DESY.

From particles to timed tracks

The next generation of hard and software for test beams

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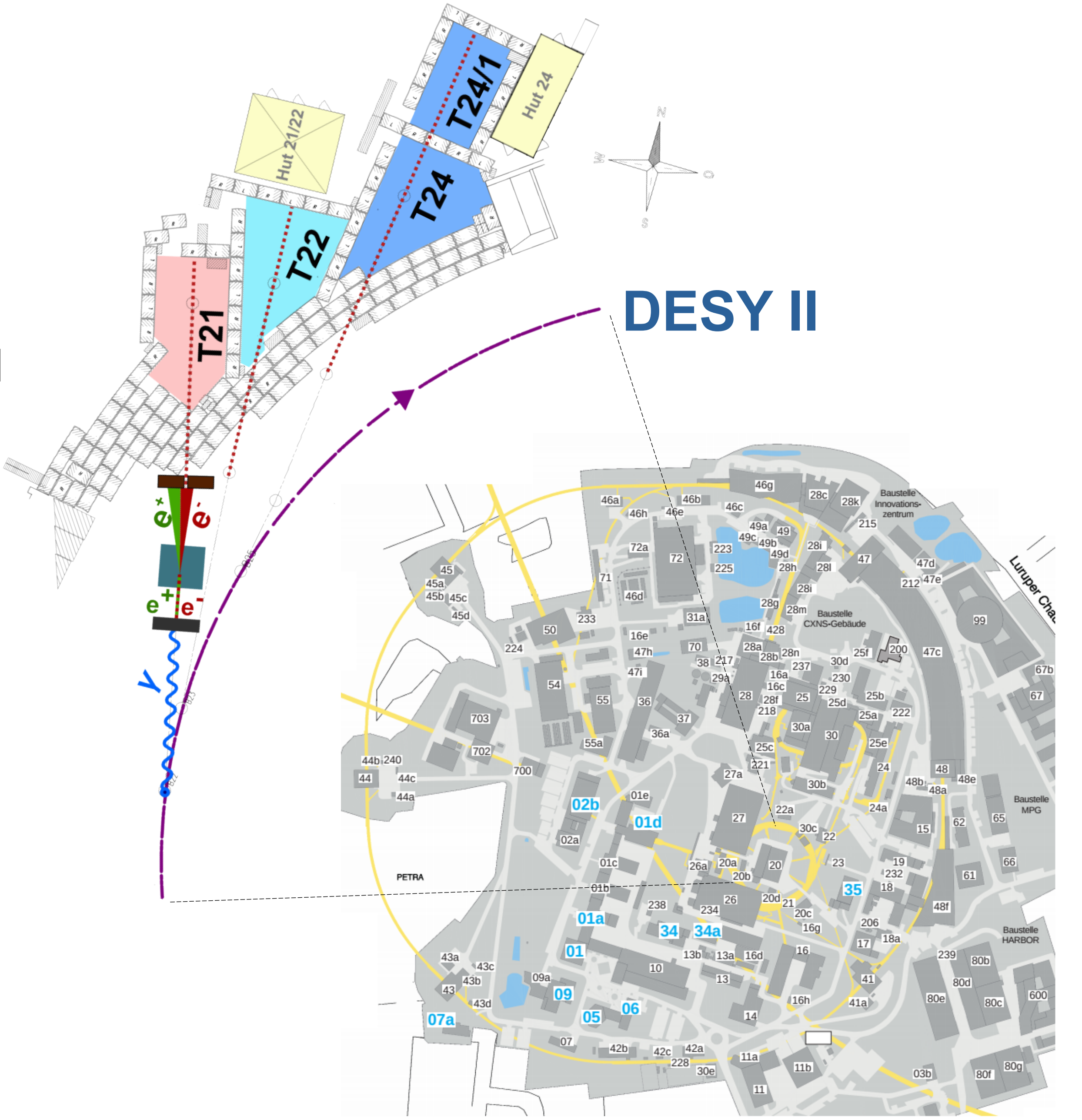
The DESY II Test Beam facility

Generating Particles for Detector Studies

- Located on DESY campus Hamburg-Bahrenfeld
- Operates parasitically at PETRA III injector: DESY II
- Provides electron beams to user groups
  - ~ 40 weeks per year
  - @ 3 independent beam lines
- Beam energies between 1 and 6 GeV
- Particle rates up to O(10 kHz / cm²) depending on set energy
- Beam generation via double conversion



Beam Telescopes

Reference systems for tracking

- Large user base
- Fully integrated in EUDAQ and TLU
- 6 layers of 50um thin senors
- Two different types available:
  - MIMOSA26 based (1x2cm^2, 18.4µm pitch, 230µs readout)
  - ALPIDE based prototype (1.5x3cm^2, ~29µm pitch, 10µs readout)
- Currently developing final ALPIDE telescope version

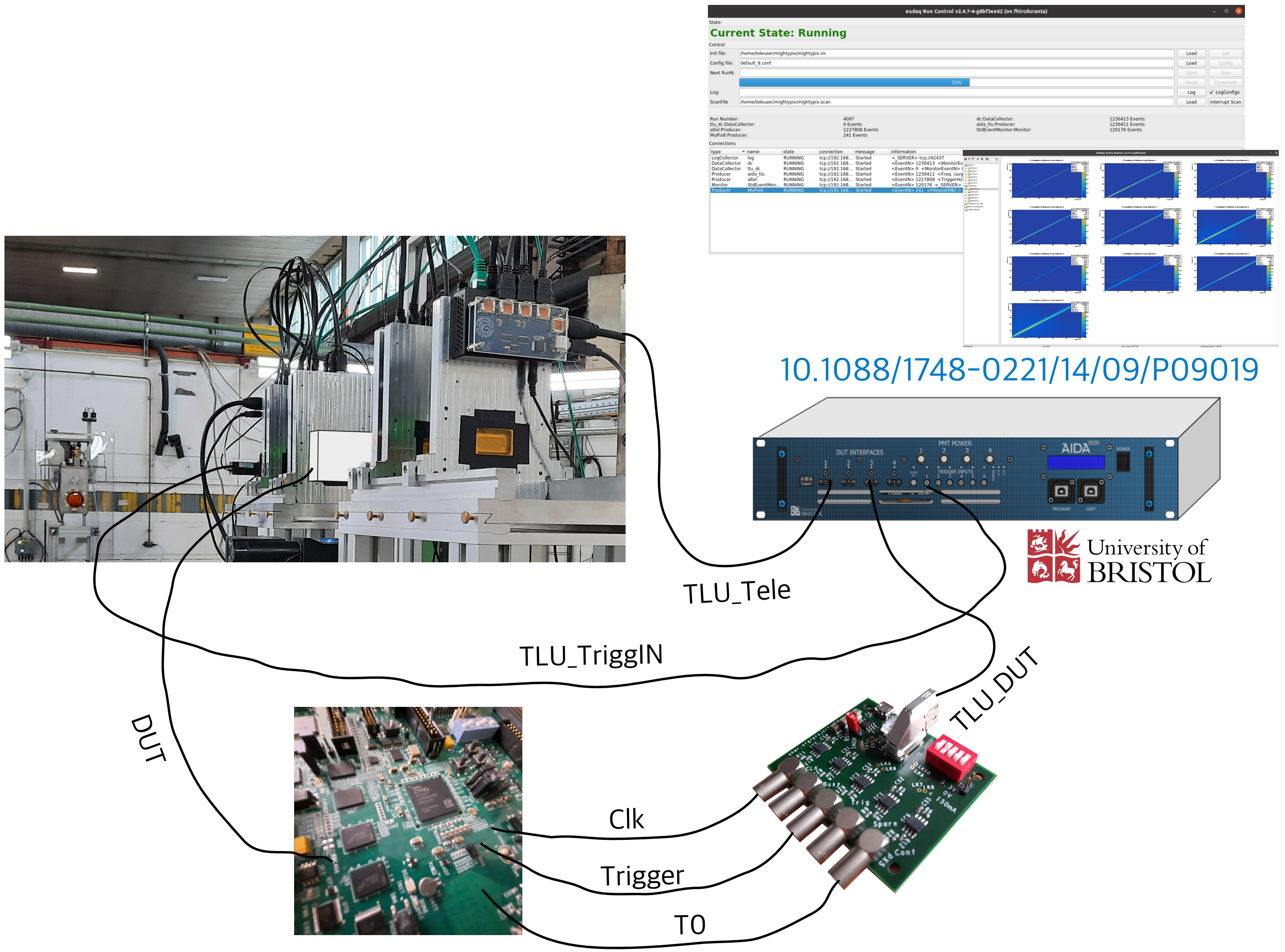
https://arxiv.org/abs/2102.11138

Synchronisation of DUTs with the telescopes

AIDA2020 TLU and EUDAQ2

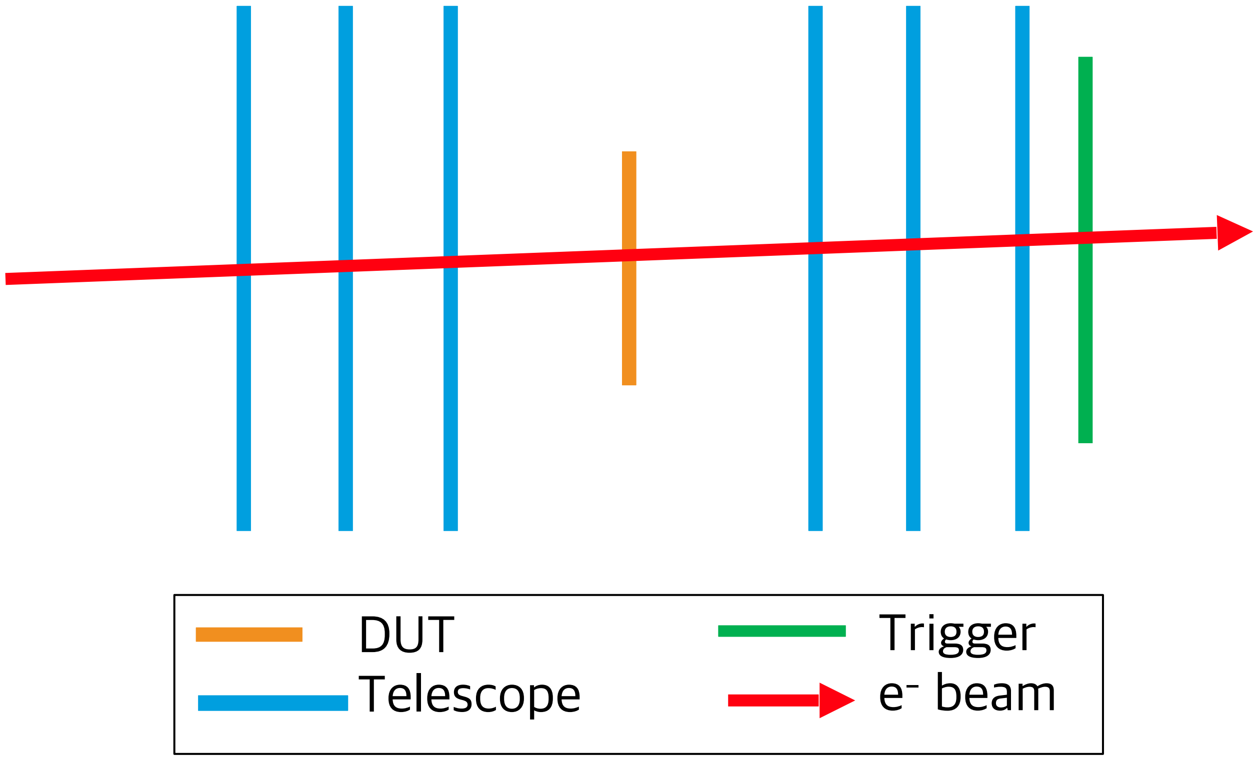
- AIDA2020 TLU:
  - Hardware interface
  - Provides global trigger
  - Different sync modes possible (handshake, clock)
- EUDAQ2:
  - Software framework
  - Used for telescope run control and data formatting
  - DUT integration not necessary but practical!

10.1088/1748-0221/14/10/P10033



From a particle to a track

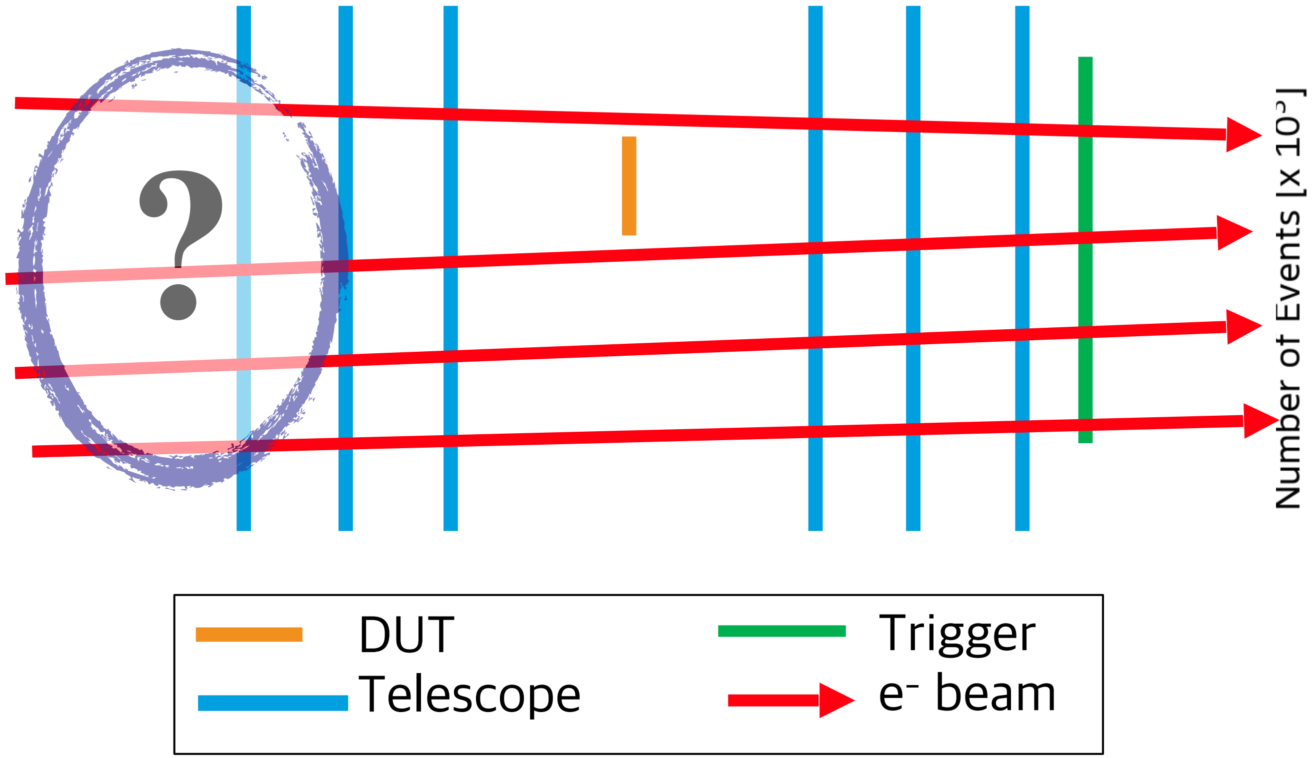
Triggering and spatial tagging

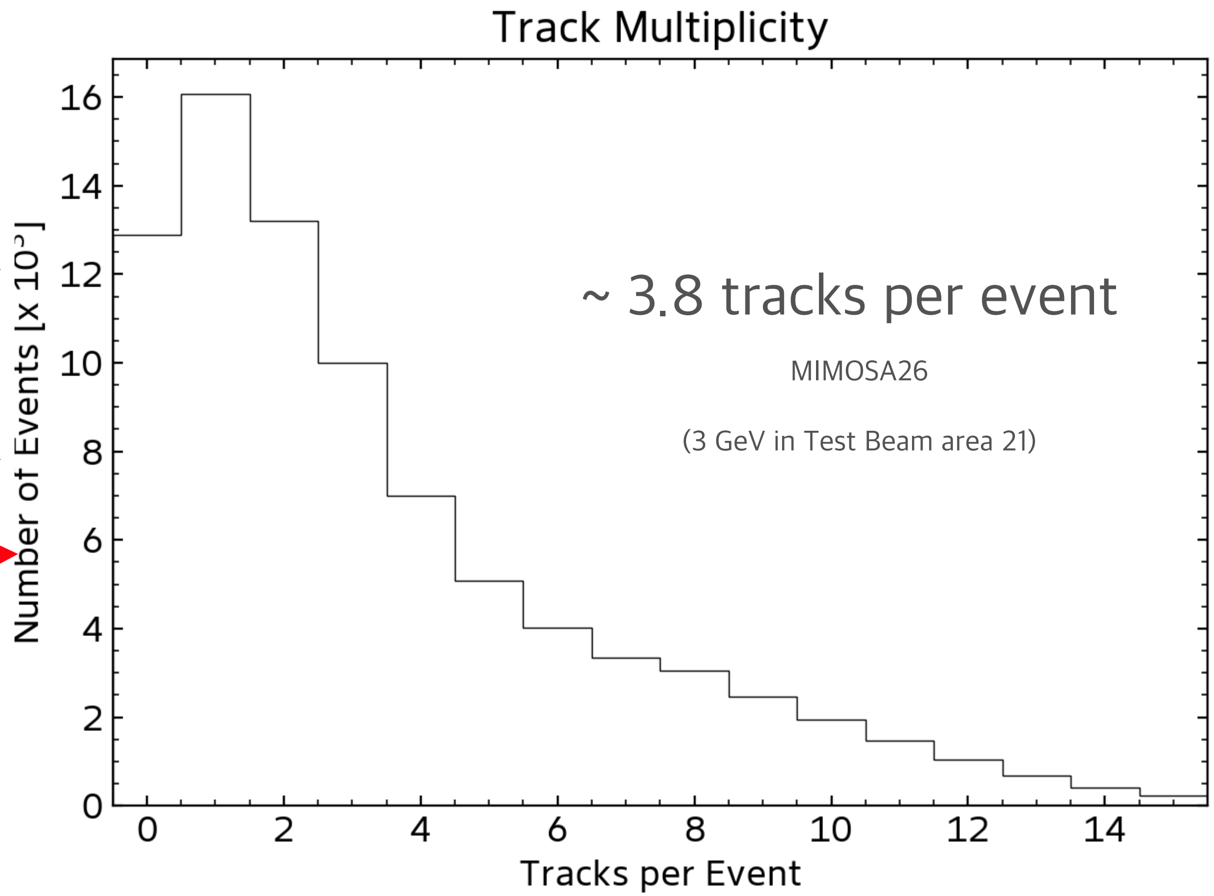


- Tagging the particles presence with a trigger scintillator
- Reference telescope to reconstruct particles trajectory
- Placing a device under test in the middle (or behind in case of a calorimeter)
- Ideally single particle events at high rates

From particles to tracks

How to solve ambiguities?





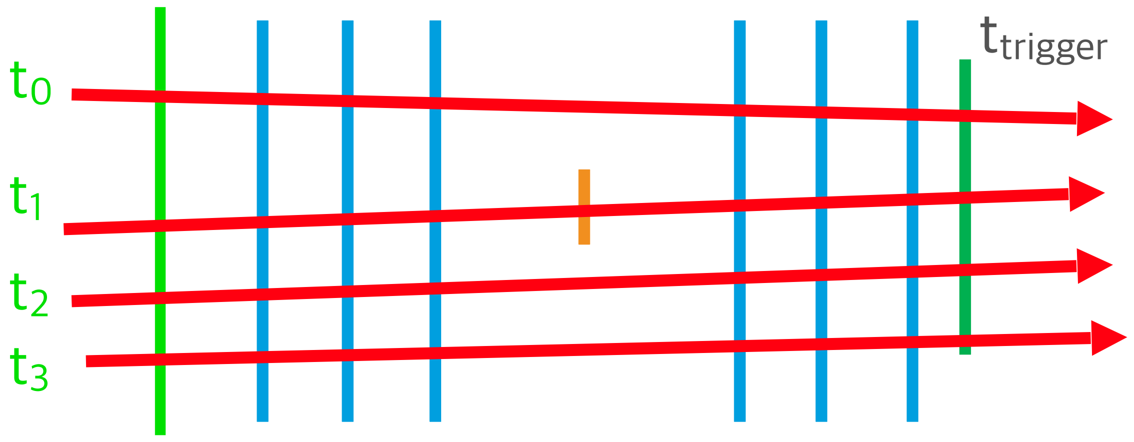
Which particle has triggered the readout and how can one ensure, that the DUT is being hit?

Adding timing to tracks and providing a segmented trigger

Resolving multiple particles per trigger

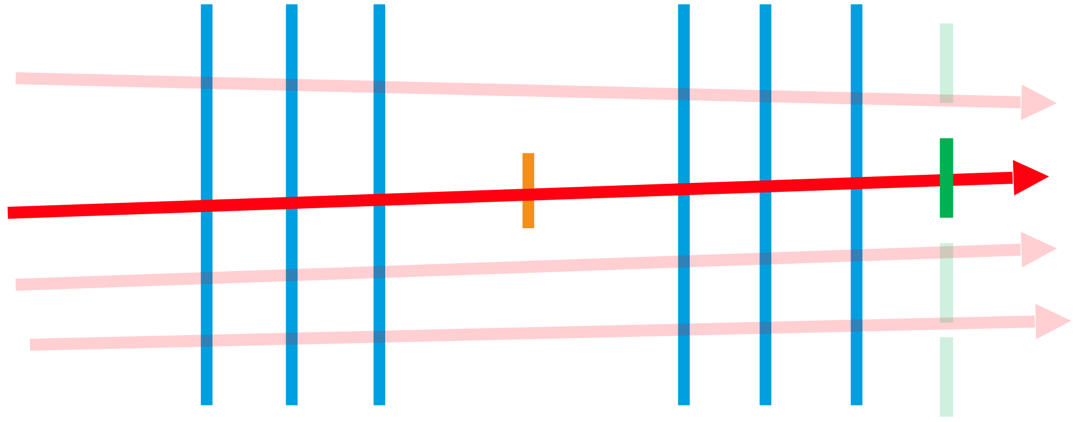
Track time stamping

- Adding time stamps to each track via an additional pixel layer
- Resolves ambiguities of which track has triggered the readout by comparing t_x to $t_{trigger}$
- Time resolution in the order of a few 10 ps ideal



Region of interest triggering

- A segmented trigger layer to match the DUT area
- Only select the tracks that go through the DUT
- Time resolution needs to be good enough to differentiate particles



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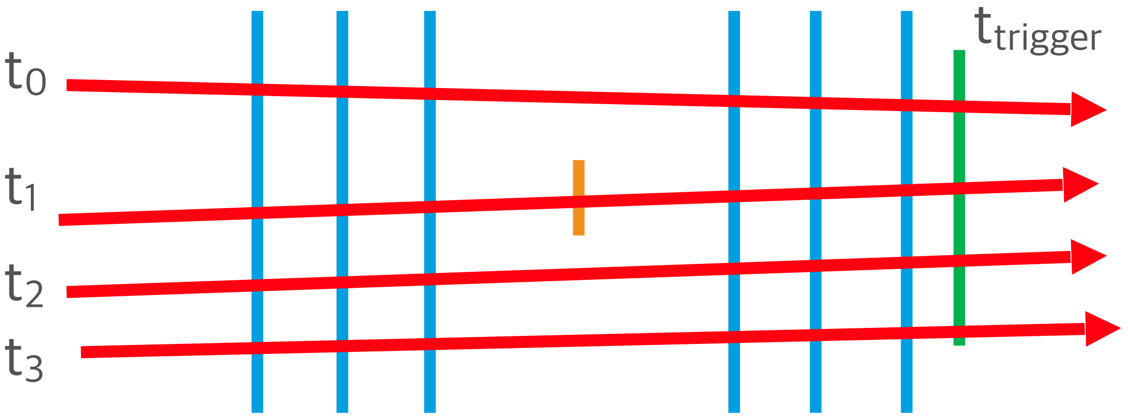

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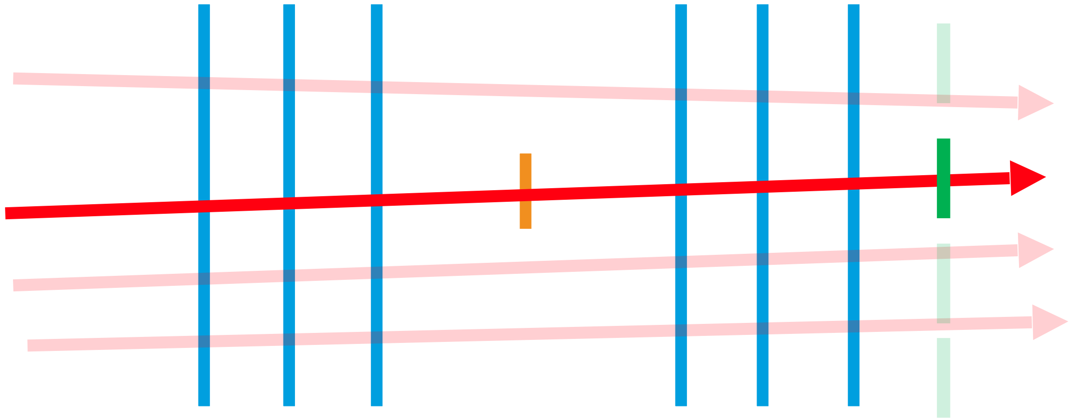
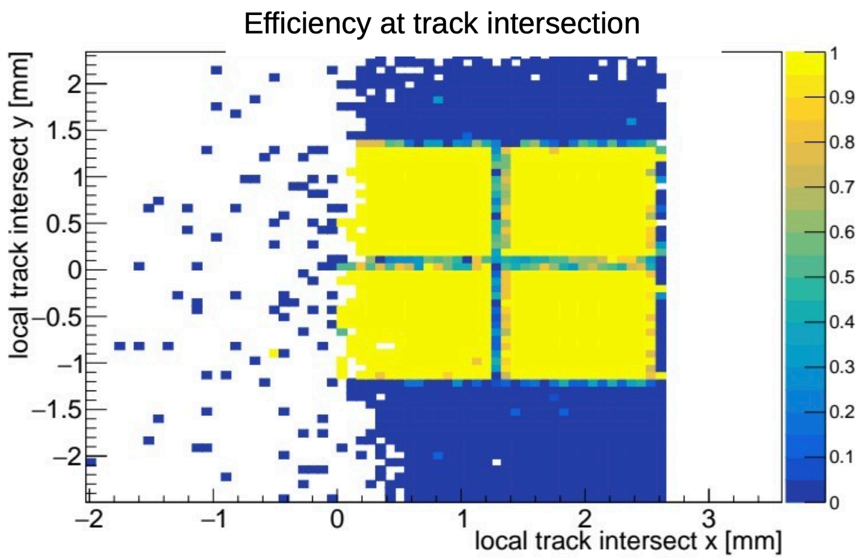


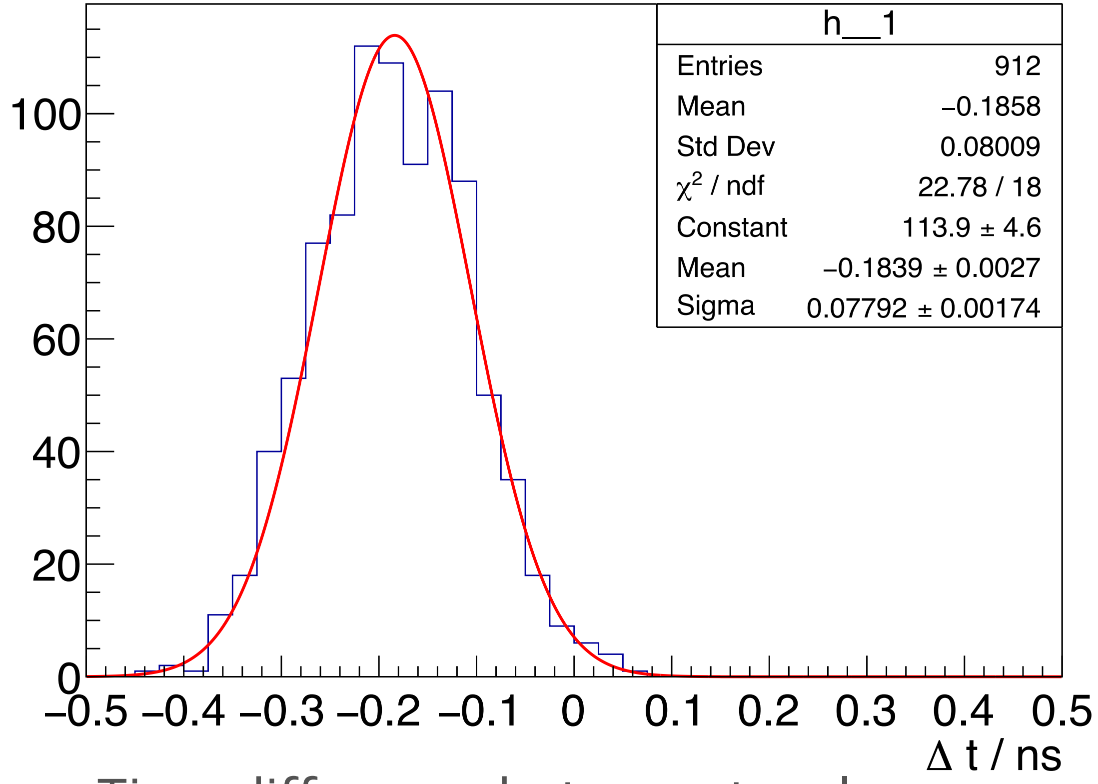
Ideally one device for both

Timing layers provided by DESY I

A few 10 ps timing with LGADs

- Providing a few 10ps time resolution
- Collaboration with University of California, Santa Barbara
- First performance results available
- Integration into EUDAQ2 ongoing
- Integrated in AIDA innova





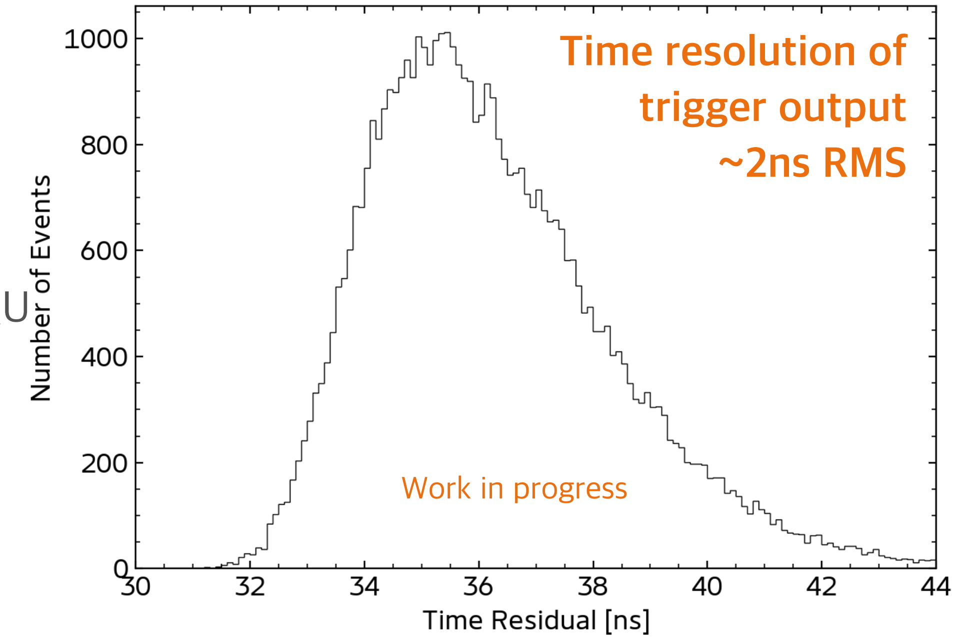
Time difference between two layers

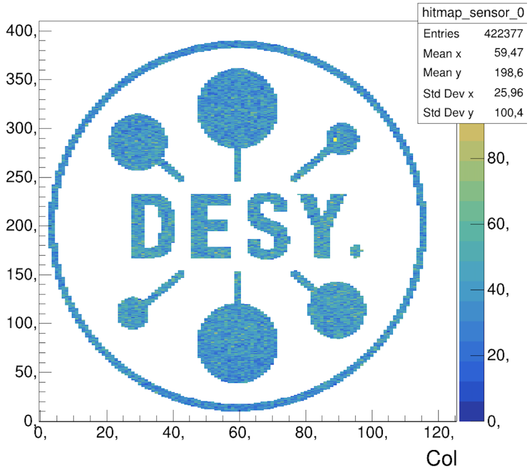
Timing layers provided by DESY II

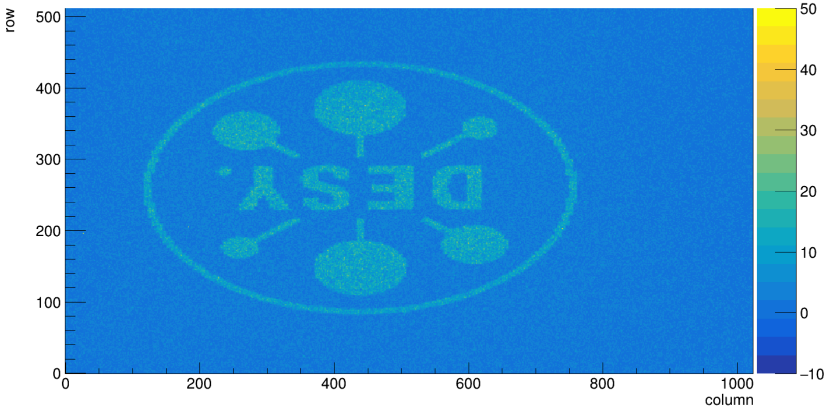
TelePix 2: Nano second timing and region of interest trigger

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386
EXZELLENZCLUSTER QUANTUM UNIVERSE

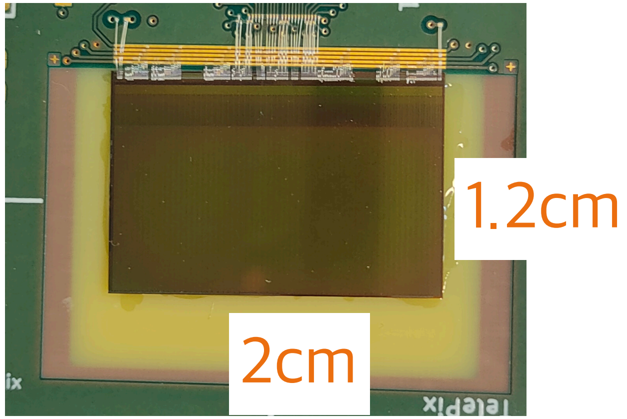
- Providing a time resolution of a few ns, trigger ~ 2ns
- Match the MIMOSA26 chip size
- Provide region of interest trigger
- Based on a HV-CMOS process and a decade of research
- Design by KIT and readout together with University of Heidelberg, funding QU
- Excellent chip performance determined:
    - >99% efficiency
    - Time resolution < 5ns







Flipped shadow on telescope

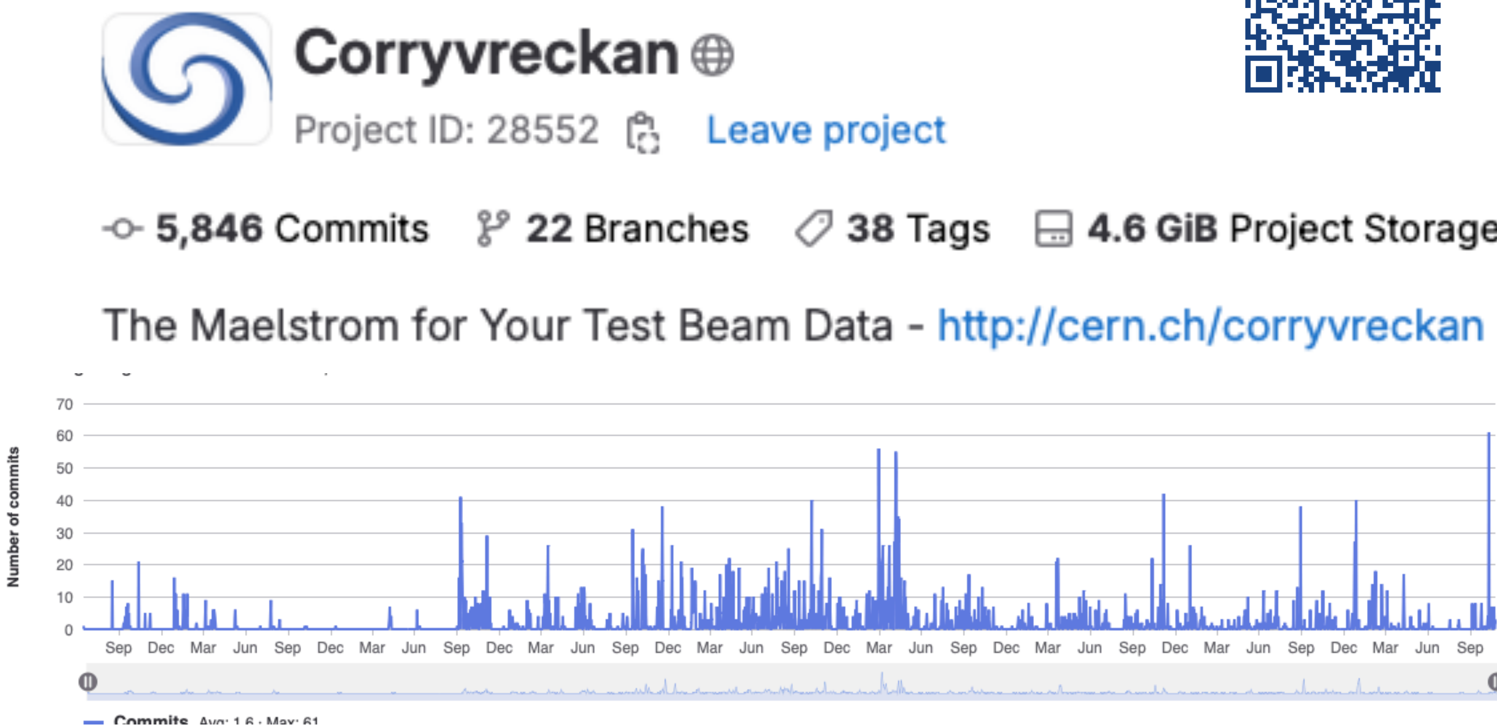


D. Dannheim et al 2021 JINST 16 P03008

Corryvreckan

Modular analysis toolkit for test beam data

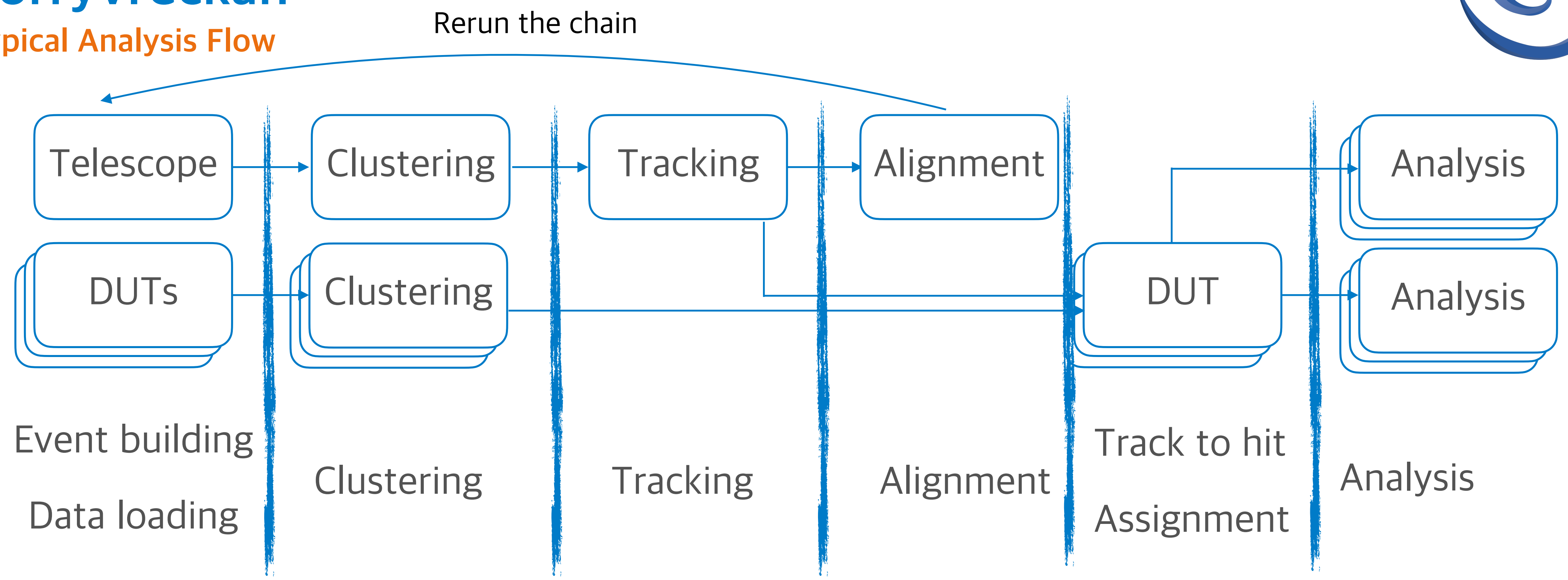
- Open source community project maintained at DESY
- Providing a modular approach on data reconstruction
- Written in modern c++
- Extensive documentation
- Native support of units in the configuration
- Automated CI with
    - Validation based on test data
    - Compilation on multiple OS
    - Code style, formatting and spelling
- Detailed review of merge requests
- Support of multiple detector geometries
- Contributions from ~50 persons, 93 forks
- TelePix2 analysis as an example

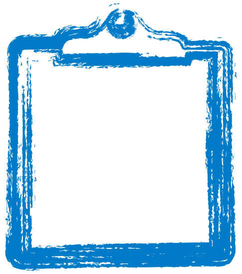



```
[Corryvreckan]
detectors_file="geo.geo"
detectors_file_updated="geo2.conf"
histogram_file="run_14745_polish.root"
number_of_tracks=10000

[EventLoaderEUDAQ2]
type="TLU"
shift_triggers = 0
adjust_event_times = [["TluRawDataEvent", -10us, +10us]]
file_name=run_001474_tlu_220331153704.raw

[EventLoaderEUDAQ2]
type="ADENIUM"
shift_triggers =0
```

Corryvreckan

Typical Analysis Flow





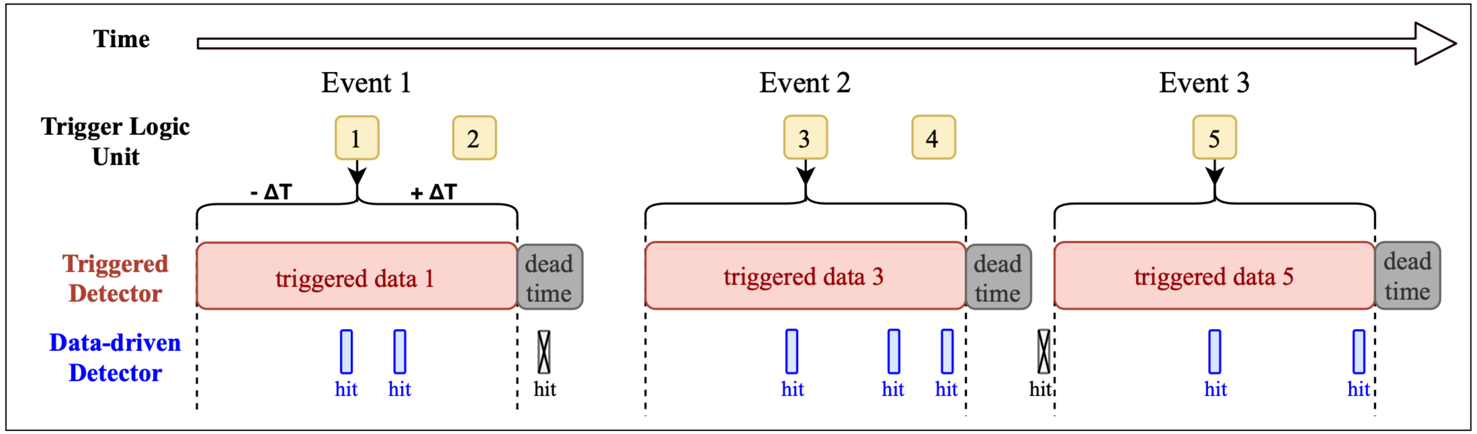
One central clipboard to store all data.

Modules can write and read from it

Event Building

Highly flexible creation of events

- Corry needs to be able to merge data from multiple sensor readout concepts:
  - ILC/CLIC like devices (shutter)
  - Data driven readout
  - Triggered readout
  - ….
- Event Building has to be flexible
- The first EventLoader in the configuration is in charge of defining the event



Default settings for DESY test beam:

- Trigger Logic unit defines the event timestamp
  - Adjust event length according to telescope integration time
- Add data from triggered telescope by ID
- Add any data from a data driven detector that has timestamps that macht the event

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Event Building II

Highly flexible creation of events

- Corry needs to be able to merge data from multiple sensor readout concepts:
  - ILC/CLIC like devices (shutter)
  - Data driven readout
  - Triggered readout
  - ….
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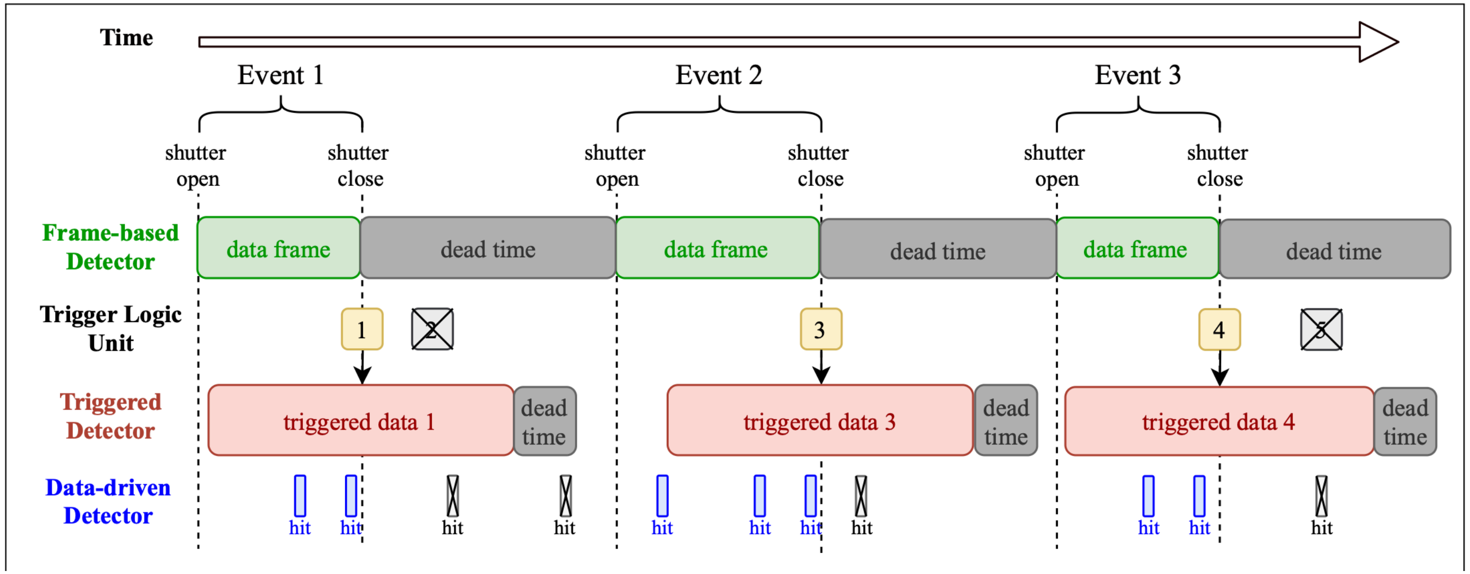


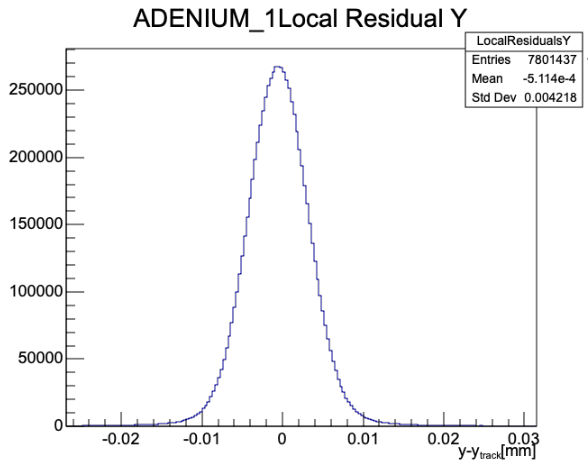
- ILC/CLIC like detector with shutter based readout defines the event
- Add matching triggers and data from triggered devices
- Need to veto tracks that are out of the shutter window.

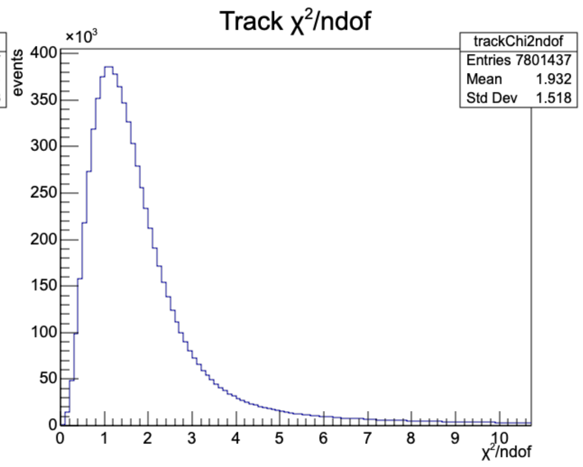
[D. Dannheim et al 2021 JINST 16 P03008]

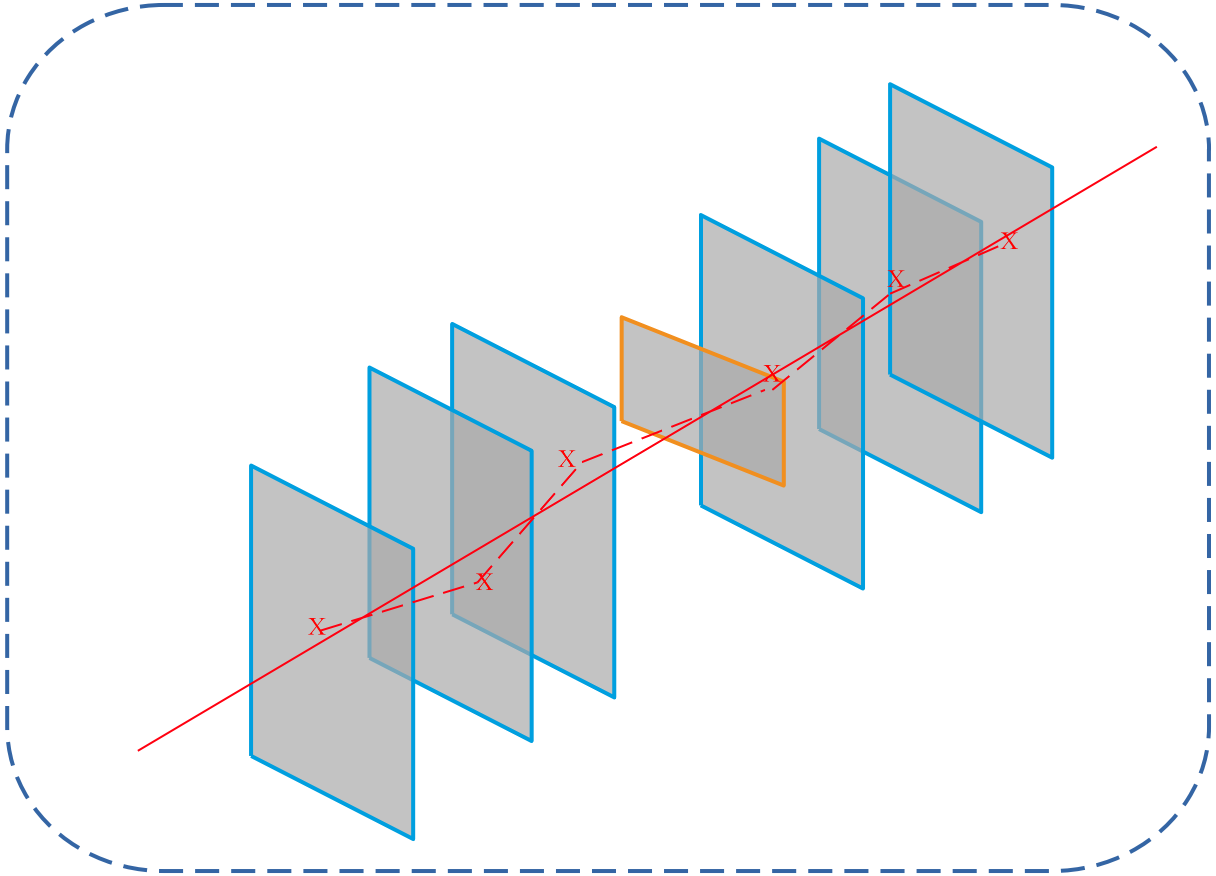
Tracking and alignment

Connecting the dots and moving the sensor to their correct positions

- Connecting the hits from the telescope layers to form a track
- Including time cuts if desired
- Available track models:
  - Straight lines
  - Multiplets with unknown scatterer at DUT
  - General Broken Lines
- Alignment based on Chi2 minimisation with TMinuit2 implementation of ROOT

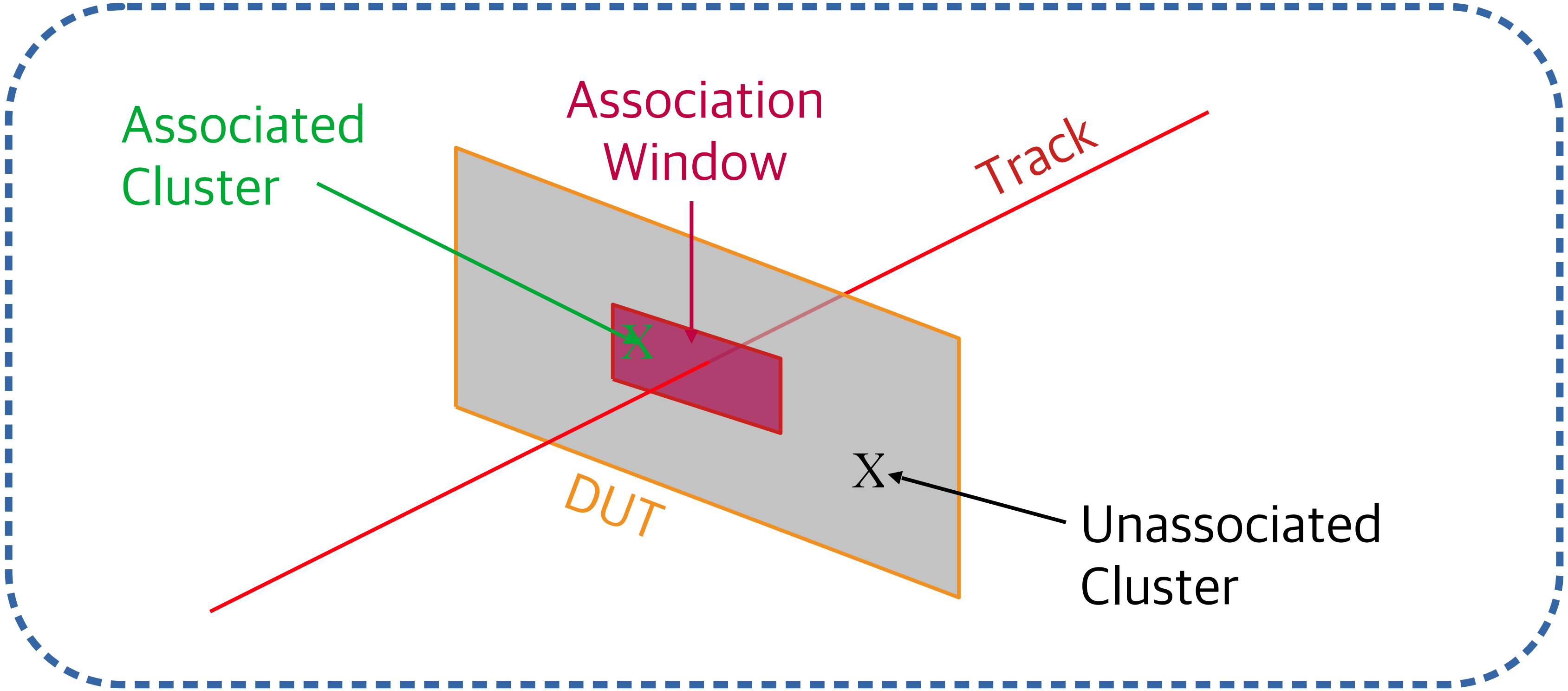






DUT Association

Finding matches between DUT hits and tracks

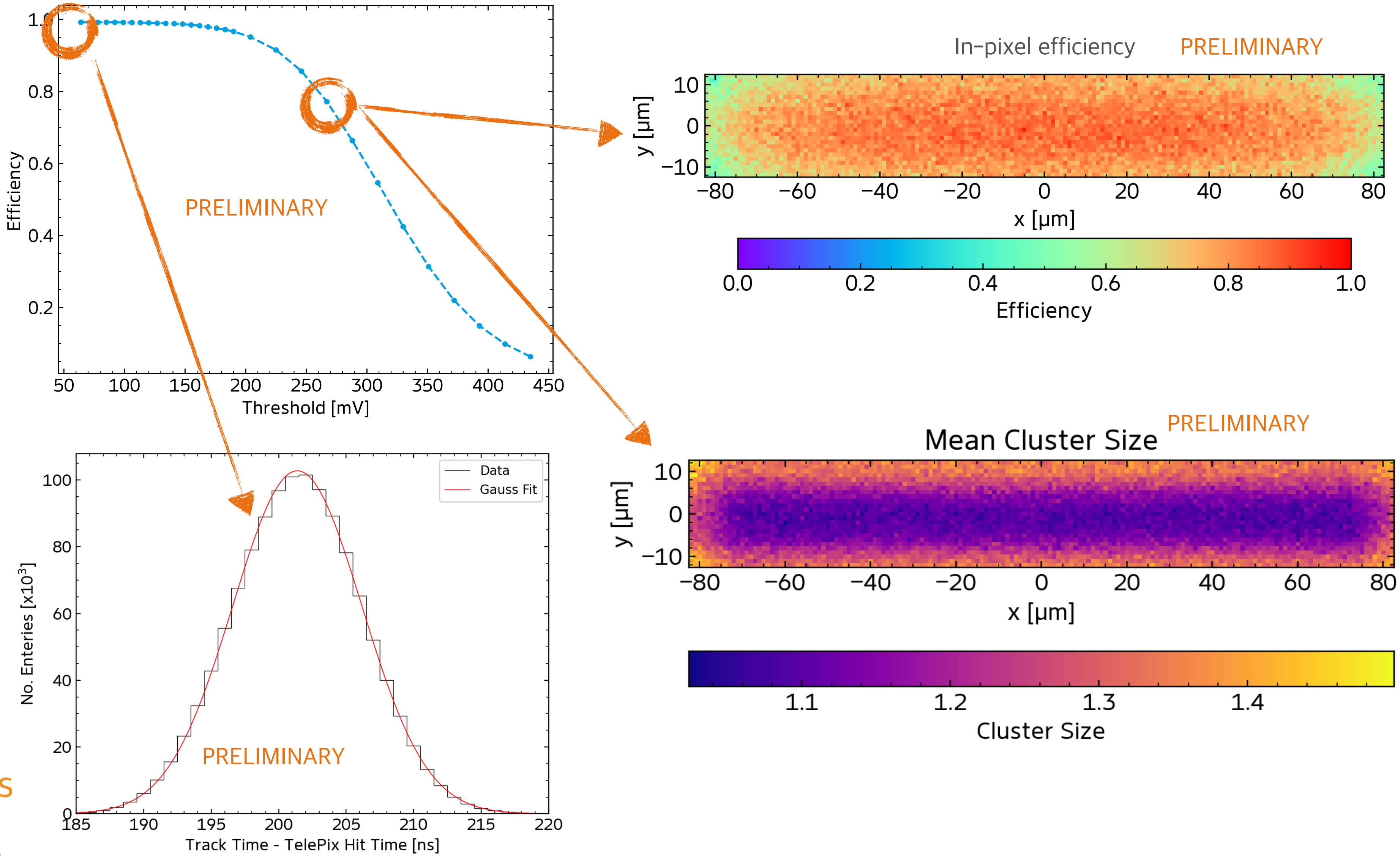


Optional association in time possible

Final results

Example results from TelePix2 at 85 V bias

- Efficiency as function of threshold
- Time resolution
- In-pixel effects
  - Clustersize
  - Efficiency
  - Timing

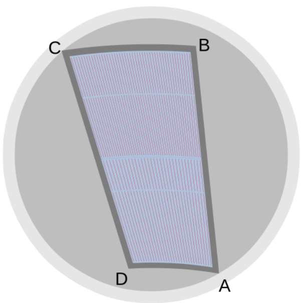


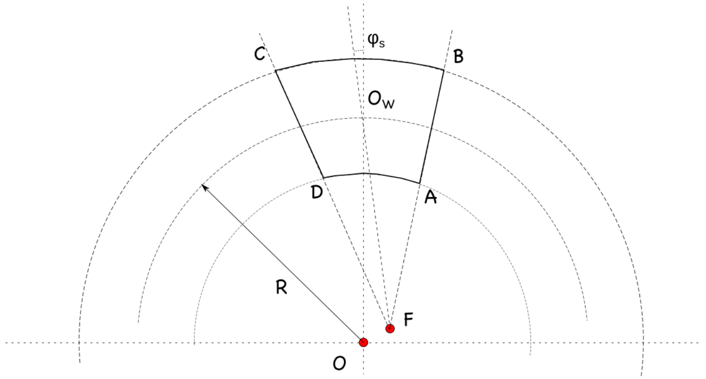
4.781 ± 0.003 ns

Exemplary new feature

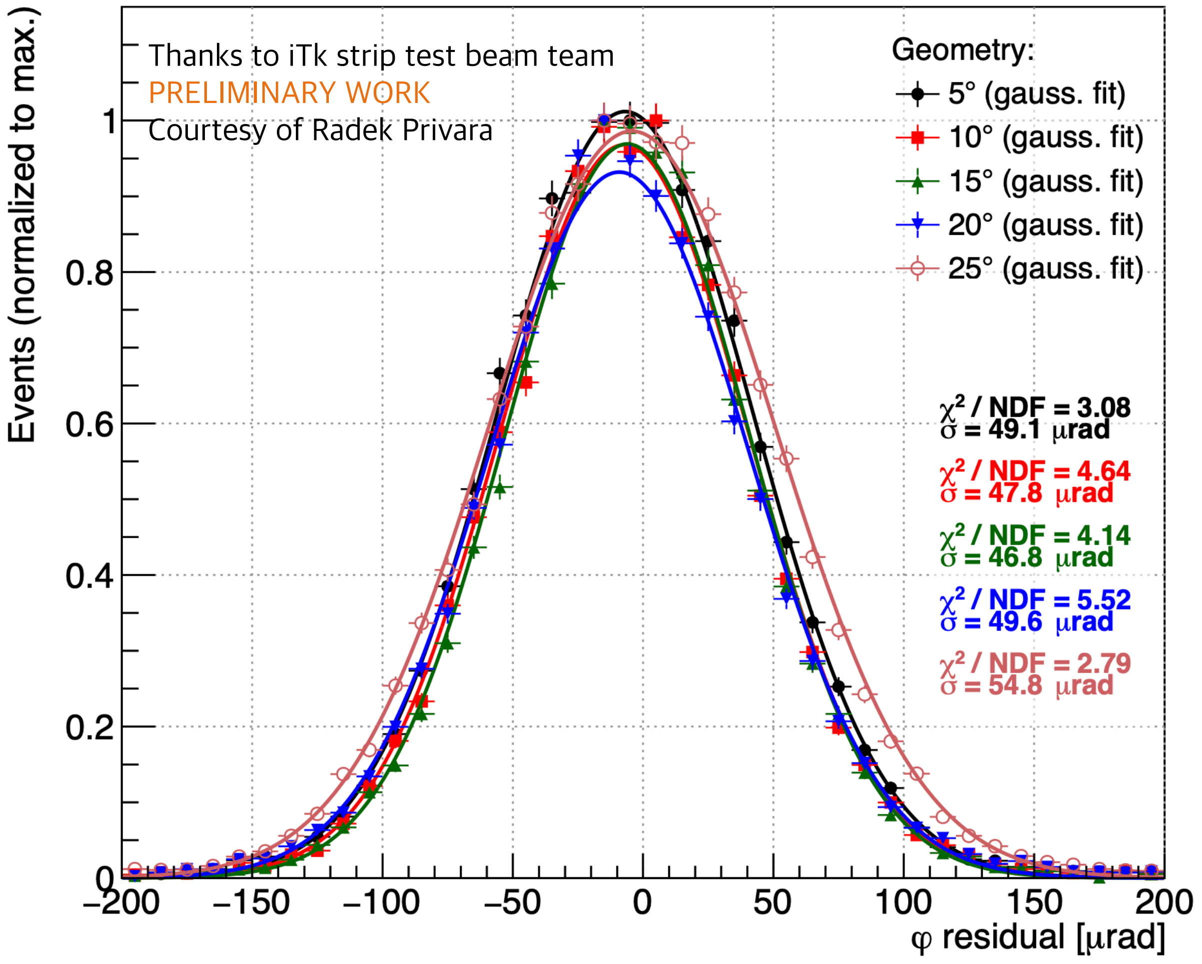
Radial strip geometries for the ATLAS iTk endcap sensors

- Implemented a new detector type "PolarDetector"
  - Transformations from global to local
  - Definition of radius, angular pitch etc
- Allows for radial strips and radial strips with a stereo angle (ATLAS iTk)
- Used in TB data analysis and validated against Allpix²





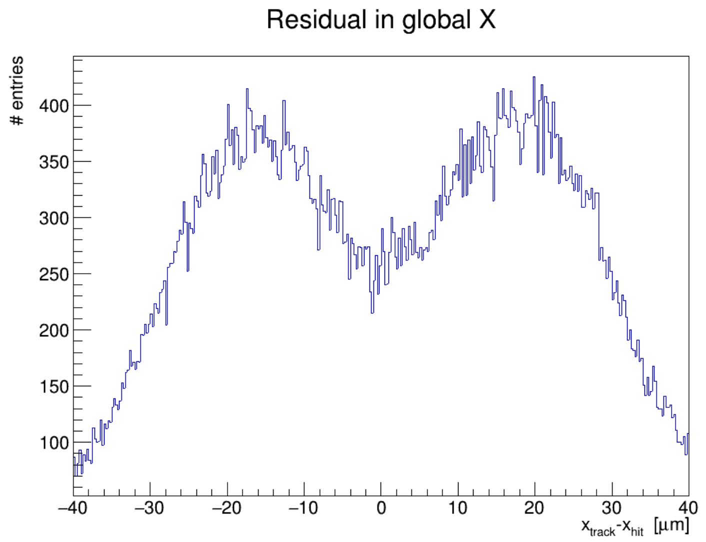
https://doi.org/10.1016/j.nima.2018.06.047

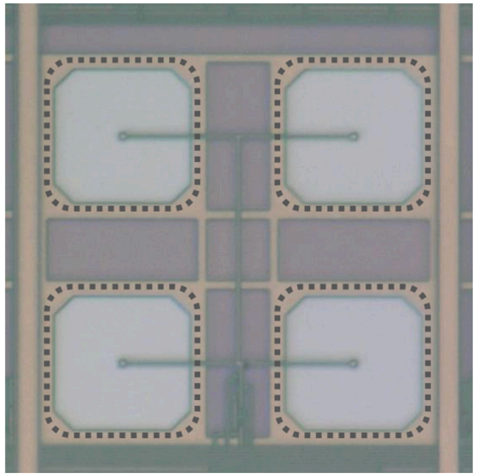


User contributions

Every contribution is welcome

- All kinds of user contributions are welcome:
  - New modules
  - New detectors
  - Bugfixes
  - Additions to existing modules
- Please follow the coding guidelines provided
- Code reviews before merge to master
- Contribution guidelines





Example: Alignment with non standard residuals for dSiPMs (see talk by F.Feindt)

MR#597

Summary

- Test beam studies are essential to qualify detector performance
- DESY offers the full package (with support of multiple other institutes)
  - Test beams
  - Tracking telescopes
  - Timing references
  - Software packages for operation, data acquisition and analysis
  - Common hardware for synchronisation

Outlook

- (Track)-timing is gaining more and more impact

  ➜ Fast references are being established
- Test beam complex will likely change within the next years as PETRA IV is on the horizon
- Continuing to improve the software packages, especially Corryvreckan gaining popularity

  ➜ Corryvreckan is open for everybody and relies on user input. Any contribution is welcome

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)

Questions?

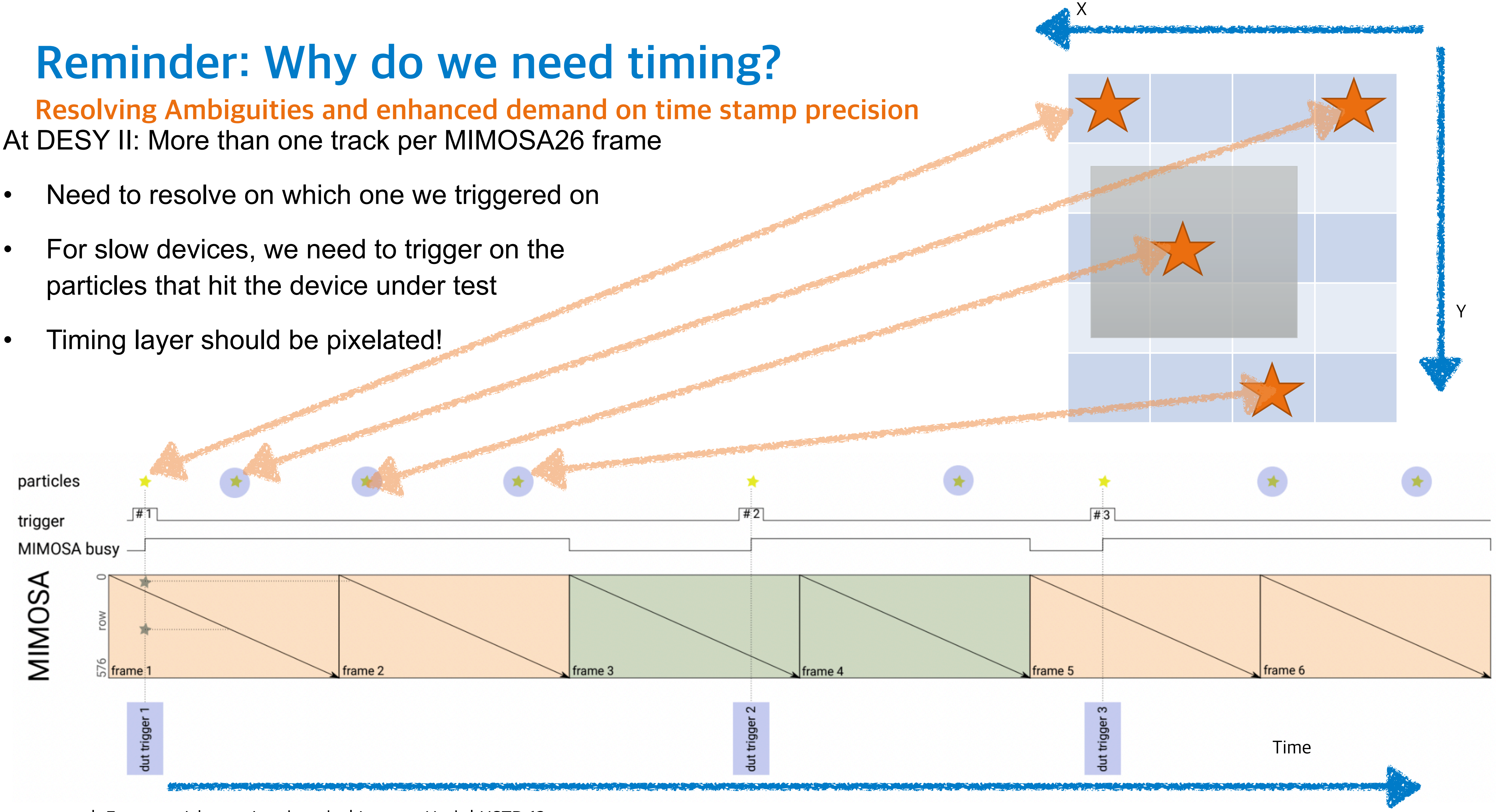
Backup

Reminder: Why do we need timing?

Resolving Ambiguities and enhanced demand on time stamp precision

At DESY II: More than one track per MIMOSA26 frame

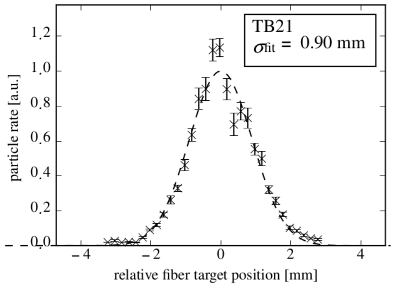
- Need to resolve on which one we triggered on
- For slow devices, we need to trigger on the particles that hit the device under test
- Timing layer should be pixelated!

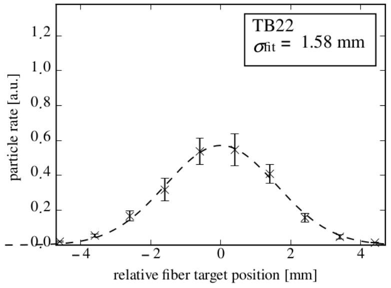


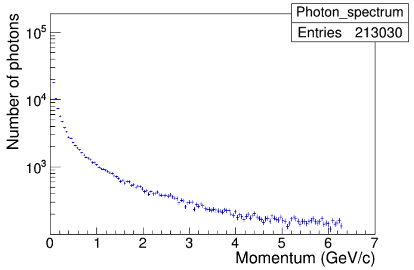
Particle rates

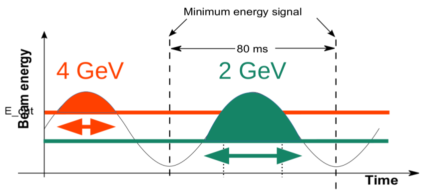
Depend on several factors

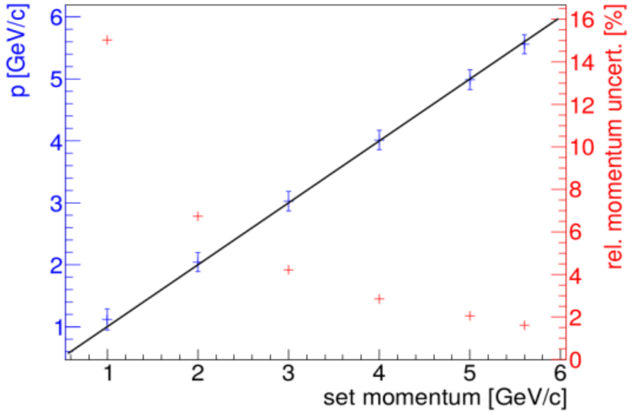
- More or less fixed: prim. and sec. target (thickness and material), PIA accumulation, PETRA operation
- Maximum O(10,000 particles s^{-1} cm^{-2})
- Beamline: T21 & T22 have higher rates than T24 (double dipole chicane)
- Energy: Bremsstrahlung spectrum + “duty cycle” + dipole/collimator
- Primary collimator settings

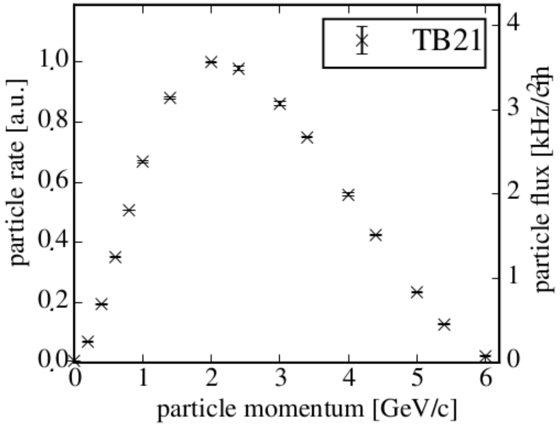








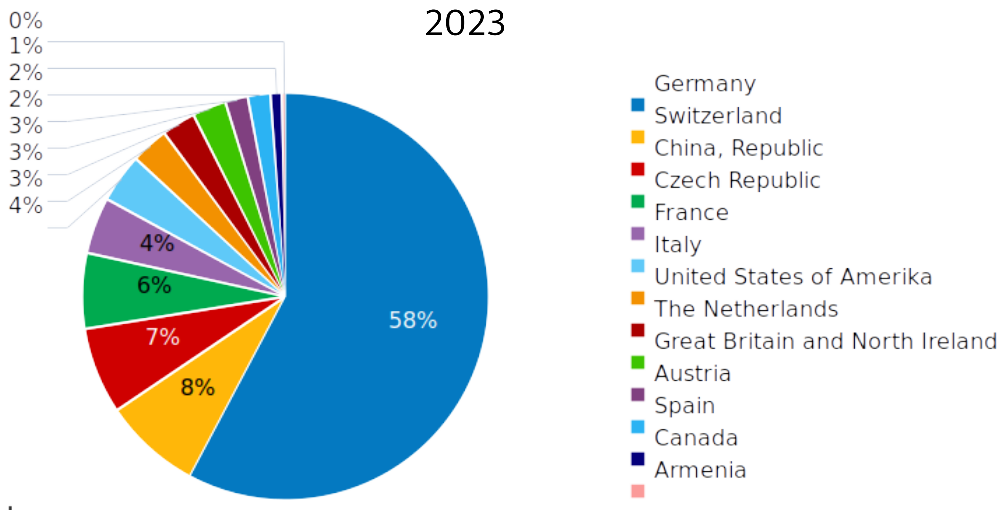


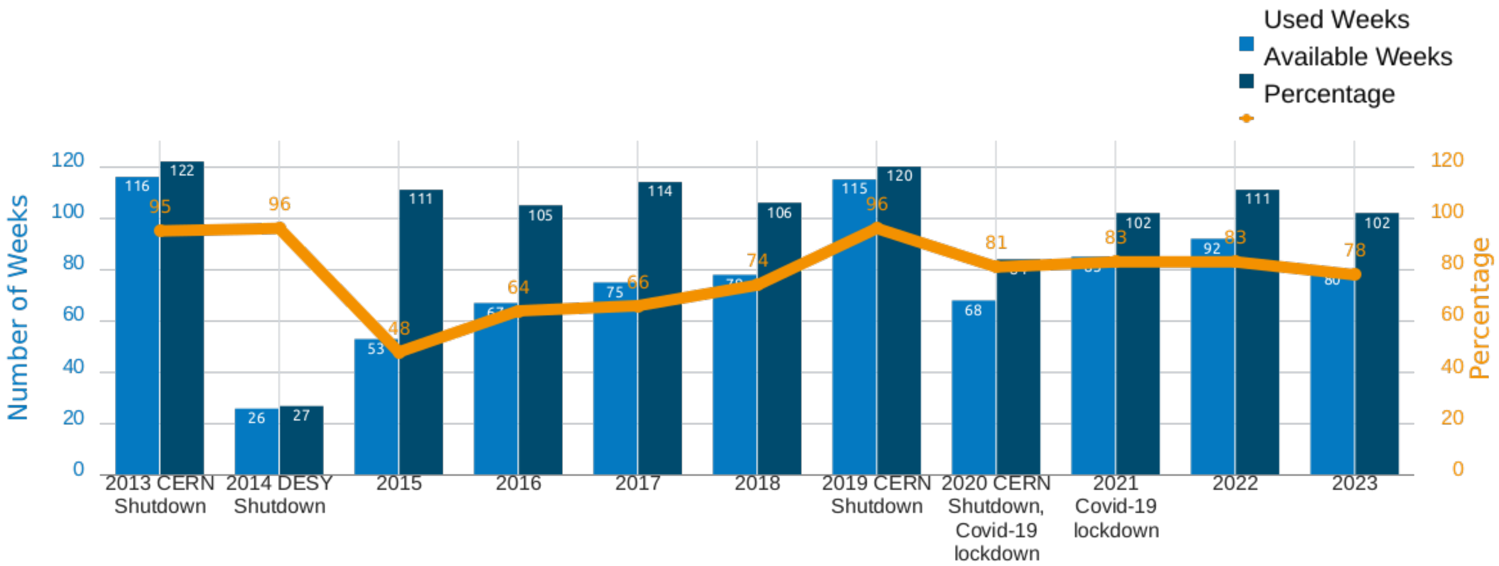


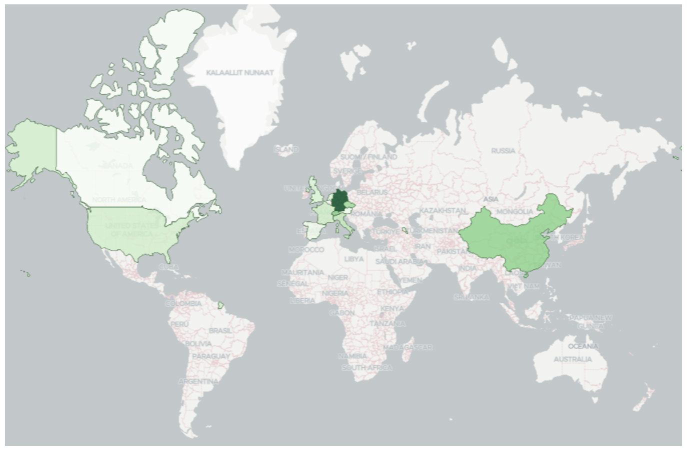
User statistics (1/2)

User origins and demand over the years

- In the past general upwards trend
- Most busy during CERN shutdowns
- 2019: Record year with over 700 users
- After 2019: You know what happened …







User statistics (2/2)

Types of usage

- Largest category over many years: LHC experiments
  - Upgrade R&D, final characterization, module testing, …
- Generic R&D catching up
- Linear collider R&D keeps decreasing