LHC-ATLAS Run3実験に向けた液体アルゴンカロリメータの新型トリガー読み出しシステムのコミッショニング

Commissioning of New Trigger Readout System of Liquid Argon Calorimeter towards the LHC-ATLAS Run3 Experiment

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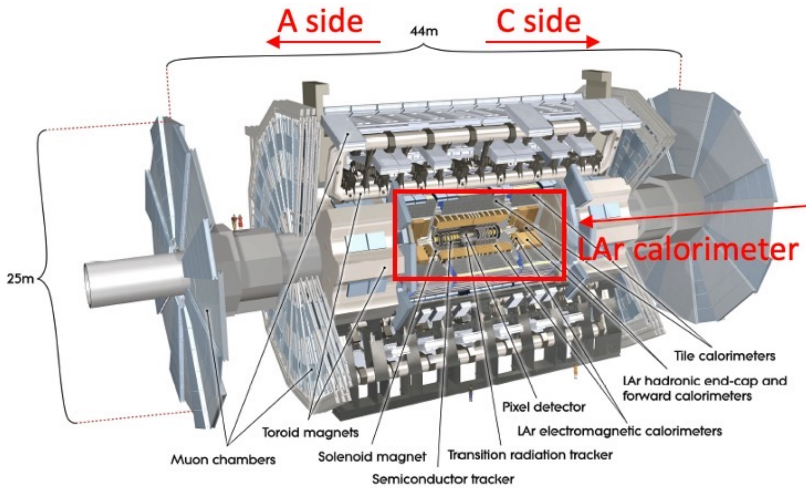
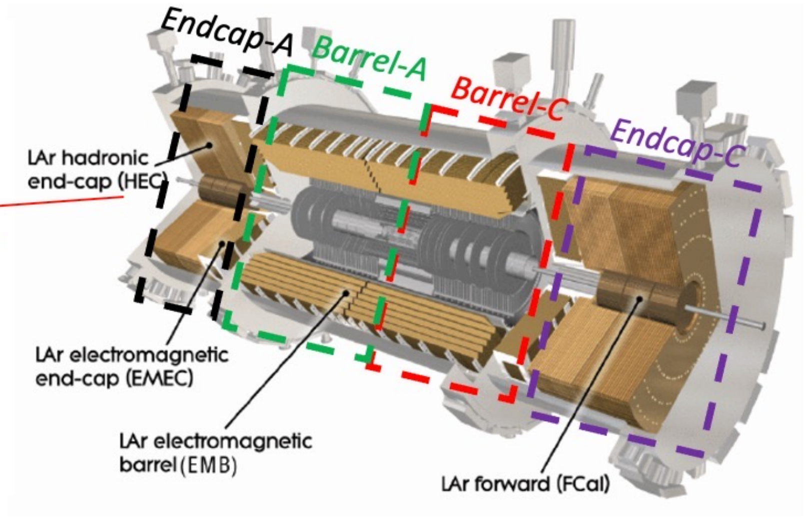
LHC-ATLAS experiment and phase-I upgrade

- Liquid Argon (LAr) Calorimeter
  - Cover the wide range $0 < |\eta| < 4.9$.
  - Provide information for level-1 trigger system.

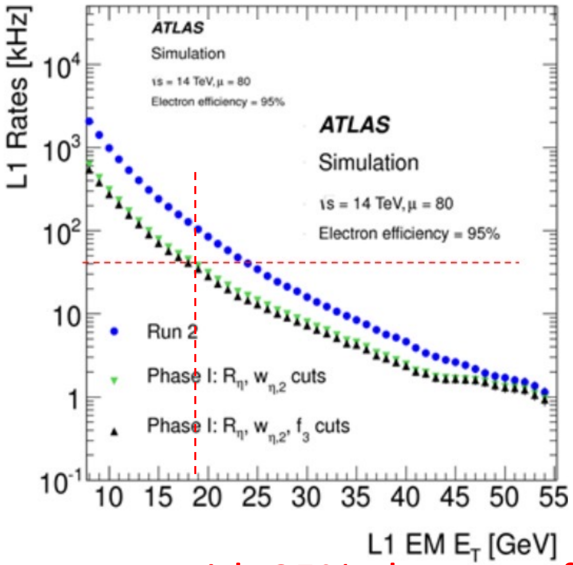




- Level-1 Trigger system
  - Used for reduce the event rate from 40 MHz to 100 kHz.
  - Use information from both calorimeters and muon detector.

- Phase-I upgrade is performed in the second long shutdown (LS2) from 2019 to 2021.

- Run 3 is scheduled to start in April 2022 at the peak instantaneous luminosity of $3\times10^{34}cm^{-2}s^{-1}$ and the c.m. energy $\sqrt{s} = 13.6$ TeV



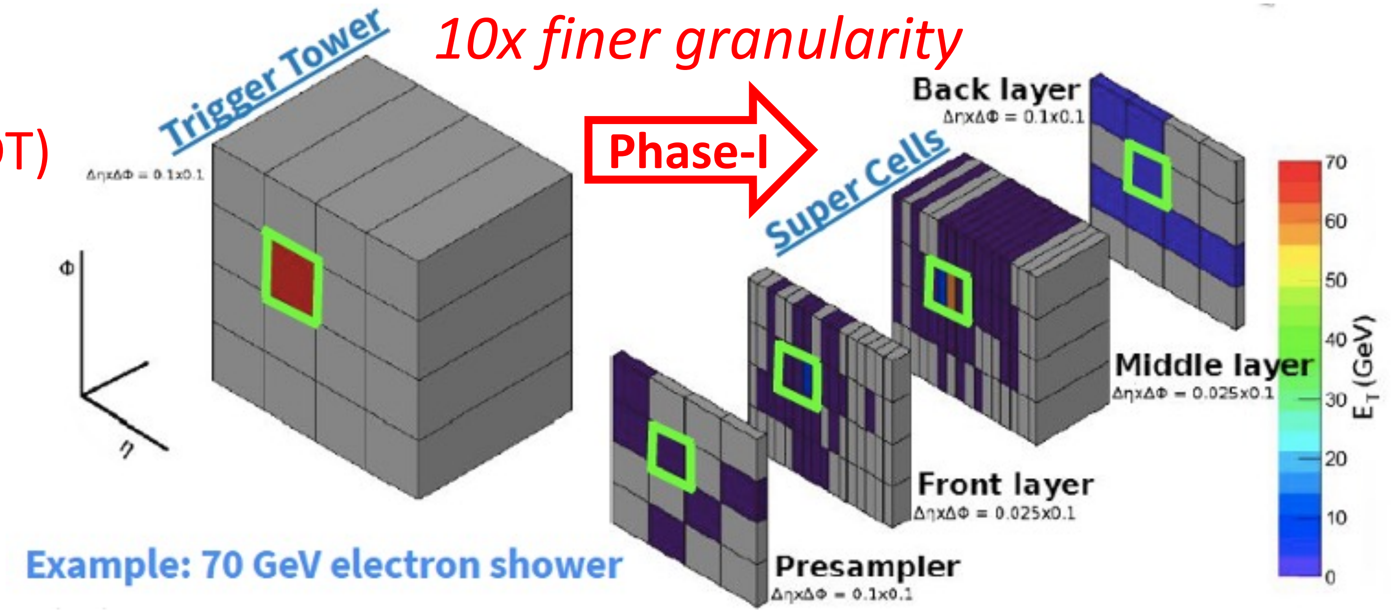
Lower events rate with 95% electron efficiency!

LAr phase-I upgrade – new readout system

- New readout system called digital trigger (DT) readout is raised for Run-3.

- The new readout cell, Super Cell (SC) with better granularity and multi-layer structure, are used for the L1 trigger system instead of legacy trigger tower.

10x finer granularity



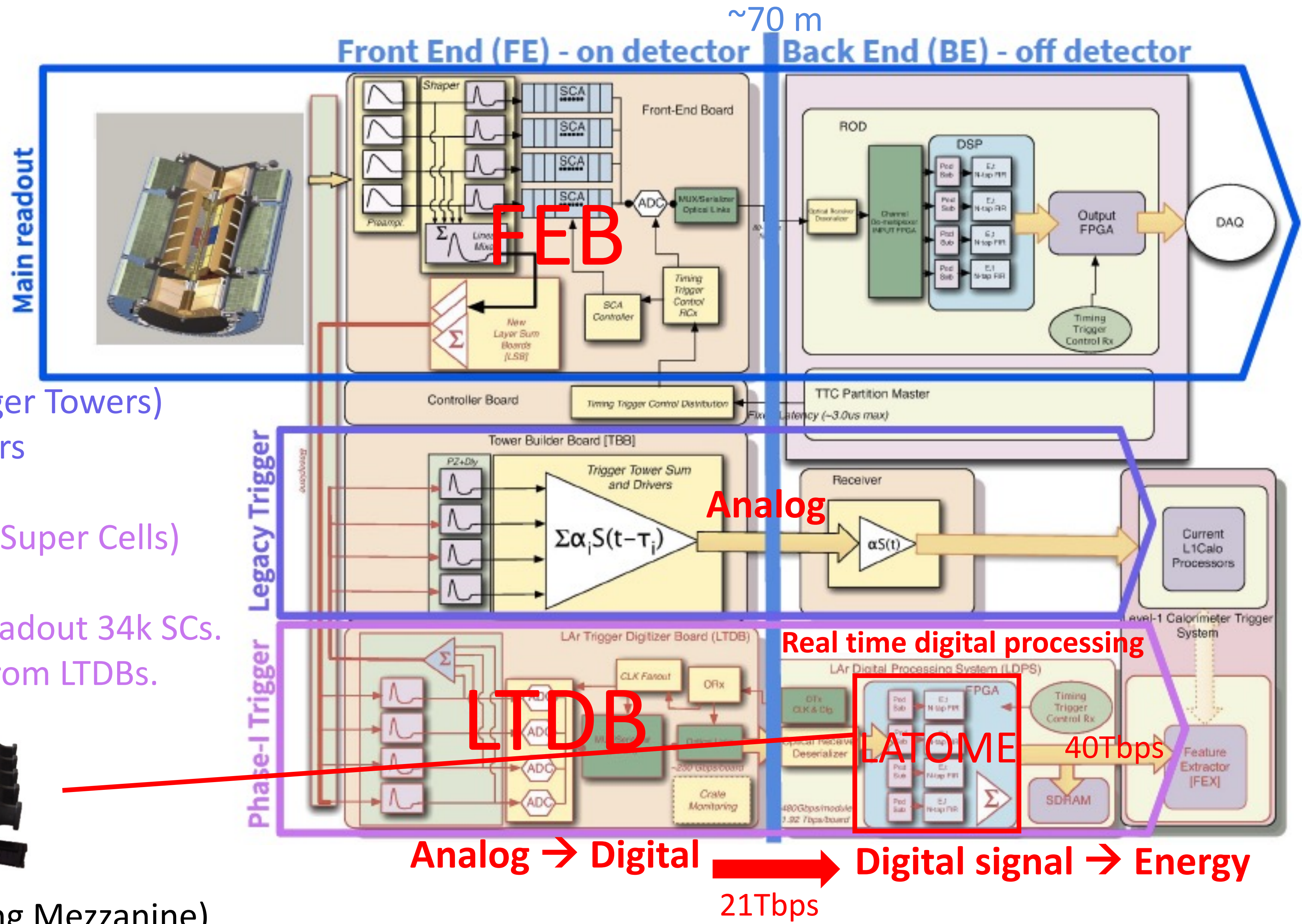
	layer	Elementary Cell	trigger tower		Super Cell	
		$\Delta\eta \times \Delta\phi$	$n_\eta \times n_\phi$	$\Delta\eta \times \Delta\phi$	$n_\eta \times n_\phi$	$\Delta\eta \times \Delta\phi$
0	presampler	0.025×0.1	4×1	0.1×0.1	4×1	0.1×0.1
1	front	0.003125×0.1	32×1		8×1	0.025×0.1
2	middle	0.025×0.025	4×4		1×4	0.025×0.1
3	back	0.05×0.025	2×4		2×4	0.1×0.1

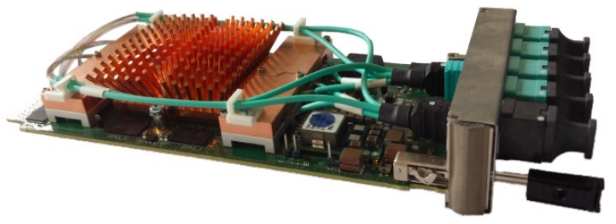
Granularity of the trigger tower and super cell

Readout paths

- Main readout path
  - FE: FEB→ calibration boards
  - BE: RODs
- Legacy trigger readout (Trigger Towers)

  FEBs → TBBs → L1Calo receivers
- New digital trigger readout (Super Cells)
  - FEB → LTDB → LDPS→ FEX
  - 124 LTDBs are equipped to readout 34k SCs.
  - 116 LATOMEs recieves data from LTDBs.

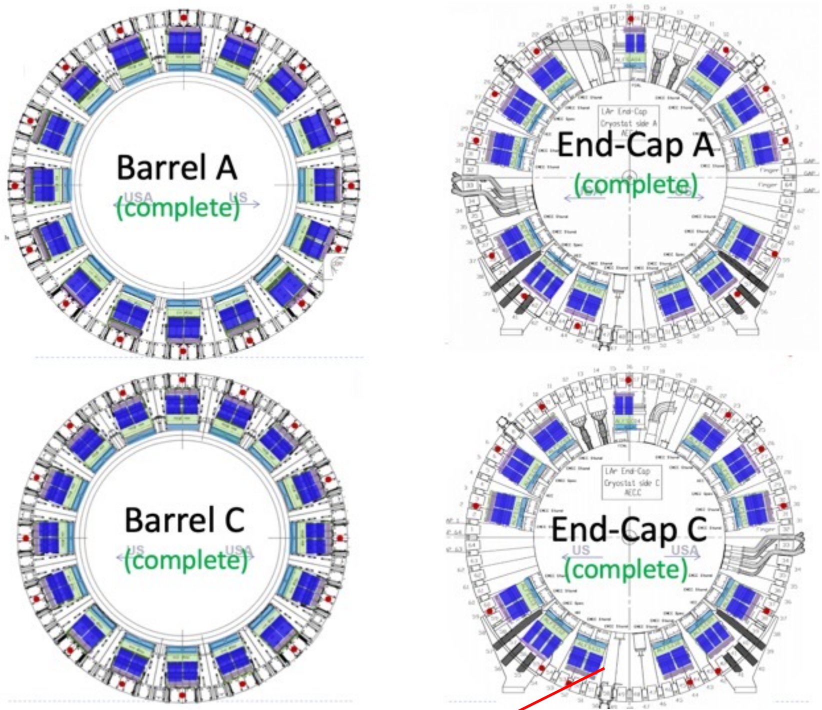


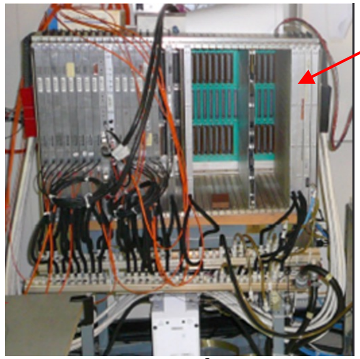


LATOME(LAr Trigger Processing Mezzanine)

FE and BE Installation

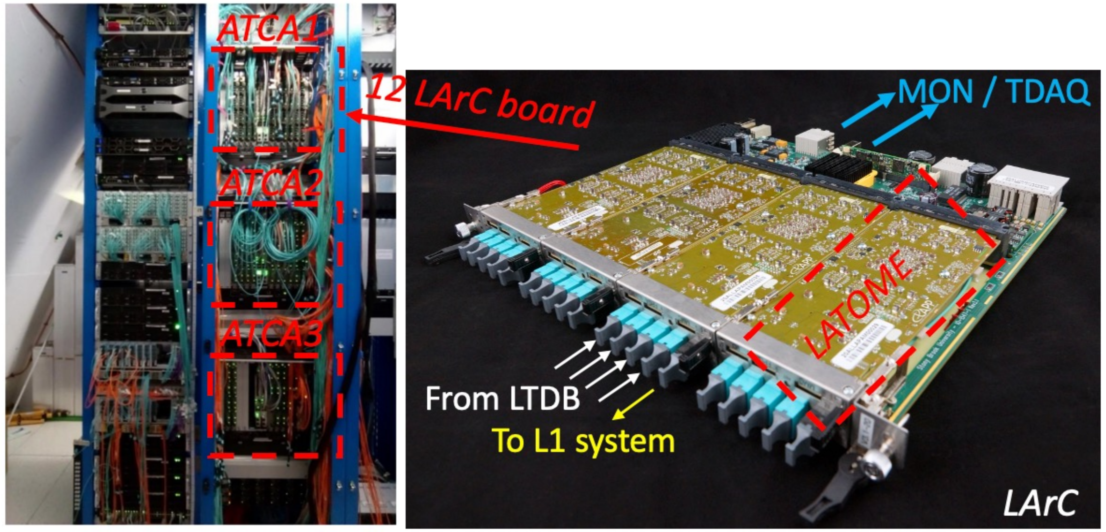
Installation started in Jan. 2019.





Front-end crate

- BE installation (LATOME-LTDB connections)
  - Installed at USA-15 counting room.
  - 3 Advanced Telecom Computer Architecture (ATCA) are used to support 30 LAr Carrier (LArC) with 116 LATOMEs in all.
  - ATCA1 → done
  - ATCA2 → done
  - ATCA3 → done



- FE installation
  1) Base plane exchange. -> done
  2) FEB re-installation. -> done
  3) 124 LTDBs installation. -> done
  4) Cooling hose replacement. -> done

All installation completed in Sep. 2021!

Research content

- Purpose: Issue the triggers in an appropriate state with the new trigger readouts system.
- What are the **basic requirements** for issuing the trigger?

We need to know…

Where: the position information of the signal

↓

When: the signal is from which bunch crossing

↓

What: the energy and pulse phase of the signal

Research content

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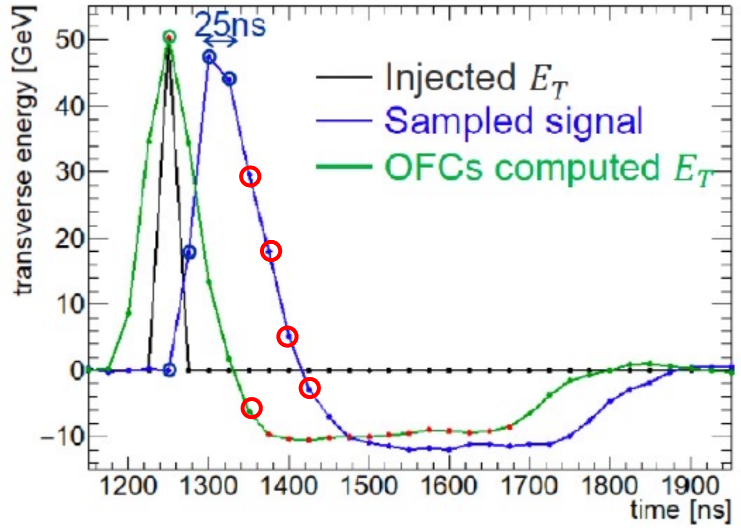
↓

What: the energy E_T and pulse phase τ of the signal

Energy reconstruction of 50 GeV inject pulse



- The Energy and pulse phase reconstructed by optimal filtering algorithm in Back-End:

$$E_T = \sum_{i=0}^{3} a_i(S_i - p) \qquad E_T\tau = \sum_{i=0}^{3} b_i(S_i - p)$$

a_i, b_i – optimal filtering coeffient (OFC)

Research content

- Purpose: Issue the triggers in an appropriate state with the new trigger readouts system.
- What are the **basic requirements** for issuing the trigger?

We need to know…

What we need to do…

Where: the position information of the signal → Check the mapping between channels of LATOMEs at the Back-End and SCs on the detector.

When: the signal is from which bunch crossing → Fix the new system latency to have a stable sampling phase for the injected pulse.

What: the energy E_T and pulse phase τ of the signal → Calibrate the OFCs used for energy and pulse phase reconstruction.

Research content

- Purpose: Issue the triggers in an appropriate state with the new trigger readouts system.
- What are the **basic requirements** for issuing the trigger?

We need to know…

What we need to do…

Where: the position information of the signal → Check the mapping between channels of LATOMEs at the Back-End and SCs on the detector.

⇒ perform by SSW scan **(Research 1)**

↓

When: the signal is from which bunch crossing → Fix the new system latency to have a stable sampling phase for the injected pulse.

⇒ perform by BCID calibration **(Research 2)**

↓

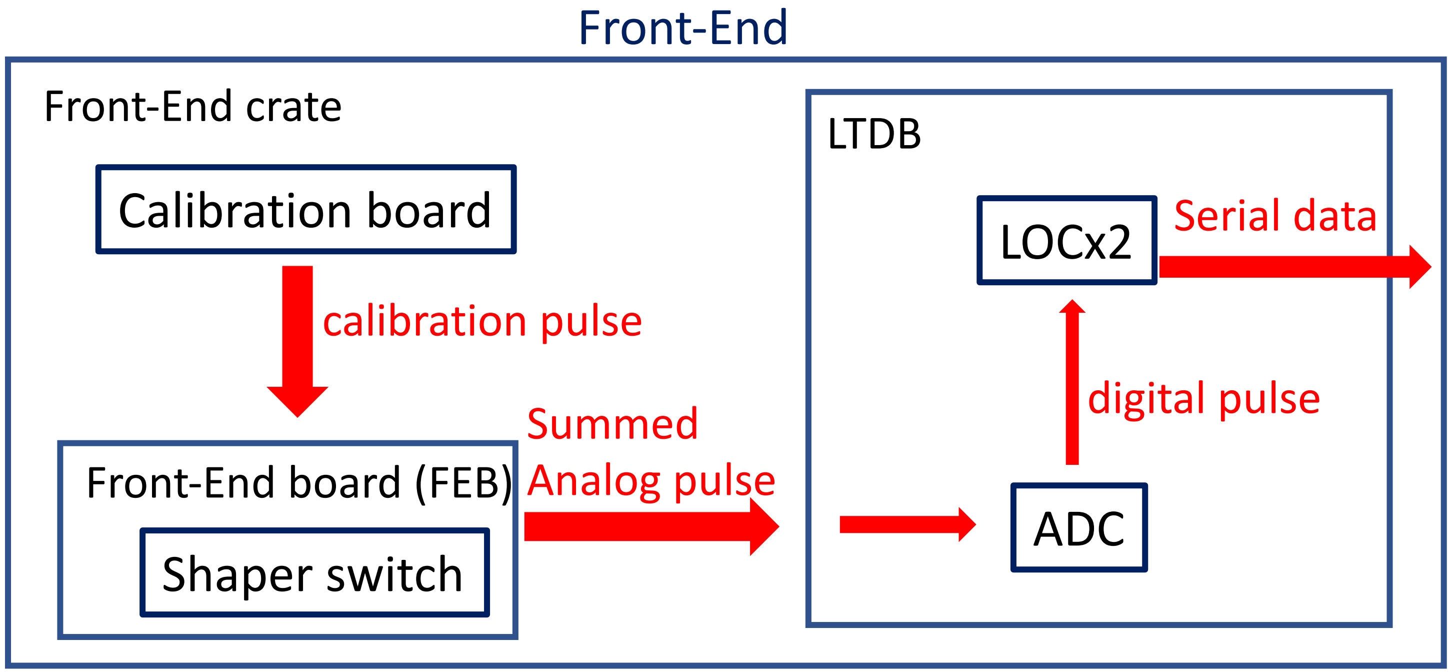
What: the energy E_T and pulse phase τ of the signal → Calibrate the OFCs used for energy and pulse phase reconstruction.

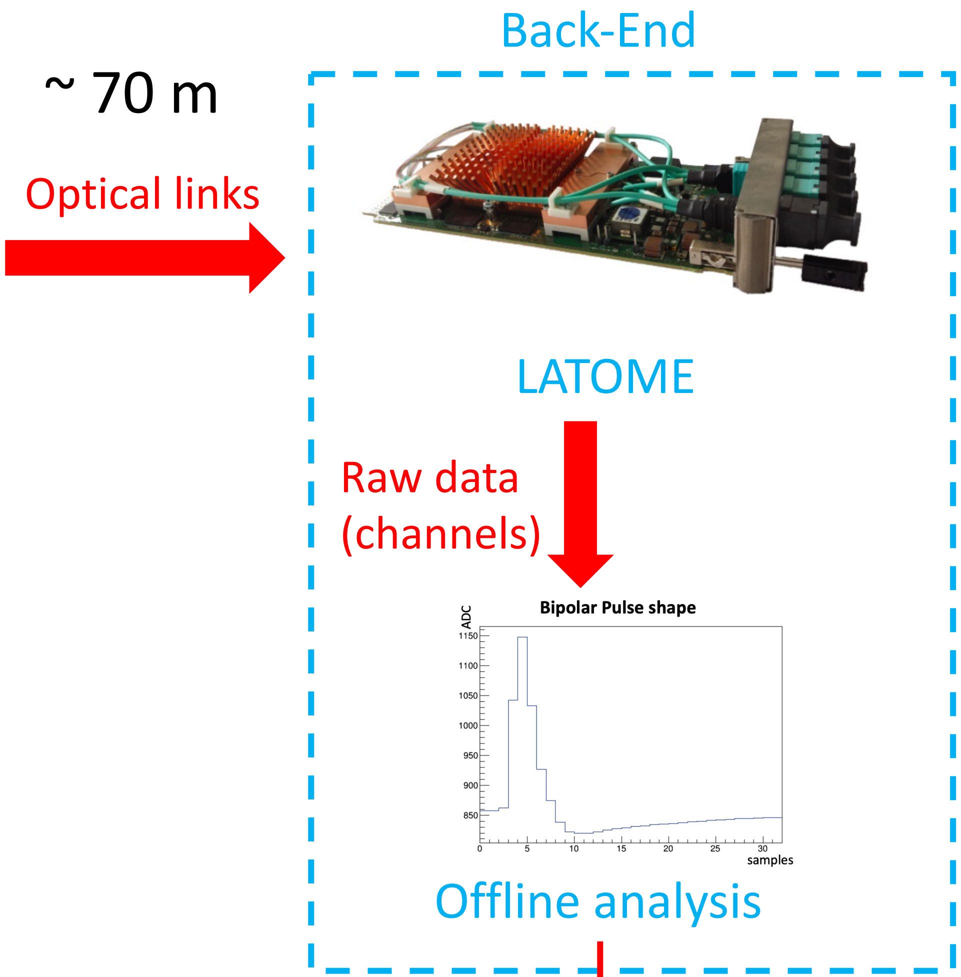
⇒ perform by calibration run

Research 1: Connectivity check

Purpose: Provide the correct mapping information of all SCs from detector to Back-End.

Connectivity check – motivation





- Potential mapping issue:
  1) Channel swap in the detector's electrode and FEB.
  2) Fiber routing problem. (including in the LTDB)
  3) LATOME remapping functionality problem.

- Validation methods:
  - **Use pulses of the calibration board.**

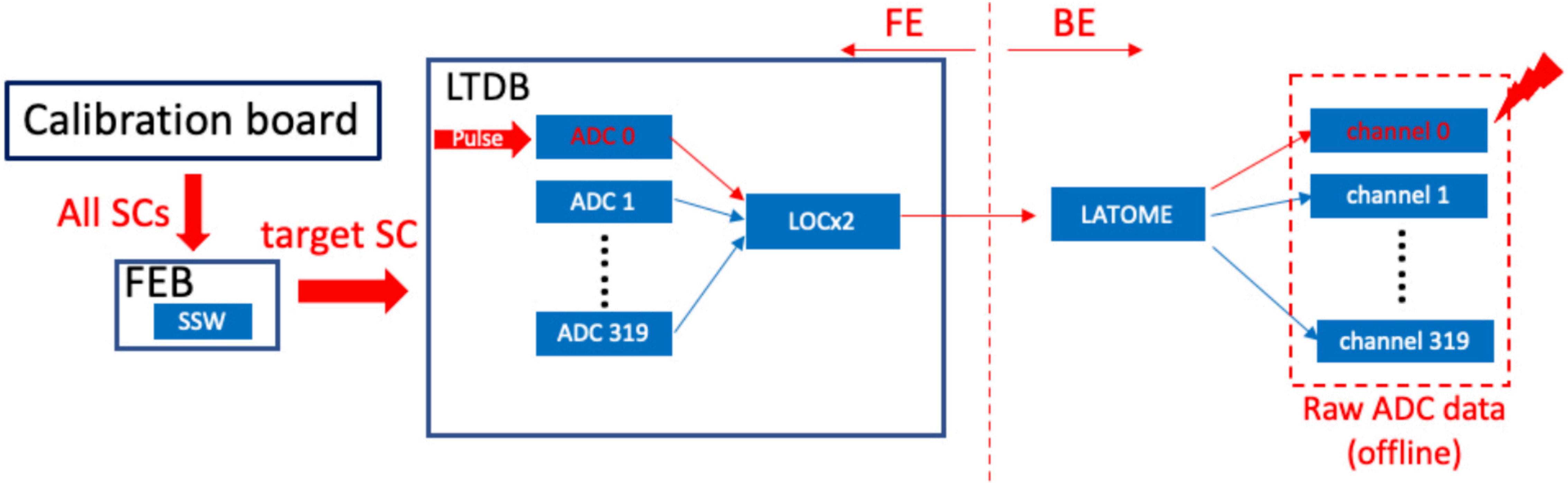
Check raw adc data to find the potential mapping issue.

→ *Shaper Switch (SSW) scan!*

Connectivity check – validation method (SSW scan)

- Workflow of SSW scan (LTDB by LTDB):

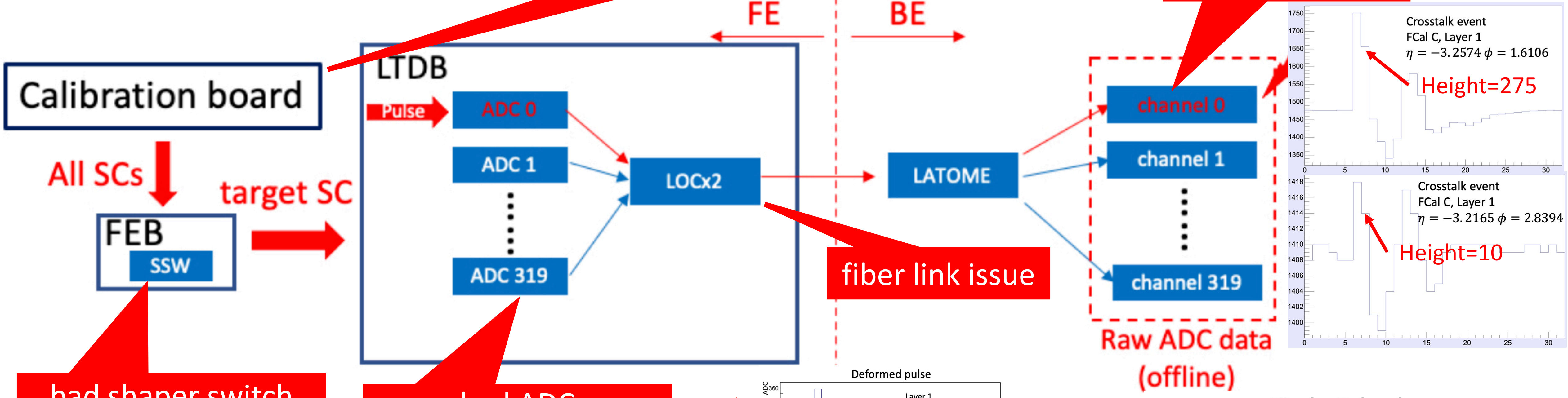
Send pulse to all SCs (up to 320) and control the shaper chip on FEB to switch on the target SC.

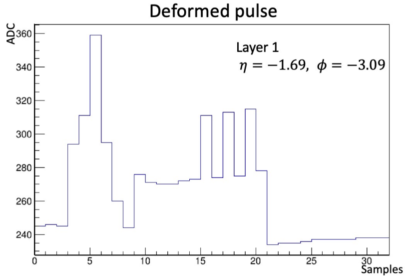


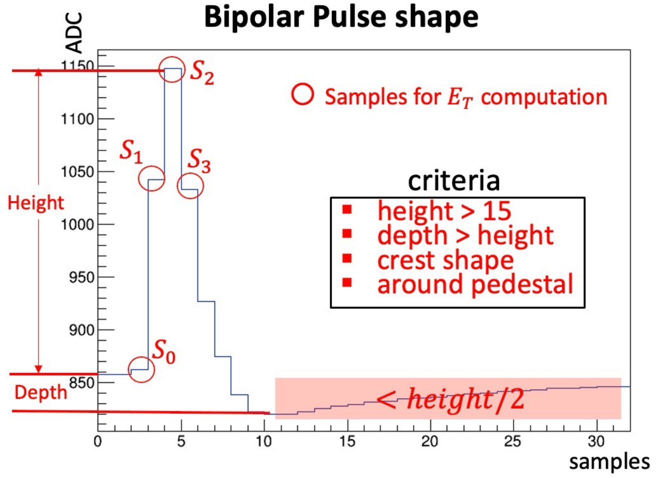
Pulse pattern: All channels → channel 0 → channel 1 …(repeat for all channels on the LTDB)

Connectivity check – troubleshooting

- Potential issues in SSW scan:



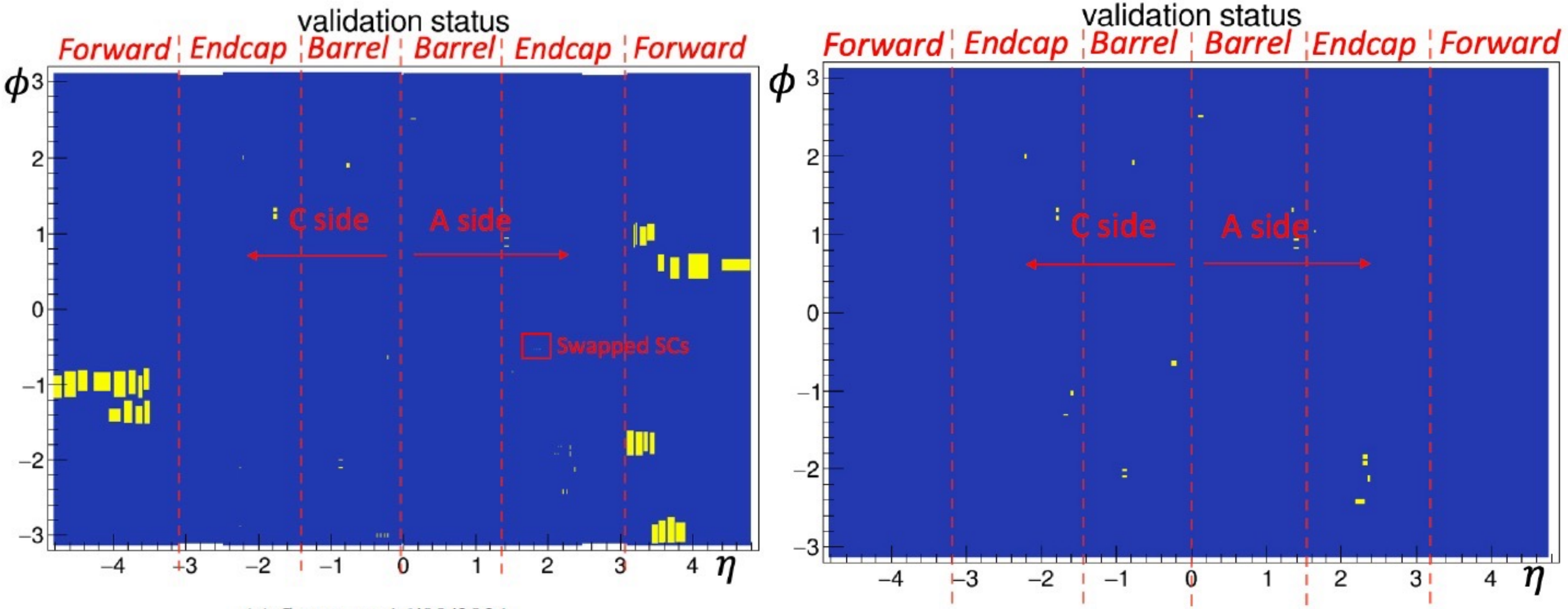




- I have developed specific algorithm using criteria on the right side to identify the problematic channels caused by above issues.

Connectivity check – auto-processing system and results

- I have developed a robust tool for this connectivity check using SSW scan.
- The tool has been implemented to the LAr calibration system so that anyone can use it.
  - 99.9% of the 34048 SCs have been validated. (Blue)
  - 1348 swapped channels found and fixed. (Green)
  - 42 problematic channels with above issue are left to be fixed. (Yellow)



(a) Status on 16/09/2021.

(b) Status on 29/12/2021.

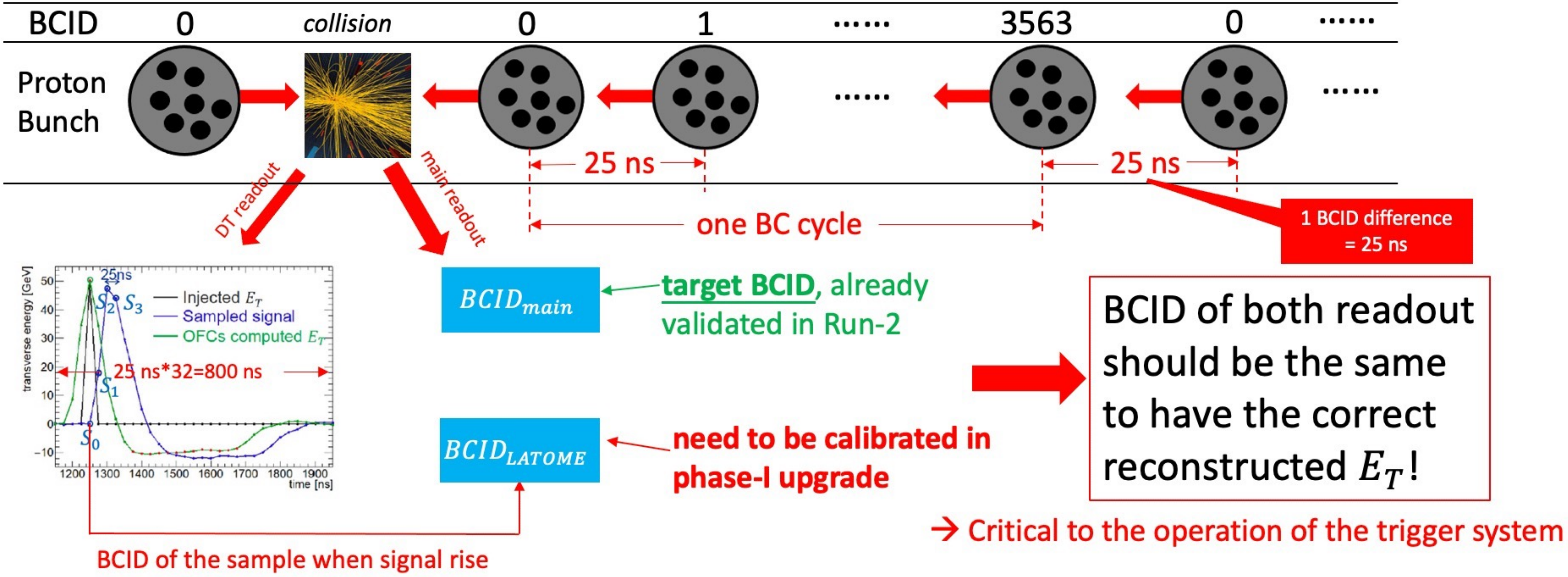
Connectivity check for SCs with SSW scan has been all completed!

Research 2: BCID calibration

Purpose: Adjust the timing of the new Digit Trigger readout.

BCID calibration – motivation

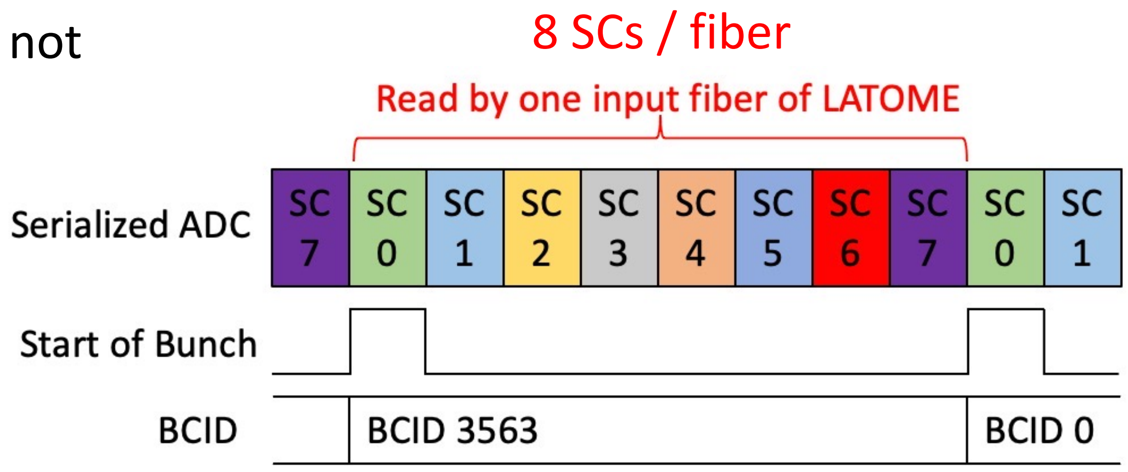
- The BCID of the pulse determines the timing of signal incidence.
- Bunch-crossing identification (BCID) in main readout and DT readout :

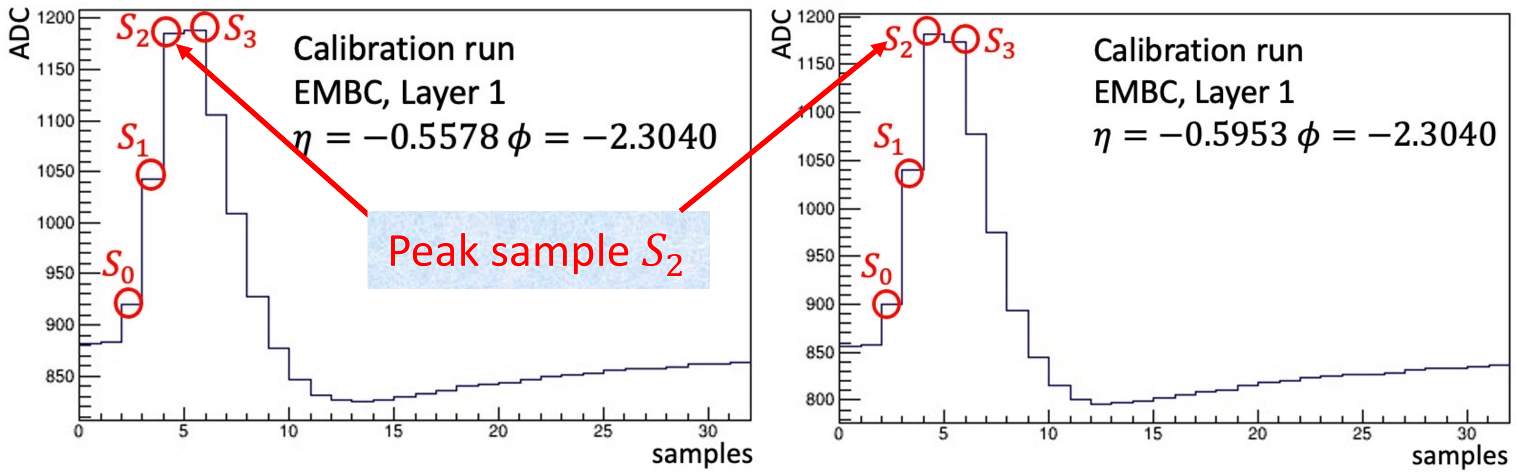


- To obtain the timing difference between both readout: $BCID_{offset} = BCID_{LATOME} - BCID_{main}$

BCID calibration – calibration method

- Calibration objective: Set $BCID_{offset}$ of all fibers to 0.
- Workflow of calibaration
  - The tuning is done fiber by fiber (1 fiber holds up to 8 SCs), not SC by SC. The BCID of SCs on the same fiber may have a difference of ± 1 BC.
  - 4458 output fibers of 116 LATOMEs to be set.
- In order to have a stable result
  - Compute the $BCID_{offset}$ after taking average samples.
  - If the difference between the samples near the crest is within height/10, the previous sample is taken as the peak.

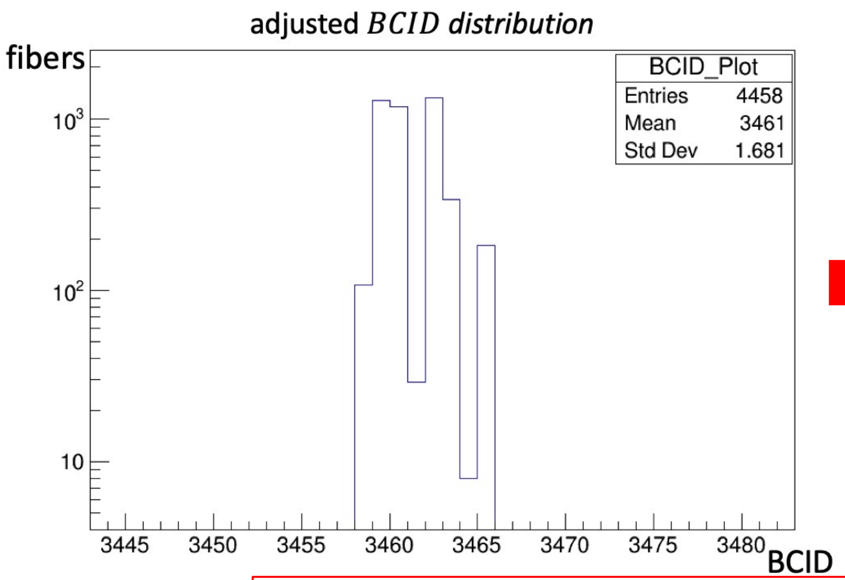




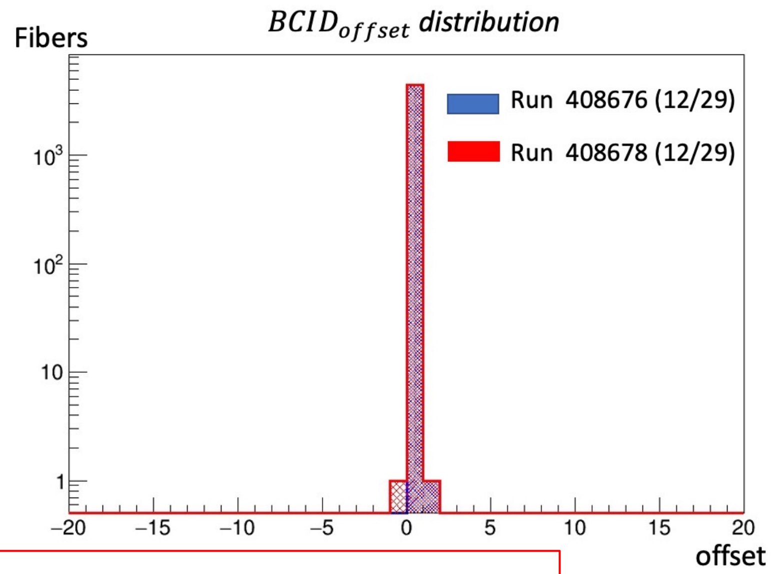
SCs on the same fiber

BCID calibration – results

- Runs with all SCs pulsed after calibration
  - Two runs obtained on the same day were used to test the stability of the results.
  - $BCID_{offset}$ of almost all fibers are set to 0. **Latency fixed**.
  - The results of calibration are the same for two runs. **Stability checked**.



$BCID_{offset}$ of calibrated fibers



BCID calibration for SCs has been all completed.
The pulse timing of DT readout is aligned with main readout!

Conclusion

- Research 1
  - Connectivity verification framework has been developed. All LTDBs have been checked. 1348 swapped channels are fixed and 42 problematic channels are remained to be fixed.

- Research 2
  - Development of the tool for Timing calibration have done.
  - BCID calibration for SCs are all complete in December 2021. The pulse timing of DT readout is aligned with main readout.
  - Currently developing tools that can monitor the stability of pulsing timing.

- Liquid Argon EM Calorimeter Phase-1 upgrade has been completed. Only fine tuning for the system is remained towards the Run-3 in April 2022.

Thanks for your attention!

BACK UP

Closest calorimeters

- EMB
- EMEC
- HEC
- FCal

In three cryostats

Using liquid argon(LAr)

- Linear behaviour
- Stability
- Radiation-hardness

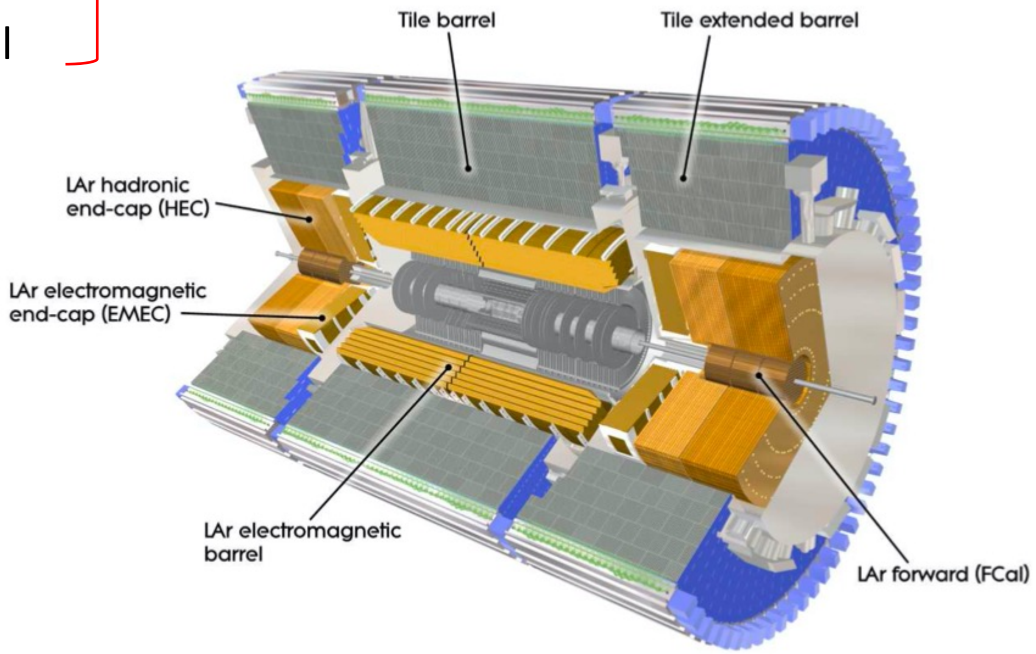
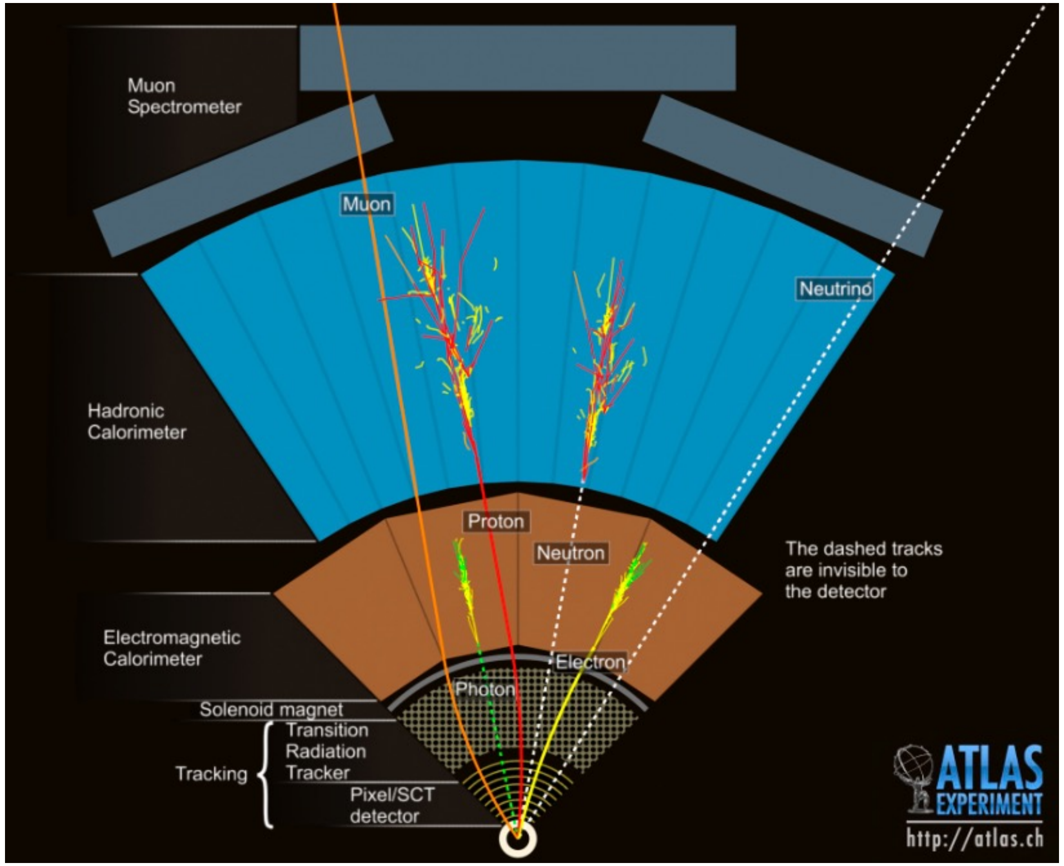
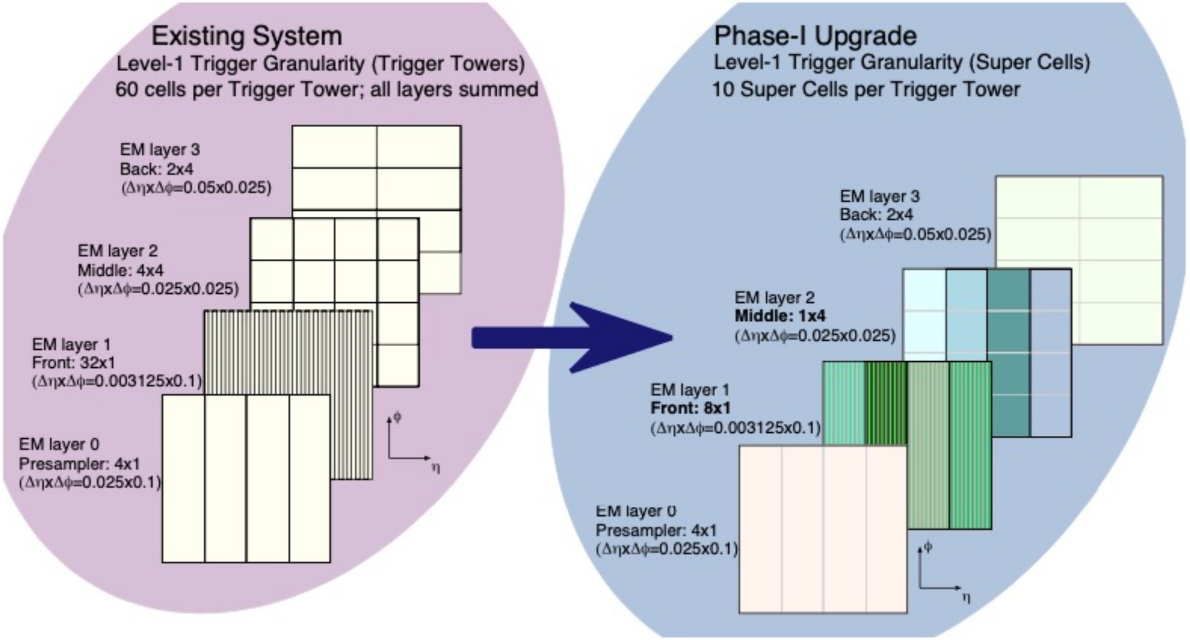


Figure 1.3: Cut-away view of the ATLAS calorimeter system.



The precision EM calorimeter

- Accordion structure with several layers
- Three in precision region ($0 < |\eta| < 2.5$)
- Two in the higher eta region($2.5 < |\eta| < 3.2$) and overlap region between EMB and EMEC
- FCal provide the EM coverage at $3.1 < |\eta| < 4.9$
- One more presampler layer in the region $0 < |\eta| < 1.8$ to measure energy loss in front of the EM calorimeters.



LAr phase-I upgrade – Back-End firmware

- LATOME modules:

➢ Low-level interface: implement all the FPGA device Ips configured in the Quartus tools.

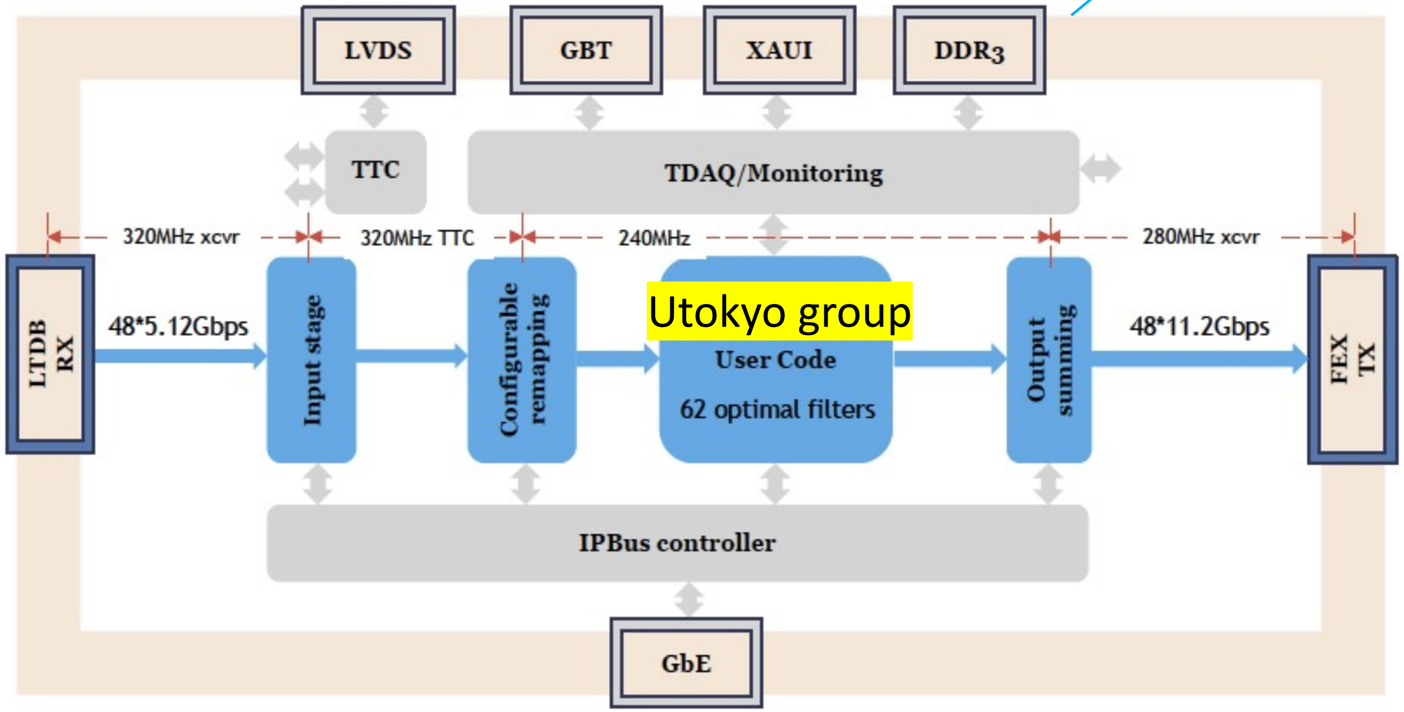
➢ Input stage: align all 48 input fibers together.

Embedded chip

➢ Configureable remapping: reorder input data according to detector topology.

➢ User code: computes Et. (develop by UTokyo group)

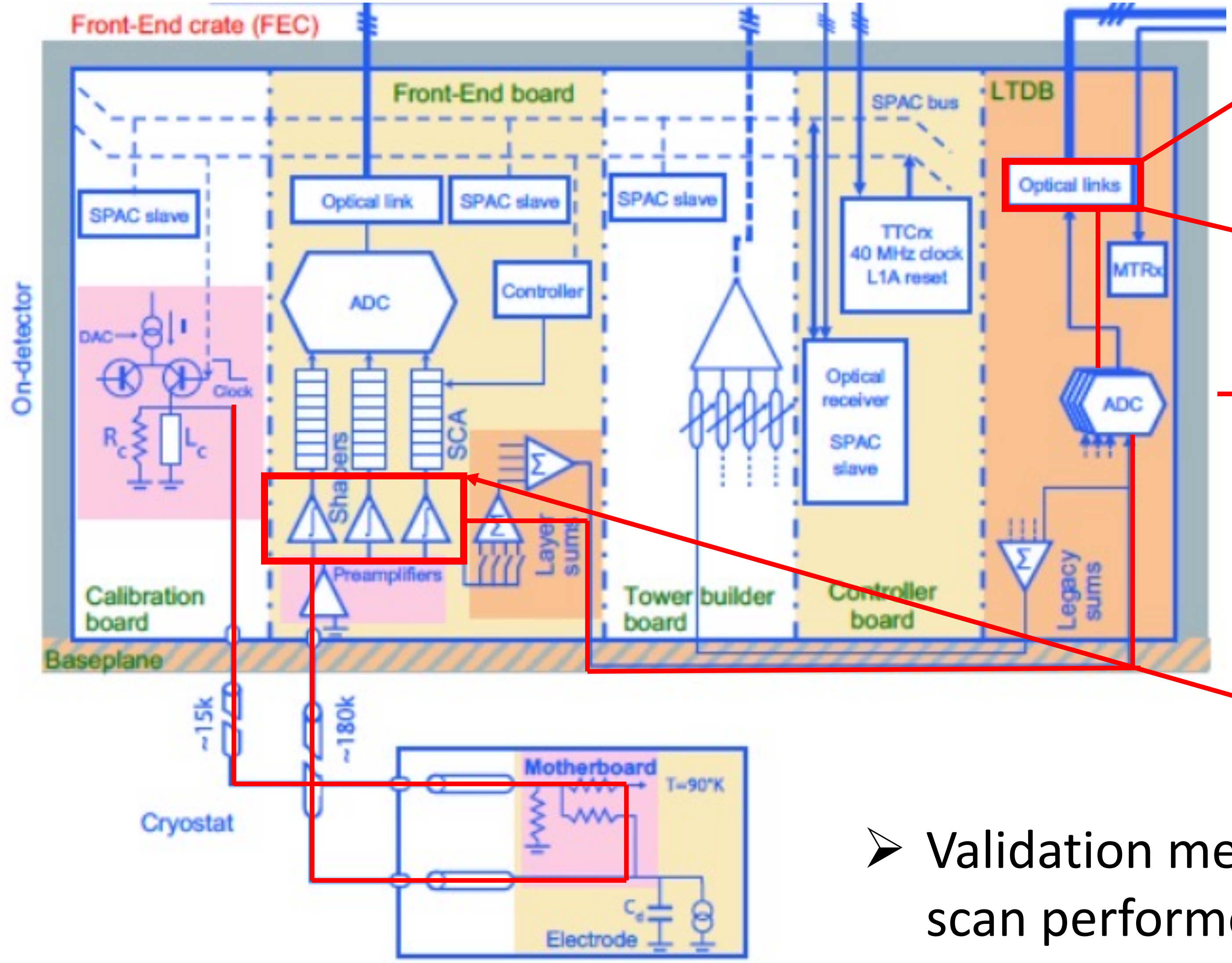
➢ Output summing: builds trigger tower energies and transfer to FEX with 48 output fibers.

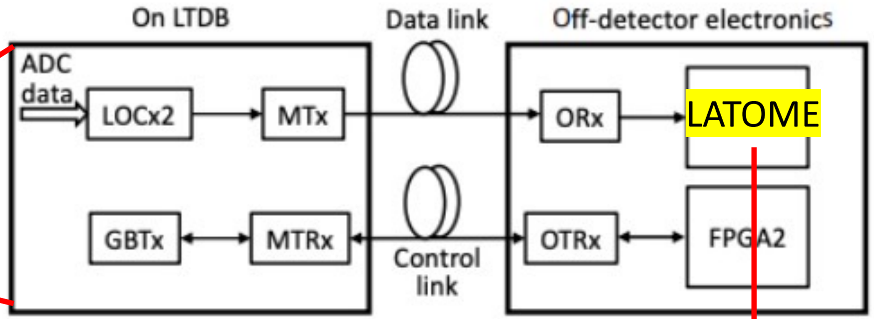


Latome firmware synopsis

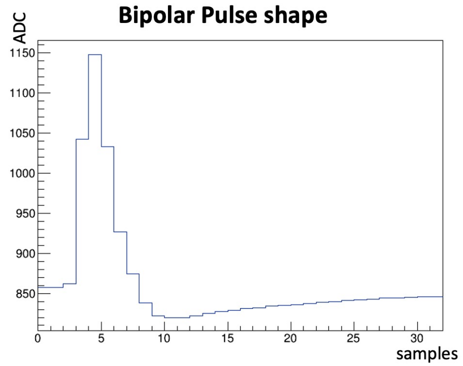
Connectivity check – calibration pulse readout path

- Motivation: make all SCs read out signals properly.





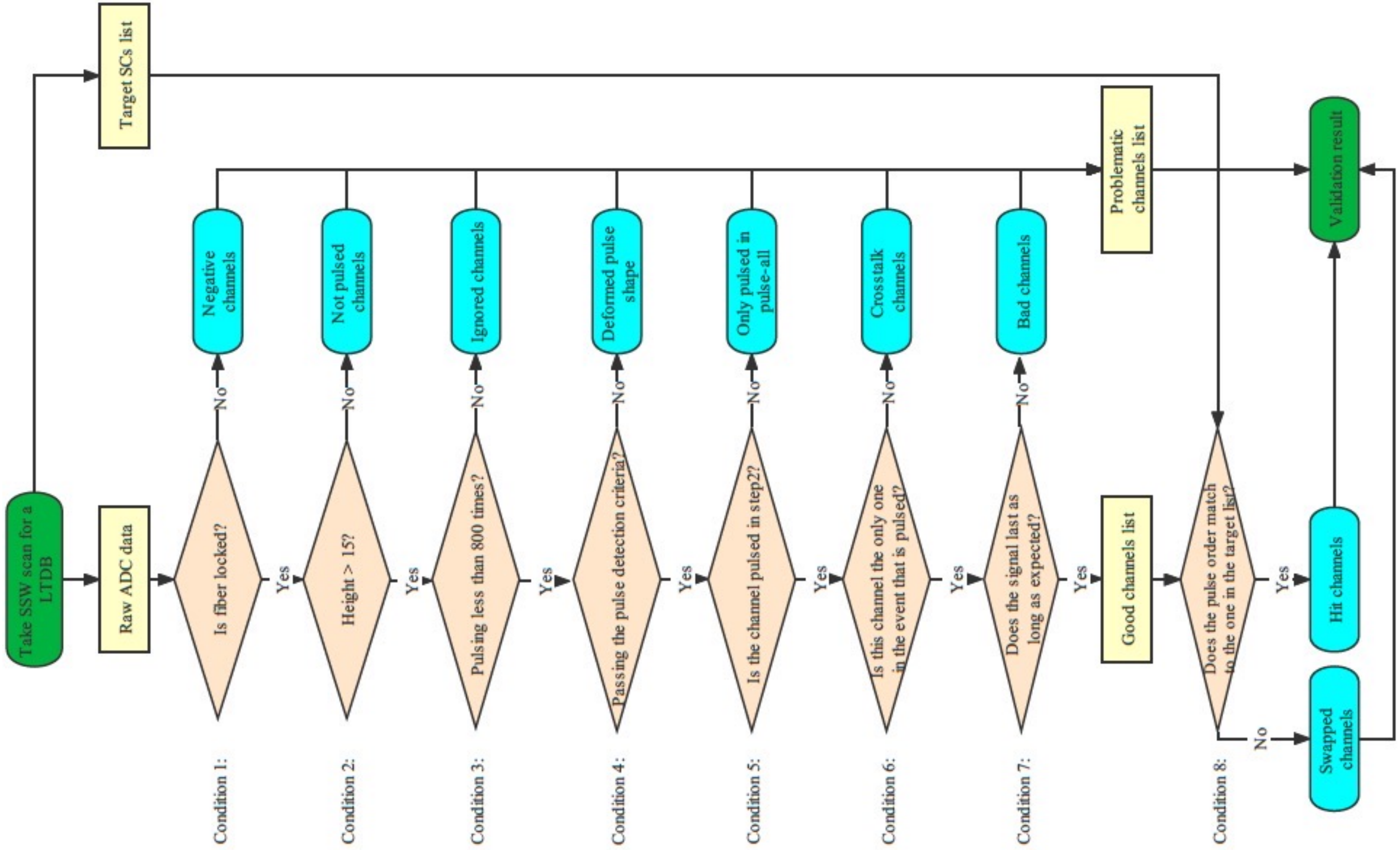
Calibration pulse path



Offline analysis

- Validation method: utilize the shaper switch (SSW) scan performed by the calibration pulse system.

Connectivity check – scan validation algorithm



BCID calibration – motivation

- To meet the requirement of the same pulse timing in both readout, $BCID_{offset}$ is required by

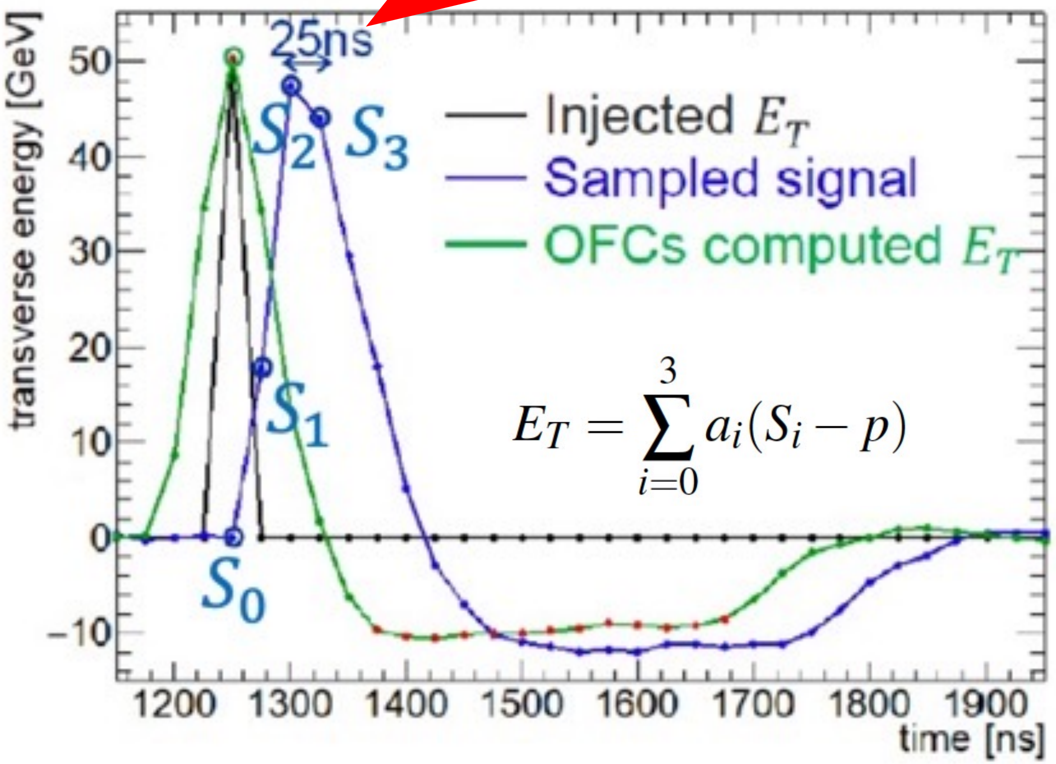
$$BCID_{offset} = BCID_{LATOME} - BCID_{main} = 0$$

- In order to determine $BCID_{LATOME}$:
  - Four samples $S_{0,1,2,3}$ are used OF algorithm, where the third sample S_2 corresponding to the peak is used to determine the pulse timing in DT readout by

$$BCID_{LATOME} = BCID_{S_0} = BCID_{S_2} - 2 = BCID_{peak} - 2$$

- Bringing the $BCID_{LATOME}$ expression about $BCID_{peak}$ into the calculation of $BCID_{offset}$

Difference between two samples equal to 1 BC (25 ns)



$$BCID_{offset} = BCID_{peak} - BCID_{main} - 2$$

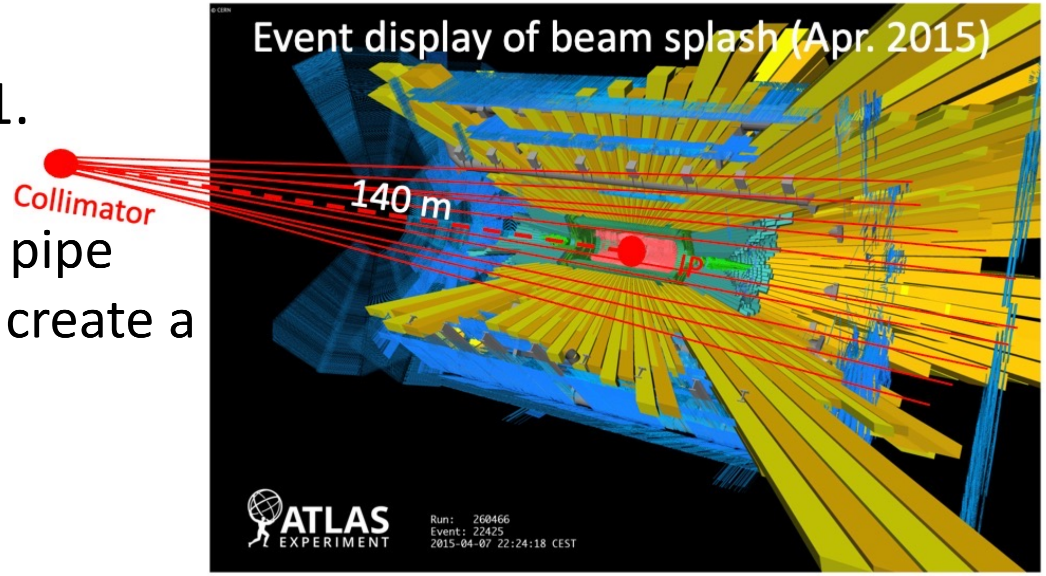
Analysis with Pilot run data

Purpose: Confirm the new DT readout system is operational and adjustable with real particles.

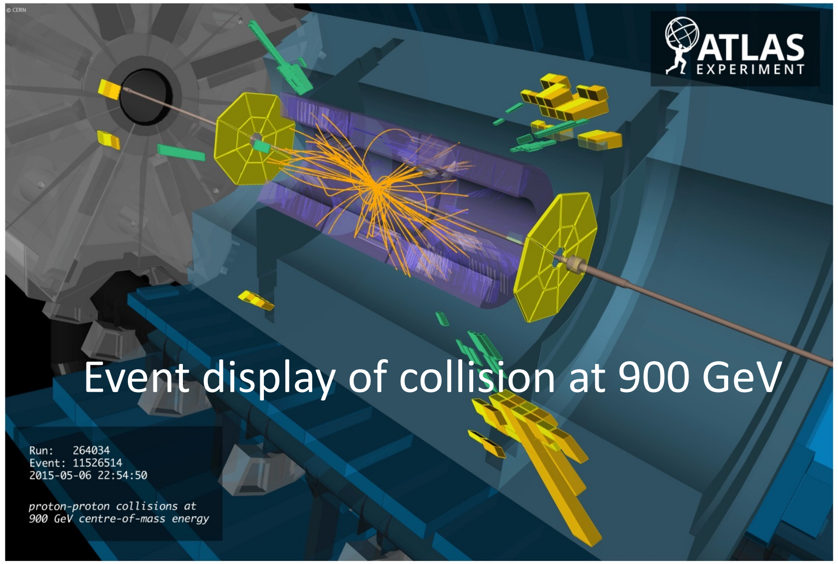
Analysis with pilot run data – pilot run

- The pilot beams were circulated at LHC in October 2021.
  - ➢ Two kinds of runs are performed: splash and collision.
  - ➢ Splash: The beam hits a collimator located along the beam pipe which is intentionally closed upstream of the detector and create a large shower.

➡ For illuminating all the subdetectors



  - ➢ Collision run operated with the center-of-mass of 900 GeV.
  - ➢ LAr calorimeter was fully powered.
  - ➢ First data-taking with real beam for the new DT trigger.
  - ➢ FCal was not well calibrated at the time.
  - ➢ BCID calibration is not fully done at the time, BCID of most fibers are adjusted by hand



Analysis with pilot run data – energy reconstruction

- OFC calibration
  - Done by calibration runs
  - Need to be performed after the stable latency is set (BCID calibration)
- Energy and timing reconstructed by LATOME:

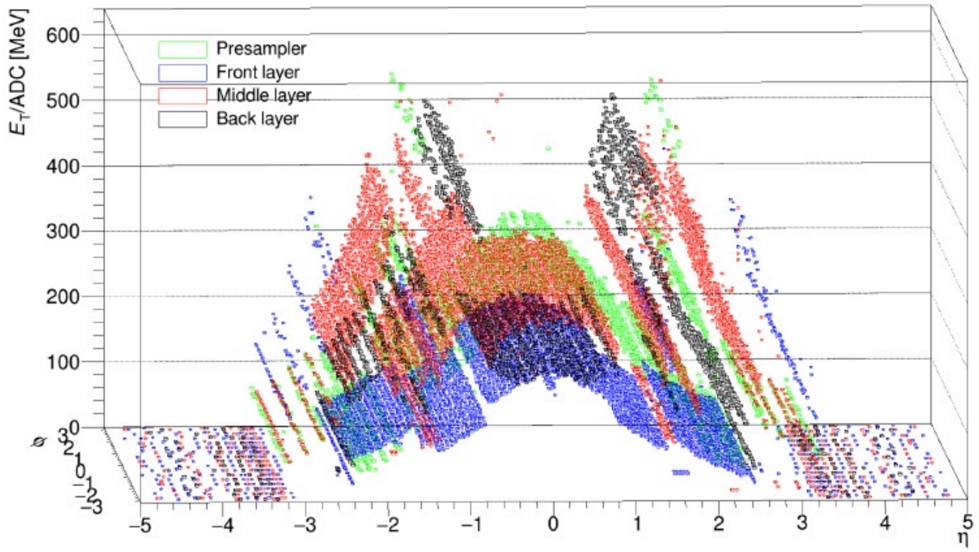
$$\begin{cases} E_T = \sum_{i=0}^{3} a_i (S_i - p) \\ E_T \tau = \sum_{i=0}^{3} b_i (S_i - p) \end{cases}$$

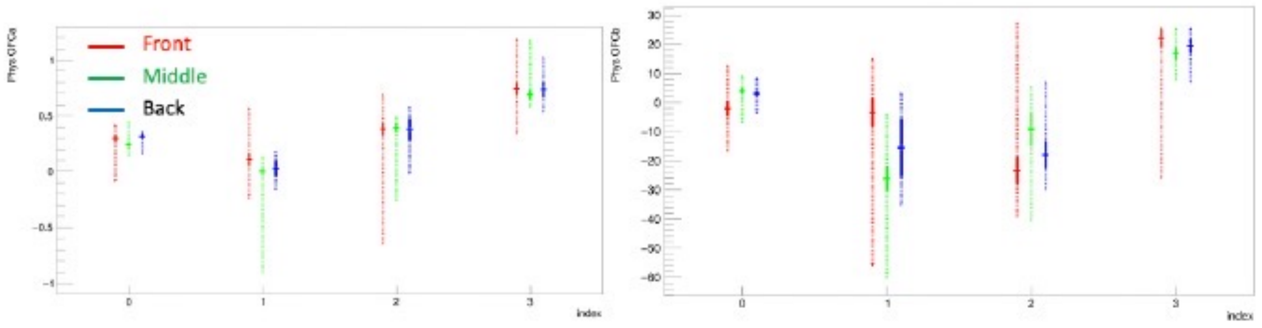
$$\begin{cases} a_i = F_{\mathrm{DAC}\to\mathrm{MeV}} \cdot F_{\mathrm{ADC}\to\mathrm{DAC}} \sin\theta \times \tilde{a}_i, \\ b_i = F_{\mathrm{BC}\to\mathrm{ns}} \cdot F_{\mathrm{DAC}\to\mathrm{MeV}} \cdot F_{\mathrm{ADC}\to\mathrm{DAC}} \sin\theta \times \tilde{b}_i, \end{cases}$$

Factor of E_T/ADC

Factor to reconstruct peak ADC

Conversion factor for τ





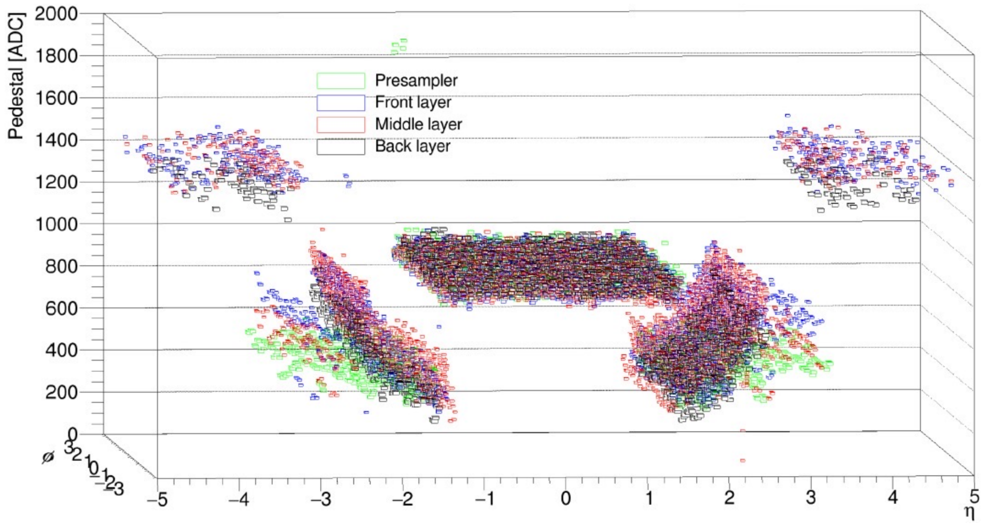
(a) OFC $\tilde{a}_i$ (b) OFC $\tilde{b}_i$

Analysis with pilot run data – general check

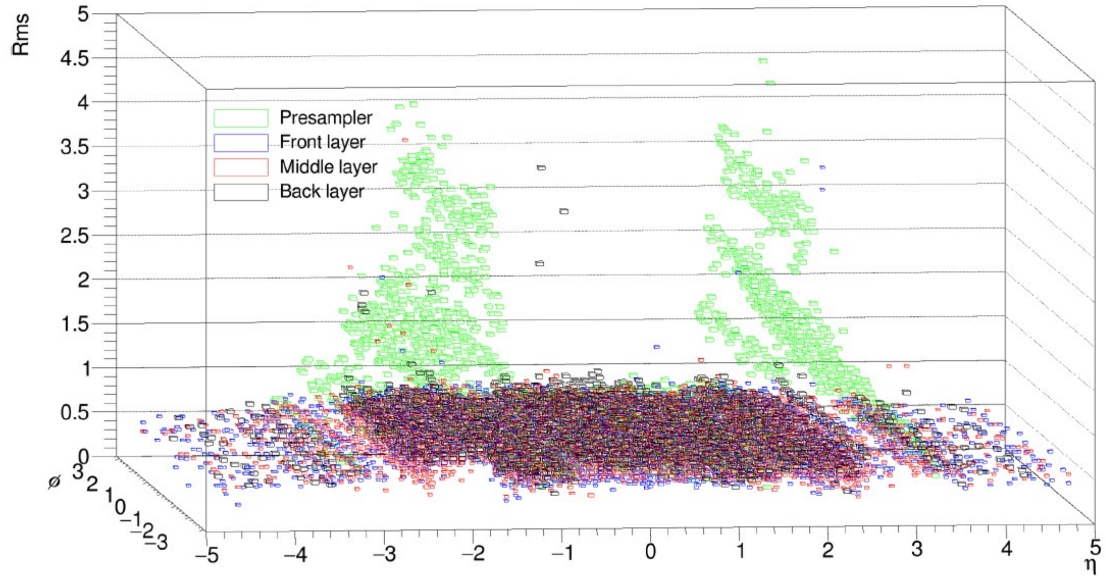
- Following runs are used for the analysis

Run number	Run type	Start time (CEST)	Stop time (CEST)	Hit / Active SCs
405396	Collision	28/10/2021 22:33	29/10/2021 06:34	15233 / 34019
405495	Splash	29/10/2021 18:30	29/10/2021 22:24	33970 / 34011
405604	Collision	31/10/2021 18:23	01/11/2021 06:02	11926 / 32771

- The pedestal and noise of the SCs are obtained by the collision run 405604.
  - ➢ A point corresponding to a SC.



Pedestals

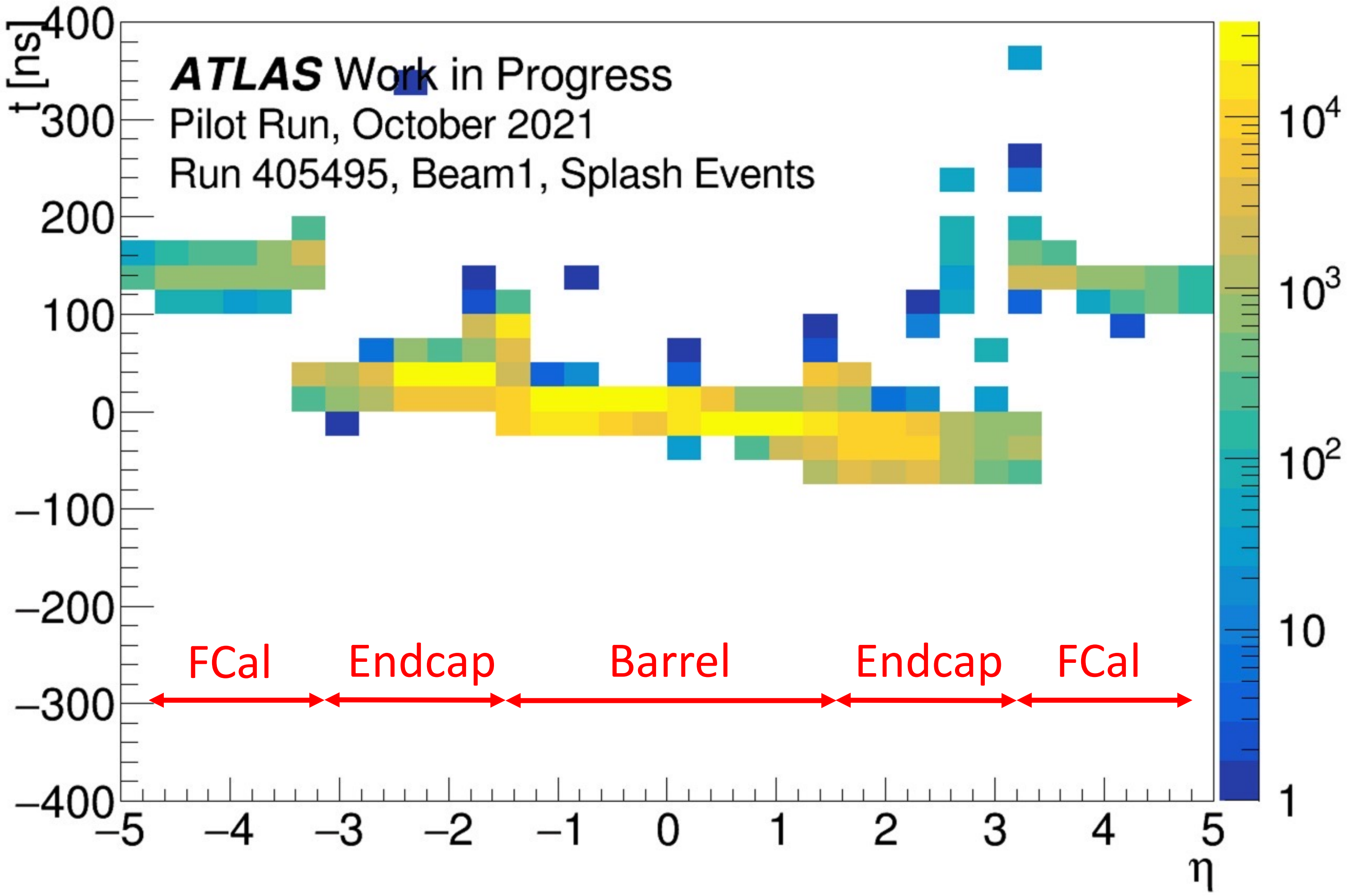


Sample RMS

➡ Almost all SCs are active in the pilot run.

Analysis with pilot run data – Timing check

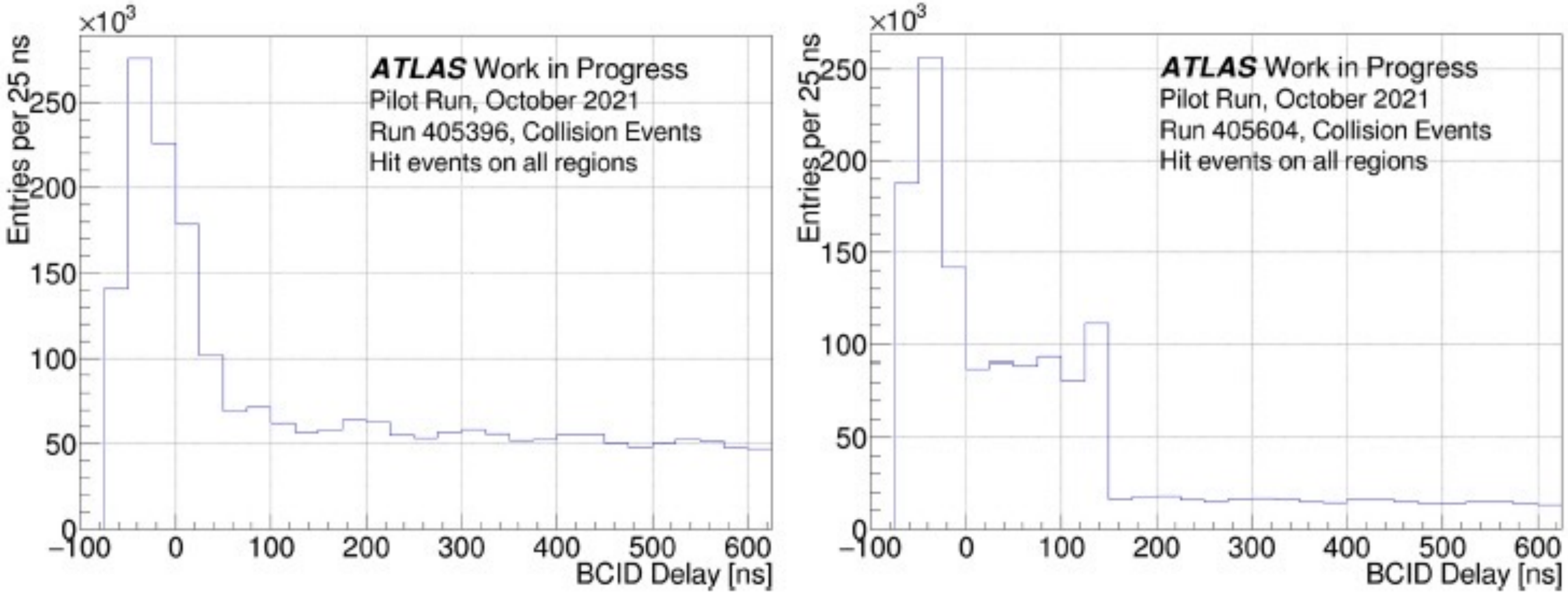
- $BCID_{offset}$ between the DT readout and the main readout is computed to check the pulse timing.
- BCID delay t = $BCID_{offset} \times 25\ ns$
- Events with height less than 20 ADC are cut off.



$BCID_{offset}$ of most SCs are around 0

Analysis with pilot run data – Timing check

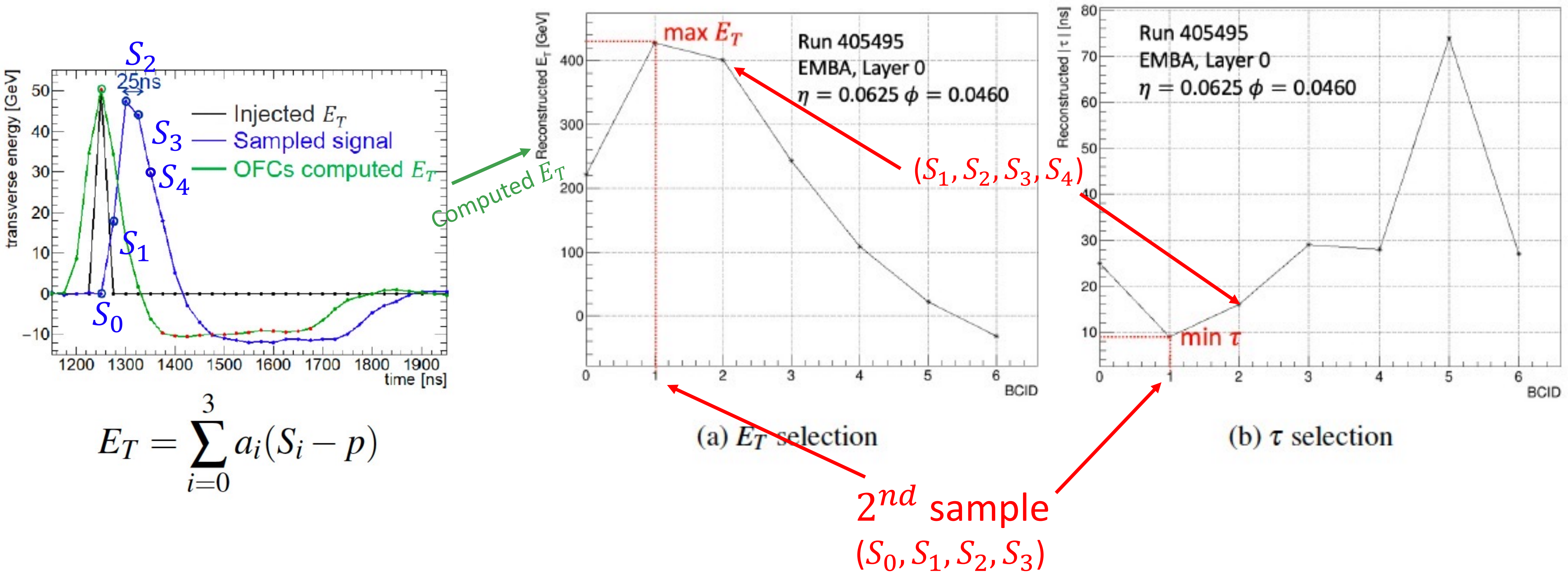
- Collisions
  - Pulse height cut is 10.
  - Noise is still considerable due to the low luminosity and low beam energy.
  - Peak samples are around the 3^{rd} , which means the offsets are around -2 BC.



(a) Run 405396 (b) Run 405604

Analysis with pilot run data – energy comparison

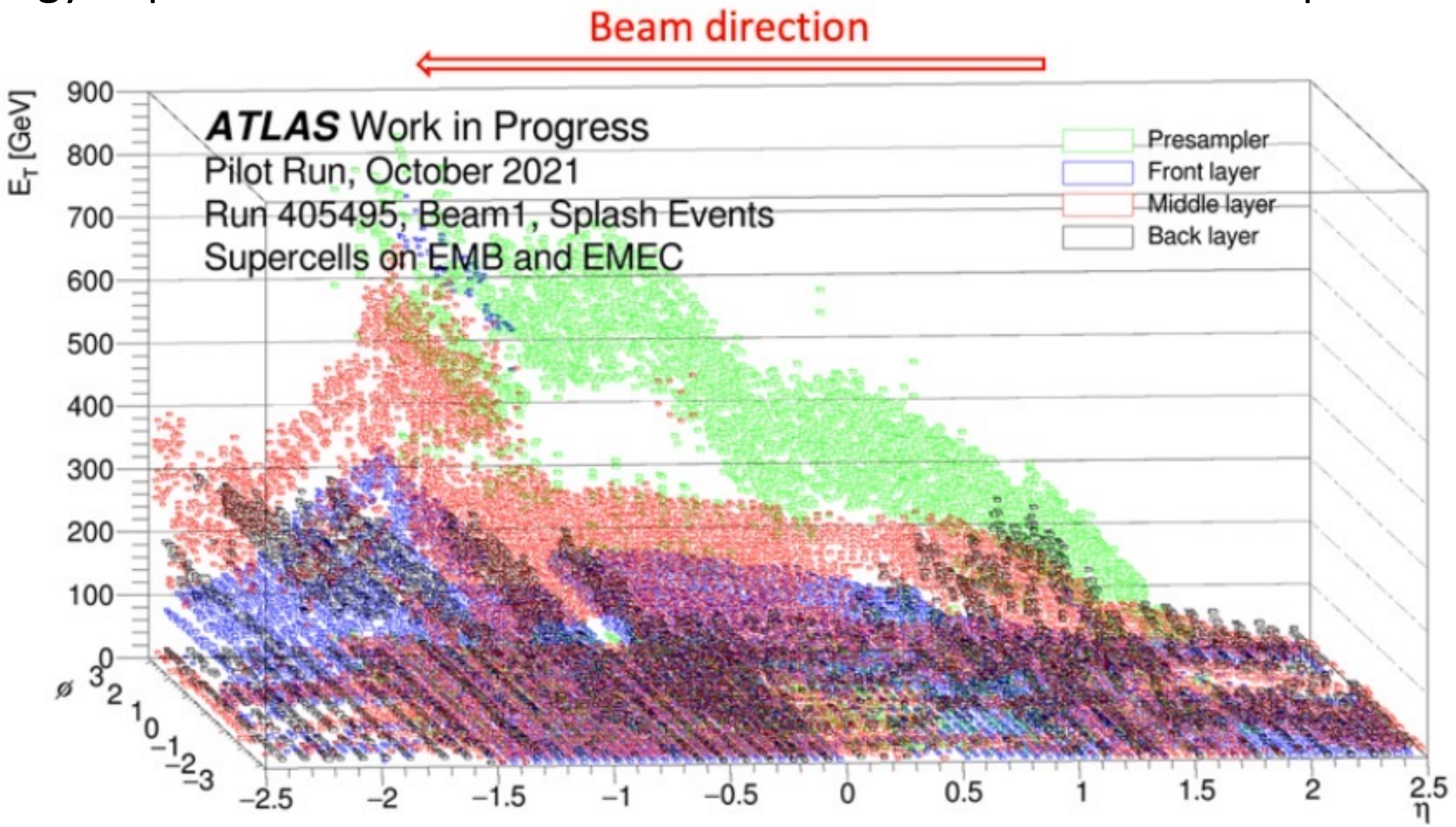
- E_t reconstruction in offline analysis using DT readout raw data (except for FCal):
  - ➢ Compute E_T and τ with different BCID.
  - ➢ Pick the BCID where max E_T matches the min τ. (if no BCID matches then skip)



$$E_T = \sum_{i=0}^{3} a_i (S_i - p)$$

Analysis with pilot run data – energy comparison

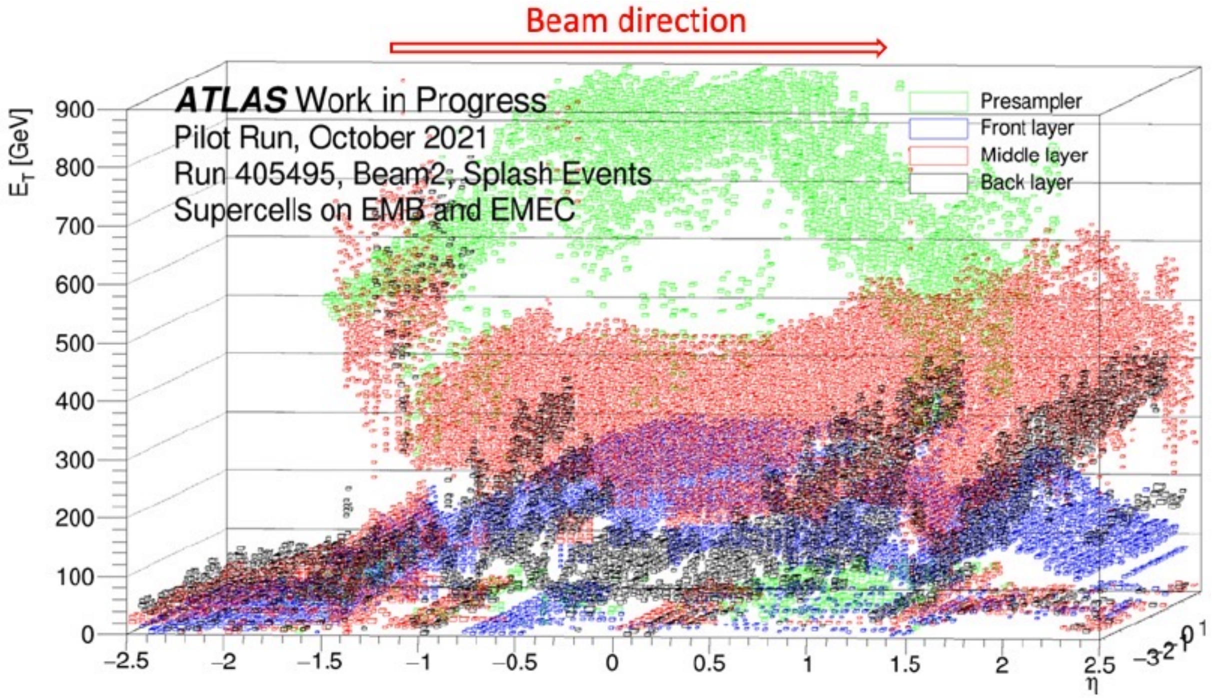
- E_T distribution constructed with DT readout raw data
  - 10 luminosity blocks with 20 events are used in the analysis of splash events.
  - 1 box represents 1 hit SC.
  - Splash events have more energy deposited than the collision events.
  - More energy deposition in the downstream of the detector for Beam 1 splash.



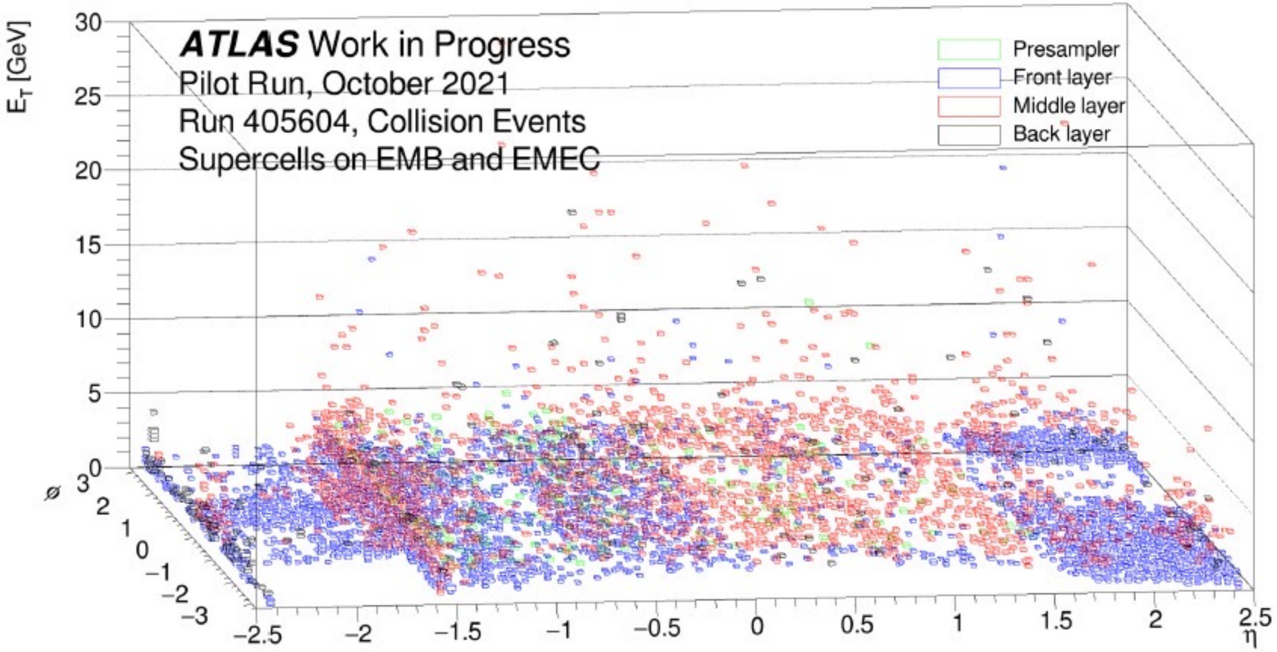
Analysis with pilot run data – energy comparison

- E_T distribution constructed with DT readout raw data

Splash events



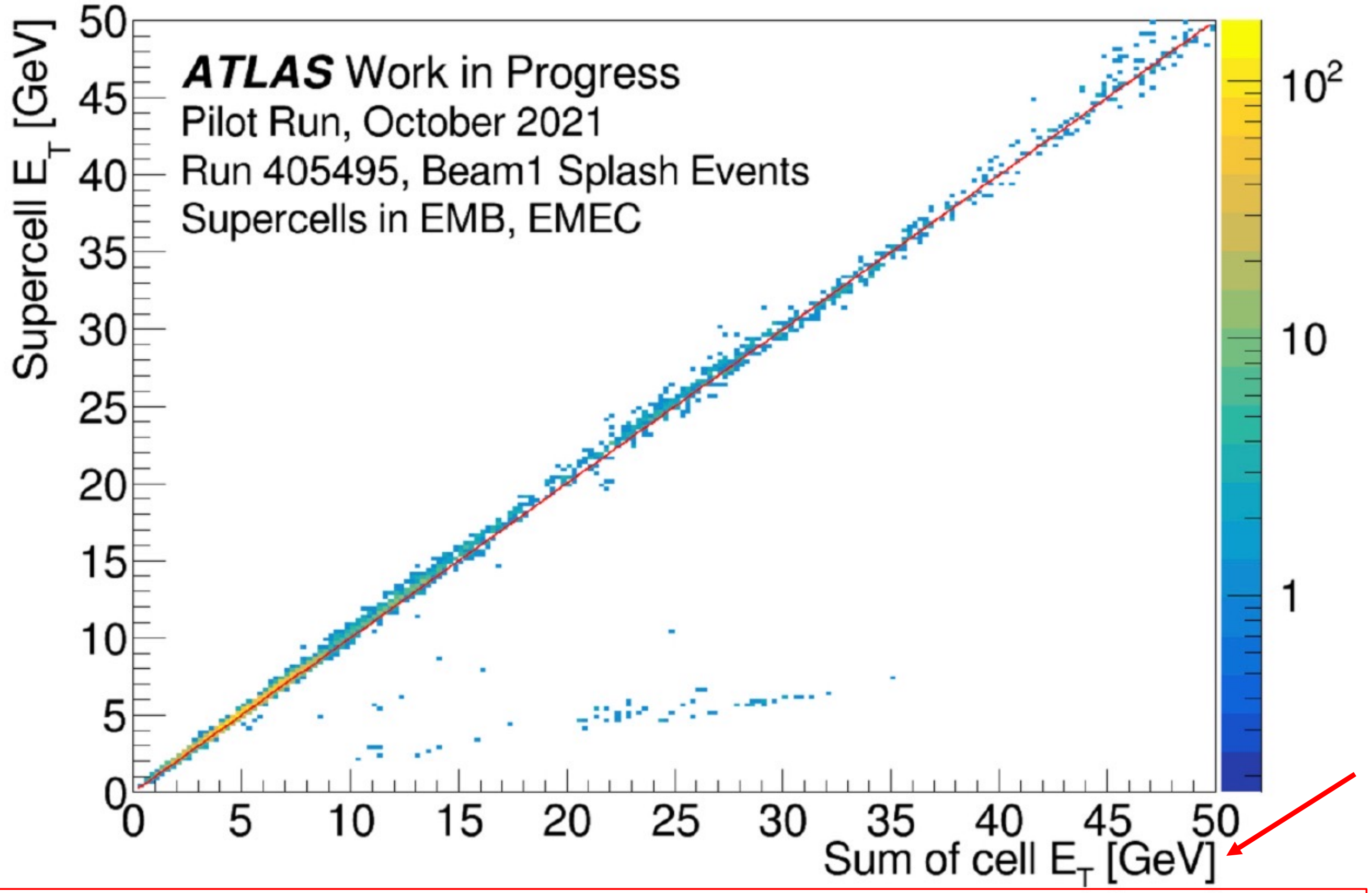
Collision events



Analysis with pilot run data – energy comparison

- Reconstructed E_T matches well between DT and main readout.

Reconstructed E_T in DT readout



Reconstructed E_T in main readout

The consistency with main readout shows that connectivity checks and BCID calibration make DT readout work as expected!