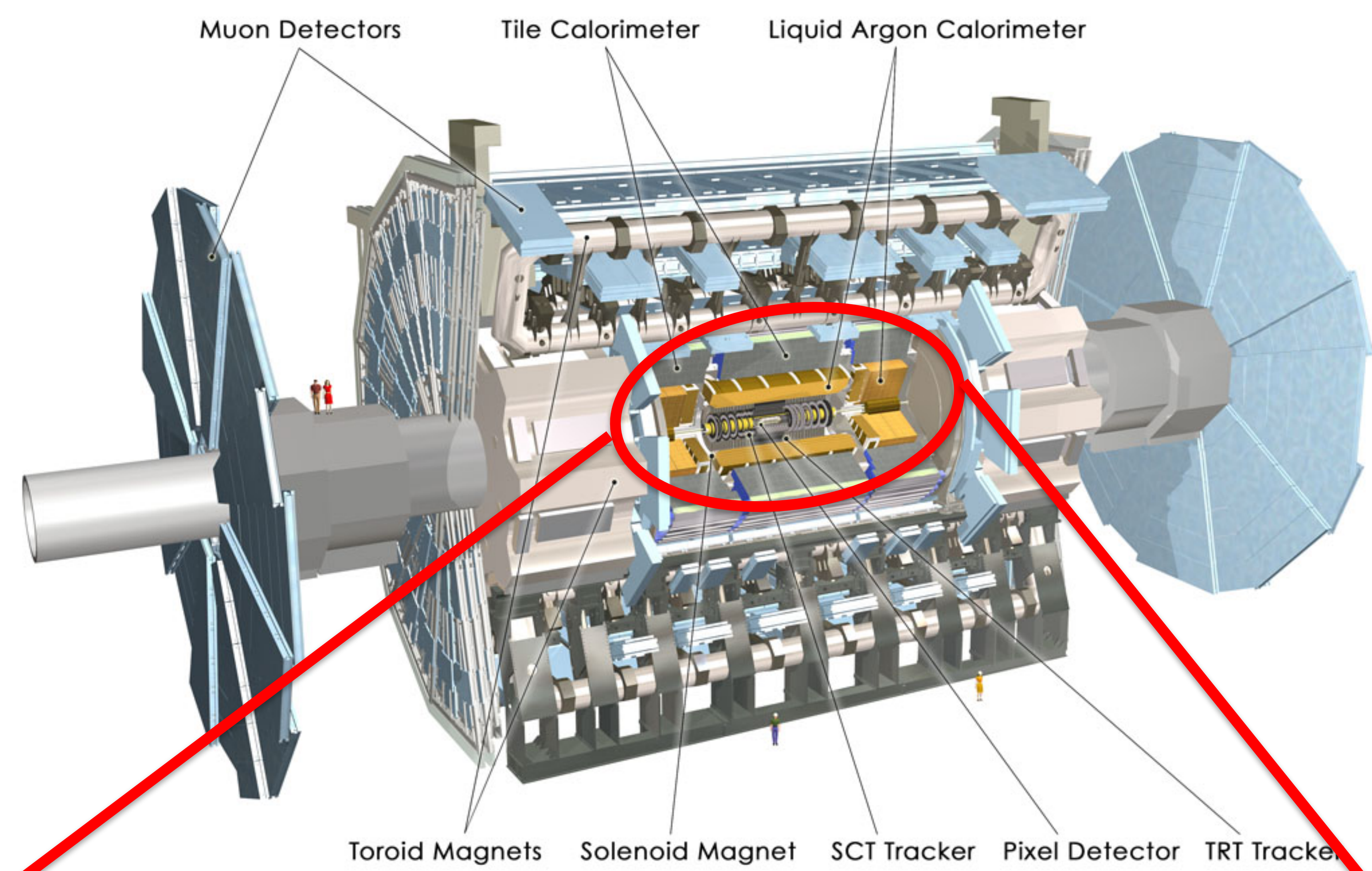
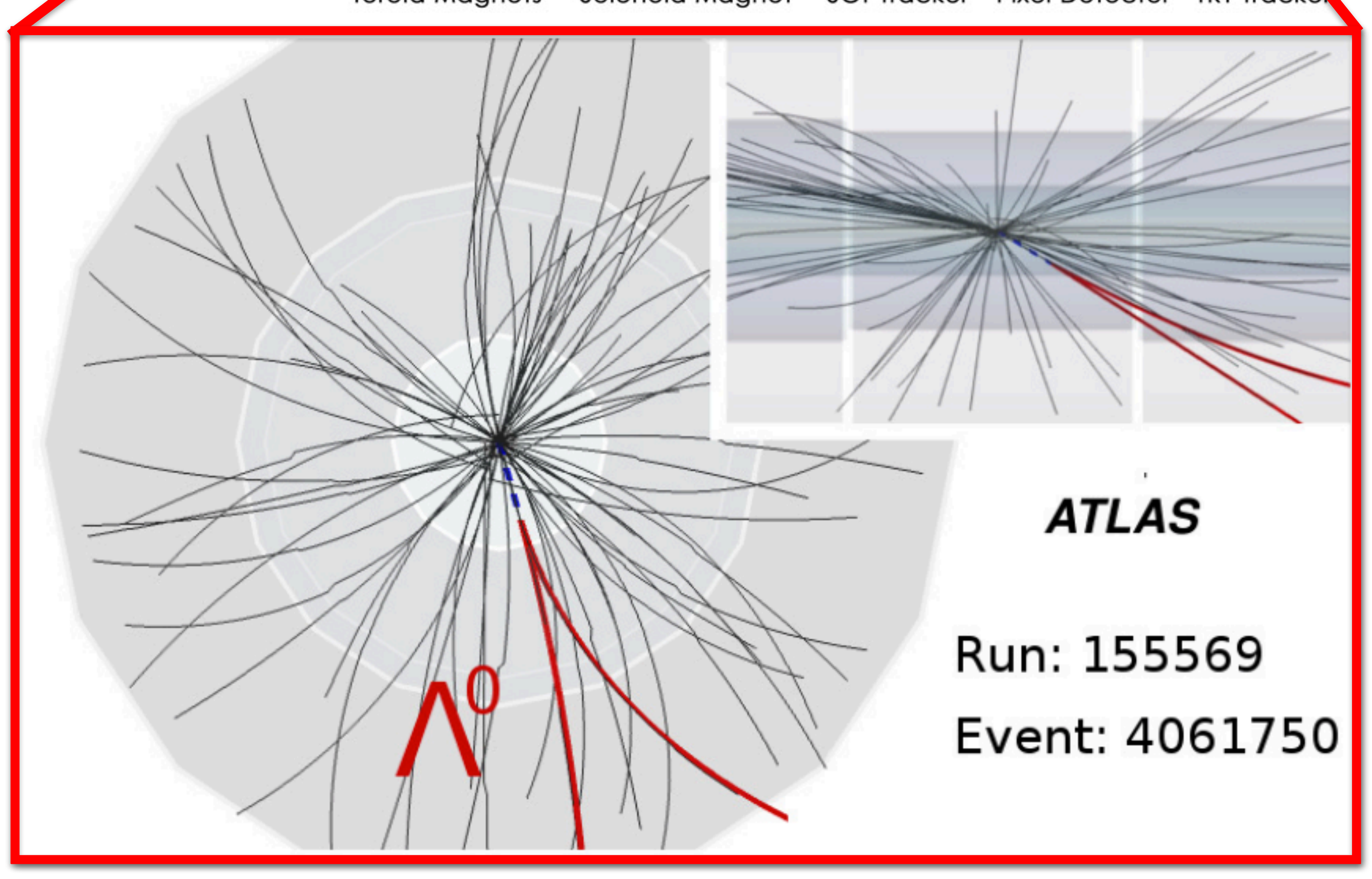
Gordon Research Seminar on Particle Physics – June 24-25 2017, HKUST, Hong Kong

Measurements of Correlations between Inclusively Produced $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\Lambda^0$, and $\bar{\Lambda}^0\bar{\Lambda}^0$ Hyperon Pairs at $\sqrt{s} = 7$ TeV in the LHC ATLAS Detector

Abstract

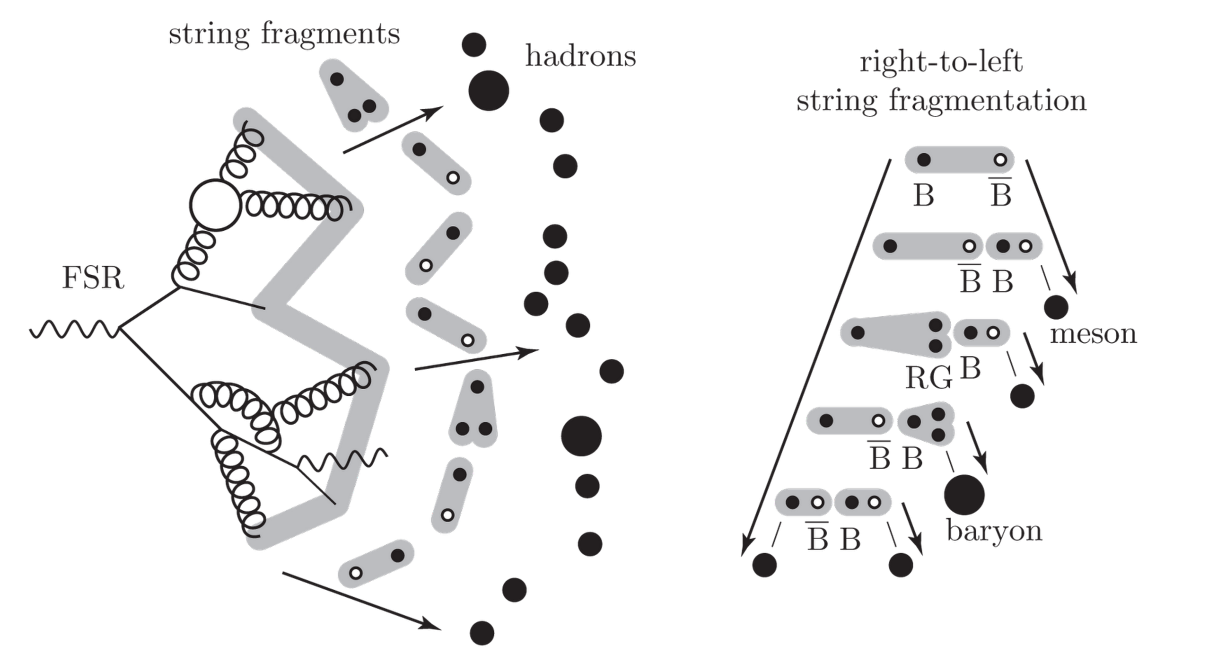
We report here the first correlation measurement of like-type and unlike-type Lambda hyperon pairs at a center-of-mass energy of 7 TeV using dataset collected at the ATLAS detector in 2010, which allows us to have a better understanding of the jet fragmentation and hadronization models. Recent results from ALICE at LHC [1] and OPAL, DELPHI, and ALPEH at LEP [2,3,4] suggested that there are serious discrepancies between data and MC predictions. In this analysis, the dynamical correlation is extracted in terms of a correlation function defined as the differential cross section ratio between data sample and event mixing sample. We discovered that the positive dynamical correlation for $\Lambda^0\bar{\Lambda}^0$ events at very small relative momentum $Q = \sqrt{-(p_1 - p_2)^2}$ and relative azimuthal angle $\Delta\phi$ is overestimated by the PYTHIA event generator in the Monte Carlo (MC) sample. For $\Lambda^0\Lambda^0 \oplus \bar{\Lambda}^0\bar{\Lambda}^0$ events, there is no significant discrepancy between data and MC sample and anti-correlation is measured at small Q and $\Delta\phi$. The spin correlation is extracted by comparing the decay angle distribution of data to an ensemble of data-driven reference sample using the minimum χ^2 method. The results are consistent with zero for $\Lambda^0\bar{\Lambda}^0$ events in $Q \in [1,10]$ GeV region and $\Lambda^0\Lambda^0 \oplus \bar{\Lambda}^0\bar{\Lambda}^0$ events in $Q \in [0,10]$ GeV region. Our results are qualitatively consistent with the predictions from the Lund string model implemented in the PYTHIA event generator. Overestimation of excess $\Lambda^0\bar{\Lambda}^0$ events near production threshold suggests that further tuning is needed for the MC generator.





Lund string model

Baryon/antibaryon production is in the non-perturbative regime in Quantum Chromodynamics. Phenomenological models are used to give predictions for different measurable quantities. One of the most successful models is the Lund string model. In this model, pair-produced quark-antiquark is connected by a color flux tube modeled by a massless relativistic string with constant tension. As the quark-antiquark pair moves apart from each other, it becomes kinematically favorable for the string to break and pop out quark-antiquark or diquark-antidiquark pairs. Mesons and baryons can then be produced in the string breaking process.



A schematics of string fragmentation in the Lund string model (Ref. 5)

As baryon production is generally suppressed by meson production, (anti)baryon-(anti)baryon pairs are separated by at least one baryon with opposite baryon number plus additional mesons while baryon-antibaryon pairs are produced closer in rank.

As a result, positive correlation is expected for baryon-antibaryon pairs and anti-correlation is expected for (anti)baryon-(anti)baryon pairs in the string model.

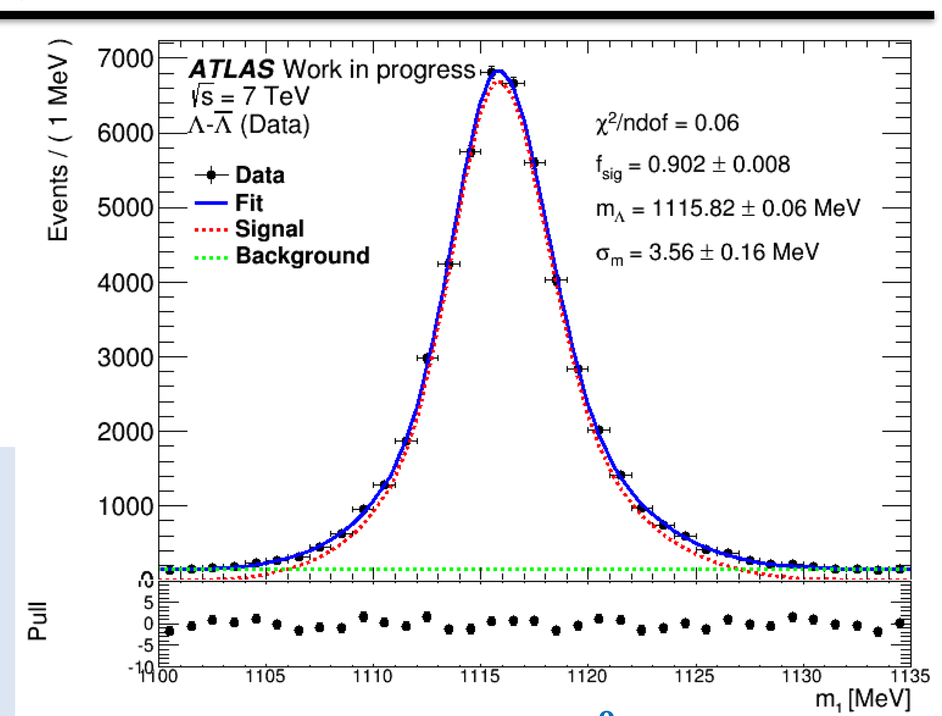
The left figure shows a string fragments into a stream of mesons and baryons.

Data and event selection

- Muon and minimum bias stream datasets from 2010 and 20M minimum bias MC sample are used in this analysis.
- Long-lived 2-prong decay candidates are reconstructed using the standard ATLAS V^0 finder package in default setting.

A brief summary of selection criteria is listed below:

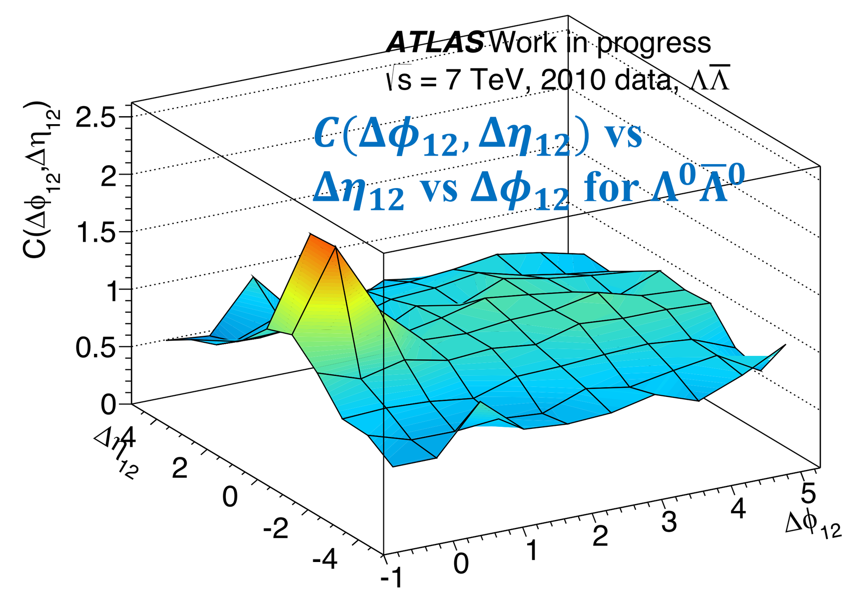
- **$m(p,\pi) \in [1100, 1135]$ MeV**
- **Vertex χ^2 prob. > 0.05**
- **Hits $_{\text{Pixel+SCT}}$ > 3 per track**
- **Fraction of high threshold TRT hits < 0.14**
- **Veto $m(e,e) \in [0, 75]$ MeV**
- **Veto $m(\pi,\pi) \in [480, 515]$ MeV**
- **L_{xy} > 15 mm**
- **$L_{xy}/\sigma_{L_{xy}}$ > 15**
- **a_0/σ_{a0} < 3**

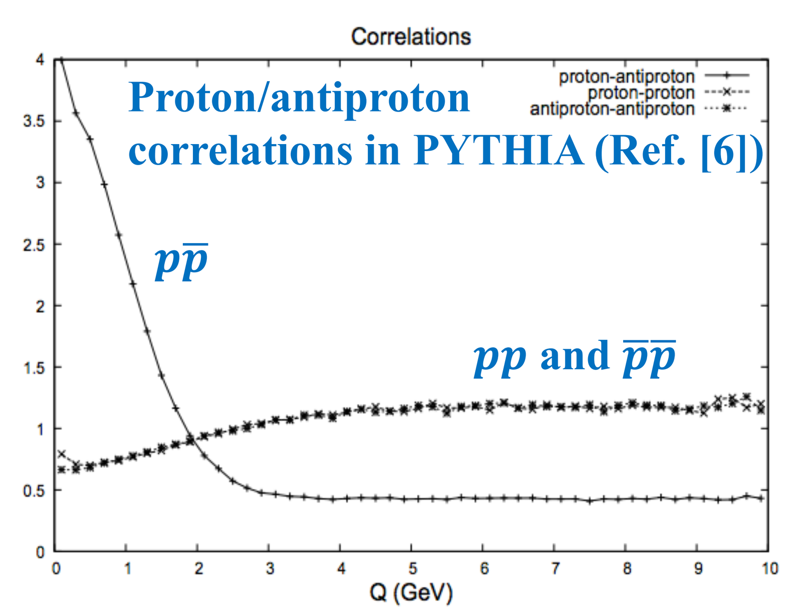


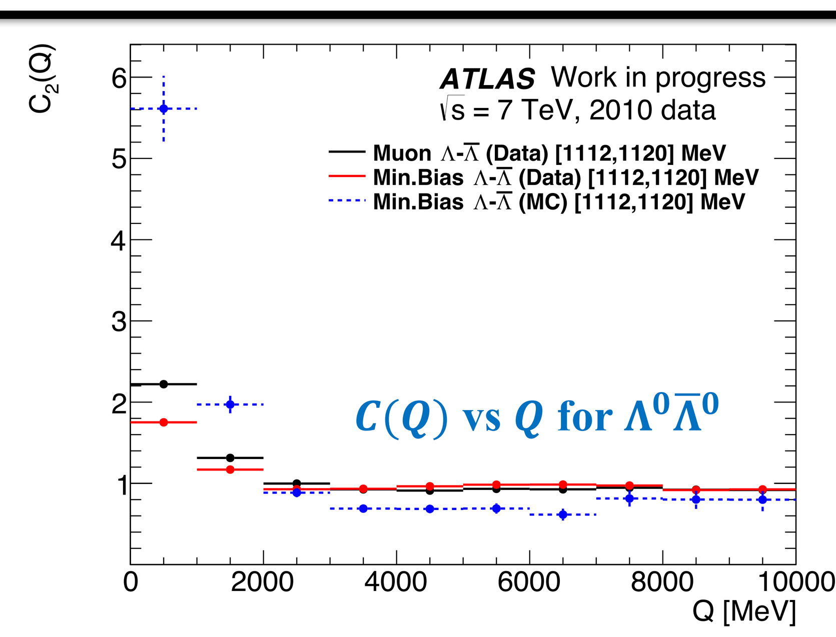
Invariant mass of Λ^0 hyperon

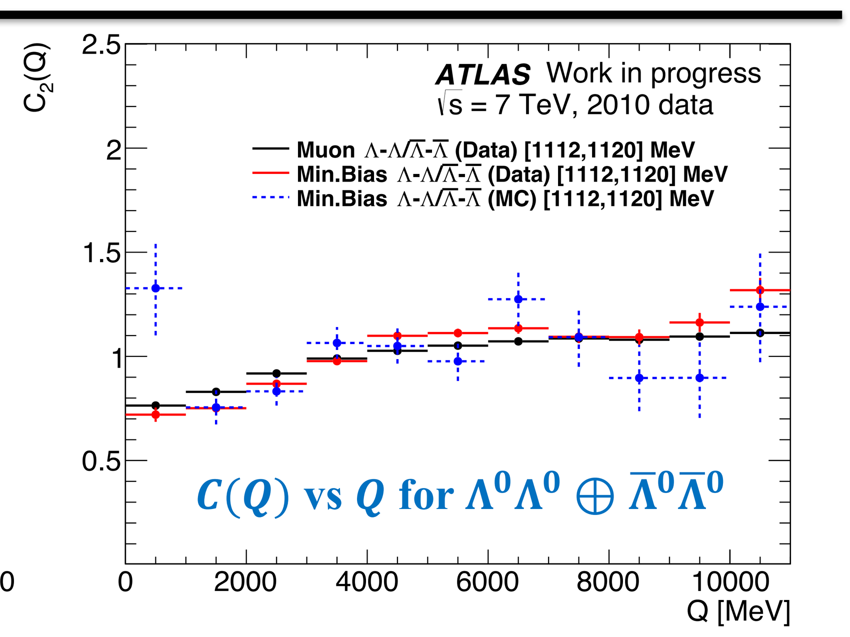
Dynamical correlation

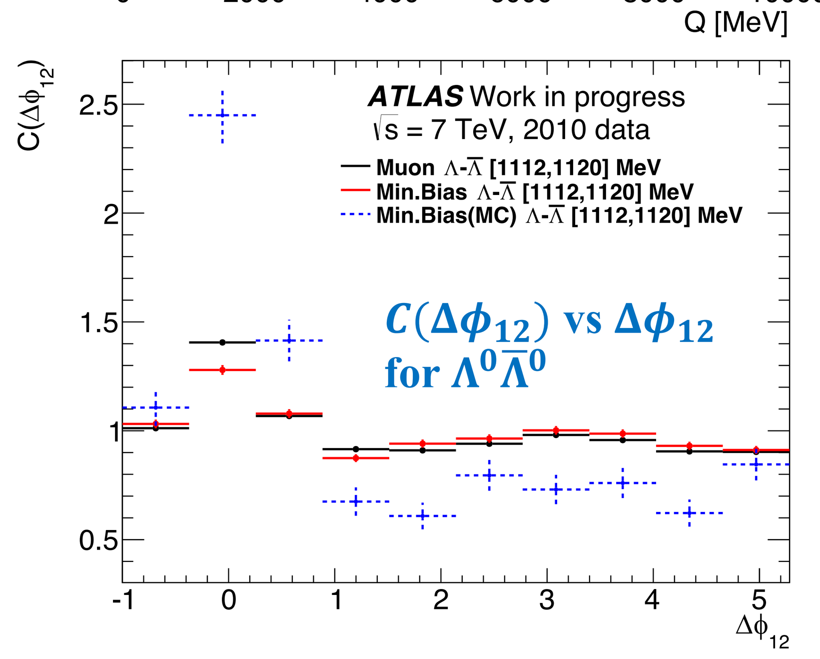
The correlation function is defined as the differential cross-section ratio $C(p_1, p_2) = \frac{S(p_1,p_2)}{B(p_1,p_2)}$ where $S(p_1,p_2) = \frac{1}{N_{exp}}\frac{d^2N_{exp}}{dp_1dp_2}$ and $B(p_1,p_2) = \frac{1}{N_{mix}}\frac{d^2N_{mix}}{dp_1dp_2}$. N_{exp} is the number of hyperon pairs selected from the same event and N_{mix} is the number of uncorrelated hyperon pairs created by mixing candidates from different events.

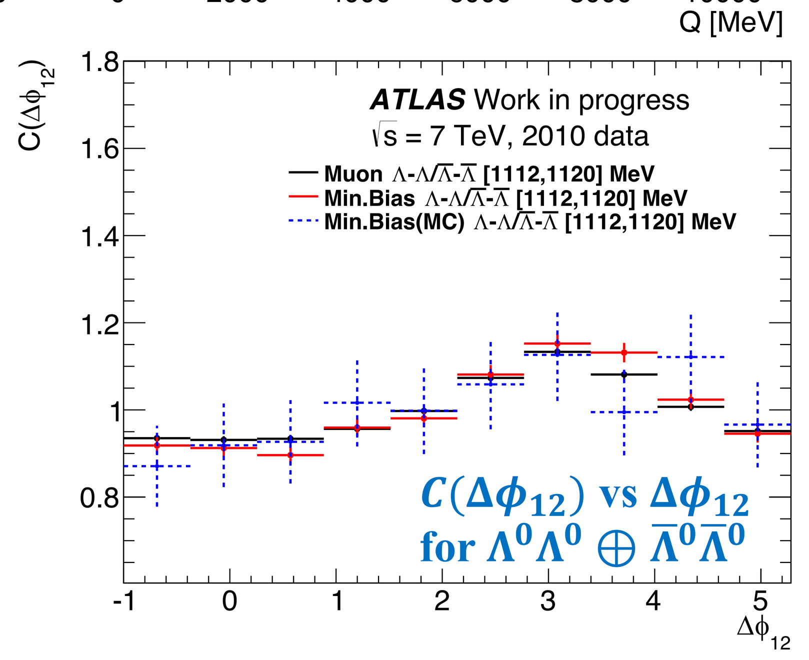












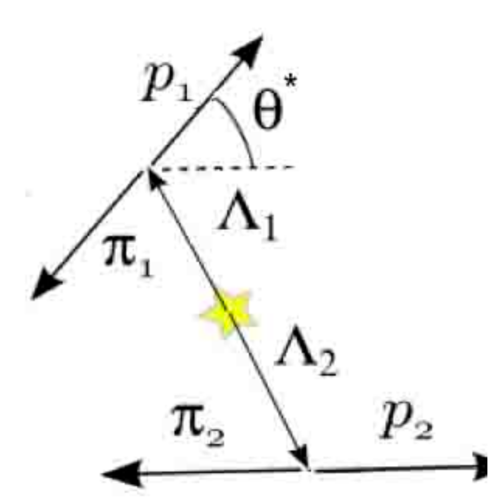
The results are compared with predictions from Monte Carlo sample generated by PYTHIA 6.421 event generator using the ATLAS minimum bias tune (AMBT1) and MRST2007LO parton distribution functions. The positive correlation of the $\Lambda^0\bar{\Lambda}^0$ events in small Q and $\Delta\phi$ is overestimated by the MC sample. For $\Lambda^0\Lambda^0 \oplus \bar{\Lambda}^0\bar{\Lambda}^0$ events, data results are consistent with MC predictions displaying similar anti-correlation at small Q and $\Delta\phi$. Similar correlations observed in di-proton/antiproton system predicted by PYTHIA may suggest that the correlations observed is universal to baryon/antibaryon production in the Lund string model.

Spin correlation

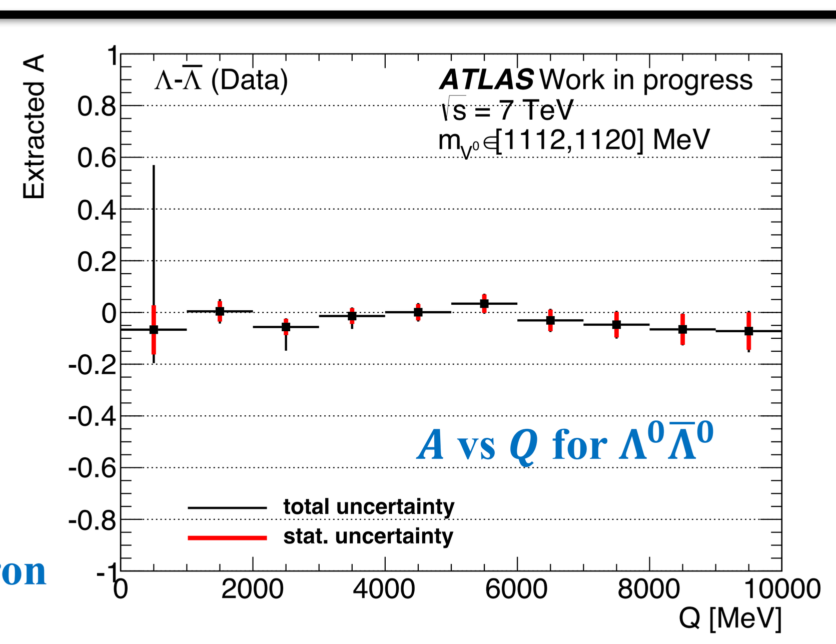
The spin correlation affects the decay angle between the decay (anti)proton in the center-of-mass frame of the hyperon pairs, as shown in the right figure.

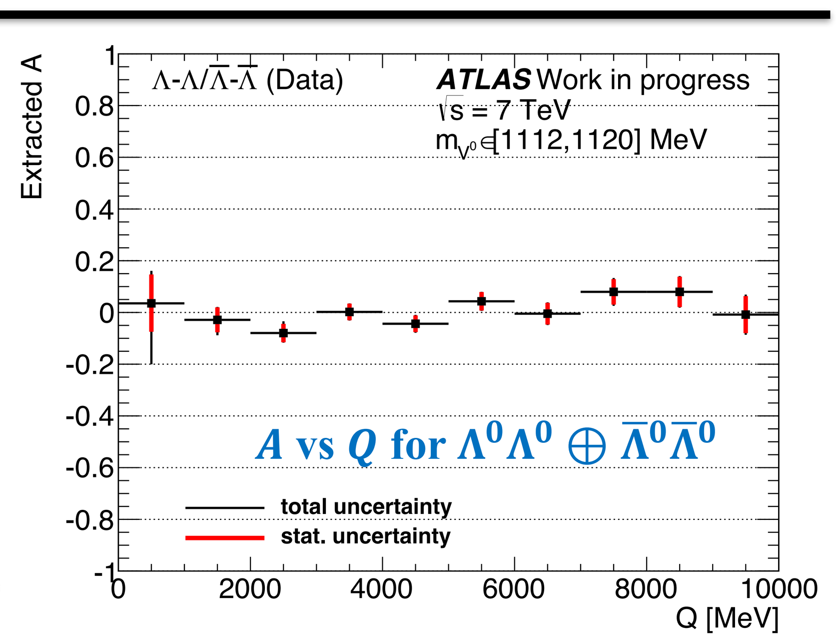
The probability distribution of the cosine of the decay angle is given by $w(cos\theta^*) = \frac{1}{4}(1 \pm A\alpha^2 cos\theta^*)$ where $A = (N_{aligned} - N_{antialigned})/N_{total}$ and $\alpha = 0.642 \pm 0.013$. The A-value of the data sample is extracted by minimizing the χ^2-statistics with templates built by weighting the decay angle distribution $cos\theta^*$ of an uncorrelated event mixing sample.

The results are consistent with zero for $\Lambda^0\bar{\Lambda}^0$ events in $Q \in [1,10]$ GeV and for $\Lambda^0\Lambda^0 \oplus \bar{\Lambda}^0\bar{\Lambda}^0$ events in $Q \in [0,10]$ GeV. The large systematic uncertainty for $\Lambda^0\bar{\Lambda}^0$ events in $Q \in [0,1]$ GeV is due to kinematic weighting of reference sample.



Decay angle θ^* of di-hyperon in the helicity frame





References

[1] ALICE Collaboration, *Insight into particle production mechanisms via angular correlations of identified particles in pp collisions at √s = 7 TeV*, **arXiv:1612.08975 [ucl-ex]** (2016) **[2]** OPAL Collaboration, *A First Measurement of the ΛΛ̄ and ΛΛ(Λ̄Λ̄) Spin Compositions in Hadronic Z⁰ Decays*, **CERN-PPE-96-068**, (1996) **[3]** DELPHI Collaboration, *Production of Λ and Λ̄ correlations in the hadronic decays of the Z⁰*, **CERN-PPE-93-171** (1993) **[4]** ALEPH Collaboration, *Fermi-Dirac Correlations in Λ Pairs in Hadronic Z⁰ Decays*, **CERN-EP-99-172** (1999) **[5]** C. Blanks, *Strangeness at LHCb*, http://imperialhep.blogspot.hk/2011/08/strangeness-at-lhcb.html (2011) **[6]** R. M. Duran Delgado, G. Gustafson, and L. Lonnblad, *String Effects on Fermi-Dirac Correlation Measurements*, **arXiv:0702241 [hep-ph]** (2007)

Hok-Chuen Cheng (University of Michigan) hccheng@umich.edu