**Thesis Brainstorm**

Title: Using cosmic-ray hodoscope data to validate misalignment measurements in small-strip thin gap chambers for the ATLAS experiment

Background – CHAP1

* ATLAS [1], LHC [2]
* Mention Athena
* ATLAS muon spectrometer [3]
* Motivation for replacing SW [4]
* NSW design (sTGC and MM)  [4]
  + Introduce sector and wedge idea, large and small, quadruplet type
* sTGC details [4]
  + Mechanical layout (pads, strips, wires) (zoom out of layer figure, or Perez-Codina 2016 fig. 2)
  + How it works: ionization, avalanche, charge spreading, gas mixture, HV
  + Charge distribution on strips to extract y, wire fired to provide x
* Detector construction process? 🡪 1 paragraph
  + Five countries, including Canada
  + Etching strip pattern 🡪 distortion
  + Briefly point to Carlson’s thesis for CMM misalignment model, although simple offset and rotation model is often used as base [5].
  + Cathode board (multilayer PCB) wound with wires, closed with another (gluing, brasses)
  + Doublet 🡪 quadruplet (pins) (gluing, brasses, microscope)
  + Result: sTGC strip misalignments
  + Cite TDR
* The alignment system [4,6] 🡪 Minimal
  + Transition: once the quadruplets are tested, they are assembled into wedges and the alignment platforms attached
  + Source plates and light fibres mounted on sTGC wedge
  + “chambers have internal alignment sensors to monitor their distortions, there is a global alignment system that monitors the positions of the chambers with respect to each other” [6]
  + Summary: Alignment system positions wedge surface, positions must be with respect to alignment platforms
* Transition: Next, description of the datasets used to characterize quadruplets in this work.

Cosmics data – CHAP2: Characterization of sTGC modules using cosmic rays

* Cosmic muons, hodoscope (figure of test bench)
* Mention gas system and slow control
* Collect 1 000 000 triggers / quadruplet, many metrics for characterization [7], but we focus on rebuilding tracks
* Explain clustering and CosmicsAnalysis, reference to reclustering appendix (would be good to have strip muon signal, but could skip. Could use generic MWPC figure you have in snippet slides of CAP poster to show signals -> PDO -> cluster)
* If required, could use mechanical design schematic to introduce wire supports (don’t think I will need)
* Say how position is extracted based on nominal position of strips (and wires)

Datasets for alignment studies – CHAP3

*Should I include a quick section on CMM data?  
  
Cosmics data*

* Misalignments cause systematic shifts of the residual [7]
* Relative coordinate system only
* Fix two layers to build coordinate system [7]
* Calculate residuals and take mean as proxy – reference to appendix A: residual histogram bin size (plot of mu\_cosmics – mu\_reclustering and how that makes residual uncertainties) – reference to appendix B: Gaussian fit vs double gaussian fit
* Show resplot means TH2F for a single quadruplet (QL2C04), for a given tracking combination
* [not shown] Show num entries TH2F to see connection with patterns due to hodoscope acceptance angle and wire support positions on three involved layers
* Section: systematics (reference
  + 2900 V vs 3100 V
  + Gaus vs doub gaus
  + DNL

*x-ray data*

* Transition: The position of each strip in ATLAS must be known to within 100um. The alignment platforms are able to position the wedge surface to within X um, (maybe in TDR? Ask people) so need strip positions wrt wedge surface
* Assembled wedges
* Source plates provide coordinate system  
  ^^^ These bullets may be duplication, shorten as required
* Interaction of x-rays with sTGC (photoeffect on copper, photoelectrons ionize gas and cause avalanches) -> many more delta rays
* X-ray gun holder
* X-ray gun
* Fitting to cluster mean, point to JINST for details [9]
* Reported uncertainties of 20 um, systematic uncertainties of 120 um. (“Private communication” and point to JINST)
* Since these parameters will be used to calculate the as-built misalignment model to locate strips in ATLAS, they should be verified

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* Could add in full edit if it feels right: CMM data section in chap 3 alignment studies:
  + Briefly point to Carlson’s thesis for CMM misalignment model

Comparison results – CHAP4

* Presentation of theoretical method for comparison
  + How we calculate the x-ray residuals and how it is different to cosmics
* Reference the residual TH2 from chap 3, which should have x-ray positions on top
* We bin around the x-ray point
* Choice of the area of the region of interest – ask Brigitte
  + DON’T GO INTO THE WEEDS. Keep it simple: balance between statistical uncertainty and size of expected local offsets.
  + Weeds:
    - Same area as x-ray is ideal
    - Statistical uncertainty ok
    - Wider than 2 wire groups for smooth patterns in TH2F
    - Smaller than scale on which we expect local offsets to vary
* Show scatter plot comparing the two for all tracking combinations
  + Uncertainty on cosmics is the sum in quadrature of the stat and sys error for mean cosmics residuals
  + Uncertainty on x-rays track positions is from polation, uncertainty on x-ray hits is 120 um, uncertainty in residual is the sum in quadrature
  + 2 populations:
    - Misaligned quad: can see correlation
    - Not misaligned: not sensitive to relative misalignments smaller than ~ 100 um
* Limitations section
  + Need at least 3 layers of data per x-ray point for this method
  + Some quadruplets do not have enough x-ray data
  + Some countries don’t collect cosmics
  + Propagating the error in the x-ray residuals makes their error very large – lose precision
* Next steps:
  + run over all quadruplets
  + Enjoy the confidence in x-ray data
  + Briefly explain progress on misalignment model in stgc-as-built-fit
  + Explain potential to constrain misalignment model with cosmics data (BRIEF, no details)
  + Cross check with other measurements of the relative misalignment parameters

Outlook and Summary:

* The work is important in the goal towards the as-built model, since it validates one of the key datasets used to derive the misalignment parameters
* Outlook
  + Next flag anomalous correlations
  + Evaluate degree of correlation over all quadruplets
  + Add cosmics residuals to alignment parameter fit, since we know the mean cosmics residuals well and they give us relative alignment information
* Importance
  + Need to know strip positions in ATLAS

Appendix A: residual histogram bin size

To assign residual distribution bin size, need uncertainty on cosmics residuals => clustering uncertainty

Show mu\_cosmics – mu\_reclustering for a quad to motivate 60 um uncertainty on cluster position

Explain how this propagates mathematically to uncertainty on residuals of < 200 um

Can also show there is no advantage in going smaller by adding plot comparing residual histogram bin size if desired

Appendix B: Study of statistical uncertainty

… residualsStudy/QS3P18\_stats/peakOfMeanErrorsDistVsTrigger.pdf

Appendix B: Study of systematic uncertainties

*Appendix B.1: Gaussian fit vs double gaussian fit*

Show the scatter plot you made to prove a Gaussian fit is sufficient and fails less often

*Appendix B.2: 2900V vs 3100V?*

*~~Appendix B.2: Why 10 cm is an appropriate bin size~~*

~~Can show rough calculation of scale on which alignments change~~

*Appendix B.3: DNL*

*[1] The ATLAS Experiment at the CERN Large Hadron Collider*, J. Instrum. **3**, S08003 (2008).

[2] L. Evans and P. Bryant, *LHC Machine*, J. Instrum. **3**, (2008).

[3] ATLAS Collaboration, ATLAS Muon Spectrometer: Technical Design Report, No. CERN-LHCC-97-022, CERN, 1997.

[4] CERN. Generva. T. L. experiments C. ATLAS Collaboration, New Small Wheel Technical Design Report, Technical Design Report No. CERN-LHCC-2013-006, CERN, 2013.

[5] E. M. Carlson, Results of the 2018 ATLAS STGC Test Beam and Internal Strip Alignment of STGC Detectors, Thesis, University of Victoria, 2019.

[6] S. Aefsky, C. Amelung, J. Bensinger, C. Blocker, A. Dushkin, M. Gardner, K. Hashemi, E. Henry, B. Kaplan, P. Keselman, M. Ketchum, U. Landgraf, A. Ostapchuk, J. Rothberg, A. Schricker, N. Skvorodnev, and H. Wellenstein, *The Optical Alignment System of the ATLAS Muon Spectrometer Endcaps*, J. Instrum. **3**, P11005 (2008).

[7] B. Lefebvre, Characterization Studies of Small-Strip Thin Gap Chambers for the ATLAS Upgrade, PhD Dissertation, McGill University, 2018.

[8] B. Lefebvre, *Precision Survey of the Readout Strips of Small-Strip Thin Gap Chambers Using X-Rays for the Muon Spectrometer Upgrade of the ATLAS Experiment*, J. Instrum. **15**, C07013 (2020).

[9] B. Lefebvre, *Precision Survey of the Readout Strips of Small-Strip Thin Gap Chambers Using X-Rays for the Muon Spectrometer Upgrade of the ATLAS Experiment*, https://doi.org/10.1088/1748-0221/15/07/C07013.