CMS ETROC Telescope and Test Beams!

12th edition of the Beam Telescopes and Test Beams Workshop

Murtaza Safdari

Session: Test beam analysis

April 17 2024

In partnership with ETROC Collaborators:


Info Panel T21
Control Room 3500
Power Supply 3389(B)
N. Meyners 3321(B)

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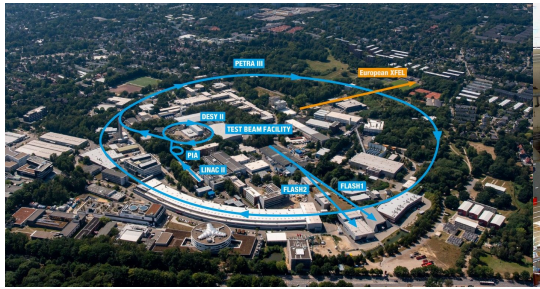
What's important for Test Beams?

Lessons learned from the ETROC2 experience so far...

- Preparation, Preparation, Preparation
- Iterate and Improve
- Monitor & Control Systematics
- Analysis with isolation of relevant effects

Start simple, follow the science...



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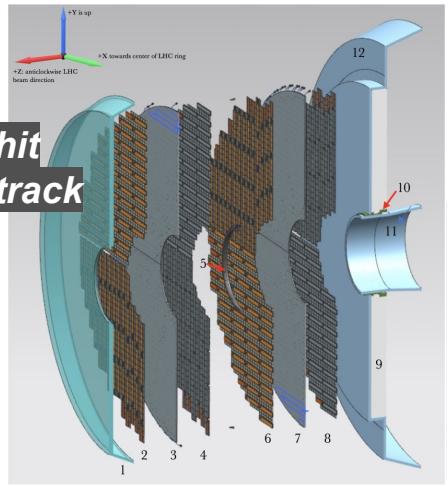
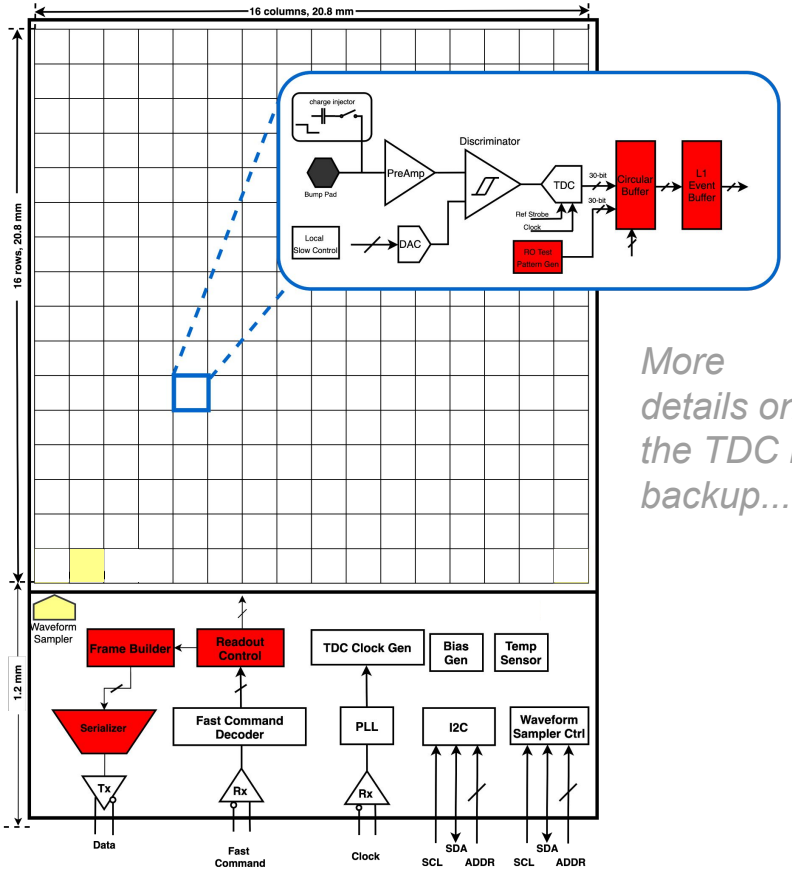
CMS Minimum Ionizing Particle Timing Detector for the HL-LHC



ETL
50 ps / hit
35 ps / track

1: ETL Thermal Screen
2: Disk 1, Face 1
3: Disk 1 Support Plate
4: Disk 1, Face 2
5: ETL Mounting Bracket
6: Disk 2, Face 1
7: Disk 2 Support Plate
8: Disk 2, Face 2
9: HGCal Neutron Moderator
10: ETL Support Cone
11: Support cone insulation
12: HGCal Thermal Screen



More details on the TDC in backup...

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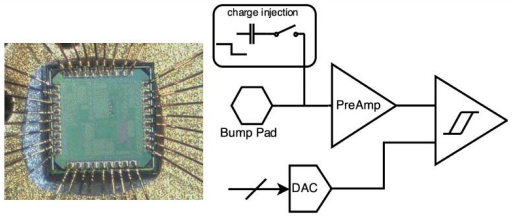
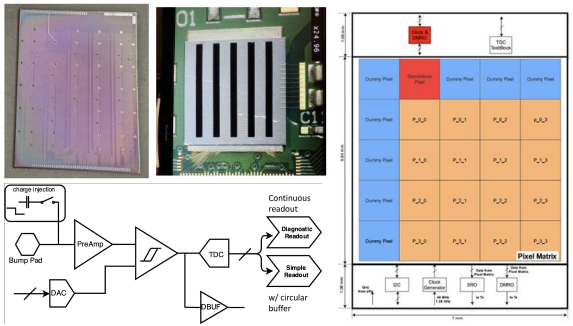
Context from Project Timeline

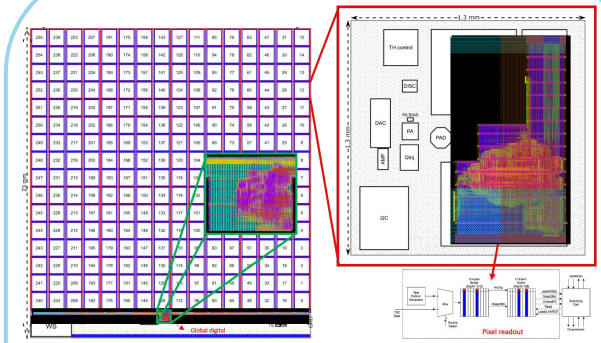
See Jongho's slides from BTTB11



ETROC0 single pixel w/ analogue front end, survives 100 MRad and reached timing resolution of ~33ps in beams with wire bonded sensor.



ETROC1 2x2 pixel array w/ full signal processing chain and H tree clock distribution, reached ~42ps in beams with wire bonded sensor.



ETROC2 16x16 pixel array with full functionality and full size H tree clock distribution, intense testing on going, here experience from recent beams at CERN and DESY.

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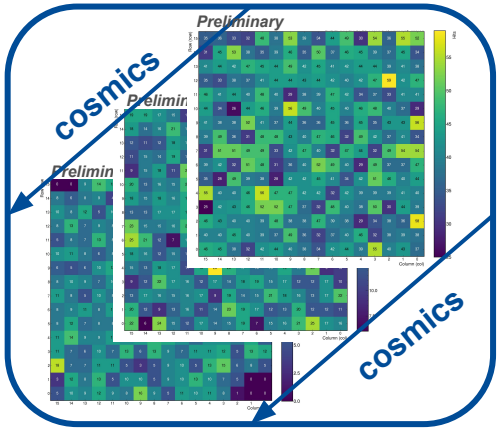
What's important for Test Beams?

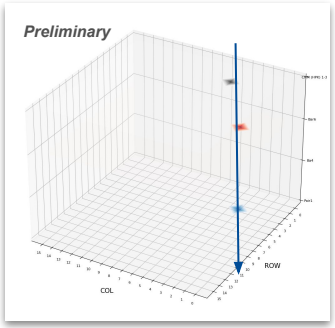
Lessons learned from the ETROC2 experience so far...

Preparation, Preparation, Preparation!

How did we prepare for ETROC2 test beams?

- **Brand new telescope** setup for ETROC2 studies
  - Inspired by ETROC0 and ETROC1 concepts...
- Extensively tested with cosmics & dummy runs
- Packing for success!





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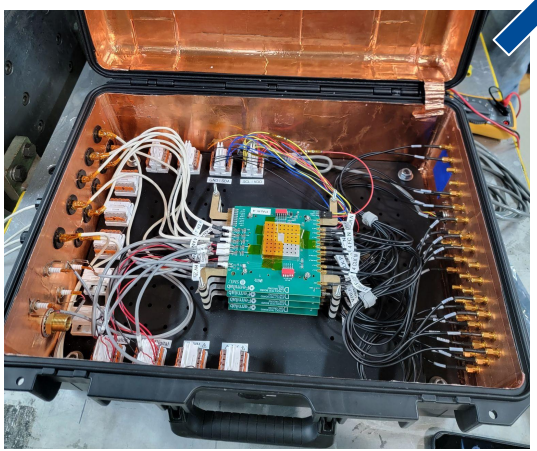
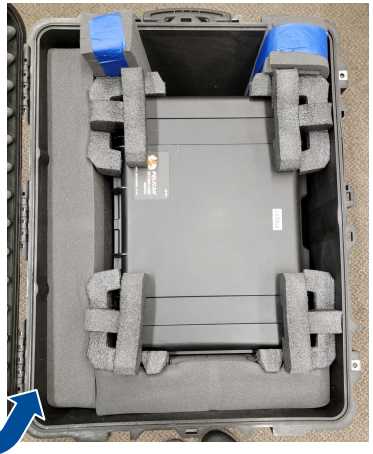
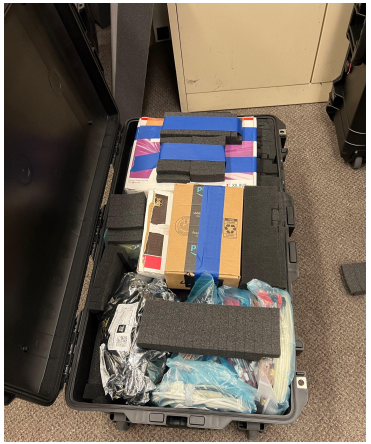
- Brand new telescope setup for ETROC2 studies
- Extensively tested with cosmics & dummy runs
- **Packing for success!**







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ETROC2's first day out! CERN September 2023 Test Beam






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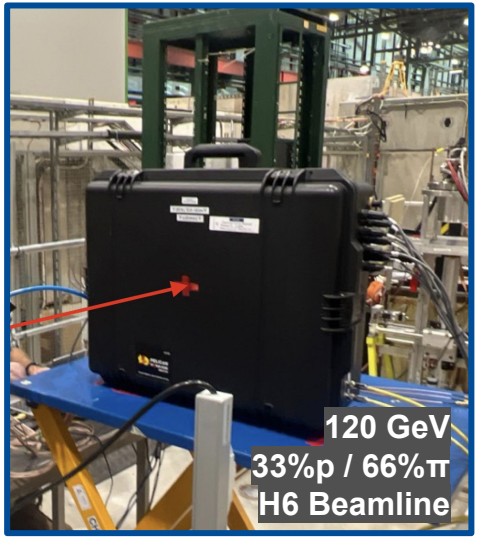
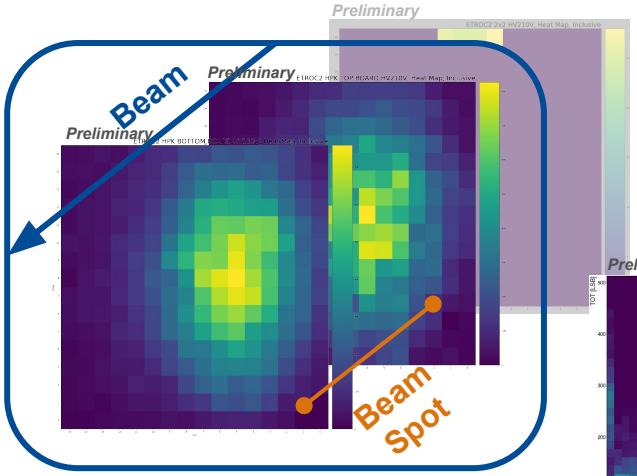
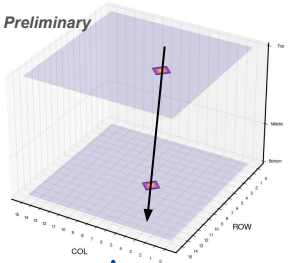
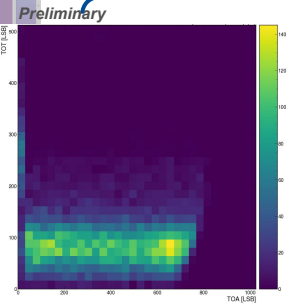
CERN September 2023 Test Beam

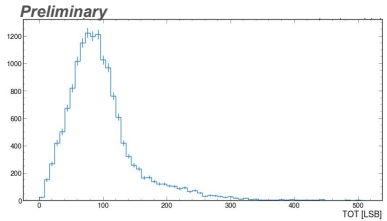
New ETROC2 telescope tested for the first time in a beam!
→ Fantastic support at CERN made ETROC science possible
→ DAQ worked on the first try!
→ Commissioned the full hardware / software pipeline at the beam

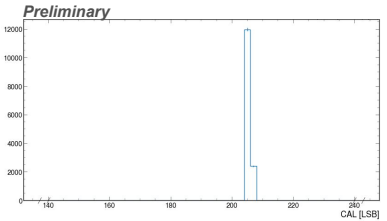






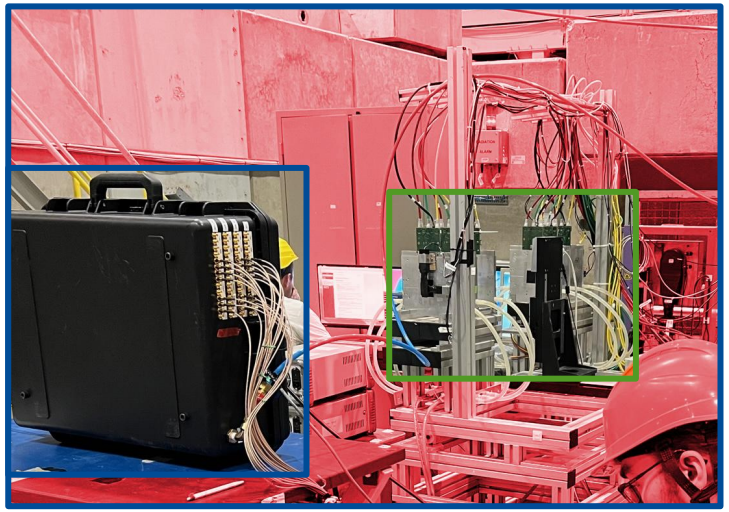






What's important for Test Beams?

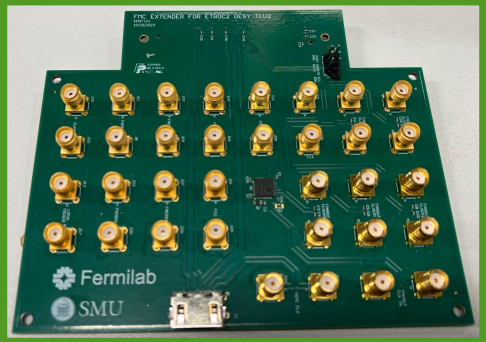
Lessons learned from the ETROC2 experience so far...



Iterate and Improve!

What did we learn from our first test beam?

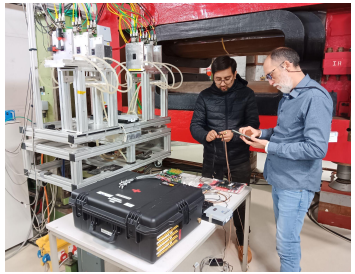
- **Telescope hardware / DAQ works!**
- Optimization needed for more robust and user -friendly telescope operation
- **The AIDA telescope's precision tracking can aid in timing studies, we should integrate!**

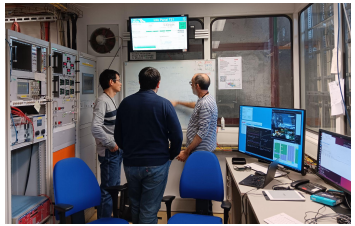


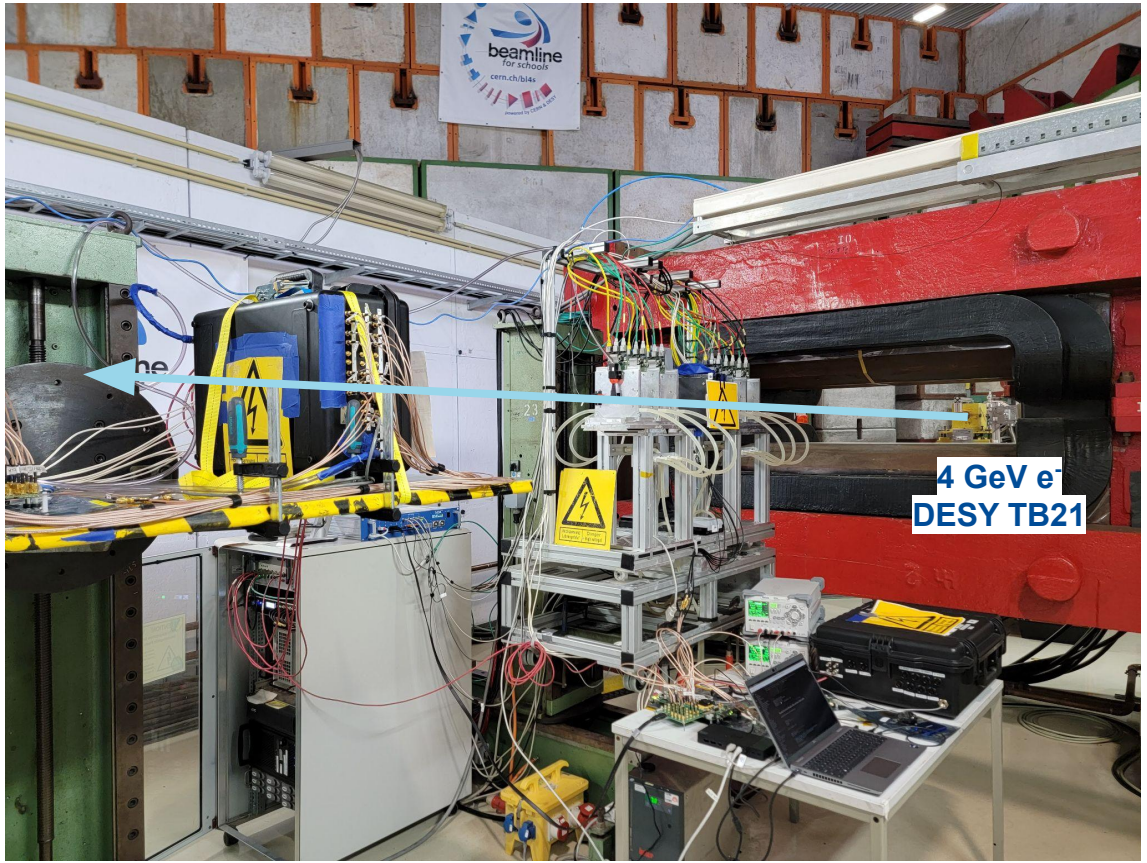
New extender card designed to allow for seamless operation with existing European test beam infrastructure

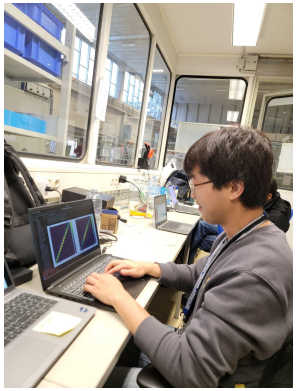
Couldn't be done without the help from Marcel, Adrian, Ralf, Lennart at DESY

ETROC2's second beam! DESY December 2023 Test beam









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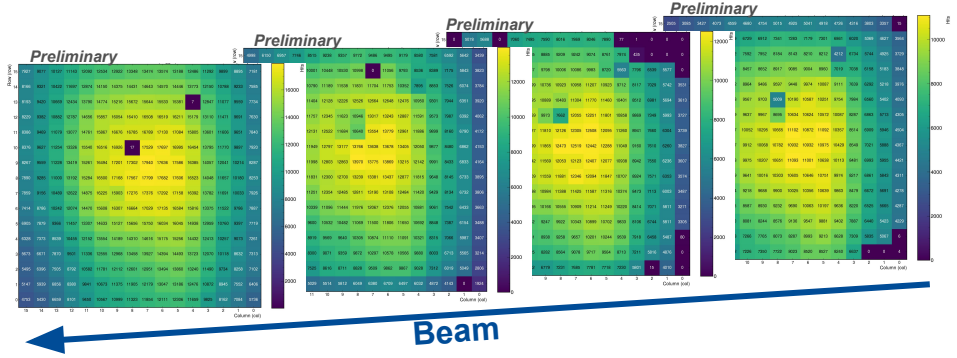
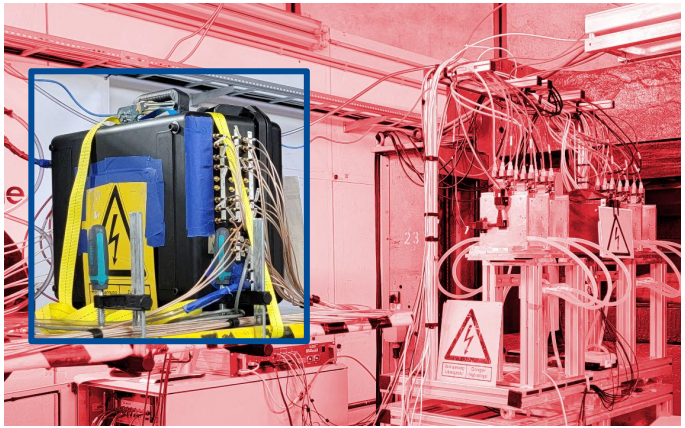
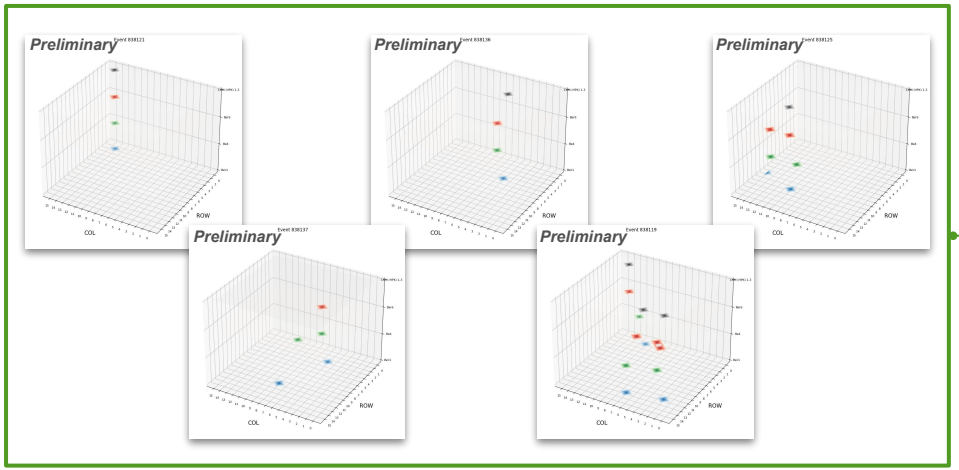
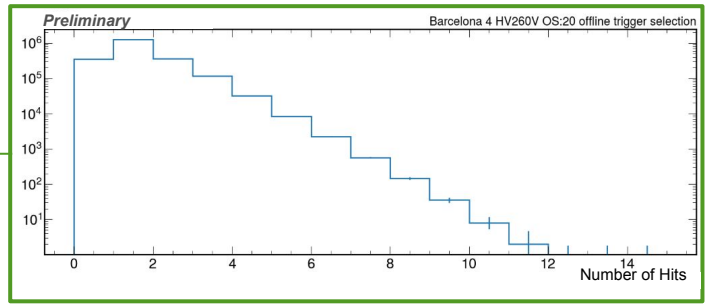
ETROC2 Telescope at DESY Dec 2023









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AIDA Integration at DESY Dec 2023

Precision tracking can enable careful study of timing performance across the pixels on ETL chips

Therefore integrating the ETROC telescope with AIDA is an important step in the characterization campaign

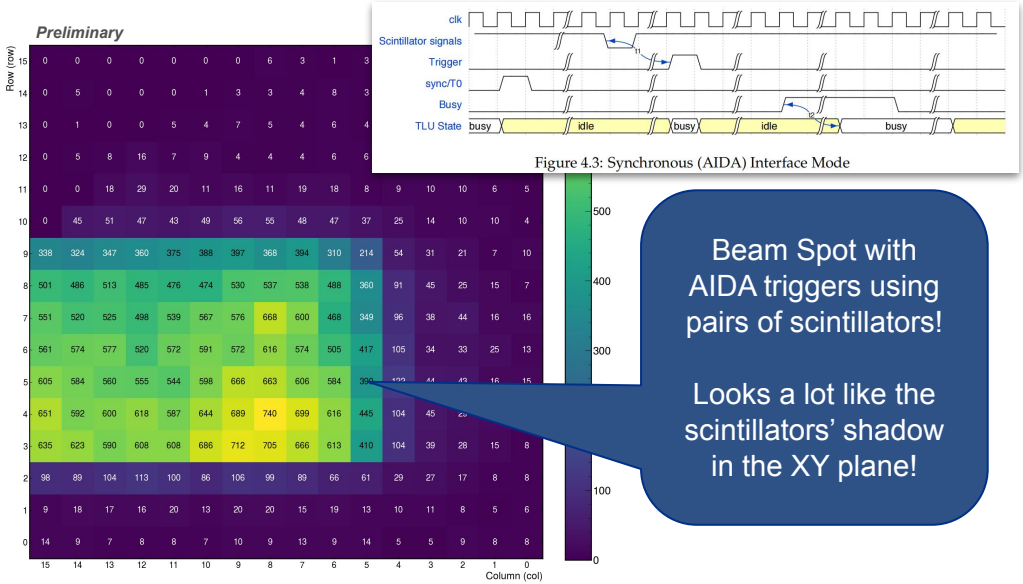
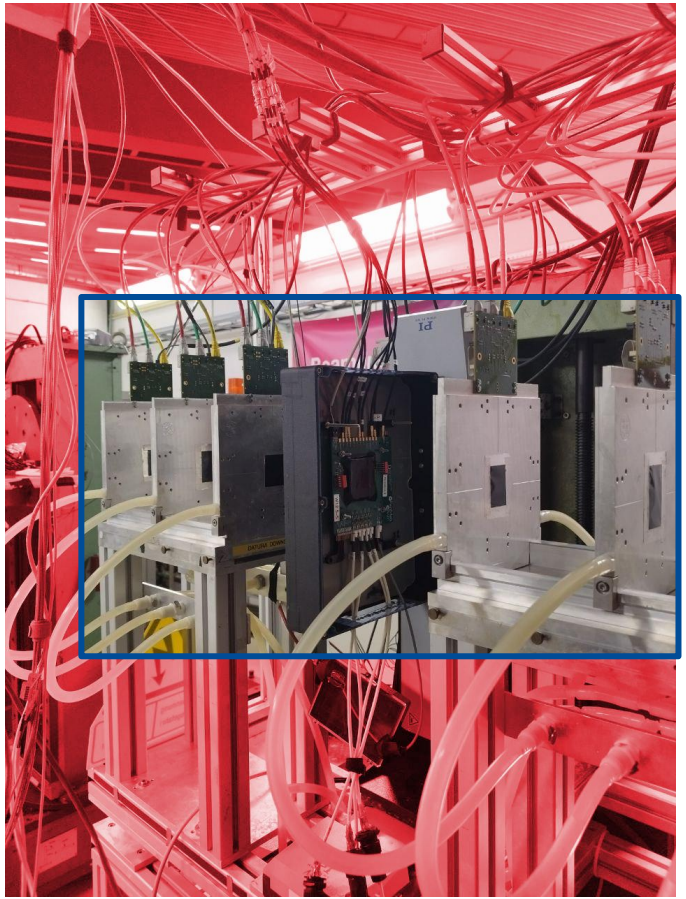


Figure 4.3: Synchronous (AIDA) Interface Mode

Beam Spot with AIDA triggers using pairs of scintillators!

Looks a lot like the scintillators' shadow in the XY plane!



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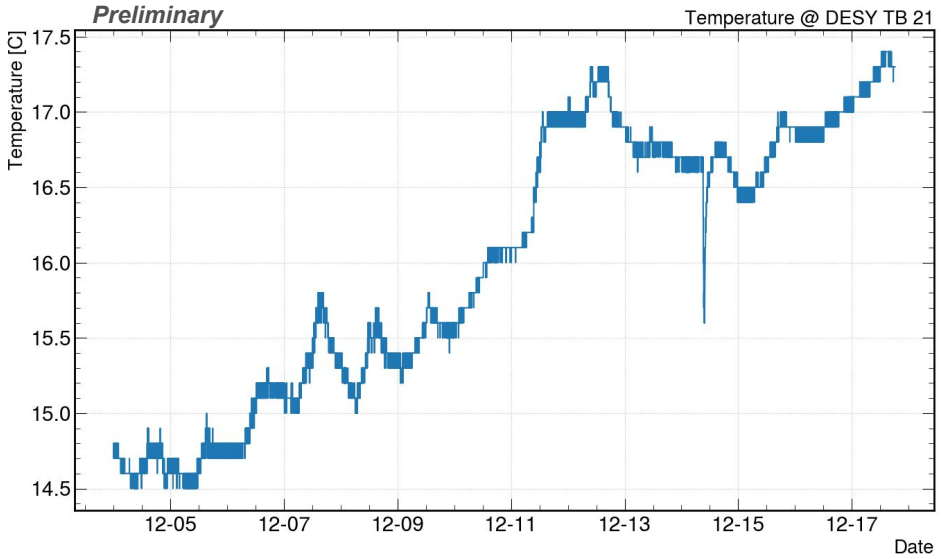
DESY Dec 2023: Temperature & Baseline Variations

Over the course of the 2 week campaign



Dry air circulation through the suitcase
No temperature control or probes inside the suitcase (Planned upgrade for the next test beam)

Important to analyse the data in appropriate bins to ensure Time Walk Correction (TWC) isn't trying to hit a moving target with floating temps & BL

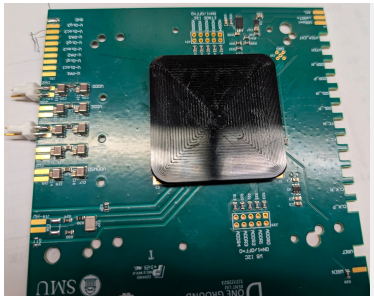
What's important for Test Beams?

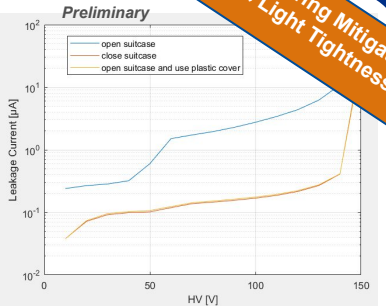
Lessons learned from the ETROC2 experience so far...

Monitor and Control Systematics!

Careful consideration of parameters that affect our chip's noise floor & timing performance is required

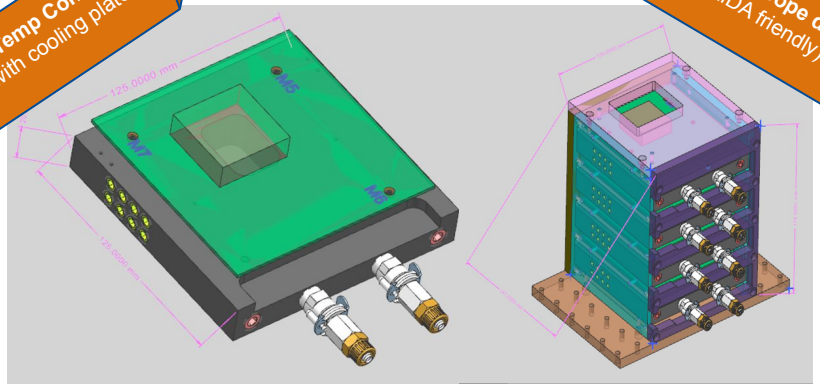
Scattering Mitigation & Light Tightness

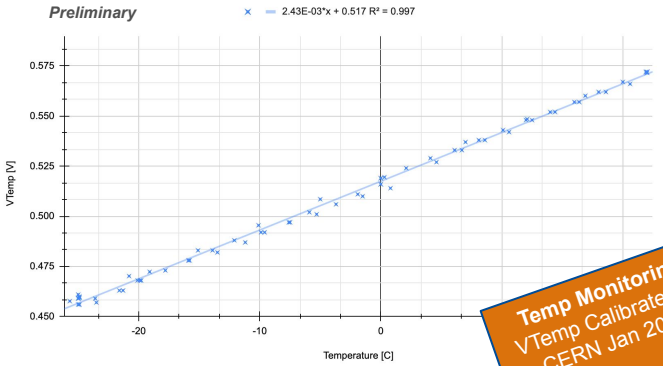




Temp Control with cooling plates

New telescope design (AIDA friendly)





Temp Monitoring VTemp Calibrated at CERN Jan 2024

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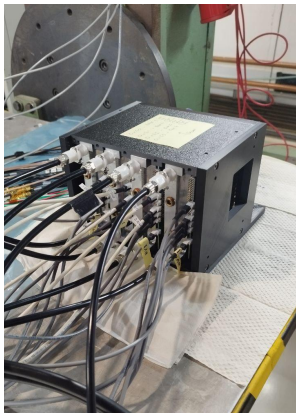
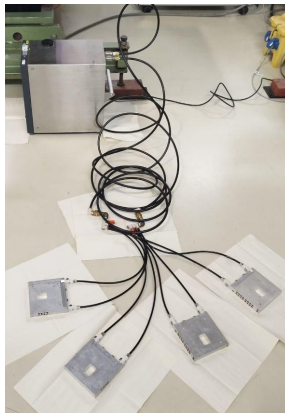
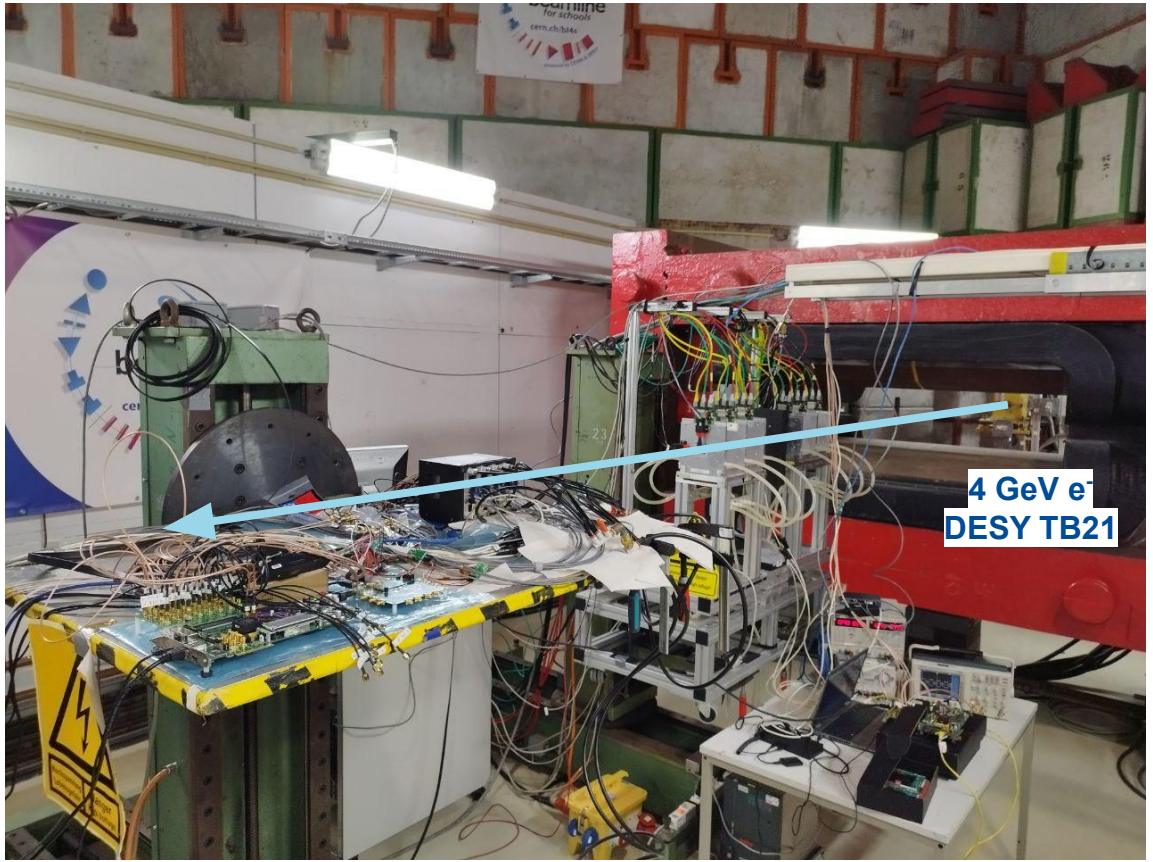
ETROC2's third beam! DESY February 2024 Test beam







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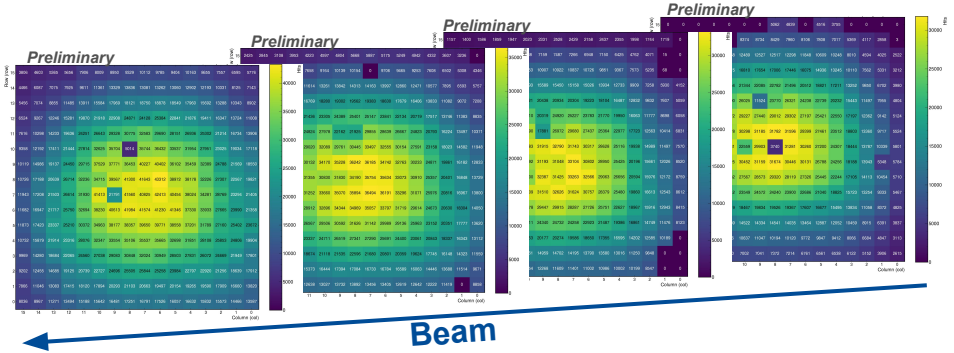
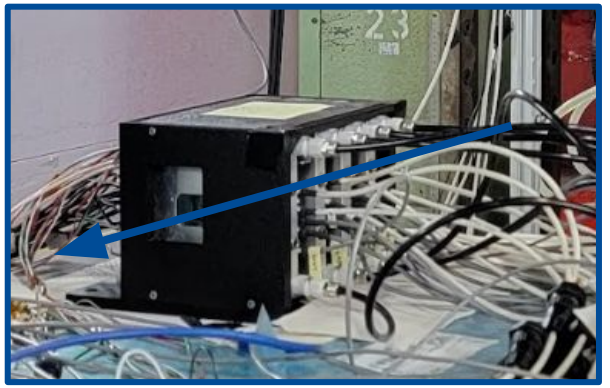
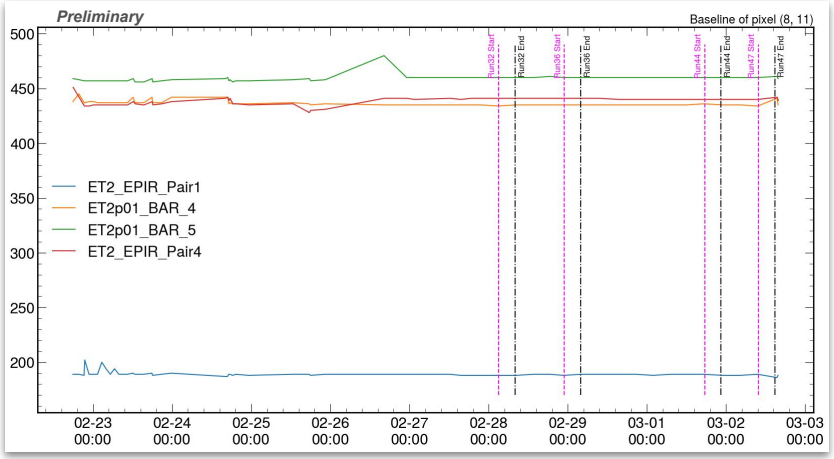
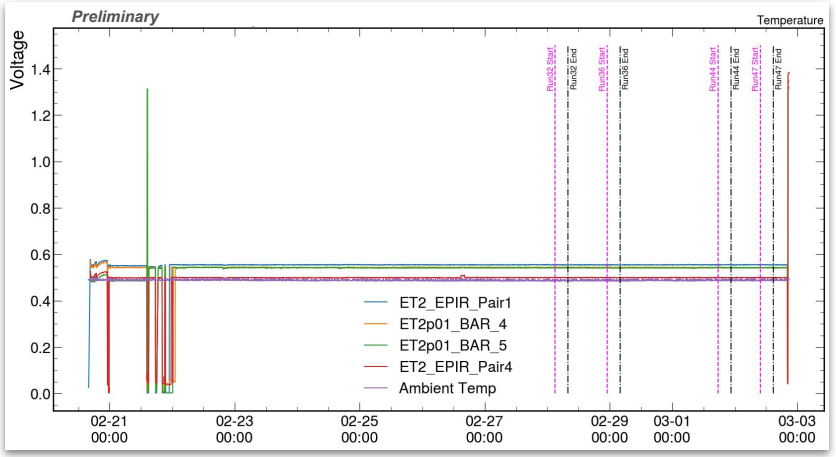
ETROC2 Telescope at DESY Feb 2024









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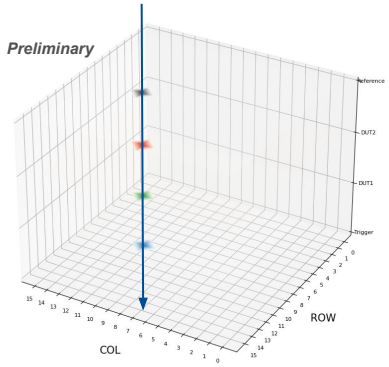
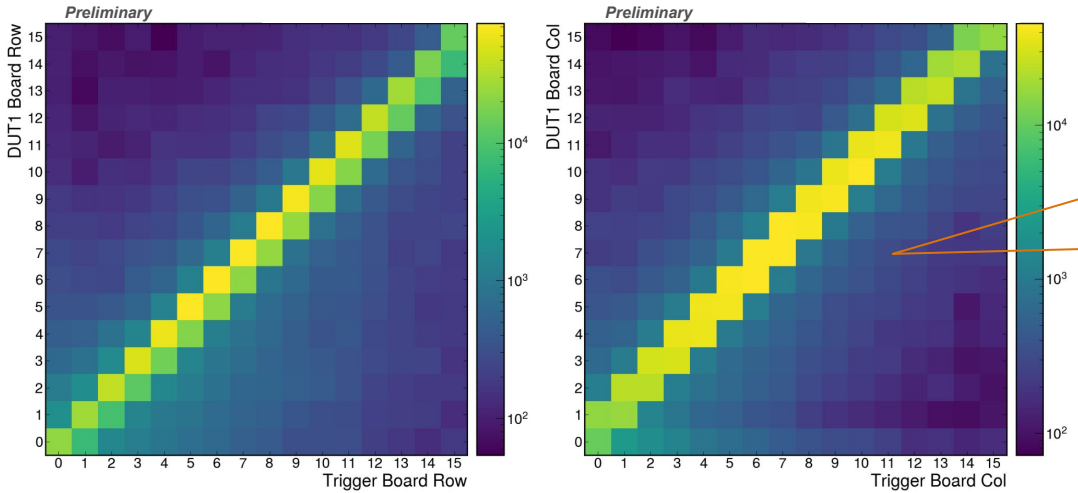
What's important for Test Beams?

Lessons learned from the ETROC2 experience so far...

Analysis with sufficient isolation of relevant effects!

Let's look at trajectory (Row 8, Col 11) across all the boards
Simple analysis enabled by the current telescope setup
Will improve with AIDA precision tracking!





Telescope alignment with the beam & between boards allows us to analyze **tracks defined by a fixed row and column**

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What's important for Test Beams?

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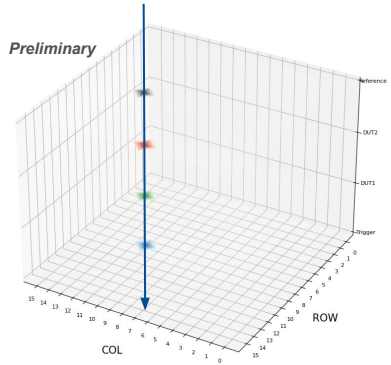
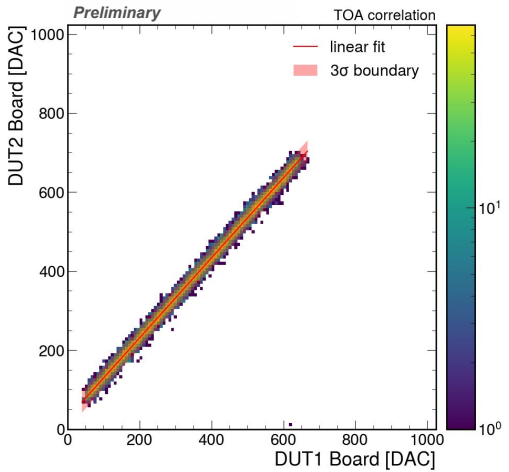
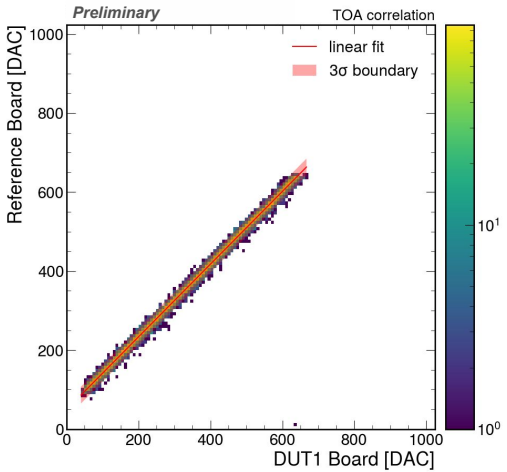
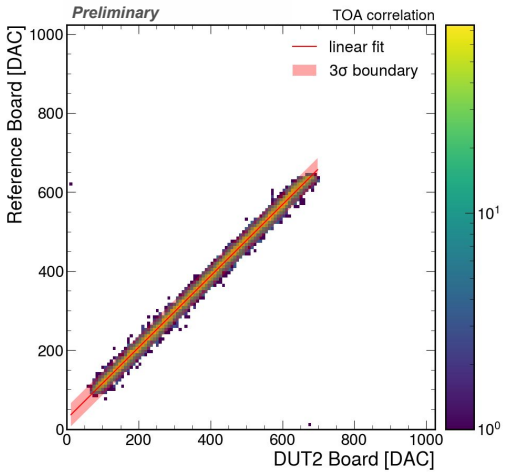
Analysis with sufficient isolation of relevant effects!

Let's look at trajectory (Row 8, Col 11) across all the boards
Simple analysis enabled by the current telescope setup
Tracks defined by hits on fixed row & column are highly correlated









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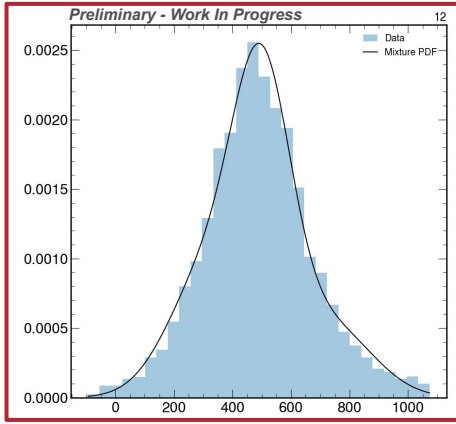
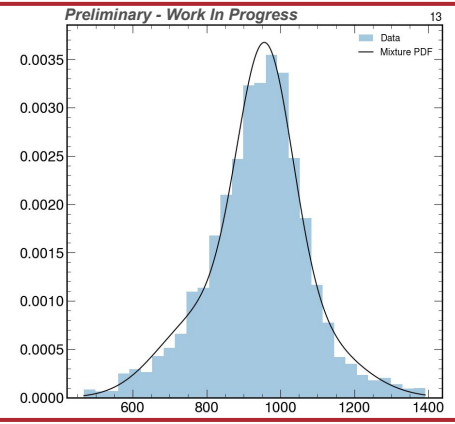
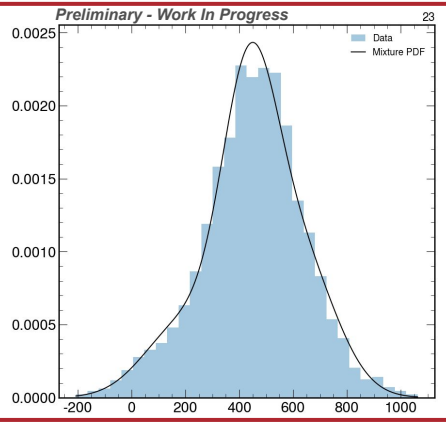
Let's look at an example track (Row 8, Col 11)

Work In Progress





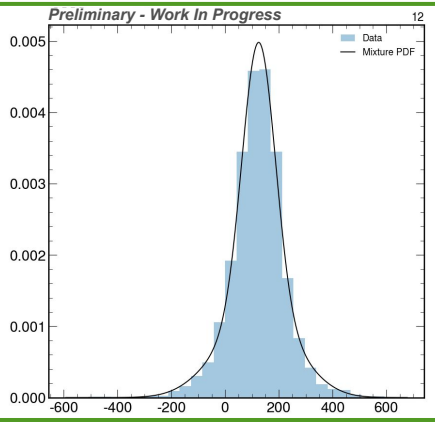


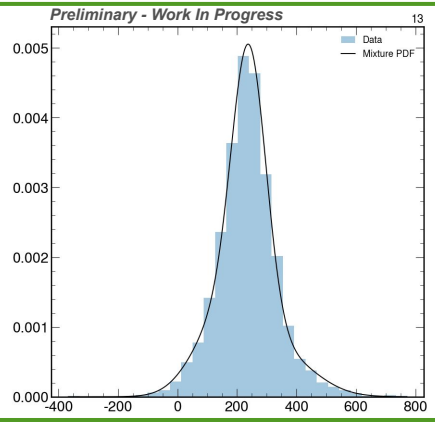
Raw Data
Pairwise ΔTOA [ps]
Before *time walk correction*

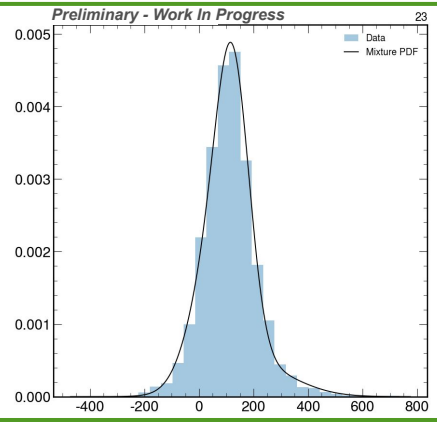
Smearing due to TOA-TOT dependence

Time walk correction
Leads to narrowing of Pairwise ΔTOA [ps]

TOA dependence on TOT is subtracted







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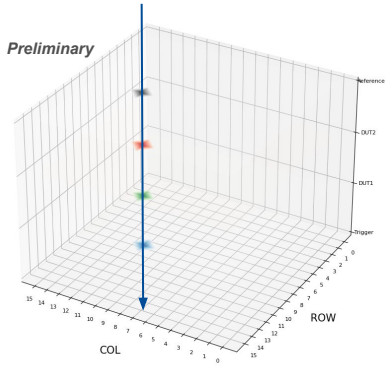
What's important for Test Beams?

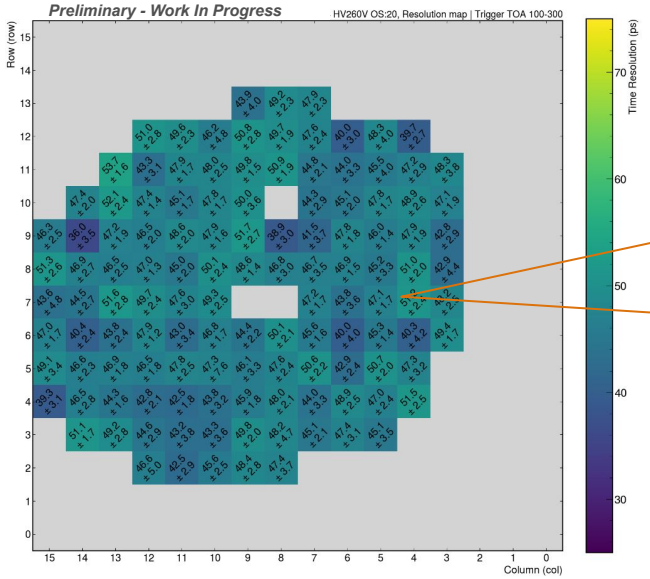
Lessons learned from the ETROC2 experience so far...

Work In Progress



Analysis with sufficient isolation of relevant effects!

Tracks defined by hits on fixed row & column are highly correlated
Procedure can be repeated for all pixels with enough statistics



Preliminary results on this DUT at a specific offset and gain

→ Resolution needs to be further disentangled from sensor & signal effects, and variations across pixels & boards

→ AIDA telescope will give us unique handle to study hits on parts of the pixels and study efficiency in detail

→ AIDA will let us study complex track topologies

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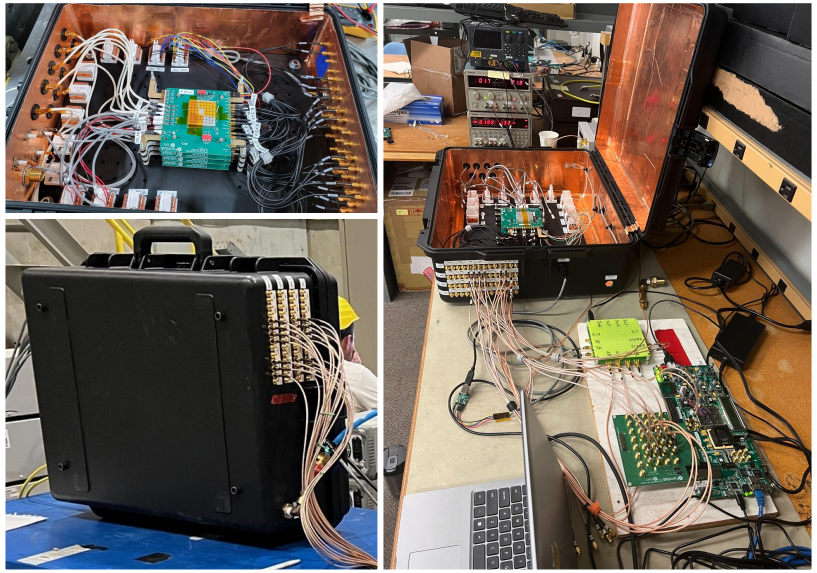
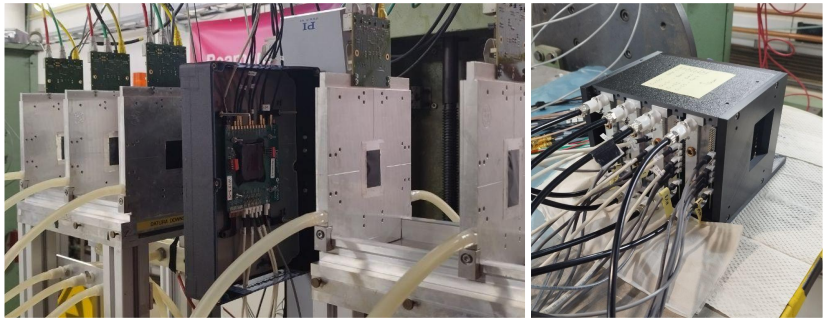
What's important for Test Beams?

Lessons learned from the ETROC2 experience so far...

- Preparation, Preparation, Preparation
- Iterate and Improve
- Monitor & Control Systematics
- Analysis with isolation of relevant effects

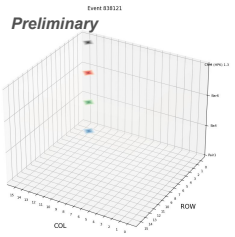
Start simple, follow the science...

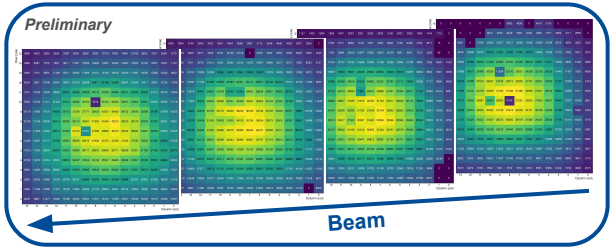




Summary

- Very fruitful start to ETROC2 testing campaign with some fantastic test beam time at CERN & DESY
  - Thanks for the critical support from CERN and DESY staff enabling this campaign
- ETROC2 chips demonstrate full functionality and good performance right off the bat!
- Building our handles on important effects and systematics to control for precision timing studies
- Calendar full of test beams, SEU tests, wafer yield tests, etc, so a lot more to come!





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Acknowledgments

- *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).*

- *The research leading to these results has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101057511.*

BACKUP

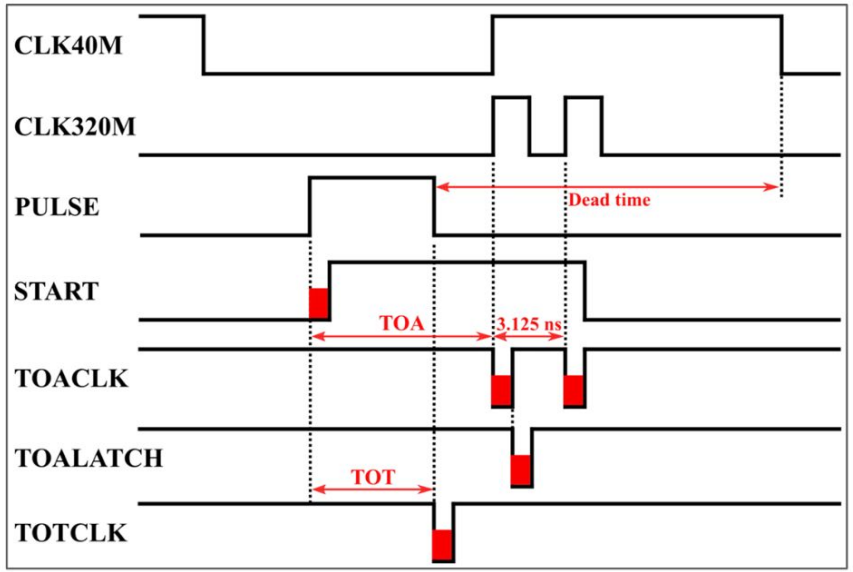
ETROC TDC

See Jongho's slides from BTTB11

- TDC requirements

	TOA bin	TOT bin	Power Consumption
Requirement	~30 ps	~100 ps	0.2 mW/pixel
Achieved	18 ps	36 ps	0.1 mW/pixel

- In-situ delay cell self-calibration technique
  - Record two timestamps using consecutive rising clock edges per hit within the known 320 MHz clock period (3.125 ns)
  - Bin size = 3.125 ns / calibration code
  - Calibration code is the difference between the two timestamps
- Important to reach the required precision using a tapped delay line with uncontrolled delay cells
- **Low power consumption** because of uncontrolled delay cells



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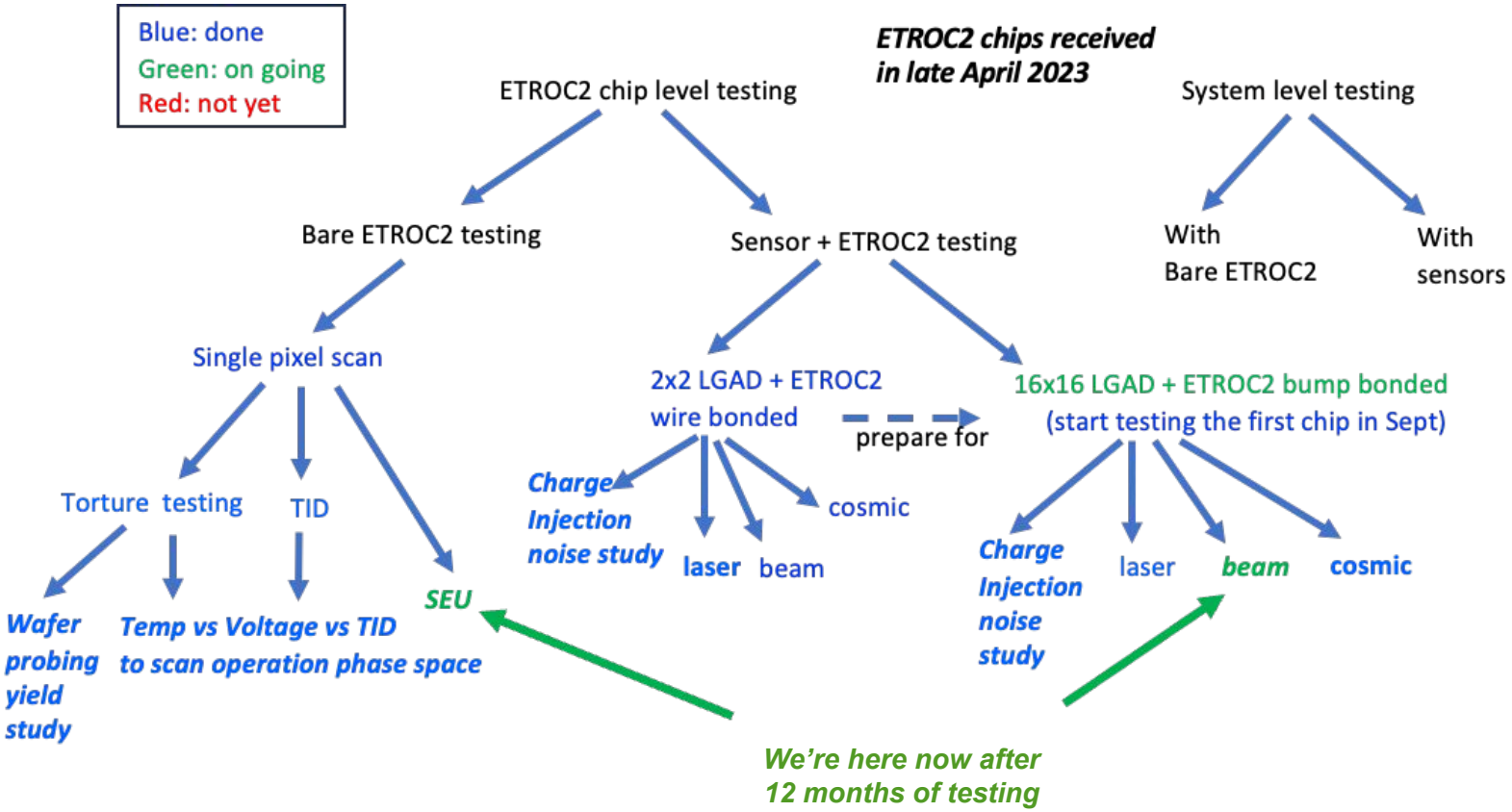
ETROC2 Testing



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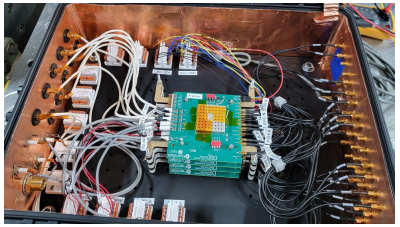
ETROC2 Telescope



What is it?

Fully self contained, self referential system for precision timing characterization of the **ETROC2 chips**

3+ chips with accompanying master **clock board** and **FPGA**

Flexibility to adapt to different **LV and HV supplies**

Modular suitcase makes the telescope portable for cosmics data taking and test beams at FNAL, CERN, DESY etc

Initial commissioning done at Sept CERN test beam

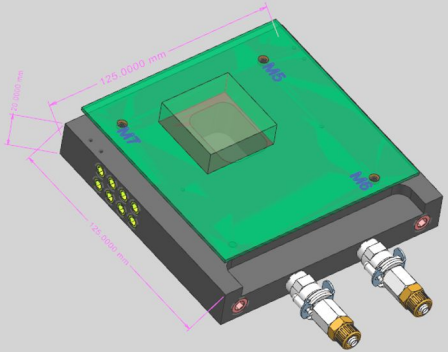
Similar to the ETROC1 telescope concept...

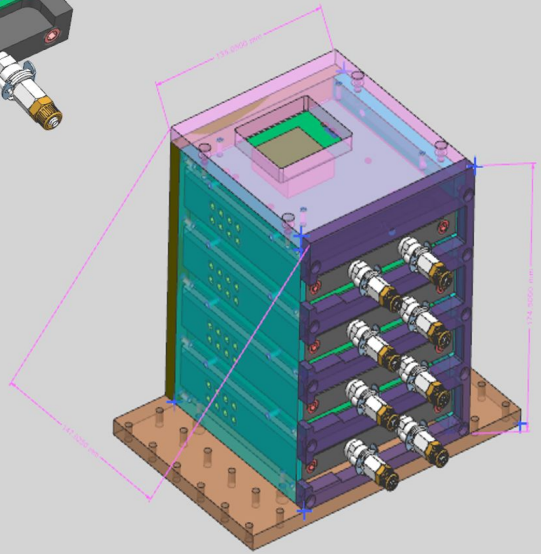
Changes made for DESY Feb 2024

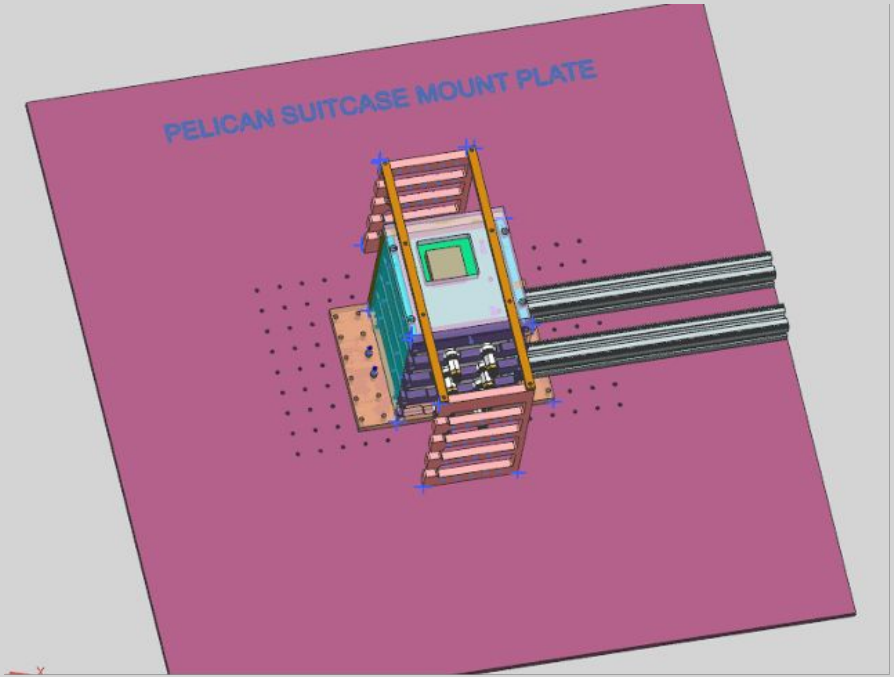
Temperature Control

Cold Blocks in 4 Slot Racks

courtesy of Abhishek Bakshi, Fermilab







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AIDA Integration
DESY December 2024 Test Beam

AIDA Integration - DESY Dec 2024

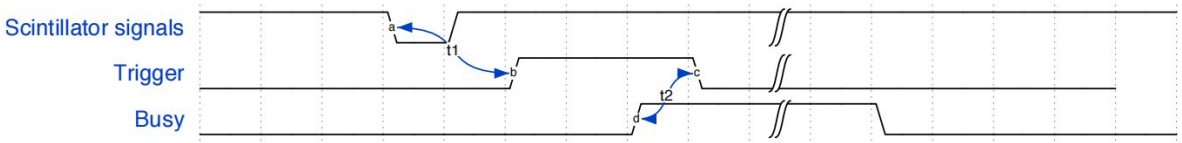

Figure 4.1: Trigger/Busy Interface Mode Timing

- Start with the simpler asynchronous mode that allows for DUT on independent clock
- Objective was to accept the TLU trigger signal over the HDMI interface and issue L1As to the ETROC2 chip
- Requires basic handshaking as it applies to the Busy signal
- Need to determine the latency of the TLU trigger wrt the local hit
    - Done with modifying L1A Delay or finding TLU Trigger - Hit overlap in FPGA

→ **Success!**

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AIDA Integration - DESY Dec 2024

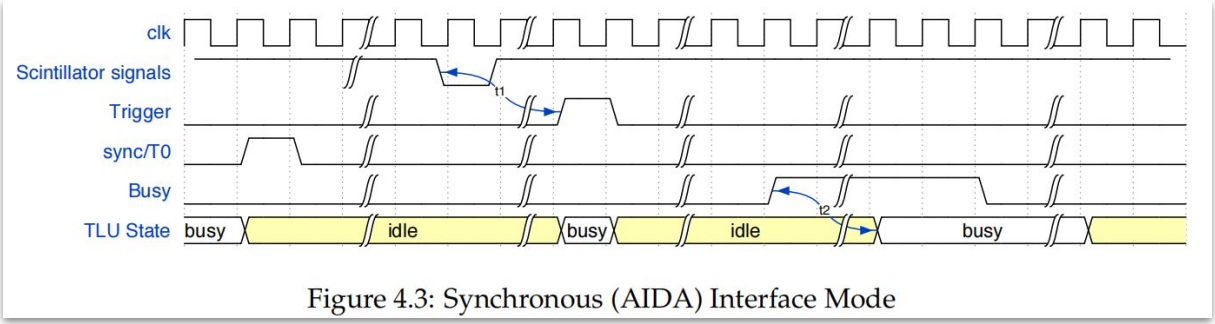

Figure 4.3: Synchronous (AIDA) Interface Mode

- AIDA Mode requires DUT to share the TLU clock
- Trigger is only asserted for one clock cycle - simplifies latency determination
    - Overlap found exactly!

→ **Success!**

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DESY Feb 2024 Test Beam

Time Walk Correction Procedure

Assumes 3 board telescope setup

1. Evaluate TOA and TOT in [ns] using the following equations

T_{bin}	3.125 / mean(CAL [code])	[ns / DAC]
TOA	12.5 - (TOA [code] x T_{bin})	[ns]
TOT	(2 x TOT [code] - floor(TOT [code] / 32)) x T_{bin}	[ns]

2. Construct the ΔTOA_i observables as $\Delta TOA_i = (TOA_j + TOA_k)/2 - TOA_i$
3. Time walk correct each ΔTOA_i using the TOT_i and a polynomial fit ***f*** (typically cubic)
4. Compute the resulting time walk corrected $TOA_i = TOA_i + f(TOT_i)$
5. Construct pairwise $T_{ij} = TOA_i - TOA_j$ and extract widths σ_{ij}
6. **Reported time resolution $\sigma_i = 1/\sqrt{2} \times \sqrt{(\sigma_{ij}^2 + \sigma_{ik}^2 - \sigma_{jk}^2)}$**