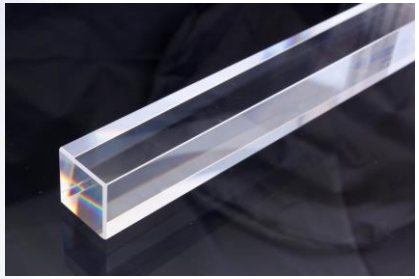

Radiation-Hard Scintillator Crystals and SiPM Array Readout for High-Energy Calorimetry

Olivier Philip*, Irina Shestakova, Silvia Sýkorová, Jaromír Šubčík, Jan Kovář, J.Kopal, Vojtěch Malý, Jindřich Houžvička, Valery Dormenev, Tanja Horn, Alexander Somov, Vladimir Berdnikov

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[2] *Crytur USA, Watertown, Massachusetts, United States of America*

[3] *Justus-Liebig-Universität Gießen, Germany*

[3] *Catholic University of America, Washington D.C, United States of America*

[4] *Thomas Jefferson National Accelerator Facility, Newport News, VA, United States of America*

Calor2024, May 20-24, 2024, Tsukuba, Japan

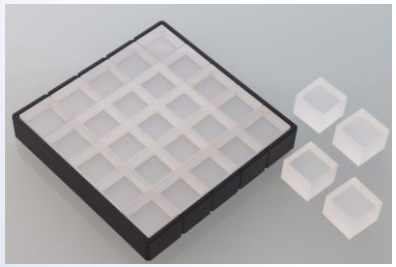
CRYTUR

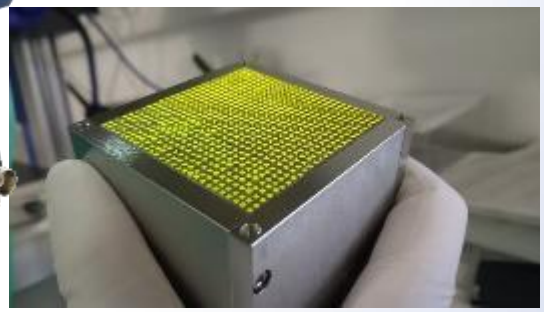
CRYTUR spol. s.r.o.

CRYTUR USA

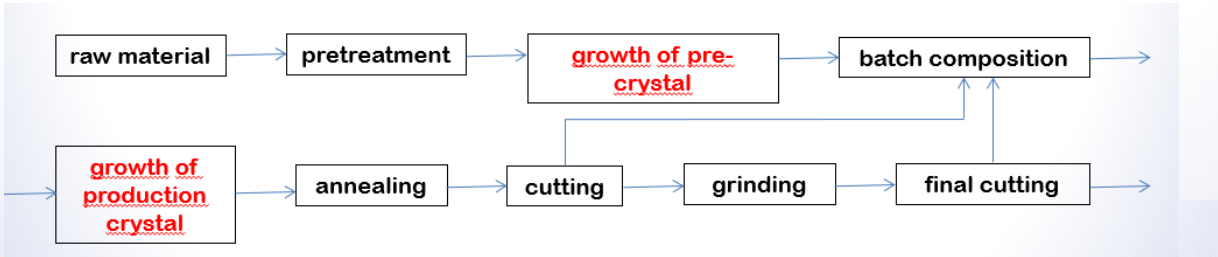
CRYTUR PRODUCTION PORTFOLIO

- 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

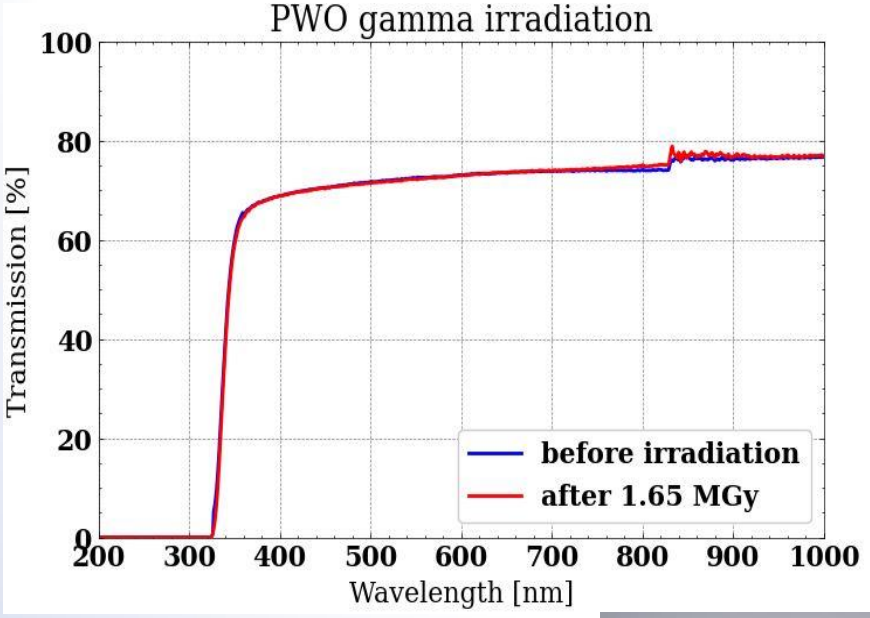


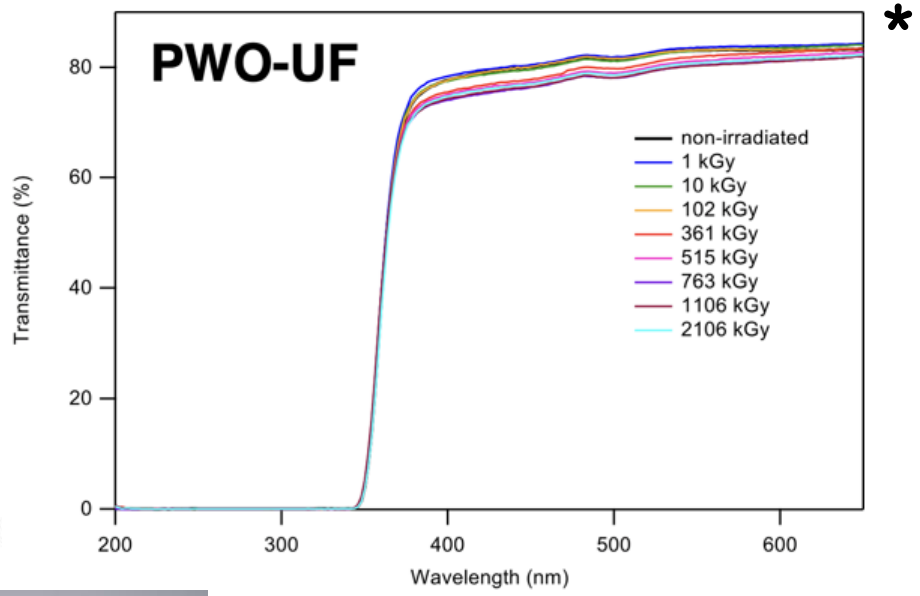


Production and manufacturing of PWO at CRYTUR



Radiation hard scintillator

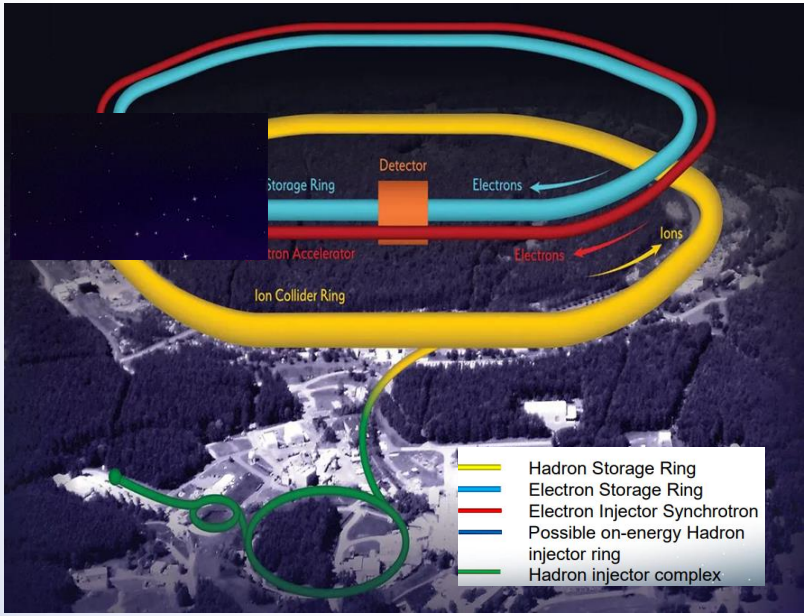




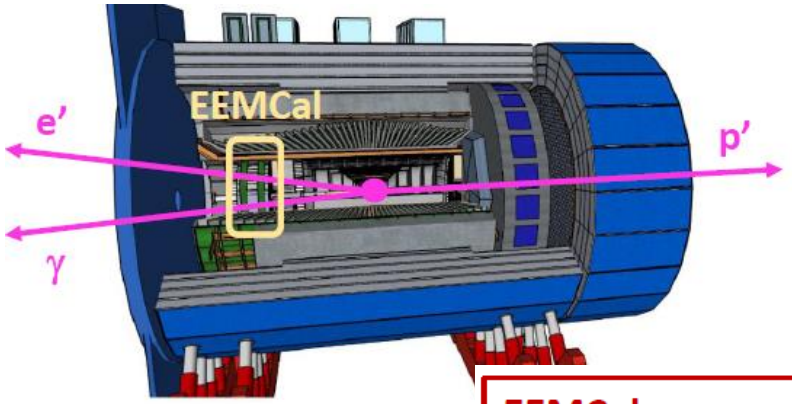
*

* Curtesy of Matthew Moulson(AIDA INNOVA WP8), INFN Frascati

EIC detectors



p: 41 GeV, 100 to 275 GeV e: 5 GeV to 18 GeV



EEMCal:
- PWO crystals
- SiPM readout

PbWO4 crystals
20 x 20 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

Initial EEEMCAL design specifications

EIC Geometry

Component	WBS	Length (cm)	Inner radius (cm)	Outer radius (cm)	Offset from center (cm)	Physical start (cm)	Physical end (cm)	Volume (m3)	Weight (kg)	Technology	Notes
LD EMCal	6.10.05	60	9	63	-174	-234	-174	0.73	4,738	PbWO4	Offset: measured from face nearest to interaction point Weight: estimated as 85% lead glass and 15% steel
Service gap		10			-320	-320	-330				Offset: measured from location nearest to interaction point

High magnetic field environment precludes use of PMTs

- ❑ Coverage:
  - -3.4 < eta < -1Rin=15cm, Rout=49cm
- ❑ Egamma:
  - 20 MeV – 20 GeV
- ❑ Energy Resolution:
  - 1% = 2.5%/sqrt(E) + 1%/E
- ❑ Spatial Resolution:
  - 1mm = 3mm/sqrt(E)
- ❑ Maximum Annual Dose at top luminosity:
  - EM: ~3krad/year (30 Gy/year)
  - Hadron: 10^10 n/cm2

- ❑ Signal dynamics:
  - 2V dynamic range
  - ADC 14 bit
- ❑ Signal Rate:
  - =<1 MHz/channel
- ❑ Digitization Gate:
  - ~(100 – 200) ns
- ❑ Sampling Rate:
  - 250 MHz
- ❑ Data sparsification/feature extraction:
  - Peak
  - Integral
  - Time
  - Pedestal
  - Number samples
  - Pulse quality
  - Pileup detection and recovery

SiPM selection

Selection criteria to reach

High spectral resolution resolution

Fast signal

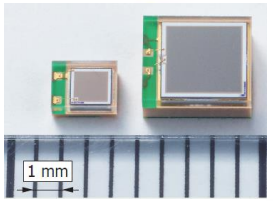
Wide dynamic range

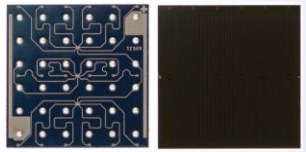
Good response linearity:

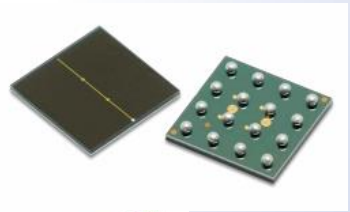
- PDE
- Capacitance
- Fill factor
- Dark counts
- Size to fill 20 mm x 20 mm area

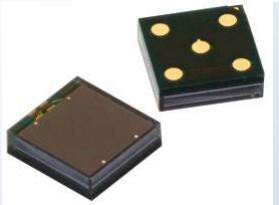
Possible candidates

- Hamamatsu S14160-3010
- Hamamatsu S14160-3015
- Hamamatsu S14160-6010
- Onsemi 60035
- Broadcom AFBR-S4N44C013 (discontinued)
- Broadcom AFBR-S4N44P014M

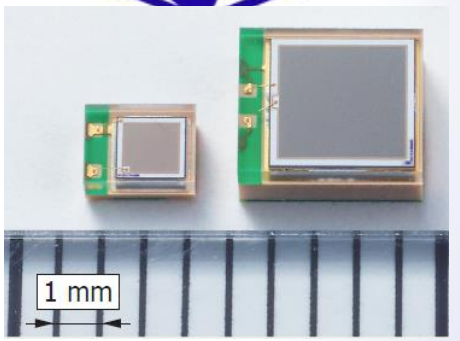




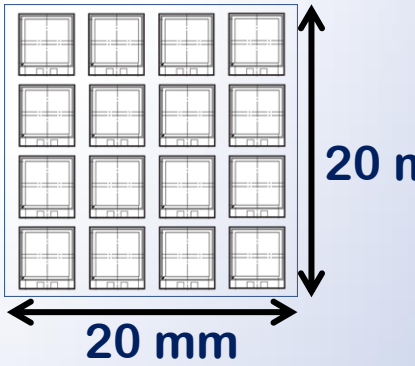




4x4 Array Hamamatsu S14160-3015

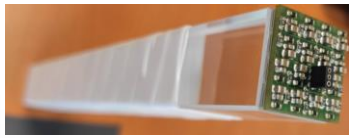


- 16 SiPMs cover 36% area of PWO side (2x2 cm^2)
- PDE @420 nm = 30 % (V_{op} = V_{BR} + 4 V = 49 V) and 40% (V_{op} = V_{BR} + 9 V = 54 V)
- Dark count rate 700 kcps (typ.)
- VOP variation within reel ±0.1V (± 8% gain)
- Anode capacitance 530 pF



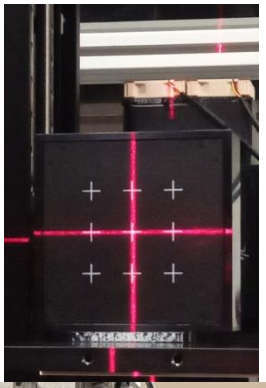
SiPM arrays are read out with double stage preamplifier developed by CRYTUR

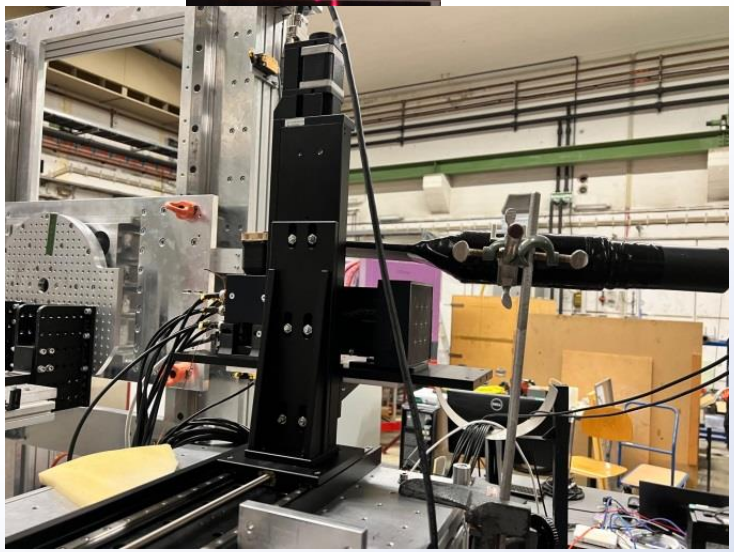
3x3 PWO detector prototype



- Prototype: 3x3 $PbWO_4$ crystals produced by CRYTUR
- Single detector unit consists of 2x2x20 cm^3 PWO covered with ERS reflecting film + Al foil
- each crystal coupled to 4x4 SiPM (Hamamatsu S14160-3015) array

Setups during Test Beams



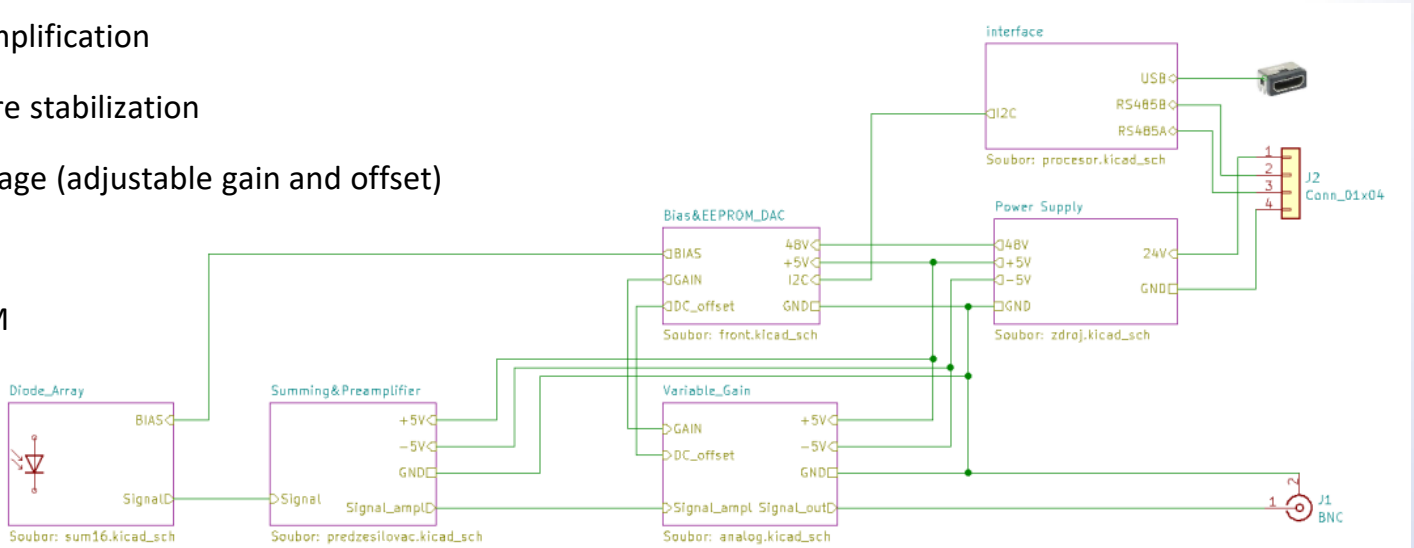


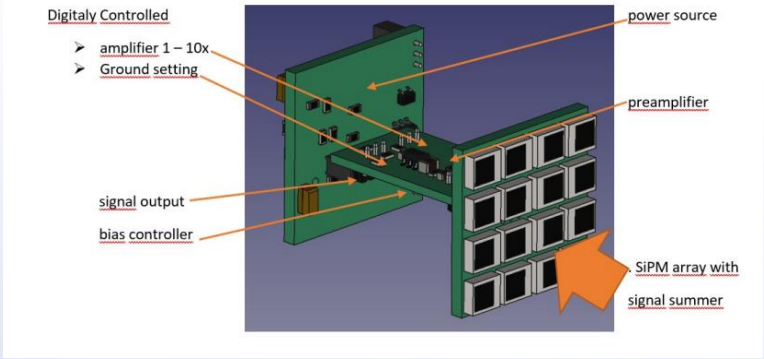
Jefferson Lab Feb.2023

Mainz MAMI June 2023

Readout electronics

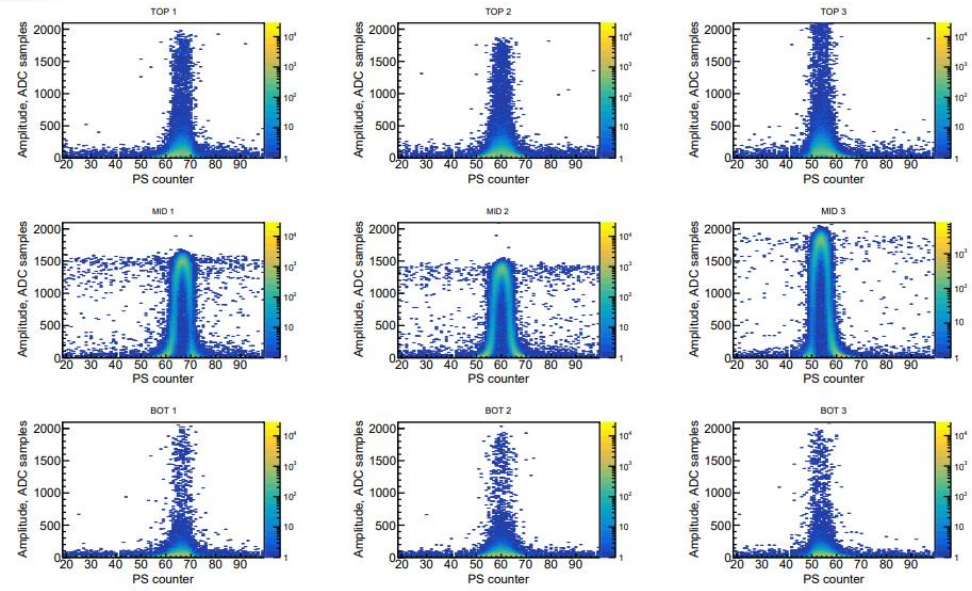
- SiPM wiring optimized for good collection of fast signals
- Summation and fast preamplification
- SiPM Bias with temperature stabilization
- Additional amplification stage (adjustable gain and offset)
- Power supplies
- Settings stores on EEPROM
- Communication interface



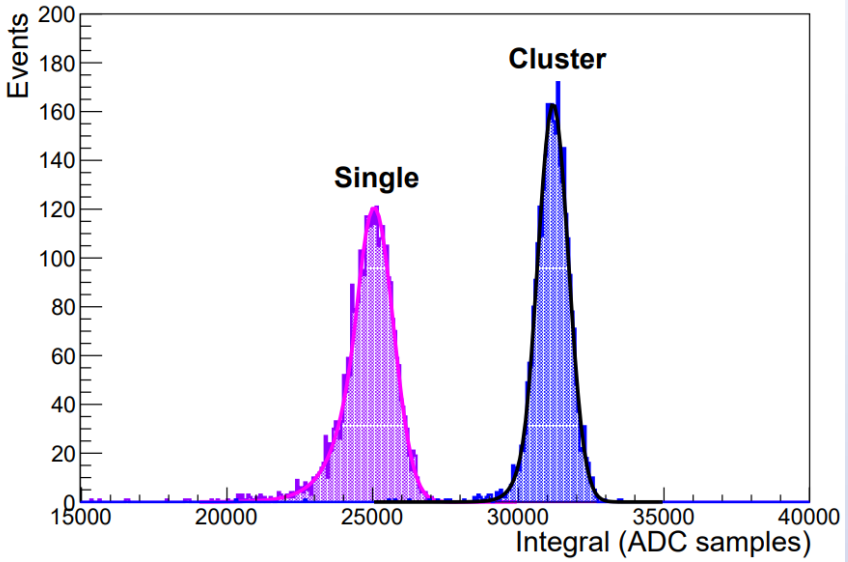


Detector response in Jefferson Lab

Energy deposition in 9 cells

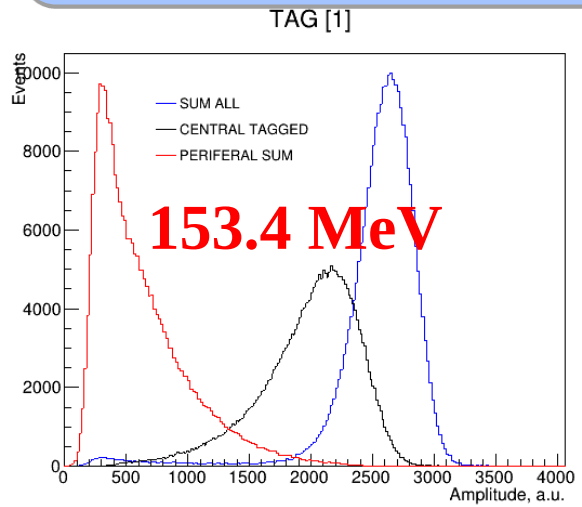


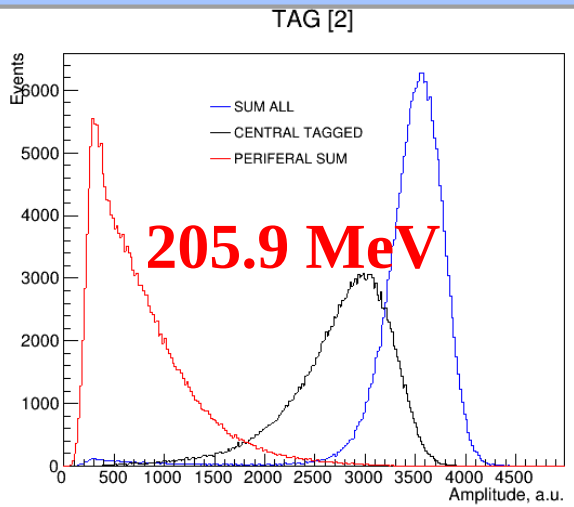
Energy resolution 5.8 GeV

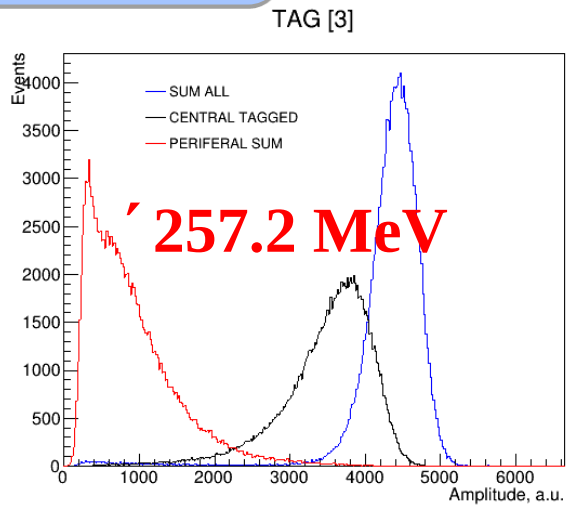


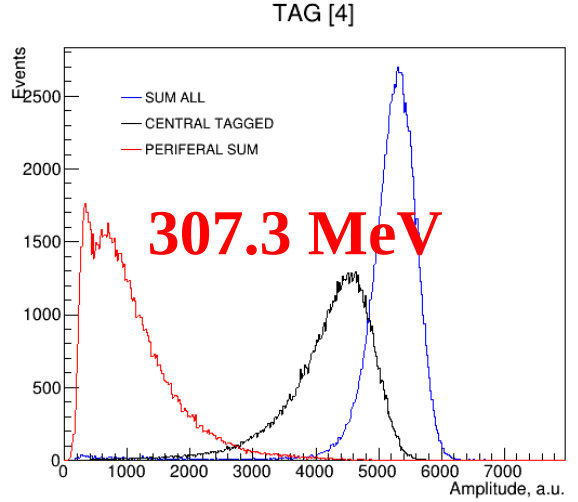
- 80% of total energy is deposited in the central cell in agreement with simulations

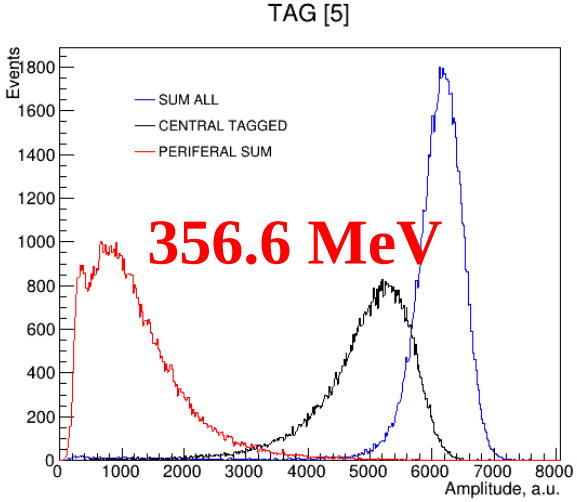
Energy distribution measured in Mainz

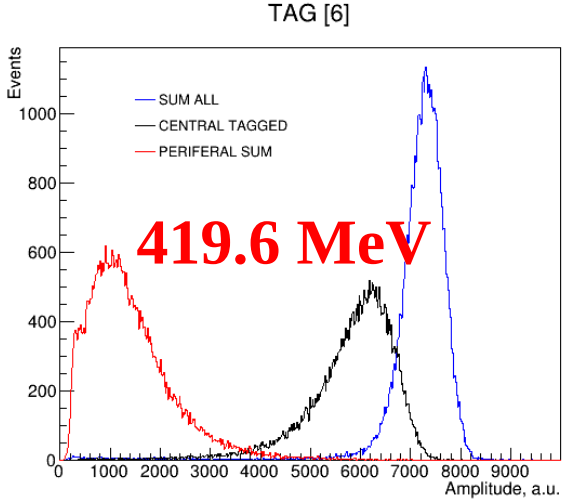






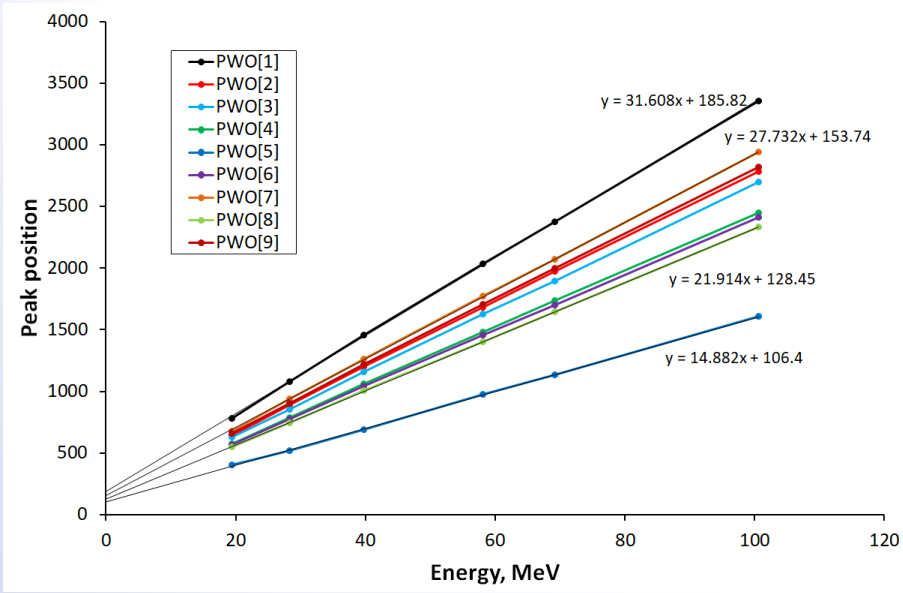




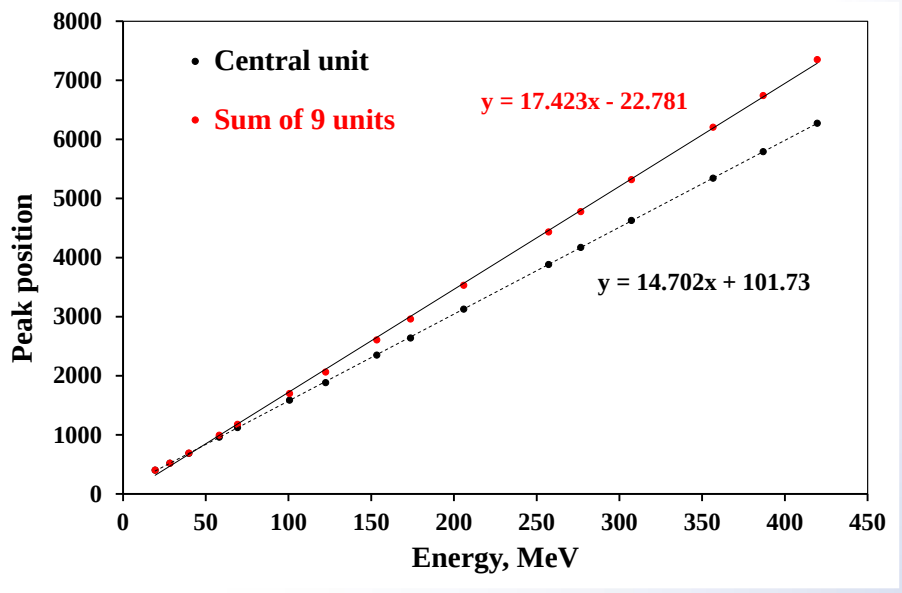


Linearity response in Mainz

For 9 modules at 6 energies



Linearity : peak position vs beam energy



Summary

- ✓ **CRYTUR** has the technology to grow and process large PWO crystals
  - ❑ with unmatched material quality
- ✓ First beam tests results with PWO/SiPM prototype 4x4 array of S14160-3015
  - ❑ 4.572 GeV and 5.797 GeV
  - ❑ 153.4 MeV, 205.9 MeV, 257.2 MeV, 307.3 MeV, 356.6 MeV, 419.6 MeV
- ✓ electronics' physical architecture is compact, modular, and scalable
- ✓ Further improvements will be investigated lower temperature (active cooling): low noise from SiPM and higher signal from $PbWO_4$
- ✓ Readout threshold optimization, the lower limit for the energy detection needs to be ~ 5MeV
- ✓ Better performance with 5x5 $PbWO_4$ crystal array, capturing full particle shower (better energy deposition and energy resolution)

Thank you for your attention!

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www.crytur-usa.com

This work was part of **the FW01010218 project** supported by Technology Agency of the Czech Republic.