Λ production in COMPASS

Aram Kotzinian

Yerevan Physics Institute & JINR, Dubna

First Λ's at COMPASS

Alexandre Korzenev

Why Λ's

Models for longitudinal Λ polarization

Conclusions

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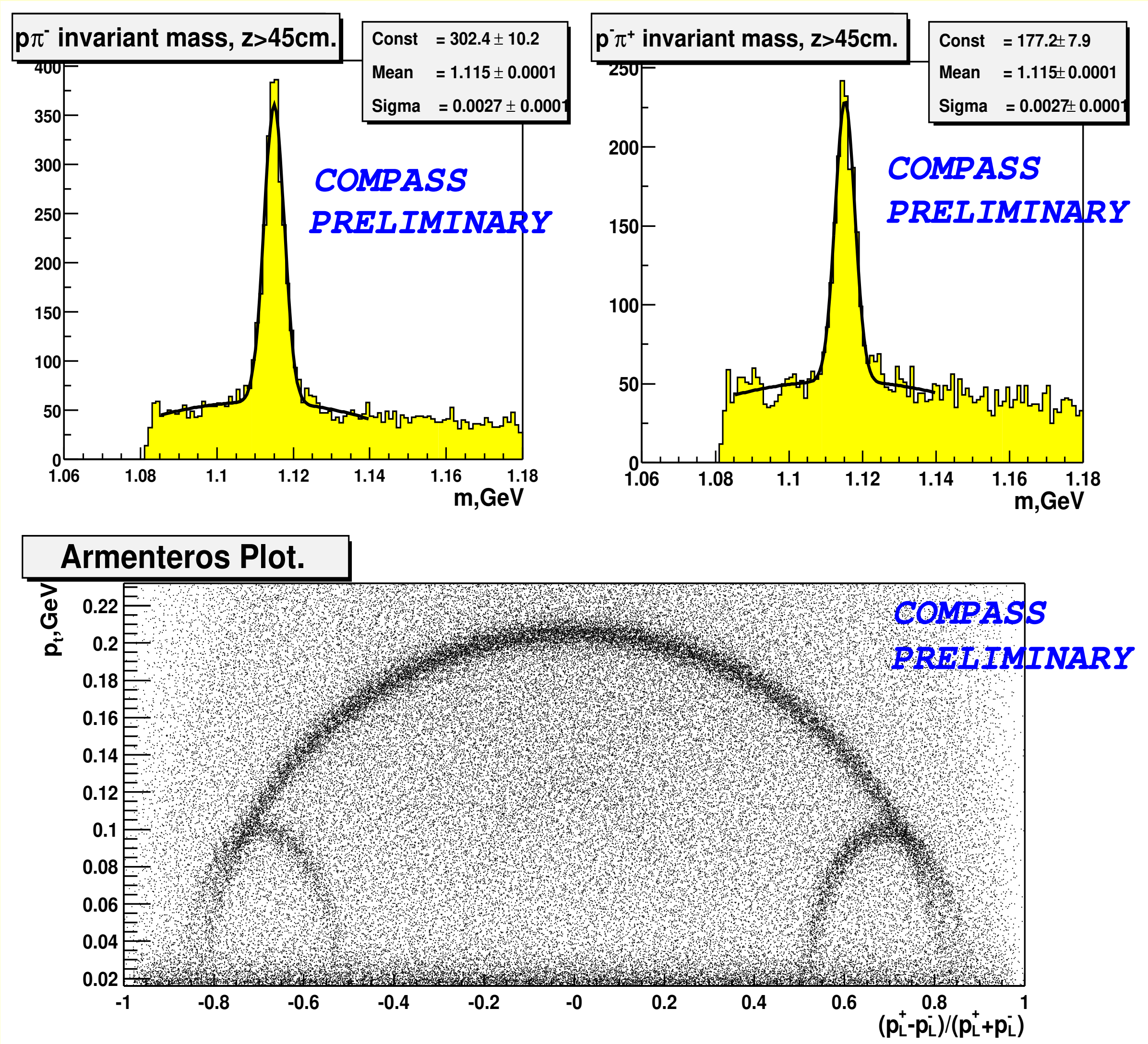
Future Physics @ COMPASS

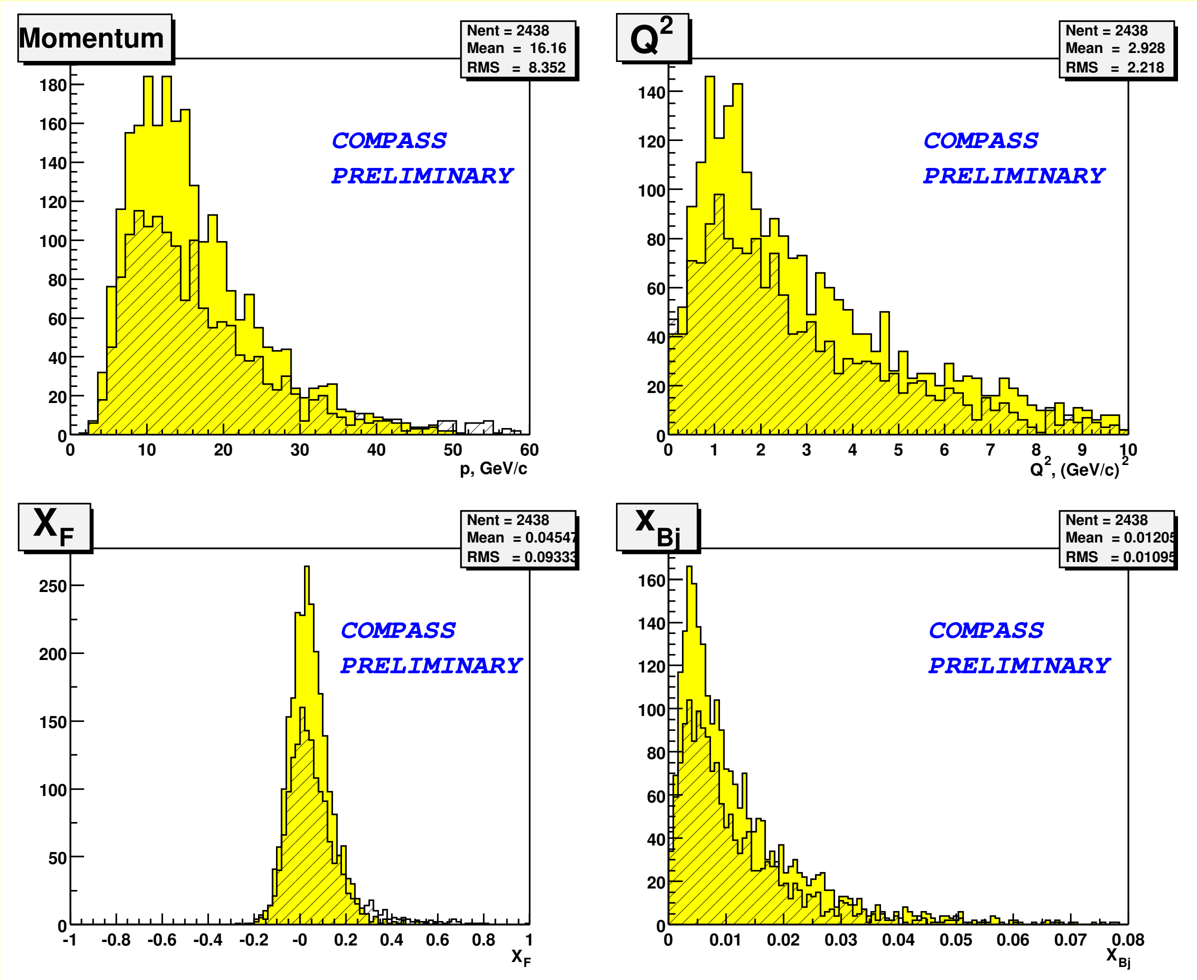
Λ & $\bar{\Lambda}$ in COMPASS



$\Lambda\bar{\Lambda}$ selection criteria.

- V^0 vertex is 15 cm downstream of target.
- Transverse momentum cut $p_t > 30\ MeV$.
- Impact distance $<$ 0.8 cm.
- With $\pi^+\pi^-$ hypothesis V^0 outside of K^0_S mass peak.

Λ & $\bar{\Lambda}$ distributions



Hatched area – $\bar{\Lambda}$

Estimated $\Lambda\bar{\Lambda}$ statistics for 2002.

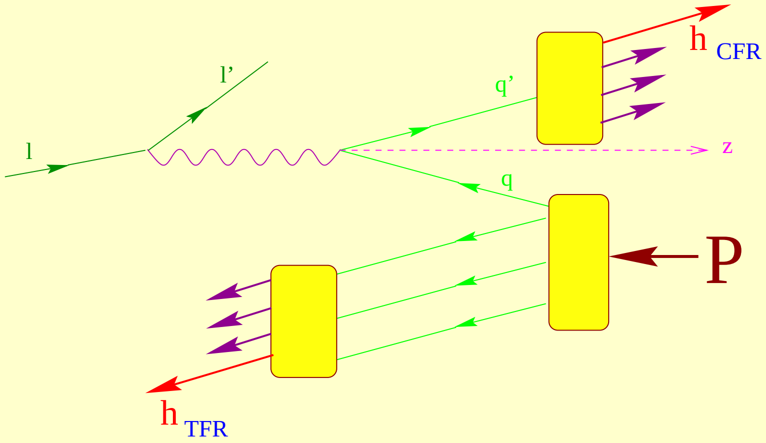
	Λ	$\bar{\Lambda}$
Number of good runs	1.7k	
Number of Λ per run	34	20
Total number of Λ	58k	34k
Total number of Λ $(Q^2 > 1)$	46k	27k

NOMAD: about 8k reconstructed Λ

TFR and CFR in SIDIS

DIS: positive ΔG or negative Δs ?

SIDIS $\Rightarrow$ "direct" measurement



Virtual boson – nucleon CMS:

$x_F > 0$ – current fragmentation (CFR)

$x_F < 0$ – target fragmentation (TFR)

Λ production on unpolarized target:
longitudinal spin transfer from lepton to hyperon

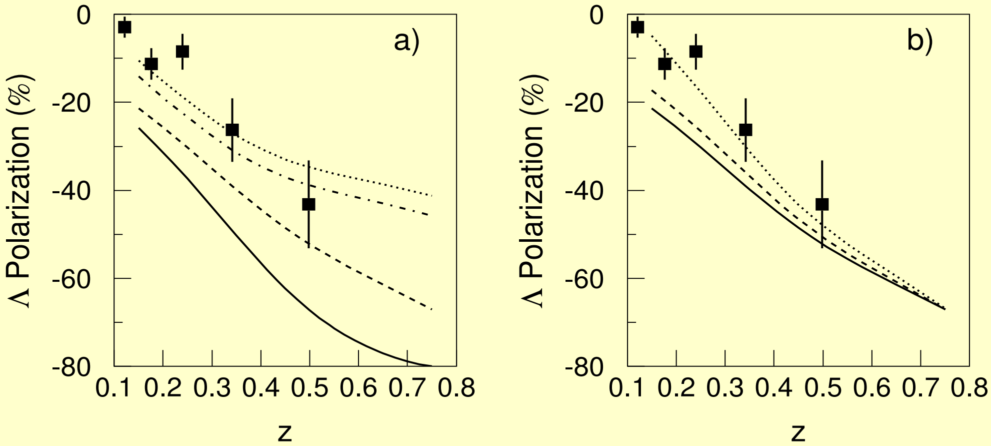
TFR $\Rightarrow$ polarized intrinsic strangeness

CFR $\Rightarrow$ spin transfer in quark fragmentation

Why Λ's

Bubble chamber experiment WA59 (1992): large negative Λ polarization (~ -0.6) in the TFR of $\bar{\nu} + N \rightarrow \Lambda + X$ was explained within polarized intrinsic strangeness model with *negatively* polarized s-quarks (J. Ellis, M. Karliner, D.E. Kharzeev & M.G. Sapozhnikov (1995); J. Ellis, D.E. Kharzeev & A. K. (1996)

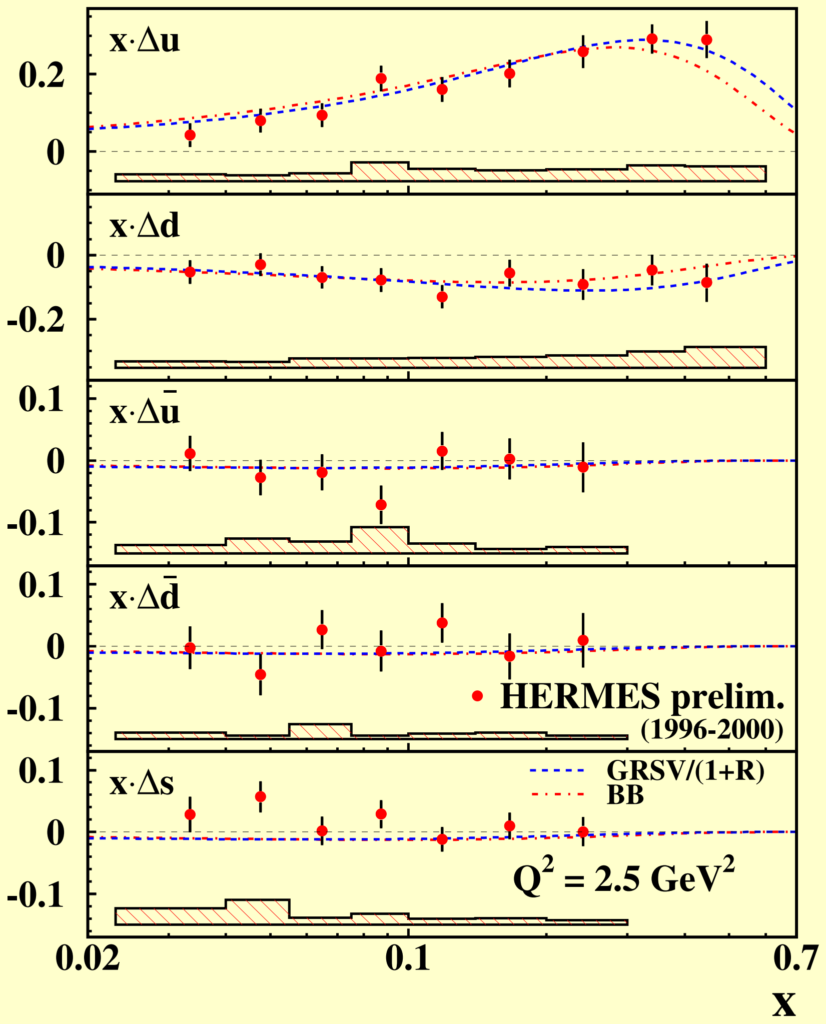
Spin transfer in the quark fragmentation



Longitudinal polarization of $\Lambda/\bar{\Lambda}$ in e^+e^- annihilation at Z^0 pole (data from DELPHI (1995), curves: A. K., A. Bravar & D. von Harrach(1998))

Many different models (for example, Burkardt & Jaffe (1993); Gustafson & Hakkinen(1993)) well describe these data

HERMES flavor decomposition



H. E.Jackson, hep-ex/0208015,
Int.J.Mod.Phys.A17:3551-3570,2002

– Light sea quarks are not significantly polarized
– Strange sea appears to be positively polarized

Purity method

In the LO approximation

$$A_1^h \simeq \frac{\sum_q e_q^2 \Delta q(x,Q^2) \int_{z_{min}}^1 dz D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) \int_{z_{min}}^1 dz D_q^h(z,Q^2)} \qquad (*)$$

HERMES: "Purity" method

$$A_1^h \simeq \sum_q P_q^h(x) \frac{\Delta q(x)}{q(x)} \qquad (**)$$

where, purity is defined as

$$P_q^h(x) = \frac{e_q^2 q(x) \int_{z_{min}}^1 dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int_{z_{min}}^1 dz D_{q'}^h(z)}$$

and calculated using LEPTO.

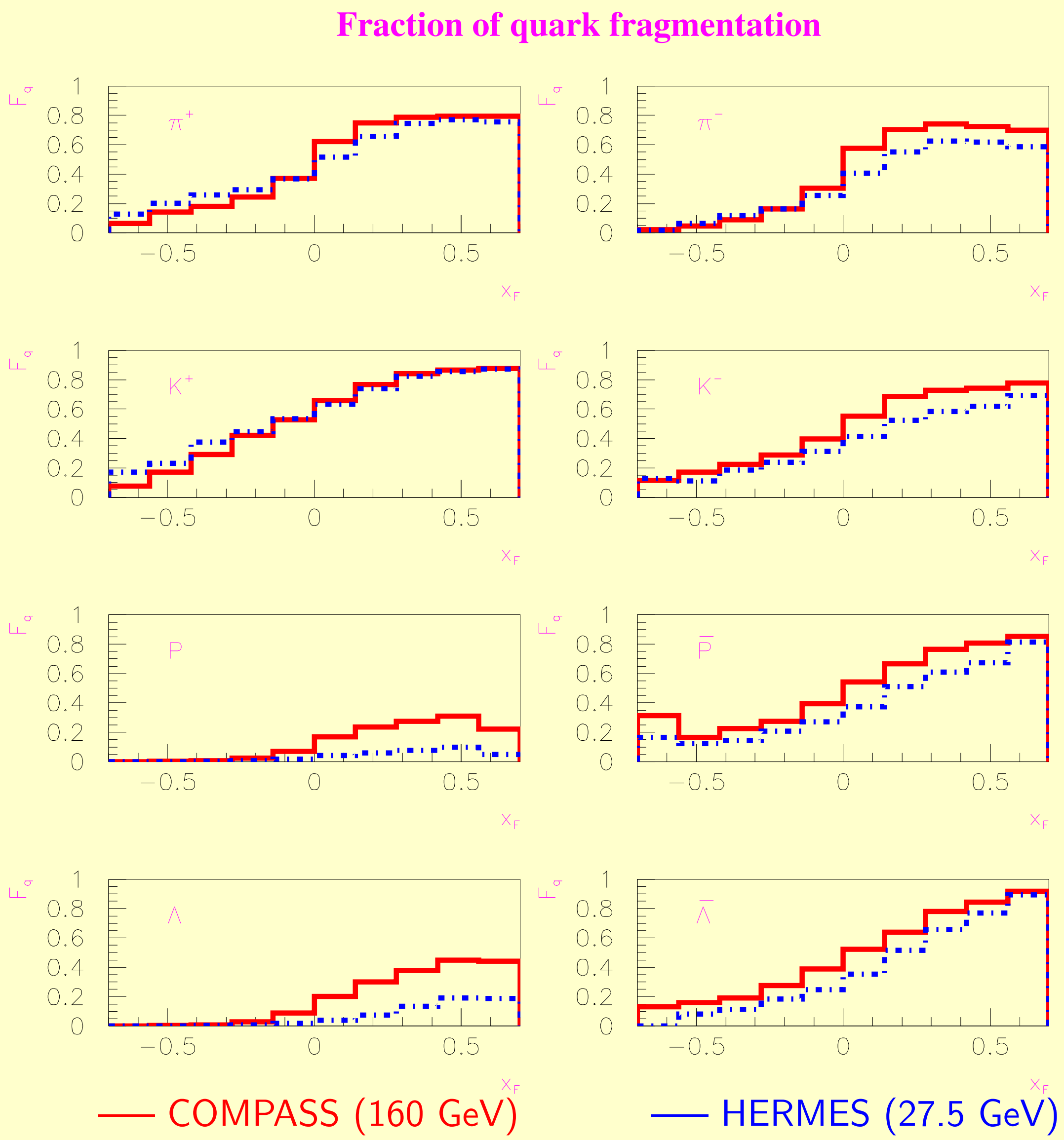
Then using measured asymmetries for different hadrons and targets find $\Delta q(x)$ by solving $(**)$

Main assumptions:

— 1: LEPTO is well tuned to data

— 2: all hadrons are from quark fragmentation

Quark fragmentation according to LEPTO



Fraction of hadrons originating from quark fragmentation depends on particle flavor and is not equal to 1 even at $x_F > 0.2 \div 0.3$

Target influence to hadron production in CFR

According to LUND model not all hadrons in the CFR are originating from the quark fragmentation

$$A_{1p}^h = \frac{\sum_q [\Delta q(x) D_q^h(z) + \Delta M_q^{h/p}(x,z)]}{\sum_q [q(x) D_q^h(z) + M_q^{h/p}(x,z)]}$$

$$M_q^{h/p}(x,z) = q(x) \cdot \tilde{M}_q^{h/p}(x,z)$$

$$\Delta M_q^{h/p}(x,z) = \Delta q(x) \cdot \Delta\tilde{M}_q^{h/p}(x,z)$$

Model A: $\Delta\tilde{M}_q^{h/p}(x,z) = \tilde{M}_q^{h/p}(x,z)$ as in PEPSI

Model B: $\Delta\tilde{M}_q^{h/p}(x,z) = 0.$ Toy model:
only quark fragmentation gives contribution to the numerator

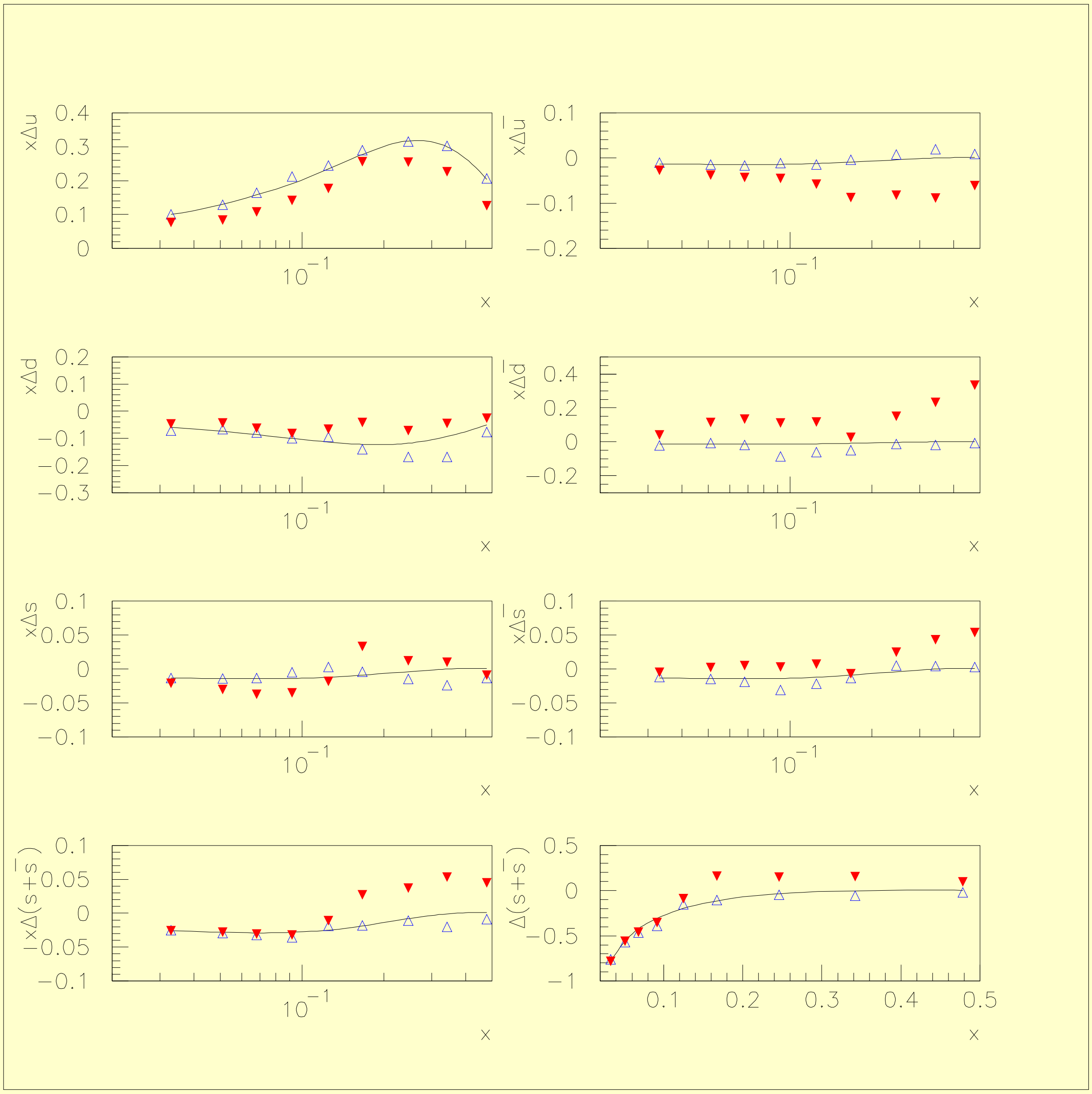
Monte Carlo exercise (E=27.5 GeV, proton)

10^8 DIS events generated for each polarization
$\pi^+, \pi^-, K^+, K^-, h^+$ and h^- selected with
$x_F > 0$, $z > 0.2$ and $p > 1\ GeV/c$
GRV98 for unpolarized $\Rightarrow$ Purities
GRSV2000 (standard scenario) $\Rightarrow$ Asymmetries
Then, solving $**$ for Δq we have:

Polarized quark distributions

open triangles – Model A:

filled triangles – Model B:



Integrated quark polarizations

Table 1: *Integrated* Δq *for* $0.02 < x < 0.7$.

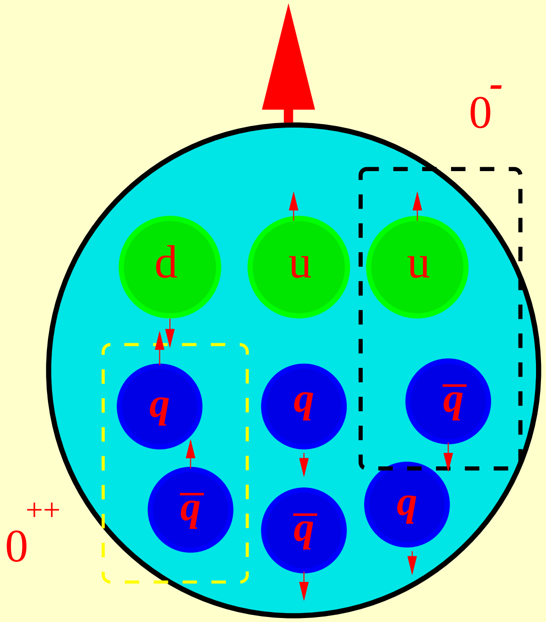
	GRV98+GRSV2000(std)		
	Input	Model A	Model B
Δu	0.721	0.680	0.456
$\Delta\bar{u}$	-0.030	-0.012	-0.162
Δd	-0.300	-0.327	-0.182
$\Delta\bar{d}$	-0.030	-0.100	0.604
Δs	-0.030	-0.035	-0.088
$\Delta\bar{s}$	-0.030	-0.031	0.104
$\Delta(s+\bar{s})$	-0.060	-0.066	0.016

negative input for $\Delta(s+\bar{s}) \Rightarrow$
positive output in the **model B:**

One have to be very careful with interpretation of measured SIDIS asymmetries when using purity method

Polarized intrinsic strangeness + $SU(6)$ model

John Ellis & Dmitry Naumov & A.K., hep-ph/0204206, (Eur. Phys. J.)



1. π, K masses are small at the typical hadronic mass scale $\Rightarrow$ a strong attraction in the $J^P = 0^-$ channel.
2. The vacuum density of $s\bar{s}$ pairs is relatively high:

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

The strange quark polarization is correlated with that of struck quark:

$$P_s = C_{sq} P_q$$

We revise the polarized intrinsic strangeness model as follows:

— introduce two parameters: $C_{sq_{val}}$ and $C_{sq_{sea}}$

— leave C_{sq} as a free parameters which are obtained from the fit to the NOMAD data.

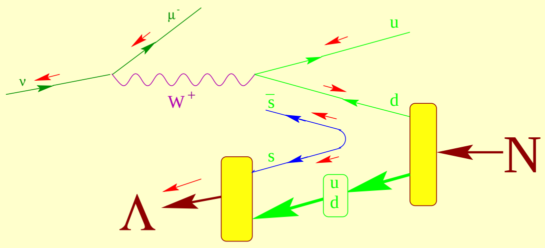
— take into account the polarization transfer from heavier strange hyperons.

The method

$$P_\Lambda^{lN}(B) = \frac{\sum_M P_s\left(B(J,M)\right) \mid \langle B(J,M) \mid \text{diquark-quark remnant} + \text{s quark} \rangle \mid^2}{\sum_M \mid \langle B(J,M) \mid \text{diquark-quark remnant} + \text{s quark} \rangle \mid^2}$$

— $P_s\left(B(J,M)\right)$ is the polarization of the strange quark in the baryon B with the spin state $\mid B(J,M)\rangle$,

— $\mid$ diquark-quark remnant + s quark $\rangle$ is the product of the wave function of the remnant diquark and the wave function of polarized s quark.



The remnant diquark-quark wave functions are:

$$|p \ominus d^\uparrow\rangle = \frac{1}{\sqrt{36}}[-\sqrt{2}(uu)_{1,0} + 2(uu)_{1,-1}]$$

$$|n \ominus d^\uparrow\rangle = \frac{1}{\sqrt{36}}[3(ud)_{0,0} + (ud)_{1,0} - \sqrt{2}(ud)_{1,-1}]$$

The wave function of polarized s quark is:

$$|s\rangle_{pol} = \frac{1}{\sqrt{2}} \mid \sqrt{(1+C_{sq})}s^\uparrow + \sqrt{(1-C_{sq})}s^\downarrow\rangle$$

Finally, the Λ polarization in lN DIS is:

$$P_\Lambda^{lN} = \sum_B \xi_B P_\Lambda^{lN}(B), \text{where } \xi_B \text{ is the fraction of } \Lambda \text{ produced via B}$$

Λ polarization in quark & diquark fragmentation

After straightforward algebra one can obtain:

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

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

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

Λ polarization from the quark fragmentation

$$P_\Lambda^q(B) = -C_q^\Lambda(B) P_q,$$

Table 2: Spin correlation coefficients in 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	5/9	5/9	5/9

The struck quark polarization

Table 3: Polarization of the struck quark in different processes.

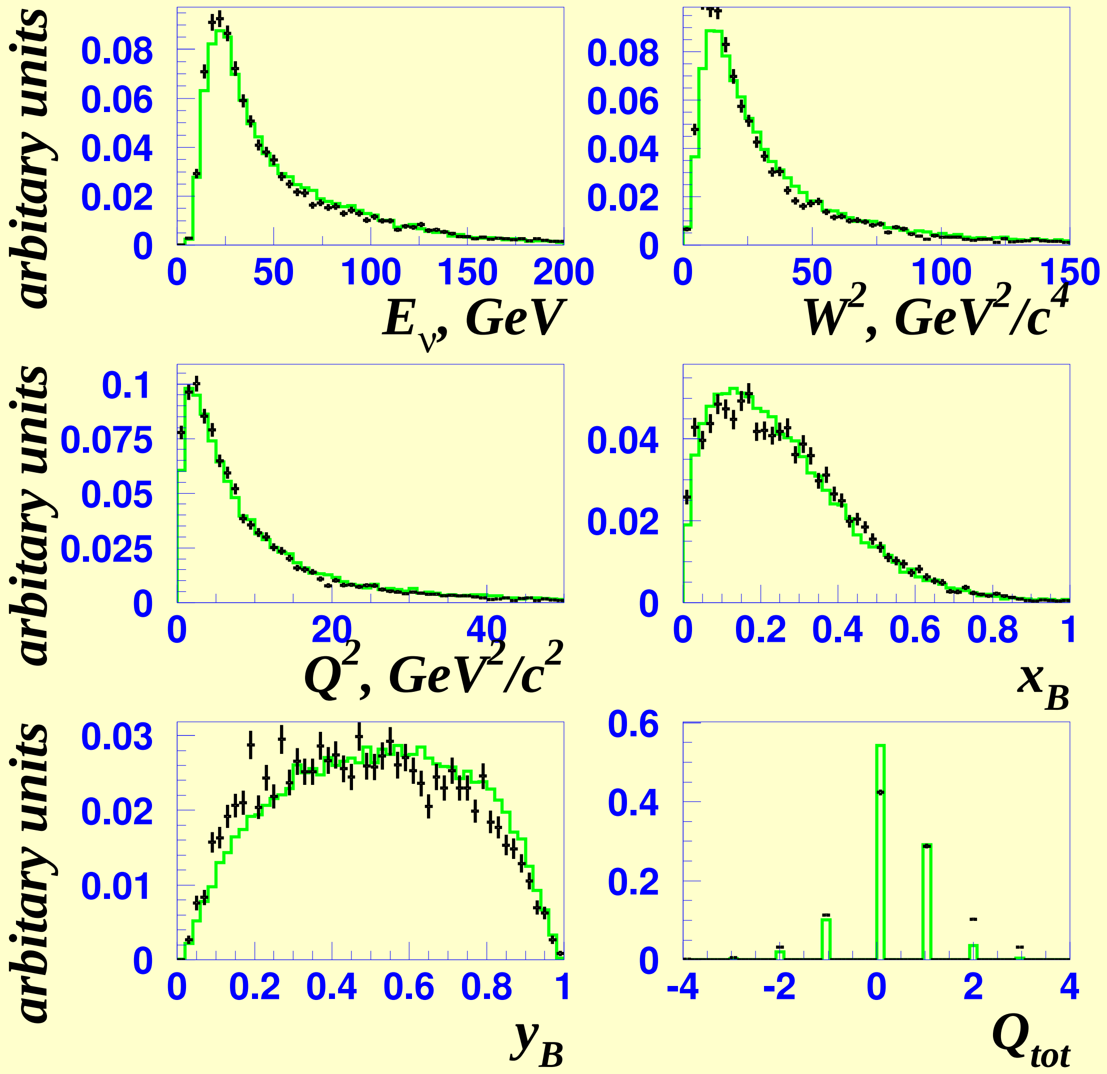
	ν CC	ν NC	$\bar{\nu}$ CC	$\bar{\nu}$ NC	$l^{\pm}$
P_d	1	$\frac{(1-\xi)^2-\xi^2(1-y)^2}{(1-\xi)^2+\xi^2(1-y)^2}$	$-$	$\frac{(1-\xi)^2(1-y)^2-\xi^2}{(1-\xi)^2(1-y)^2+\xi^2}$	$-P_B D(y)$
P_u	$-$	$\frac{(1-2\xi)^2-4\xi^2(1-y)^2}{(1-2\xi)^2+4\xi^2(1-y)^2}$	1	$\frac{(1-2\xi)^2(1-y)^2-4\xi^2}{(1-2\xi)^2(1-y)^2+4\xi^2}$	$-P_B D(y)$

In this table $\xi = 2/3 \sin^2\theta_W$, P_B is the longitudinal beam polarization, and $D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$ is the virtual photon depolarization factor, while y represents the relative energy loss of the lepton.

To predict Λ polarization one needs to know their origin and relative yields in different channels.

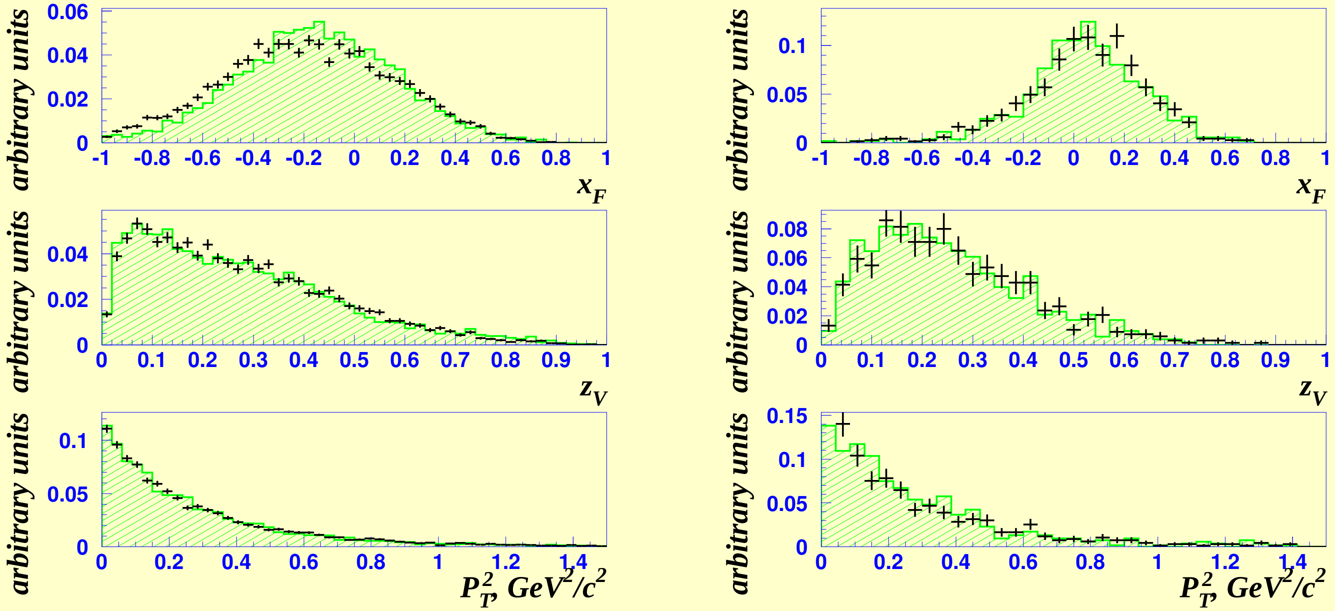
We use Lund string fragmentation model incorporated in LEPTO6.5.1 and JETSET7.4
In this approach we know the hyperons parents and LEPTO can be well tuned in all kinematic domains.

Λproduction at NOMAD



DIS variable distribution in NOMAD ν_μ CC data and MC (green line)

Λ & $\bar{\Lambda}$ production at NOMAD



Hadron variable distribution in NOMAD ν_μ CC data and MC (green) for Λ (left) and $\bar{\Lambda}$ (right) production

Λ production in LEPTO

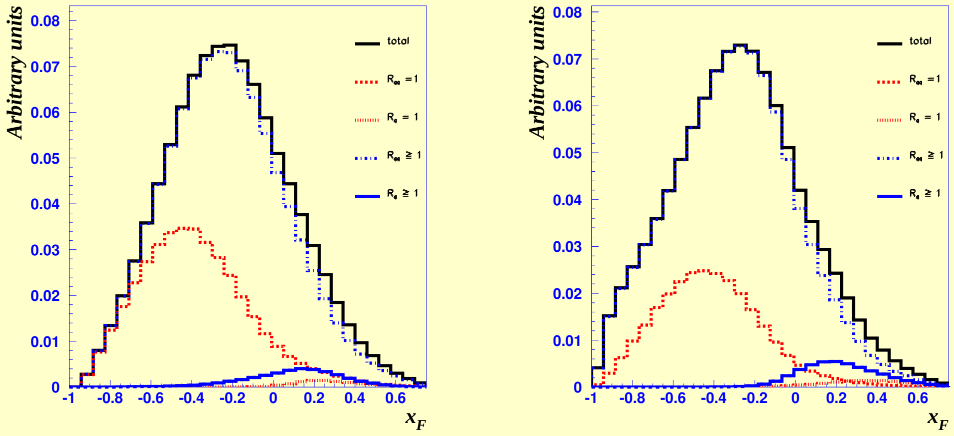


Figure 1: Left: ν_μ CC, $E_\nu = 43.8$ GeV, Right: μ^+, $E_\mu = 160$ GeV. x_F distribution of all Λ hyperons (solid line), of those originating from the di-quark fragmentation and of those originating from the quark fragmentation for two models A and B (see the legend on the plots).

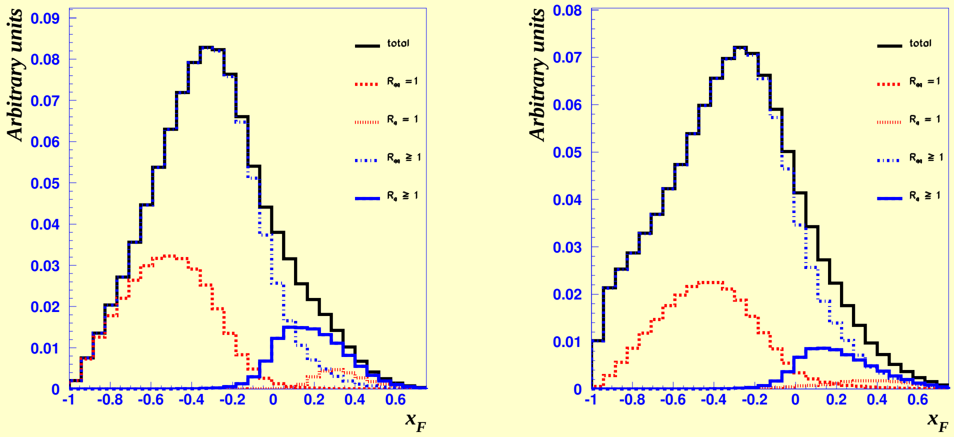


Figure 2: Left: ν_μ CC, $E_\nu = 500$ GeV, Right: μ^+, $E_\mu = 500$ GeV. x_F distribution of all Λ hyperons (solid line), of those originating from the di-quark fragmentation and of those originating from the quark fragmentation for two models A and B (see the legend on the plots).

Spin transfer model

All hadrons are ordered according to their rank from quark or diquark end. We consider two extreme cases when polarization transfer is nonzero:

model A:

- the hyperon contains the stuck quark: $R_q = 1$
- the hyperon contains the remnant diquark: $R_{qq} = 1$

model B:

- the hyperon originates from the stuck quark: $R_q \geq 1$
- the hyperon originates from the remnant diquark: $R_{qq} \geq 1$

Fixing free parameters

We vary two correlation coefficients ($C_{sq_{val}}$ and $C_{sq_{sea}}$) in order to fit our models A and B to the NOMAD Λ polarization data. Scattering of the exchange W boson on the sea quark can be enhanced within a sample of Λ hyperons with low x_{Bj} or high W^2. A strong target nucleon effect was found by the NOMAD as well. Therefore we fit to the following 4 NOMAD points to find our free parameters:

- νp: $P_x^\Lambda = -0.26 \pm 0.05(stat)$,
- νn: $P_x^\Lambda = -0.09 \pm 0.04(stat)$,
- $W^2 < 15$ GeV^2: $P_x^\Lambda = -0.34 \pm 0.06(stat)$,
- $W^2 > 15$ GeV^2: $P_x^\Lambda = -0.06 \pm 0.04(stat)$.

As a result of these fits we find:

model A: $C_{sq_{val}} = -0.35 \pm 0.03$ and $C_{sq_{sea}} = -0.95 \pm 0.03$

model B: $C_{sq_{val}} = -0.25 \pm 0.03$ and $C_{sq_{sea}} = 0.15 \pm 0.03$

The coefficients found are considerably different for models A and B

Results are almost independent of spin transfer mechanism in the quark fragmentation

Results

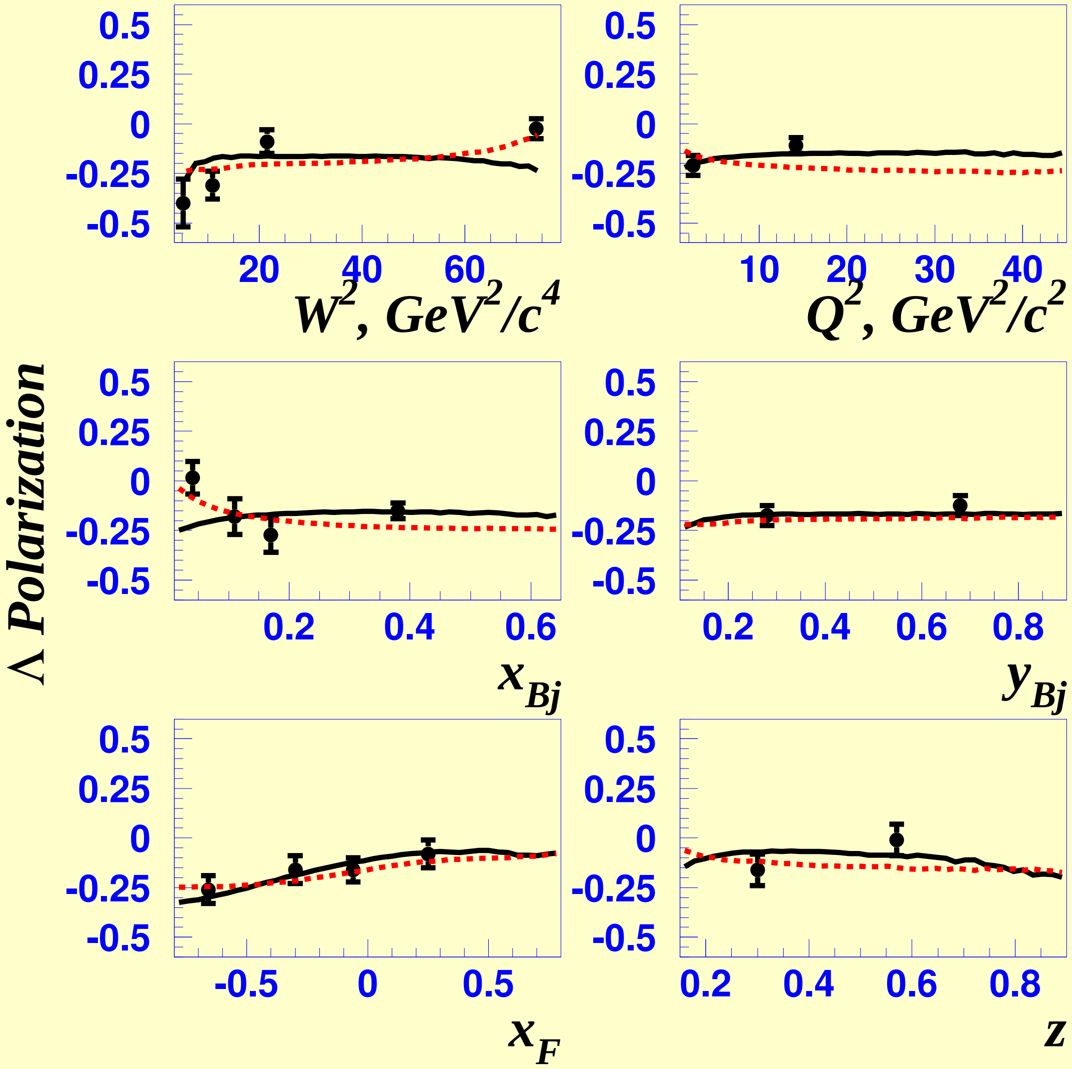


Figure 3: Our model predictions (model A - solid line, model B - dashed line) for polarization of Λ hyperons produced in ν_μ charged current DIS interactions off nuclei as functions of W^2, Q^2, x_{Bj}, y_{Bj}, x_F and z (at $x_F > 0$). The points with error bars are from NOMAD.

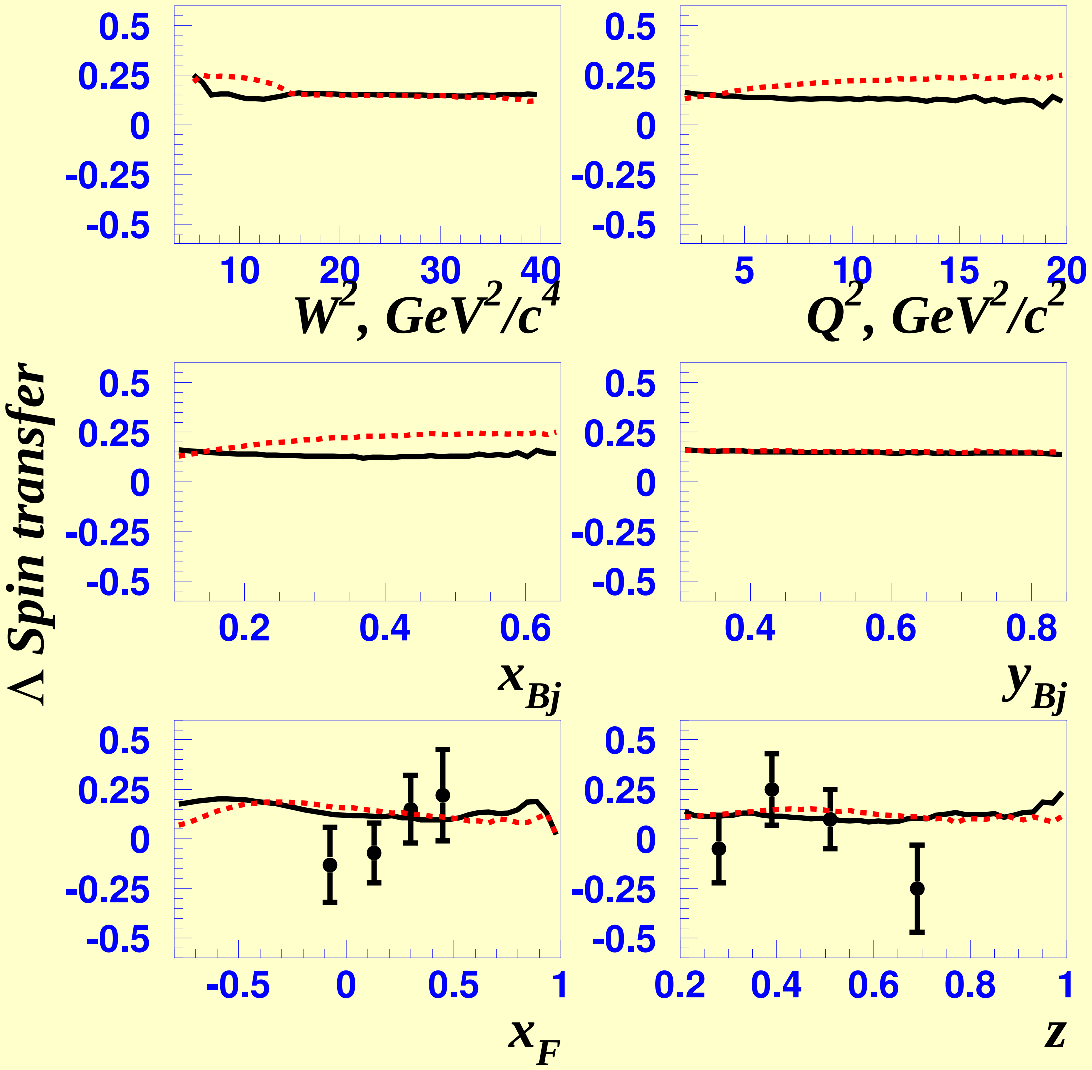


Figure 4: Our model predictions (model A - solid line, model B - dashed line) for the spin transfer of Λ hyperons produced in e^+ DIS interactions off nuclei as functions of W^2, Q^2, x_{Bj}, y_{Bj}, x_F and z (at $x_F > 0$). ($E_e = 27.5$ GeV) The points with error bars are from HERMES

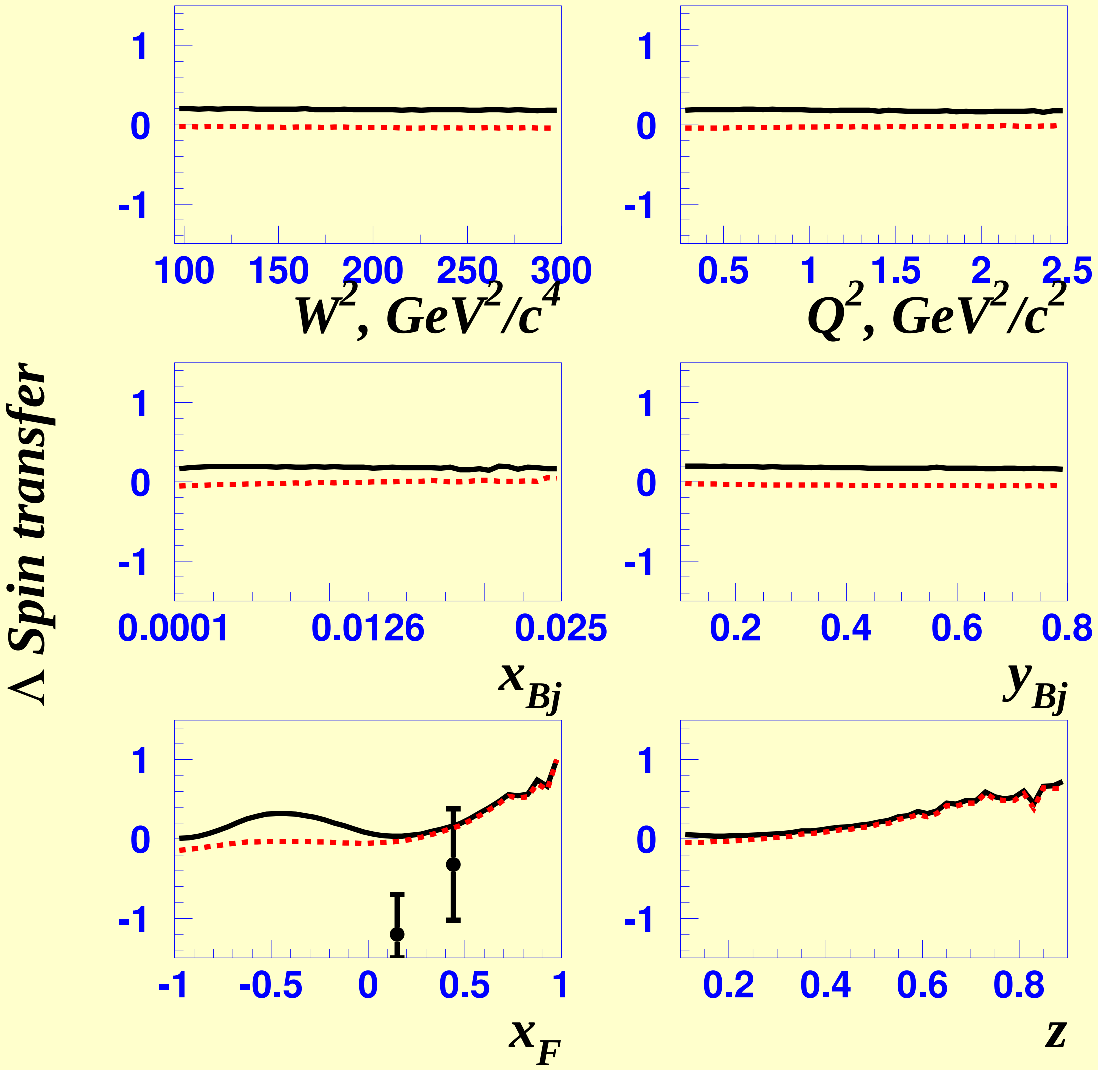


Figure 5: Our model predictions (model A - solid line, model B - dashed line) for the spin transfer of Λ hyperons produced in μ^+ DIS interactions off nuclei as functions of W^2, Q^2, x_{Bj}, y_{Bj}, x_F and z (at $x_F > 0$). ($E_\mu = 470$ GeV)

Predictions for COMPASS

The spin-correlation coefficient for the sea quark is different in **model A:** and **model B:**

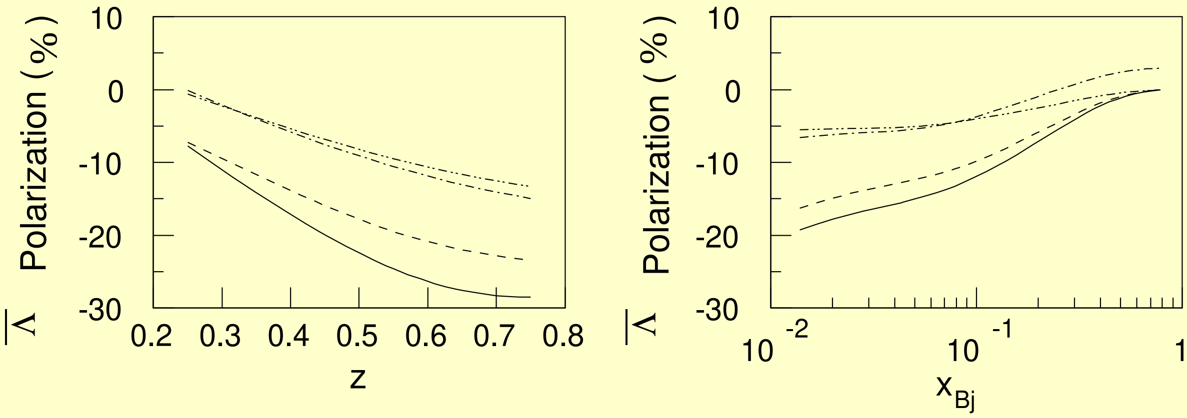
$x_{min} = 0.003$ in the COMPASS, so we expect different polarizations of Λ in these two cases:

Table 4: Λ *polarization in* μ^+ *DIS predicted for the COMPASS experiment for* $Q^2 > 1.$ *GeV*^{2}, $x_F > -0.2$ *and* $0.5 < y < 0.9$.

P_Λ (%)	Target nucleon		
	isoscalar	proton	neutron
model A	-7.3	-7.3	-7.2
model B	-0.4	-0.4	-0.4

Contary to Λ's, $\bar{\Lambda}$'s produced in the CFR are mainly originating from the quark fragmentation.

Old calculations (to be revised)
A.K., A. Bravar & D. von Harrach (1998)
predict significant polarization in CFR:



Predictions for $\bar{\Lambda}$ polarization in COMPASS for different mechanisms of spin transfer:

———— *NQM*

– – –– *BGH (SU(6)+heavier hyperons)*

$\cdots$ *and* $- \cdot -$ *BJ*

Conclusions

Λ's @ COMPASS

- The preliminary analysis of 2002 data shows that COMPASS will collect about 100k of Λ and $\bar{\Lambda}$
- A polarized intrinsic strangeness + SU(6) model is able to describe all available data on Λ longitudinal polarization in SIDIS in full kinematic range
- Within this model the NOMAD data imply negatively polarized strange see in the proton
- Further checks of this model is possible in COMPASS
- Energies in the running experiments are too low to distinguish between different (SU(6) and BJ) models for spin transfer in quark fragmentation for Λ production
- $\bar{\Lambda}$ production can be a good candidate for this task