Transversity and Λ polarization at COMPASS

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Content of this talk

- The physics case
- Data analysis
- Results
- Interpretation
- Conclusions and perspectives

The physics case

Introduction

At leading order in collinear QCD, nucleon structure is described by three PDFs:

unpolarized PDF	helicity	transversity
$f_1^q(x)$	$g_1^q(x)$	$h_1^q(x)$
$\downarrow$	$\downarrow$	$\downarrow$
very well known	well known	NEW!

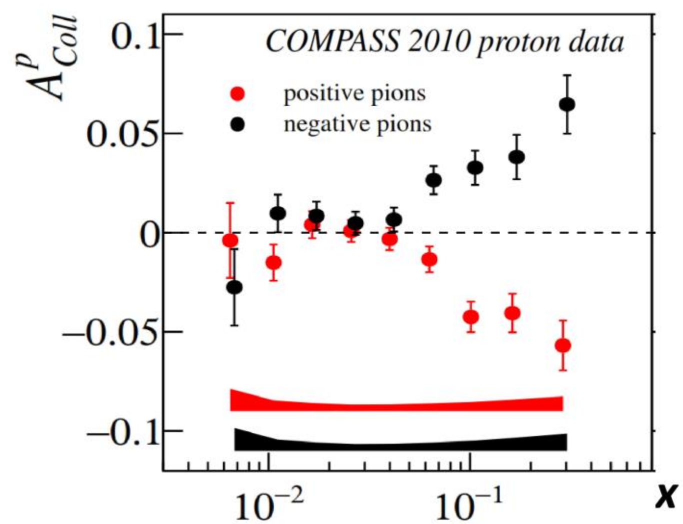
Transversity, introduced by Ralston and Soper in 1979 and rediscovered in early Nineties, accessible in SIDIS looking at:

- **Collins and dihadron asymmetry**

  results from HERMES and COMPASS
- **Λ polarimetry**

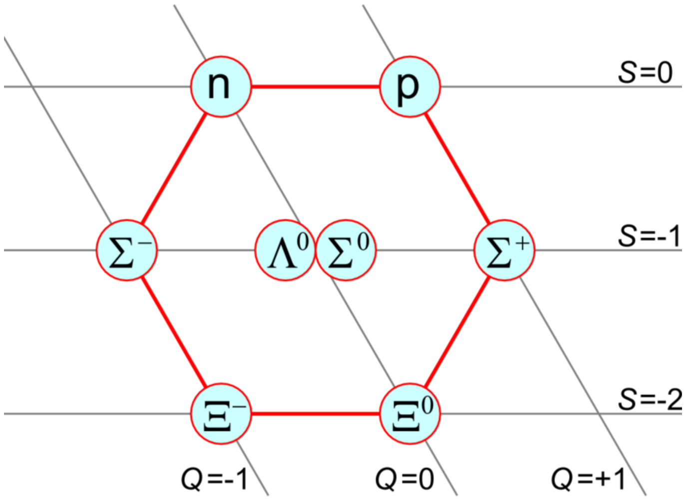
  so far only preliminary results from COMPASS

[Baldracchini et al., 1981] [Artru and Mekhfi, 1990] [Jaffe and Ji, 1992]



[COMPASS coll., Phys. Lett., B744:250,2015]

Λ self-analyzing decay



Λ MAIN PROPERTIES

- Mass $M_\Lambda = 1115.7\ \mathrm{MeV}/c$
- Spin-parity $J^P = \frac{1}{2}^+$
- Isospin $I = 0$
- Valence quark content uds
- $\Lambda \to p\,\pi^-$ (BR 63.9%)
- $\tau = (2.632 \pm 0.020)\ 10^{-10}\mathrm{s}$

Λs reveal their polarization P_Λ through an angular asymmetry in the emission of decay protons (self-analyzing decay)

$$\frac{dN}{d\cos\theta} \propto 1 + \alpha P_\Lambda \cos\theta$$

$\alpha = 0.642 \pm 0.013$ weak decay asymmetry parameter

θ angle between Λ spin and proton momentum in Λ rest frame.

Transversity-induced polarization

In the **SIDIS** process $\ell p^{\uparrow} \rightarrow \ell' \Lambda X$,

- with target **nucleon transversely polarized** and
- knowing that **transversity is different from zero**

the quark polarization can be transmitted to the Λ according to the expression

$$P_{\Lambda}^{raw}(x,z) = f\, P_T\, D_{NN} \frac{\sum e_q^2 h_1^{q(\bar{q})} H_1^{\Lambda,q(\bar{q})}(z)}{\sum e_q^2 f_1^{q(\bar{q})} D_1^{\Lambda,q(\bar{q})}(z)}$$

being f the dilution factor, P_T the target polarization and D_{NN} the depolarization factor.

Two remarks on this expressions. It holds true:

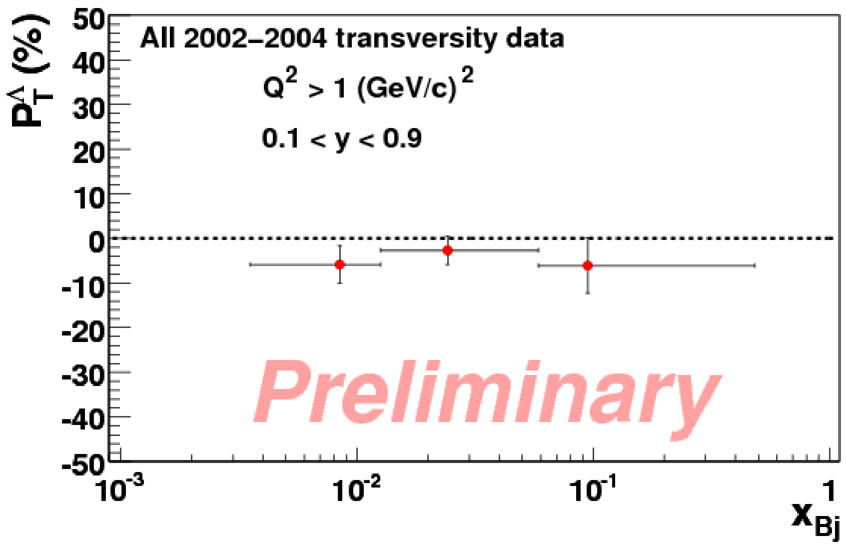
- assuming collinear kinematics ($\Lambda \parallel \gamma$, low p_t)
- in the current fragmentation region

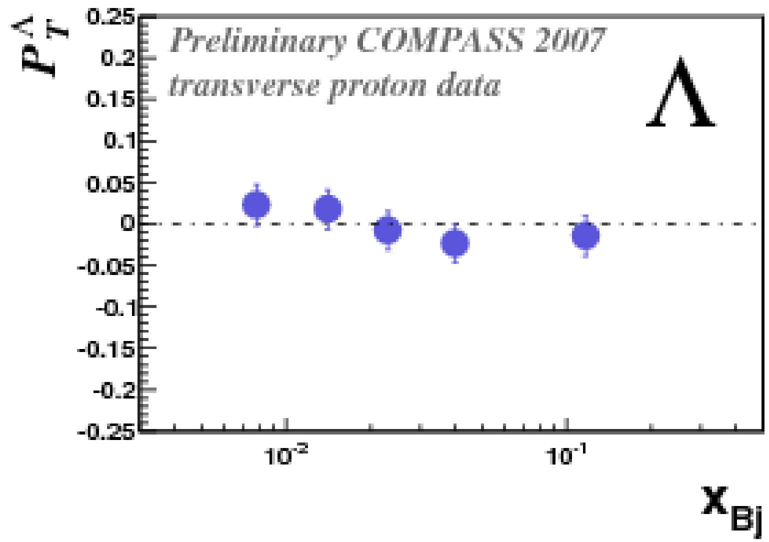
→ our choice $\mathrm{z} > 0.2, \mathrm{x}_F > 0$

Transversity-induced polarization

It's a statistically limited measurement, but still interesting,

So far, only preliminary results from COMPASS
(on polarized deuteron and proton target – 2007 only)





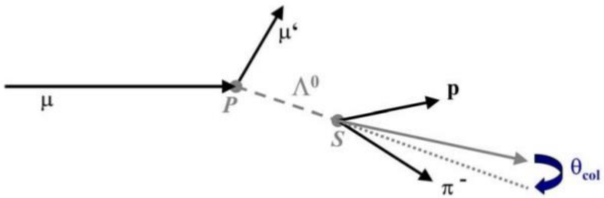
In this talk: results from the complete COMPASS transversely polarized proton data set.

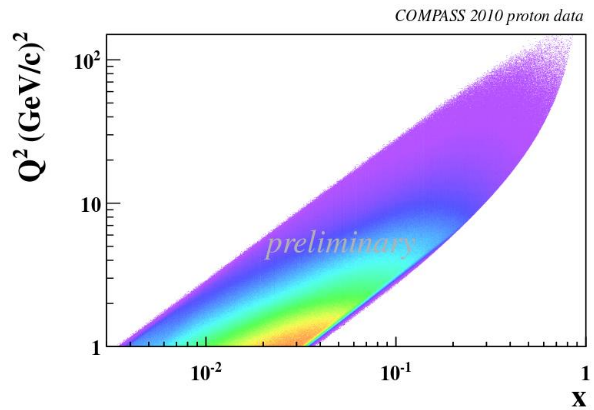
Data analysis

Λ selection procedure

DIS events:

- $Q^2 > 1$ $(\mathrm{GeV/c})^2$
- $W > 5$ $(\mathrm{GeV/c^2})$
- $0.1 < y < 0.9$
- $x > 0.003$





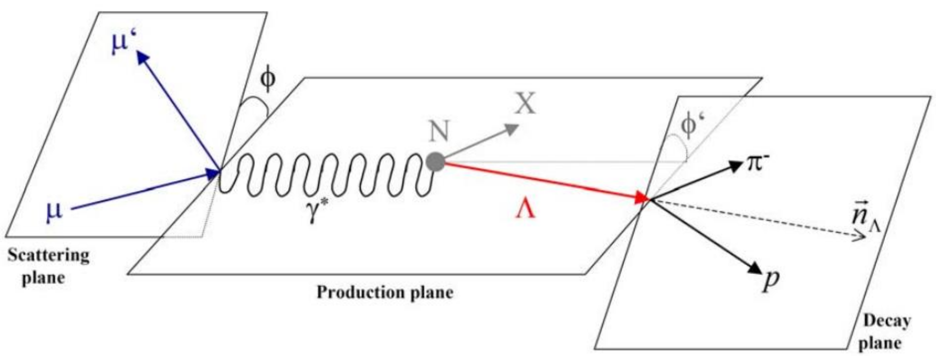
Final state candidates: two charged particles from the decay vertex (V^0s) with

- opposite charge
- momenta > 1 GeV/c
- $p_T > 23$ MeV/c

to reject $e^+ e^-$ from γ conversion

- $\theta_{coll} = \arccos \frac{\boldsymbol{p_\Lambda \cdot PS}}{|\boldsymbol{p_\Lambda \cdot PS}|} < 7$ mrad
- PID with RICH detector

no direct identification of proton but veto on other particles

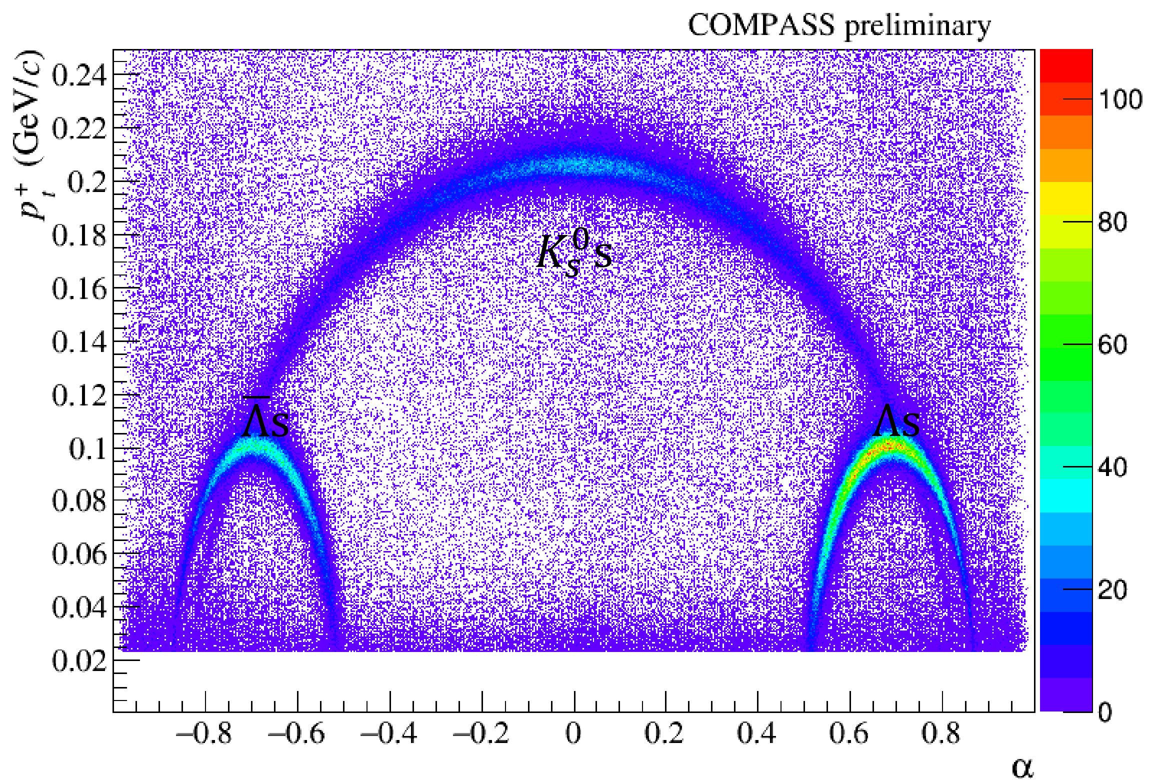


Armenteros plot

Longitudinal momentum asymmetry $\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$ VS transverse momentum p_T of one the decay particles in the V^0 rest frame.

Λs on the rightmost arc, $\bar{\Lambda}$s on the leftmost.

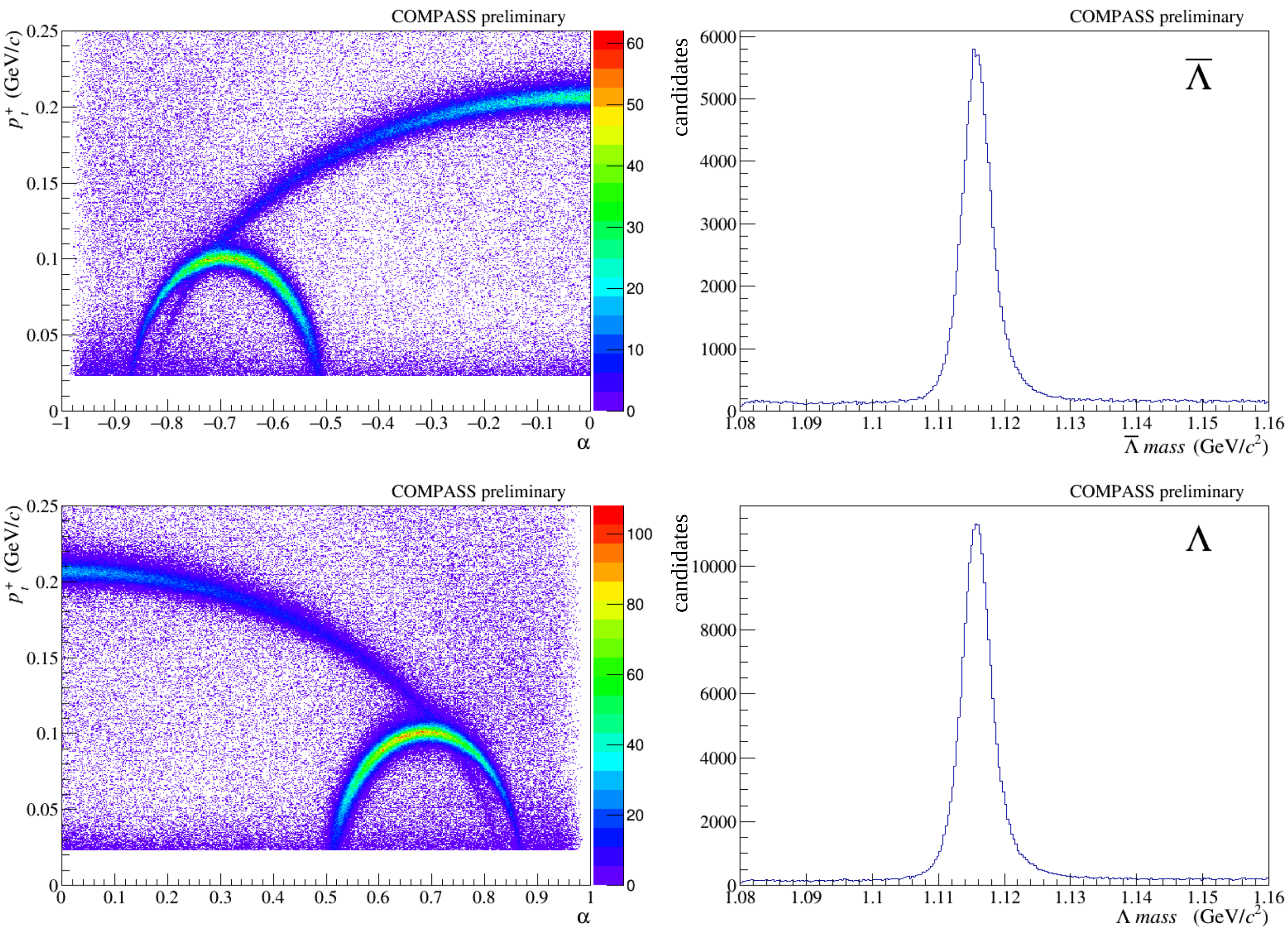
The leftover K_S^0s appear on the large symmetric arc (anyway removed by the forthcoming mass cut).



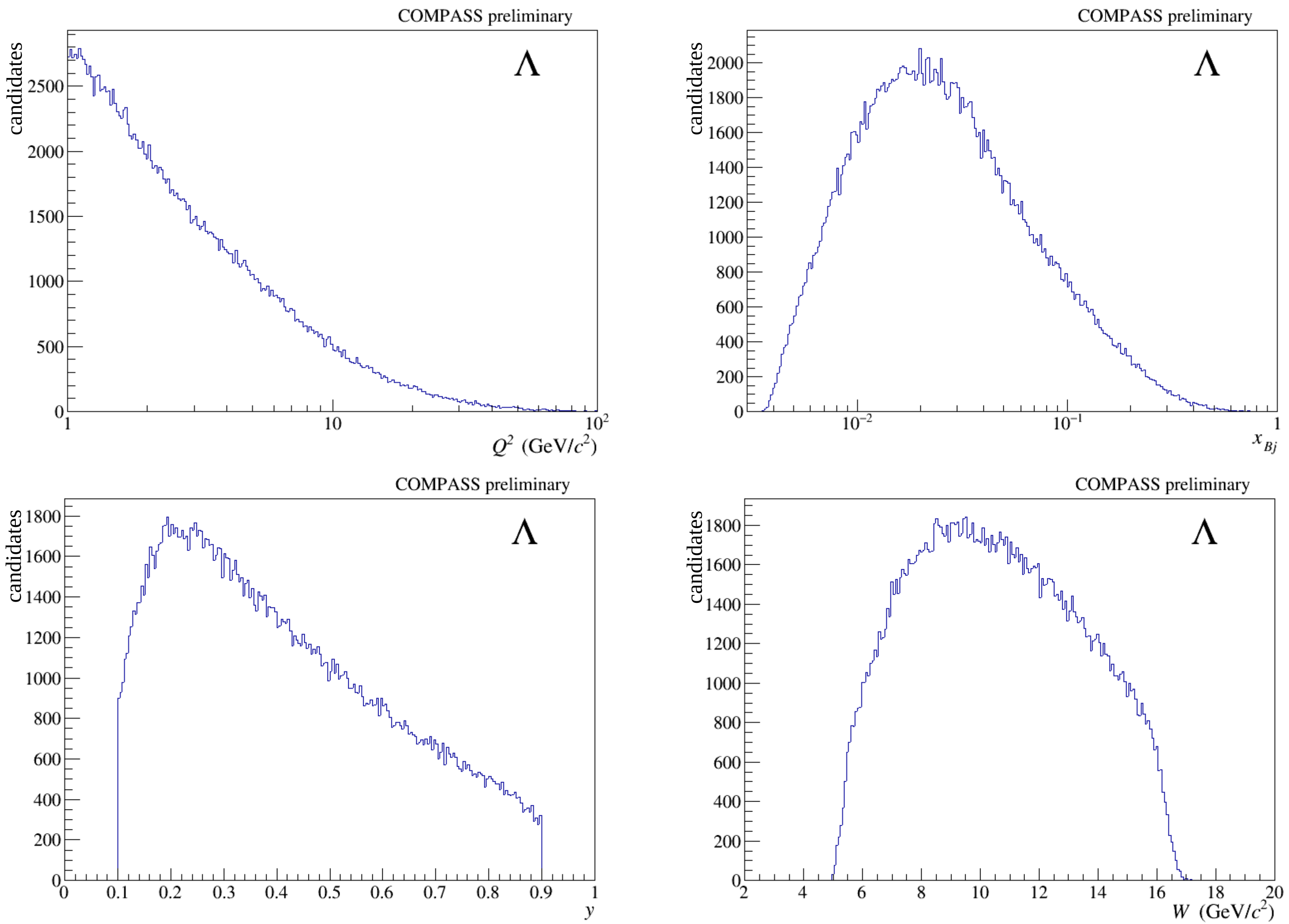
Final $\Lambda - \bar{\Lambda}$ candidates

In the mass peak ~ 305 000 Λs, 154000 $\bar{\Lambda}$s.

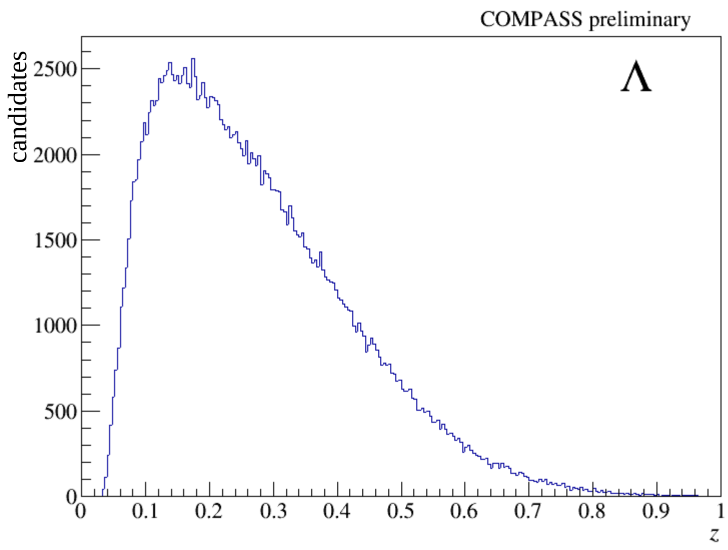
Very clean signal with low background (anyway taken into account)

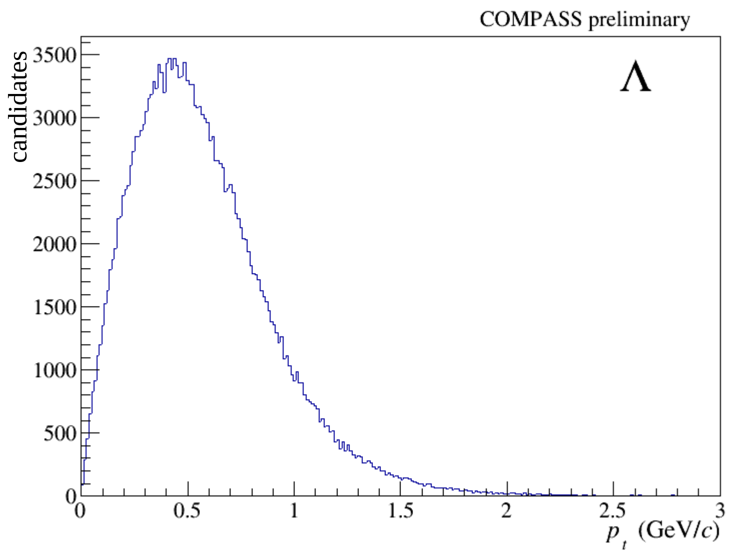


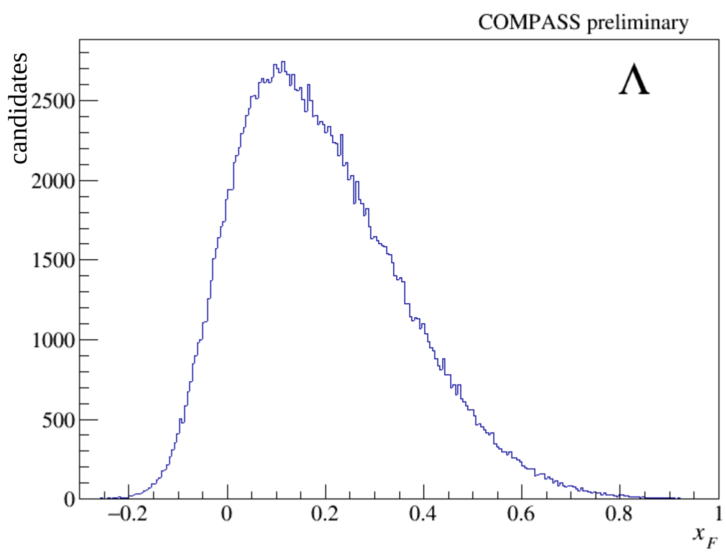
Kinematic distributions: Q^2, x, y, W (Λs)



Kinematic distributions: z, p_t, x_F (Λs)

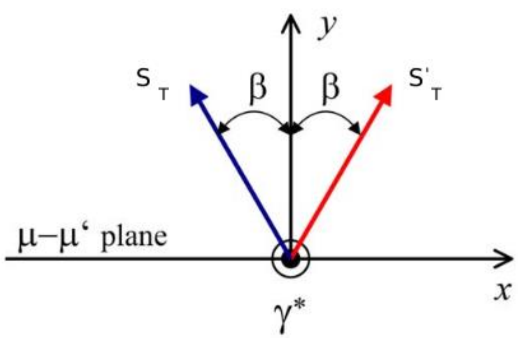


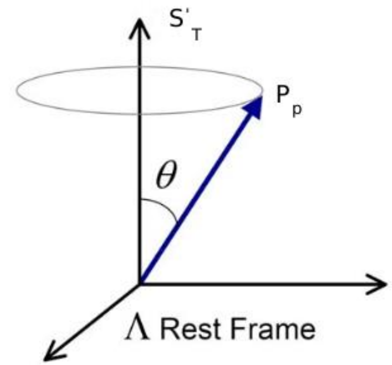




Extraction of polarization

P_Λ is to be measured in the Λ rest frame as an angular asymmetry in the distribution of the proton wrt the outgoing quark spin direction [Mulders – Tangerman, 1996]



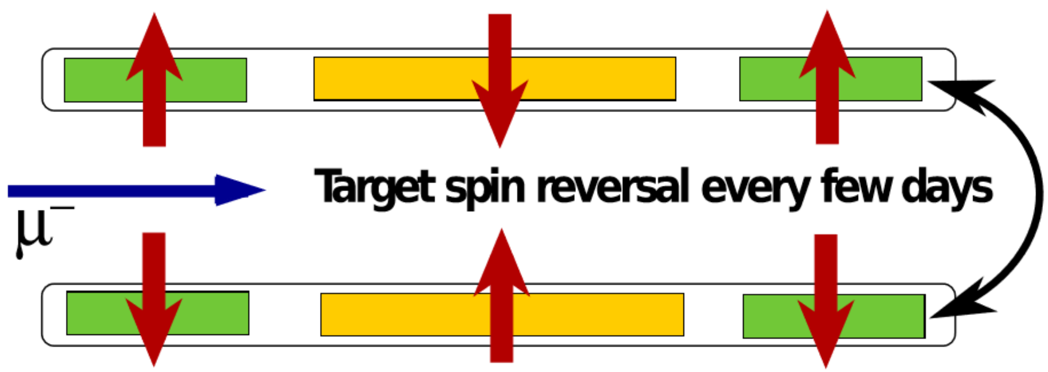


- Initial quark spin S_T parallel to the target polarization vector (transverse in the lab)
- Final quark spin S_T' reflection of S_T wrt normal to the scattering plane
- Event by event procedure

Extraction of polarization

Polarization extracted using standard COMPASS methods that take advantage of:

- Polarized target geometry and
- Polarization reversal during data taking - to get rid of the spectrometer acceptance
- Standard studies on systematic effects give $\sigma_{syst} < 0.8\ \sigma_{stat}$.



Results

Results: all Λs and $\bar{\Lambda}$s

Polarization has been measured as a function of x, z and p_t for both Λs and $\bar{\Lambda}$s :

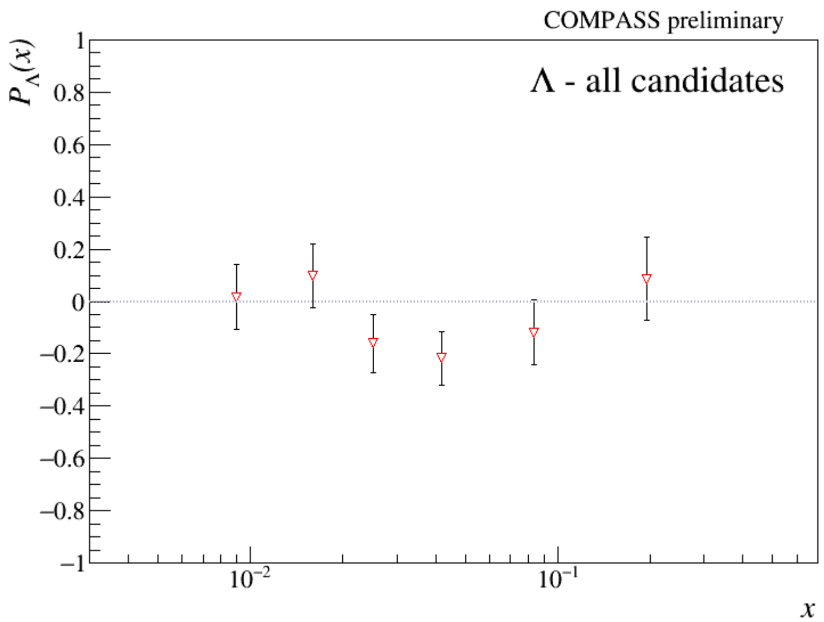
$$P_{\Lambda}^{raw}(x,z) = f\ P_T\ D_{NN} \frac{\sum e_q^2 h_1^{q(\bar{q})} H_1^{\Lambda,q(\bar{q})}(z)}{\sum e_q^2 f_1^{q(\bar{q})} D_1^{\Lambda,q(\bar{q})}(z)}$$

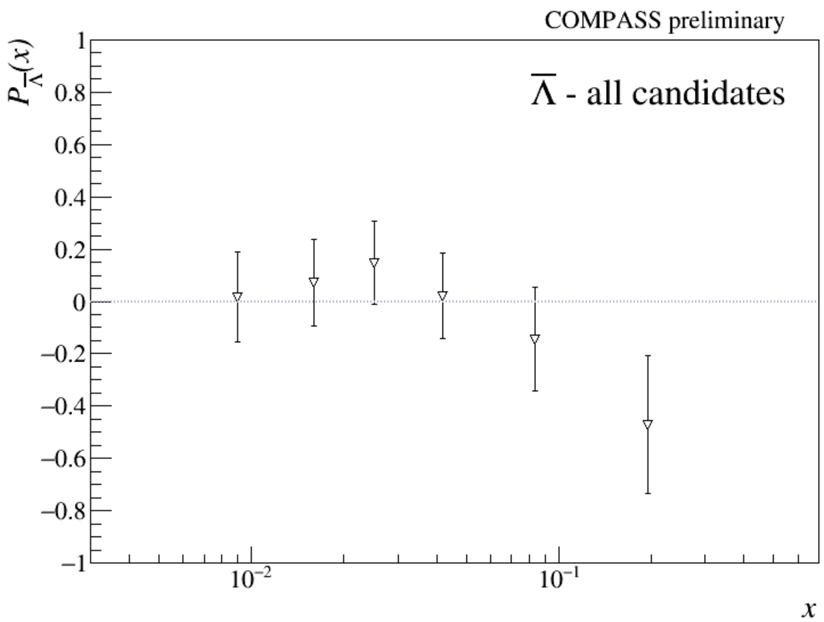
Note: Polarization plots are given here divided by f, P_T and D_{NN} **(spin transfer)**.

$$P_{\Lambda}\ (x,z) = \frac{\sum e_q^2 h_1^{q(\bar{q})} H_1^{\Lambda,q(\bar{q})}(z)}{\sum e_q^2 f_1^{q(\bar{q})} D_1^{\Lambda,q(\bar{q})}(z)}$$

Results: all Λs and $\bar{\Lambda}$s

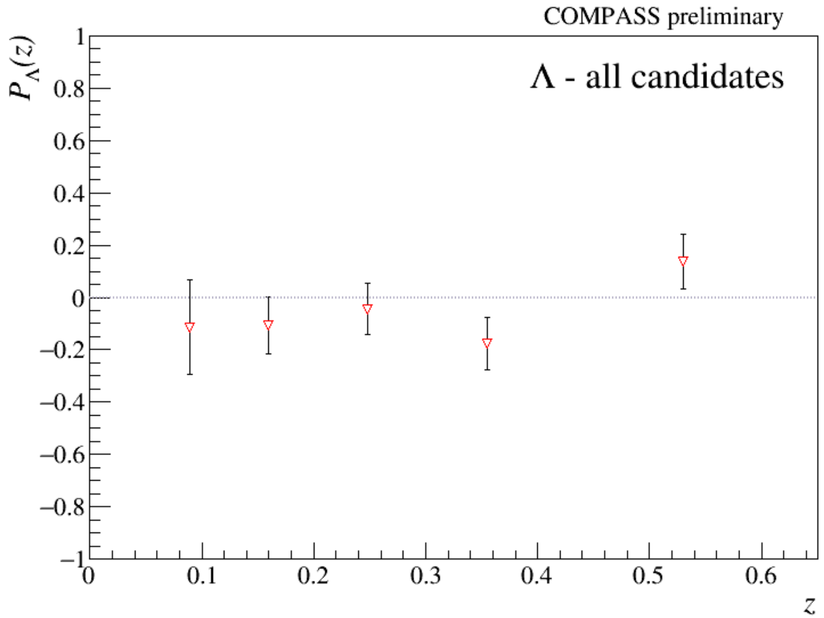
$$P_{\Lambda(\bar{\Lambda})}(x)$$

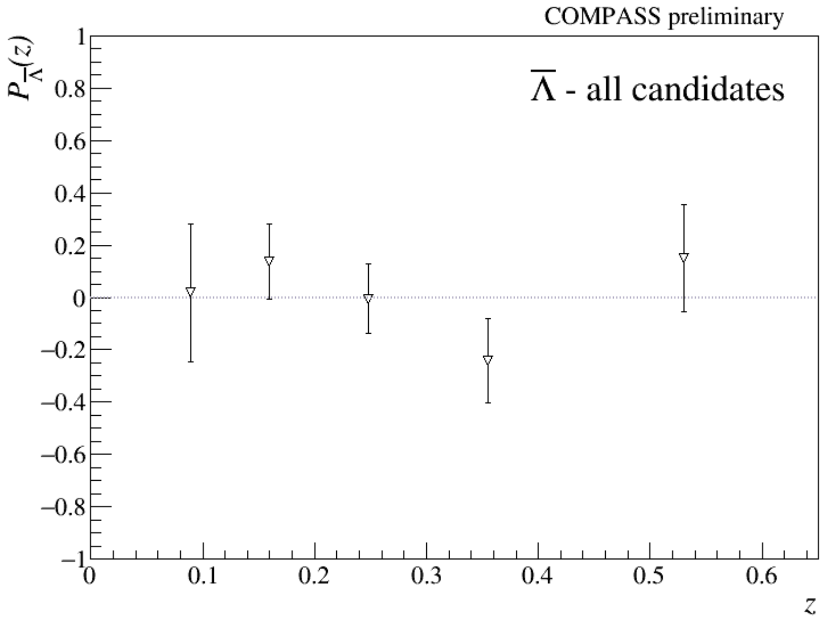




Results: all Λs and $\bar{\Lambda}$s

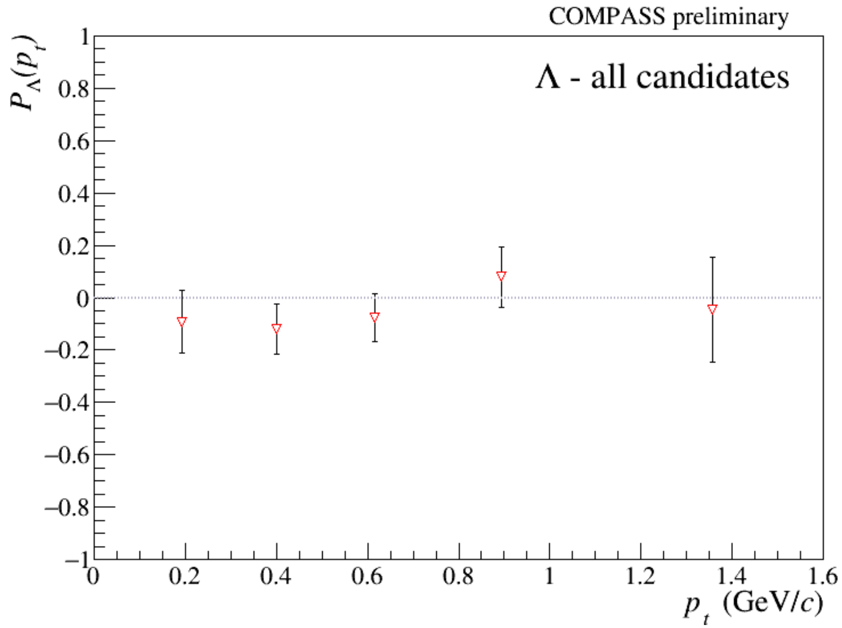
$$P_{\Lambda(\bar{\Lambda})}(z)$$

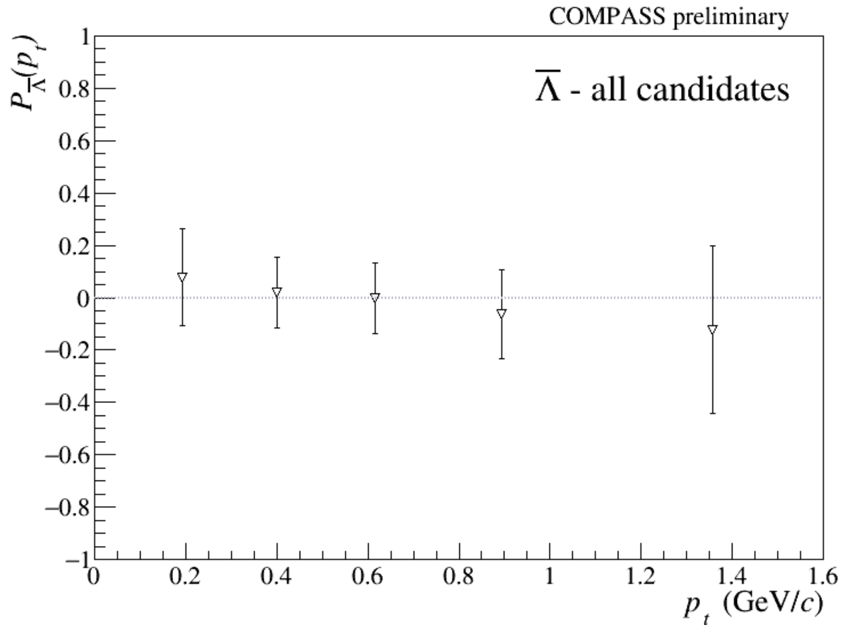




Results: all Λs and $\bar{\Lambda}$s

$$P_{\Lambda(\bar{\Lambda})}(p_t)$$





Results

Polarization has also been measured in six other kinematic regions:

- High z : z >0.2 and x_F >0 **("current" fragmentation region)**
- Low z : z <0.2 or x_F<0 **("target" fragmentation region)**
- High x : x >0.032 **($\mathbf{h}_1^{u,d}(x)$ different from zero)**
- Low x : x <0.032
- High p_t : p_t >1 GeV/c
- Low p_t : p_t <1 GeV/c

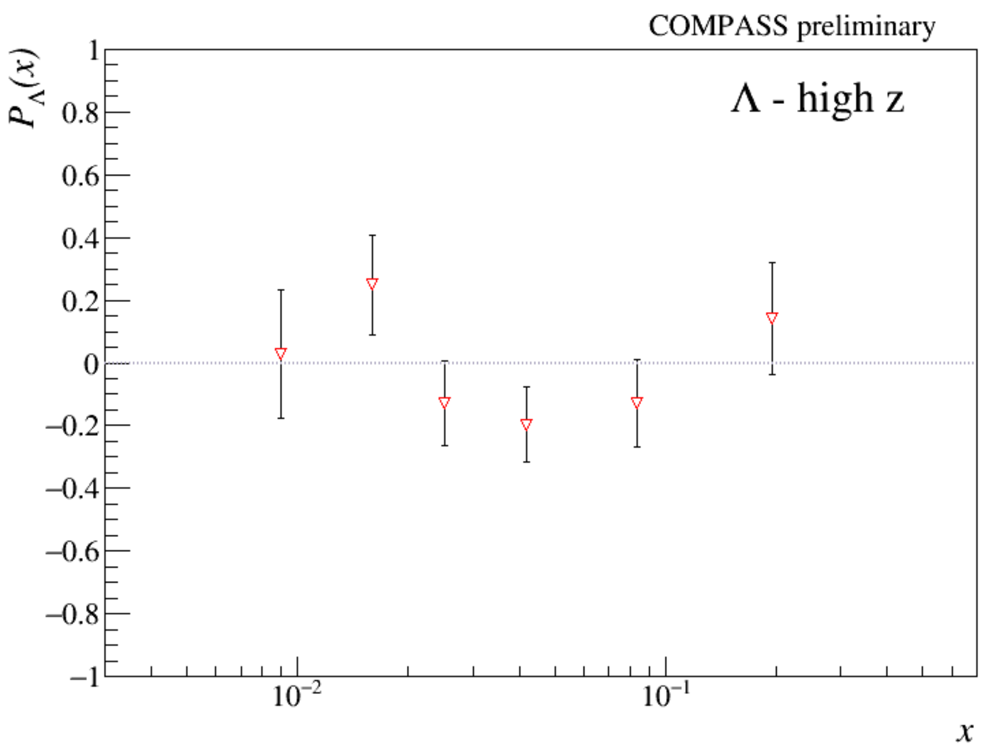
In general, as in the case of all Λs and $\bar{\Lambda}$s, polarizations are found compatible with zero.

Interpretation

Focus on $P_\Lambda(x)$ for high z

Interpretation for directly produced Λ : we neglect the spin transfer to Λ from heavier hyperons

$$P_\Lambda(x,z) = \frac{\sum e_q^2 h_1^{q(\bar{q})} H_1^{\Lambda,q(\bar{q})}(z)}{\sum e_q^2 f_1^{q(\bar{q})} D_1^{\Lambda,q(\bar{q})}(z)}$$



What can we learn from our results?

We **KNOW** that:

- $h_1^u(x)$ and $h_1^d(x)$ are different from zero at large x;
- $h_1^{\bar{u}}(x)$ and $h_1^{\bar{d}}(x)$ are compatible with zero.

We can **ASSUME** that:

- $h_1^{\bar{s}}(x) \sim 0$;
- negligible contribution from $\bar{q}$ in unpolarizd fragmentation process;
- isospin symmetry at work: $D_1^{\Lambda,u}(\mathrm{z}) = D_1^{\Lambda,d}(\mathrm{z})$ and $H_1^{\Lambda,u}(\mathrm{z}) = H_1^{\Lambda,d}(\mathrm{z})$;
- $D_1^{\Lambda,s}(\mathrm{z}) = \mathrm{c}_1 D_1^{\Lambda,u}(\mathrm{z})$ with constant c_1;
- Analogously, if $H_1^{\Lambda,u}(\mathrm{z}) \neq 0$, $H_1^{\Lambda,s}(\mathrm{z}) = c_2 H_1^{\Lambda,u}(\mathrm{z})$.

The quantity $1/c_1$ is usually referred to as strangeness suppression factor. In [J-J. Yang, Phys Rev D65 2002] it is put at 0.44.

Three different hypotheses

With these ingredients we can write a simplified expression for P_Λ:

$$P_\Lambda(x,z) = \frac{\left[4h_1^u(x) + h_1^d(x)\right]H_1^{\Lambda,u}(z) + h_1^s(x)H_1^{\Lambda,s}(z)}{\left[4f_1^u(x) + f_1^d(x) + c_1 f_1^s(x)\right]D_1^{\Lambda,u}(z)}$$

Now, we can interpret the data according to **three different hypotheses**:

1. Transversity is a valence object
2. Polarization is entirely due to the s quark (SU(6) approach)
3. Quark-diquark model [J-J. Yang, Nucl Phys A699:562-578, 2002]

Note: simplified expression looks interesting with a deuteron target:

$$P_\Lambda(x,z) = \frac{5(h_1^u(x) + h_1^d(x))H_1^{\Lambda,u}(z) + 2h_1^s(x)H_1^{\Lambda,s}(z)}{5(f_1^u(x) + f_1^d(x))D_1^{\Lambda,u}(z) + 2f_1^s(x)D_1^{\Lambda,s}(z))} \approx \frac{2h_1^s(x)H_1^{\Lambda,s}(z)}{5(f_1^u(x) + f_1^d(x) + 2c_1 f_1^s(x))D_1^{\Lambda,u}(z)}$$

Hypothesis 1: transversity a valence object

If transversity is a valence object, then $h_1^s(x) \approx 0$ and

$$P_\Lambda(x) = \frac{\left[4h_1^u(x) + h_1^d(x)\right]}{\left[4f_1^u(x) + f_1^d(x) + c_1 f_1^s(x)\right]} \frac{\int dz H_1^{\Lambda,u}(z)}{\int dz D_1^{\Lambda,u}(z)}$$

$$\rightarrow R(x) = \frac{\int dz H_1^{\Lambda,u}(z)}{\int dz D_1^{\Lambda,u}(z)} = \frac{\left[4f_1^u(x) + f_1^d(x) + c_1 f_1^s(x)\right]}{\left[4h_1^u(x) + h_1^d(x)\right]} P_\Lambda(x)$$

c_1	$< R >$
2	-0.39 ± 0.73
3	-0.38 ± 0.75
4	-0.37 ± 0.76

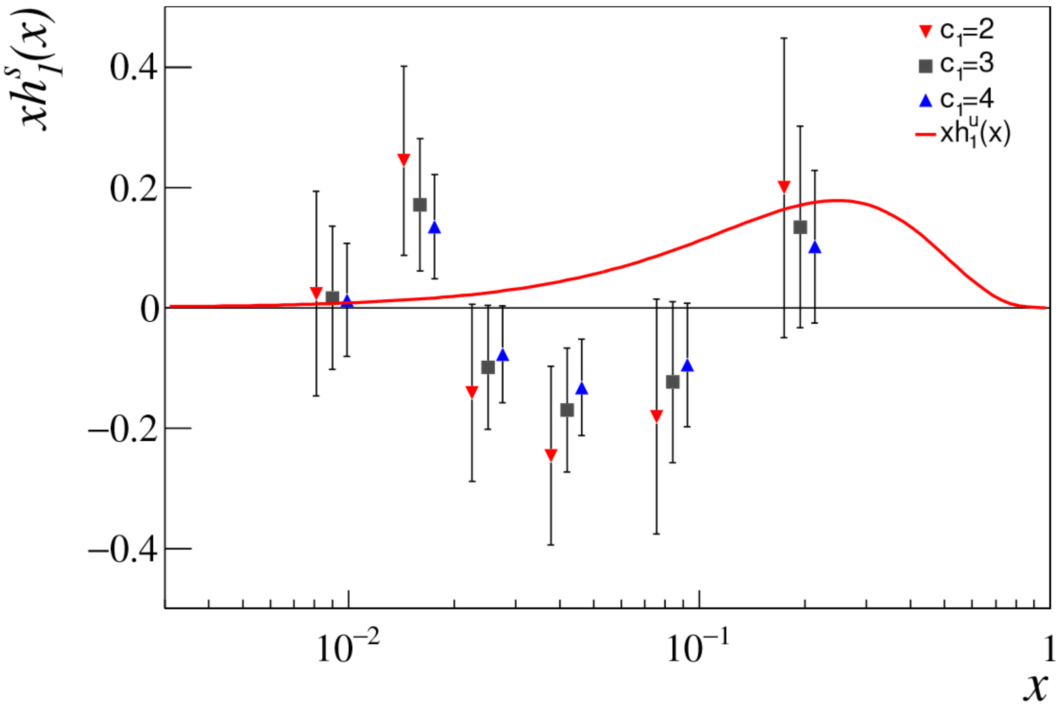
First extraction of $R(x)$, largely compatible with zero, weak dependence on c_1.

Hypothesis 2: polarization due to s quark only

If P_Λ is due to s quark only, then $H_1^{\Lambda,u}(z) = H_1^{\Lambda,\mathrm{d}}(z) = 0$. Assuming $H_1^{\Lambda,s}(z) = D_1^{\Lambda,s}(z)$,

$$P_\Lambda(x) = \frac{c_1 h_1^s(x) D_1^{\Lambda,u}(z)}{\left[4f_1^u(x) + f_1^d(x) + c_1 f_1^s(x)\right] D_1^{\Lambda,u}(z)}$$

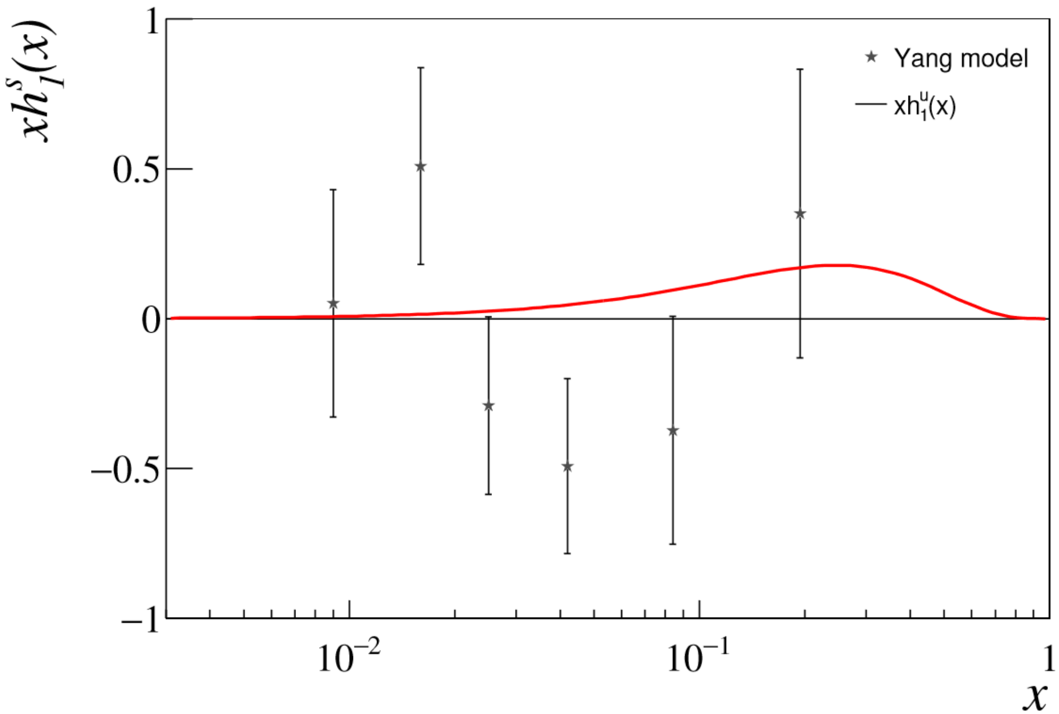
$$\rightarrow h_1^s(x) = \left(\frac{4f_1^u(x) + f_1^d(x)}{c_1} + f_1^s(x)\right) P_\Lambda(x)$$



Hypothesis 3: Quark-diquark Yang model

P_Λ is written in terms of flavor (F) and spin structure functions $(\widehat{W})$. $h_1^s(x)$ can be accessed.

$$P_\Lambda(x,z) = \frac{\left(4h_1^u(x) + h_1^d(x)\right)\frac{1}{4}\left[\widehat{W}_S^{(u)}(z)F_S(z) - \widehat{W}_V^{(u)}(z)F_M(z)\right] + \boldsymbol{h_1^s(x)}\,\widehat{W}_S^{(s)}(z)}{\left(4f_1^u(x) + f_1^d(x)\right)\frac{1}{4}\left[F_S(z) + 3F_M(z)\right] + f_1^s(x)}$$



Conclusions and perspectives

Conclusions and perspectives

- Transversity-induced polarization of Λ hyperons in SIDIS measured using the whole COMPASS transversely polarized proton data set.
- Λ and $\bar{\Lambda}$ polarizations evaluated in their rest frame along the outgoing quark spin; measured in seven kinematic regions, generally compatible with zero.
- Three main hypothesis to interpret the results:

1. the first (transversity a valence object) gives the integrated ratio of the fragmentation functions $H_1^{\Lambda,u}$(z) and $D_1^{\Lambda,u}$(z), compatible with zero;
2. the second (only s quark counts) allows for an extraction of $xh_1^s(x)$ dependent on the parameter $c_1 = D_1^{\Lambda,s}(z)/D_1^{\Lambda,u}(z)$;
3. the third (quark-diquark model) again gives $xh_1^s(x)$ without assumptions on the fragmentation functions.

- Even if definite conclusions cannot be drawn, mainly due to the statistical uncertainty, this is a contribution to a longstanding issue
- Ratios of fragmentation functions are extracted here for the first time
- Much more could be studied with new deuteron data.

thank you!