Λ polarization with a transversely polarized proton target at COMPASS

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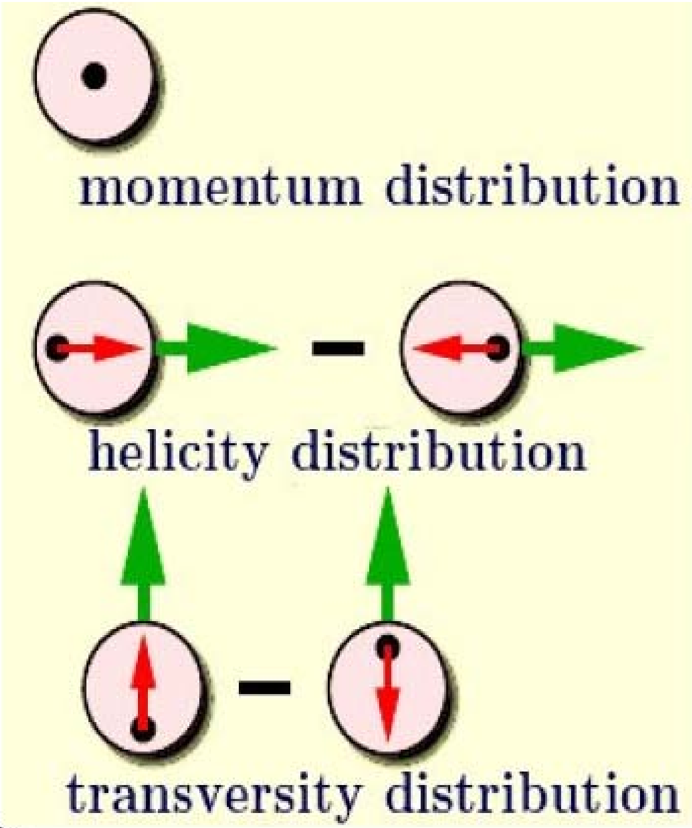
on behalf of the COMPASS collaboration

06 October 2008

Parton Distribution Functions in Quark Parton Model



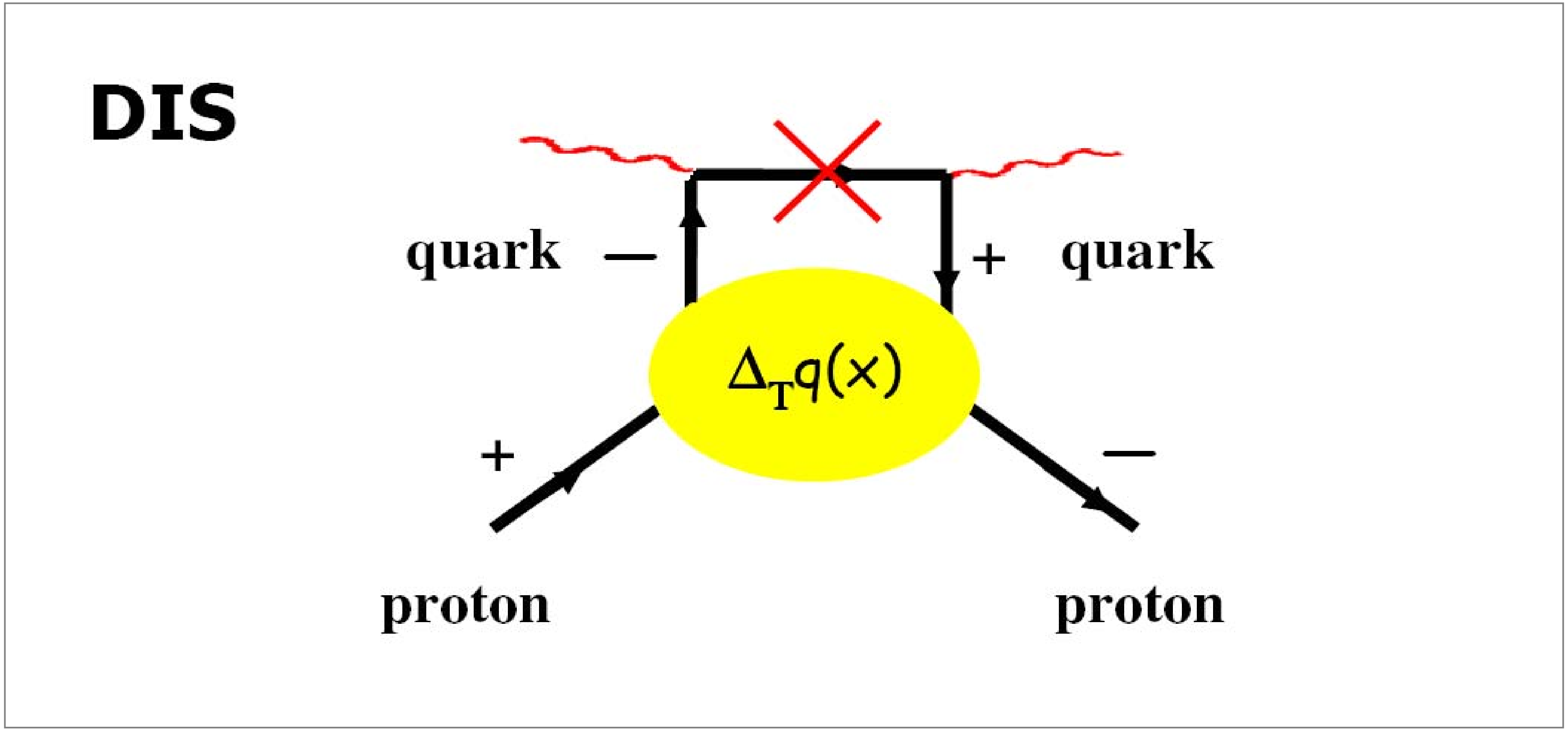
$q(x)$ => well known - unpolarized DIS

$\Delta q(x)$ => known - polarized DIS

$\Delta_T q(x)$ => Need further investigation!

$\Delta_T q(x)$ not accessible in DIS

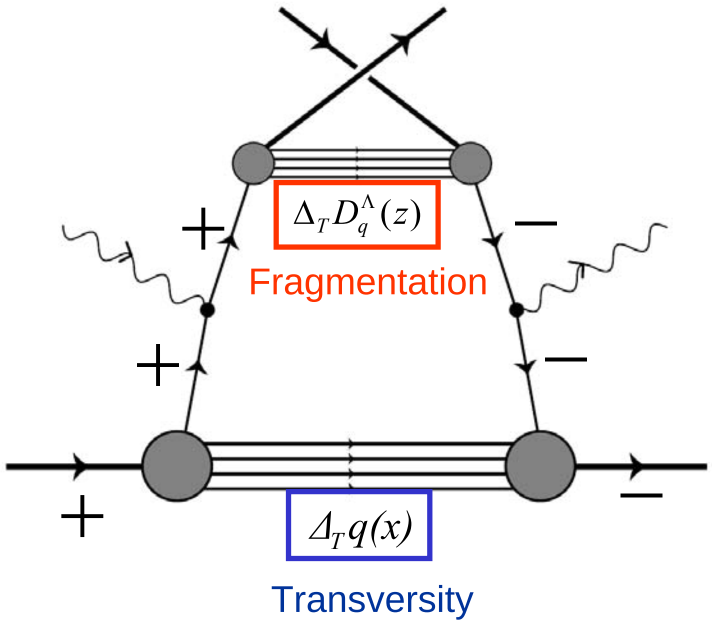
Measurement of transversity effects



To measure chiral-odd $\Delta_T q(x)$, another chiral-odd coupling partner is required.

Measurement of transversity in SIDIS

SIDIS @ $Q^2 > 1$ (GeV/c^2)

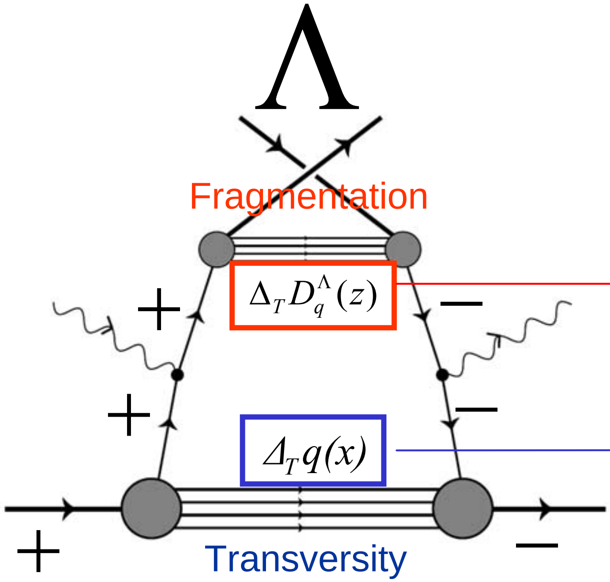


Accessible by production of

- $lN^{\Uparrow} \rightarrow l'hX$: Collins function
- $lN^{\Uparrow} \rightarrow l'h_1h_2X$: Interference fragmentation function
- $lN^{\Uparrow} \rightarrow l'\Lambda^{\Uparrow}X$: Λ polarization

Transversity can be measured in SIDIS on a transversely polarized target via "Λ polarimetry".

Transverse Λ Polarization



$$\mu N^{\Uparrow} \rightarrow \mu' \Lambda^{\Uparrow} X$$ @ SIDIS ($Q^2 > 1$ (GeV/c)^2)

Differentiate between terms $\Delta_T D(z)$ and $\Delta_T q(x)$ due to factorization in x and z?

Transverse Λ polarization in a transversely polarized target

$$P^\Lambda \propto \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_q^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}$$

$\Delta_T q(x)$ = transversely polarized quark distribution

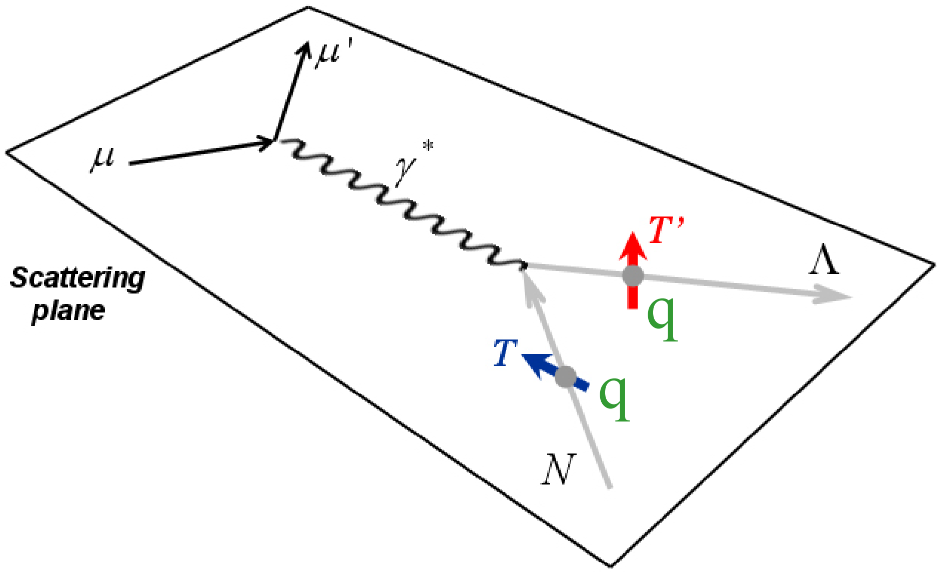
$q(x)$ = unpolarized quark distribution function

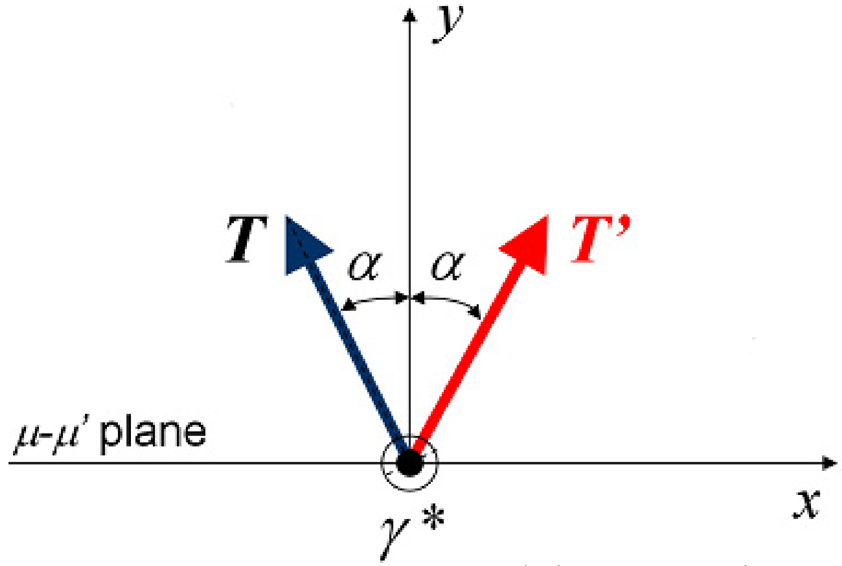
$\Delta_T D_q(z)$ = transversely polarized fragmentation

$D_q(z)$ = unpolarized fragmentation function

Coordinate System

Spin quantization axis for the measurement of transverse Λ polarization





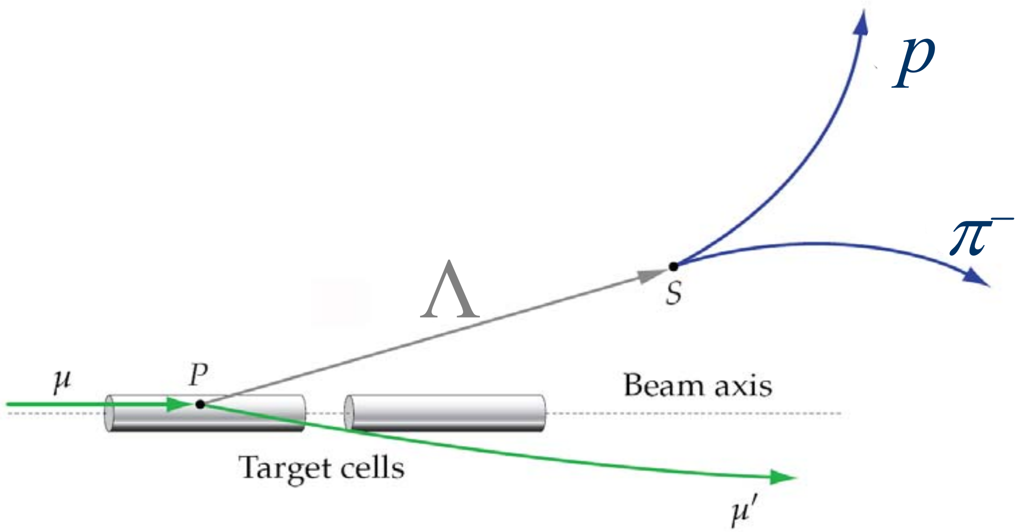
M. Anselmino & F. Murgia : Spin effects in the fragmentation of a transversely polarized quark, Physics Letters B 483 (2000) 74-86

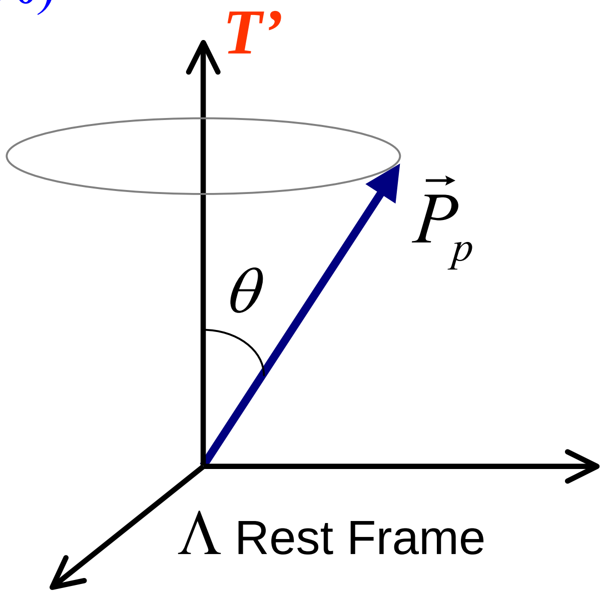
T : component of target spin perpendicular to γ*
T' : symmetric of the ***T*** w.r.t. the normal of the scattering plane

If ***q*** fragments into a Λ hyperon, then the measurement of P^{Λ} w.r.t. ***T'*** gives information about the initial quark polarization in the nucleon.

What is the Λ polarization?

Self-analyzing weak decay : $\Lambda \rightarrow p\pi^{-}$ (BR ≈ 64%)





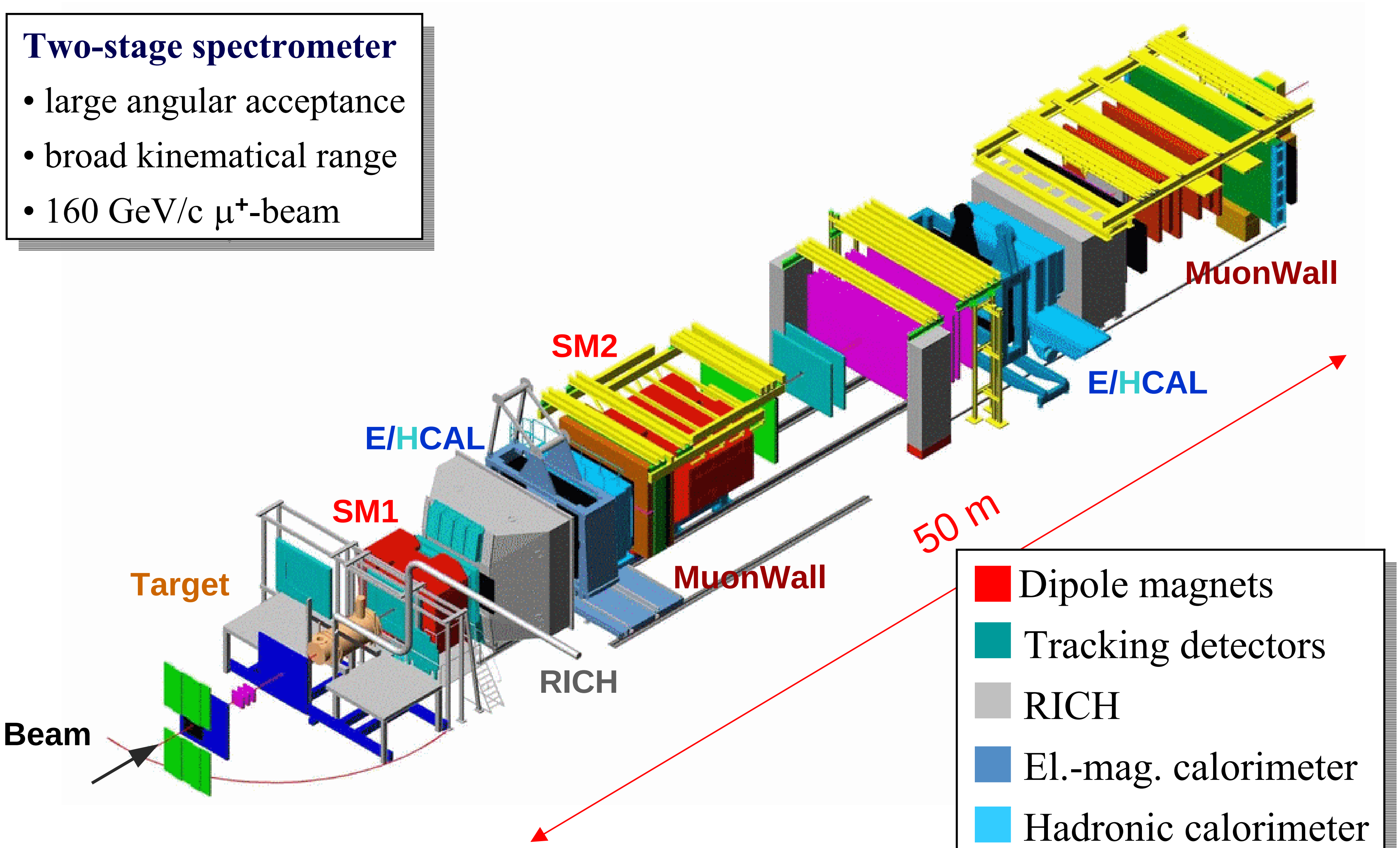
Λ polarization P^{Λ} with respect to spin analyzer ***T ’*** reveals itself in the angular distribution of decay proton :

$$N(\theta) \propto 1 + \alpha\, P_T^{\Lambda} \cos\theta$$

θ : angle of proton decay w.r.t ***T’*** in Λ rest frame
α = ± 0.643 (asymmetry parameter of Λ and $\bar{\Lambda}$)

The COMPASS Spectrometer

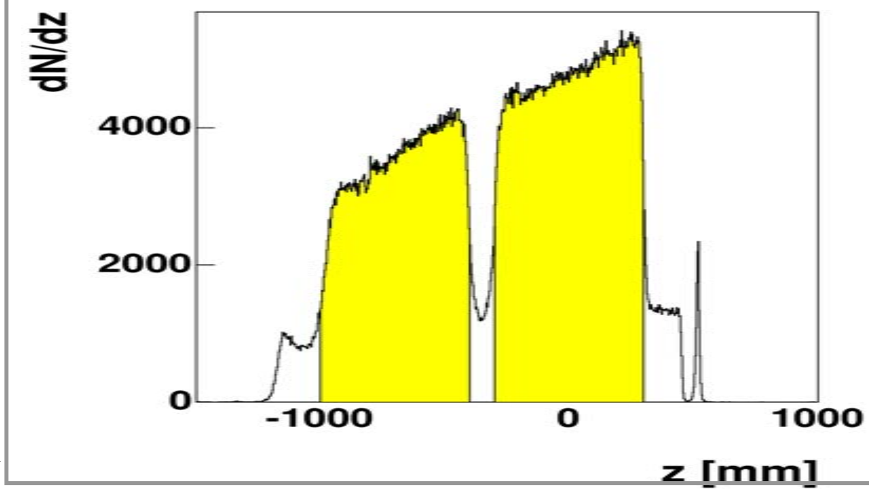
Two-stage spectrometer
- large angular acceptance
- broad kinematical range
- 160 GeV/c μ^+-beam



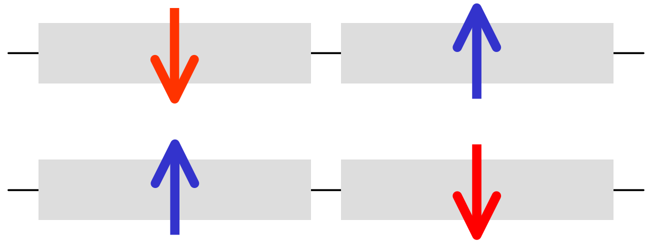
[hep-ex/0703049, NIM A 577, 455 (2007)]

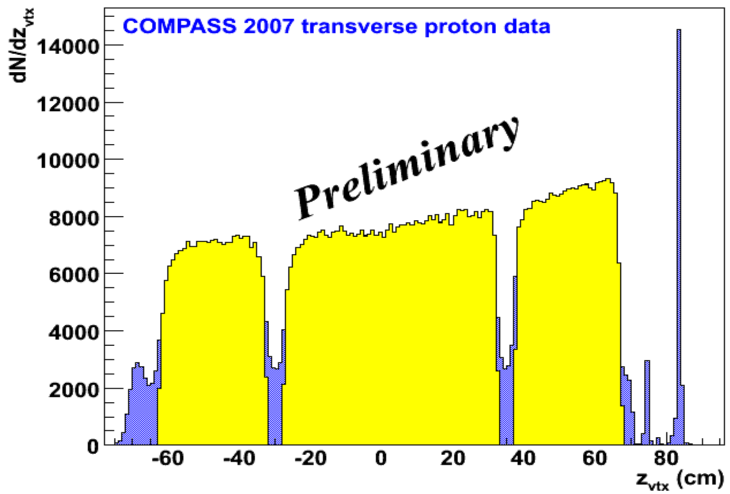
The Polarized Target

In transversity mode: weekly reversal of polarization → period 1 and 2.

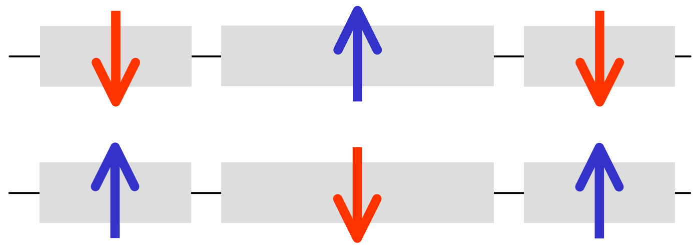


2002-2004 deuteron target ^{6}LiD :
Two 60 cm long target cells
with opposite polarizations:





2007 proton target NH_3 :
Three target cells to reduce possible false asymmetries & new solenoid with larger acceptance from 2006:

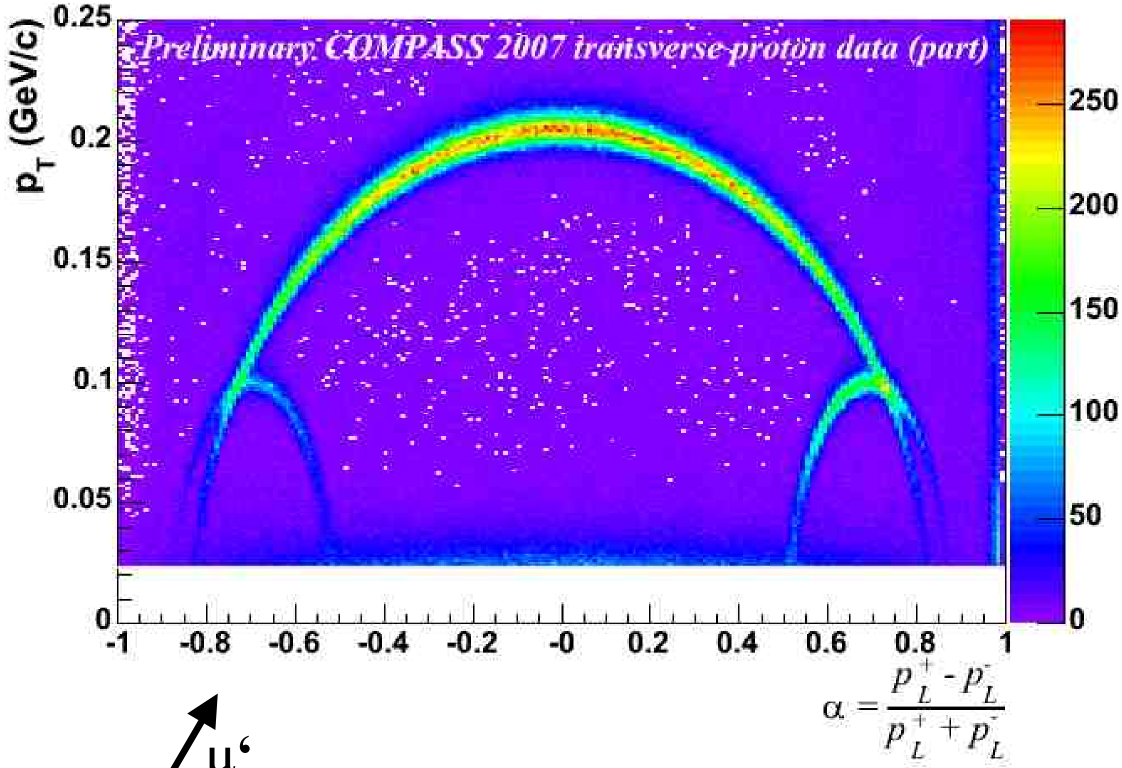


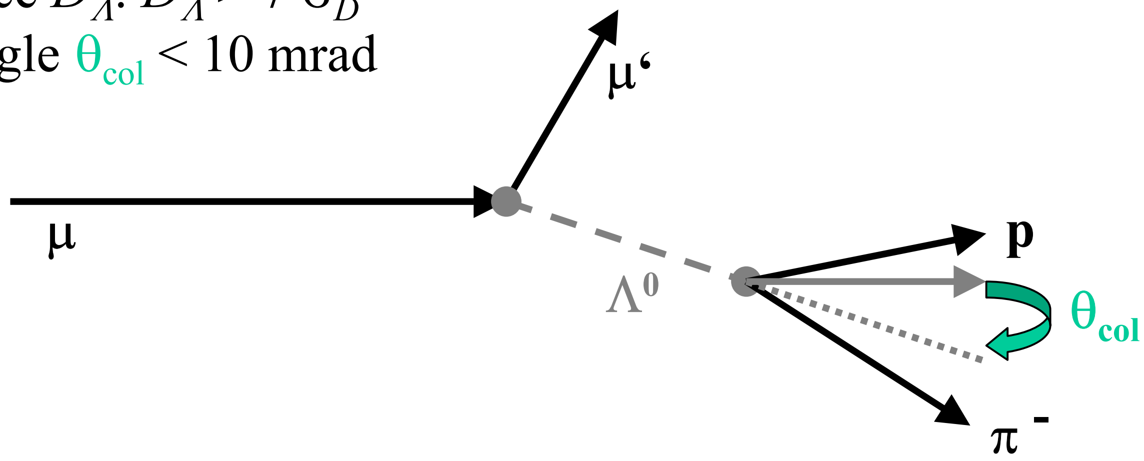
Identification of $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$, $K^0 \to \pi^+\pi^-$

Data Selection

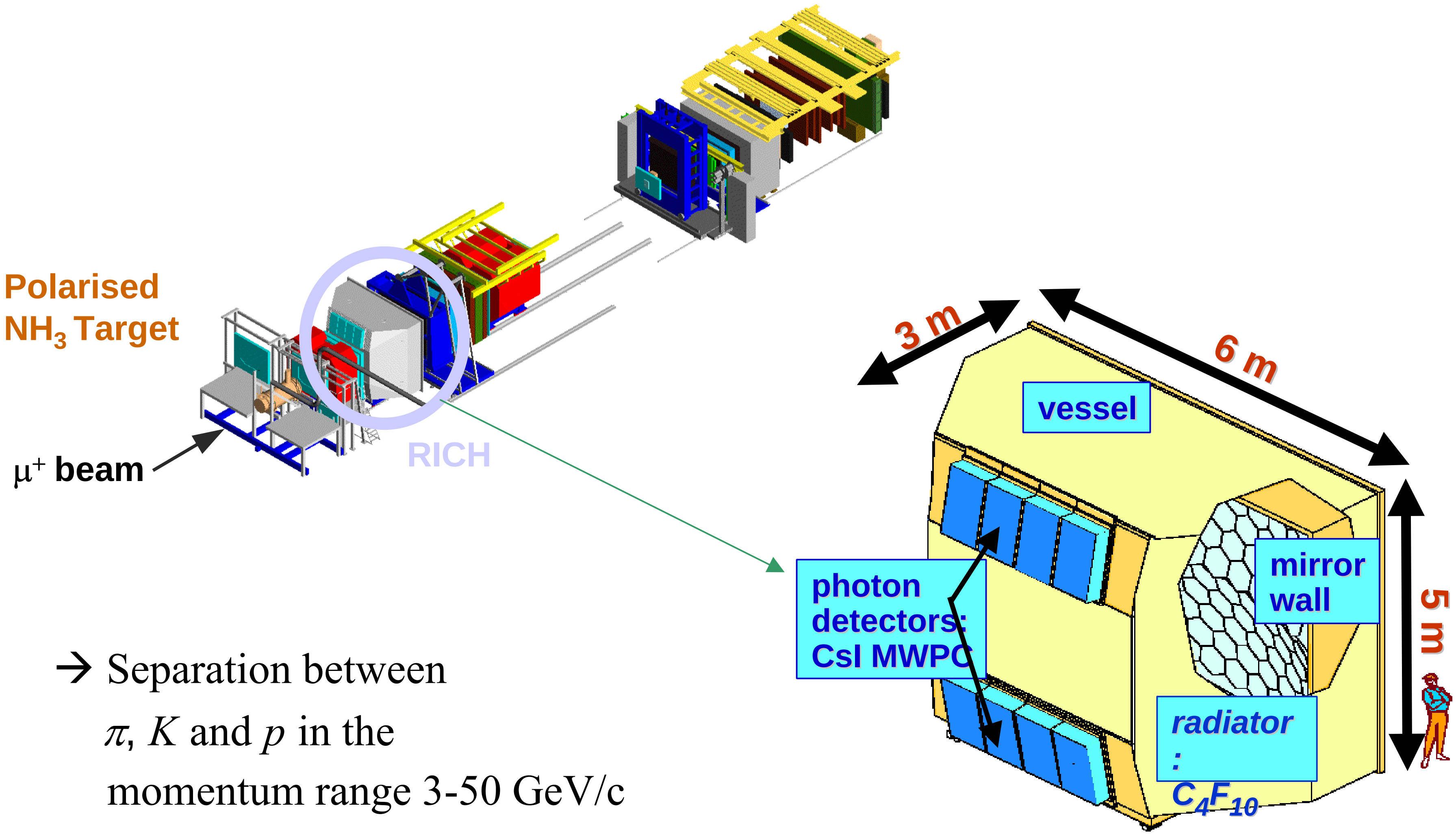
- V^0 vertex must be downstream of primary vertex.
- $P_T > 23$ MeV/c to exclude e^+e^- pair-production
- $P_{decay} > 1$ GeV/c for proton and pion
- $Q^2 > 1$ (GeV/c)^2 (DIS event)
- $0.1 < y < 0.9$
- Application of RICH in 2007
- Λ decay distance D_Λ: $D_\Lambda > 7\,\sigma_D$
- Collinearity angle $\theta_{col} < 10$ mrad

Armenteros-Podolanski-Plot



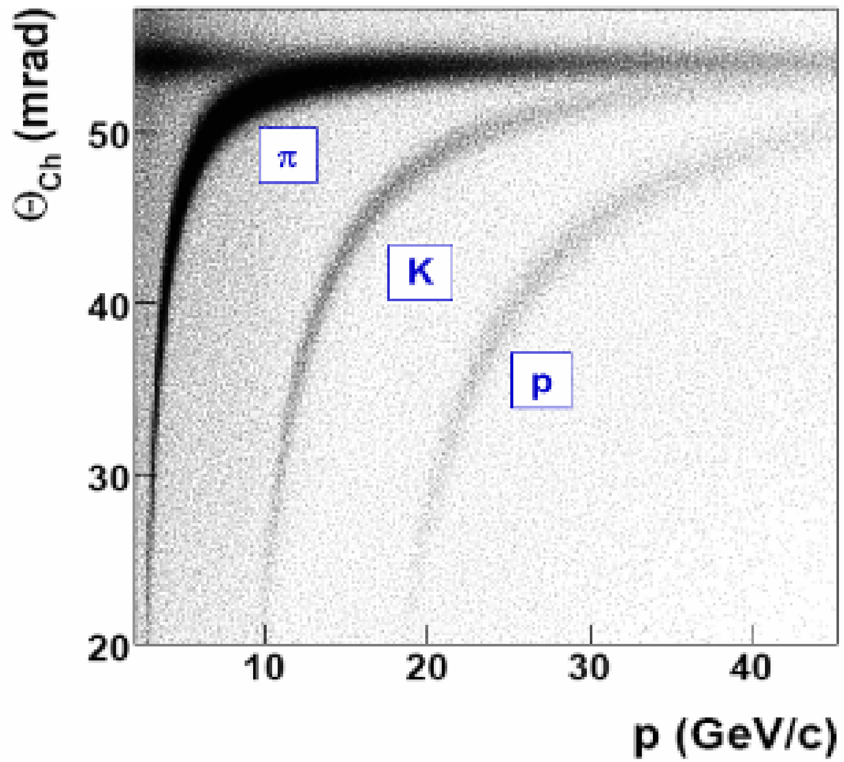


Λ selection using RICH in 2007



→ Separation between π, K and p in the momentum range 3-50 GeV/c

Λ selection using RICH in 2007



- Hadron masses calculated from the measured cherenkov angle θ_{ch}

- Threshold momenta:

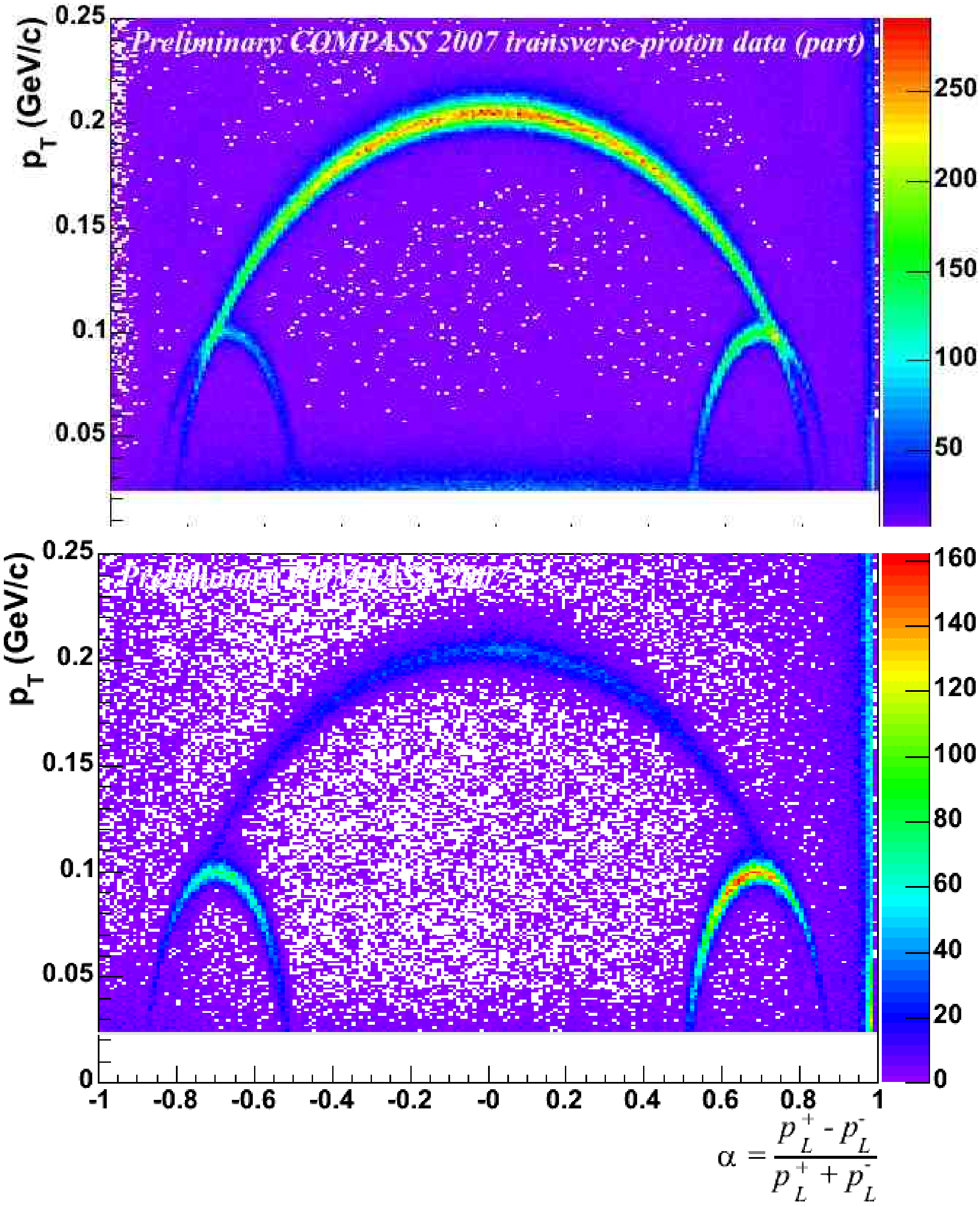
  $P_\pi \sim$ 2 GeV/c
  $p_K \sim$ 9 GeV/c
  $p_P \sim$ 17 GeV/c

- Likelihood methods are used to reject pion and kaon for proton candidate in the decay of Λ ($\Lambda \rightarrow p\pi^-$) and $\overline{\Lambda}$ ($\overline{\Lambda} \rightarrow \overline{p}\pi^+$)

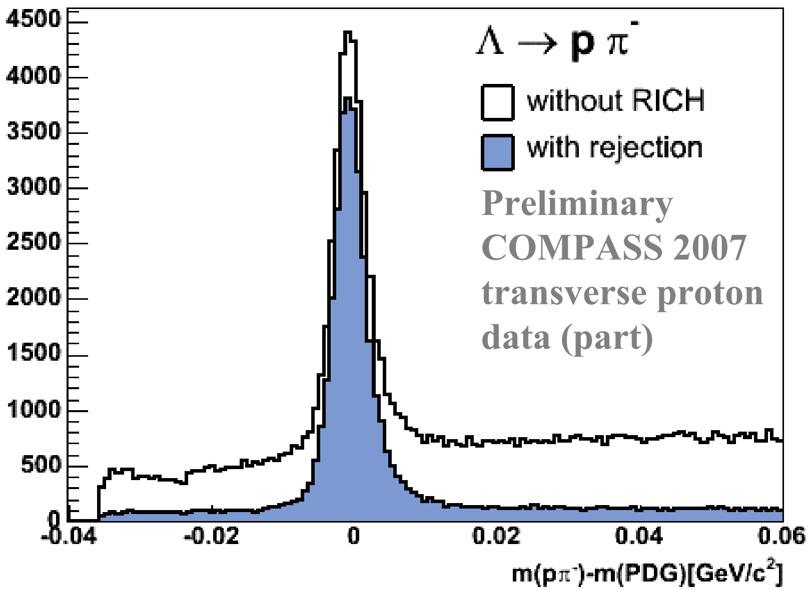
Armenteros-Plot

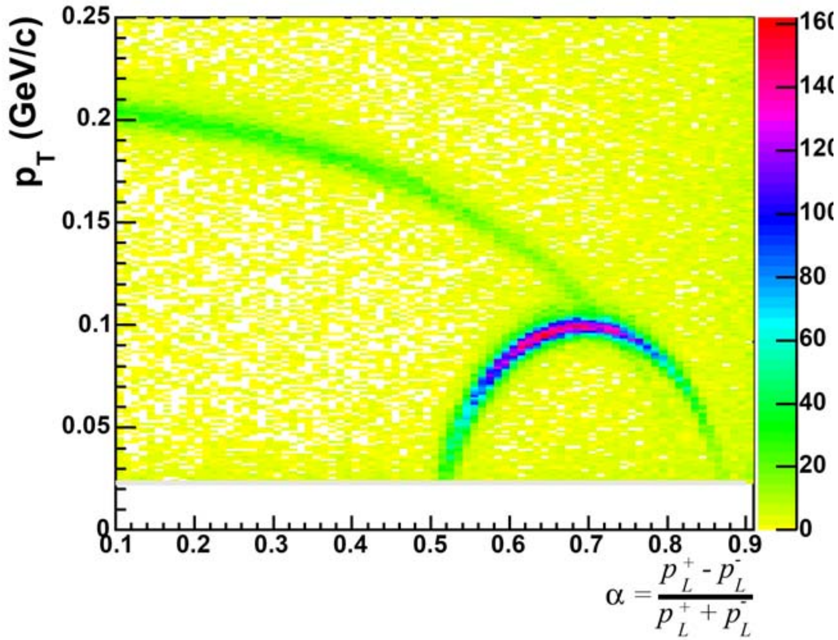
Before application of RICH cut:

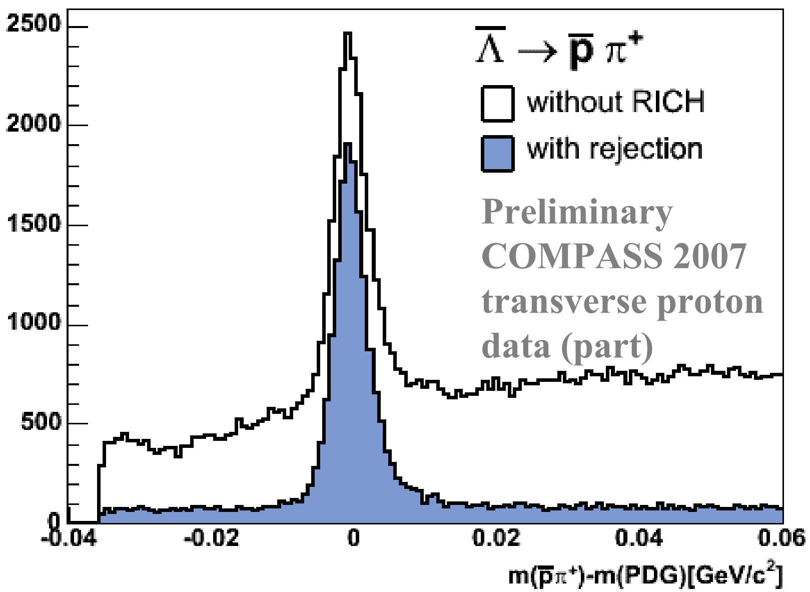
After application of RICH cut:

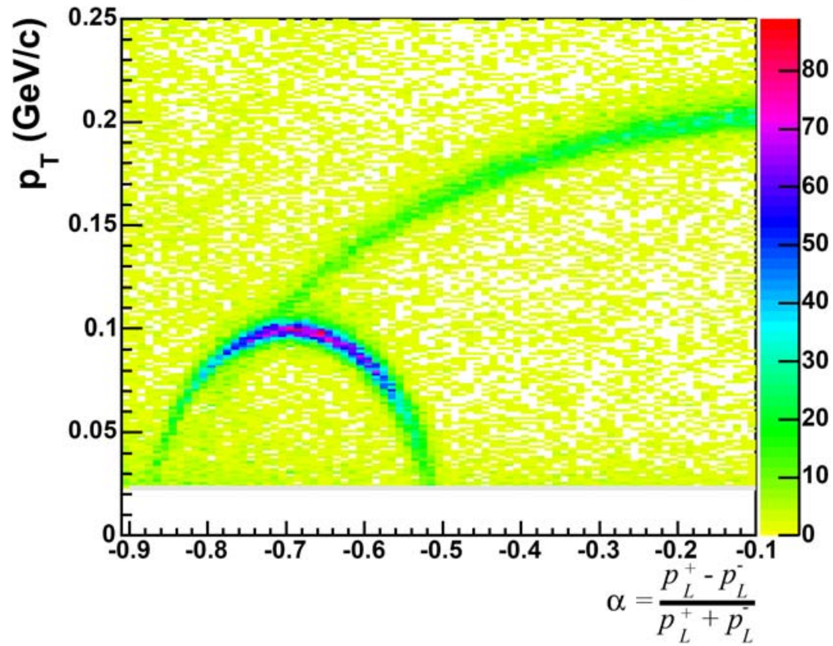


Using RICH as veto

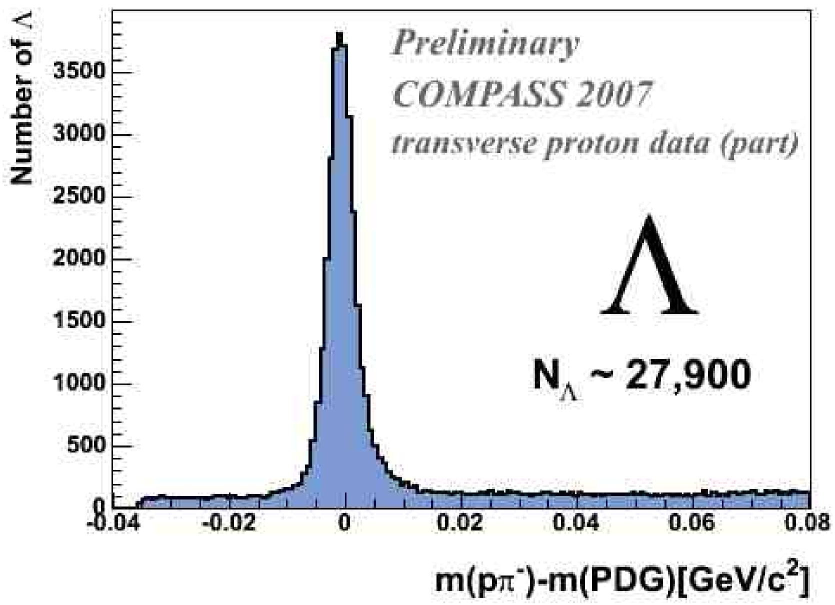


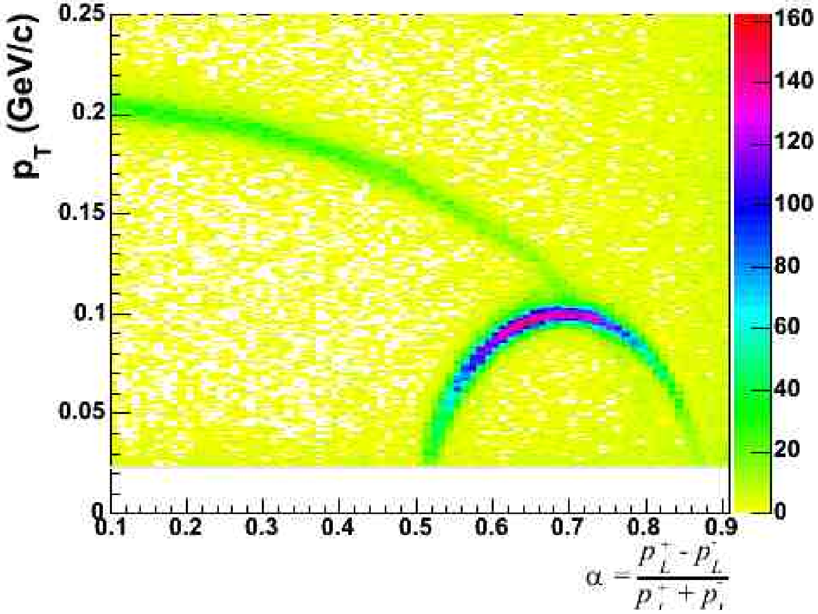


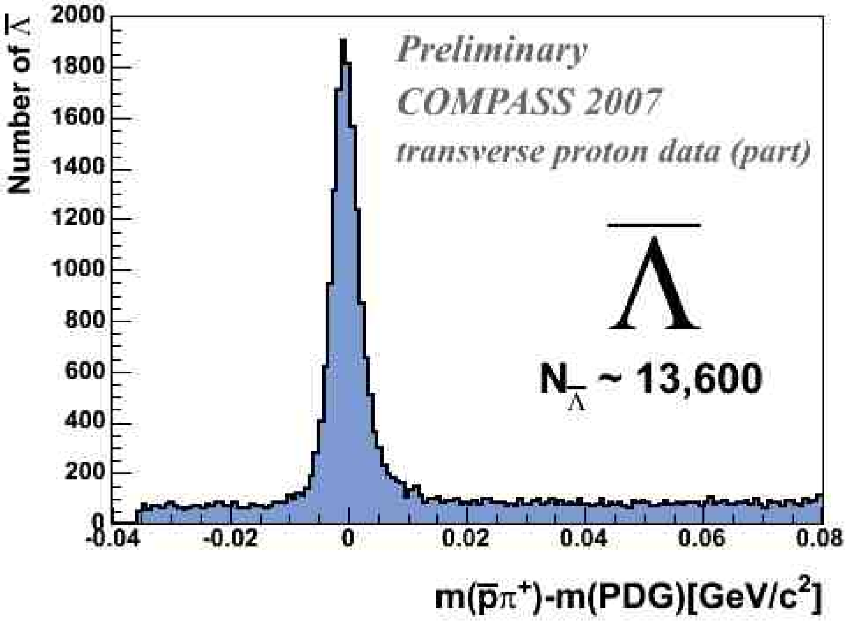


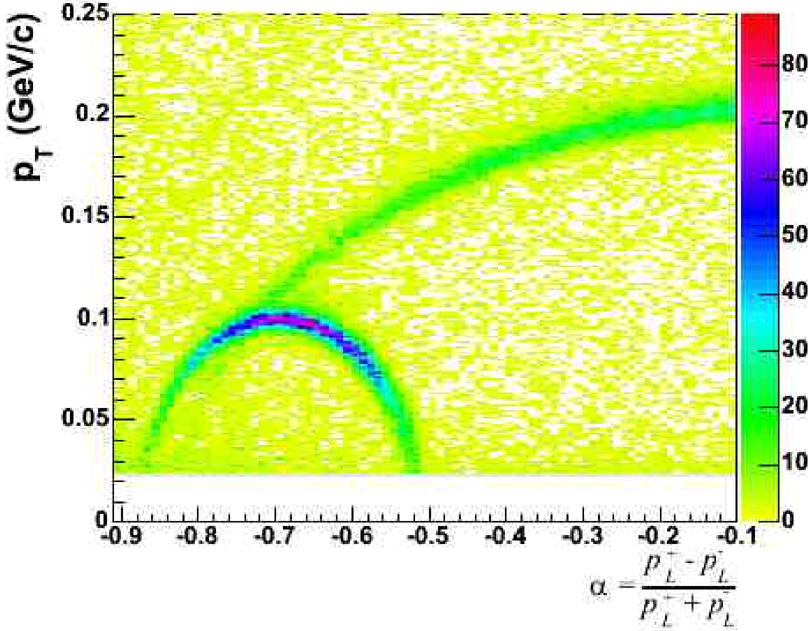


Invariant mass of Λ & $\overline{\Lambda}$ in 2007









Extraction of Λ polarization

Exploit symmetry

- In general, the proton angular distribution is distorted by the non-ideal experimental acceptance:

$$N_{\exp}(\theta) \propto \left[1 + \alpha\, P_T^{\Lambda} \cos(\theta)\right] \cdot Acc(\theta)$$

- Extract acceptance correction from data using up-down symmetry of angular distribution. Recombination of data samples from target cells and two target polarizations gives ratio:

$$\varepsilon_T(\theta) = \frac{[\sqrt{N_1^{\uparrow}(\theta)N_2^{\uparrow}(\theta)} + \sqrt{N_1^{\downarrow}(\pi-\theta)N_2^{\downarrow}(\pi-\theta)}] - [\sqrt{N_1^{\uparrow}(\pi-\theta)N_2^{\uparrow}(\pi-\theta)} + \sqrt{N_1^{\downarrow}(\theta)N_2^{\downarrow}(\theta)}]}{[\sqrt{N_1^{\uparrow}(\theta)N_2^{\uparrow}(\theta)} + \sqrt{N_1^{\downarrow}(\pi-\theta)N_2^{\downarrow}(\pi-\theta)}] + [\sqrt{N_1^{\uparrow}(\pi-\theta)N_2^{\uparrow}(\pi-\theta)} + \sqrt{N_1^{\downarrow}(\theta)N_2^{\downarrow}(\theta)}]}$$

where $\uparrow, \downarrow$: Target-spin orientations
1, 2 : Periods of data taking

Extraction of Λ polarization

"Geometrical mean" method grants independence from acceptance effects with stability assumption $\mathrm{Acc}^{\Uparrow}_{1(2)}(\theta) = \mathrm{Acc}^{\Downarrow}_{2(1)}(\theta),\ \mathrm{Acc}^{\Uparrow}_{1(2)}(\pi-\theta) = \mathrm{Acc}^{\Downarrow}_{2(1)}(\pi-\theta)$

$$\varepsilon_T(\theta) = \frac{[\sqrt{N_1^{\uparrow}(\theta)N_2^{\uparrow}(\theta)} + \sqrt{N_1^{\downarrow}(\pi-\theta)N_2^{\downarrow}(\pi-\theta)}] - [\sqrt{N_1^{\uparrow}(\pi-\theta)N_2^{\uparrow}(\pi-\theta)} + \sqrt{N_1^{\downarrow}(\theta)N_2^{\downarrow}(\theta)}]}{[\sqrt{N_1^{\uparrow}(\theta)N_2^{\uparrow}(\theta)} + \sqrt{N_1^{\downarrow}(\pi-\theta)N_2^{\downarrow}(\pi-\theta)}] + [\sqrt{N_1^{\uparrow}(\pi-\theta)N_2^{\uparrow}(\pi-\theta)} + \sqrt{N_1^{\downarrow}(\theta)N_2^{\downarrow}(\theta)}]}$$
$$= \alpha\, P_T^{\Lambda} \cos\theta$$

If only two $\cos\theta$ bins are used, P^{Λ} simplifies to

$$P_T^{\Lambda} = \frac{\varepsilon_T(\theta_i)}{\alpha\langle\cos\theta_i\rangle} \xrightarrow{i=2} P_T^{\Lambda} = \frac{\varepsilon_T(\theta)}{2\alpha}$$

for i = 1,…,n = number of $\cos\theta$-bins

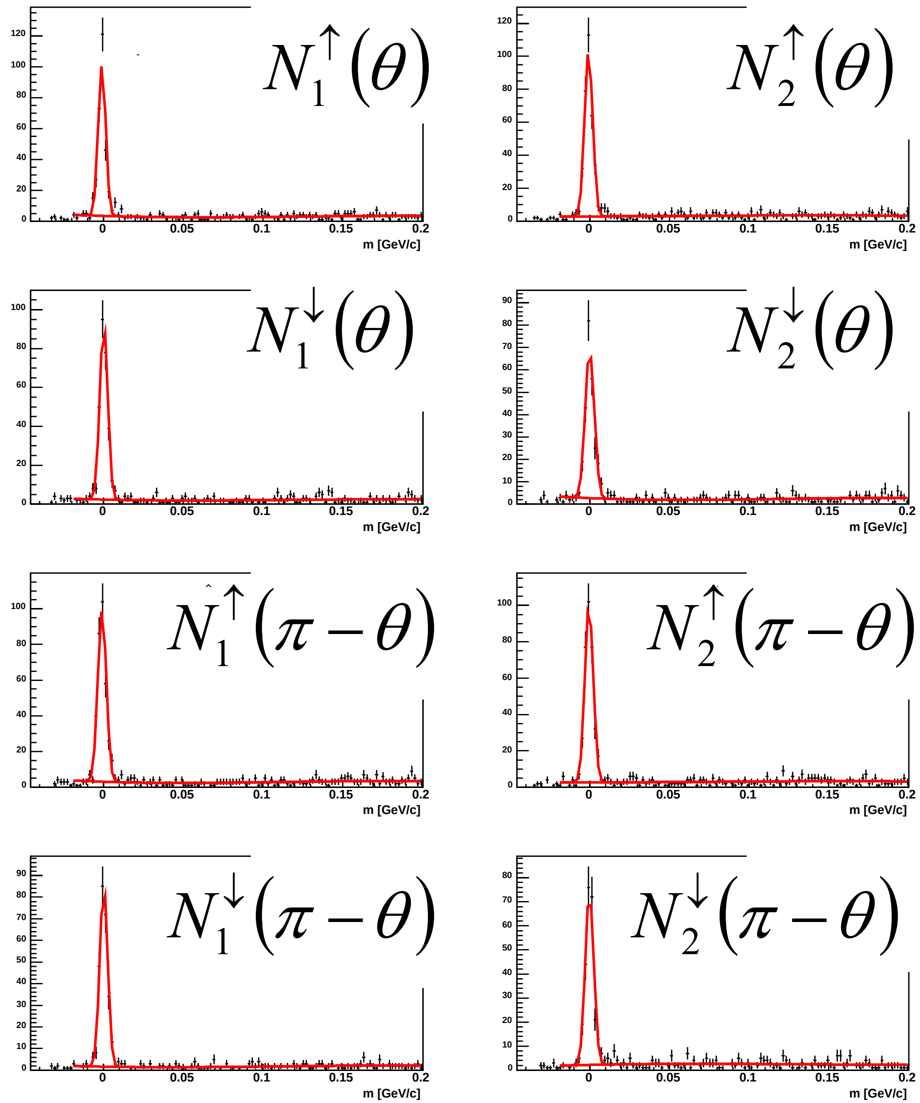
Extraction of Λ polarization

$$P_T^{\Lambda} = \frac{\varepsilon_T(\theta)}{2\alpha} = \frac{1}{2\alpha}\frac{[\sqrt{N_1^{\uparrow}(\theta)N_2^{\uparrow}(\theta)} + \sqrt{N_1^{\downarrow}(\pi-\theta)N_2^{\downarrow}(\pi-\theta)}] - [\sqrt{N_1^{\uparrow}(\pi-\theta)N_2^{\uparrow}(\pi-\theta)} + \sqrt{N_1^{\downarrow}(\theta)N_2^{\downarrow}(\theta)}]}{[\sqrt{N_1^{\uparrow}(\theta)N_2^{\uparrow}(\theta)} + \sqrt{N_1^{\downarrow}(\pi-\theta)N_2^{\downarrow}(\pi-\theta)}] + [\sqrt{N_1^{\uparrow}(\pi-\theta)N_2^{\uparrow}(\pi-\theta)} + \sqrt{N_1^{\downarrow}(\theta)N_2^{\downarrow}(\theta)}]}$$

- 8 independent invariant mass distributions.
- Fit functions：

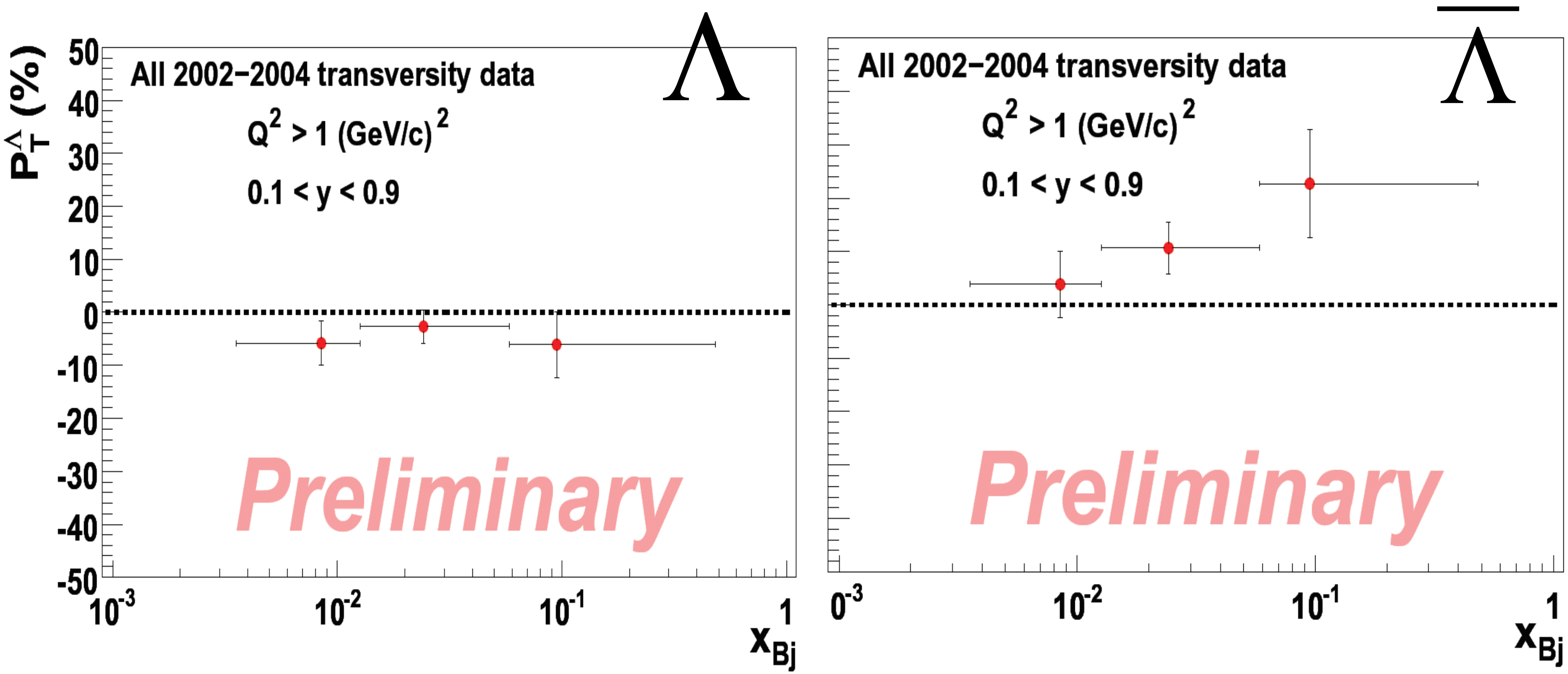
$$\frac{A}{\sqrt{2\pi\sigma}}\exp^{\frac{-(m-\overline{m})^2}{2\sigma^2}} + \text{pol}(3)$$

- Fit results are 8 event numbers.
- Calculate value of $P_T{}^{\Lambda}$.
- Procedure done
  in 3 x_{Bj} bins (deuteron target),
  in 5 x_{Bj} bins and 5 z bins (proton target).



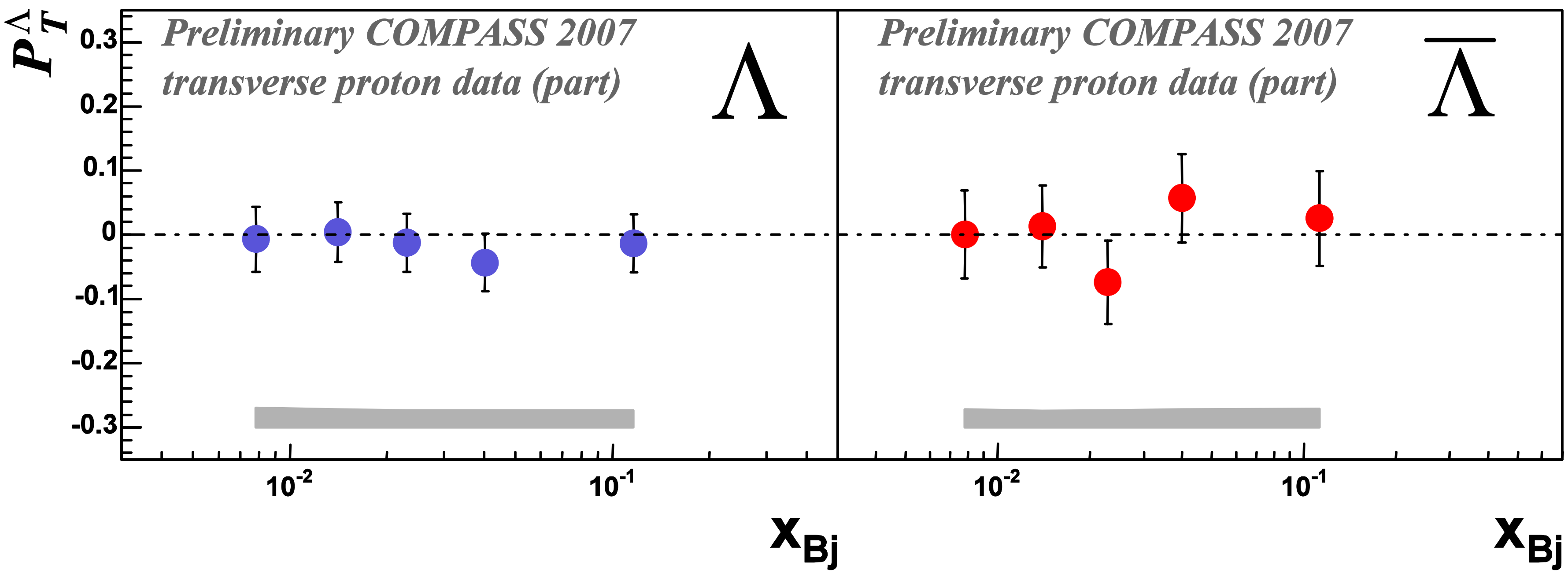
Transverse Λ & $\bar{\Lambda}$ Polarization with deuteron target

- Analysis for 2002-2004 data with no RICH identification.
- Only statistical errors are shown and systematic effects have been estimated not to be larger than the statistical errors.
- Small tendency for $\bar{\Lambda}$, but not significant for deuteron target.



Transverse Λ & $\overline{\Lambda}$ Polarization with proton target

- With ~60% higher statistics than deuteron data and RICH identification, 5 x_{Bj} and z bins are possible for 2007 data (instead of 3 for deuteron data).
- Systematic errors have been estimated to be smaller than statistical errors from false polarization.
- No dependence on x_{Bj} with proton target.



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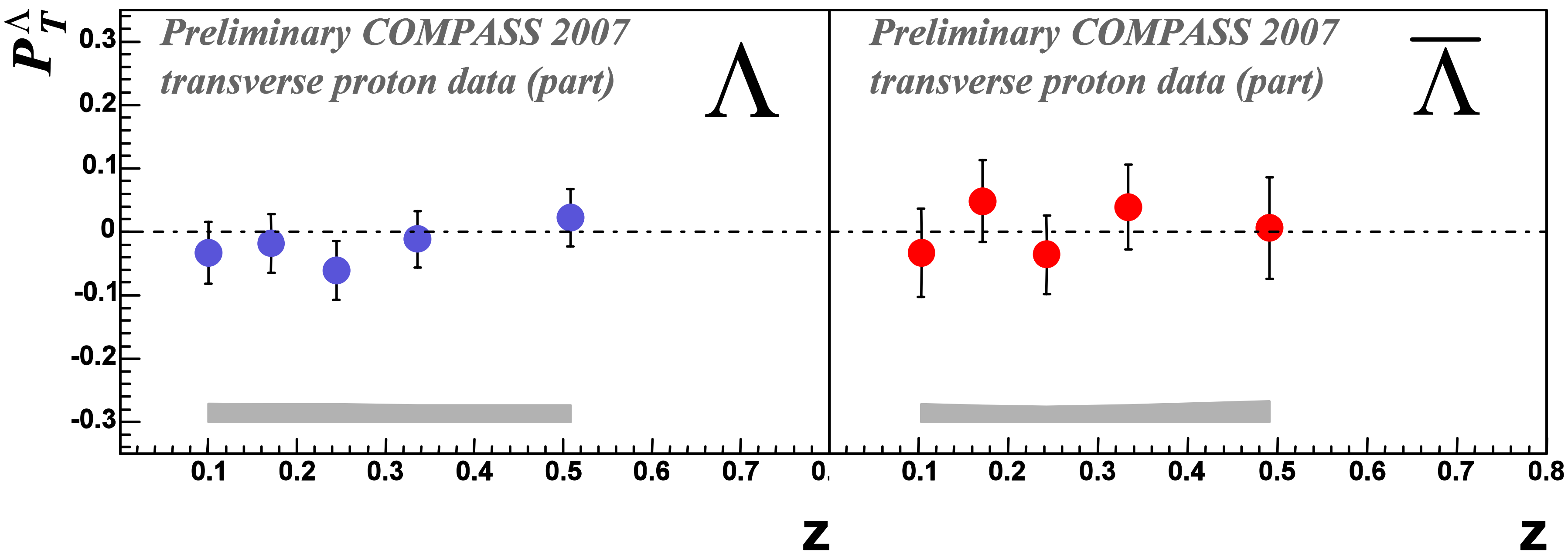
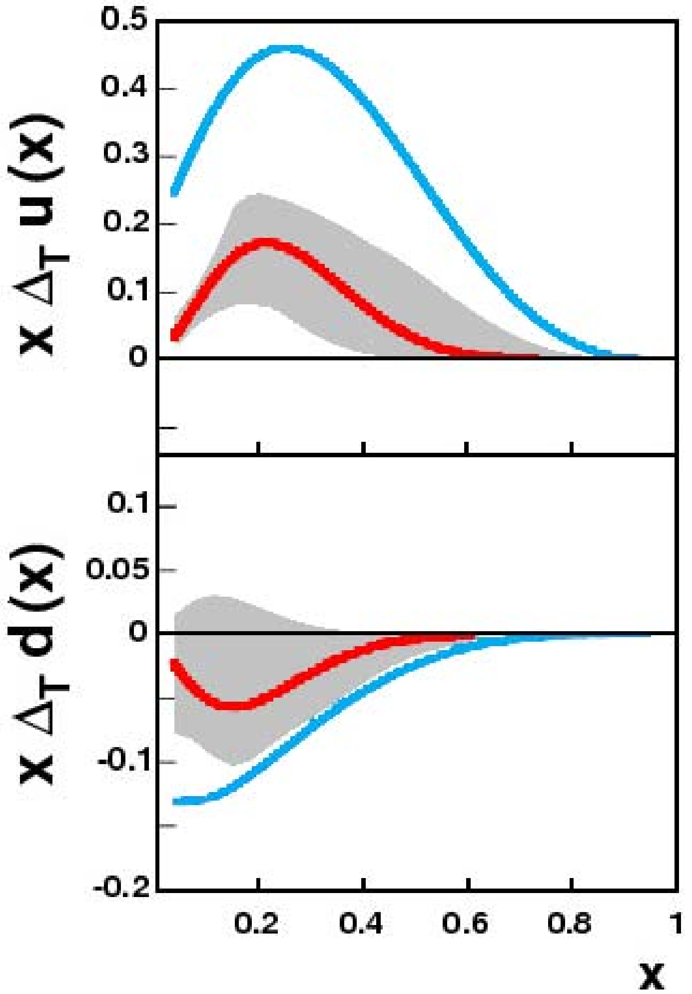


Interpretation of results

HERMES / COMPASS / BELLE combined results from Collins asymmetry



Anselmino et al: hep-ex 0701006

Expected influence for proton target:

$2 \cdot \Delta_T u(x)$

$1 \cdot \Delta_T d(x)$

➔ Positive $\Delta_T q(x)$ is expected.

$$\rightarrow \quad P^{\Lambda} \propto \frac{\sum_q e_q^2 \, \Delta_T q(x) \, \Delta_T D_q^{\Lambda}(z)}{\sum_q e_q^2 q(x) D_q^{\Lambda}(z)}$$

➔ $\Delta_T D(z)$ seems to be very small.

Summary & Outlook

Data taking in 2007 on a proton target

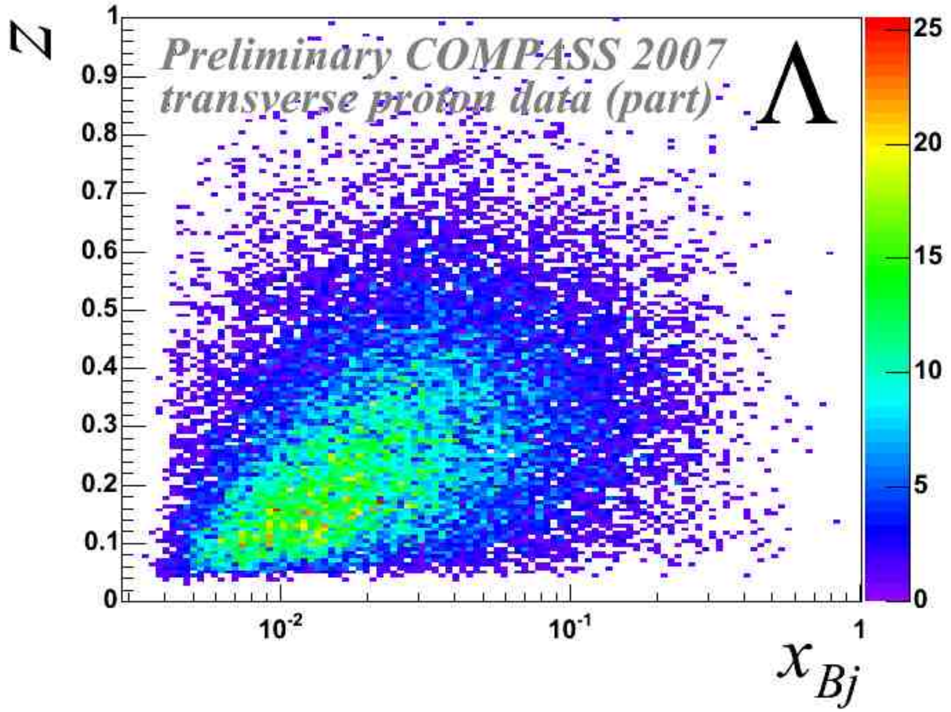
- 50% of time dedicated to transverse measurements.
- Very good working RICH used to reduce background (~15:1 versus ~3:1).
- Λ & $\bar{\Lambda}$ unpolarized, no dependence on x_{Bj} for analyzed part of data sample.
- Fragmentation function as function of z seems quite small.

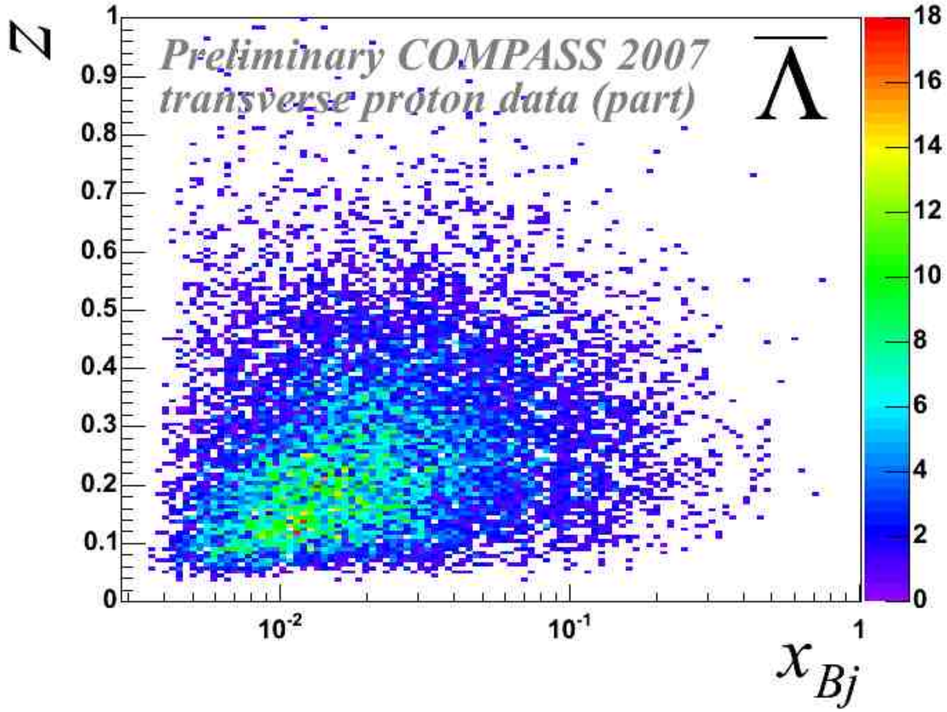
Analysis of the whole 2007 proton data sample with full production will follow, allowing us to extend the kinematic range into high x_{Bj} and z.

Thank you!

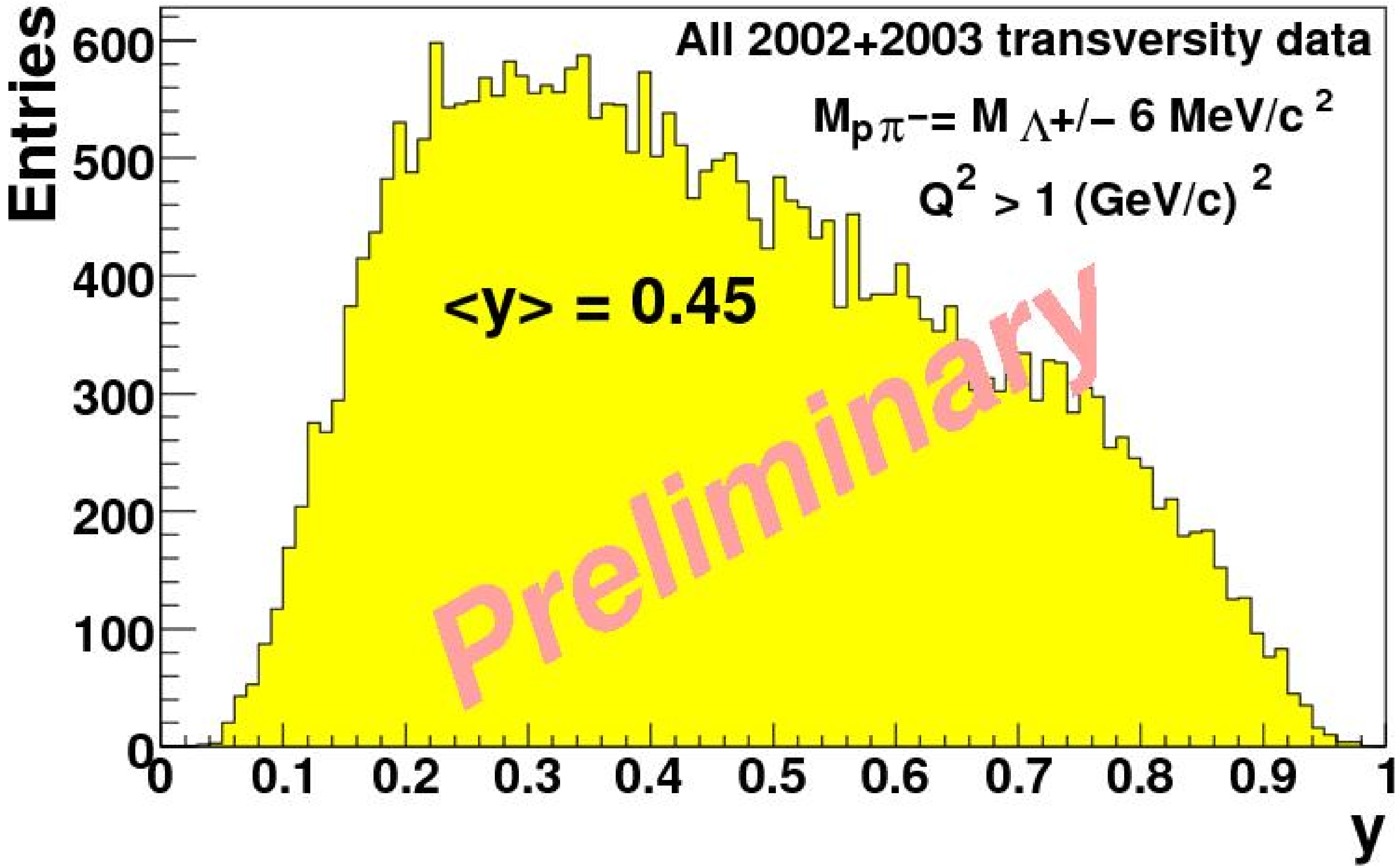
Backup slides

Hadronic z vs. x_{Bj} of 2007 data

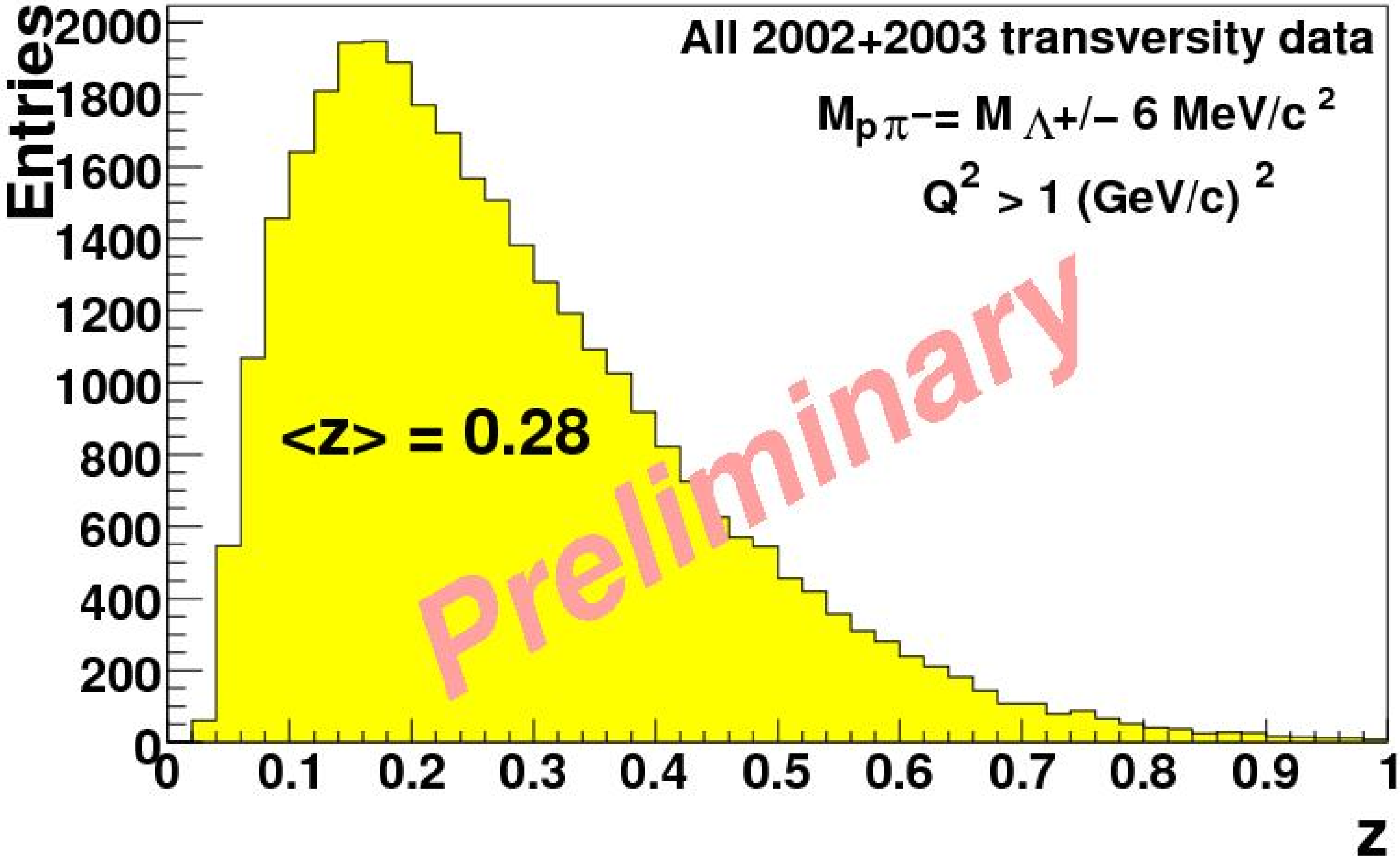




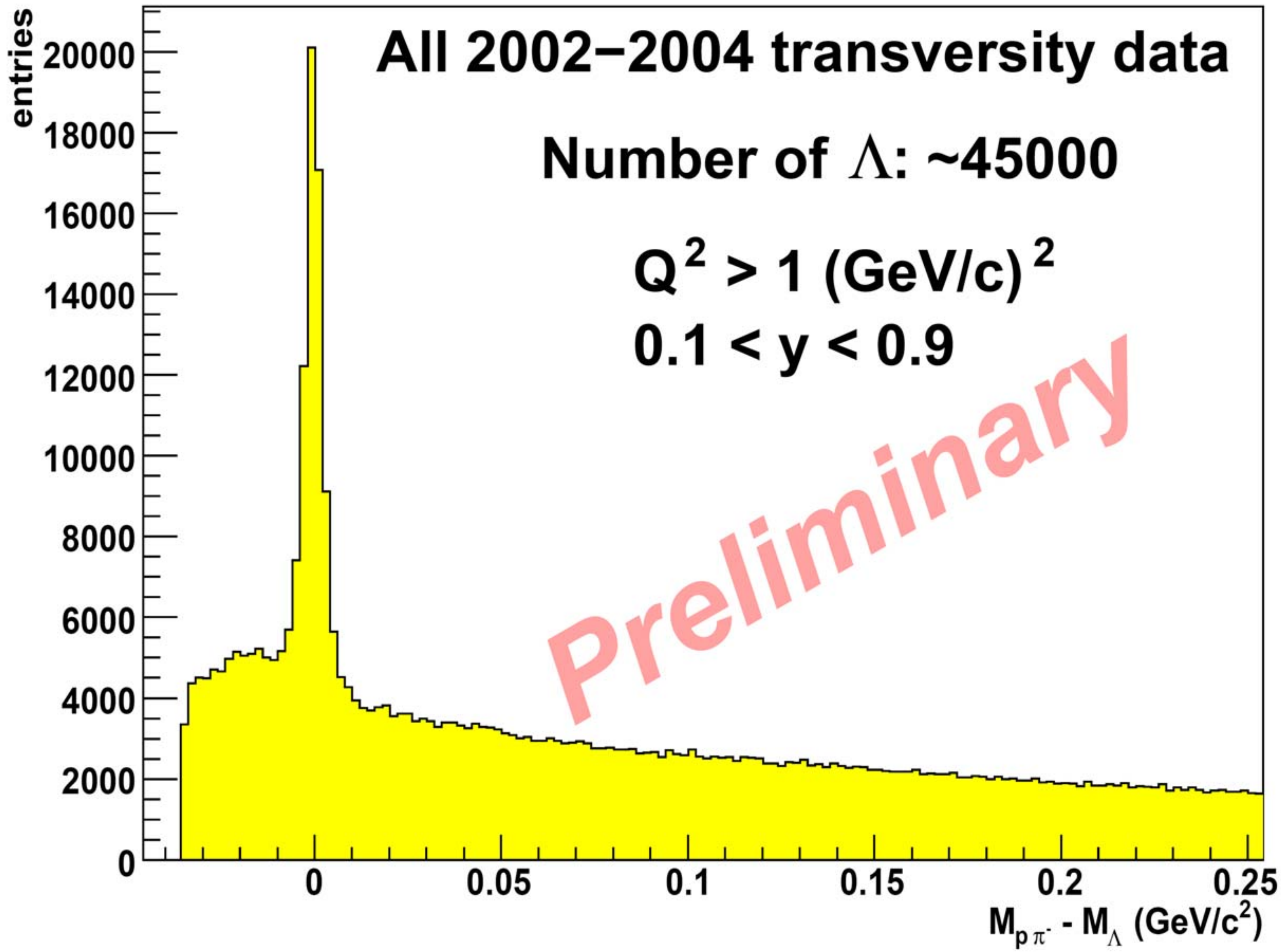
Kinematic distributions of 2002-2003 data



Kinematic distributions of 2002-2003 data



Λ mass spectra of 2002-2004 data



Λ mass spectra of 2002-2004 data