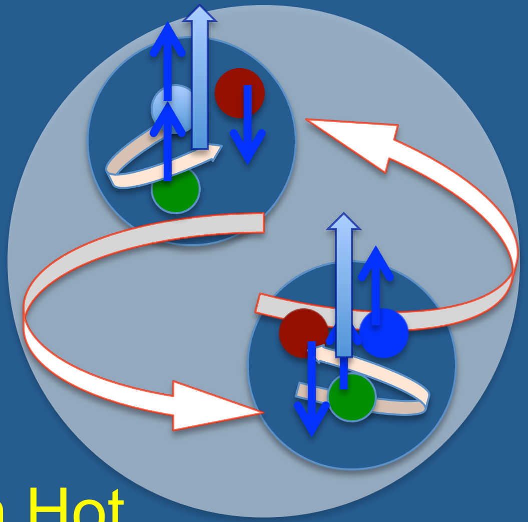
Observables for quarks and gluons orbital angular momentum distributions



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2nd Workshop on High p_T Physics in Hot and Dense Nuclear Matter

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Spin Crisis is far from over: open questions (and ramifications)

- ✓ Gluon spin contribution to the sum rule has a large error
- ✓ Role of Orbital Angular Momentum is being explored
- ✓ Transverse spin (sum rules…?)
- ✓ Existence of large Single Spin Asymmetries (SSA) in QCD: e.g. Polarized hyperon production
- ✓ The deuteron: new structure functions, b_1, b_2, and access to gluons OAM due to the cancellation of proton and neutron anomalous magnetic moments

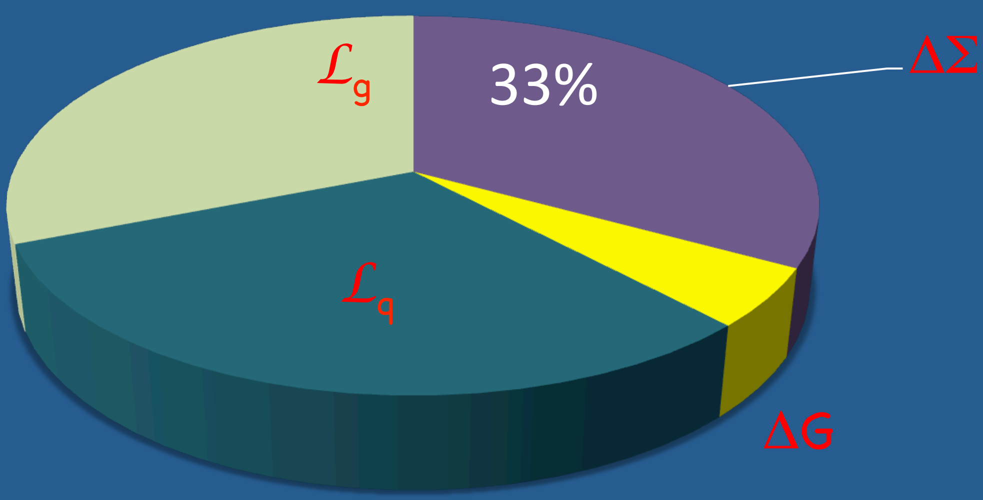
Outline

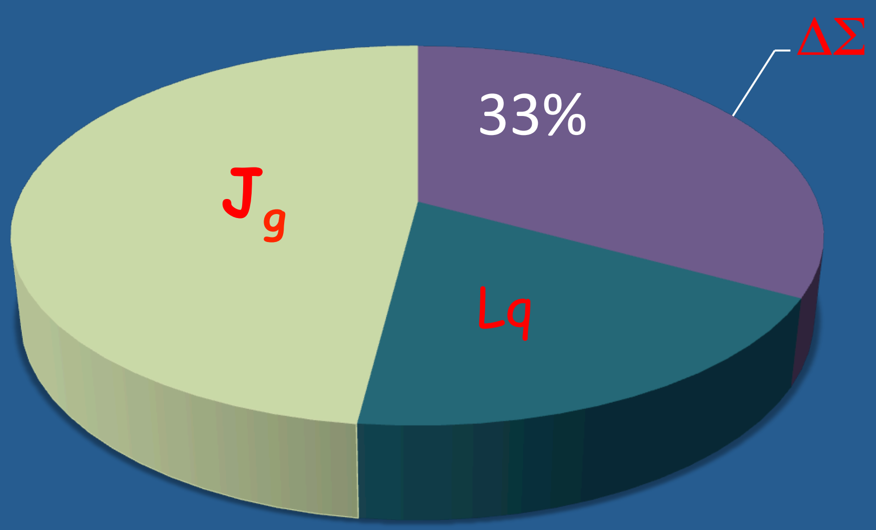
1. Definitions
2. Measurements/Observables
3. Partonic interpretation
4. The parity issue
5. Spin 1
6. Conclusions

The spin crisis in a "cartoon"

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \mathcal{L}_q + \Delta G + \mathcal{L}_g$$

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$





Jaffe Manohar

Ji

How does OAM enter the picture in QCD?

?

Define Angular Momentum through the QCD Energy Momentum Tensor

$$T^{\mu\nu} = \frac{1}{4} i q \bar{\psi}\left(\gamma^{\mu}\overleftrightarrow{D}^{\nu} + \gamma^{\nu}\overleftrightarrow{D}^{\mu}\right)\psi + Tr\left\{F^{\mu\alpha}F_{\alpha}^{\nu} - \frac{1}{2} g^{\mu\nu} F^{2}\right\} \rightarrow M^{\mu\nu\lambda} = x^{\nu}T^{\mu\lambda} - x^{\lambda}T^{\mu\nu}$$

AM density

Momentum density

Energy density

Momentum density

T^{00}	T^{01}	T^{02}	T^{03}
T^{10}	T^{11}	T^{12}	T^{13}
T^{20}	T^{21}	T^{22}	T^{23}
T^{30}	T^{31}	T^{32}	T^{33}

Shear stress

Pressure

Sum Rule: Part I

First define the angular momentum components

$$M^{\mu\nu\lambda} = x^{\nu} T^{\mu\lambda} - x^{\lambda} T^{\mu\nu} \quad \Rightarrow \quad J_q^i = \varepsilon^{ijk} \int dz^- d^2 z \ M^{+jk}$$

then parametrize the EMT in terms of form factors A, B, C

$$T^{\mu\nu} = A(\gamma^{\mu}\bar{P}^{\nu} + \gamma^{\nu}\bar{P}^{\mu}) + B\left(\frac{i\sigma^{\mu\alpha}\Delta_{\alpha}}{2M}\bar{P}^{\nu} + \frac{i\sigma^{\nu\alpha}\Delta_{\alpha}}{2M}\bar{P}^{\mu}\right) + C\frac{\Delta^{\mu}\Delta^{\nu} - \Delta^2 g^{\mu\nu}}{M}$$

Finally, connect the EMT matrix element with AM components

$$J_q = \frac{1}{2}\left(A_q + B_q\right) \Rightarrow \sum J_q + J_g = \frac{1}{2}$$

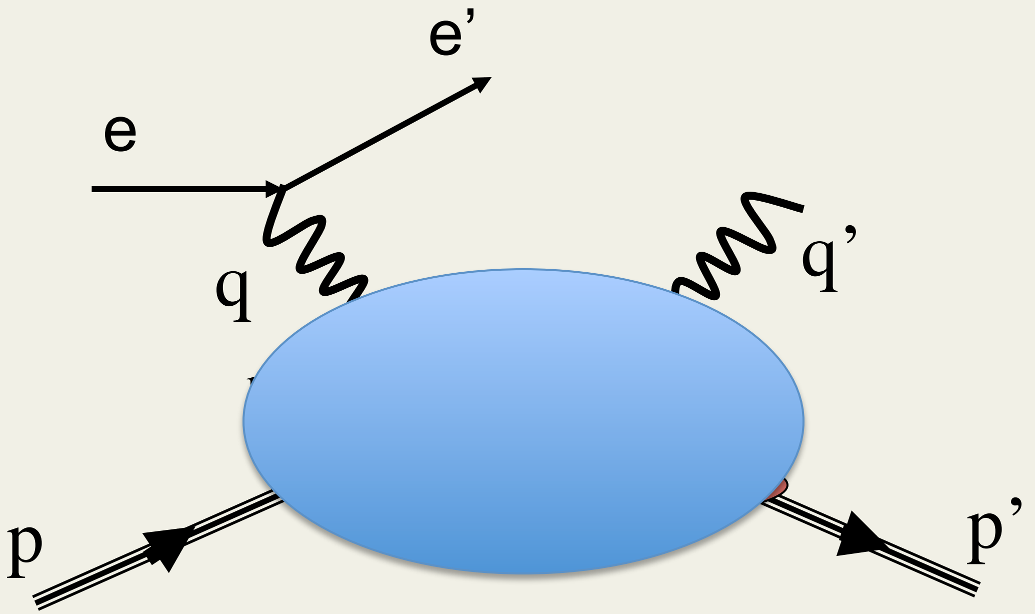
Jaffe Manohar (1990)
Ji (1997)

Sum Rule: Part II

The second part of the sum rule is about finding a Partonic Interpretation and the Observables

This allows one to connect in QCD the EMT form factors to the 2nd moments of generalized parton distributions (GPDs)

1997: X. Ji suggests Deeply Virtual Compton Scattering (DVCS) as a way to observe J_q, J_g



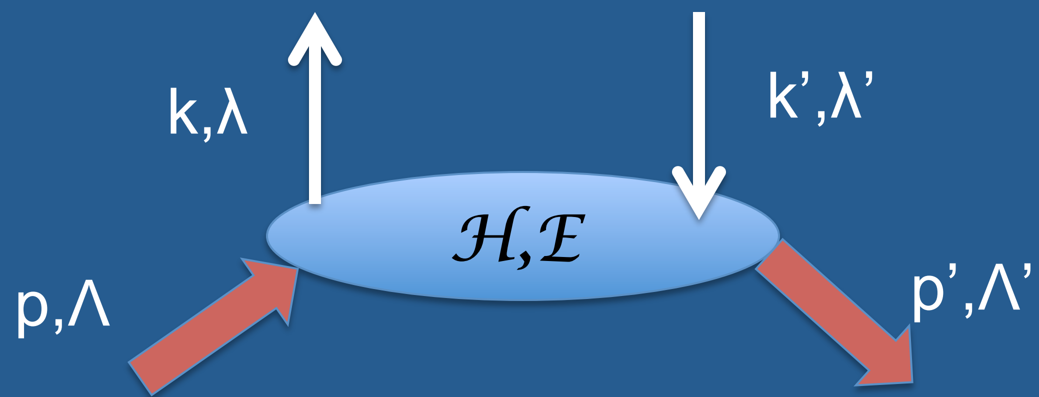
$$\frac{1}{2}\int dx\, x\left[H_{q,g}(x,0,0)+E_{q,g}(x,0,0)\right]=A_{q,g}+B_{q,g}=J_q+J_g$$

$J_q \rightarrow \Delta\Sigma+L_q$

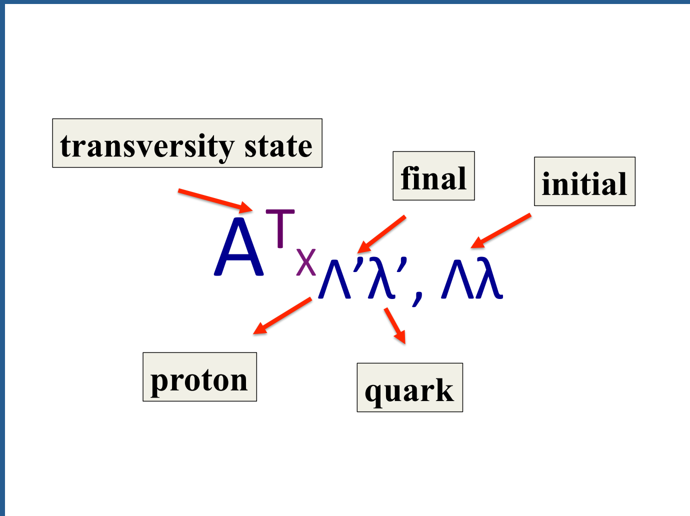
Quark-quark correlator: vector
Quark-quark correlator: axial vector

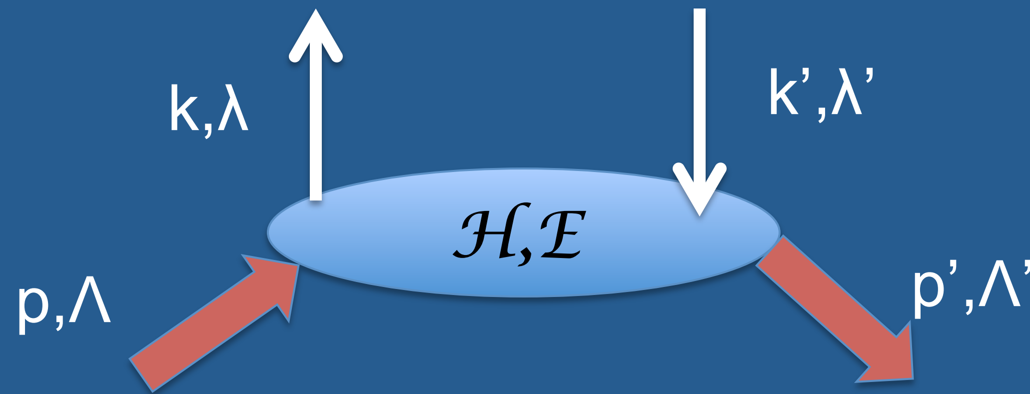
$$W^{\gamma^+\gamma_5}_{\Lambda\Lambda'} = \frac{1}{2}\int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p', \Lambda' \mid \bar{\psi}\left(-\frac{z}{2}\right)\gamma^+\gamma_5\psi\left(\frac{z}{2}\right) \mid p, \Lambda\rangle_{z^+=0,\mathbf{z}_T=0}$$

$$\begin{aligned} W^{\gamma^+\gamma_5}_{\Lambda\Lambda'} &= \frac{1}{2P^+}\overline{U}(p',\Lambda')\left[\gamma^+\gamma_5\widetilde{H} + \frac{\gamma_5\Delta^+}{2M}\widetilde{E}\right]U(p,\Lambda) \\ &= \Lambda\delta_{\Lambda,\Lambda'}\widetilde{H} + \delta_{\Lambda,-\Lambda'}\frac{\Delta_1 - i\Lambda\Delta_2}{2M}\zeta\widetilde{E} \end{aligned}$$



Helicity Amplitudes

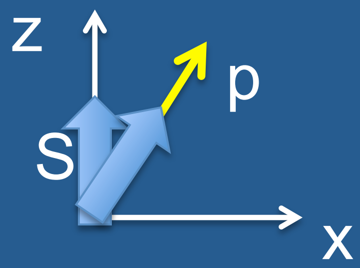




$$A_{\Lambda'\lambda',\Lambda\lambda} = \int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p', \Lambda' \mid \mathcal{O}_{\lambda'\lambda}(z) \mid p, \Lambda \rangle \big|_{z^+=0} \, ,$$

$$\mathcal{O}_{++}(z) = \bar{\psi}\left(-\frac{z}{2}\right)(1+\gamma_5)\gamma^+\psi\left(\frac{z}{2}\right)$$
$$\mathcal{O}_{--}(z) = \bar{\psi}\left(-\frac{z}{2}\right)(1-\gamma_5)\gamma^+\psi\left(\frac{z}{2}\right)$$

Jacob Wick helicity: $h = \vec{S} \cdot \vec{p}$



$\neq$ light front helicity

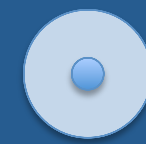
Parity relations: $$A_{-\Lambda'-\lambda',-\Lambda-\lambda} = (-1)^{\Lambda'+\lambda'-\Lambda-\lambda} A_{\Lambda'\lambda',\Lambda\lambda}$$

(because helicity and LF helicity are related by a unitary transformation the parity relations are invariant, M. Diehl, Phys. Rep.)

Connection with GPDs

Helicity basis

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



$$i\frac{\Delta_2}{M}E = A_{++,-+} + A_{+-,--} - A_{-+,++} - A_{--,+-}$$

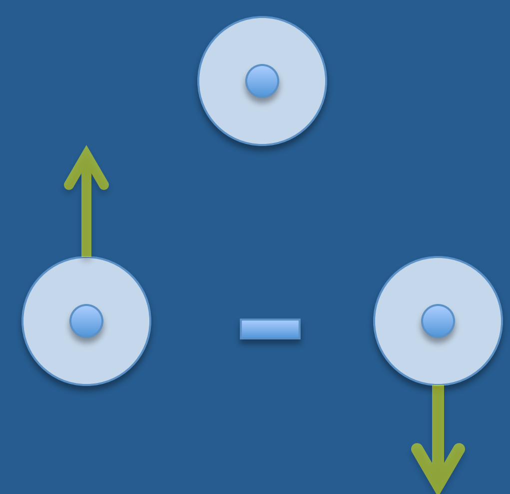
?

Transversity basis

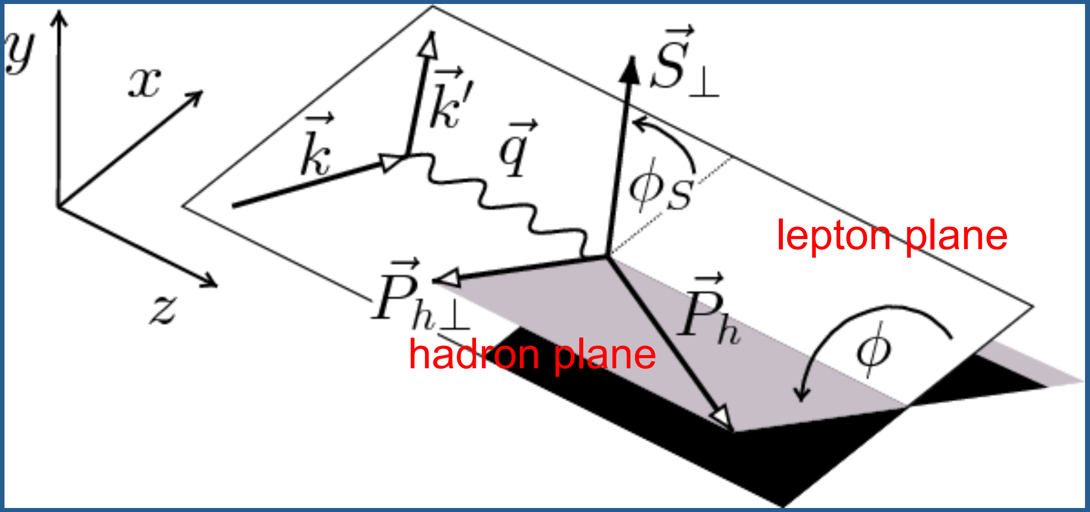
$$\pm|Y\rangle = \frac{1}{\sqrt{2}}\left(|+\rangle \pm i|-\rangle\right)$$

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

$$i\frac{\Delta_2}{M}E = A^{Y}_{++,++} + A^{Y}_{+-,+-} - A^{Y}_{-+,-+} - A^{Y}_{--,--}$$



Observables



$$A_{LU} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \Rightarrow \frac{\sqrt{t_0 - t}}{2M}\left[F_1\mathcal{H} + \xi(F_1 + F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right]$$

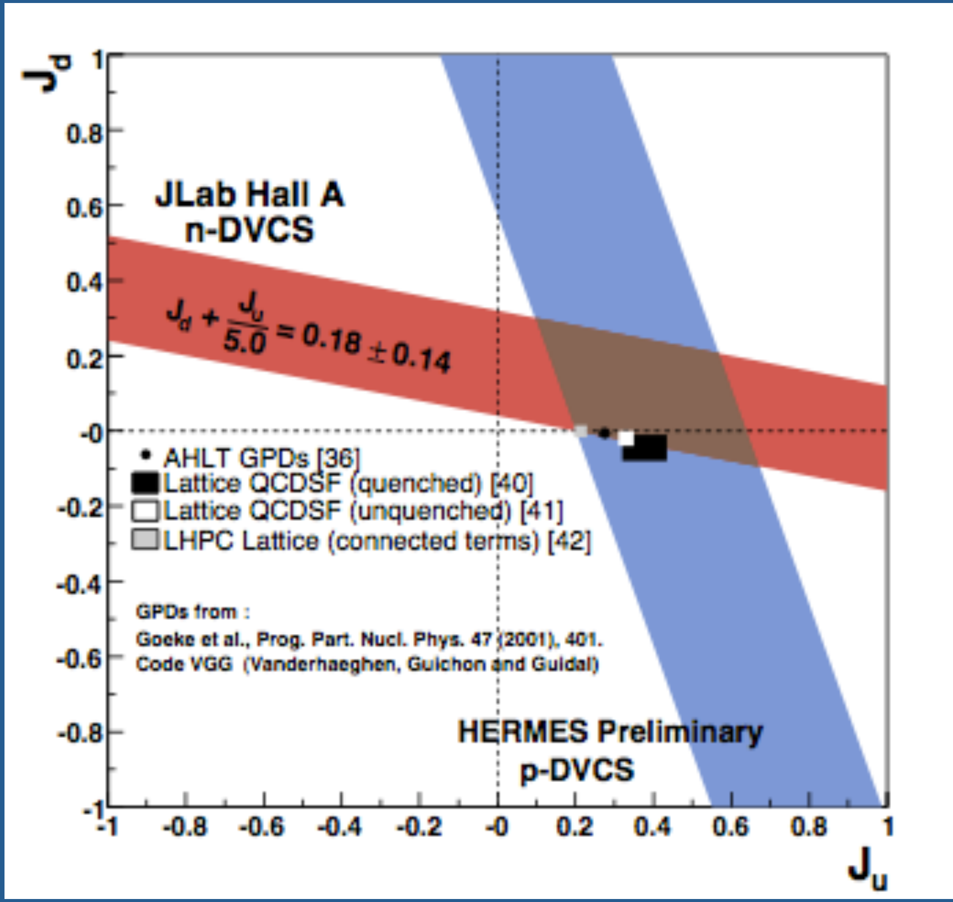
$$A_{UL} = \frac{d\sigma^{\Uparrow} - d\sigma^{\Downarrow}}{d\sigma^{\Uparrow} + d\sigma^{\Downarrow}} \Rightarrow \frac{\sqrt{t_0 - t}}{2M}\left[F_1\tilde{\mathcal{H}} + \xi(F_1 + F_2)\mathcal{H} - \frac{t}{4M^2}F_2\,\xi\tilde{\mathcal{E}}\right]$$

$$A_{UT} = \frac{d\sigma^{\Rightarrow} - d\sigma^{\Leftarrow}}{d\sigma^{\Rightarrow} + d\sigma^{\Leftarrow}} \Rightarrow \frac{t_0 - t}{4M^2}\left[-F_1\mathcal{E} + \xi(F_1 + F_2)\xi\tilde{\mathcal{E}} + F_2\,\mathcal{H}\right]$$

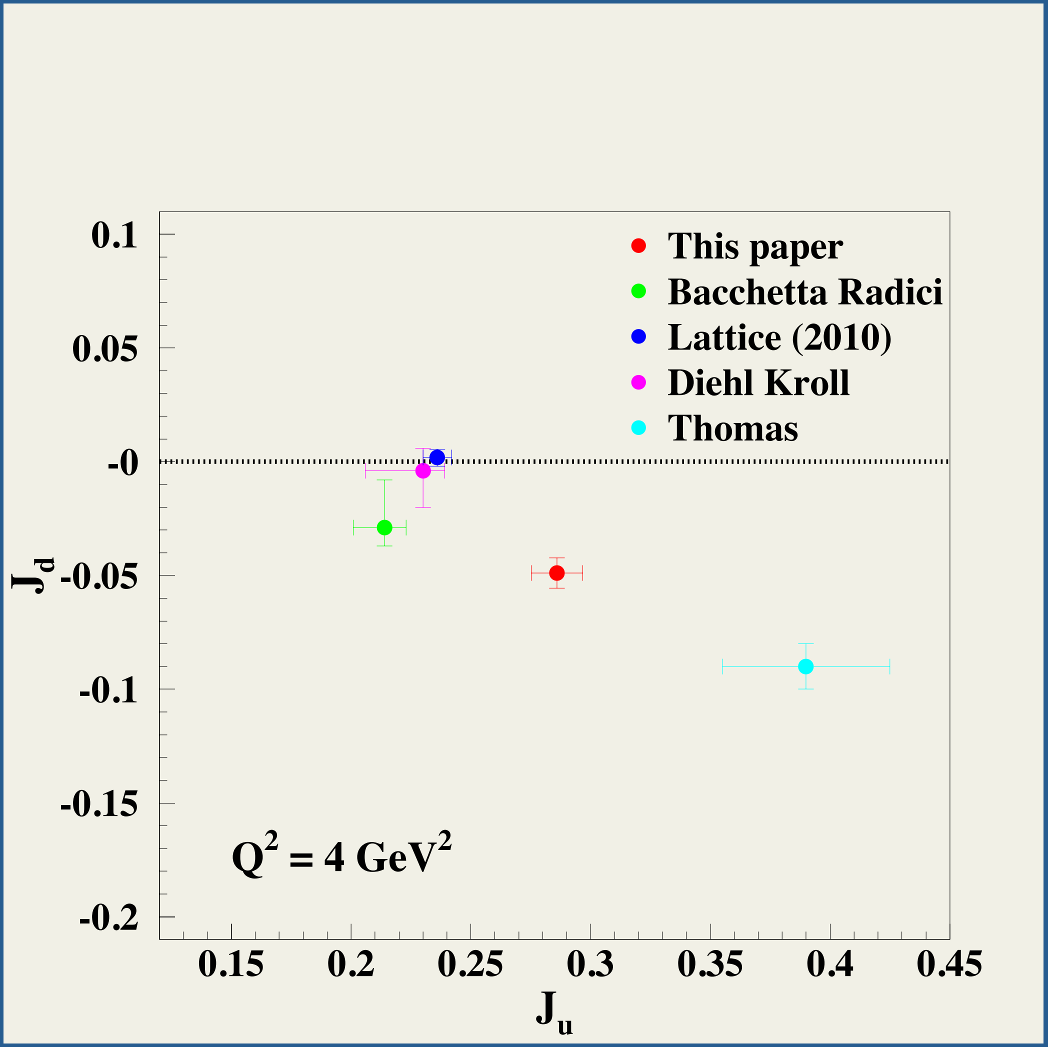
Belitsky, Kirchner, Mueller, NPB629 (2002)

Observables

$J_q = 1/2\ \Delta\Sigma + L_q$



Model dependent extractions of J_u and J_d



O. Gonzalez Hernandez et al., Phys. Rev. C88, 065206; arXiv:1206.1876

The other approach: Jaffe Manohar

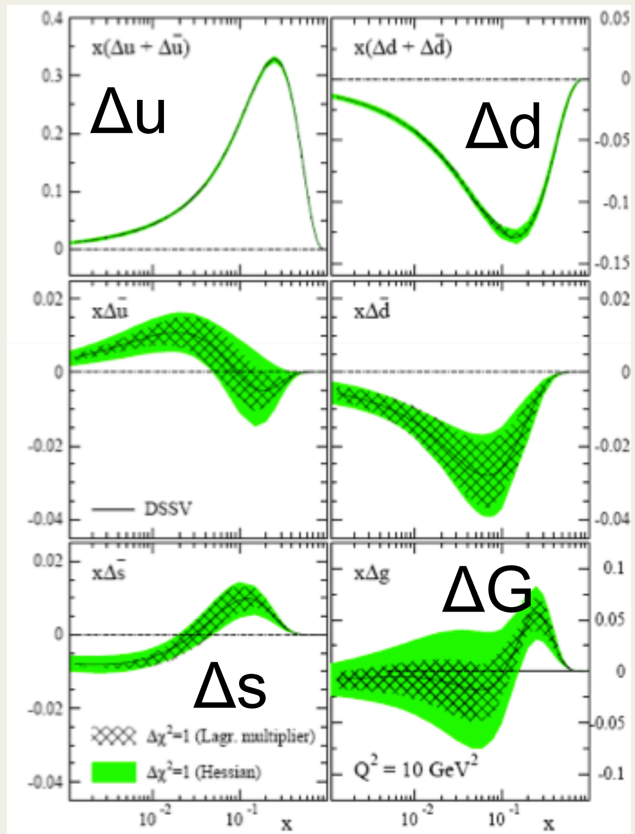
In LC gauge rewrite AM using Dirac eqn. to isolate spin terms

$$M^{+12} = \frac{1}{2} q_+^\dagger \gamma^5 q_+ + \frac{1}{2} i q_+^\dagger (\vec{x} \times \partial)^3 q_+ + Tr(\varepsilon^{+-ij} F^{+j} A^j) + 2i Tr F^{+j} (\vec{x} \times \partial) A^j$$

ΔΣ ? ΔG ?

Jaffe Manohar's partonic picture: $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \mathcal{L}_q + \Delta G + \mathcal{L}_g$

- quark and gluon spin components are identified with the n=1 moments of spin dependent structure functions from DIS ➔ $\Delta\Sigma$ and ΔG.



Observables!

We now know where OAM could enter the picture … but what is the interpretation of quark and gluon fields OAM

?

Consider twist 3 contributions

OAM can be defined through a relation analogous to Ji's at tw 2

$$\int dx\, x G_2 = -\frac{1}{2}\int dx\, x(H+E) + \frac{1}{2}\int dx\, \tilde{H}$$

Polyakov et al. (2000)
Hatta (2011)

$-L_q$ $-J_q$ S_q

$$W^{\gamma^i}_{\Lambda'\Lambda} = \frac{1}{2P^+}\overline{U}(p',\Lambda')\left[\frac{\Delta_T^i}{M}G_1 + \frac{i\sigma^{ji}\Delta_j}{M}G_2 \frac{Mi\sigma^{i+}}{P^+}G_4 + \frac{\Delta_T^i}{P^+}\gamma^+ G_3\right]U(p,\Lambda),$$

Twist 3 decomposition of hadronic tensor in various notations

Polyakov et al. [13]	$2G_1$	G_2	G_3	G_4
Meissner et al. [3]	$2\widetilde{H}_{2T}$	$\widetilde{E}_{2T}$	E_{2T}	H_{2T}
Belitsky et al. [16]	E^3_+	$\widetilde{H}^3_-$	$H^3_+ + E^3_+$	$\frac{1}{\xi}\widetilde{E}^3_-$

TABLE I: Comparison of notations for different twist 3 GPDs.

arXiv:1310.5157

G_2 can describe both canonical (Jaffe Manohar) and Ji's OAM

Ji $L_q(x) = L_q^{WW}(x) + \overline{L}_q(x)$ → F-type tw3

JM $\mathcal{L}_q(x) = L_q^{WW}(x) + \overline{\mathcal{L}}_q(x),$ → D-type tw3

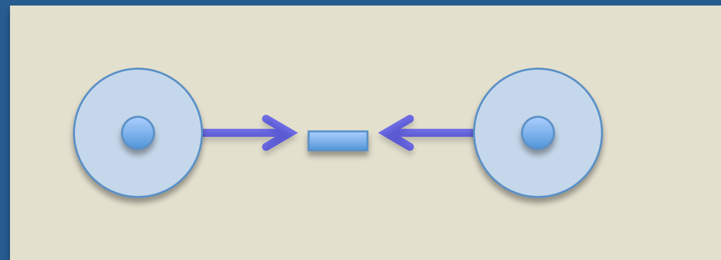
Hatta, 2011

$$\int dx\, x G_2 = -\int dx\, L_q^{WW}$$

$$\int dx\, x^2 G_2^{tw3} = -\frac{2}{3} d_2$$

← !!

In arXiv:1310.5157 we asked what is the spin configuration corresponding to quark OAM?



Helicity Amplitudes analysis done using twist 3 GTMDs

$$-\frac{4}{P^+}\left[\frac{\bar{\mathbf{k}}_T\cdot\mathbf{\Delta}_T}{\Delta_T}F_{27}+\Delta_T F_{28}-\left(\frac{\bar{\mathbf{k}}_T\cdot\mathbf{\Delta}_T}{\Delta_T}G_{27}+\Delta_T G_{28}\right)\right] = A^{tw3}_{++,++}+A^{tw3}_{+-,+-}-A^{tw3}_{-+,-+}-A^{tw3}_{--,--}$$

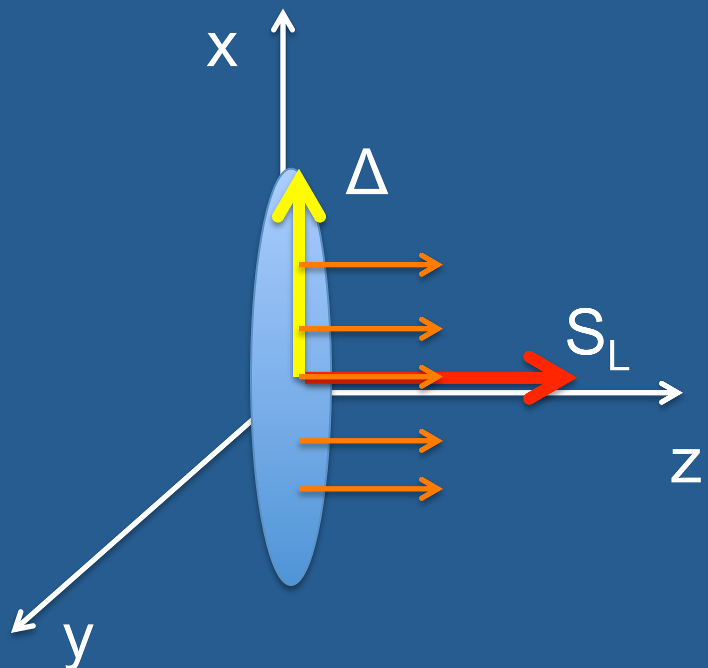
G_2 $\tilde{G}_2$

contains one bad component

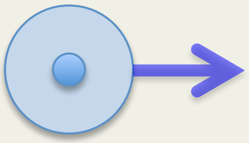
Knowing the helicities configuration allows us to interpret why we have a net OAM in the proton

G_2 → $\sigma_{ij}\Delta^j \Rightarrow \vec{S}_L \times \vec{\Delta}$

If the proton is polarized longitudinally, the quark distribution is going to be displaced transversely, along Δ

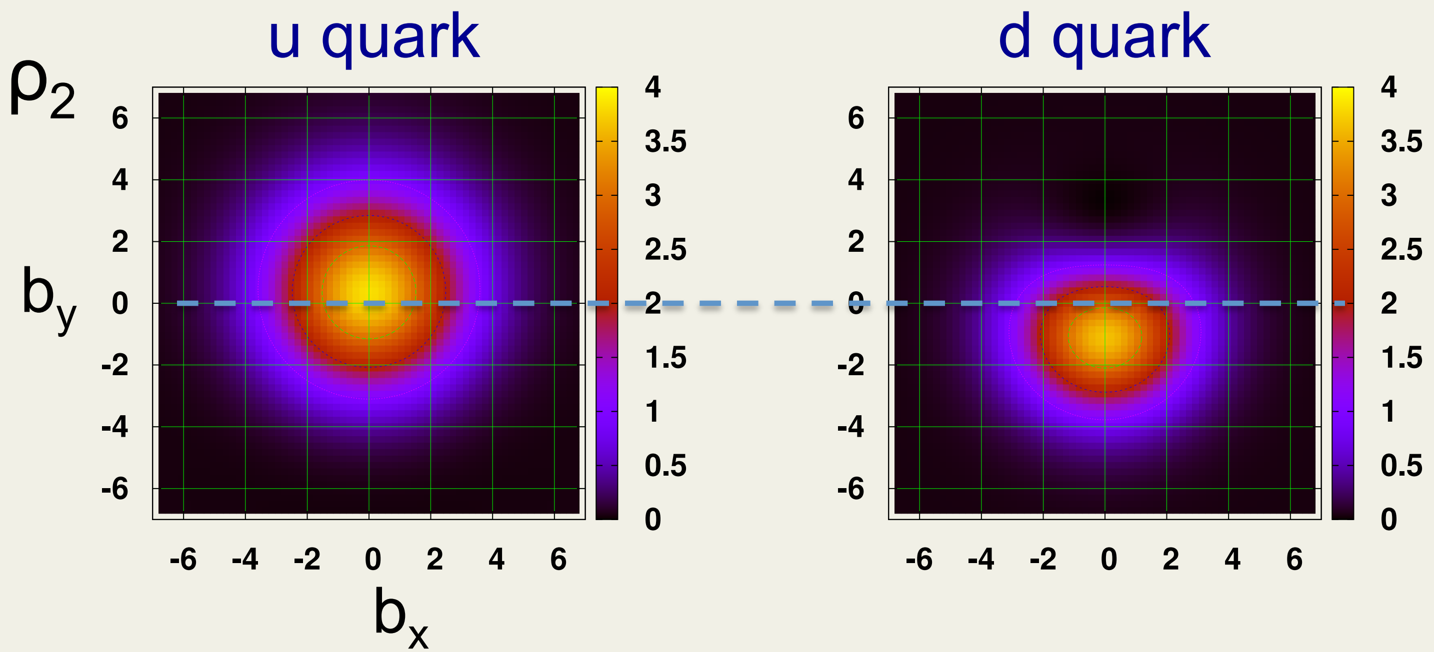


Distribution of an unpolarized quark in a proton polarized along the longitudinal axis



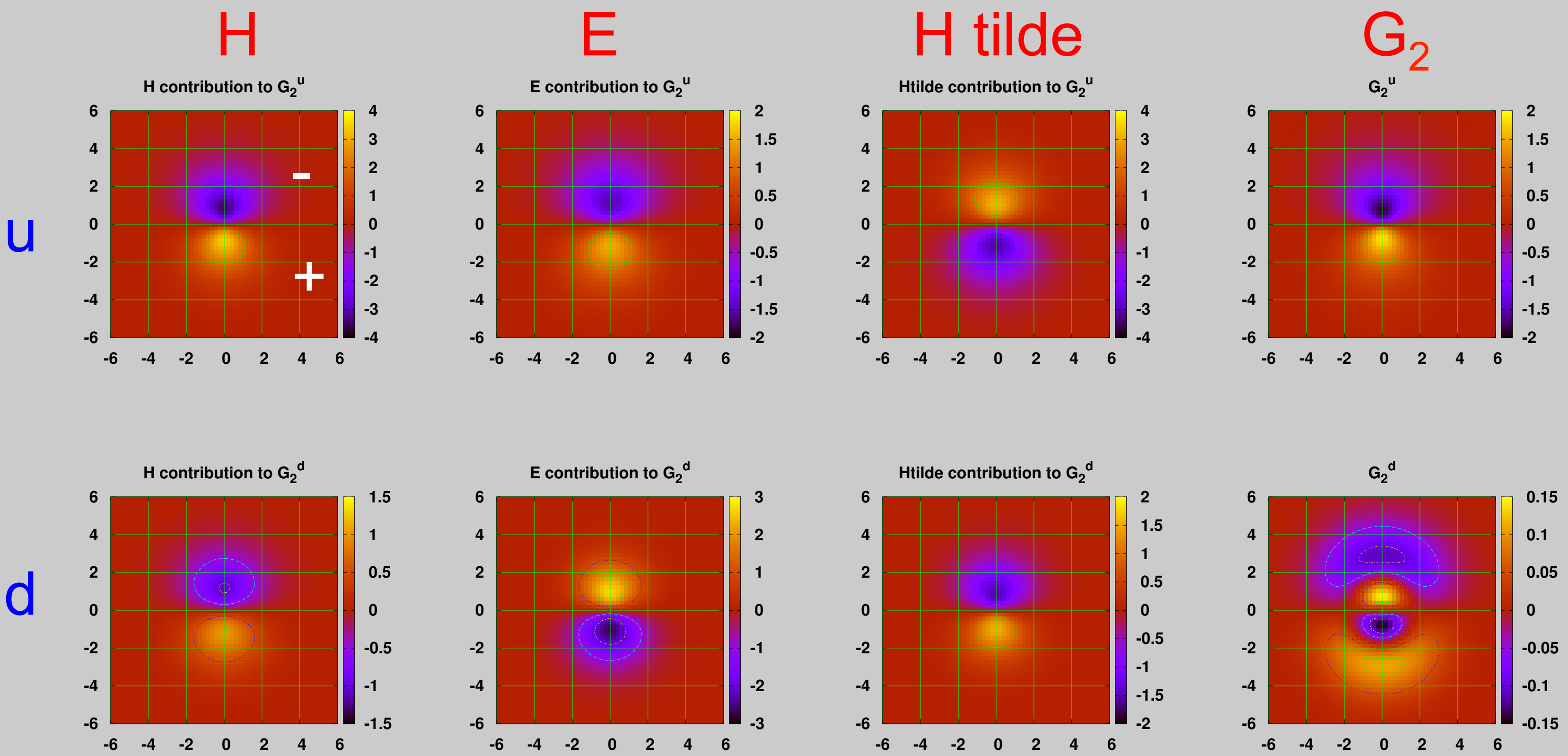
$$\left(A_{++,++}+A_{+-,+-}+A_{-+,-+}+A_{--,--}\right)+\left(A^{tw3}_{++,++}+A^{tw3}_{+-,+-}-A^{tw3}_{-+,-+}-A^{tw3}_{--,--}\right)$$

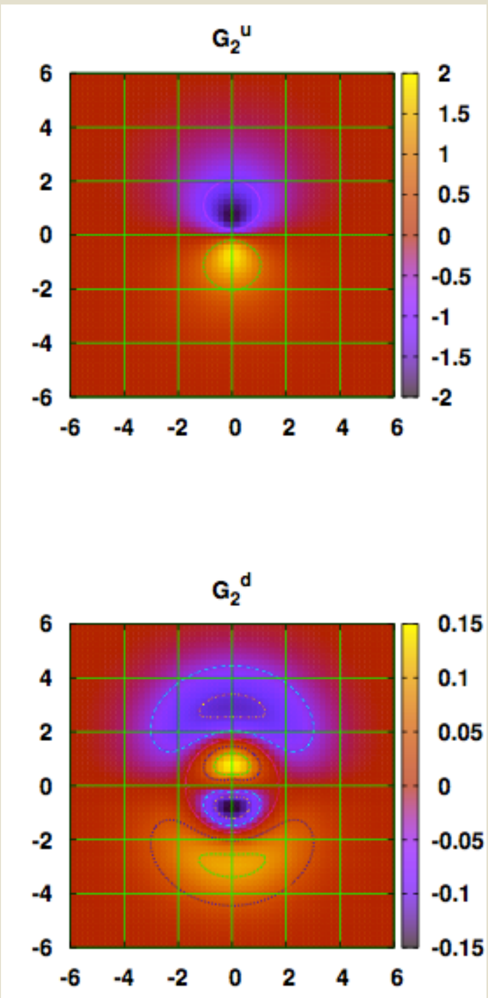
$$\approx H-i\Delta_2 G_2$$



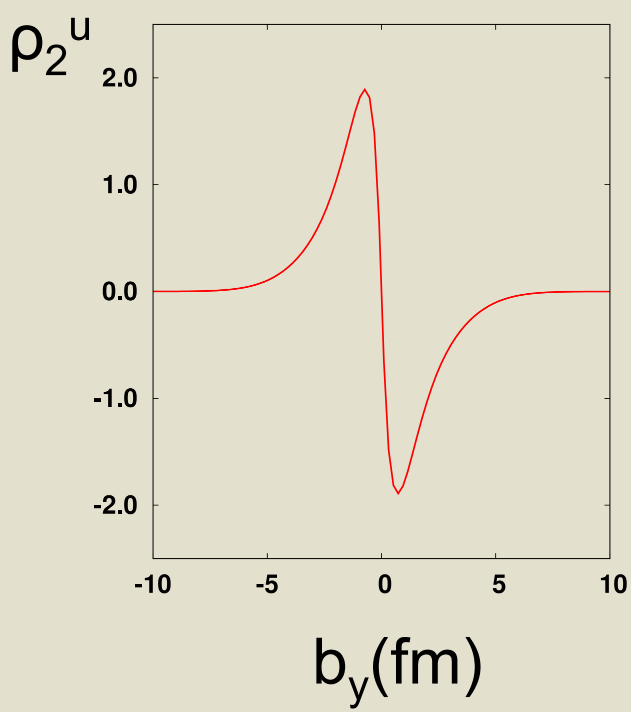
Calculation done in WW approximation using the reggeized diquark model

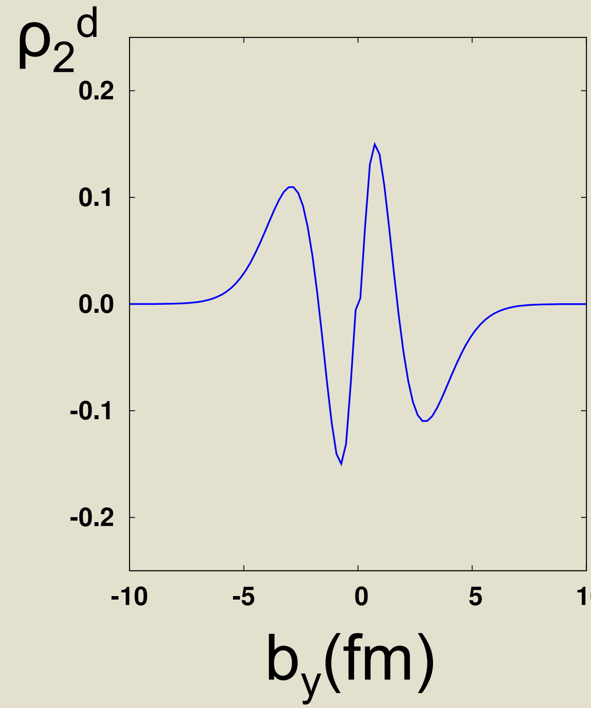
$$L_q(x,0,0) = x\int_x^1 \frac{dy}{y}\left(H_q(y,0,0) + E_q(y,0,0)\right) - x\int_x^1 \frac{dy}{y^2}\widetilde{H}_q(y,0,0),$$



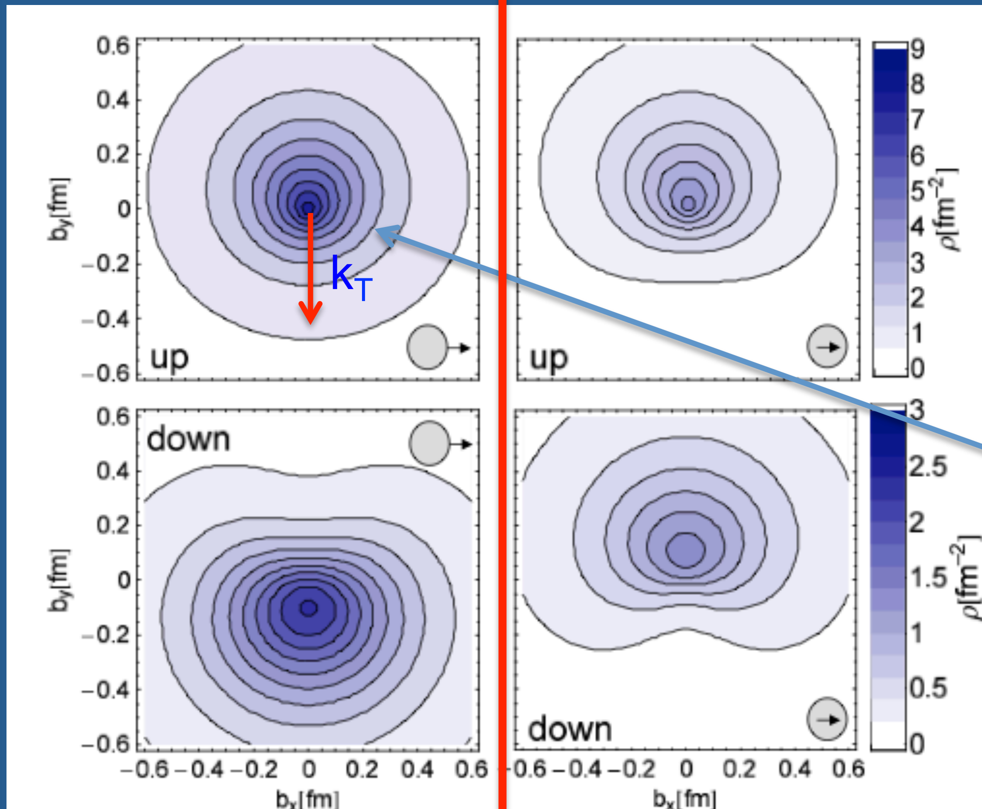


in 2D





Analogous situation as for E wrt. transverse spin (M. Burkardt)

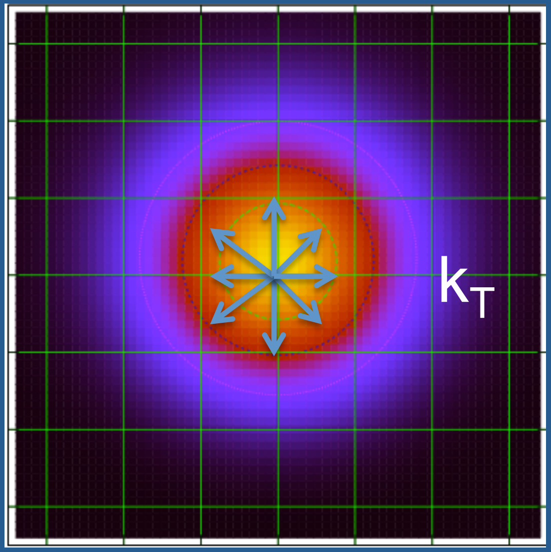


E $\rightarrow$ $\sigma^{+j}\Delta_j \Rightarrow \vec{S}_T \times \vec{\Delta}$

The net b corresponds to net k_T in the opposite direction (attractive color force due to FSI)

$$\left(A^X_{++,++} + A^X_{+-,+-} + A^X_{-+,-+} + A^X_{--,--}\right) + \left(A^X_{++,++} + A^X_{+-,+-} - A^X_{-+,-+} - A^X_{--,--}\right)$$

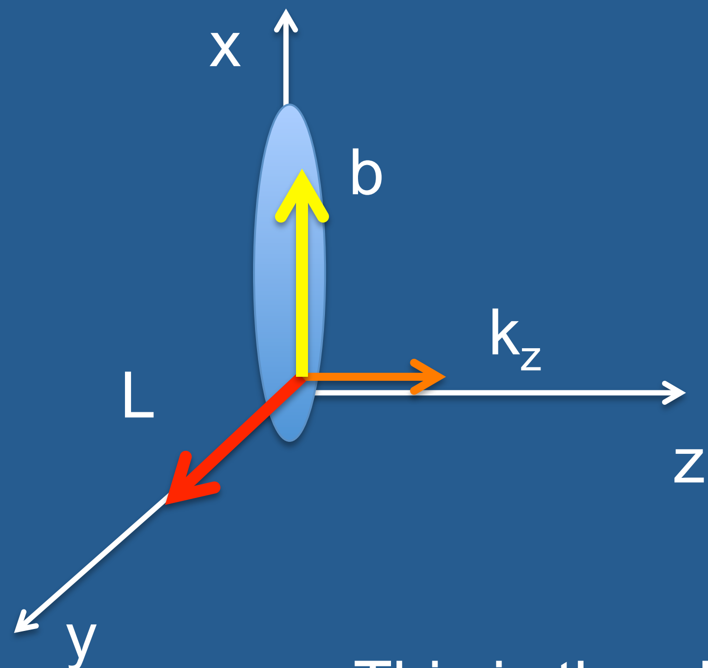
$$\approx H - i\Delta_2 E$$



For G_2 there is no preferential/"net" direction of k_T wrt. the "net" displacement along the +y axis

- No FSI (see gauge link contribution at ∞, M. Burkardt, "torque")
- No k_T contribution perpendicular to Δ (parity violating)

“Net” OAM can exist in the transverse (orthogonal) direction!



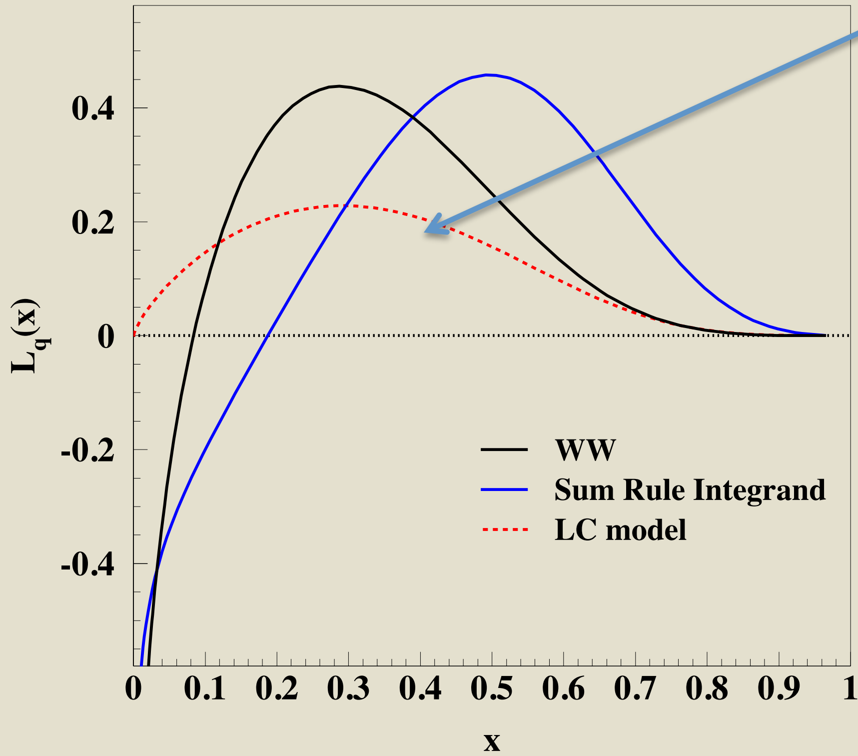
This is the physical meaning of G_2

Now that we understand all this, can we measure OAM?

First of all notice that in Wandzura Wilczek approximation

$$L_q(x,0,0) = x\int_x^1 \frac{dy}{y}(H_q(y,0,0)+E_q(y,0,0)) - x\int_x^1 \frac{dy}{y^2}\widetilde{H}_q(y,0,0),$$

$\neq F_{14}$!

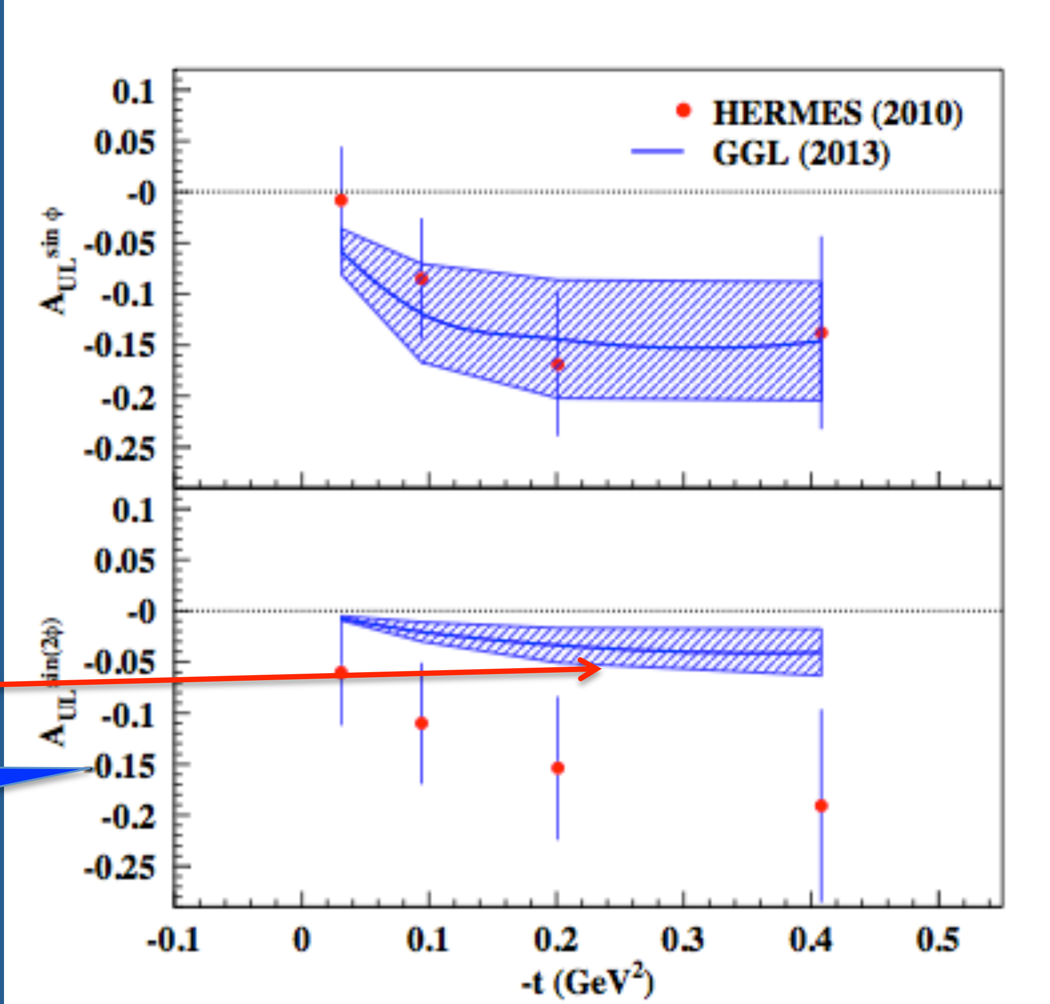


DVCS on a longitudinally polarized target

$$A_{UL,L} = \frac{N_{s_z=+} - N_{s_z=-}}{N_{s_z=+} + N_{s_z=-}} = \frac{\sqrt{2\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi}}{F_{UU,T} + \epsilon F_{UU,L}} + \frac{\epsilon \sin 2\phi F_{UL}^{\sin 2\phi}}{F_{UU,T} + \epsilon F_{UU,L}}$$

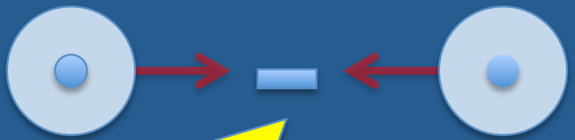
sin 2φ term is tw 3!

WW, small ξ



Jlab data in progress!
Avakian, Pisano

Parity issues with twist 2 GTMDs



$$\sigma_{ij} k_T^i \Delta_T^j \Rightarrow \vec{S}_L \cdot \left(\vec{k}_T \times \vec{\Delta}_T \right)$$

Parity Odd: proton spin dotted into OAM

✓The amps will cancel unless they are imaginary:

$$A_{++,++} = A^*_{--,--} \,;\; A_{+-,+-} = A^*_{-+,-+}$$

✓But this cannot be, as seen from CM system - at leading order - these will be real – all in same plane so there can be no relative phase between helicity amps.

✓ VERY IMPORTANT CAVEAT:

On Light Front this does not happen because what is conserved is Light Front Parity, not P and T separately

C.Carlson&C.R. Ji, PRD67 (2003)

BUT THAT IS NOT PARITY!!!

F_{14}

- It is not OAM (naïve identification)
- It decouples from direct measurements of TMD/GPD observables
- Can it be measured at all?

Finally, how do we make a connection with polarization observables and OAM in heavy ions collisions?

An important probe of Single Spin Asymmetries in QCD

SSA in QCD,

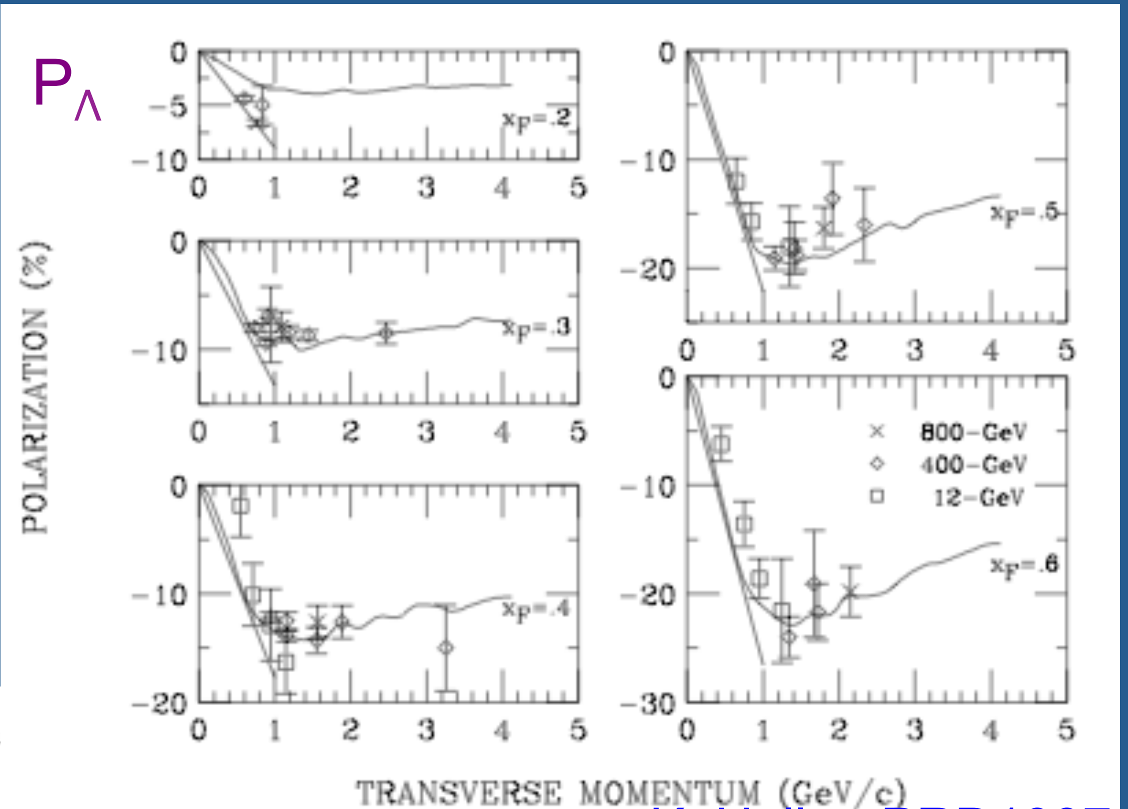
$$\frac{d\sigma(qq \to q^{\uparrow}q) - d\sigma(qq \to q^{\downarrow}q)}{d\sigma(qq \to qq)} = \alpha(Q^2)\frac{m_q}{\sqrt{s}}f(\theta). \quad (1)$$

Kane, Pumplin, Repko, 70's

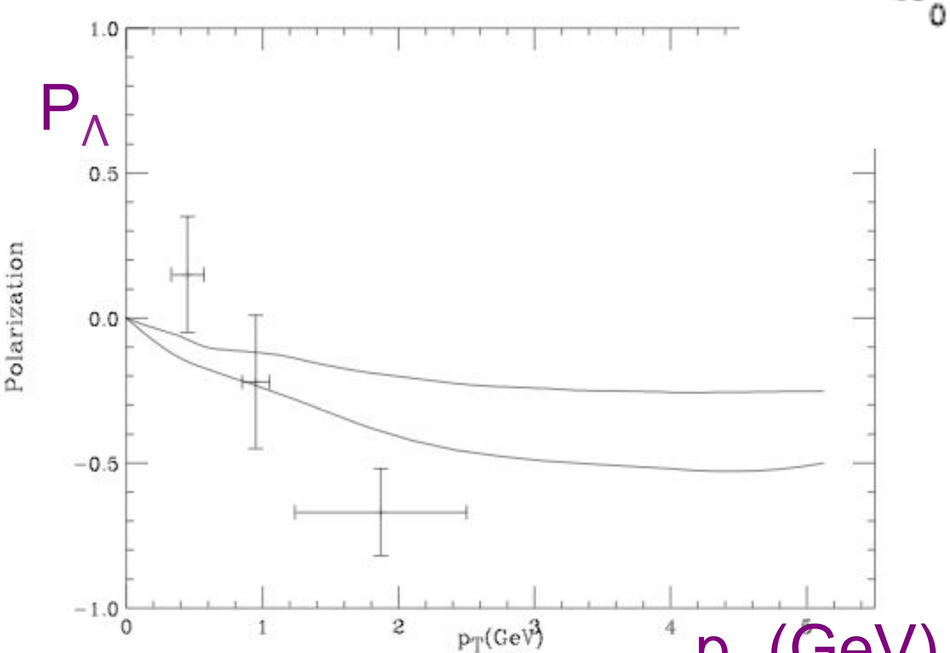
is predicted to be small, but …

….. measurements showed high transverse polarization values

$$pp \to \Lambda^{\uparrow}(\Lambda_c^{\uparrow})X$$

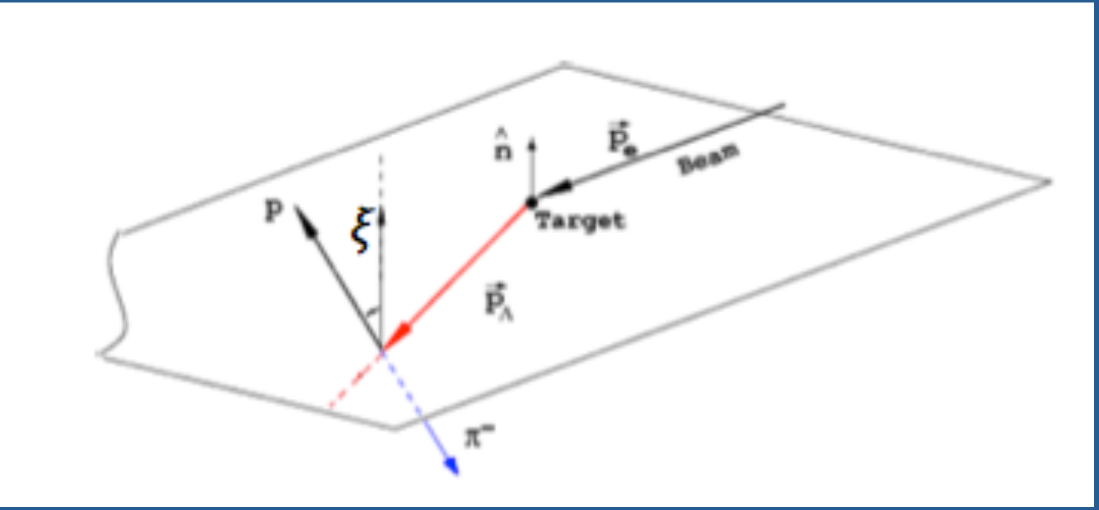


K. Heller, PRD1997

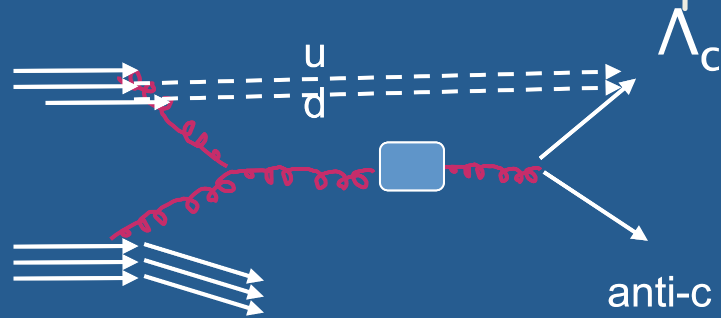


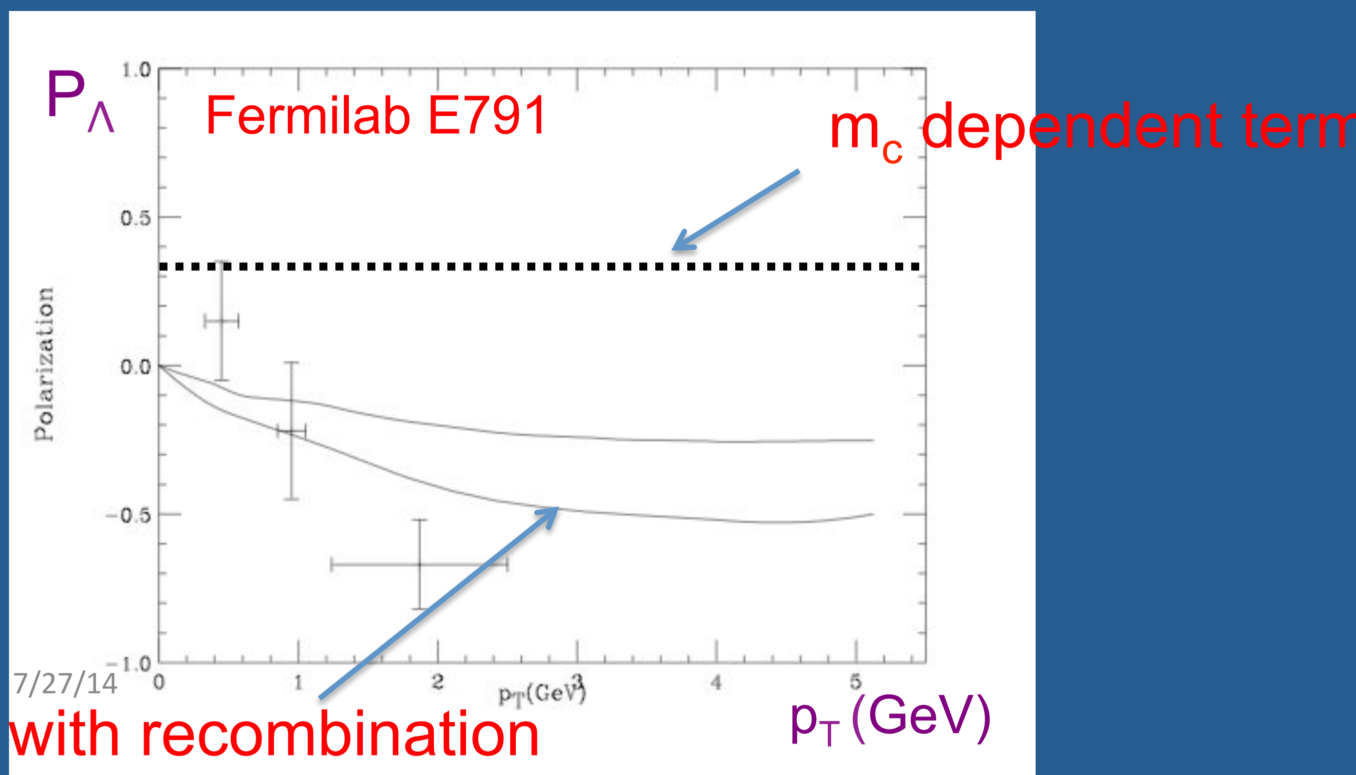
Ramberg, PL1994

$$\frac{dN}{d\xi} = 1 + \alpha_{\Lambda} P_{\Lambda}^{T} \cos\xi$$



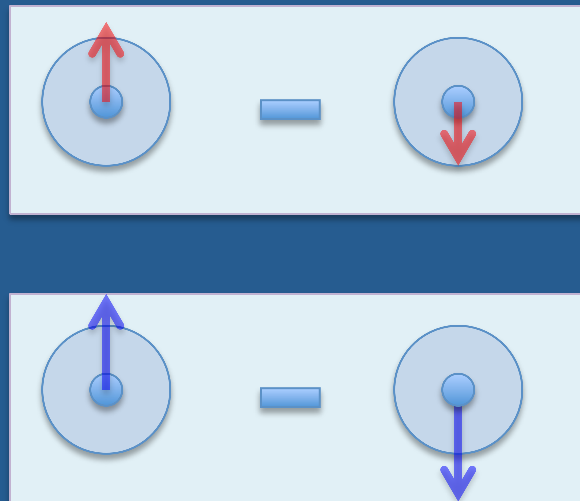
… Early models (Dharmaratna and Goldstein, 90's) → a form of "recombination" should be present; recent calculations (Betz et al., X. Wang et al., use Wigner distribution based interpretations)





$h_1^{\perp}$

$f_{1T}^{\perp}$



Ah ha!
This is the same argument that allows us to observe the T-odd TMDs by understanding the role of the gauge links

$f_{1T}^{\perp}$

S.J. Brodsky et al. / Physics Letters B 530 (2002) 99–107

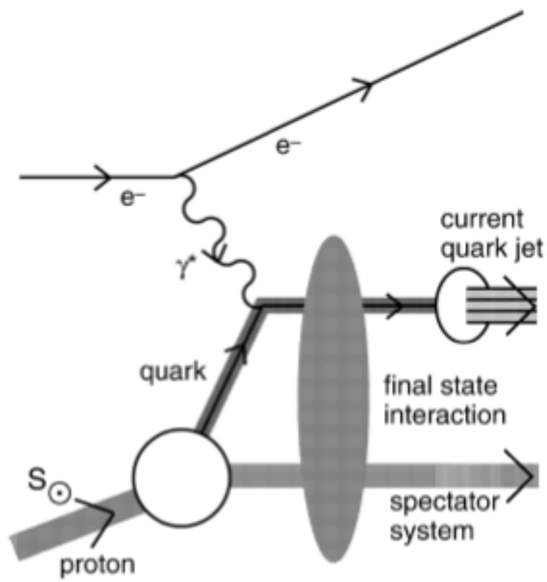
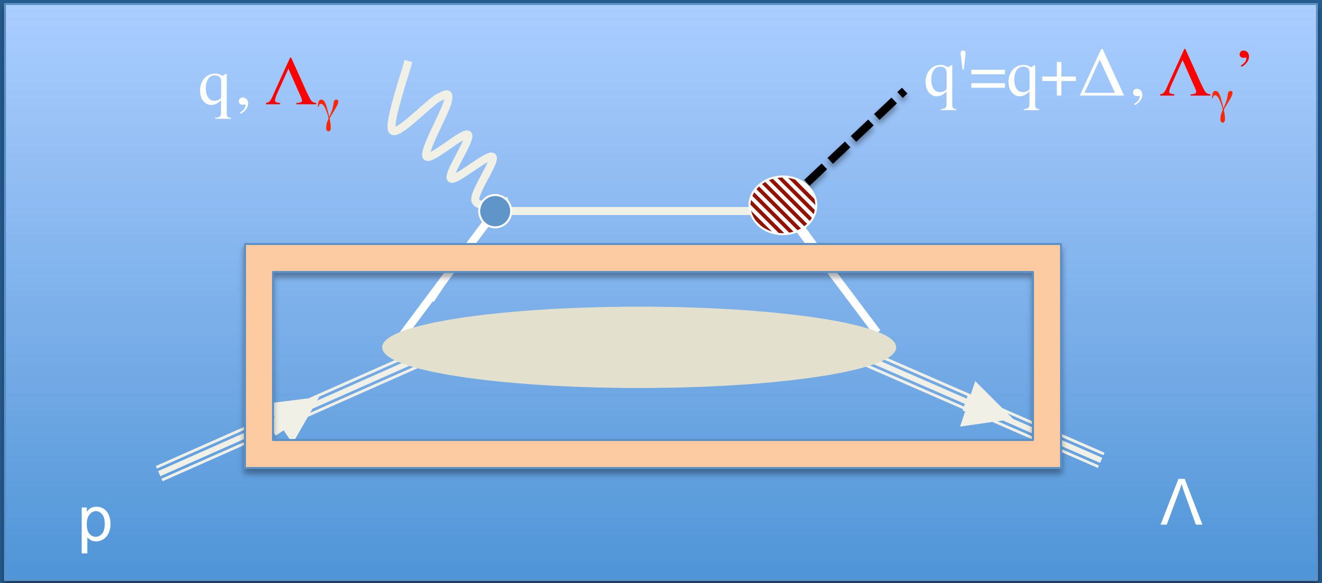


Fig. 1. The final-state interaction in the semi-inclusive deep inelastic lepton scattering $\ell p^{\uparrow} \to \ell' \pi X$.

And that allows us to observe GPDs through Single Spin Asymmetries (SSA)

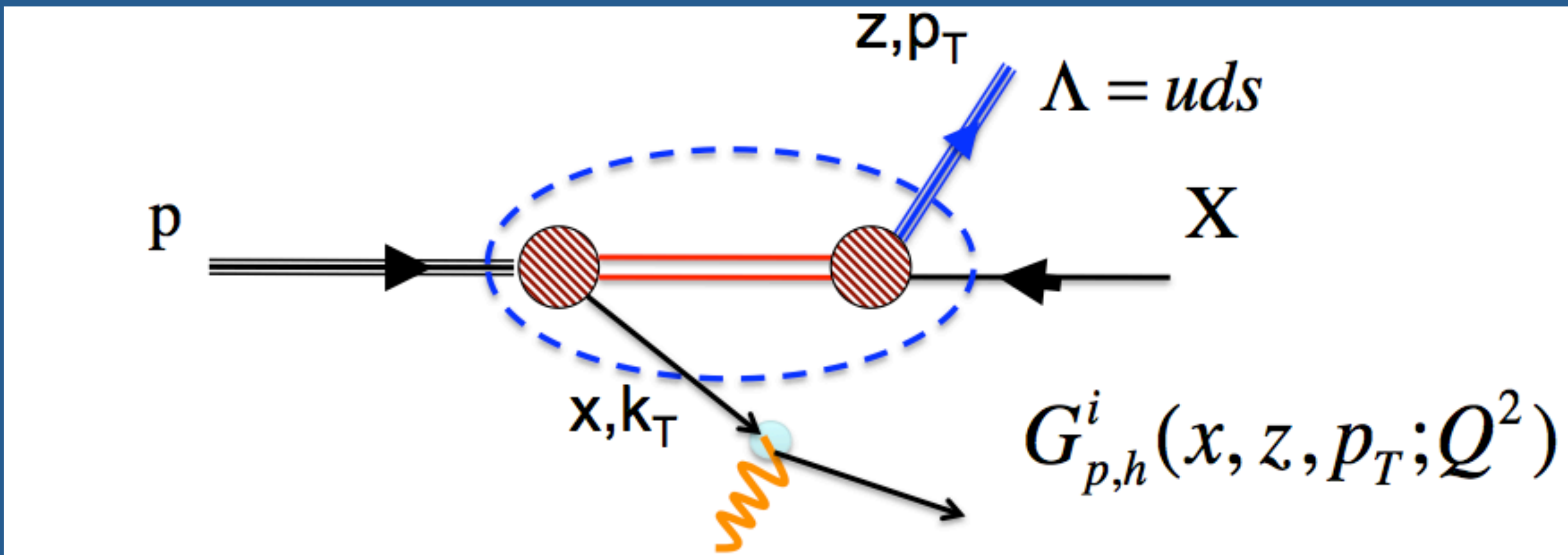
$$2\tilde{\mathrm{H}}_T + \mathrm{E}_T \leftrightarrow h_1^{\perp}$$

$$\mathrm{E} \leftrightarrow f_{1T}^{\perp}$$



… we are in the process of modeling this with Generalized Fracture Functions

Transverse Spin Asymmetries for Λ in Target Fragmentation region



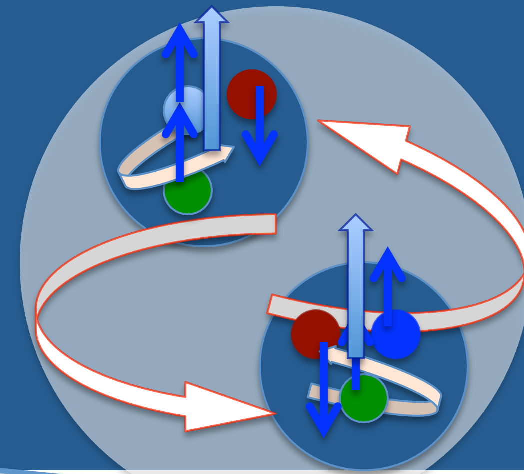
Fracture Function (Trentadue and Veneziano)

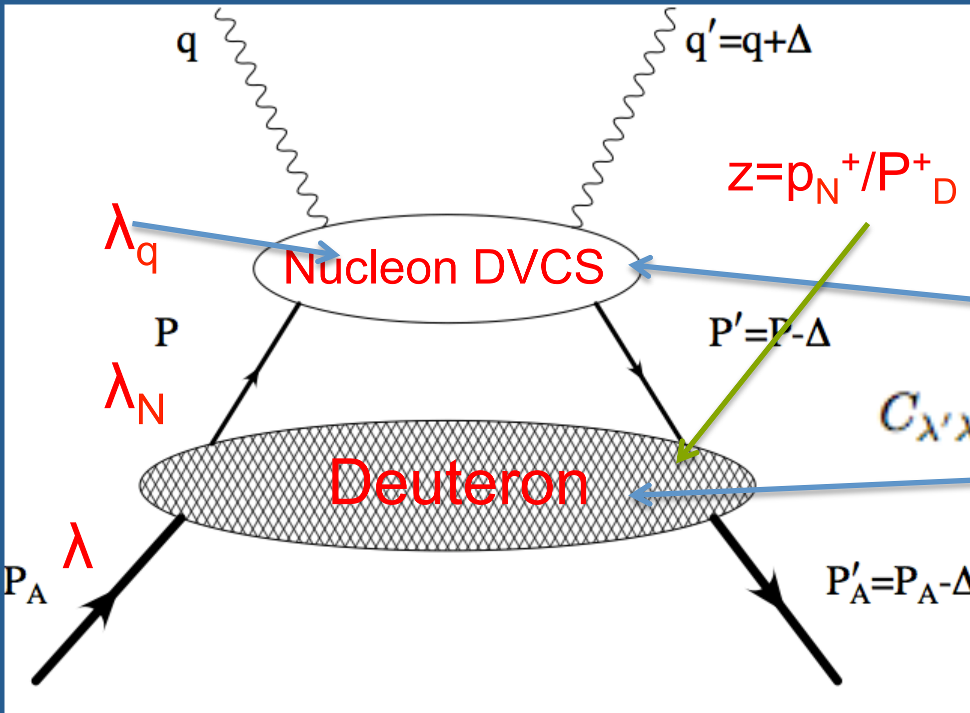
$$\mathcal{F}^{\lambda_q}_{\Lambda_N;\Lambda'_\Lambda,\Lambda_\Lambda}(x,k_T,z,p_T,Q^2) = \sum_{\Lambda_X}\int\frac{d^3P_X}{(2\pi)^3 2E_X}\int\frac{d^4\xi}{(2\pi)^4}e^{ik\cdot\xi}$$

$$\times\langle P,\Lambda_N\mid\bar{\psi}^{\lambda_q}(\xi)\mid P_h,\Lambda'_\Lambda;X\rangle \times \langle P_h,\Lambda_\Lambda;X\mid\psi^{\lambda_q}(0)\mid P,\Lambda_N\rangle.$$

Sum Rules in Deuteron

(work with Kunal Kathuria)





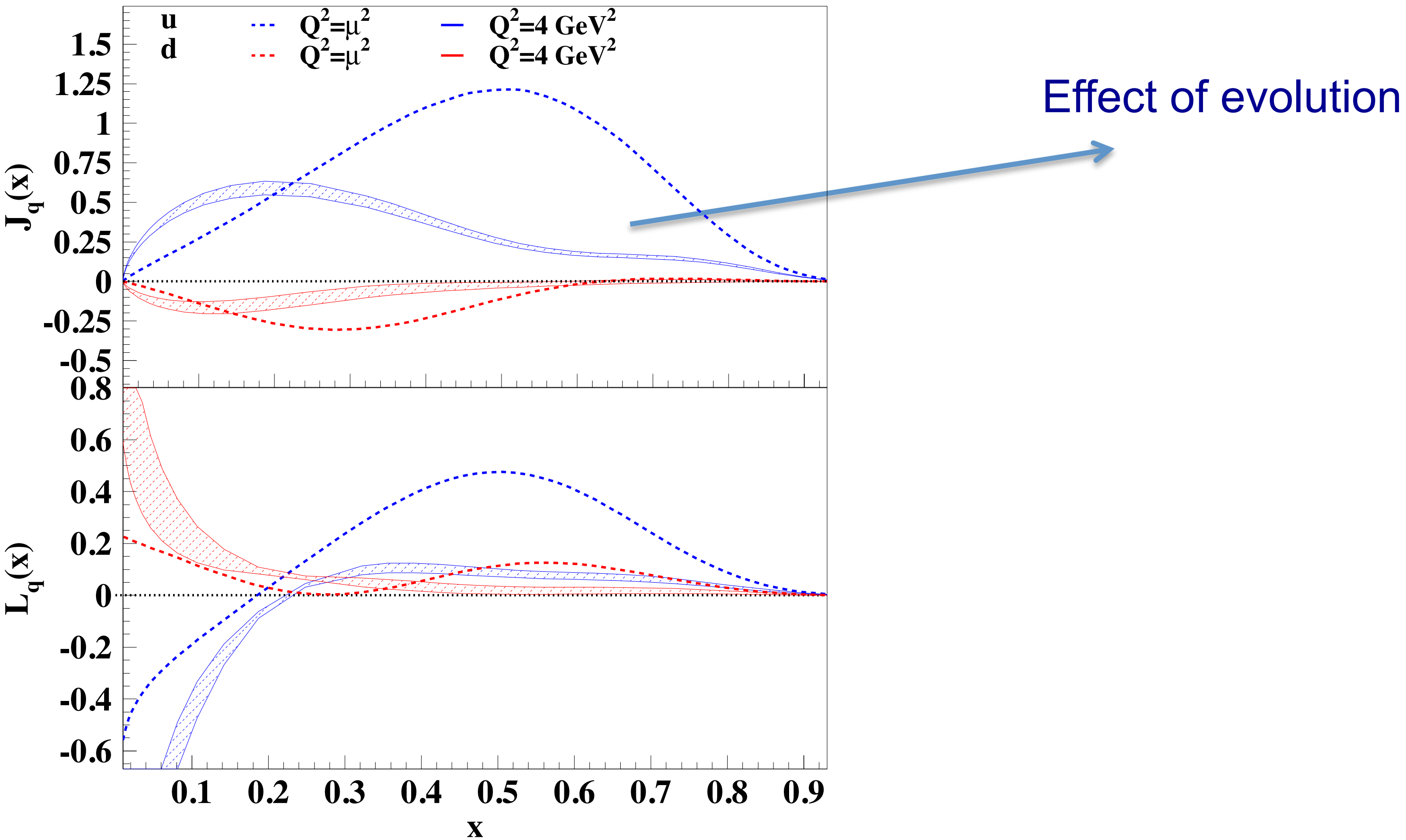
$$C_{\lambda'\lambda'_q,\lambda\lambda_q} = \sum_{\lambda_N,\lambda'_N} B_{\lambda'\lambda'_N,\lambda\lambda_N} \otimes A_{\lambda'_N\lambda'_q,\lambda_N\lambda_q}$$

Spin 1 systems, due to

1) The presence of additional L components (S+D-waves)
2) Isoscalarity

provide a crucial test the working of the angular momentum sum rules

How does Ji sum rule differ from JM in the deuteron?



Using GPDs from Goldstein, Gonzalez Hernandez, SL, PRD84

Deuteron Angular Momentum Sum Rule

Phys.Rev. D86 (2012) 036008

Longitudinal

$$J_q = \frac{1}{2}\int dx\, x\left[H_q(x,0,0) + E_q(x,0,0)\right],$$

Nucleon

$$J_q = \frac{1}{2}\int dx\, x\, H_2^q(x,0,0),$$

Deuteron

$F_1+F_2= G_M$

G_M

Transverse Deuteron

Differently from the nucleon, in the transverse case, we are not finding the same relation (other GPDs describing charge and tensor component enter…). More details later…

Observables: DVCS from deuteron

$$A_{UT} \approx -\frac{4\sqrt{D_0}}{\Sigma}\Im m\left[\mathcal{H}_1^*\mathcal{H}_5 + \left(\mathcal{H}_1^* + \frac{1}{6}\mathcal{H}_5^*\right)(\mathcal{H}_2 - \mathcal{H}_4)\right]$$

subleading

Can the deuteron help us understand the role of gluon OAM?
(Brodsky, Gardner, 2006)

By connecting L_g to SSA in $lD \to l'\pi^{\pm}D'$

$$A_{UT}^{\pi^\pm}(\phi,\phi_s) \equiv \frac{1}{|\langle S_p\rangle|}\left(\frac{N_{\pi^\pm}^{\uparrow}(\phi,\phi_s) - N_{\pi^\pm}^{\downarrow}(\phi,\phi_s)}{N_{\pi^\pm}^{\uparrow}(\phi,\phi_s) + N_{\pi^\pm}^{\downarrow}(\phi,\phi_s)}\right) \equiv A_{UT}^{C}\sin(\phi+\phi_S) + A_{UT}^{S}\sin(\phi-\phi_S) + \cdots \neq 0$$

Both L_q and L_g contribute! Since L_q disappears because of isospin symmetry, if A^{UT}_{π} is 0 then L_g is 0

- Angular momentum in spin 1 ➔arXiv:1101.0581
- Observability of OAM➔arXiv:1310.5157
- GPDs from flavor separated form factors ➔arXiv:1206.1876
- Chiral odd approach ➔arXiv:1311.0483, submitted
- Chiral even approach➔arXiv:1012.3776, submitted

Conclusions and … to explore …

- ✓ G_2, a twist 3 generalized parton distribution, can be measured directly, and it is interpreted as partonic OAM.

- ✓ We showed the helicity and spin structure of this quantity, that it can replace the previously suggested one, and that it does not violate Parity
- ✓ Hyperon polarization in pp collisions is yet another aspect of the spin problem and it is a manifestation of the same issues that affect TMDs

- ✓ Measurements at LHC will help clarify, but electron scattering experiments are crucial to explore the reaction mechanism (factorization and universality)

- ✓ We have been suggesting developments in the formalism based on the concept of GPDs (generalized fracture functions) that can describe all spin phenomena from the multi-GeV to TeV regimes.

Back up


THE MIRROR DID NOT SEEM TO BE OPERATING PROPERLY.

Several misidentifications in Kanazawa et al. (and in Lorce's talk)

1) The argument that $\sigma_{ij} k_T^i \Delta_T^j$ conserves parity because it is a scalar is wrong: this quantity is not a scalar but the product of different vector components
2) The difference between Parity and LF Parity transformations shows up in the evaluation of the matrix element for F_{14}

AM sum rule is obtained by connecting the quark matrix elements of n=2 term

$$\langle p'|\bar{\psi}(0)\gamma^{\mu} iD^{\nu}\psi(0)|p\rangle = \bar{U}(p',\Lambda')\gamma^{\mu}U(p,\Lambda)\bar{P}^{\nu} A_{20}(t) - \bar{U}(p',\Lambda')\frac{i\sigma^{\alpha\mu}\Delta_{\mu}}{2M}U(p,\Lambda)\bar{P}^{\nu} B_{20}(t) + \frac{\Delta_{\mu}\Delta_{\nu}}{M}\bar{U}(p',\Lambda')U(p,\Lambda)C_{20}(t)$$

with the matrix elements of the energy momentum tensor

$$\langle p'|T_q^{\mu\nu}|p\rangle = \bar{U}(p',\Lambda')\left[\gamma^{(\mu}\bar{P}^{\nu)}A(t) - \bar{P}^{(\nu}i\sigma^{\mu)\alpha}\frac{\Delta_{\alpha}}{2M}B(t) + \frac{\Delta^{\mu}\Delta^{\nu} - g^{\mu\nu}\Delta^{2}}{M}C(t)\right]U(p,\Lambda)$$

$$\frac{1}{2}\int dx\, x\Big(H(x,0,0) + E(x,0,0)\Big) = J_z^{q,g}$$

$$\bar{u}(p',\Lambda')i\sigma^{ij}\frac{\bar{k}_i\Delta_j}{M^2}u(p,\Lambda)\; F_{14}(x,0,\mathbf{k}_T^2,\mathbf{k}_T\cdot\mathbf{\Delta}_T,\mathbf{\Delta}_T^2;\eta)$$

$$= 2iM\frac{(\bar{\mathbf{k}}_T\times\mathbf{\Delta}_T)_z}{M^2}\Lambda\delta_{\Lambda\Lambda'}\; F_{14}(x,0,\mathbf{k}_T^2,\mathbf{k}_T\cdot\mathbf{\Delta}_T,\mathbf{\Delta}_T^2;\eta)$$

Parity

LF Parity

$$\bar{u}(\tilde{p}',-\Lambda'_{LF})(\mathbf{S}_L\cdot\mathbf{k}_T\times\bar{\mathbf{\Delta}}_T)u(\tilde{p},-\Lambda_{LF})F_{14}(x,0,\mathbf{k}_T^2,\mathbf{k}_T\cdot\mathbf{\Delta}_T,\mathbf{\Delta}_T^2;\eta) =$$

$$(\eta_P)^2\, 2iM\frac{(\bar{\mathbf{k}}_T\times\mathbf{\Delta}_T)_z}{M^2}(\Lambda_{LF})\delta_{\Lambda_{LF}\Lambda'_{LF}}\; F_{14}(x,0,\mathbf{k}_T^2,\mathbf{k}_T\cdot\mathbf{\Delta}_T,\mathbf{\Delta}_T^2;\eta) \quad (4)$$

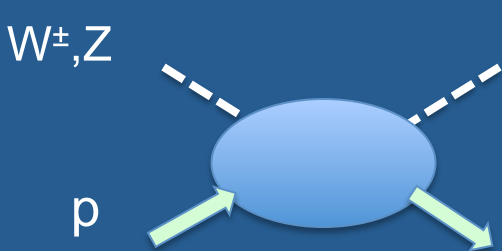
F_{14} appears in the unintegrated structure functions for deep inelastic scattering with electroweak currents

$$\frac{1}{4}\left(T_{1\,\frac{1}{2};1\,\frac{1}{2}}+T_{1\,-\frac{1}{2};1\,-\frac{1}{2}}+T_{-1\,\frac{1}{2};-1\,\frac{1}{2}}+T_{-1\,-\frac{1}{2};-1\,-\frac{1}{2}}\right)=T_1,$$ F_1

$$\frac{1}{4}\left(T_{1\,\frac{1}{2};1\,\frac{1}{2}}-T_{1\,-\frac{1}{2};1\,-\frac{1}{2}}+T_{-1\,\frac{1}{2};-1\,\frac{1}{2}}-T_{-1\,-\frac{1}{2};-1\,-\frac{1}{2}}\right)=\frac{\nu}{M^2}\sqrt{1+\frac{M^2Q^2}{\nu^2}}\;A_1,$$ A_1

$$\frac{1}{4}\left(T_{1\,\frac{1}{2};1\,\frac{1}{2}}-T_{1\,-\frac{1}{2};1\,-\frac{1}{2}}-T_{-1\,\frac{1}{2};-1\,\frac{1}{2}}+T_{-1\,-\frac{1}{2};-1\,-\frac{1}{2}}\right)=-\frac{\nu}{M^2}S_1+\frac{Q^2}{M^2}S_2+S_3,$$ G_1

$$\frac{1}{4}\left(T_{1\,\frac{1}{2};1\,\frac{1}{2}}+T_{1\,-\frac{1}{2};1\,-\frac{1}{2}}-T_{-1\,\frac{1}{2};-1\,\frac{1}{2}}-T_{-1\,-\frac{1}{2};-1\,-\frac{1}{2}}\right)=\frac{\nu}{2M^2}\sqrt{1+\frac{Q^2M^2}{\nu^2}}\;T_3,$$ F_3



X.Ji, NPB402 (1993)

$$
\begin{aligned}
G_1 \;\propto\;& (g'_V g_V + g'_A g_A) \otimes (A_{++,++} - A_{-+,-+} + A_{--,--} - A_{+-,+-}) && g_1 \\
&+ (g'_V g_A + g'_A g_V) \otimes (A_{++,++} - A_{-+,-+} - A_{--,--} + A_{+-,+-}) && F_{14}
\end{aligned}
$$

parity odd

$$
\begin{aligned}
A_1 \;\propto\;& (g'_V g_V + g'_A g_A) \otimes (A_{++,++} - A_{-+,-+} - A_{--,--} + A_{+-,+-}) && F_{14} \\
&+ (g'_V g_A + g'_A g_V) \otimes (A_{++,++} - A_{-+,-+} + A_{--,--} - A_{+-,+-}), && g_1
\end{aligned}
$$

F_{14} is the parity odd contribution to g_1 and the parity even contribution to A_1!