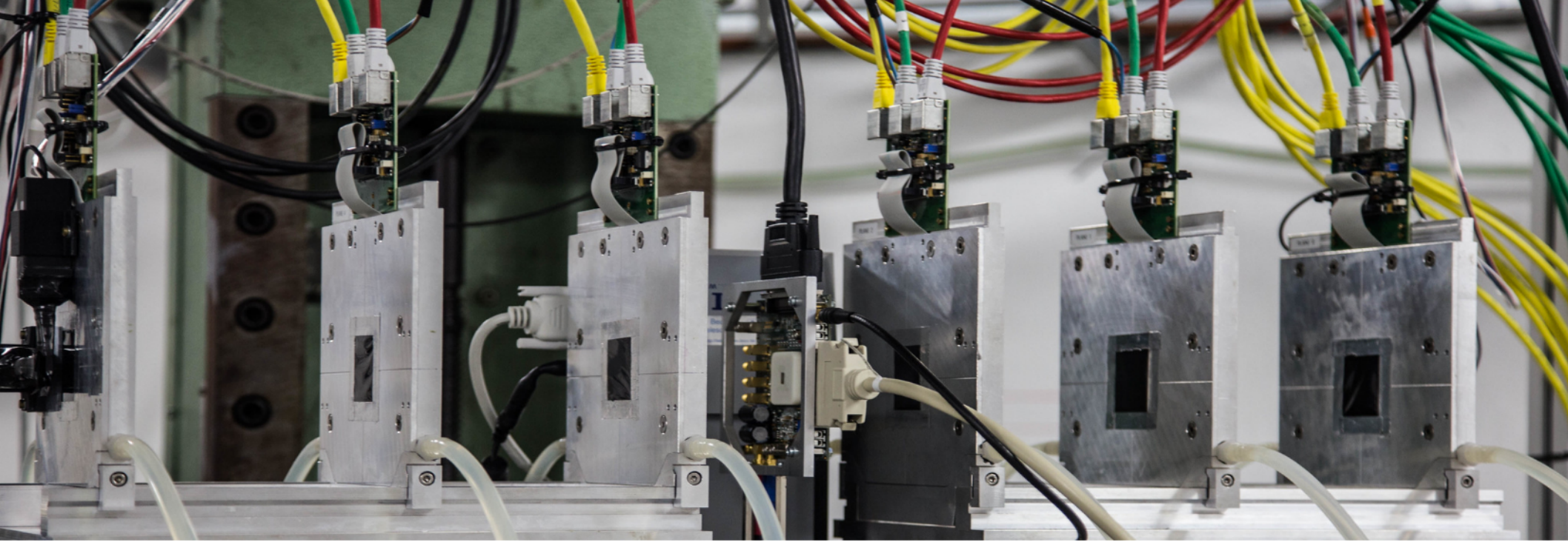


EUDET-Type Beam Telescopes and Beyond

Adrian Herkert on behalf of the DESY telescope crew

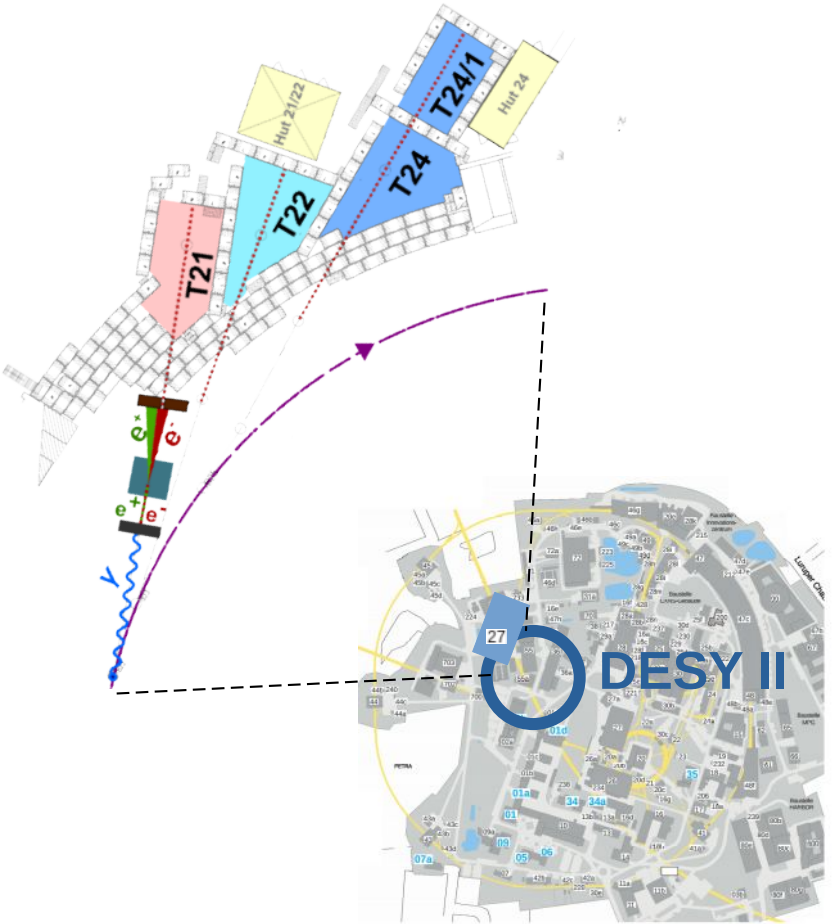
BTTB10, 20 June 2022, Lecce

HELMHOLTZ AIDA innova DESY.

The DESY II Test Beam Facility

Reminder

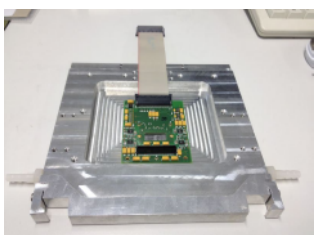
- Dedicated talk earlier today **R. Diener, 3:00 PM**
- Test beam user facility
  - Located in Hamburg, Germany
  - Open ~ 40 weeks per year
  - 3 independent beam lines
- $e^{+/-}$, momenta between 1 and 6 GeV
- Up to $\mathcal{O}$(10,000 particles s^{-1} cm^{-2}) (energy dependent)
- EUDET-type beam telescope in each area
  - 50 µm MAPS → Small amount of material in beam
  - Used for ~ ¾ of all beam times



EUDET-type beam telescopes (1/3)

System overview

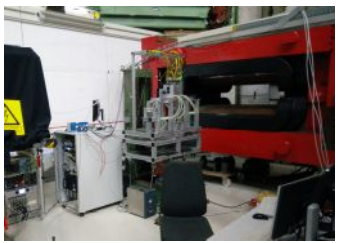
- 6 layers of MIMOSA26 monolithic active pixel sensors (MAPS)
  - ams 350 nm CMOS process
  - Sensor size: 2 cm x 1 cm
  - Thickness: 50 µm
  - Pixel size: 18.4 µm x 18.4 µm
  - Rolling-shutter RO (115 µs per cycle, 2 cycles read out per trigger)
    - Other than that no hit time information
- DAQ based on NI crate, trigger logic unit (TLU) and EUDAQ software



EUDET-type beam telescopes (2/3)

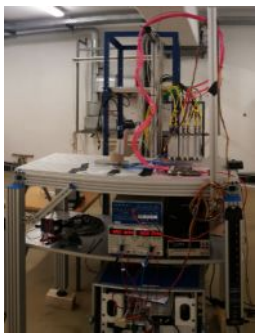
Current locations

- DESY (3)



- CERN (2)


- ELSA (Bonn) (1)



- SLAC/ TRIUMF (1)

Azalea: Back to CERN this summer

AIDA-2020-managed

Self-managed

EUDET-type beam telescopes (3/3)

Current status

On the upside ...

- Stable operation since many years
- Large user base at CERN and DESY with lots of experience, working EUDAQ producers, etc.
- Still excellent spatial resolution (down to ~ 2 µm) due to
  - small pixels
  - thin monolithic sensors

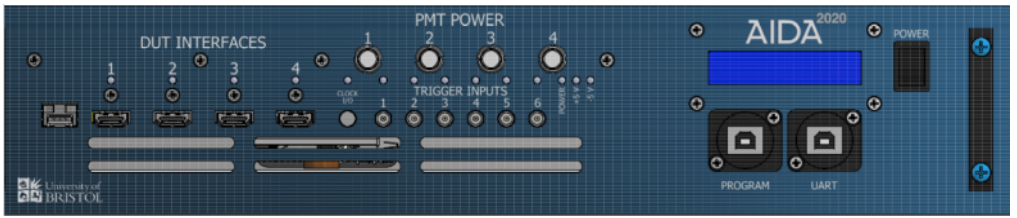
  also at lower energies (DESY)

Drawbacks & concerns

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

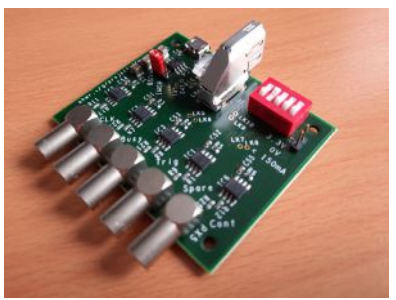
AIDA Trigger Logic Unit (TLU) (1/2)

I/O & modes of operation



- 6 trigger inputs
- 4 DUT channels
  - HDMI with CALICE standard pinout
  - RJ45 adapters & LEMO breakout boards available
- Operable in
  - handshake (EUDET) mode or
  - synchronous mode,

  both with option to send trigger numbers
- Talk on next (similar) version: **D. Cussans, Tue, 10:20 AM**



AIDA Trigger Logic Unit (TLU) (2/2)

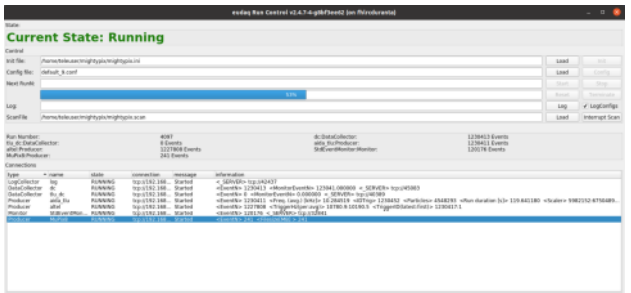
Production & where to find operation instructions

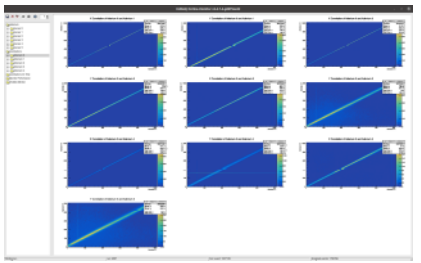
- Production of ~ 30 pieces finished this spring
  - All sold, shipping done
  - Currently no second production run planned
- User manual:
  https://ohwr.org/project/fmc-mtlu/blob/master/Documentation/Main_TLU.pdf
- Integrated in EUDAQ2
  - Example config files in eudaq repo in user/eudet/misc/conf/aida_tlu/
- Hands-on tutorial on EUDAQ2 and TLU: **L. Huth, Thu, 2:00 & 4:30 PM**
- A word of caution:
  There is **NO** fully working EUDET TLU at DESY anymore.
  If you have still been relying on one, please make the switch as soon as possible.

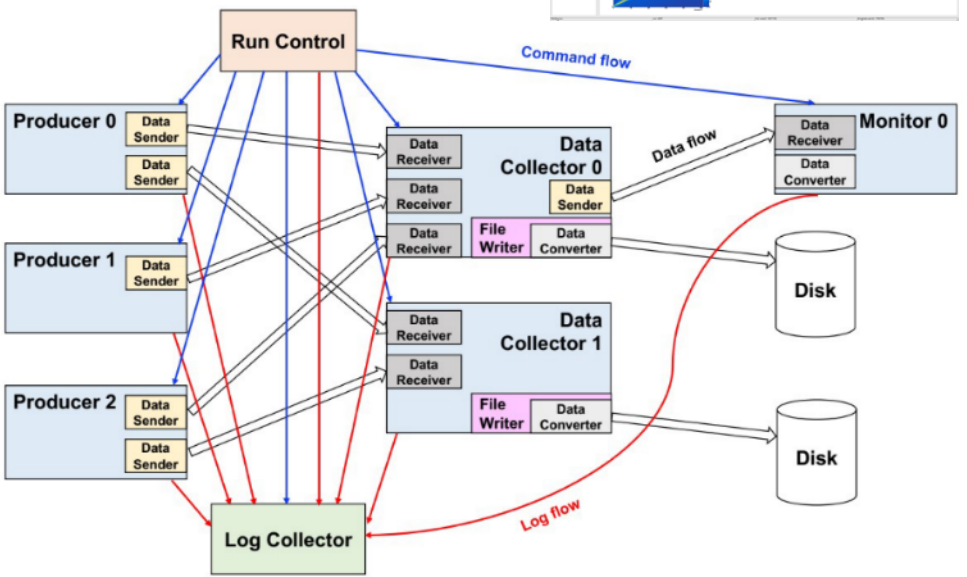
EUDAQ2

Architecture

- *Run Control* is central instance that steers all other components within the network
- *Log Collector* is the other central instance that collects log messages
- A physical device is represented as implementation of a *Producer*
- Data from producer are converted to *StdEvent*s via a *Converter*
  - Can then be interpreted by *StdEventMonitor* for basic data quality checks
- *Data Collector*s write data to disc – either directly or merged data streams from different detectors (e.g. by *TriggerID*)

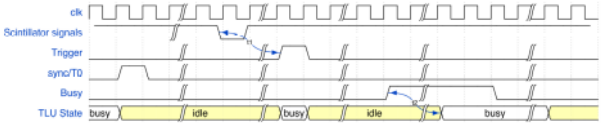






DUT integration

and some common misconceptions



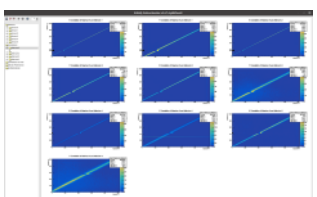
from TLU Manual

- EUDAQ / TLU a priori independent software framework / hardware module
- DAQ of EUDET-type telescopes built around them because they represent a flexible interface for DUTs or any other additional detector (e.g. timing layer)
- EUDAQ does **NOT** replace the DAQ system of a DUT. It just provides a framework to interface several systems
- EUDAQ also does **NOT** provide telescope track information → For that one has to run offline analysis software
  - We recommend Corryvreckan

Tutorial, F. Feindt, Tue & Thu

- Integration on hardware level:
  - TLU trigger
  - TLU clock, T0, …
- Integration in EUDAQ:
  - Implement *Producer*
    - Use Init, Config, Start, Stop signals
  - *Converter*: ‘raw’ data → *StdEvents*
  - Examples in repo!

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



Telescope development

Goals within the scope of AIDAinnova

- Upgrade EUDET-type telescopes with best suited current option for a pixel sensor: ALPIDE
  - Monolithic
  - Small pitch (29.24 µm x 26.88 µm)
  - Highly available
  - Well characterized
  - ~ 10 times faster readout than MIMOSA26
- Long-term: Upgrade with new state-of-the-art MAPS (still to be developed)
- Development of new small-pitch MAPS

- Development of fast timing layers for the EUDET-type telescopes
  - Timepix4
  - LGADs

M. van Beuzekom 6:20 PM

- Fast timing support by
  - TLU
  - EUDAQ2
- New online monitoring for EUDAQ2
- ...

A new ALPIDE-based telescope

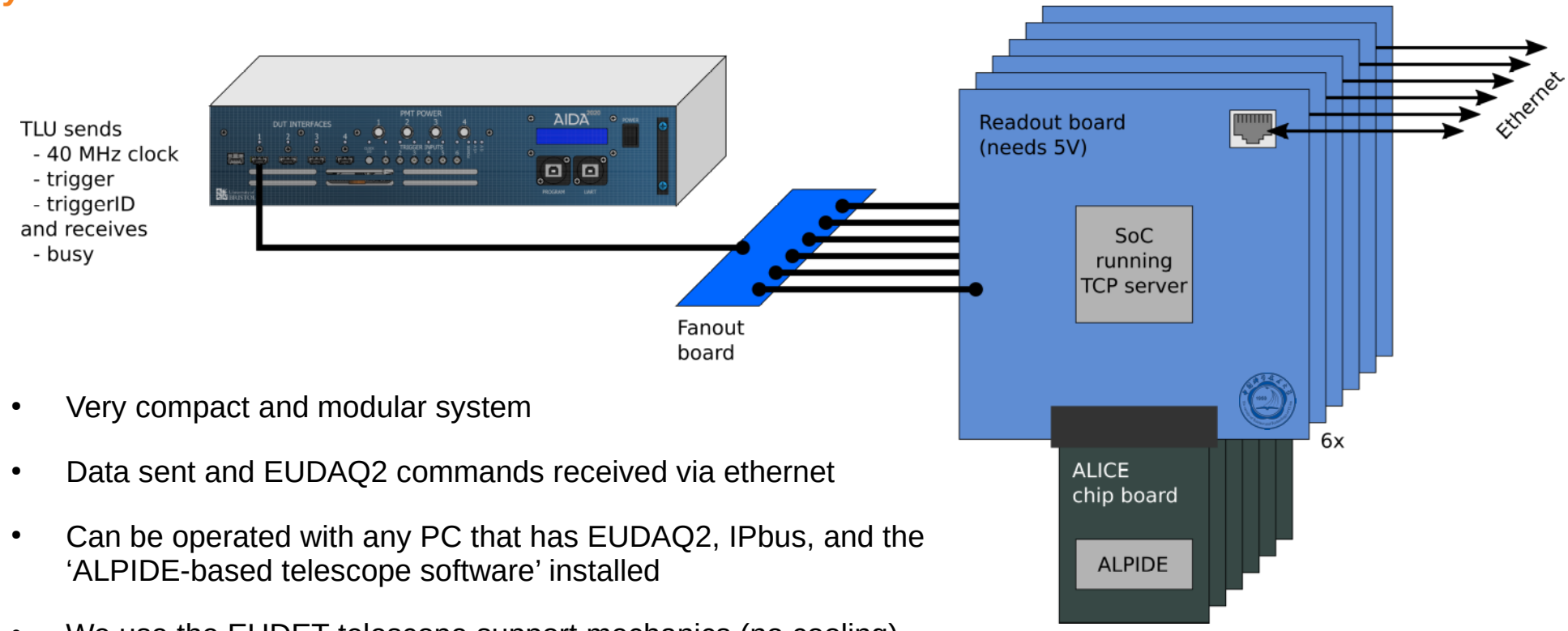
First prototype

- DESY Hamburg finally got an end-user license allowing us to buy and use ALPIDE sensors
- We received the first couple of bonded sensors, thanks to the ALICE collaboration
- Readout board, firmware, software for prototype prepared by Yi Liu and USTC
- From user's perspective in terms of operation the prototype looks like EUDET-type telescope
  - There is even the option available to mimic the M26 data format

- It was already successfully used by first user group
- It will replace Azalea at DESY so we'll remain with one telescope per beamline

ALPIDE-based telescope prototype (1/2)

System overview



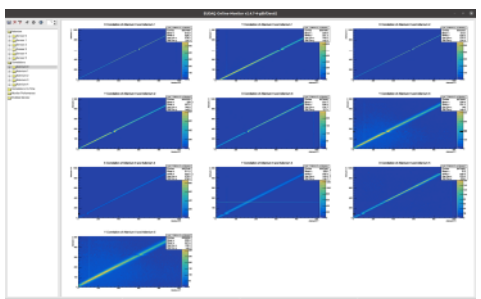
- Very compact and modular system
- Data sent and EUDAQ2 commands received via ethernet
- Can be operated with any PC that has EUDAQ2, IPbus, and the ‘ALPIDE-based telescope software’ installed
- We use the EUDET telescope support mechanics (no cooling)

ALPIDE-based telescope prototype (2/2)

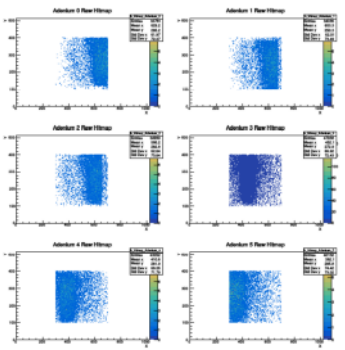
First results

- Rate capability
  - Up to ~ 10,000 triggers/s → ≲ 1 track/event
  - ~ 35,000 triggers/s tested with additional timing layer and data quality was found to be good
  - 90,000 triggers/s runs without crashing, but data still needs to be checked

Correlations



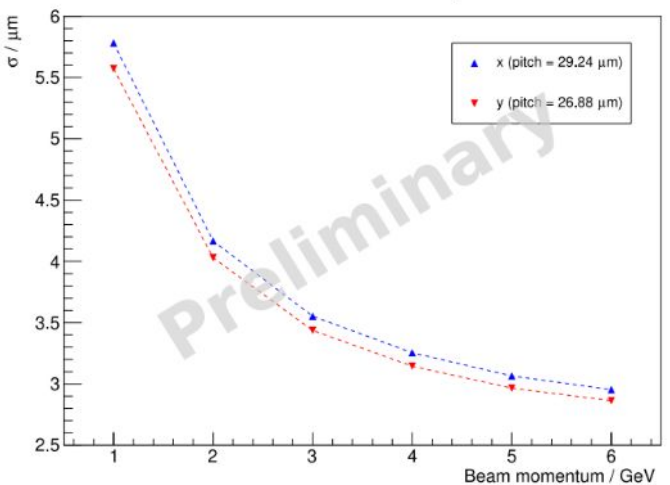
Hitmaps (RoI mask)



Determined using GBL and 7th layer:

- $\sigma_{intrinsic} = sqrt(\sigma_{biased} * \sigma_{unbiased})$
- $\sigma = sqrt(\sigma_{unbiased}^2 - \sigma_{intrinsic}^2)$

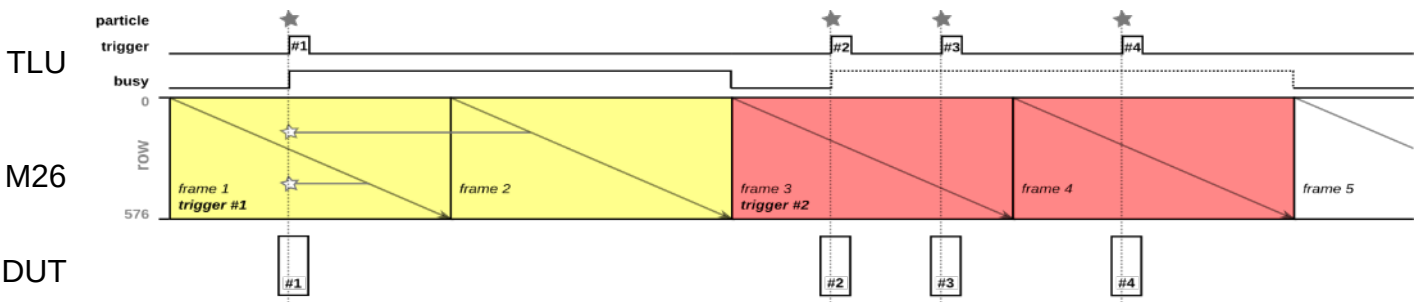
Track resolution at DUT position



Timing layers (1/3)

Introduction

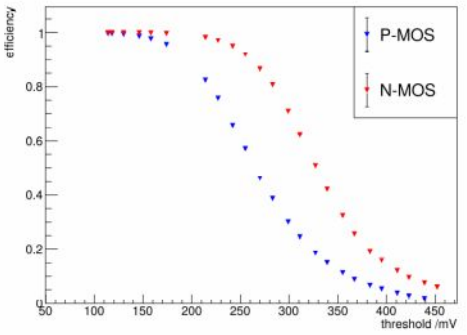
- What for?
  - Timing-based studies
  - Increase data taking efficieny
    - Register multiple triggers while telescope is busy (ignoreBusy + TriggerID)
    - Telescope tracks can be associated with correct trigger by using additional time information in tracking
- Already established:
  - FEI4 (25ns frames, trigger): Setup available at DESY but no expertise in operating it (several user groups have expertise themselves)
  - Timepix3 (σ ≈ 1ns, no trigger): Currently one setup available at DESY but used also outside of the test beam

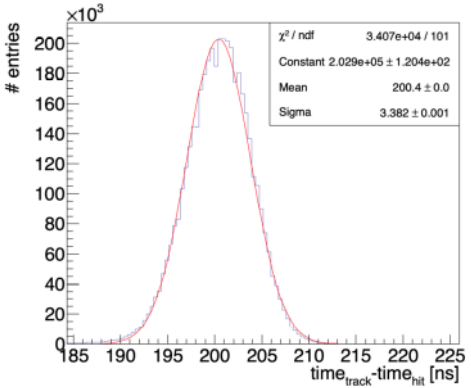


Timing layers (2/3)

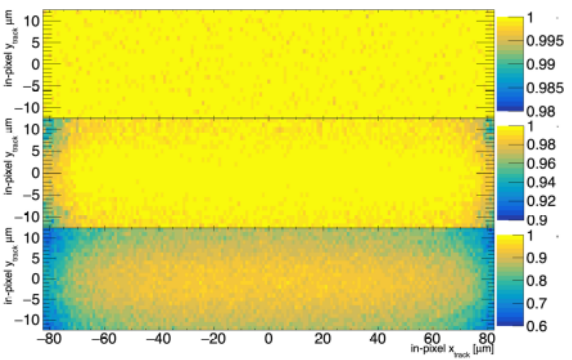
TelePix

- HV-MAPS (180nm HV-CMOS process)
  - Designed at KIT and Uni Heidelberg
- Small scale demonstrator (~ 5mm x 3mm)
- Pixel size: 160µm x 25µm
- ToA measurement: σ ≈ 3.4ns
- Trigger output:
  - Delay compared to scintillator+PMT: ~ 25ns
    - Fluctuation with σ ≈ 4ns
- Individual pixel masking capability allows for realization of a region-of-interest trigger
- Full-scale version funded and awaited for this year





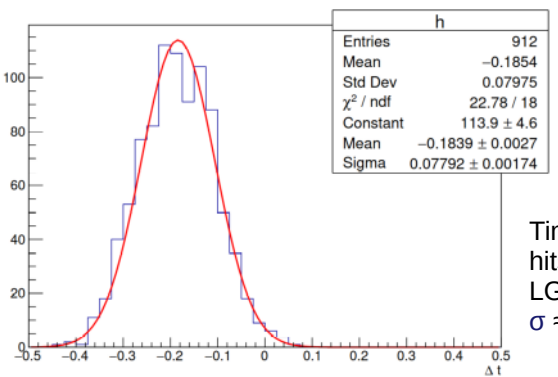
Efficiency within pixel for 3 different thresholds



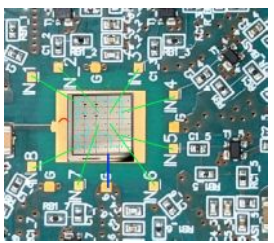
Timing layers (3/3)

LGADs

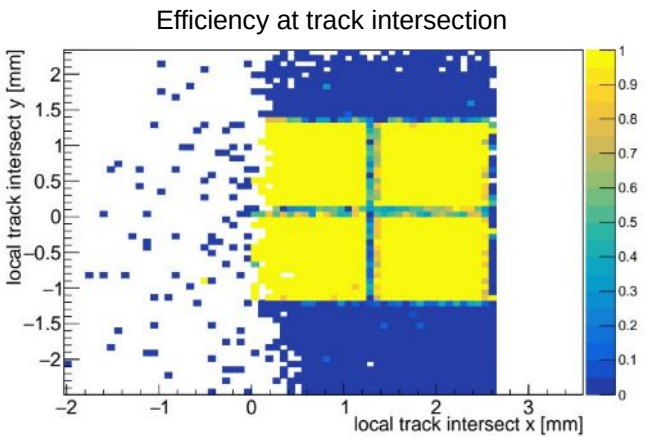
- First tests with commercial LGAD arrays (Hamamatsu), thanks to UCSB
- 5 x 5 diodes per array, 1.3mm pitch
- Four diodes read out via four channels of a digital waveform analyzer



Time difference of hits in two consecutive LGAD arrays, $\sigma \approx 77$ps



- Nice example for a rather rudimentary integration into EUDET-type telescope system:
  - Trigger ID decoded from the stored waveform sent by the TLU



Summary

EUDET-type beam telescopes

- Important part of test beam infrastructure at CERN and DESY
  - Large user bases
  - Stable operation
  - Excellent spatial resolution
- But:
  - Precise time information missing
  - Several components approaching end-of-life

Beam telescope development

- First ALPIDE-based prototype
  - Successfully tested by users
  - Will replace Azalea at DESY
- Work on several new options for timing layers ongoing
  - TelePix (HV-MAPS)
    - Full-scale version expected for this year
  - LGADs

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