A compact size, 64-channel, 80..125 MSPS, 14-bit dynamic range ADC module for the PANDA Electromagnetic Calorimeter

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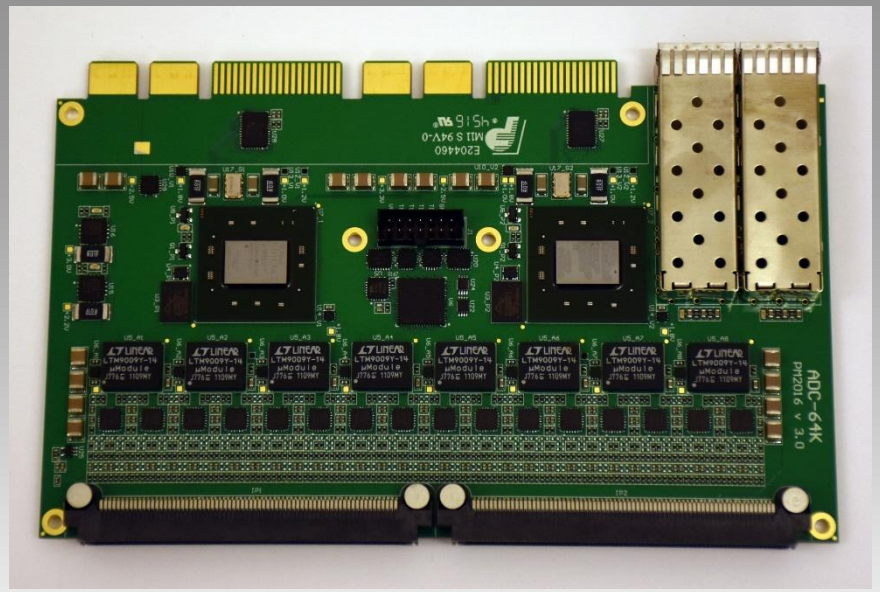
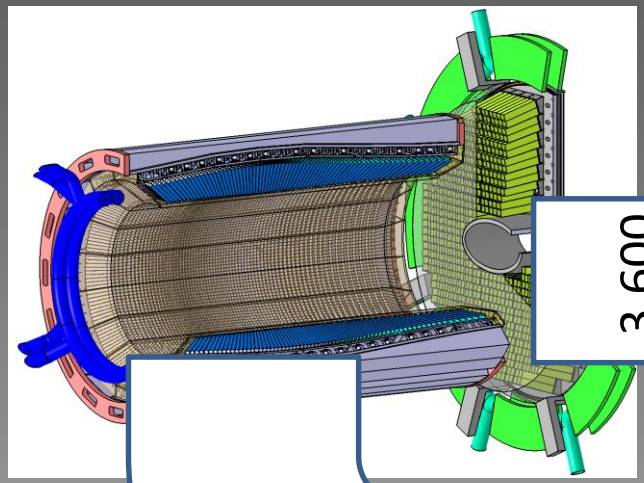
M. F. Preston, K. Makonyi, Per-Erik Tegner, Stockholm University, Sweden
P. Schakel, M. Kavatsyuk, KVI Groningen, The Netherlands
J. Müllers, University Bonn, Germany
M. Albrecht, Ruhr University Bochum, Germany



ADC for EMC

- PANDA EMC Readout System



3,600

11,952

Photosensor VPTT

Preamplifier Basel

Photosensor APD

Preamplifier APFEL (GSI)

14400

47808

225 ADC 64-ch

375 ADC 128ch

225

125

22 Data Concentrator, 16-ch

22

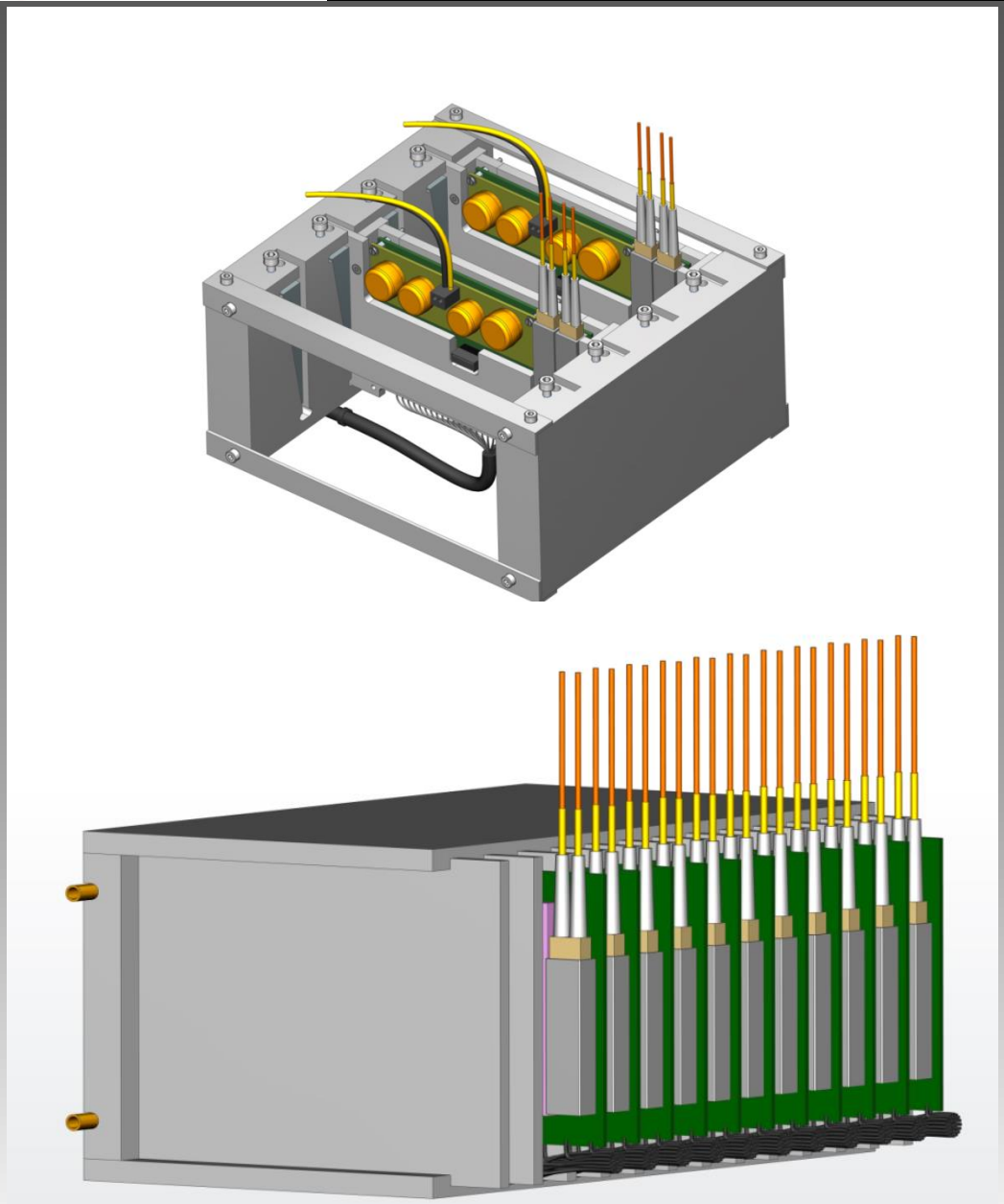
Compute Node

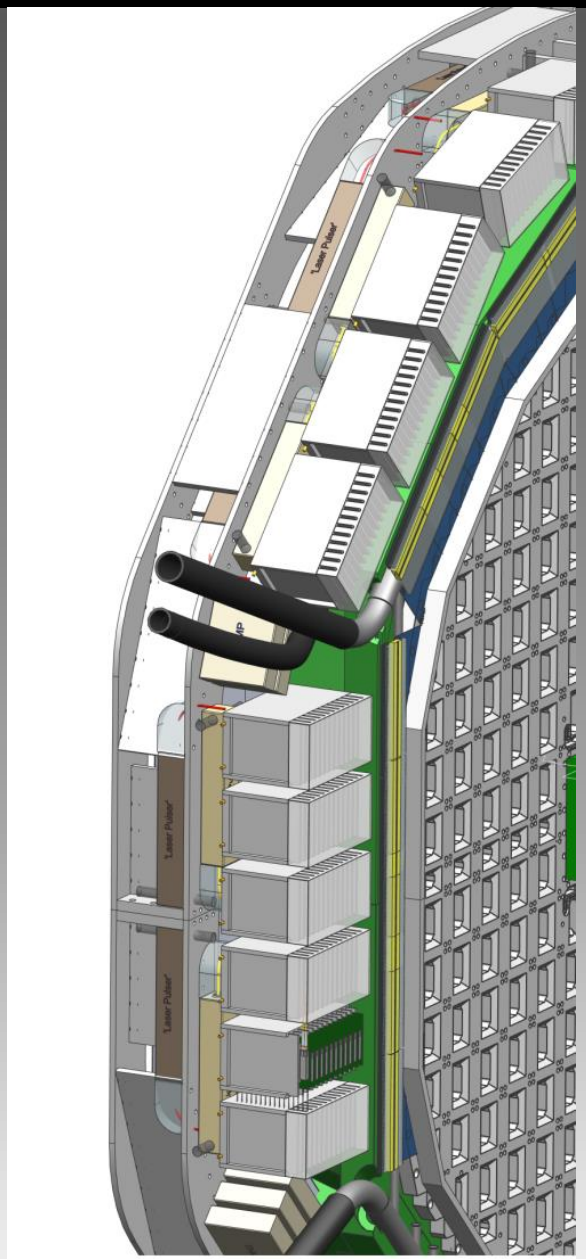
- **15000 channels**
- **Dual photosensor readout**
- **Dual range**

- **High channel density**

ADC for EMC-Endcap

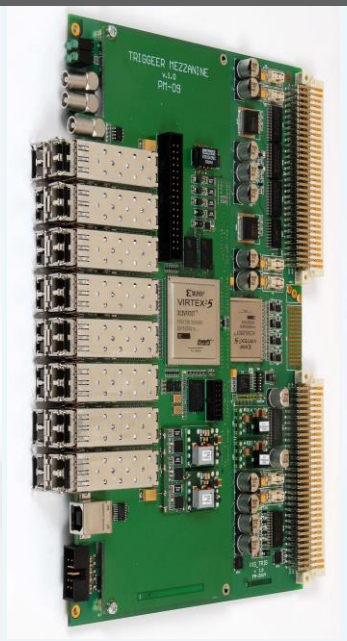
- Encapsulation and Cooling





ADC for EMC

- SADC development for PANDA



2008
16-ch, 12-bit
160 MSPS ADC
Used for the first tests, sold to WIENER

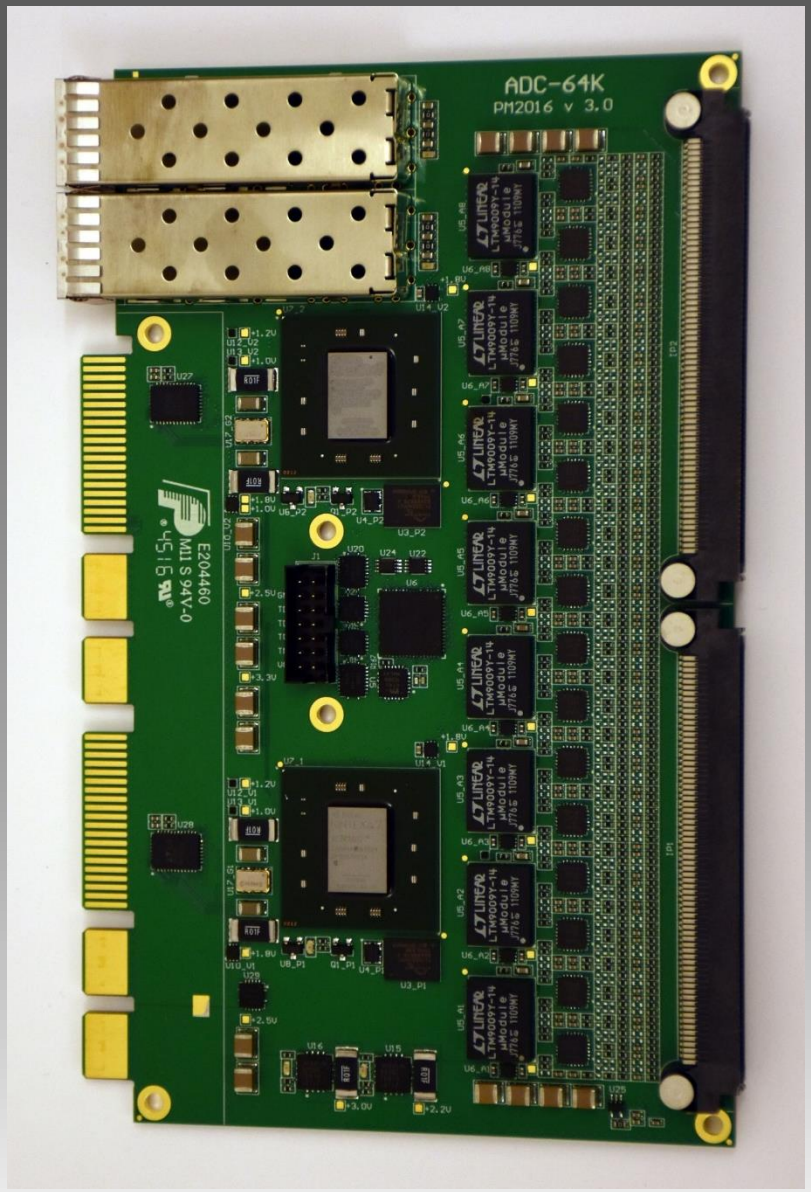
2010
16-ch, 2GBit/s
Optical Data Concentrator
Used in many experiments including WASA, KLOE2

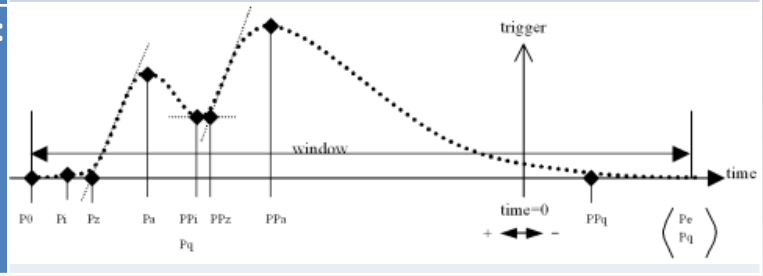
2011
16-ch, 14-bit
125 MSPS ADC
Virtex-5
Used for evaluation of DSP algorithms

2012
32-ch, Dual-range, 14-bit
80 MSPS ADC
Virtex-6
Used for first data taking and durability tests

2017
64-ch, 14-bit
125 MSPS ADC
Kintex-7
Close-to-final prototype

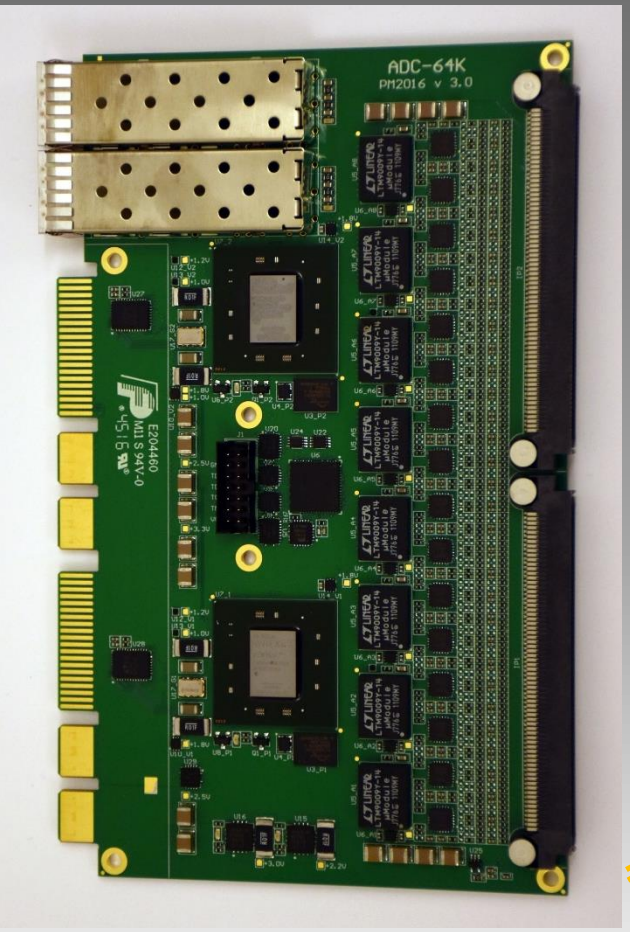
ADC for EMC
- ADC_64K



ADC Model	ADC_32DR	ADC_64K
No. of channels	32 (64)	64
Sampling rate	80-125 MSPS	
Input coupling	DC, positive, negative, diff	
Resolution (ampl)	14-bit dual range	14-bit
Input Connector	uFL	Samtec
Baseline	0V	
Input range (dual)	±1.0V, ±60 mV	±2,2V, ±140 mV
Noise	100uV	
Data retention/ch.	25us	
Input filter	Active-filter/Amplifier	Active filter/Amplifier
Interface	Optical, SFP, LC-type, 2 Gbit/s	
Feature extraction:		

ADC for EMC-Endcap
– Design idea

SADC Prototype

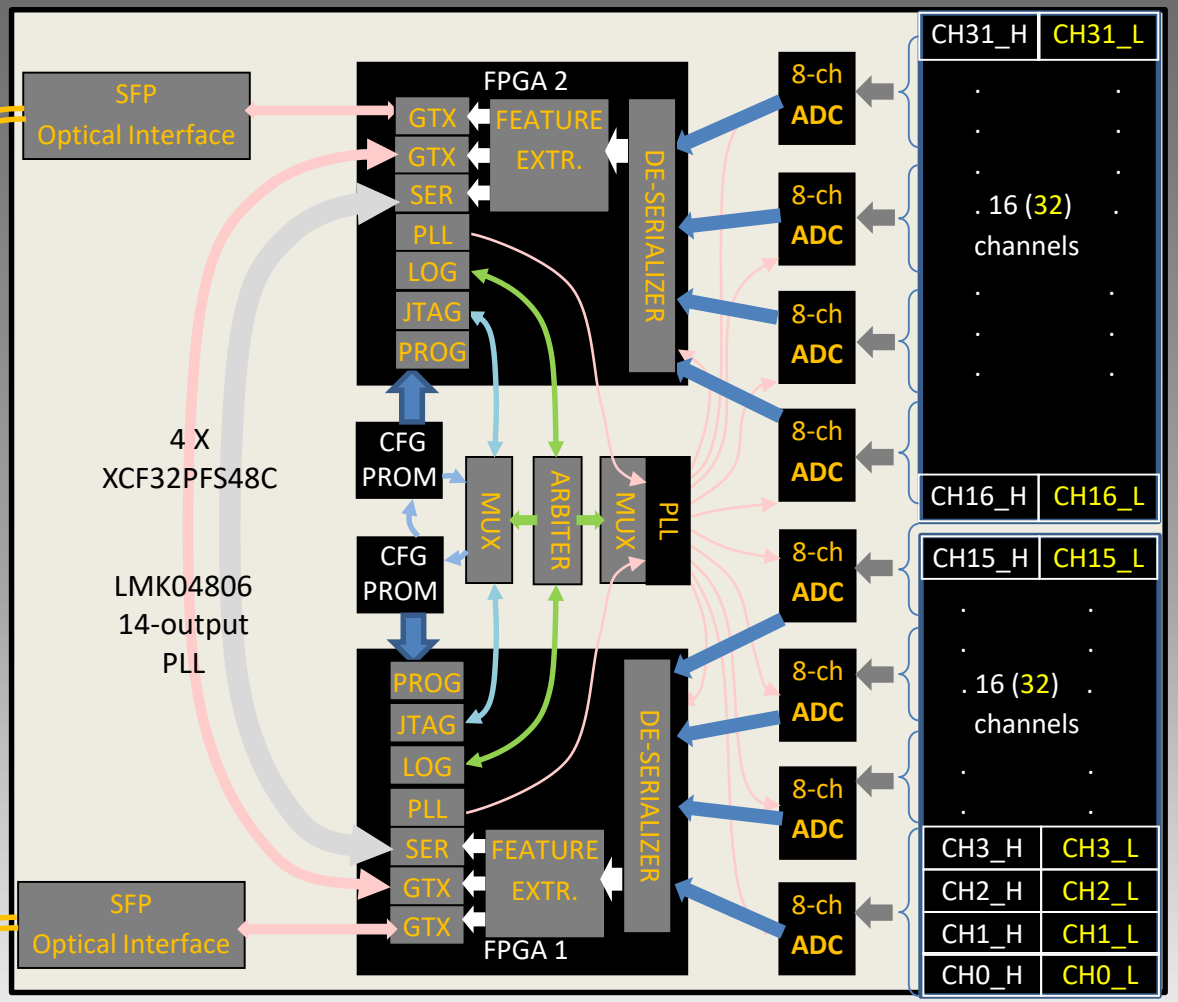


2 X
Finisar
2.1 Gbit/s

2 X
XC7K160T-
1FFG484C

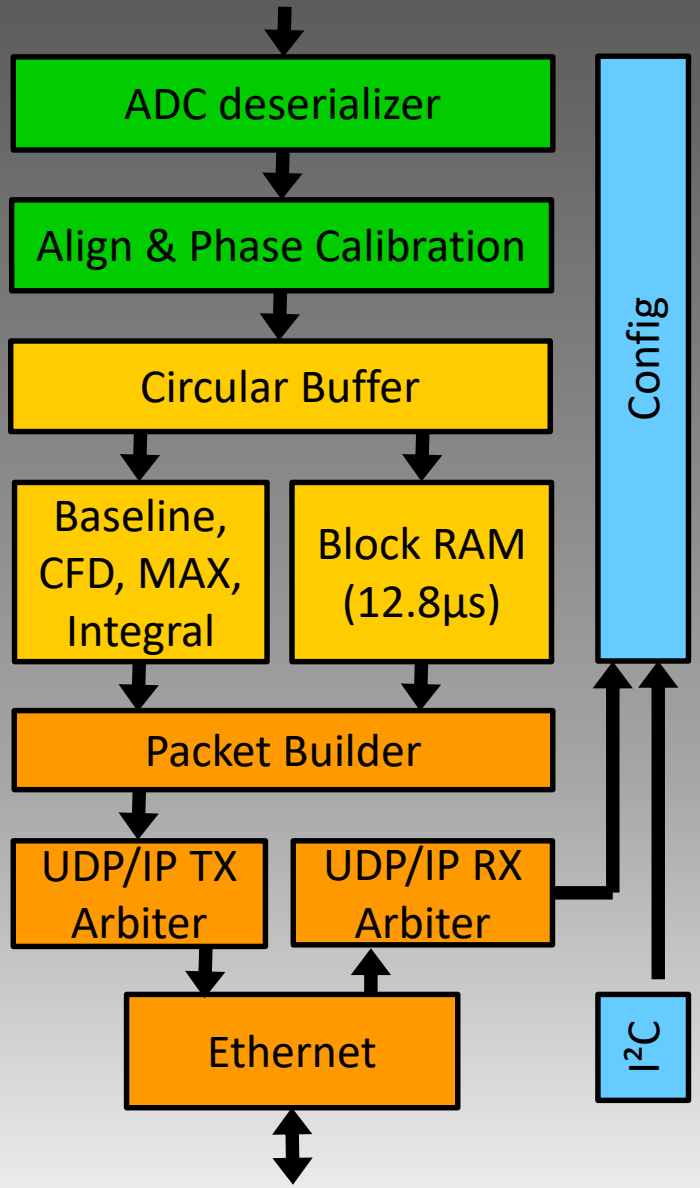
8 X
LTM9009-14
14-Bit, 80-Msps
Low Power
Octal ADCs

64 X
ADA4940-2
Low Power
diff op-amp



ADC for EMC-Endcap

- Test Firmware



Written for Crystal Barrel @ ELSA (Bonn) by Johannes Müllers

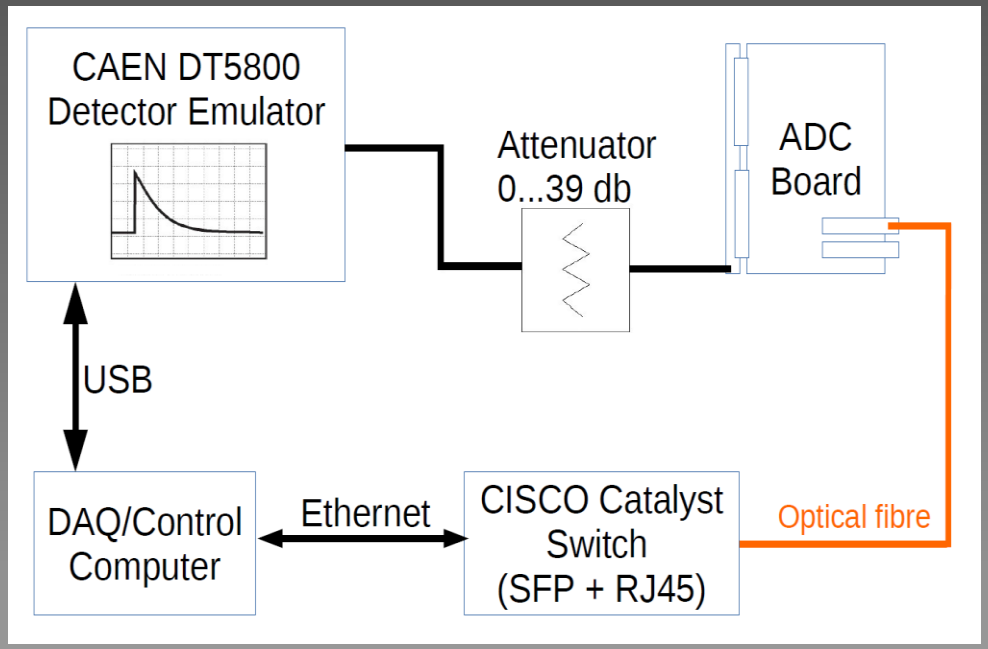
Partly based on firmware written by Pawel Marciniewski

- ADC-interface,
- PLL control,
- Noise filter,
- Baseline,
- Pulse amplitude,
- Pulse integral
- CFD discrimination
- Triggering

- **1G/2.5G Ethernet PCS/PMA** (free, Xilinx IP)
- **Tri Mode Ethernet MAC** (commercial, Xilinx IP)
- **1G eth UDP/IP stack** (free, OpenCores)

ADC for EMC-Endcap

- ADC performance tests

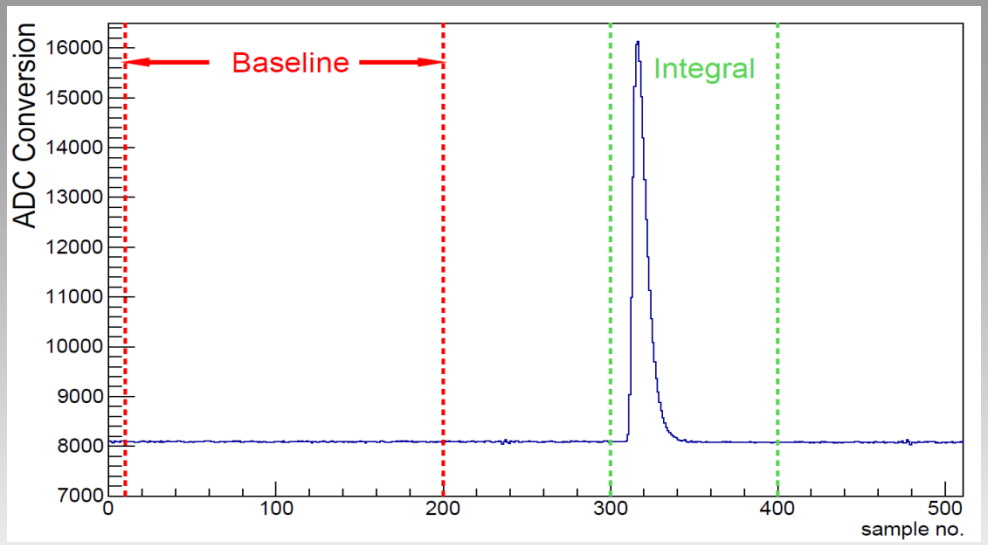


Performed at Ruhr Universität Bochum

Malte Albrecht

(Tests proposed by Pawel Marciniewski)

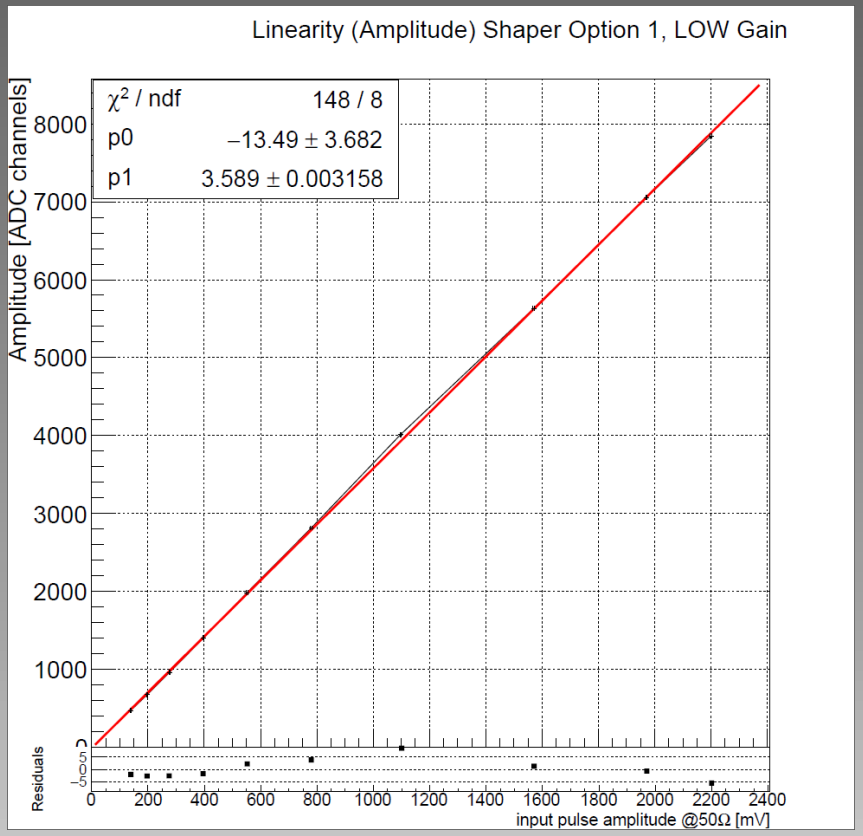
- ”Bonn” firmware
- CAEN DT5800 programmable pulse generator
- Ethernet switch

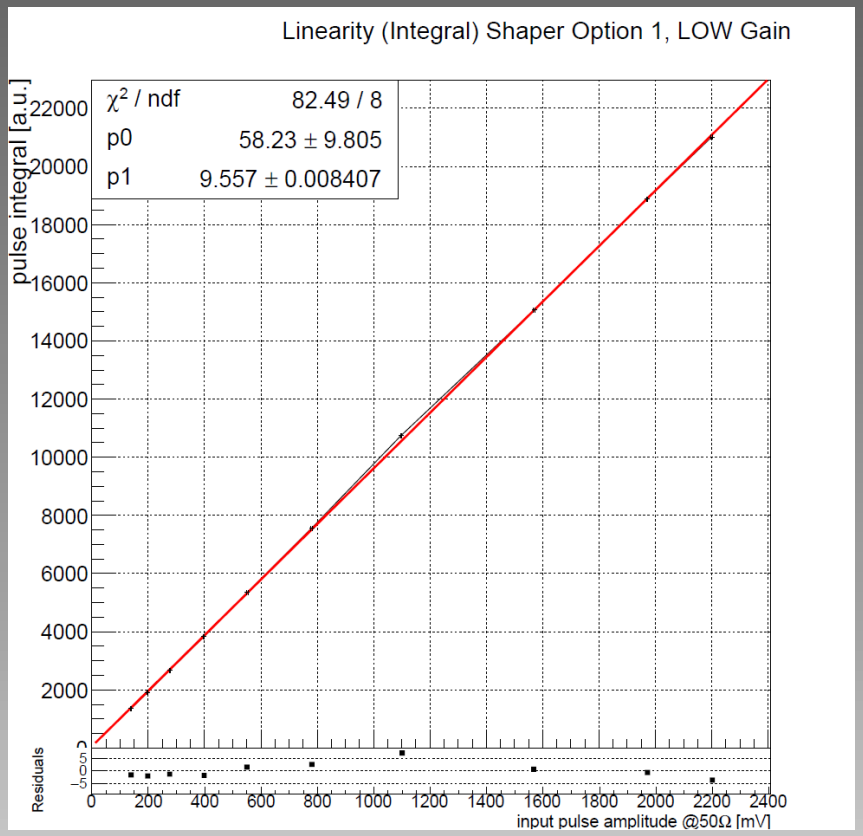


- **Noise**
- **Pulse response/bandwidth**
- **Linearity (Amplitude and Integral)**
- **Resolution**
- **Pile-up resolution (pending)**

ADC for EMC-Endcap

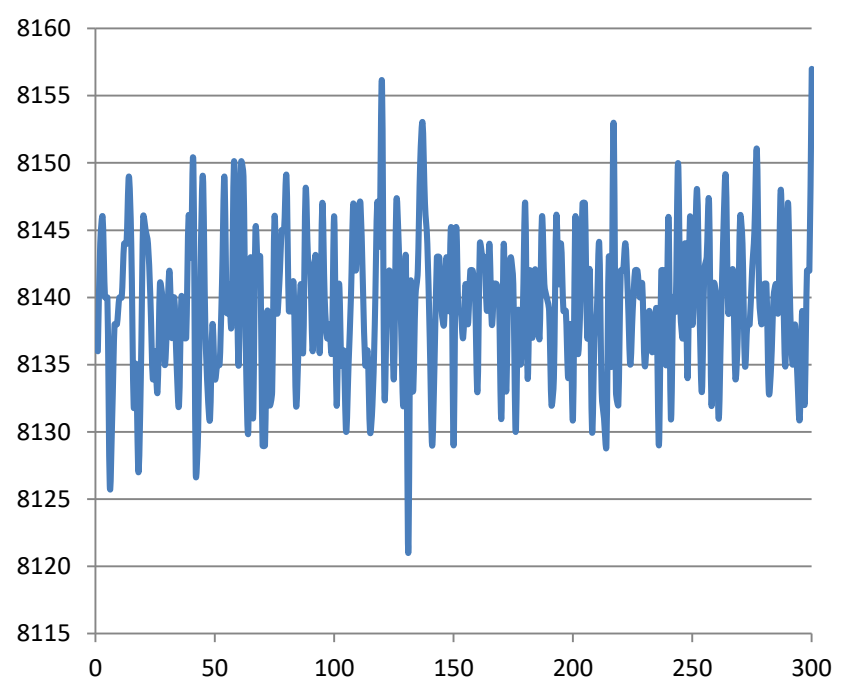
- ADC performance tests

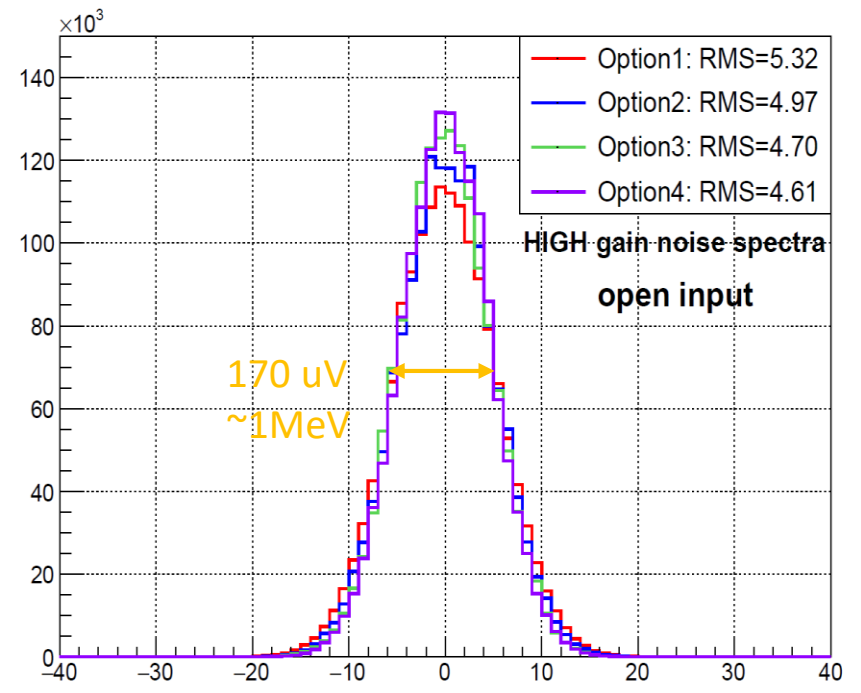




ADC for EMC-Endcap

- ADC performance tests

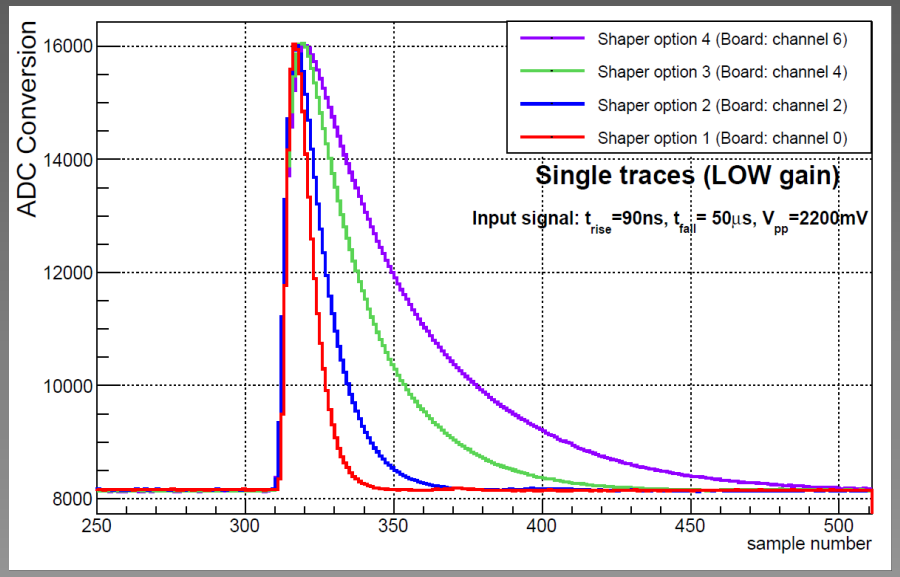


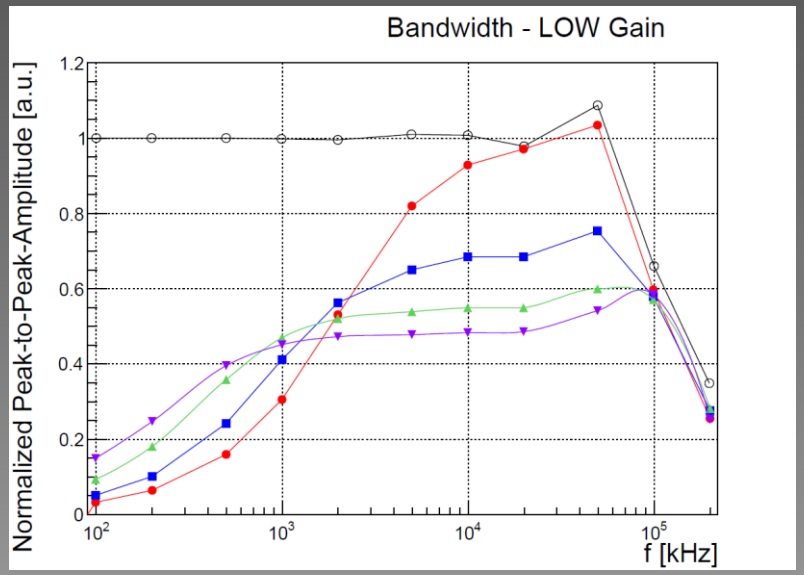


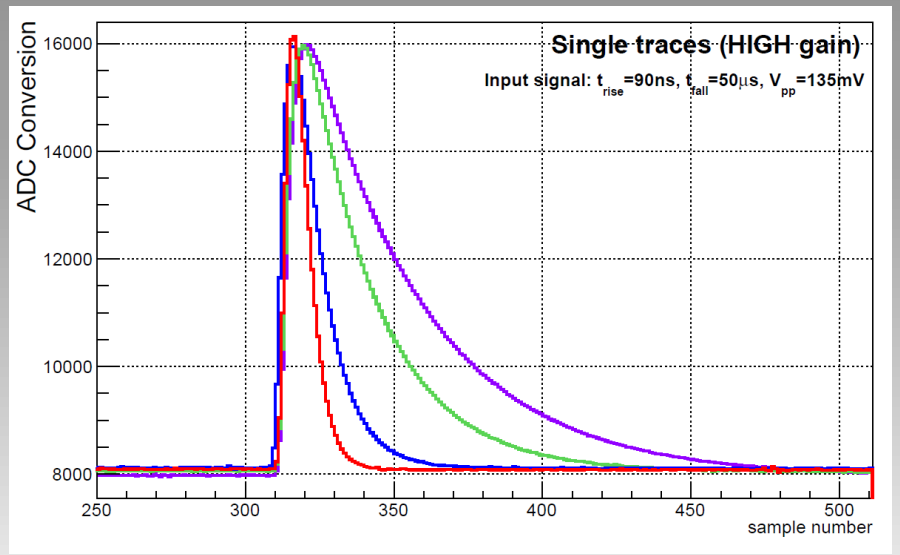
Taking the energy conversion coefficient and the overall gain of the system into account, the noise of 170 uV corresponds to 1 MeV, which fulfills the basic requirement of the experiment.

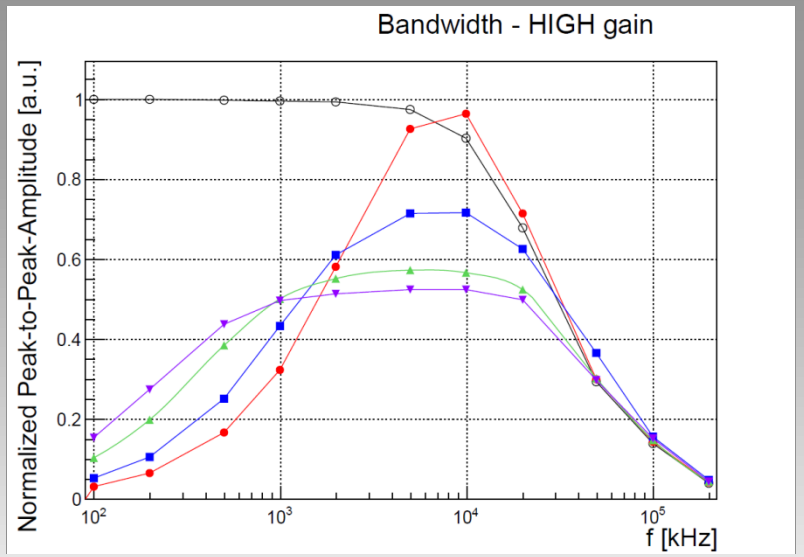
ADC for EMC-Endcap

- ADC performance tests



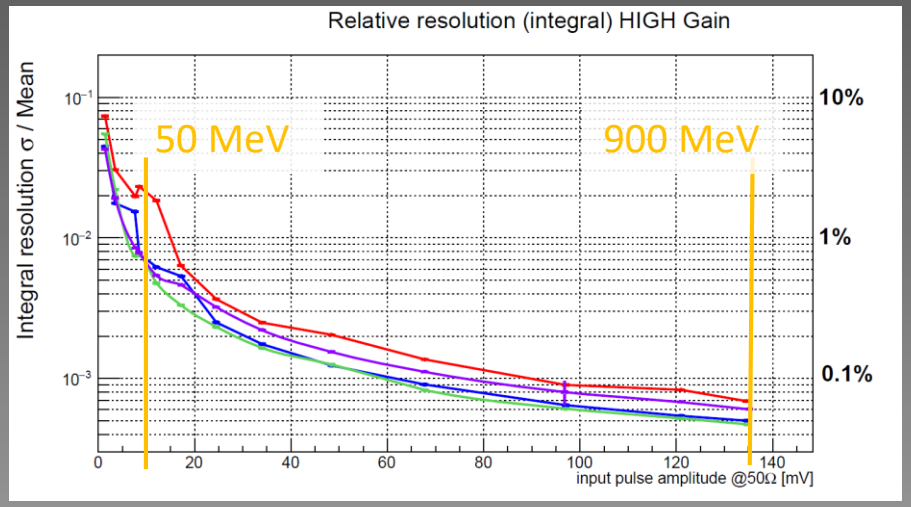


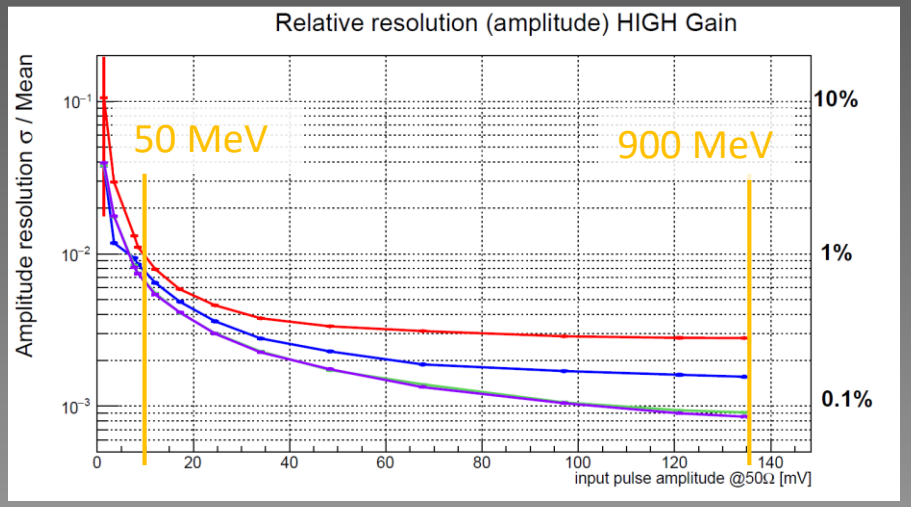


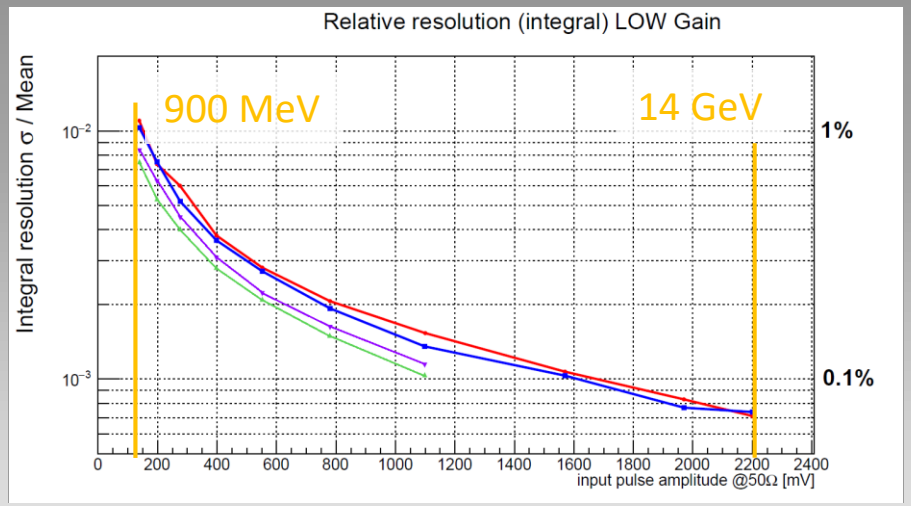


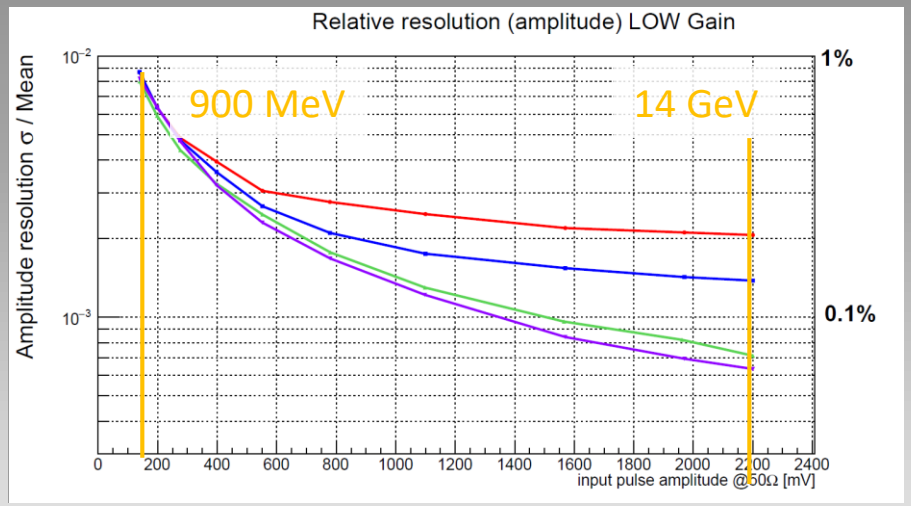
ADC for EMC-Endcap

- ADC performance tests



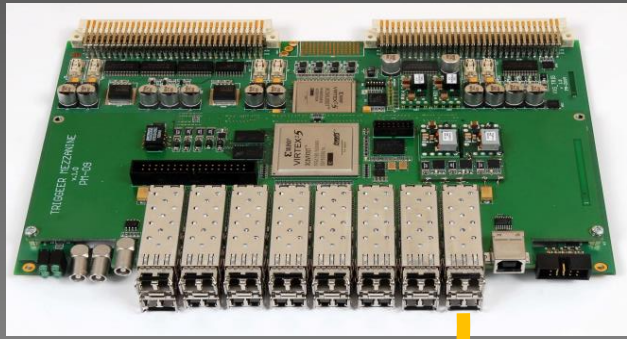






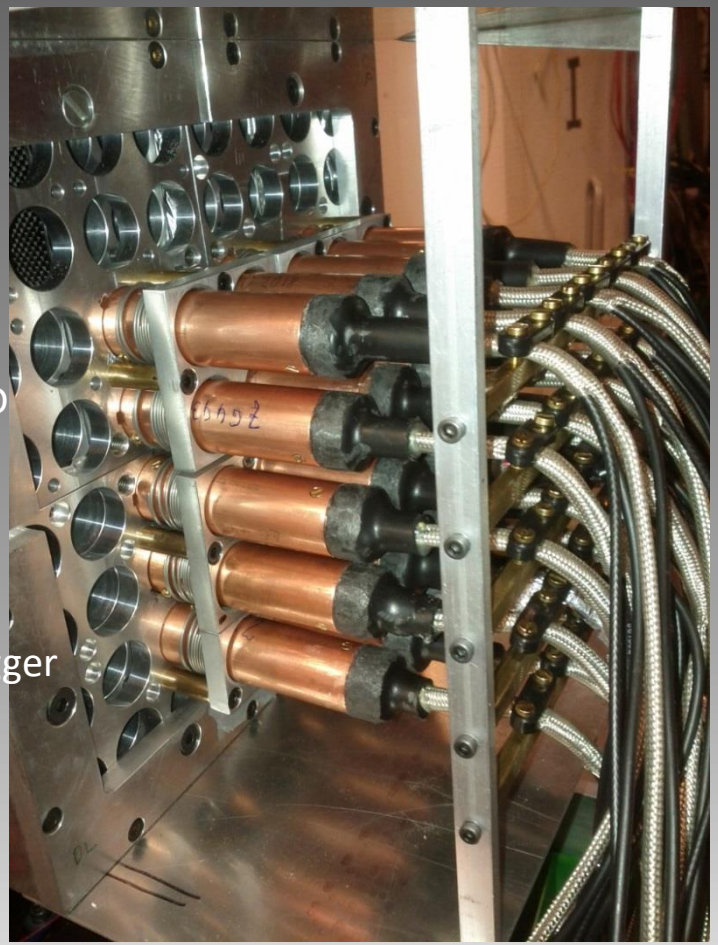
ADC for EMC-Endcap

- $PbWO_4$/VPTT tests at Max Lab



ATLB (VME Optical Data Concentrator)

$PbWO_4$ + VPTT
100uV/MeV



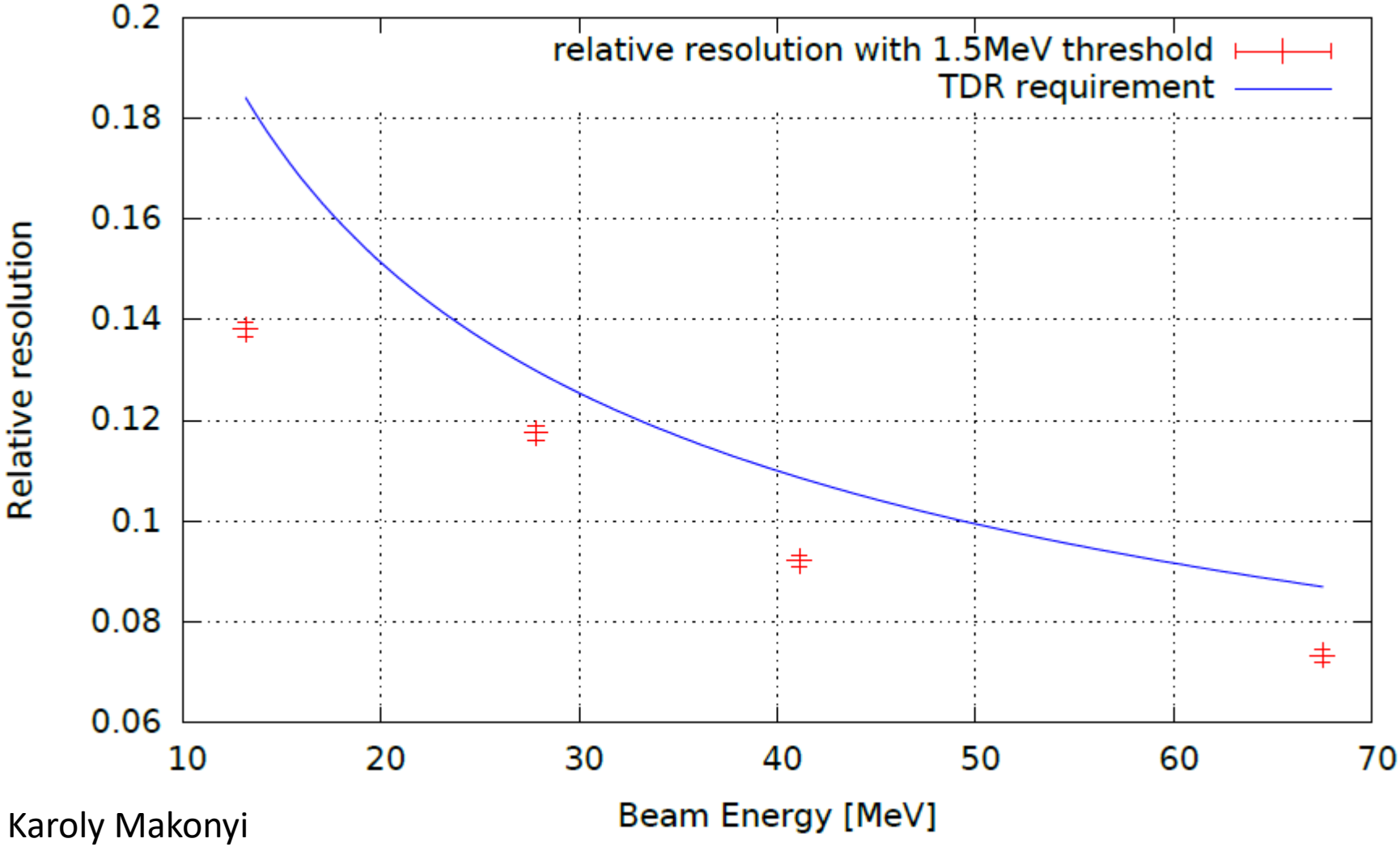
Data Format

- Event No
- Trigger Time Stamp
- X9
  - Ch. No
  - Ch. Time Stamp
  - Ch. Amplitude
  - Ch. Integral
  - Ch. Raw Data 0
  - .
  - Ch Raw Data 63
- Read Word Count

ADC for EMC-Endcap

- $PbWO_4$/VPTT tests at Max Lab

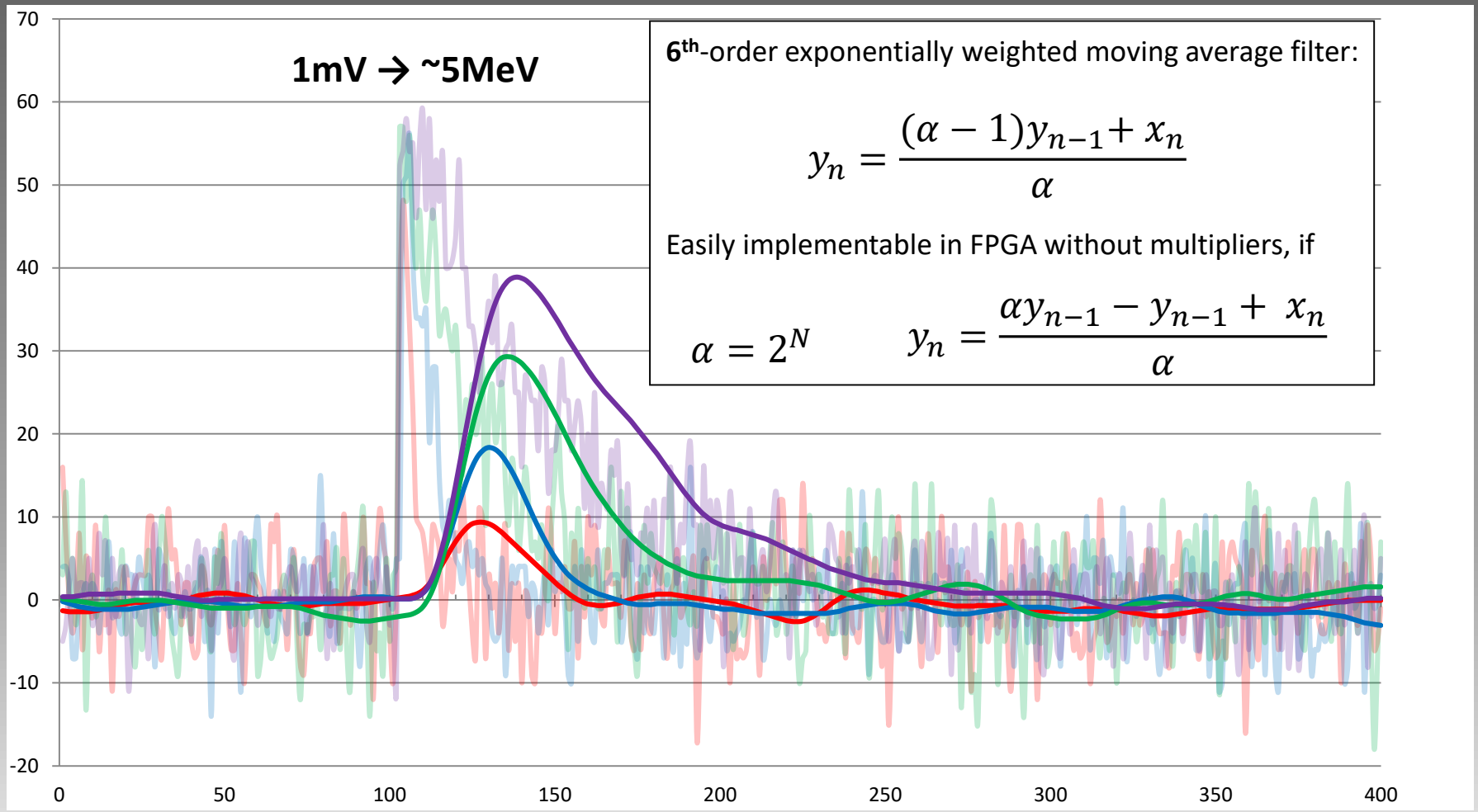
Relative Energy Resolution



Karoly Makonyi

ADC for EMC-Endcap

- ADC performance tests



6th-order exponentially weighted moving average filter:

$$y_n = \frac{(\alpha - 1)y_{n-1} + x_n}{\alpha}$$

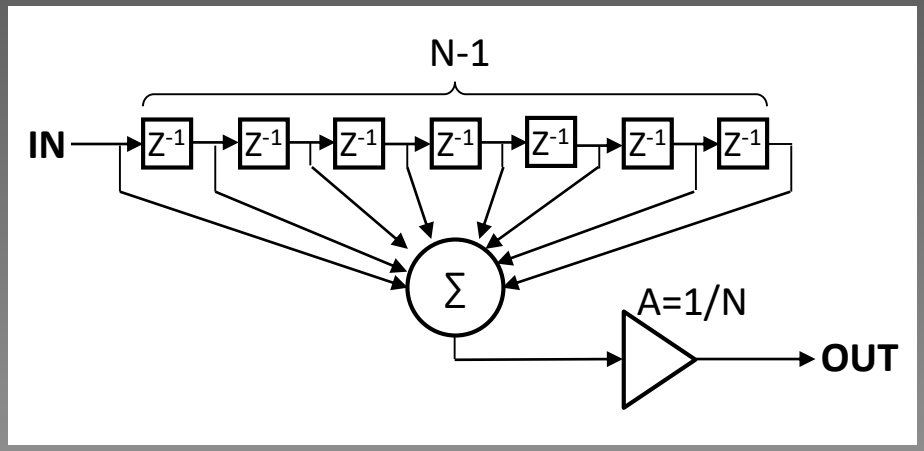
Easily implementable in FPGA without multipliers, if

$$\alpha = 2^N \qquad y_n = \frac{\alpha y_{n-1} - y_{n-1} + x_n}{\alpha}$$

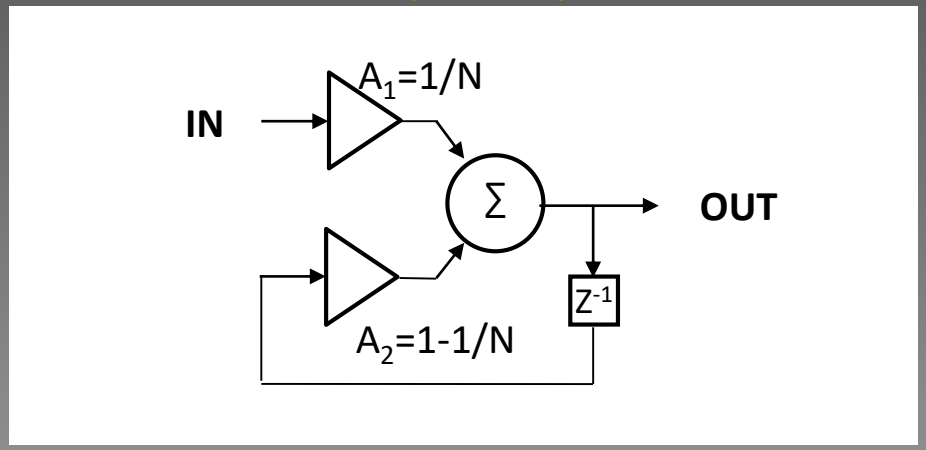
ADC for EMC-Endcap

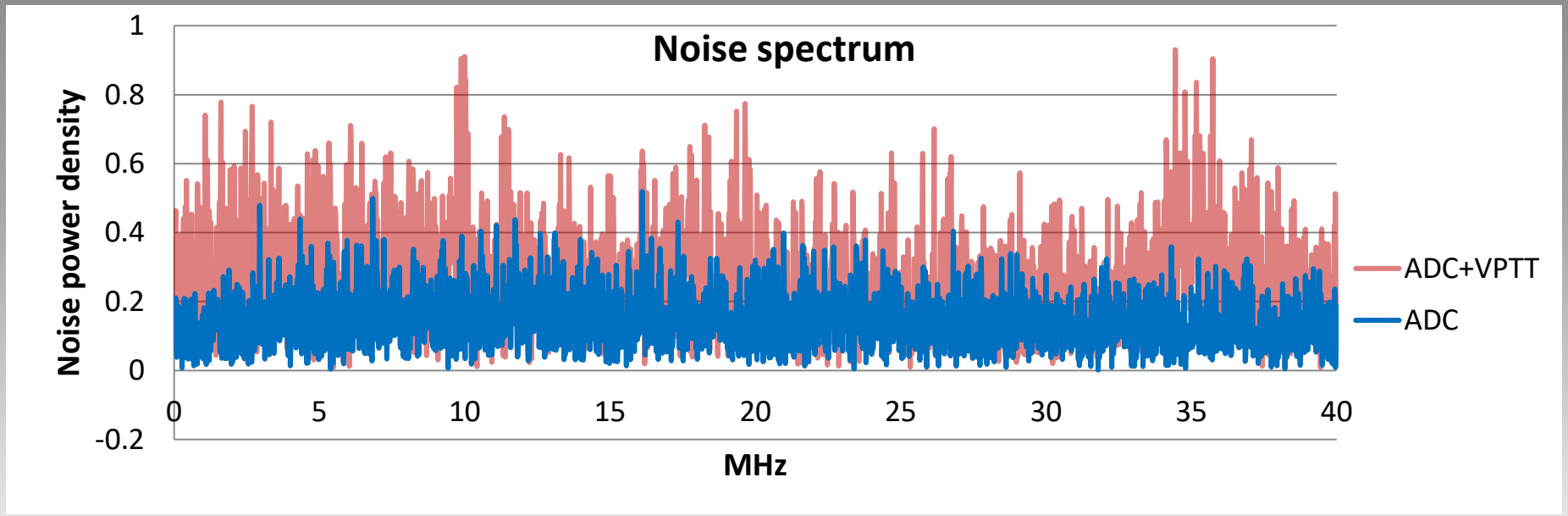
- Digital Low-Pass filters

Moving Average (MA)



Exponentially Weighted Moving Average (EWMA)

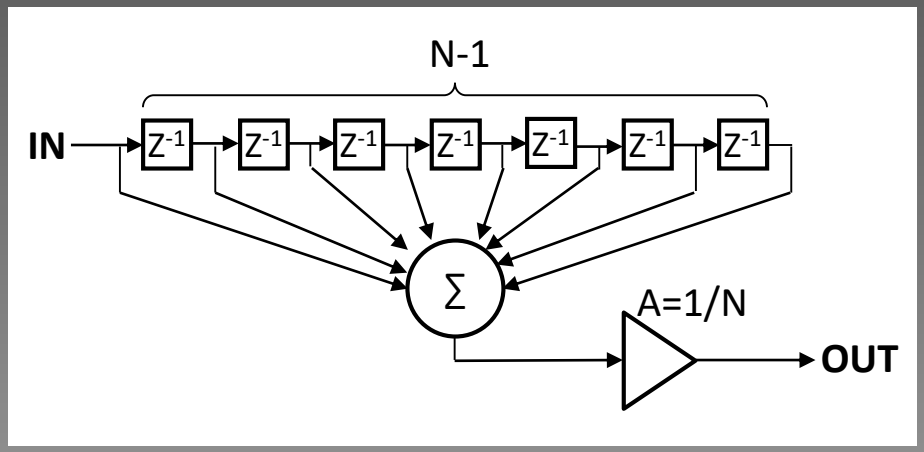




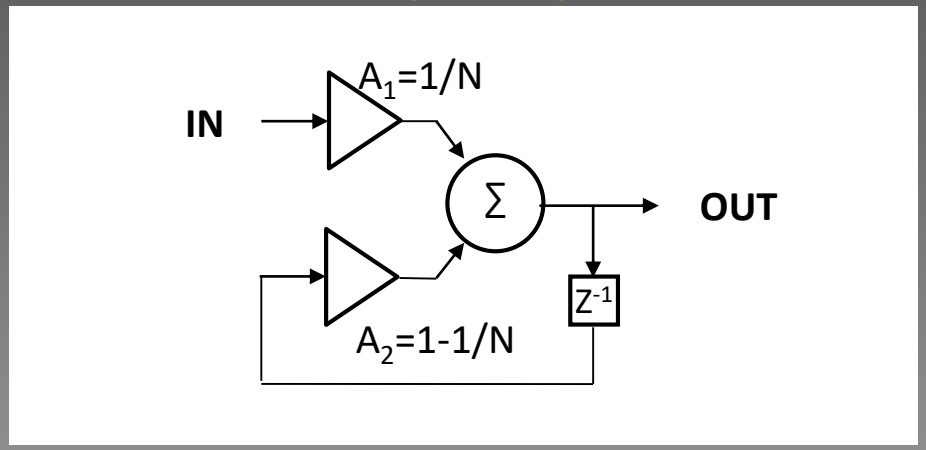
ADC for EMC-Endcap

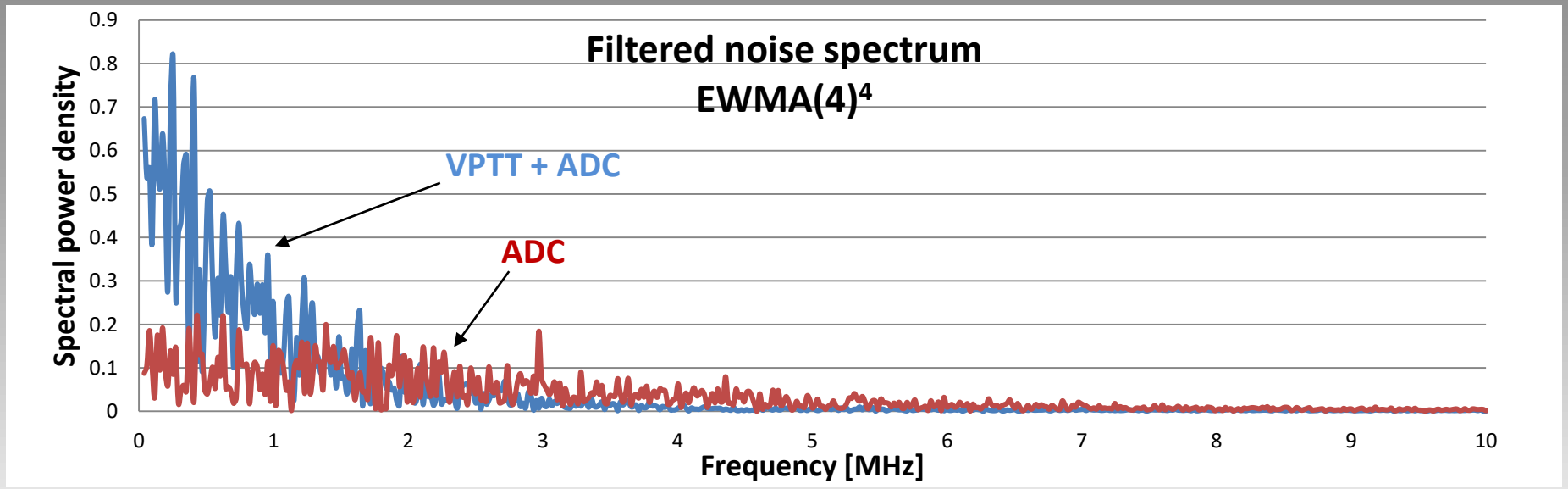
- Digital Low-Pass filters

Moving Average (MA)



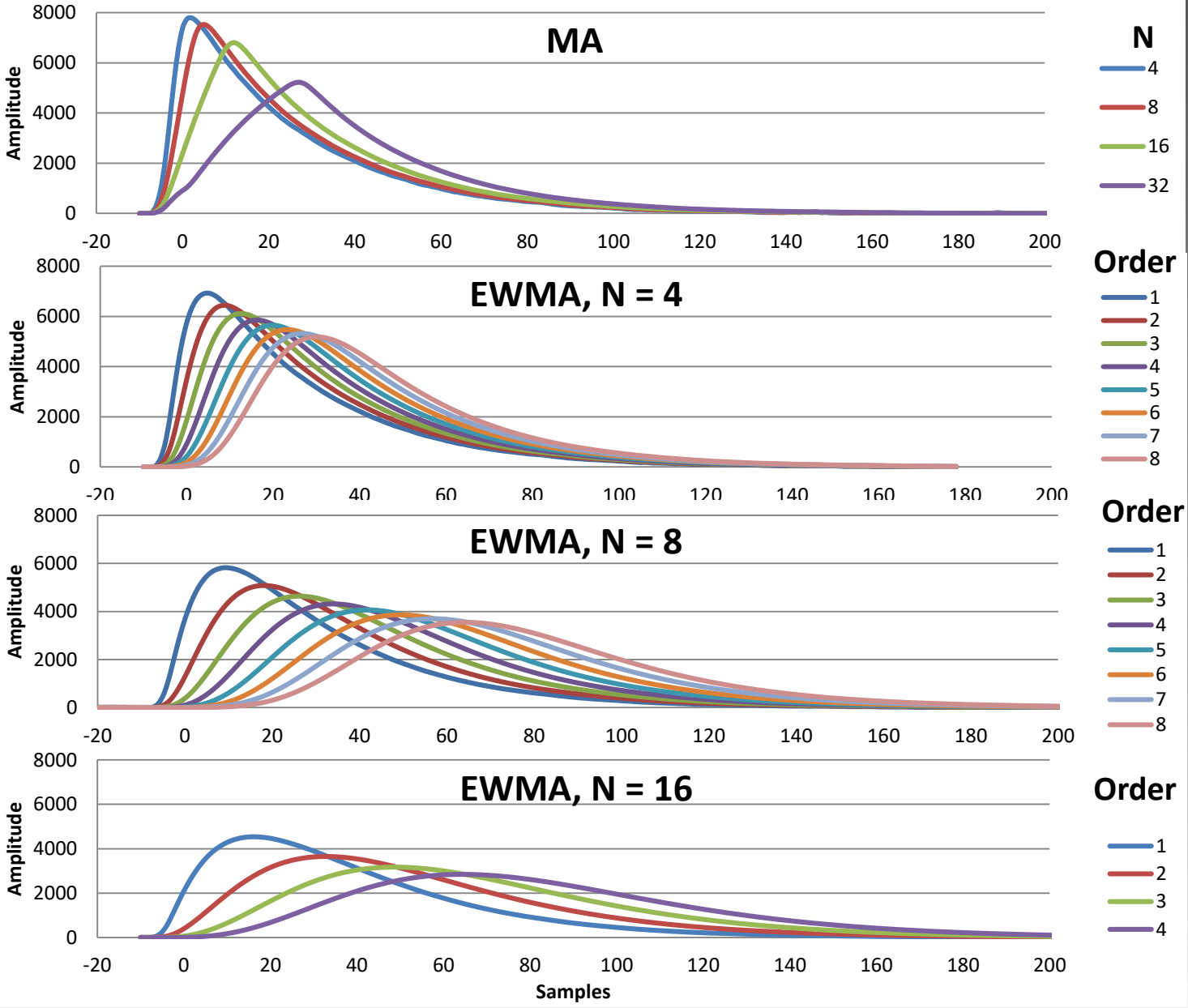
Exponentially Weighted Moving Average (EWMA)





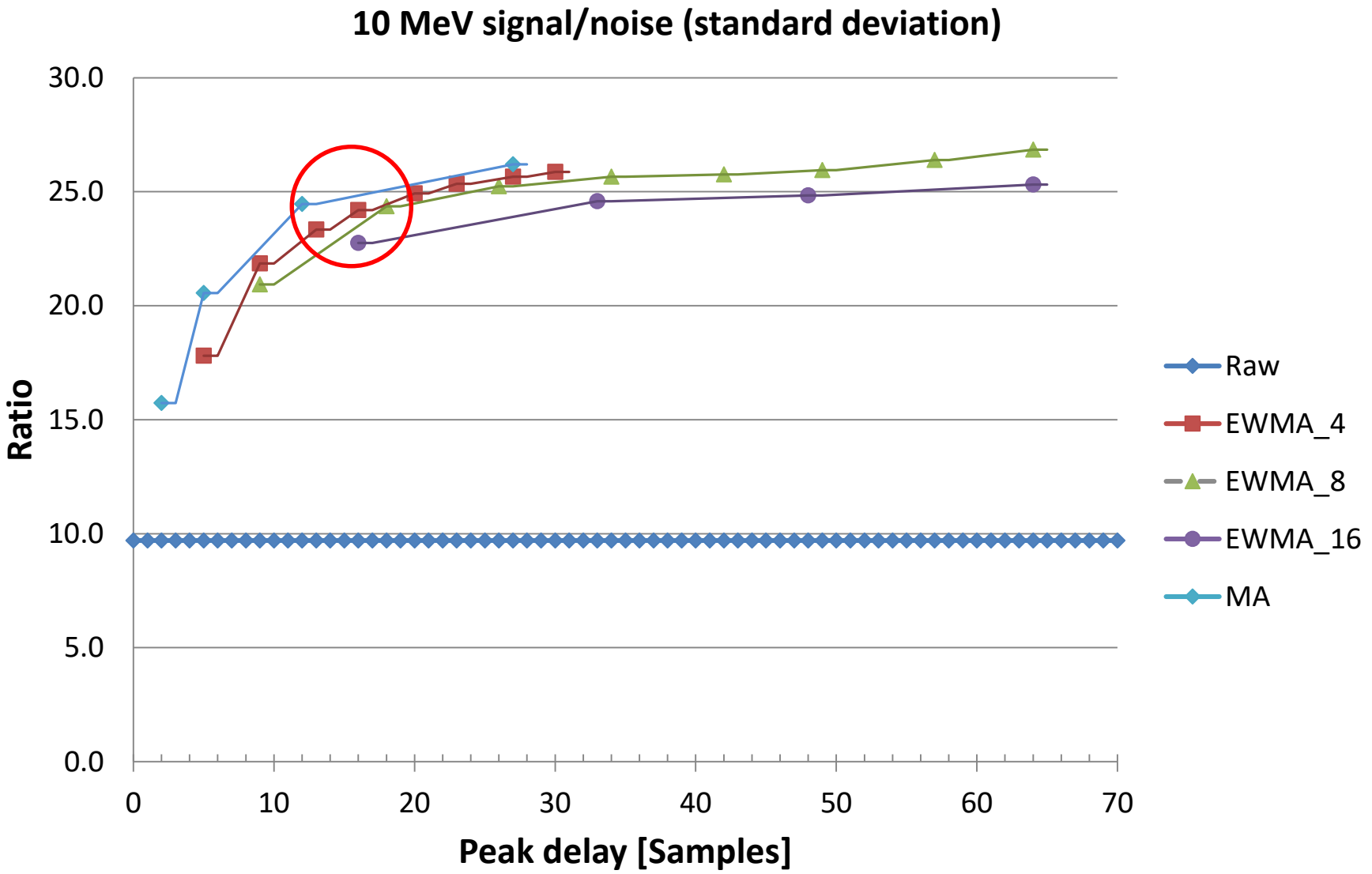
ADC for EMC-Endcap

- Digital Low-Pass filters



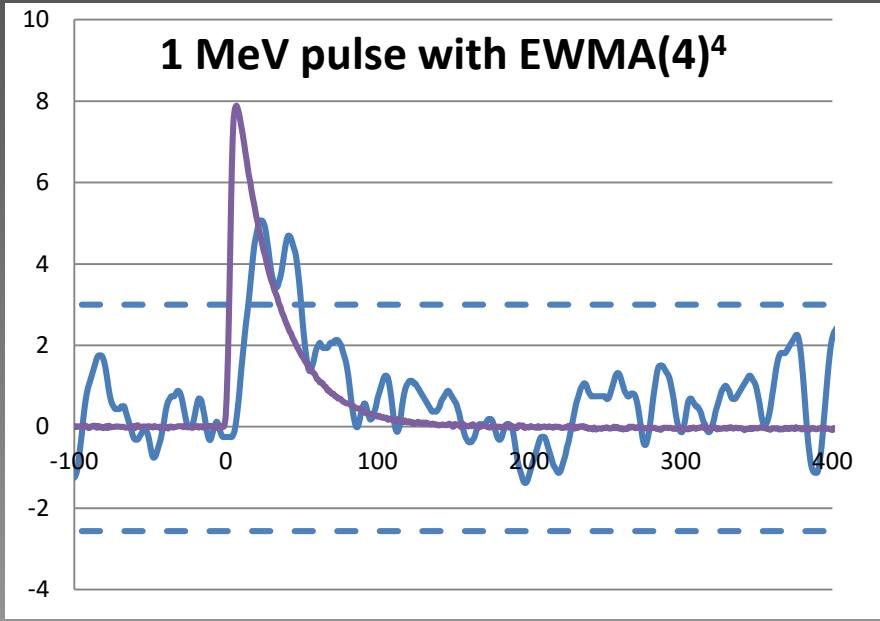
ADC for EMC-Endcap

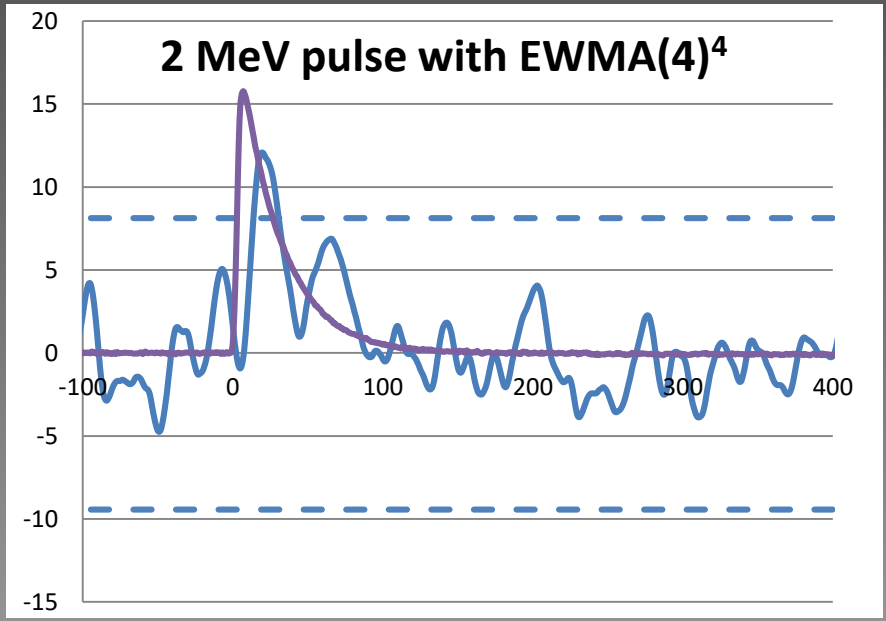
- Digital Low-Pass filters

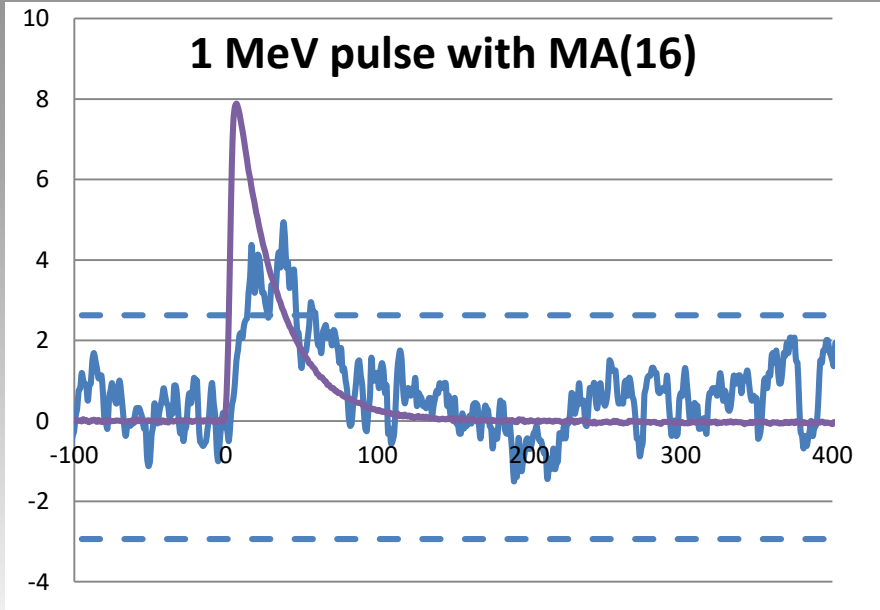


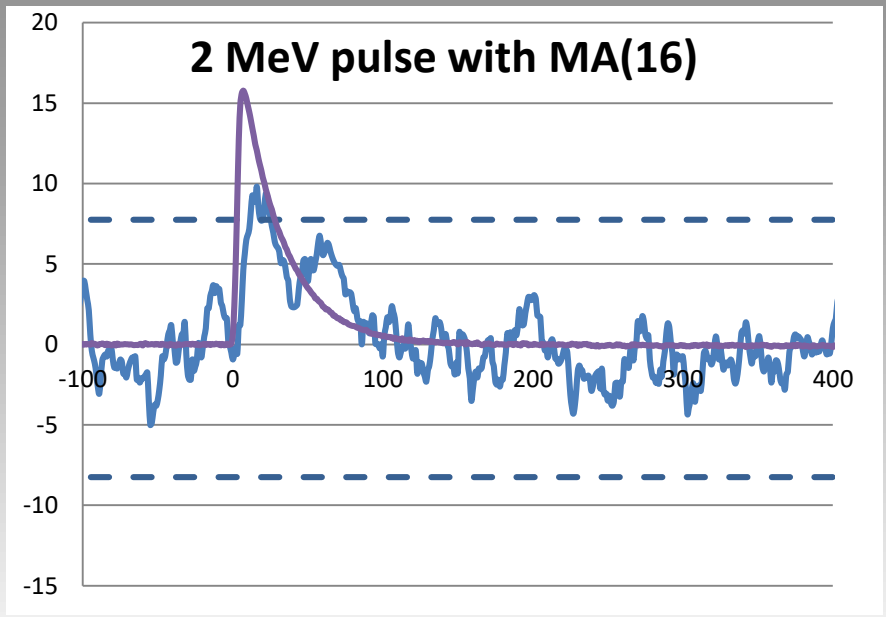
ADC for EMC-Endcap

- Assessing the dynamic range for ADC









ADC for EMC-Endcap

- Signal tail reconstruction

Exponential decay

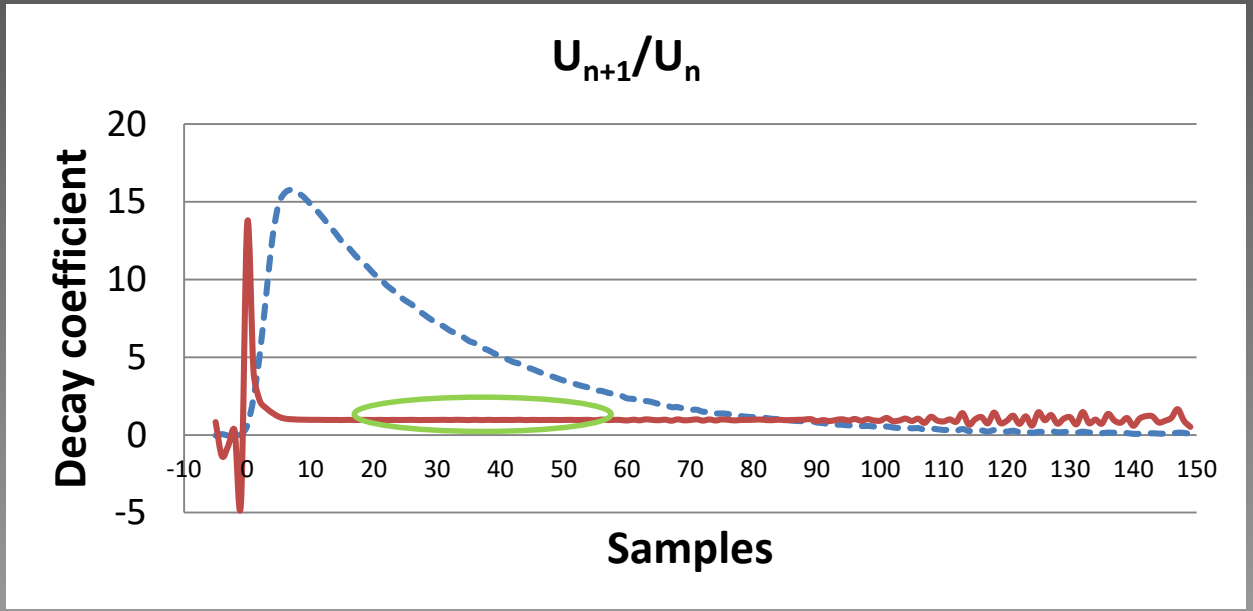
$$U_n = Ae^{-\frac{n}{\tau}}$$

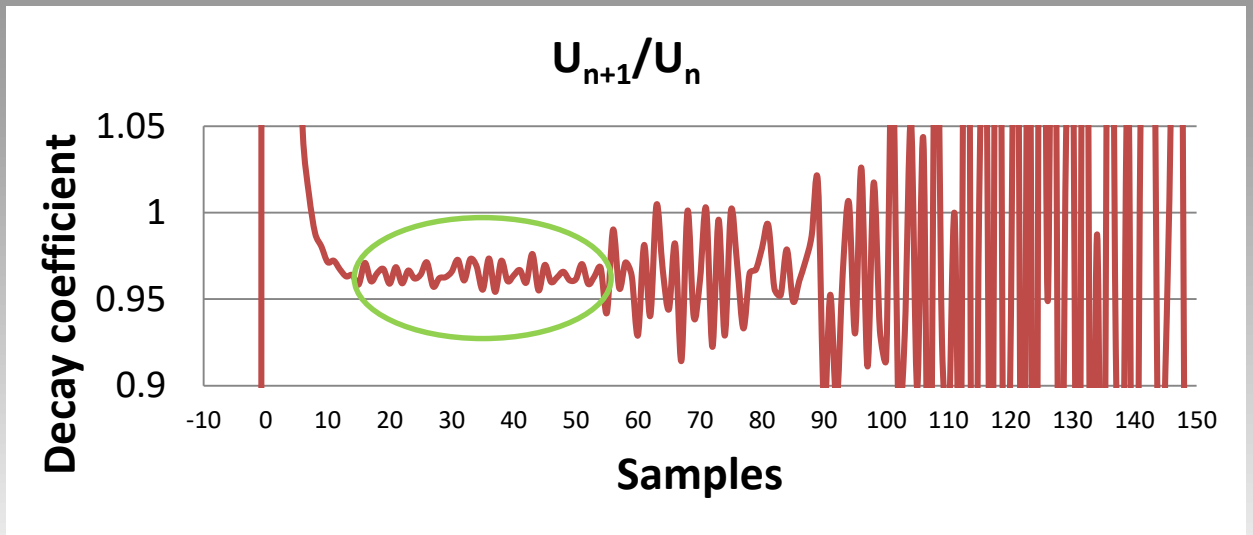
$$U_{n+1} = Ae^{-\frac{n+1}{\tau}}$$

$$\frac{U_{n+1}}{U_n} = e^{-\frac{1}{\tau}}$$

Decay coefficient

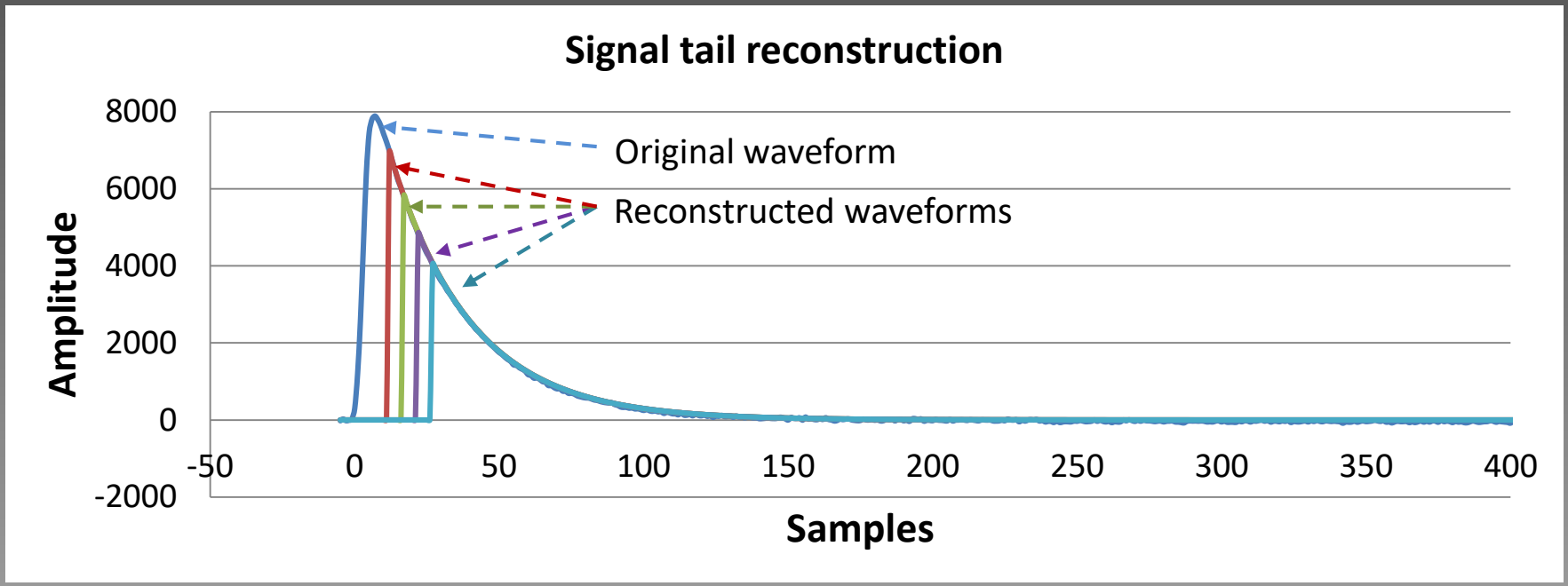
$$\frac{U_{n+1}}{U_n} = 0{,}96478$$

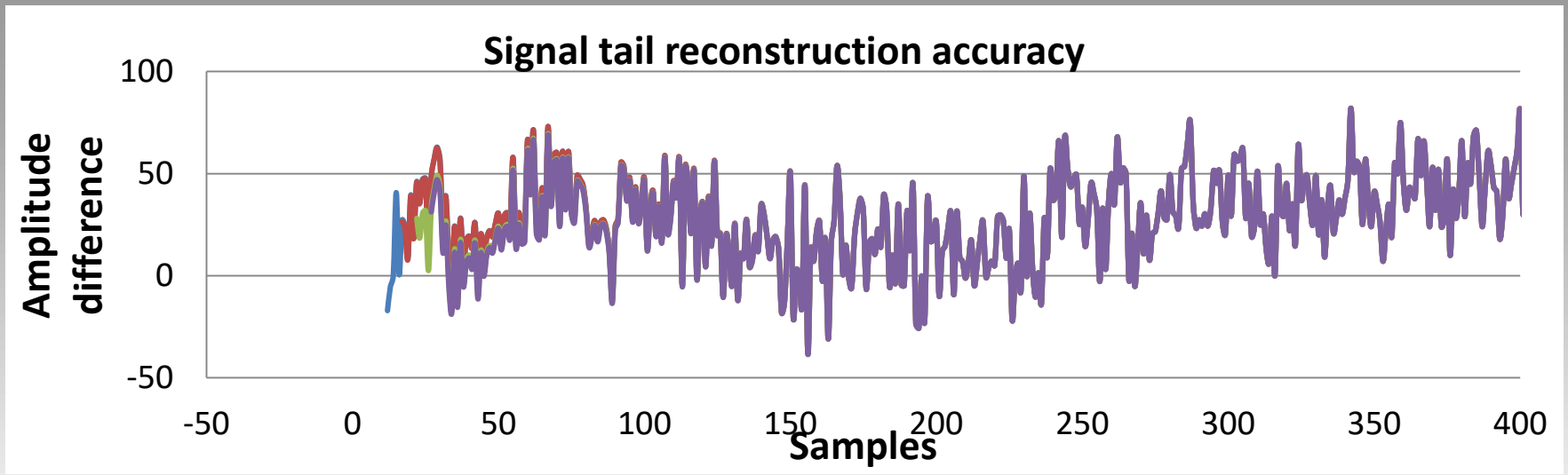




ADC for EMC-Endcap

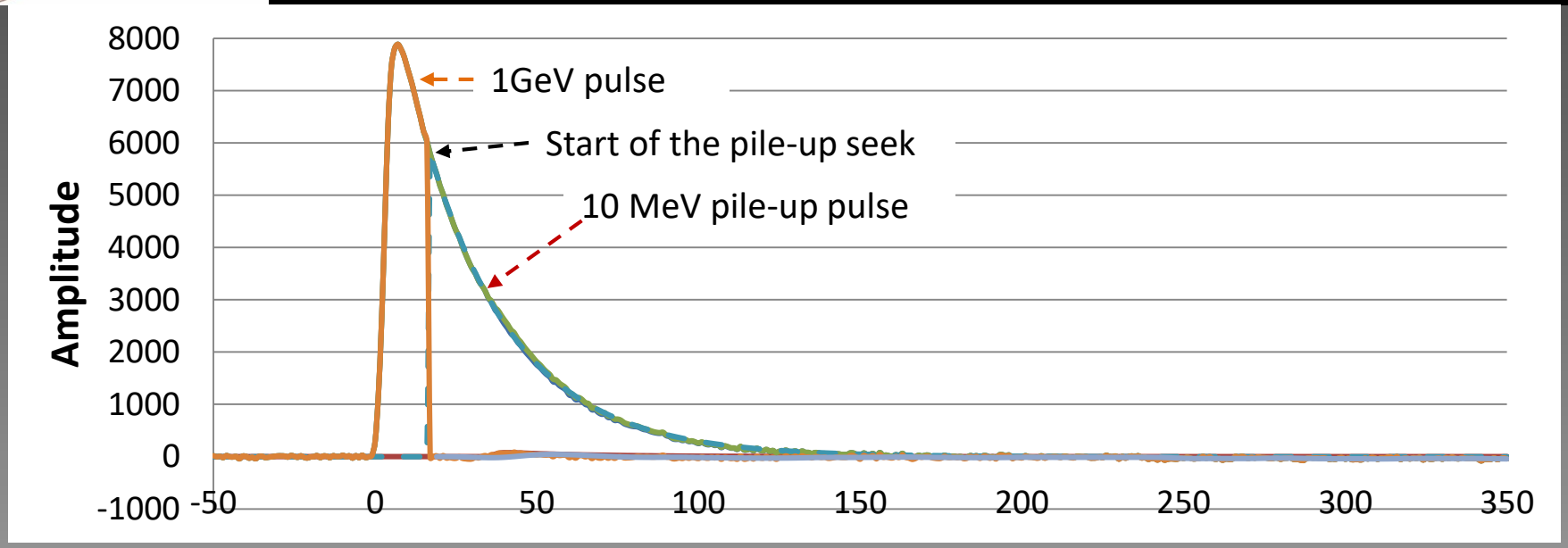
- Signal tail reconstruction

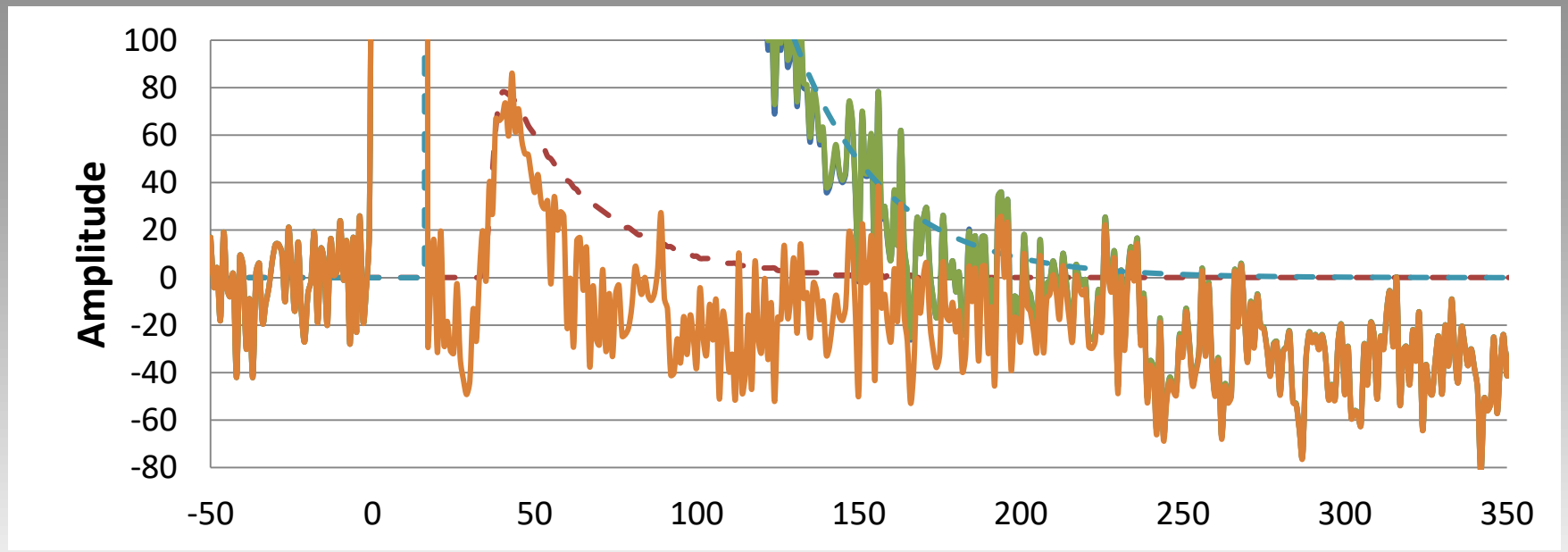




ADC for EMC-Endcap

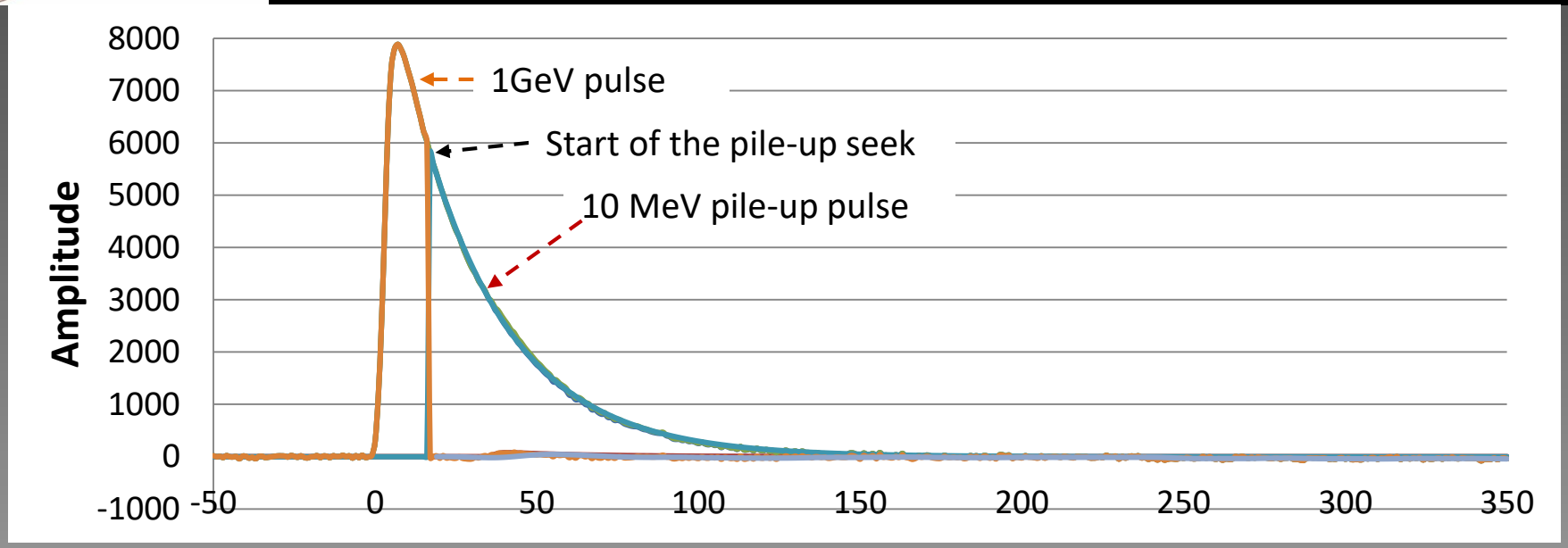
- Pile-up recognition

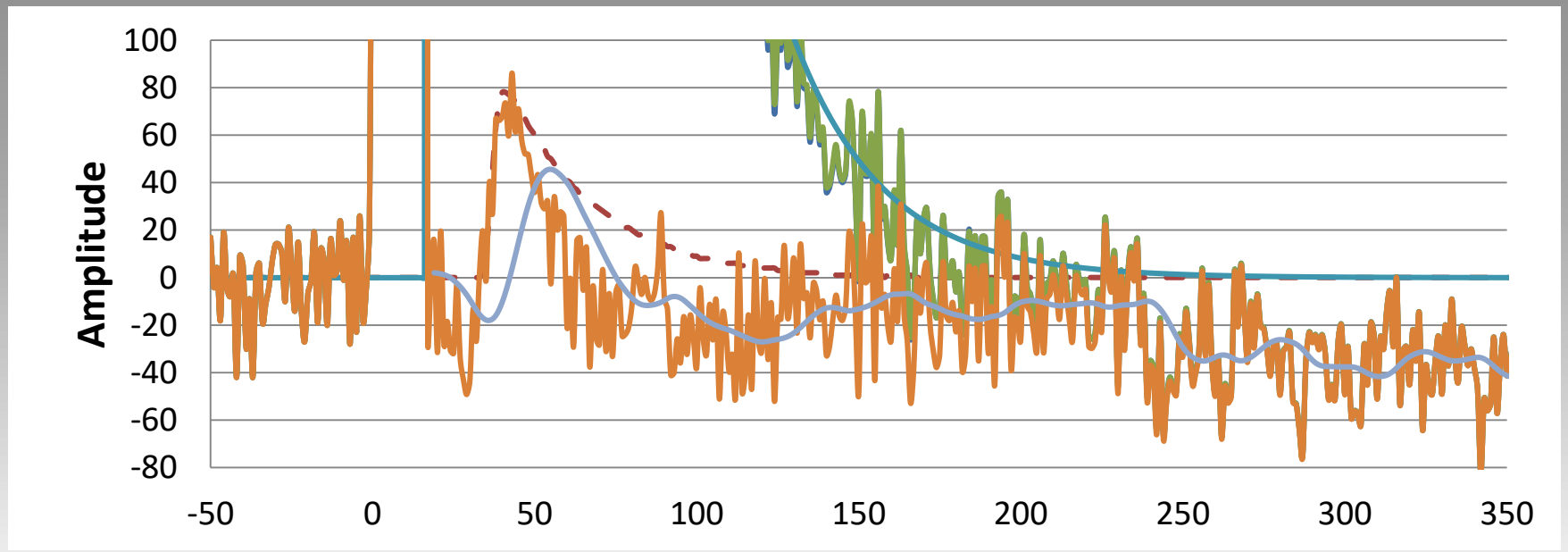




ADC for EMC-Endcap

- Pile-up recognition

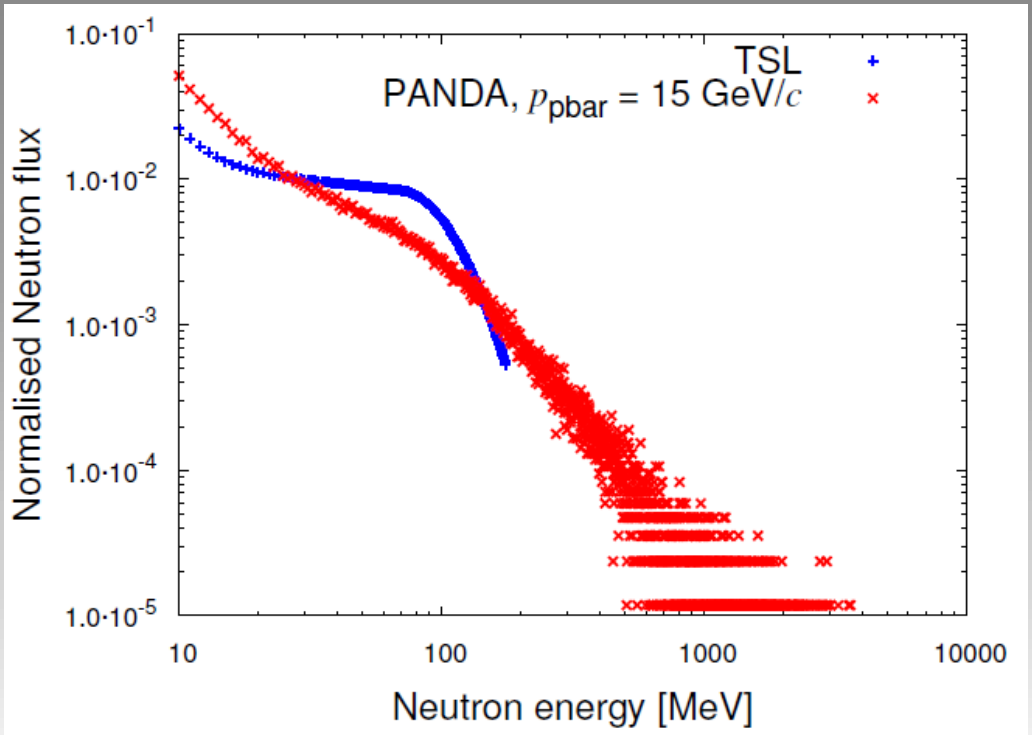




ADC for EMC

- Neutron irradiation

- The board was irradiated in June 2016 at the The Svedberg Laboratory (TSL) in Uppsala. Firmware prepared at KVI.
- Board placed in the Standard User Position (SUP), beam perpendicular to the board. One FPGA read out.
- Neutron flux between $5 \cdot 10^5$ and $1 \cdot 10^6$ s^{-1} cm^{-2} (>10 MeV).



ADC for EMC

- Neutron irradiation of the ADC_64K_2

The cross section for an SEU is given by:

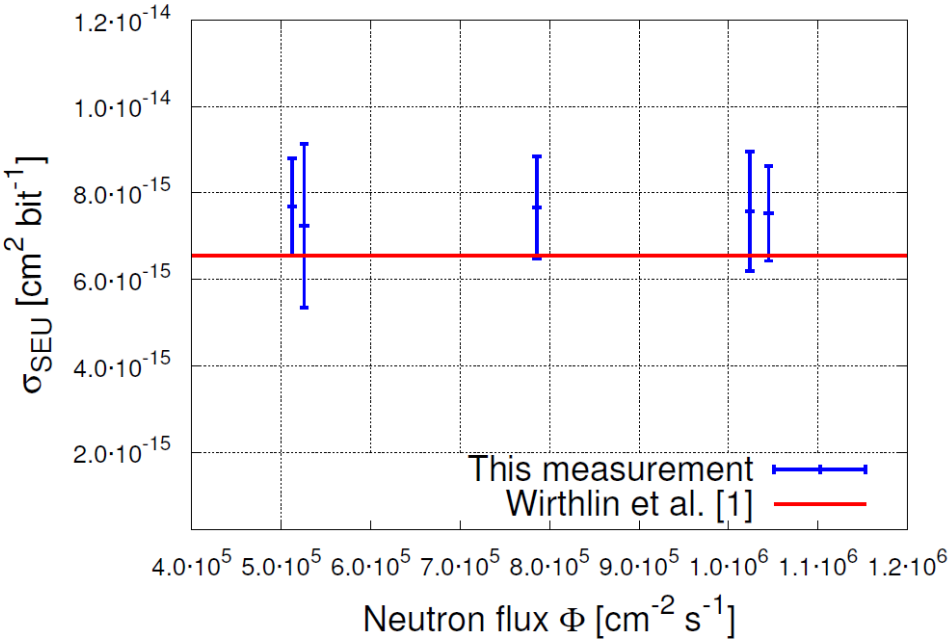
$$\sigma_{\mathrm{SEU}} = \frac{N_{\mathrm{SEU}}}{T_{\mathrm{meas}} \cdot \Phi_{\mathrm{n}} \cdot N_{\mathrm{bits}}}$$

Number of SEU

Measurement duration

Neutron flux

Total number of bits



[1] Wirthlin, M. J. et al. (2014) *JINST*. **9** C01025. ← Larger Kintex-7 @ TSL

- Neutron irradiation of the ADC_64K_2

MTBF calculation

(calculations performed by Markus Preston, Stockholm University)

$\sigma_{SEU} = 7.58 \cdot 10^{-15}$ (± 7%) $cm^2\ bit^{-1}$
$pp_{bar} = 15$ GeV/c
$L = 2 \cdot 10^{32}\ cm^{-2}\ s^{-1}$

Scaled Neutron Flux:
$\Phi_n = 150\ cm^{-2}\ s^{-1}$ (at position of digitisers)

Per digitizer board:

$r_{SEU} = 1.0 \cdot 10^{-4}\ s^{-1}$ → MTBF = **2.7 h** automatically correctable
$r_{SEU} = 3.5 \cdot 10^{-6}\ s^{-1}$ → MTBF = **90 h** needing reconfiguration (<200 ms)

Entire system (600 digitizers)

$r_{SEU} = 0,056\ s^{-1}$ → MTBF = **17,8 s** automatically correctable
$r_{SEU} = 0,002\ s^{-1}$ → MTBF = **529 s** needing reconfiguration (<200 ms)

Proton irradiation scheduled for November 2016

ADC for EMC-Endcap

- Manpower

	Uppsala
Hardware design	- Pawel Marciniewski
	Stockholm
Software/analysis	- Markus Preston, Karoly Makonyi
	KVI Groningen
Firmware/software	- Peter Schakel, Myroslav Kavatsyuk
	Uni Bonn
Firmware/software	- Johannes Muellers
	Uni Bochum
Software -/analysis	- Malte Albrecht

Thank You !