Transversity and Λ polarization at COMPASS

TRANSVERSITY 2017

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The physics case

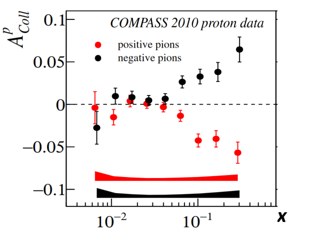
Introduction

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, rediscovered in early Nineties, accessible in SIDIS looking at:

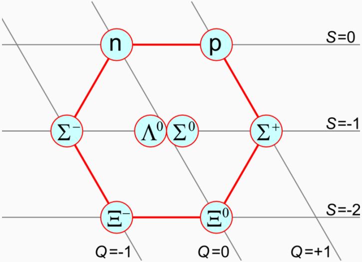
- Collins and dihadron asymmetry
  results from HERMES and COMPASS
- Λ polarimetry
  so far only preliminary results from COMPASS



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

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

Λ self-analyzing decay



Λ MAIN PROPERTIES

mass $M_\Lambda = 1115.7$ MeV/c

spin-parity $J^P = \frac{1}{2}^+$

isospin I=0

valence quark content *uds*

$\Lambda \rightarrow p\pi^-$ (BR 63.9%)

$\tau = (2.632 \pm 0.020) \times 10^{-10}$s

Λs reveal their polarization P_Λ through an angular asymmetry in the emission of the 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-transmitted transverse polarization

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

- **if** the target nucleon is transversely polarized, and
- **if** transversity is different from zero

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

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

(with f dilution factor, P_T target polarization and D_{NN} depolarization factor).

Such Λ *transversity-transmitted transverse polarization* can be accessed through the angular distribution of the decay proton.

Underlying conditions

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

This formula holds true:

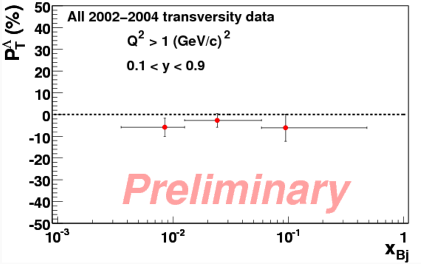
- assuming **collinear kinematics** (Λ parallel to γ)
- in the **current fragmentation region**
  our choice: $z > 0.2$ and $x_F > 0$

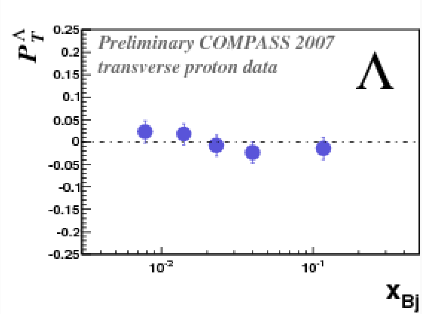
Transversity-transmitted transverse polarization

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

So far, only preliminary results from COMPASS experiment:

(on deuteron and on proton target - 2007 only, raw asymmetries)

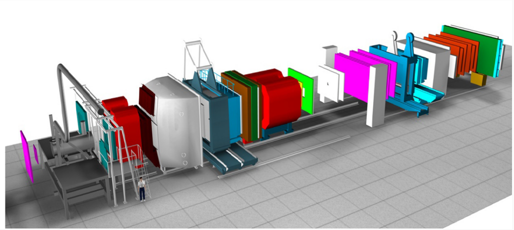




In this talk: results from the complete COMPASS proton data set.

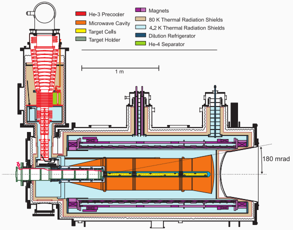
COMPASS experiment @ CERN

COMPASS is a two-stage, fixed target spectrometer located in CERN North Area, at the end of SPS M2 beamline. Designed for hadron spectroscopy and structure, but very versatile and universal.



Main features:

1. muon, electron or hadron beams (20-250 GeV),
2. solid state polarized targets
   as well as liquid hydrogen target,
3. advanced tracking and PID.

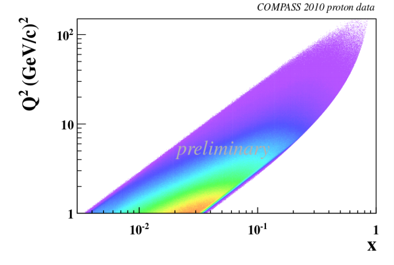


Data analysis

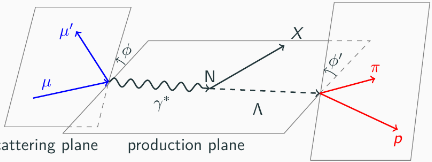
Λ selection procedure

DIS events

- $Q^2 > 1$ (GeV/c)^2;
- $x > 0.003$;
- $W > 5$ GeV/c^2;
- $0.1 < y < 0.9$.



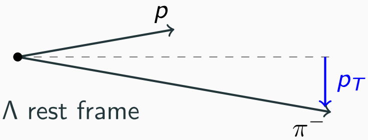
Final state candidates: two charged particles from the decay vertex (V^0s).



Λ selection procedure

To reconstruct the V^0s, the 2 outgoing particles must have:

- opposite charge;
- momenta larger than 1 GeV/c;
- p_T >23 MeV/c to reject e^+e^- from γ conversion.

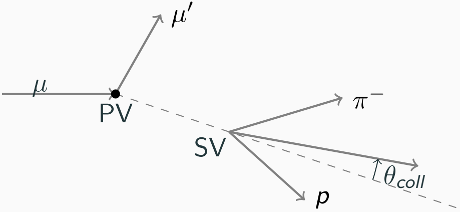


FURTHER REQUESTS:

- collinearity angle $\theta_{coll} < 7$ mrad;
- PID with RICH detector.

Λ selection procedure

- To better select the Λs stemming from the interaction vertex: cut on the ***collinearity angle*** θ_{coll} between the reconstructed Λ direction $\vec{p}_\Lambda$ and the vector $\vec{v}$ linking interaction and decay vertices.



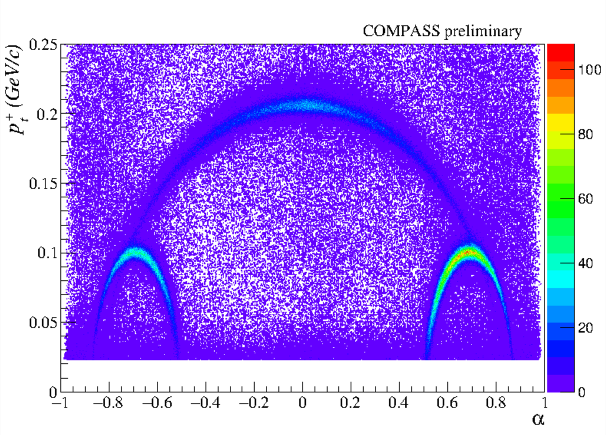
$$\theta_{coll} = \text{arccos}\left(\frac{\vec{p}_\Lambda \cdot \vec{v}}{|\vec{p}_\Lambda||\vec{v}|}\right) < 7 \text{ mrad}$$

- **Particle identification with RICH**
  - for Λs, h^+ must not be an e^+, π^+, K^+
  - for $\bar{\Lambda}$s, h^- must not be an e^-, π^-, K^-

Armenteros plot

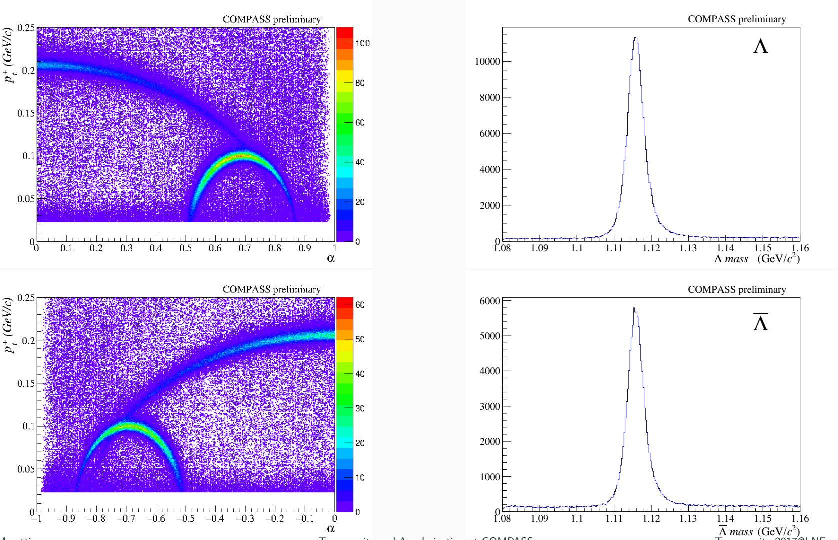
Scatter-plot between the longitudinal momentum asymmetry $\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$ and the transverse momentum p_T of one of the decay particles, in the V^0 system.

Λs on the right, $\bar{\Lambda}$s on the left and the leftover K_s^0s on the largest, symmetric arc.

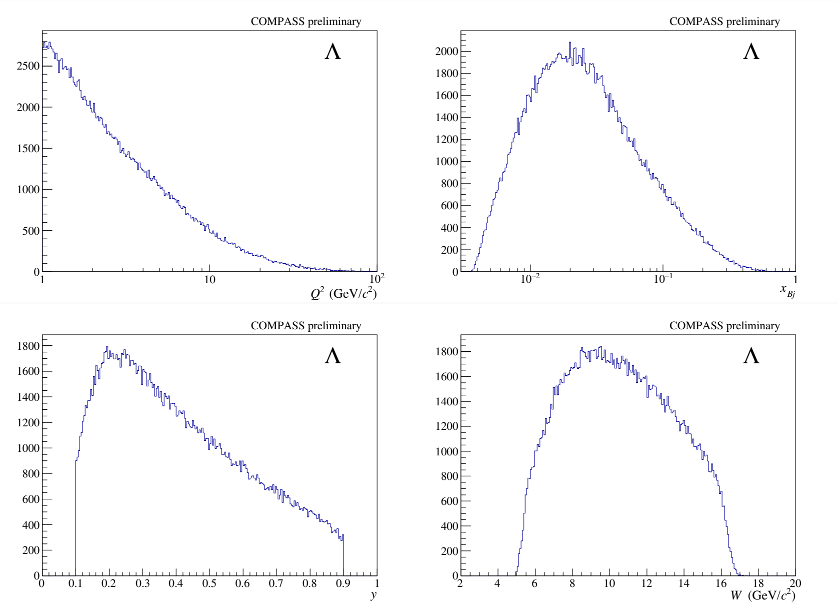


Final Λ - $\bar{\Lambda}$ candidates

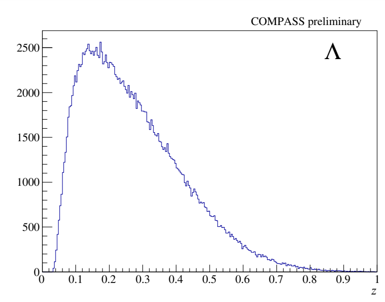
In the mass peak: $\sim 305 \cdot 10^3 \Lambda$s, $\sim 154 \cdot 10^3 \bar{\Lambda}$s. Very clear signal with low background.

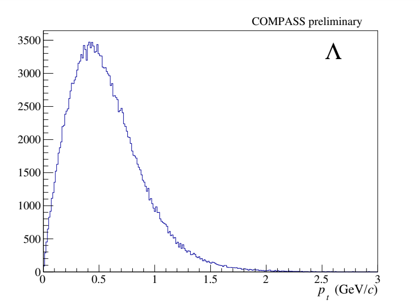


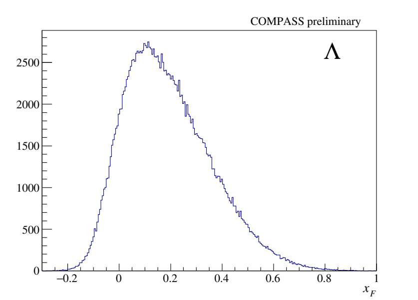
Kinematic distributions: Q^2, x, y and W for Λs



Kinematic distributions: z, p_t and x_F for Λs





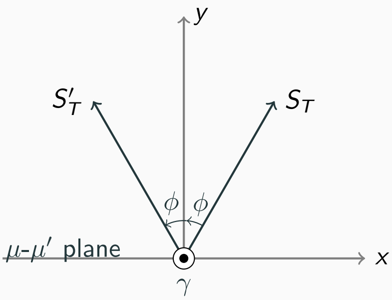


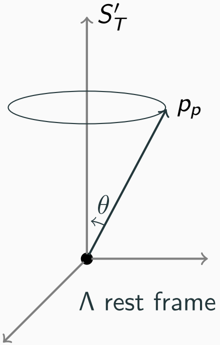
Extraction of polarization

P_Λ has 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)
- Final quark spin S'_T: reflection of S_T wrt the normal to the scattering plane
- Event-by-event procedure



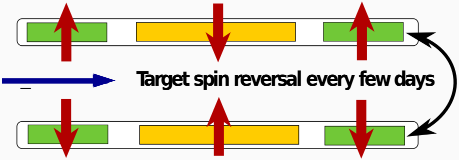


Extraction of polarization

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.

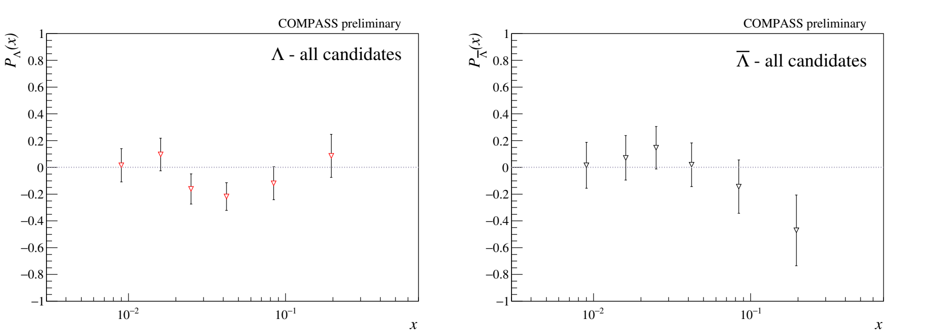
$$P_{\Lambda}^{raw}(x,z) = fP_T D_{NN} \frac{\sum_{q(\bar{q})} e_q^2 h_1^{q(\bar{q})}(x) H_1^{\Lambda/q(\bar{q})}(z)}{\sum_{q(\bar{q})} e_q^2 f_1^{q(\bar{q})}(x) D_1^{\Lambda/q(\bar{q})}(z)}$$

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

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

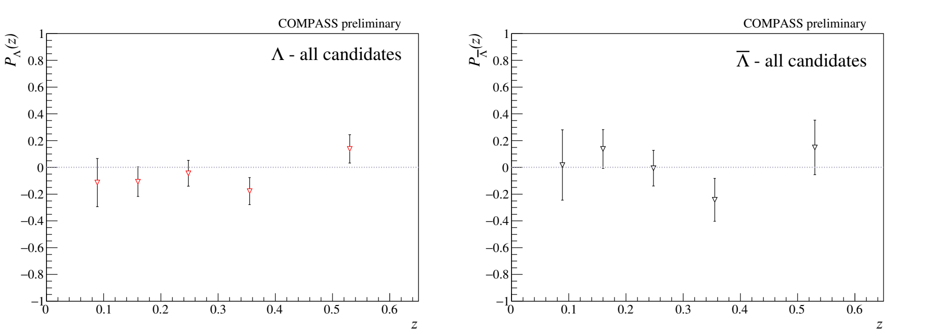
Results: all Λs and $\bar{\Lambda}$s

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



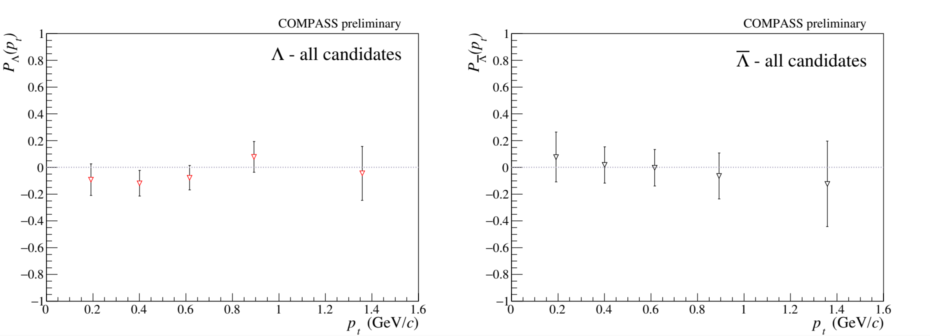
Results: all Λs and $\bar{\Lambda}$s

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



Results: all Λs and $\bar{\Lambda}$s

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



Results

Polarization has also been measured in six other kinematic regions:

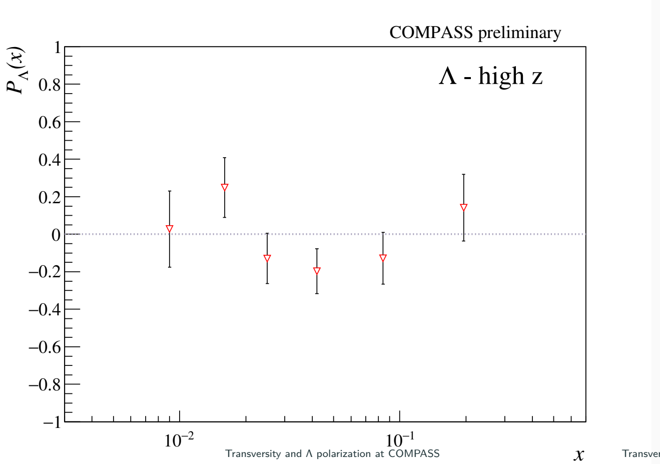
- high z: $z > 0.2$ and $x_F > 0 \leftarrow$ ("current" fragmentation region)
- low z: $z < 0.2$ or $x_F < 0 \leftarrow$ ("target" fragmentation region)
- high x: $x > 0.032 \leftarrow$ (h_1^u different from zero)
- low x: $x < 0.032$
- high p_t: $p_t > 1$ GeV/c
- low p_t: $p_t < 1$ GeV/c

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

Interpretation

Focus on $P_\Lambda(x)$ for high z ($z > 0.2$ and $x_F > 0$)

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



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,
- $h_1^{\bar{u}}$ and $h_1^{\bar{d}}$ compatible with zero.

We ASSUME that

- $h_1^{\bar{s}}(x) \approx 0$,
- negligible contribution from $\bar{q}$ in unpolarized fragmentation process,
- isospin symmetry at work: $D_1^{\Lambda/u} = D_1^{\Lambda/d}$ and $H_1^{\Lambda/u} = H_1^{\Lambda/d}$,
- $D_1^{\Lambda/s} = c_1 \cdot D_1^{\Lambda/u}$, with constant c_1. (Analogously, if $H_1^{\Lambda/u} \neq 0$, $H_1^{\Lambda/s} = c_2 \cdot H_1^{\Lambda/u}$)

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

Three different hypotheses

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

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

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 ($\rightarrow$ SU(6)),
3. Quark-diquark model [J.-J. Yang, Nucl.Phys.,A699:562–578,2002]

Note: simplified expression even more interesting on a deuteron target!

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

Hypothesis #1: transversity a valence object

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

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

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

c_1	$< \mathcal{R} >$
2	-0.39 $\pm$ 0.73
3	-0.38 $\pm$ 0.75
4	-0.37 $\pm$ 0.76

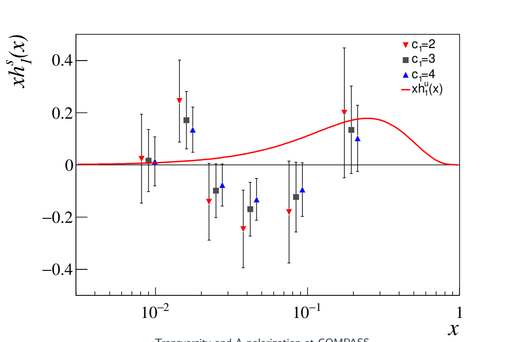
First extraction of $\mathcal{R}$, largely compatible with zero, weak dependence on c_1.

Hypothesis #2: polarization due to s quark only

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

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

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

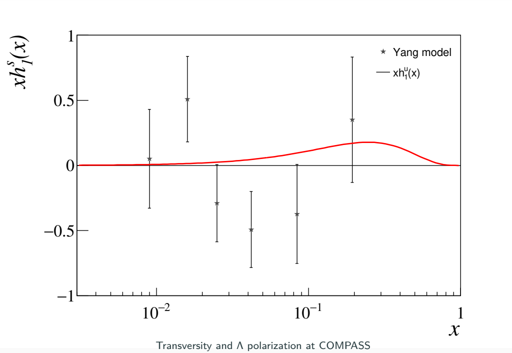


Hypothesis #3: Quark-diquark Yang model

P_Λ is written here in terms of given *flavour* (F) and *spin structure functions* ($\hat{W}$):

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

$\Rightarrow h_1^s(x)$ can be accessed.



Summary

Summary

- *Transversity-transmitted transverse* 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 hypotheses to interpret Λ polarization results:
    1. The first (transversity a valence object) gives the integrated ratio of the fragmentation functions $H_1^{\Lambda/u}$ and $D_1^{\Lambda/u}$, compatible with zero,
    2. The second (only s quark counts) allows for an extraction of $xh_1^s(x)$ dependent on the parameter $c_1 = D_1^{\Lambda/s}/D_1^{\Lambda/u}$,
    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, due to the statistical uncertainty, this is a fresh contribution to a longstanding issue,
- Ratios of fragmentation functions are extracted here for the first time,
- Much could be studied with more deuteron data.

thank you