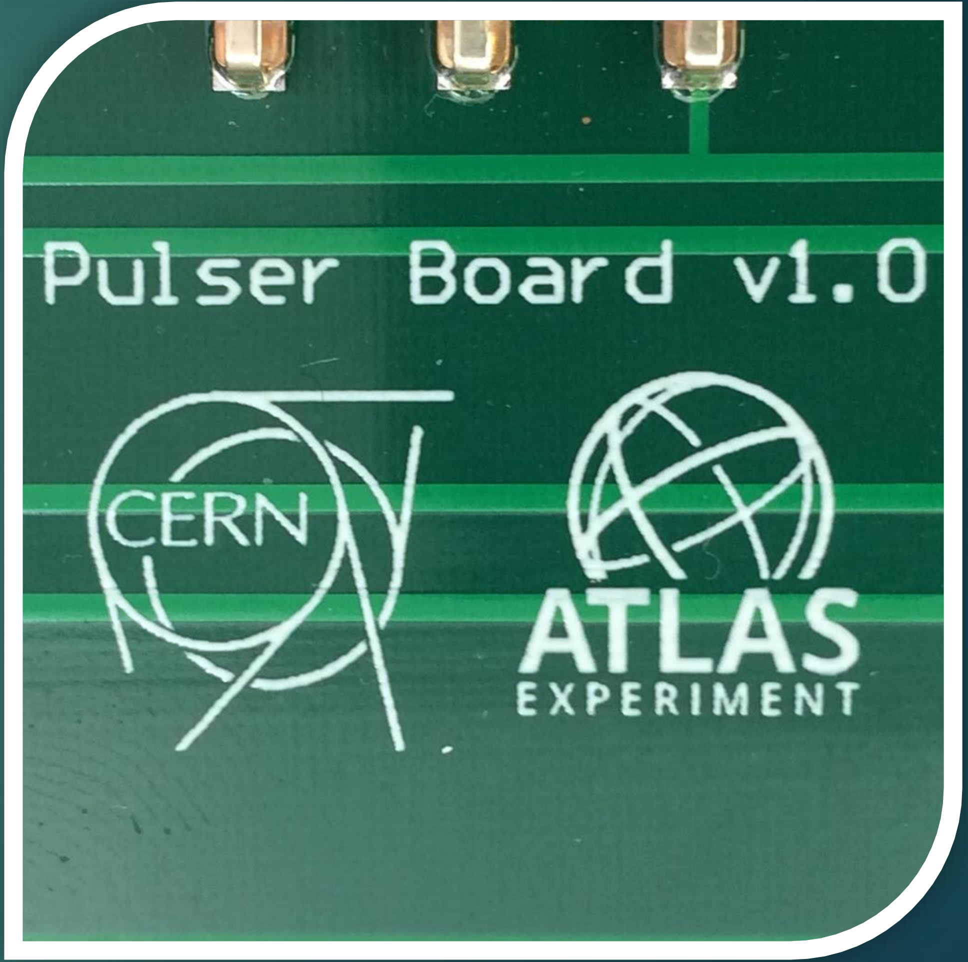
Characterization of the sTGC Detector Using the Pulser System

FOR THE ATLAS NEW SMALL WHEEL

BY: IAN RAMIREZ-BEREND

Talk Outline

- Background and Motivations
    - ATLAS and the New Small Wheel
- Small-Strip Thin Gap Chambers
    - Layout and Design
- Pulser System Overview
    - System Requirements
    - Implementation
- Results
- Experimental Learning

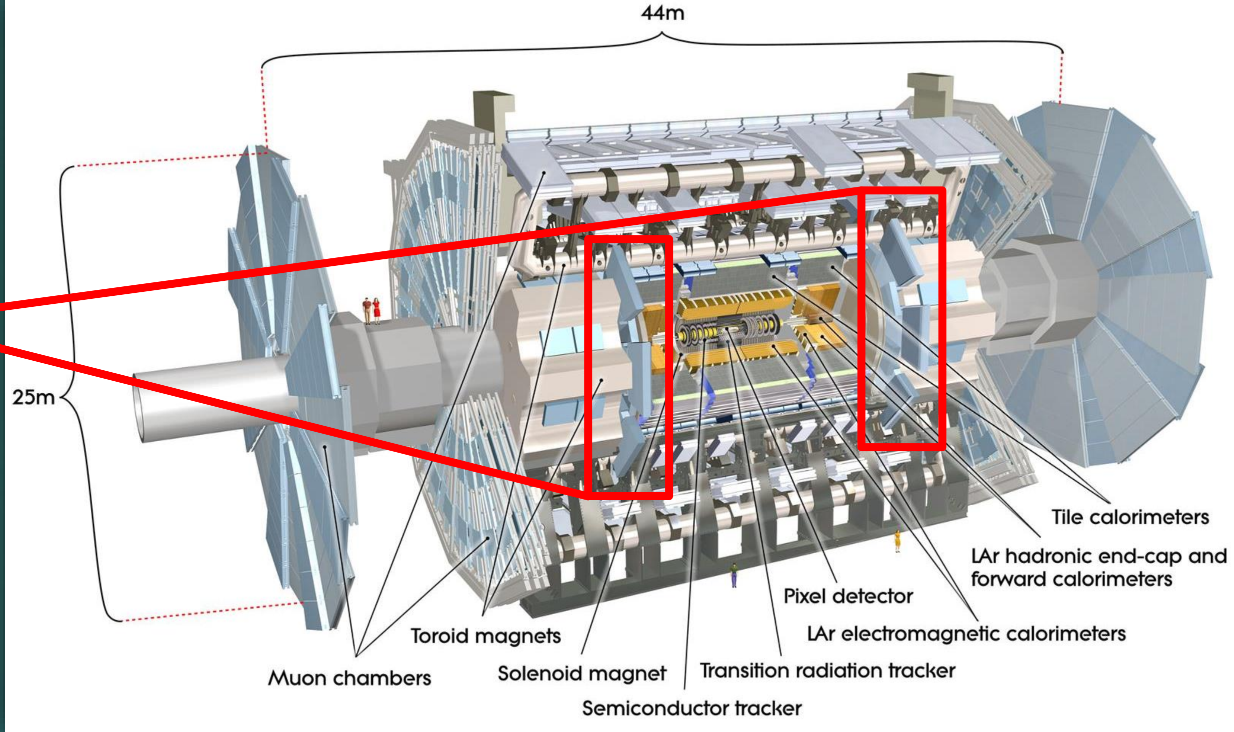


ATLAS and the NSW Update

BACKGROUND AND MOTIVATIONS

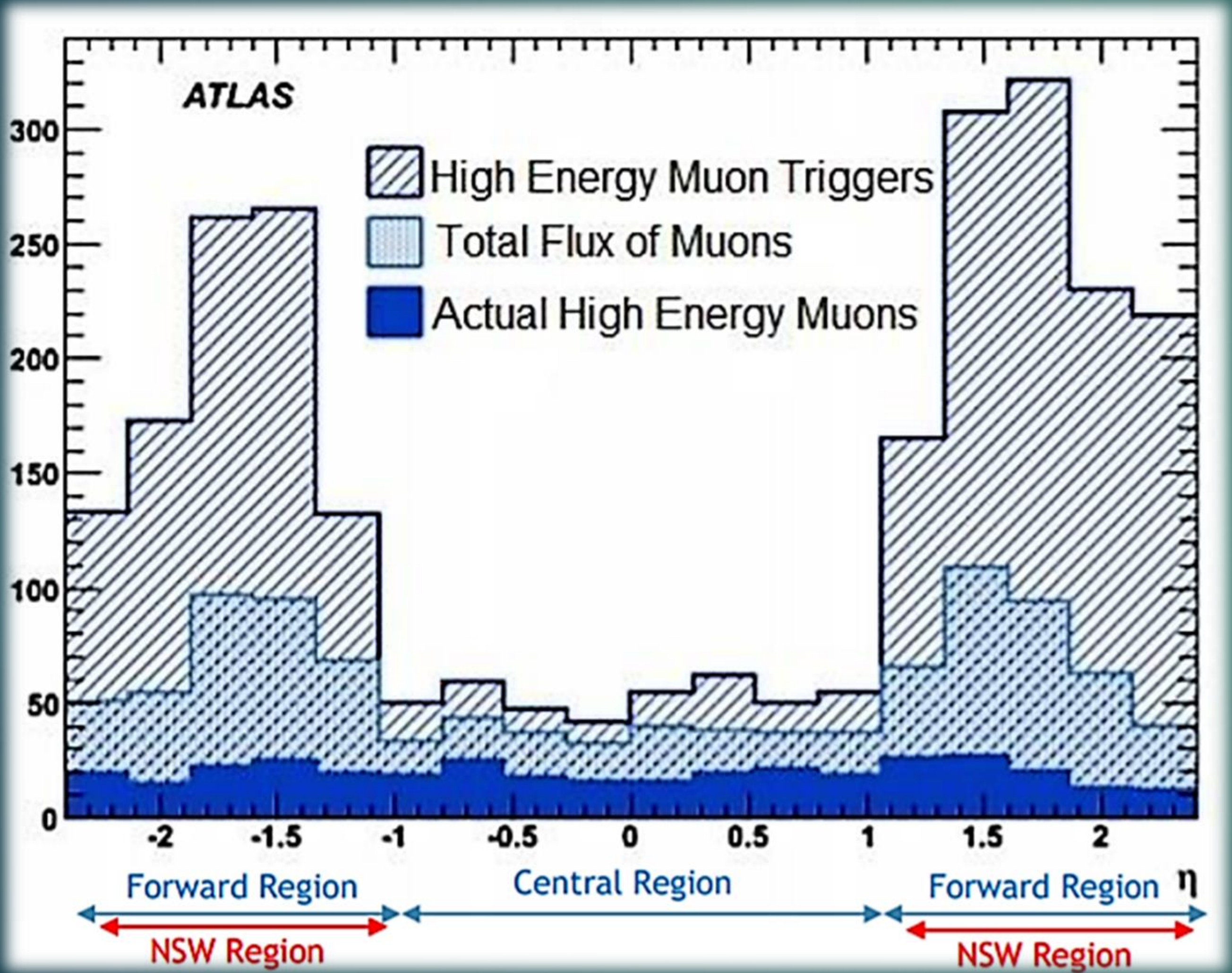
The ATLAS Experiment

- Largest of the four major experiments at the Large Hadron Collider (LHC) at CERN
- General purpose detector, involved in the discovery of the Higgs Boson



- **Small Wheel**
- Made up of four independent systems: Inner Tracker, Magnet System, Hadronic Calorimeter, and Muon Spectrometer
- Small Wheel represents inner-most component of the Muon Spectrometer

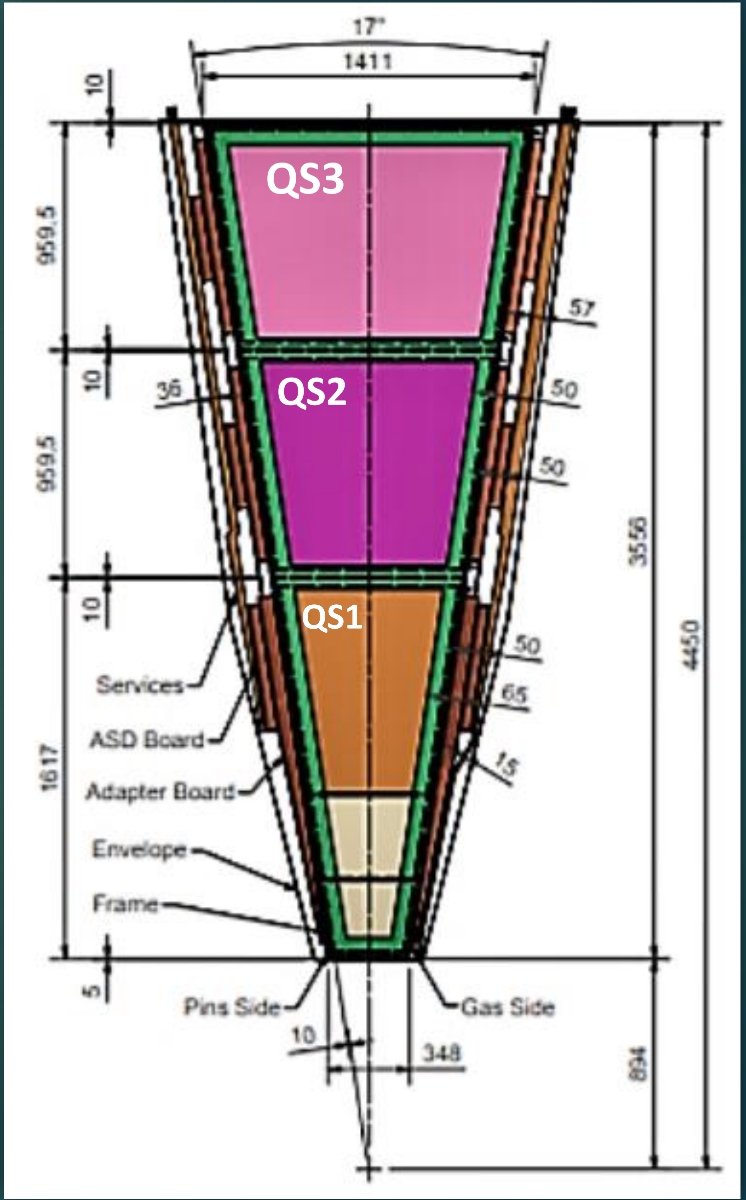
The New Small Wheel (NSW) Update



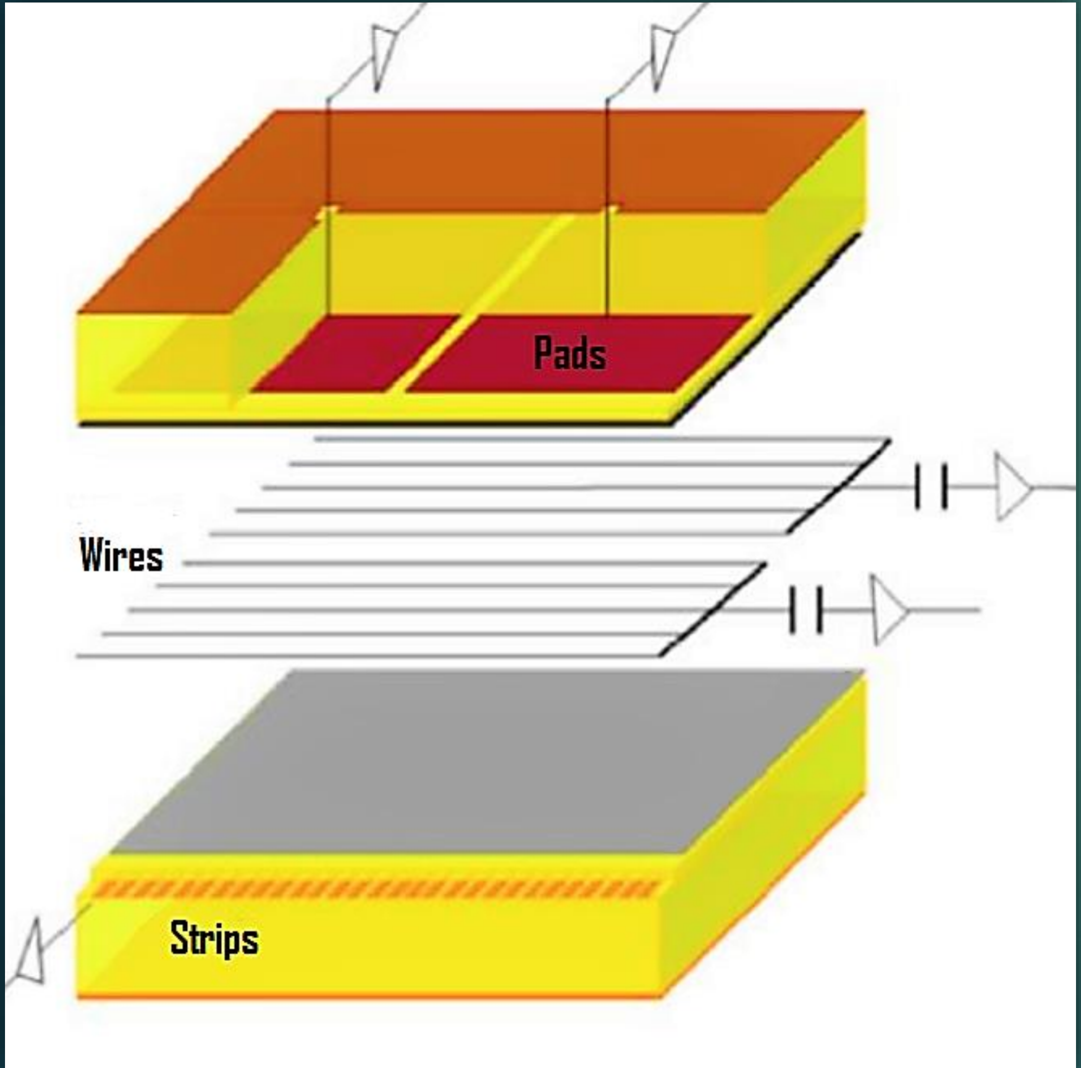
- Replace current Small Wheel detectors with two new models:
  - small-Strip Thin Gap Chambers (sTGC) for excellent angular resolution (<1mrad)
  - micromegas (MM) for muon tracking
- sTGC is an excellent candidate for early trigger system due to angular resolution and location within ATLAS
- Improve trigger quality of the muon spectrometer
  - **90% of high energy muon triggers in 2012 were fake** (mostly late-stage protons from secondary collisions)

Small-Strip Thin Gap Chambers

- Wheel made of two wedge sizes (Large and Small), with eight modules of each, covers whole ϕ coordinate around beamline
- Each wedge broken up into three sizes
- Each size made up of detector gaps (single sTGC)
- 4 gaps make up a Quadruplet (quad), base module of the detector
- One quad of each size makes up a wedge
- Carleton contributing one sTGC type of each wedge size
- Focus on small sector sTGC: QS3 (at top of diagram)



sTGC Design



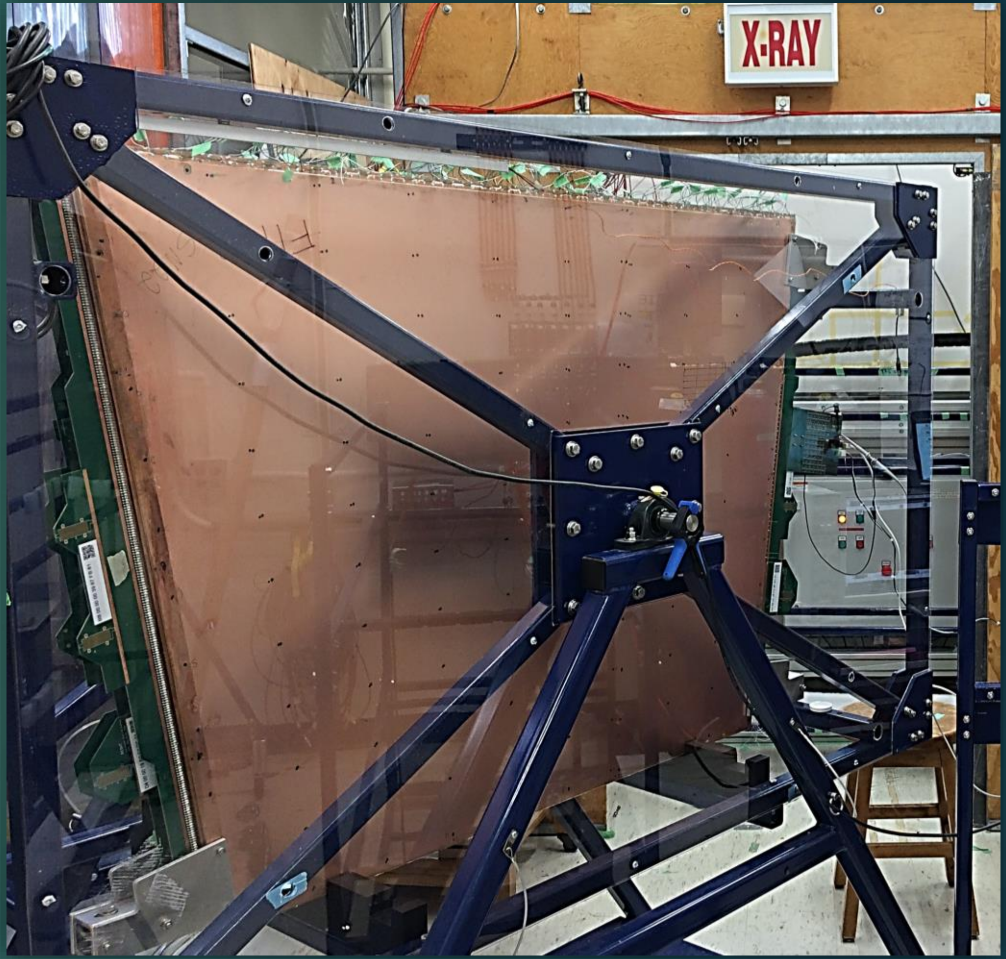
- Basic Design: Multi-Wire Proportional Chamber
  - Two Cathode planes (pads and strips)
  - High Voltage (~3kV) wires as Anode in between
- Gas Gap of 2.8mm
  - Strip separation: 3.2mm
  - Wire separation: 1.8mm
- Pads: Region of Interest Determination
  - Fast 3 of 4 coincidence within a Quad for trigger
- Strips: Angular Resolution
  - Gives η coordinate of muon track within 1mrad
  - Points back towards interaction point to eliminate false triggers
- Wires: give ϕ coordinate of muon track

The sTGC Pulser System

SYSTEM OVERVIEW

The sTGC Pulser System

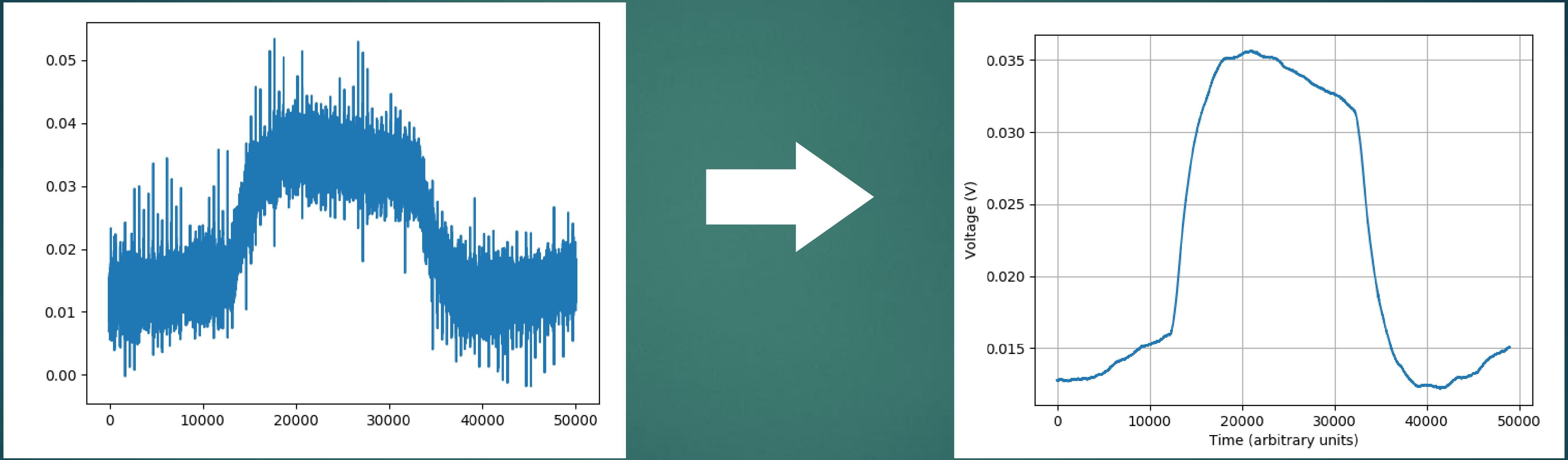
- **Goal:** Test electrical connectivity of all readout elements (pads/strips/wires) to confirm their functionality
- **Motivations:** Malfunctioning readout elements leaves holes in the ATLAS detection system, reduces the efficiency of the muon spectrometer
- **Test Procedure:**
  - Pulse HV line with square wave at 20V peak-to-peak (20Vpp)
  - Measure response signal from external adapter boards (AB)
  - Process through microprocessor on Pulser Board (PB) and digitize with oscilloscope
- **Analysis:** Sort signals to determine results (if signal was seen or not), collect meta-data (amplitudes, variances, means, etc.) to study response of the sTGC



Testing setup at Carleton University

Signal Processing

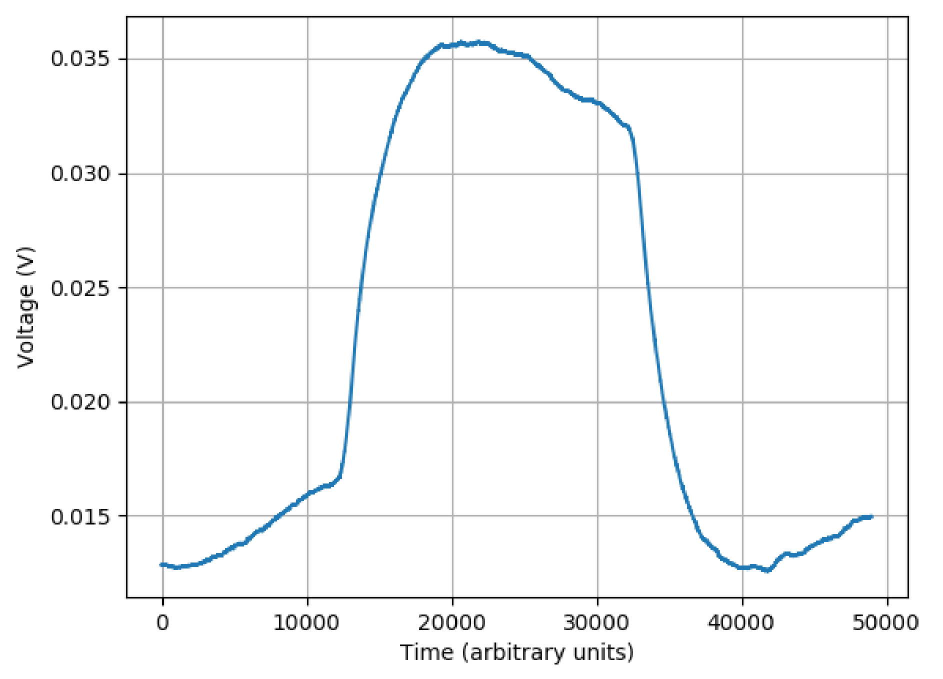
- Processing starts with a smoothing function that produces a clear waveform
- Analog signal from chamber is inherently noisy, reflected in the raw data



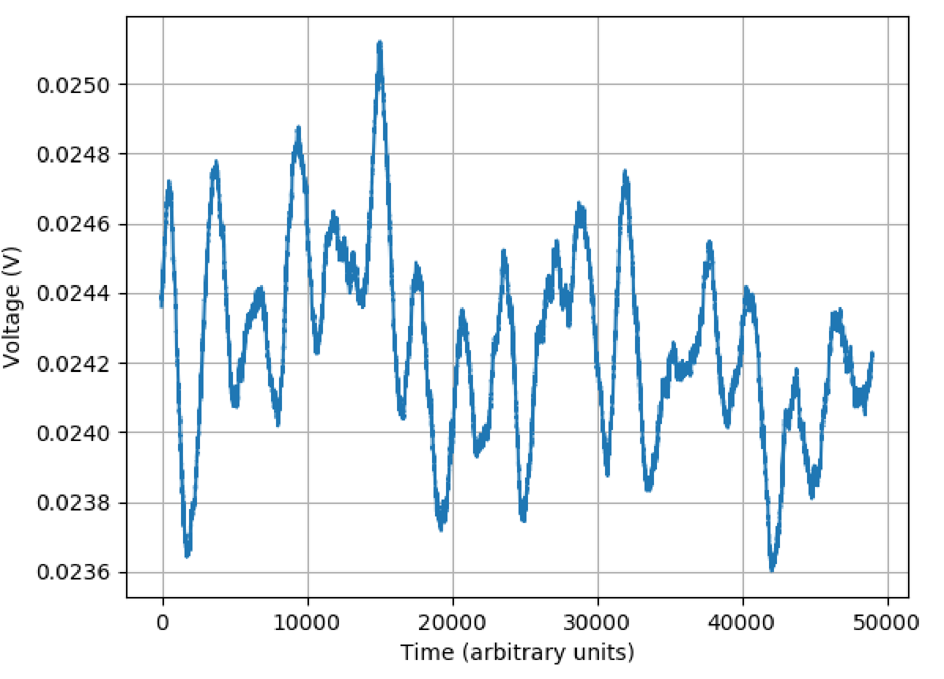
- Noise is kept by digitization process in the oscilloscope, appears as stray peaks in signal
- Averaging function creates a smooth waveform with clear Vpp value

Signal Sorting

- Next, the system sorts the waveforms to determine where a signal was found
- Measures the amplitude (Vpp), mean and variance of the channel to determine signal quality

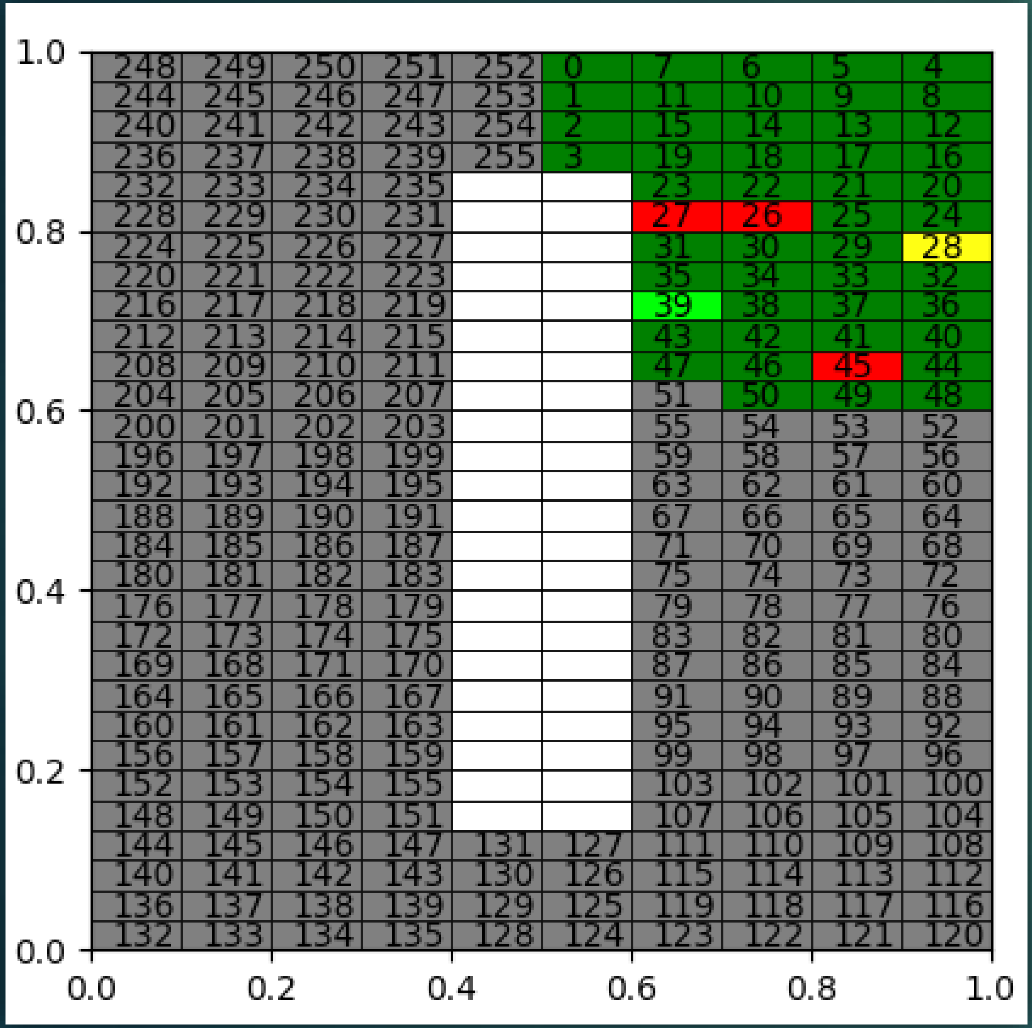


VS.



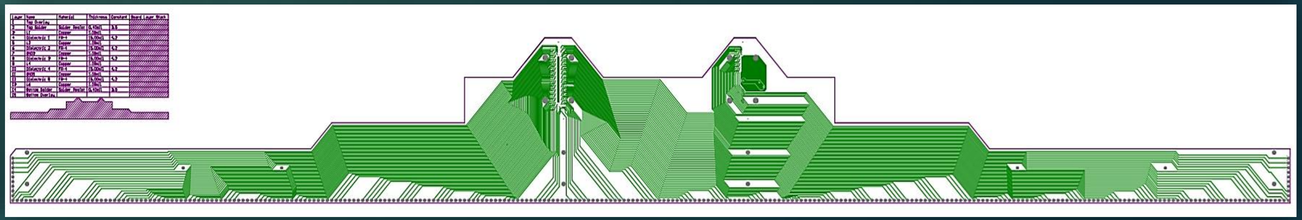
- Signal will have clear regions of high variance and large amplitude
- Can also account for ‘false positives’, such as high variance noise, or low amplitude signals

Signal Mapping



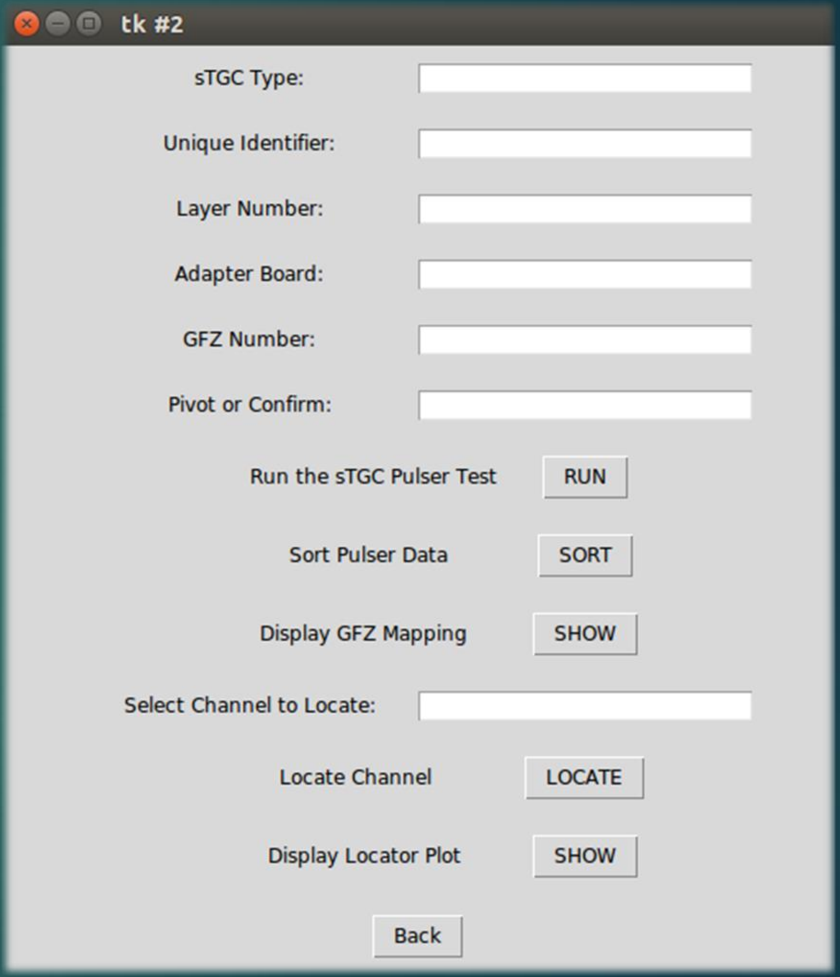
248	249	250	251	252	0	7	6	5	4
244	245	246	247	253	1	11	10	9	8
240	241	242	243	254	2	15	14	13	12
236	237	238	239	255	3	19	18	17	16
232	233	234	235			23	22	21	20
228	229	230	231			27	26	25	24
224	225	226	227			31	30	29	28
220	221	222	223			35	34	33	32
216	217	218	219			39	38	37	36
212	213	214	215			43	42	41	40
208	209	210	211			47	46	45	44
204	205	206	207			51	50	49	48
200	201	202	203			55	54	53	52
196	197	198	199			59	58	57	56
192	193	194	195			63	62	61	60
188	189	190	191			67	66	65	64
184	185	186	187			71	70	69	68
180	181	182	183			75	74	73	72
176	177	178	179			79	78	77	76
172	173	174	175			83	82	81	80
169	168	171	170			87	86	85	84
164	165	166	167			91	90	89	88
160	161	162	163			95	94	93	92
156	157	158	159			99	98	97	96
152	153	154	155			103	102	101	100
148	149	150	151			107	106	105	104
144	145	146	147	131	127	111	110	109	108
140	141	142	143	130	126	115	114	113	112
136	137	138	139	129	125	119	118	117	116
132	133	134	135	128	124	123	122	121	120

- System maps signal back to two locations:
  - Position on GFZ connector (physical connection between PB and AB)
  - Position in the Chamber (where AB connects to readout element)
- GFZ map (left) organized by:
  - Green: Channel Passed
  - Light Green: High Signal
  - Yellow: Low Signal
  - Red: Channel Failed
  - Grey: No Channel Connected
- Can locate signal origin from AB using trace map diagrams (below)



Implementation and Testing

- The Pulser System is controlled by a graphical user interface (GUI)
- Uses Python Tk interface in a Linux environment
- Serves two main purposes:
  - Configuration of the physical set (communicates with Arduino on PB and the Scope)
  - Run the various programs of the Pulser test:
    - Data acquisition
    - Signal Processing and Sorting
    - Signal Mapping and Locating
- Canadian sTGC Construction Process:
  - Cathode Board Prep. (TRIUMF) → Quad Assembly (Carleton) → **Pulser Testing (Carleton)** → Cosmic Ray Testing (McGill) → CERN
- Crucial to test at various stages of construction to identify problems early so that they can be fixed
- Ensures all electronics and readout elements are functional before the detector is sent to McGill, and eventually CERN



Results

PROGRESS OF THE STGC PULSER SYSTEM

Current Results

- **Five quads completed** with all adapter boards attached
- **Quad 1 is at CERN**, running tests in the ATLAS Test-beam
    - 100% of readout elements are functional
- **Quads 2 and 4 have been fully tested** and are at McGill, ready to be sent to CERN
    - 100% of readout elements on Quad 2 are functional
    - Only 1 strip on Quad 4 was found to be dead (can have 2/quad without affecting the efficiency of the NSW)
- Quad 3 was damaged and testing has stopped for now
- **Quad 5 has recently been finished** and testing is ongoing

Experimental Learning

- Accelerator/Collider Characteristics:
  - Beam Energy
  - Luminosity
  - Pseudorapidity
- Particle Detector Physics:
  - MWPCs
  - Geometry, Alignment, and Redundancy
  - Charge Build-up and Avalanche in a physical system
  - ATLAS trigger system
  - Signal Determination and Analysis
- Electronics:
  - Microprocessors
  - Interactions of diodes, capacitors and resistors in complex systems
- Computer Science:
  - Linux
  - Graphical User Interfaces
  - Matplotlib (Math library and toolkit for python)
  - Signal Sorting Techniques

Conclusion


Quad 1 being lowered into the test-beam at CERN

- The sTGC pulser system is a necessary part of the characterization process for the detector, and has been crucial in the construction process for identifying problems
- The system has made considerable progress since its initial stages, and is almost at the point where it can been completely implemented by technicians without external support
- The SPS has also proved to be a useful tool for external research into the response of the sTGC signals
- **Looking Forward:** a similar characterization model will have to be developed for the large sector sTGC, the QL2

Special Thanks To:

- Dr. Alain Bellerive (Supervisor)
- Stephen Weber
- Dr. Chav Chhiv Chau
- Dr. Jesse Heilman
- The sTGC Collaboration at Carleton

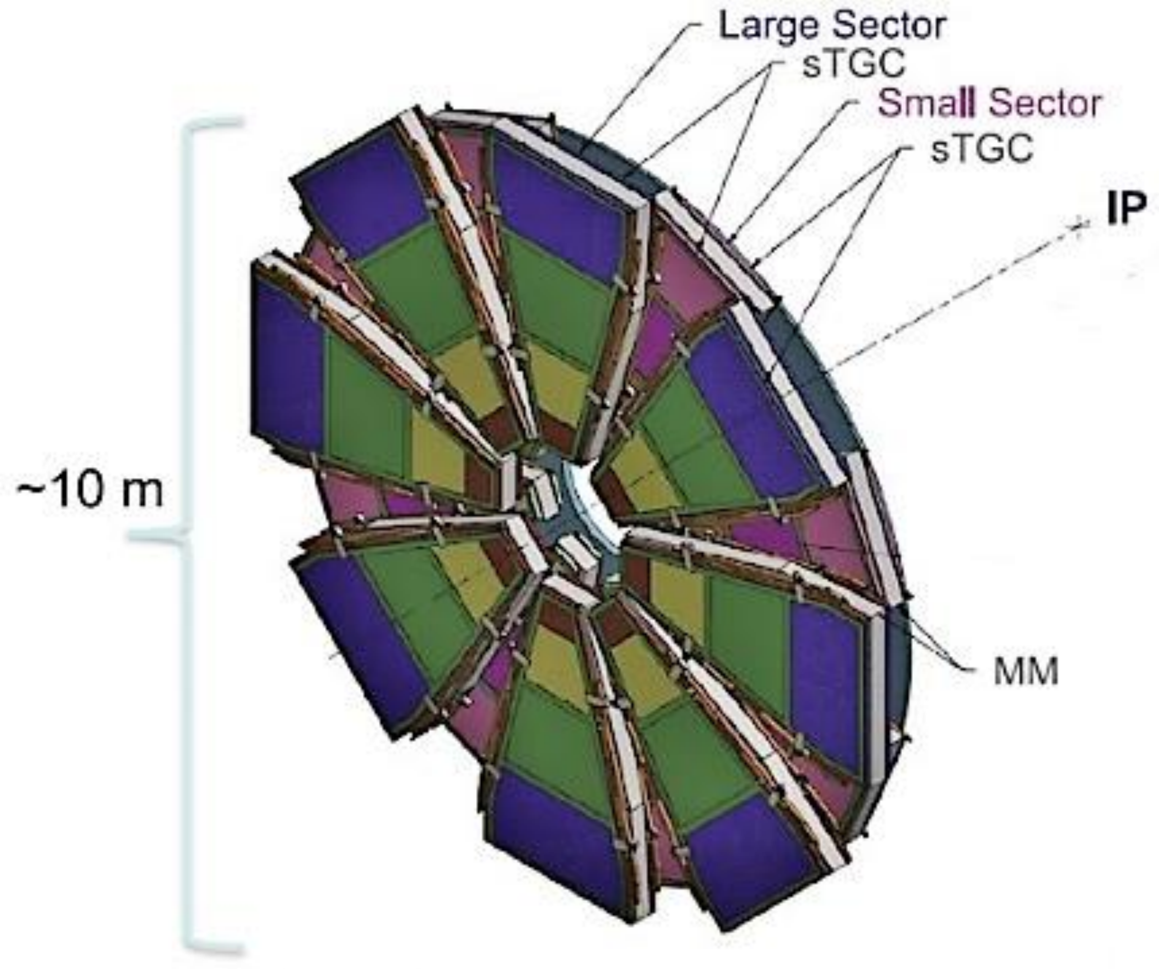
…And Thank You For Listening.

Any Questions?

Extra Material

The New Small Wheel (NSW) Update

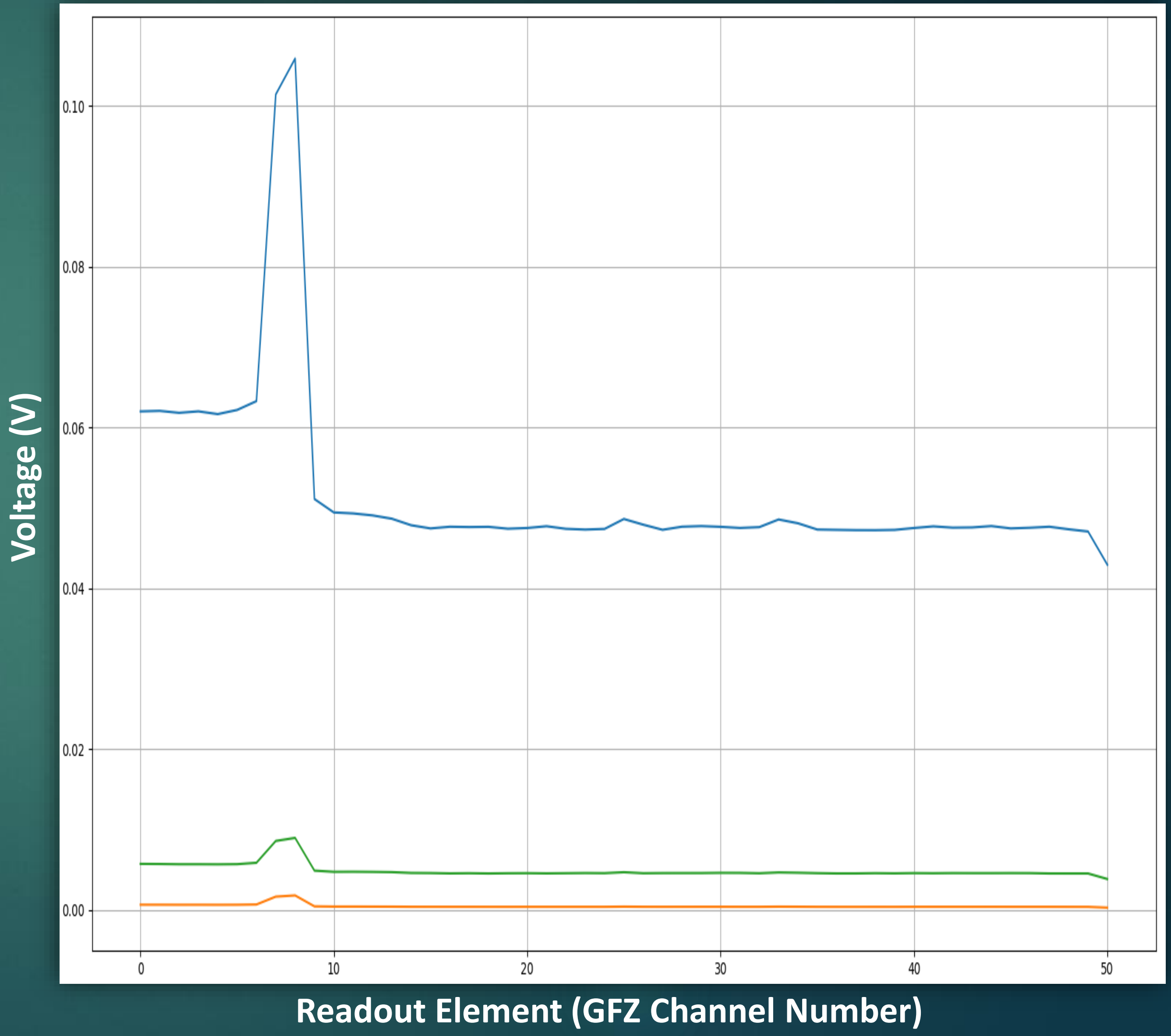
- NSW Layout:
  - Large and Small Sectors made up of 16 Wedges (8 per sector)
  - Small Sector Wedge covers 17° in ϕ
  - Large Sector Wedge covers 28° in ϕ
- The NSW Update:
  - Replace current small wheel with two new detectors:
  - Small-Strip Thin Gap Chambers (sTGC) for excellent angular resolution (<1mrad)
  - Micromegas (MM) for muon tracking
- Why replace the Small Wheel?
  - Increased radiation levels degrades the current detectors
  - Introduce Level-1 Trigger in the Muon Spectrometer



New Small Wheel overview

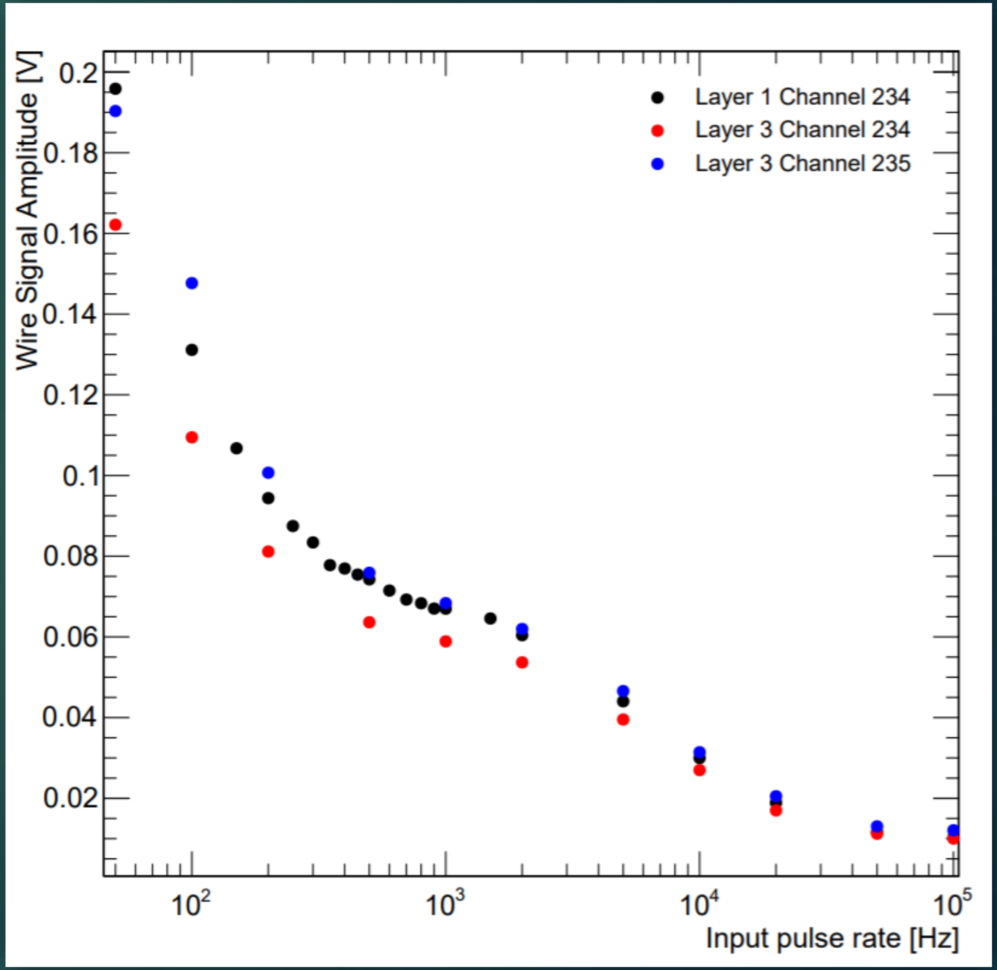
The Sorting Algorithm

- 1. Compute mean and variance of the whole waveform
- 2. Measure the amplitude
- 3. Determine relative shape and noise, use this to determine Sorting Function Response (SFR), acts as a quality factor
  - High SFR indicates low noise, high amplitude
  - Low SFR indicated high noise, low amplitude
- 4. Pass SFR through a series of conditionals to determine level of signal (high, low, normal, or dead)
- Based on Carleton parameters:
  - SFR > 0.002 = PASS
  - SFR < 0.0015 = FAIL



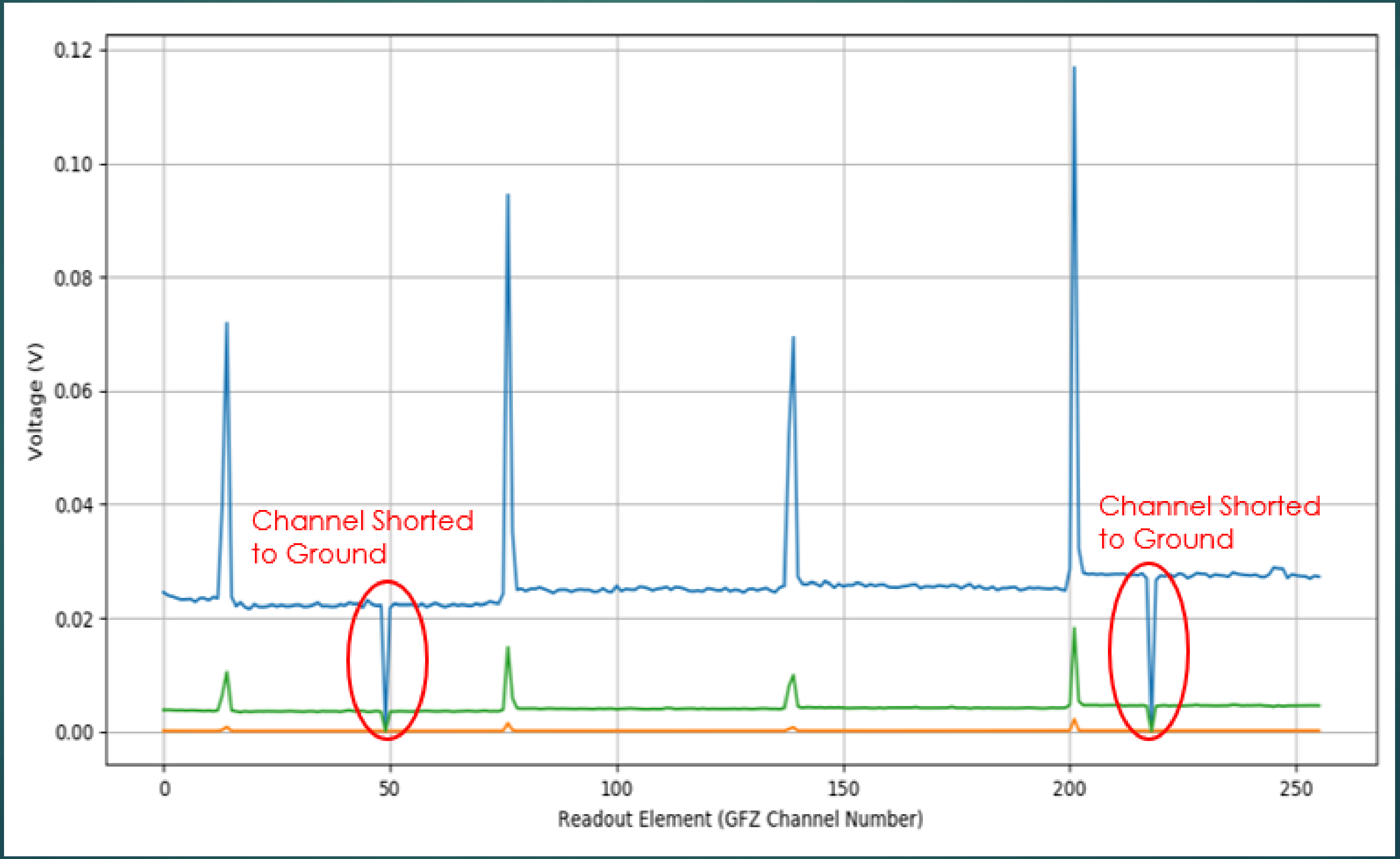
Attenuation Studies

- Measure the attenuation of readout element signals due to external Wire Adapter Board (WAB) electronics
- Two layers of WAB: wire 1 boards (W1B) and wire 2 boards (W2B)
  - W1B contains external electronics (diodes, capacitors, and resistors)
  - W2B used for signal routing
- Interested in difference before and after W1B
  - Without W1B: Average Amplitude $= 51\text{mV} \pm 1\text{mV}$
  - With W1B: Average Amplitude $= 27\text{mV} \pm 0.6\text{mV}$
  - Significant (~50%) reduction in signal amplitude
- Measure attenuation of wire signal due to frequency on input pulse:
  - At low frequency: high signal distortion
  - At high frequency: low signal amplitude
  - Optimal range between 500 and 1000 Hz
- See plot to right



Short to Ground Simulation

- Very clear result, complete loss of signal
- Easy to identify and therefore easy to address



Short Between Elements Simulation

- Expected to increase signal (amplitude proportional to area of readout element)
  - 2 elements shorted = 2x area of the elements = 2x signal amplitude
- Observational result: signal averaged between shorted channels
  - 2 elements shorted = $(\frac{A_1+A_2}{2})$, Only observable in elements with large difference in signal amplitude