GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Improvement of the

EUDET Telescope Timing Performance

Overview:

The EUDET telescopes ⟶ **Timing Measurements** ⟶ **Conclusion**

→ using the **AIDA TLU**

→ using the **Timepix3**

→ Tips for **Corryvreckan**

9th BTTB Workshop (virtual)

Lecce, Italy, February 9th, 2021

Jens Kröger

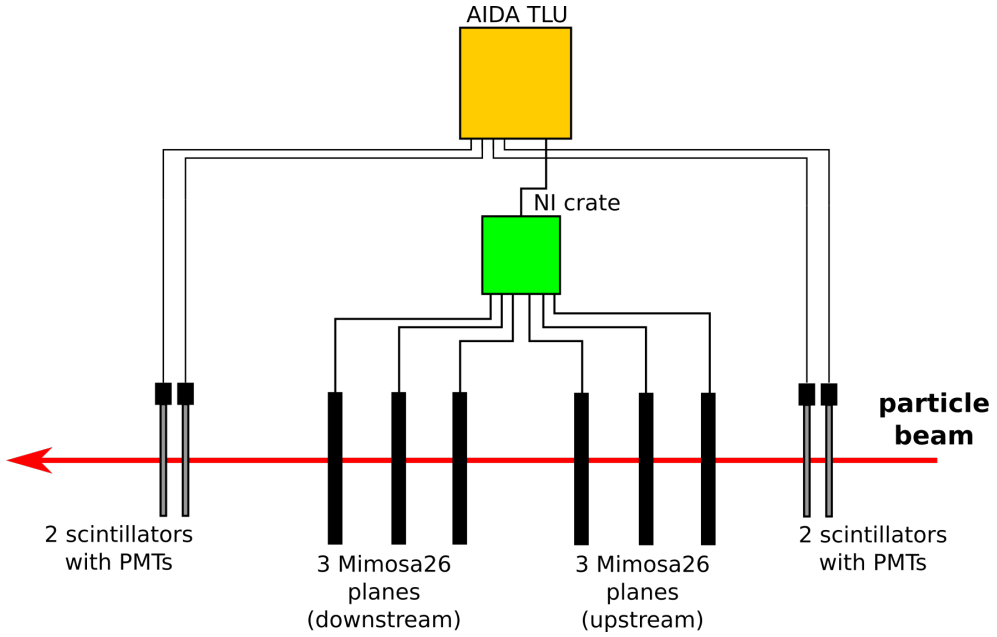
Heidelberg University & CERN

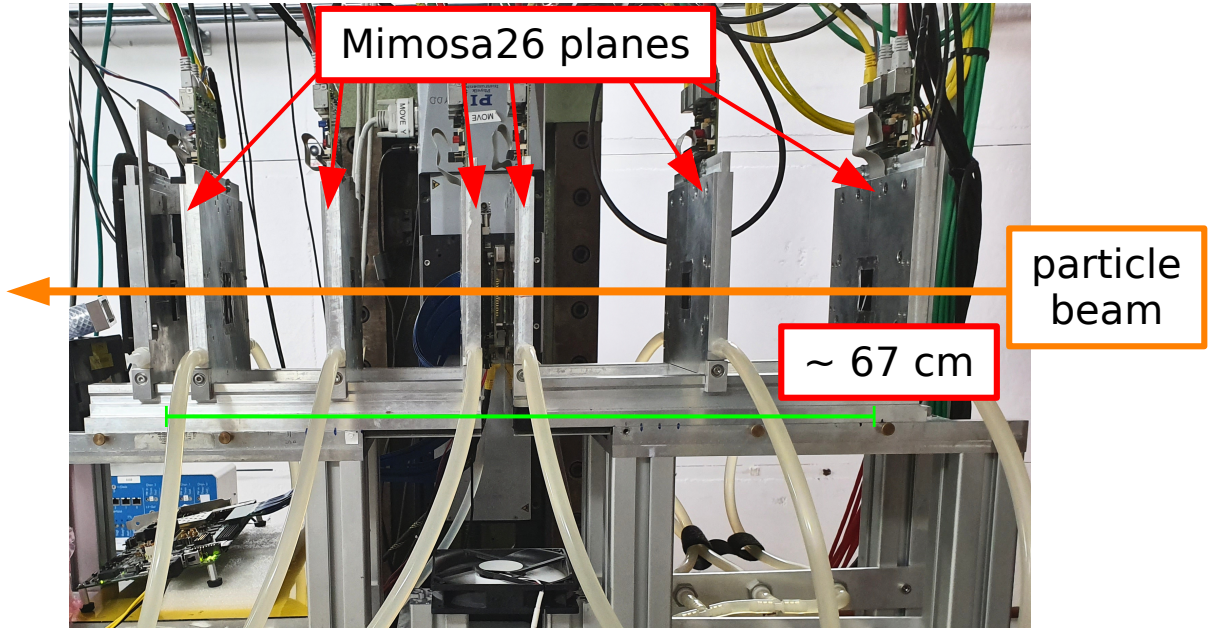
on behalf of the CLICdp Collaboration

The EUDET Telescopes

Talk by A. Herkert: https://indico.cern.ch/event/945675/contributions/4181051/

- **AIDA Trigger Logic Unit (TLU)** → provides **global clock** (time sync.)
  + triggers Mimosa Readout
- 2-3 scintillators + PMTs → input to TLU, **large area**
- 6 Mimosa26 planes → good spatial resolution,
  "no" timing (2x 115µs bins rolling shutter)

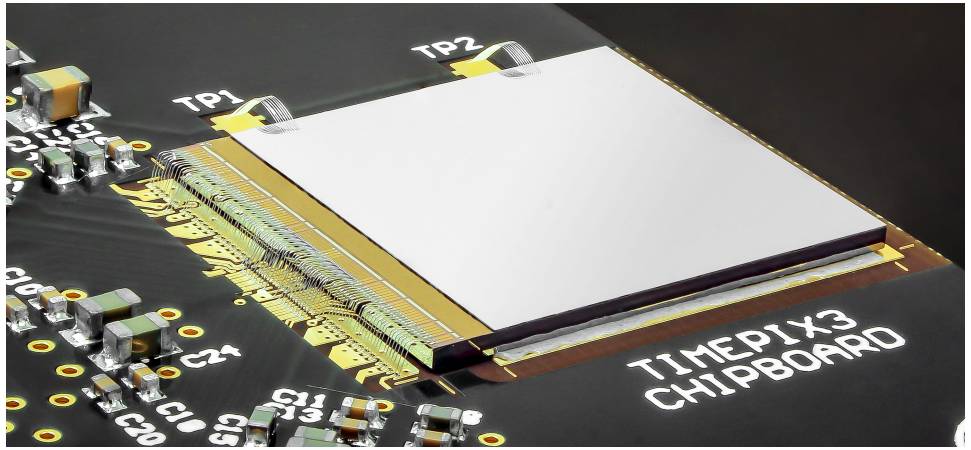


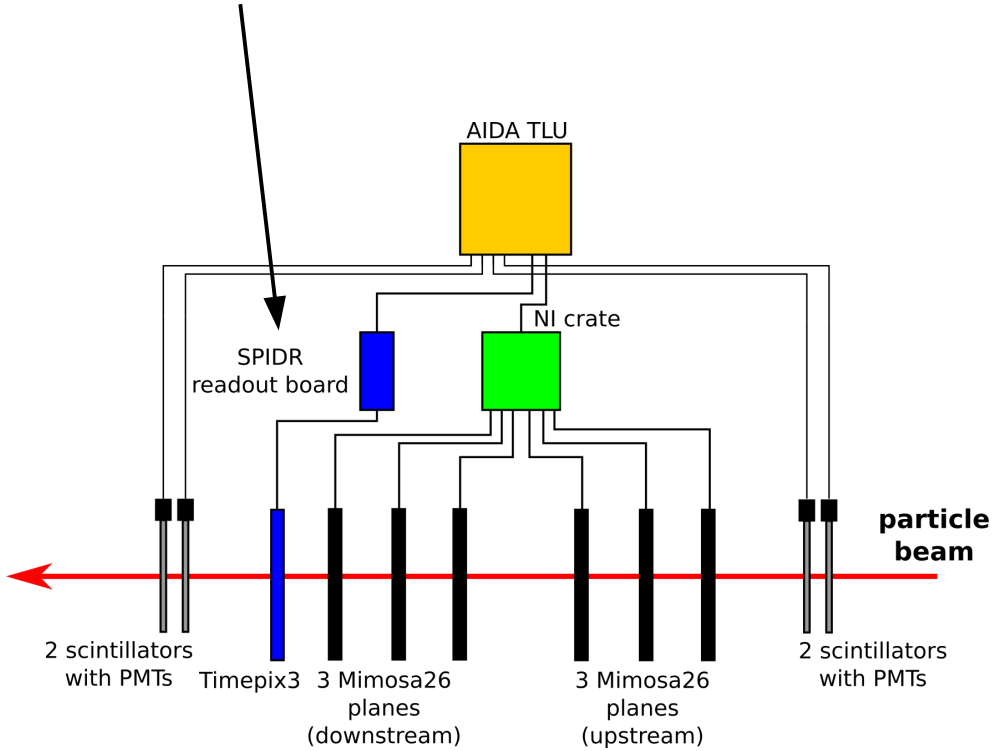


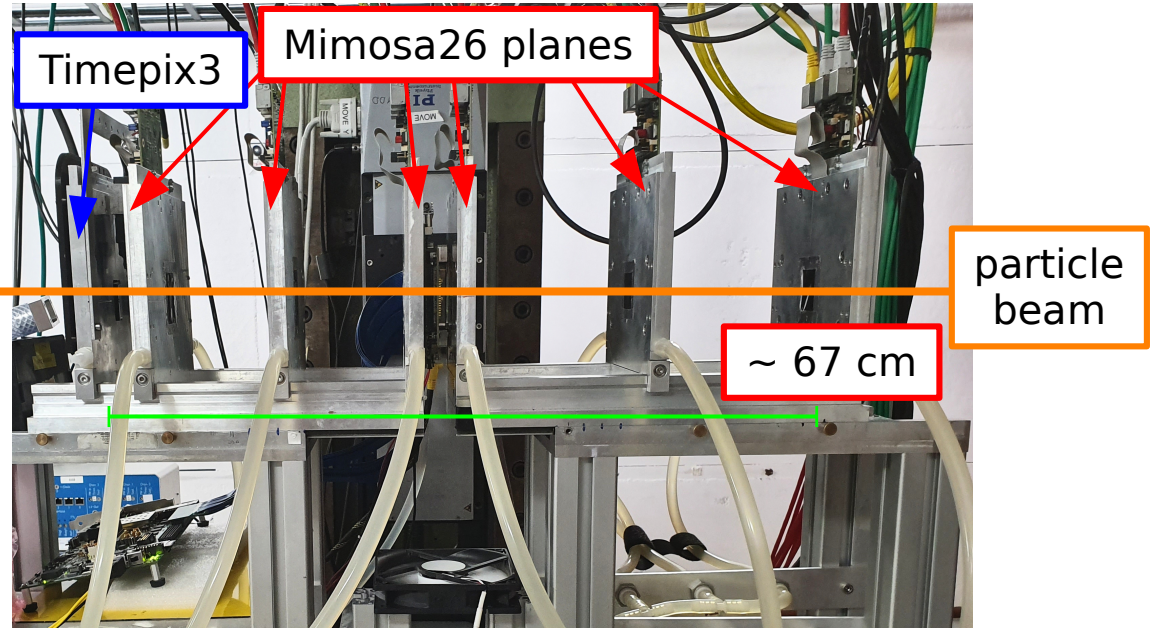
The EUDET Telescopes + Timepix3

- AIDA TLU
- 2-3 scintillators + PMTs
- 6 Mimosa26 planes

- **Timepix3** → **nanosecond track timestamps**

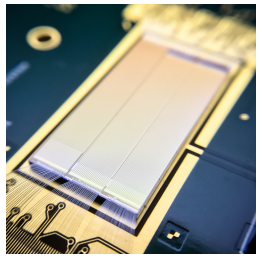
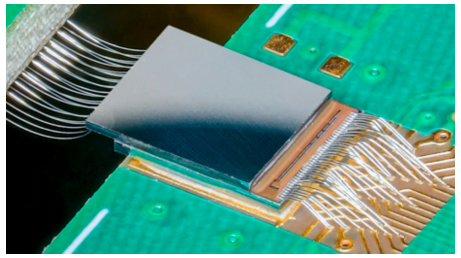
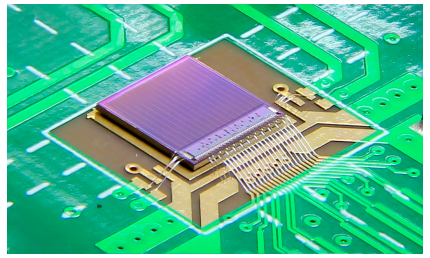




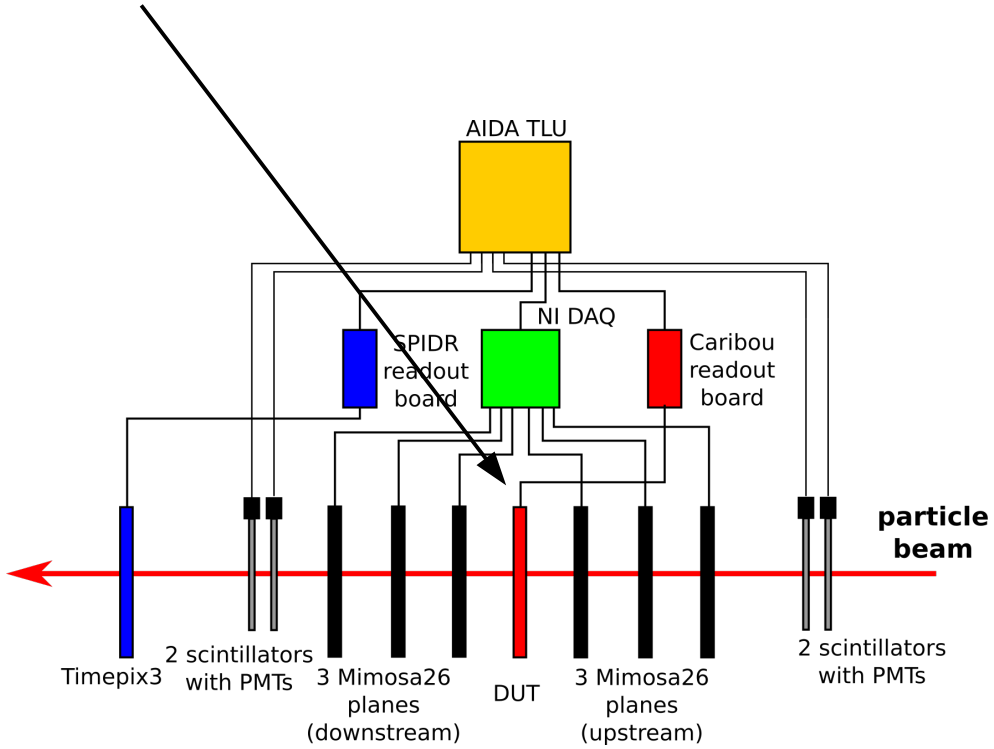


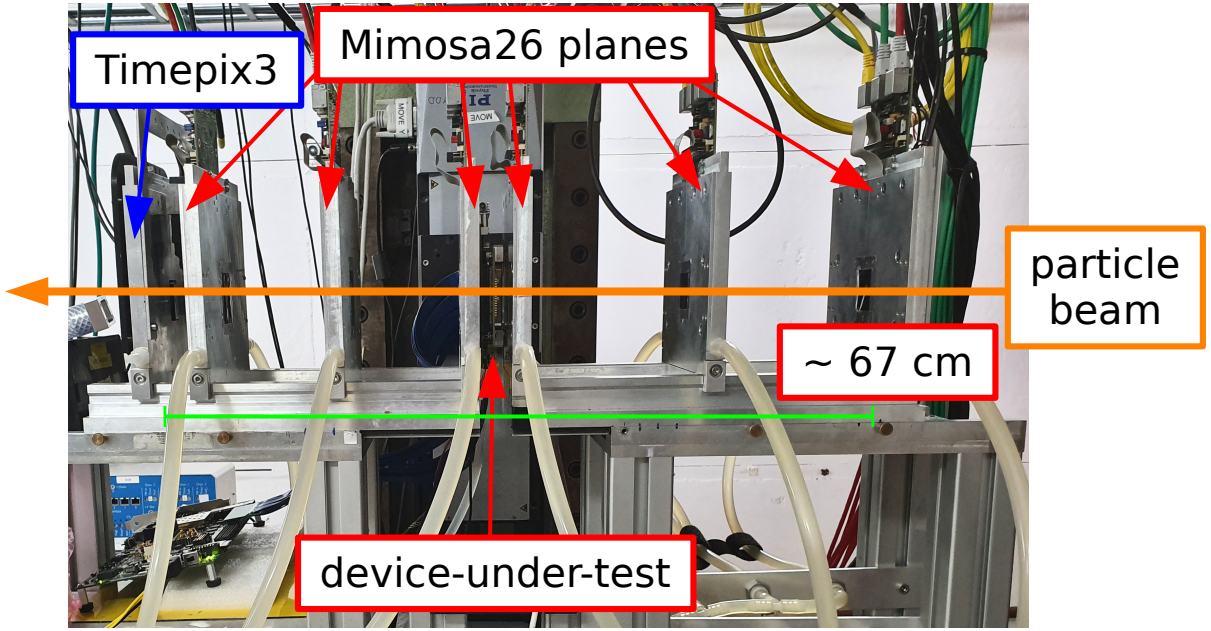
The EUDET Telescopes + Timepix3 + DUT

- AIDA TLU
- 2-3 scintillators + PMTs
- 6 Mimosa26 planes
- Timepix3
- **DUT**

→ ATLASpix
→ CLICpix2 Talk by M. Williams https://indico.cern.ch/event/945675/contributions/4159777/
→ CLICTD Talk by K. Dort https://indico.cern.ch/event/945675/contributions/4159771/

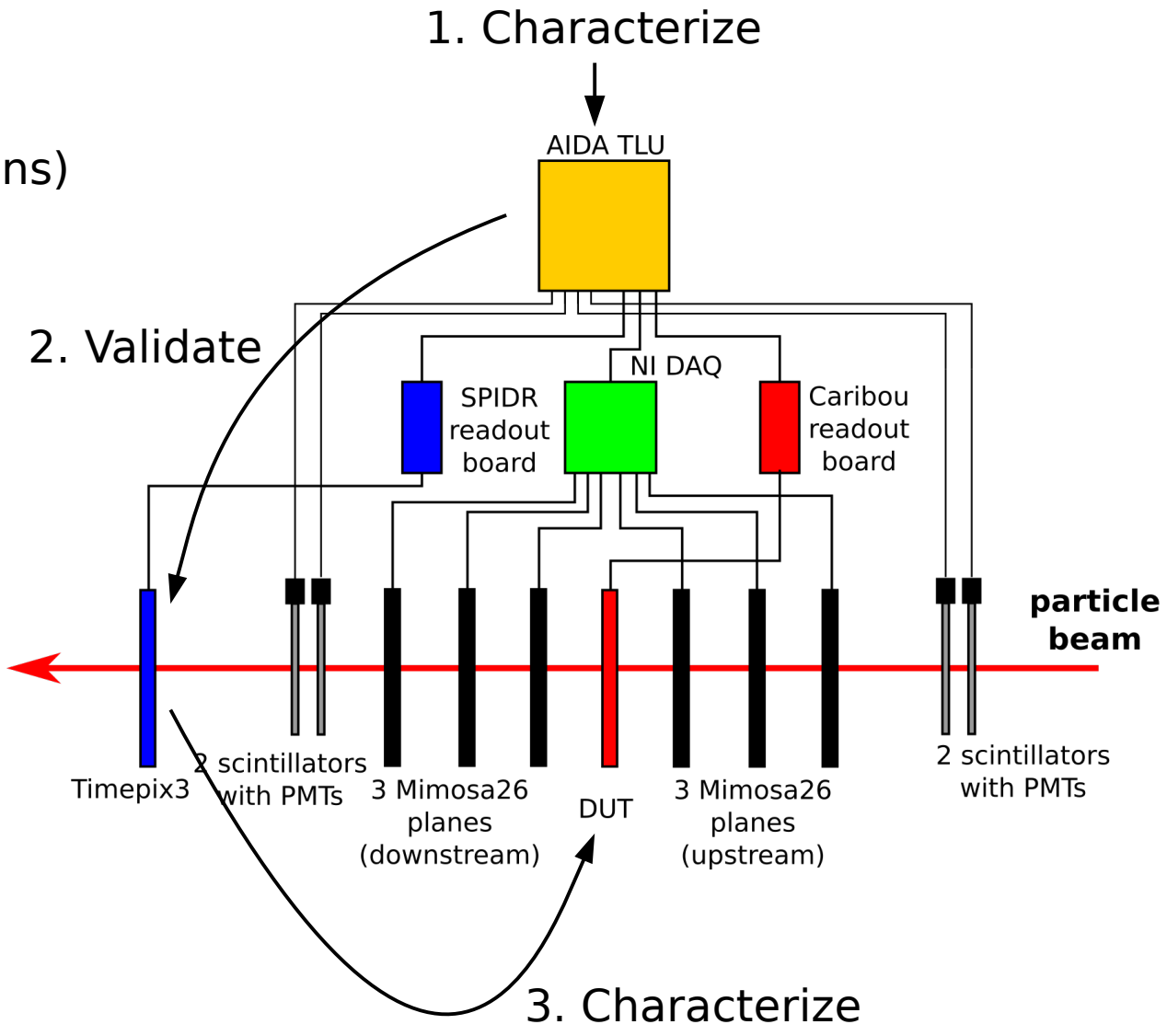




Motivation: Why improve the timing reference?

- Goal:
  - characterize time resolution of **DUT** O(5-10ns)
- Method:
  - need **precise track timestamp** O(1 ns)

    → use **Timepix3**
- but first:
  - **validate Timepix3** performance with TLU
  - **characterize TLU** with scintillators+PMTs



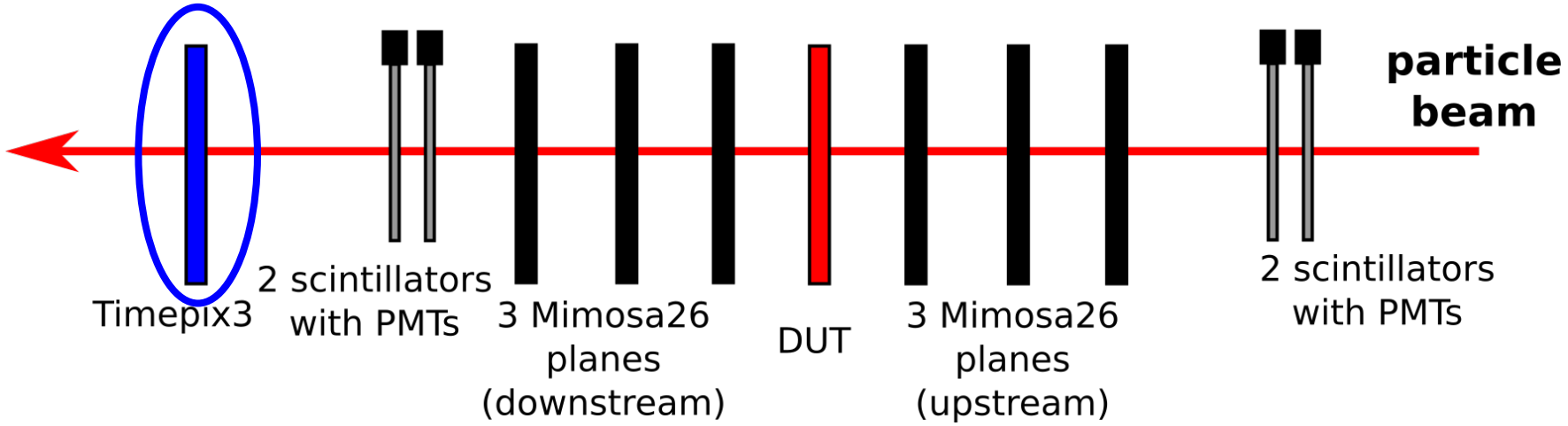
Track Time Tagging with the Timepix3

Situation at DESY:

- **Mimosa26** hits (**>>** 100µs) with **multiple** trigger timestamps
  - ***large area*** *scintillators →* ***Which trigger*** *timestamp belongs to* ***which track****?*

- require **Timepix3** for **unambiguous** track time:

  → *track timestamp = Timepix3 timestamp*



The AIDA TLU

Talk by D. Cussans: https://indico.cern.ch/event/945675/contributions/4160093/

- 4x LEMO for **PMT power**
  - up to 12 V
- 6 LEMO **trigger inputs** → **scintillators + PMTs**
  - configurable coincidence logic
  - we used only 2-3
- 4x HDMI **output**
  - MIMOSA26 telescope
  - SPIDR (Timepix3)
  - Caribou (DUT) Talk by E. Buschmann: https://indico.cern.ch/event/945675/contributions/4160095/

rack mount version: same functionality

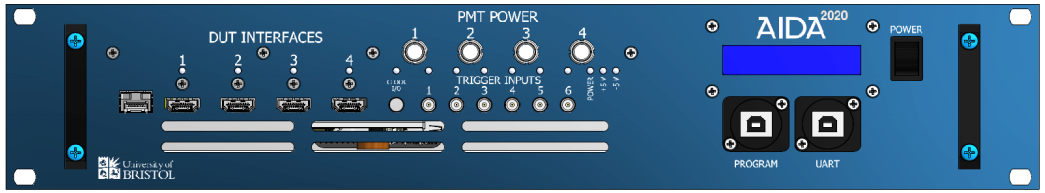
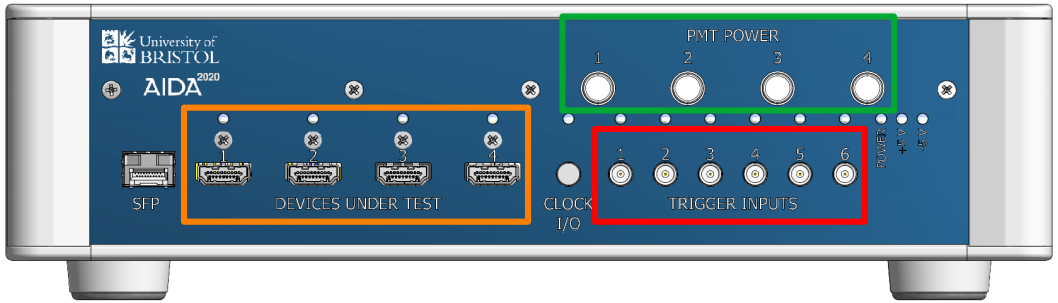


table top version:



Trigger timestamps:

- “coarse” coincidence timestamp
  - **25 ns** binning
- “fine” trigger timestamps
  - for each trigger input (up to 6)
  - **780 ps** binning

→ high-precision timestamp:
”coarse + fine”

TLU Trigger Timestamps

Previously:

- only coarse timestamp
  - limited to 25ns/√12 ~ 7.2ns
  - far worse than intrinsic scintillator + PMT timing

→ not good enough as reference for us

Now:

- "coarse+fine"
  including time-of-flight/delay for each trigger
  - **2 scintillators: 600 ps**
  - 3 scintillators: 450 ps

Note: scintillators not tuned → potential for improvement!

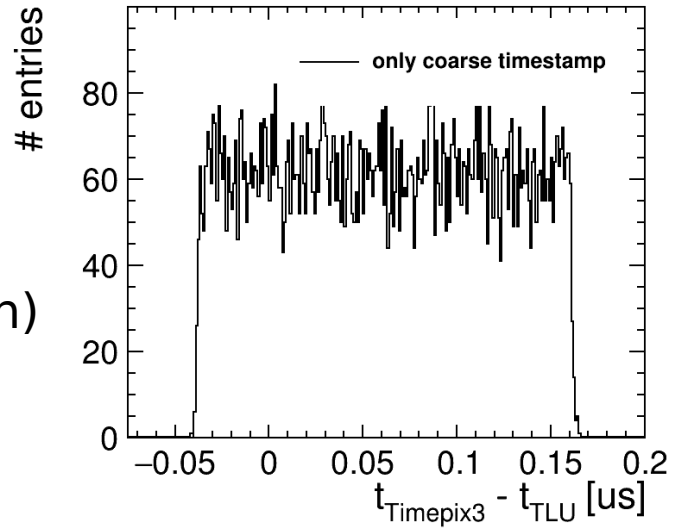
Required Changes:

→ More details here and here

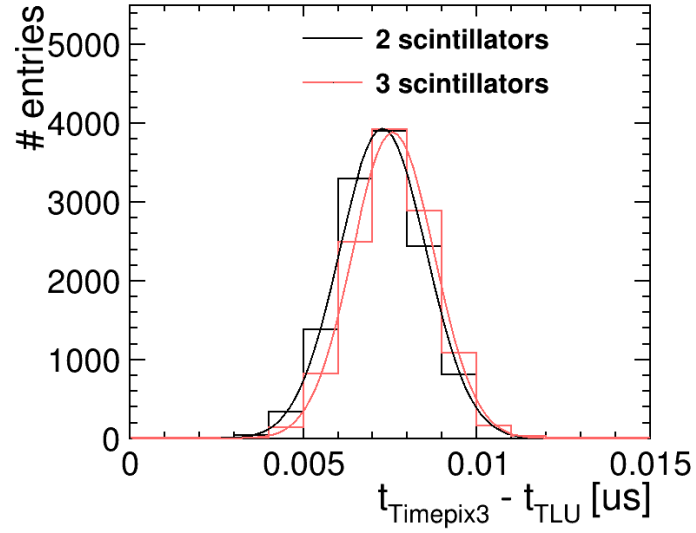
- Firmware of the AIDA TLU → David Cussans
  - trigger polarity
  - extend fine timestamps from 5-bit to 8-bit
- Reconstruction (EUDAQ2 + Corryvreckan)
  - combine "coarse + fine" correctly
    (overflow of fine timestamps)
  - consider time-of-flight/delay between triggers

time correlations with Timepix3:

previously: only coarse



now: coarse+fine



Corryvreckan: How to use fine the trigger timestamps?

- relevant READMEs:
  - Corryvreckan: EventLoaderEUDAQ2
  - EUDAQ2: TLU

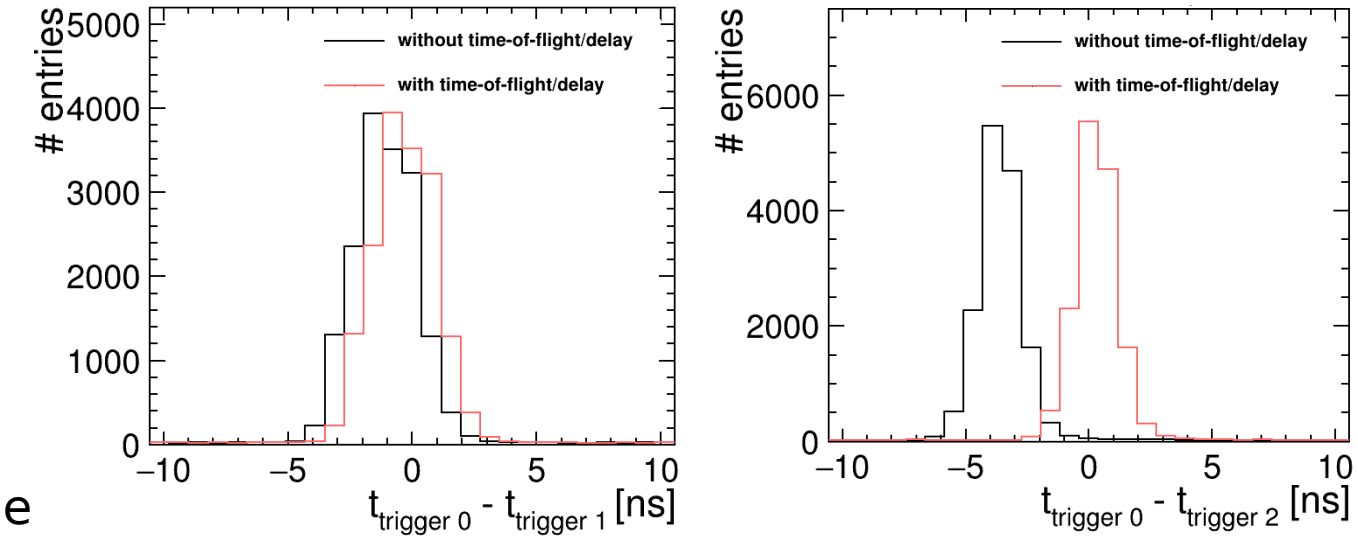
- to obtain effective **time-of-flight/delay**:

```
[EventLoaderEUDAQ2]
name = "TLU_0"
…
get_tag_histograms = true
```

- determine shift from zero, add to config file

```
# time-of-flight [780ps bins]
tof_scint0 = 0 # 0ns
tof_scint1 = 1 # 1.07ns
tof_scint2 = 5 # 3.92ns
```

correlation between trigger timestamps



For more details attend the **Hands-on Corryvreckan**
https://indico.cern.ch/event/945675/contributions/4184960/

How to measure the Timepix3 resolution?

- TLU: scintillators + PMTs
  - trigger 0 vs. trigger 1
  - trigger 0 vs. trigger 2
  - trigger 1 vs. trigger 2

$$\sigma_{\text{trigger i vs. trigger j}} = \sqrt{\sigma_i^2 + \sigma_j^2}$$

- precise TLU timestamp
  ~ (trigger 0 + trigger 1)/2

$$\sigma_{\text{TLU}} = \frac{\sqrt{\sigma_0^2 + \sigma_1^2}}{2}$$

- TLU vs. Timepix3 (only “clean” if Gaussian):

$$\sigma_{\text{Timepix3}} = \sqrt{\sigma^2_{\text{correlation TLU vs. Timepix3}} - \sigma^2_{\text{TLU}}}$$

Expectation:

Timing Studies by Florian Pitters
→ see CLICdp-Pub-2019-001

Our sample:
- **~ 1.5 ns** without calibration
- **~ 1.1 ns** with lab calibration
- ~ 0.9 ns with lab + test-beam calibration

Timepix3: Timing Performance

	without calibration		**with** calibration	
	RMS [ns]	σ_{Gauss} [ns]	RMS [ns]	σ_{Gauss} [ns]
2 triggers	1.74 ⟷	1.46	1.27 ⟷	1.26
3 triggers	1.65 ⟷	1.36	1.20 ⟷	1.19

After calibration:
Gaussian shape → can be deconvoluted

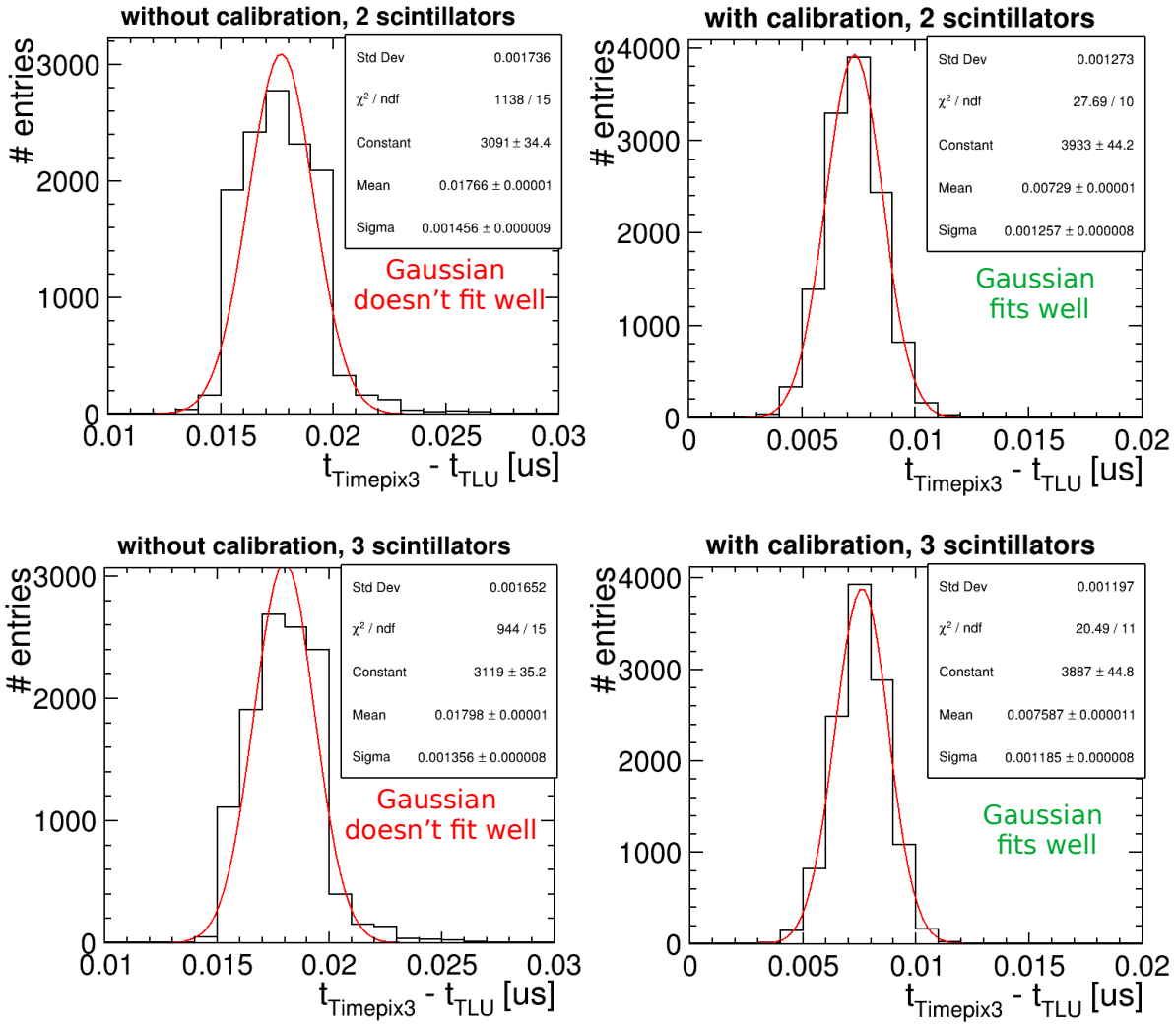
After subtracting TLU resolution:

$$RMS = \sigma_{Gauss} = 1.1 \text{ ns}$$ (as expected)

→ fully sufficient for all our DUTs

Note: Also cross-validated analysis with SPS data (2015)

time correlations between TLU and Timepix3:



Corryvreckan: How to apply the Timepix3 Calibration?

- relevant README:
  - Corryvreckan: EventLoaderEUDAQ2
  - EUDAQ2: Timepix3

For more details attend the
Hands-on Corryvreckan
https://indico.cern.ch/event/945675/contributions/4184960/

- add path/to/calibration in event loader:

```
[EventLoaderEUDAQ2]
name = "Timepix3_0"
…
calibration_path_tot = path/to/calib_tot.txt
calibration_path_toa = path/to/calib_toa.txt
```

- Assembly **W5_E2** available at DESY upon request

  ✉ → contact DESY telescope support (S. Spannagel, L. Huth)

In Conclusion:

Acknowledgment:
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).

"Supported by the H2020 project AIDA-2020, GA no. 654168."

Significantly improved time resolution:

	previously	now
AIDA TLU trigger timestamp	**O(10ns)** "coarse"	**450 – 600 ps** "coarse + fine"
Timepix3 track timestamp	**1.5 ns** without calibration	**1.1 ns** with calibration

- Gaussian → can be deconvoluted
- AIDA TLU:
  trigger timestamp from **large area** scintillators
- Timepix3:
  unambiguous track timestamp

- integrated in EUDAQ2 + Corryvreckan

  → ready for use

Possible further steps:

- Timepix3 fully calibrated: 0.9ns
  - but requires further analysis work
- track timestamp
  = **TLU timestamp** closest to Timepix3
  → Corry: [ImproveReferenceTimestamp]
- scintillators+PMTs:
  - tune voltage
  - combine more than 2-3:

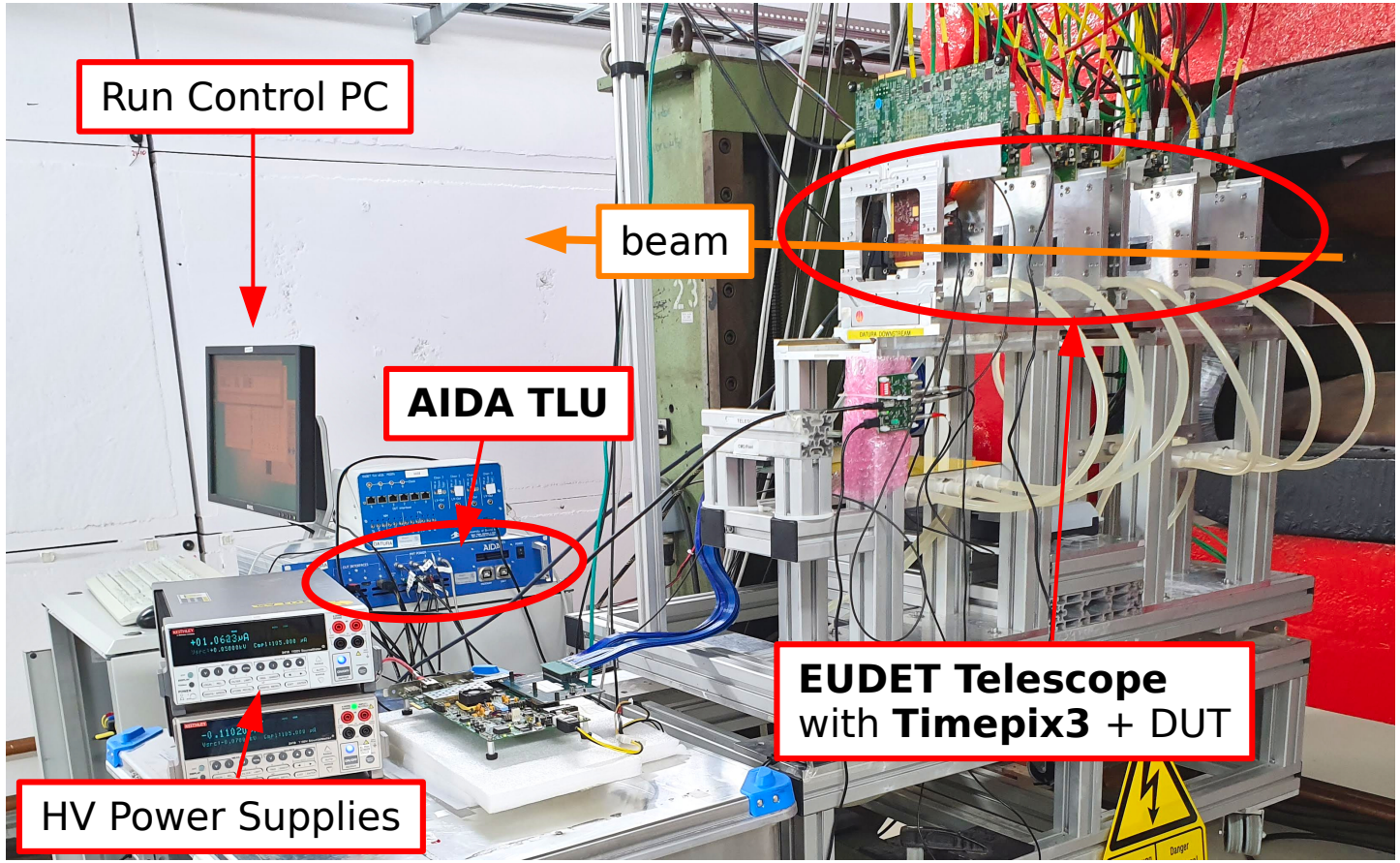
$$\sigma_t = \frac{\sqrt{\sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2}}{n}$$

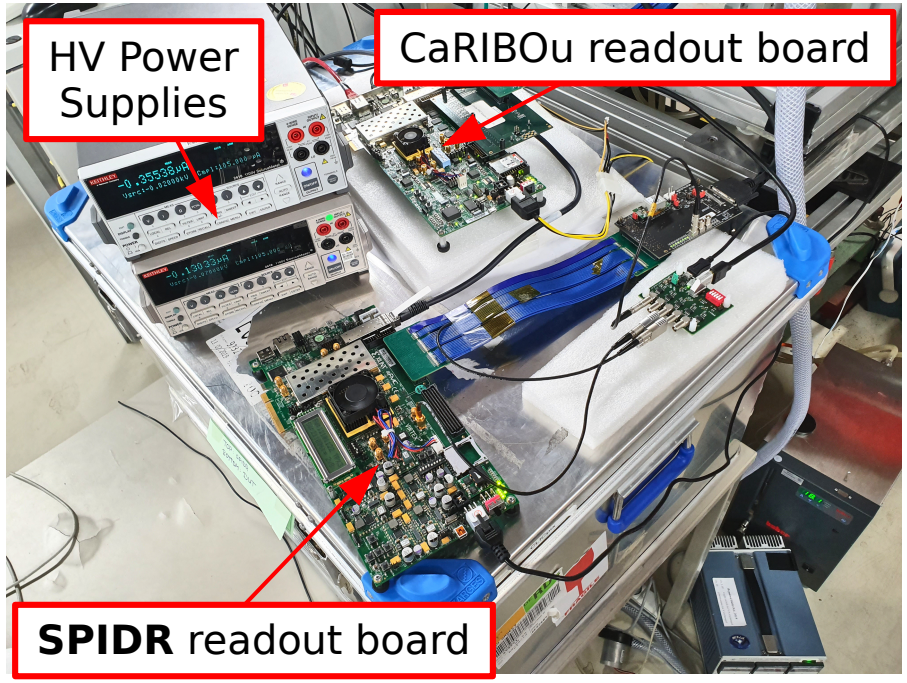
Backup

in case there are some questions...

Test-Beam Setup at DESY

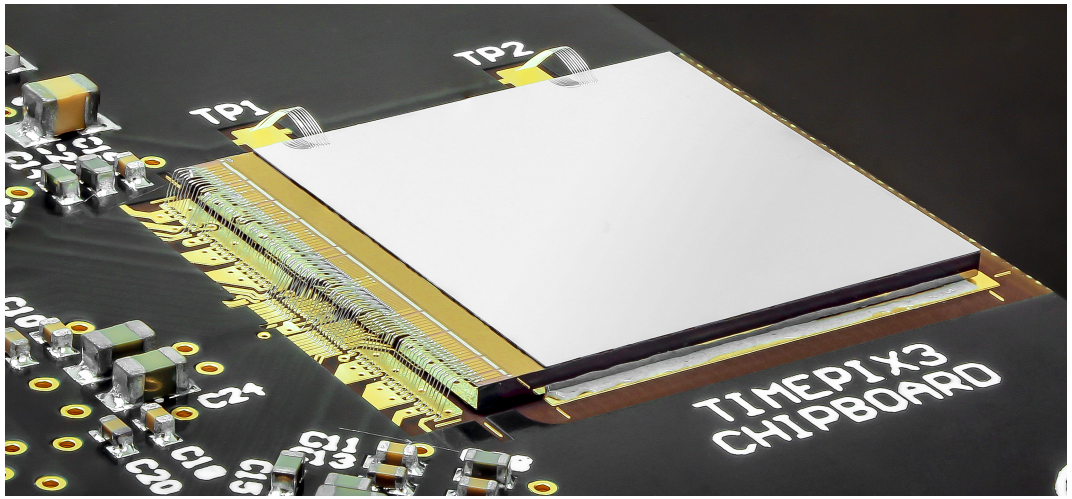
typical beam conditions:
5.4 GeV electrons @ few kHz





More Details on the Timepix3

At DESY, we used assembly W5_E2:



- available on request for other users
- Timepix3 ASIC + planar sensor (100 µm):
  - 256 x 256 pixels
  - pixel pitch: 55 x 55 µm²
- nominal conditions:
  - bias = -20 V → same at DESY
  - thres = 1160 DAC → thres = 1200 DAC at DESY (“noise free”)

Also studied by

Niloufar Alipour Tehrani

https://www.research-collection.ethz.ch/handle/20.500.11850/164813

Florian Pitters

https://cds.cern.ch/record/2649493
https://cds.cern.ch/record/2654139/
https://cds.cern.ch/record/2714709?ln=en

Timepix3 Calibration

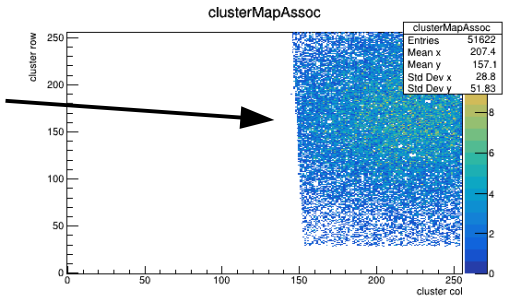
Florian Pitters:
→ see CLICdp-Pub-2019-001

1) timewalk calibration:

- based on lab data, available for full sensor
- Concept:
  - inject test-pulse into digital in-pixel logic
  - inject test-pulse into analogue front-end → timewalk → fit function

2) delay calibration:

- based on test-beam data, available only for top right corner
- clock propagation top/bottom + 16 column periodicity



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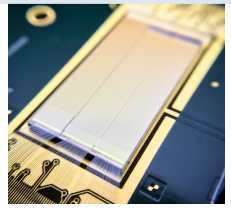
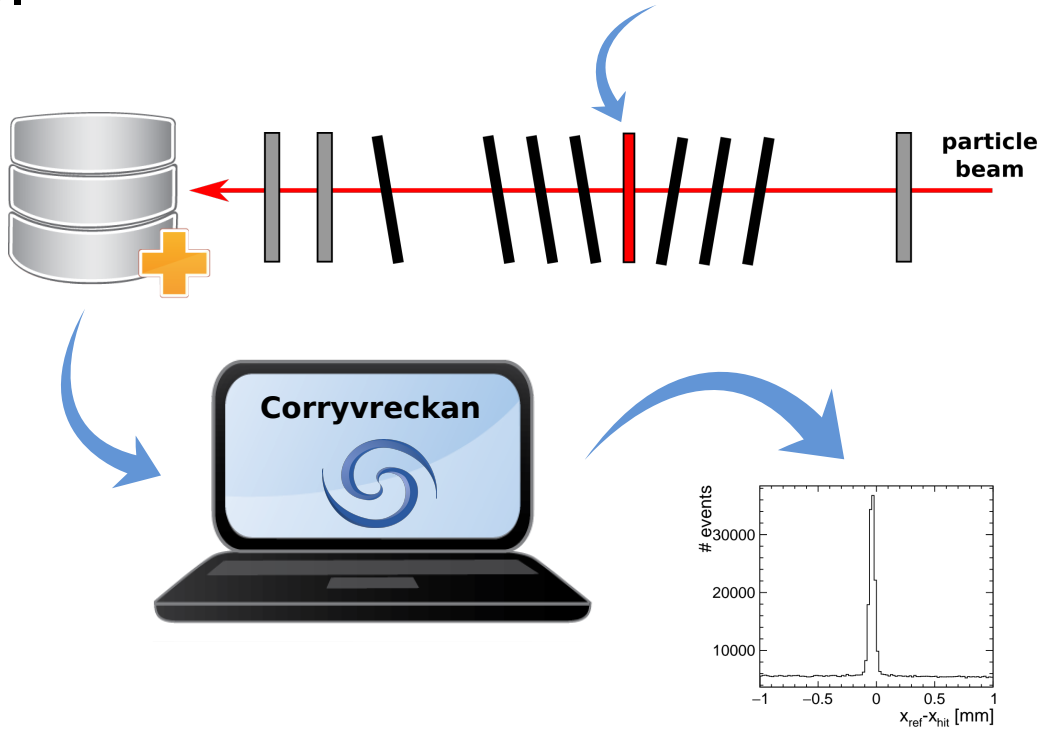
Reconstruction with Corryvreckan



A **reconstruction and analysis** tool for pixel sensor test beam data



- modular structure
  - framework core
  - modules for specific tasks
- highly flexible and configurable
- easy to understand
  - written in modern C++
  - comprehensive documentation (> 100 pages!)

Visit our website:
https://cern.ch/corryvreckan

Check out the repository:
https://gitlab.cern.ch/corryvreckan/corryvreckan

Event Definition & Offline Event-Building

event = coherent time frame (or data slice) including:

- pixel data
- triggers (time + ID)
- other numbers associated with these data (e.g. temperature)

offline event-building: define extend of event on-the-fly

- do not rely on “event structure” within data
- combine data from different detector systems offline + in a flexible way

Caribou – the readout system

- versatile, open-source, linux-based
- fast & simple implementation of new detectors
  → “fast prototyping”
- **universal:**
  - FPGA board
  - Control & Readout (CaR) board
  - “most of the” firmware/software
- **chip-specific:**
  - chip board
  - “some” firmware/software blocks