Measurement of correlation of Λ pairs with the ATLAS detector

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Introduction

Λ^0 (uds) Lightest baryon containing a strange quark

Mass = 1115.683 +/- 0.006 MeV

Mean life = (2.632 +/- 0.020) x 10^{-10} s

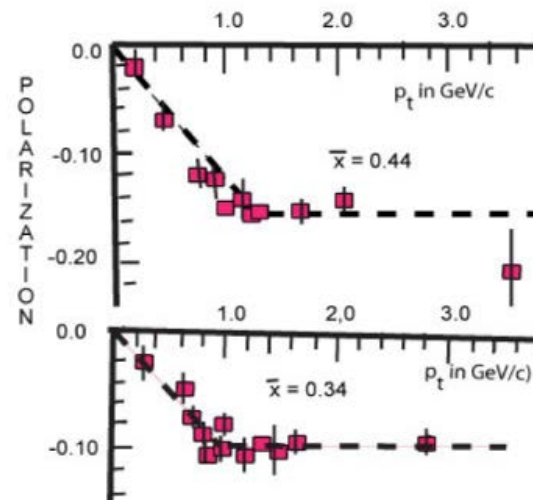**Parity-violating decay parameter** ← **First measured at UMich!**

α = 0.642 +/- 0.013 (Λ^0 -> pπ^-)

Major decay channels

$\mathcal{BR}$ (Λ^0 -> pπ^-) = (63.9 +/- 0.5)%

$\mathcal{BR}$ (Λ^0 -> nπ^0) = (35.8 +/- 0.5)%

Unresolved polarization puzzle

Some recent hyperon measurements at ATLAS

➢ Λ^0 and anti-Λ^0 polarization (**arXiv:1412.1692**)

➢ K_s and Λ^0 production (**arXiv:1111.1297**)

➢ α_b parity-violating asymmetry parameter and helicity amplitude for Λ^0_b decay (**arXiv:1404.1071**)
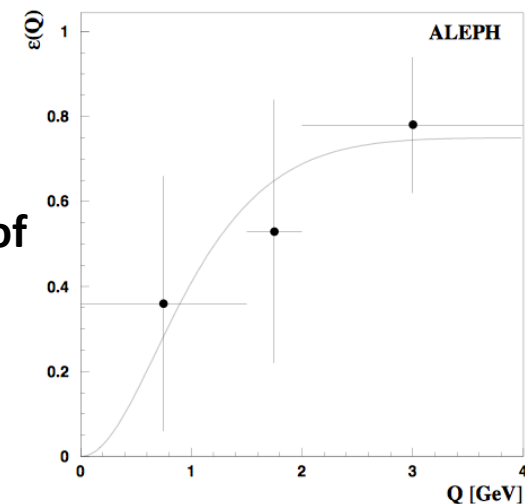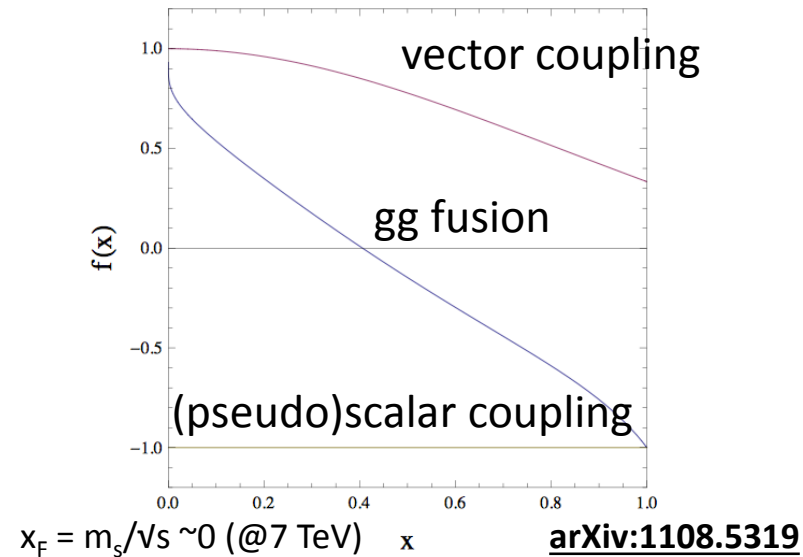
Source: PDG booklet (2012)

Motivation

- As a probe to ssbar and hence **quark-antiquark pair production**, e.g. Lund string model (arXiv:1108.5319)

- Previous measurements carried out at OPAL, DELPHI, SELEX and ALEPH at lower energies

- **Fermi-Dirac correlation** (identical fermions in vicinity forbidden to be in the same quantum state) between like-type Λ^0 hyperon pairs observed

Correlation function f(x)

vector coupling

gg fusion

(pseudo)scalar coupling

$x_F = m_s/\sqrt{s} \sim 0$ (@7 TeV)   x   **arXiv:1108.5319**

ALEPH

Suppression of S = 1 state

Q [GeV]

Decay angles

Decays:

$$\Lambda^0 \to p\pi^-, \ \bar{\Lambda}^0 \to \bar{p}\pi^+$$

Single particle decay angle PDF:

$$w(\cos\theta^*) = \frac{1}{2}\left(1 + \alpha P \cos\theta^*\right)$$
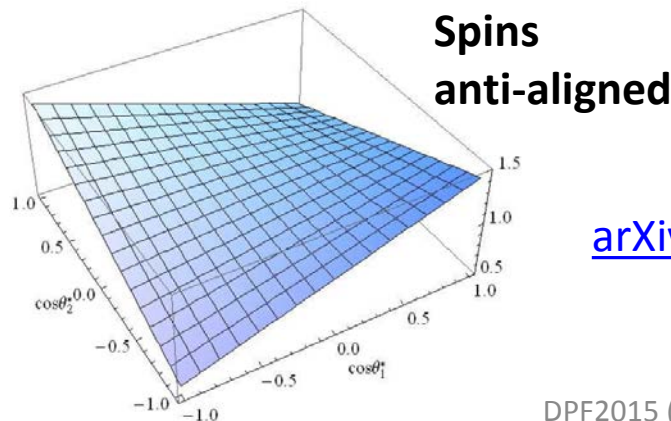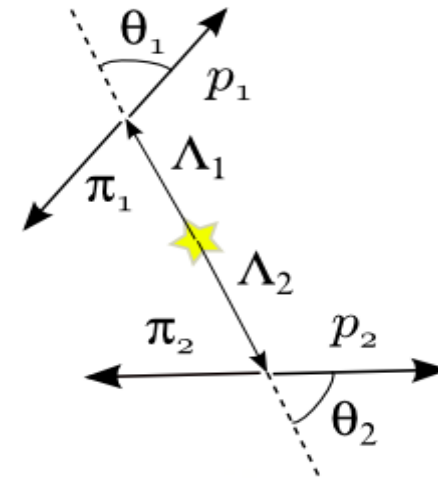
α: **parity-violation decay parameter**
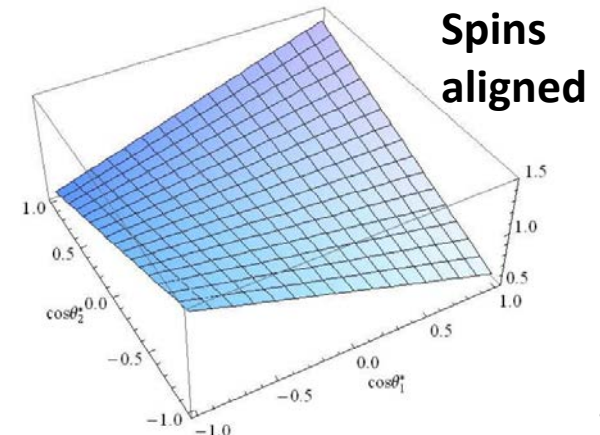*P*: **polarization in the direction of parent**

2D joint decay angles PDF:

$$\frac{d^2 N}{d\cos\theta_1 d\cos\theta_2} = \frac{N_{totol}}{4}\left(1 + P_1\alpha\cos\theta_1\right)\left(1 - P_2\alpha\cos\theta_2\right) \ \text{ for } \Lambda^0 \ \bar{\Lambda}^0$$

Spins anti-aligned: (P_1, P_2) = (1, 1) or (-1, -1) ➜ **PDF** $\propto \left(1 - \alpha^2 \cos\theta_1 \cos\theta_2\right)$

Spins aligned: (P_1, P_2) = (1, -1) or (-1, 1) ➜ **PDF** $\propto \left(1 + \alpha^2 \cos\theta_1 \cos\theta_2\right)$

Spins anti-aligned

Spins aligned

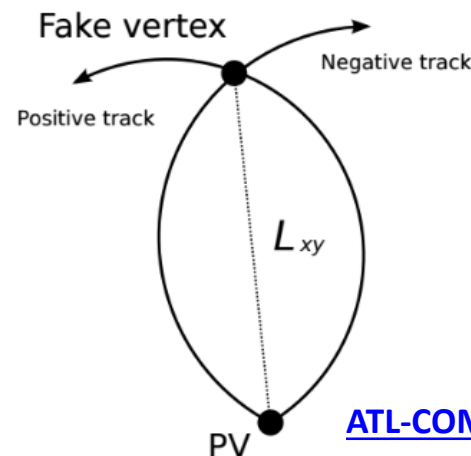

arXiv:1108.5319

Data and event selection

Data sample

- Data 2010, √s = 7 TeV, collected at ATLAS
- Muon stream with trigger selection removed to maximize data statistics

Reconstruction and Selection

- ATLAS `V0Finder` is used to reconstruct secondary vertex
- Λ^0 invariant mass, track quality,

γ removal, K_s removal, A_0 and L_{xy} cuts
(See backup for more details)

ATL-COM-PHYS-2011-1672

Λ^0 invariant mass after selection

Selection results

| V⁰ type	$\Lambda^0 \bar{\Lambda}^0$	$\Lambda^0 \Lambda^0$	$\bar{\Lambda}^0 \bar{\Lambda}^0$	$\Lambda^0 \bar{\Lambda}^0$
	(Selected from same event)			(uncorrelated)
Events	295k	140k	114k	4.9M
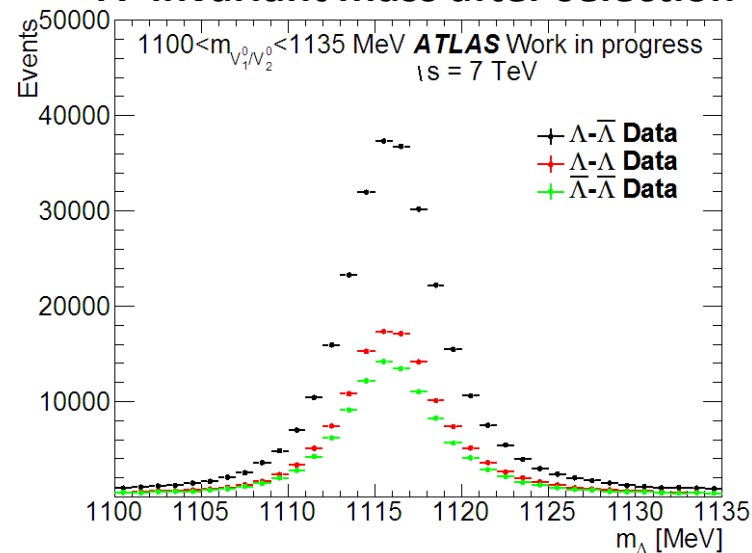
Analysis strategy

1. Build data-driven templates for different A's using uncorrelated sample, weighted by the factor $(1 - A_{True}\alpha^2\cos\theta_1^{reco}\cos\theta_2^{reco})$

2. Templates are weighted to kinematics of data iteratively

3. Correlation parameter $\langle\cos\theta_1\cos\theta_2\rangle - \langle\cos\theta_1\rangle\langle\cos\theta_2\rangle$ is calculated for data and templates
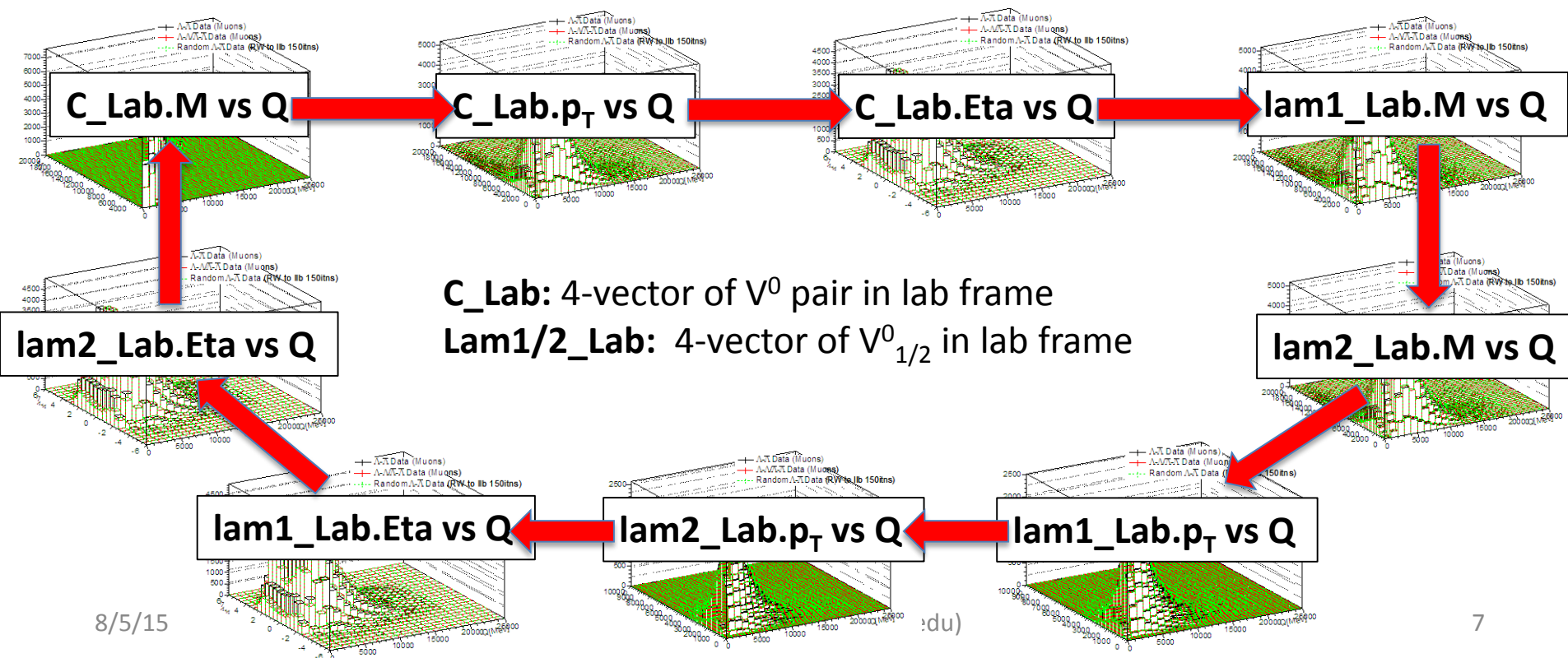
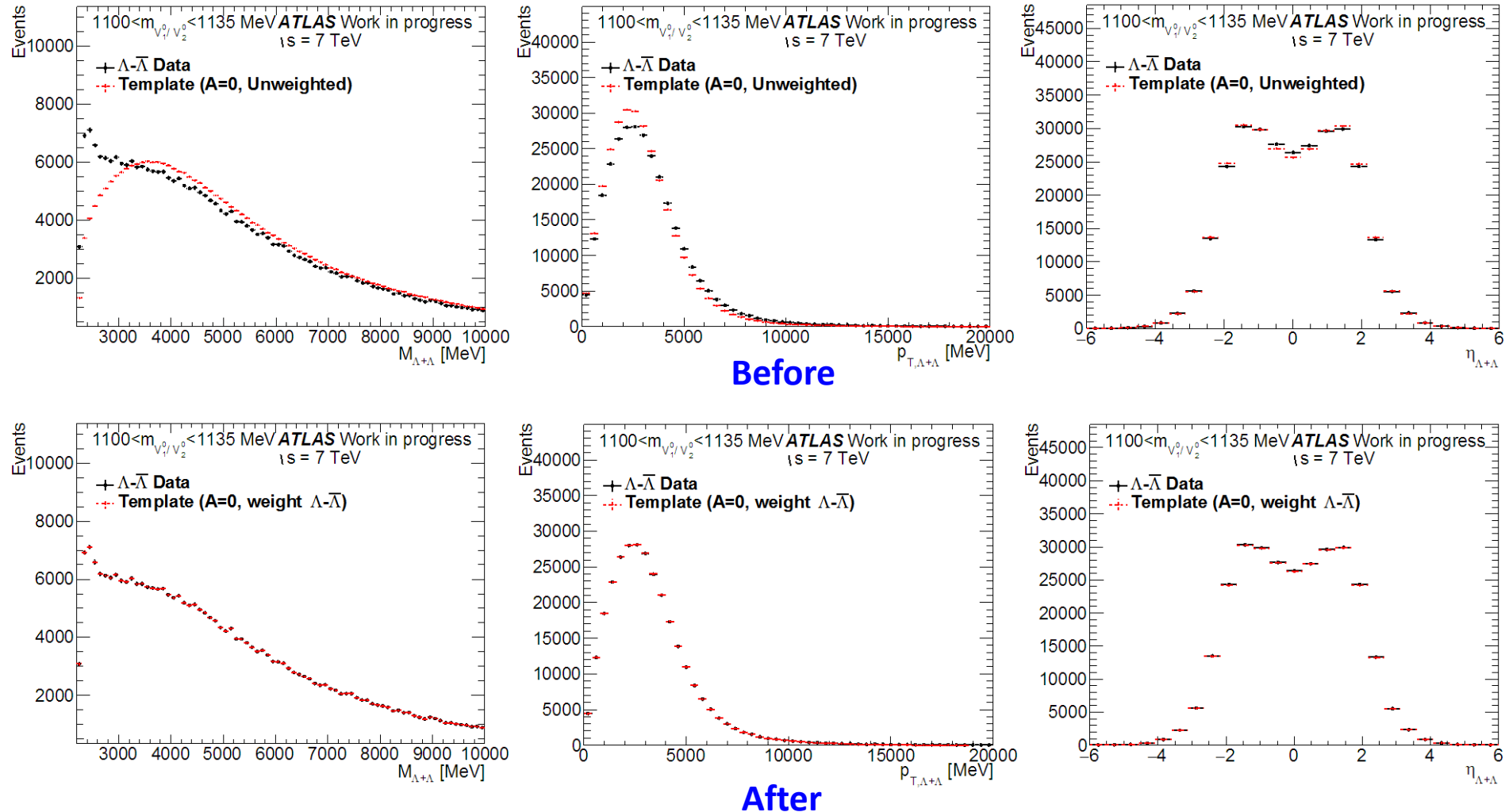4. A is extracted from data as a function of Q
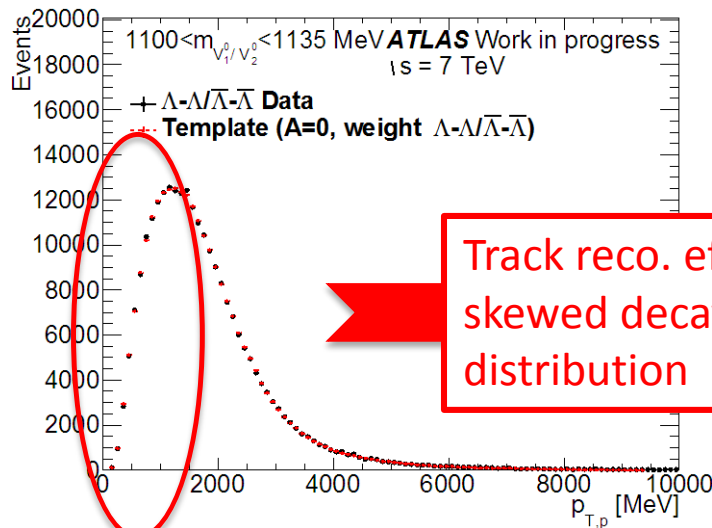
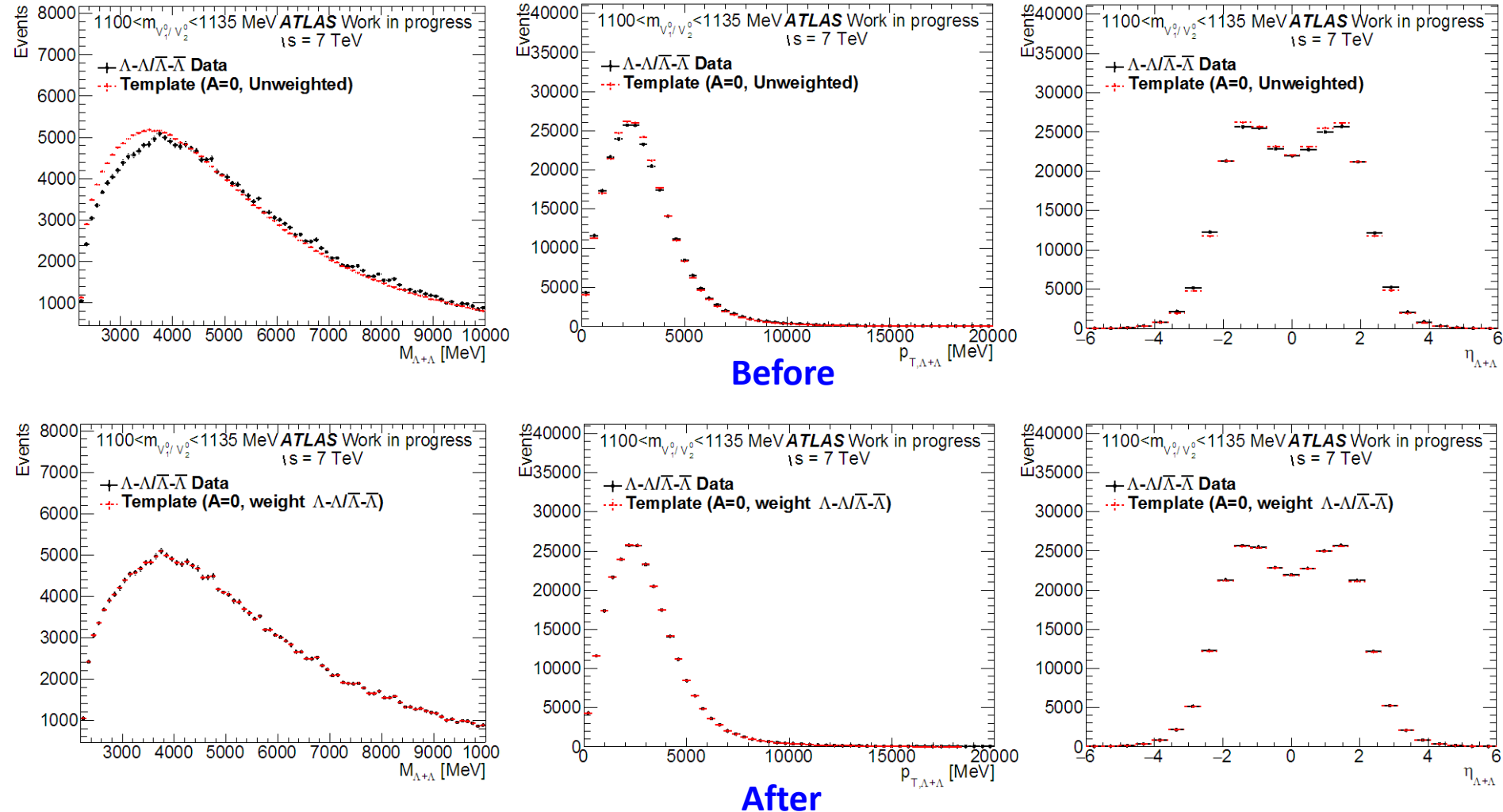Track reco. efficiency skewed decay angle distribution
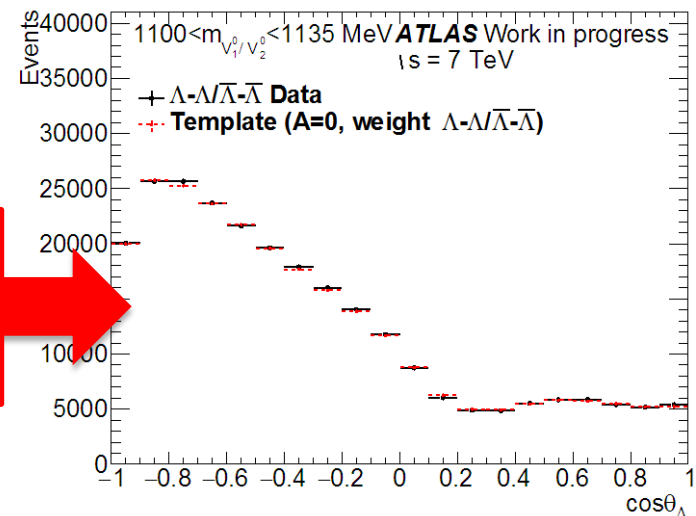
Iterative weighting

- Detector effects depend on kinematics of V^0 pairs -> affect efficiency and acceptance as well as value of corr. para.
- 9 variables listed below were used to weight templates to data in bins of relative 4-momenta Q

C_Lab.M vs Q → **C_Lab.p_T vs Q** → **C_Lab.Eta vs Q** → **lam1_Lab.M vs Q**

C_Lab: 4-vector of V^0 pair in lab frame
Lam1/2_Lab: 4-vector of $V^0_{1/2}$ in lab frame

lam2_Lab.Eta vs Q

lam2_Lab.M vs Q

lam1_Lab.Eta vs Q ← **lam2_Lab.p_T vs Q** ← **lam1_Lab.p_T vs Q**

Kinematics before and after weighting

Before

After

Kinematics before and after weighting

Before

After

Correlation parameter vs Q

- Correlation parameter defined as

  $$<\cos\theta_1\cos\theta_2> - <\cos\theta_1><\cos\theta_2>$$

- Calculated for data and template as a function of relative 4-momenta Q (**Right**)

- Structure caused by track p_T threshold (**Below:** test with toy MC for diff. cuts)
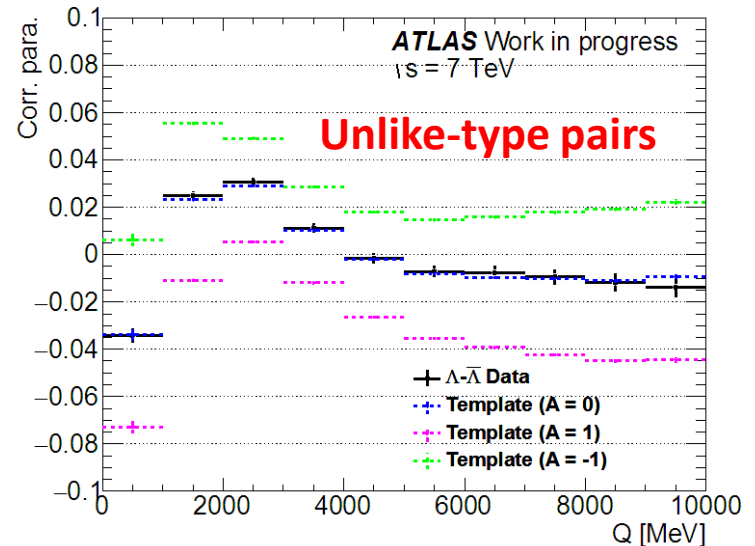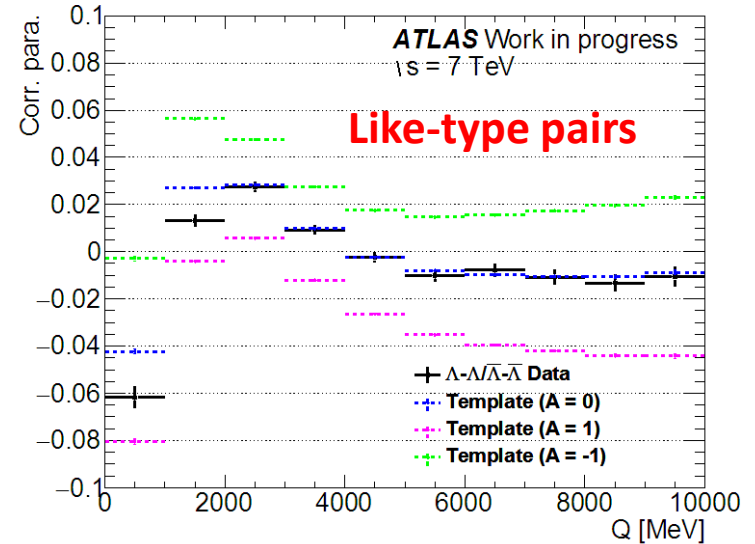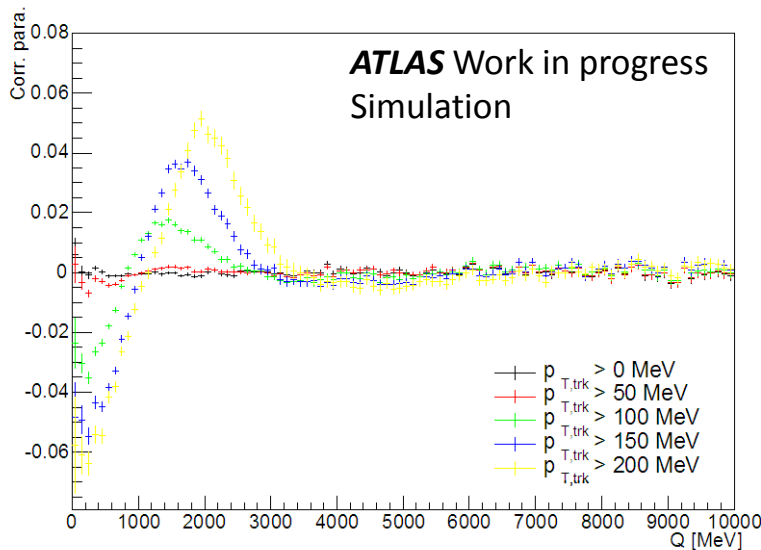
Extraction of A

- **Bin-by-bin** extraction of A, quadratic interpolation between templates
- A is extracted by looking for A_{True} where data and template interpolation curves cross (**Green arrow below**)
- Data and template statistical uncertainties computed by varying corr. para. of **data** and **templates** up and down by 1 σ respectively
- More templates at different A values to finalize our results

0 < Q < 1000 (MeV)
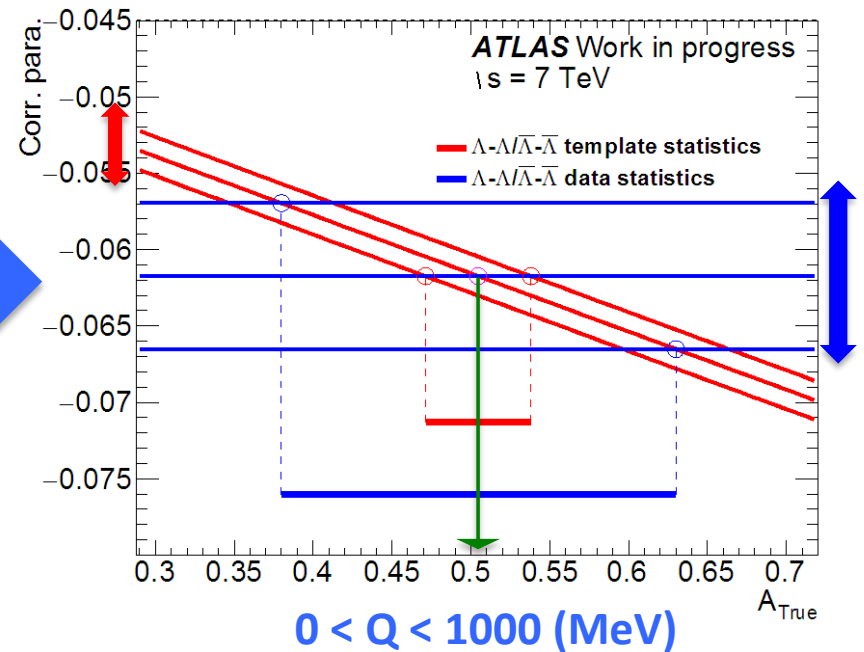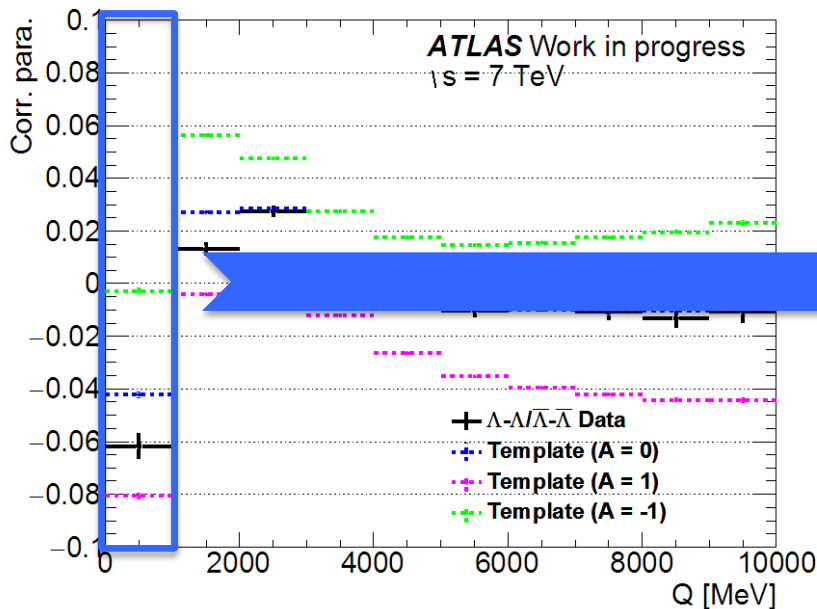
Extraction of A (Con't)

- **Unlike-type:** all consistent with A = 0 within statistical uncertainty for 0<Q<10 GeV **(Top right plot)**

- **Like-type:** deviation from A = 0 for Q<2 GeV **(Bottom right plot)**

- Data and template statistics added in quadrature
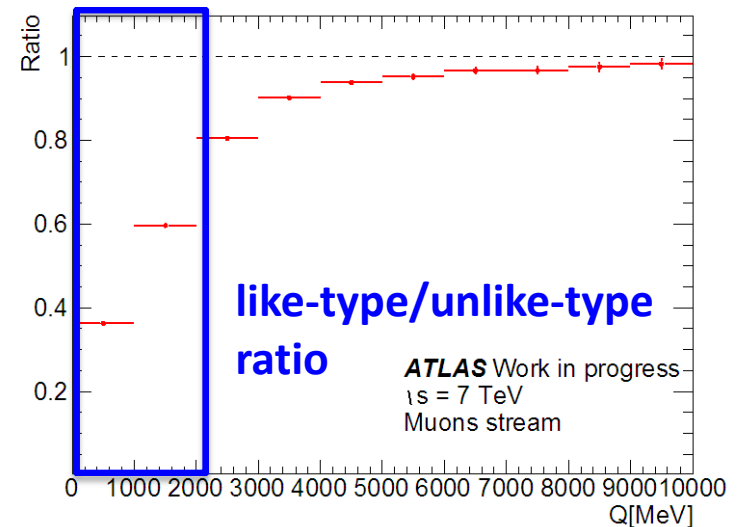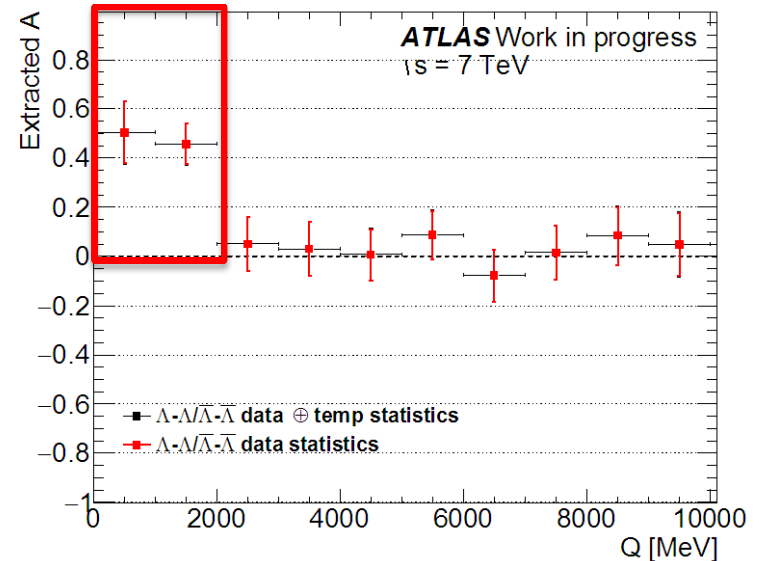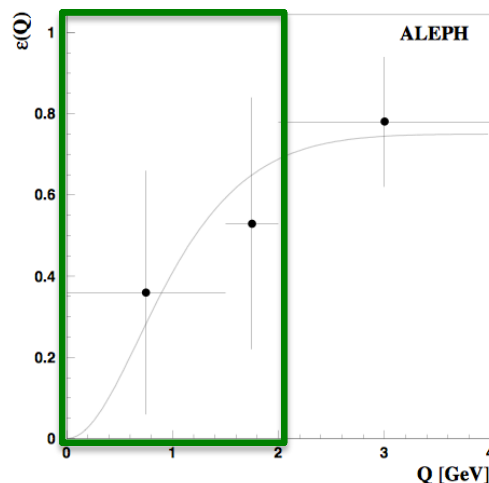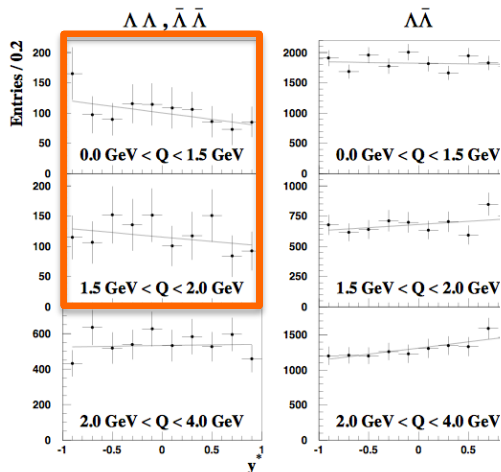
- Uncertainty dominated by data statistics
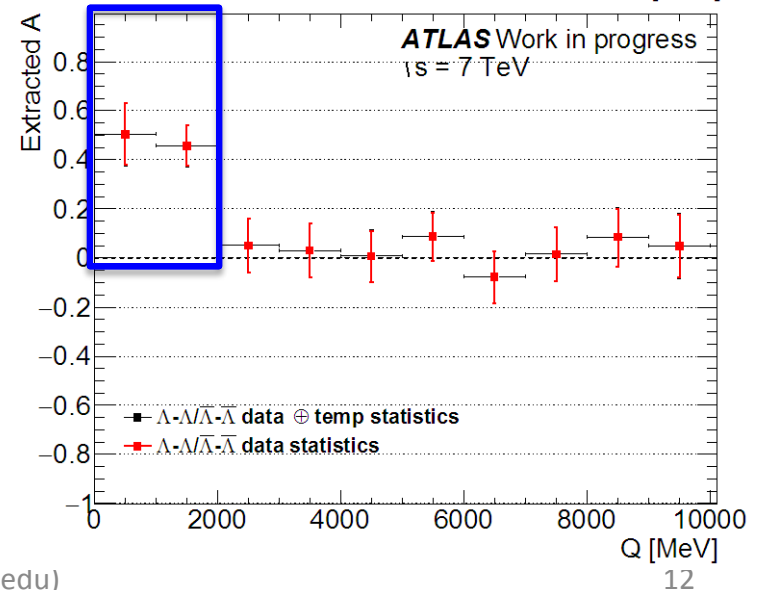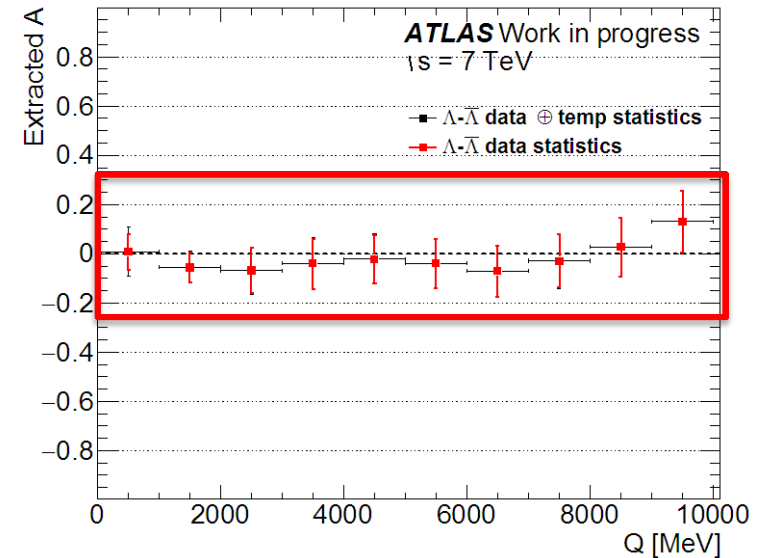
Fermi-Dirac correlation

Our results (Right)

- Non-zero correlation for Q<2 GeV
- Depletion of differential XS for like-type events
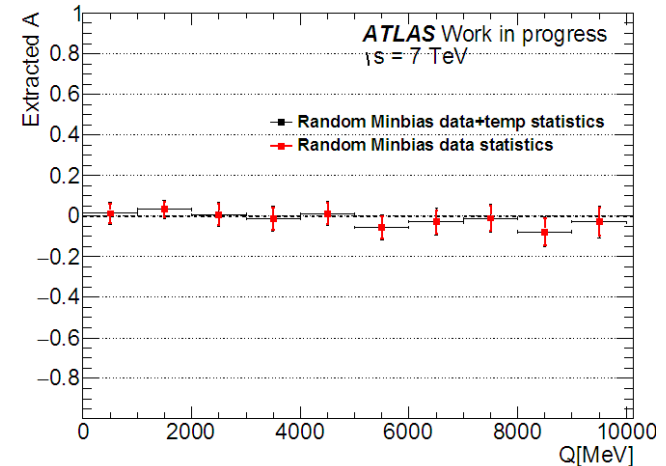
ALEPH results (Below)

- Non-zero correlation for like-type events for Q<2 GeV
- Suppression of S=1 state

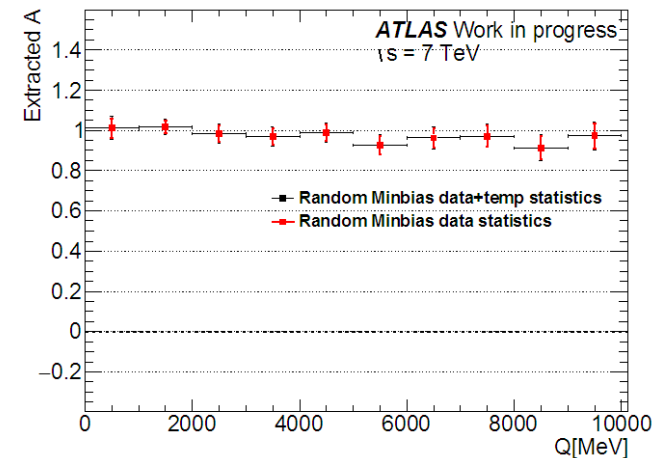**like-type/unlike-type ratio**

Systematic uncertainties

Ongoing work on systematics:

- **Template statistics ✓**

- **Kinematic weighting**

- Decay angle resolution

- Background

- Histogram binning

- Track p_T resolution

- Track p_T scale

- Uncertainty of α parameter

Tested effect of **kinematic weighting** on uncorrelated (above) minbias sample and one weighted to A = 1 (below)

Summary

- No correlation observed for $\Lambda^0 \bar{\Lambda}^0$ pairs, consistent with previous measurements
- Hints of **non-zero correlation between like-type Λ^0 hyperon pairs** in small **Q(< 2 GeV)** region
- **Fermi-Dirac suppression** observed for like-type Λ^0 hyperon pairs in the same region
- Ongoing work on systematic uncertainties
- Many other new hyperon physics results coming from ATLAS soon! (ATLAS SoftQCD public results)
- Stay tuned!

BACKUP

DPF2015 (hccheng@umich.edu)
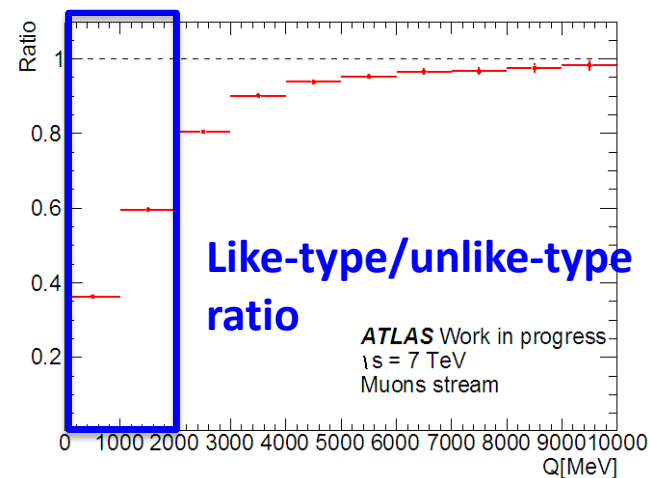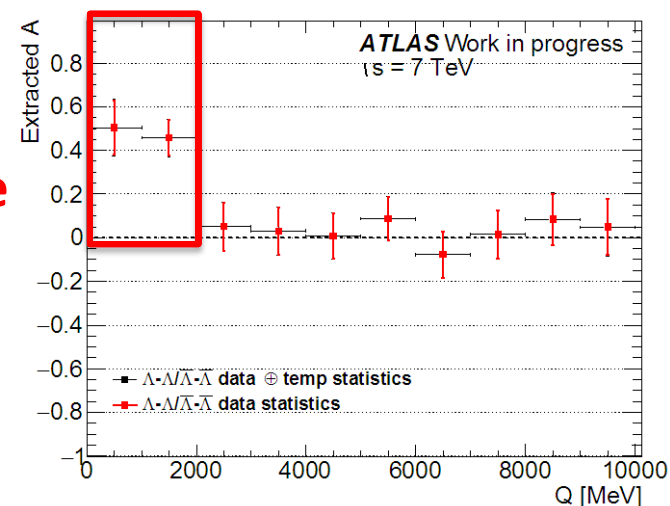
- Two dimensional decay distribution:
    - $\frac{d^2 N}{d\cos\theta_1 \, d\cos\theta_2} = \frac{N_{total}}{4}(1 + P_1\alpha\cos\theta_1)(1 - P_2\alpha\cos\theta_2)$
    - where $\alpha = 0.642 \pm 0.013$.

- For production via scalar $^3P_0$ or pseudoscalar $^1S_0$ coupling, the spins will be antialigned and we have either $P_1 = 1$, $P_2 = 1$ or $P_1 = -1$, $P_2 = -1$.
    - $\propto (1 - \alpha^2 \cos\theta_1 \cos\theta_2)$

- For production via vector coupling, the spins will be aligned and we have either $P_1 = 1$, $P_2 = -1$ or $P_1 = -1$, $P_2 = 1$
    - $\propto (1 + \alpha^2 \cos\theta_1 \cos\theta_2)$

- Hence, we define A as follow:
    - $w(\cos\theta_1, \cos\theta_2) = 1 + A\alpha^2 \cos\theta_1 \cos\theta_2$
   - where $A = \frac{N_{aligned} - N_{antialigned}}{N_{total}}$.

Λ^0 Selection

- Selection criteria for Λ^0 and $\overline{\Lambda^0}$
    - $1100\,MeV < M_\Lambda < 1135\,MeV$
    - $0.05 < \chi^2$ probability < 1
    - Number of Pixel and SCT hits on both track greater than 3
    - $A_0 < 3$
    - Fraction of the TRT high threshold hits < 0.14
    - Gamma Removal: $M_{\gamma\gamma} < 75\,MeV$
    - Ks Removal: $480\,MeV < M_{\pi\pi} < 515\,MeV$
    - $L_{xy} > 15\,mm$
    - $L_{xy}/\sigma_{L_{xy}} > 15$
- Selection criteria for candidate events
    - At least one Λ^0 and one $\overline{\Lambda^0}$ in each event.

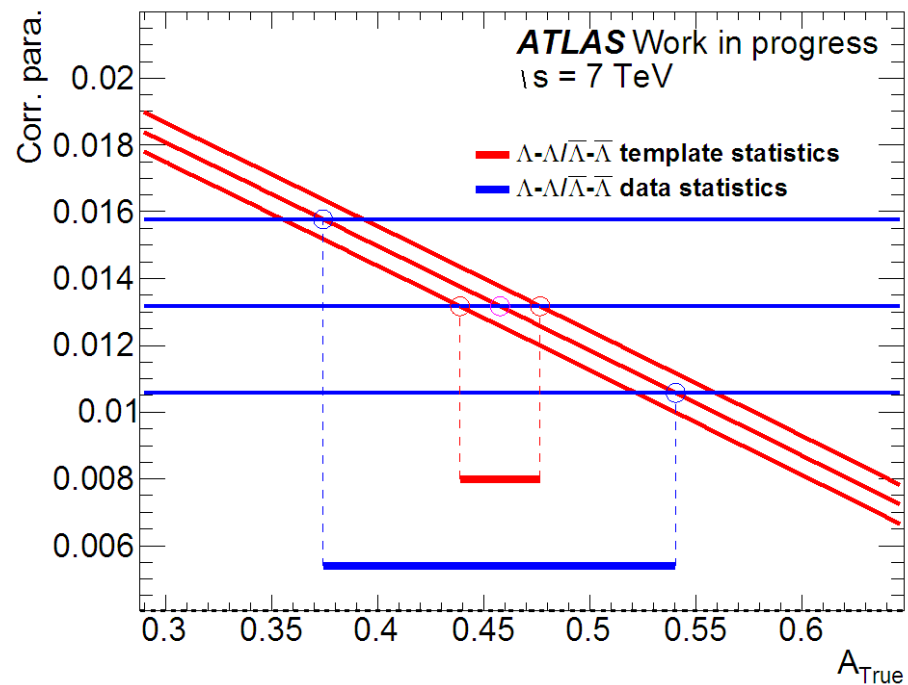# Kinematic distributions
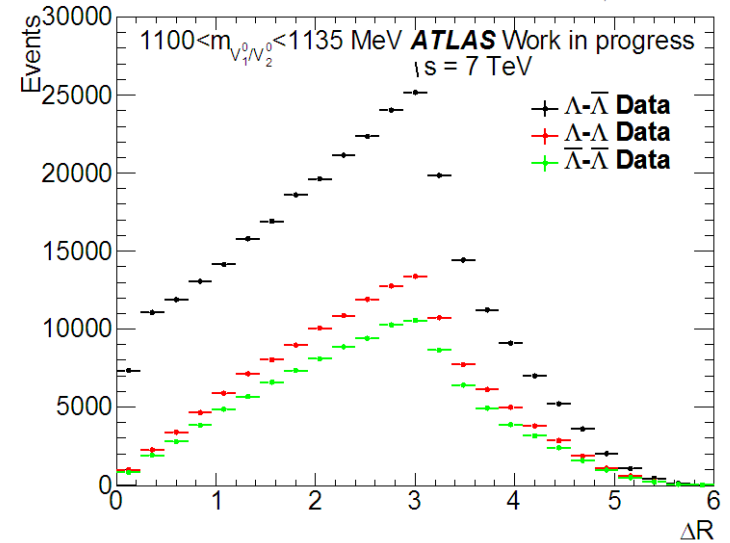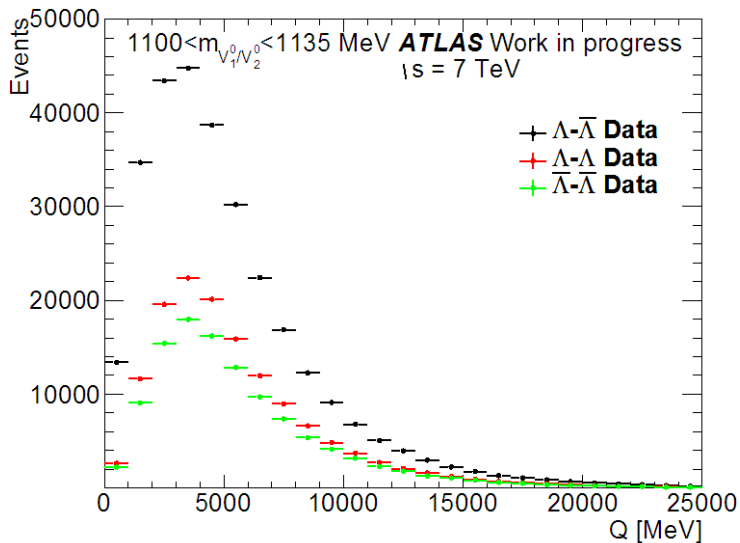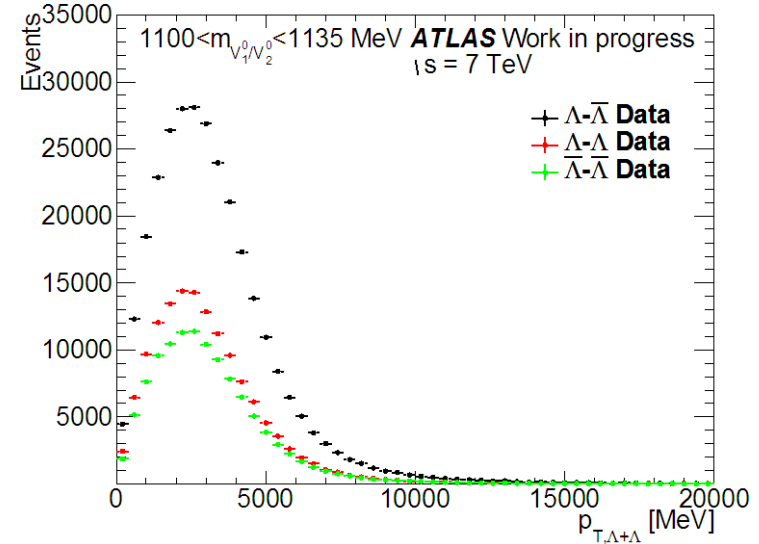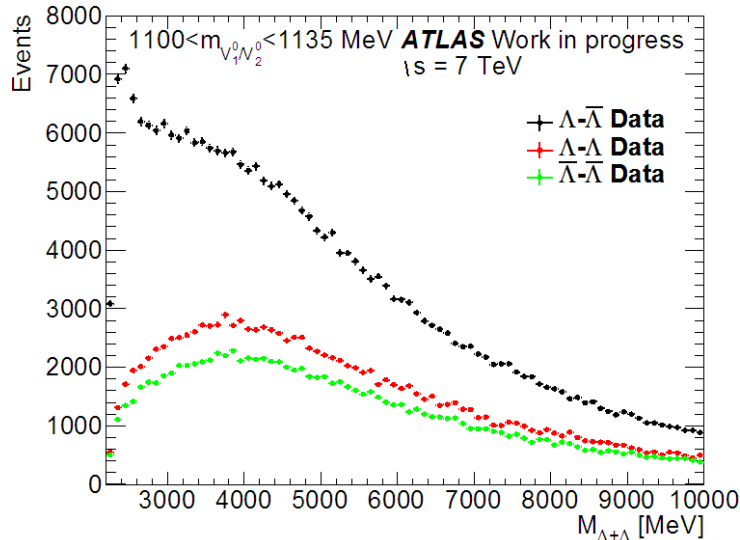
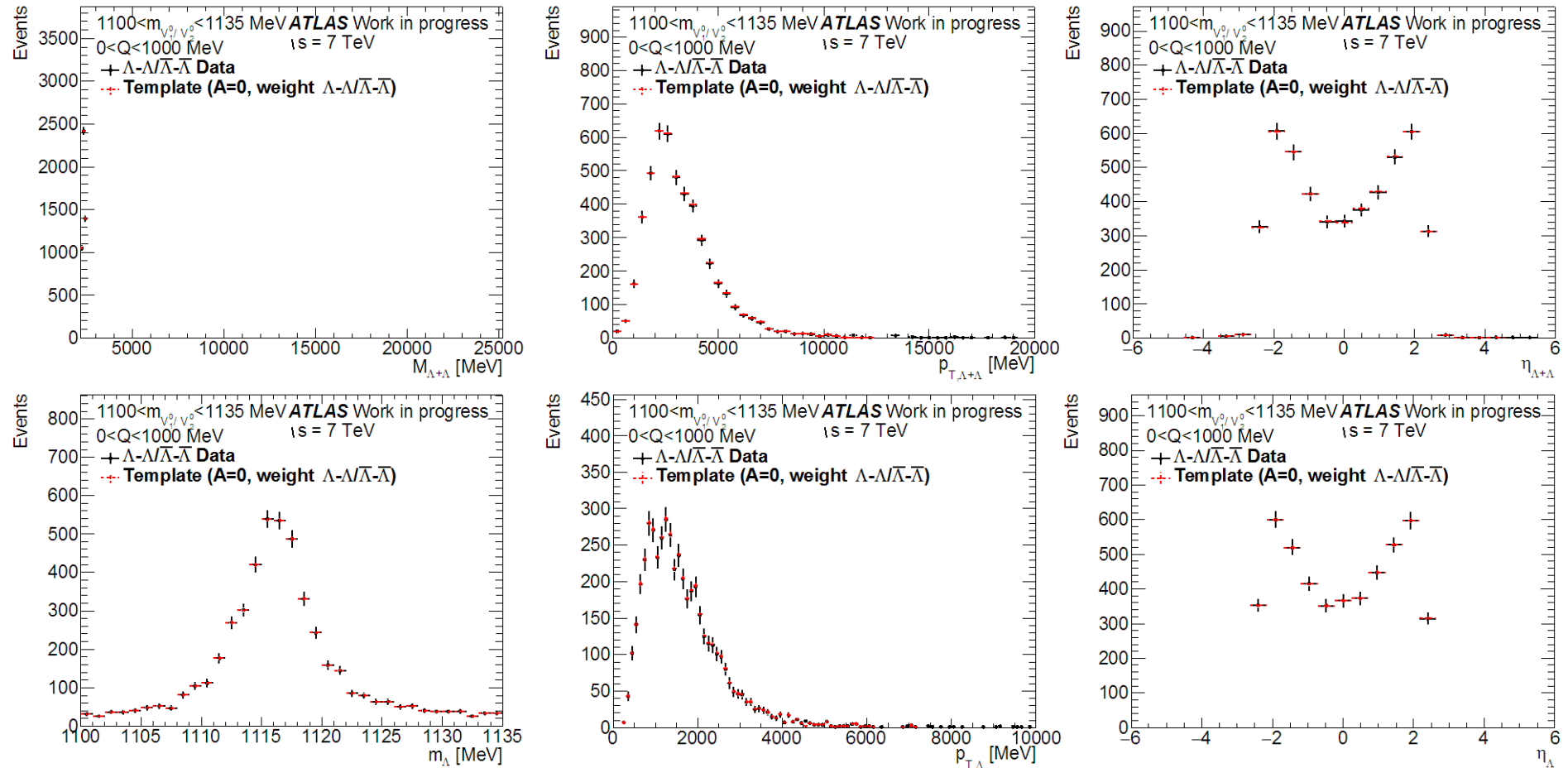# Extraction of A in first two bins (Q<2GeV) for like-type hyperon pairs
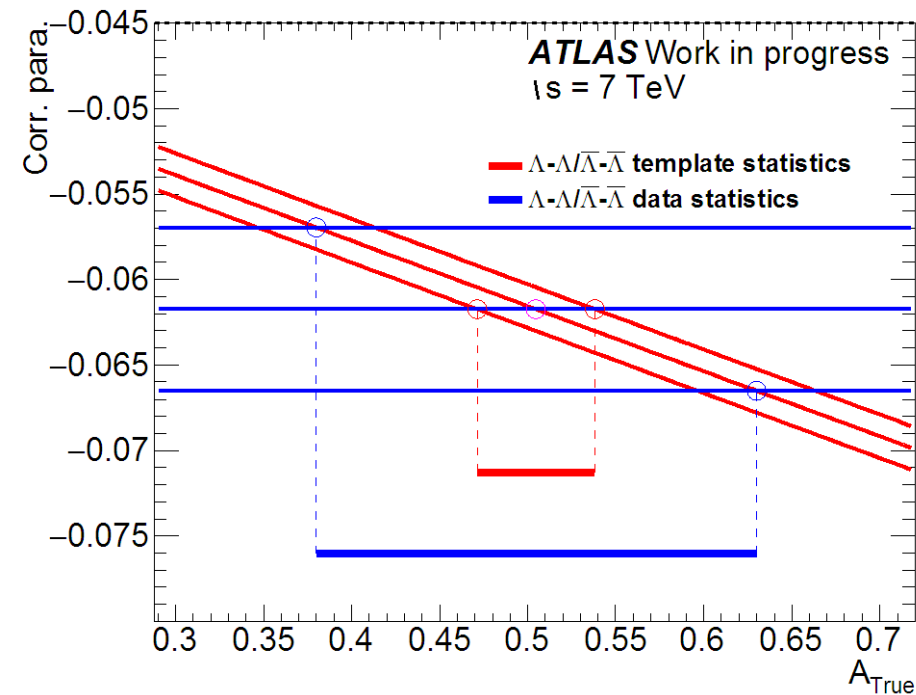
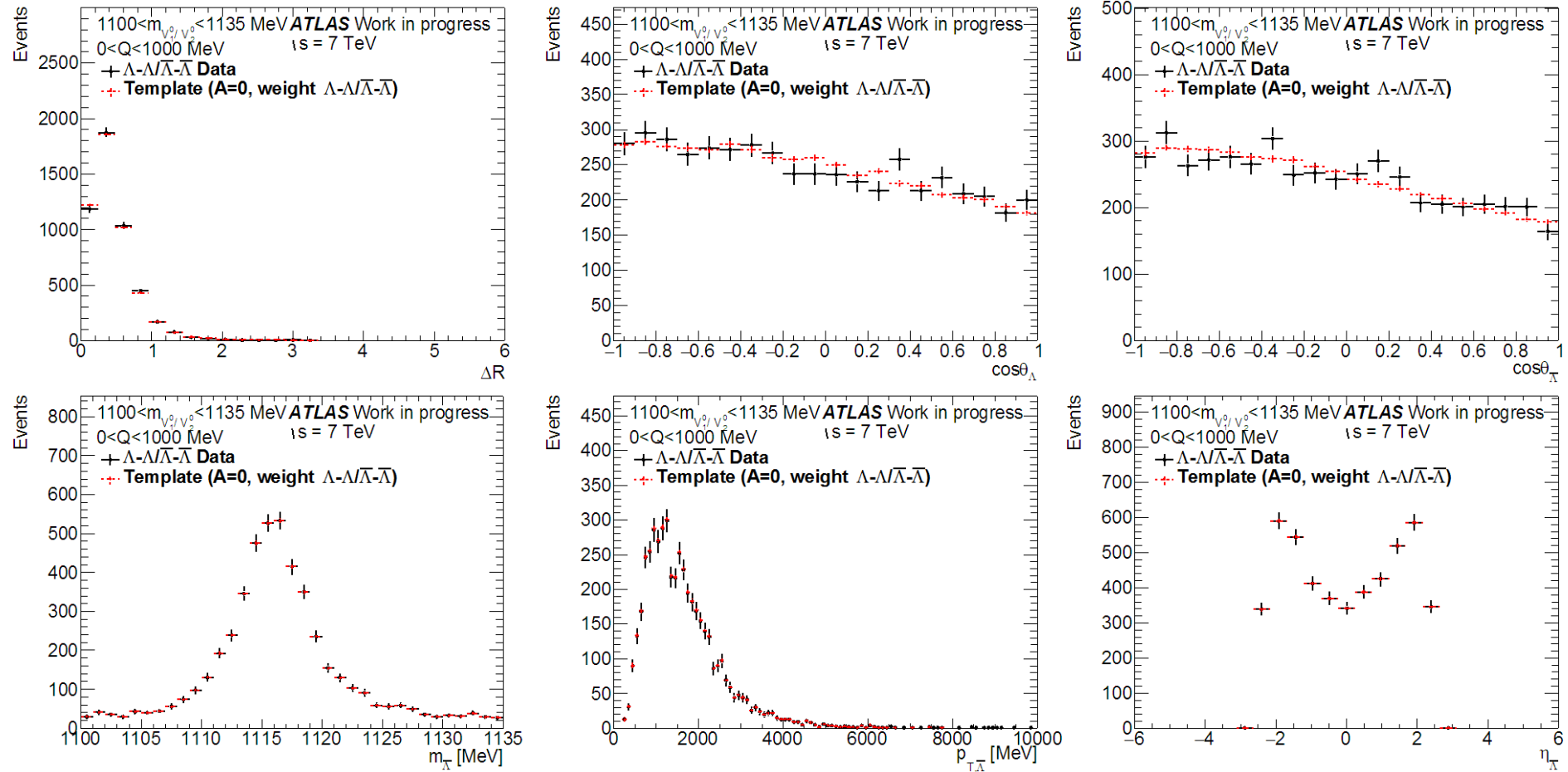0 < Q < 1000 (MeV)
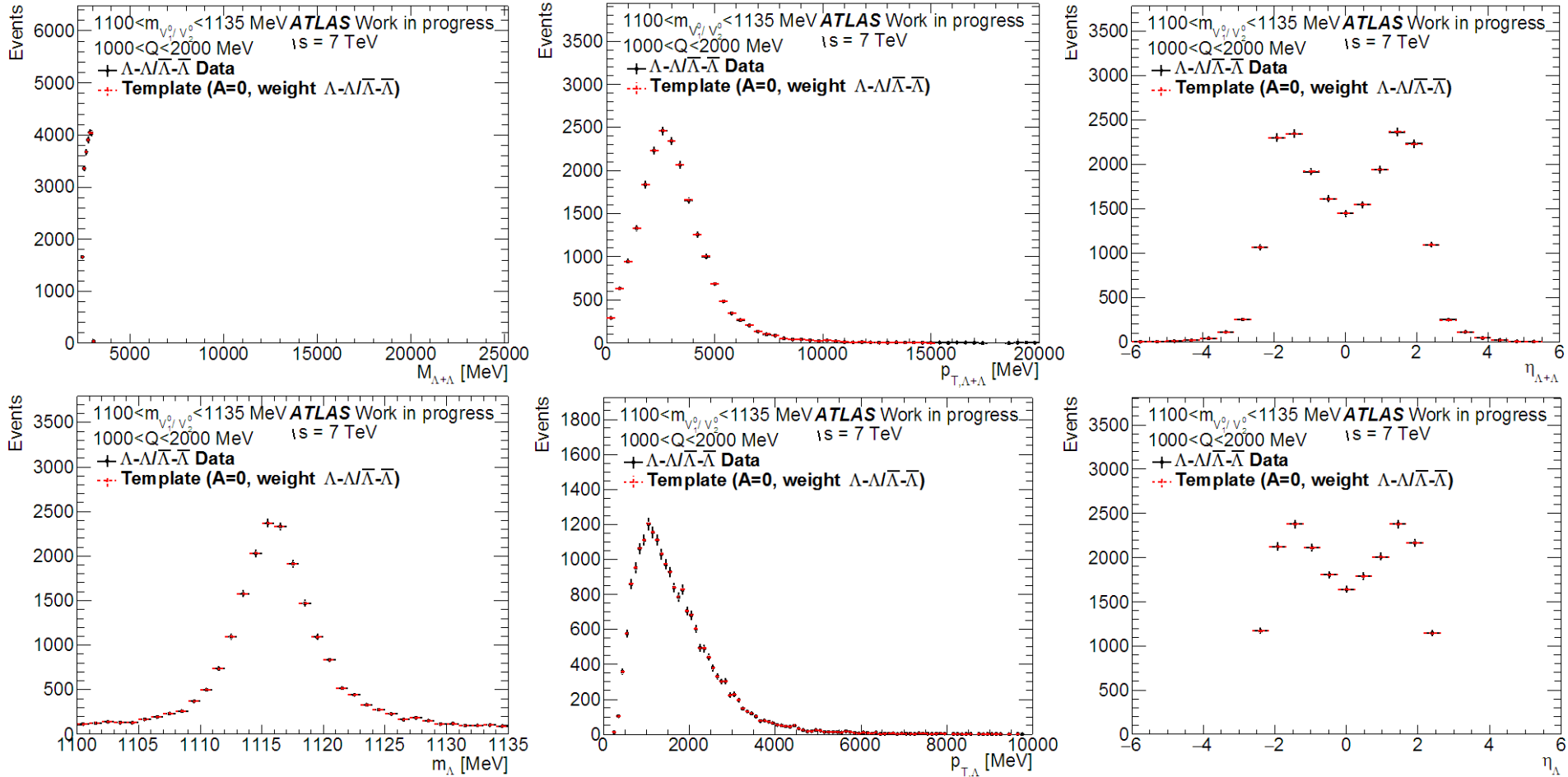
1000 < Q < 2000 (MeV)
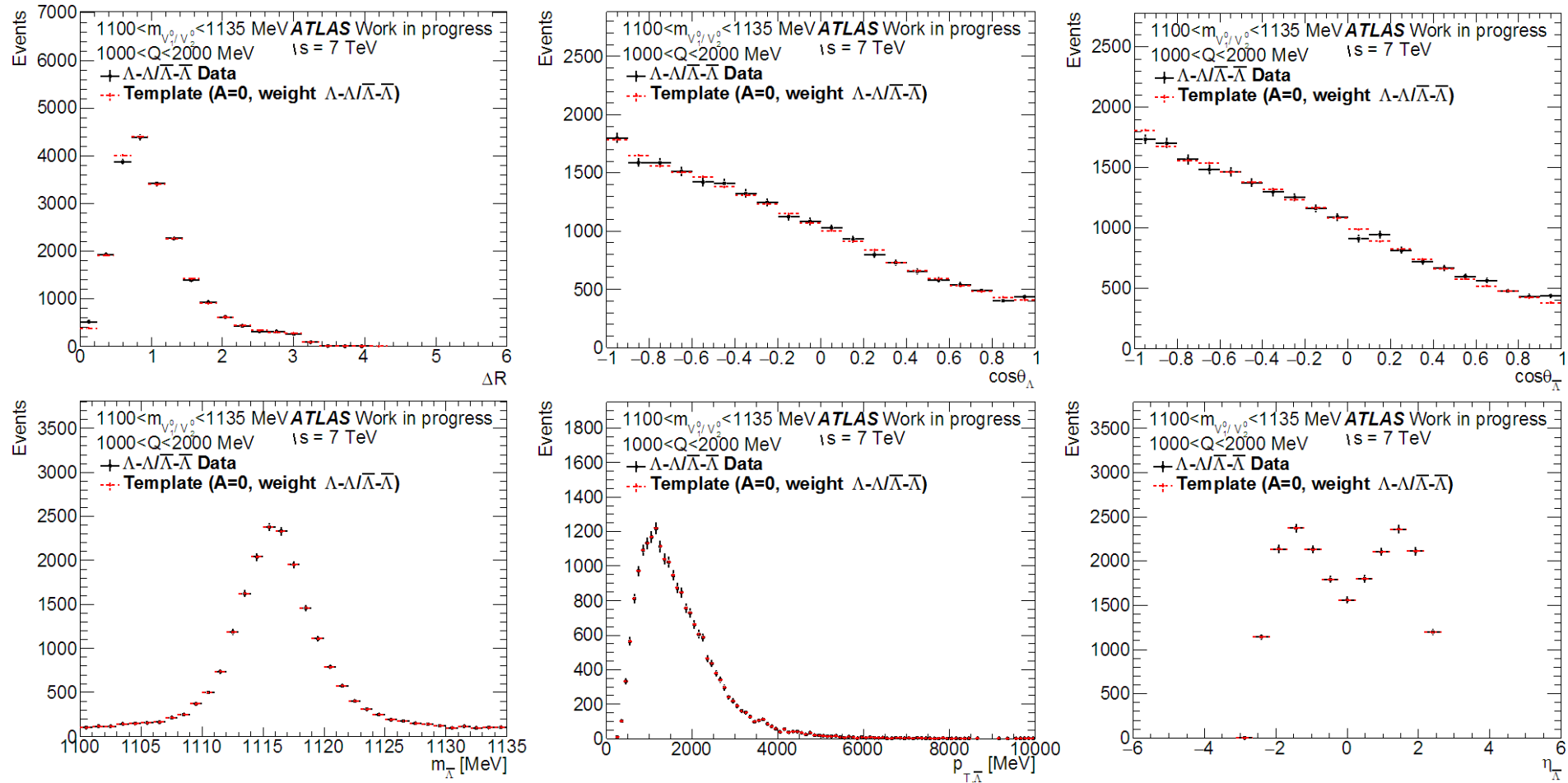
Kinematics 0 < Q < 1000 (MeV)

Kinematics 0 < Q < 1000 (MeV)

Kinematics 1000 < Q < 2000 (MeV)

Kinematics 1000 < Q < 2000 (MeV)

Λ$_b$ polarization measurement

D. Zhang, H. Cheng