Polarization of Inclusive Λ_c's in a Hybrid Model

G. Goldstein

hep-ph/9907573

W.G.D. Dharmaratna & G.G.
PRD 53 1073 (96)
" 41 1731 (90)

$p + p \rightarrow \Lambda_c^+{\uparrow} + X$

$\pi + p \rightarrow \Lambda_c^+{\uparrow} + X$

$\text{hadron} + \text{hadron} \longrightarrow \underset{\substack{\text{Flavor}\\ Q}}{\Lambda_{\text{Heavy}}}{\uparrow} + X$

Kinematic region: high s
small p_T

$$\underset{\frac{1}{2}^+}{\Lambda_Q} \sim \underbrace{u\,d}\,Q \quad (+\underset{+\text{sea}}{\text{gluons}} + \vec{L})$$

$\bar{3}$ color-antisymmetric
flavor (isospin = 0)
spin 0

$\Rightarrow \Lambda_Q$ polarization carried by Q (mostly)

other ideas: Lund model – Andersson et al;
from $\Lambda{\uparrow}$ deGrand & Miettinen;
Soffer & Törnqvist; Sawed;
⋮

all to explain large, negative $\mathbb{P}_\Lambda$

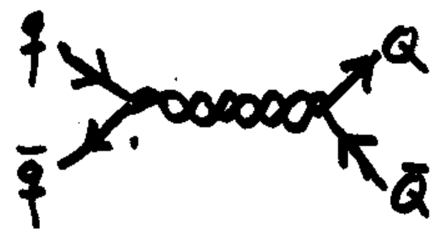
How does Q get produced polarized?

parton + parton $\rightarrow Q_{\uparrow} + \bar{Q} + \cdots$

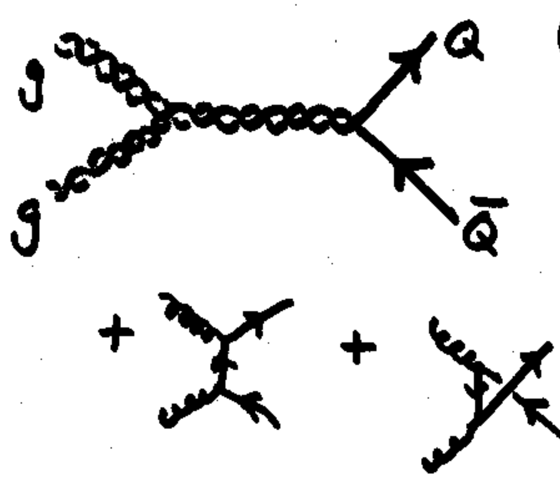
QCD processes

Lowest order

$q + \bar{q} \rightarrow Q + \bar{Q}$



$g + g \rightarrow Q + \bar{Q}$



(several '81)

All relatively <u>real</u>

$\Rightarrow$ No single Q polarization

$$P_Q \propto \sum_{\substack{a,b,d \\ \text{helicities}}} f^*_{ab,cd}\, f_{ab,c'd}\, (\vec{\sigma}\cdot\hat{n})_{c'c}$$

$$\propto \operatorname{Im} \sum f_{ab,+d}\, f^*_{ab,-d}$$

$\Rightarrow$ Need phase difference of flip $\otimes$ non-flip

(Kane, Pumplin, Repko '78)

Non-flip vertices for $m_q=0$ QCD

Flip requires $m_q \neq 0$.

$g+g \to Q+\bar{Q}$

$\mathcal{O}(\alpha_s)$ REAL

$\mathcal{O}(\alpha_s^2)$ COMPLEX

only need Im part (-Cutkosky rule)

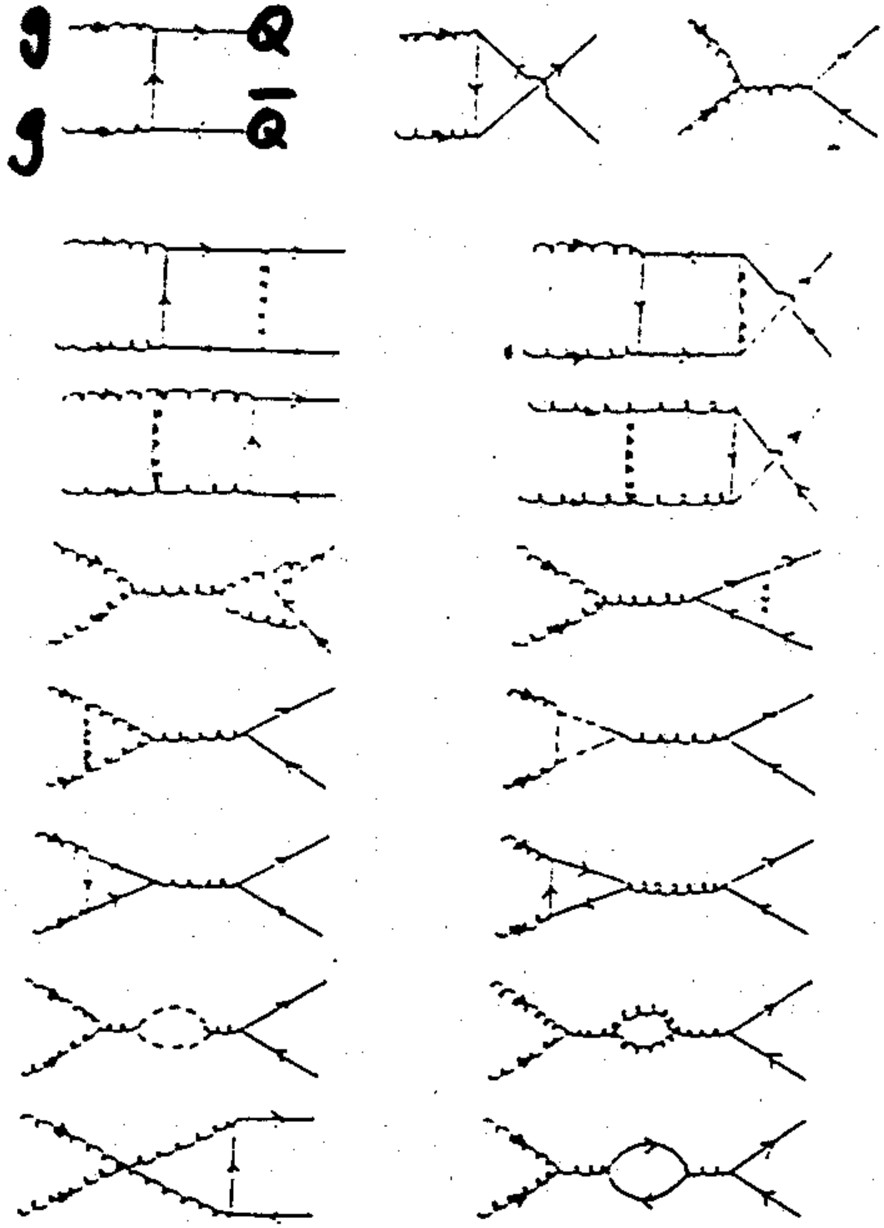
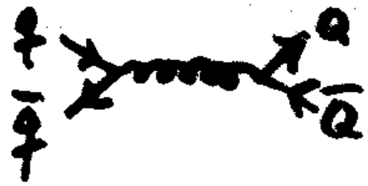
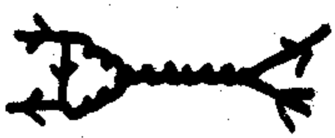


FIG. 1. Feynman diagrams for gluon fusion, $g+g\to s+\bar{s}$. In the second order, only the diagrams which contribute to the imaginary amplitude are shown.

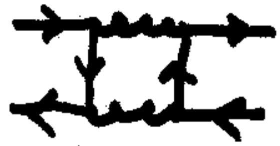
$$q+\bar{q} \to Q+\bar{Q}$$



$\mathcal{O}(\alpha_s)$



$\mathcal{O}(\alpha_s^2)$



$\cdots$

P_Λ is an interference phenomenon

Scale of $\alpha_s(Q^2)$ set by $Q^2 \sim M_Q^2 \gg \Lambda_{QCD}^2$

$g + g \to Q + \bar{Q}$

gluon quark

$$\mathcal{P} = \alpha_s \frac{m(p^2 - k^2\cos^2\theta)}{24kD\sin\theta}\left[(N_1 + N_2)Y_+ + (N_1 - N_2)Y_- + N_3 \ln\frac{(p-k)}{(p+k)} + N_4 + 18k^3\sin^2\theta\cos\theta(\Sigma_1 + \Sigma_2)\right], \qquad (1)$$

where

$$D = (9k^2\cos^2\theta + 7p^2)(k^4\cos^4\theta - 2k^2m^2\sin^2\theta - p^4),$$

$$N_1 = 9k^2\cos^3\theta(p^2 + 2k^2) + 6kp\cos\theta(27p^2 + 11kp - 27k^2) + 27k^4\cos\theta,$$

$$N_2 = kp\cos^2\theta(11p^2 + 76k^2) - 162p^2m^2 + 33k^3p,$$

$$N_3 = p\cos\theta[243m^2p\cos^4\theta - \cos^2\theta(324m^2p - 54k^3) + 22kp^2 - 243m^2p + 164k^3],$$

$$N_4 = -\tfrac{1}{4}k\sin^2\theta\cos\theta[72\cos^2\theta(27p^3 - 18k^2p + k^3) + 27(\underset{96}{\cancel{97}}k^2p - 24p^3) - 8(22kp^2 + 45k^3)],$$

← (Bernreuther et.al. '96)

$$\Sigma_1 = \frac{2}{p^2}\sum_i \sqrt{p^2 - m_i^2}(2p^2 + m_i^2)\theta(p - m_i),$$

$$\Sigma_2 = \frac{1}{p^2}\sum_i \left[3m_i^2 p \ln\left(\frac{p - (p^2 - m_i^2)^{1/2}}{p + (p^2 - m_i^2)^{1/2}}\right) - 4(p^2 - m_i^2)^{3/2}\right]\theta(p - m_i),$$

i = interal fermions

$$Y_\pm = \ln\left(\frac{(p \pm k\cos\theta)^2}{m^2}\right).$$

$q + \bar{q} \to Q + \bar{Q}$

$$\mathcal{P} = -\frac{\alpha_s m_2}{24p^2k^3\sin\theta D}\left[N_1 + E^4k^2m_1^2(56X_- + 16X_+) + N_2\ln\left(\frac{E+k}{E-k}\right) + N_3\ln\left(\frac{E+p}{E-p}\right)\right], \qquad (21)$$

where

$$D = 4E^4 + 2E^2(m_1^2 + m_2^2 - E^2)\sin^2\theta + 2m_1^2m_2^2\cos^2\theta,$$

$$N_1 = -p^3k\sin^2\theta[(4k^3 + 72Em_2^2 + 36E^3)p\cos\theta + 40E^3k],$$

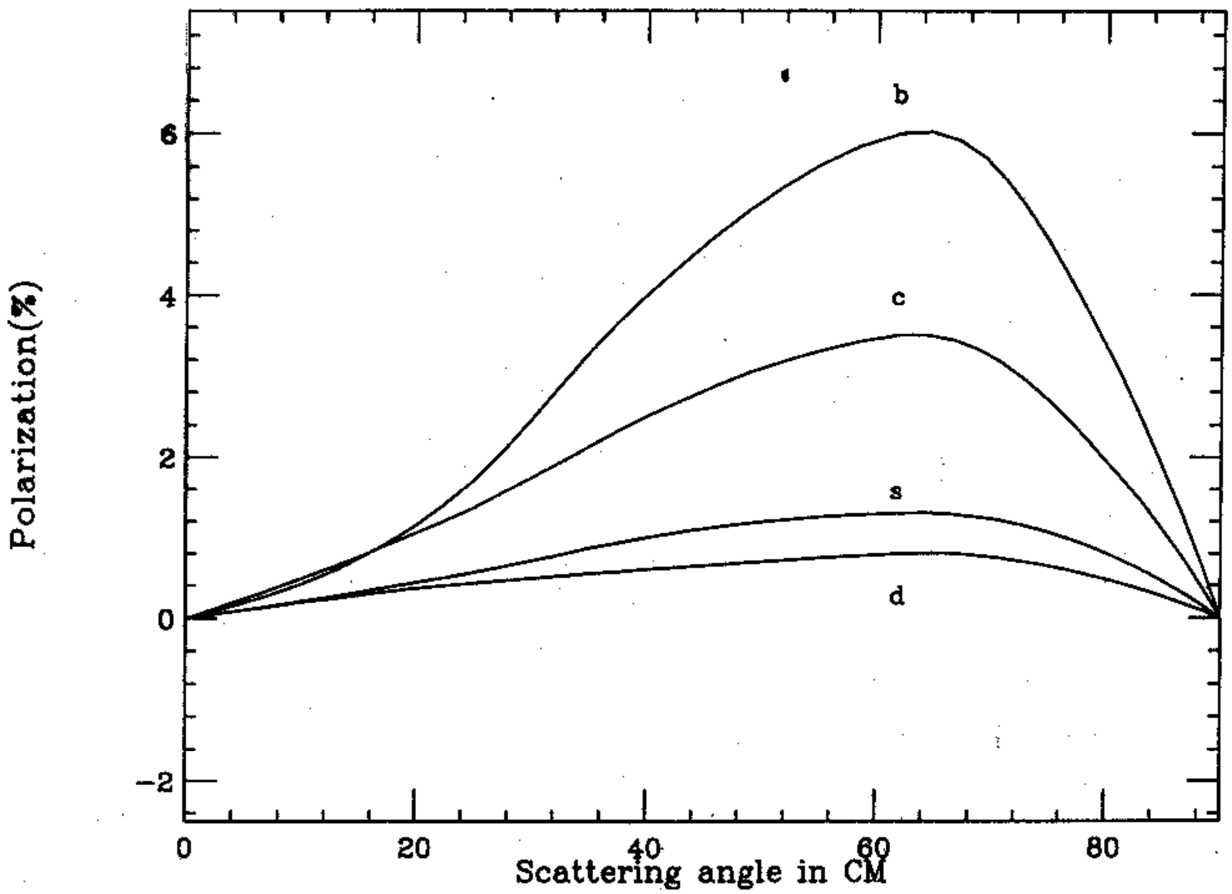
$$N_2 = E^2p[p^2m_2^2\sin^2\theta(54p\cos\theta + 20k) + k^2m_1^2(36p\cos\theta - 40k)],$$

$$N_3 = 4E^2pk^2m_1^2(18k\cos\theta - 5p),$$

$$X_\pm = \frac{p(3kp\cos\theta \pm p^2 \pm 2k^2)}{2E\sqrt{(E^2 \pm kp\cos\theta)^2 - m_1^2m_2^2}}\ln\left\{\frac{(E^2 \pm kp\cos\theta) - \sqrt{(E^2 \pm kp\cos\theta)^2 - m_1^2m_2^2}}{(E^2 \pm kp\cos\theta) + \sqrt{(E^2 \pm kp\cos\theta)^2 - m_1^2m_2^2}}\right\},$$

m_1, p : q

m_2, k : Q



$g+g \to Q_\uparrow + \overline{Q}$ for $Q = d, s, c, b$

(13 GeV + 13 GeV)

$\mathbb{P}(\pi-\theta) = -\mathbb{P}(\theta)$

$\to$ backward Q has $\mathbb{P}<0$

Magnitude $\to$ 6% for $Q=b$

E_g will be convoluted with incoming structure functions

Recombination: $Q_\uparrow \rightarrow \Lambda_{Q\uparrow}$ at small p_T!

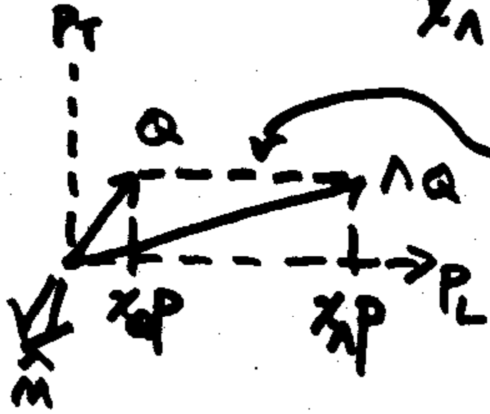
$$Q + \text{diquark} \rightarrow \Lambda_Q \supset Q + (ud)$$

$$x_\Lambda \quad \sim \underbrace{\tfrac{1}{3}x_\Lambda}_{x_Q} + \tfrac{2}{3}x_\Lambda$$

$$\text{or} \quad x_\Lambda \sim \tfrac{2}{3} + x_Q$$

Try linear mapping:

$$x_\Lambda = a + b\,x_Q$$



(deGrand, Miettinen '81)

Q gets accelerated $\sim \Delta \vec{P}_L$

spin of Q experiences Thomas precession

$$\vec{\omega}_T = (\gamma - 1)\frac{\vec{v}\times\vec{a}}{v^2}$$

$$\sim \vec{P}_Q \times \Delta\vec{P}_L \sim -\hat{n}$$

Energy shift $-\vec{S}\cdot\vec{\omega}_T \;\propto\; \underline{+\vec{S}\cdot\hat{n}}$

so $\langle \vec{S}\cdot\hat{n}\rangle < 0$ is energetically favored

Negative Q "seed" polarization is <0 & Thomas-recombination enhances $\mathbb{P}_Q \rightarrow \mathbb{P}_\Lambda = A\,\mathbb{P}_Q$

(Semi-classical calculation with confining force to $\vec{a}$)

$$\mathbb{P}_\Lambda(x_F, p_T) = A\,\mathbb{P}_Q(x_Q(x_F), p_T)$$ for each $g(x_1)+g(x_2)$

or $q(x_1)+\bar{q}(x_2)$

For final $\overset{(\pi)}{p} + p \to \Lambda_Q + X$

$$\frac{d^2\sigma(\uparrow \text{or} \downarrow)}{dx_Q\,dp_T} = \sum_{i,j} \int_0^1 dx_1 \int_0^1 dx_2\, f_i^{p,\pi}(x_1) f_j^{p}(x_2)\, \frac{d^2\sigma_{ij}(\uparrow \text{or} \downarrow)}{dx_Q\,dp_T}$$

$$P_\Lambda(x_F, p_T) = A\, \frac{d^2\sigma(\uparrow) - d^2\sigma(\downarrow)}{d^2\sigma(\uparrow) + d^2\sigma(\downarrow)}\Bigg|_{\substack{x_F = a + b x_Q \\ p_T}}$$

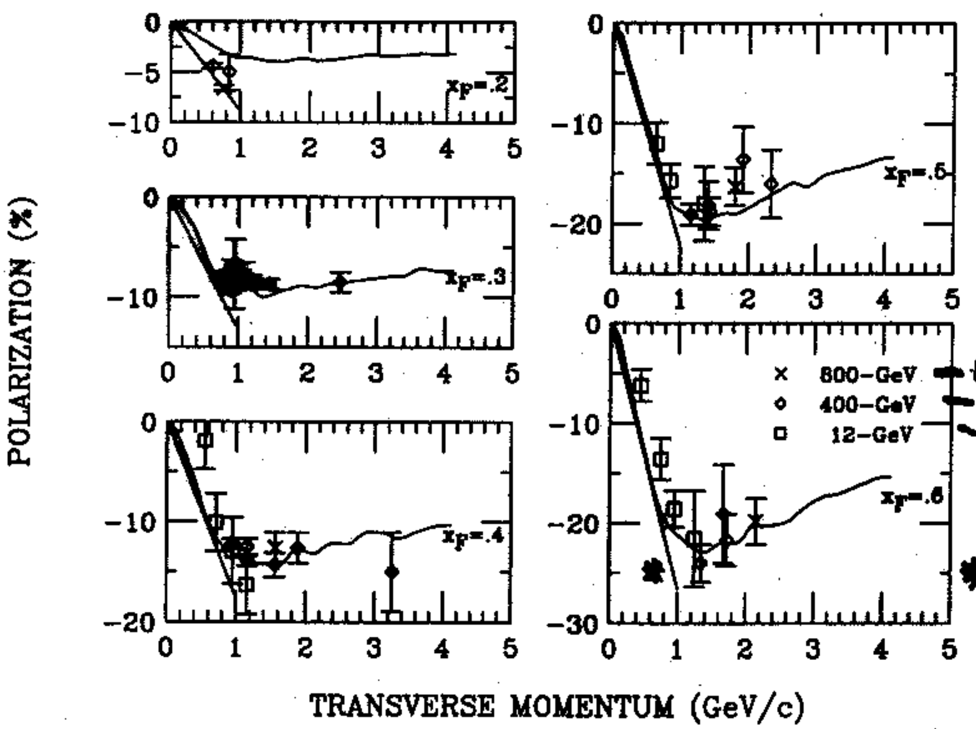
For $p+p \to \Lambda_s + X$ fit one data point

$A \simeq 2\pi$, $a = 0.86$, $b = 0.70$

Reproduces (x_F, p_T) dependence of data
(with very slow E dependence) (Heller '97...)

How many $\Sigma^0 \to \gamma\Lambda$? 20-30% (Lundberg et al. '89)

$\Rightarrow$ More direct Λ polzn.



Ramberg et al '94
Lundberg " '89
Heller " '78

*Exclusive data at 27.5GeV Felix et al. '99

Scaling up from $Q=s$ to $Q=c$ is straightforward from $\mathbb{P}$ eqns for

gg or $\bar{q}q \to c\bar{c}$.

Seed polarization increases by ~3.

For recombination with fixed force/mass, should have same Thomas factor.
But overall recombination could scale as M_{hadron}, so factor of (Efremov & Teryaev '82)

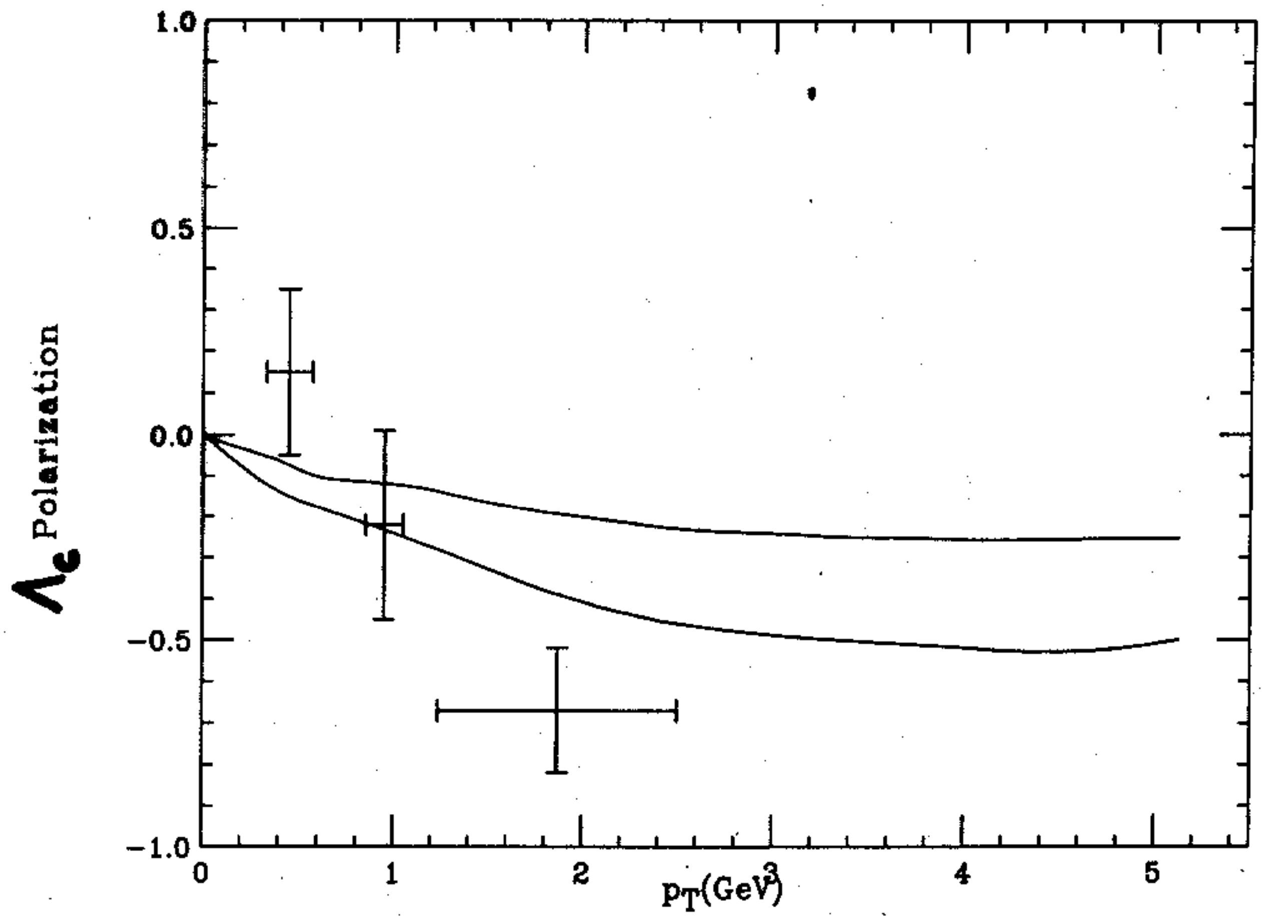
$$M_{\Lambda_c}/M_{\Lambda} \sim 2.$$

$\pi^- p \to \Lambda_c + X$

$\pi^- \supset d\bar{u} \Rightarrow \bar{u}u \to c\bar{c}$ contributes

& $gg \to c\bar{c}$

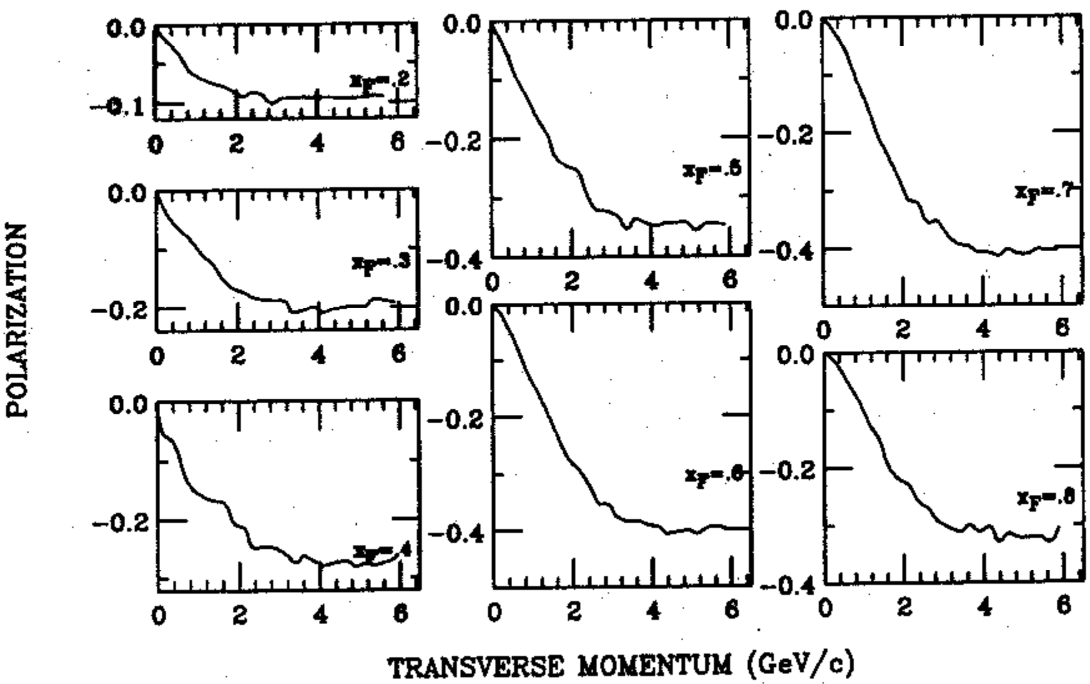
Need $f^{\pi}_{\bar{u}, g}(x_1)$ from Duke-Owens, ...



Data: Aitala et al. (E791) 1999

$\pi^- p \to \Lambda_c X$

see also ACCMOR '94


POLARIZATION
TRANSVERSE MOMENTUM (GeV/c)
x_F=.2
x_F=.3
x_F=.4
x_F=.5
x_F=.6
x_F=.7
x_F=.8

To be done:

Σ, Ξ, Ω ... Pol'zn

Other c & b Baryons

sophisticated recombination

- proper $(1-x_F)^{\alpha} e^{-\beta p_T^2}$
- $x_Q \to x_{\Lambda_Q}$
- A or $A(x_Q, x_F, p_T)$?

Conclusion – $\Lambda\uparrow$ model scales up to $\Lambda_c\uparrow$

$m_s \to m_c \Rightarrow$ Pol'zn

No change of $x_Q \to x_{\Lambda_Q}$ mapping

No change of A

Detailed p_T & x_F dependence is unique to this hybrid model