Λ and $\bar{\Lambda}$ polarization at COMPASS

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On behalf of the COMPASS collaboration

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Deep Inelastic Scattering

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Outline

- Introduction
- COMPASS experiment
- Longitudinal Λ & $\bar{\Lambda}$ polarization
- Transversity from transverse Λ & $\bar{\Lambda}$ polarization
- Conclusion & outlook

Why Λ polarization in deep inelastic scattering?

Ideal probe to study spin effect

- Self analyzing weak decay $\Lambda \rightarrow p\pi^-$ $(\mathrm{Br} \approx 64\%)$

- Various spin aspects can be studied

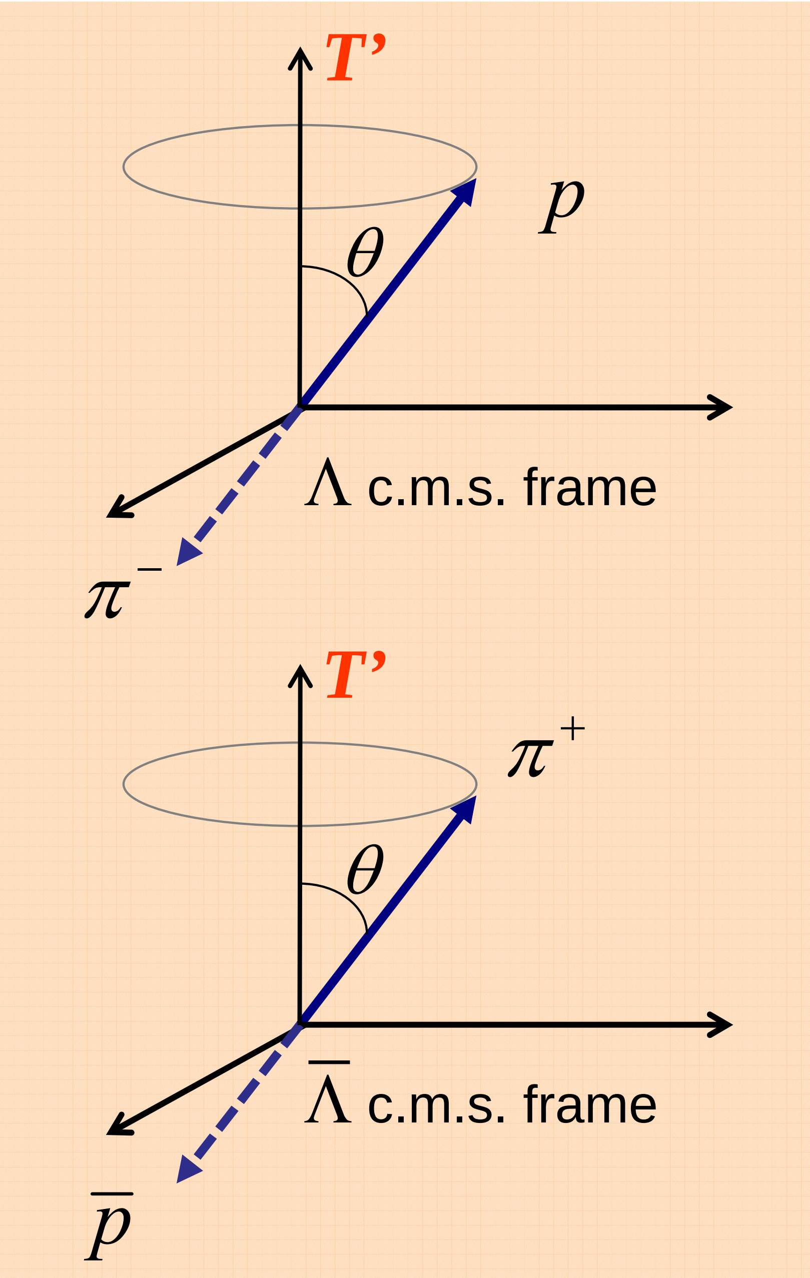
  $lN \rightarrow l'\Lambda X$ with longitudinally polarized lepton-beam & longitudinally / transversely polarized target

- Λ polarization can be used as a tool in the investigation of the spin of nucleon : $\Delta q(x),\ \Delta_T q(x)$

- Λ production should be a sensitive probe for $s(x)$

Λ polarization

Angular distribution of decay product of Λ hyperon



- Decay violates parity → not isotropic

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1+\alpha\, P^{\Lambda}_{T'}\cos\theta)$$

- Slope of the daughter baryon cosθ distribution is given by

$$\alpha\, P^{\Lambda}_{T}$$

- If spin of Λ is being perfectly in direction *T'*

$$P^{\Lambda}_{T} = 1 \quad \& \quad \alpha = 0.642$$

- Magnitude of asymmetry parameters are same for Λ and $\bar{\Lambda}$ (no *CP* violation!)

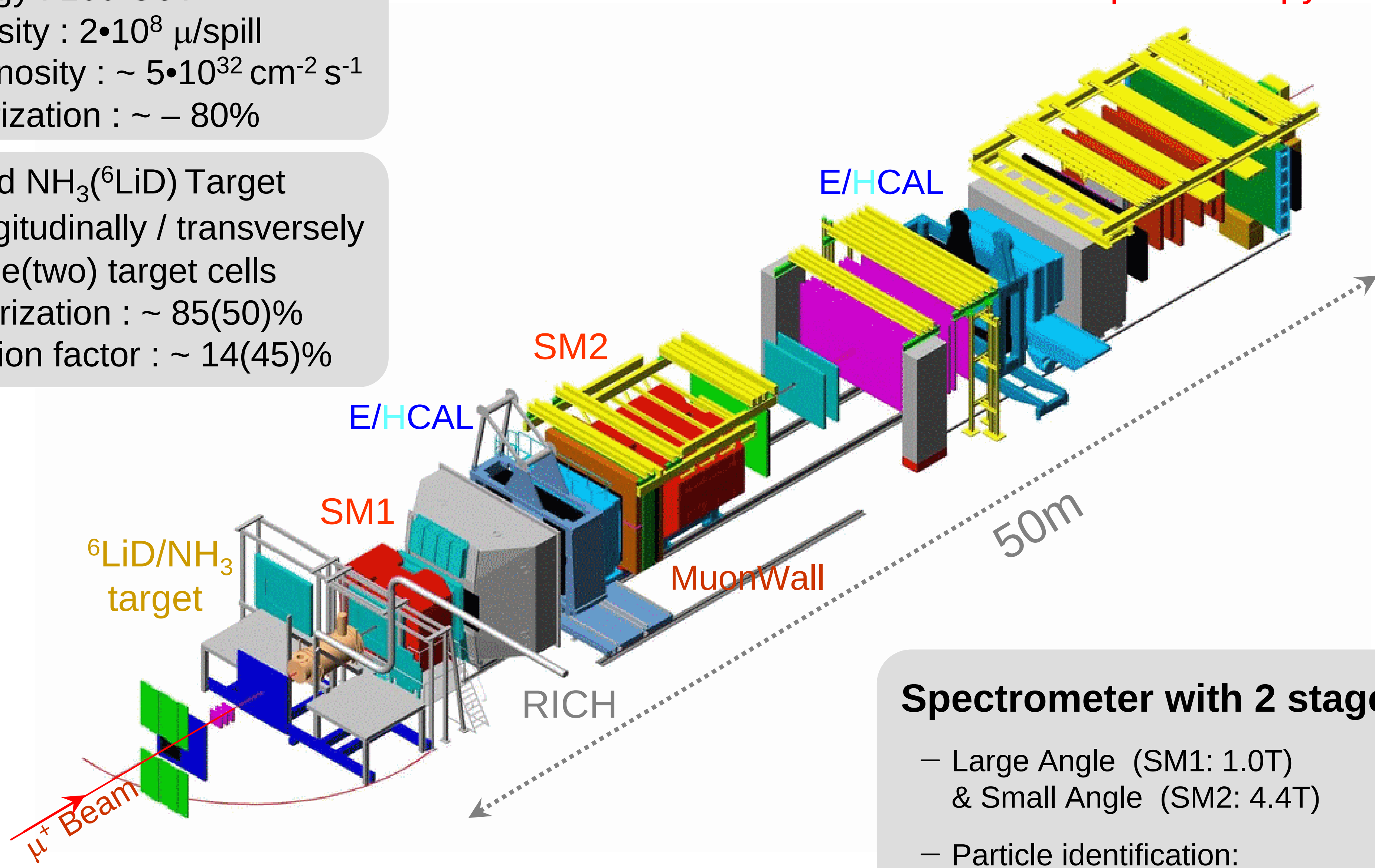
$$\alpha = \pm 0.642 \pm 0.013$$

COMPASS spectrometer

Polarized μ^+ beam
- Energy : 160 GeV
- Intensity : $2 \cdot 10^8$ μ/spill
- Luminosity : ~ $5 \cdot 10^{32}$ cm^{-2} s^{-1}
- Polarization : ~ – 80%

Polarized NH_3(^{6}LiD) Target
- Longitudinally / transversely
- Three(two) target cells
- Polarization : ~ 85(50)%
- Dilution factor : ~ 14(45)%

Common Muon and Proton Apparatus for Structure and Spectroscopy



Spectrometer with 2 stages
- Large Angle (SM1: 1.0T) & Small Angle (SM2: 4.4T)
- Particle identification: RICH , μF, ECAL, HCAL

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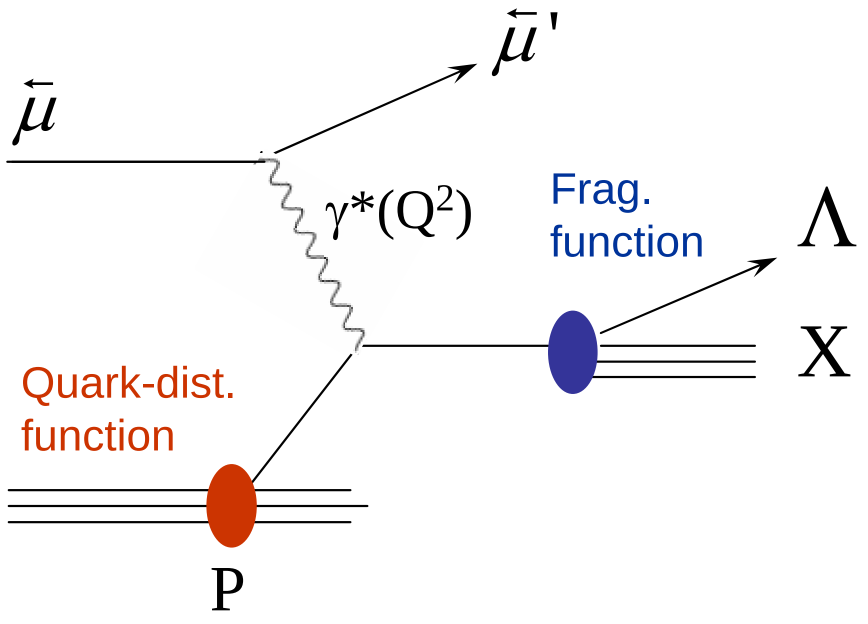
Longitudinal Λ production



In current fragmentation : $x_F > 0$

- Study of the quark to baryon fragmentation processes $q \to \Lambda$ (spin transfer mechanism)
- Test of the strangeness quark and antiquark symmetry $s(x) \neq \bar{s}(x),\ \Delta s(x) \neq \Delta\bar{s}(x)$

Longitudinal Λ polarization in DIS

$$P_\Lambda = \frac{d\sigma^{l\vec{N}\to\vec{\Lambda}X} - d\sigma^{l\vec{N}\to\overleftarrow{\Lambda}X}}{d\sigma^{l\vec{N}\to\vec{\Lambda}X} + d\sigma^{l\vec{N}\to\overleftarrow{\Lambda}X}} = P_B D(y) \frac{\sum_q e_q^2 q(x) \Delta D_q^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}$$

$q(x)$ = unpolarized quark distribution function
$\Delta D_q(z)$ = polarized fragmentation function
$D_q(z)$ = unpolarized fragmentation function

P_B = Beam polarization
Depolarization factor :

$$D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$$

Longitudinal Λ polarization

Unpolarized target ($|P_T|$ = 0 %)

Spin transfer : $$D_{LL} = \frac{P_\Lambda}{P_B D(y)} = \frac{\sum_q e_q^2 q(x) \Delta D_q^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}$$

Polarized target

In addition, the polarization can transfer from polarized quark

$$P_\Lambda = \frac{\sum_q e_q^2 [P_B D(y) q(x) + f\ P_T \Delta q(x)] \cdot \Delta D_q^\Lambda(z)}{\sum_q e_q^2 [q(x) + P_B D(y) f\ P_T \Delta q(x)] \cdot D_q^\Lambda(z)}$$

$\Delta q(x)$ = polarized quark distribution function
$q(x)$ = unpolarized quark distribution function
$\Delta D_q(z)$ = polarized fragmentation function
$D_q(z)$ = unpolarized fragmentation function

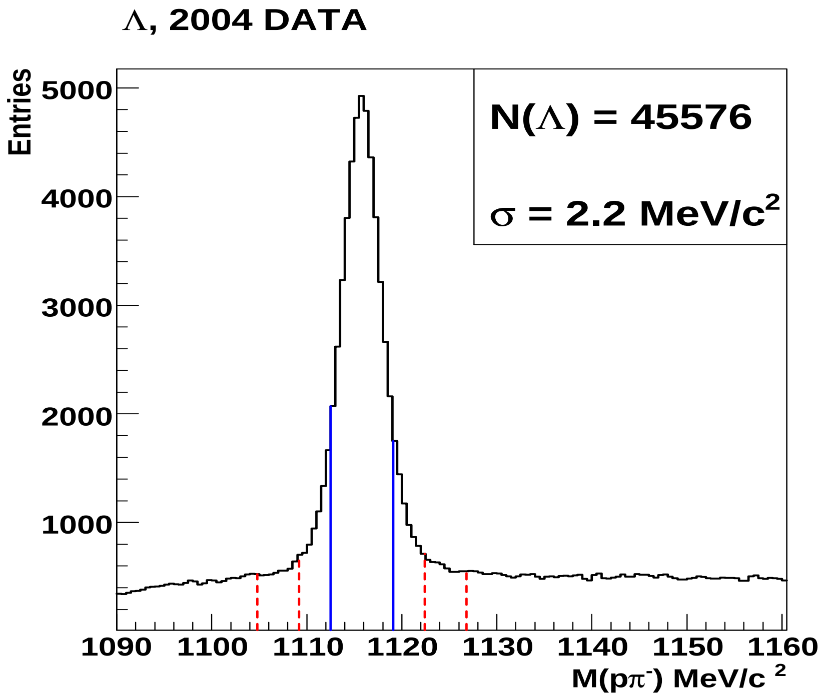
P_B = Beam polarization
P_T = Target polarization
f = Dilution Factor
Depolarization factor : $D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$

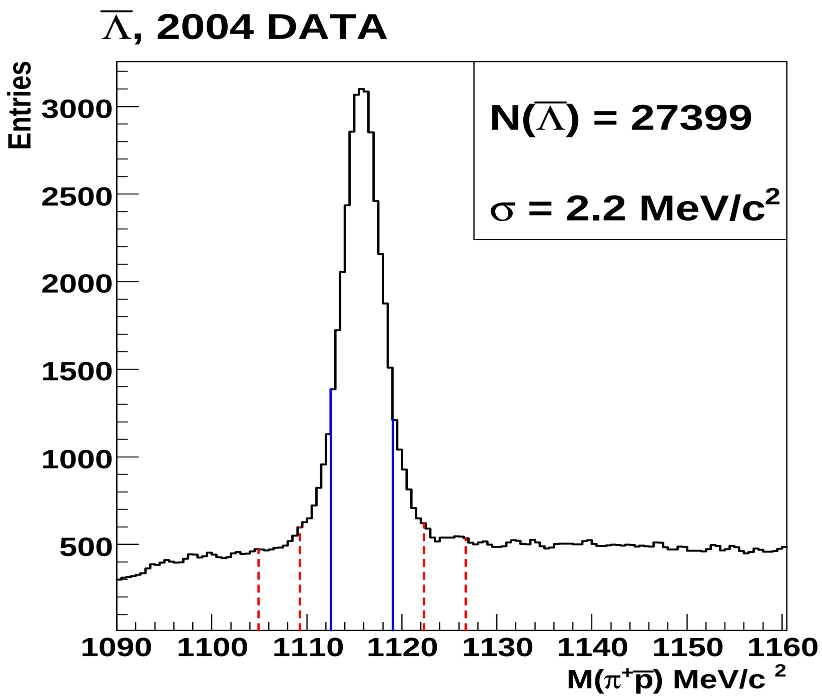
Is there a dependence of the hyperon polarization on target polarization?

Polarization asymmetry : $$\frac{\Delta P_\Lambda}{P_\Lambda} = \frac{P_{-P_T}^\Lambda - P_{+P_T}^\Lambda}{P_{-P_T}^\Lambda + P_{+P_T}^\Lambda}$$

no measurement exist

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





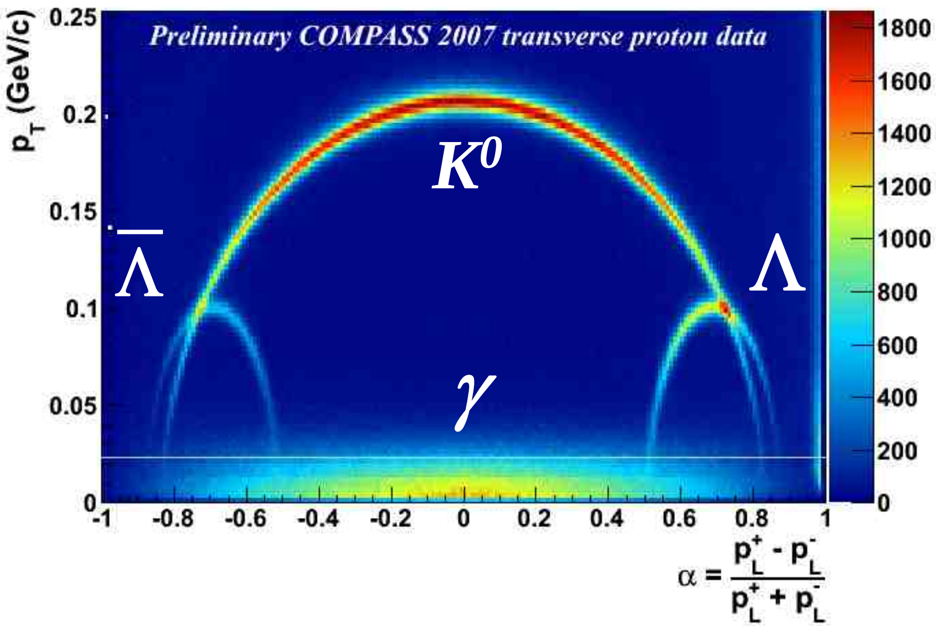
Eur. Phys. J. C64 (2009) 171

- Sidebin subtraction method to obtain the number of Λs in each cosθ bins

$$N_\Lambda \sim 70{,}000 \qquad N_{\bar{\Lambda}} \sim 40{,}000$$

- No particle ID used in the Λ selection

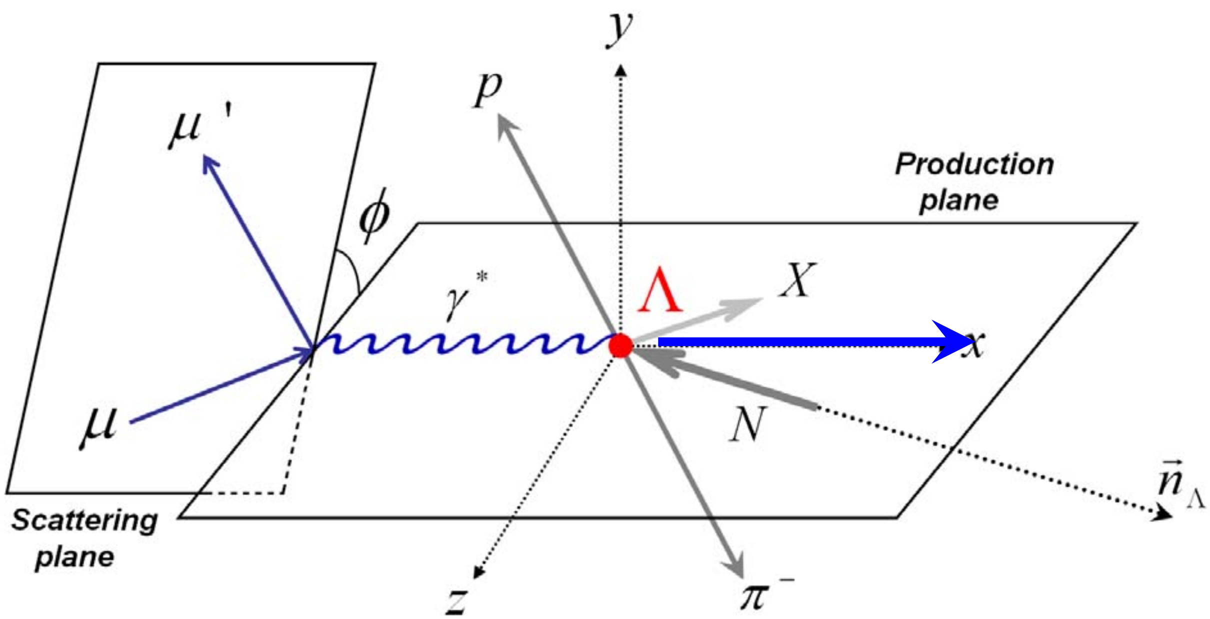
- Main background contributions



  – kinematically indistinguishable K^0
  – e^+e^- pairs from γ conversion
  – combinatorial background

Extraction of longitudinal Λ polarization

Spin analyzer for the measurement of longitudinal Λ polarization



Quantization axis along

virtual photon γ*

Angular distribution of the proton w.r.t γ* in Λ helicity frame

Extraction of Λ polarization by "bin-by-bin method"

– subdivision of Λ sample into bins of cosθ

– number of Λs from invariant mass distribution for each bin

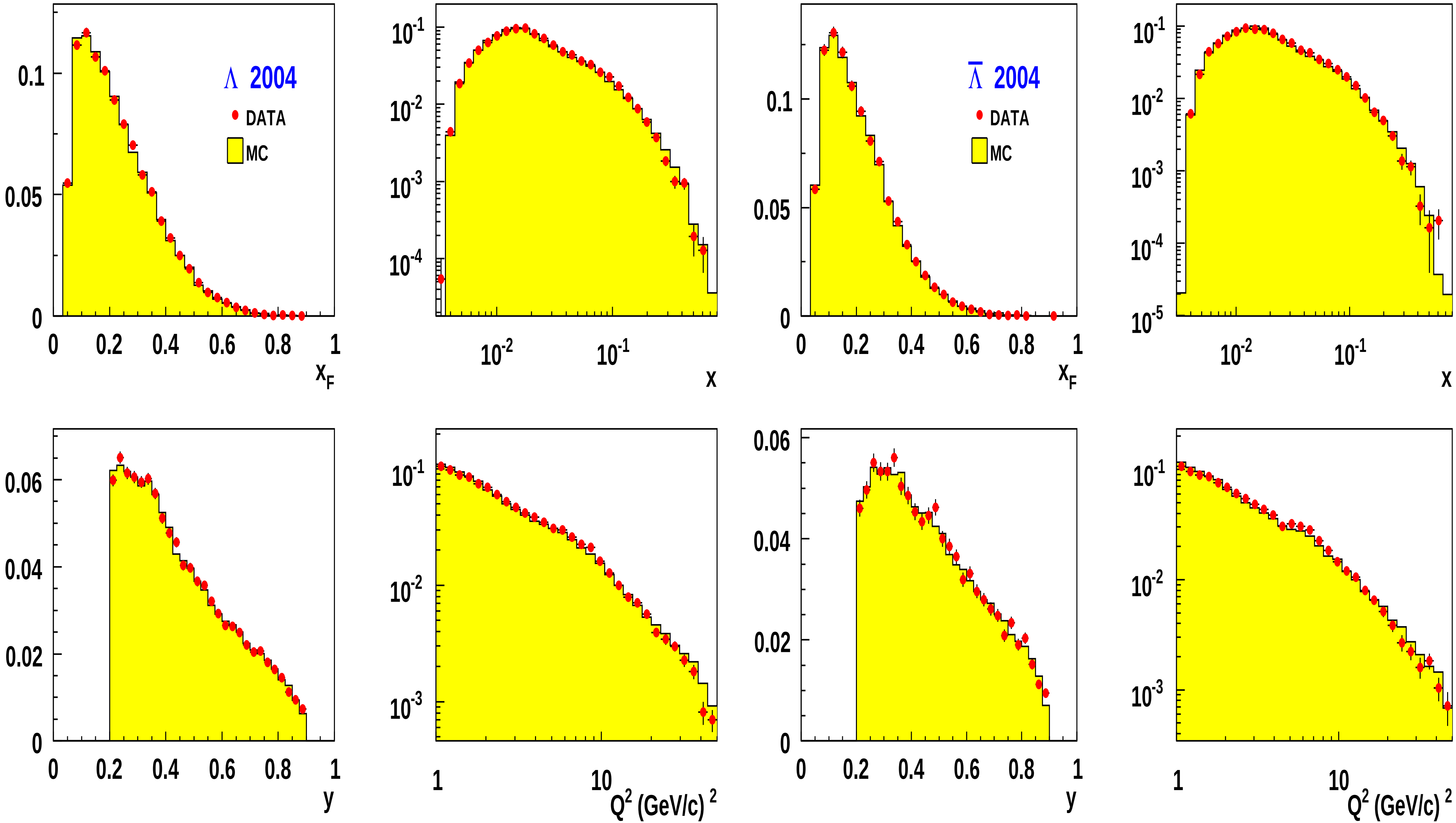
– polarization from fit parameter of acceptance corrected cosθ distribution

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1+\alpha\, P_{T'}^{\Lambda}\cos\theta)\cdot Acc(\theta)$$

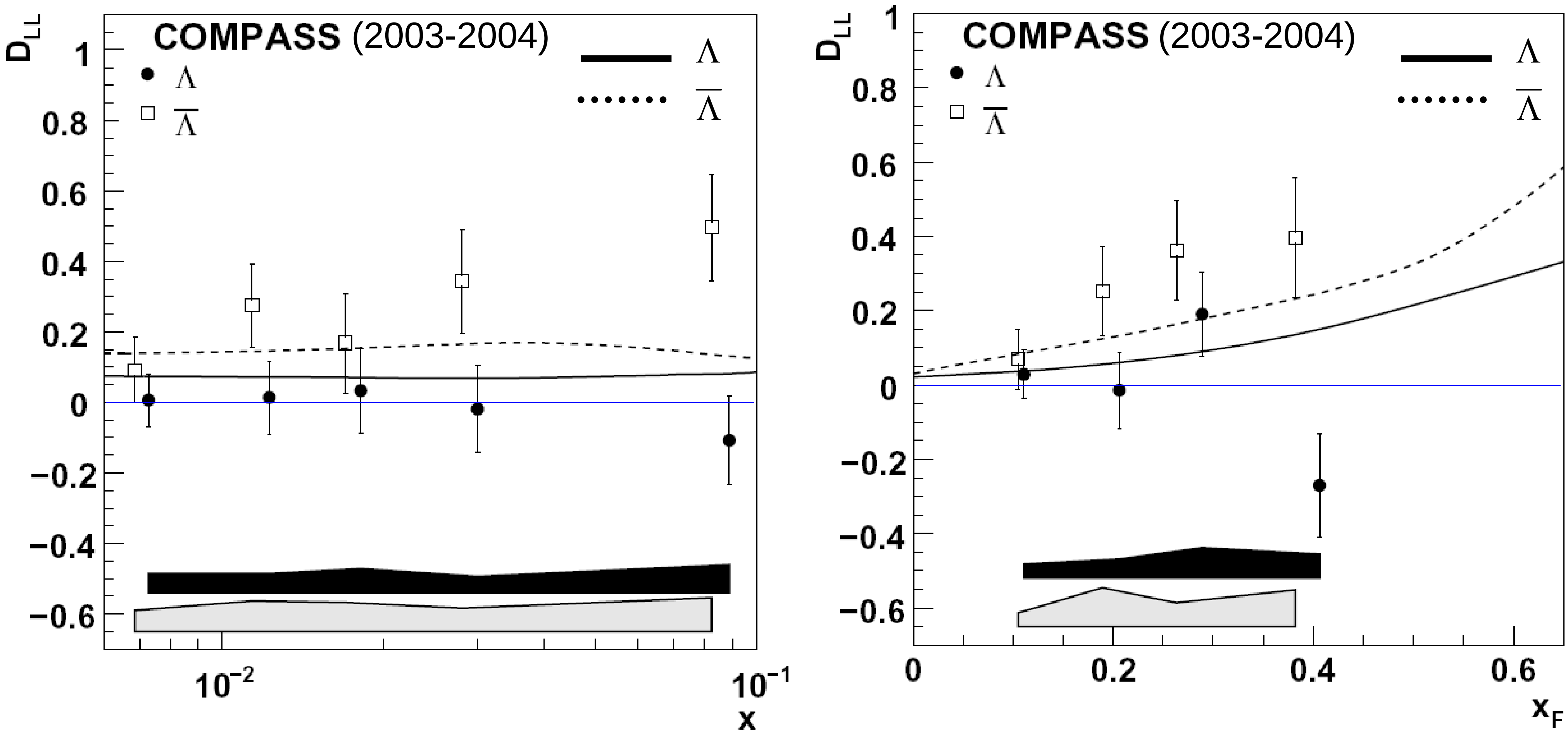
Kinematic distribution

Acceptance correction function from MC simulations (LEPTO) of unpolarized Λ & $\bar{\Lambda}$

$\rightarrow$ perfect agreement between data and MC in all kinematics

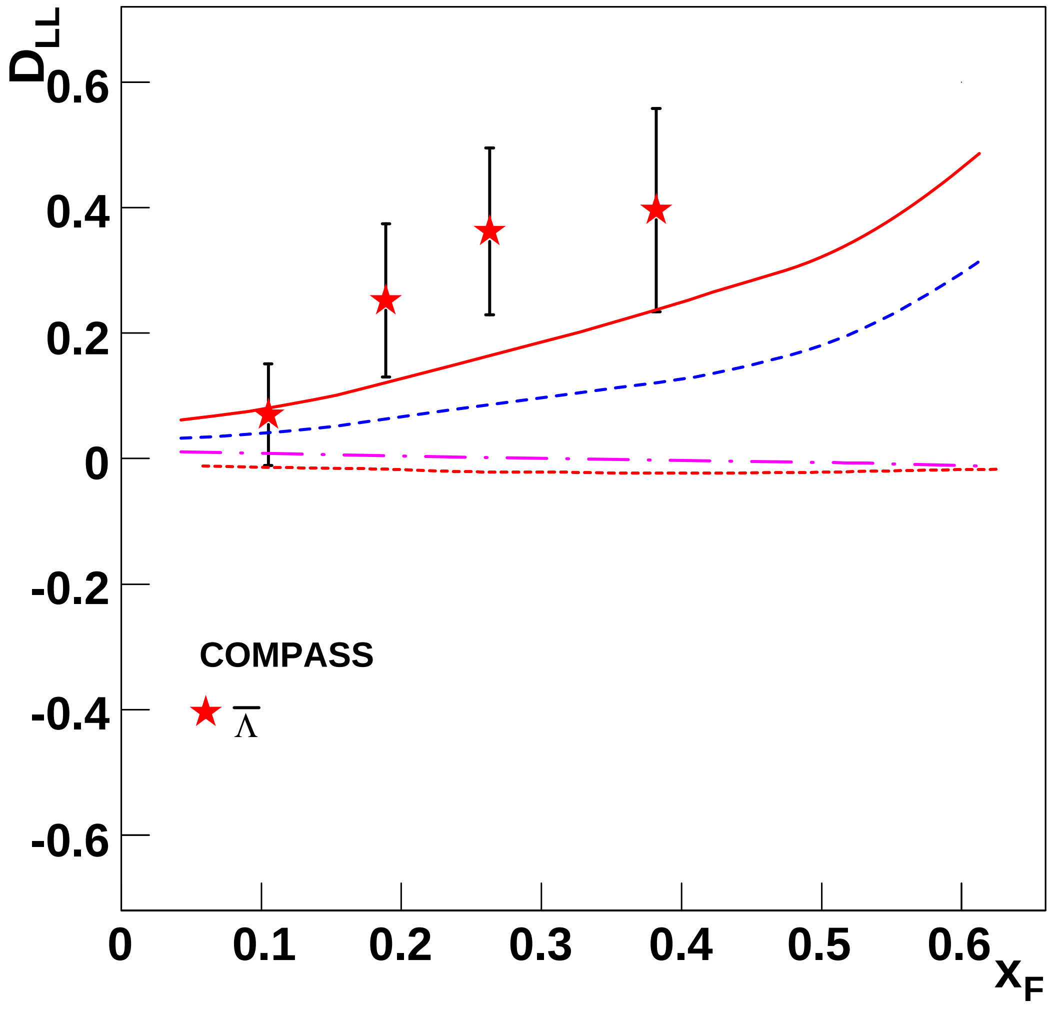


Results of spin transfer



- Spin transfer : $D_{LL}^{\Lambda,\bar{\Lambda}} = P_{\Lambda,\bar{\Lambda}} / (P_B D(y))$
  - $D_{LL}^{\Lambda} = -0.012 \pm 0.047 \pm 0.024 \quad D_{LL}^{\bar{\Lambda}} = +0.249 \pm 0.056 \pm 0.049$
  - spin transfer to $\bar{\Lambda}$ increase significantly at high x_F
- Theory prediction by J.Ellis et al., Eur. Phys. J. C52 (2007) 603
  - CTEQ5L(PDF) & SU(6) model : $D_{LL}^{\Lambda} < D_{LL}^{\bar{\Lambda}}$

Results of spin transfer



- Influence of different PDFs

$$D_{LL}^{\bar{\Lambda}}(\bar{s}) \neq 0$$

CTEQ5L, BJ model

GRV98LO, SU(6) model

$$D_{LL}^{\bar{\Lambda}}(\bar{s}) = 0$$

CTEQ5L, BJ model

GRV98LO, SU(6) model

- Sensitive to the strangeness distribution

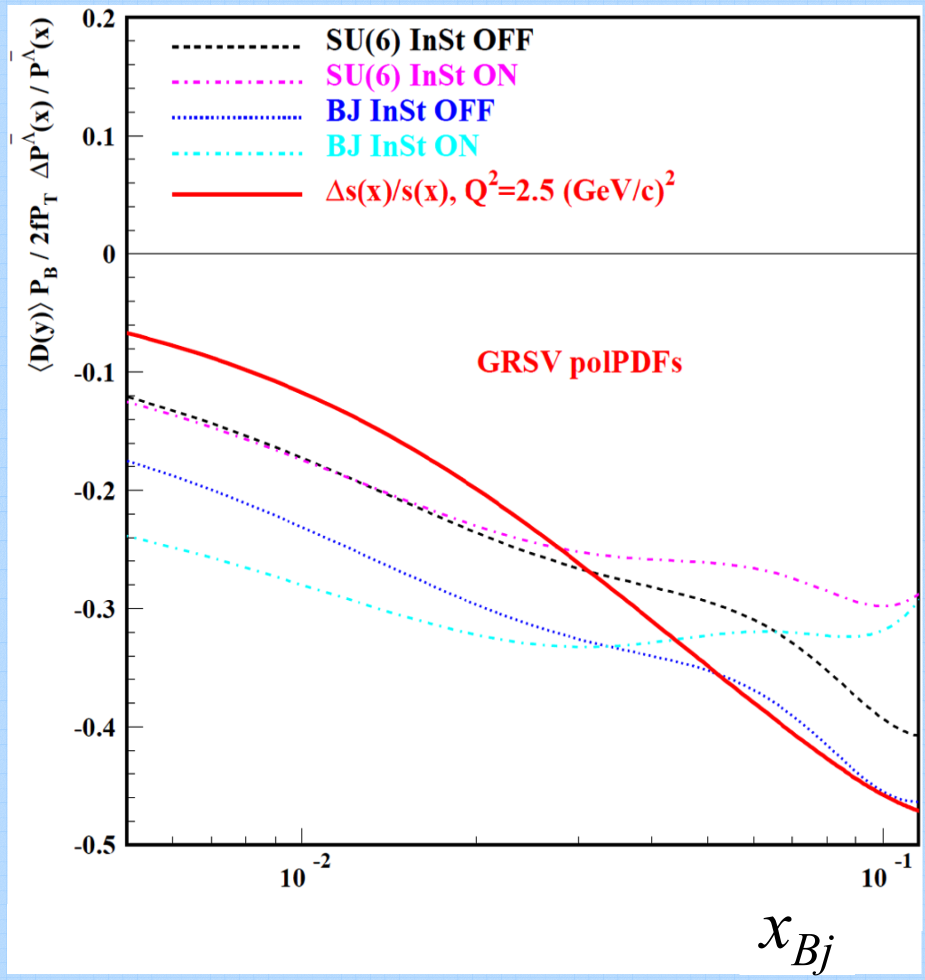
$$\bar{s}(x)_{\text{CTEQ5L}} > \bar{s}(x)_{\text{GRV98LO}}$$

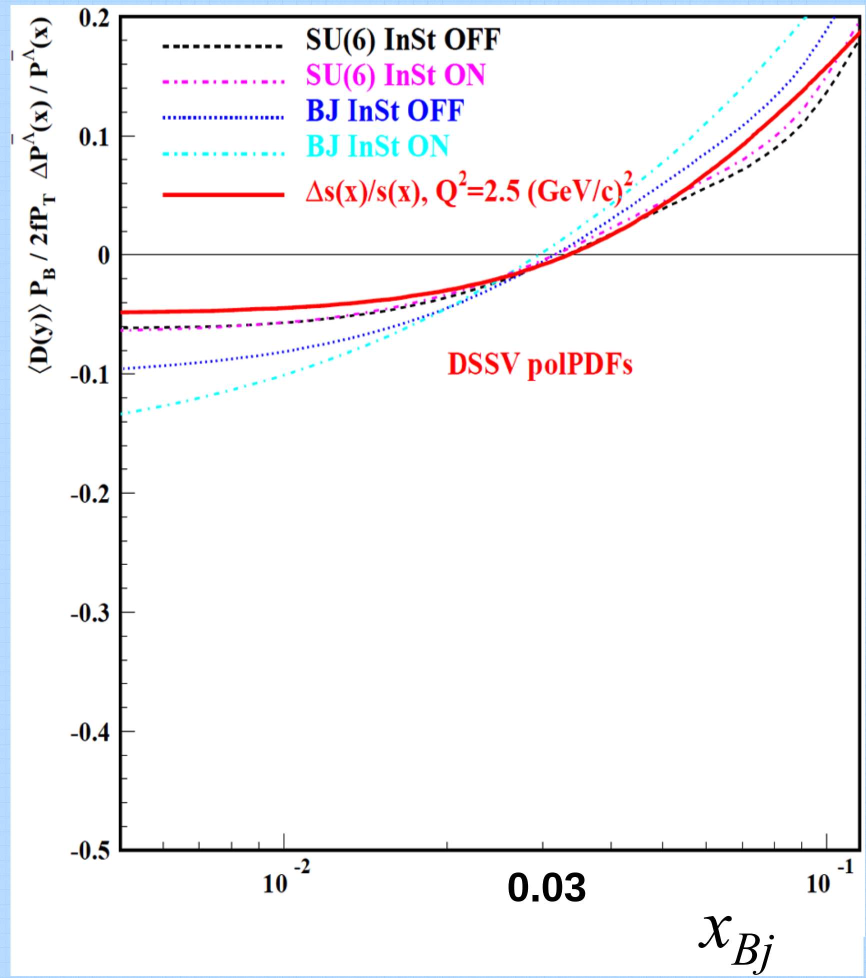
Data on the spin transfer to Λ and $\bar{\Lambda}$ could be used for the determination of

$$s(x) \neq \bar{s}(x)$$

Polarization asymmetry

Prediction for polarization asymmetry : Model calculation by A. Kotzinian @ DIS09

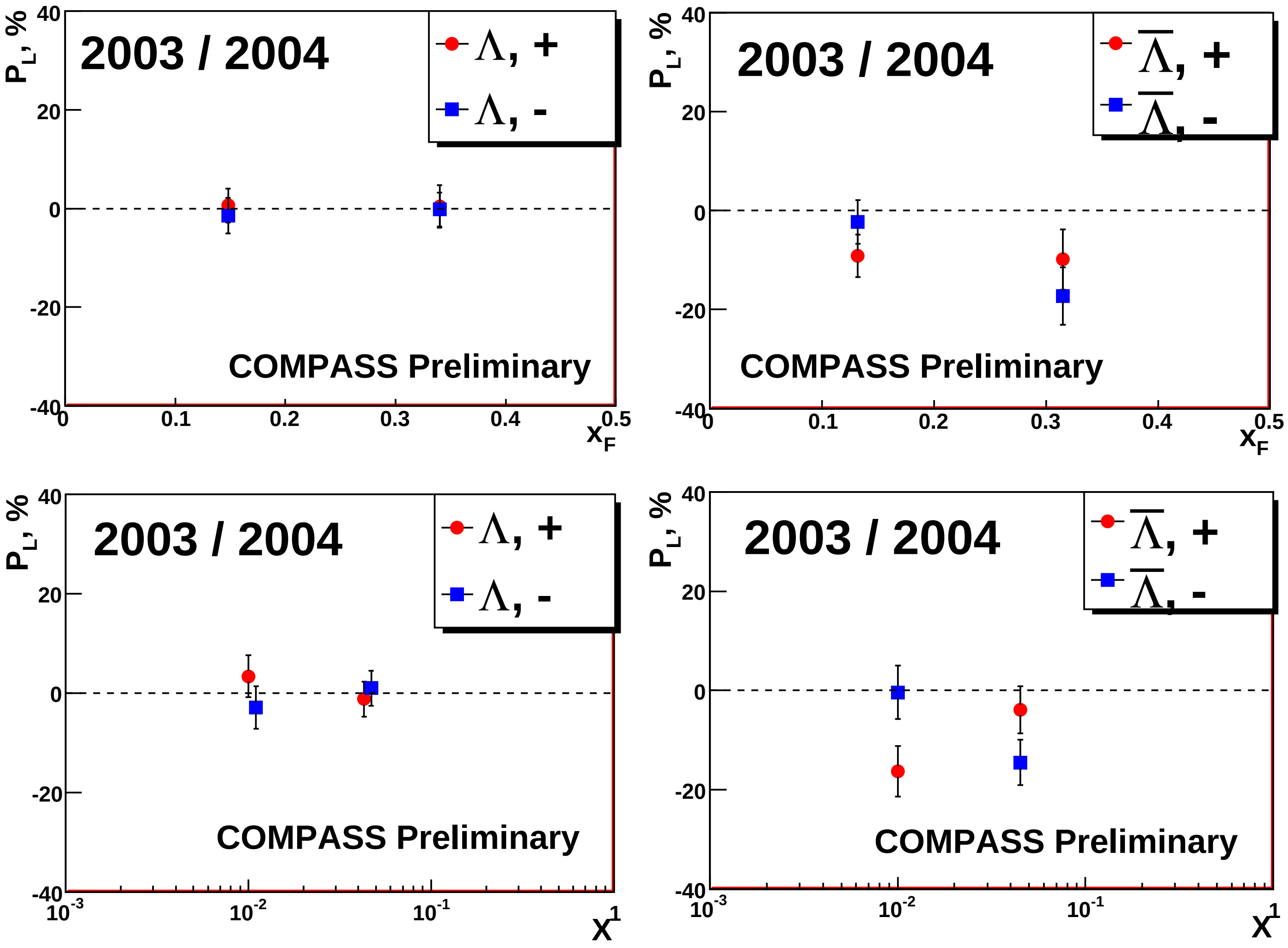


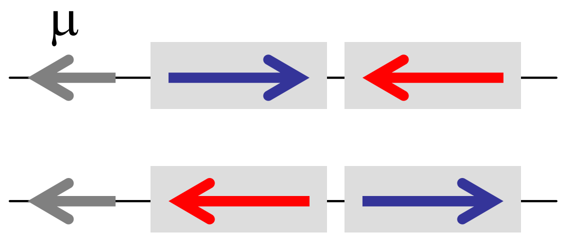


- Determination of the spin transfer dependence on the target polarization allows to fix $\Delta s(x)$ and $\Delta\bar{s}(x)$

- To verify sign change of Δs for DSSV, measure ΔP in two bins at $x_{Bj} \sim 0.03$

Dependence on the target polarization





+ : target pol. is same to μ pol.

– : target pol. is opposite to μ pol.

Averaged over full kinematics : $\Delta P^{\Lambda} = P_{+}^{\Lambda} - P_{-}^{\Lambda} = -0.01 \pm 0.04$

$$\Delta P^{\bar{\Lambda}} = P_{+}^{\bar{\Lambda}} - P_{-}^{\bar{\Lambda}} = +0.01 \pm 0.05$$

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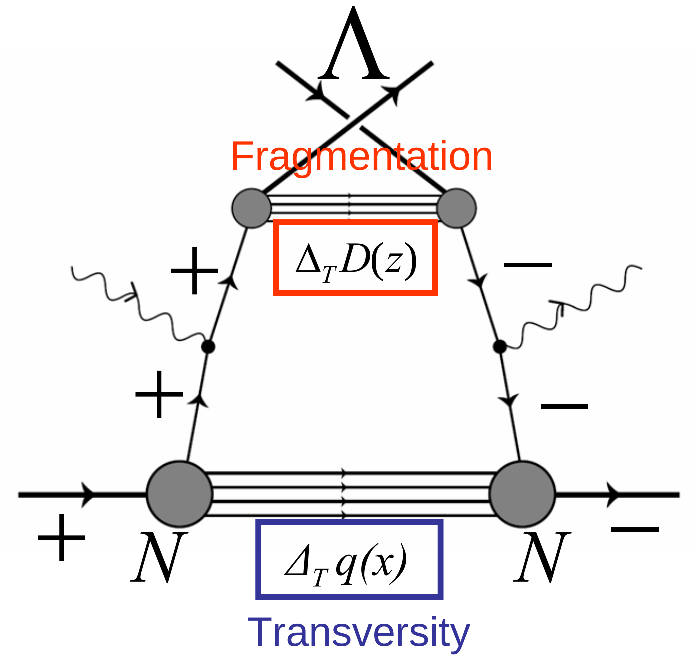
Transverse Λ polarization



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

- Transversity $\Delta_T q(x)$ can be measured on a transversely polarized target via "Transverse Λ polarization"

- To measure chiral-odd $\Delta_T q(x)$, requires another chiral-odd partner $\Delta_T D(z)$

Transverse Λ polarization from transversely polarized target

$$P_\Lambda = \frac{d\sigma^{lN^{\Uparrow} \to l'\Lambda^{\Uparrow} X} - d\sigma^{lN^{\Uparrow} \to l'\Lambda^{\Downarrow} X}}{d\sigma^{lN^{\Uparrow} \to l'\Lambda^{\Uparrow} X} + d\sigma^{lN^{\Uparrow} \to l'\Lambda^{\Downarrow} X}} = f\, P_T D_T(y) \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_q^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}$$

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

$q(x)$ = unpolarized quark distribution function

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

$D_q(z)$ = unpolarized fragmentation function

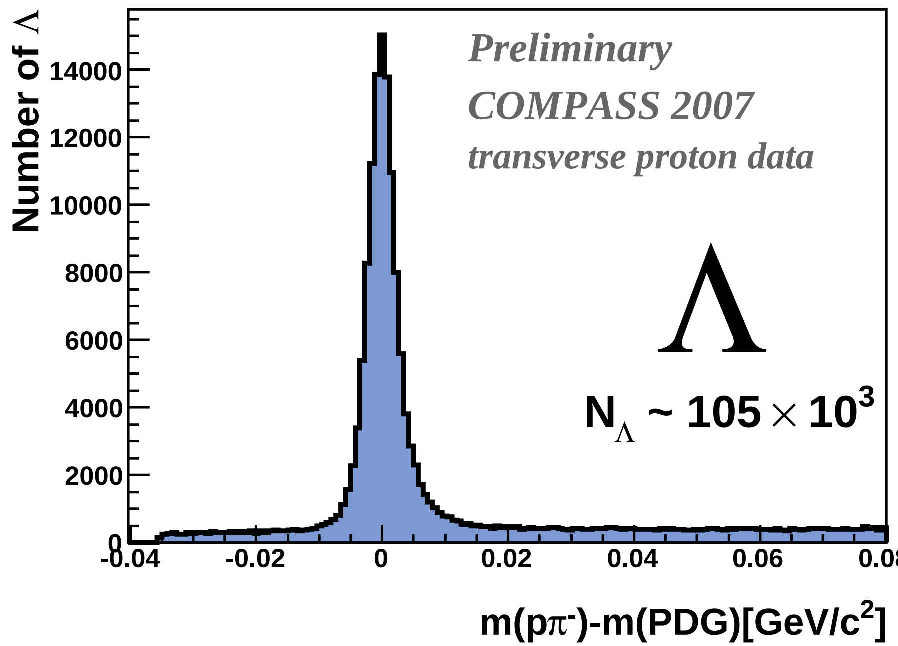
P_B = Beam polarization

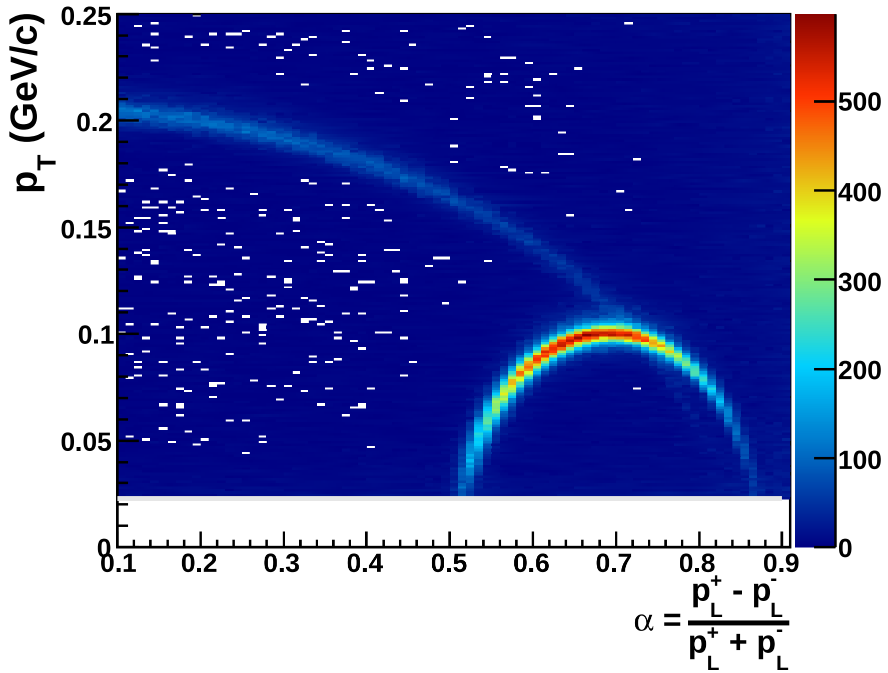
P_T = Target polarization

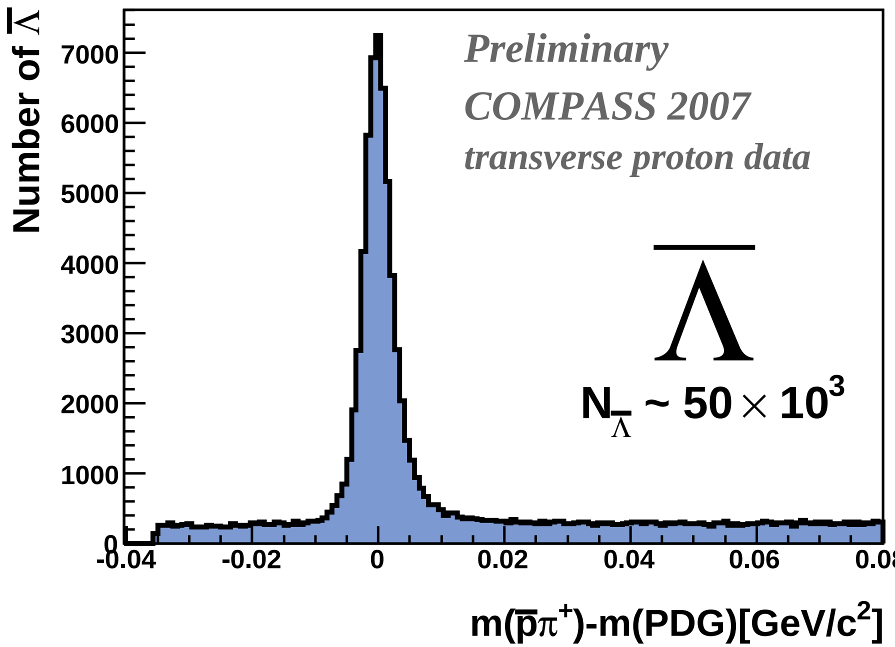
f = Dilution Factor

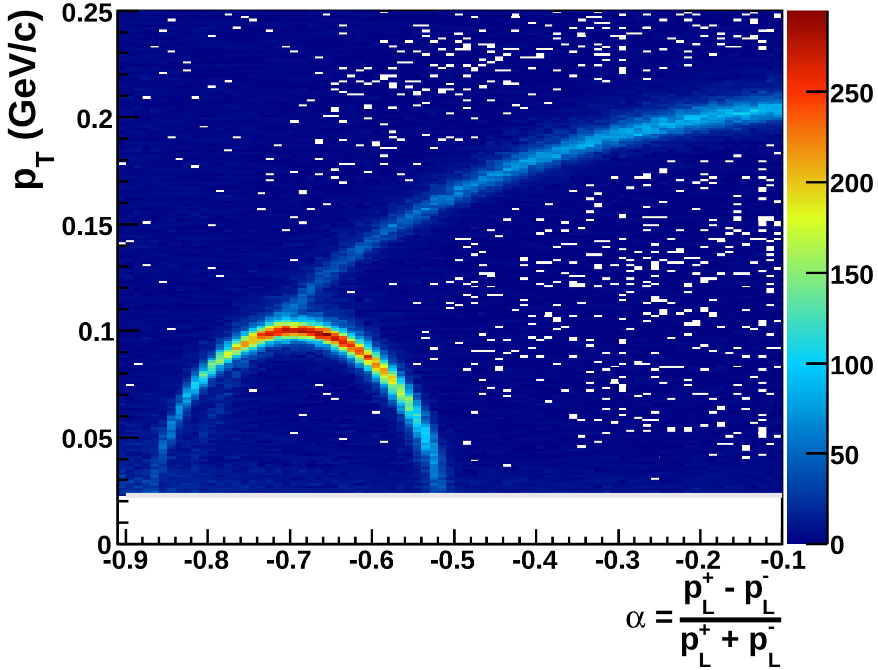
Depolarization factor : $D_T(y) = \frac{2(1-y)}{1+(1-y)^2}$

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



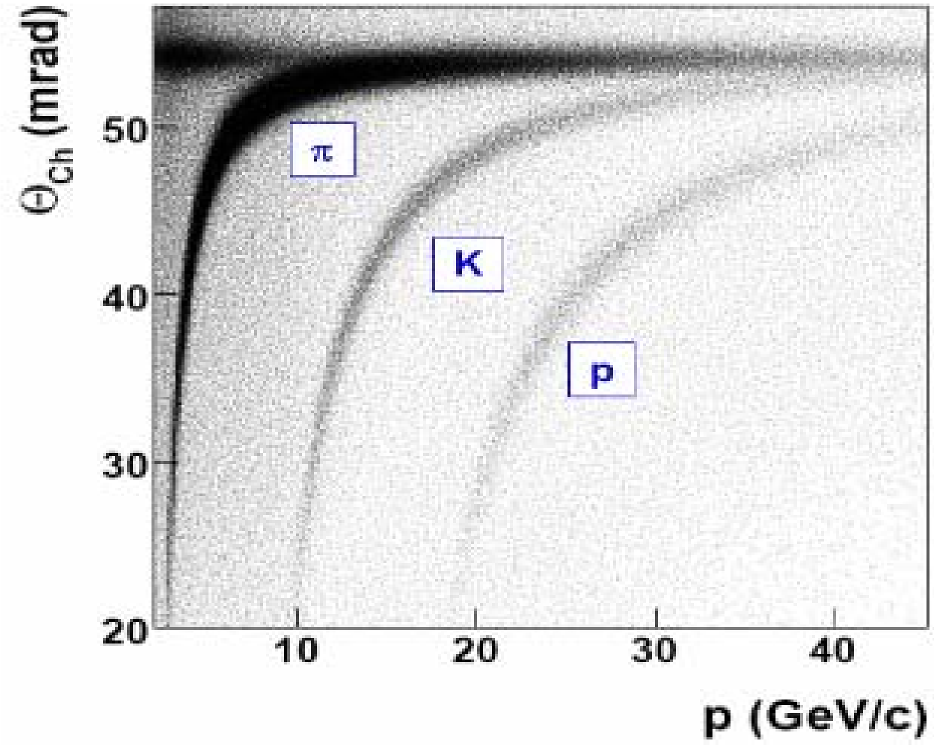






Λ selection : RICH application

Particle Identification by RICH



Threshold momenta

$p_{\pi}\sim$ 2 GeV/c

$p_{K}\sim$ 9 GeV/c

$p_{P}\sim$ 17 GeV/c

- Hadron masses calculated from the measured cherenkov angle θ_{ch}
- Separation between π, K and p in the momentum range 2~50 GeV/c
- $\pi^{+}, K^{+}(\pi^{-}, K^{-})$ veto for proton (anti-proton) candidate
- Likelihood methods are used to reject π and K for proton candidate in the decay of $\Lambda \rightarrow p\pi^{-}$ and $\overline{\Lambda} \rightarrow \overline{p}\pi^{+}$

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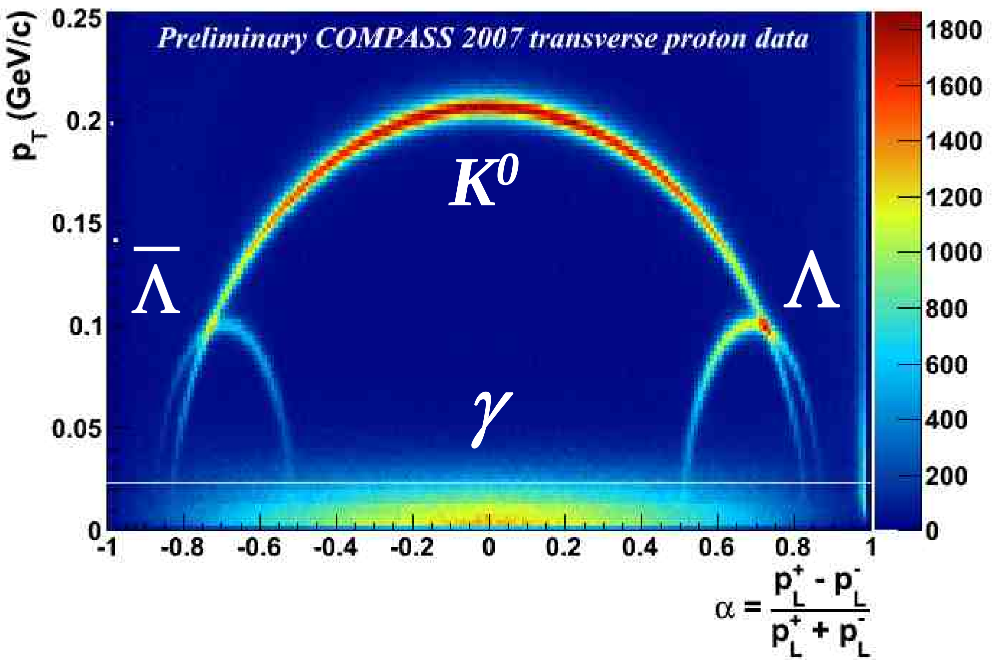

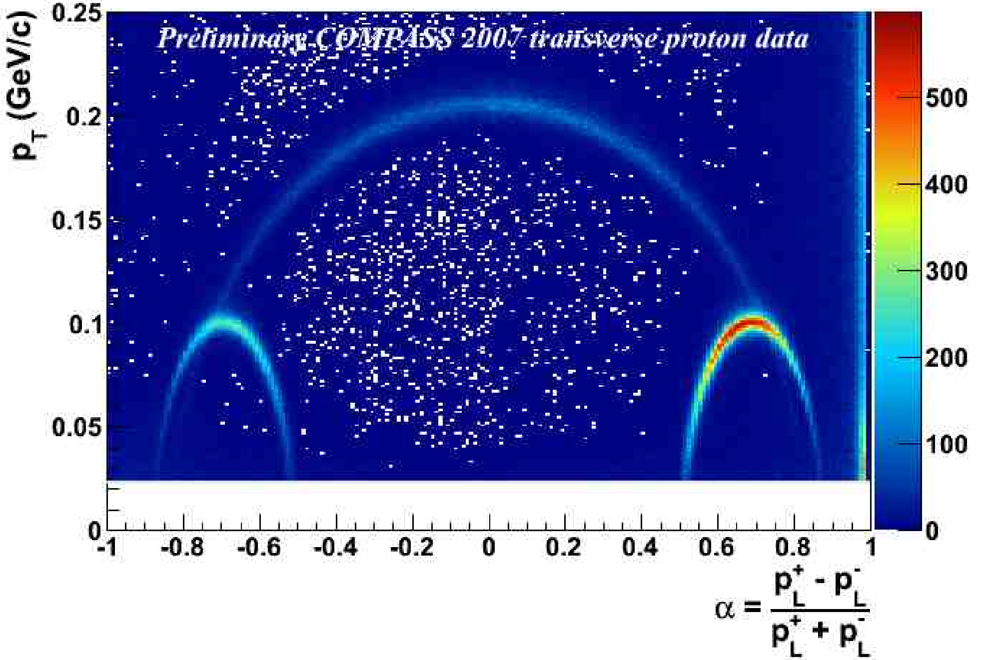

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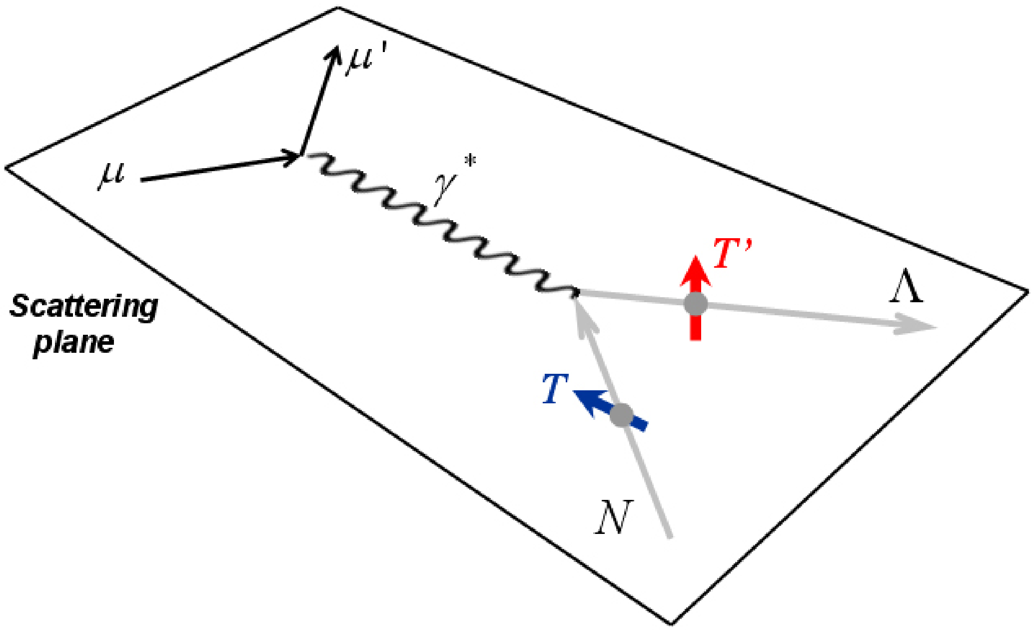
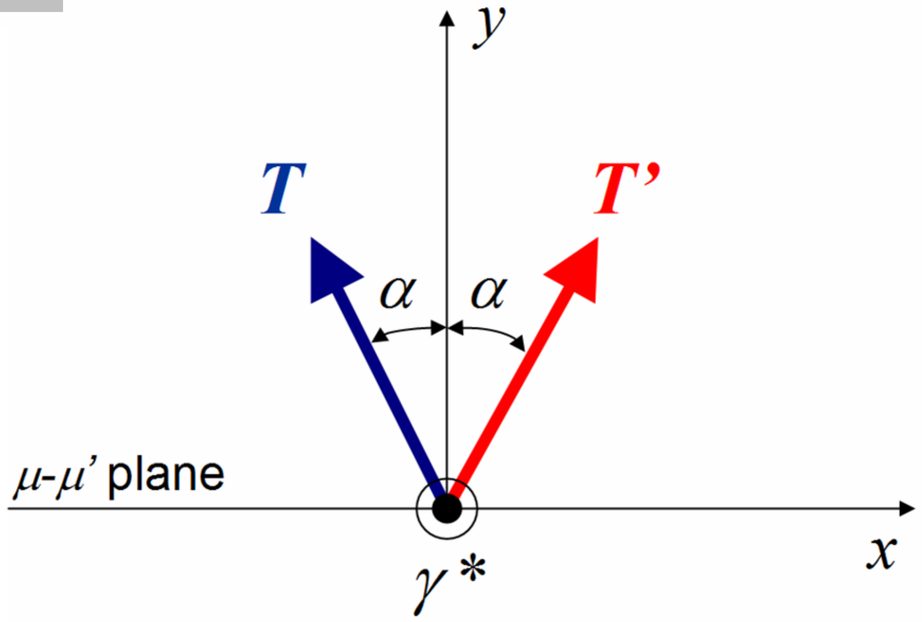
Extraction of transverse Λ polarization

Quantization axis for transverse Λ polarization



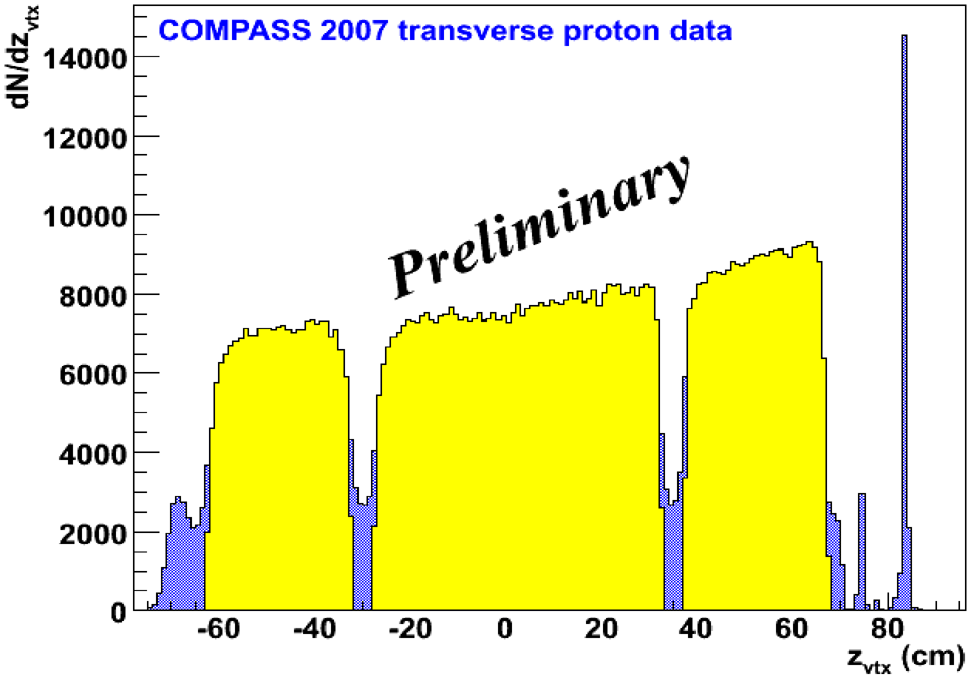


M. Anselmino & F. Murgia,
Physics Letters B 483 (2000) 74-86

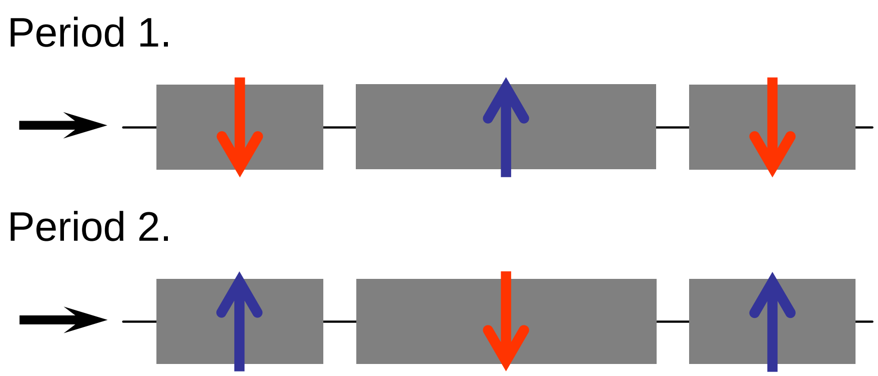
T (initial quak spin) : component of target spin perpendicular to γ*
T' (final quark spin) : symmetric of the ***T*** w.r.t. the normal to the scattering plane

If q fragments into Λ hyperon, the measurement of polarization w.r.t. ***T'*** reveals information about the initial quark polarization in the nucleon

Acceptance cancellation



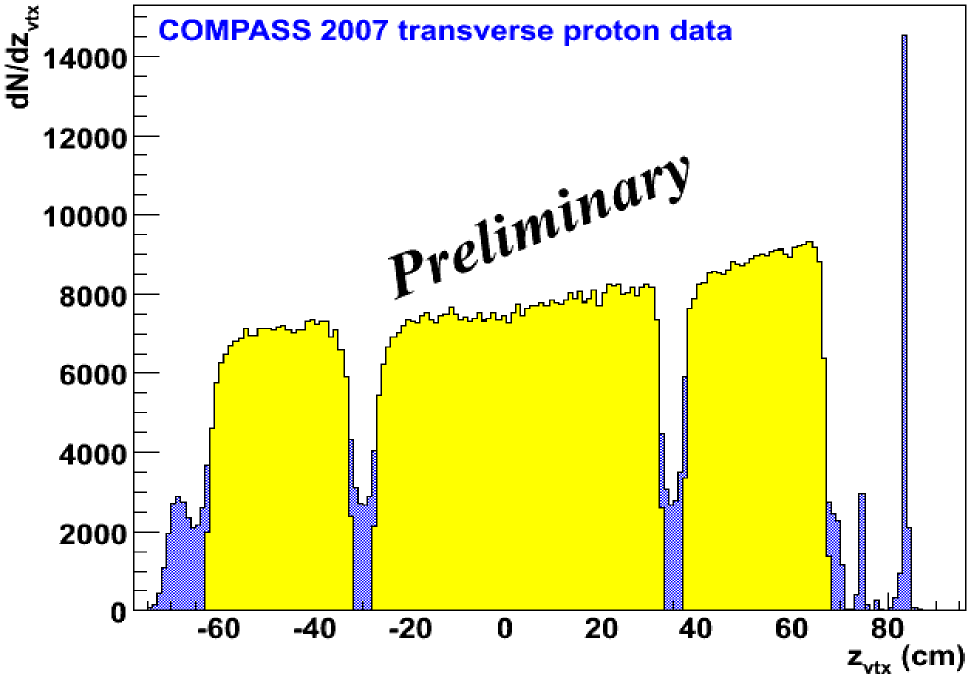
Three target (NH^3) cells with weekly reversal target polarizaiton in 2007 :



Acceptance cancellation by "geometrical mean method" :

- extraction from data itself using up-down symmetry of angular distribution
- unnecessary a MC to correct acceptance
- additional symmetries two target polarizations & two configurations

Acceptance cancellation



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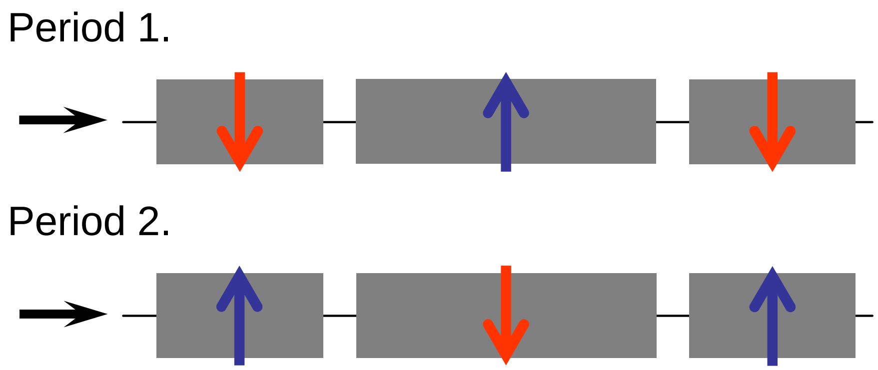


Asymmetry with recombination of Λ data samples :

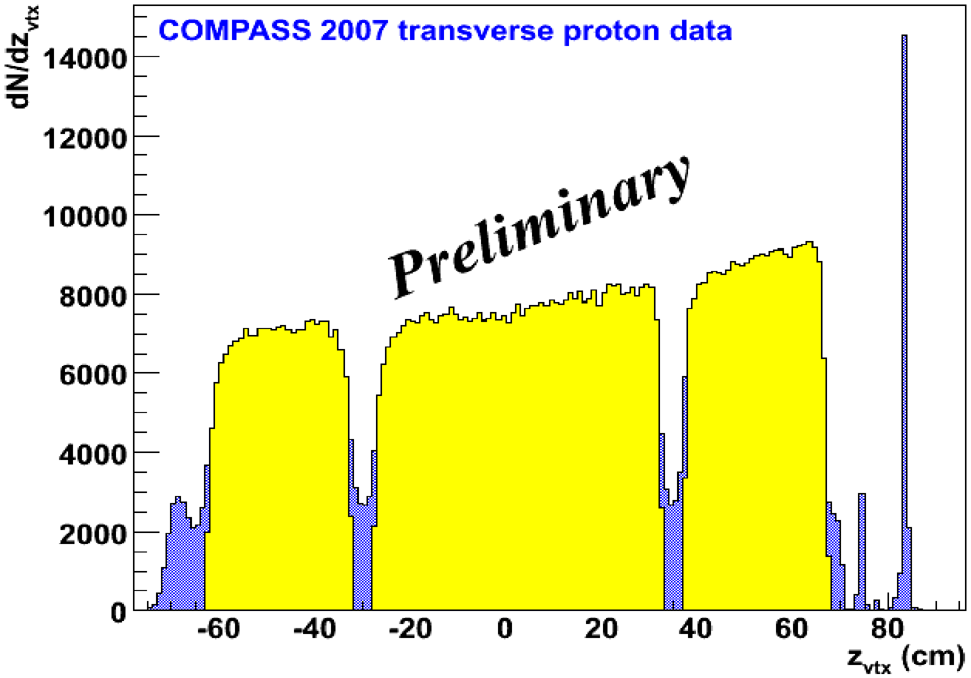
$$\varepsilon(\theta)=\frac{N^{N^{\Uparrow}\Lambda^{\Uparrow}}-N^{N^{\Uparrow}\Lambda^{\Downarrow}}}{N^{N^{\Uparrow}\Lambda^{\Uparrow}}+N^{N^{\Uparrow}\Lambda^{\Downarrow}}}=\frac{[\sqrt{N_1^{\uparrow}(\theta^+)N_2^{\uparrow}(\theta^+)}+\sqrt{N_1^{\downarrow}(\theta^-)N_2^{\downarrow}(\theta^-)}]-[\sqrt{N_1^{\uparrow}(\theta^-)N_2^{\uparrow}(\theta^-)}+\sqrt{N_1^{\downarrow}(\theta^+)N_2^{\downarrow}(\theta^+)}]}{[\sqrt{N_1^{\uparrow}(\theta^+)N_2^{\uparrow}(\theta^+)}+\sqrt{N_1^{\downarrow}(\theta^-)N_2^{\downarrow}(\theta^-)}]+[\sqrt{N_1^{\uparrow}(\theta^-)N_2^{\uparrow}(\theta^-)}+\sqrt{N_1^{\downarrow}(\theta^+)N_2^{\downarrow}(\theta^+)}]}$$

\# of Λs : $N(\theta)=\frac{N_0}{2}(1+\alpha\, P_{T'}^{\Lambda}\cos\theta)\cdot Acc(\theta)$

Assumption : constant acceptance & target polarization

$$\frac{Acc_1^{\uparrow}(\theta)}{Acc_1^{\downarrow}(\theta)}=\frac{Acc_2^{\downarrow}(\theta)}{Acc_2^{\uparrow}(\theta)} \qquad P_T^1=P_T^2$$

Acceptance cancellation



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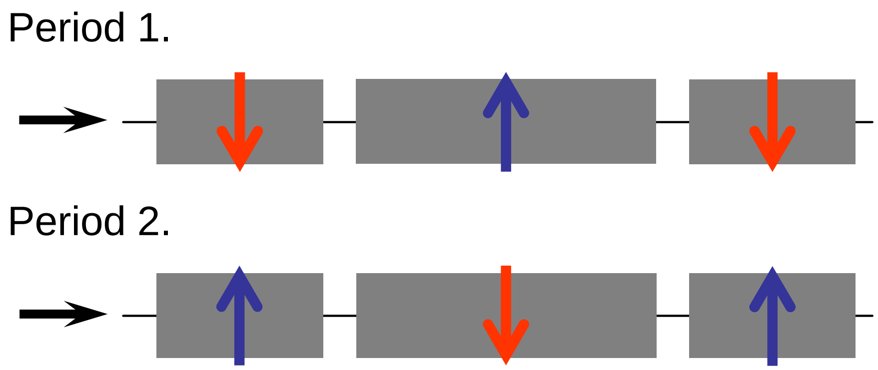
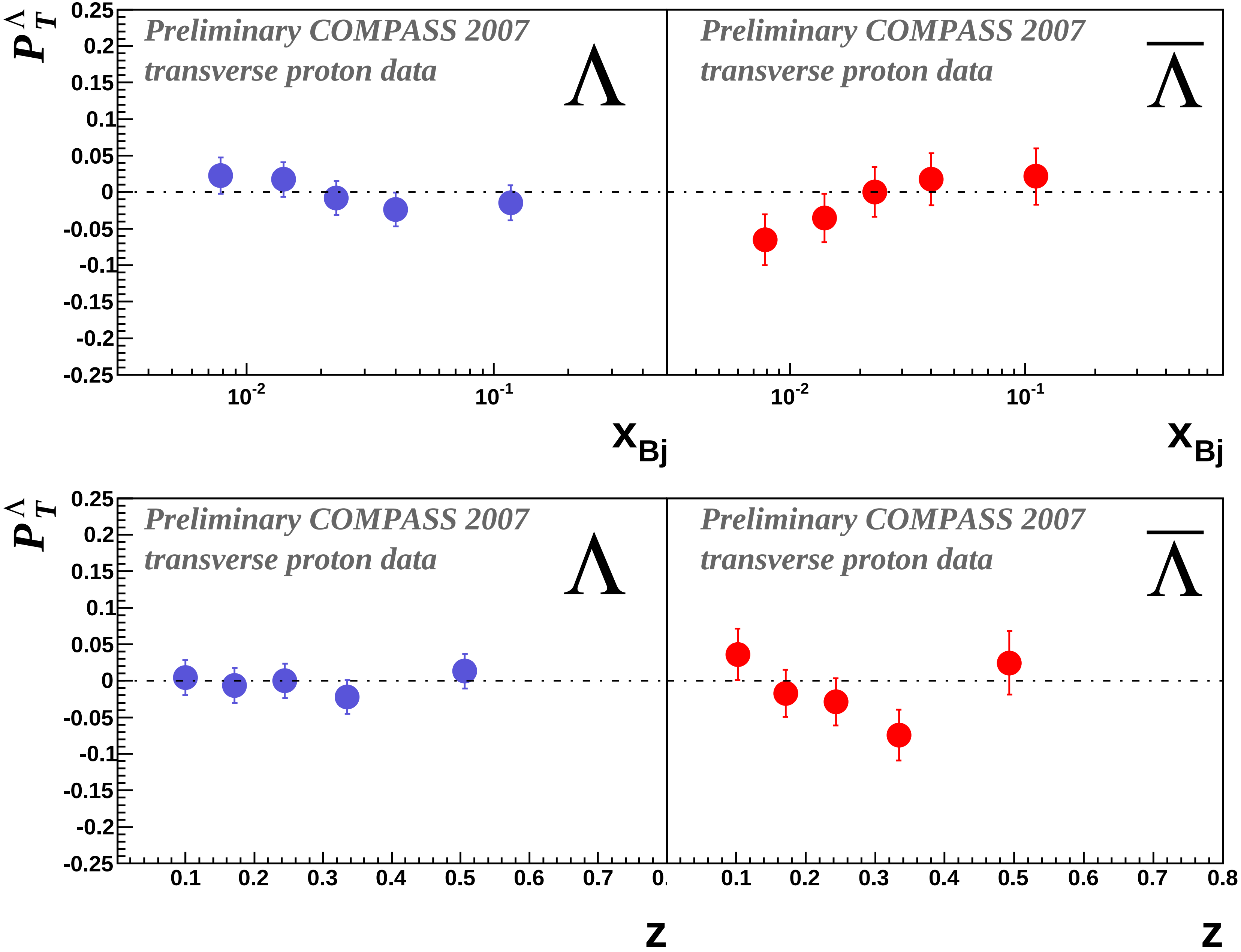


- Acceptance terms are canceled out in the asymmetry, leaving only the terms proportional to the polarization

$$\varepsilon_T(\theta) = \alpha P_\Lambda \cos\theta$$

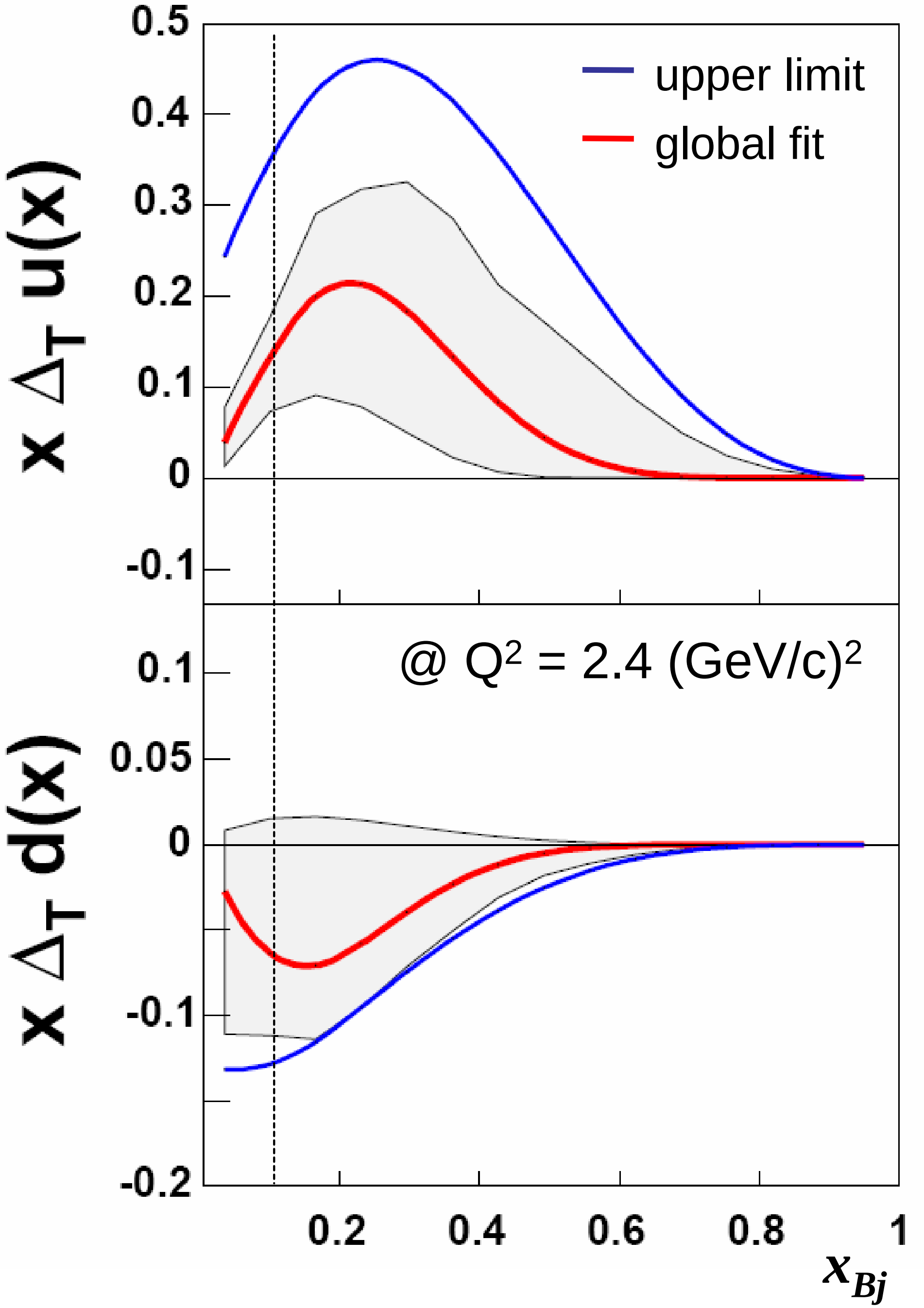
- need counting rate from 8 different data samples to extract polarization

Transverse Λ & $\bar{\Lambda}$ polarization



Systematic errors have been estimated to be smaller than statistical errors : $\sigma_{sys.} \leq 0.74\sigma_{stat.}$

Interpretation of results



Anselmino et al: Phys. Rev. D 75, 054032 (2007)

- HERMES / COMPASS / BELLE combined results for collins asymmetry

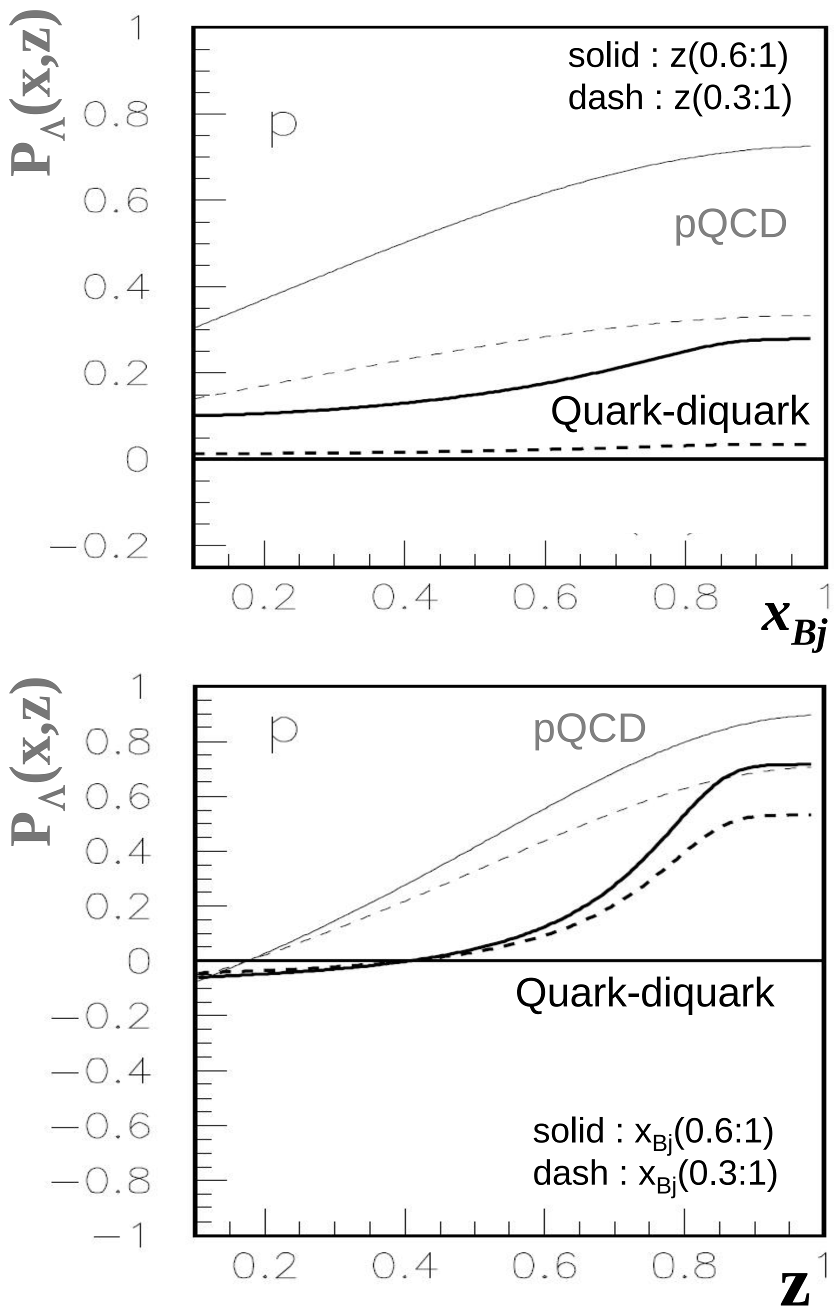
- For proton target a positive $\Delta_T q(x)$ is expected :

$$2 \cdot \Delta_T u(x) + 1 \cdot \Delta_T d(x) > 0$$

- $\Delta_T D(z)$ seems to be small in $0 < z < 0.5$:

  nearly no analyzing power

Interpretation of results



Bo-Qiang. Ma et al: Phys. Rev. D 64, 014017 (2001)

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- For proton target a positive $\Delta_T q(x)$ is expected :

  $$2\cdot\Delta_T \mathrm{u}(x) + 1\cdot\Delta_T \mathrm{d}(x) > 0$$

- $\Delta_T D(z)$ seems to be small in $0 < \mathrm{z} < 0.5$:

  nearly no analyzing power

- pQCD model :
  $\Delta_T \mathrm{d}(x)$ / $\mathrm{d}(x)$ is positive
  Quark-diquark model :
  $\Delta_T \mathrm{d}(x)$ / $\mathrm{d}(x)$ is negative

- Need extended kinematics :

  $x_{Bj} > 0.1$ and $\mathrm{z} > 0.5$

Conclusion & outlook

Longitudinal Λ polarization

First measurement of dependence of the longitudinal Λ polarization on the target polarization

– spin transfer : $D_{LL}^{\Lambda} \neq D_{LL}^{\bar{\Lambda}}$

– no significant dependence on target pol. is found for Λ and $\bar{\Lambda}$

– work in progress with 2006 proton data

Transverse Λ polarization

First measurement of transversity via „transverse Λ polarization" from transversely polarized proton target

– no clear x_{Bj} and z dependence with proton target

– $\Delta_T D_q^{\Lambda}(z)$ seems to have no analyzing power in COMPASS kinematics

– 2010 data will allow to reduce the statistical error by factor 2