**Thesis Brainstorm**

STATUS:  
Just missing a section on cosmics rays and physics motivation for LHC & ATLAS

CONCLUSIONS:

* The x-ray method is validated by the cosmics method
* Cosmics provides relative alignment info complementary to alignment info from other characterization datasets
* NSW is a necessary part of hi-lumi upgrade that ensures the future of particle physics at the energy frontier, which motivates my project

Background – CHAP1

*Intro: Brief overview, starting with Hi-Lumi motivation*

*Background:*

* *Physics Motivation [NEW, 2021-09-30]*
* OPTIONS: Physics motivation section 2.1
  + Goal: explain in broad strokes why studying particle physics at colliders is worth studying
  + Need to establish the particles of the standard model, BSM theories
  + Establish the standard model and beyond the standard model
    - One sentence what is the standard model
    - Explain the particles
    - Establish the power of accelerators to study the standard model (Higgs, SM measurements, searches)
* LHC
  + Basic function
  + Luminosity
  + Luminosity links accelerator and statistical power of measurements
  + HL-LHC [1] offers 3000 fb^-1 compared to 30 fb^-1 in run 1 and 190 fb^-1 in run 2
  + Figure: HL-LHC timeline
  + Importance of upgrade is that LHC is energy frontier [expand]
    - LHC is Higgs and top factory
    - Accelerators at energy frontier have a long history of discovery
    - Unique globally
* ATLAS [2]
  + Cylindrical general purpose detector
  + Establish the power of ATLAS
    - Cross section measurement plot
    - Historical discoveries on ATLAS timeline
  + Barrel and endcap/forward
  + ATLAS coords
  + Partons collide, physics occurs
  + Transverse momentum and energy are conserved
  + Each detector subsystem in charge of a different group of particles
  + Inner tracker basics, figure
  + Calorimeter basics, figure
  + Trigger
    - Can’t record at 40 MHz so ATLAS has multi-level trigger system
    - L1 hardware has max rate of 100 kHz [3]
    - Pass from HLT software [4] stores event data for analysis
    - Quoting run-2 trigger rates [5]
  + Muon Spectrometer [6]
    - Magnet system basics
    - MDTs for precision offline tracking
    - RPCs in barrel and TGCs in endcaps for triggering
    - Introduce small wheel, big wheel, outer wheel
    - Triggering condition in endcaps: In run-2 added requirement for coincidence in small-wheel because of high fake rate from background particles generated in end-cap toroid. Requirement helps, but limited eta coverage and position resolution in current TGC layer [7]
* Motivation for replacing SW [8]
  + 7-fold increase in luminosity
  + Background rate increases linearly, which is a problem for triggering and tracking
    - Tracking: MDT efficiency decreases by 35% at current highest hit rate (300 kHz)
      * At hi-lumi 300 kHz a pretty normal hit rate
      * Means we’ll lose hits in the small wheel, degrading muon momentum resolution
      * Affect searches for Z’, W’, pseudo-scalar Higgs [7]
    - Triggering: At run-3 luminosity, 60 kHz of max 100 kHz acceptable at L1 will be from SW
      * Just raising the muon p\_T threshold helps, but you lose interesting physics
  + Figure: quarter cut of ATLAS showing three muon tracks
  + NSW solves these problems with tracking chambers designed for high rate and triggering chambers with better eta coverage and angular resolution
* NSW design [8]
  + Two technologies, sTGC (primary trigger) and MM (primary tracker), but both do either for redundancy
  + 100 um position resolution per detector plane (100 um is the current working goal, in TDR desired resolution is 40 um)
  + 4 detector planes of each type make quadruplets
  + Wedges
  + Sectors
  + Figure: Quad, wedge, sector, NSW
* MM details
  + Brief operating principle
  + Optimal for high rate environment, precision tracking
  + Figure of operating principle from NSW TDR
* sTGC details [8], figure: sTGC internals from Benoit
  + Gas ionization, gas mixture
  + Wires between two cathode boards
  + Pads, strips
  + HV on wires, ionization, avalanche, electrodes pick up signal, cross hatching of wires and strips gives position
  + Wire position resolution is 10mm, strip position resolution is 45 um
  + Quadruplet angular resolution of 1 mrad is achievable [7,9]
  + Strip boards have brass inserts for alignment
  + Brass inserts supposed to provide an external reference to be used in ATLAS alignment system
* Detector construction process

*Originally Brigitte, you had said to keep this very short. So far I have not.*

* + Five countries, including Canada. Focus on Canadian process
  + Cathode boards are multilayer PCB with electrodes etched on
  + Etching strip pattern 🡪 distortion; shape of brasses distorted
  + Briefly point to Carlson’s thesis for CMM misalignment model, although simple offset and rotation model is often used as base [10].
  + Cathode board (multilayer PCB) wound with wires, closed with another (gluing, brasses)
  + Doublet 🡪 quadruplet (pins) (gluing, brasses, microscope)
  + Quads to McGill for cosmic ray testing
  + Quads to CERN to be installed on NSW
  + Time-of-writing status update: NSW-A lowered
  + Cite TDR
* The alignment system [8,11] 🡪 Minimal
  + NSW TDR only gives idea of alignment system, details have been presented internally.
  + Original goal: Position of any 3 chambers traversable by a track wrt one another in eta with accuracy of 40 um [7]
  + Alignment platforms installed on wedges
  + Light fibres routed to alignment platforms
  + Light from fibres monitored during operation by BCAMs
  + Monitoring position of alignment platforms would have been sufficient if chamber internal alignment controlled to within 40um [8]
    - Didn’t happen: non-conformities in etched strip pattern, misalignment from brasses
  + Useful quote: “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” [11]
  + Misalignments in Canadian quads random [10]
  + Now trying to measure local strip pattern offsets with respect to alignment platforms with x-ray data, skipping brasses as alignment reference
  + Figure: Alignment scheme (BCAMS -> light fibres -> ~~brasses~~ / x-ray data -> strips
  + GOAL OF THESIS: VALIDATE X-RAY DATASET
* Transition: Chapter breakdown

Cosmics data – CHAP2: Characterization of sTGC modules using cosmic rays – WRITTEN NOT SENT

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

*Chapter intro*

* Canadian production line

*Cosmic rays [NEW 2021-09-30]*

*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 [12], 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 – SENT TO BRIGITTE

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

* Misalignments cause systematic shifts of the residual [12]
* Relative coordinate system only
* Fix two layers to build coordinate system [12]
* 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 [13]
* 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 – SENT TO BRIGITTE

* 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 – SENT TO BRIGITTE

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

[2] T. A. Collaboration, E. Abat, J. Abdallah, A. A. Abdelalim, A. Abdesselam, O. Abdinov, B. A. Abi, M Abolins, H. Abramowicz, E. Acerbi, B. S. Acharya, R. Achenbach, M. Ackers, D. L. Adams, F. Adamyan, T. N. Addy, M Aderholz, C. Adorisio, P. Adragna, M. Aharrouche, S. P. Ahlen, F. Ahles, A. Ahmad, H. Ahmed, G. Aielli, P. F. Åkesson, T. P. A. Åkesson, A. V. Akimov, S. M. Alam, J. Albert, S. Albrand, M. Aleksa, I. N. Aleksandrov, M. Aleppo, F. Alessandria, C Alexa, G. Alexander, T. Alexopoulos, G. Alimonti, M. Aliyev, P. P. Allport, S. E. Allwood-Spiers, A. Aloisio, J Alonso, R. Alves, M. G. Alviggi, K. Amako, P. Amaral, S. P. Amaral, G. Ambrosini, G. Ambrosio, C. Amelung, V. V. Ammosov, A. Amorim, N. Amram, C. Anastopoulos, B. Anderson, K. J. Anderson, E. C. Anderssen, A. Andreazza, V. Andrei, L Andricek, M.-L. Andrieux, X. S. Anduaga, F. Anghinolfi, A. Antonaki, M. Antonelli, S. Antonelli, R. Apsimon, G Arabidze, I. Aracena, Y. Arai, A. T. H. Arce, J. P. Archambault, J.-F. 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