NEW SMALL WHEEL MICROMEGAS TRIGGER SIMULATION ANALYSIS

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The ATLAS Detector

The ATLAS detector is structured in three concentric cylindrical sub-detector systems :

- **Inner Detector (ID)**

  [Inner Tracker Upgrade (**ITk**) - 2025]

- **The calorimeter system:**
  - Electromagnetic calorimeter (ECAL)
  - Hadronic calorimeter (HCAL)

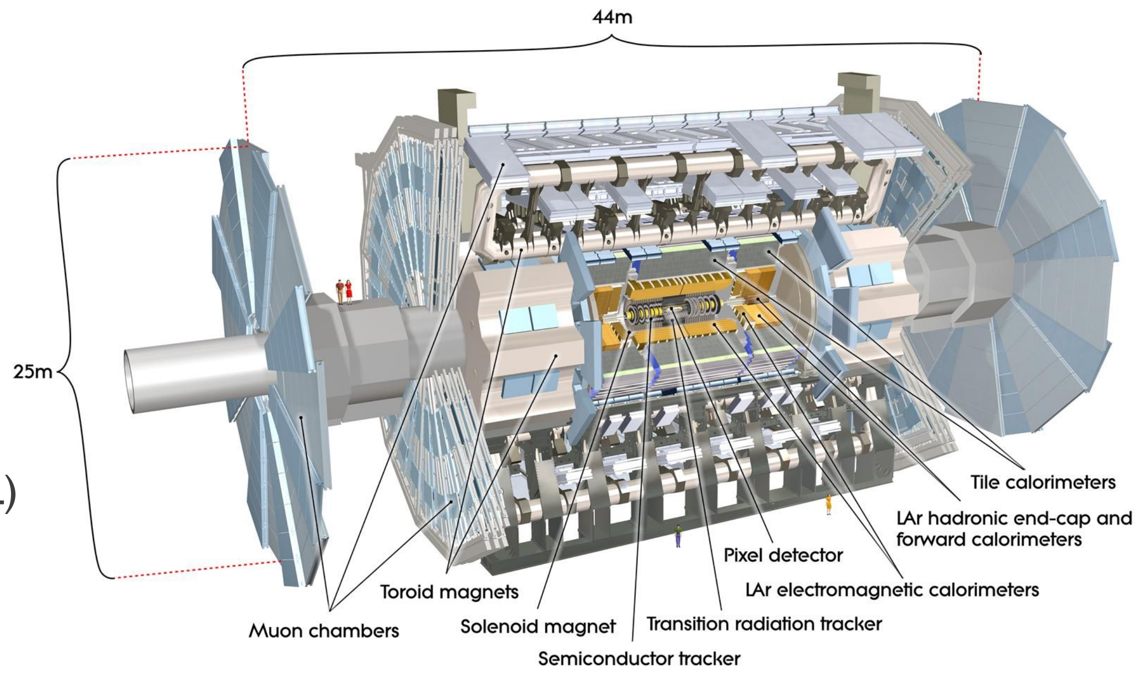
  [Lar Calorimeter electronics upgrade]

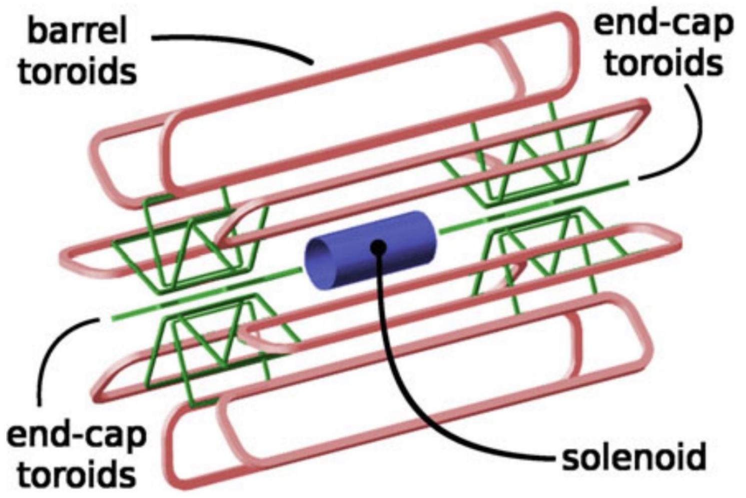
- **The Muon Spectrometer (MS)**

  [New Small Wheels]

These sub-detectors are divided longitudinally in three regions:

- the central part, called ***barrel***
- the two edges of the cylinder, called ***end-caps***





ATLAS Muon System

The MS is composed of two groups of detectors :

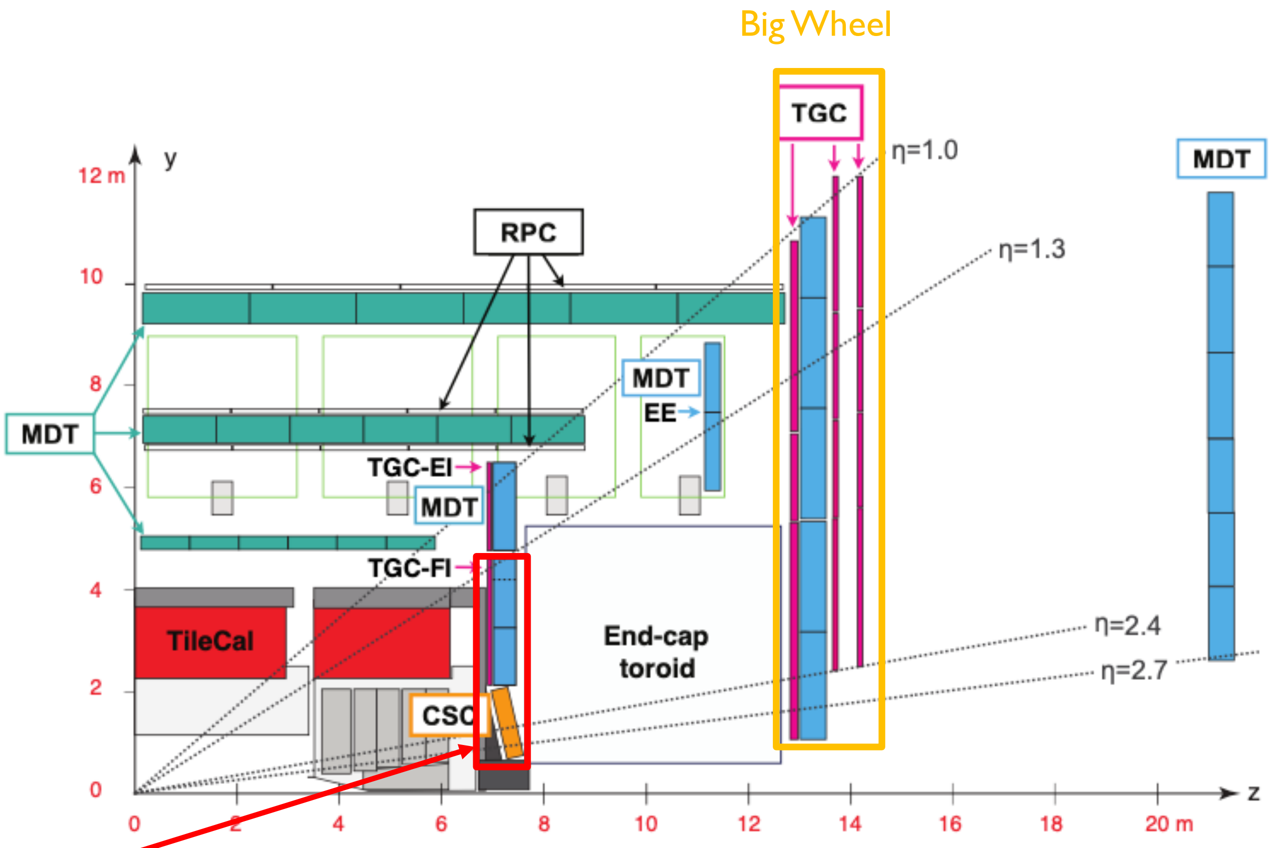
- *Resistive Plate Chambers (RPC) and the Thin gap Chambers (TGC)*

  → high timing resolution

- *Monitored Drift Tubes (MDT) and the Cathode Strip Chambers (CSC)*

  → high position resolution

- NSW was installed and replaces the detectors of the first station

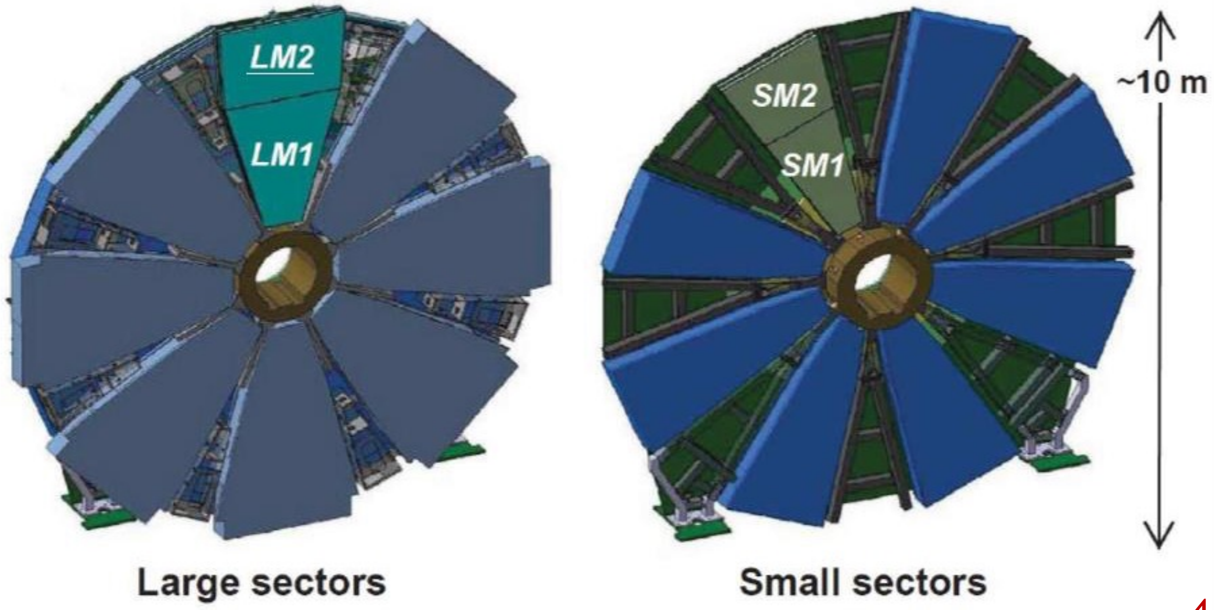


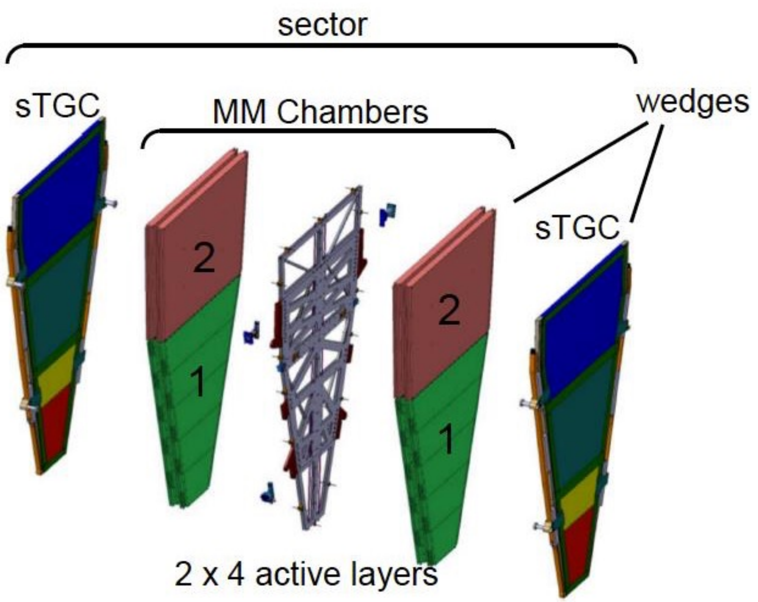
New Small Wheel (NSW)

ATLAS Muon System Update

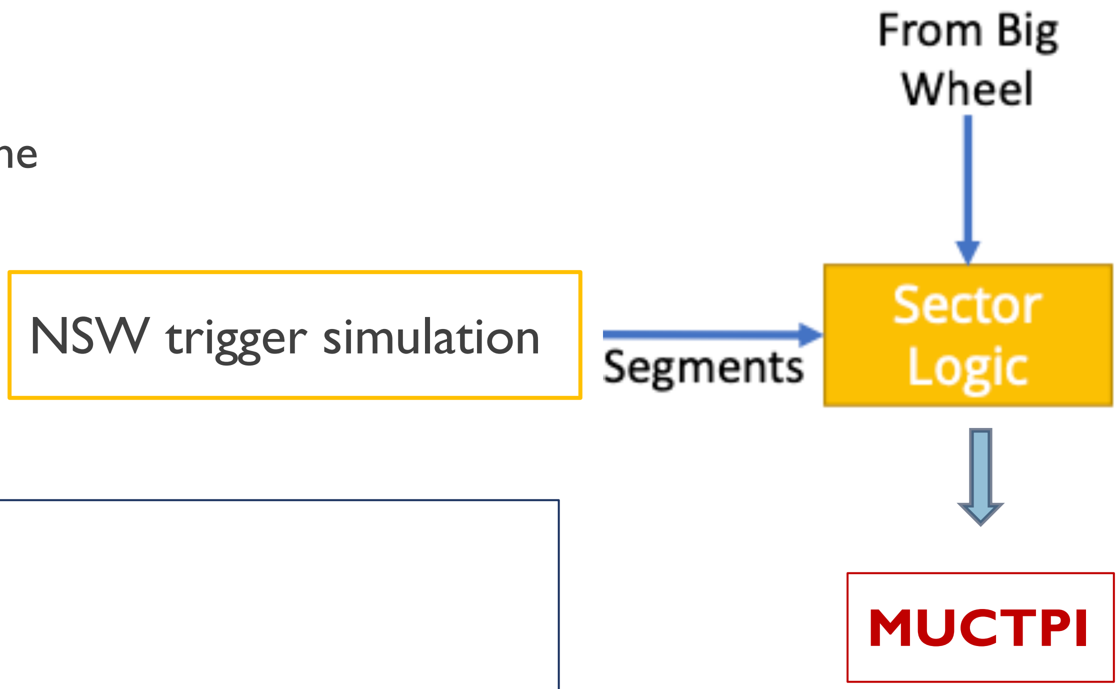
- The ATLAS New Small Wheels utilize two innovative detector technologies :
  - small-strip Thin Gap Chambers (sTGC), as the primary trigger
  - Micromegas (MM) as the primary precision tracker
    - Study particles at the high rates expected from the HL-LHC
    - Improve spatial resolution → Confirm whether a particle originated from the interaction point

      Reduction unwanted background events
- Each wheel is composed of 16 sectors (8 Small and 8 Large) [sTGC-MM-MM-sTGC]





- Micromegas (MM) and sTGC triggers are stand-alone triggers, each using its 8 detector layers in each NSW sector
- Algorithm finds trigger candidates and provide a RoI for the matching of the NSW segment with the Big Wheel



Micromegas trigger simulation analysis

- Angular variable reconstruction
- Definition and description of segment output parameters (ϕ_{id} , R_{id})
- Validation of the correct trigger operation *finding possible errors/bugs*

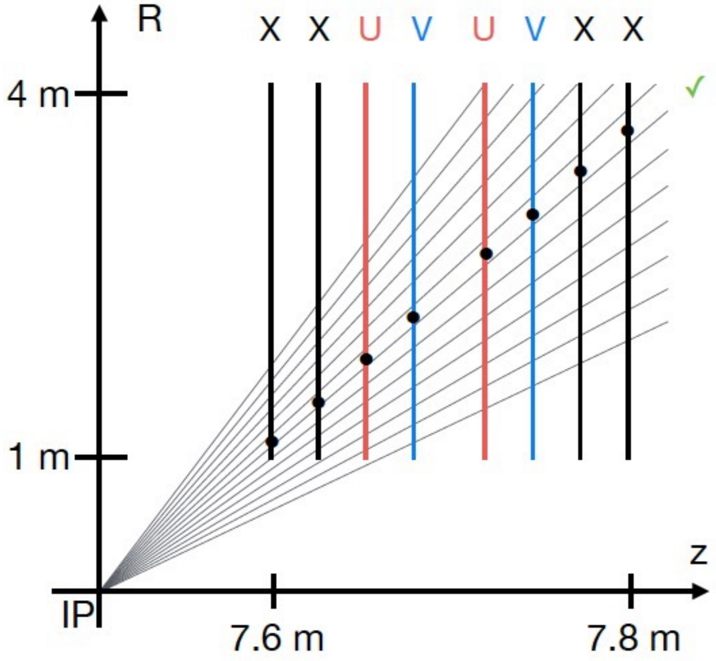
- Evaluation of performance is crucial for the optimization and hardware implementation of the trigger logic

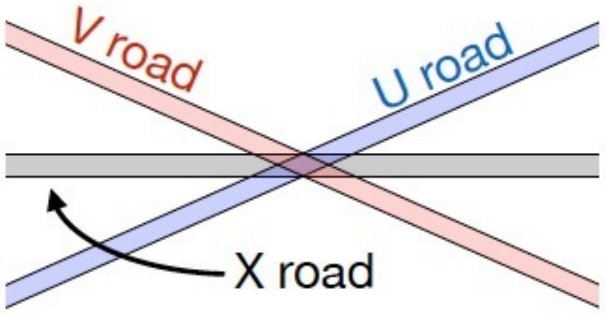
MICROMEGAS L1 TRIGGER ALGORITHM

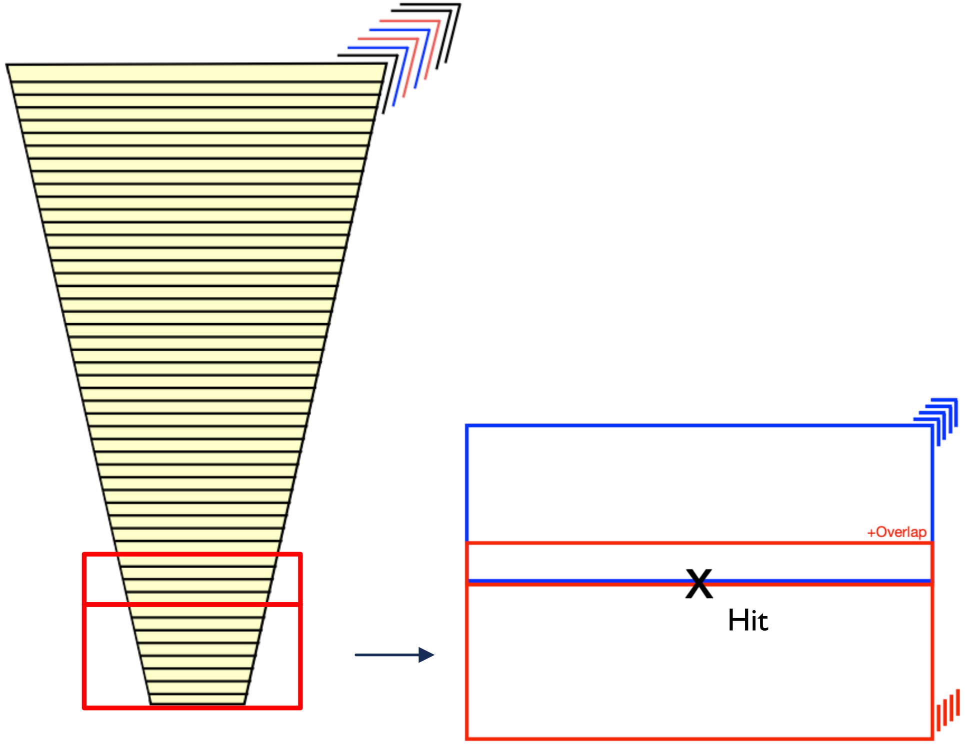
- **DiamondRoads algorithm** : segmentation of the RZ space in roads of 8 strips (~3.5 mm) depending on the $slope = \frac{strip\ R}{strip\ Z}$
- Requirement : roads with at least N(X) and N(U/V) hits, intersecting in 1 point → **diamond**

2X+1U+1V

- Road overlap (4 strips ~1.75 mm) : for capturing *all* hits when muon traverses boundary of two roads
- Possibility of having multiple triggers for the same track! Best candidate to be choosen (for now taking the one with more planes)

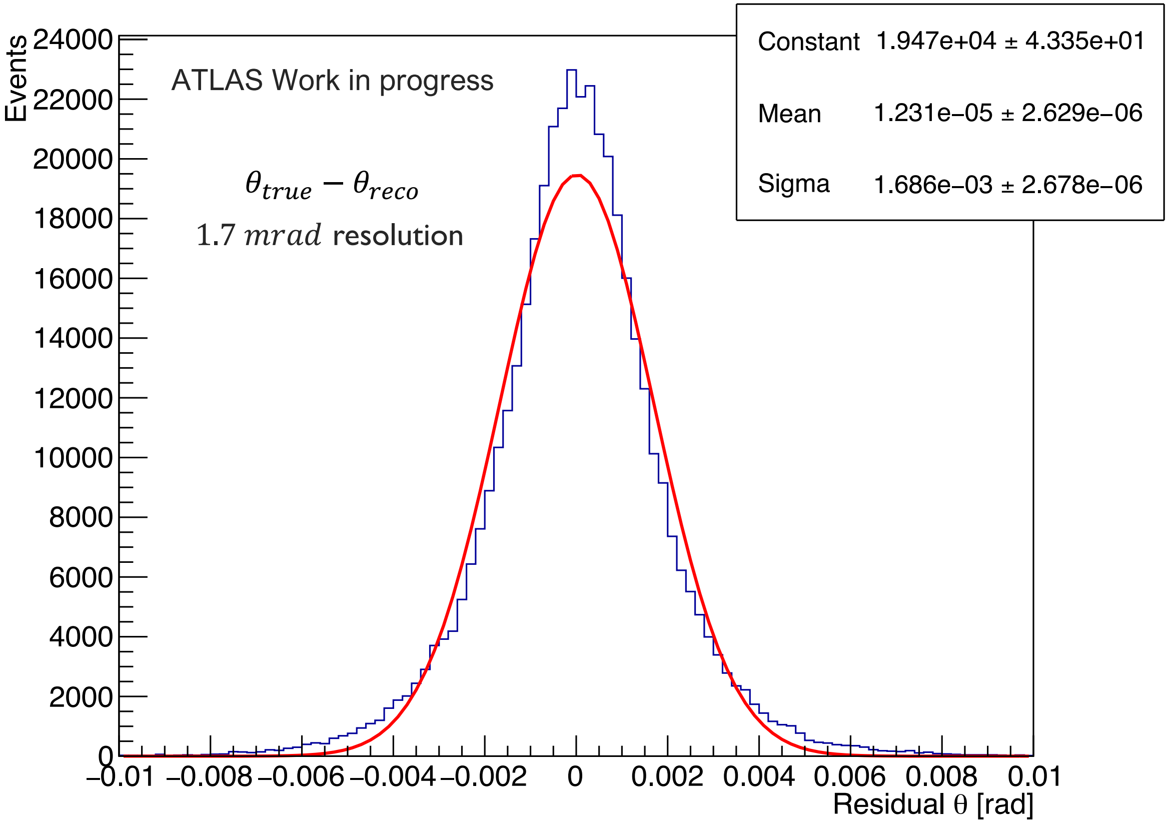




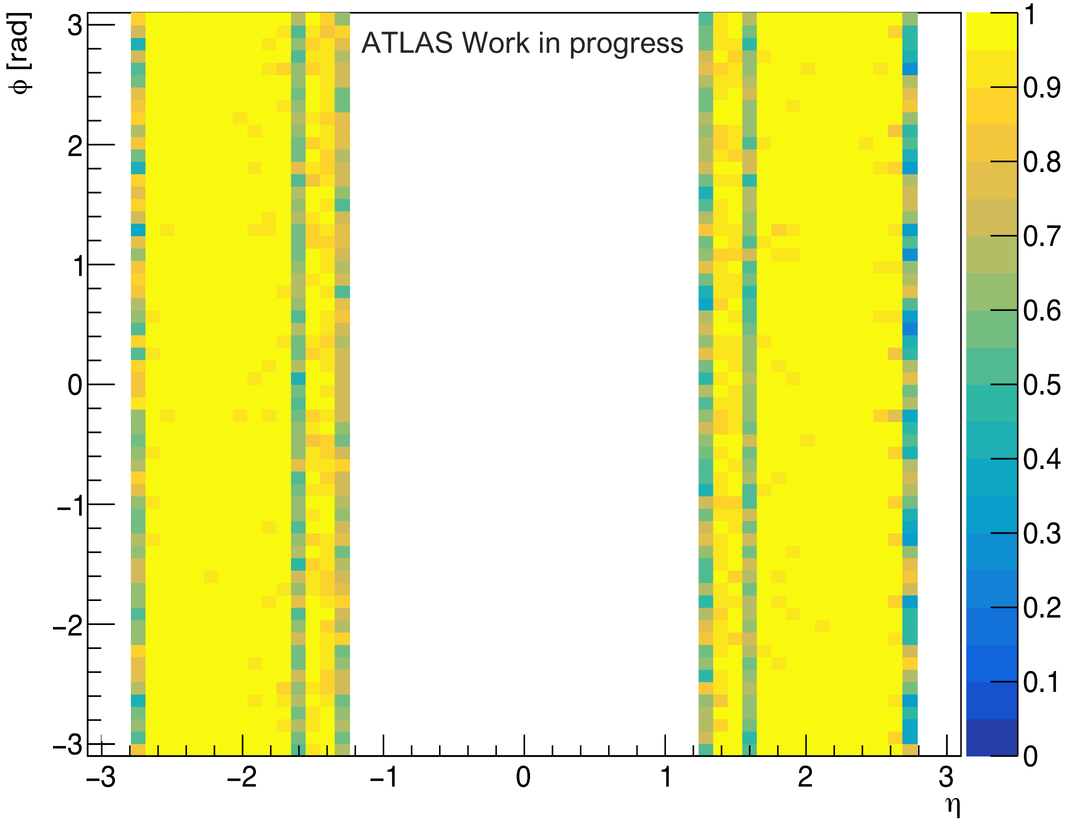


RESOLUTION AND EFFICIENCY STUDIES

- Great $\boldsymbol{\theta}$ resolution: 1.7 $mrad$

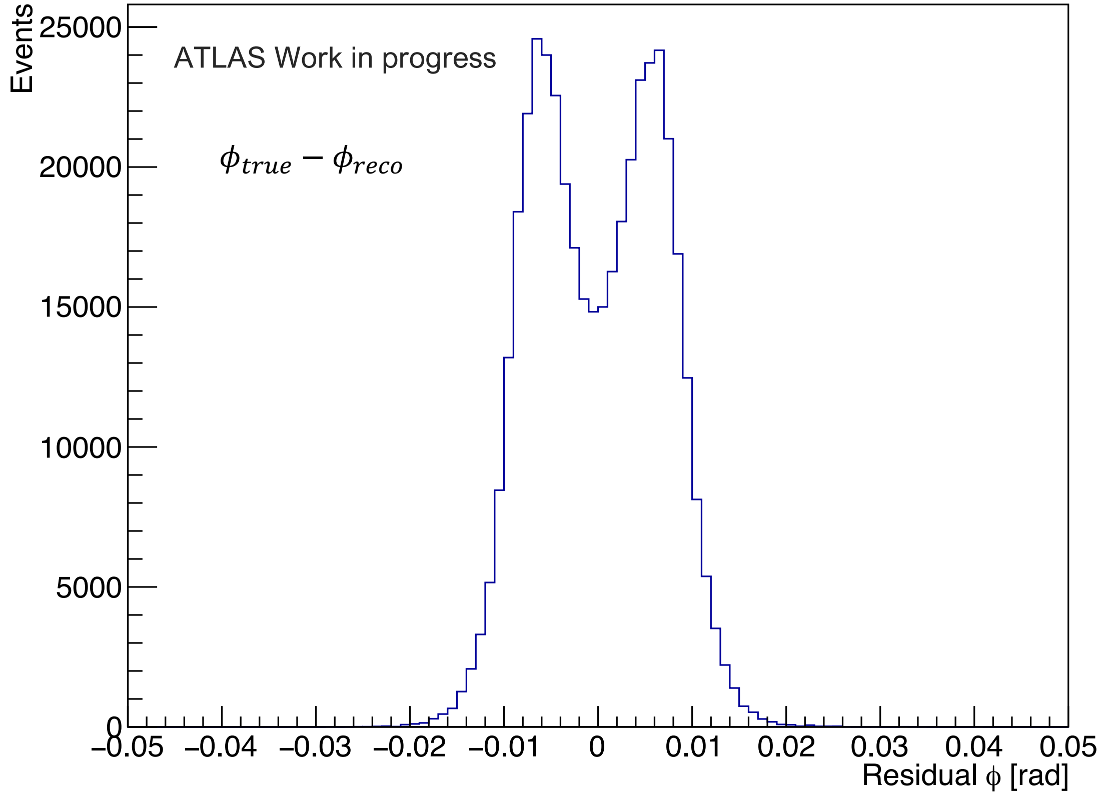


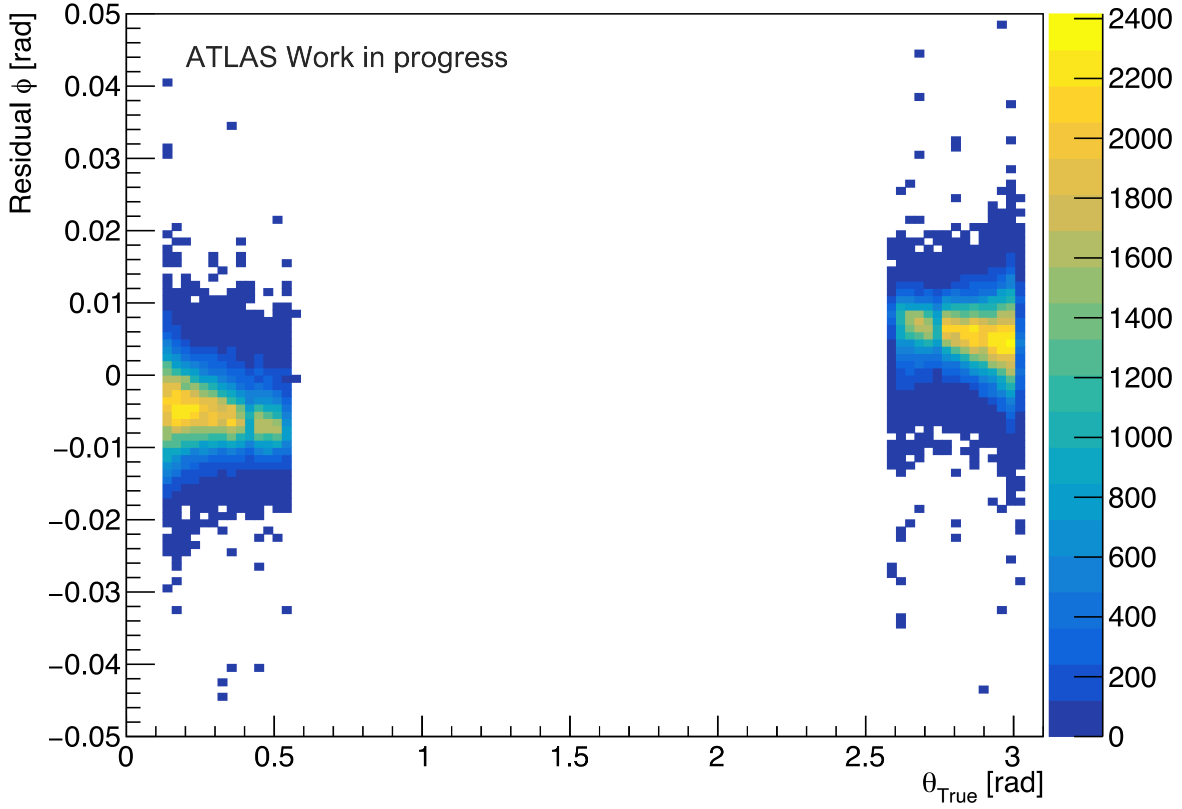
- Efficiency drops show the gaps between the NSW modules



RESOLUTION AND EFFICIENCY STUDIES

The double-peak problem is visible in ϕ residual distribution





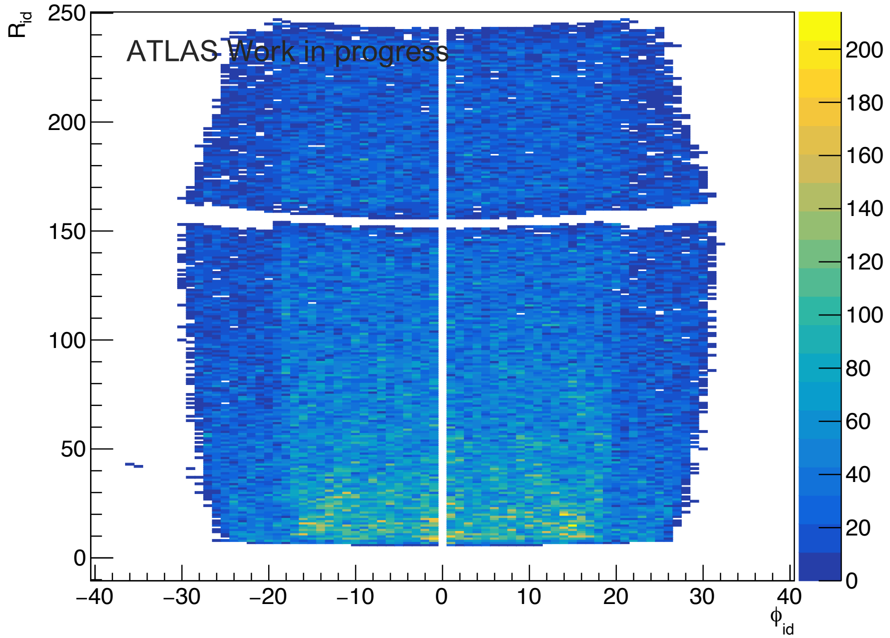
→ Under investigation to be solved

The residuals for ϕ are larger in the regions furthest from the beam and show the shift in different directions (z dependence)

NEW SMALL WHEEL TRIGGER PROCESSOR

- On every bunch crossing, the NSW Trigger Processor sends to the Sector Logic up to 8 unique track segment that point to the Big Wheel
- Micromegas can provide up to 8 segments (sTGC up to 4) per sector

Sector Logic receives 8 total segments (4 MM and 4 sTGC) per sector per BC



Segment Output Parameters

R_{ID} *(integer between 0-256 increasing in the outward radial direction)*

$$R_{id} = \frac{z_{min} tan(\theta) - R_0}{16\ mm}$$

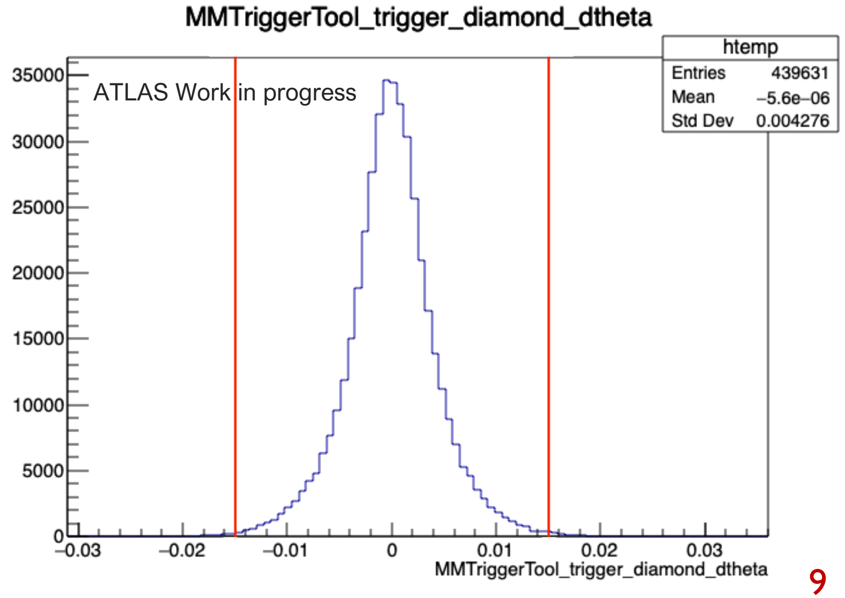
ϕ_{ID} *(integer ±1° →±31° for Large Sectors, ±1°→±22° for Small Sectors)*

It is defined locally with ϕ = 0 along the radial axis of simmetry of each sector

$$\phi_{ID} = \frac{\phi_{local}}{9\ mrad}$$

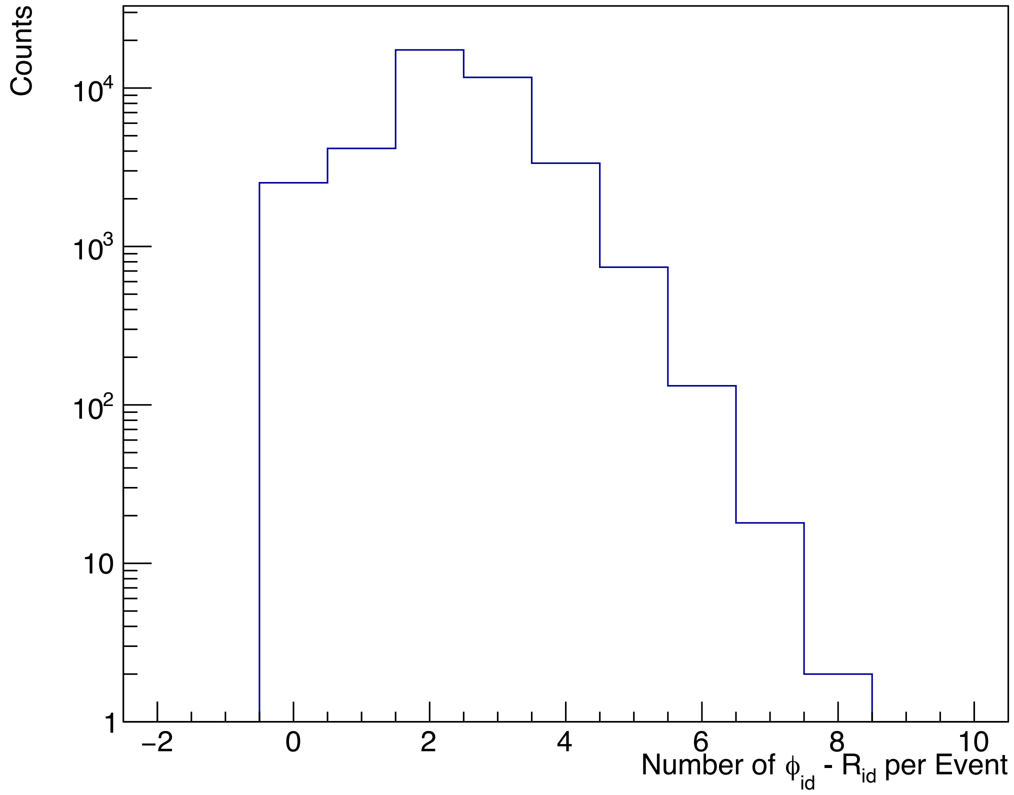
➢ Definition of Region-of-Interest (RoI)

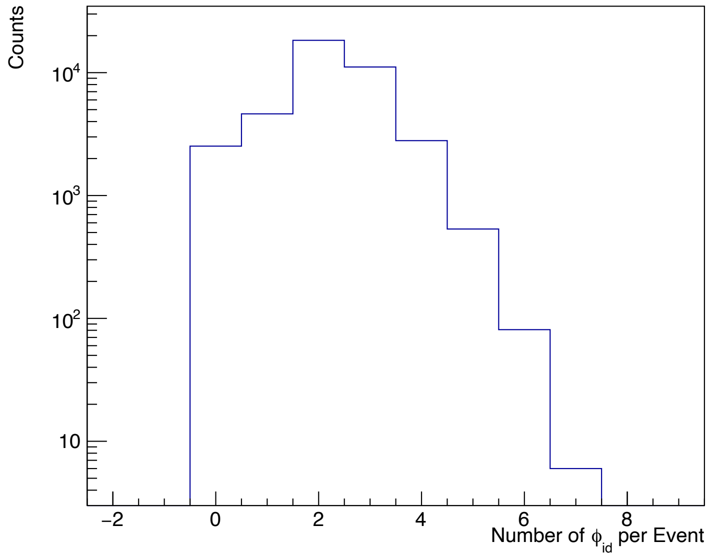
$\Delta\theta$ $(|\Delta\theta| \leq 15\ mrad)$ *is the angular deviation of the locally defined segment from the infinite momentum track*

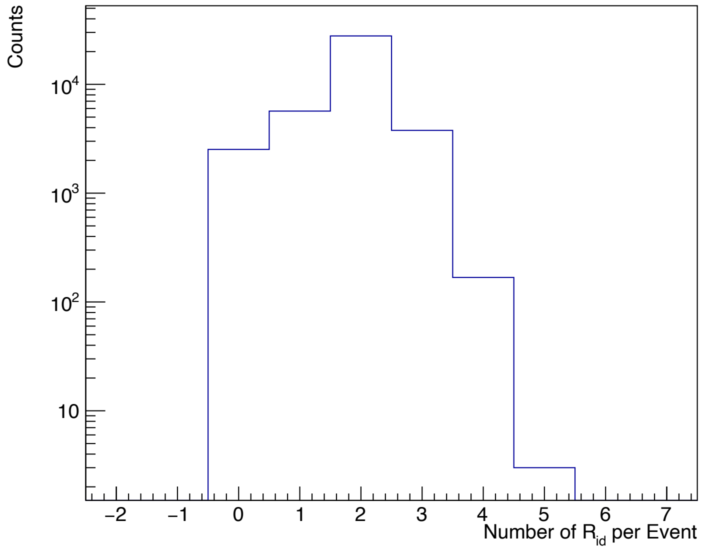


DIFFERENT NUMBER OF ϕ_{ID} - R_{ID} PER EVENT

→ We evaluated the multiplicity of candidates (ϕ_{id} - R_{id} pairs) we find

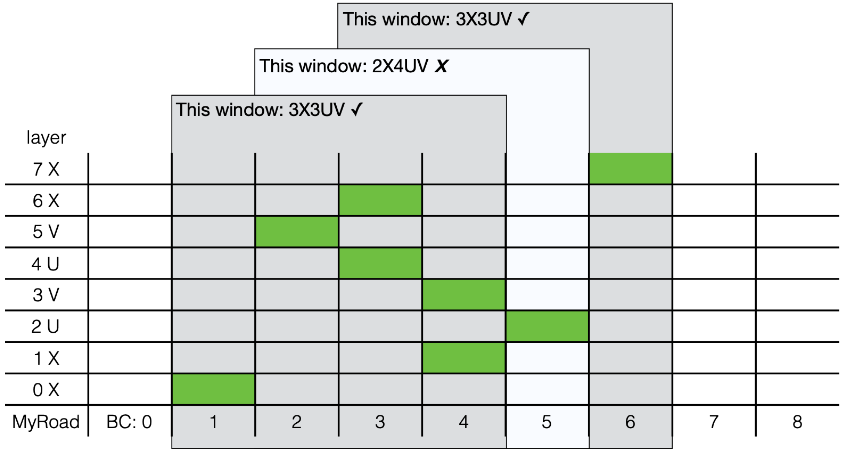






→ In particular, this plot defines how many candidates we have (here the duplicates are not considered)

NUMBER OF ϕ_{ID} - R_{ID} PER BCID PER SECTOR



The limit is 8 segments per sector and per BCID

In the same simulated event :
→ Different time hits

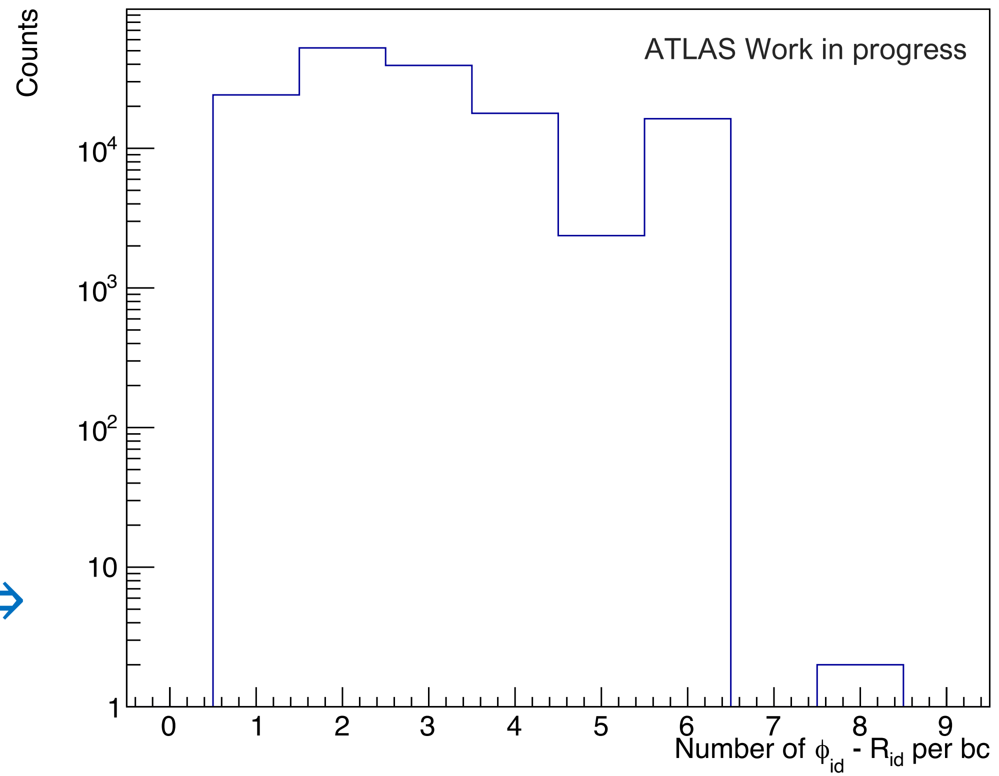
⇒ different candidates with the same ID (*duplicates*)

due to the different windows of 4 BCID that we use to find the coincidences

Each candidate is thus assigned a BCID in addition to the R_{id} and ϕ_{id}

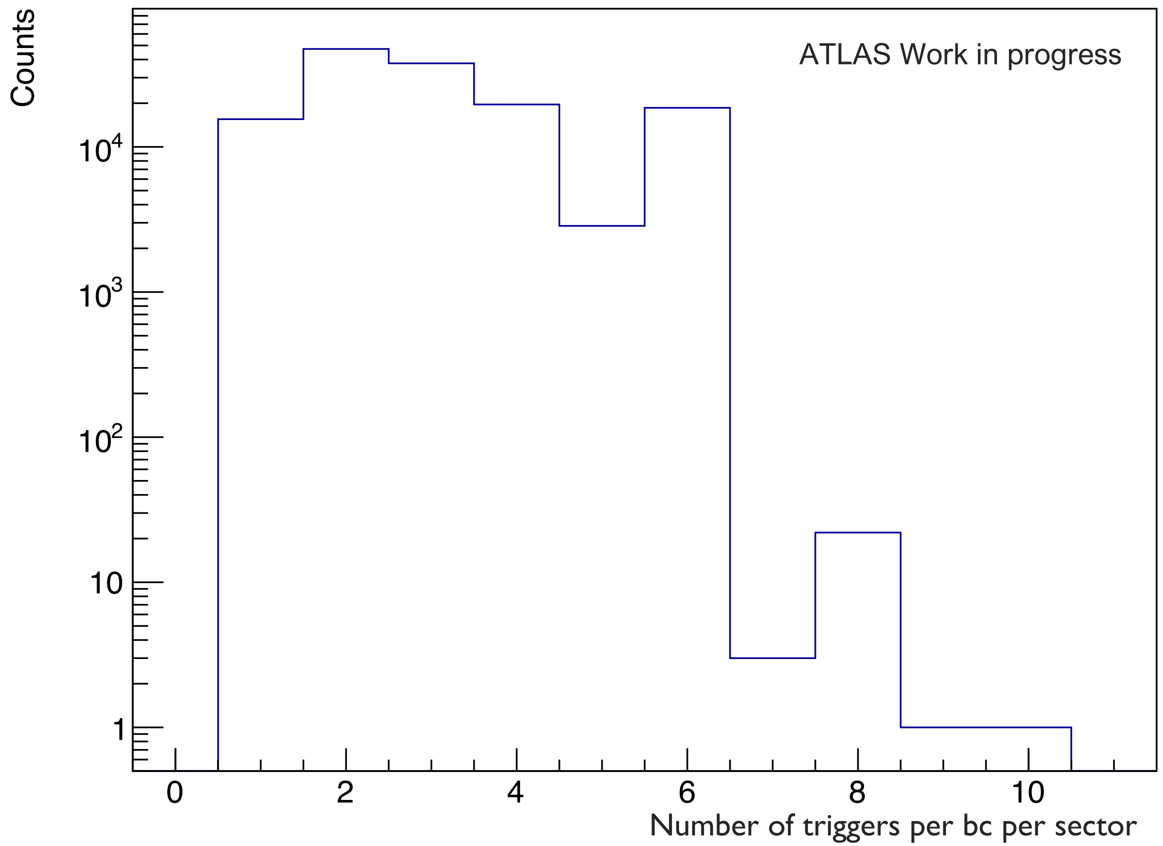
- ➢ Separate counting of candidates that are in different BCIDs

⇒



NUMBER OF ϕ_{ID} - R_{ID} PER BCID PER SECTOR

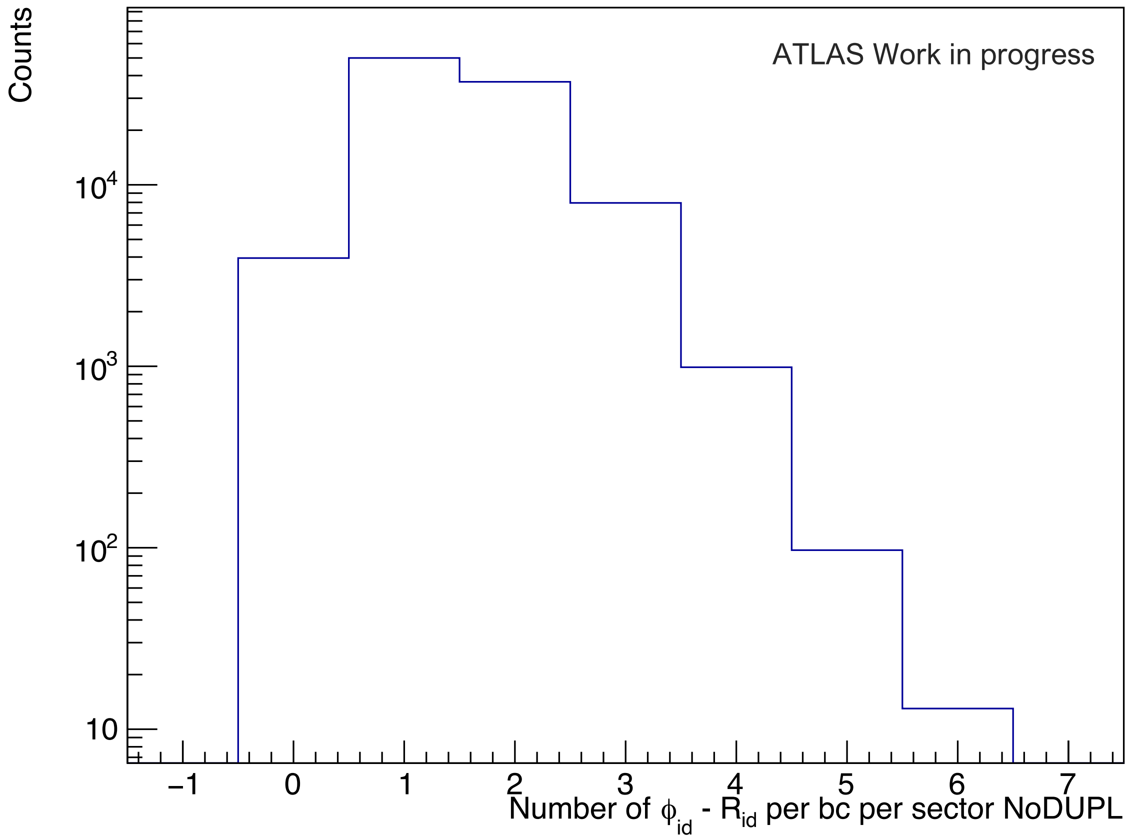
- Number of triggers per BC per Sector



Different pairs and duplicates are all counted

This count is important in case we fail in electronics to remove duplicates and are forced to take them all

- Number of $\phi_{id} - R_{id}$ per BC per Sector



Duplicates are not counted

This count shows the case where electronics can make a selection and remove duplicates

SUMMARY AND CONCLUSIONS

- ❑ Great $\boldsymbol{\theta}$ resolution and angular efficiency
- ❑ Highlighting of problems in angular ϕ reconstruction, that is currently under investigation to be solved
- ❑ Study of the output segment parameters to identify duplicates and candidates with different $\phi_{id} - R_{id}$, useful as a baseline for further studies with background

⇨ The study of trigger rates with background (pile up, cavern background) and $Z \rightarrow \mu^+\mu^-$ sample

⇨ Fix of the correct timing (and hit skimming) and re-evaluation of performances to emulate NSW hardware

THANKS FOR YOUR ATTENTION

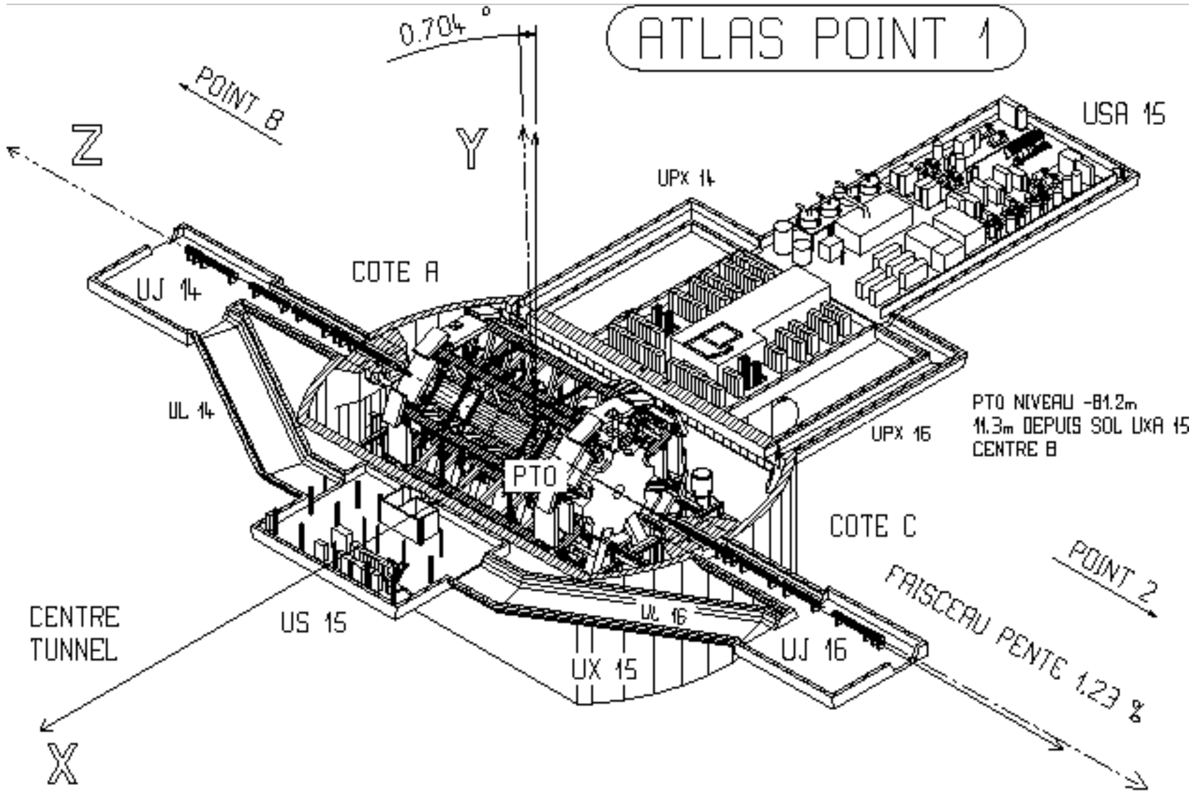
BACK-UP

The ATLAS Detector

Coordinate System

It is a *xyz* right-handed reference system centered in the nominal interaction point of the beams.

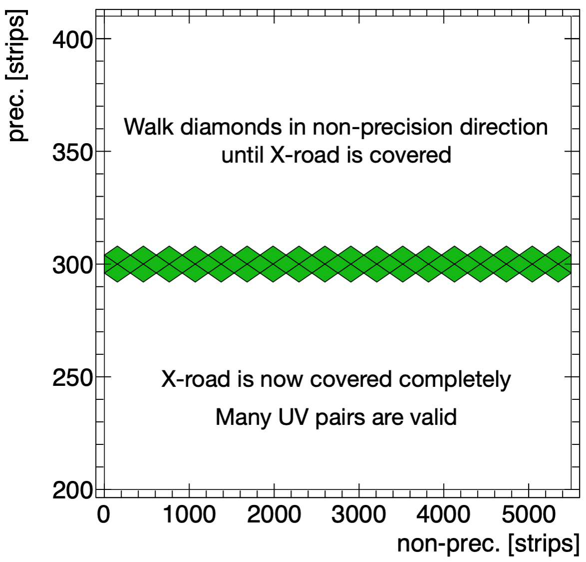
This reference system is usually defined by *cylindrical* coordinates : the azimuth angle ϕ, measured around the beam, and the polar angle ϑ, measured with respect to the beam axis.



MICROMEGAS L1 TRIGGER ALGORITHM

Possibility of having multiple triggers for the same track

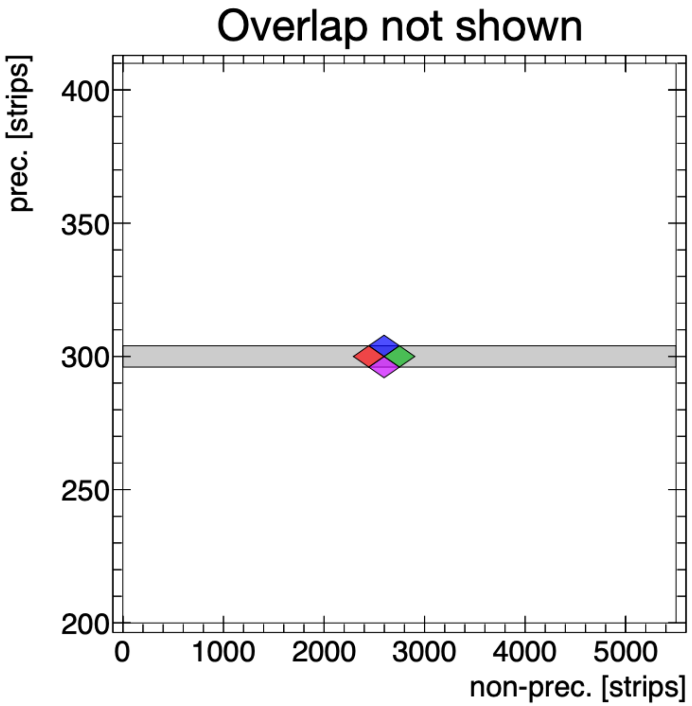
For each X-road, there is a collection of U/V-road-pairs which are valid

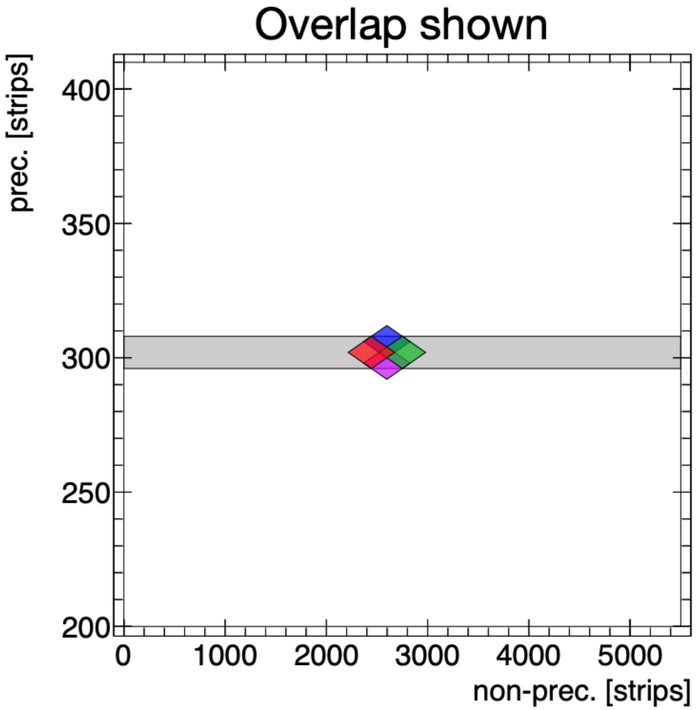


- **Diamond Overlap**

With no overlap, no risk of muon passing through multiple diamonds

With overlap, lots of opportunities for muon to pass through diamonds





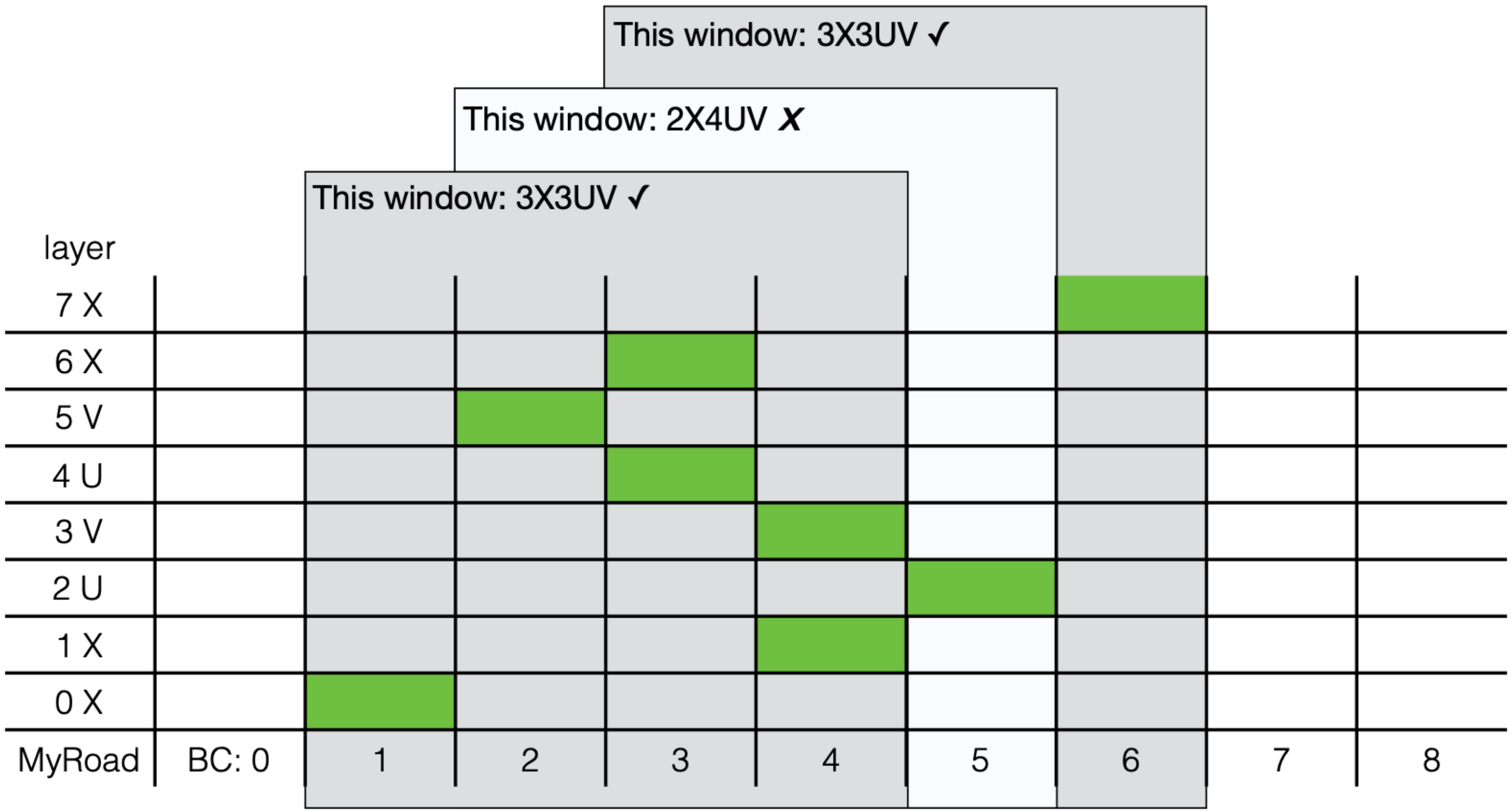
Multiple diamonds

↓

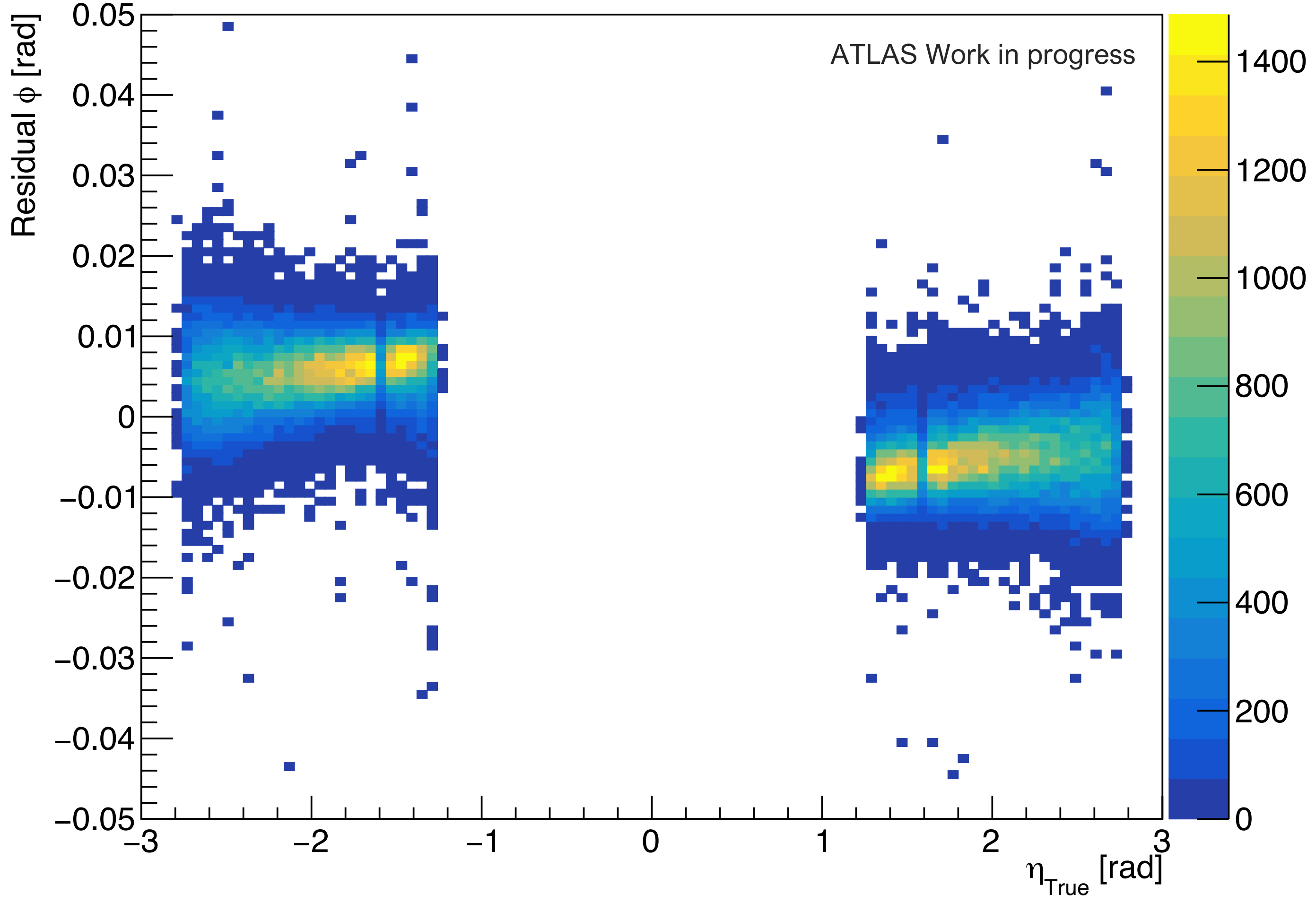
Multiple triggers

MICROMEGAS L1 TRIGGER ALGORITHM

- Sliding window of 4 BCs, in which the coincidence logic is verified
- Triggers only issued when at least one hit "has reached maximum age"
- Life-like example: one muon can make many triggers

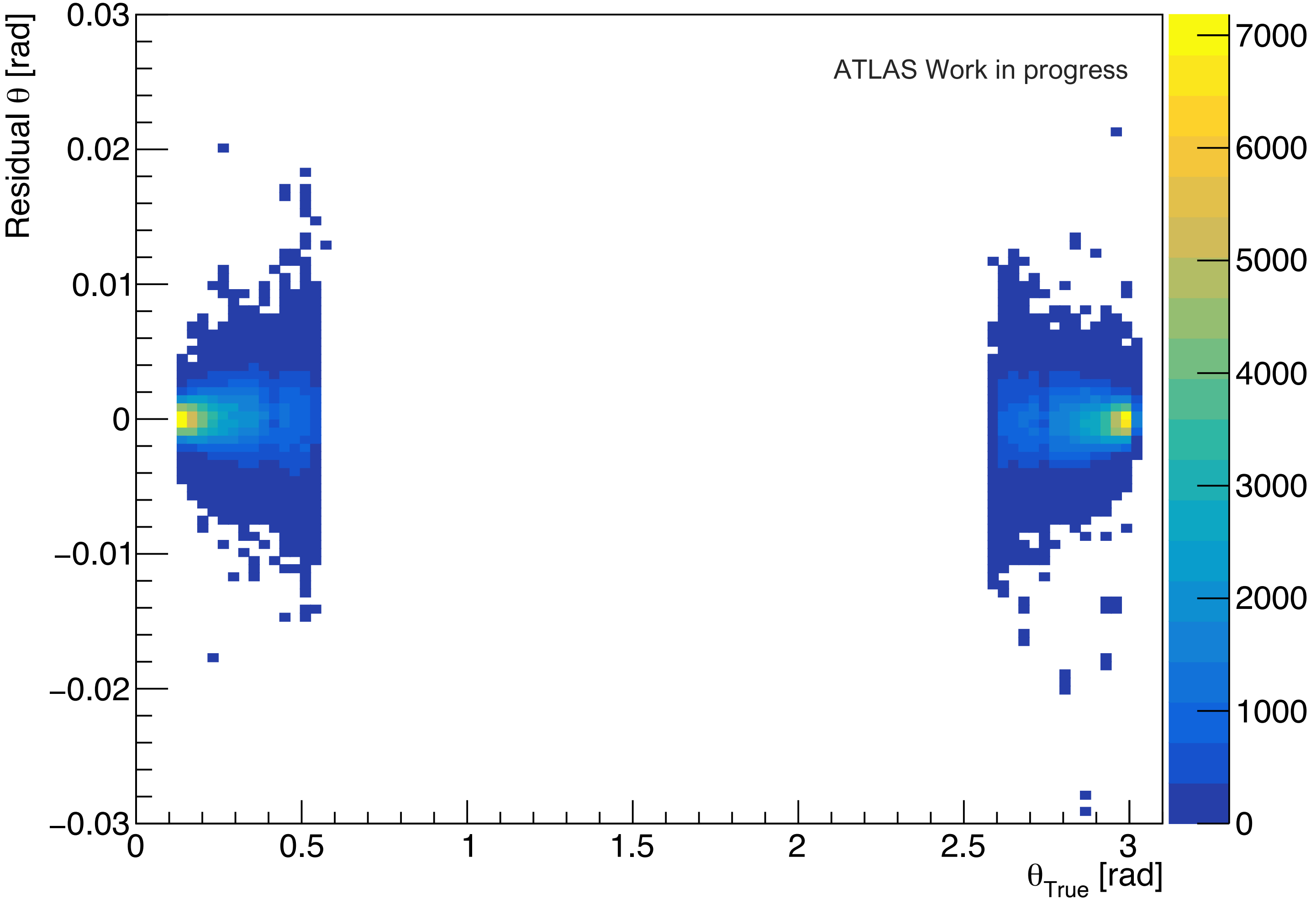


CURRENT RESIDUALS - ϕ



The residuals for ϕ are larger in the regions furthest from the beam and show the shift in different directions (z dependence)

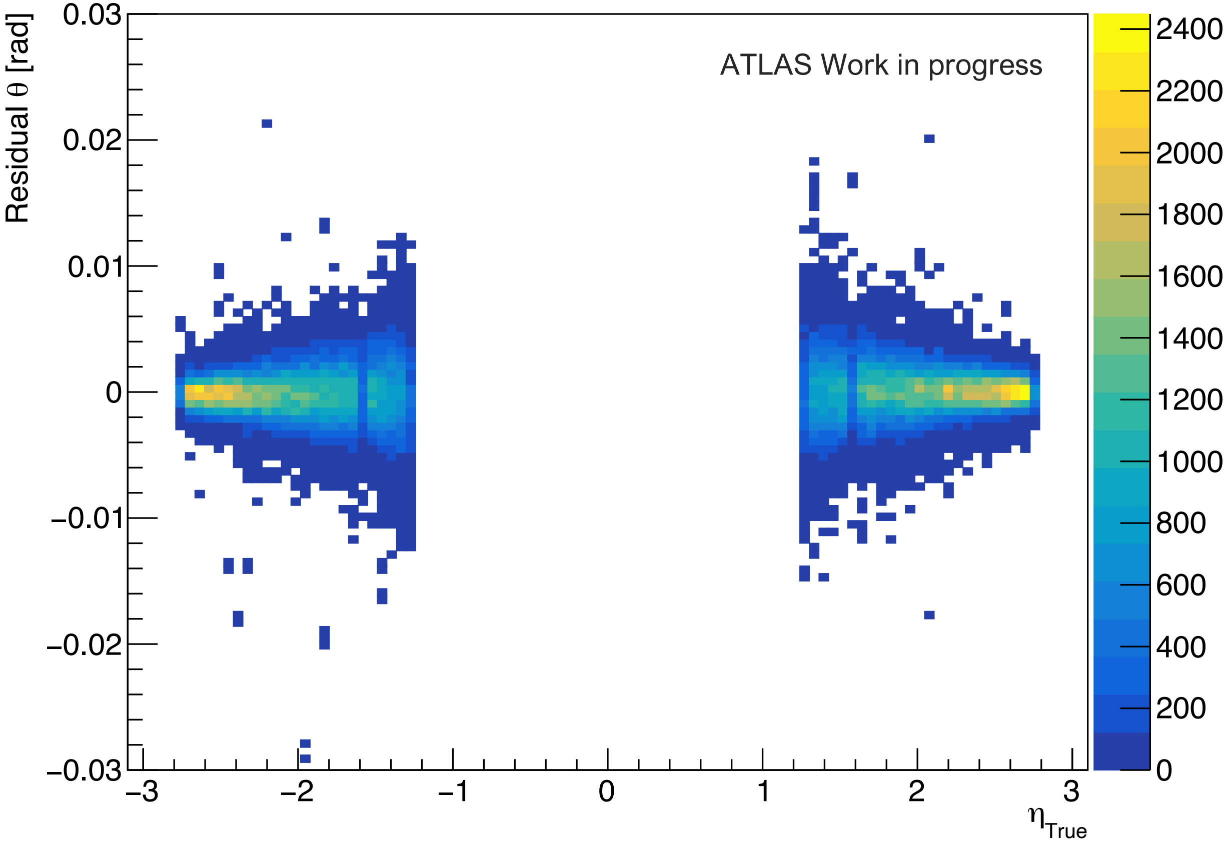
CURRENT RESIDUALS - ϑ

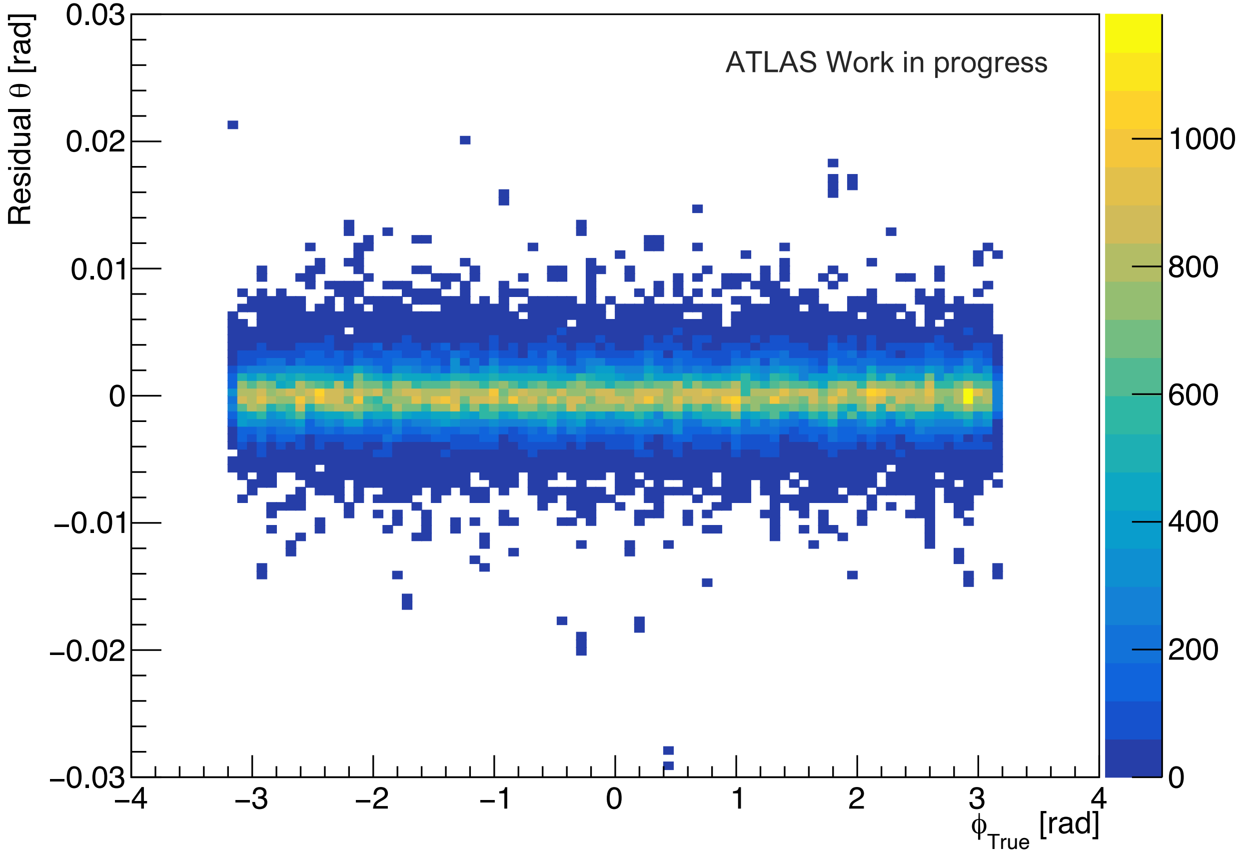


The residuals for ϑ are larger in the regions furthest from the beam

CURRENT RESIDUALS - ϑ

The residuals for ϑ are larger in the regions furthest from the beam





The increase in ϑ residuals along η axis is more evident, while along ϕ is more or less uniform

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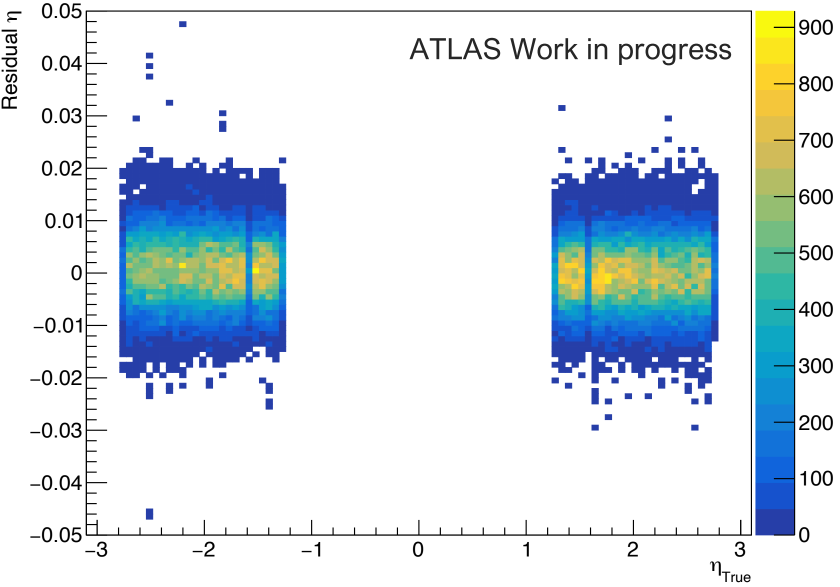
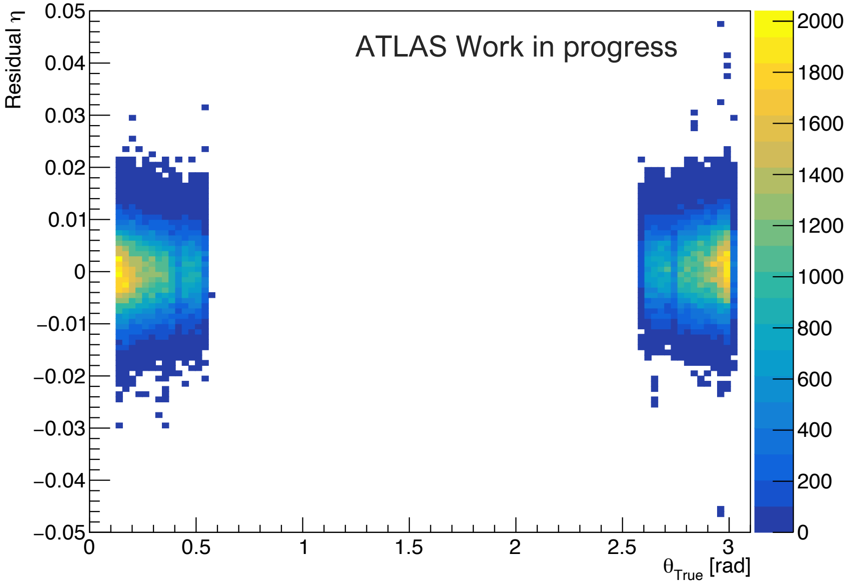
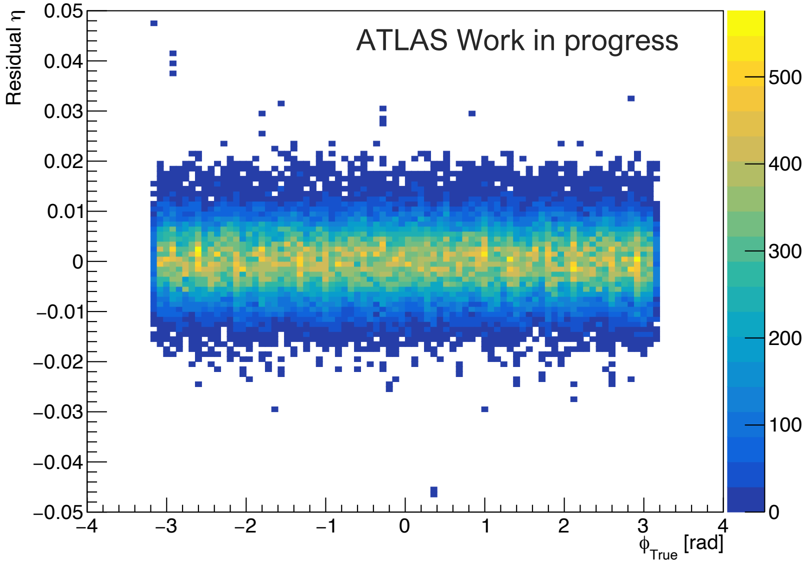
CURRENT RESIDUALS - η



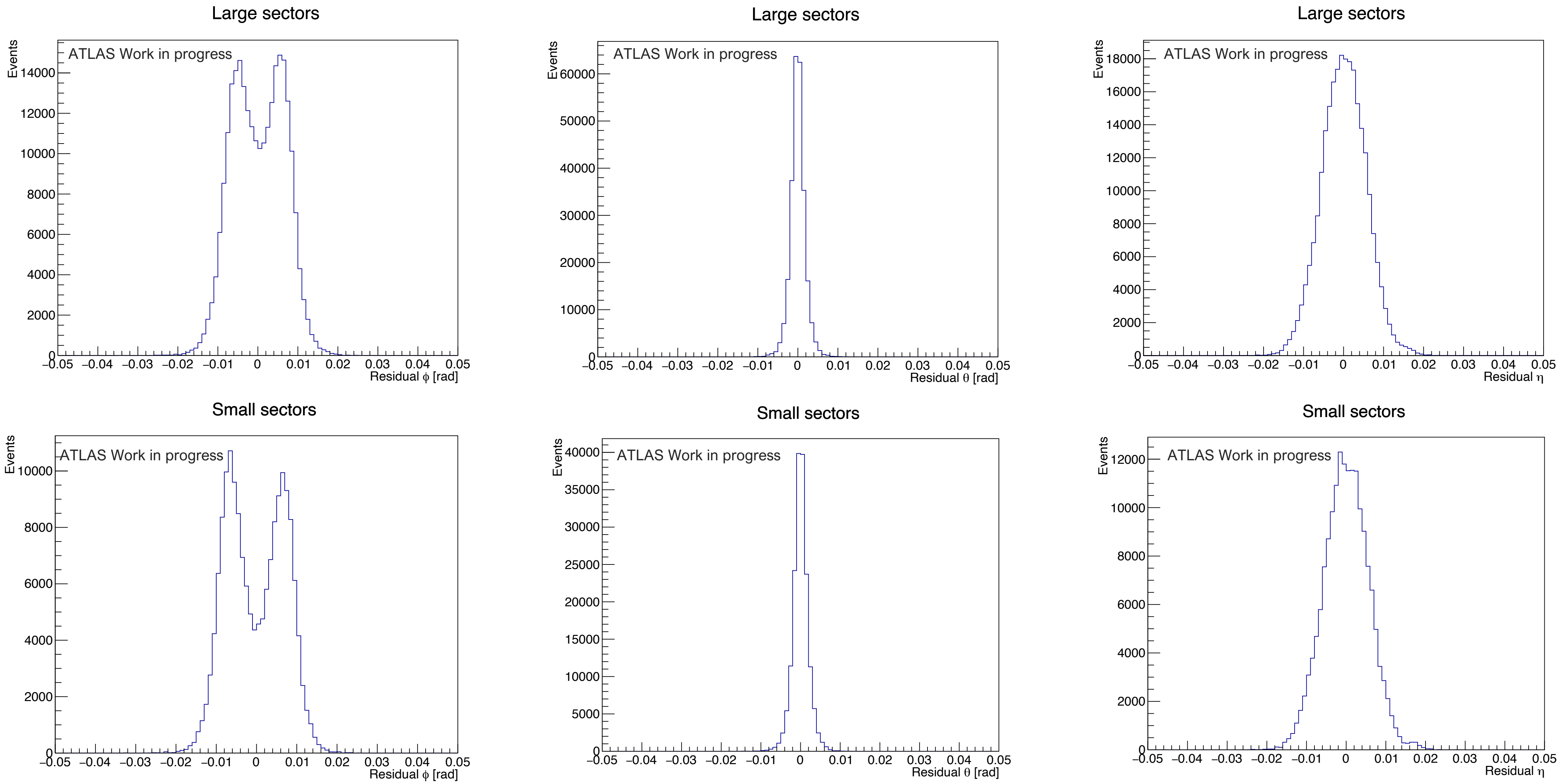




The distribution shows how residuals become larger in the regions closest to the beam

RESIDUALS – LARGE / SMALL SECTORS

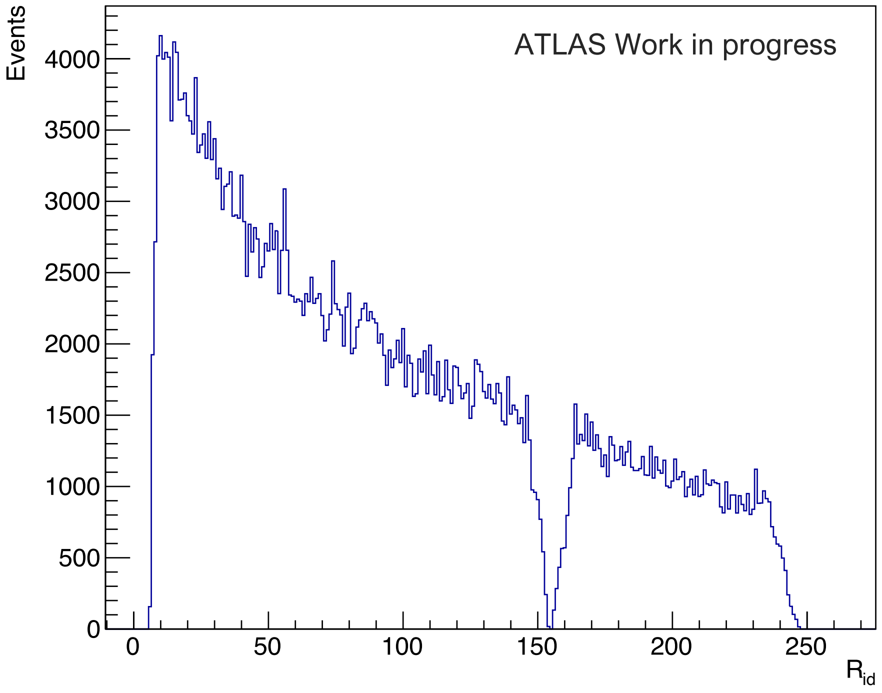
- Double peaks visible in ϕ residuals distribution, problem with some shift in the reconstructed track or in the road building

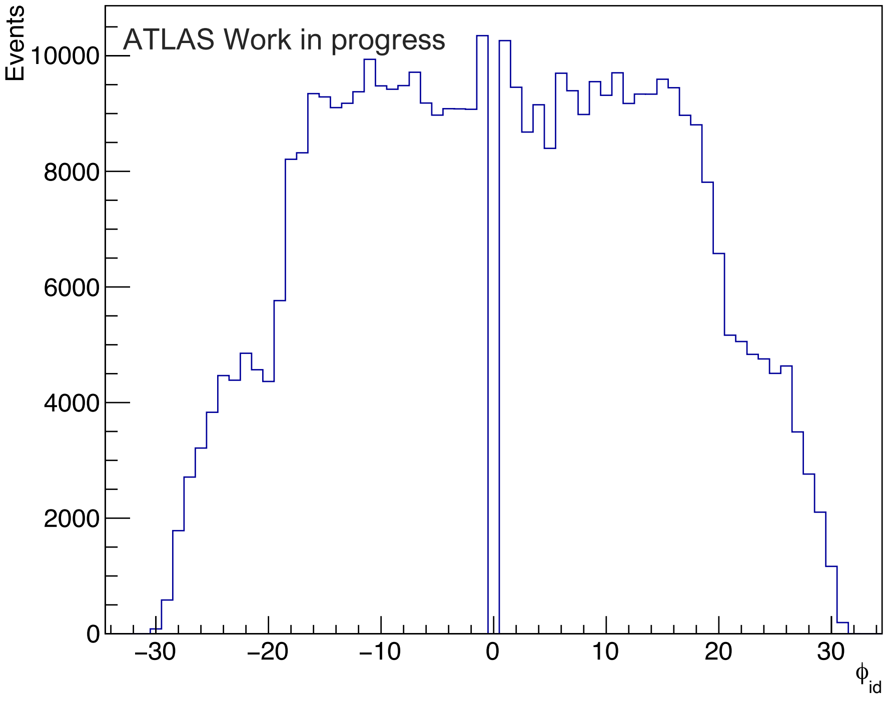


R_{ID} & ϕ_{ID} DISTRIBUTIONS

First of all , we calculate the segment parameters, checking that they are in the right ranges

- The gap between MM modules is visible in the R_{ID} distribution
- The R_{ID} bins near the beam are more populated
- The ϕ distribution centre is more populated due to the Large-Small overlap



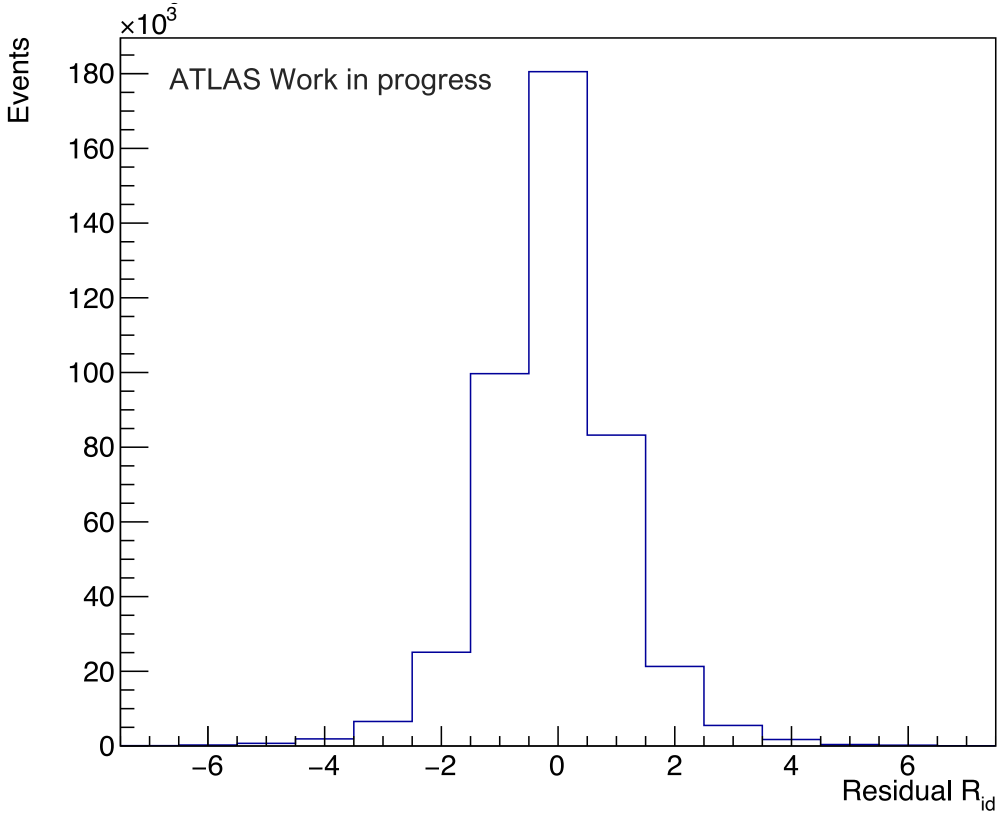


$$R_{ID} = \frac{z_{min}tan(\theta) - R_0}{16\ mm}$$

$$\phi_{ID} = \frac{\phi_{local}}{9\ mrad}$$

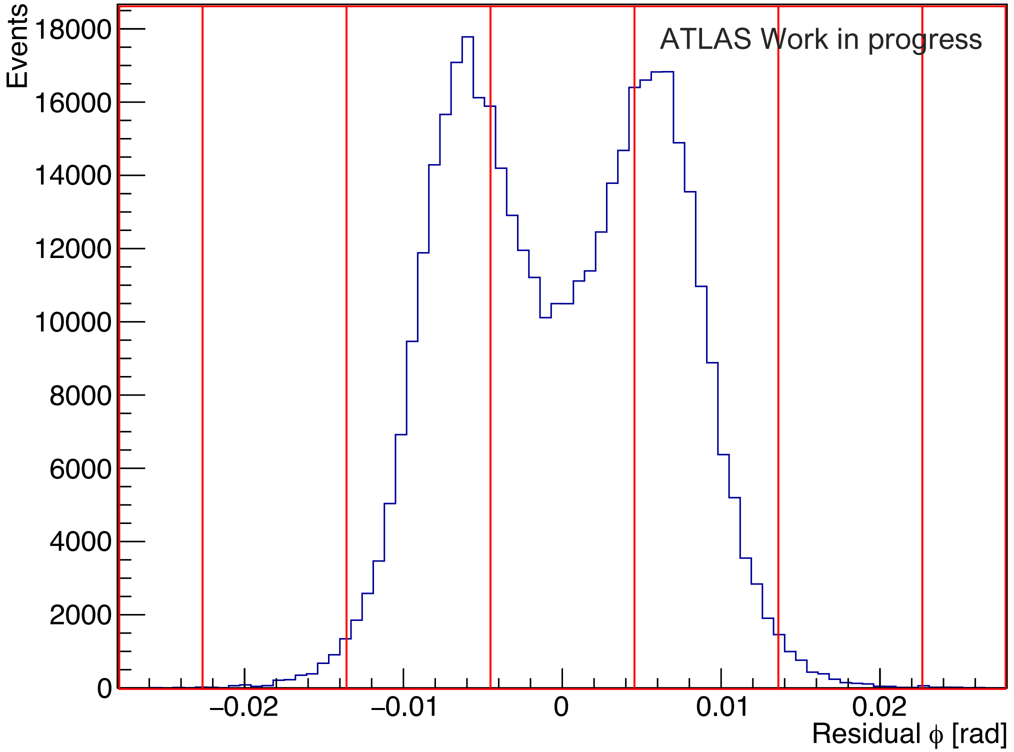
R_{ID} & ϕ_{ID} RESIDUALS

The study of the resolutions of R_{ID} and ϕ_{ID} allows us to say if we reconstruct the position in a good way or not



The plot shows how duplicates go in neighboring bins

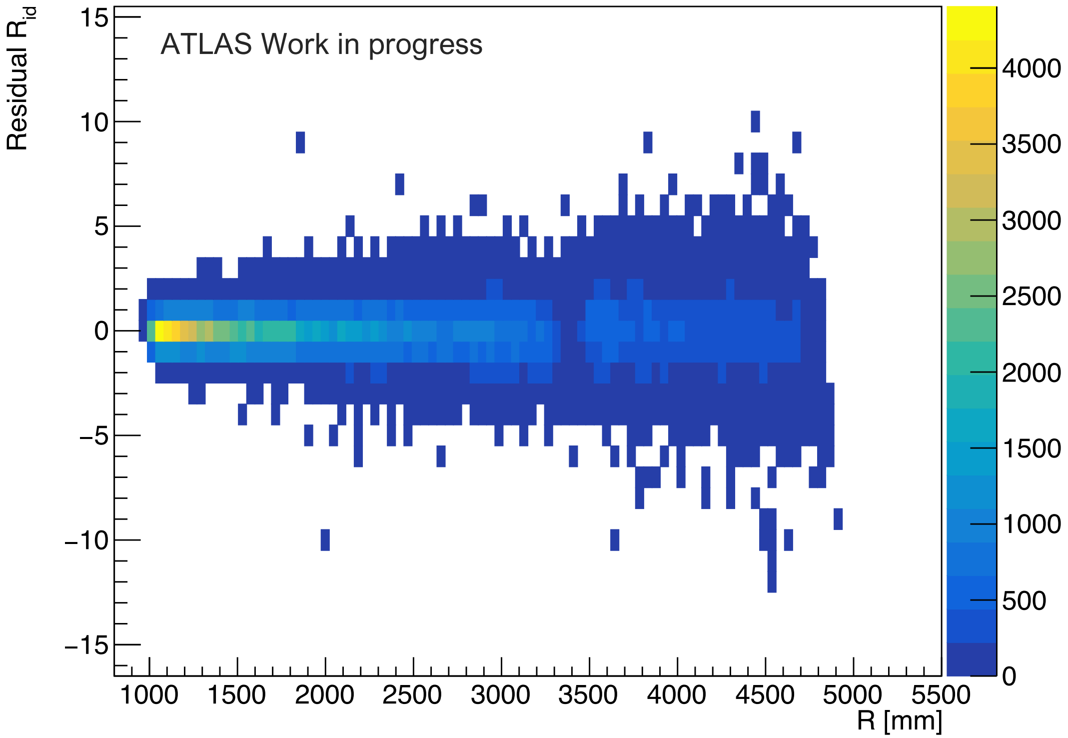
Red space = ±4.5 mrad

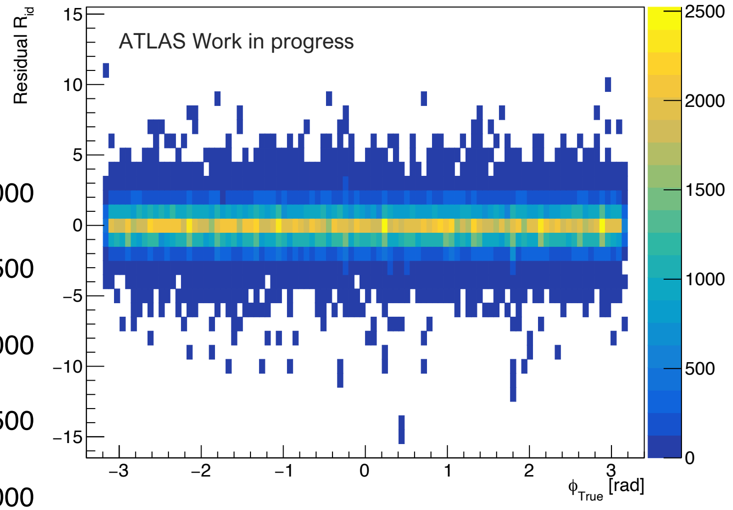


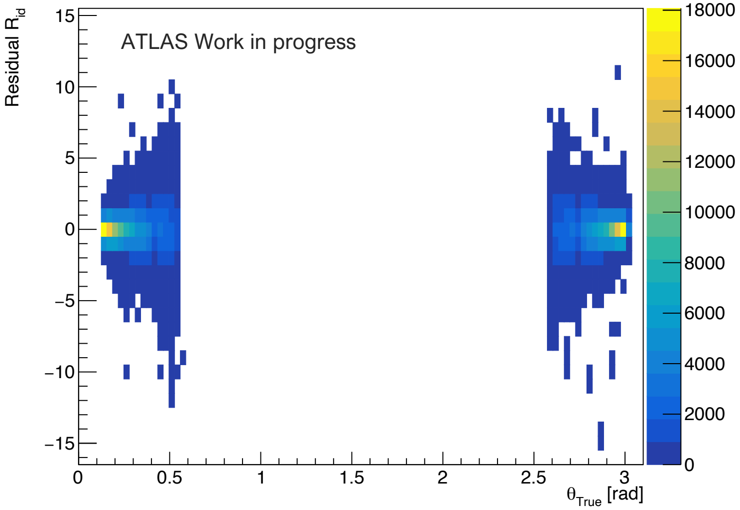
The shifts are accentuated by the double peak reco problem

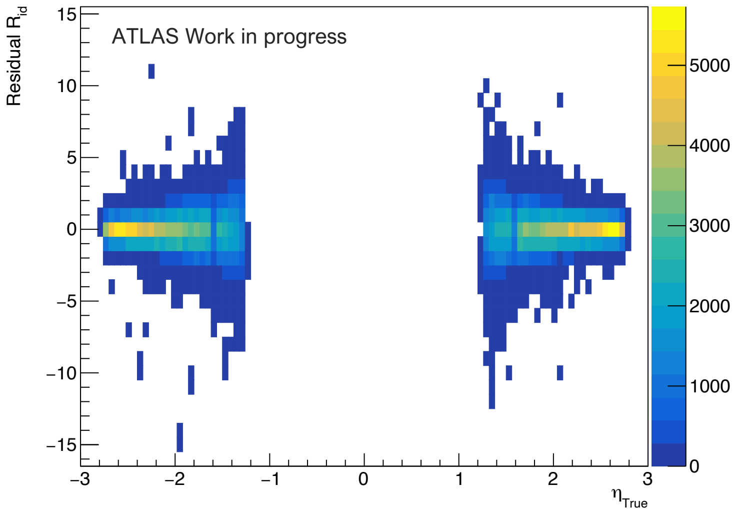
MORE COMPLETE R_{ID} RESIDUALS STUDY

We analyze the R_{ID} as function of all angular variables to have a more complete picture and highlight that duplicates go in nearby bins



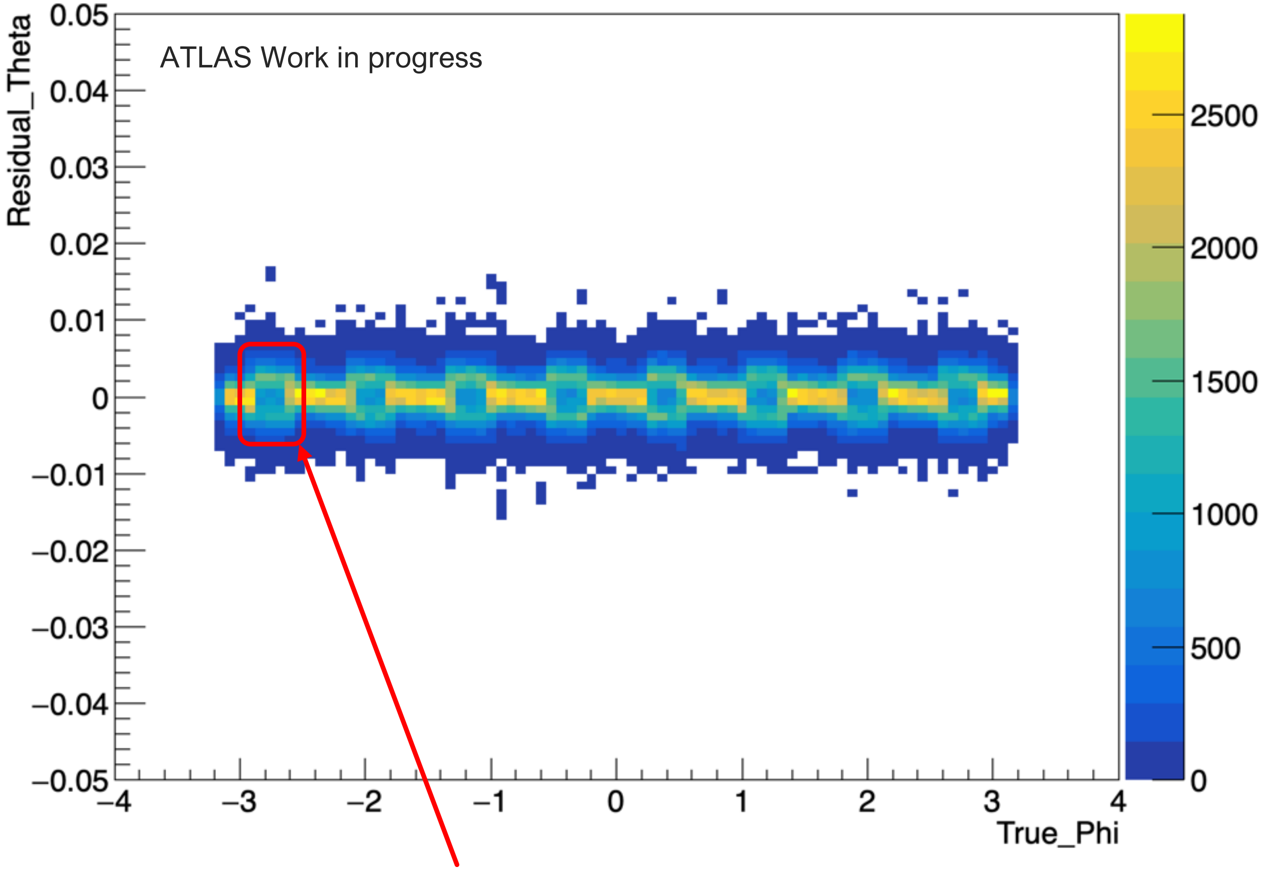


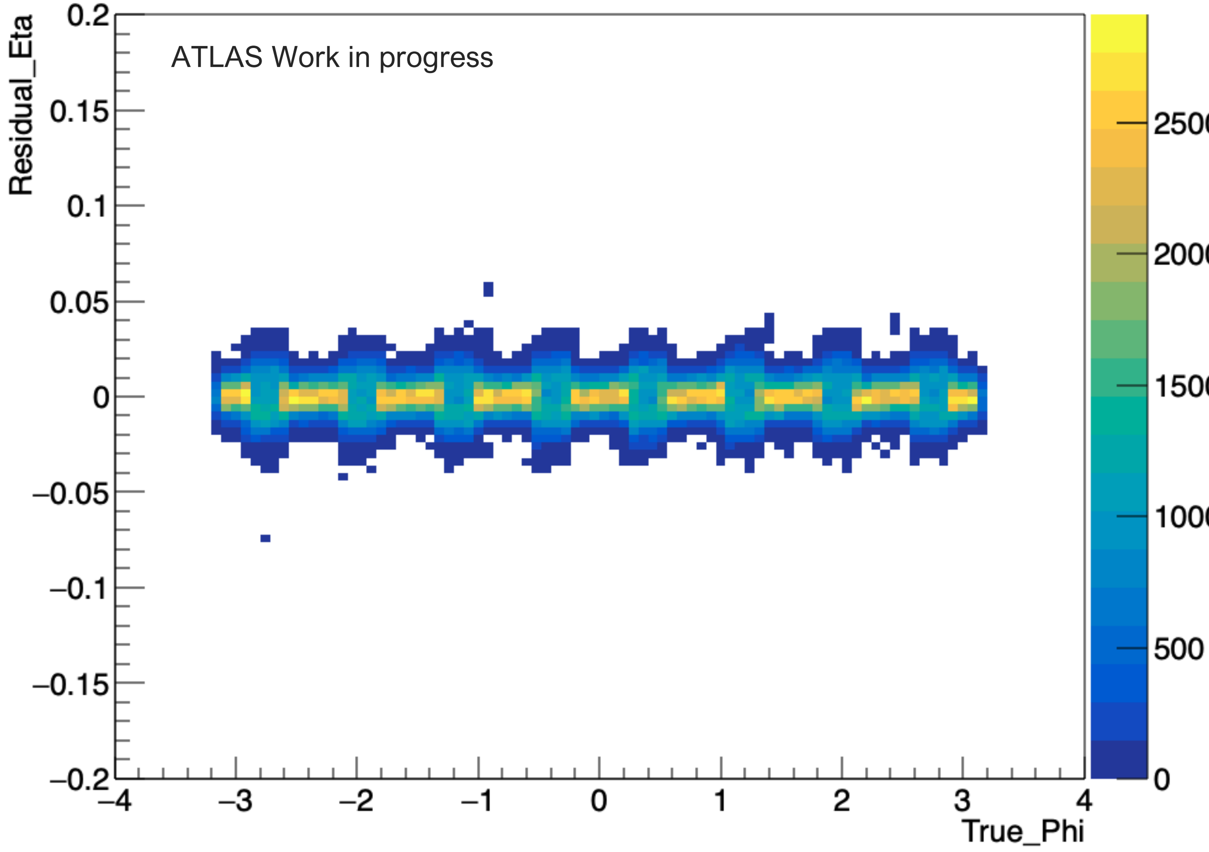




R_{id} shift from *truth* value is due to R_{id} is not correct for ϕ

PREVIOUS VERSION RESIDUALS PROBLEM - η , ϑ





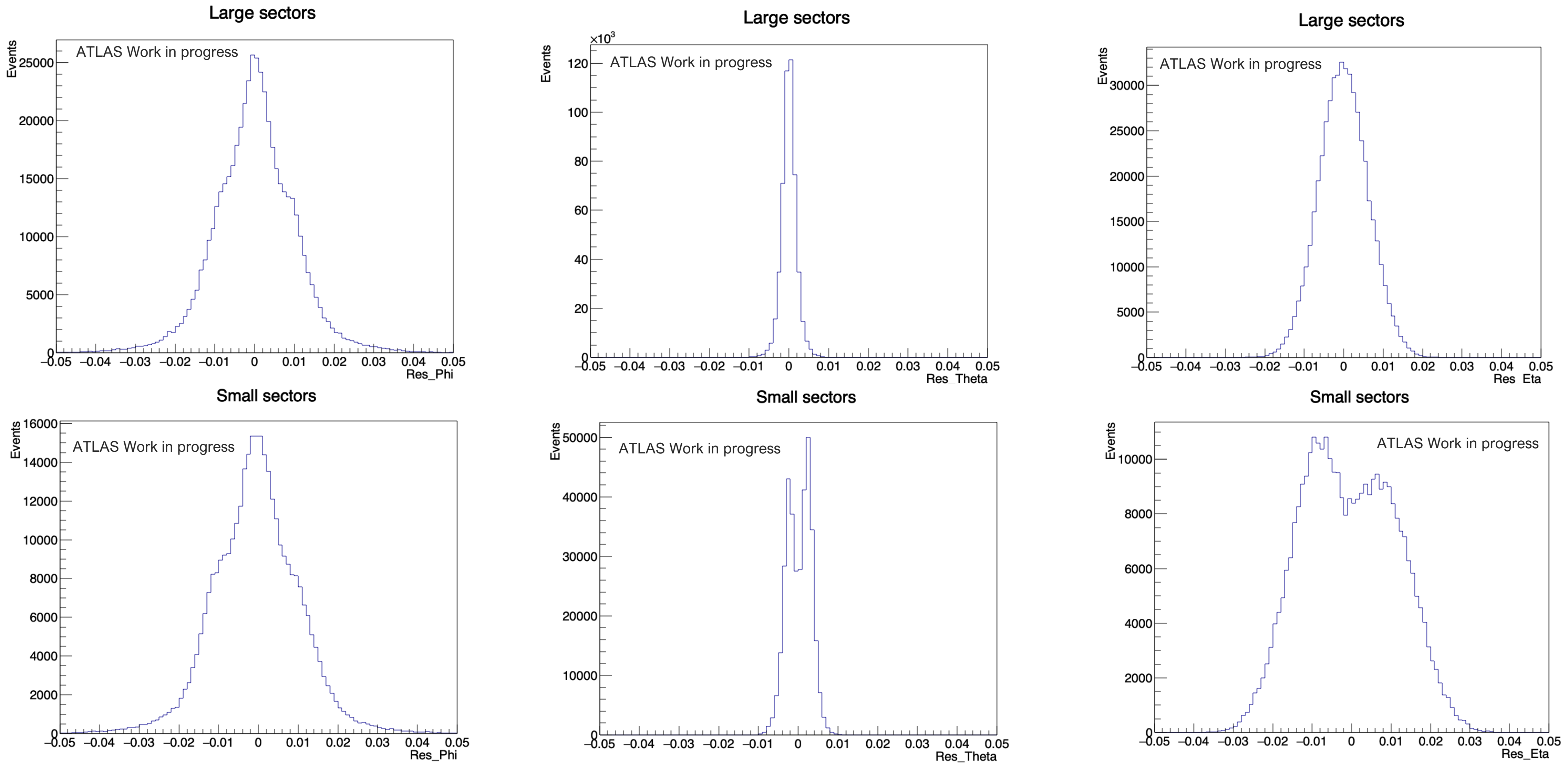
Double peaks for Small Sectors :

Considering the 2 NSWs togheter *but* they have a different shift

91000 events and not 40000 as in current version

PREVIOUS VERSION PROBLEM RESIDUALS – LARGE / SMALL SECTORS

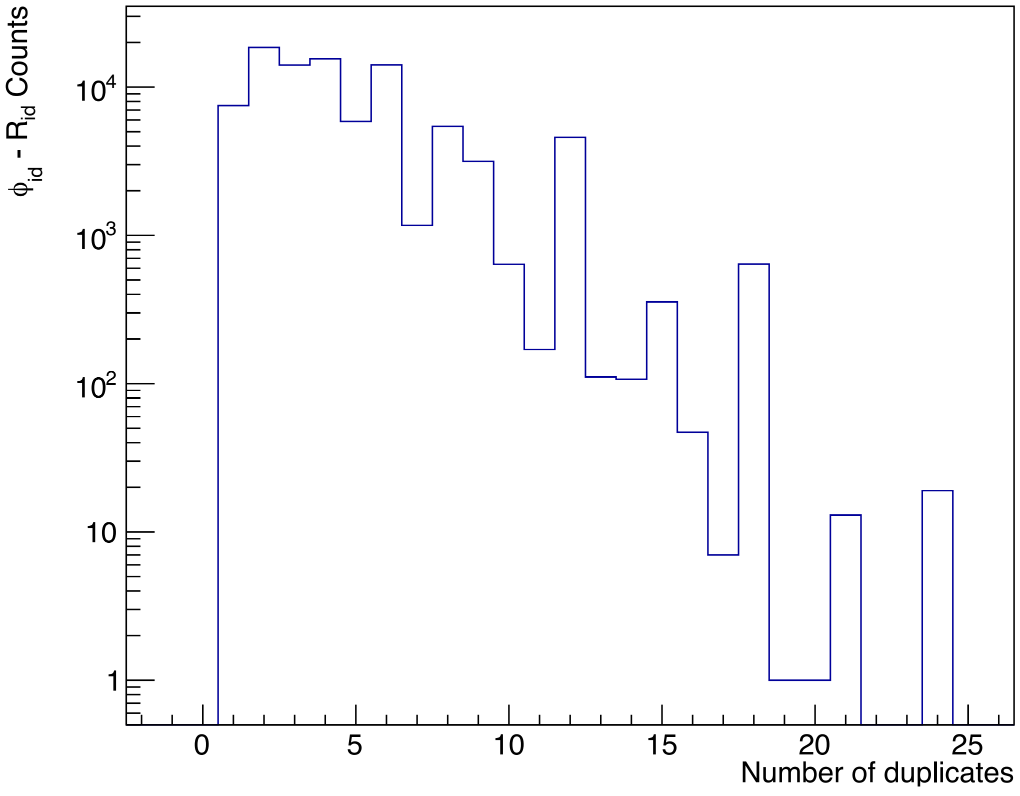
- Double peaks visible in some residuals distribution, problem with some shift in the reconstructed track or in the road building

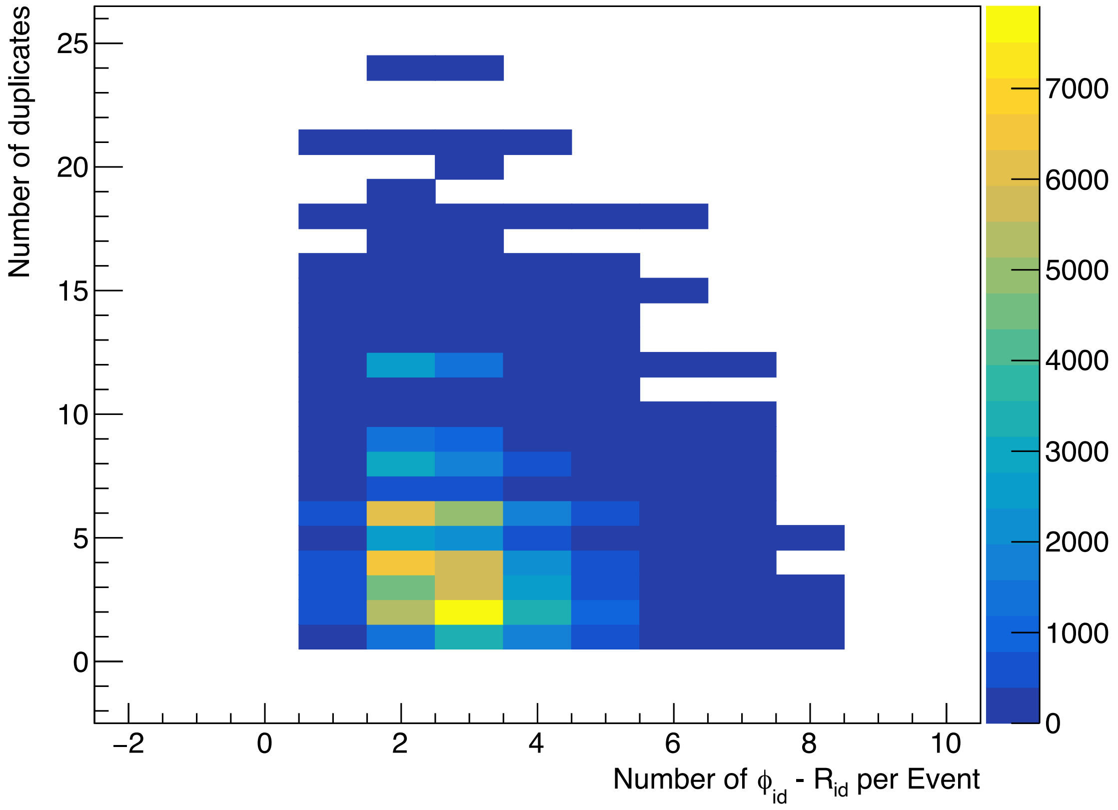


DUPLICATES OF ϕ_{ID} - R_{ID}

Counting how many duplicate candidates there are for each event

→ i.e. how many tracks have the same R_{id} and ϕ_{id} per event



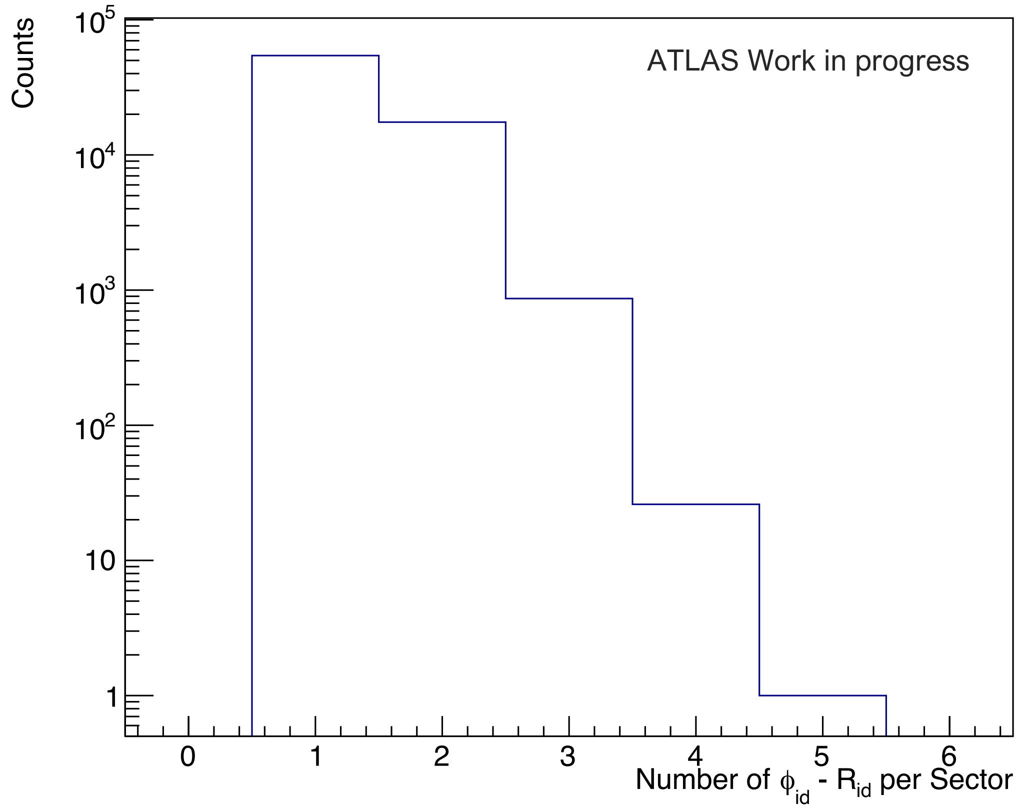


→ The duplicates that go in different RoI are not too many

NUMBER OF ϕ_{ID} - R_{ID} PER SECTOR

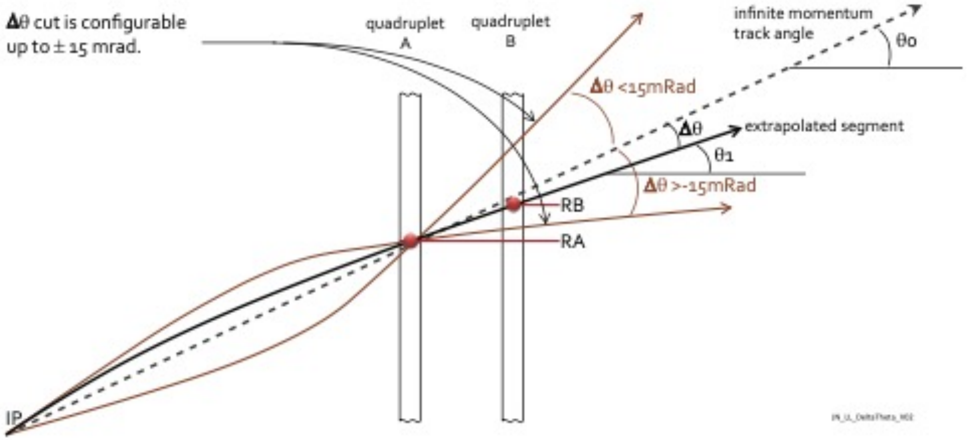
Despite this problem, the number of pairs of IDs per NSW sector is within the limit (8 segments per sector)

- It will be useful as baseline to see what will happen with the background later



→ We take a timing of the hits that is not completely aligned with what we will have in the hardware. This (ongoing) correction could further reduce the number of candidates and duplicates

BCID ANALYSIS $(cut\ on\ \Delta\theta)$



$\Delta\theta$ is the angular deviation of the locally defined segment from the infinite momentum track

Limit for valid configuration : $|\Delta\theta| \leq 15\ mrad$

- Electronics discard all segments with $|\Delta\theta| > 15\ mrad$

We tried to impose this cut to see how many candidates and duplicates are discarded because out of range

but

A noticeable change in the count was **not** obtained

(The out-of-range events, i.e. the final parts of the tails of the $\Delta\theta$ distribution, are minimal) →