Peformance of Prototypes for the Barrel Part of the $\overline{\text{P}}$ANDA Electromagnetic Calorimeter

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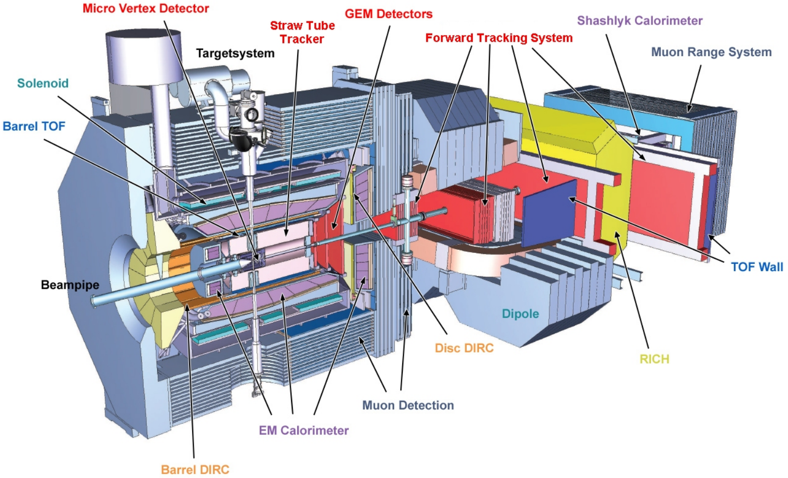
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

HIC for FAIR Helmholtz International Center

Introduction

$\overline{\text{P}}$ANDA Detector

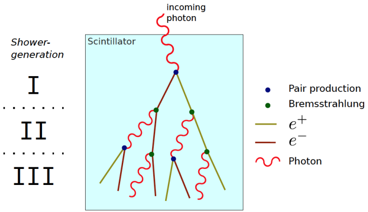
- fixed target experiment with $\overline{\mathrm{p}}$-beam (1.5-15 $\mathrm{GeV/c}$) on p
- details: talk by Alicia Sanchez-Lorente



Calorimetry

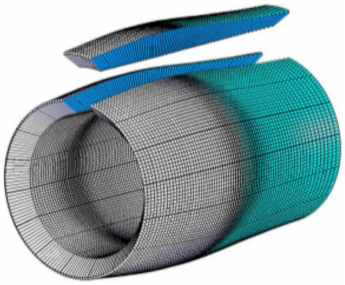
Why a calorimeter?

A lot of physics channels with photons



$\overline{\text{P}}$ANDA Barrel EMC

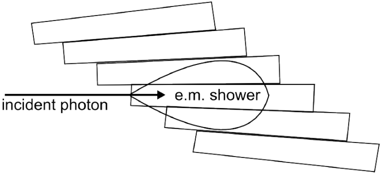
- design and PWO crystals adapted from the CMS ECAL
- much lower photon energies $\rightarrow$ more light needed $\rightarrow$ operation temperature at -25° C $\rightarrow$ PWO-II
- 11360 PWO-II crystals divided into 16 slices each containing 11 tapered crystal geometries



EMC

Requirements for the EMC

- compact and radiation hard material
- sufficient energy, time and spatial resolution
- capability of handling high interaction rates
- geometrical coverage



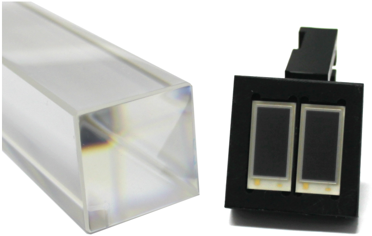
Properties PWO-II

Density	8.28 g/cm^3
Radiation length	0.89 cm
Molière radius	2.0 cm
Decay time	6.5 ns
dE/dx (minimum ionising particle)	10.2 MeV/cm
Light yield (LY) relative to NaI at -25 °C	2.5 %

LAAPD

Characteristics

- 200 μm thick
- thin conversion layer to prevent nuclear counter effect
- high QE in the wavelength range of PWO
- insensitive to magnetic field
- 1 cm^2 effective area

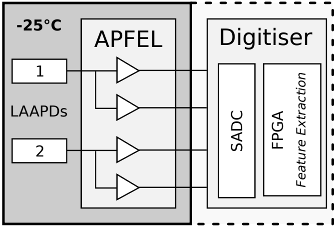


Advantages of two LAAPDs

- low energy threshold for 10 MeV photons $\rightarrow$ collect as much scintillation light as possible
- improves energy resolution at low energies
- rejection of fake events caused by neutrons
- backup

Readout Electronics

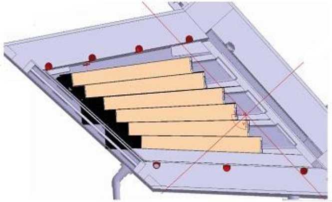
- each crystal equipped with two LAAPD which are read out simultaneously by one APFEL ASIC 1.4
- two channels with different gains
- dynamic range (1 MeV up to 12 GeV) of 10000
- programmable amplification between 16-32
- autocalibration possible
- event rate capability: up to 500 kHz
- low power consumption: 55 mW

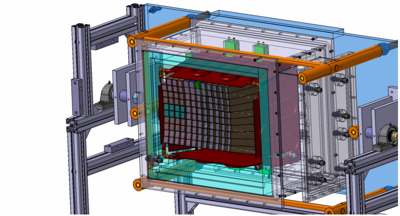


ENC	$<$ 1 fC
Max. input charge	$>$ 6 pC
Detector capacitance	300 pF
Event rate per Channel	up to 350 kHz
Operation temperature	-25 °C
Power consumption	$<$ 60 mW/ch
Number of channels	$\approx$ 22000

Prototypes

PROTO60 vs. PROTO120





PROTO60

- single APD readout with 1 cm^2 effective area (quadratic)
- low-noise low-power charge sensitive preamplifier (LNP)
- required resolution parameters achieved

PROTO120

- 120 PWO crystals of type 1, 2 and 3
- 2 LAAPDs per crystal
- APFEL readout 1.4 with final dynamic range
- close to final mechanics

Energy Resolution of the $\overline{\text{P}}$ANDA Barrel EMC

Impact of the energy resolution

- accuracy of the invariant mass determination, such as J/ψ states
- influences determination of the E/p ratio of e^- and e^+

$$\frac{\sigma}{E} = \frac{2\%}{\sqrt{E/\mathrm{GeV}}} \oplus 1\%$$

Statistical term

- Poisson statistics of the light collection process
- crucial because of low energies and low LY of PWO
- needed to identify light mesons (π^0 and η) which contribute significantly to the background
- reconstructed width of less than 8 $\mathrm{MeV}/\mathrm{c}^2$ (π^0) and 30 $\mathrm{MeV}/\mathrm{c}^2$ (η) $\rightarrow$ 2%

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Constant term

- resolution limit at high energies coming from crystal properties and leakage of energy
- a linear response and a cross calibration are crucial
- limit determined by the separation of e^- and e^+ from π's via their E/p ratio
- should be comparable to the momentum resolution of the tracking detectors to prevent a deterioration of $\mathrm{E}/\mathrm{p} \rightarrow 1\%$

Energy Threshold

Impact of the energy threshold

- reconstruction of low energetic photons which are a major contribution to many background channels
- charmonium physics program: many interesting channels have a significantly lower production ratio than the expected background contribution $\rightarrow$ detect all photons for efficient background rejection

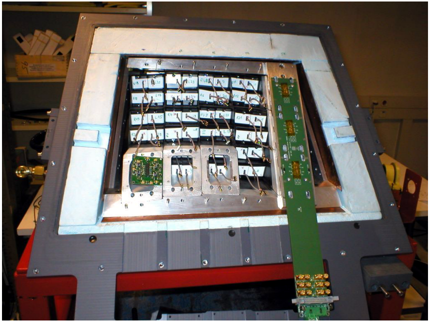
Limitation of the energy threshold

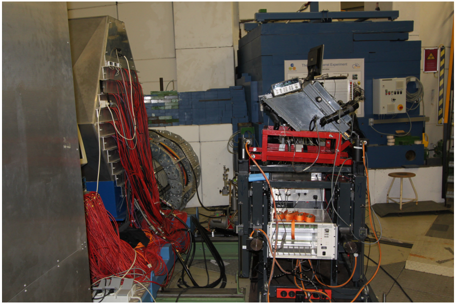
- electronic noise of a single channel
- distribution of the deposited energy at low energies

Required energy threshold

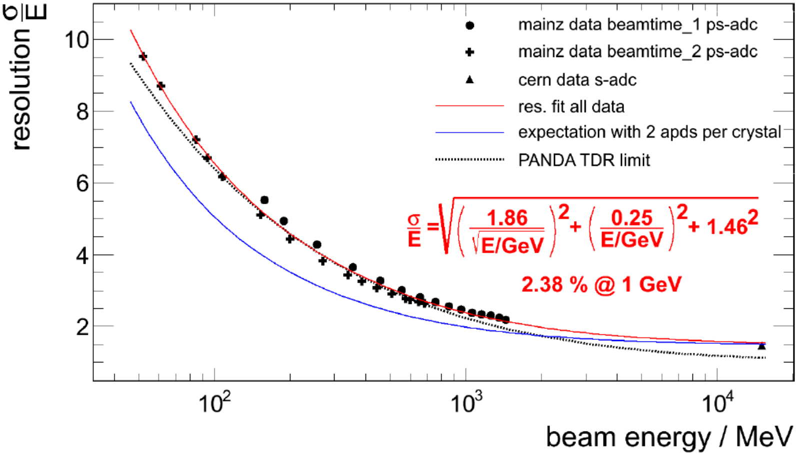
- compromise threshold of 10 MeV $\rightarrow$ single crystal threshold of 3 MeV
- simulations with threshold of 10 MeV: only 1% of the π^0-mesons cannot be reconstructed
- simulations with threshold of 30 MeV: already 10% cannot be reconstructed

PROTO60





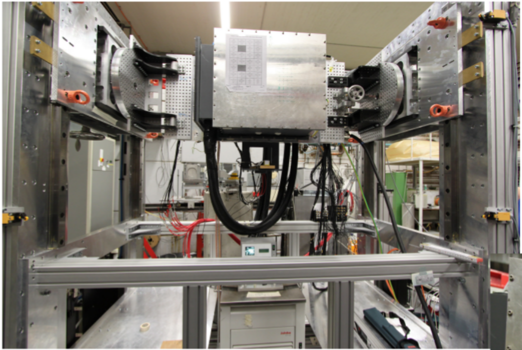
Energy Resolution PROTO60

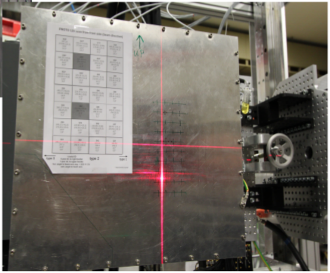


- low noise level (summation threshold 0.85 MeV)
- good agreement with the requirements in the TDR

Beamtime PROTO120

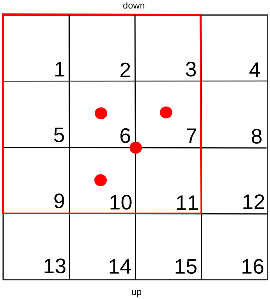
Beamtime in April 2015

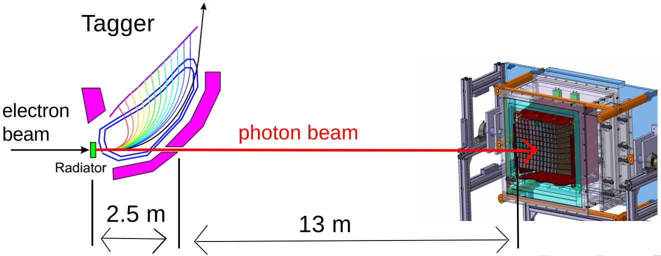




Setup of the Matrix

- read out 16 crystals (64 channels) of type II with SADCs (SIS3302)
- 830 MeV tagged photon beam
  - calibration run in each crystal
  - long run in the center of 3x3 (crystal 6), center of 4x4 and crystal 7 and 10
- only relative gain 32 analysed

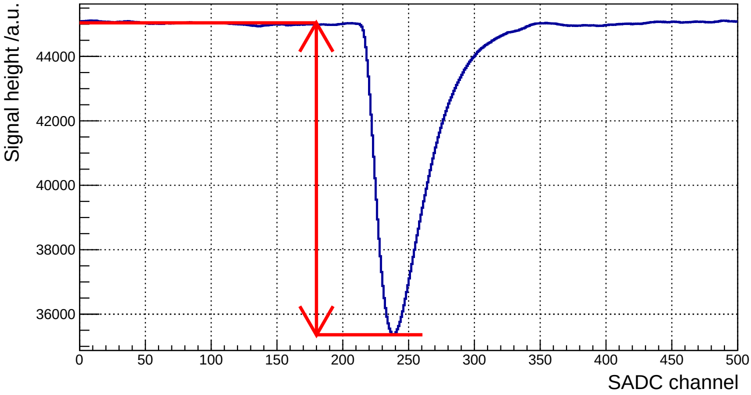




Feature Extraction

Feature Extraction

- one sampled event (20 ns per bin)



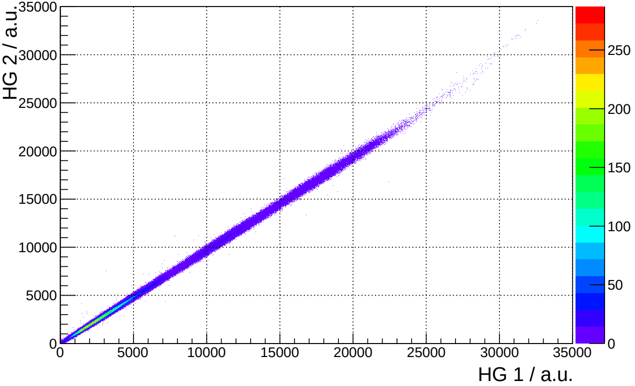
Energy information

Energy = Baseline - Minimum

Calibration and Analyse

APD Calibration

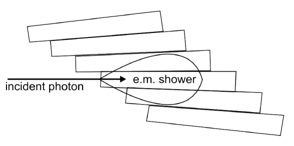
- **1. step**: summing up information of both APDs



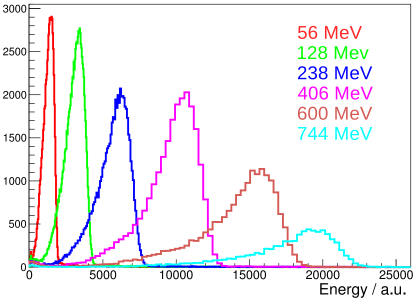
- APD linearity of the central crystal for the high gain branch
- plotted are signal amplitudes of both APDs
- slope used as scaling factor for calibration

Relative Beam Calibration

Why a cross calibration?



- shower distributes over a number of crystals
- information has to be summed up
- cross calibration is necessary because each module is read out individually



Cross calibration

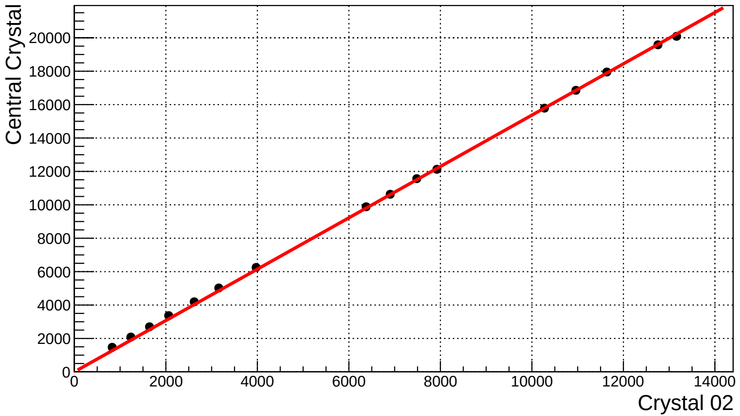
- runs with beam in center of each crystals
- tagged lineshapes of each crystal are plotted with Novosibirsk function:

$$f(x) = Ae^{-\frac{1}{2}\left(\frac{\ln^2(1+\Lambda\tau(x-\mu_{max}))}{\tau^2}+\tau^2\right)}$$

with $\Lambda = \frac{\sinh(\tau\sqrt{\ln 4})}{\sqrt{\ln 4}\tilde{\sigma}}$, asymmetry τ, width $\tilde{\sigma} \equiv \frac{FWHM}{2\sqrt{\ln 4}}$ and mode μ_{max}

Cross calibration

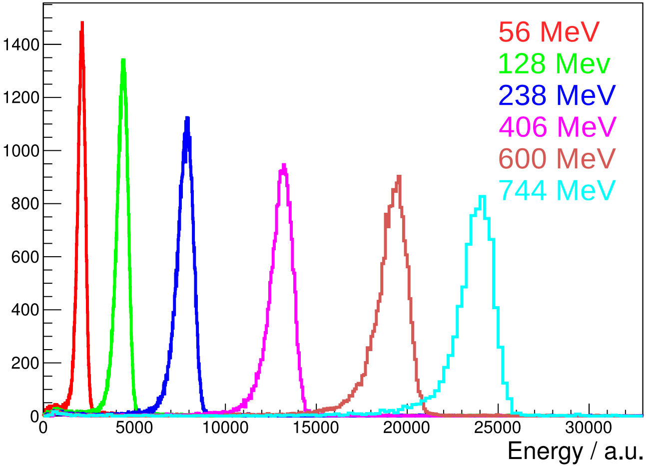
central crystal is used as reference crystal to calibrate the matrix



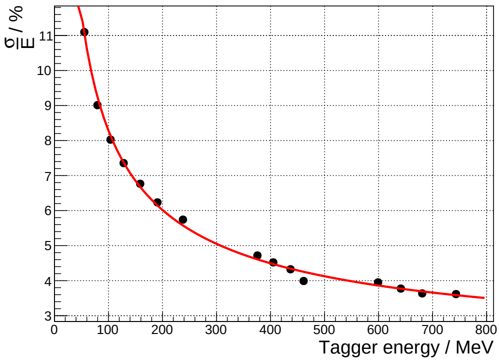
Energy resolution

Energy Resolution

- calibrated 3×3 matrix is summed with a summation threshold of 2.7 MeV
- summed lineshapes are fitted with a Novosibirsk function
- energy resolution is defined as σ/E



Energy Resolution



Fit parametrization

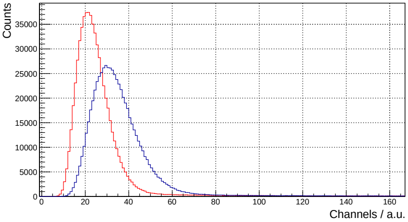
$$\frac{\sigma}{E} = \frac{0.16\%}{E/\mathrm{GeV}} \oplus \frac{2.46\%}{\sqrt{E/\mathrm{GeV}}} \oplus 2.32\%$$

Noise

Noise Level

Definition of noise

- electronic noise: RMS of the baseline (without presence of a signal)
- summation threshold = mean + 3σ (99.7% of noise contribution rejected)

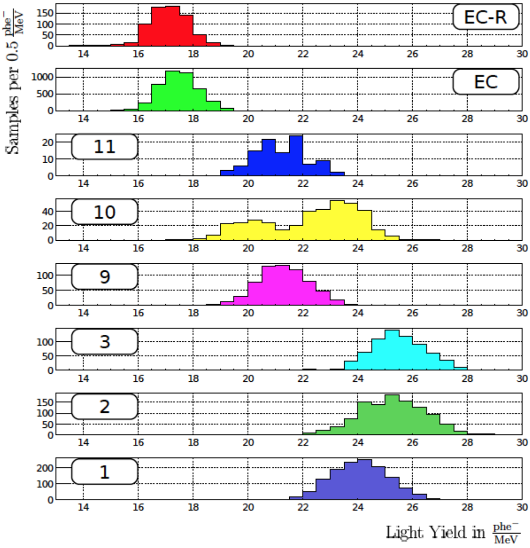


Noise level

- HG1: 0.72 MeV (electronic noise) $\rightarrow$ summation threshold: 2.7 MeV
- too high for foreseen triggerless readout
- Adding traces before feature extraction: 1.8 MeV
- $\Rightarrow$ Improvement of $\sqrt{2}$ by adding traces

Non-uniformity in light collection

Distribution of the Light Yield for Tapered Crystals



⇒ the larger the level of tapering, the higher the light yield output

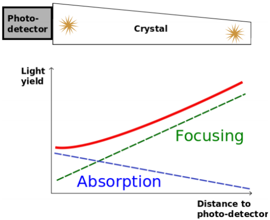
Influence of Light Collection Non-uniformity on the Energy Resolution

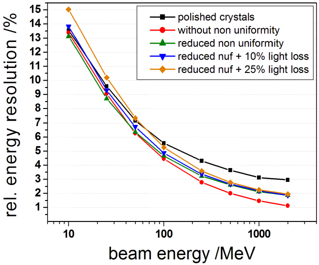
What is NUF?

- interplay between focussing and absorption of the produced scintillation light
- possibility: linearizing light collection by one depolished crystal side

Simulation with GEANT4

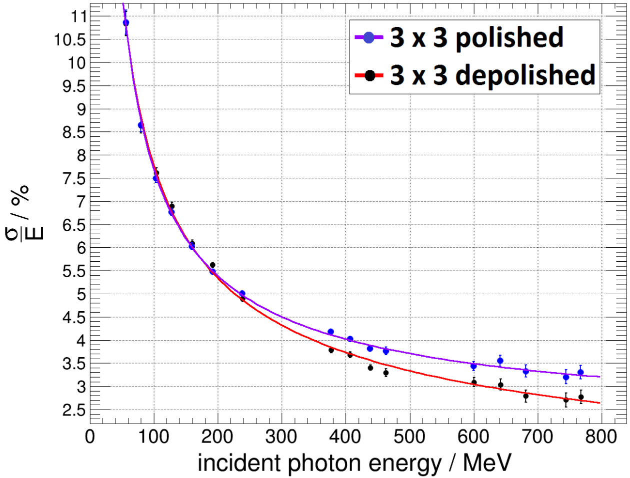
- simulation includes NUF, photon statistics and APD characteristics (no single photon tracking)
- interaction in center of type 1 section
- threshold = 1.6 MeV



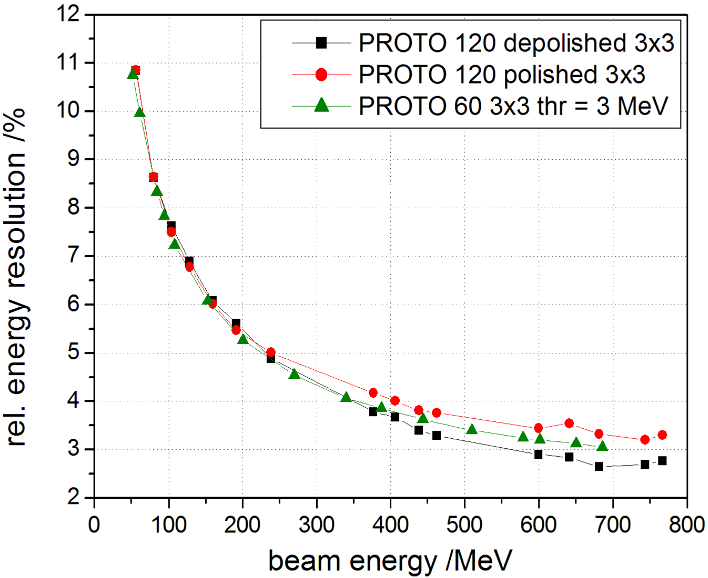


Experimental Results of Depolished Matrix

- comparison of the energy resolution of a 3x3 polished and a 3x3 depolished matrix



Comparison with PROTO60



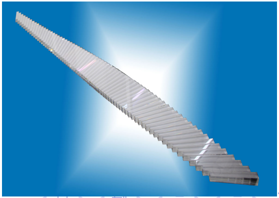
Summary & Outlook

Summary

- successful beamtime tests with two prototypes of the Barrel EMC
- overall concept of the Barrel EMC is fixed
- energy resolution sufficient but still room for improvement
- effective noise of the PROTO120 higher than PROTO60
- direction of improvement:
  - cross calibration
  - test with a 5×5 matrix needed
- depolished: better energy resolution but losing light

Outlook

goal: build a slice at the end of the year



Thank you for your attention!

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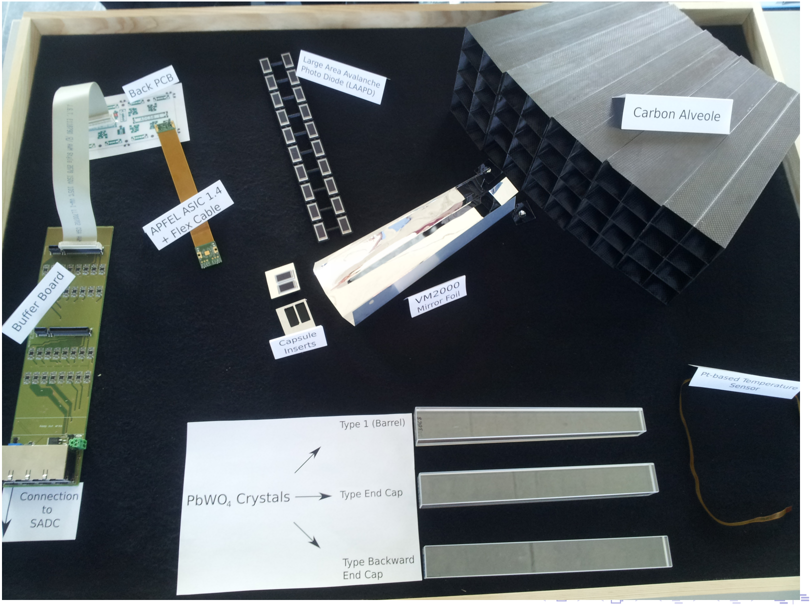
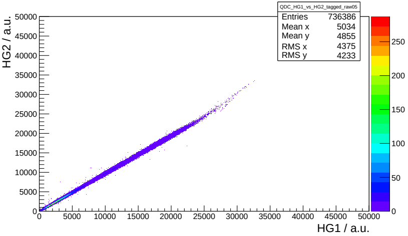
Backup

Assembly

Readout

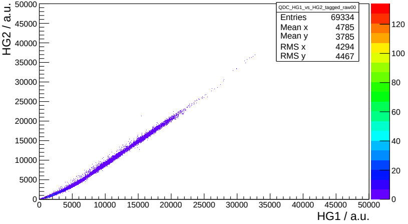

Back PCB
Large Area Avalanche Photo Diode (LAAPD)
Carbon Alveole
APFEL ASIC 1.4 + Flex Cable
Buffer Board
VM2000 Mirror Foil
Capsule Inserts
Pt-based Temperature Sensor
Type 1 (Barrel)
$PbWO_4$ Crystals
Type End Cap
Type Backward End Cap
Connection to SADC

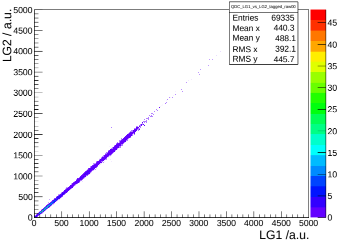
APD linearity



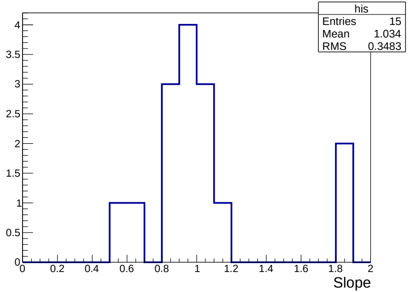
APD linearity

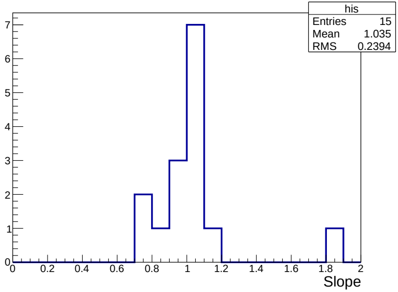
- HG of the central crystal (upper left), HG of crystal 1 (lower left) and LG of crystal 1 (lower right)
- Kink due to wrong ASIC programming
- linear part fitted and used as APD calibration





Slopes

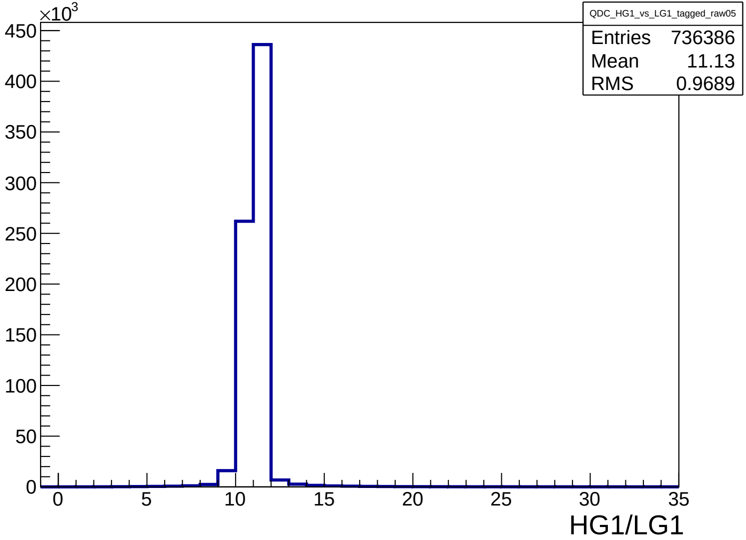




Slopes

- Distribution of APD linearity slopes for HG (left) and LG (right)
- Variation possibly due to wrong APD gain

Gain

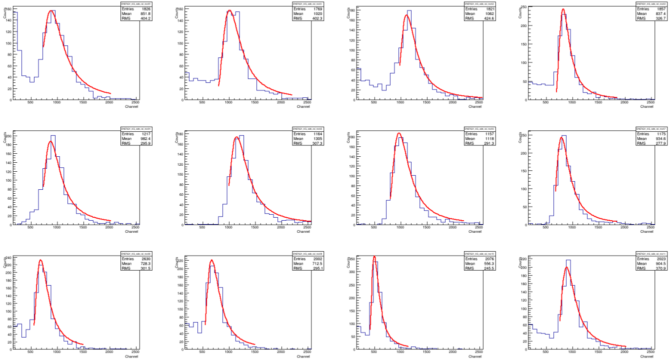


QDC_HG1_vs_LG1_tagged_raw05
Entries 736386
Mean 11.13
RMS 0.9689
×10³
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
HG1/LG1

Cosmic calibration

Method

- absolute calibration based on energy deposition of cosmic muons
- horizontal 26.5 MeV and vertical 220 MeV energy deposition
- calibration factor (horizontal 44.1 ch/MeV and vertical 44.5 ch/MeV) different to GEANT4 based calibration (39.2 ch/MeV)



Comparison of obtained energy resolutions with different calibrations