Λ Polarization Measurements at COMPASS

Boris Grube
on behalf of the COMPASS collaboration

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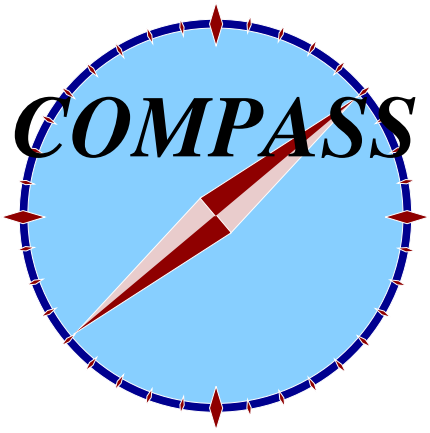
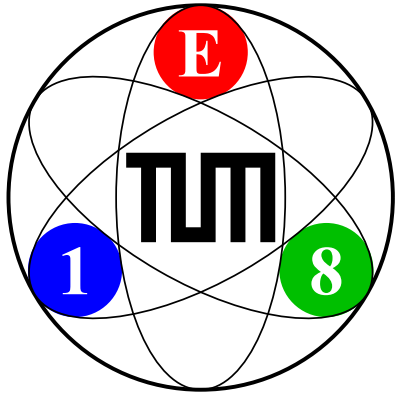
Physik Department E18
Garching, Germany



DIS06
XIV International Workshop
on Deep Inelastic Scattering
Tsukuba, 21st April 2006



Outline

Why Λ polarization?

Ideal probe to study spin effects in high energy reactions

Self-analyzing weak decay $\Lambda \to p\,\pi^-$, BR ≈ 64 %

- Parity violation: polarization P_S^Λ w.r.t. analyzer $\vec{S}$ reveals itself in angular distribution of decay daughters

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta} = \frac{N_0}{2}\left(1 + \alpha_\Lambda P_S^\Lambda \cos\theta\right)$$

with θ proton angle w.r.t. $\vec{S}$ in Λ rest frame

$\alpha_\Lambda = 0.642 \pm 0.013$ decay assymmetry parameter

Extraction of **angular distributions**

- Suppression of background contaminations
- Correction of apparatus effects (acceptance)

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The Experimental Setup

Fixed target experiment @ CERN SPS

- 2-stage spectrometer
- longitudinally polarized 160 GeV/c μ^+-beam
- Longitudinally/transversely polarized ^{6}LiD target

Setup 2003 (topview)

COMPASS is able to study all aspects of Λ polarization.

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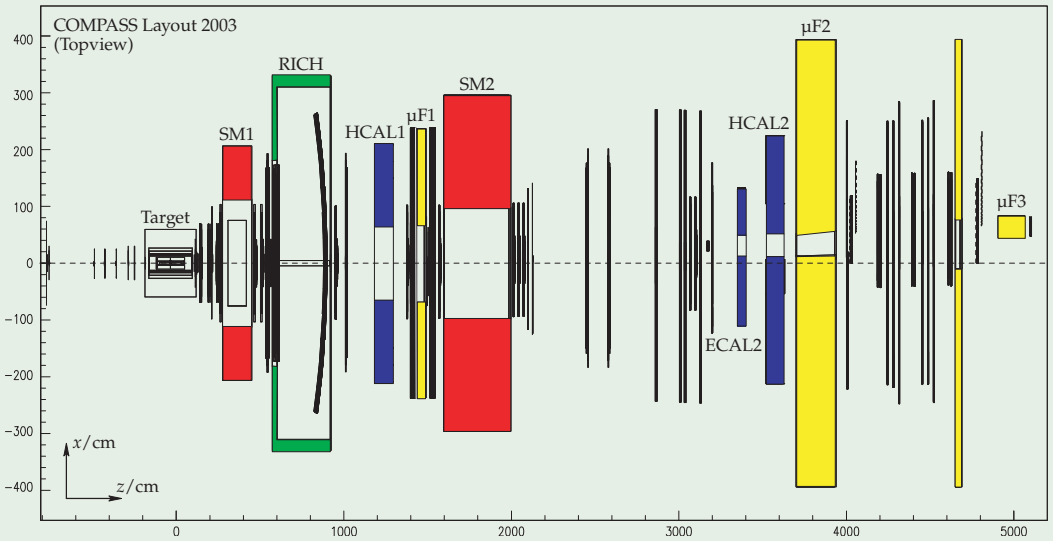

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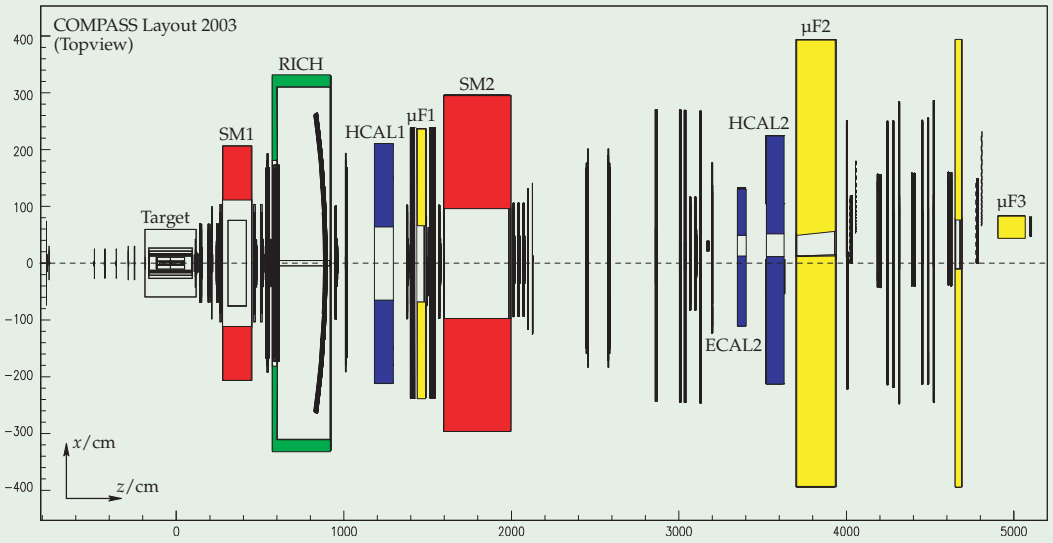

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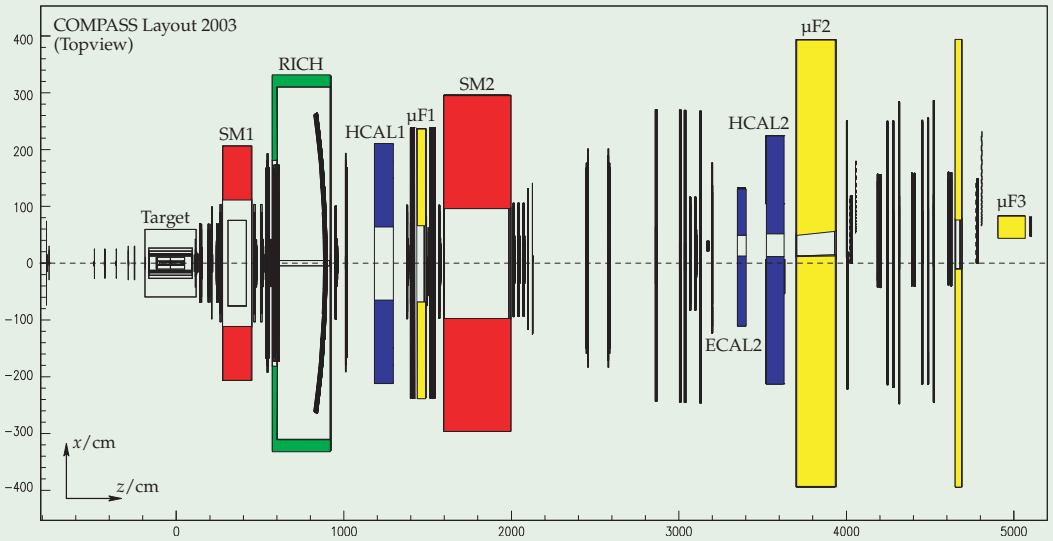

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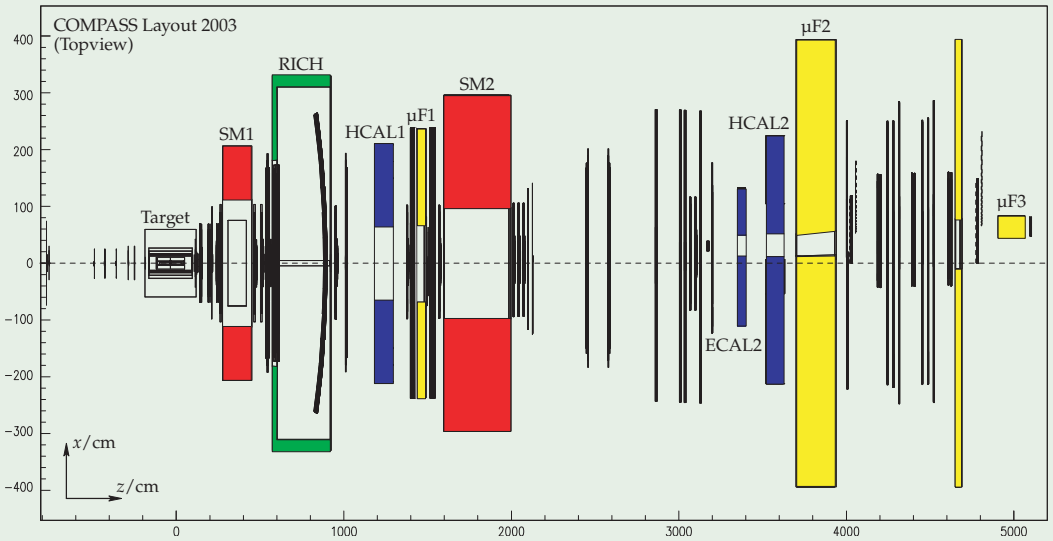

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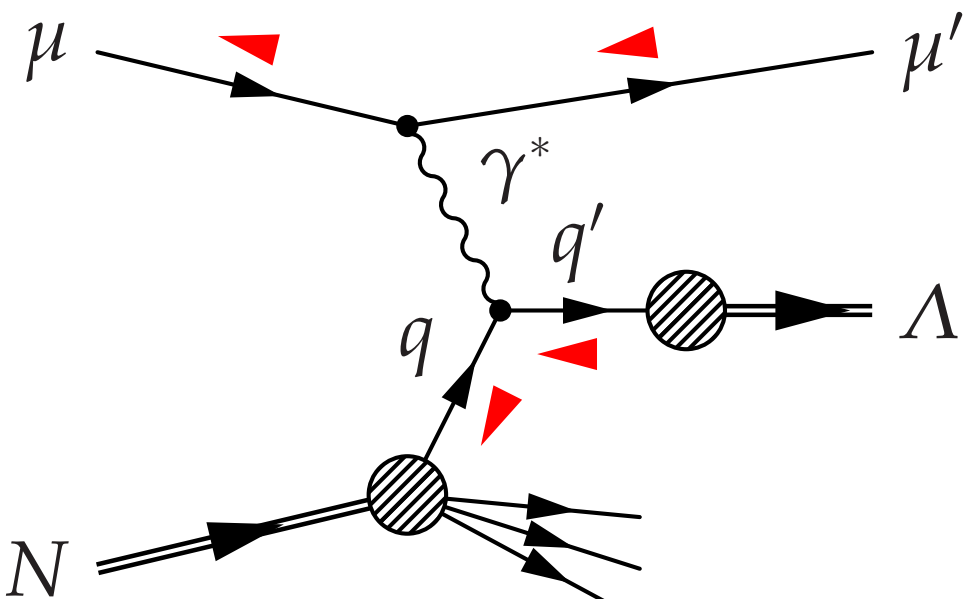
Outline

Long. Λ Polarization in Current Fragmentation Region



Accessible physics

- Study of spin transfer process $q^{\rightarrow} \rightarrow \Lambda^{\Rightarrow}$
- Λ spin structure
- Test of $q\bar{q}$ symmetry of strange sea in nucleon:

$$s(x) \quad \text{vs.} \quad \bar{s}(x)$$

$$\Delta s(x) \quad \text{vs.} \quad \Delta\bar{s}(x)$$

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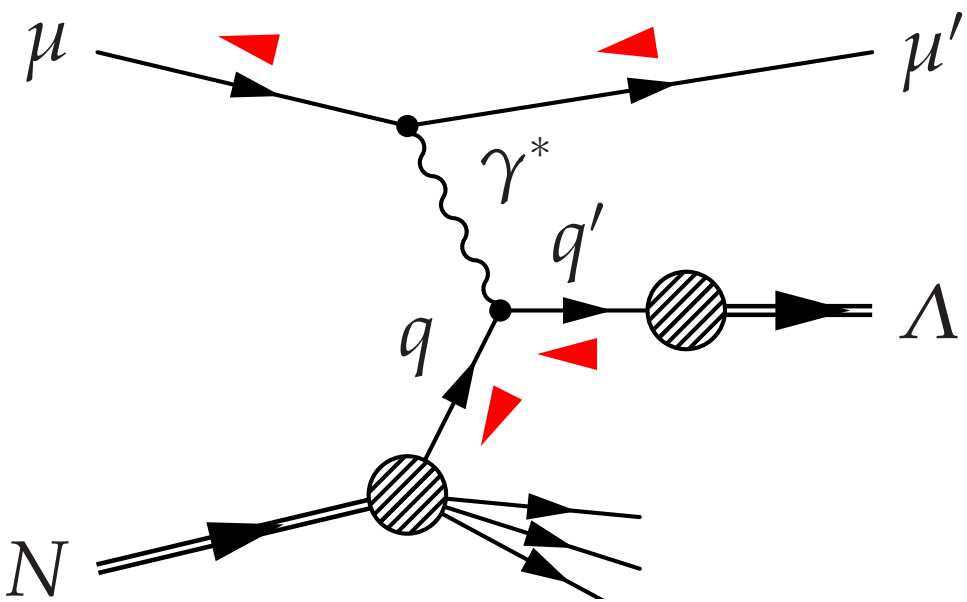

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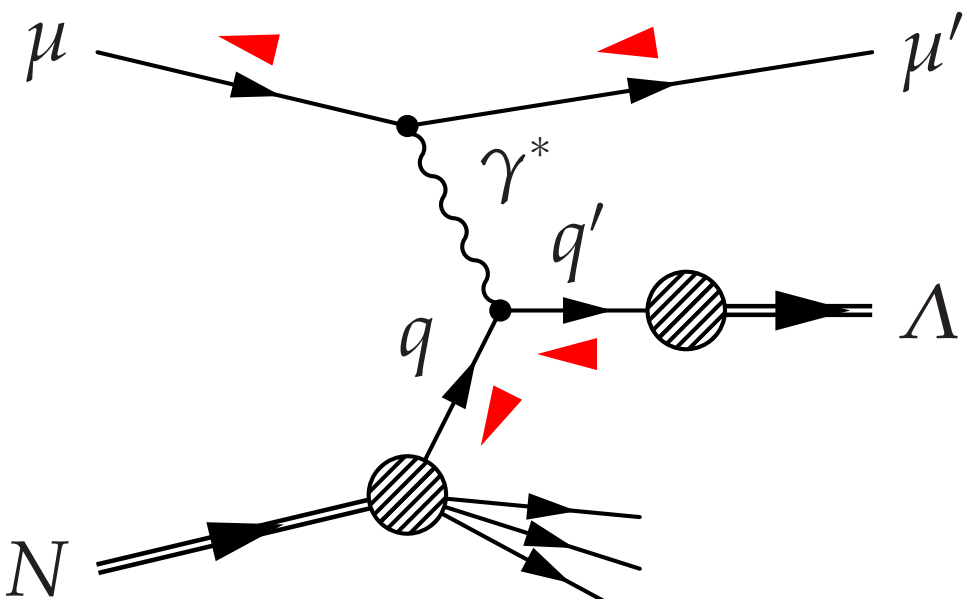

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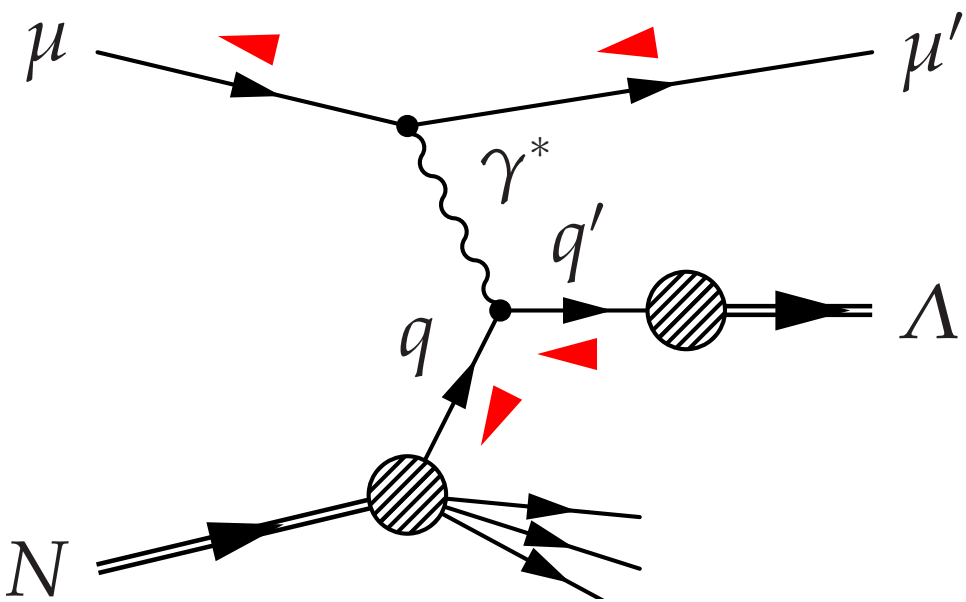

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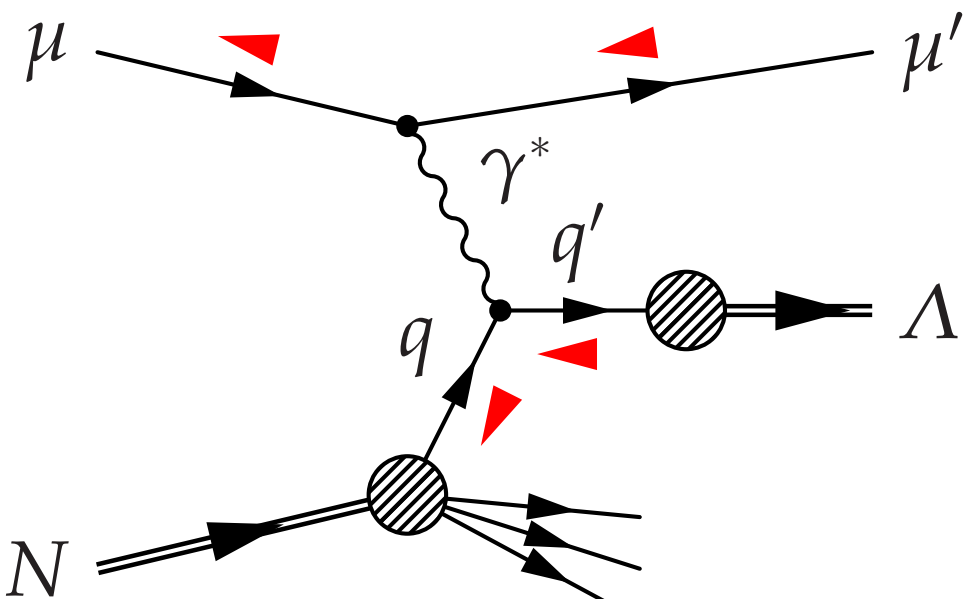

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Longitudinal Λ Polarization – Parton Model

Assuming $x_F > 0$ and quark fragmentation

$$P_L^{\Lambda} = \frac{\sum_q e_q^2 \left[P_B \cdot D_L(y) \cdot q(x_{Bj}) + f \cdot P_N \cdot \Delta q(x_{Bj})\right] \Delta D_{\Lambda/q}(z_h)}{\sum_q e_q^2 \left[q(x_{Bj}) + f \cdot P_N \cdot P_B \cdot D_L(y) \cdot \Delta q(x_{Bj})\right] \hat{D}_{\Lambda/q}(z_h)}$$

with $D_L(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$ longitudinal depolarization factor

P_B beam polarization ≈ -76 %

f target dilution factor ≈ 0.45

P_N target polarization ≈ 50 %

Measurement of polarized fragmentation function $\Delta D_{\Lambda/q}(z_h)$

averaging over target polarization $\Longrightarrow$ $P_N = 0$

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Extraction Method for Angular Distributions

Longitudinal polarization

- Analyzer along virtual photon direction
- Angular distribution of proton w.r.t. γ^* in Λ rest frame

Bin-by-bin Method

- Event-by-event identification of hyperons **not** required
- Subdivision of sample into bins in $\cos\theta$
- For each bin invariant mass histogram
- Fit of histogram $\Longrightarrow$ number of Λs from fit parameter

$\Longrightarrow$ **background corrected angular distribution**

Acceptance correction

from MC simulations (LEPTO) of unpolarized $\Lambda(\bar{\Lambda})$ decays

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MC improved Background Description

Background contributions

- No particle ID used in Λ selection
- kinematically indistinguishable K^0_S
- Combinatorial background
- e^+e^- pairs from γ conversion

Kaon Background from MC

- Kaon distribution $K(m_{p\pi^-})$
- Data are fitted with $\text{Gauss}(x) + aK(x) + c_0 + c_1 x$

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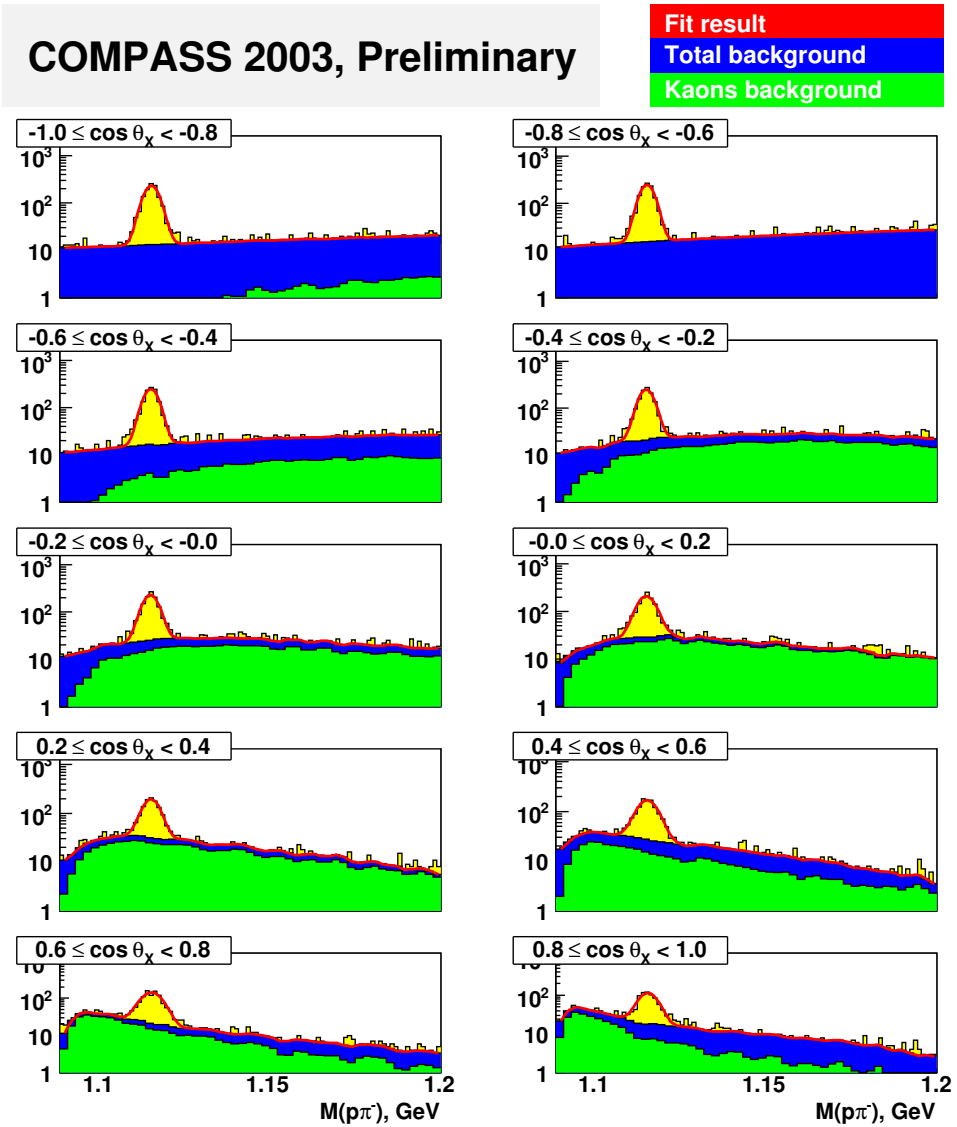

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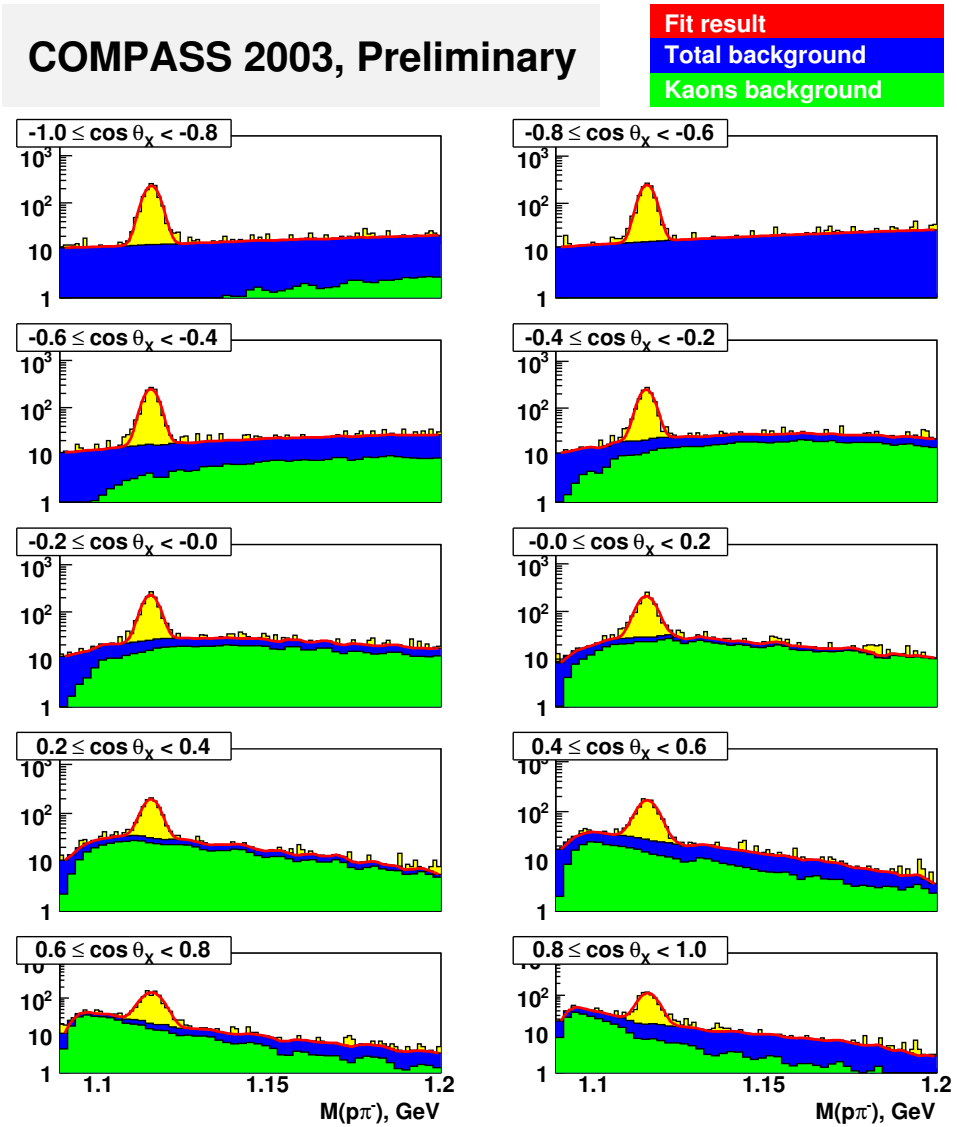

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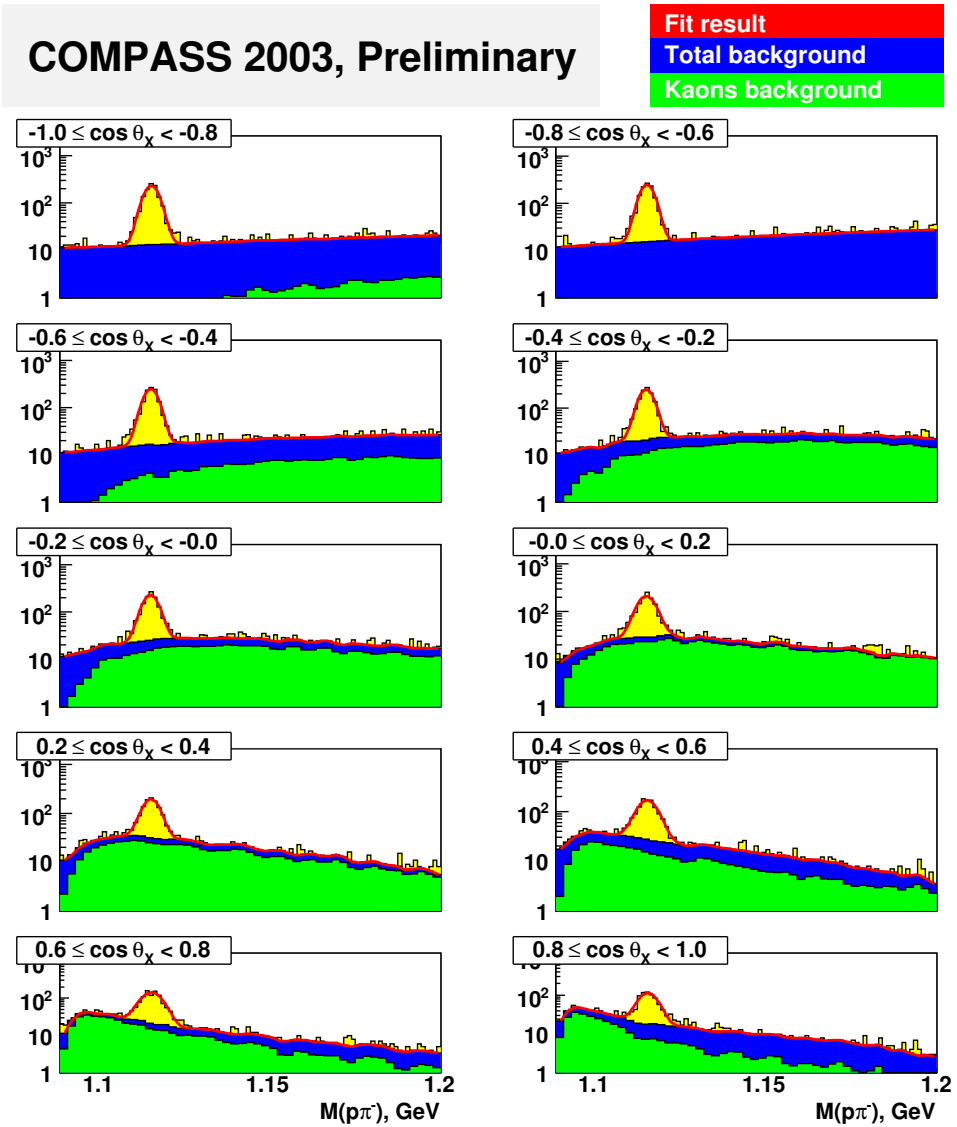

Kinematics of Λ Prod. (2003, $Q^2 > 1\,\mathrm{GeV}^2$)

Total statistics 2003

31,000 Λs
18,000 $\bar{\Lambda}$s

Mean values

$\langle x_{Bj} \rangle = 0.0283$
$\langle x_F \rangle = 0.23$

$\langle y \rangle = 0.48$
$\langle z \rangle = 0.29$

$\langle Q^2 \rangle = 3.55\,\mathrm{GeV}^2$
$\langle W \rangle = 11.7\,\mathrm{GeV}$

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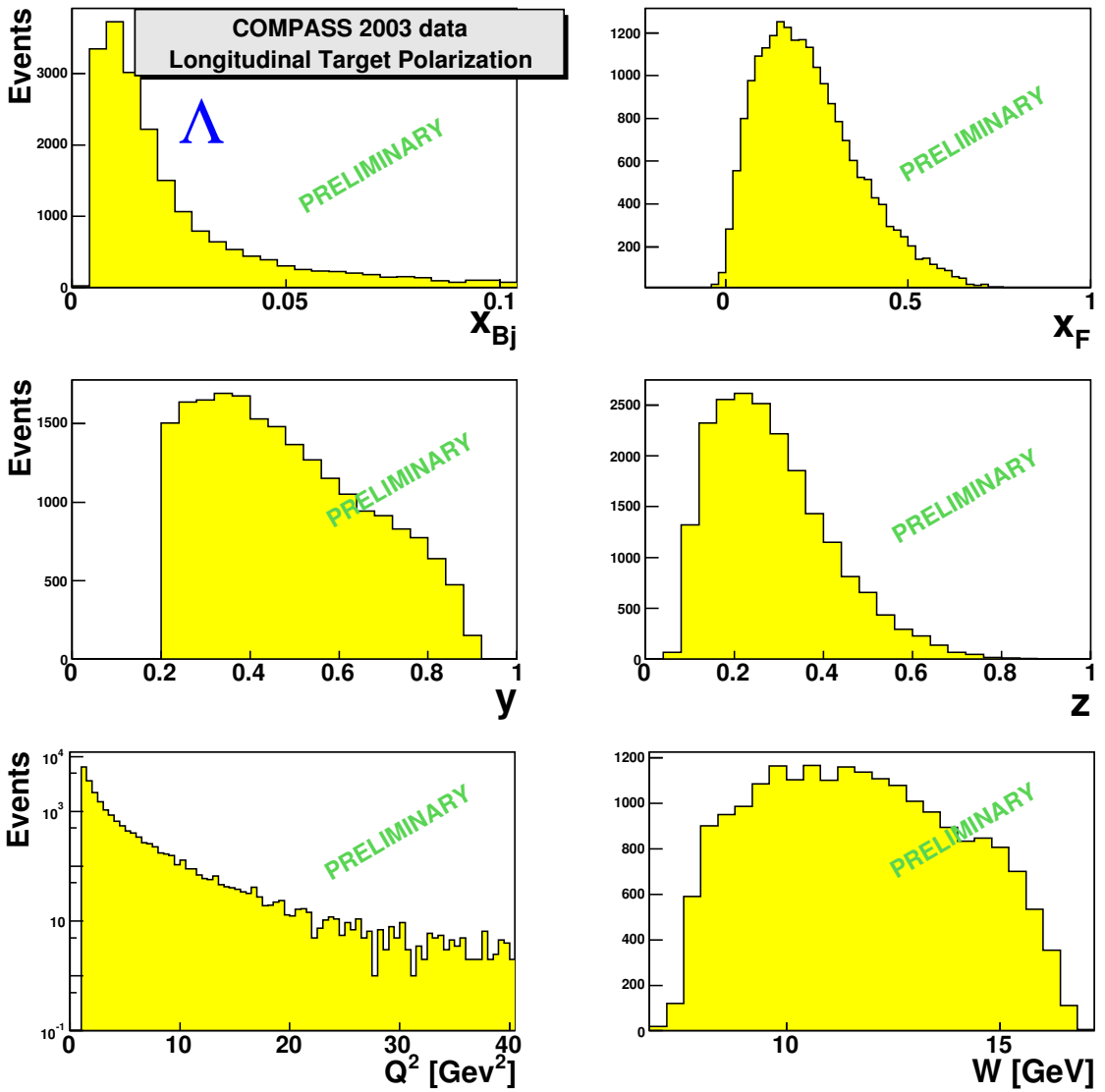
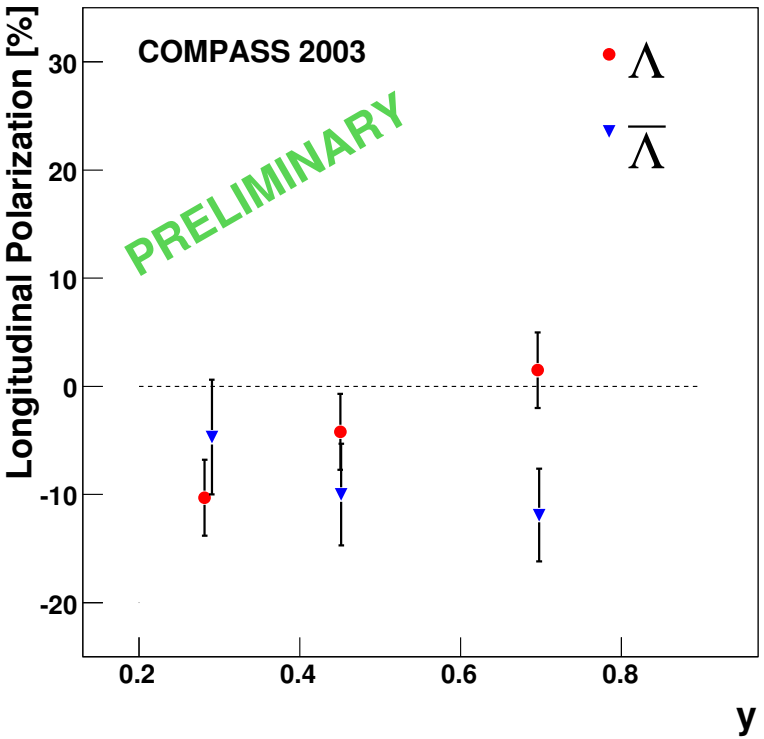
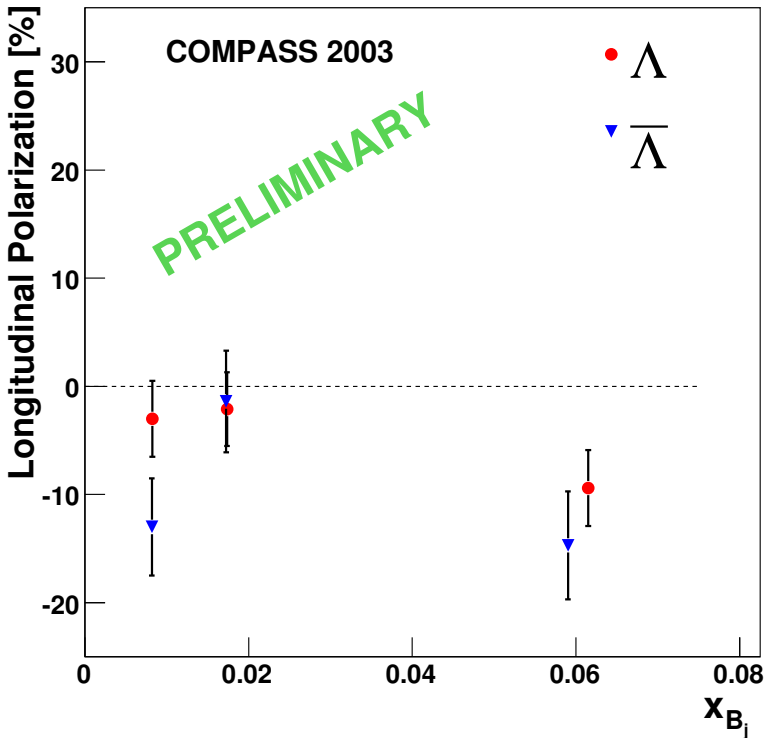


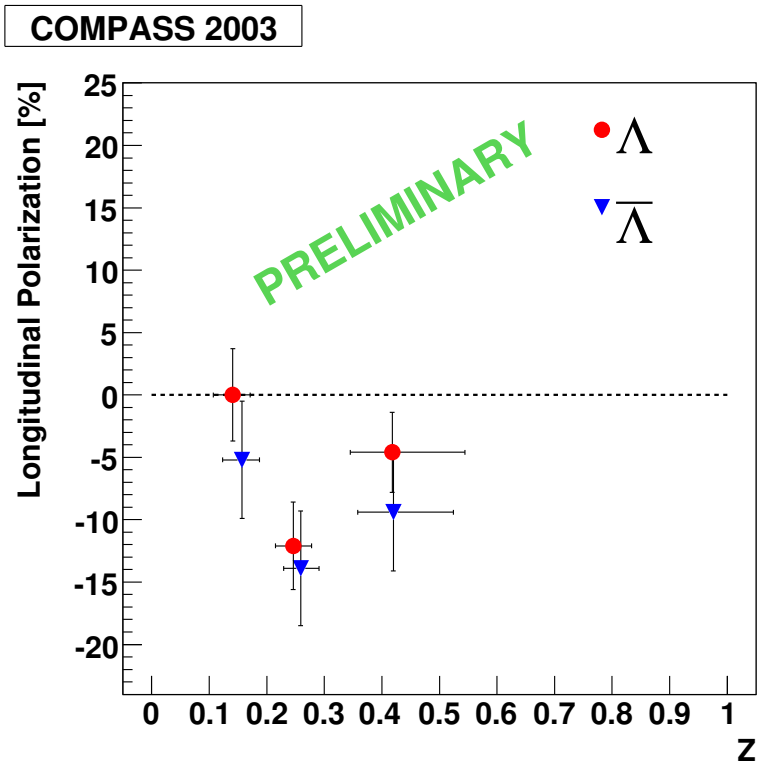
y- and x_{Bj}-Dependence of long. Pol., $Q^2 > 1\,\mathrm{GeV}^2$

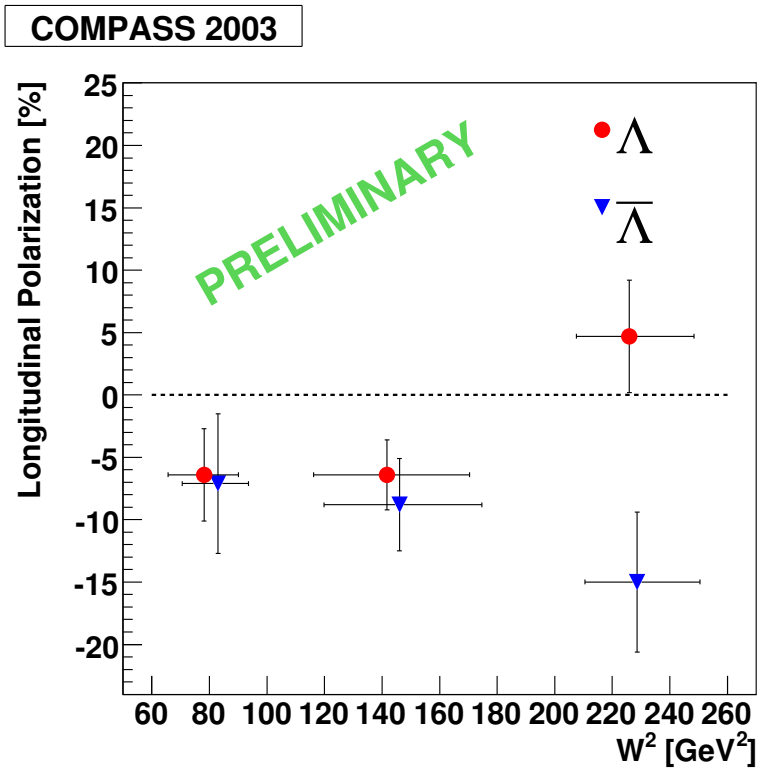




Systematic errors $< 5\,\%$

z- and W^2-Dependence of long. Pol., $Q^2 > 1\,\mathrm{GeV}^2$





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Outline

Λ production from transversely polarized target

Transversely polarized target

Measured process: $\mu\, N^{\Uparrow} \longrightarrow \mu'\, \Lambda^{\Uparrow}\, X$

Underlying elementary QED process: $\gamma^* q^{\uparrow}$ scattering

Transverse Λ polarization gives information about initial transverse quark polarization $\Delta_T q(x_{Bj})$ in nucleon

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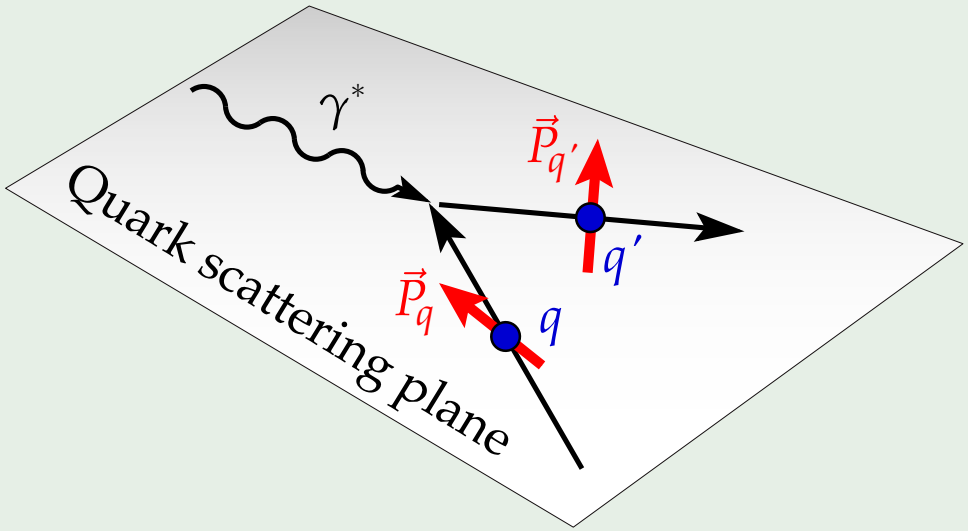

Transverse Λ polarization gives information about initial transverse quark polarization $\Delta_T q(x_{Bj})$ in nucleon

Λ production from transversely polarized target

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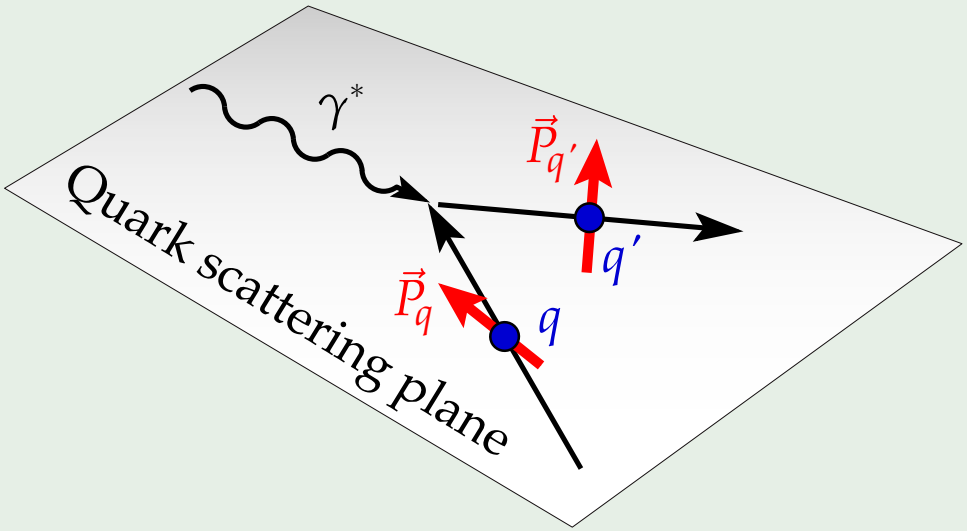

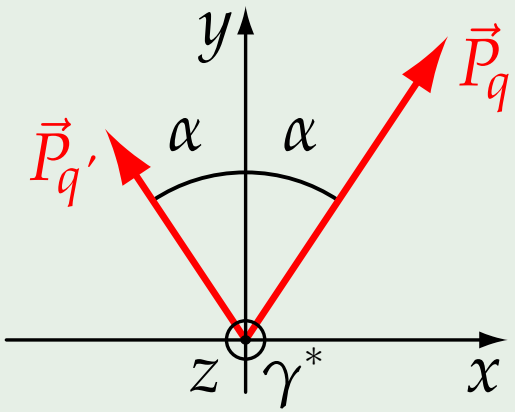

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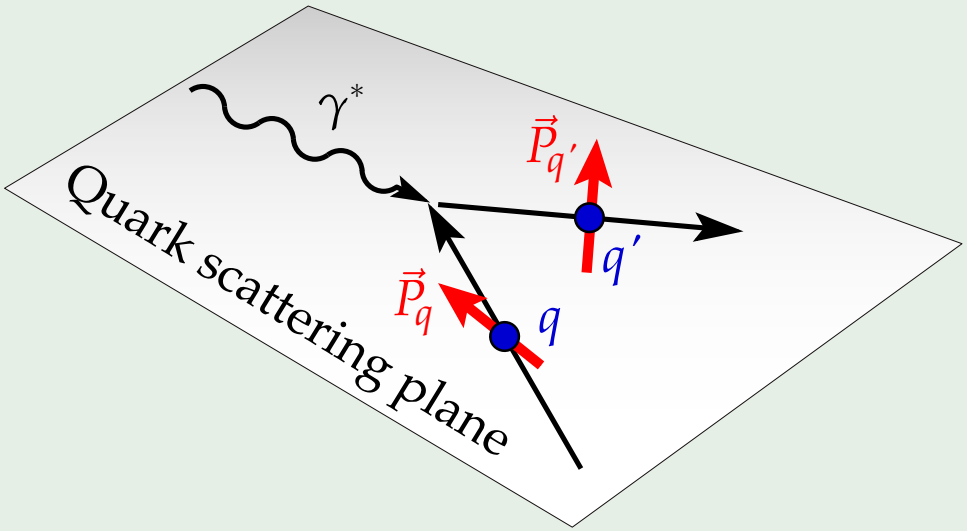

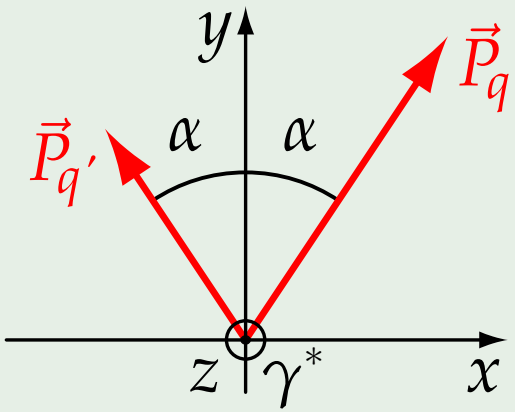

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Λ polarization and Transversity

Assuming $x_F > 0$ and quark fragmentation

$$P_T^{\Lambda} = f \cdot P_N \cdot D_T(y) \frac{\sum_q e_q^2 \, \Delta_T q(x_{Bj}) \, \Delta_T D_{\Lambda/q}(z_h)}{\sum_q e_q^2 \, q(x_{Bj}) \, \hat{D}_{\Lambda/q}(z_h)}$$

with $D_T(y) = \frac{2(1-y)}{1+(1-y)^2}$ transverse depolarization factor

f target dilution factor ≈ 0.45

P_N target polarization ≈ 50 %

Chiral-odd partner of $\Delta_T q(x_{Bj})$: **transversity fragmentation function**

$$\Delta_T D_{\Lambda/q}(z_h) \equiv D_{\Lambda^{\Uparrow}/q^{\uparrow}}(z_h) - D_{\Lambda^{\Downarrow}/q^{\uparrow}}(z_h)$$

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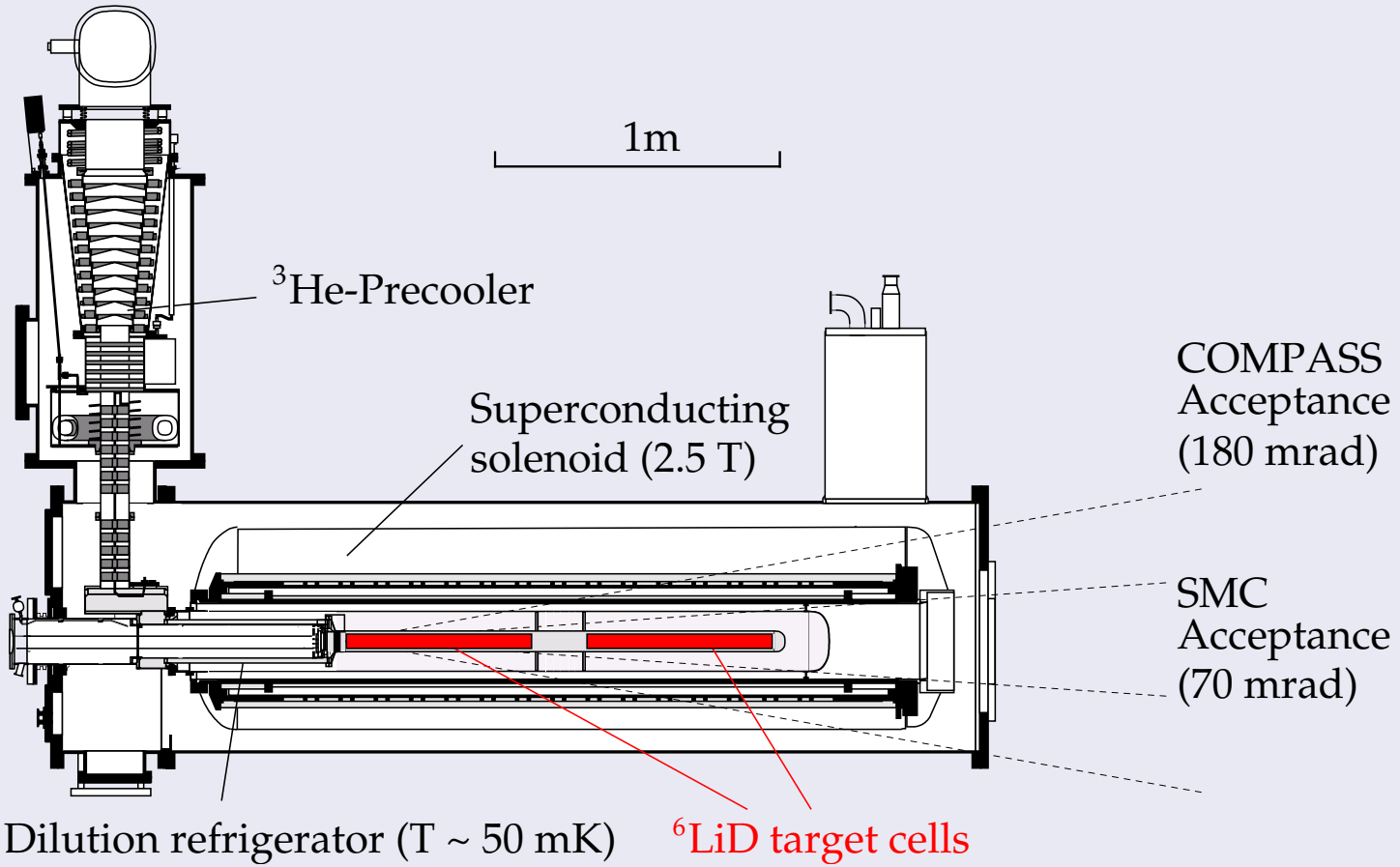
COMPASS Polarized Target



- 2 target cells, each 60 cm long
- 0.5 T magnetic dipole field sustains transverse polarization

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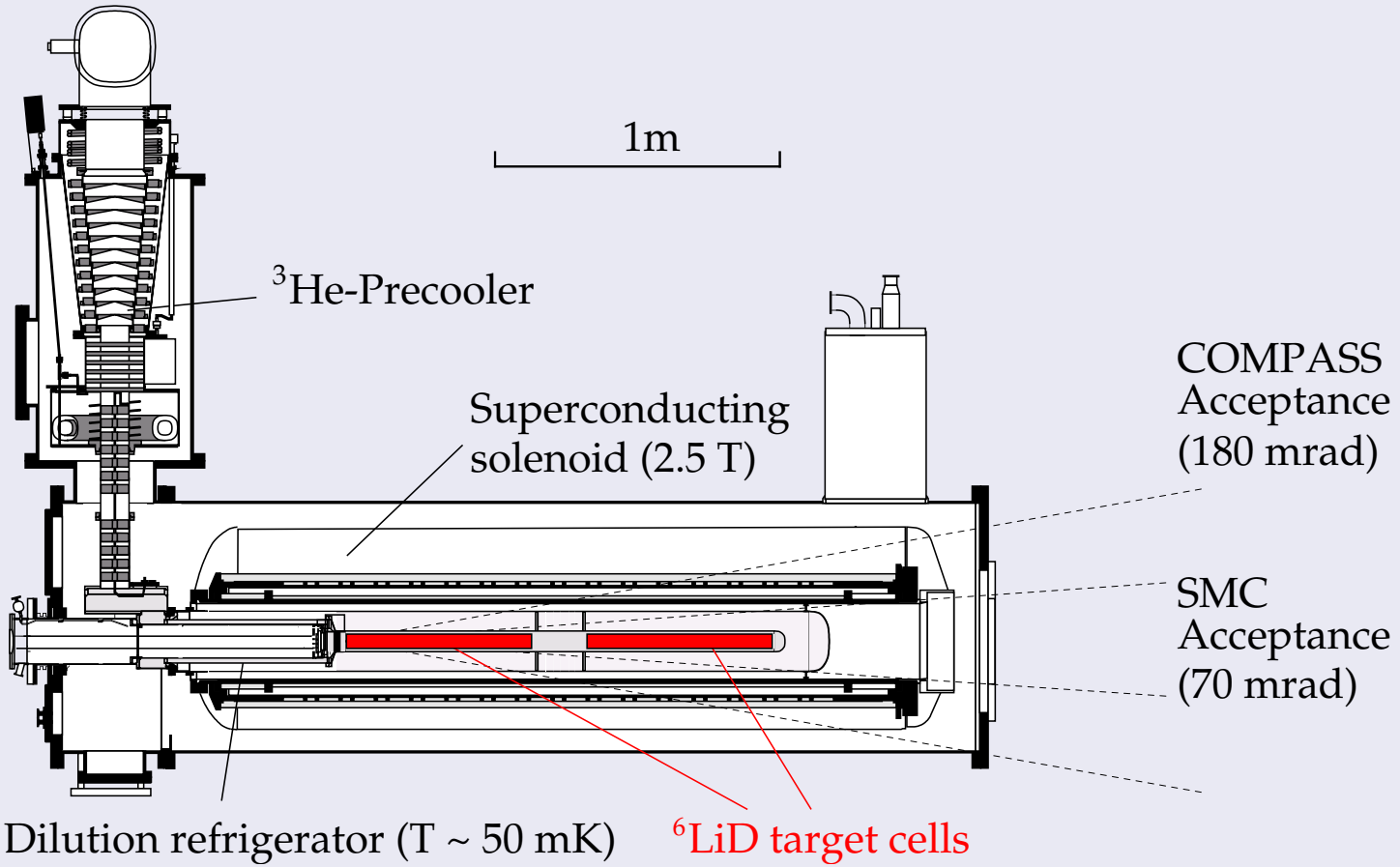

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Acceptance Correction – Bias Canceling

- Background subtraction using bin-by-bin method

Exploit symmetry

Assumptions

- Constant target polarization: $P_N^{(1)} = P_N^{(2)}$
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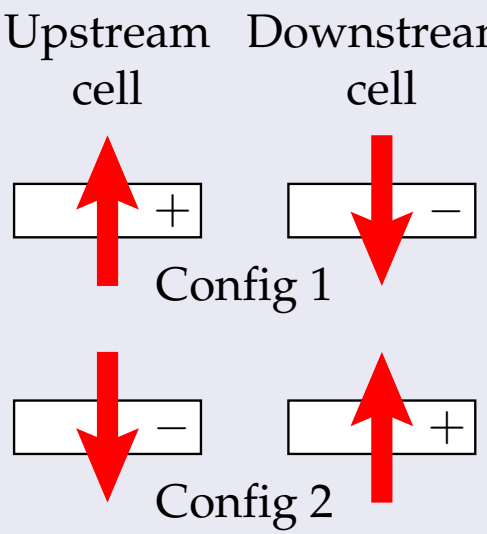

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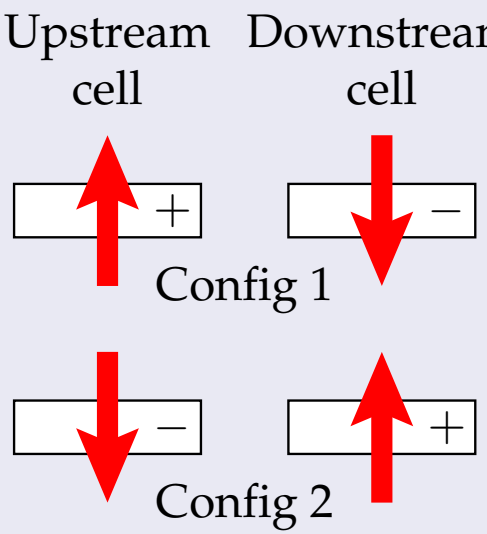

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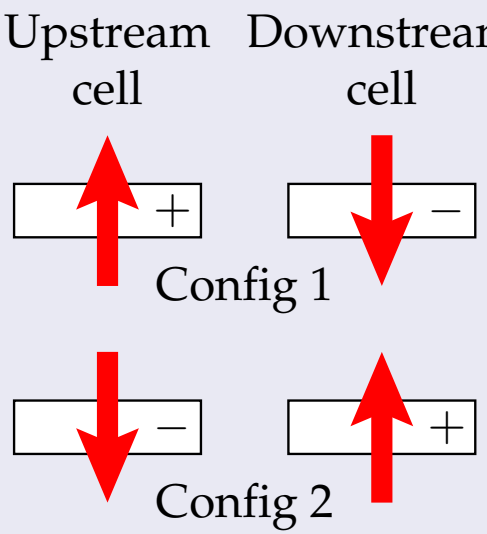

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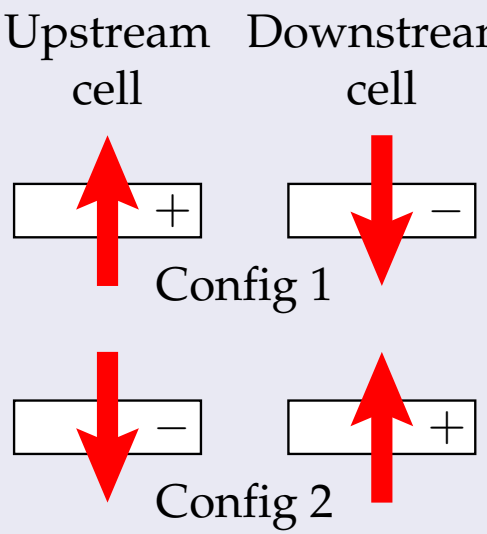

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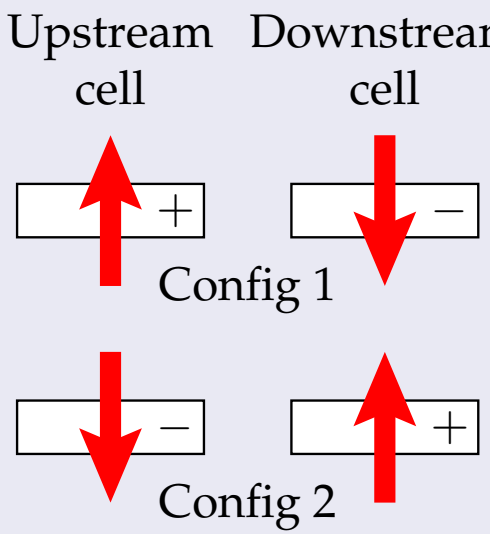

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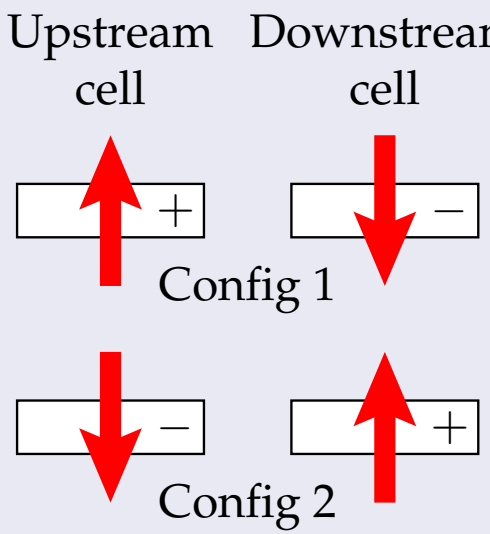

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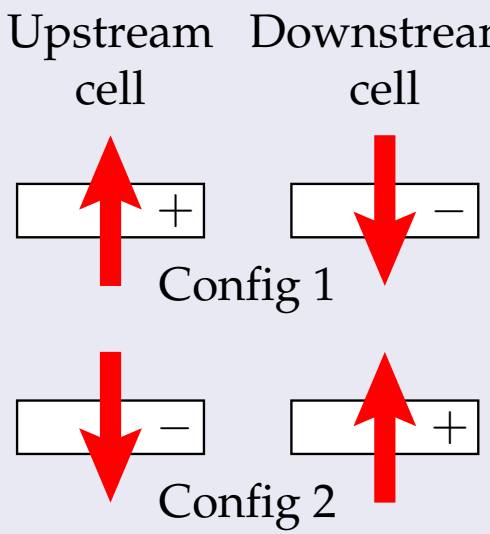

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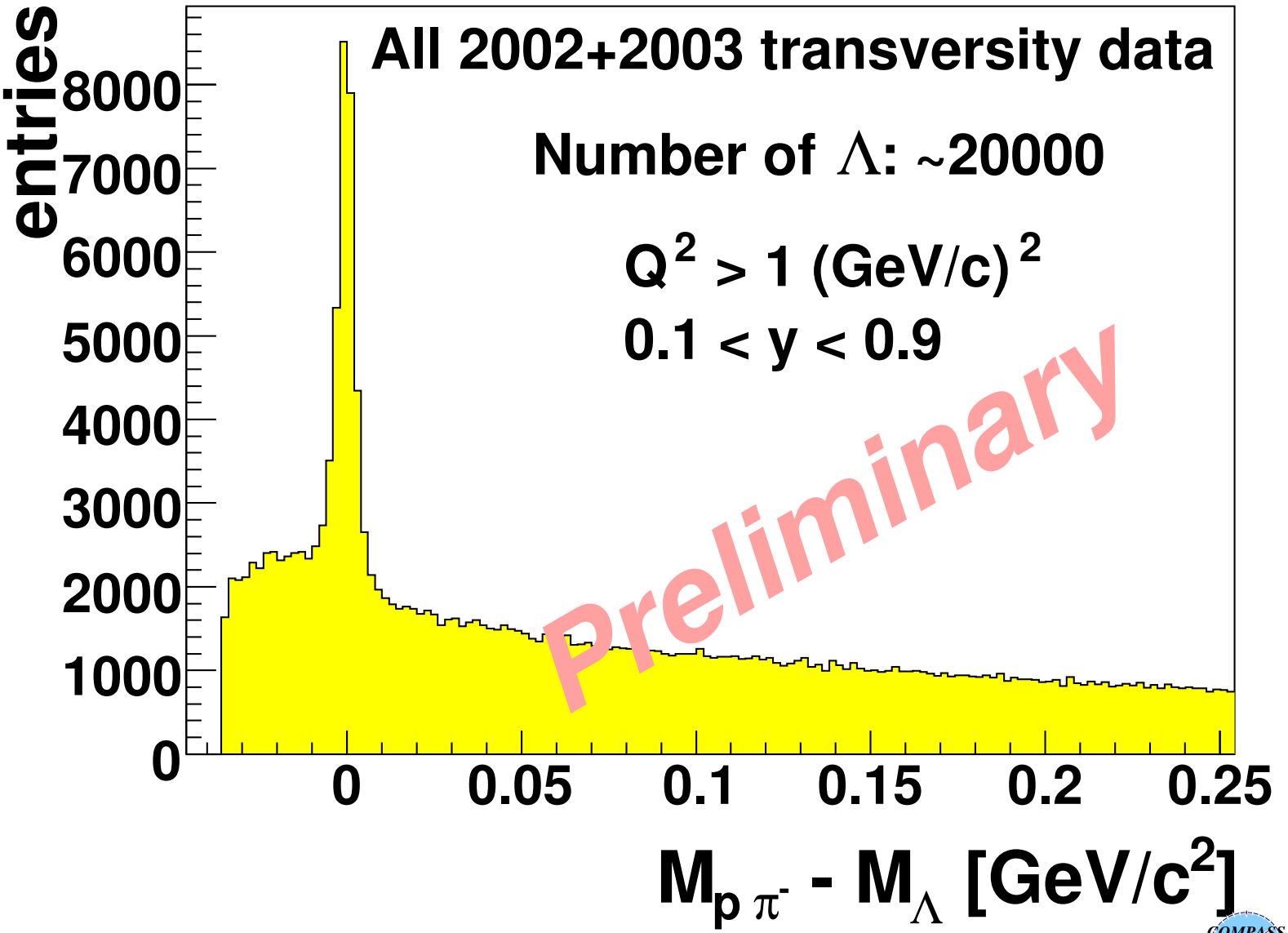
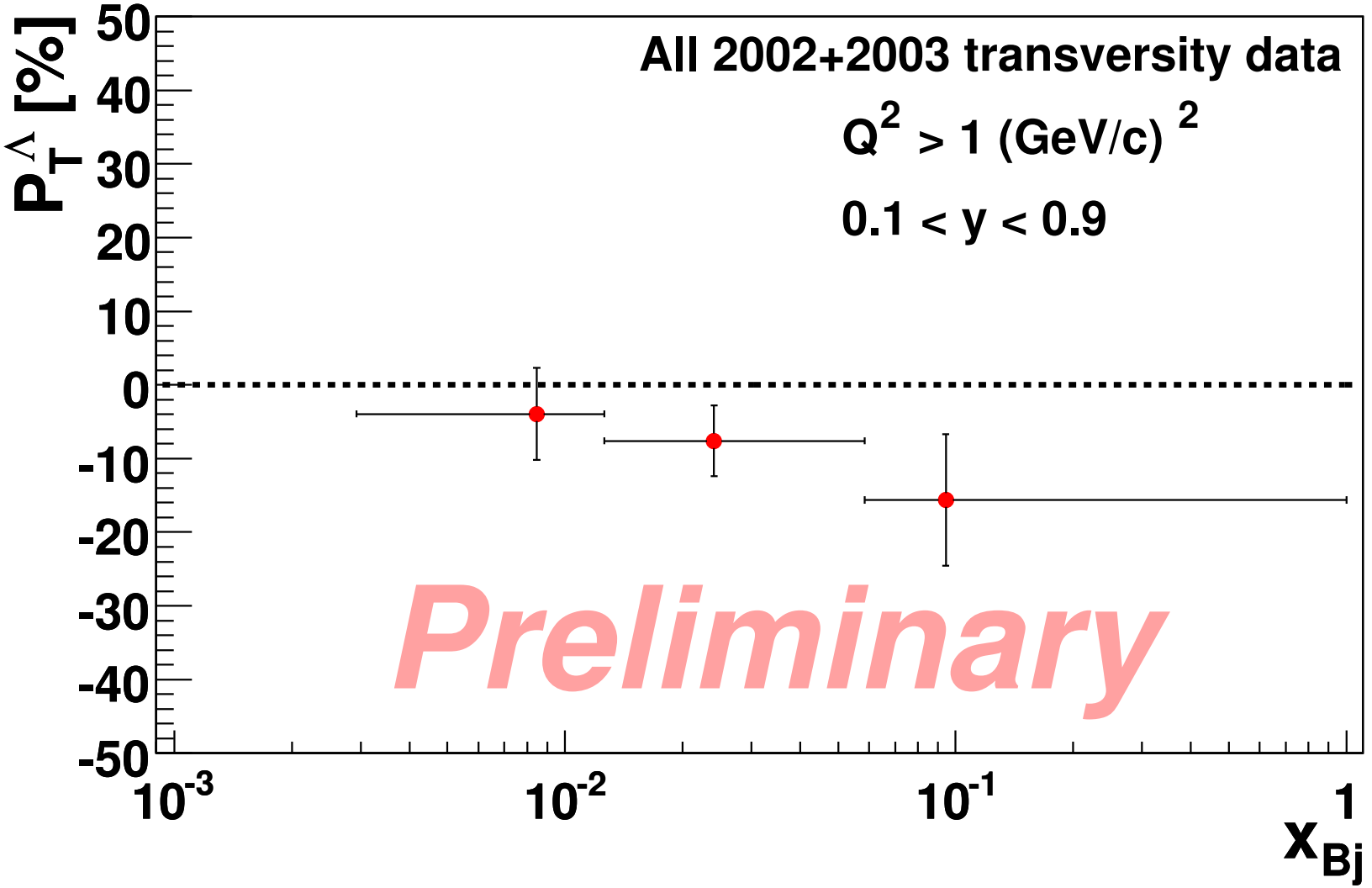
Overall available Statistics (2002-03, $Q^2 > 1\,\mathrm{GeV}^2$)



x_{Bj}-Dependence of Transv. Λ Polarization, $Q^2 > 1\,\mathrm{GeV}^2$



Outline

Spontaneous Transverse Hyperon Polarization

Production of polarized hyperons in **unpolarized** inclusive reactions

Parity conservation

Polarization transverse to production plane

Naïve expectation

- High energy $\Longrightarrow$ large number of production channels: comparable magnitudes + various relative phases
- Random interference $\Longrightarrow$ small polarization

Big surprise 1976 at Fermilab

- Discovery of sizeable transverse polarization $P_T^{\Lambda} = -28 \pm 8$ % in $p\,\mathrm{Be} \longrightarrow \Lambda^{\uparrow} X$ @ $p_{\mathrm{Beam}} = 300$ GeV/c
- No model is able to explains all experimental data
- Only few data from photo-production

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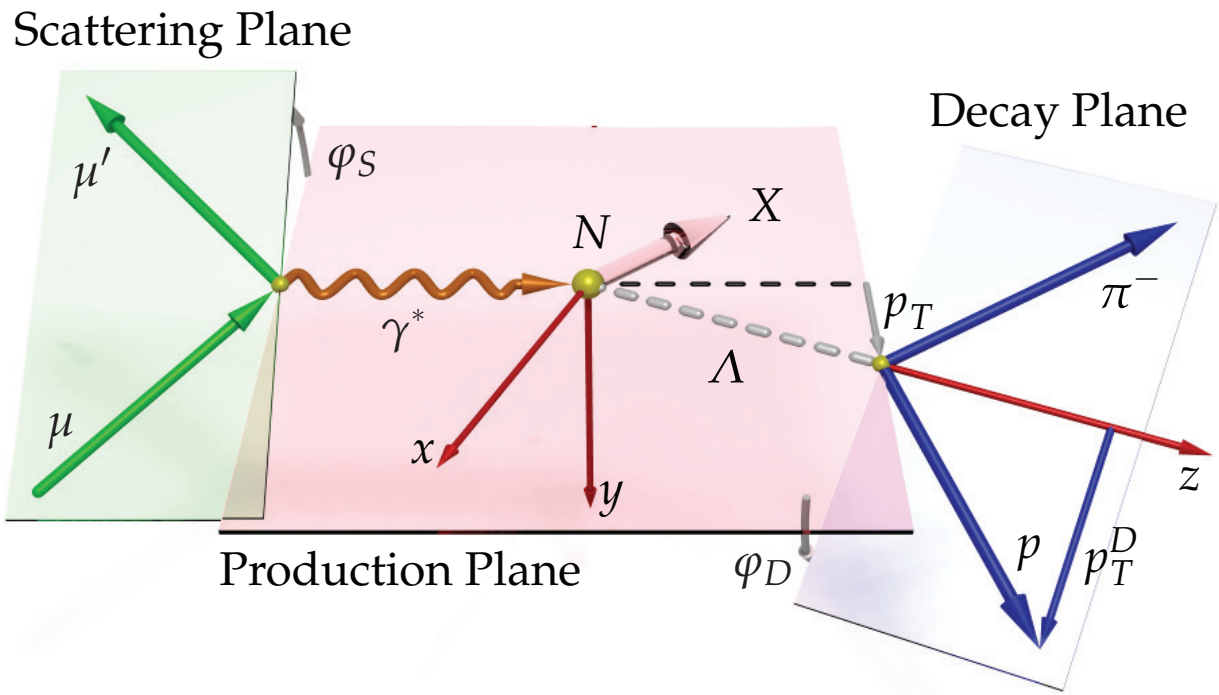
Hyperon Production in unpolarized Reaction

- Inclusive hyperon production in reaction $\mu\, N \longrightarrow \mu'\, \Lambda^{\Uparrow}\, X$
- Quasi-real virtual photon γ^* with $\langle Q^2 \rangle \approx 0.36\,\mathrm{GeV}^2$
- Analyzer along production plane normal



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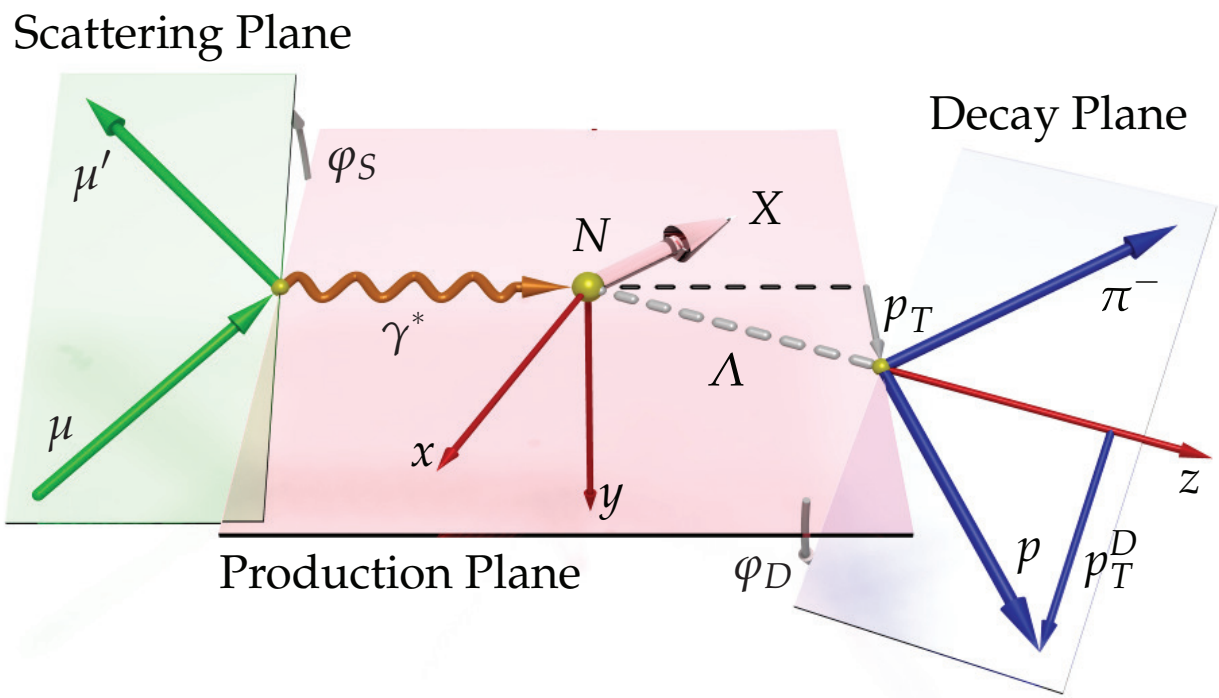

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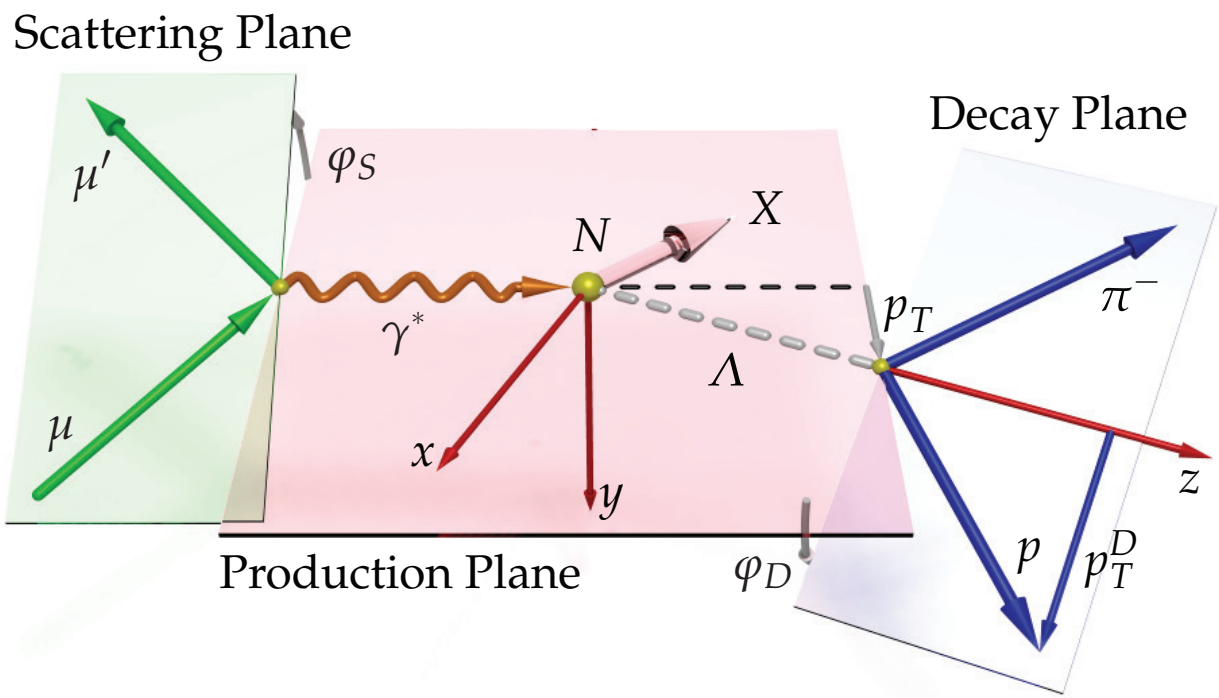
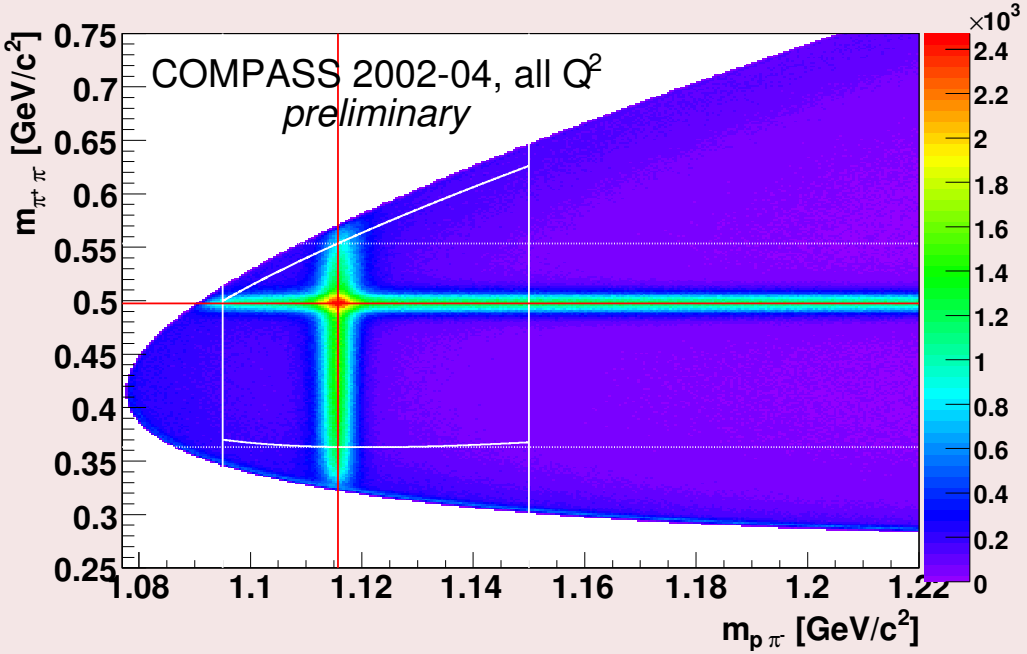


Background Subtraction and Acceptance Correction

Bin-by-bin method – separation of K^0 background

- Expansion of Λ invariant mass histogram with K^0 mass



- Full two-dimensional fit in $(m_{p\pi^-}, m_{\pi^+\pi^-})$ plane
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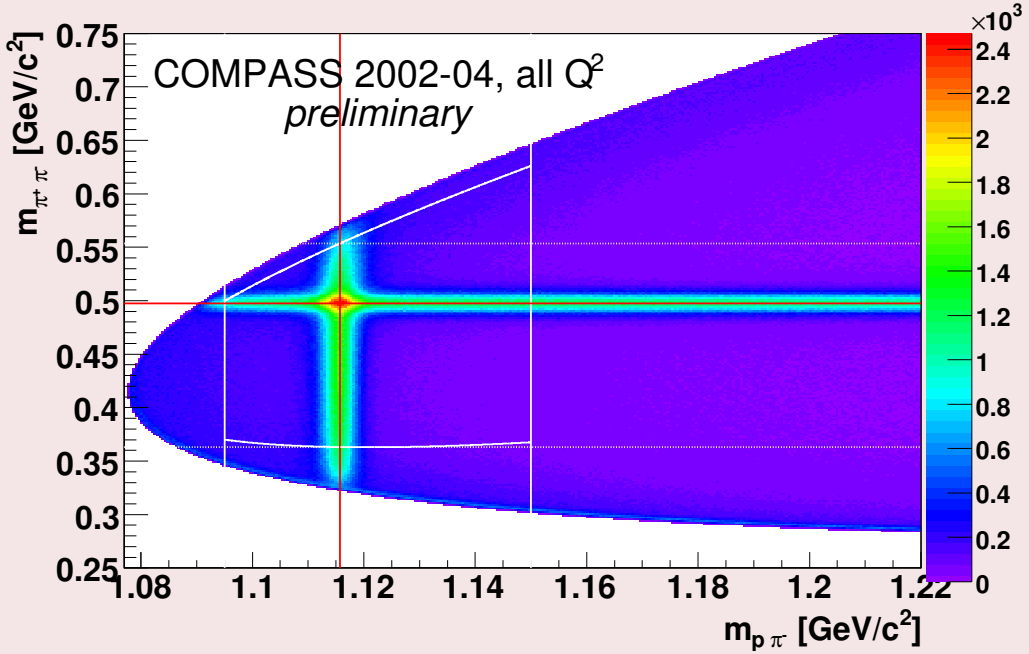

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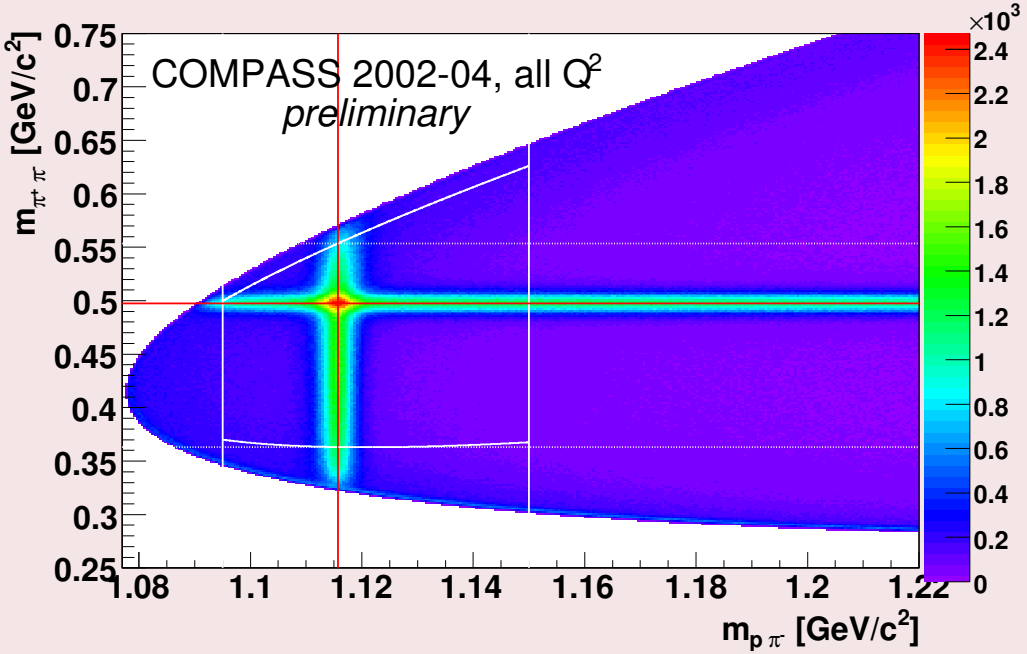

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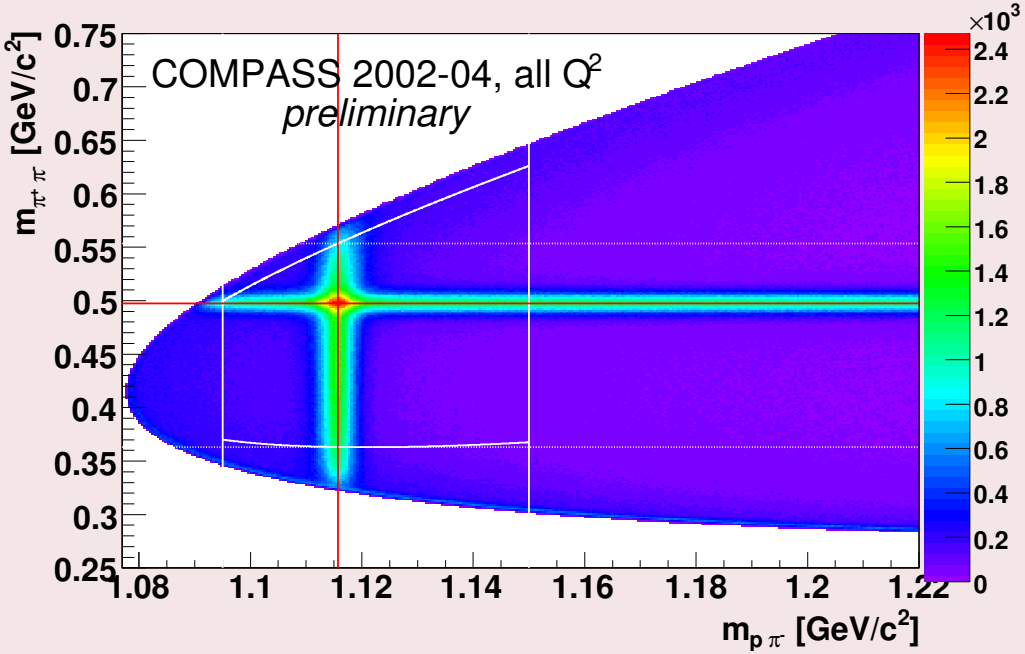

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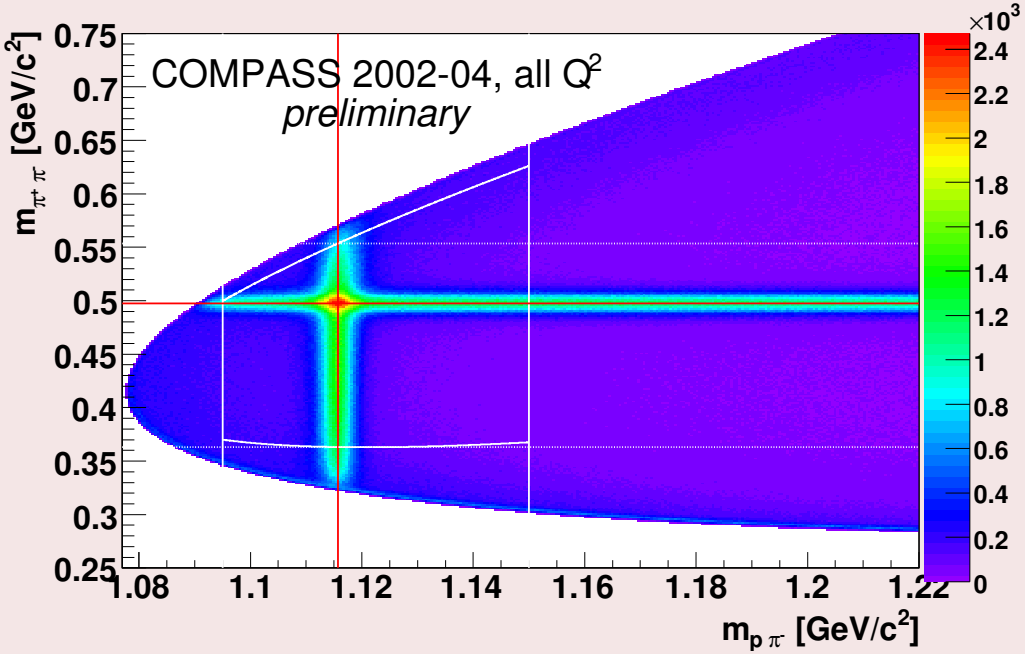

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Results

First analysis on 2002 data, all Q^2

- 160,000 Λs and 85,000 $\bar{\Lambda}$s
- Small positive Λ polarization:
  $P_T^{\Lambda} = +2.7 \pm 0.9(\text{stat.}) \pm 1.1(\text{sys.})$ %
  - Sign opposite to Λ polarization in p and π^- beams
  - Same sign as in K^- beam
  - Much lower absolute value
- $\bar{\Lambda}$ unpolarized: $P_T^{\bar{\Lambda}} = -0.3 \pm 1.4(\text{stat.}) \pm 1.8(\text{sys.})$ %

Work in progress

- 2002 sample only 10 % of available statistics
- 2002-04, all Q^2: $1.6 \cdot 10^6$ Λs and $0.9 \cdot 10^6$ $\bar{\Lambda}$s
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- 2002-04, all Q^2: $1.6 \cdot 10^6$ Λs and $0.9 \cdot 10^6$ $\bar{\Lambda}$s
- Analysis nearly finalized

Results

First analysis on 2002 data, all Q^2

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  - Sign opposite to Λ polarization in p and π^- beams
  - Same sign as in K^- beam
  - Much lower absolute value
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Longitudinal polarization transfer

- 2003 data sample
- Similar longitudinal polarization of Λ and $\bar{\Lambda}$
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Transverse polarization transfer

- 2002 + 2003 transversity data sample
- Slight tendency to negative polarizations
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Both analyses

Significant increase of statistics with 2004 data

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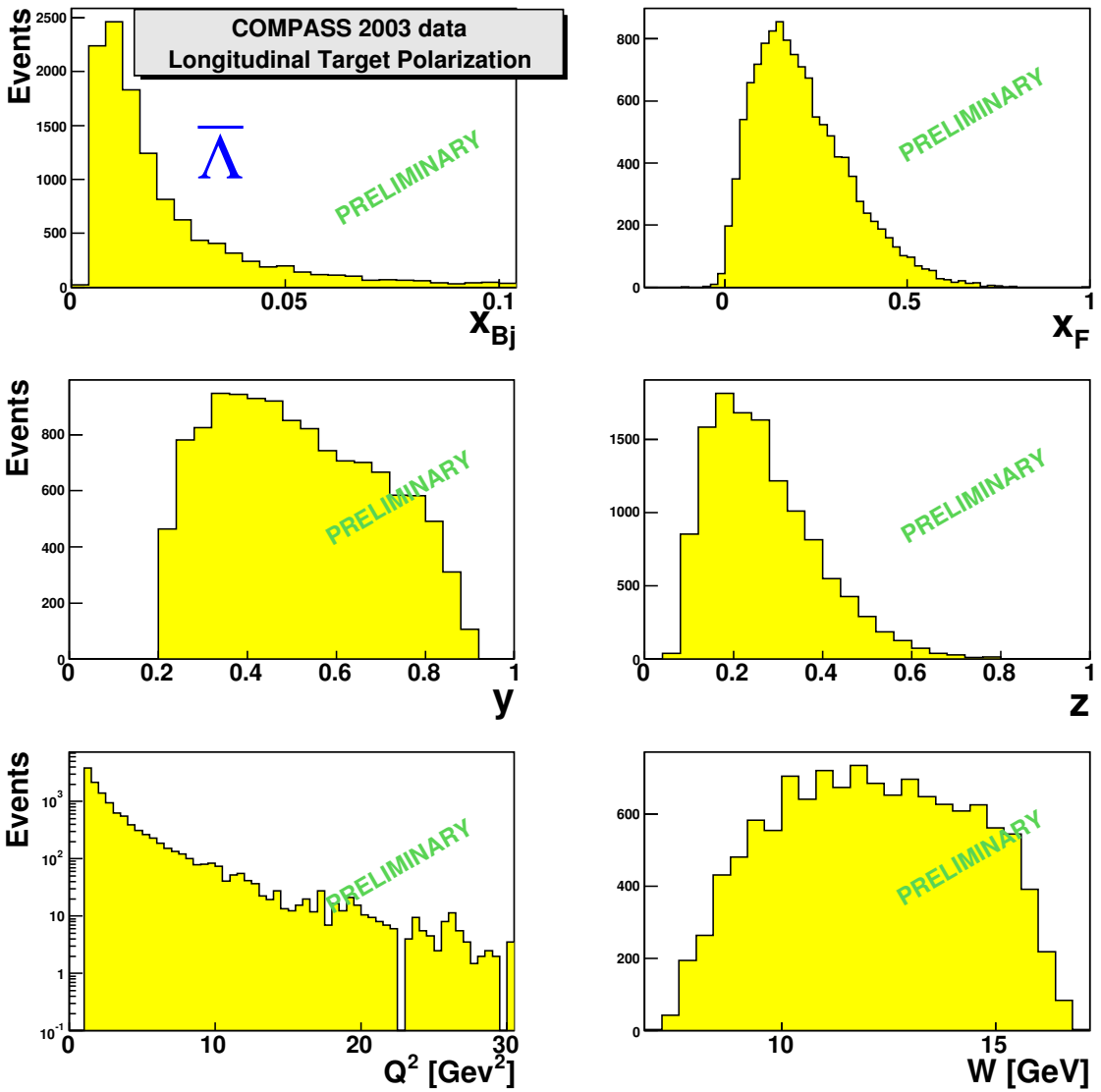
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

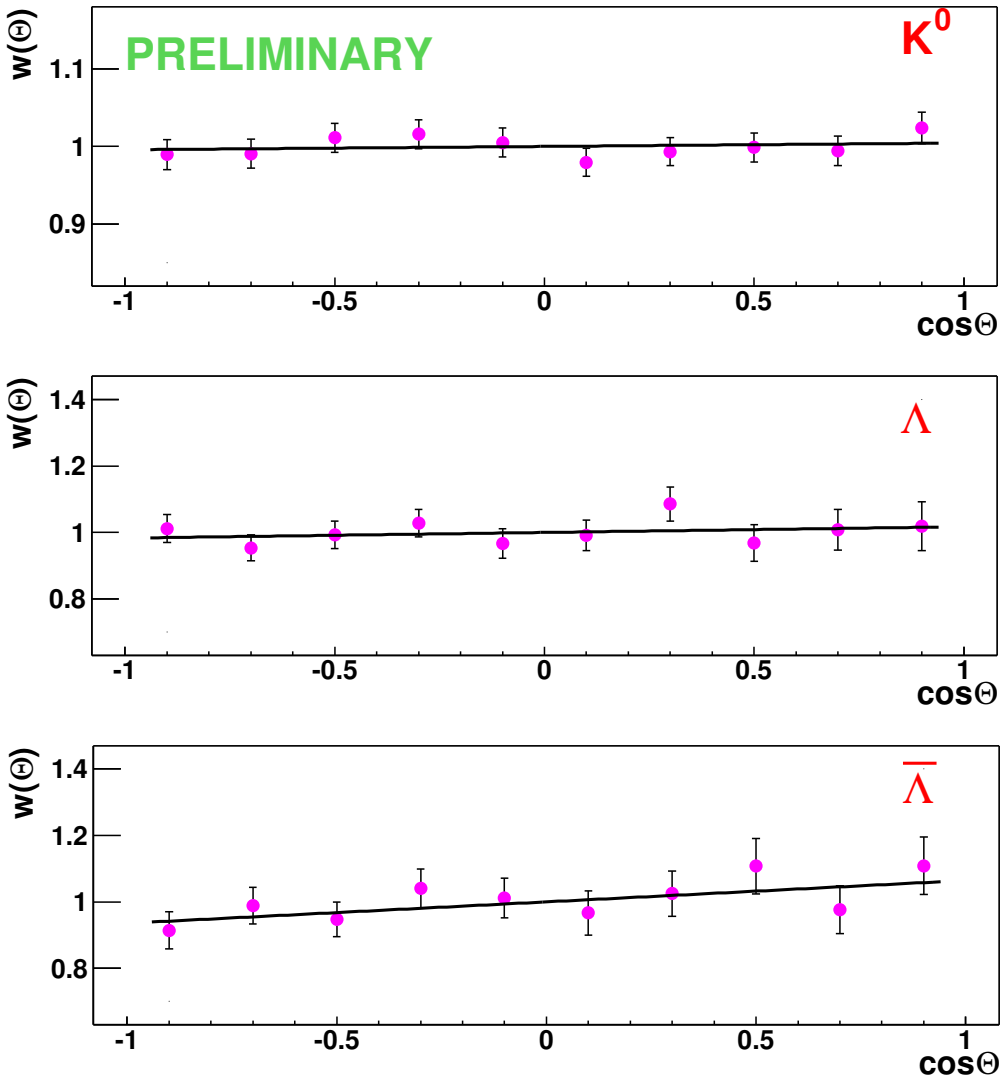
Kinematics of $\bar{\Lambda}$ Prod. (2003, $Q^2 > 1\,\mathrm{GeV}^2$)



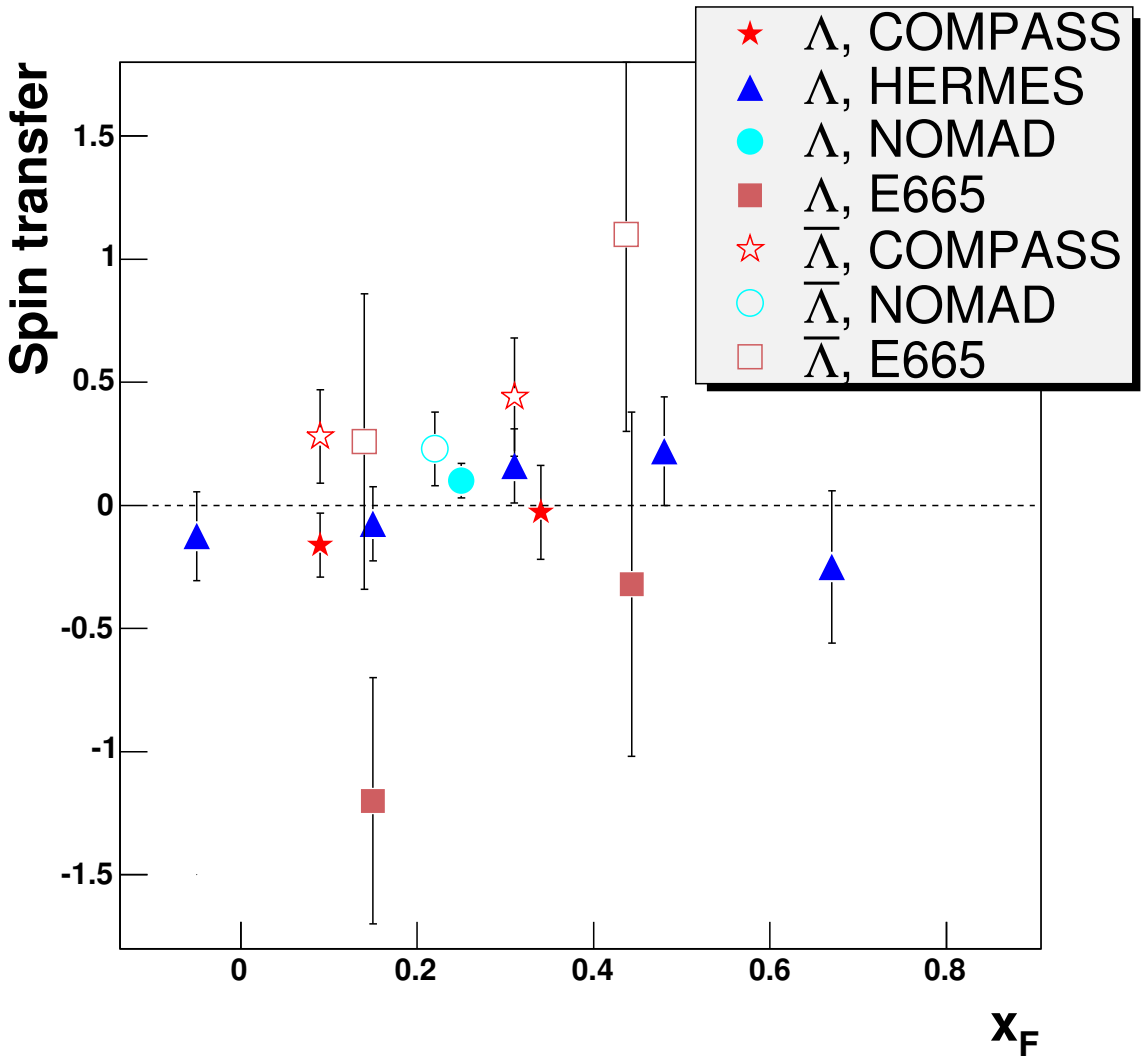
Mean values

$$\langle x_{Bj} \rangle = 0.0258$$
$$\langle x_F \rangle = 0.21$$
$$\langle y \rangle = 0.51$$
$$\langle z \rangle = 0.27$$
$$\langle Q^2 \rangle = 3.50\,\mathrm{GeV}^2$$
$$\langle W \rangle = 12.1\,\mathrm{GeV}$$

Angular Distributions (2002, $Q^2 > 1\,\mathrm{GeV}^2$)

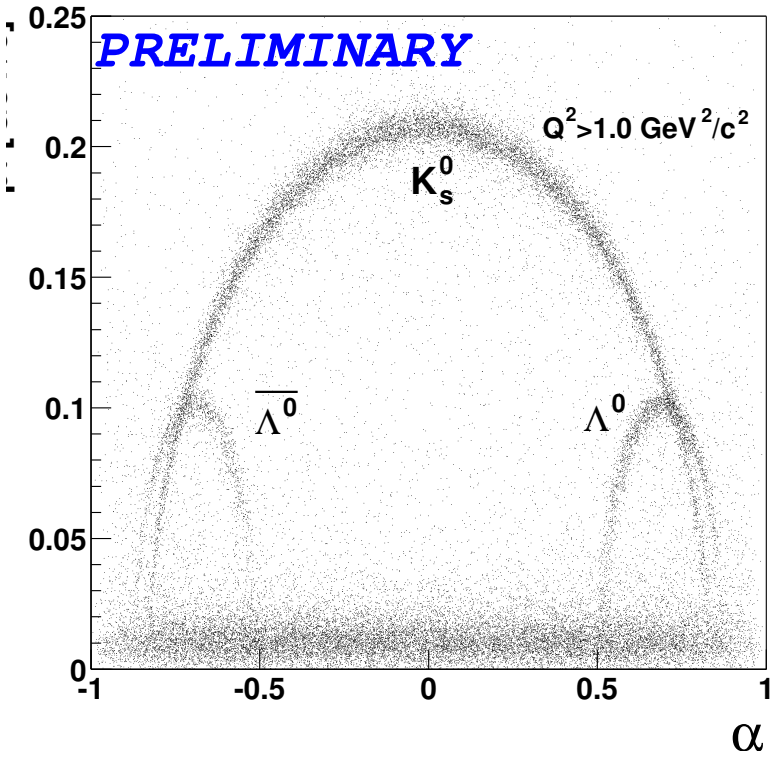


Spin Transfer to Λ and $\bar{\Lambda}$ (2002, $Q^2 > 1\,\mathrm{GeV}^2$)

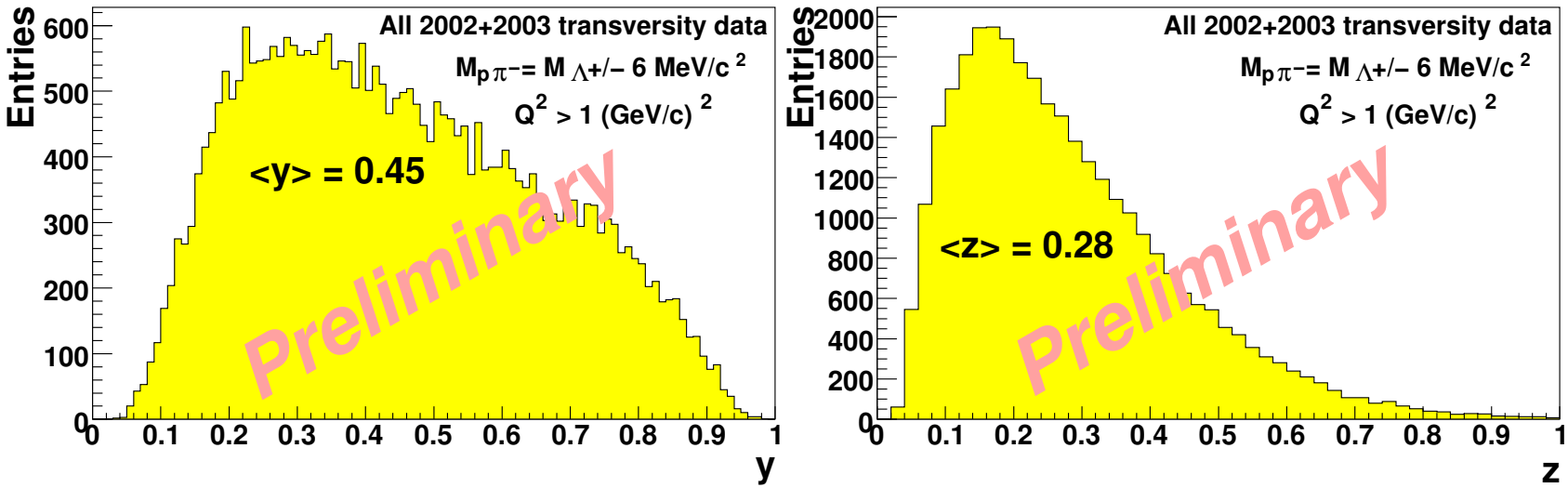


Selection cuts

- Primary vertex in target
- Secondary V^0 vertex outside of target
- Collinearity angle $\theta_{\text{col}} < 10\,\text{mrad}$
- V^0 decay daughters: $p > 1$ GeV/c and $p_T > 23$ MeV/c
- V^0 momentum $p_{V^0} > 10$ GeV/c
- DIS cut: $Q^2 > 1\,\text{GeV}^2$ and $0.2 < y < 0.9$

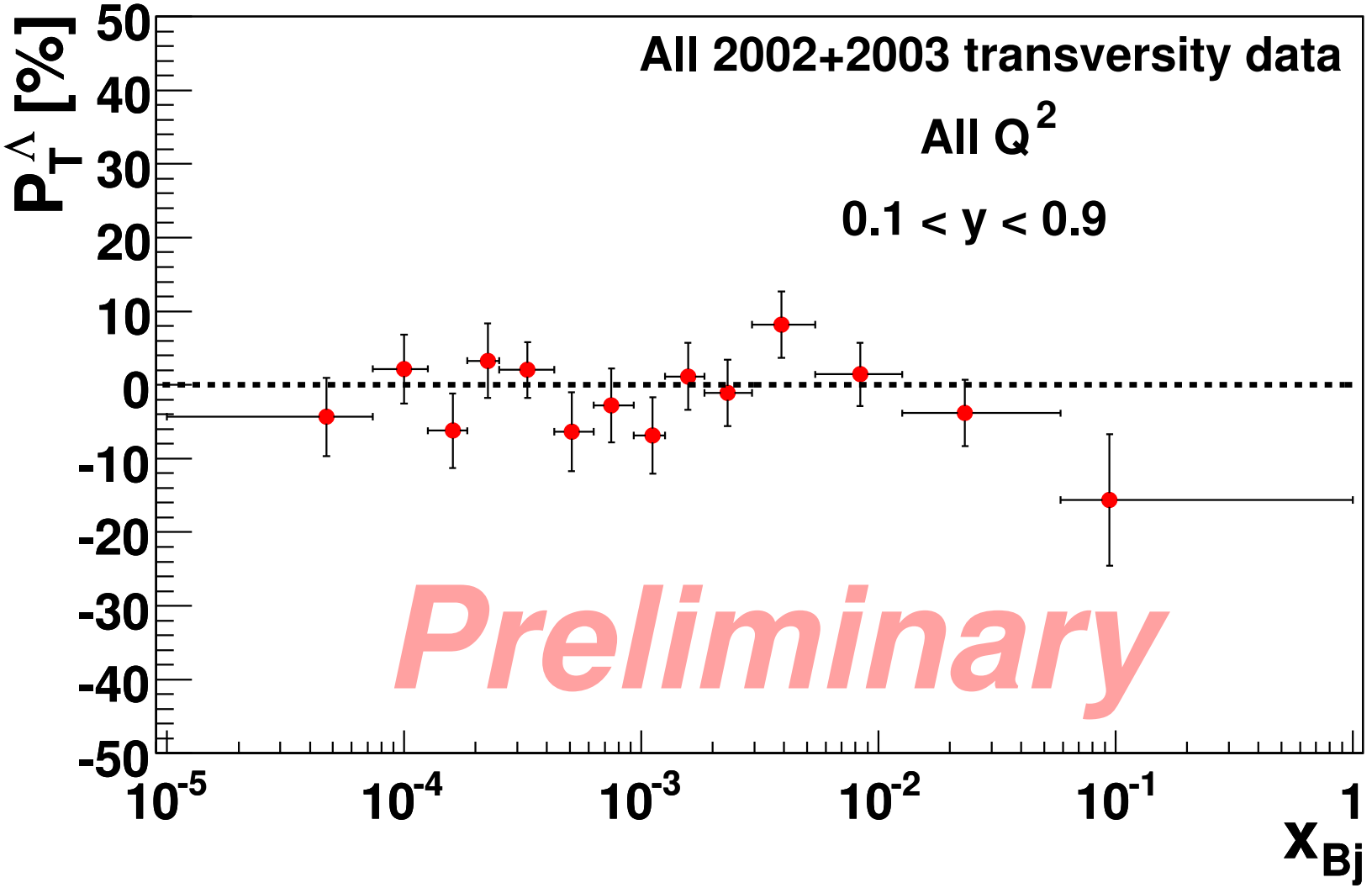


Kinematics of Λ Production



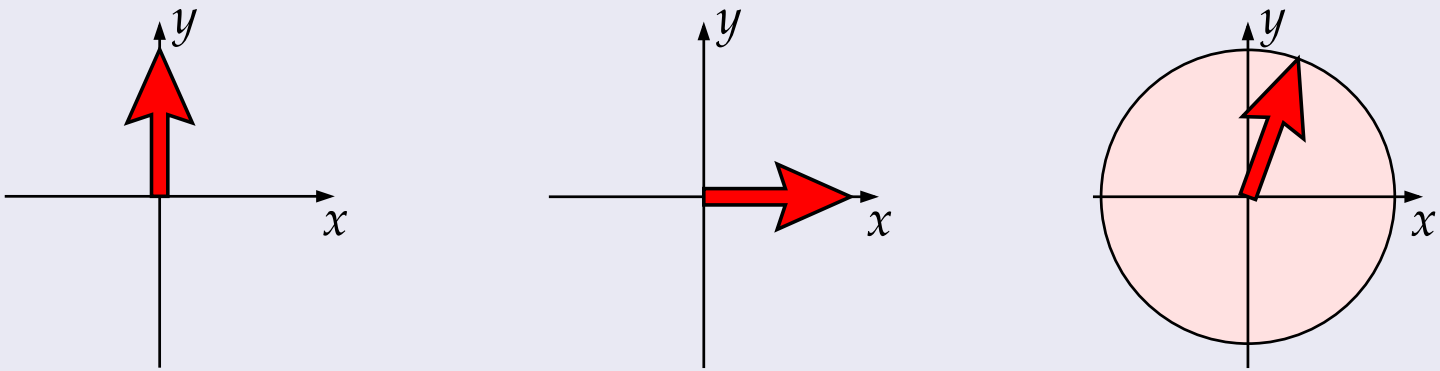
- Mean virtual photon transverse depolarization factor $\langle D_T(y) \rangle \approx 0.8$
- Majority of Λs produced in current fragmentation region $x_F > 0$
- Accessible x_{Bj} ranges
  - All Q^2: $10^{-5} < x_{Bj} < 1$
  - $Q^2 > 1\,\mathrm{GeV}^2$: $3 \cdot 10^{-3} < x_{Bj} < 1$

x_{Bj}-Dependence of Transv. Λ Polarization, All Q^2



Study of systematic Effects

- False K^0 polarization
- Subdivision of target cells into two halves
- Artificial change of orientation of target polarization: horizontal, random orientation



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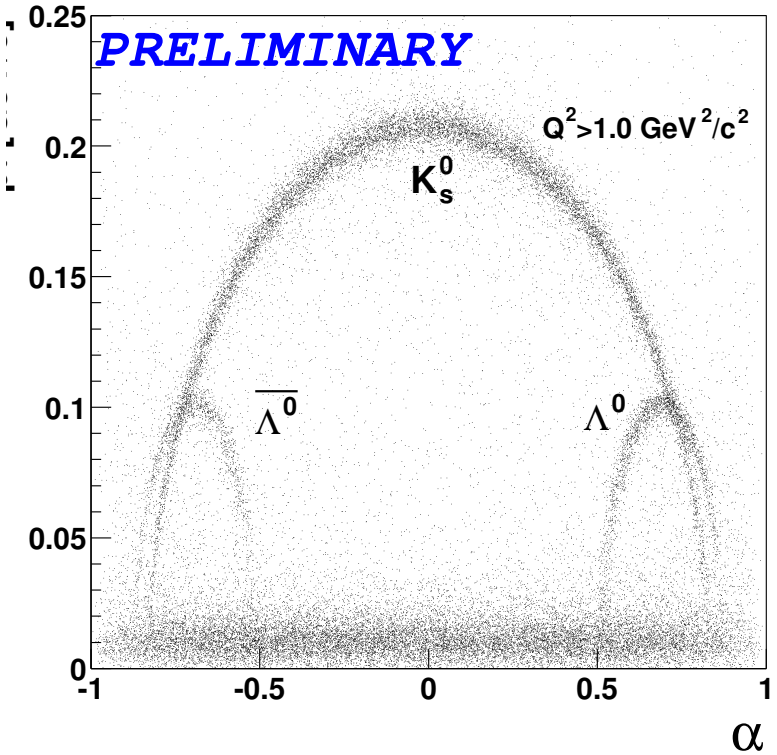
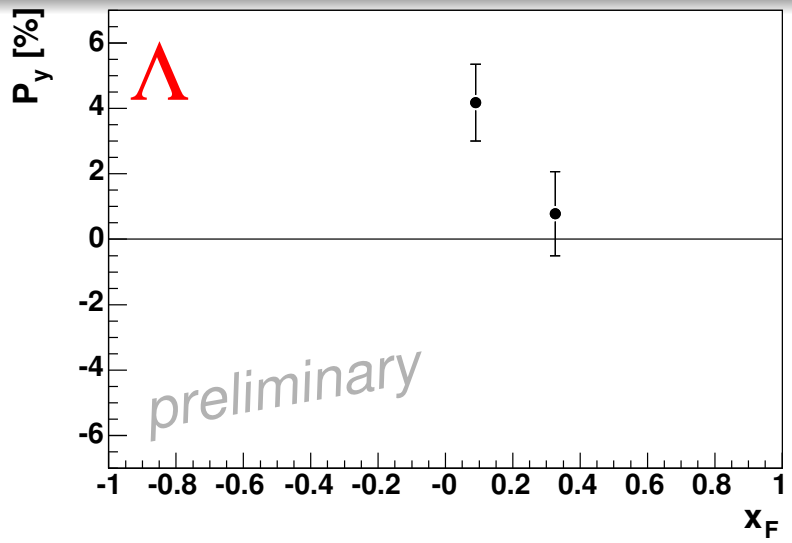
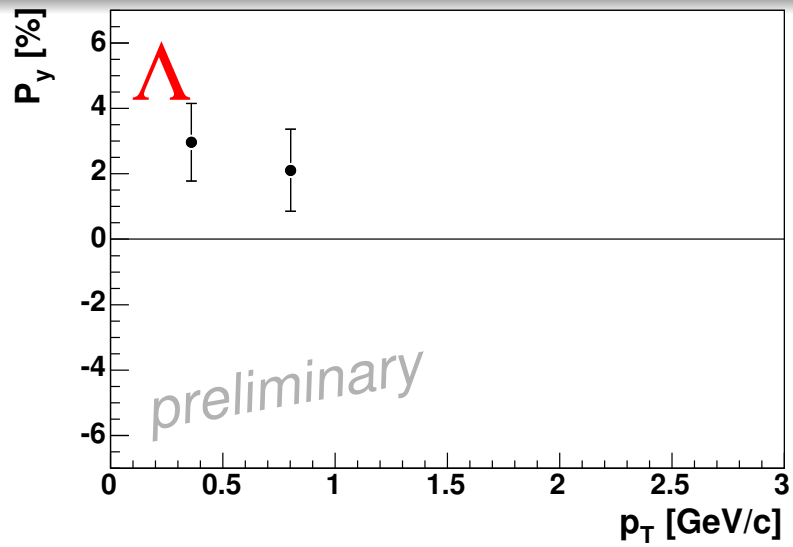
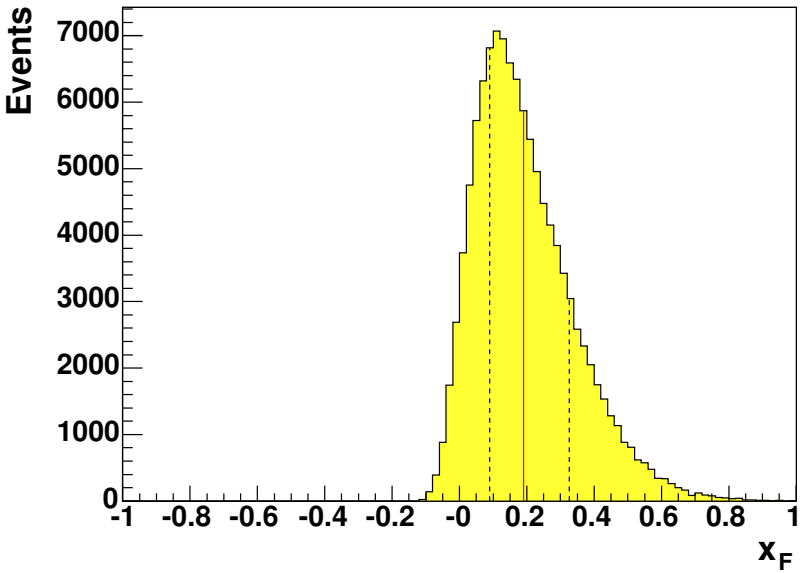
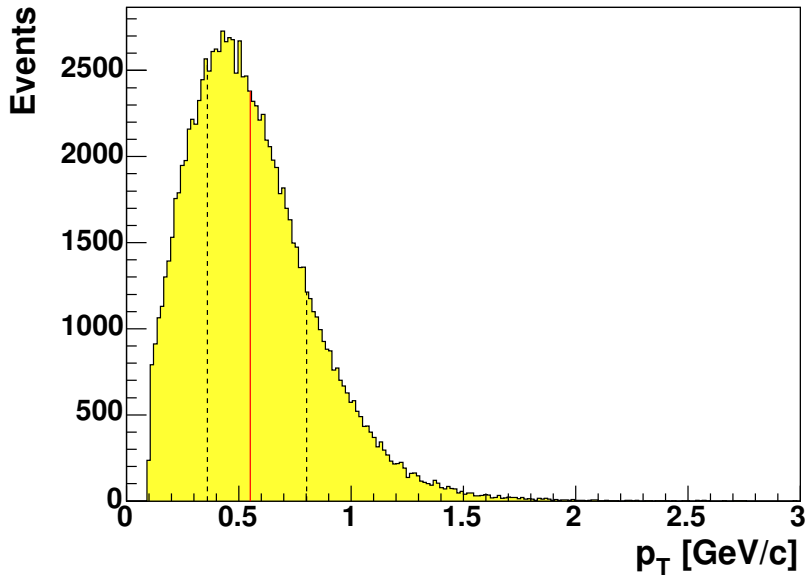


Dependence of Λ Pol. on x_F and p_T (2002 Data, all Q^2)









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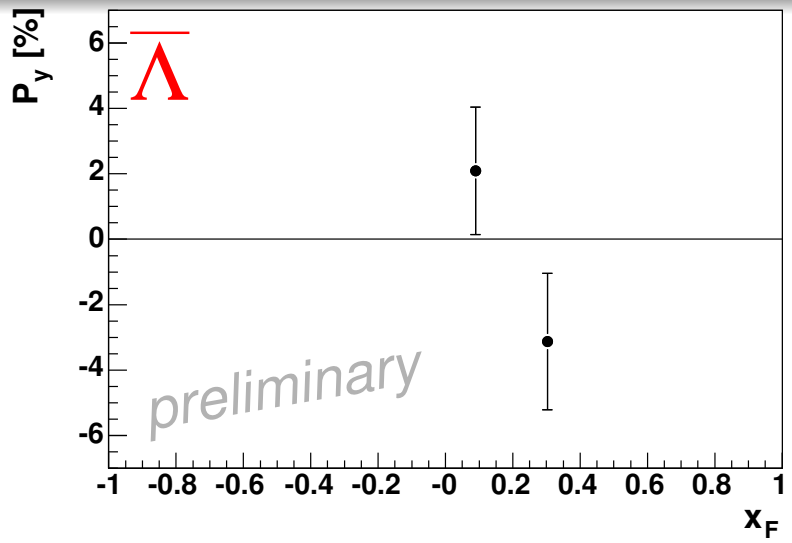
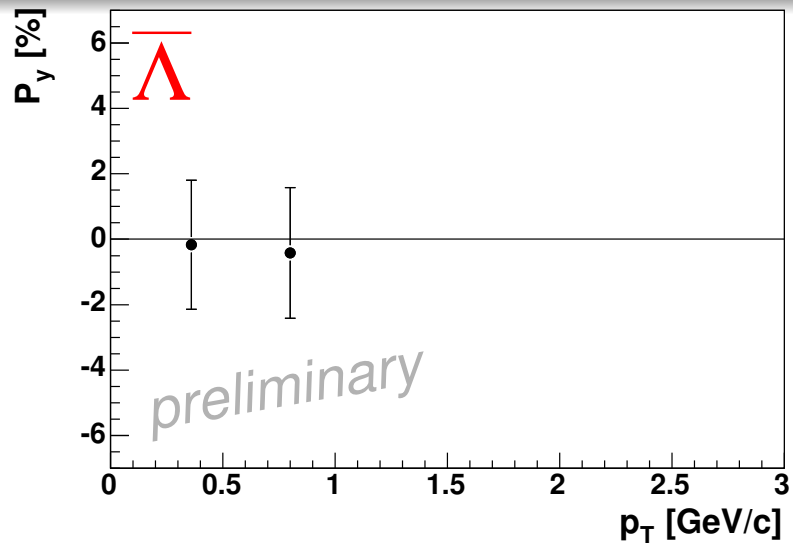
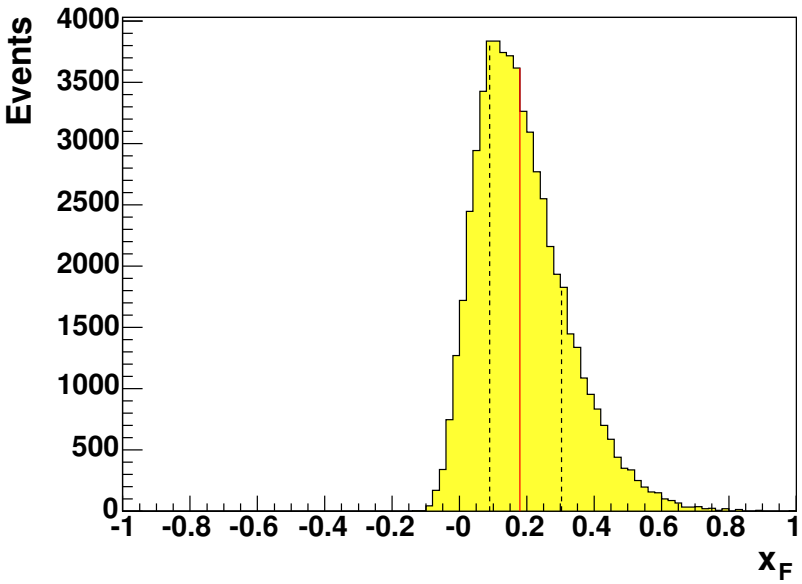
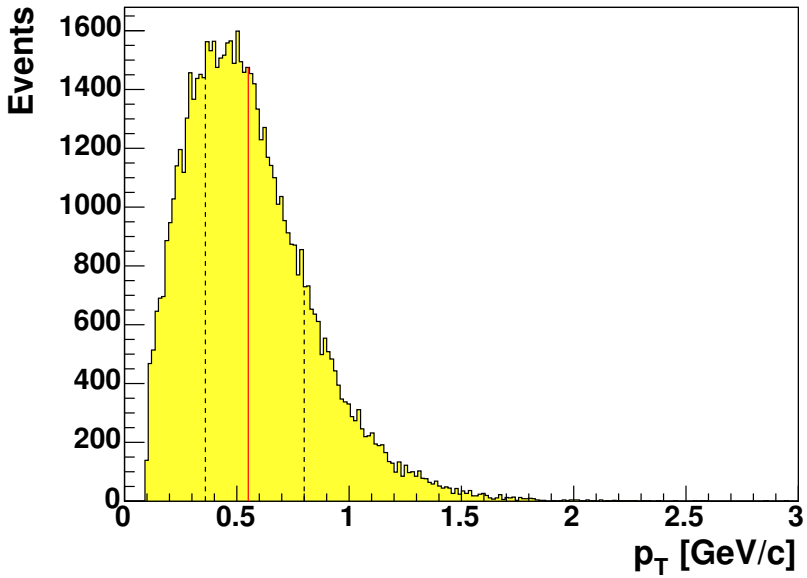


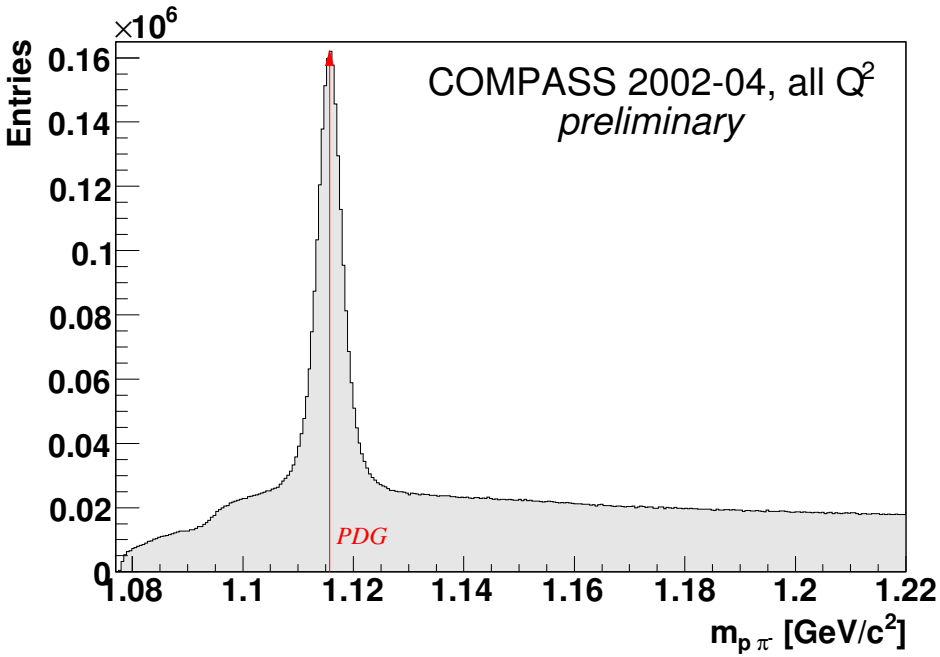






Overall available Statistics (2002-04, all Q^2)

$1.6 \cdot 10^6$ Λs



$0.9 \cdot 10^6$ $\bar{\Lambda}$s