Feature-Extraction Algorithms for the PANDA Electromagnetic Calorimeter

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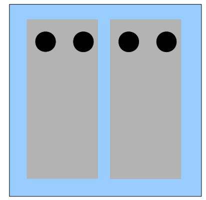
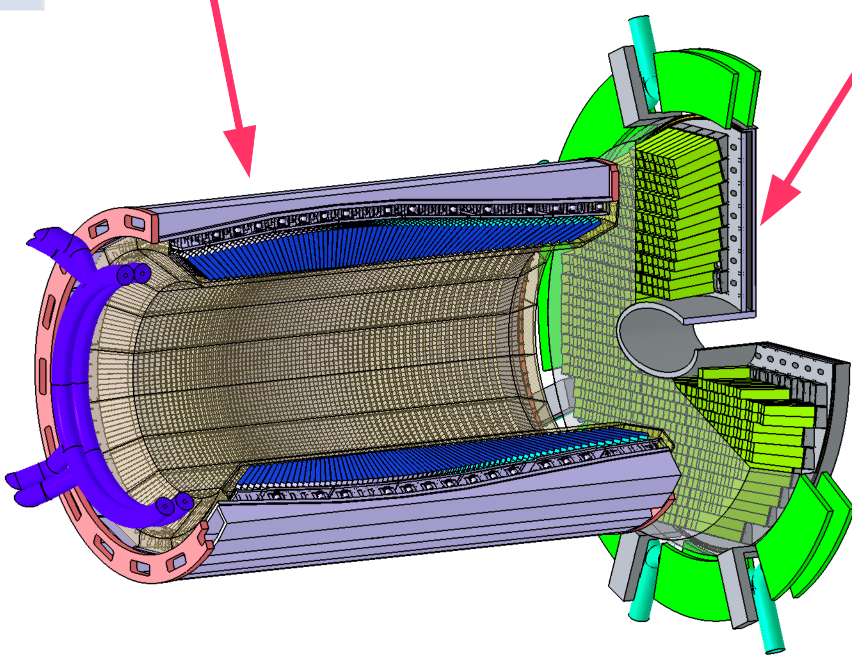
- **Sampling ADC readout**
- **On-line data processing**
- **Precise energy/time of the pulse**

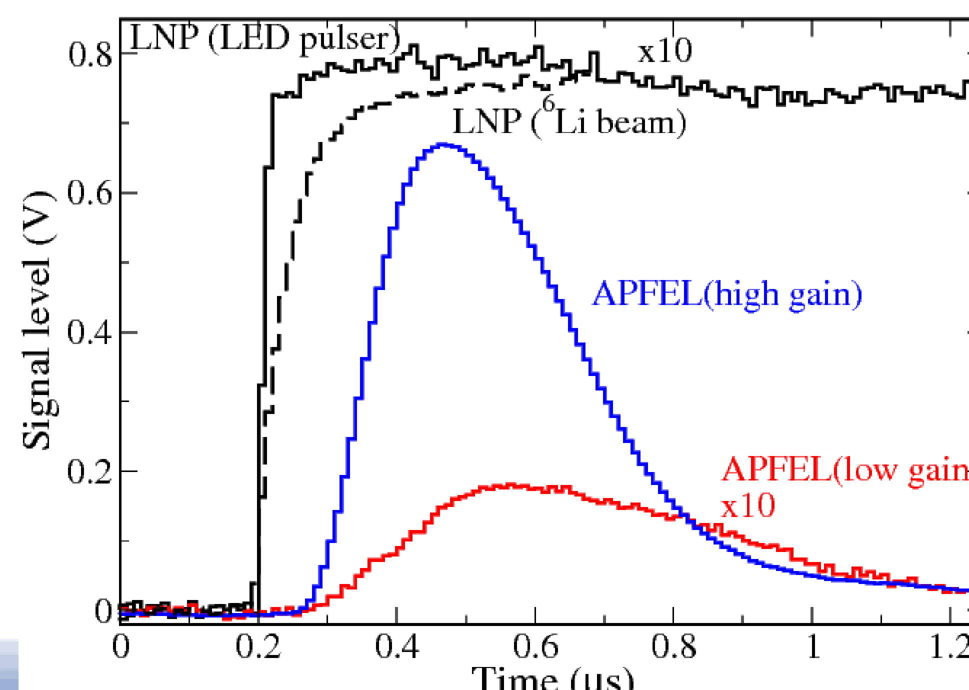
Electromagnetic Calorimeter (EMC)



Barrel:
- 2 LAAPD per crystal
- APFEL ASIC preamp. (GSI):
  - two independent channels
  - two ranges per channel
  - built-in shaper

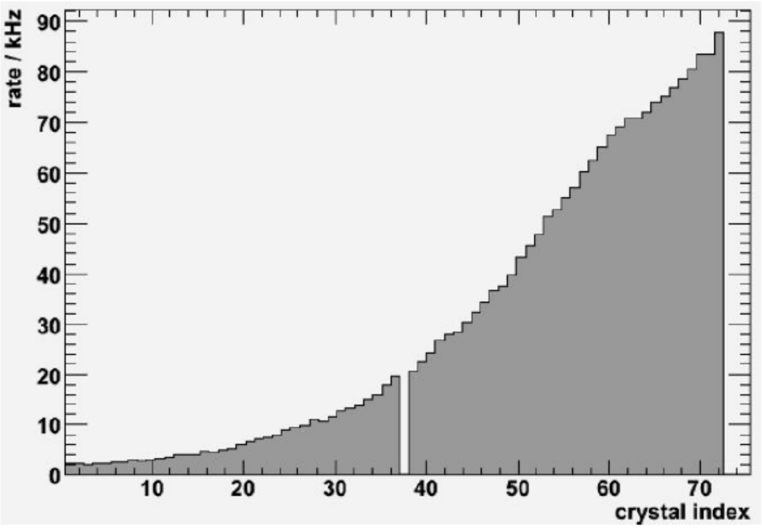
End-cap:
- One VPT per crystal
- Discrete-component LNP preamp. (Basel)
  - Single range
  - no shaper (25 μs time constant)
  - build-in 50 Ω line driver





Expected Single-Crystal Rates (EMC TDR)

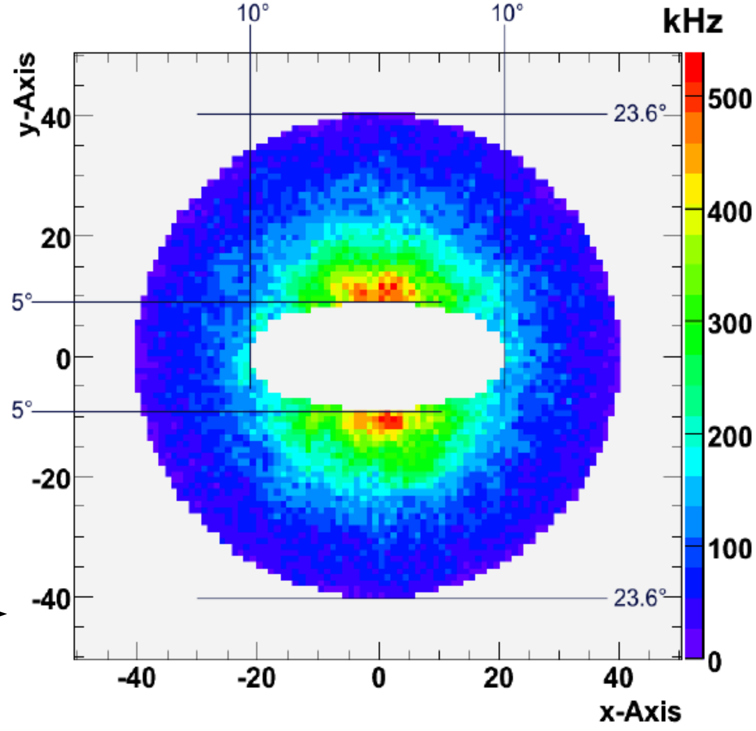
Barrel



Max. rate:
100 kHz
150 kHz
250 kHz

Max. rate:
500 kHz
750 kHz
1.25 MHz

End-cap

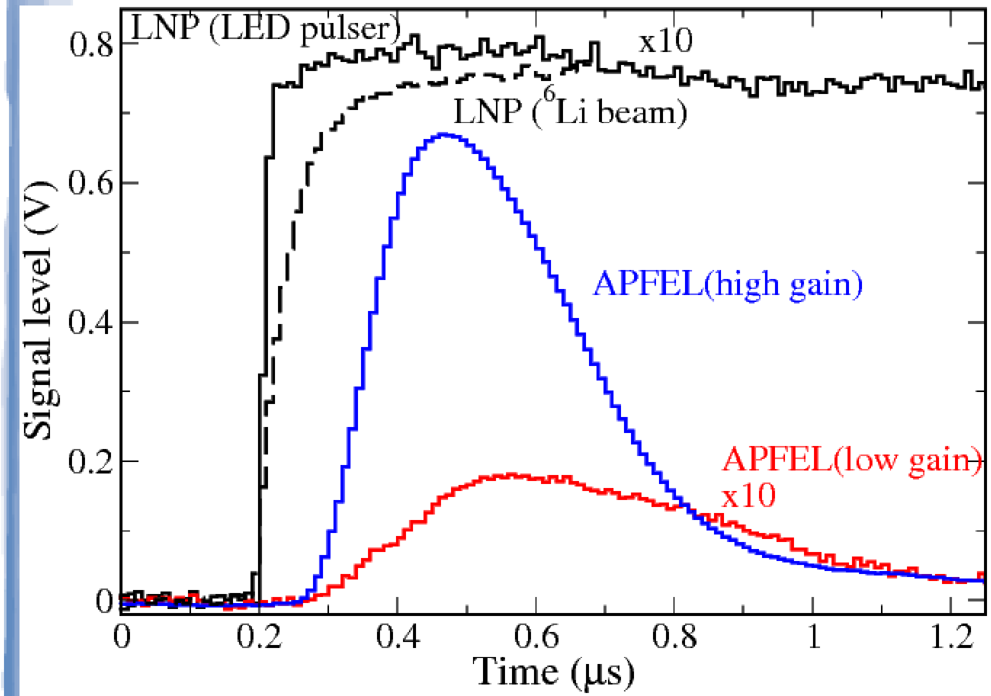


Rates in TDR are estimated for 20 MHz interaction rate.
Electronics should be prepared for 30/50 MHz!

Optimal signal shaping:

- Optimize energy resolution / dynamic range
- Minimize pile-up probability – shorten the pulse-length

Pulse Treatment



LNP preamplifier:

- Shaper is required:
  - Analogue
  - Digital
- Shaper optimization for:
  - Energy/Time resolution
  - Hit-rate capability

ASIC preamplifier:

- Shaper is optimized for energy resolution/dynamic range
- Pile-up treatment is mandatory

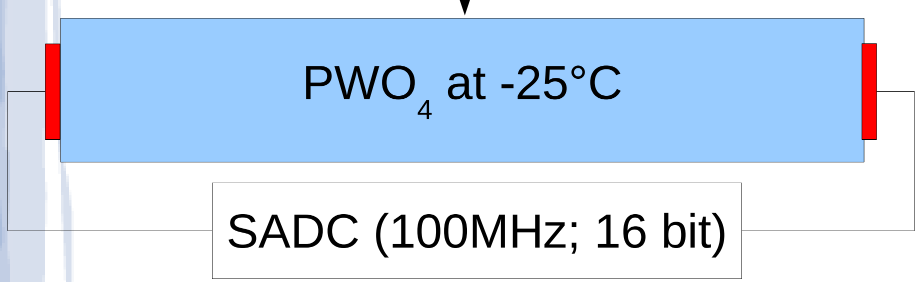
Experimental Setups

- Measurements are done using SADC (16 bit, 100 MHz) directly coupled to the preamplifier
- 10 μs long traces are stored for each event
- Traces are analysed in software
- VHDL implementation is ready

Single-crystal setup

Cosmic rays
LED light pulser

^{6}Li 2 A·GeV beam at GSI, Darmstadt (~180 MeV energy deposit)



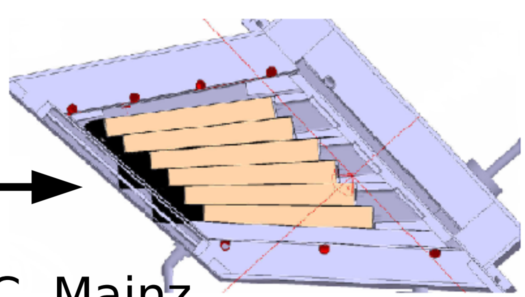
LAAPD + LNP/ASIC preamp.

"Proto60" – EMC prototype of 60 crystals

(SADC readout of 3×3 crystals matrix)

0.1 – 1.4 GeV
γ-rays

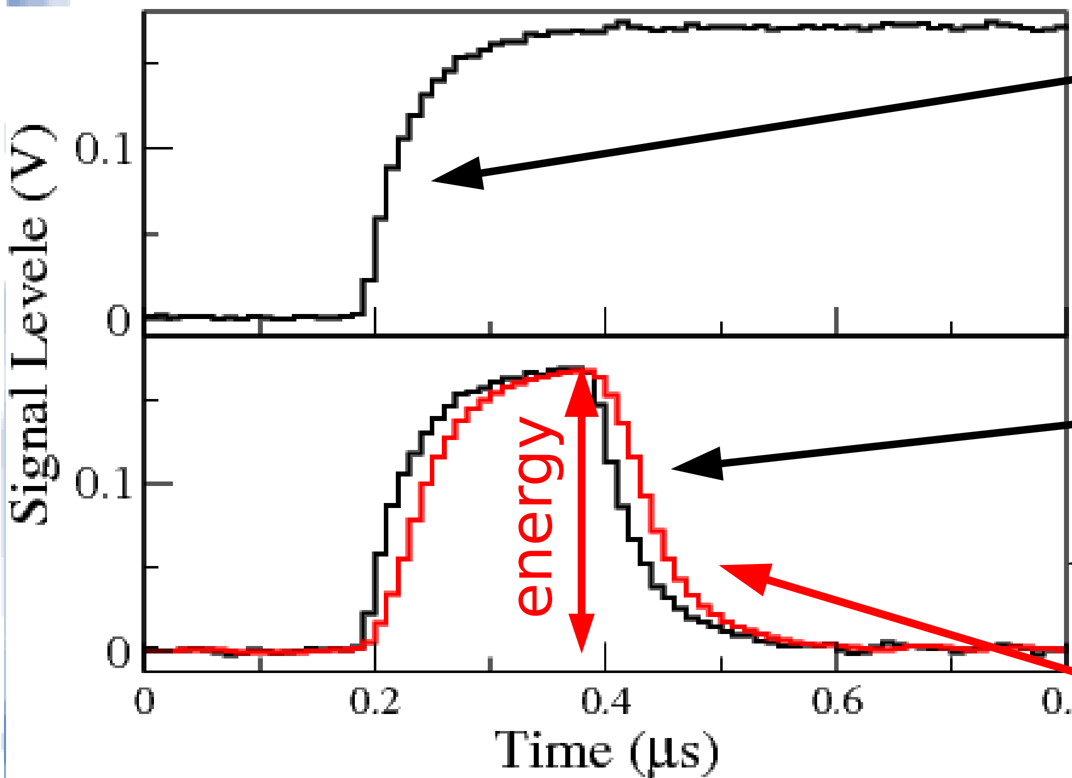
Tagged-photon facility at MAMI-C, Mainz



LAAPD + LNP preamp.

LNP Preamplifier
Signal Treatment

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)

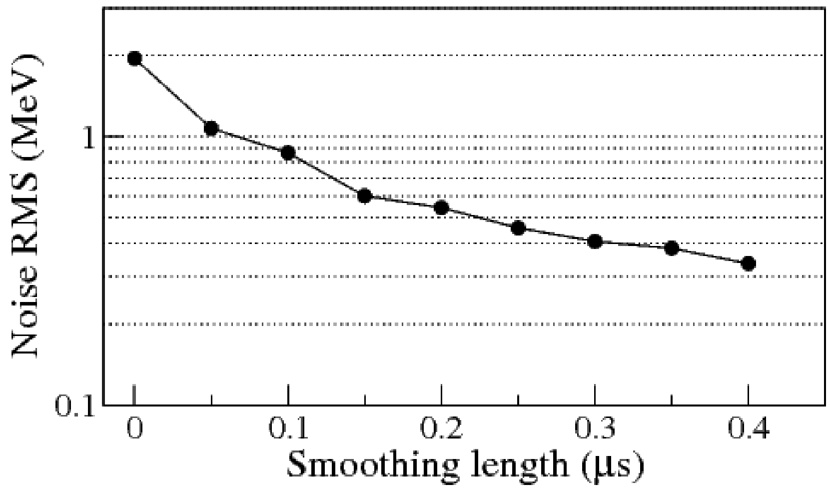
This signals is used for the **triggering** and **energy** readout

Energy resolution and noise level depends only on the 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.

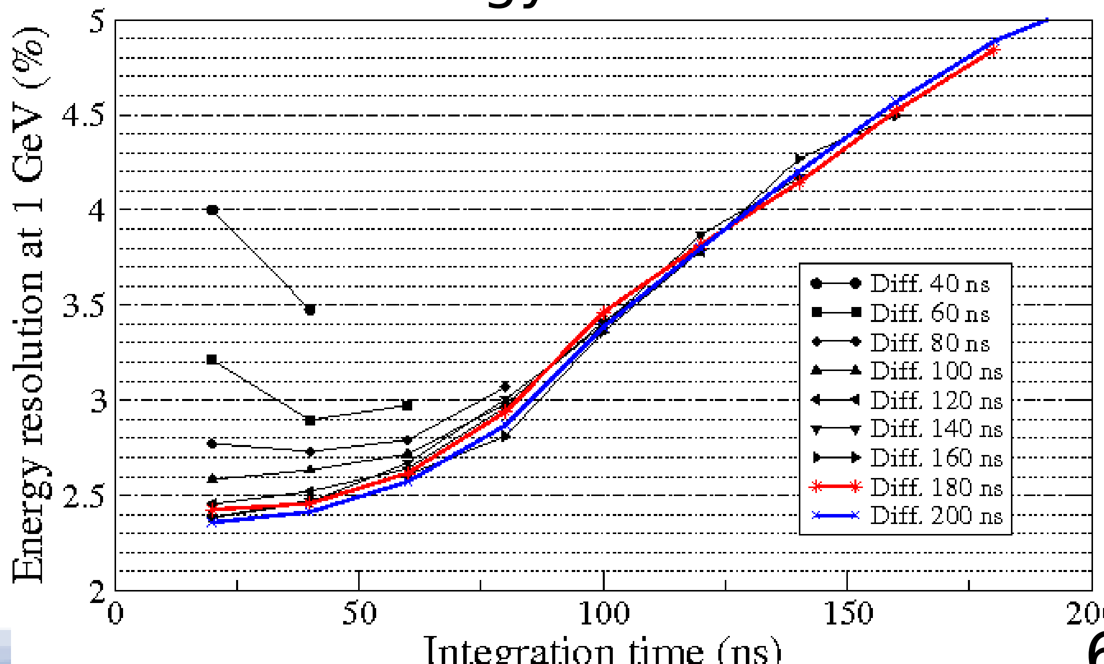
Triggering Threshold and Energy Resolution

Noise level as a function of the smoothing length



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

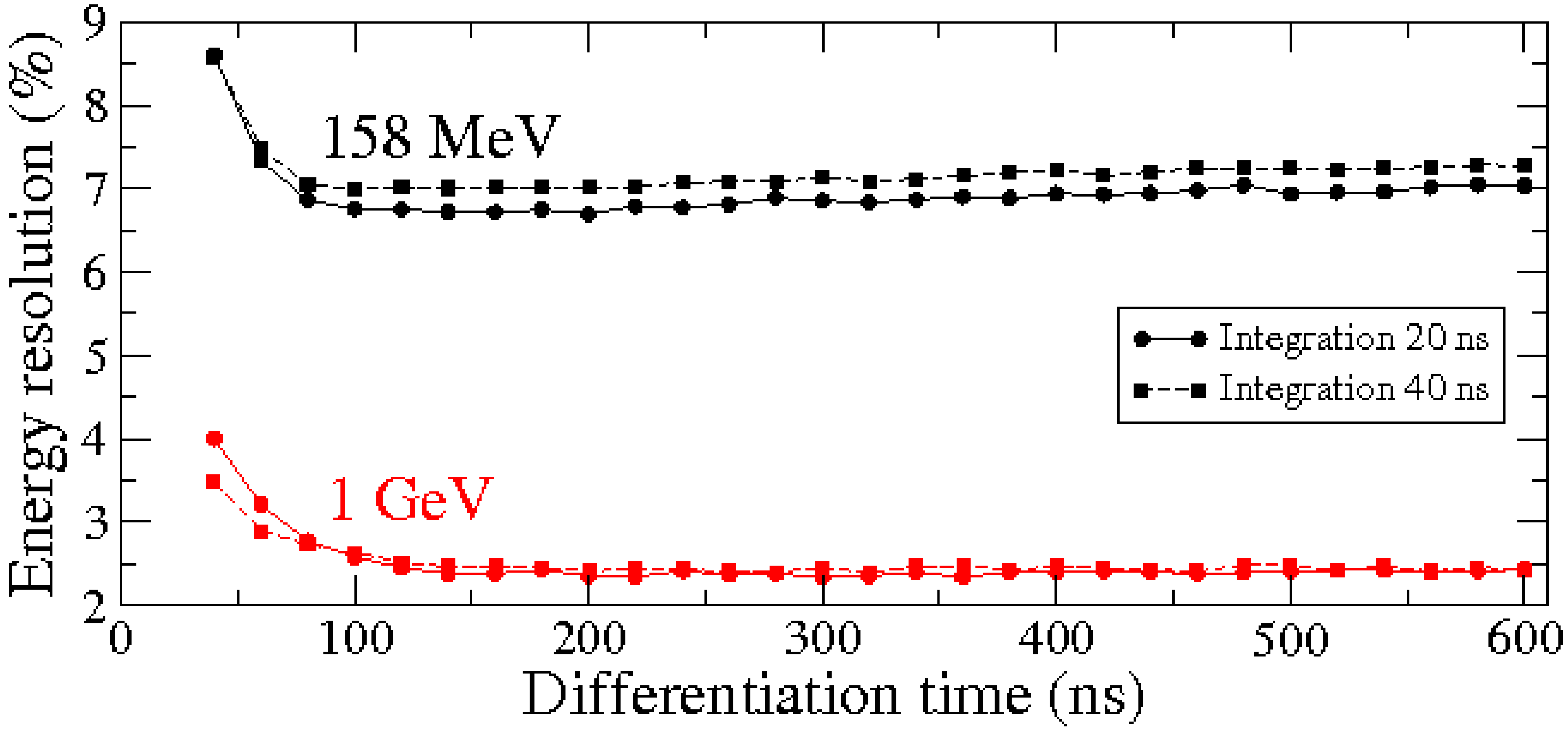
Effect of filtering on the energy resolution



At low diff. time constants additional integration reduces the resolution!

Forward End-Cap LNP preamlifier

Scan of the differentiation parameter



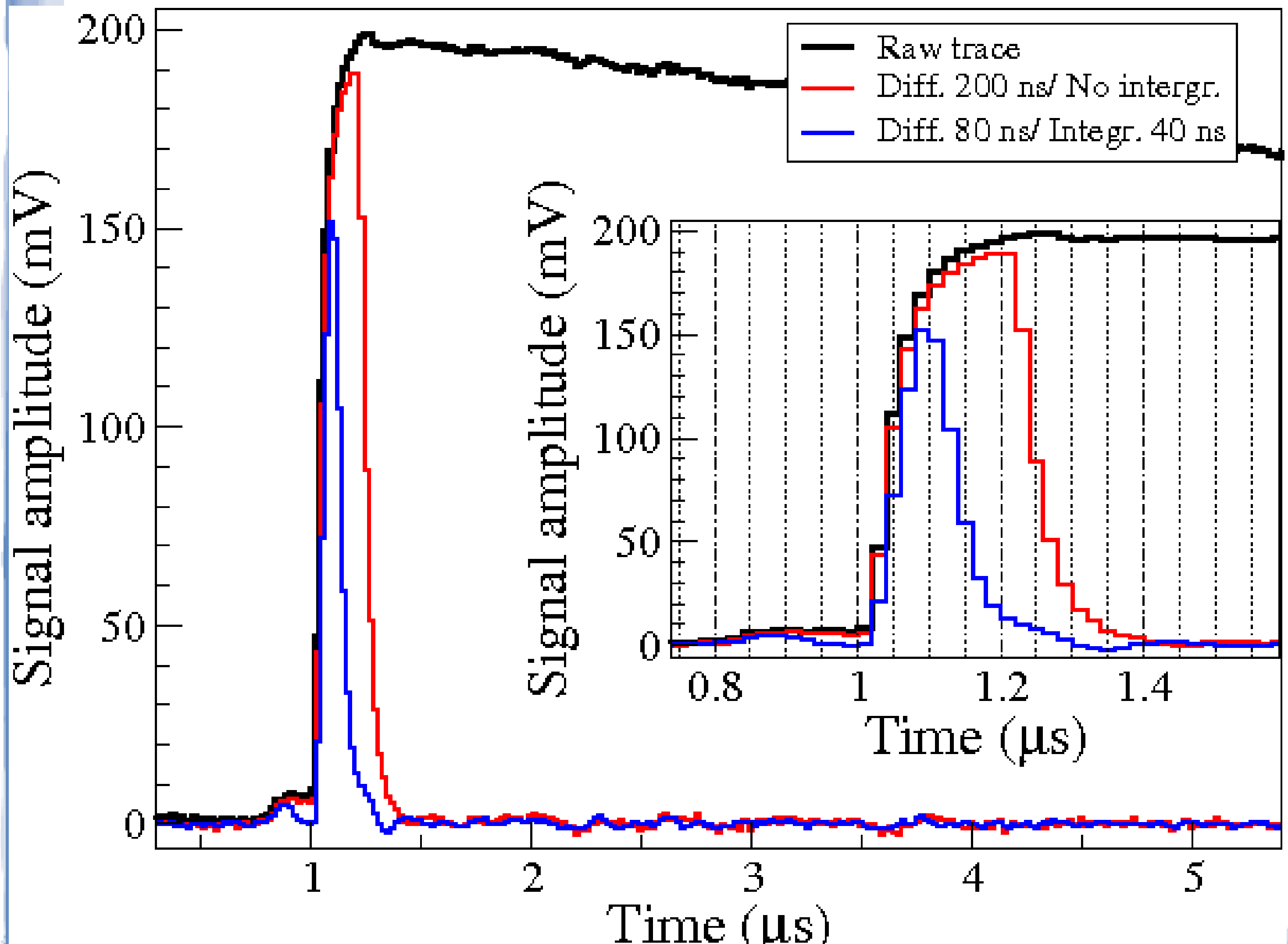
Resolution saturates at about 200 ns

⇒

The rise-time of the signal (with slow component) is about 200 ns

Forward End-Cap
LNP preamlifier

Pulse shapes



Long rise-time with slow component never observed with LED light pulser (same LAAPD+preamp)

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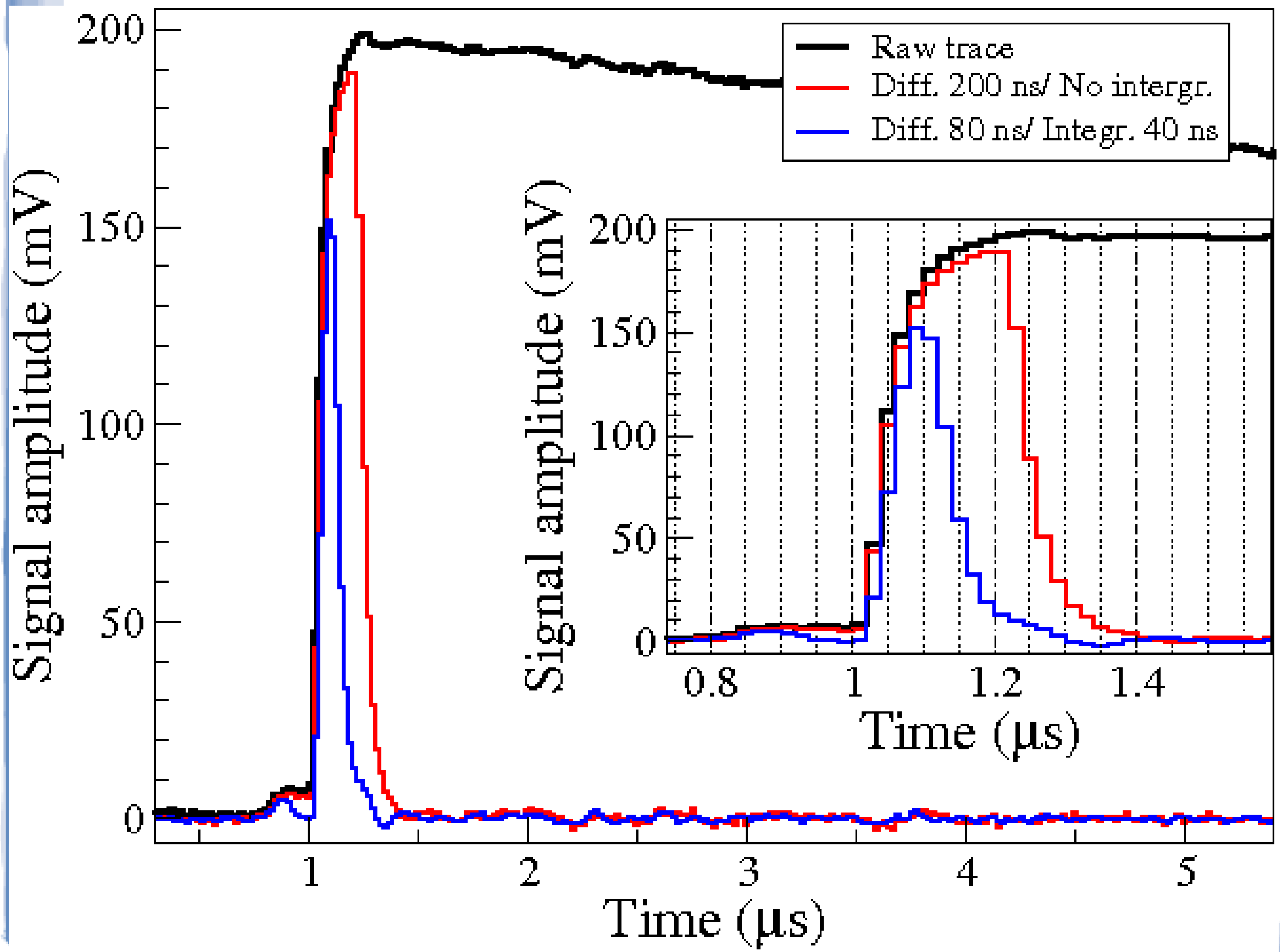
Feature of PWO?

Forward End-Cap LNP preamlifier

Pulse shapes



Short diff. time does not allow to avoid pile-up but reduces resolution

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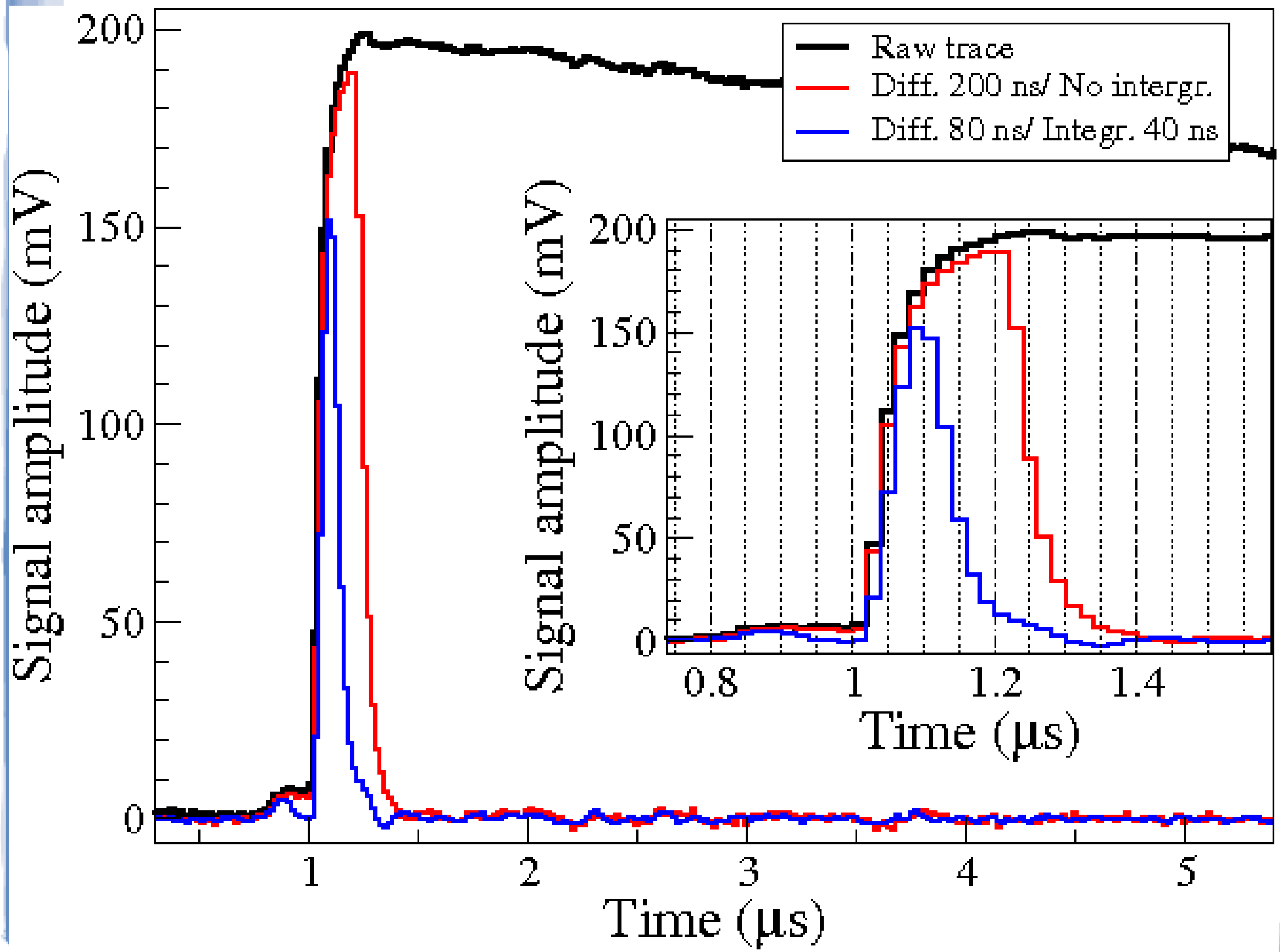
Pulses close than 400 ns require **pile-up treatment**

Forward End-Cap LNP preamlifier

Pulse shapes



Another way of treatment:

The tail has exponential behaviour

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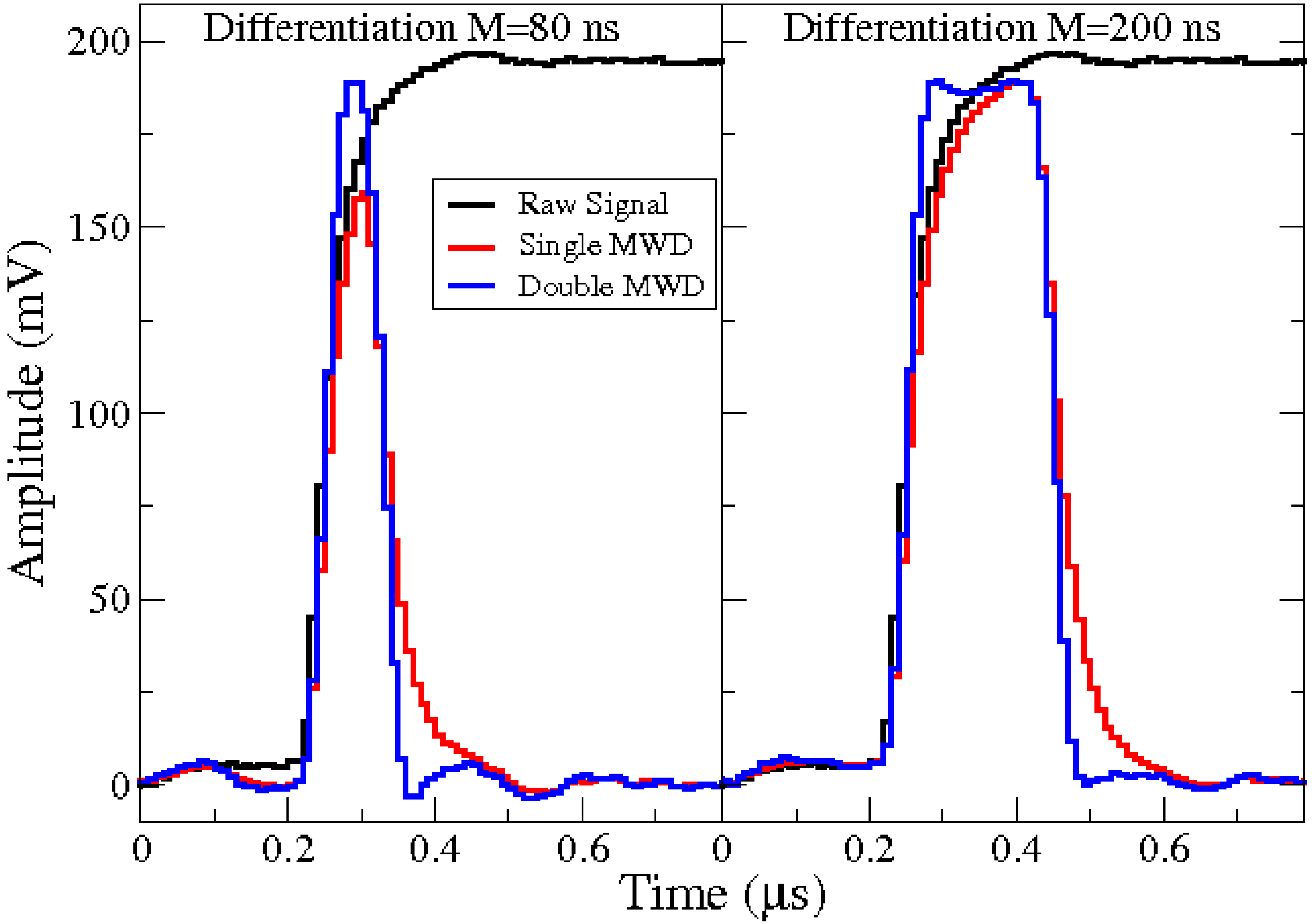
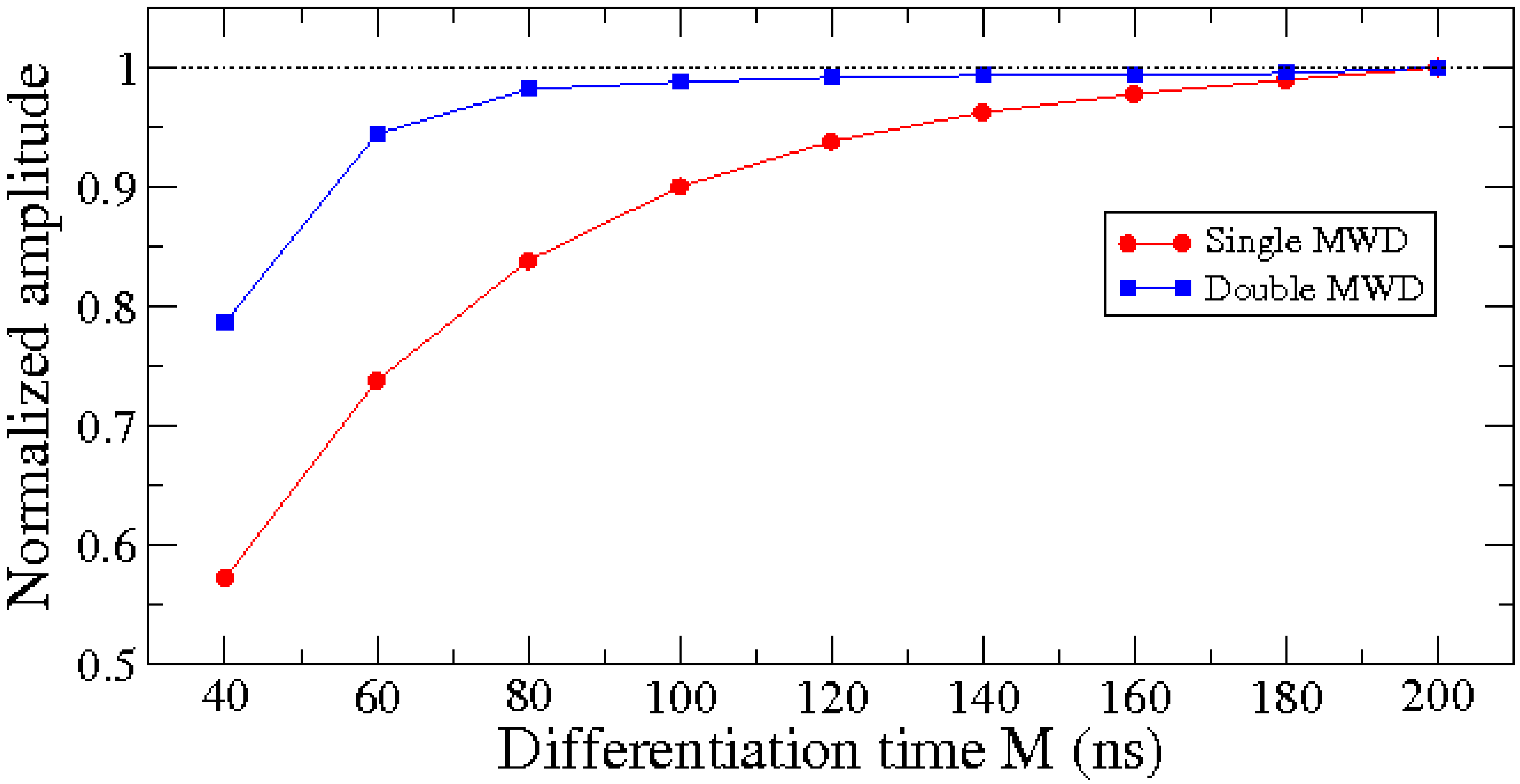
Can be corrected by additional MWD filter

Effect of Second MWD on the Pulse Shape



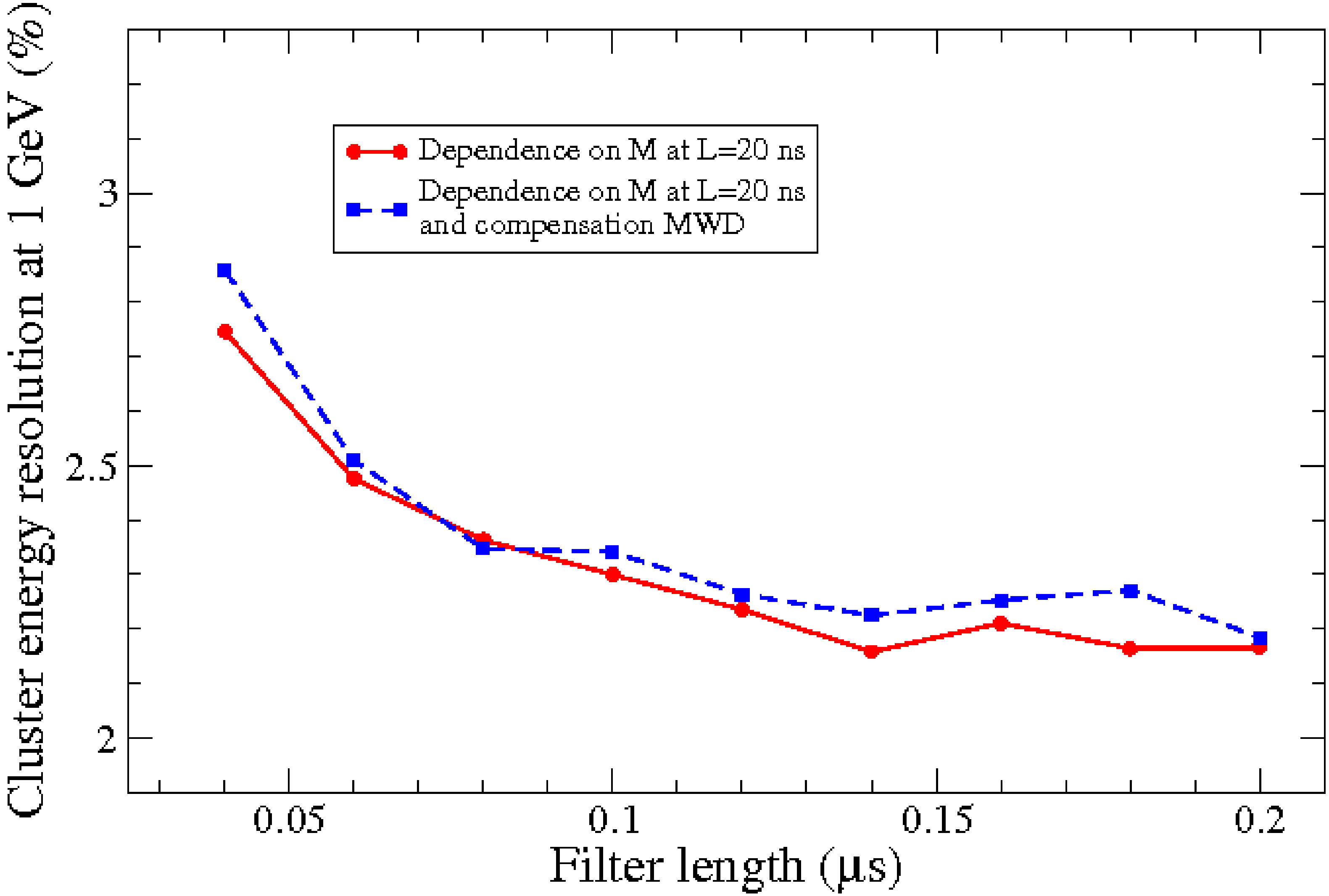
- The slow component of the signal can be compensated!
- Does this effect the pulse detection threshold and energy resolution?

Effect of Second MWD on the Pulse Amplitude



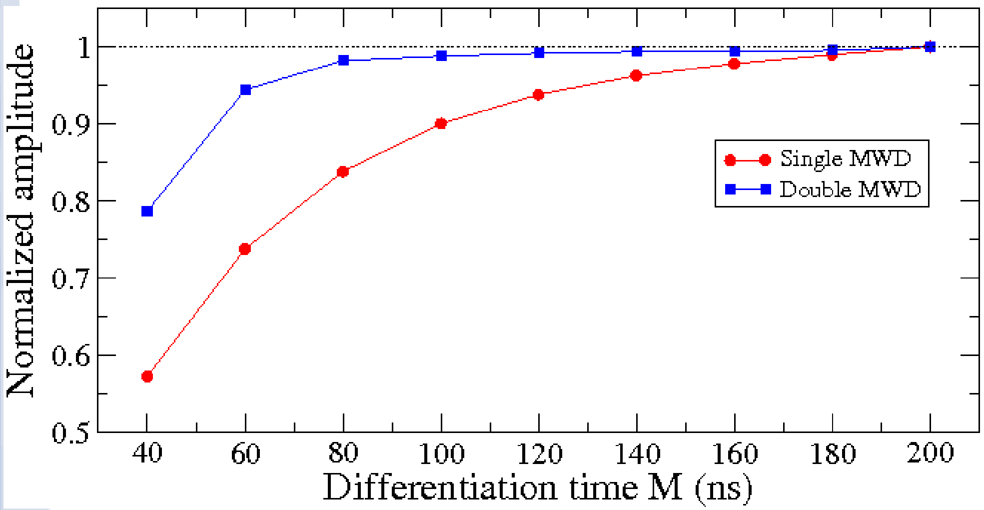
- The noise level is not changed by the second MWD.
- Second MWD filter does allow to recover the pulse amplitude – improves effective triggering threshold

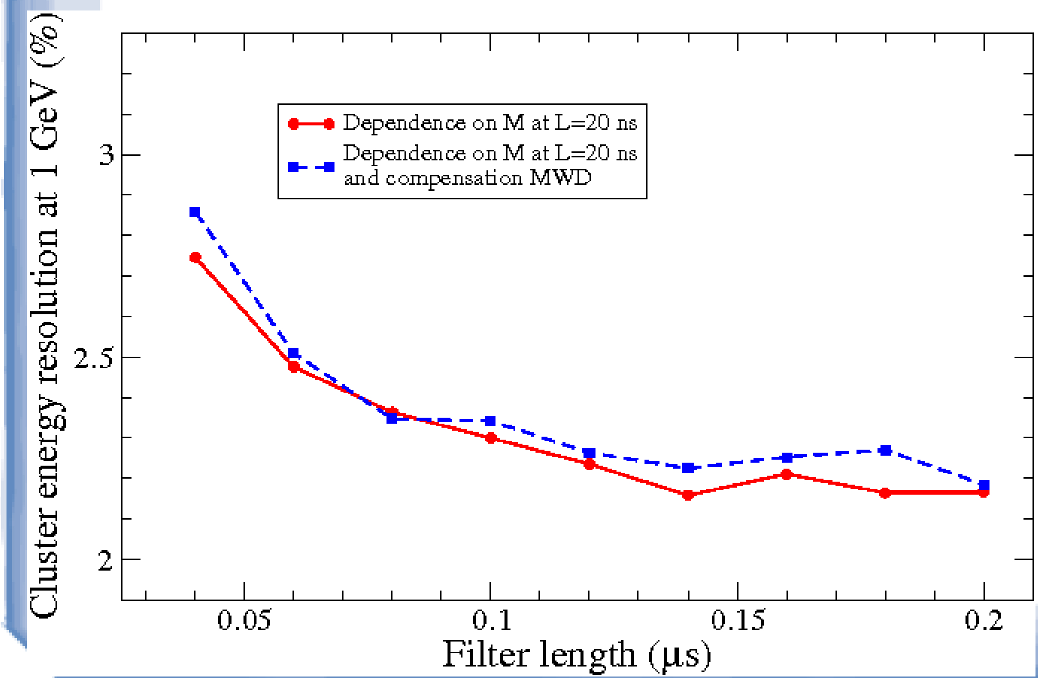
Effect of Second MWD on the Energy Resolution



- The noise level is not changed by the second MWD.
- Second MWD filter does allow to recover the pulse amplitude – improves effective triggering threshold

Effect of Second MWD on the Pile-up (20 MHz interaction rate)





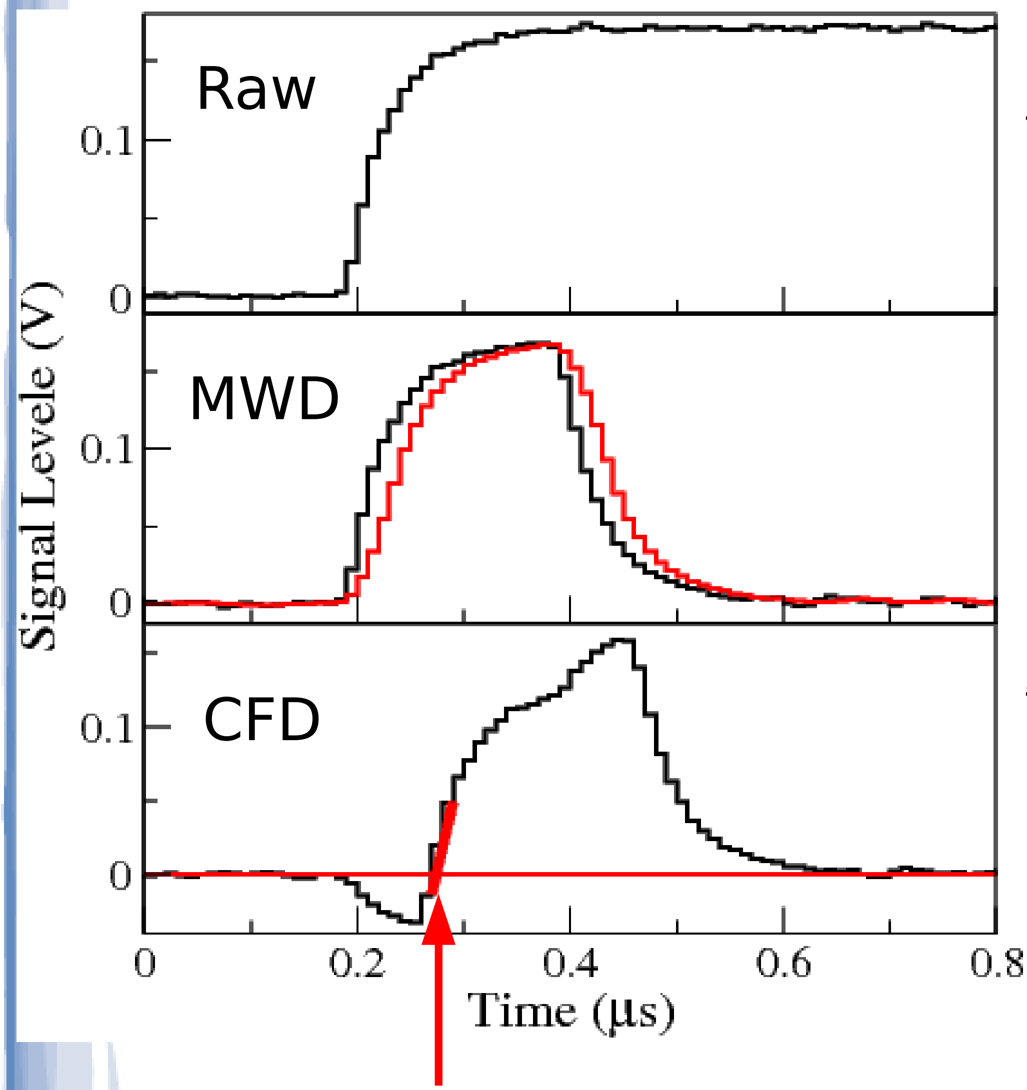
Due to the long component pulse width ~400 ns = 18% pile-up

Double MWD filtering:

- M ~ 80 (60) ns
- E-res ~ 2.4 (2.5) %
- Pile-up ~ 7.8 (5.8) %
- Triggering: 98 (95) pulse amplitude restored

Additional treatment may allow to reduce effective pile-up at the cost of energy and time resolution

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)

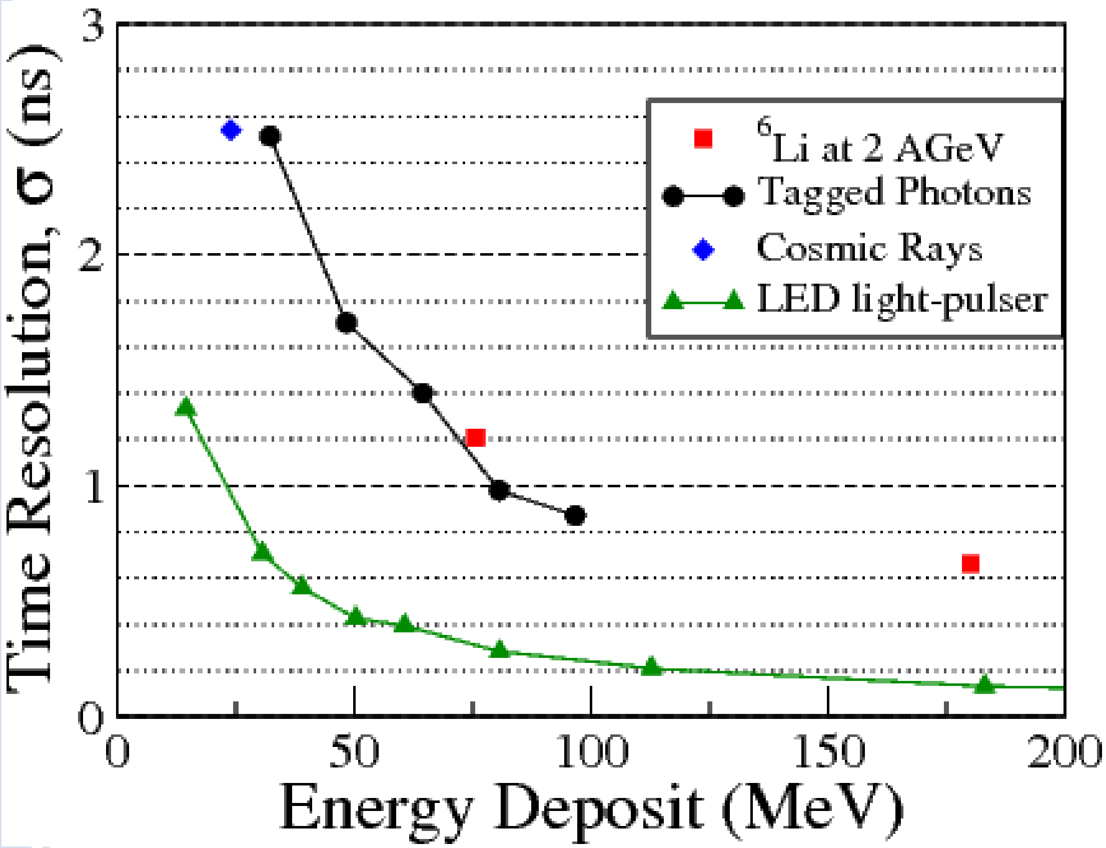
- Delay *d* = signal rise time
- Fraction *R* – to select most linear part of the signal leading edge

⋆ *N* – number for the linear regression

⋆ Symmetry around zero level

Time Resolution
(Used sampling rate 100/50 MHz)

Time resolution as a function of energy deposit



Limiting factor:

- Long rise time of the signal ~70 ns (LED light-pulser rise-time ~10 ns)

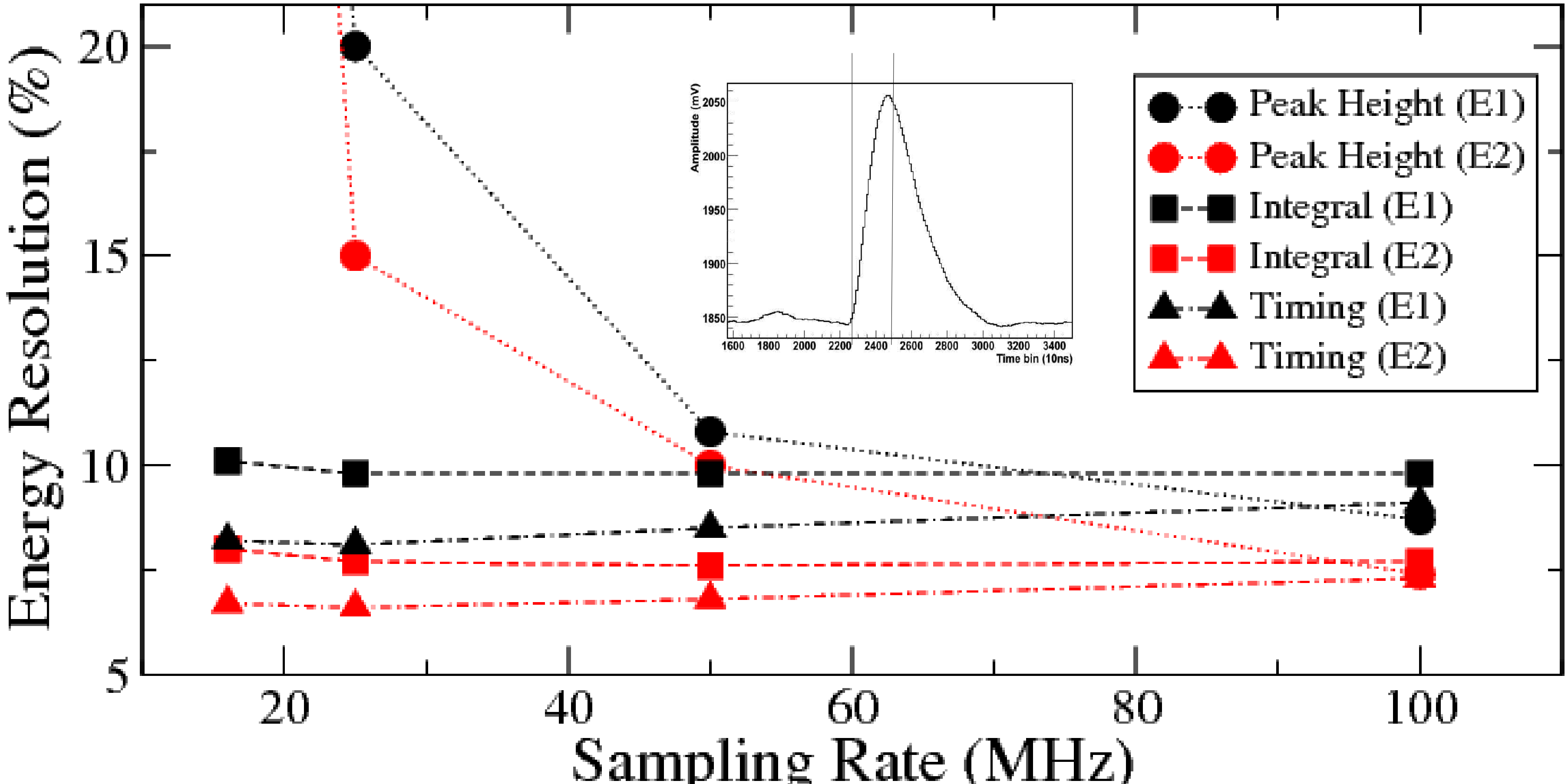
It is possible to achieve time resolution much (×20) higher than SADC sampling rate

An dedicated measurement with PROTO60 is done last week → more precise test

Time Resolution

(Used to measure pulse height)

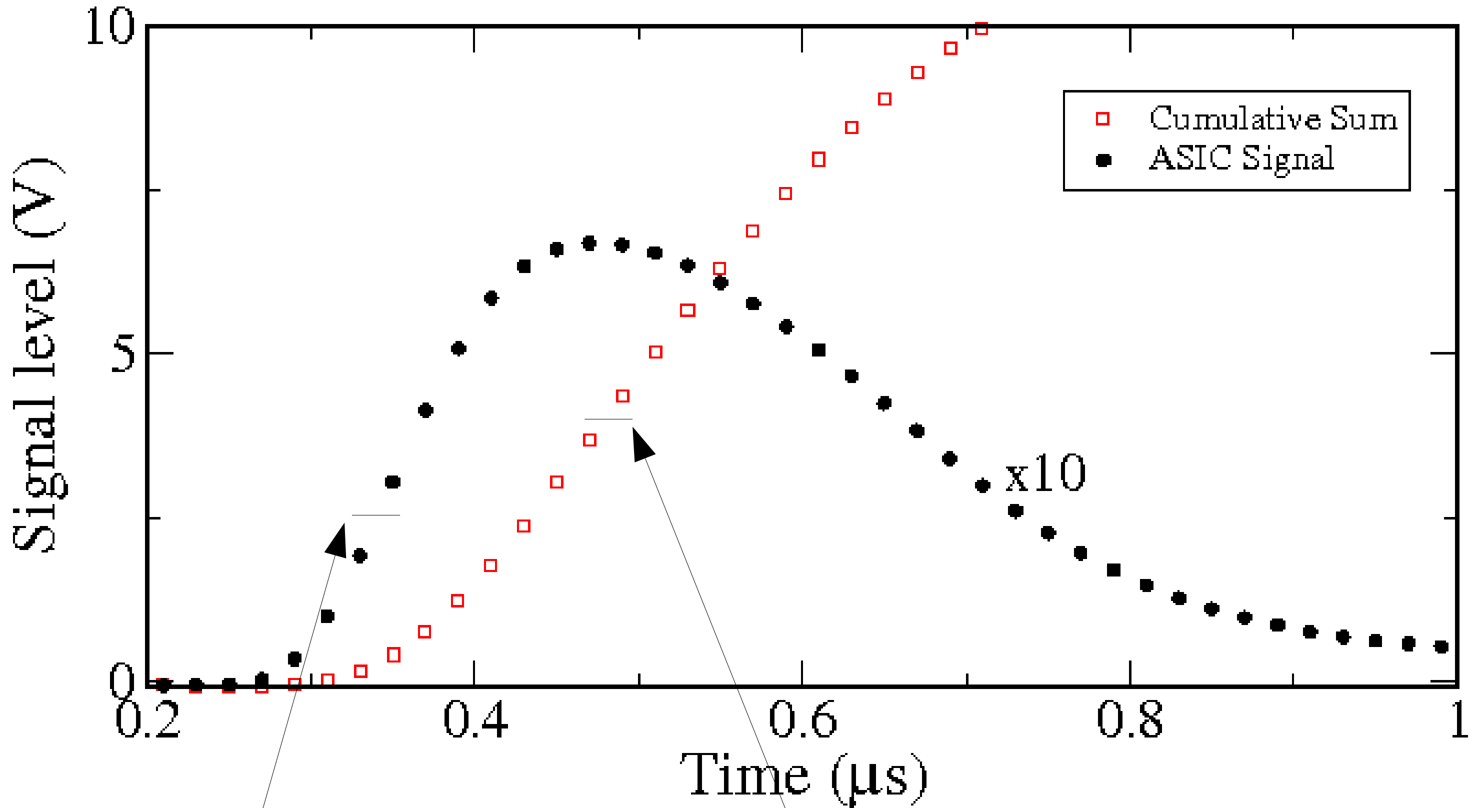
Extraction of the energy information from the digitized pulse:
(Energy resolution as a function of SADC sampling rate)



Time Resolution

Used to measure pulse height

Method explanation

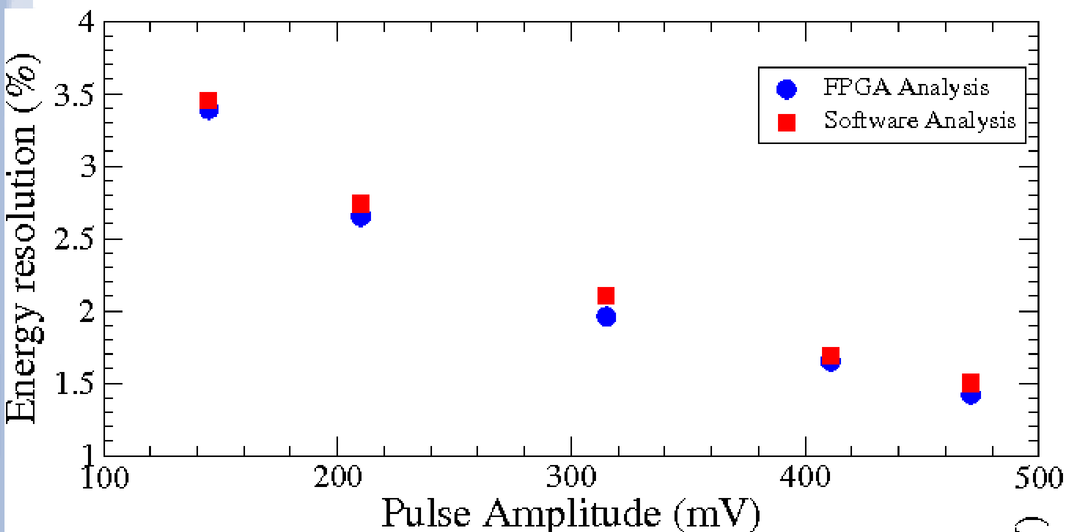


Fraction known from the CFD method

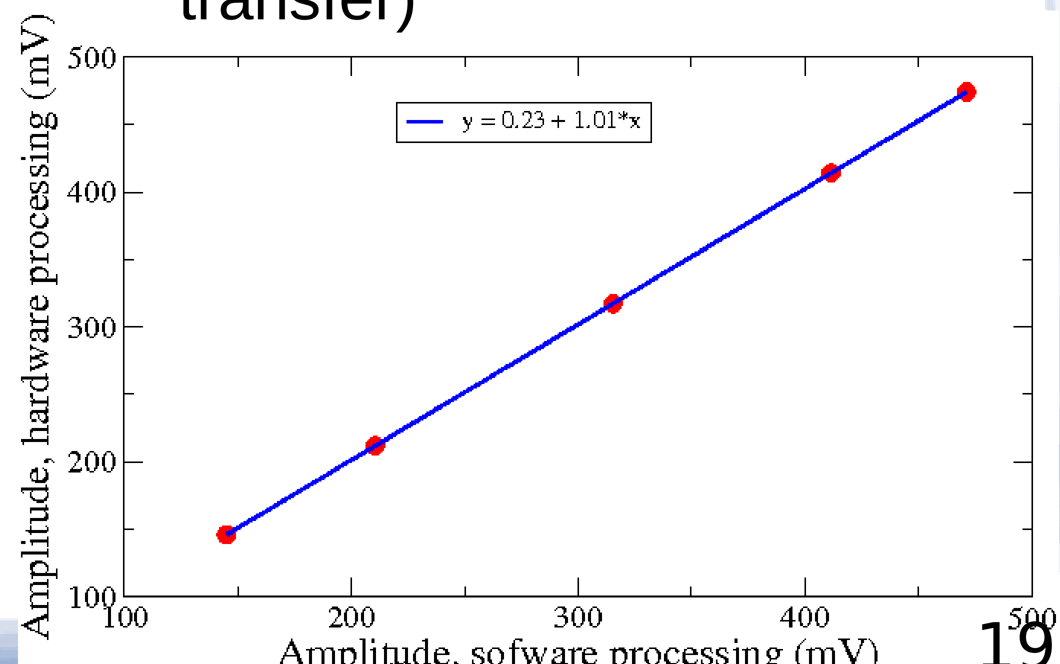
The **Fraction** (from CFD) used for linear interpolation of the cumulative sum

VHDL implementation

Energy



- Data taken with LED light-pulser
- Measurements done with 100 MHz 16 bit SADC
- Analysis performed in:
  - Software
  - Hardware (Xilins Spartan FPGA demo board, serial data transfer)



The VHDL implementation is working.

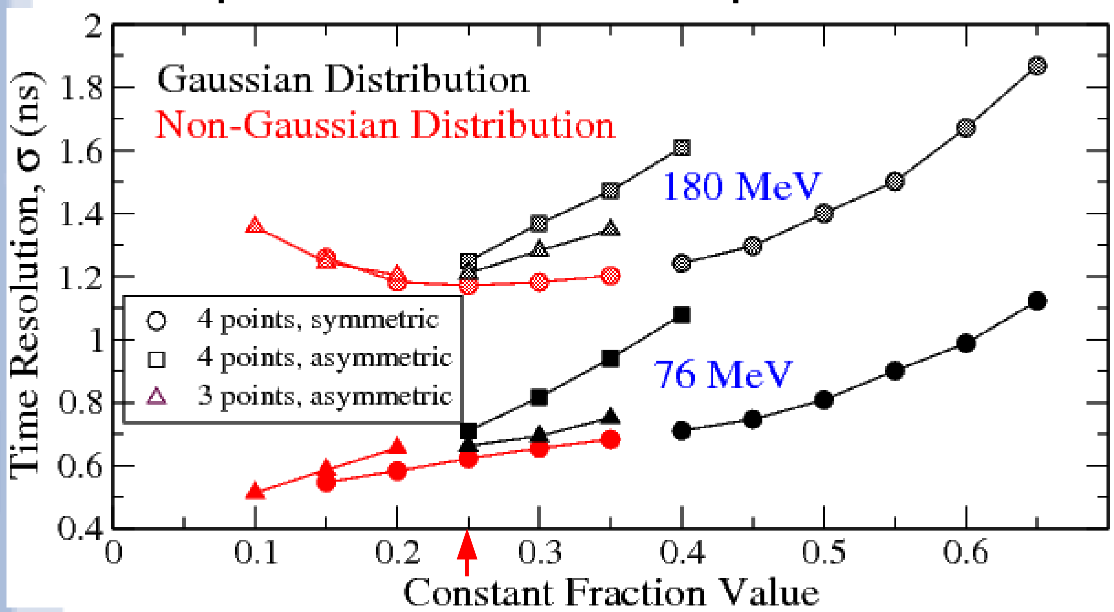
Next step – port to existing SADC (in progress)

Conclusions

- Digital filtering allows to accept higher rates for the EMC end-cap
  - The performance of the analogue shaper has to be investigated
- The “digital CFD” produces time stamps with much higher precision than SADC sampling rate
- The precise timing allows precise measurement of the pulse amplitude at lower sampling rate
- The VHDL implementation of presented feature-extraction algorithms is ready
- Development of simple pile-up correction algorithms is in advanced stage

Timing
(Parameters Tuning)

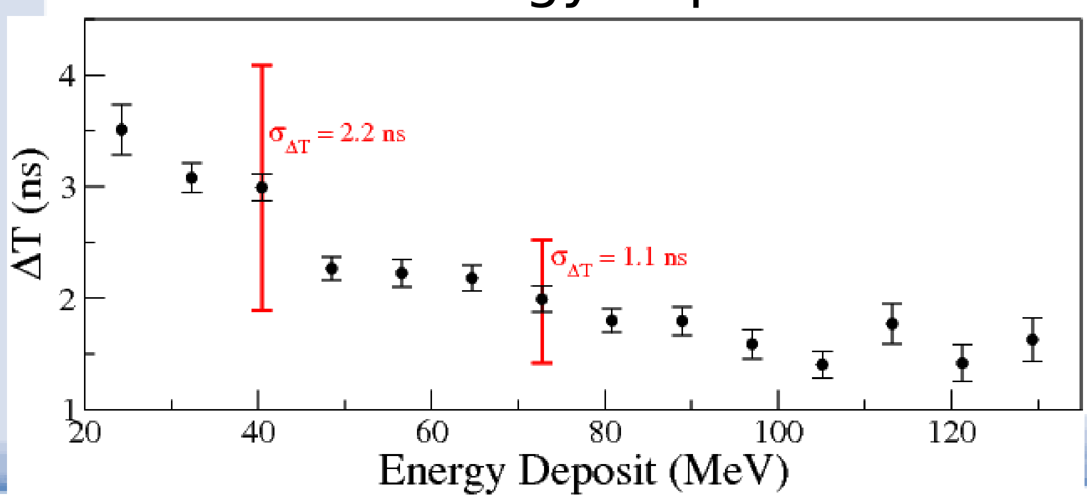
Dependence on the parameters



Best results achieved for:

- *R*=1/4 (easy to implement in FPGA)
- 3-point linear regression

Time-stamp position dependence on energy deposit



Digital implementation of CFD is not completely free from the “Walk” effect – can be corrected in the analysis