COMMISSIONING AND FIRST MEASUREMENTS WITH LHC COLLISIONS OF BIS78 RPCS, AN INNOVATIVE DETECTOR FOR ATLAS HL-LHC UPGRADES

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XVI Workshop on Resistive Plate Chambers and Related Detectors (RPC2022)

ATLAS EXPERIMENT

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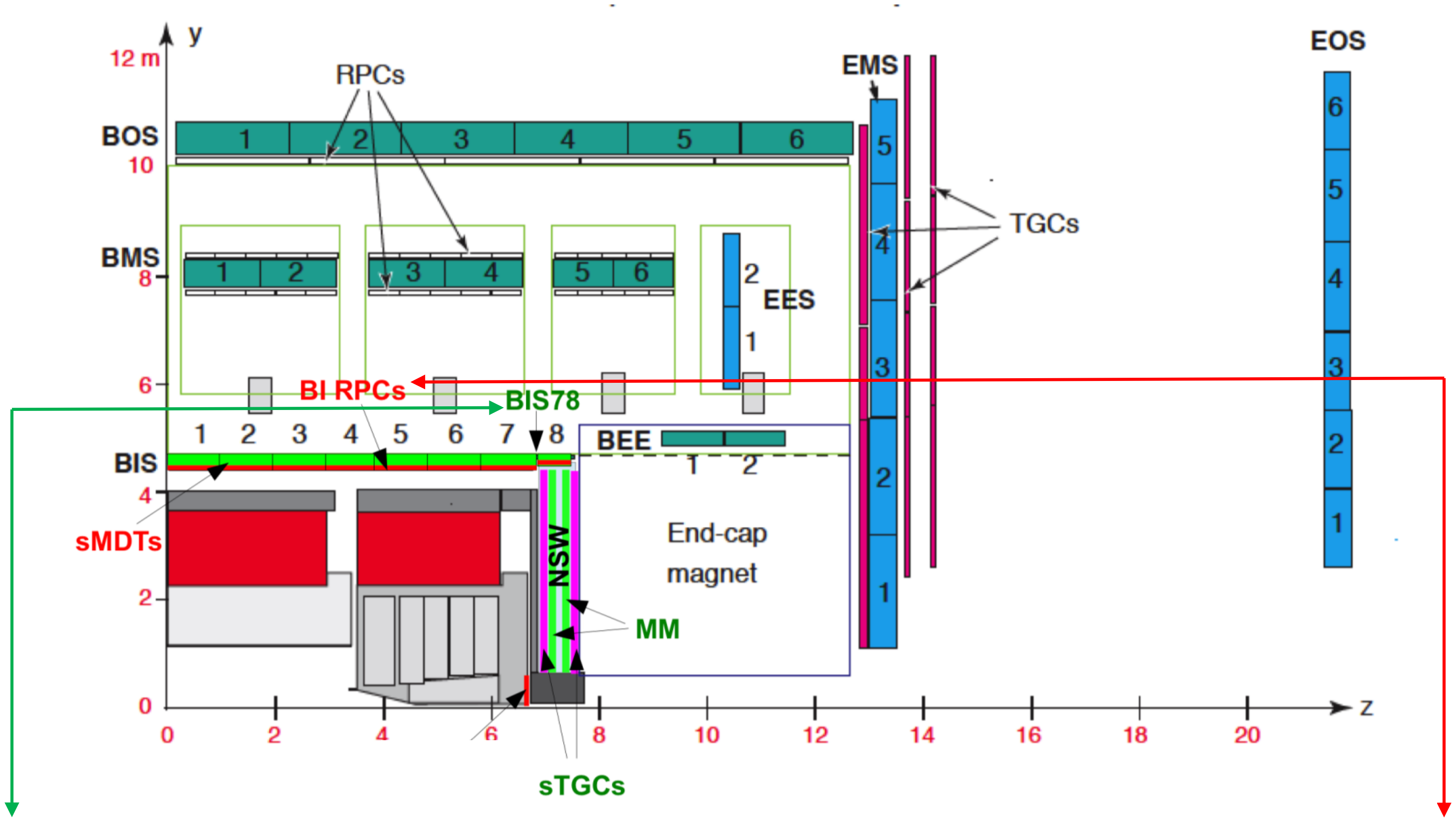
ATLAS RPC UPGRADE PROJECTS FOR HI-LHC



The BIS78 project provides a new generation RPC system to be installed in the barrel-endcap transition region at 1.0 <|η|< 1.3, to complete the non instrumented area which is not covered by NSW chambers installed in parallel to BIS78, and reduce the fake muon rate. This project is considered as a solution for **ATLAS end-cap**.

Phase-1 RPC BIS78 upgrade is considered as a pilot project for the Phase-2 RPC BI upgrade.

The Phase-2 BI project consist of the extension of the RPC chambers to the whole ATLAS inner barrel to recover the holes and increase the redundancy. BI chambers will inherit most of the BIS78 technology. This project is considered as a solution for **ATLAS barrel.**

BIS-78 PROJECT

Due to the narrow available space, the legacy Monitored Drift Tubes (MDTs) were replaced with:

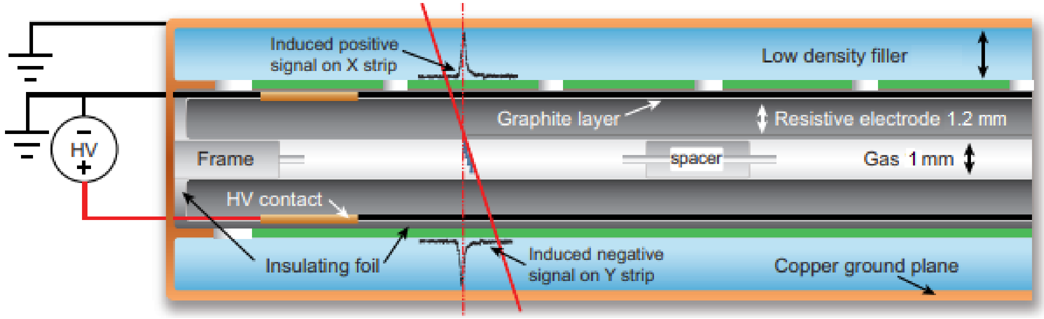
16 new muon stations (16 + 16 BIS7/8 RPC) made of:

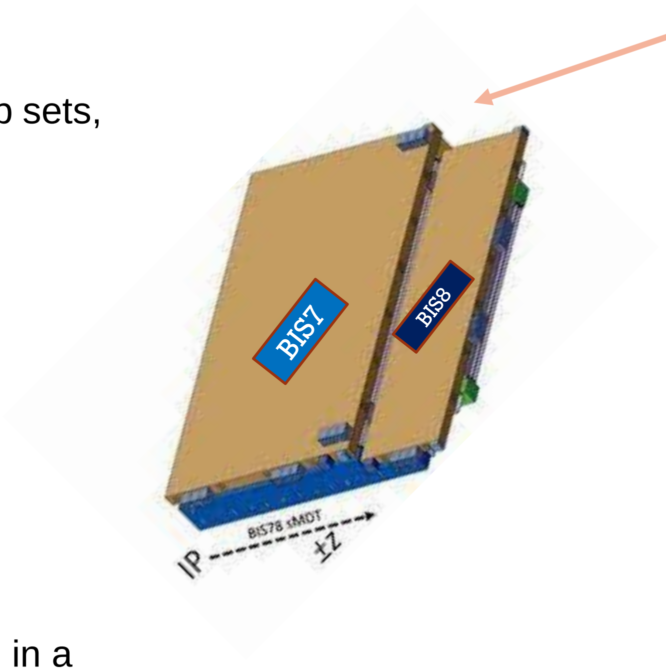
- one small diameter tubes MDT chamber
- two RPC triplets (~ 150 m^2, 10% of the BI Chambers)

8 stations (ATLAS Side-A) have already been installed in 2021.

Each chamber is composed by 3 identical singlets:

- A singlet is composed by 2 readout panels with 2 orthogonal strip sets, which are sandwiching a gas gap, including the FE electronics.





- A singlet is a self sufficient and fully independent detector closed in a Faraday cage, able to provide a 2D + t localization of the muon.
- A triplet can provide muon candidates with a local 2 out of 3 coincidence.

BIS-78 Technology

Gas Gaps

- Thinner gas gap -> improved time resolution
- Thinner electrodes -> Lower detector weight
- Peaked (non-exp) charge distribution with less developed charge -> improved working point
- Almost one half the current operation voltage

Comparison of the important parameters of the legacy RPCs and BIS78:

Detector parameters	ATLAS RPC	BIS78 RPC
Gas gap width	2 mm	1 mm
Electrode Thickness	1.8 mm	1.2 mm
Time Resolution	≈ 1 ns	≈ 0.4 ns
Space Resolution	≈ 6 mm	≈ 1 mm
Gaps per chamber	2	3
Gas Mixture	ATLAS Standard	ATLAS Standard
Readout	2D Orthogonal	2D Orthogonal
FE technology	GaAs	Si&Si-Ge
FE Effective Threshold	2-3 mV	0.2-0.3 mV
FE Power consumption	30 mW/ch	12 mW/ch

➡ **New Generation RPCs Space-Time Resolution: 1 mm x 0.4 ns**
➡ **Rate capability up to 10 kHz/cm^2**

Front End electronics

New amplifier and discriminator →High gain, low noise

- Higher rate capability
- Radiation hardness
- Inexpensive high performance low power FE

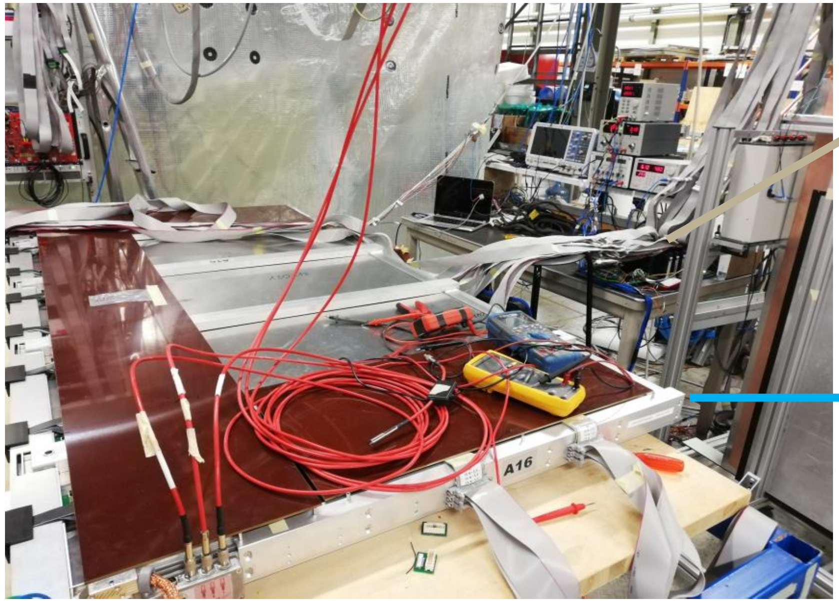
Amplifier in Silicon	
Gain	0.2 - 0.4 mV/fC
Power Consumption	3 -5 V, 1 - 2 mA
Band Width	100 MHz

Discriminator in SiGe	
Threshold	0.5 mV
Power Consumption	2 - 3 V, 4 -5 mA
Band Width	100 MHz

Challenge: Integration the FE electronics into faraday cage of a singlet in a proper way to exploit the features of the electronics.

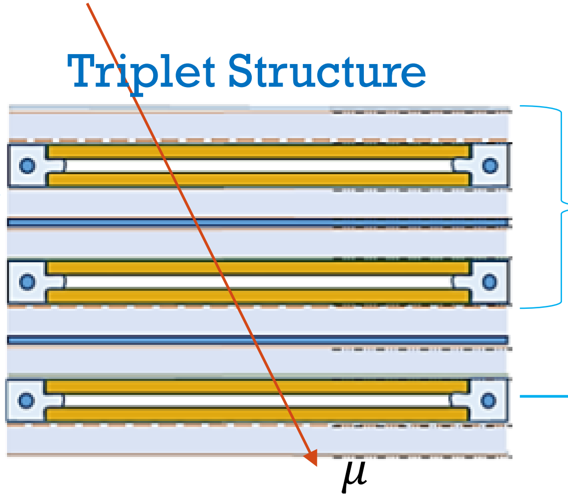
BIS78 PERFORMANCE TESTS

Our test bench in Muon Construction Site



Triggered Data

Trigger with a 2 out of 3 layers local coincidence through FPGA. Hardware Trigger Selection is with a broad time selection!



Software Trigger Selection Criteria (FINE) :

We are selecting 2 out of 3 layers fully efficient (@5.8kV) as trigger layers for tracking of the muon!

- Time Distance: 5 ns coincidence both in eta & phi
- Channel Distance: ±1 strips

There is no selection cut on the TEST Layer!

Commissioning Tests:

HV	Trigger	Test Name	Note/Description
All Layers HV On @WP	OFF	Checking the Map	Mask some random channels for all layers and validate it with the channel profile results
HV Off	OFF	Electronic Noise	1 Run
HV Off	ON	Correlated Electronic Noise	1 Run
4000V	OFF	Electronic Noise due to HV	1 Run
1 Layer On @WP (2 Layers Off)	ON	Independence Test	3 Runs
2 Layers On @WP (1 Layer Off)	ON	Fake Muon Check (correlated noise due to the chamber)	3 Runs
All Layers On @WP	OFF	Chamber Noise	1 Run
All Layers On @WP	ON	Trigger / Efficiency Check	1 Run
2 Layers On @WP - 1 Layer HV scan	ON	Efficiency Scan	3 Runs

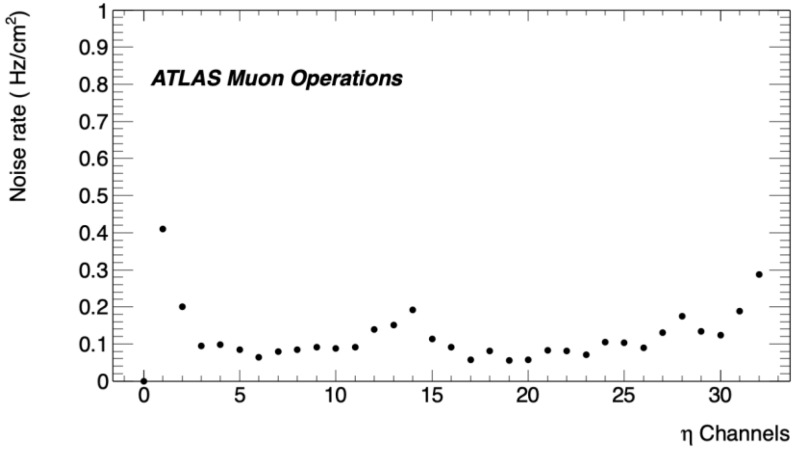
RESULTS FOR BIS-78 AT PRECOMMISSIONING LEVEL

All RPC triplets were tested with cosmic rays.

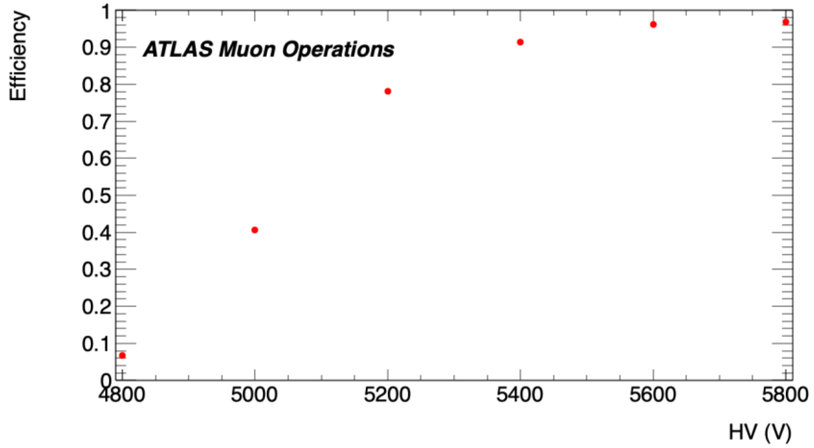
Selection Criteria:

Efficiency ≥ 95%
Noise < 1 Hz $/cm^2$
Dead Channels < 1%
Cluster size ≤ 3

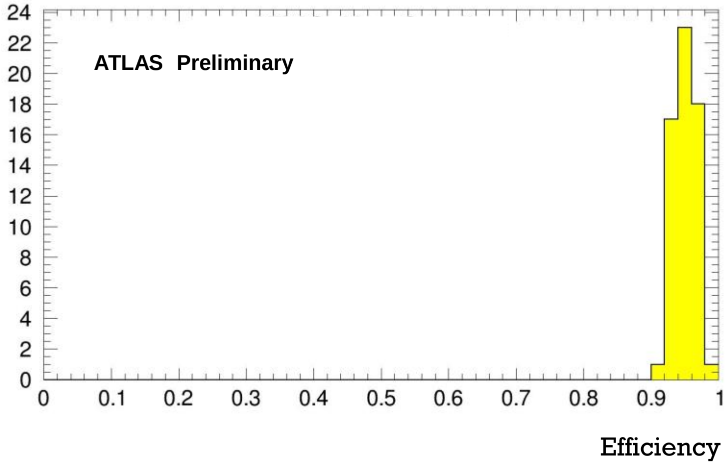
Noise rate of a single panel



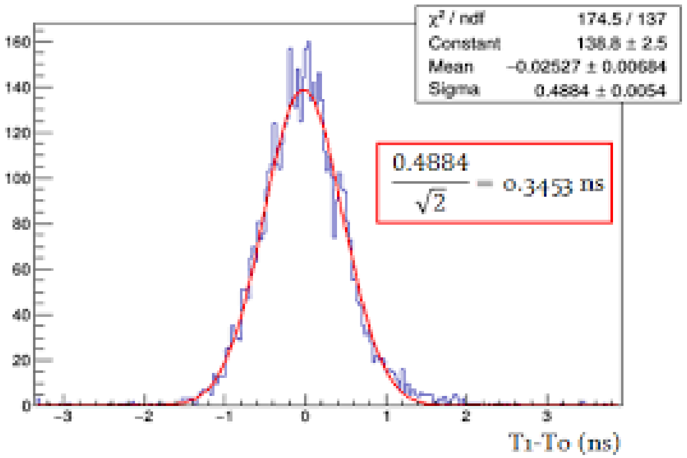
Single Gap Efficiency



Statistics of Single Gap Efficiency



Time Resolution



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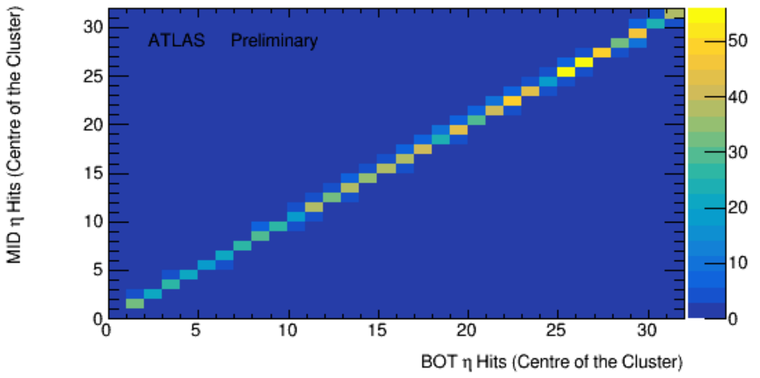
Results:

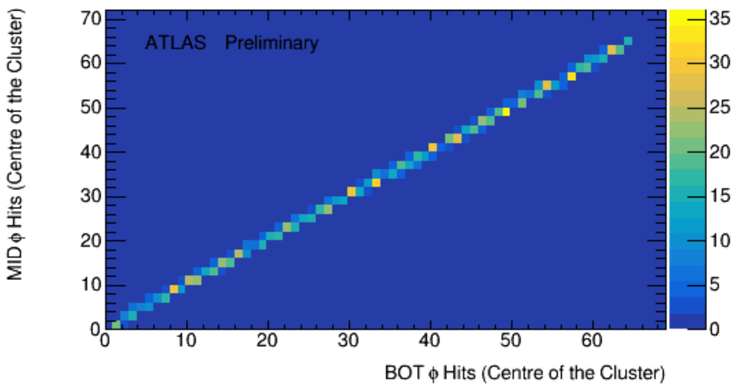
- ✓ Efficiency: 92%-93% at 5,6kV and ~95% at 5,8kV for the singlets
- ✓ Cluster size: 1.3-1.5 for Eta layer and 1.5-1.8 for Phi layer
- ✓ Dead Channels: Less than 1%
- ✓ Noise: ~0.4 Hz/cm^2 for Eta layer - Phi layer
- ✓ Time resolution: ~0.35 ns with time walk correction

FIRST CHECKS IN CAVERN FOR A12

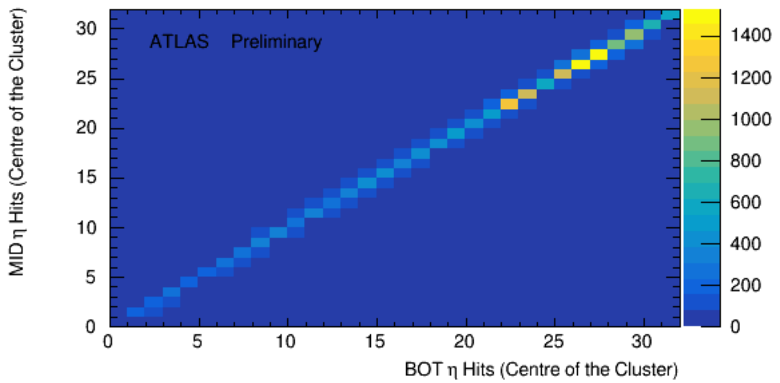
Hardware Trigger + Software Trigger on the Trackers

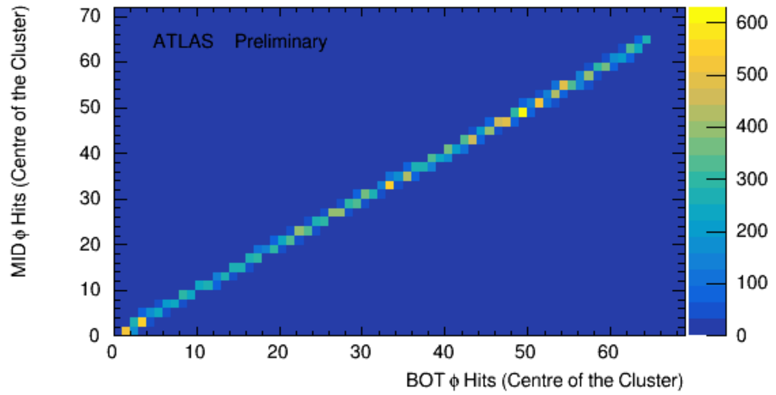
Triggered Data with Cosmics





Triggered Data with Beam





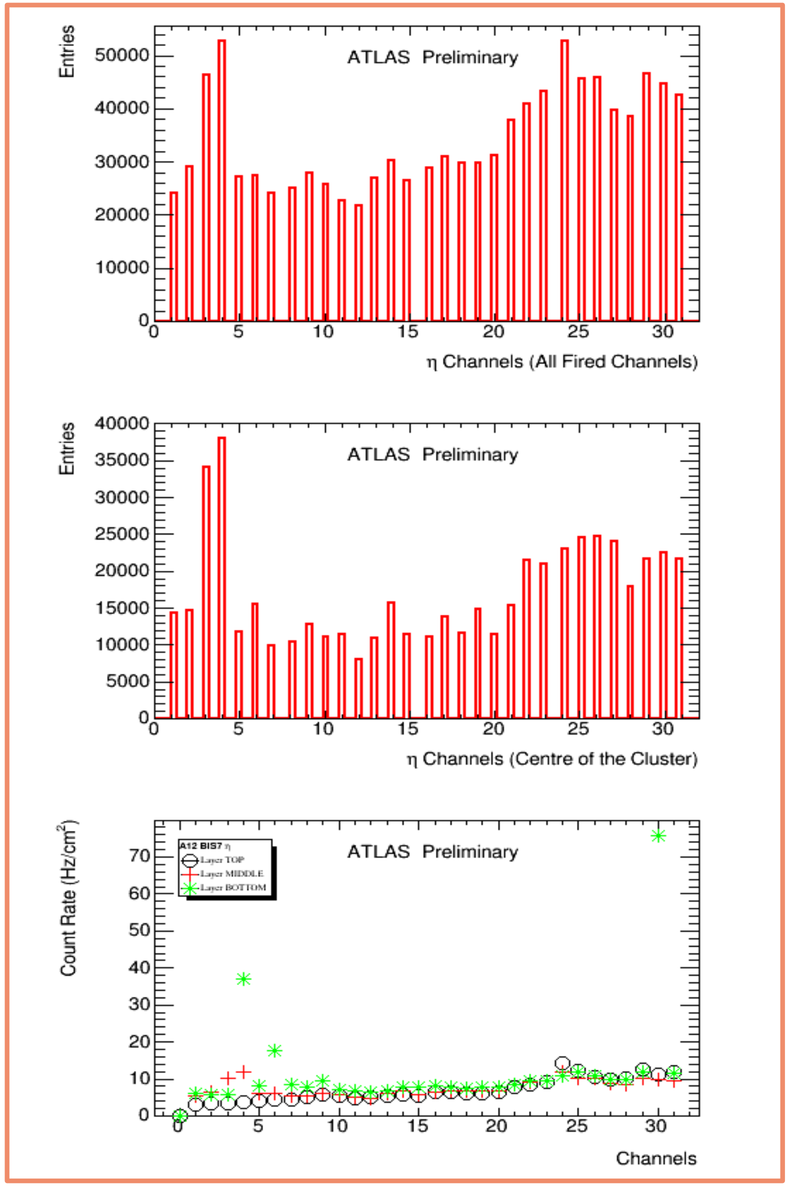
➢ A12 chamber structure
- 3 Singlet → 1 triplet

➢ Method:
- Keeping all layers HV ON @WP
- Triggered Data: 30 min. run with Cosmics and Stable Beam
  - TOP/BOT→ trigger layers
  - MIDDLE → TEST layer
- Checking the chamber main conditions

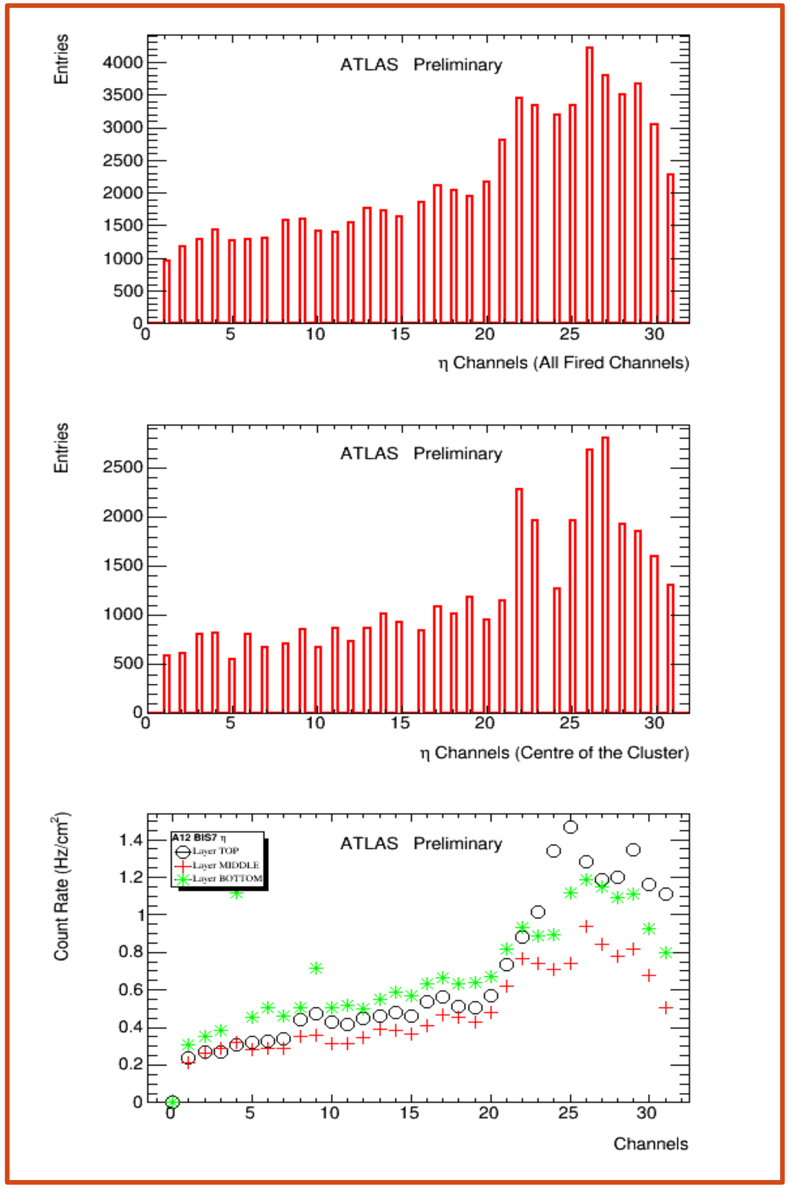
➢ Result:
- The chamber is working and aligned, cabling is correct!
- We have higher counts through the pseudo-rapidity!

ETA CHANNEL PROFILES FOR MIDDLE LAYER OF A12

Triggerless Data for the Test Layer (MIDDLE) | **Triggered Data for the Test Layer (MIDDLE)**



Hardware Trigger + Software Trigger



➢ A12 chamber structure

- 3 Singlet → 1 triplet

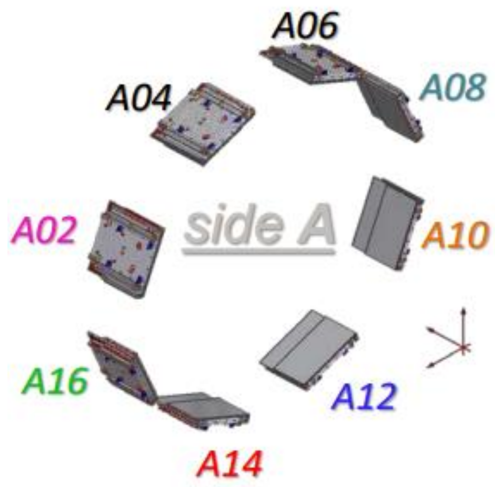
➢ Method:

- Keeping all layers HV ON @WP
- Triggered Data→ 30 min. data with Stable Beam
  - TOP+BOTTOM→trigger layers
- Triggerless Data→30 min. data with Stable Beam
  - Random Trigger

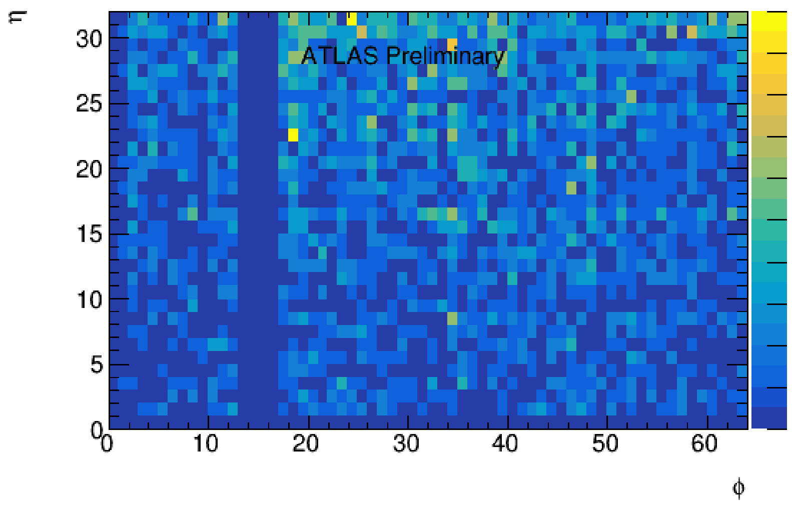
➢ Result:

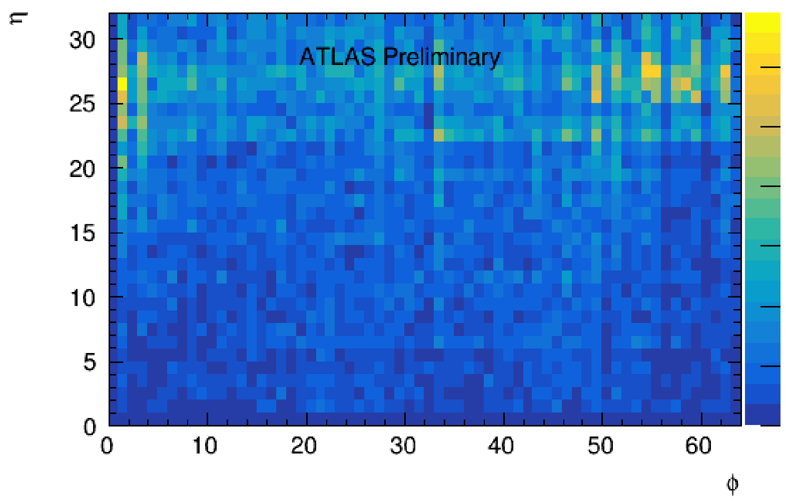
- All the background is eliminated by FINE selection!

TRIGGER MAPS OF A06 & A12 MIDDLE LAYERS

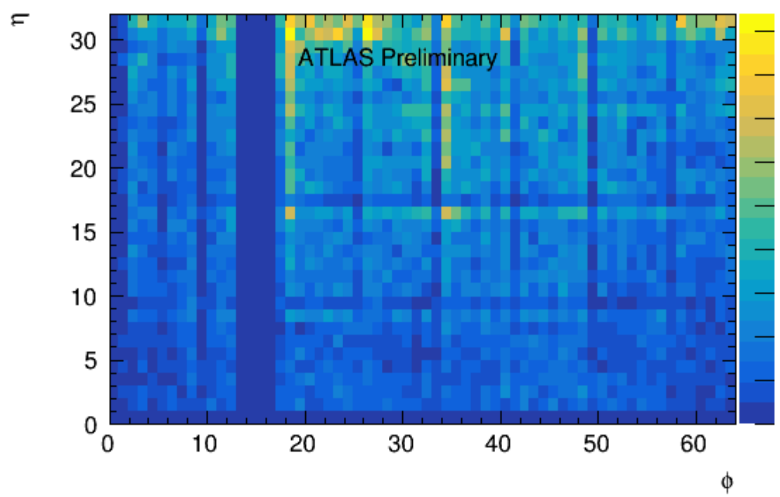


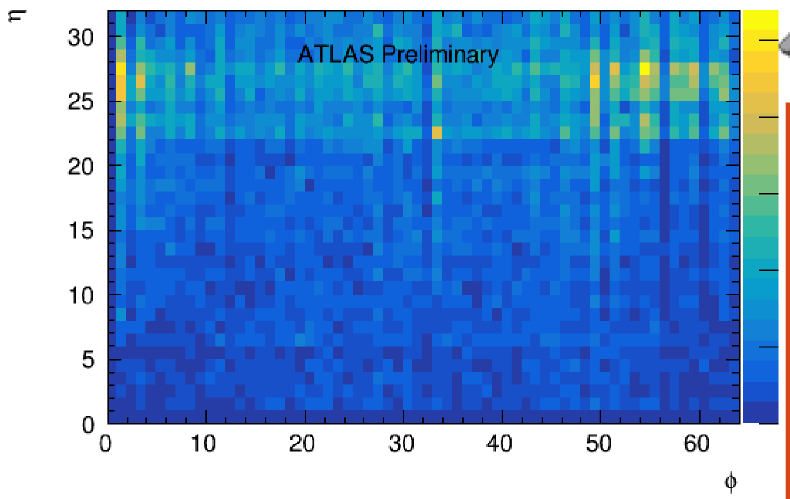
Triggerless Data





Triggered Data





- ➢ A12 chamber structure
- 3 Singlet → 1 triplet

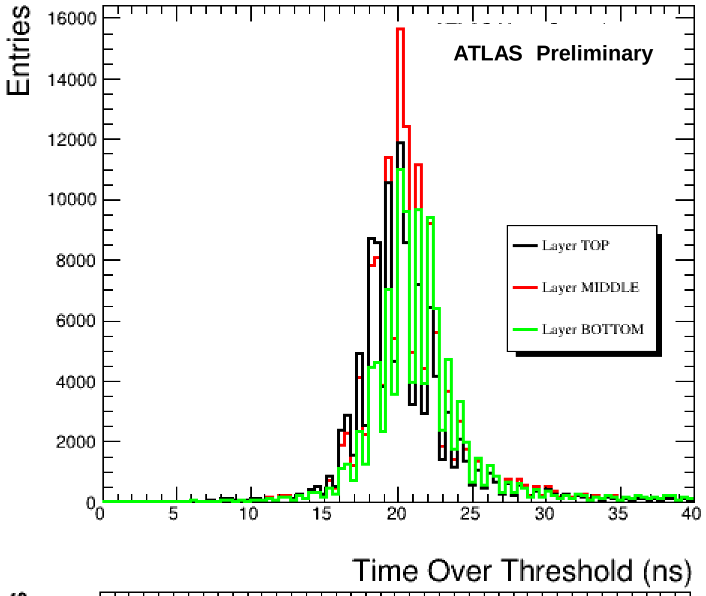
- ➢ Method:
- Keeping all layers HV ON @WP
- Triggered Data: 30 min. run with Stable Beam
  - MID/BOT→trigger layers
- Triggerless Data: 30 min. run with Stable Beam
  - Random Trigger

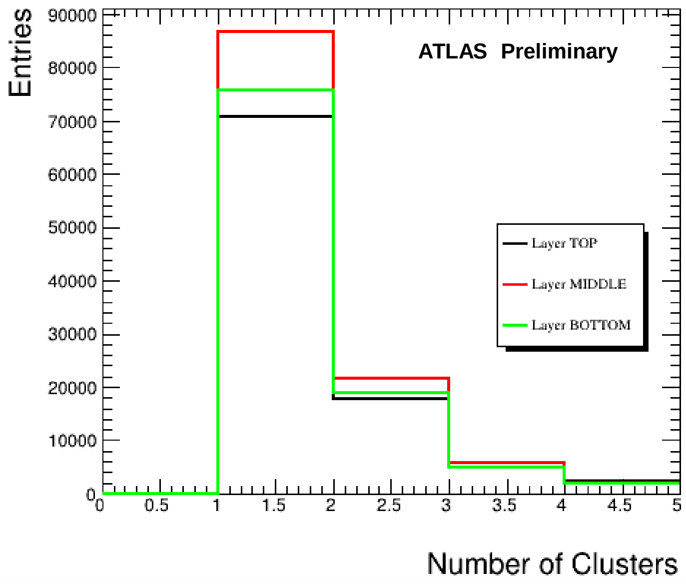
- ➢ Result:
- The chamber is selective and follows the beam

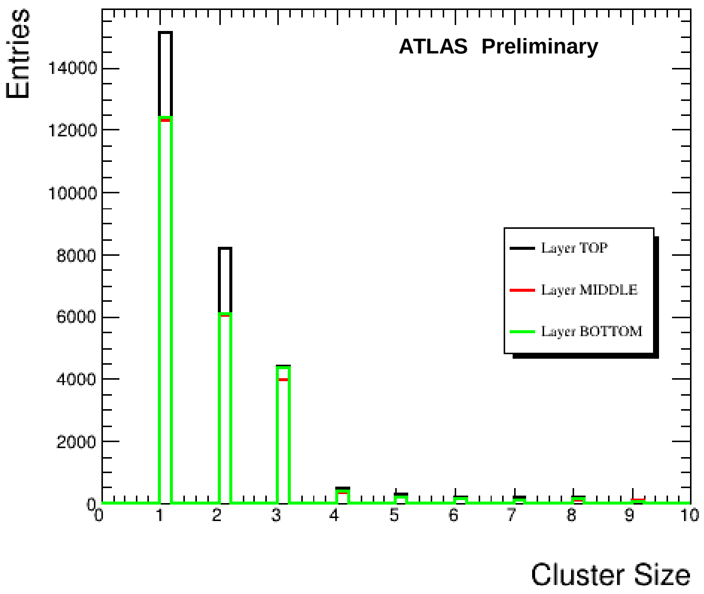
A12 BIS7 ETA & PHI TIME AND CLUSTER DISTRIBUTIONS

✓ Hardware Trigger + Software Trigger on Trigger Layers

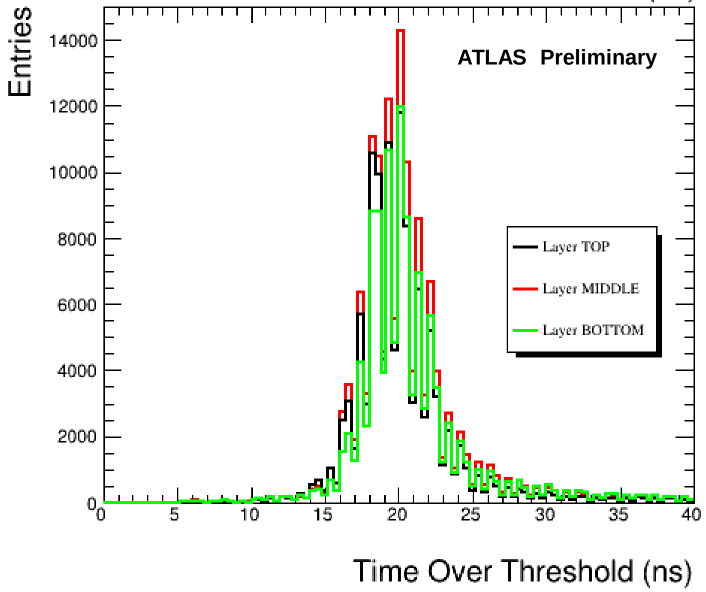
✗ TEST Layer Distributions without any selection for muons!

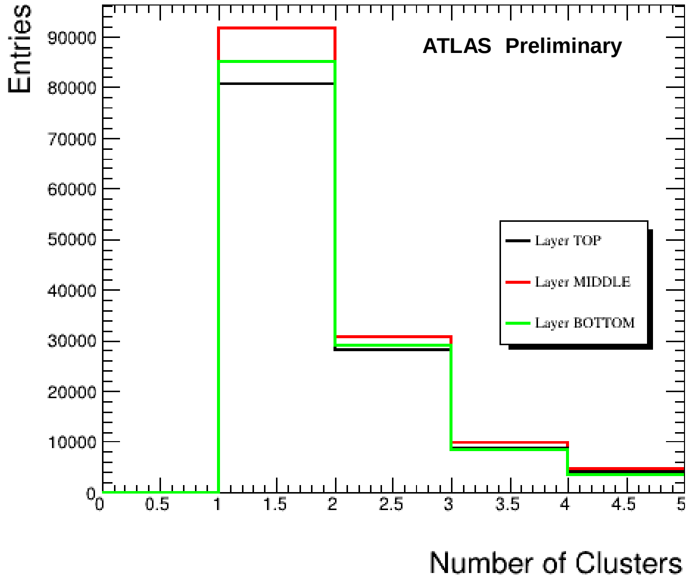


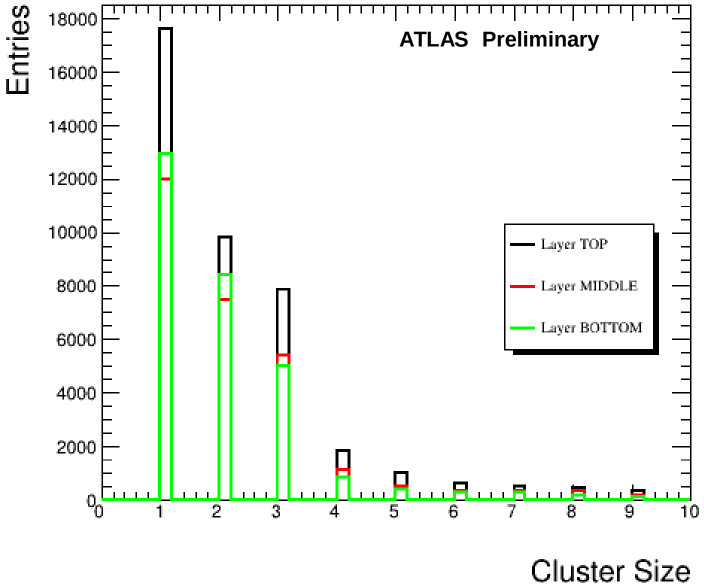




ETA

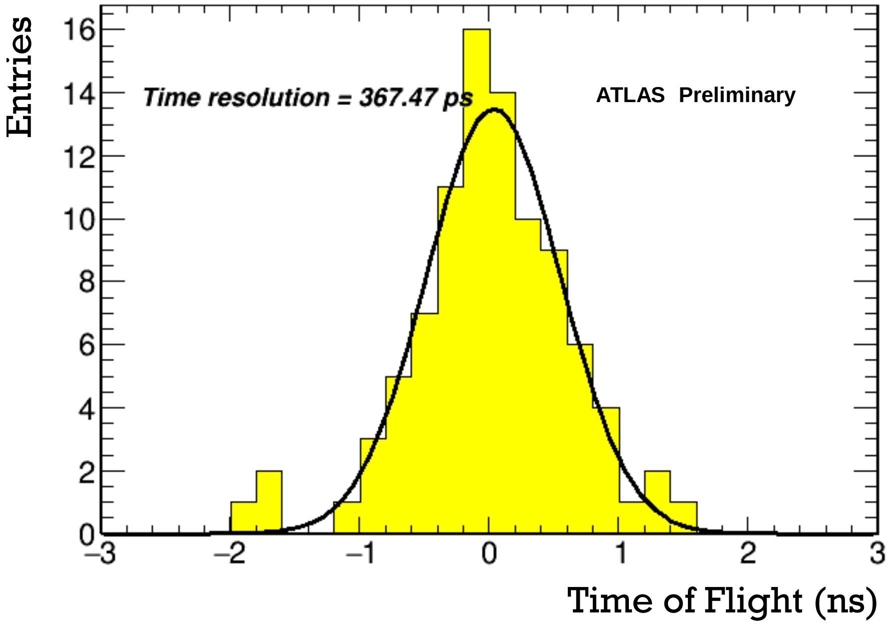




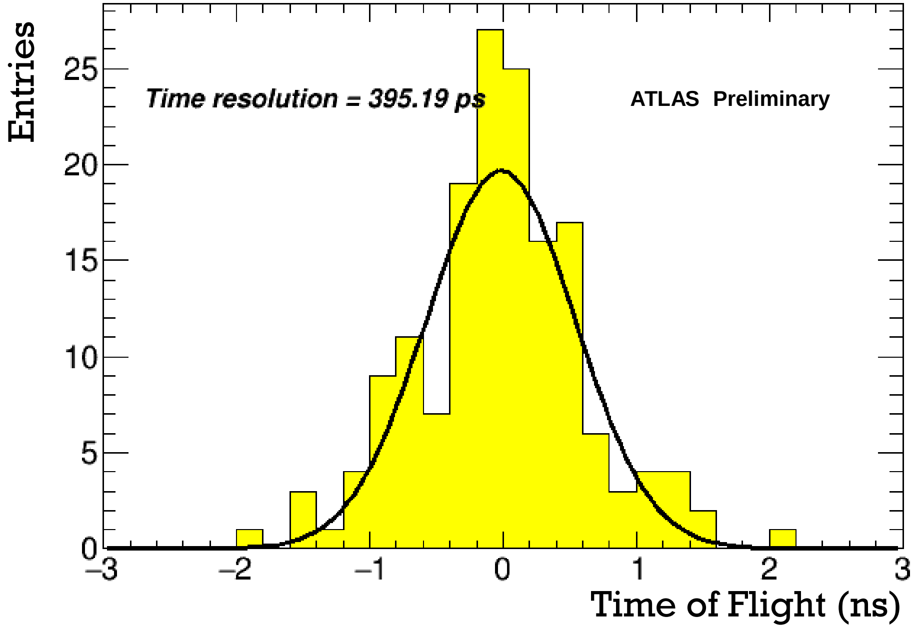


PHI

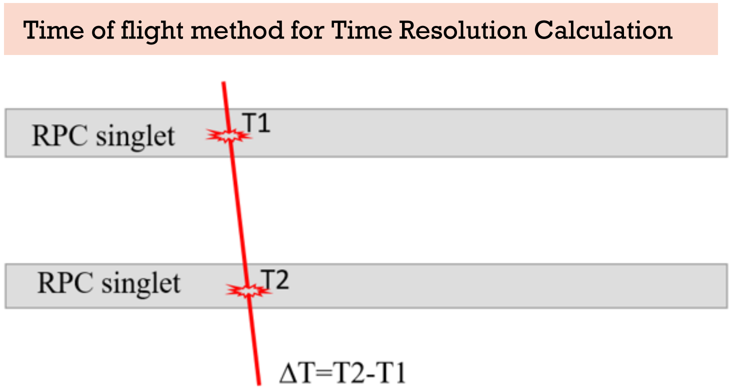
TIME OF FLIGHT FOR A12



a) Middle & Bottom Eta Strip Number 9



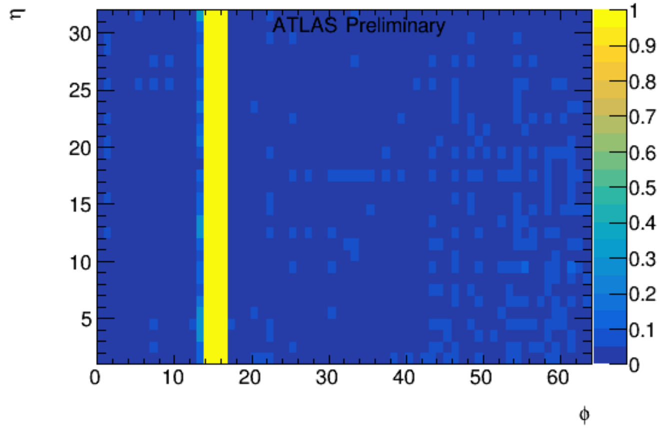
b) Middle & Bottom Eta Strip Number 25



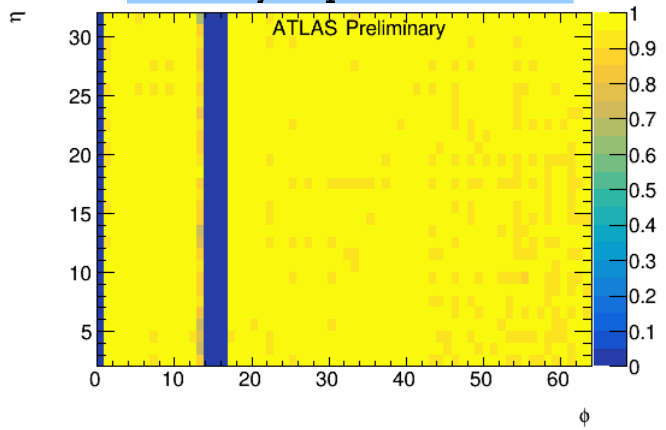
Single gap resolution between 0.35-0.4 ns is confirming the perfect time resolution of the BIS78 Chambers.

A06 EFFICIENCY CHECK

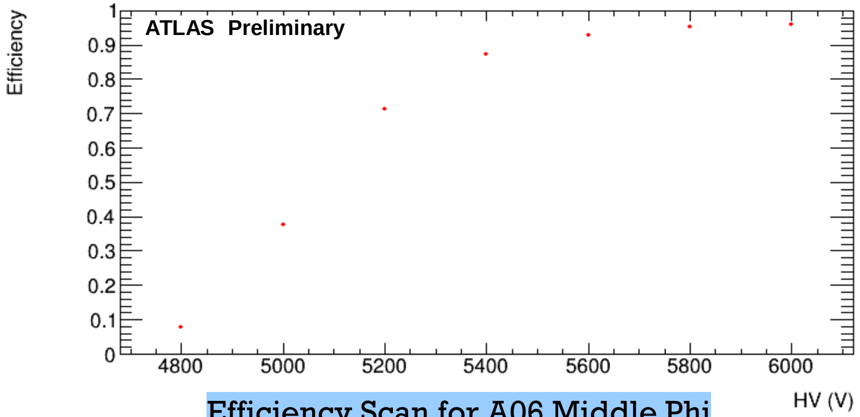
Inefficiency Map for A06 Middle



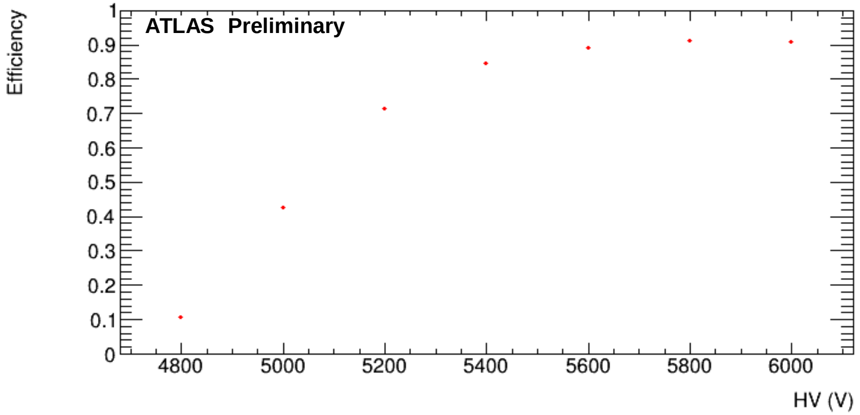
Efficiency Map for A06 Middle



Efficiency Scan for A06 Middle Eta



Efficiency Scan for A06 Middle Phi



- A06 chamber structure
  - 3 Singlet → 1 triplet
- Method:
  - Keep all layers HV ON @WP
  - Triggered Data→ 30 min. data with Stable Beam
    - TOP/BOT→trigger layers
  - For Efficiency Scan:
  - Keeping 2 Layers @WP, taking 10 min. data for the test layer (MID) for each HV point
    - TOP/BOT→Trigger layers
- Result:

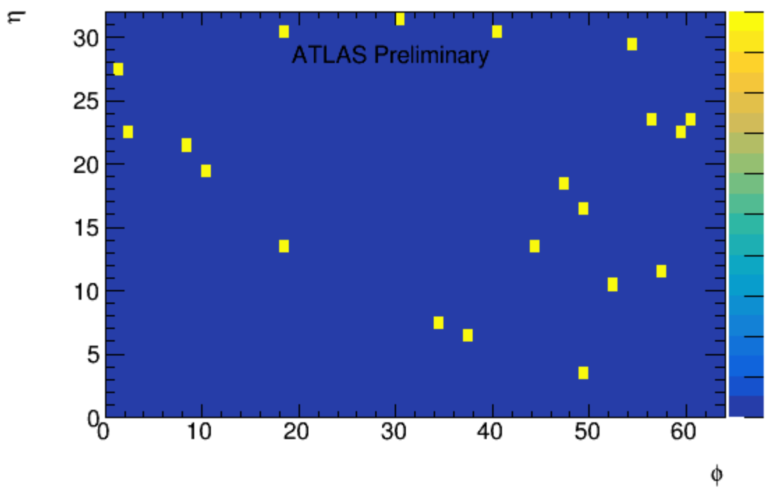
A06 is efficient!

- Efficiency curve seems fine!
  - Eta eff: %95
  - Phi eff: %91

THE INDEPENDENCE TEST FOR MIDDLE LAYER OF A12

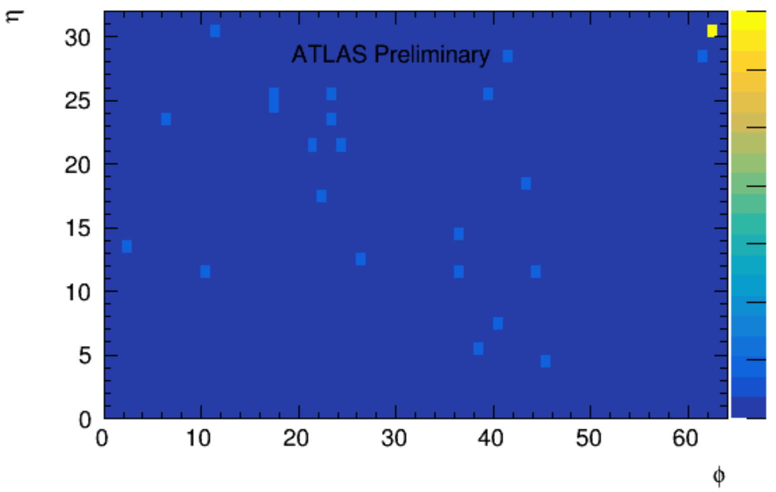
Only MIDDLE Layer HV ON

MIDDLE Trigger Profile with Stable Beam

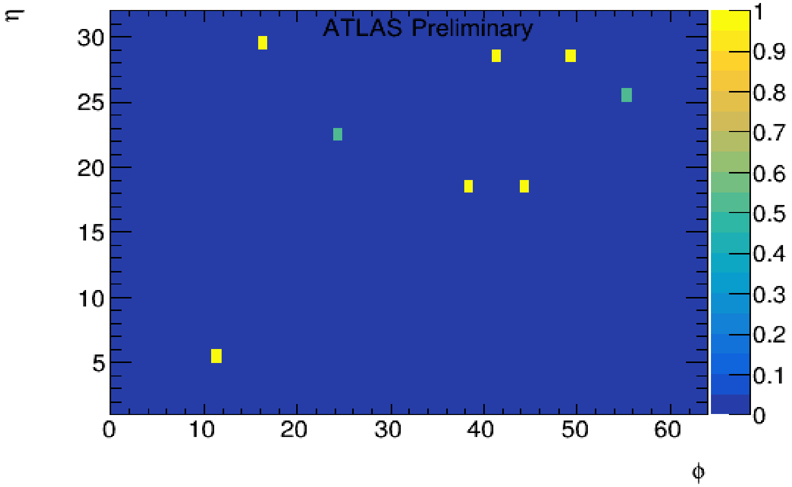


TOP & BOTTOM Layers HV ON

MIDDLE Trigger Profile with Stable Beam



MIDDLE Efficiency Profile with Stable Beam



- A12 chamber structure
  - 3 Singlet → 1 triplet
- Aim:

Checking the fake trigger generation when only the MIDDLE layer is OFF!
Checking the fake trigger generation when only the MIDDLE layer is ON!

- Method:

a) Middle layer ON @WP – Other 2 layers OFF
   - Triggered Data: 30 min. run with Stable Beam
   - MID&BOT→trigger layers

b) Middle layer OFF – Other 2 layers ON
   - Triggered Data: 30 min. run with Stable Beam
   - MID&BOT→trigger layers

- Result:
  - We have 20 counts in 600 sec. → 10^{-2} Hz → 10^{-6} Hz/cm^2 Not comparable with the LHC rate!

SUMMARY

- ✓ As a pilot project, the BIS78 Side-A chambers for Phase-I were installed and the chambers are still under commissioning in ATLAS cavern.
- ✓ It is planned to implement the selection criteria for all the layers (trigger+test) into the PAD hardware in future. The current algorithm is only for Cosmic Ray studies!
- ✓ The BIS78 chambers are efficient and selective.
- ✓ These tests are also for the Phase-2 chambers, which have sufficiently same type of electronics and the concept of the Faraday cage, so will light the way for the procedures of the tests for BI.

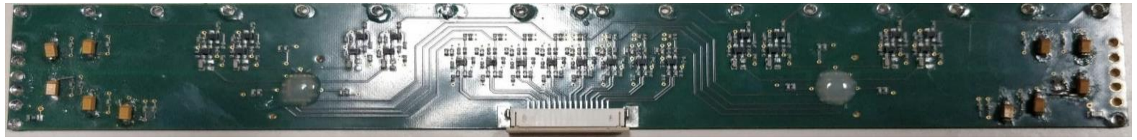
THANK YOU

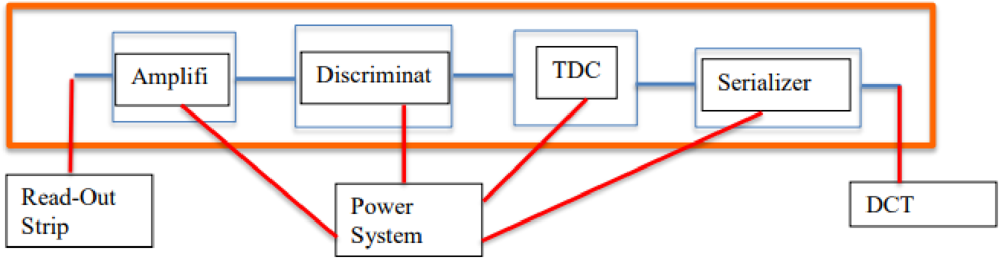
BACKUP: DIFFERENCE OF BIS-78 AND BI-PROJECTS

- Strip panel filler material: Forex (BIS78) to be replaced with paper honeycomb to have better panel rigidity.
- Gas gaps: 4 gas inlets instead of 2 to provide the uniformity of the gas flow inside the chambers.
- HV connection: Connection point of the HV at one side of the chamber instead on the top of the chamber in order to have a flat surface.
- Mechanics: Service integration and the cable routing into the chamber due to the lack of enough space since the chambers will be inserted a place which is not foreseen.

Difference in Readout scheme:

- Electronics: Discrete component amplifier from BIS78 and a new FE ASIC in SiGe with integrated, discriminator, 100 ps TDC and serializer.
- DCT boards for readout: Two low-cost FPGAs on each board, each one reading 256 serial receivers.





A12 EFFICIENCY SCAN