The Structure of Λ Hyperon:

Theory & Experiment

Bo-Qiang Ma (Peking University)

Outline

- The Motivation
- Distribution and Fragmentation Functions
- Case Study: $e^+ + e^- \to \vec{\Lambda} + X$
- Case Study: $\vec{l} + N \to \vec{\Lambda} + X$
- Case Study: $\bar{\Lambda} / \Lambda$ Ratio in $l + N \to l' + \Lambda(\bar{\Lambda}) + X$
- Conclusions

Our View of the Proton

with history

- Point-Like — 1919
- Finite Size with Radius — 1930s-1950s
- Quark Model — 1960s
- QCD and Gluons — 1970s
- Puzzles and Anomalies — 1980s-present

  - Quark Sea of the Nucleon
  - Baryon-Meson Fluctuations
  - Statistical Features
  - ....

Surprises & Unknown

about the Quark Structure of Nucleon: Sea

- **Spin Structure:** $\Sigma = \Delta u + \Delta d + \Delta s \approx 0.3$

  "puzzle": where is the proton's missing spin

- **Strange Content** $\Delta s \neq 0 \quad s(x) \neq \bar{s}(x)$

  Brodsky & Ma, PLB381(96)317

- **Flavor Asymmetry** $\bar{u} \neq \bar{d}$

- **Isospin Symmetry Breaking** $\bar{u}_p \neq \bar{d}_n \quad \bar{d}_p \neq \bar{u}_n$

  Ma, PLB 274 (92) 111
  Boros, Londergan, Thomas, PRL81(98)4075

Unknown about the nucleon: valence

$x \to 1$ behaviors of flavor and spin

- **Flavor**

$\frac{d(x)}{u(x)} \to 0$ Diquark Model

$\frac{d(x)}{u(x)} \to \frac{1}{5}$ pQCD

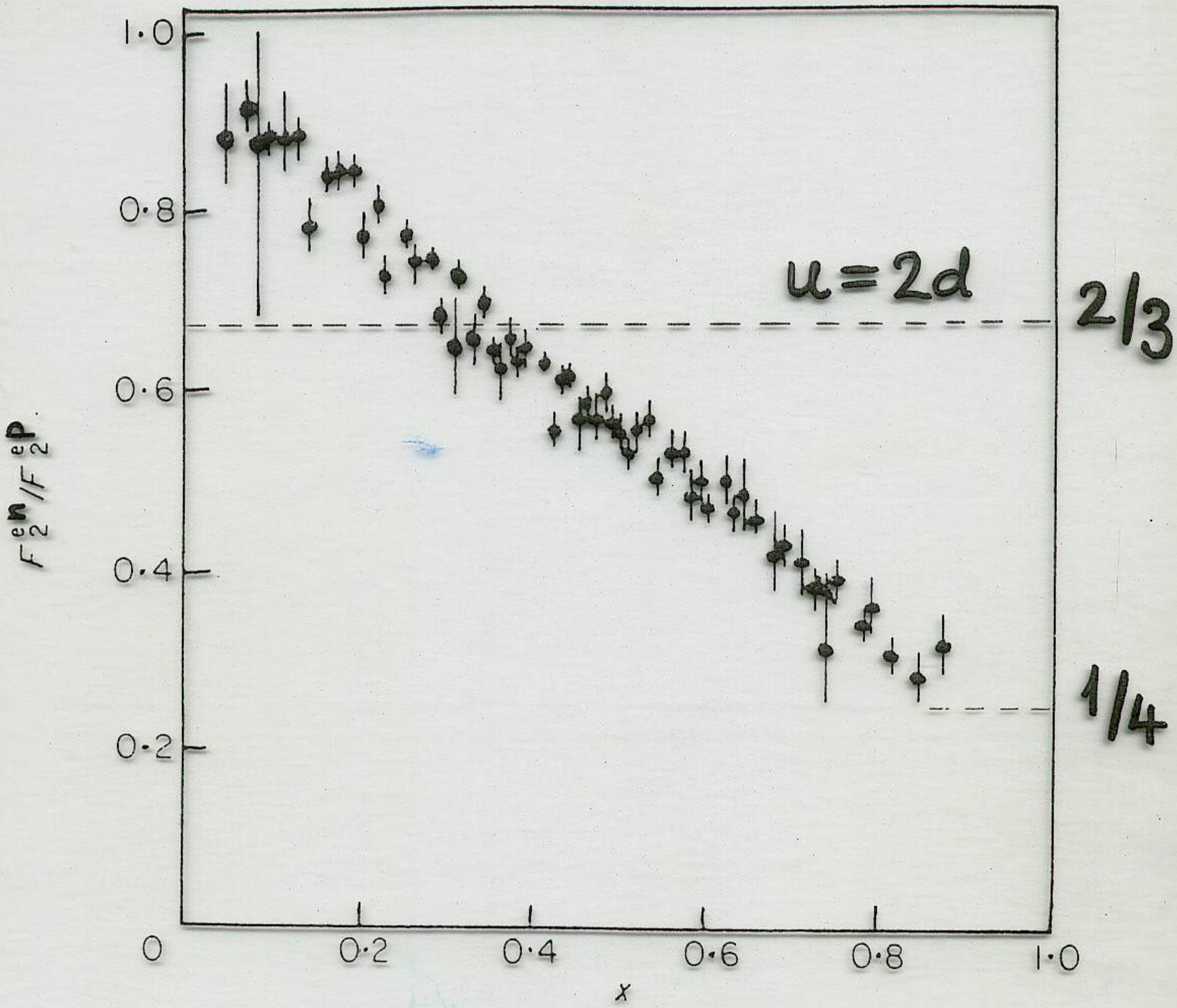
$\frac{F_2^n(x)}{F_2^p(x)} \to \frac{1}{4}$ Diquark Model

$\frac{F_2^n(x)}{F_2^p(x)} \to \frac{3}{7}$ pQCD

- **Spin**

$\frac{\Delta d(x)}{d(x)} \to -\frac{1}{3}$ Diquark Model

$\frac{\Delta d(x)}{d(x)} \to 1$ pQCD



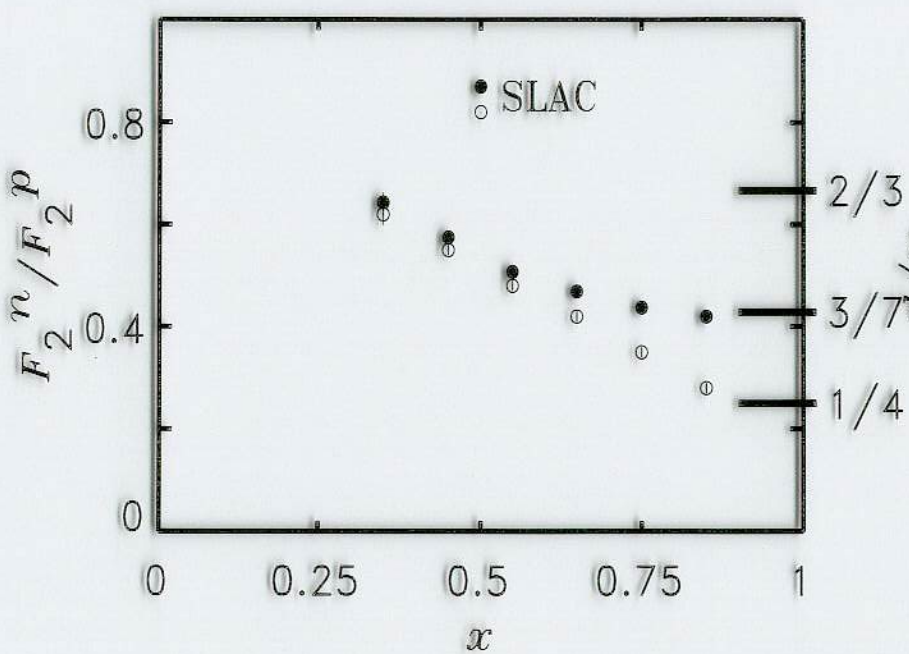
An Introduction to Quarks and Partons

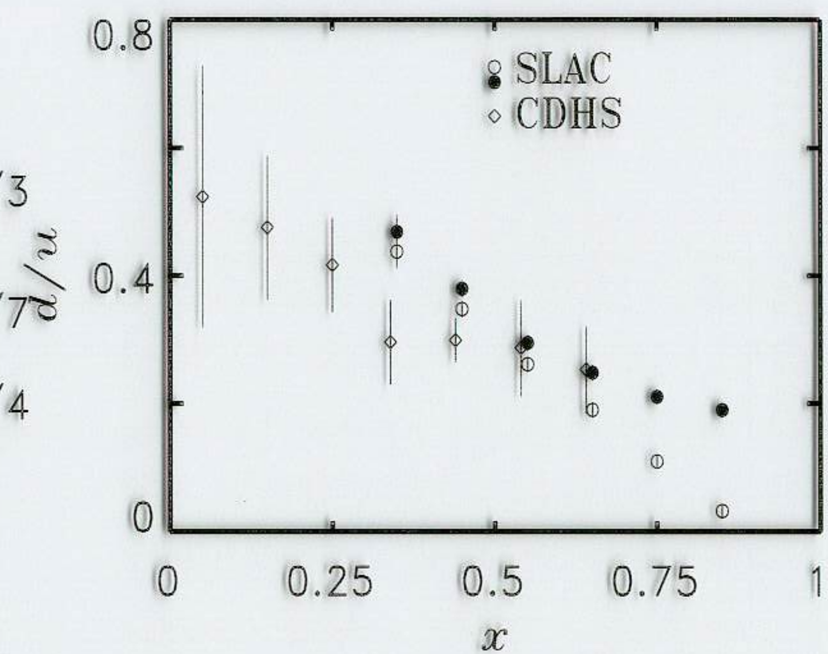
F. E. Close
Rutherford Laboratory
Didcot, Oxfordshire

ACADEMIC PRESS
LONDON NEW YORK SAN FRANCISCO

Flavor Content of the Proton

with nuclear binding correction

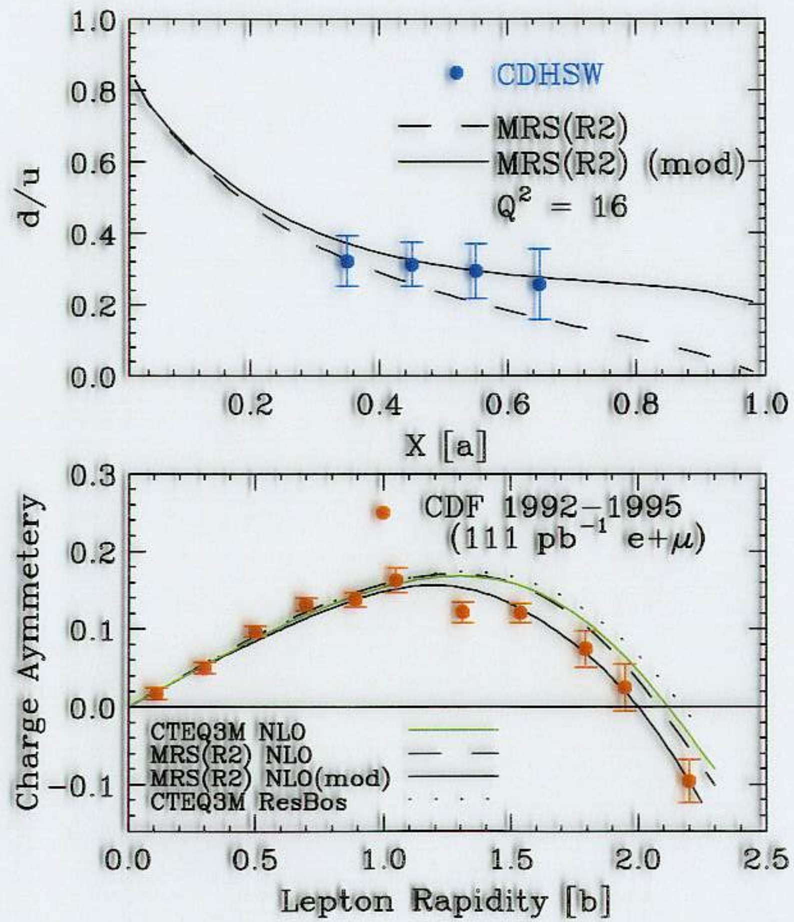




W.Melnitchouk & A.W. Thomas
PLB 377(1996) 11

Flavor Content of the Proton

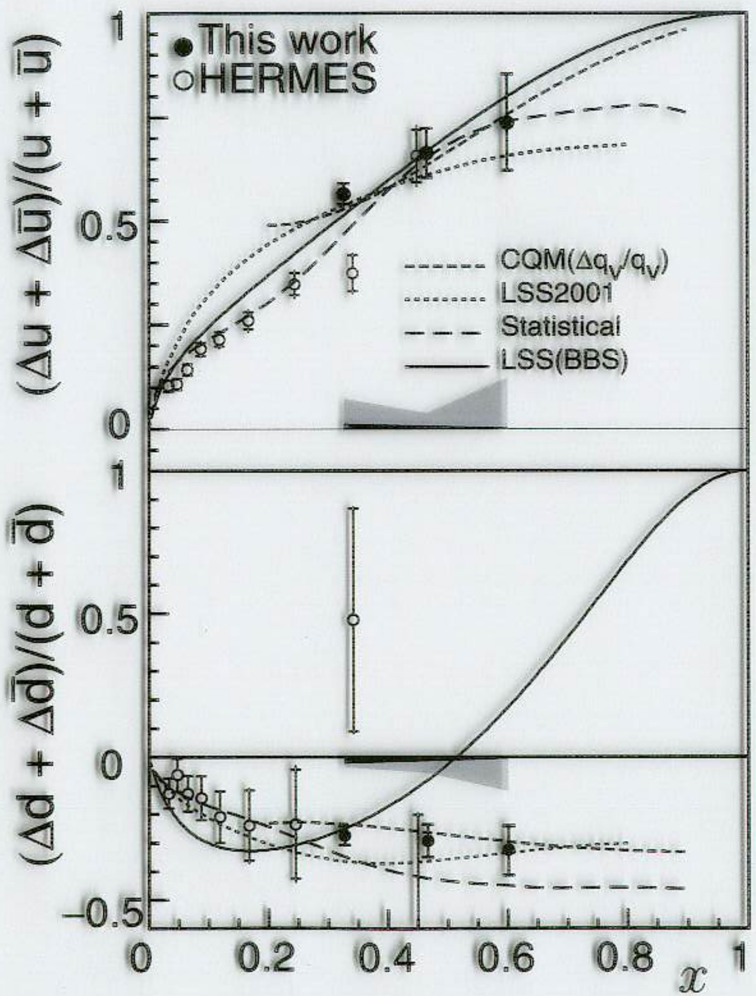
from DIS neutrino data analysis



U.K. Yang & A. Bodek
PRL 82 (1999) 2467.

Quark Helicity Distributions of Proton

Measurements at JLAB and HERMES



JLAb Hall A Collaboration
nucl-ex/0308011, PRL

Present Status

of the Flavor and Spin Contents of the Proton

- Flavor favors pQCD
- Spin favors diquark model

Contradiction!

How to Test Various Theories ?

N Quark Structure → • High Precision of Known Quantities

• New Quantities δq

↓ new domain

Λ Quark Structure

" Λ Physics "

PRL 70 (93) 2537

Burkardt-Jaffe SU(3) Argument:

$$\int_0^1 dx\, g_1^{e\Lambda}(x) = \frac{1}{18}(2\Sigma - D)$$

$$= \int_0^1 dx\, g_1^{ep}(x) - \frac{1}{18}(2D + 3F)$$

$$= -0.042 \pm 0.019$$

$$\Delta u^\Lambda = \Delta d^\Lambda = \frac{1}{3}(\Sigma - D) = -0.23 \pm 0.06$$

$$\Delta s^\Lambda = \frac{1}{3}(\Sigma + 2D) = 0.58 \pm 0.07$$

whereas the Quark Model predicts

$$\Delta u^\Lambda = \Delta d^\Lambda = 0$$

$$\Delta s^\Lambda = 1$$

PRL 82 (99) 2250

Ma - Soffer

u. d polarizations in Λ

is related to s polarization in N

- $P(uuds\bar{s}) = \Lambda(uds)\,K^+(u\bar{s})$

- $$\begin{cases} \Lambda(udsu\bar{u}) = P(uud)\,K^-(s\bar{u}) \\ \Lambda(udsd\bar{d}) = n(udd)\,K(s\bar{d}) \end{cases}$$

Phys. Lett. B477 (2000) 107. hep-ph/9906424

Ma-Schmidt-Yang $x \to 1$ behaviors

- Flavor

$$\frac{u(x)}{s(x)} \to 0 \quad \text{Diquark Model}$$

$$\frac{u(x)}{s(x)} \to \frac{1}{2} \quad \text{pQCD}$$

- $$\frac{\Delta s(x)}{s(x)} \to 1$$

$$\frac{\Delta u(x)}{u(x)} \to 1$$

$\Delta u(x) = \Delta d(x) > 0$ at large x

$$\int_0^1 dx\, \Delta u(x) = \int_0^1 dx\, \Delta d(x) \leq 0$$

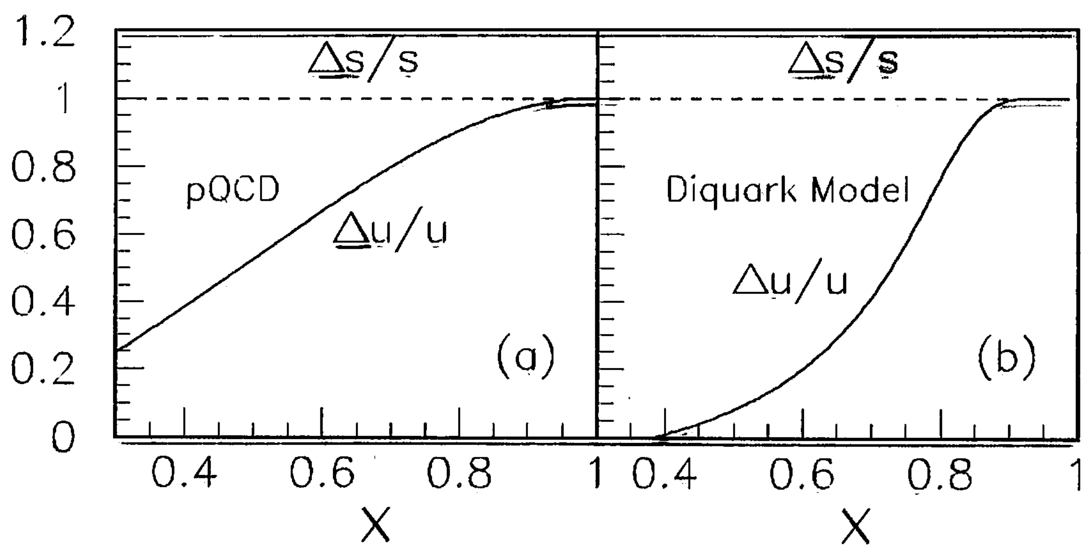


Figure 2: The ratios $\Delta s(x)/s(x)$ for the valence strange quark (dashed curves) and $\Delta u(x)/u(x)$ for the up and down valence quarks (solid curves) of the Λ from (a) pQCD and from (b) the SU(6) quark-diquark model.

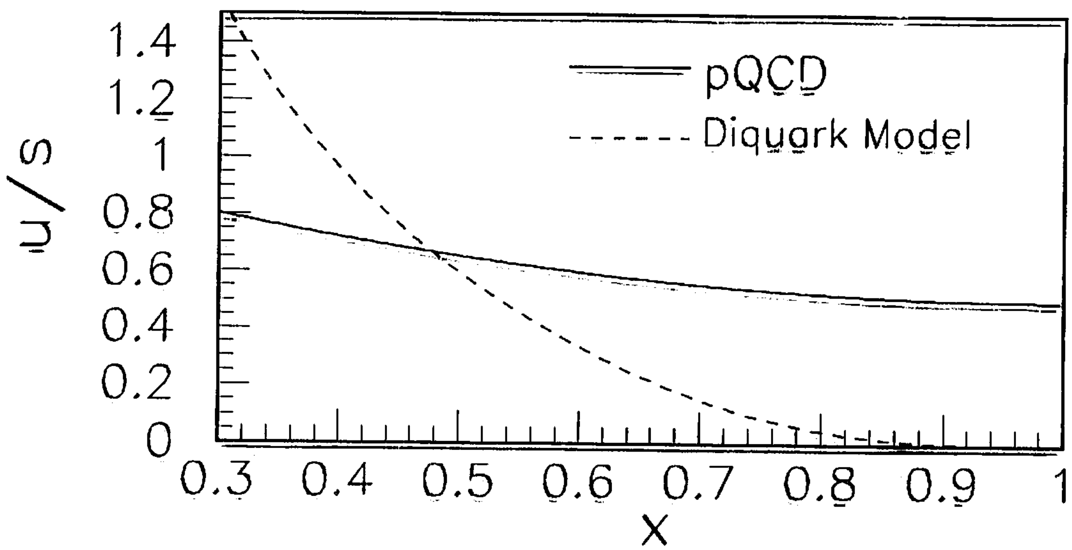


Figure 1: The ratio $u(x)/s(x)$ of the Λ from pQCD (solid curve) and the SU(6) quark-diquark model (dashed curve).

Quark-Diquark Model

S(ud) s

D(ds) u

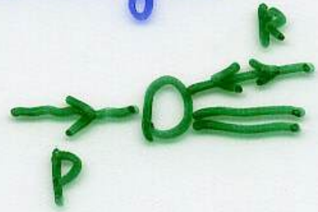
$u^{\uparrow} S(ds)$ $M_D = M_S$

$u^{\downarrow} V(ds)$ $M_D = M_V > M_S$

$$\psi(x) \approx e^{-\alpha\left(\frac{k_\perp^2 + M_q^2}{x} + \frac{k_\perp^2 + M_D^2}{1-x}\right)}$$

at $x \to 1$ $\psi_V(x) \ll \psi_S(x)$

pQCD Analysis



$q_h(x) \sim (1-x)^p$ $p = 2n - 1 + 2|\Delta S_z|$

$\Delta S_z = S_q - S_p$

$S_q = S_p$ $|\Delta S_z| = 0$

$S_q \neq S_p$ $|\Delta S_z| = 1$ suppressed

Λ-Hyperon Case

- naive quark model predicts:

$$\Delta u = \Delta d = 0\,, \quad \Delta s = 1$$

- Jaffe-Burkardt predict:

$$\Delta u = \Delta d = -0.2 \quad \Delta s = 0.6$$

- We predict:

$$\frac{\Delta u}{u} = \frac{\Delta d}{d} \to 1 \quad \text{at} \quad x \to 1$$

in Both quark-diquark model

and pQCD analysis

How to Measure $q^{\wedge}(x)$, $\Delta q^{\wedge}(x)$?

$$x = \frac{Q^2}{2p\cdot q}$$

$$q^{\wedge}(x) \propto D_q^{\wedge}(z)$$

$$z = \frac{2p\cdot q}{Q^2}$$

- space-like   time-like
- The Gribov-Lipatov reprocity relation
- parton distribution & parton fragmentation duality

A New Relation between distribution and fragmentation functions

V. Barone, A. Drago, B.-Q. Ma

Phys. Rev. C 62 (2000) 062201(R)

$$\frac{1}{z} D(z) = q\left(\frac{1}{z}\right)$$ Drell-Yan-Levy Relation

$$q\left(\frac{1}{z}\right) \simeq q\left(2-\frac{1}{z}\right)$$

$$\frac{1}{z} D(z) \simeq q\left(2-\frac{1}{z}\right)$$

$$\frac{1}{z} D(z) \simeq q(z)$$

$$z \to 1$$

B.-Q. Ma, I. Schmidt, J. Soffer, & J.-J. Yang

Phys. Lett. B 547 (2002) 245.

Various Processes to Measure $D_q^{\Lambda}(z)$, $\Delta D_q^{\Lambda}(z)$

- $e^+e^- \rightarrow \vec{\Lambda} + X$ — M. Burkardt & R. L. Jaffe PRL 70 (93) 2537
- $\vec{e} N \rightarrow \vec{\Lambda} + X$ — R. L. Jaffe. PRD 54 (96) R6581
- $p\vec{p} \rightarrow \vec{\Lambda} + X$ — D. de Florian, M. Stratmann, & W. Vogelsang, PRL 81 (98) 530
- $\nu N \rightarrow \vec{\Lambda} + X$ — $\dfrac{\Delta D_u^{\Lambda}(z)}{D_u^{\Lambda}(z)}$ — Kotzinian-Bravar-von Harrach, EPJ C2 (98) 329.

PRL 82 (99) 2467

Ma-Soffer Proposal:

Complete flavor separation of

$D_q^{\Lambda}(z)$, $\Delta D_q^{\Lambda}(z)$, $D_{\bar{q}}^{\Lambda}(z)$, $\Delta D_{\bar{q}}^{\Lambda}(z)$

- $\nu N \rightarrow \mu^- \vec{\Lambda} X$
- $\bar{\nu} N \rightarrow \mu^+ \vec{\Lambda} X$
- $\nu N \rightarrow \mu^- \vec{\bar{\Lambda}} X$
- $\bar{\nu} N \rightarrow \mu^+ \vec{\bar{\Lambda}} X$

Ma-Schmidt-Yang hep-ph/9907556

Nucl. Phys. B 574 (2000) 331

Σ^+ Valence: $x \to 1$

$\frac{s}{u} \to 0$ Diquark Model

$\frac{s}{u} \to \frac{1}{5}$ pQCD

$\frac{\Delta s}{s} \to -\frac{1}{3}$ Diquark Model

$\frac{\Delta s}{s} \to 1$ pQCD

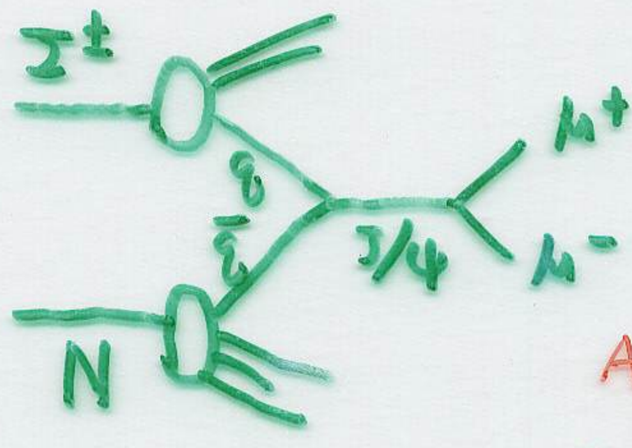
$\frac{\Delta u}{u} \to 1$

- Bigger difference at middle x

The Advantage of $\Sigma^{\pm}$

charged, as beam

$$\Sigma^{\pm} + N \rightarrow \mu^{+}\mu^{-} + X$$



Alberg et al. PLB 389 (96) 367

Ma, Schmidt, Yang, hep-ph/9[illegible]

The quark distributions can be measured

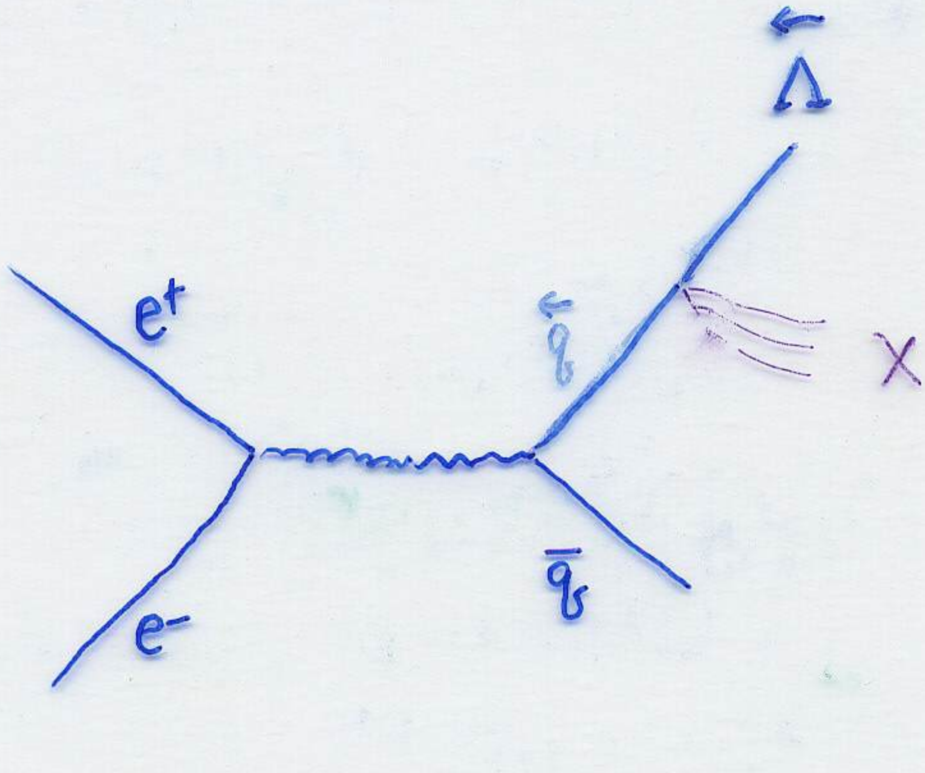
New Domain for { Theorists
Experimentalists

"Λ Physics"

The Quark Structure of Λ

spin & flavor

Quark Structure of Λ from Λ Polarization in Z^0 Decays



Λ Polarization

$$P_\Lambda = - \frac{\sum_q A_q \left(\Delta D_q^\Lambda(z) - \Delta D_{\bar{q}}^\Lambda(z) \right)}{\sum_q C_q \left(D_q^\Lambda(z) + D_{\bar{q}}^\Lambda(z) \right)}$$

$$P_q = \begin{cases} -0.67 & q = u, c \\ -0.94 & q = d, s, b \end{cases}$$

Λ Wave Function:

The SU(6) Quark Model

$$|\Lambda^{\uparrow}\rangle = \frac{1}{2\sqrt{3}}\left[(u^{\uparrow}d^{\downarrow} + d^{\downarrow}u^{\uparrow}) - (u^{\downarrow}d^{\uparrow} + d^{\uparrow}u^{\downarrow})\right] s^{\uparrow}$$

$$+ \text{(cyclic permutation)}$$

The Quark-Diquark Model

$$|\Lambda^{\uparrow}\rangle = \frac{1}{\sqrt{12}}\Big[V_0(ds)\,u^{\uparrow} - V_0(us)\,d^{\uparrow}$$

$$- \sqrt{2}\,V_{+1}(ds)\,u^{\downarrow} + \sqrt{2}\,V_{+1}(us)\,d^{\downarrow}$$

$$+ S(ds)\,u^{\uparrow} + S(us)\,d^{\uparrow} - 2S(ud)\,s^{\uparrow}\Big]$$

Unpolarized quark distributions for Λ:

$$u_v(x) = d_v(x) = \frac{1}{4} a_{V(qs)}(x) + \frac{1}{12} a_{S(qs)}(x)$$

$$s_v(x) = \frac{1}{3} a_{S(ud)}(x)$$

Polarized quark distributions

$$\Delta u_v(x) = \Delta d_v(x)$$

$$= -\frac{1}{12} a_{V(qs)}(x) W_{V(qs)}(x) + \frac{1}{12} a_{S(qs)}(x) W_{S(qs)}(x)$$

$$\Delta s_v(x) = \frac{1}{3} a_{S(ud)}(x) W_{S(ud)}(x)$$

The Brodsky-Huang-Lepage Prescription of Light-Cone Wave Function

$$\varphi(x,\vec{k}_\perp) = A_D \exp\left(-\frac{1}{8\alpha_D^2}\left[\frac{m_q^2+\vec{k}_\perp^2}{x} + \frac{m_D^2+\vec{k}_\perp^2}{1-x}\right]\right)$$

$$a_{D(q_1 q_2)}(x) \propto \int [d^2\vec{k}_\perp]\, |\varphi(x,k_\perp)|^2$$

$$\int_0^1 dx\; a_{D(q_1 q_2)}(x) = 3$$

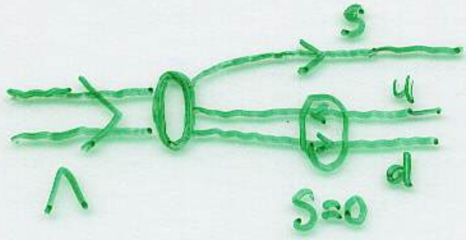
$$W_q(x,\vec{k}_\perp) = \frac{(k^+ + m_1)^2 - \vec{k}_\perp^2}{(k^+ + m_1)^2 + \vec{k}_\perp^2}$$

$$W_{D(q_1 q_2)}(x) = \int [d^2\vec{k}_\perp]\, W_{D(q_1 q_2)}(x,\vec{k}_\perp)\, |\varphi(x,\vec{k}_\perp)|^2 \Big/ a_{D(q_1 q_2)}(x)$$

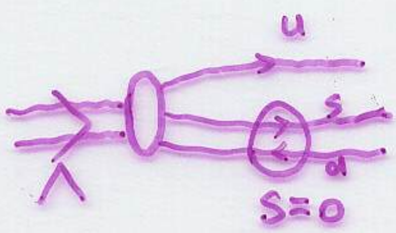
$m_q = 330$ u, d $\quad m_s = 480 \quad \alpha_D = 330$

$m_{S(ud)} = 600$, $m_{S(qs)} = 750$, $m_{V(qs)} = 950$

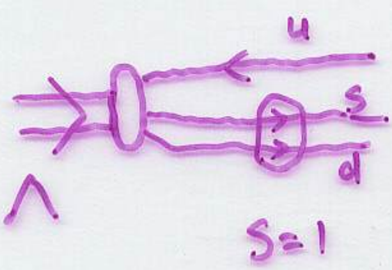
At large x: $a_{S(ud)}(x) > a_{S(qs)}(x) > a_{V(qs)}(x)$



Naive Quark Model



Spectator Diquark Model



$$\psi \propto e^{-\frac{M_S^2 \cdots}{1-x}}$$

suppressed at large x

$$\vec{S}_1 \cdot \vec{S}_2 = \frac{1}{2}(\vec{S}_1 + \vec{S}_2)^2 - \left(\frac{1}{2}\vec{S}_1^{\,2} + \frac{1}{2}\vec{S}_2^{\,2}\right)$$

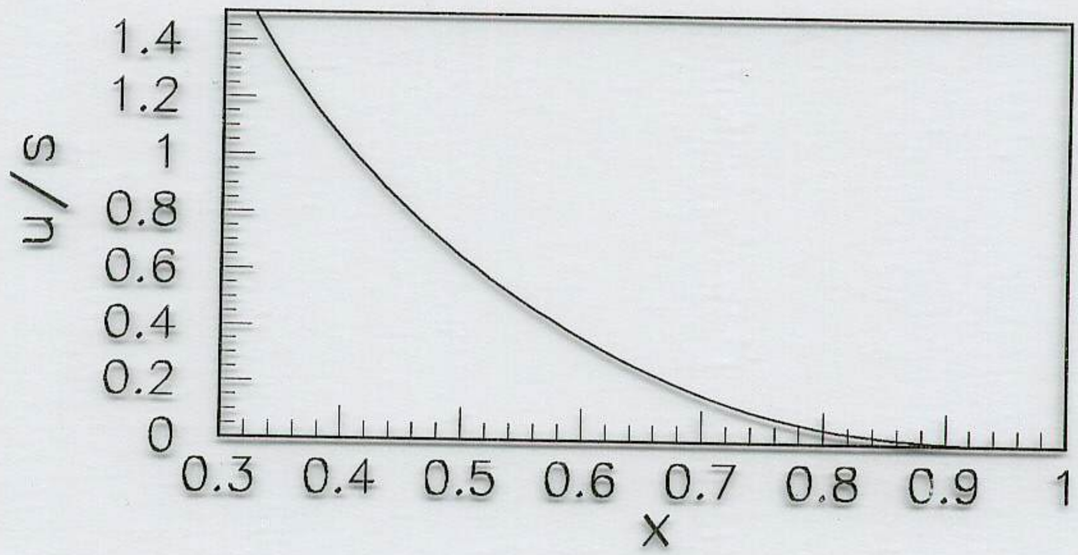


Figure 1: The ratio $u(x)/s(x)$ of the Λ in the SU(6) quark-diquark model

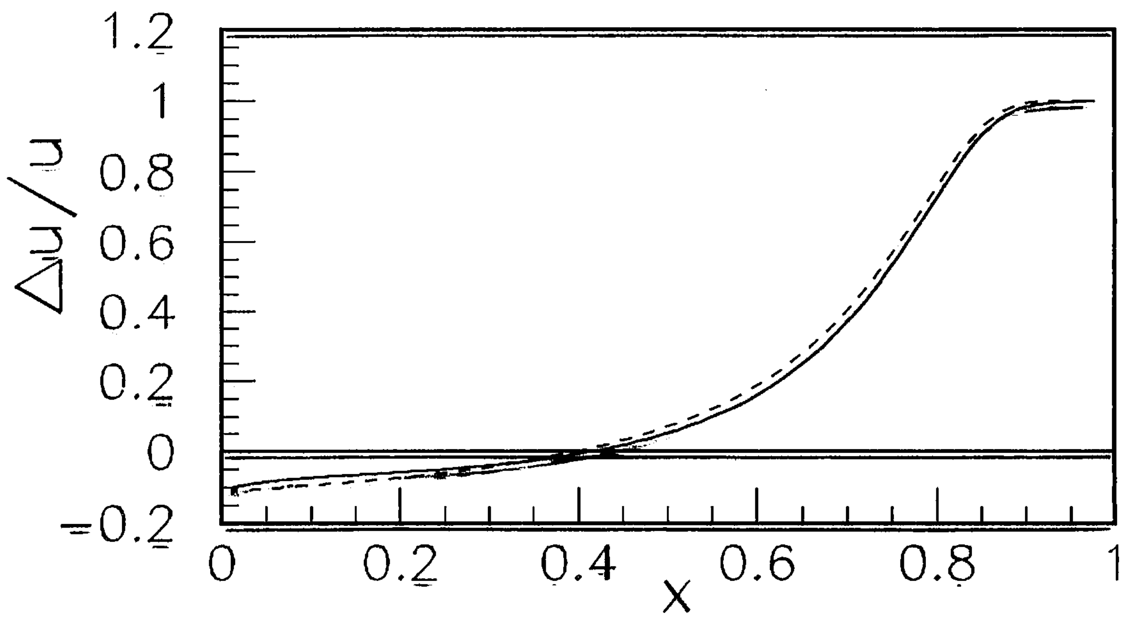


Figure 3: The ratio $\Delta u(x)/u(x)$ for the up and down valence quarks of the Λ in the SU(6) quark-diquark model. The solid and dotted curves are the corresponding results with (solid) and without (dotted) the Melosh-Wigner rotation.

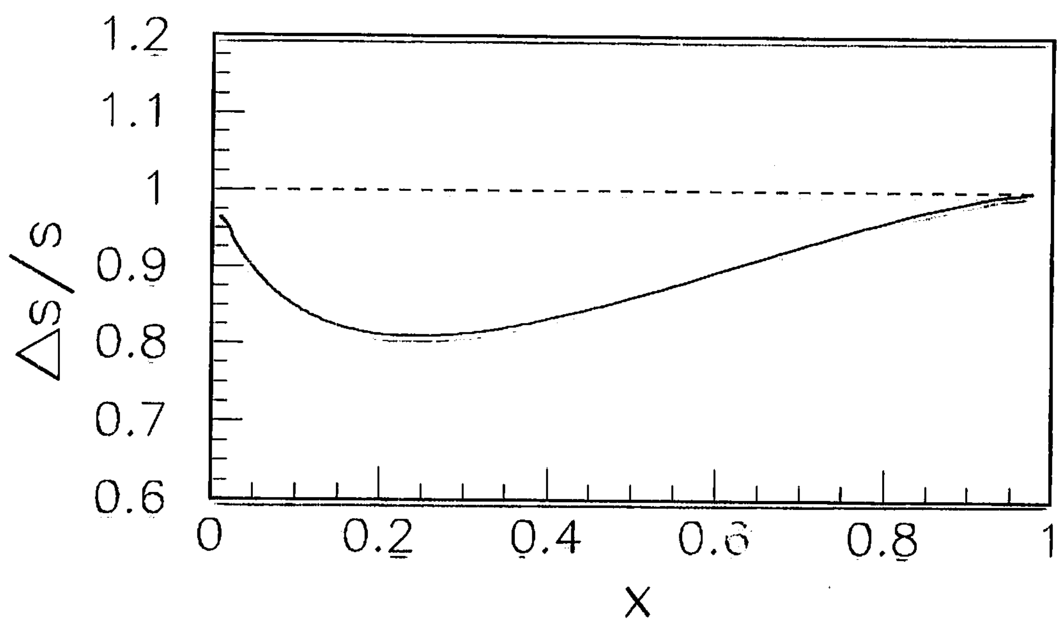


Figure 2: The ratio $\Delta s(x)/s(x)$ for the valence strange quark of the Λ in the SU(6) quark-diquark model. The solid and dotted curves are the corresponding results with (solid) and without (dotted) the Melosh-Wigner rotation.

PRD 61 (2000) 034017
by B.-Q. Ma, I. Schmidt, and J.-J. Yang

Longitudinal Λ-Polarization P_Λ in e^+e^--Annihilation in the Quark-Diquark Model

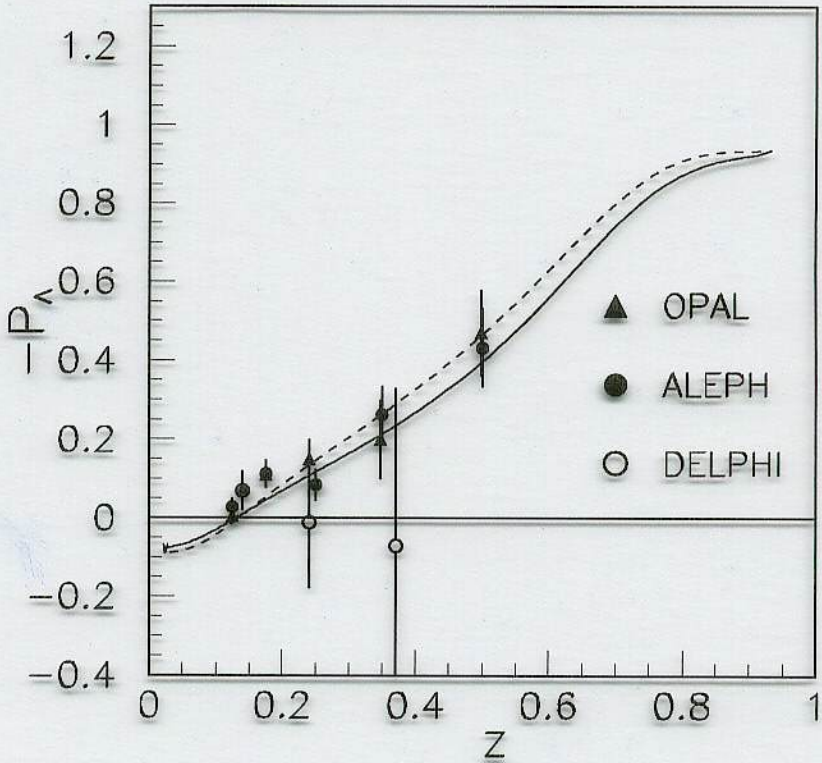


Figure 4: **The comparison of the experimental data for the longitudinal Λ-polarization P_Λ in e^+e^--annihilation process at the Z-pole with the theoretical calculations in the SU(6) quark-diquark model. The solid and dotted curves are the corresponding results with (solid) and without (dotted) the Melosh-Wigner rotation.**

pQCD Analysis

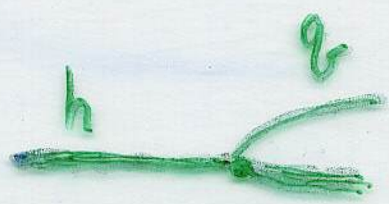
S.J. Brodsky, M. Burkardt, I. Schmidt
NPB 441 (95) 197.

Counting rule:

$$q_h(x) \sim (1-x)^p$$

$$p = 2n - 1 + 2\Delta S_z$$

$$\Delta S_z = |S_z^q - S_z^h| = 0, 1$$



Λ:

$$u^{\uparrow} = d^{\uparrow} = \frac{1}{2} \quad ; \quad u^{\downarrow} = d^{\downarrow} = \frac{1}{2}$$

$$s^{\uparrow} = 1 \quad , \quad s^{\downarrow} = 0$$

valence quark: $q^{\uparrow}(x) \sim x^{-\alpha}(1-x)^3$

$$q^{\downarrow}(x) \sim x^{-\alpha}(1-x)^5$$

$\alpha \approx \frac{1}{2}$

$$B_n = B(1-\alpha, n+1) = \int_0^1 dx \; x^{-\alpha}(1-x)^n$$

Case 1: $u^{\uparrow}(x) = d^{\uparrow}(x) = \frac{1}{2B_3} x^{-\frac{1}{2}}(1-x)^3$

$$u^{\downarrow}(x) = d^{\downarrow}(x) = \frac{1}{2B_5} x^{-\frac{1}{2}}(1-x)^5$$

$$s^{\uparrow}(x) = \frac{1}{B_3} x^{-\frac{1}{2}}(1-x)^3$$

$$s^{\downarrow}(x) = 0$$

$B_3 = \frac{32}{35} \quad B_5 = \frac{512}{693}$

Case 2:

$$\Delta s = \int_0^1 dx \; \Delta s(x) = 0.6$$

$$\Delta u = \Delta d = \int_0^1 dx \; \Delta u(x) = -0.2$$

$$u^{\uparrow}(x) = d^{\uparrow}(x) = A_u \, x^{-\frac{1}{2}} (1-x)^3$$

$$u^{\downarrow}(x) = d^{\downarrow}(x) = C_u \, x^{-\frac{1}{2}} (1-x)^5$$

$$s^{\uparrow}(x) = A_s \, x^{-\frac{1}{2}} (1-x)^3$$

$$s^{\downarrow}(x) = C_s \, x^{-\frac{1}{2}} (1-x)^5$$

$$A_u = 0.4/B_3 \; ; \quad C_u = 0.6/B_5$$

$$A_s = 0.8/B_3 \; ; \quad C_s = 0.2/B_5$$

$$s = \int_0^1 dx \; s(x) = 1$$

$$u = d = \int_0^1 dx \; u(x) = 1$$

$$A_u = A_s/2$$

Case 3:

$$u^{\uparrow}(x) = d^{\uparrow}(x) = A_u x^{-\frac{1}{2}}(1-x)^3 + B_u x^{-\frac{1}{2}}(1-x)^4$$

$$u^{\downarrow}(x) = d^{\downarrow}(x) = C_u x^{-\frac{1}{2}}(1-x)^5 + D_u x^{-\frac{1}{2}}(1-x)^6$$

$$s^{\uparrow}(x) = A_s x^{-\frac{1}{2}}(1-x)^3 + B_s x^{-\frac{1}{2}}(1-x)^4$$

$$s^{\downarrow}(x) = C_s x^{-\frac{1}{2}}(1-x)^5 + D_s x^{-\frac{1}{2}}(1-x)^6$$

$B_4 = \frac{256}{[illegible]}$

$B_6 = \frac{2048}{3003}$

$$s = A_s B_3 + B_s B_4 + C_s B_5 + D_s B_6 = 1$$

$$u = A_u B_3 + B_u B_4 + C_u B_5 + D_u B_6 = 1$$

$$\Delta s = A_s B_3 + B_s B_4 - C_s B_5 - D_s B_6 = \underline{0.7}$$

$$\Delta u = A_u B_3 + B_u B_4 - C_u B_5 - D_u B_6 = \underline{-0.1}$$

BJ $\begin{cases} 0.1 \\ -0.2 \end{cases}$

inputs: $A_u = 1/B_3$, $C_u = 2/B_5$, $C_s = 2/B_5$

$A_u = 1/B_3$; $B_u = -0.55/B_4$; $C_u = 2/B_5$; $D_u = -1.45/B_6$

$A_s = 2/B_3$; $B_s = -1.15/B_4$; $C_s = 2/B_5$; $D_s = -1.85/B_6$

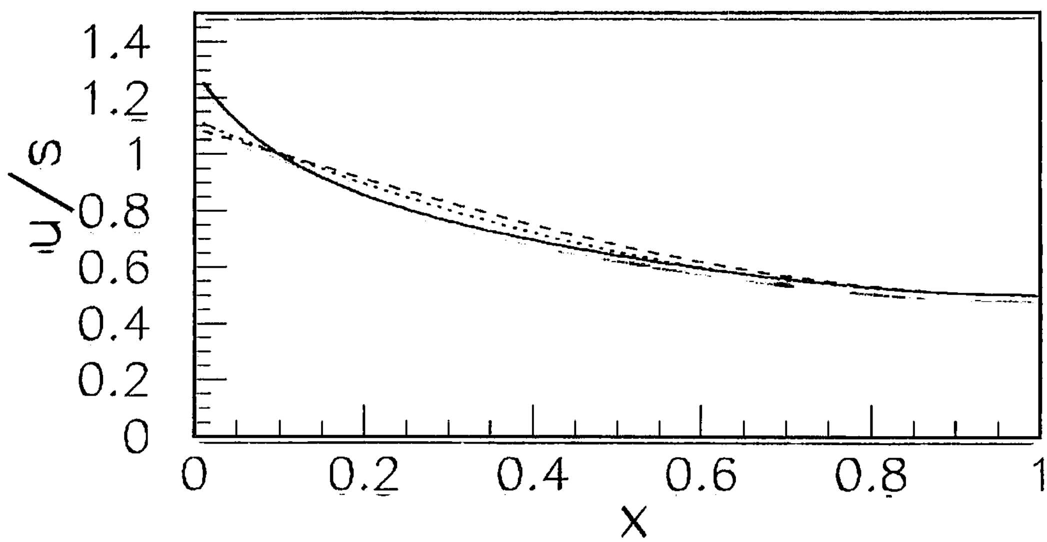


Figure 6: The ratio $u(x)/s(x)$ of the Λ in the pQCD analysis with three cases: case 1 (dotted curve); case 2 (dashed curve); and case 3 (solid curve).

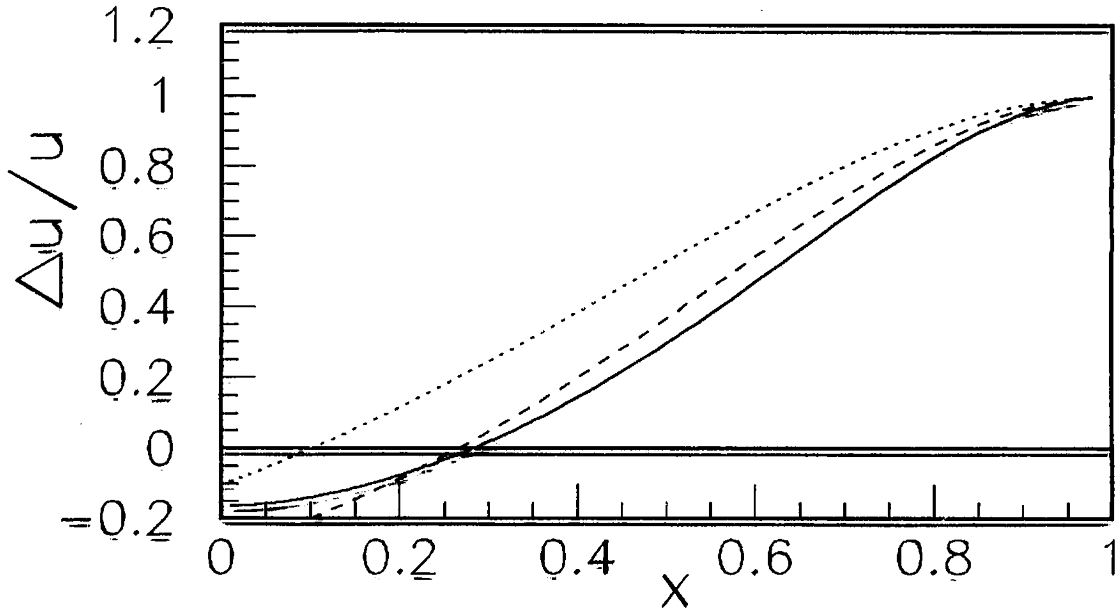


Figure 8: The ratio $\Delta u(x)/u(x)$ for the up and down valence quarks of the Λ in the pQCD analysis with three cases: case 1 (dotted curve); case 2 (dashed curve); and case 3 (solid curve).

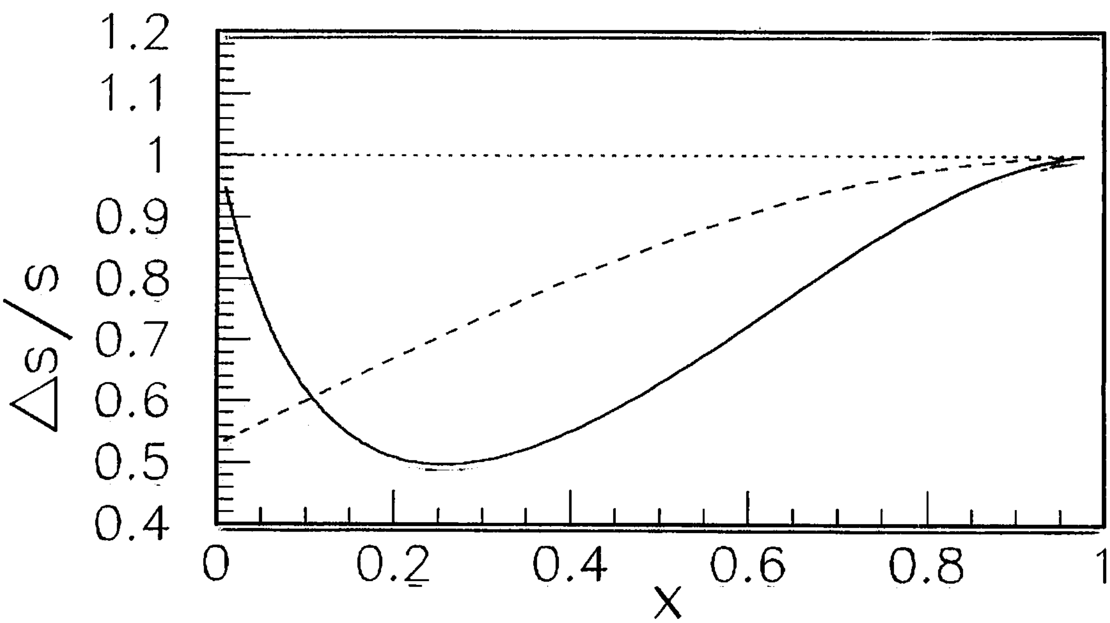


Figure 7: The ratio $\Delta s(x)/s(x)$ for the valence strange quark in the pQCD analysis with three cases: case 1 (dotted curve); case 2 (dashed curve); and case 3 (solid curve).

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Longitudinal Λ-Polarization P_Λ in e^+e^--Annihilation in pQCD based Analysis

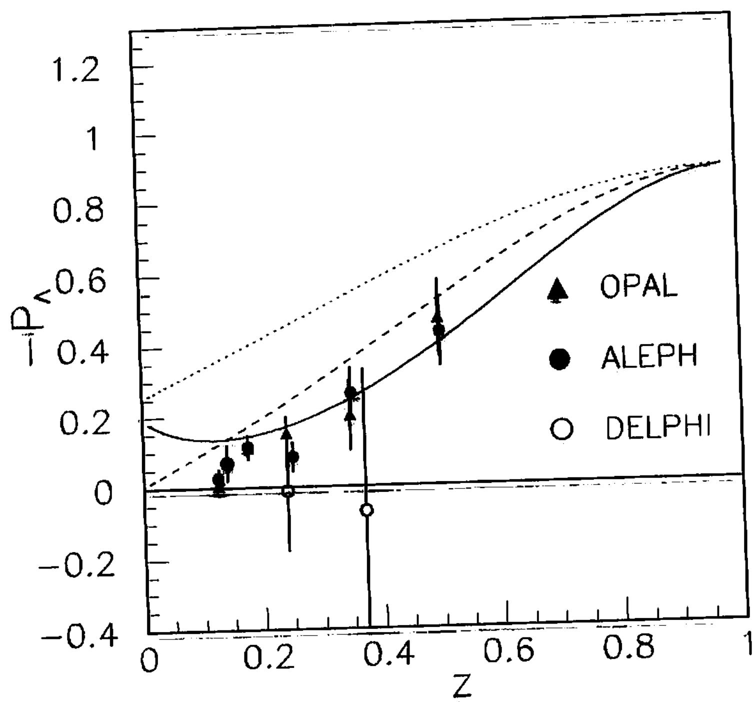


Figure 5: **The comparison of the experimental data for the longitudinal Λ-polarization P_Λ in e^+e^--annihilation process at the Z-pole with the theoretical calculations in the the pQCD analysis with three different cases: (a) case 1: the SU(6) quark-model spin distributions for the quark helicities (dotted curves); (b) case 2: the Burkardt-Jaffe values for the quark helicities (dashed curves) ; (c) case 3: the canonical form of quark distributions (solid curves).**

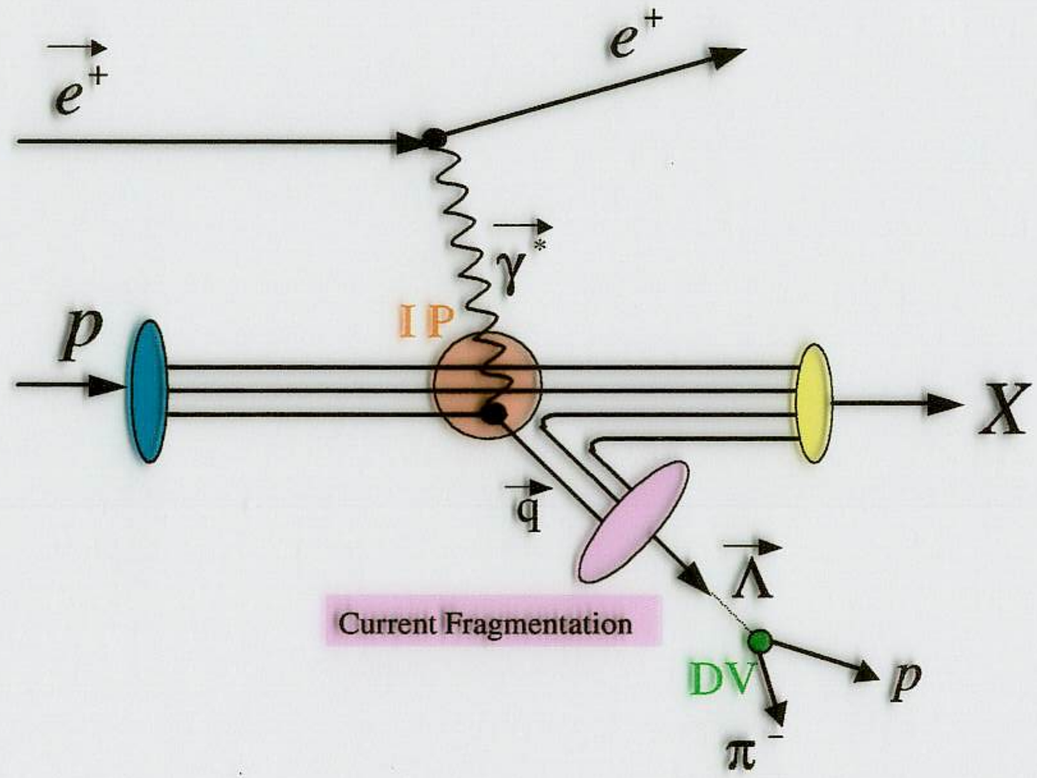
Flavor separation at $e^+e^- \to \vec{\Lambda} X$

is not sensitive

$$P_u = -0.67$$

$$P_d = P_s = -0.94$$

Spin Transfer to Λ in Semi-Inclusive DIS



PLB 477 (2000) 107 (hep-ph/9906424)

Prediction by B.-Q. Ma, I. Schmidt, and J.-J. Yang

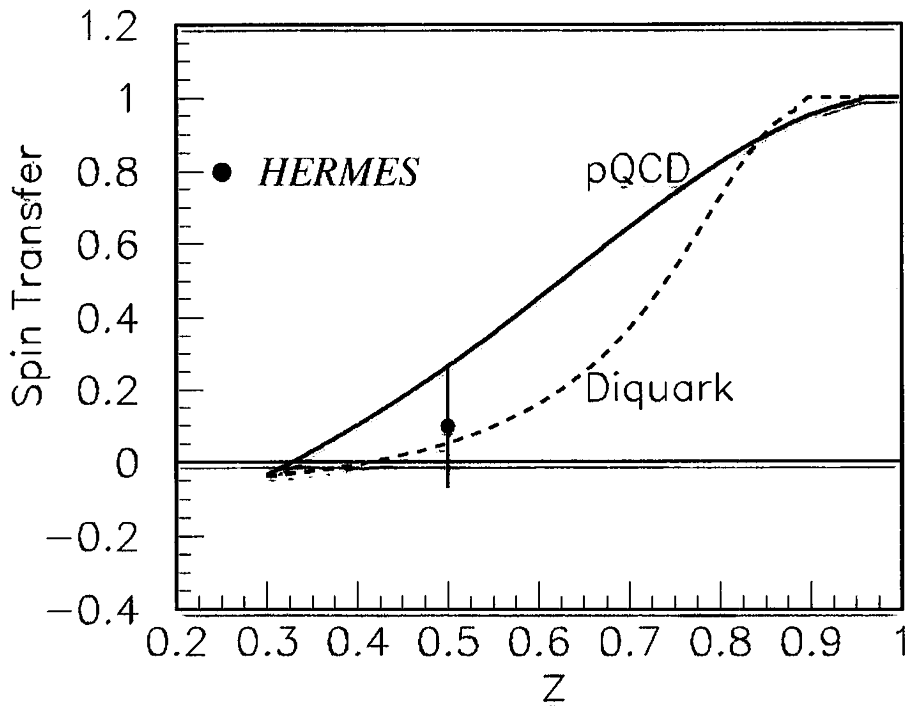


Figure 1: **The predictions of the longitudinal spin transfer to the Λ in deep inelastic scattering of polarized lepton on the nucleon target from pQCD analysis (solid curve) and the SU(6) quark-diquark model (dashed curve) by B.-Q. Ma, I. Schmidt, and J.-J. Yang, PLB 477 (2000) 107 (hep-ph/9906424). The data point is the experimental result by the HERMES collaboration, hep-ex/9911017.**

How to Reconstruct Λ Events

- Look for events with three tracks: DIS positron, positive hadron, negative hadron
- Assume positive / negative hadron = proton / pion

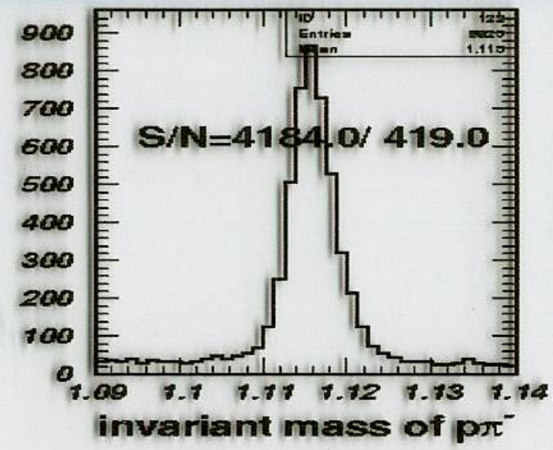
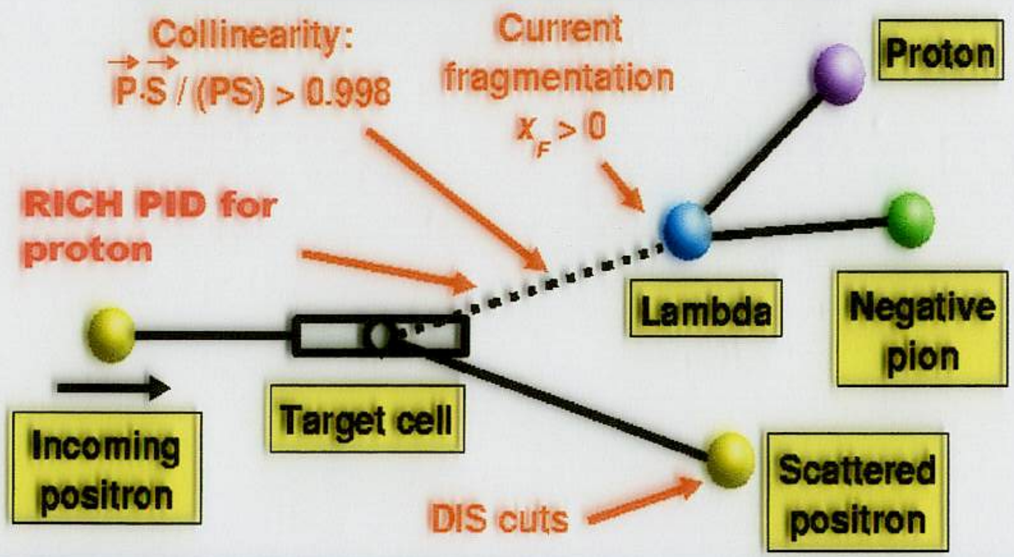


Diagram of applied cuts



Feynman x variable:

$x_F = p_{||} / p_{beam}$

In virtual photon / target center of mass frame

The Longitudinal Spin Transfer to Λ

Semi-Inclusive Λ Production in PDIS

$\vec{e}N \rightarrow e\Lambda X$, $\Lambda \rightarrow p\pi^-$

The Polarization of Λ

$$P_\Lambda = P_B \cdot D(y) \cdot S_\Lambda(z)$$

P_B: *Beam Polarization*

$D(y)$: *Depolarization factor* $(y = E_{\gamma^*}/E_e)$

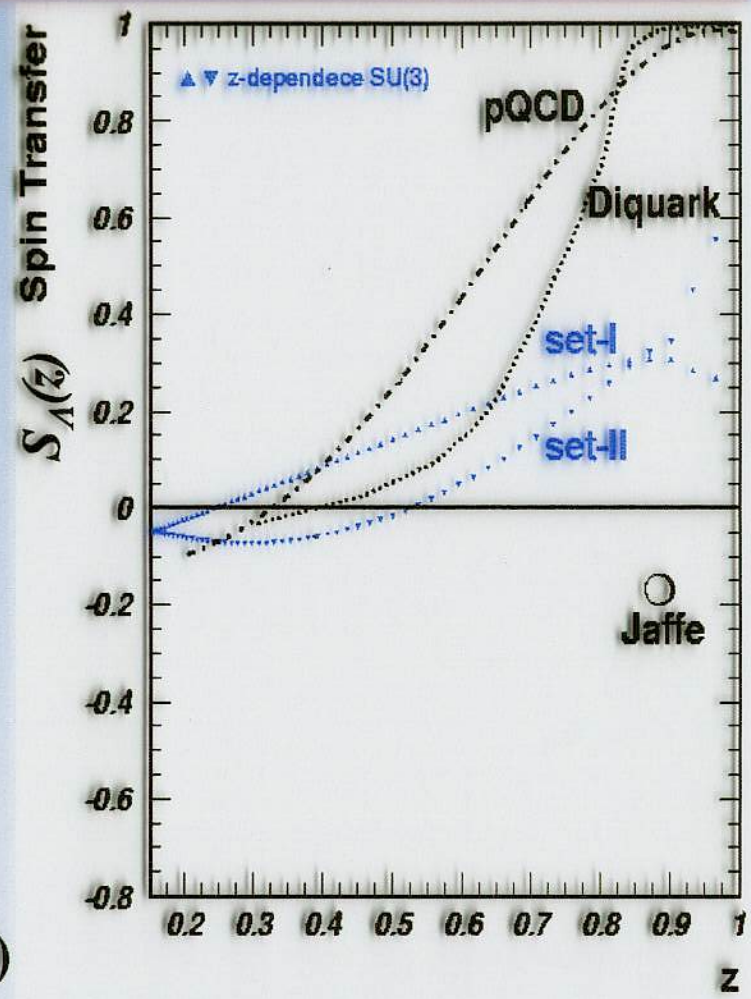
$$D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$$

$S_\Lambda(z)$: *Λ spin transfer* $(z = E_\Lambda/E_{\gamma^*})$

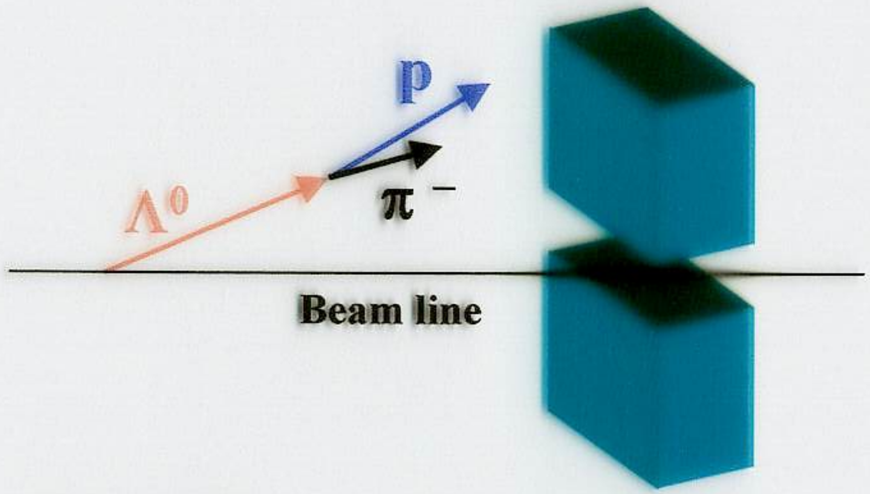
$$S_\Lambda(z) \approx \frac{\Delta D_u^\Lambda(z)}{D_u^\Lambda(z)}$$

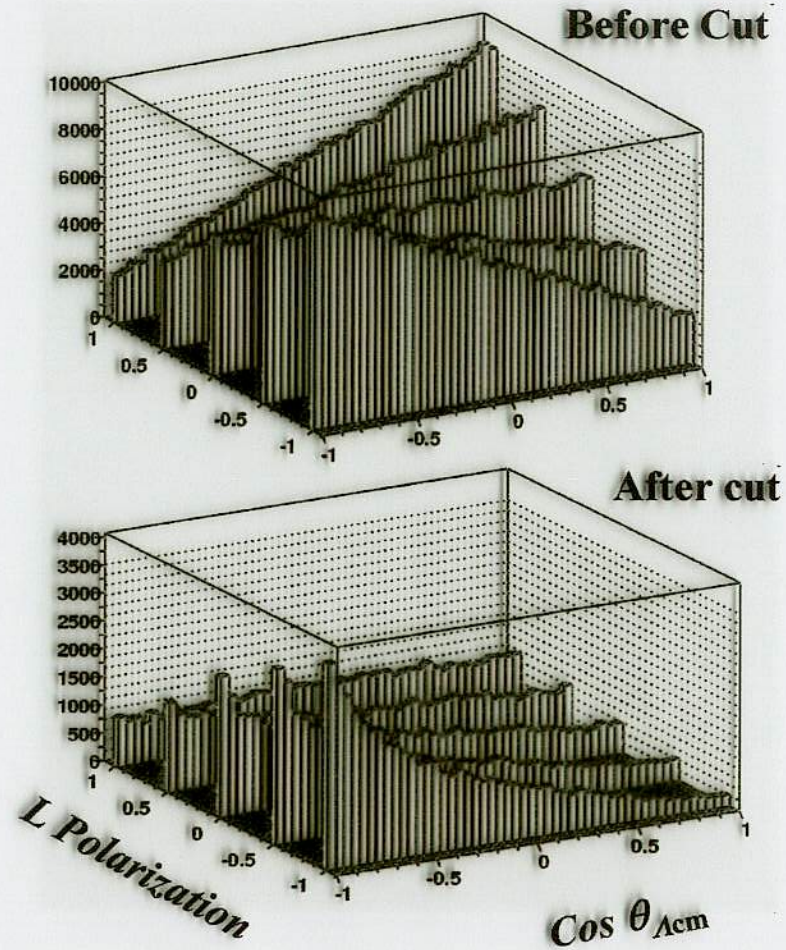
In Λ rest frame

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^0}{d\Omega}(1 + \beta P_\Lambda \cos\theta_{p\Lambda})$$



Acceptance Correction -- Simulation





Basic Idea

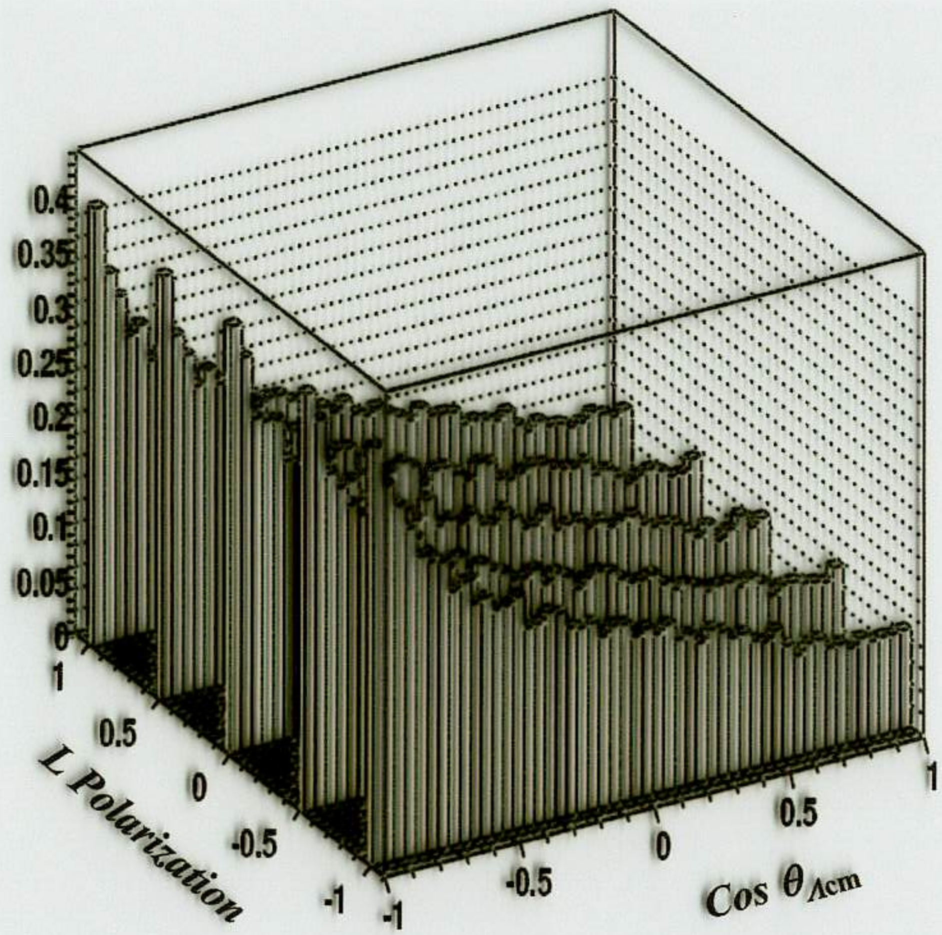
Using Reco. Λ energy and vertex
Using window cut at Z=275 from data simulate decay proton and pion to see if they are in the acceptance window

Acceptance Correction -- The correction function

Correction Method 1

From simulation we obtained the correction function as left

After careful check we learned that correct function is *independent* to the Lambda polarization!!!



Correction Method 2

$$\frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}} = \beta P_{\Lambda} \cos\theta$$

Extract Spin Transfer S_Λ From Data

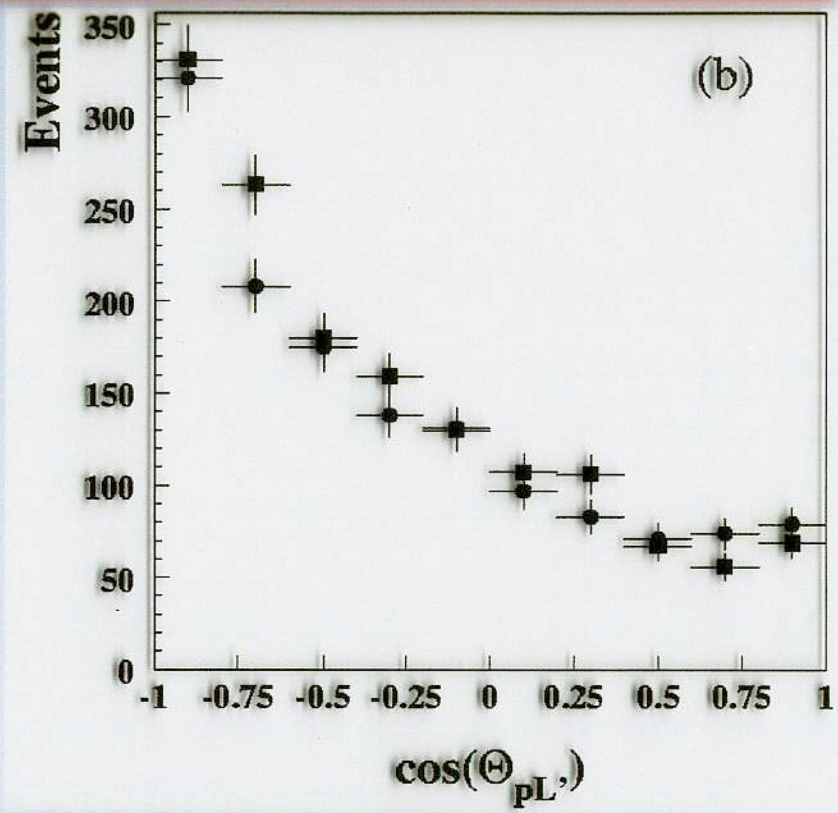
Limited geometric acceptance + loss of low momentum pions

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^0}{d\Omega}(1 + \beta P_\Lambda \cos\theta_{p\Lambda})$$

⇓

$$\frac{d\sigma}{d\Omega} \times C(\vec{p}_\Lambda, \vec{r}_{decay}, \theta_{p\Lambda})$$

$$= \frac{d\sigma^0}{d\Omega}(1 + \beta P_\Lambda \cos\theta_{p\Lambda}) \times C(\vec{p}_\Lambda, \vec{r}_{decay}, \theta_{p\Lambda})$$



Square and Circle for different beam helicities

How to deal with $C(\vec{p}_\Lambda, \vec{r}_{decay}, \theta_{p\Lambda})$ *???*

Answer: ***Helicity Balance Method !!!***

Method (Helicity balance method)

$$\| P_B \| = \frac{\int P_B(t) L(t) dt}{\int L(t) dt} = \frac{1}{N_{event}} \sum_{event} P_B \quad \text{.........................(1)}$$

$$< P_B D_y \cos\theta > = \frac{\| P_B \| < D_y \cos\theta >_0 + \beta \| P_B^2 \| < D_y^2 \cos^2\theta >_0 S_\Lambda}{1 + \beta \| P_B \| < D_y \cos\theta >_0 S_\Lambda} \quad \text{..................(2)}$$

$$\text{if}: \quad \| P_B \| = 0 \quad \text{.........................(3)}$$

$$\text{Then:} \quad S_\Lambda = \frac{< P_B D_y \cos\theta >}{\beta \| P_B^2 \| < D_y^2 \cos^2\theta >} \quad \text{.........................(4)}$$

to satisfy (3), one can use **DIS** or **Hadron pairs** or some other **Unpolarized case** as monitor

Random drop run or set P_B threshold value to satisfy (3)

See internal-note:98-091: *Extraction of Λ polarization from unpol runs S.Belostotski*

A Close Look At Helicity Balance Method

$$< P_B \cos\theta_{p\Lambda} >= \frac{\| P_B \| < \cos\theta_{p\Lambda} >^0 + \beta S_\Lambda \| P_B^2 \| < D(y)\cos^2\theta_{p\Lambda} >^0}{1 + \beta S_\Lambda \| P_B \| < \cos\theta_{p\Lambda} >^0}$$

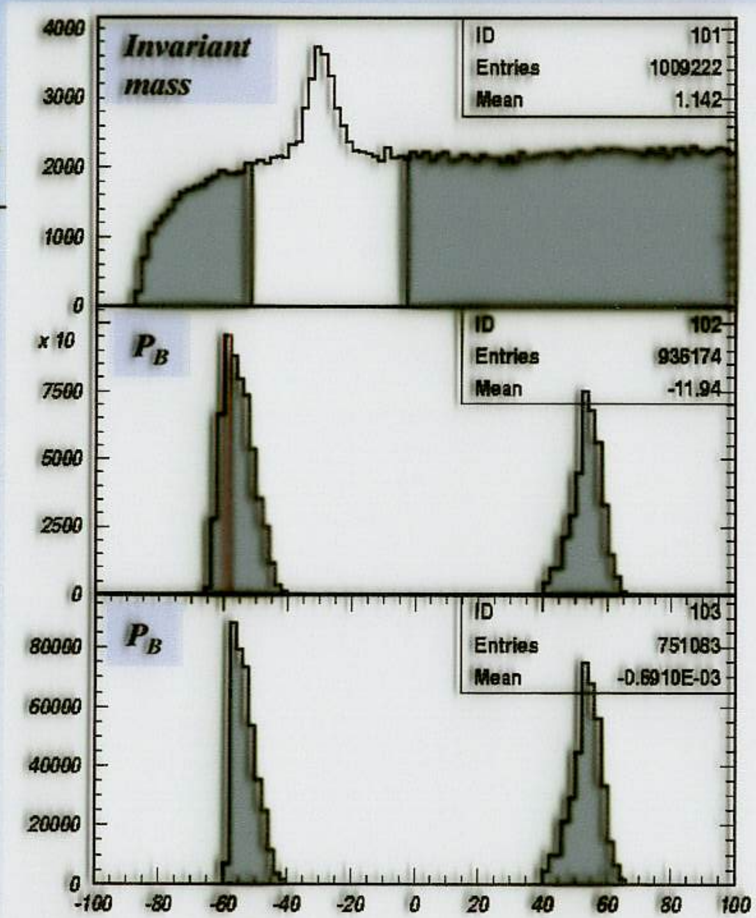
$$\| P_B \| = \frac{\int P_B dL}{L} \quad \| P_B^2 \| = \frac{\int P_B^2 dL}{L}$$

If $\| P_B \| = 0$ ***then***

$$< P_B \cos\theta_{p\Lambda} >= \beta S_\Lambda \| P_B^2 \| < D(y)\cos^2\theta_{p\Lambda} >$$

But how to get $\| P_B \| = 0$

$$\| P_B \| = \frac{\int P_B dL}{L} = \frac{\int P_B dN_{pair}}{N_{pair}} =< P_B >= 0$$



Can we do that without helicity balance?

What do we gain from helicity balance?

- **Get rid of acceptance correction**
- **Normalization**

$$\frac{dN}{d\Omega}=\frac{d\sigma^0}{d\Omega}(1+\beta\cdot P_B\cdot D(y)\cdot S_\Lambda\cdot\cos\theta_{p\Lambda})\times C(\vec{p}_\Lambda,\vec{r}_{decay},\theta_{p\Lambda})\times L$$

$$\left(\frac{dN^+}{d\Omega}\frac{1}{L^+}-\frac{dN^-}{d\Omega}\frac{1}{L^-}\right)/\left(\frac{dN^+}{d\Omega}\frac{1}{L^+}+\frac{dN^-}{d\Omega}\frac{1}{L^-}\right)=\frac{\beta S_\Lambda(P_b^+D^+(y)-P_b^-D^-(y))}{2+\beta S_\Lambda(P_b^+D^+(y)+P_b^-D^-(y))}$$

Acceptance correction is eliminated and only the Normalization problem remains, one can use N_Λ or N_{pair} for the normalization

Re-evaluation of the two methods

---advantages & disadvantages

HBM method:

every point is efficiently used

errs (bad events) sensitive

ideal balanced set with good events is crucial

err-bar is smaller

NM method:

bulk shape is more important

errs (bad events) tolerant

no requirement of balanced set

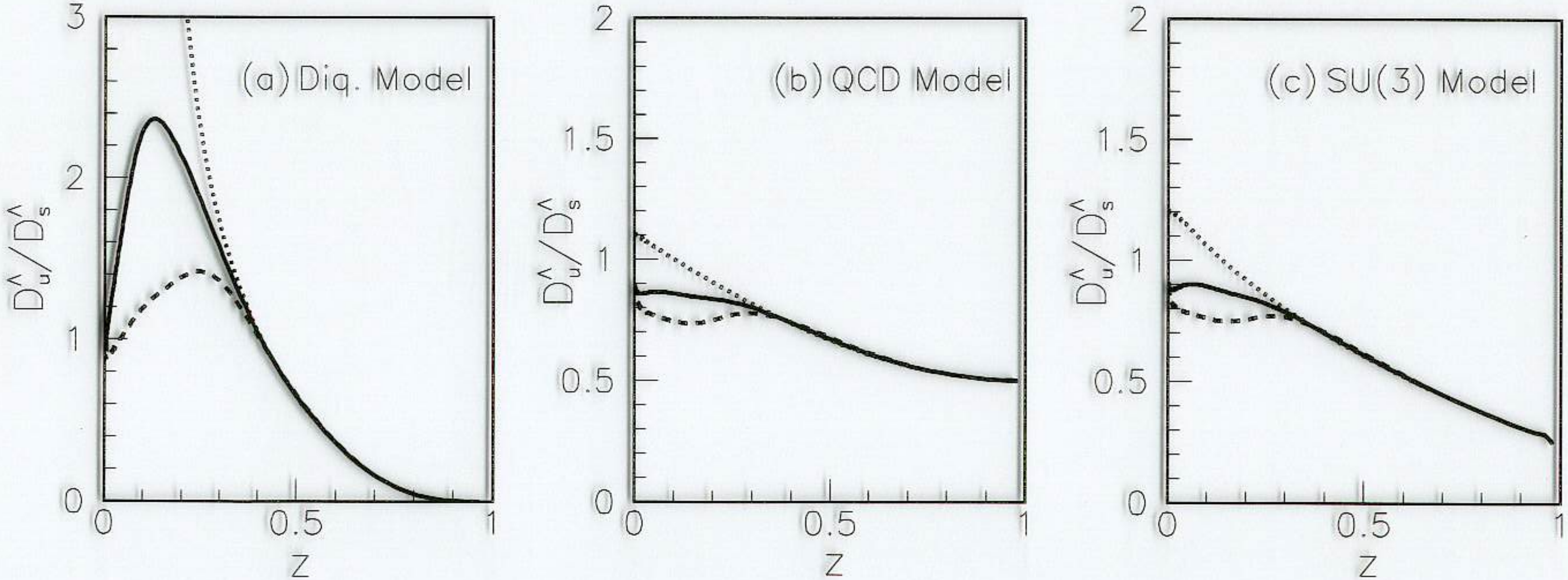
err-bar bigger

$\bar{\Lambda}/\Lambda$ Ratio in DIS Production

- A sensitive quantity that can provides information about the flavor structure of Λ hyperon.

B.-Q. Ma, I.Schmidt, J.-J. Yang
Phys. Lett. B 574 (2003) 35

The flavor structure of Lambda
u/s ratio with x-dependence



Theortical Formula(I)

The x-dependent ratio of $\bar{\Lambda}/\Lambda$ cross sections is defined as

$$R(x) = \frac{\int_0^1 \mathrm{d}z \int \mathrm{d}y \frac{\mathrm{d}^3\sigma^{\bar{\Lambda}}}{\mathrm{d}x\mathrm{d}y\mathrm{d}z}}{\int_0^1 \mathrm{d}z \int \mathrm{d}y \frac{\mathrm{d}^3\sigma^{\Lambda}}{\mathrm{d}x\mathrm{d}y\mathrm{d}z}}, \quad (1)$$

Theoretical Result(I)

Different Models and parameters gives different Result:

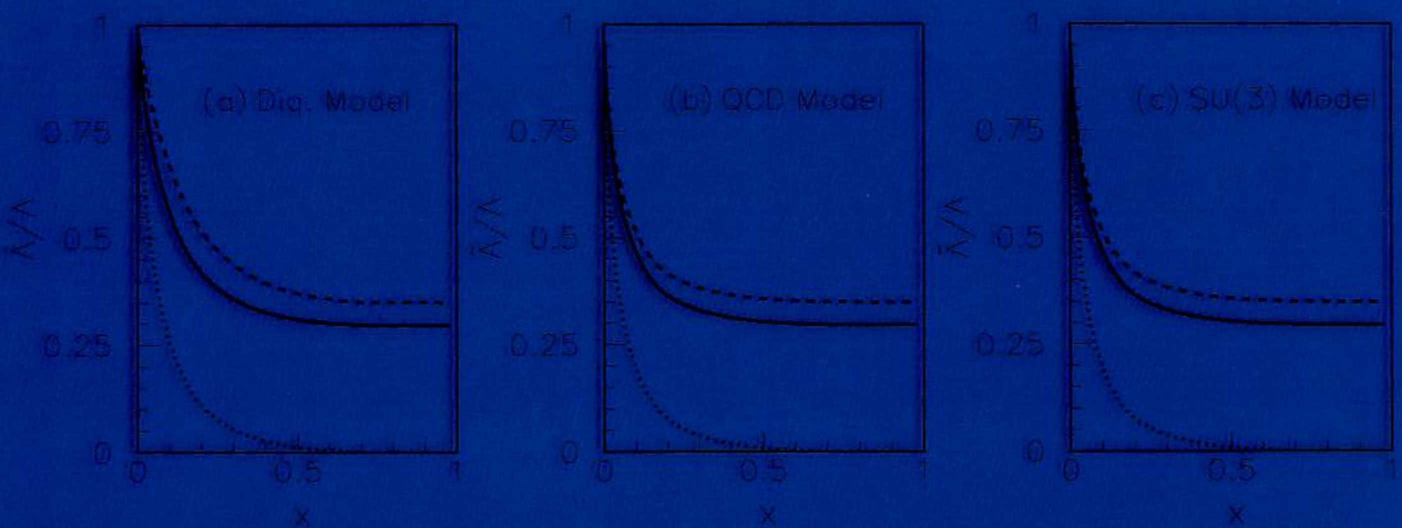


Figure 1 : The x-dependence of the $\bar{\Lambda}/\Lambda$ ratio $R(x)$ in three different models, with the three different curves corresponding to three options of the unfavored fragmentation.

Theoretical Formula(II)

and the z-dependence ratio is defined as

$$R(z) = \frac{\int_{x_{min}}^{x_{max}} \mathrm{d}x \int \mathrm{d}y \frac{\mathrm{d}^3\sigma^{\bar{\Lambda}}}{\mathrm{d}x\mathrm{d}y\mathrm{d}z}}{\int_{x_{min}}^{x_{max}} \mathrm{d}x \int \mathrm{d}y \frac{\mathrm{d}^3\sigma^{\Lambda}}{\mathrm{d}x\mathrm{d}y\mathrm{d}z}}, \quad (2)$$

where x_{min} and x_{max} depends on the data from experiments.

Theoretical Result(II)

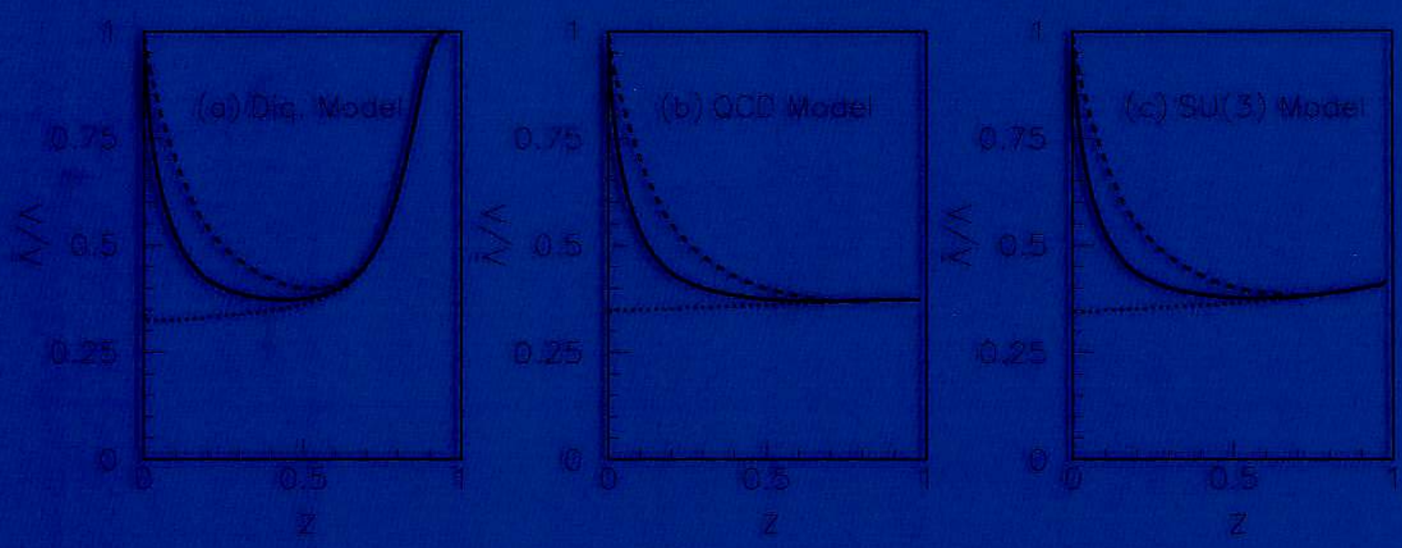


Figure 2: The z-dependence of the $\bar{\Lambda}/\Lambda$ ratio $R(z)$ in three different models, with the three different curves corresponding to three options of the unfavored fragmentation. $x_{min} = 0.02$, $x_{max} = 0.5$.

Conclusion

Directions for Physics related to Nucleon Structure

N → High Precision & New Quantities

↓

$\Lambda, \Sigma^{\pm}$ "new physics"

The Spin & Flavor Structure of Baryons

New Domain for { Theorists, Experimentalists }