Latest Development of PWO-Based Detectors for Electromagnetic Calorimetry

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CRYTUR

History of PWO

- building of PANDA detector - production of PWO-II at BTCP
- after bankruptcy of BTCP: 6700 missing prisms for PANDA
- 2015: re-started PWO production at Crytur (terminated in 90´s), new R&D period
- 2017: delivered 112 prisms meeting requirements for PWO-II.
- 1Q 2018: increasing of production capacity, start of mass production
- 2Q2023: about 3100 crystals delivered so far

Production of PWO – crystal growth

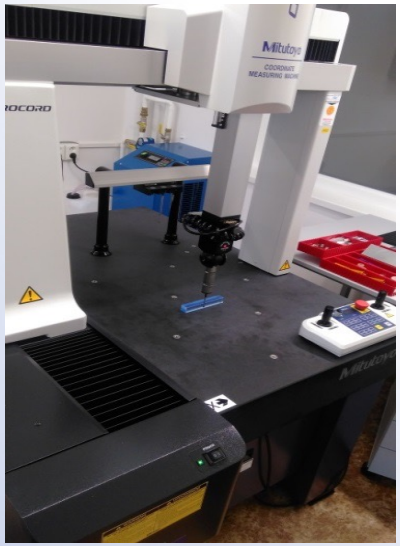
Production of PWO – machining

- cutting on wire saw
  - minimalization of kerfs
  - gentle method

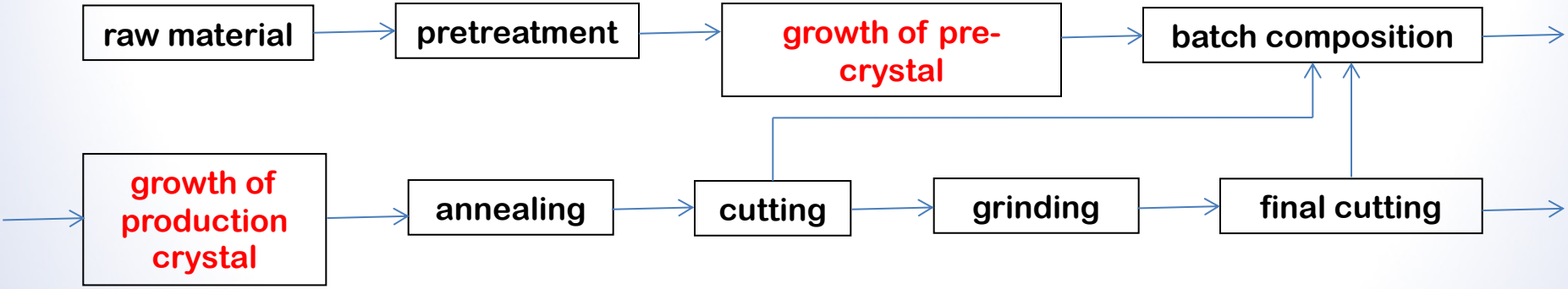
- grinding with SiC
- polishing with diamond
- meeting ecology and health protection requirements

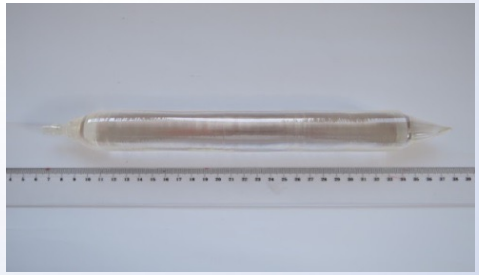
Production of PWO – quality control

- 3D coordinate measuring machine
- device for LY measurement
- spectrometer
- method for radiation hardness measurement in Mikrotron MT25 in Prague
- With help of the Prague group



Technological diagram





PRODUCTION QUALITY

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Scintillating crystals for the Neutral Particle Spectrometer in Hall C at JLab

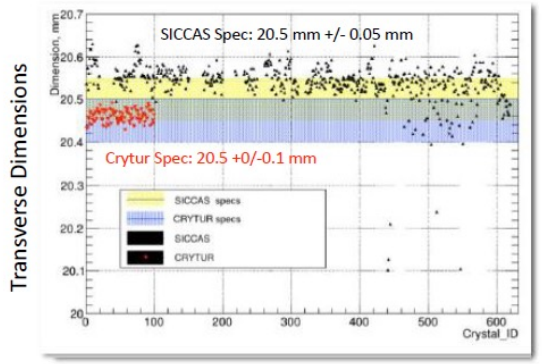
T. Horn [a,b,*], V.V. Berdnikov [a], S. Ali [a], A. Asaturyan [c], M. Carmignotto [b], J. Crafts [b], A. Demarque [d], R. Ent [b], G. Hull [e], H.-S. Ko [e,f], M. Mostafavi [d], C. Munoz-Camacho [e], A. Mkrtchyan [c], H. Mkrtchyan [c], T. Nguyen Trung [e], I.L. Pegg [a], E. Rindel [e], A. Somov [b], V. Tadevosyan [c], R. Trotta [a], S. Zhamkochyan [c], R. Wang [e], S.A. Wood [b]

PRODUCTION QUALITY

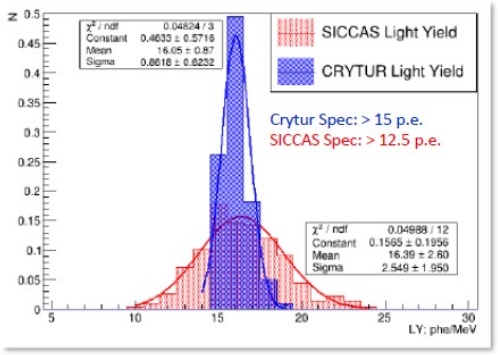
PWO Crystal Quality

- Characterized 560 SICCAS crystals and 350 Crytur crystals
- SICCAS rejection rate ~ 35% for crystals received from 2017-2019 due to visual/mechanical defects (22% due to transmission or LY)
- Crytur acceptance rate 100% so far

Mechanical Tolerances



Light Yield



Light yield

Radiation Hardness

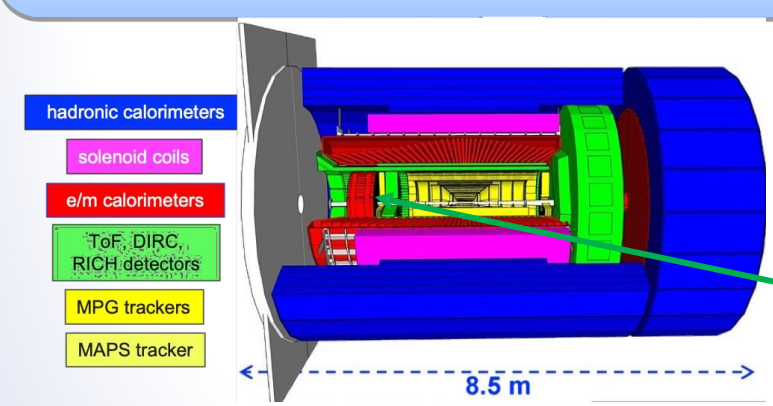
Exposure: 30 Gy ^{60}Co

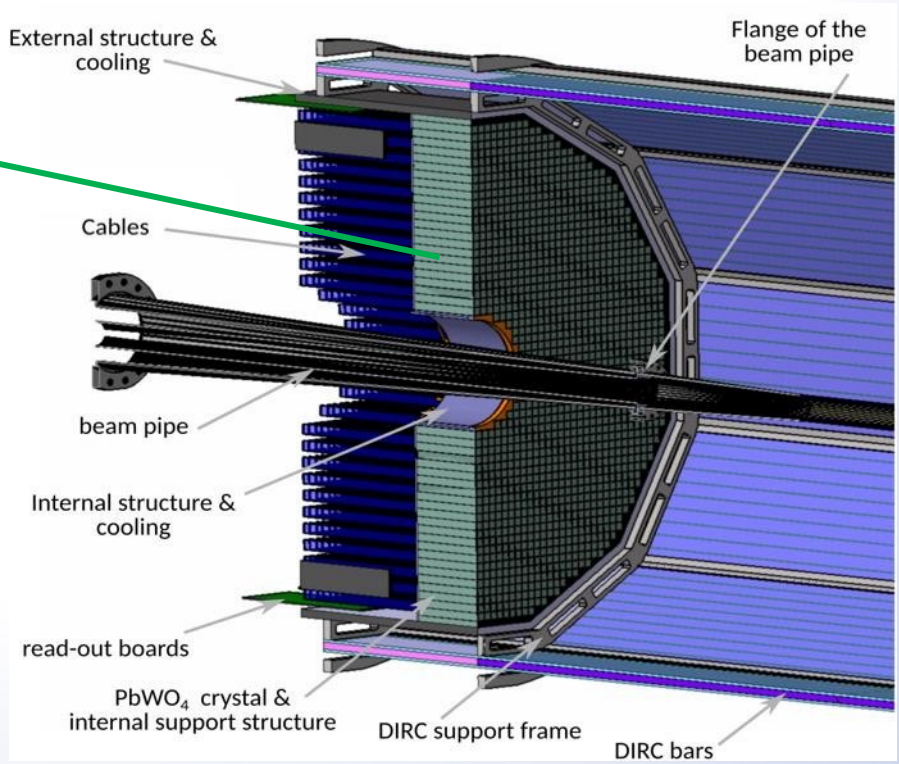
PRODUCTION

- Totally 3100 crystals were produced since start in 2016
- About 800 pcs for PANDA
- 2200 pcs for Jefferson Lab
- 100 crystals for INFN

- Yearly capacity currently about 750 crystals

EIC detectors





$PbWO_4$ crystals (20 x 20 x 200 mm^3) for the Electron Endcap Electromagnetic Calorimeter (EEEMCAL)

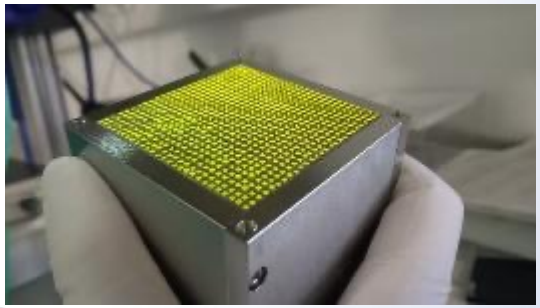
Density (g/cm^3)	8.28
Hardness (Moh)	4
Refractive index	2.17
Melting point (°C)	1123
Crystal structure	Tetragonal symmetric
Hygroscopic	No
Wavelength max emission (nm)	420
Decay constant (ns)	5 - 15
Photon yield (ph/MeV)	15 - 25
Molière radius (cm)	2.0

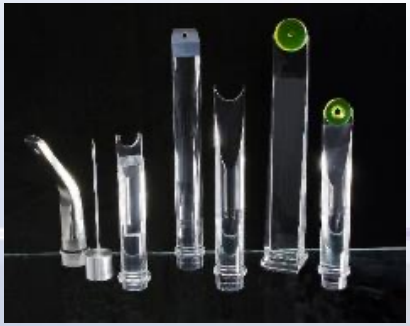
INTEGRATED OPTO-ELECTRONIC SOLUTIONS

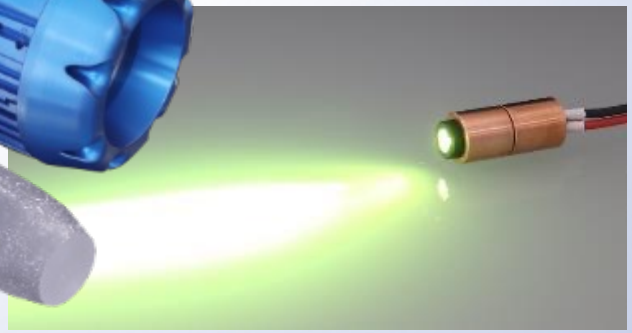
CRYTUR wants to offer complete solution, including mechanics and electronics

PRODUCTION PORTFOLIO

- Global No. 1 supplier of detection units for electron microscopy
- The largest European manufacturer of laser rods
- Leader in single-crystal phosphors for high power LED/LD
- Very strong in radiation detectors







Initial EEEMCAL design specifications

Overview of Initial EEEMCal Design Specifications

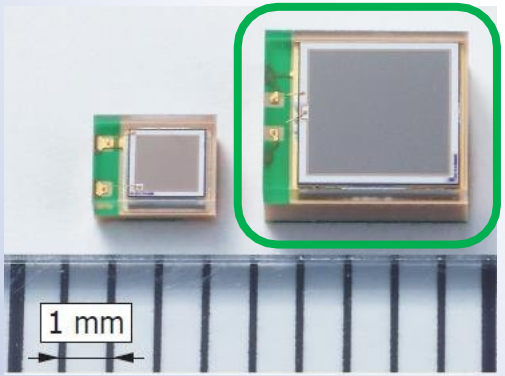
- Coverage: -3.5 < eta < -1
  Rin=15cm, Rout=49cm
- Egamma:
  20 MeV – 20 GeV
- Energy Resolution:
  1%+2.5%/sqrtE+1%/E
- Spatial Resolution:
  - 1mm+3mm/sqrtE
- Maximum Annual Dose at top luminosity:
  - EM: ~3krad/year (30 Gy/year)
  - Hadron: 10^10 n/cm2
- Signal dynamics
  - 2 V dynamic range
  - ADC bits
- Signal Rate: =<1 MHz/channel
- Digitization Gate: ~(100-200) ns
- Sampling Rate: 250 MHz
- Peaking Time: ~4ns
- Data sparsification/feature extraction
  - Peak
  - Integral
  - Time
  - Pedestal
  - Number samples
  - Pulse quality
  - Pileup detection and recovery

High magnetic field environment precludes use of PMTs

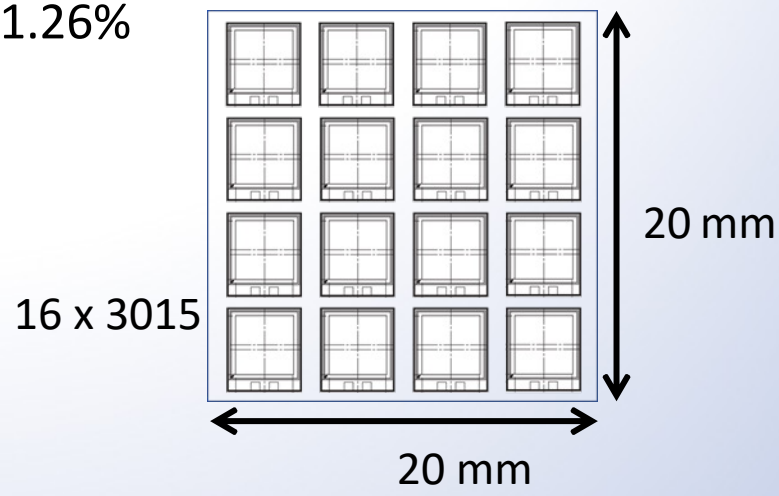
SiPM?

Good candidate: Hamamatsu S14160-3015

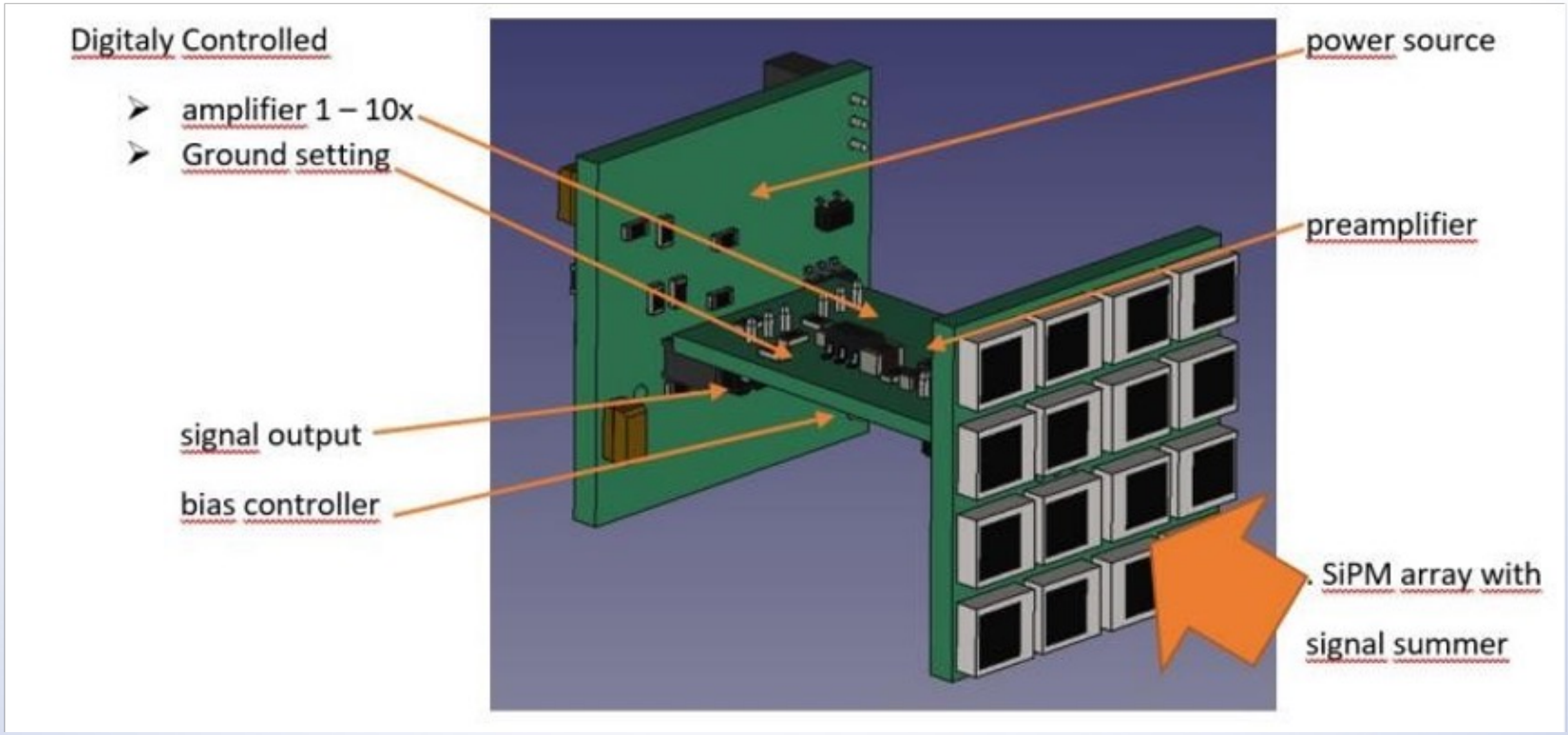
- 3 mm x 3 mm
- PDE 32% (420 nm)
- 15 µm microcells
- Anode capacitance 530 pF
- Dark count rate 700 kcps (typ.)
- VOP variation within reel
  ±0.1V (± 8% gain)



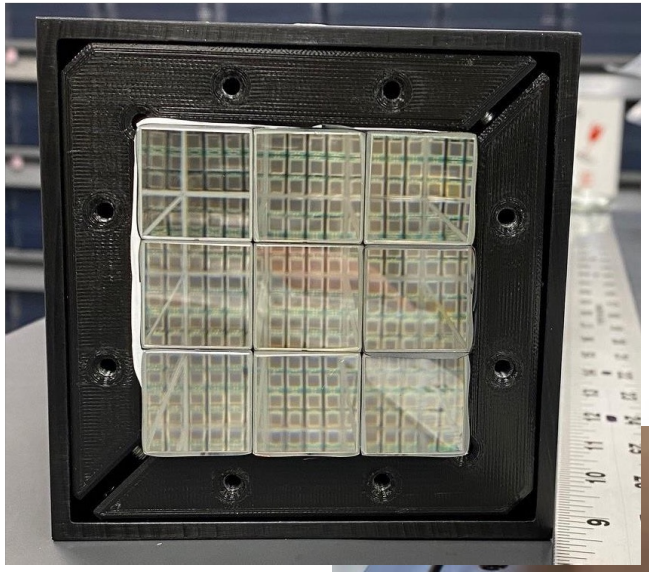
- ➢ 16 pcs to fill 20 mm x 20 mm
- ➢ Active fill: 36% of area
- ➢ Rough computation for # activated cells for 15GeV deposited in crystal: 1588/SiPM
- ➢ Expected Integral Non-linearity at 15GeV: 1.26%



Mechanical assembly



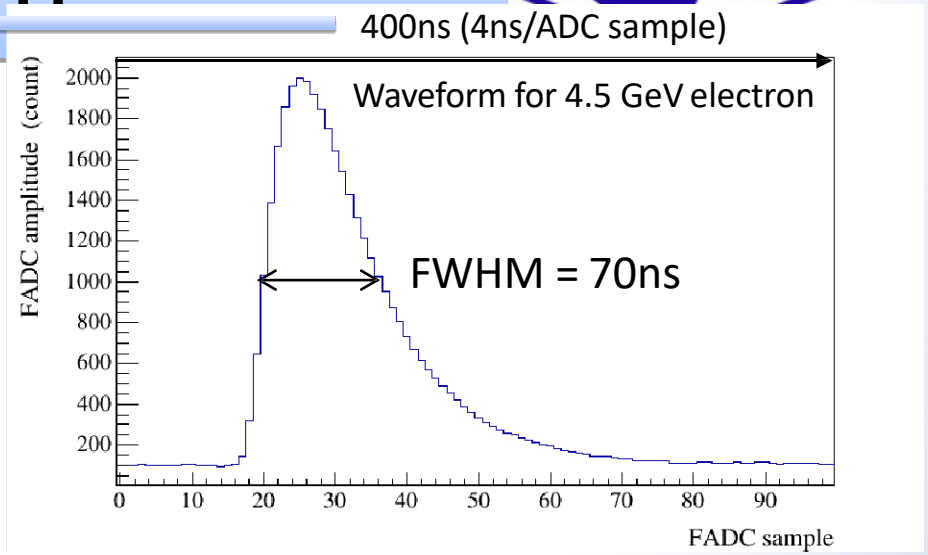
Detector prototype

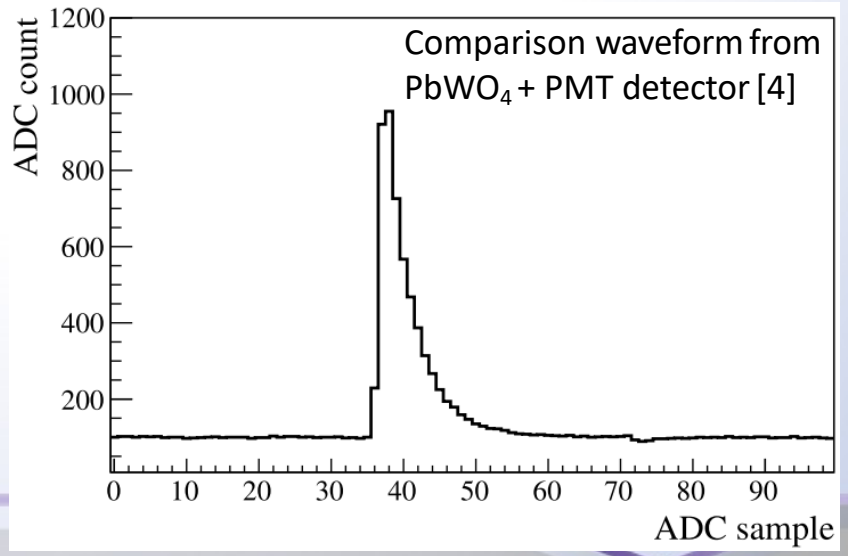


3x3 $PbWO_4$ crystals (20 x 20 x 200 mm^3)
Each crystal coupled to 4x4 SiPM array
Low power consumption, no active cooling required

Signal acquisition

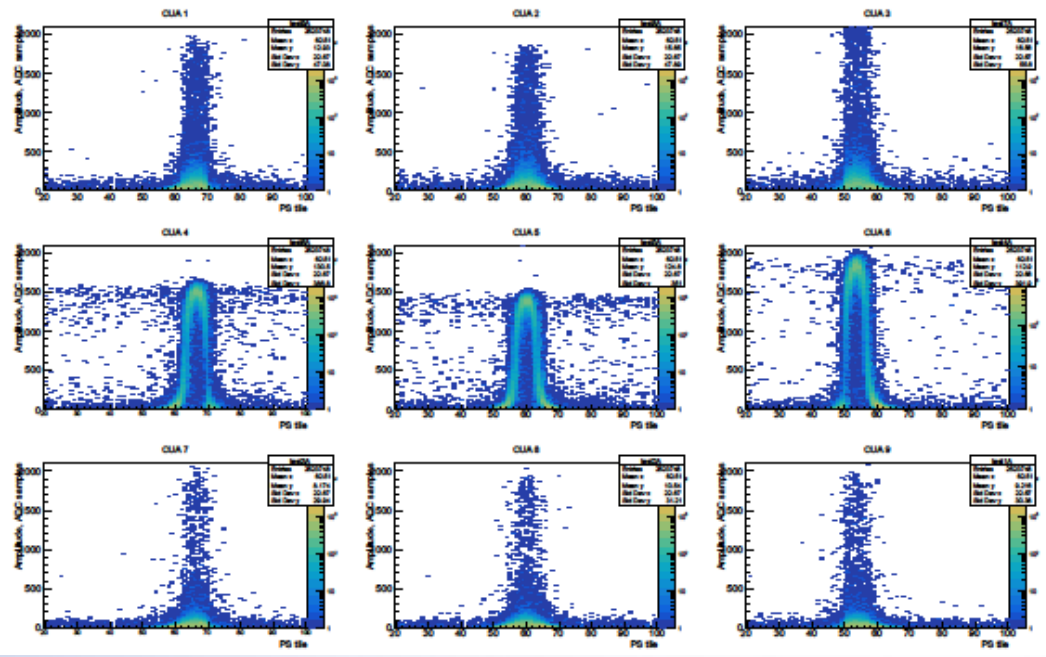
Detector output to ADC
50 ft long LEMO-LEMO cable
JLab fADC250 digitizer [3]
1V dynamic range
12 bit ADC



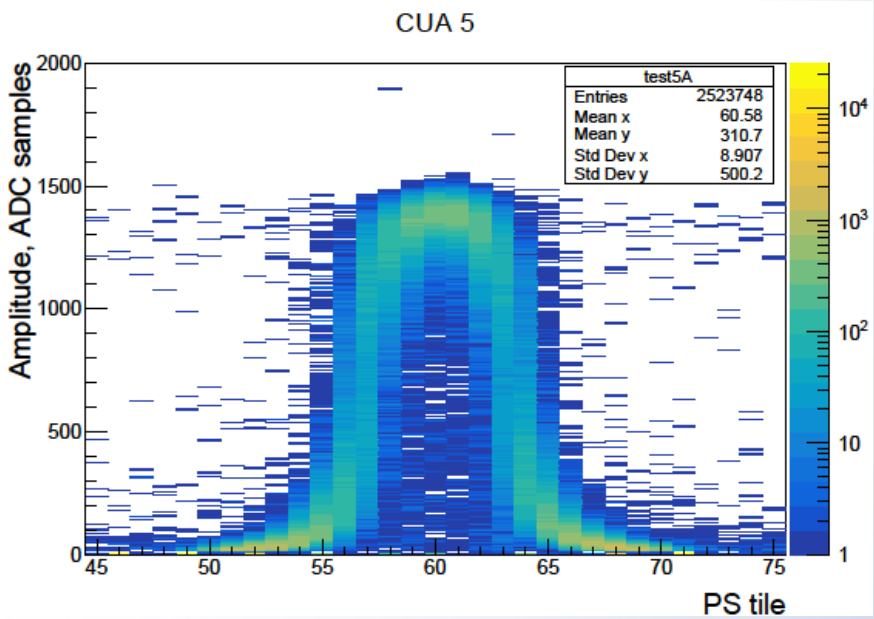


3A VME64x, 16-Channel, Pipelined 250 MSPS Flash ADC With Switched Serial (VXS) Extension, F.J. Barbosa et al., Thomas Jefferson National Accelerator Facility, Newport News, Virginia
4A. Asaturyan et al., “Electromagnetic calorimeters based on scintillating lead tungstate crystals for experiments at Jefferson Lab”,Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,Volume 1013, 2021, 165683, ISSN 0168-9002, https://doi.org/10.1016/j.nima.2021.165683

Detector response measurements

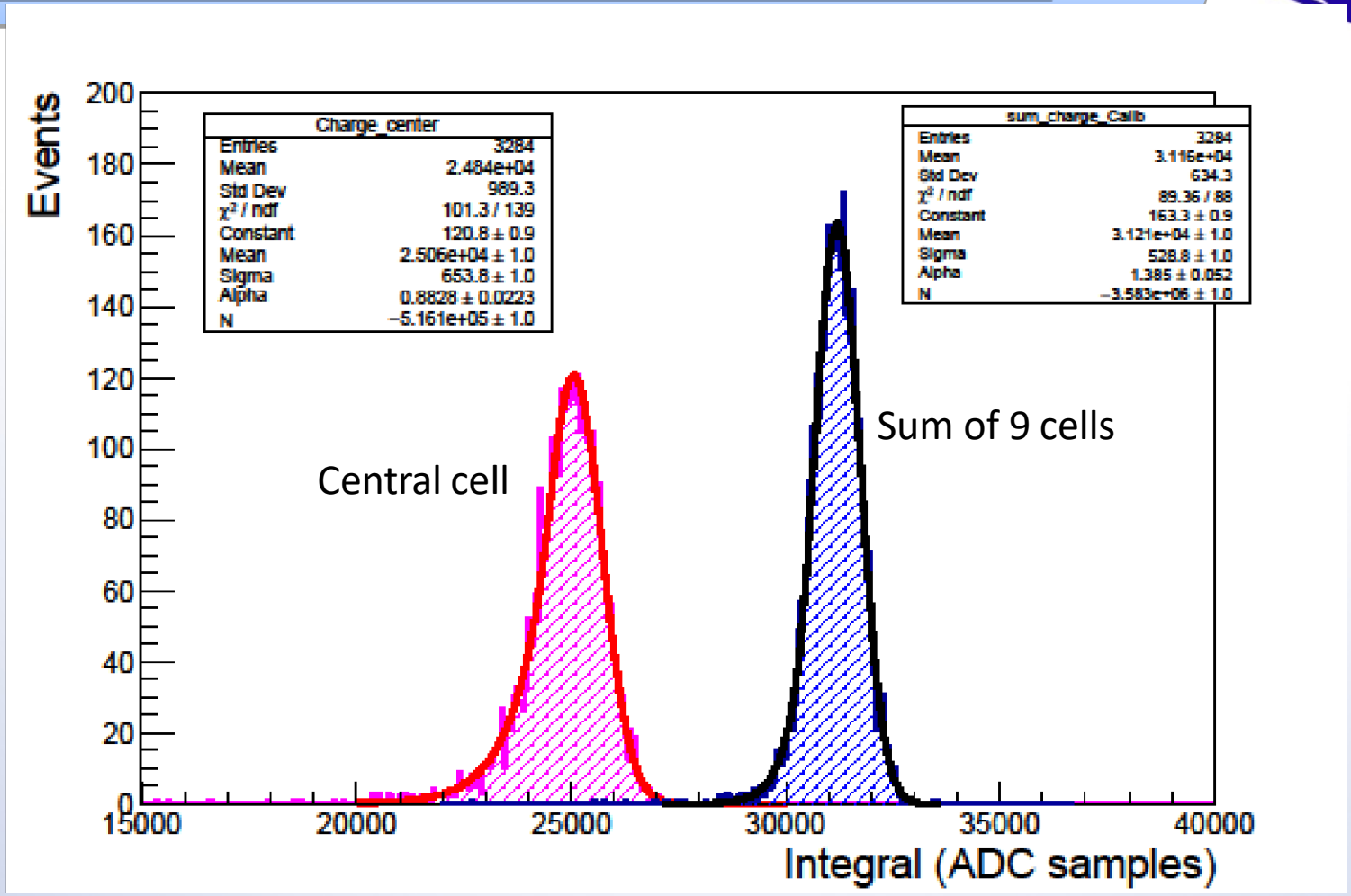


Charge response of 3x3 channels vs. pair spectrometer tile number (energy)



Central cell charge response vs. pair spectrometer tile number (energy)

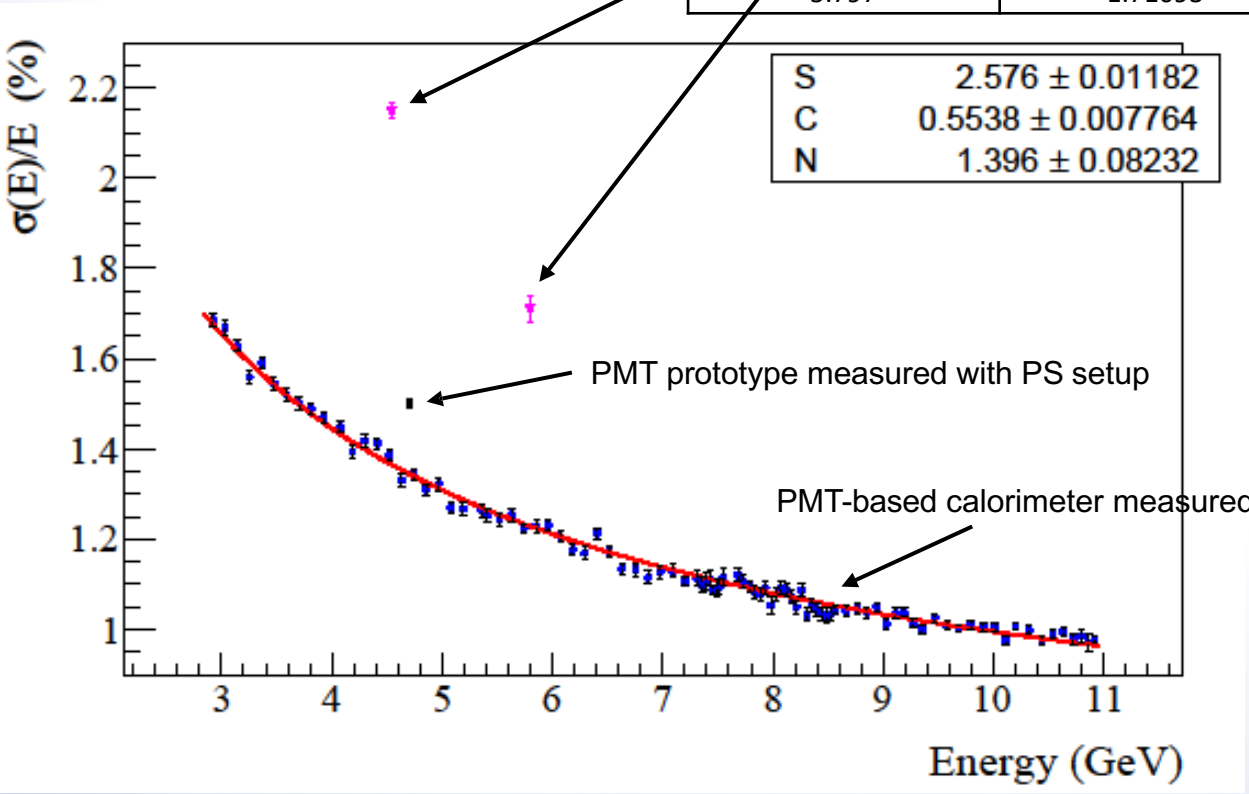
Energy resolution for 5.8GeV electrons

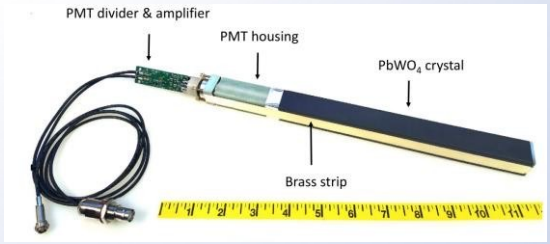


80% of total energy is deposited in the central cell in agreement with simulations

Spectral resolution results

Energy (GeV)	Resolution (%)	Res_error
4.542	2.14872	0.01644
5.797	1.71093	0.02872





Hamamatsu 4125

Summary

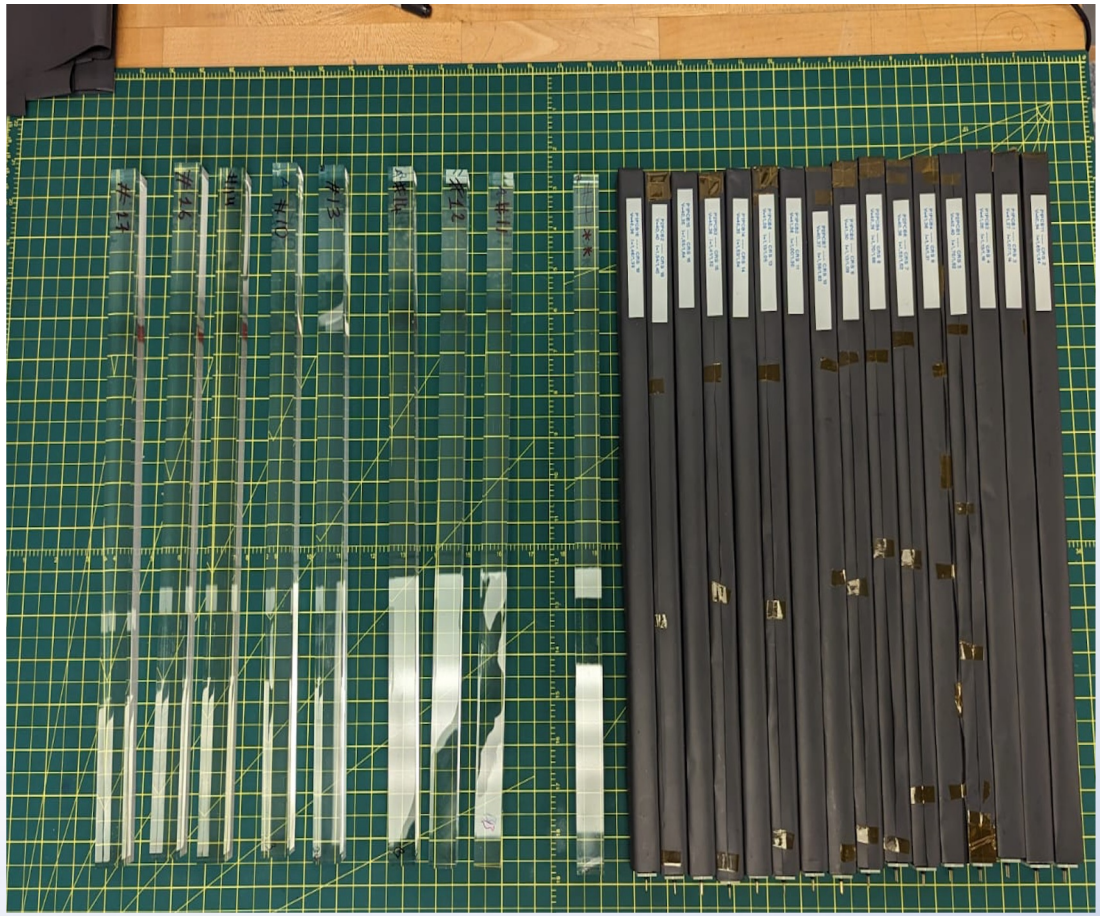
- Very first beam test results with PWO/SiPM prototype
- 4x4 array of S14160-3015 covers 20 mm x 20 mm with active coverage of 36%
- S14160-3015 have low capacitance, high PDE and low dark counts
- No sensitivity to magnetic field
- No High voltage required
- 3x3 $PbWO_4$ prototype goal to validate electronics design and performance for high energy physics applications
- Results on energy resolution are promising. Further tests planned for different energy ranges < 1 GeV with precise calibration of each module for defined energy
- Further improvements will be investigated
  - lower temperature (active cooling): low noise from SiPM and higher signal from $PbWO_4$
  - Readout threshold optimization
- Better performance with 5x5 $PbWO_4$ crystal array, capturing full particle shower (better energy deposition and energy resolution)

Glass instead of crystal

Glass developer by Scintilex

Tested in Jefferson Lab

20x20x400mm elements

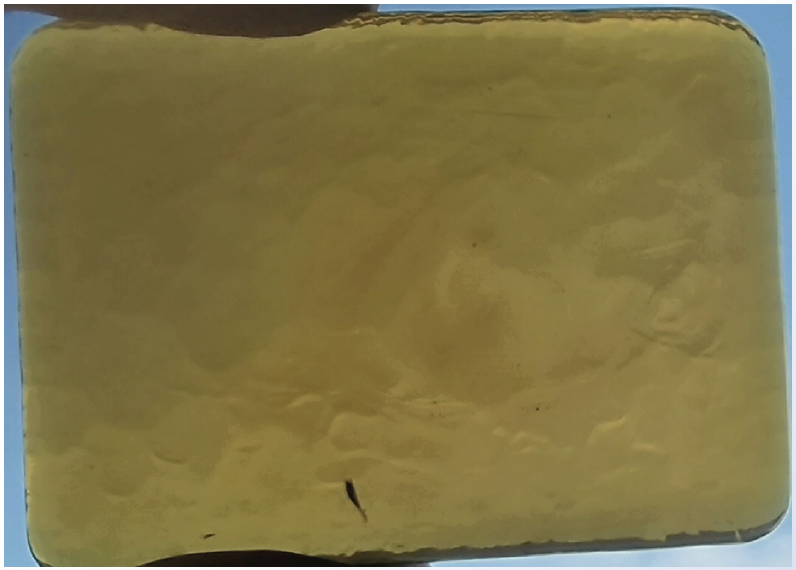


Gd-based glass

Developed by team of Mikhail Korjik
Decay time 60 ns, LY=2000 ph/MeV

8x50x70mm piece of defect and bubble-free glass prepared by Preciosa two weeks ago – melting point over 1500 C.

Still needs to be annealled and measured in CRYTUR



Summary

- **2Q2023 - 3100 PWO crystals delivered so far, without rejects**
- **3200 crytals need to be delivered for EIC**
- **Yearly capacity 750 crystals**
- **CRYTUR developed SiPM-based fast read-out electronics (FWHM=70 ns)**
- **3x3 PWO element with SiPM reaches a resolution of 2,14% at 4,5 GeV and 1,7% at 5,8GeV**
- **Work on scintillating glass continues**