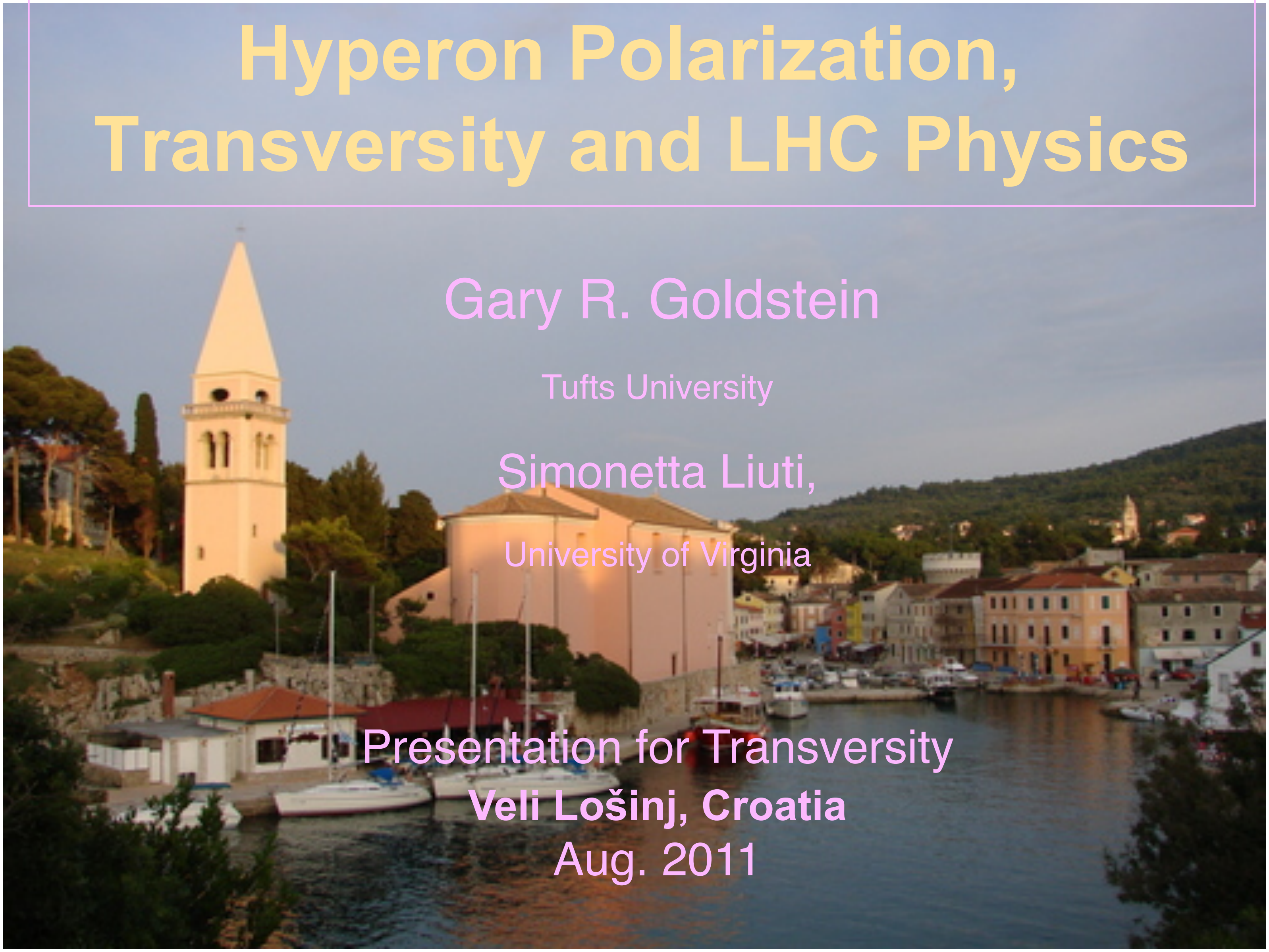

Hyperon Polarization, Transversity and LHC Physics

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Presentation for Transversity

Veli Lošinj, Croatia

Aug. 2011

Outline

$\Lambda_{s,c,b}$ polarization Puzzles and Uses

I. Large polarization in hadron processes

I. Very large p+p→ A_N , A_{NN} , π's (see A. Krisch talk)

II. Very large Pol'zn for inclusive Λ & Σ

III. Intriguing Systematics

IV. Explanations? **Basic evidence** for non-perturbative systematics of hadron structure & formation.

V. Charmed & heavy hyperons (Fermilab fixed target)

VI. Will hyperons maintain large Pol'zn?? Need understanding of NPQCD mechanism

VII. If we do not understand large SSA's we do not understand NPQCD ! (even Drell-Yan signs – see O. Denisov & D. Sivers talk)

II. Leptoproduction of Λ_s & Σ_s (theory workplace)

I. Not outstanding Single Spin Asymmetries ***yet***

II. Large double correlations at small Q^2

III. Analysis more tractable

IV. Which formalism is most useful? TMDs, GPDs, Generalized Fracture Functions?

Outline (cont'd)

I. Large polarization in hadron processes

II. Leptoproduction of Λ_s & Σ_s

III. Tool to get into transversity –

  I. Chen, GG, Jaffe, Ji ($e^+e^- \rightarrow \Lambda_s$ antiΛ_s X)

  II. "off-diagonal" SIDIS via Transversity odd distributions (intrinsic charm?)

  III. Target fragmentation: GPDs, Fragmentation functions, Fracture Functions (many authors: D.Boer; M. Anselmino. et al.; A. Kotzinian; . . .)

  IV. Collider production – target or central region (e.g. D. Sivers)

IV. TMDs, GPDs, Generalized Fracture Functions

  I. Why GPDs? Phases and transversity - - -

  II. Preliminary results & relations

Transversity - some history

- 2-body scattering amps - Exclusive hadronic
  - $f_{a,b;c,d}(s,t)$ with spin projections a,b;c,d
- What *spin* frame leads to simplest description of theory or data? Amps to observables?
  - **helicity** has easy relativistic covariance - theory
  - states of $\mathbf{S}\cdot\mathbf{p}$, e.g. $|+1/2\rangle$, $|-1/2\rangle$, etc.
  - **transversity:** eigenstates of $\mathbf{S}\cdot(\mathbf{p}_1\times\mathbf{p}_2)$
    $|\pm 1/2\,)_T = \{|+1/2\rangle \pm (i)\, |-1/2\rangle\}/\sqrt{2}$ for spin 1/2, etc.

Especially for relating to **single spin asymmetries** - only $\mathbf{S}\cdot\mathbf{n}$

Goldstein & Moravcsik, Ann.Phys. 1976

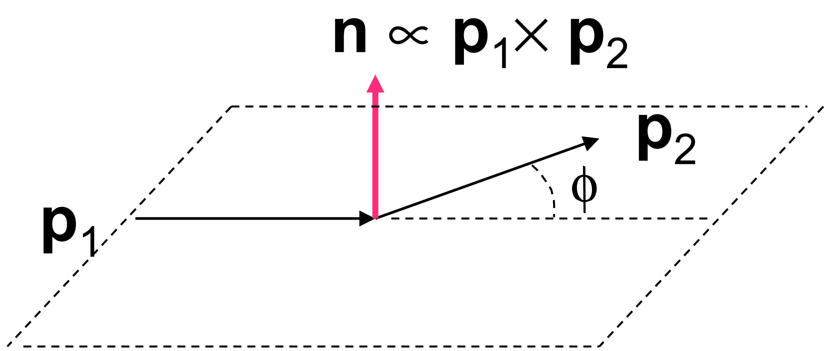
Transversity & simplicity

- states of $\{S\cdot(p_1 \times p_2)\}$ are transversity **normal** to scattering plane
  - $|\pm 1/2\,)_T = \{|+1/2> \pm (i)\, |-1/2>\}/\sqrt{2}$ for spin 1/2
  - Spin 1: $|\pm 1)_T = \{|+1> \pm\sqrt{2}\,|0> + |-1>\}/2$

    $|\,0)_T = \{|+1> - |-1>\}/\sqrt{2}$
  - photon: $|\pm 1)_T = \{|+1> + |-1>\}/\sqrt{2}$ linear polzn normal to plane

Phases & SSA

- Single Spin Asymmetries (SSA) in 2-body
- Parity allows only <**S**·**n**> non-zero for any single spinning particle. Requires some helicity flip or chirality flip for m=0 quarks & phase.



Cross section for spin S·**n**= +1/2 minus that for S·**n**= -1/2

$<\mathbf{S}\cdot\mathbf{n}> \propto \Sigma f^{*}_{ab,cd}[\sigma\cdot\mathbf{n}]_{dd'} f_{ab,cd'} \propto \Sigma \, \mathrm{Im}[f^{*}_{ab,c+} \, f_{ab,c-}]$ for D's SSA

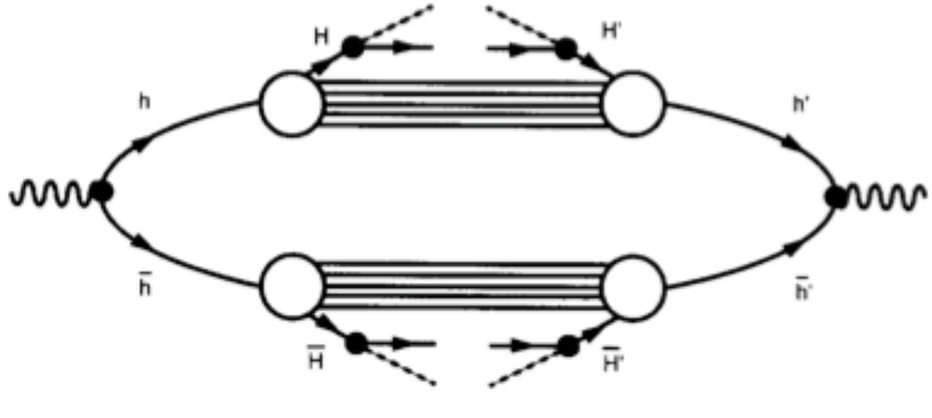
n requires some $\mathbf{p}_2$ transverse to $\mathbf{p}_1$

(at quark level? m=0 & PQCD - no SSA)

- Inclusive A+B->X+D: sum over all C particles & relate to A+B +anti-D forward elastic. GRG & J.F.Owens (76)

K. Chen et al./Nuclear Physics B 445 (1995) 380–396

Tool for determining transversity transfer or $H_1(z)$



$$\hat{f}_1(z)=\tfrac{1}{4}z\int\frac{d\lambda}{2\pi}e^{-i\lambda/z}\langle 0|\not{n}\psi(0)|\Lambda(PS)X\rangle\langle\Lambda(PS)X|\bar{\psi}(\lambda n)|0\rangle\,,$$

$$\hat{g}_1(z)=\tfrac{1}{4}z\int\frac{d\lambda}{2\pi}e^{-i\lambda/z}\langle 0|\not{n}\gamma_5\psi(0)|\Lambda(PS_{\parallel})X\rangle\langle\Lambda(PS_{\parallel})X|\bar{\psi}(\lambda n)|0\rangle\,,$$

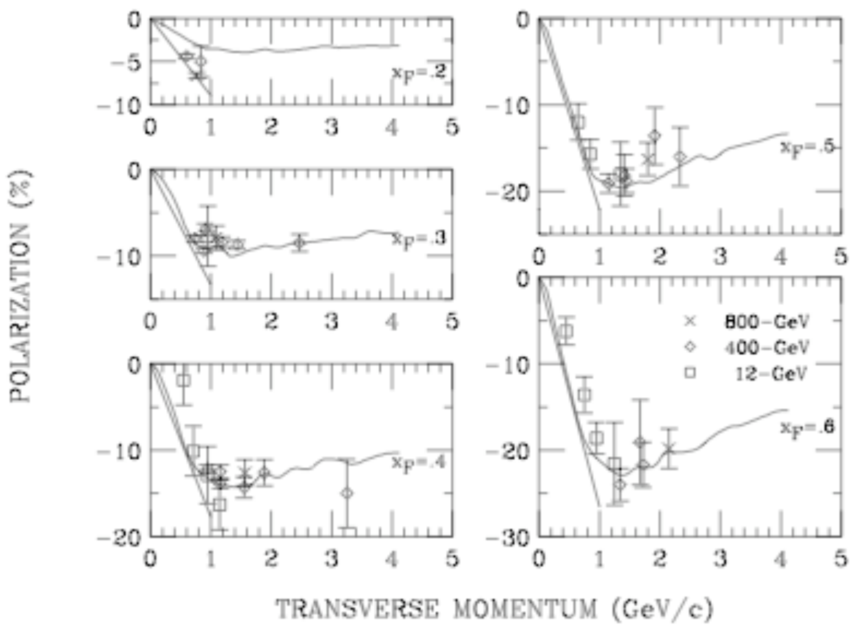
$$\hat{h}_1(z)=\tfrac{1}{4}z\int\frac{d\lambda}{2\pi}e^{-i\lambda/z}\langle 0|\not{n}\gamma_5\not{S}_{\perp}\psi(0)|\Lambda(PS_{\perp})X\rangle\langle\Lambda(PS_{\perp})X|\bar{\psi}(\lambda n)|0\rangle\,,$$

Predicts small back to back transverse spin correlations
ALEPH measurement at Z mass (ave. over Λ Λbar):

$$P_T^{\Lambda}=0.016\pm0.007\quad\text{for } p_T>0.3\ \text{GeV}/c\,,$$

$$P_T^{\Lambda}=0.019\pm0.007\quad\text{for } p_T>0.6\ \text{GeV}/c\,,$$

Large polarization in hadron+hadron



p+p→Λ+ X Polzn(Λ)

compiled by K.Heller (1997)

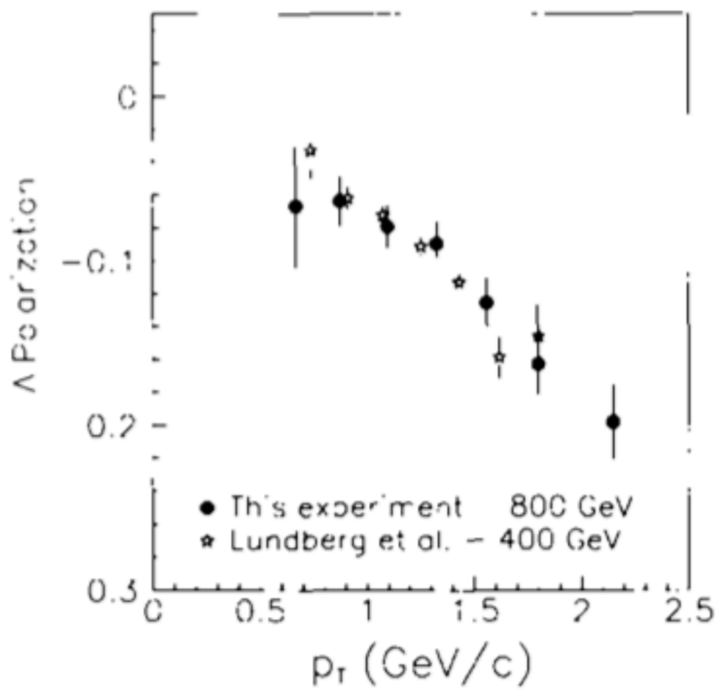


Fig. 4. Lambda polarization versus production transverse momentum (p_T). For comparison, data for 400 GeV production (Ref. 10) are also shown.

Ramberg, et al.,(FNAL) PLB338, 403 (1994)

Evolving Ideas about Source of Λ Polarization in Hadrons (p+p)

- Semi-classical: Lund; Thomas precession; SU(6) re Λ,Σ,Ξ
- Q Field Th: Single polarization requires amplitude interference => Real x Im part & helicity flip
- Kane, Pumplin, Repko: PQCD→P_Λ~ $\alpha(\hat{s})m_q / \sqrt{\hat{s}}$

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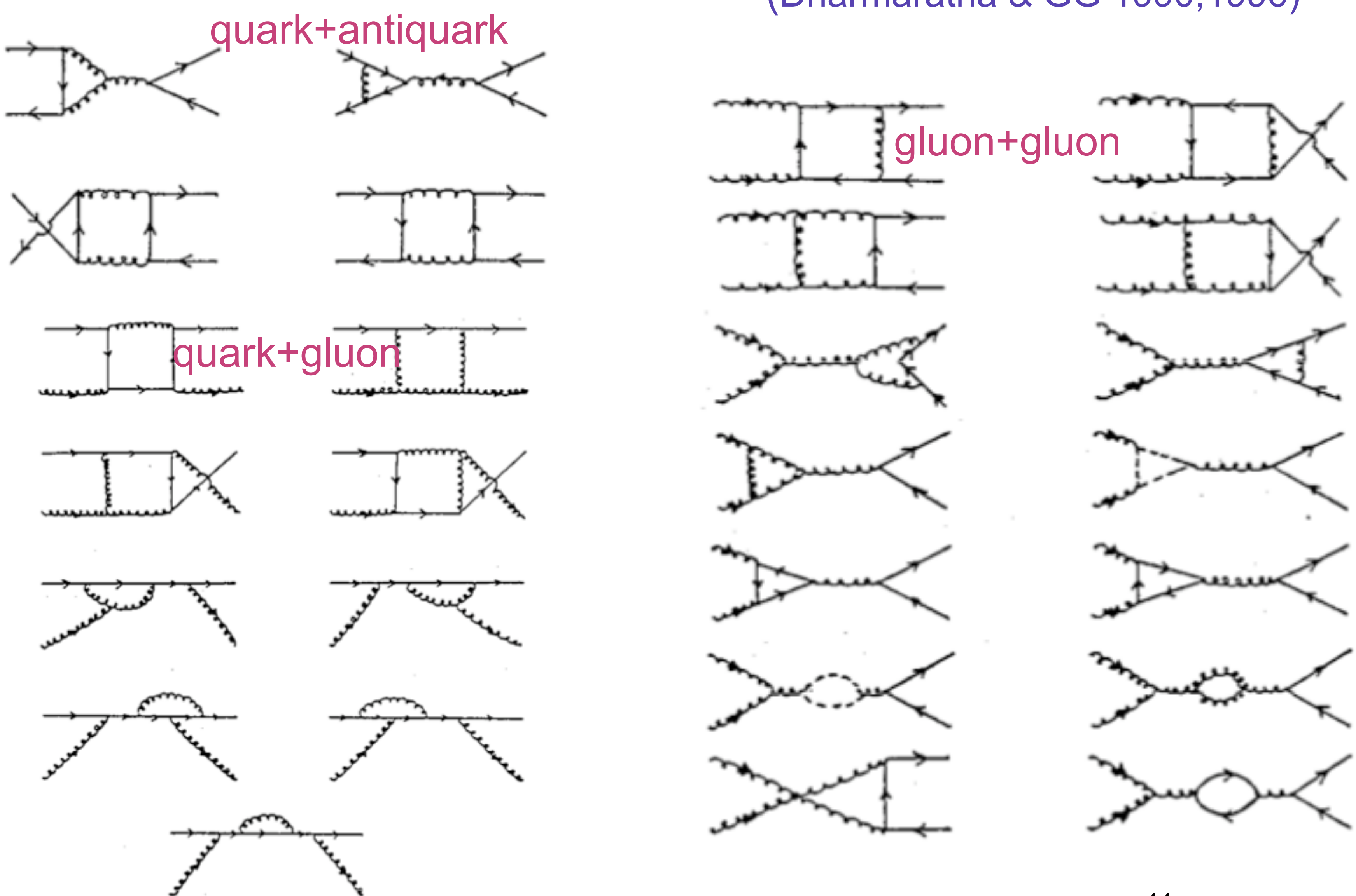
- Complete order α_s calculation of quark, antiquark, gluon 2-body scattering →*s*⇑+*s*bar imbedded in hadron+hadron pdf's (but small m_S) (Dharmaratna & GG 1990,1996) How does s⇑get translated to Λ⇑ & enhanced?

Contributions to order α_S Imaginary Part

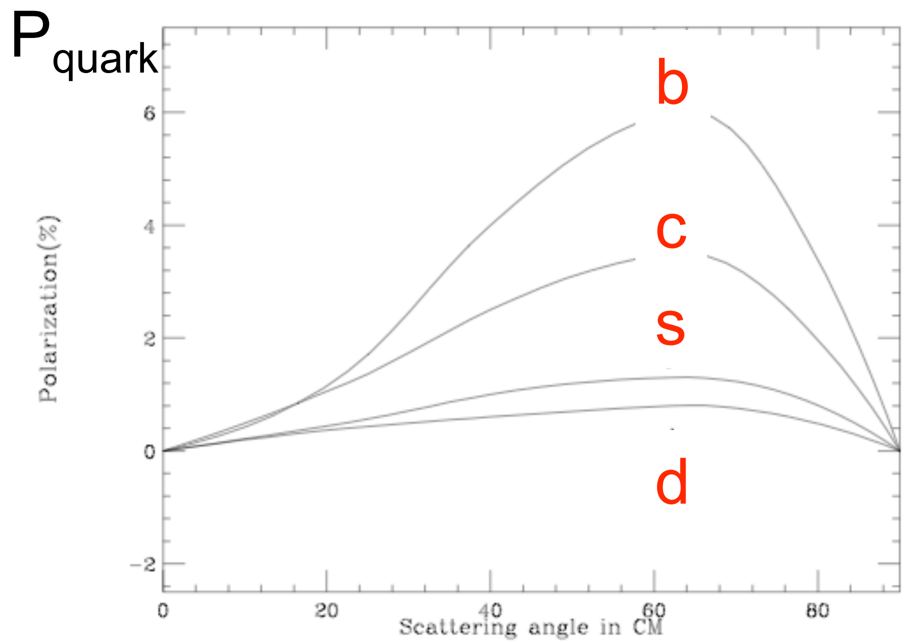
(Dharmaratna & GG 1990,1996)



P_{quark} vs. flavor
from gluon fusion
grows with flavor

Does this give larger P_{hadron} for heavier flavor?

What sets scales? quark "mass" or hyperon mass



$g+g \to Q + X$

Polzn(Q)~ $m_Q/\sqrt{s}$

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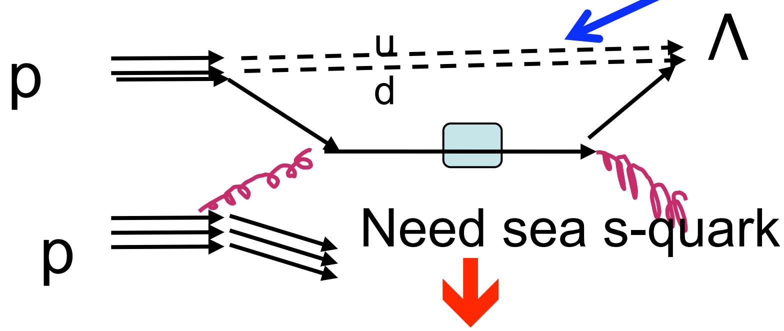
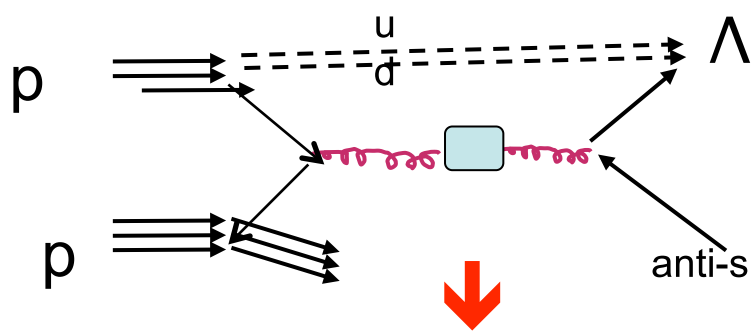
- How does s⇑ get translated to Λ⇑ & enhanced?
- Soft "Recombination" with (ud) remnant of N.

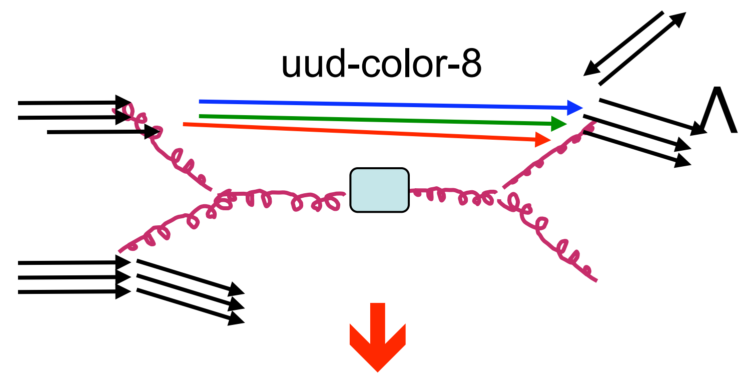
How to get to hyperon Polz'n?

Soft "Recombination" with (ud) remnant of proton





Need light antiquark



Box represents loop contributions to Im part. Seen as *GPD* already have Im part!

Model of hyperon polarization

Dharmaratna & GRG (1990,96,99)

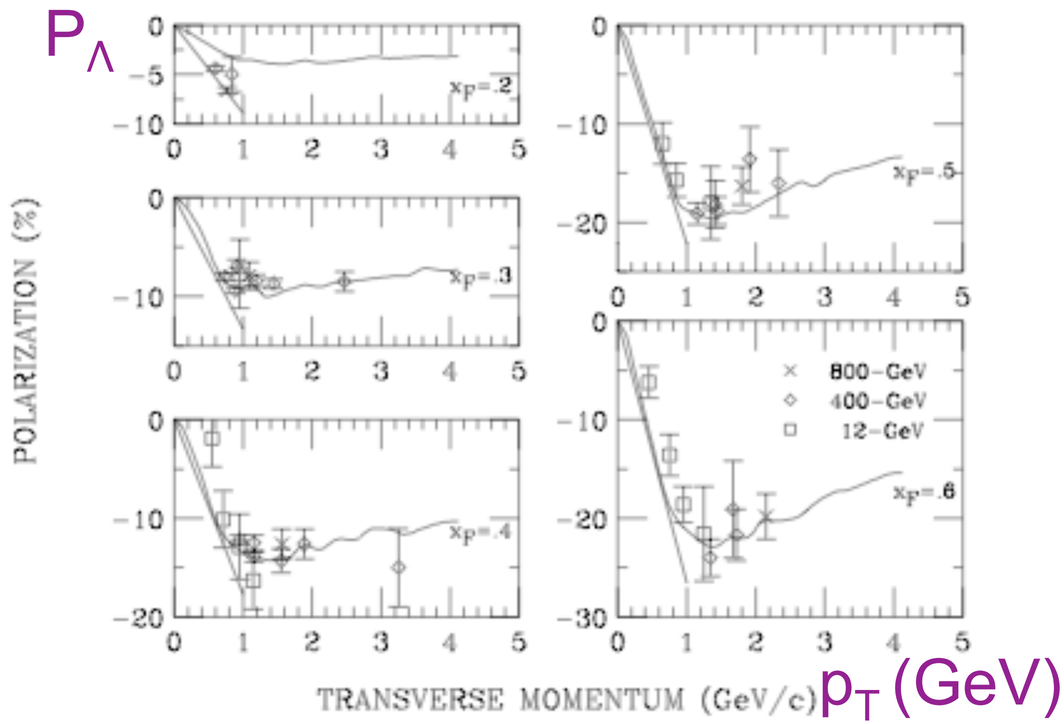
1. p+p $\to \Lambda\uparrow$ +X has large negative P_Λ with flat s dependence & growth with p_T (see Heller . . .)

2. Clues: $K^- p \to \Lambda\uparrow$ +X at 176 GeV/c or $\sqrt{s}$=18GeV
Polzn even larger - need *s*-quark?

3. Simple factorization expectation
Kane, Pumplin, Repko
$P_\Lambda \sim \alpha(\hat{s}) m_q / \sqrt{\hat{s}}$

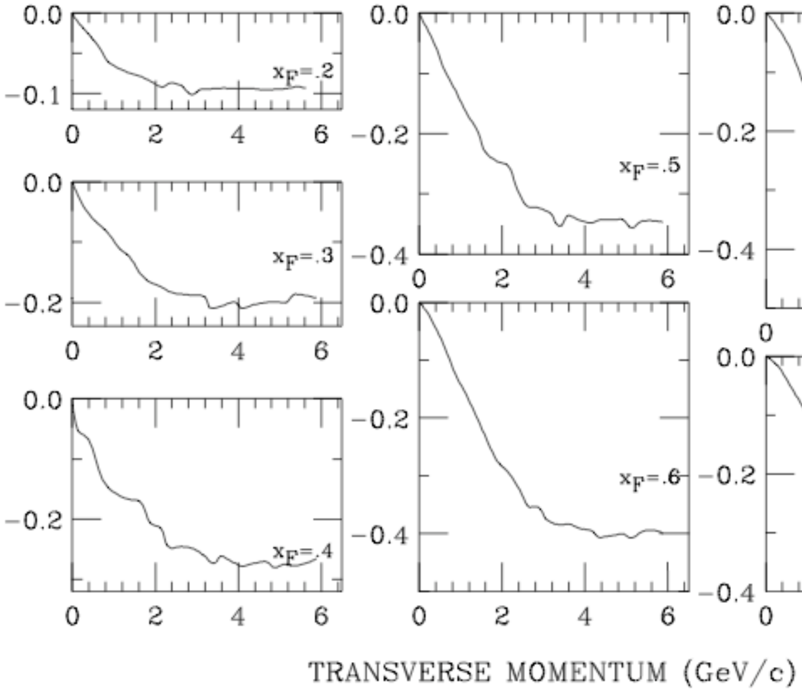
helicity flip ~ m_q/hard energy scale
Soft phenomenon?

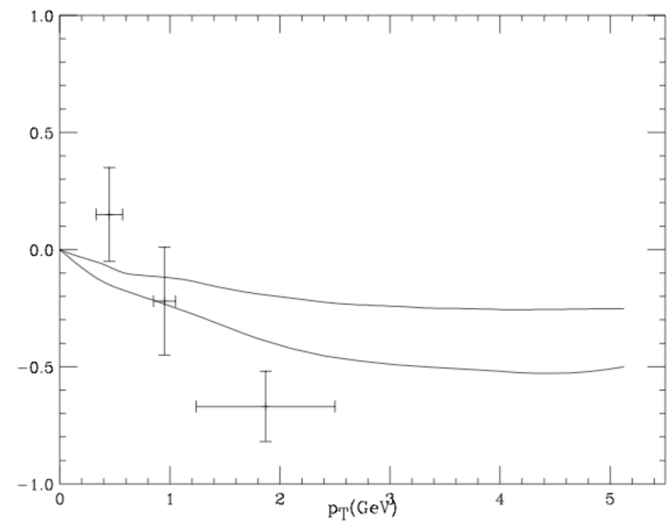
Dharmaratna & GRG: 1. Gluon fusion dominant mechanism for producing polarized
massive quark pair
2. Low p_T phenomenon
3. Recombination rules



p+p$\to\Lambda$+ X Polzn(Λ)
compiled by K.Heller (1997)

Charmed Hyperon Polarization





p_T (GeV)

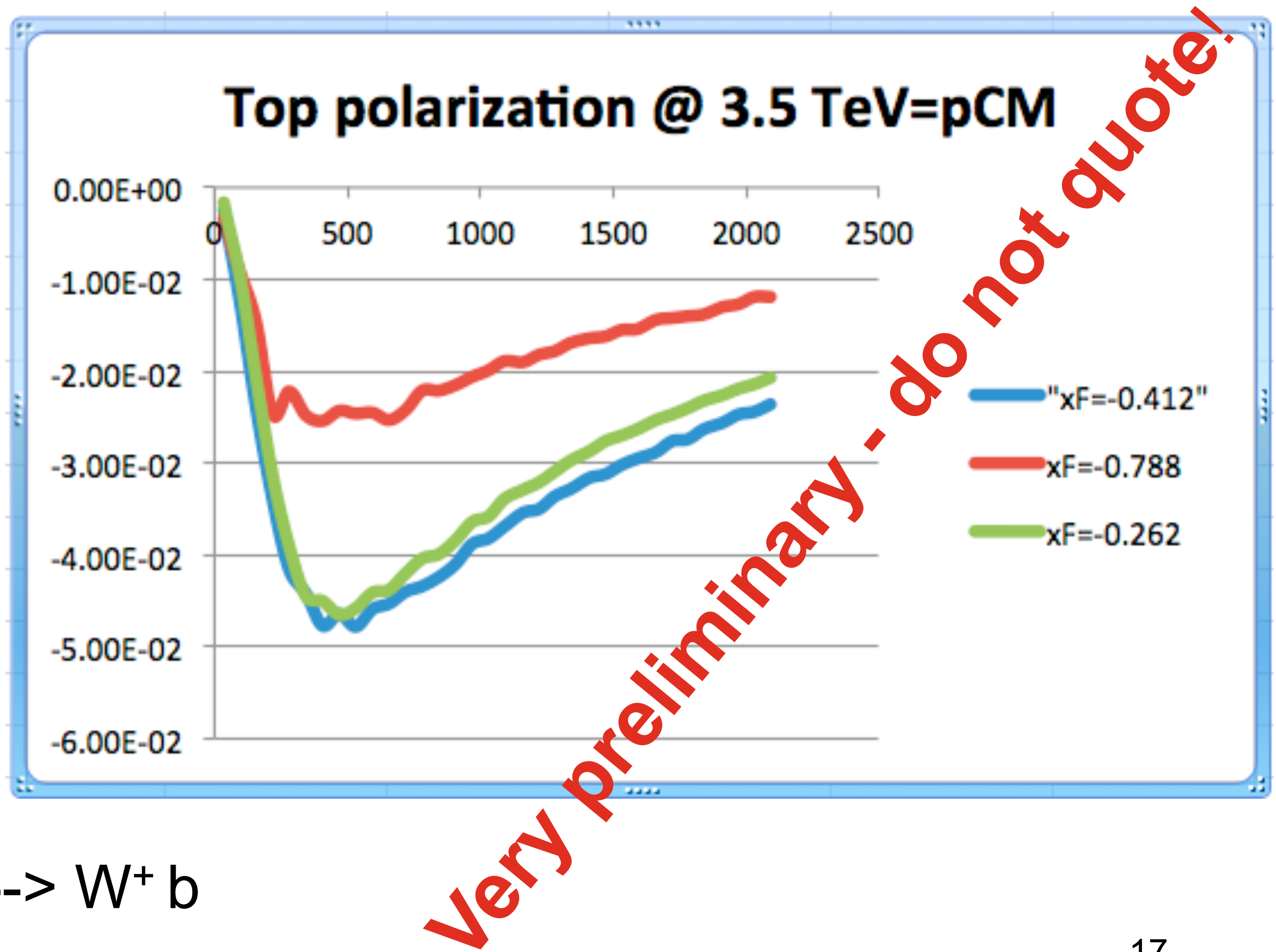
$P(\Lambda_c)$ vs. p_T (GeV) for several x_F values)

E.M. Aitala, et al. (E791 Collaboration) "Multidimensional Resonance Analysis of Λ_c+ → pK− π+" , Fermilab 1999.

$P(\Lambda_c)$ does not fall off with p_T

Trend to be tested?

Direct measure of hard process - top polarization



Analyze t--> W^+ b

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- How does s⇑ get translated to Λ⇑ & enhanced?
- Soft "Recombination" with (ud) remnant of N.
- **NPQCD must play a significant role in our understanding of orbital angular momentum & hadron formation.**

Evolving Ideas about Source of Λ Polarization in Hadrons

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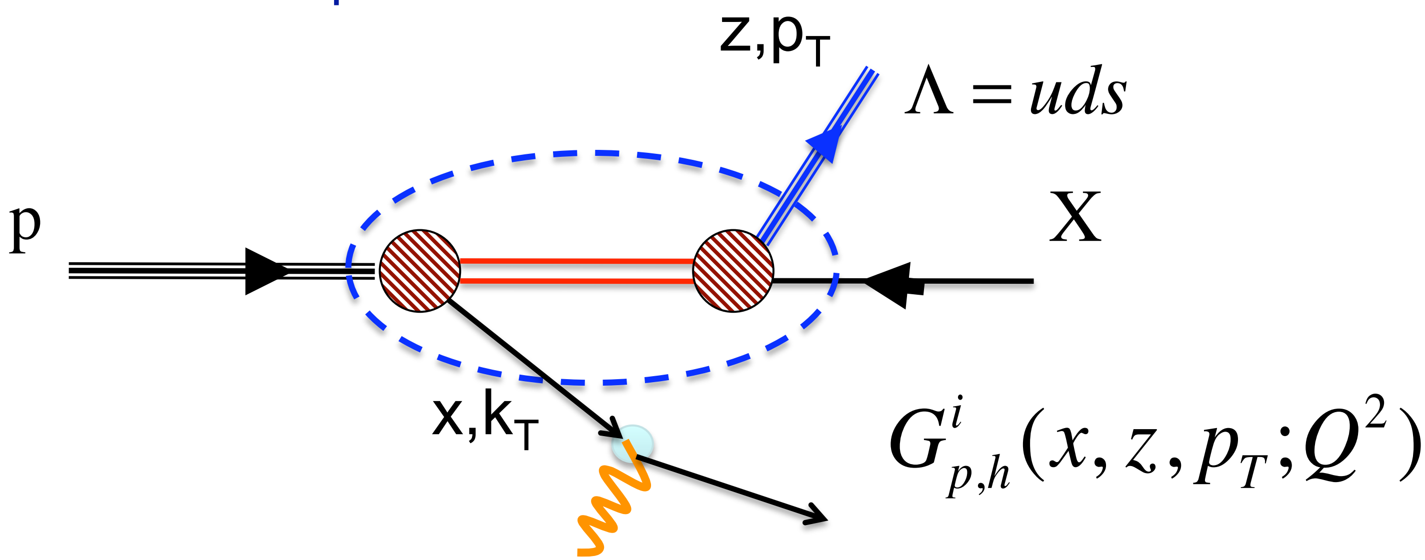
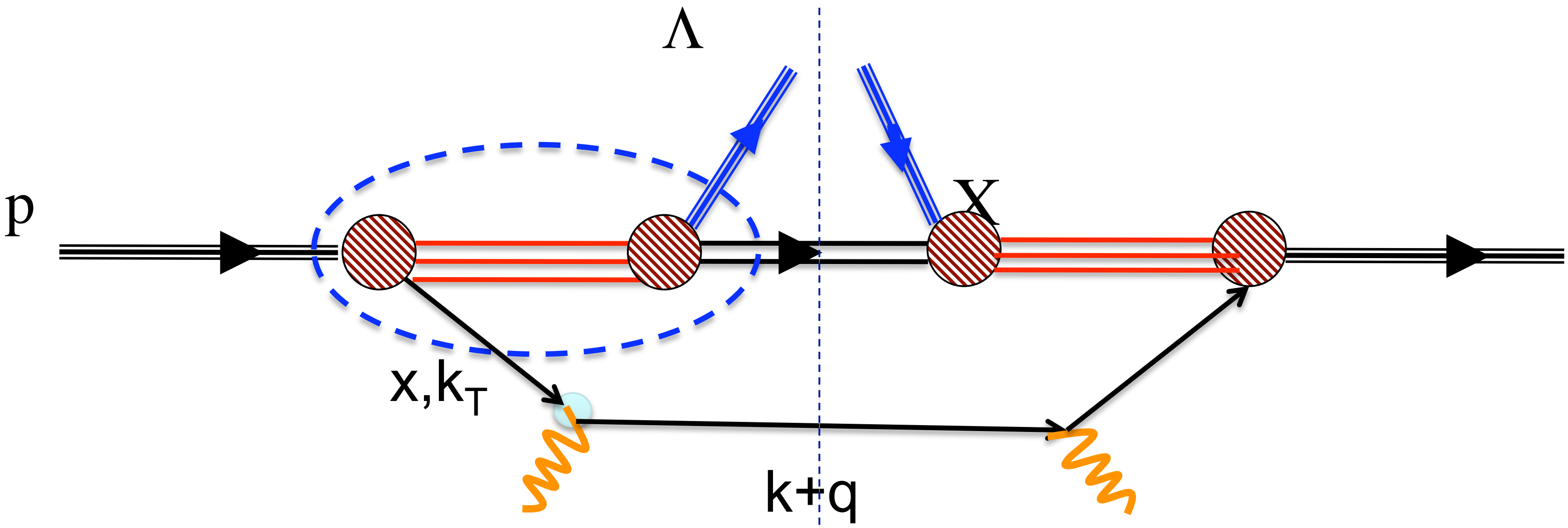
- How does s⇑ get translated to Λ⇑ ?
- Consider electroproduction of Λ's. Prelude to hadron production. QCD more under control.
  - Soft matrix elements from TMDs & SIDIS or GPDs &/or Fracture Functions

Electroproduction of Λ

Simple tree level model for extended fracture function
(Trentadue & Veneziano)
Diquark spectator & fragmentation
"dσ" squares & sums over X states with anti-s flavor
Diquark→Λ+s-bar simple vertex



$z=E_\Lambda/(1-x)E_{\gamma P\ CM}$ for target fragment
or $P_\Lambda^+=z(1-x)P^+$



$$(P-k)^2 = m_s^2 + \frac{M_\Lambda^2}{z} + \frac{1-z}{z}\left(\vec{P}_{\Lambda T} - \frac{z}{1-z}\vec{P}_{XT}\right)^2$$

Dipole form factors dampen P→u + diq vertex

Λ, diquark, struck quark all on shell

$$k^2 = xM^2 - \frac{\vec{k}_T^2}{(1-x)} - \frac{x}{(1-x)}(P-k)^2$$

$\delta((k+q)^2) \rightarrow x = x_{Bj}$

diquark model extended fracture function

$$(P-k)^2 = m_s^2 + \frac{M_\Lambda^2}{z} + \frac{1-z}{z}\left(\vec{P}_{\Lambda T} - \frac{z}{1-z}\vec{P}_{XT}\right)^2$$

$$k^2 = xM^2 - \frac{\vec{k}_T^{\,2}}{(1-x)} - \frac{x}{(1-x)}(P-k)^2$$

$$\mathcal{F}^{\lambda_q}_{\Lambda_N,\Lambda_\Lambda}(x,k_T,z,p_T,Q^2) = \sum_{\Lambda_X}\int \frac{d^3P_X}{(2\pi)^3 2E_X}\int \frac{d^4\xi}{(2\pi)^4} e^{ik\cdot\xi}\langle P \mid \bar{\psi}(\xi) \mid P_h; X\rangle\langle P_h; X \mid \psi(0) \mid P\rangle.$$

quark correlator for Extended Fracture Functions

helicity labels $<P, \Lambda_N|$ & $|P_h, \Lambda_\Lambda ; X>$

For unpolarized dσ, sum over all helicity labels.

For polarized Λ, keep floating

diquark model extended fracture function

In the spectator model

$$\mathcal{F}^{\Lambda_\Lambda,\Lambda'_\Lambda}_{\lambda_q,\Lambda_N}(x,k_T,z,p_T,Q^2) = A_{\Lambda_N,\lambda_q}\sum_{\Lambda_X} B^{\Lambda_\Lambda,\Lambda'_\Lambda}_{\Lambda_X}$$

where

$$A_{\Lambda_N,\lambda_q} = \mid \phi_{\lambda,\Lambda}(k,P)\mid^2,$$

with

$$\phi_{\Lambda,\lambda}(k,P) = \Gamma(k)\frac{\bar{u}(k,\lambda_q)U(P,\Lambda_N)}{k^2-m^2},$$

and

$$k = P - P_X - P_\Lambda \quad \Rightarrow k^2 = k^2(x,\mathbf{k}_T,z,\mathbf{p}_T)$$

whereas

$$B^{\Lambda_\Lambda,\Lambda'_\Lambda}_{\Lambda_X} = \tilde{\phi}^*_{\Lambda_X,\Lambda'_\Lambda}(P_X,P_h)\tilde{\phi}_{\Lambda_X,\Lambda_\Lambda}(P_X,P_h),$$

with

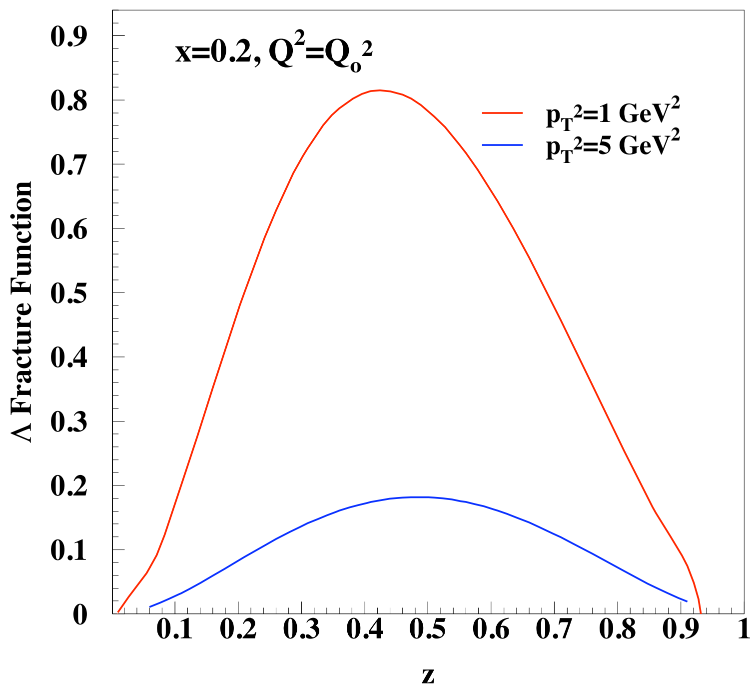
$$\tilde{\phi}_{\Lambda_X,\Lambda_\Lambda}(P_X,P_h) = \Gamma(P_X)\bar{v}(P_X,\Lambda_X)U(P_h,\Lambda_\Lambda)$$

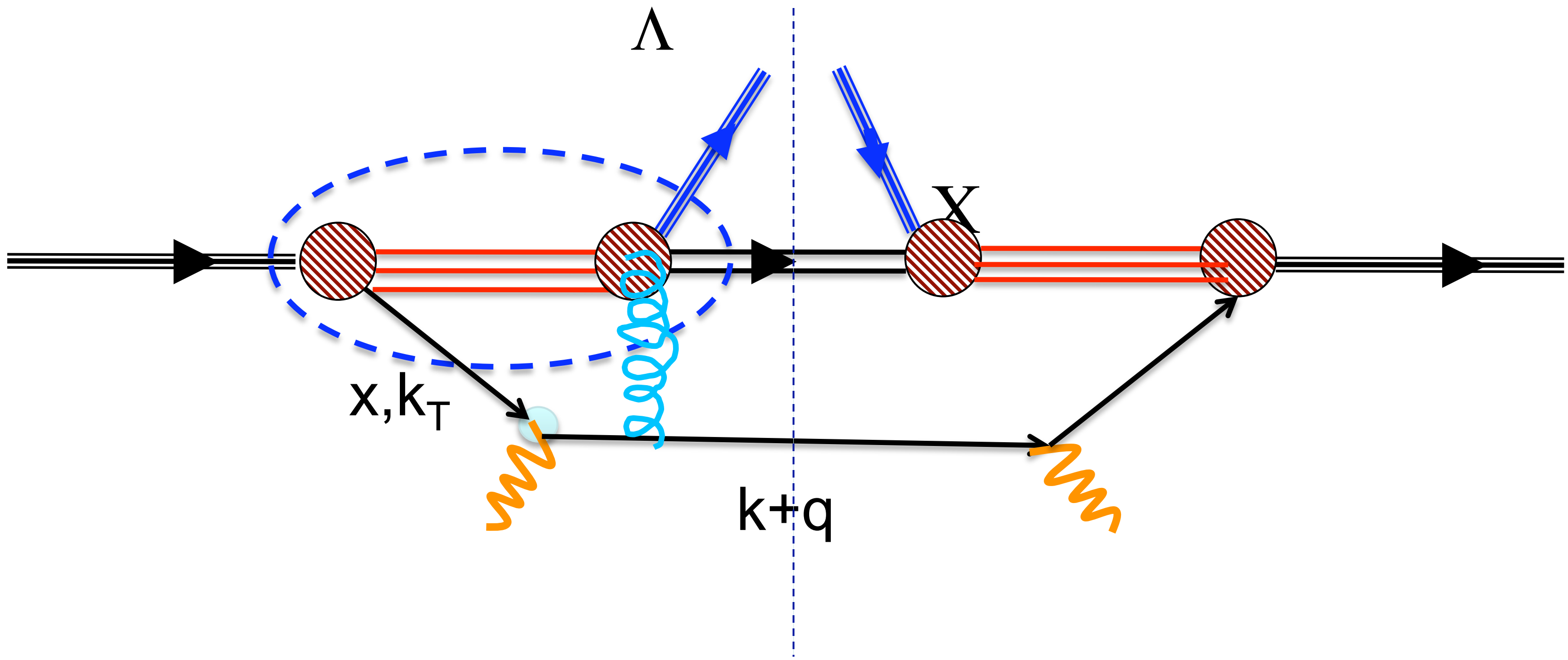
diquark model extended fracture function

$$\sum_{\Lambda_X} B_{\Lambda_X}^{\Lambda_\Lambda,\Lambda'_\Lambda} = (1-x)^2\left([-zM_X + (1-z)M_\Lambda]^2 + p_T^2\right)\delta_{\Lambda_\Lambda,\Lambda_\Lambda}$$

A_{Λ_N,λ_q} is squared & summed over

$$\to f(x,k_T)/(k^2 - m_{dipole}^2)^4 \quad]_{P_X^2=(P-k-P_\Lambda)^2=m_s^2}$$





Spin dependence?

a. non-trivial quark or proton-Λ spin correlation ➔ axial diquark

b. SSA need phase ➔ beyond tree

Figure shows final state interaction contribution to $\Lambda\Uparrow$

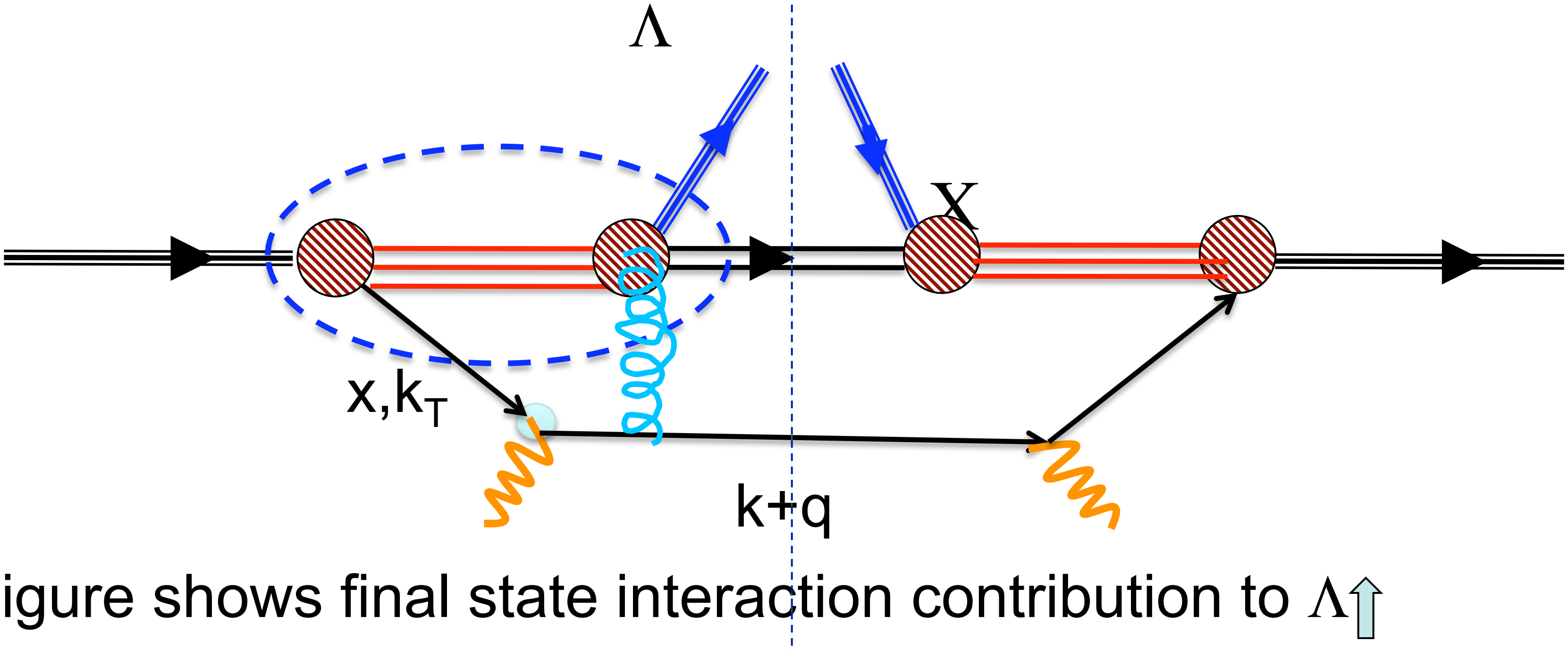
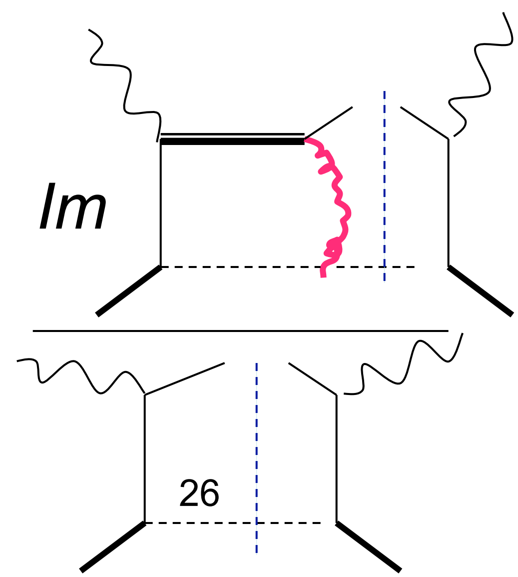


Figure shows final state interaction contribution to Λ⇧

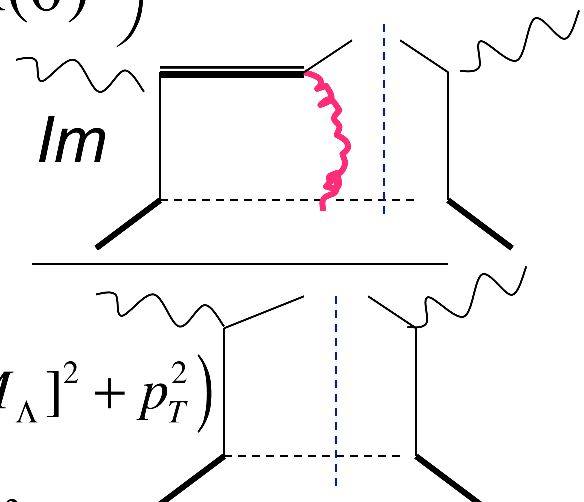


Final State Interactions or gauge links . . . .

Recall f.s.i. (e.g. Brodsky, Hwang & Schmidt; Gamberg & Goldstein, etc.)

$$P_y = C_F \alpha_s(\mu^2) \frac{(xM+m)k_x}{[(xM+m)^2+\vec{k}_\perp^2]} \frac{\Lambda(\vec{k}_\perp^2)}{\vec{k}_\perp^2} \ln\left(\frac{\Lambda(\vec{k}_\perp^2)}{\Lambda(0)}\right)$$

$$\Lambda(\vec{k}_\perp^2) = \vec{k}_\perp^2 + x(1-x)\left(-M^2 + \frac{m^2}{x} + \frac{\lambda^2}{1-x}\right)$$



For Frac.Fn. model replace denom with $\left([-zM_X + (1-z)M_\Lambda]^2 + p_T^2\right)$

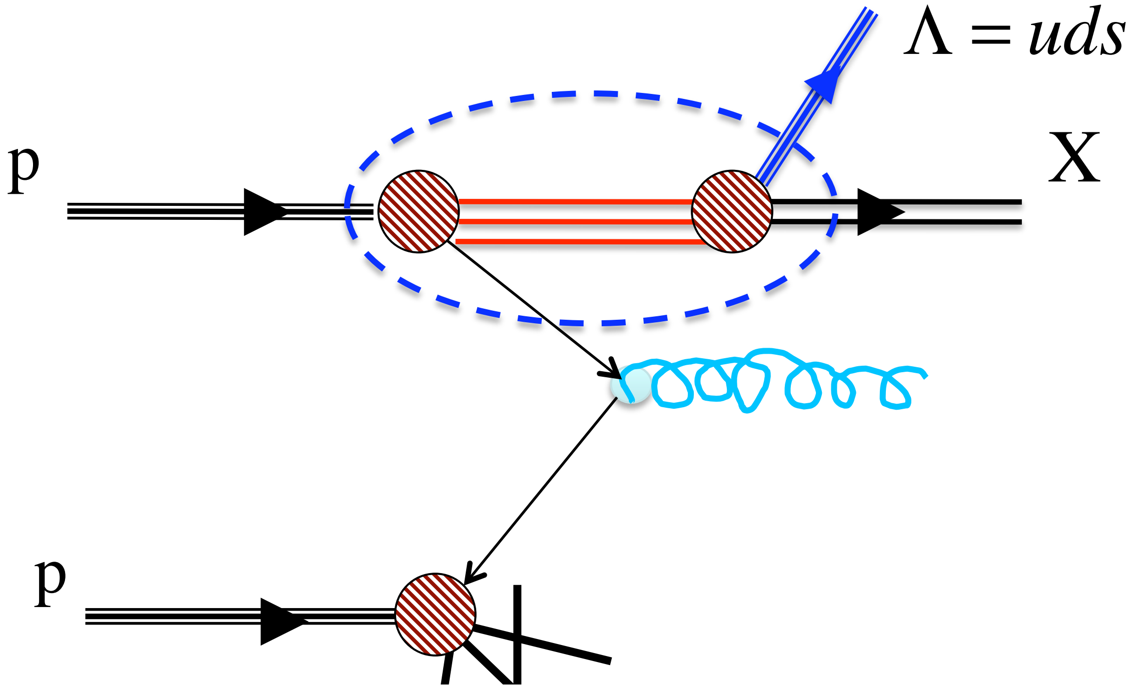
$$\Omega(\vec{k}_T^2, \vec{p}_T^2) = xM^2 - \{\vec{k}_T^2 + x[m_s^2 + \frac{M_\Lambda^2}{z} + \frac{1-z}{z}(\vec{p}_T - \frac{z}{1-z}\vec{p}_{XT})^2]\}/(1-x)$$

numerator with $(1-x)^2 k_T (zM_X - (1-z)M_\Lambda^2)$ from Im flip $\times$ non-flip

PDFs + Fracture functions

Incorporated into P + P

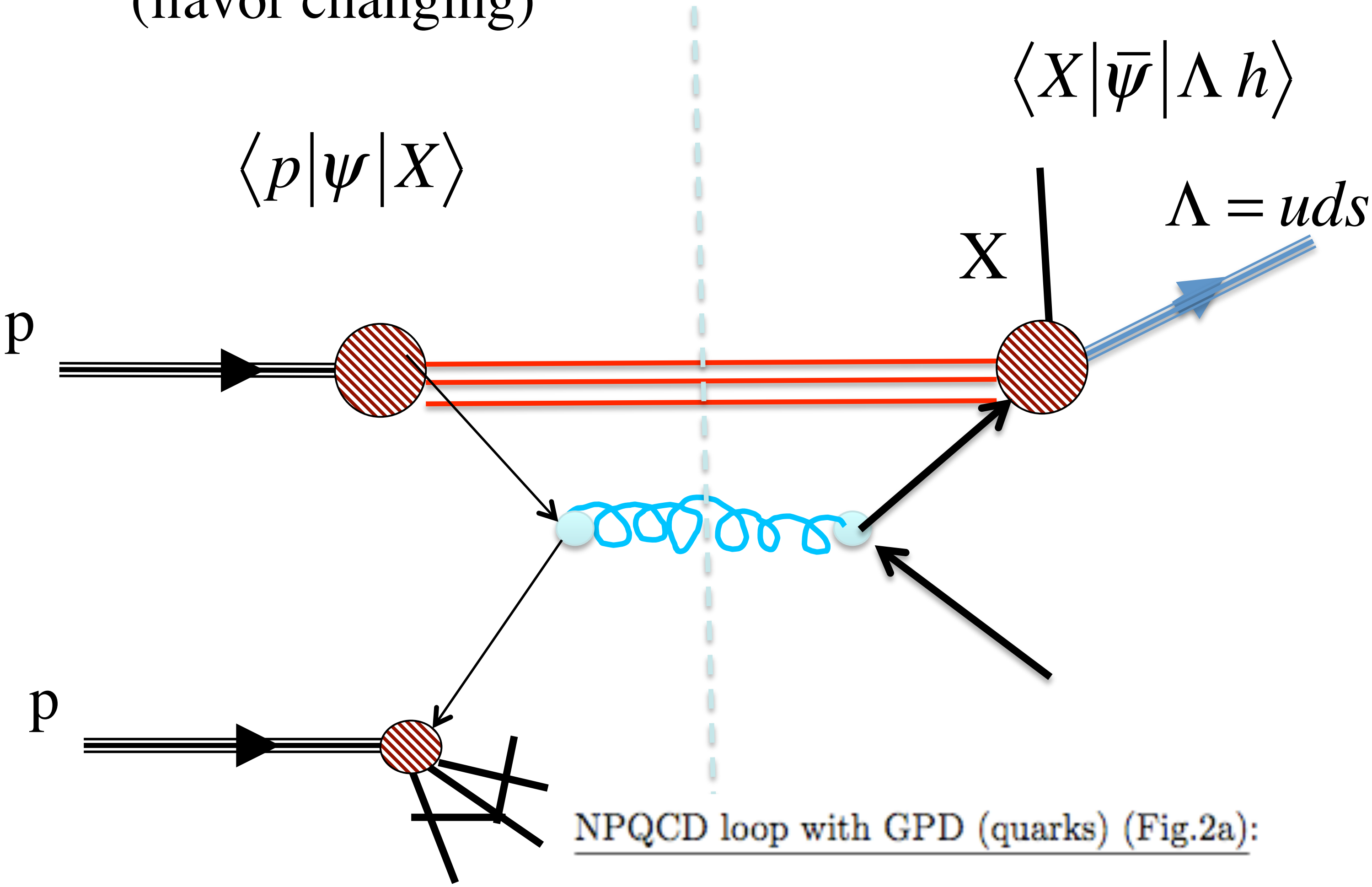
$\langle p|\bar{\psi}|\Lambda\, X\rangle$



Formally, for a quark-nucleon FF,

$$\mathcal{F}(x, k_T, z, p_T, Q^2) = \sum_X \int \frac{d^3P_X}{(2\pi)^3 2E_X} \int \frac{d^4\zeta}{(2\pi)^4} e^{ik\cdot\zeta} \times \langle P \mid \bar{\psi}(\zeta) \mid P_{hadron}; X\rangle \times \langle P_{hadron}; X \mid \psi(0) \mid P\rangle. \quad (6)$$

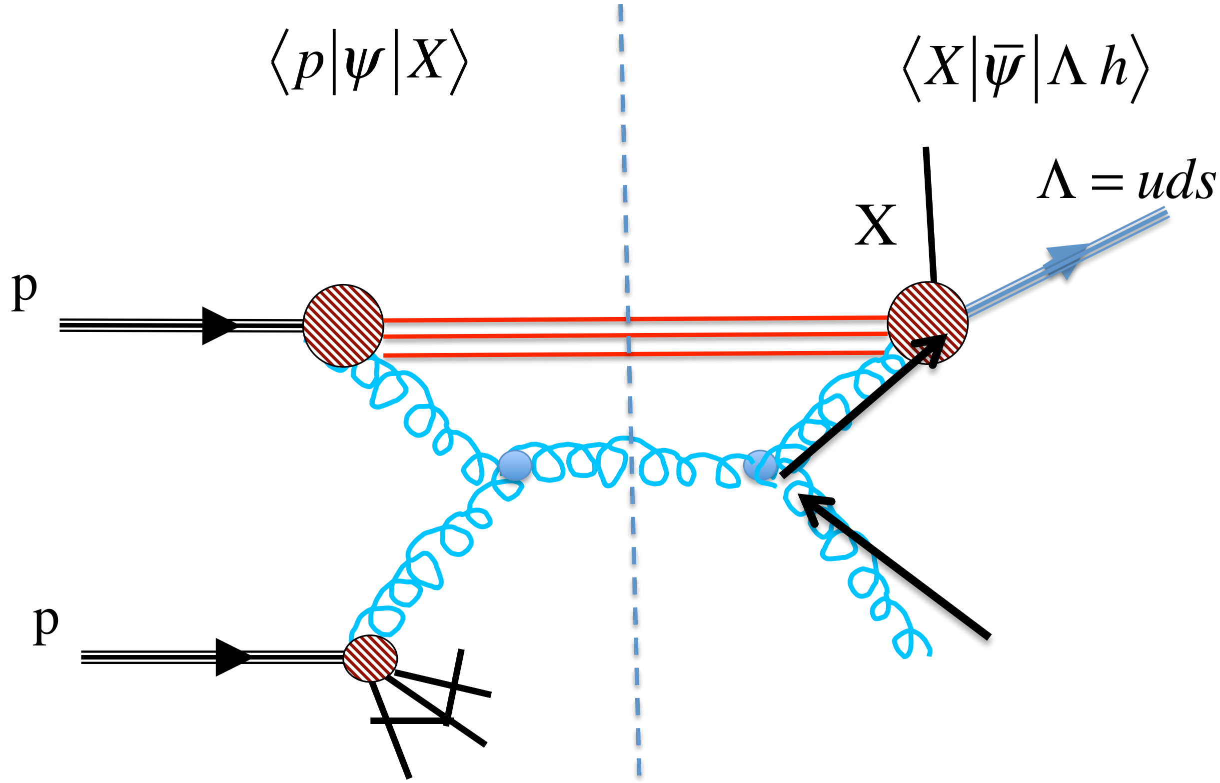
Generalized Fracture Function ➔ extended GPDs (flavor changing)



NPQCD loop with GPD (quarks) (Fig.2a):

$$\int dx_1 dx_2 \, [\mathcal{H}^*_{N\to Y}\mathcal{H}_{N\to Y}](x_1,\zeta,t,Q^2)$$
$$\times \; f(x_2,Q^2)\hat{\sigma}^{LO}_{12\to sX}(x_1,x_2,x^s_F,p_T)$$

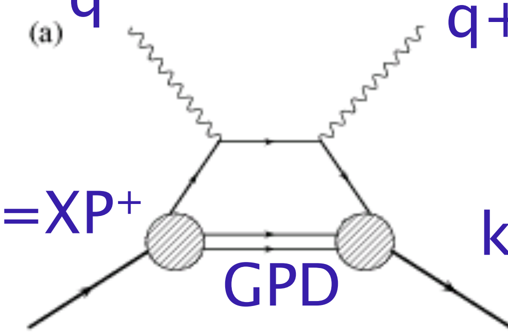
Generalized Fracture Function



Gluon fusion is largest source of polarized quarks & gluons . . .
Gluons will be plentiful at LHC. Move toward Gluon GPDs

DVCS & DVMP $\gamma^*(Q^2)+P \rightarrow (\gamma \text{ or meson})+P'$

partonic picture



q

$q+\Delta$

$\{ k_T$, $k^+=XP^+$

$k'_T=k_T-\Delta$, $k'^+=(X-\zeta)P^+ \}$

GPD

P^+

$P'^+=(1-\zeta)P^+$, $P'_T=-\Delta \}$

Factorized
"handbag"
picture

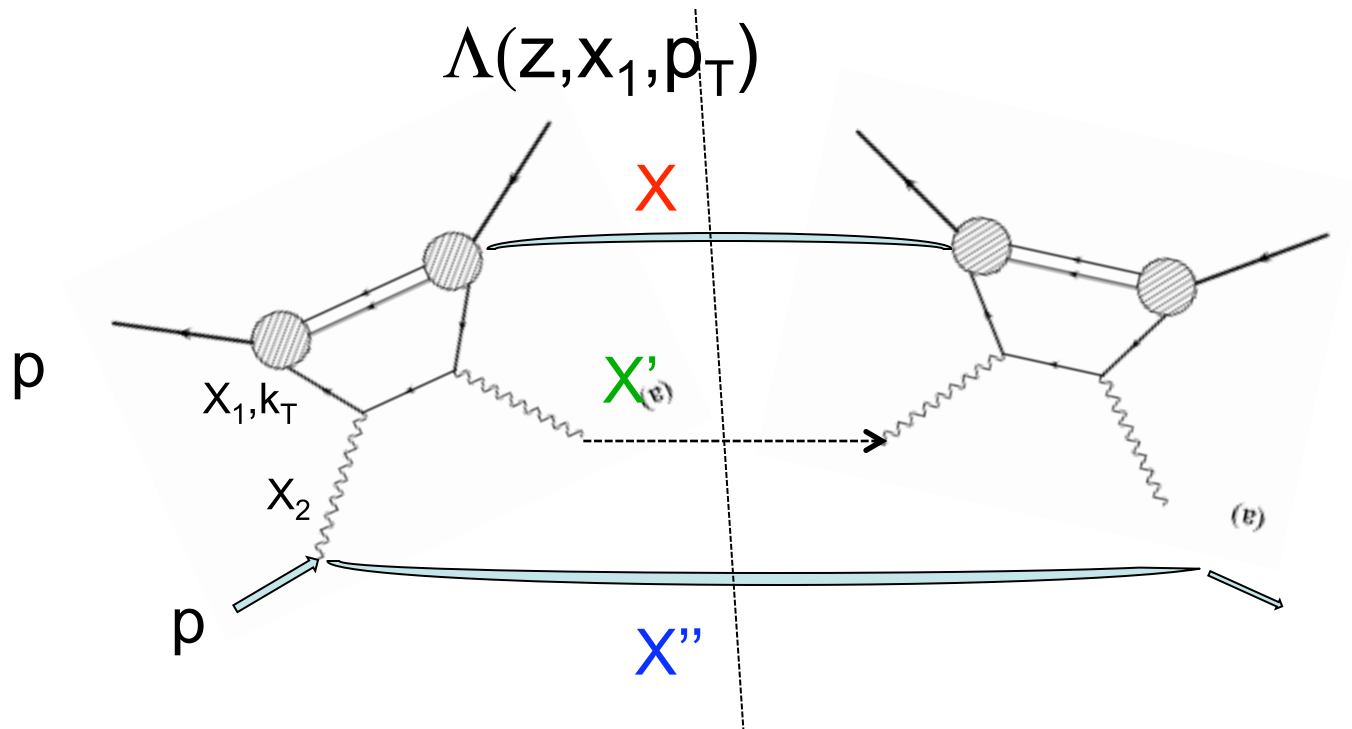
$\zeta \rightarrow 0$
Regge

Quark-spectator
quark+diquark

$X>\zeta$ DGLAP
$X<\zeta$ ERBL

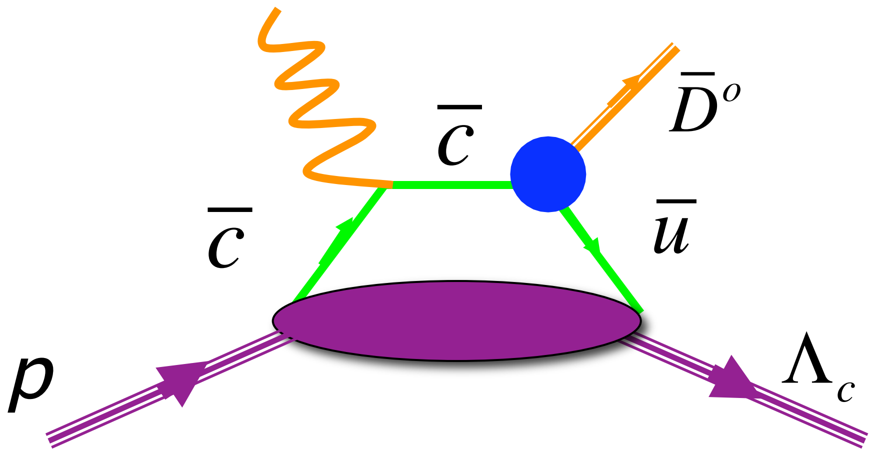
see Ahmad, GG, Liuti, PRD79, 054014, (2009) for first chiral odd GPD
G.G., O. Gonzalez Hernandez, S. Liuti, PRD84, 034007 (2011)

GPD source of Λ⇧
CFF→ Re & Im parts



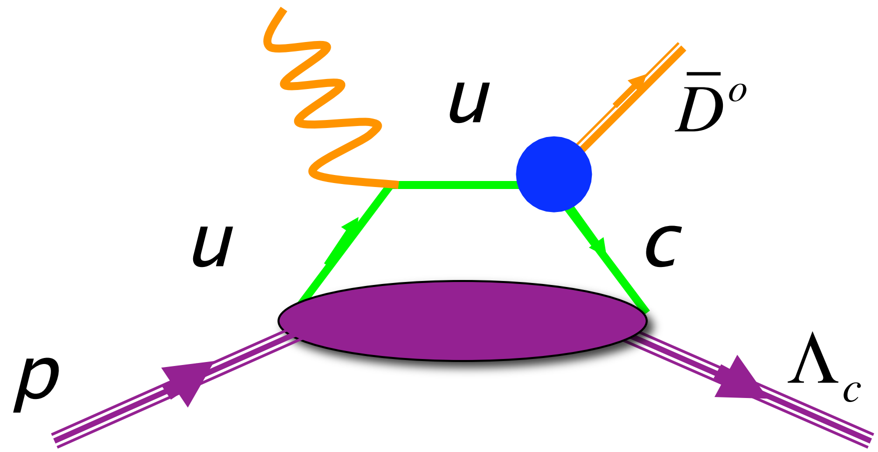
Each line has helicity summed over except Λ_Λ&Λ'_Λ
Real & Im CFF multiplied for Polzn

Flavor off-diagonal GPDs – example: charm production



$\propto H_c$

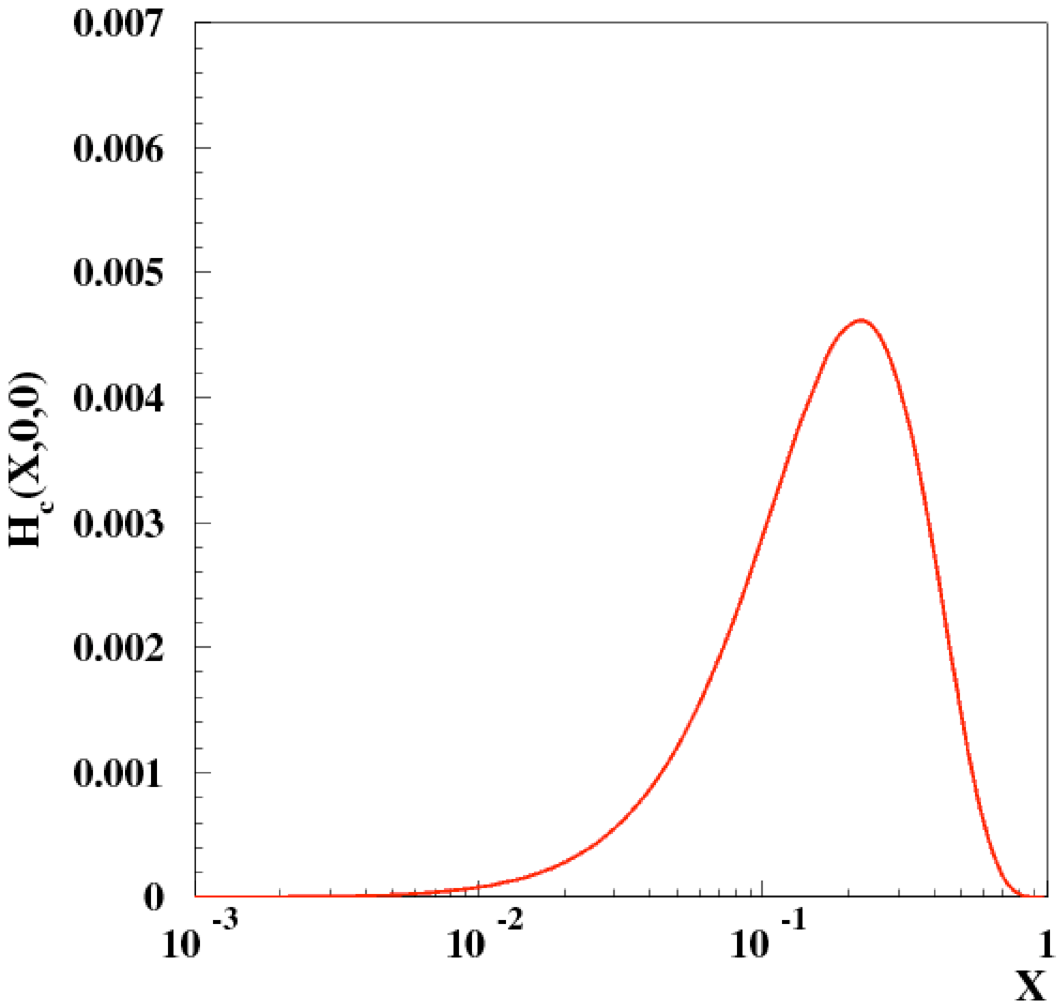
$p \rightarrow$ c-bar + cuud



$\propto H_u$

$p \rightarrow u + ud$

Example charm GPD

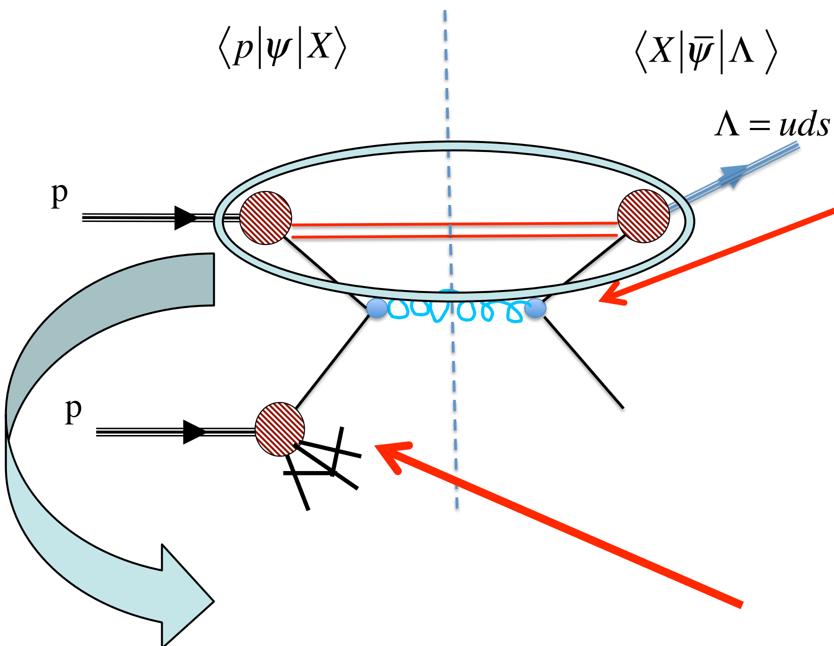


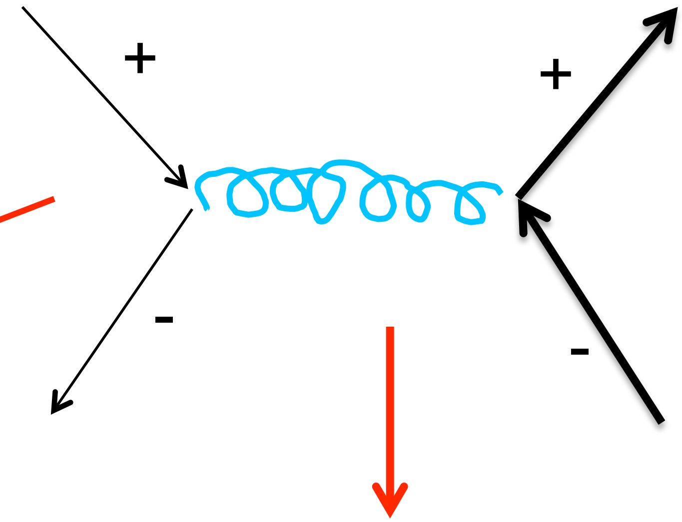
Next fold into x_2P^- as "q" & pdf's. Extract Im from $x=\zeta$ & Real from P.V. integral. Then Polzn can be straightforwardly determined.

GG & Liuti, Proc. EIC Meeting SBU, Sept.2010.

Qualitative results

Generalized (Flavor Changing) Parton Distribution





Chiral even “GPD”s

Pdf’s or TMDs

$A_{\Lambda(\Lambda)\,\lambda(s),\,\Lambda(P)\,\lambda(u)}(x_1,\zeta,p_T \text{ or } t, \text{ s-hat})$

➔ $A_{\Lambda(\Lambda)\,+,\,\Lambda(P)\,+}$ & $A_{\Lambda(\Lambda)\,-,\,\Lambda(P)\,-}$

GPD definitions

Momentum space nucleon matrix elements of quark field correlators

see, e.g. M. Diehl, Eur. Phys. J. C 19, 485 (2001).

$$\frac{1}{2}\int\frac{dz^-}{2\pi}\,e^{ixP^+z^-}\langle p',\lambda'|\,\bar\psi(-\tfrac{1}{2}z)\,\gamma^+\psi(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0} = \frac{1}{2P^+}\bar u(p',\lambda')\left[H^q\,\gamma^+ + E^q\,\frac{i\sigma^{+\alpha}\Delta_\alpha}{2m}\right]u(p,\lambda),$$

$$\frac{1}{2}\int\frac{dz^-}{2\pi}\,e^{ixP^+z^-}\langle p',\lambda'|\,\bar\psi(-\tfrac{1}{2}z)\,\gamma^+\gamma_5\,\psi(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0} = \frac{1}{2P^+}\bar u(p',\lambda')\left[\tilde H^q\,\gamma^+\gamma_5 + \tilde E^q\,\frac{\gamma_5\Delta^+}{2m}\right]u(p,\lambda),$$

Chiral even GPDs

$$\frac{1}{2}\int\frac{dz^-}{2\pi}\,e^{ixP^+z^-}\langle p',\lambda'|\,\bar\psi(-\tfrac{1}{2}z)\,i\sigma^{+i}\,\psi(\tfrac{1}{2}z)\,|p,\lambda\rangle\Big|_{z^+=0,\,\mathbf{z}_T=0} = \frac{1}{2P^+}\bar u(p',\lambda')\left[H_T^q\,i\sigma^{+i} + \tilde H_T^q\,\frac{P^+\Delta^i-\Delta^+P^i}{m^2} + E_T^q\,\frac{\gamma^+\Delta^i-\Delta^+\gamma^i}{2m} + \tilde E_T^q\,\frac{\gamma^+P^i-P^+\gamma^i}{m}\right]u(p,\lambda).$$

Chiral odd GPDs

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Recall that helicity amps are linear combinations of GPDs

$$
\begin{aligned}
A_{+,+;+,+} &= \sqrt{1-\xi^2}\left[\frac{H+\tilde{H}}{2} - \frac{\xi^2}{1-\xi^2}\frac{E+\tilde{E}}{2}\right] \\
A_{-,+;-,+} &= \sqrt{1-\xi^2}\left[\frac{H-\tilde{H}}{2} - \frac{\xi^2}{1-\xi^2}\frac{E-\tilde{E}}{2}\right] \\
A_{+,+;-,+} &= -\frac{\sqrt{t_0-t}}{4M}(E-\xi\tilde{E}) \\
A_{-,+;+,+} &= \frac{\sqrt{t_0-t}}{4M}(E+\xi\tilde{E})
\end{aligned}
$$

for chiral even GPDs and

$$
\begin{aligned}
A_{+-,++} &= -\frac{\sqrt{t_0-t}}{2M}\left[\widetilde{H}_T + \frac{1+\xi}{2}E_T - \frac{1+\xi}{2}\widetilde{E}_T\right] \\
A_{++,--} &= \sqrt{1-\xi^2}\left[H_T + \frac{t_0-t}{4M^2}\widetilde{H}_T - \frac{\xi^2}{1-\xi^2}E_T + \frac{\xi}{1-\xi^2}\widetilde{E}_T\right] \\
A_{+-,-+} &= -\sqrt{1-\xi^2}\,\frac{t_0-t}{4M^2}\,\widetilde{H}_T \\
A_{++,+-} &= \frac{\sqrt{t_0-t}}{2M}\left[\widetilde{H}_T + \frac{1-\xi}{2}E_T + \frac{1-\xi}{2}\widetilde{E}_T\right],
\end{aligned}
$$

for chiral odd GPDs, where for consistency with previous literature we have

In diquark spectator models $A_{++;++}$, etc. are calculated directly. Inverted -> GPDs

Invert to obtain model for GPDs

Scalar diquark:

$A_{++,-+} = - A_{++,+-}$

$A_{-+,++} = - A_{+-,++}$

$A_{++,++} = A_{++,--}$

$$H(x,\xi,t) = \frac{1}{\sqrt{1-\xi^2}}(A_{+,+;+,+} + A_{-,+;-,+}) - \frac{2M\xi^2}{\Delta(1-\xi^2)}(A_{+,+;-,+} - A_{-,+;+,+})$$

$$E(x,\xi,t) = -\frac{2M}{\Delta}(A_{+,+,-,+} - A_{-,+;+,+})$$

$$\tilde{H}(x,\xi,t) = \frac{1}{\sqrt{1-\xi^2}}(A_{+,+;+,+} - A_{-,+;-,+}) + \frac{2M\xi}{\Delta(1-\xi^2)}(A_{+,+,-,+} + A_{-,+;+,+})$$

$$\tilde{E}(x,\xi,t) = \frac{2M}{\Delta\xi}(A_{+,+,-,+} + A_{-,+;+,+})$$

for chiral even GPDs and

$$H_T(x,\xi,t) = \frac{1}{\sqrt{1-\xi^2}}(A_{+,+;-,-} + A_{-,+;+,-}) + \frac{2M\xi}{\Delta(1-\xi^2)}(A_{+,+;+,-} - A_{-,+;-,-})$$

$$\xi E_T(x,\xi,t) - \tilde{E}_T(x,\xi,t) = \frac{2M}{\Delta}(A_{+,+;+,-} - A_{-,+;-,-})$$

$$E_T(x,\xi,t) + \tilde{E}_T(x,\xi,t) = \frac{\Delta}{2M(1-\xi)}[2A_{+,+;+,-} + \frac{4M}{\Delta\sqrt{1-\xi^2}}A_{-,+;+,-}]$$

double flip

$$\tilde{H}_T(x,\xi,t) = \frac{4M^2}{\Delta^2\sqrt{1-\xi^2}}A_{-,+;+,-}$$

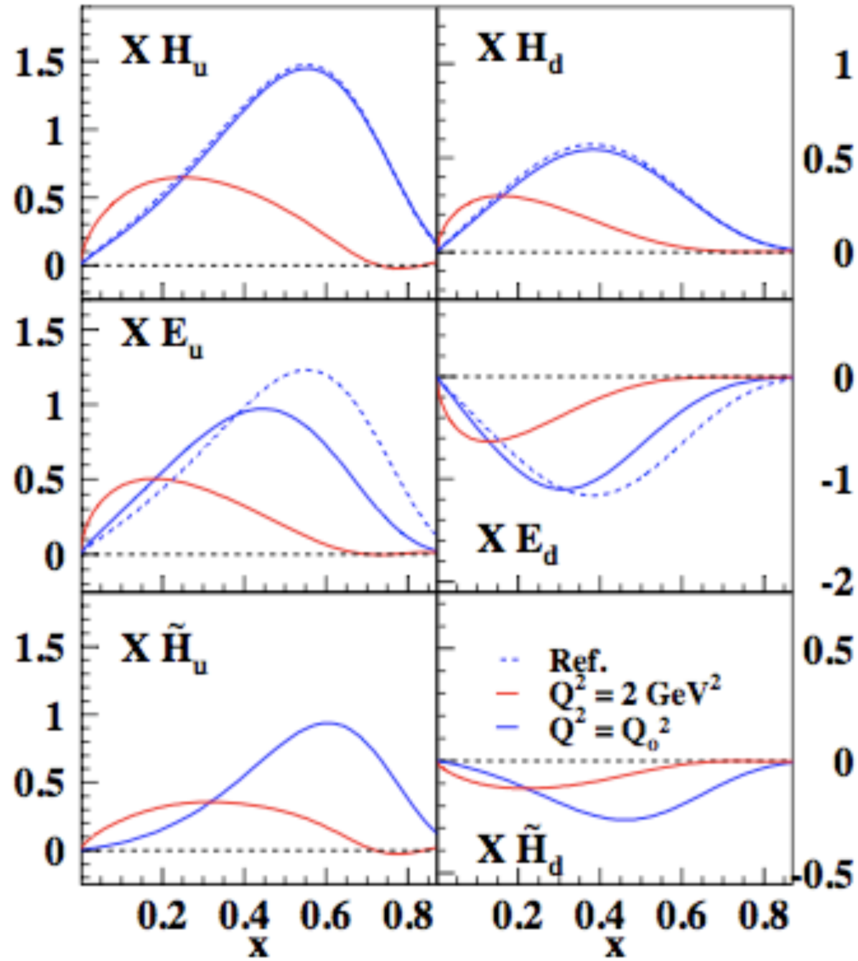


FIG. 6: (color online) GPDs $F_q(X,0,0) \equiv \{H_q, E_q, \widetilde{H}_q\}$, for $q = u$ (left) and $q = d$ (right), evaluated at the initial scale, $Q_o^2 = 0.0936$ GeV^2, and at $Q^2 = 2$ GeV^2, respectively. The dashed lines were calculated using the model in Refs.[24, 25] at the initial scale.

Summary

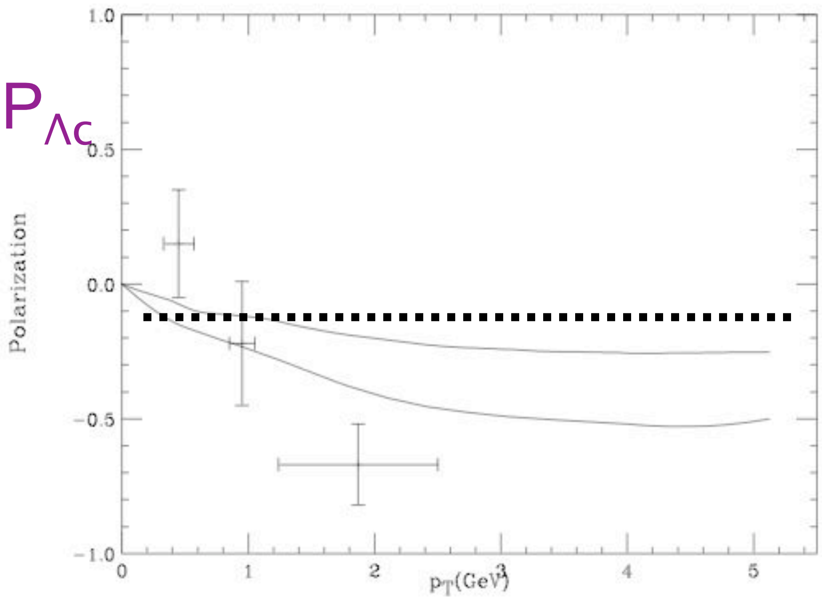
- Hyperon polarization is touchstone for understanding transversity & hence NPQCD
- Several ways to begin to explain phenomena
- “Upside down” TMDs with f.s.i.
- Extended GPDs ➔Extended Fracture Functions
- Work in progress

Hyperon and Charmed Hyperon Polarization

GG, S. Liuti ~ with P. Di Nezza

Interpretation in new language of GPDs?:
Generalized Fracture Functions
(Trentadue & Veneziano)

$P_{\Lambda c}$



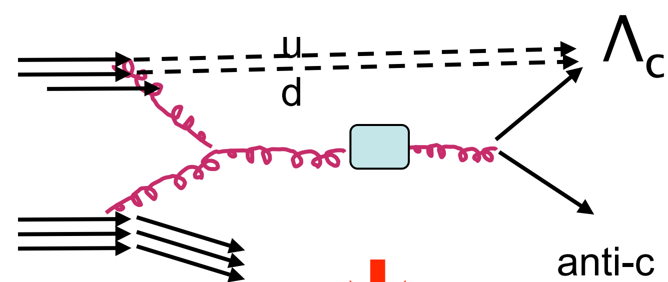
p_T (GeV)

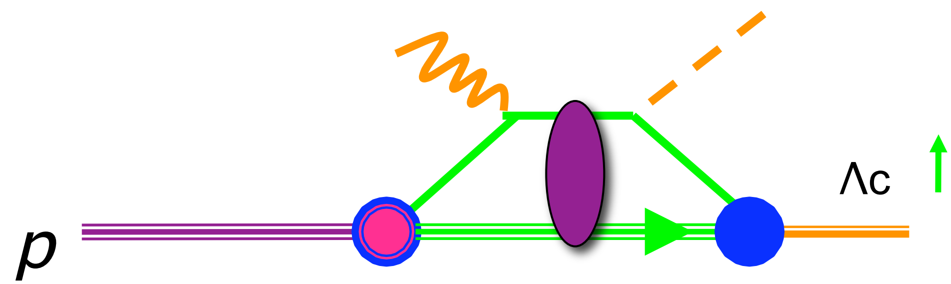
$\pi+p\rightarrow\Lambda_C+X$ Polzn(Λ_C) E791

$\Lambda_C^+\rightarrow p+\pi^++K^-$

Large mass scale

$$G^i_{p,h}(x,z;\zeta,t)$$





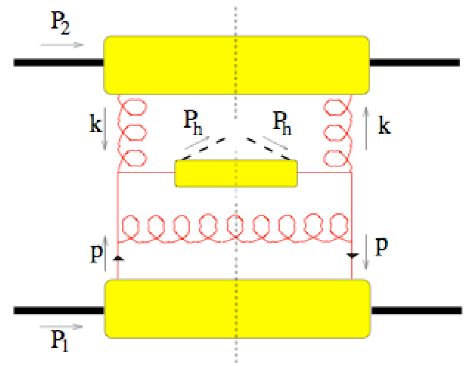
Target Fragmentation approach

$D_{1T}^{\perp}$ has been extracted from fixed target $p + p(Be) \to \Lambda^{\uparrow}(\bar{\Lambda}^{\uparrow}) + X$ data

Anselmino, D.B., D'Alesio & Murgia, PRD 63 (2001) 054029

D. Boer, DIS 2010

Outstanding puzzle!



Collinear Factorization

Non Collinear Factorization

$$P_\Lambda \sim q(x_1) \otimes g(x_2) \otimes \hat{\sigma}_{qg \to qg} \otimes ?$$

Go beyond collinear factorization, Insert k_T and polarization dependent Fragmentation function

➔Polarizing Fragmentation Function
Does this vitiate gluon fusion?