Two photon physics at e^+e^- colliders

周剑

山东大学(青岛)
SHANDONG UNIVERSITY, QINGDAO

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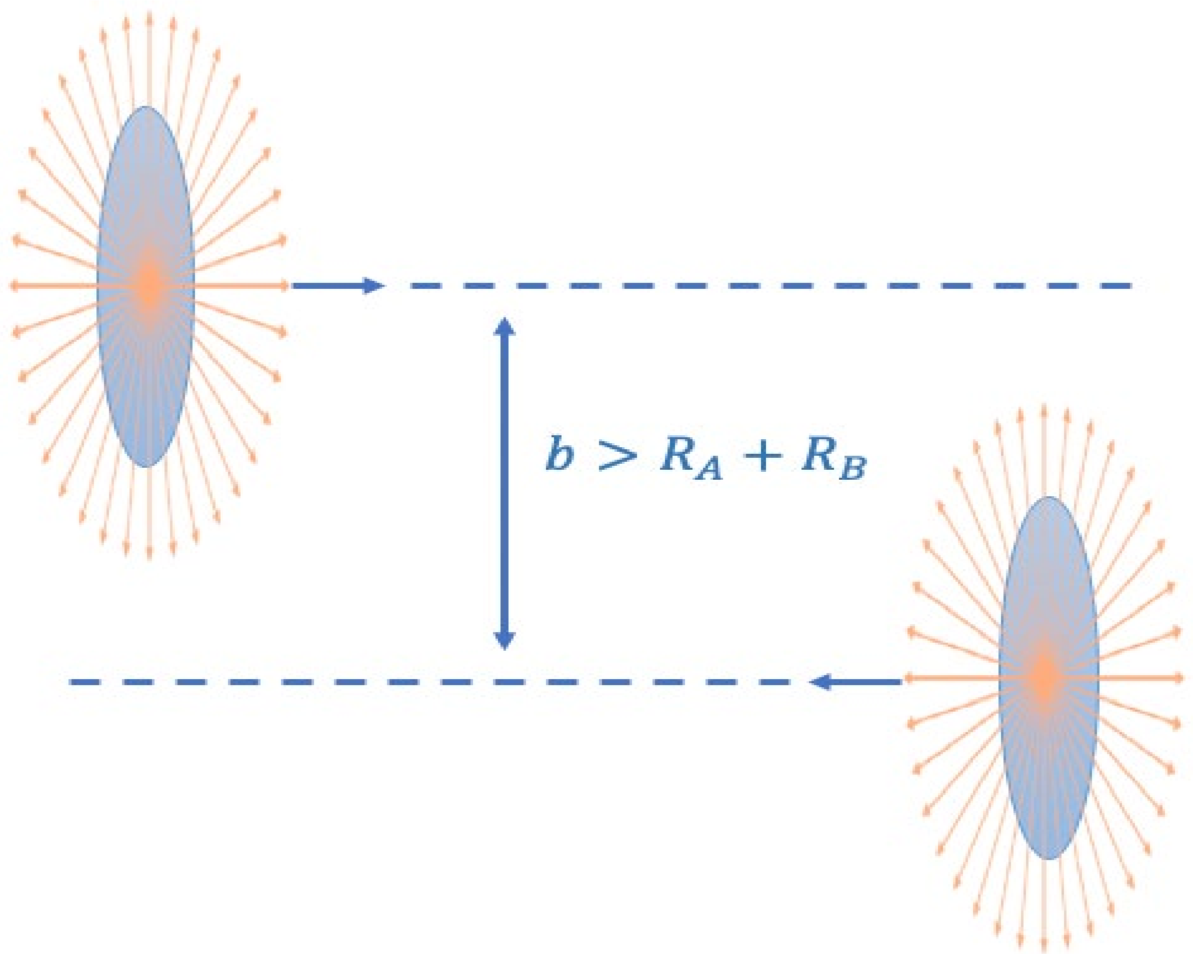
Outline:

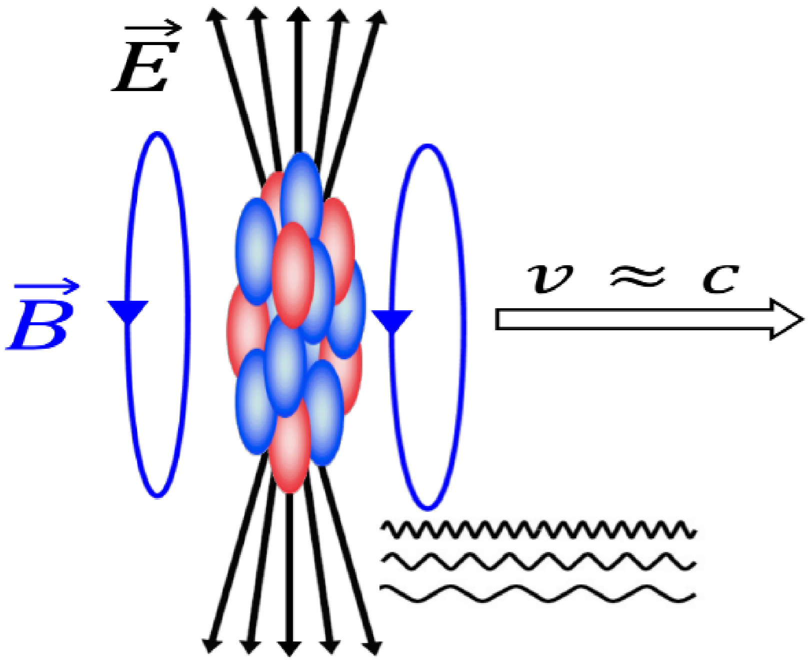
- Introduction
- Linear polarization of quasi-real photons
- Pion pair production
- Conclusions

重离子超边缘碰撞

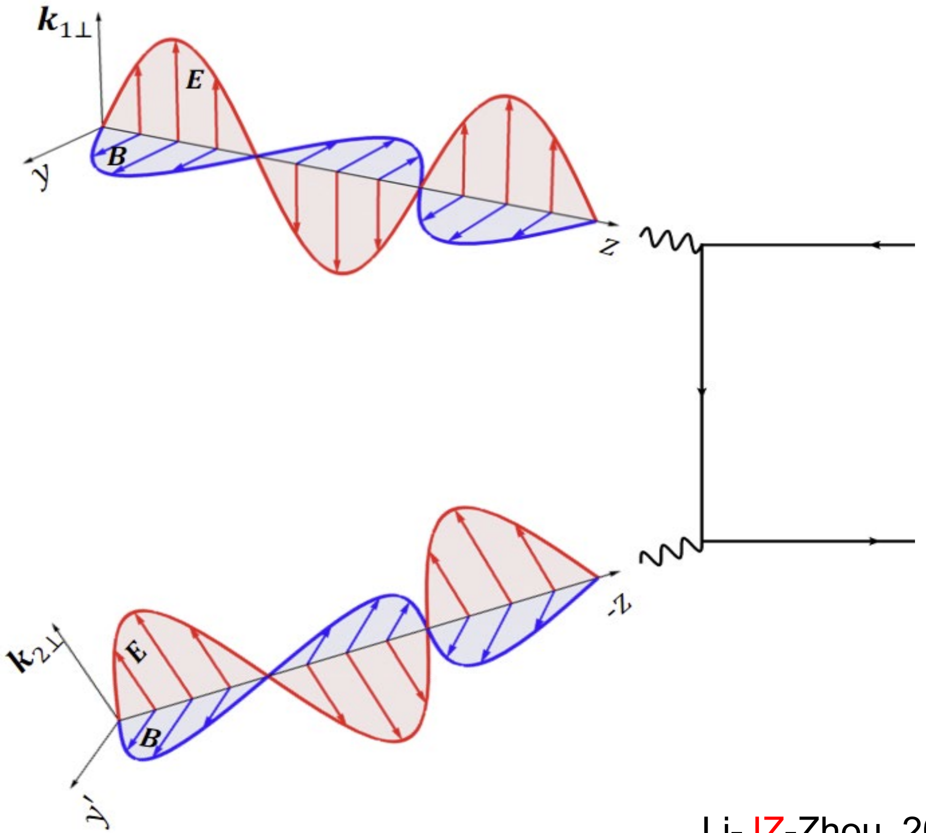


一次金核-金核对撞相当于4000万次质子-质子对撞！

The boosted Coulomb potential



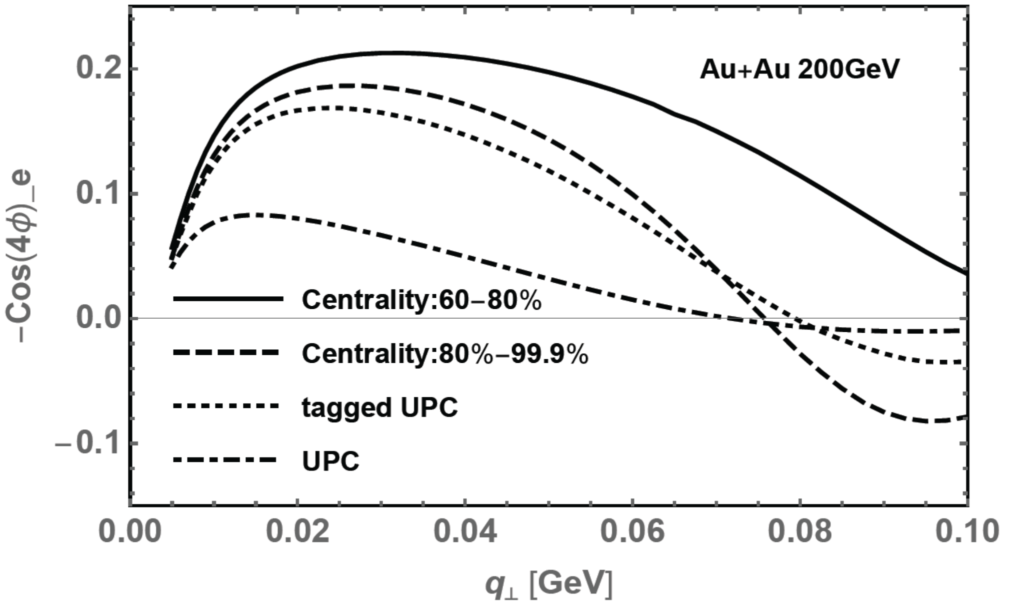
E. Fermi, 1924
Weizascker--Williams 1934



Li-JZ-Zhou, 2019

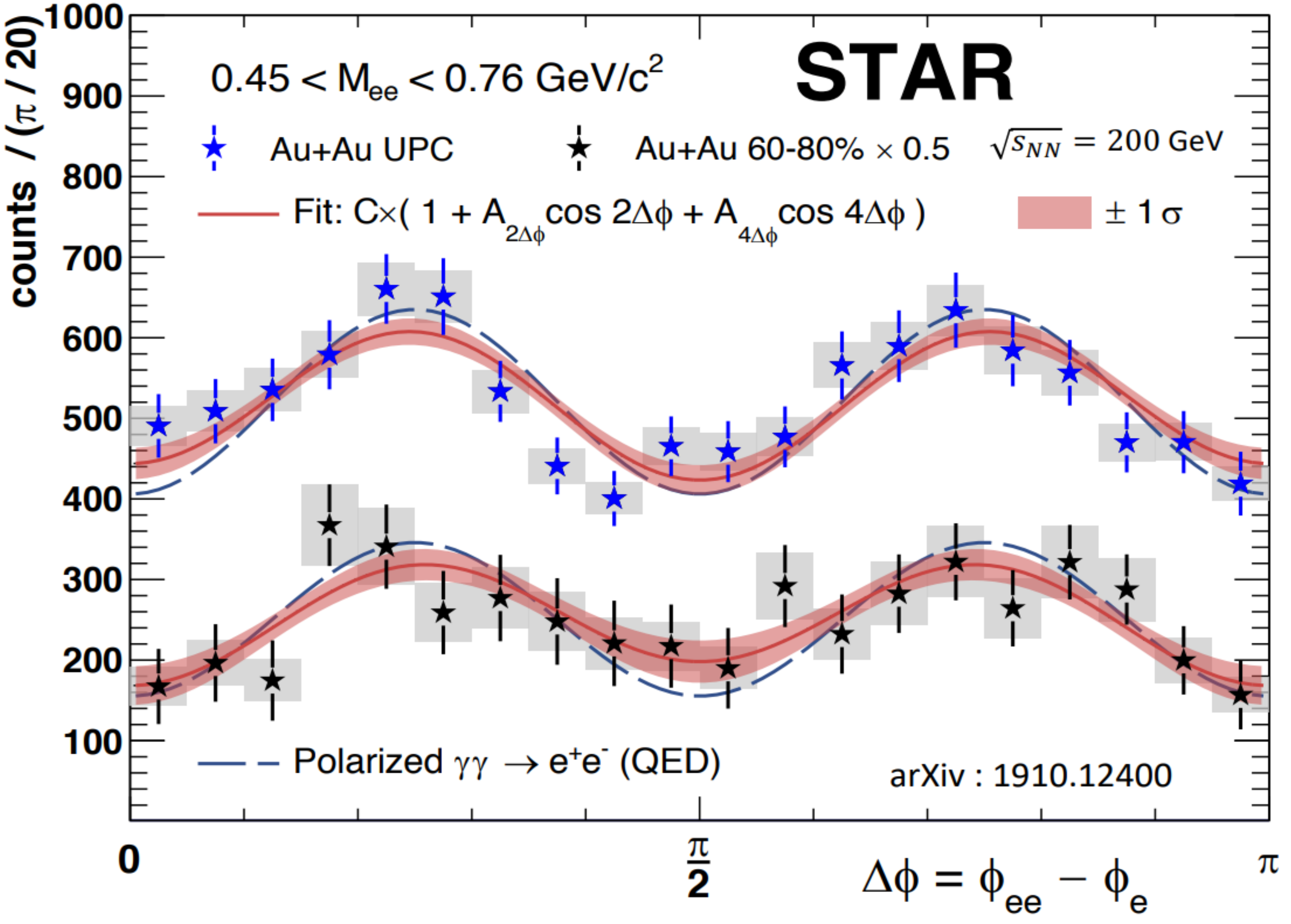
Linear polarization of photons: induce cos4ϕ modulation in di-lepton production.

Verified by STAR experiment



Li-JZ-Zhou, 2020

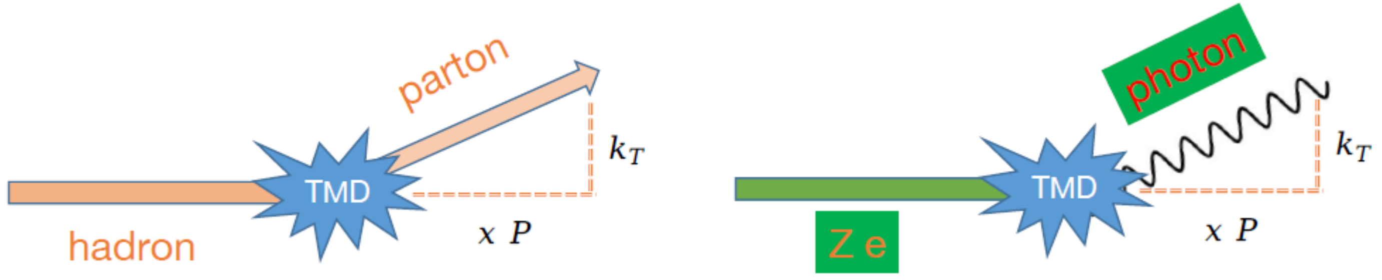
STAR collaboration, PRL, 2021



	Measured	QED calculation
Tagged UPC	16.8%±2.5%	16.5%
60%-80%	27%±6%	34.5%

Linearly polarized photon

relativistically moving charged particles will introduce electromagnetic field
the photons are linearly polarized due to their transverse momentum



gluon/photon TMD (transverse-momentum-dependent) factorization:

$$\int \frac{2dy^- d^2y_\perp}{xP^+(2\pi)^3} e^{ik\cdot y} \langle P|F_+^\mu(0)F_+^\nu(y)|P\rangle\Big|_{y^+=0} = \delta_\perp^{\mu\nu} f_1(x,k_\perp^2) + \left(\frac{2k_\perp^\mu k_\perp^\nu}{k_\perp^2} - \delta_\perp^{\mu\nu}\right) h_1^\perp(x,k_\perp^2),$$

Mulders, Rodrigues, PRD63(2001)

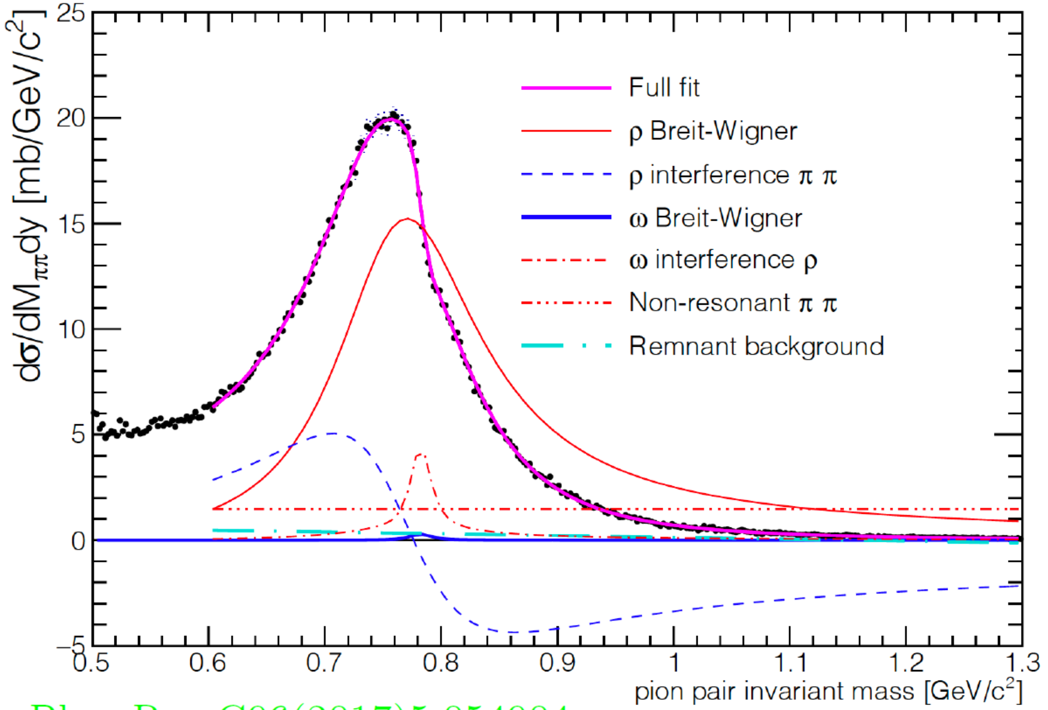
$f_1(x,k_\perp^2) = h_1^\perp(x,k_\perp^2)$, small-x gluons/photons are highly linearly polarized.

A. Metz and J. Zhou, 2011, C. Li, J. Zhou and YZ, 2019

Collinear factorization: $\sigma \sim \text{PDFs}(x) \otimes$ hard part
TMD factorization: $\sigma \sim \text{TMDs}(x,k_T) \otimes$ hard part

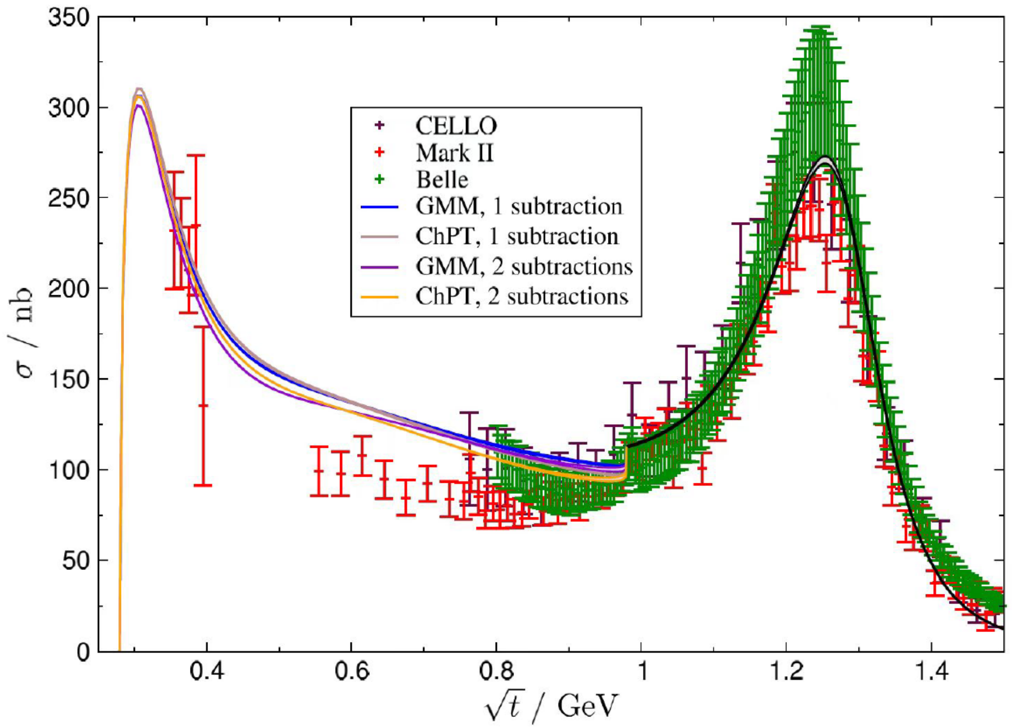
direct pion pair production, e^+e^- collider vs. UPC

UPC : only low invariant mass is possible



STAR, Phys.Rev.C96(2017)5,054904

e^+e^- collider, not effected by ρ resonance

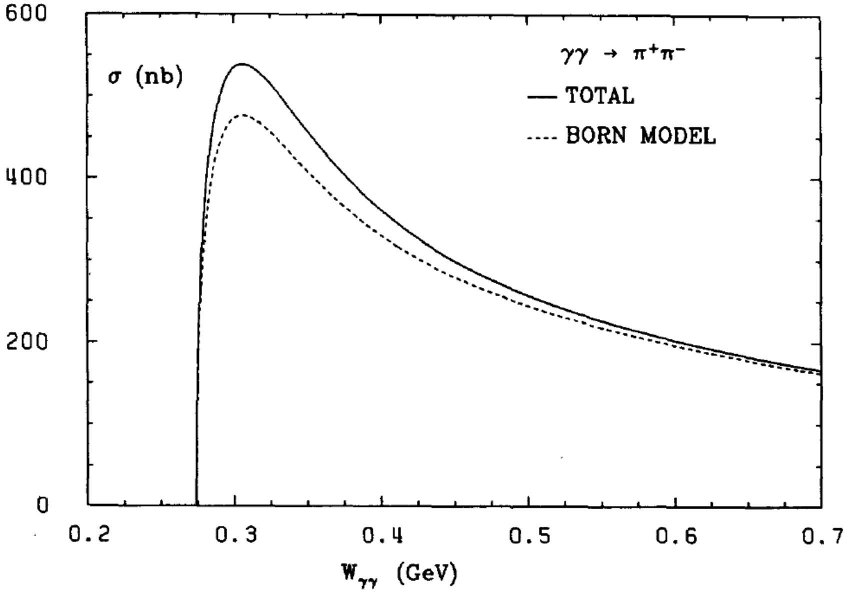


Conclusion: to study the polarization effect of poin pair production from $\gamma\gamma$ fusion,

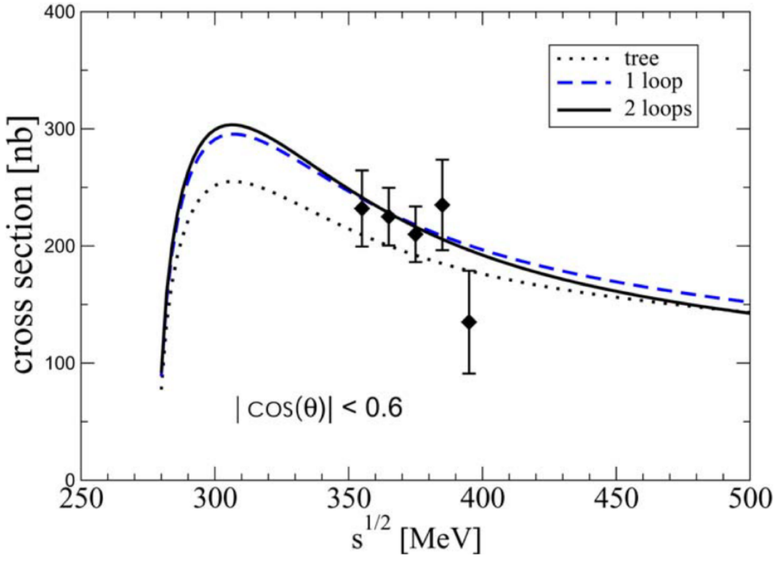
e^+e^- collider is better

Some ChPT calculations for $\gamma\gamma \to \pi\pi$

e.g.,



J.BIJNENS and F. CORNET, NPB296(1988)557-568



J. Gasser et al., NPB745(2006)84–108

$$A_{\gamma\gamma\to\pi^+\pi^-} = 2ie^2\left\{C\varepsilon_1\cdot\varepsilon_2 - \frac{p_1\cdot\varepsilon_1 p_2\cdot\varepsilon_2}{p_1\cdot k_1} - \frac{p_1\cdot\varepsilon_2 p_2\cdot\varepsilon_1}{p_1\cdot k_2}\right\}$$

$$C = 1 + \frac{4Q^2}{f_\pi^2}(L_9^r + L_{10}^r) - \frac{1}{16\pi^2 f_\pi^2}\left(\frac{3}{2}Q^2 + \frac{1}{2}m_\pi^2\ln^2 g_\pi(Q^2) + m_K^2\ln^2 g_K(Q^2)\right)$$

Dipoin production in e$^+$e$^-$ collider, data-driven method

Ling-Yun Dai and M.R. Pennington, "Comprehensive Amplitude Analysis of $\gamma\gamma \to \pi^+\pi^-, \pi^0\pi^0$ and $\overline{K}K$ below 1.5 GeV", PRD90, 036004 (2014)

$$\frac{d\sigma}{d\Omega} = \frac{\rho(s)}{128\pi^2 s}[|M_{+-}|^2 + |M_{++}|^2],$$

partial wave expansions of the amplitudes:

$$M_{++}(s,\theta,\phi) = e^2\sqrt{16\pi}\sum_{J\geq 0} F_{J0}(s) Y_{J0}(\theta,\phi),$$

$$M_{+-}(s,\theta,\phi) = e^2\sqrt{16\pi}\sum_{J\geq 2} F_{J2}(s) Y_{J2}(\theta,\phi).$$

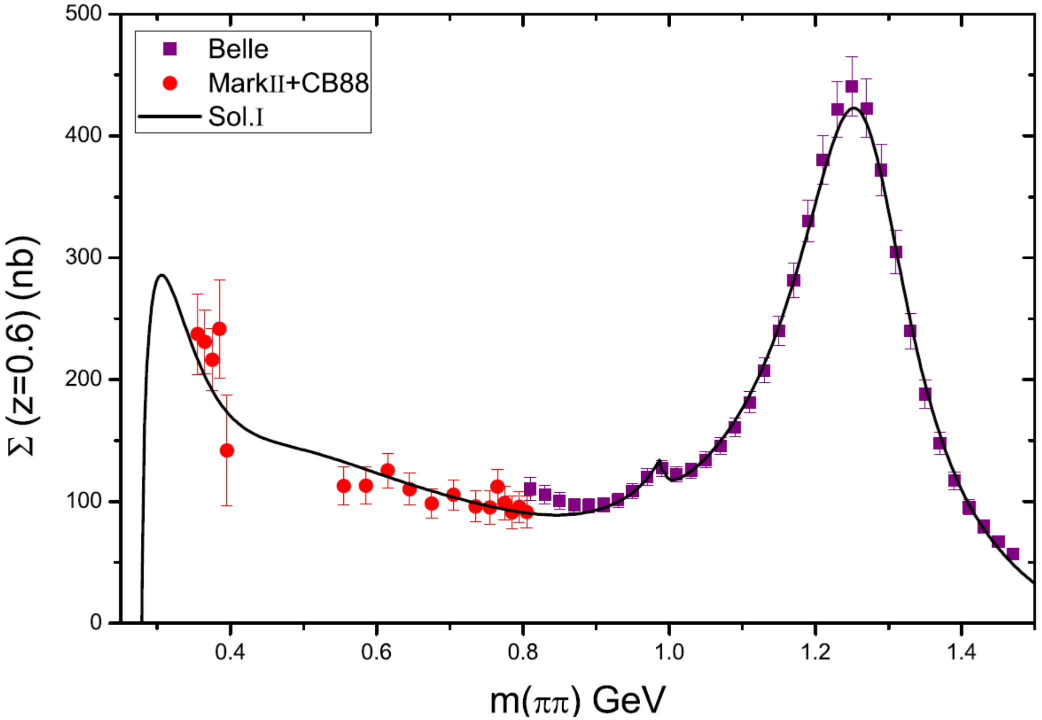
isospin decomposition of the amplitudes:

$$\mathcal{F}_\pi^{+-}(s) = -\sqrt{\frac{2}{3}}\mathcal{F}_\pi^{I=0}(s) - \sqrt{\frac{1}{3}}\mathcal{F}_\pi^{I=2}(s),$$

$$\mathcal{F}_\pi^{00}(s) = -\sqrt{\frac{1}{3}}\mathcal{F}_\pi^{I=0}(s) + \sqrt{\frac{2}{3}}\mathcal{F}_\pi^{I=2}(s),$$

$$\mathcal{F}_K^{+-}(s) = -\sqrt{\frac{1}{2}}\mathcal{F}_K^{I=0}(s) - \sqrt{\frac{1}{2}}\mathcal{F}_K^{I=1}(s),$$

$$\mathcal{F}_K^{00}(s) = -\sqrt{\frac{1}{2}}\mathcal{F}_K^{I=0}(s) + \sqrt{\frac{1}{2}}\mathcal{F}_K^{I=1}(s).$$



Dipoin production in e^+e^- collider, data-driven method

cross section in helicity amplitude form with linealy polarized photon:

$$\frac{d\sigma}{d^2p_{1\perp}d^2p_{2\perp}dy_1dy_2} = \frac{1}{16\pi^2Q^4}\int d^2k_{1\perp}d^2k_{2\perp}$$
$$\times\ \delta^2(q_\perp - k_{1\perp} - k_{2\perp})x_1x_2$$
$$\times\ \left\{\frac{1}{2}\left(|M_{+-}|^2 + |M_{++}|^2\right) f(x_1,k_{1\perp}^2)f(x_2,k_{2\perp}^2)\right.$$
$$-\ \cos(2\phi_1)\mathrm{Re}[M_{++}M_{+-}^*]\, f(x_2,k_{2\perp}^2)h_1^\perp(x_1,k_{1\perp}^2)$$
$$-\ \cos(2\phi_2)\mathrm{Re}[M_{++}M_{+-}^*]\, f(x_1,k_{1\perp}^2)h_1^\perp(x_2,k_{2\perp}^2)$$
$$+\ \frac{1}{2}\left[\cos 2(\phi_1-\phi_2)|M_{++}|^2 + \cos 2(\phi_1+\phi_2)|M_{+-}|^2\right]$$
$$\left.\times\ h_1^\perp(x_1,k_{1\perp}^2)h_1^\perp(x_2,k_{2\perp}^2)\right\}$$

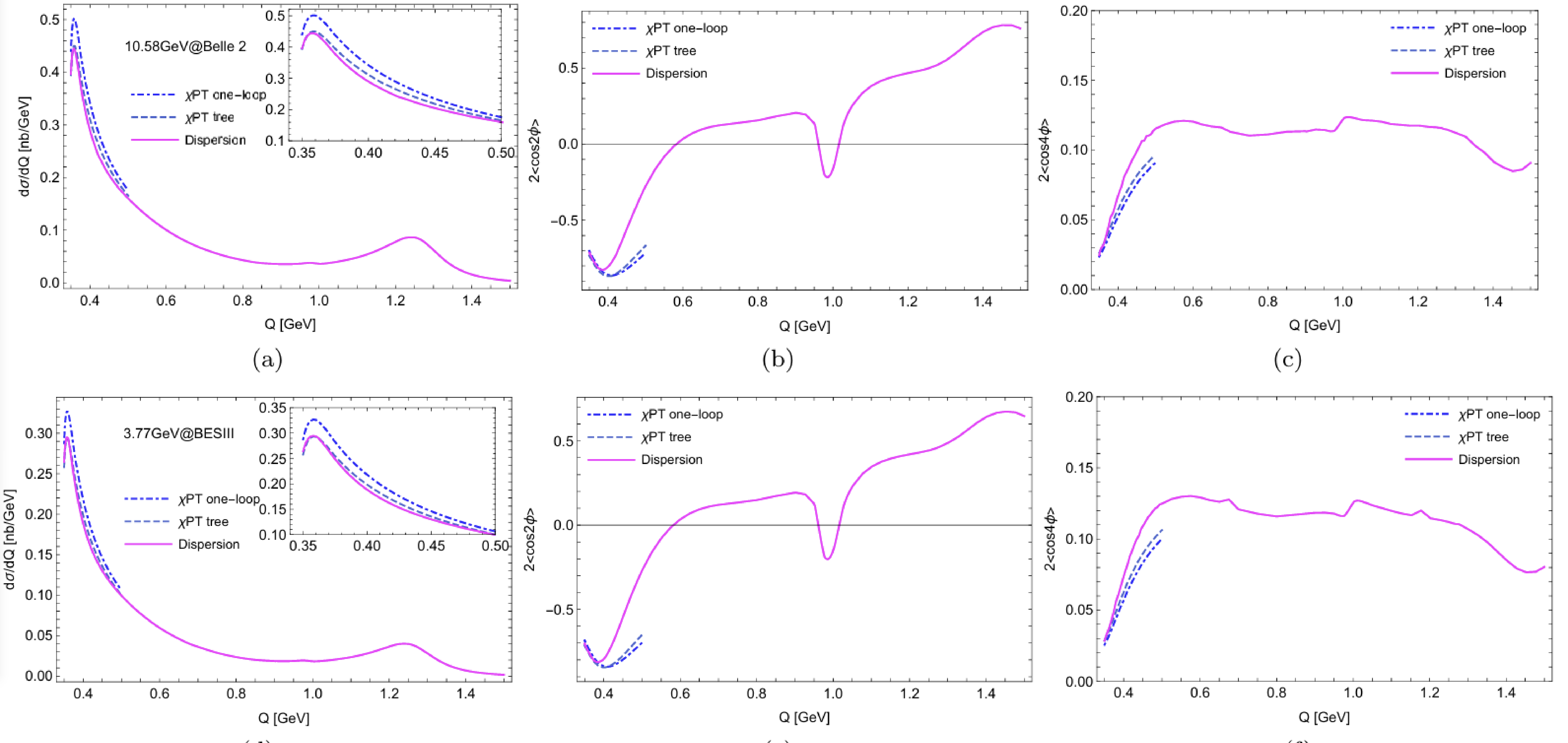
→ Reduce to collinear factorization after integrating over $k_{1,2\perp}$, → $\frac{1}{2}(|M_{++}|^2 + |M_{+-}|^2)$ff

→ Contribute to $\cos(2\phi)$ azim. Assym., induced by linearly polarized photon, Involve the relative phase between M_{++} and M_{+-}

→ Contribute to $\cos(4\phi)$ azim. Assym.

数值结果

非极化截面　Cos2ϕ 方位角不对称　Cos4ϕ 方位角不对称



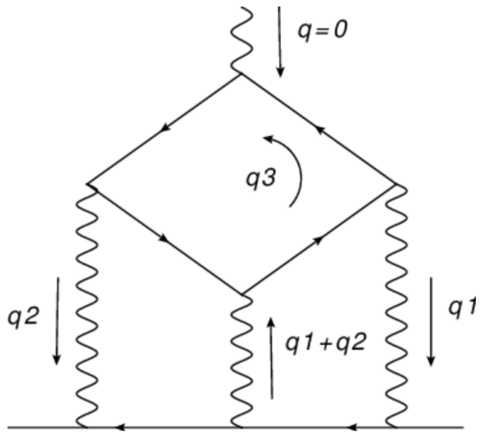
(a)　(b)　(c)

Phenomenological impact

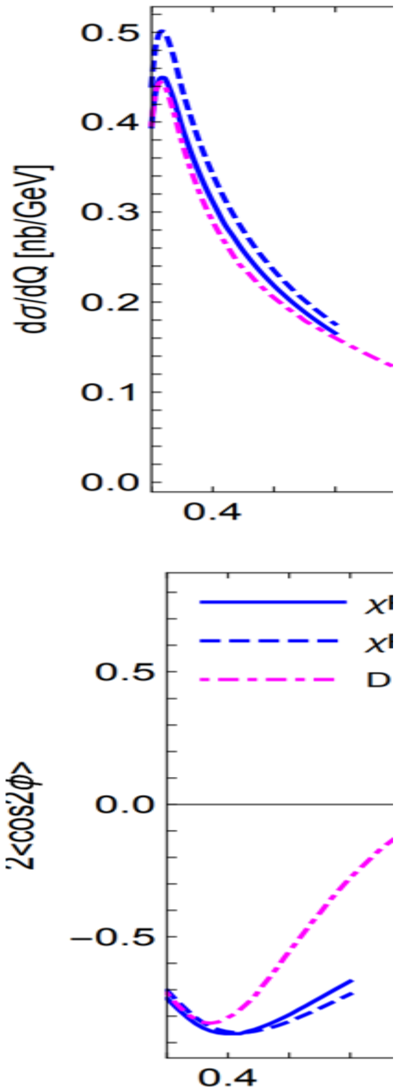
➢直接抽取相因子!

$$\cos(2\phi_1)\mathrm{Re}[M_{++}M^*_{+-}]$$

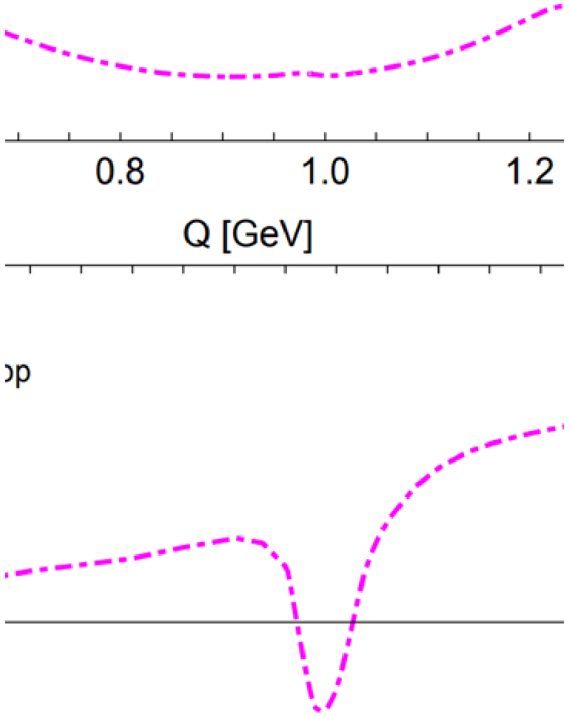
提供重要的色散关系输入:
hadronic LbL contribution to g_2



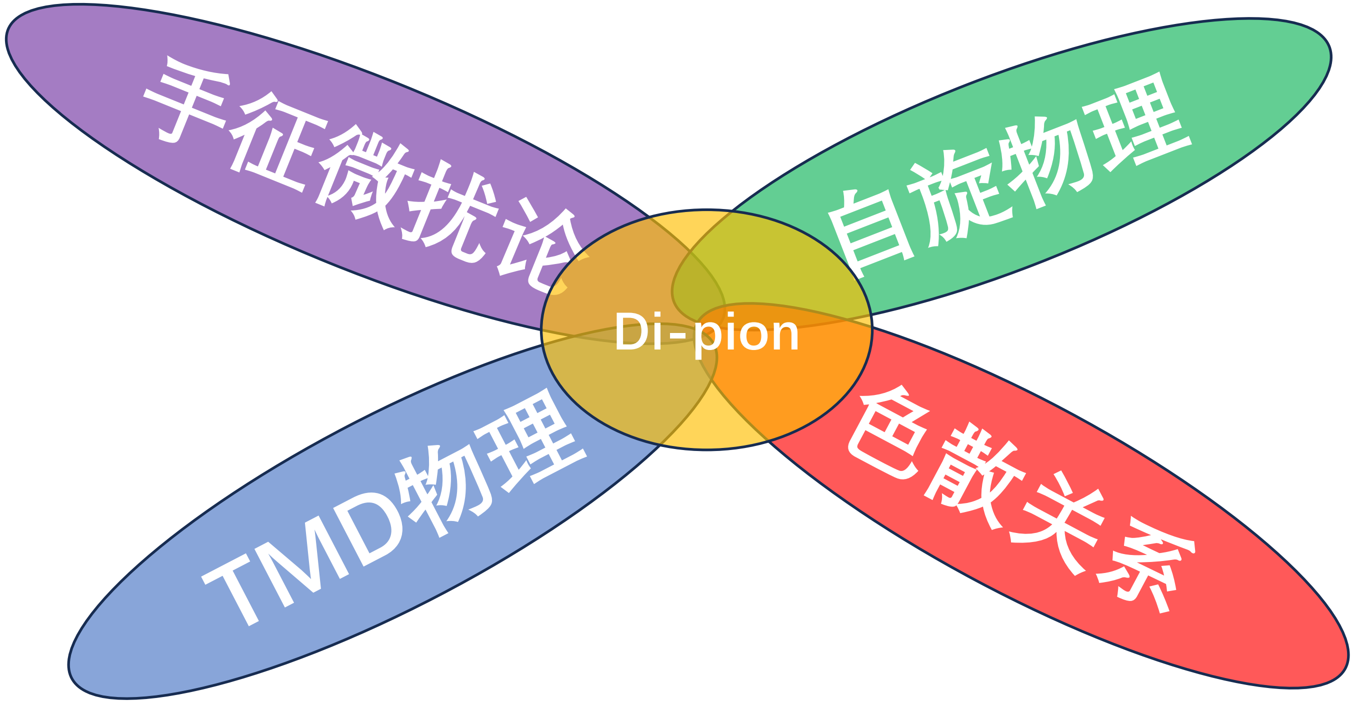
➢ 测试手征微扰论适用范围



➢ 研究共振态结构



多方向交叉研究

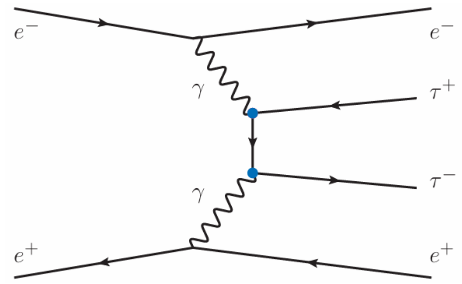


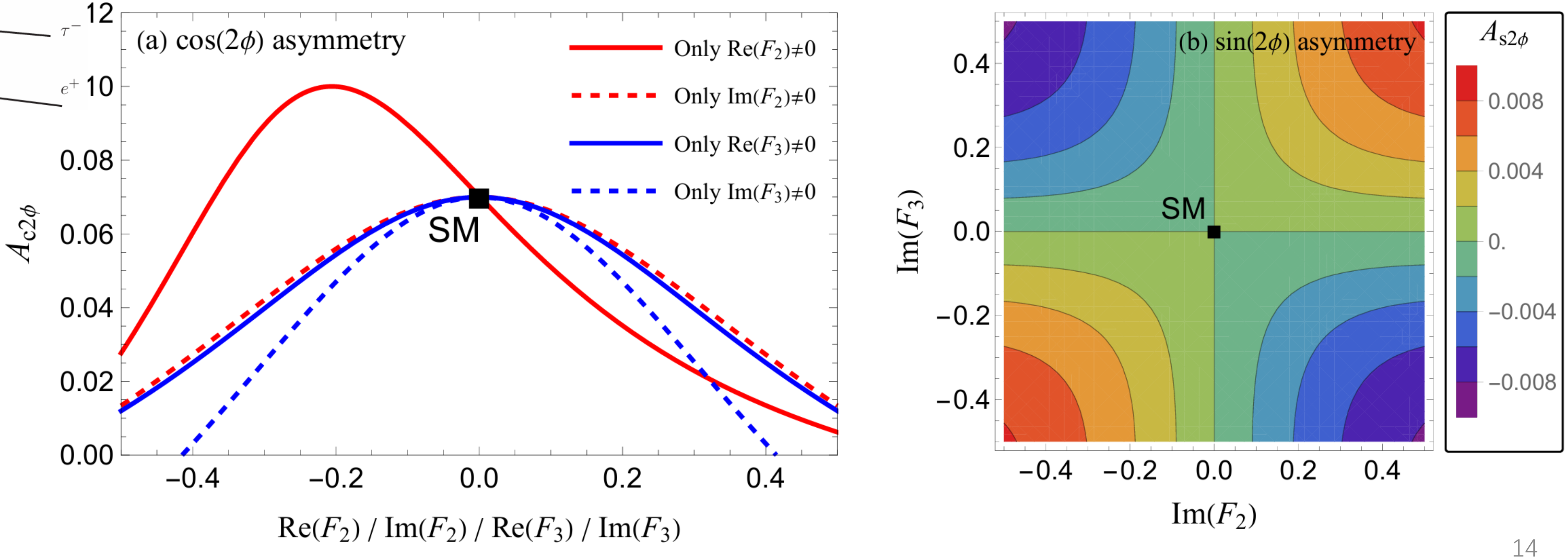
◆连续被7位PRL referees 拒审稿

e⁺e⁻对撞机上双光子过程另外一个有趣应用

Linearly Polarized Photon Fusion as a Precision Probe of the Tau Lepton Dipole Moments at Lepton Colliders

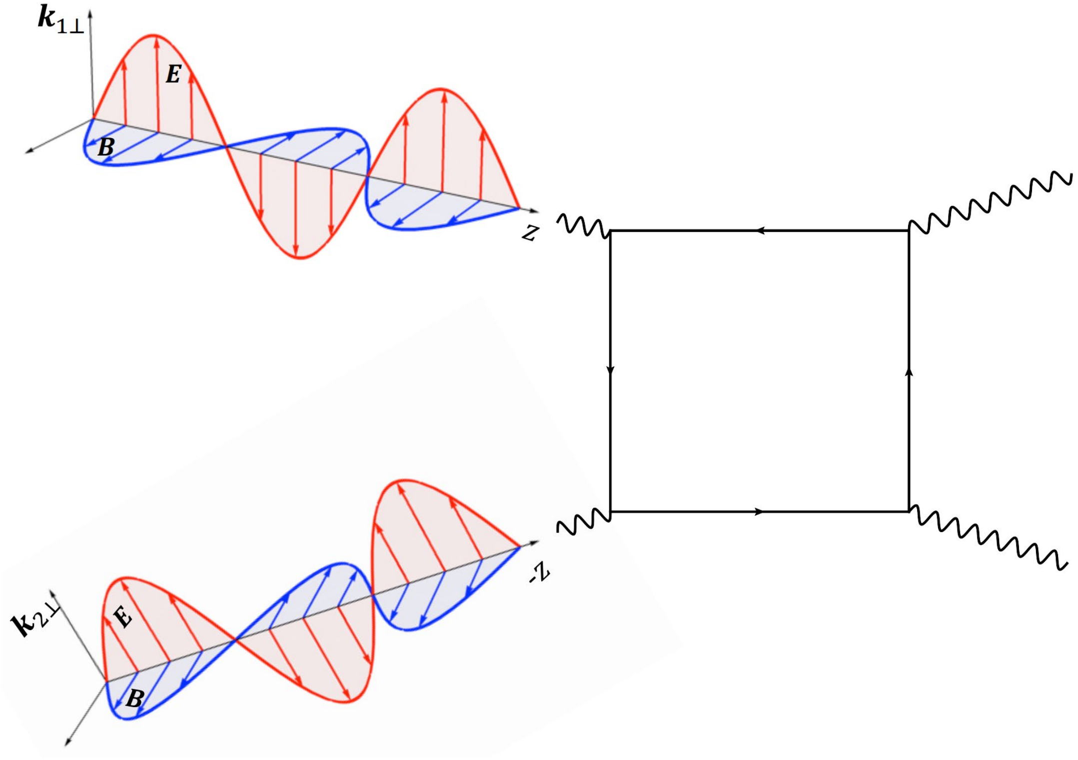
Ding Yu Shao,[1,2,3,*] Hao Xiang,[1] Fang Xu,[1,†] Bin Yan,[4,5,‡] and Cheng Zhang[6,§]





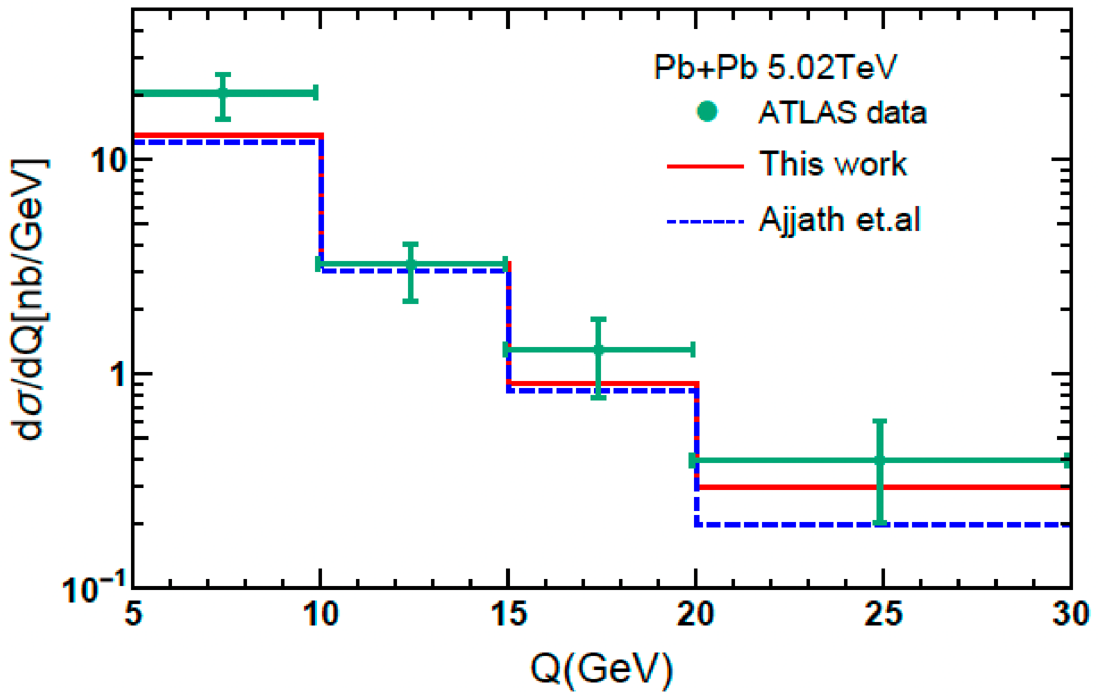
LHC上超边缘碰撞的光光散射中的方位角不对称性

贾宇，林硕，周剑，周雅瑾，arXiv:2410.13781

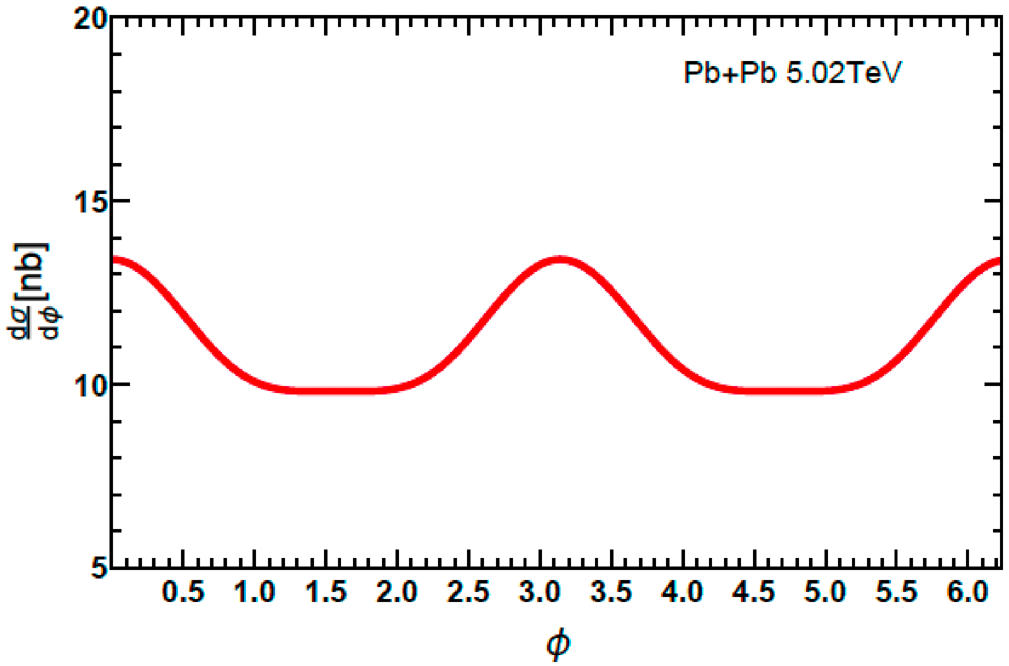


- 作为真空极化和量子非线性的直接表现，弹性光光散射(LbL)被认为是标准模型最迷人的基本过程之一；
- 强光光散射(HLbL)是缪子反常磁矩理论不确定性的主要来源；
- LHC上最近测量了超边缘碰撞上光光散射过程，但是与理论计算有一定的偏差。考虑光子的线性极化，我们重新研究了这个过程。
- 首次在光光散射中研究方位角不对称性。

Numerical results



Unpolarized cross section



azimuthal modulation

Summary:

- 光光对撞过程有丰富的唯象学研究潜力
- e^+e^- 对撞机上研究TMD自旋物理有良好前景

Thank you!

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