**Thesis Brainstorm**

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

Background – CHAP1

*Start it off with hi-lumi motivation*

* LHC and HL-LHC [2]
* ATLAS [1]
  + Cylindrical general purpose detector
  + Partons collide, physics occurs
  + Transverse momentum and energy are conserved
  + Each detector subsystem in charge of a different group of particles
  + Inner tracker basics
  + Calorimeter basics
  + Magnet system basics
  + Trigger
  + (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

Do I need to include cosmics cuts? X-ray cuts? 🡪 Maybe another appendix

*Chapter intro*

* Canadian production line

*Lab Infrastructure*

* Cosmic muons, hodoscope (figure of test bench)
* How trigger works, pass to front end boards
* Readout PDO for channels above threshold (footnote neighbour triggering) (prototype board and ASIC) – no need to mention decoder, data assembled based on detector geometry, note collaborators (citations not necessary)
* Each muon event corresponds to one trigger
* Chamber operation also requires gas system, slow control, HV.
* We run at 2900V (close to nominal) and 3100V – why? FEBs not optimized for pad readout
* Collect 1 000 000 triggers / quadruplet, many metrics for characterization [7], but we focus on rebuilding tracks

*Tracking analysis*

* CosmicsAnalysis calculates high-level characterization metrics
* Rebuilding tracks
* X-coordinate from wires, uncertainty in x
* Y-coordinate from strips
* Explain clustering and CosmicsAnalysis,
* Motivate uncertainty in y, reference to reclustering appendix (would be good to have strip muon signal, but could skip.   
  FIGURE: generic MWPC figure you have in snippet slides of CAP poster to show signals -> PDO -> cluster)  
  FIGURE: Sample cluster
* Say how tracks are extracted based on nominal position of strips (and wires)
* If required, could use mechanical design schematic to introduce wire supports (don’t think I will need)

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.