TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

Test Beam Performance Measurements of Novel Thin Gap Detectors for the ATLAS Experiment Upgrade

2015 CAP Congress

Edmonton, AB

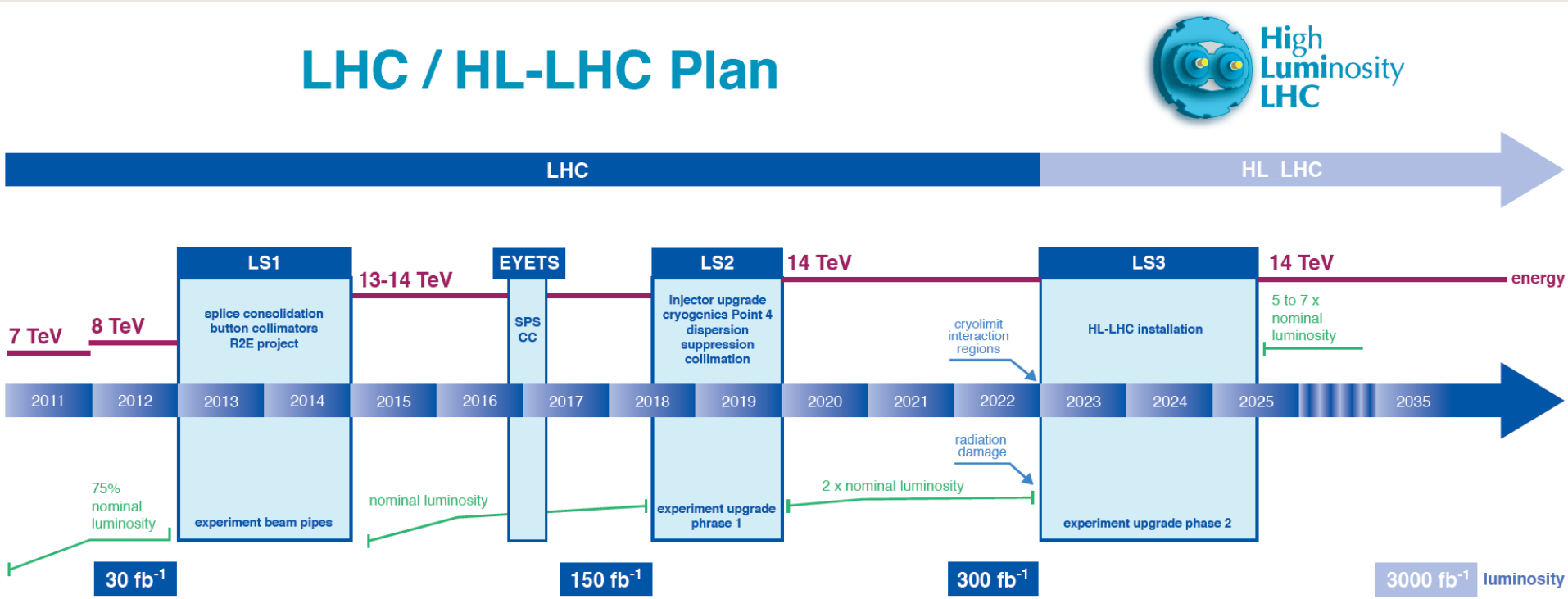
Sébastien Rettie, University of British Columbia & TRIUMF

on behalf of the ATLAS New Small Wheel Group

Outline

- Motivation
- The New Muon Small Wheel Upgrade
  - small-strip Thin Gap Chambers (sTGC)
- Full-size Prototype Test Beam at FNAL
  - Experimental Setup
  - Results
- Summary and Outlook

Harsher Conditions at the LHC



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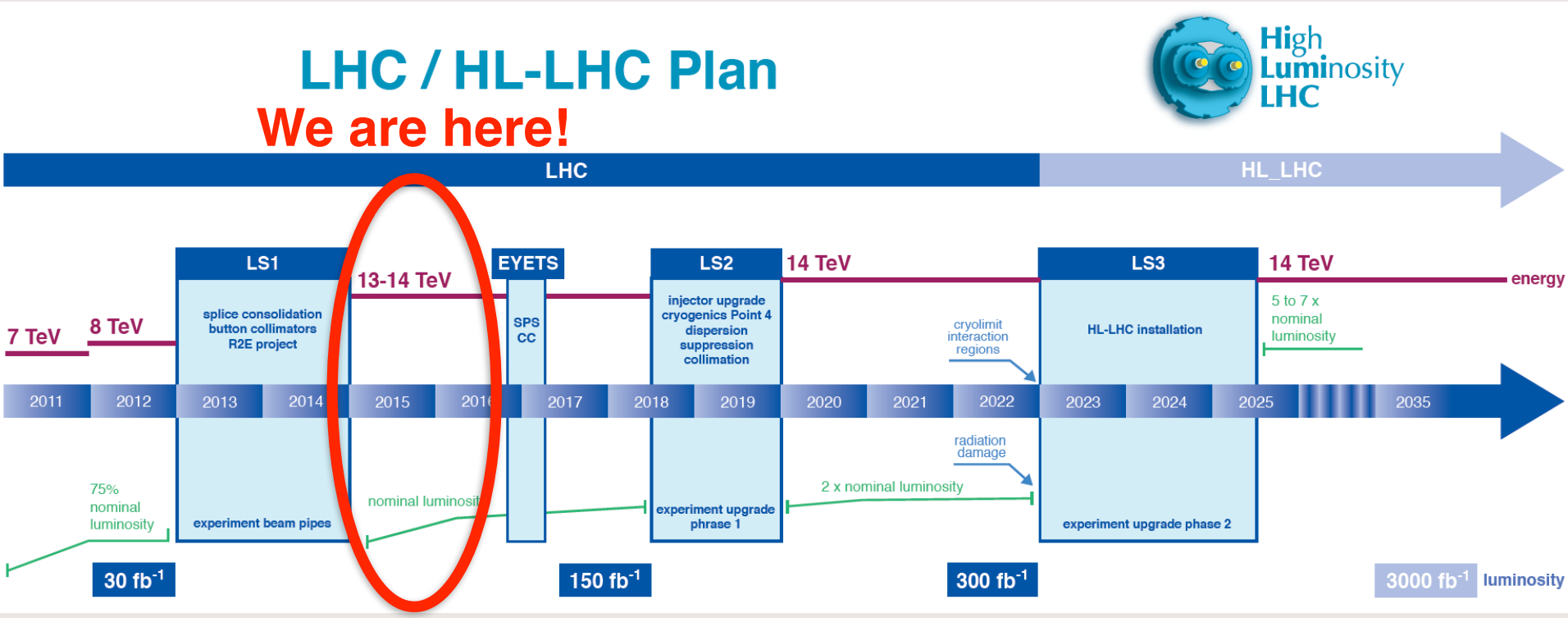

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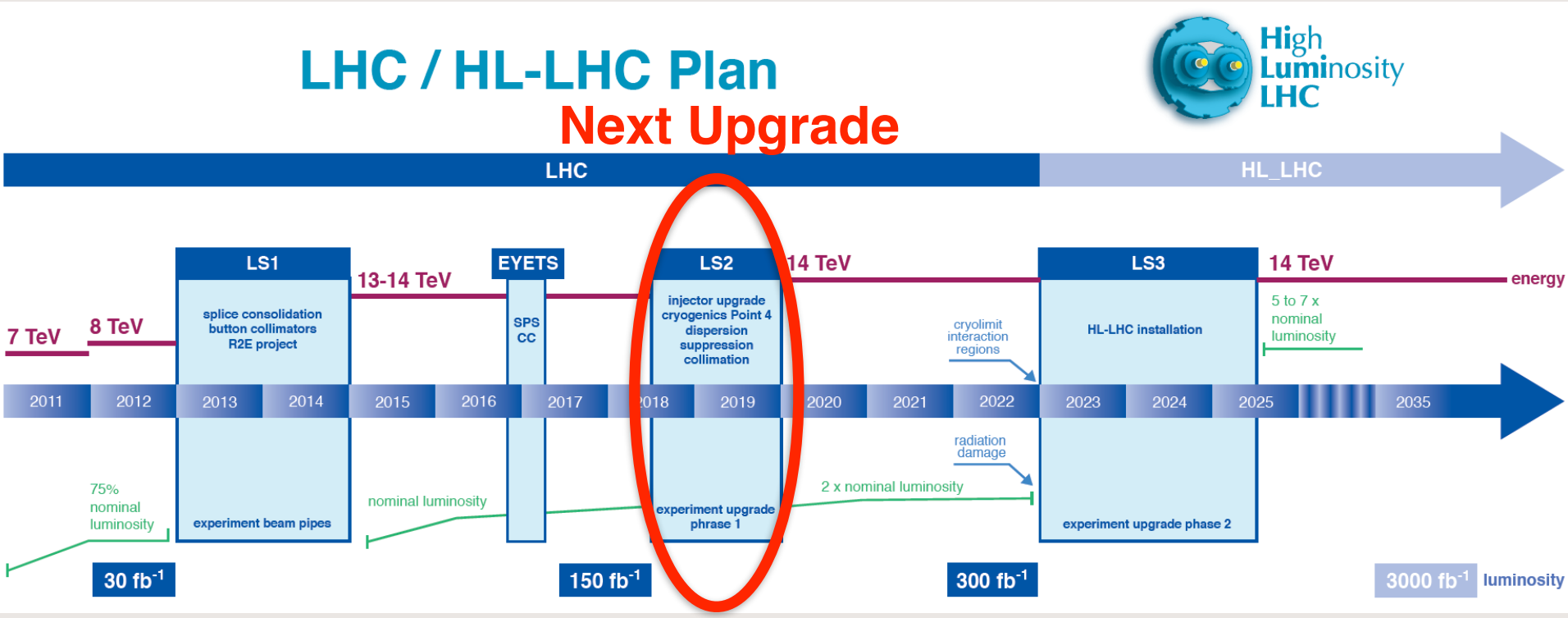

Trigger Bandwidth Limitations in ATLAS

- ATLAS subsystems level 1 readout bandwidth: 100 kHz.
- Allowed level 1 bandwidth for muon triggers: 20 kHz.
- Two options:

Trigger Rate	*Muon p_T > 20 GeV*	*Muon p_T > 40 GeV*
Without NSW	*60 kHz*	*29 kHz*
With NSW	*22 kHz*	*10 kHz*

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  - Improve the trigger system: New Small Wheel (NSW)!

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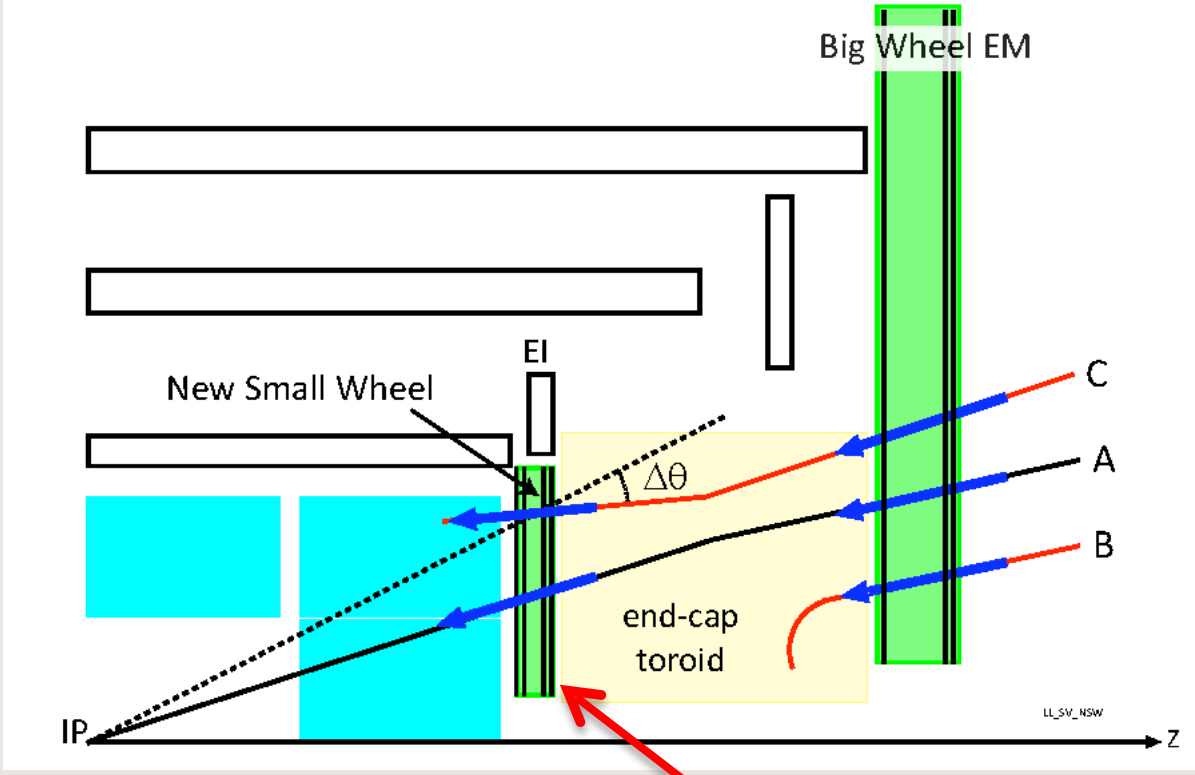
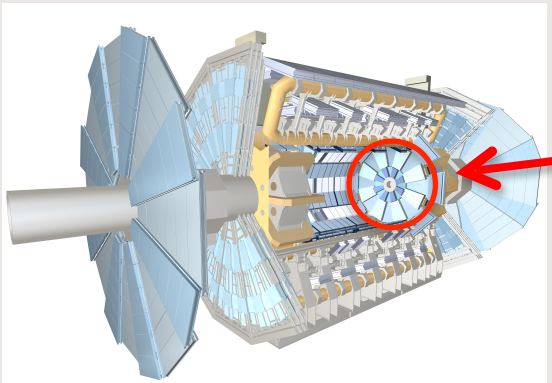
The New Muon Small Wheel (NSW)

- Current Small Wheel triggers on A, B, and C tracks.
- NSW will only keep A tracks.
- B tracks will be rejected because there is no matching track in the NSW.
- C tracks will be rejected because the NSW track does not point to the interaction point.





"Small Wheel"

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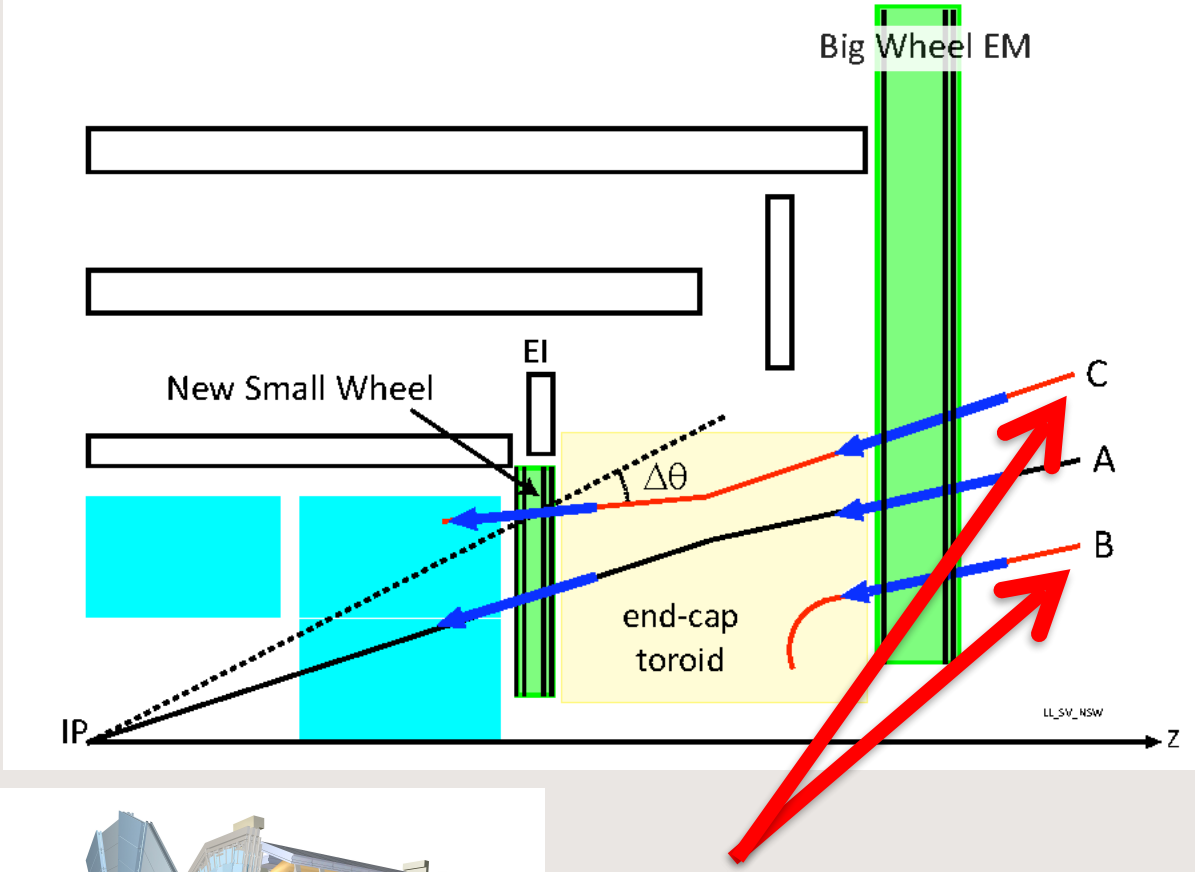
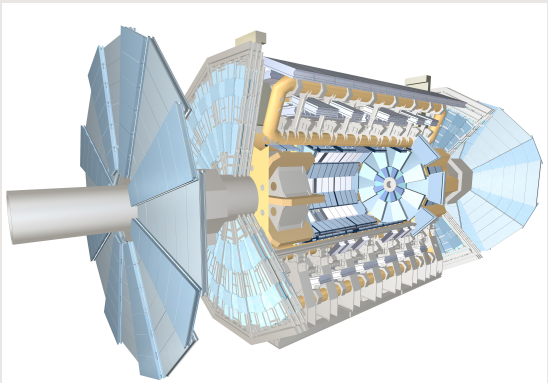
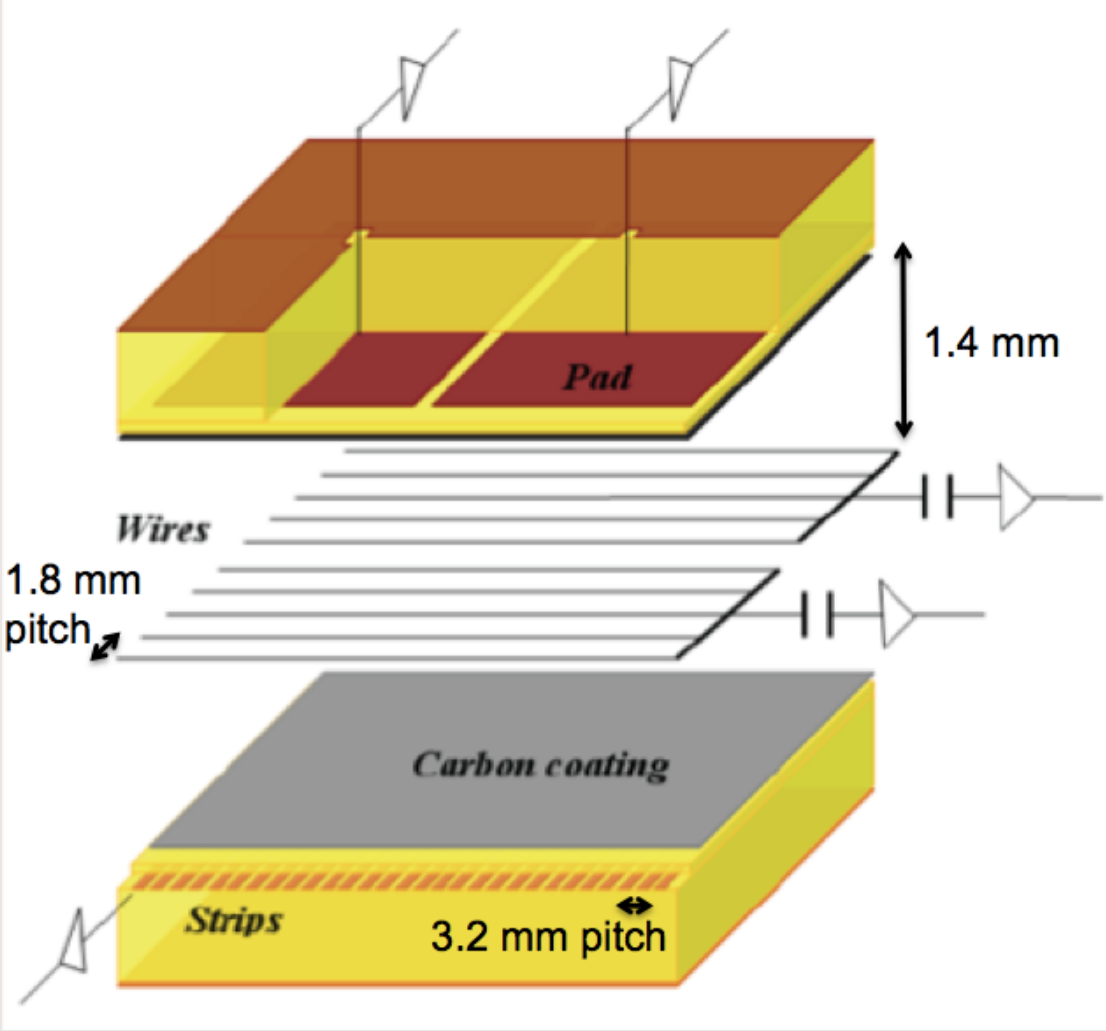




Fake (unwanted) triggers

small-strip Thin Gap Chambers (sTGC)

- Gas mixture flows in sTGC: n-pentane / CO_2 (45% / 55%).
- Cathode: Pads and Strips.
- Anode: Wires.
- Readout the **pads** for **triggering**.
- Readout the **strips** and **wires** for **tracking**.
- Signal related to charge deposited on pads and strips.
- 64 channels per readout chip (VMM).



“Module -1”

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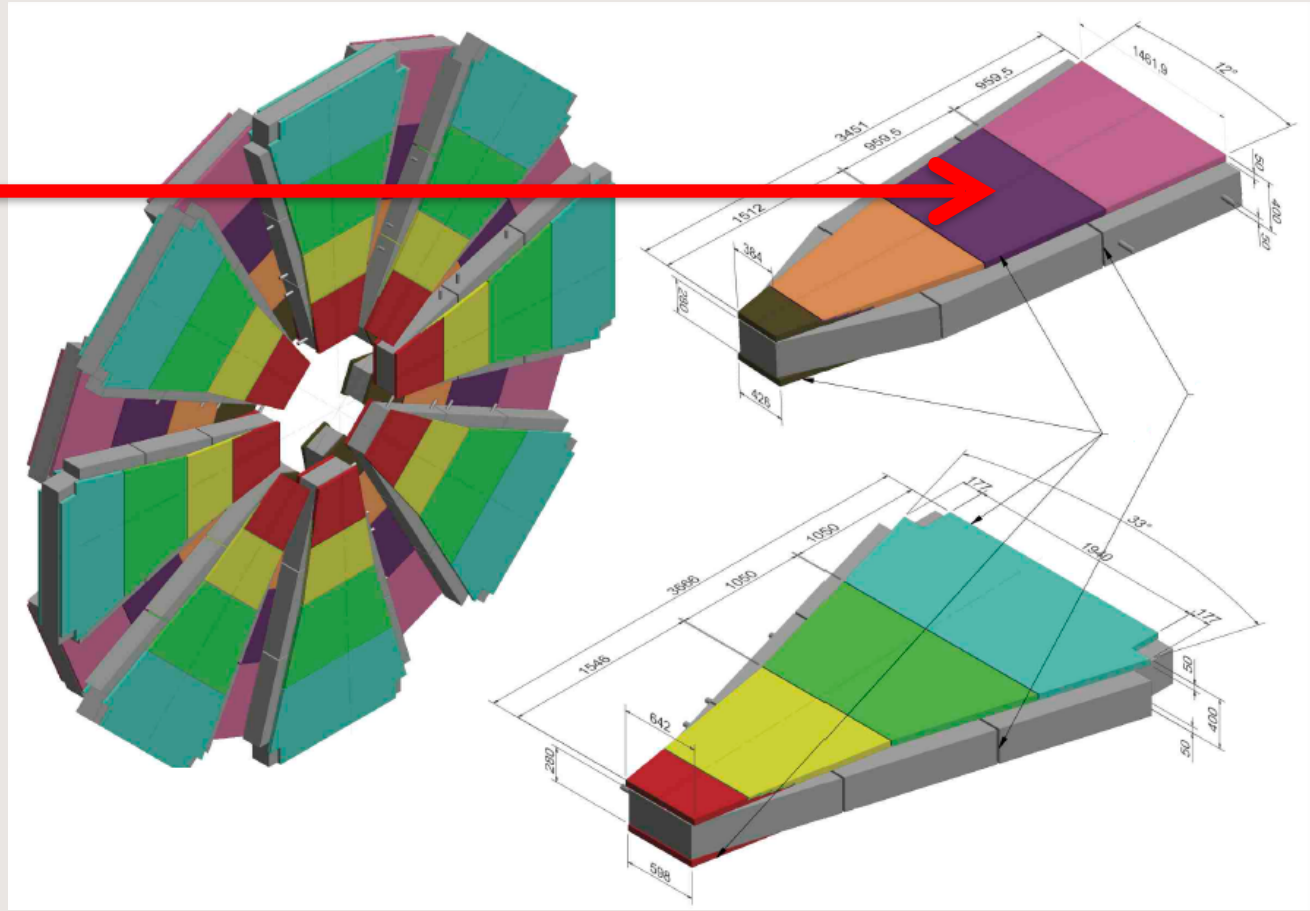
- Prototype sector of the NSW
- Composed of 4 sTGC layers

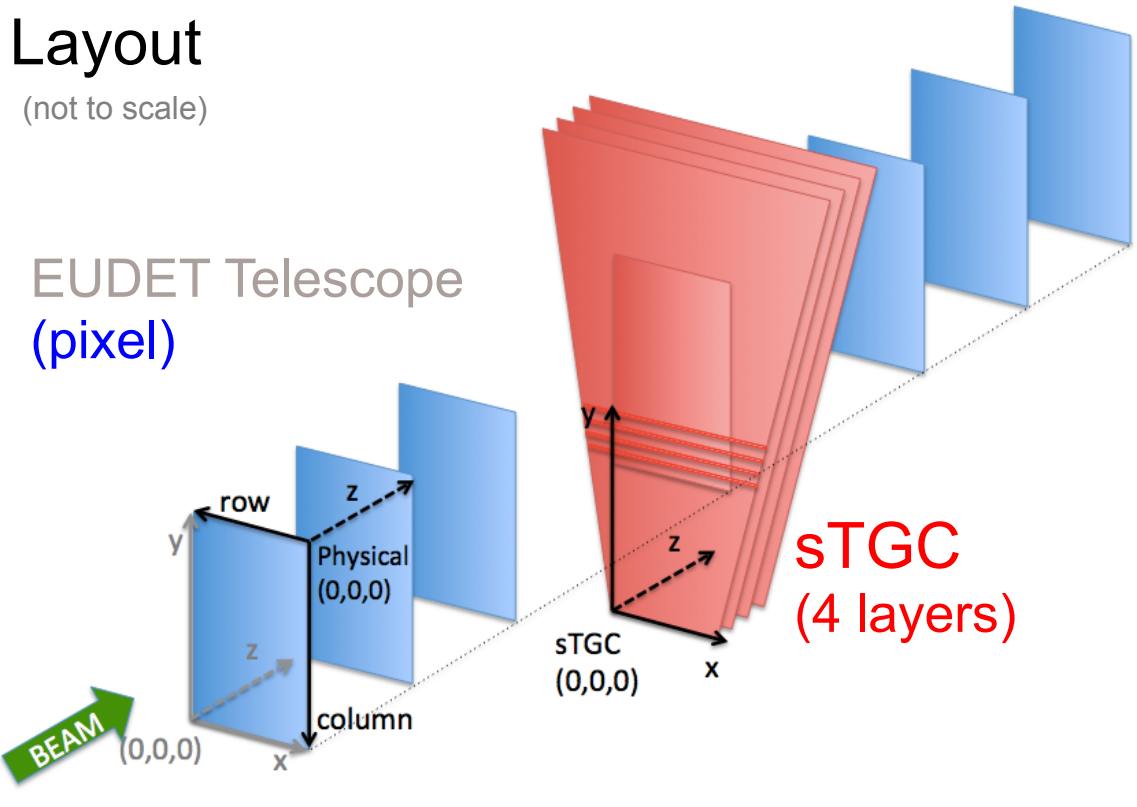


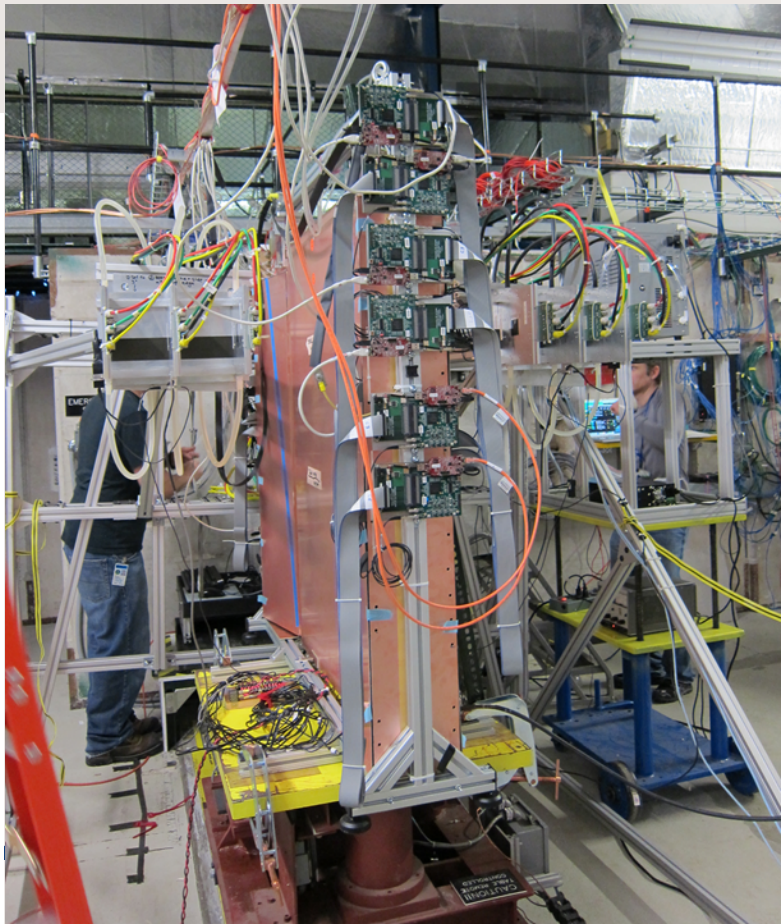
Fermilab Test Beam (May 2014)

- 32 GeV pion beam
- Pixel Telescope
- Module -1
- Readout (VMM1)
- Motion Table

Layout

(not to scale)





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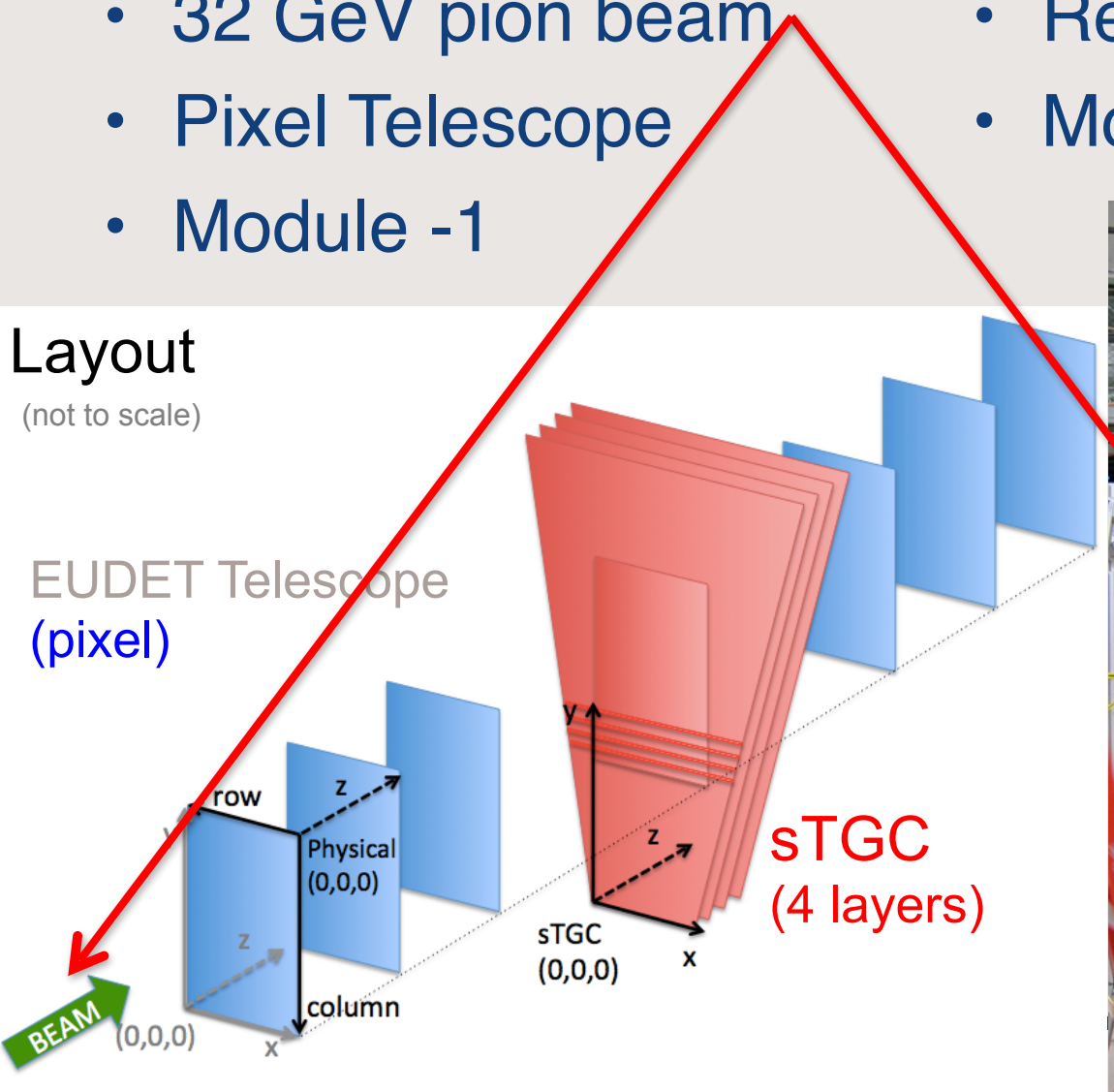

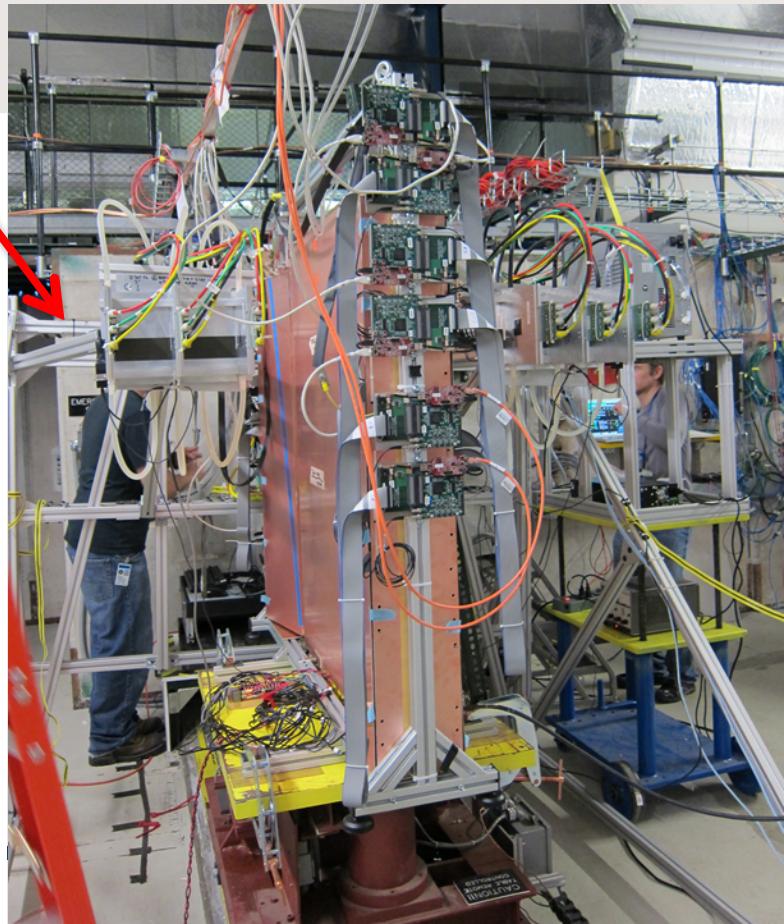

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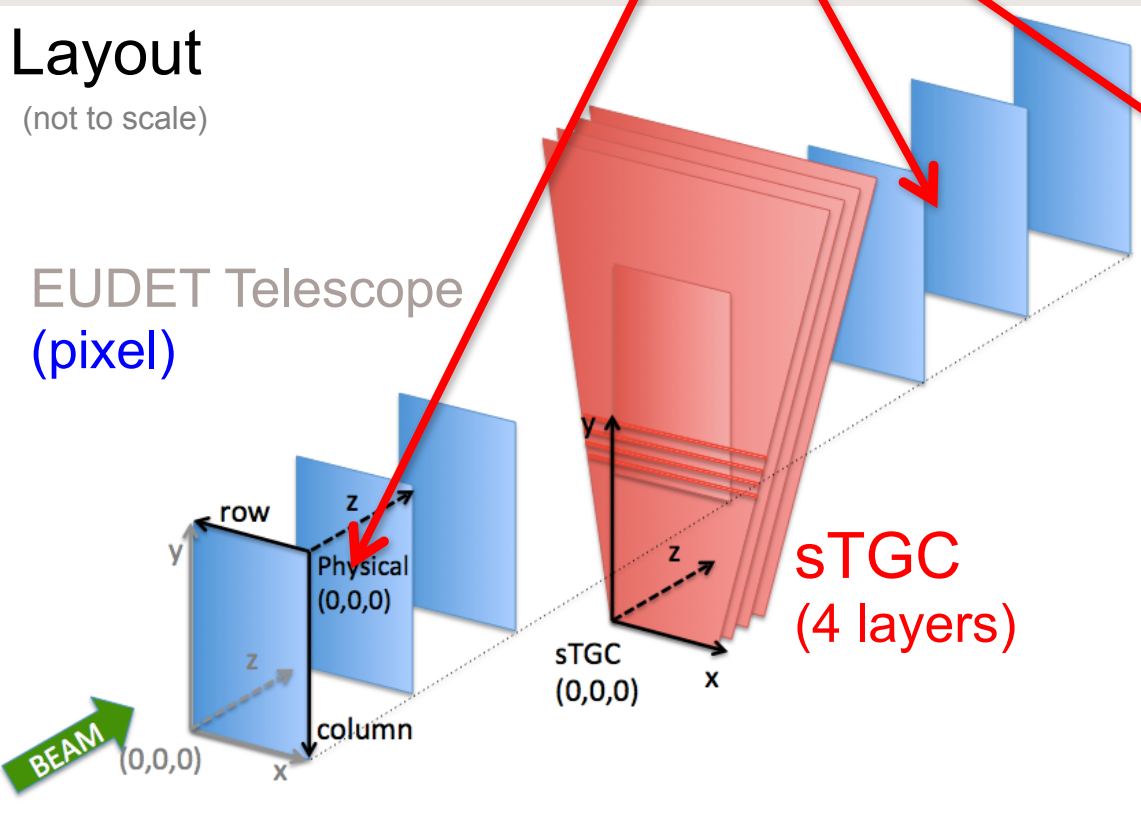

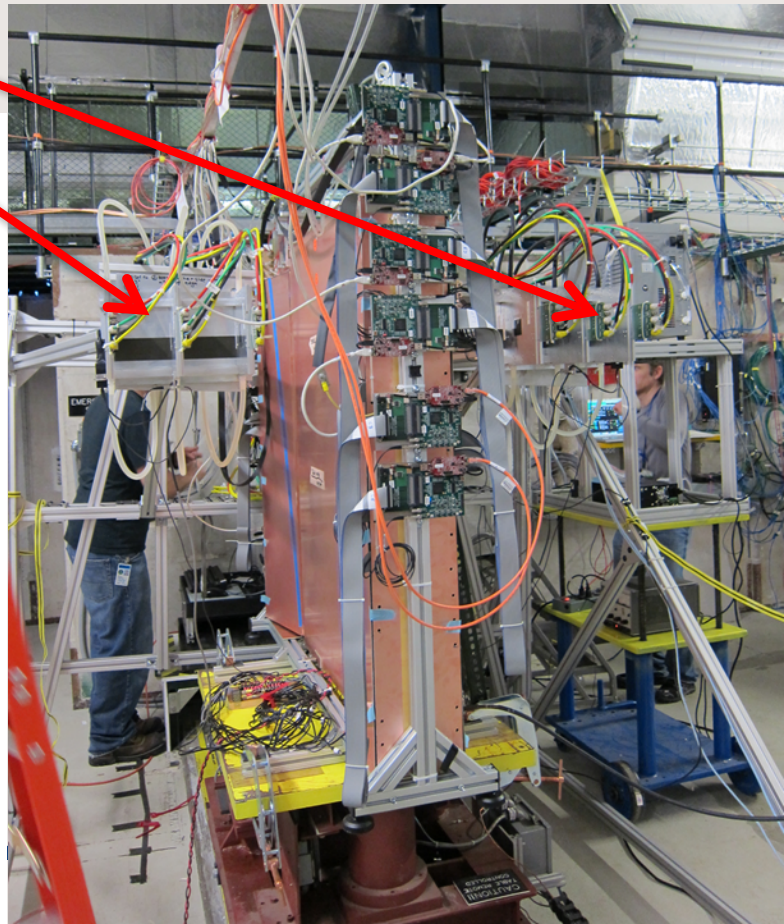

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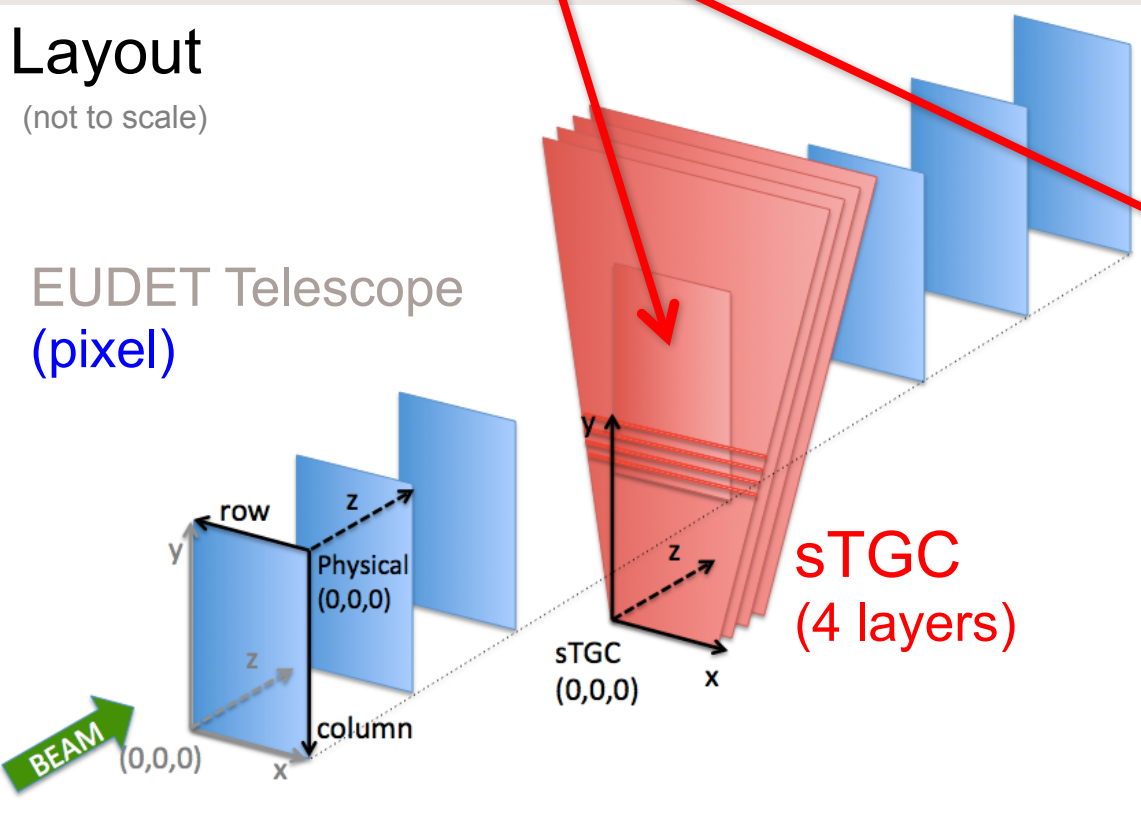

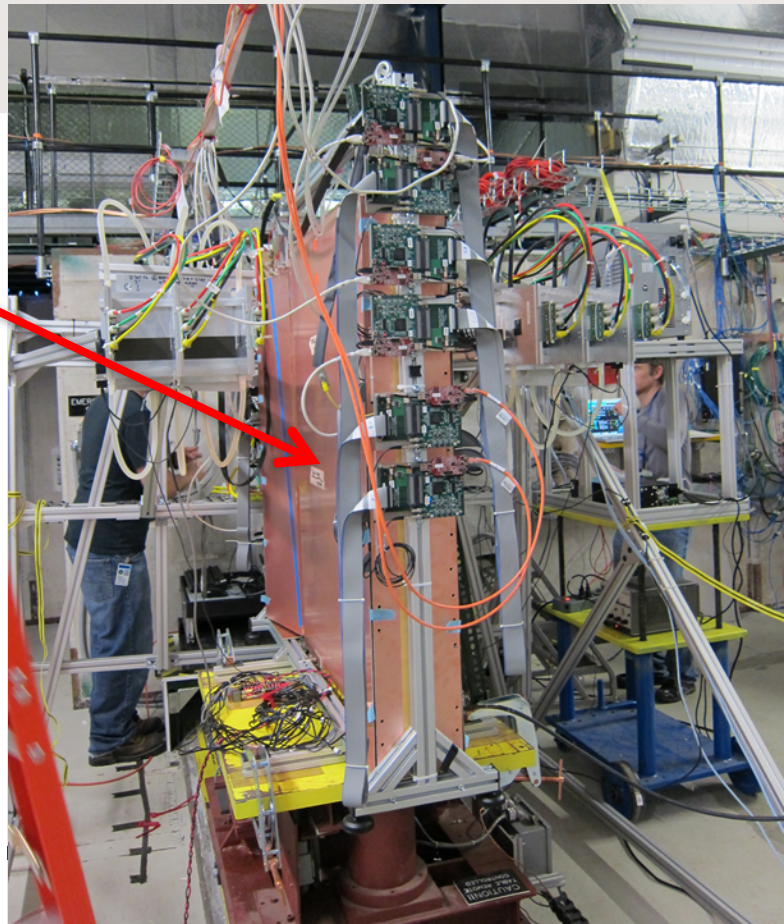

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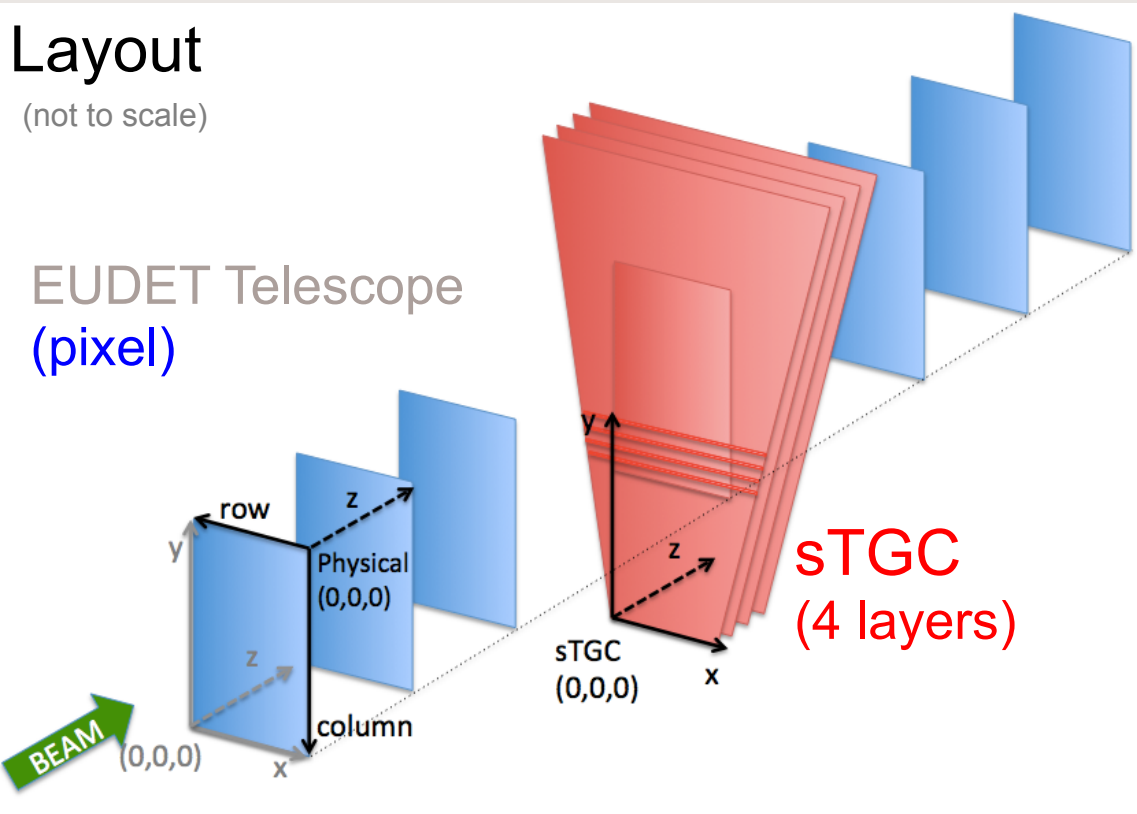

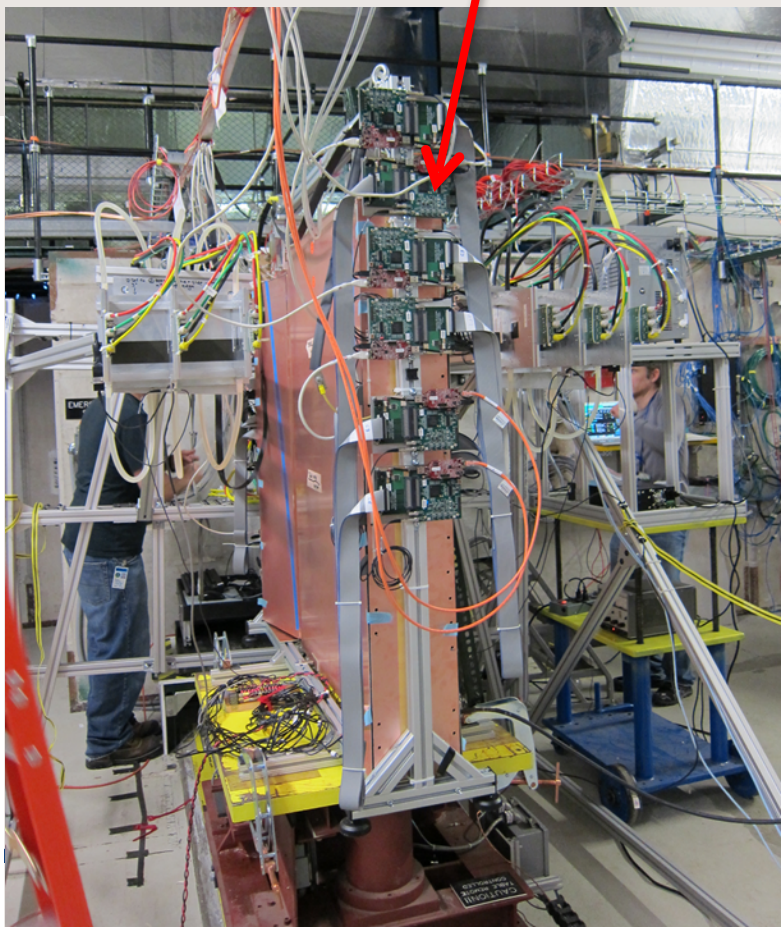

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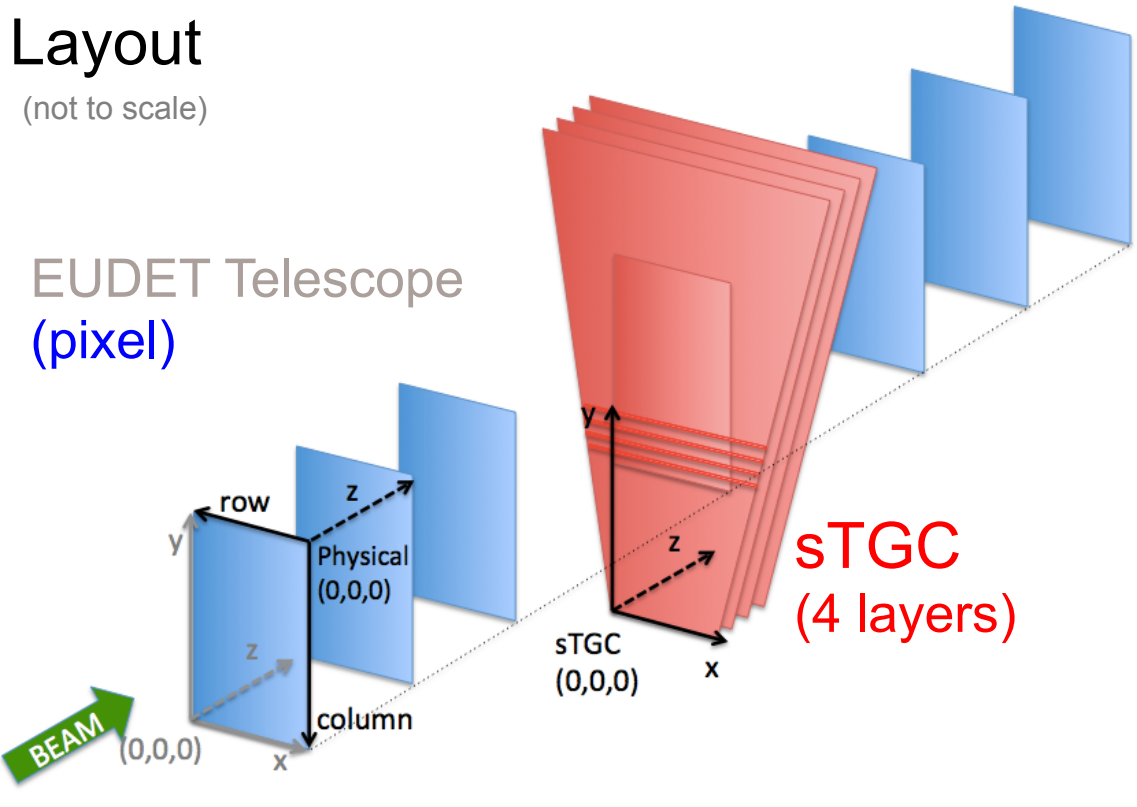
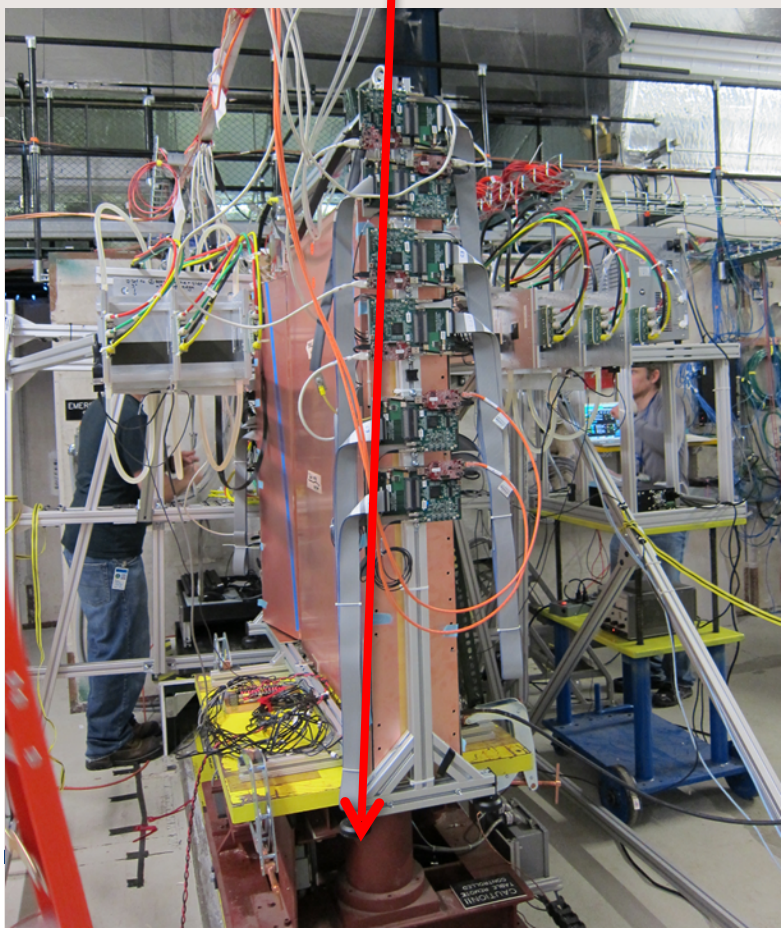
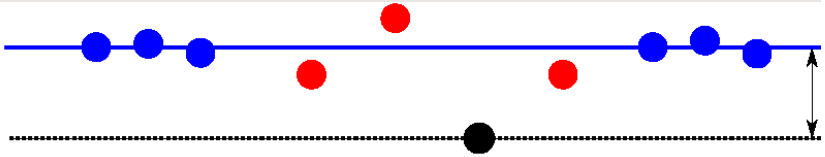


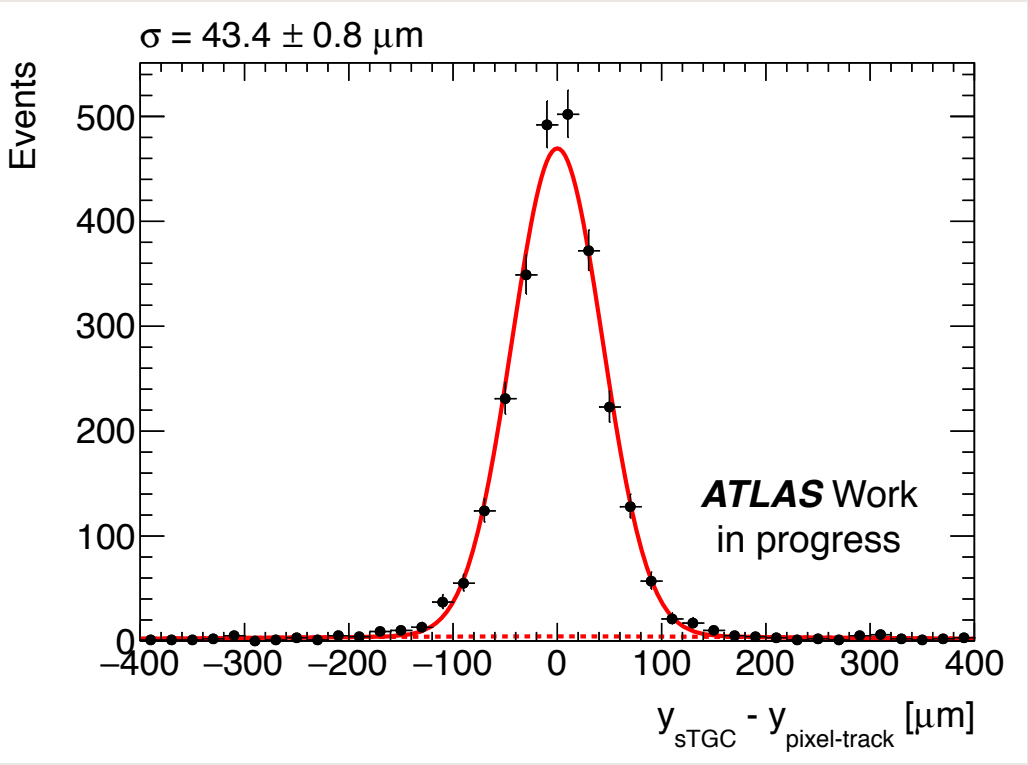


Pixel Telescope

- Each telescope plane has ~5 μm resolution
- 6 telescope planes total



Residual wrt Pixel Telescope



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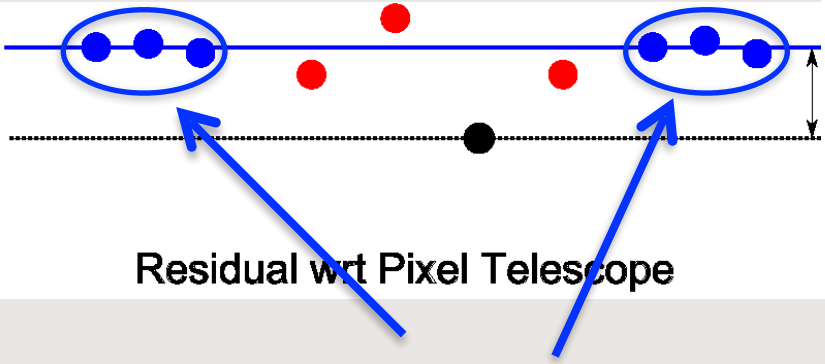

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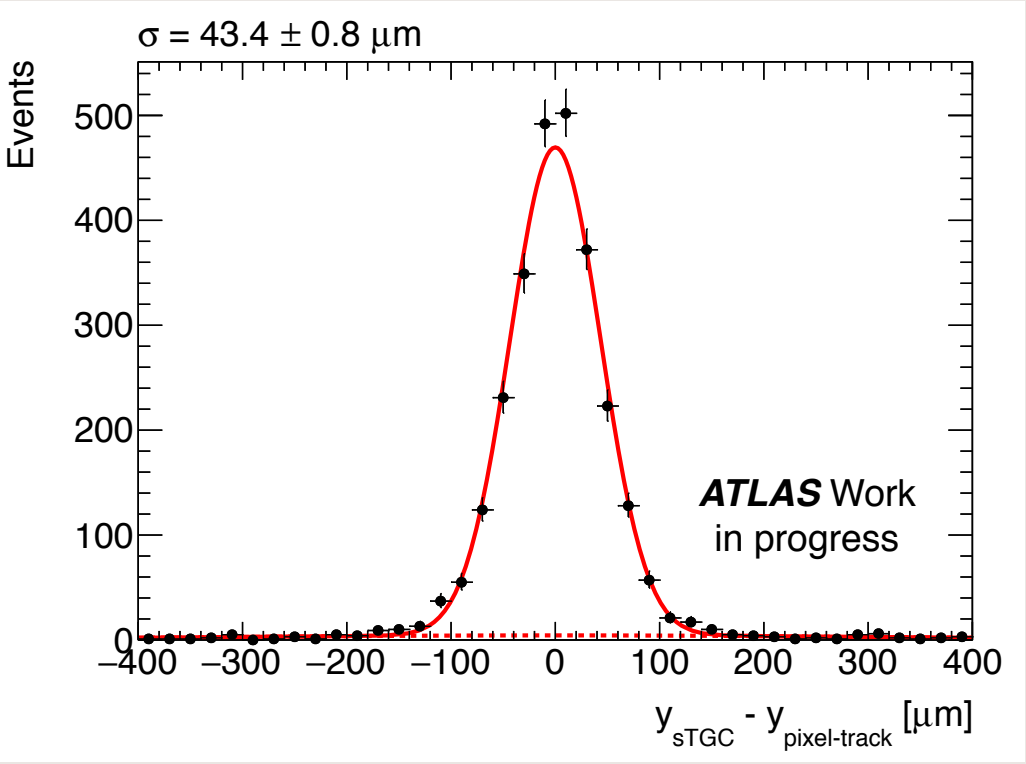

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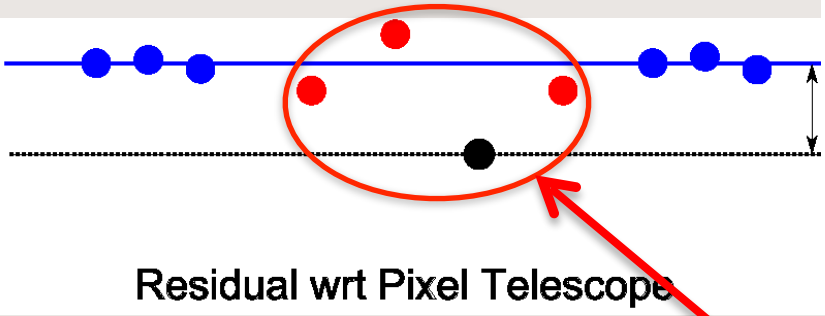
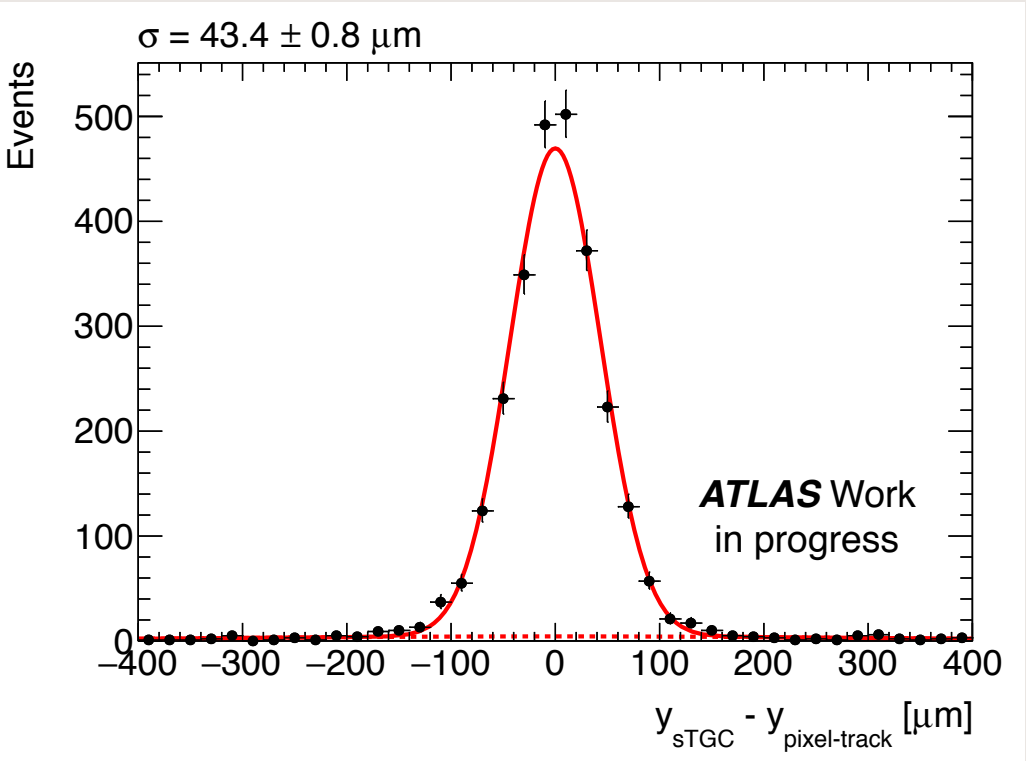
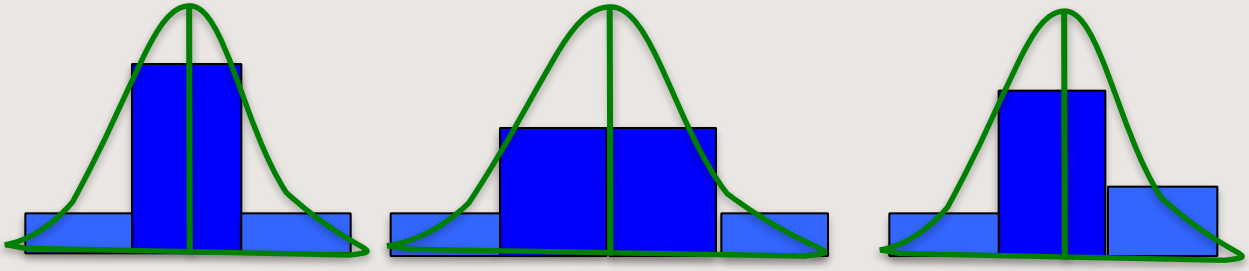


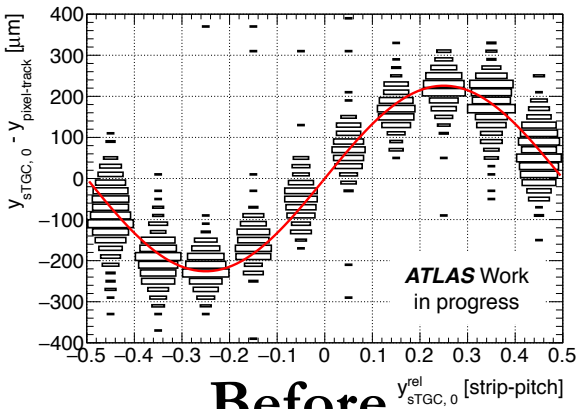


Module -1

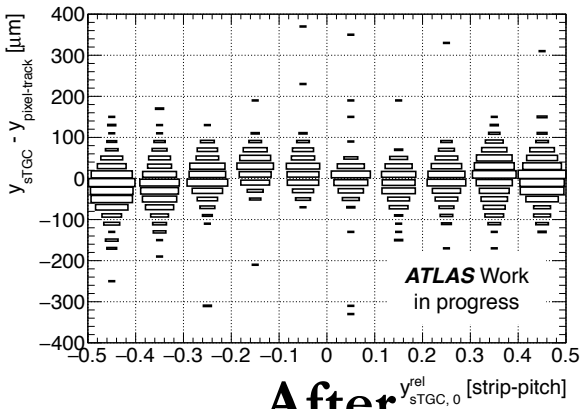
“S-shape” Correction

- Y-axis: difference between strip cluster mean and pixel track cluster
- X-axis: difference between strip cluster mean and closest gap
- Deviation of the expected hit position from the measured one depends on the hit position
- Differential non-linear effect





Before



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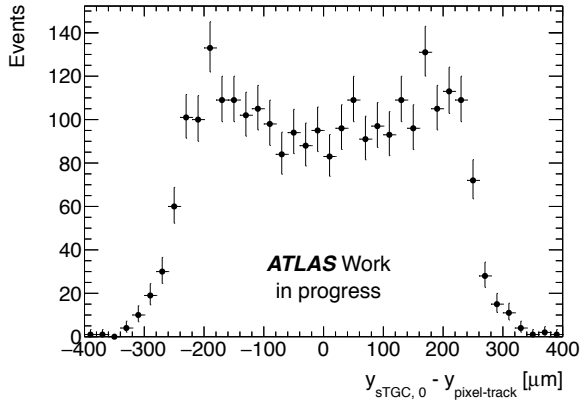

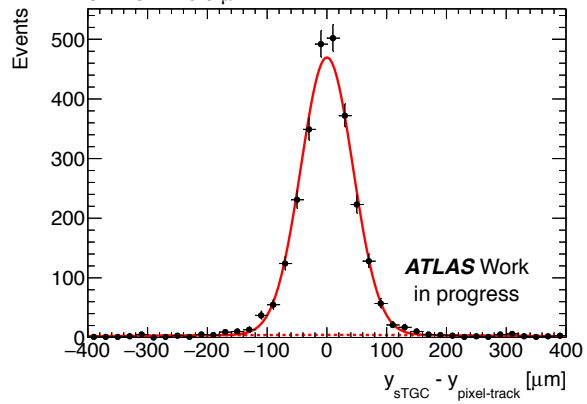

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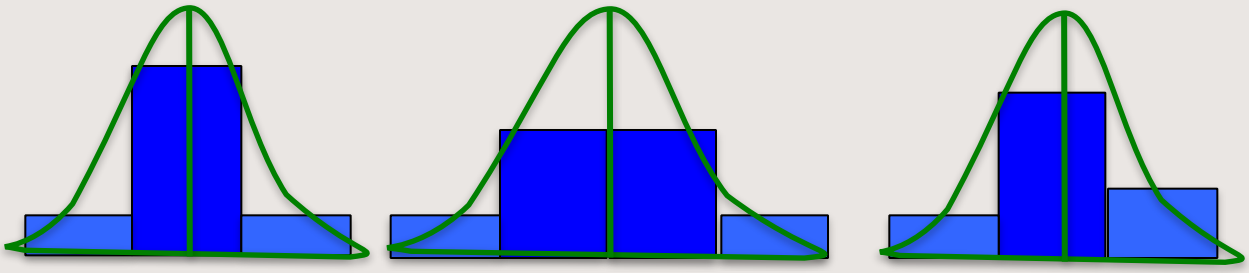
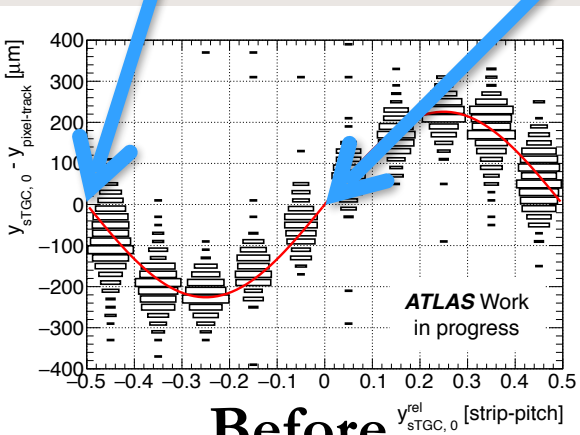


No deviation



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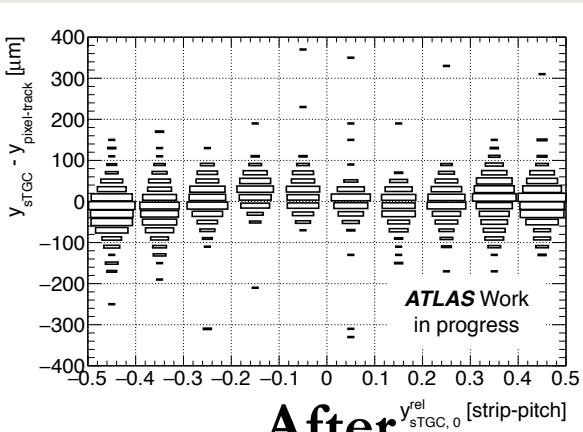

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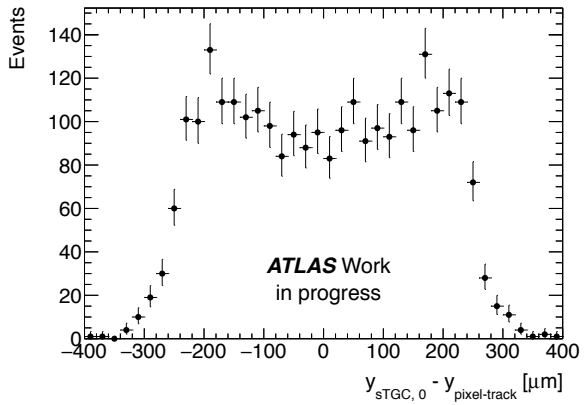

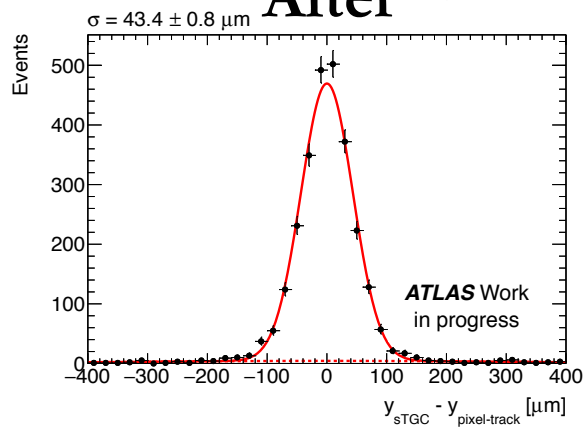

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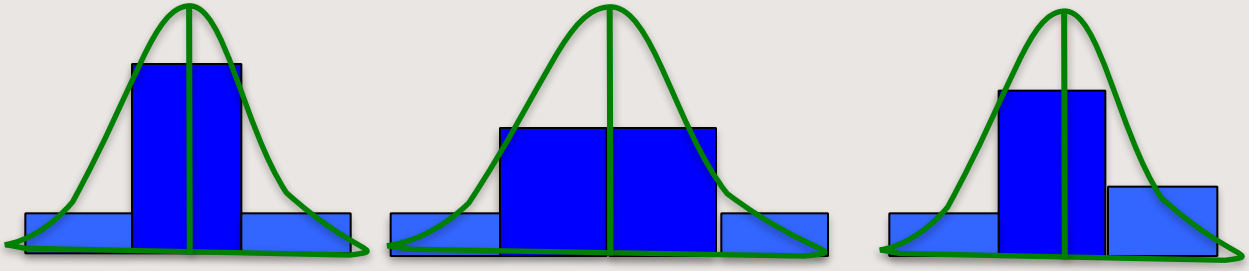
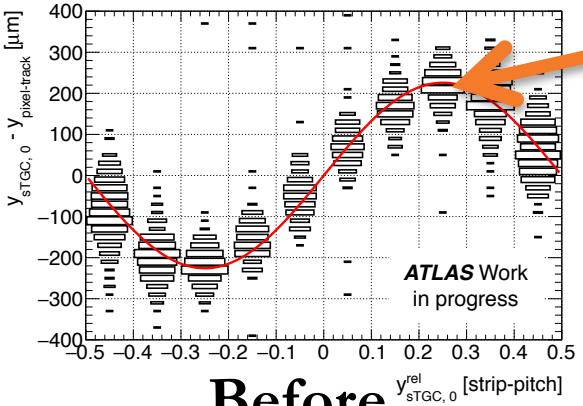


Deviation towards strip center



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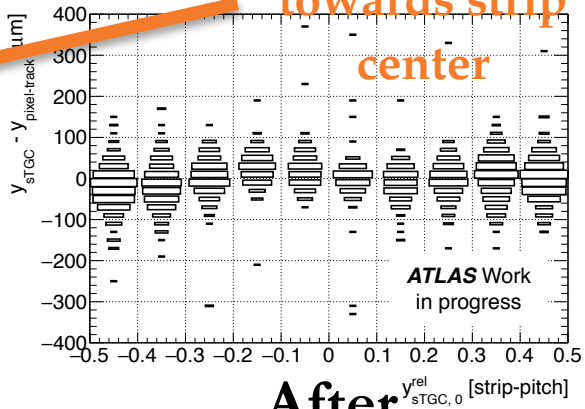

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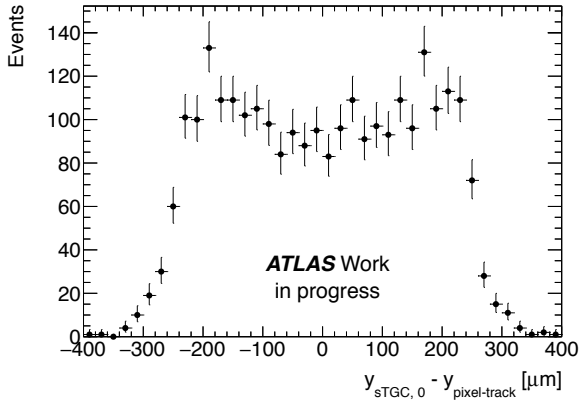
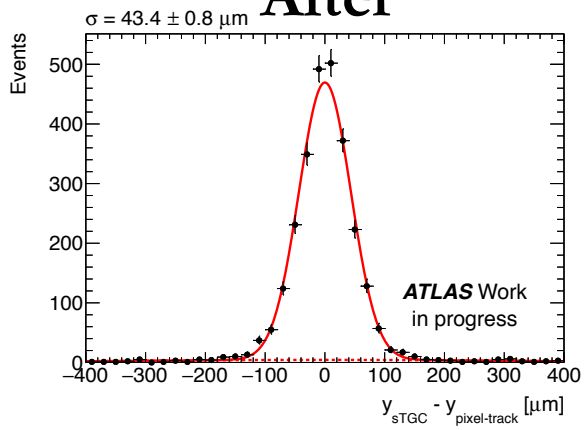
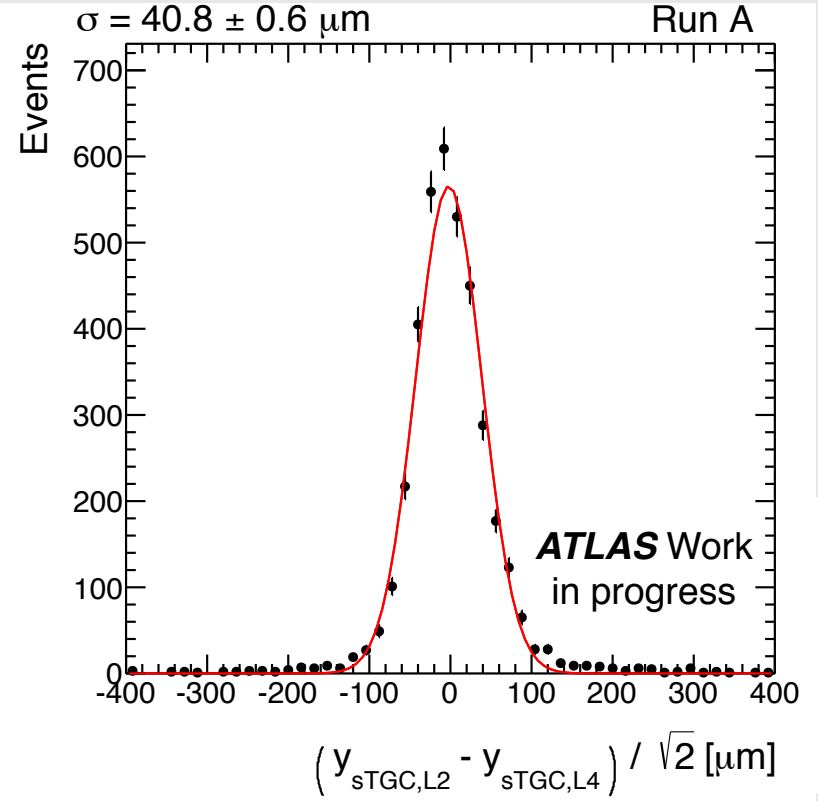
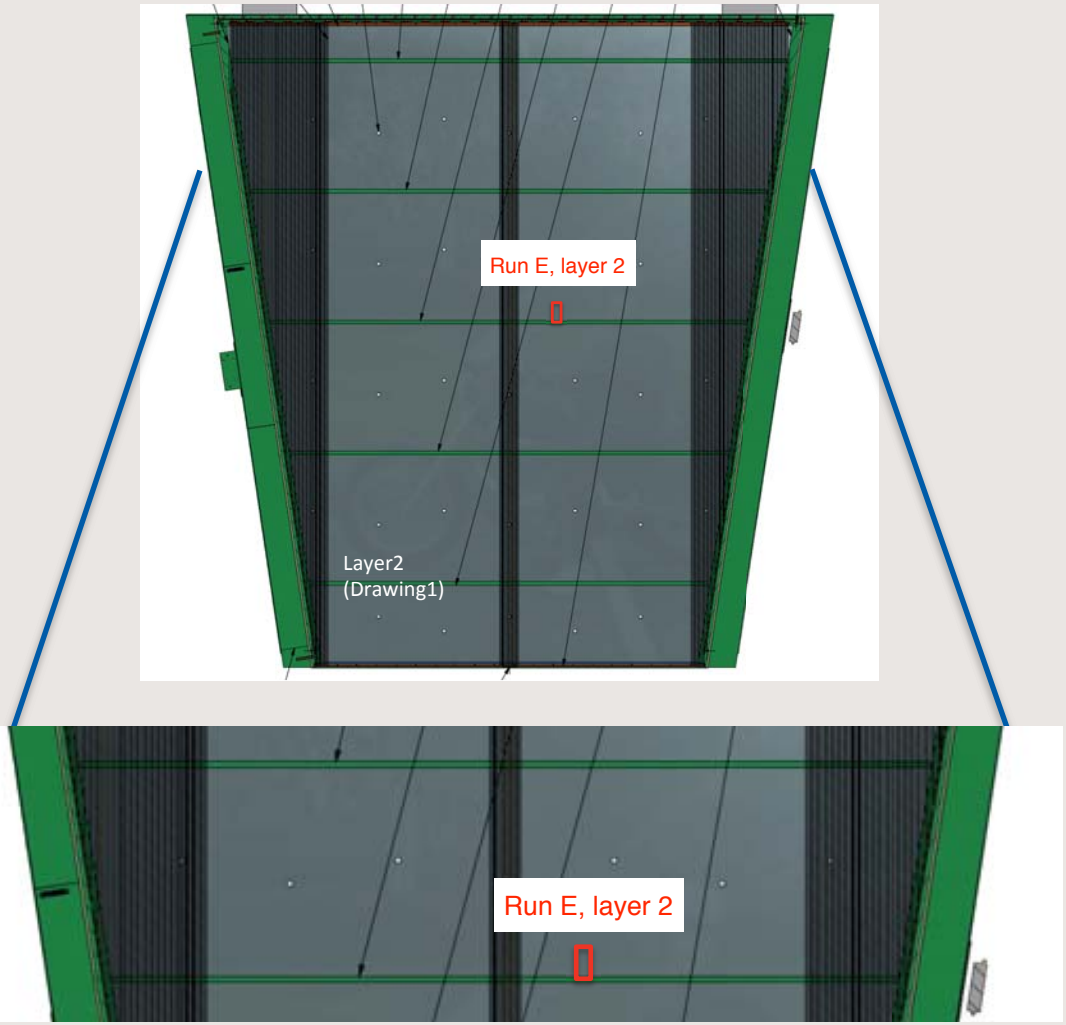




Pairwise Residuals

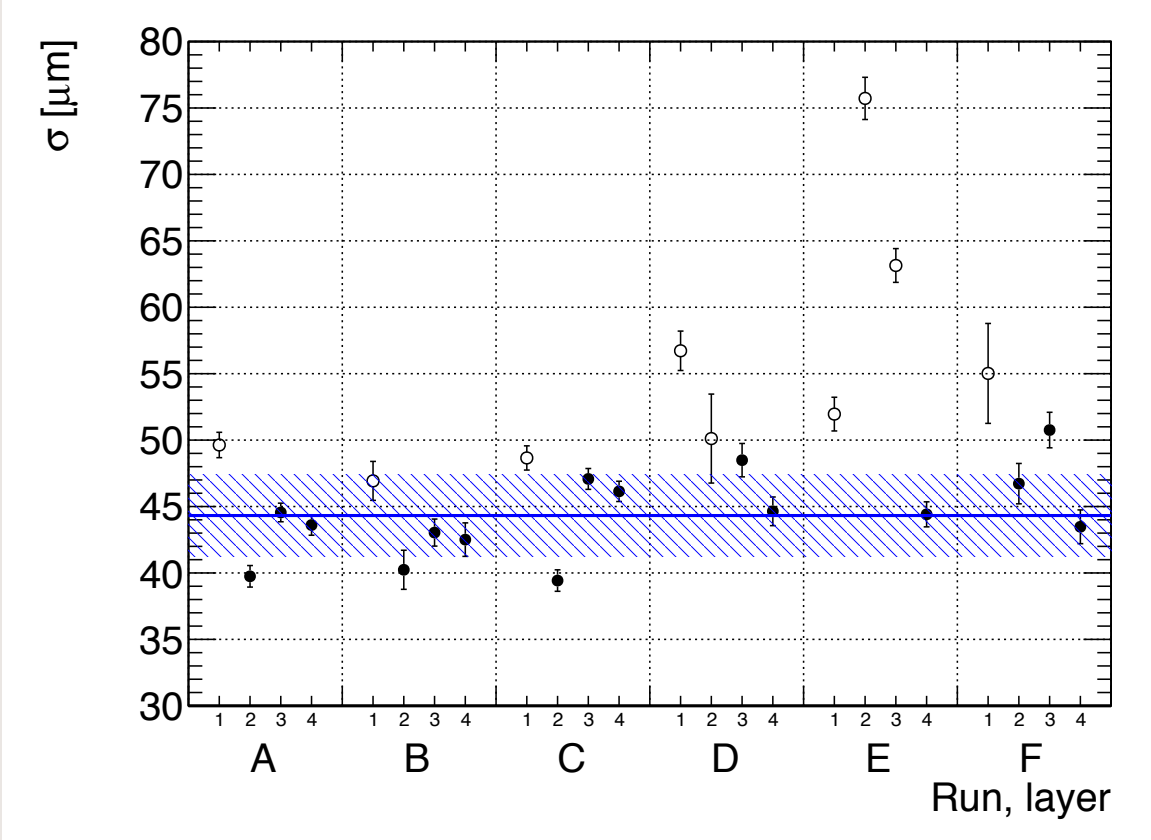
- Some runs have beam hitting module -1 wire support or spacer button.
- $(y_{sTGC,Li} - y_{sTGC,Lj}) / \sqrt{2}$





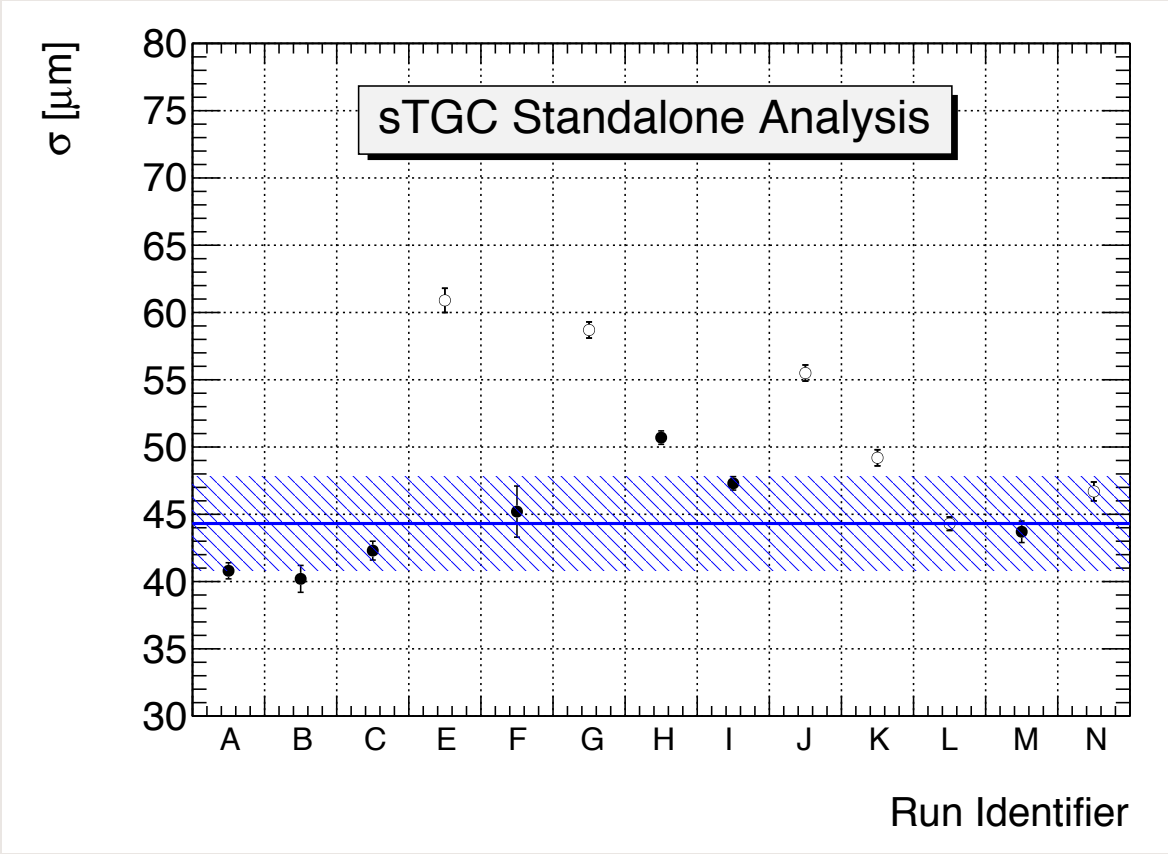
sTGC-telescope Analysis Results

- Nominal
- Special
  - "Per channel" pedestal corrections not available for layer 1.
  - Dead channel for run D layer 2.
  - Wire support and button in tested region for run E layers 2 and 3.



sTGC Standalone Analysis Results

- Nominal
- Special
  - Wire support in tested region for runs E, G, J, K, L, N.
- Use pairwise residuals.
- Apply the “s-shape” correction extracted with the pixel telescope.
- Different runs probe different parts of the module -1.



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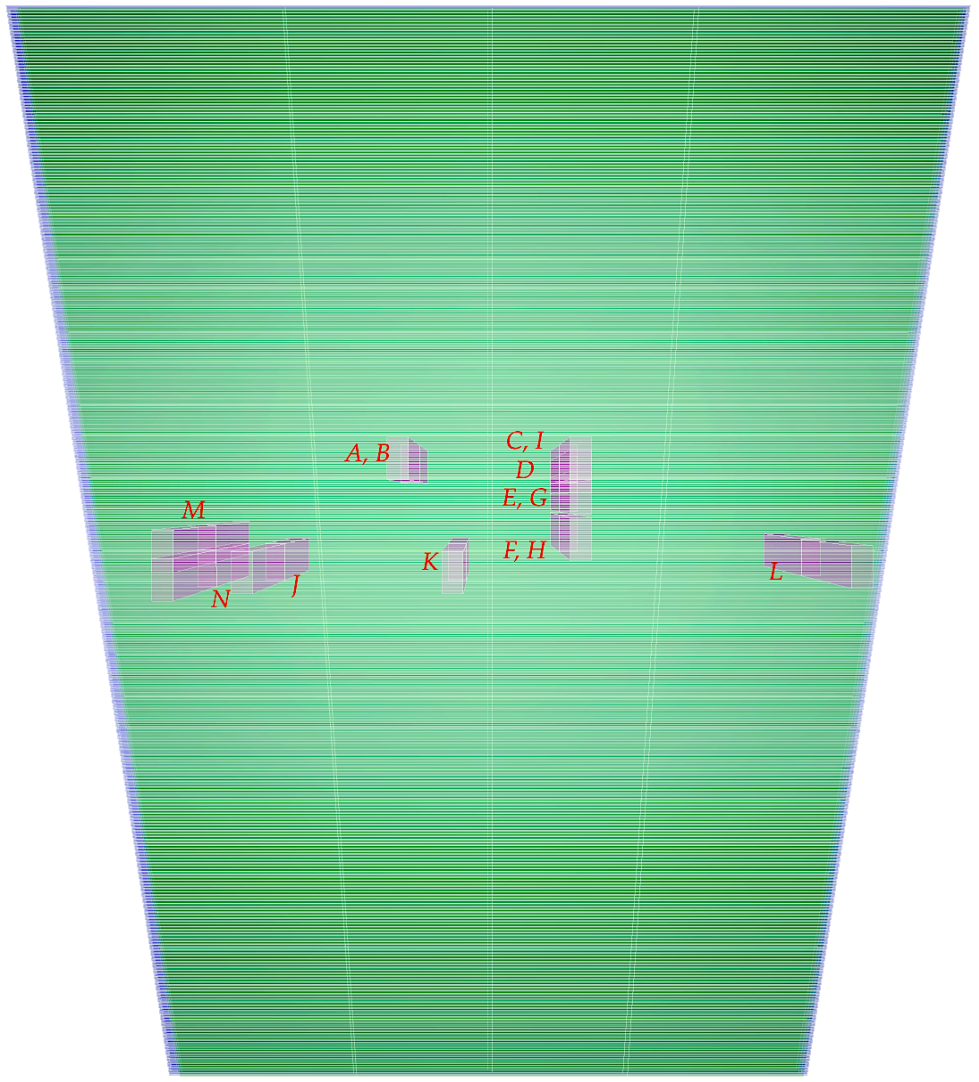


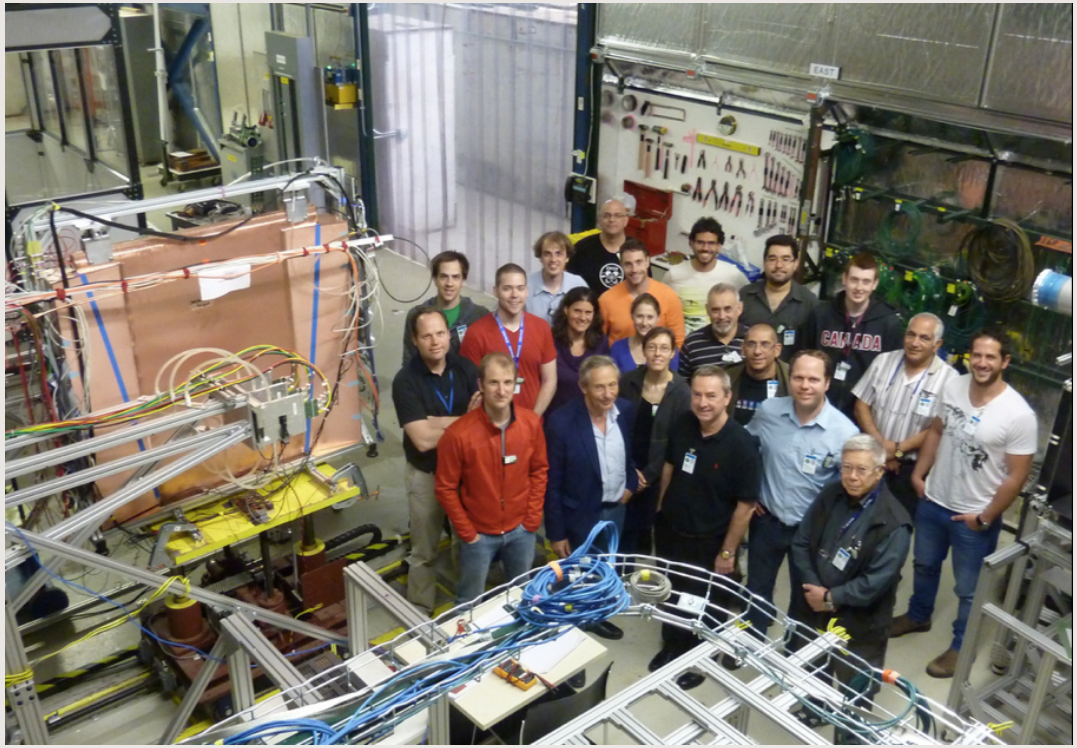
Conclusion

- The NSW is a key Phase-1 upgrade.
- Achieved spatial resolution of “module -1” around 50 µm; well within design requirement of 100 µm.
- NIM paper in preparation.
- Next steps: Construct a Canadian prototype and test it.

TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

Thank you!



Merci!

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McGill | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

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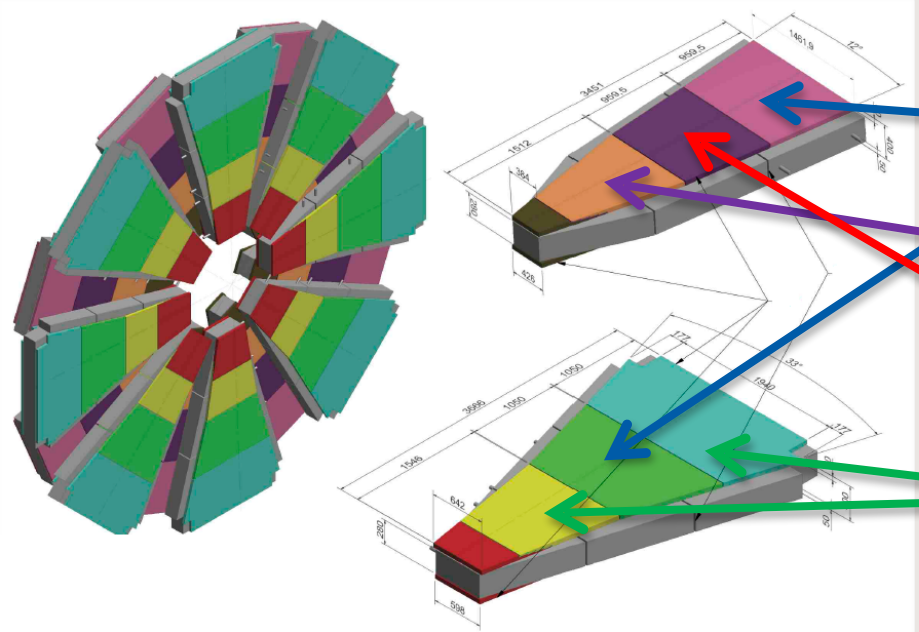
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

Backup

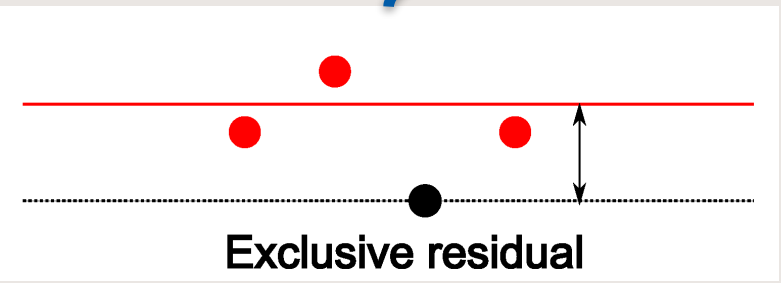
The New Muon Small Wheel (NSW)

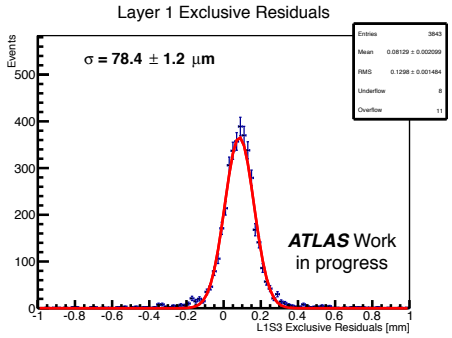


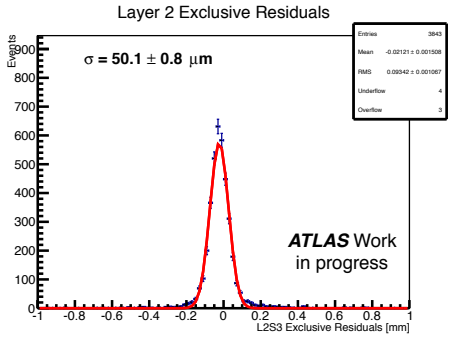
- International effort
  - Canada
    - 32 quadruplets + 8 spares
  - Chile
    - 32 quadruplets + 4 spares
  - China
    - 32 quadruplets + 4 spares
  - Israel
    - 64 quadruplets + 8 spares

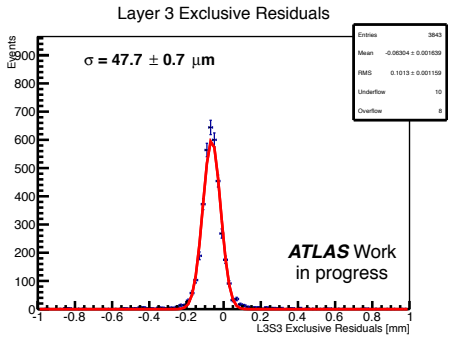
- TRIUMF
  - Cathode board production: graphite spraying and chamber wall assembly.
  - Quality control for all received parts.
- Carleton
  - Anode wire winding and quadruplet assembly.
- McGill
  - Cosmic ray testing.

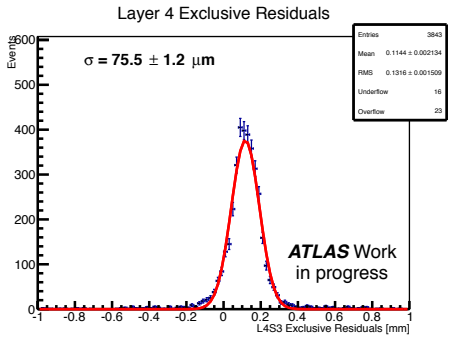
Residuals

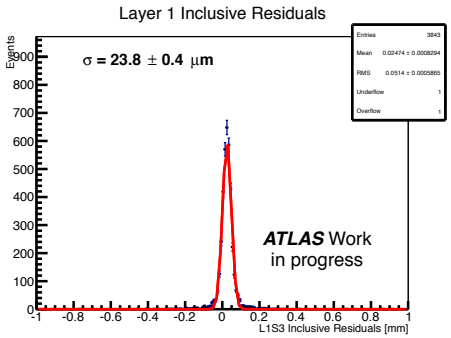

Exclusive residual

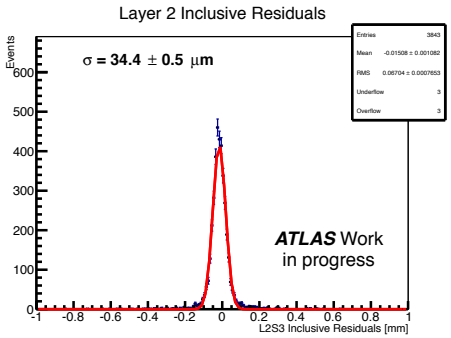

Layer 1 Exclusive Residuals
σ = 78.4 ± 1.2 μm
ATLAS Work in progress
L1S3 Exclusive Residuals [mm]

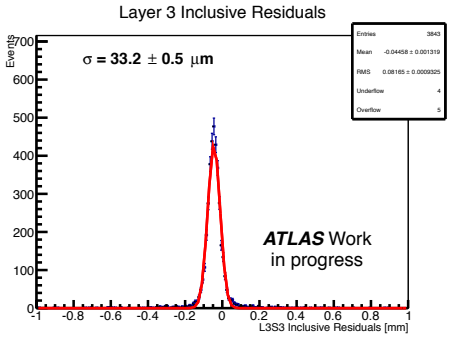

Layer 2 Exclusive Residuals
σ = 50.1 ± 0.8 μm
ATLAS Work in progress
L2S3 Exclusive Residuals [mm]

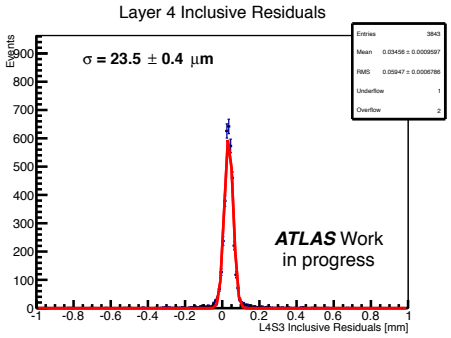

Layer 3 Exclusive Residuals
σ = 47.7 ± 0.7 μm
ATLAS Work in progress
L3S3 Exclusive Residuals [mm]


Layer 4 Exclusive Residuals
σ = 75.5 ± 1.2 μm
ATLAS Work in progress
L4S3 Exclusive Residuals [mm]


Layer 1 Inclusive Residuals
σ = 23.8 ± 0.4 μm
ATLAS Work in progress
L1S3 Inclusive Residuals [mm]

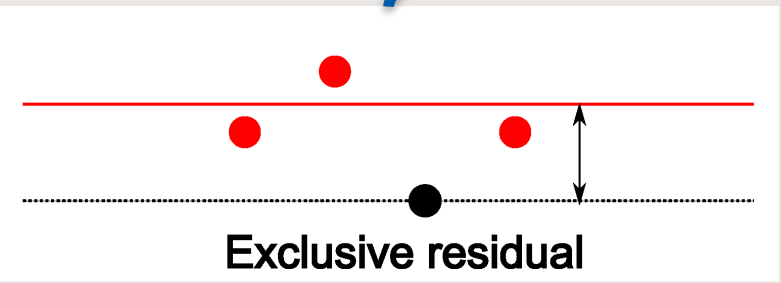

Layer 2 Inclusive Residuals
σ = 34.4 ± 0.5 μm
ATLAS Work in progress
L2S3 Inclusive Residuals [mm]

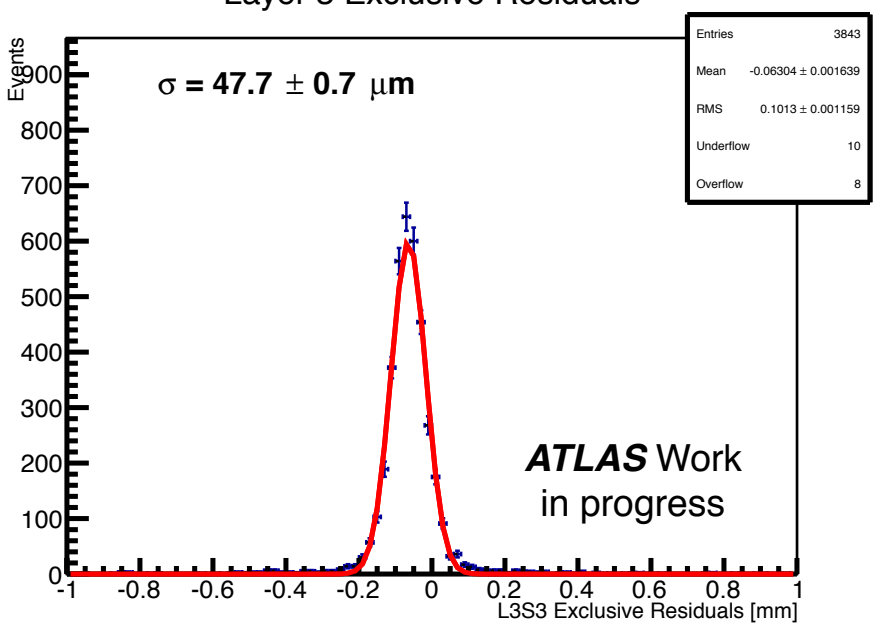

Layer 3 Inclusive Residuals
σ = 33.2 ± 0.5 μm
ATLAS Work in progress
L3S3 Inclusive Residuals [mm]

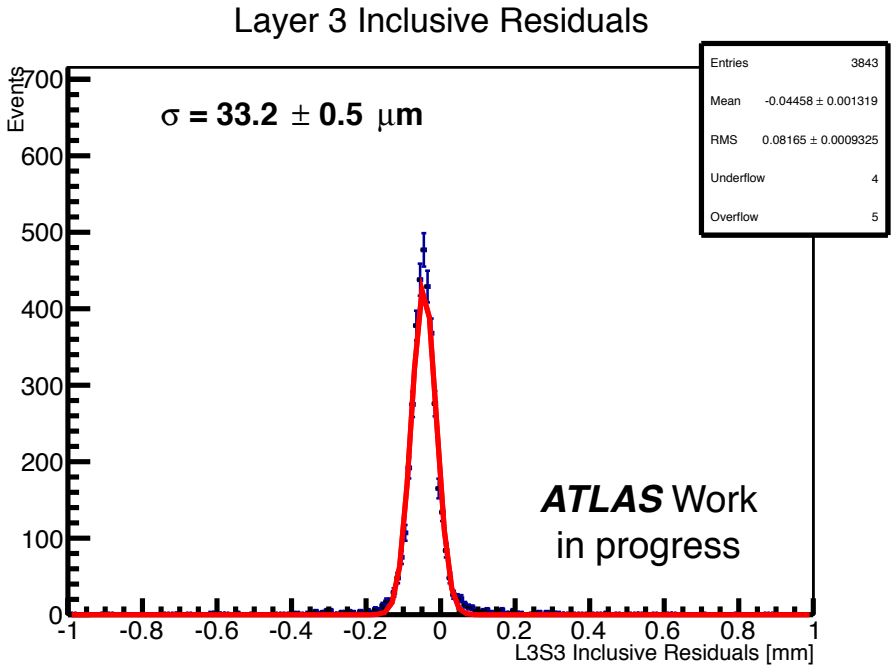

Layer 4 Inclusive Residuals
σ = 23.5 ± 0.4 μm
ATLAS Work in progress
L4S3 Inclusive Residuals [mm]

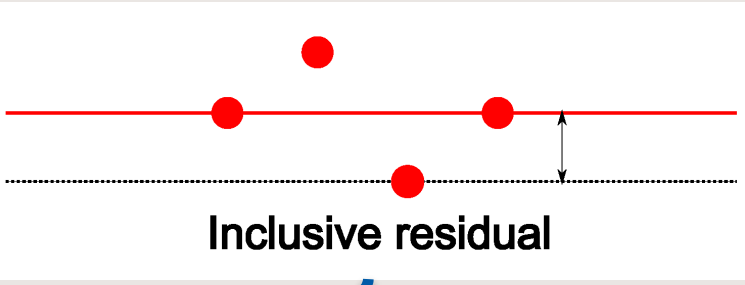

Inclusive residual

Residuals


Exclusive residual

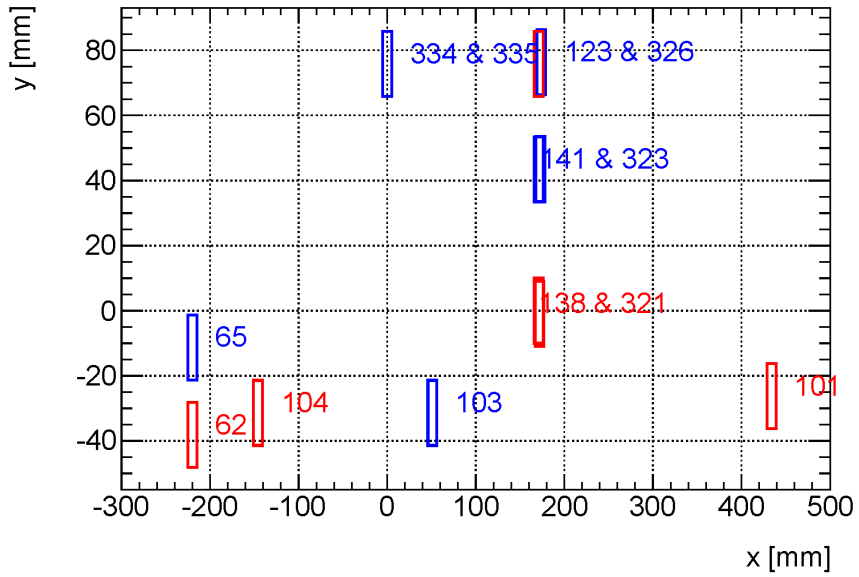

Layer 3 Exclusive Residuals
σ = 47.7 ± 0.7 μm
Entries 3843
Mean -0.06304 ± 0.001639
RMS 0.1013 ± 0.001159
Underflow 10
Overflow 8
Events
ATLAS Work in progress
L3S3 Exclusive Residuals [mm]

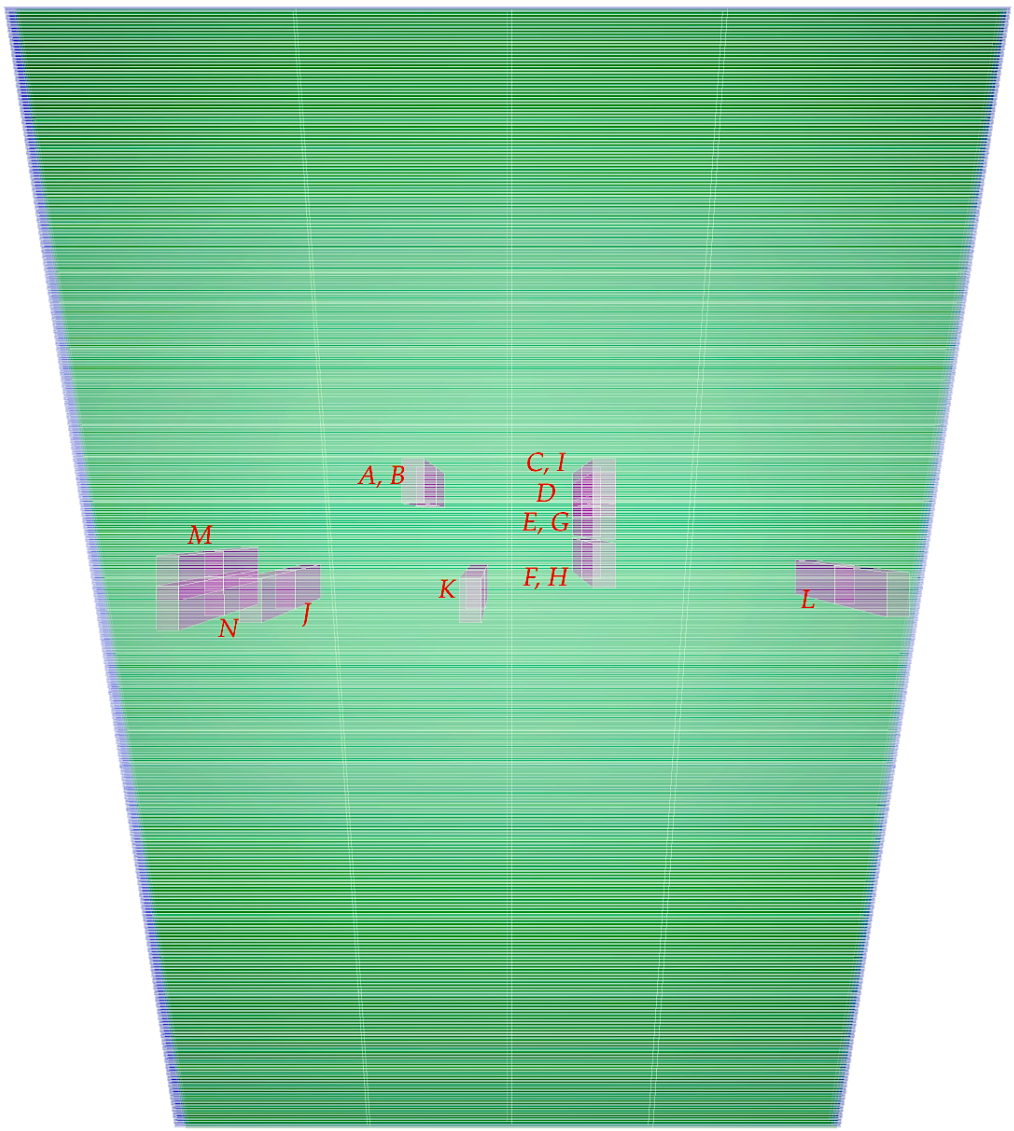

Layer 3 Inclusive Residuals
σ = 33.2 ± 0.5 μm
Entries 3843
Mean -0.04458 ± 0.001319
RMS 0.08165 ± 0.0009325
Underflow 4
Overflow 5
Events
ATLAS Work in progress
L3S3 Inclusive Residuals [mm]


Inclusive residual

Good Runs

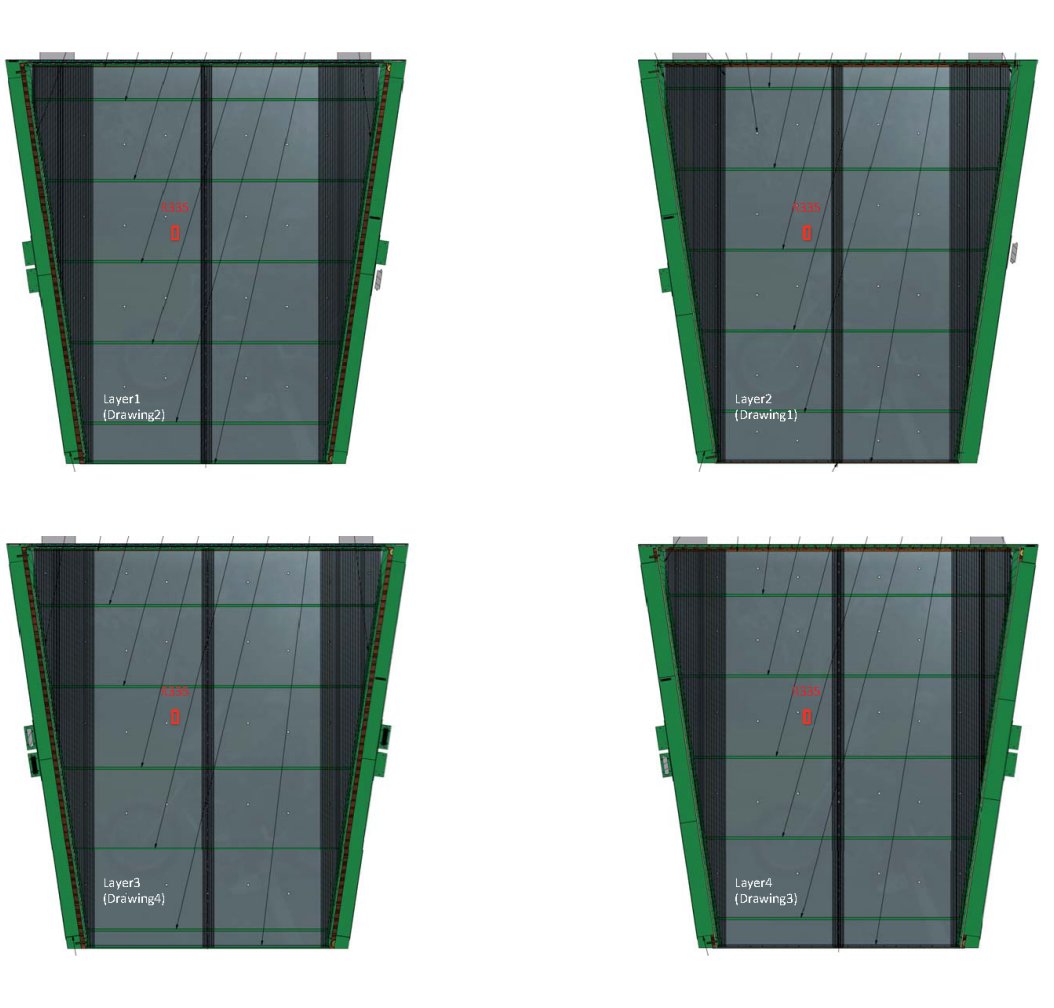
- Runs having good data that is analyzable



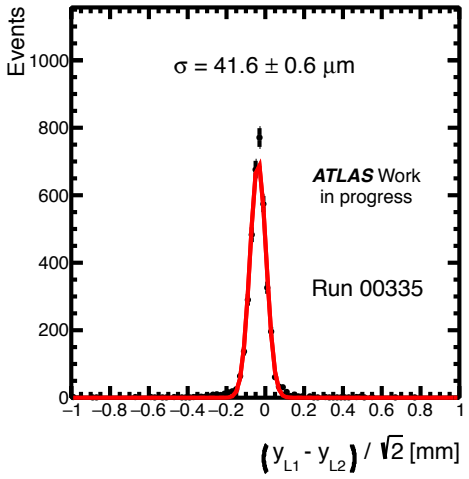


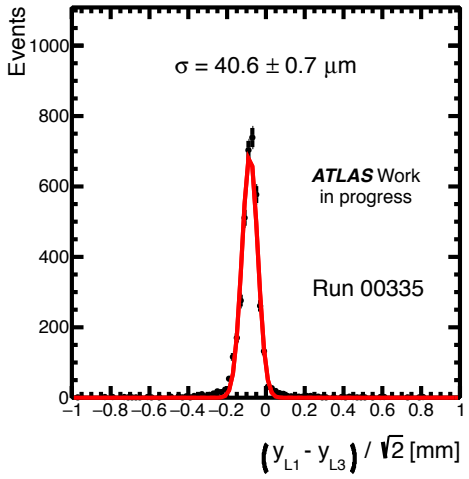
Runs 334 and 335

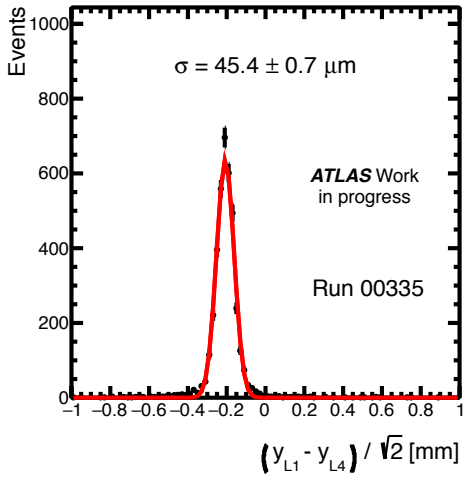
- All layers free of support structures

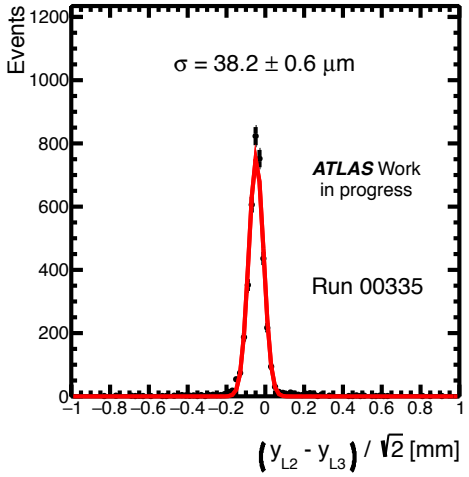


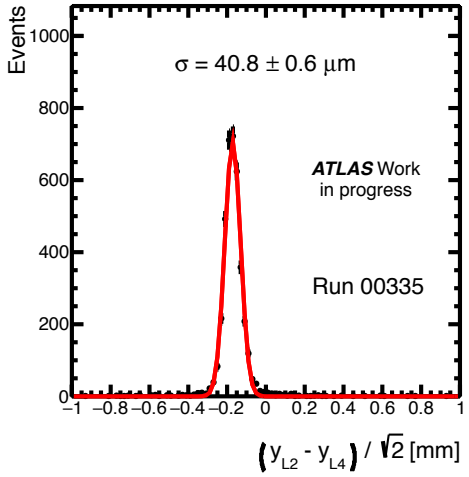
Run 335

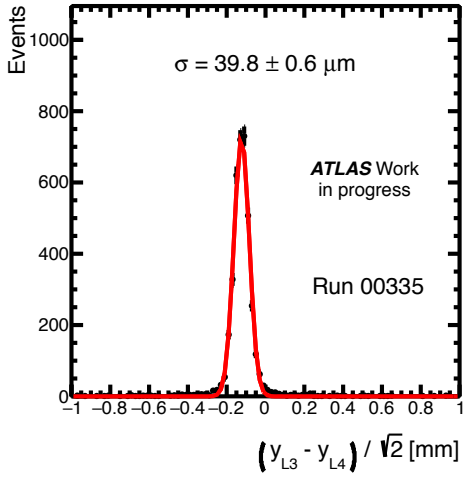

Events
σ = 41.6 ± 0.6 μm
ATLAS Work in progress
Run 00335
(y_L1 - y_L2) / √2 [mm]


Events
σ = 40.6 ± 0.7 μm
ATLAS Work in progress
Run 00335
(y_L1 - y_L3) / √2 [mm]


Events
σ = 45.4 ± 0.7 μm
ATLAS Work in progress
Run 00335
(y_L1 - y_L4) / √2 [mm]

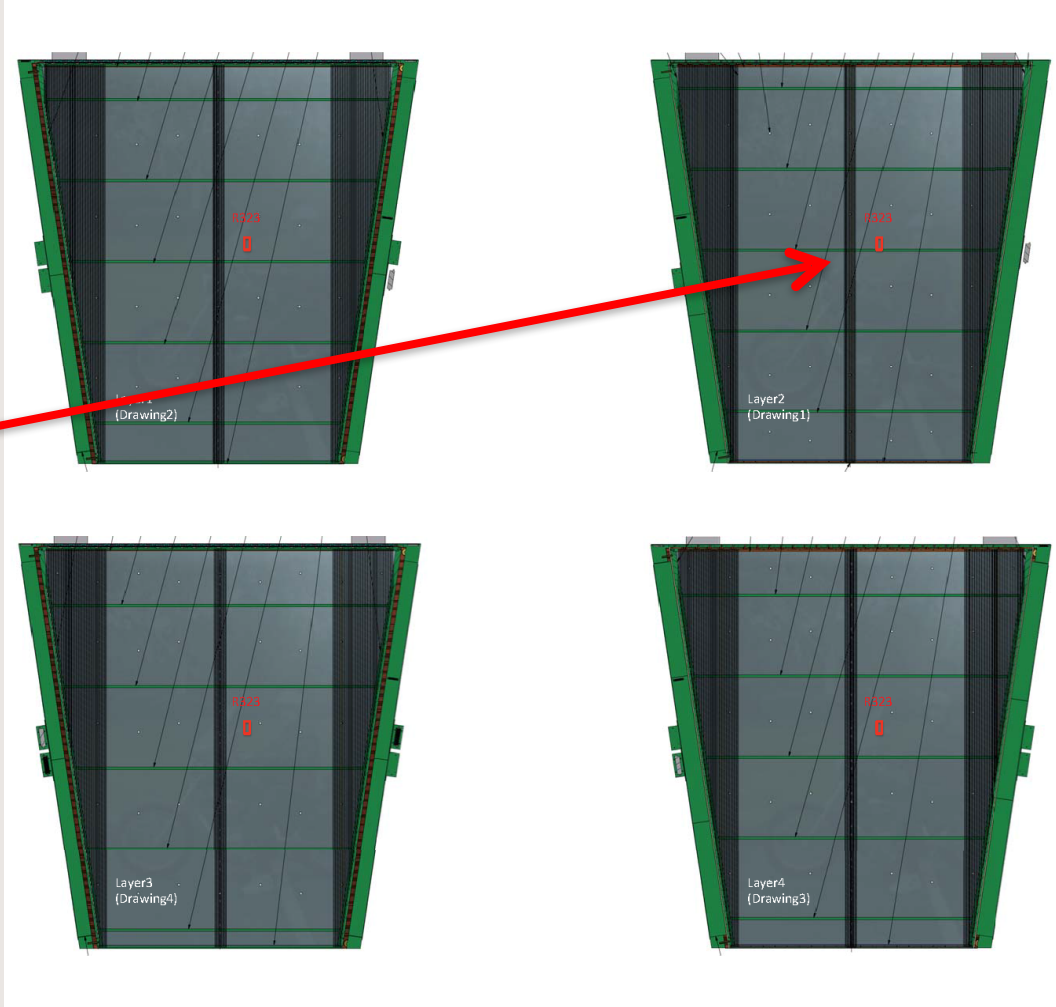

Events
σ = 38.2 ± 0.6 μm
ATLAS Work in progress
Run 00335
(y_L2 - y_L3) / √2 [mm]


Events
σ = 40.8 ± 0.6 μm
ATLAS Work in progress
Run 00335
(y_L2 - y_L4) / √2 [mm]


Events
σ = 39.8 ± 0.6 μm
ATLAS Work in progress
Run 00335
(y_L3 - y_L4) / √2 [mm]

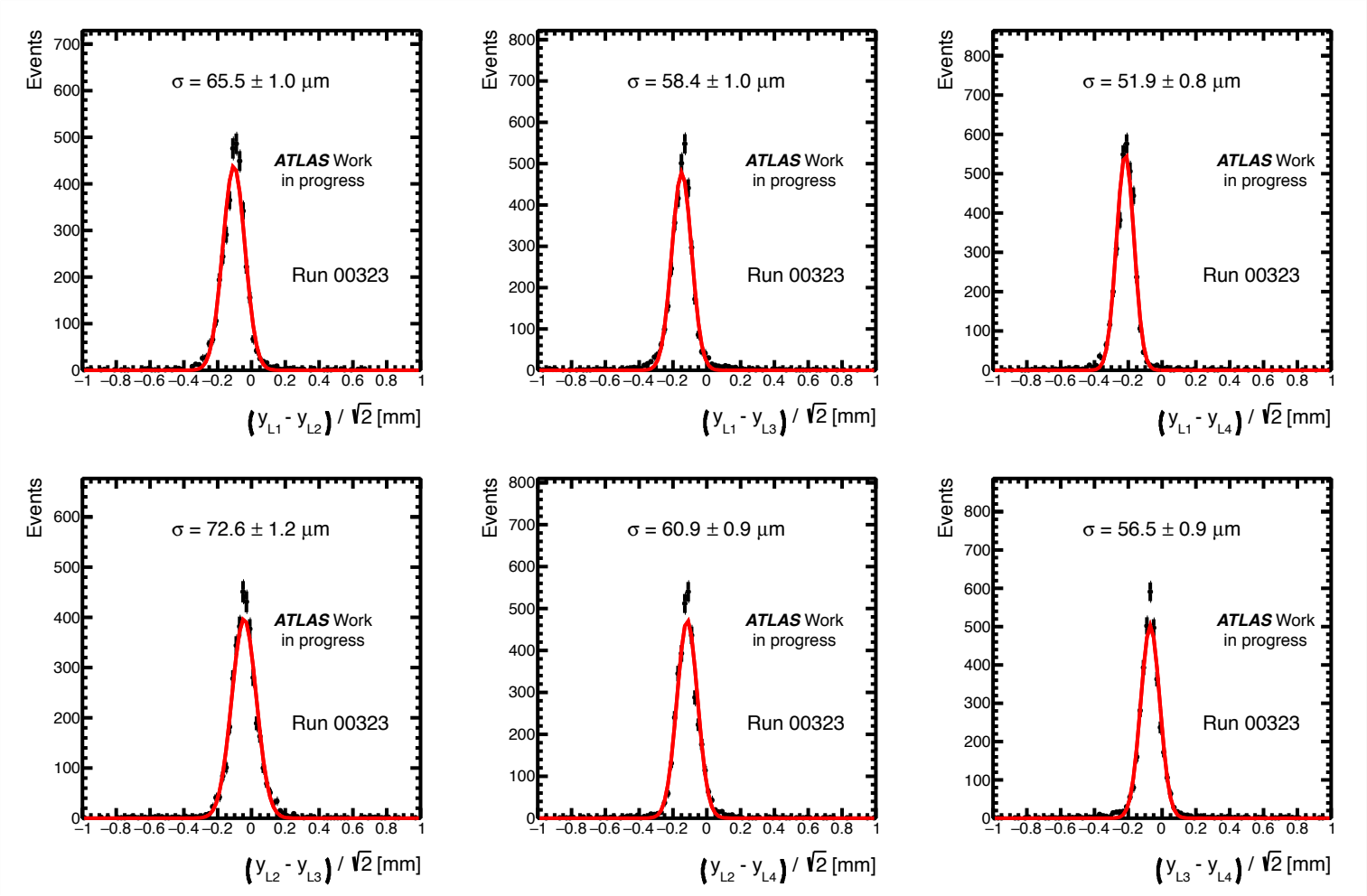
Run 323

- Layer 2 is being hit on support structure



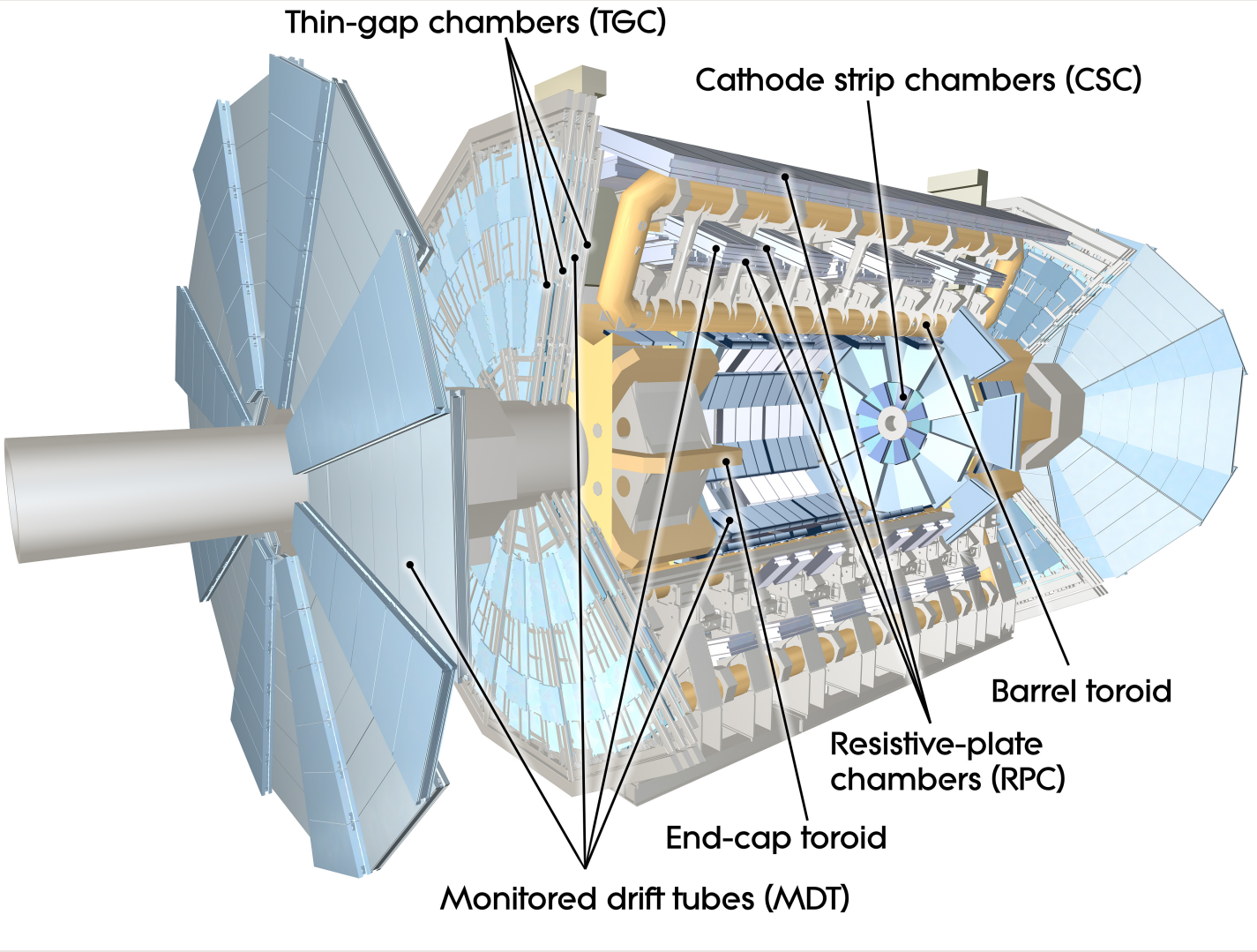
Run 323

- Residuals are systematically worse for pairing with layer 2.



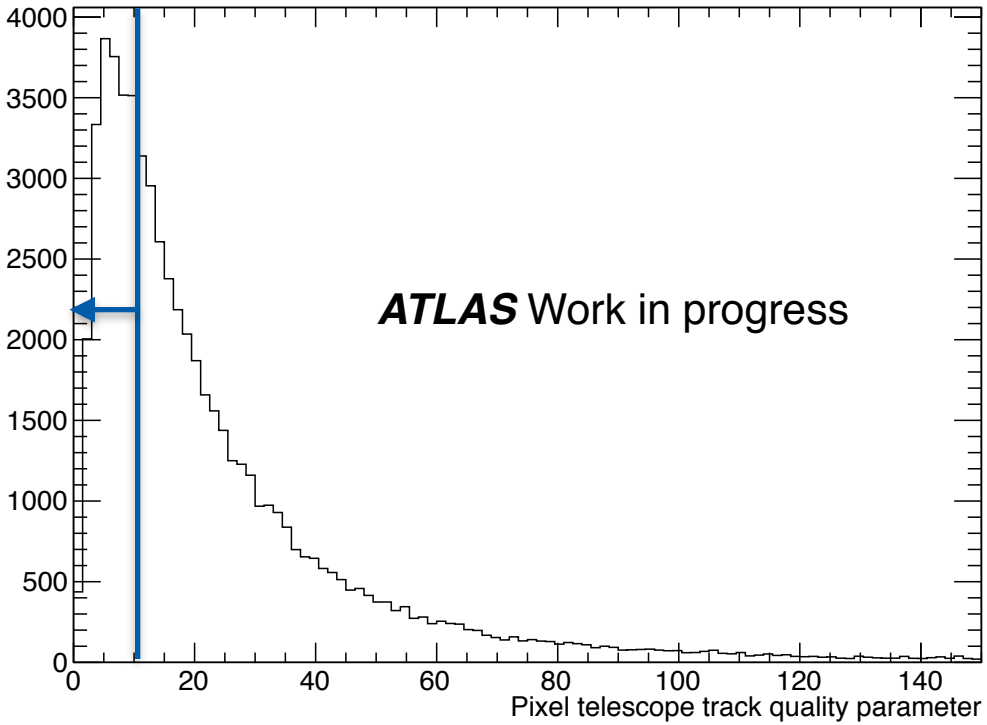
Fake Muons in ATLAS

- Fakes come mostly from activation in the end-cap toroid.



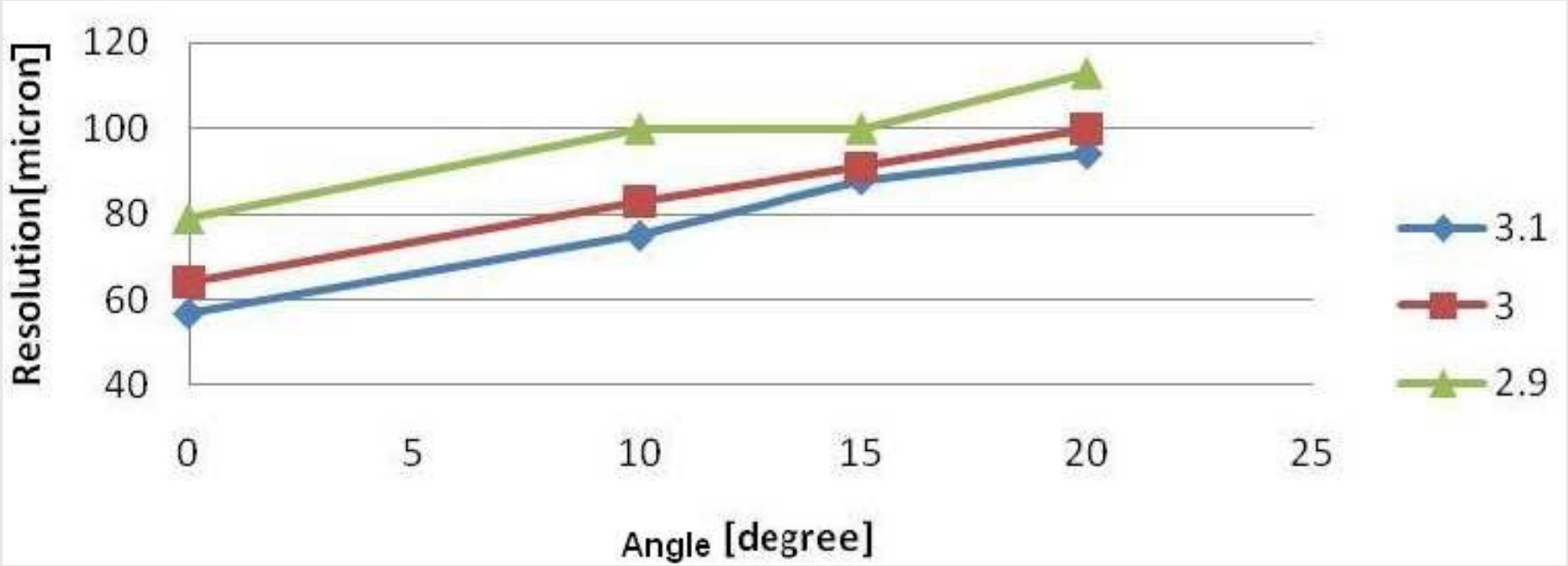
Pixel Tracks

- Require $\chi^2 < 10$
- Allows for very straight tracks
- Removes most multiple scattering events.



σ vs. Impact Angle

- From previous test beam efforts.
- For difference HV values.

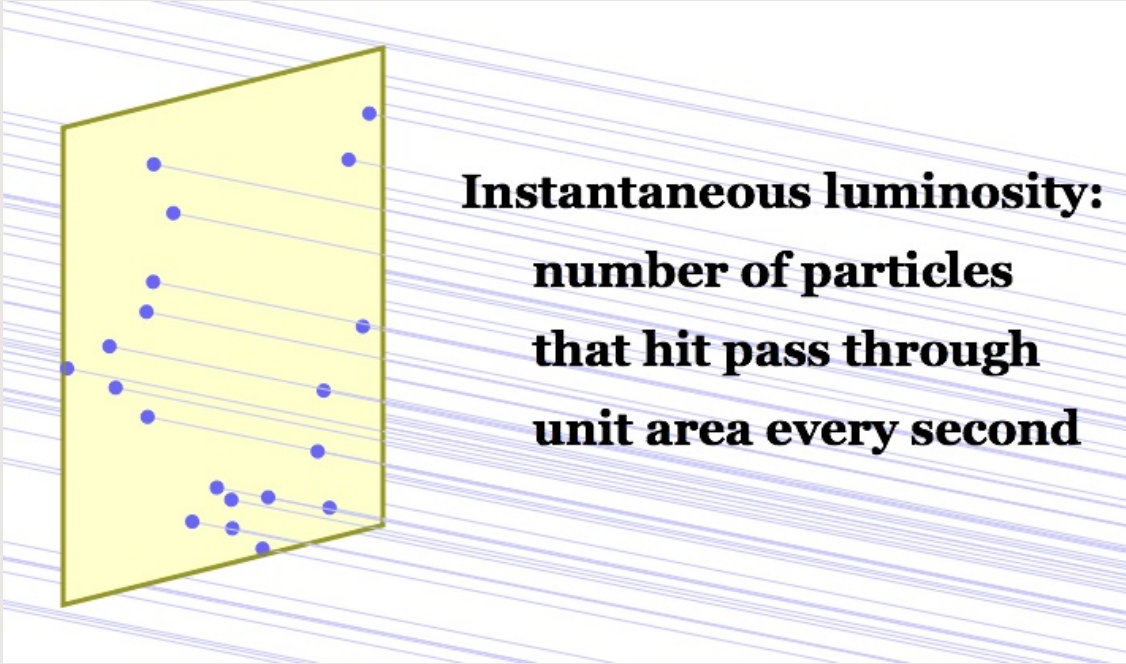


Event Selection

- Clustering
  - Only select cluster having 3, 4, or 5 hits
  - Require max bin of cluster not be next to zero bin
  - Require all bins close to max bin: $(bin - bin_{max}) < 2$
- Require all 4 layers be hit
- At most two 3-hit clusters in event
- TDO Cuts
- Corrections
  - “Per channel” pedestals applied, except for layer 1
  - -0.5 strip length offset for L2 and L4 by construction
  - $corr = -A*\sin(2\pi*yrel)$
  - *A* depends on size of cluster and layer of module -1
  - $yrel = mean_{cluster} - TMath::Nint(mean_{cluster})$

Instantaneous Luminosity

- The instantaneous luminosity is a measure of how many particles (blue) pass through a surface of unit area (yellow) in unit time (not shown.)

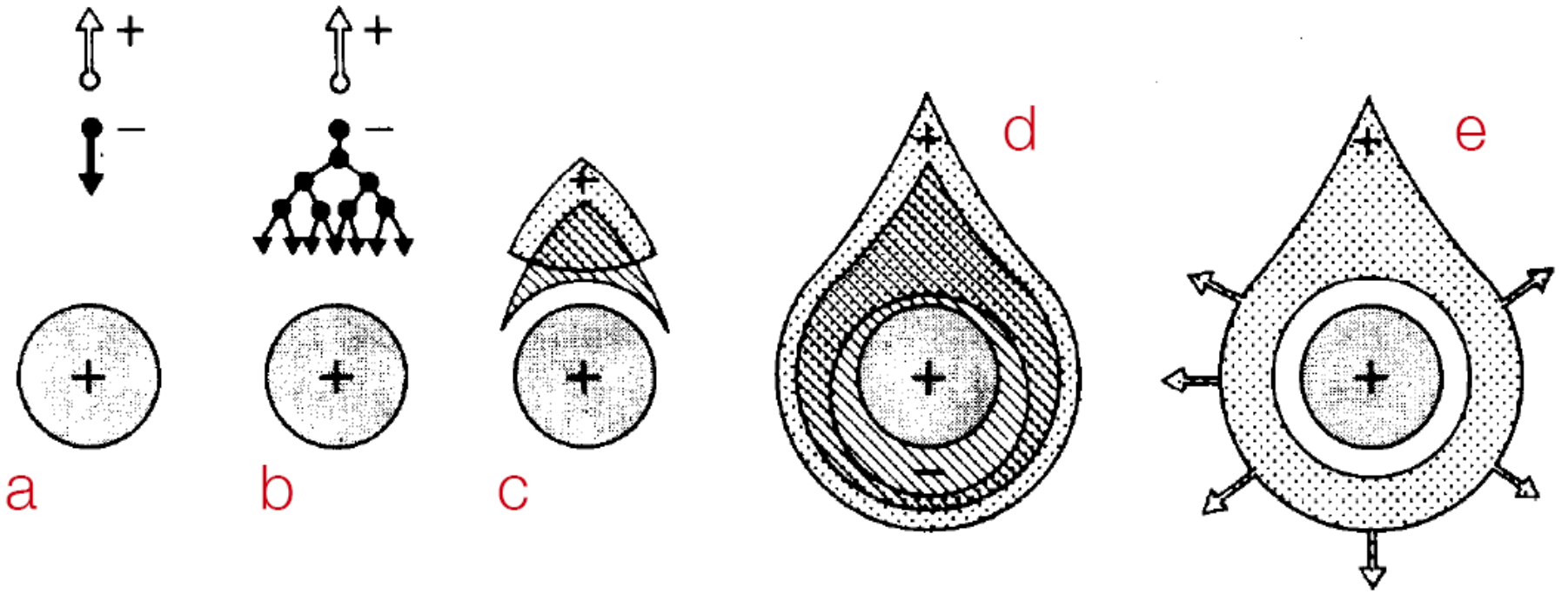


What is an inverse femtobarn?

- Measurement of particle-collision events per femtobarn; a measure of both the collision number and the amount of data collected.
- One inverse femtobarn corresponds to approximately 100 trillion (10^{12}) proton-proton collisions.
- Luminosity: ratio of the number of expected events detected per unit time to the interaction cross-section.

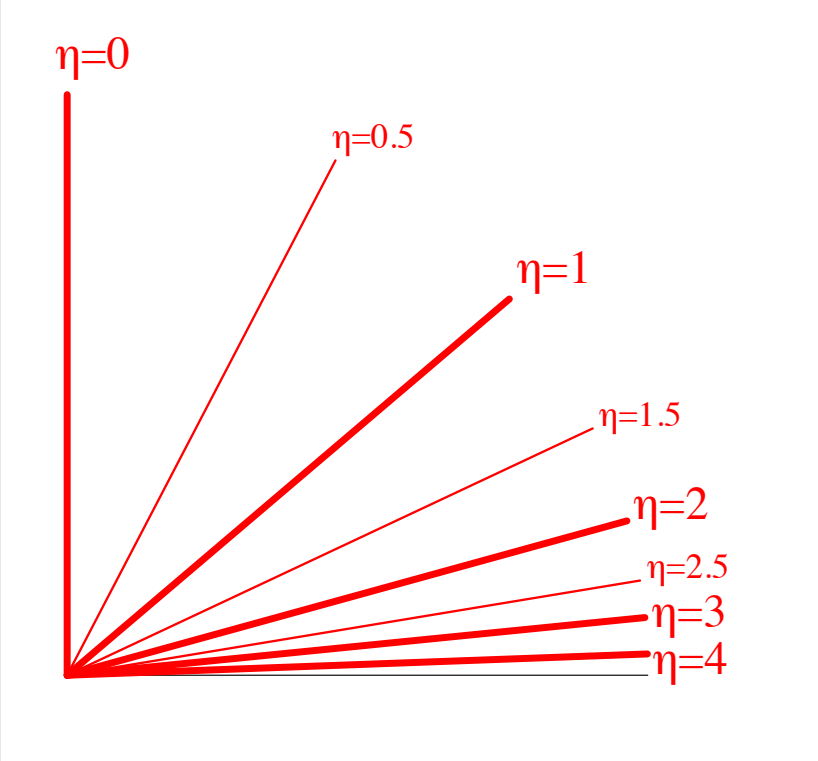
How Avalanches Form

a. Electron is attracted to anode.
b. Avalanche multiplication starts due to high E field.
c. Lateral diffusion; Coulomb repulsion between same-charge particles.
d. Drop-like avalanche is formed around the anode wire.
e. Electrons are collected rapidly (~1 ns) and ions drift towards cathode. This generates the signal at the electrodes.



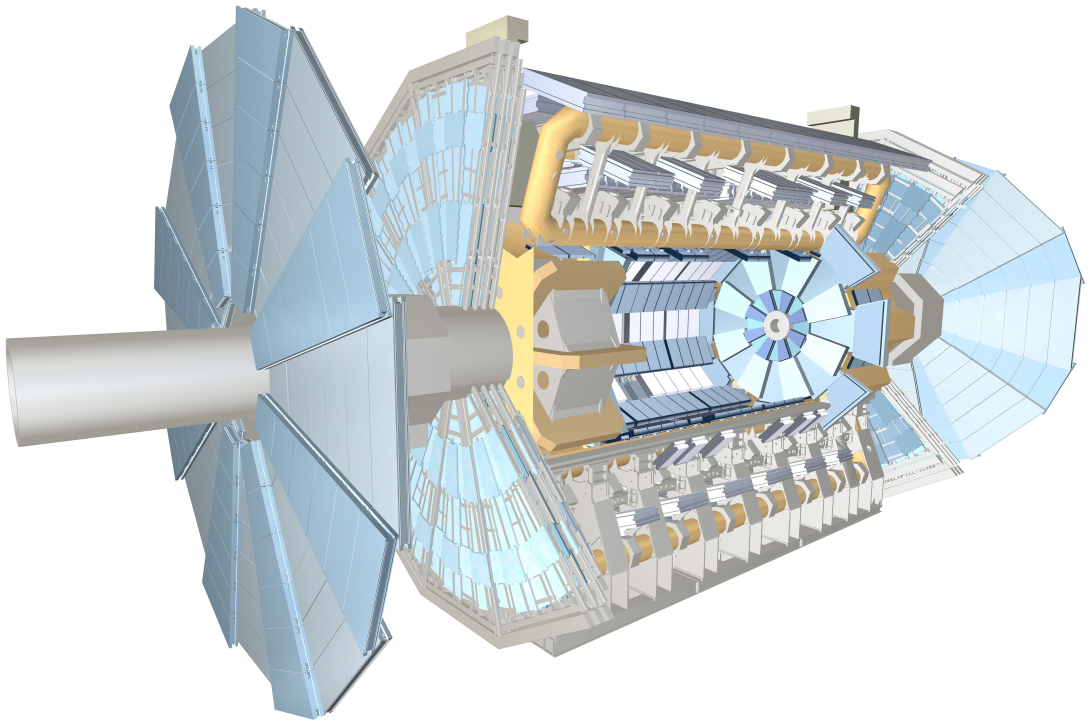
Pseudorapidity (η)

- $\eta = -\ln[\tan(\theta/2)]$
- NSW coverage is
  - $1.3 < \eta < 2.7$
  - $15 < \theta < 40$



The ATLAS Detector at the LHC

- ATLAS is a multipurpose particle detector



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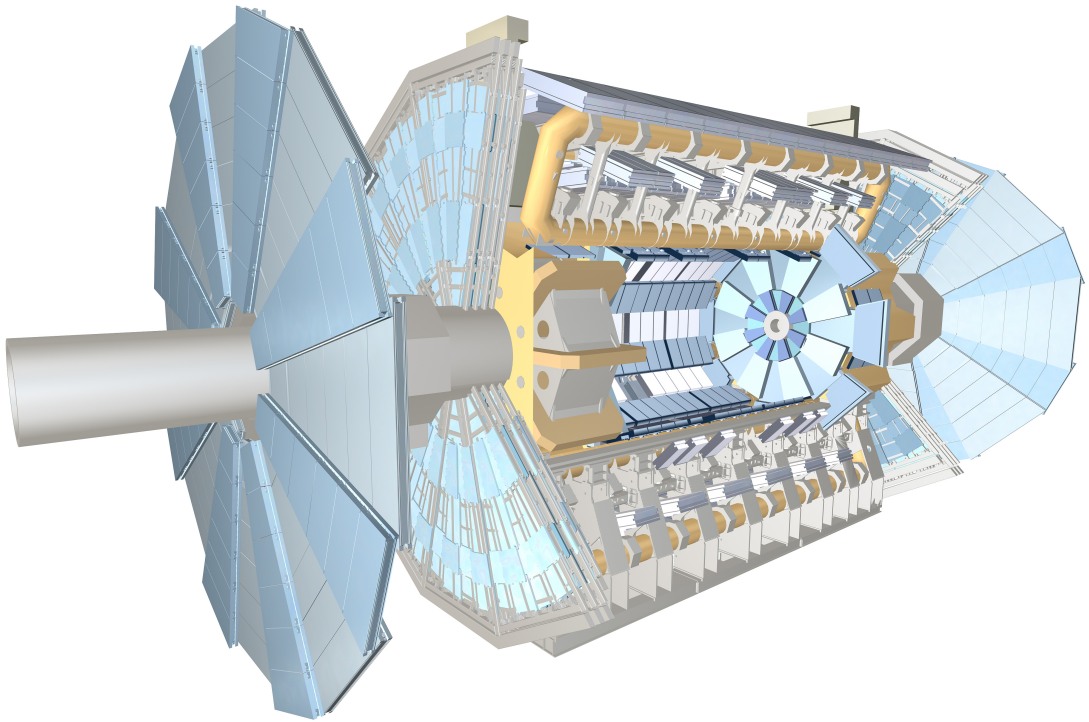
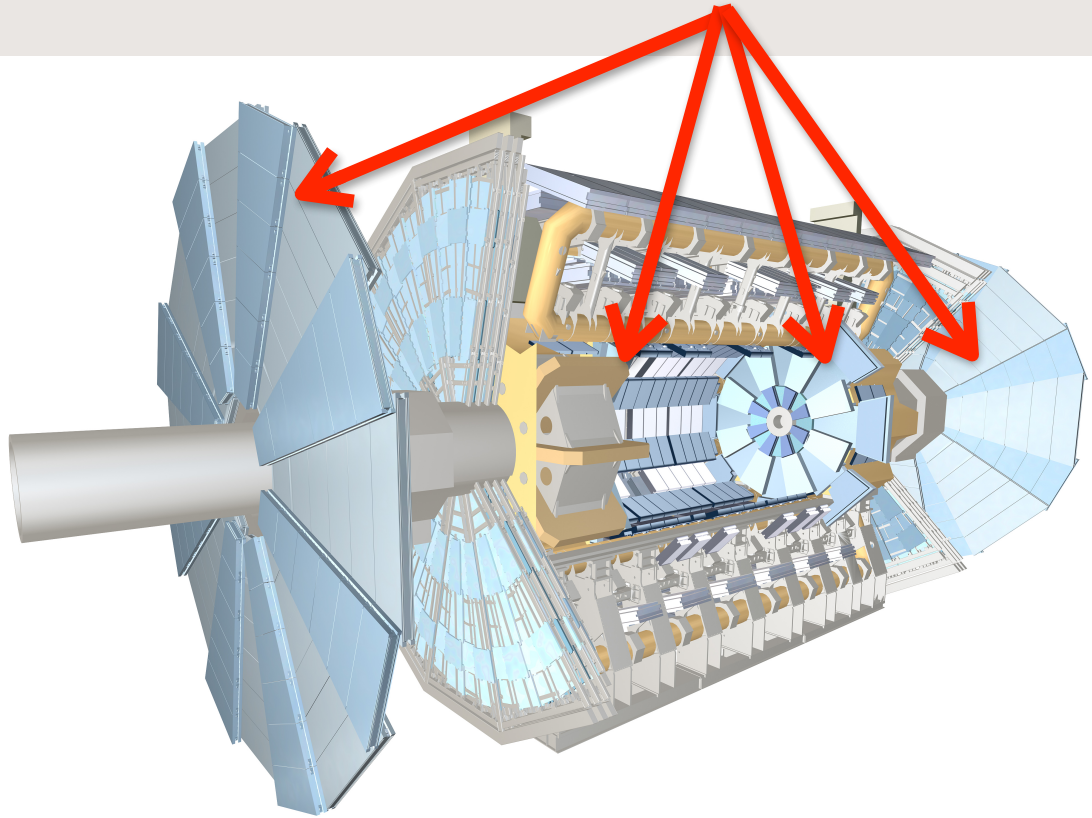


The ATLAS Detector at the LHC

- ATLAS is a multipurpose particle detector
- Endcap muon detectors



The ATLAS Detector at the LHC

- ATLAS is a multipurpose particle detector
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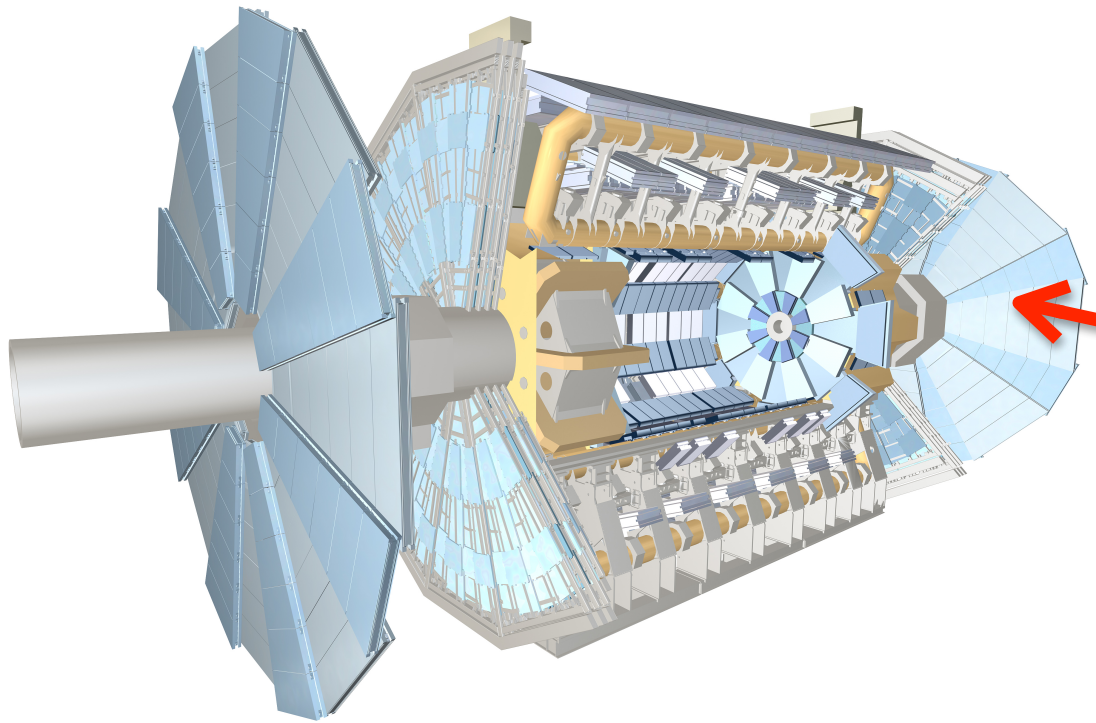
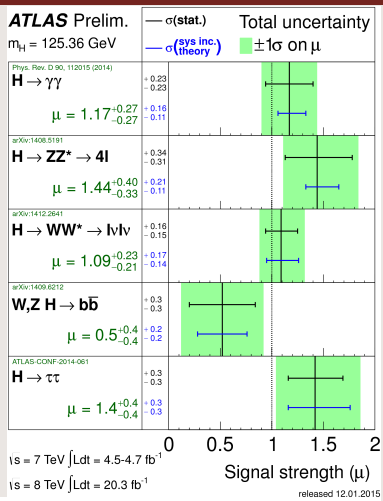


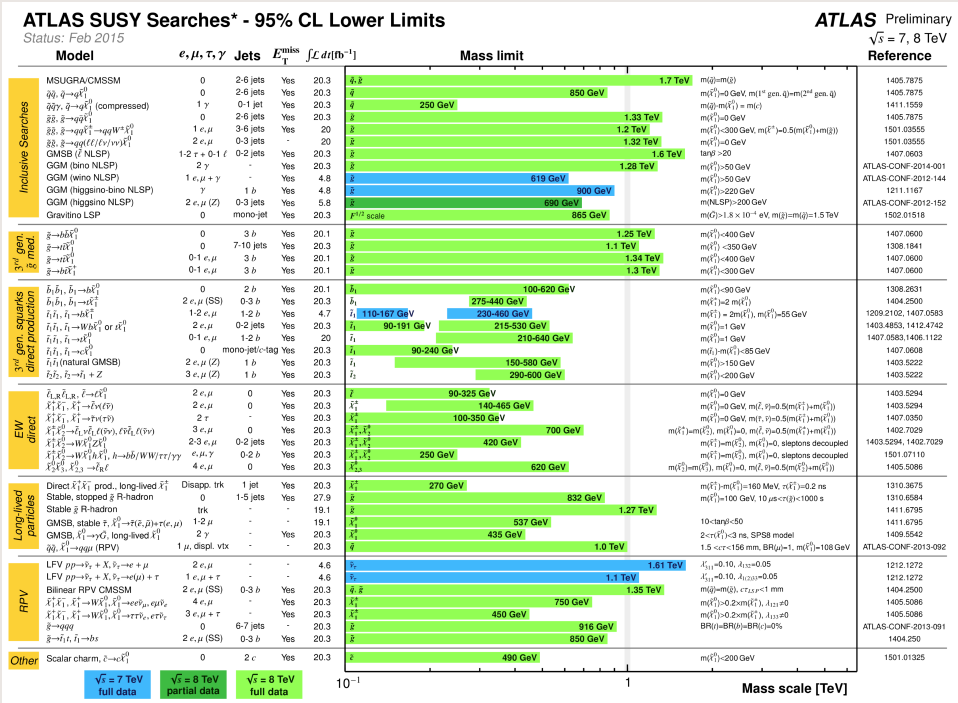
TRIUMF

UBC

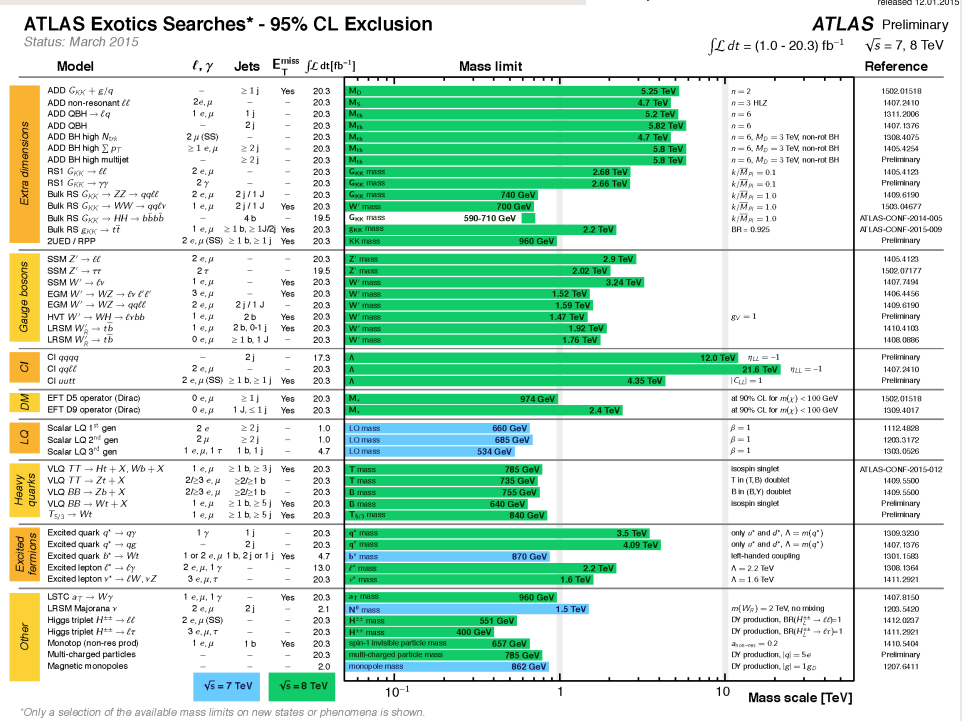
What Now?

- Higgs Precision Measurements
- Beyond the Standard Model Physics Searches
- SUSY, Extra dimensions, etc.
- All these searches need higher energy collisions, and more data





*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.



*Only a selection of the available mass limits on new states or phenomena is shown.

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