Particle identification with Straw Tube Tracker

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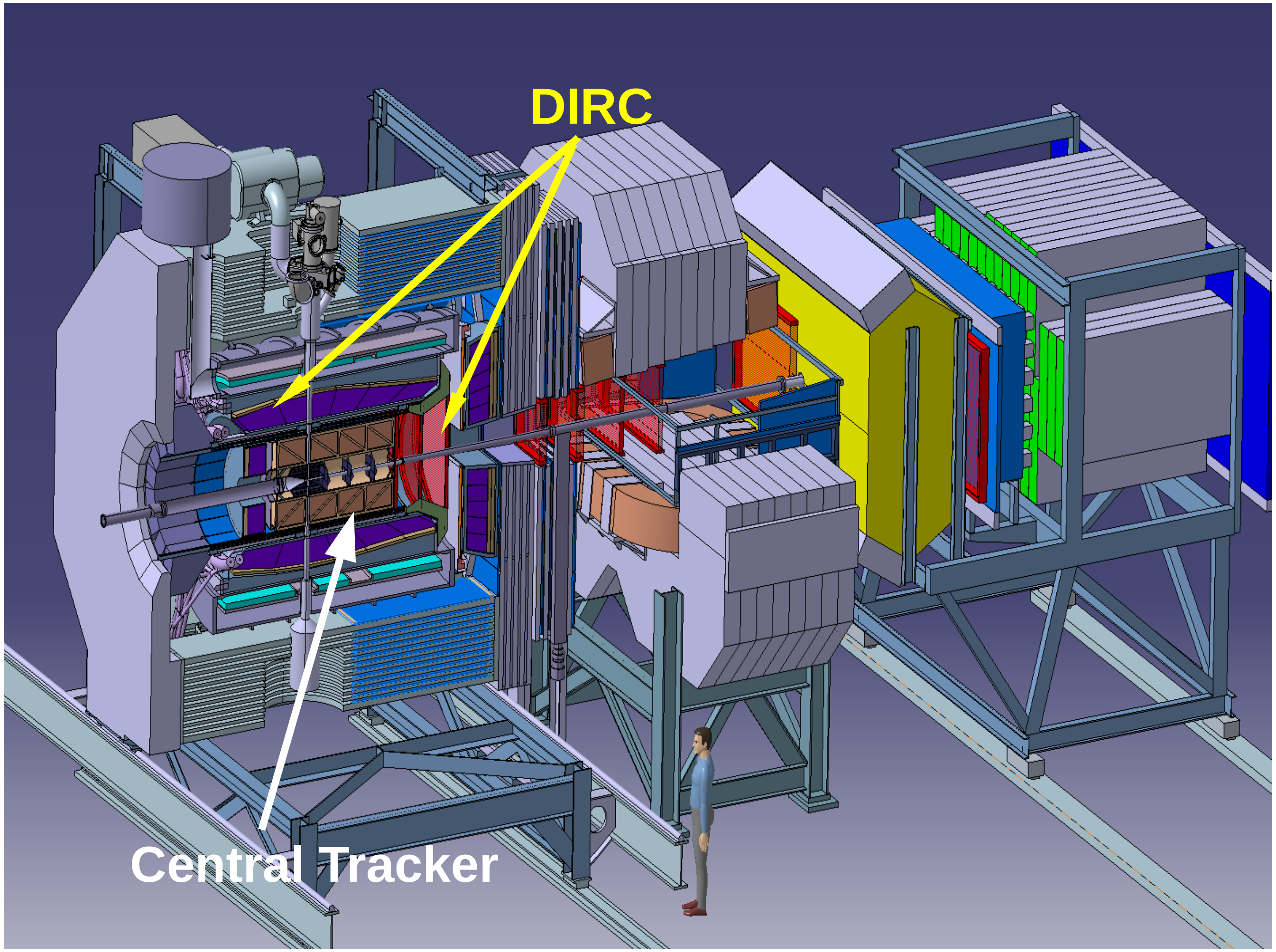
Motivation

Low momenta (< 1.GeV/c) pions, kaons and protons are below detection threshold of PANDA-DIRC detectors.

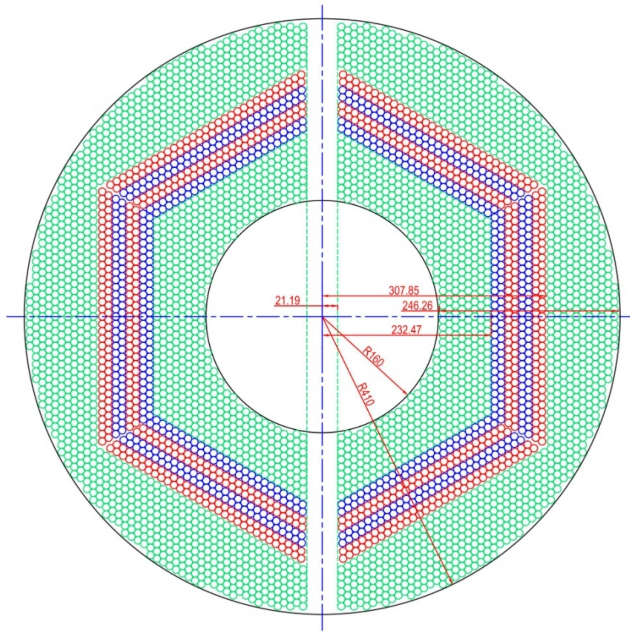
Can these particle be identified in central tracker ?

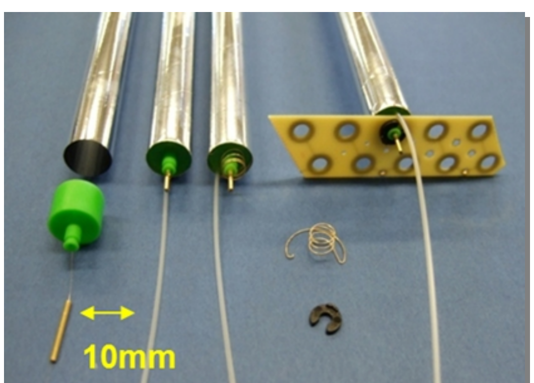
The feasibility study of the energy resolution of the multilayer Straw Tube Tracker (STT) was undertaken.

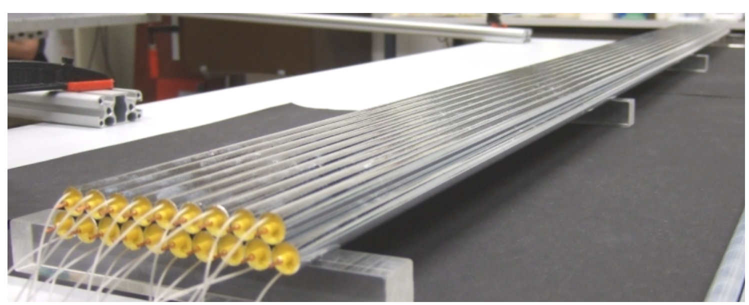


Central Tracker of PANDA

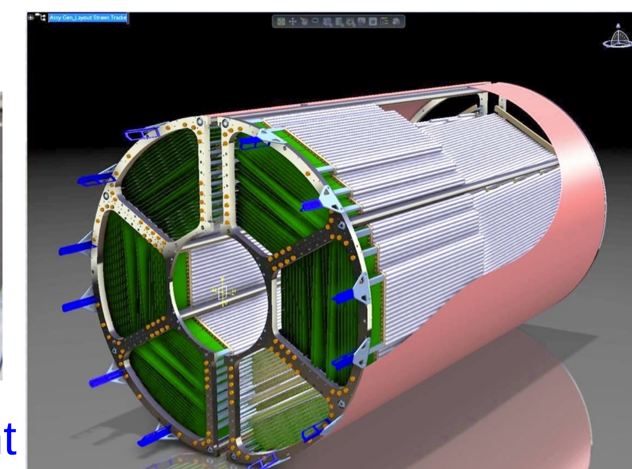
- **4636 Straw tubes** in
- **23-27 planar layers** in 6 hexagonal sectors
  - 15-19 axial layers (green)
  - 4 stereo double-layers for 3D reconstr.
  - ±2.89° skew angle (blue / red)
- Time readout (isochrone radius)
- Amplitude readout (energy loss)
- $\sigma_{r\Phi} \sim 150\ \mu m$, $\sigma_z \sim 3.0$ mm (single hit)
- $\sigma_p \sim 1$ - 2% at B=2 Tesla
- **$X/X_0 \sim 1.2\%$** ($^2/_3$ tube wall + $^1/_3$ gas)
- R_{in}/R_{out}: 150 / 418 mm
- Length: 1500mm + 150mm (RO upstr.)





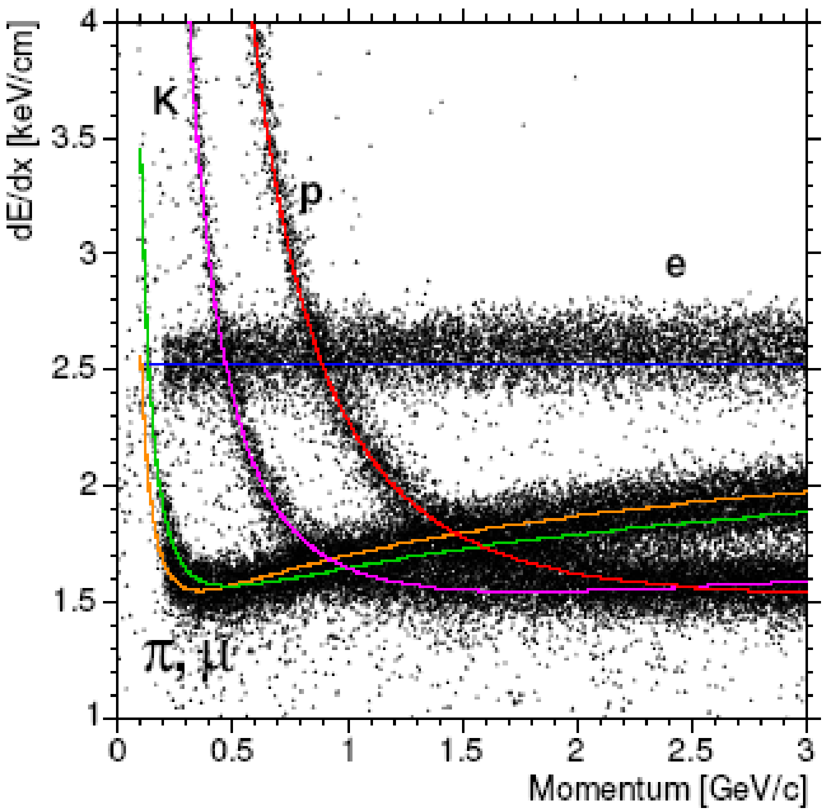


Peter Wintz, COSY-TOF experiment



Identification of particles

Specific energy loss of particles



Difficulties for STT:

1. Small "displacement" of the curves → energies (and momenta) must be measured precisely

   But: energy loss is statistical process of the Landau distribution

2. Main task of SST is a precise determination of the tracks → fast response, short time signal

   But: energy measurement requires longer charge collection time and signal processing

Momentum – from curvature of the particle path in magnetic field (tracking)

Energy loss – derived from signal analysis

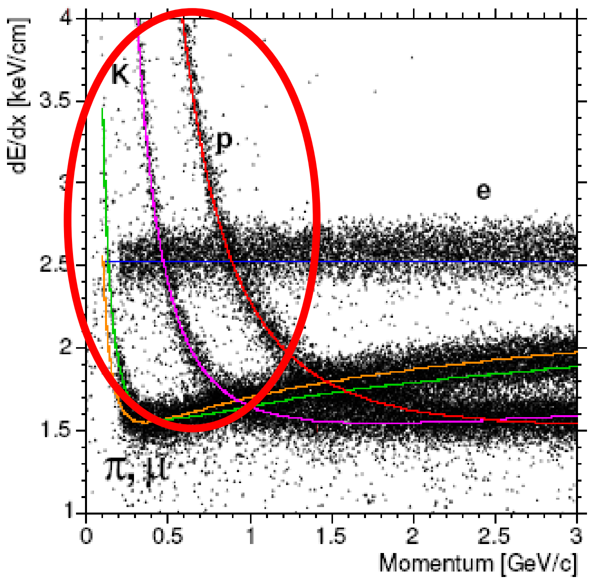
Factors influencing energy-loss resolution

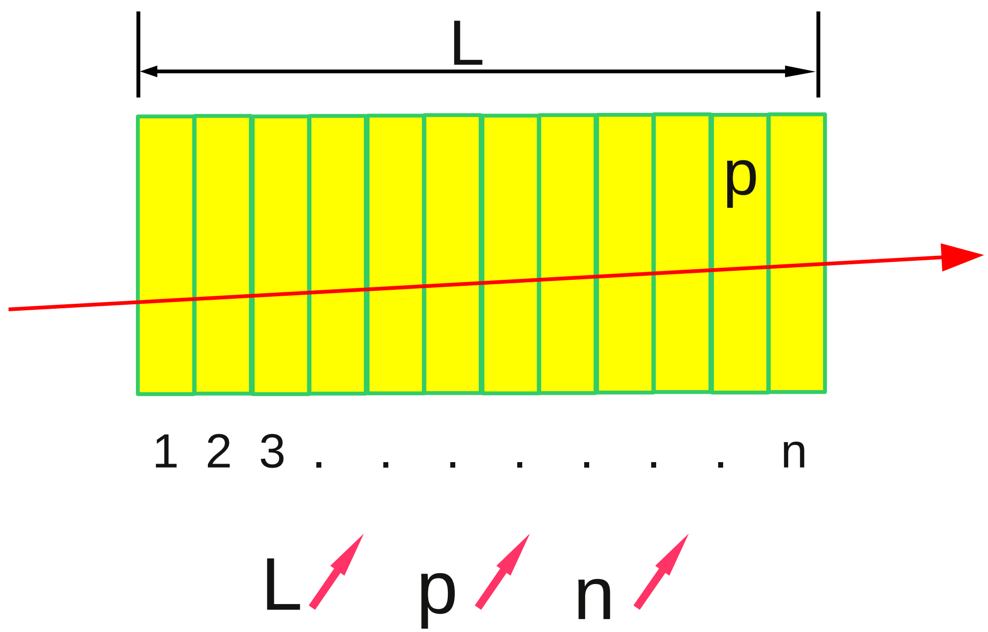
Precision of energy loss measurement depends on amount of primary charge released in the medium, thus important factors are:

→ particle energy (at low energies better resolution),

→ effective thickness of the detector (detection length x gas pressure),

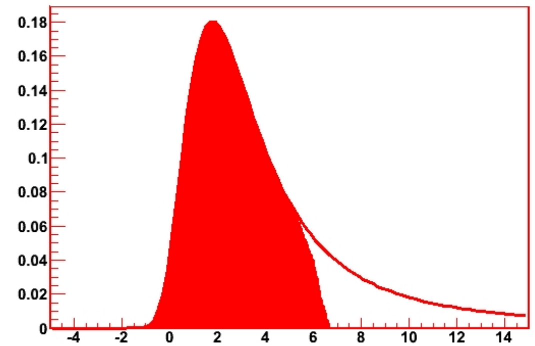
→ number of individual sampling elements (number of straw tubes).





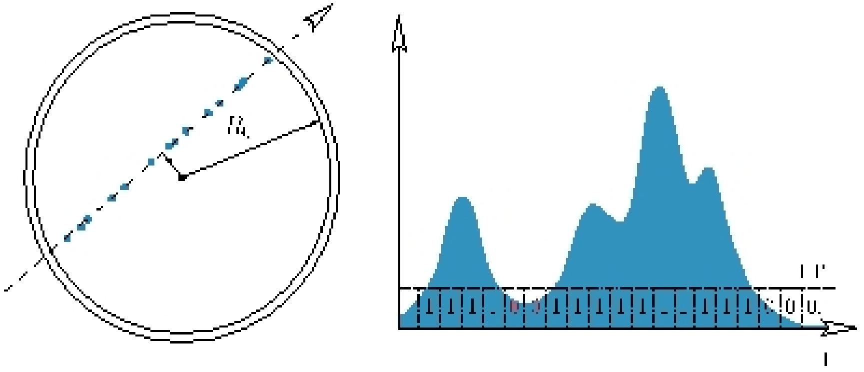
Energy measurement with gaseous detectors

Direct measurement of energy-loss
(by collecting of the total output charge)



Selective measurement of the energy-looses
with rejection of the high energy events
(truncation mean method)

Deducing of the energy-losses
from the timing signals –
Time over Threshold



Counting of the numbers
of created ionization clusters

For all methods accurate determination of the actual path length in each straw is needed, as well as a uniform gain calibration of all channels.

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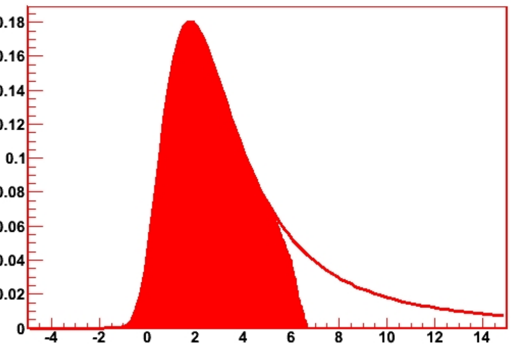

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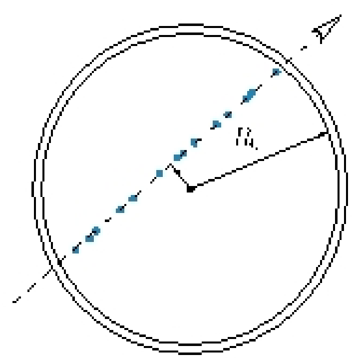

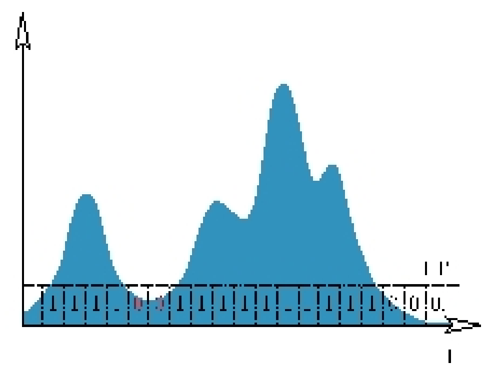

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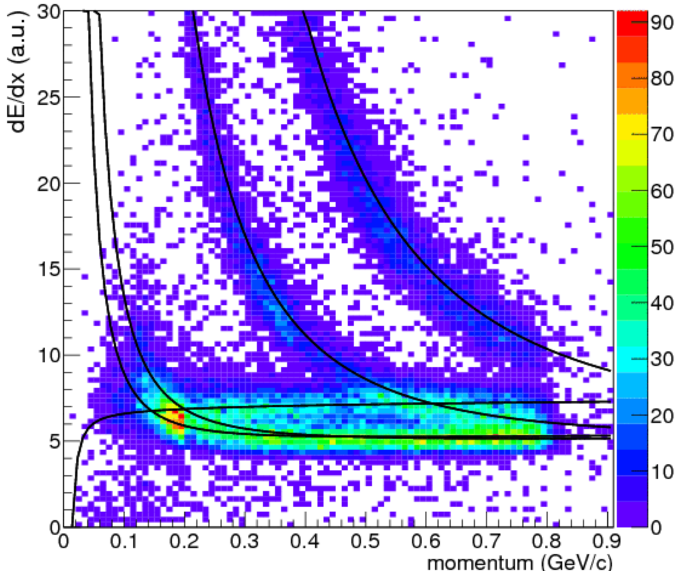
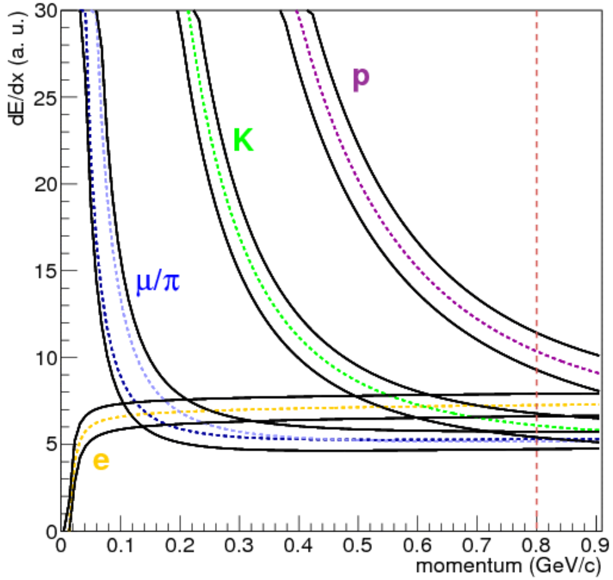
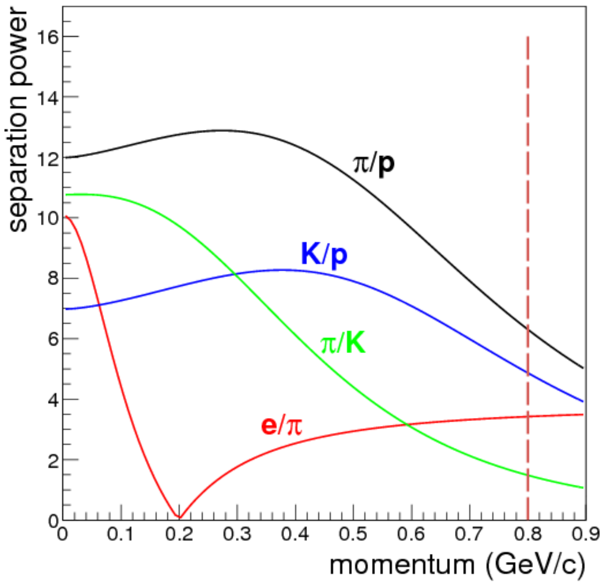
Simulations of dE/dx for PANDA-STT





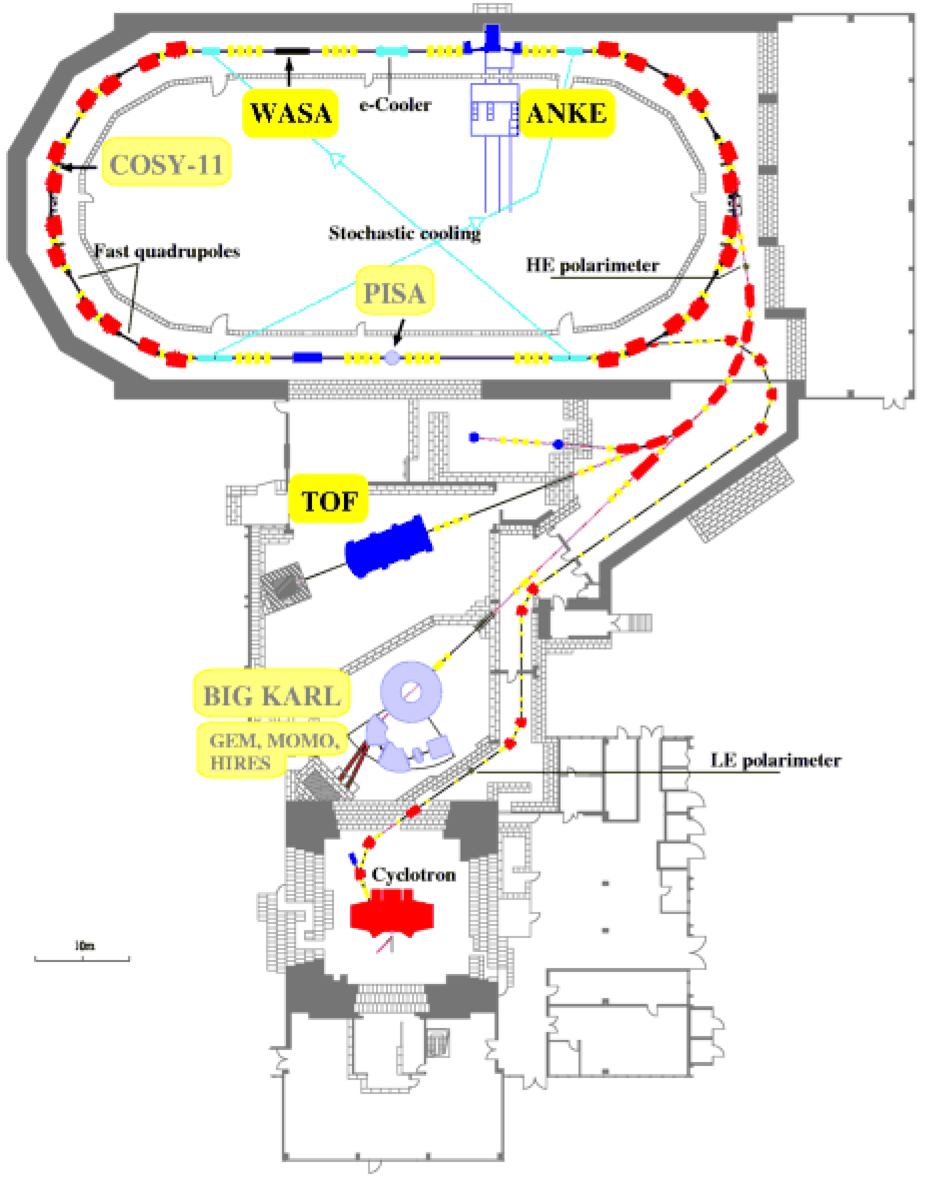
Simulations for PANDA-STT performed by Pavia group

- FFE response included
- energy loss derived from charge collection
- truncation mean applied

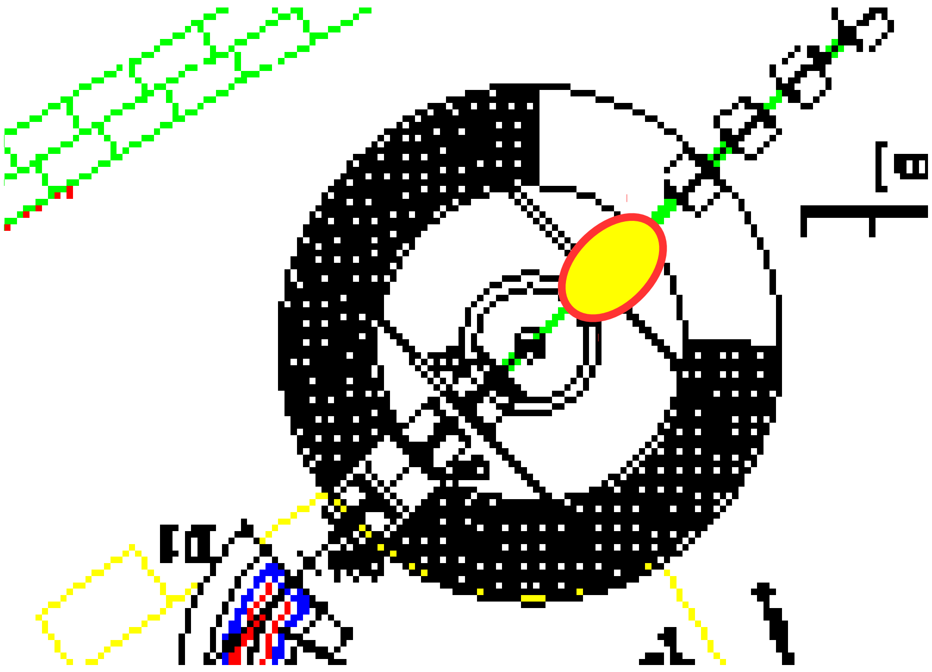


If energy resolution < 10 %

Experimental investigations at COSY



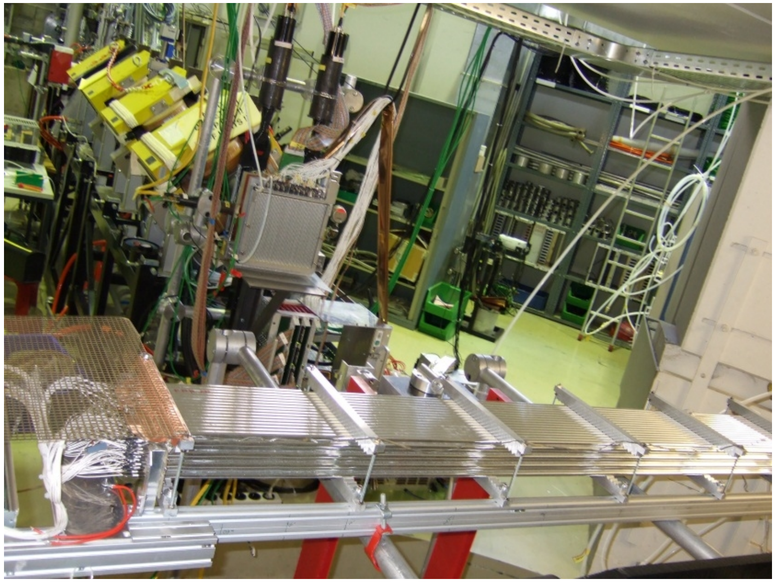
TEST PLACE at BIG KARL



- proton beam
- momentum: 0.6 - 3.0 GeV/c
- intensity: 10^3 - 10^9

Experimental setups

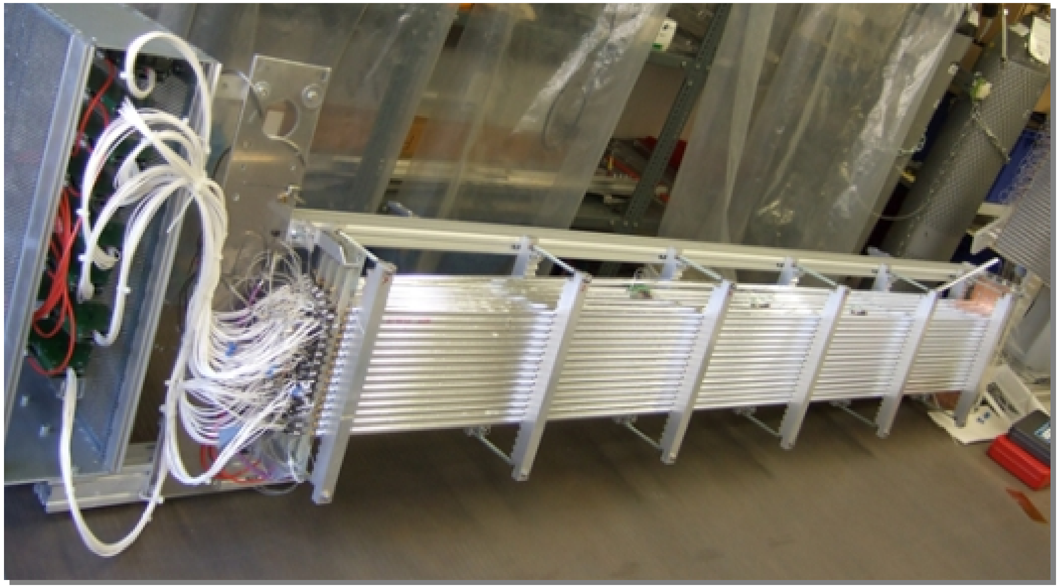
Three small-scale setups were used for energy loss measurement (each of them equipped with different front-end electronics.



Setup are formed out of self supporting double layers.

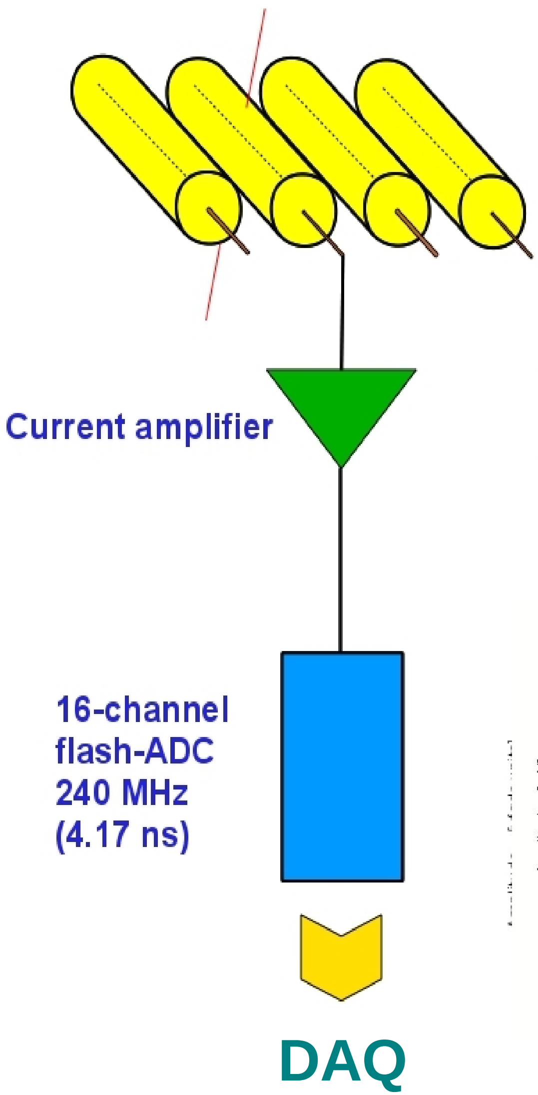
Each layers consist of 16 tubes:

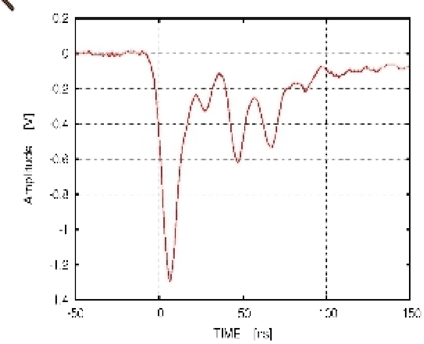
- 1.5 m long
- Φ 10 mm
- 30 μm wall thickness
- 20 μm anode wire
- 1 bar overpressure
- gas mixture: Ar/CO2 (90/10)

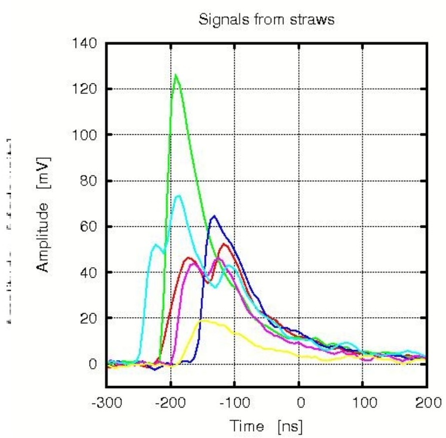


Front end- and digital electronics

Initial readout used for energy loss tests







Transresistance amplifier
- 8 ns rise-time,
- gain factor 360,
- differential output
- total integration time ~ 7 ns

12 Bit sampling ADCs (developed by ZEL FZJ + Uppsala University)

240 MHz sampling frequency

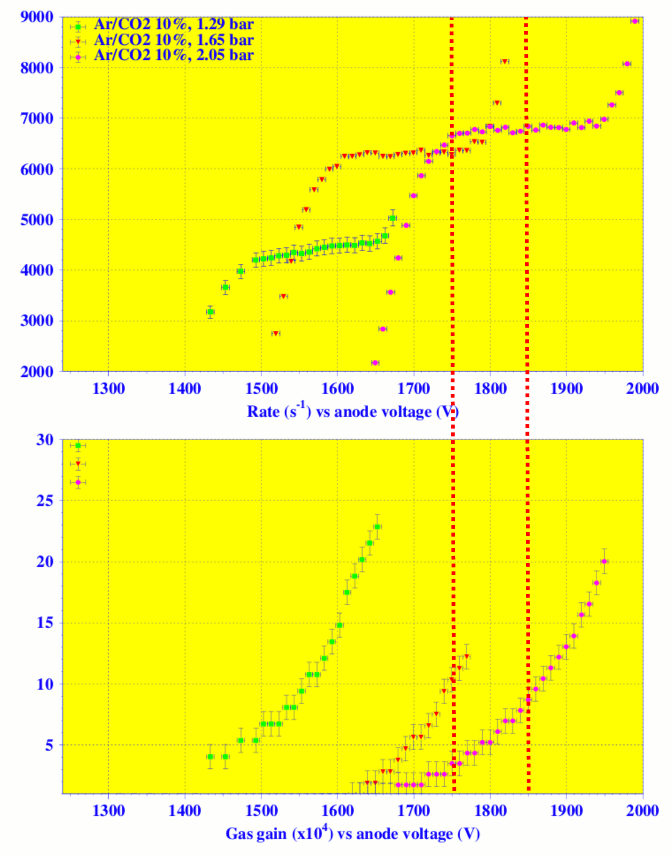
Many algorithms implemented in FPGA :

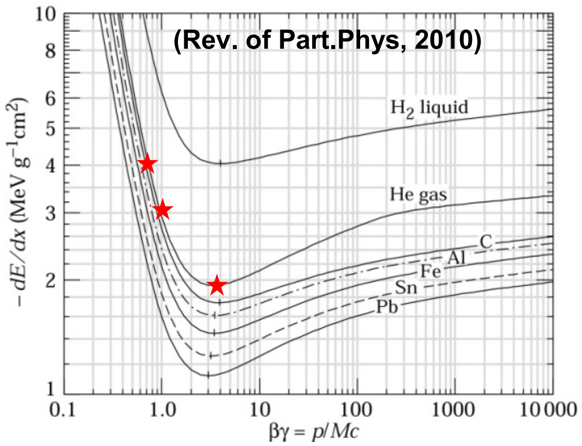
- **baseline restoration**
- **cluster detection**
- **pileup detection**
- **constant fraction discriminator**
- **time measurement (better than 1 ns)**

Energy loss measurements

Tests

Tests performed with the COSY proton beam at 0.64-, 1.0-, and 2.95 GeV/c momentum.

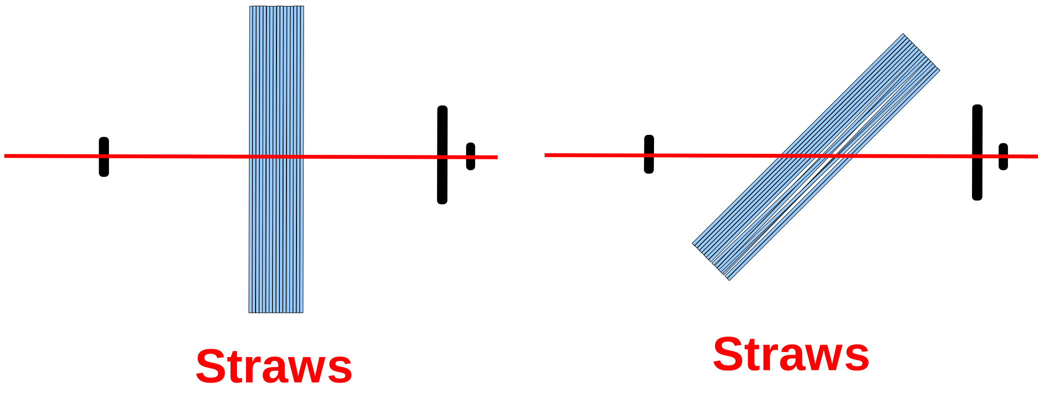




Detector gas gain kept at the level about 5 * 10^4

Gas mixture: Ar+Co2(9/1) at 2 bar

Proton impinging angle: 90 deg, 45 deg

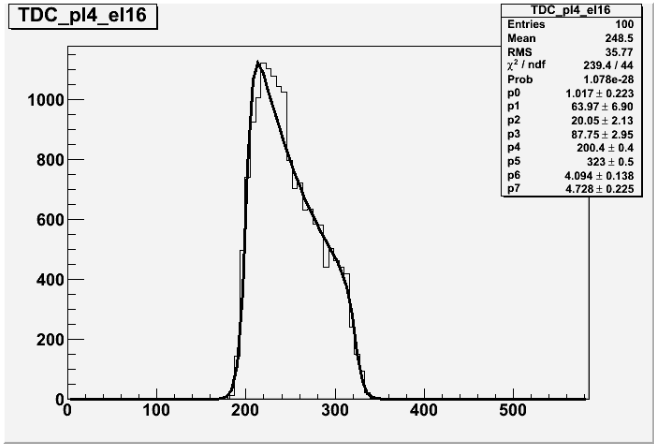


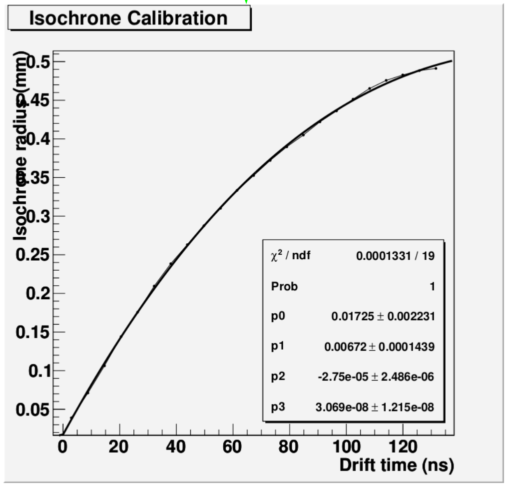
Energy loss measurements

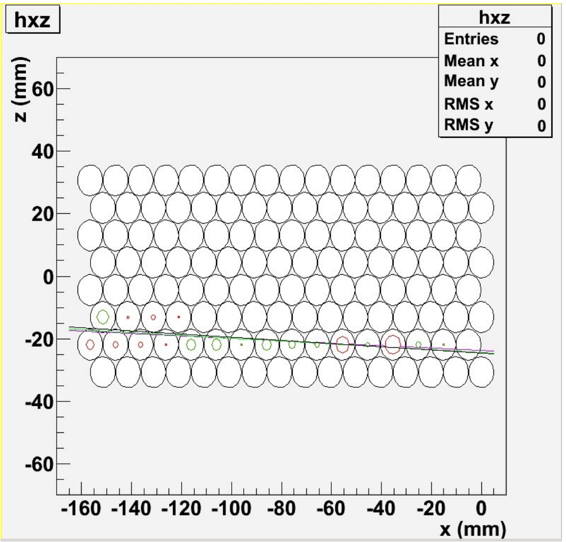
Analysis method

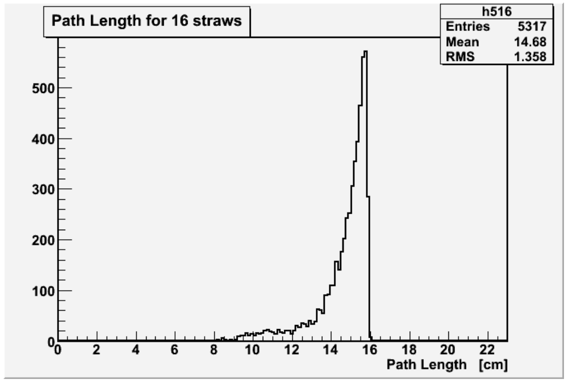
1. Tracking:

- drift time spectra,
- calibration of radius – drift time,
- geometrical track reconstruction in 2D,
- calculation of path length.







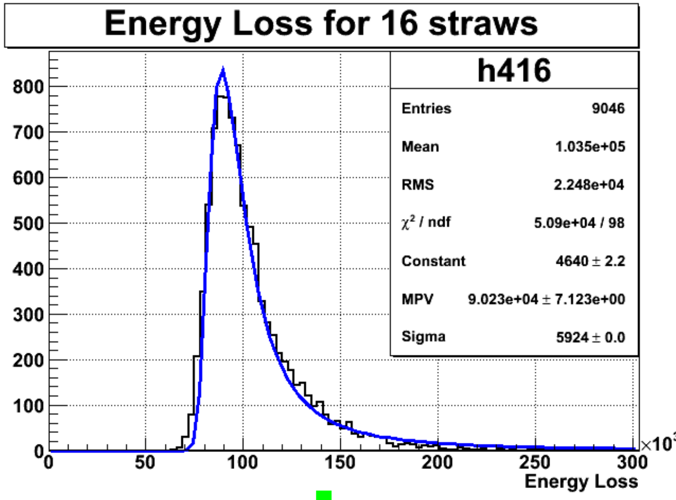


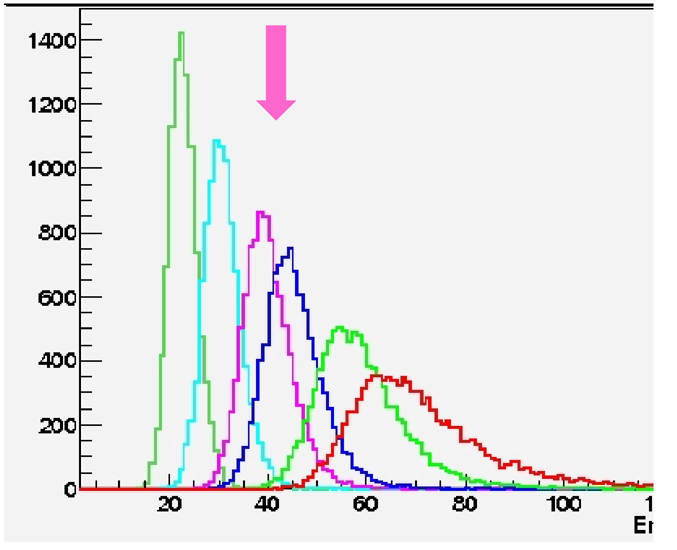
Energy loss measurements

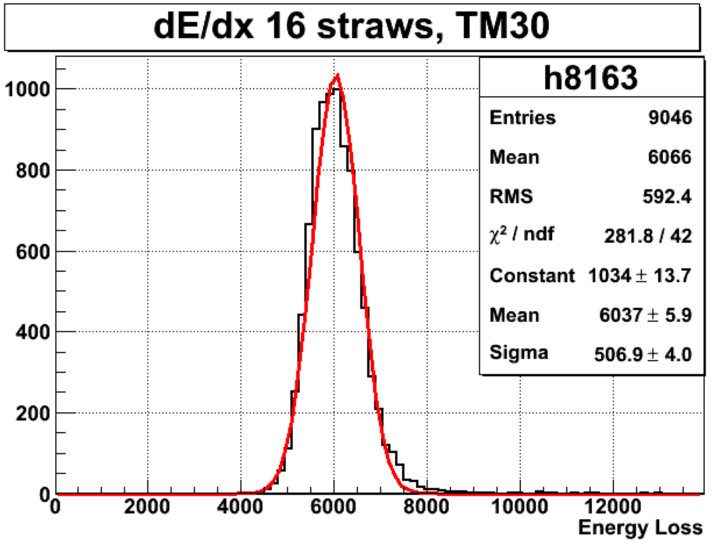
Analysis method – cont.

2. Energy-loss Spectra:

- energy-loss spectra for reconstructed tracks,
- truncation mean – cut of largest energy losses per track,
- calculation of path-lengths for “truncated” events,
- calculate specific energy-losses per path length

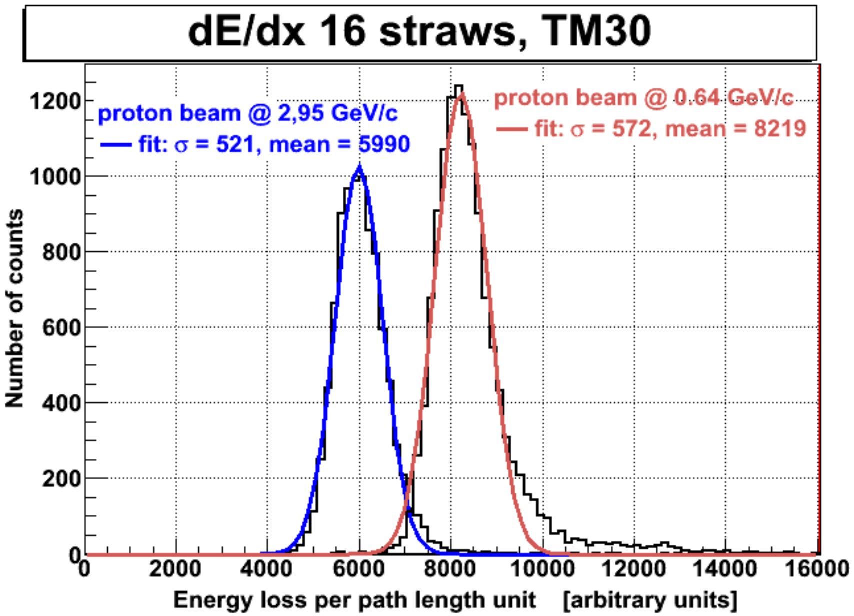






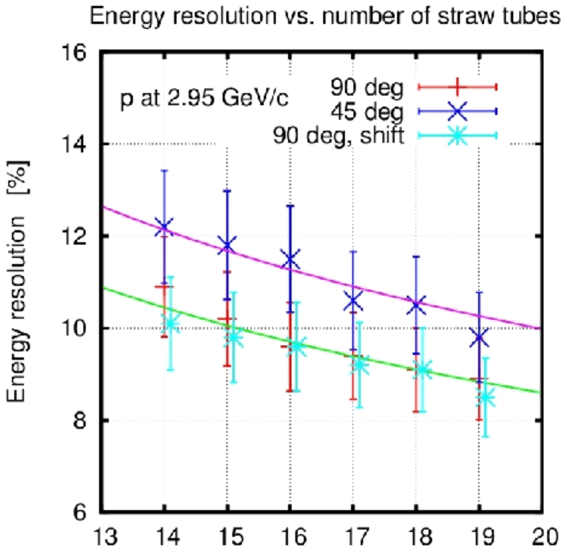
Energy loss measurements

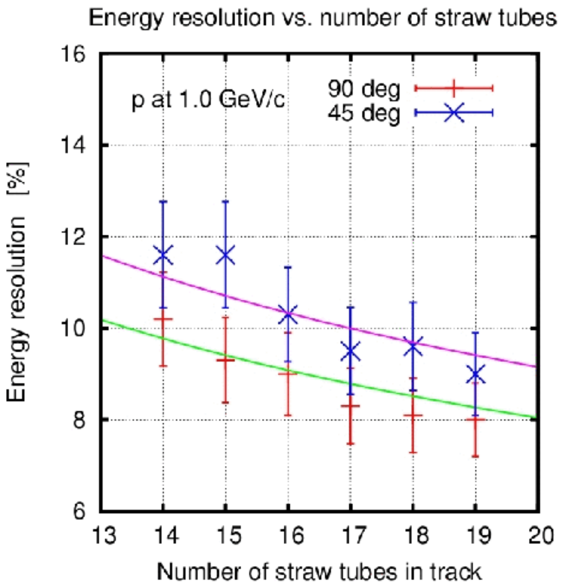
Results



The best achieved energy resolution
(with 16 straws and at 0.64 GeV/c proton momentum):

$$\sigma_{dE/dx} = 7 \pm 1\ \%$$



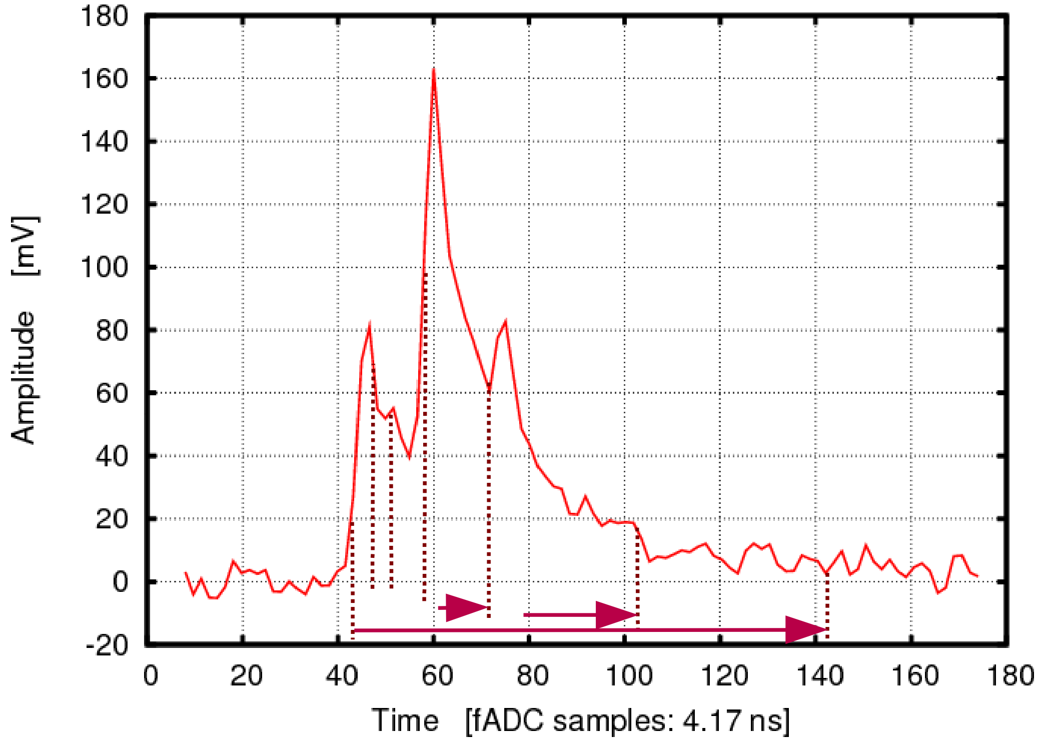


Energy loss measurements

Various fractions of charge

In experiment, due to expected high counting rate, charge integration over long drift time is not affordable.

Which fraction of the signal charge has to be collected in order to estimate the energy loss with sufficient precision ?



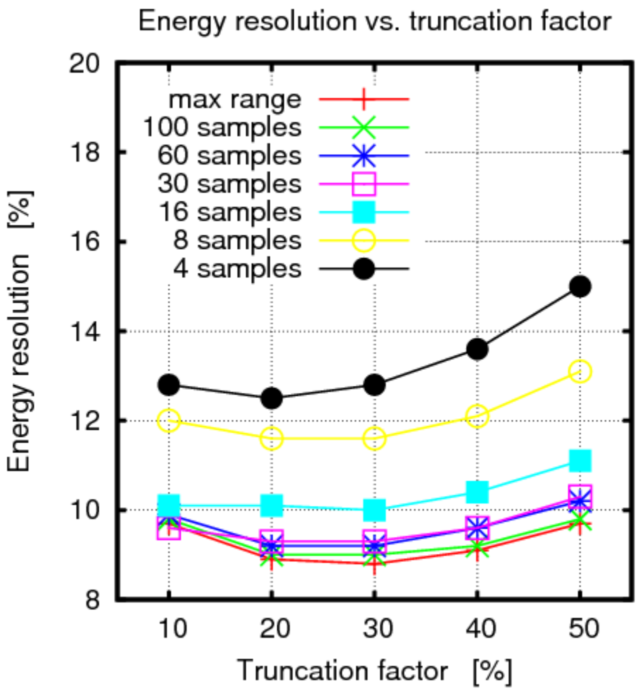
Check for integration over:

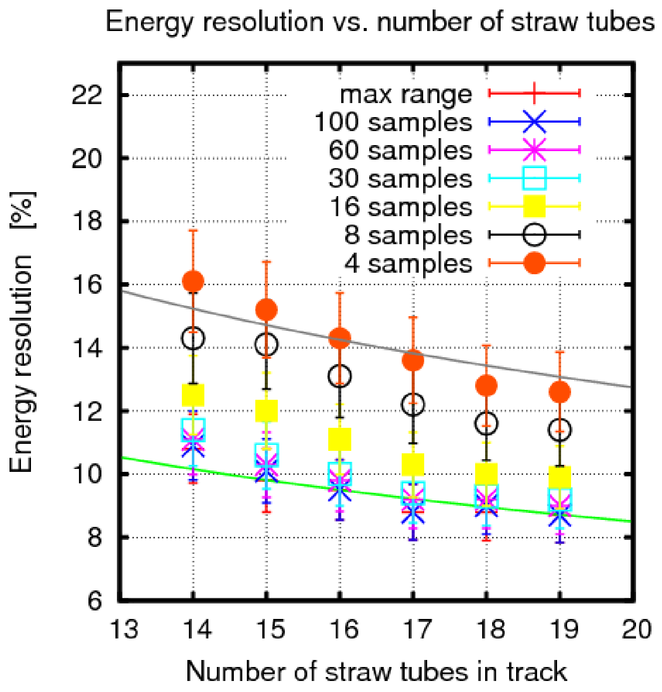
- 4 samples,
- 8 samples,
- 16 samples,
- 30 samples,
- 60 samples,
- 100 samples

1 sample = 4.17 ns

Energy loss measurements

Various fractions of charge - results





Since almost whole charge is comprised in the first 40 – 60 samples shortening of the integration up to 30 samples causes only minimal deterioration of the energy resolution.

Integration over first 16 samples (~ 67 ns) spoils resolution from 9 % to 10 % .
For 8 samples (~ 33 ns) resolution is worse by additional 2 % .
Charge contained within the first 4 samples only (~ 17 ns) allows for resolution of 13 % .

Intermediate conclusions

Results of the tests of the energy loss measurement in STT with the use of monoenergetic proton beam and with application of truncated mean method have shown that achievable energy resolution is of the order of 8 %.

Shortening of integration time of the signals until ~ 60 ns do not spoil the energy resolution more then 1 %.

In experimental conditions of PANDA experiment, with the use of full scale STT (up to 27 layers) the expected resolution is not worse.

Front End Electronics suitable both for precise timing as well as for energy loss measurement is needed.

Time + Energy oriented FEE

1. ASIC – specialized, programmable chip allowing for tail cancellation and baseline restoration:
   - time information (digital) (+ Time over Threshold → energy)
   - energy information (analog)

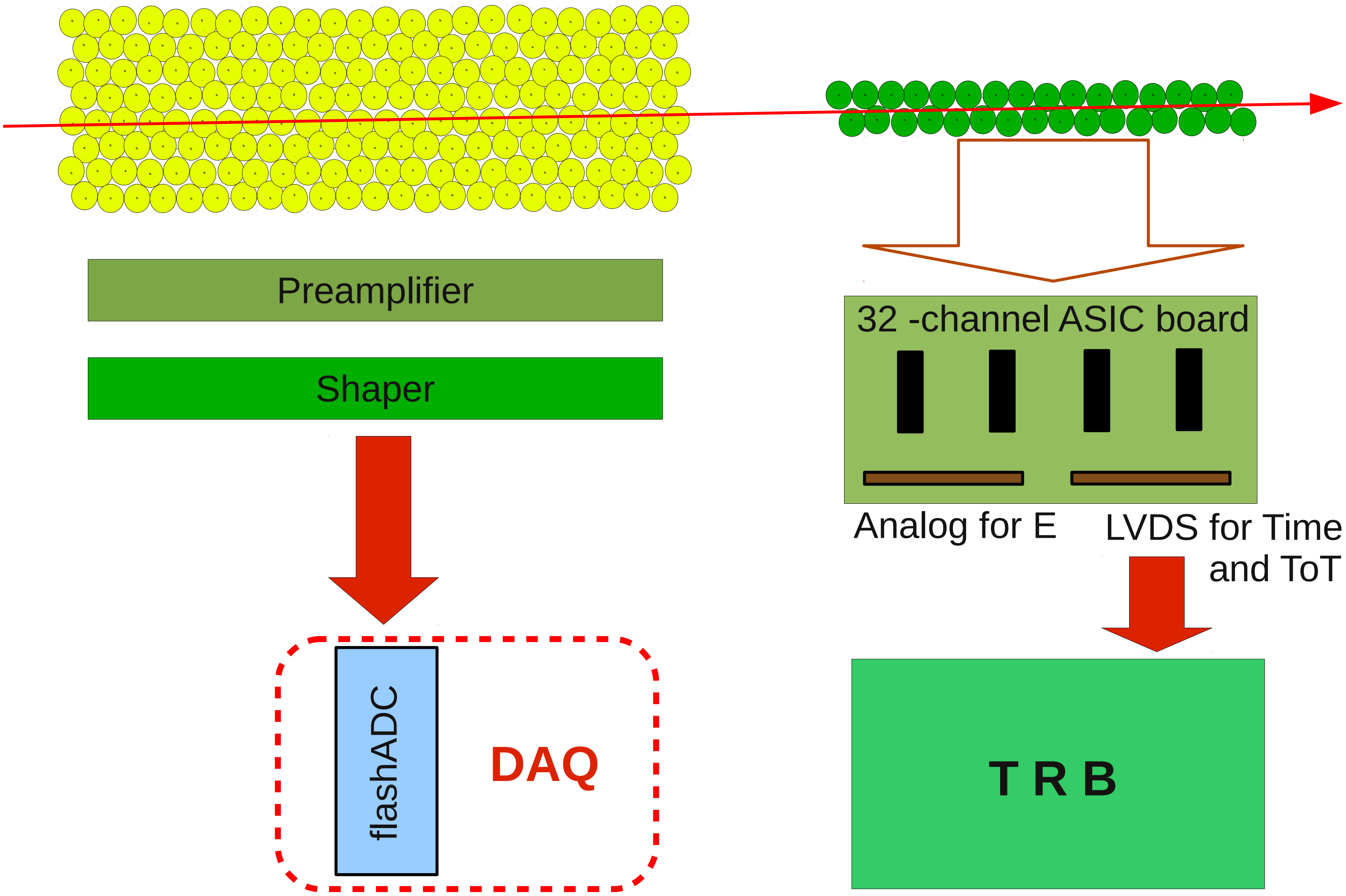
   Digitizer: Trigger and Readout Board with on-board DAQ (TRB)

   AGH University + Jagiellonian University Kraków (Poland)

2. Signal booster + Shaper + FPGA-FlashADC; fixed optimal integration time, tail cancellation, baseline restoration:
   - time information (from FPGA discriminators)
   - energy information (from FPGA amplitude search procedure)

   FZ Juelich (Germany) + INP PAN Kraków (Poland)

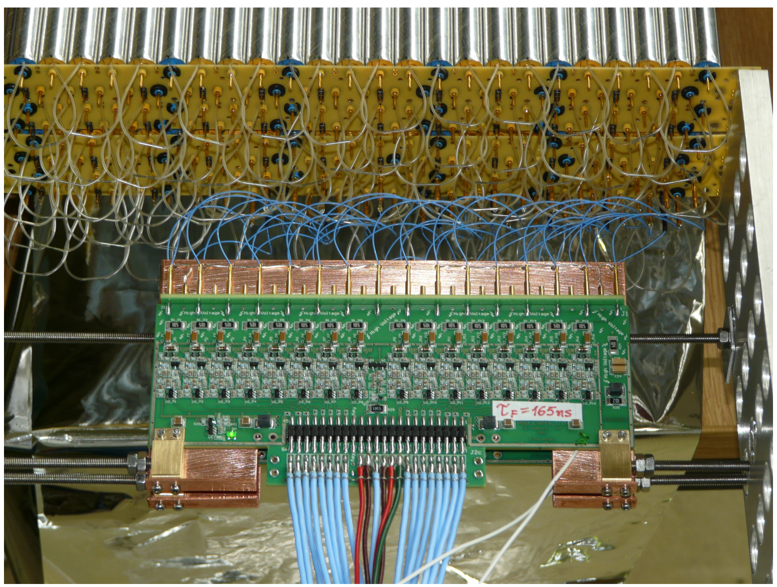
Recent test of STT FEE test at COSY proton beam



Time + Energy oriented FEE

Signal booster

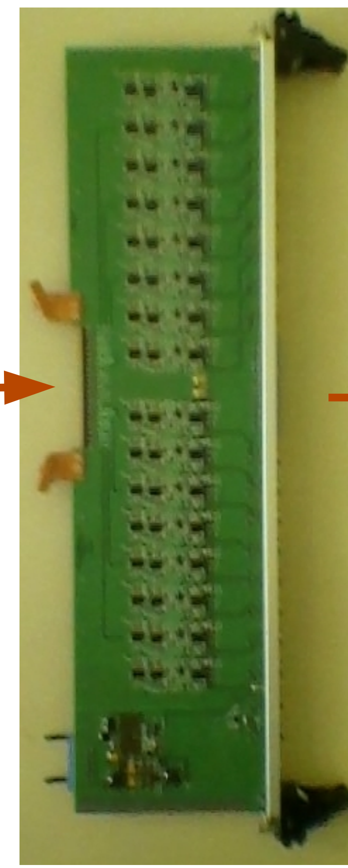
Low power charge sensitive
Preamplifier (installed at detector)



up to 5 m

Shaper

Tail cancellation & BLR



FPGA flashADC

K. Pysz

Time + Energy oriented FEE

Signal booster

16-channel charge preamplifier:

- input impedance adjusted to straw impedance;
- 2 stages:

- **integration amplifier,**
- **voltage amplifier (gain factor 4).**

Shaper

16 channel shaping amplifier:

- differential input amplifier (gain 1.4);
- signal tail cancellation;
- three integration stages;
- baseline restoration circuit at last integration stage.

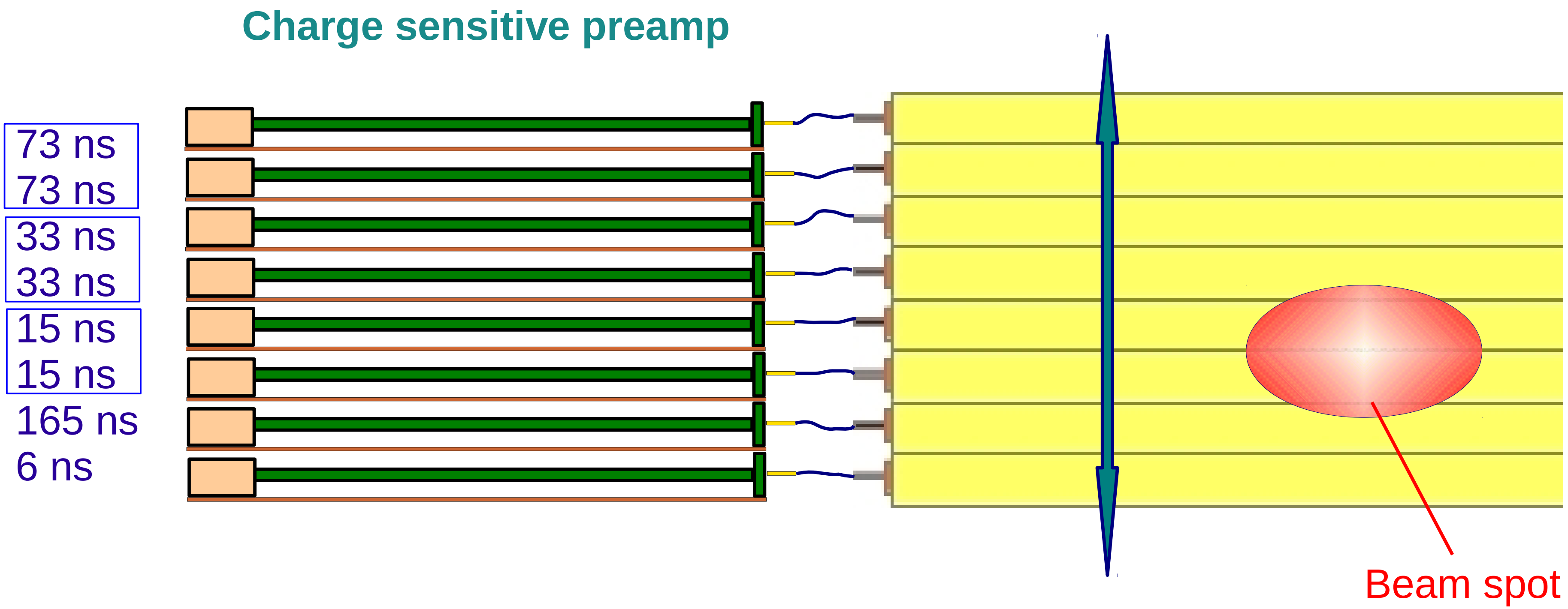
Total gain of each channel of whole system: 2.3 mV/fC
Noise level (peak-to-peak): 2 fC

Intermediate signal transmission: concentric cable up to 5 m long

8 prototypes installed and tested at proton beam together with PANDA STT prototype. Available integration constants τ : 6-, 15-, 33-, 73-, 165 ns.

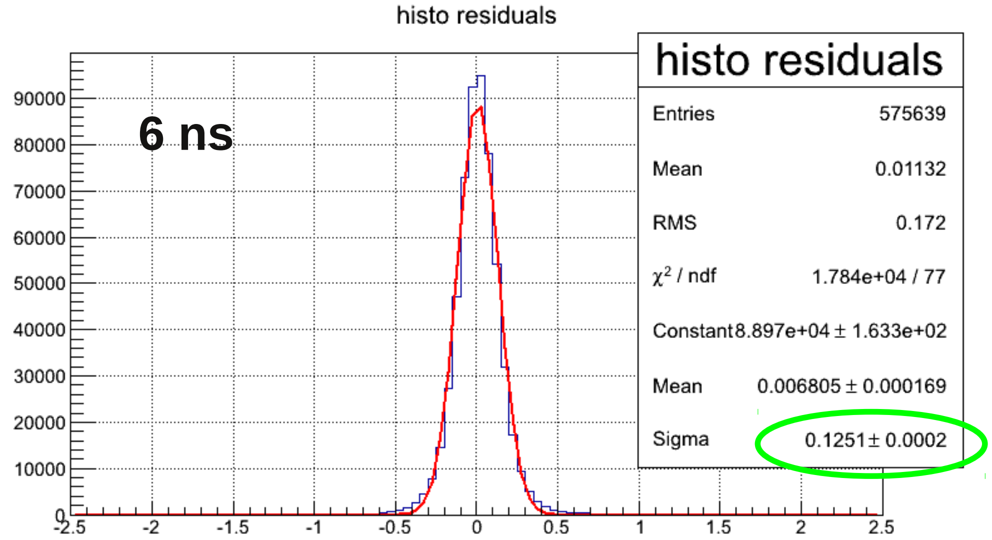
Search for optimal integration time of the system allowing simultaneous precise measurement of time and energy.

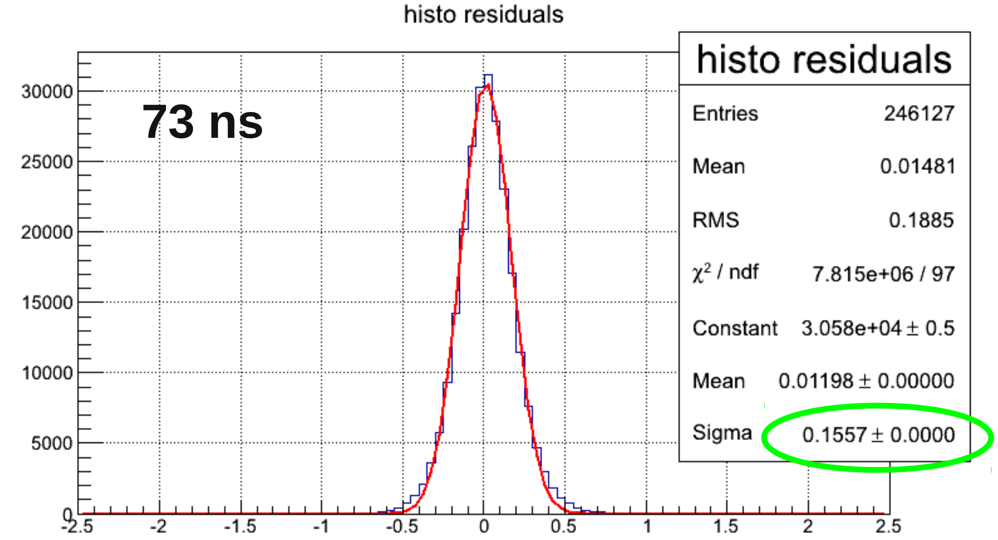
Testing of various integration times

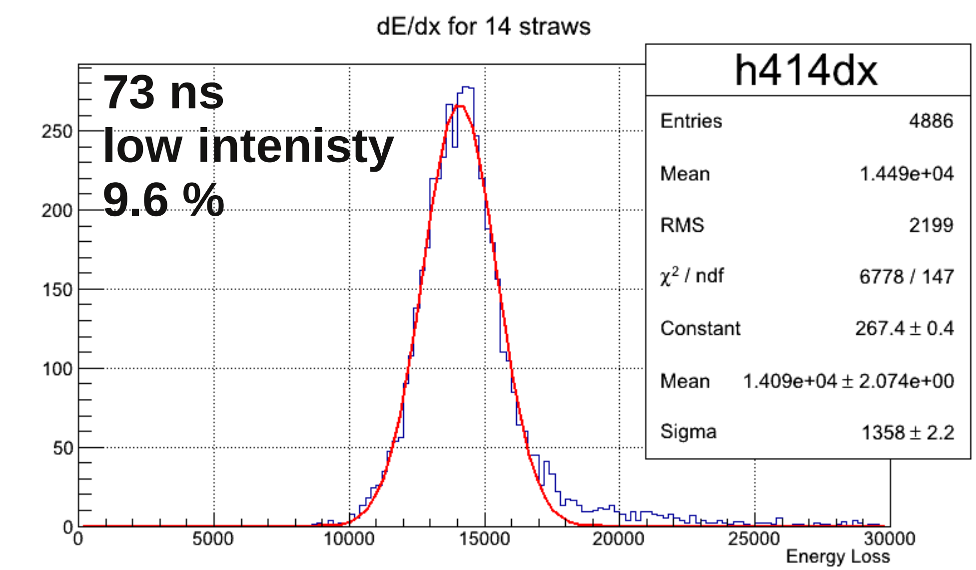


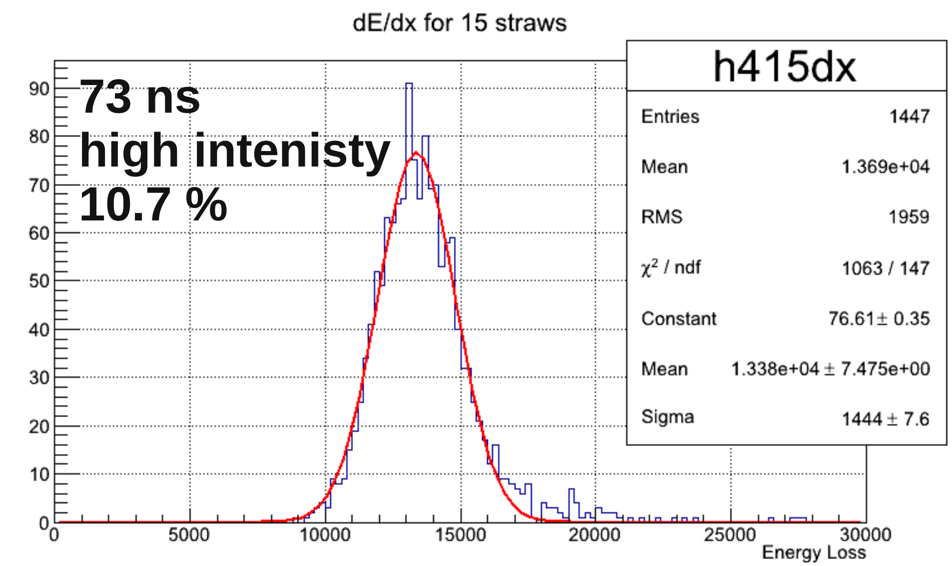
Tracking and analysis of data sets for different time constants
→ time resolution
→ energy resolution

Energy- and position resolution







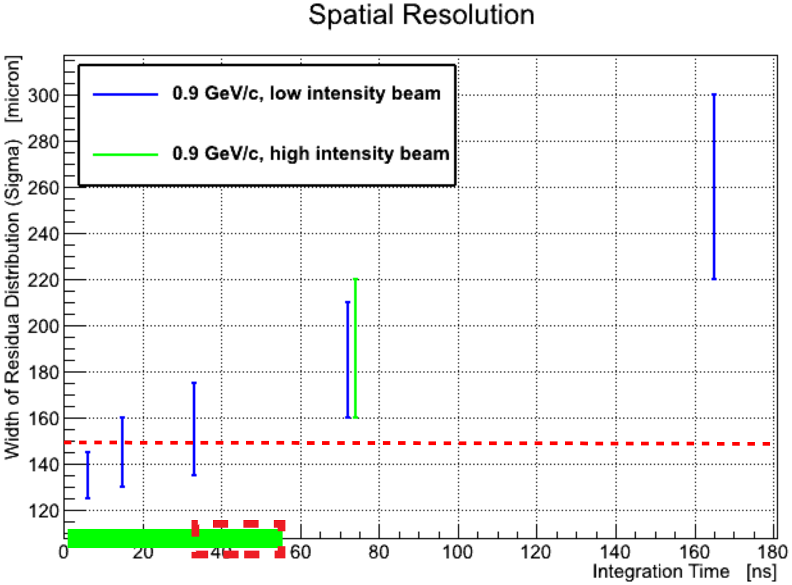


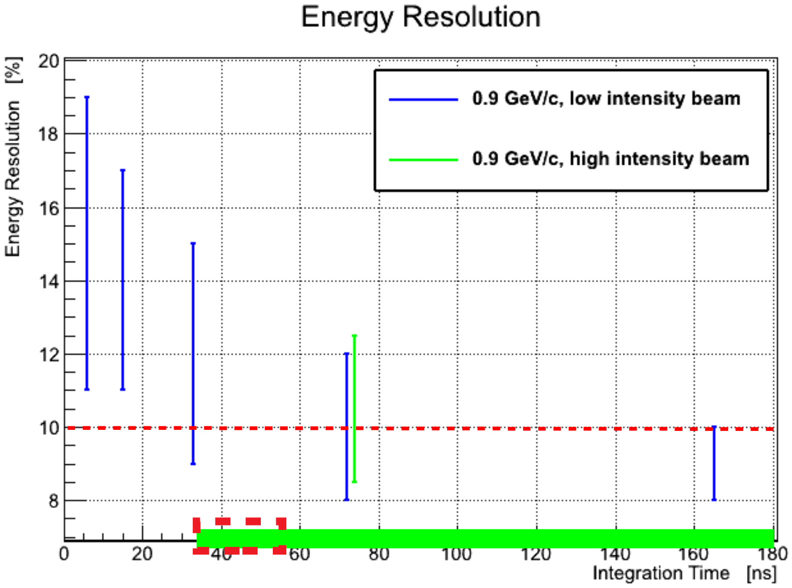
Spatial- and Energy resolution

Spreads of obtained results origin from various gas amplification, threshold levels, discriminator type, track length, ….

Demanded spatial resolution: < 150 µm
Demanded energy resolution: < 10 %

With signal integration constant of 40 – 60 ns simultaneous and sufficiently precise energy- and position resolution is feasible.





Tests of ASIC

Very useful information about ASIC properties and its operation were gained.

They will have impact on the design of version 2 of ASIC.

Dedicated meeting was held in Kraków on 28.02-1.03.2013 (→ see Paola's talk).

Data analysis is ongoing.

Conclusions

1. Capability of STT of measuring simultaneously and precisely time and energy was demonstrated.

2. Integration of STT output signals over 40- 60 ns assures required spatial resolution as well as demanded for PID energy resolution.

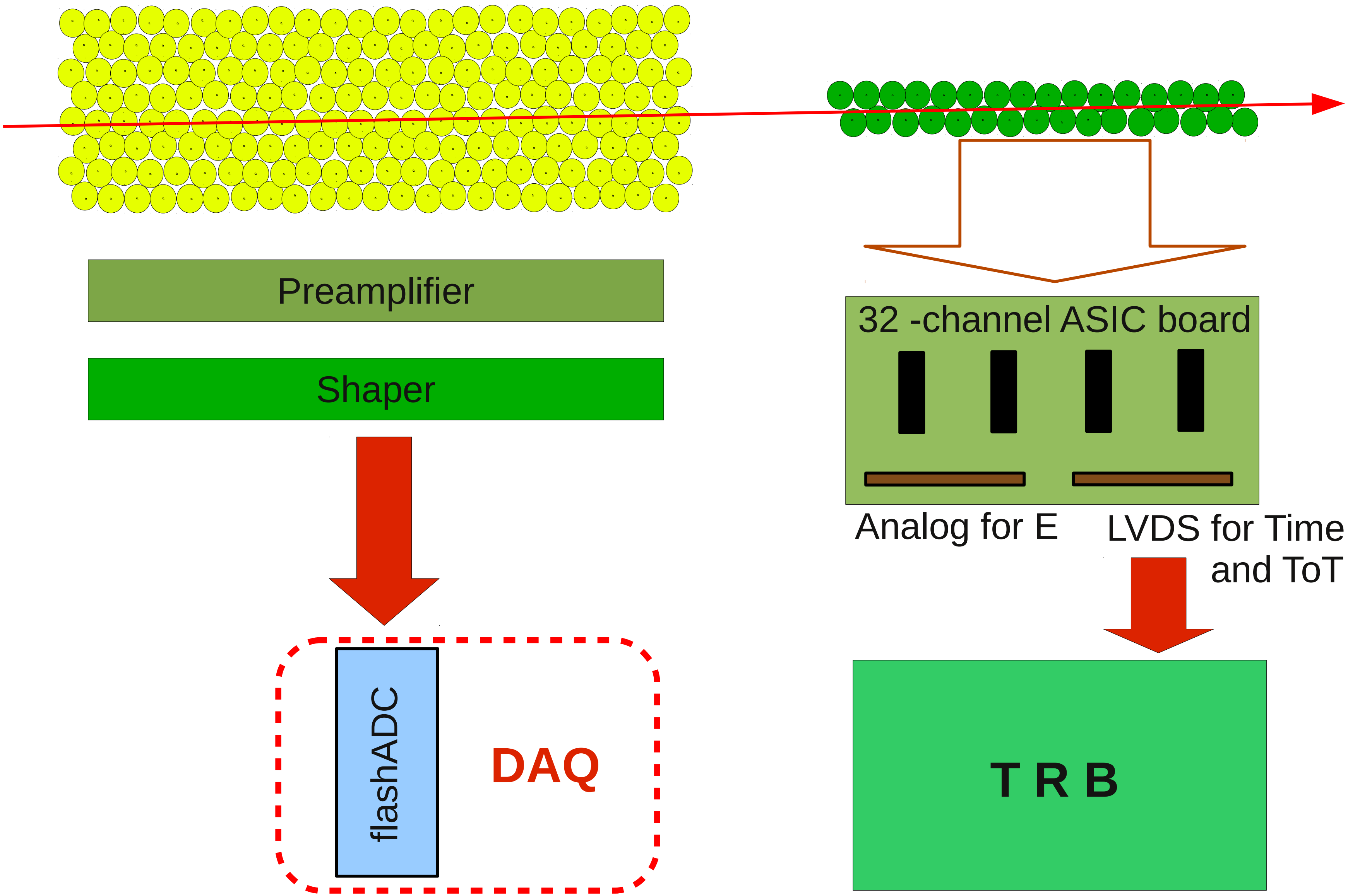
3. The results of the test with the use of shaping FFE are consistent with those obtained earlier for the current amplifier.

4. Energy measurement by means of Time over Threshold (ASIC) is under examination.

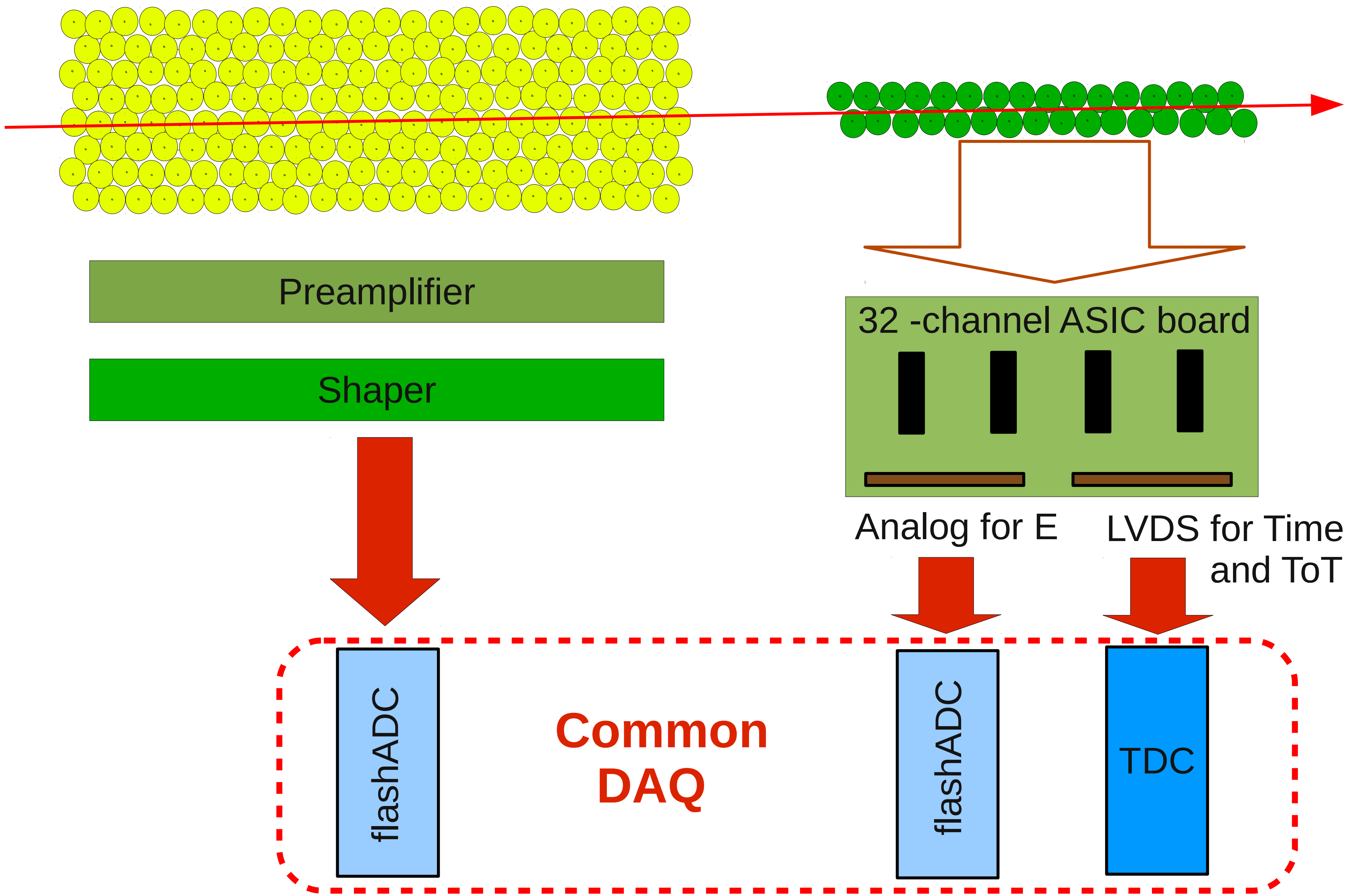
Thank you !

Backup slides

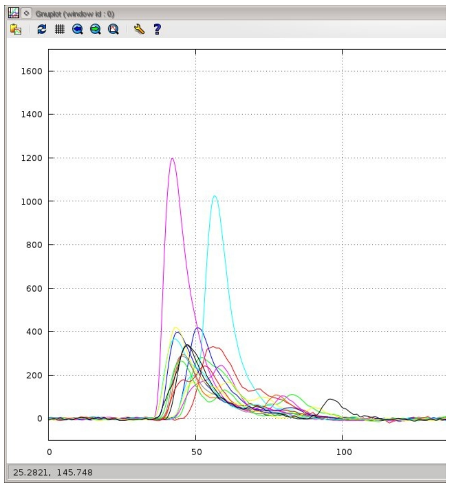
STT FEE test at COSY proton beam during September FAIR week



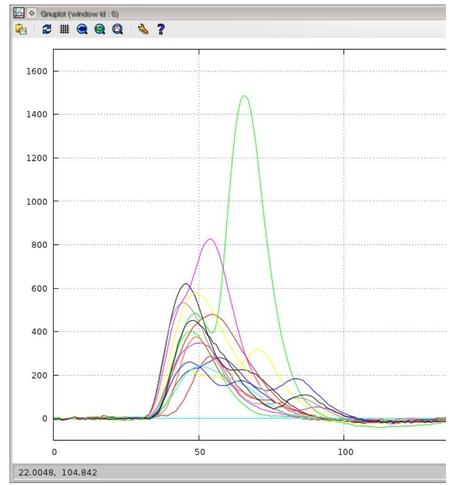
STT FEE test at COSY proton beam during September FAIR week



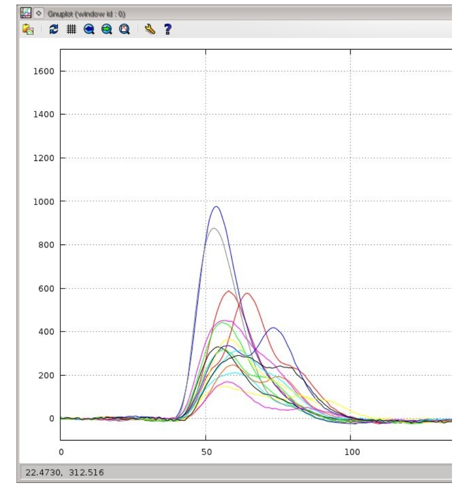
Signals



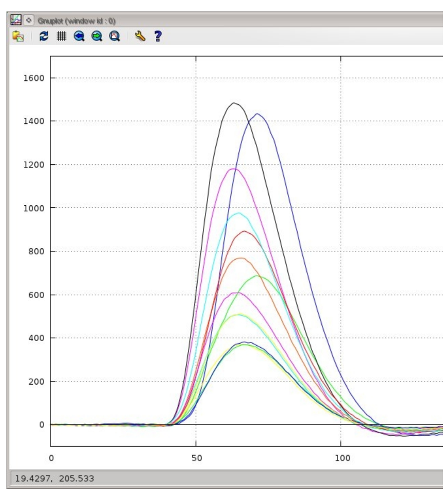
6 ns



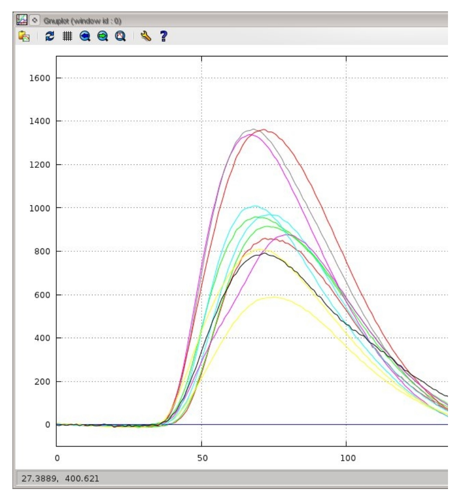
15 ns



33 ns



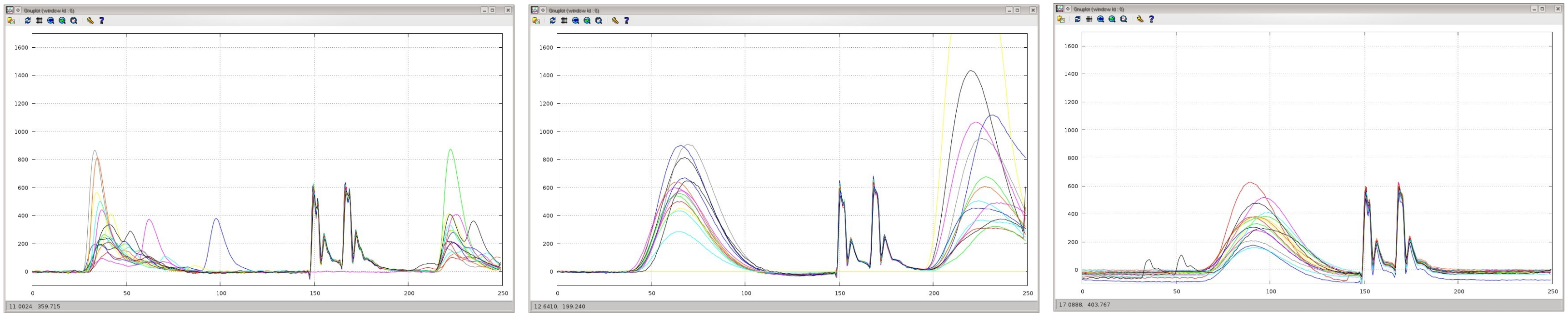
73 ns



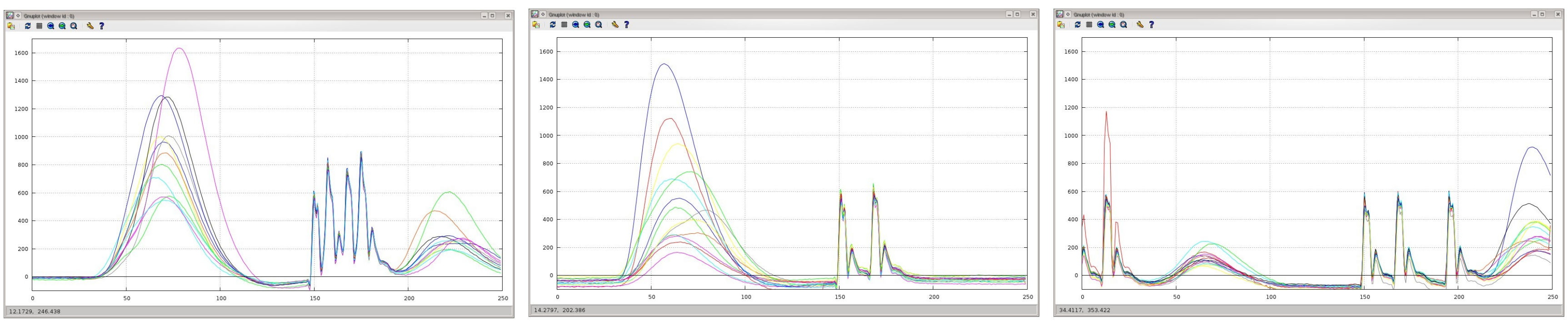
165 ns

Stability of baseline

Low beam intensity



High beam intensity



Both for low beam intensity as well as for high beam intensity there are few percent of events with shifted baseline. This effect comes from baseline determination in fQDC. Correction of the baseline is usually possible and easy.

Precision of the timing

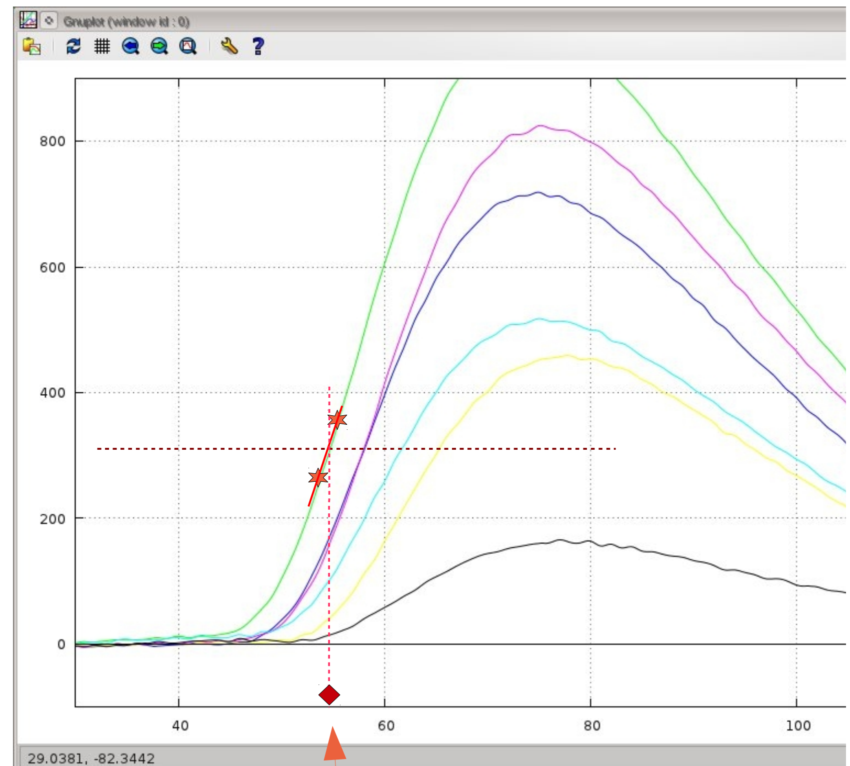
Leading Edge Discriminator:

straight line fitted to closest 2 samples around intersection with selected level.

Calculation of the exact time of intersection.

Constant Fraction Discriminator:

same technique but at selected fraction of signal amplitude.

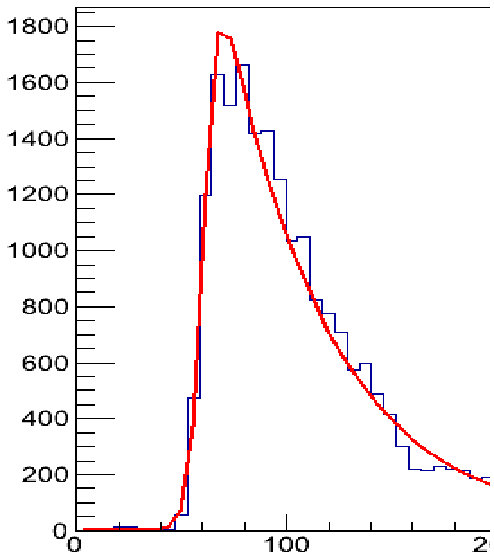


time with precision better then 1 sample

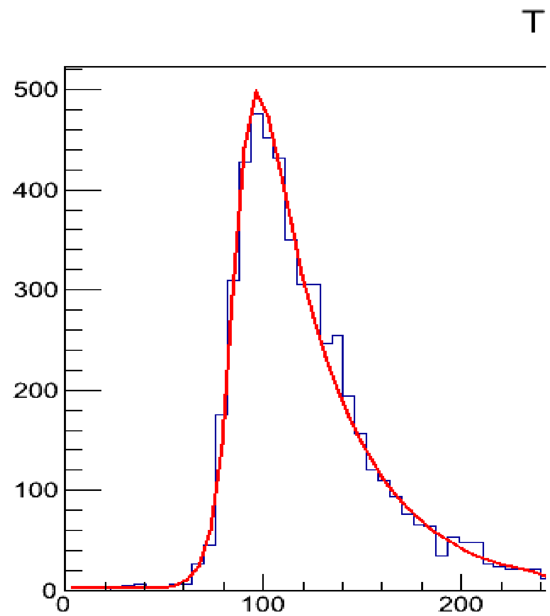
Tracking

Out of sorted events the drift time spectra are produced. They have already reasonable length.

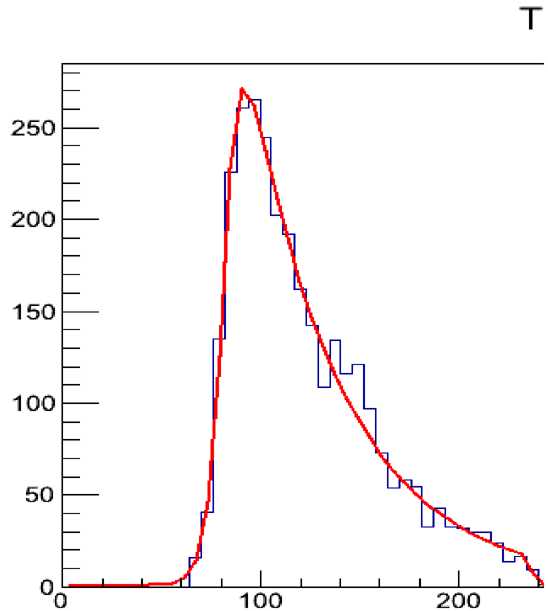
Envelope function is fitted to the drift time spectra. It is carefully checked if the rising slopefor each of drift time spectrum is correctly fitted. Only then correct t_0-s are obtained.



6 ns



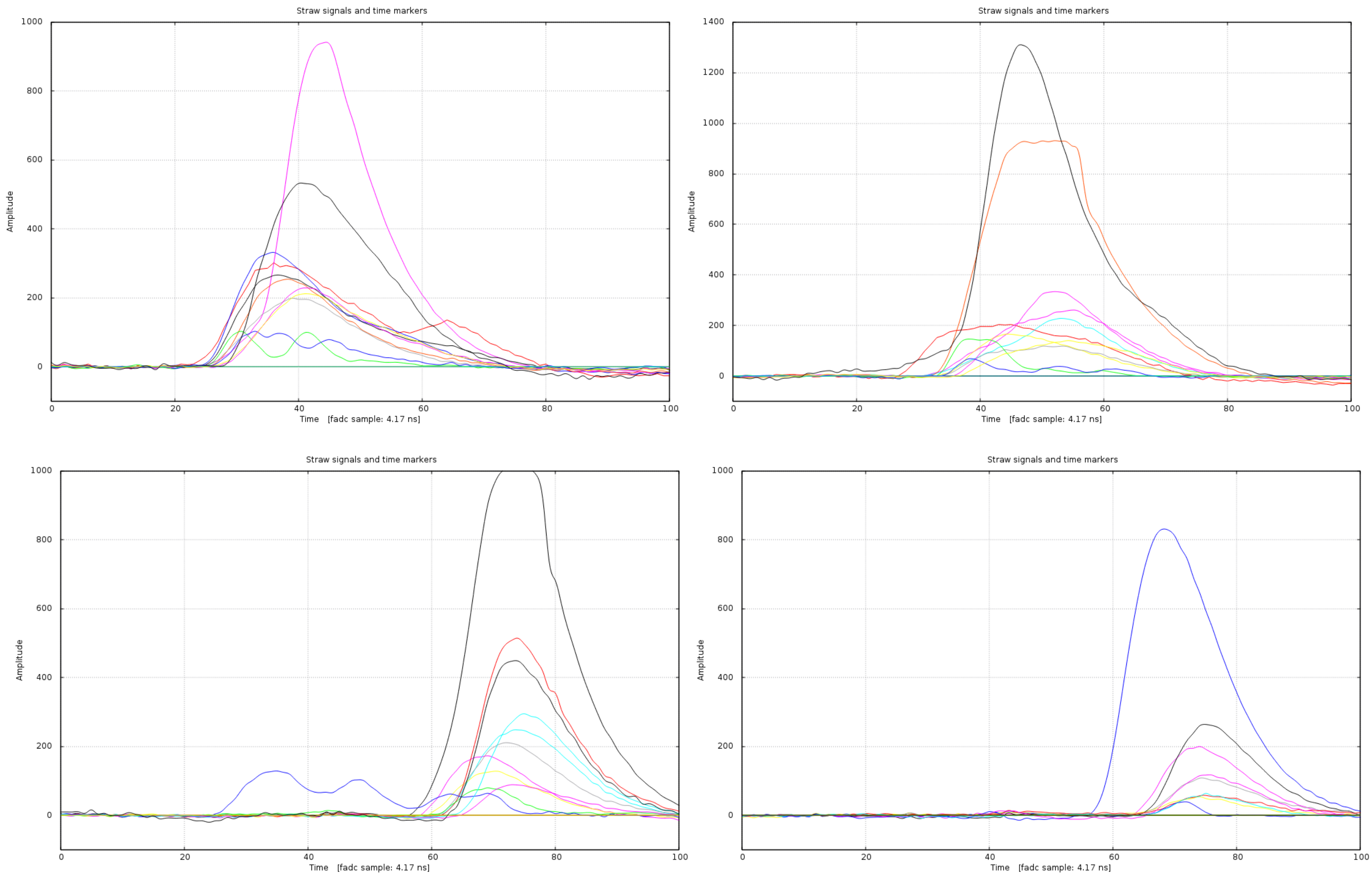
73 ns



165 ns

Garfield simulated time – radius calibration curve used for hit position calculation

ASIC analog signals (FlashADC)

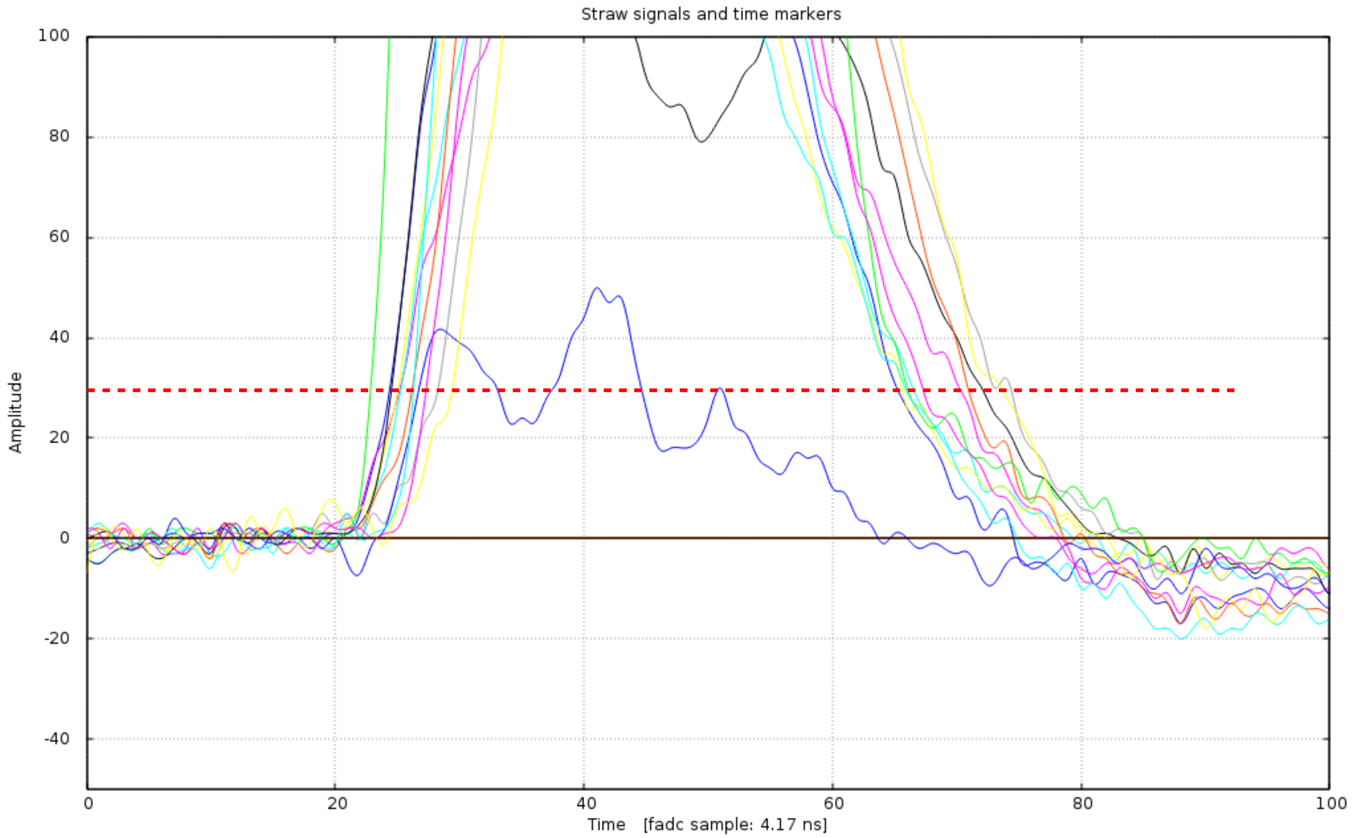


K. Pysz

Time information from ASIC

Timing for analog signals:

Leading Edge Discriminator



Aim: selection of the optimal integration time of the shaper allowing for required timing resolution as well for sufficient energy resolution

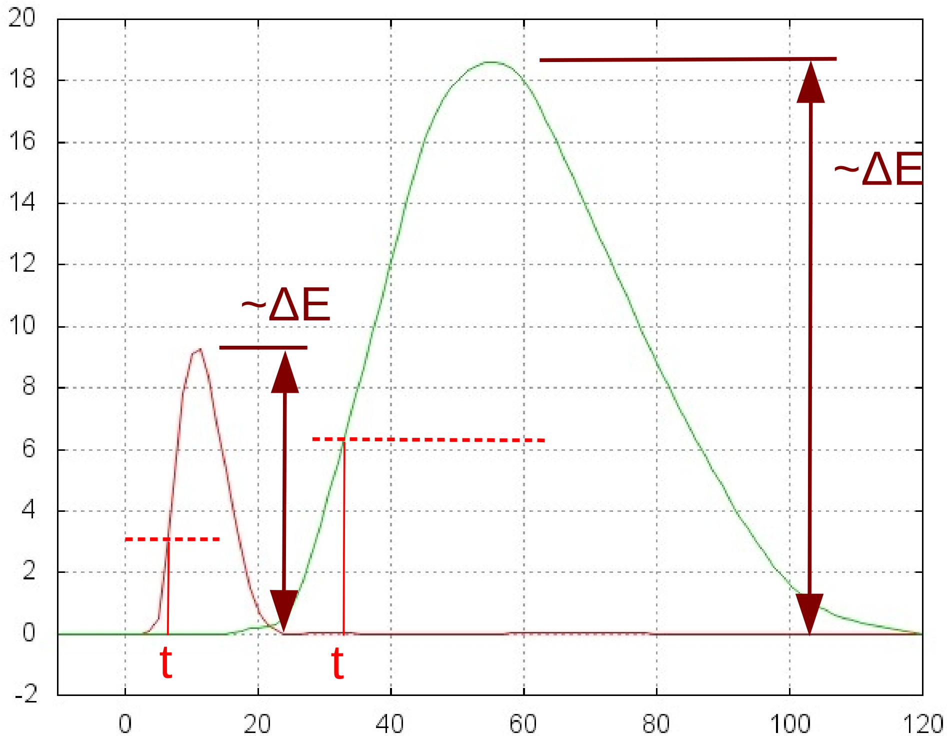
Available shapers

τ: Proper work up to:

6 ns	(6 MHz),
15 ns	(4 MHz),
33 ns	(3 MHz),
73 ns	(2 MHz)'
165 ns	(1.3 MHz)

FPGA Const. Fraction Disc.: ~ 1 ns

FPGA analysis



τ_1 τ_2