20.47	20.46	46.9	72.6	79.3	17.90	93.10	0.40							NPS Clean Room
113869	TRUE	Few	Few	Good	TRUE	1. box	200.00	199.97	20.50	20.47	20.49	20.48	20.50	20.48	20.48	20.49	20.49	49.8	72.1	79.4	20.80	93.90	0.49							NPS Clean Room
143916	TRUE	None	Few	Good	TRUE	10. box	200.00	199.98	20.50	20.50	20.49	20.48	20.48	20.45	20.44	20.45	20.44	44.0	70.2	77.3	18.40	92.60	0.51							NPS Clean Room
033915	TRUE	None	Few	Good	TRUE	10. box	200.00	199.99	20.50	20.49	20.49	20.49	20.50	20.45	20.47	20.46	20.47	41.4	69.1	77.3	17.00	93.20	0.60							NPS Clean Room
013902	TRUE	Few	Few	Good	TRUE	10. box	200.00	199.94	20.50	20.45	20.44	20.44	20.43	20.47	20.47	20.48	20.48	43.0	71.5	79.1	19.70	92.70	0.69							NPS Clean Room
113896	TRUE	Few	None	Good	TRUE	10. box	200.00	199.98	20.50	20.46	20.45	20.45	20.44	20.45	20.46	20.45	20.46	46.7	71.2	78.7	20.30	92.30	0.79							NPS Clean Room
023872	TRUE	Few	None	Good	TRUE	10. box	200.00	199.96	20.50	20.46	20.46	20.46	20.46	20.49	20.47	20.48	20.46	43.6	71.0	78.9	19.10	91.90	0.78							NPS Clean Room
183918	TRUE	None	Few	Good	TRUE	10. box	200.00	199.96	20.50	20.42	20.45	20.44	20.46	20.46	20.47	20.47	20.47	44.9	72.3	79.9	20.30	92.20	0.59							NPS Clean Room
143873	TRUE	Few	Few, One End	Good	TRUE	10. box	200.00	199.94	20.50	20.44	20.44	20.42	20.42	20.48	20.48	20.46	20.47	41.7	70.5	78.5	18.20	93.60	0.67							NPS Clean Room
063876	TRUE	None	Few	Good	TRUE	10. box	200.00	199.95	20.50	20.43	20.45	20.42	20.44	20.50	20.47	20.49	20.47	41.1	71.4	78.8	16.20	93.70	0.78							NPS Clean Room
013886	TRUE	Few	None	One End	TRUE	10. box	200.00	199.96	20.50	20.45	20.44	20.42	20.42	20.45	20.45	20.46	20.46	43.7	71.8	79.6	20.30	93.20	0.62							NPS Clean Room
023923	TRUE	Few	Few	Good	TRUE	10. box	200.00	199.96	20.50	20.47	20.47	20.44	20.44	20.46	20.48	20.48	20.49	44.1	71.6	78.8	19.60	91.80	0.88							NPS Clean Room
93829	TRUE	Few	Few	Good	TRUE	2. box	200.00	199.98	20.50	20.43	20.44	20.43	20.44	20.45	20.46	20.44	20.45	44.6	71.4	79.0	19.40	92.90	0.82							NPS Clean Room
83817	TRUE	Few	Few	Good	TRUE	2. box	200.00	199.97	20.50	20.43	20.42	20.44	20.43	20.46	20.44	20.46	20.45	43.2	71.8	79.2	17.30	92.80	0.78							NPS Clean Room
63837	TRUE	Few	Few	Good	TRUE	2. box	200.00	199.97	20.50	20.45	20.45	20.44	20.44	20.46	20.47	20.46	20.47	43.4	71.5	79.6	16.20	93.90	0.68							NPS Clean Room
53823	TRUE	None	One End, Few	Good	TRUE	2. box	200.00	199.95	20.50	20.42	20.43	20.41	20.42	20.44	20.42	20.44	20.43	45.0	72.8	79.6	18.30	92.90	0.88							NPS Clean Room
123819	TRUE	Few	Few, One End	Good	TRUE	2. box	200.00	199.96	20.50	20.43	20.42	20.42	20.41	20.45	20.45	20.45	20.45	43.5	69.6	77.6	16.30	93.50	0.65							NPS Clean Room
53833	TRUE	Few	Few	Good	TRUE	2. box	200.00	199.97	20.50	20.45	20.47	20.44	20.45	20.49	20.47	20.49	20.47	47.0	72.2	78.6	19.80	93.90	0.50							NPS Clean Room
183862	TRUE	Few	Few, One End	Good	TRUE	2. box	200.00	199.95	20.50	20.47	20.48	20.46	20.47	20.49	20.47	20.46	20.44	44.8	71.3	78.5	20.10	92.10	0.54							NPS Clean Room
123847	TRUE	Some	Few	Good	TRUE	2. box	200.00	199.95	20.50	20.42	20.45	20.41	20.44	20.48	20.46	20.49	20.47	44.1	70.8	78.2	17.20	93.10	0.62							NPS Clean Room
73777	TRUE	Few	Few	Good	TRUE	2. box	200.00	199.96	20.50	20.43	20.43	20.43	20.42	20.47	20.45	20.47	20.46	45.0	71.3	78.6	16.40	93.30	0.59							NPS Clean Room
203782	TRUE	Few	None	Good	TRUE	2. box	200.00	199.97	20.50	20.43	20.45	20.43	20.44	20.45	20.42	20.45	20.42	45.6	71.9	79.8	16.80	92.10	0.71							NPS Clean Room
184105	TRUE	Few	None	One End	TRUE	21. box	200.00	199.96	20.50	20.43	20.44	20.43	20.43	20.46	20.46	20.45	20.45	42.4	71.3	79.2	18.50	90.20	0.59							NPS Clean Room
094102	TRUE	Few	None	Good	TRUE	21. box	200.00	199.96	20.50	20.43	20.43	20.42	20.42	20.45	20.45	20.45	20.45	44.8	72.2	79.0	20.70	91.30	0.75							NPS Clean Room
014067	TRUE	Few	None	Good	TRUE	21. box	200.00	199.96	20.50	20.44	20.44	20.43	20.44	20.46	20.45	20.46	20.45	45.3	72.0	78.7	19.50	91.10	0.84							NPS Clean Room
114122	TRUE	Few	Few	Good	TRUE	21. box	200.00	199.97	20.50	20.44	20.44	20.42	20.42	20.45	20.47	20.45	20.46	44.2	72.1	78.6	18.50	92.30	0.61							NPS Clean Room
044066	TRUE	Few	None	Good	TRUE	21. box	200.00	199.97	20.50	20.42	20.46	20.41	20.45	20.45	20.45	20.45	20.45	43.6	71.9	78.7	19.70	91.80	0.83							NPS Clean Room
044081	TRUE	None	Few	Good	TRUE	21. box	200.00	199.97	20.50	20.43	20.43	20.42	20.43	20.44	20.45	20.45	20.46	47.0	71.4	78.1	19.90	92.30	0.66							NPS Clean Room
144108	TRUE	Few	Few	Good	TRUE	21. box	200.00	199.95	20.50	20.45	20.45	20.43	20.42	20.47	20.46	20.45	20.44	44.0	72.5	79.9	18.20	91.30	0.65							NPS Clean Room
204064	TRUE	Few	Few	Good	TRUE	21. box	200.00	199.97	20.50	20.43	20.43	20.42	20.42	20.46	20.47	20.45	20.46	44.4	71.9	78.1	21.20	90.30	0.65							NPS Clean Room
054082	TRUE	None	One End	Good	TRUE	21. box	200.00	199.97	20.50	20.42	20.46	20.41	20.45	20.47	20.47	20.47	20.47	42.9	71.1	78.2	19.80	93.30	0.80							NPS Clean Room
044118	TRUE	None	Few, One End	Good	TRUE	21. box	200.00	199.97	20.50	20.44	20.44	20.43	20.43	20.46	20.47	20.46	20.46	45.5	73.0	79.0	19.10	92.30	0.91							NPS Clean Room
23783	TRUE	Many	None	Good	TRUE	3. box	200.00	199.97	20.50	20.43	20.43	20.44	20.44	20.44	20.41	20.44	20.42	47.8	71.9	79.3	16.70	93.20	0.73							NPS Clean Room
203851	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.97	20.50	20.45	20.44	20.47	20.46	20.45	20.47	20.45	20.47	43.9	71.6	79.1	17.70	92.20	0.74							NPS Clean Room
93867	TRUE	None	Few	One End	TRUE	3. box	200.00	199.97	20.50	20.48	20.46	20.50	20.49	20.47	20.49	20.47	20.49	44.2	71.3	78.9	19.10	93.40	0.73							NPS Clean Room
83774	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.97	20.50	20.44	20.43	20.42	20.41	20.44	20.43	20.44	20.44	43.7	71.6	79.3	18.60	93.10	0.91							NPS Clean Room
83842	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.96	20.50	20.44	20.45	20.43	20.43	20.46	20.44	20.47	20.45	43.8	71.5	78.8	17.70	92.80	0.68							NPS Clean Room
43834	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.96	20.50	20.45	20.48	20.43	20.45	20.46	20.46	20.46	20.47	44.5	71.0	78.3	19.40	92.90	0.83							NPS Clean Room
13814	TRUE	Some	Few	Good	TRUE	3. box	200.00	199.93	20.50	20.44	20.44	20.43	20.44	20.43	20.43	20.43	20.42	45.4	72.4	78.3	18.60	93.70	0.75							NPS Clean Room
93852	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.96	20.50	20.48	20.47	20.50	20.49	20.47	20.49	20.48	20.50	43.0	70.9	79.3	17.70	93.70	0.74							NPS Clean Room
103835	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.97	20.50	20.47	20.47	20.48	20.47	20.47	20.45	20.47	20.45	44.8	71.0	78.7	18.50	93.60	0.73							NPS Clean Room
163767	TRUE	Few	Few	Good	TRUE	3. box	200.00	199.95	20.50	20.43	20.44	20.44	20.44	20.46	20.47	20.45	20.46	45.2	72.2	78.9	17.30	92.10	0.52							NPS Clean Room
113772	TRUE	Few	Few	Good	TRUE	4. box	200.00	199.98	20.50	20.41	20.42	20.42	20.42	20.48	20.44	20.48	20.43	45.3	71.3	78.4	18.30	91.20	0.72							NPS Clean Room
113744	TRUE	None	Few	Good	TRUE	4. box	200.00	199.98	20.50	20.41	20.46	20.42	20.46	20.44	20.48	20.45	20.49	45.5	70.7	77.6	18.60	92.10	0.55							NPS Clean Room
63775	TRUE	Few	Few	Good	TRUE	4. box	200.00	199.97	20.50	20.44	20.45	20.43	20.45	20.46	20.44	20.46	20.44	45.3	71.9	79.0	18.60	93.70	0.42							NPS Clean Room
33810	FALSE	Some	Few	Good	TRUE	4. box	200.00	199.96	20.50	20.43	20.45	20.42	20.43	20.44	20.46	20.44	20.46	37.7	69.9	79.1	16.10	94.70	0.36							NPS Clean Room

Crystal characterization results



NPS Crystal+PMT+Cable module map



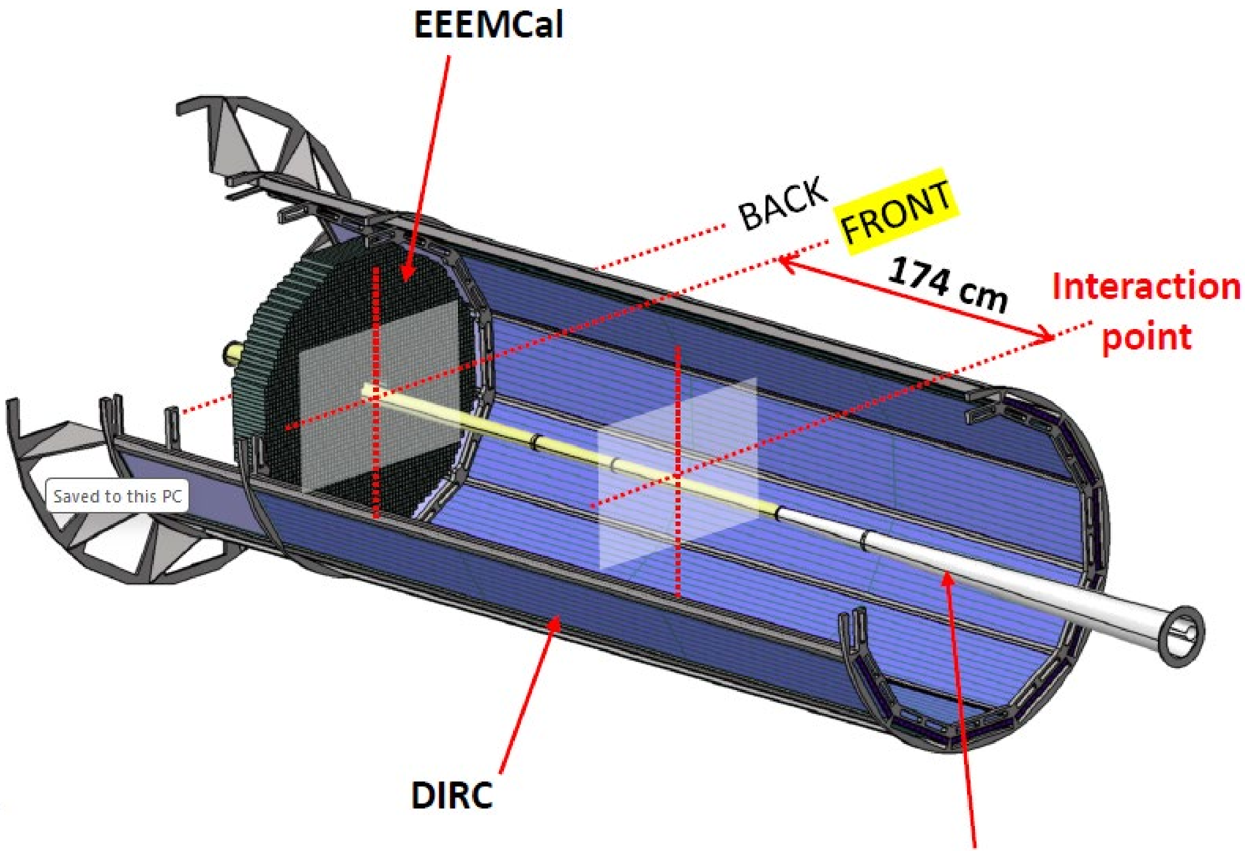
Crystal images are documented along with the numerical characteristic

Mechanical Design Overview

Physics Considerations
- Distance interaction point/EEEMCal = 174 cm
- Minimize the material & space between crystals
- Be as close as possible to the beampipe
- Optimize radiation lengths in front of the detector as possible, e.g., material budget is a consideration for the pfRICH (not shown)

Thermal Considerations
- Good stability of the room temperature around 23^{o}C
- Temperature stability for crystals to within 0.1^{o}C
- About 1500 W to dissipate

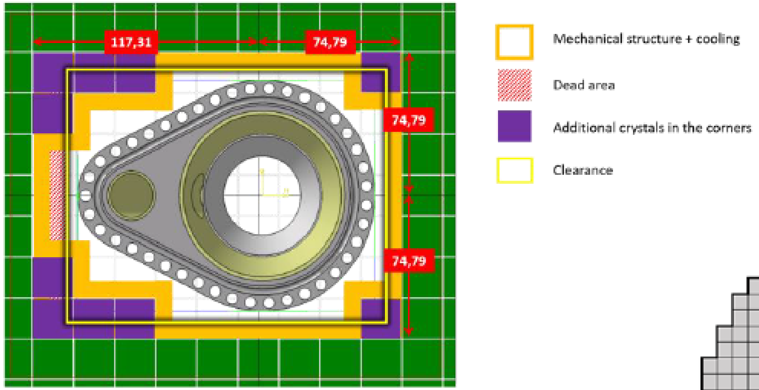
Installation Considerations
Removing the detector in one block
Respect clearance between beam pipe and the DIRC

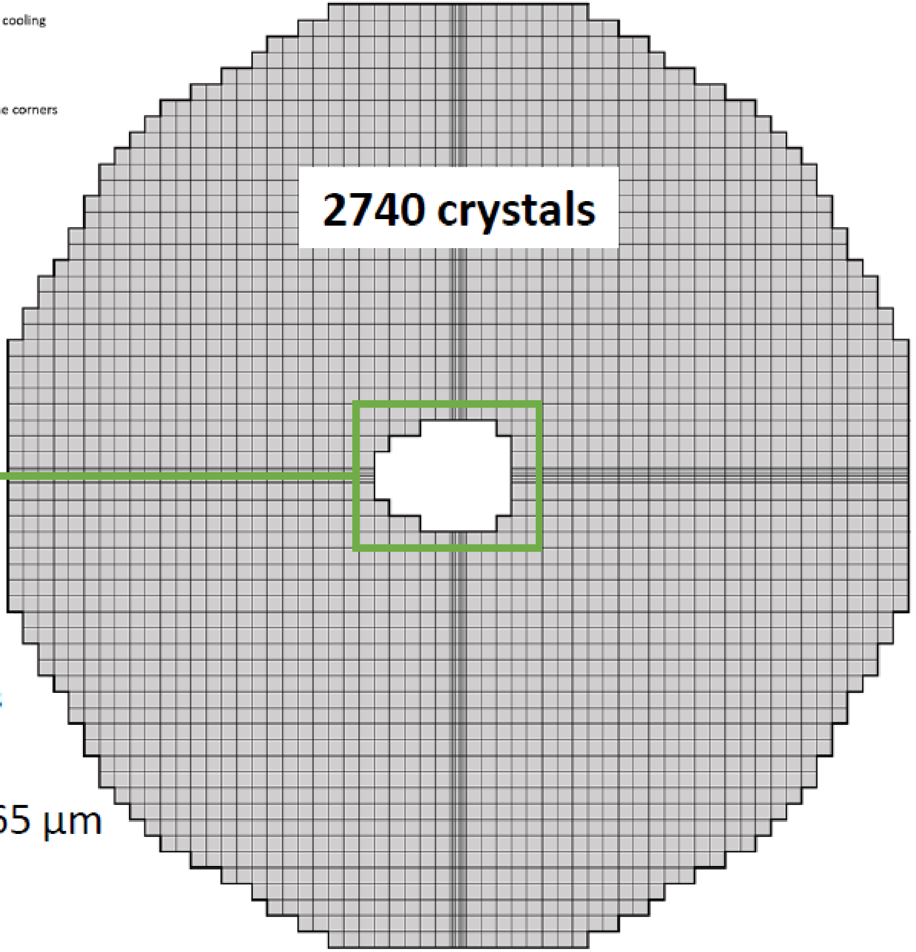


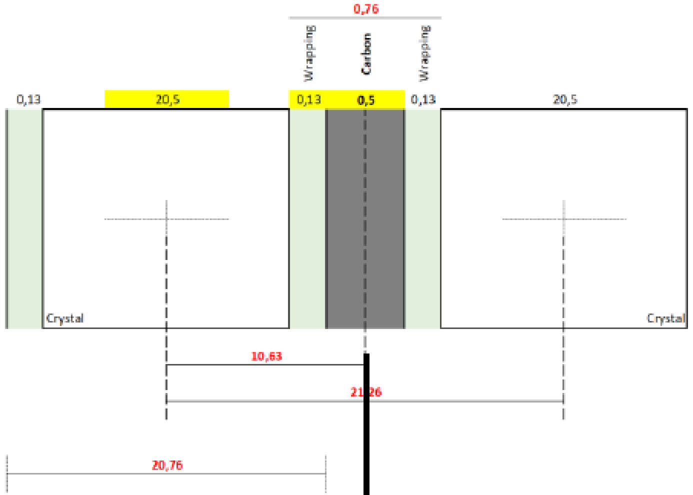
Positioning of the EEEMCal

Crystal Configuration

Crystal configuration is defined
Main clearances are defined

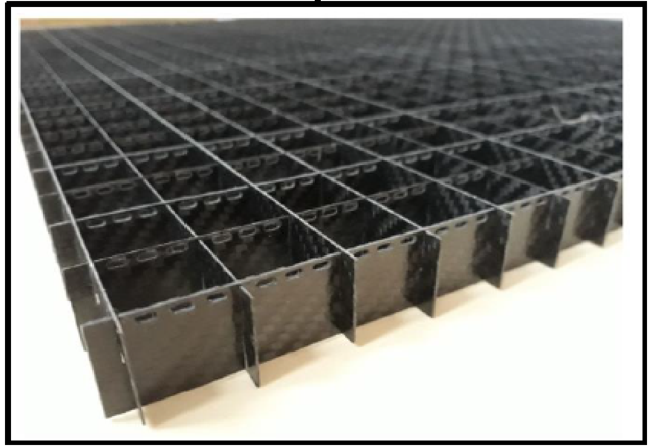






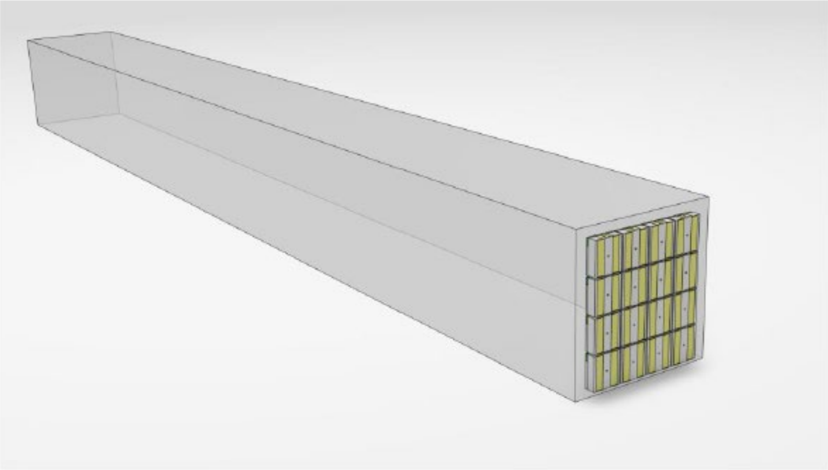
Crystals:

- Material: PWO ($PbWO_4$)
- Size= $20.5^{+0-0.5} \times 20.5^{+0-0.5}$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

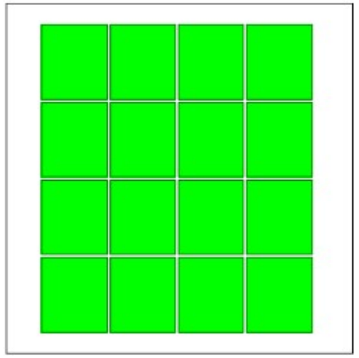


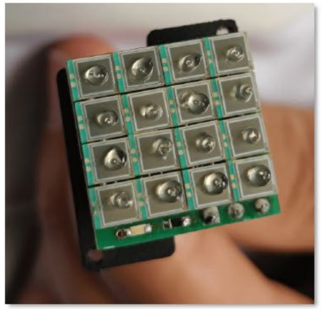
Carbon plate (NPS calorimeter)

MPPC Configuration and Coupling to Crystal

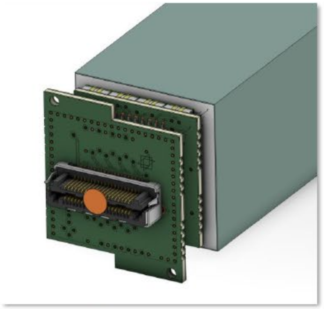


Active surface SiPM		34,27 %
Distance SiPM / Cristal	H	1,250 *mm*
Distance SiPM / Cristal	L	2,250 *mm*

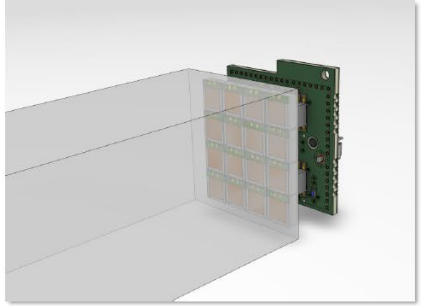




Optical grease



Daughter board – PCB connectors



Assembly Crystal + PCB

MPPC

- ❑ Active surface 3mm x 3mm
- ❑ External size: 4.35mm x 3.85mm
- ❑ Reference: S14160-3015PS
- ❑ 16 MPPC per crystal → 43840 MPPC
- ❑ Space between MPPC: 0.2mm
- ❑ Surface covered by MPPC: ~34%

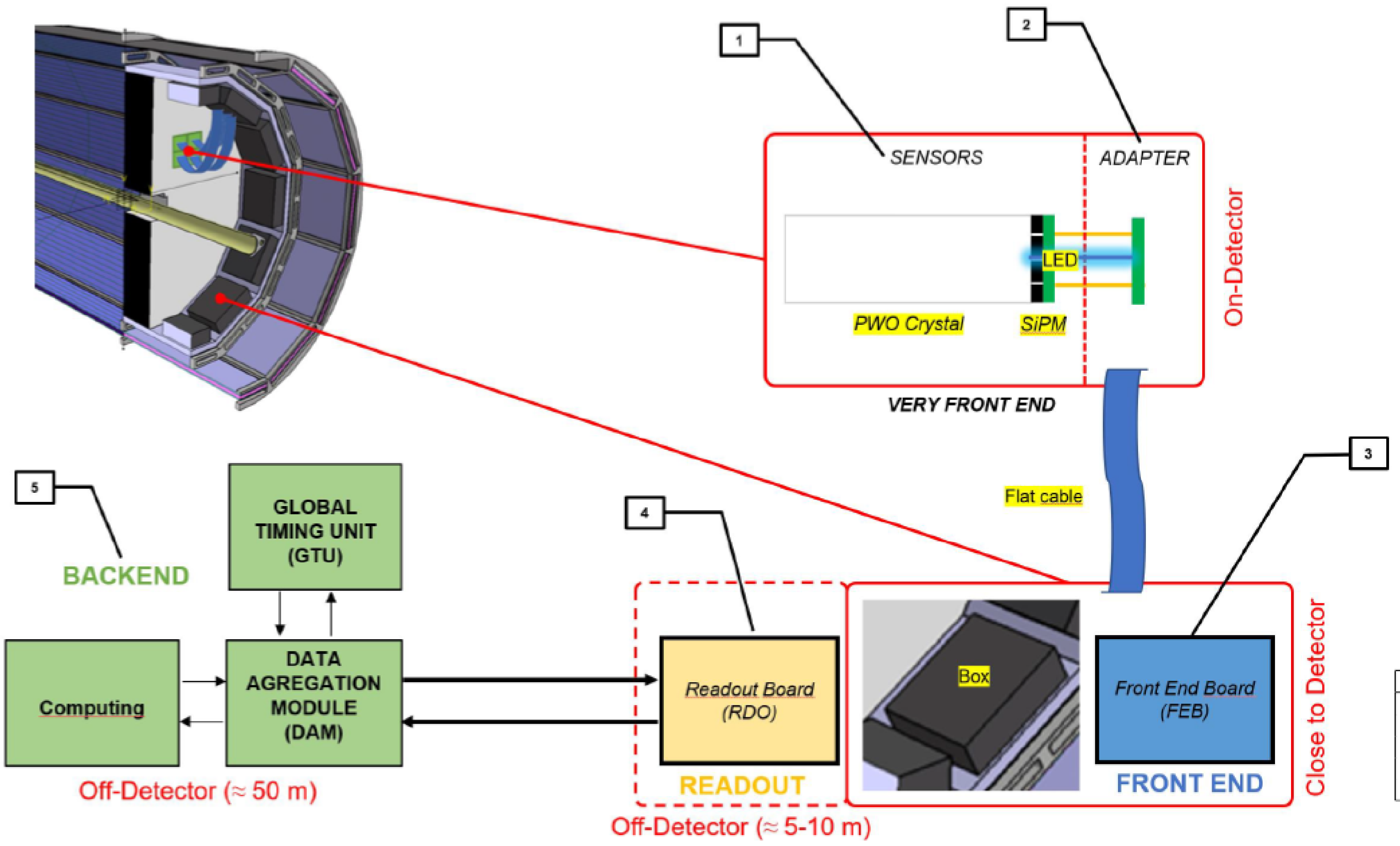
Choice of MPPC done

❑ Coupling to Crystal (Very Front End)

- ❑ 4x4 MPPC coupled with optical grease
- ❑ 1 PCB with the MPPC welded
- ❑ 1 PCB with the output connecter plugged on the PCB MPPC

Readout/DAQ Overview

Work on FEE ongoing
Location of power depends on FEE

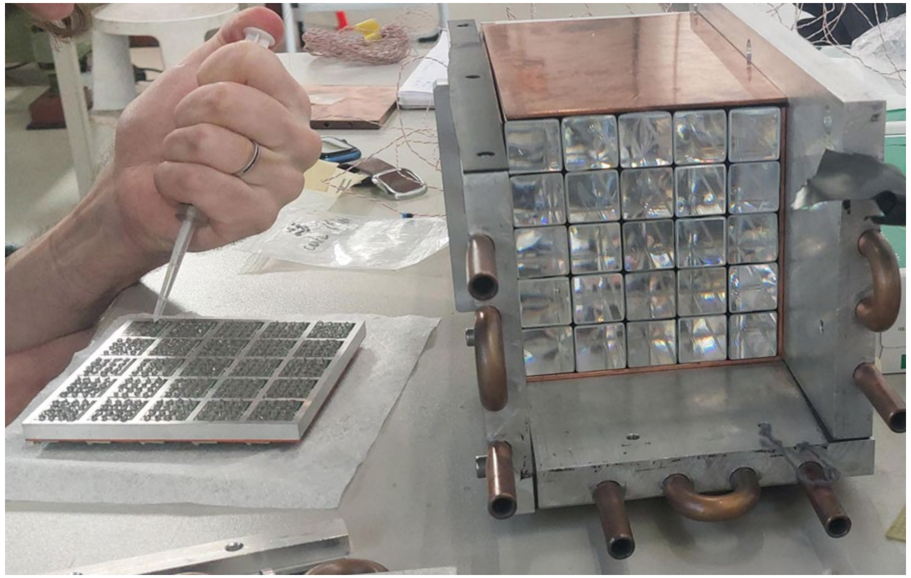


To keep in mind:

- Location of the power: into the FEB & the RDO
- No power on the very front end (+10W for SiPM after one year)
- Current discussion on the design of the FEB

n°	Designation	Description	In charge
1	SENSORS	SiPM	CUA, collaboration
2	ADAPTER	PCB SiPM	IJCLab, OMEGA
3	Front End Board (FEB)	ASIC	Oakridge, LLR, OMEGA
4	Readout Board (RDO)	FPGA	BNL, LLR
5	BACKEND	GTU, DAM, Computing	BNL

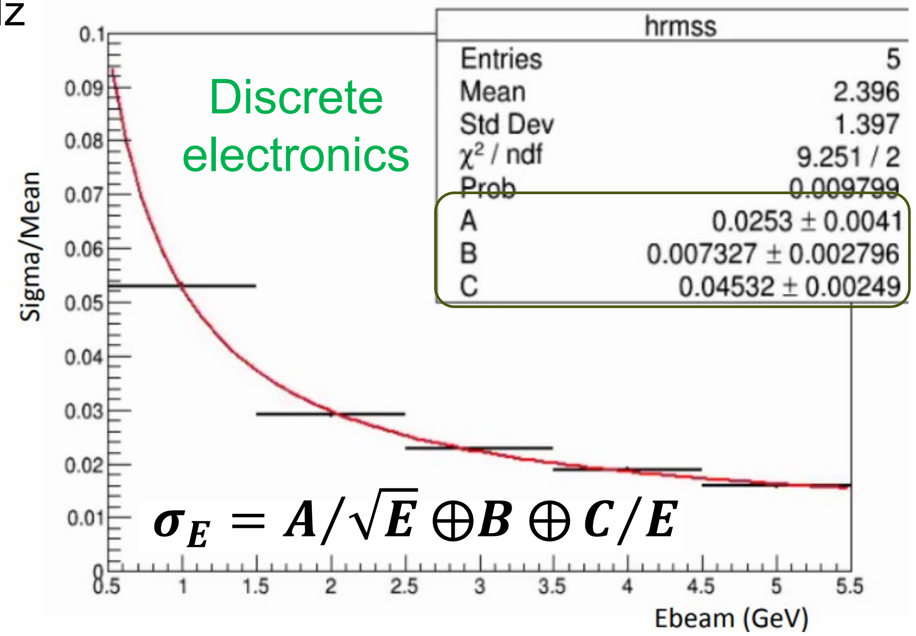
DESY beam test (spring 2025)



- 25 PWO crystals from CRYTUR
- SiPM readout
- Cooling and temp control

- 1 – 5 GeV electron beam through a 2x2 mm^2 collimator
- Triggered by 2 scintillators
- Typical DAQ rates: ~50-100 Hz

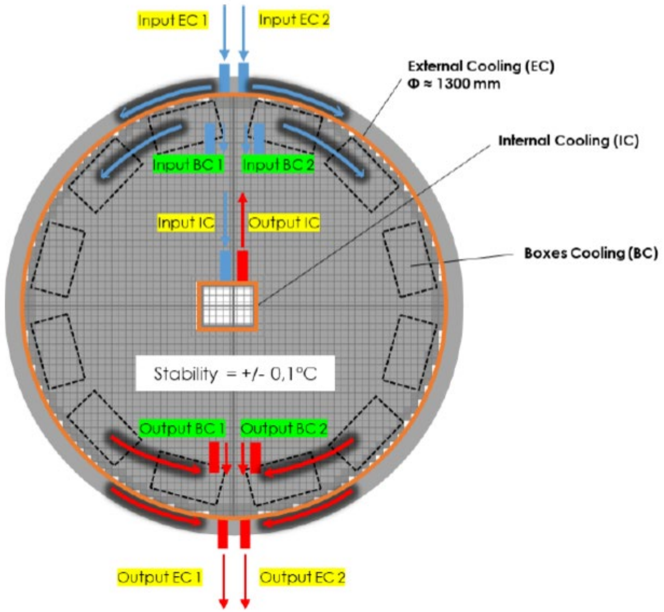
Two readout option tested:
- Readout with H2GCROC3b chip
- Preamp board & CAEN V1725S 14-bit 250MS/s digitizers

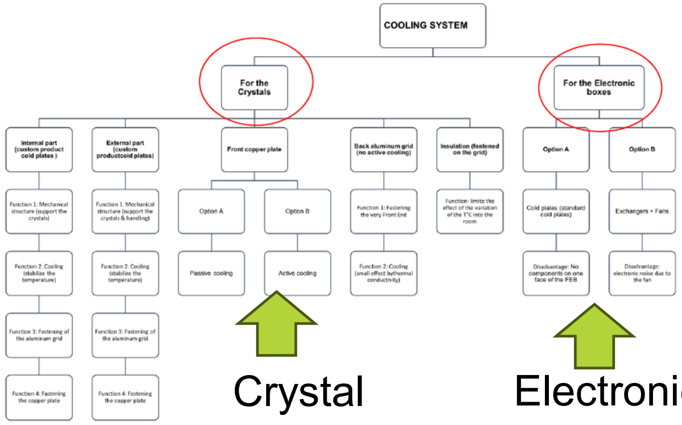


- Successful readout of all 400 channels with both set of electronics
- Significant noise (1/E) term in the energy resolution not yet understood:
  - Likely PS instability due to large capacitance of sensors
  - H2GCROC3b electronics suffered some additional issues (eg. poor grounding in some adaptor boards)
  - Potential light leaks or beam energy spread (under investigation)

Upcoming 2nd campaign at DESY this Fall with improved setup

Cooling Overview and Requirements





Crystal cooling

Electronics cooling

2 main objectives:

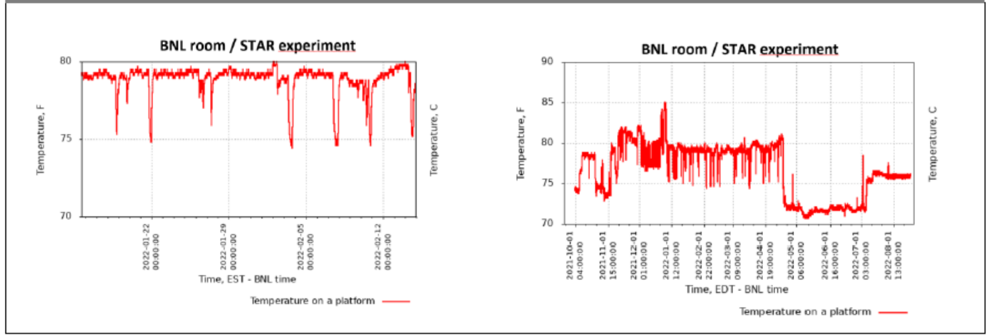
- Stabilize the temperature of the crystals to within 0,1°C
- Dissipate the power of the FEB (& RDO) ≈ 1500 W

Cooling environment is known

3 main parameters for the sizing:

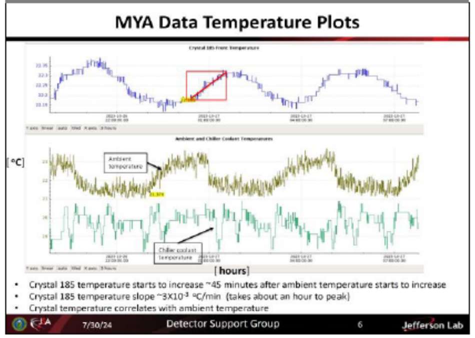
- The amplitude of the temperature variations in the experimental hall → $\Delta T = 3°C$
- The frequency/period of the temperature variations in the experimental hall → 6 hours < T < 12 hours
- The location of the power to dissipate → Power on electronic boxes

RHIC/ STAR experiment data



Temperature evolution | Long period

NPS data

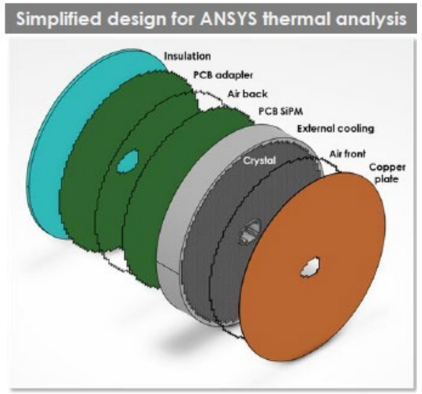


Temperature evolution | Short period

Thermal Simulations

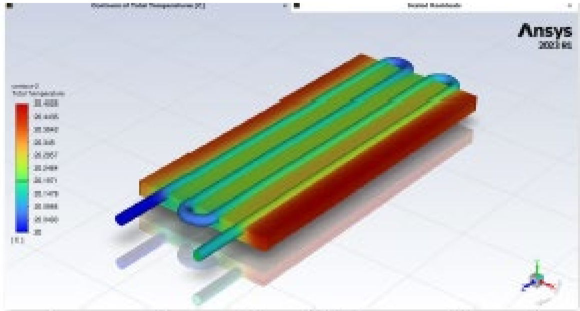
Thermal simulations with advanced design available

Simple Model



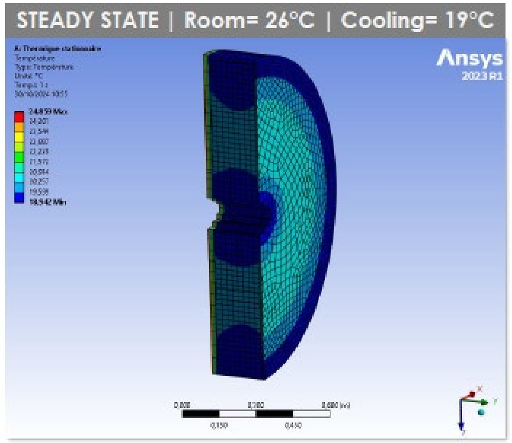
Check impact of room temperature variation and insulation

Steady State



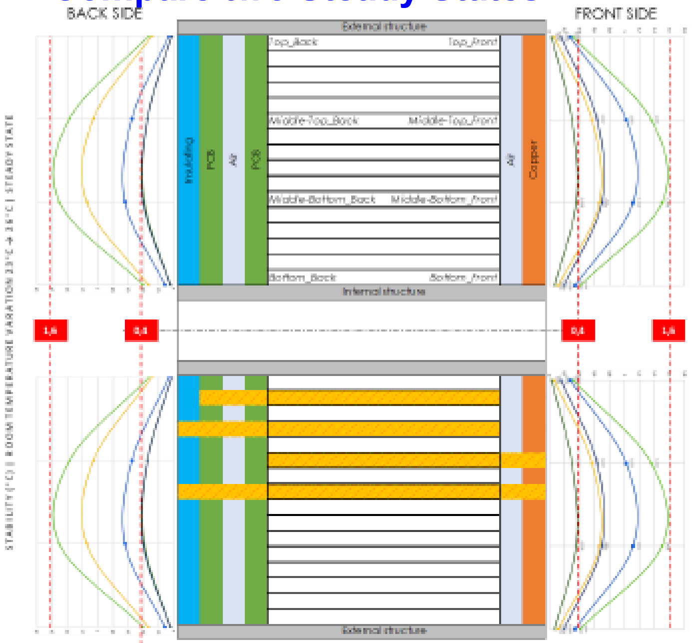
Fluent simulation of a cold plate to validate the homogeneity of the cooling

External and internal cooling at the same temperature



Exemple of results at 26°C
Temperature distribution on the crystals

Compare two Steady States



Two steady states comparison

Model:

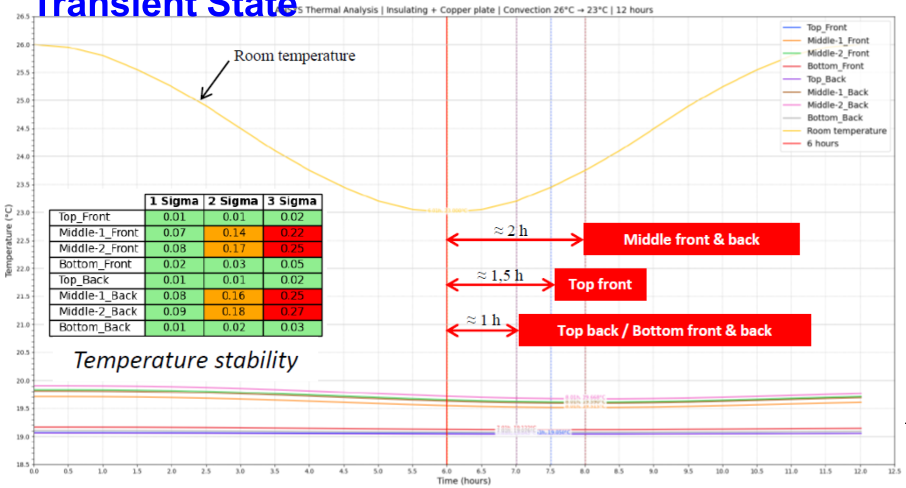
- 1st simulation: Steady state with temperature room= 23°C
- 2nd simulation: Steady state with temperature room= 26°C

→ Comparison (worst case)

Results:

- Without insulation: ΔT (stabilty) = **1,6°C**
- With insulation (foam, air and copper): ΔT (stability) = **0,4°C**

Transient State



	1 Sigma	2 Sigma	3 Sigma
Top_Front	0.01	0.01	0.02
Middle-1_Front	0.07	0.14	0.22
Middle-2_Front	0.08	0.17	0.25
Bottom_Front	0.02	0.03	0.05
Top_Back	0.01	0.01	0.02
Middle-1_Back	0.08	0.16	0.25
Middle-2_Back	0.09	0.18	0.27
Bottom_Back	0.01	0.02	0.03

Temperature stability

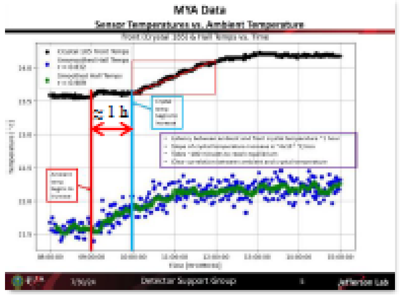
Evolution of the temperature for a variation of the room temperature from 26°C to 23°C in 6 hours and 23°C to 26°C in 6 hours

Model:

- 26°C → 23°C in 6 hours
- T= 12 hours
- Start from the steady state at room= 26°C

Results:

- ΔT (stabilty) < **0,1°C**
- 1 hour < Shift (inertia) < 2 hours
- In accordance with the NPS data

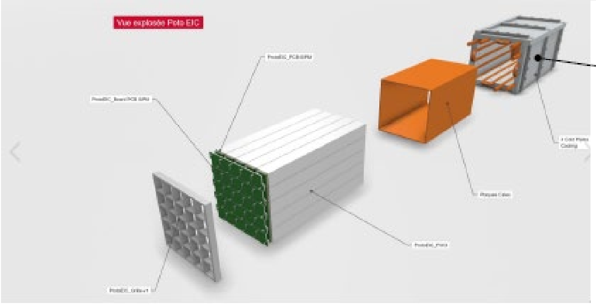


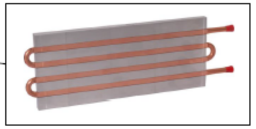
NPS experiment temperature data

Tanja Horn

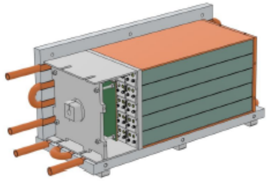
Thermal Tests

Room Temperature Tests





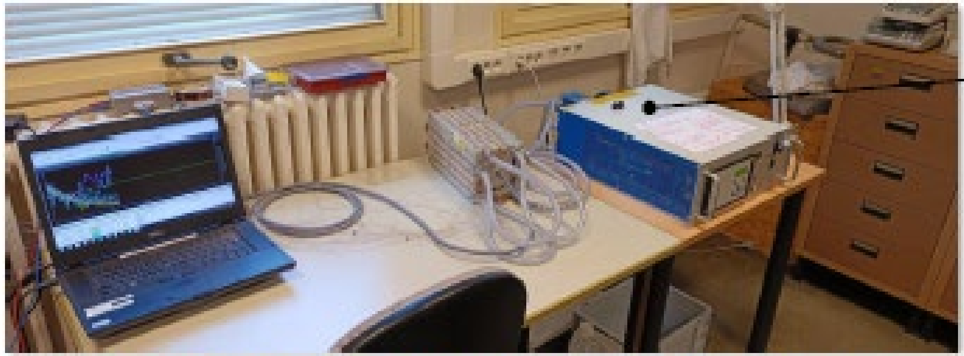
4 standard cold plates



Possibilty to put 25 crystals

Room= 19°C – 27°C | PCB= ON, OFF & Cycle | Cooling= ON & OFF

Results	Standard deviation 1 σ										
	101 (C)	102 (C)	103 (C)	104 (C)	105 (C)	106 (C)	107 (C)	108 (C)	T° pcb	T° plate	T° ext
Heat ON - Chiller OFF	0,15	0,11	0,11	0,09	0,09	0,08	0,04	0,04	0,12	0,07	0,09
Heat ON - Chiller ON	0,11	0,08	0,07	0,07	0,06	0,06	0,05	0,05	0,08	0,07	0,26
Heat OFF - Chiller ON	0,05	0,06	0,04	0,04	0,03	0,03	0,02	0,02	0,04	0,03	0,12
Heat ON cycle - Chiller ON	0,57	0,09	0,06	0,07	0,13	0,06	0,08	0,07	8,83	0,65	0,14
Heat OFF - T chiller = 19°C → 0°C	2,05	1,99	1,99	2,06	1,99	2,06	2,04	2,03	1,62	1,90	0,76



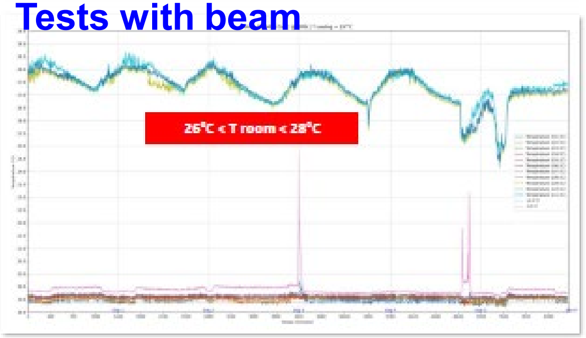
Setup of the thermal with prototype 5x5 (with cooling)

Chiller
Stability = +/- 0,1°C

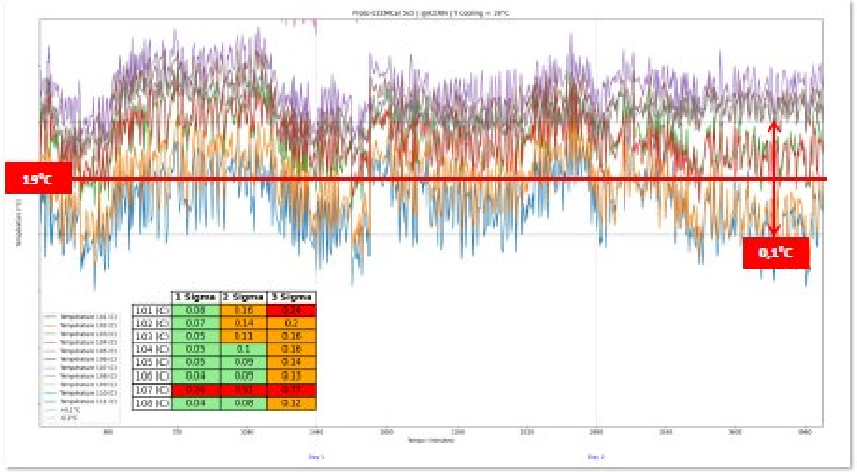
Without cooling
Stability = +/- 0,5°C

With cooling
Stability = +/- 0,1°C

Tests with beam



Room= 26°C – 28°C | T= 3 days | Cooling= 19°C

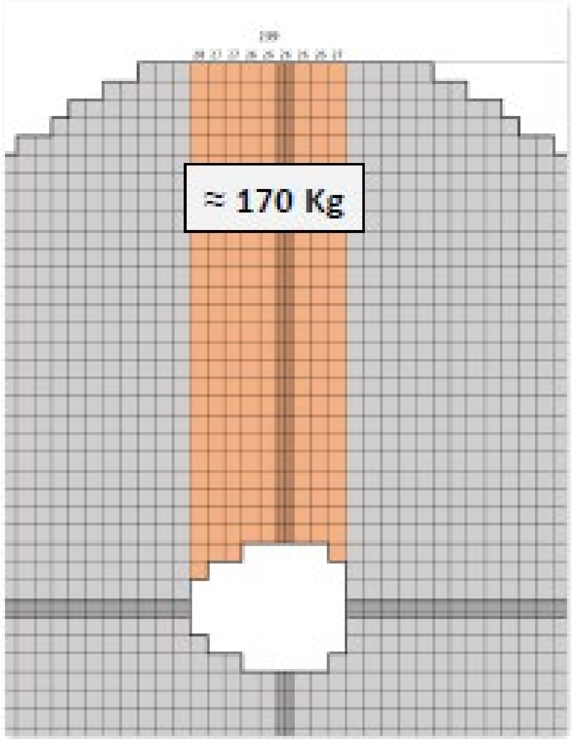


Evolution of the temperature of the crystals during the beam test at CERN

Beam test @ CERN:

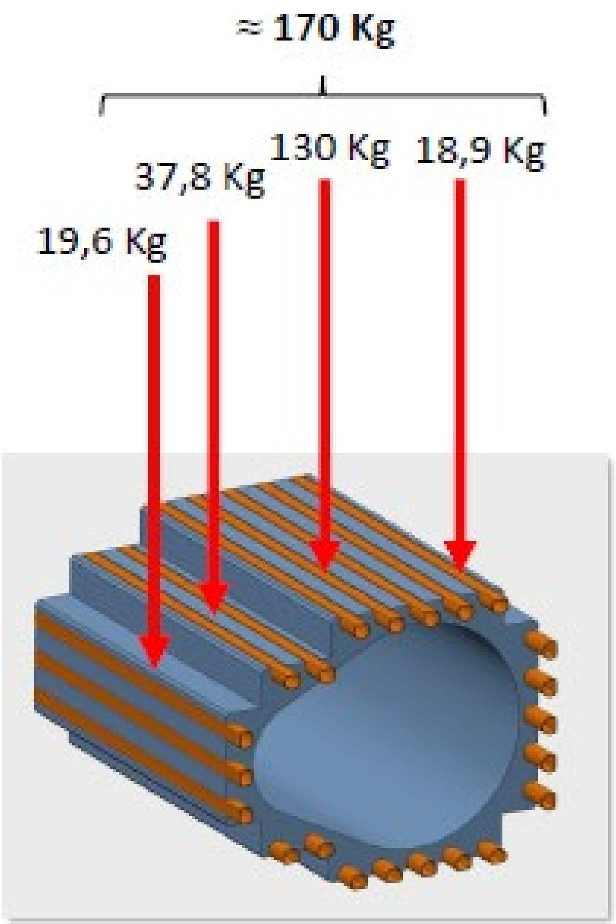
- Temperature stability under +/- 0,1°C
- Problem on one sensor (107, out of use)

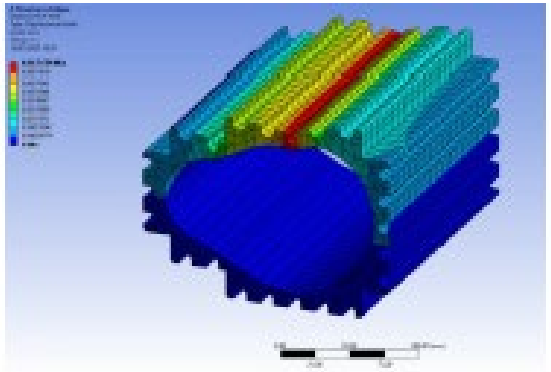
Mechanical Design – Internal Structure



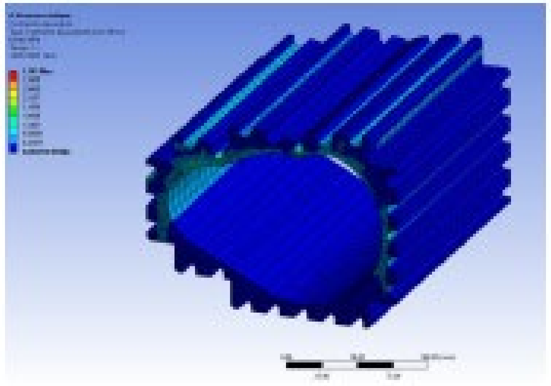
FEA (Finite Element Analysis) Model:

- 239 crystals stacked on the internal structure
- Without copper tubes for the FEA



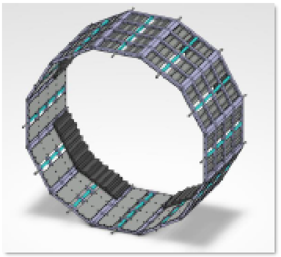


Displacement < 0,01 mm



Stress < 3 Mpa

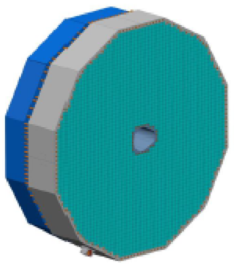
Mechanical Design – External Structure



2022

Assembly of rings and plates

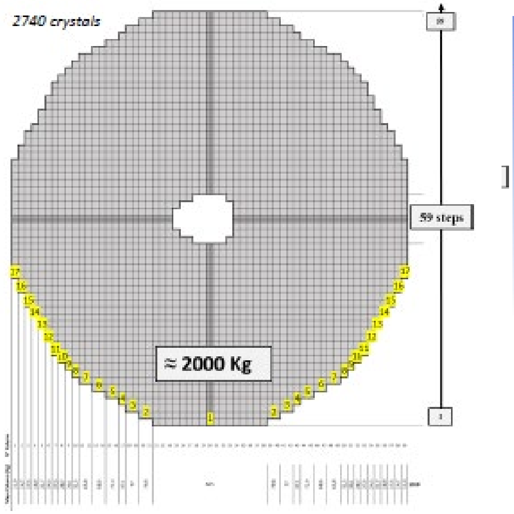
-	+
Assembly	Cheap
Cooling	
Stress & Deflection	

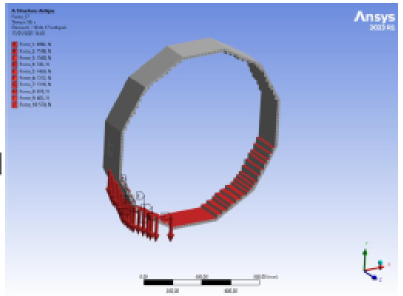


2024

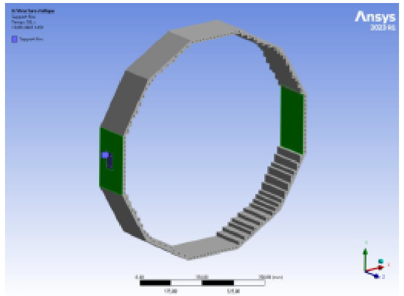
Monobloc

-	+
Expensive	Cooling
Production	Stress & Deflection
Corrosion	No assembly

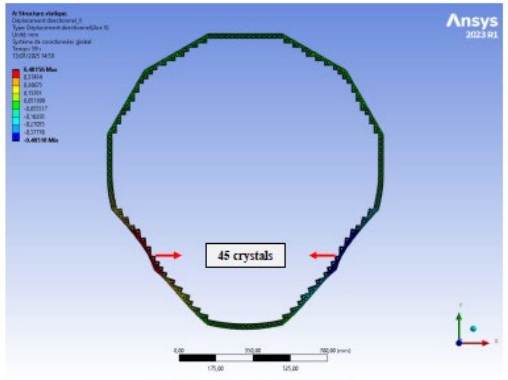




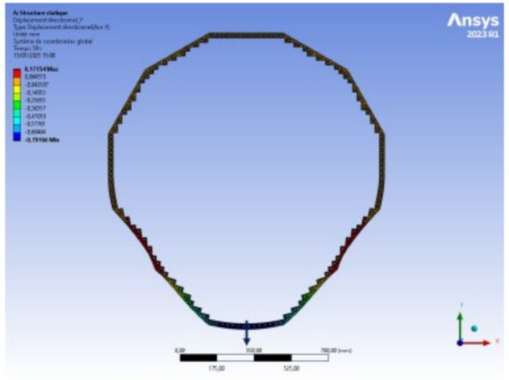
FEA Model:
- 1 face at the center
→ 665 Kg
- 16 other faces on both sides
→ 626,5 Kg x2 (11,9 kg to 79,8 Kg)
- 59 steps to check the deflection during the assembly



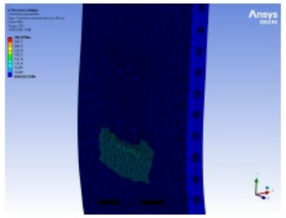
FEA Model:
- Worst case: fastened at 3 and 9 o'clock
- The way to fasten the structure increase the results in terms of stress



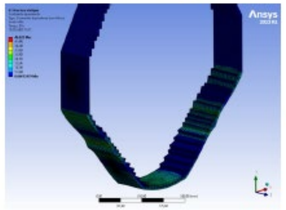
Displacement X < 0,5 mm



Displacement Y < 0,8 mm



Small surface
→ Stress= 342 MPa

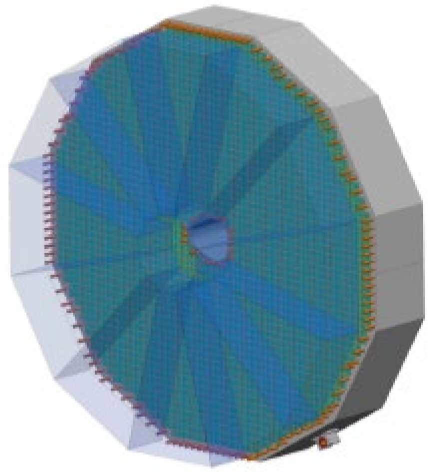


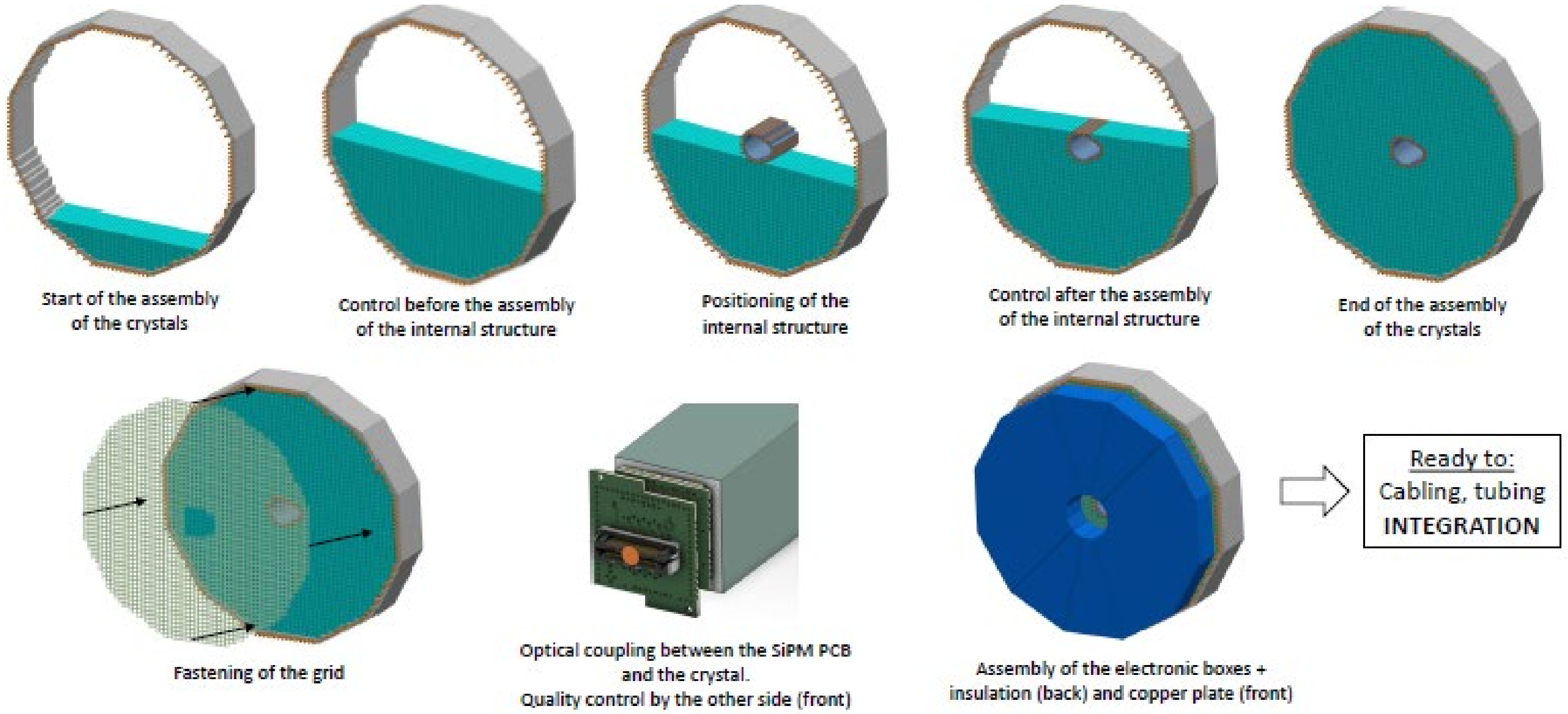
Large surface
→ Stress= 47 MPa

Results:
- Displacement X < 0,5 mm → No stress on the crystals (45 crystals +0,025)
- Displacement Y < 0,8 mm for the worst case
- Displacement Y = 0,36 mm for step 26 (just before the assembly of the internal structure)
- Stress: Optimization required

Results of FEA are encouraging
Perform FEA simulation with advanced design
Choose means of production for structures (machining or foundry)

Mechanical Design – Assembly





List of materials to install:

- Crystals
- Mechanical structures (internal & external)
- Grid (fastening of the PCB)
- Copper plate, Insulation
- Cooling
- Electronic boxes, Cables

Geographical location:

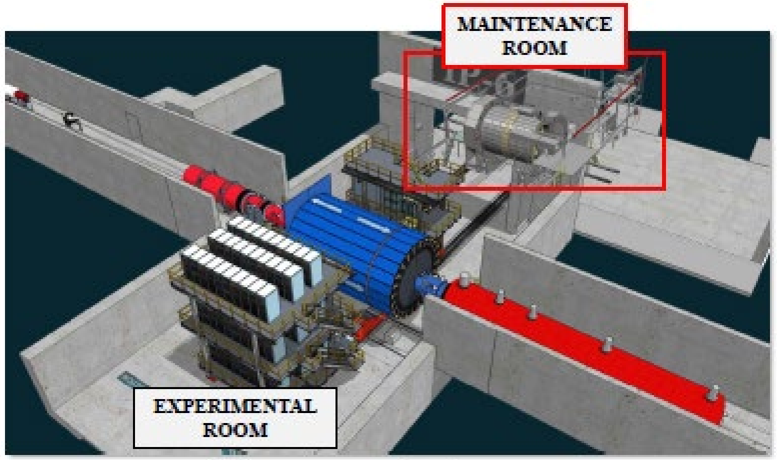
- Crystals → USA
- Mechanics, cooling → France
- Electronics, cables → France (a priori)
- Transport by plane in flight-cases

Options considered for the assembly:

- Pre assembly without crystals @IJCLab (Orsay, France)
- Assembly @Jlab or/and @BNL

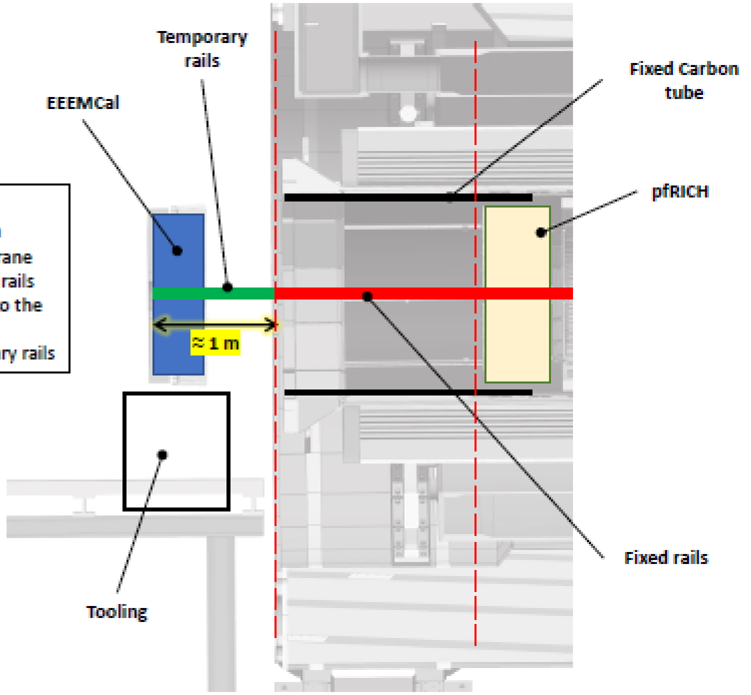
Procedure ongoing
Depends on very front-end and FEB
Assembly test at IJCLab
Still deciding on the final assembly at JLab or BNL

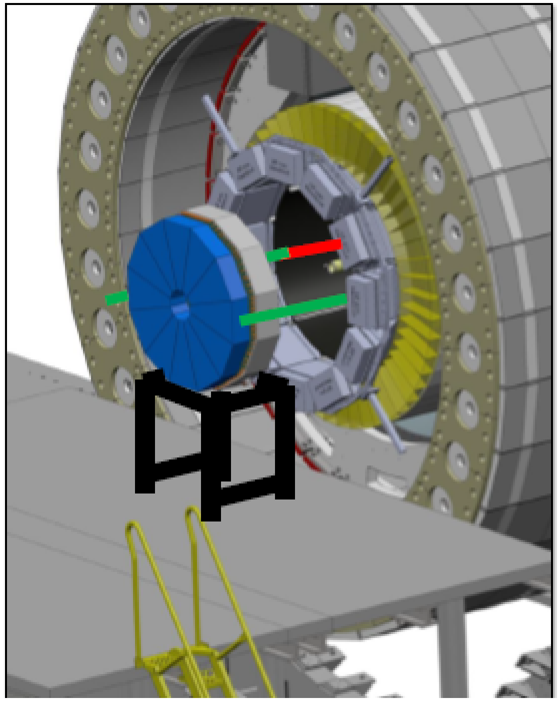
Mechanical Design – Installation

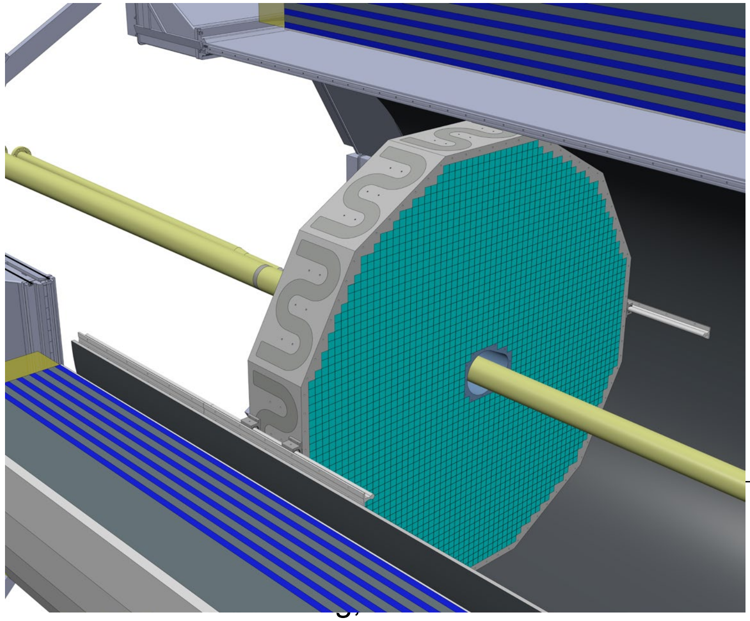


Overview of the experimental and maintenance rooms

Steps:
- Put the detector on a tooling with bridge crane
- Fasten the temporay rails
- Slide the detector into the carbon tube
- Remove the temporary rails





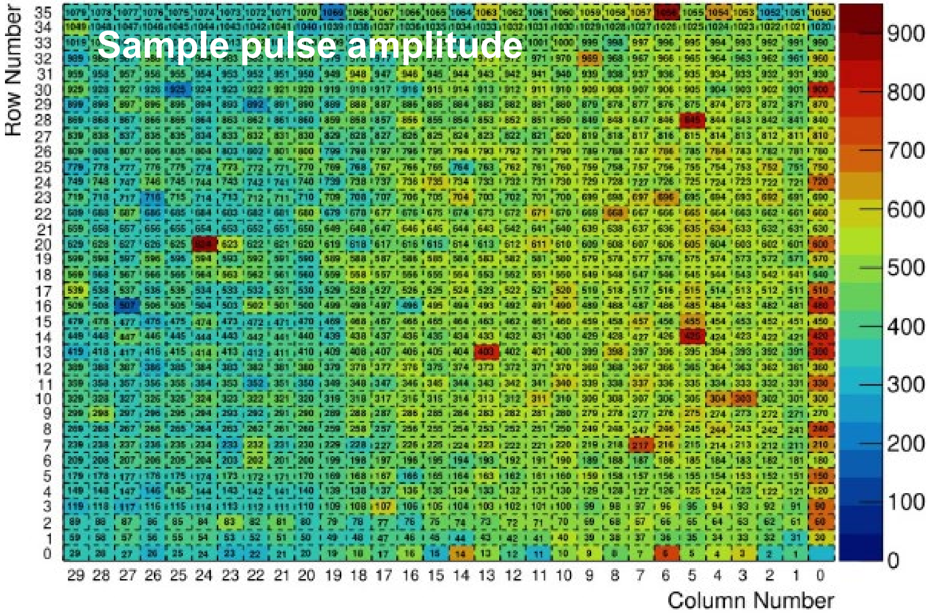


Backward ECAL fixed with rails to the GST (global support tube) in carbon fiber and showing the external cooling structure planned with FSW technology

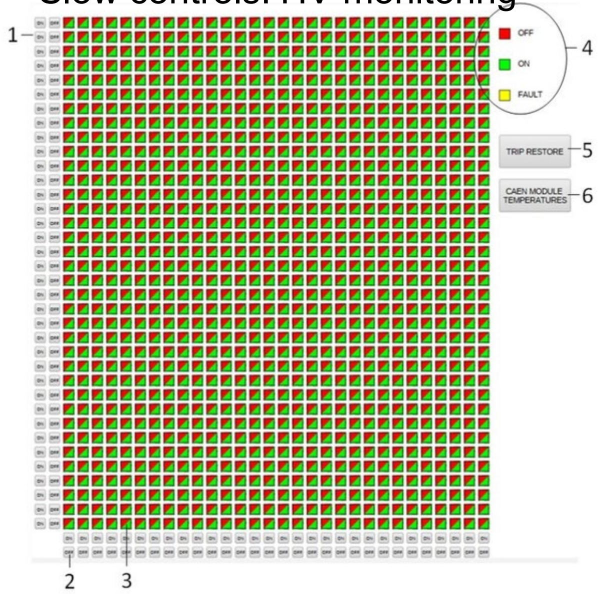
Define positioning of the rails for insertion of detector
Study handling of the detector
Services depend on FEB and cooling

Software/Simulation Development

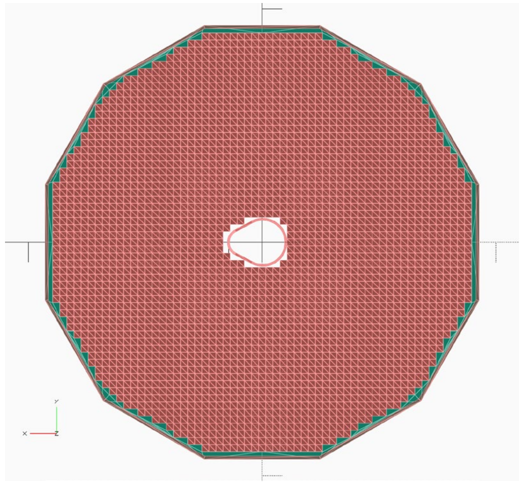
- Software builds on experience from JLab projects (e.g., HYCAL, FCAL, NPS, etc.)
- Anticipated to follow a similar workflow



Slow controls: HV monitoring



EEEMCAL in ePIC simulation framework



EEEMCAL performance

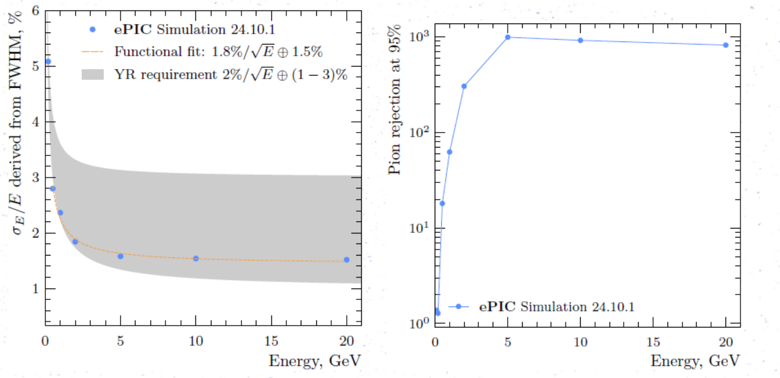


Figure 8.128: EEEMCal performance estimated from single particle simulations using the full ePIC detector geometry. Left: energy resolution as a function of the incident particle energy. Right: pion rejection factor as a function of energy and different values of electron efficiency.

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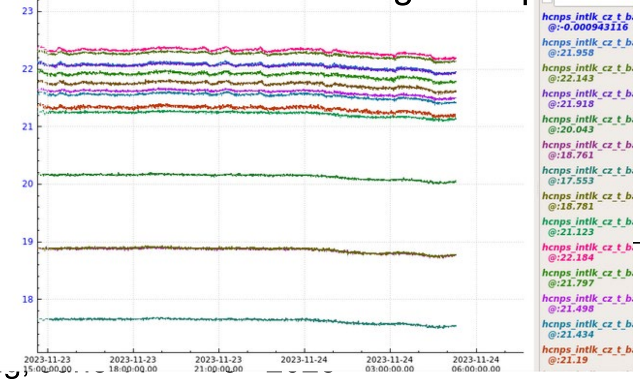
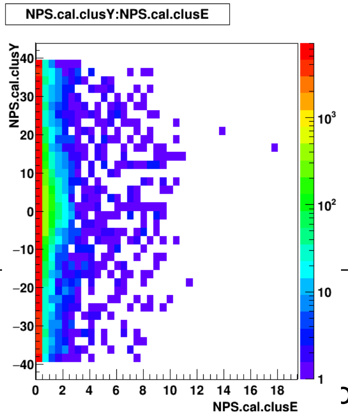
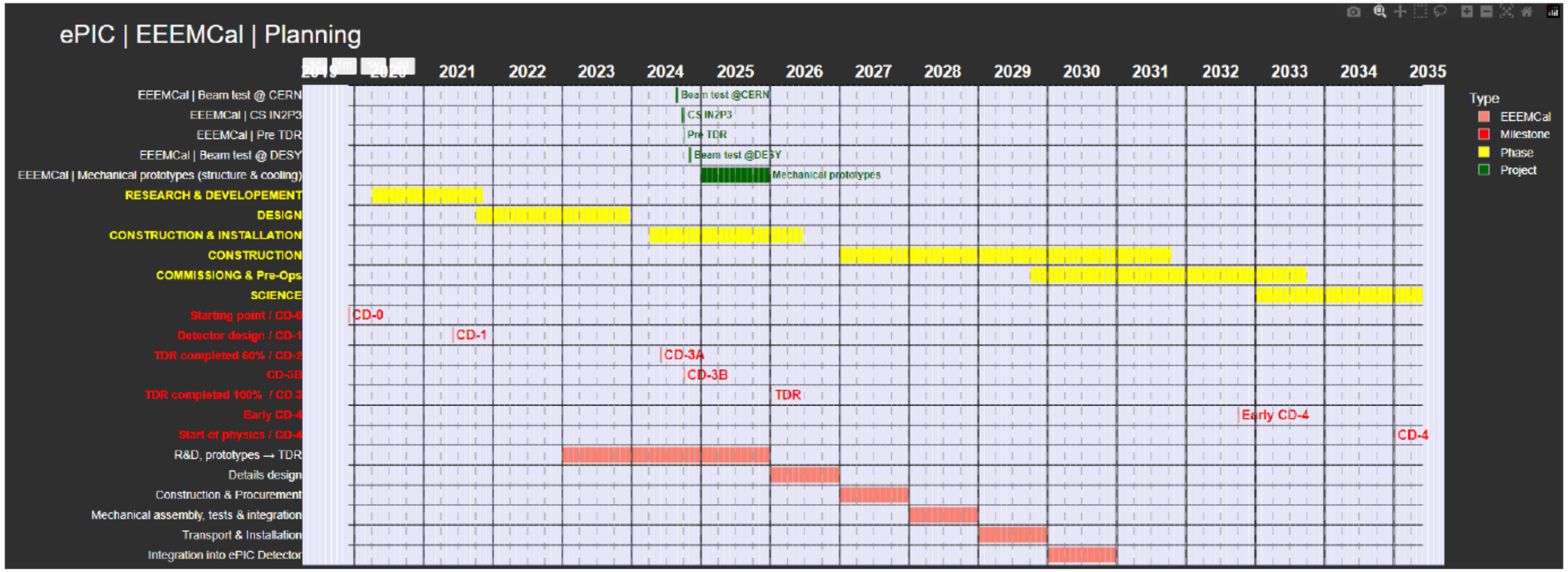
Online diagnostic plots





Organization and Development Overview

Item	Institutions
Crystals	CUA, UKY, JMU, MIT
MPPC	ACU, OU, Lehigh, FIU
Mechanical	IJCLab-Orsay
Signal Processing	IJCLab-Orsay, OU, ACU
Simulations and Software	AANL, UKY, AU, W&M



Front-End Board (FEB)
→ Location of the power to dissipate
→ Better estimation of the cables needed
→ Design of the FEB

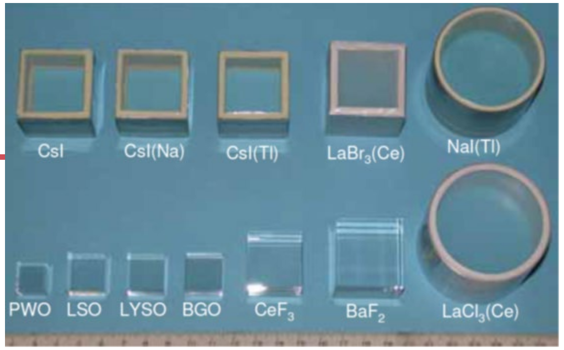
Mechanical design:
→ Internal structure + cooling
→ External structure + cooling
→ FEA simulation with advanced design
→ Thermal simulation with advanced design

Installation requirements
→ Clearances
→ Location of the rails for the assembly
→ Services

Summary

- Design of EEEMCAL is nearing 90% completion.
- Crystal first (140) articles have passed QA
- Remaining technical work in FEE is progressing well and expected to reach 90% mark soon
- Thermal simulations complete
- Multiple prototype beam tests completed, engineering articles complete and last phase of beam tests ongoing
- Last aspects of integration (FEE and associated cooling) need to be finalized after test beam completed
- Still deciding on final assembly at JLab or BNL
- EEEMCAL is on track to be technically ready for baselining at the end of the year

Context for $PbWO_4$ Specifications



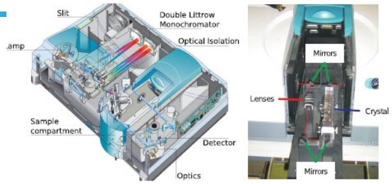
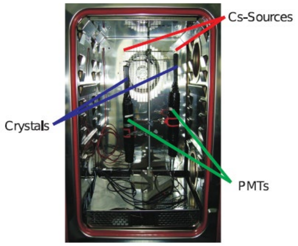
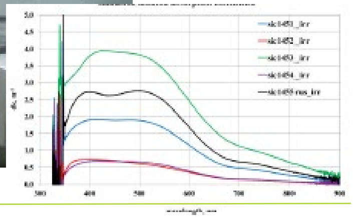
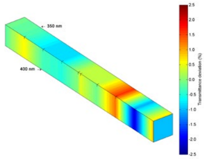
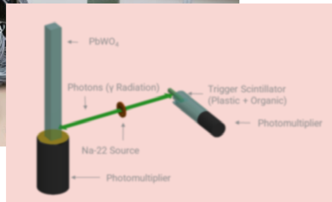
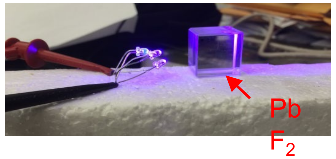
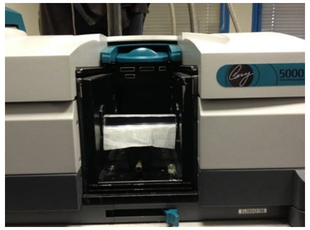
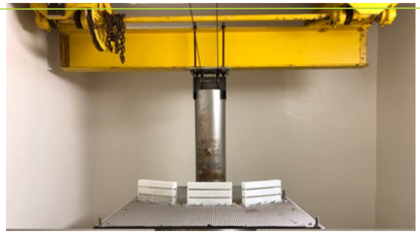
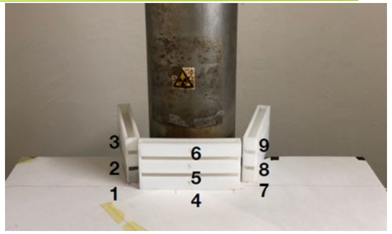
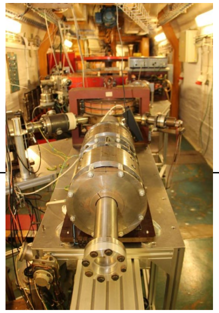
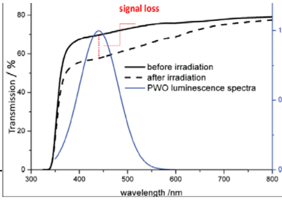
In general, for high-precision electromagnetic calorimetry, the following are of relevance:

- Smaller radiation length for smaller longitudinal size
- Smaller Moliere radius allowing higher granularity
- Smaller decay time
- Better energy resolution. Larger number of photoelectrons per MeV to reach higher resolution
- Smaller constant term contribution to energy resolution, mainly due to non-uniformity and gaps, to readout and noise. → for sensitivity checks need tests with detector prototypes in beam
- Reasonable temperature dependence to light yield
- Higher radiation hardness (EM and/or hadron fluences)

Parameter ======= Material	Density (g/cm^3)	Rad. Length (cm)	Moliere Radius (cm)	Decay time (ns)	Light Yield (γ/MeV)	dLY/dT (%/°C)	Rad. Hard. (krad)
NaI(Tl)	3.67	2.59	4.13	245	41000	-0.2	1--2
CsI(Tl)	4.51	1.86	3.57	1220	60000	0.4	1
CsI	4.51	1.86	3.57	35 6	1600 400	-0.6 -1.4	1
BaF_2	4.89	2.03	3.1	650 0.9	16000 2000	-1.9 0.1	>50
CeF_3	6.16	1.70	2.41	30	2800	~0.1	>100
(BGO) $Bi_4Ge_3O_{12}$	7.13	1.12	2.23	300	8000 4000	-0.9 -1.6	>1000 (recovery
(PWO) $PbWO_4$	**8.3**	**0.89**	**2**	**30 10**	**40 240**	**-2.5**	**>1000**
SciGlass	3.7-4.5	2.2-2.8	2--3	20-50	500-2000	None	>1000

$PbWO_4$ meets the requirements of an extremely fast, compact, and radiation hard scintillator material providing sufficient luminescence yield to achieve good energy resolution.

QA facilities at Universities

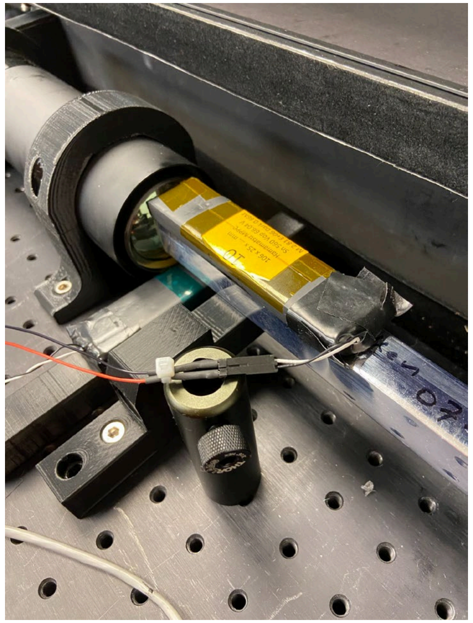
	Optical Transmittance (L/T)	Crystal light yield and timing	Radiation Hardness and recovery
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN	 Modified Varian Cary 5000 spectrometer	 Cs-137 source and calibrated 2-inch PMT (Hamamatsu R2059-01) with QE(420nm)=24%.	 Co-60 sources 
THE CATHOLIC UNIVERSITY OF AMERICA	  Perkin-Elmer Lambda 950 spectrometer	   Na-22 source and 2-inch PMT (XP2262)	  x-ray irradiation system (Faxitron CP-160)
IJCLab Irène Joliot-Curie	 Varian Cary 5000 spectrometer	 Cs-137 source and 2-inch PMT	  Co-60 source, 222 TBq, simultaneous irradiation of nine crystals/water; different dose rates possible
CHARLES UNIVERSITY			   Electrons 5.5 MeV < E_e < 16.6 MeV; adjust beam intensity to illumination with g rays (Co-60, 30 Gy)

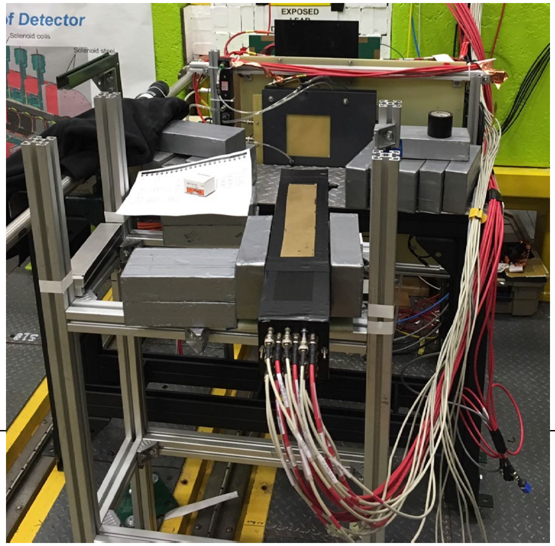
Electron-Ion Collider

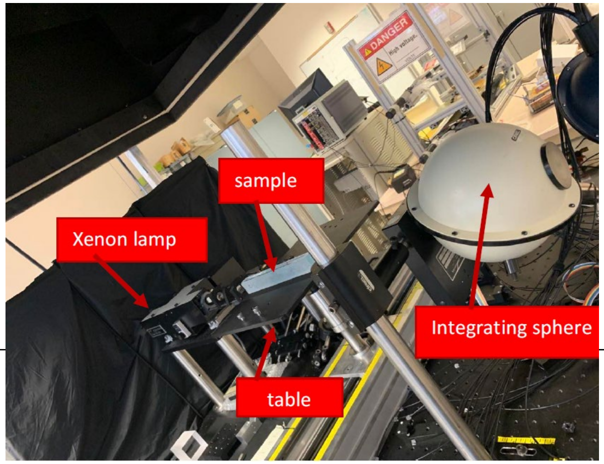
JLab crystal test facility for $PbWO_4$ QA and prototype

Jefferson Lab
Thomas Jefferson National Accelerator Facility

- ❑ Dedicated cleanroom facility for crystal characterization
  - ➢ Mitutoyo QM - for mechanical dimensions measurements. Precise to 1 micron.
  - ➢ Crystal Light Yield measurements
  - ➢ Optical transmittance with integrating sphere
  - ➢ Radiation hardness in beam
- ❑ Beam test facility with tagged photon beam up to 4-5 GeV
  - ➢ Technique demonstrated successfully for NPS can be adapted for EIC prototype tests







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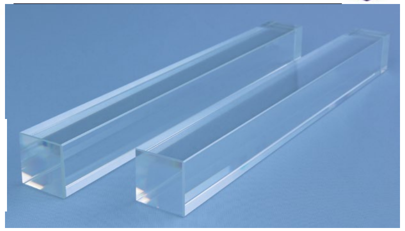
$PbWO_4$ crystal production for JLab Projects

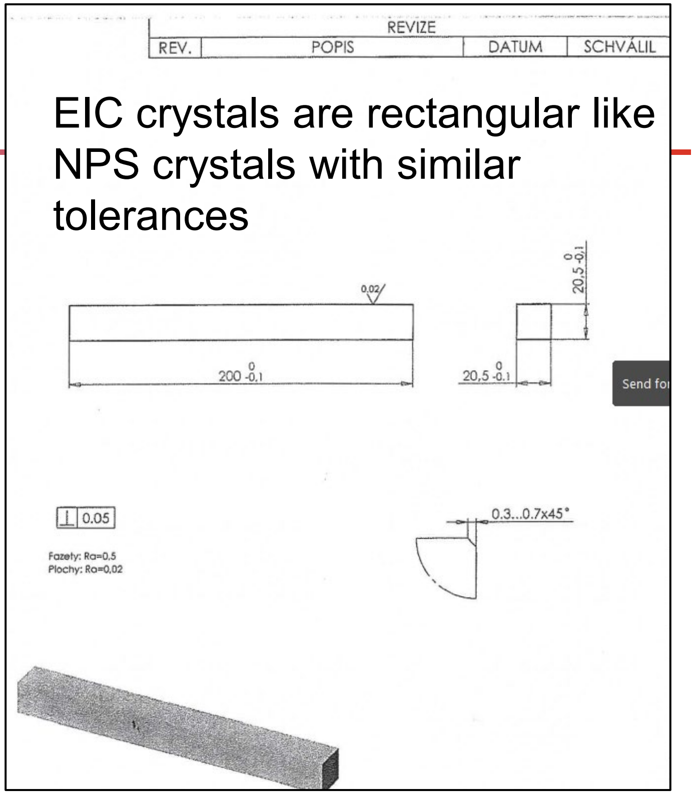
Production of PWO crystals at CRYTUR – Turnov, Czech Republic

- long tradition in the production of inorganic scintillators. Restart of PWO production in 2014
  - ➢ production based on Czochralski technology



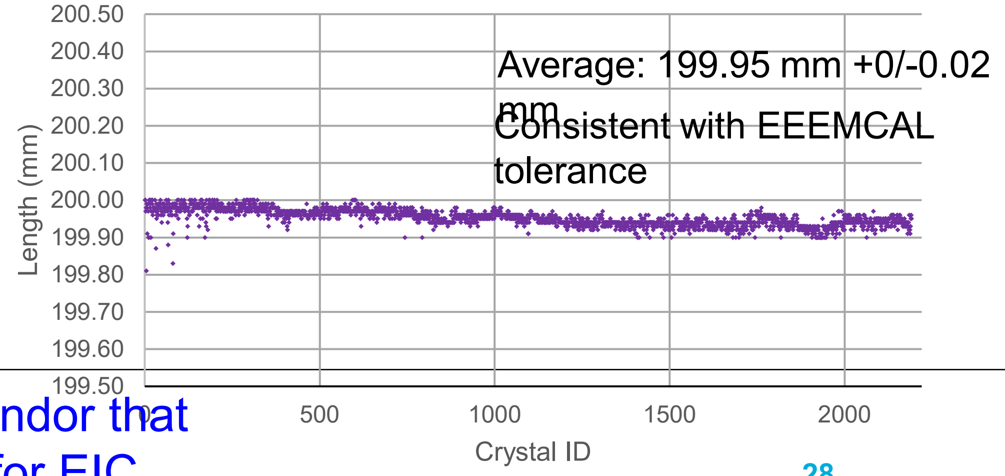
7

- ❑ ~2190 PWO crystals delivered continuously for projects at JLab since 2017
- ❑ Crystals used for both NPS and FCAL-2
- ❑ All 1100 NPS crystals for NPS passed the NPS quality assurance tests (similar for FCAL-2)



EIC crystals are rectangular like NPS crystals with similar tolerances

Length uniformity of CRYTUR crystals (2017 – present)



CRYTUR is a well established and tested vendor that can deliver crystals of the quality needed for EIC