Nuclear dependent CosΦ azimuthal asymmetry in SIDIS

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Outline

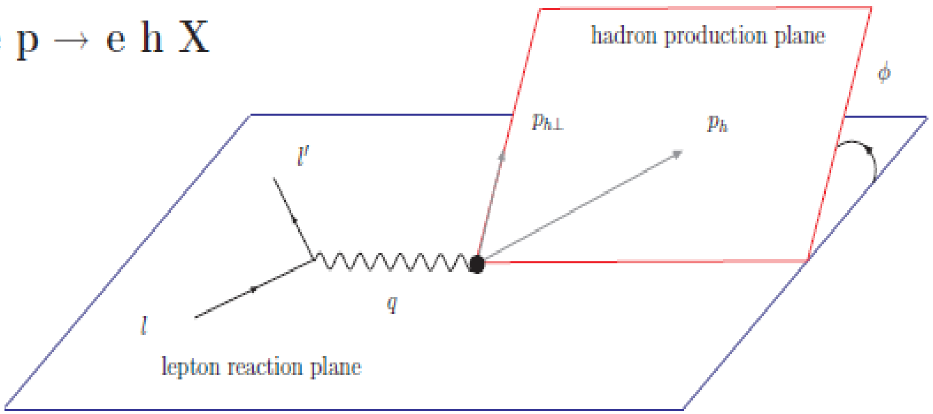
- 1: Introduction: CosΦ asymmetry in SIDIS
- 2: CosΦ asymmetry at small x

  Collaboration with Feng Yuan
- 3: CosΦ asymmetry at intermediate(or large) x

  Collaboration with Jianhua Gao
- 4: Summary

Azimuthal asymmetry in SIDIS off nucleon

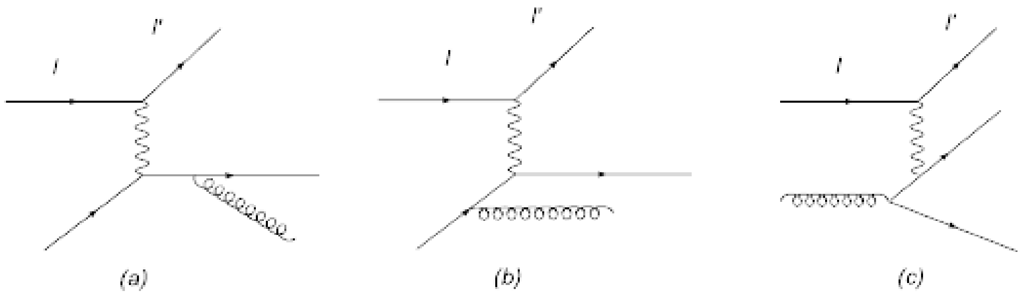
$e\ p \rightarrow e\ h\ X$



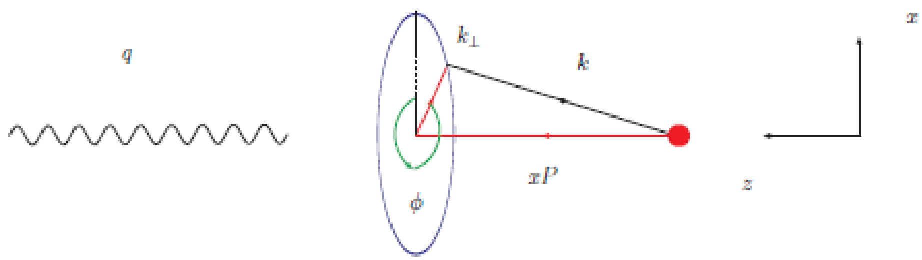
Unpolarized cross section,

$$\frac{d\sigma}{d\phi} = A + B\cos\phi + C\cos 2\phi$$

High p_T, gluon radiation
Georgi and Politzer 78



Low p_T, parton intrinsic transverse momentum Cahn 78



Azimuthal asymmetry in SIDIS off nuclei

eA->ehX

Multiple scattering leads to the nuclear dependent $\mathrm{Cos}\,\Phi$ asymmetry in SIDIS off large nuclei in both small x and intermediate x region.

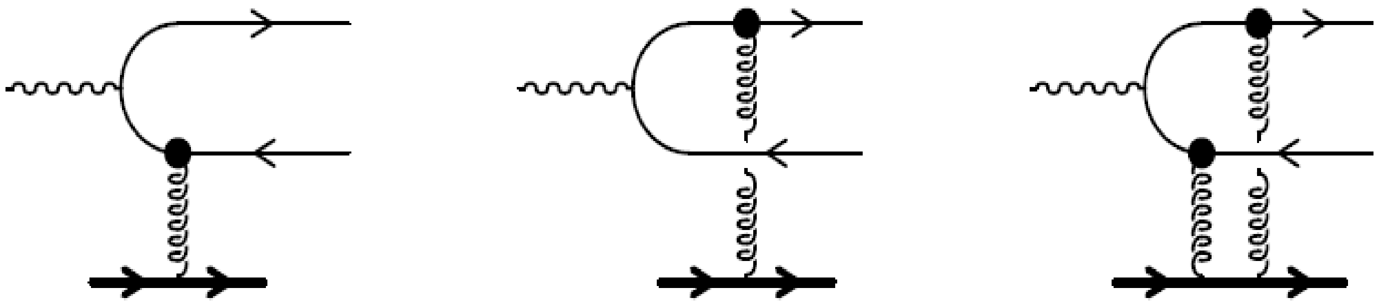
- Test our understanding of the saturation physics & collinear higher twist formalism.
- Provide an alternative way of studying the small x gluon distribution.

Cos Φ asymmetry at small x

General structure of SIDIS cross section :

$$\frac{d\sigma}{dx_B dQ^2 dy d^2 l_\perp} = \frac{4\pi\alpha_{em}^2 s}{Q^4}\left\{(1-y+\frac{y^2}{2})F_{UU} - (2-y)\sqrt{1-y}\cos\phi F_{UU}^{\cos\phi}\right\}$$

Three relevant diagrams for SIDIS amplitude,



Azimuthal average differential cross section has been calculate. **Mueller 99**

The corresponding observable in Drell-Yan process has been studied in CGC framework

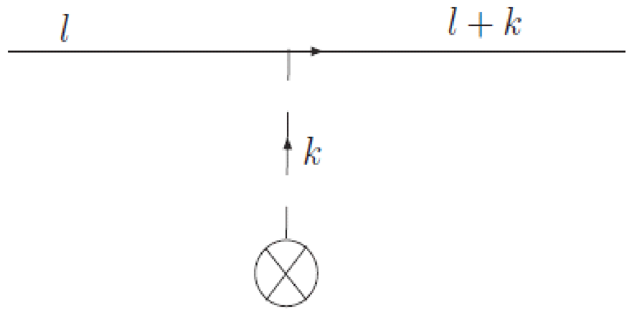
Gelis and Jalilian-Marian 06

Collaborator: Feng Yuan

Cos Φ asymmetry at small x

Propagation of a fast moving quark in an external gluon field

$$2\pi i\delta(k^-)\frac{i\not{l}}{l^2+i\epsilon}i\not{P}[U-1](k_\perp)\frac{i(\not{l}+\not{k})}{(l+k)^2+i\epsilon}$$



I. Balitsky 96
Mclerran and Venugopalan 98

$$U(k_\perp)=\int\frac{d^2x_\perp}{(2\pi)^2}e^{ik_\perp\cdot x_\perp}<\mathrm{P}e^{ig\int_{-\infty}^{+\infty}dx^-A_+(x^-,x_\perp)}>_A$$

Thereby, dipole amplitude reads:

$$\mathrm{M}^\mu=e\int\frac{d^4k_1}{(2\pi)^4}2\pi\delta(k_1^-)\bar{u}(l)\not{P}\frac{\not{l}-\not{k}_1}{(l-k_1)^2+i\epsilon}\gamma^\mu\frac{\not{l}-\not{q}-\not{k}_1}{(l-q-k_1)^2+i\epsilon}\not{P}u(l-k-q)$$
$$\times\left[U(k_{1\perp})U^\dagger(k_\perp-k_{1\perp})-1\right]$$

Hadronic tensor: $W^{\mu\nu}\sim M^\mu M^{*\nu}$

Cross section: $\sigma\sim W^{\mu\nu}L_{\mu\nu}$

Collaborator: Feng Yuan

Cos Φ asymmetry at small x

$$F_{UU} = \frac{N_c Q^2}{32\pi^6}\int dz d^2b d^2r_\perp d^2r'_\perp \left[z^2+(1-z)^2\right] e^{il_\perp\cdot(r_\perp-r'_\perp)}\nabla_{r_\perp}K_0(\sqrt{\rho}r_\perp)\nabla_{r'_\perp}K_0(\sqrt{\rho}r'_\perp)$$
$$\times\left\{1+\exp\left[-\frac{Q_s^2(r_\perp-r'_\perp)^2}{4}\right]-\exp\left[-\frac{Q_s^2r_\perp^2}{4}\right]-\exp\left[-\frac{Q_s^2{r'_\perp}^2}{4}\right]\right\}$$

Mueller 99

$$F_{UU}^{\cos\phi} = \frac{N_c Q^2}{32\pi^6}\int dz d^2b d^2r_\perp d^2r'_\perp 2z(1-z)(2z-1)$$
$$\times\frac{i}{2}Qe^{il_\perp\cdot(r_\perp-r'_\perp)}\hat{l}_\perp\cdot\left[\nabla_{r_\perp}K_0(\sqrt{\rho}r_\perp)K_0(\sqrt{\rho}r'_\perp)-K_0(\sqrt{\rho}r_\perp)\nabla_{r'_\perp}K_0(\sqrt{\rho}r'_\perp)\right]$$
$$\times\left\{1+\exp\left[-\frac{Q_s^2(r_\perp-r'_\perp)^2}{4}\right]-\exp\left[-\frac{Q_s^2r_\perp^2}{4}\right]-\exp\left[-\frac{Q_s^2{r'_\perp}^2}{4}\right]\right\}$$

Remark: It is easy to identify that $F_{UU}^{\cos\phi}$ originates from $\gamma_T^*\gamma_L^*$ interference contribution.

Collaborator: Feng Yuan

Cos Φ asymmetry at small x

In the intermediate transverse momentum region: $Q_s \ll l_T \ll Q$
we employ the power expansion in Q_s/l_T,

$$\frac{d^2 F_{UU}}{d^2 b} = \frac{N_c}{8\pi^4}\left(\frac{2}{3}\frac{Q_s^2}{l_\perp^2} + \frac{4}{5}\frac{Q_s^4}{l_\perp^4}\right)\sum_f e_f^2$$

$$\frac{d^2 F_{UU}^{\cos\phi}}{d^2 b} = \frac{N_c}{8\pi^4}\frac{|l_\perp|}{Q}\left(\frac{1}{3}\frac{Q_s^2}{l_\perp^2} + \frac{4}{15}\frac{Q_s^4}{l_\perp^4}\right)\sum_f e_f^2$$

Notice: the first terms recover the results from linear perturbative calculation.

$$\frac{d^2 < \cos\phi >}{d^2 b} = \frac{(2-y)\sqrt{1-y}}{1-y+\frac{y^2}{2}}\frac{d^2 F_{TL}/d^2 b}{d^2 F_{TT}/d^2 b} = \frac{(2-y)\sqrt{1-y}}{1-y+\frac{y^2}{2}}\frac{l_\perp}{Q}\left[\frac{1}{2} - \frac{1}{5}\frac{Q_s^2}{l_\perp^2}\right]$$

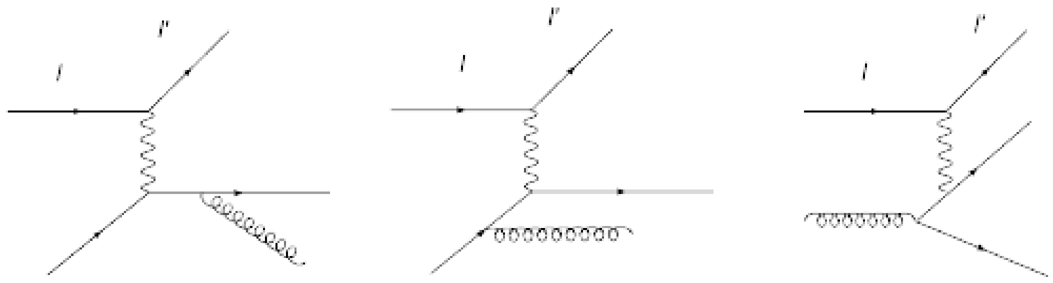
When A>>1, $$\frac{d^2 < \cos\phi >_{eA}}{d^2 b} - \frac{d^2 < \cos\phi >_{ep}}{d^2 b} = -\frac{(2-y)\sqrt{1-y}}{1-y+\frac{y^2}{2}}\frac{l_\perp}{Q}\frac{1}{5}\frac{Q_{s,A}^2}{l_\perp^2}$$

Conclusion: the asymmetry is suppressed due to the nuclear enhanced saturation scale.

Collaborator: Feng Yuan

Cos Φ asymmetry at intermediate(or large) x

When $l_T >> \Lambda_{QCD}$, the collinear approach can apply



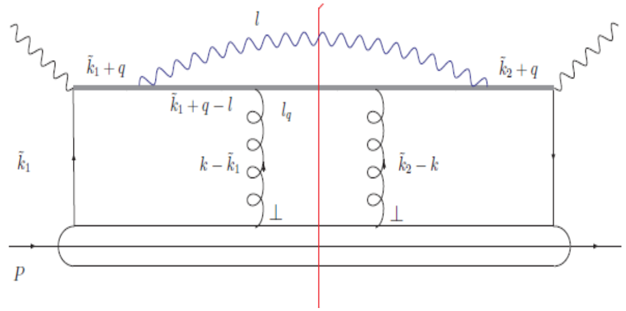
(a) (b) (c)

Nuclear dependent Cos Φ asymmetry at low l_T
Gao, Liang, Wang 10

To extract strong nuclear dependent Cos Φ asymmetry effect, one has to go beyond leading twist treatment and take into account twist-4 contribution.

Two types of twist-4 contributions in the light cone gauge:

- ➢ k_T expansion contribution
- ➢ A_T exchange contribution



Collaborator: Jianhua Gao

Cos Φ asymmetry at intermediate(or large) x

As a result, three types of correlators relevant for SIDIS,

$$\langle \bar{\psi} \partial_\perp \partial_\perp \psi \rangle \quad \langle \bar{\psi} \partial_\perp A_\perp \psi \rangle \quad \langle \bar{\psi} A_\perp A_\perp \psi \rangle$$

For $\Lambda_{QCD} << l_T << Q$, perturbative calculation valid.
In the current fragmentation region, according to general power counting:

The diagrams with one more transverse polarized gluon exchange
get suppressed by one more power of Λ_{QCD}/Q.

Collins, Soper 81
Ji, Ma and Yuan 04

Power behavior for Cos Φ asymmetry,

$$\langle \bar{\psi} \partial_\perp \partial_\perp \psi \rangle \sim \frac{l_T}{Q} \frac{\Lambda_{QCD}^2}{l_T^2}$$

$$\langle \bar{\psi} \partial_\perp A_\perp \psi \rangle \sim \frac{l_T}{Q} \frac{\Lambda_{QCD}^2}{l_T^2}$$

$$\langle \bar{\psi} A_\perp A_\perp \psi \rangle \sim \frac{l_T}{Q} \frac{\Lambda_{QCD}^2}{Q l_T}$$

$\longrightarrow$ Significantly simplify the calculation

Collaborator: Jianhua Gao

Cos Φ asymmetry at intermediate(or large) x

Moreover, in the light cone gauge with advanced boundary condition,

$$\langle\bar{\psi}\partial_\perp\partial_\perp\psi\rangle \sim \int k_T^2 f^A(x,k_T)d^2k_T$$

For example: $$F_{UU} = \frac{1}{l_T^2}\frac{\alpha_s}{2\pi^2}\sum_f x e_f^2 P\left(\frac{\xi}{z}\right) D(\xi) \int d^2k_T \left[1+\frac{k_T^2}{l_T^2}\right] f_1(x,k_T)$$

Nuclear dependent part of the asymmetry would be determined by:

$$\int k_T^2 f^p(x,k_T)d^2k_T - \int k_T^2 f^A(x,k_T)d^2k_T$$

K_T broadening effect results from the final state interaction, which is encoded in the gauge link.

Liang, Wang and ZJ. 08

Additional work is in progress…

Collaborator: Jianhua Gao

Summary

- CosΦ asymmetry is suppressed by the nuclear enhanced Q_s in the small x region.
- CosΦ asymmetry is suppressed by the k_T broadening in the large x region.