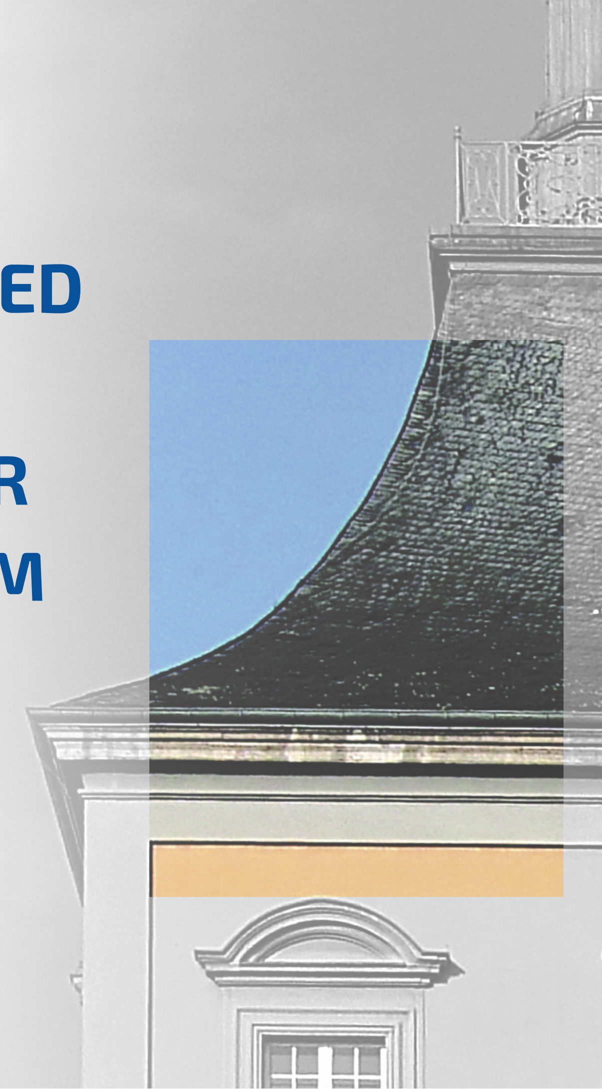
CHARACTERIZATION OF AN IMPROVED TIME REFERENCE PLANE AND DEVELOPMENT OF A NEW TRIGGER SYSTEM FOR AN EUDET-TYPE BEAM TELESCOPE

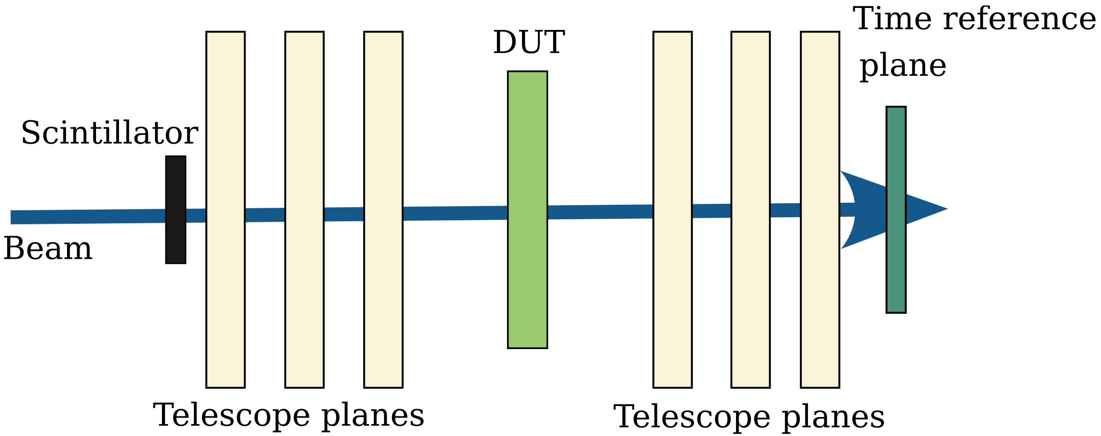


MASTER COLLOQUIUM

Rasmus Partzsch

03.13.24

Introduction EUDET-Type Beam Telescope



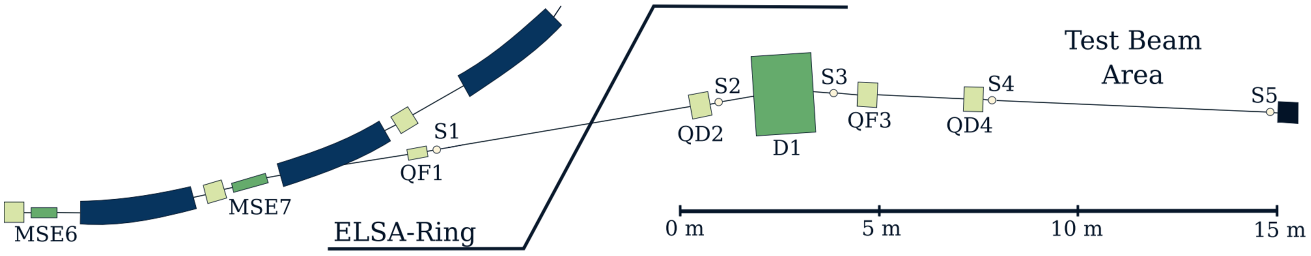
- Reference tracking detector
- Characterization and development of detectors (DUT)

- Multiple EUDET-type beam telescopes are in use, providing a common hardware
- Flexible testing setup

- Tracking detector consists of semiconductor pixel detectors
- Precise spatial and temporal tracking through device under test (DUT)

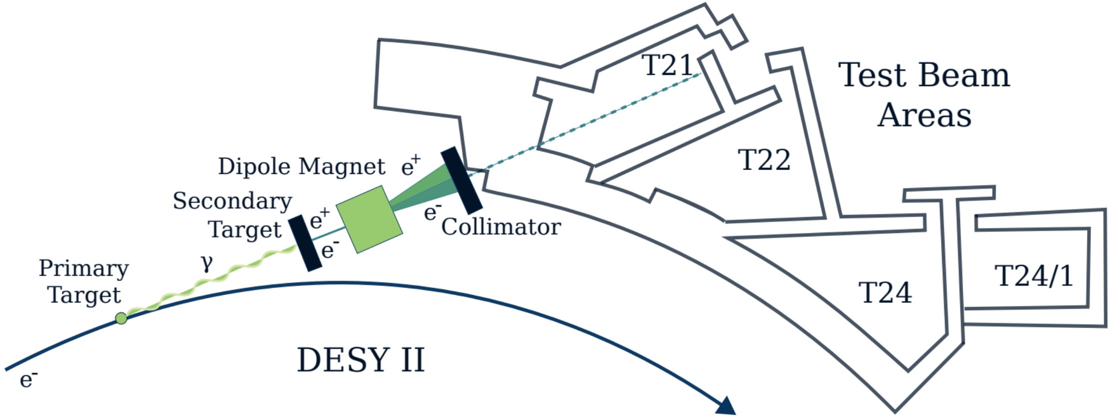
[4]

Introduction Test Beam Areas



ELSA test beam area:

- Primary beam
- Variable beam spot
- Particle rate (~kHz - MHz)
- Energy (< 3.4 GeV)



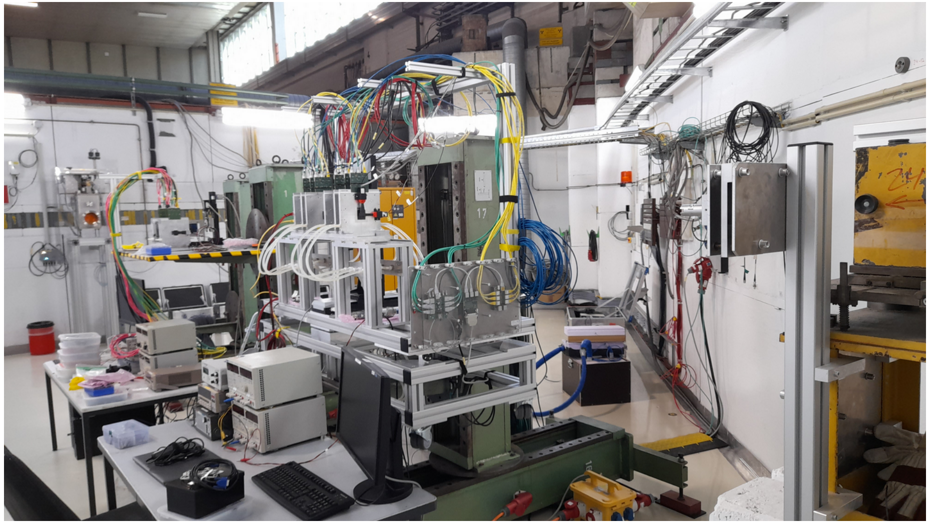
DESY test beam areas:

- Tertiary beam
- Full control over tertiary beam
- Energy and particle rate variable (1 GeV – 6 GeV) and (≲ 5 kHz)

[2, 3]

Outline

- The test beam telescope ANEMONE
  - The MIMOSA26 high resolution detector
- Trigger logic unit (TLU) of ANEMONE
  - AIDA-TLU
- Python based control software for the AIDA-TLU
  - Dynamic tests
  - Integration in the ANEMONE readout
- The time reference plane
- Track reconstruction efficiency
- Test beam studies



The Test Beam Telescope ANEMONE

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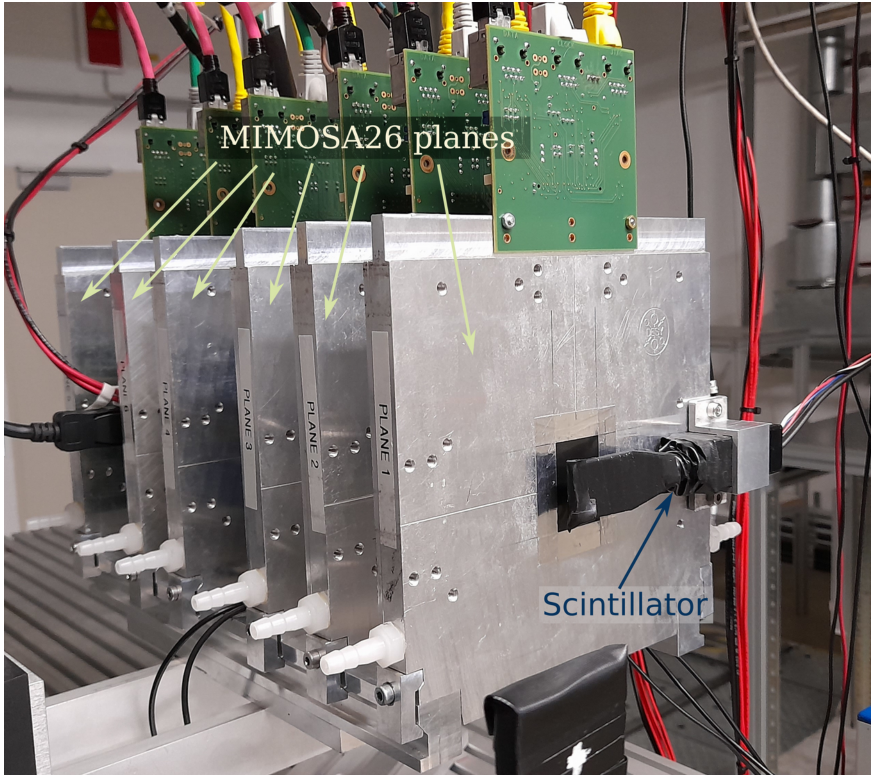
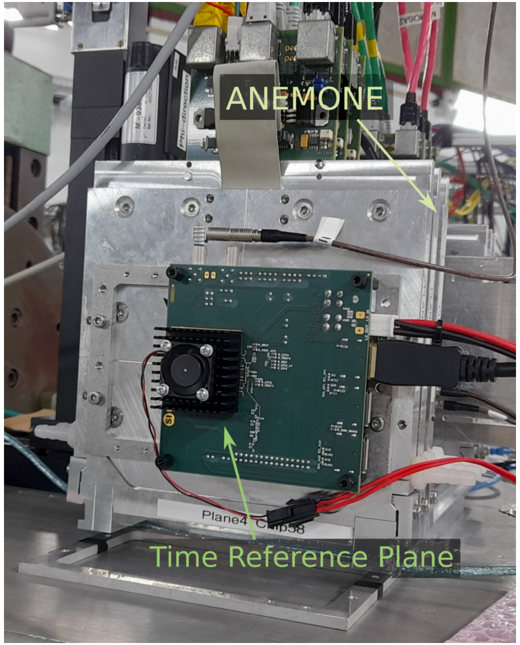
ANEMONE A Nice EUDET Mimosa Bonn Telescope

- 6x MIMOSA26 high spatial resolution planes (ANEMONE)
- 1x Time reference plane for time resolution
- Scintillator(s) for trigger generation



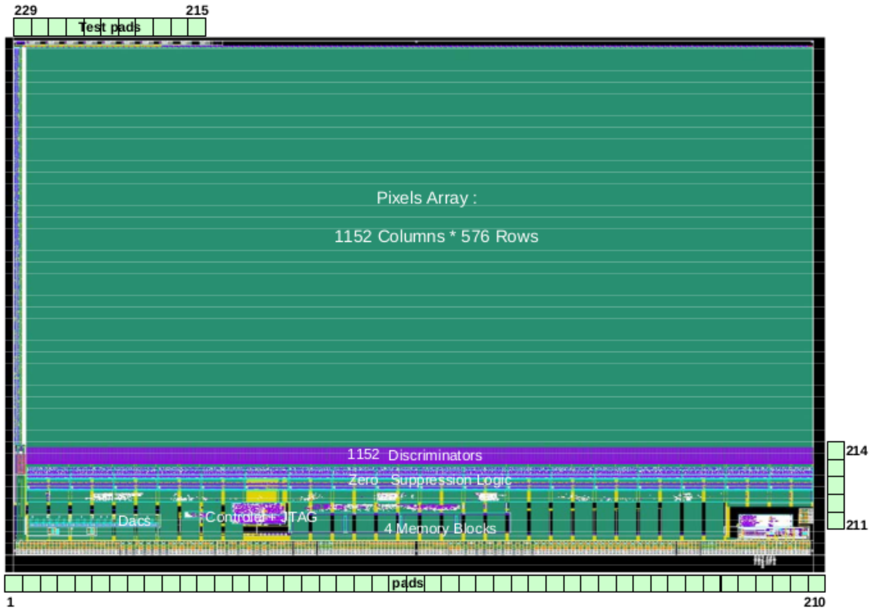


The MIMOSA26 High Resolution Detector

- 18.4 x 18.4 µm² pixel size
- 576 x 1172 pixel matrix
- 10.51 x 21.45 mm² active area
- 115.2 µs readout time

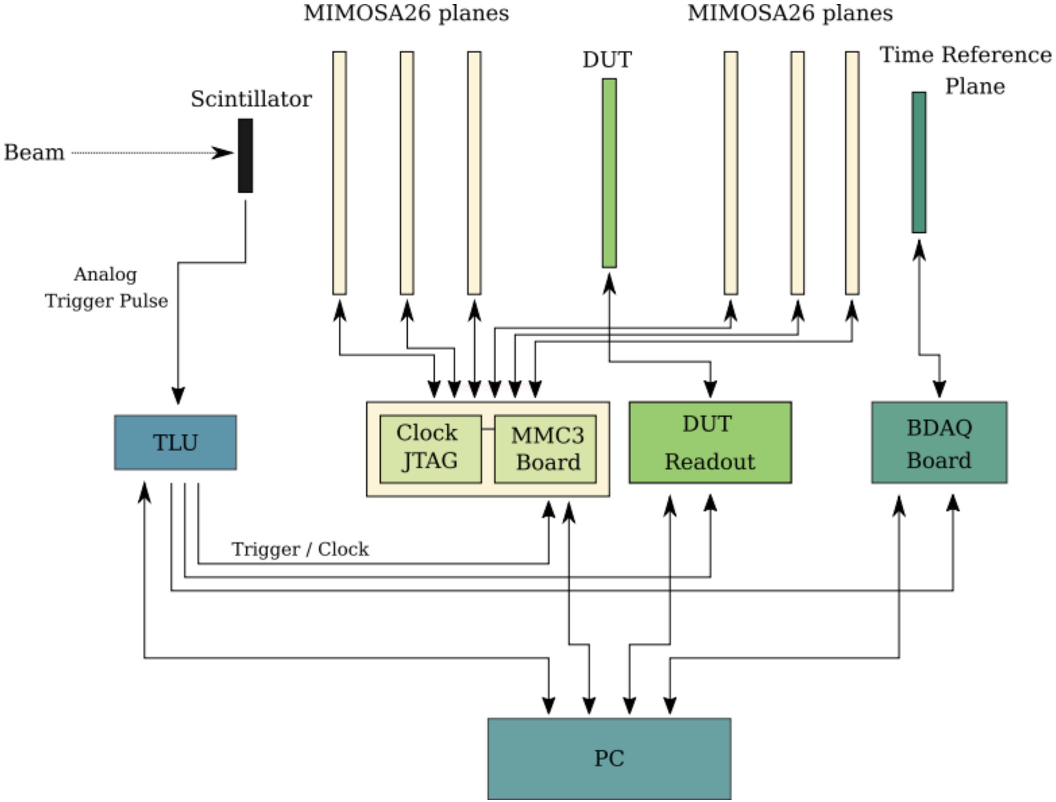
- Rolling shutter readout
  - Columns are read in parallel where rows are read one after the other
- One Readout frame takes 115.2 µs
  - Hits occurring in one readout frame can be placed into next readout frame

→ an effective time resolution of 2 x 115.2 µs



[5]

Hardware Components of ANEMONE



- Scintillator trigger signals distributed to devices
- Each device has its own readout board
- Readout boards are connected to a PC
- Control of devices using Python based Software

- Upgrades to the test beam telescope
  - TLU
  - Time reference plane

Trigger Logic Unit of ANEMONE

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The Trigger Logic Unit of ANEMONE

EUDET-TLU

AIDA-TLU

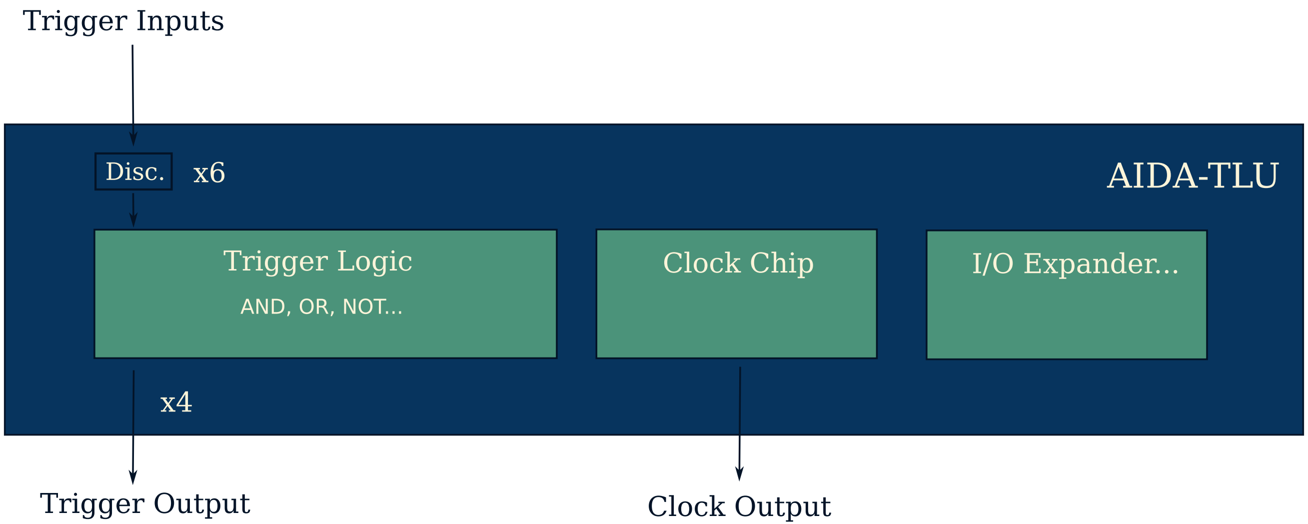
- TLU distributes trigger signals to different devices
- Hit synchronization of individual devices to create events

- Upgrade of EUDET-TLU to AIDA-TLU
- **EUDET-TLU → AIDA-TLU**
  - Different communication protocols, to multiple individual devices
  - Faster trigger sampling
  - Scintillator threshold setting in software

[6, 7]

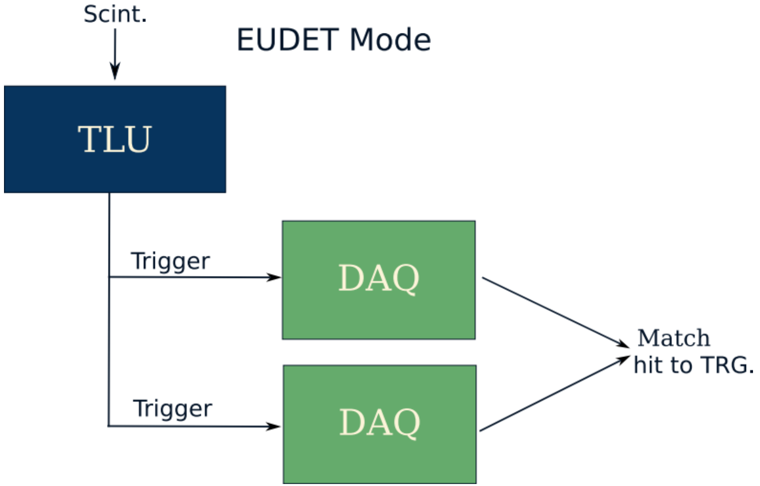
The AIDA-TLU

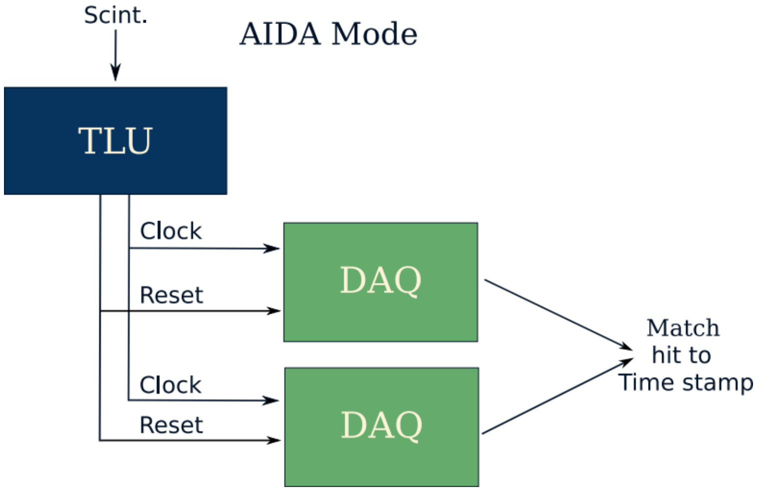
- 6x Trigger inputs
- 4x PMT power supply
- 4x HDMI DUT interfaces (Trigger Output, Clock Output…)
- Discriminator for trigger input threshold
- Stretch and delay of trigger pulses
- Trigger forming logic between trigger inputs using Boolean logic (AND, OR, NOT…)



[5]

TLU Operation in Conjuction with a DUT





EUDET Mode

- Synchronization between devices using trigger number which is sent in addition to trigger

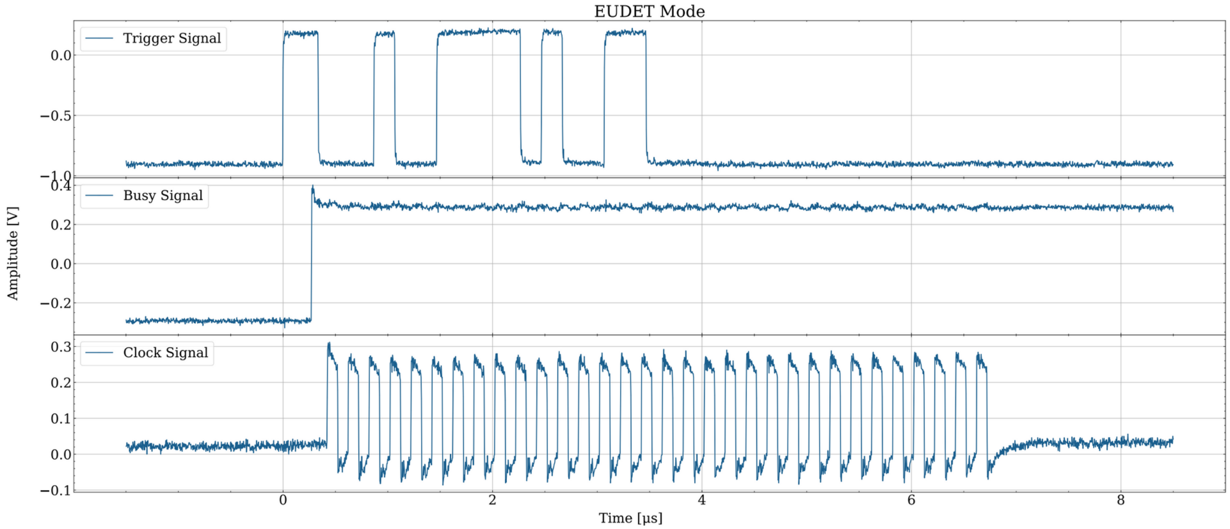
AIDA Mode

- TLU distributes clock to DAQ and a reset for timestamps
- DAQ runs with common clock / time stamp
- Synchronization of hit using common time stamp (useful for untriggered devices)

Operating Modes of the AIDA-TLU

EUDET Mode (Handshake)

- DUT accepts TRIGGER from TLU and answers by asserting BUSY
- DUT clocks out TLU trigger number (external trigger number)



AIDA Mode (No Handshake)

- TRIGGER are sent continuously
- DUT can veto new trigger by asserting BUSY

[5]

Python Based Control Software for the AIDA-TLU

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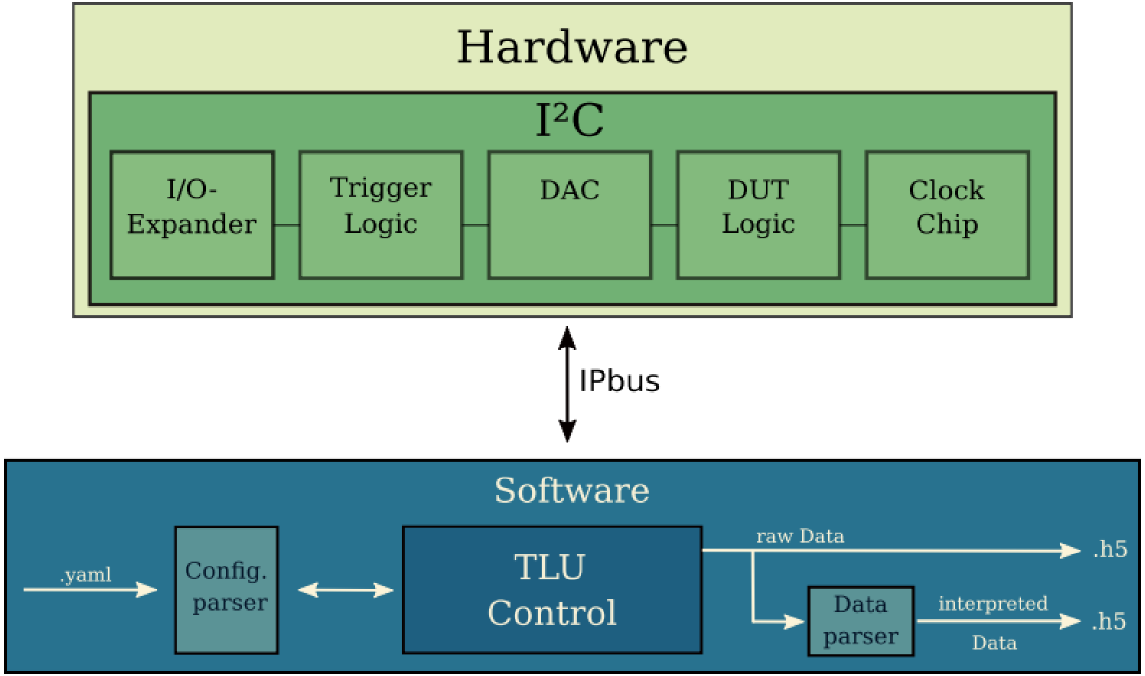
The AIDA-TLU Control Software



- Development of new custom Software

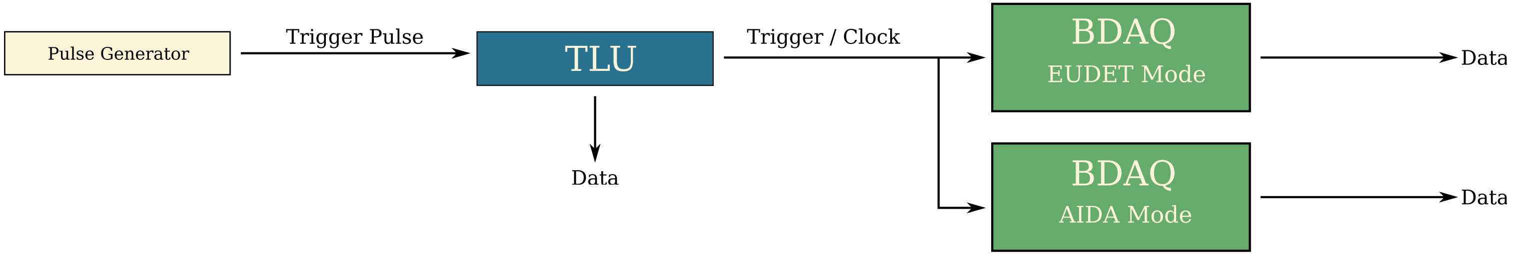
- Inputs configuration file to set trigger logic, operation modes…
- Outputs compressed .h5 files with trigger number, trigger timestamp…

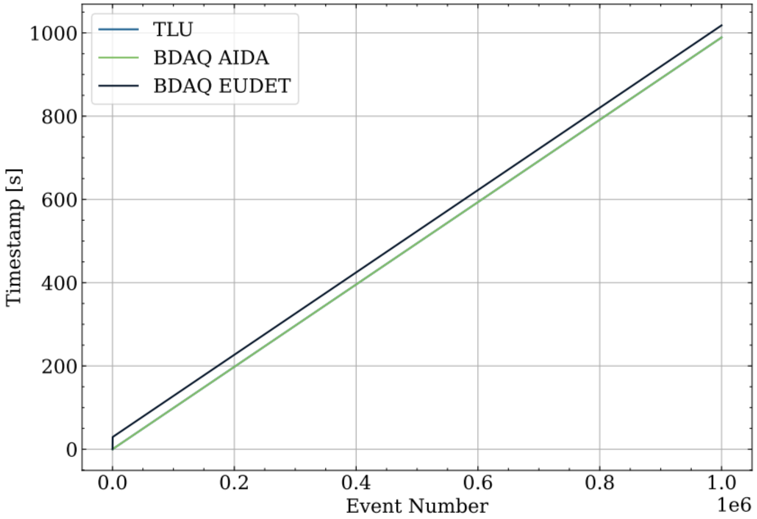
- The TLU hardware is controlled with a PC using IPbus as the register read/writing protocol
- I²C is the serial communication bus between hardware components

- Control over terminal command lines

[8]

Dynamic Tests of the AIDA-TLU and the Control Software





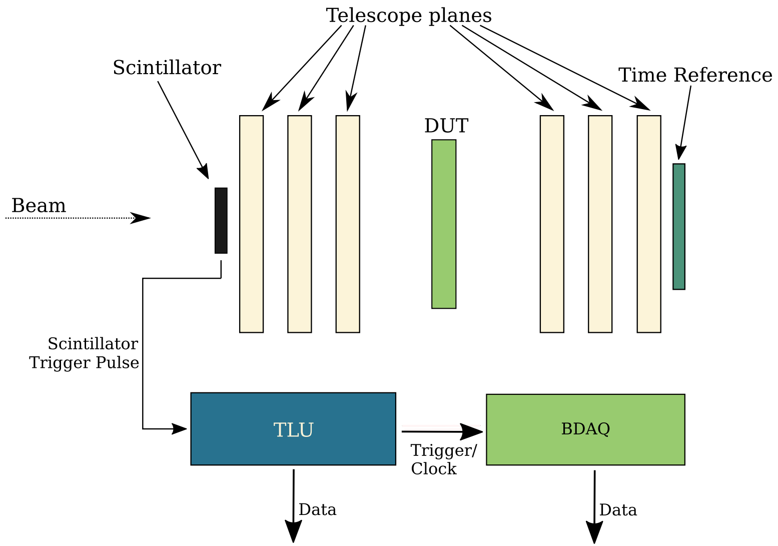
Test setup

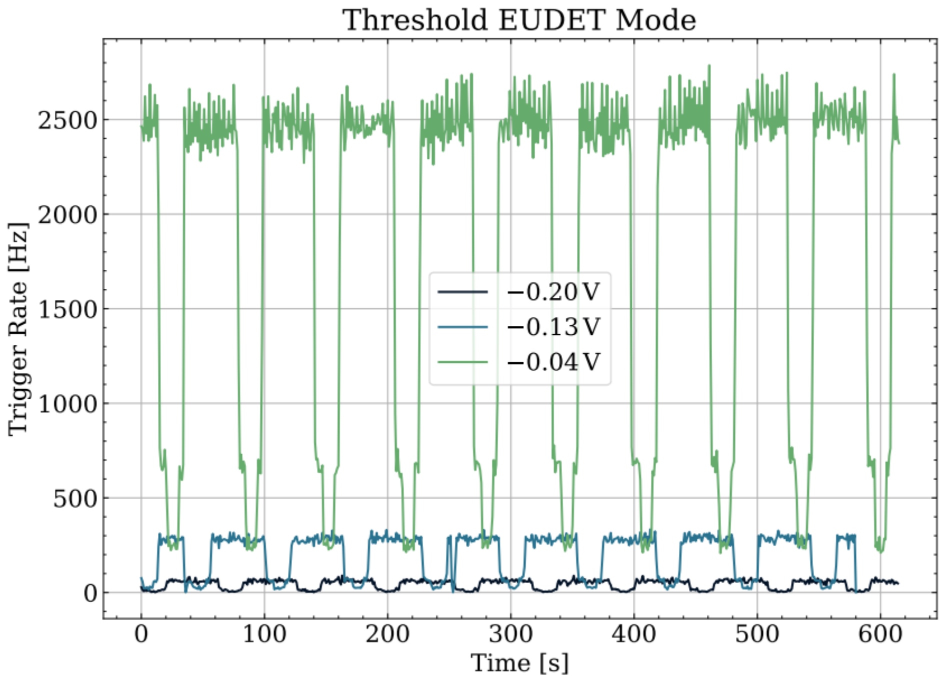
- Using a pulse generator for pseudo scintillator analog signals
- BDAQ boards are used as DAQ
- Test readout in responds to TLU operation
- Test of operation modes, timestamp, trigger logic...

Dynamic Tests of the AIDA-TLU and the Control Software

Repetition of tests at DESY test beam

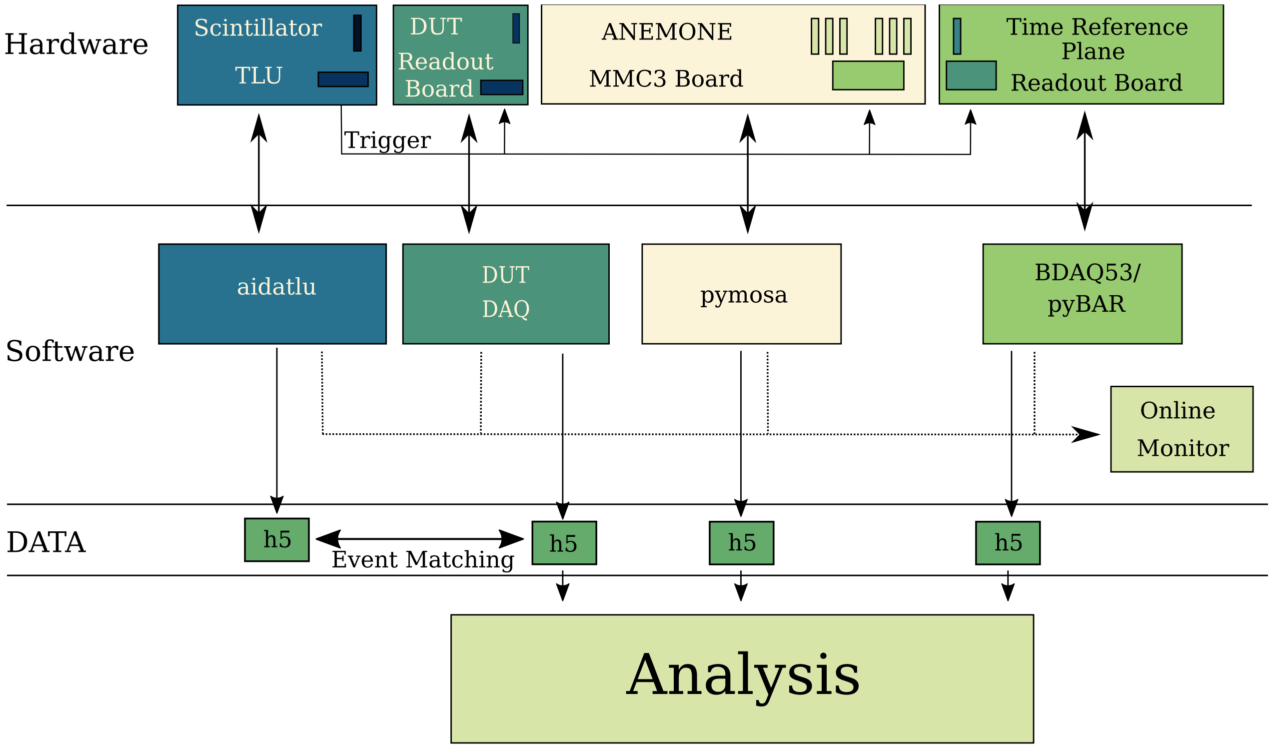
- Electron beam and scintillator together wit BDAQ board





Integration of the AIDA-TLU Control Software into the ANEMONE Readout Infrastructure

- Existing ANEMONE test beam infrastructure has a modular software framework
- Each device is connected to a readout board, controlled using a Python based control software
- Outputs are individual h5 data files
- Data files are merged in Analysis
- Data files from AIDA-TLU allow additional method of event matching



The Time Reference Plane

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The Time Reference Plane

New time reference plane

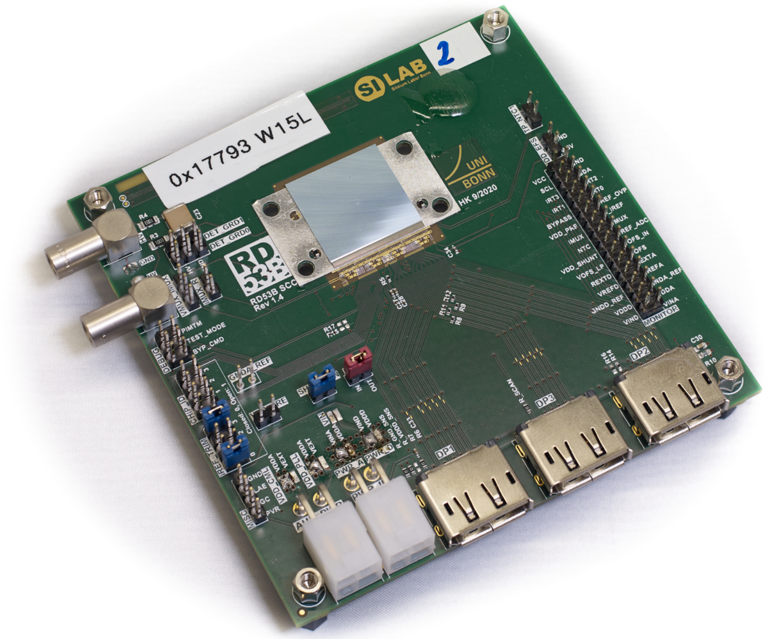
- Chip availability
- Software support

ATLAS FE-I4 (currently used)

- 250x50 μm^2 pixel size
- 80 x 336 pixel matrix
- 20 x 16.8 mm^2 active area
- 25 ns time stamping capabilities

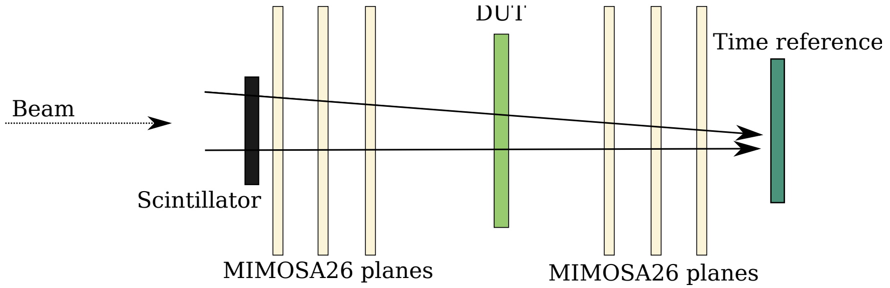
ITkPix (upgraded)

- 50x50 μm^2 pixel size
- 400 x 384 pixel matrix
- 20 x 19.2 mm^2 active area
- 25 ns time stamping capabilities



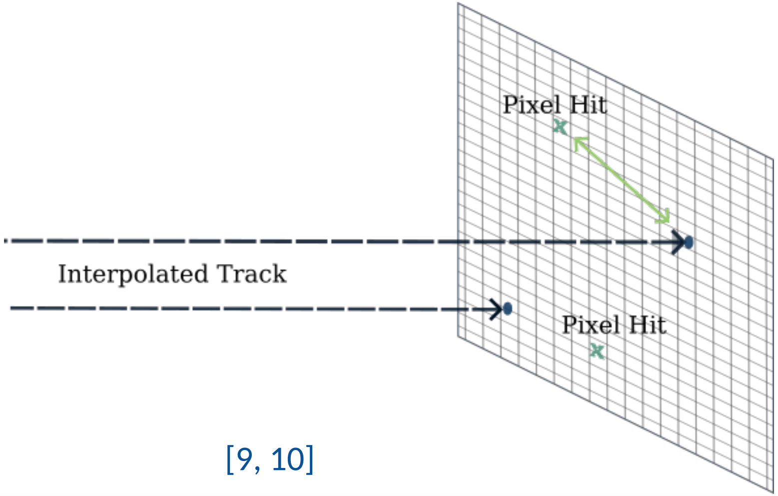
[11, 12]

Time Reference Plane



- Readout frame of MIMOSA26 planes: 115.2 µs
- Assignment of hits to track is not always possible
- Multiple tracks (trigger) in one readout frame

- Time reference plane for spatial assignment of track to time reference



[9, 10]

Track Reconstruction Efficiency

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The Track Reconstruction Efficiency

- Characterize performance of time reference planes

- Quality of tracks through residuals:

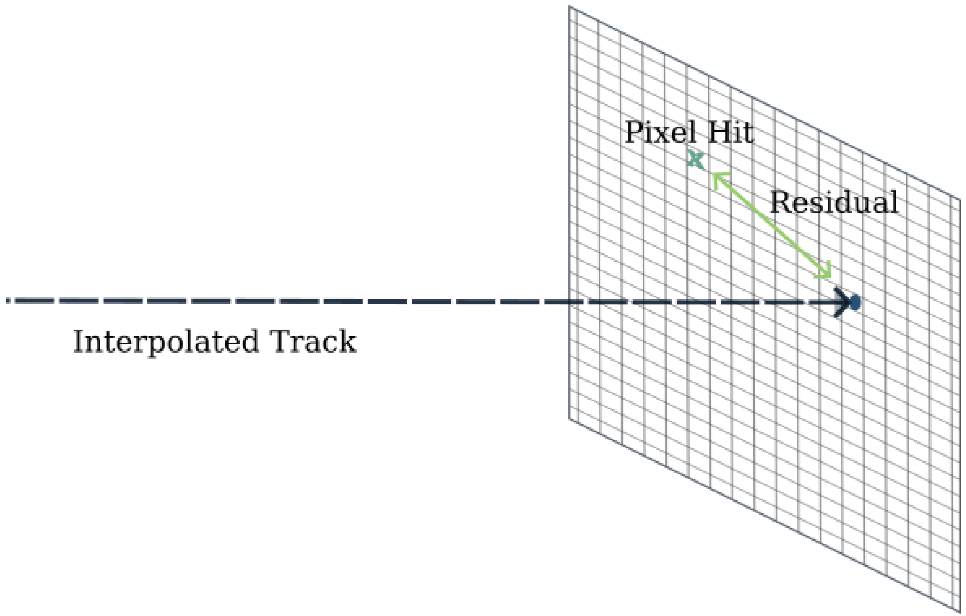
  $X_{res} = X_{track} - X_{hit}$

  $Y_{res} = Y_{track} - Y_{hit}$

- Parameter to estimate the percentage of correctly reconstructed tracks:

  Track reconstruction efficiency

- Ratio of correctly reconstructed tracks to wrongly reconstructed tracks

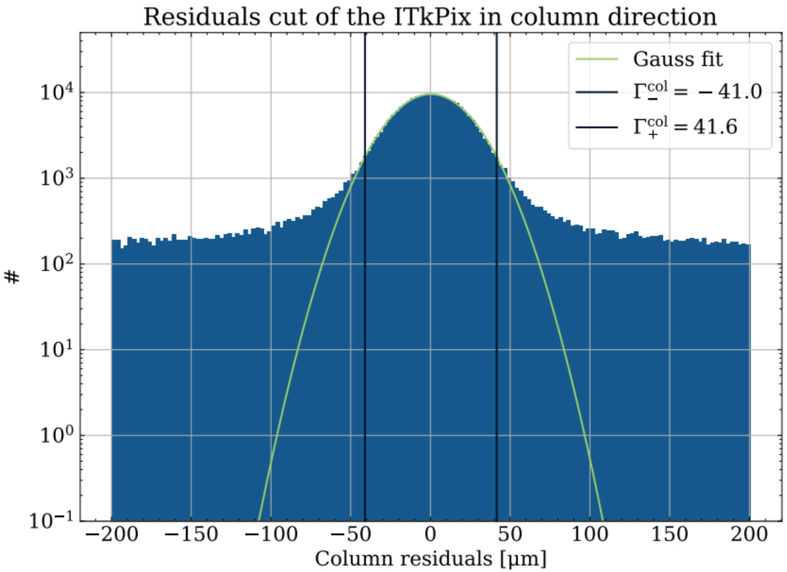


Determination of the Track Reconstruction Efficiency

- Residuals are calculated for each track in row and column direction and fitted using Gaussian functions

- Cut row residuals using column residuals
- Determine cut distances from fits:

  Gauss function for ITkPix: $\Gamma_{cut} = \mu \pm (FWHM/2 + \sigma)$



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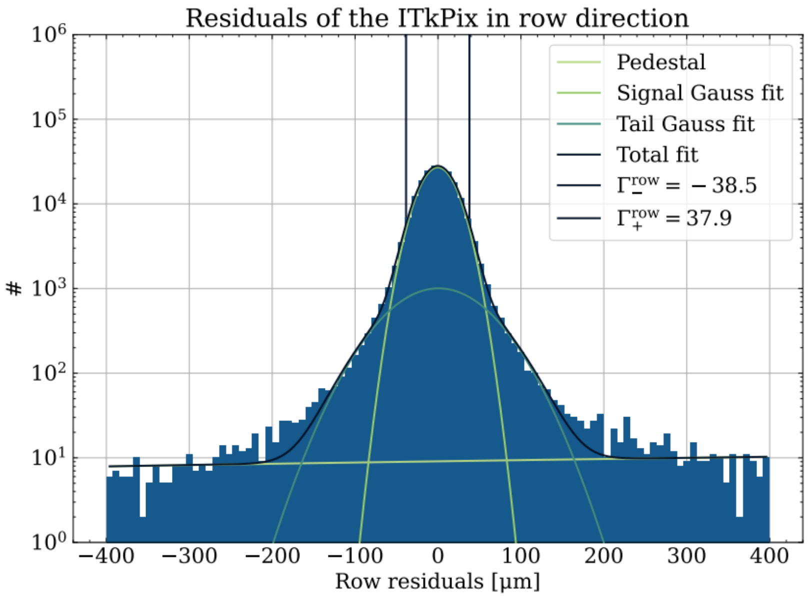
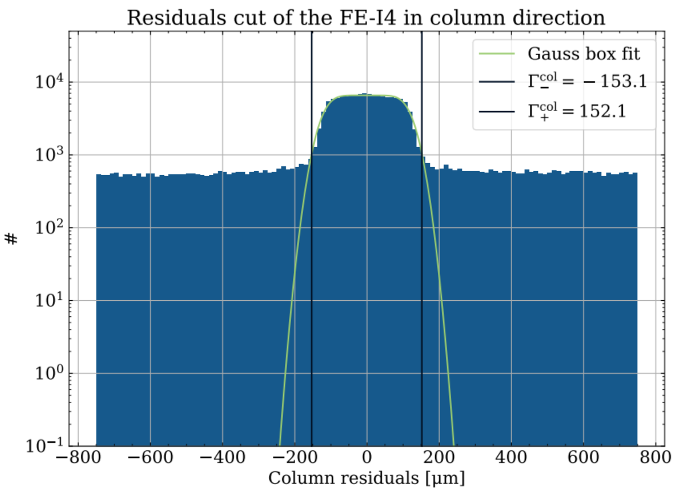
Determination of the Track Reconstruction Efficiency

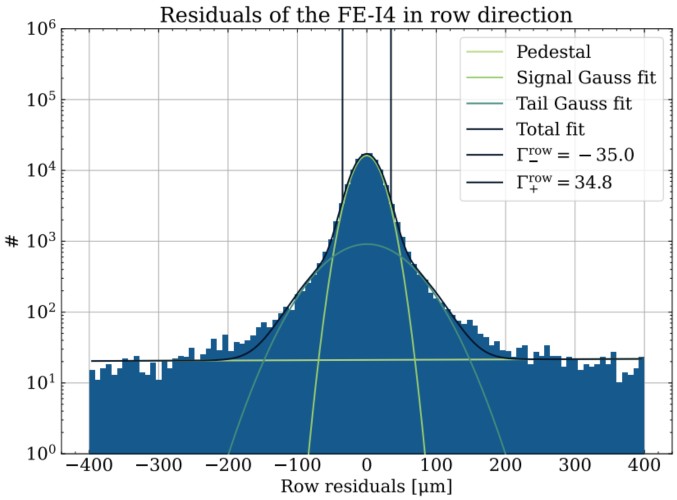
- Remaining residuals fit: Fit = Gauss + Gauss + linear
  Fit = Signal + Tail + Pedestal

- Signal: correct reconstructed tracks
- Tail: track with larger residuals due to multiple scattering
- Pedestal: wrongly reconstructed tracks
- $\Gamma_{cut} = \mu \pm (FWHM/2 + \sigma)$ of signal function



Track Reconstruction Efficiency of the FE-I4





- Larger residuals of FE-I4 in column direction required a Gauss-Box fit with cut: $\Gamma_{cut} = \mu \pm (d_{box}/2 + \sigma)$
- Same cut in row directions as ITkPix: $\Gamma_{cut} = \mu \pm (FWHM/2 + \sigma)$

Track Reconstruction Efficiency

Track reconstruction efficiency is calculated from the integral over the signal and pedestal functions:

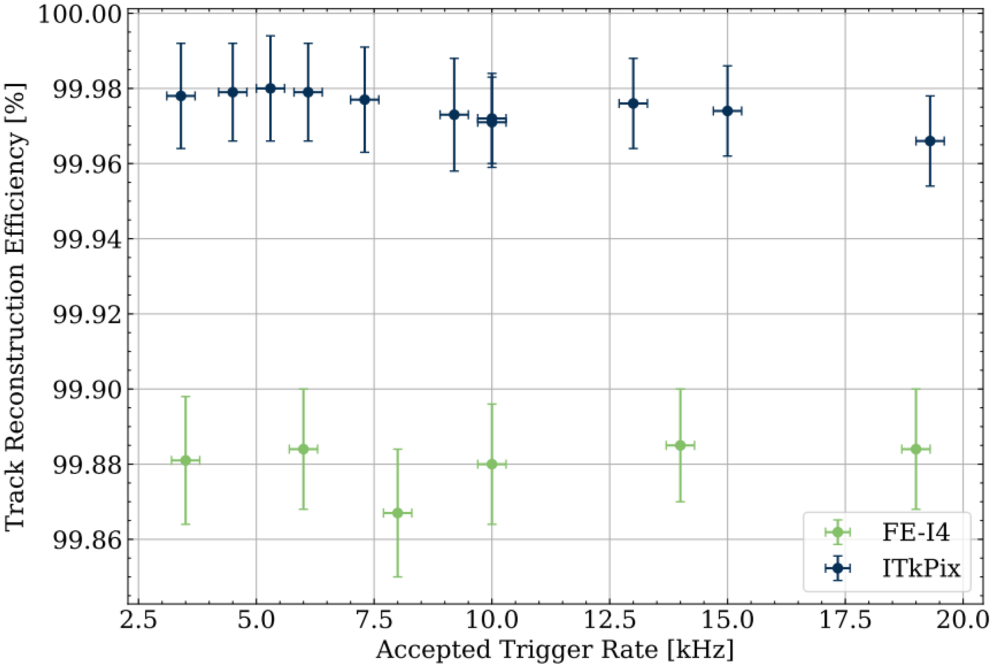
$$TRE = \frac{\int_{\Gamma} f_{Sig} \, dX_{Res}}{\int_{\Gamma} f_{Sig} + f_{Ped} \, dX_{Res}}$$

Using track reconstruction efficiency the quality of tracks between FE-I4 and ITkPix is compared:

FE-I4: TRE = (99.79 ± 0.05) %
ITkPix: TRE = (99.94 ± 0.03) %

Small improvement of ITkPix over FE-I4 during a test beam at DESY with particle rates ~ 2 kHz

Dependence of the Track Reconstruction Efficiency on the Particle Rate



- Measured at test beam ELSA
- Accepted trigger rate from the TLU to devices
- No clear dependency of track reconstruction on particle rate
- ITkPix performs better at all measured particle rates

Test Beam Studies

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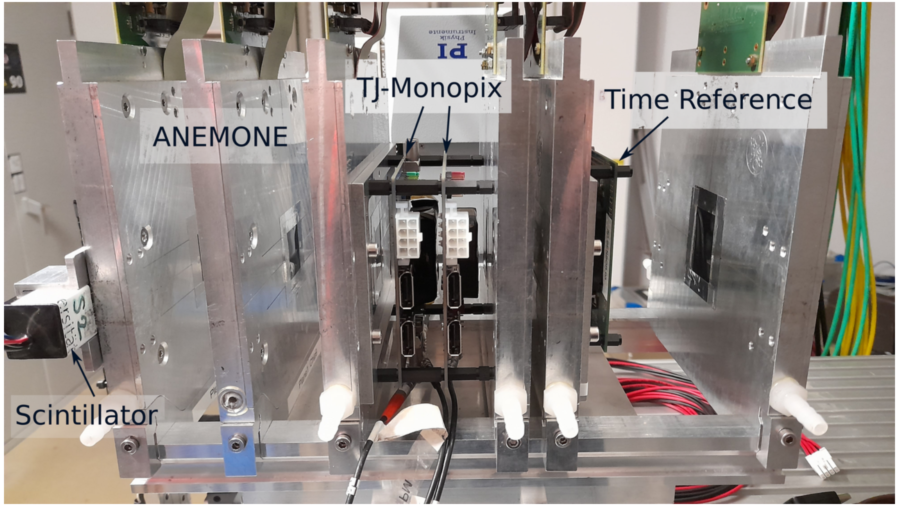
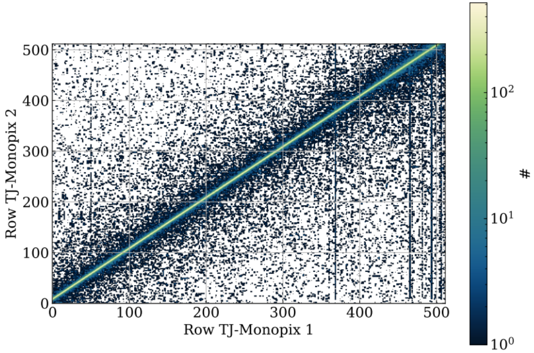
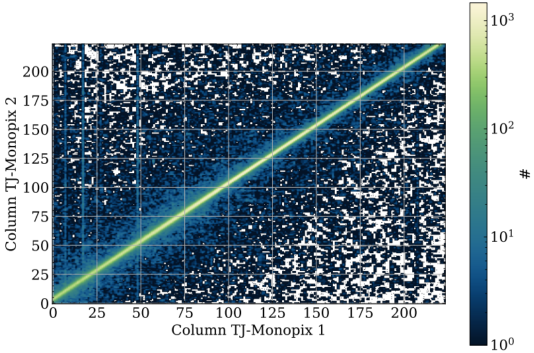
Two TJ-Monopix2 in AIDA Mode





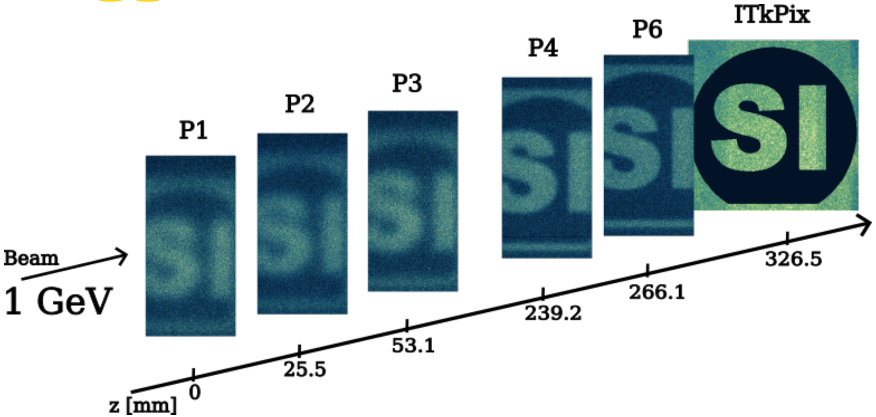


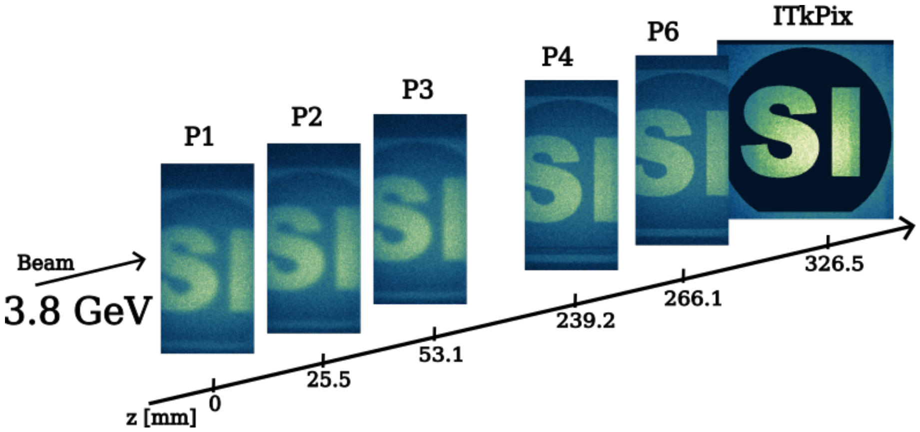
- Test beam setup at ELSA using two TJ-Monopix2 as DUTs
- TJ-Monopix2 in AIDA operating mode
- No trigger information needed, pure time stamp correlation

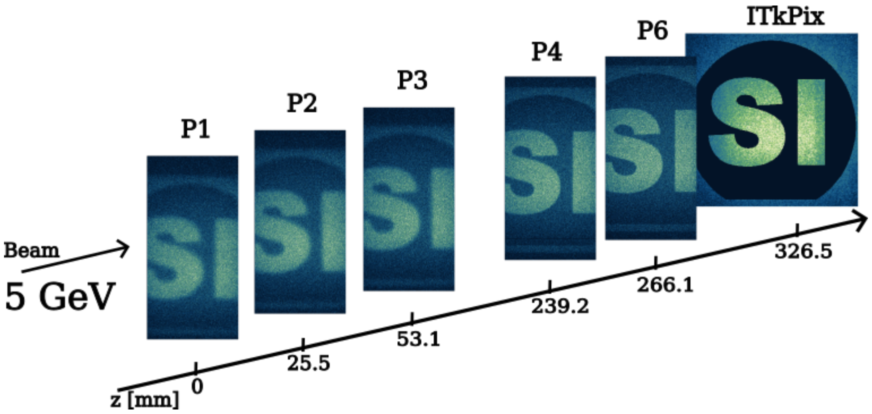
Region of Interest Trigger

- Enabled HitOR mask of ITkPix as ROI

- Three runs @1 GeV, @3.8 GeV and @5 GeV at DESY
- Mean scattering angle: $\theta_0 \sim 1/p$







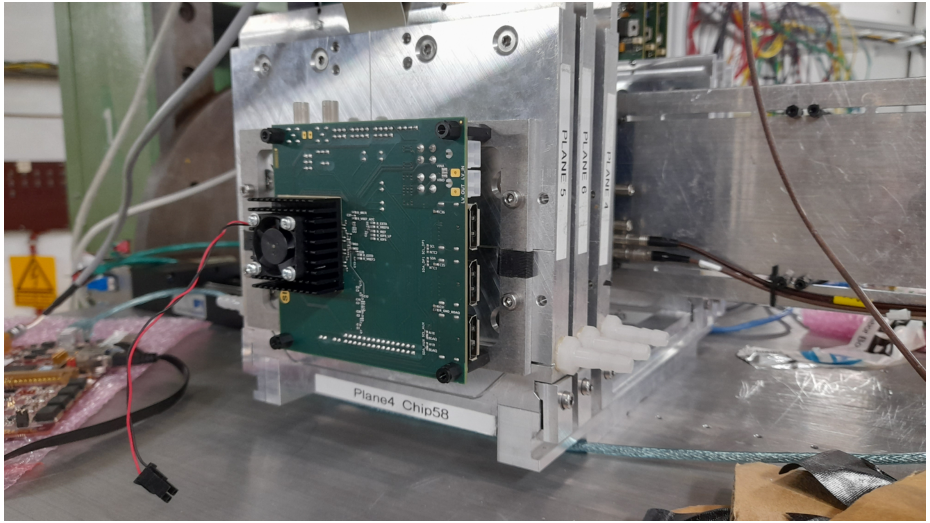
Conclusion

- Integration of the AIDA-TLU in the ANEMONE test beam infrastructure
  - Verified custom Python based control software
  - Provides multiple operating modes
  - Complex trigger logic (for example ROI)
  - Successfully, tested during test beam campaigns

- Replacement of FE-I4 with ITkPix as time reference plane
  for the test beam telescope ANEMONE
  - Slightly increased
    track reconstruction efficiency
  - Consistent for higher particle rates

Outlook

- Output of the discriminated scintillator signal from the TLU as timing reference
- Characterization of ROI-trigger using (multiple) scintillators
- Reduce material budget of the cooling setup for the ITkPix time reference plane



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Thank you for your attention!

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

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Backup

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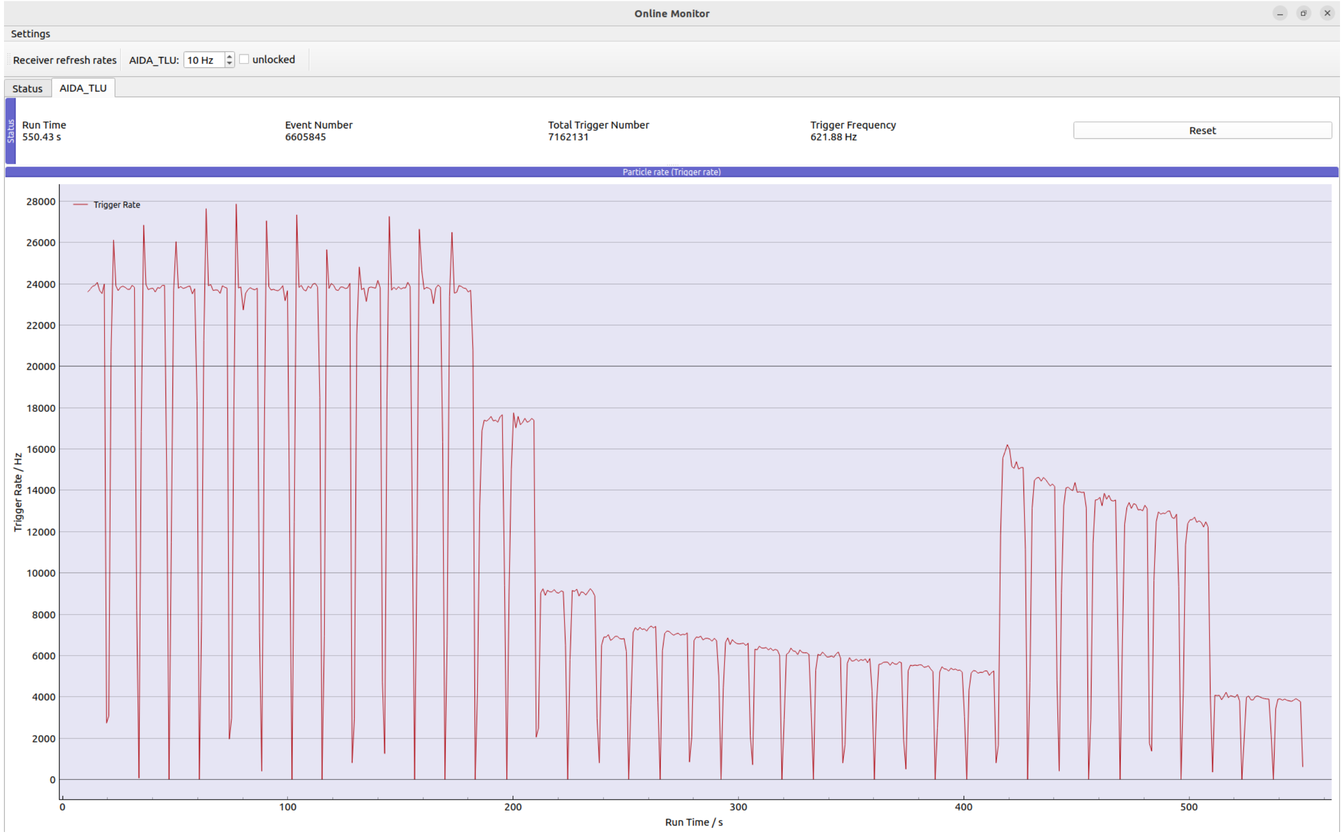
Trigger Logic of the AIDA-TLU

DEC	I5	I4	I3	I2	I1	I0	PATTERN	CONFIG. WORD
0	0	0	0	0	0	0	0	0xE
1	0	0	0	0	0	1	1	
2	0	0	0	0	1	0	1	
3	0	0	0	0	1	1	1	
4	0	0	0	1	0	0	0	0x0
5	0	0	0	1	0	1	0	
6	0	0	0	1	1	0	0	
7	0	0	0	1	1	1	0	
8	0	0	1	0	0	0	0	0x0
9	0	0	1	0	0	1	0	
10	0	0	1	0	1	0	0	
				⋮				
61	1	1	1	1	1	0	0	0x0
62	1	1	1	1	1	0	0	
63	1	1	1	1	1	1	0	

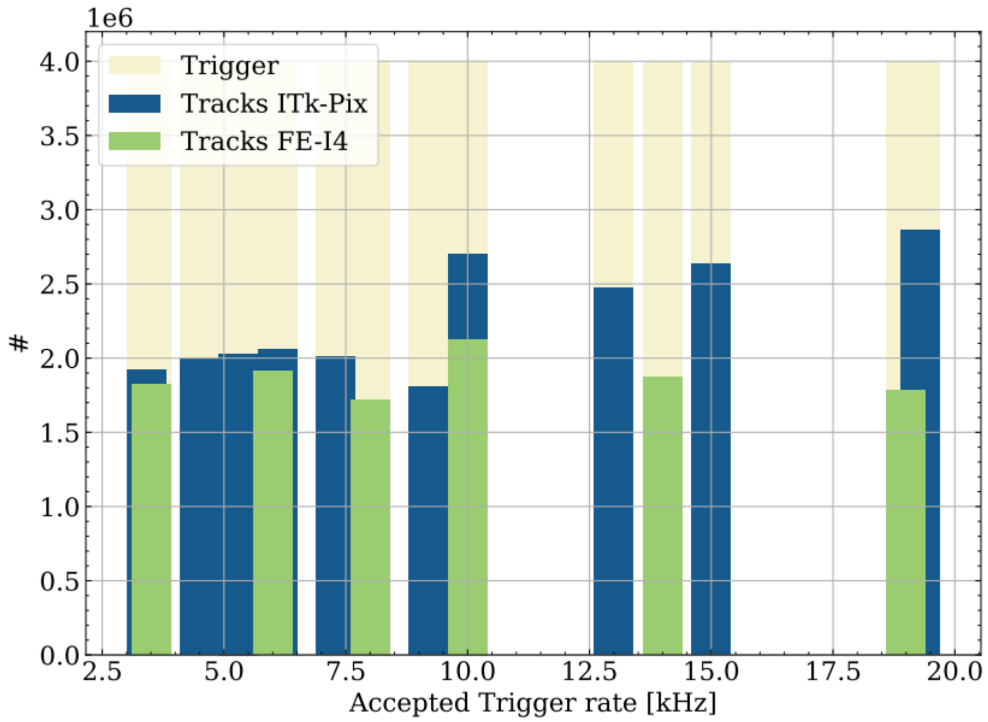
- 6 trigger inputs each in a binary state (HIGH or LOW)
  - $2^6 = 64$ possible trigger patterns
- To set trigger configuration
  - Set a 1 in the pattern row for all valid trigger patterns
  - Configuration word is the hexadecimal representation of the valid trigger patterns.

[5]

Online Monitor AIDA-TLU



ELSA test beam data



Trigger Rate to Cluster Rate