Systematic Studies of sTGC QC Measurements

BRANDON DEATH

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CARLETON UNIVERSITY

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Outline

- New Small Wheel (NSW)
- General Design of small-strip Thin Gap Chambers (sTGC)
- Significance of NSW
- sTGC Assembly Process @ Carleton University
- Analysis Motivation
- Implications for Detector
- Results
- Conclusion

New Small Wheel (NSW)

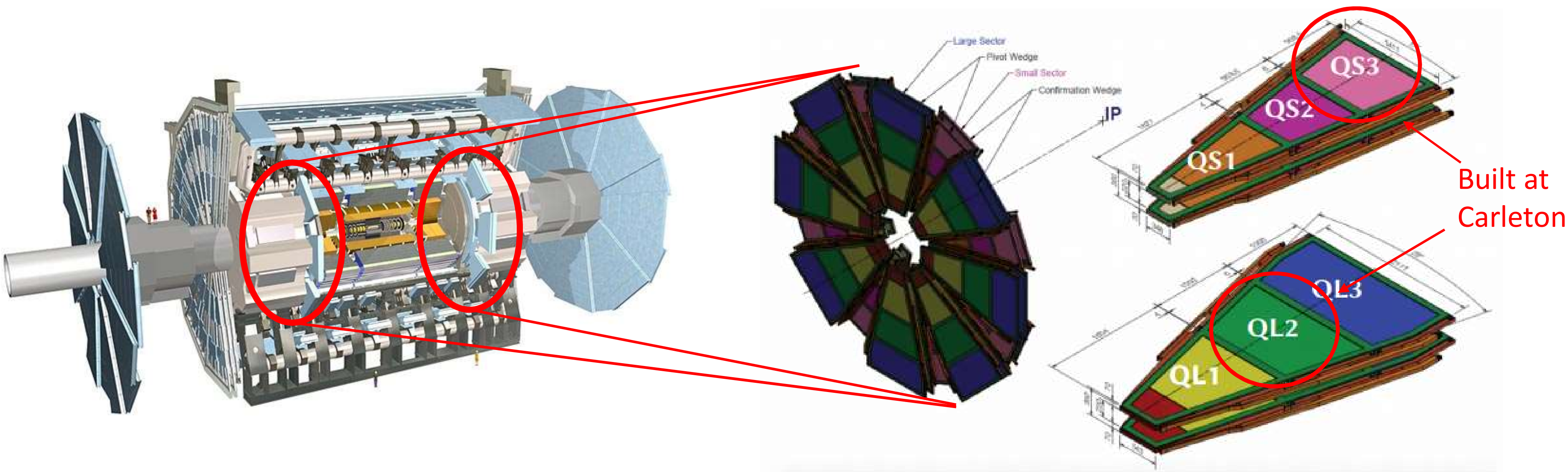


Figure 1: General Design of New Small Wheel within ATLAS [1][2]

sTGC General Design - Quadruplet

Not to scale

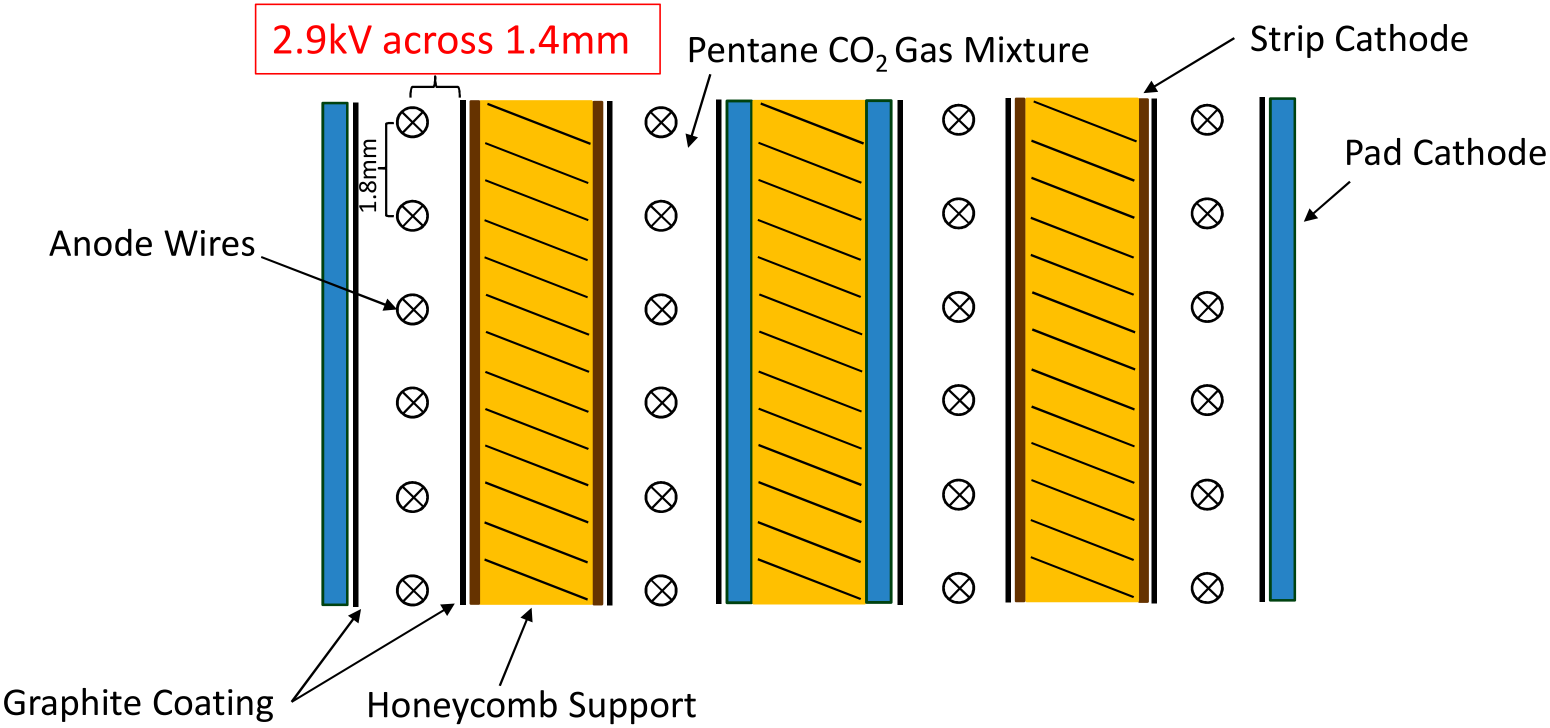
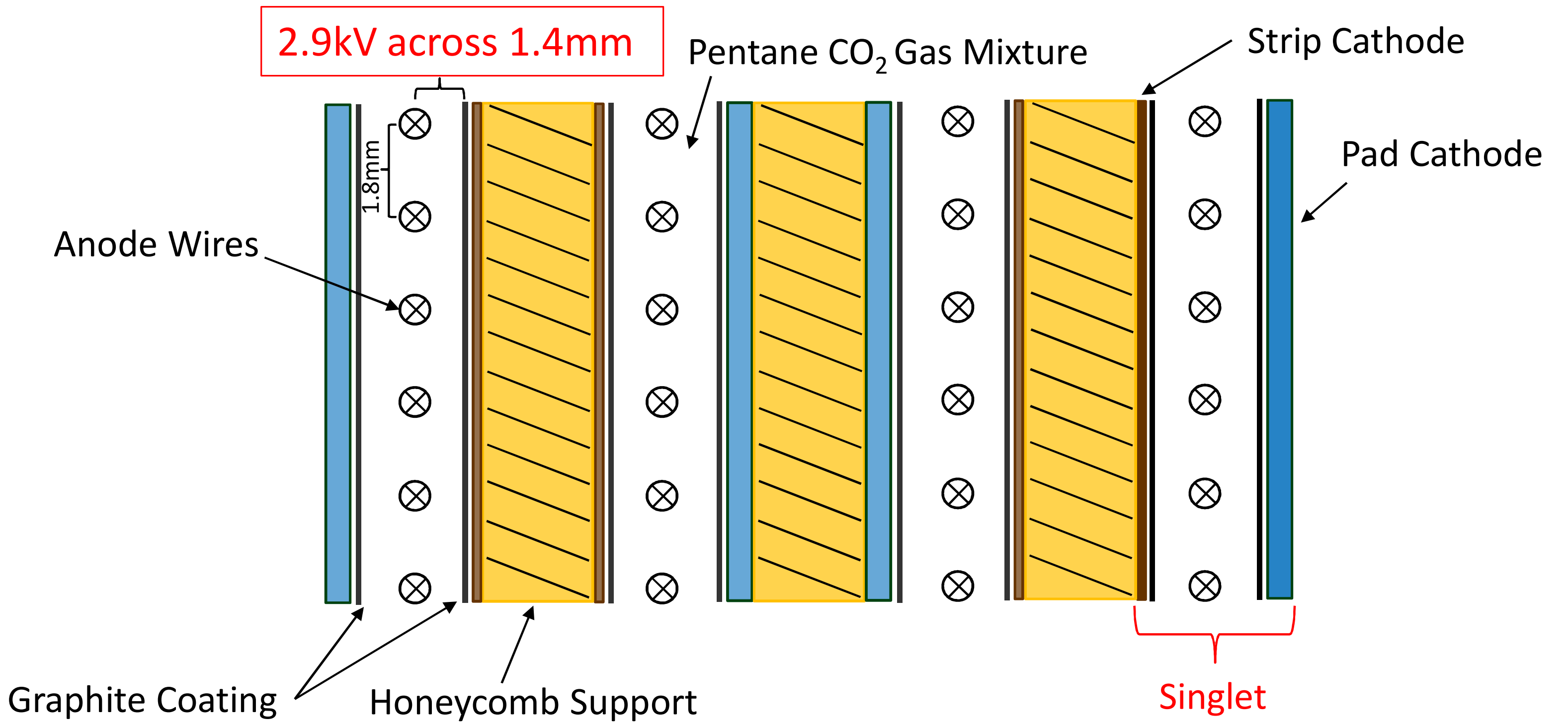


Figure 2: Basic diagram of Quadruplet design

Figure 3: Image of a Quadruplet during a Pulser Test

sTGC General Design - Quadruplet

Not to scale



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sTGC General Design - Quadruplet

Not to scale

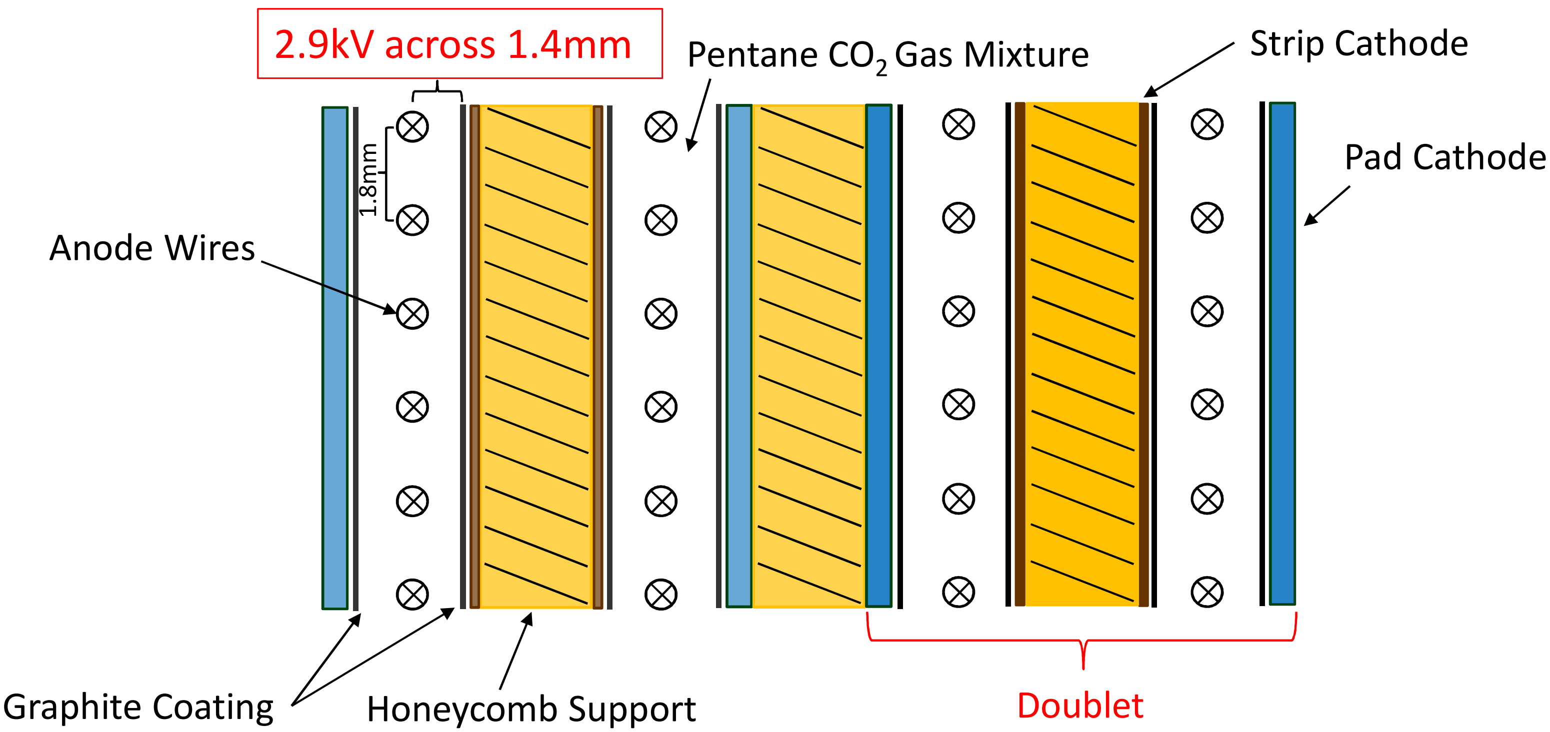


Figure 2: Basic diagram of Quadruplet design

Figure 3: Image of a Quadruplet during a Pulser Test

sTGC General Design - Quadruplet

Not to scale

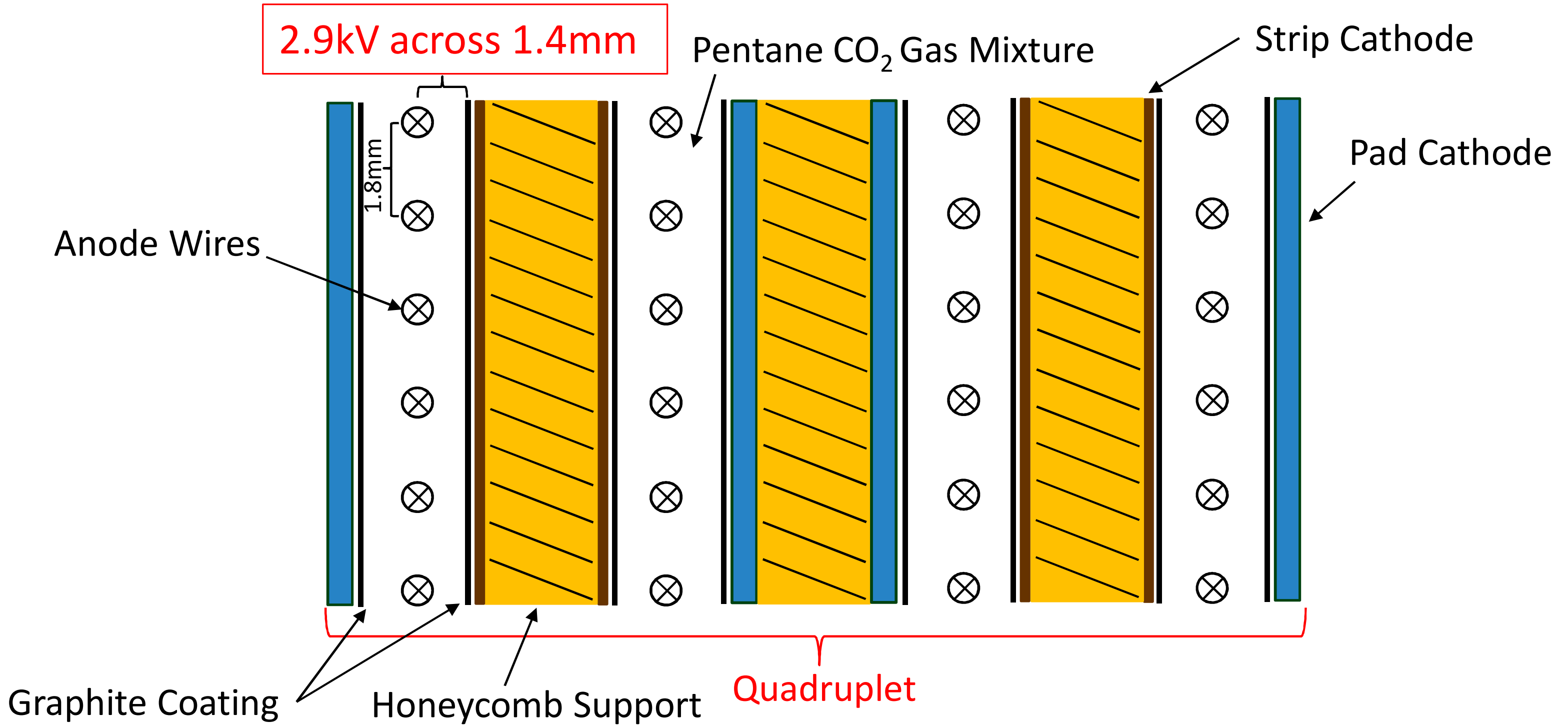


Figure 2: Basic diagram of Quadruplet design

Figure 3: Image of a Quadruplet during a Pulser Test

sTGC Detection Event

Not to scale

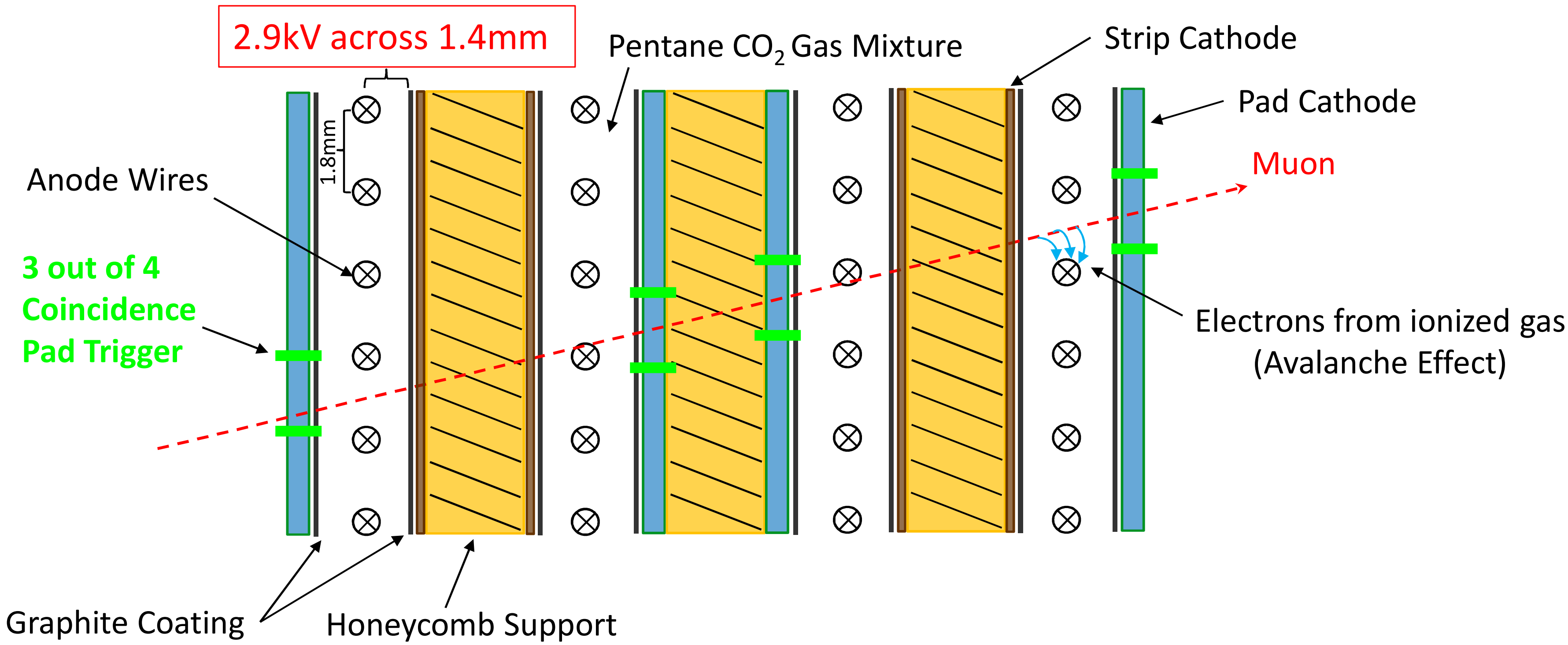


Figure 4: Quadruplet diagram showing muon event

sTGC Detection Event

Not to scale

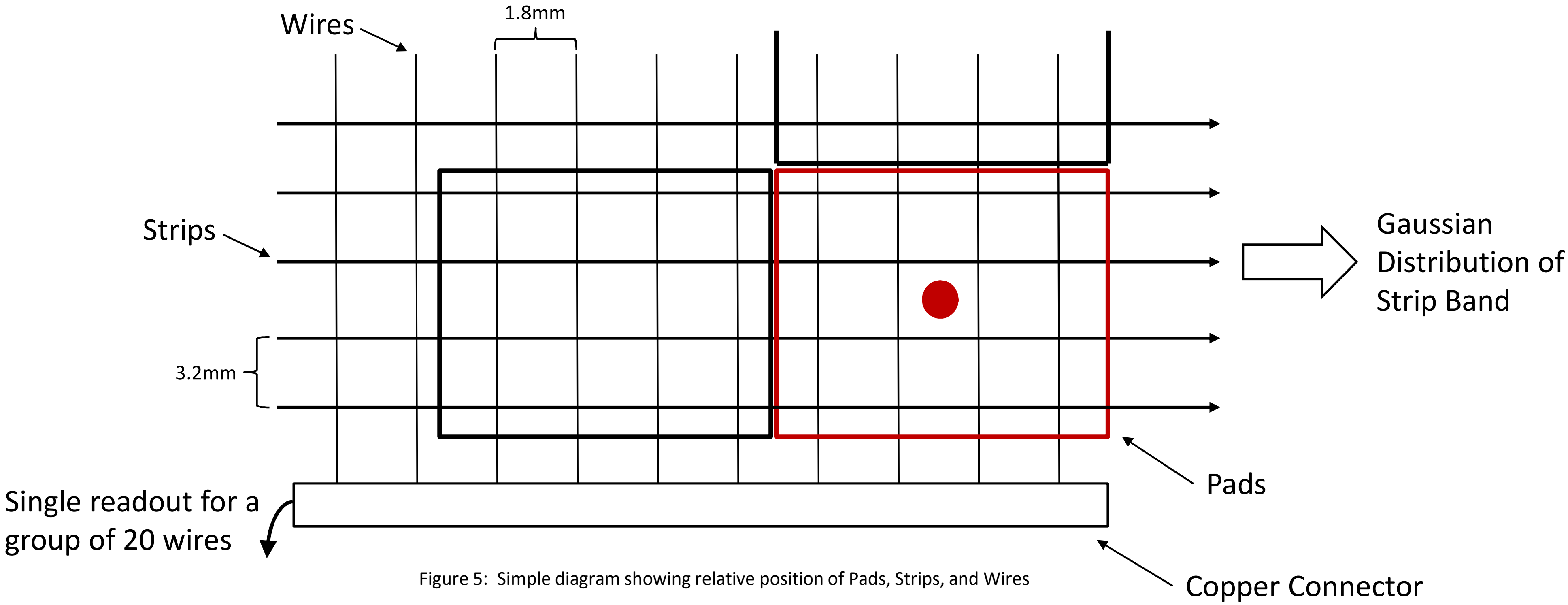


Figure 5: Simple diagram showing relative position of Pads, Strips, and Wires

Significance of NSW

- Currently 90% of Muon triggers are FALSE [3]
  - Will only get worse with increased luminosity
- sTGC provides additional trigger to reduce amount of false detections
- Quicker response time
  - Needed for High-Luminosity upgrade to LHC
- Improves precision tracking
  - Spatial resolution of ~150µm

	L1MU threshold (GeV)	Level-1 rate (kHz)
Currently	$p_T > 20$	60 ± 11
	$p_T > 40$	29 ± 5
	$p_T > 20$ barrel only	7 ± 1
Upgrade	$p_T > 20$ with NSW	22 ± 3
	$p_T > 20$ with NSW and EIL4	17 ± 2

Figure 6: Level-1 Single Muon Trigger Rates [3]

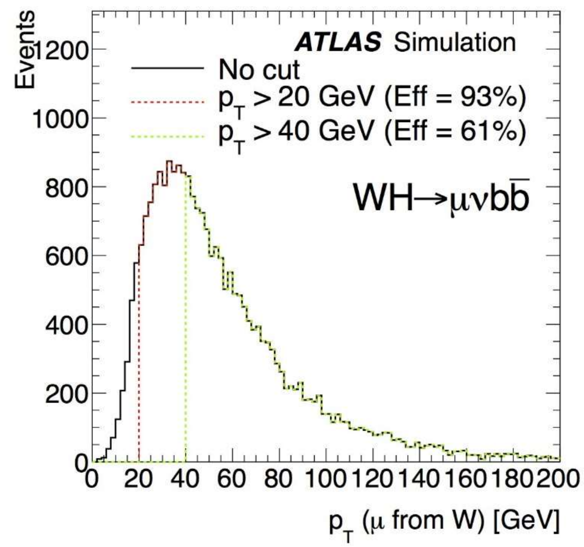


Figure 7: Simulated number of events showing various threshold cut-offs

sTGC Assembly @ Carleton University

- Receive Pad/Strip Boards from TRIUMF
- Wind Pad boards with 50 µm gold-plated tungsten wires using winding table (1.8mm pitch)
- Glue boards together into a Singlet (or "Gas Volume")
  - Measure 19-point thickness and 12x10 planarity
- Glue two Singlets into a Doublet (w/ Honeycomb)
  - Measure 19-point thickness and 12x10 planarity
- Glue two Doublets into a Quadruplet (w/ Honeycomb)
  - Measure 19-point thickness and 12x10 planarity
- Glue copper Protection Covers (PC) to either side of Quad
- Attach adapter boards and electronics
- Many QC tests are performed (Pulser, HV, X-Ray)

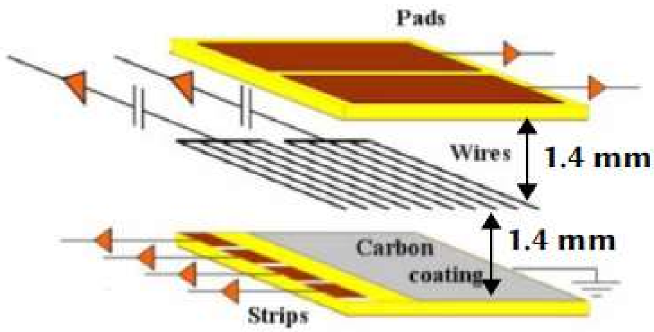


Figure 8: Assembly of Singlet (Gas Volume) [2]

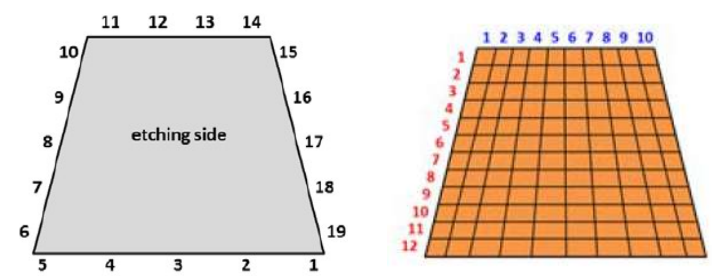


Figure 9: Thickness (Left) and Planarity (Right) Measurement Locations [4]

Motivation for Analysis

- Measurements are taken at each stage of Quad assembly
- Used to examine construction process
  - Ensure each part falls within allowed tolerances
  - Gives an overview of how well assembly process has gone so far
- Look for patterns across all Quads
  - Outliers (misentered data or otherwise)
  - Notable discrepancies in measurements
  - Systematic patterns in construction process
- Infer how construction variations will affect the physics involved
- Calibration of detector after installation

Implications for Detector

Thickness Measurements

- Key to the sTGC is tracking resolution (~150µm)
- Inaccurate thickness measurements lead to offset wire position, which affects the tracking of particles

Planarity Measurements

- LASER units are glued onto surface of NSW sTGC wedges
- Calibrate position of wedge with reference point to global coordinate system of ATLAS
- sTGC wedge surfaces must be very flat to give precise calibration

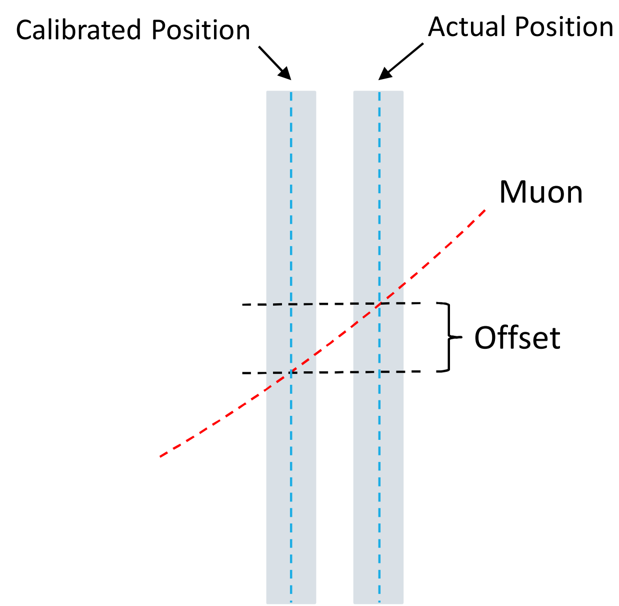


Figure 10: Depiction of offset position tracking with inaccurate calibration

Implications for Detector

X-Ray Test

- Excite gas at different regions and measure the detector's current response
- Very dense electric field lines (2.9kV across 1.4mm)
- *Small* changes in *thickness* produce a *large* change in *gain* (100µm ~ 30%)
- Inaccurate gain will cause incorrect Muon energy calibration

My Work

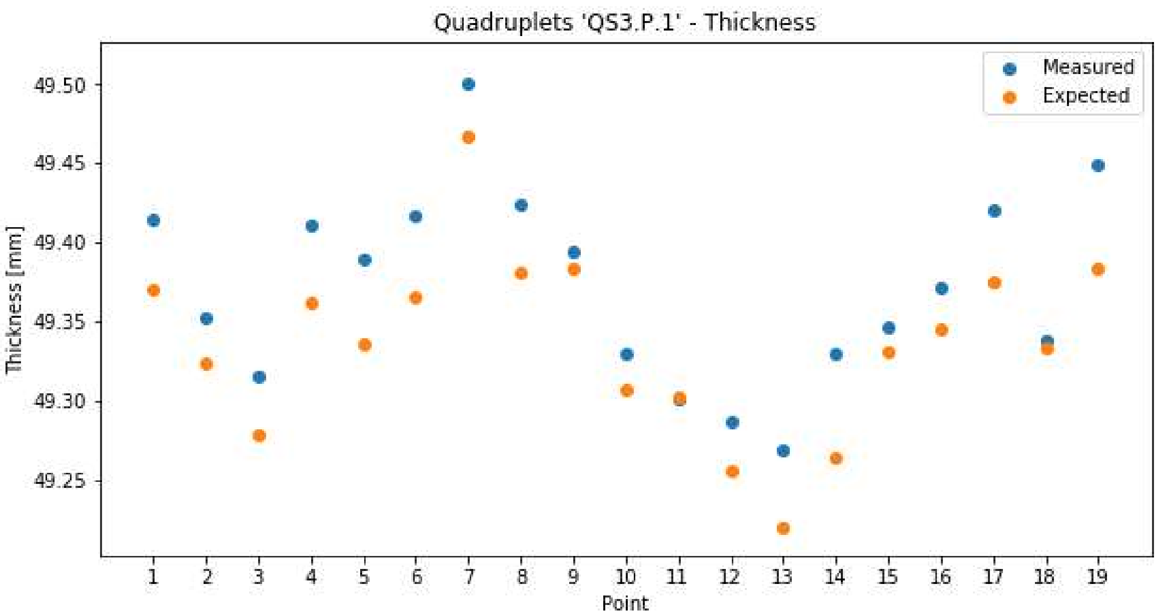
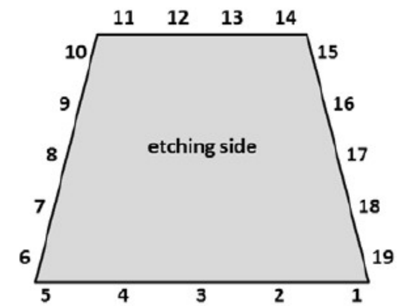
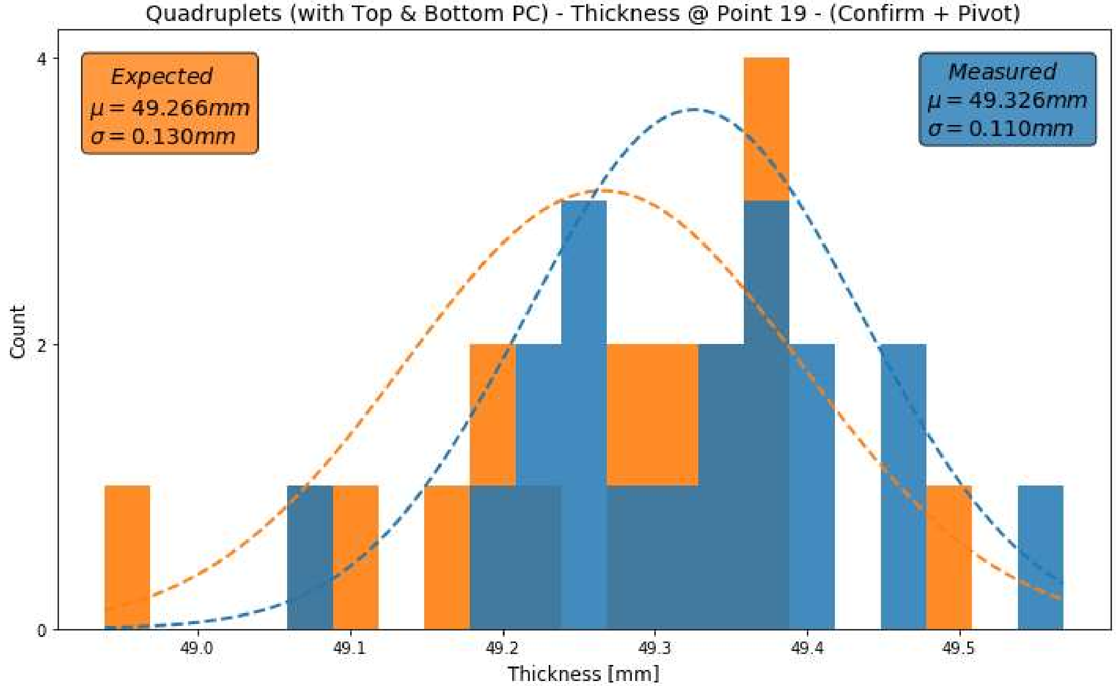


Figure 11: Raw Data of the thickness measured at 19 points around perimeter of Quadruplet QS3.P.1



19-Point Thickness Measurement around perimeter

19-Point Thickness Analysis – QS3



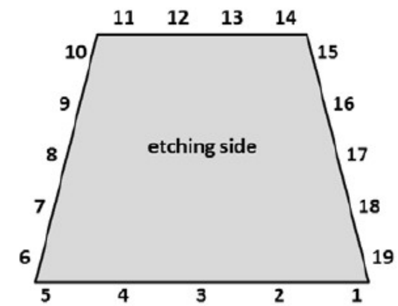


Figure 12: Histogram of the measured thickness at Point 19 across all Quadruplets with both Protection Covers

19-Point Thickness Analysis – QS3

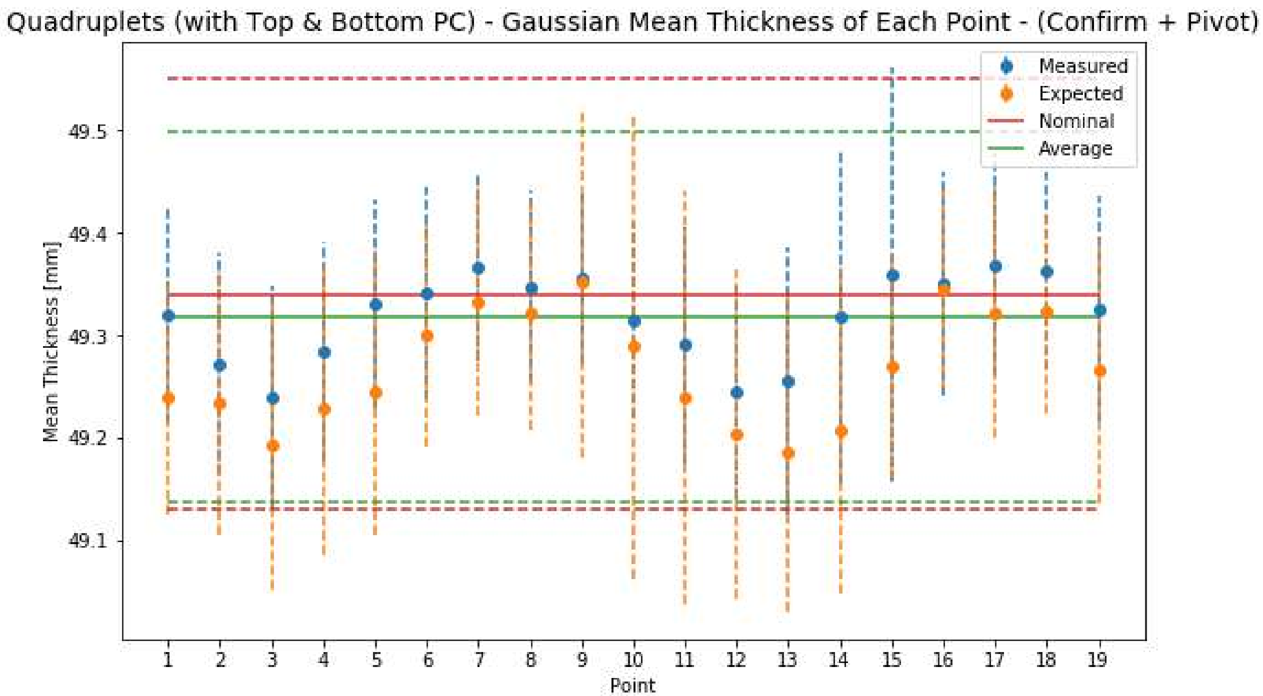
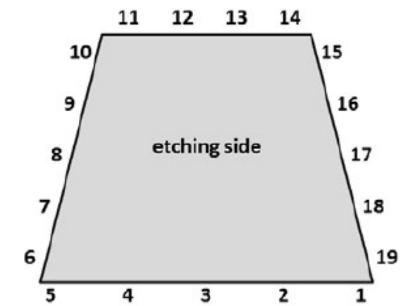


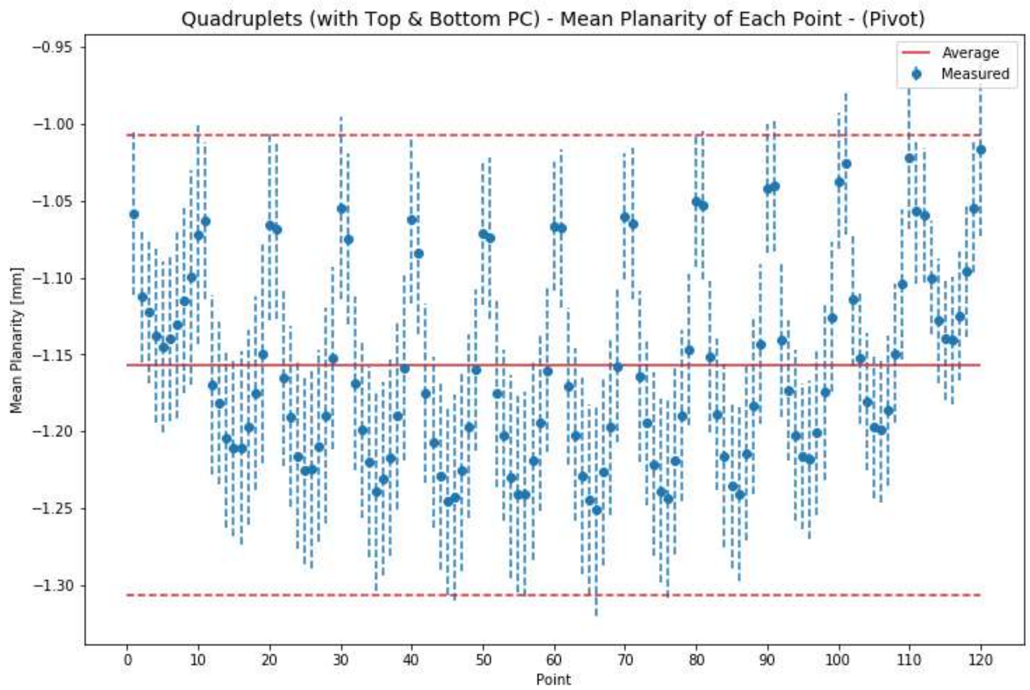
Figure 13: Mean thickness and uncertainty taken from Gaussian fits of histogram across all 19 measurement points

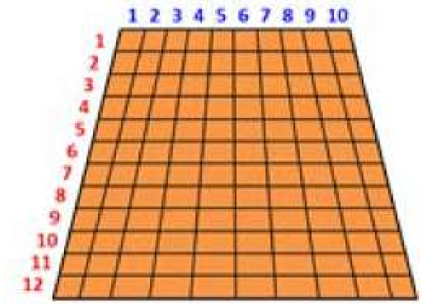


Mean thickness of each point falls within tolerances:

Nominal ± 210µm
Average ± 180µm

Planarity Analysis – QS3





12x10 = 120 Points

Mean planarity of each point falls within tolerance:

Average ± 150µm

Figure 14: Mean planarity and uncertainty taken from Gaussian fits of histograms across all 120 measurement points

Planarity Analysis – QS3

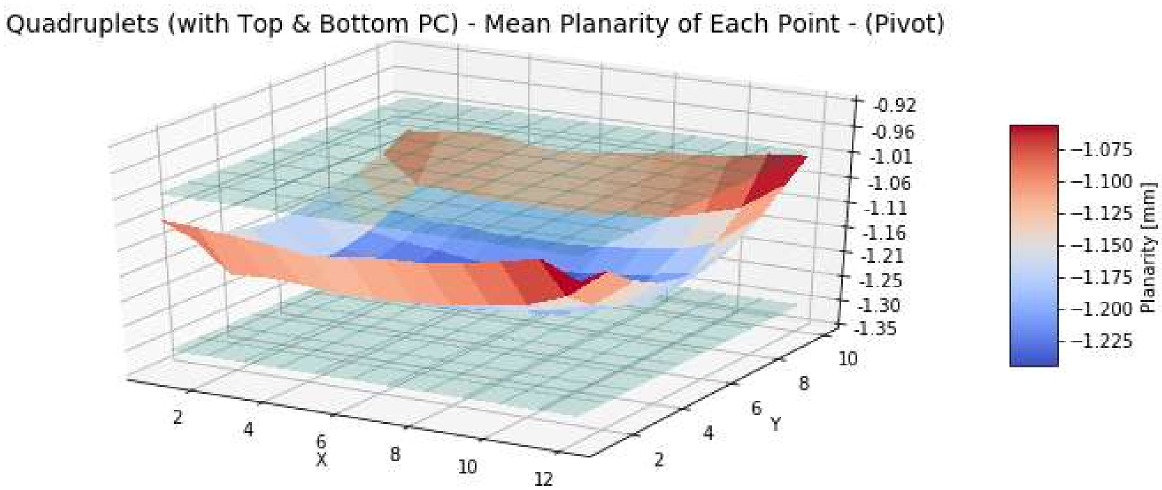
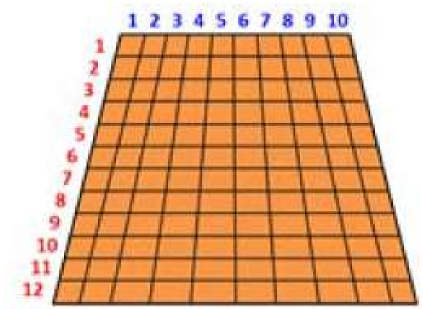


Figure 15: 3D Plot of mean planarity values shown in Figure 13.



12x10 = 120 Points

Mean planarity of each point falls within tolerance:

Average ± 150µm

Example X-Ray Test Analysis – QS3

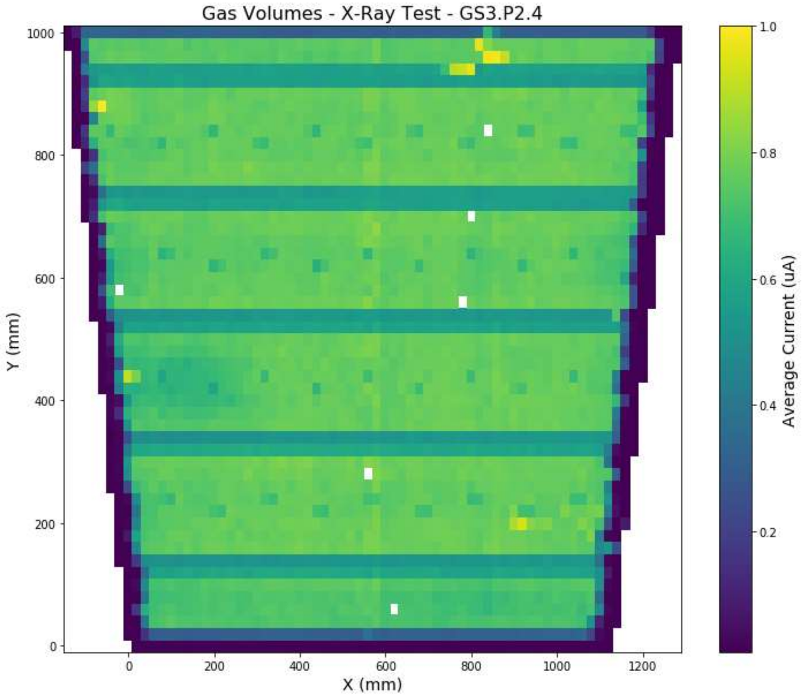


Figure 16: Heatmap of Current measured at each location during X-Ray Test

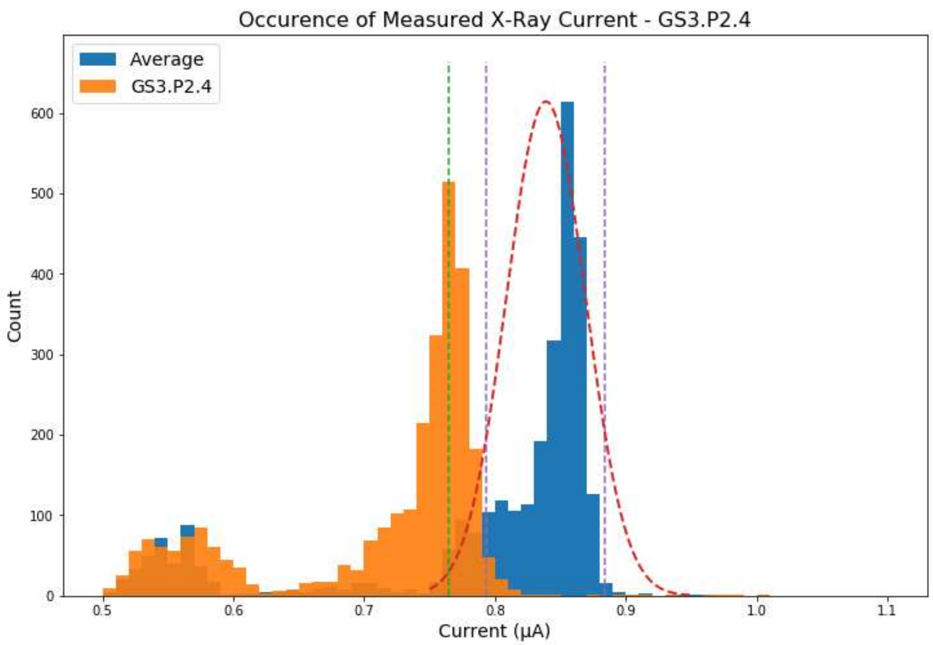


Figure 17: Histogram of heatmap bin Current compared with average Gap 2 Pivot Singlets

Conclusion

- I have developed a Python script to be used as an analysis tool during assembly of sTGC detectors as well as for calibration during & after installation
- It will be available for all international collaborators to use during their sTGC production as well

<u>Further Additions to Analysis Tool</u>

- X-Ray Test
  - Correlate to thickness/planarity measurements
  - Compare with cosmic ray test results
- High Voltage Tests
  - Checks for breakdown of gap (sparking, current leak, inconsistencies)
- Pulser Test
  - Tests connectivity of wires, strips and boards
  - Used to troubleshoot during assembly process
  - Records waveform shape and Vpp for each channel

Questions?

References

1) *Brookhaven and the Large Hadron Collider*, Brookhaven National Laboratory, Stony Brook University
[Accessed June 21, 2019]
https://www.bnl.gov/ATLAS/

2) Chav Chhiv Chau, *Upgrade of the ATLAS Muon Spectrometer Thin Gap Chambers and their electronics for the HL-LHC phase*, ATLAS Muon Collaboration, Carleton University, February 21,2019
http://cds.cern.ch/record/2666950/files/ATL-MUON-SLIDE-2019-076.pdf

3) *ATLAS New Small Wheel Technical Design Report*, ATLAS Collaboration, CERN-LHCC-2013-006, ATLAS-TDR-20-2013, p.173, July 2013

4) *sTGC Assembly Manual*, ATLAS Muon Collaboration, April 5,2018

Additional Slides

NSW Trigger

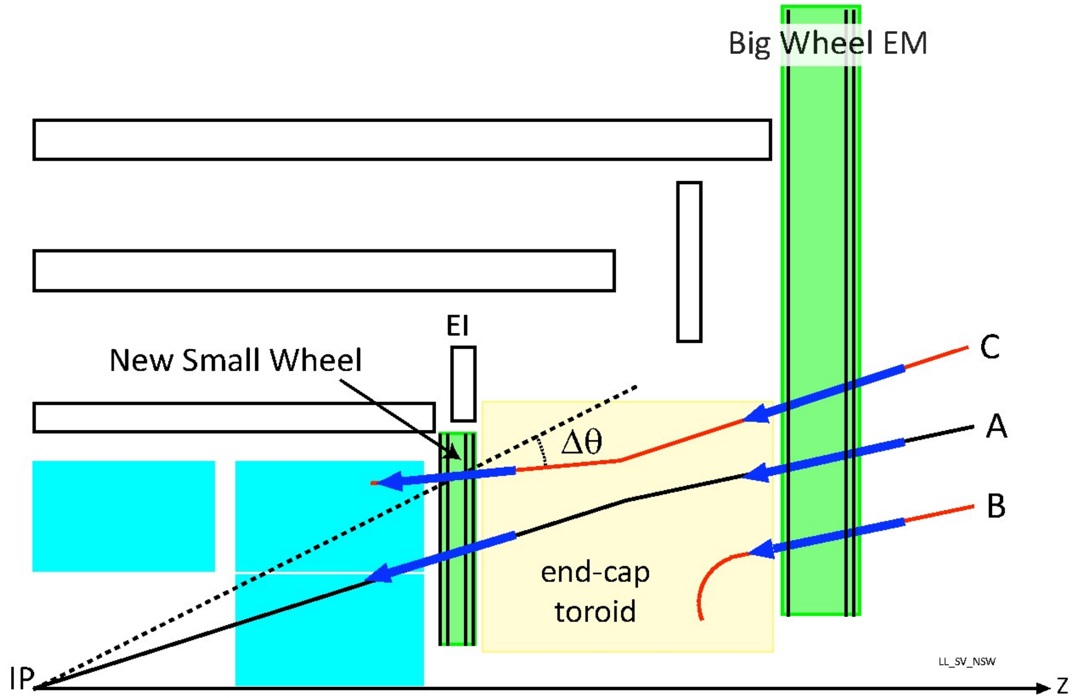


Figure 18: Diagram showing how the NSW can be an additional trigger to help reduce false detections

sTGC Assembly Stages

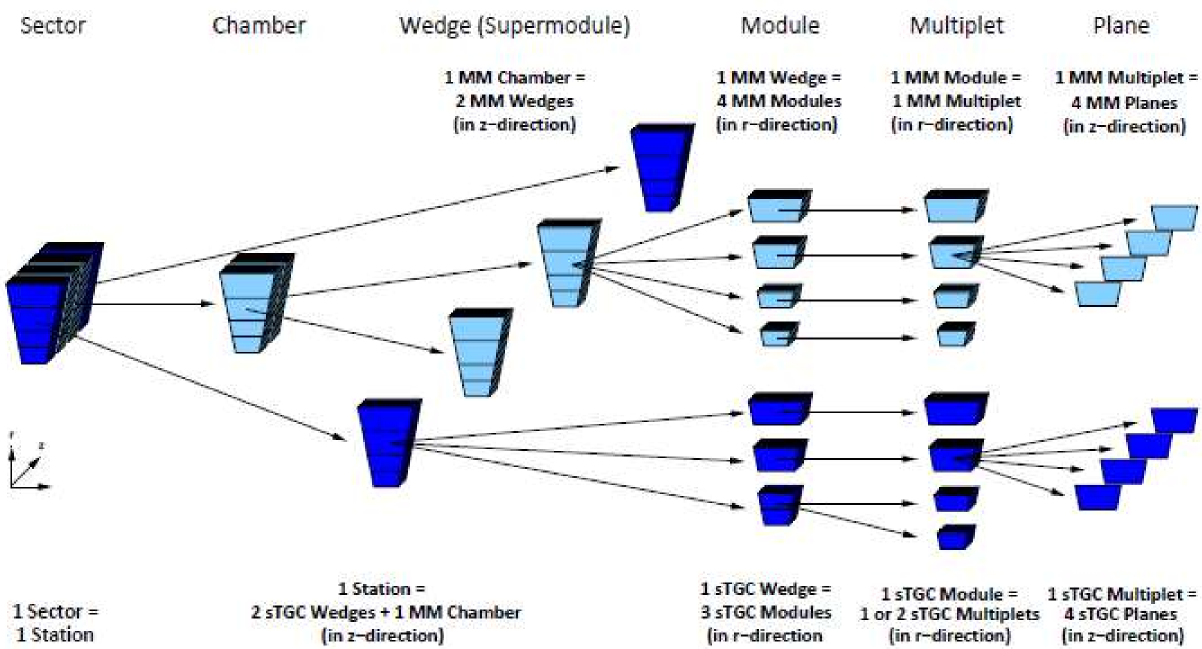


Figure 19: Assembly stages of a NSW wedge [4]

sTGC Assembly Parts

- Cover Wire Rules
- Doublets
- Gas Volumes
- Half-Pads
- Half-Strips
- Honeycomb Frames
- Pad Plates
- Protection Cover Plates
- Protection Covers
- Quadruplets
- Strip Plates
- Wire Rulers
- Wire Supports

			Active Area						Frames (peripheral) area						Total		
		Layer	Elem.	Material Code	Material Name	Scheme 0 PS200	Scheme 1 PS150	Scheme 2 P150S200	Elem.	Material Code	Material Name	Scheme 0 PS200	Scheme 1 PS150	Scheme 2 P150S200	Scheme 0 PS200		
	Honey + cover	Cover	8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018	0.20		
			7	2	FR4	0.183	0.183	0.183	7	2	FR4	0.183	0.183	0.183			
		Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
		Honeycomb	11	8	Epoxy	0.025	0.025	0.025								5.26	
			16	3	Paper	4.950	4.870	4.870	15	7	Fiber glass	5.000	4.920	4.920	5.00		
			11	8	Epoxy	0.025	0.025	0.025									
		Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
Doublet 2	Gas volume 4	Pad Board	8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
			3	2	FR4	0.200	0.150	0.150	3	2	FR4	0.200	0.150	0.150			
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018	1.50		
			2	2	FR4	1.065	1.165	1.165	2	2	FR4	1.065	1.165	1.165			
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
			4	2	FR4	0.183	0.183	0.183	4	2	FR4	0.183	0.183	0.183			
		Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
		Gas Volume	9	5	Graphite	0.010	0.010	0.010									
			13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400		5.91	
			14	6	Tungsten	0.050	0.050	0.050	12	8	Epoxy	0.050	0.050	0.050	2.85		
			13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400			
			9	5	Graphite	0.010	0.010	0.010									
		Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
		Strip Board	6	2	FR4	0.200	0.150	0.200	6	2	FR4	0.200	0.150	0.200			
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018	1.50		
			5	2	FR4	1.265	1.365	1.365	5	2	FR4	1.265	1.365	1.365			
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
	Honeycomb	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
		Honeycomb	11	8	Epoxy	0.025	0.025	0.025									
			16	3	Paper	4.950	4.870	4.870	15	7	Fiber glass	5.000	4.920	4.920	5.00	5.06	16.88
			11	8	Epoxy	0.025	0.025	0.025									
		Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
	Gas volume 3	Strip Board	8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
			5	2	FR4	1.265	1.365	1.365	5	2	FR4	1.265	1.365	1.365	1.50		
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
			6	2	FR4	0.200	0.150	0.200	6	2	FR4	0.200	0.150	0.200			
		Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
		Gas Volume	9	5	Graphite	0.010	0.010	0.010									
			13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400			
			14	6	Tungsten	0.050	0.050	0.050	12	8	Epoxy	0.050	0.050	0.050	2.85		
			13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400		5.91	
			9	5	Graphite	0.010	0.010	0.010									
		Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
		Pad Board	4	2	FR4	0.183	0.183	0.183	4	2	FR4	0.183	0.183	0.183			
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
			2	2	FR4	1.065	1.165	1.165	2	2	FR4	1.065	1.165	1.165	1.50		
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
			3	2	FR4	0.200	0.150	0.150	3	2	FR4	0.200	0.150	0.150			
			8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			

	Layer	Elem.	Material Code	Material Name	Scheme 0 PS200	Scheme 1 PS150	Scheme 2 P150S200	Elem.	Material Code	Material Name	Scheme 0 PS200	Scheme 1 PS150	Scheme 2 P150S200	Scheme 0 PS200		
Honeycomb	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
	Honeycomb	11	8	Epoxy	0.025	0.025	0.025									
		16	3	Paper	4.950	4.870	4.870	15	7	Fiber glass	5.000	4.920	4.920	5.00	5.06	
		11	8	Epoxy	0.025	0.025	0.025									
	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
Doublet 1 / Gas volume 2	Pad Board	8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
		3	2	FR4	0.200	0.150	0.150	3	2	FR4	0.200	0.150	0.150			
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018	1.50		
		2	2	FR4	1.065	1.165	1.165	2	2	FR4	1.065	1.165	1.165			
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
		4	2	FR4	0.183	0.183	0.183	4	2	FR4	0.183	0.183	0.183			
	Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
	Gas Volume	9	5	Graphite	0.010	0.010	0.010									
		13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400		5.91	
		14	6	Tungsten	0.050	0.050	0.050	12	8	Epoxy	0.050	0.050	0.050	2.85		
		13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400			
		9	5	Graphite	0.010	0.010	0.010									
	Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
	Strip Board	6	2	FR4	0.200	0.150	0.200	6	2	FR4	0.200	0.150	0.200			
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018	1.50		
		5	2	FR4	1.265	1.365	1.365	5	2	FR4	1.265	1.365	1.365			
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
Doublet 1 / Honeycomb	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
	Honeycomb	11	8	Epoxy	0.025	0.025	0.025									
		16	3	Paper	4.950	4.870	4.870	15	7	Fiber glass	5.000	4.920	4.920	5.00	5.06	16.88
		11	8	Epoxy	0.025	0.025	0.025									
	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
Doublet 1 / Gas volume 1	Strip Board	8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
		5	2	FR4	1.265	1.365	1.365	5	2	FR4	1.265	1.365	1.365	1.50		
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
		6	2	FR4	0.200	0.150	0.200	6	2	FR4	0.200	0.150	0.200			
	Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
	Gas Volume	9	5	Graphite	0.010	0.010	0.010									
		13	1	CO2-np	1.420	1.420	1.420	1	2	FR4	1.400	1.400	1.400			
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		9	5	Graphite	0.010	0.010	0.010									
	Glue							10	8	Epoxy	0.030	0.030	0.030	0.03		
	Pad Board	4	2	FR4	0.183	0.183	0.183	4	2	FR4	0.183	0.183	0.183			
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
		2	2	FR4	1.065	1.165	1.165	2	2	FR4	1.065	1.165	1.165	1.50		
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
		3	2	FR4	0.200	0.150	0.150	3	2	FR4	0.200	0.150	0.150			
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
Honey + cover	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
	Honeycomb	11	8	Epoxy	0.025	0.025	0.025									
		16	3	Paper	4.950	4.870	4.870	15	7	Fiber glass	5.000	4.920	4.920	5.00		
		11	8	Epoxy	0.025	0.025	0.025								5.26	
	Glue	10	8	Epoxy	0.030	0.030	0.030	10	8	Epoxy	0.030	0.030	0.030	0.03		
	Cover	7	2	FR4	0.183	0.183	0.183	7	2	FR4	0.183	0.183	0.183	0.20		
		8	4	Copper	0.018	0.018	0.018	8	4	Copper	0.018	0.018	0.018			
Total					49.34	49.34	49.54				49.34	49.34	49.54	49.34	49.34	49.34