Testbeam Measurements of ATLAS ITk-Strip Modules

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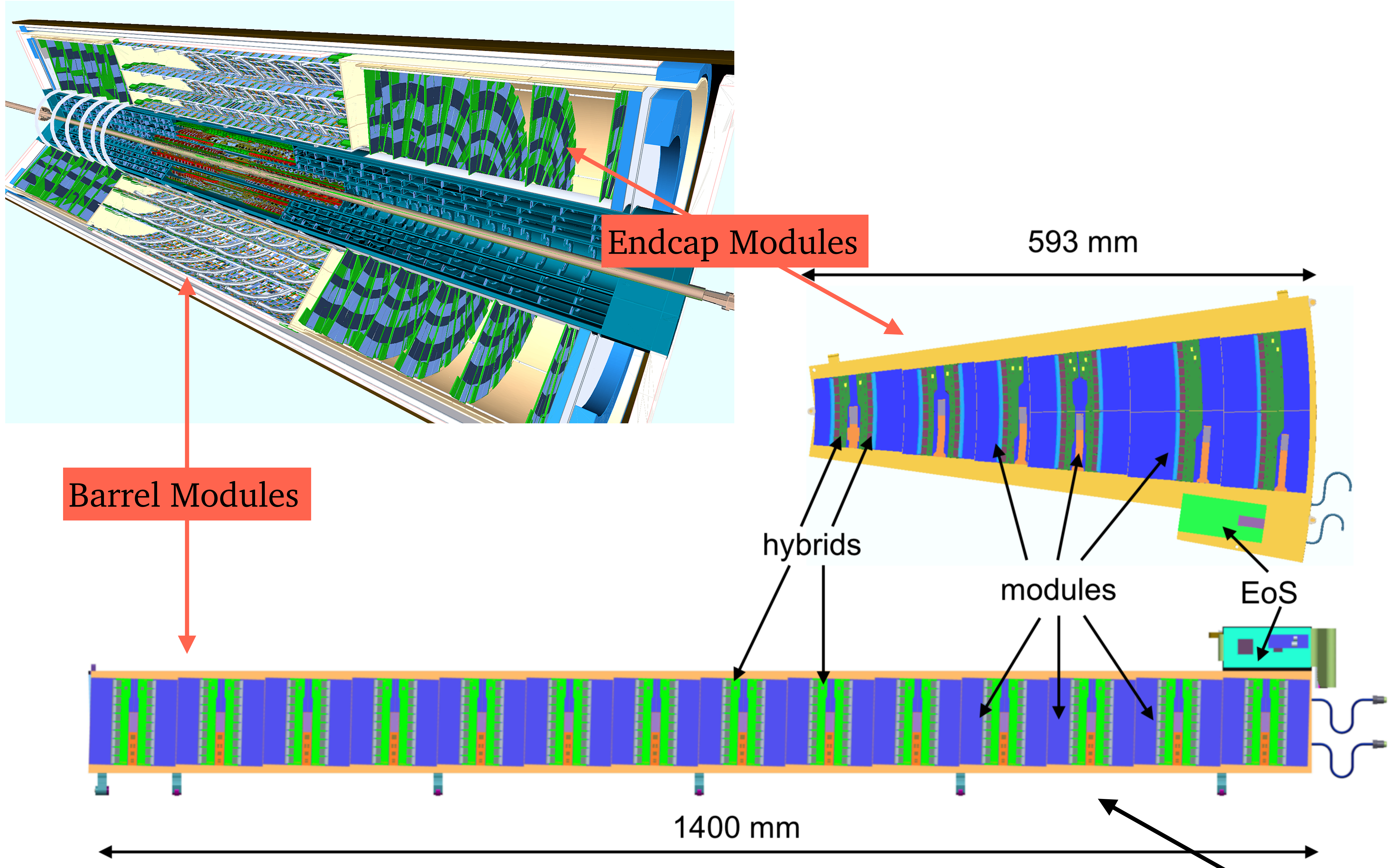
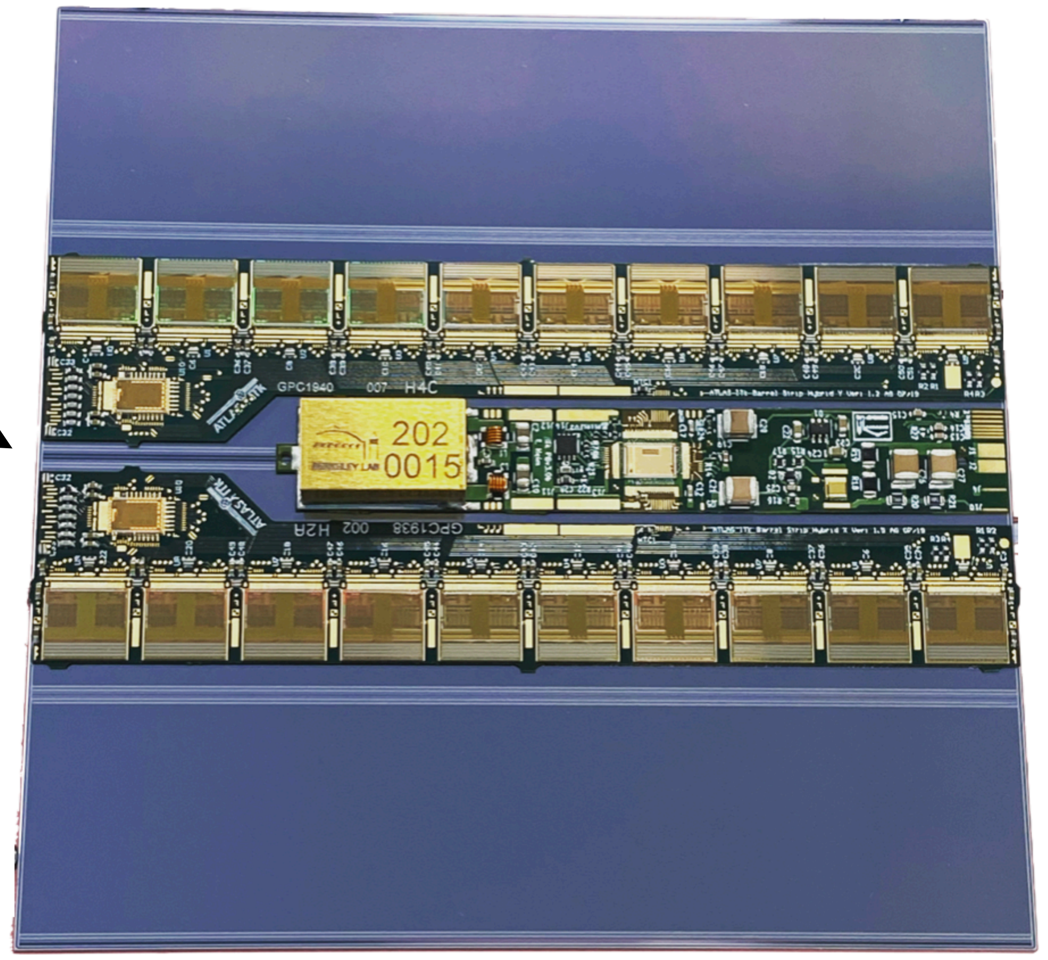
ATLAS EXPERIMENT

ATLAS ITK Strip Detector



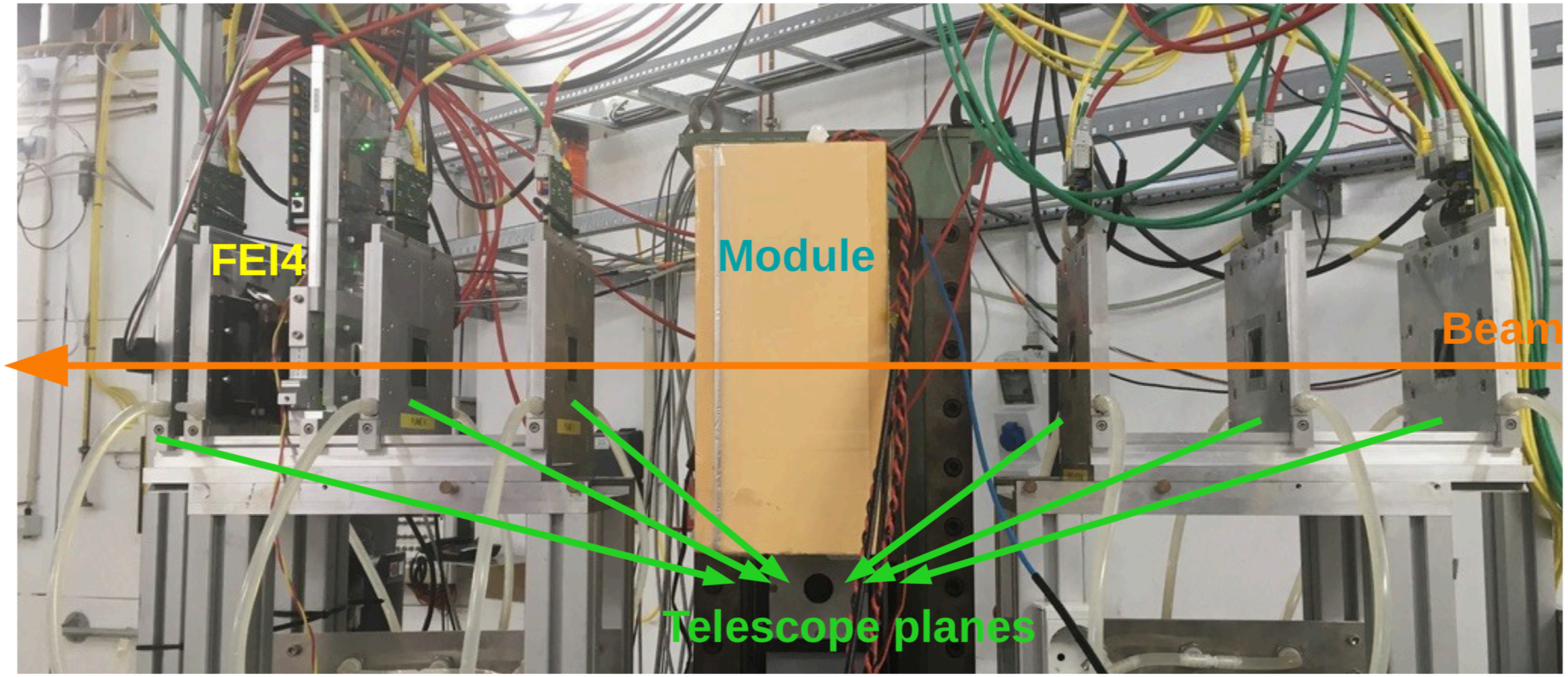
- HL-LHC will allow for more proton-proton collisions per bunch crossing
- The ATLAS detector needs to upgrade the tracking detectors to cope with increased occupancies and radiation damage
- The Inner Tracker (ITk) is an all silicon detector with pixel and strip modules found in both the barrel and endcap regions
- For more information on the ITk see talk by Dengfeng Zhang



Key Testbeam Motivations

- Check performance before and after irradiation
- Measure Efficiency and Noise Occupancy

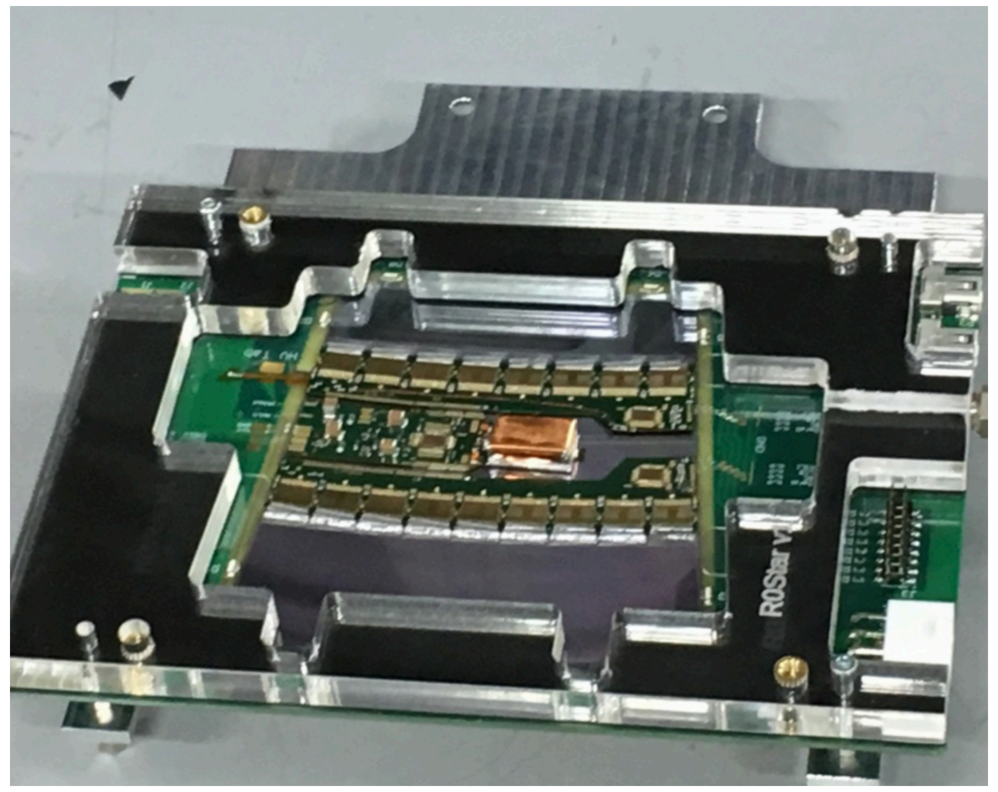
DESY Testbeam and the EUDET-type Telescope

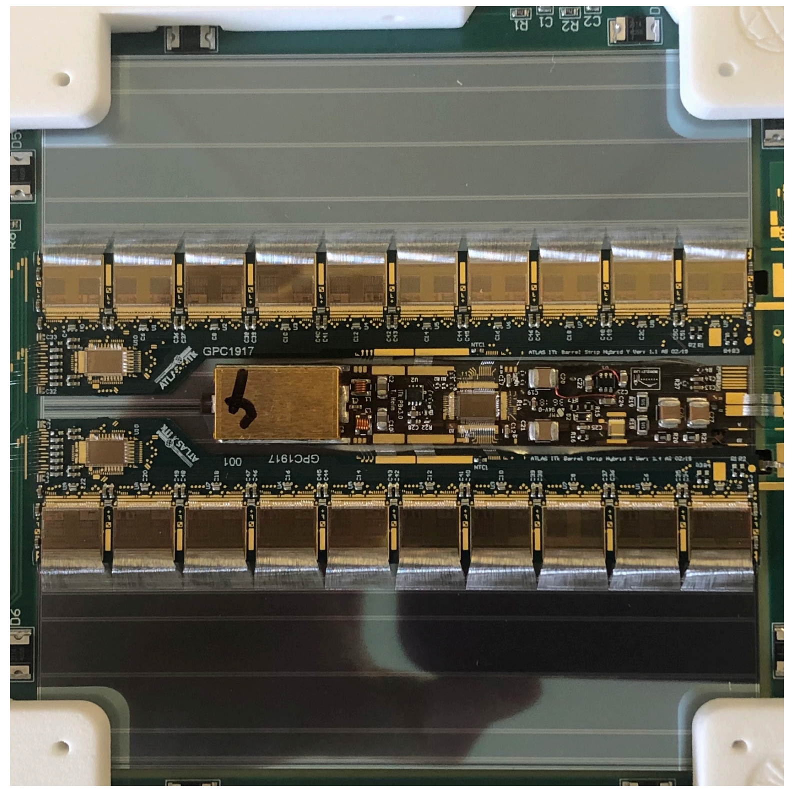


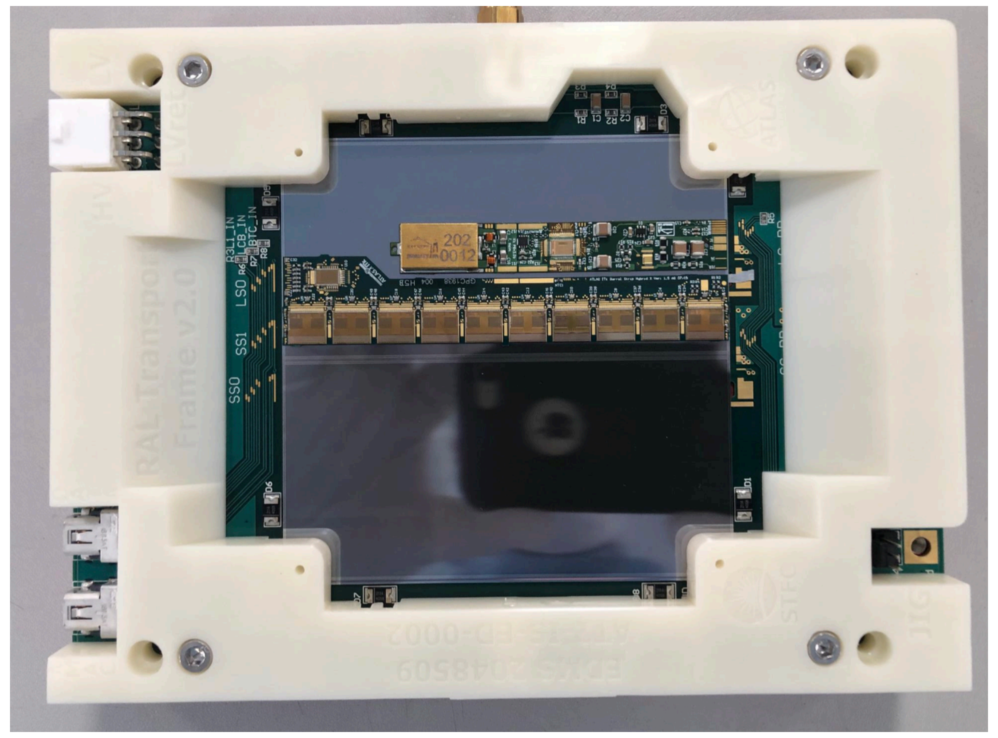
- DESY provides an electron beam with energy up to 6 GeV
- The DUTs are installed in the centre on a rotational stage
- FEI4 is needed for time tagging the telescope tracks (Alpide used in June 2019 data taking)
- Telescope has a pointing resolution ~5-10 µm

Modules tested in 2019

- April - non-irradiated LS and R0 modules
- June - irradiated R0 module
- September - non-irradiated SS and irradiated LS modules







Difficult Year for the ITk Strip Testbeam Activities

No new data taking so far in 2020

- Covid-19 has meant that there has been limited beam time at DESY and travel restrictions makes it very difficult for colleagues to travel to Hamburg
- Worldwide laboratory & university closures have slowed module production meaning that there is limited modules available for testing
- Optimistic that in the next few weeks we can take some new data with endcap petal or study timing plane options

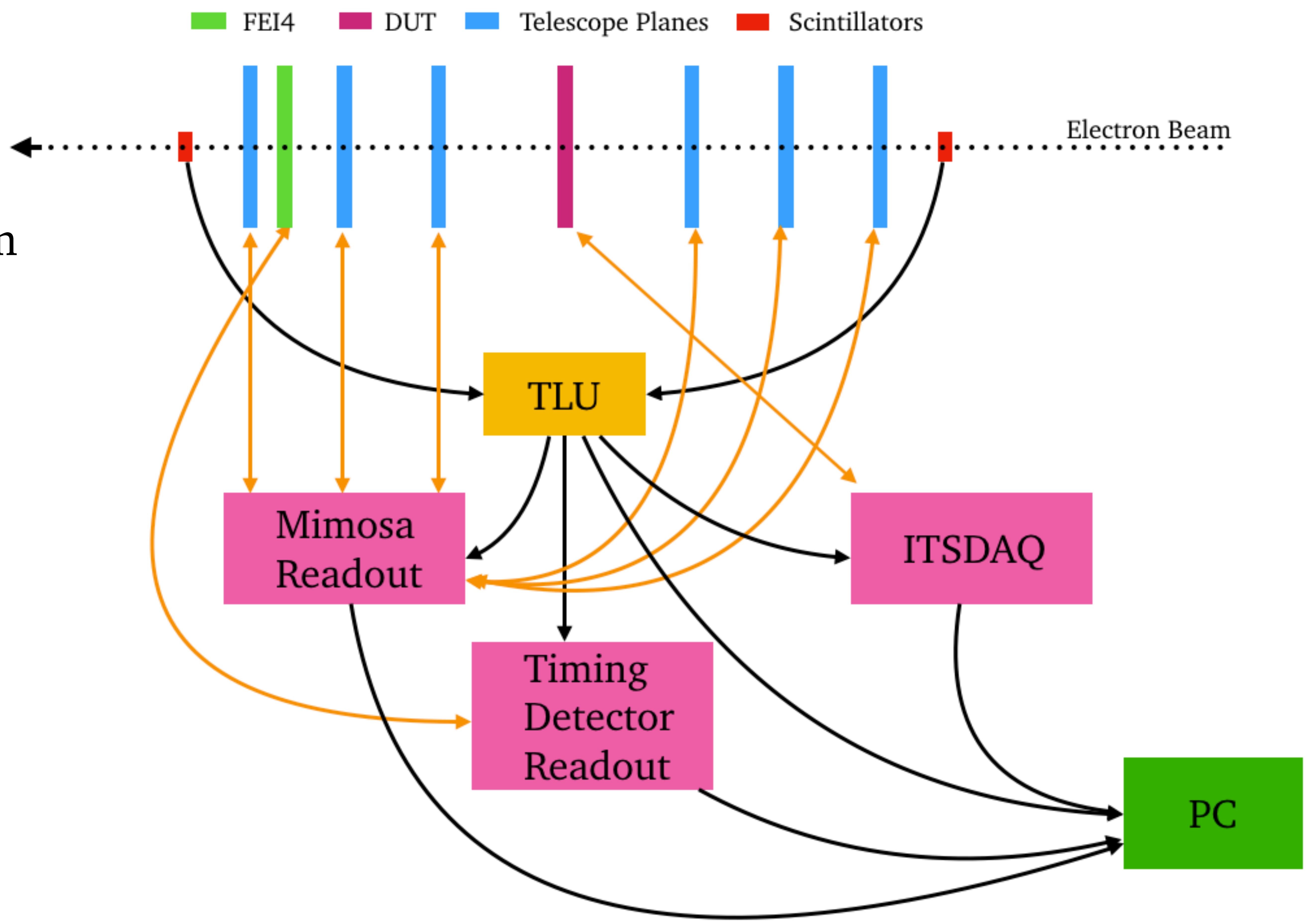
Data reconstruction issues with 2019 data

- Troubles reconstructing data using **EUTelescope**, specifically data when the DUT is placed at an angle and when implementing the radial geometry of the endcap modules
  - EUTelescope is an ageing software where many of the developers have moved on, therefore difficult to solve issues when they arise
- Data desynchronisation problem
  - During analysis of **April 2019 Testbeam** data we found that only **~30%** of events within a run were synchronised
  - Due to sub event information mismatching

This talk will discuss the steps we have taken to improve the data reconstruction

Desynchronisation of Testbeam Data

- What does desynchronised data mean?
  - There is a mix up of the sub-event information
  - Events are assembled with sub-event information from each subsystems
  - Sometimes the wrong DUT event information is assigned to the wrong ITSDAQ event information
- Need to compare the event IDs
  - **TTCBCID from ITSDAQ & RAWBCID from the DUT**

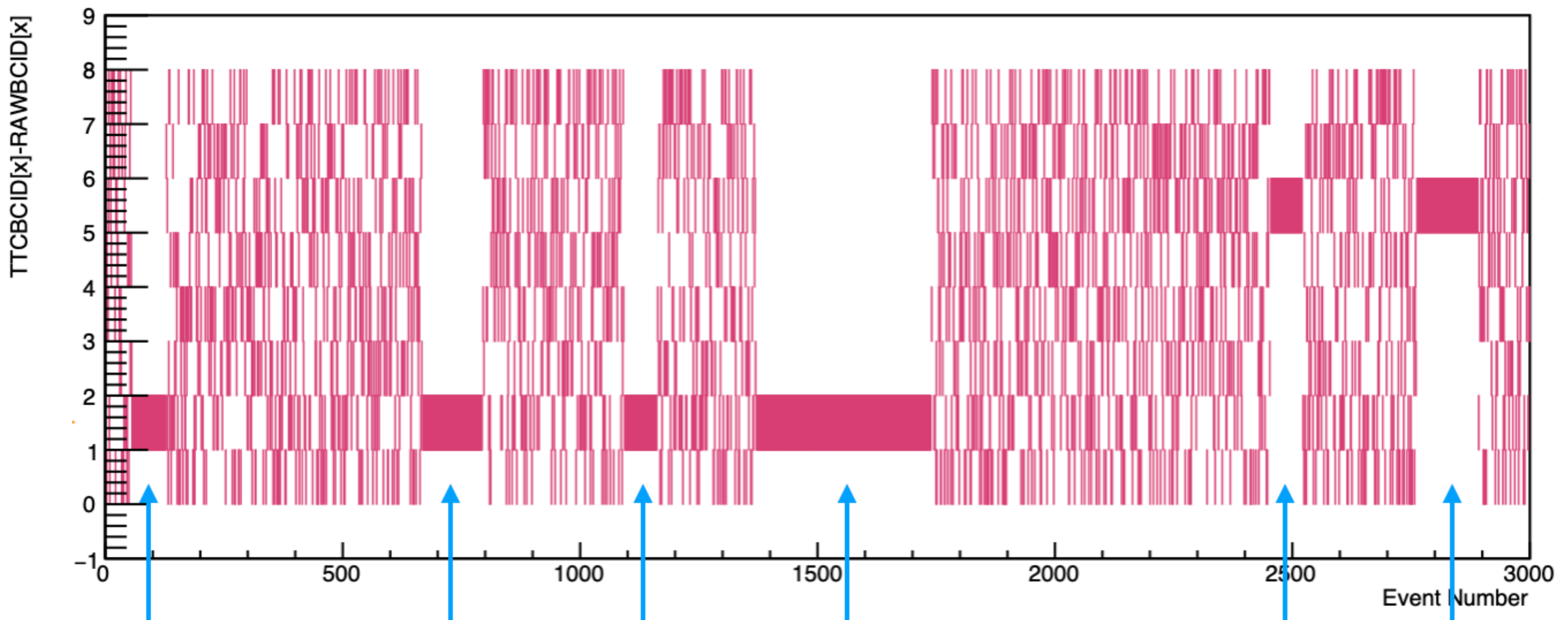


*ITK Strip DAQ (ITSDAQ) software

Comparing the TTCBCID and the RAWBCID

Event Number	TTCBCID	RAWBCID	TTCBCID-RAWBCID*
0	1	4	5
1	7	2	5
2	7	2	5
3	5	0	5
4	3	6	5
5	2	5	5
6	1	4	5
7	7	2	5
8	0	3	5
9	3	6	5
10	4	7	5
11	2	5	5
12	2	5	5
13	0	3	5
14	7	2	5
15	2	5	5
16	0	5	3
17	5	3	2
18	1	0	1
19	5	4	1
20	1	0	1
21	1	4	5
22	3	4	7
23	0	6	2
24	3	3	0
25	6	6	0

- The TTCBCID and the RAWBCID are 3 bit timestamps and therefore range from 0 to 7
- The difference between the TTCBCID and the RAWBCID **does not have to be 0** but has to be constant for the data to be synchronised
- For some reason, there are regions in the data where the difference is no longer constant meaning that the data becomes desynchronised



Synced regions are when the difference between the TTCBCID and the RAWBCID are constant

*MODULO((TTCBCID+8) - (RAWBCID))

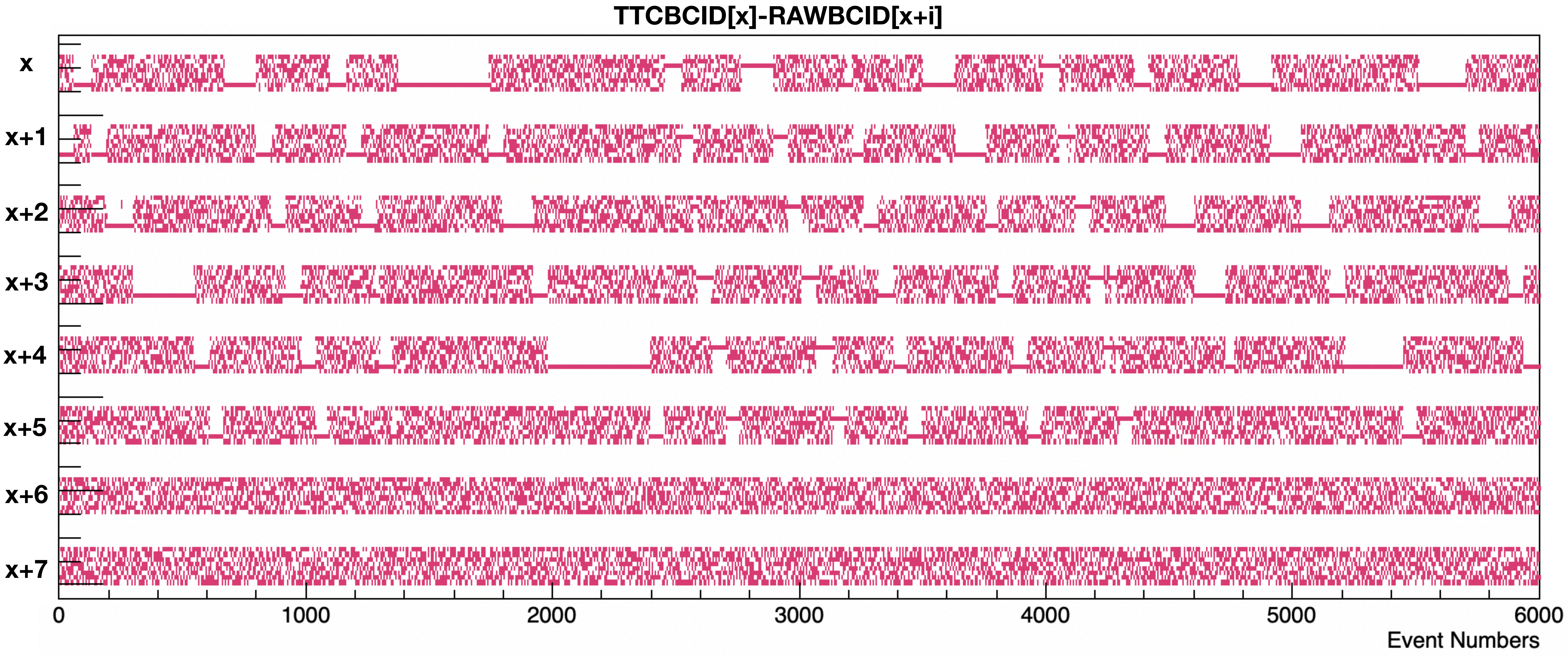
Comparing the TTCBCID and the RAWBCID

Event Number	TTCBCID	RAWBCID	TTCBCID-RAWBCID	
0	1	4	5	
1	7	2	5	
2	7	2	5	
3	5	0	5	
4	3	6	5	
5	2	5	5	
6	1	4	5	
7	7	2	5	
8	0	3	5	
9	3	6	5	
10	4	7	5	
11	2	5	5	
12	2	5	5	
13	0	3	5	
14	7	2	5	
15	2	5	5	
16	0	5	3	
17	5	3	2	5
18	1	0	1	5
19	5	4	1	5
20	1	0	1	5
21	1	4	5	5
22	3	4	7	5
23	0	6	2	5
24	3	3	0	5
25	6	6	0	5

- To try and resynchronise the data, the DUT hits need to matched back to the correct event
- To do this, you need to look at the DUT hits from neighbouring events
- This example shows that the exact DUT event information may only be 1 event away from the correct event
- To fully synchronise the data we need to compare the difference between TTCBCID of event x to that of the RAWBCID of event x+i where i is between 0 and 7.
  - **TTCBCID[x]-RAWBCID[x+i]**
  - Plot this difference as a function of the event number (x) to see if regions of the data become synchronised

*MODULO((TTCBCID+8) - (RAWBCID))

Comparing the TTCBCID and the RAWBCID



Creating a New Event

- Within one event there are 5 sub-event information stored
  - ITS_ABC ← Associated to the DUT
  - ITS_TTC
  - NiRawDataEvent
  - TluRawDataEvent
  - USBPIXI4

  } Associated to the Telescope and ITSDAQ

- To create a new synchronised event we need to know the event number for the telescope sub-event information and how many events you need to skip to get the corresponding DUT sub-event information

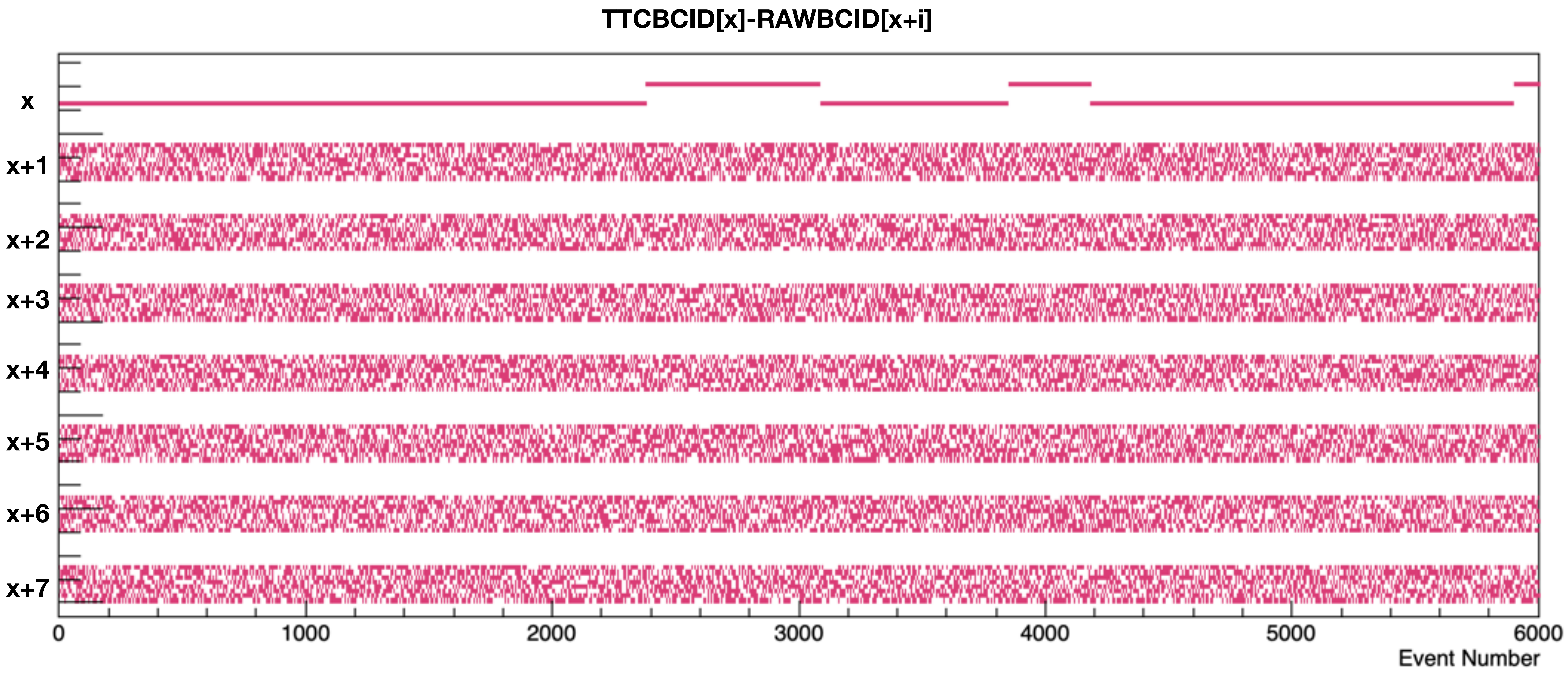
- To do this we need a look up table that lists the TTCBCID event number and RAWBCID event number that will be a maximum 5 events away

TTC	RAW	Shift
1	2	1
2	3	1
3	4	1
4	5	1
5	6	1
6	7	1
7	8	1
8	9	1
9	10	1
10	11	1
11	12	1
12	13	1
13	14	1
14	15	1
15	16	1
16	17	1

52	53	1
53	54	1
54	55	1
56	56	0
57	57	0
58	58	0
59	59	0
60	60	0
61	61	0

183	184	1
184	185	1
185	186	1
186	187	1
187	188	1
190	192	2
191	193	2
192	194	2
193	195	2
194	196	2
195	197	2
196	198	2
197	199	2
198	200	2
199	201	2
200	202	2
201	203	2
202	204	2
203	205	2
204	206	2
205	207	2

New Synchronised Data

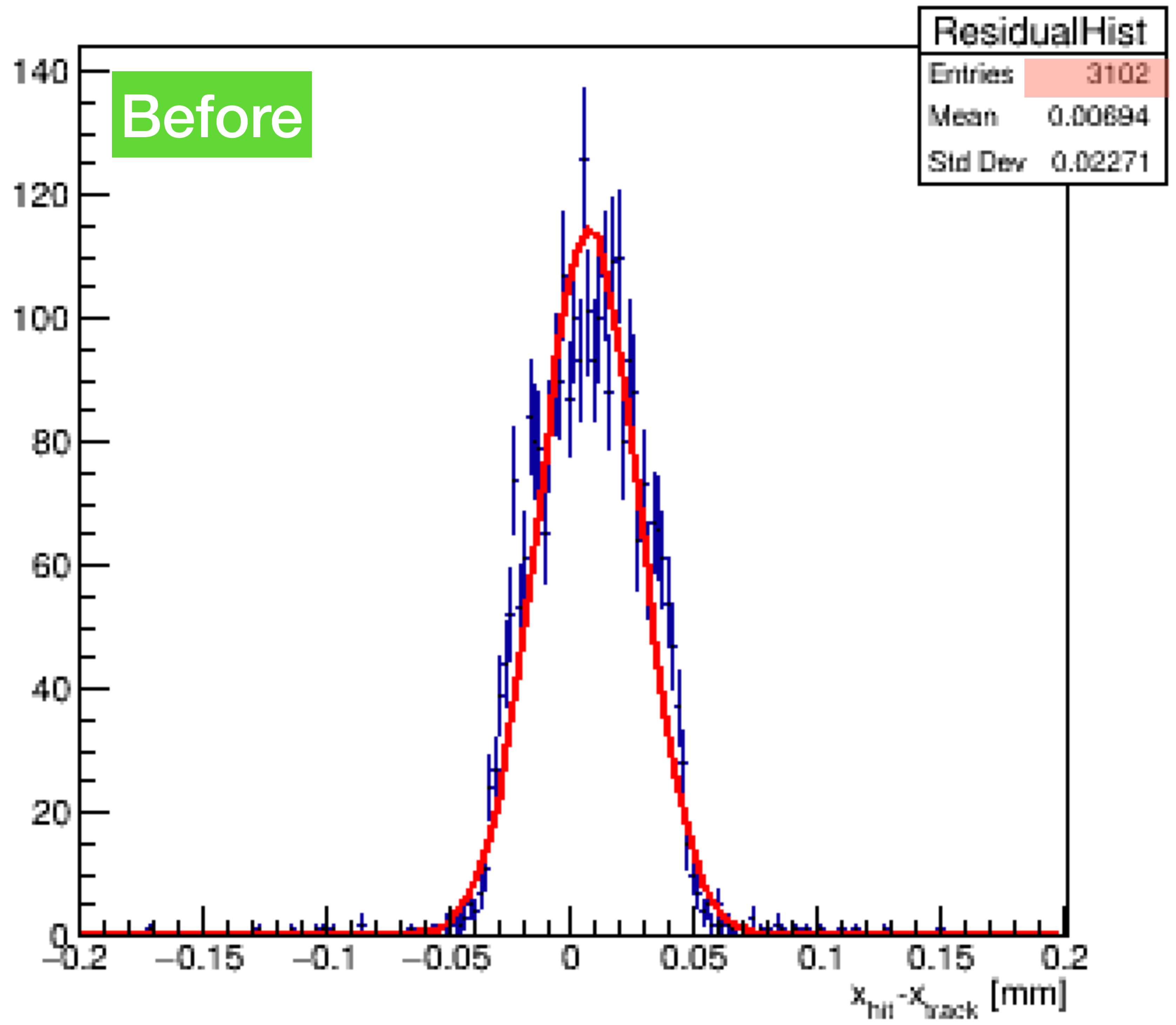


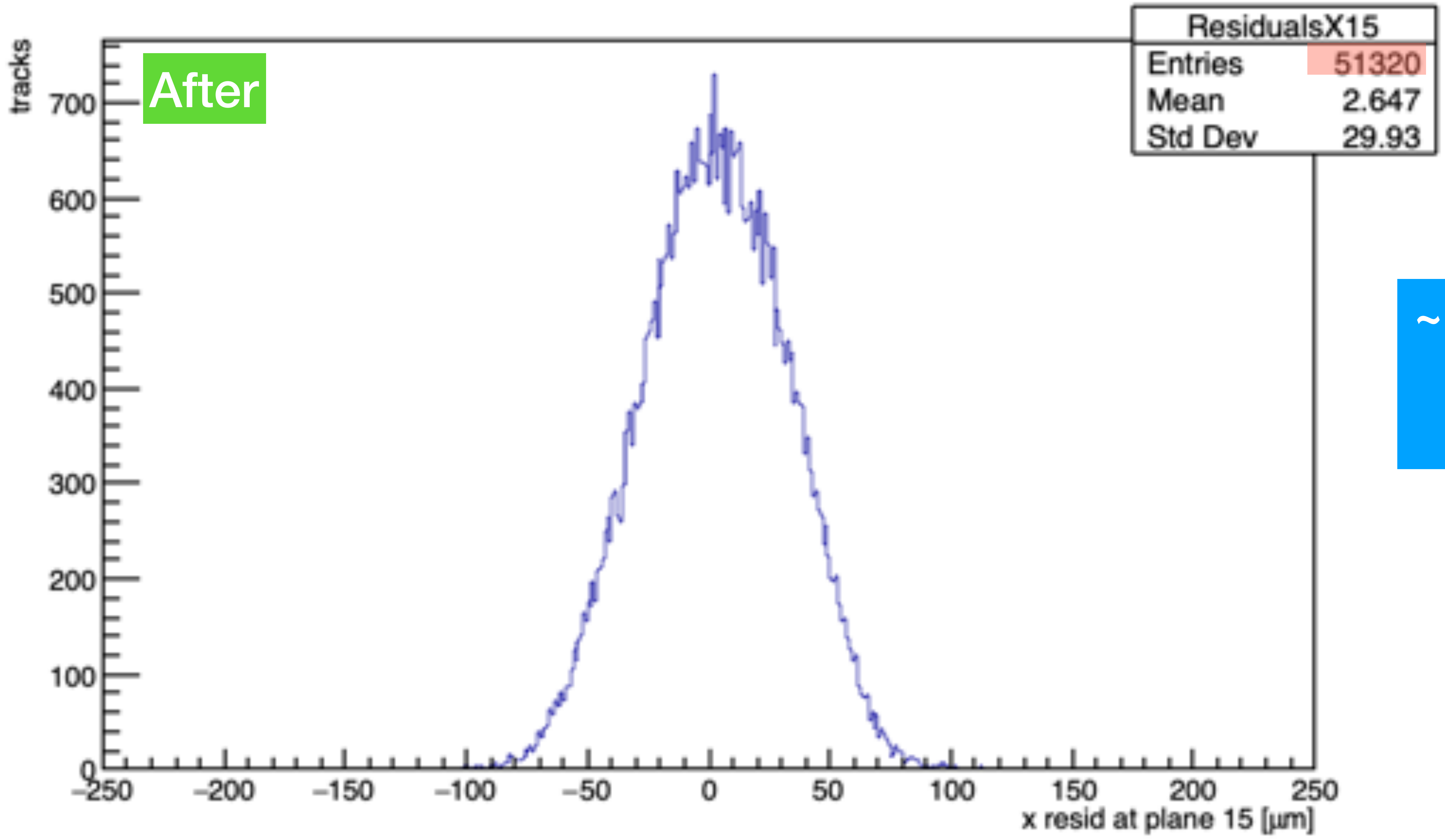
- Once you create the new raw file, you then compare the TTCBCID[x]-RAWBCID[x+i] to see if the run is now synced

Recovered Statistics for an Example Scan

Threshold Scan

- Before any correction is applied this threshold scan had around **29.5%** (σ=1.3%) of events synchronised
- After the desync correction was applied the number of events synchronised was around **96.8%** (σ=1.9%)
- The new raw file can then be used as an input into EUTelescope for reconstruction

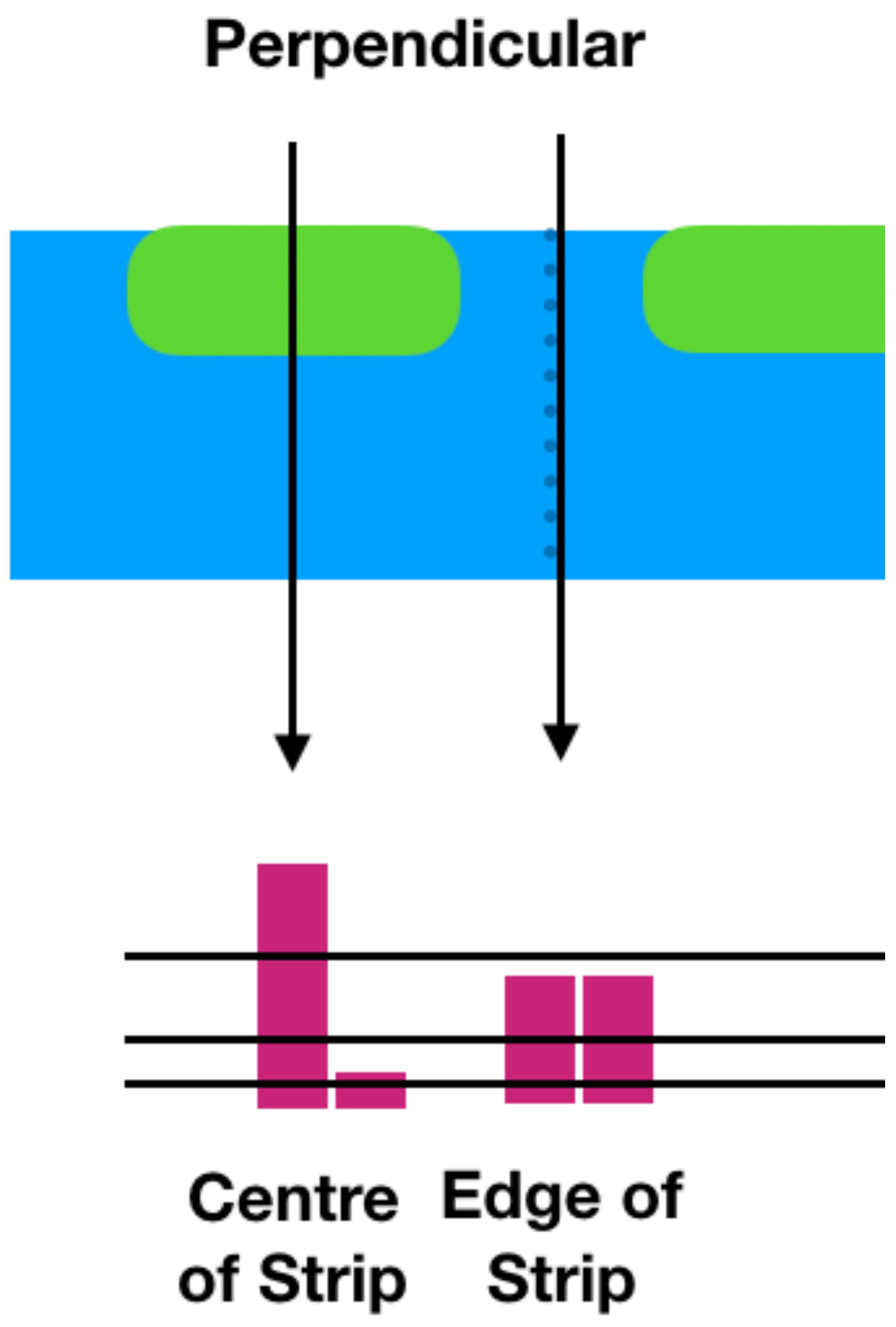


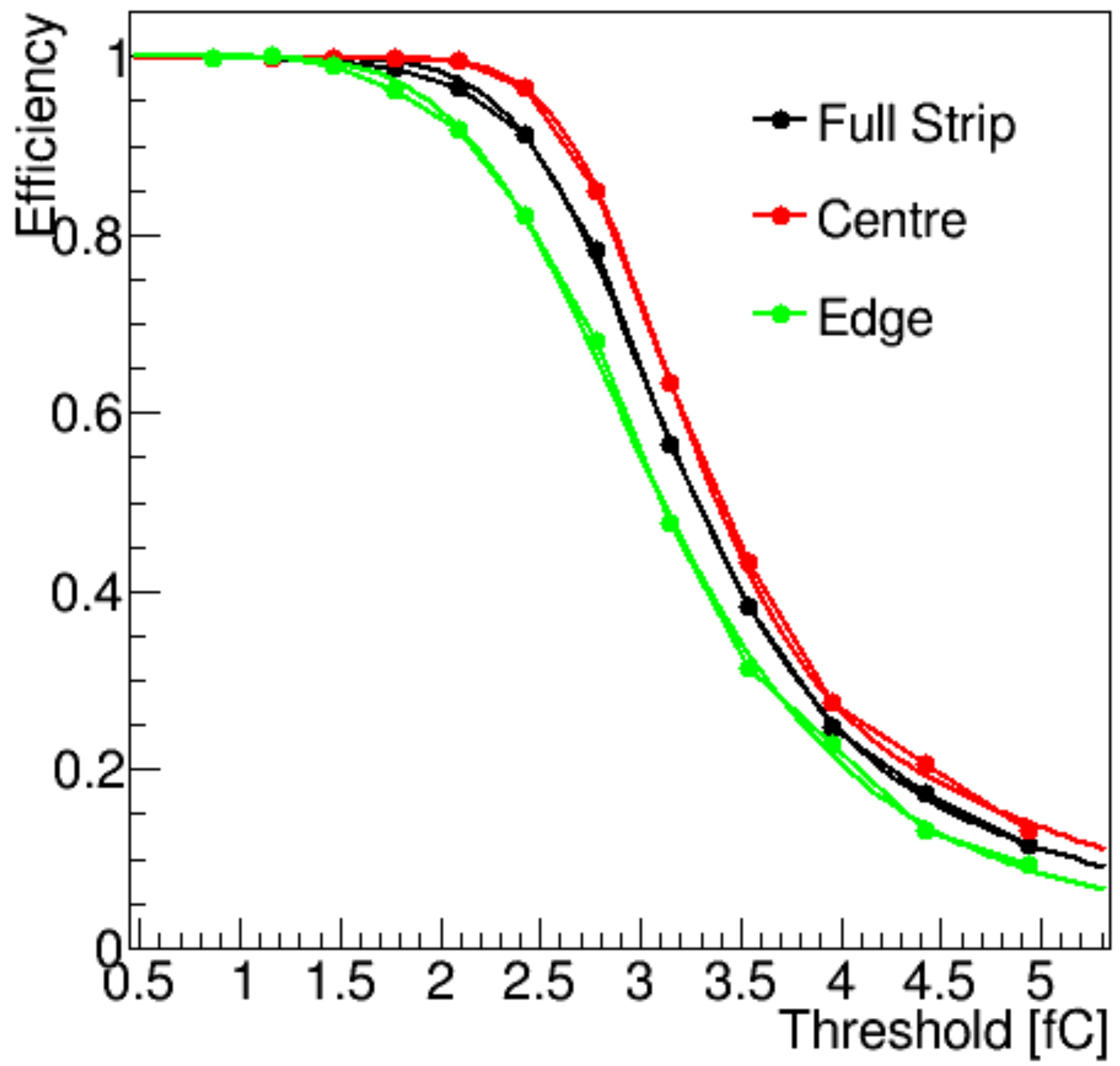


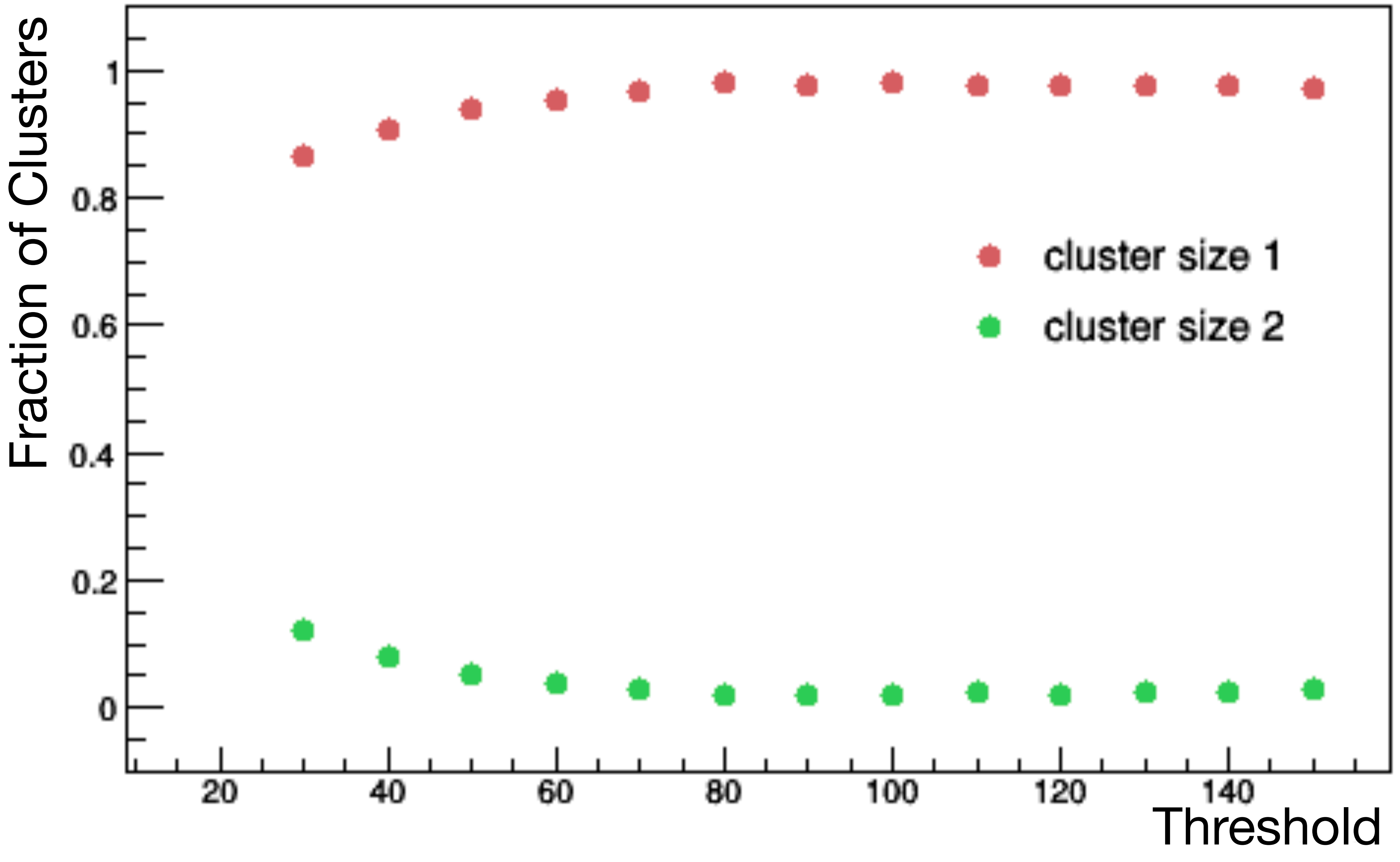
~16 times more events than before

Not all events make it though the EUTelescope Tracking Cuts

Preliminary Results from Non-Irradiated LS Module

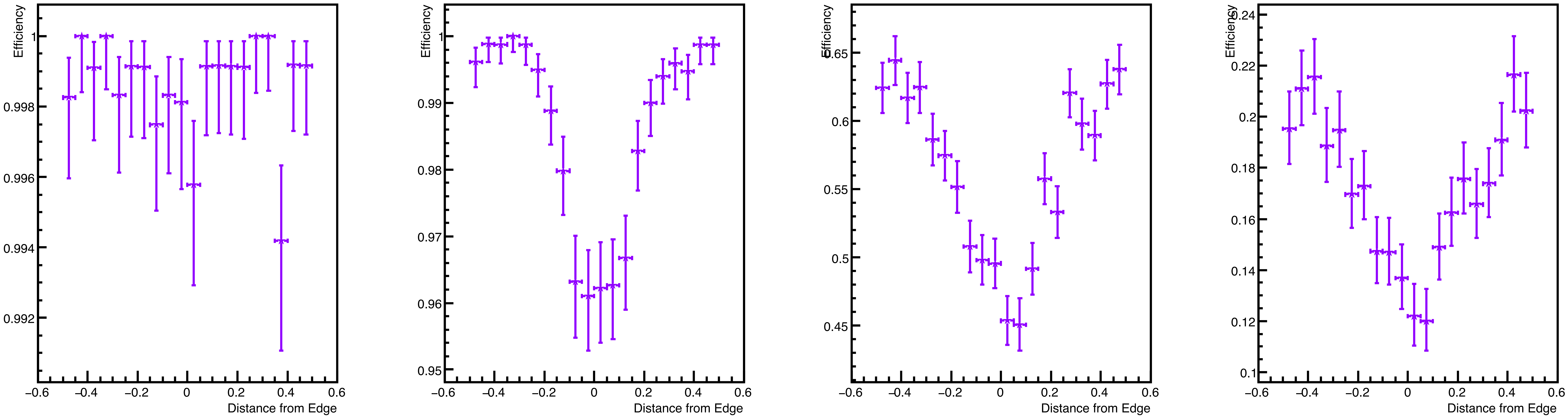






- Charge sharing depends on the intra-strip hit position
- If the track hits the edge between two strips, charge is shared but the charge signals in each strip are smaller and more susceptible to being lost at higher thresholds
- The efficiency decreases with increasing threshold and is lower at the edge of the strip
- Higher fraction of size one clusters with increasing thresholds

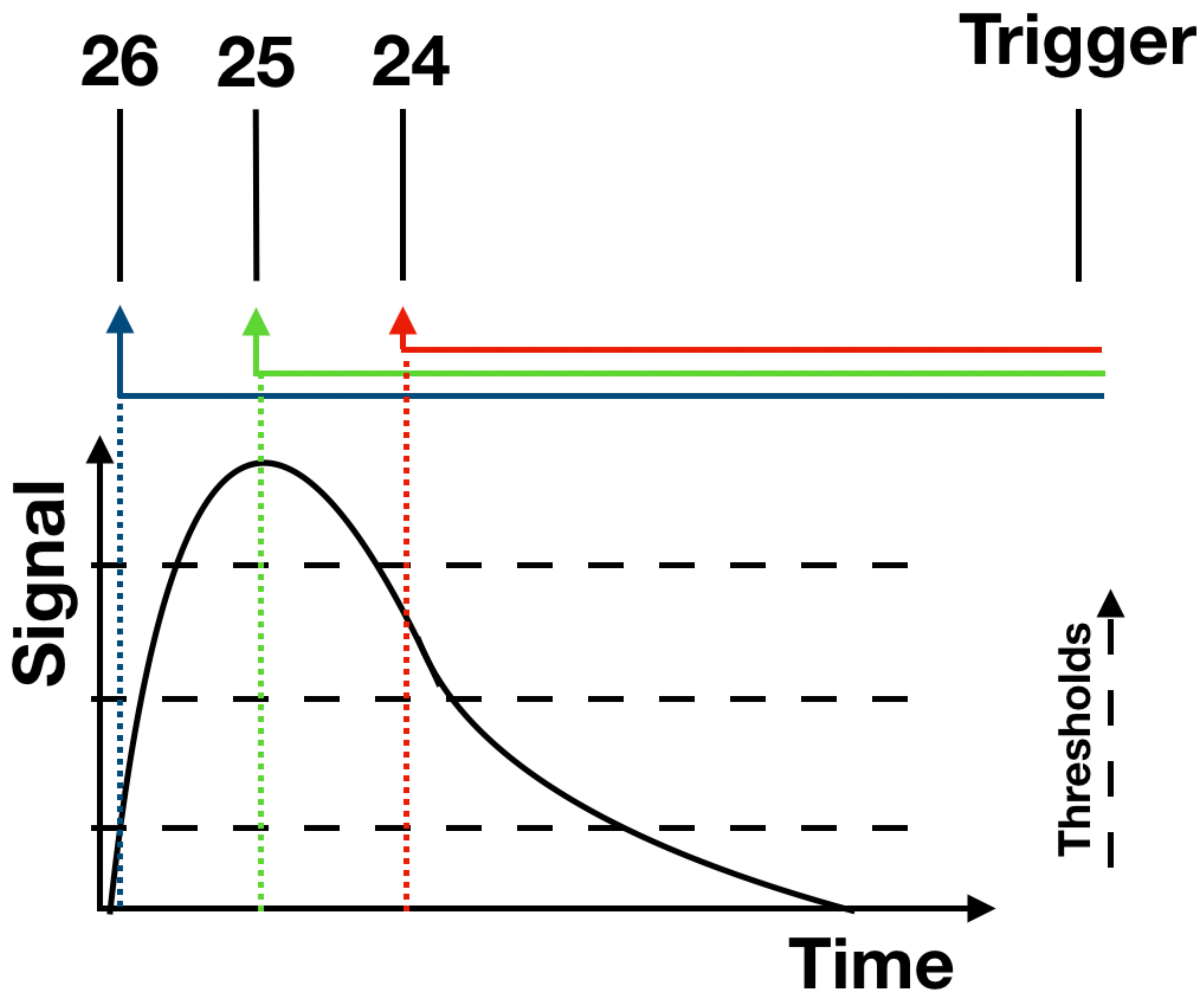
Preliminary Results from Non-Irradiated LS Module

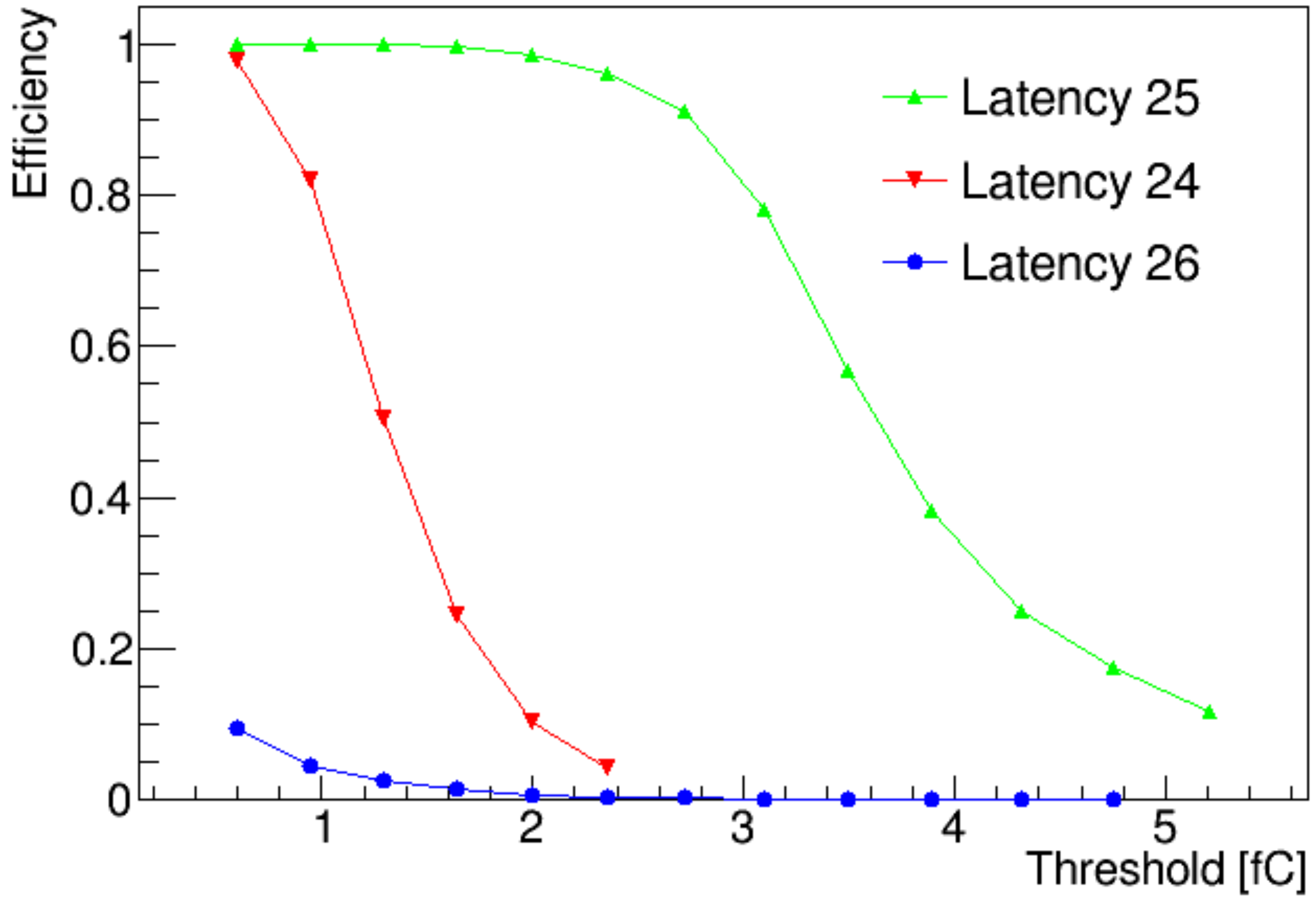


Intra-Strip Efficiency depending on the threshold

- At low threshold the full strip is >99% efficient
- As the thresholds start to increase, there is a clear dip in efficiency at the edge of the strip
- The overall efficiency over the strip decreases with increasing threshold as expected

Preliminary Results from Non-Irradiated LS Module

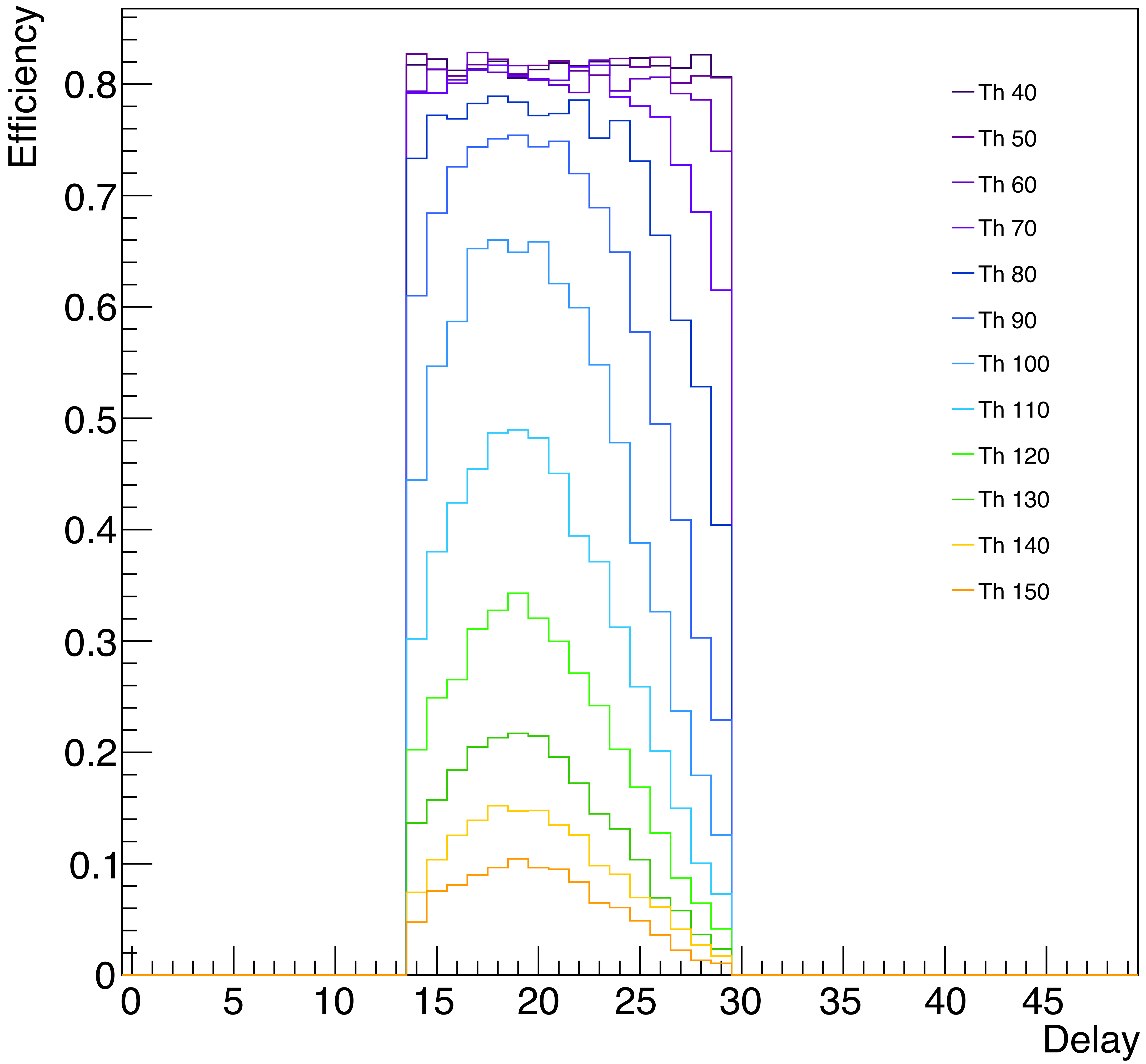




Latency

- The optimum latency is 25
- At a latency of 24, there is still high efficiency at low thresholds due to high charge signals but the efficiency drops quickly with increasing thresholds
- At a latency of 26, due to shape of the charge signal, the efficiency is very low and drops to almost zero with increasing thresholds

Preliminary Results from Non-Irradiated LS Module



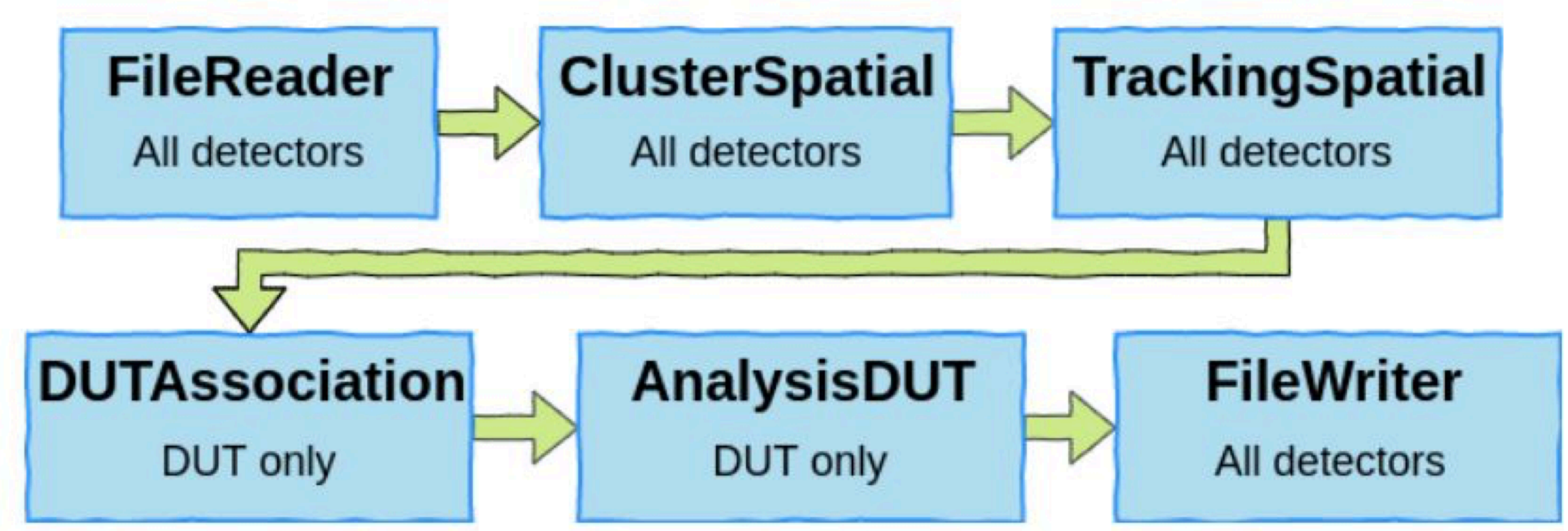
Delay

- ToA for the trigger pulse from the scintillators within the bunch crossing, measured in time delay.
- 16 steps per bunch crossing ~1.6s per step
- The longer the delay the later the pulse arrived in the clock cycle
- Efficiency is highest at the peak of the pulse
- At very low threshold you have full efficiency due to large and long pulse lengths

Moving from EUTelescope to Corryvreckan

Corryvreckan

- A reconstruction and analysis tool for pixel sensor test beam data
- Flexible, fast and lightweight reconstruction framework based on a modular concept of the reconstruction chain
- Users build their own reconstruction chain
- Written in modern C++ and reduces external dependencies to a minimum (ROOT)
- Well documented* and is an active ongoing development



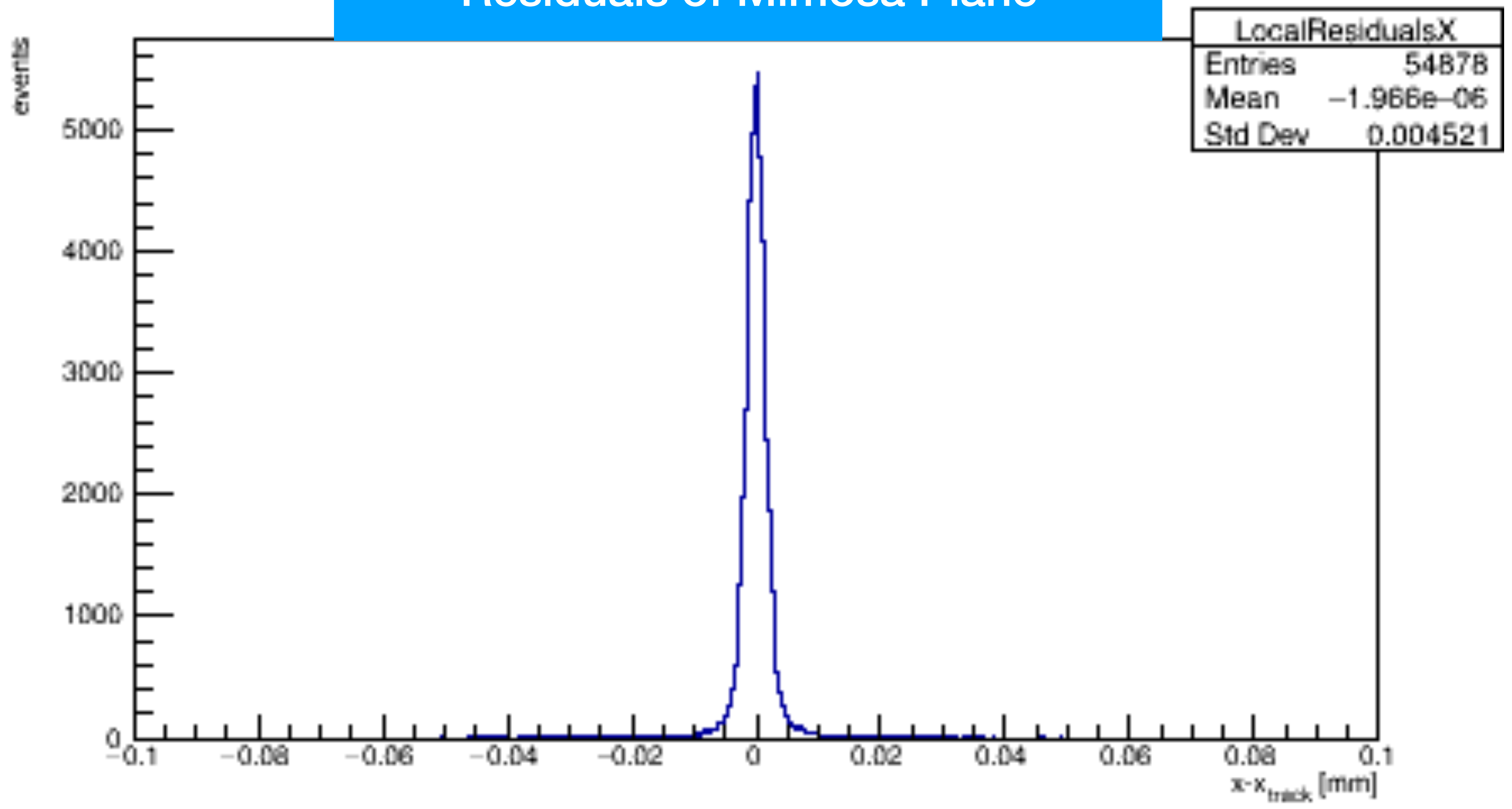
***https://arxiv.org/pdf/1912.00856.pdf**

Moving from EUTelescope to Corryvreckan

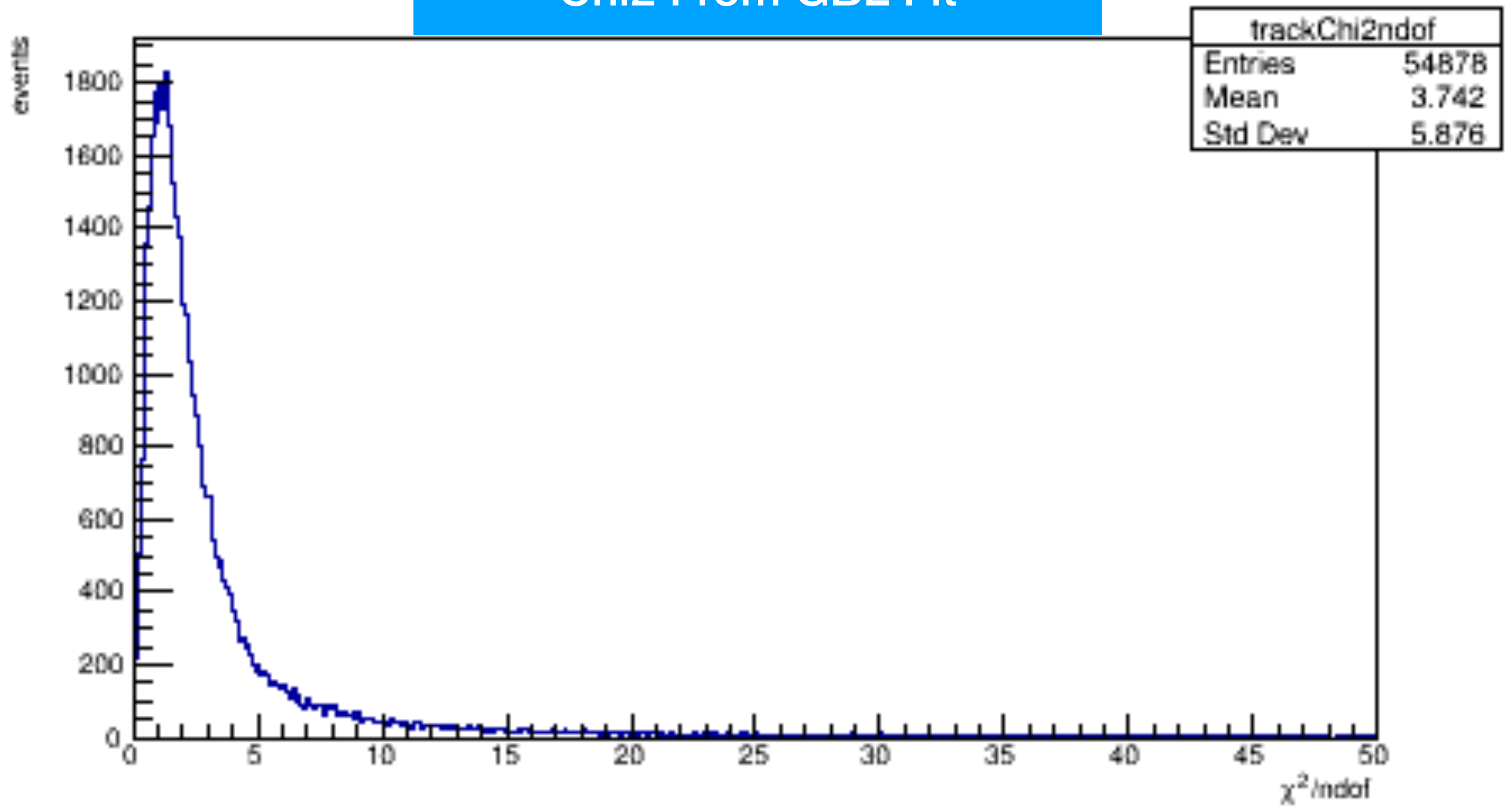
- Corryvreckan is widely tested in the pixel community but new to ITk Strip
- The ITk strip community is actively trying to implement Corryvreckan on 2019 data
- Should be straight forward for barrel modules but radial geometry will need to be implemented for the endcap modules
- First steps is to use the simplest geometry, for example the LS module
- Then compare the LS results reconstructed using Corryvreckan to previous results using EUTelescope
- Once this is achieved the radial geometry will be implemented to allow for endcap analysis

Preliminary Results from Corryvreckan

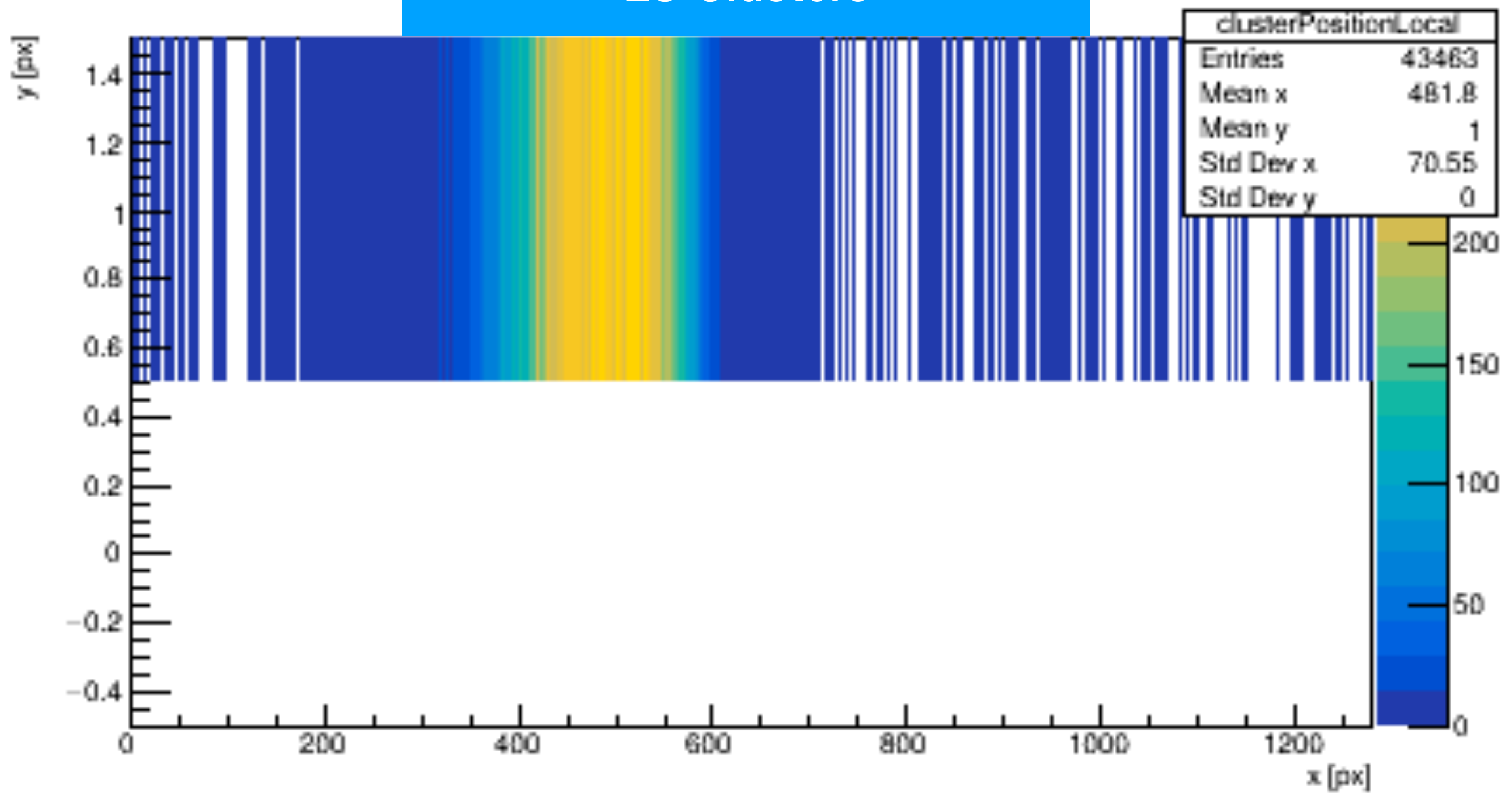
Residuals of Mimosa Plane



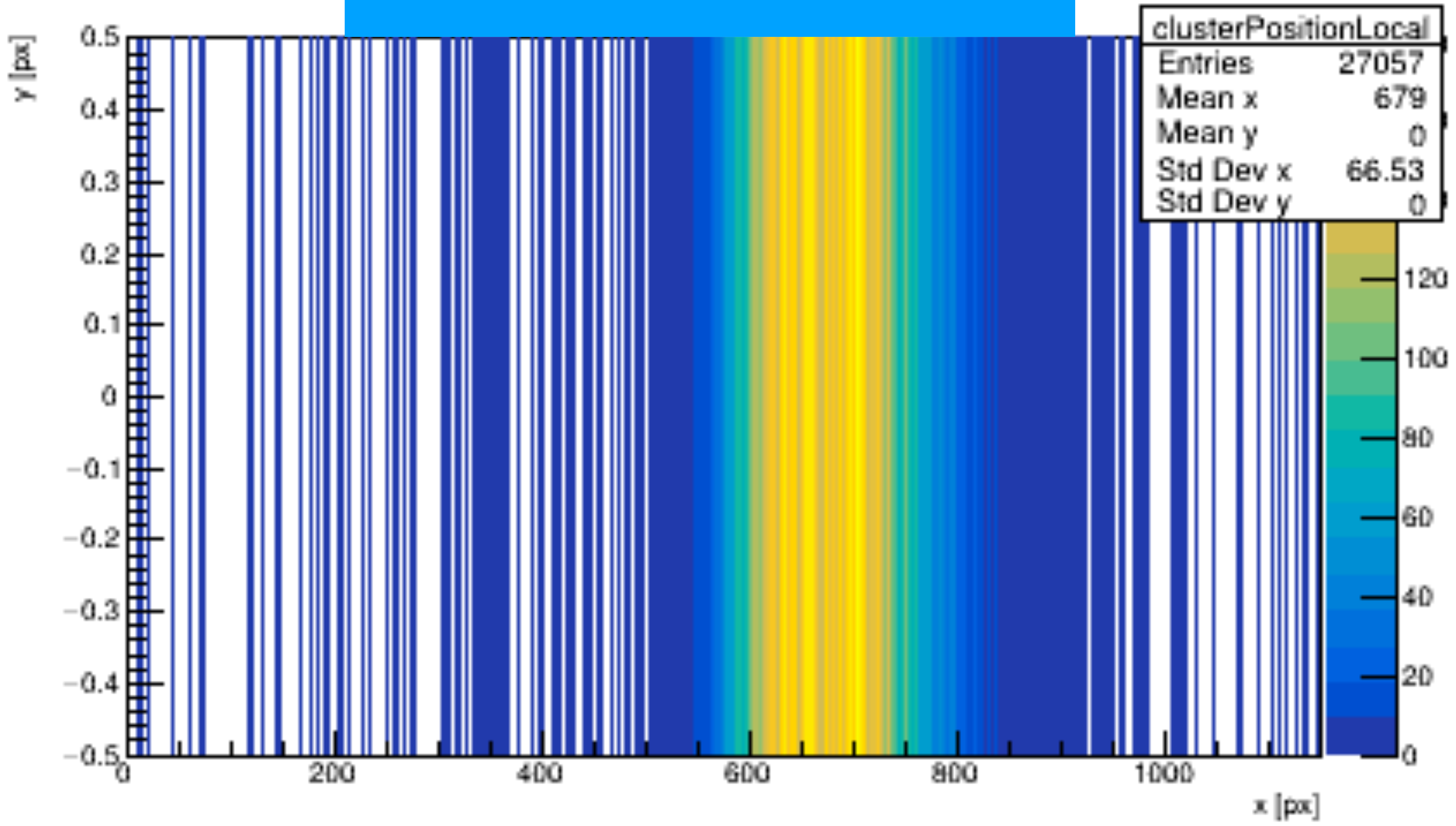
Chi2 From GBL Fit



LS Clusters



R0 Clusters

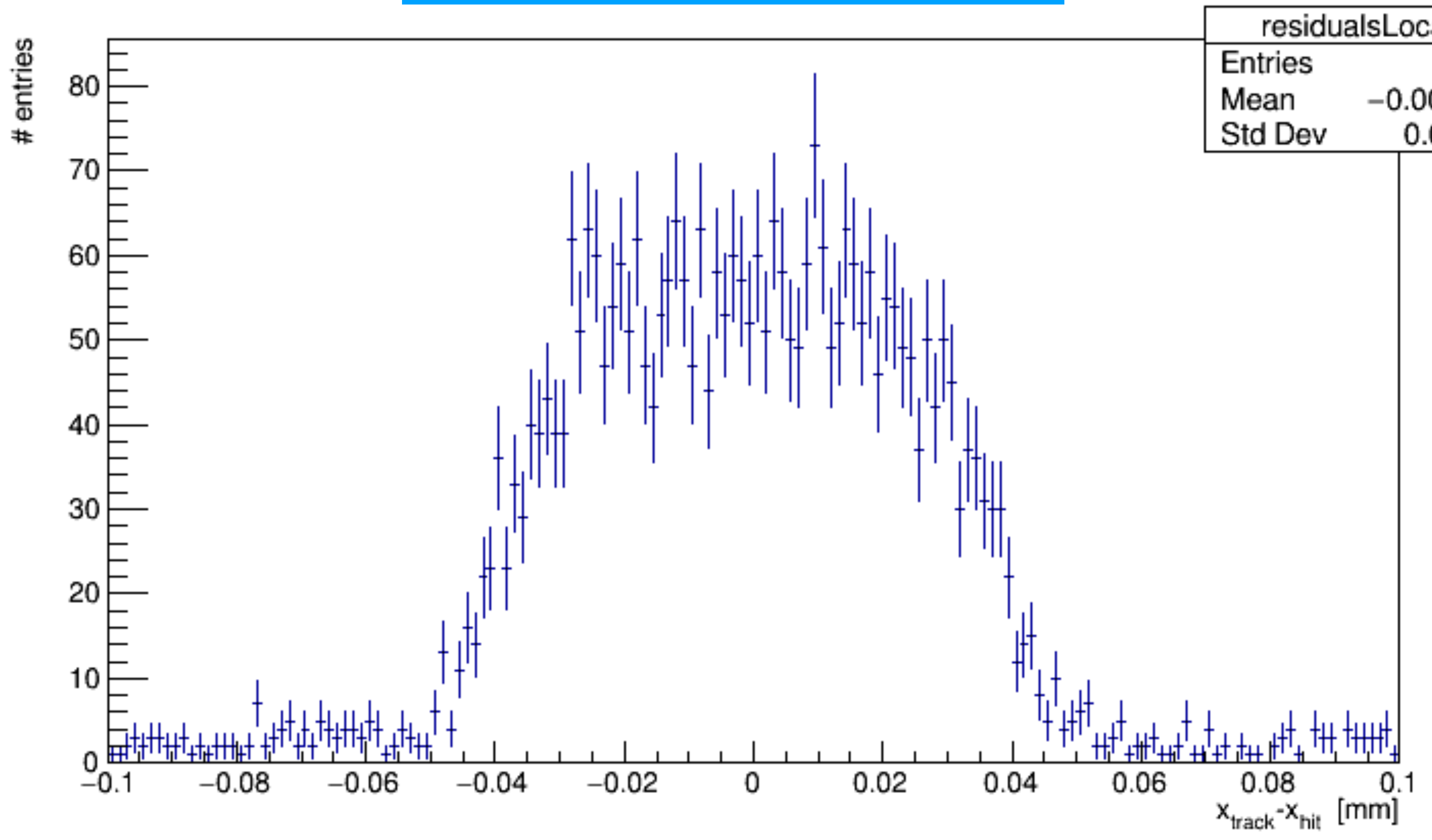


Preliminary Results from Corryvreckan

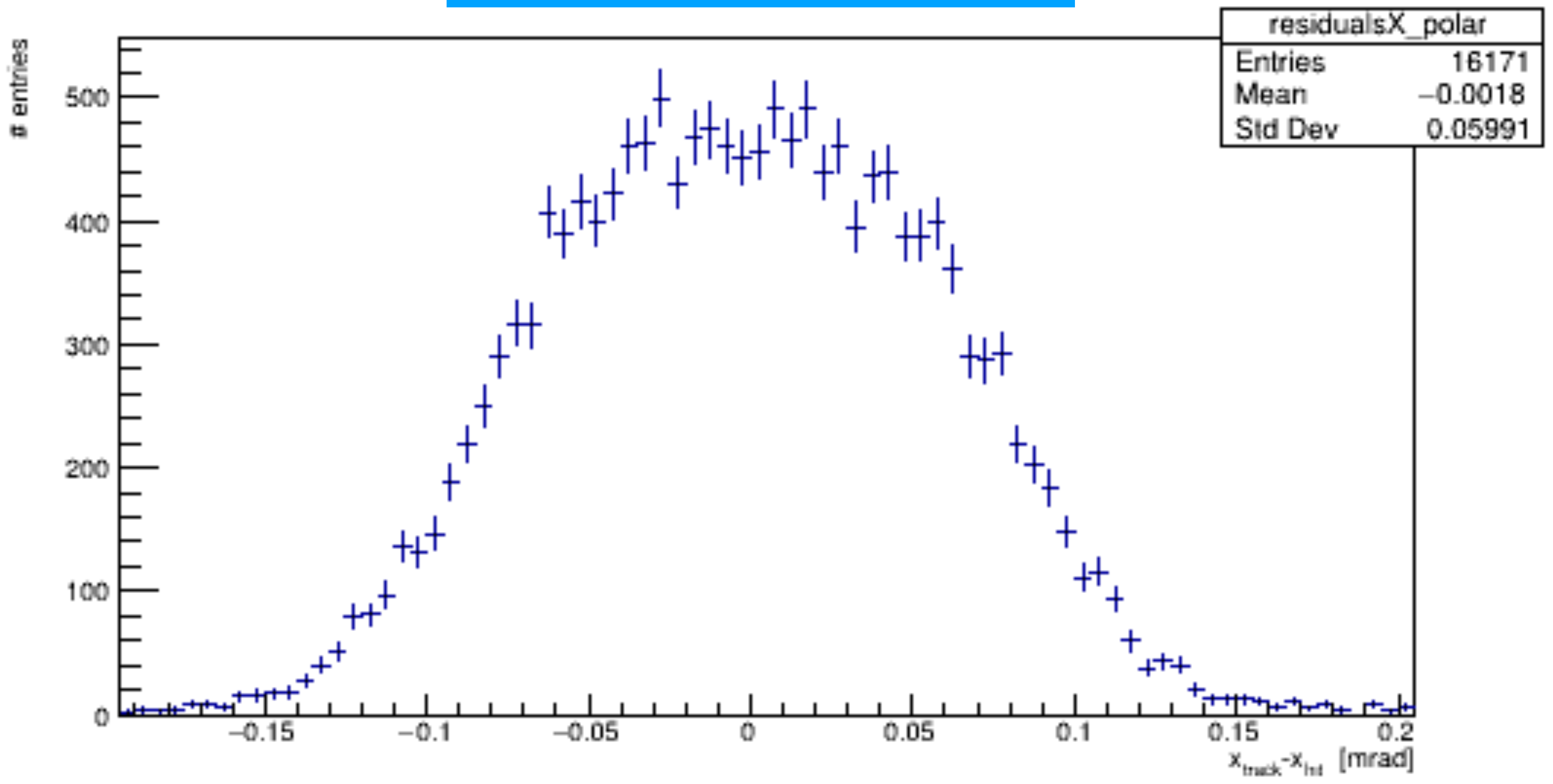
Alignment results of LS/R0

- LS strip module is considered as N*1 pixel detectors
- R0 module is implemented with a polar coordinate system as a typical EndCap detector
- The preliminary studies from non-rotated data shows reasonable alignment results

Residuals of LS Module



Residuals of R0 Module



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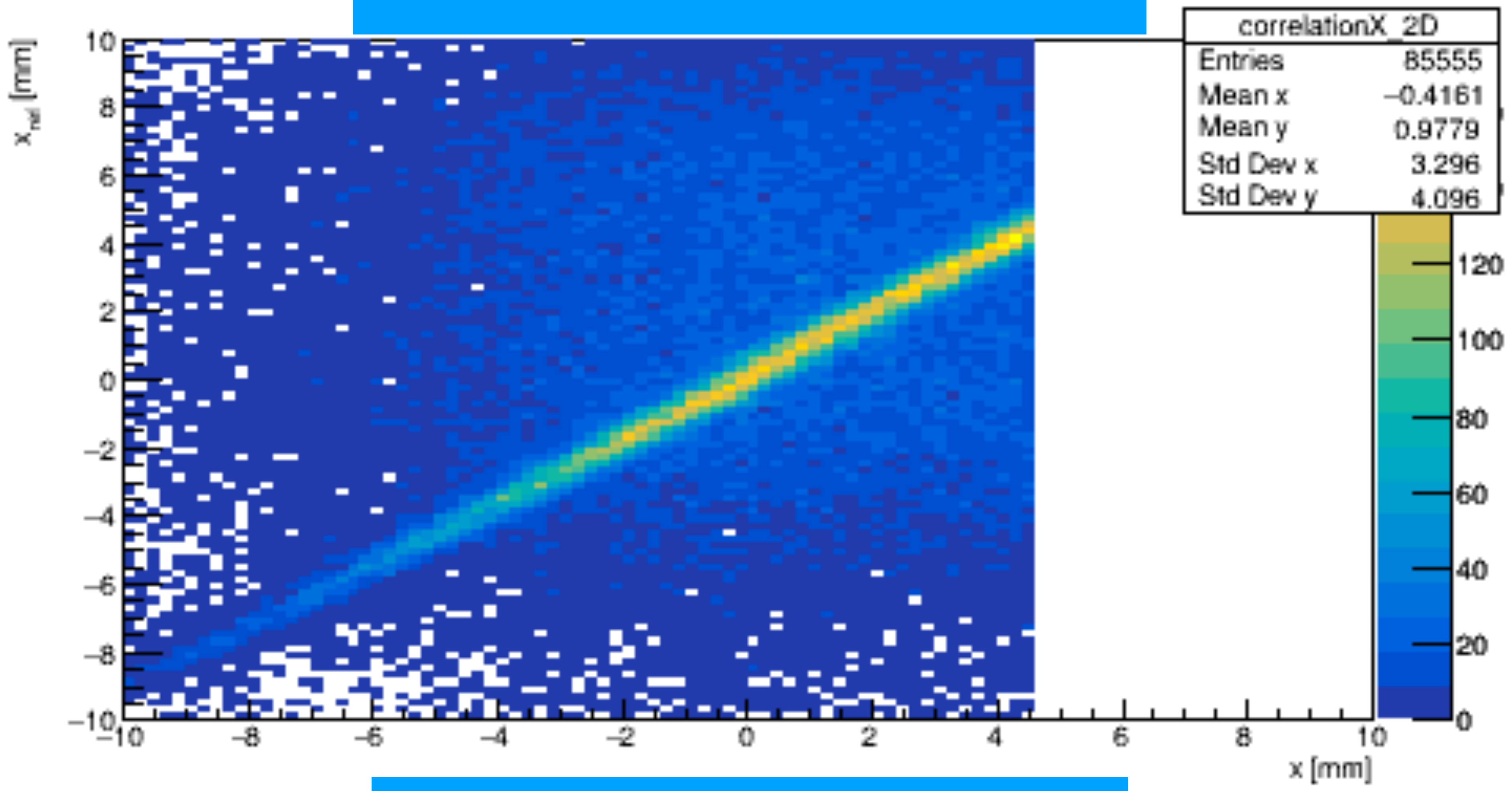
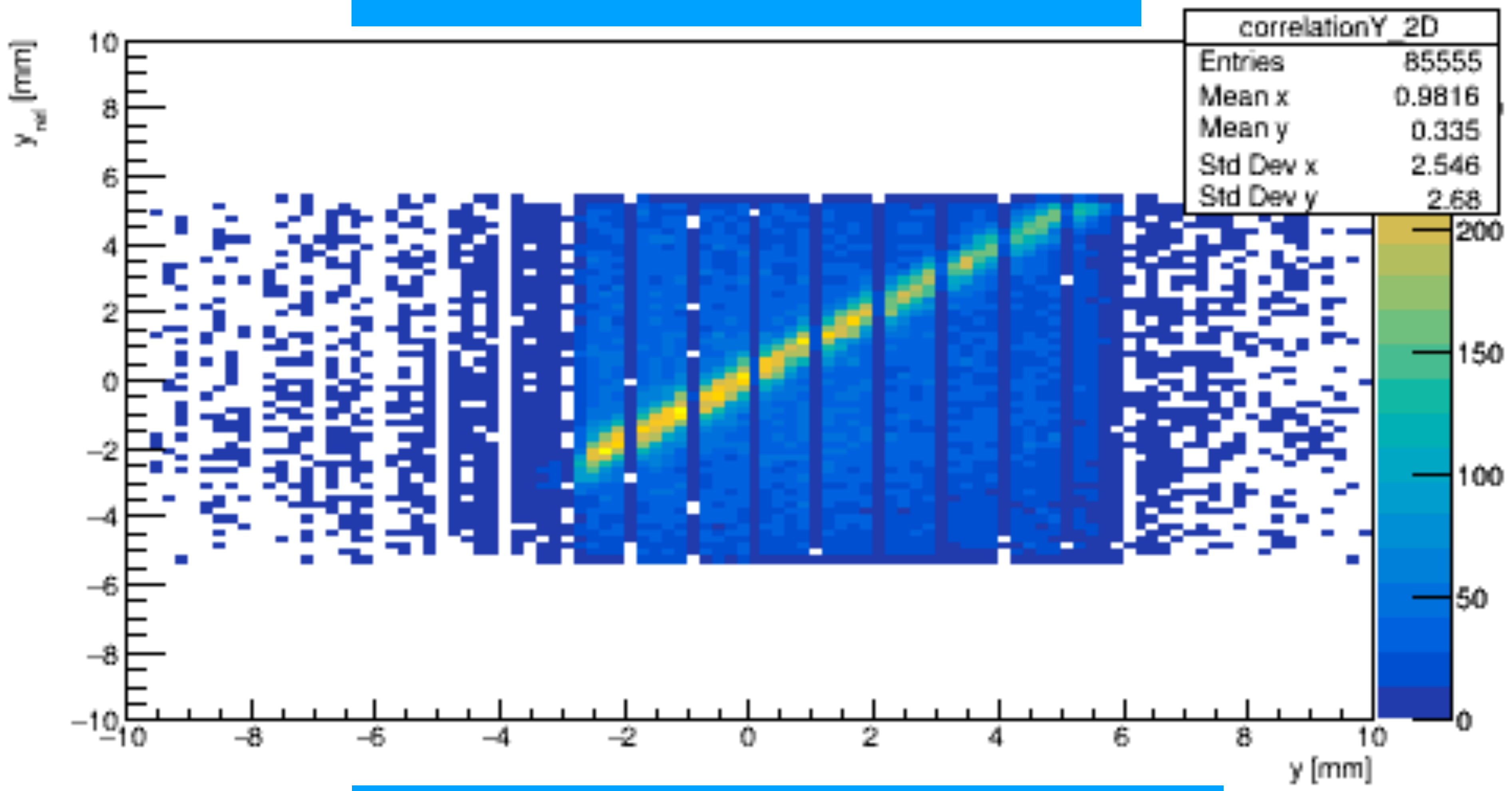
Preliminary Results from Corryvreckan

Integration of FEI4 Timing plane

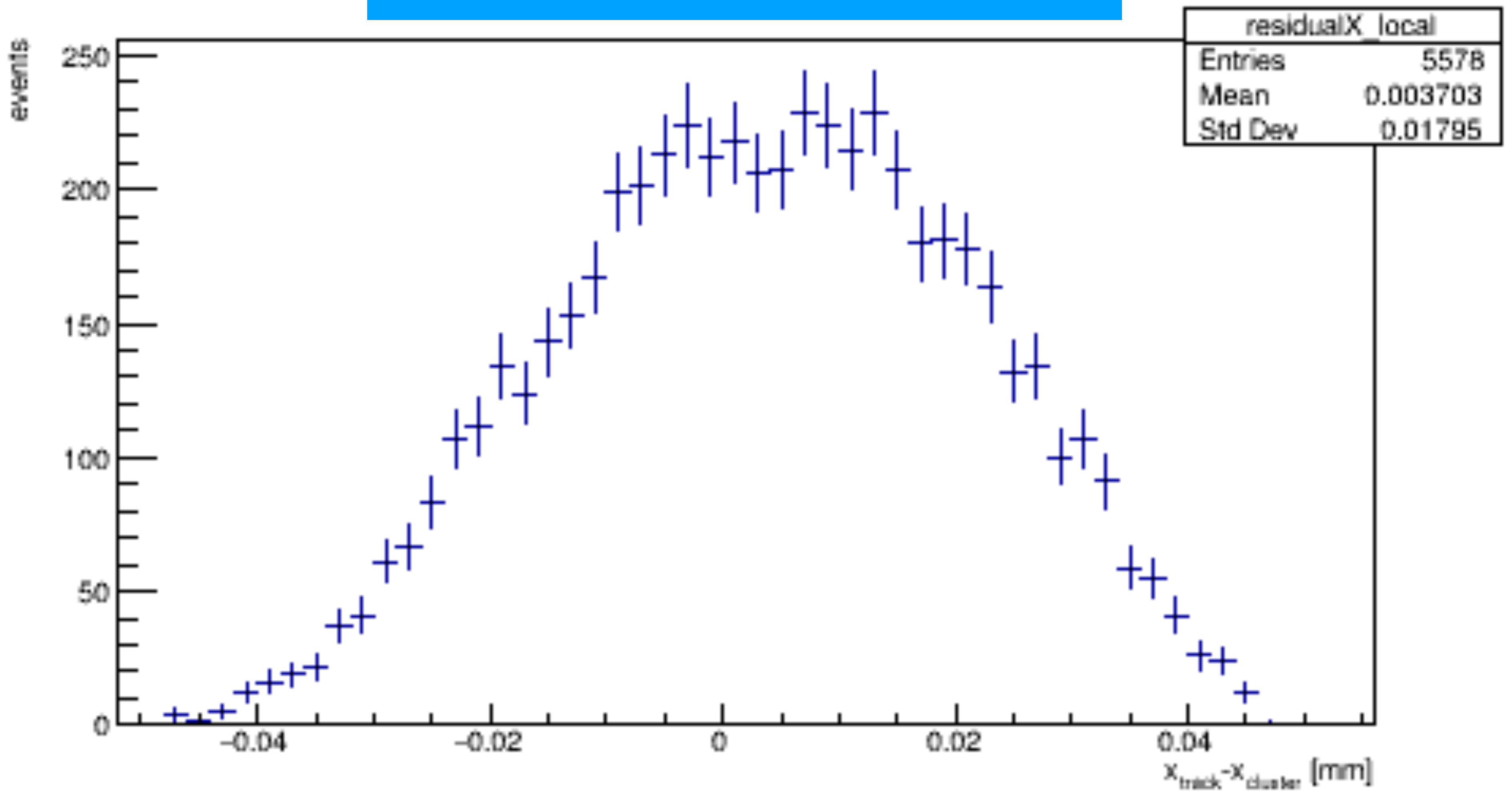
Correlations of X



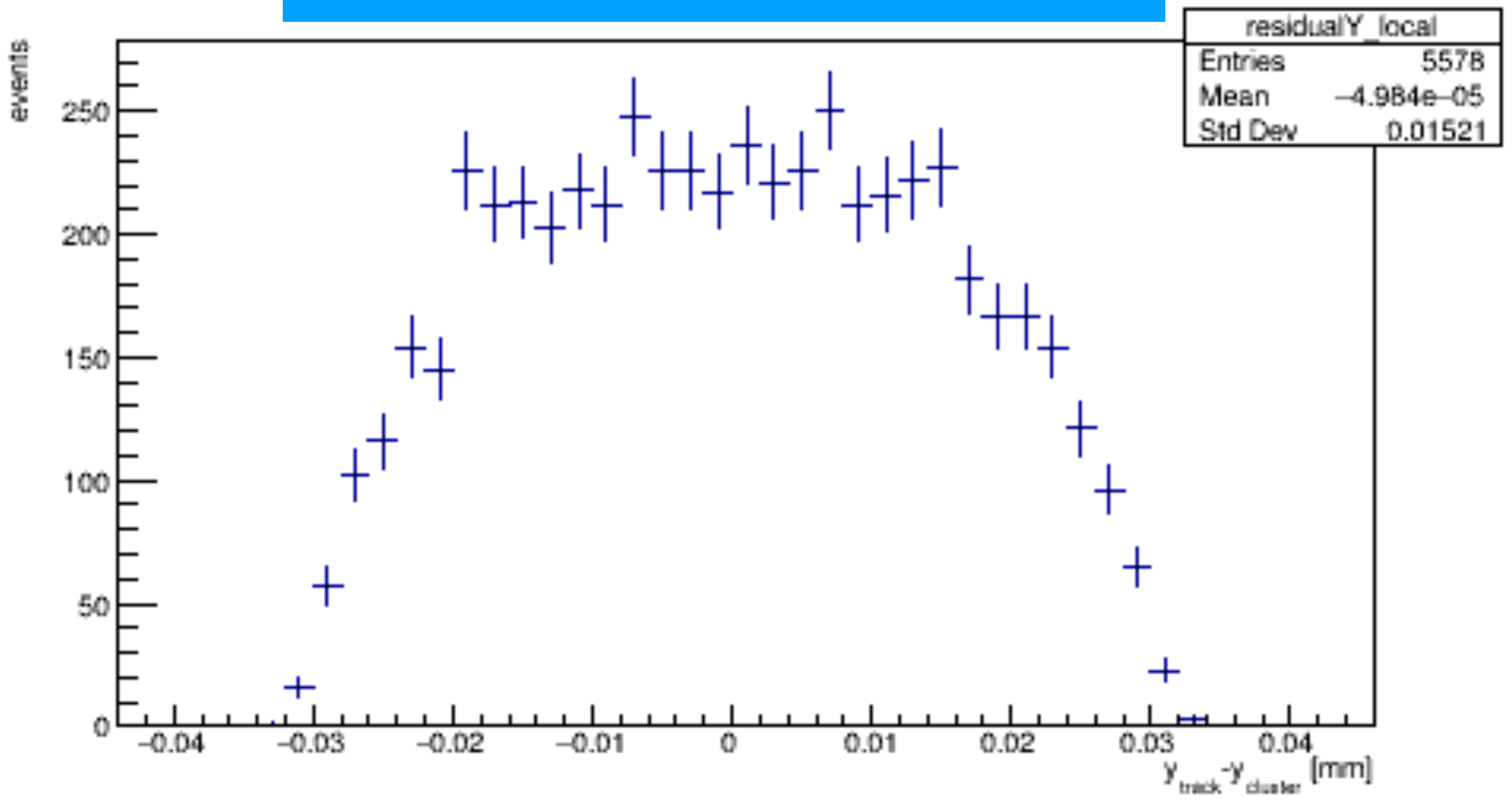
Correlations of Y



Biased Residuals X



Biased Residuals Y



Conclusions

- No new data in 2020 so far but optimistic that there will be some in the coming day
- Backlog of data from 2019 that is still being analysed
- Desynchronisation correction has been applied to recover data due to mismatch events
- Preliminary analysis has been preformed on LS data using EUTelescope
- Issues reconstructing angled DUT data and endcap data using EUTelescope therefore trying to reconstruct using Corryvreckan
- Corryvreckan should be a more straight forward software to implement due to ongoing development and good documentation
- Progress has been made reconstructing LS data with Corryvreckan and compares fairly well with EUTelescope reconstruction
- Next steps are to implement endcap geometry and encourage other ITk groups members to install and learn Corryvreckan