Constant Fraction Discriminator for NA62 experiment at CERN

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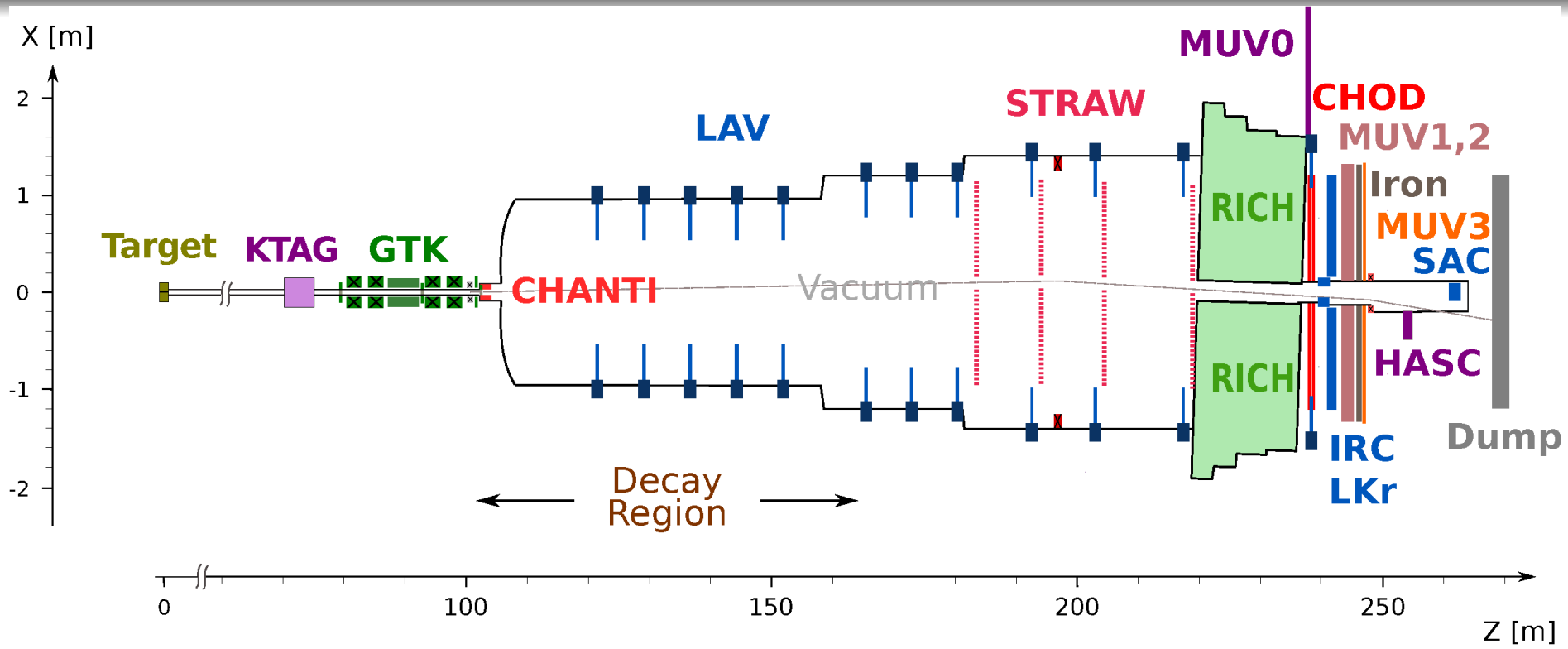
NA62 Detector at CERN



SPS Beam:

- 400 GeV/c protons
- 1.9×10^{12} p/spill
- 3.5 s spill
- $\sim 10^{18}$ POT/year

Secondary beam:

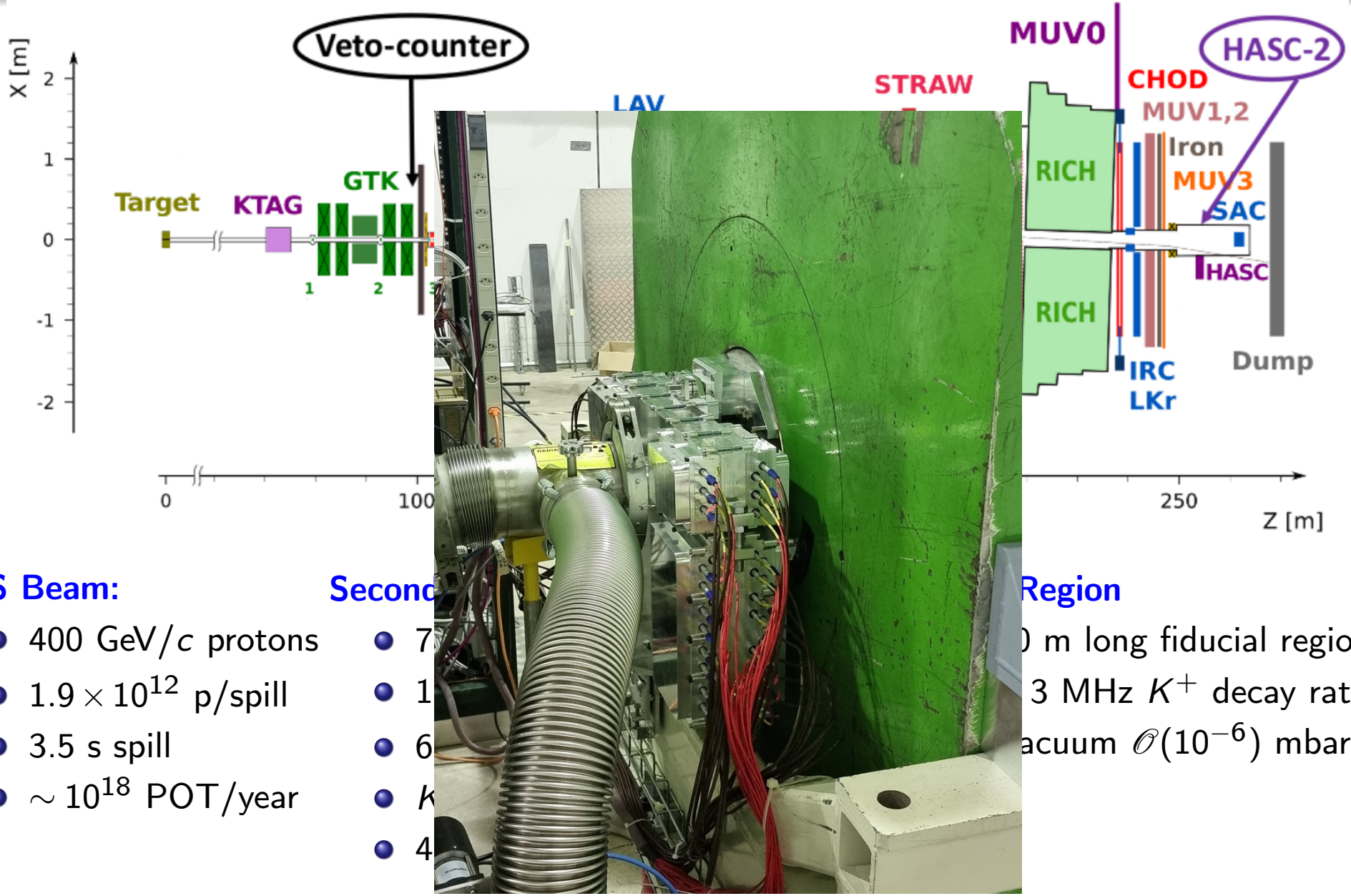
- 75 GeV/c momentum, 1% RMS
- 100 μrad divergence (RMS)
- 60×30 mm^2 transverse size
- $K^+(6\%)/\pi^+(70\%)/p(24\%)$
- 450 MHz of particles at GTK3

Decay Region

- 60 m long fiducial region
- ~ 3 MHz K^+ decay rate
- Vacuum $\mathcal{O}(10^{-6})$ mbar

[The NA62 Collaboration, JINST 12 (2017) P05025]

NA62 Detector at CERN - VetoCounter



SPS Beam:

- 400 GeV/c protons
- 1.9×10^{12} p/spill
- 3.5 s spill
- $\sim 10^{18}$ POT/year

Second

- 7
- 1
- 6
- K
- 4

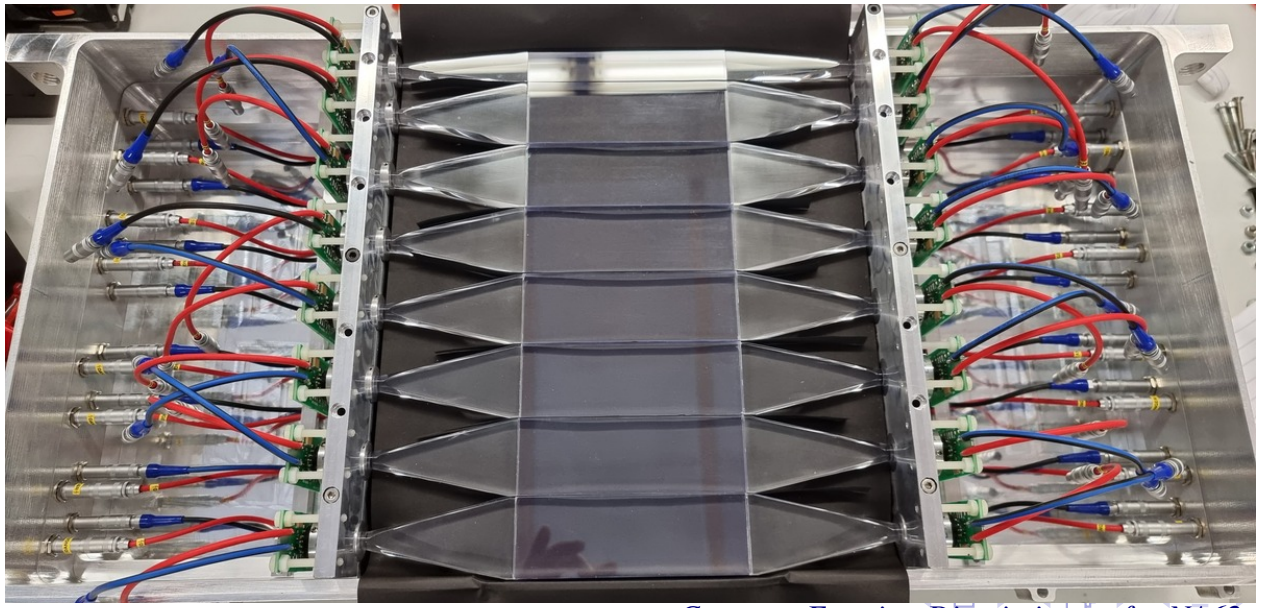
Region

-) m long fiducial region
- 3 MHz K^+ decay rate
- acuum $\mathcal{O}(10^{-6})$ mbar

[The NA62 Collaboration, JINST 12 (2017) P05025]

Motivation - VetoCounter detector for NA62 experiment

- NA62 experiment @CERN is doing precision measurements with Kaons
- One of the main limitations is a background from decays happening upstream of the fiducial volume
- A detector made of scintillating tiles with precise timing was proposed to detect particles from these upstream decays
- It should be able to detect charged particles (MIPs) and also photons (lead block converter)

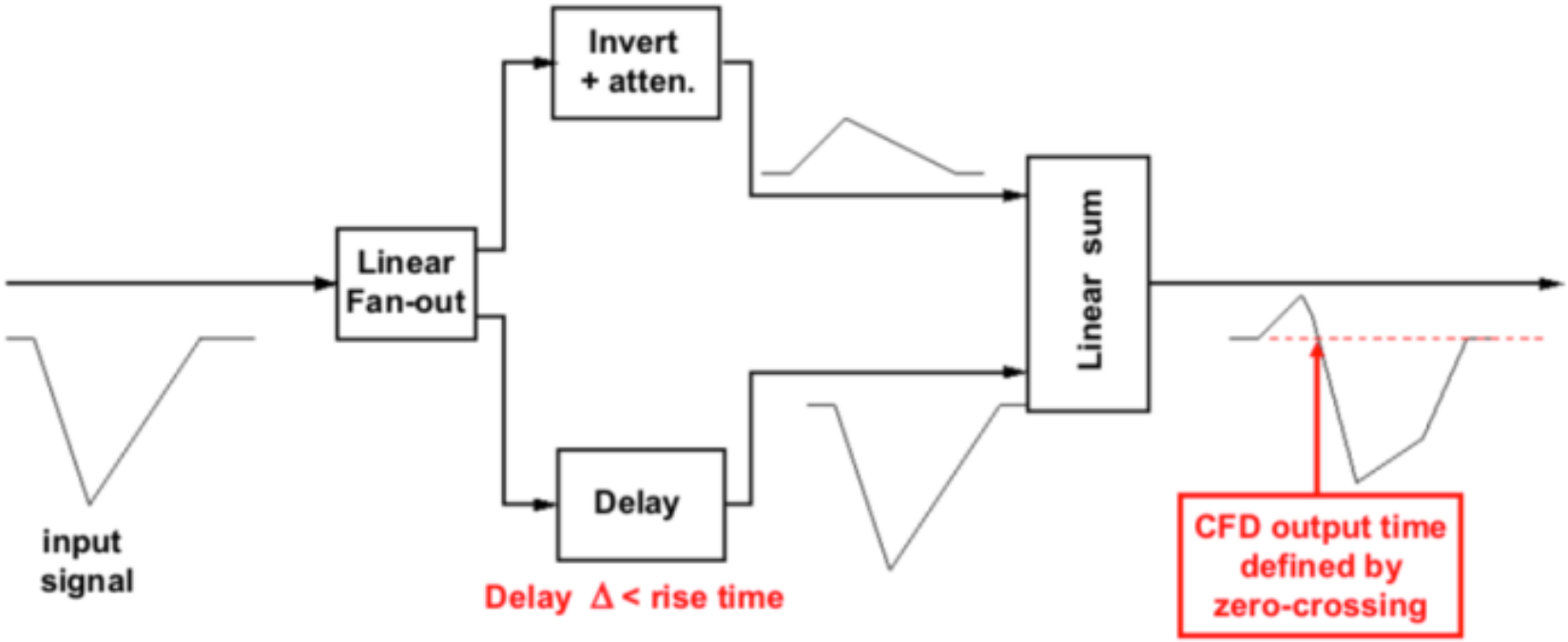


Detector requirements

- Analogue signal processing from fast PMTs attached to the scintillator - rise time around 1 ns
- Time resolution of the detector better than 200 ps
- Wide dynamic range of 1:30 of input signals
- Processed signal suitable for fast digitization in TDC
- Two Time-over-Threshold (ToT) measurements with different thresholds
- Standard leading edge discriminator timing performance suffers from time walk caused by varying signal amplitude while threshold is fixed
- Solution: Constant Fraction Discriminator (CFD) - eliminates the time walk by introducing variable threshold that follows the signal amplitude

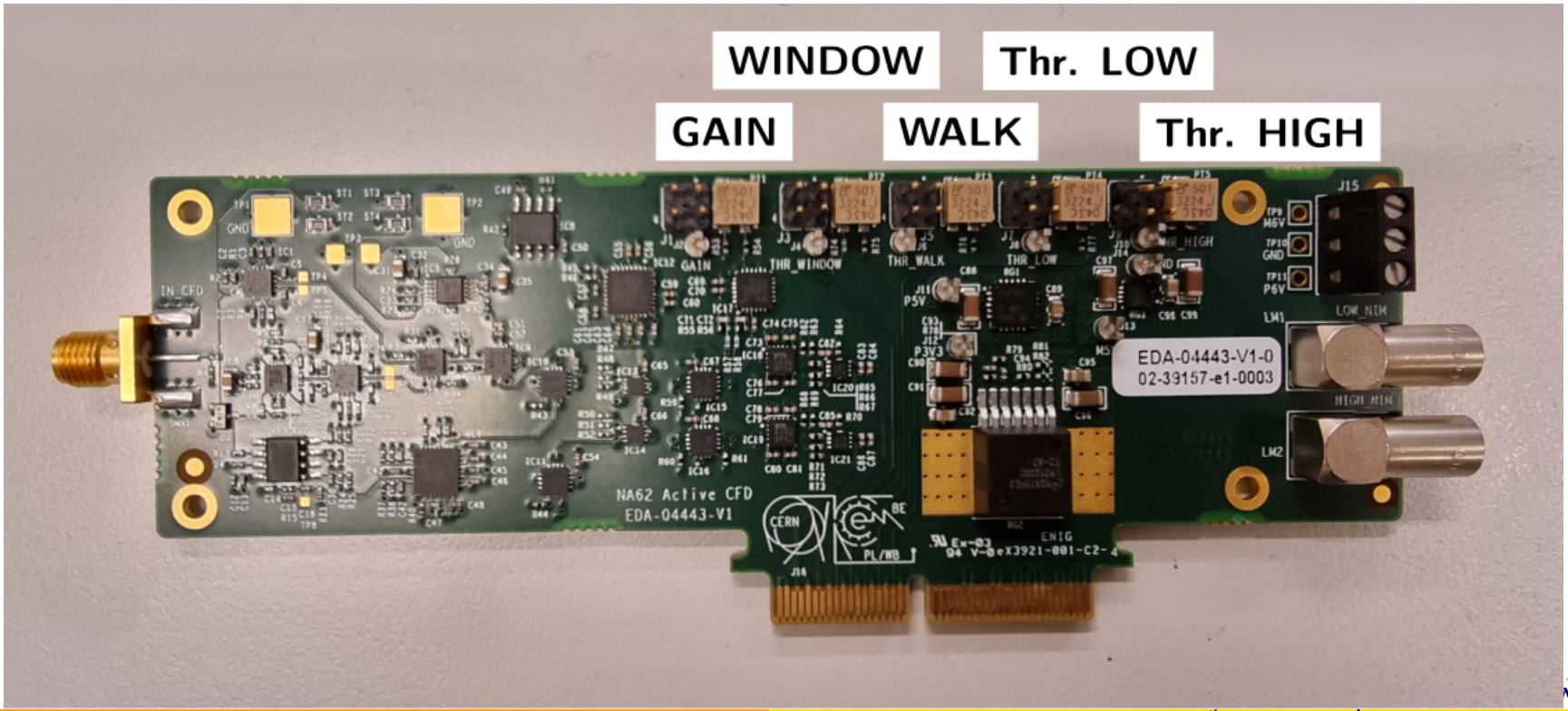
CFD functionality - reminder

- The constant fraction of input signal is subtracted from full amplitude delayed input signal
- In active CFD, the delayed signal is amplified by inverse attenuation ratio - it improves dynamic range and time resolution
- The final signal has a zero crossing point (walk) which is fixed for signals with different amplitudes



New CFD

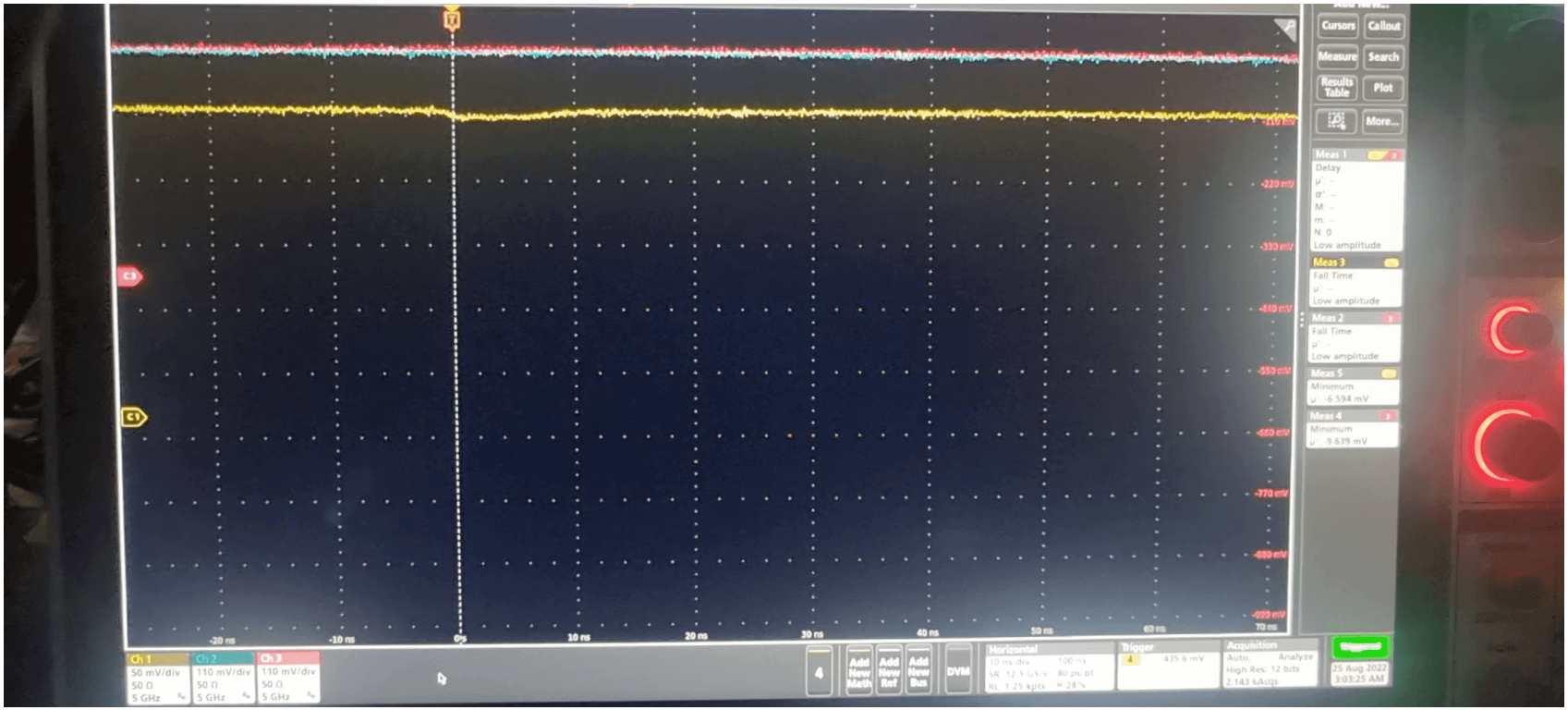
- Five potentiometers to control CFD and provide the "energy measurement"
  - All five parameters can be set either manually on the board, or through the DCS commands - the mode is selected by a jumper position
  - Check of the parameter values returned as a response to set command
- Output of LOW and HIGH thresholds channels
  - Out pulse width represents ToT
  - If the pulse does not pass the threshold its width is fixed (timeout)



CFD control parameters

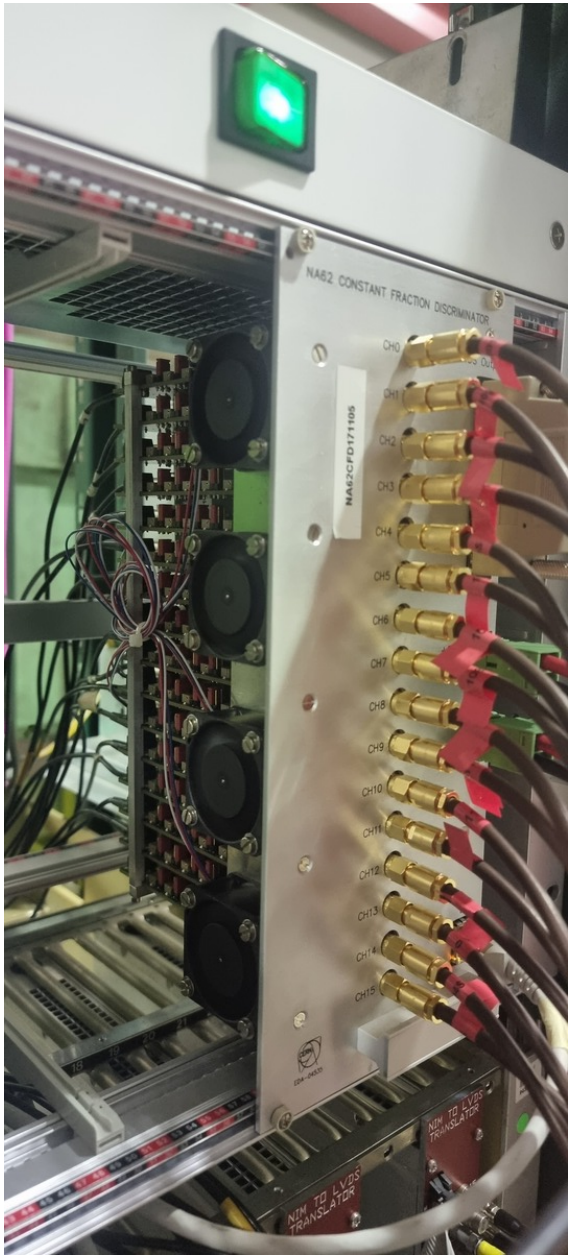
- WINDOW threshold - opens functionality of CFD for duration of the valid signal (prevents oscillations)
- GAIN - characterize the amplification of inverted signal - can be tuned for different input pulse shapes
- WALK - threshold around the zero crossing point after sum of two signal lines
- LOW/HIGH thresholds
  - rising edge defined by CFD time
  - trailing edge depends on the input pulse amplitude
  - width of the output signal represents ToT measurement
  - if the LOW/HIGH threshold not passed, width of the pulse is fixed at 34 ns
  - LVDS and NIM output
- Selectable delay line could be soldered on the prepared pads

CFD demonstration



Motherboard

Standard EURO 6U card



Front panel:

- SMA connectors of CFDs
- LVDS cable socket - collects LVDS outputs for TDC - 32 channels cable with SCSI III connector to TDC
- Power cables
- Ethernet connector for remote communication

Inside:

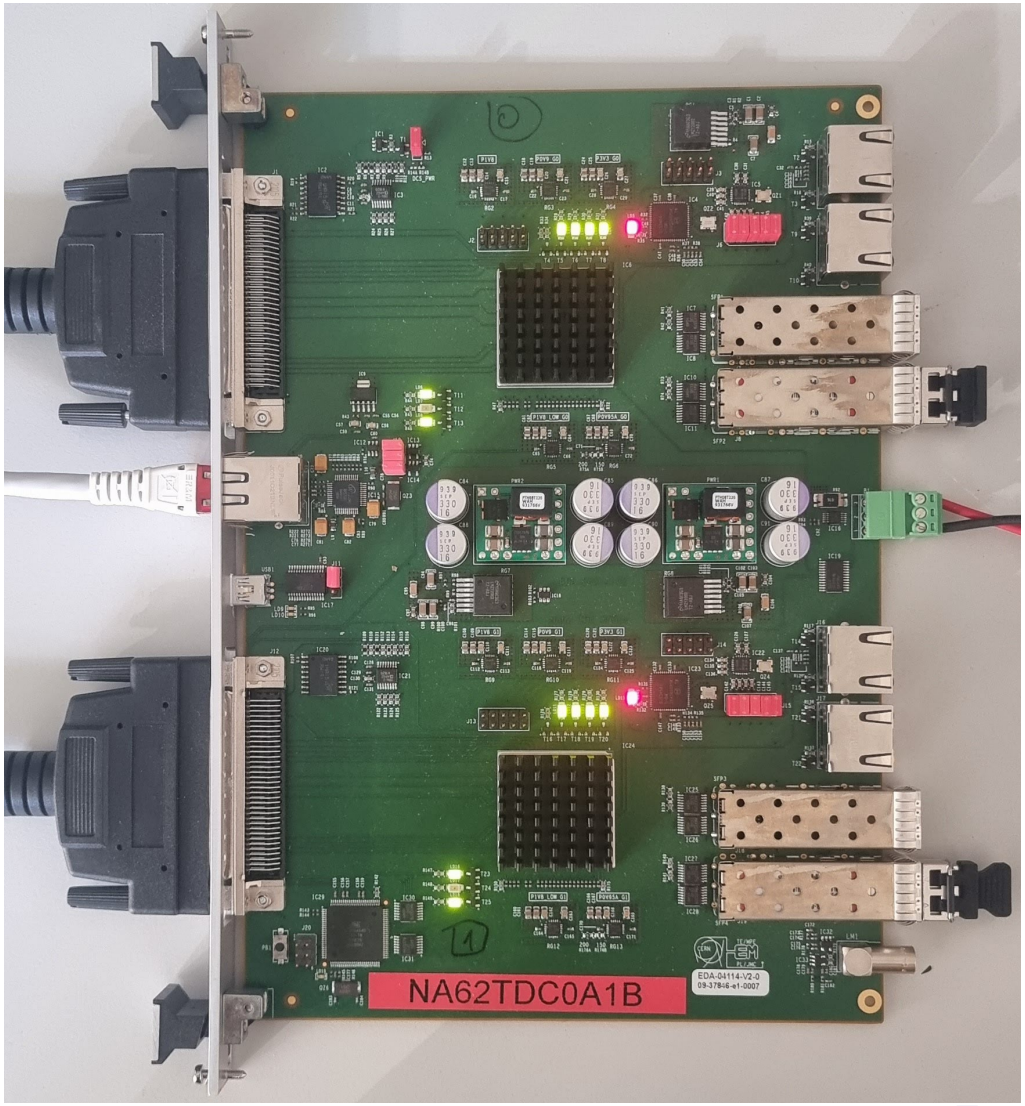
- 16 CFD boards + cooling fans

Back side:

- LEMO connectors for NIM outputs

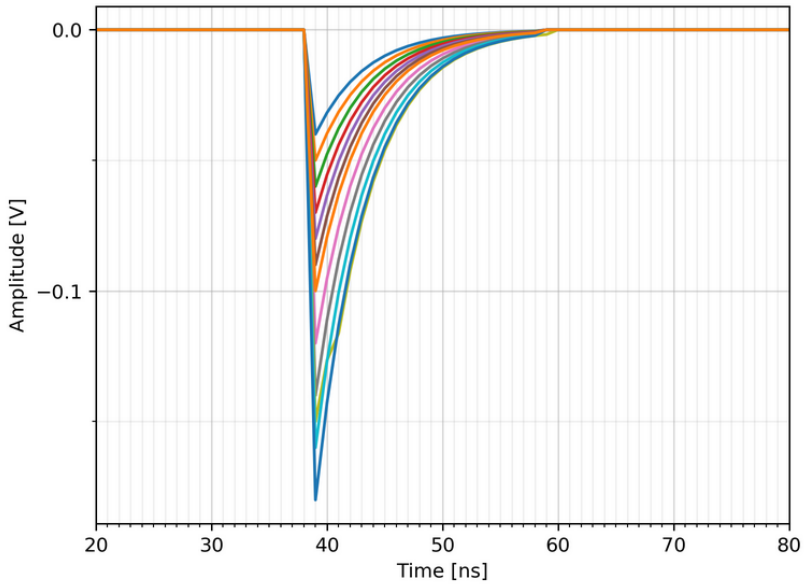
TDC collecting the signals from CFD

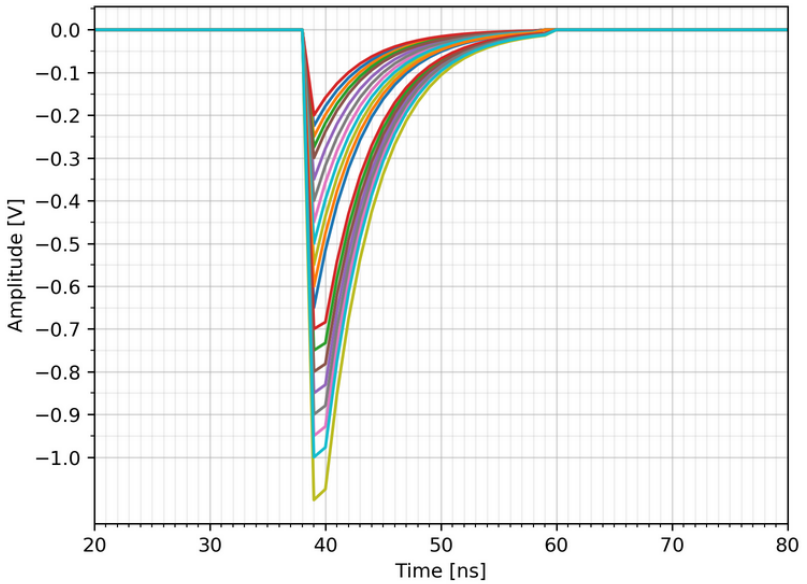
FPGA based TDCs connected via optical links to trigger-less future read-out based on FELIX (ATLAS co-development)



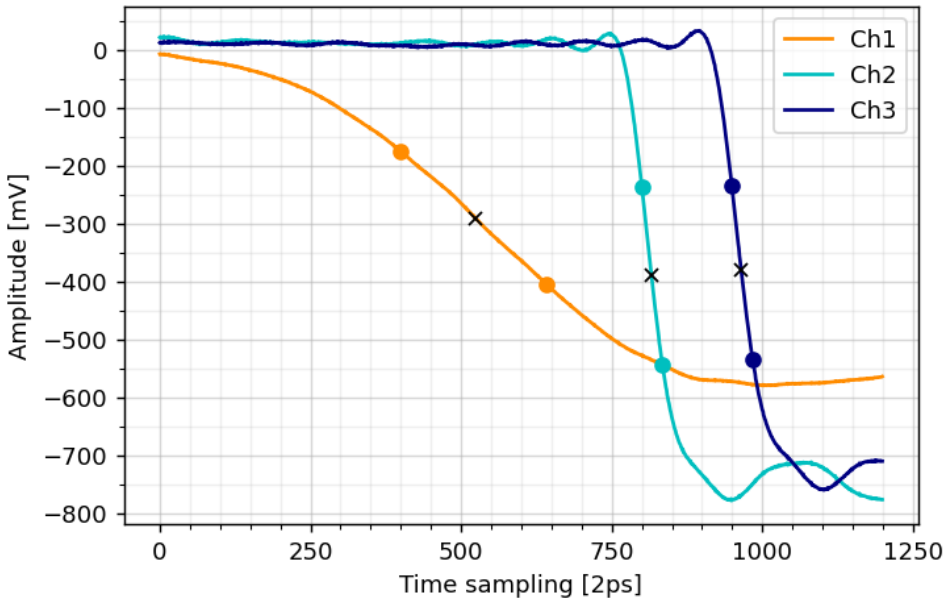
Test of new CFDs in the lab with AWG

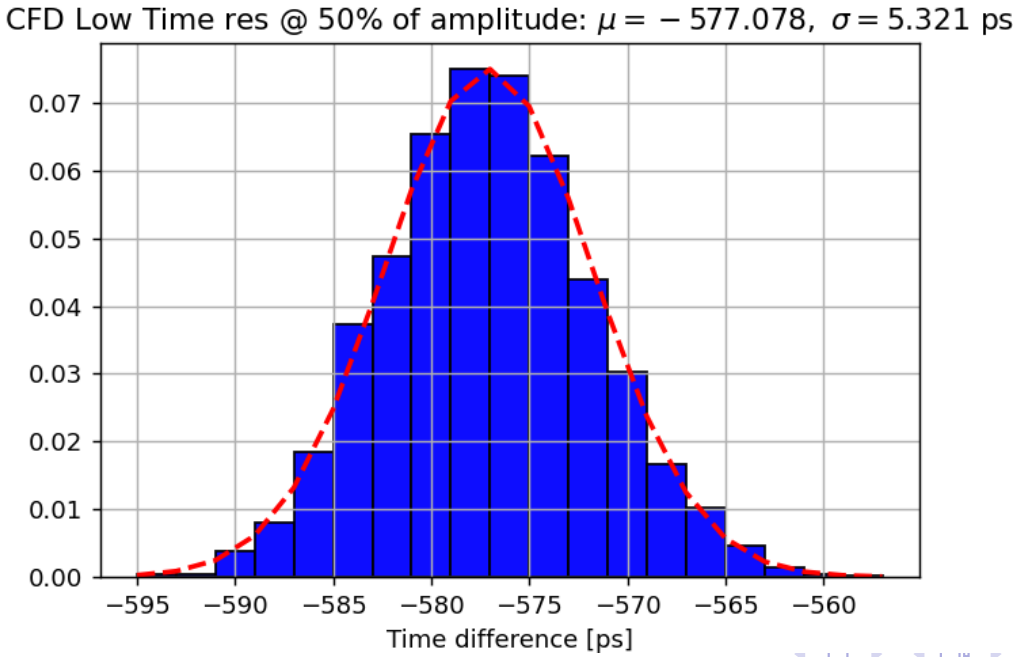
- Arbitrary waveform generator Tektronix AWG5012C
  - two identical output signals and marker used for triggering the oscilloscope
  - one generated signal goes to CFD, one to the scope MSO-64 (2.5GHz, 25GS/s)
- For small amplitudes AWG output connected through the attenuator
- Measuring the time difference between the input and output pulse in 50% of the amplitude
- Varying the pulse height by more than an order of magnitude
- The variation at a given amplitude is just a few ps
- Systematic error due to double AWG output is about 10 ps



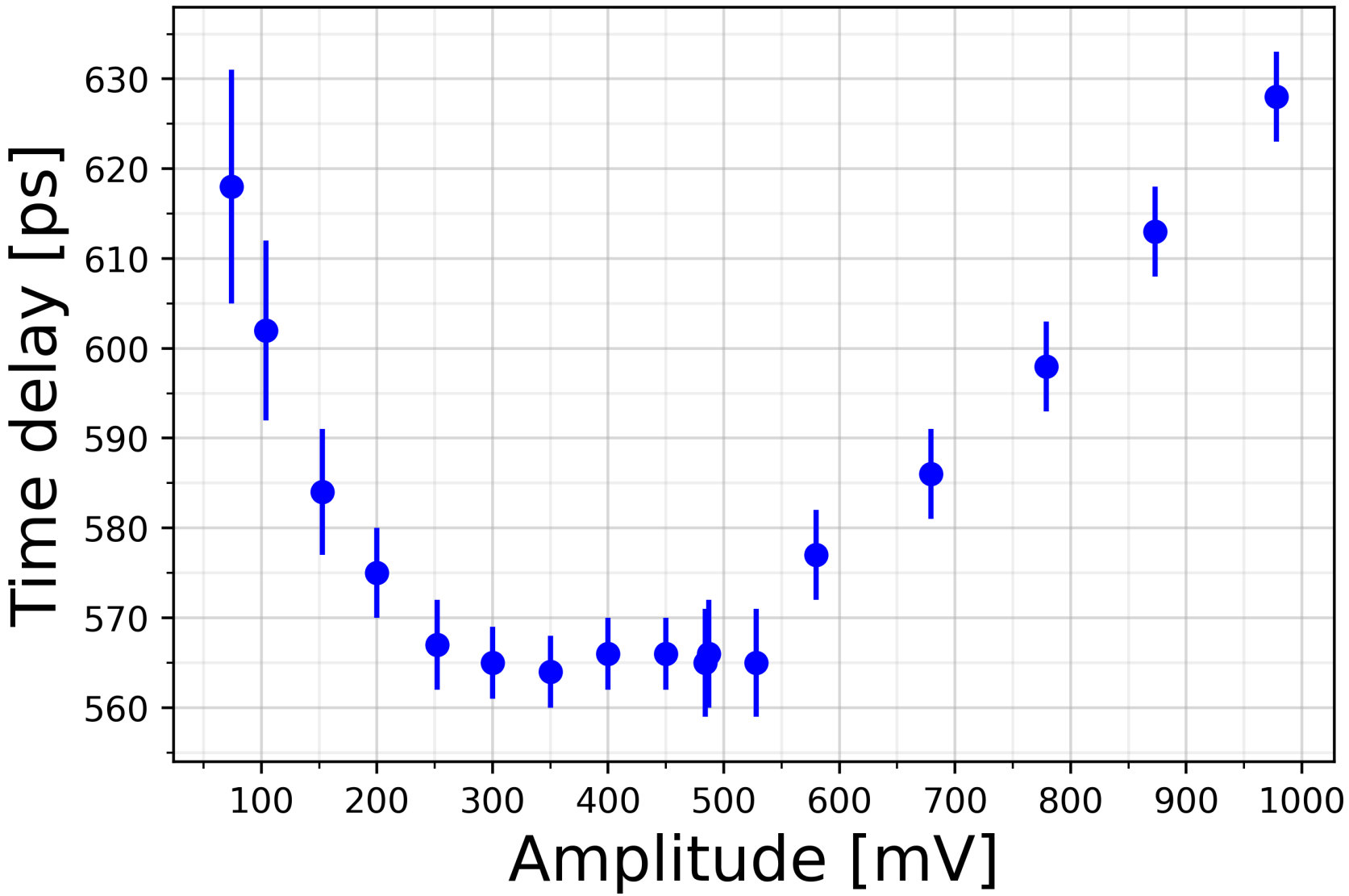


CFD time resolution



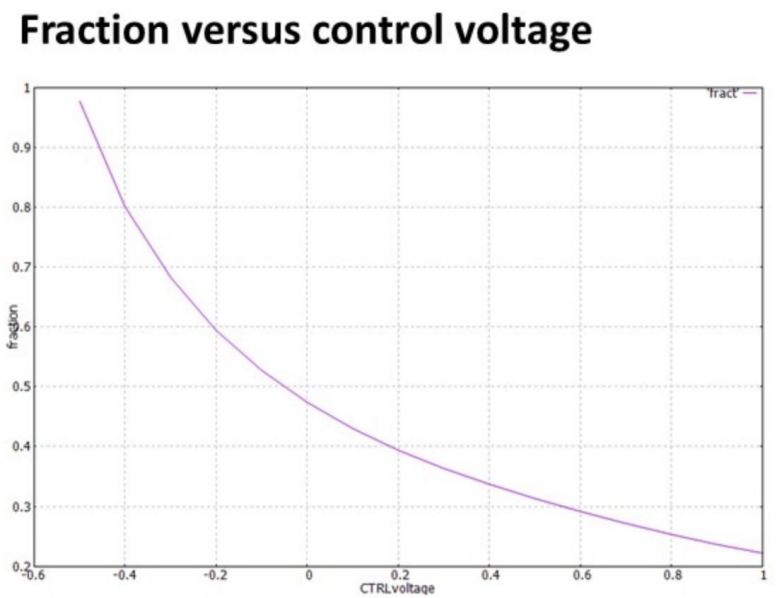


CFD time resolution



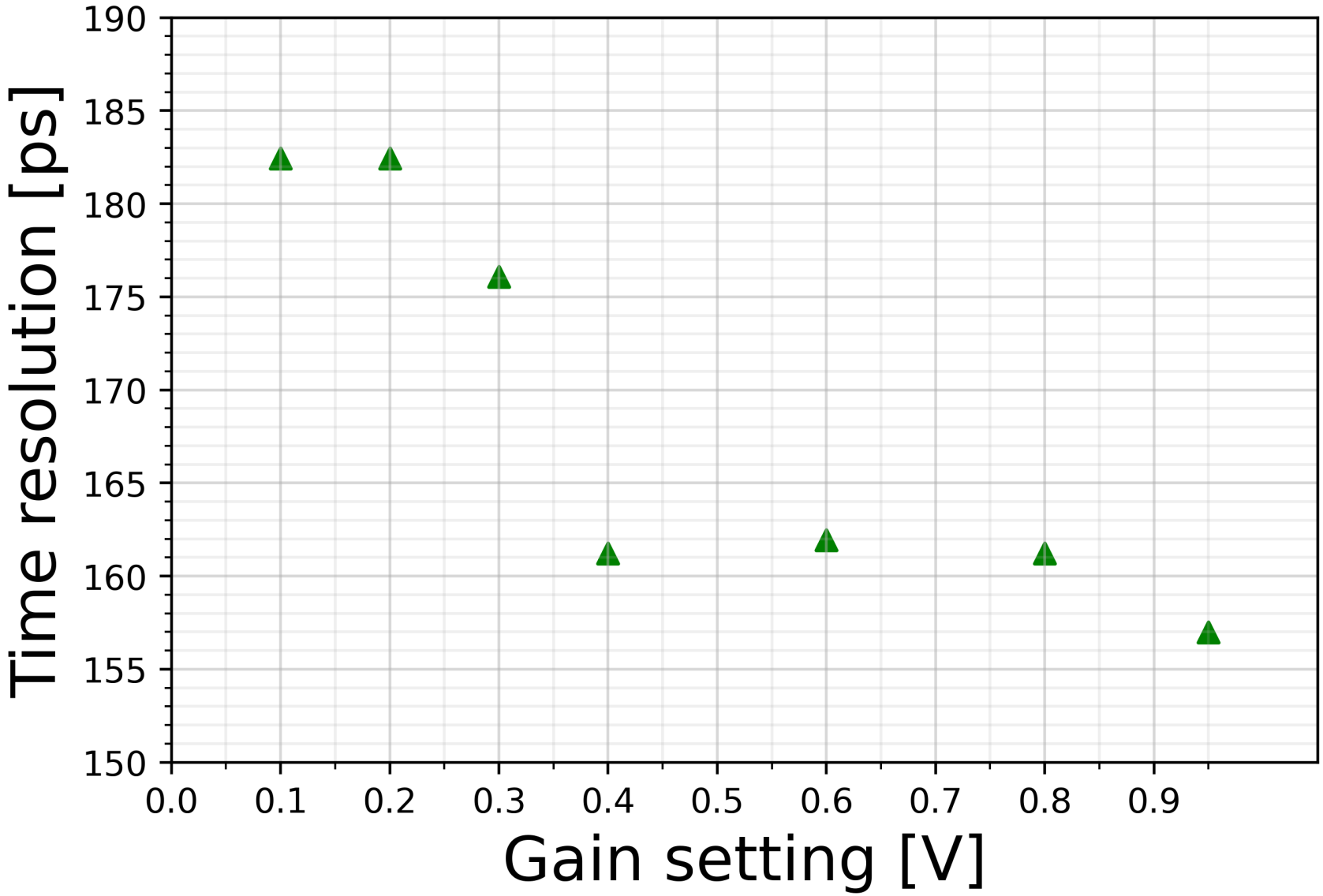
Test of new CFDs in the lab with cosmic rays

- Test setup:
  - 4 tiles (two PMTs each) in the "black box"
  - Two external tiles in coincidence define trigger
  - Signals from the tested PMTs fed through CFD to the oscilloscope
  - Measuring the time difference of rising edges defined by the CFD between internal tiles
- Changing the CFD setting:
  - GAIN from 0.1 to 0.95 V
  - WALK from 0.05 mV to 0.5 V



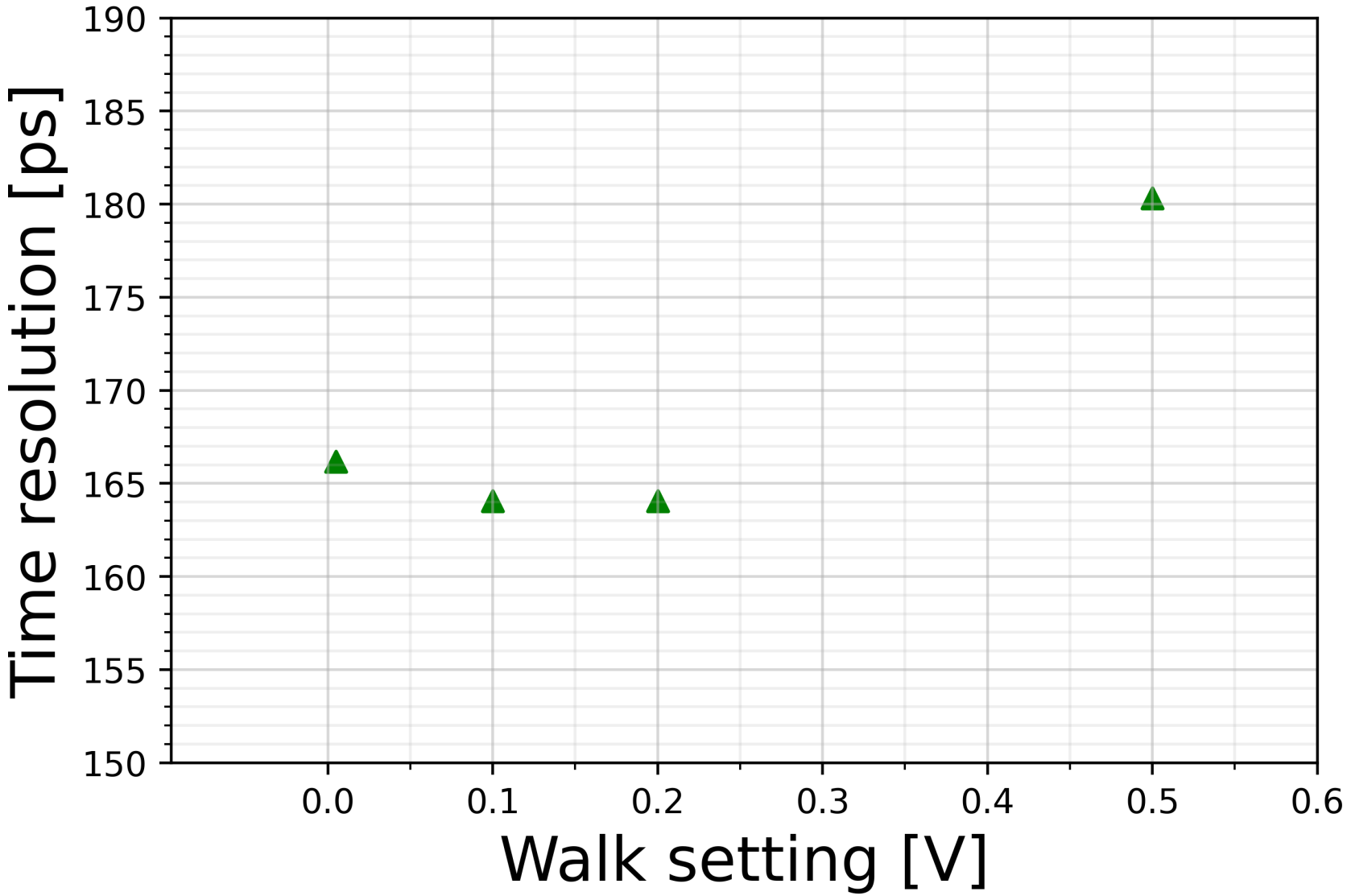
Varying the GAIN

- Resolutions on the CFD output of LOW threshold



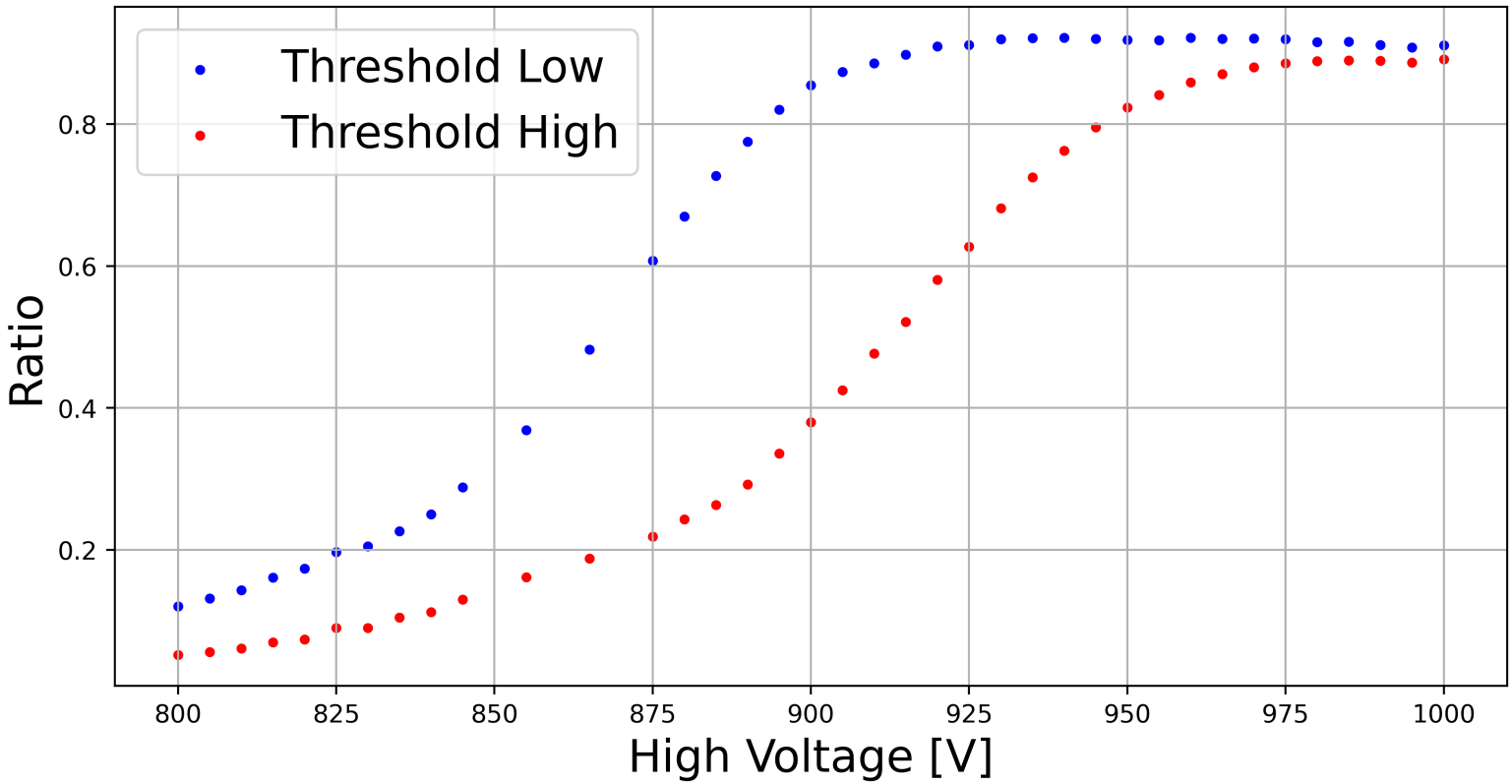
Varying the WALK

- Resolutions of the CFD output of LOW threshold



Example of use - Calibration

- CFD thresholds used for detector calibration
- HV scan performed on installed detector during the muon run
- Low/High threshold set to -60 mV/ -80 mV
- Ratio of events passing Low/High thresholds as a function of PMT HV



Summary

- CFD performance
  - The CFD has a time variation of few tens of ps over a wide rannge of amplitudes
- CFDs at NA62 experiment
  - CFDs were successfully installed and commissioned in the experiment since May 2022
  - No major issues observed
  - We found and set the optimal settings of CFDs for VetoCounter using cosmic rays and muon run
  - All requirements fulfilled
  - CFD LVDS output signals processed by newly developed FPGA based TDCs connected via optical links to trigger-less future read-out based on FELIX (ATLAS co-development)
  - NIM signals fed in parallel to the standard NA62 read-out based on TEL62 used for commissioning of the new read-out