Longitudinal target polarization dependence of $\bar{\Lambda}$ polarization and polarized strangeness PDF

Aram Kotzinian

CEA-Saclay, IRFU/Service de Physique Nucléaire, 91191 Gif-sur-Yvette, France

On leave in absence from YerPhI, Armenia and JINR, Russia

International Workshop on

Strangeness polarization in semi-inclusive and exclusive Lambda production

ETC*, Trento, 27—31 October 2008

- Λ ($\bar{\Lambda}$) polarization
  - Unpolarized target
    - Strangeness distribution
  - Polarized target
    - Polarized strangeness
- Conclusions

Simple model: LO, independent fragmentation for current fragmentation region

$$P_T = 0 \quad \Rightarrow \quad P^{\bar{\Lambda}} = P^{\bar{\Lambda}}_{P_B,0} = D(y) P_B \frac{\sum_q e_q^2 q(x) \Delta D_q^{\bar{\Lambda}}(z)}{\sum_q e_q^2 q(x) D_q^{\bar{\Lambda}}(z)}$$

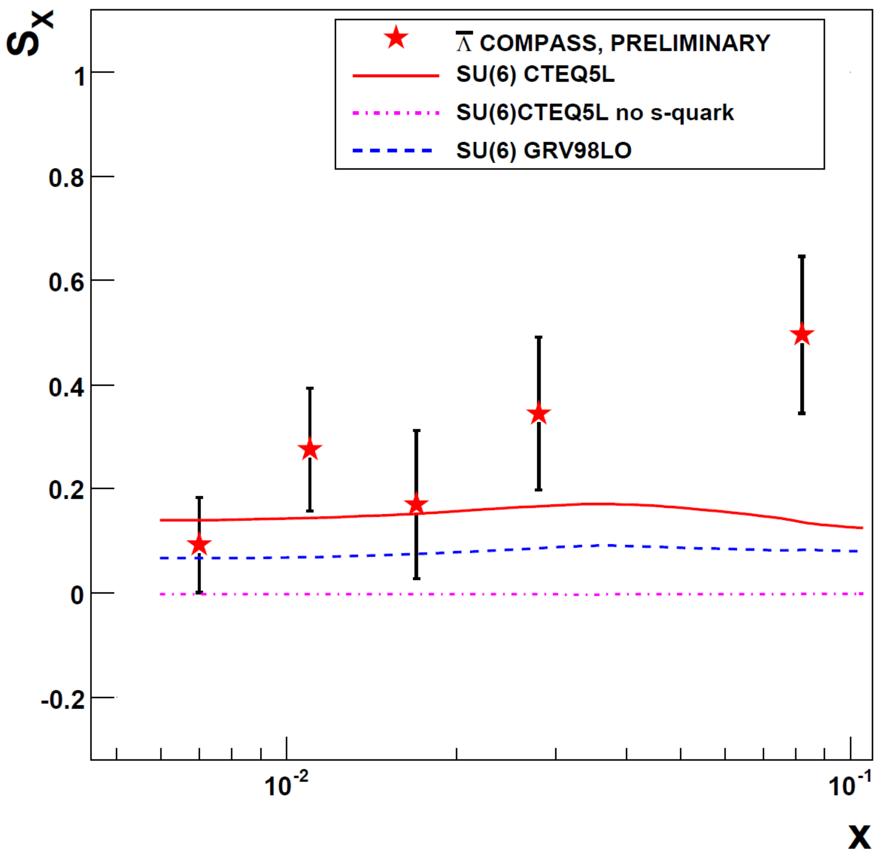
$SU(6)$ Model: only $\Delta D_{\bar{s}}^{\bar{\Lambda}}(z) \neq 0$

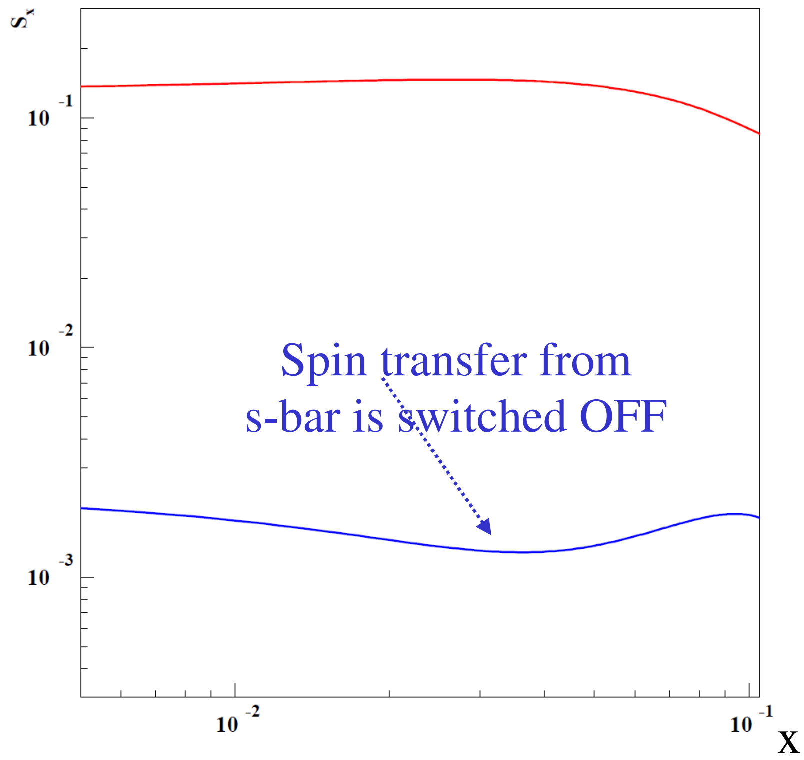
$$\Delta D_{\bar{s}}^{\bar{\Lambda}}(z) = D_{\bar{s}}^{\bar{\Lambda}}(z)$$

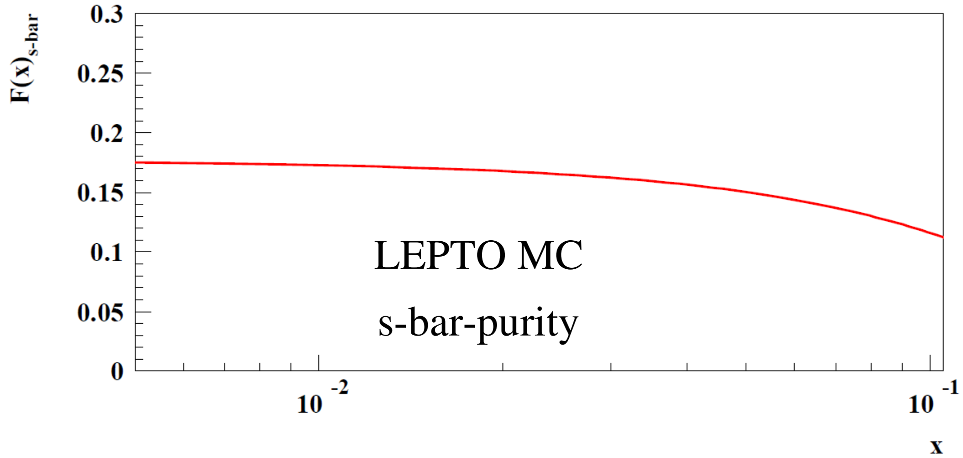
$$S_x^{\bar{\Lambda}} = \frac{P^{\bar{\Lambda}}}{D(y) P_B} \approx \frac{\frac{1}{9} \bar{s}(x) D_{\bar{s}}^{\bar{\Lambda}}(z)}{\sum_q e_q^2 q(x) D_q^{\bar{\Lambda}}(z)} := F_{\bar{s}}(x,z)$$

Fraction of events with hard scattering off s-bar

Unpolarized target





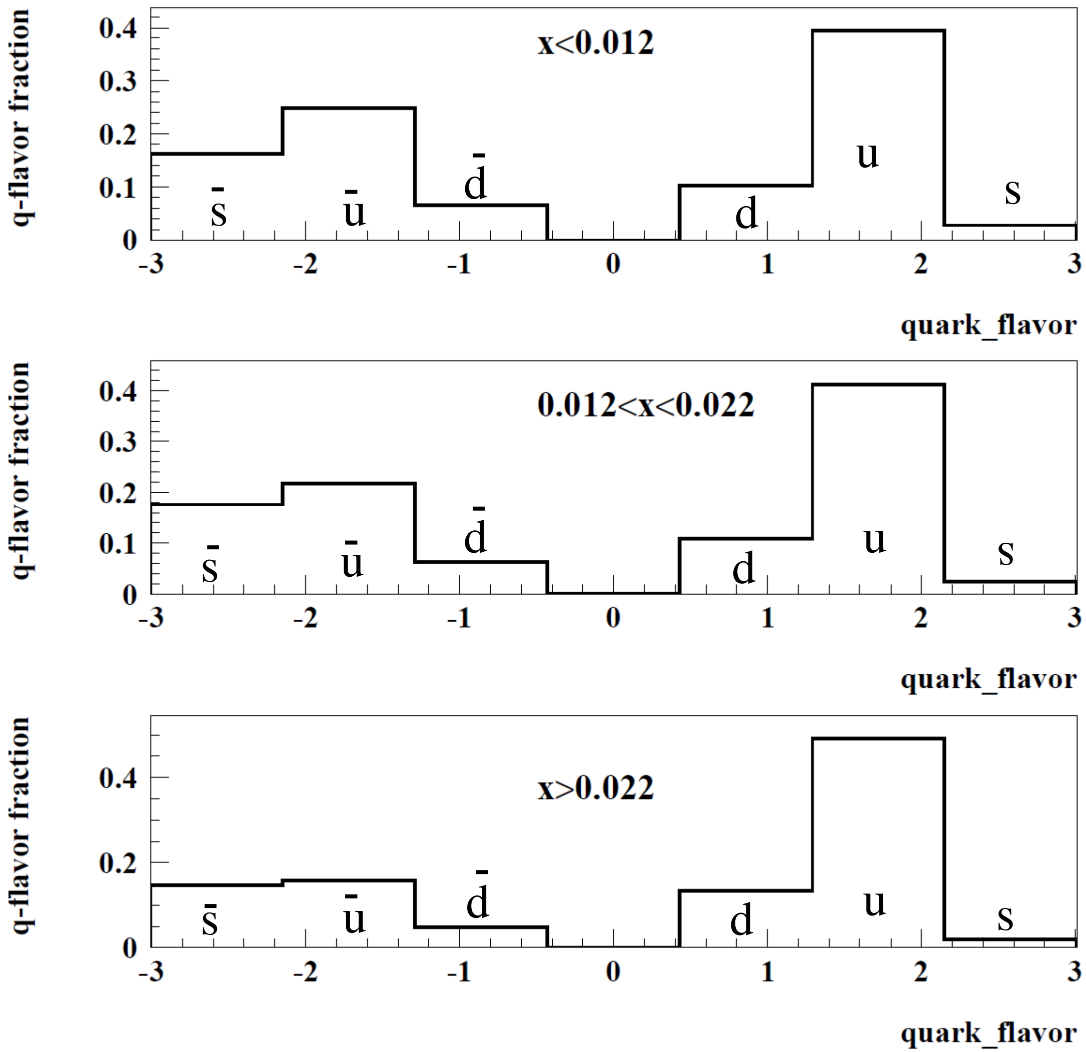


Best description with SU(6)

model for spin transfer.

$\bar{\Lambda}$ polarization = s(x) filter

Quark type fraction in anti-Lambda production



LEPTO MC

with CTEQ5L

and COMPASS cuts

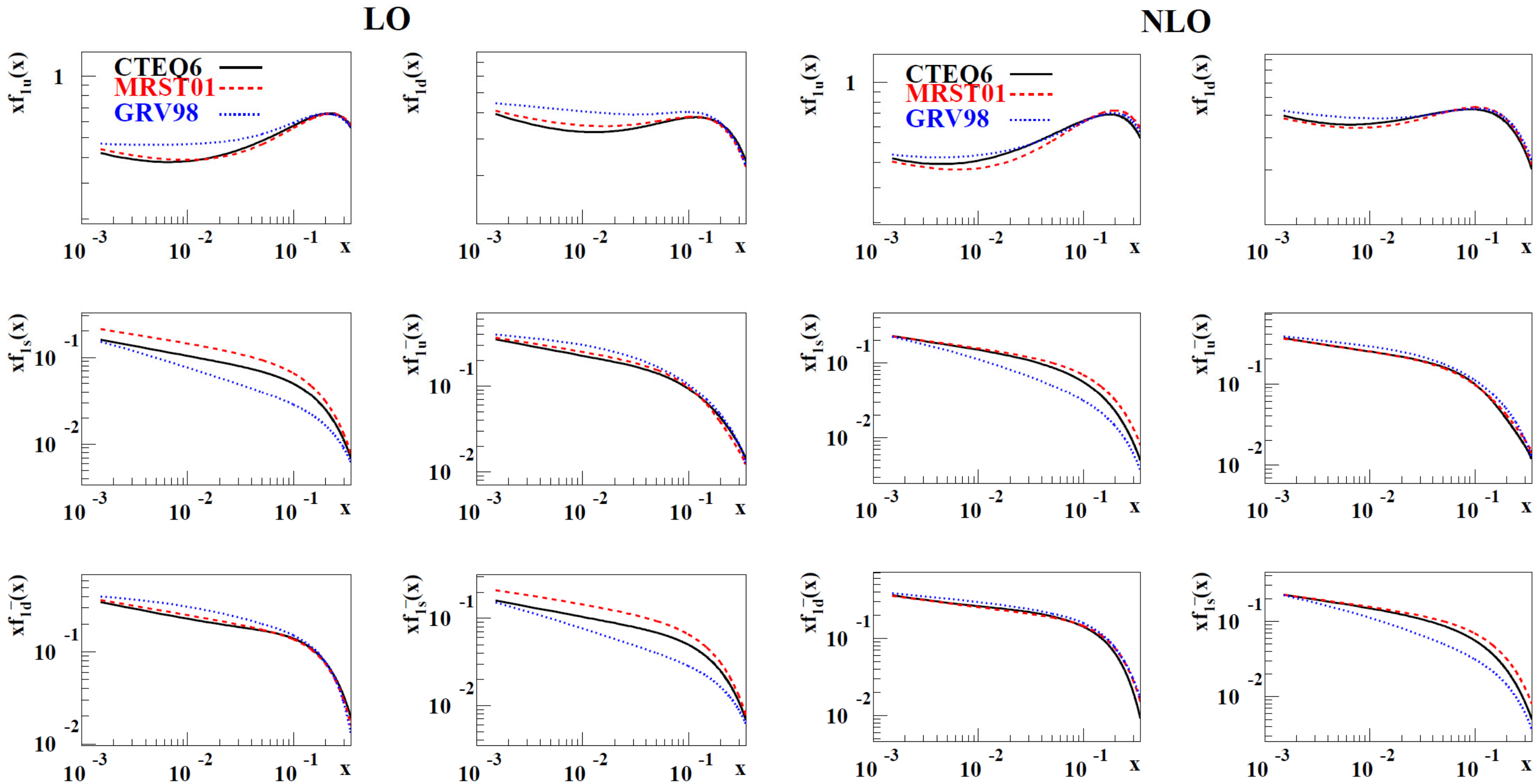
In contrast to K production asymmetry, here mainly s-quark contributes to

$P^{\bar{\Lambda}}$ and $\Delta P^{\bar{\Lambda}}$

$F_{\bar{s}}(x) \approx 0.11 \div 0.2$

for $x \leq 0.1$

PDFs



$$Q^2 = 2.5\ (\mathrm{GeV/c})^2$$

Hyperon production x-section and polarization for polarized beam and target

From general considerations for double and triple longitudinal polarization observables:

$$\sigma^{\bar{\Lambda}}_{P_B,\pm P_T} = \sigma^{\bar{\Lambda}}\left(1 \mp P_B P_T \frac{\Delta\sigma^{\bar{\Lambda}}}{\sigma^{\bar{\Lambda}}}\right)$$

$$P^{\bar{\Lambda}}_{P_B,\pm P_T} = \frac{P_B S_B \pm P_T S_T}{1 \mp P_B P_T \dfrac{\Delta\sigma^{\bar{\Lambda}}}{\sigma^{\bar{\Lambda}}}}$$

Target polarization sign is written explicitly

Beam polarization contains sign

Polarization Asymmetry $A_{P^{\bar{\Lambda}}}(x)$

$$P^{\bar{\Lambda}} := \frac{1}{2}\left(P^{\bar{\Lambda}}_{P_B,-P_T} + P^{\bar{\Lambda}}_{P_B,P_T}\right)$$

$$\Delta P^{\bar{\Lambda}} := P^{\bar{\Lambda}}_{P_B,-P_T} - P^{\bar{\Lambda}}_{P_B,P_T}$$

Note that $P^{\bar{\Lambda}} = P^{\bar{\Lambda}}_{P_B,0}$ if muon flux before and after target polarization reversal remains unchanged

$$A_{P^{\bar{\Lambda}}}(x) := \frac{\Delta P^{\bar{\Lambda}}(x)}{P^{\bar{\Lambda}}(x)}$$

Factorized parton model

$$P^{\bar\Lambda}_{P_B,P_T} = \frac{\sum_q e_q^2 \left[D(y)P_B - fP_T \frac{\Delta q(x)}{q(x)} \right] q(x)\Delta D_q^{\bar\Lambda}(z)}{\sum_q e_q^2 \left[1 - D(y)P_B fP_T \frac{\Delta q(x)}{q(x)} \right] q(x) D_q^{\bar\Lambda}(z)}$$

Triple-spin effect similar to one induced by g_{1T}.

$$P_T^{eff} = fP_T \approx \begin{cases} 0.2 \; for \; \text{Deuteron} \\ 0.14 \; for \; \text{Proton} \end{cases}$$

$$\langle D(y) \rangle \approx 0.5 - 0.85, \quad \left| \frac{\Delta q(x)}{q(x)} \right| \le 0.5$$

$$\left| D(y)P_B fP_T \frac{\Delta q(x)}{q(x)} \right| \le 0.85 \cdot 0.8 \cdot 0.2 \cdot 0.5 = 0.068$$

We can neglect pol.dep. part in denom.

Formulas are more complicated when intrinsic strangeness is taken into account, but results are almost unchanged

$A_{P^{\bar\Lambda}}(x)$ in simplified SU(6) model

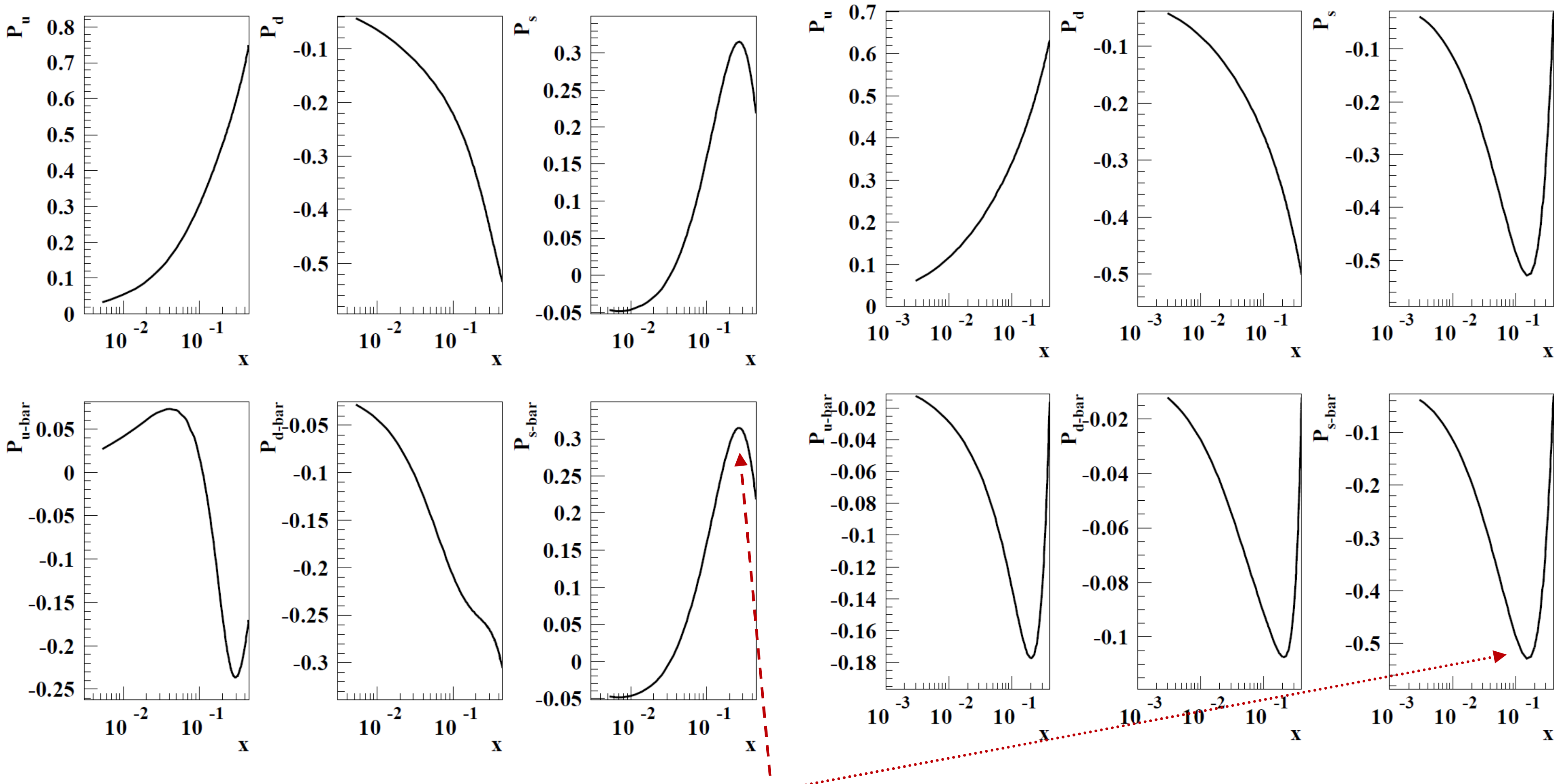
$$P^{\bar\Lambda} \approx \langle D(y)\rangle P_B \frac{\frac{1}{9}\bar{s}(x)D_{\bar{s}}^{\bar\Lambda}(z)}{\sum_q e_q^2 q(x) D_q^{\bar\Lambda}(z)}, \quad \Delta P^{\bar\Lambda} \approx 2fP_T \frac{\Delta\bar{s}(x)}{\bar{s}(x)} \frac{\frac{1}{9}\bar{s}(x)D_{\bar{s}}^{\bar\Lambda}(z)}{\sum_q e_q^2 q(x) D_q^{\bar\Lambda}(z)}$$

$$\frac{\Delta\bar{s}(x)}{\bar{s}(x)} \approx \frac{\langle D(y)\rangle P_B}{2fP_T} \frac{\Delta P^{\bar\Lambda}(x)}{P^{\bar\Lambda}(x)}$$

$$\frac{\langle D(y)\rangle P_B}{2fP_T} \approx 1, \text{ for COMPASS Deuteron target}$$

$$\frac{\Delta\bar{s}(x)}{\bar{s}(x)} \approx \frac{\Delta P^{\bar\Lambda}(x)}{P^{\bar\Lambda}(x)} = A_{P^{\bar\Lambda}}(x)$$

Status of quarks polarization



DSSV+MRST02

2008

$$|P_{\bar{s}}| \leq 0.5$$

GRSV+GRV

2000

HERMES isoscalar method 1

DIS and K^+ & K^- production in Deuterium target

$$Q(x) = u(x) + \overline{u}(x) + d(x) + \overline{d}(x)$$

$$S(x) = s(x) + \overline{s}(x)$$

$$\Delta Q(x) = \Delta u(x) + \Delta\overline{u}(x) + \Delta d(x) + \Delta\overline{d}(x)$$

$$\Delta S(x) = \Delta s(x) + \Delta\overline{s}(x)$$

$$A_1(x,Q^2) = \frac{5\Delta Q(x,Q^2) + 2\Delta S(x,Q^2)}{5Q(x,Q^2) + 2S(x,Q^2)}$$

$$A_1^K(x,Q^2) = \frac{\Delta Q(x)[4\int D_u^K(z)dz + \int D_d^K(z)dz] + 2\Delta S(x)\int D_s^K(z)dz}{Q(x)[4\int D_u^K(z)dz + \int D_d^K(z)dz] + 2S(x)\int D_s^K(z)dz}$$

$$= \frac{\Delta Q(x)\int D_{\text{non-étrange}}^K(z)dz + \Delta S(x)\int D_{\text{étrange}}^K(z)dz}{Q(x)\boxed{\int D_{\text{non-étrange}}^K(z)dz} + S(x)\boxed{\int D_{\text{étrange}}^K(z)dz}}$$

HERMES isoscalar method 2

$$\begin{pmatrix} A_D(x) \\ \\ A_D^K(x) \end{pmatrix} = C_R(x,Q^2) \begin{pmatrix} P_Q(x) & P_S(x) \\ \\ P_Q^K(x) & P_S^K(x) \end{pmatrix} \begin{pmatrix} \frac{\Delta Q(x)}{Q(x)} \\ \\ \frac{\Delta S(x)}{S(x)} \end{pmatrix}$$

$$P_Q(x) = \frac{5Q(x)}{5Q(x)+2S(x)}$$

$$P_S(x) = \frac{2S(x)}{5Q(x)+2S(x)}$$

$$P_Q^K(x) = \frac{Q(x)\int \mathcal{D}^K_{\text{non-étrange}}(z)dz}{Q(x)\int \mathcal{D}^K_{\text{non-étrange}}(z)dz + S(x)\int \mathcal{D}^K_{\text{étrange}}(z)dz}$$

$$P_S^K(x) = \frac{S(x)\int \mathcal{D}^K_{\text{étrange}}(z)dz}{Q(x)\int \mathcal{D}^K_{\text{non-étrange}}dz + S(x)\int \mathcal{D}^K_{\text{étrange}}dz}$$

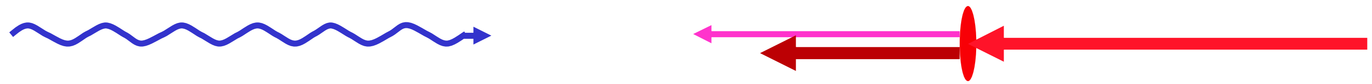
Two unknown integrals -- from unpolarized data

Fracture function approach in MC even genarators

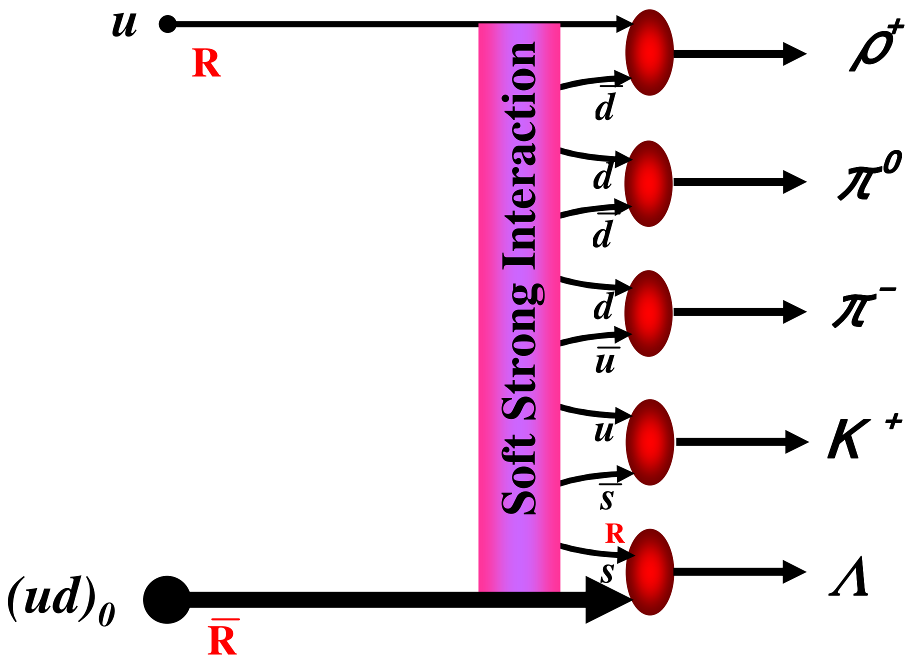
PDF and hard scattering are factorized from hadronization:

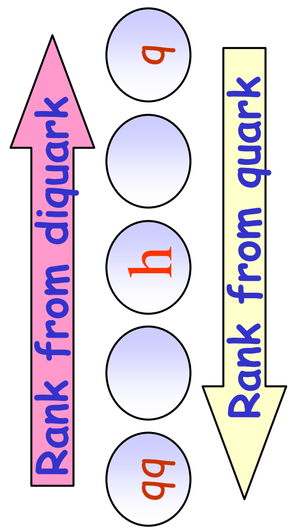
$$d\sigma^{lN\to lhX} = \sum_q f_q(x,\mathbf{k}_\mathbf{T},\mathbf{s}_q;\mathbf{S}_N)\otimes d\sigma^{lq\to lq}\otimes H^q_{h/N}(x,\mathbf{k}_\mathbf{T},\mathbf{s}_q;x_F,\mathbf{p}_\mathbf{T}^h;\mathbf{S}_N)$$

- Before



- After hard scattering





Target remnant in Polarized SIDIS

JETSET is based on SU(6) quark-diquark model

$$p^+ = \frac{1}{\sqrt{18}}\{u^+[3(ud)_{0,0} + (ud)_{1,0}] - \sqrt{2}u^-(ud)_{1,1} - \sqrt{2}d^+(uu)_{1,0} + 2d^-(uu)_{1,1}\}$$

$$n^+ = \frac{1}{\sqrt{18}}\{d^+[3(ud)_{0,0} + (ud)_{1,0}] - \sqrt{2}d^-(ud)_{1,1} - \sqrt{2}u^+(dd)_{1,0} + 2u^-(dd)_{1,1}\}$$

$$\Delta q(x) = q_+(x) - q_-(x)$$

$$u_+(x) \rightarrow p^+ \ominus u^+ \Longrightarrow \begin{cases} \{(ud)_{0,0} \cdots\cdots u^+\}, & w = 0.9 \\ \{(ud)_{1,0} \cdots\cdots u^+\}, & w = 0.1 \end{cases}$$

90% scalar

$$u_-(x) \rightarrow p^- \ominus u^+ \Longrightarrow \{(ud)_{1,-1} \cdots\cdots u^+\}, \quad w = 1$$

100% vector

$$d_+(x) \rightarrow n^+ \ominus u^+ \Longrightarrow \{(dd)_{1,0} \cdots\cdots u^+\}, \quad w = 1$$

$$d_-(x) \rightarrow n^- \ominus u^+ \Longrightarrow \{(dd)_{1,-1} \cdots\cdots u^+\}, \quad w = 1$$

Probabilities of different string spin configurations depend on quark and target polarizations, target type and process type

Fragmentation functions in LEPTO
Dependence on target remnant spin state

Example: valence ***u***-quark is removed from proton. Default LEPTO: the remnant (***ud***) diquark is in 75% (25%) of cases scalar (vector)

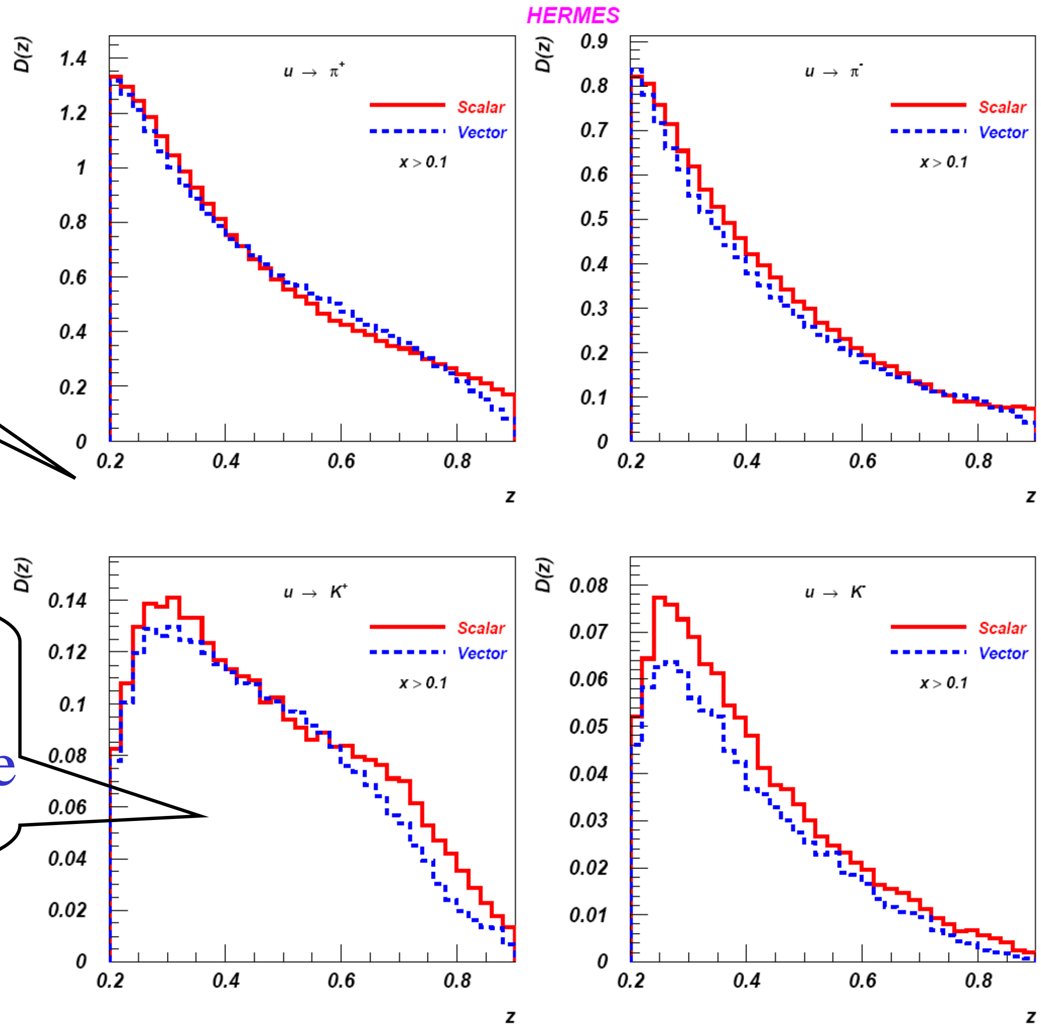
$\{(ud)_0 \cdots\cdots u\}, \qquad w=1.$

$\{(ud)_1 \cdots\cdots u\}, \qquad w=1.$

Even in unpolarized LEPTO there is a dependence on target remnant spin state

(ud)$_0$: first rank Λ is possible

(ud)$_1$: first rank Λ is impossible



More general approach

- x-z factorization was not checked
  - Extract unknown integrals of fragmentation functions in different subsets of x-bins and compare them
- Missing term in the (polarized) SIDIS equation related to polarization dependent hadronization

A.K. EPJ C44, 211 (2005)

Neglected

$$A_1^h(x,z,Q^2) = \frac{\sum_q e_q^2 q(x,Q^2) H_{q/N}^h(x,z,Q^2) \left(\frac{\Delta q(x,Q^2)}{q(x,Q^2)} + \boxed{\frac{\Delta H_{q/N}^h(x,z,Q^2)}{H_{q/N}^h(x,z,Q^2)}} \right)}{\sum_q e_q^2 q(x,Q^2) H_{q/N}^h(x,z,Q^2) \left(1 + \boxed{\frac{\Delta q(x,Q^2) \Delta H_{q/N}^h(x,z,Q^2)}{q(x,Q^2) H_{q/N}^h(x,z,Q^2)}} \right)}$$

Asymmetry

$$A_{1N}^{h,Exp}(x,z,Q^2)=\frac{\sum_q e_q^2\left(\Delta q(x,Q^2)H_{q/N}^h(x,z,Q^2)+q(x,Q^2)\Delta H_{q/N}^h(x,z,Q^2)\right)}{\sum_q e_q^2\left(q(x,Q^2)H_{q/N}^h(x,z,Q^2)+\Delta q(x,Q^2)\Delta H_{q/N}^h(x,z,Q^2)\right)}$$

$$\approx A_{1N}^{h,Std}(x,z,Q^2)+\frac{\sum_q e_q^2 q(x,Q^2)\Delta H_{q/N}^h(x,z,Q^2)}{\sum_q e_q^2 q(x,Q^2)H_{q/N}^h(x,z,Q^2)}$$

$$\cong A_{1N}^{h,Std}(x,z,Q^2)+\varepsilon(x,z,Q^2)$$

The standard expression for SIDIS asymmetry is obtained when

$$H_{q/N}^h(x,z,Q^2)\to D_q^h(z,Q^2) \qquad \Delta H_{q/N}^h(x,z,Q^2)\to 0$$

Only standard part of expression for asymmetry contains quark polarizations

$$A_{1N}^{h,Std}(x,z,Q^2)=A_{1N}^{h,Exp}(x,z,Q^2)-\varepsilon(x,z,Q^2)$$

Modeling ε in LEPTO

$$\varepsilon(x,z,Q^2)=\frac{\sum_q e_q^2 q(x,Q^2)\Delta H^h_{q/N}(x,z,Q^2)}{\sum_q e_q^2 q(x,Q^2) H^h_{q/N}(x,z,Q^2)}$$

LEPTO: HERMES tuning

parl(4)=probability of scalar diquark

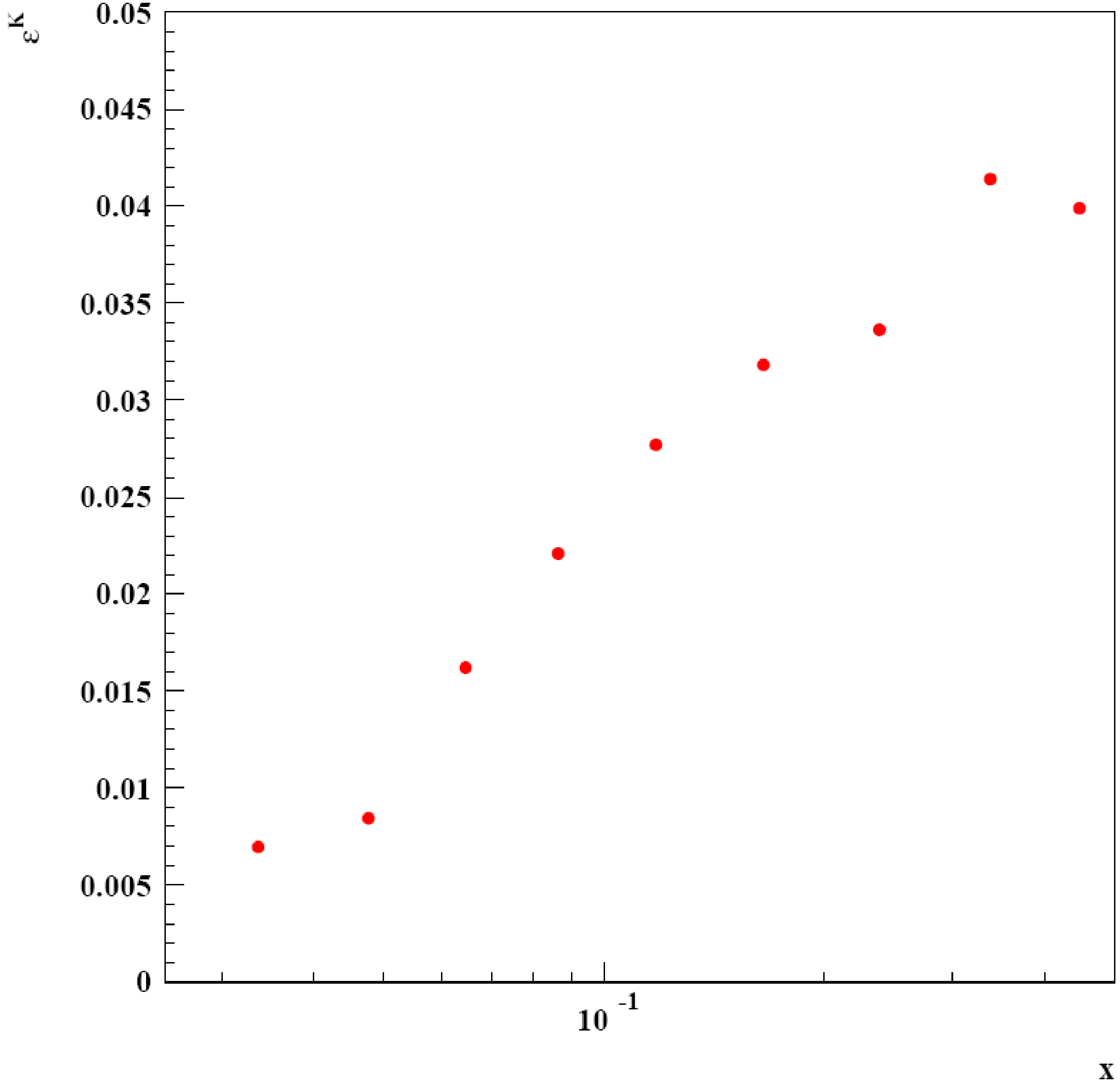
$$parl(4)=0.9 \Rightarrow N^{K/N}_{++} \propto \left(1+(1-y)^2\right)\sum_q e_q^2 q(x) H^{K/N}_{++},$$

$$parl(4)=0.0 \Rightarrow N^{K/N}_{+-} \propto \left(1+(1-y)^2\right)\sum_q e_q^2 q(x) H^{K/N}_{+-}$$

$$\varepsilon^K_d(x,z,Q^2)=\frac{N^{K/p}_{++}+N^{K/n}_{++}-N^{K/p}_{+-}-N^{K/n}_{+-}}{N^{K/p}_{++}+N^{K/n}_{++}+N^{K/p}_{+-}+N^{K/n}_{+-}}$$

ε(x)

LEPTO with
HERMES
tuning and cuts
CTEQ6 LO
K^+, K^- production
off deuterium target



Strange quarks polarization 2

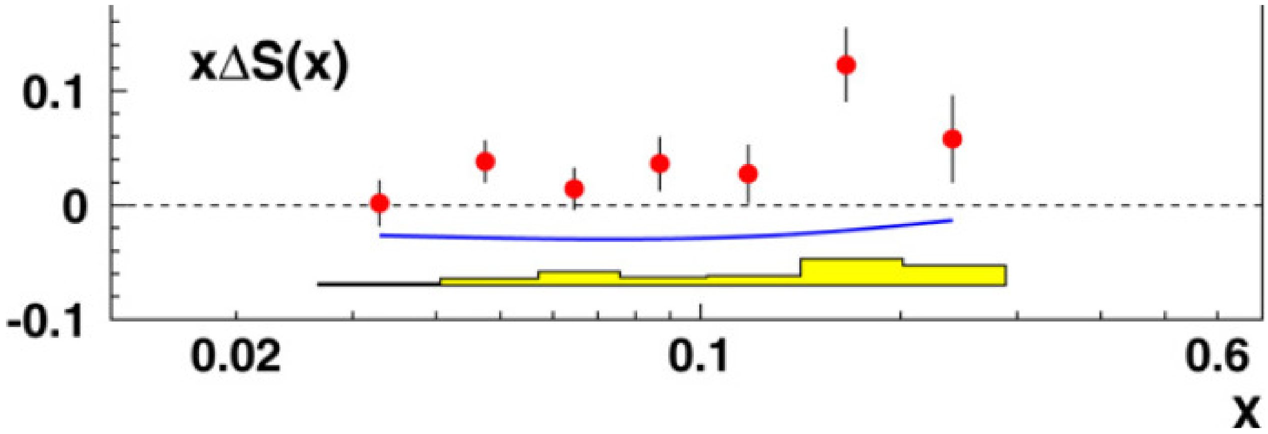
Data from Ahmed El Alaoui PhD thesis, 2006

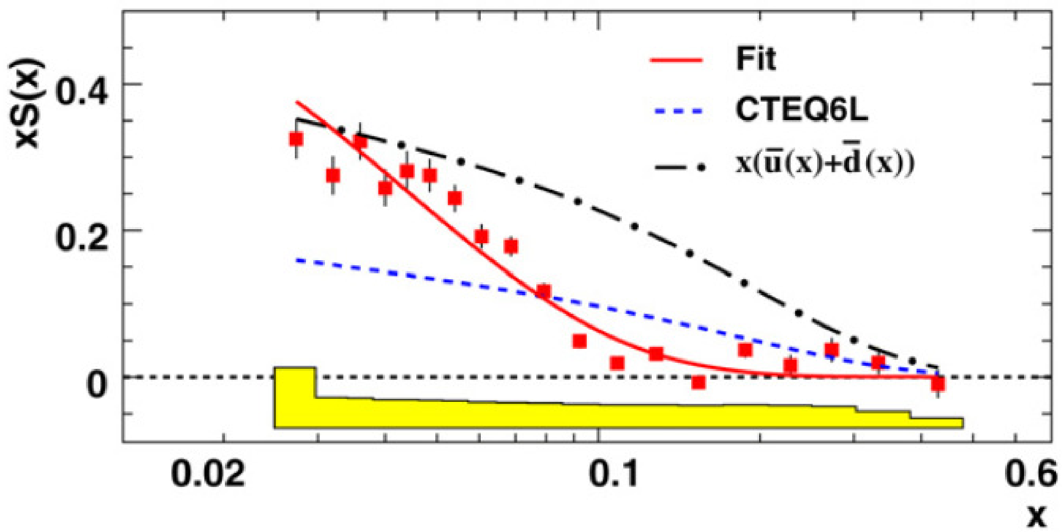
$$\Delta S_{HERMES} = \int_{0.02}^{0.3} dx \Delta S(x) = \sum_{i=1}^{7} \frac{\Delta S}{S}(x_i)_{HERMES} \int_{x_i}^{x_{i+1}} dx S(x) = 0.0055$$

$$\Delta S_{\varepsilon-corr} = \int_{0.02}^{0.3} dx \Delta S(x) = \sum_{i=1}^{7} \frac{\Delta S}{S}(x_i)_{\varepsilon-corr} \int_{x_i}^{x_{i+1}} dx S(x) = -0.027$$

New value is more than one standard deviation away

HERMES final results

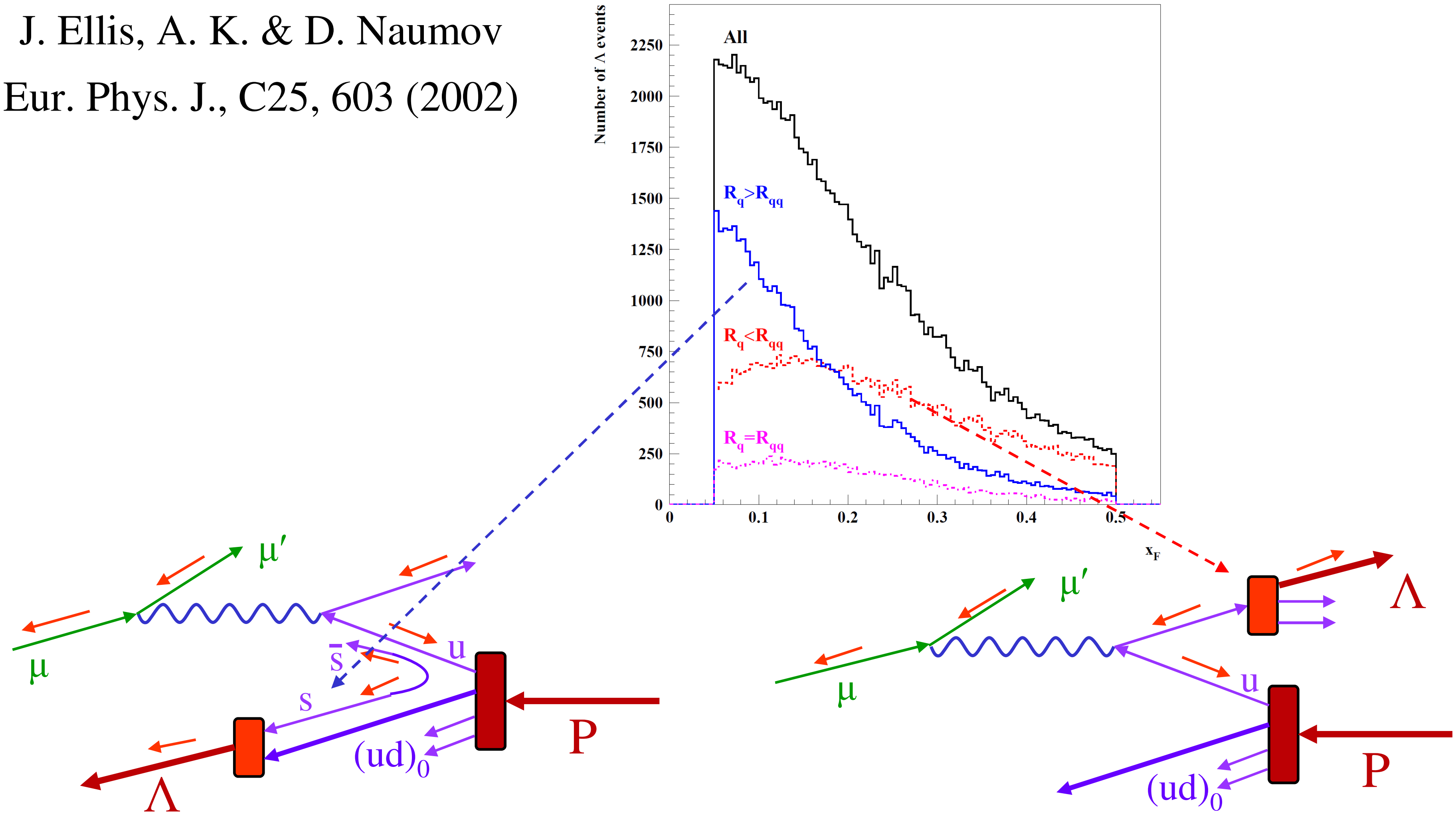




Intrinsic Strangeness Model for Λ polarization

J. Ellis, A. K. & D. Naumov

Eur. Phys. J., C25, 603 (2002)



$R_{qq} < R_q$: spin transfer from intrinsic strangeness and polarized diquark via heavier hyperons

$R_q < R_{qq}$: spin transfer only from final quark

Parameters of model

Spin transfer from qq side

$$P_\Lambda^{\nu\, d}(\text{prompt};N) = P_\Lambda^{\bar\nu\, u}(\text{prompt};N) = P_\Lambda^{l\, u}(\text{prompt};N) = P_\Lambda^{l\, d}(\text{prompt};N) = C_{sq}\cdot P_q,$$

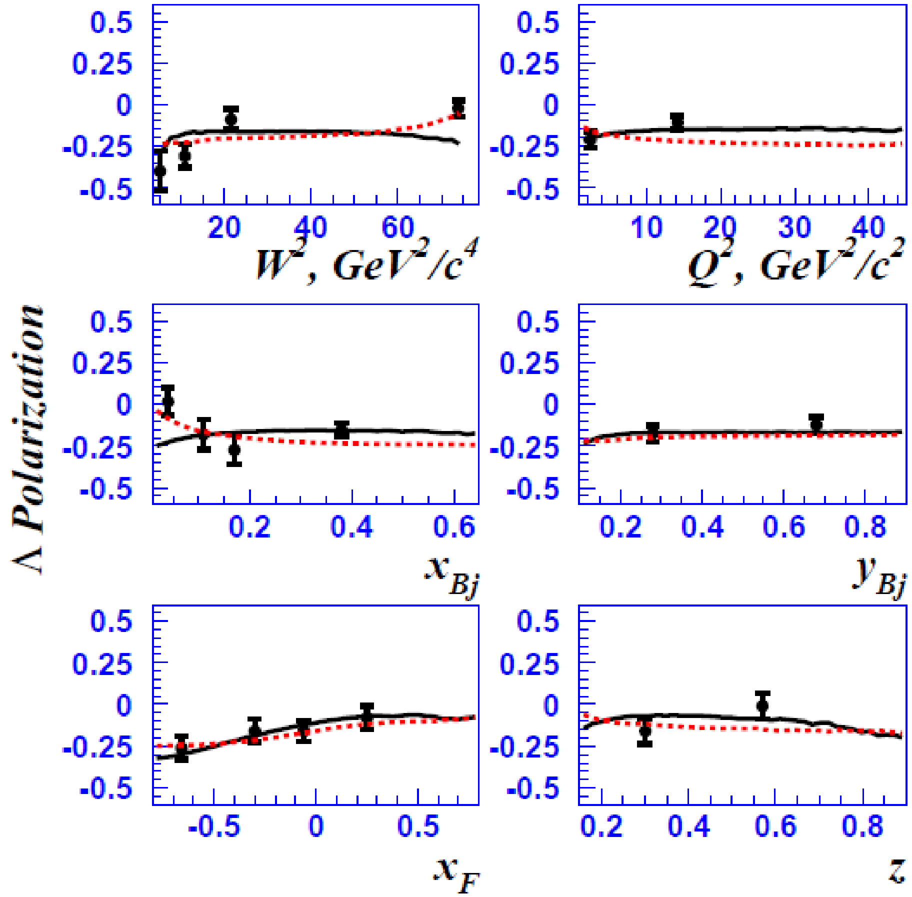
$$P_\Lambda^{\nu\, d}(\Sigma^0;n) = P_\Lambda^{\bar\nu\, u}(\Sigma^0;p) = P_\Lambda^{l\, u}(\Sigma^0;p) = P_\Lambda^{l\, d}(\Sigma^0;n) = \frac{1}{3}\cdot\frac{2+C_{sq}}{3+2C_{sq}}\cdot P_q,$$

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

Spin transfer from q side

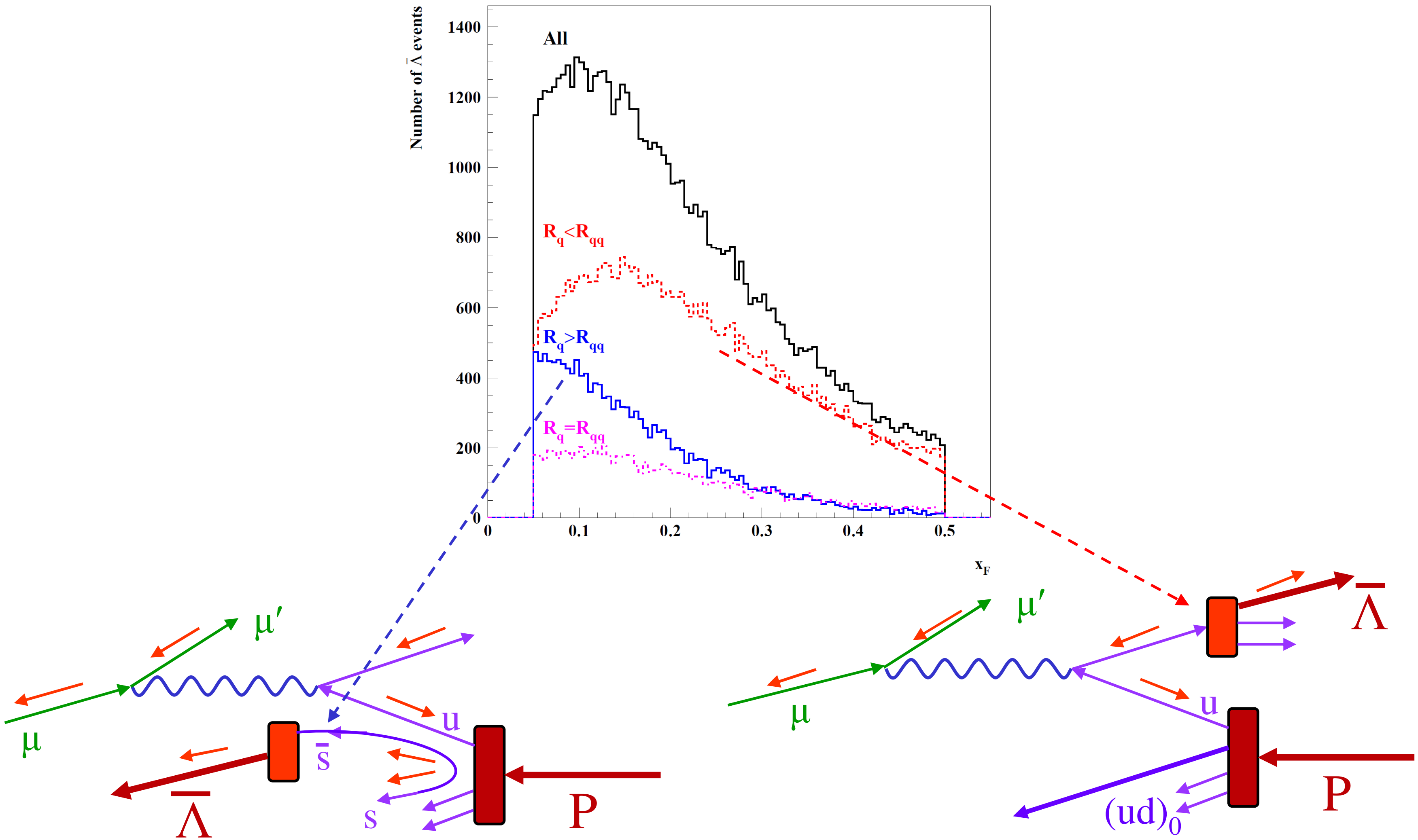
Λ^0's parent	$C_u^{\Lambda^0}$		$C_d^{\Lambda^0}$		$C_s^{\Lambda^0}$	
	$SU(6)$	BJ	$SU(6)$	BJ	$SU(6)$	BJ
quark	0	−0.18	0	−0.18	1	0.63
Σ^0	−2/9	−0.12	−2/9	−0.12	1/9	0.15
Ξ^0	−0.15	0.07	0	0.05	0.6	−0.37
Ξ^-	0	0.05	−0.15	0.07	0.6	−0.37
$\Sigma^\star$	5/9	–	5/9	–	5/9	–

NOMAD data



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

$\bar{\Lambda}$ polarization



$R_{qq}<R_q$: spin transfer only from intrinsic strangeness

$R_q<R_{qq}$: spin transfer only from final quark

Model calculations with LEPTO

Nomad settings and $c_{\bar{s}q} = c_{sq}$

Symbolic notations: Lund Model is realization of Fracture Functions.

Spin transfer via heavy hyperons is taken into account.

$$P^{\bar{\Lambda}}_{P_B,P_T}(x, x_F, \ldots) = \frac{P_q(x, x_F, \ldots) + P_{qq}(x, x_F, \ldots)}{N(x, x_F, \ldots)}$$

$$P_q(x, x_F, \ldots) = \sum_{q(R_q \le R_{qq})} e_q^2 \left[D(y)P_B - fP_T \frac{\Delta q(x)}{q(x)} \right] q(x) D_q^{\bar{\Lambda}}(z) S_q^{\bar{\Lambda}}$$

$$P_{qq}(x, x_F, \ldots) = -\sum_{q(R_q > R_{qq})} e_q^2 \left[D(y)P_B - fP_T \frac{\Delta q(x)}{q(x)} \right] q(x) D_q^{\bar{\Lambda}}(z) c_{\bar{s}q} S_q^{\bar{\Lambda}}$$

$$N(x, x_F, \ldots) = \sum_q e_q^2 \left[1 - D(y)P_B fP_T \frac{\Delta q(x)}{q(x)} \right] q(x) D_q^{\bar{\Lambda}}(z)$$

Separately calculate numerator and denominator by reweighting events

COMPASS cuts

$Q^2>1$ (GeV/c)^2; $0.2<y<0.9$

Primary vertex: $-100<z<100$ or $-30<z<30$ (cm)

Decay vertex: $35<z_{dec}<140$ (cm)

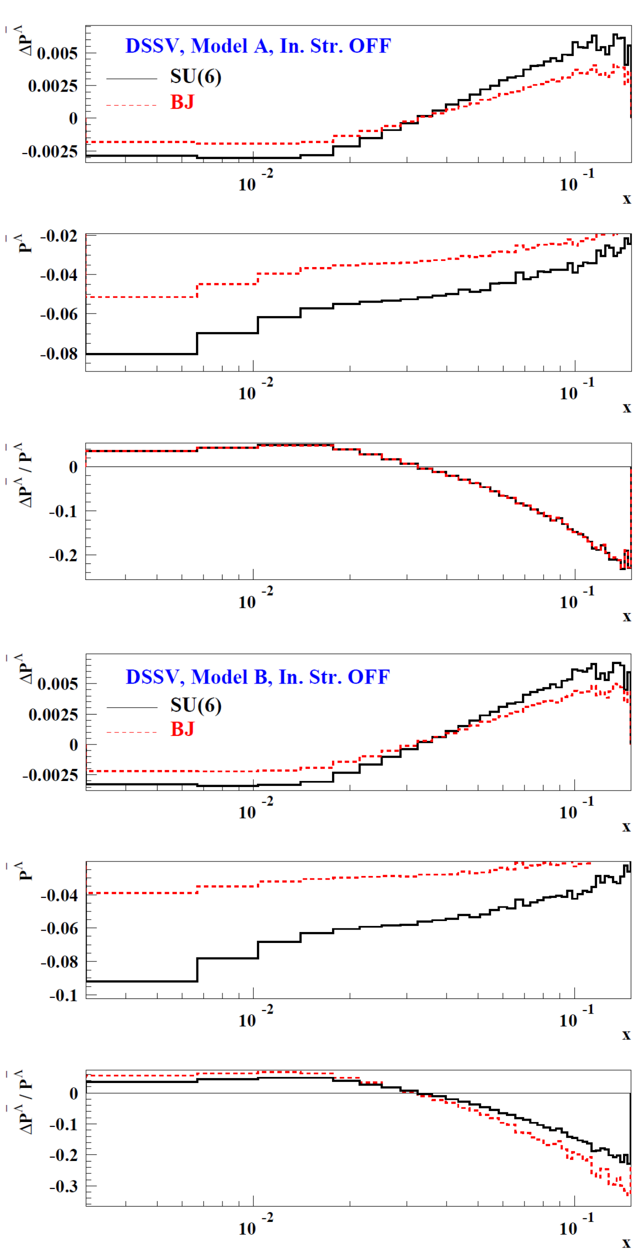
Vertexes colinearity cut: $\theta_{col}=0.01$

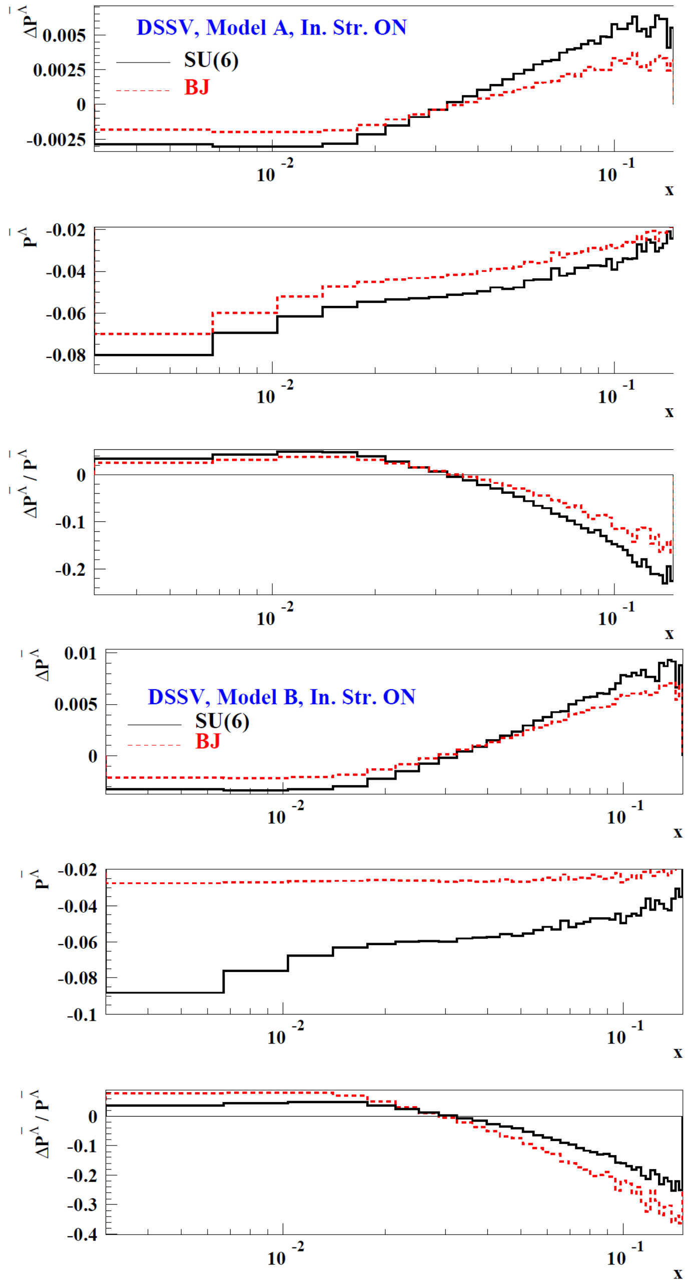
Decay particles momentum: $p>1$ GeV/c

Feynman variable: $0.05<x_F<0.5$

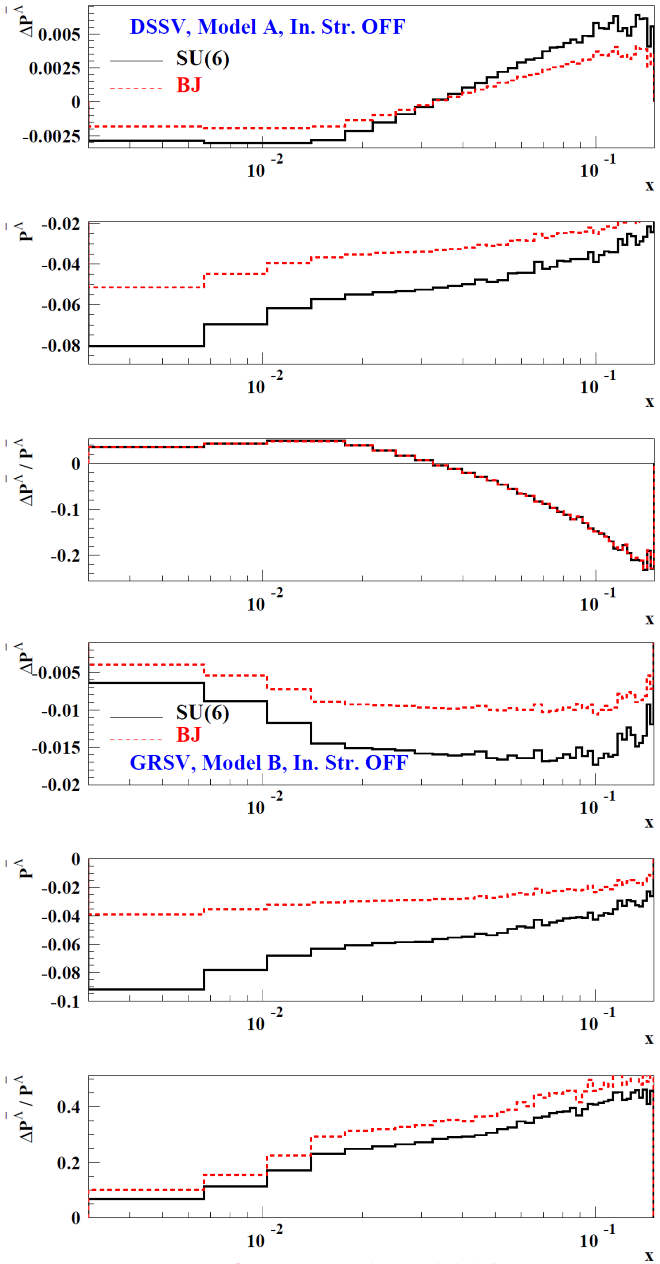
Λ rest frame decay angle cut: $\cos(\theta^*)<0.6$

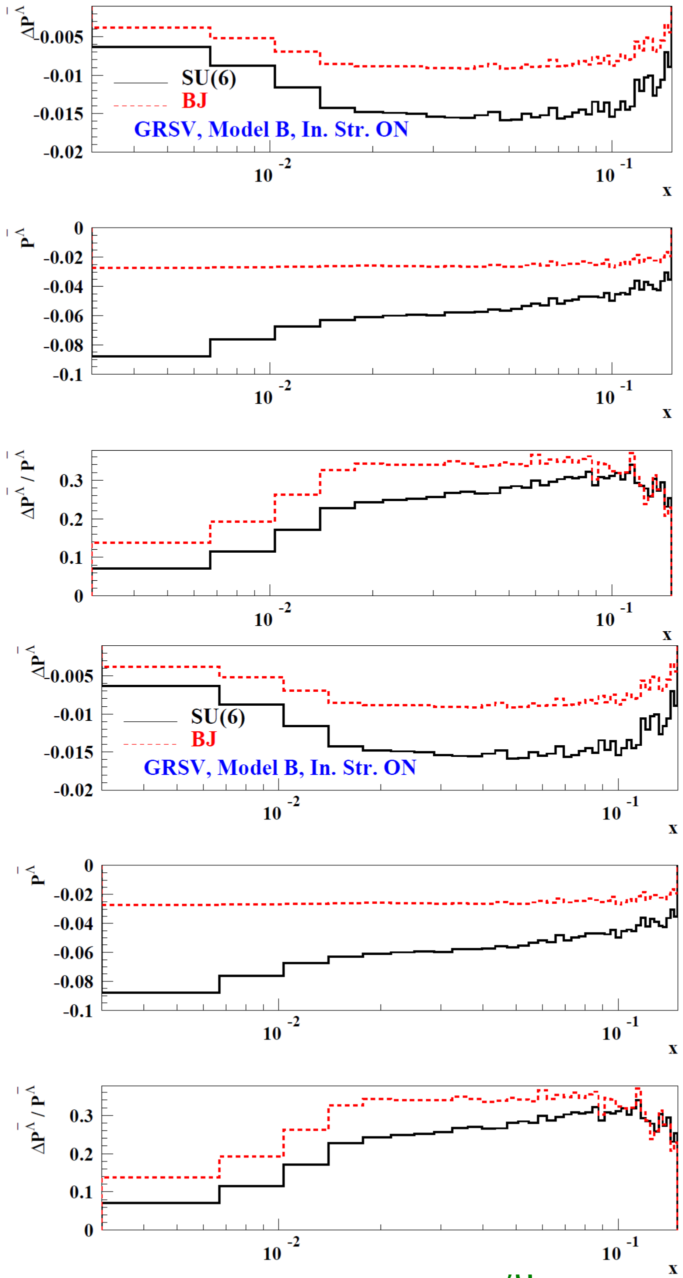
Spin transfer model dependence (DSSV PDFs)



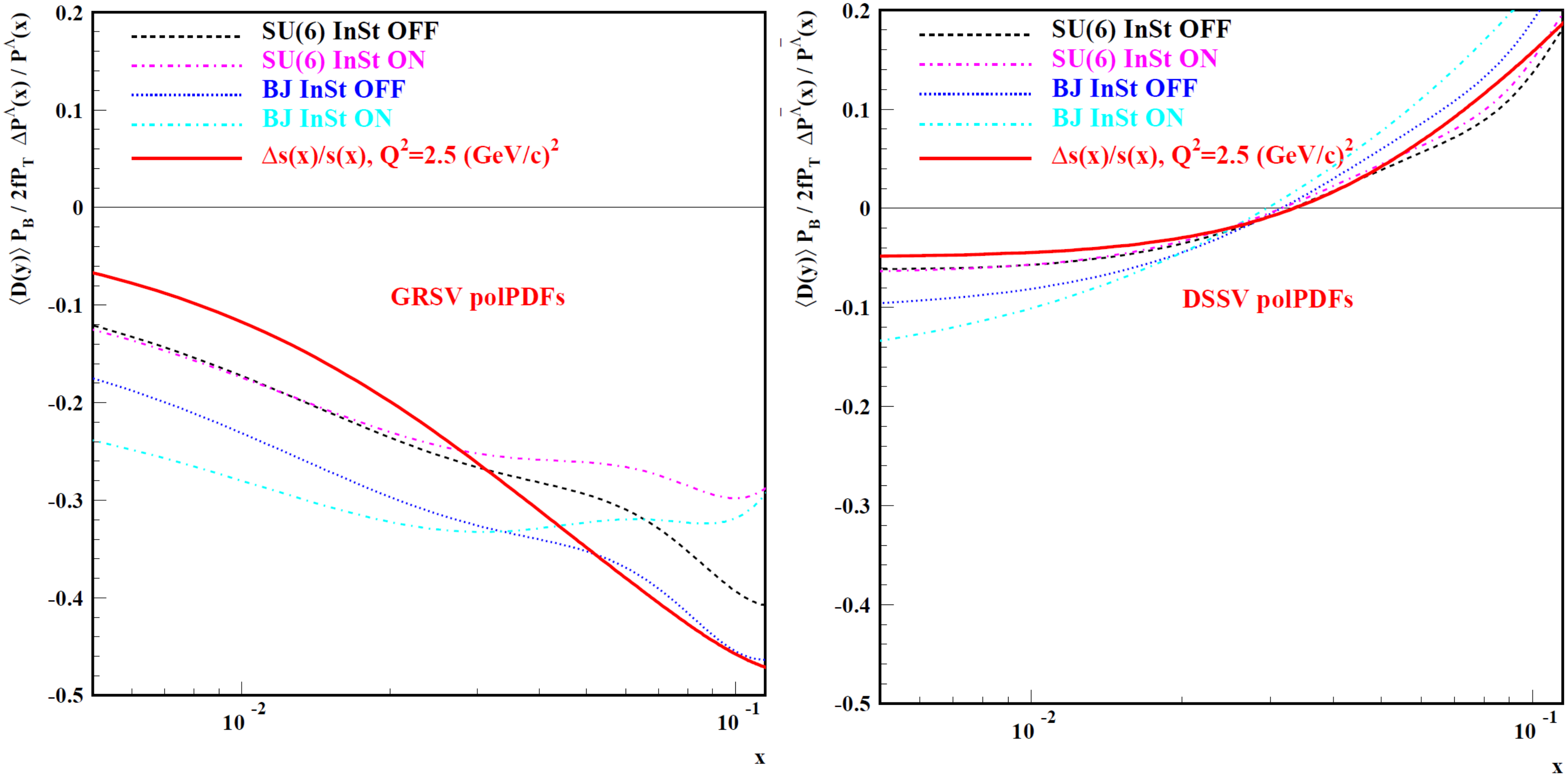


Spin transfer model dependence (GRSV PDFs)





Dependence on pol. PDFs



To verify sign change of $\Delta\bar{s}$
measure in two bins of x: x<0.03 and 0.03<x<0.1

Short conclusions

- (Anti)Lambda polarization measurements in SIDIS of polarized leptons off unpolarized and polarized targets can shed light both on unpolarized and polarized s-bar distributions and hyperon production and spin transfer mechanism
  - Anti-Lambda polarization on unpolarized target depends on spin transfer model.
  - Polarization asymmetry weakly depend on spin transfer model and strongly depends on strangeness polarization
- (Anti)Lambda is well suited filter for strangeness study

Λ V !