Longitudinal Λ Polarization at HERMES

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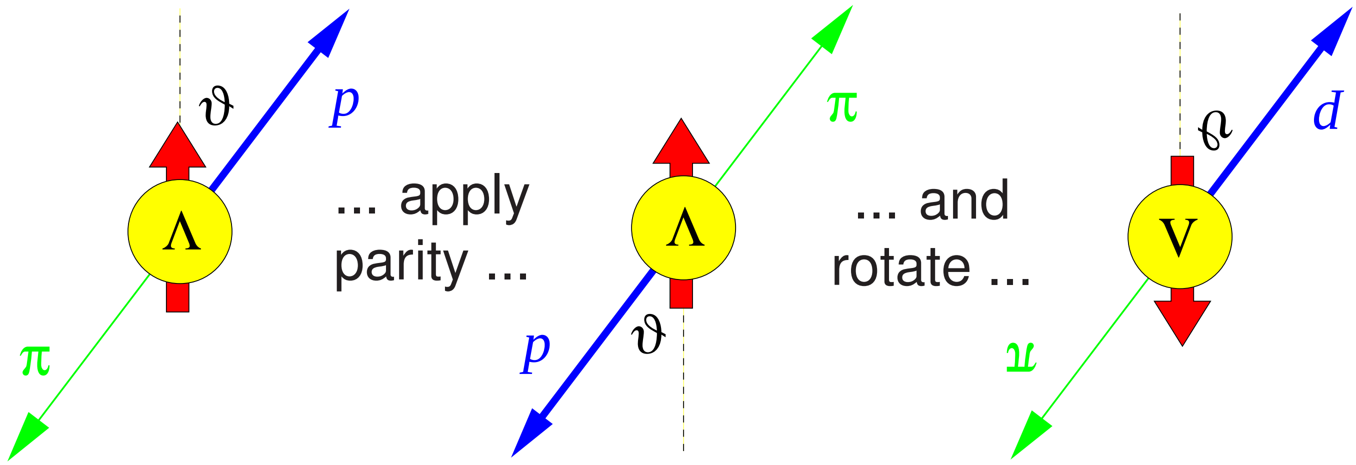
- The Λ ***Hyperon*** : a unique particle in spin physics
- ***HERMES results*** on spin-transfer $D_{LL'}$
- ***Monte Carlo model*** of $D_{LL'}$
- ***Interpretation and Outlook***

Λ: The Final State Polarimeter

In Λ rest frame, **proton** prefers to be emitted along
Λ spin direction ➡ **parity-violating** weak decay



$$\frac{dN}{d\Omega_p} \sim (1 + \alpha \vec{P}^{\Lambda} \cdot \hat{k}_p) = (1 + \alpha P^{\Lambda} \cos\theta_p)$$

$\alpha = 0.642$ ... θ_p is relative to ***true*** Λ polarization direction

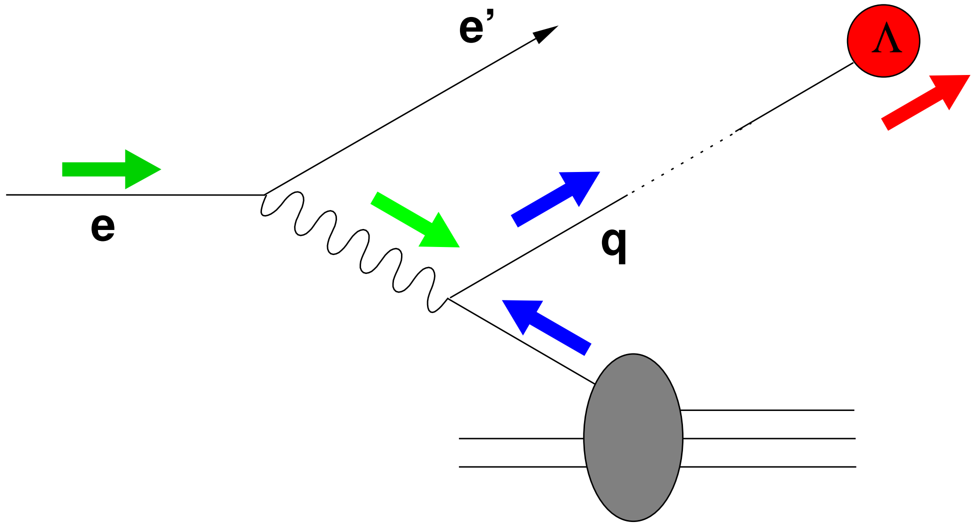
Λ spin structure

	Constituent q Model			SU(3) from nucleon*		
	Δu	Δd	Δs	Δu	Δd	Δs
p	+4/3	-1/3	0	+0.83	-0.43	-0.10
n	-1/3	+4/3	0	-0.43	+0.83	-0.10

* ***Burkardt & Jaffe*** : use measured p, n values +
SU(3)-symmetric flavour rotation to obtain hyperon values

Λ	**0**	**0**	**1**	**-0.17**	**-0.17**	**+0.63**
Σ^0	+2/3	+2/3	-1/3	+0.37	+0.37	-0.43
Ξ^0	-1/3	0	+4/3	-0.43	-0.10	0.83

Longitudinal Λ Polarization



$$\boxed{z \equiv \frac{E_\Lambda}{\nu}}$$

Using **polarized beam** and unpolarized target, measure ***longitudinal spin transfer*** in fragment$^{\underline{n}}$ from **struck** $q \rightarrow \boldsymbol{\Lambda}$

$$P_\Lambda = P_{\mathrm{beam}} \cdot D(y) \;\; \mathbf{D_{LL'}}$$

final state Λ polarization

struck quark polarization

spin transfer

$$\mathbf{D_{LL'}} = \frac{\sum e_q^2 q(x) \Delta D_q^\Lambda(z)}{\sum e_q^2 q(x) D_q^\Lambda(z)} = \sum \frac{\Delta D_q^\Lambda(z)}{D_q^\Lambda(z)} \cdot \omega_q^\Lambda(x)$$

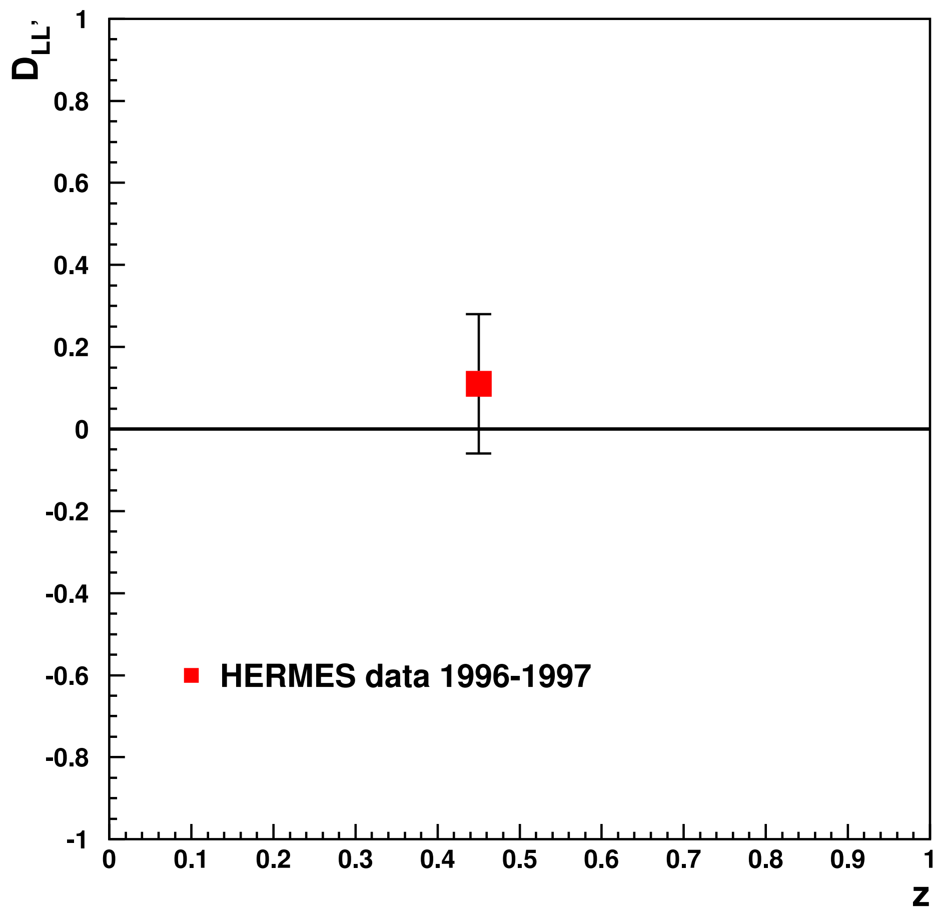
"purity"

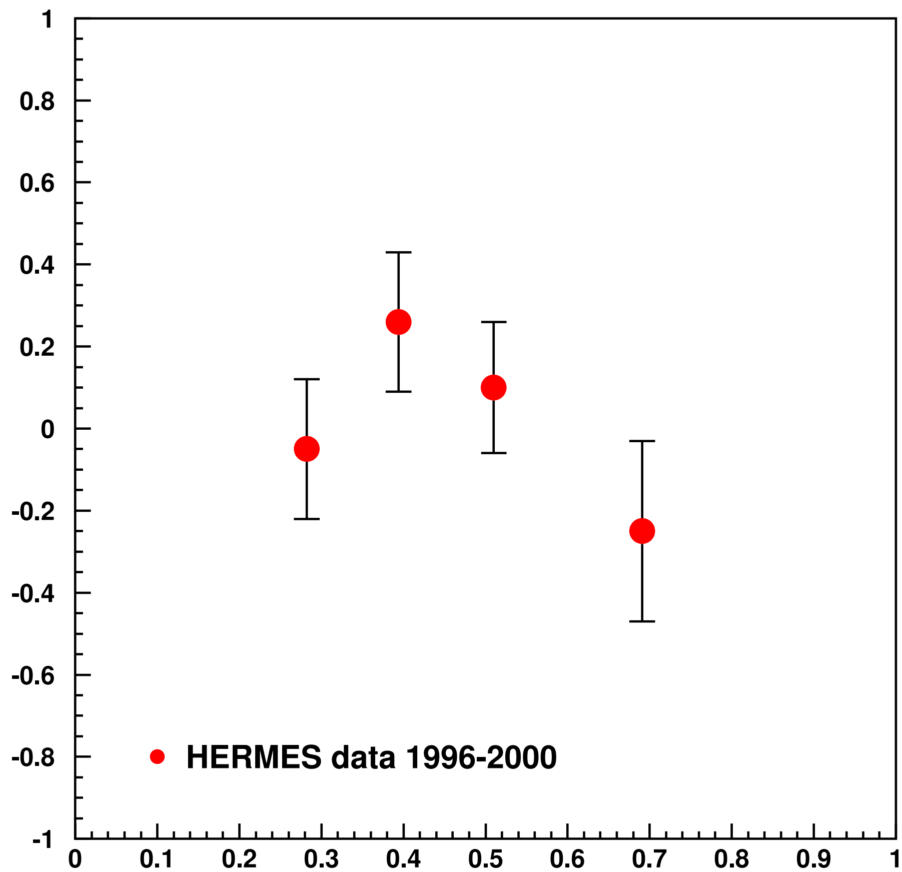
Spin transfer $\mathbf{D_{LL'}}$ sensitive to

- ***helicity conservation*** of quarks in fragmentation
- ***spin structure*** Δq^Λ of Λ itself

Experimental results

Spin–transfer data





$D^{\Lambda}_{LL'}$ = **0.04 ± 0.09**

- **Spin transfer is small and appears to decrease at high *z***

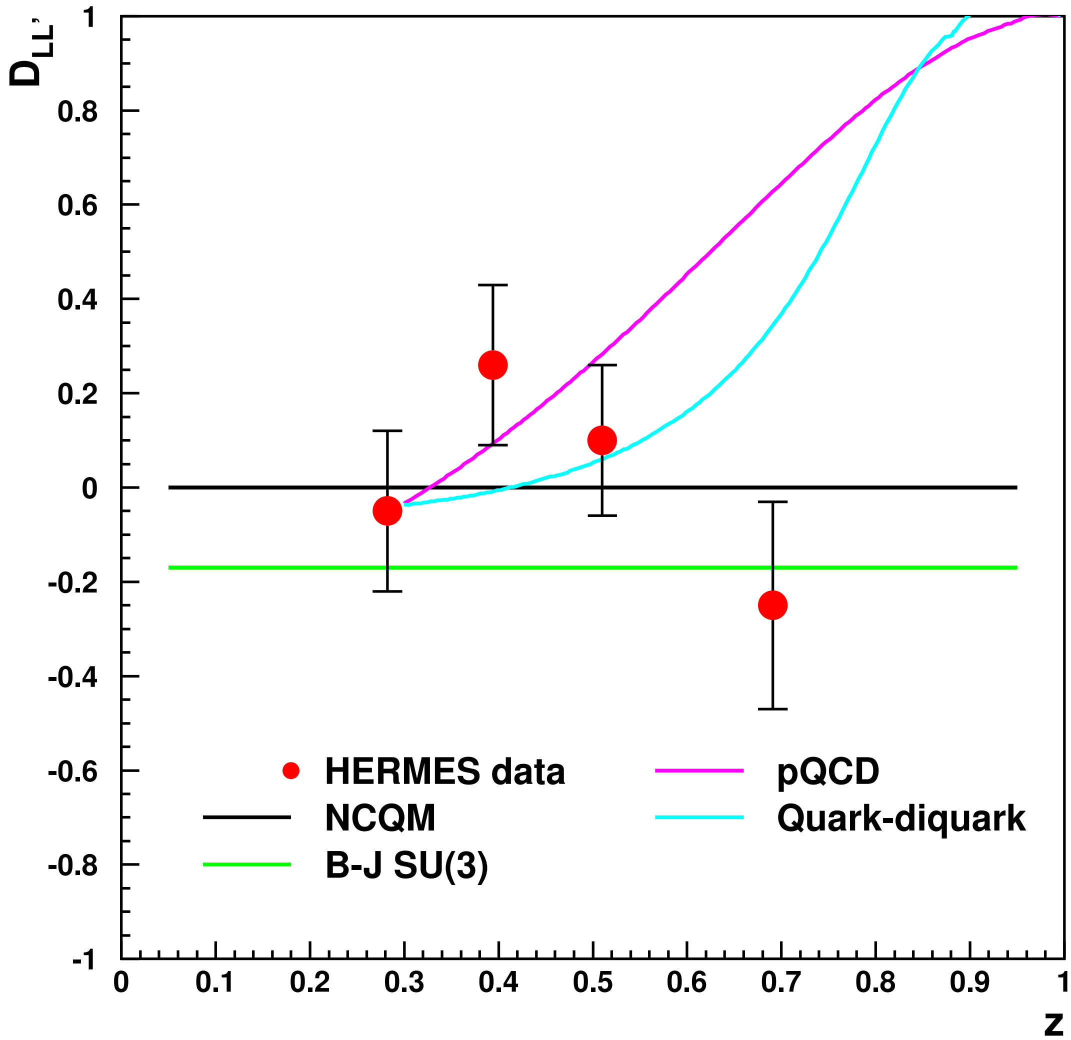
Model Predictions for $D_{LL'}$

Λ produc$^{\underline{n}}$ in DIS dominated by scattering from ***u quarks***

z-independent estimates

$D_{LL'} \approx \Delta u^{\Lambda}/u^{\Lambda}$

- **CQM** : $D_{LL'} \approx 0$
- **B-J SU(3)** : $D_{LL'} \approx -0.17$



z-dependent estimates

Ma et al, EPJC 16 657, PRD 65 034004

- **pQCD-based** and
- **quark-diquark** models predict

$\frac{\Delta q^{\Lambda}}{q^{\Lambda}} \to 1$ for all flavours $\Rightarrow$ spin transfer should ***rise with z***

Λ Spin Structure as $x \to 1$

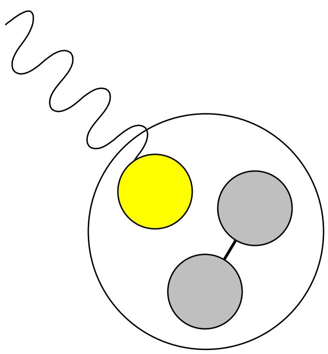
- **Gribov-Lipatov relation** $\boxed{q_h(x) \propto D_q^h(z)}$

endpoint easy to see:

$z_\Lambda \to 1$
Λ carries all energy ν of struck quark

$x_\Lambda \to 1$
struck q carries all energy of Λ

① Quark-Diquark Model



spectator diquark D in scalar or vector state

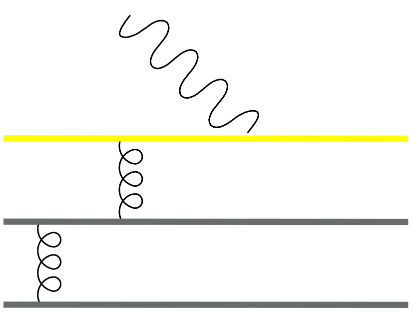
$$\psi_D(x, k_\perp) \sim \exp -[\frac{1}{8\beta_D^2}(\frac{m_q^2 + k_\perp^2}{x} + \frac{m_D^2 + k_\perp^2}{1-x})]$$

... as $x \to 1$, VECTOR diq config$^{\underline{\text{n}}}$ suppressed

$$\frac{d}{u} \to 0 \qquad \frac{F_2^n}{F_2^p} \to \frac{1}{4}$$

$$\frac{\Delta u}{u} \to 1 \qquad \frac{\Delta d}{d} \to -\frac{1}{3}$$

② pQCD Model



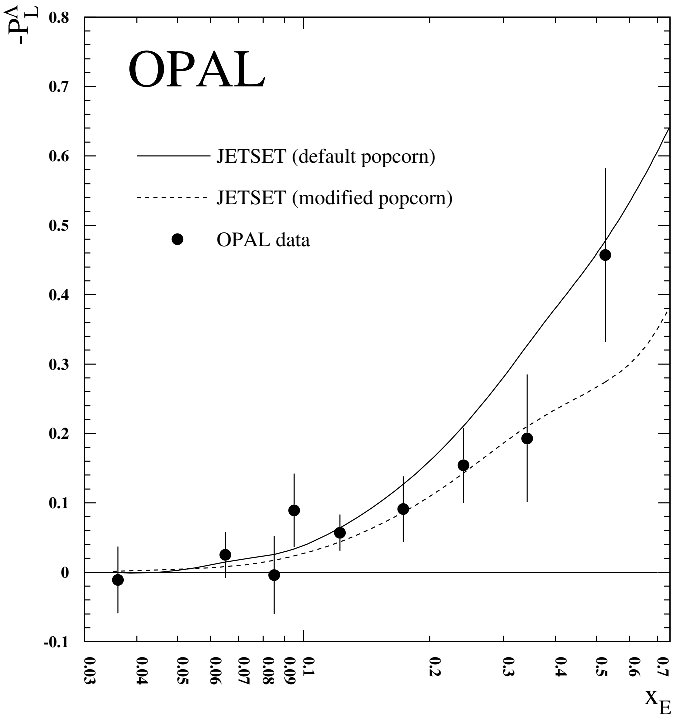
$x \to 1$ wavefn obtained from "normal" wavefn by exchange of large invariant mass gluons from spectator q's ... propagators $\sim \frac{1}{p^2}$ small
$\to$ small couplings, perturbative methods possible

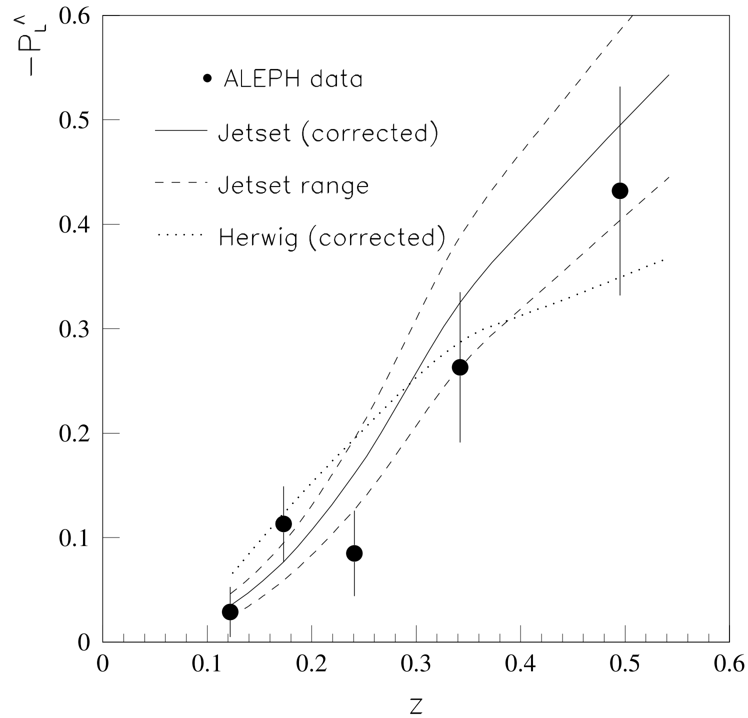
$$\frac{d}{u} \to \frac{1}{5} \text{ thus } \frac{F_2^n}{F_2^p} \to \frac{3}{7}, \quad \frac{\Delta q}{q} \to 1 \text{ for } u \text{ and } d$$

For Λ: Both models predict $\frac{\Delta q^\Lambda}{q^\Lambda} \to 1$ for all flavours!

ALEPH and OPAL: $e^+e^- \to Z \to \vec{q}\vec{\bar{q}} \to \vec{\Lambda}$

Large Λ polarization observed





Monte Carlo Model explains data well:

- **Hyperon Spin Structure:** simple CQM model
- **Fragmentation Process:**

  (1) Perfect ***helicity conservation*** of primary quark

  (2) Quarks from string breaks ***unpolarized***

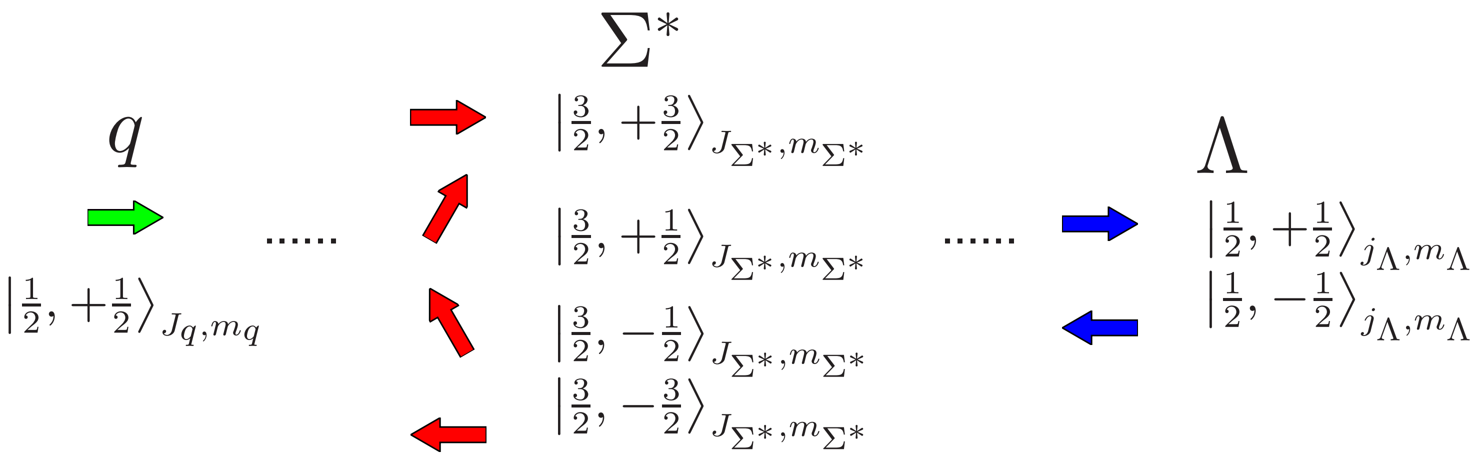
- Λ's originating from decay of **Heavier Hyperons** taken into account

→ only hyperons ***containing*** the primary, polarized quark are polarized

Modelling $D_{LL'}$

Calculate spin-xfer from $q^{\uparrow} \rightarrow \Lambda^{\uparrow}$,
through decay of Σ^{*}, Σ^{0}, Ξ

following Ashery, Lipkin, PLB 469 (1999) 263



production probability $R^{q\uparrow}_{m_{\Sigma^*}}$ $\otimes$ decay probability $D_{m_{\Sigma^*} \rightarrow m_\Lambda (m_x)}$

$$= \frac{\langle \Sigma^*; m_{\Sigma^*} | \hat{n}^{\uparrow}_q | \Sigma^*; m_{\Sigma^*} \rangle}{\sum_{m_{\Sigma^*}} \langle \Sigma^*; m_{\Sigma^*} | \hat{n}^{\uparrow}_q | \Sigma^*; m_{\Sigma^*} \rangle}$$

$$= |\langle J_{\Sigma^*}, m_{\Sigma^*} | m_\Lambda m_x \rangle|^2$$

e.g. Polarization of Λ formed from quark $q^{\uparrow}$ via Σ^* decay:

$$P^{\Lambda}_{q} = \sum_{m_{\Sigma^*}} R^{q\uparrow}_{m_{\Sigma^*}} \sum_{m_\Lambda} D_{m_{\Sigma^*} \rightarrow m_\Lambda (m_x)} \cdot \left(\frac{m_\Lambda}{j_\Lambda} \right)$$

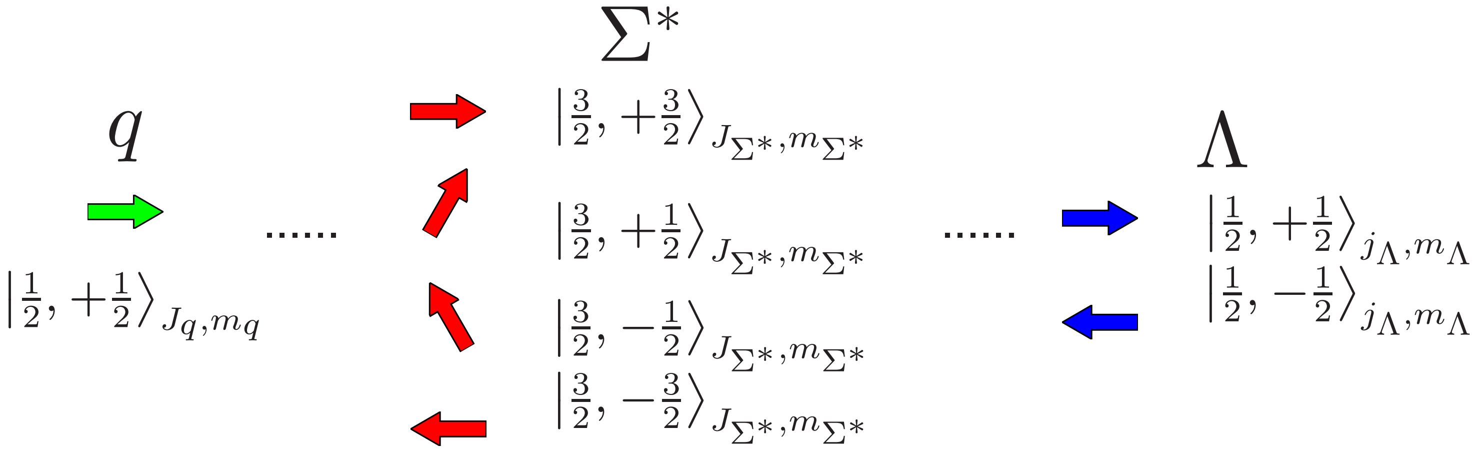
① Decay part

C-G coefficients, model-independent

Σ^* (spin-3/2) $\rightarrow \Lambda\pi$ (p-wave): $\boxed{P^{\Lambda} = P^{\Sigma^*}}$

$\Sigma^0 \rightarrow \Lambda\gamma$: $\boxed{P^{\Lambda} = -\frac{1}{3} P^{\Sigma^0}}$

$\Xi \rightarrow \Lambda\pi$: $\boxed{P^{\Lambda} = P^{\Xi}}$



② Production part

Expectation values of number operator $\hat{n}^{q\uparrow}$ related to first moments of parton distributions. In hyperon Y,

$$\begin{aligned}\langle \hat{n}_q^{\uparrow}\rangle_{m_Y=+J_Y} &= \frac{q_Y+\Delta q_Y}{2}\\ \langle \hat{n}_q^{\uparrow}\rangle_{m_Y=-J_Y} &= \langle \hat{n}_q^{\downarrow}\rangle_{m_Y=+J_Y} = \frac{q_Y-\Delta q_Y}{2}\end{aligned}$$

... for other m_Y states, interpolate betw these limiting values

➡ Polarization of hyperon Y formed from quark $q^{\uparrow}$:

$$\langle P_q^Y\rangle = \sum_{m_Y}\langle \hat{n}_q^{\uparrow}\rangle_{m_Y}\cdot\left(\frac{m_Y}{J_Y}\right) = \frac{\Delta q_Y}{q_Y}\cdot\frac{1}{2J_Y+1}\sum_{m_Y}\left(\frac{m_Y}{J_Y}\right)^2$$

<u>for spin-1/2 baryons (Λ,Σ,Ξ)</u>

$$\langle P_q^Y\rangle = \frac{\Delta q^Y}{q^Y}$$

<u>for spin-3/2 baryons (Σ^*)</u>

$$\langle P_q^Y\rangle = \frac{5}{9}\,\frac{\Delta q^Y}{q^Y}$$

$\Rightarrow$ Polarization of a hyperon produced from a polarized quark $\sim$ polarization of the quark in that hyperon

Spin-Transfer Coefficients C_q^Y

Spin transfer $D_{LL'}$ = Λ polarization given 100% polarized struck quarks (i.e. after γ-depolarizaton correction).

$$D_{LL'} = \sum_q \sum_Y f_q^Y C_q^Y$$

$\mathbf{f_q^Y}$ **= subprocess fraction** for producing Λ containing struck quark q, through parent hyperon Y

$\mathbf{q}$ = u, d, s (struck quark present in top-level hyperon Y)
= n (struck quark **NOT** present in Y)

$\mathbf{C_q^Y}$ **= spin-transfer coefficient** for same process:
$C_q^Y = \langle P_q^Y \rangle \cdot$ (decay part for $Y \to \Lambda$)

Δq^Y in Constituent Quark Model

$Y\backslash q$	Δu	Δd	Δs
Λ	0	0	+1
Σ^{*0}	+1	+1	+1
Σ^0	+2/3	+2/3	-1/3
Ξ^0	-1/3	0	+4/3

C_q^Y in Constituent Quark Model

$Y\backslash q$	u	d	s	n
Λ	0	0	+1	0
Σ^{*0}	+5/9	+5/9	+5/9	0
Σ^0	-2/9	-2/9	+1/9	0
Ξ^0	-1/3	0	+2/3	0

C_q^Y in SU(3) Symmetric Model (Burkardt & Jaffe)

$Y\backslash q$	u	d	s	n
Λ	-0.17	-0.17	+0.63	0
Σ^{*0}	+0.13	+0.13	+0.18	0
Σ^0	-0.12	-0.12	+0.14	0
Ξ^0	-0.43	-0.10	+0.42	0

C_q^Y in SU(3) Valence Model (Ashery & Lipkin)

$Y\backslash q$	u	d	s	n
Λ	-0.07	-0.07	+0.73	0
Σ^{*0}	+0.13	+0.13	+0.18	0
Σ^0	-0.16	-0.16	+0.11	0
Ξ^0	-0.33	0.00	+0.47	0

Struck Quark Tracing in JETSET

Simple assumptions on helicity conservation in fragmentation:

- helicity of struck quark 100% conserved
- helicity of other quarks 100% random

$\Rightarrow$ spin-transfer $C_q^Y = 0$ if parent hyperon Y does not contain struck quark

Must trace q_{struck} through JETSET $\rightarrow$ ***MSTU(16) = 2***

Tracing OFF $\rightarrow$ MSTU(16) = 1

I	particle/jet		KS	KF	orig	p_x	p_y	p_z	E	m
4	e+		1	-11	1	-1.514	-0.667	11.262	11.383	0.001
5	(u)		13	2	0	1.964	0.432	16.227	16.351	0.006
6	(ud_0)		13	2101	2	-0.450	0.235	0.081	0.774	0.579
7	(u)	A	12	2	5	1.964	0.432	16.227	16.351	0.006
8	(ud_0)	V	11	2101	6	-0.450	0.235	0.081	0.774	0.579
9	(string)		11	92	7	1.514	0.667	16.308	17.125	4.959
10	(pi0)		11	111	9	1.143	0.582	9.025	9.117	0.135
11	(rho+)		11	213	9	0.131	-0.810	3.518	3.672	0.663
12	(rho-)		11	-213	9	0.237	0.357	1.094	1.454	0.857
13	p+		1	2212	9	0.003	0.537	2.671	2.881	0.938
14	gamma		1	22	10	0.804	0.385	5.843	5.911	0.000
15	gamma		1	22	10	0.338	0.197	3.182	3.206	0.000

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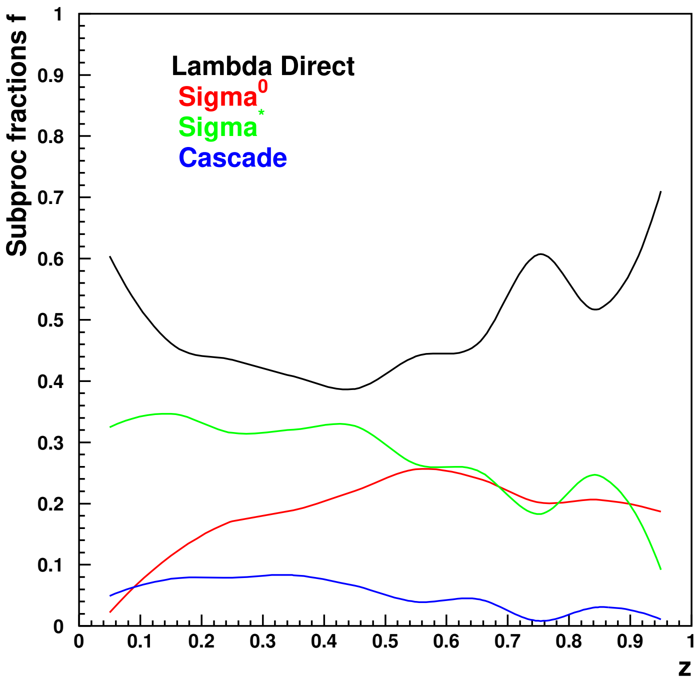
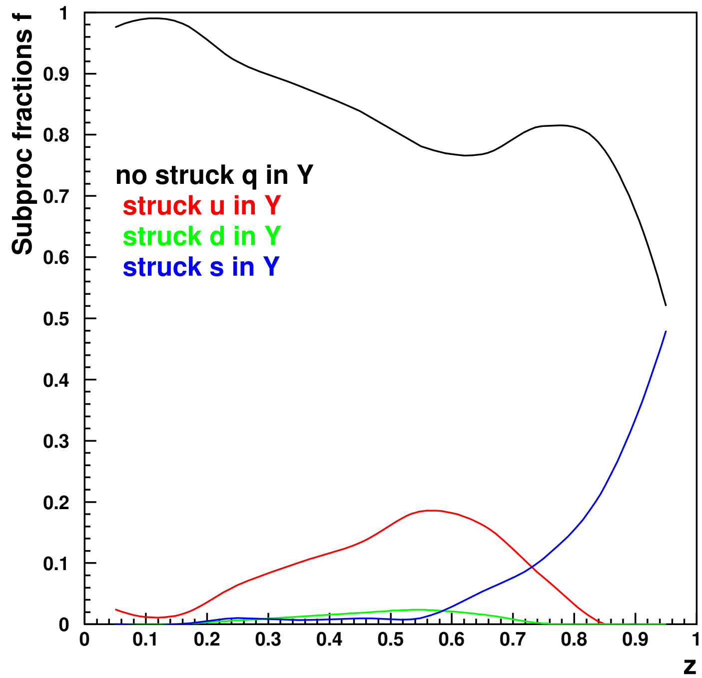
Monte carlo results

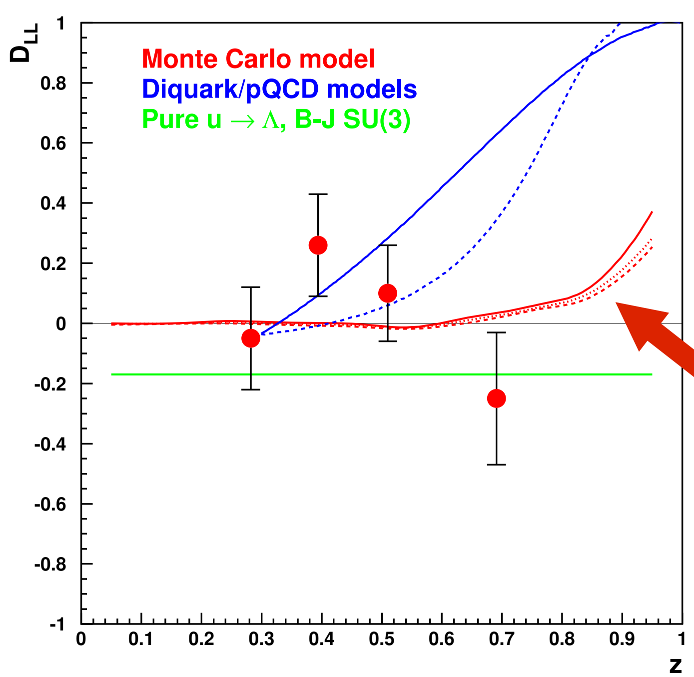
Direct sources of Λ



Quark parents of Λ



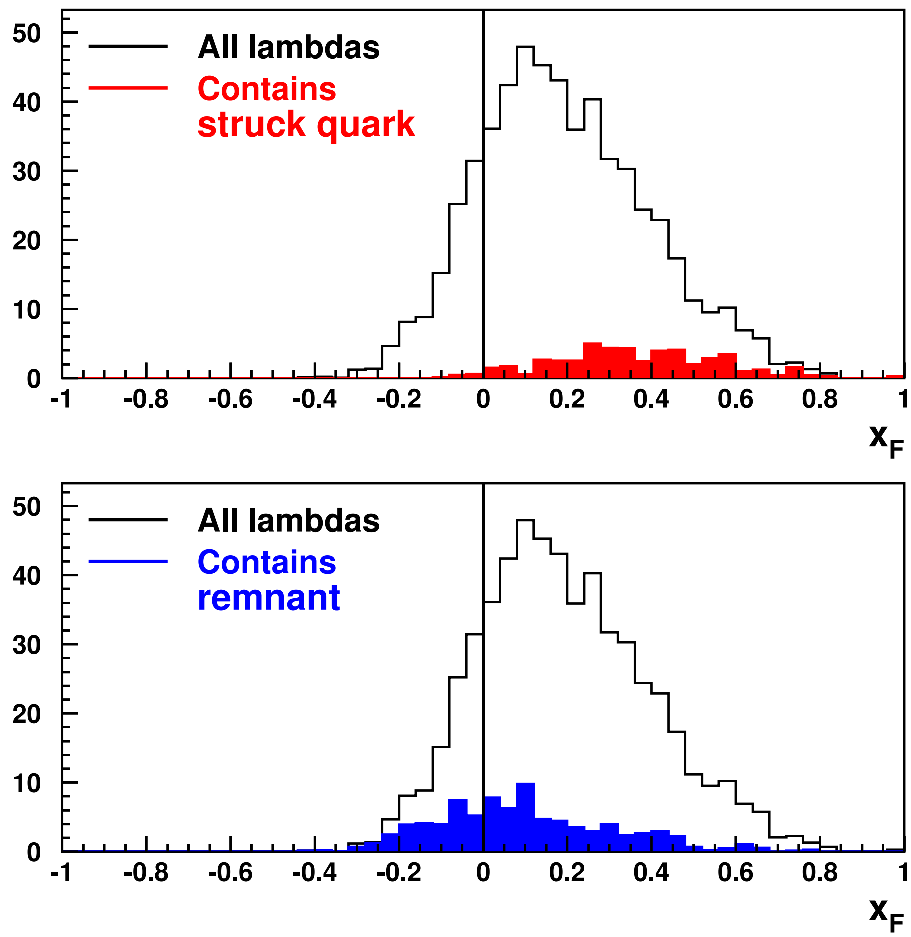
Final spin–transfer models



- **Significant contribution from heavy hyperon decays: 40% – 60% of all lambdas**
- **Very few lambdas contain struck quark: about 10% on average!**
- **Spin–structure models are relatively unimportant in comparison with monte carlo subprocess fractions**

Λ's from target remnant

Lambda x_F distributions



- **Most Λ's from struck quark are produced in forward region ($x_F > 0$)**
- **Significant number of Λ's from target remnant also have $x_F > 0$!!**
- **Lambda production mechanisms are complicated by influence of target remnant**

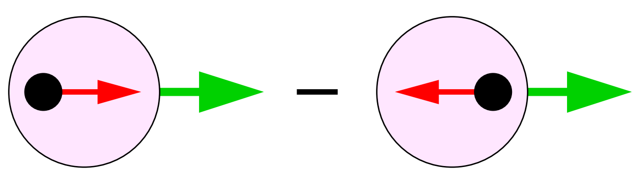
Future Access to Transversity with Λ?

Final State Polarization Idea: *R. Jaffe*

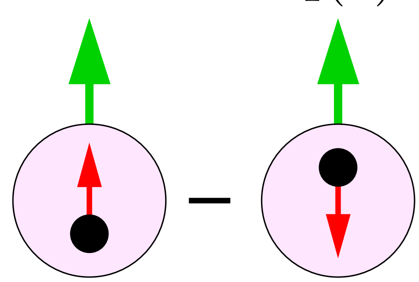
$$\boxed{d\sigma_{\mathrm{UTT}} \sim \cos(\phi^l_S + \phi^l_{S_h}) \cdot \mathbf{h_1}(x)\, \mathbf{H_1^{\perp}}(z)}$$

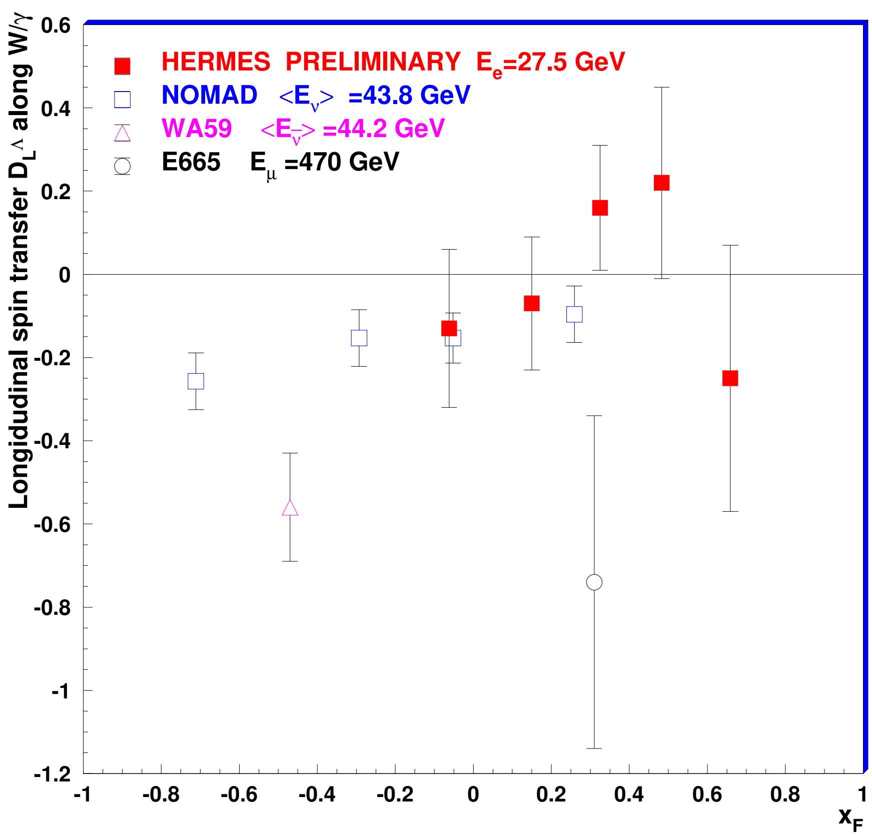
Method requires significant ***spin transfer***
from ***quark to*** Λ in fragmentation process ...

Longitudinal *spin transfer:* $G_1(z)$



Transverse *spin transfer:* $H_1(z)$



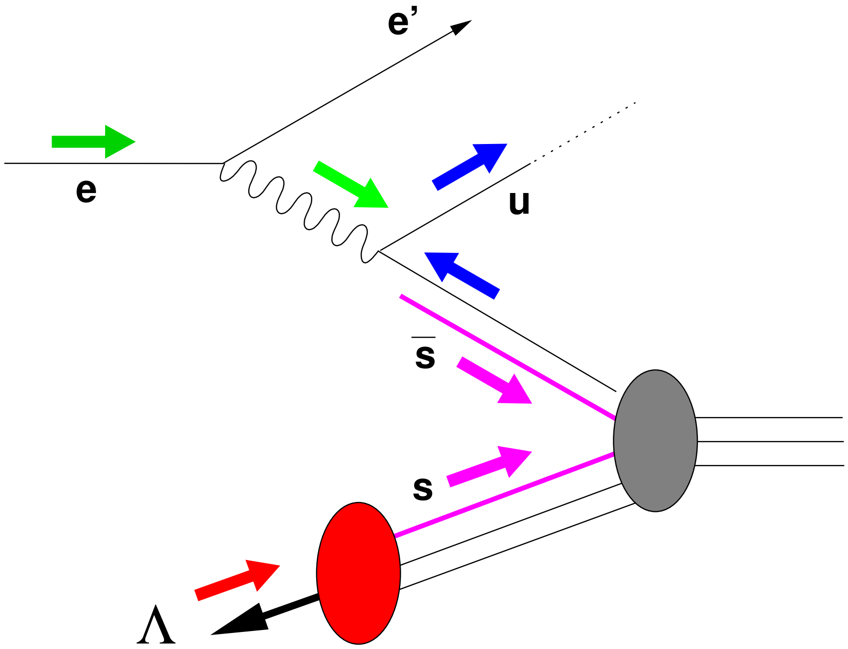


⋮

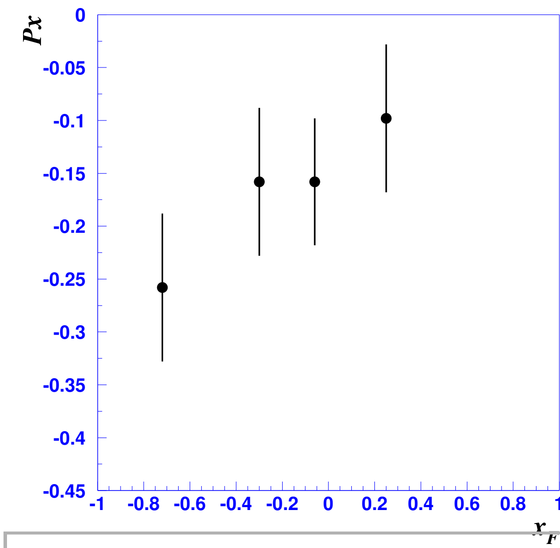
But 2000 data indicates **small** $G_1(z)$

$H_1(z)$ probably small too,
$\Rightarrow \Lambda^{\uparrow}$ likely ***not*** usable
as **polarimeter** for
initial-state quark

Λ Polarization at $x_F < 0$: Δs in proton



NOMAD, $E_\nu = 43$ GeV



$\Rightarrow \mathbf{D_{LL'}} < \mathbf{0}$ at $\mathbf{x_F} < \mathbf{0}$

Model of Ellis, Kharzeev, Kotzinian

ZPC 69 (1996) 467

- polarized $\vec{e}$ beam fixes struck u spin
- struck u and remnant $\bar{s}$ are in ***spin-singlet state***
  (attractive channel in QCD)
- $s\bar{s}$ pairs from proton sea are in $^3P_0$ ***state***
  (to get vacuum quantum numbers $J^{PC} = 0^{++}$)
- Λ spin is carried by s quark

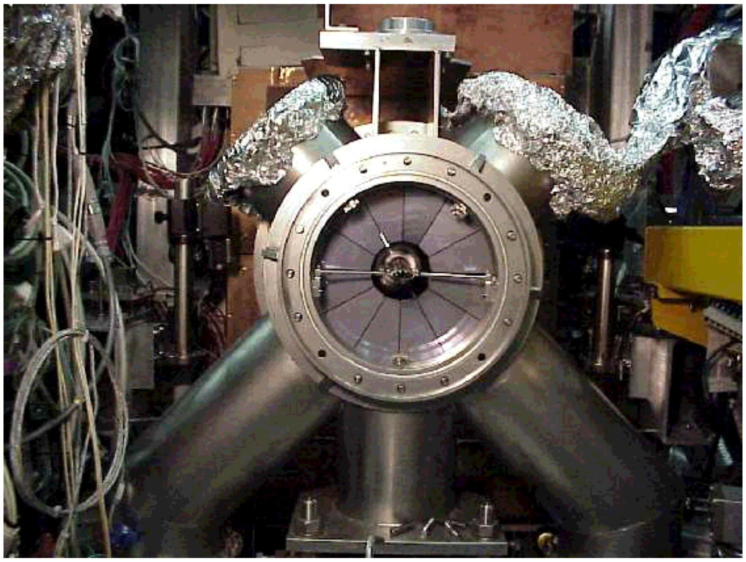
... but with polarized beam and target ...

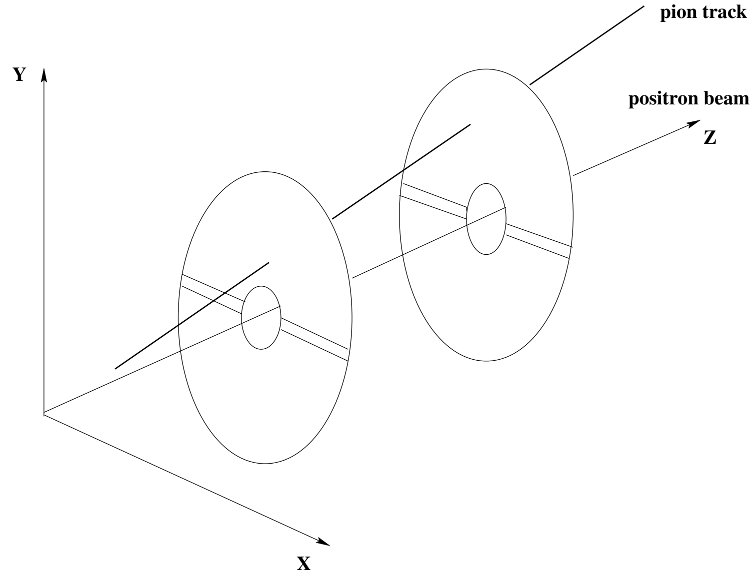
P_Λ directly sensitive to s-quark spin, and $\therefore$ to $\mathbf{\Delta s}$ ***in proton***

$$P_\Lambda = \frac{\sum_i e_i^2 \,[\, P_T \mathbf{\Delta q_i(x)} - P_B D(y) q_i(x) \,] c_{sq}}{\sum_i e_i^2 \,[\, q_i(x) - P_B P_T D(y) \mathbf{\Delta q_i(x)} \,]}$$

Silicon Lambda Wheels

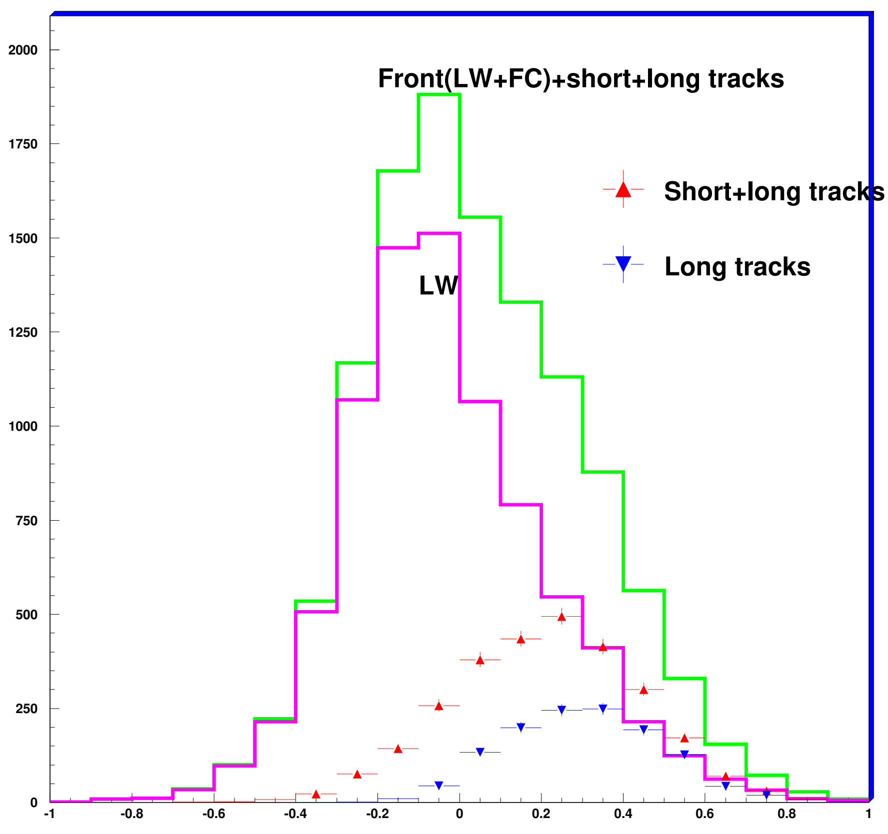
New detector installed in 2001 near target cell





idea: detect π^- from Λ at **large angles** $\Rightarrow$

open up acceptance in target-fragmentation region $x_F < 0$



Conclusions

- Small **spin transfer** observed: from 1996 - 2000 data,

  $$D_{LL'}^{\Lambda} = 0.04 \pm 0.09 \quad \text{at } x_F > 0$$

  Consistent with **no z-dependence** from z = 0.2 – 0.7

- Significant contribution from **heavier hyperon decays** (about 40 - 60%)

- **Very few** Λ's contain **struck quark** (about 10%); explains small spin transfer, in one model

- Even at $x_F > 0$, many Λ's contain **target remnant**

  ⇒ can't use Λ as "polarimeter" for initial-state quark spin in intermediate-energy DIS

  ⇒ CAN use Λ to explore target fragmentation region ... possible sensitivity to Δs?

- New **Lambda Wheels** recently installed: open up acceptance to target-fragmentation region at $x_F < 0$