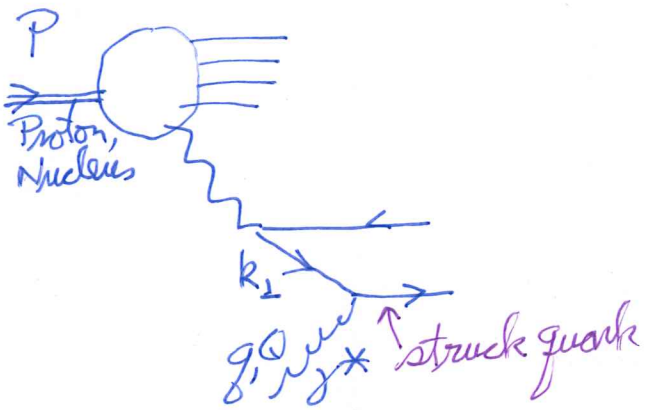
Physics Opportunities at an EIC

Topics

- Pictures of small-x DIS
- SIDIS and variants
- $\hat{q}$ for cold matter
- Spin and strangeness in the proton
- Diffractive vector meson production
- Coherent diffraction
- Saturation, nuclear shadowing and the unitarity (black disc) limit

1. Complementary pictures of small-x DIS

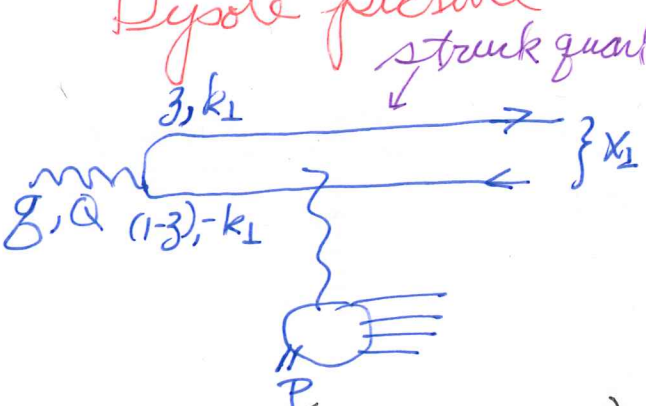
Bjorken picture



$q = (q_0, q_\perp, 0)$

q_0 small

Dipole picture



$q = \left(\sqrt{q^2 - Q^2}, 0, 0, q\right)$

$z(1-z) \simeq k_\perp^2 / Q^2$

Dipole $\sigma_T^{\gamma^*} = \int \frac{d^2 x_\perp}{4\pi} \int_0^1 \frac{dz}{z(1-z)} \left| \Psi_T(x_\perp, Q, z) \right|^2 \sigma^{q\bar{q}}(x_\perp, Y)$

$x_\perp Q \sqrt{z(1-z)} \simeq 1$

When struck quark z is measured then

$x_\perp^2 \simeq \frac{1}{Q^2 z(1-z)}$ or $k_\perp^2 \simeq Q^2 z(1-z)$

so dipole size is (roughly) fixed by leading jet or leading hadron measurement. In perturbation theory $\int_{\Lambda^2}^{Q^2} \frac{dk_\perp^2}{k_\perp^2}$ makes interpretation of scattering difficult. Measuring z should help.

2. Leading particle(s) (jet(s)) measured; inelastic

(i) Compare $\gamma^* p$ and $\gamma^* A$

$$(\Delta p_\perp^2)_{A-P} = \underbrace{\hat{q}\langle L\rangle}_{Q_s^2}$$ gives $\hat{q}$ for cold matter

(ii) In a 2 jet (or two leading particle) measurement with $z \simeq 1/2$, get $\hat{q}$ from azimuthal decorrelations in eA.

(iii) In going from a jet with $z \simeq 1/2$ to large z should see $\frac{\sigma_{\gamma^* A}}{\sigma_{\gamma^* p}}$ go from A^{1} to $A^{2/3}$. Large z gives large $x_\perp$ for dipole and shadowing (saturation) should be seen. (Energy loss contamination?)

Comments: (a) shadowing

In dipole picture without evolution quark shadowing comes from multiple scattering of dipole. Leading twist quark shadowing

In Bjorken picture this quark shadowing is a depletion of the $q\bar{q}$ partonic component in the nucleus.

(b) $\hat{q}$

$\hat{q}$ is the only medium parameter which can enter in hard or semi-hard reactions in matter. $\hat{q}$ is equivalent to the gluon distribution of the nucleus.

3. Spin, strangeness and the constituent quark model

Constituent quark model works well for many static properties of baryons

$$\mu_B \simeq \sum_{f \in B} \mu_f \quad \text{good to } 10\%$$

$$G_A \simeq (P| \int^{+}_{5\mu} |N) \quad \beta\text{-decay}$$

The quark model says

$$(P_s| \int^{\text{singlet}}_{5\mu} |P_s) = s_\mu [\Delta u + \Delta\bar{u} + \Delta s + \Delta\bar{s} + \Delta d + \Delta\bar{d}]$$

$$= s_\mu \cdot 1 \quad \leftarrow \text{quark model}$$

(a) g_1^p, g_1^n + SU(3)$_{\text{poor}}$ gives $\approx s_\mu$ small and also gives a significant negative $\Delta s + \Delta\bar{s}$

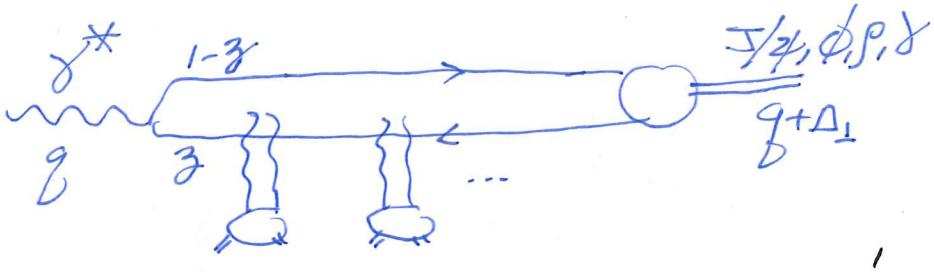
(b) However SIDIS measurements give $\Delta s + \Delta\bar{s}$ near 0.
DSSV+ gives about $1/3 \cdot s_\mu$, far from the quark model.

EIC should give definitive results

Unlikely quark spin will give the total proton spin.
A breakdown of constituent quark picture

Perhaps most interesting issue is strangeness in proton
$s + \bar{s}$ not small but SIDIS suggests $\Delta s + \Delta\bar{s}$ small
HAPPEX ... suggest strange quarks contribute little to vector form factor
Likely!? Strange quarks play little role in proton binding

4. Coherent diffractive vector meson production



$$\frac{d\sigma^{\gamma^* A\to VA}}{d\Delta_\perp^2} = \frac{1}{16\pi}\left|\int\frac{d^2x_\perp}{4\pi}\int d^2b_\perp\, e^{-ib_\perp\cdot\Delta_\perp}\int_0^1 dz\, \Psi_V^*(x_\perp,z)\,\tilde{\sigma}^{q\bar{q}}(x_\perp,b_\perp)\,\Psi_{\gamma^*}(x_\perp,z,Q)\right|^2$$

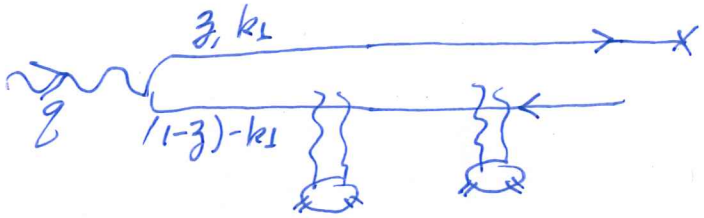
Ψ_{γ^*} is perturbative and known

$\Psi_{J/\psi}$ is reliable; reasonable phenomenological determination of Ψ_ϕ

$\tilde{\sigma}^{q\bar{q}}(x_\perp,b_\perp)$ can be determined from fourier transform of $\sqrt{\frac{d\sigma^{\gamma^* A\to VA}}{d\Delta_\perp^2}}$. Map out $b_\perp$ dependence of $\tilde{\sigma}^{q\bar{q}}(\langle x_\perp\rangle, b_\perp)$ and also its energy dependence.

For J/ψ the determination of $\sigma^{q\bar{q}}$ is a determination of the $b_\perp$-dependent gluon distribution of a nucleus.

5. Coherent diffractive DIS. Low mass final states



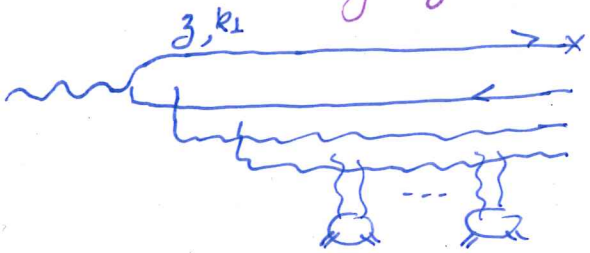
Measure forward hadron or jet

(i) Again, $\hat{q}\langle L\rangle = (\Delta p_1^2)_{A-P}$

(ii) In going from $z=1$ to $z=1/2$ should see $\frac{\sigma_{\gamma^* A}}{\sigma_{\gamma^* P}}$ go from $A^{2/3}$ to $A^{4/3}$

Not so contaminated by energy loss.

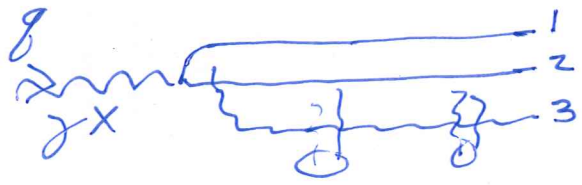
Note: For large z



diffractive (elastic) "shadow" of inelastic reactions is just the $q\bar{q}$ state (with no gluons).

(6) Challenging measurement. Gluon dipole

Coherent scattering; 3 jet events



$\underline{k}_1 + \underline{k}_2 + \underline{k}_3 \simeq 0$

$k_{1\perp}, k_{2\perp} \gg k_{3\perp}$

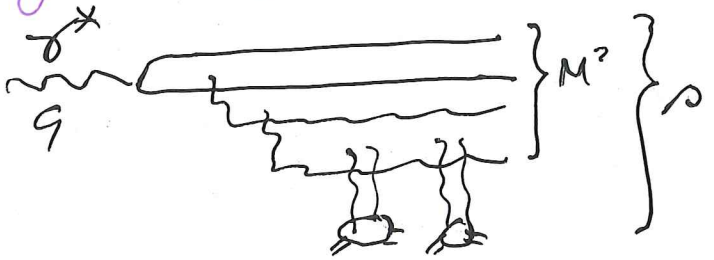
"correlation limit"

Scattering looks like gluon dipole. Stronger $p_\perp$-broadening, by $\frac{N_c}{C_F}$; faster approach to saturation.

Ideally $k_{1\perp}, k_{2\perp} \sim 2\text{-}3$ GeV

$k_{3\perp} \sim 1$ GeV

(7) Pressing limits of energy; large mass diffraction



$Y_0 = \ln s/M^2$

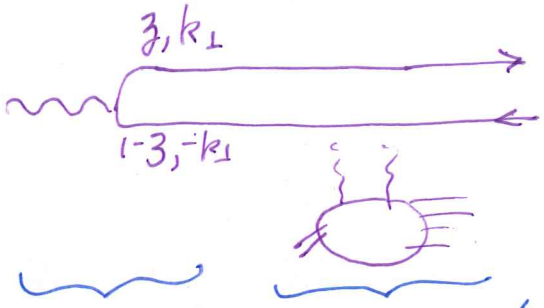
$Y = \ln s/Q^2$

When $Y, Y_0, Y-Y_0$ all moderate size, say 2-4,

$$\frac{\sigma^{diff}}{\sigma^{tot}} = \text{const}\left[\frac{Y}{(Y-Y_0)\,Y_0}\right]^{3/2}$$

$3/2$ - characteristic exponent for ancestry problem in branching random walk

8. Evolution

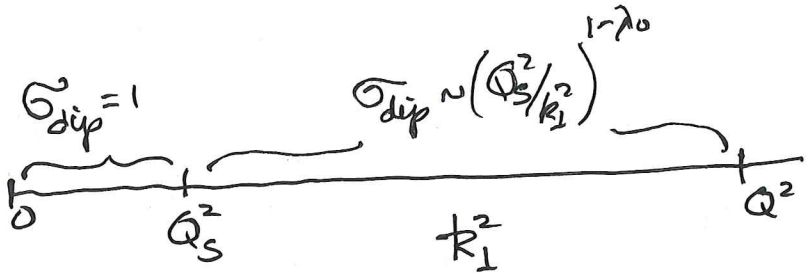


$$dP_{\not z} \propto \frac{dk_\perp^2}{Q^2} \qquad \sigma_{dip} \propto \left(\frac{Q_s^2}{k_\perp^2}\right)^{1-\lambda_0}$$

– gluon shadowing, $\lambda_0 \simeq 0.37$

$k_\perp > Q_s$ (scaling region)

$$dF_2 \sim \left(\frac{Q_s^2}{Q^2}\right)^{1-\lambda_0} \frac{dk_\perp^2}{k_\perp^2} \left(\frac{k_\perp^2}{Q^2}\right)^{\lambda_0}$$



F_2 dominated by $k_\perp^2 \sim Q^2$! In contrast to lowest order DGLAP where

$$\int_{Q_s^2}^{Q^2} \frac{dk_\perp^2}{k_\perp^2} \sim \ln Q^2/Q_s^2$$

and all $k_\perp^2$-regions are (logarithmically) comparable