Revision of the $\overline{\text{P}}$ANDA Calorimeter Front-End operating parameters

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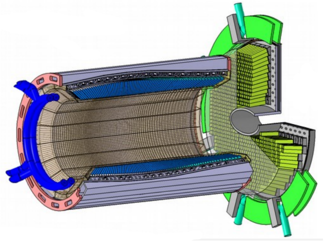
Structure

Main focus on the front-end electronics parameters of the Barrel-EMC, due to them having a major impact on the signal quality and signal-to-noise-ratio.



Technical Design Report for: $\overline{\text{P}}$ANDA Electromagnetic Calorimeter (EMC)

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

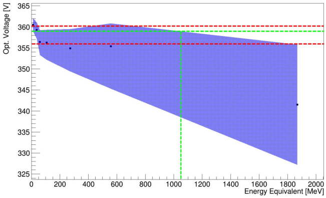
Large Area Avalanche Photodiode Gain Optimization for the APFEL ASIC Preamplifiers of the $\bar{\mathrm{P}}$ANDA Calorimeter

Bachelor thesis
by Kim Tabea Giebenhain
from Biebertal
August 22, 2019

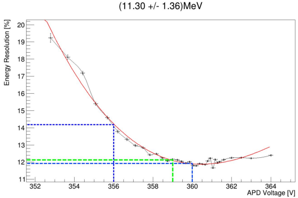
Justus-Liebig University, Giessen
II. Institute of Physics

Initial corrector: Prof. Dr. Kai-Thomas Brinkmann
Secondary corrector: Prof. Dr. Claudia Höhne
Technical supervisors: Dr. Markus Moritz & Dr. Hans-Georg Zaunick

Kim Giebenhain determined an optimal gain for a high energy resolution and therefore a good signal-to-noise-ratio.
The results were generated with a light pulser.



"Optimum energy resolution. The shaded area represents a 0.2% resolution loss tolerance. The red lines show the chosen limits for the optimal voltage and the green line shows the selected optimal voltage."



"Optimal energy resolution measurement at 11.3 MeV. The optimal energy resolution at ≈ 360 V is indicated as well as the energy resolution for the lower limit at 357 V."

The APD was most efficient while operated at 359 V ($\rightarrow$ APD-Gain: 500).

The energy resolution for light pulser pulses

- improved from 43 % to 12 % for low energies (11.3 MeV)
- remained mainly constant for high energies (>200 MeV)

compared to an APD-Gain of 150.

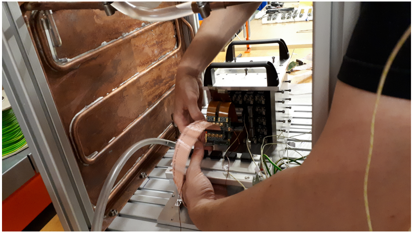
Results still had to be proven in an actual accelerator experiment.
More questions arose in the preparations:

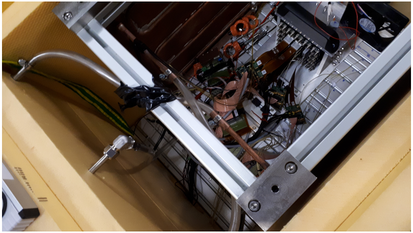
- Improvement through usage of two APDs instead of one?
- Energy resolution wished for the prototypes achievable?
- Both channels of the APFEL needed?

Structure

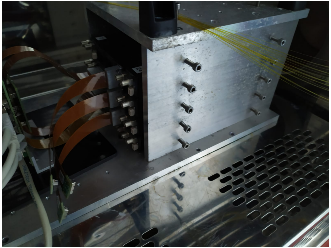
The setup for the beamtime at MAMI A2 tagger hall in Mainz contained the following components:

- 3 x 3 PWO-II Scintillator Matrix
- Complete readout-chain:
    - LAAPDs (2 per crystal)
    - APFEL-ASICs (1 per detector)
    - Apfelmatrices (Backplanes, 1 for 4 ASICs)
    - Bufferboards
    - $\overline{\text{P}}$ANDA-SADC
- Cooling box with a refrigerated circulator for holding a temperature of -25 °C
- Light pulser with glass fibres



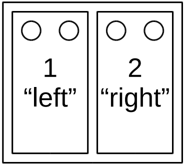


PWO-Matrix



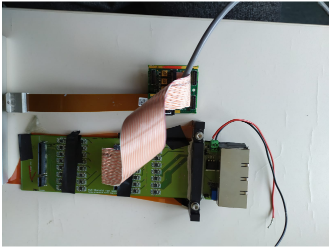
Nine square PWO-II crystals wrapped in reflective foil, put in shrinking tube and equipped with two LAAPDs each, were arranged in a 3 by 3 matrix.

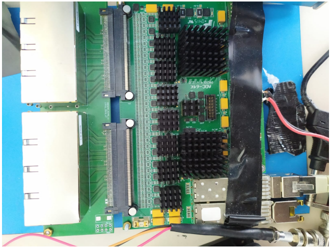
1	4	7
2	5	8
3	6	9



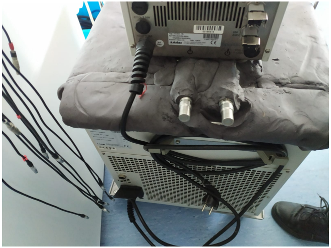
Readout

One APFEL-ASIC per detector gives output to an APFEL-Matrix and a Bufferboard.
This in turn delivers the signal to the $\overline{\text{P}}$ANDA SADC (v2.0) designed by Pawel Marciniewski.





Cooling

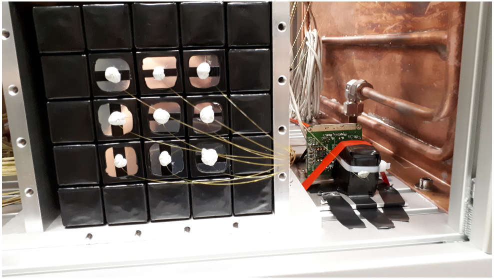


Setup was installed in an aluminium box:

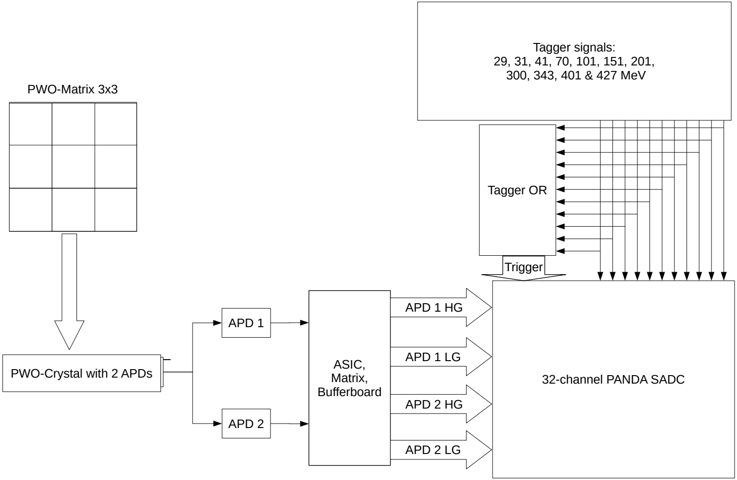
- Thermally insulated
- Copper sheets and pipes
- Fans for homogeneity
- Temperature sensors for monitoring

Light pulser

Light-fibre at every crystal, for later calibration.
Response to light pulser was monitored for calibration of the individual detector settings, as well as the response of a reference detector to the same signal.



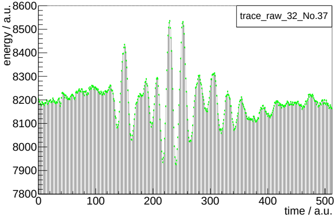
Overview

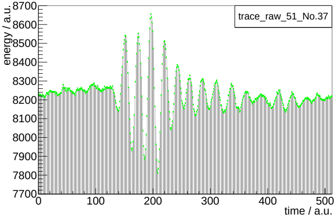

Tagger signals:
29, 31, 41, 70, 101, 151, 201,
300, 343, 401 & 427 MeV
PWO-Matrix 3x3
Tagger OR
Trigger
APD 1
APD 2
PWO-Crystal with 2 APDs
ASIC,
Matrix,
Bufferboard
APD 1 HG
APD 1 LG
APD 2 HG
APD 2 LG
32-channel PANDA SADC

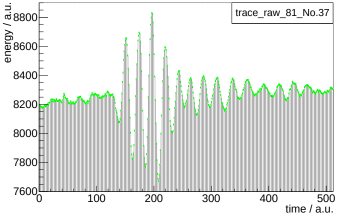
ASIC\APD	150	300	400	500
LG(×1)	Beam&LP	Beam&LP	Beam&LP	Beam&LP
HG(×16)	Beam&LP	Beam&LP	Beam&LP	Beam&LP
HG(×32)	Beam&LP	Beam&LP	Beam&LP	Beam&LP
HG(×16)				Cosmic

Structure

Pick-up







The pick-up signal appeared coincident in all channels.
The source is still not known.

Feature extraction

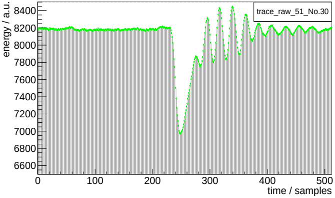
Simple peak-sensing algorithm:

1. find highest/lowest energy value and corresponding time
2. average other data points to construct baseline
3. Subtraction gives the energy in ADC-channels

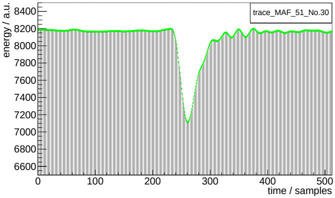
Gives a coarse idea of the signal height and is used for sorting of events.

Moving average filter

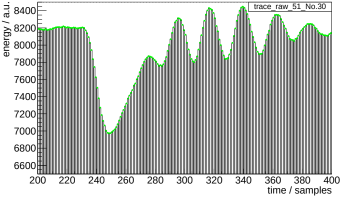
$$y(n) = \frac{1}{L} \cdot \sum_{k=0}^{L-1} x(n-k)$$



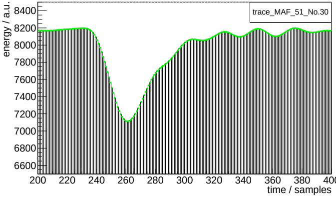
raw data



Moving Average $L = 20$

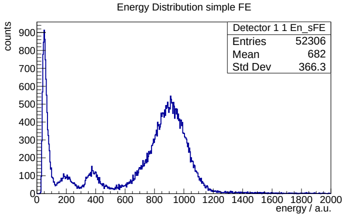


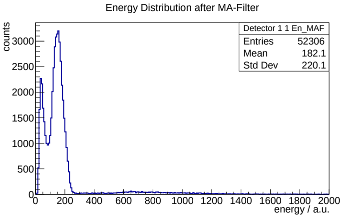
raw data zoom

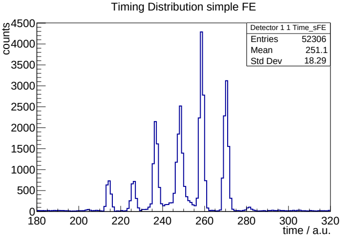


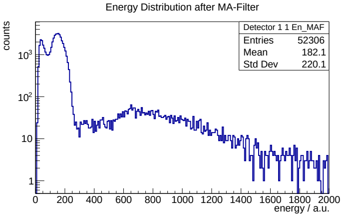
Moving Average $L = 20$ zoom

Event selection on cosmic data

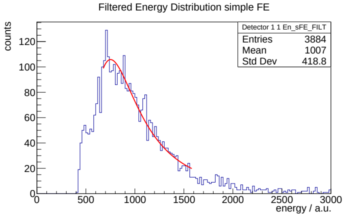


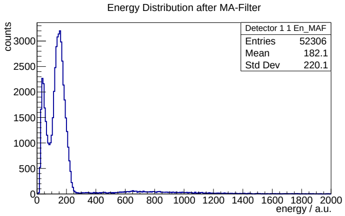


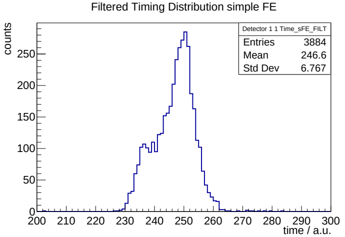


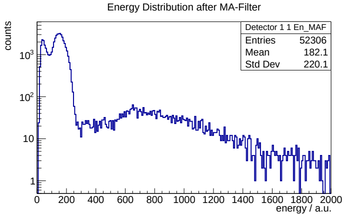


Event selection on cosmic data



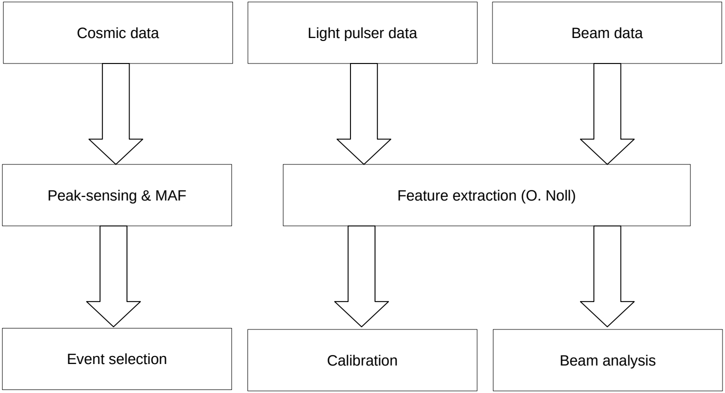






Feature extraction

Actual feature extraction by Oliver Noll's algorithm.
It's used for determining the timing and energy information of the events.
All following results are generated using this feature extraction.

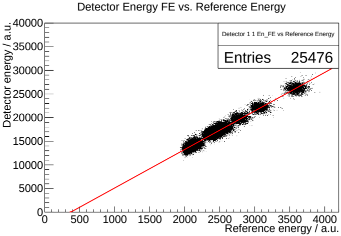


Calibration

Most probable value of deposited energy in one crystal: 28.14 MeV (derived from GEANT4 calculations)

Calibration factor: $M(ch) = \frac{28.14\,\text{MeV}}{MPV(ch)}$

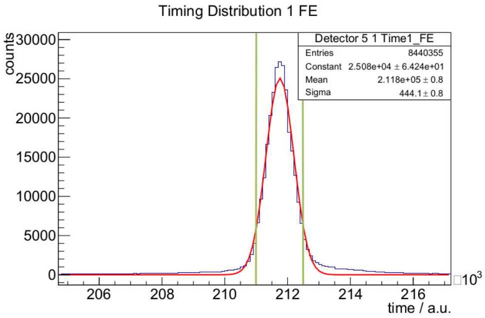
Only valid for APD gain 500 and ASIC gain x16, other settings are calibrated by comparing slopes of the light pulser measurements.

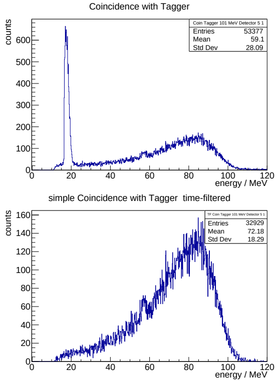


$$M_{ASIC,APD}(ch) = \frac{28.14\,\text{MeV}}{MPV(ch)} \cdot \frac{m_{16,500}(ch)}{m_{\text{ASIC,APD}}(ch)}$$

Timecuts

Several timecuts have been applied, to further sort out noise signals. The first cut was applied by the time of the central detector. The chosen window was 211000 to 212500 a.u., being roughly 2σ.

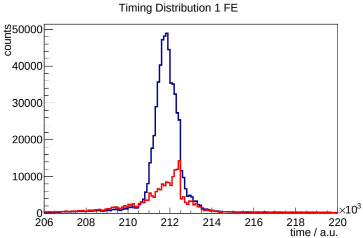


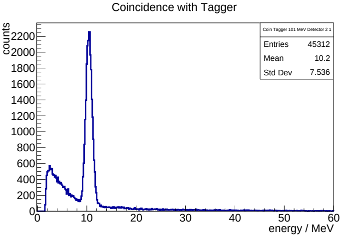


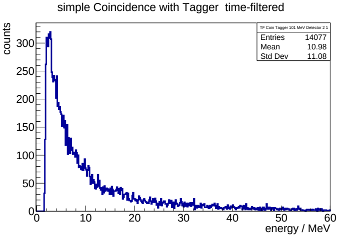
Timing and energy data of central detector coincident with Tagger 101 MeV with and without time filter

Timecuts

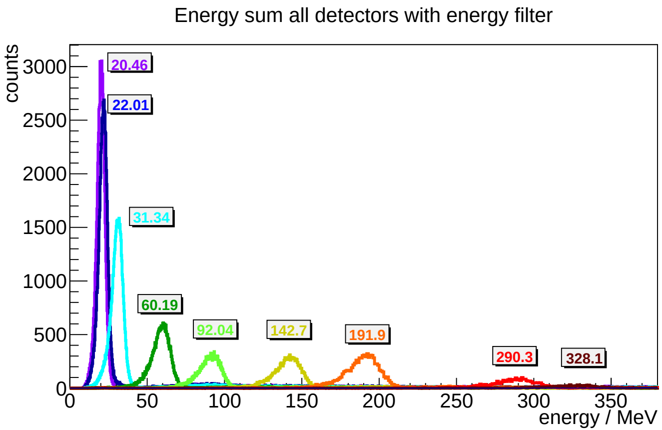
Another timecut was applied on the non-central detectors by the time difference between central and non-central signal.







Lineshapes



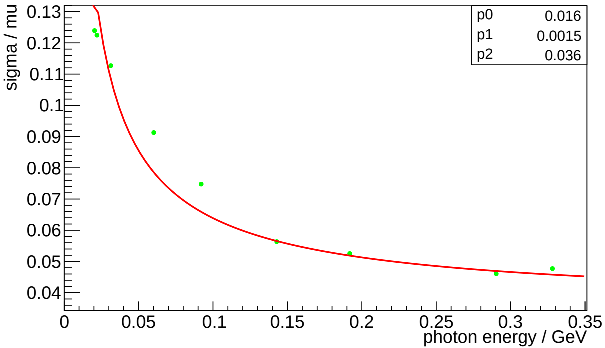
Lineshapes for HG16, APD 500

Additional to the lineshape, the energy resolution $\frac{\sigma}{E}$ is determined. Plotting the energy resolution against the energy results in the response function.

Response function

The response function follows a dependence like the following:

$$\frac{\sigma}{E} = \sqrt{\left(\frac{p_0}{\sqrt{E}}\right)^2 + \left(\frac{p_1}{E}\right)^2 + p_2^2}$$



Response function for ASIC-Gain 16 and APD-Gain 500

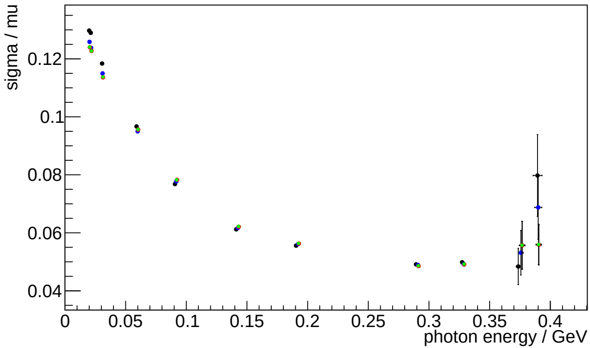
Energywise event selection

Up to this point, three different energy filters have been used for event-selection:

- Central detector has to detect signals above 1 MeV
- Feature extraction applies filter after FIR and only handles signals above 0.3 MeV
- When adding up detectors to the total deposited energy, a filter is applied, the single-crystal (SC) threshold

The effect of the SC-threshold especially, has been further analysed.

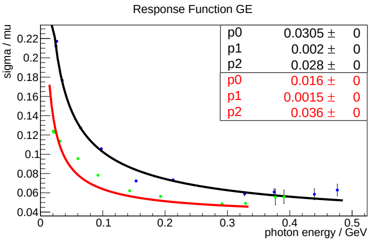
SC-threshold



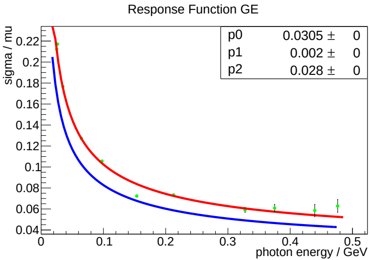
Response function for ASIC-gain 16 and APD-gain 500
SC-thresholds: black 3 MeV, blue 2 MeV, red 1 MeV and green 0.5 MeV

Optimal single-crystal threshold for APD-gain 500: 0.5 MeV
Optimal single-crystal threshold for APD-gain 150: 1-2 MeV

Comparison

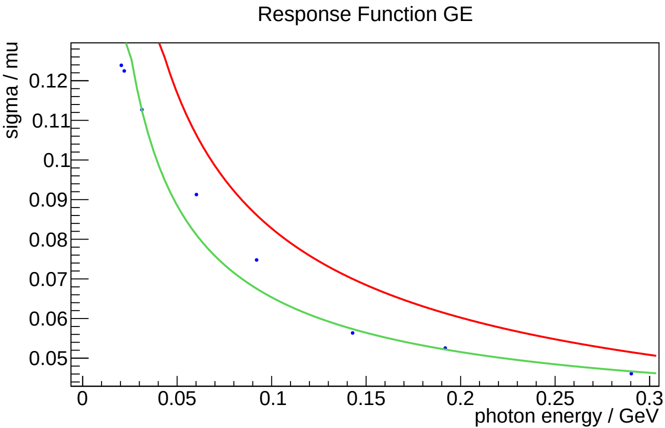


Response functions: black curve: APD-gain 150, red curve: APD-gain 500



Response functions: red curve: APD-gain 150, blue curve: PROTO120

Comparison



Response functions: green curve: APD-gain 500, red curve: PROTO120

Lowest energy data points at ≈30 MeV show an improvement of more than 3 %

Comparison

Parameter	PROTO120 / %	APD 150 / %	APD 500 / %
p_0	2.46		
p_1	0.16		
p_2	2.32		

p_0: photonstatistic term
p_1: electronic term
p_2: constant term

Comparison

Parameter	PROTO120 / %	APD 150 / %	APD 500 / %
p_0	2.46		
p_1	0.16		
p_2	2.32		

p_0: photonstatistic term p_1: electronic term p_2: constant term	Results for Gain 150 expected to be worse because of lower light yield due to crystal geometry. $\Rightarrow p_0 \approx 3.0\,\%$

Comparison

Parameter	PROTO120 / %	APD 150 / %	APD 500 / %
p_0	2.46	3.05	
p_1	0.16	0.2	
p_2	2.32	2.8	

p_0: photonstatistic term
p_1: electronic term
p_2: constant term

Results for Gain 150 expected to be worse because of lower light yield due to crystal geometry.
$\Rightarrow p_0 \approx 3.0\,\%$

Results match expectations.

Comparison

Parameter	PROTO120 / %	APD 150 / %	APD 500 / %
p_0	2.46	3.05	1.6
p_1	0.16	0.2	0.15
p_2	2.32	2.8	3.6

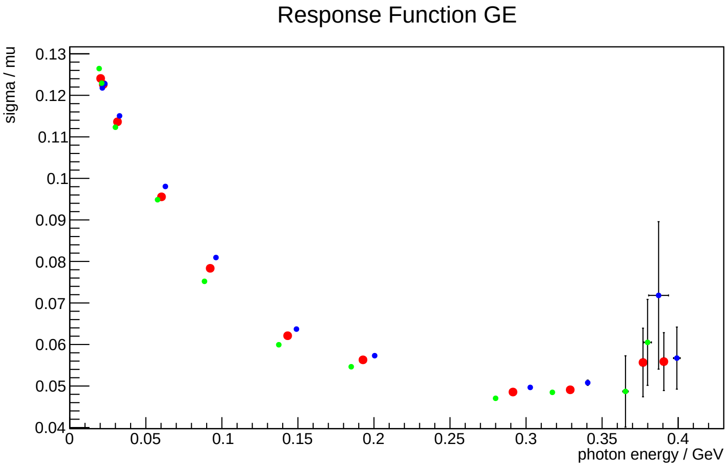
p_0: photonstatistic term p_1: electronic term p_2: constant term	Results for Gain 150 expected to be worse because of lower light yield due to crystal geometry. $\Rightarrow p_0 \approx 3.0\,\%$
Results match expectations.	Significantly reduced statistic term! $\rightarrow$ Signal-to-noise-ratio of APDs

Dynamic range

Dynamic range for the low gain ASIC-branch, assuming that the max. detectable energy is roughly 12 times higher than the range of the high gain branch: 2.2 GeV.
Usage of APD-gain 500 up to 40°, respectively 50° possible, without losing information.

Structure

Optimization of calibration factors



Comparison of energy resolutions with different calibration factors on the central detector: red: initial data, green: central detector times 0.95, blue central detector times 1.05.
No correction of the absolute calibration!

Tasks ahead

Currently, the calibration factors are optimized by a genetic algorithm.

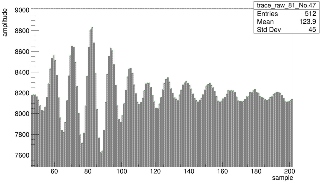
The remaining tasks for the analysis include:

- Energy resolution for remaining settings
- Improve existing fits as possible
- Timing resolution for different settings
- Position resolution for different settings
- Determination of noise level

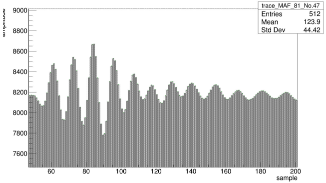
Structure

Addendum

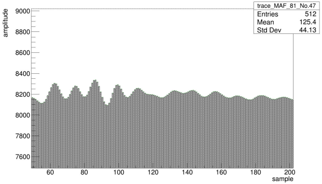
$$y(n) = \frac{1}{L} \cdot \sum_{k=0}^{L-1} x(n-k)$$



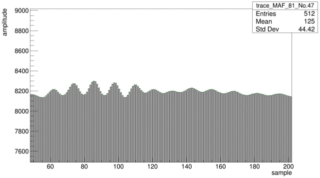
raw data



Moving Average $L = 5$



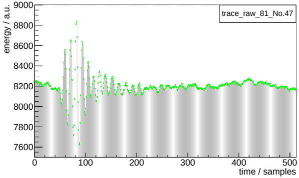
Moving Average $L = 10$



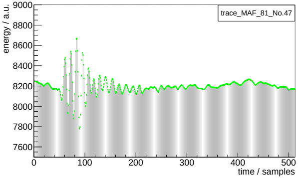
Moving Average $L = 20$

Addendum

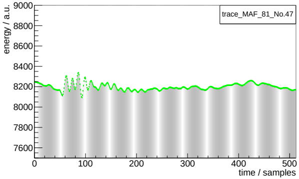
$$y(n) = \frac{1}{L} \cdot \sum_{k=0}^{L-1} x(n-k)$$



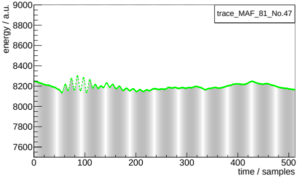
raw data



Moving Average $L = 5$

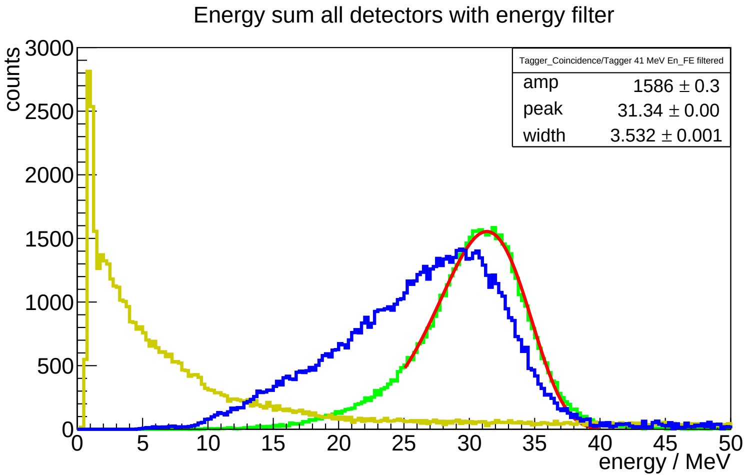


Moving Average $L = 10$



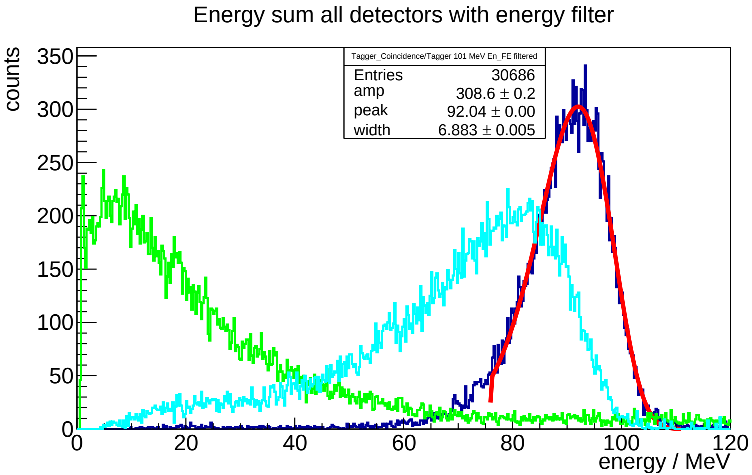
Moving Average $L = 20$

Addendum



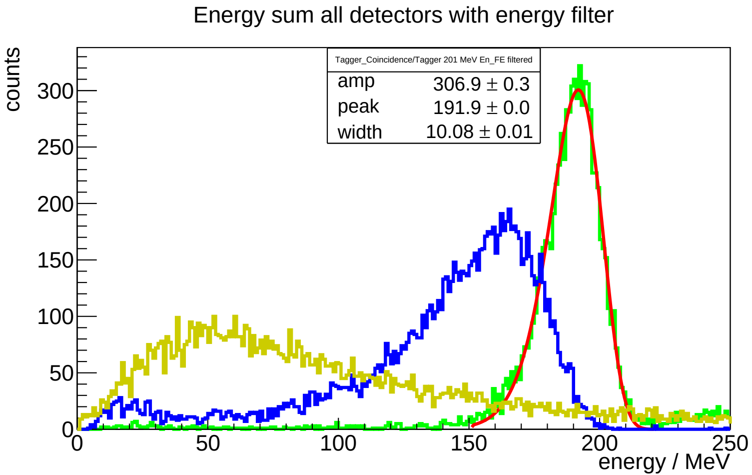
Lineshape for the 41 MeV tagger channel

Addendum



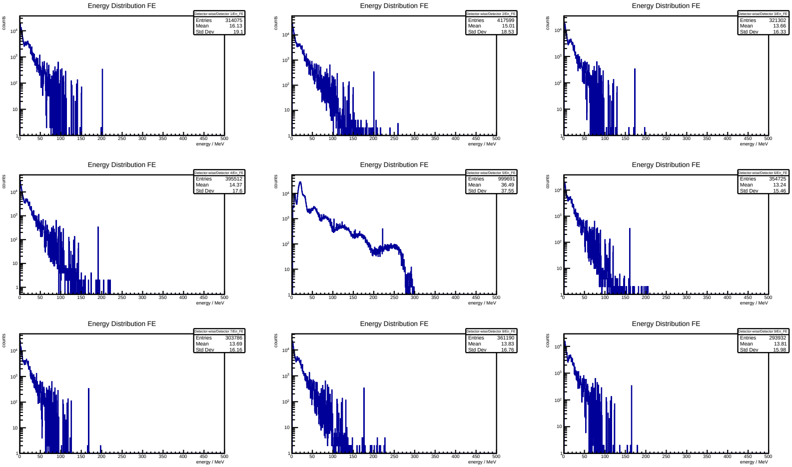
Lineshape for the 101 MeV tagger channel

Addendum



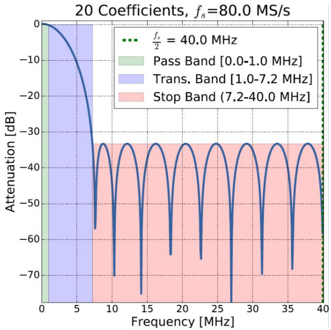
Lineshape for the 201 MeV tagger channel

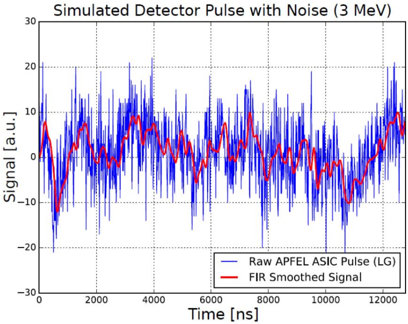
Addendum


Energy Distribution FE
Entries 314075
Mean 16.13
Std Dev 19.1
Energy Distribution FE
Entries 417599
Mean 15.01
Std Dev 18.53
Energy Distribution FE
Entries 321302
Mean 13.66
Std Dev 16.33
Energy Distribution FE
Entries 395512
Mean 14.37
Std Dev 17.6
Energy Distribution FE
Entries 999691
Mean 36.49
Std Dev 37.55
Energy Distribution FE
Entries 354725
Mean 13.24
Std Dev 15.46
Energy Distribution FE
Entries 303786
Mean 13.69
Std Dev 16.16
Energy Distribution FE
Entries 361190
Mean 13.83
Std Dev 16.76
Energy Distribution FE
Entries 293932
Mean 13.81
Std Dev 15.98
counts
energy / MeV

Addendum

"$\overline{\text{P}}$ANDA Feature Extraction" by Oliver Noll:



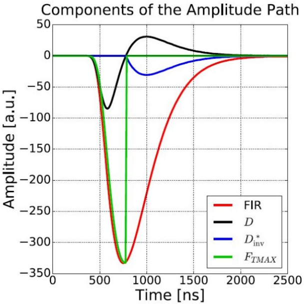


Digital Signal Processing for the EMC PANDA Collaboration Meeting 19/3, Talk by Oliver Noll

Specially tailored for use in $\overline{\text{P}}$ANDA, with the APFEL-ASICs.
"Low-pass filter" through finite impulse responds filtering.

Addendum

"$\overline{\text{P}}$ANDA Feature Extraction" by Oliver Noll:



$$D[i] = T[i] - T[i-r]$$

$$D^*_{\text{inv}}[i] = -\Theta(-D[i]) \cdot D[i]$$

$$\Theta(x) \mapsto \begin{cases} 0: & x < 0 \\ 1: & x \geq 0 \end{cases}$$

$$D_s[i] = D[i] + D^*_{\text{inv}}[i]$$

$$D_s[i] \mapsto \begin{cases} F_{TMAX}[i] = F_{TMAX}[i-1] + \frac{D_s[i]}{r} & : D_s[i] < 0 \\ F_{TMAX}[i] = 0 & : D_s[i] = 0 \end{cases}$$

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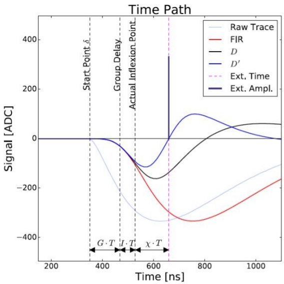
Rising edge and correct amplitude, by first derivative.
Cancelling of the falling edge is important for pileup correction.

Addendum

"$\overline{\text{P}}$ANDA Feature Extraction" by Oliver Noll:



$$f(x) = -A \cdot e^{\frac{-N(x-\delta)}{\tau}} \cdot \left(\frac{x-\delta}{\tau}\right)^N$$

$$f''(x) = 0$$

$$I = \frac{\tau(\sqrt{N}-1)}{\sqrt{N}}$$

Theory inflexion point

$$T_0 = \delta + I$$

$$T_0 = i_0 + \frac{D'[i_0]}{D'[i_0] - D'[i_1]}$$

Between sample interpolation

D is already the first derivative. Thus, D' is the second one

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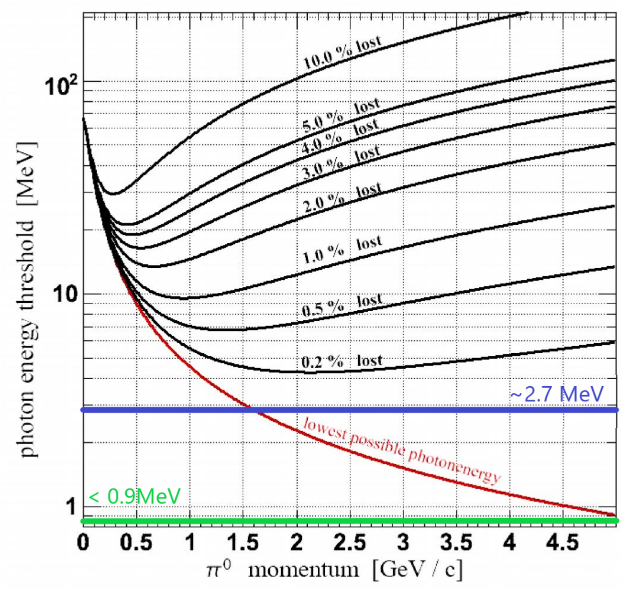
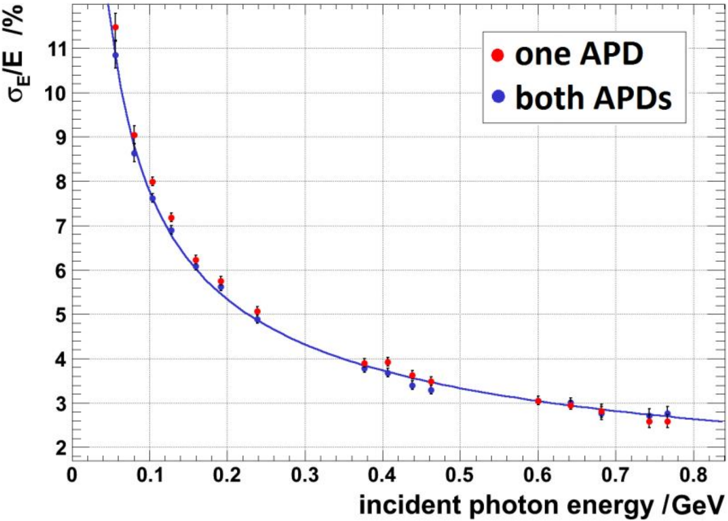
Second derivative inflexion point together with some interpolation increases time resolution.

Addendum



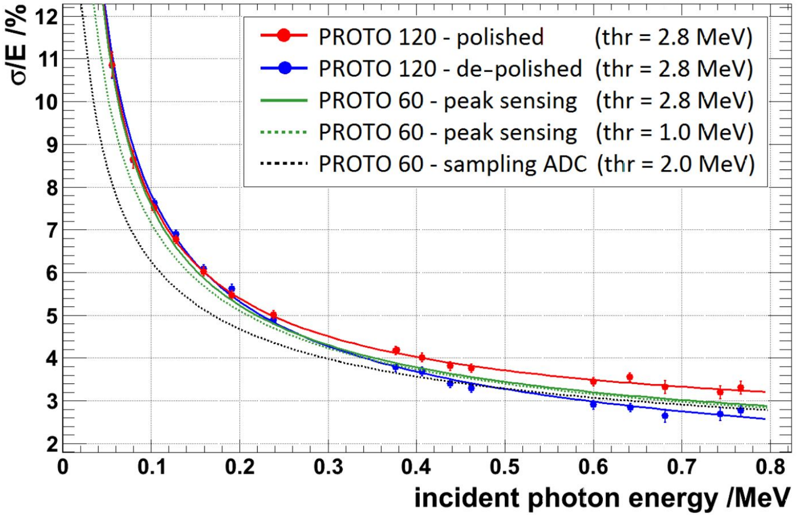
photon energy threshold [MeV]
10^2
10
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
π^0 momentum [GeV / c]
10.0 % lost
5.0 % lost
4.0 % lost
3.0 % lost
2.0 % lost
1.0 % lost
0.5 % lost
0.2 % lost
~2.7 MeV
lowest possible photonenergy
< 0.9MeV

Addendum



σE/E /%
11
10
9
8
7
6
5
4
3
2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
incident photon energy /GeV
one APD
both APDs

Addendum



σ/E /%
12
11
10
9
8
7
6
5
4
3
2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
incident photon energy /MeV
PROTO 120 - polished (thr = 2.8 MeV)
PROTO 120 - de-polished (thr = 2.8 MeV)
PROTO 60 - peak sensing (thr = 2.8 MeV)
PROTO 60 - peak sensing (thr = 1.0 MeV)
PROTO 60 - sampling ADC (thr = 2.0 MeV)