The **Electromagnetic** Performance of the **Dual Readout Calorimeter** in 2024 Test Beam Experiment

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on behalf of Korea Dual Readout Calorimeter Collaboration

Dual-readout meeting (indico)
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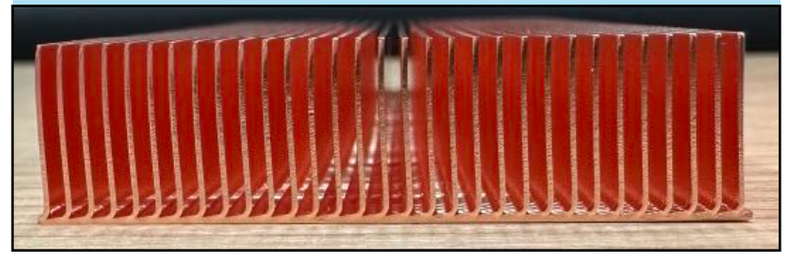
Supported by KiSTi www.kisti.re.kr

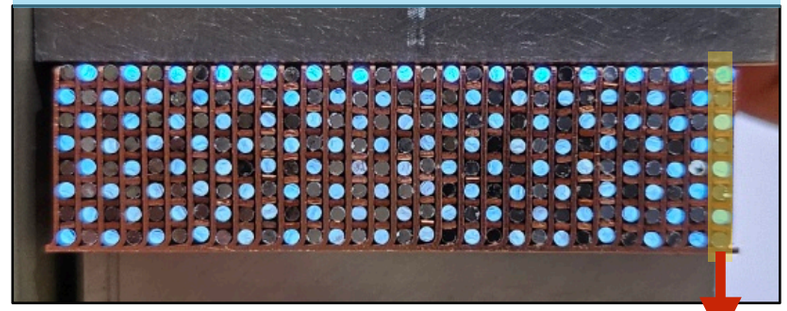
Introduction: **2024** Test Beam

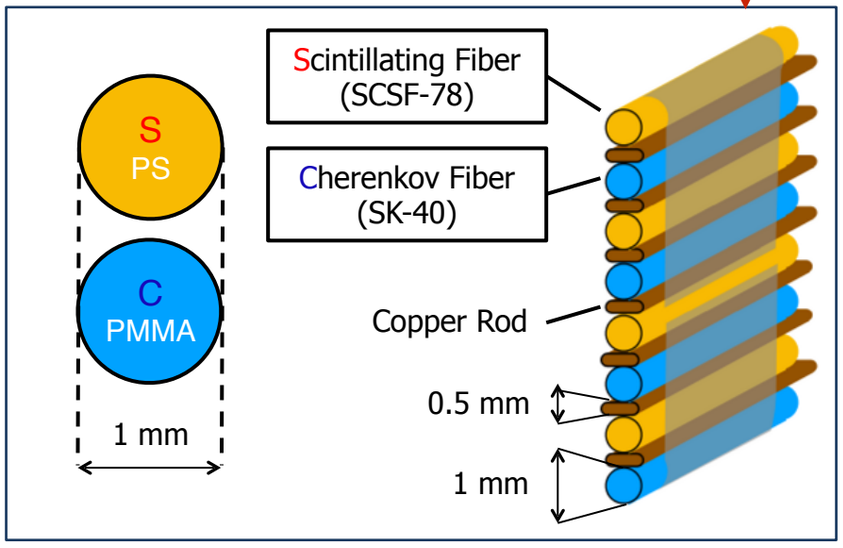
- [1] Detector
  - DRC tower: **copper** absorber + **C&S fibers**
    - **Sky-fin heat sink shape** copper blocks + C&S fibers are inserted with the copper rods

Sky-fin heat sink shape copper blocks



Example: Front of a DRC tower





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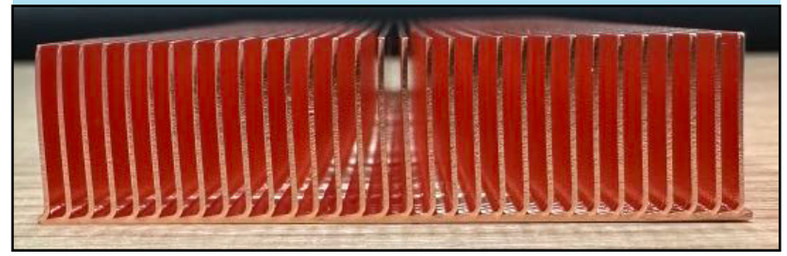
  - Total **36** towers (9 modules) are produced for TB2024
    - Stacked in a square shape: 29 cm × 29.9 cm × 2.5m
    - On top of the modules used in TB2022
      (not used for this study)

Sky-fin heat sink shape copper blocks



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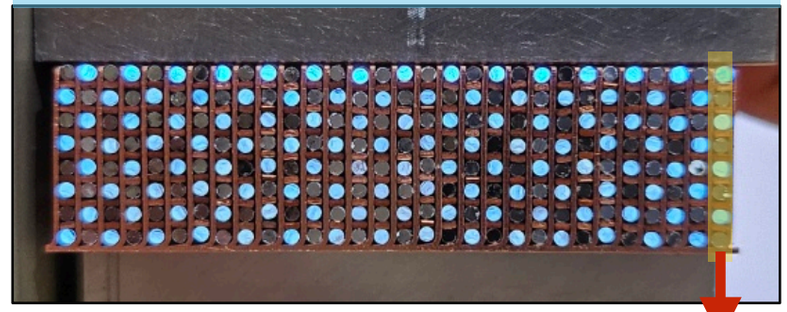
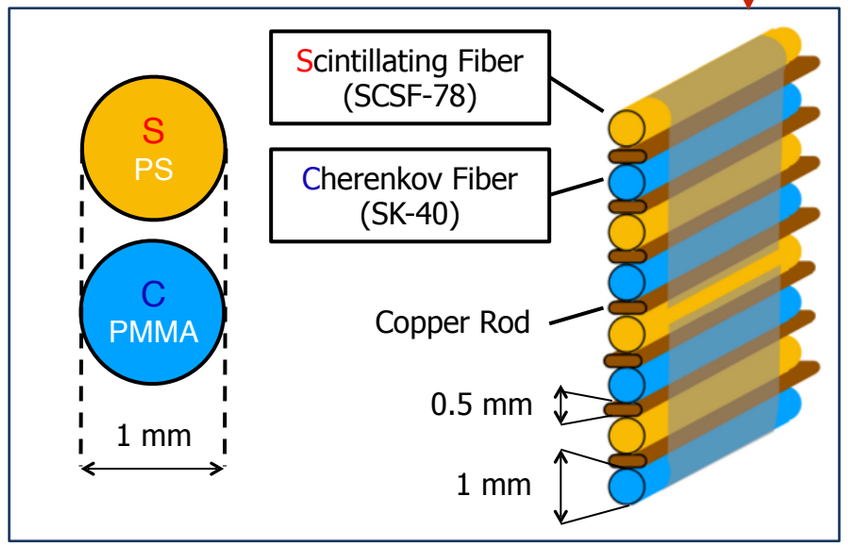
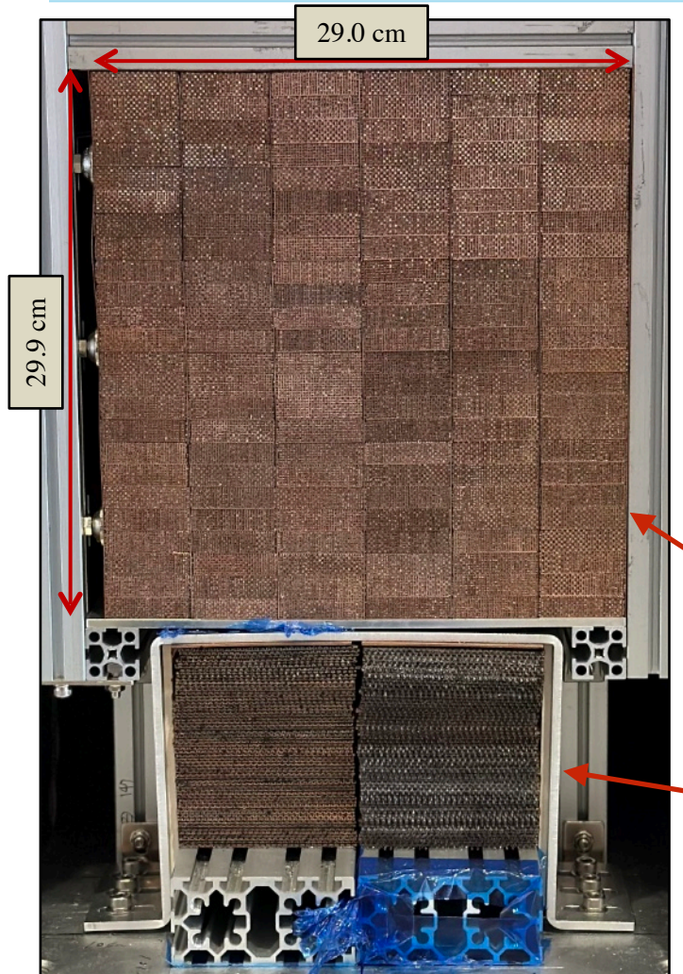




Front view of the detector



Side view of the detector

TB2024 modules

TB2022 modules

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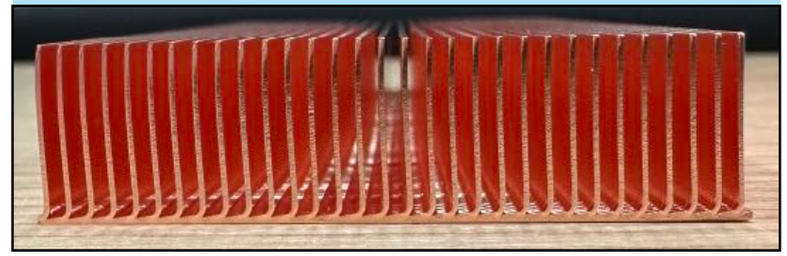

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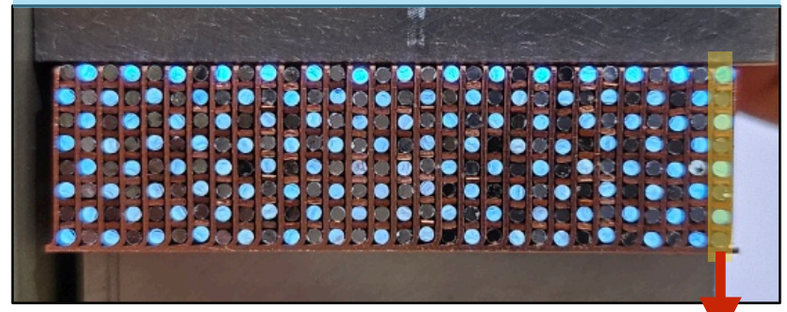

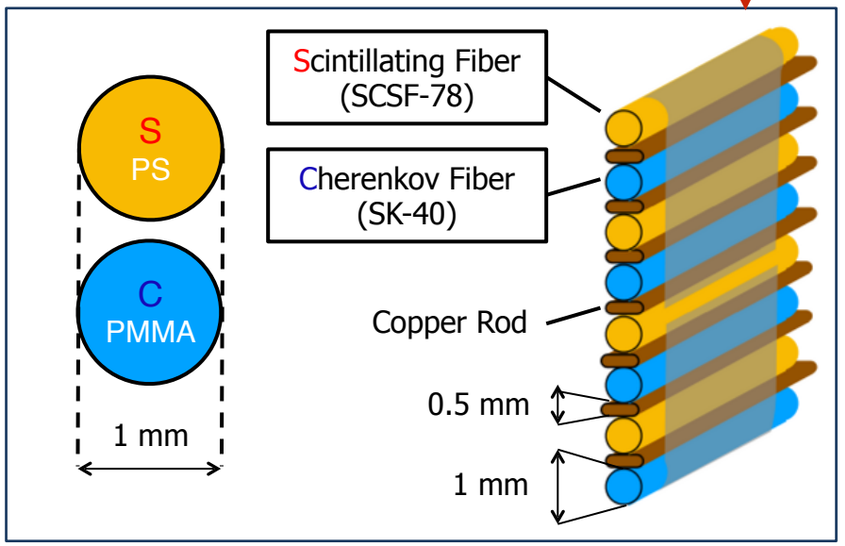

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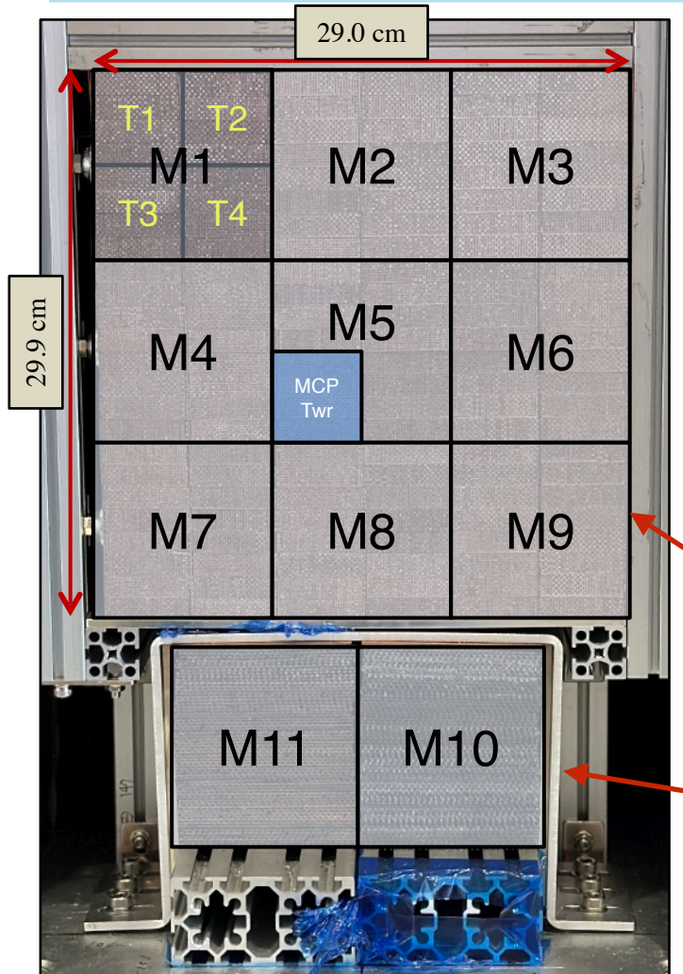


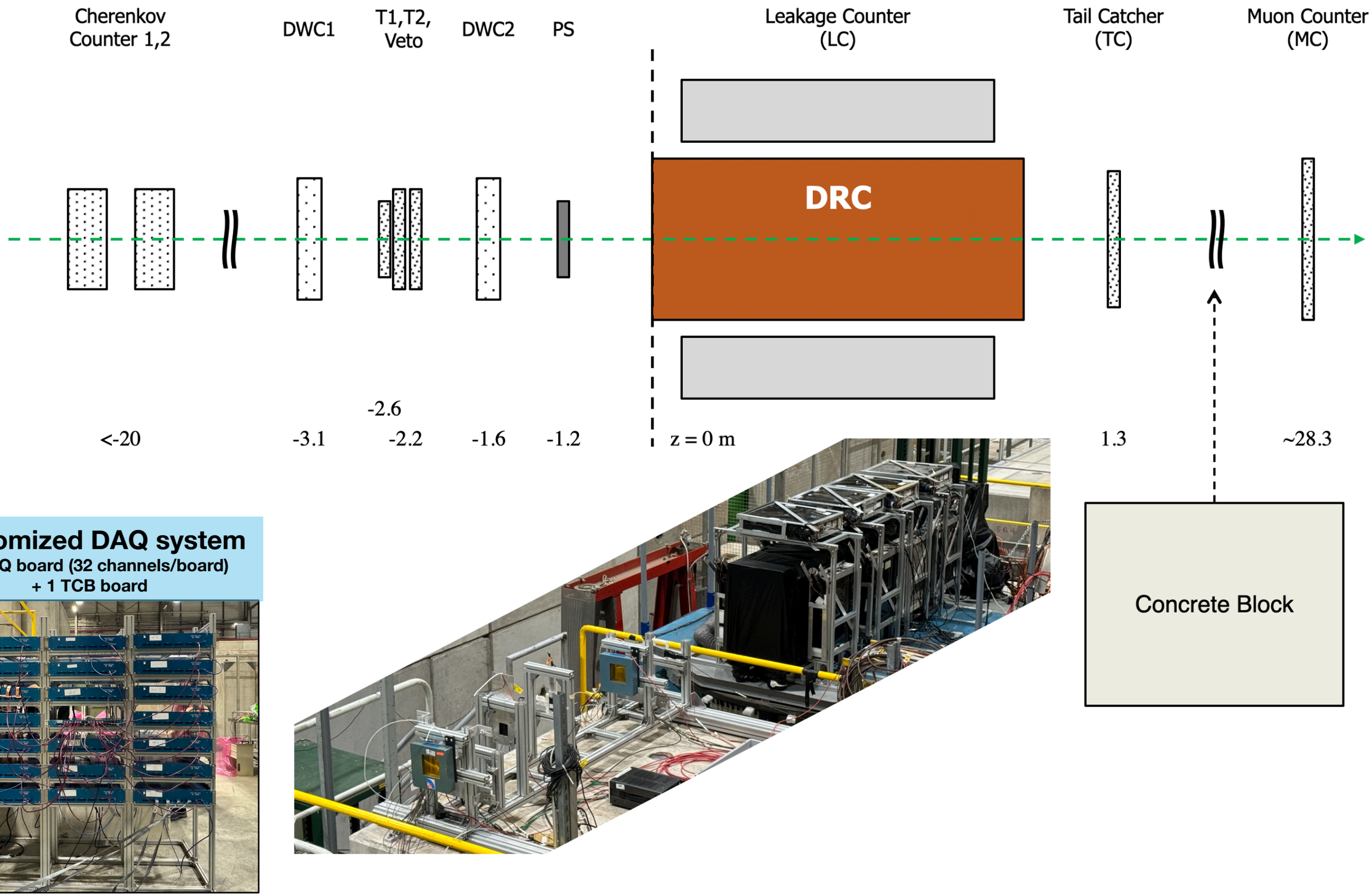
Side view of the detector

TB2024 modules

TB2022 modules

Introduction: **2024** Test Beam

- [2] **Experimental setup**

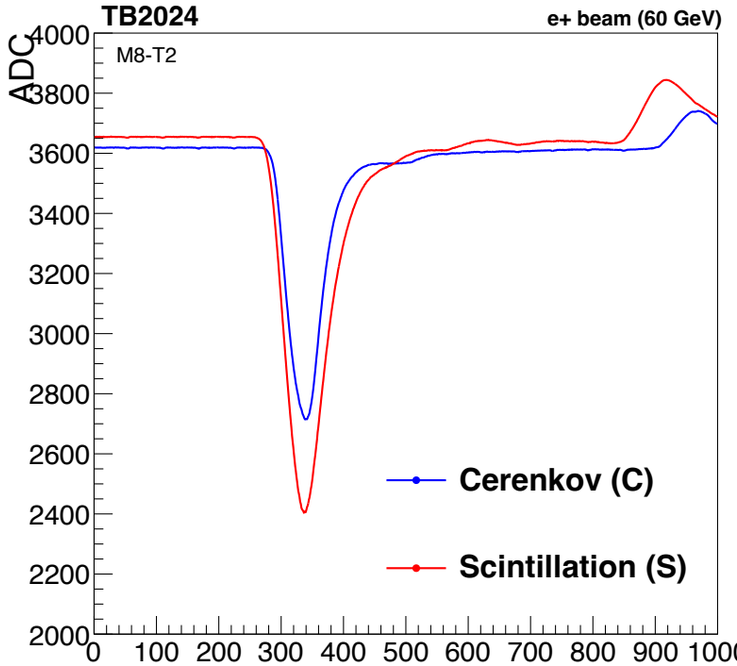


Customized DAQ system
30 DAQ board (32 channels/board)
+ 1 TCB board

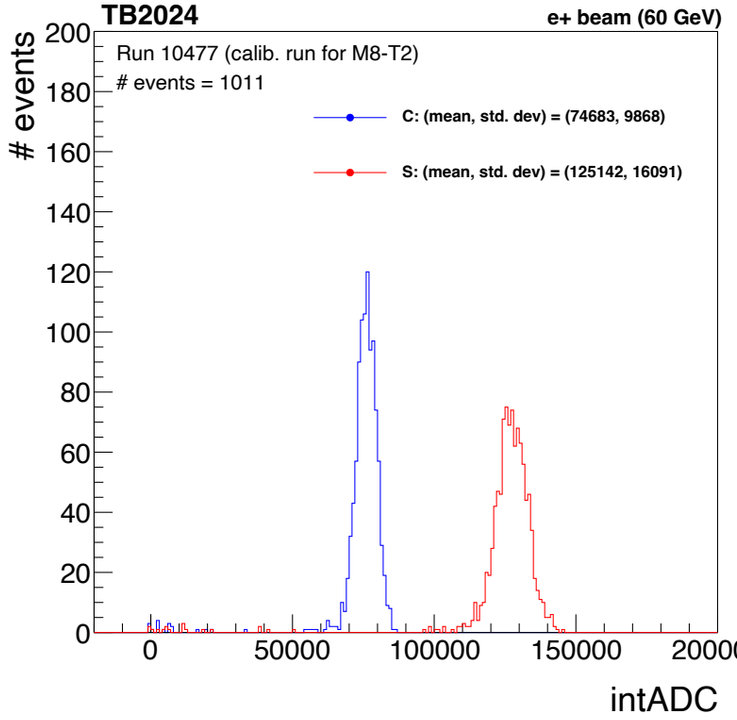
Introduction: **Analysis Procedure**

- [1] Determination of **integration range** for the DRC signal
  - Integral of ADC over a range ("intADC")
    $\propto$ energy deposit in the tower
  - Take the range covering the DRC signal (peak)
    in ADC vs. time distribution
    - Based on averaged shape over many events ("averaged time structure")
- [2] **Event selection**
  - To keep the events from the pure e+ beam only
  - Use the signal from auxiliary detectors
    - Delayed wire chamber (DWC), Preshower (PS) and Muon counter (MC)
- [3] **Calibration**: convert "intADC" to energy deposit [GeV]
  - Using the data with 60 GeV e+ beam for each tower
  - Multiply a constant
    to convert the obtained intADC to a energy unit
- [4] EM performance **results**
  - Obtain the resolution per each energy point
    - Total 7 points: 10, 20, 30, 40, 60, 80, 100 GeV

Example: (averaged) ADC vs. time

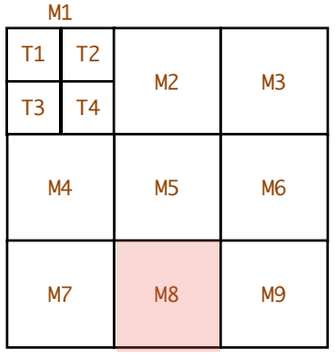


Example: intADC distribution



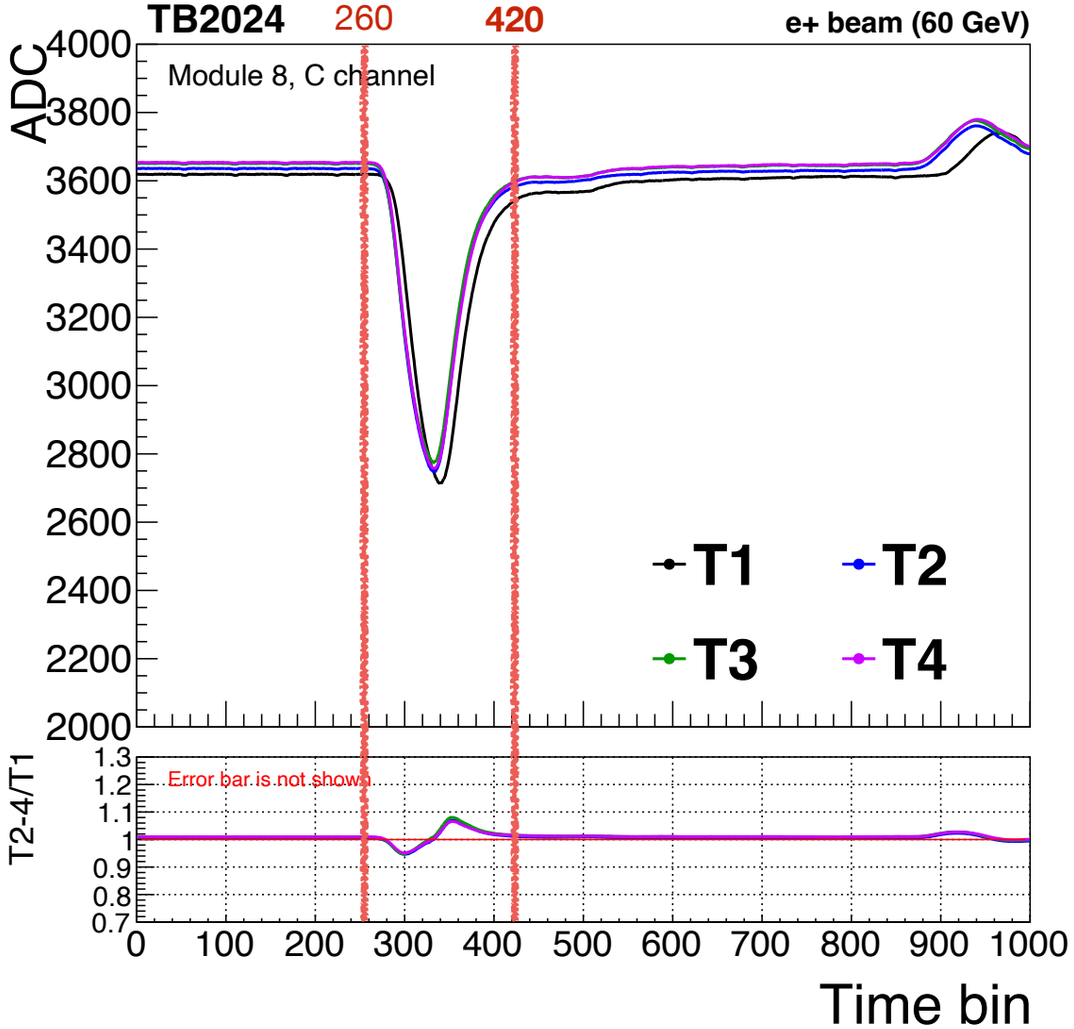
Determination of **Integration Range** for the DRC Signal

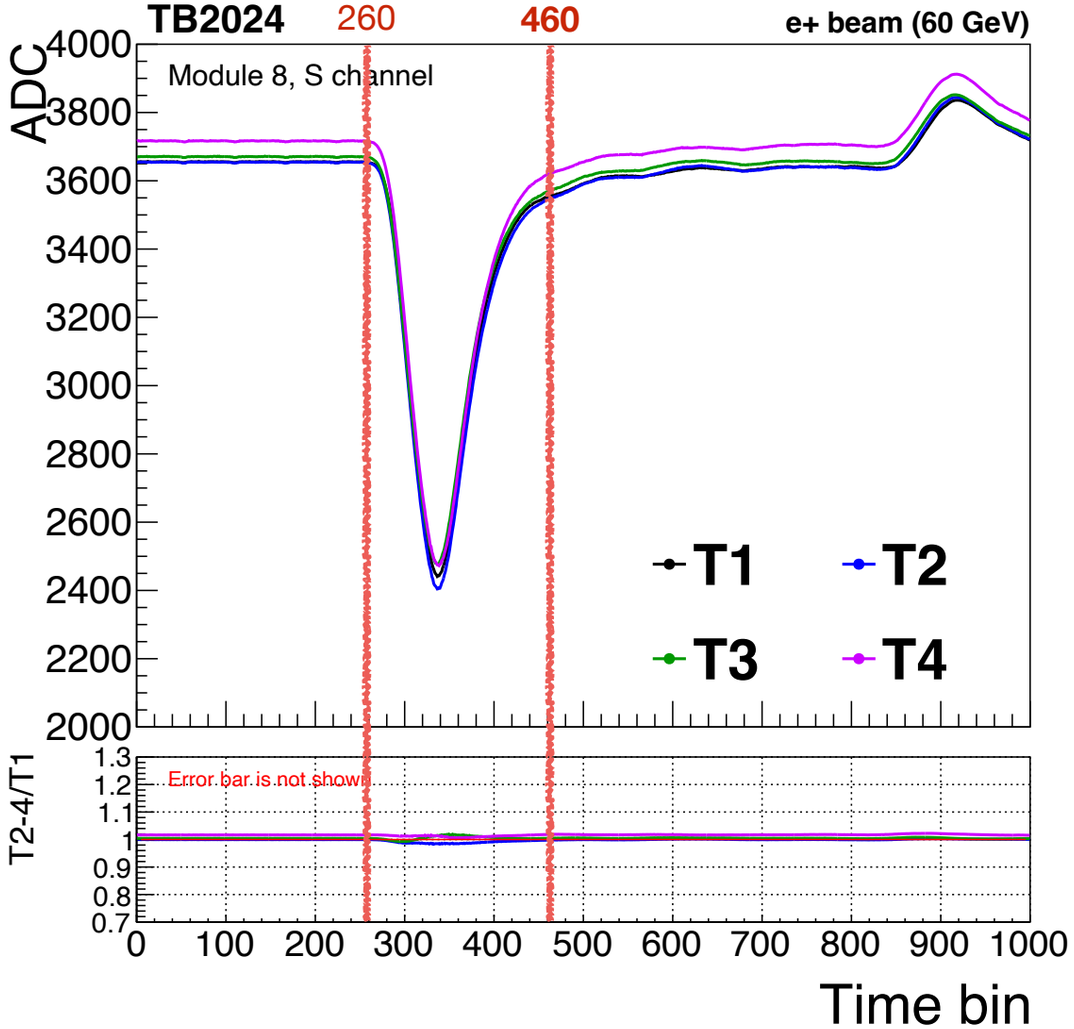
- Determine the range that covers the DRC signal (peak)
  - Using the averaged ADC vs. time ("averaged time structure")
  - S channel has larger signal than C channel: take a larger range to fully cover the peak
  - **[260, 420] for C channel; [260, 460] for S channel**
  - The range covers the peak well <u>over all modules</u>
    - Except for M5 due to its (slightly) different timing: dedicated range is applied (backup)



Example of an average time structure: Module 8

Cherenkov (C) channel	**Scintillation (S) channel**





Determination of **Integration Range** for the DRC Signal

DREAM FOR FUTURE

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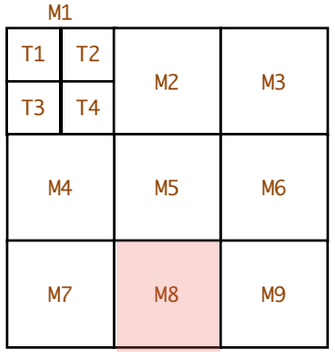
  - Using the averaged ADC vs. time ("averaged time structure")
  - S channel has larger signal than C channel: take a larger range to fully cover the peak
  - **[260, 420] for C channel; [260, 460] for S channel**
  - **Integral of ADC: sum of all ADCs within the range from the pedestal**



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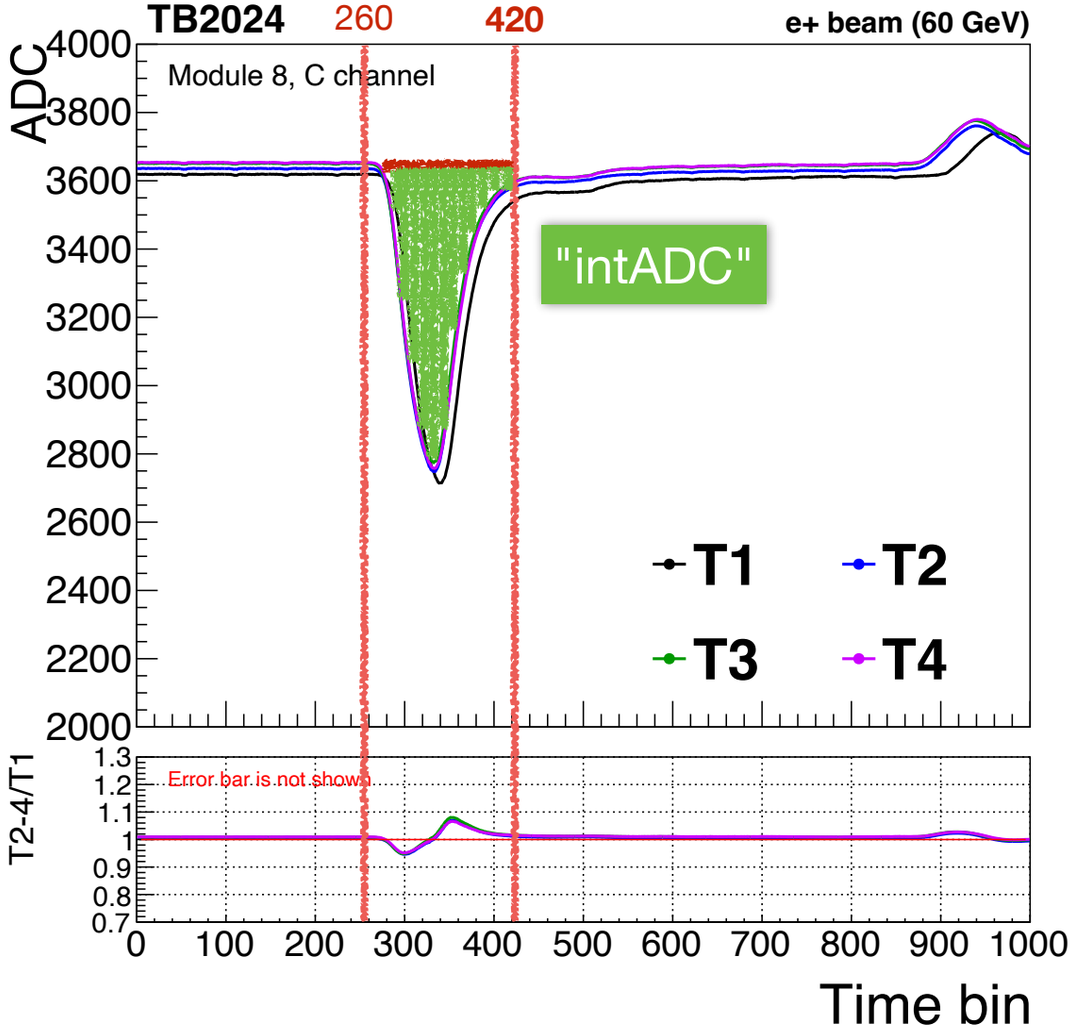
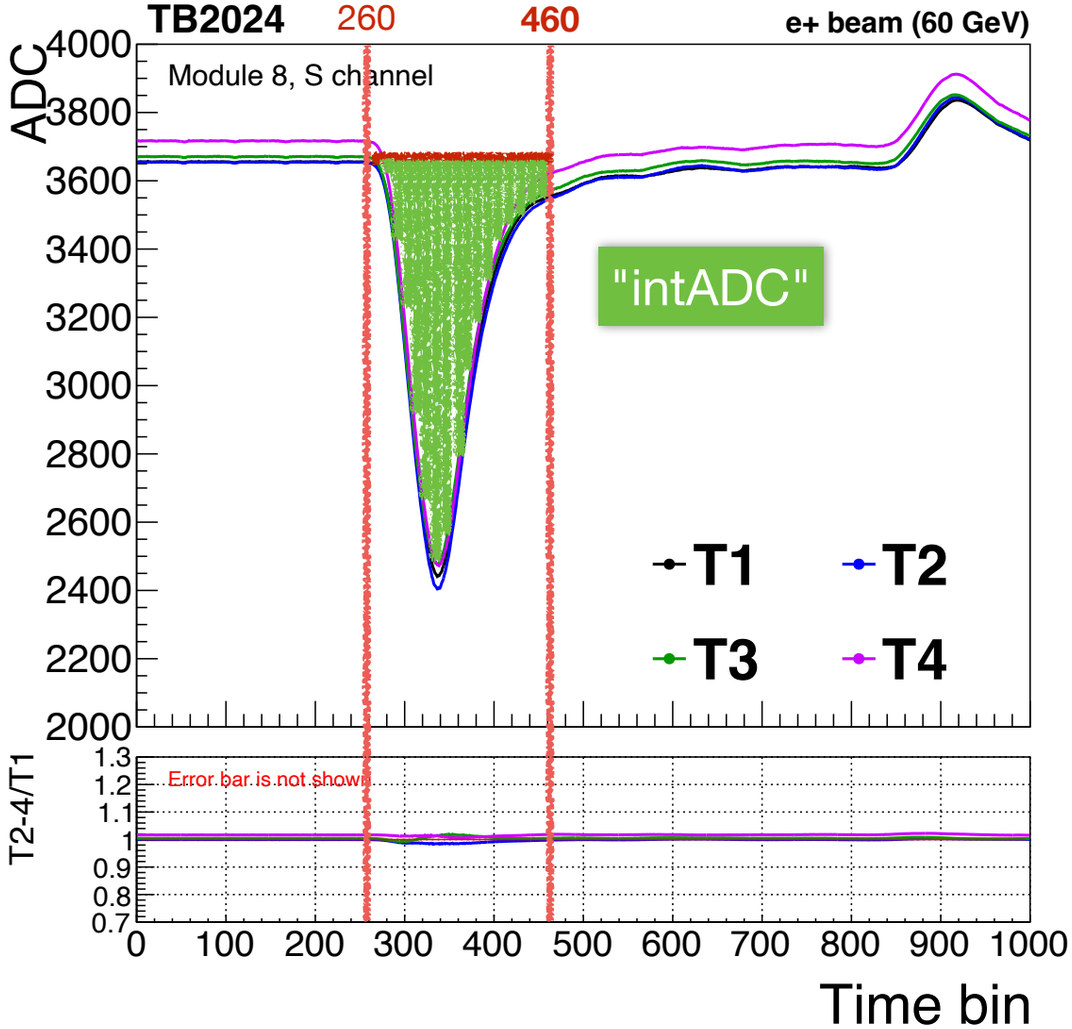
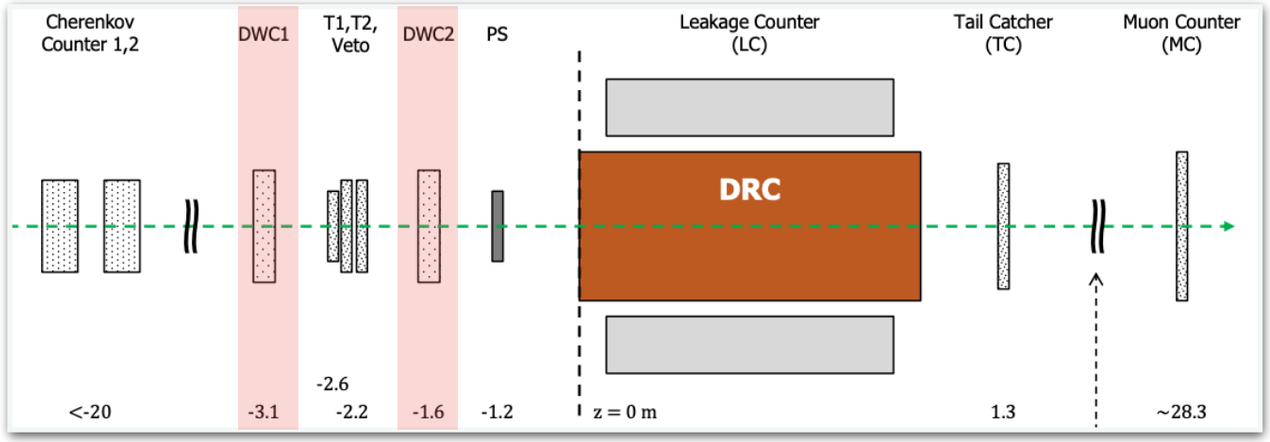


Scintillation (S) channel



Event Selection: **Delayed Wire Chamber** (DWC)

- DWC: Control the **beam shape** in front of the DRC modules
  - Measure the 2D position (x, y) of the incident beam
  - Two DWC detectors: DWC1 and DWC2
    - The **correlation** requirement between the positions of DWC1 and DWC2: powerful to suppress the **inclined** beam

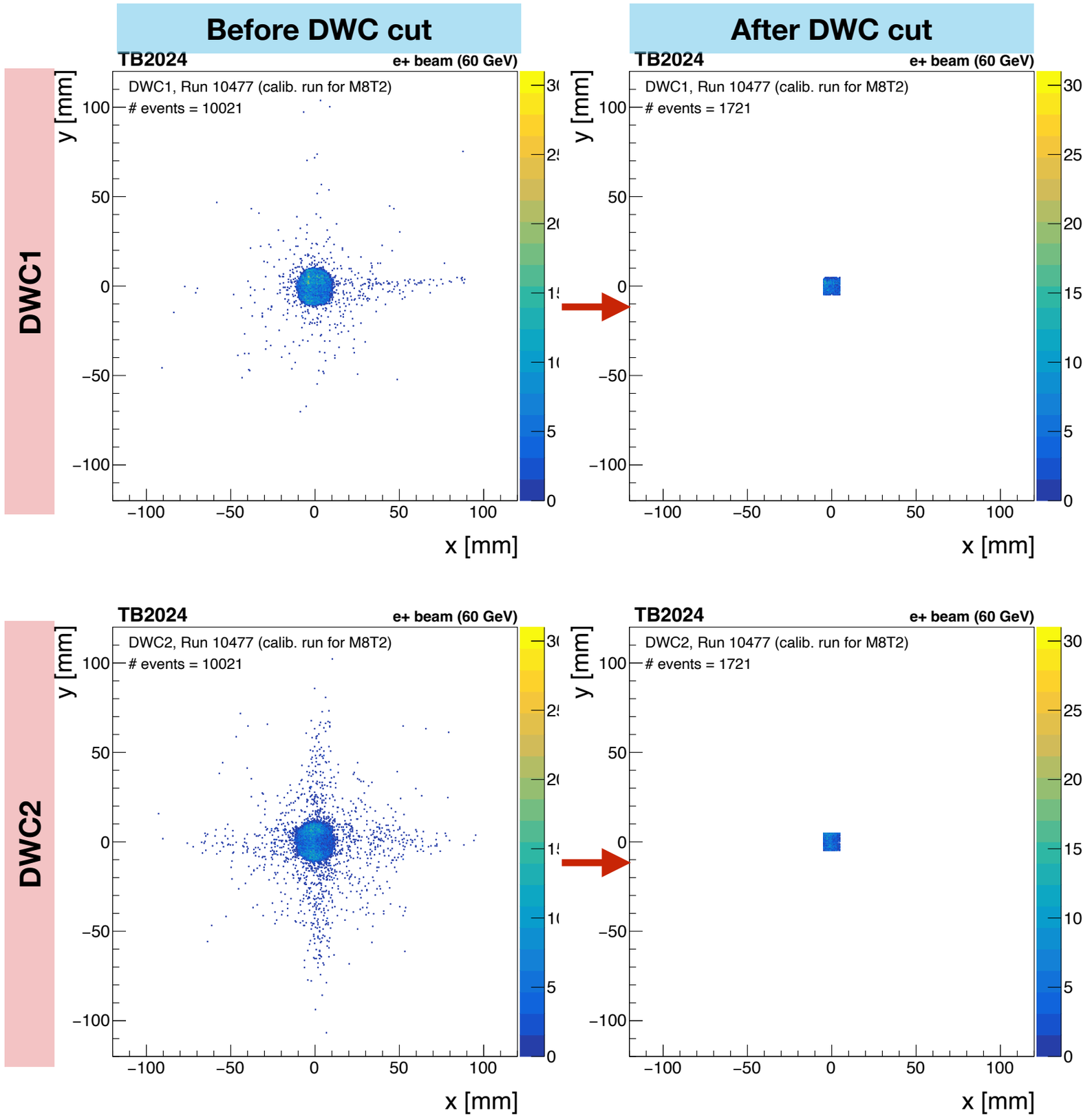


- Event selection with DWC: select the events with the beam **directed to the DRC center**

Event selection criteria for DWC	
Variable	**Criteria**
size, DWC1	**-5 < x < 5 , -5 < y < 5 mm** (10 mm × 10 mm square)
size, DWC2	**-5 < x < 5 , -5 < y < 5 mm** (10 mm × 10 mm square)
Correlation (DWC1, DWC2)	$\|x^{DWC1}-x^{DWC2}\| < 4$ mm $\|y^{DWC1}-y^{DWC2}\| < 4$ mm

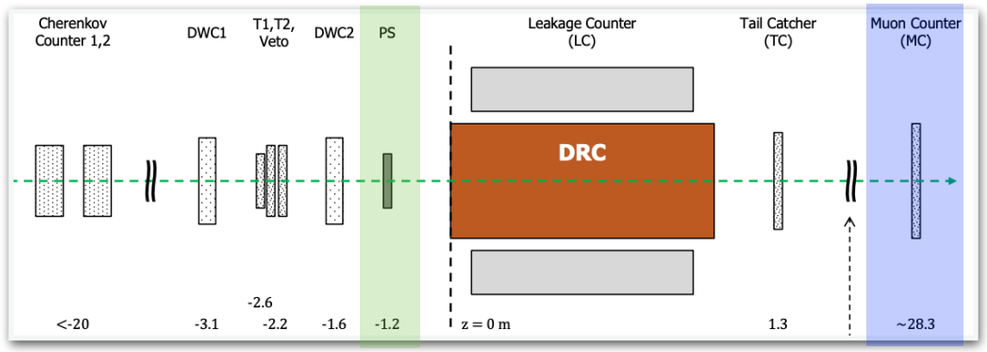
Event Selection: **Delayed Wire Chamber** (DWC)

- Comparison before vs. after cut
  - Example of a run with ~10k events
    - Directed to M8-T2
  - The cuts are applied as intended
  - ~17% events survived (10021 → 1721)



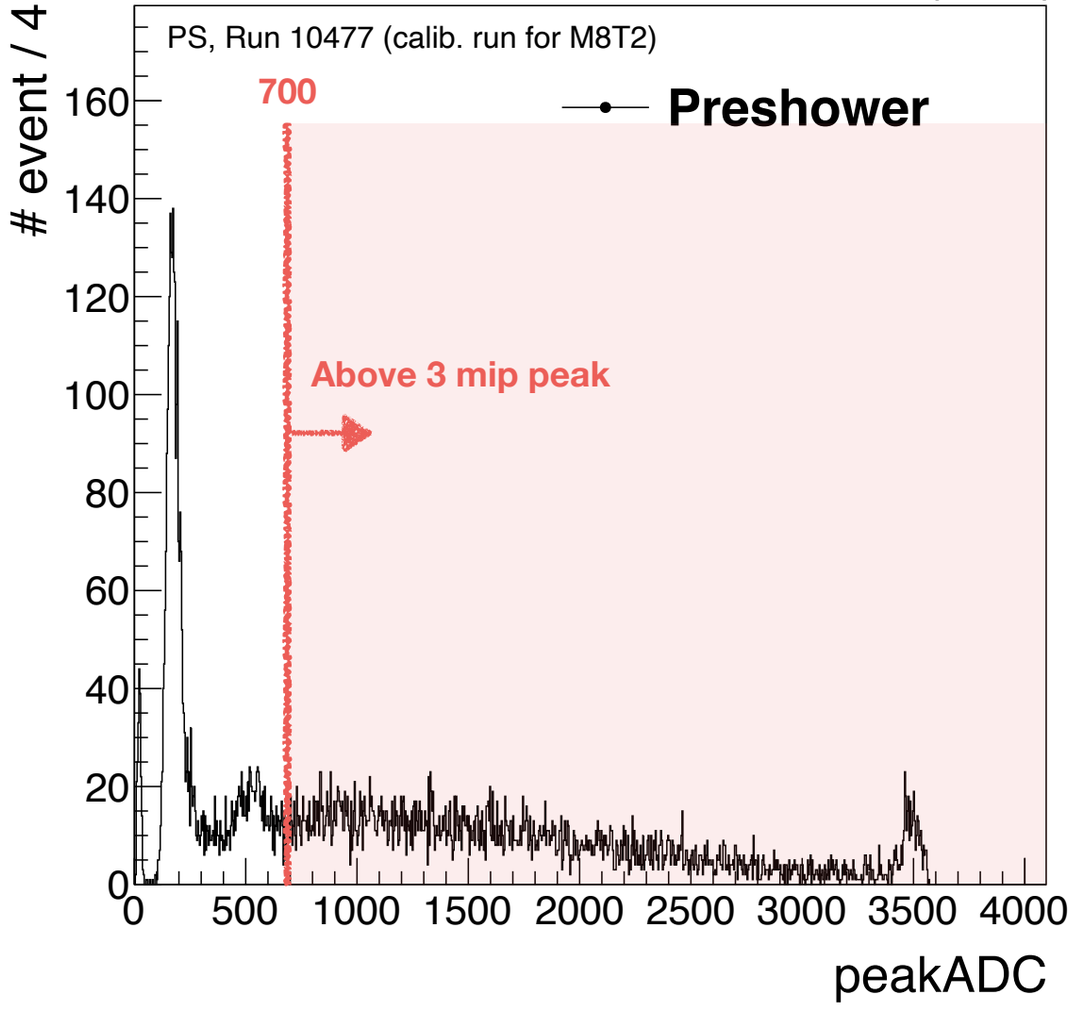
Event Selection: **Preshower** (PS) & **Muon Counter** (MC)

- **Preshower**: induce a shower for e+ in front of the DRC
  - $e^{\pm}$: (e^{+}, e^{-}) pairs from the shower
    → 3, 5 ... minimum ionizing particle (mip) peak
  - $\mu^{\pm}$ & hadrons: hardly interact → 1 mip peak
  - **Select > 3 mip peak** to reject muons & hadrons
- **Muon counter**: make a signal if muon is detected
  - **Select pedestal** of the muon counter to reject muons

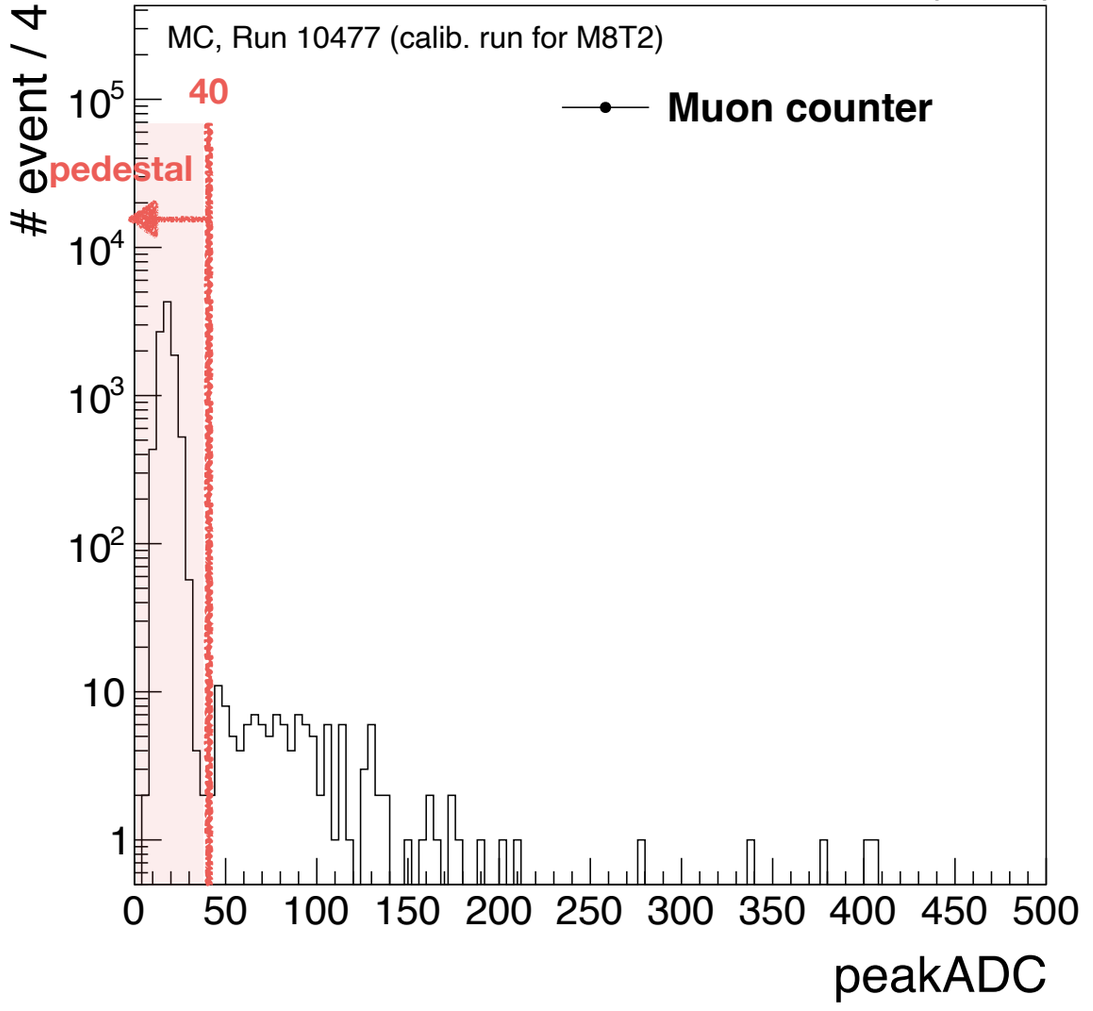


Example of the peak of ADC ("peakADC") distribution without any cut applied

Preshower



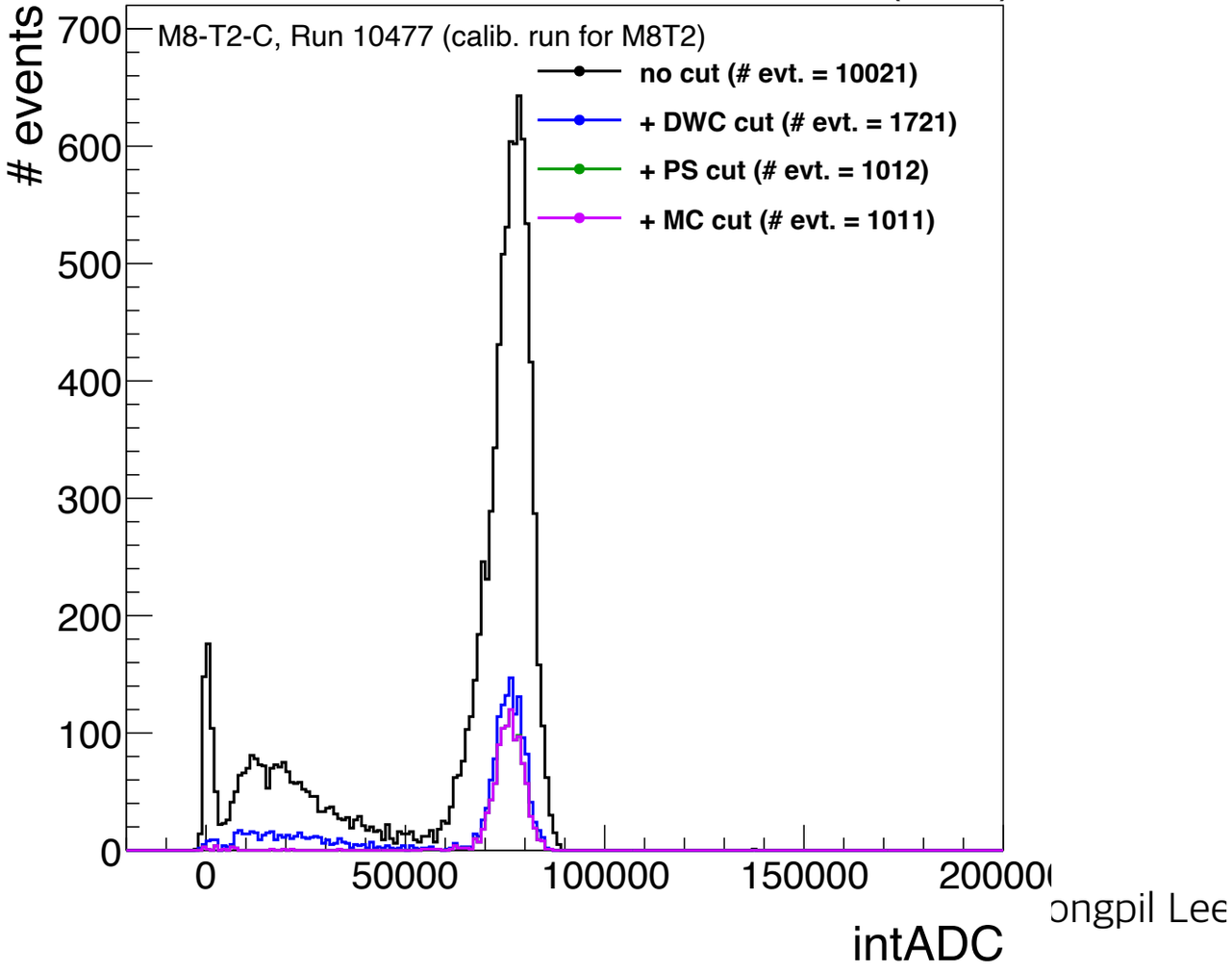
Muon counter

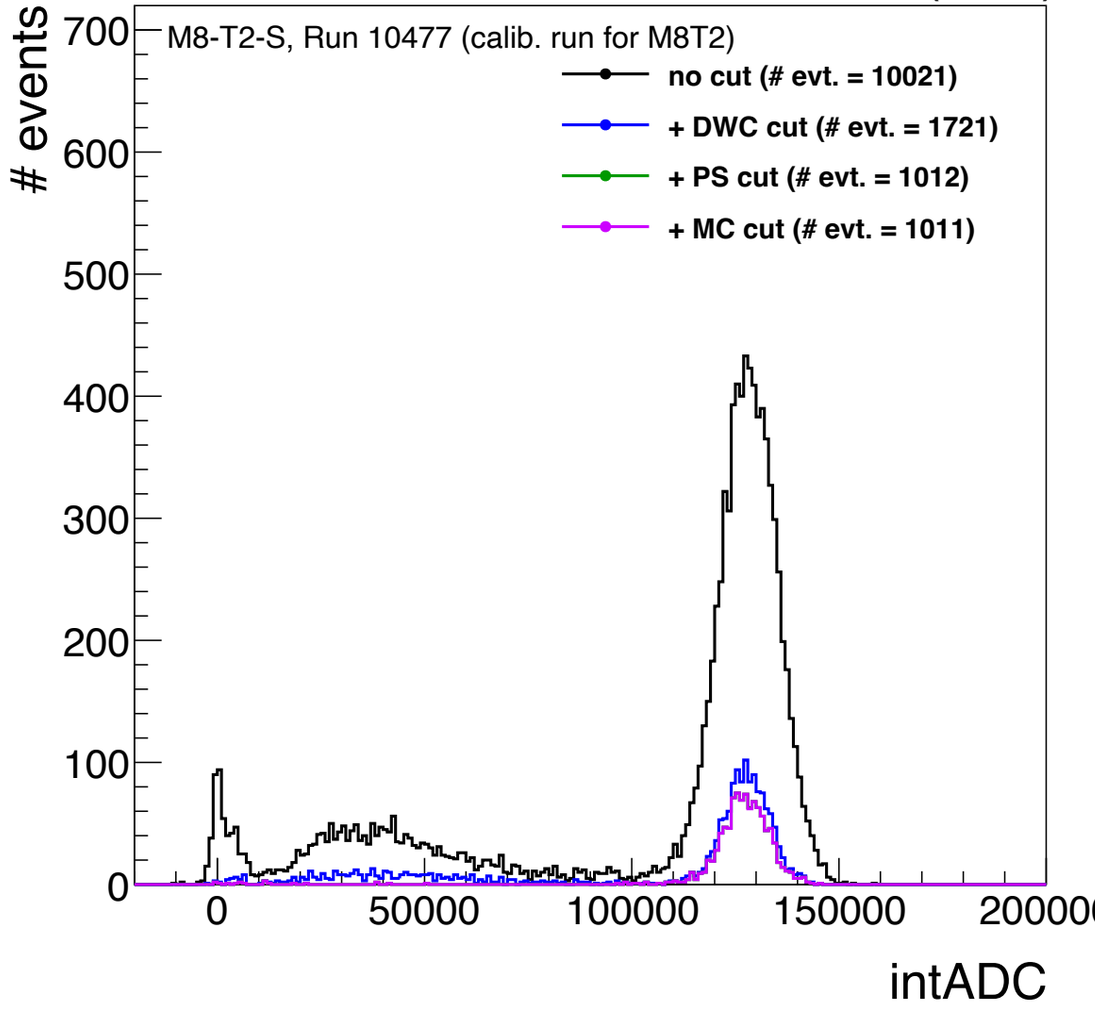


Event Selection: Cut Effects on DRC Signal

- Huge effect of **DWC** requirements (tight selection was applied)
- **Residual** backgrounds (muons & hadrons) below the peak region: **rejected by PS & MC**
- **~10%** events are survived after the event selection

Example of IntADC distribution @ Module 8, Tower 2 (M8-T2): ~10k events



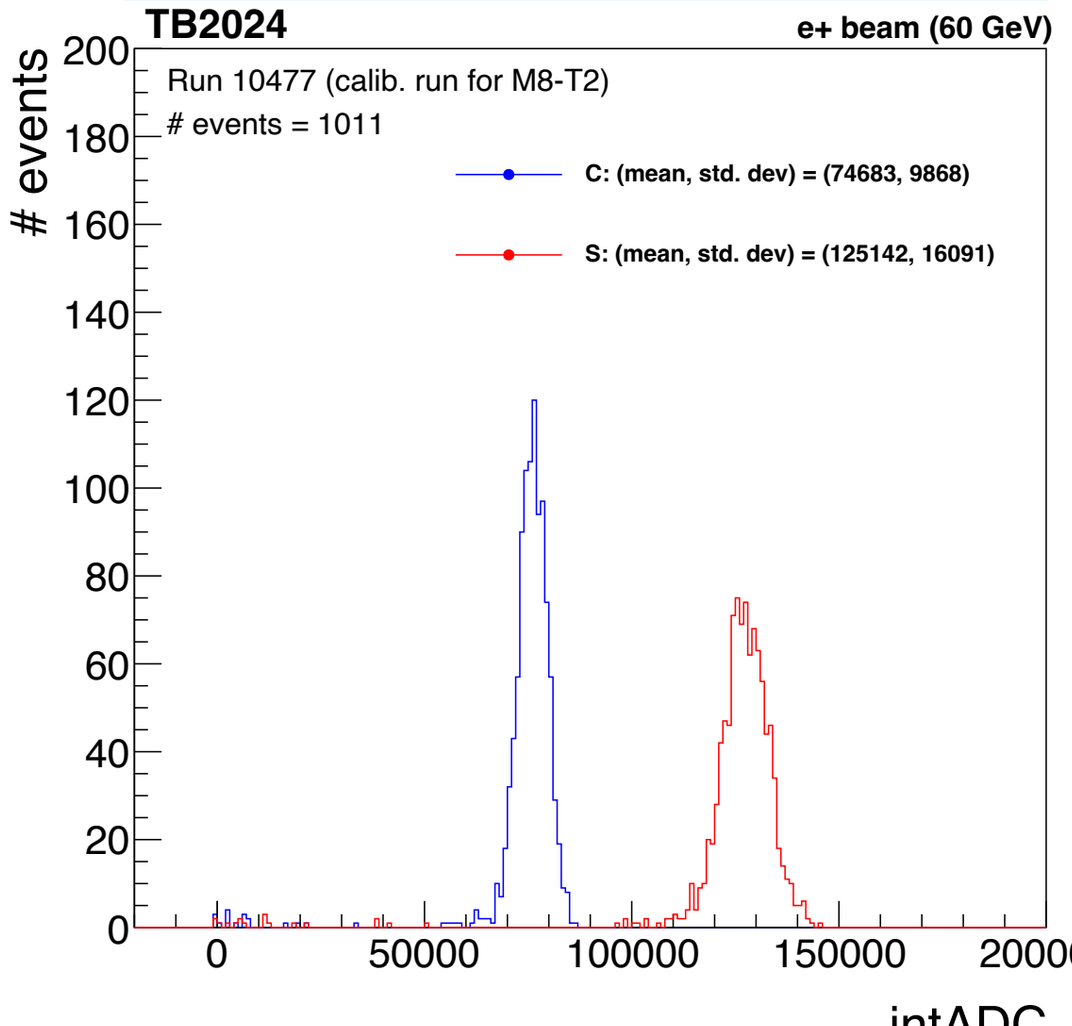


Calibration: Convert from IntADC to Energy Deposit

- Using the data with 60 GeV e+ beam for each tower (total 36 runs)
  - Observed intADC distribution: corresponds to 60 GeV energy deposit
    → Calibration constant (conversion factor) = **60 GeV / mean(intADC) for each tower**
- Before vs. after applying the calibration constant: M8-T2 as an example
  - Mean value is close to 60 GeV as expected

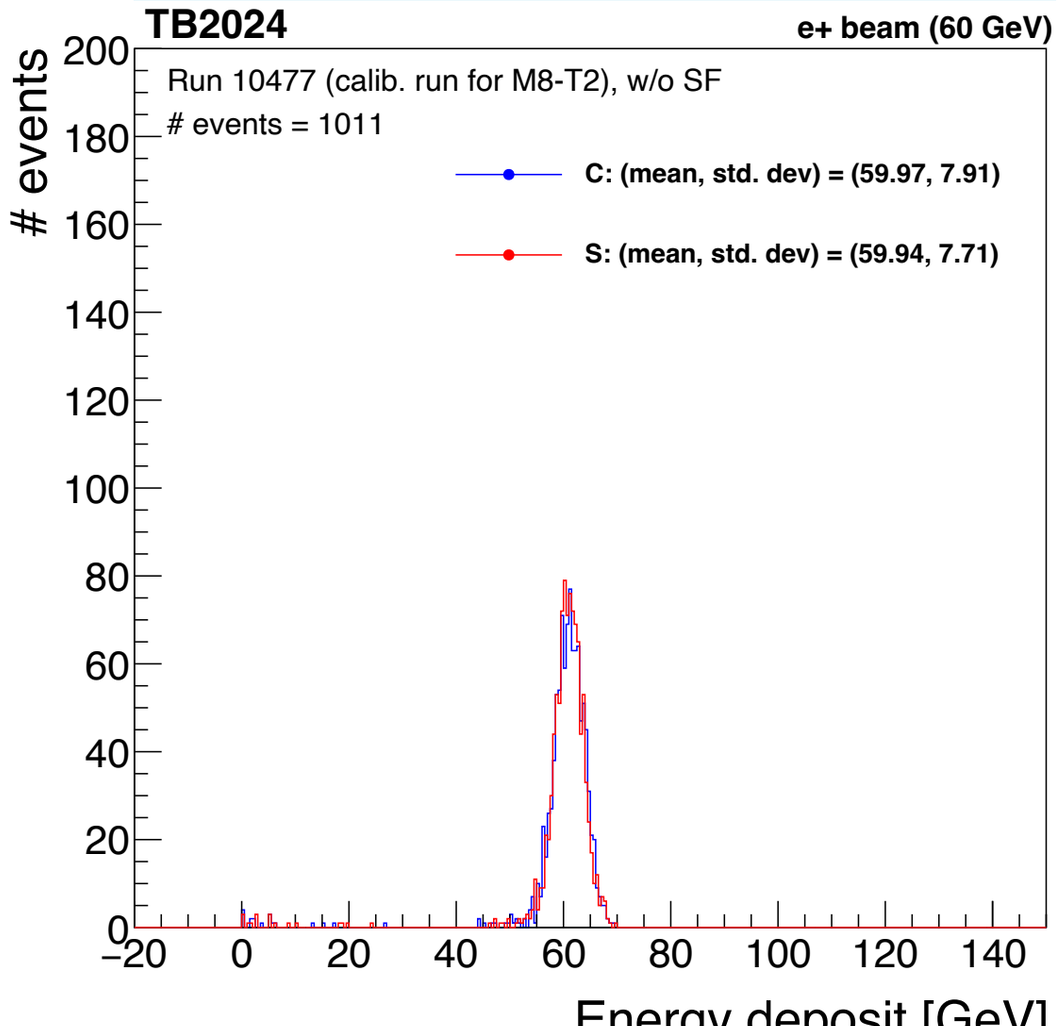
Example: signal on M8-T2

intADC



× calib. const.

Energy deposit

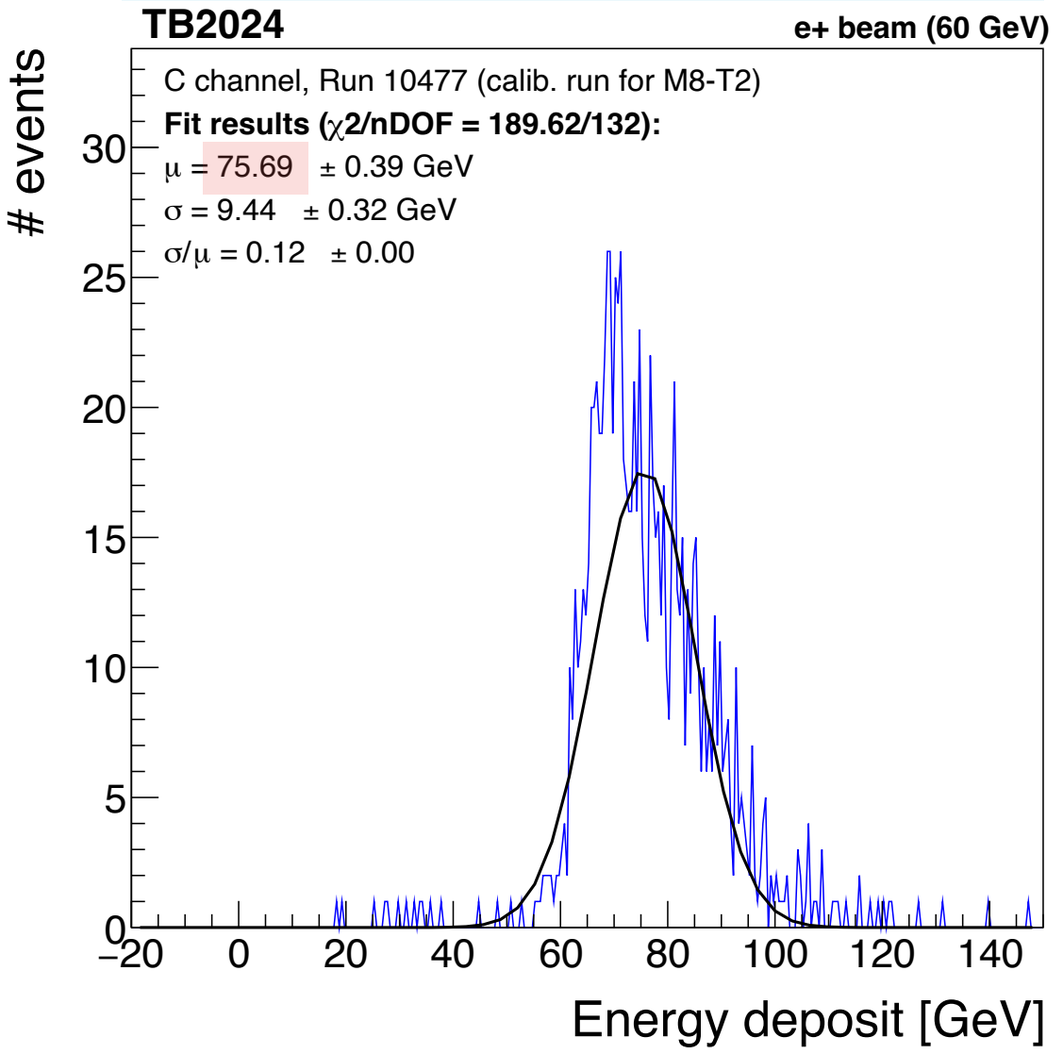


Second Calibration: Scale Factor

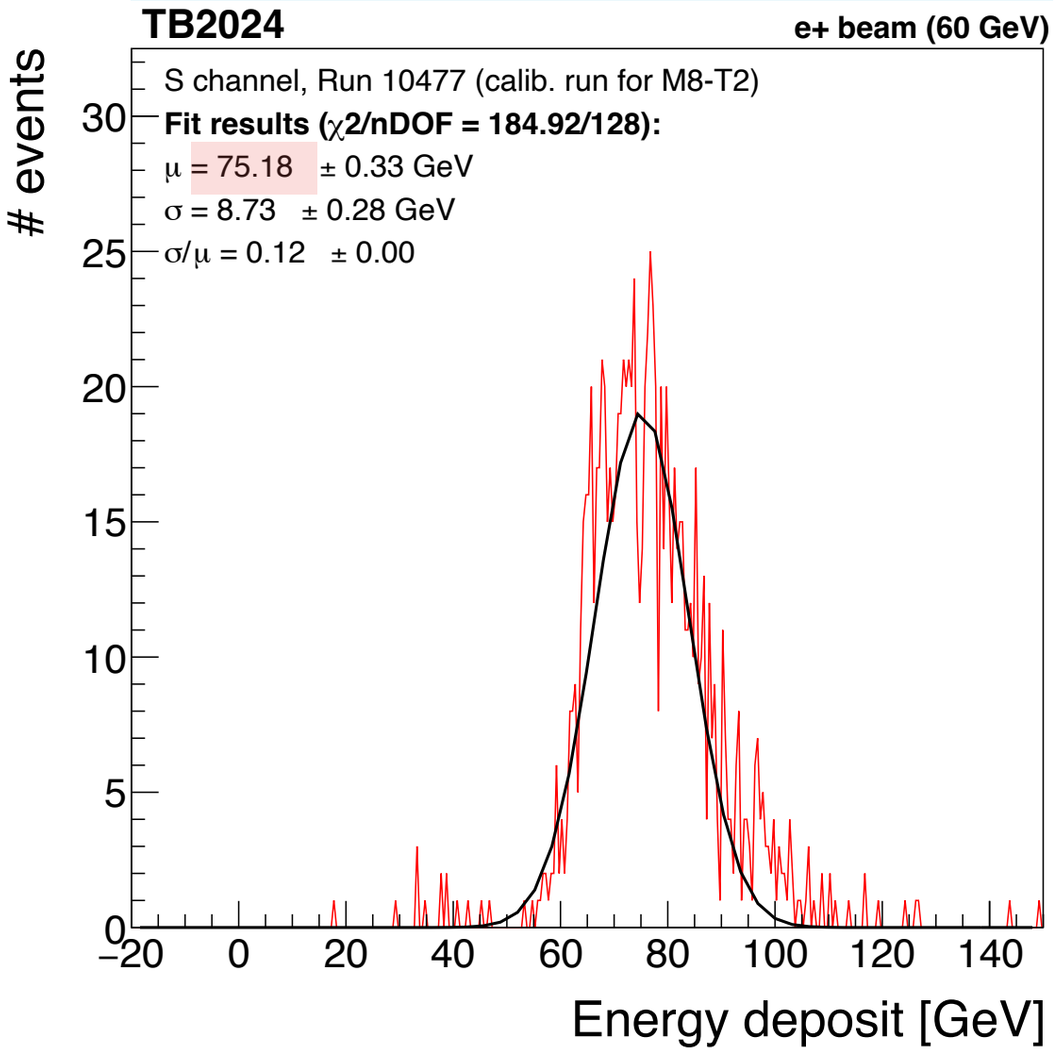
- **Match** the total energy deposit on DRC to the expected deposit on the DRC size
- Scale factor = **59.52 GeV / mean(total energy deposit in the DRC)**
  - 59.52 GeV = 60 GeV * 99.2%
    - 99.2%: expected energy deposit fraction from the simulation
  - SF(C) = 59.52 / 75.69 ~ **0.786**; SF(S) = 59.52 / 75.18 ~ **0.792**

Total energy deposit to the DRC (energy sum of all towers) before SF

C channel

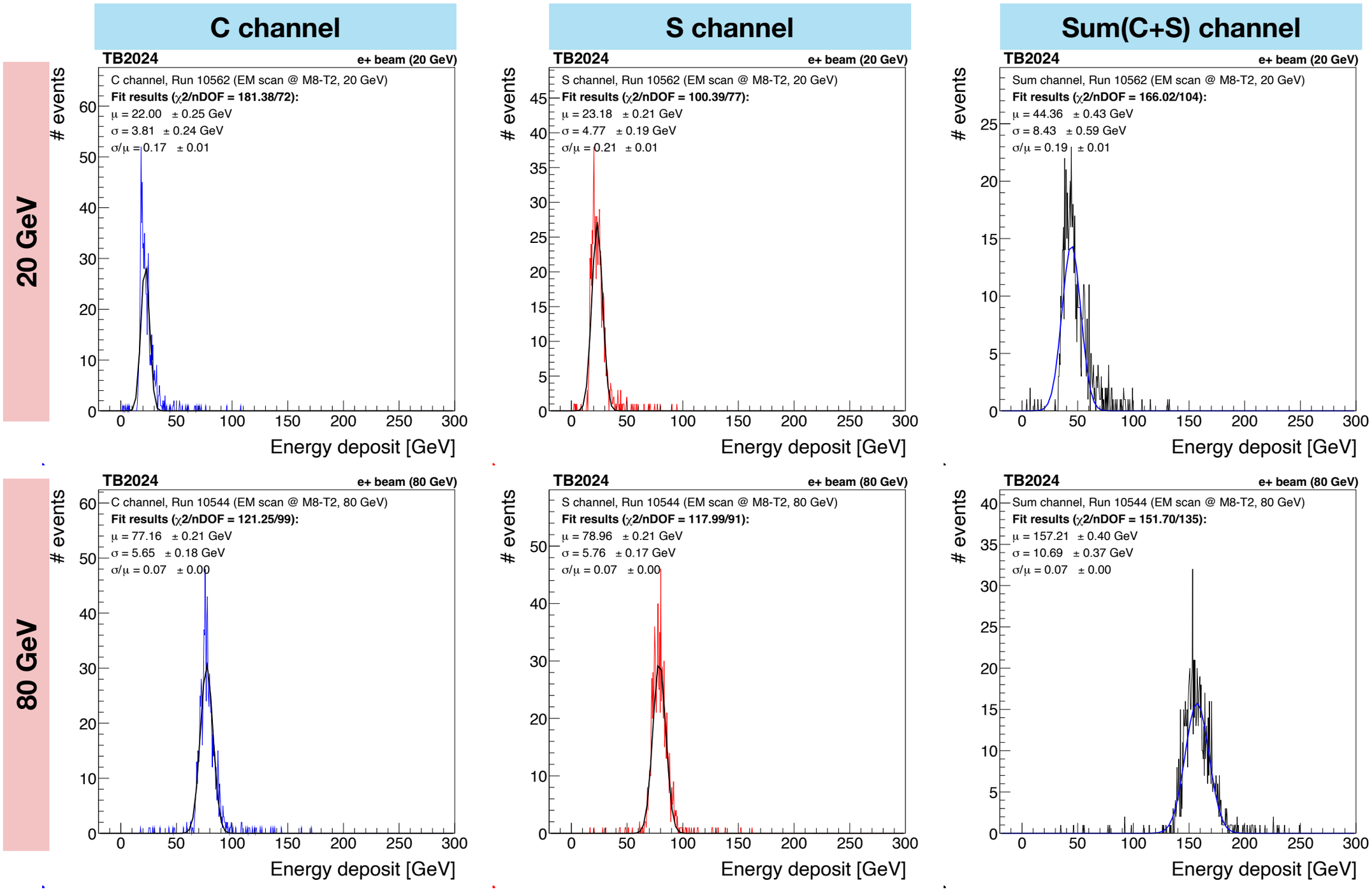


S channel



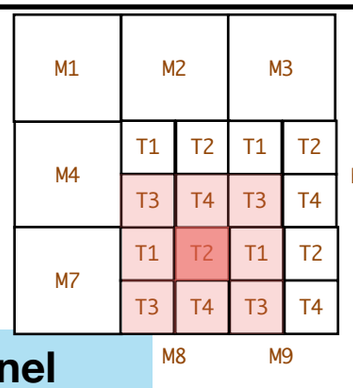
Energy Scan Results (Center: M8-T2)

- ✓ Two representative cases (20 and 80 GeV): Follow the **gaussian** distribution as expected
- ✓ However, the distribution seems too broad: maybe a noise effect from small-signal towers?
  - ✓ Check the distribution **using the towers near the center only (9 towers)**

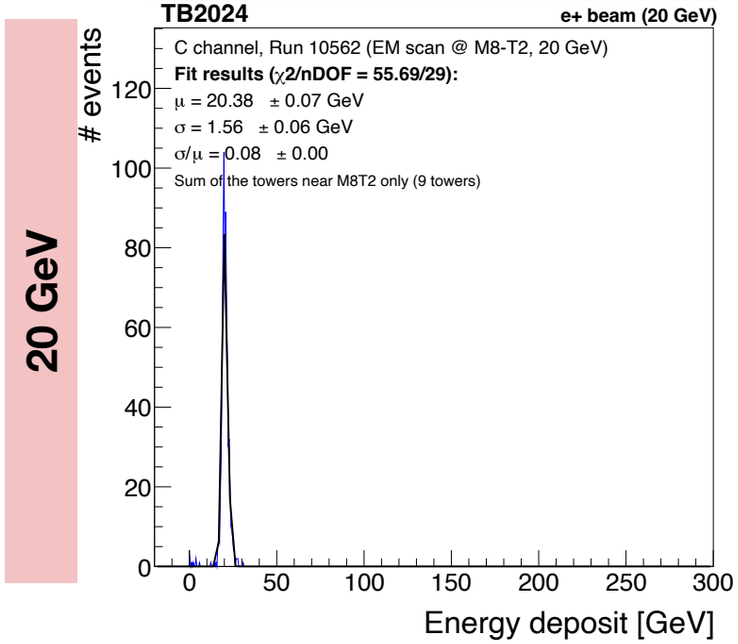


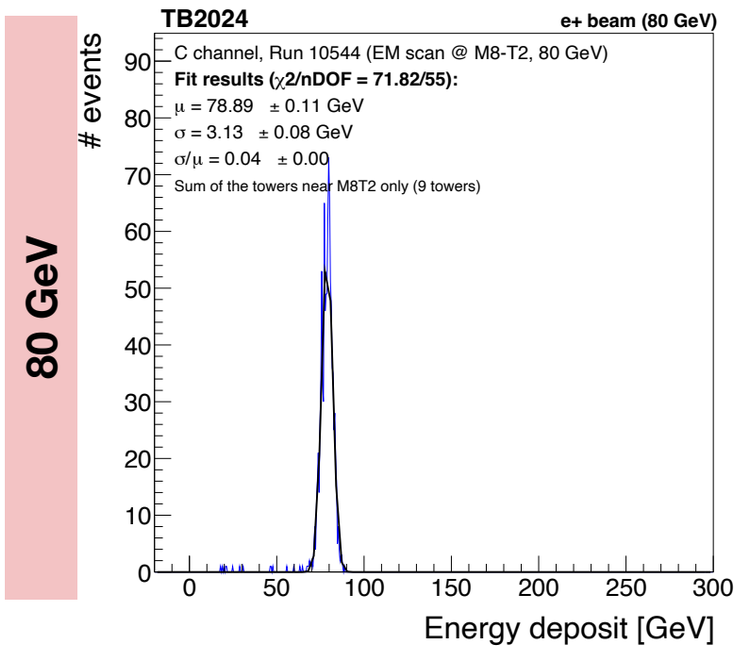
Energy Scan Results (Center: M8-T2)

- ✓ Distribution **using the towers near the center only (9 towers)**
  - ✓ The resolution has been **significantly improved** & **close to our expectation** from the simulation
  - ✓ The effect of the noise from small-signal towers (far from the beam center): under investigation

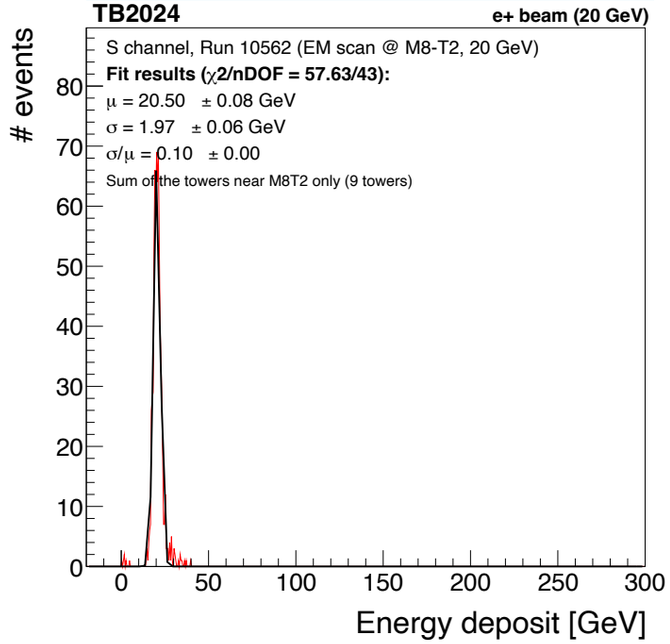


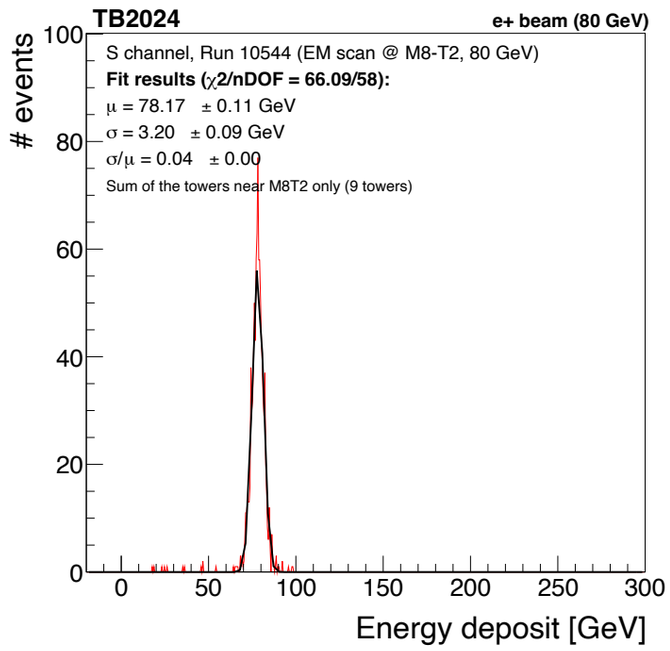
C channel



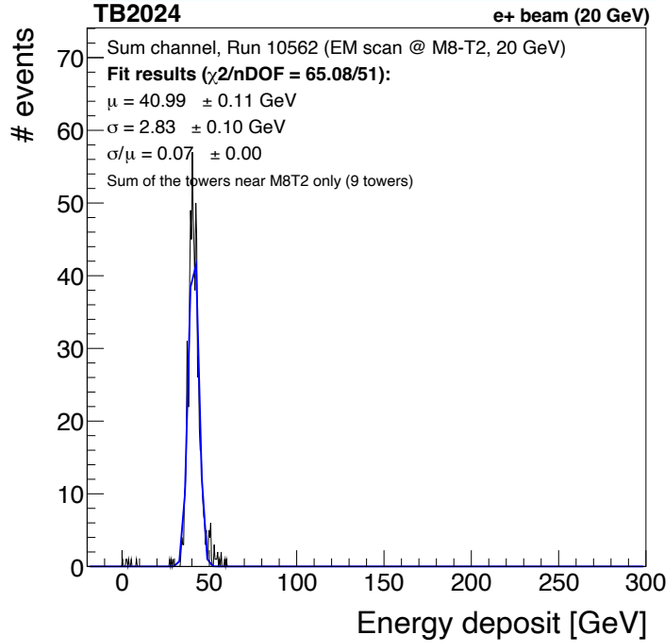


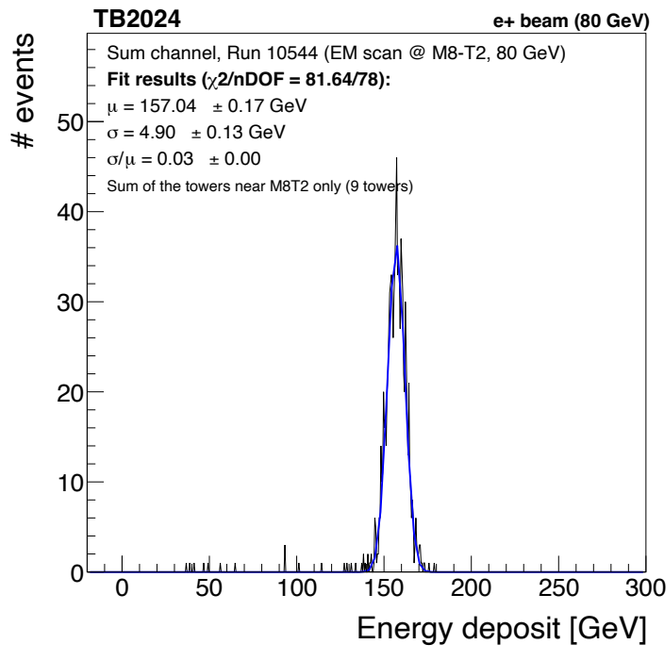
S channel





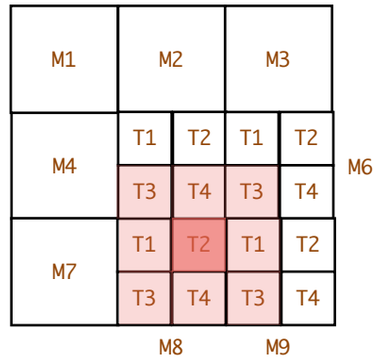
Sum(C+S) channel





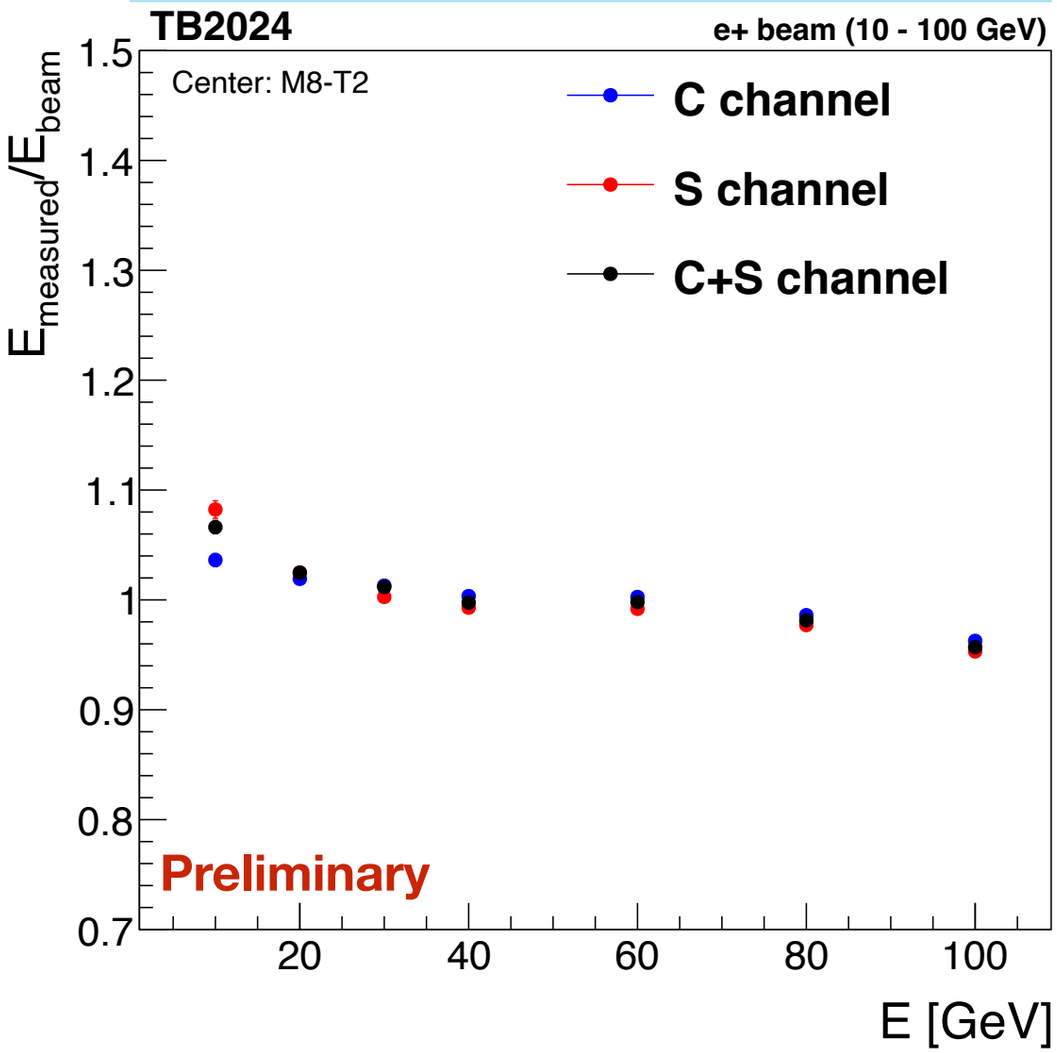
EM Resolution & Linearity: **Use 9 Towers Near the Center Only**

- Linearity & Resolution vs. energy using the **9 towers near the center only**
  - Linearity: close to 1.0 within ~5% in general
  - EM resolution: stochastic term < 20% in the summation channel

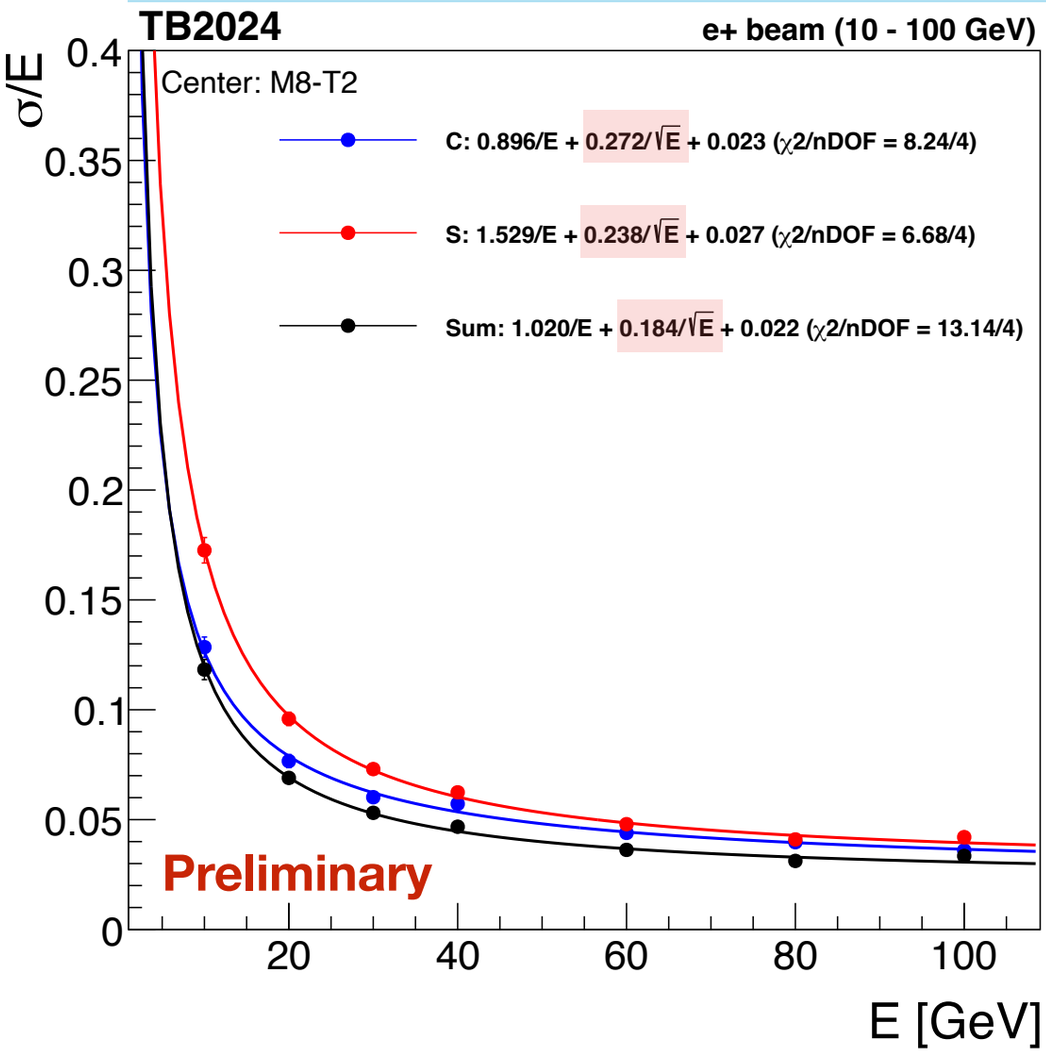


EM resolution & linearity results

Linearity



EM resolution vs. E



Summary

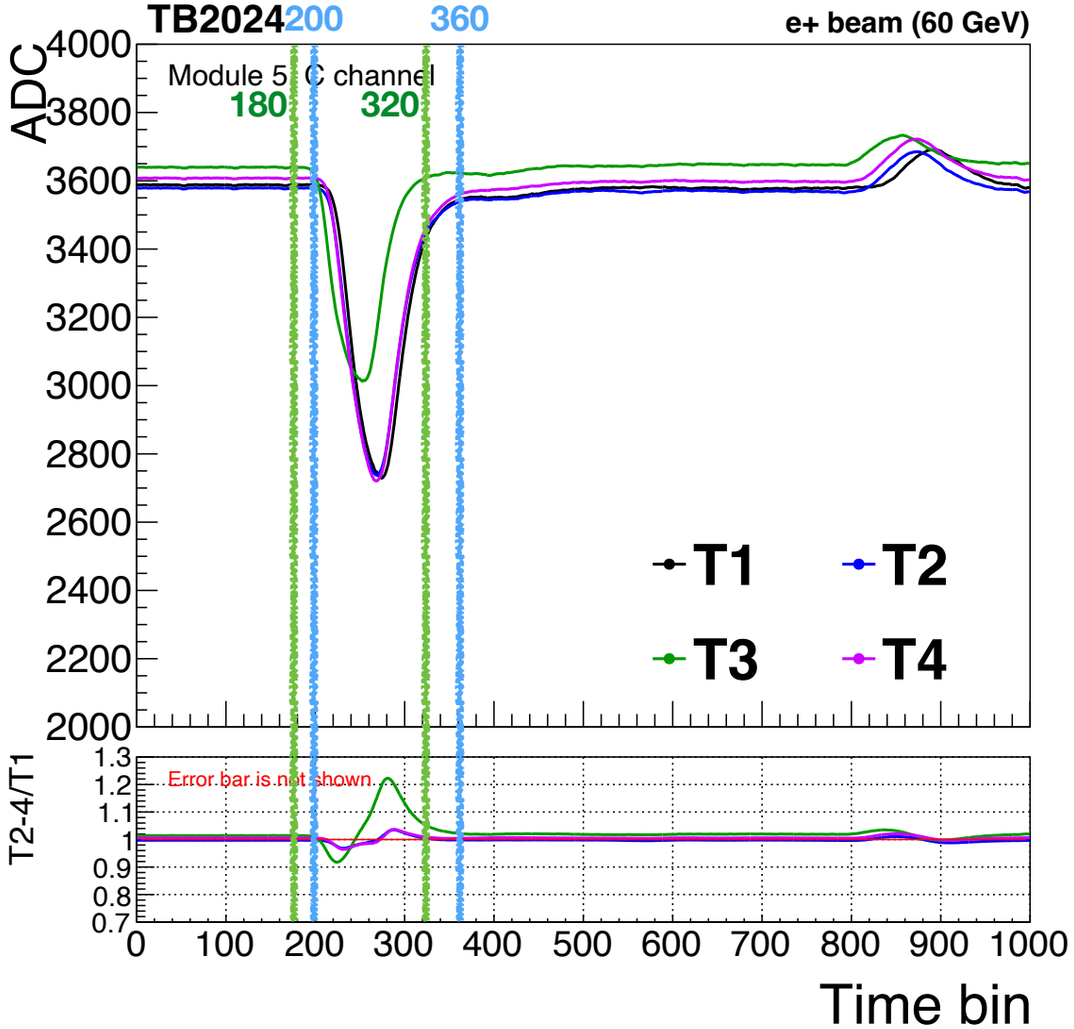
- Preliminary EM performance of the dual-readout calorimeter is presented
  - With the detector based on **copper** absorber in heat sink shape + C&S fibers inserted
    - Total 36 towers (9 modules) was produced by Korean group
  - Using the data collected in test beam experiment at **SPS H8** on **August 2024**
  - The results using all towers seem to be degraded from its expected performance: suspect **a noise effect** from the small-signal towers
  - The results based on the towers **near the center**: shows **reasonable** results
- Next step
  - Investigation on the noise effect & find a way to improve the results if possible
    - In terms of the time structure & pedestal distributions, etc
  - Develop a strategy to reduce the noise effect for the next test beam experiments

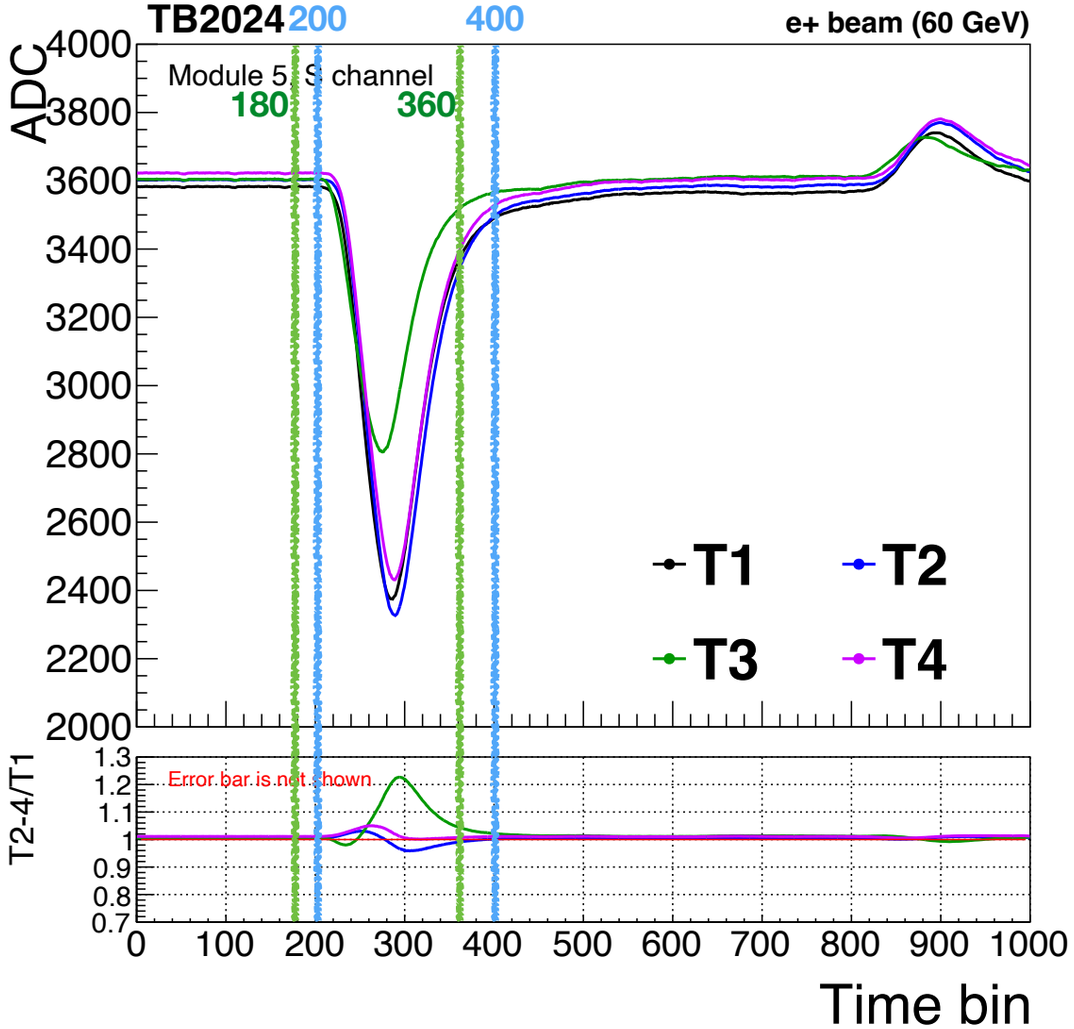
Backup

Average Time Structure: Module 5

- Integration range for M5 is adjusted because of its different timing than the other modules
  - T1, T2, T4: [200, 360] for C channel; [200, 400] for S channel
  - T3: [180, 320] for C channel; [180, 360] for S channel
    - Different timing characteristic due to its special PMT (MCP-PMT)

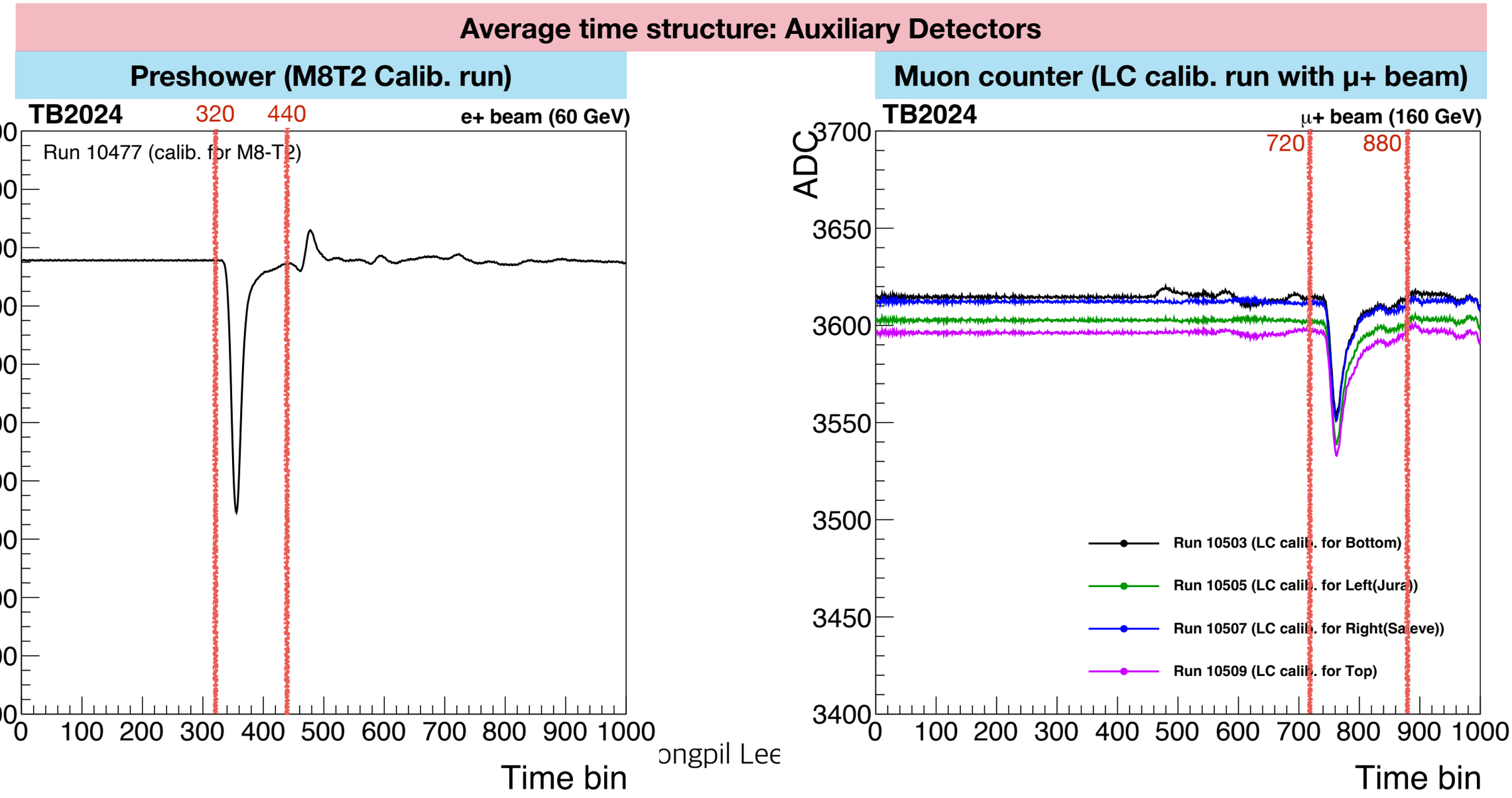
Average time structure: M5	
C channel	S channel





Average Time Structure: Aux. Detectors

- Determine the range for aux. detectors by checking the structure as well
  - Remark: only peakADC will be used → not sensitive to the fine tuning of the range
  - **Preshower: [320, 440]**
    - Consistency between runs is checked (over calibration runs: backup) → **common range over all runs**
  - **Muon counter: [720, 880]**
    - Consistent over the μ+ beam runs → **common range over all runs**



Event Selection: PS & MC

- Check the peakADC distribution before vs. after the cut applied
  - After preshower cut: ~40% rejected
  - After muon counter cut: almost no effect (already pure enough)
- Survival fraction of total event selection**: ~10%** (10021 → **1011** for Run 10477)