EIC与EicC中胶子GTMD的研究

郑杜鑫

山东高等技术研究院

基于2304.05784

合作者：周剑，Shohini Bhattacharya

目录 / OUTLINE

目录 / OUTLINE

背景介绍

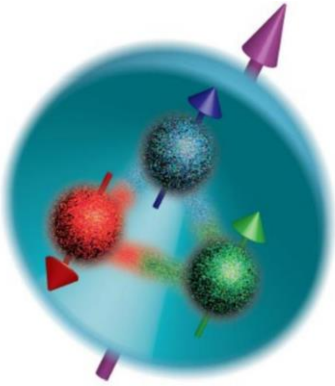
朗德因子：

$$\mu_p = g\mu_B$$

$$g = 2.79$$

1933, Stern

夸克模型：



1960s, Gell-Mann, Zweig

质子自旋危机

1988, EMC

$$\Delta\Sigma(Q^2 = 10.7GeV^2) = 0.060 \pm 0.047 \pm 0.069$$

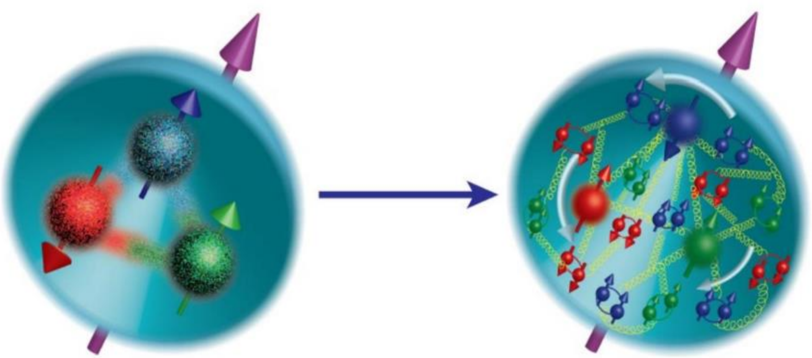
背景介绍

Jaffe-Manohar分解

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + l_q + \Delta g + l_g$$

$\Delta\Sigma \approx 0.3$ $\Delta g \approx 0.2$

Jaffe, Manohar, 1990



背景介绍

6.3. CONSTRUCTING AND INTERPRETING SUM RULES

With an eye toward making contact with the parton model we construct a sum rule from eq. (6.19) in an "infinite momentum" frame, $p^3 \equiv p_\infty \to \infty$. [We could just as well use light-cone variables, M^{+ij} etc., in the rest frame.]

$$\frac{1}{2} = \left\langle p_\infty^0, s^0 \middle| \int d^3x \left[i\psi^\dagger(\boldsymbol{x} \times \boldsymbol{\nabla})^3 \psi + \tfrac{1}{2}\psi^\dagger \sigma^3 \psi \right.\right.$$

$$\left.\left. + 2\,\mathrm{Tr}\{E^k(\boldsymbol{x} \times \boldsymbol{\nabla})^3 A^k + (\boldsymbol{A} \times \boldsymbol{E})^3\} \right] \middle| p_\infty^0, s^0 \right\rangle / 2E(2\pi)^3 \delta^3(0) . \quad (6.39)$$

Not gauge invariant!

Ji求和规则

$$\frac{1}{2} = J_q + J_g = \frac{1}{2}\Delta\Sigma + \mathrm{L}_q + J_g$$

Xiangdong Ji, 1996

$$J_{q,g} = \frac{1}{2}\int_{-1}^{1} dx\, x [H_{q,g}(x,\xi,0) + E_{q,g}(x,\xi,0)]$$

GPD函数， DVCS！

背景介绍

量子力学中

$$< A >= \int dx \int dk\, A(x,k) W(x,k)$$

Wigner函数

直观定义:

$$L_z^{q/g} = \int dx \int d^2k d^2b\, (\mathrm{b}_\perp \times k_\perp)_z W(x, b_\perp, k_\perp)$$

Wigner 函数 —傅里叶变换→ 广义横动量依赖的部分子分布函数GTMD

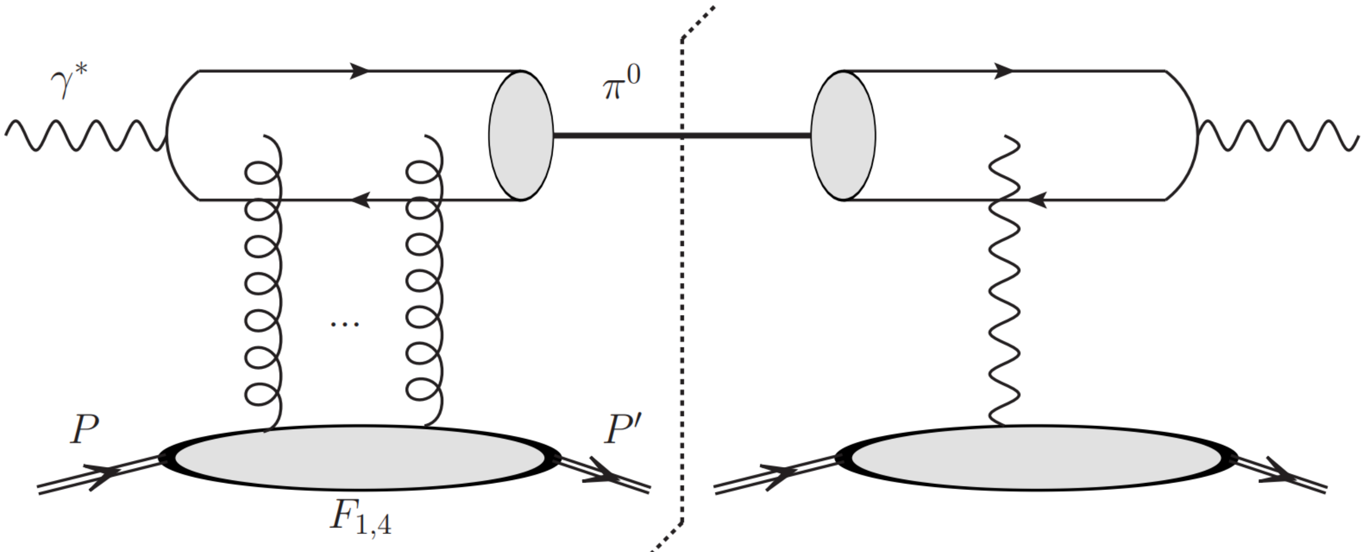
$$xL_{g,q}(x,\xi) = -\int d^2k_\perp \frac{k_\perp^2}{M^2} F_{1,4}^{g,q}(x, k_\perp, \xi, \Delta_\perp = 0)$$

$$L_{g,q} = \int_0^1 dx\, L_{g,q}(x, \xi = 0)$$

目录 / OUTLINE

遍举π^0产生过程中$F_{1,4}$的测量

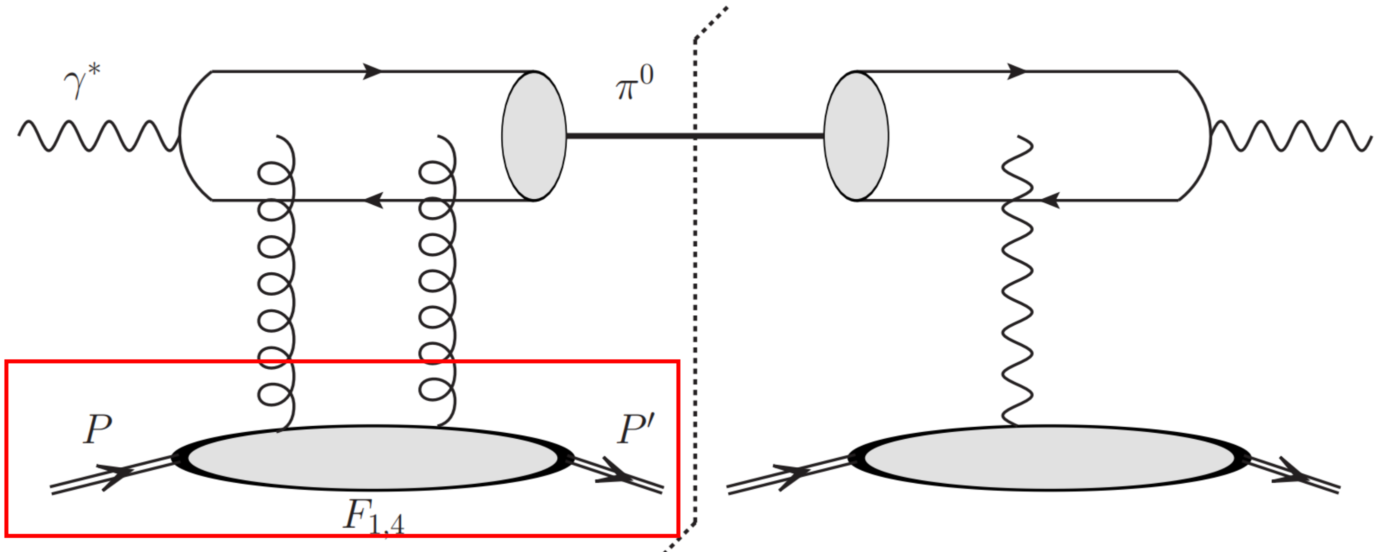
$$e(l) + p(p, \lambda) \longrightarrow \pi^0(l_\pi) + e(l') + p(p', \lambda')$$



$$Q^2 = -q^2 = -(l - l')^2$$
$$t = (p' - p)^2$$
$$x_B = \frac{Q^2}{2p \cdot q}$$

$$\xi = \frac{p^+ - p'^+}{p^+ + p'^+}$$
$$y = \frac{p \cdot q}{p \cdot l}$$
$$\Delta = p' - p$$

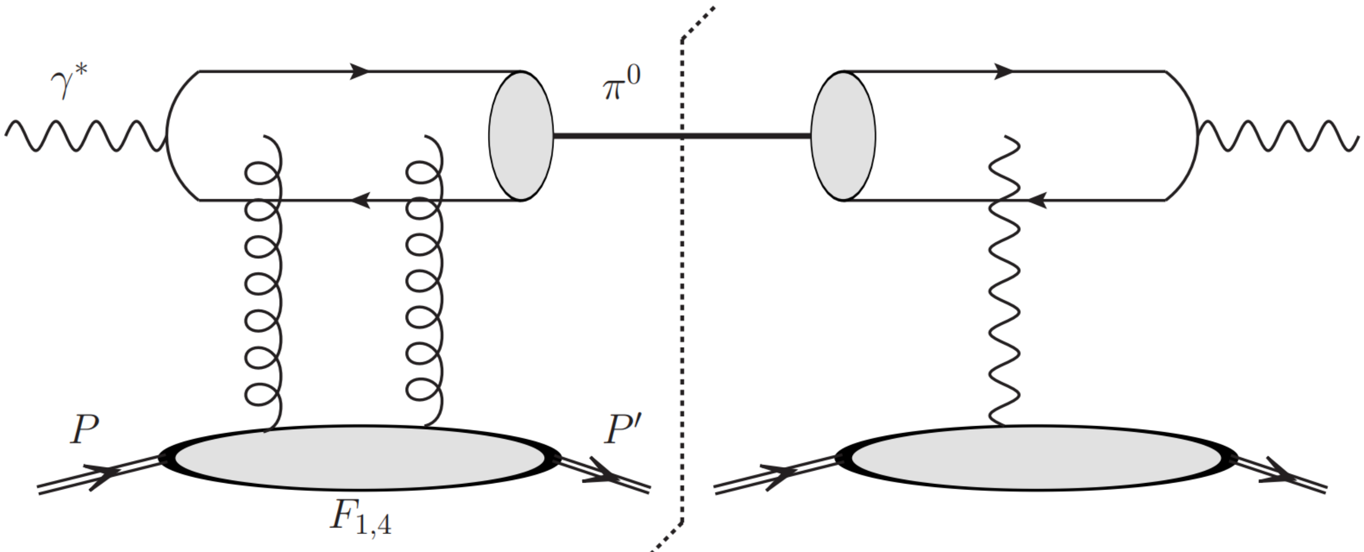
遍举π^0产生过程中$F_{1,4}$的测量



$$W^{g\,[ij]}_{\lambda,\lambda'}(P,\Delta,x,\vec{k}_\perp) = \frac{1}{P^+}\int \frac{dz^-\, d^2\vec{z}_\perp}{(2\pi)^3}\, e^{ik\cdot z}\, \langle p',\lambda'|\, F_a^{+i}(-\tfrac{z}{2})\, \mathcal{W}_{ab}(-\tfrac{z}{2},\tfrac{z}{2})\, F_b^{+j}(\tfrac{z}{2})\,|p,\lambda\rangle\Big|_{z^+=0}$$

$$\begin{aligned}
W^g_{\lambda,\lambda'} &= \delta^{ij}_\perp\, W^{g\,[ij]}_{\lambda,\lambda'} \\
&= \frac{1}{2M}\,\bar{u}(p',\lambda')\left[F^g_{1,1} + \frac{i\sigma^{i+}k^i_\perp}{P^+}F^g_{1,2} + \frac{i\,\sigma^{i+}\Delta^i_\perp}{P^+}F^g_{1,3} + \frac{i\sigma^{ij}k^i_\perp\Delta^j_\perp}{M^2}F^g_{1,4}\right]u(p,\lambda) \\
&= \frac{1}{M\sqrt{1-\xi^2}}\Bigg\{\left[M\delta_{\lambda,\lambda'} - \frac{1}{2}\Big(\lambda\Delta^1_\perp + i\Delta^2_\perp\Big)\delta_{\lambda,-\lambda'}\right]F^g_{1,1} + (1-\xi^2)\Big(\lambda k^1_\perp + ik^2_\perp\Big)\delta_{\lambda,-\lambda'}\,F^g_{1,2} \\
&\qquad + (1-\xi^2)\Big(\lambda\Delta^1_\perp + i\Delta^2_\perp\Big)\delta_{\lambda,-\lambda'}\,F^g_{1,3} + \frac{i\varepsilon^{ij}_\perp k^i_\perp\Delta^j_\perp}{M^2}\left[\lambda M\delta_{\lambda,\lambda'} - \frac{\xi}{2}\Big(\Delta^1_\perp + i\lambda\Delta^2_\perp\Big)\delta_{\lambda,-\lambda'}\right]F^g_{1,4}\Bigg\}
\end{aligned}$$

遍举π^0产生过程中$F_{1,4}$的测量



自旋依赖部分:

宇称!

$$\mathcal{M}_L \propto \int d^2k_\perp \left\{ H(x,\xi,k_\perp)\Big|_{k_\perp=0} + \frac{\partial H(x,\xi,k_\perp)}{\partial k_\perp^\mu}\Big|_{k_\perp=0} k_\perp^\mu + \ldots \right\} k_\perp \times \Delta_\perp \lambda \delta_{\lambda,\lambda'} F_{1,4}^g$$

$$\mathcal{M}_L \propto \int d^2k_\perp (\epsilon_\perp^{\gamma^*} \times k_\perp)(k_\perp \times \Delta_\perp)\lambda\delta_{\lambda,\lambda'} F_{1,4}^g \propto (\epsilon_\perp^{\gamma^*} \cdot \Delta_\perp)\lambda\delta_{\lambda,\lambda'} \int d^2k_\perp \frac{1}{2} k_\perp^2 F_{1,4}^g$$

$$\mathcal{M}_R^* \propto \epsilon_\perp^{\gamma^*} \times \Delta_\perp$$

遍举π^0产生过程中$F_{1,4}$的测量

自旋依赖部分截面

$$\frac{d\Delta\sigma}{dtdQ^2dx_Bd\phi} = -\sin(2\phi)\frac{\alpha_{em}^3\alpha_s f_\pi^2(1-y)\xi x_B\mathcal{F}(t)}{3Q^8N_c} \times\left[\int_0^1 dz\frac{\phi_\pi(z)}{z(1-z)}\right]^2 \mathrm{Im}\left[\int_{-1}^1 dx\frac{F_{1,4}^{(1)}(x,\xi,\Delta_\perp)/M^2}{(x+\xi-i\epsilon)^2(x-\xi+i\epsilon)^2}\right]$$

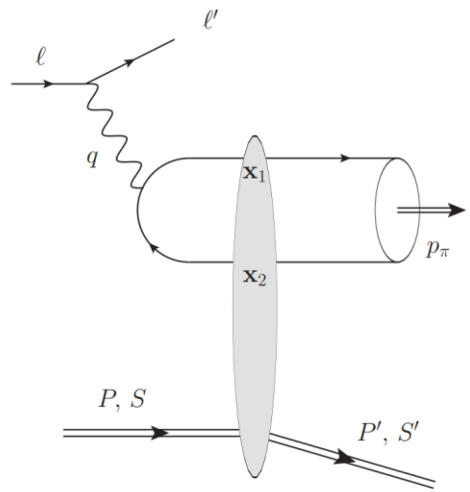
C宇称:

$$\mathrm{Im}\int_{-1}^1 dx\frac{\mathrm{Re}F_{1,4}^{(1)}(x,\xi,\Delta_\perp)}{(x+\xi-i\epsilon)^2(x-\xi+i\epsilon)^2}=0$$

$$\mathrm{Im}\int_0^1 dx\frac{\frac{\mathrm{Im}F_{1,4}^{(1)}(x,\xi,\Delta_\perp)}{M^2}}{(x+\xi)^2(x-\xi+i\epsilon)^2} < \mathrm{Im}\int_0^1 dx\frac{\frac{\mathrm{Re}F_{1,4}^{(1)}(x,\xi,\Delta_\perp)}{M^2}}{(x+\xi)^2(x-\xi+i\epsilon)^2} \approx -\frac{\pi}{2\xi}\frac{\partial}{\partial x}L(x,\xi)|_{x=\xi}$$

遍举π^0产生过程中$F_{1,4}$的测量

自旋无关部分



$$\frac{d\sigma^{odderon}}{dtdQ^2dx_B} \approx \frac{\pi^5\alpha_{em}^2\alpha_s^2 f_\pi^2}{8x_B N_c^2 M^2 Q^6}\left[1-y+\frac{y^2}{2}\right]\left[\int_0^1 dz \frac{\phi_\pi(z)}{z(1-z)}\int d^2k_\perp \frac{k_\perp^2 x f_{1T}^{\perp g}(x,k_\perp^2)}{k_\perp^2+z(1-z)Q^2}\right]^2$$

Boussarie, Hatta, Szymanowski, Wallon, 2019

Primakoff过程

$$\frac{d\sigma^{Pri}}{dtdQ^2dx_B} \approx \frac{\alpha_{em}^4(2\pi)[1+(1-y)^2]f_\pi^2}{x_B Q^6 \Delta_\perp^2}\frac{1-\xi}{1+\xi}\mathcal{F}^2(t)\left[\int_0^1 \frac{dz}{6z(1-z)}\phi_\pi(z)\right]^2$$

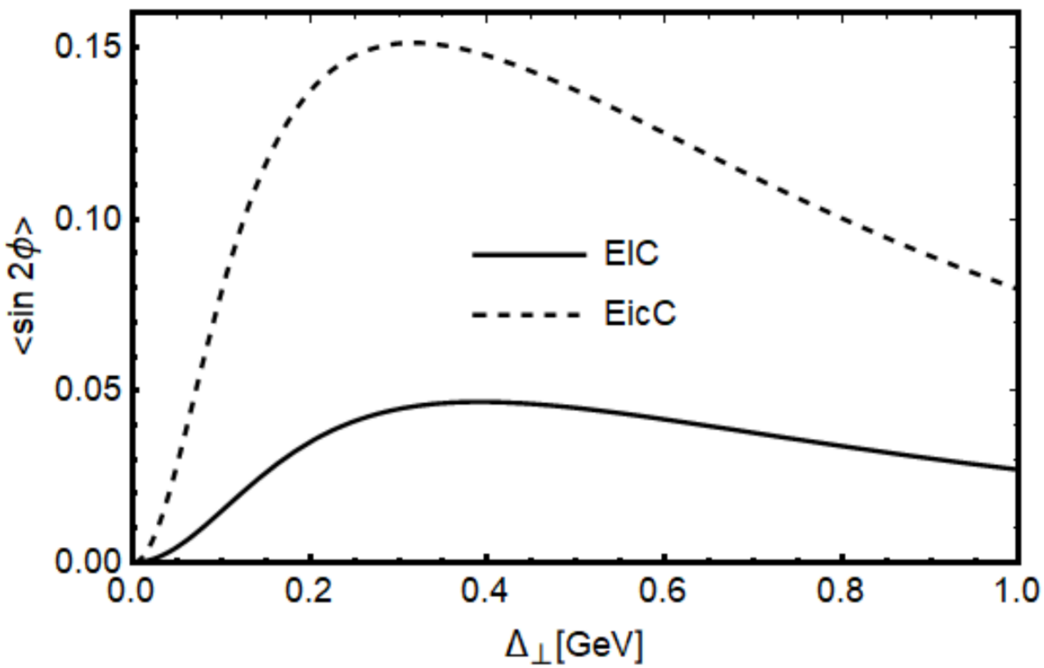
目录 / OUTLINE

- 背景介绍
- 遍举π^0产生过程中$F_{1,4}$的测量
- 数值结果
- 总结

数值结果

方位角不对称:

$$\langle \sin(2\phi) \rangle = \frac{\int \frac{d\Delta\sigma}{d\mathcal{P}.\mathcal{S}.} \sin(2\phi)\ d\mathcal{P}.\mathcal{S}.}{\int \left[\frac{d\sigma^{Pri}}{d\mathcal{P}.\mathcal{S}.} + \frac{d\sigma^{odderon}}{d\mathcal{P}.\mathcal{S}.} \right] d\mathcal{P}.\mathcal{S}.}$$



EIC: $y = 0.02,\ Q^2 = 10\,\mathrm{GeV}^2,\ \sqrt{S_{ep}} = 100\ \mathrm{GeV}$

EicC: $y = 0.5,\ Q^2 = 3\ \mathrm{GeV}^2,\ \sqrt{S_{ep}} = 16\ \mathrm{GeV}$

目录 / OUTLINE

总结

1. 利用遍举π^0产生电子-纵向极化质子对撞过程的末态方位角不对称性，我们可以获得对GTMD函数$F_{1,4}$虚部的约束；
2. 末态不对称性来自于强相互作用与电磁相互作用的干涉项，实验上会产生$\sin 2\phi$的末态方位角分布；
3. 我们给出了在未来EIC和EicC实验中该方位角不对称大小的一个数值估算。

谢谢！