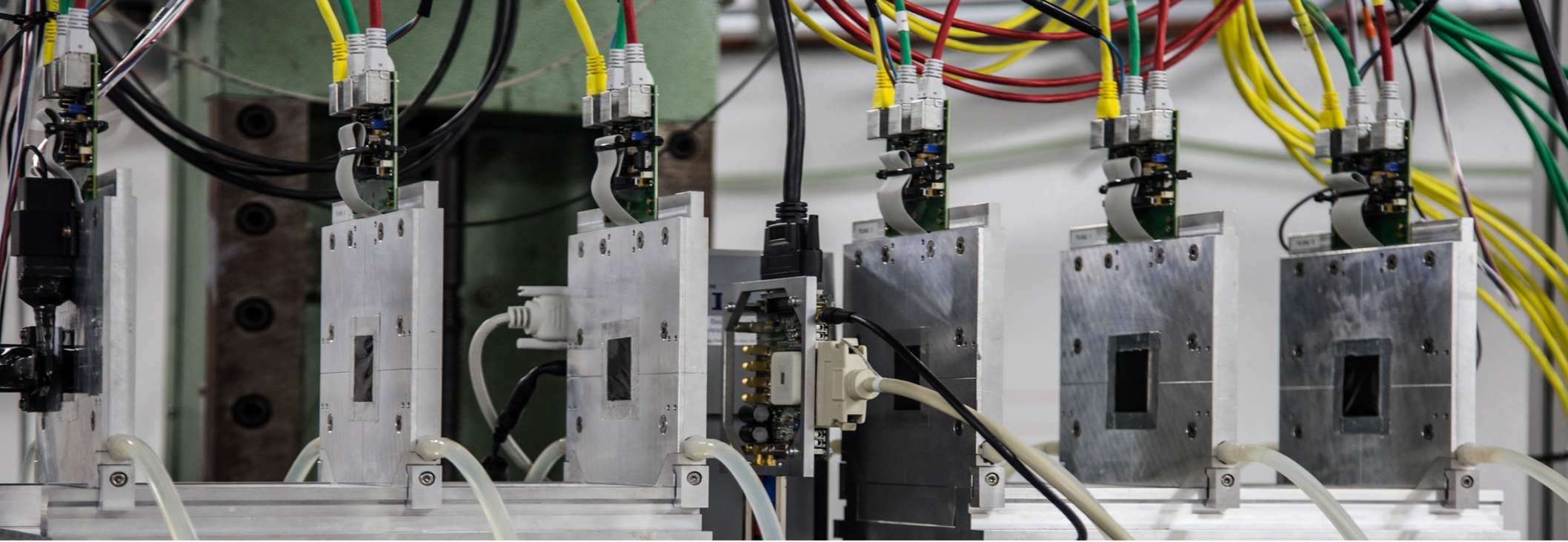


Beam Telescopes at the DESY II Test Beam Facility

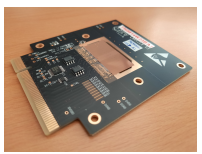
Adrian Herkert on behalf of the DESY test beam crew

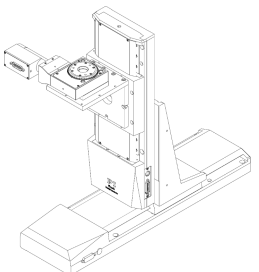
BTTB11, 18 April 2023, Hamburg

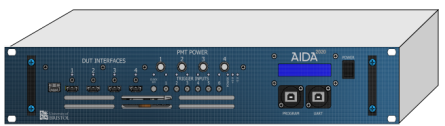
HELMHOLTZ AIDA innova DESY.

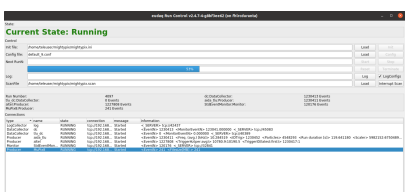
Contents

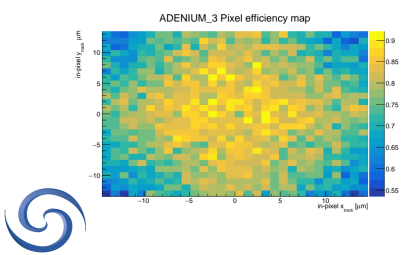
- Short reminder on the DESY II Test Beam facility
- Overview of the beam telescopes
  - EUDET-type (MIMOSA26)
  - Adenium (ALPIDE)
- Plans for telescope upgrades
- Steps to using a telescope
  - DUT integration
    - Mechanical
    - DAQ synchronization (AIDA TLU)
    - Software (EUDAQ2)
  - Data analysis (Corryvreckan)







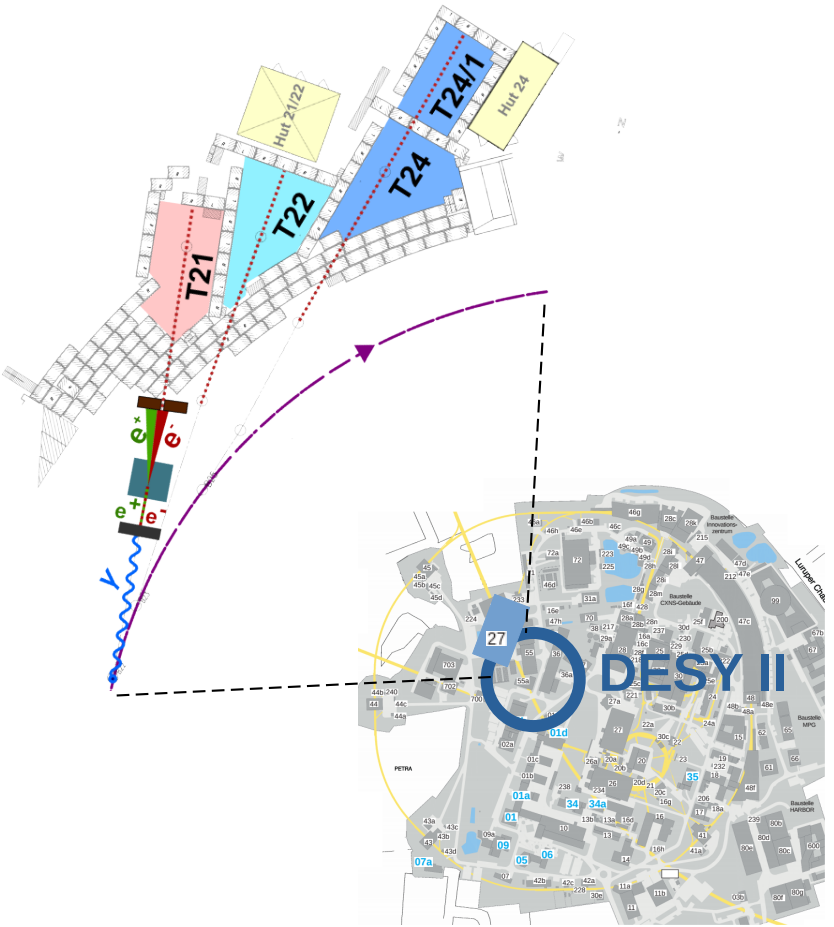




The DESY II Test Beam Facility

Quick reminder

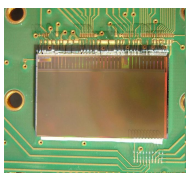
- Dedicated talk on Monday, ‘Facilities’ session
- Test beam user facility
  - Located here at DESY Hamburg
  - User operatoins ~ 40 weeks per year
  - 3 independent beam lines
- $e^{+/-}$, momenta between 1 and 6 GeV
- Up to $\mathcal{O}$(10,000 particles s^{-1} cm^{-2}) (energy dependent)
- One beam telescope installed at each area
  - 50 µm MAPS → Small amount of material in beam
  - Used for ~ ¾ of all beam times

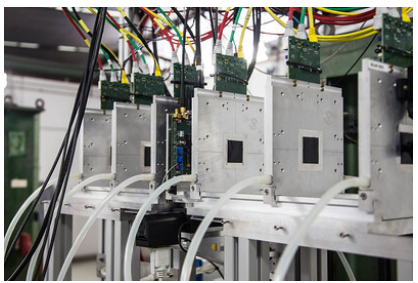


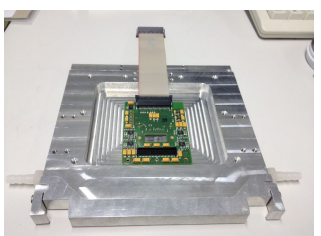
EUDET-type beam telescopes (1/3)

Overview

- 6 layers of MIMOSA26 MAPS (thinned to 50 µm)
  - Active area: 2 cm x 1 cm
  - Pixel size: 18.4 µm x 18.4 µm
  - Rolling-shutter RO (115 µs per cycle, 2 cycles read out per trigger)
    - Other than that no hit time information
- DAQ system uses ...
  - AIDA TLU and EUDAQ2 software
    - for flexible DUT integration
  - several legacy components:
    - e.g. NI controller that is out of production



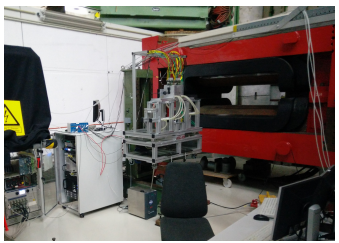




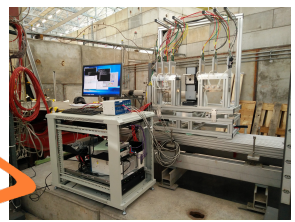
EUDET-type beam telescopes (2/3)

Current locations of the 7 copies

- DESY (2)

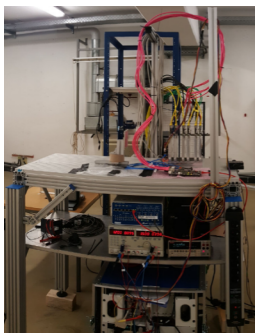


- CERN (3)



Azalea: Back @ CERN

- ELSA (Bonn) (1)



- SLAC/ TRIUMF (1)

AIDA-supported

‘Self’-supported

EUDET-type beam telescopes (3/3)

From today's perspective

On the plus side ...

- Successful operation for more than a decade
  - Large user base with lots of experience
- Track pointing resolution down to ~ 2 µm (also at lower energies like at DESY)
- Unique in their flexibility for DUT integration (due to use of TLU and EUDAQ2)

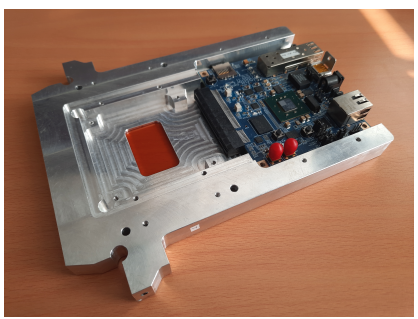
But ...

- No precise time information from telescope alone
- Manageable particle rates limited (ambiguities in 230 µs frames)
- MIMOSA26 sensors deteriorate
  - ~ 5 bonded spares left
- DAQ depends on legacy components (NI crate)

The new third beam telescope at DESY (1/2)

Adenium - an ALPIDE-based prototype

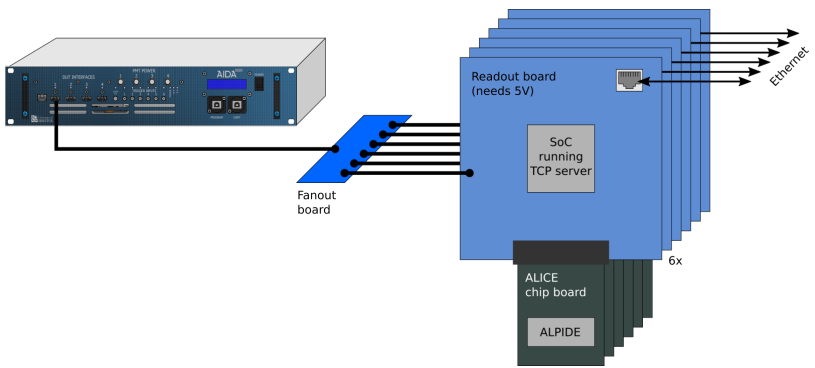
- Since last year DESY Hamburg has an end-user license for ALPIDE sensors
- Telescope prototype designed and produced by Y. Liu and USTC (https://arxiv.org/abs/2102.11138)
- Commissioning and testing phase completed successfully
- Now permanently in user operation (currently installed in T24 replacing Azalea)



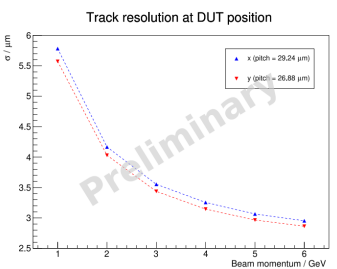
The new third beam telescope at DESY (2/2)

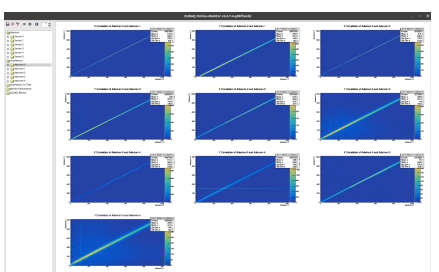
Short system and performance overview

- Each telescope layer ...
  - features its own SoC
    - that runs TCP server
  - receives clock, trigger, and trigger ID from AIDA TLU; sends busy
  - sends data packages over ethernet



- From user's perspective it works like EUDET-type telescope (because TLU and EUDAQ2), but:
  - Better tracking efficiency
  - Less noise
  - Shorter readout time frames (10 µs) → $\lesssim$ 1 track/frame up to ~ 10^4 triggers/s
  - Slightly worse track pointing resolution





Plans for telescope upgrades

ALPIDE

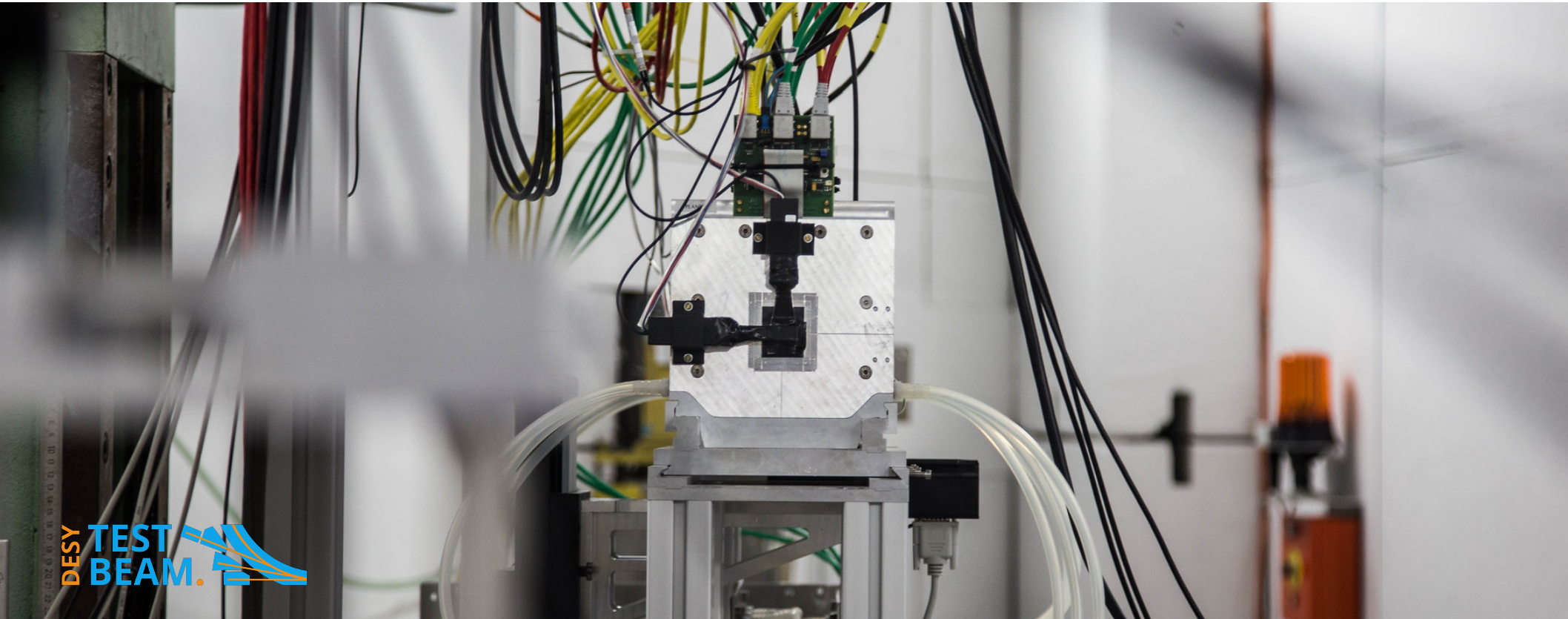
- More ALPIDE-based telescopes to be delivered in the scope of AIDAinnova WP3.2
- ALPIDEs bonded to chip boards have been ordered
- Unfortunately, Adenium will stay the only telescope of its kind at DESY
- Started new in-house design
  - Based on one central SoC
  - Use Caribou components. e.g. PEARY software

Timing layers

- Important for both more efficient data taking and precise reference time measurements
- Already in use: FEI4, Timepix3, TelePix (mini)
- Currently being commissioned:
  Full-size TelePix

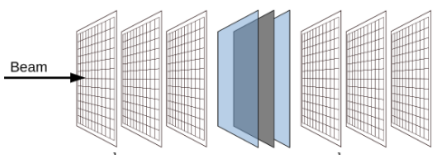
  Following talk, A. Wintle
- Planned in the scope of AIDAinnova WP3.3
  - Timepix4
  - LGADs
  - TLU with ps timing support

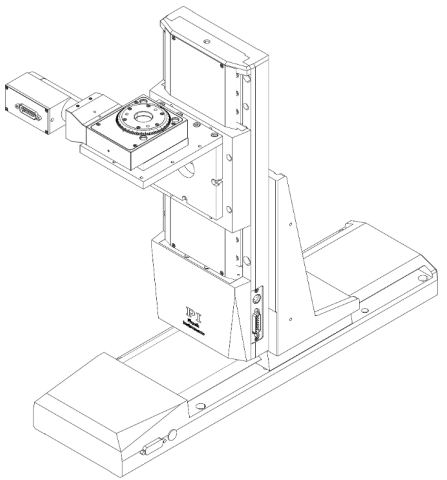
Steps to using a beam telescope

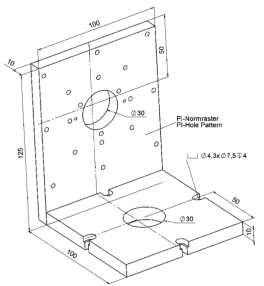


Mechanical integration of a DUT

And positioning of telescope layers

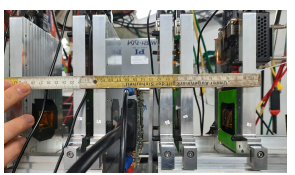


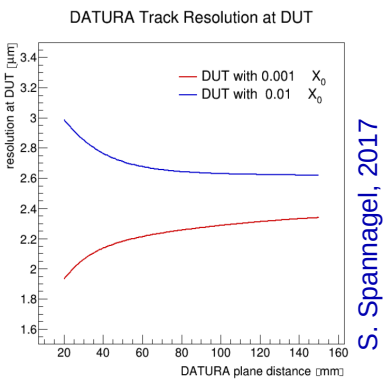




- Intended to place DUT in center
- XY- and rotation tables provided by DESY with different mounting options (max. load: 8kg)
- Also possible to use telescope layer jigs to mount additional detectors

  https://confluence.desy.de/display/BTDITB/Mounting+a+DUT
- Positions of the telescope layers can and should be adjusted
  - Optimal positions depend on material budget of DUT
- GBL track resolution calculator:
  https://github.com/simonspa/resolution-simulator
- Don’t forget to measure z-positions!



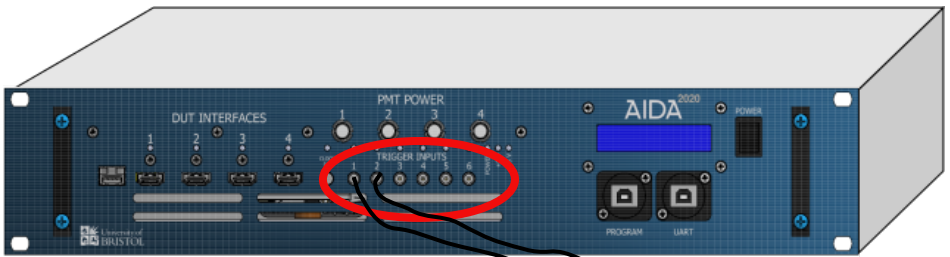


S. Spannagel, 2017

Trigger Logic Unit (TLU) (1/2)

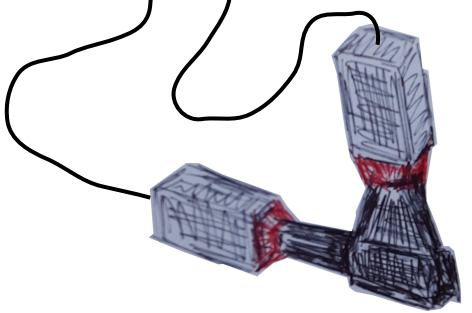
Hardware unit to “synchronize” multiple DAQ systems

- 6 trigger inputs (LEMO connectors)
  - Input voltage range [-5:+5]V
    → Accepts NIM and TTL signals,
    but polarity needs to be configured!
  - Individually programmable discriminators with range [-1.3:+1.3]V
  - Configurable coincidence logic
    (any combination of AND, OR, veto)
- Trigger detectors:
  - DESY provides scintillator-PMT assemblies
  - Users are free to add detectors or use theirs instead



https://ohwr.org/project/fmc-mtlu/blob/master/Documentation/Main_TLU.pdf

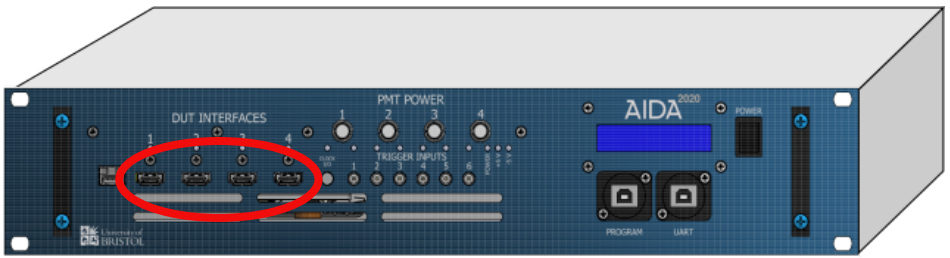
University of BRISTOL



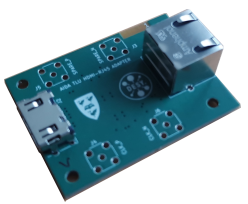
Trigger Logic Unit (TLU) (2/2)

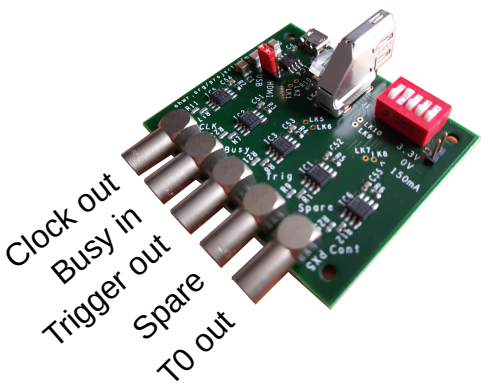
Hardware unit to “synchronize” multiple DAQ systems

- 4 “DUT” interfaces (HDMI)
  - One used for telescope
  - Splitter boards available at DESY
  - Basically two modes of operation
    - Handshake mode:
      TLU sends trigger and waits for busy to go up and down
    - Synchronous mode:
      TLU doesn’t wait for busy after sending trigger
  - Optional to send also trigger ID



https://ohwr.org/project/fmc-mtlu/blob/master/Documentation/Main_TLU.pdf

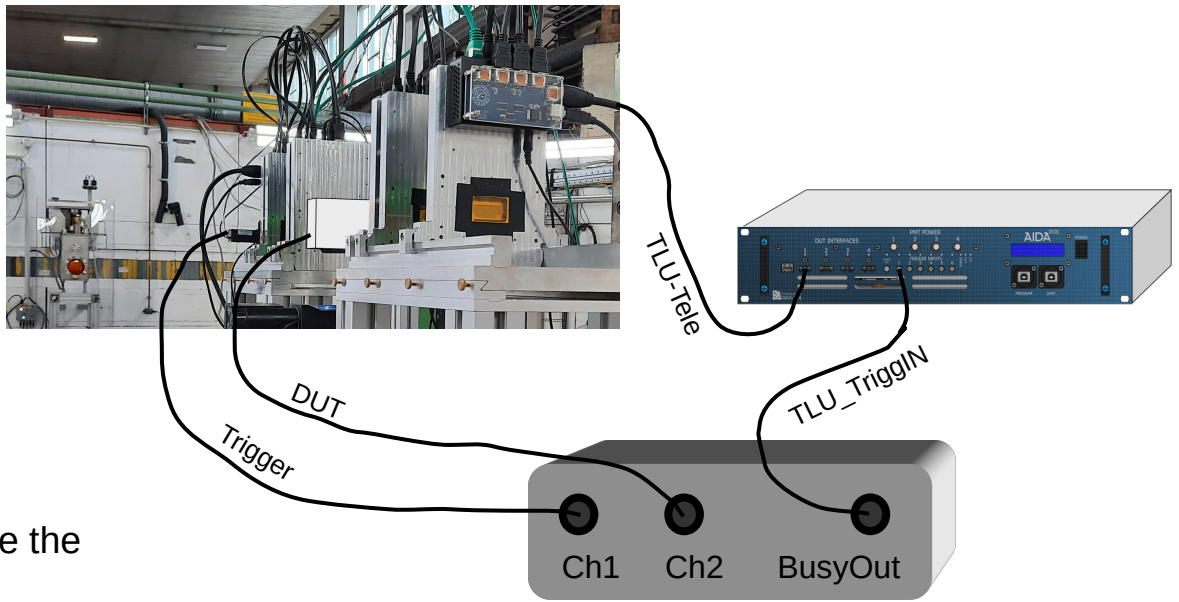




Examples of how to utilize the TLU (1/3)

1: Minimum amount of integration

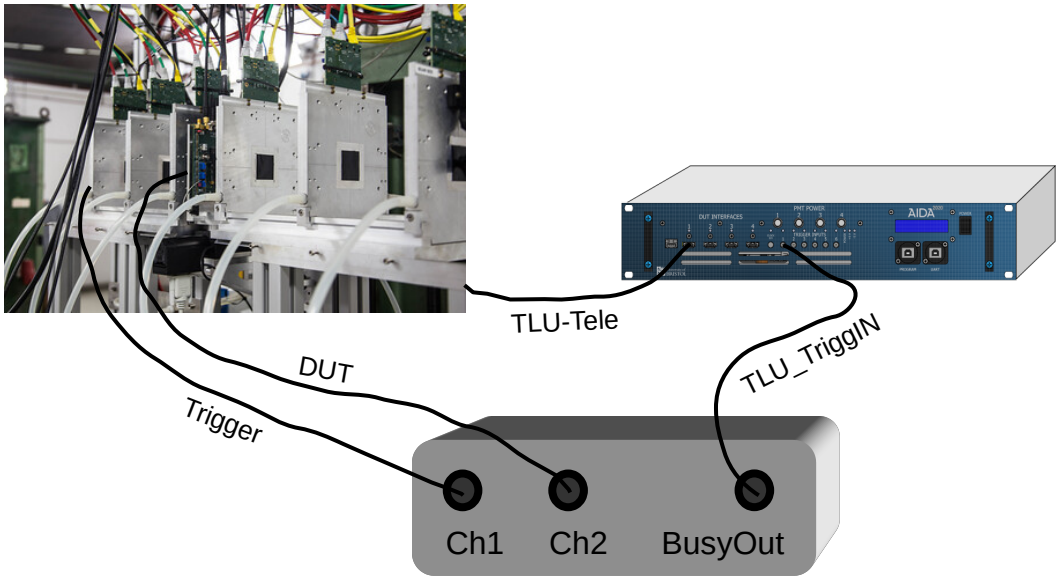
- User DAQ system: Digitizer
  - Ch1 connected to trigger detector
  - Ch2 connected to DUT
  - 180 µs dead time
- BusyOut of digitizer used as trigger input for TLU
- TLU triggers Adenium readout (10 µs)
- Event number and trigger ID should be the same and can both be used for synchronization



Examples of how to utilize the TLU (2/3)

1.5: Still minimum amount of integration

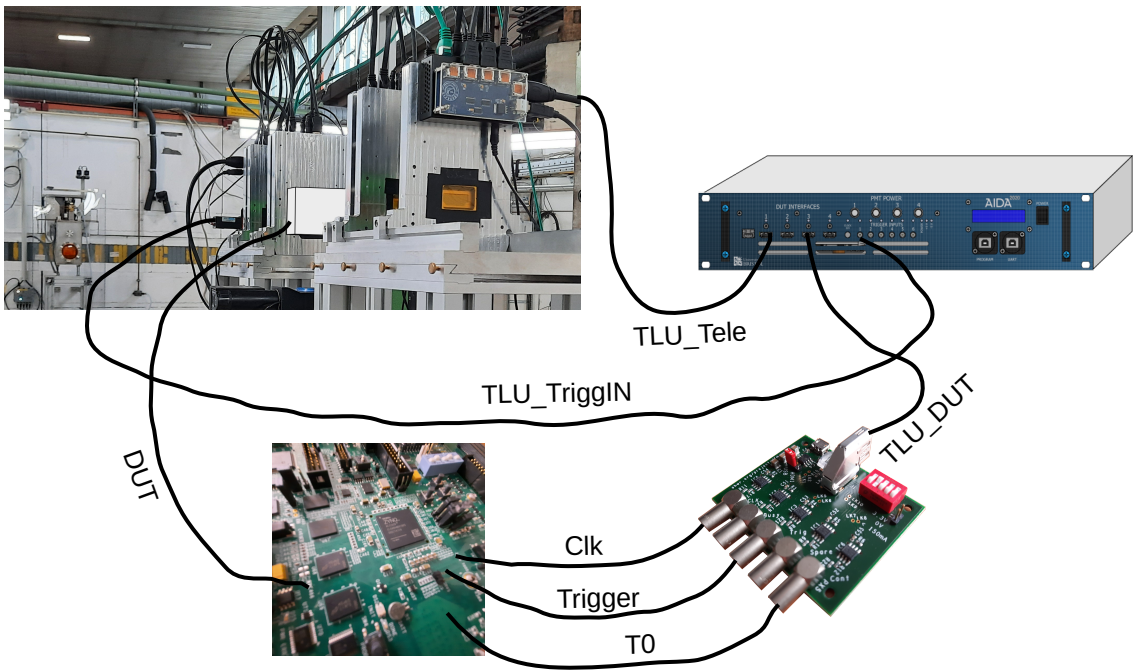
- Same user DAQ as before
- But this time MIMSA26 telescope
  → 230 µs readout time
- For 180 µs < t < 230 µs after trigger, digitizer can send the next one but telescope isn't ready
- Synchronization can be ensured by configuring TLU to ignore telescope's busy signal
  → Triggers during telescope readout get registered by TLU and tigger ID counts up
- Note: In 230 µs, probability to record additional track with no matching DUT hit is high



Examples of how to utilize the TLU (3/3)

2: Truly synchronous

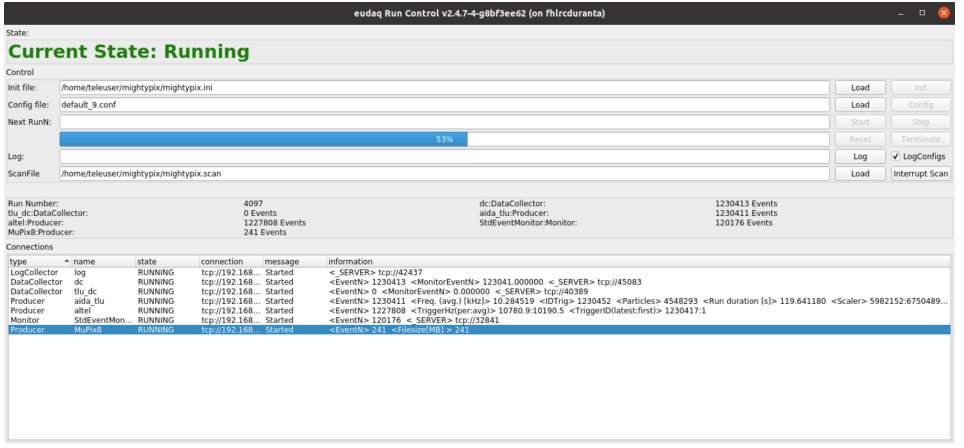
- User DAQ with custom firmware
  - Running on external clock provided by TLU
  - Synchronous reset via T0
  - Receives TLU triggers (and timestamps them) and trigger ID
- Synchronization via trigger ID or via timestamps



The software side of data acquisition (1/2)

EUDAQ2 – A framework to interface multiple DAQ systems

- TLU and the telescopes are integrated in it
- Their operation is steered via Runcontrol GUI
- TLU needs to be configured according to the used setup
  → This requires some adjustment in the TLU part of the EUDAQ2 config file




```
# DUTs
DUTMask = 0x1

# Define mode:
DUTMaskMode = 0xFC # 1st is reading out Trigger ID

# Coincidence of input 0 to 3 (telescope)
#trigMaskHi = 0x00000000
#trigMaskLo = 0x00008000
```

- Example start scripts and and config files in repo: /eudaq/user/eudet/misc/.

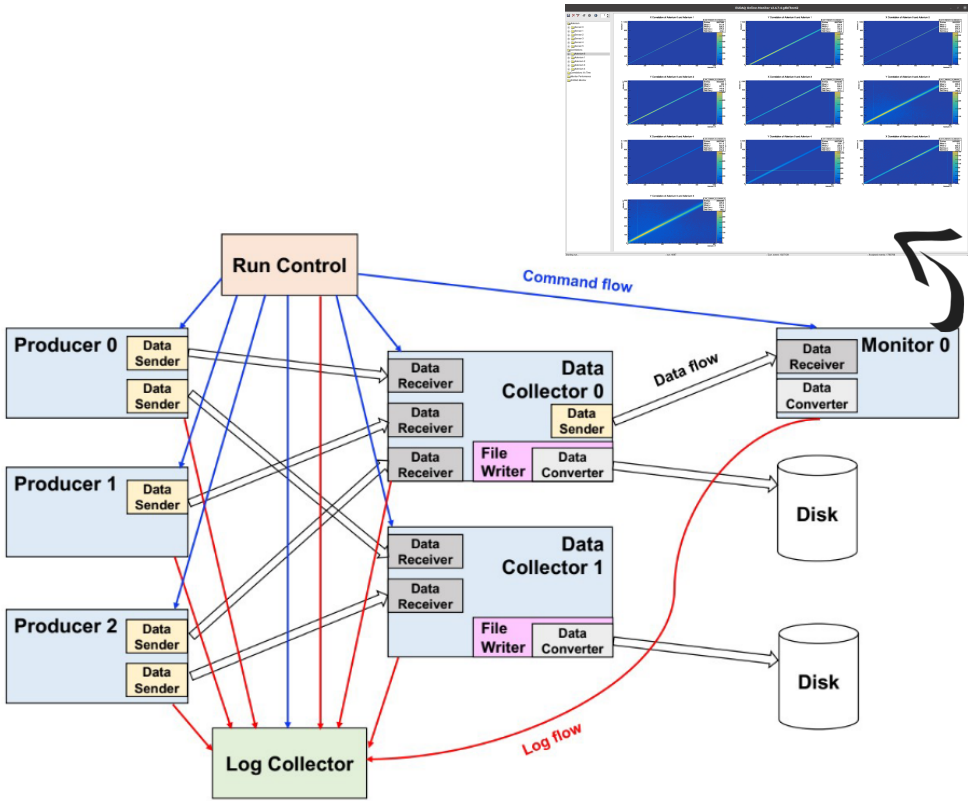
The software side of data acquisition (2/2)

Integration of a DUT in EUDAQ2

- Not a must but makes things more convenient
- Modules most likely to be implemented first:
  - *Producer* represents a device

```
void DoInitialise() override;
void DoConfigure() override;
void DoStartRun() override;
void DoStopRun() override;
void DoReset() override;
void DoTerminate() override;
void RunLoop() override;
```

  - *Converter* converts raw data into EUDAQ2 *StdEvent* format
- Examples for user code again in repo: /eudaq/user/.
  Includes also ‘Dummy’ and ‘example’

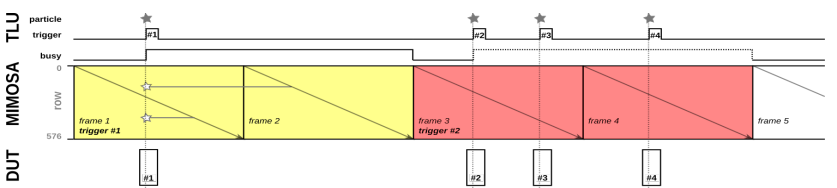


Telescope data (1/2)

What you get

- File with telescope *StdEvents*:
  - One Event corresponds to one telescope readout and includes
  - Hits (column, row) from individual layers
  - ID of the trigger that started the readout
- And file with TLU *StdEvents*:
  - Every trigger should yield one event
  - Event includes trigger ID and timestamp
- Or one file with merged telescope and TLU events (when using e.g. TriggerIDSyncDataCollector)

- Things to be aware of:
  - Some hits correspond to particles, some to noise
  - Data analysis needs to be performed by user to get track information from hits
  - One will not necessarily find one track per telescope event
    - Multiple or no tracks also possible



Telescope data (2/2)

What to do with it

Tutorial, F. Feindt,
Tue & Thu afternoon

- Recommend software framework for test beam data analysis is Corryvreckan

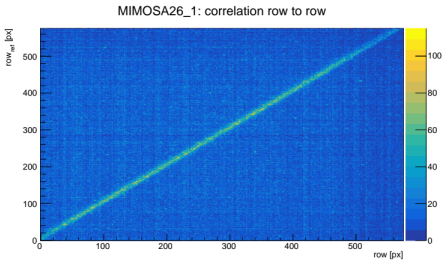
  https://gitlab.cern.ch/corryvreckan/corryvreckan

- User manual & tutorials:
  https://project-corryvreckan.web.cern.ch/project-corryvreckan/

- Reading of telescope data is implemented (requires EUDAQ2 installation)

- User must implement *EventLoader* module for DUT data

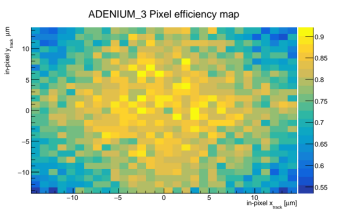
  Script to produce dummy module in repo:
  corryvreckan/etc/addModule.sh




```
[Tracking4D]
track_model="gbl"
momentum=4GeV
min_hits_on_track = 6
spatial_cut_abs = 200um, 200um
exclude_dut = true
unique_cluster_usage=true

[AlignmentTrackChi2]
```

```
orientation = -0.0405081deg,0.0308251deg,0.617706deg
position = 404.777um,3.063um,-404mm
```



Closing remarks

Contacts and additional information

- For questions ahead of beam time:
  telescope-coor@desy.de
- For on-site support:
  telescope-support@desy.de
- Confluence (under development):
  https://confluence.desy.de/display/BTDITB/Home

Call for your support

- If you publish or present results based on data taken at the DESY II Test Beam, please include the following acknowledgement:

  “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).”

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA no 101004761.