THE ATLAS RPC UPGRADE PROJECT FOR THE HIGH LUMINOSITY LHC PROGRAM

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Vienna Conference on Instrumentation (VCI2022)

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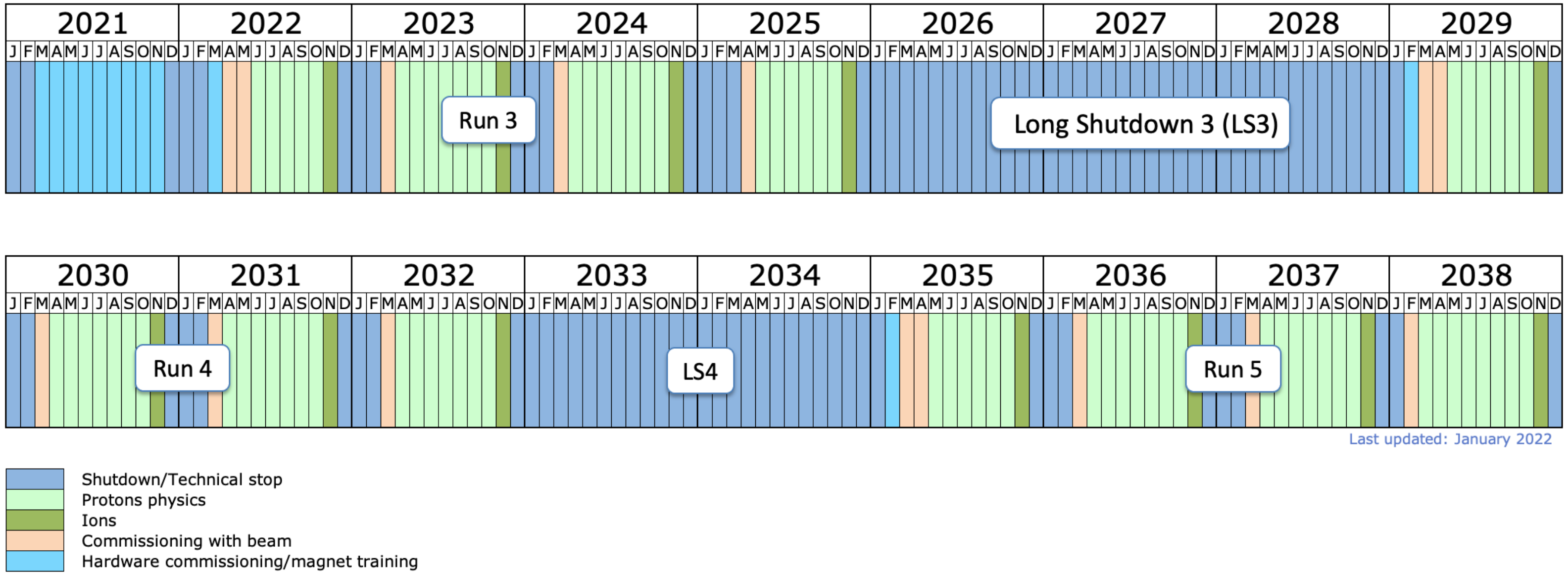
HIGH LUMI-LHC PROGRAM



MOTIVATION

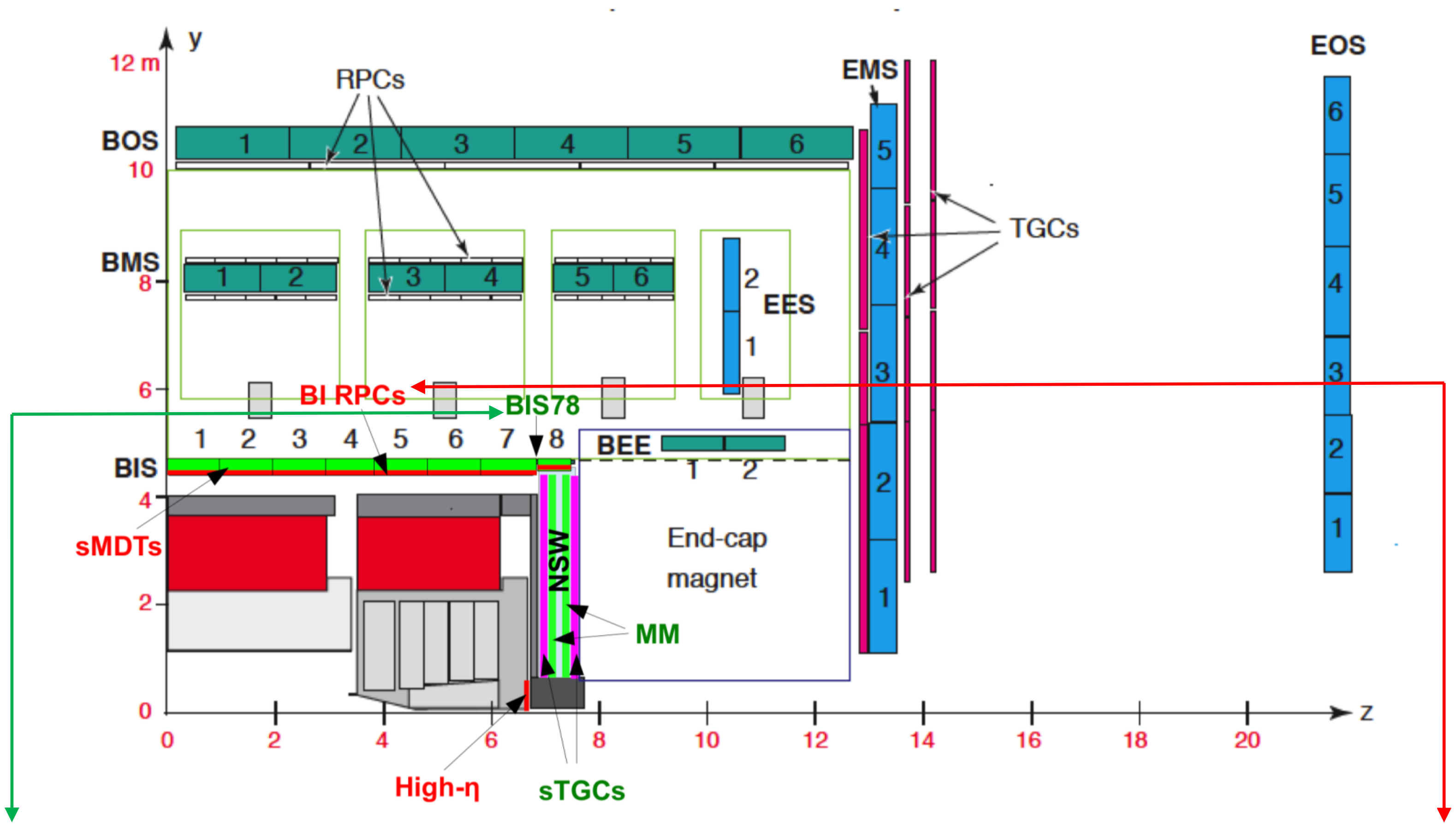
Higher energy and luminosity will allow researchers to probe beyond the current boundaries for:

- more accurate measurements of Higgs boson and the new particles
- The observation of rare processes
- Search for supersymmetric particles
- Dark matter searches
- The electroweak symmetry breaking

HL-LHC will take shape in two phases: **Phase-1** in 2022 and **Phase-2** in 2027.

- The instantaneous luminosity will increase up to 5-7 x $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (nominal LHC luminosity: $10^{34}cm^{-2}s^{-1}$), and the expected integrated luminosity will be 4000 fb^{-1}.
- The proposed upgrade will affect the aging of the detectors caused by the increase of the rates and background conditions and the current muon trigger rate will be beyond the design safety factor in the ATLAS barrel region.
- To provide Phase-II trigger and readout requirements, and maintain the performance of the muon system under the HL-LHC conditions, **two project are planned for the ATLAS-RPC detectors.**

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, and reduce the fake muon rate. This project is considered as a solution for **ATLAS end-cap.**

BIS78 is considered as a pilot project for the Phase II 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

- RPC-BIS78 is a Small Size Project.
  - Core Cost < 0.5 MCHF

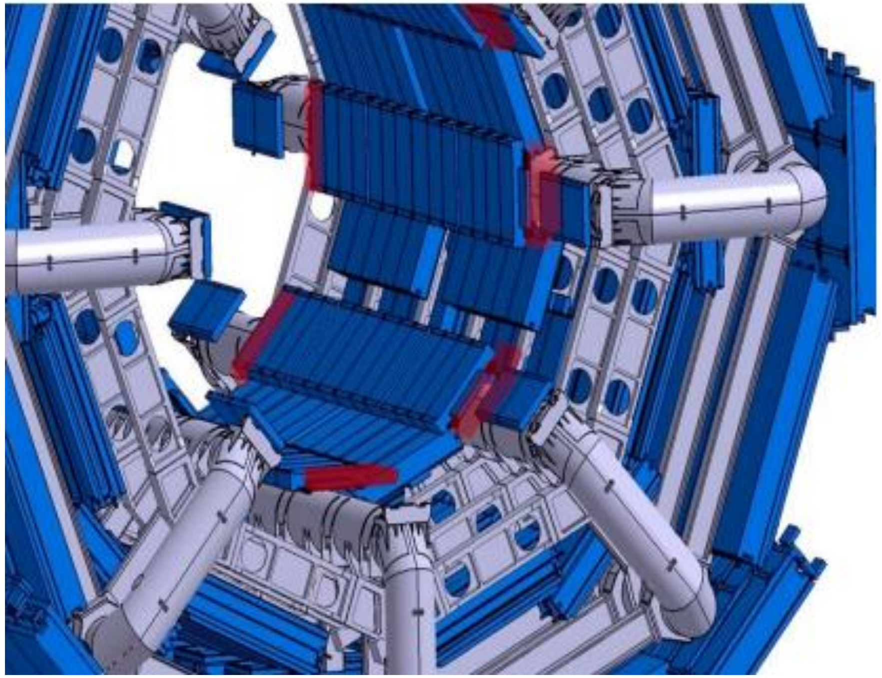
Due to the narrow available space, the legacy Monitored Drift Tubes (MDTs) are replaced with:

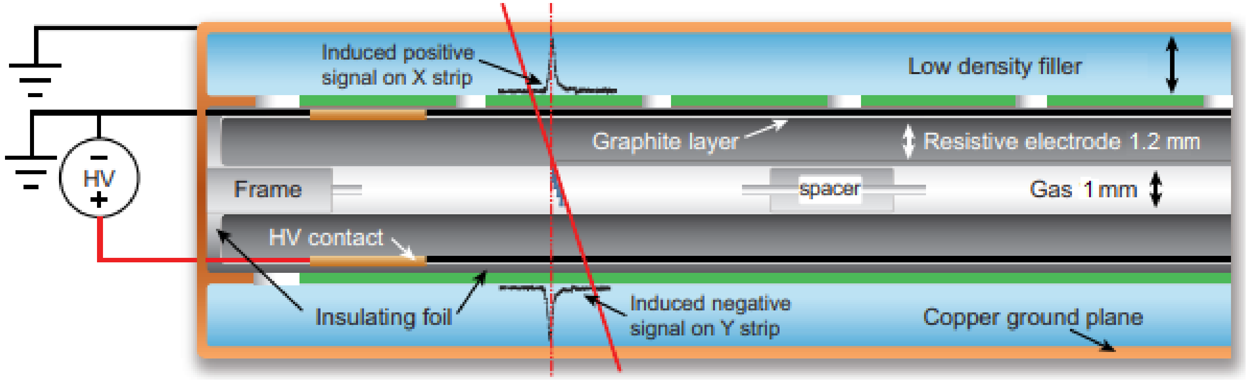
16 new muon stations made of:

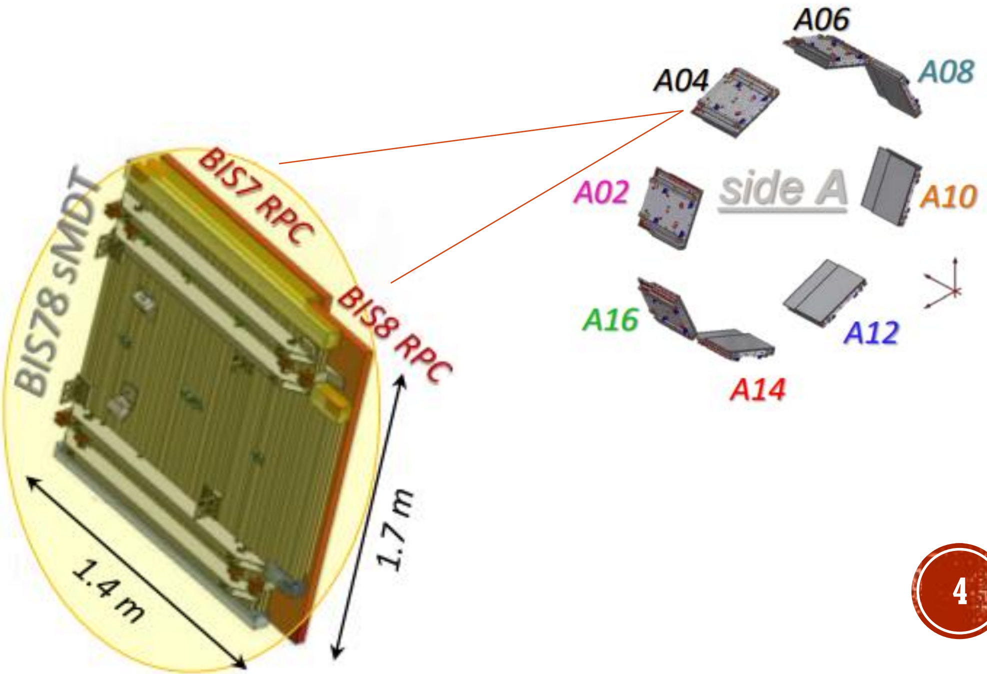
- one small diameter tubes MDT chamber to recuperate the space for:
- two RPC triplets (BIS7 and BIS8)

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

- Each triplet is composed by 3 independent singlets of 2 m^2, each providing a 2D + t localization of the muon.
- A triplet can provide muon candidates with a local 2 out of 3 coincidence.







BIS-78 Project

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:

	Standard RPC	BIS78 RPC
Effective Threshold	1 mV	0.3 mV
Power Consumption	30 mW	6 mW
Technology	GaAs	BJT Si + SiGe
Gap Width	2 mm	1 mm
Operating Voltage	9600 V	5800 V
Charge x Hit	30 pC	5 -7 down to 3 pC
Electrode Thickness	1.8 mm	1.2 mm
Time Resolution	1 ns	0.4 ns
Gaps per Chamber	2	3

→ **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

- 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 the singlet in a proper way to exploit the features of the electronics.

RESULTS FOR BIS-78

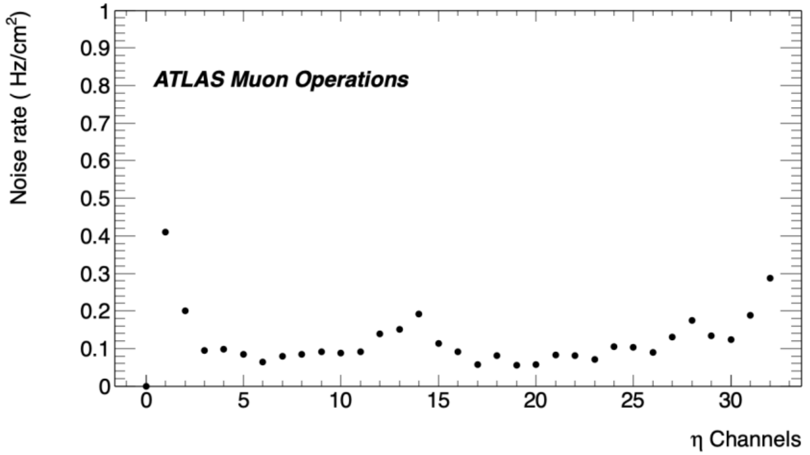
All RPC triplets were tested with cosmic rays.

Selection Criteria:

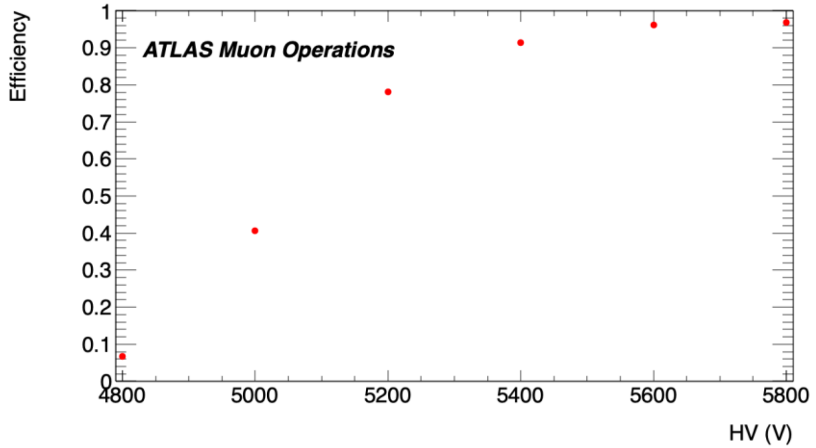
Efficiency > 95%
Noise < 1 Hz $/cm^2$
Dead Channels < 1%
Cluster size $\leq$ 3

- ✓ 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

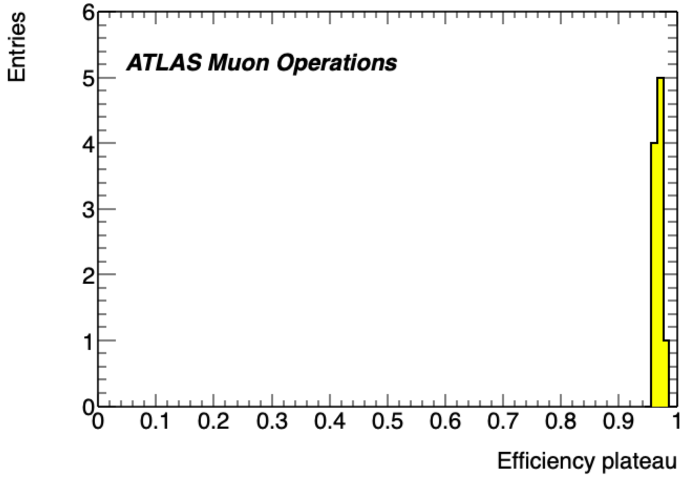
Noise rate of a single panel



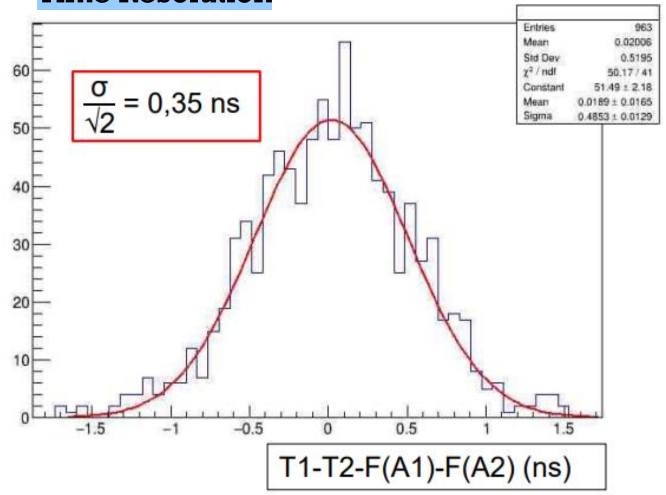
Single Gap Efficiency



Statistics of Single Gap Efficiency



Time Resolution



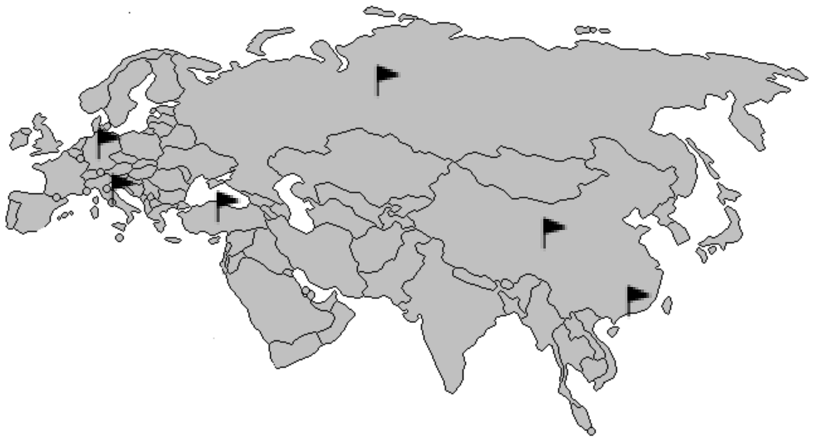
https://agenda.infn.it/event/19942/contributions/108483/attachments/70585/88142/RPC2020_LP.pdf

https://atlas.web.cern.ch/Atlas/GROUPS/MUON/PLOTS/MDET-2021-01/

BI-RPCS SCOPE

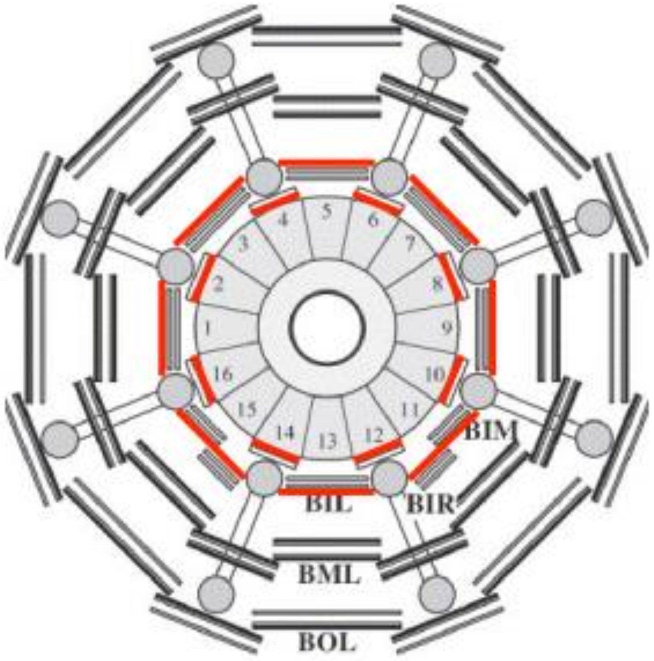
SCOPE

- Ensure high performance and long term operation to the muon trigger in the barrel.
- Extend the discovery potential of the Experiment by maximizing coverage, selectivity and Time of Flight performance.



DELIVERABLES

- 96 BIS triplet chambers for the 8 small BI sectors
  - includes 288 singlets (and gas gap) and 572 strip panels
- 118 BIL triplet chambers for 6 out of 8 large BI sectors
  - Total 178 triplets, 534 singlets (and gas gaps), 1068 strip panels
- BIR-BIM for sectors 11 and 15
  - the layout of these special sectors is still under study by Atlas TC
- 16 BIS7 and 16 BIS8 retrofitting (updating the FE electronics)
- Related power and gas distribution system



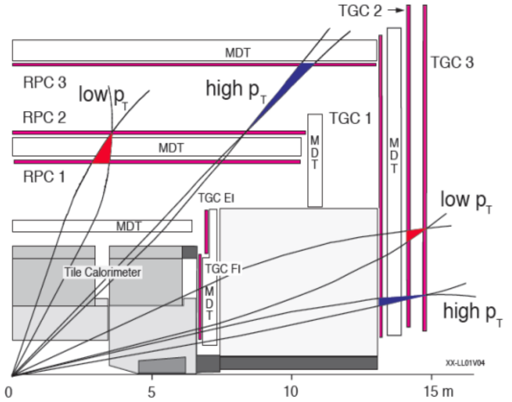
TRIGGER COVERAGE OF ATLAS-BARREL

High-Pt trigger acceptance currently limited at ~73% in Atlas barrel due to partially instrumented regions like feet and toroid magnet.

Present trigger is composed of 4 +2 layers.
The current ATLAS RPCs will be operated in extended period wrt original time.
This limited redundancy could be a problem for the ageing of the detectors.

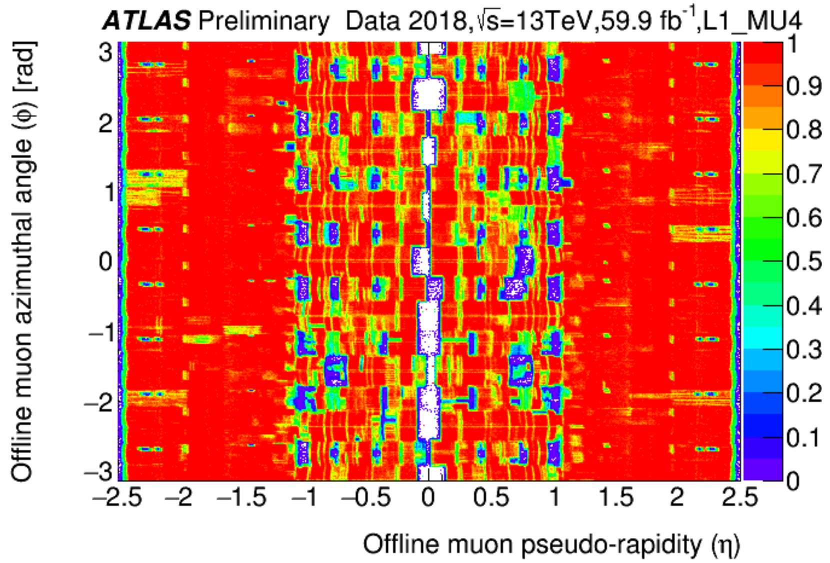
Solution: Improving of the acceptance for the barrel muon trigger via installing the new trigger stations in the inner layer of the spectrometer.

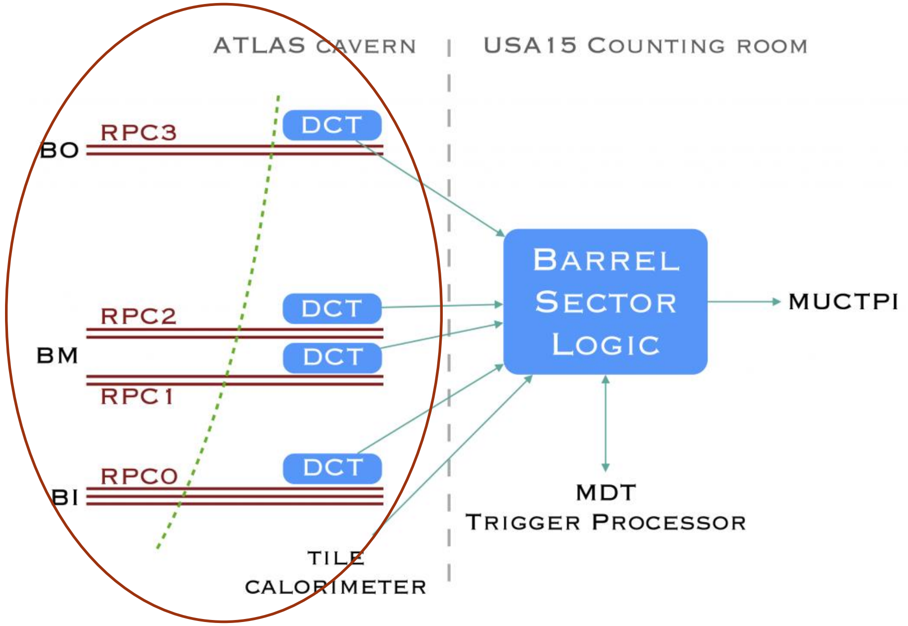
- Increasing the number of measurement stations from 2 → 3
- Increasing the number of independent layers from 6 → 9



Trigger algorithm based on RPC hit coincidence:

- **Low-p_T** trigger (p_T<10GeV) uses the two BM stations
- **High-p_T** trigger (p_T>10GeV) requires an additional confirmation on the BO station



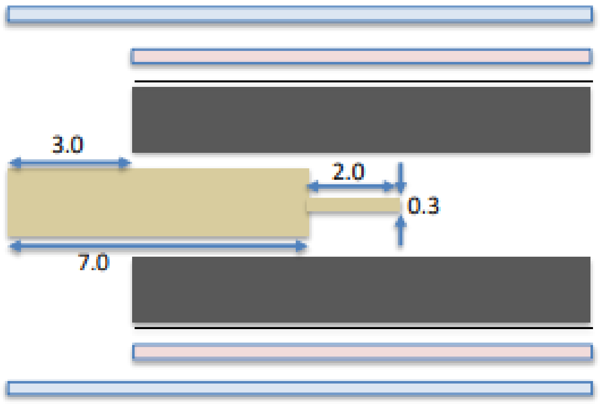


Trigger Requirement	Acceptance wrt to Muon Reconstruction η < 1.05
RPC1 && RPC2 && RPC3	73%
RPC0 && (RPC1 || RPC2) && RPC3	82%
Any 3 out of 4 chamber layers	88%
(any 3 out of 4) || (inner && outer)	96%

BI CHAMBER DESIGN & ACHIEVEMENTS

Gas gap Design: Preliminary design parameters of BI-RPCs:

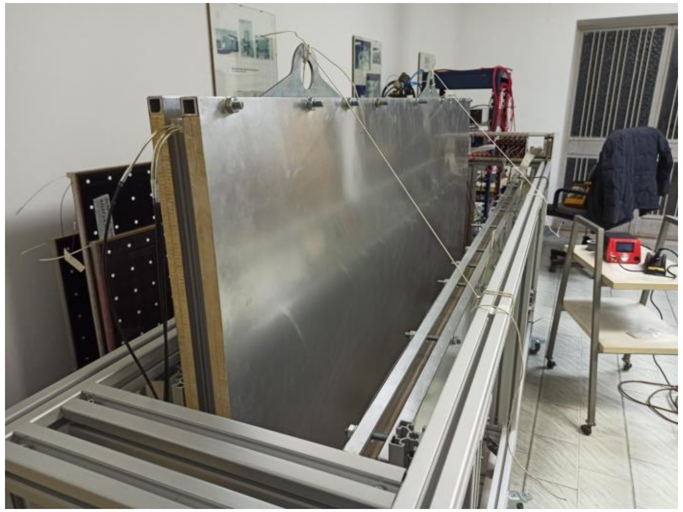
mm	Material
0.180 ± 0.010	PET
0.080 ± 0.030	Hot melt
0.000 ± 0.000	Graphite Paint
1.300 ± 0.050	Electrode - HPL (bakalite)
1.000 ± 0.015	Polycarbonate (gas gap)
1.300 ± 0.050	Electrode - HPL (bakalite)
0.000 ± 0.000	Graphite Paint
0.080 ± 0.030	Hot melt
0.180 ± 0.010	PET
4.120 ± 0.195	**Total Thickness**

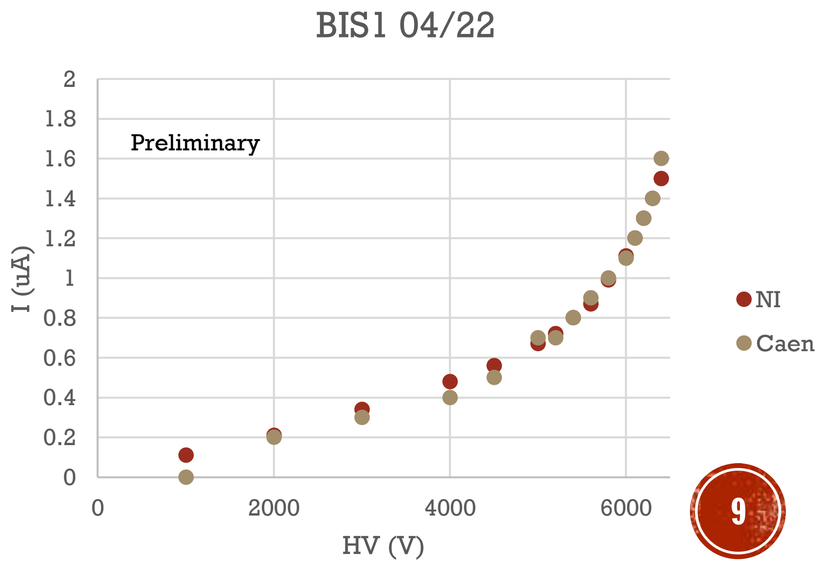


An assambled singlet

Gas Gap Validation: The gas gaps were inserted between two pre-curved panels designed to maintain uniform pressure on the spacers.

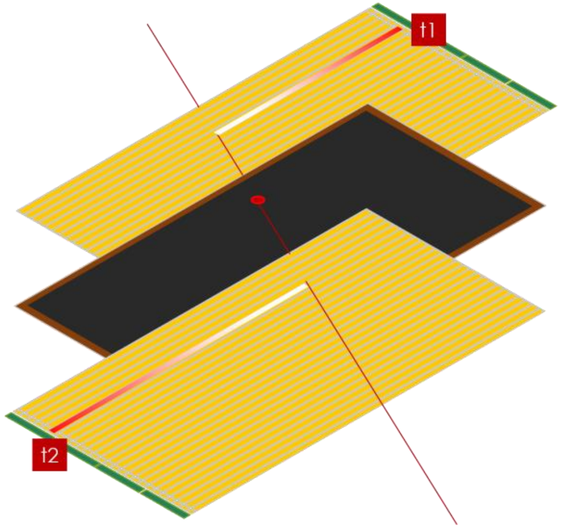
- The first experimental results show how the trend of the current as a function of the high voltage is consistent with the acceptance criteria.





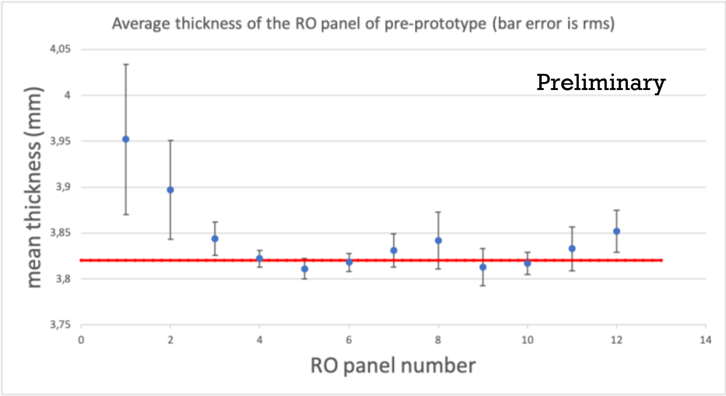
New gas volumes were made using the selected bakalite plates. HPL production also showed a very good performance as expected!

BI READOUT DESIGN & ACHIEVEMENTS



Readout Design: Preamplifier + Discriminator + LVDS transmitter also TDC + Serial driver

- New baseline is eta-eta readout with phi from time difference (to determine the incident position) at the 2 ends of the chamber.
  - Saving the electronics channels
  - Reducing the dead area on the long side (the bending direction of ATLAS magnet)

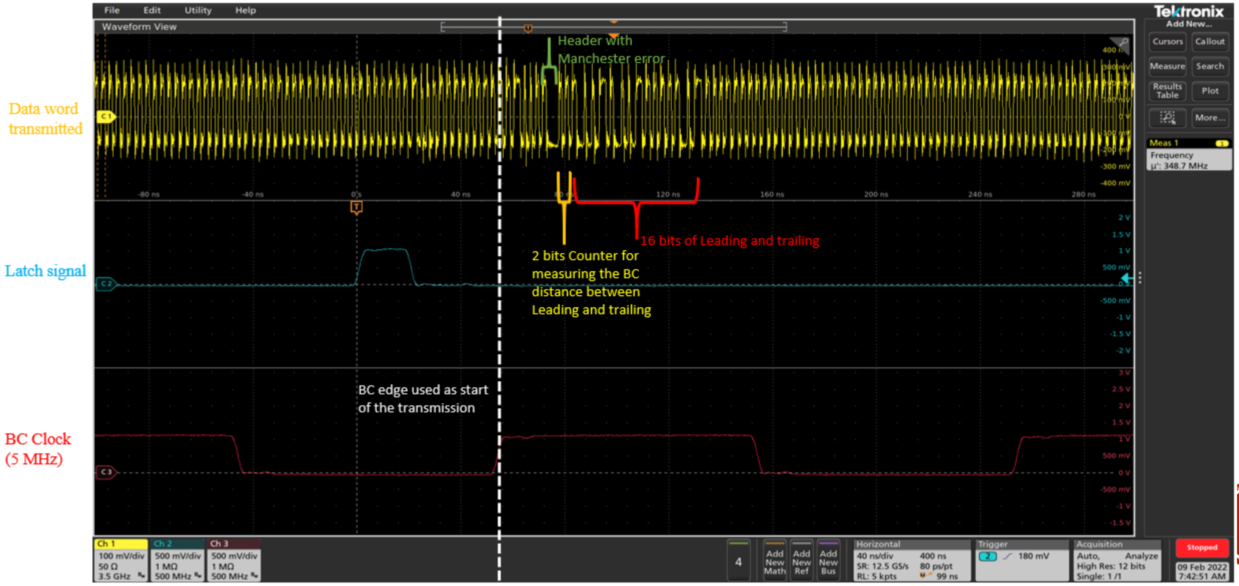


Readout Panel Validation: Requirements is that the strip panels should be flat since the gas gap is delicate.

- 12 panel have been assembled between end of July and October 2021 and the results show that panels are locally flat!

Front End Electronics: We were able to measure the time difference in between two fronts by reading the data as a correctly Manchester encoded word containing the digitized pulse timing.

- The discriminator channels are working properly.
- The TDC and the digital part (VCO+scaler+scaler reset system+ latches+digital logic+transmission logic+Manchester encoder) have been succesfully tested for a VCO frequency up to 3.2 GHz.

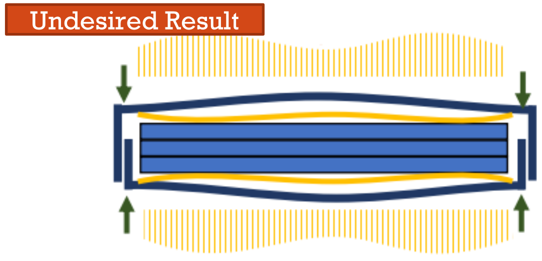


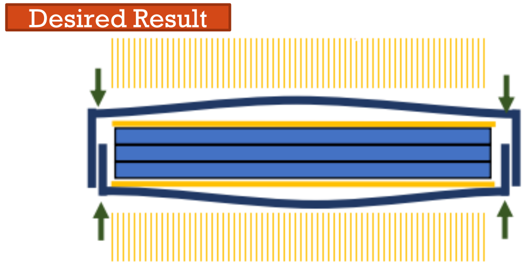
Picture shows how the data words are correctly encoded and transmitted along with the header and the counter as expected!

BI MECHANICS DESIGN & ACHIEVEMENTS

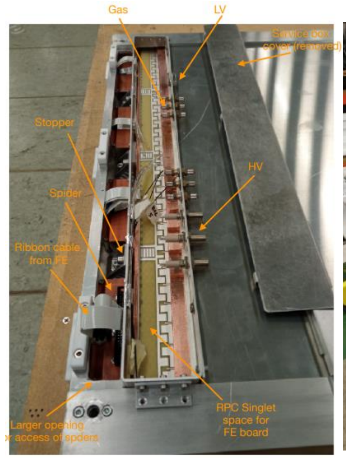
The detector requires a very smooth force distribution on the gas gap surface to avoid any deformation on the gaps gap! A decreased gap size would lead to a larger electric field and higher current at the same operating voltage.

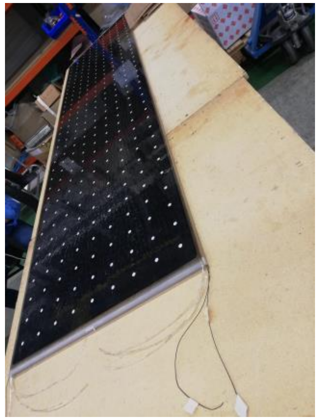
- Mechanics should compress the structure in an even way that the pressure inside the gap can be up to +3mb!





- Mechanics reinforcement → great improvement by adding stringers. The simulation studies are ongoing to improve the status.



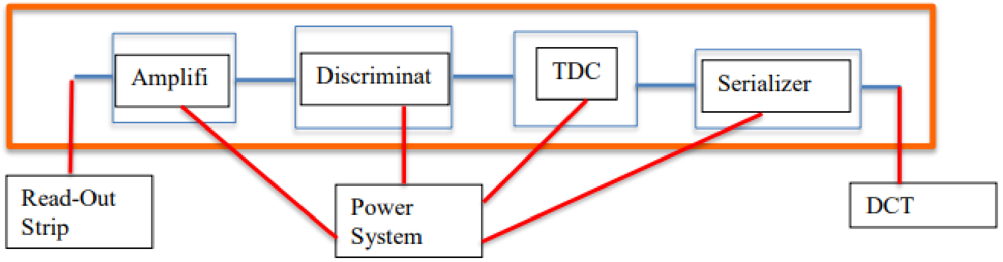


DIFFERENCE OF BIS-78 AND BI-PROJECTS

- 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.



SUMMARY

- ✓ The methods of the ATLAS RPC upgrade towards the HL-LHC have been well defined for the production of the new generation RPCs.
- ✓ As a pilot project, the BIS78 Side-A production for Phase-I was completed and the chambers were integrated into the ATLAS detector.
- ✓ Phase-2 BI chamber pre-production is ongoing in all the aspects.
- ✓ Benefit from the upgrade, the new generation RPCs indicate a wider use field in the future.

THANK YOU