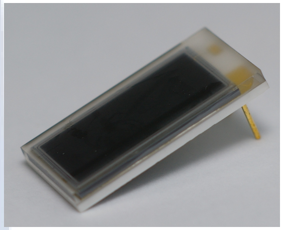
Front-End Electronics and Feature-Extraction Algorithm for the PANDA Electromagnetic Calorimeter



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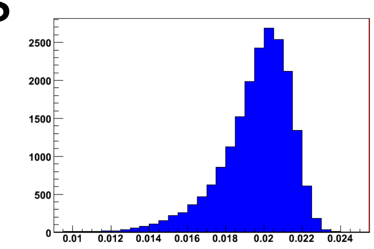
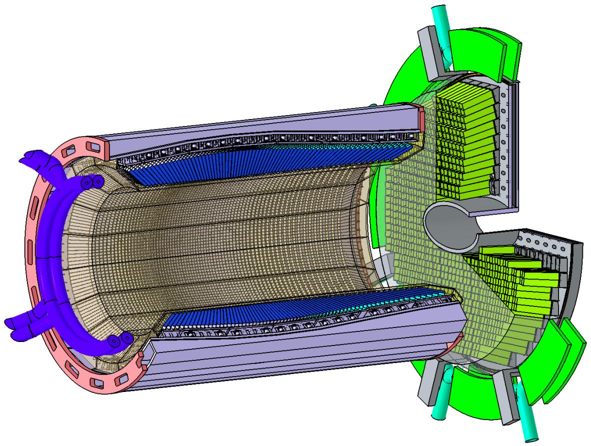




- **Sampling ADC readout**
- **Precise timing of the pulse**
- **Energy resolution**
- **High-rate capability**

AntiProton Annihilation at DArmstadt (PANDA)

PANDA spectrometer employs fixed target and **cooled antiproton** beam:

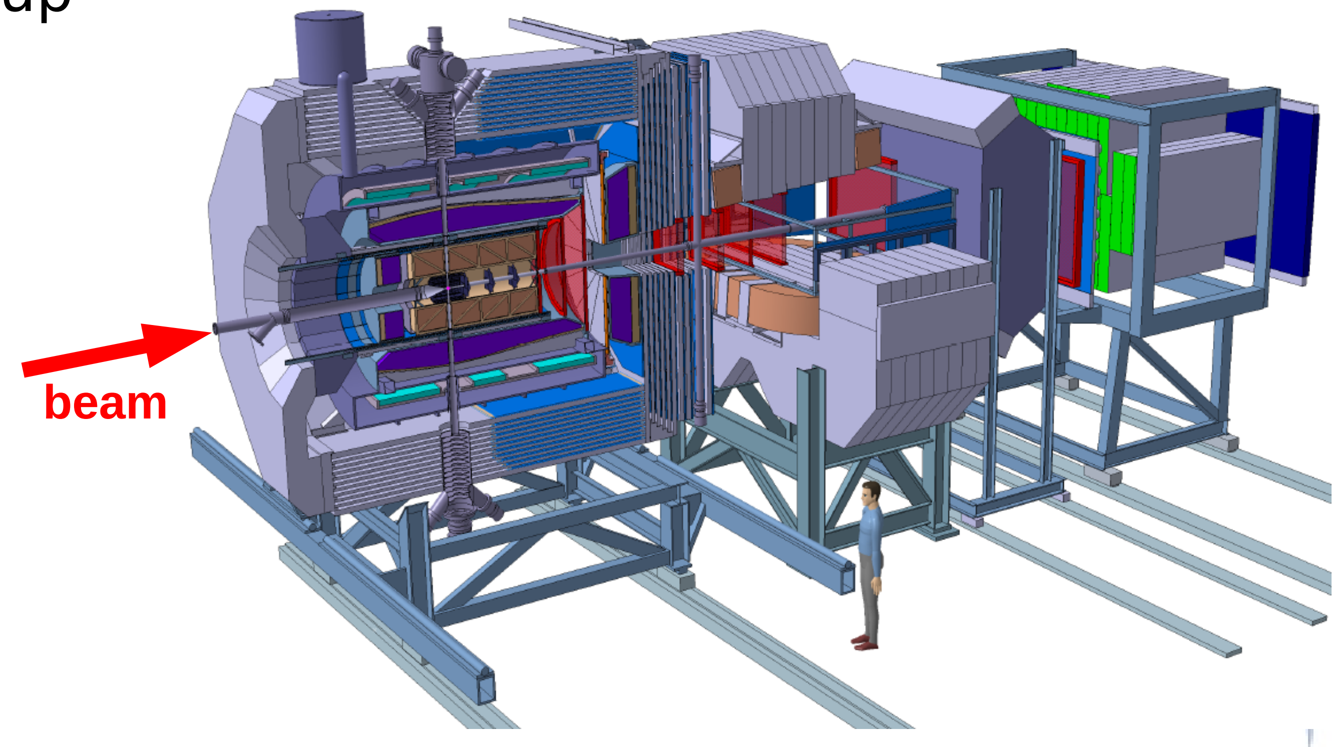
- momentum range 1.5 GeV/c to 15 GeV/c
- Luminosity: 10^{31} – 10^{32} $cm^{-2}s^{-1}$

PANDA physics goals:

- Hadron spectroscopy up to charm
- Structure of nucleons

PANDA detector is a triggerless system:

- Each subdetector is selftriggered



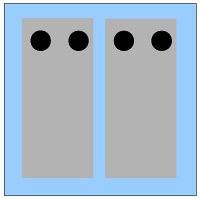
Electromagnetic Calorimeter (EMC)

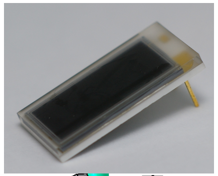
Requirements summary:

- Large dynamic range for photons (1 MeV – 10 GeV)
- High energy resolution ($\leq 1\% + (\leq 2\%)/\sqrt{E}$)
- High counting rate capability (up to 500 kHz per channel)

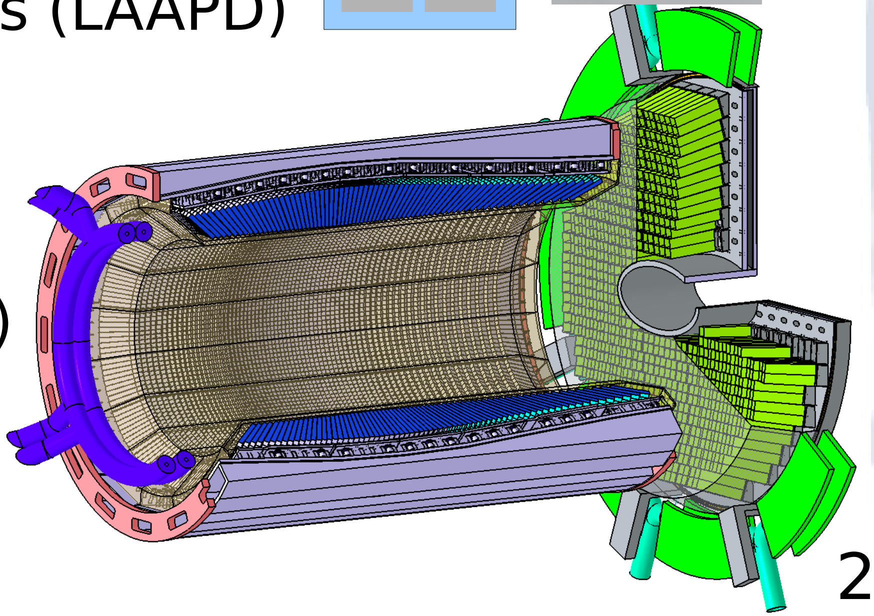
Construction summary:

- EMC consists of ~16000 PWO-II crystals operated at -25°C
- *Barrel and backward end-cap*:
  - Each crystal equipped with two Large Area Avalanche Photo Diodes (LAAPD) 14×6.8 mm^2 sensitive area each





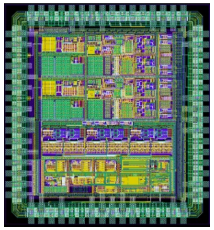
- *Forward end-cap:*
  - Each crystal read out by one Vacuum Photo Triode/Tetrode (VPT)



EMC Preamplifiers

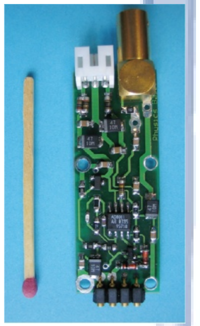
Barrel

APFEL ASIC,
GSI design
(two-channel, dual-range,
ASIC, built-in shaper:
240 ns peaking time,
~800 ns total pulse-length)

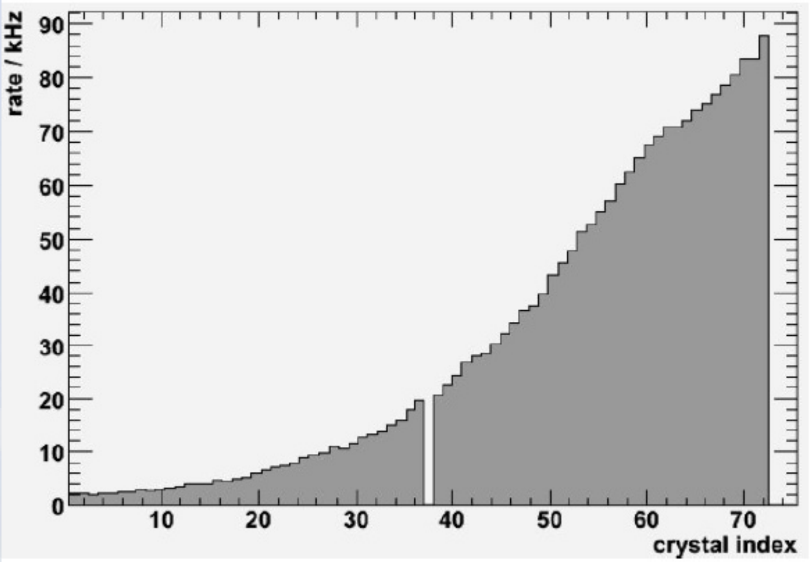


End-cap

Low Noise low Power (LNP),
Basel design
(one-channel, single-range,
discrete-component,
non-shaped output:
25 μs discharge constant)

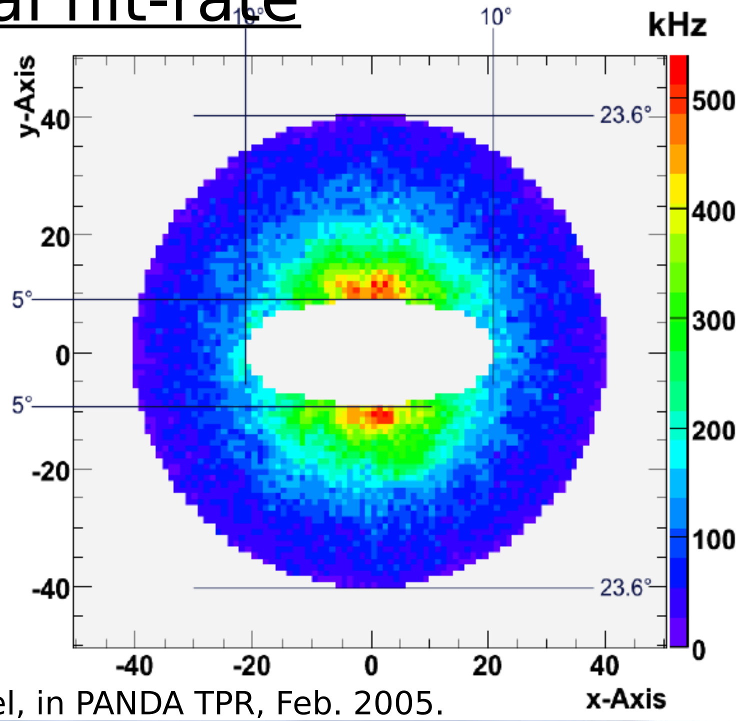


Expected single-crystal hit-rate



Max. rate:
100 kHz

Max. rate:
500 kHz



LNP discrete-component preamplifier: W. Erni, M. Steinacher, Univ. Basel, in PANDA TPR, Feb. 2005.
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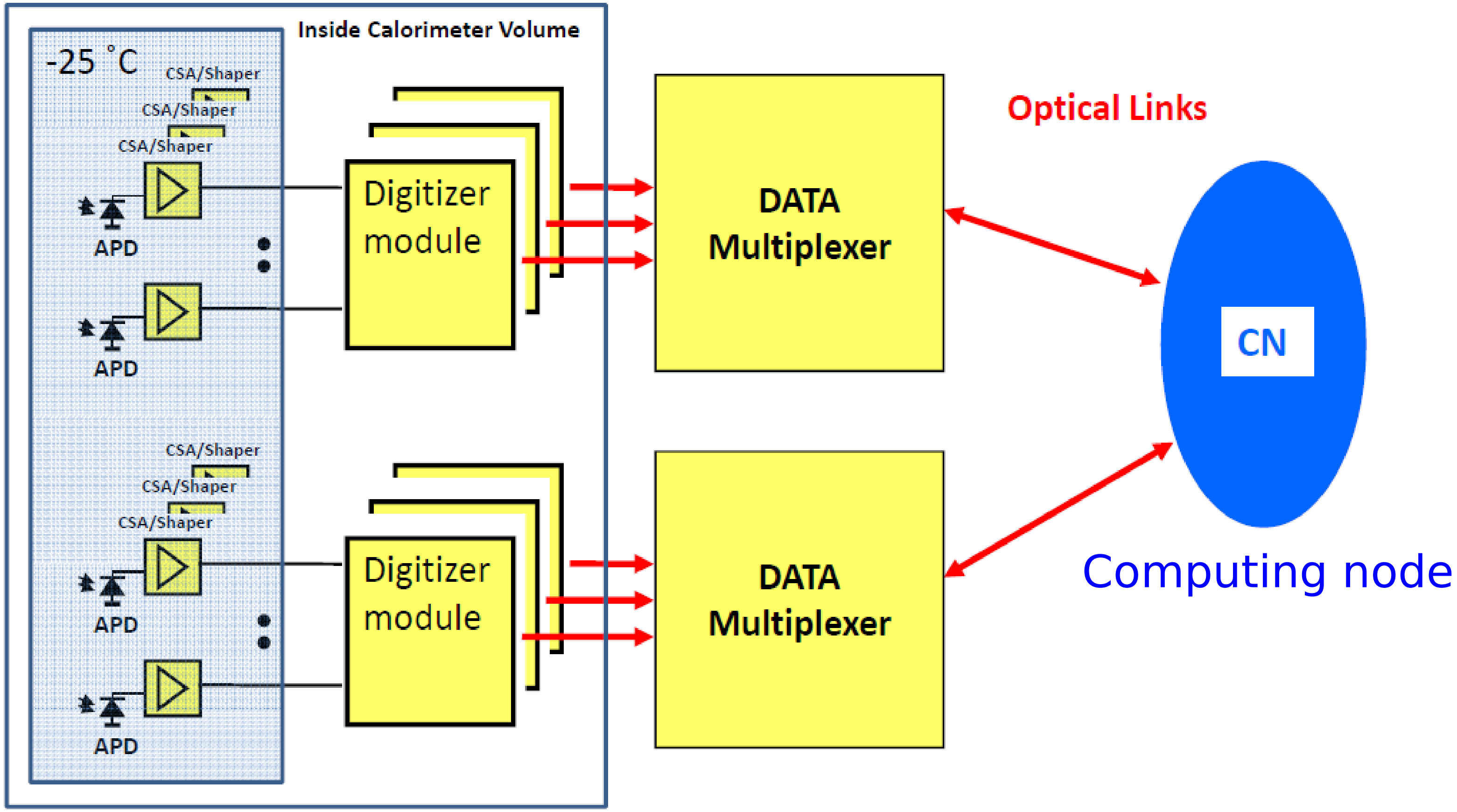
EMC Readout Scheme



Digitizer module:

- Consists of Sampling ADC (SADC) and feature-extraction module (FPGA/ASIC-based)
- Has to be low-power (placed inside the calorimeter volume)

Experimental Setup

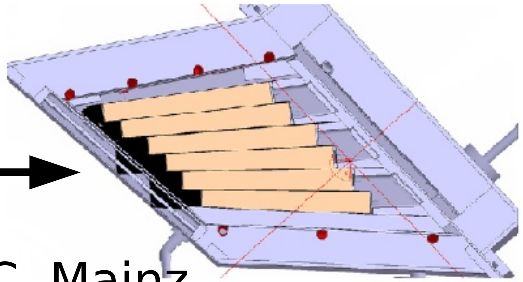
- Measurements are done using SADC (14 bit, 50 MHz) directly coupled to the preamplifier
- 10 μs long traces are stored for each event
- Traces are analysed in software
- VHDL implementation is in the testing phase

"Proto60" – EMC prototype of 60 crystals

(SADC readout of 3×3 crystals matrix)

0.1 – 1.4 GeV
γ-rays

Tagged-photon facility at MAMI-C, Mainz



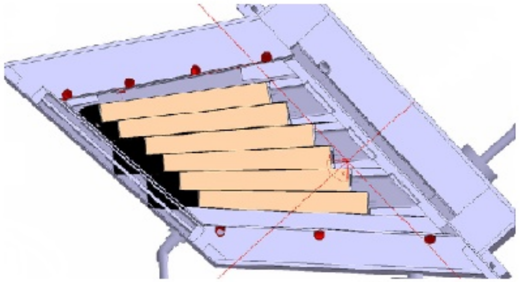
Proto60 design:

- PWO crystal shape: part of the Barrel EMC
- One LAAPD per crystal (10×10 mm²)
- LNP preamplifier

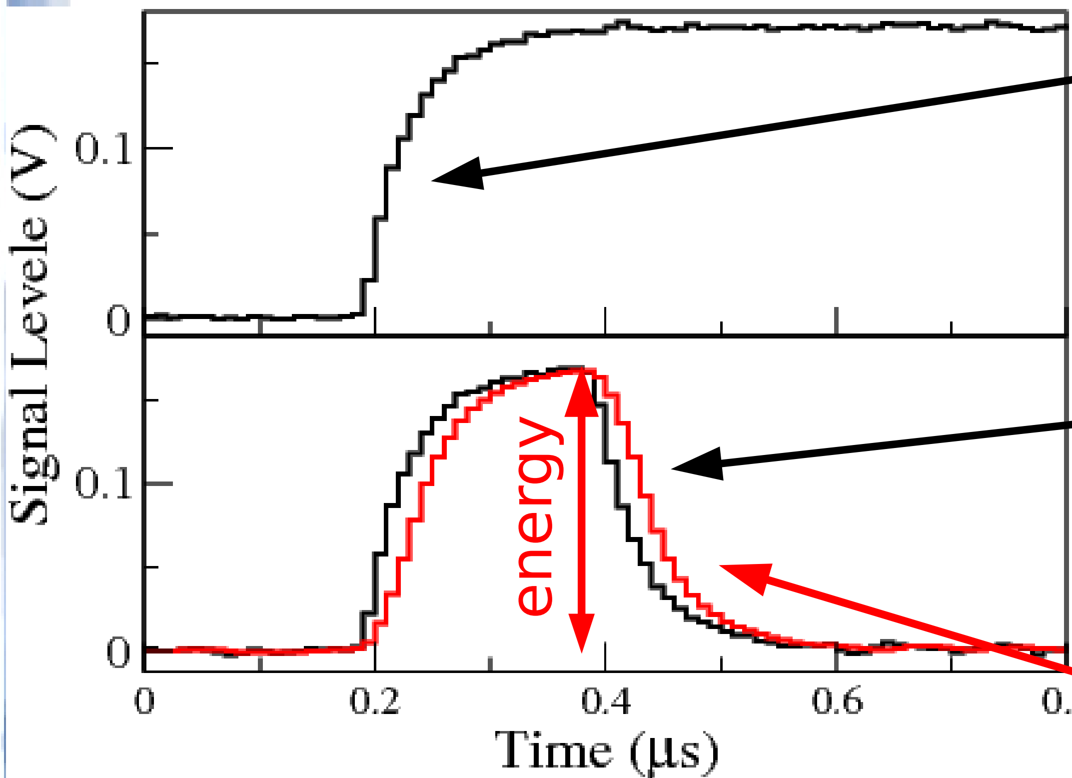
Experimental Setup: Proto60

Main goals of Proto60 test experiments:
(Front-end electronics issues)

- Measure achievable **energy** and **time** resolution
- Develop and test the performance of feature-extraction algorithm
- Test high rate capability – up to 500 kHz
- Based on the measurements estimate the resulting EMC performance



Pulse Processing
(Triggering and Energy)



Raw Trace
τ=25 µs – decay constant

Moving Window Deconvolution[1]
– differentiation + PZC
(MWD) filtering:

$$MWD_M(n) = x_n - x_{n-M} + \frac{\ln 2}{\tau} \sum_{i=n-M}^{n-1} x_i$$

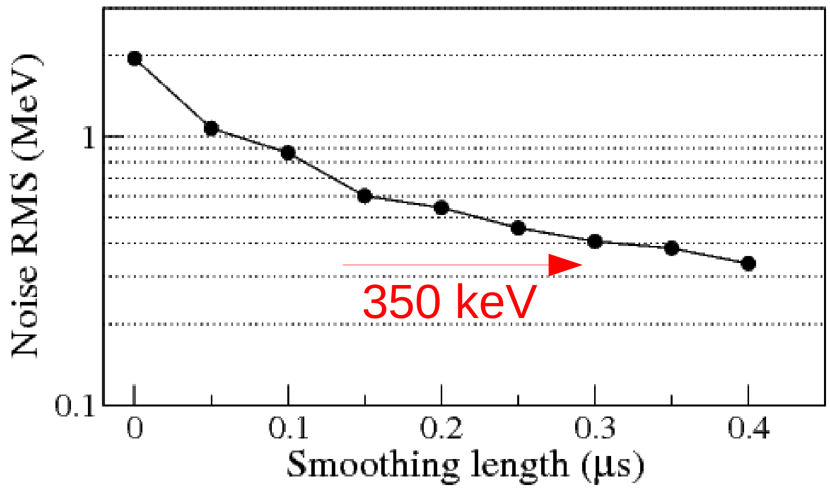
Smoothed MWD signal
integration
(moving averaging, MA)
This signal is used for the **triggering** and **energy** readout

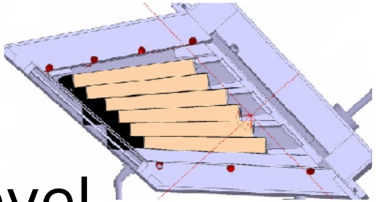
Energy resolution and noise level depends on the differentiation and smoothing length

1. A. Georgiev, W. Gast, IEEE Trans. Nucl. Sci. NS-40 (1993) 770; J. Stein *et al.*, Nucl. Instr. Meth. B 113 (1994) 141.

Triggering Threshold and Energy Resolution

Noise level as a function of the smoothing length

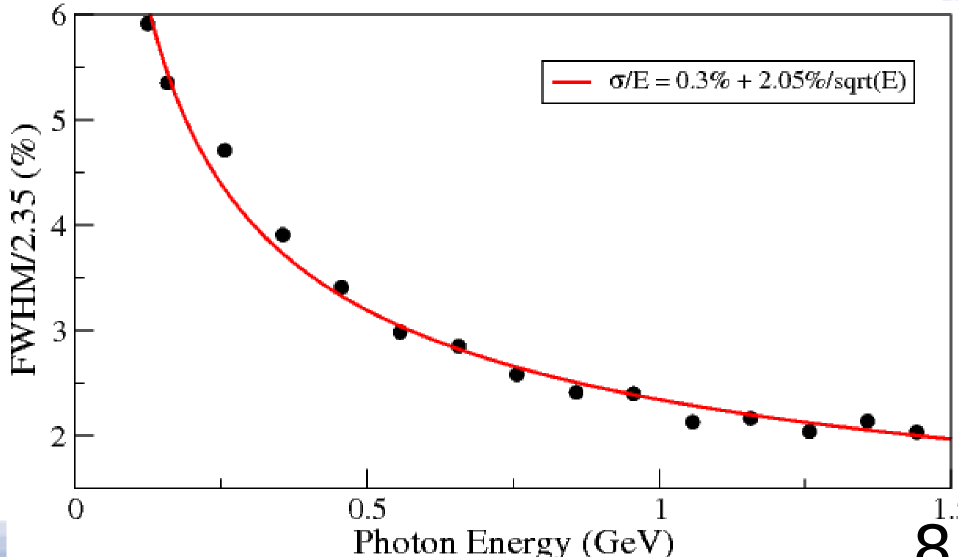




<u>Smoothing:</u>

- decreases noise level
- increases pulse length – pileup correction needed

Energy resolution (3x3 crystals) measured using high-energy tagged photons



<u>Requirement:</u>

$\sigma/E = \leq 1\% + (\leq 2\%)/\sqrt{E}$

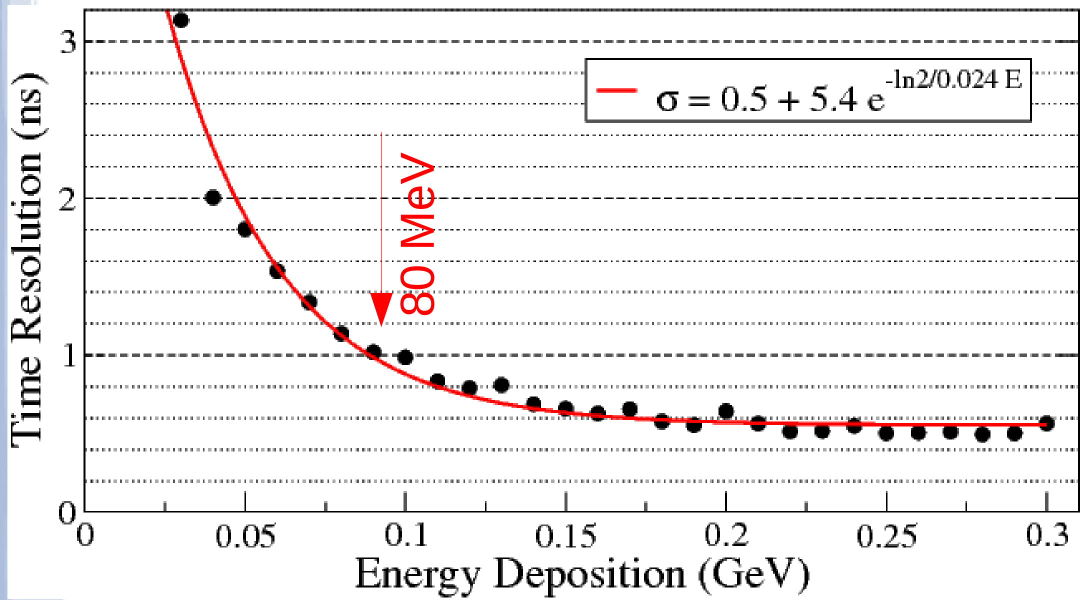
almost fulfilled

EMC will have two times larger photosensor than “Proto60”

→ ~√2 improvement expected

Time Resolution
using Sampling ADC readout

Time resolution as a function of energy deposition (sampling rate 50 MHz – 20 ns)

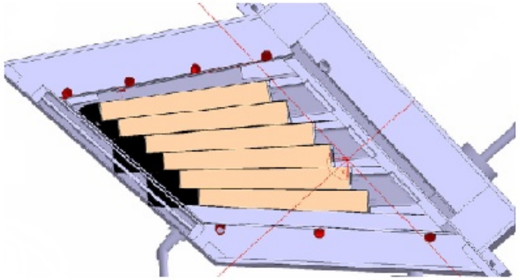


It is possible to achieve time resolution much (×20) higher than SADC sampling rate

Time-stamp is generated using digital implementation of **Constant-Fraction Discrimination** (CFD)

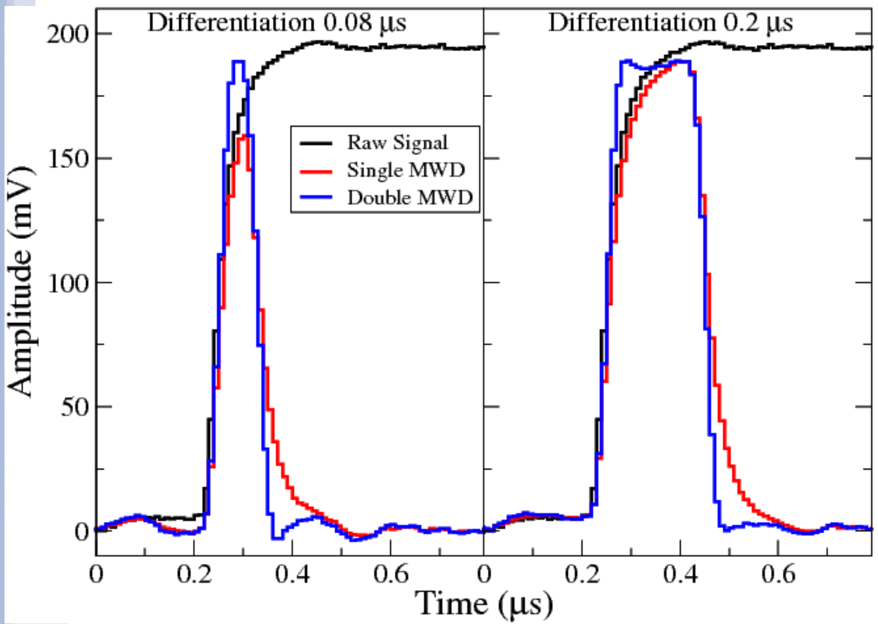
Time-resolution measurement:

- Proto60 set-up
- Tagged photons are shot between two PWO crystals to achieve two ~ equal energy depositions
- Time-difference between two crystals is used to derive time resolution

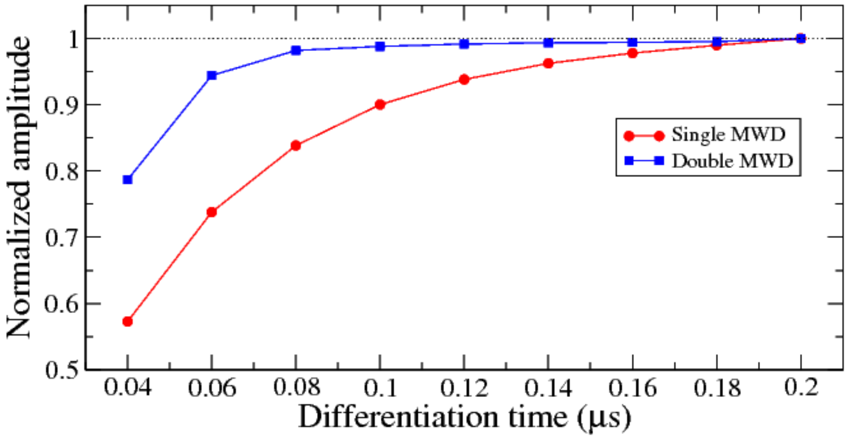


High-Rate Capability
SADC-Readout Advantages

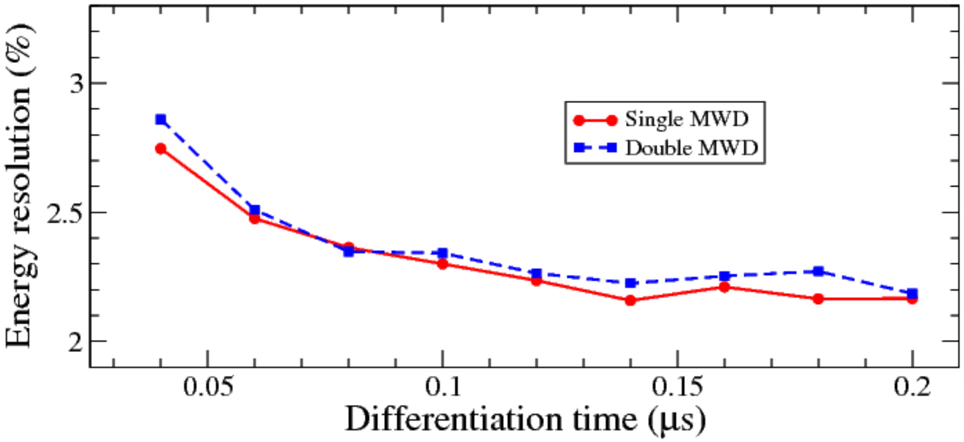
LNP pulse-shape before and after single/double MWD filtering



Pulse-amplitude recovery (double MWD filtering)



Cluster energy resolution at 1 GeV



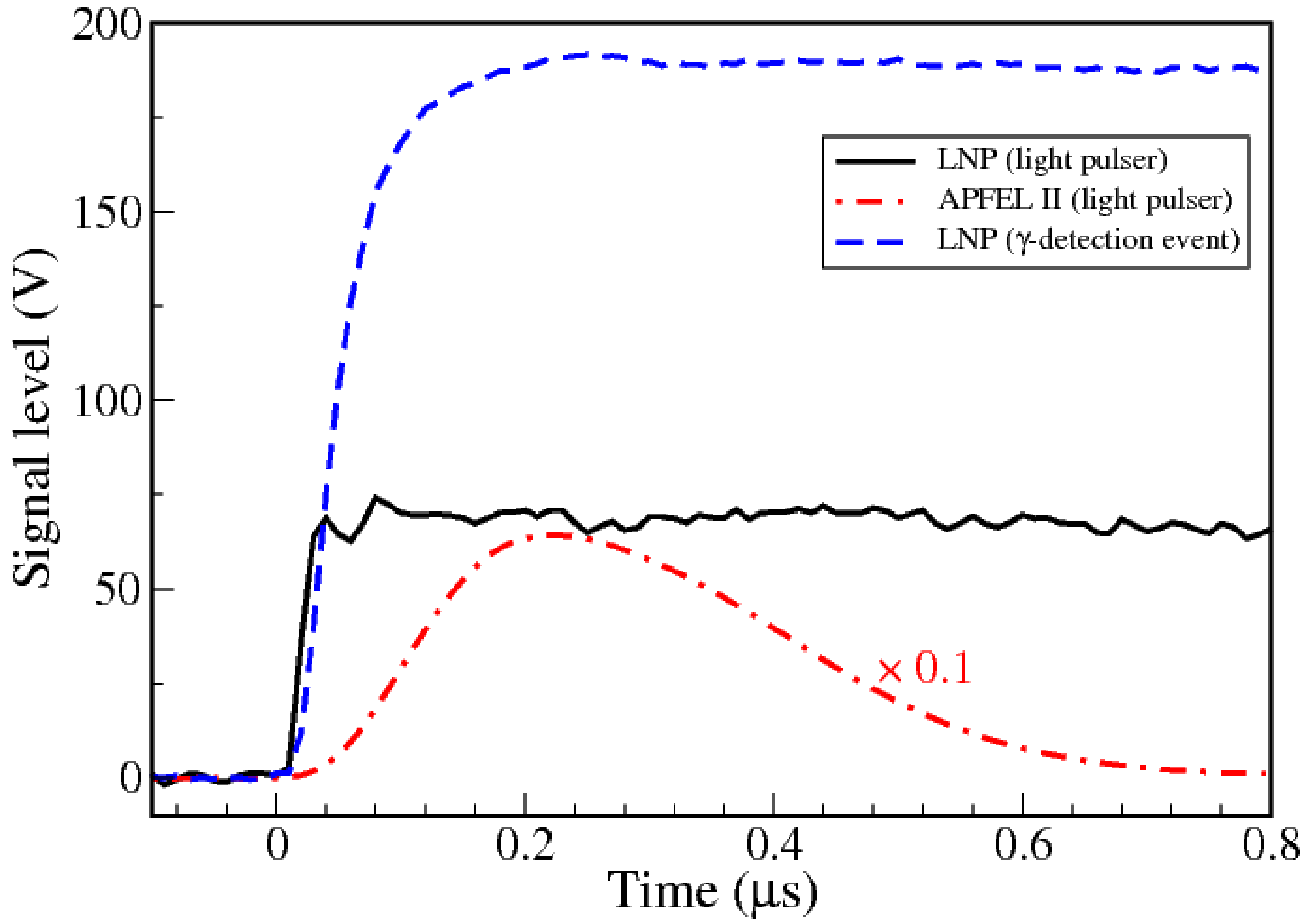
- Double MWD allows to reduce 2.5 times minimum pulse-width – not achievable with analogue electronics
- Maximum hit-rate capability improves from 130 to 330 kHz

Conclusions

- SADC readout of the PANDA EMC allows to achieve design goals:
  - Large dynamic range (1 MeV – 10 GeV)
  - Low trigger threshold (~1 MeV)
  - High time resolution (<1 ns for E_γ>80 MeV)
  - Improved performance at high counting rates (130 kHz → 330 kHz, without pile-up correction)
- The “digital CFD” produces time stamps with much higher (×20) precision than SADC sampling rate
- The feature-extraction algorithm is implemented in VHDL for the on-line SADC data-processing
- Development of simple pile-up correction algorithm is in advanced stage

EMC Preamplifiers

Pulse shapes from EMC preamplifiers



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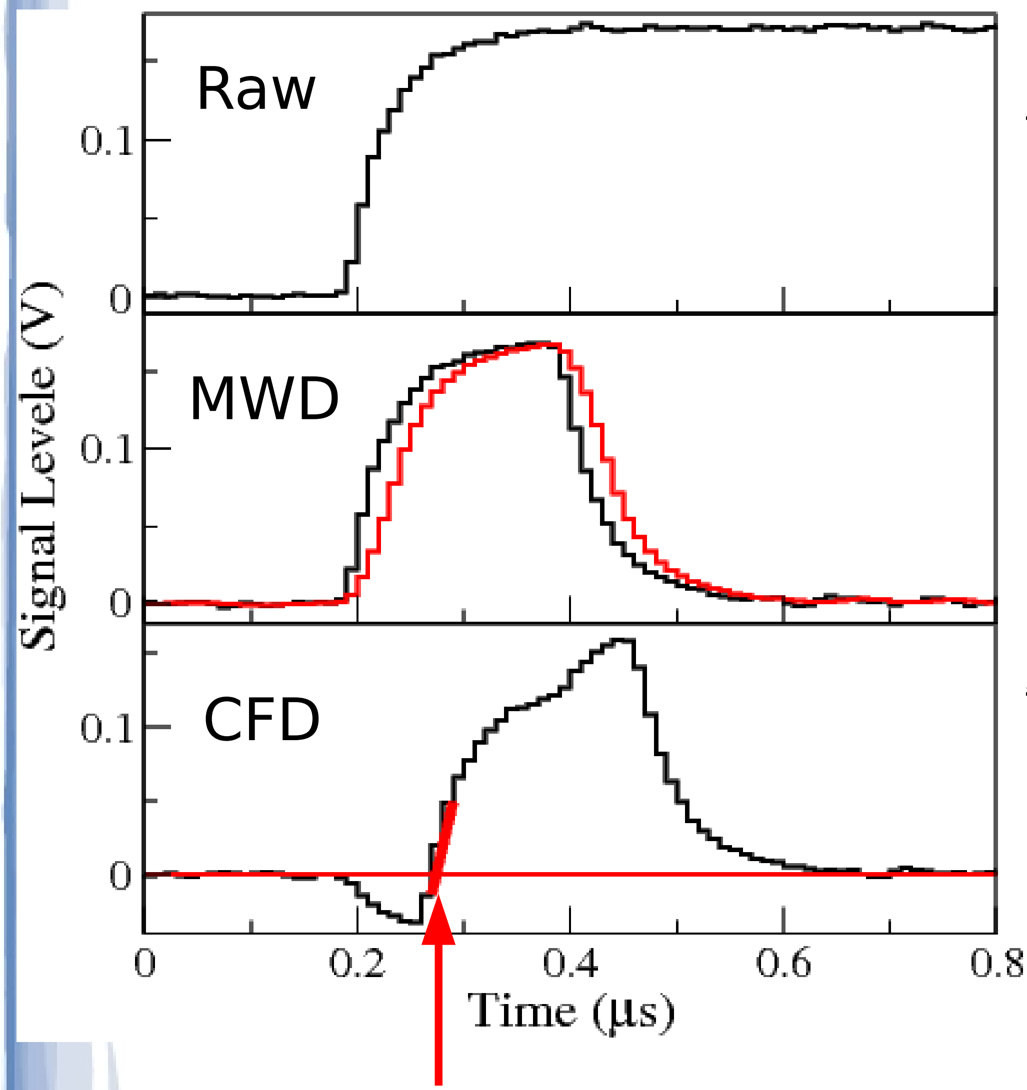
Pulse Processing
(Precise Timing)



Time stamp: zero-crossing
(linear regression)

Precise timing:

- **more accurate** than the SADC sampling rate
- Constant Fraction Discrimination (CFD) is used

Analogue-like implementation:

CFD(n) = MWD(n-*d*) – *R*·MWD(n)

- Delay *d* = signal rise time
- Fraction *R* – to select most linear part of the signal leading edge
- ⋆ *N* – number for the linear regression
- ⋆ Symmetry around zero level