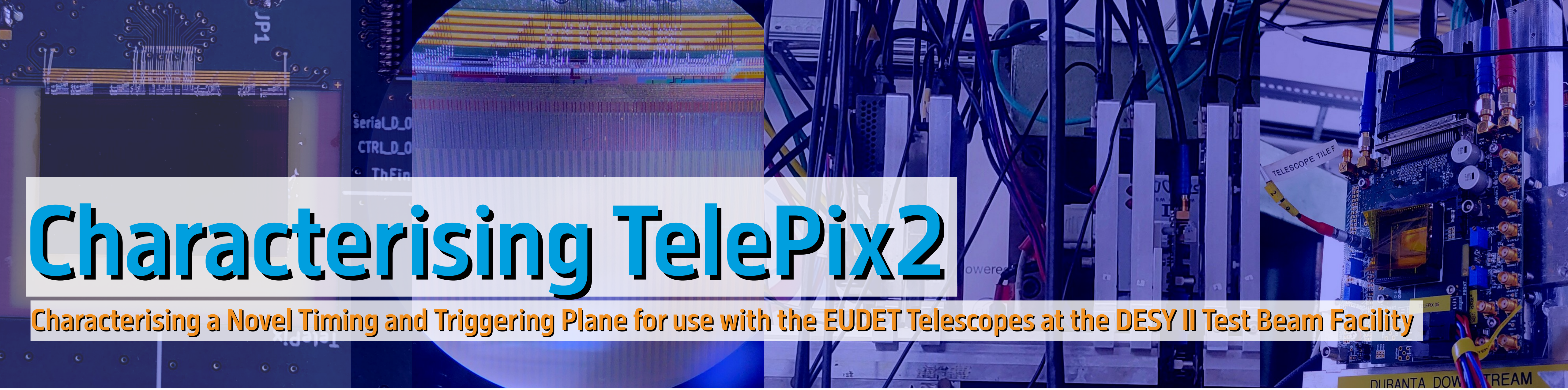


Characterising TelePix2

Characterising a Novel Timing and Triggering Plane for use with the EUDET Telescopes at the DESY II Test Beam Facility

Arianna Wintle on behalf of the TelePix2 Team, HighRR Seminar

15/11/2023

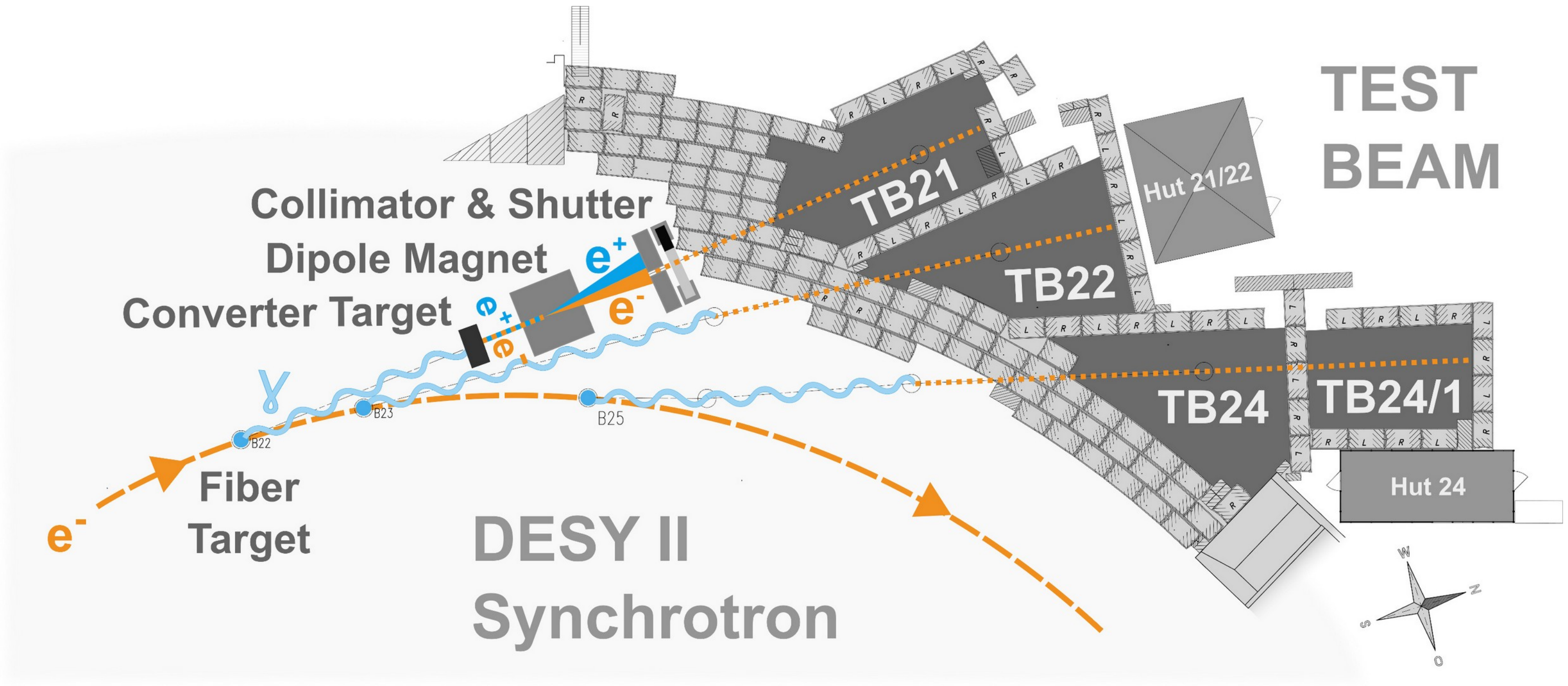
EXZELLENZCLUSTER
QUANTUM UNIVERSE

HELMHOLTZ

HGSFP

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

The DESYII Test Beam Facility



Three independent beamlines at the DESY II synchrotron

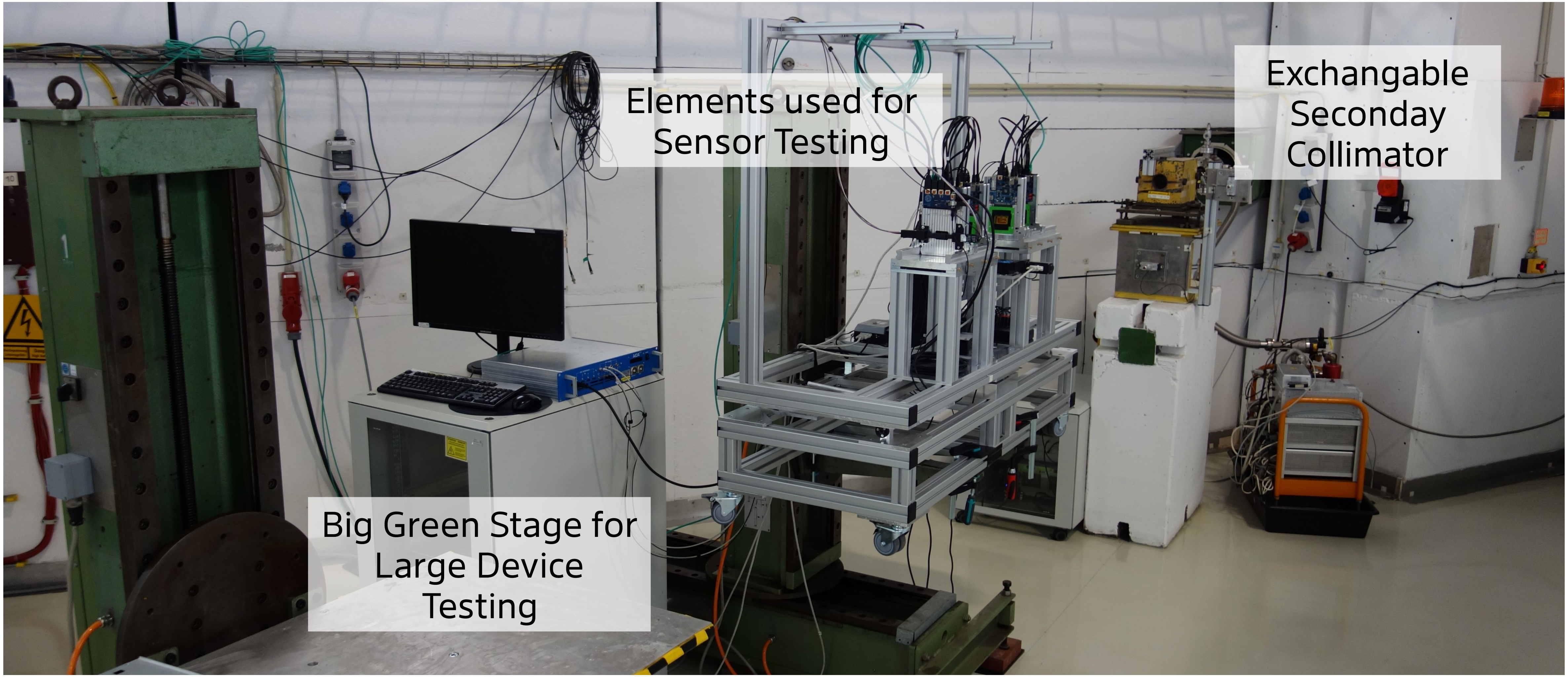
→ Typically used for **detector R&D for characterisation**

→ Offers **e^- or e^+** beam with user selectable momentum from **1-6 GeV/c**

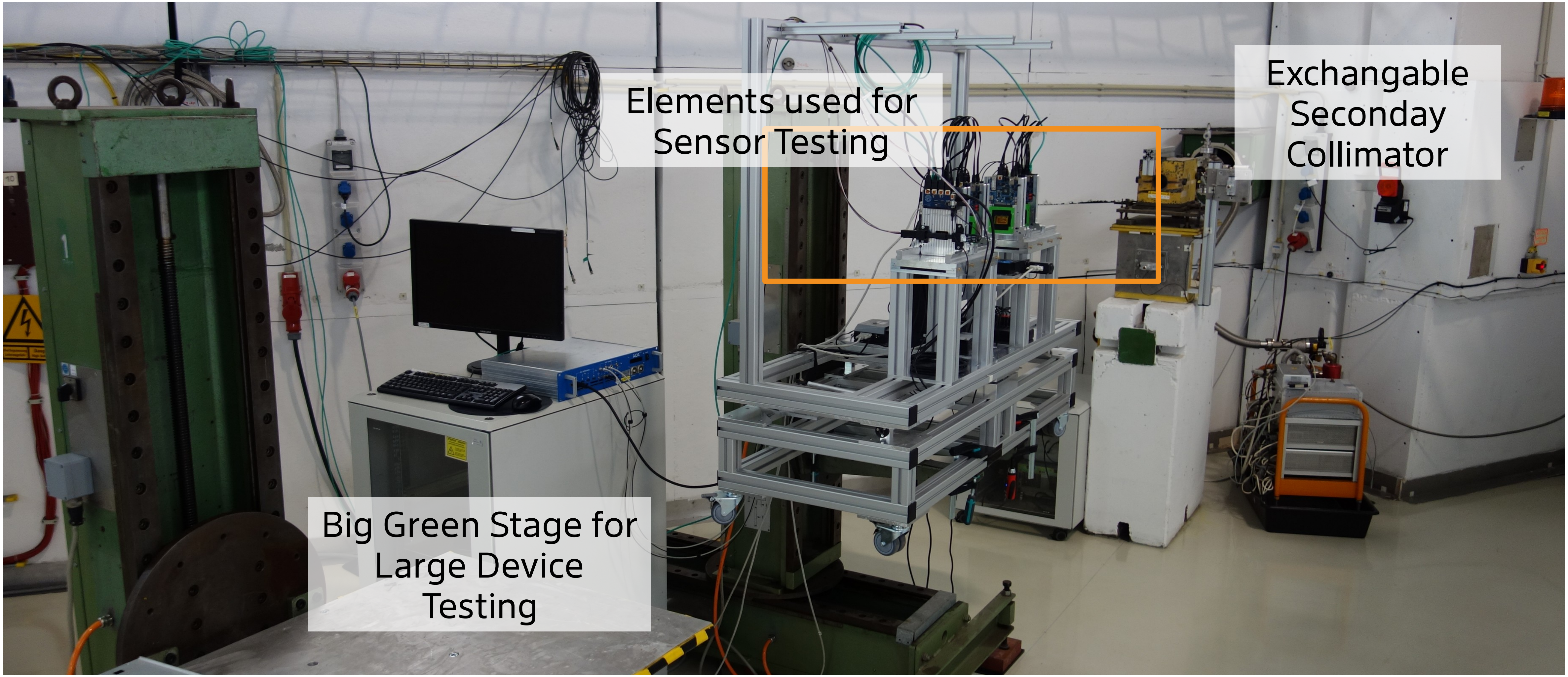
→ **Shutter and primary collimator** remote controllable

→ Exchangeable fixed size **secondary collimator**

Inside the Test Beam Area



Inside the Test Beam Area

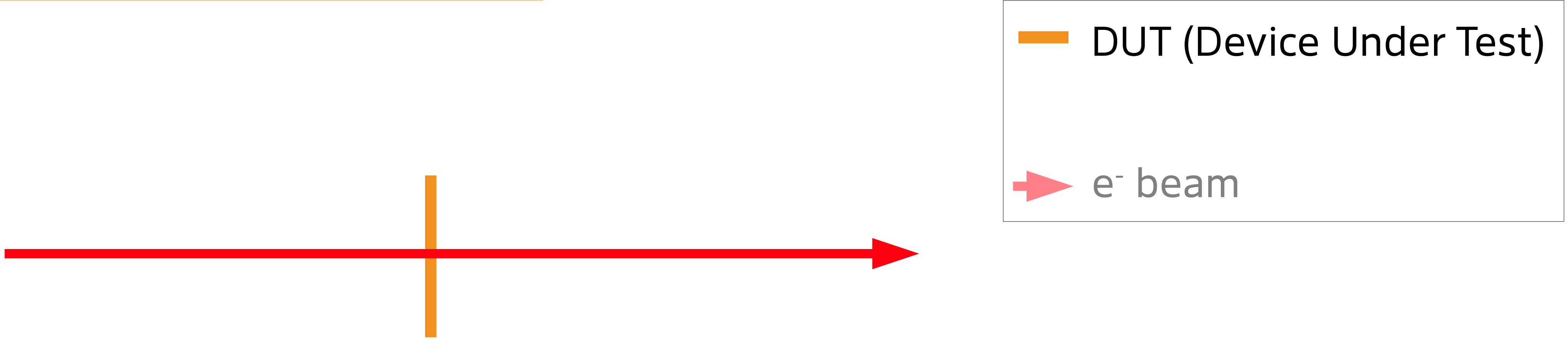


Test Beam Set Up

For Sensor Characterisation

DUT (Device Under Test)
Range of different sizes and operating conditions

Parameters to test:
- Efficiency
- Time Resolution & Spatial Resolution
- Behavior under a magnetic field

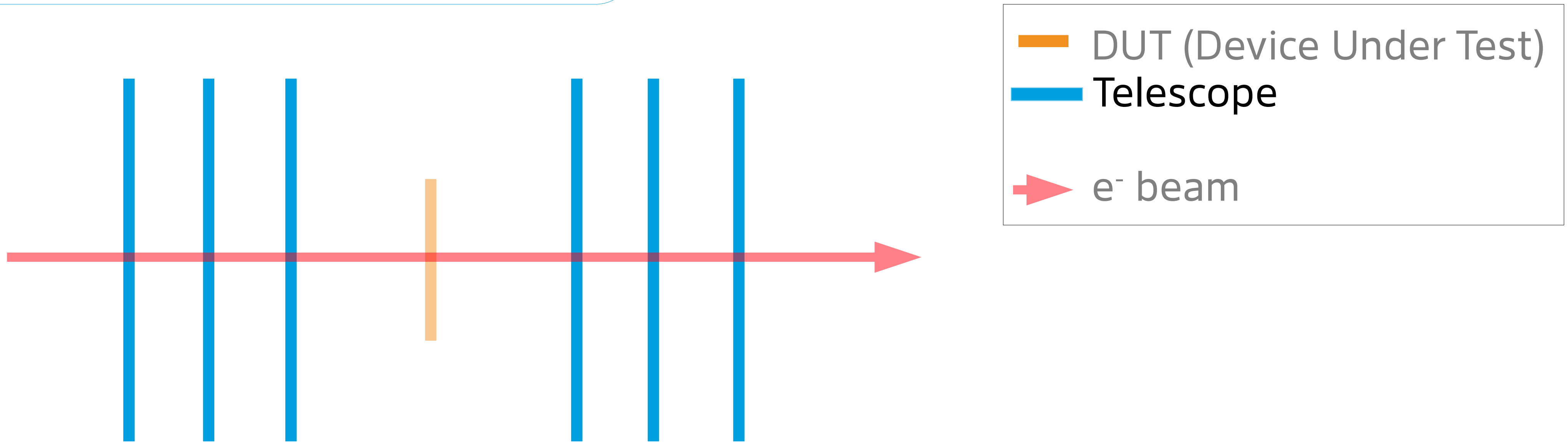


Test Beam Set Up

For Sensor Characterisation

Telescope
Multiple sensor planes
Allow precise track reconstruction

At DESY II Test Beam Facility two types with two different readout times:
Mimosa (~ 230 µs) & **Adenium** (~ 10 µs)

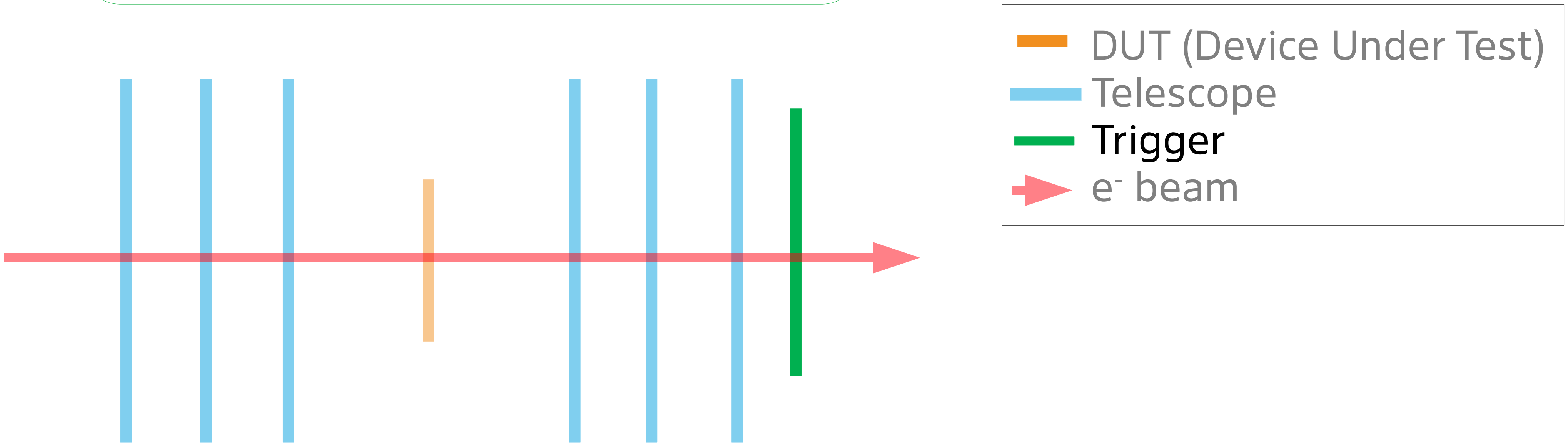


Test Beam Set Up

For Sensor Characterisation

Trigger

- Tag the presence of particles
- Important for reducing noise (event based readout)

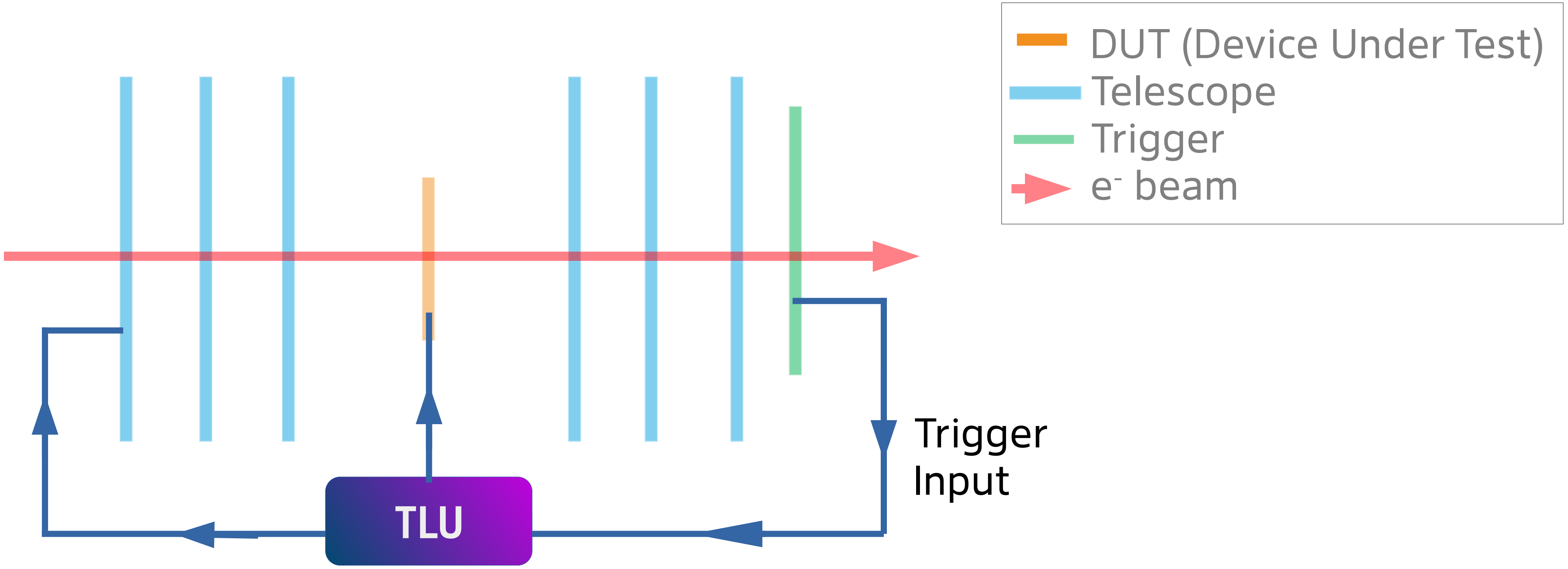


Test Beam Set Up

For Sensor Characterisation

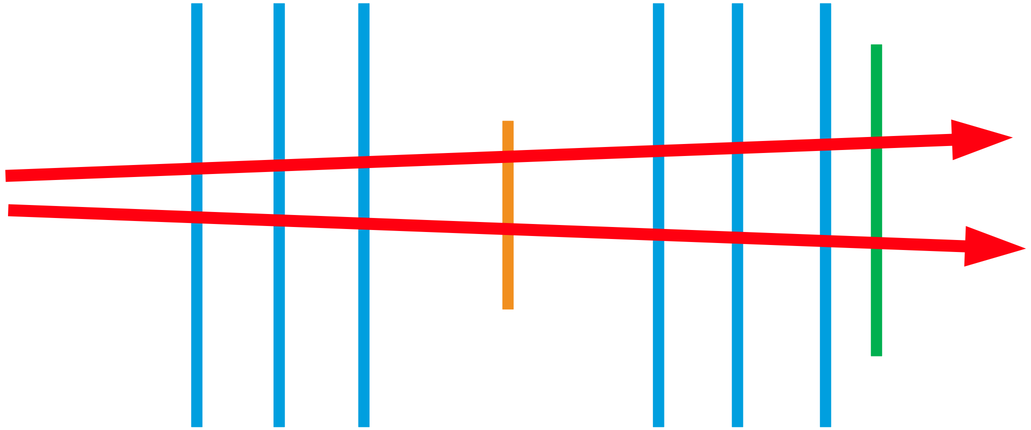
Trigger Logic Unit

- Trigger on an arbitrary logical combination of 6 triggering inputs
- Synchronisation of multiple devices: exchange trigger ID or common clock and reset



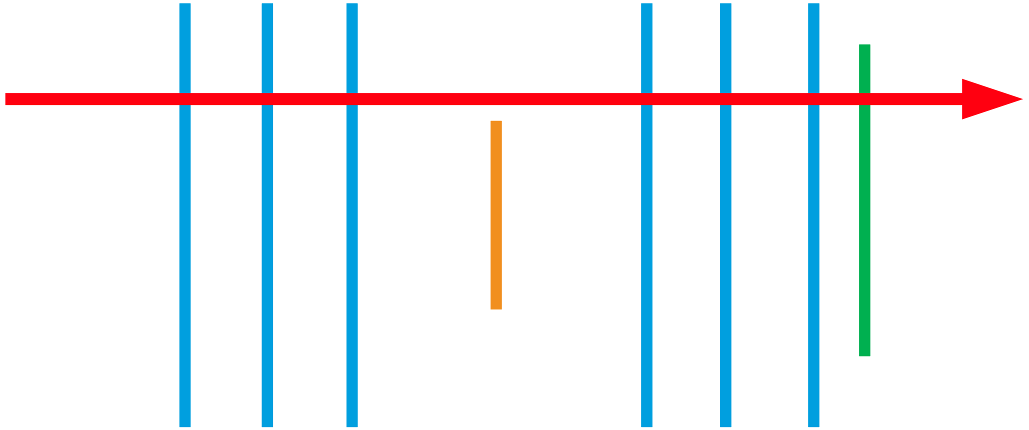
Timing and ROI Triggering Plane

Slow telescope readout & high particle rates



Multiple tracks within one readout → Impossible to associate which track belongs to which trigger

Mismatch in trigger and DUT size



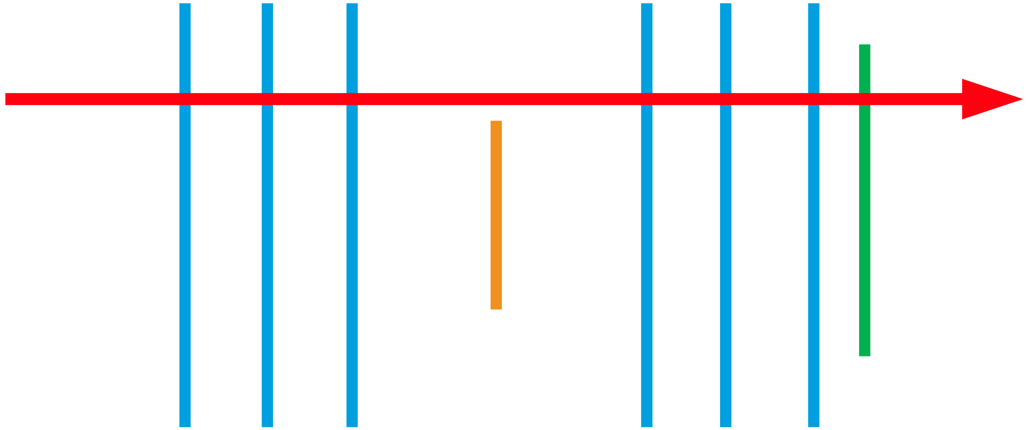
Trigger on uninteresting events → Inefficient data taking

Timing and ROI Triggering Plane

Slow telescope readout & high particle rates

Multiple tracks within one readout → Impossible to associate which track belongs to which trigger

Mismatch in trigger and DUT size



Trigger on uninteresting events → Inefficient data taking

Timing and ROI Triggering Plane

Slow telescope readout & high particle rates

Multiple tracks within one readout
→ Impossible to associate which track belongs to which trigger

Mismatch in trigger and DUT size

Trigger on uninteresting events
→ Inefficient data taking

Timing and ROI Triggering Plane

DUT	Trigger
Telescope	e⁻ beam

Slow telescope readout & high particle rates

Mismatch in trigger and DUT size

Multiple tracks within one readout → Impossible to associate which track belongs to which trigger

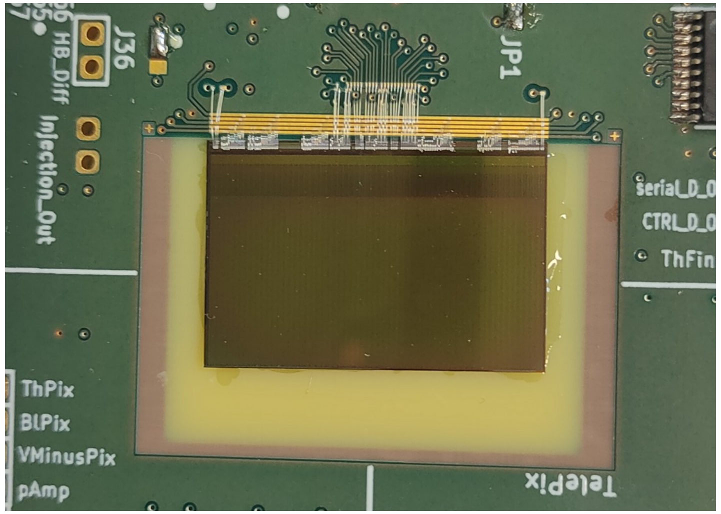
Trigger on uninteresting events → Inefficient data taking

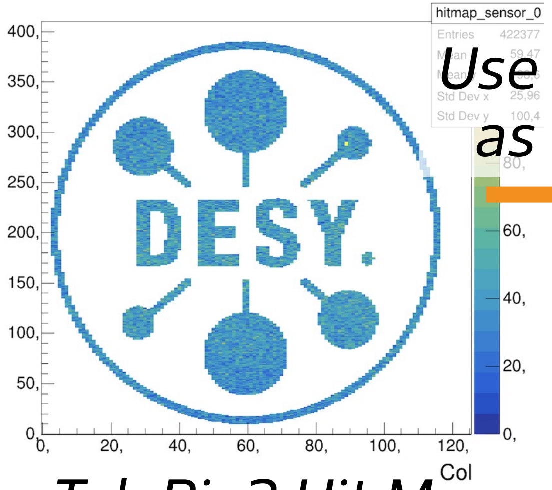
TelePix2

Key Features

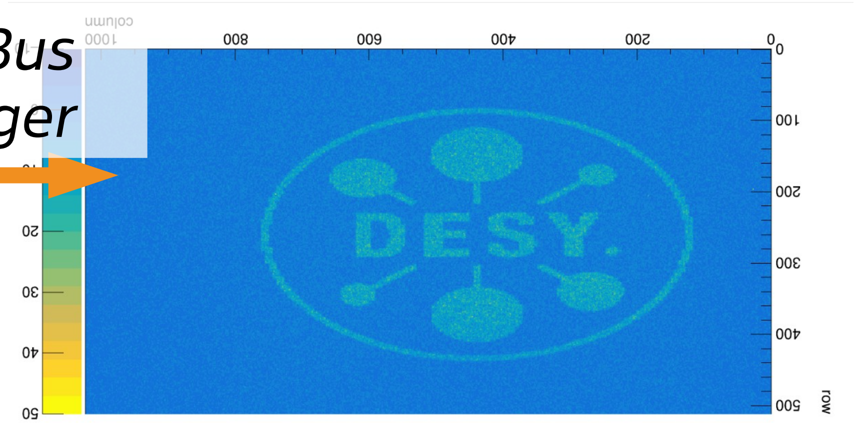
- **HVMAPS** sensor with a **fine timestamp (4 ns)**
- Fast output for a **user-configurable ROI trigger** (HitBus)
- A **low material budget** (0.0011 from 100 µm silicon)

Pixel Size: 165 x 25 µm
Columns x Row: 120 x 400
Chip size: 20.015 x 13.130 mm





Use HitBus as trigger



TelePix2 Hit Map

Telescope Plane Hit Map

Work in Progress

Preliminary

All the following results are preliminary, the analysis is a work in progress and results might still change.
Data was taken from a test beam at the DESY II test beam facility (area 22 beam energy 4 GeV) carried out in October 2023.

Another alignment, systematic checking of various cuts, is still being carried out.

Analysis Flow

Test beam analysis and reconstruction

- Event Loading
- ↓ Clustering
- ↓ Tracking
- ↓ DUT Association
- ↓ Alignment
- ↓ Analysis

Use of Corryvreckan in analysis

- Very flexible, modular and configurable, open source and free to use

Data is grouped into events, then passed through a reconstruction chain

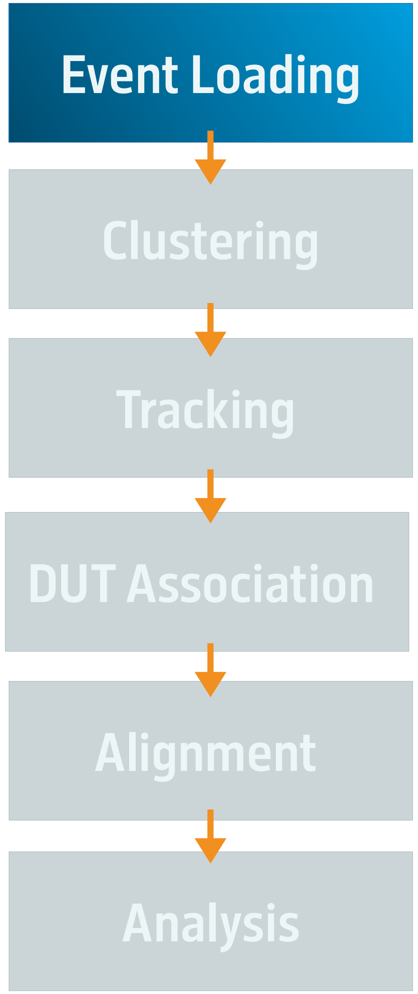
Configuration file:
- Which modules with what parameters and order

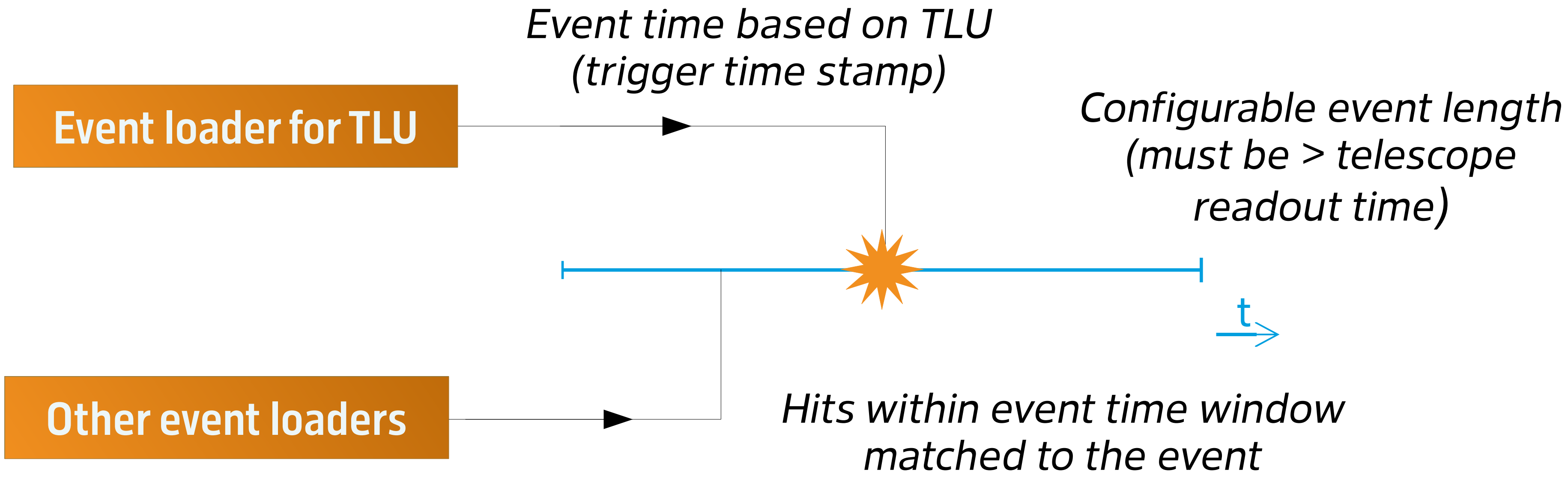
Geometry file:
- Relative positions & rotation of sensors

Corryvreckan Paper: D. Dannheim et al 2021 JINST 16 P03008

Event Loader

Event definition





Merged TelePix2 data-driven readout with triggered readout of telescope

Specific event loaders include:

- EventLoaderEUDAQ2 for telescope data and TLU data
- EventLoaderMuPixTelescope for TelePix data and any data recorded with the HV-MAPS DAQ of Heidelberg

Clustering

Pixels to Clusters

Event Loading
↓
Clustering
↓
Tracking
↓
DUT Association
↓
Alignment
↓
Analysis

Group **nearest neighbors** together

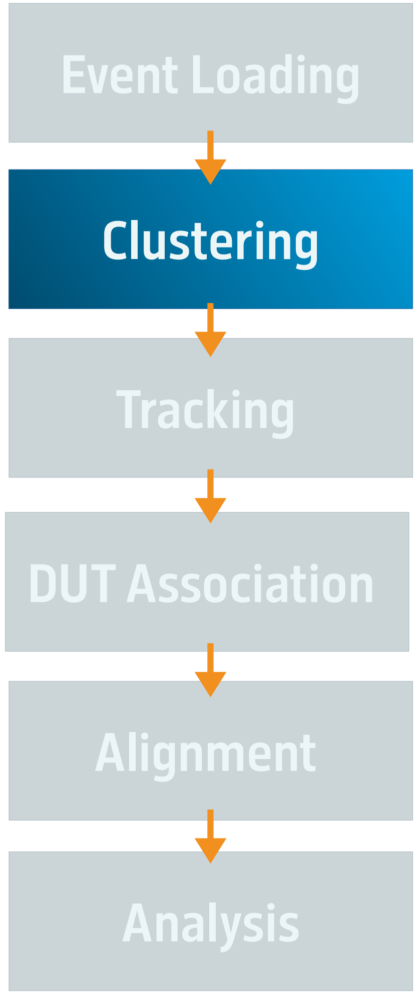
- Can also use a time cut to improve accuracy
- Center of gravity used as hit position

Note: telescope readout slow, timestamp for the telescope clusters must come from the trigger time stamp

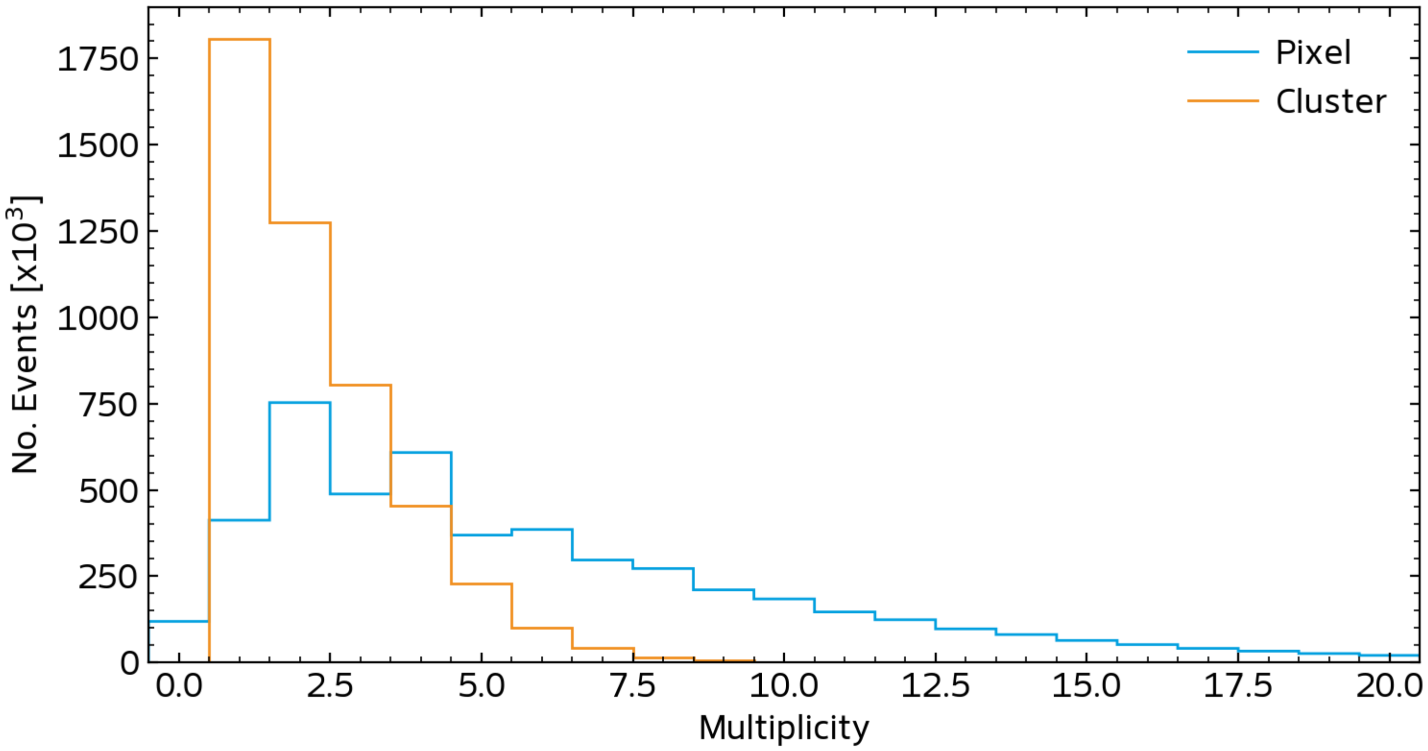
Modules used here are ClusteringSpatial and Clustering4D

Clustering

Pixels to Clusters



Comparison of no. pixels hit and no. clusters per event for 1st Adenium plane

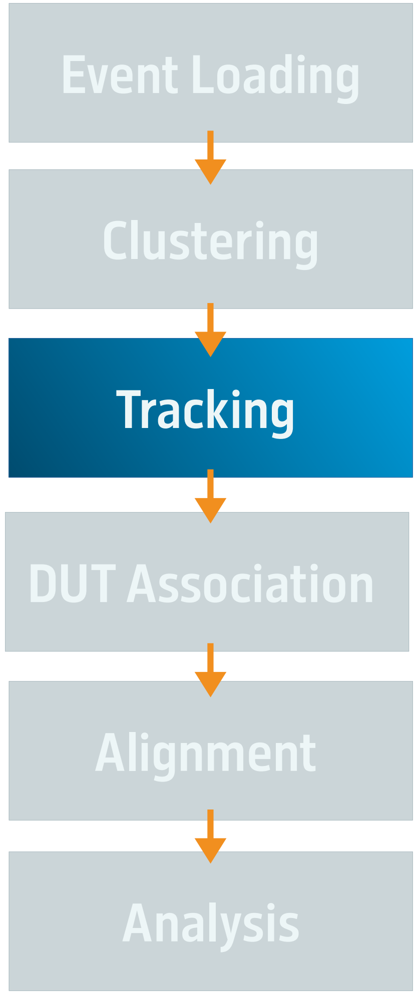


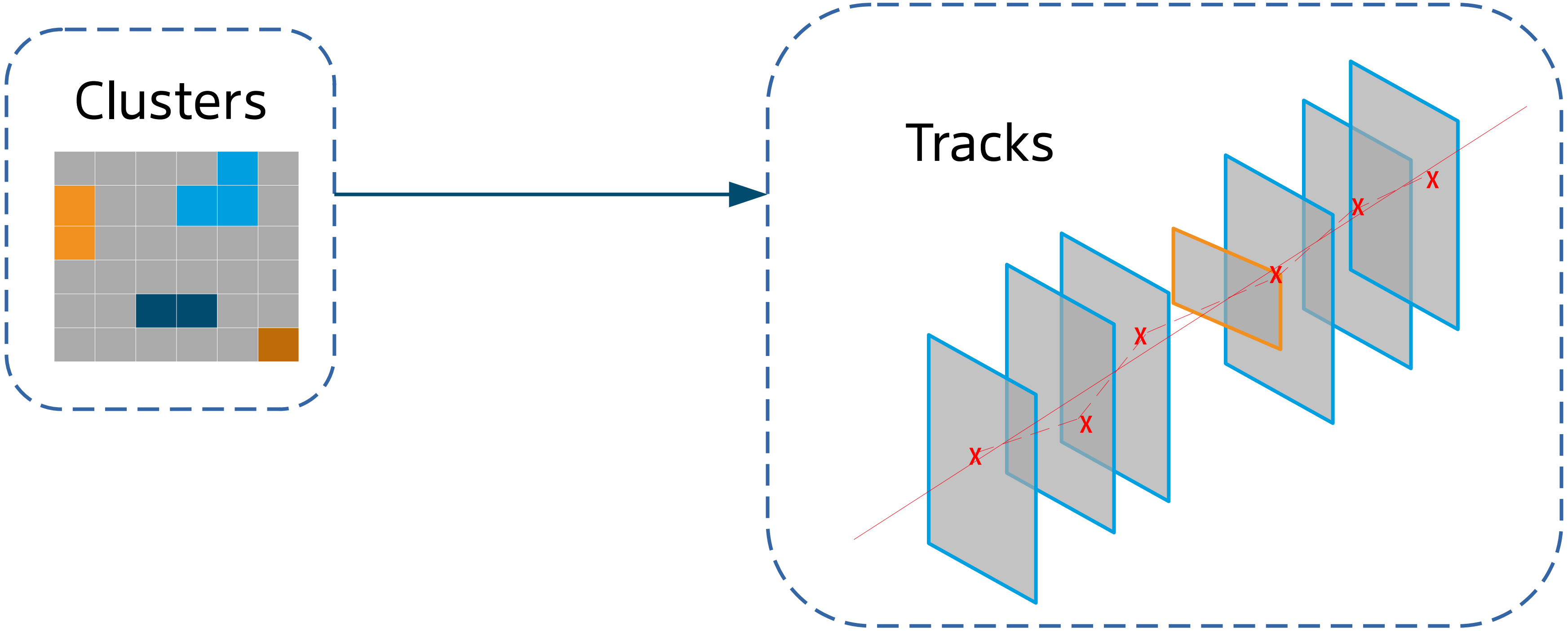
Pixel Multiplicity > Cluster Multiplicity

→ Effective clustering

Tracking

Clusters to Tracks





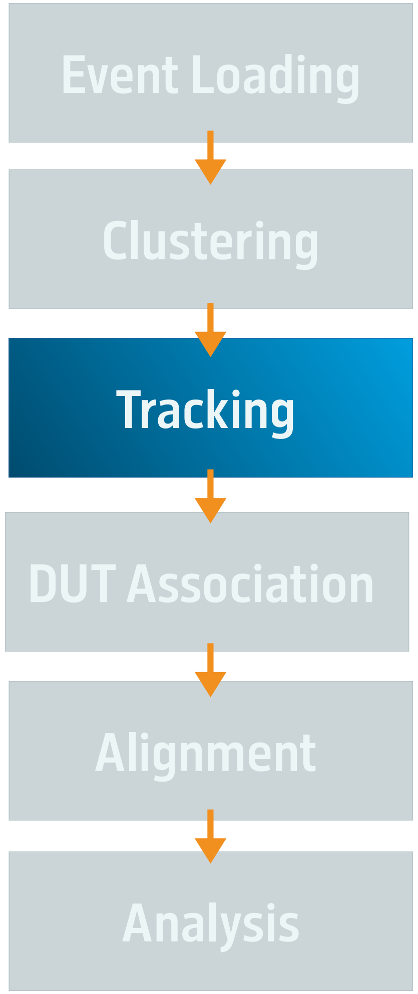
Connect clusters in different planes into one track.

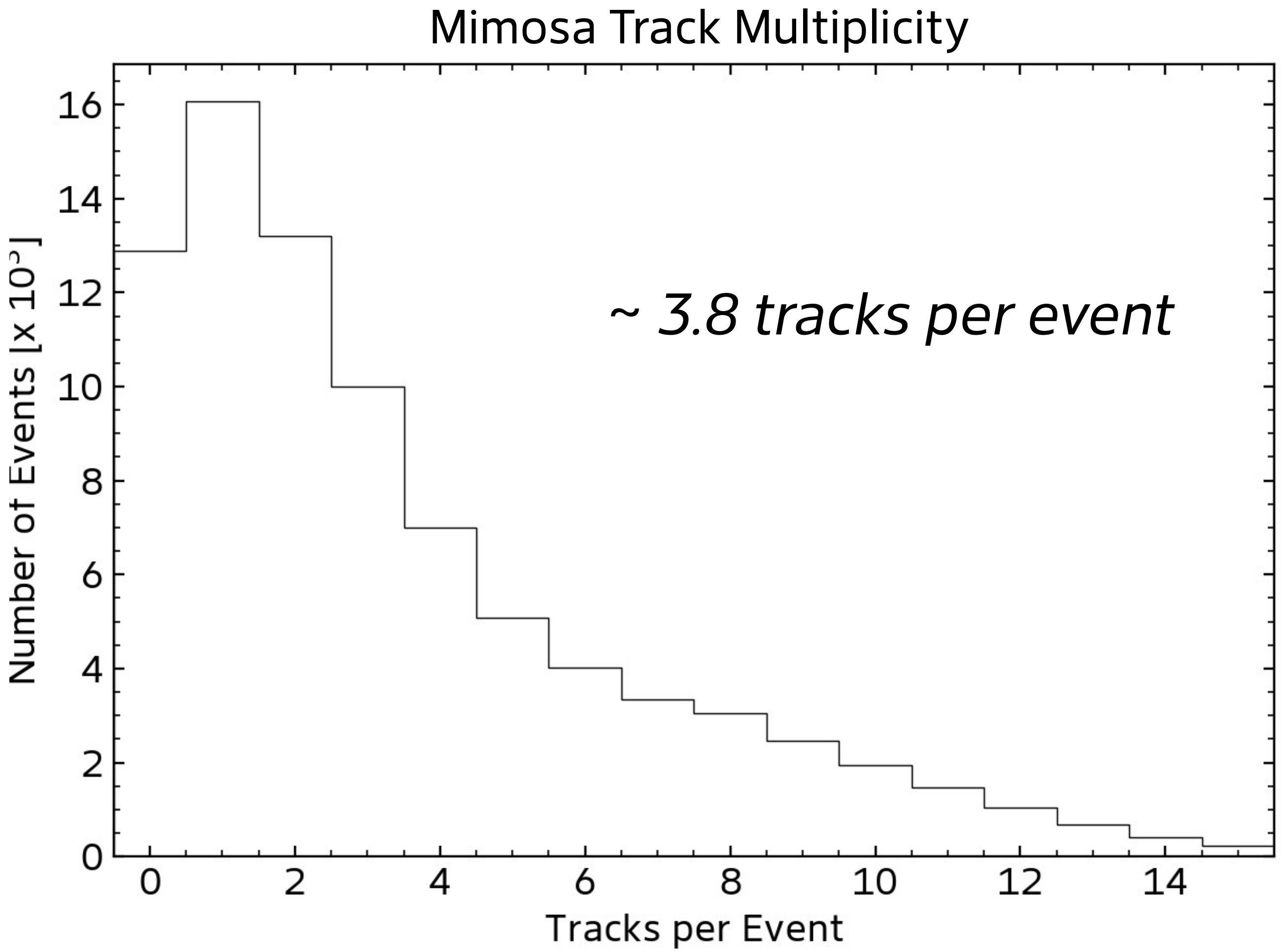
- Here using General Broken Lines (GBL) model: **allows for scattering at planes and in the air between**.
- Now able to calculate **track intersection** with the DUT

Module used here is Tracking4D

Tracking

Clusters to Tracks

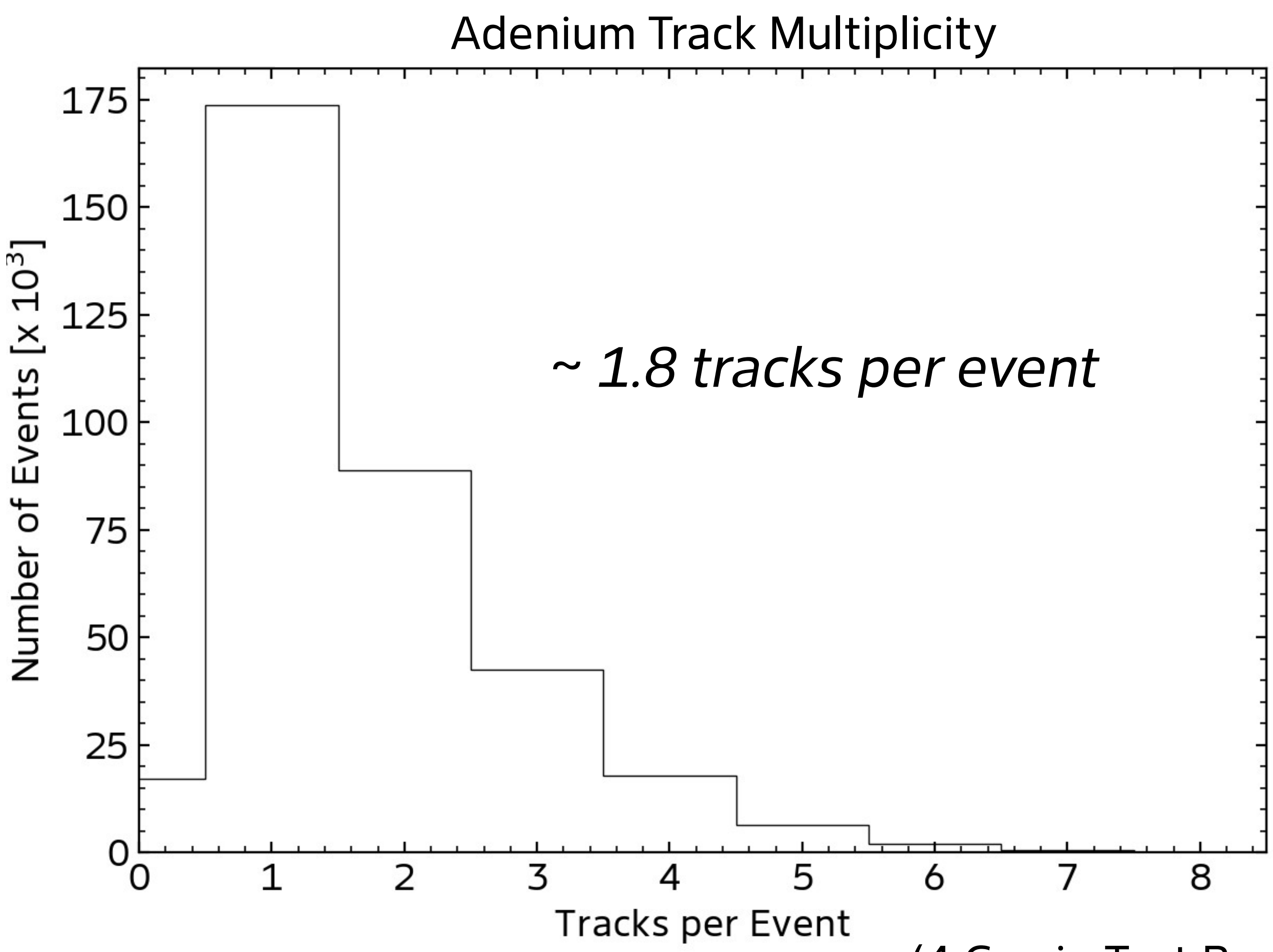




(3 GeV in Test Beam area 21)

Tracking
Clusters to Tracks

- Event Loading
- Clustering
- **Tracking**
- DUT Association
- Alignment
- Analysis



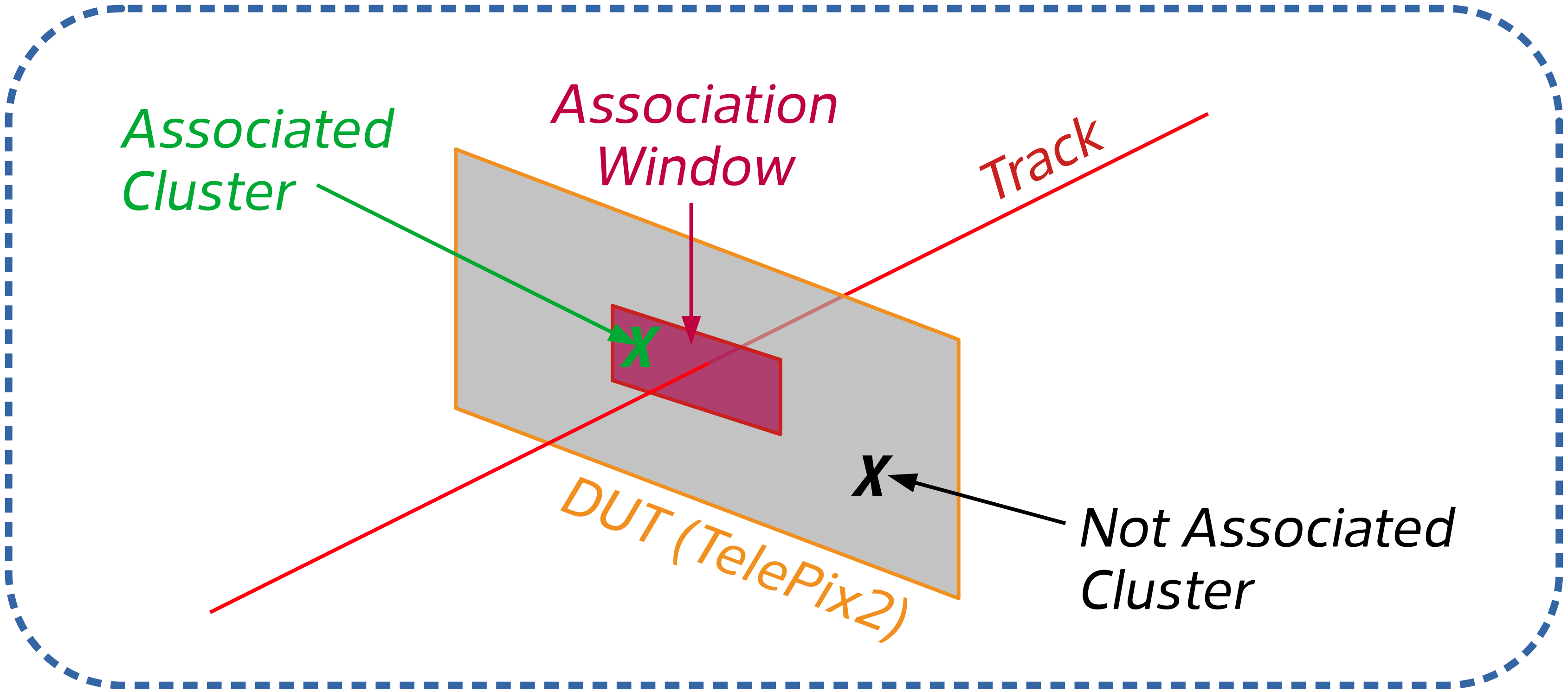
(4 Gev in Test Beam area 22)

Subsequent analysis filtered to 1 track per event

DUT Association

Matching DUT Hits to Telescope Tracks

- Event Loading
- Clustering
- Tracking
- **DUT Association**
- Alignment
- Analysis



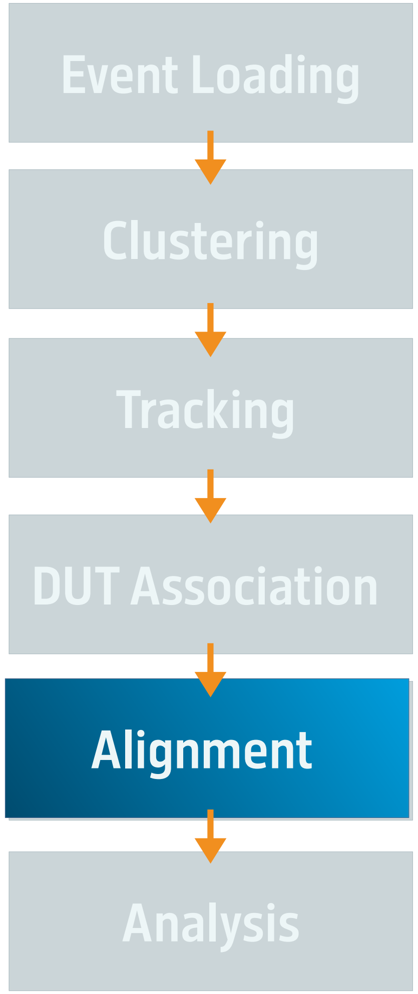
If the **DUT cluster** lies within a **spatial and time window** of the track intersection

→ associate this cluster with the track

Module used here is DUTAssociation

Alignment

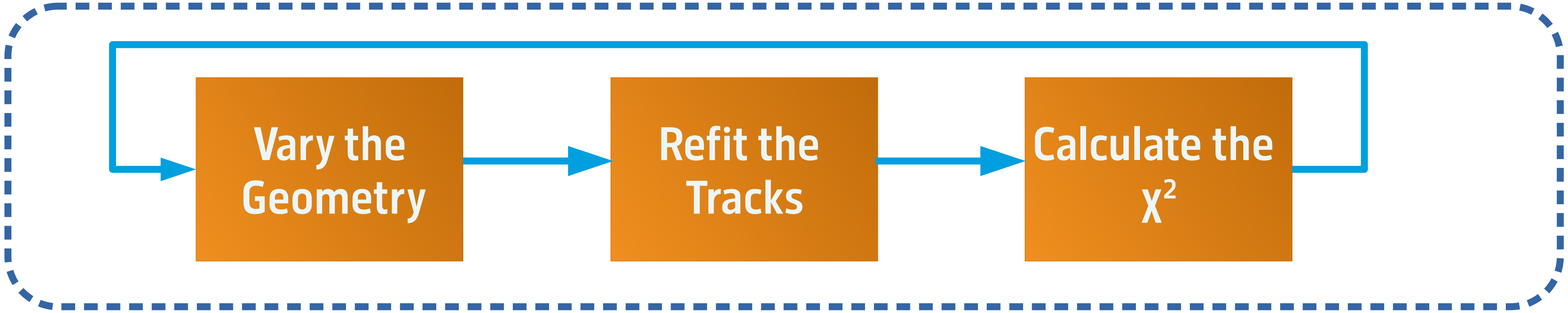
Matching Physical Position



Difficult to **match measured geometry** in geometry file with the **precise physical locations.**

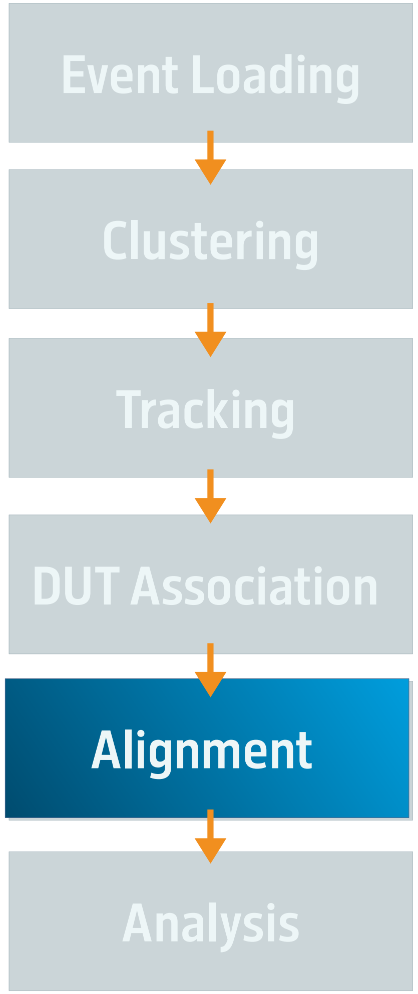
→ Rely on alignment modules to instead precisely align sensors

Iteratively adjust geometry (position and rotation) to **minimise the total χ^2 of the track.** Minimiser is TMinuit2 based.



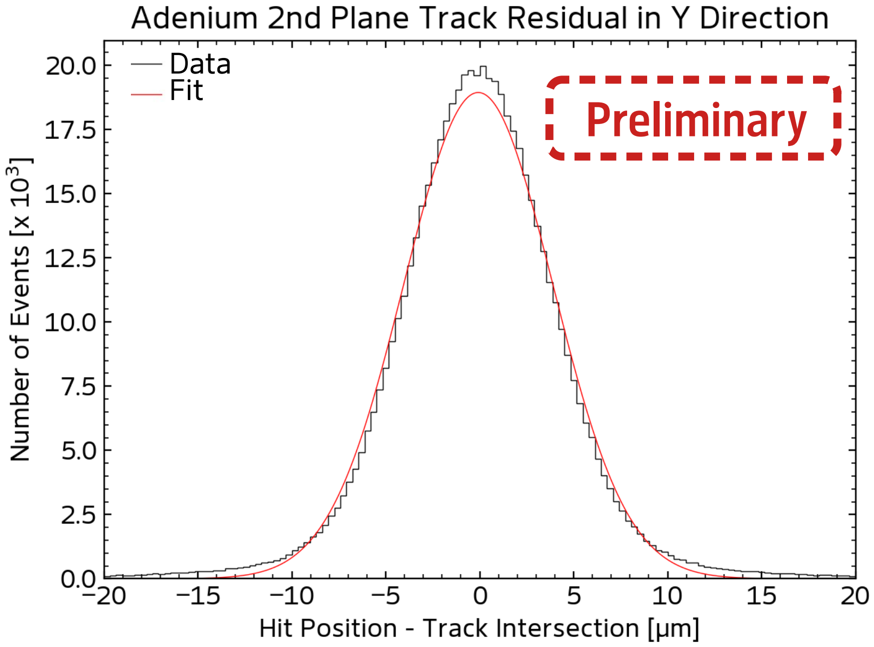
Carried out separately for Telescope (Adenium) with AlignmentTrackChi2 and DUT (TelePix) AlignmentDUTResidual

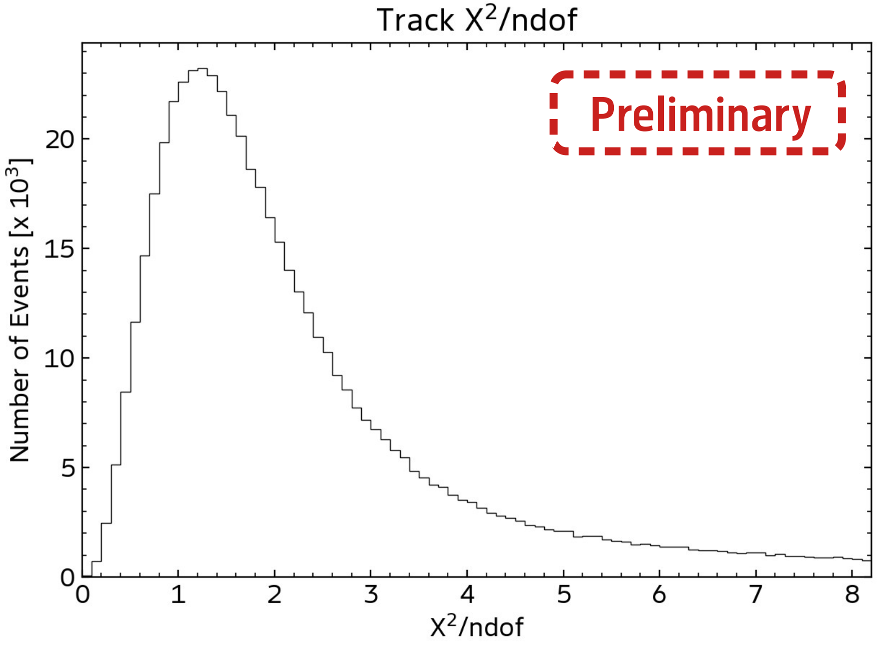
Alignment
Matching Physical Position



A good alignment results in:

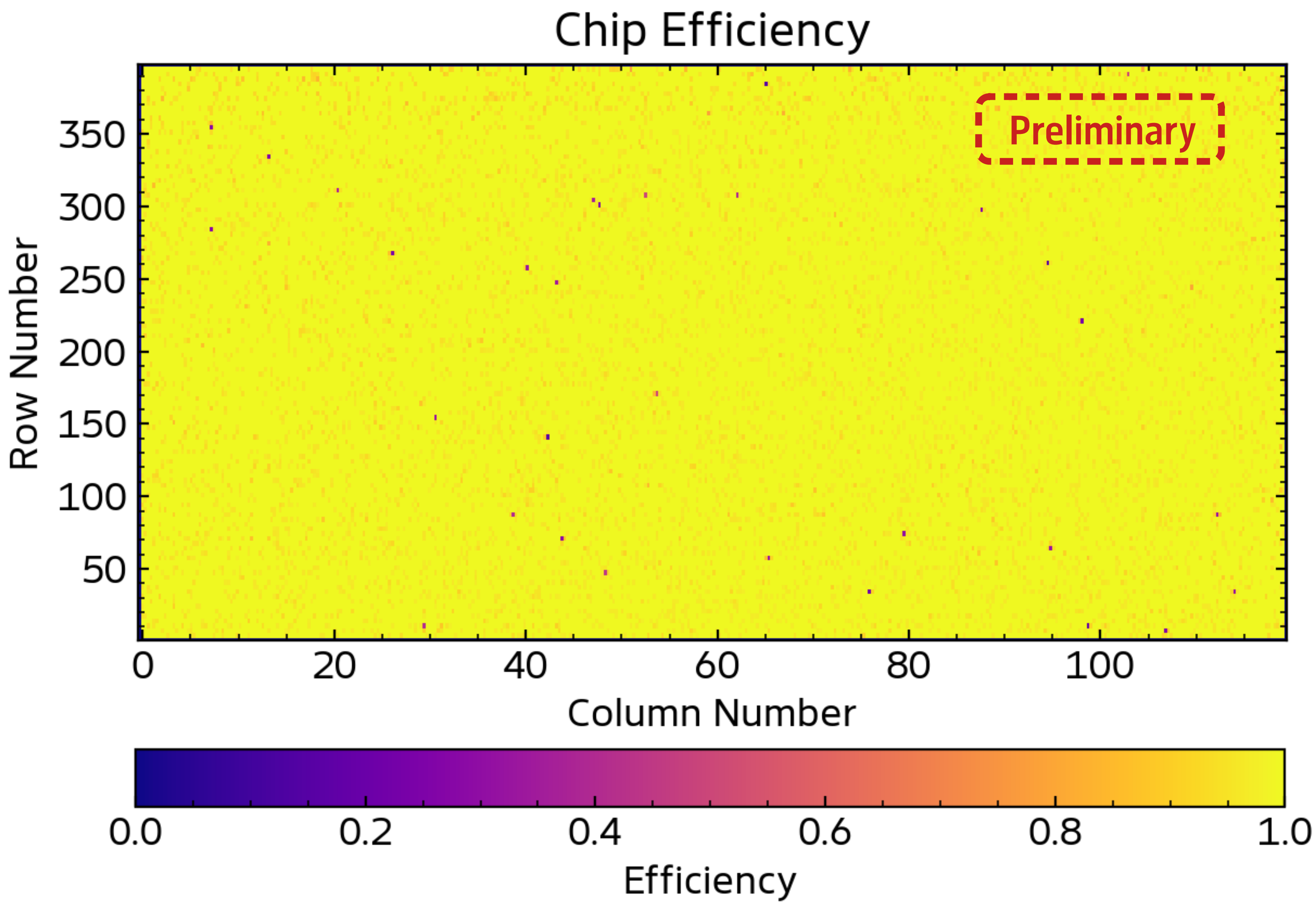
- Track residuals centered around 0 μm
- A χ^2 divided by the number of degrees of freedom peaking around 1.





Efficiency

$$\text{Efficiency} = \frac{\text{Tracks with an Associated DUT Hit}}{\text{Tracks that intersect the DUT}}$$

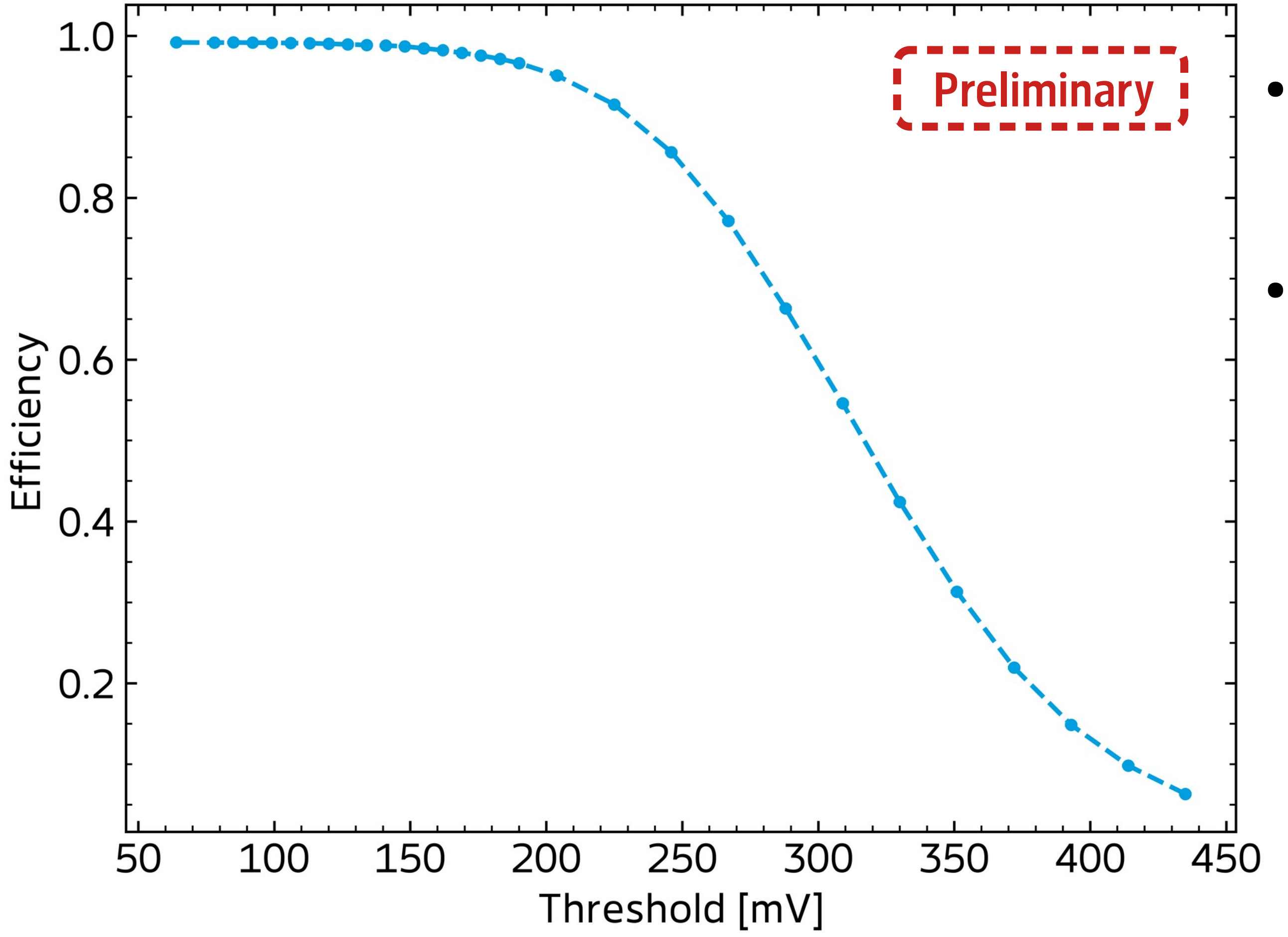


* Statstical efficiency

At a bias of 85 V
& a threshold of 57 mV
Efficiency of
99.204 ± 0.008 %

Efficiency vs Threshold

Efficiency changes with respect to threshold of pixel comparator

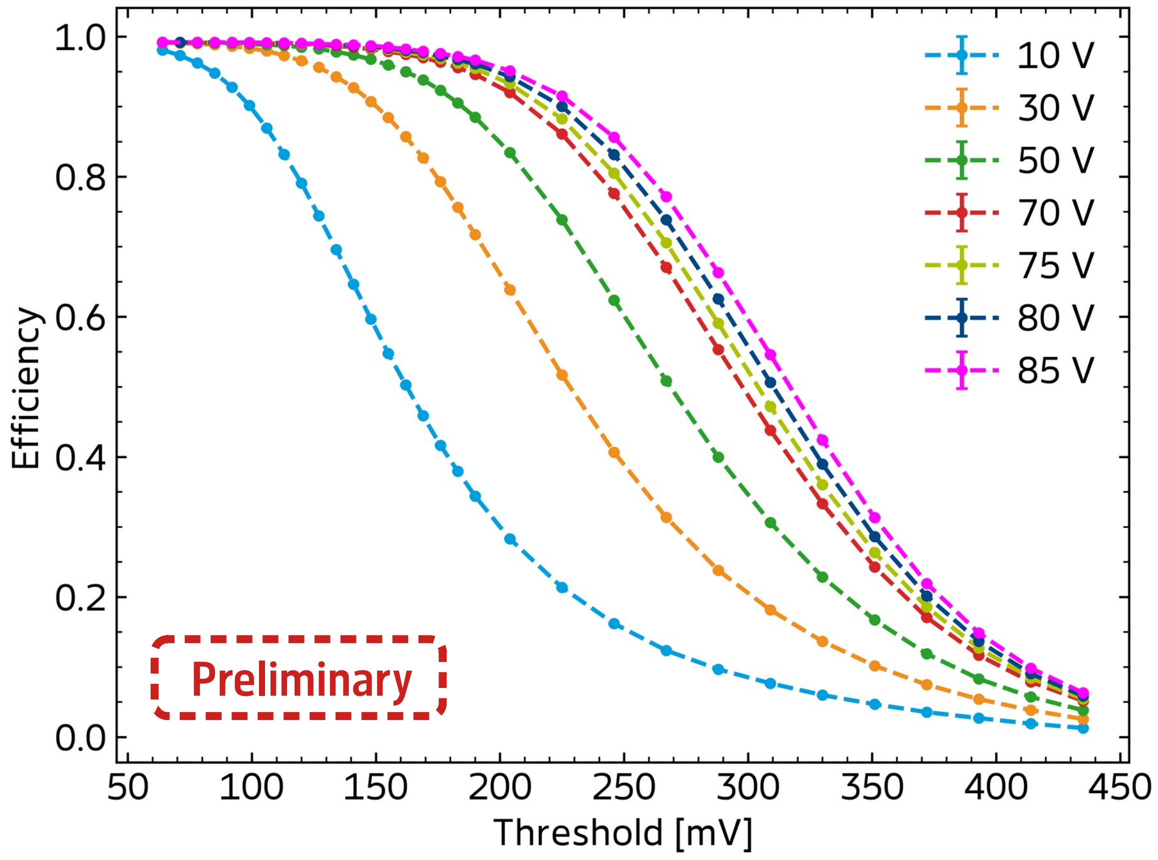


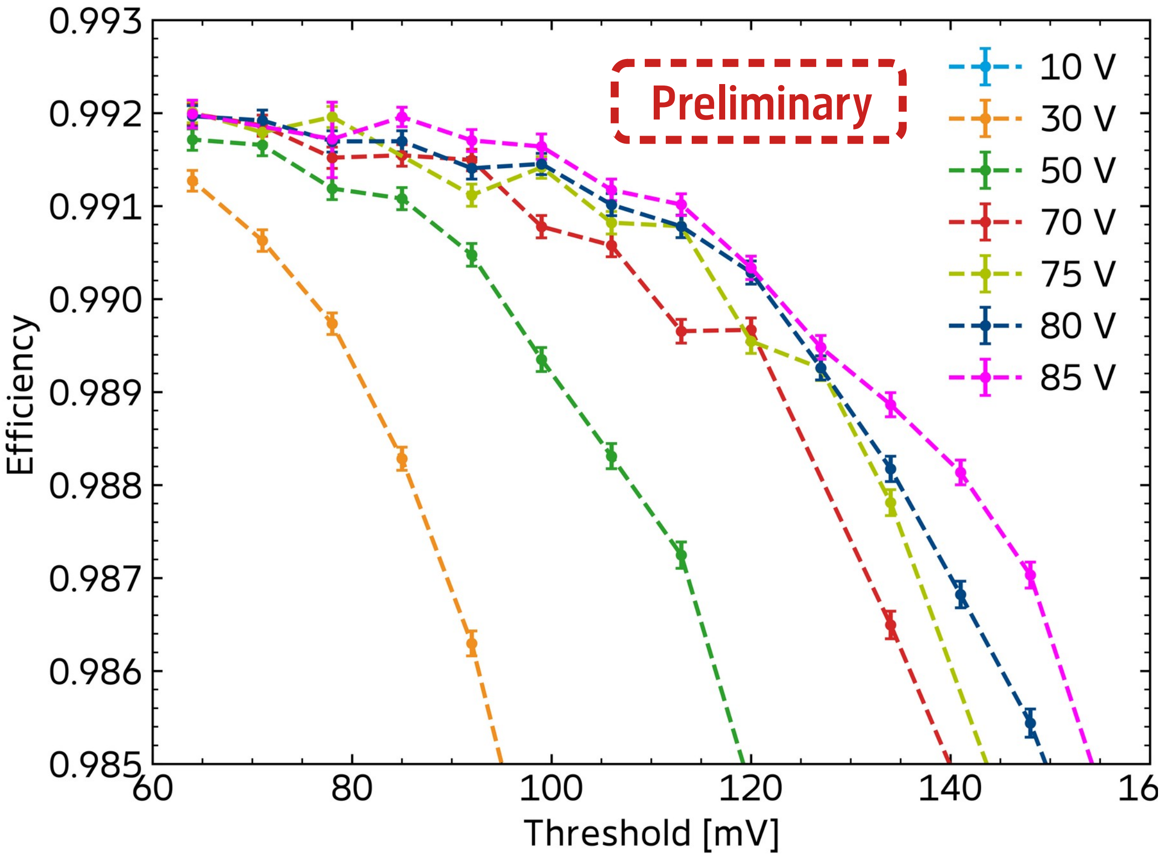
- Greater the plateau →
  Greater the suitable operating region

- Could not decrease threshold further
  Started to be effected by noise

Bias is at 85 V

Efficiency vs Threshold for Different Voltages

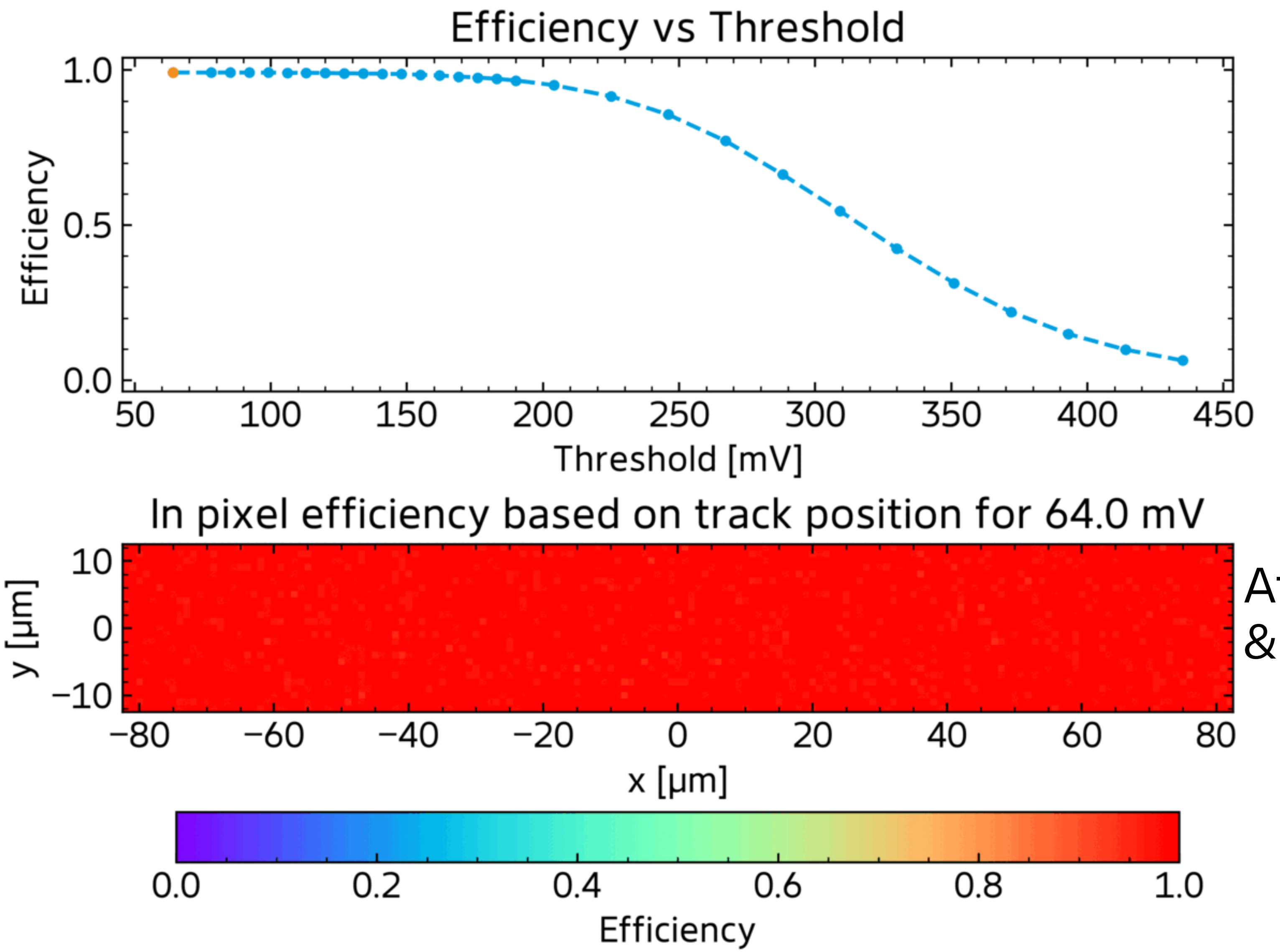




Higher bias voltage → Greater depletion region → More charge collected

In-Pixel Efficiency

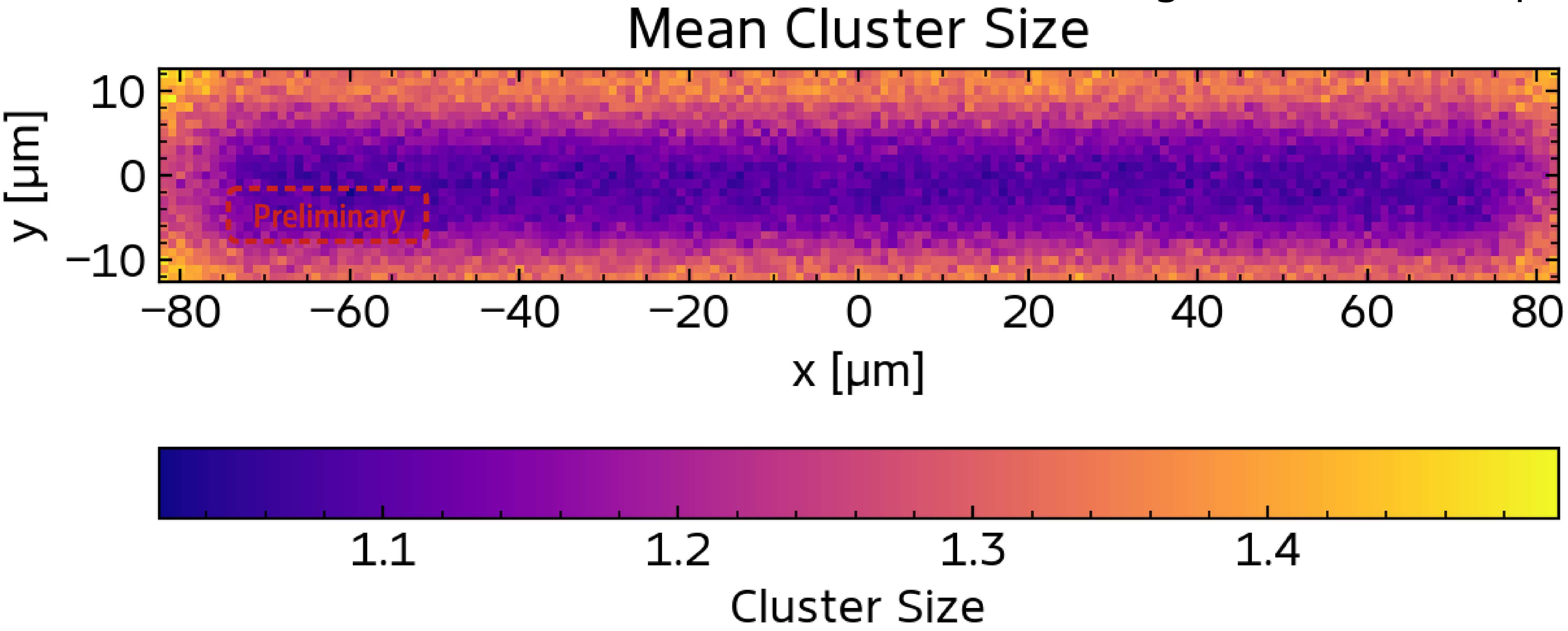
Full Pixel



At a bias of 85 V
& a threshold of 57 mV

In-Pixel Mean ClusterSize

Larger cluster size in pixel

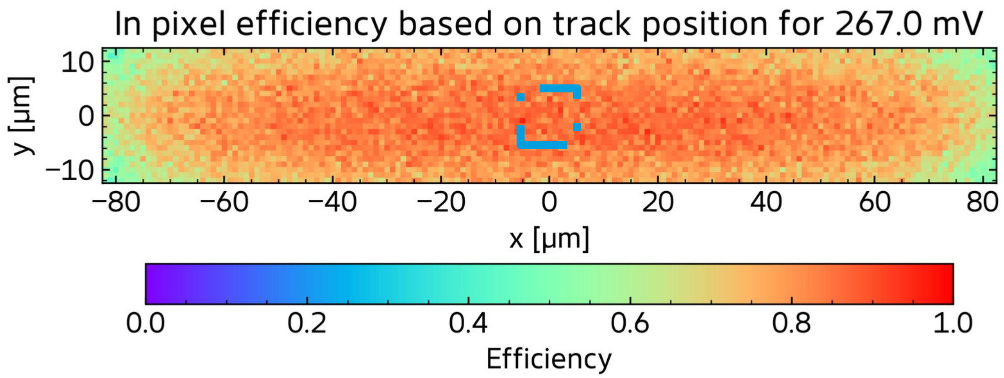


Bias 85 V and threshold 57 mV

In Pixel Efficiency

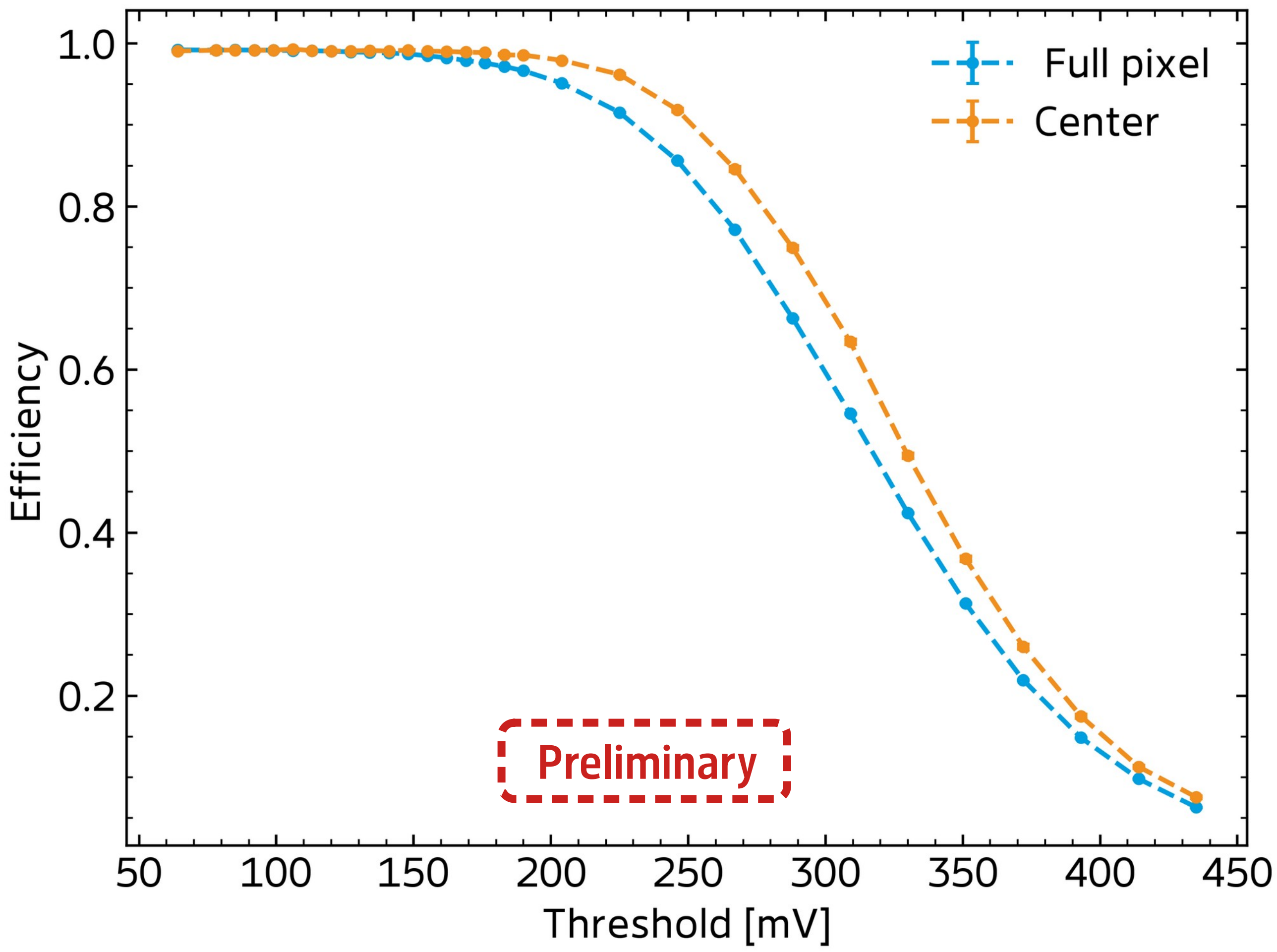
Full Pixel and Center of Pixel Comparison

- Efficiency in the center 10 x 10 μm in each pixel calculated



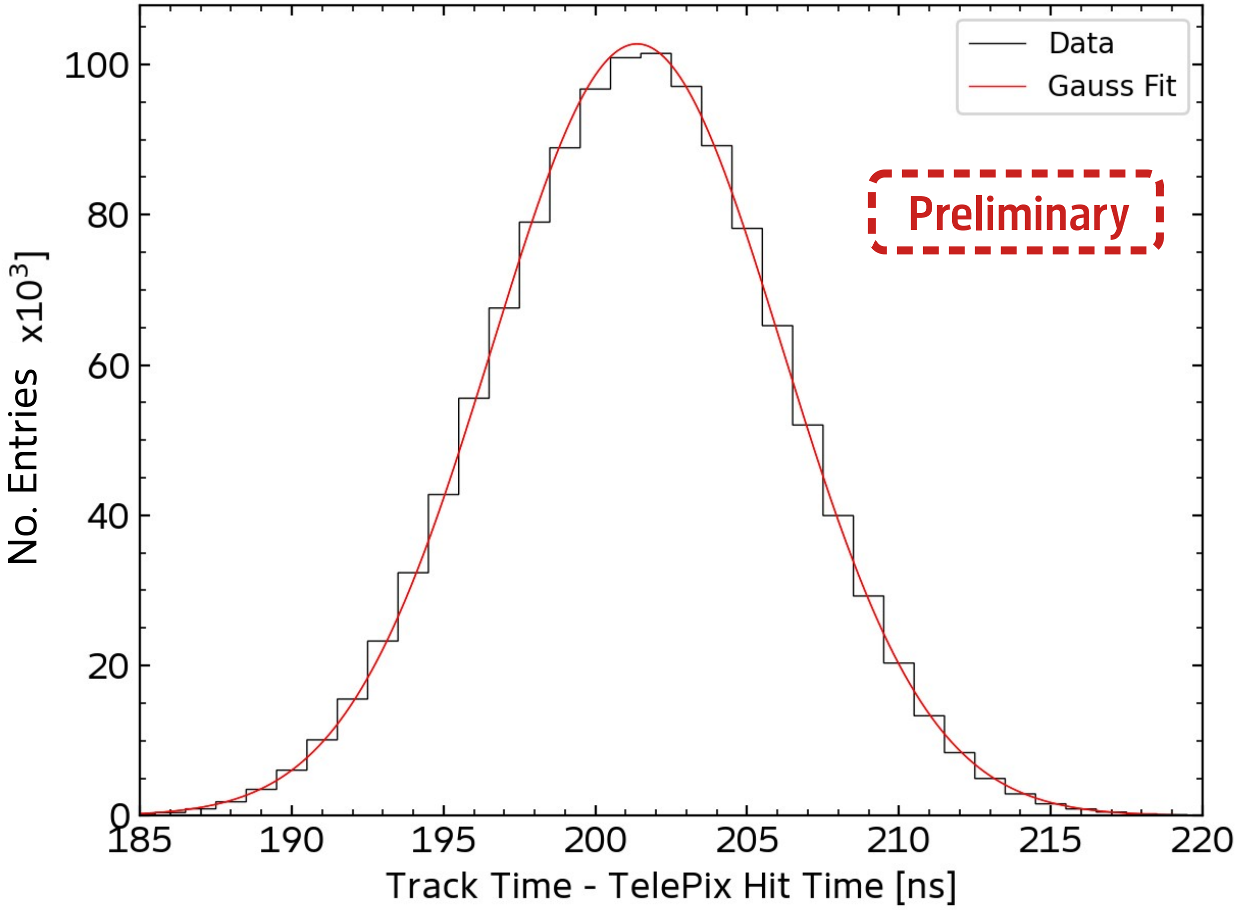
- Larger plateau when looking at center of each pixel only

- Bias of 85V



Timing Resolution

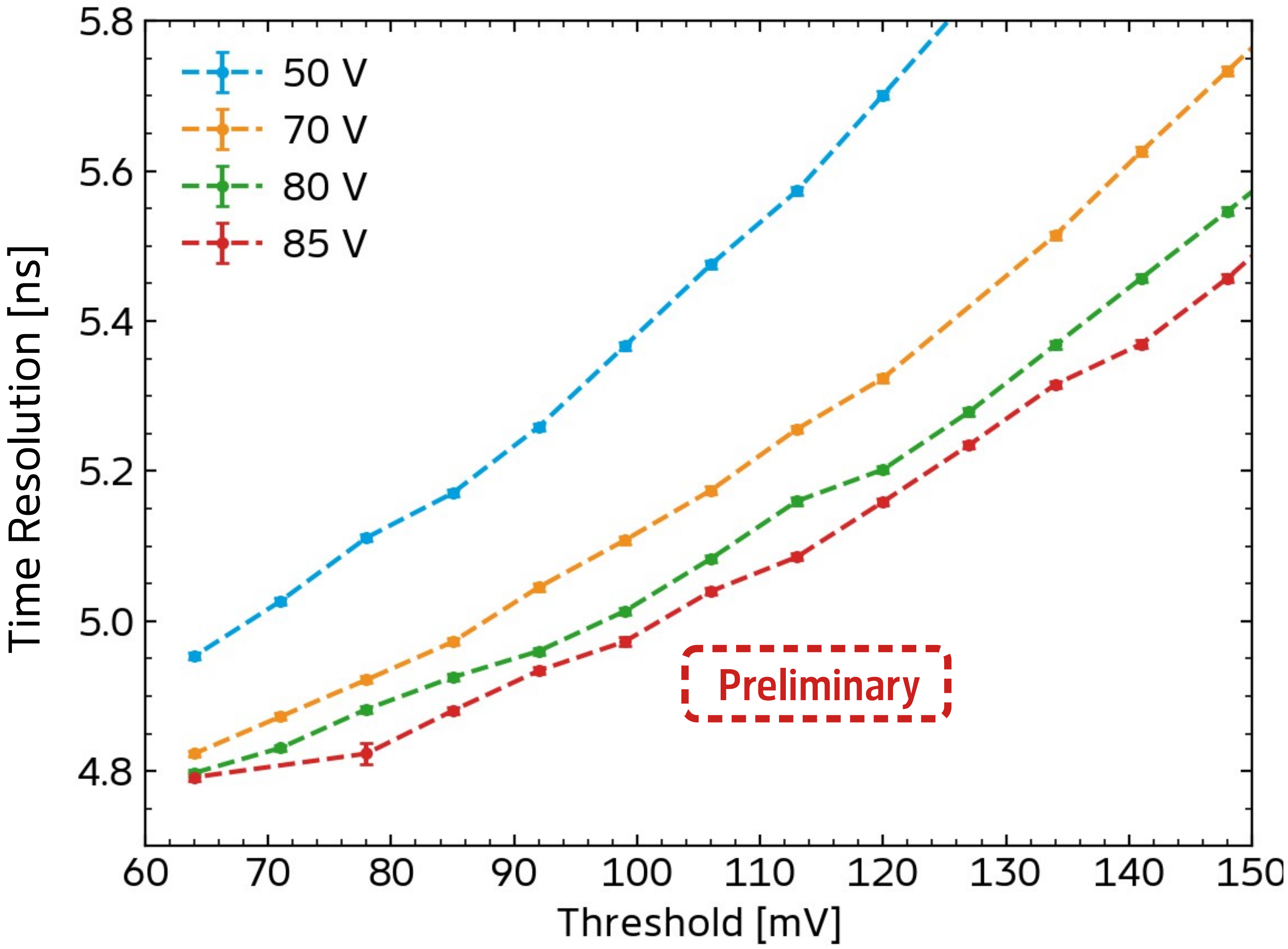
Ideal Case



Time resolution taken as the **σ of a Gaussian fit** of the time residual

At a bias voltage of 85 V and a threshold of 57 mV a time resolution of **4.781 ± 0.003 ns.**

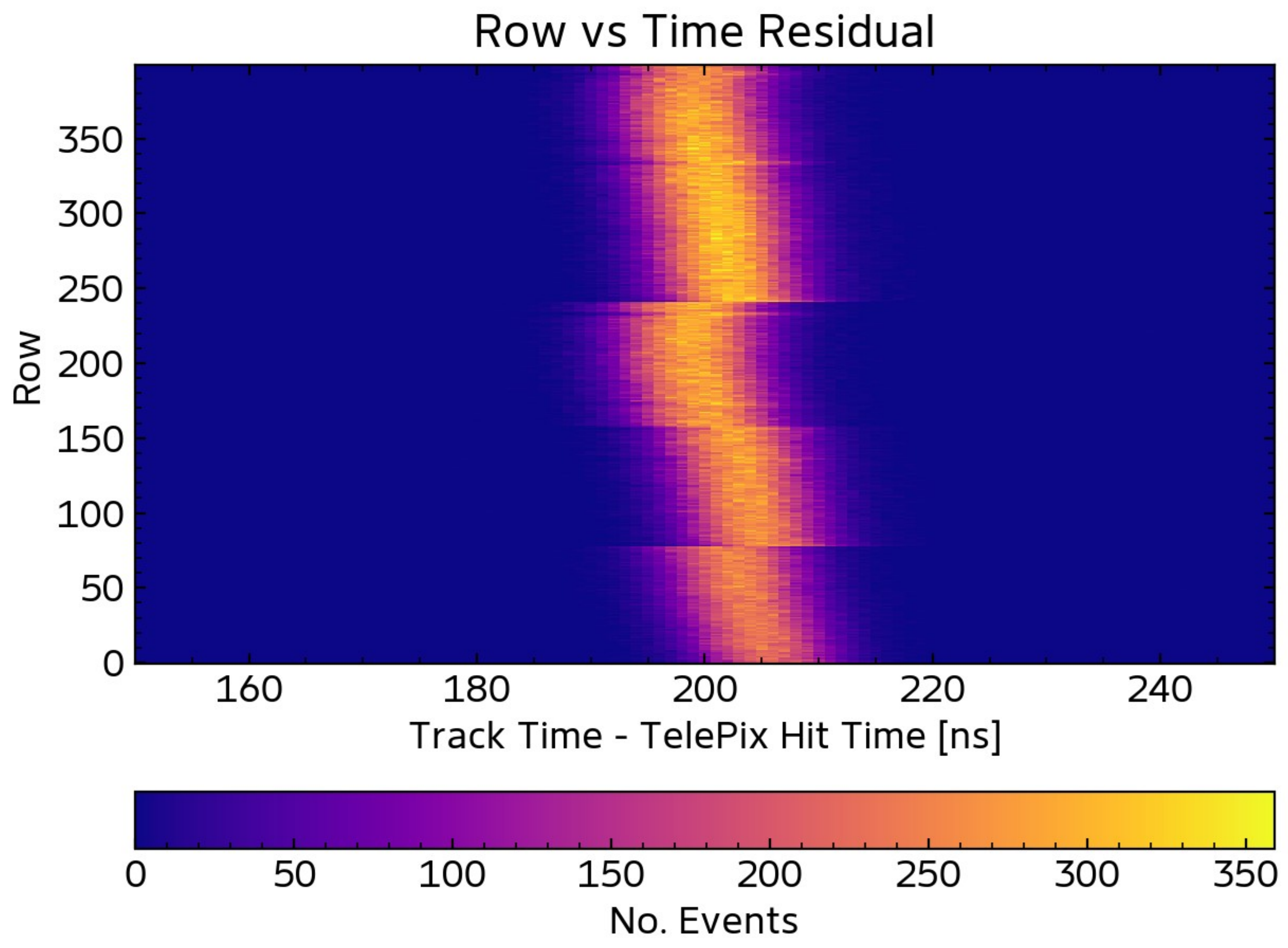
Timing Resolution with Threshold and Voltage



Still a benefit in time resolution with a reduction in threshold

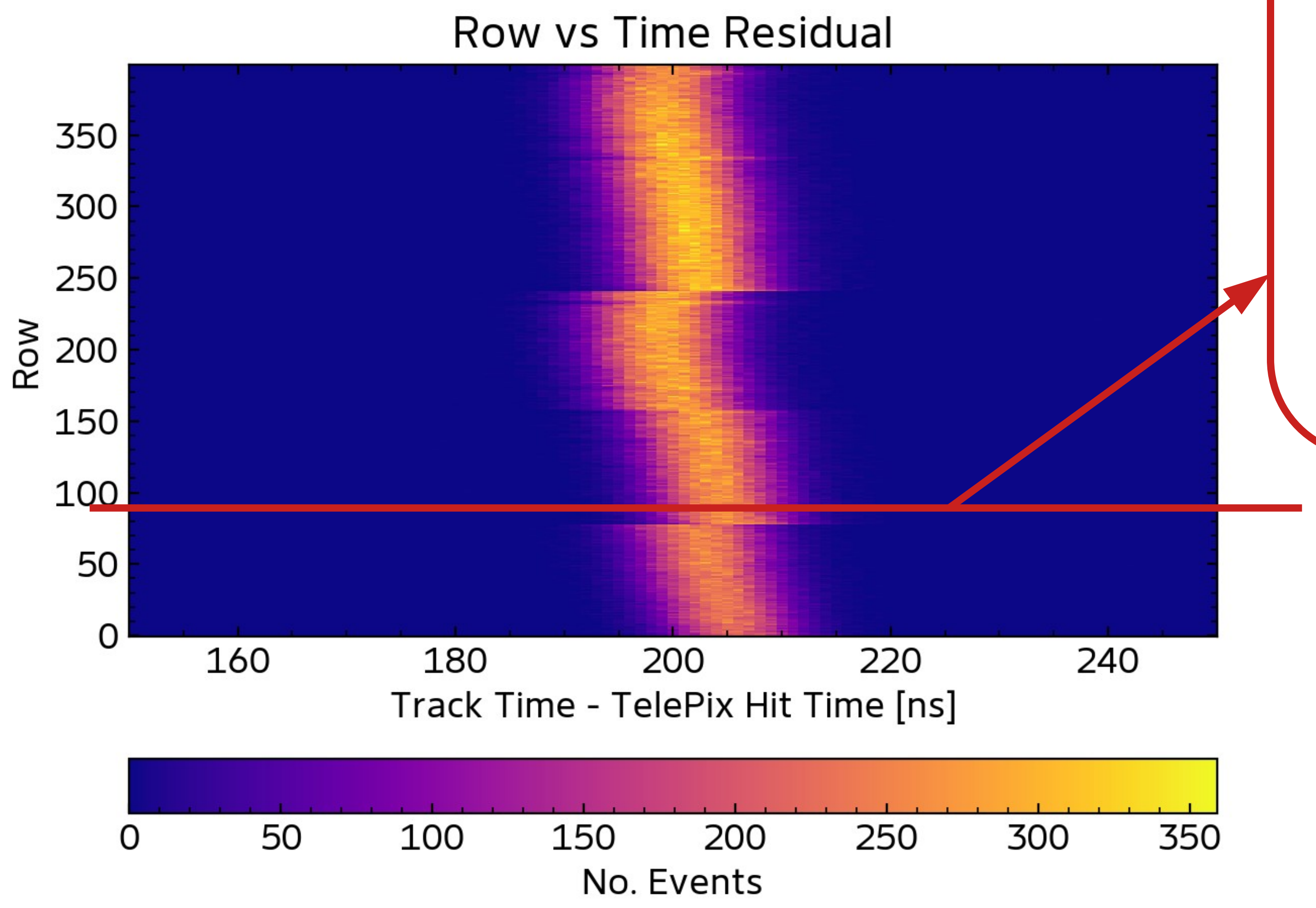
Time Residual Corrections

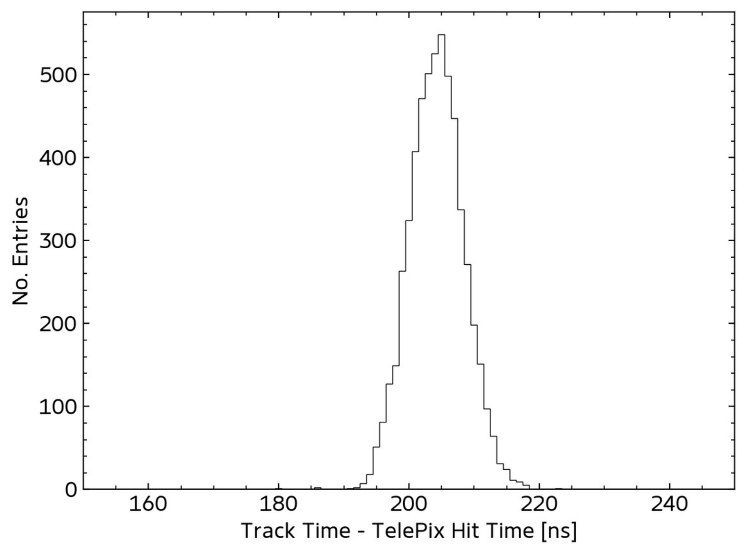
Preliminary



Bias 85 V and threshold 57 mV

Time Residual Corrections

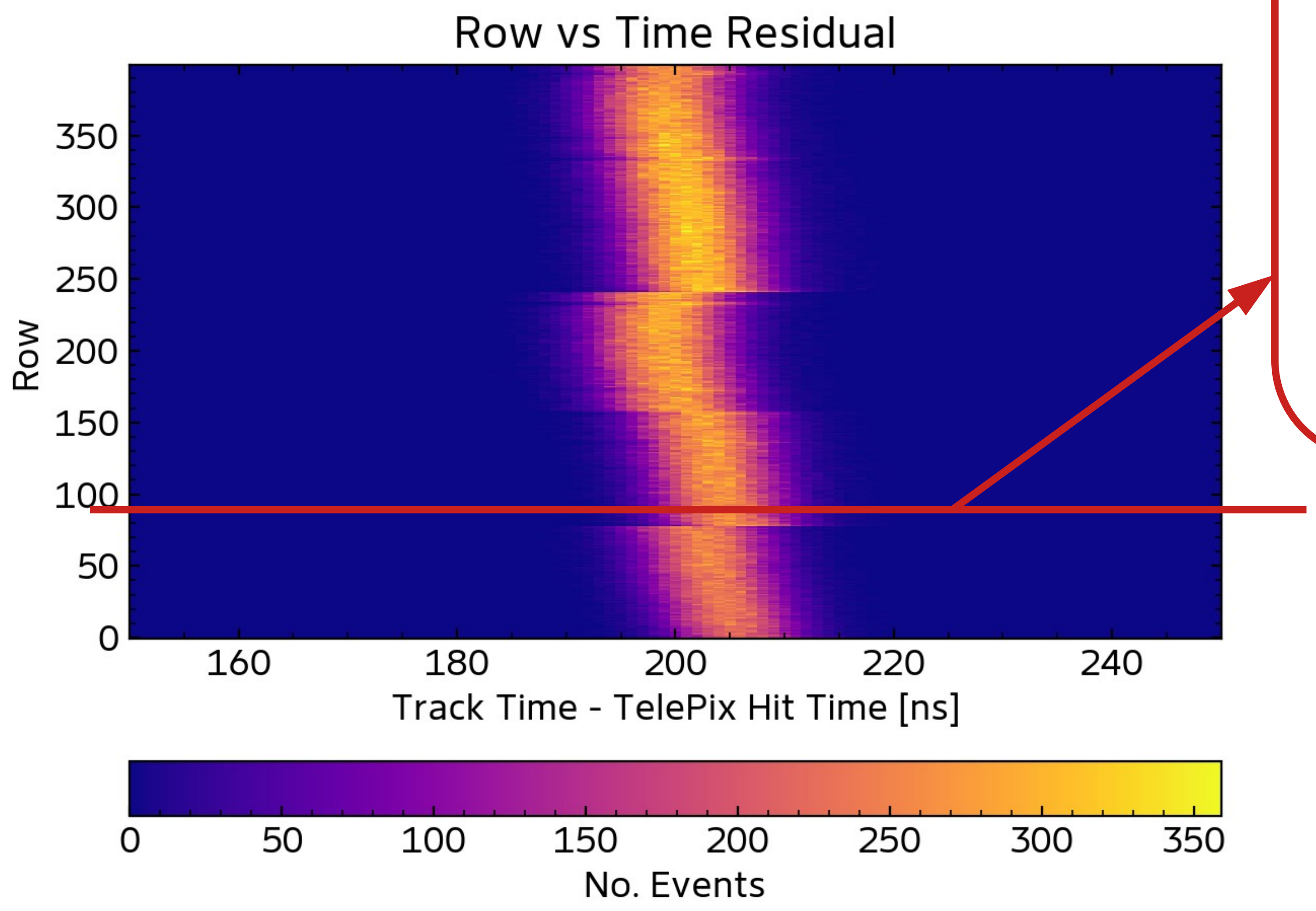


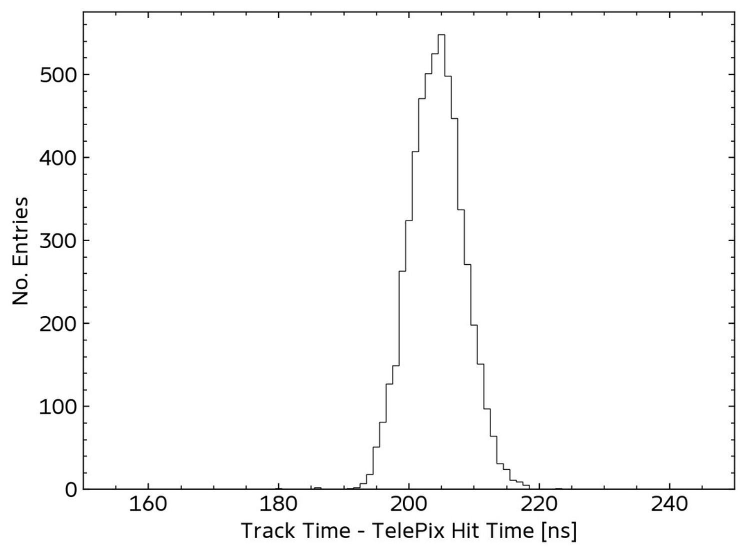


Bias 85 V and threshold 57 mV

Time Residual Corrections

Preliminary





Gauss Fit

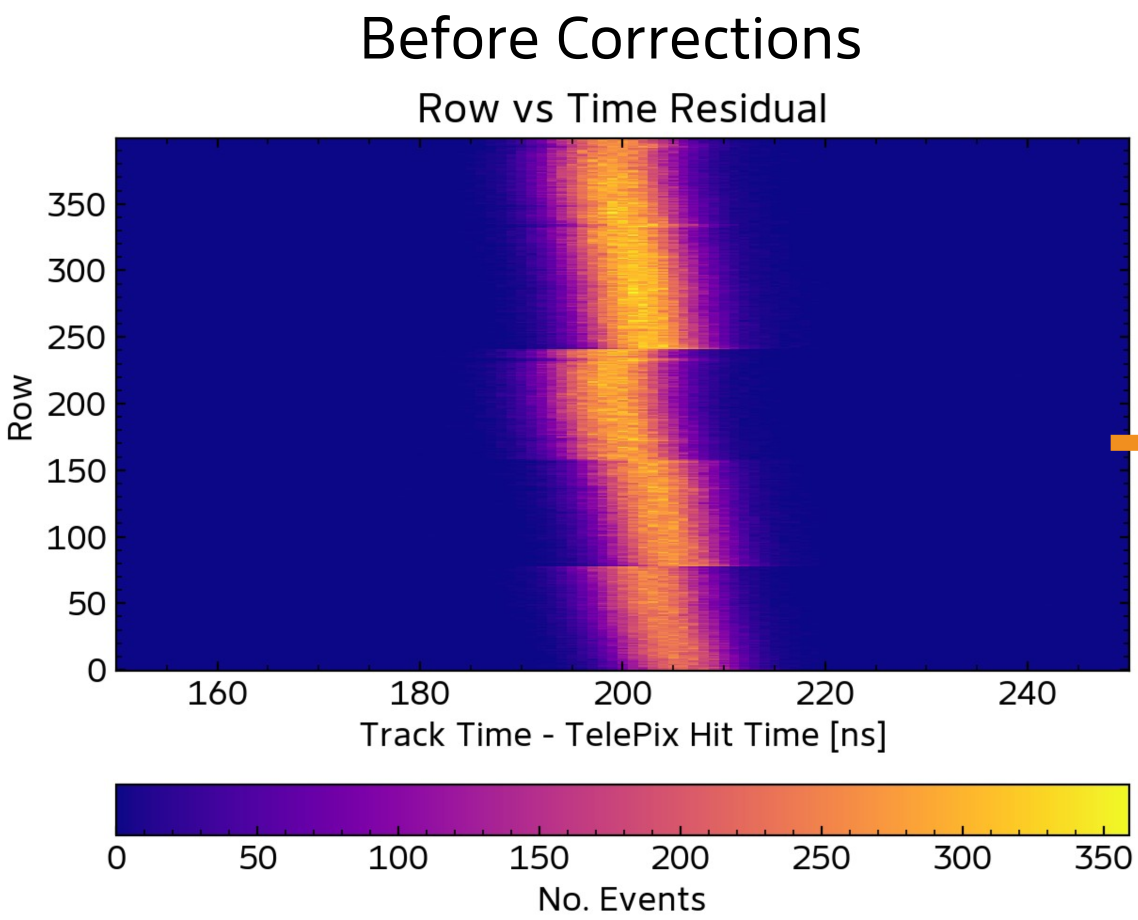
Extract Mean

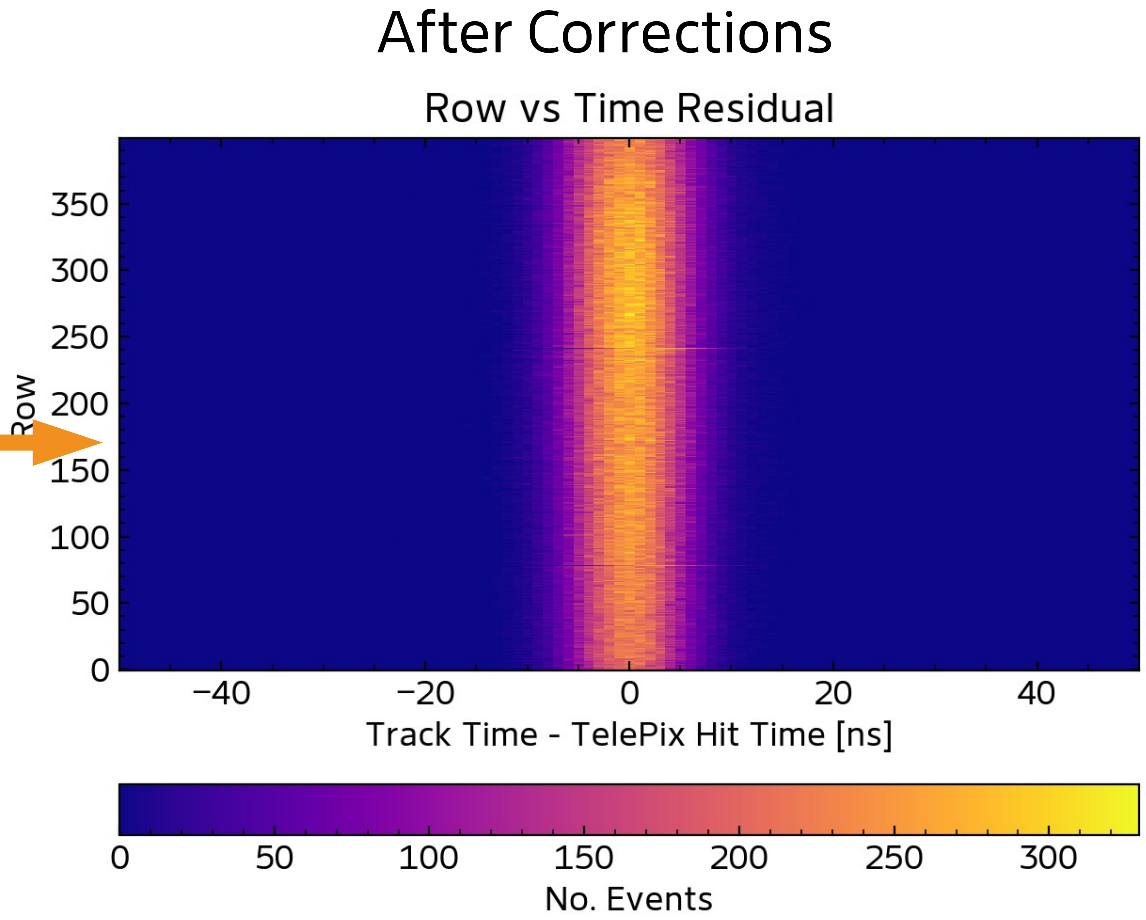
Reload data &
Shift each timestamp by the mean

Bias 85 V and threshold 57 mV

Time Residual Corrections

Preliminary





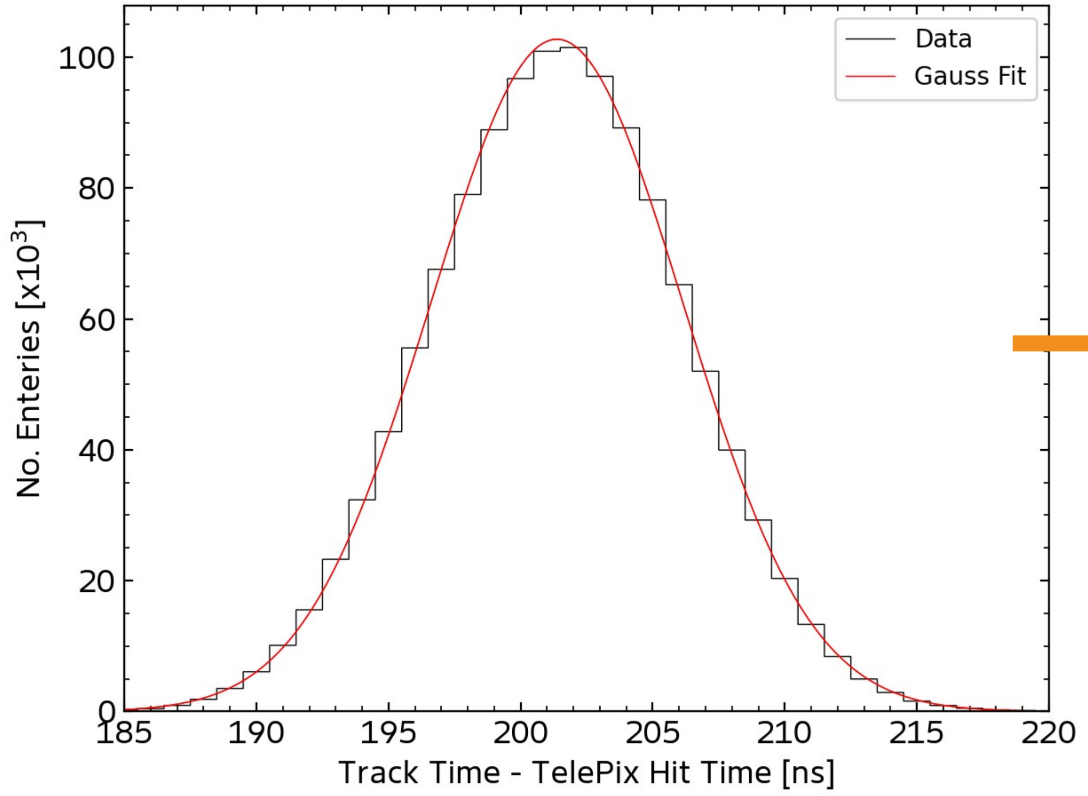
This must be done offline
And requires processing the data twice

Bias 85 V and threshold 57 mV

Time Residual Corrections

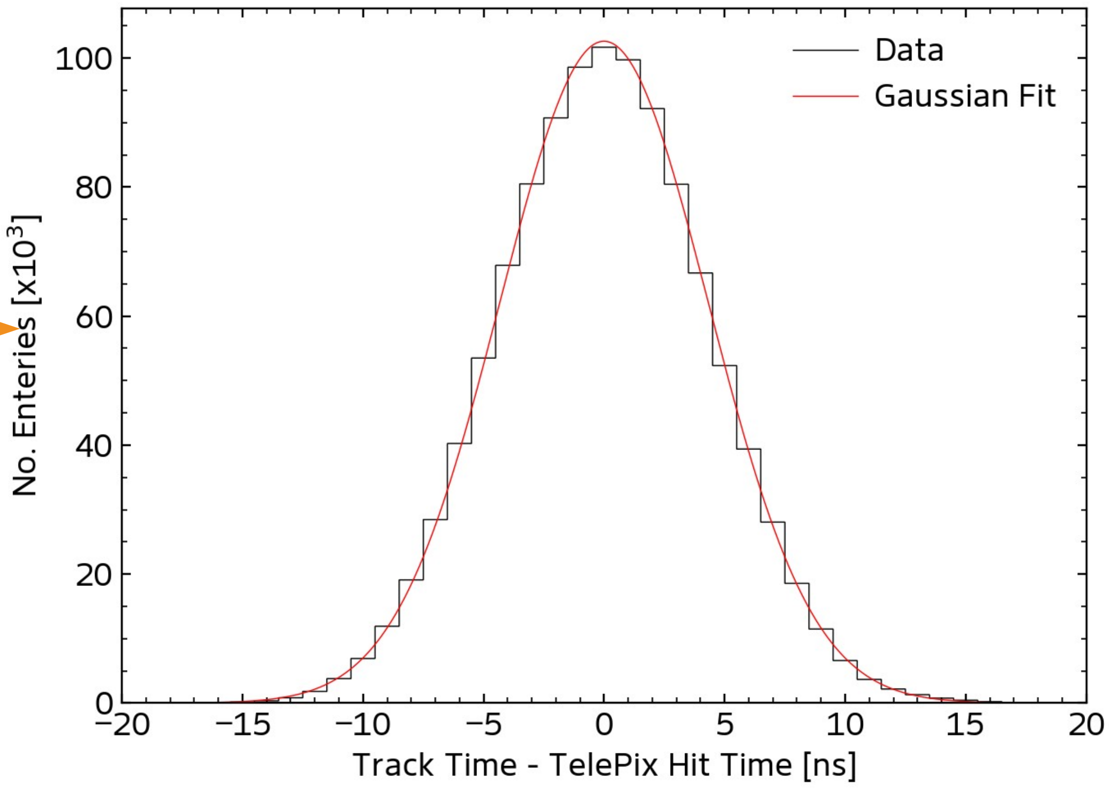
Preliminary

Before Corrections



4.781 ± 0.003 ns

After Corrections

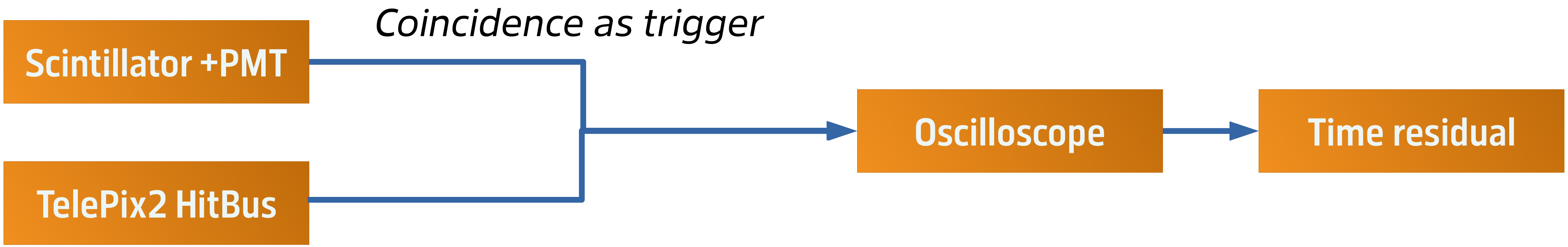


4.315 ± 0.003 ns

Bias 85 V and threshold 57 mV

HitBus Measurements
Method

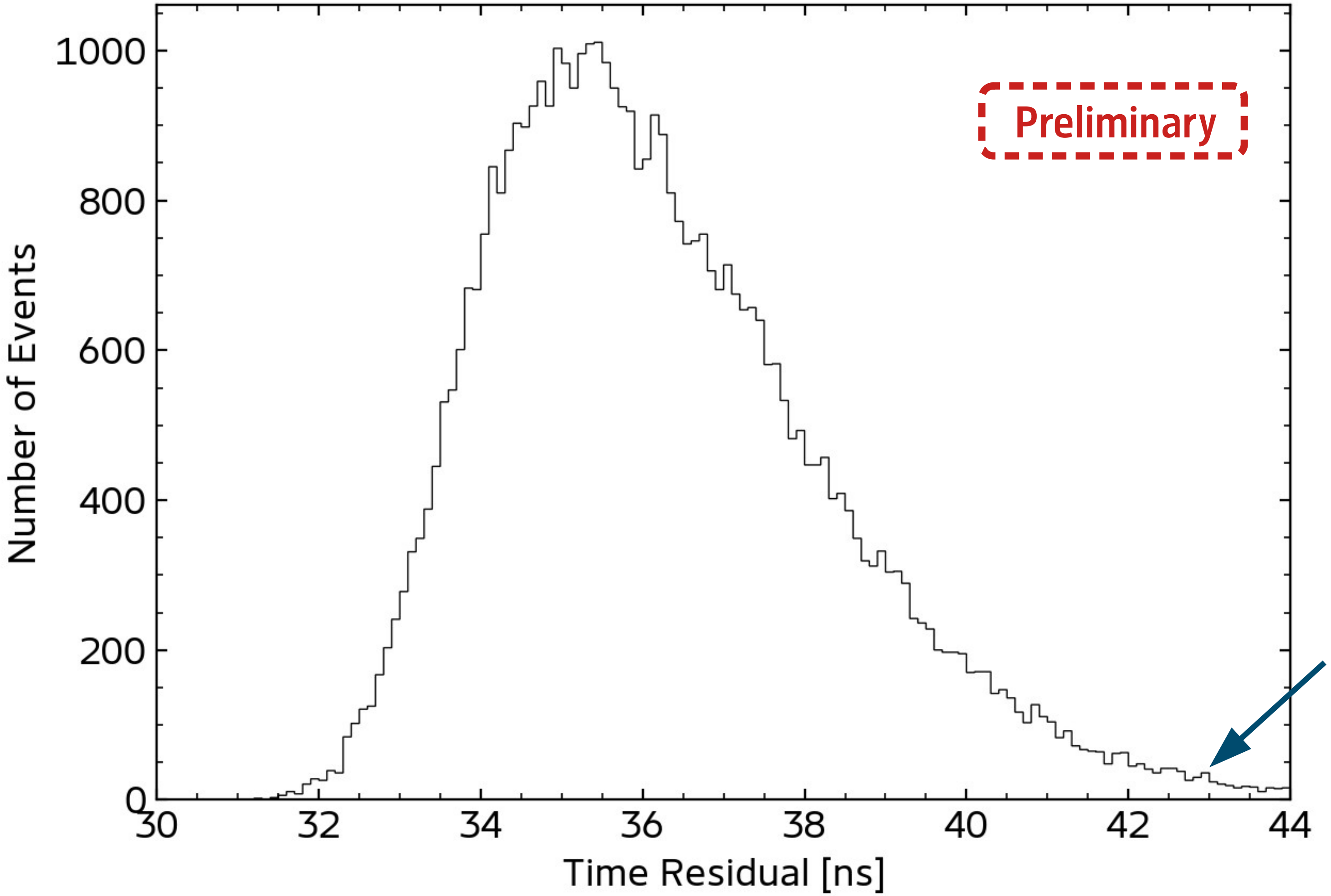
HitBus = Fast trigger output



Time Residual = Time at half maximum of scintillator – Time at half maximum of TelePix Hitbus

Hitbus Measurements

Result



Deviations from the standard Gauss distribution yet to be understood.

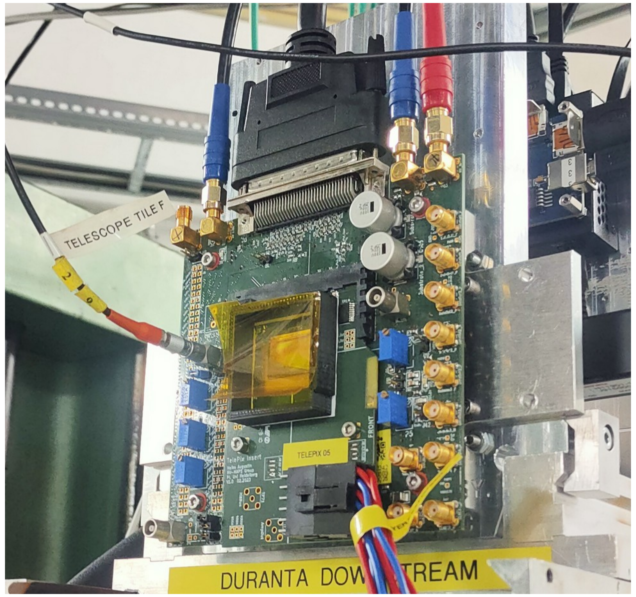
Preliminary measurements show an RMS of **≈ 2 ns**

Taken with at a bias of 85 V and threshold of 64 mV

Slight background from imperfect triggering scheme

Conclusion

TelePix2 currently being used by users!



- Working ROI trigger
- Hitbus time resolution of ≈ 2 ns
- Efficiency 99.204 ± 0.008 %
- Uncorrected time resolution 4.781 ± 0.003 ns
- Offline corrected time resolution 4.315 ± 0.003 ns

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)

Thank you for listening!

Questions?

Beam Telescopes at DESY II Testbeam facility

Most requested infrastructure by users (82% in 2022)

2 different types installed at desy **EUDET-Type** (TB21 & TB24) and **Adenium** (TB22)

	EUDET-Type	Adenium
Sensor	Mimosa26	Alpide
Active Area	2 x 1 cm	3 x 1.5 cm
Pixel Pitch	18.4 x 18.4 µm	29.24 x 26.88 µm
Read Out Time	> 115 µs	10 µs

High-Voltage Monolithic Active Pixel Sensors

HV-MAPS

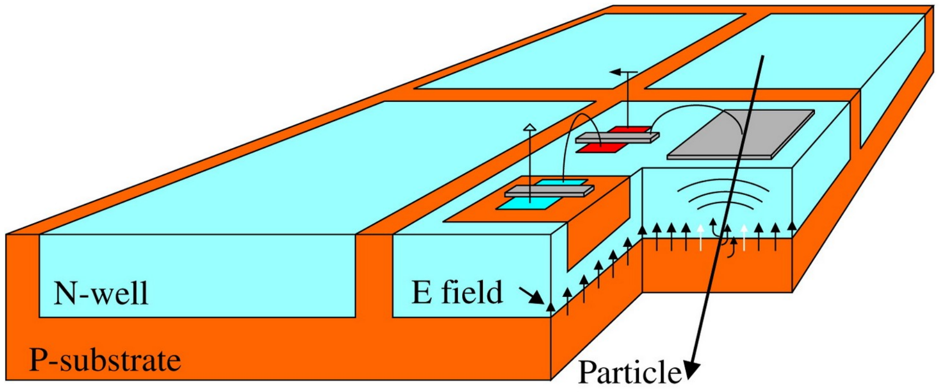
- **Hybrid** sensors bump bond a separate readout and sensor chip together
  - Can be **costly** to manufacture and have a **high material budget**

- **Monolithic** sensors integrate readout and sensor onto one chip:
  - But charge collection **via diffusion** → **too slow** for high rate applications

---

HV-MAPS embed readout inside pixel electrode

- **Higher biasing voltage** → collection **via drift (faster)**
- Can result in improved:
  - Signal amplitude
  - Charge collection speed
  - Radiation tolerance



Ivan Perić, NIM 582 (2007) 876-885