Fast, Compact Readout of $PbWO_4$ crystals with SiPM arrays for Future Collider Calorimeters

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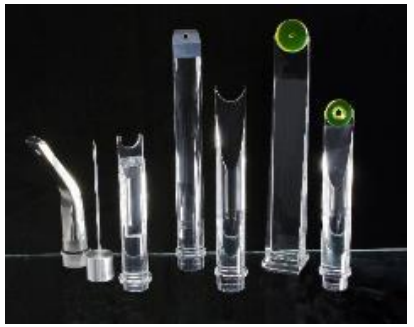
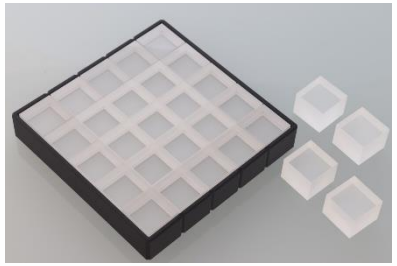
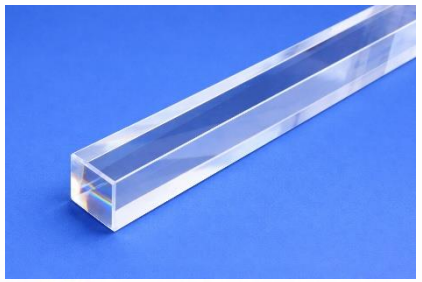
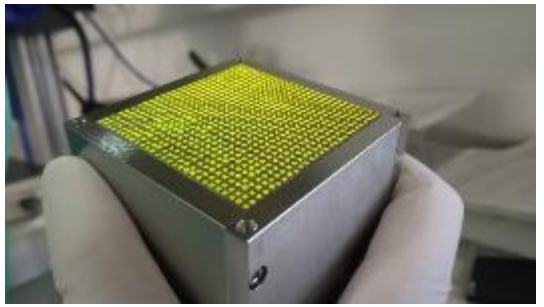
CRYTUR: Synthetic Crystal Growth and Opto-Electronic Solutions

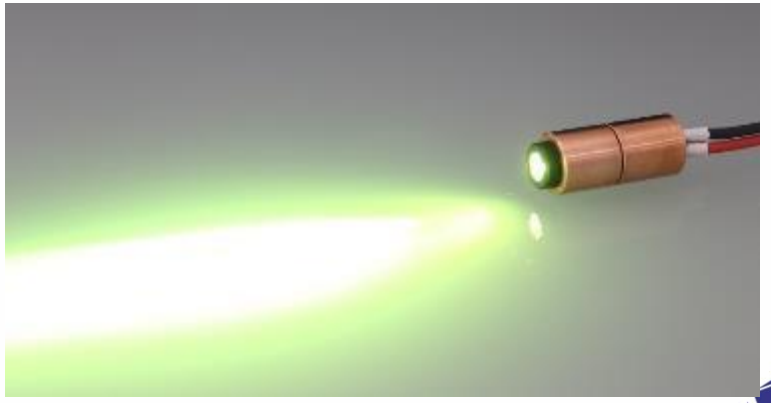
- Major supplier of detection units for electron microscopy
- European leader in laser rod manufacturing
- Developer of single-crystal phosphors for high-power LED/LD systems
- Active in the development of radiation hard materials and detectors











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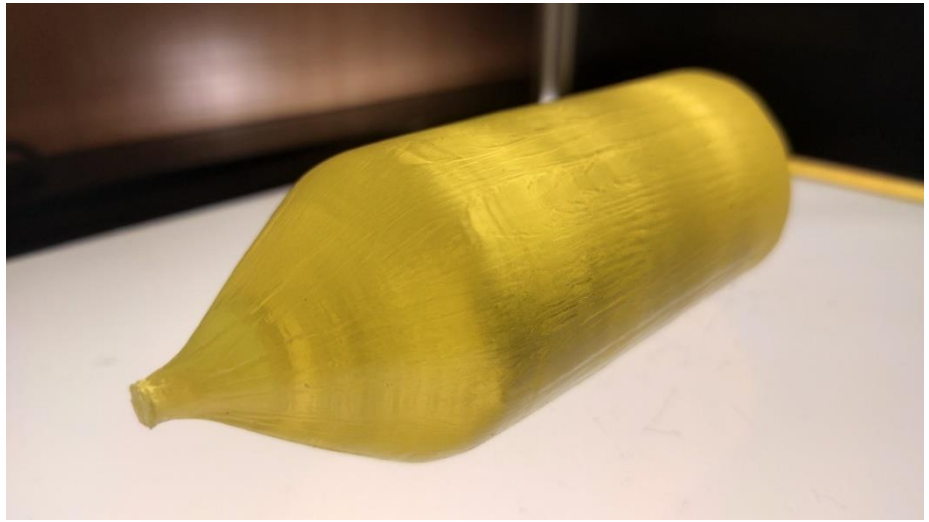
Radiation hard crystals for calorimetry applications
YAG:Ce, GGAG+

YAG:Ce

GGAG:Ce



- In-house crystal growth facilities
- Experience with optical, scintillation crystals
- Controlled atmosphere and temperature gradients

- High optical homogeneity
- Low defect density (dislocations, inclusions)
- Doping control and compositional uniformity
- Reproducible, scalable growth processes

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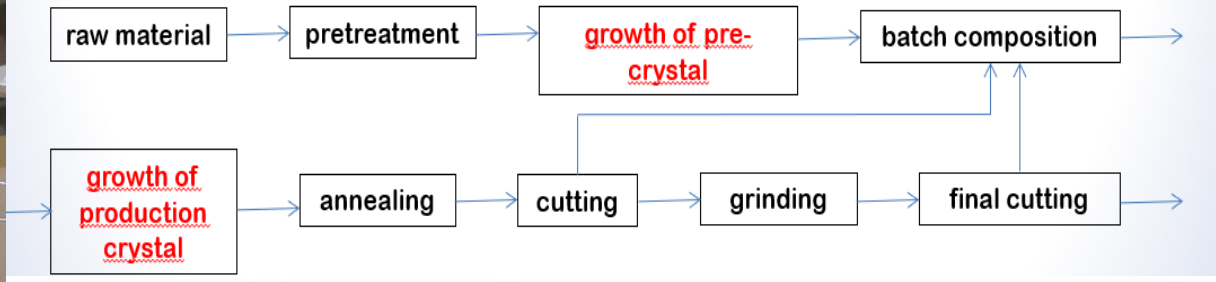
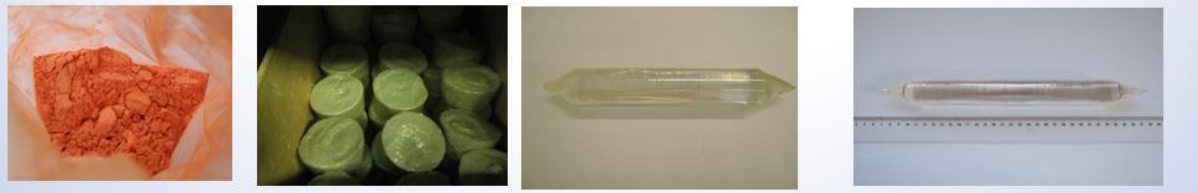
PWO crystal growth at CRYTUR

A multi-step process that results
in unparalleled quality of the **PWO** crystals

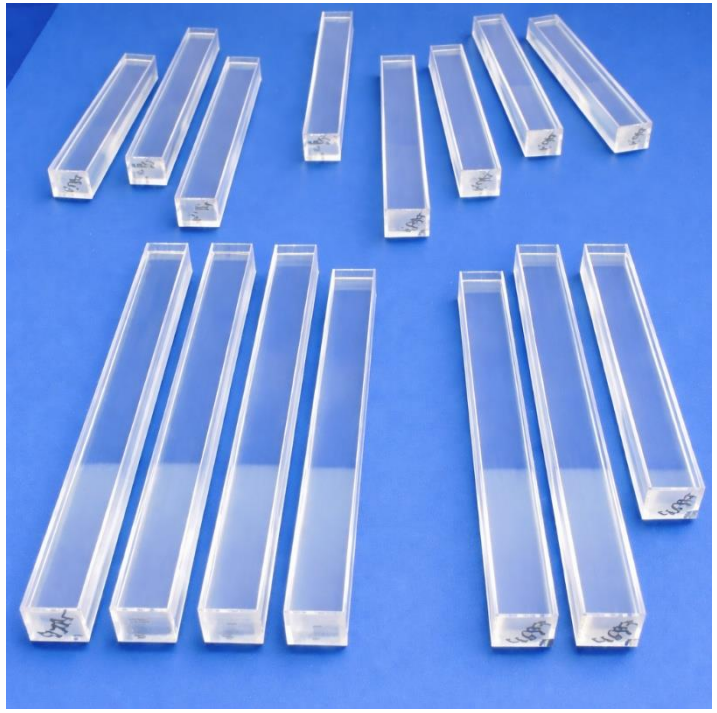


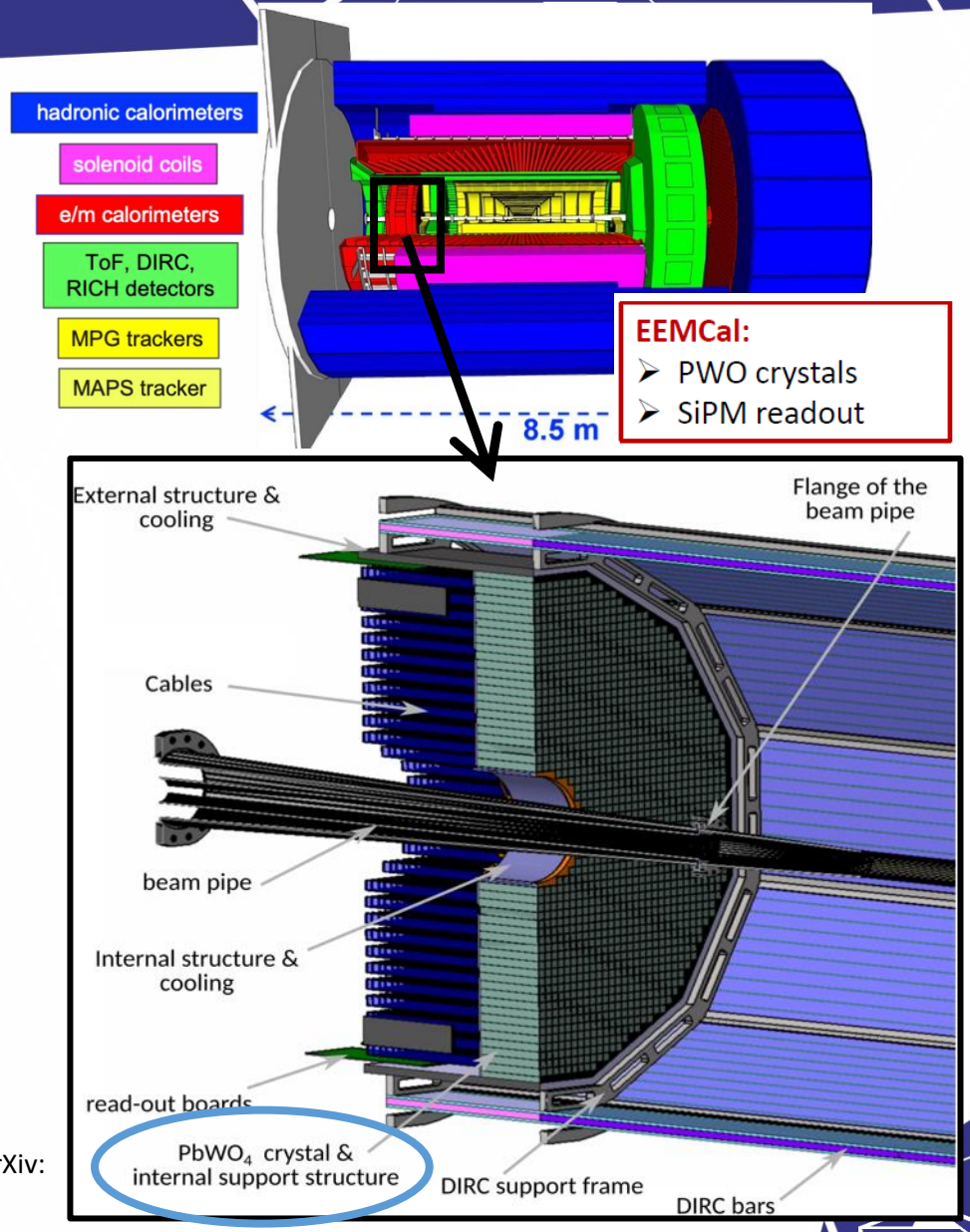


Motivation : EIC detectors

- PbWO4 crystals 20.5 x 20.5 x 200 mm3
  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



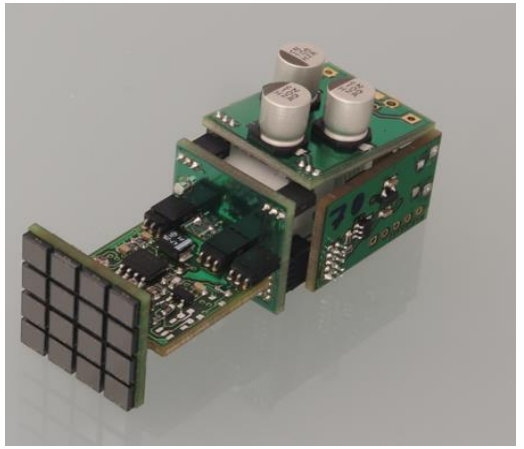


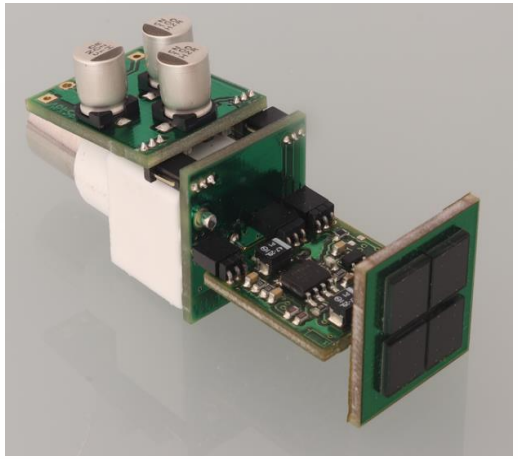
[1] R. Abdul Khalek et al., Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, arXiv: 2103.05419 (2021).

SiPM selected

- High spectral resolution
- Fast signal
- Wide dynamic range
- Good response linearity
- PDE
- Capacitance
- Fill factor
- Dark counts
- Size to fill 20 mm x 20 mm

Manufacturer	Hamamatsu	
type	S1460-30-15	S14160-6010
active area [mm]	3x3	6x6
pitch [mm]	15	10
pixels	39,984	359,011
efficiency [%/420nm]	32	18
dark count [kcps]	2,100	10,000
Gain	3,6x10^5	1,8x10^5
Capacitance [pF]	530	2,200
Gain * efficiency [10^3]	115.2	32.4
pixels per crystal	639,744	1,436,044
dark count per crystal	33,600	40,000
pixels/darkcount	19	36
signal / dark count	6.09	6.46

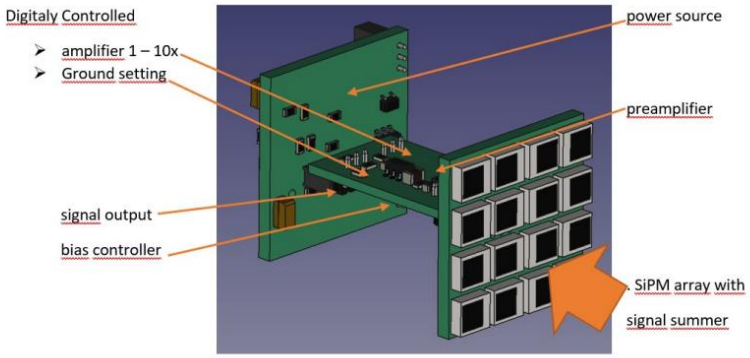


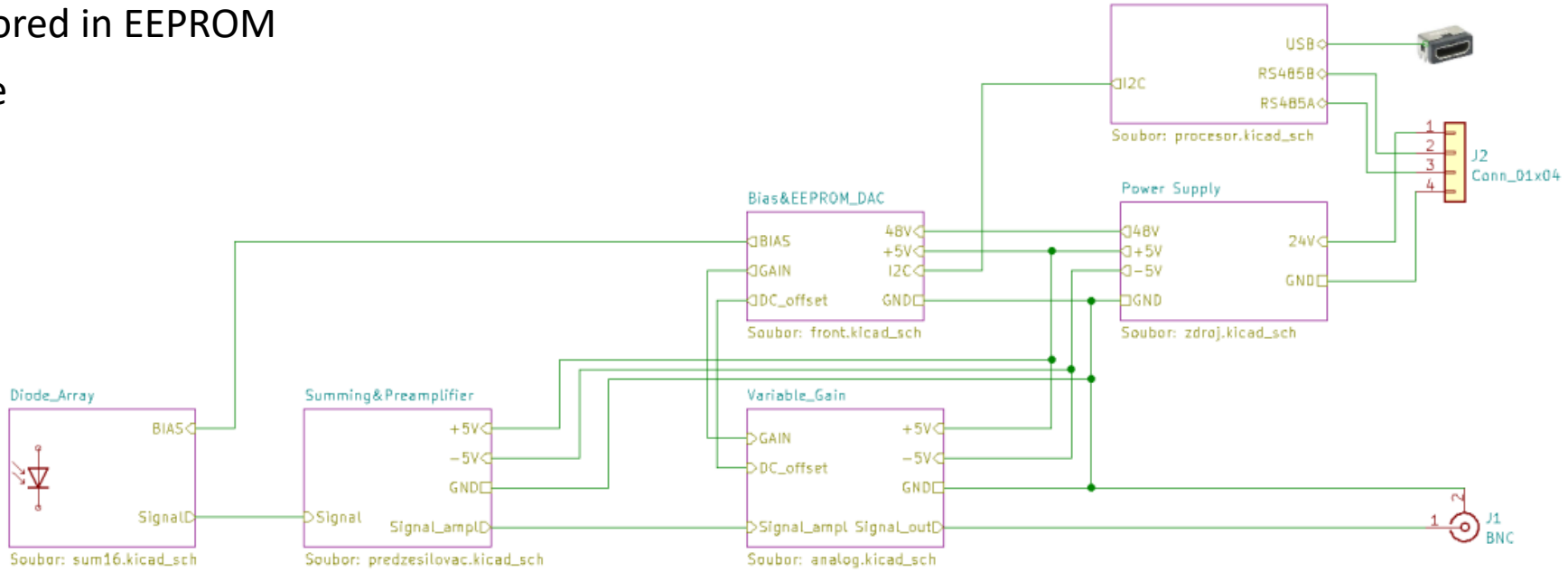


- We have good experience with Broadcom SIPMs but for different type of crystals(YAP:Ce)

Compact readout electronics

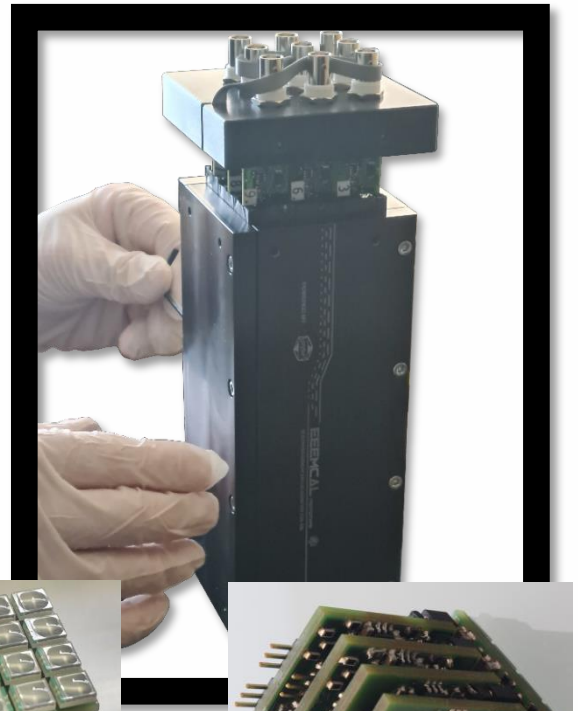
- SiPM wiring optimized for efficient collection of fast signals
- Signal summation and fast preamplification
- SiPM biasing with temperature stabilization
- Additional amplification stage with adjustable gain and offset
- Power supplies
- Configuration settings stored in EEPROM
- Communication interface

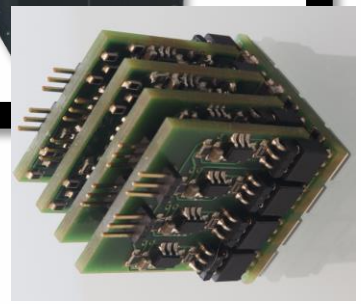




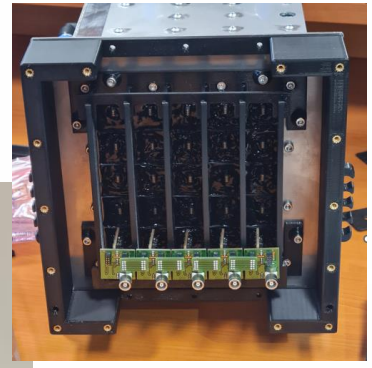
PWO prototypes by CRYTUR

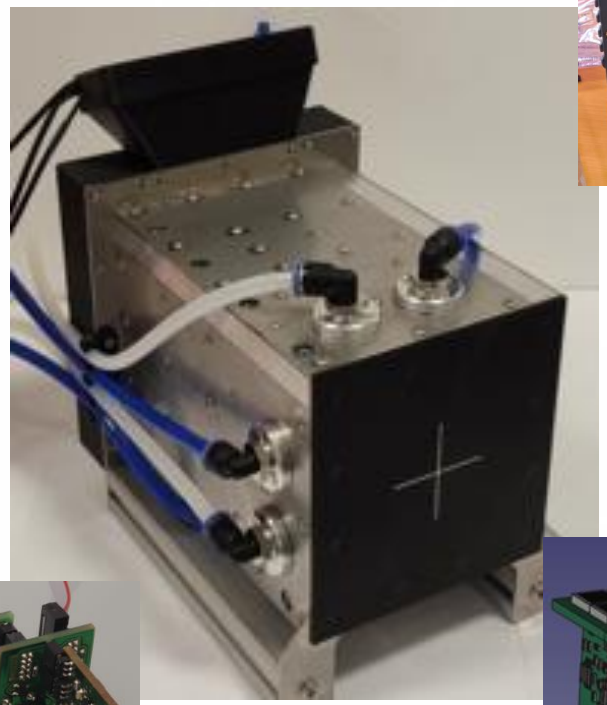
3x3 PWO crystals

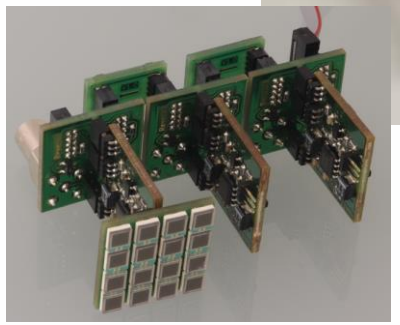


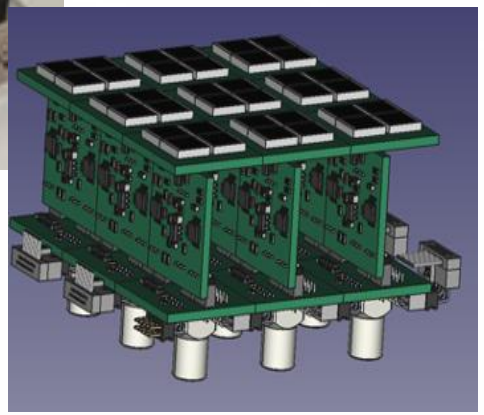


5x5 PWO crystals









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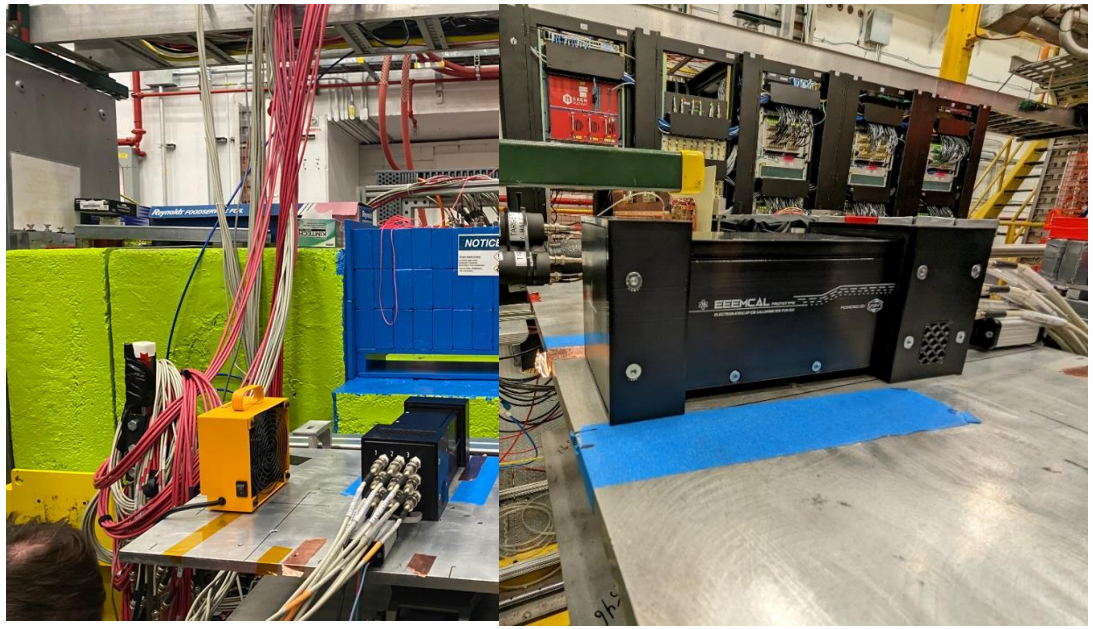
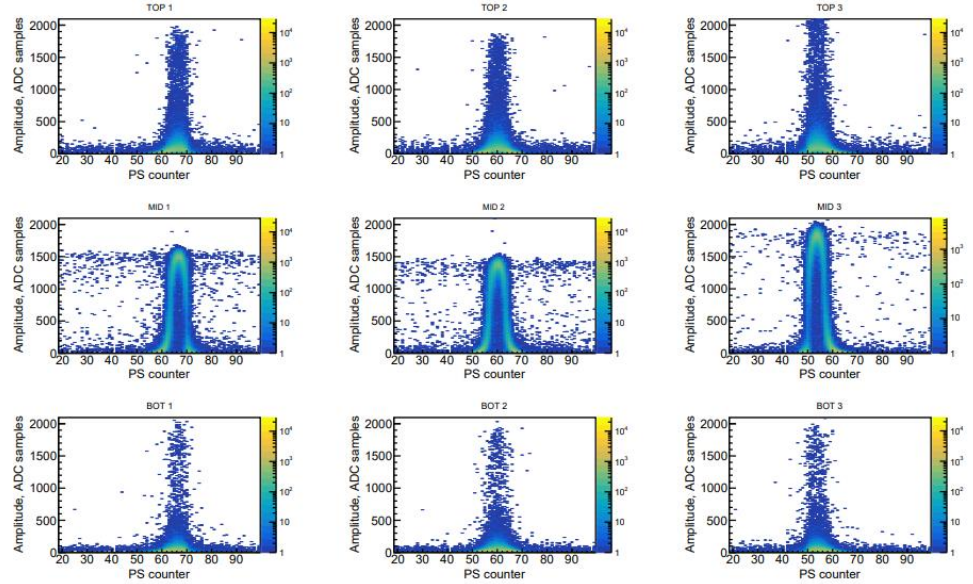
Test Beam Campaigns

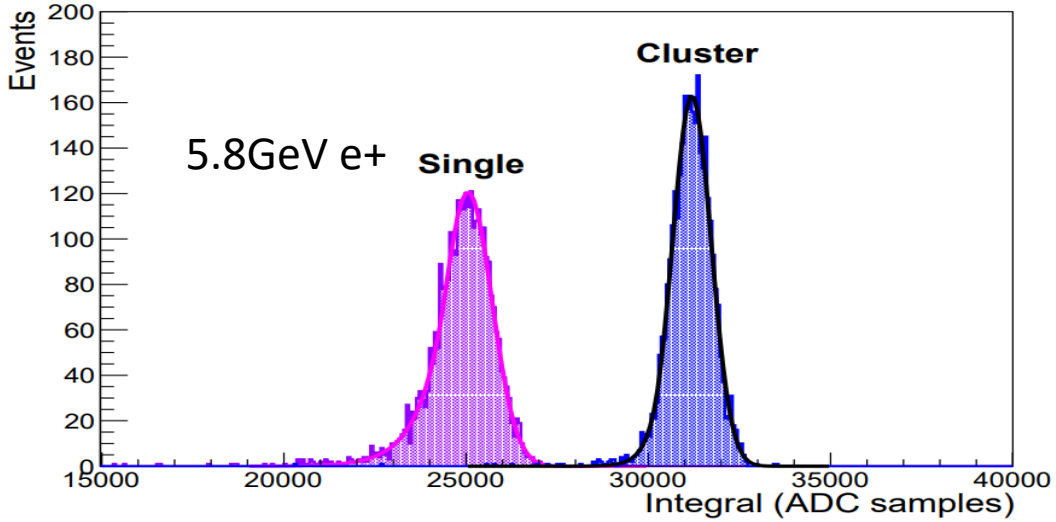
Beam	Facility	Configuration	Particles	Energy range	Purpose
TB1	**Jefferson Lab(USA)**	**3x3 PWO prototype** Single detector unit consists of 2x2x20 cm^3 PWO covered with ERS reflecting film + Tedlar foil Each crystal coupled to 4x4 SiPM (Hamamatsu S14160-3015) array,15um; PDE @420 nm = 32 % single SiPM (3x3 mm^2) has 39984 microcells; 16 SiPMs cover 36% area of PWO side (2x2 cm^2)	e^+	4.5, 5.7 GeV	Energy resolution
TB2	**MAMI (Mainz, Germany)**	**3x3 PWO prototype**	γ	19.4–410 MeV	Limitations at low energies, energy resolution
TB3	**DESY (Hamburg, Germany)**	**5x5 PWO prototype** Each crystal coupled to 2x2 SiPM S14160-6010; single SiPM (6x6 mm2) has 359011 active cells -10um pitch; 4 SiPMs cover 36% area of PWO side (2x2 cm2) ; PDE @420 nm = 18 %	e^-	1–5 GeV	Energy resolution, linearity

Test beam in Jefferson Lab Hall D



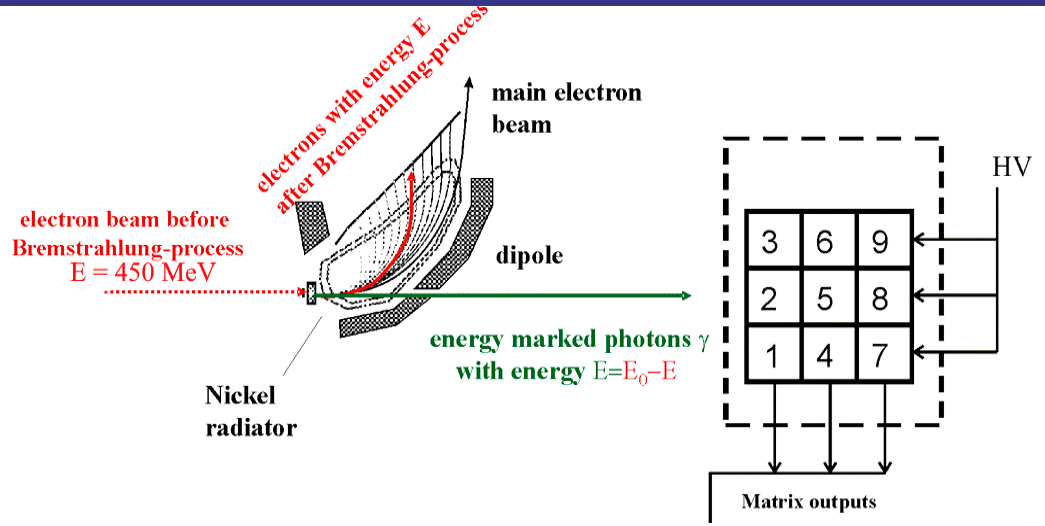


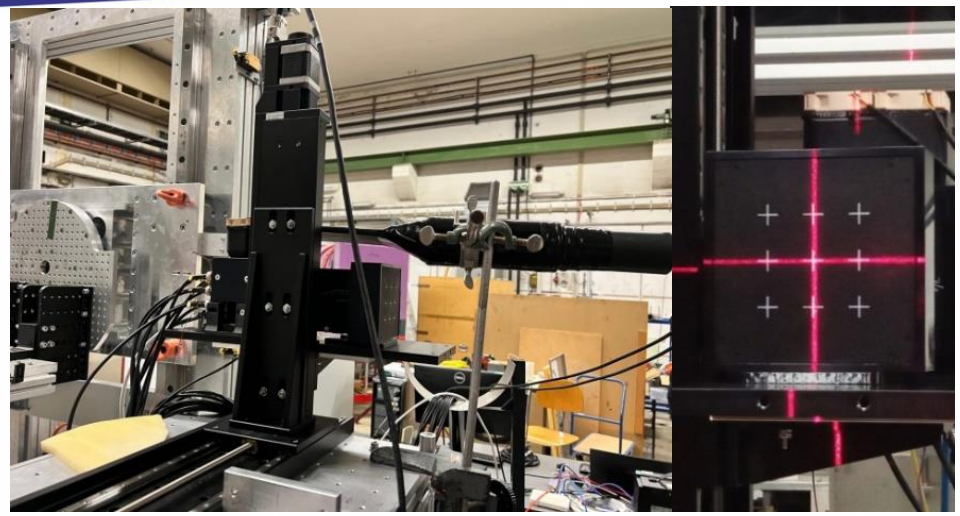
Energy (GeV)	Resolution (%)	Res_error
4.542	2.14872	0.01644
5.797	1.71093	0.02872



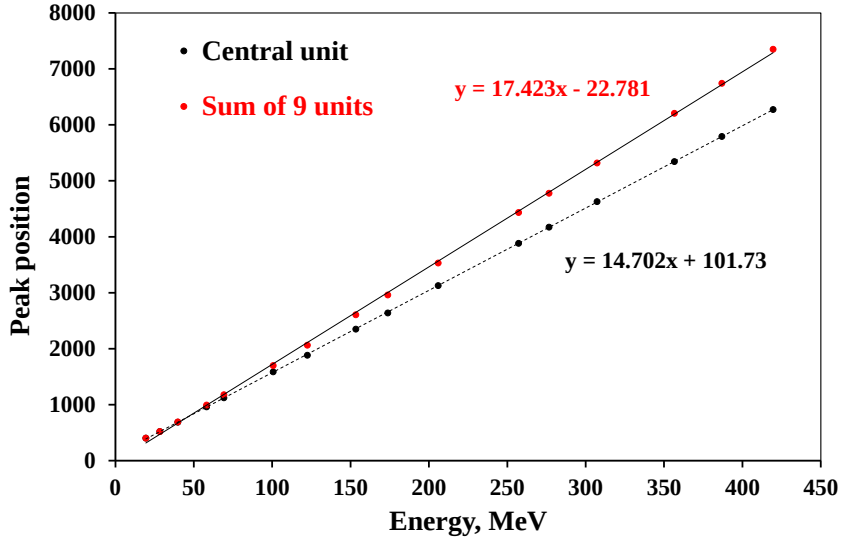
Test Beam in MAINZ

Gamma energies from 19.4 MeV to 419.6 MeV

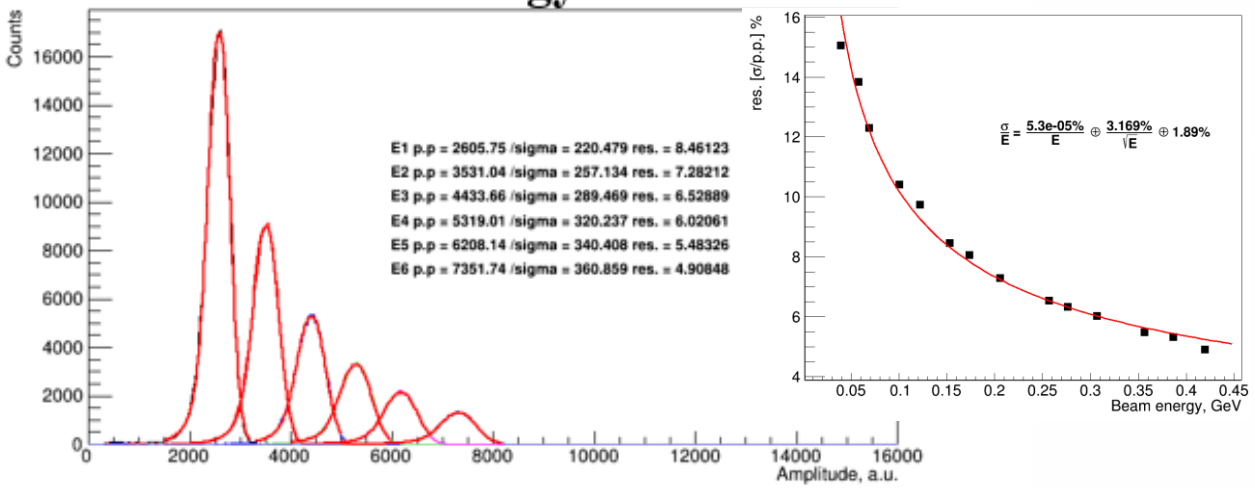




Response linearity check, peak position vs beam energy



Sum of 9units energy distribution



Data acquisition was done with 16 channel digitizer CAEN V17309 channels (Nr 1-9) connected with PWO array outputs

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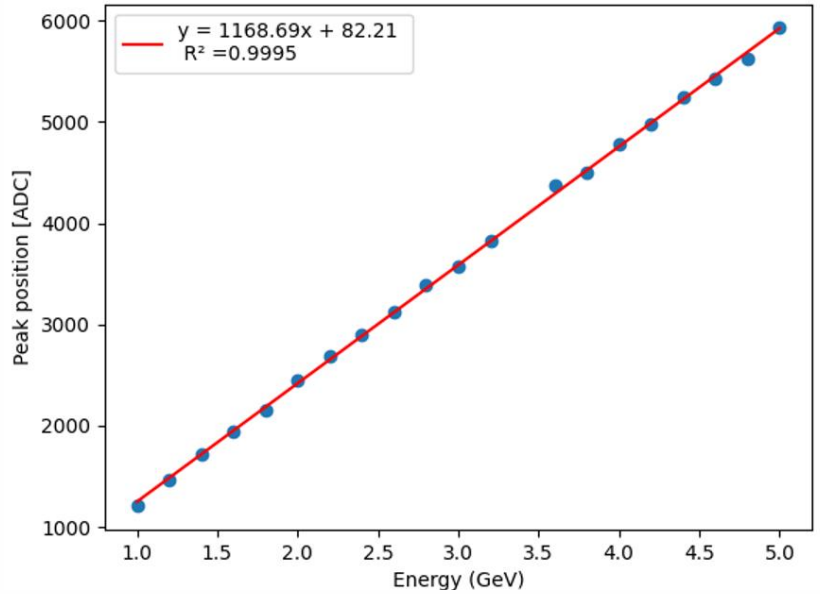
Test Beam in Desy, electrons 1 – 5 GeV

Courtesy of Prof. Douglas K. Hasell and his team

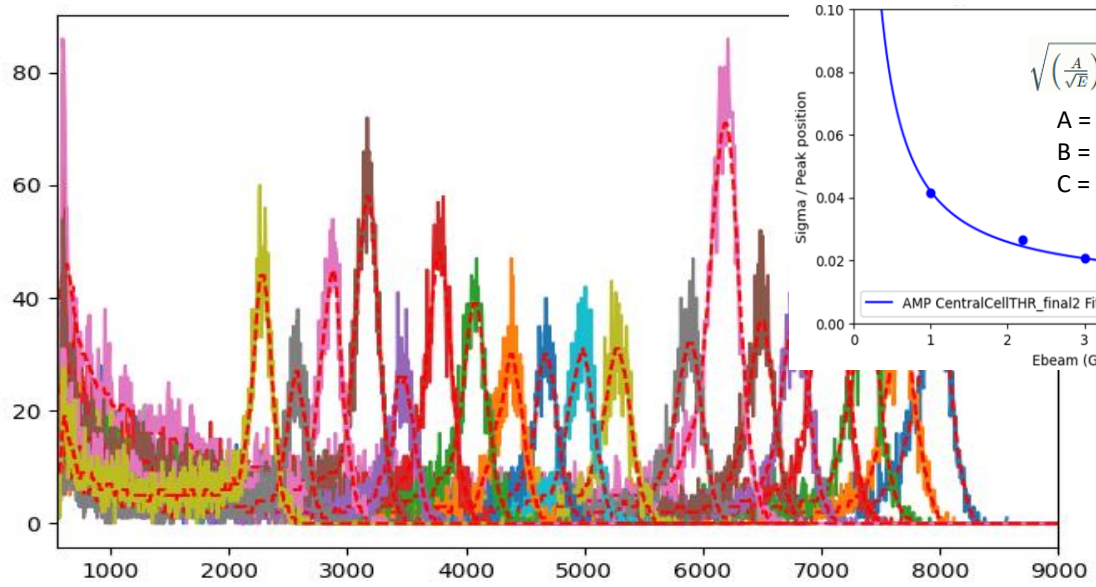
- 5x5 PWO prototype
- 2x2 SiPM Hamamatsu S14160-6010
- Triggered with two plastic + PMT detectors
- Beam collimated with 2 mm pinhole
- DAQ – Caen

  2x **16-channel 14-bit 500/250 MS/s Digitizer(MIT setup)**

Response linearity check, peak position vs beam energy



Energy distributions



Conclusions

- **CRYTUR** possesses a broad portfolio of unique technologies, including crystal growth, electronics design and manufacturing, production of sophisticated optics, precision mechanics, and cleanroom assembly.
- **CRYTUR** has developed compact, modular, and scalable readout electronics for **PWO crystals**, featuring low power consumption and enabling straightforward maintenance and replacement.
- **CRYTUR prototypes** have demonstrated a good response to electrons (e^-), positrons (e^+), and gamma radiation at medium and high energies; validation of the design is ongoing.
- Further applications are being actively explored.

Acknowledgements

- We are grateful to Dr. Alexander Somov, Dr. Vladimir Berdnikov and Professor Tanja Horn, for their support in testing our prototype at **Jefferson Lab.**
- We express our sincere appreciation to Dr. Valery Dormenev (Justus Liebig **University Giessen**, Germany) for his invaluable support in making the measurements at MAMI (Mainz) possible.
- We acknowledge the **EEEMCAL group** for enabling the testing at DESY, and we express our sincere appreciation to **Professor Douglas K. Hasell** (MIT) for granting access to their DAQ system at DESY.

Thank you for your attention!

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