Longitudinal polarization of $\Lambda/\bar{\Lambda}$ hyperons in lepton-nucleon deep inelastic scattering

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Preface

Paper: Longitudinal Polarization of Lambda and anti-Lambda Hyperons in Lepton-Nucleon Deep-Inelastic Scattering., John Ellis, Aram Kotzinian, Dmitry Naumov, Mikhail Sapozhnikov, hep-ph/0702222. Accepted to European Physics Journal C in 2007.

Basic conclusions of our work:

- We demonstrate that new COMPASS data can sharpen two free parameters of our model
- An accurate measurement of $\Lambda, \bar{\Lambda}$ lngitudinal polarization in COMPASS and HERA gives a new method to measure $s(x), \bar{s}(x)$ in the nucleon.
- The spin structure of $\Lambda, \bar{\Lambda}$ hyperons could be extracted from the same data (SU(6) и BJ models)
- Finally, we emphasize that the nucleon polarized strangeness is reflected in a longitudinal polarization of Λ hyperons which can be measured in COMPASS, HERA, JLAB

Outline

Outline

1. Introduction to nucleon strangeness
   - Why $\Lambda/\bar{\Lambda}$?

2. Our work
   - Theoretical kitchen
   - Results

3. Conclusions

What do we know about the strangenss in nucleon?

- s quarks carry about 4% of the nucleon spin at $Q^2 = 20$ ГэВ ©CCFR
- combination of electric and magnetic form-factors is small: $G_E + 0.39G_M = 0.025 \pm 0.020 \pm 0.014$ ©HAPPEX, $G_E + 0.225G_M = 0.039 \pm 0.034$ ©A4
- s quark contributes little to the magnetic moment of nucleon: $-0.1 \pm 5.1\%$ ©SAMPLE

On the other hand:

"Spin crysis" suggests that the quarks carry only $\sim 1/3$ of the nucleon spin with $\Delta s \approx -10\%$!

How else the strangeness can be measured?

- di-muon events in (anti) neutrino
  - doable but involves large uncertainties in m_c and hadronization. Not sensitive to $\Delta s \ldots$
- neutrino and anti-neutrino cross-sections asymmetry:

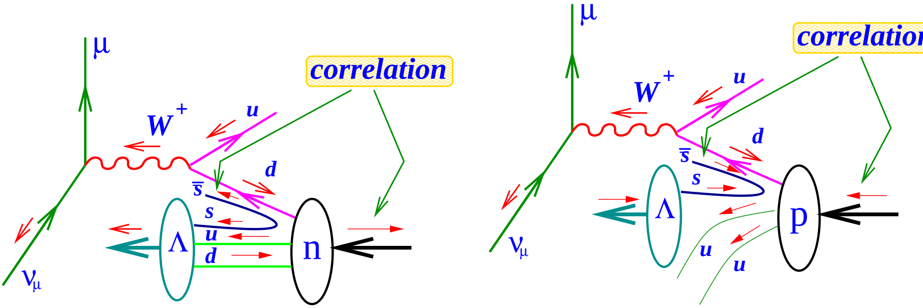
$$A = \frac{\nu_{NC} - \bar{\nu}_{NC}}{\nu_{CC} - \bar{\nu}_{CC}}$$

gives a road to strange form-factors and thus to Δs.
©W.A.Alberico, S.M.Bilenky, C.Maieron, hep-ph/0102269

  - an excelent idea but VERY difficult experimentally...

Λ и Δs

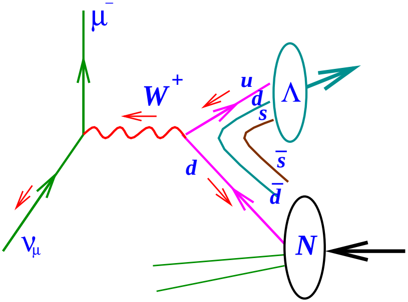
In SU(6) model the $\Lambda/\bar{\Lambda}$ spin is carried by $s/\bar{s}$, thus a possible Δs can be transfered to Λ hyperon and measured in $\Lambda \to p + K_s^0$



Idea

Measure P_Λ in lepton-nucleon DIS to feel Δs in the nucleon

Spin structure of Λ



Bukrhard, Jaffe noted that using SU(6) and the "spin crysis" for the proton one gets the same "spin crysis" for Λ:

$$\Delta u_\Lambda = \Delta d_\Lambda \approx -20\%$$

$\Lambda/\bar{\Lambda}$ vs $s(x)/\bar{s}(x)$

- Today $s(x)/\bar{s}(x)$ are badly known
- Various parametrizations differ by 100% (as GRV98 and CTEQ5L)
- If $\Lambda/\bar{\Lambda}$ are produced from fragmentation of $s(x)/\bar{s}(x)$ than one can expect the final hyperon polarization to be proportional to $s(x)$ for Λ and $\bar{s}(x)$ for $\bar{\Lambda}$

Outline

Ingredients

- Interaction of lepton with nucleon
- Hadron fragmentation
- What is the mother of a hadron?
- Polarization of hadrons

Interaction of lepton with nucleon

We use LEPTO 6.1 package to model interactions of lepton (charged or neutrino) with nucleon. The following bugs were corrected by us:

- In LEPTO 6.1 it was missing the lepton scattering off sea u, d quarks
  - the bug was corrected and the author of LEPTO 6.1 was informed
- To model a nucleus LEPTO 6.1 “reweights“ quark distributions of protons and neutrons accordning to their fractions. This is OK for unpolarized case but wrong for polarized physics.
  - We first generate samples with protons and neutrons targets, perform polarization analyses and then mix events proportionally to the cross-sections.

Hadron fragmentation

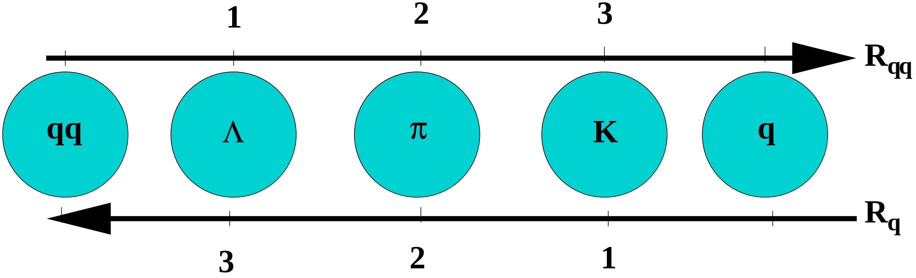
We use JETSET7.4 package to model hadron fragmentation of quarks, di-quarks. JETSET has many free parameters tunable from experiments:

- we used the parameters tuned by the NOMAD Collaboration, which describe yields of Λ и $\bar{\Lambda}$ hyperons, produced promtly or from decays of $(\Sigma^*, \Sigma^0, \Xi)$. ©Artem Chukanov

Hadron rank or what is the hadron mother

In order to assign a polarization to the hadron one has to order hadrons in the hadrons string: decide is the considered hadron close to fragmenting quark or close to the target nucleon remnant. To account this we introduce two ranks:

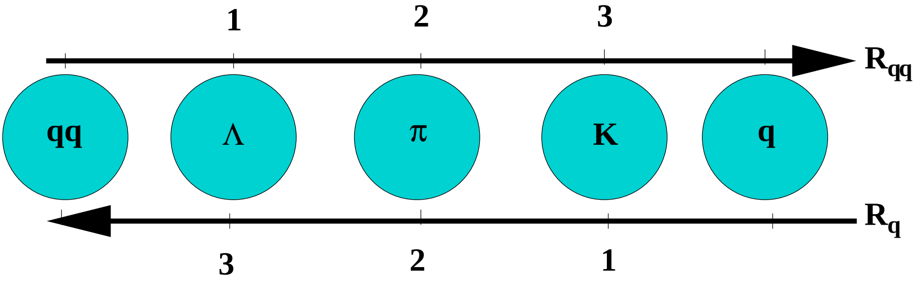
- R_q - hadron number from the quark end of the string
- R_{qq} - hadron number from the target nucleon remnant



Hadron rank or what is the hadron mother

We consider two extreme cases to get an estimate of theory uncertainty.

- **Model A**: Restrict spin transfer in (di)quark fragmentation to hyperons with $(R_{qq} = 1, R_q \neq 1)$ $R_{qq} \neq 1, R_q = 1$;
- **Model B**: Allow spin transfer in (di)quark fragmentation to hyperons with $(R_{qq} > R_q)$ $R_{qq} < R_q$.



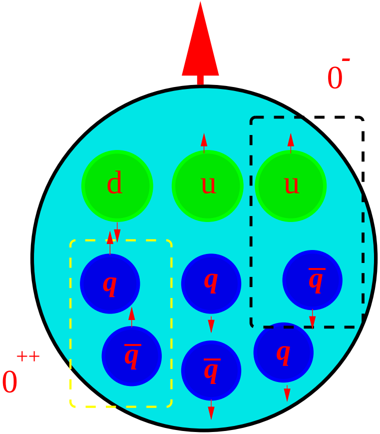
Polarization of hadrons. Quarks fragmentation

If a hadron is produced from the quark fragmentation (promtly or via heavier resonance), it could be polarized. The spin transfer is computed for SU(6) and “spin crysis“ BJ models:

Таблица: *Spin correlation coefficients in the SU(6) and BJ models.*

Λ's parent	C_u^Λ		C_d^Λ		C_s^Λ	
	SU(6)	BJ	SU(6)	BJ	SU(6)	BJ
quark	0	-0.18	0	-0.18	1	0.63
Σ^0	-2/9	-0.12	-2/9	-0.12	1/9	0.15
Ξ^0	-0.15	0.07	0	0.05	0.6	-0.37
Ξ^-	0	0.05	-0.15	0.07	0.6	-0.37
$\Sigma^\star$	5/9	–	5/9	–	5/9	–

Polarization of hadrons. Di-quarks fragmentation



Model of polarized strangeness

1. small mass of pseudo scaler mesons π, K, η means strong attraction with quantum numbers $J^P = 0^-$.
2. Vacuum density of strange pairs is quite large

$$\langle 0|\bar{u}u|0\rangle \approx \langle 0|\bar{d}d|0\rangle \approx (250\text{MэB})^3,$$
$$\langle 0|\bar{s}s|0\rangle \approx (0.8 \pm 0.1)\langle 0|\bar{u}u|0\rangle.$$

This model was suggested in works of Ellis, Sapozhnikov, Kotzinian and Kharzeev

Polarization of hadrons. Di-quarks fragmentation

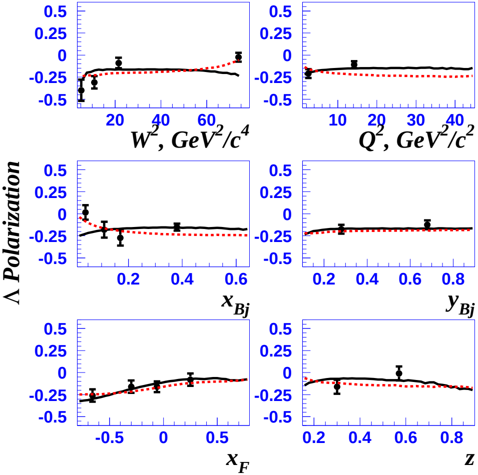
We do not know how strong is the correlation between spins of struch quark and sea strange (anti)quark. We introduce two free parameters $C_{sq_{sea}}, C_{sq_{val}}$. We fit these parameters from the NOMAD data:

$$\textbf{Model A:} C_{sq_{val}} = -0.35 \pm 0.05, C_{sq_{sea}} = -0.95 \pm 0.05.$$
$$\textbf{Model B:} C_{sq_{val}} = -0.25 \pm 0.05, \quad C_{sq_{sea}} = 0.15 \pm 0.05.$$

Spin transfer to Λ is computed as:

$$C_\Lambda^{l\,u}(prompt; N) = C_\Lambda^{l\,d}(prompt; N) = C_{sq},$$
$$C_\Lambda^{l\,u}(\Sigma^0; p) = C_\Lambda^{l\,d}(\Sigma^0; n) = \frac{1}{3} \cdot \frac{2 + C_{sq}}{3 + 2C_{sq}},$$
$$C_\Lambda^{l\,u}(\Sigma^{\star 0}; p) = C_\Lambda^{l\,d}(\Sigma^{\star 0}; n) = C_\Lambda^{l\,d}(\Sigma^{\star +}; p) =$$
$$C_\Lambda^{l\,u}(\Sigma^{\star -}; n) = -\frac{5}{3} \cdot \frac{1 - C_{sq}}{3 - C_{sq}}.$$

Description of the NOMAD data



John Ellis, Aram Kotzinian, Dmitry V. Naumov published a paper in 2002 with predictions for Λ hyperons polarization for various experiments **Eur.Phys.J.C25:603-613,2002.**

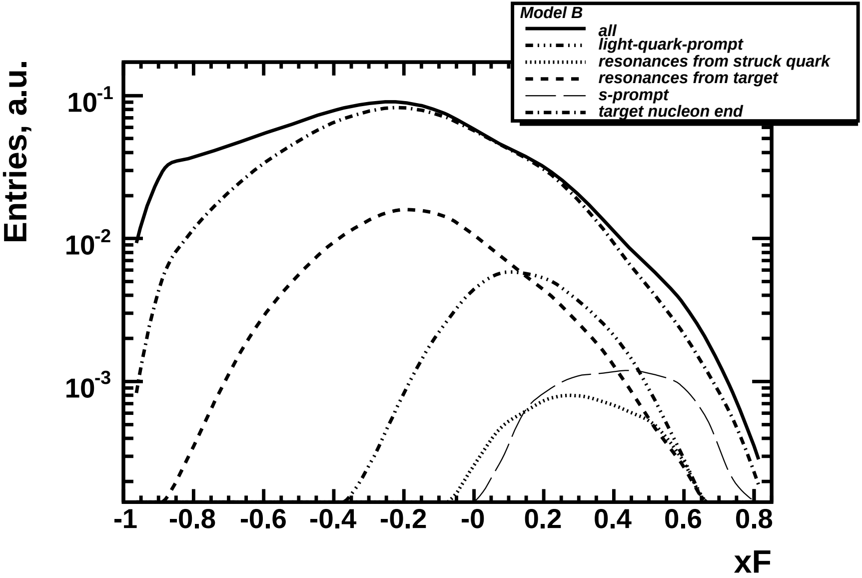
What is our aim in this work 5 years later?

1. Predictions for $\bar{\Lambda}$ for COMPASS, HERA
2. Predictions for Λ for JLAB, COMPASS, HERA
    1. The NOMAD data are restricted to $x > 0.05$. We need smaller x to better fix $C_{sq_{sea}}, C_{sq_{val}}$. For this purpose the COMPASS data is essential.
3. Study a dependence of spin transfer to $s(x)/\bar{s}(x)$ для COMPASS, HERA

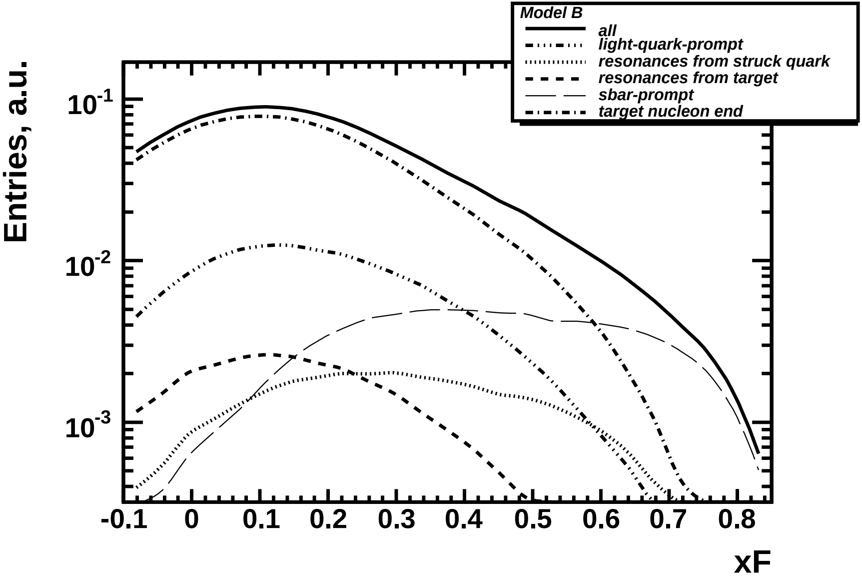
Distributions of x_F for $\Lambda/\bar{\Lambda}$

- Let us examine distributions of x_F for $\Lambda/\bar{\Lambda}$ in different kinematic domains.
- What is the fraction of $\Lambda/\bar{\Lambda}$ produced from fragmentation of quark, di-quark, or resonance?

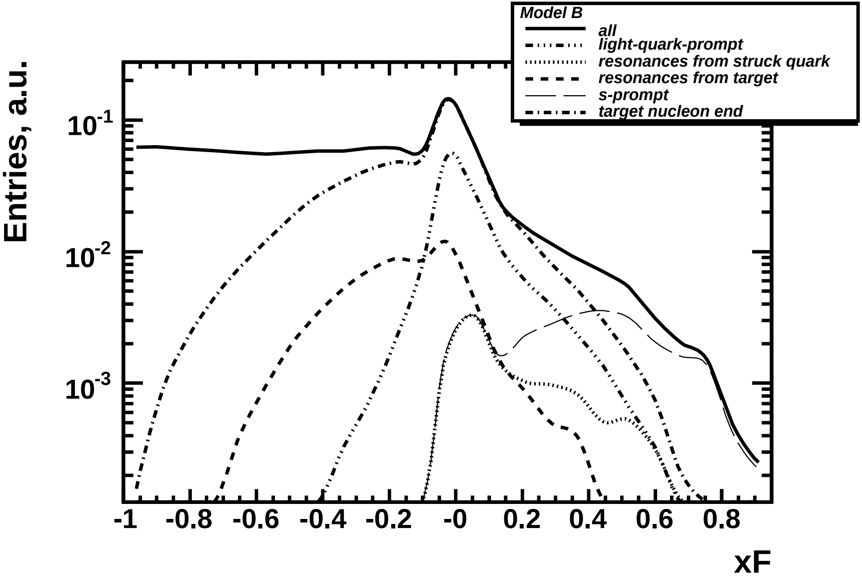
Distributions of x_F для Λ in COMPASS



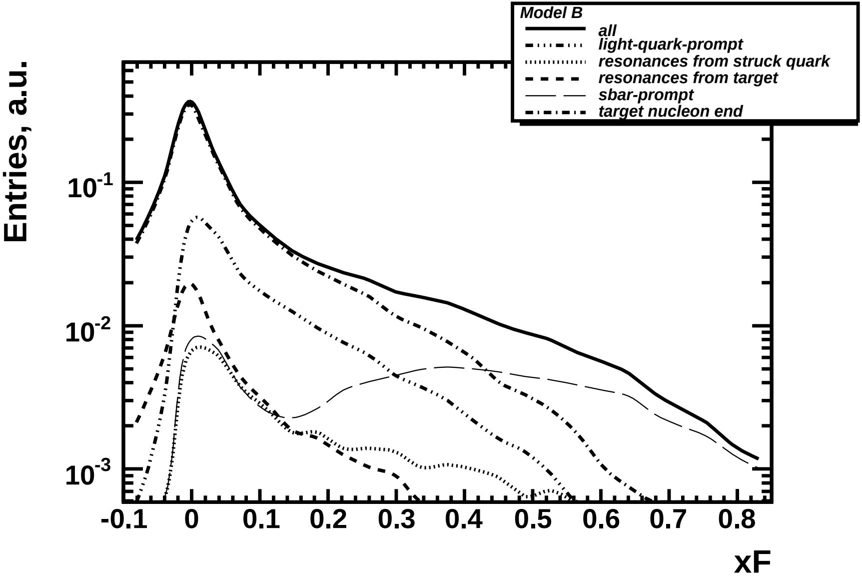
Distributions of x_F для $\bar{\Lambda}$ in COMPASS



Distributions of x_F для Λ in HERA



Distributions of x_F для $\bar{\Lambda}$ in HERA



Resume

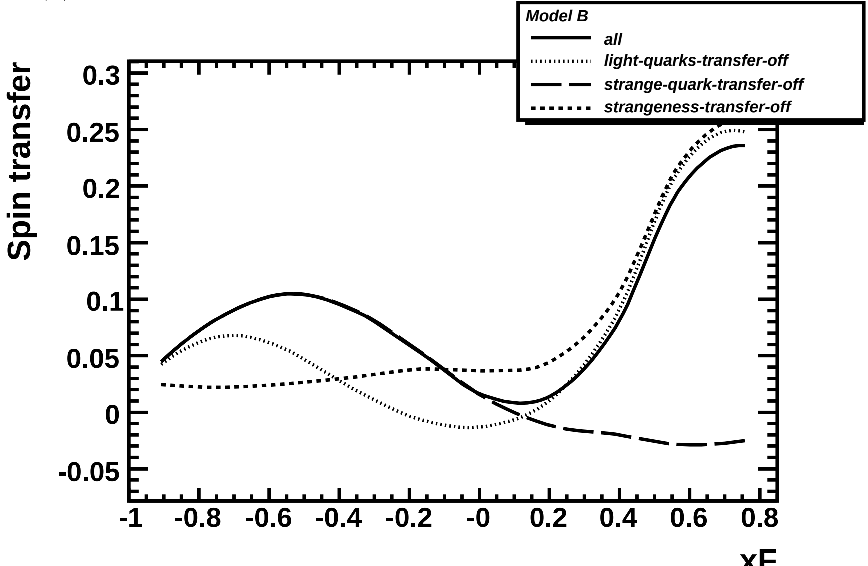
- For the COMPASS energy the dominant mechanism of Λ production is the di-quark fragmentation. $\bar{\Lambda}$ are produced mainly from $\bar{s}$ fragmentation.
- For the HERA energy quark and diquark mechanisms are well separated, however a new mechanism becomes effective - quark-antiquatk string fragmentation, like in $e^+ - e^-$ collisions. Thus it is not instructive to require really very large energies for such studies

Spin transfer to $\Lambda/\bar{\Lambda}$

- How it depends on kinematics?
- How large it is?
- What are the main sources?

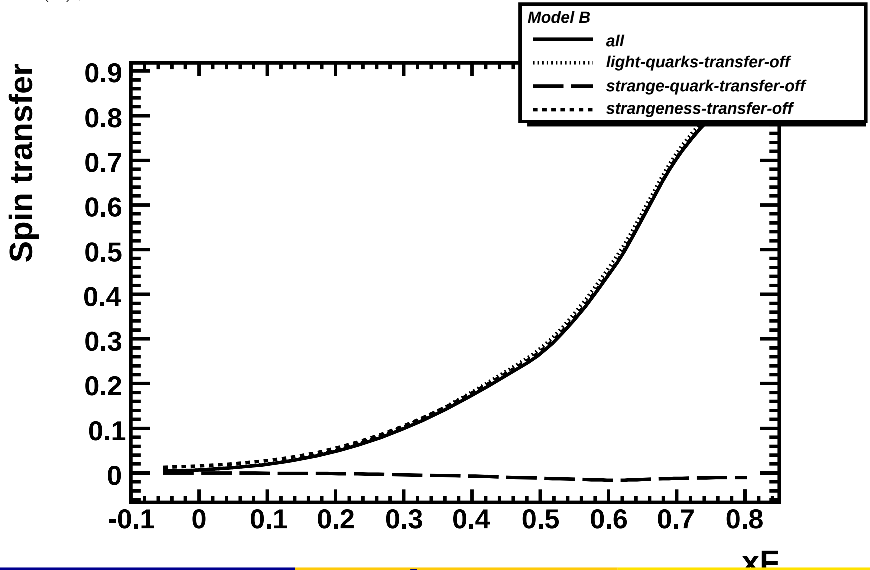
Spin transfer to Λ in COMPASS

SU(6), Model B



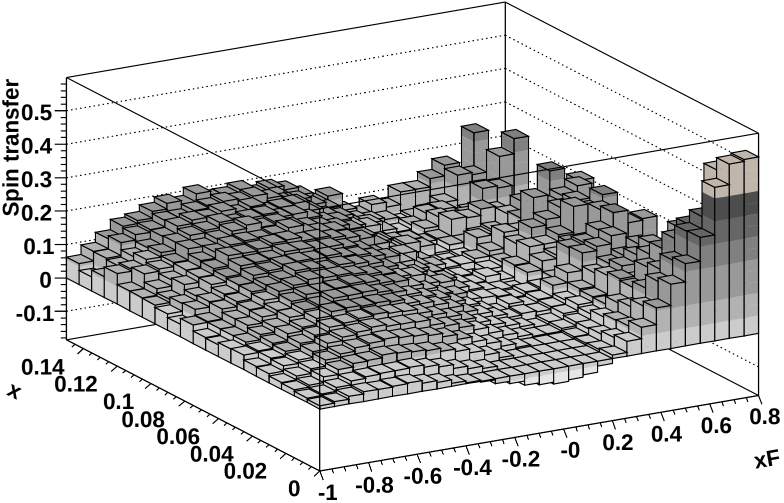
Spin transfer to $\bar{\Lambda}$ in COMPASS

SU(6), Model B



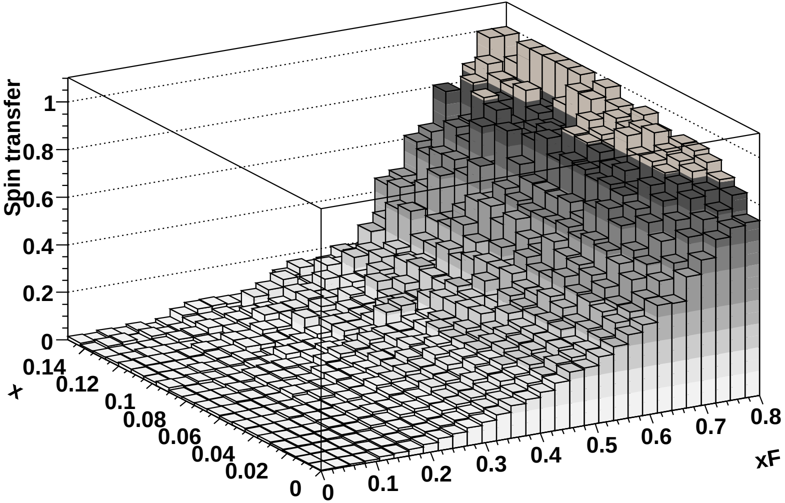
Spin transfer to Λ in COMPASS

SU(6), Model B



Spin transfer to $\bar{\Lambda}$ in COMPASS

SU(6), Model B



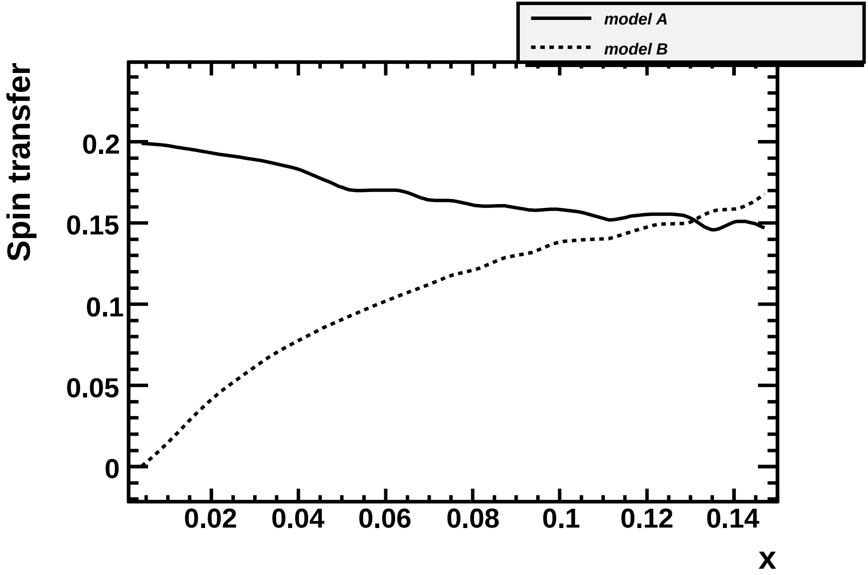
Resume

- Apparent domains in x_F, x - sources of $\Lambda/\bar{\Lambda}$ polarization - due to di-quark (only for Λ) and quark fragmentations.
- Polarization of $\bar{\Lambda}$ is essentially defined by $\bar{s}$ fragmentation. Thus it could be an instrument to study $\bar{s}(x)$

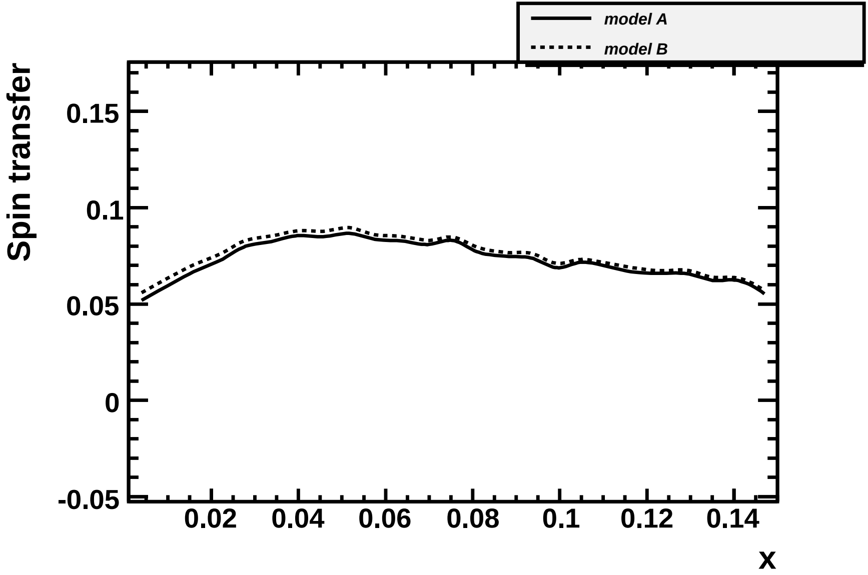
Models A and B for $\Lambda/\bar{\Lambda}$

- How sensitive are our predictions on model of tagging of particles?
- Is it possible to reduce theor. uncertainy?

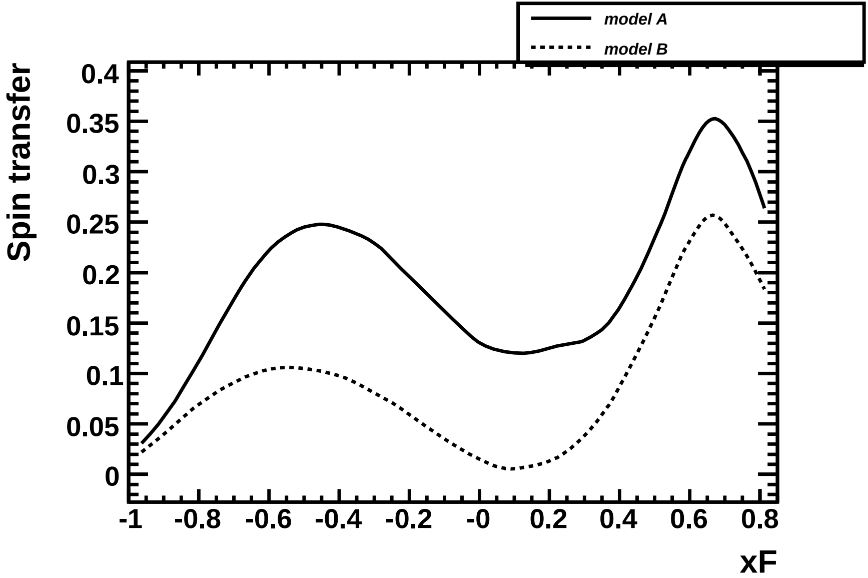
Models A and B for Λ in COMPASS



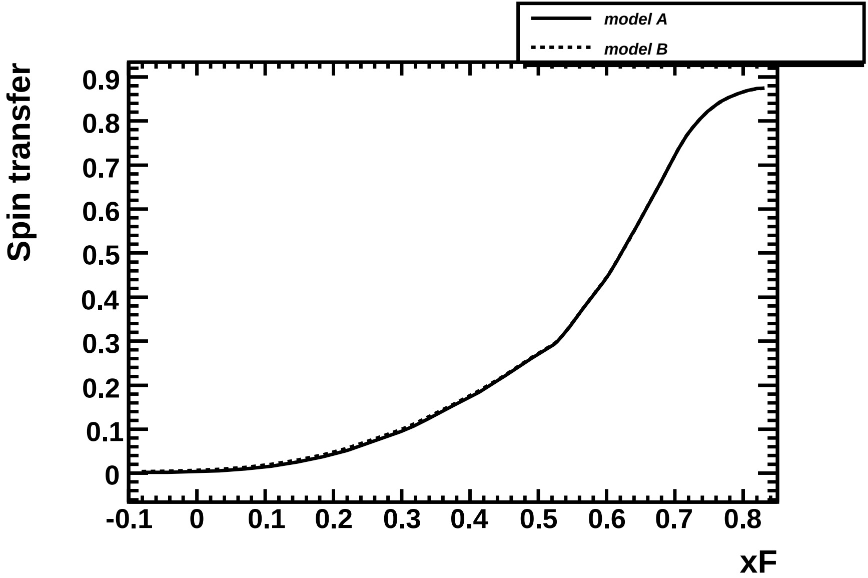
Models A and B for $\bar{\Lambda}$ in COMPASS



Models A and B for Λ in COMPASS



Models A and B for $\bar{\Lambda}$ in COMPASS



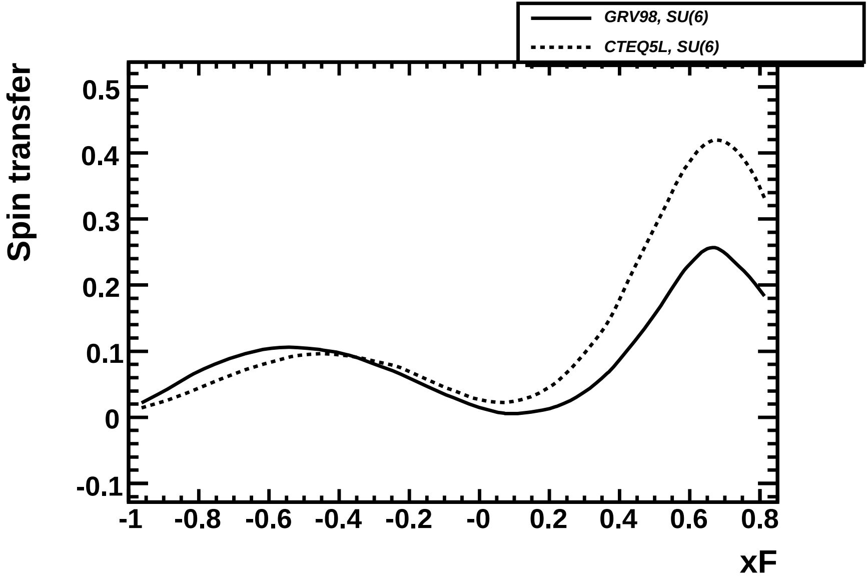
Resume

- Predictions for Λ strongly depend on models A and B. This dependence is due to much smaller x accessile in COMPASS an not accessible in NOMAD used to tune the parameres. We need the COMPASS data to fix the parameters and reduce systematics.
- Predictions for $\bar{\Lambda}$ are practically insensitive to A and B tagging. This is very valuable to have a model independet probe of $\bar{s}(x)$!

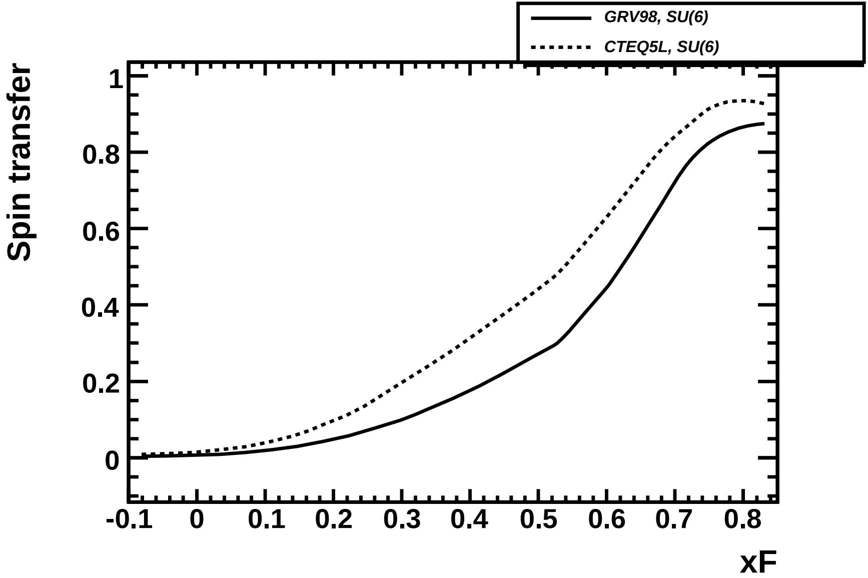
Comparison of GRV98 and CTEQ5L for $\Lambda/\bar{\Lambda}$

- How sensitive our predictions on parametrizations of strange sea in the nuclen?

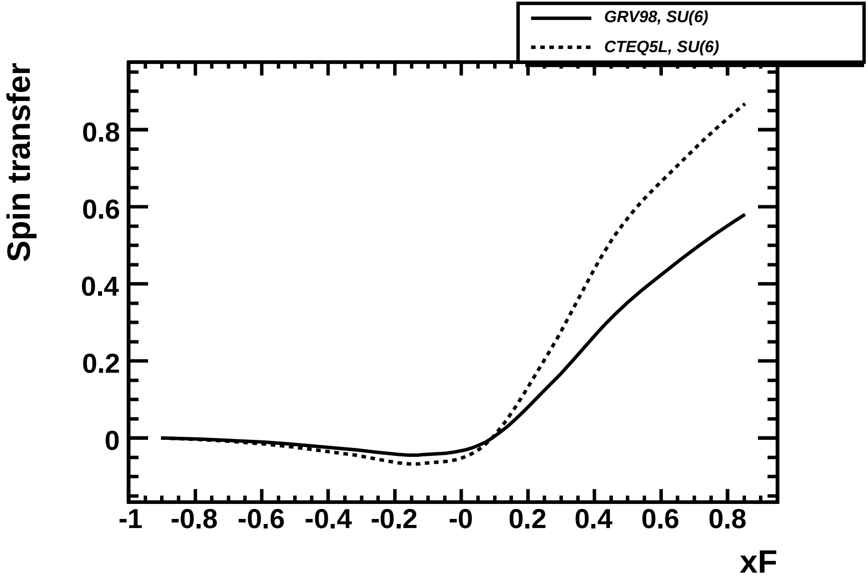
Comparison of GRV98 and CTEQ5L for Λ in COMPASS



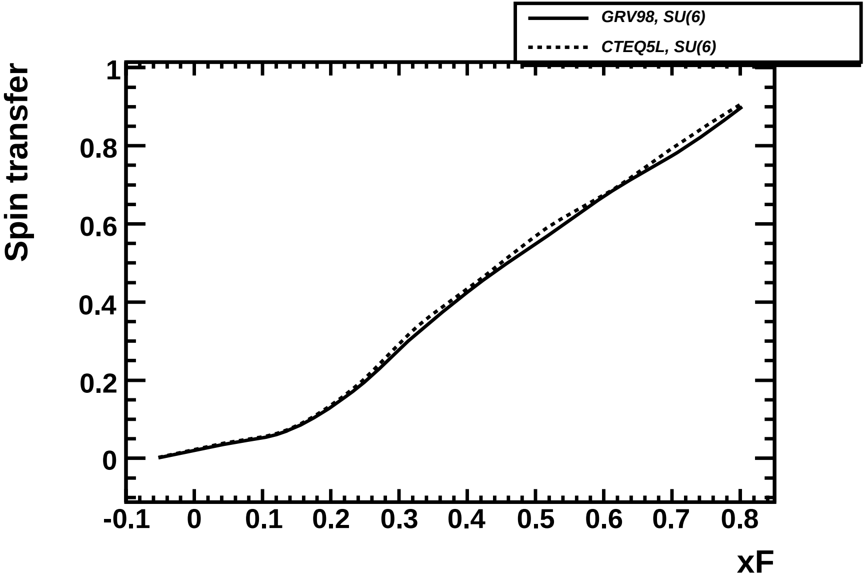
Comparison of GRV98 and CTEQ5L for $\bar{\Lambda}$ in COMPASS



Comparison of GRV98 and CTEQ5L for Λ in HERA



Comparison of GRV98 and CTEQ5L for $\bar{\Lambda}$ in HERA



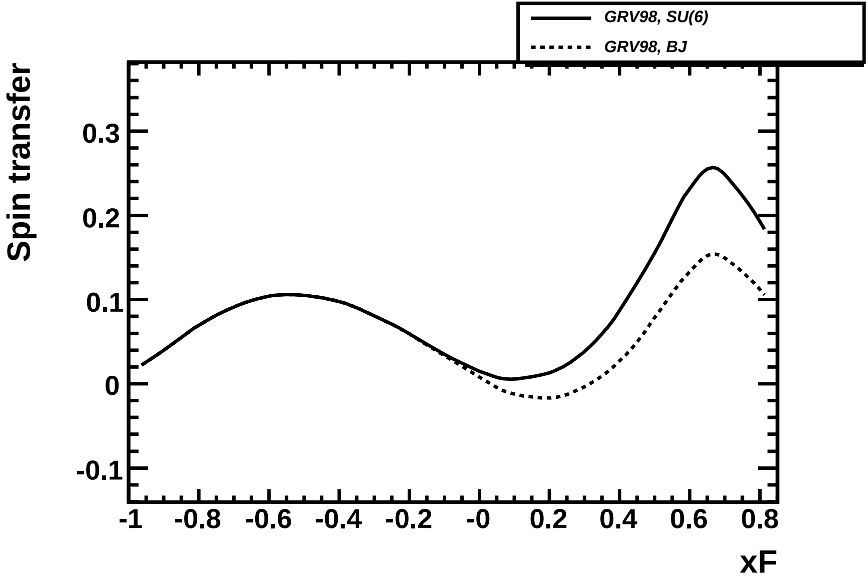
Resume

- An accurate measurement of spin transfer to $\Lambda/\bar{\Lambda}$ can be probe$s(x)$ и $\bar{s}(x)$.
- For COMPASS this effect is present for both $\Lambda/\bar{\Lambda}$, while HERA would be sensitive only with Λ
- There is no sense to require large energy because new mechanisms (like in e^+e^-) becomes more and more effective thus loosing sensitivity to $s(x)$ and $\bar{s}(x)$.

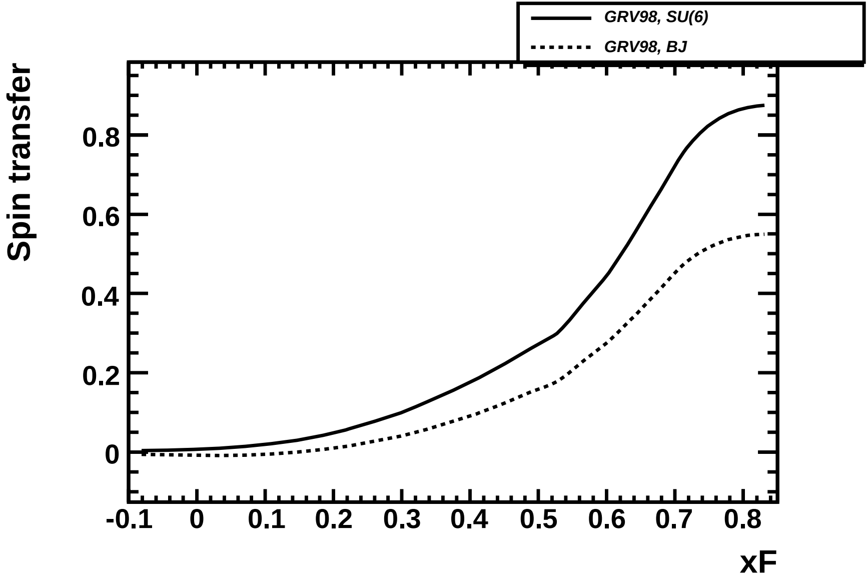
Comparison of SU(6) and BJ for $\Lambda/\bar{\Lambda}$

- Can we learn from an experiment about the “spin crysis“ for$\Lambda/\bar{\Lambda}$?

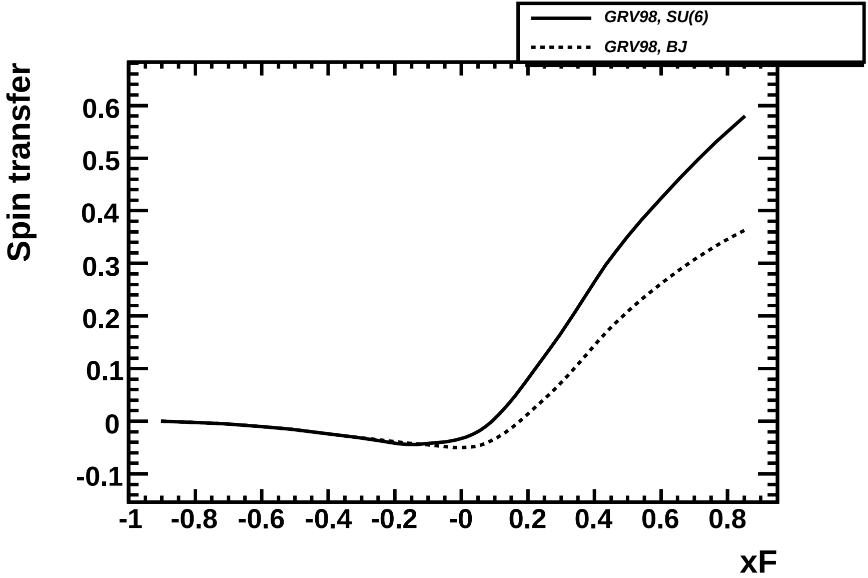
Comparison of SU(6) and BJ for Λ in COMPASS



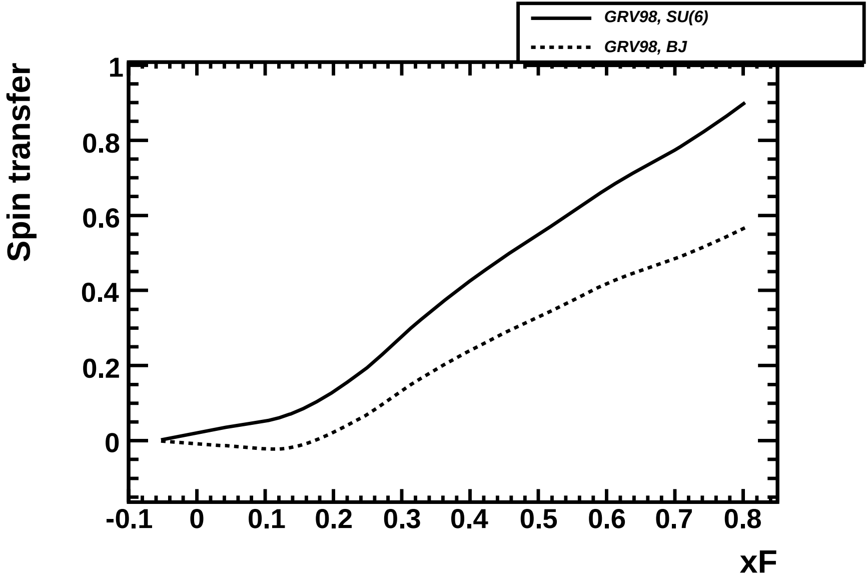
Comparison of SU(6) and BJ for $\bar{\Lambda}$ in COMPASS



Comparison of SU(6) and BJ for Λ in HERA



Comparison of SU(6) and BJ for $\bar{\Lambda}$ in HERA



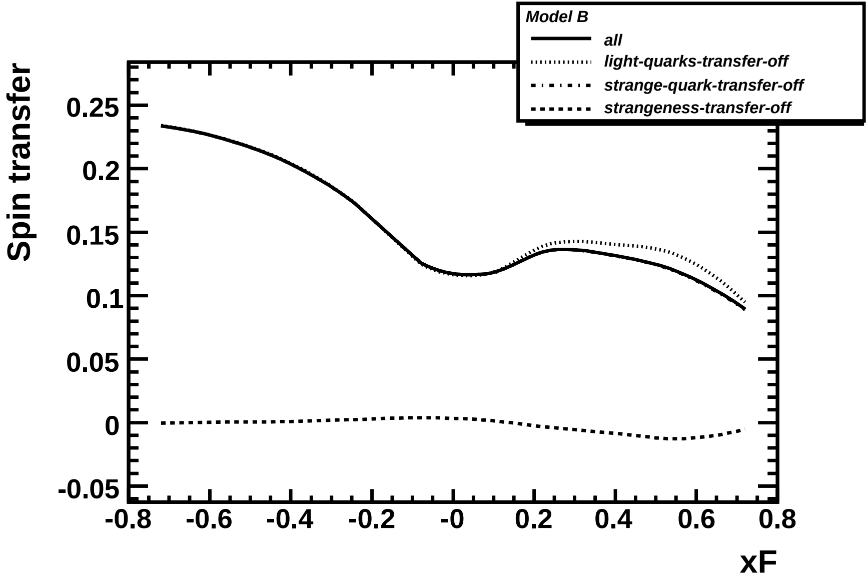
Краткие выводы

- An accurate measurement of spin transfer to $\Lambda/\bar{\Lambda}$ gives a possibility to study the spin structure of $\Lambda/\bar{\Lambda}$

Sensitivity to polarized strangeness of Λ

- What will change if we switch off the spin stanfer from nucleon strangeness, i.e. $C_{sq} = 0$?

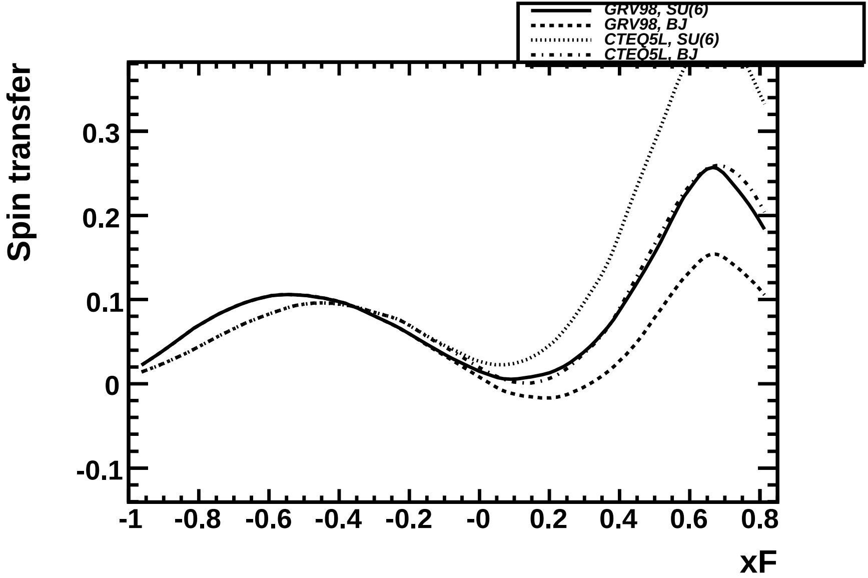
Sensitivity to polarized strangeness of Λ in JLAB



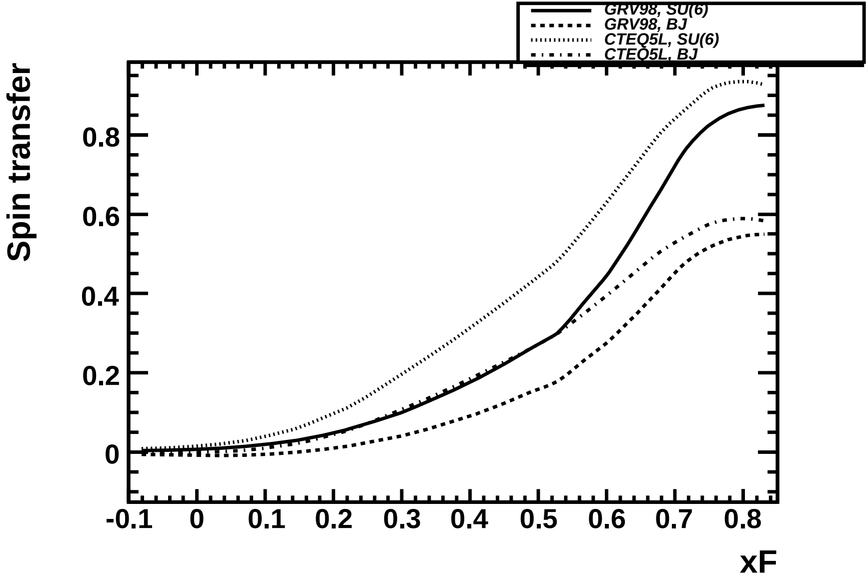
Resume

- Spin transfer to Λ in JLAB is defined by polarized strangeness. Thus JLAB could be essential to define C_{sq}.

Spin transfer to Λ in COMPASS for various $s(x)$, BJ, SU6



Spin transfer to $\bar{\Lambda}$ в COMPASS for various $\bar{s}(x)$, BJ, SU6



Outline

Conclusions

- New data of COMPASS can sharpen domain of two free parameters of our model
- An accurate measurement of polarization of $\Lambda, \bar{\Lambda}$ in COMPASS and HERA gives a new method to measure $s(x), \bar{s}(x)$ in nucleon
- Spin structure of $\Lambda, \bar{\Lambda}$ can be extracted from the same data
- Polarized nucleon strangeness can be extracted from measured Λ polarization in COMPASS, HERA, JLAB