Evolution of EUDET-type telescopes and future plans

Common beam telescopes, DAQ and reconstruction tool

Jan Dreyling-Eschweiler (DESY) for the DESY telescope and test beam crew
BTTB6, Zurich, Switzerland, January 17th 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY TEST BEAM. AIDA 2020

DESY

2 goals of this talk

State of the EUDET-type beam telescope package as an infrastructure

Trigger the community for a future joint effort

DISCLAIMER: This talk is mainly based on my experience since 2015 and my historical research.

Starting in 2006 with EUDET

Building up an infrastructure for EUropean DETector research & development

Available online at www.sciencedirect.com
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ELSEVIER
Nuclear Instruments and Methods in Physics Research A 569 (2006) 53–56
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

A pixel telescope for detector R&D for an international linear collider

Tobias Haas

Deutsches Elektronensynchrotron, D-22603 Hamburg, Germany

Available online 2 October 2006
for the EUDET Collaboration

Abstract

A beam telescope based on monolithic active pixel technology will be developed within the EUDET collaboration, a coordinated detector R&D programme for a future international linear collider. The telescope will consist of up to six sensor planes. The telescope

Tobias Haas (2006), https://doi.org/10.1016/j.nima.2006.09.011

Starting in 2006 with EUDET

Building up an infrastructure for EUropean DETector research & development

Initial motivation and plan

- Tool of detector R&D for **linear** collider
  (DUTs: CCD, DEPFET, CMOS...)
- Source of **1-6 GeV** electrons or other
- Operating in a **magnetic** field
- Using **pixel** sensors for **3+3** planes
- **Infrastructure** for trigger, integration and readout

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DUT = Device under test

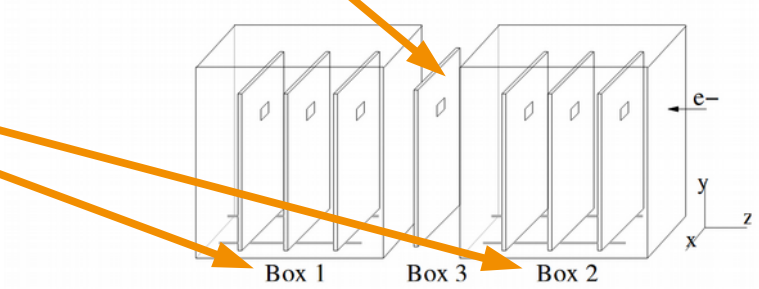


Figure 5: Mechanical concept with three separate areas for the two reference arms and the DUT.

Ingrid Gregor (2007), EUDET-Report-2007-05

Proposed & realized layouts...

... to meet the test needs

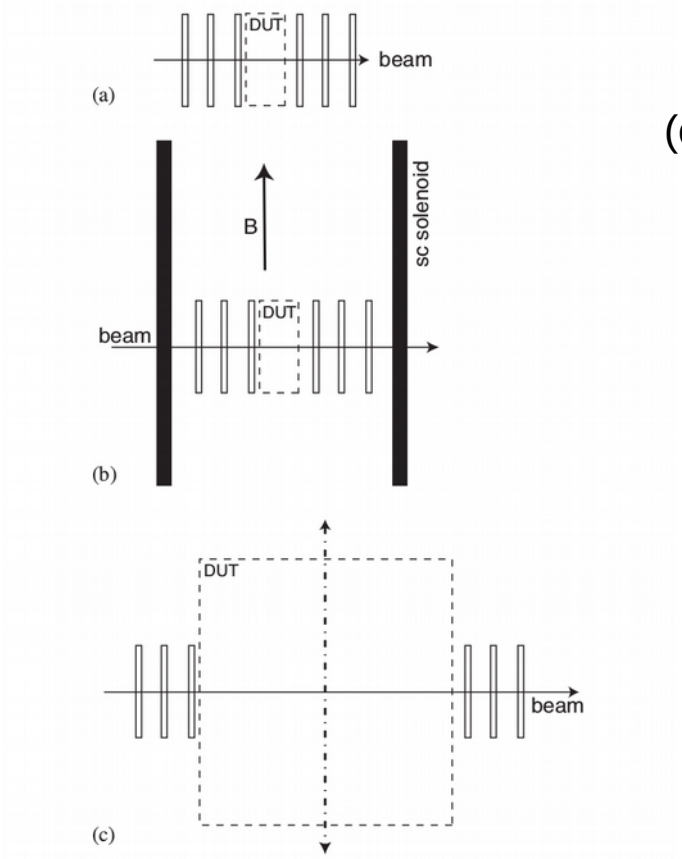


Fig. 2. Three foreseen layouts for the beam telescope; (a) a compact layout for characterization of high precision devices, (b) a compact layout inside a magnetic field and (c) a two-arm geometry for the use with larger DUTs.

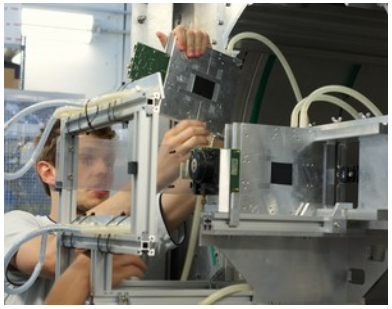
T. Haas (2006), https://doi.org/10.1016/j.nima.2006.09.011
I. Gregor (2007), EUDET-Report-2007-05

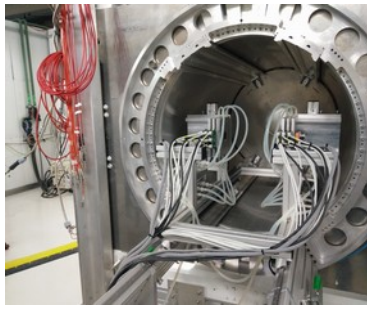
Standard setup
(e.g. spatial resolution)

DUT < 0.5m
dz = 2-150mm

Magnet setup
(e.g. Lorentz angle)

DUT < 0.3m
dz = 2-100mm





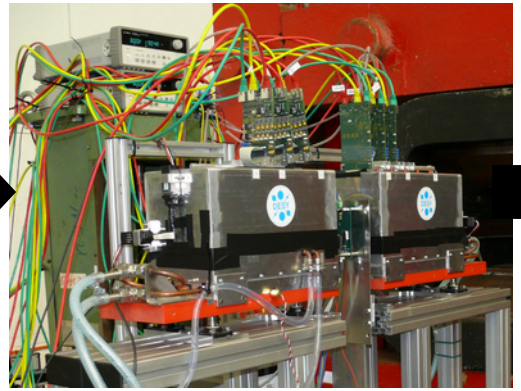
Two-arm geometry
(e.g. e/γ-separation)

"DUT" > 0.5m
dz = 2-150mm

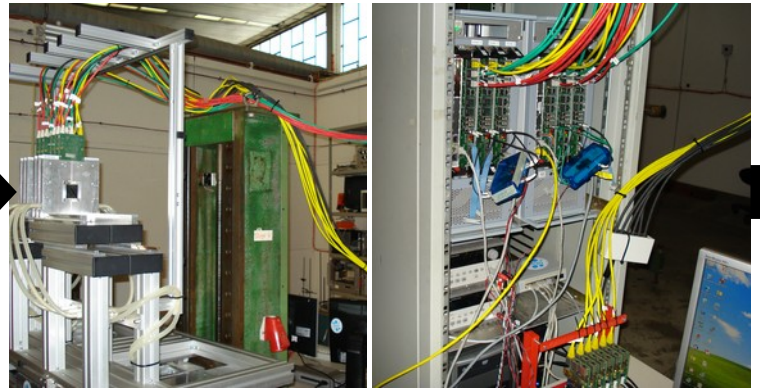
Device Evolution

Prototyping – commissioning – development and optimization

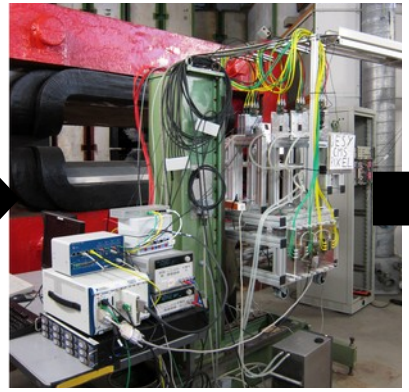
2007 3-plane demonstrator



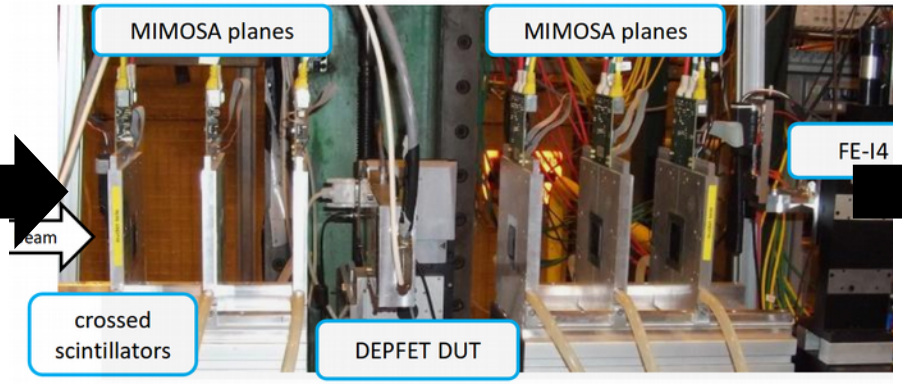
2009 Mimosa26-prototype



2011 mechanics and EUDRB DAQ



2012 final mechanics and NI DAQ

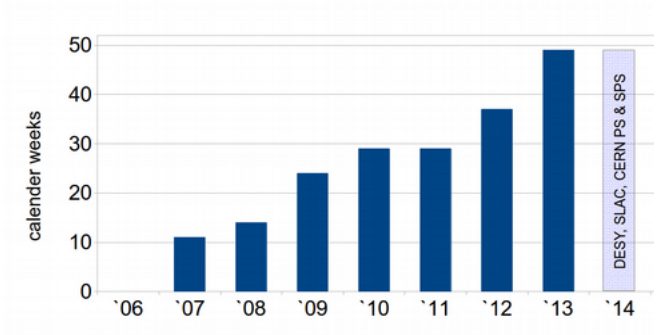


2012 user-driven extensions

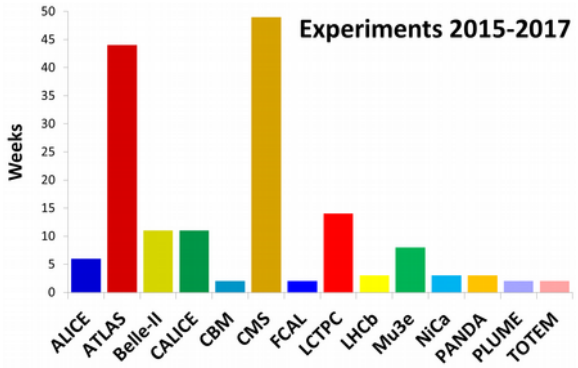
2016 "pre-commercial" optimization

Usage & infrastructure evolution

User demand, devices and people



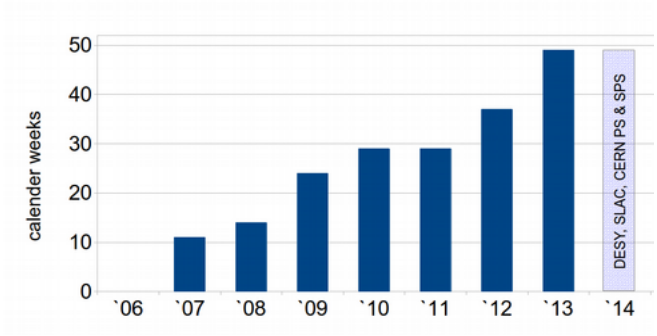
Total telescope demand analysed by *Igor Rubinsky*



At the DESY test beam incl. **75% telescope usage**

Usage & infrastructure evolution

User demand, devices and people



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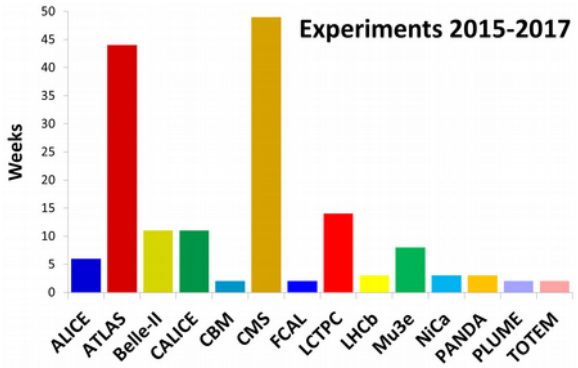


At the DESY test beam incl. **75% telescope usage**

2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

EUDET | AIDA | AIDA2020 ?

Prototype | Demonstrator

1st telescope EUDET-type (Mimosa26, NI COTS) → "AIDA" telescope now at SPS

2nd telescope "ANEMONE" for Bonn

3rd telescope "DATURA" at DESY

4th telescope "ACONITE" for ATLAS now at SPS

5th telescope "CALADIUM" now at SLAC

6th telescope "DURANTA" at DESY

7th telescoppe "AZALEA" at PS

"BTTB1" "BTTB2" BTTB3 BTTB4 BTTB5 BTTB6

*T. Haas, **I. Gregor**, …* — *Hanno Perrey* — ***Hendrik Jansen*** ?

Igor Rubinsky — ***Jan Dreyling-Eschweiler*** ?

E. Corrin, … — *Simon Spannagel* — ***Andre Rummler*** ?

Richard Peschke — *Yi Liu* ?

Tobias Bisanz ?

EUDET-type telescopes family today

Seven copies around the world at 5 different beam test beam facilities

Talk by Mengqing (Thursday)

Talk by Meng-qing/Uwe

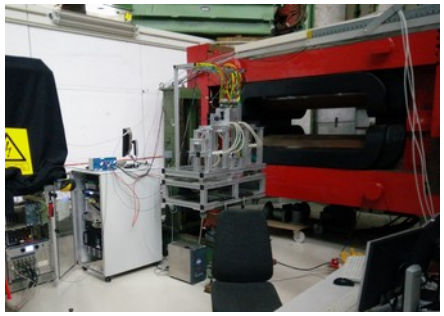
Talk by Ralf (yesterday)

Carleton UNIVERSITY

SLAC NATIONAL ACCELERATOR LABORATORY

Contact:
Carsten Hast

CALADIUM @ SLAC in Stanford, USA



DATURA @ TB21

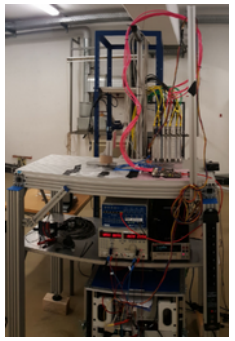
DURANTA @ *TB22*

TB contact:
Ralf Diener, Norbert Meyners, Marcel Stanitzki
Telescope contact:
Hendrik Jansen, Jan Dreyling-Eschweiler

AZALEA @ PS, T10

AIDA @ SPS, H6B

ACONITE @ SPS, H6A



ANEMONE @ BONN / ELSA

Talk by Dennis (yesterday)

ELSA

SI LAB Silizium Labor Bonn

TB contact:
Daniel Elsner
Telescope contact:
David-Leon Pohl

CERN

SPS/PS contact:
Henric Wilkens
Telescope contact:
André Rummler

Talk by Maarten (this morning)

Talk by Alexander (this morning)

Behind this story: Joint effort of experts

Sensor, trigger and DAQ R&D, integration and development

From 2006: initial EUDET packages

- Pixel Sensor (CNRS/IPHC Strasbourg)
  from Mimotel to ***Mimosa26***
- Sensor DAQ (DESY, CNRS/IPHC)
  from EUDRB (VME64x) to ***NI DAQ***
- ***Mechanics*** and integration (DESY)
- Synchronization (Univ. of Bristol)
  trigger logic units: ***EUDET TLU***
- Common DAQ software (DESY)
  EUDAQ version 1
- ILC Software (DESY)
  LCIO, Gear, Marlin – ILCSoft

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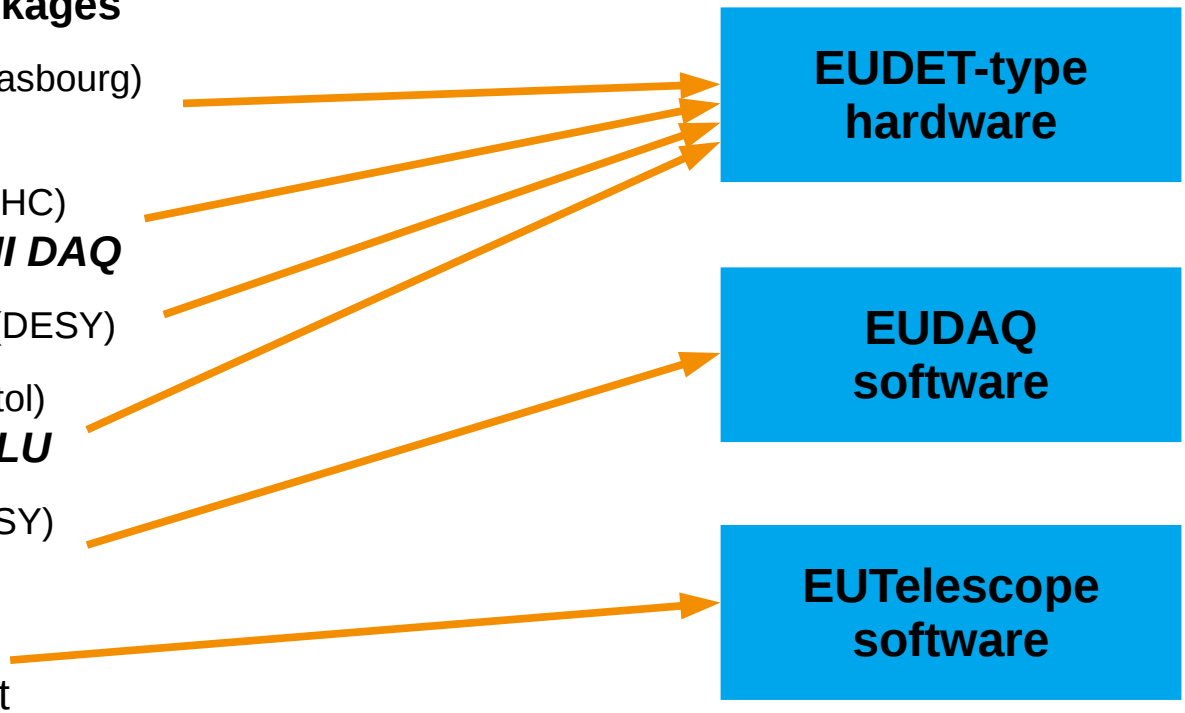

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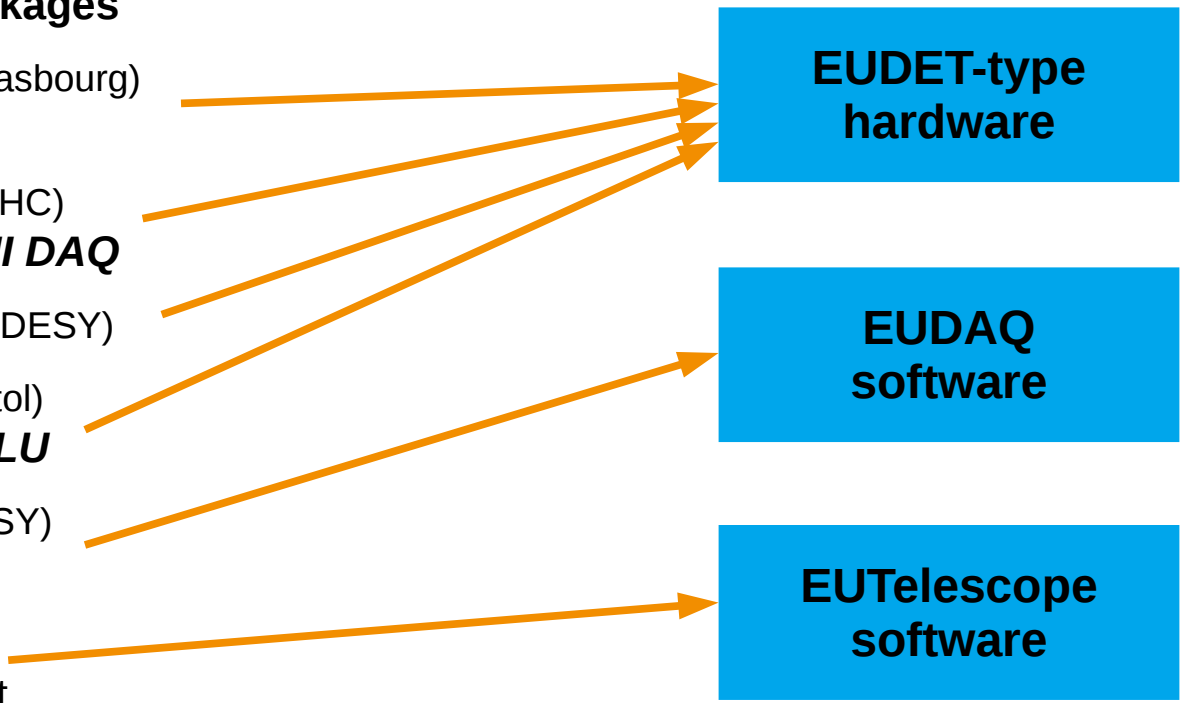

From 2009: Infrastructure improvements & User-driven development

- Upgrades: EUDAQ2 + AIDA TLU
- FEI4 as timing plane and ROI trigger
- Many more…

The common EUDET-type package

Common DUT integration from data taking over track reconstruction to results

Interfaces

EUDET-type hardware

- DUT integration e.g. at µm-precise stages
- LEMO/RJ45 for TLU communication

EUDAQ version 1

- Producer (DUT interface)
- DataConverter (Online Monitor and analysis interface)

EUTelescope incl. GBL tracking

- DUT implementation
- extensions (e.g. radial strips)

Talk by Edo/ Xiaocong (Friday)

Applications and usage

Many and various **user results** over the last decades!
→ see e.g. BTTB contributions

The common EUDET-type package

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Interfaces

EUDET-type hardware	**EUDAQ** version 1	**EUTelescope** incl. GBL tracking
• DUT integration e.g. at µm-precise stages • LEMO/RJ45 for TLU communication	• Producer (DUT interface) • DataConverter (Online Monitor and analysis interface)	• DUT implementation • extensions (e.g. radial strips)

Talk by Edo (Friday)

Applications and usage

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OUTLINE

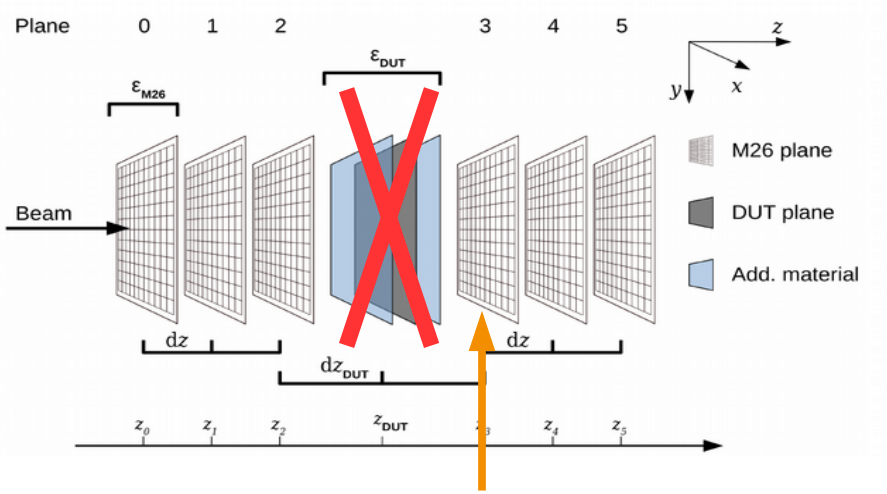
1) No DUT operation for **sensor resolution and telescope performance**

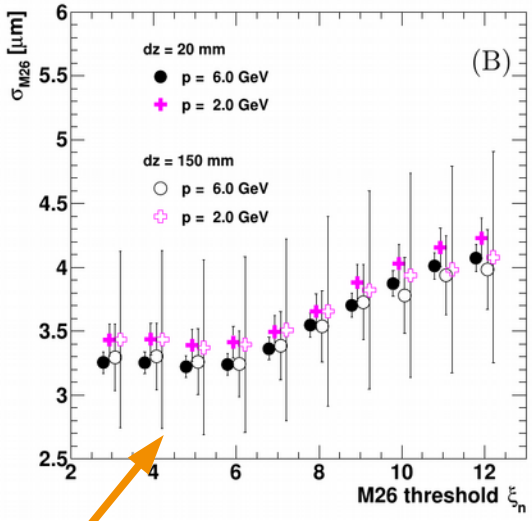
2) Passive DUT (= SUT) operation for **material budget studies**

3) Data taking performance: Upgrades towards **higher rates...**

1) Sensor resolution and response

Mimosa26 characterization





Jansen, H. et al. EPJ Techn Instrum (2016) 3: 7. https://doi.org/10.1140/epjti/s40485-016-0033-2

Mimosa26 sensor as DUT

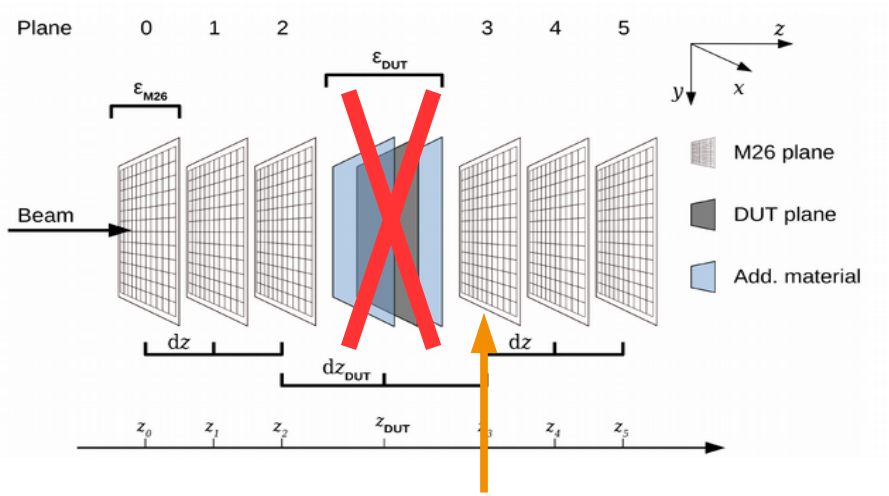
- MAPS (binary AMS 350 nm CMOS)
- 1152x576 pixels, ~20 mm x 10 mm area
- pitch: **18.4 µm** → binary resolution: **5.3 µm**

Results using GBL tracking

- avg. intrinsic res. σ_{M26} = **3.24 µm** @ th. 6

1) Sensor resolution and response

Mimosa26 characterization



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Results using GBL tracking

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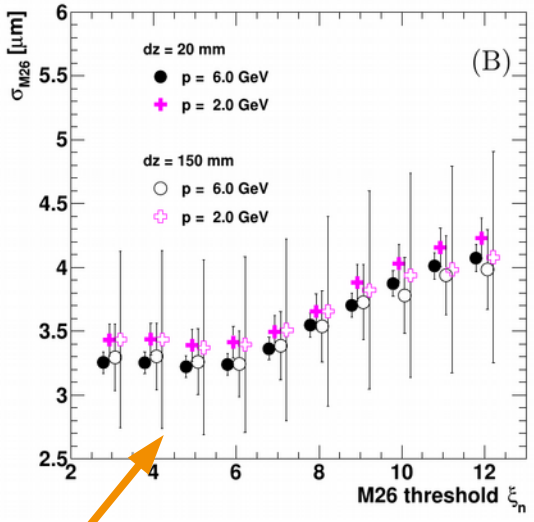
- charge sharing → cluster → intra-pixel distribution
- Allows track resolution predictions...



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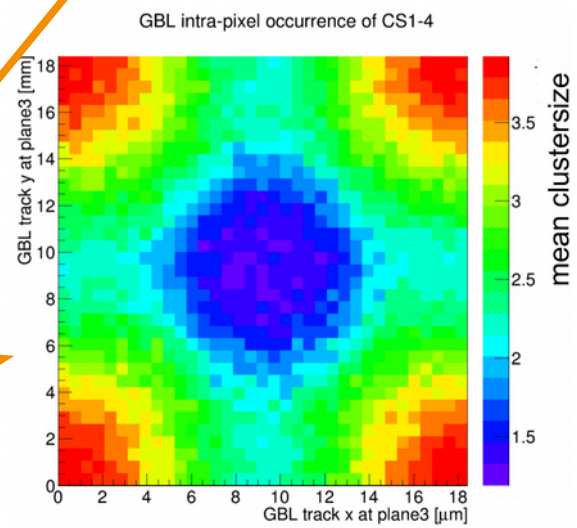
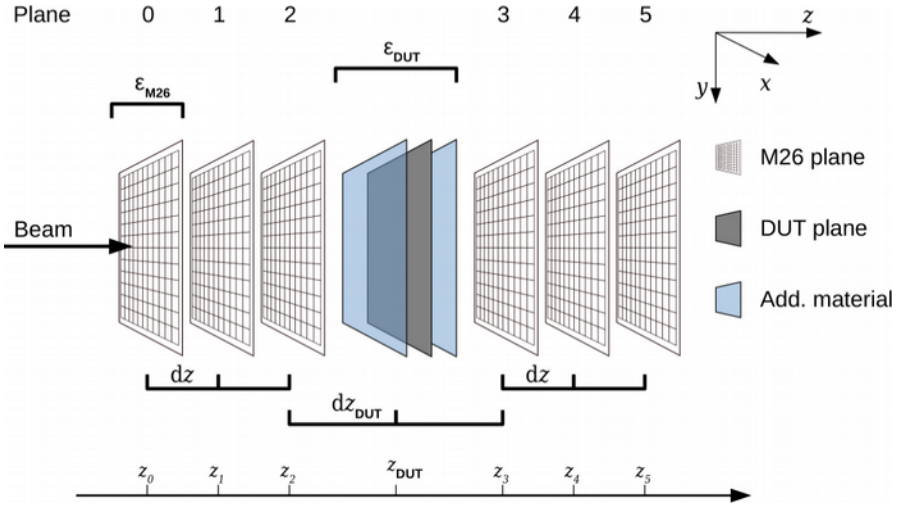
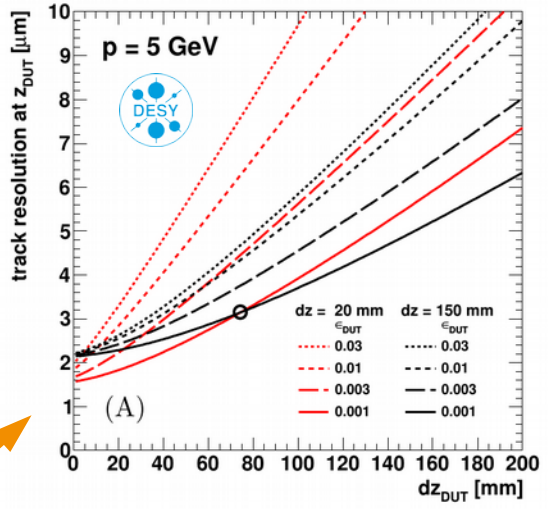


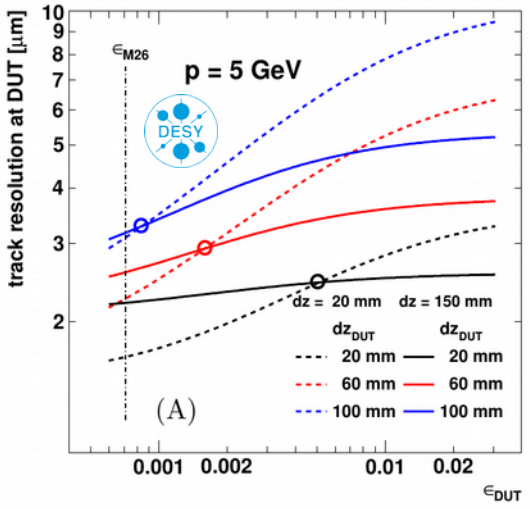
Jansen, H. et al. (2016) PIXEL2016

1) Resolution predictions for users' setup

Telescope characterization







High track resolution through

- high energy and less material
- **small telescope-DUT distance dz_{DUT}**
- **"thin" DUT: narrow** setup (dz ~ 20mm)
  "thick" DUT: wide setup (dz ~ 150mm)

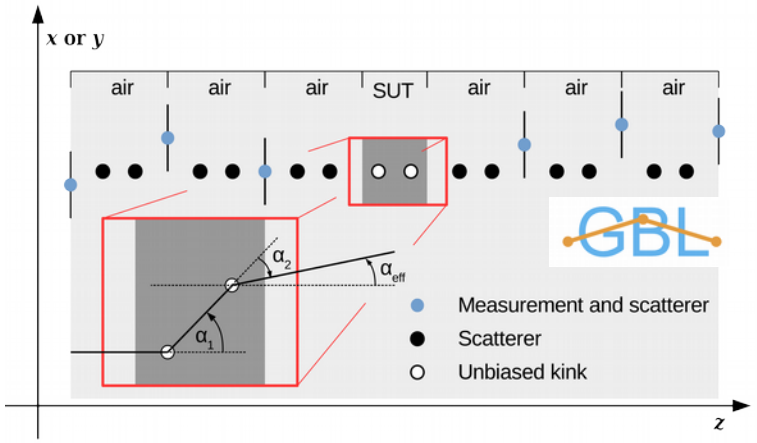
→ Calculate your setup: **goo.gl/kR9VGS**

- depends on multiple scattering ...

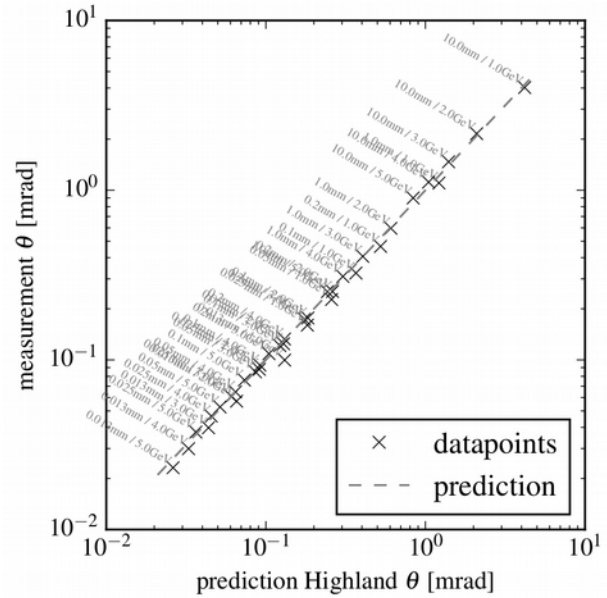
Jansen, H. et al. EPJ Techn Instrum (2016) 3: 7. https://doi.org/10.1140/epjti/s40485-016-0033-2

2) Material Budget studies

DUT → Sample under test (SUT)



Aluminum samples from 13 µm to 1 cm

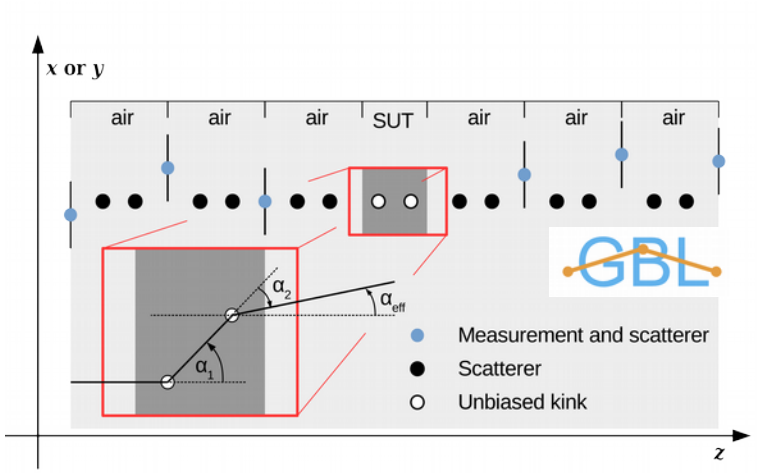


Getting scattering angle Θ

- Track model for GBL, e.g. two scatterers
- Kink angle (α) distribution
- Θ width of distribution

2) Material Budget studies

DUT → Sample under test (SUT)



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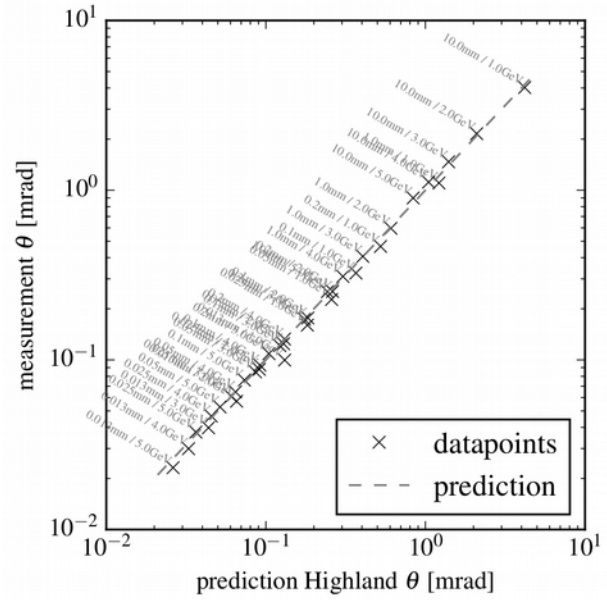

Getting scattering angle Θ

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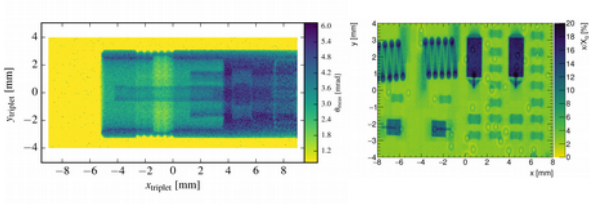
Applications

- X0 measurements
- Imaging (2D or 3D)



Talk by Jan-Hendrik
Tutorial by Michaela

Talk by Hendrik/Paul

Collaborative effort

- X0 scattering day on 30th Nov. 2017
- Exchange with (Benjamin Schwenker, Ulf Stolzenberg) Uni Göttingen

3) Data-taking performance

EUDET mode

EUDET-type hardware ⟷ **EUDAQ 1**

Strategy

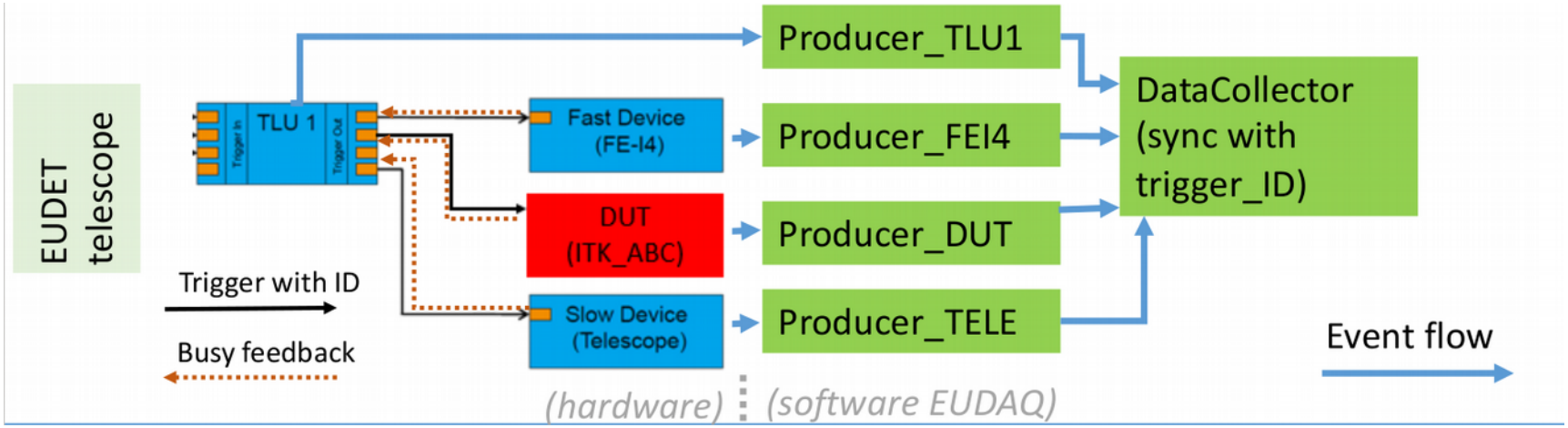
→ trigger from TLU

→ busy for read-out from DUTs

→ one data collector

The data taking is limited by the slowest device.

Exemplary setup



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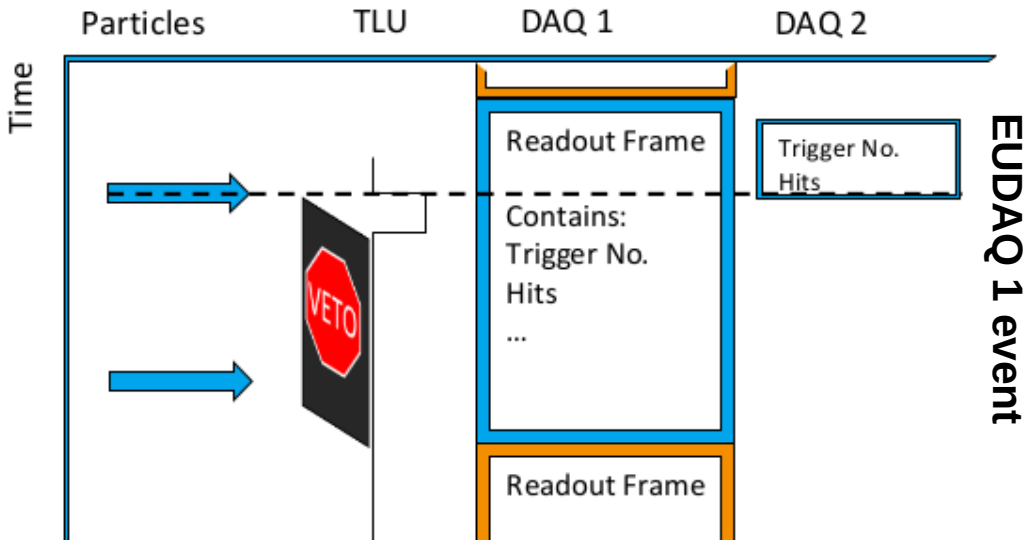
EUDET mode

EUDET-type hardware ⟷ **EUDAQ 1**



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MimosaDAQ:

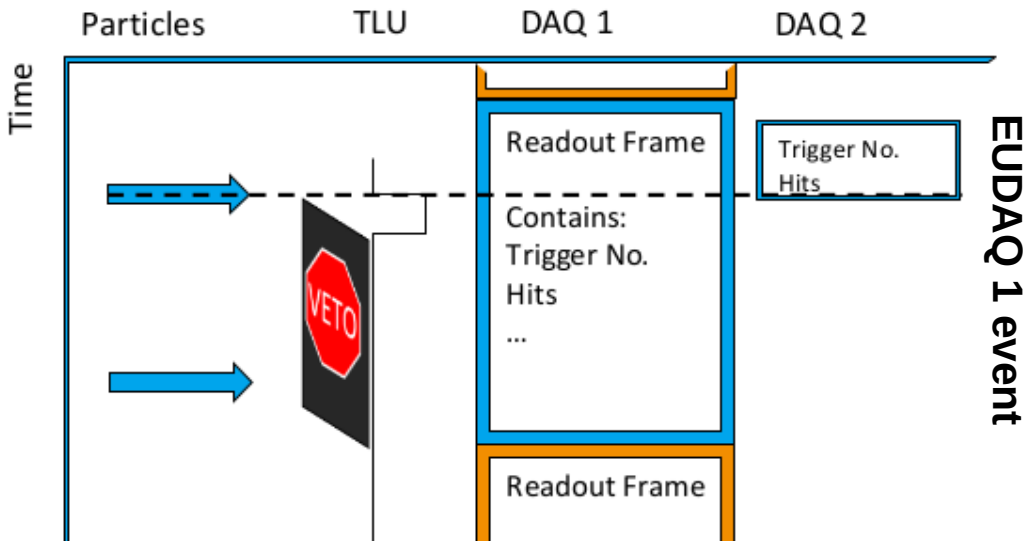
- Mimosa26 is continuously read-out line by line
- Two subsequent Mimosa frames are necessary

→ **Readout time: 2x115.2 µs (= 4.3 kHz)**

3) Data-taking performance

EUDET mode

EUDET-type hardware ⟷ **EUDAQ 1**



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EUDET-type telescope performance:

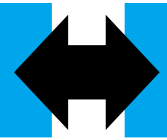
- MimosaDAQ
- EUDET TLU
- EUDAQ 1

~ 2 kHz trigger/event rate at beam conditions

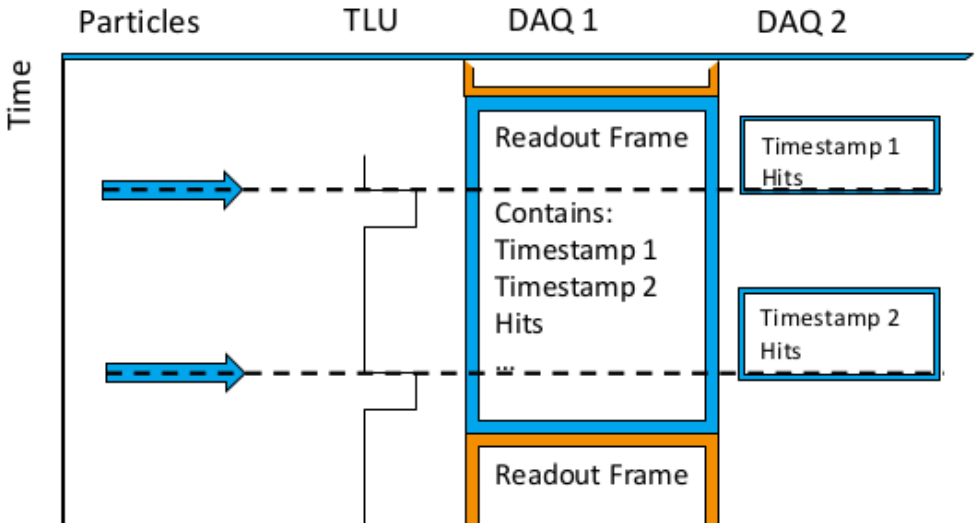
3) AIDA mode: Getting faster…

Towards a higher time resolution

MimosaDAQ
AIDA TLU



EUDAQ 2

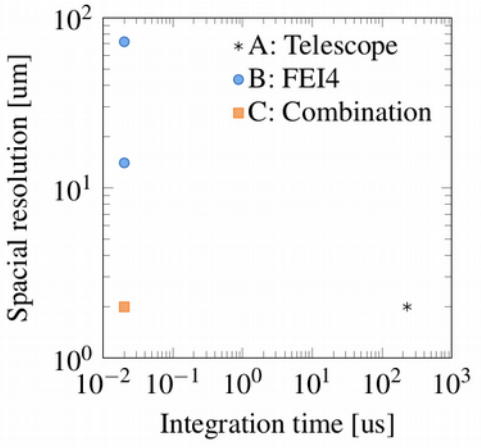


Strategy

→ *triggers* from TLU

→ sync. by a *common clock*

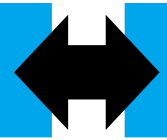
→ opt. *multiple* data collectors



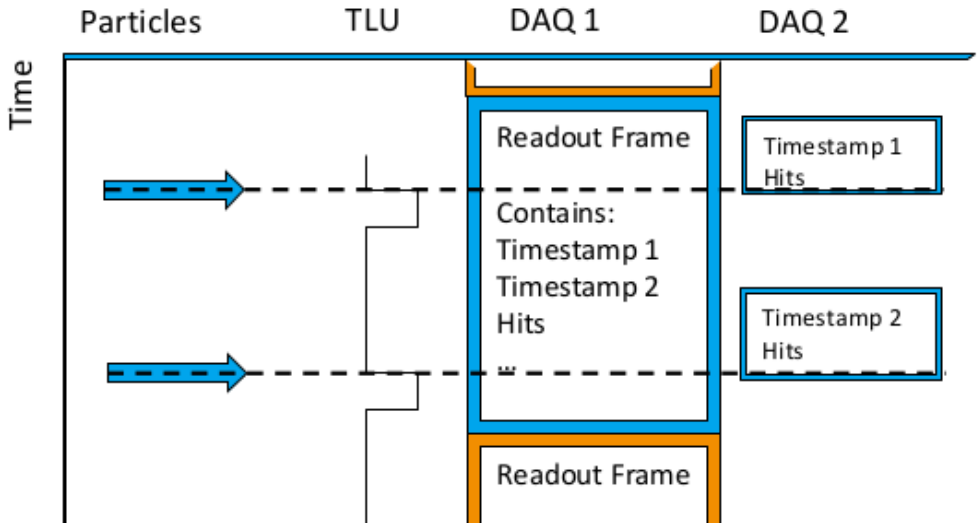
3) AIDA TLU and EUDAQ2

Towards a higher time resolution

MimosaDAQ
AIDA TLU



EUDAQ 2



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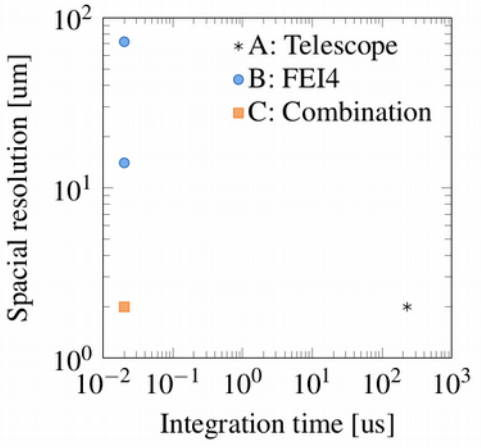


Recent problems & solutions during realisation:

- DUT-DAQ communications has to be updated → *EUDET mode* option
- Limited by slowest device → *individual busy* option

Talk by David on the AIDA TLU

→ **backward compatible for "EUDET-mode-DUTs" with new EUDAQ2 flexibility**

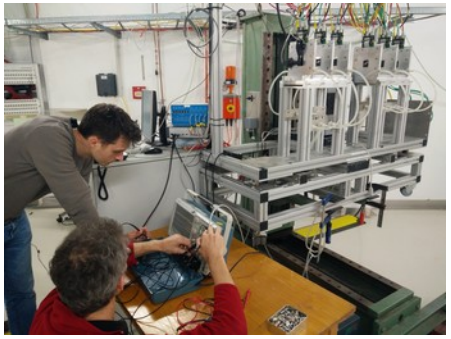
3) Results in 2017 and next steps...

… for a higher trigger rate and time-resolved track rate

MimosaDAQ AIDA TLU ⟷ **EUDAQ 2** → **EUTelescope**

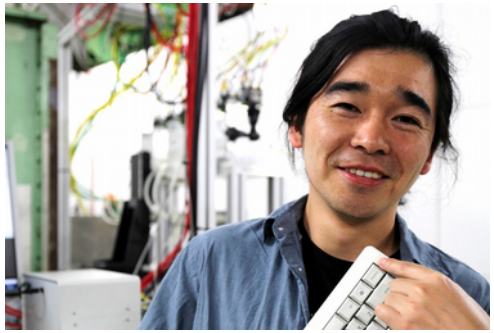
Results in 2017

- AIDA (FMC) TLU v4 ready



Results in 2017

- EUDAQ2 release [*Yi Liu*]



Todos

- Event definition(s)
- External event merger or internal event processor

Next steps

- Further tests for recommended user setup this February
- New Mimosa DAQ incl. FEI4 DAQ? → MMC3 board

Talk by Yannick

Portal & References

- **telescopes.desy.de**

Reference

- **eudaq.github.io**

Reference

- **eutelescope.web.cern.ch**

Lessons learnt

A personal collection

What was good?

- Common infrastructures has enabled detector R&D
- Mimosa26
  - Spatial resolution
  - Material budget → thickness 50 µm
- EUDAQ as common DAQ
- Central coordination, user support and user-driven development
- Community development → BTTB
- Sustainability in Frameworks
  - WP15.2: infrastructure for tracking
  - WP5: common DAQ
  - DESY HEP strategy

Lessons learnt

A personal collection

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- Sustainability in Frameworks
  - WP15.2: infrastructure for tracking
  - WP5: common DAQ
  - DESY HEP strategy

What can be improved?

- Sensor/Timing
  - New technologies (faster, ...)
  - Radiation hardness
- Flexible and robust mechanics
- Reconstruction SW
  - EUTelescope accessibility
  - Scope of reconstruction software
- Data and software interfaces
- Manpower on software maintenance and documentation

Summary and Outlook

Summary

- A common beam telescope infrastructure has been developed in the last decade
- The infrastructure provides
  - common setup and user interfaces
  - high-precision tracking
  - Modular and user-driven development
- The infrastructure is maintained and supported by dedicated experts

Summary and Outlook

Summary

- A common beam telescope infrastructure has been developed in the last decade
- The infrastructure provides
  - common setup and user interfaces
  - high-precision tracking
  - Modular and user-driven development
- The infrastructure is maintained and supported by dedicated experts

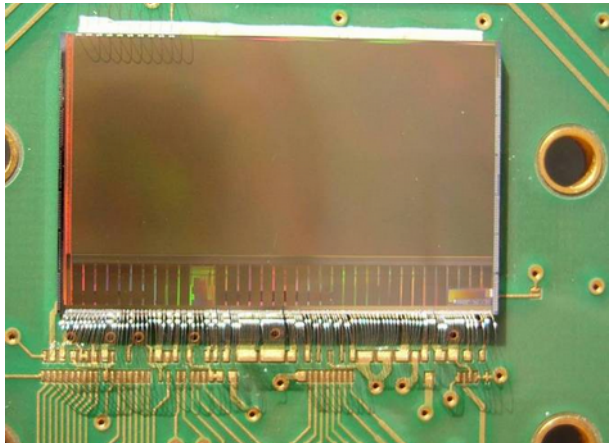
Future Plans

- User release for AIDA TLU – EUDAQ2 – EUTelescope package
- New MimosaDAQ?
  → 8.7 kHz frame rate
- Support in 19/20
- User needs/wishes, JRA Telescope 202x

Forum this evening

Backup

Mimosa 26 pixel sensors

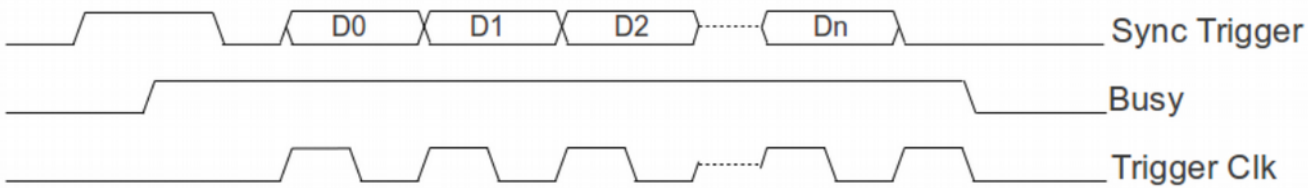


- AMS 350 nm CMOS
- 18.4 um x 18.4 um
- 1152 x 576 pixels
- Roughly 10 mm x 20 mm
- Thickness: specs 50 um, measurement (55 ± 3) um
- HR epitaxial layer of 20 um thickness
- Binary resolution 5.3 um, improved by charge sharing
- Protected by 25 um Kapton on each side
- Material budget of sensor plus Kapton: ε = 7.5e-4

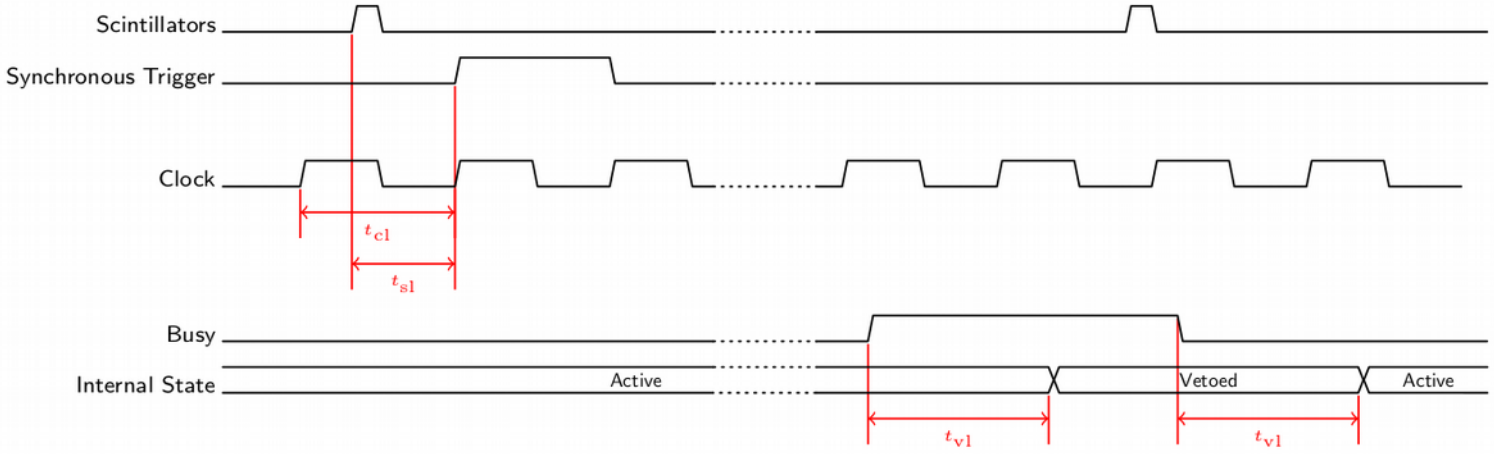
Trigger Logic Unit

EUDET and AIDA TLU

EUDET Handshake (Trigger/busy with trigger number)

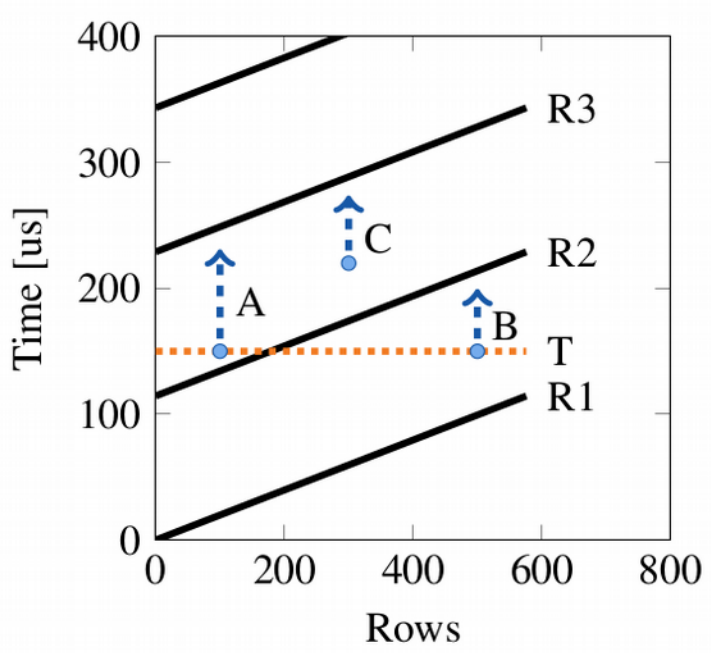


Synchronous mode (New for AIDA TLU)

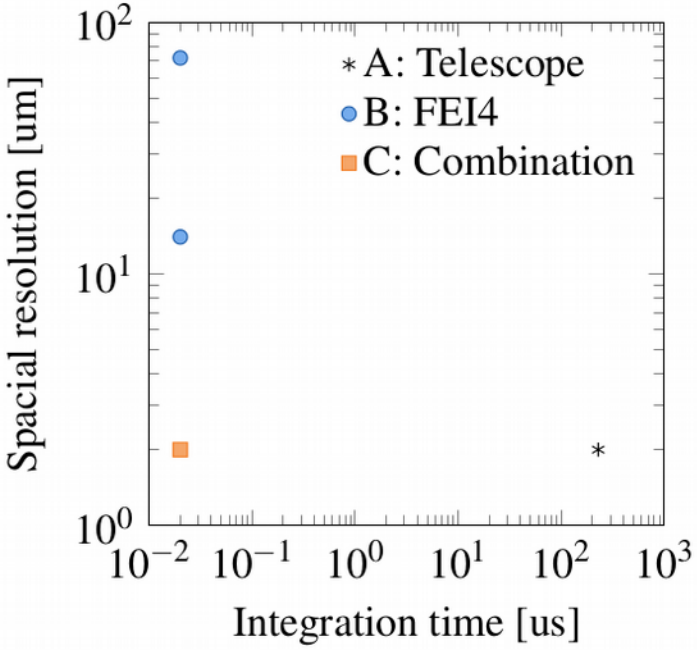


Timing of the telescope

Rolling Shutter and combination with FEI4



(a)



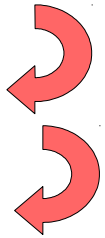
(b)

Figure 6.2 (a) Rolling shutter readout of the MIMOSA26 sensor. [R1,R2,R3] indicate the readout cycles. Hits are indicated with [A,B,C]. [T] trigger time.
(b) Pixel size versus the integration time of the specific readout system. [A] Performance of the telescope with six MIMOSA26 planes. Integration time $\approx 2 \times 114.5\,\mu s$. *Spacial resolution* $\approx 2\,\mu m$. *[B] ATLAS FEI4 APIX sensor. Integration time 25 ns. Spacial resolution* $\approx 14 \times 72\,\mu m^2$. *[C] combination of both system into one setup.*

Rates, rates, rates!

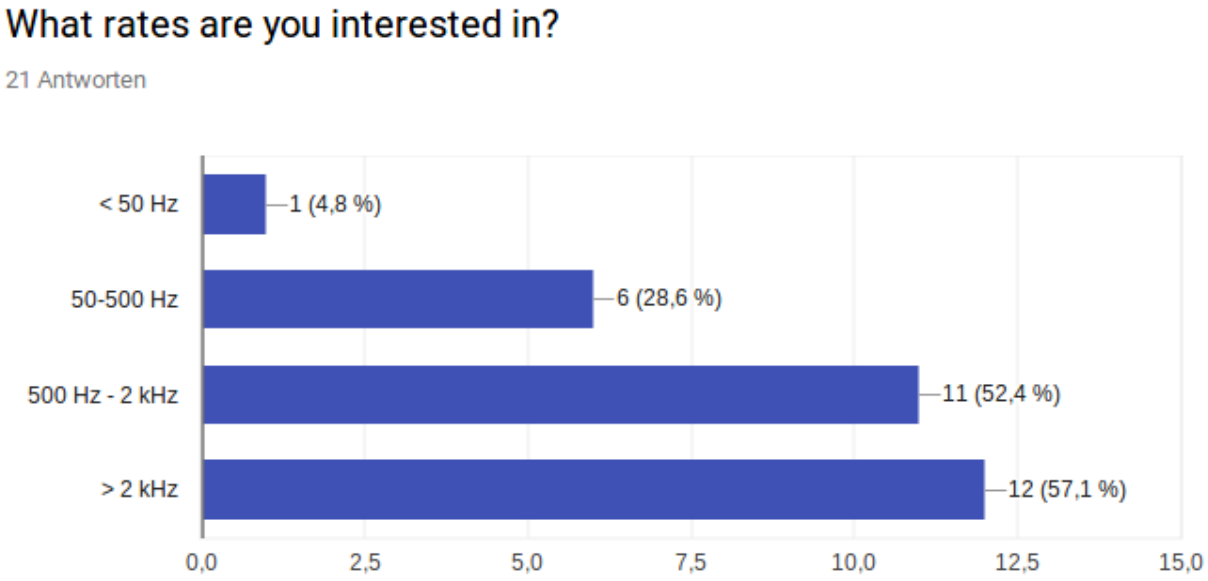
What rate are we taking about?

- Particle rate (source spectrum)
- Trigger rate (HW)
- **Track rate** (SW, after reco)



efficiency

efficiency



Rates and timing at a telescope

Two goals for a telescope device (incl. reconstruction software)

- **Rates** of reconstructed tracks:
  - For scattering measurements, X0 studies, …
  - Depends on:
    - **Source** (particle flux/structure) and **sensor** (RO and geometry) define the track rate [#/frame] = **particle flux [#/s/m^2] * time resolution [s/frame] * active area [m^2]** * efficiency
    - **Reco software** (Track finding algorithm) defines the reco limit [#/frame] = maximal track rate [#/frame]

- **Timing** of reconstructed tracks:
  - For efficiency measurements, …
  - Depends on:
    - **Sensor**: time resolution / information

Status and limit of the EUDET-tscope

one telescope *frame*

#	EUDAQ	TLU	Telescope	#Trigger	***Max track rate***	Timing reference	***Max timed-track rate***
1	1	EUDET (trigger ID, global busy)	Mimosa26 (115.2us, 2cm^2)	1	Reco limit	FEI4 (25ns, 4cm^2)	1
2	2	AIDA mixed-mode	Mimosa26 (115.2us, 2cm^2)	n	Reco limit	FEI4 (25ns, 4cm^2)	min(n, Reco limit)
3	2	AIDA (common clk, Asynch.)	Mimosa26 (115.2us, 2cm^2)	n	Reco limit	FEI4 (25ns, 4cm^2)	min(n, Reco limit)

Estimated limit (if hits are uniformly distributed)

Reco limit (e.g. ~30 tracks per frame) * frame rate (~ 8.7 kHz)
= **limit of track rate ~ 250 kHz**

Heading

Subheading, optional

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