DT DPG Exercise on Segments

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CMS Physics Object & Data Analysis School

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CMS

HTTP://CERN.CH/GO/D9BT

IT'S EVERYONE'S RESPONSIBILITY TO:

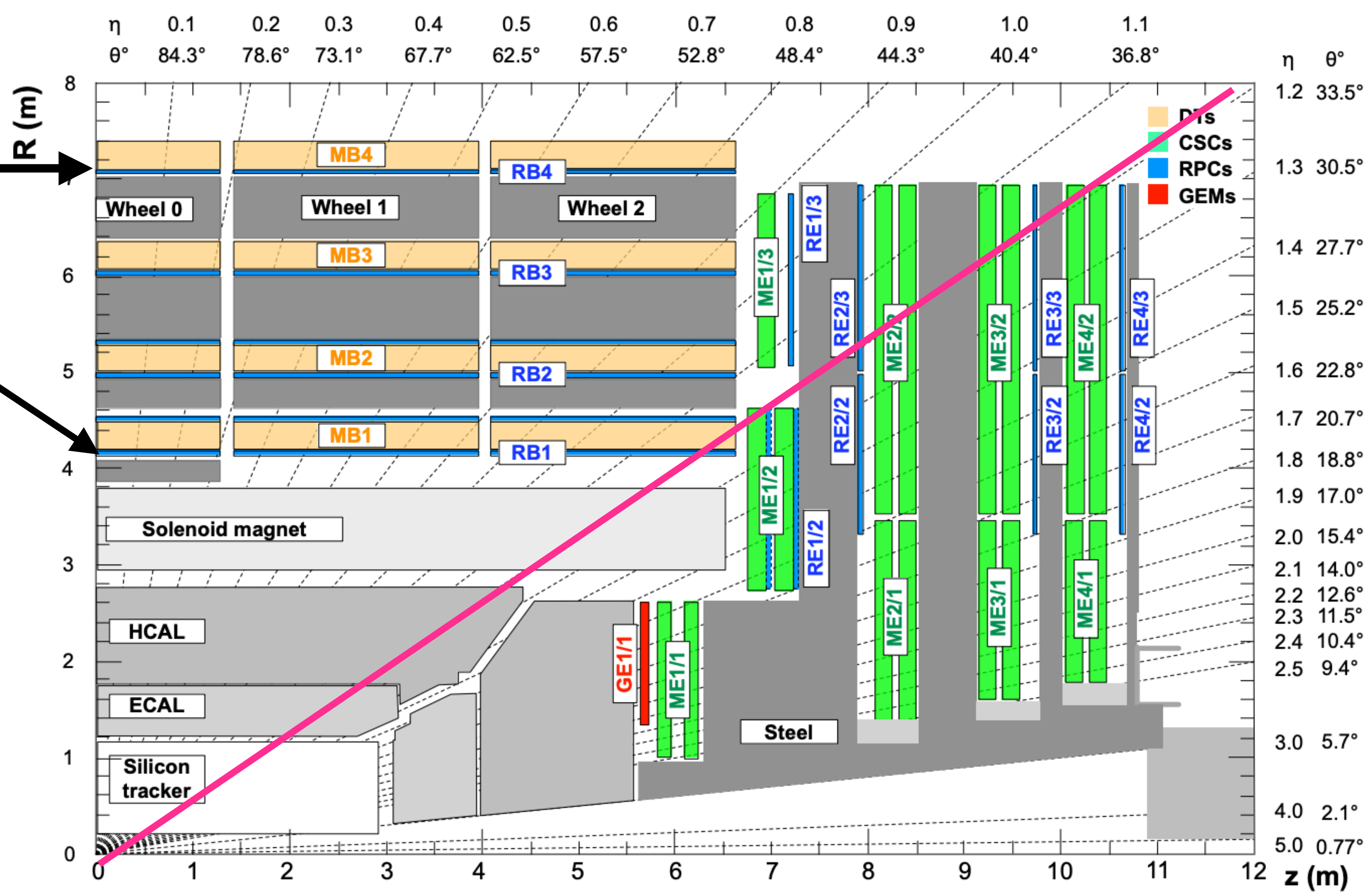
- Maintain a professional environment in an atmosphere of tolerance and mutual respect.
- Abstain from all forms of harassment, abuse, intimidation, bullying and mistreatment of any kind.
- This includes intimidation, sexual or crude jokes or comments, offensive images, and unwelcome physical conduct.
- Keep in mind that behaviour and language deemed acceptable to one person may not be to another.
- Help our community adhere to the code of conduct and speak up when you see possible violations.

Outline

- CMS Drift Tube (DTs) Chambers
  - Introduction, layout, design
- Local reconstruction (hit/segment) in Drift Tubes
- DT Trigger system
- Introduction to the DT calibrations
- DT exercise on Segments

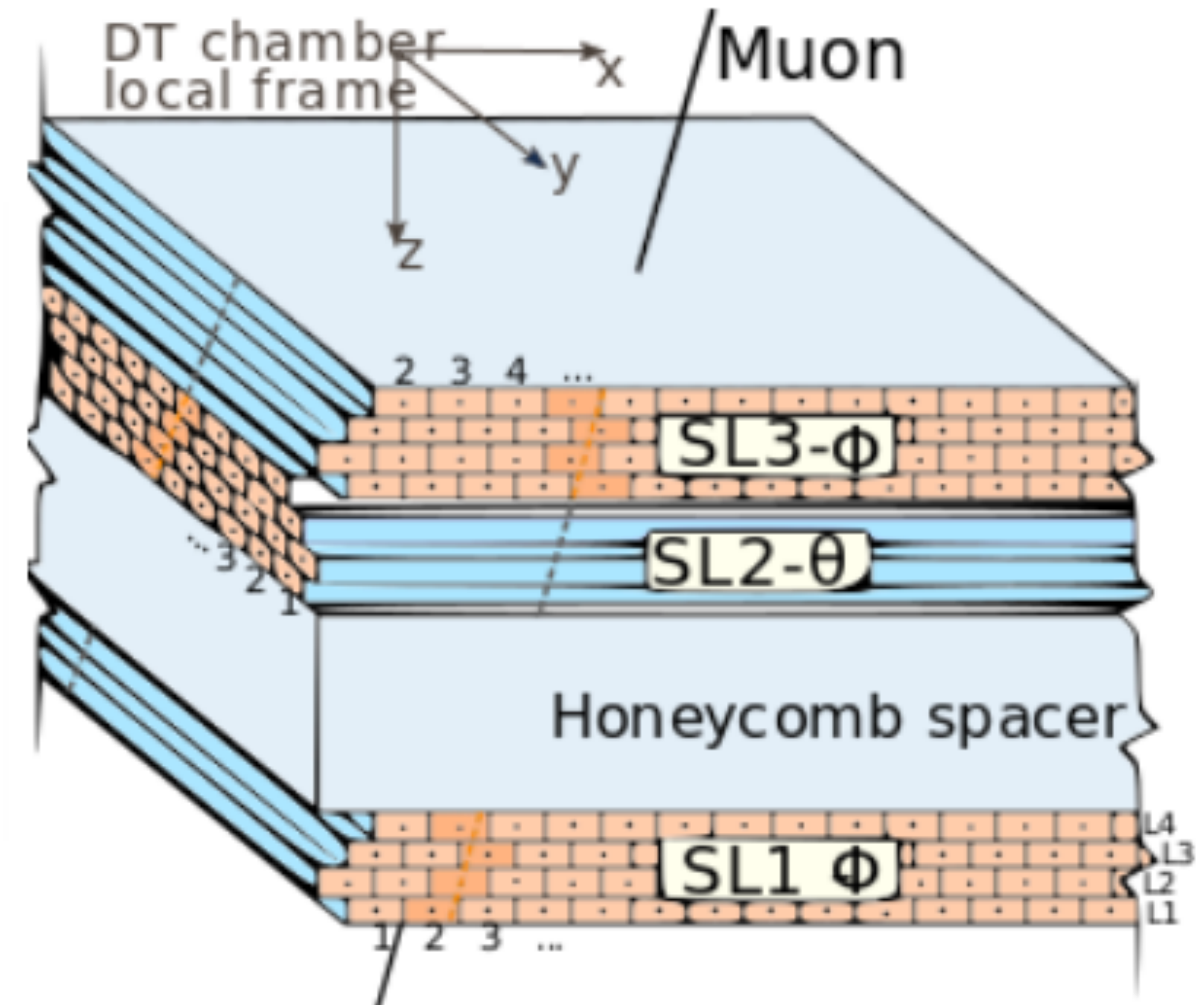
❋ **Gitlab link : https://gitlab.cern.ch/cms-podas23/dpg/dt-dpg-exercise**

DT : Overview



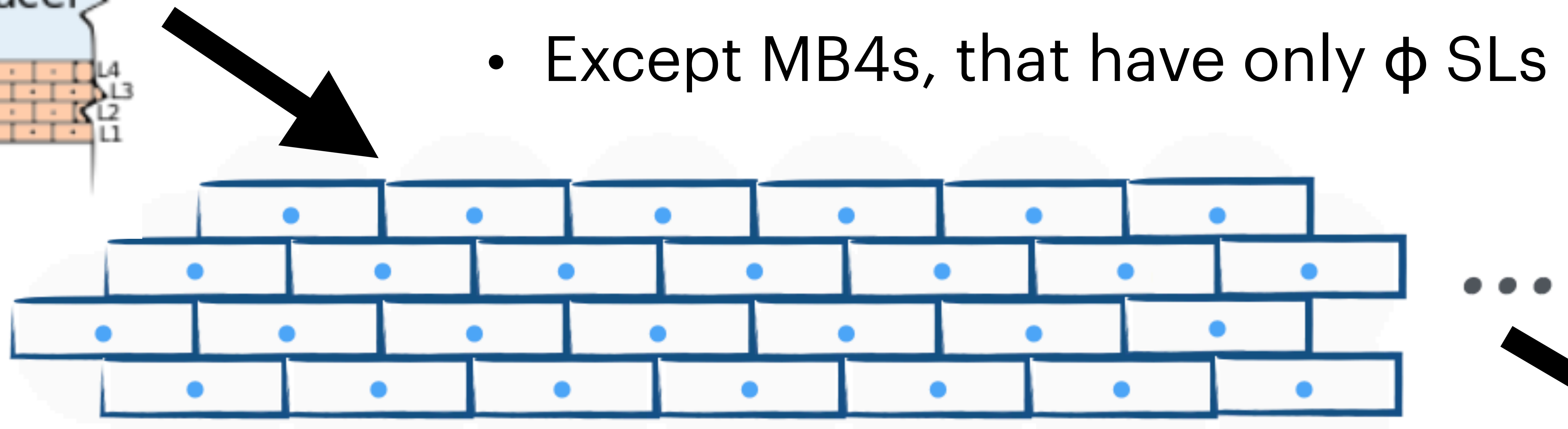
- DTs are a tracking detector with trigger capabilities
- The full system consists of 250 chambers
- Covers the muon spectrometer barrel $|\eta| \leq 1.2$

Layout of a DT Chamber

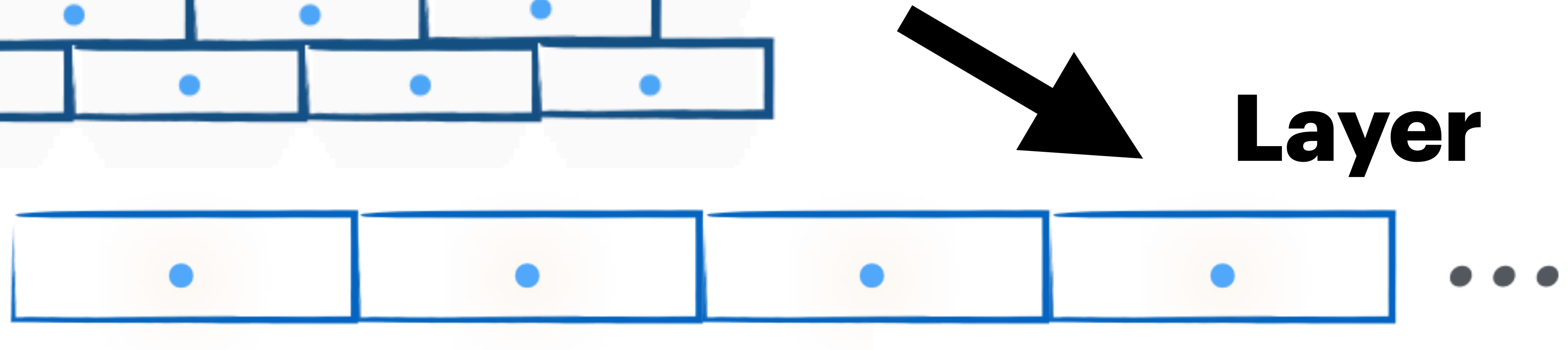


Chamber

- 3 superlayers (SL) per chamber
  - 2 ϕ SLs: wires parallel to beam axis, measure R-ϕ (the plane where a muon bends)
  - 1 θ SL: wires normal to beam axis, measures R-z
- Except MB4s, that have only ϕ SLs

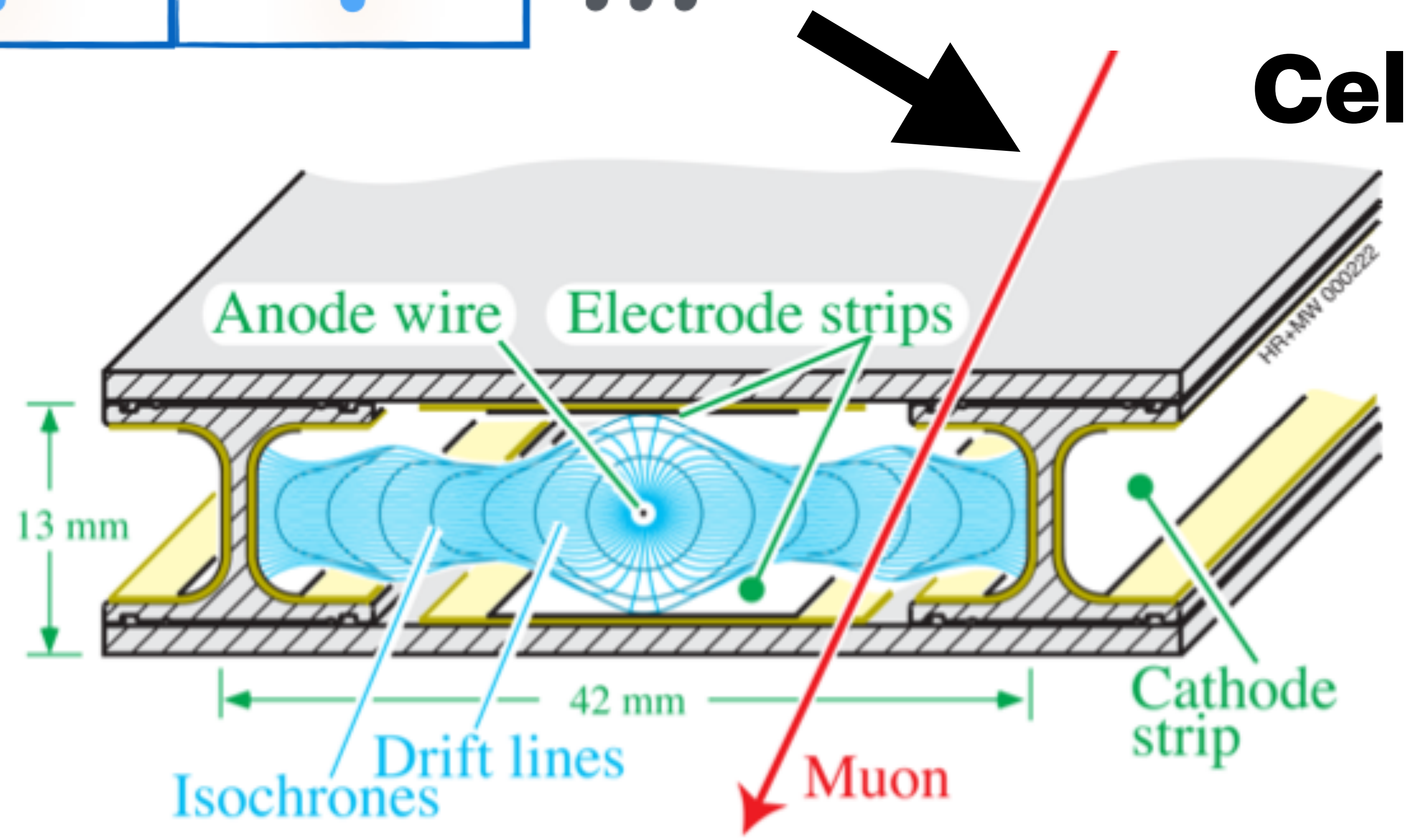


Superlayer



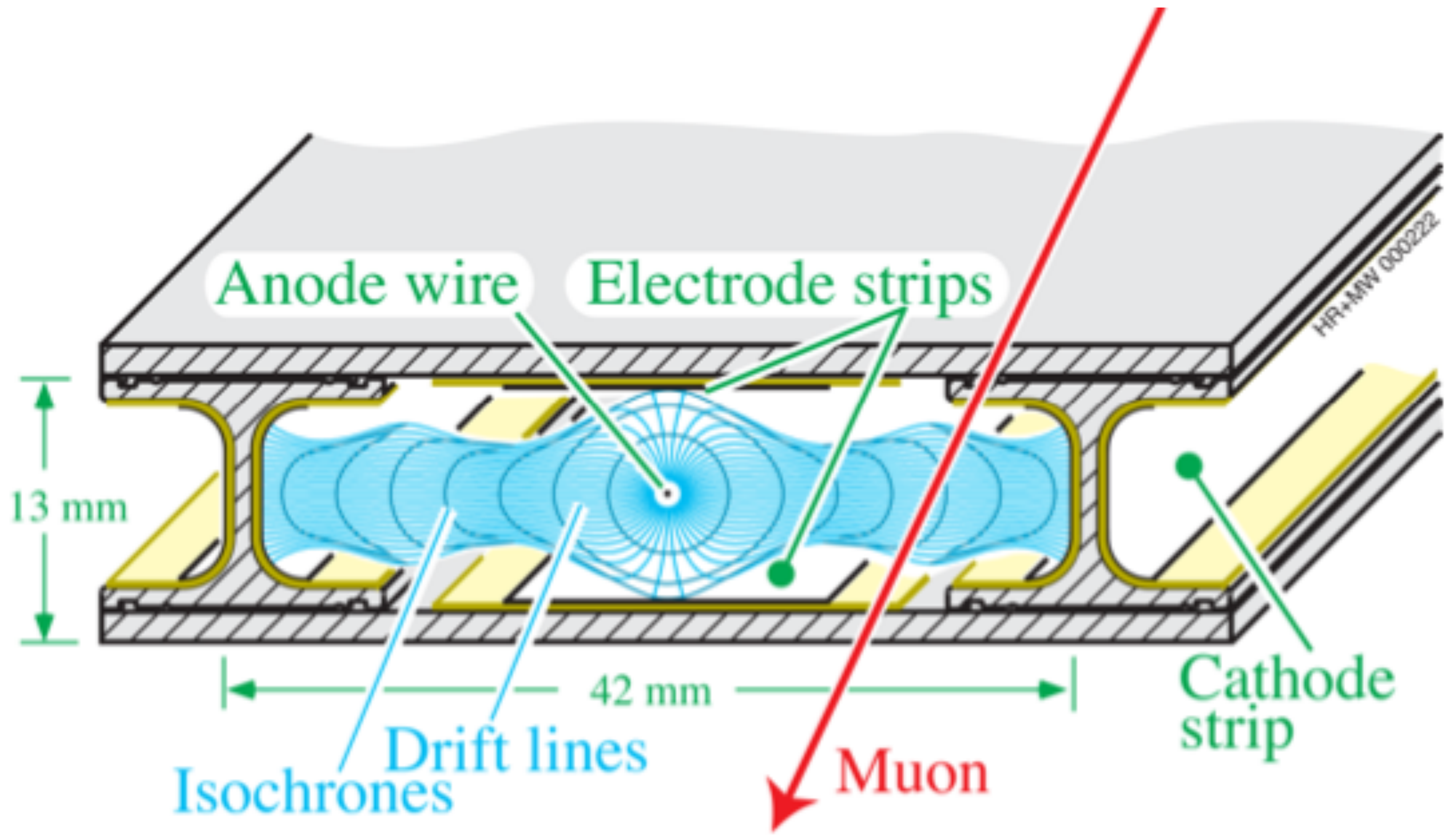
Layer

- SLs built of 4 layers (numbered: 1 to 4):
  - ➡Layers of odd/even number staggered of half-cell
- Layers built of consecutive cells:
  - # of cells per ϕ layer varies from 49 (MB1) to 96 (MB4)
  - θ layer have (usually) around 57 cells



Cell

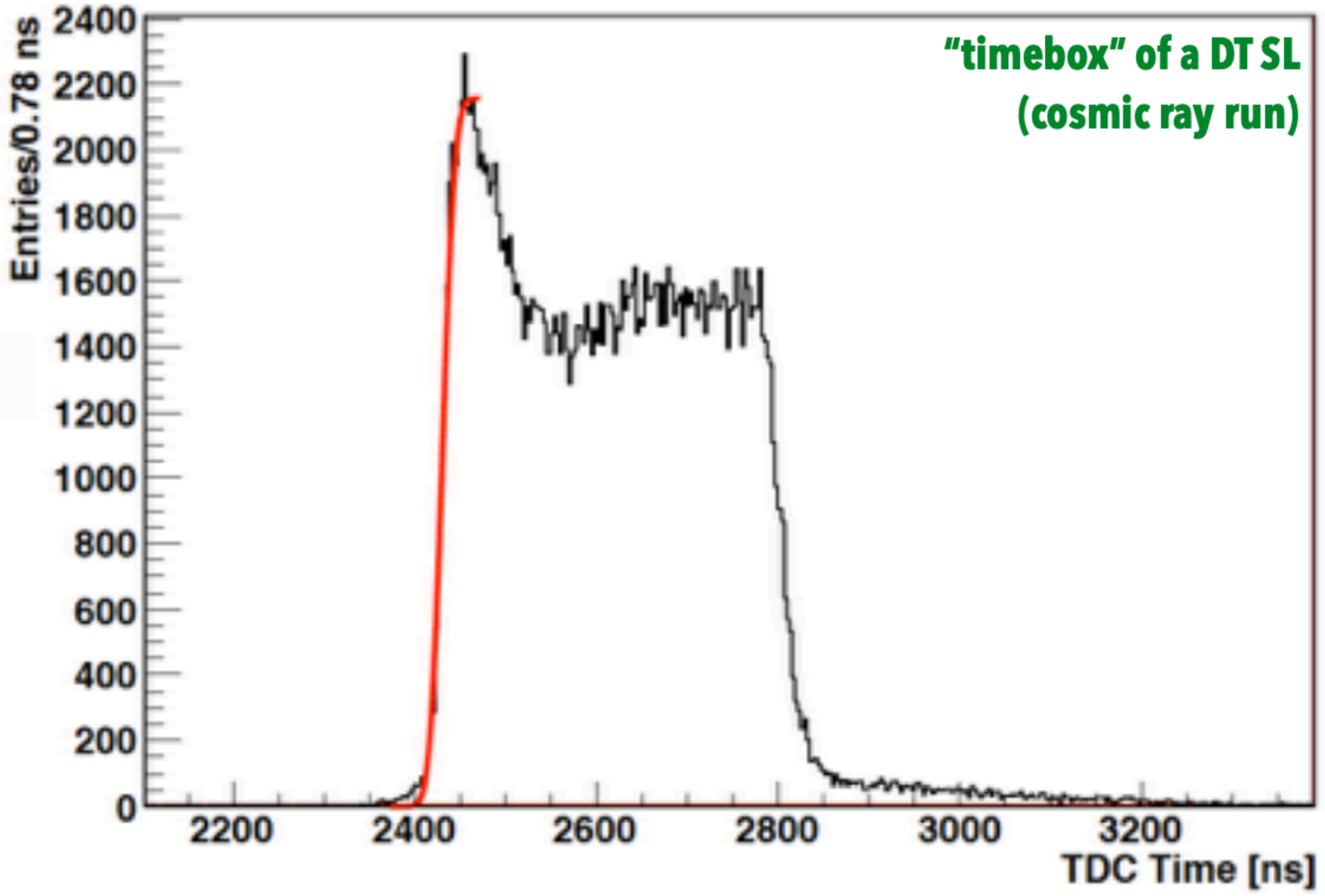
The Drift Cell



- DT cell structure :
  - ➡Size : 4.2 cm x 1.3 cm
  - ➡Anode wire (50 µm thick, 3600 V)
  - ➡2 cathode strips (I beams , -1200 V)
  - ➡2 extra electrode strips (improve field shape)

❋ **Designed to get almost uniform drift velocity**

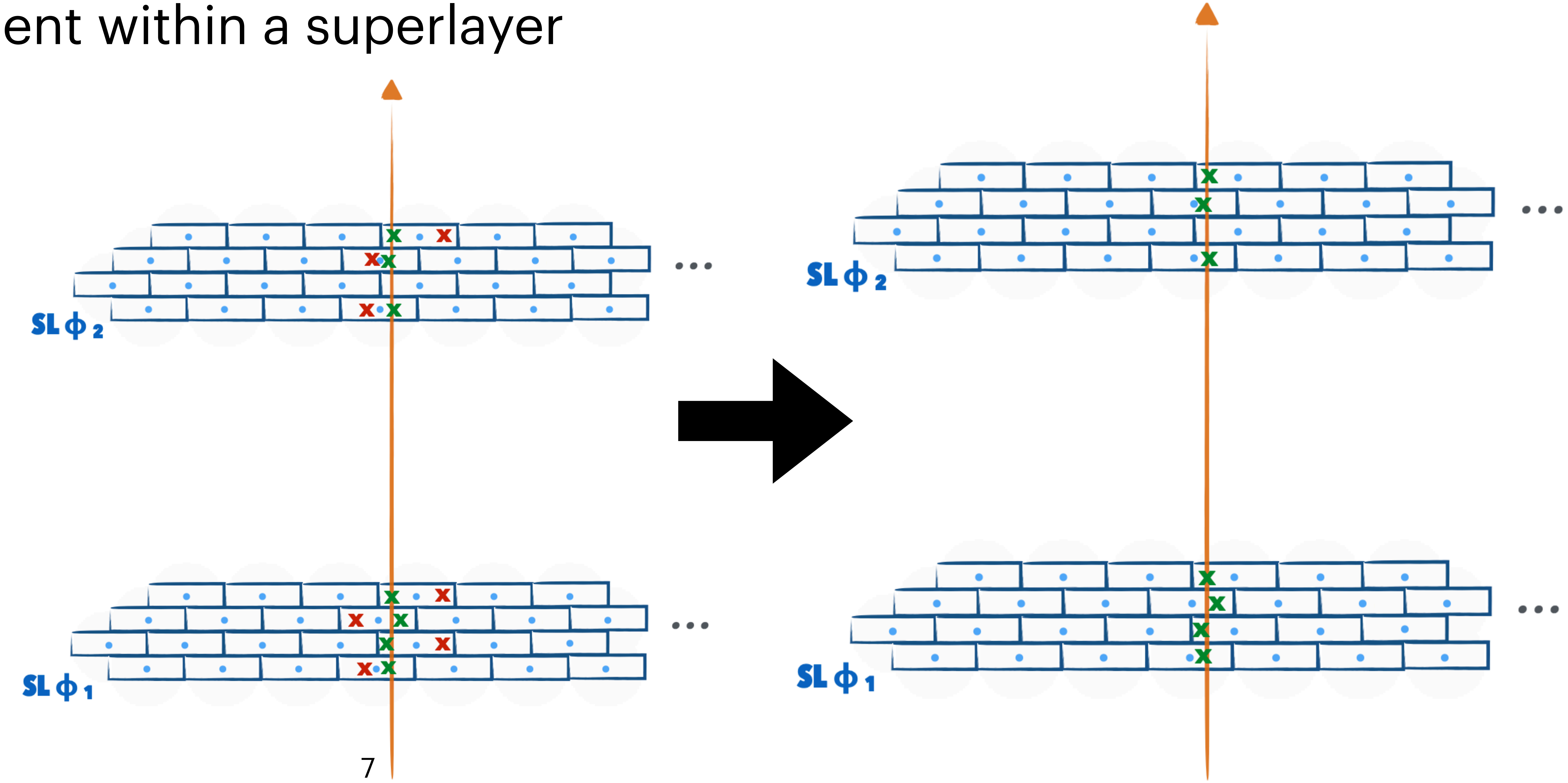
- Working principle :
  - ➡A muon crosses the cell ➜ ionizes the gas producing charge
  - ➡The charge drifts toward the wire ➜ it gets multiplied (large ΔV)
  - ➡L1 trigger “accepts” the event ➜ the signal is read
  - ➡ Time pedestals (t0) are subtracted (*) ➜ time is converted to position



❋ **Time pedestals get measured by the DT calibration process, explained in next slides**

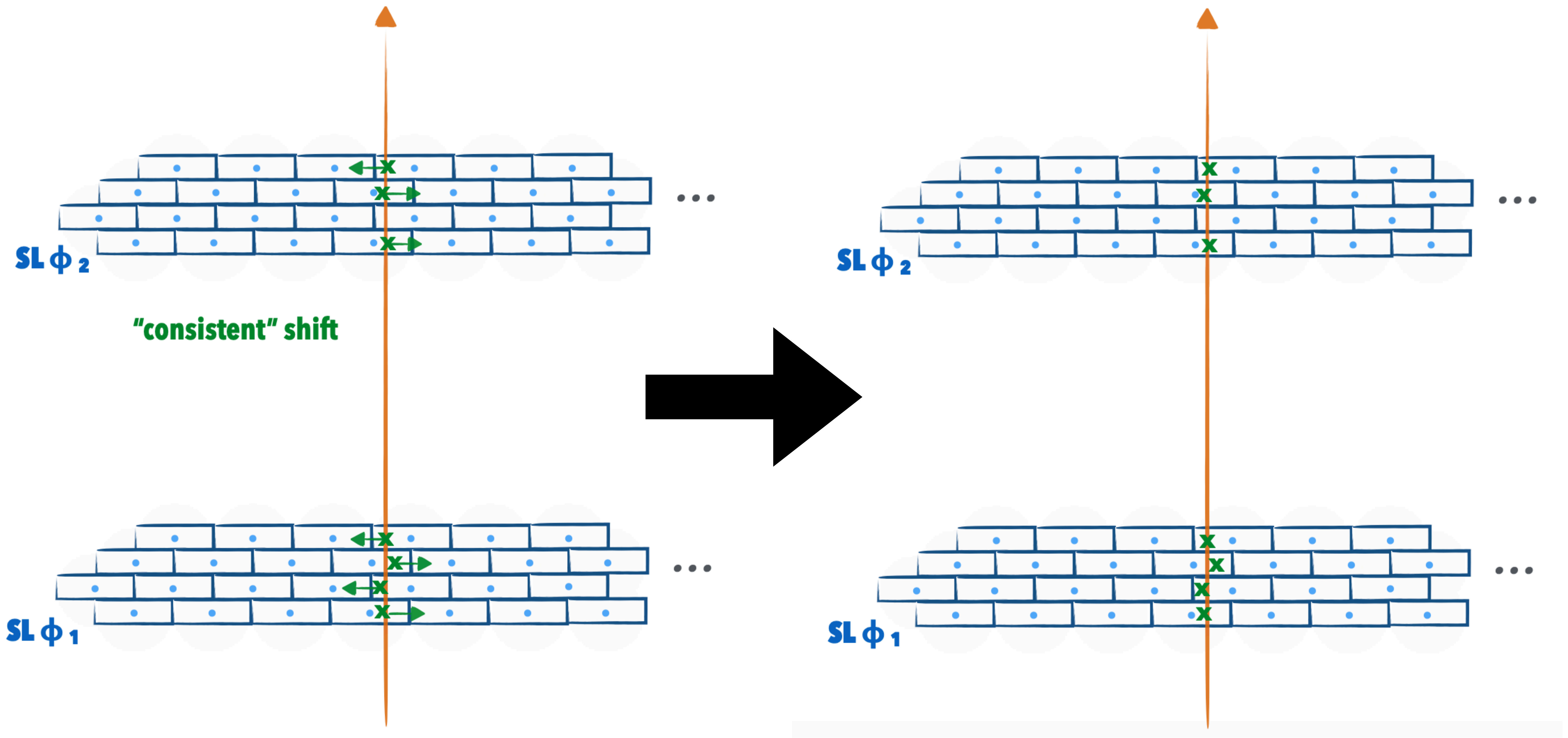
DT Local Reconstruction

- DT local reconstruction starts from the "RecHits"
  - ➡Built by computing the drift distance corresponding to the measured drift time
  - ➡Reconstruction at the cell level : the L/R ambiguity is unsolved and the position of the hit along the wire is not yet determined
- Hits are used to build a segment within a superlayer
- Segment reconstruction logic :
  - ➡Select a set of hits by fitting them in a straight line
    - L/R ambiguity is solved



DT Local Reconstruction

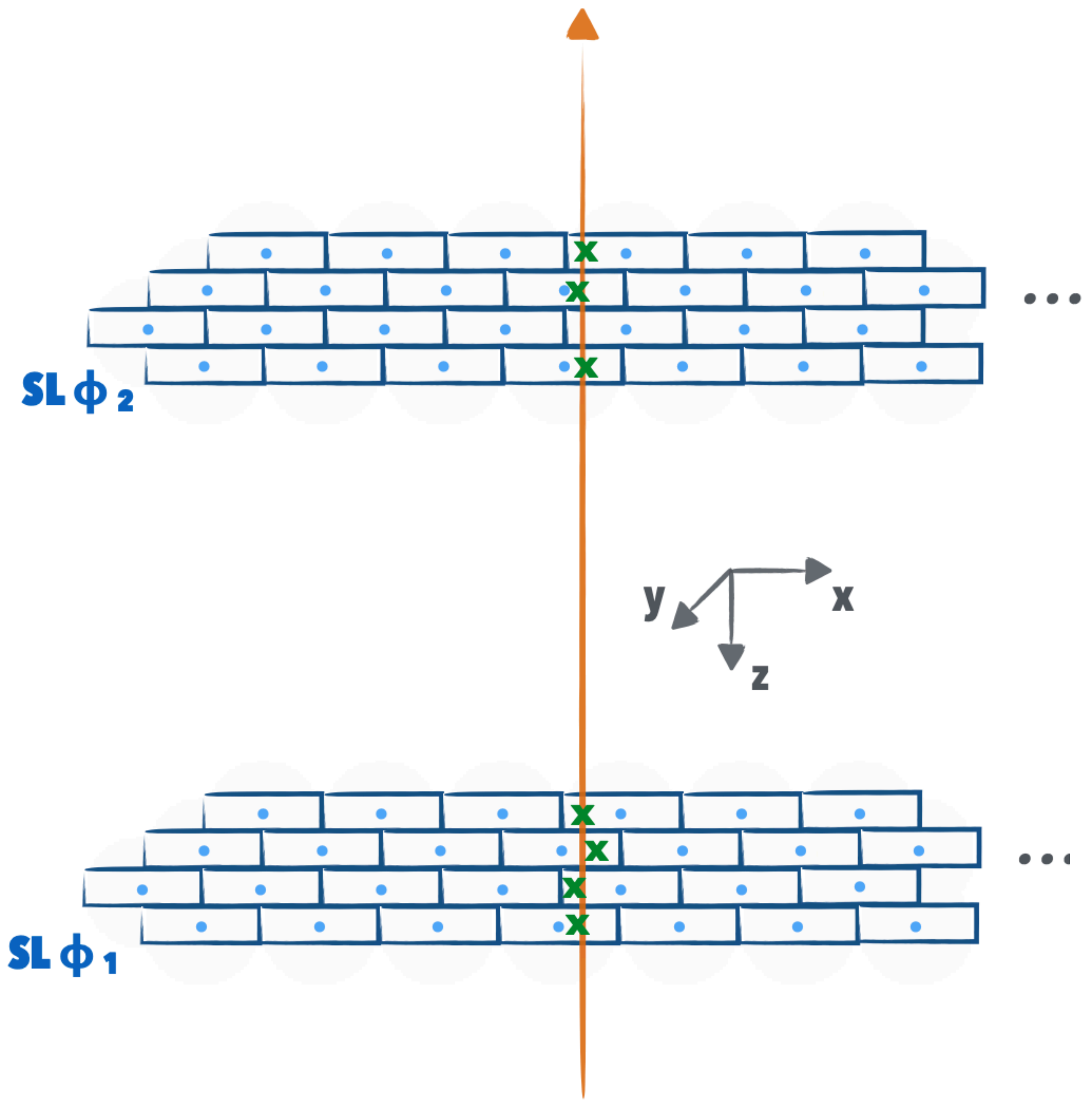
- Segment reconstruction logic :
  - ➡ Select a set of hits by fitting them in a straight line
    - ✓ Segment time (t) is included as fit parameter
      - time induces a “consistent” shift of hits
      - Can be measured if d.o.f. are enough

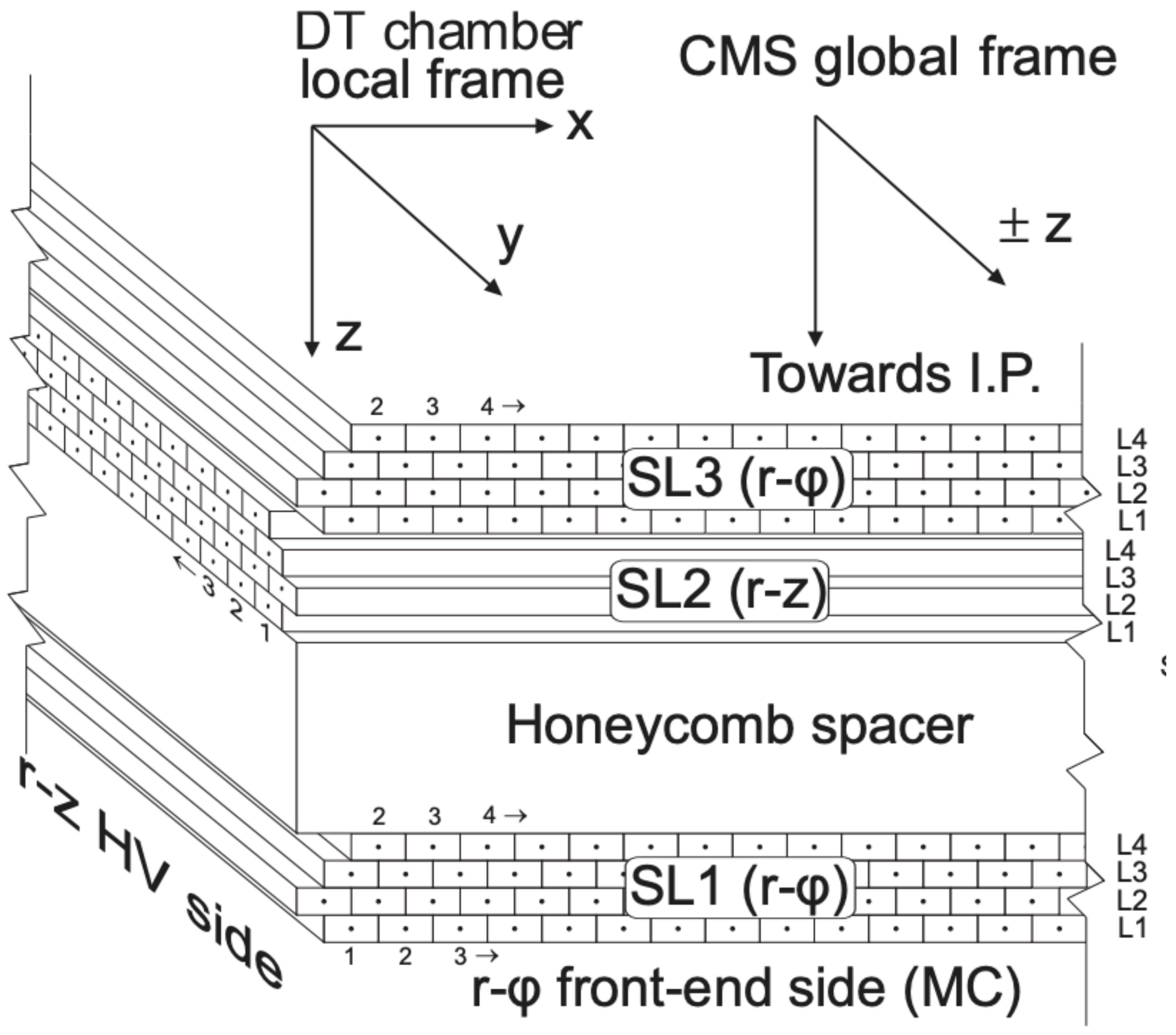


- Schema shown here for R-ϕ, fit also performed in θ
  - ➡ information from both views can be combined
    - Refit (correcting for signal propagation along wires)
    - Improved segment resolution
  - ➡ Multiple segments/chamber give pairing ambiguity
    - Solved when muon tracks are built

DT Local Reconstruction

- **DT local coordinates**
  - ➡Cartesian reference frame
    - Local x: measured by ϕ SLs
    - Local y: measured by θ SL
    - Local z: points toward inner part of CMS
    - Origin: ~ centre of a chamber

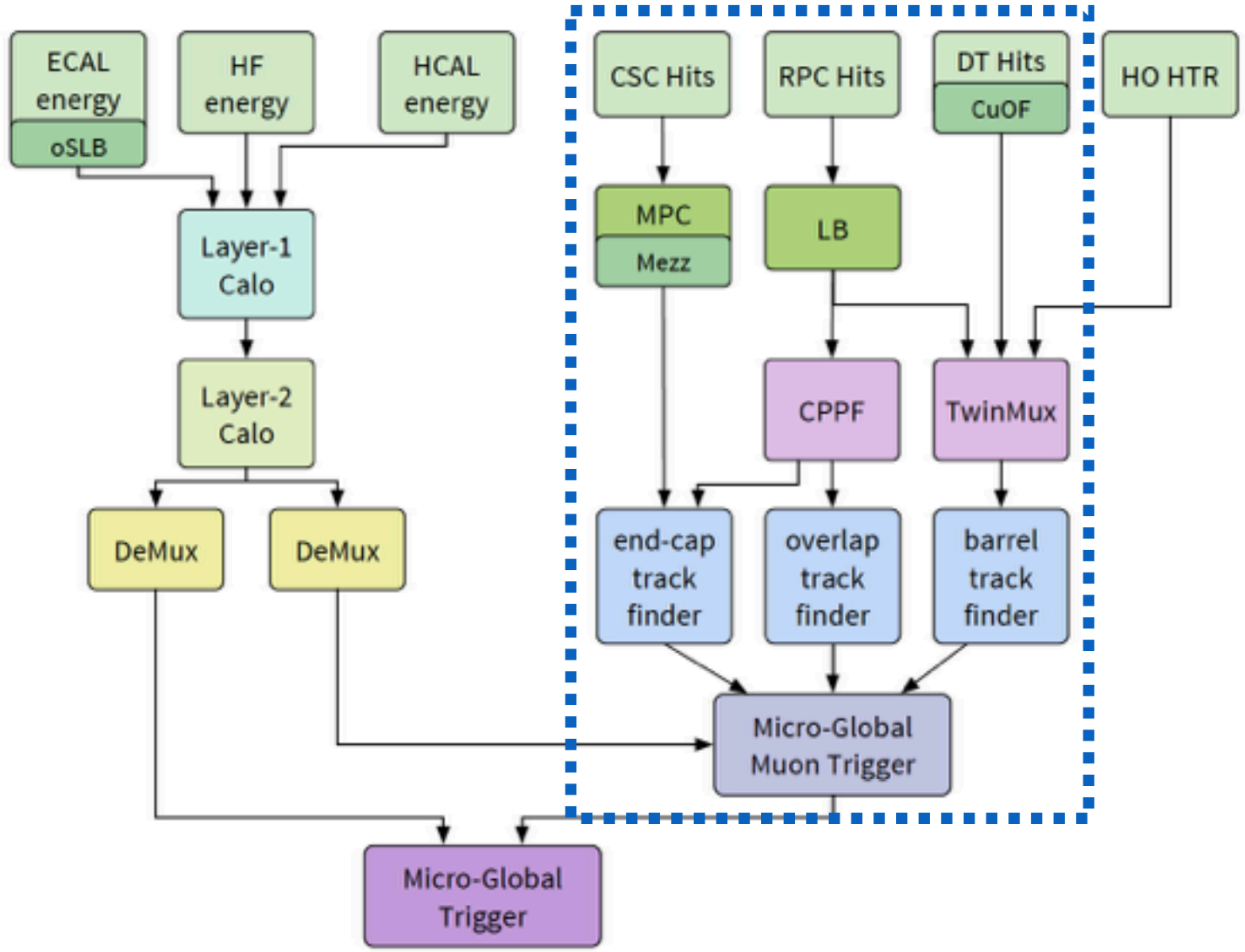




- **Some jargon :**
  - ➡Segments from R-ϕ and R-z are called 2D segments
  - ➡Their combination is a 4D segment

L1 Trigger Architecture

- L1 Trigger gets input from muon chambers / calorimeters
  - Often processed at detector level → **trigger primitives (TP)**



- Uses it to build L1 candidates (μ, e/ɣ, , jets, MET, …)
  - That are used (potentially combined) to accept/reject events

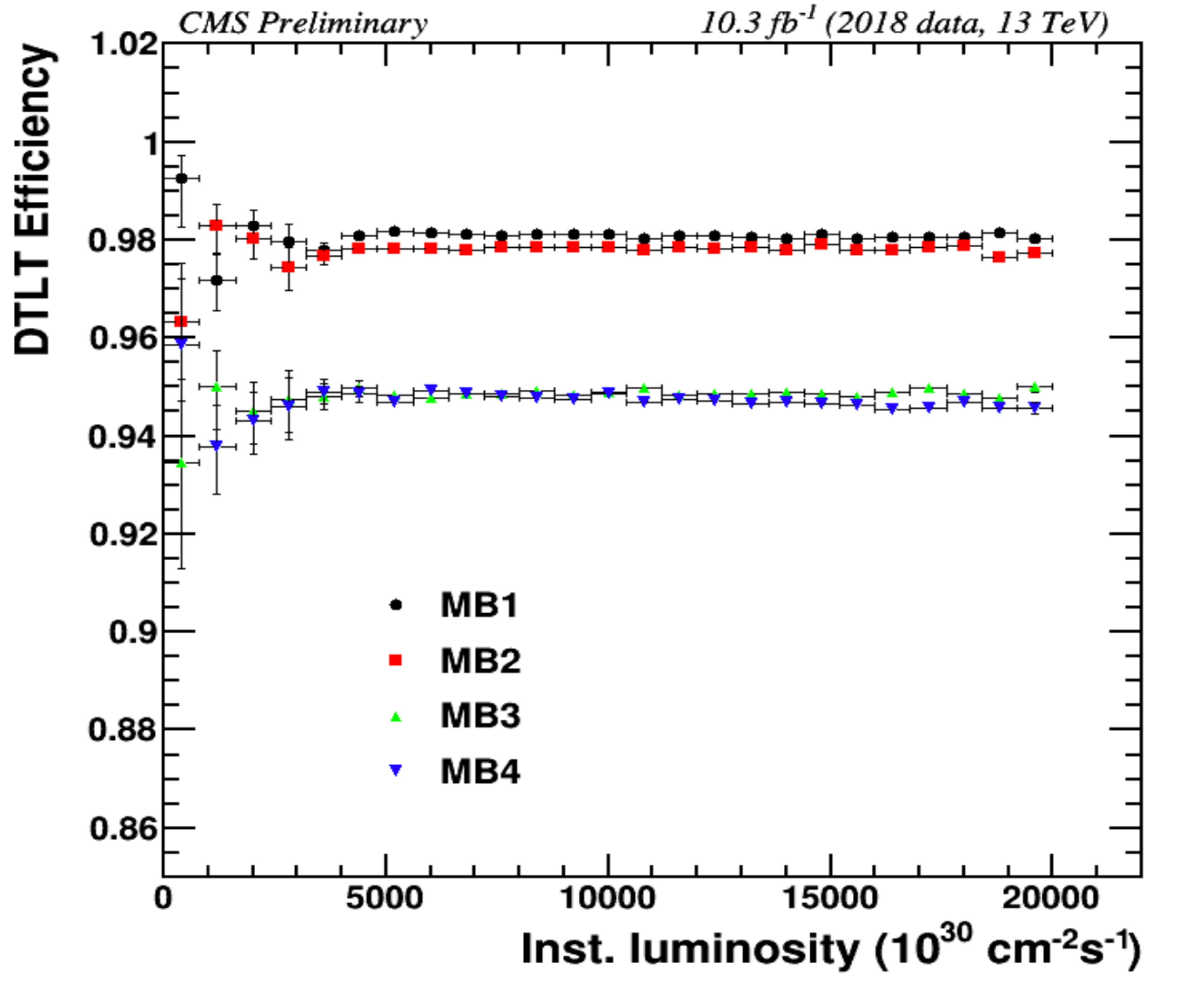
L1 Muon Trigger architecture

- CSC/DTs ➜ compute trigger segments
- RPCs ➜ provide hits
- Information can be combined "locally" (**TwiMux**)
- Or injected directly into **track-finders (TF)**
- **Three TFs operate in different η regions:**
  - ➡Barrel TF (BMTF): |η| up to ~ 0.9
  - ➡Overlap TF (OMTF): ~ 0.89 < |η| < 1.2
  - ➡Endcap TF (EMTF): ~ 1.2 < |η| < 2.4
- **The micro Global Muon Trigger (μGMT):**
  - ➡Gets L1 μ tracks from the TFs
  - ➡remove duplicates where/when needed
  - ➡Can compute calo isolation
    - In a cone around a L1 μ candidate

DT Trigger Primitives & Twinmux

A DT trigger primitive must :

- Perform BX identification
  - ➡BMTF run on primitives with same BX!
- Measure precisely position/direction
  - ➡BMTF track-building and pT assignment
- Have high efficiency
- generate limited amount of fakes/ghosts



- Primitives are built by the on-board DT chamber electronics
  - ➡Implemented as Application Specific Integrated Circuit (AISC)
  - ➡Pipelined algorithm, working with fixed latency
- Twinmux system receives the information about DT trigger primitives
- This information is merges with "RPC-only " primitives for the MB1 & MB2 stations by the Twinmux system, which eventually provides correction to BX assignments at the output of the Twinmux
  - In MB3 & MB4, just **one layer of RPC is present, therefore no RPC-only trigger**
- **RPC timing information improves the BX assignment in barrel**, reducing in particular the **"pre-firing" probability** to wrongly assign a trigger primitive to BX=-1
  - The improved BX identification **increases the efficiencies of Mb1 & MB2**

Introduction to the DT Calibration

- Input to the local reconstruction : **TDC measurements stored in "DT Digis"**
  - Create by decoding ("unpacking") the raw output of the **Data Acquisition (DAQ) system**
  - For MC samples, digis are created by **"digitisation"** from the **"GEANT simulated hits"**
- The reconstructed hit position $\mathbf{X_{hit} = t_D \times V_{Drift}}$

  ➡ t_D is the time of the ionisation electrons to reach the anode wire with a velocity $\mathbf{v_{Drift}}$
- We define $\mathbf{t_D}$ by difference of the time when ionisation electron reach at the anode ($\mathbf{t_{TDC}}$) and the time when it is produced ($\mathbf{t_{ped}}$)
  - Where the $\mathbf{t_{ped}}$ is the sum of different contributions coming from
    - ➡ The time of flight (TOF) of the muon from the interaction point to the cell ($\mathbf{t_{TOF}}$)
    - ➡ The propagation time of the signal along the anode wire ($\mathbf{t_{prop}}$)
    - ➡ Delay due to the different cable lengths between individual channels and read-out electronic ($\mathbf{t_0}$)
    - ➡ The latency of the Level-1 trigger ($\mathbf{t_{L1}}$)

$$\mathbf{X_{hit} = (t_{TDC} - t_0^{wire} - t_{L1} - t_{TOF} - t_{Prop}).V_{Drift}}$$

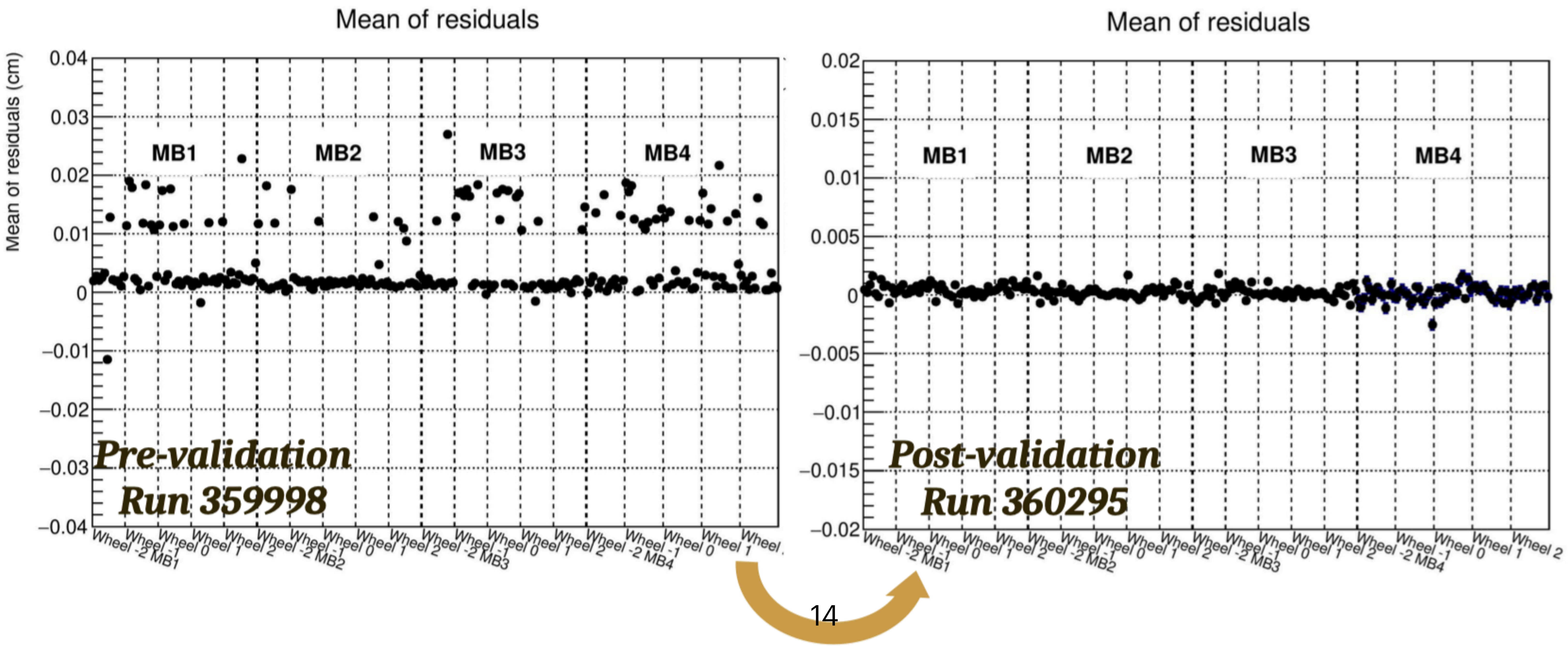
- We applied a synchronisation procedure called **"DT Calibration"** to find $\mathbf{X_{hit}}$ with maximum accuracy

Introduction to DT Calibration

- Two main parameters that we determine for the DT calibrations
  - ➡ $\mathbf{V_{Drift}}$: average drift velocity, depends on gas conditions & High voltage (HV)
  - ➡ $\mathbf{t_{ped}}$: combination of different contributions in digit time ($\mathbf{t_0^{wire}}$, $\mathbf{t_{L1}}$, $\mathbf{t_{TOF}}$, $\mathbf{t_{Prop}}$)
- $\mathbf{t_0^{wire}}$ - difference of the signal path lengths from each wire to the readout electronics is corrected
  - Sending simultaneous "test pulses" to the front-ends and computing the difference between the measured times and a reference value
  - $\mathbf{t_0^{wire}}$ do not change in the absence of hardware intervention, need to be computed rarely
- Once $\mathbf{t_0^{wire}}$ corrections were applied, the absolute time pedestal called $\mathbf{t_{trig}}$ computed optimising the distribution of the **hit of the residual (should be peaked at zero)**
  - ➡ **Hit Residual** is the distance between any hit and the intersection of the reconstructed segment with the layer it belongs to and average value is measured for each super layer

DT Calibrations step & Validation

- **Step 1 :** Run $\mathbf{V_{Drift}}$ calibration with recent **Global Tag (GT), output will give $\mathbf{V_{Drift}}$ db file**
- **Step 2 : Take input the $\mathbf{V_{Drift}}$ db file derived from step 1,** Run $\mathbf{t_{Trig}}$ workflow, in order to calculate the calibration constants, output will give $\mathbf{t_{Trig}}$ db file
- **Step 3 :** Run the Validation workflow taking both db files created in step 1 & 2, in order to validate residual distributions after applying the calibration derived in previous step
- Two Criteria of validation : **mean and sigma of the residuals**
  - The mean should be **centred to zero, lower than 50 microns**
  - The sigma of residuals is supposed to stay **between 200 μm** (MB1/2/3 with 3 SL) to 300 μm (MB4, only 2SL)



DT Calibration in Run 3

- At the beginning of new data-taking period, following HW interventions, we check the synchronisation of individual chamber clocks with LHC, in order to reduce trigger pre-firing and optimise the trigger performance

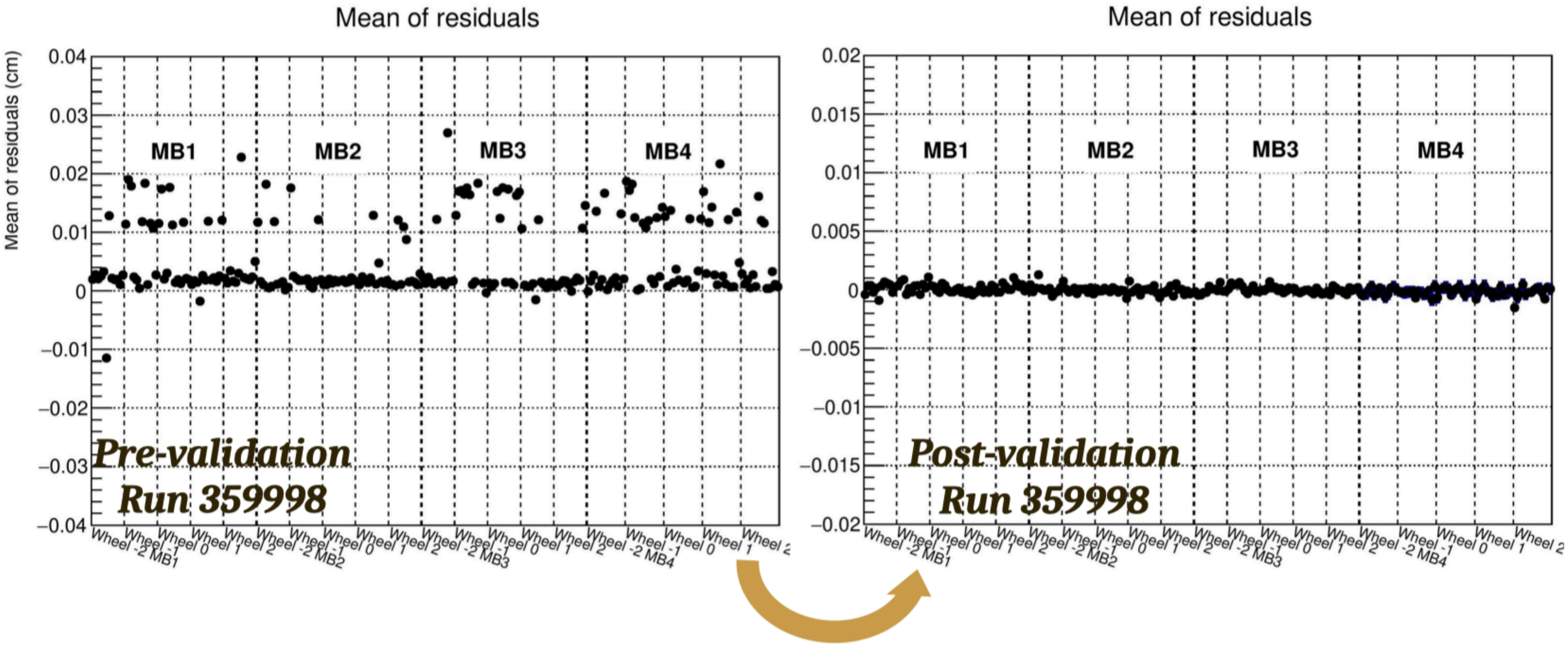
    ➡ In 2022, small corrections were needed due to the installation of the Slice Test in YB2/Sec12 (installed during LS2) and non-working RPC chambers, hence not contributing to the TwinMux

    ➡ Trigger synchronisation applied in 2022 Run 3 from Run 359750 (beginning of Collisions era E of 2022)

- DT calibration team has produced new DT tTrig calibration for HLT, Express and PromptReco,

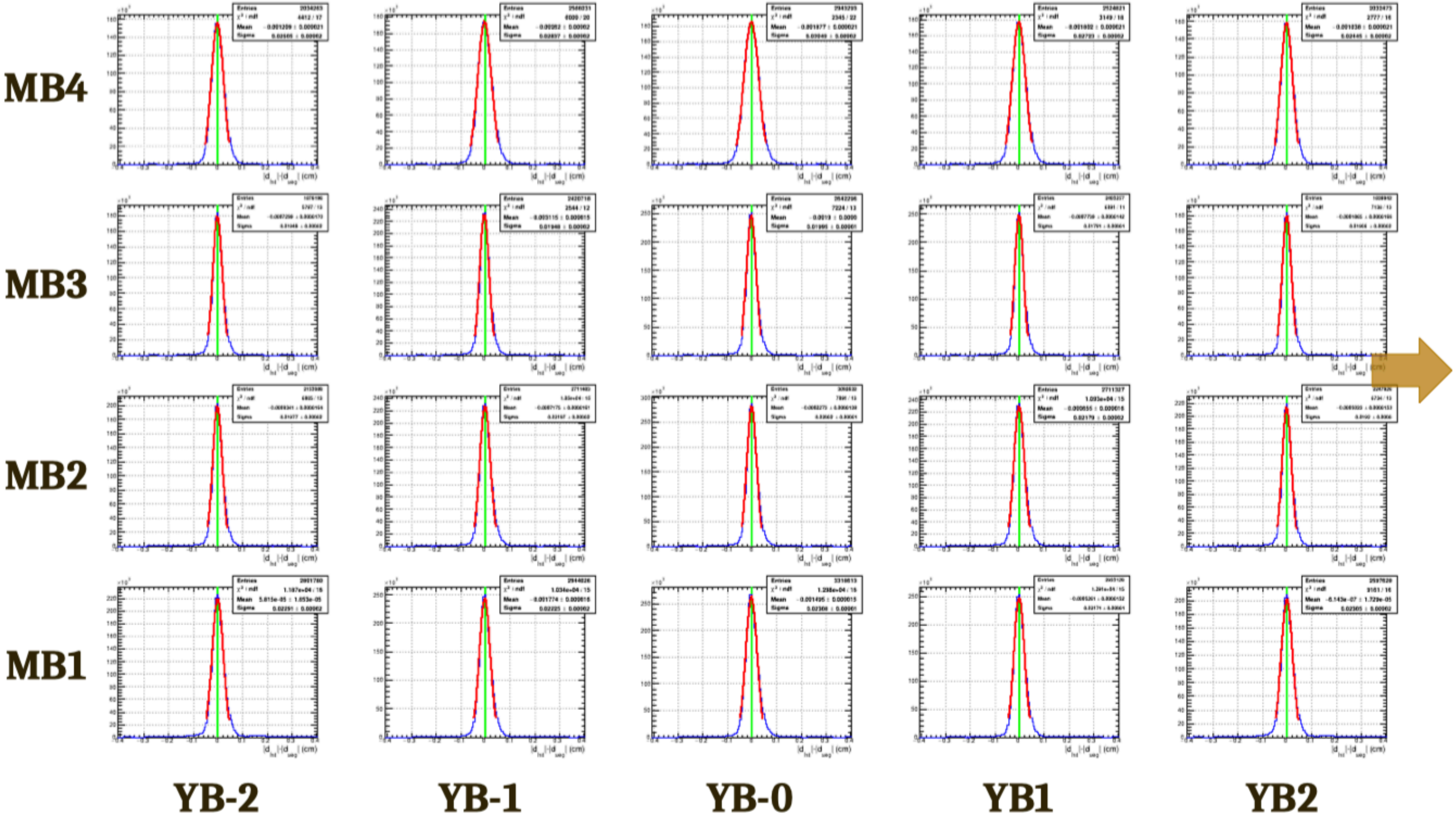
    - Corrects for small offsets introduced by the local trigger fine synchronisation starting from Run 359750
    - Used ExpressPhysics dataset with FEVT data format
    - Only small shifts (~1-2 ns) were observed ➔ consistent with the fine sync applied before Run 359750
    - Global tag **124X_dataRun3_Express_v5** : effective with ReReco of eras E, F, G & with first data-taking in 2023

Mean of residual before & after Validation



- After retrieving calibration constants & applying them during validation ➔ mean of residuals looks much more improved!

Residual distribution after Calibration



- φ SL only, all sectors
- Calibration corrected shifts from 0 in mean of residuals
  - ➔ Great!

Exercise

What is to be done in the exercise

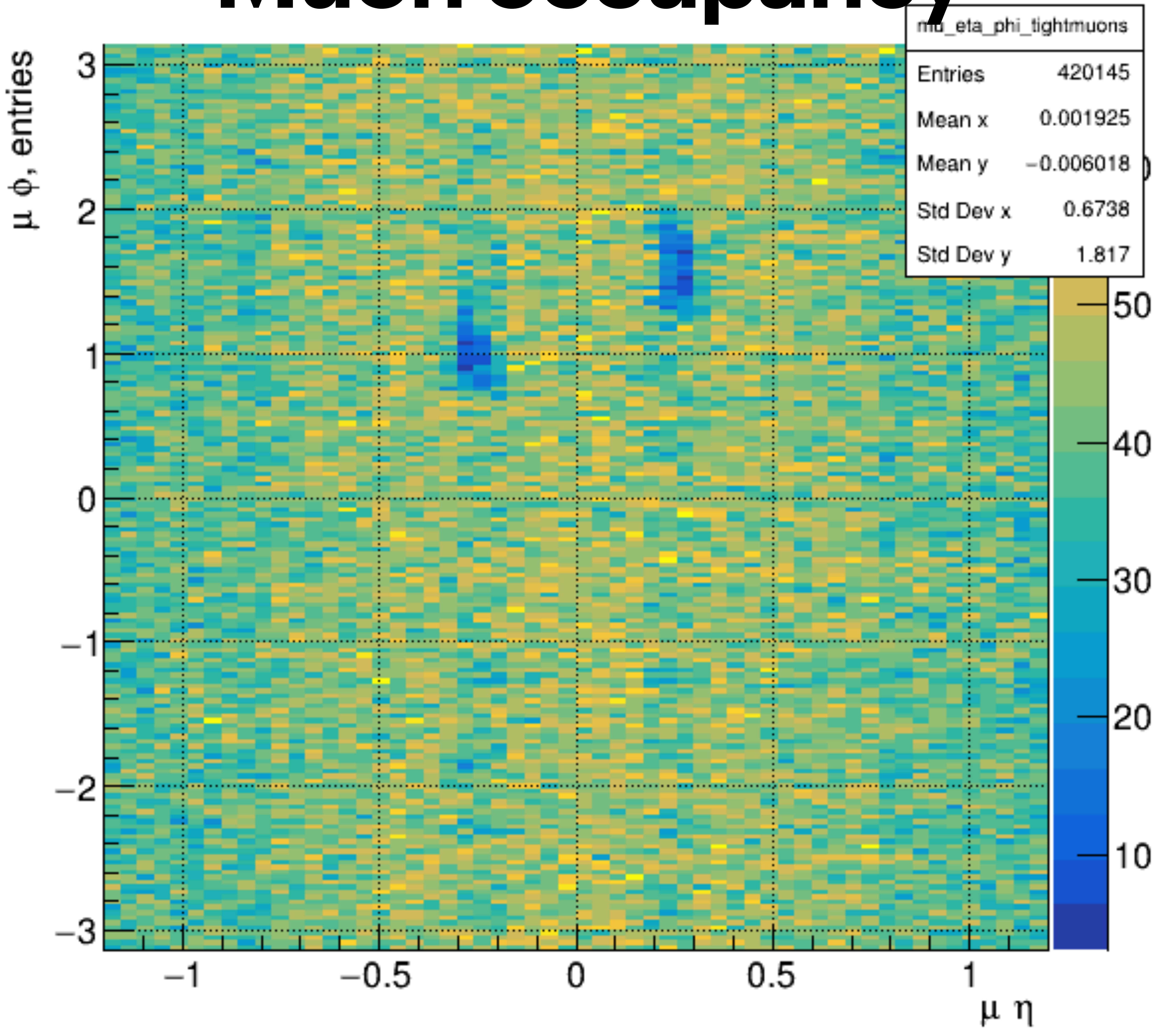
- Starting with the reco muons in barrel and requiring the cuts to select only good quality muons, we then look for the standalone muons with matched DT segment
- We plot the basic distributions related to the DT segments, e.g. the Wheel/sector/station they belongs to and the timing of the segment
- A muon ntuple root file contains the branches with all the information that will be required to perform the exercise

What is to be done in the exercise

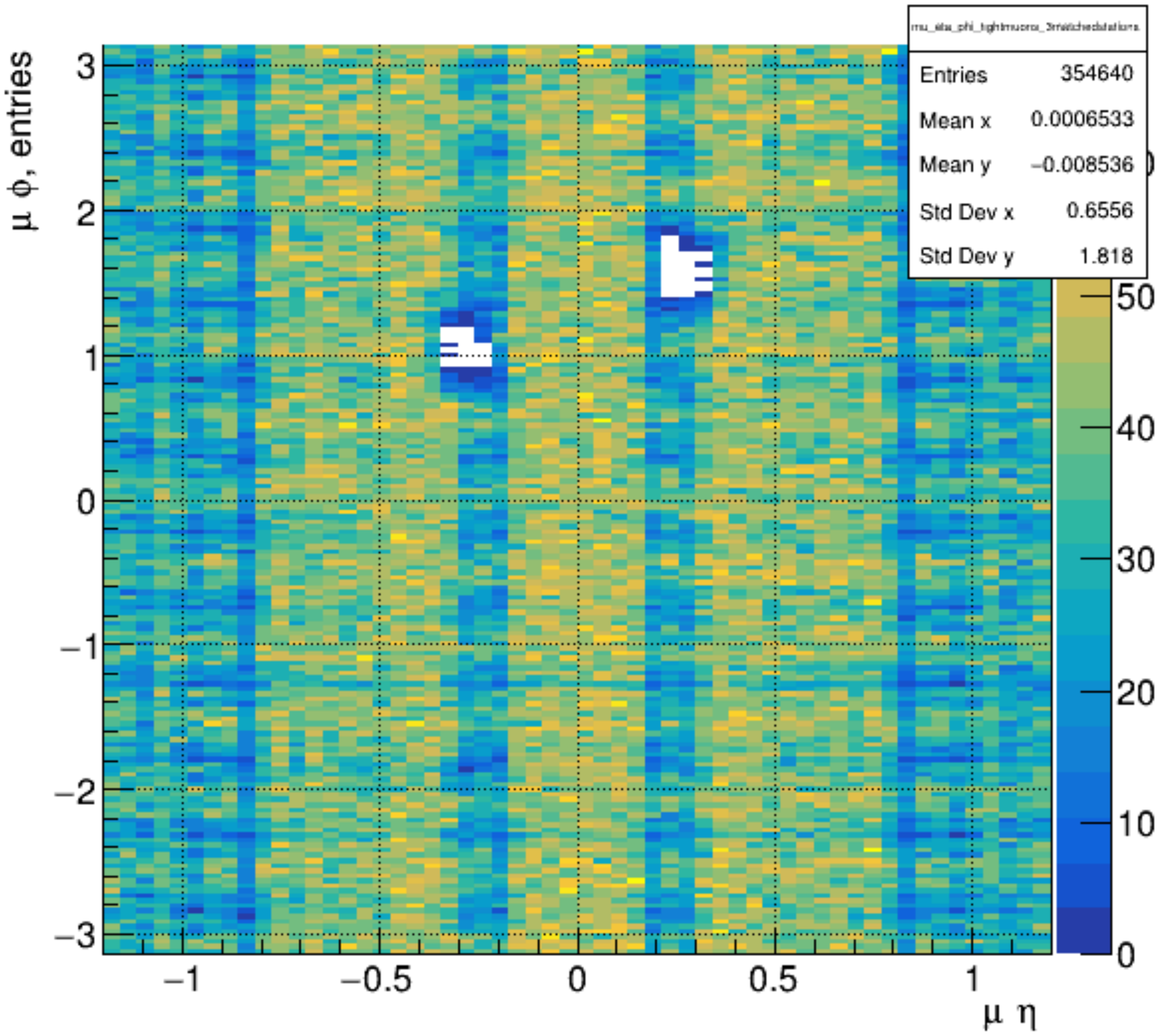
- **Part 1 :**
  - Adding a plot of muon occupancy requiring the number of matched stations >= 3 in the barrel region
  - Comparing it with the plot without any matched station requirement
- **Part 2 :**
  - Removed the quality criteria on the muon selection and add a plot to draw the DT segment time (put y-axis on log scale)
  - Analysing the shape of the plot compared with the plot with quality cuts
- **Part 3 :**
  - Add a plot to check the number of hits present in a good segment

Backup Slides

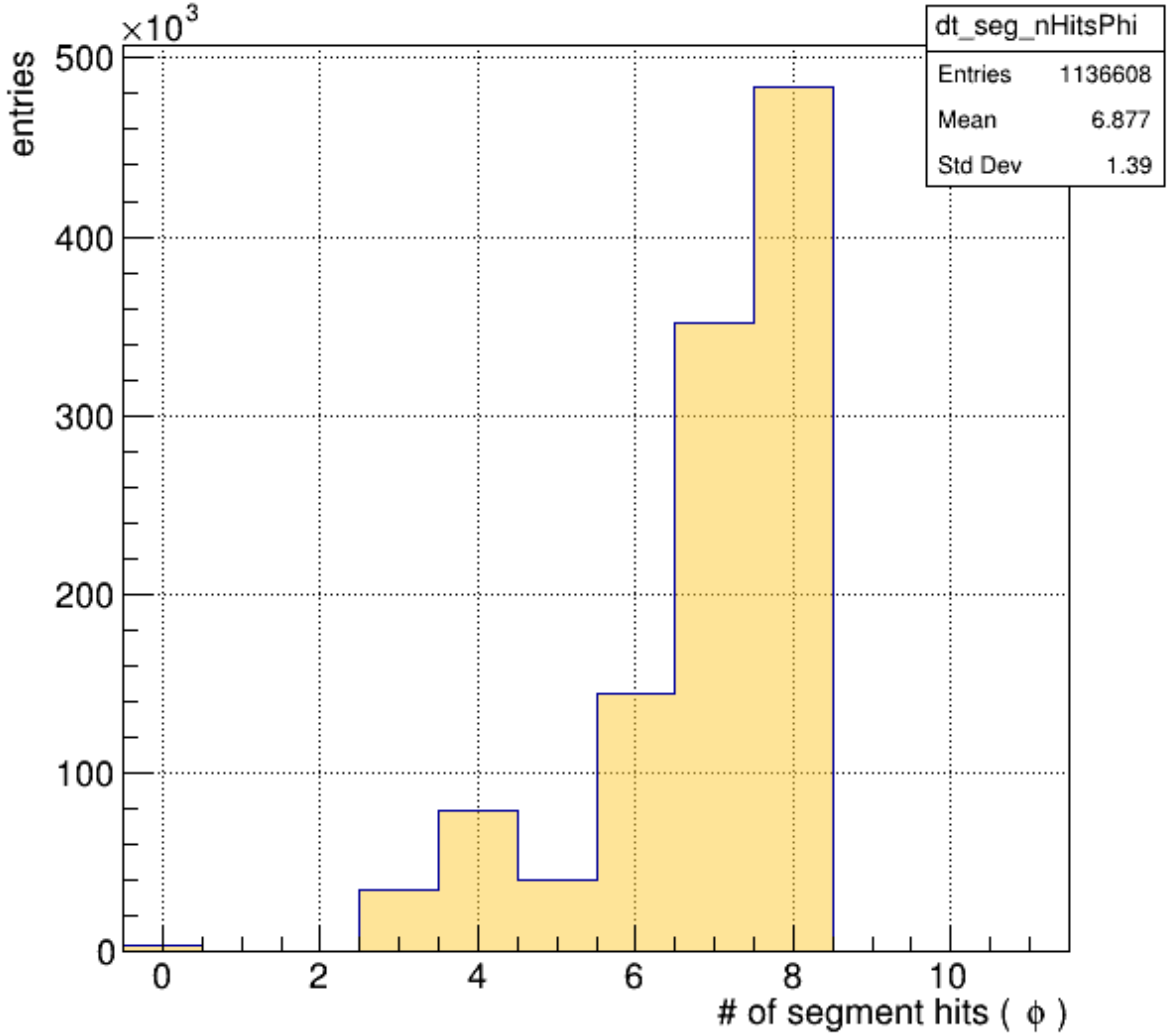
Muon occupancy



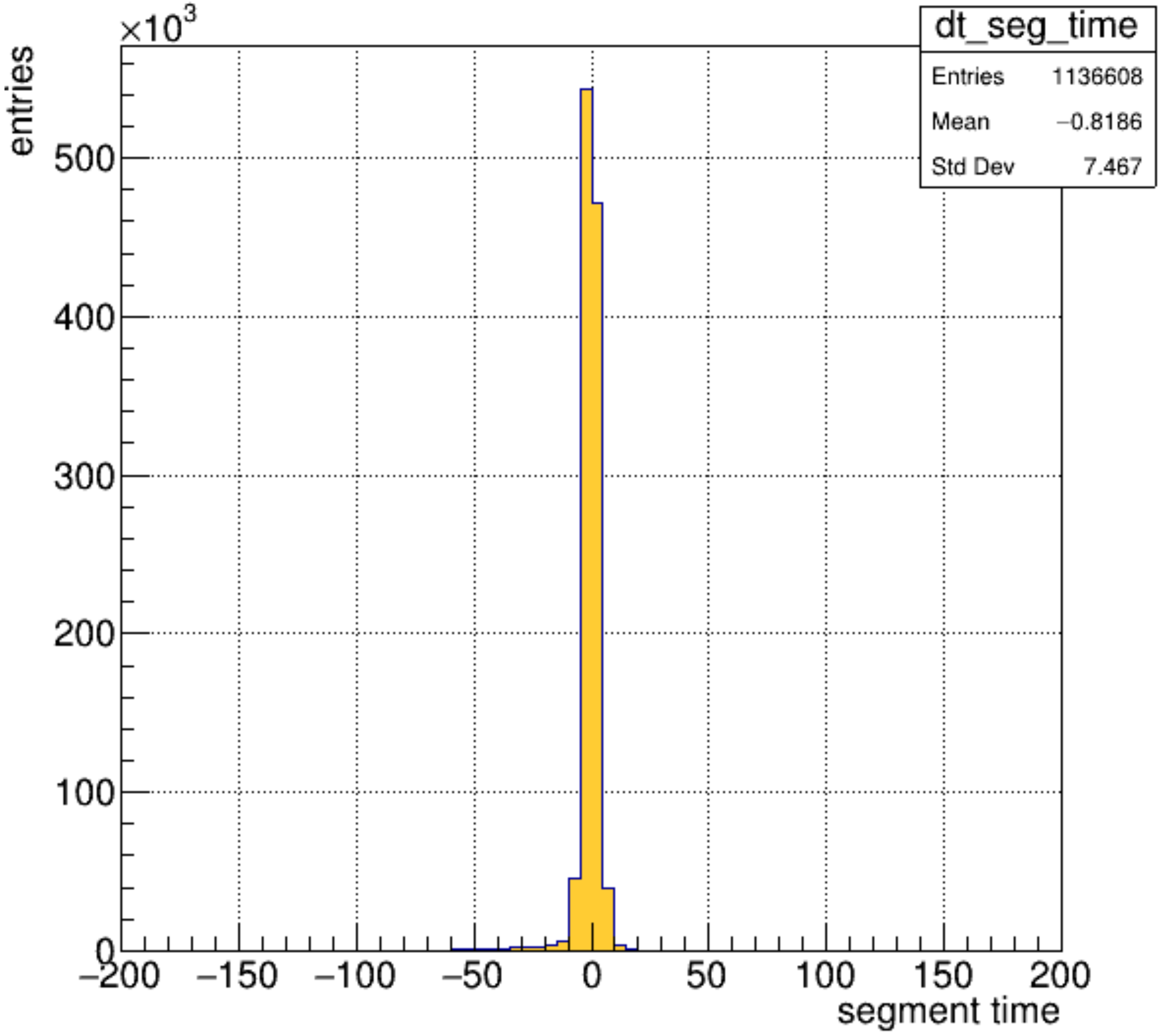
Muon occupancy requiring >= 3 matched muon stations



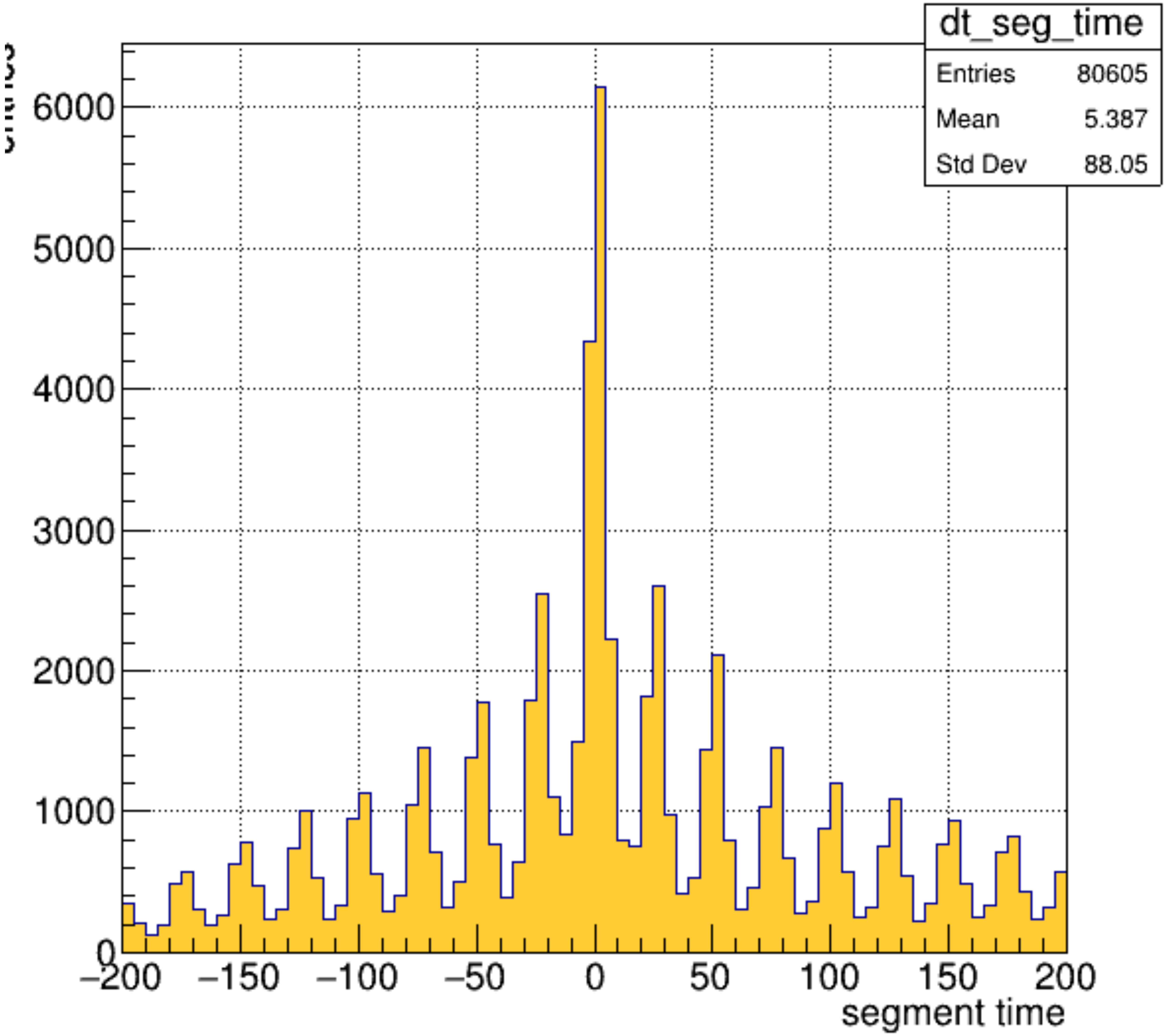
of Hits per Segment



DT Segment time for muons with tight quality selections



DT Segment time for all muons

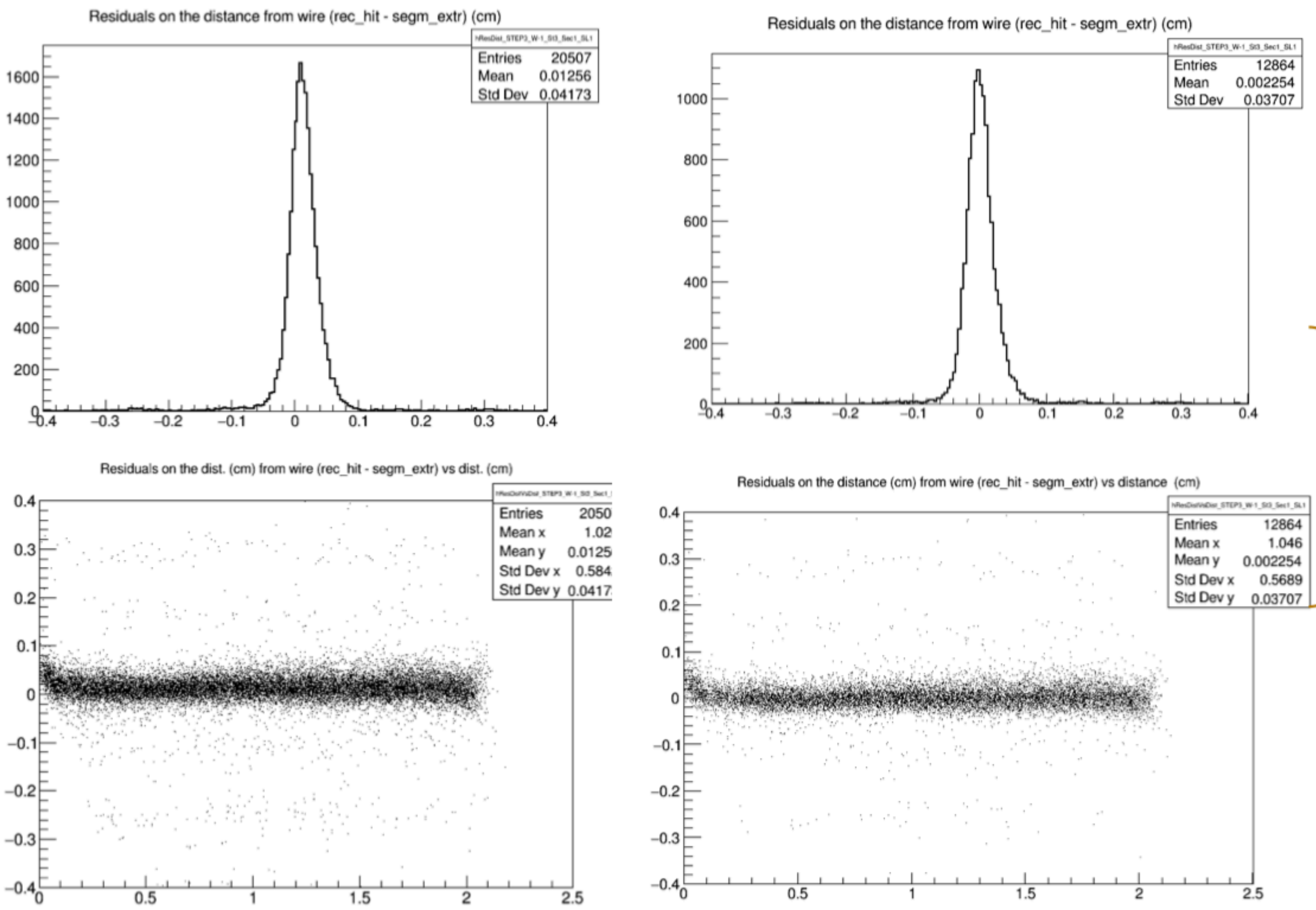


Residuals before & after Validation

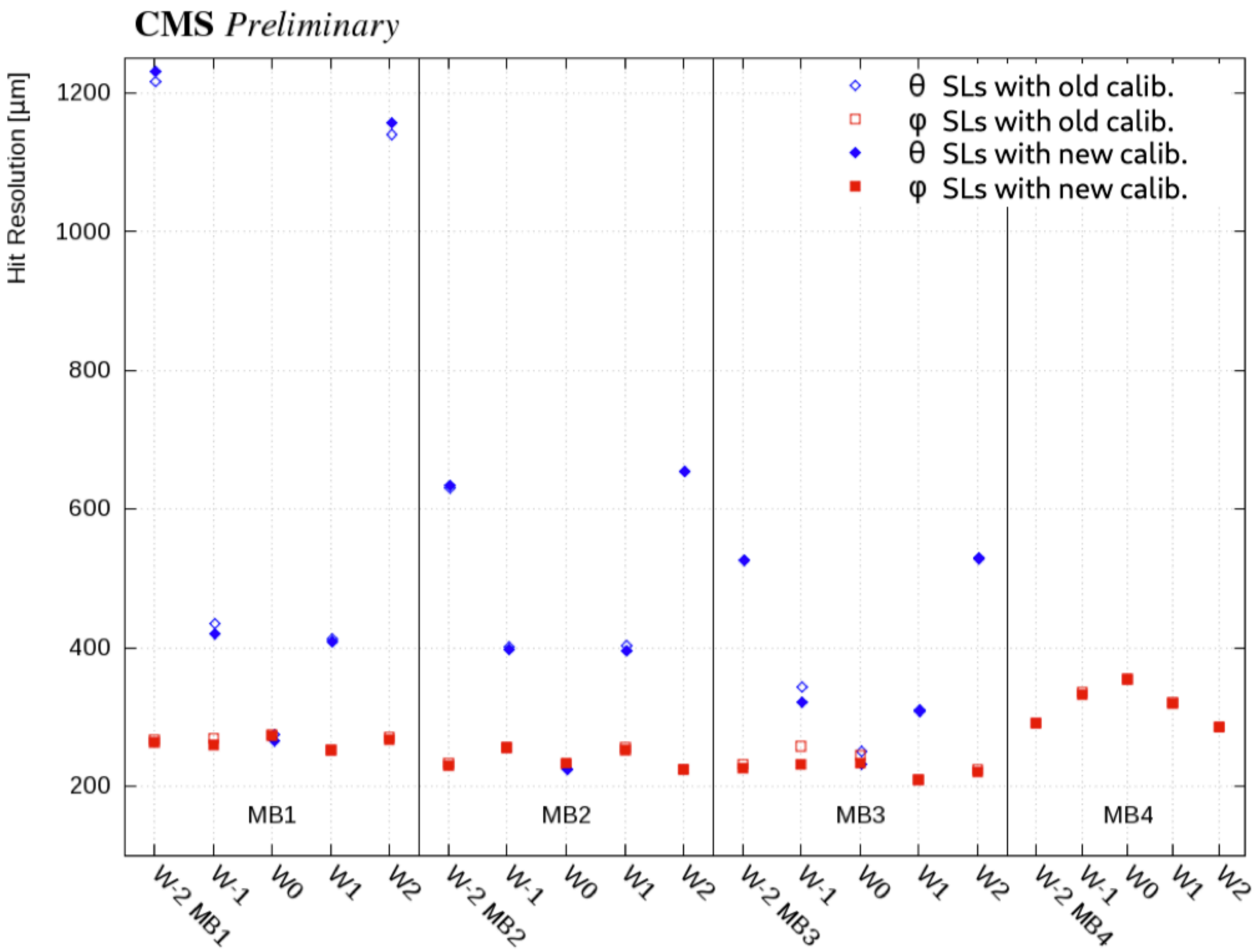
Run 359998, YB-1, MB3, Sec1, SL1

Pre-validation

Post-validation



Hit Resolution in Era E, 2022 before & after Calibration



- Measured hit resolution in DT φ and θ Super Layers station-by-station & wheel-by-wheel
- Results obtained from the spread of residuals before & after updated calibration
- No major changes in comparison to past performances

DT Time Measurements

- Position reconstruction in DT is based on a time-to-distance conversion of signals in individual drift cells
- With the perfect calibration, hits will form a perfectly straight line
- Deviation from a straight line signals some timing offset either on the detector side or the track arrived out-of-time
- The size of this offset can be translated to a time measurement
- Timing is calculated at the level of 2D segments by performing a 3-parameter (position, direction, time) fit to the hit positions.