QCD AND THE NUCLEON'S SPIN

Outline

- Theoretical background
- What does a spinning proton look like under an infinitely powerful microscope ?
  (X. Ji, H. Tang, PH)
- How to consistently define, measure, and evolve a quark orbital angular momentum distribution ?
  (X. Ji, W. Lu, PH)
- What connects single-spin asymmetry to OAM and DVCS ?
- How can gluon angular momentum be measured ?

Angular Momentum In QCD

- The canonical AM tensor,

$$M_c^{\alpha\mu\nu} = x^\mu T^{\alpha\nu} - x^\nu T^{\alpha\mu} - i\frac{\delta \mathcal{L}}{\delta(\partial_\alpha \Phi)} \Sigma^{\mu\nu} \Phi$$

leads to a sum rule:

- $J^{12}|P\uparrow\rangle = \frac{1}{2}\hbar\,|P\uparrow\rangle$

$$\tfrac{1}{2} = \tfrac{1}{2}\Sigma_q + L_q + \Sigma_g + L_g$$

where,

QUARK

$$\tfrac{1}{2}\Sigma_q = \langle P\uparrow | \int d^3x\, \psi^\dagger \tfrac{1}{2}\Sigma_z \psi\, | P\uparrow\rangle$$

$$L_q = \langle P\uparrow | \int d^3x\, \psi^\dagger (x^1\partial^2 - x^2\partial^1)\psi\, | P\uparrow\rangle$$

GLUON

$$\Sigma_g = \langle P\uparrow | \int d^3x\, (E^1 A^2 - E^2 A^1)\, | P\uparrow\rangle$$

$$L_g = \langle P\uparrow | \int d^3x\, E^i (x^2\partial^1 - x^1\partial^2) A^i\, | P\uparrow\rangle$$

- A simple picture but gauge dependent. Must search for a better alternative to $M_c^{\alpha\mu\nu}$.

A gauge-invariant decomposition (J_i)

- $M^{\alpha\mu\nu} = M_c^{\alpha\mu\nu} + \partial_\beta B^{[\mu\beta][\nu\lambda]}$ gives exactly the same physics. So choose $B^{[\mu\beta][\nu\lambda]}$ appropriately!

- The improved form: $M^{\alpha\mu\nu} \equiv x^\mu T^{\alpha\nu} - x^\nu T^{\alpha\mu}$ is,
  1) Conserved, $\partial_\alpha M^{\alpha\mu\nu} = 0$.
  2) Obeys $M^{\alpha\mu\nu} + M^{\nu\alpha\mu} + M^{\mu\nu\alpha} = 0$.
  3) Gauge-invariant

- The correct definitions follow:

$$\vec{J}_q = \int d^3r \left[\psi^\dagger \tfrac{1}{2} \vec{\Sigma} \psi + \psi^\dagger \vec{r} \times (-i\vec{D})\psi \right]$$

$$\vec{J}_g = \int d^3r \; \vec{r} \times (\vec{E} \times \vec{B})$$

- Further separation into gluon spin and OAM is impossible.

Scale Dependence

$q^2 = -Q^2$

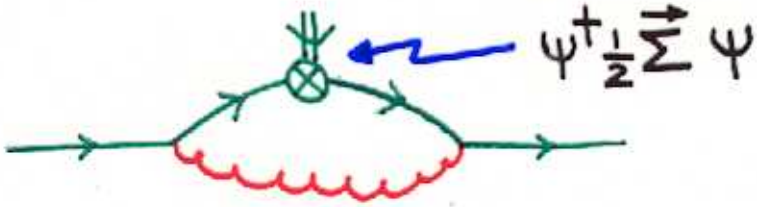
$Q^2 \to \infty$

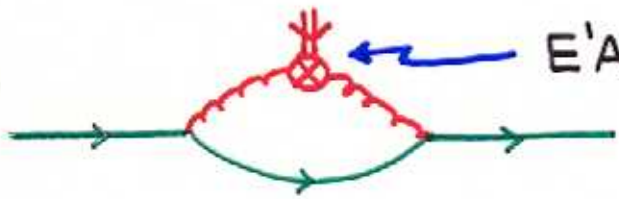
- DIS sees quarks but quarks have meaning only at a particular scale:

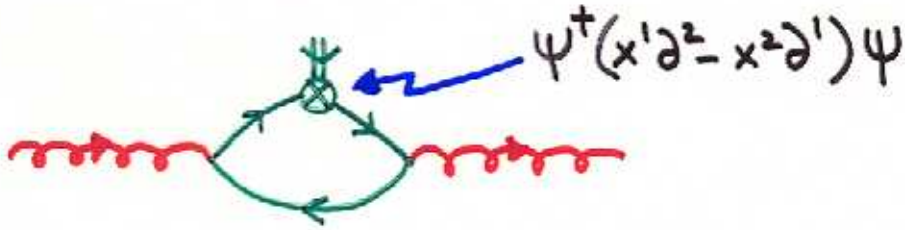
$$q = Z_F^{-\frac{1}{2}} q_0 \,, \quad A^\mu = Z_A^{-\frac{1}{2}} A_0^\mu$$

∴ All composite operators like $\psi^\dagger \Sigma \psi$ are scale-dependent and need renormalization.

- The evolution with scale Q^2 of all spin components is perturbatively calculable:







- Calculation yields evolution equation:

$$\frac{d}{dt}\begin{bmatrix}\Delta\Sigma_q\\ \Delta\Sigma_g\\ L_q\\ L_g\end{bmatrix} = \frac{\alpha_s}{2\pi}\begin{bmatrix}0 & 0 & 0 & 0\\ \frac{3}{2}C_F & \frac{1}{2}\beta_0 & 0 & 0\\ -\frac{2}{3}C_F & \frac{1}{3}n_f & -\frac{4}{3}C_F & \frac{1}{3}n_f\\ -\frac{5}{6}C_F & -\frac{11}{2} & \frac{4}{3}C_F & -\frac{1}{3}n_f\end{bmatrix}\begin{bmatrix}\Delta\Sigma_q\\ \Delta\Sigma_g\\ L_q\\ L_g\end{bmatrix}$$

$$t = \log\frac{Q^2}{\mu^2}$$

$$C_F = \frac{4}{3}\,,\quad \beta_0 = 11 - \frac{2}{3}n_f$$

This is an initial-value problem that needs a starting set of values:

$$\left\{\Delta\Sigma_q(Q_0^2),\ \Delta\Sigma_g(Q_0^2),\ L_q(Q_0^2),\ L_g(Q_0^2)\right\}$$

- For gauge-invariant combinations:

$$\frac{d}{dt}\begin{bmatrix}J_q\\ J_g\end{bmatrix} = \frac{\alpha_s}{2\pi}\begin{bmatrix}-\frac{4}{3}C_F & \frac{1}{3}n_f\\ \frac{4}{3}C_F & \frac{1}{3}n_f\end{bmatrix}\begin{bmatrix}J_q\\ J_g\end{bmatrix}$$

$$J_q = \frac{1}{2}\Sigma_q + L_q\,,\quad J_g = \Sigma_g + L_g$$

- Solution of evolution equation:

$$J_q(t) = \frac{1}{2}\frac{3n_f}{16+3n_f} + e^{-\frac{\alpha_s}{18\pi}(16+3n_f)t}$$

$$J_g(t) = \frac{1}{2}\frac{16}{16+3n_f} - e^{-\frac{\alpha_s}{18\pi}(16+3n_f)t}$$

CONCLUSION:

Given infinite resolving power we know the protons' spin-structure!

$$J_q \xrightarrow{Q^2\to\infty} \frac{1}{2}\frac{3n_f}{16+3n_f} = 0.264706\cdots$$

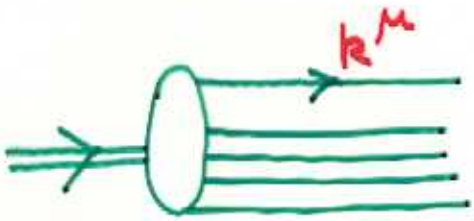
$$J_g \xrightarrow{Q^2\to\infty} \frac{1}{2}\frac{16}{16+3n_f} = 0.235294\cdots$$

ORBITAL ANGULAR MOMENTUM

- Classically $\vec{L} = \sum_i \vec{r}_i \times \vec{p}_i$. Depends upon reference frame.
- In QCD, $\vec{L}_q = \int d^3r \, \psi^\dagger \vec{r} \times \frac{1}{i}\vec{D}\psi$.

GOAL: Construct a quark OAM density such that it is,

(1) Gauge-invariant
(2) Twist-two
(3) Evolves calculably with Q^2
(4) Experimentally measureable



$k^\mu = (xP^+, k^-, \vec{k}_\perp)$

$x \equiv$ Feynman x

$n^2 = p^2 = 0$, $n \cdot p = 1$

Recall: $\Delta\Sigma_q = \int_{-1}^{1} dx \, \Delta q(x)$

↑ quark spin distribution

In general distributions define moments $f_n = \int dx \, x^{n-1} f(x)$ and vice-versa.

- Construct operators whose m.e.s would lead to moments of $L_q(x)$:

$$\bar{\psi}\gamma^+(x^1\partial^2_- - x^2\partial^1)\,iD^+\cdots iD^+\psi \quad \leftarrow \text{fails}$$

$$\bar{\psi}\gamma^+(x^1 D^2_- - x^2 D^1)\,iD^+\cdots iD^+\psi \quad \leftarrow \text{also fails}$$

- So go back to the basics – the Lorentz Group

$$O_q^{\beta\mu_1\cdots\mu_n} \equiv \bar{\psi}(\xi)\gamma^{(\beta} i\overleftrightarrow{D}^{\mu_1}\cdots i\overleftrightarrow{D}^{\mu_n)}\psi(\xi)$$

means symmetrize and subtract trace

O_q is now guaranteed to belong to an IR, hence twist.

- Define generalized ang. mom. tensor:

$$\mathcal{M}_q^{\alpha\beta\mu_1\cdots\mu_n} \equiv \xi^\alpha O_q^{\beta\mu_1\cdots\mu_n}(\xi) - \xi^\beta O_q^{\alpha\mu_1\cdots\mu_n}(\xi)$$

Take matrix element in nucleon state:

$$\langle PS|\int d^4\xi\, \mathcal{M}_q^{\alpha\beta\mu_1\cdots\mu_n}(\xi)|PS\rangle$$

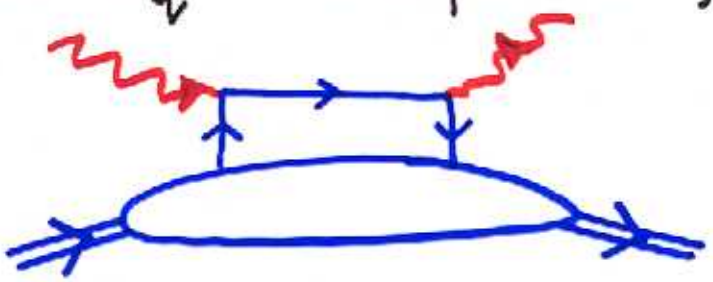
$$\equiv J_{qn} * \text{tensor structures built from } P^\mu, S^\mu, \varepsilon_{\alpha\beta\cdots}$$

↑ "reduced matrix element" or moment.

- Define total AM density from J_{qn}:

$$\int_{-1}^{1} dx\, x^{n-1} J_q(x) \equiv J_{qn}$$

- To relate $J_q(x)$ to experiment, recall DVCS:



$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P'S'| \bar{\psi}(-\tfrac{\lambda}{2}n) \not{n} \psi(\tfrac{\lambda}{2}n) |PS\rangle$$

$$= H_q(x,\xi,t)\, \bar{U}(P') \not{n} U(P) + E_q(x,\xi,t)\, \bar{U}(P') \frac{i\sigma^{\mu\nu} n_\mu \Delta_\nu}{M} U(P)$$

with, $P^\mu = (1+\xi)p^\mu - \frac{1}{2}\Delta^\mu$

$P'^\mu = (1-\xi)p^\mu + \frac{1}{2}\Delta^\mu$

- Take non-diagonal m.e. of $\mathcal{M}_q^{\alpha\beta\mu_1\cdots\mu_n}$. Then compare with moments of E_q. Same operators!

but,

$$J_q(x) = \tfrac{1}{2} x q(x) + \tfrac{1}{2} x E_q(x, \xi=0, \Delta^2=0)$$

$$J_q(x) = \tfrac{1}{2}\Delta q(x) + L_q(x)$$

$$\Longrightarrow \quad \boxed{L_q(x) = \tfrac{1}{2} x q(x) - \tfrac{1}{2} x \Delta q(x) + \tfrac{1}{2} x E_q(x)}$$

- How big is $E_q(x) \equiv E_q(x, \xi=0, \Delta^2=0)$?

We do not know as yet, but:

$$\int_{-1}^{+1} dx\, E_q(x) = \kappa_u + \kappa_d + \kappa_s$$

$$= 0.33 \pm 0.39$$

Maybe $L_q(x)$ can be entirely determined by $q(x)$ and $\Delta q(x)$!

Evolving $L_q(x,Q^2)$ with Q^2

- Spin is frame-independent, OAM is not. So make choice, use $i\not{D}\psi=0$, and manipulate:

$$\int d^3\xi\, \mathcal{M}^{12+}_q(\xi) = S^+_q + \tilde{L}^+_q + \Delta L^+_q$$

where,

$$S^+_q = \int d^3\xi\ \bar{\psi}\gamma^+\frac{\Sigma^3}{2}\psi$$

$$\tilde{L}^+_q = \int d^3\xi\ \bar{\psi}\gamma^+(x^1 iD^2 - x^2 iD^1)\psi$$

$$\Delta L^+_q = \int d^3\xi\ \bar{\psi}\gamma^+(x^1\gamma^2 - x^2\gamma^1)\psi$$

- Under renormalization $\tilde{L}^+_q$ mixes with ΔL^+_q. The correct OAM is:

$$L^+_q = \tilde{L}^+_q + \Delta L^+_q$$

- Establish evolution for all moment of $L_q(x)$:

$$\frac{d}{dt}L_{qn} = \gamma_{qq}(n+1)L_{qn} + \frac{1}{2}\left[\gamma_{qq}(n+1) - \Delta\gamma_{qq}(n)\right]\Sigma_n + \gamma_{qg}(n+1)J_{gn} - \frac{1}{2}\Delta\gamma_{qg}\Delta g_n$$

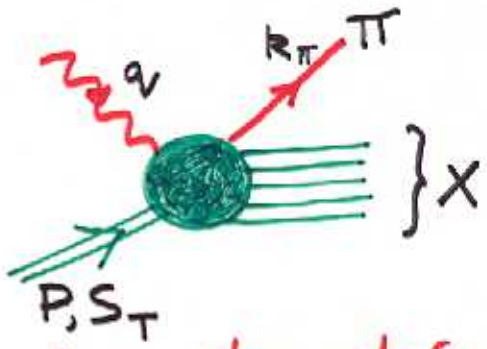
Comments: 1) Holds to all orders in α_s.

2) γ_{qq} etc have already been computed.

QUARK OAM AND SINGLE-SPIN ASYMMETRY

The Process:

$\gamma^* + P \rightarrow \pi + X$

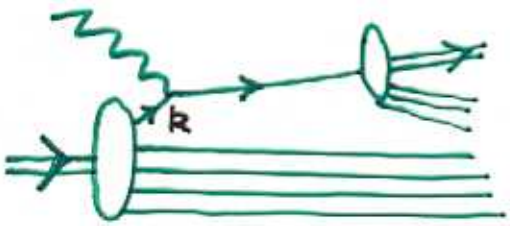


$A \sim i \vec{S}_T \cdot \vec{k}_\pi \times \vec{q}$ in target rest frame

$\sim \frac{i}{M} \varepsilon_{\mu\nu\alpha\beta} P^\mu S_T^\nu k_\pi^\alpha q^\beta$ more generally

QPM Picture:

Since $Q^2 \sim 2\text{-}6\ \text{GeV}^2$, $\therefore$ single quark should dominate



$d\sigma \sim f_{1T}^{\perp}(x, \vec{k}_\perp) \otimes D^{\pi}(z)$ $\quad x \equiv \frac{k^+}{P^+}$

↳ "Sivers function"

The Puzzle:

$f_{1T}^{\perp}$ vanishes because of time-reversal invariance.

$\frac{1}{2} \int d^3\xi\, e^{ik\cdot\xi} \langle P | \bar{q}(0) \not{n} q(\xi) | P \rangle$

(Mulders, Boer, Boglione) $= f_{1T}^{\perp}(x, k_\perp)\, i \varepsilon_{\mu\nu\alpha\beta} P^\mu S^\nu k^\alpha n^\beta$

- Interpretation of $f_{1T}^{\perp}$:

  - • = nucleon spin in $\hat{x}$ direction
  - • = nucleon spin in $-\hat{x}$ direction

So $f_{1T}^{\perp}$ is the unpolarized quark distribution inside a transversely polarized nucleon.

- Another T-odd function is $h_1^{\perp}(x, \vec{k}_T^{\,2})$ (Mulders)

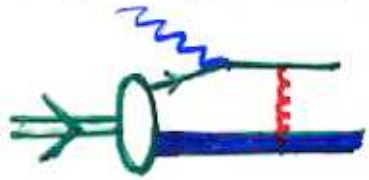
$$\int \frac{d^3\xi}{(2\pi)^3} e^{ik\cdot\xi} \langle PS|\bar{q}_\alpha(0) q_\beta(\xi)|PS\rangle$$

$$= h_1^{\perp}(x, k_T^2) \frac{i}{2M} [\not{k}_T, \not{P}]_{\beta\alpha}$$

Interpretation of $h_1^{\perp}$: density of transversely polarized quarks inside an unpolarized nucleon.

History since Jan 2002

1) Brodsky, Hwang, Schmidt use a diquark model to show that final state interactions can give SSA:



2) Collins points out why his earlier proof of $f_{1T} = 0$ was wrong:

$$\langle P | \bar{q}(0) U^{\dagger}(\infty, 0) U(\infty, \xi) \bar{q}(\xi) | P \rangle$$

$$U(\infty, \xi) = \mathcal{P} \exp\left(-ig \int_{\xi^-}^{\infty} d\xi^- A^+\right)$$

In $A^+ = 0$ gauge $U = 1$. No FSI !

3) Ji and Yuan show that singular behavior in $A^+ = 0$ gauge can be fixed by modifying U:

$$U(\infty, 0) \longrightarrow \mathcal{P} \exp\left(-ig \int d\xi_{\perp} \cdot A_{\perp}(\xi^- = \infty, \xi_{\perp})\right)$$

4) Belitsky, Ji, Yuan show how a transverse gauge link arises in $A^+ = 0$ gauge.

OAM and SSA are connected:

1) From QM, $|\uparrow\rangle_x = \frac{1}{\sqrt{2}}|\uparrow\rangle_z + \frac{1}{\sqrt{2}}|\downarrow\rangle_z$

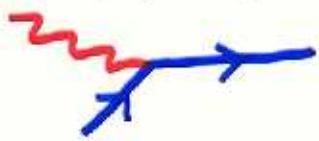
$|\downarrow\rangle_x = \frac{1}{\sqrt{2}}|\uparrow\rangle_z - \frac{1}{\sqrt{2}}|\downarrow\rangle_z$

2) $\sigma(\gamma^* + N_x \to F)$

$\propto \mathrm{Im}\, \mathcal{A}^*(\uparrow \to \downarrow)\mathcal{A}(\downarrow \to \uparrow)$

Hence, the target helicity must flip.

3) Fact: the struck quark with $m = 0$ cannot flip helicity:

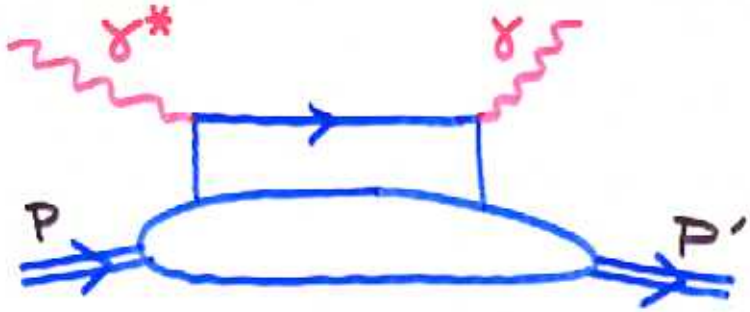


4) But transverse momentum $\Leftrightarrow$ OAM can cause one unit of AM transfer:

$$Y_{1\pm1}(k) \sim \frac{1}{\sqrt{2}}(k_x \pm i k_y)$$

So, no OAM $\Rightarrow$ no SSA!

Generalization to DVCS



- Define two new T-odd distributions:

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P'S'|\bar{Q}(-\tfrac{1}{2}\lambda n)\, Q(\tfrac{1}{2}\lambda n)|PS\rangle \Big|_{\xi^+=\xi_\perp=0}$$

$$= \frac{1}{4M} \mathcal{F}_{1T}^{\perp}(x,\xi,\Delta_T^2)\, \varepsilon_{\mu\nu\rho\sigma} \gamma^\mu P^\nu \frac{\Delta_T^\rho}{M} \bar{U}\gamma^\sigma\gamma^5 U$$

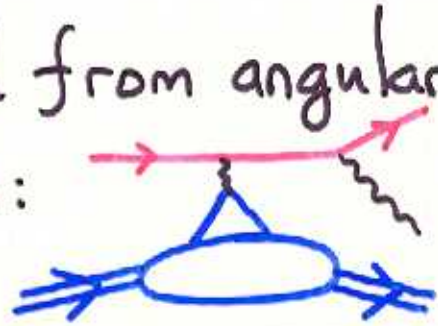
$$+ \frac{1}{4M} \mathcal{H}_1^{\perp}(x,\xi,\Delta_T^2)\, \sigma_{\mu\nu} \frac{\Delta_T^\mu}{M} P^\nu \bar{U} U$$

- Gauge links are vital:

$$Q(\xi^-,\xi_\perp) = \mathcal{P} e^{-ig\int_{\xi^-}^{\infty} d\eta^- A^+(\eta^-,\xi_\perp)}\, q(\xi^-,\xi_\perp)$$

- In $A^+=0$ gauge $\mathcal{F}_{1T}^{\perp}$ and $\mathcal{H}_1^{\perp}$ apparently vanish. In fact they are just as large as any other OFPD.

- $\mathcal{F}_{1T}^{\perp}$ and $\mathcal{H}_1^{\perp}$ can be isolated from angular dependence in B-H interference:

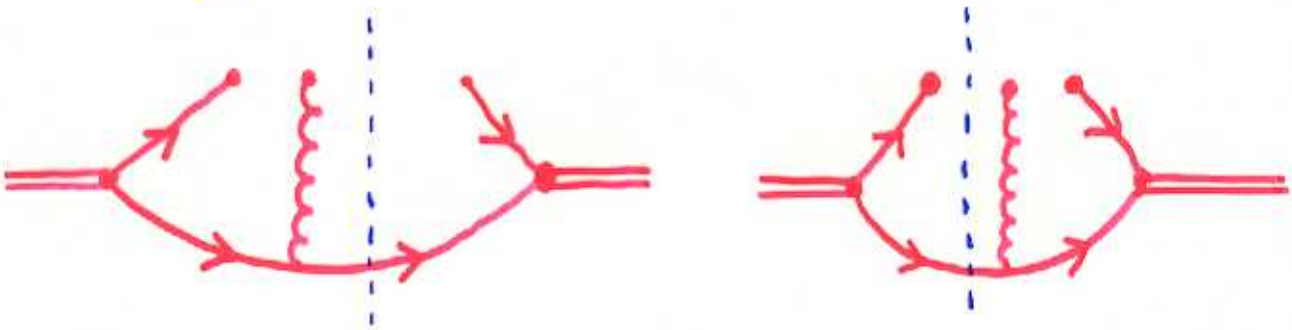


Estimation of $F_{1T}^{\perp}$ and $\mathcal{H}_1^{\perp}$:

- **Diquark model:**

$$\mathcal{L} = -\bar{q} N \phi^* - i e_2 \phi^* \overleftrightarrow{\partial_\mu} \phi * A^\mu$$

- **Leading contributions:**



- **Definition of momenta:**

$$\bar{P}^\mu = \frac{1}{2}(P' + P)^\mu$$

$$\Delta^\mu = P'^\mu - P^\mu$$

In terms of light-cone vectors:

$$P^2 = n^2 = 0 \,, \quad P \cdot n = 1$$

$$\bar{P}^\mu = P^\mu + \frac{1}{2}\bar{M}^2 n^\mu$$

$$\Delta^\mu = -2\xi\left[P^\mu - \frac{1}{2}\bar{M}^2 n^\mu\right] + \Delta_\perp^\mu$$

$$\bar{M}^2 = M^2 - \frac{1}{4}\Delta^2$$

Evaluation of loop integral:

1) Eikonal factor:

$$\frac{1}{q^+ + i\varepsilon} = P\left(\frac{1}{q^+}\right) + i\pi\,\delta(q^+)$$

2) Contour integration order:

$$\int dq^+ \int d^2q_\perp d^2k_\perp \int dq^- \, dk^-$$

RESULT:

$$\mathcal{F}_{1T}^{\perp} = \frac{g^2 e_1 e_2}{64\pi^3}(1-x)^2 M^2 \frac{\xi}{[\Lambda(\xi)-\Lambda(-\xi)]}\left\{f_0 + \frac{\Delta_\perp^2}{M^2} f_2 + \cdots\right\}$$

for $x > \xi$

$$f_0 = \text{Log}\,\frac{\Lambda(\xi)}{\Lambda(-\xi)}$$

$$f_2 = \frac{(1-x)^2 M^4}{[\Lambda(\xi)-\Lambda(-\xi)]^3}\left\{[\Lambda(\xi)-\Lambda(-\xi)] + \frac{1}{2}[\Lambda(\xi)+\Lambda(-\xi)]\log\frac{\Lambda(\xi)}{\Lambda(-\xi)}\right\}$$

$$\Lambda(\xi) = (1+\xi)(1-\xi^2)(x-\xi) \times\left\{\frac{(1-x)m^2}{x-\xi} + \lambda^2 - \frac{(1-x)M^2}{1-\xi}\right\}$$

For $x < \xi$ all q^-, k^- poles lie on the same side $\Longrightarrow \mathcal{F}_{1T}^{\perp} = 0.$

For greater insight consider $\xi \to 0$, $\Delta_T^2 \to 0$

$$F_{1T}^{\perp} \to \frac{g^2 e_1 e_2}{64\pi^3} \frac{(1-x)\xi}{\frac{m^2}{M^2} - x\left[1 - \frac{\lambda^2}{M^2(1-x)}\right]}$$

- In the diquark model, the two distributions are proportional to each other:

$$H_1^{\perp}(x, \xi, \Delta_T^2) = \frac{1}{4(1-x)} F_{1T}^{\perp}(x, \xi, \Delta_T^2)$$

- The $P\left(\frac{1}{q^+}\right)$ part is much more complicated analytically .....

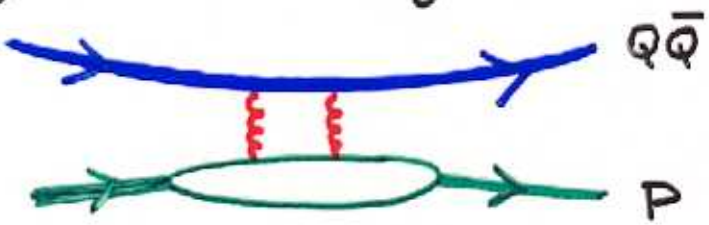
GLUON CONTRIBUTION TO NUCLEON SPIN FROM $Q\bar{Q}$ - NUCLEON SCATTERING

- Heavy quarkonia are hydrogenic:

$$a_0 \sim \frac{1}{\alpha_s M_Q} \xrightarrow{M_Q \to \infty} 0$$

$$\varepsilon_0 \sim \alpha_s^2 M_Q \longrightarrow \infty$$

- Interactions with normal hadrons is via singlet gluon exchanges:



- QCD multipole expansion or OPE gives:

$$\mathcal{M} = \frac{1}{2}\sum_{n=2}^{\infty} d_n a_0^3 \varepsilon_0^{2-n} v_{\mu_1} \cdots v_{\mu_n} \langle P' | O^{\mu_1 \cdots \mu_n} | P \rangle$$

[Bhanot & Peskin]

d_n = simple numbers

v_μ = quarkonium velocity, assumed constant.

$$O^{\mu_1 \cdots \mu_n} = F^{\mu_1 \rho} iD^{\mu_2} \cdots iD^{\mu_n} F_\rho^{\ \mu_n}$$

- Work in $Q\bar{Q}$ rest frame:

$$E' = E = \sqrt{\vec{p}^2 + m^2}$$

$$t = -4\vec{p}^2 \sin^2\frac{\theta}{2}$$

For $\theta \ll 1$ calculate $\mathcal{M}$,

$$\mathcal{M} = \frac{1}{2} a_0^3 \varepsilon_0^2 \sum_{n=2}^{\infty} d_n \left(\frac{\gamma m}{\varepsilon_0}\right)^n \left\{ 2A_{no} + \gamma B_{no} \langle i\sigma\cdot\hat{n}\rangle \theta \right\}$$

where,

$$\langle i\sigma\cdot\hat{n}\rangle = \begin{cases} \pm 1 & \text{with spin-flip} \\ 0 & \text{without spin-flip} \end{cases}$$

- A_{no} = moment of usual gluon distribution

$$A_{no} = \int_{-1}^{+1} dx\, x^{n-1} G(x, \varepsilon_0^2)$$

(A_{20} = mom fraction carried by gluons ~ 0.5)

- B_{no} is related to gluon angular momentum distribution:

$$\int_{-1}^{+1} dx\, x^{n-1} J_g(x) \equiv J_n$$

$$= \frac{1}{2}(A_{no} + B_{no})$$

So in principle we can deduce $J_g(x)$!

- But $J(x)$ comes from a traceless operator,

$$F^{(\mu_1\rho} i\overleftrightarrow{D}^{\mu_2} \ldots i\overleftrightarrow{D}^{\mu_n} F_\rho^{\ \mu_n)} - \text{traces}$$

Do we know how to subtract traces ?

- Fortunately for $n=2$ we do!

$$T^\mu{}_\mu = \frac{\beta(g)}{2g^3} F^{\mu\nu} F_{\mu\nu}$$

$$\beta(g) = -\frac{9g^3}{16\pi^2}$$

RESULTS

$$\mathcal{M} = \frac{1}{6} d_2 m^2 a_0^2 \left(\frac{16\pi^2}{9} + 2A_{20}(\gamma^2 - \tfrac{1}{4}) \right)$$
$$+ \frac{1}{6} d_2 m^2 a_0^3 (\gamma - 1)\left[(\gamma + \tfrac{1}{4})A_{20} + \gamma(\gamma+1)B_{20} \right] \langle i\sigma \cdot \hat{n} \rangle \theta$$

$$\gamma = \frac{1}{\sqrt{1-v^2}}, \quad d_2 = \frac{28}{27}\pi$$

An equivalent effective potential exists:

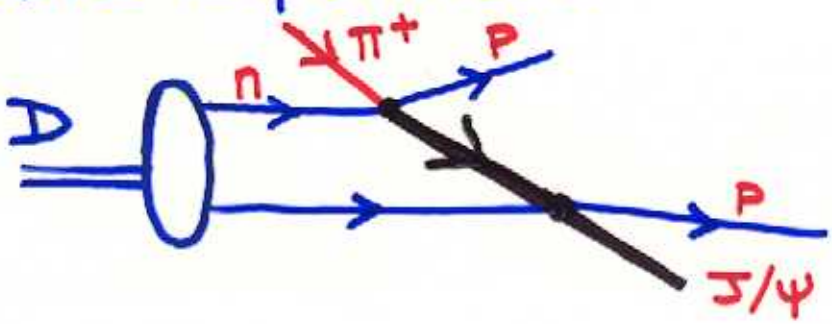
$$V_{Q\bar{Q}-N} = V_1(r) + \nabla V_2(r) \cdot (i\vec{\sigma} \times \vec{\nabla})$$

where V_1 and V_2 are constrained by,

$$\int_0^\infty dr\, r^2 V_1(r) = \frac{d_2 m a_0^3}{48\pi}\left(\frac{16\pi^2}{9} + \frac{3}{2} A_{20} \right)$$

$$\int_0^\infty dr\, r^2 V_2(r) = \frac{d_2 a_0^3}{48\pi M}\left(\frac{5}{8} A_{20} + B_{20} \right)$$

Possible Experiment:



Conclude:

- The nucleons' asymptotic spin structure is simple

$$J_q \xrightarrow{Q^2\to\infty} \frac{1}{2}\frac{3n_f}{16+3n_f}, \quad J_g \xrightarrow{Q^2\to\infty} \frac{1}{2}\frac{16}{16+3n_f}$$

- Quark OAM is well-defined and needs extraction from DVCS.

- An OFPD measureable in DVCS connects naturally to the Sivers function.

- Extracting the gluonic component of the total AM requires better ideas!