UPC轻子对产生中的软光子辐射效应研究

周剑

山东大学（青岛）
SHANDONG UNIVERSITY，QINGDAO

Collaborators: D. Y. Shao, C. Zhang, Y. J. Zhou,
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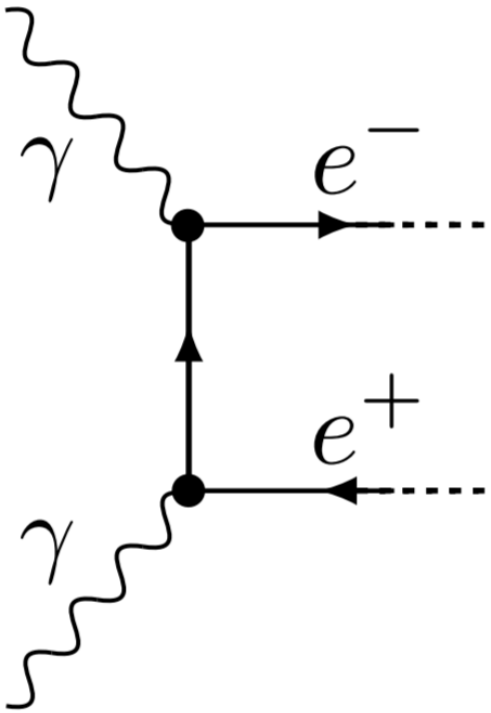
Outline

- Background
- Resummation formula at low qt
- Resummation formula at low acoplanarity
- Summary

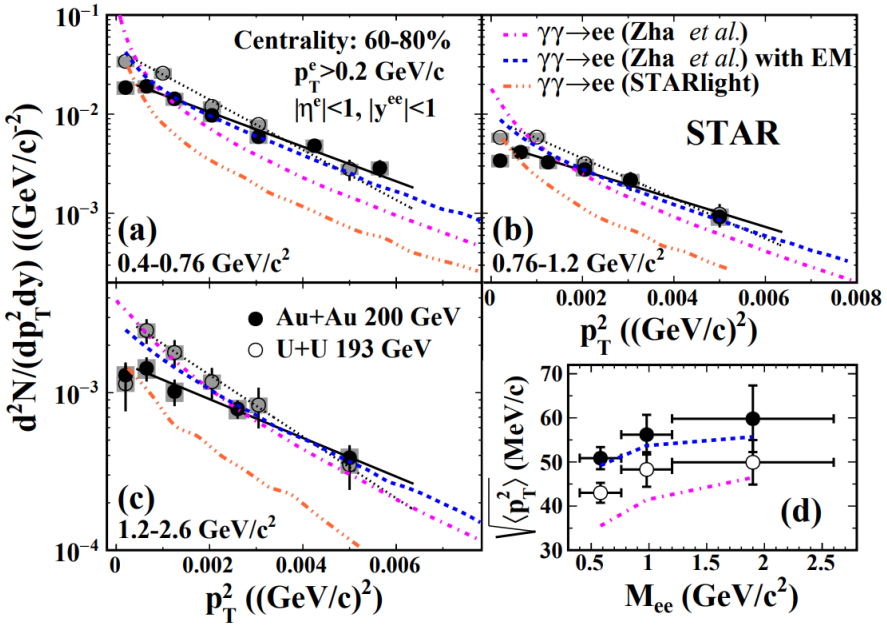
Motivations

- Set a baseline for QGP study
- Determine photon flux: standard candle.
- Strong field QED
- Challenge for factorization theorem
- BSM search
- Playground for resummation

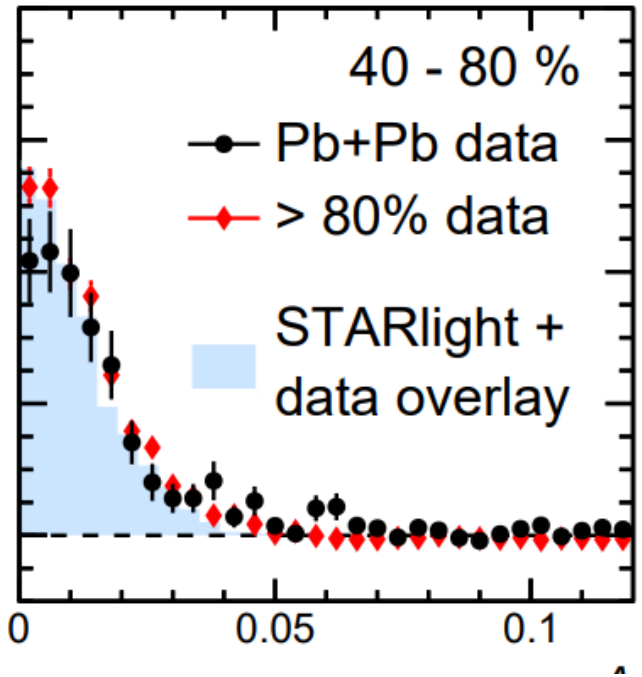


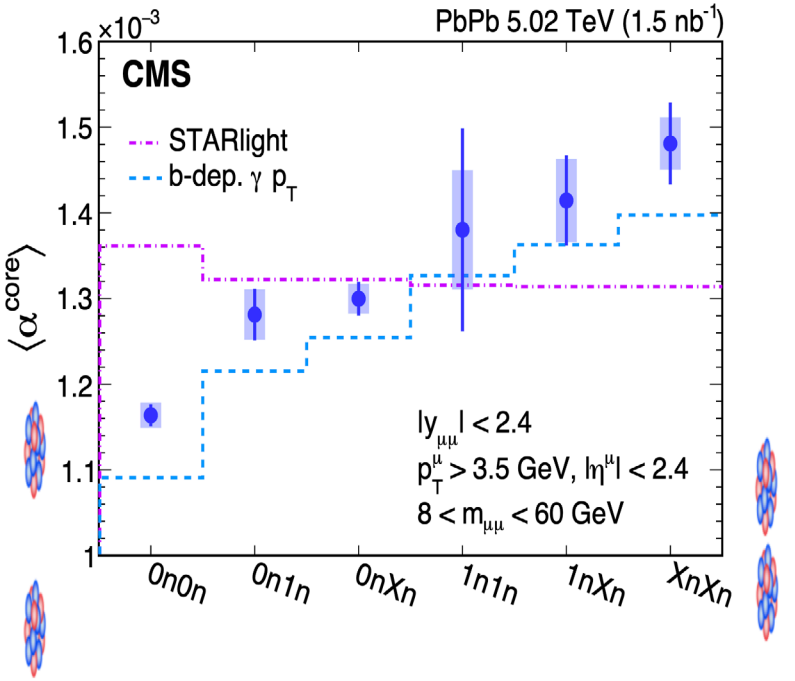
Dip structure and bt dependent qt distribution

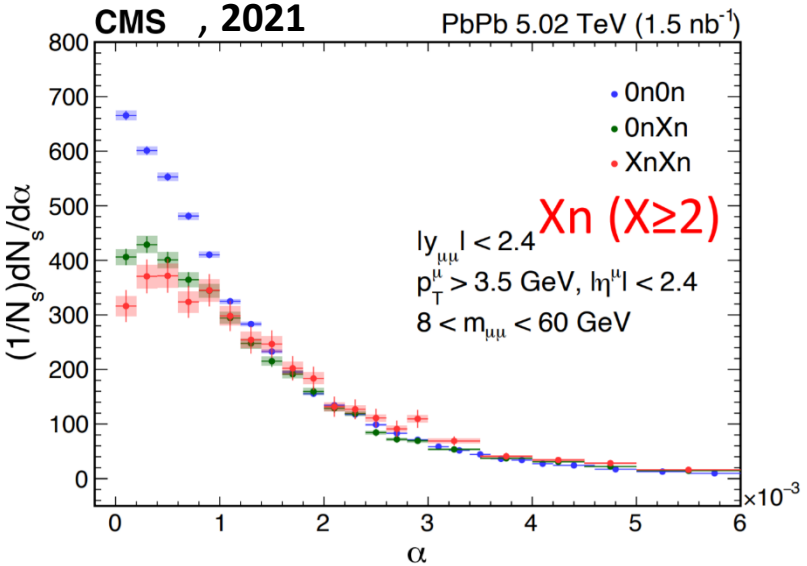
STAR, 2018

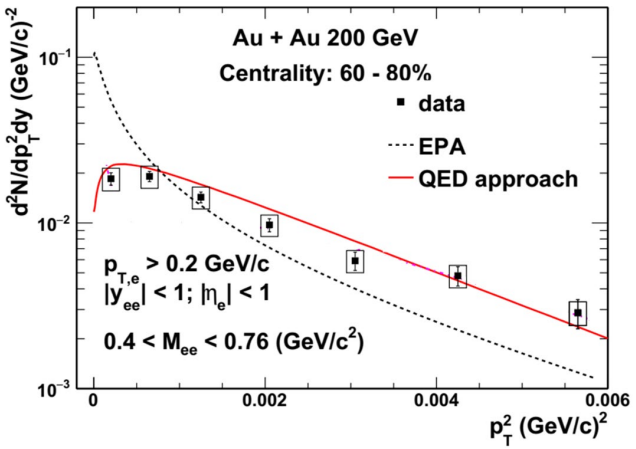


ATLAS 2018









- WW approximation is not sufficient!

Chi Yang, Shuai Yang, Zebo Tang, Wangmei Zha, Daniel Brandenberg, Zhangbu Xu, et.al.

Verified by STAR experiment

STAR collaboration, 2021

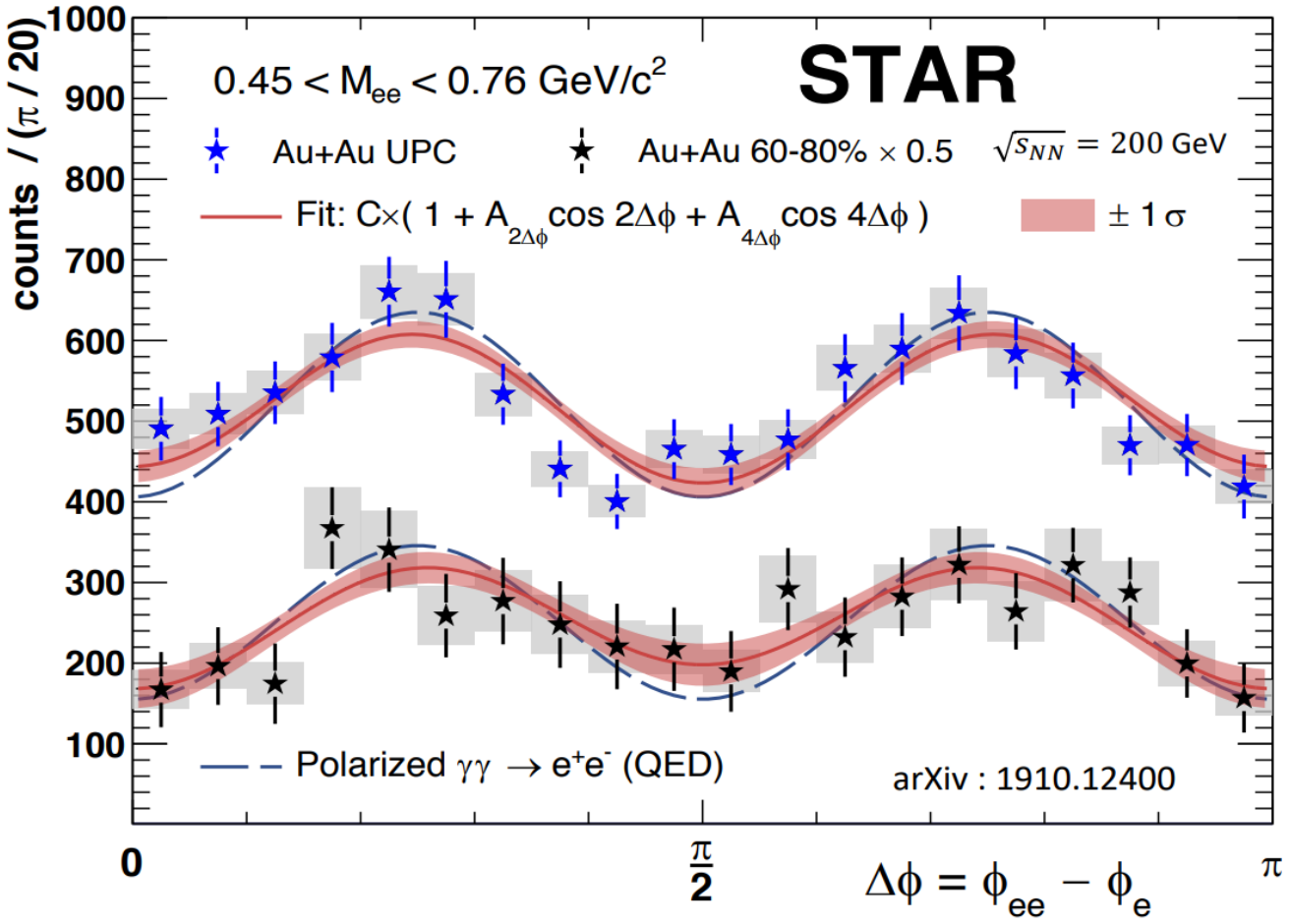
- Experimental cut:

  $0.45GeV^2<Q^2<0.76GeV^2$

  $P_t>200MeV$, $|y|<1, q_t<100MeV$

Li-JZ-Zhou, 2020

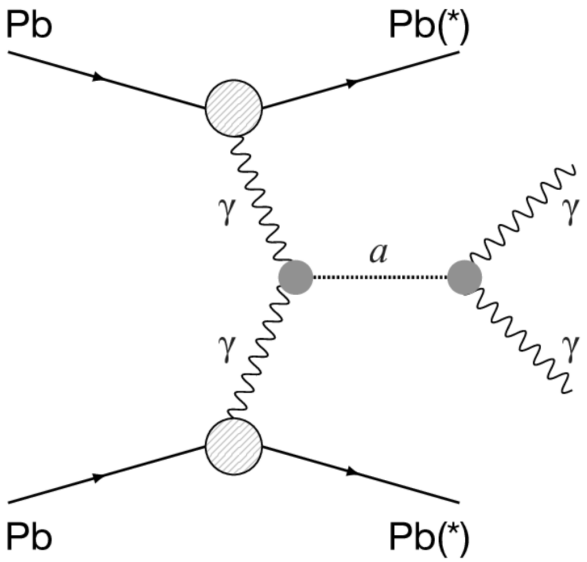
	Measured	QED calculation
Tagged UPC	**16.8%±2.5%**	**16.5%**
60%-80%	27%±6%	34.5%



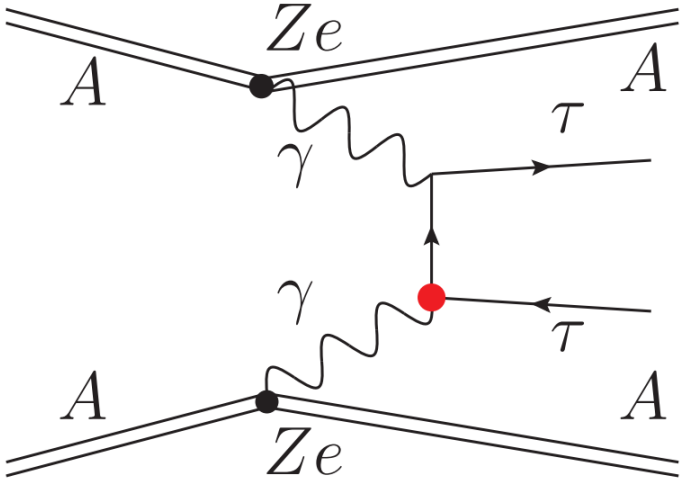
Cos2ϕ in muon pair production, USTC team Tang-Zhou, et.al.

Linearly polarized photons: new experimental tool

➢ BSM: axion search & constrain EDM of tau lepton



Knapen-Lin-Lou-Melia, 2017



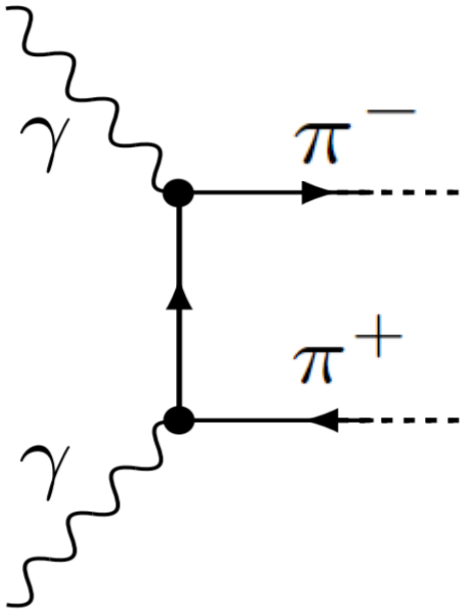
Shao-Yan-Yuan-Zhang, 2023

➢ Hadron spectrum: determine the quantum numbers of X(6900) from photon-photon fusion in UPCs

SCNU team： Niu-Wang-Wang-Yang, 2022

Pion pair production in photon-photon collisions

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



● Constrain the amplitude via dispersion relation.

Dai-Pennington, 2014

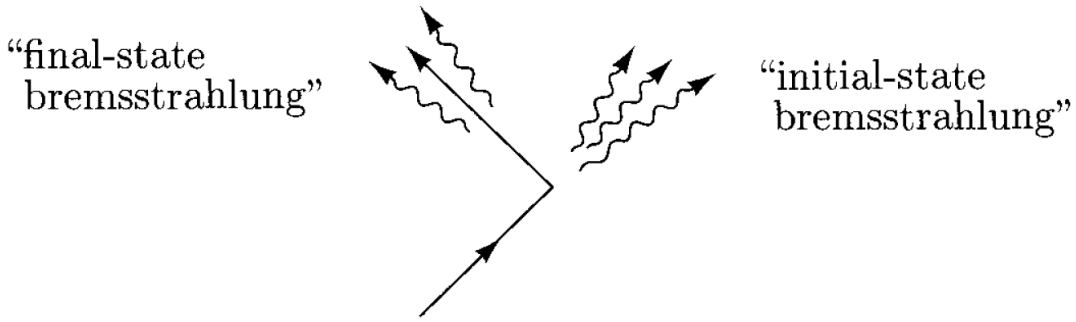
How to access the relative phase?

$$< \cos 2\phi > \propto \mathrm{Re}[M_{++} M^*_{+-}]$$

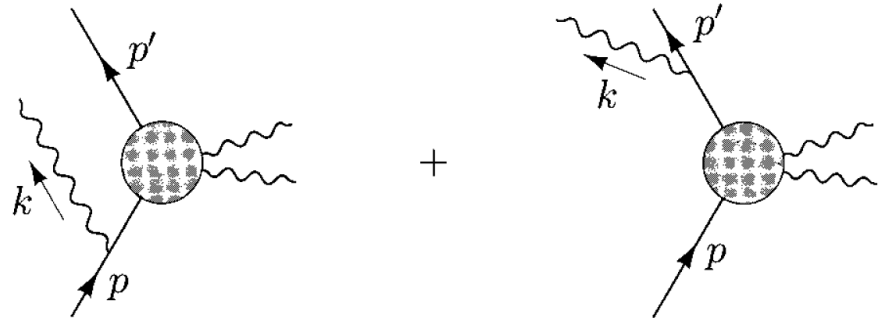
Work in progress with Yu Jia & Ya-jin Zhou. For more detailed discussion, Ya-jin's talk

Sudakov resummation I

- In classical electrodynamics,
  soft bremsstrahlung radiation is inevitable,
  when charged particle receive a sudden kick.



- Question: The probability that a hard scattering occurs and no hard bremsstrahlung radiations E_l



$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{measured}} \approx \left(\frac{d\sigma}{d\Omega}\right)_0 \left[1 - \frac{\alpha}{\pi}\log\left(\frac{-q^2}{m^2}\right)\log\left(\frac{-q^2}{E_\ell^2}\right) + \mathcal{O}(\alpha^2)\right]$$

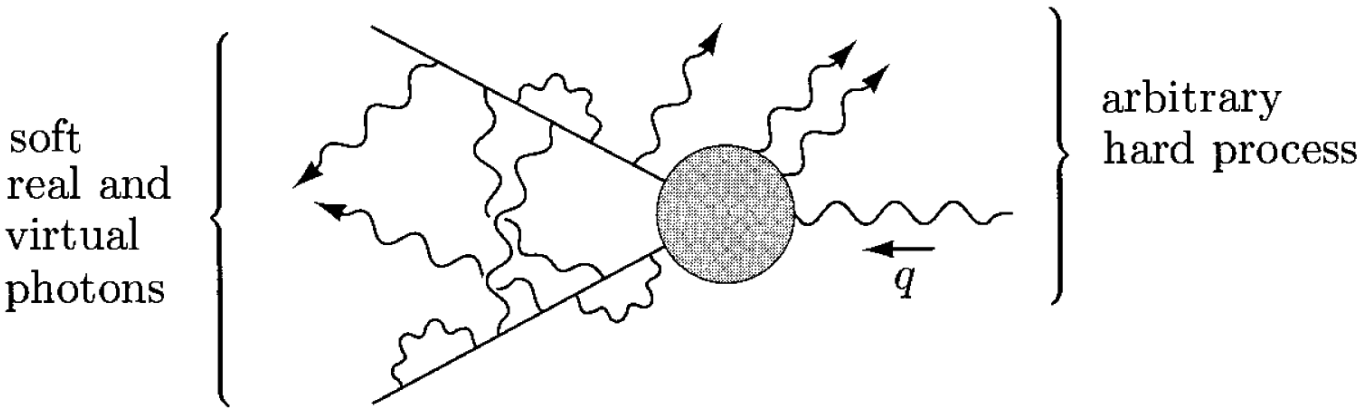
Sudakov double logarithm

Born cross section

Chapter 6, An introduction to quantum field theory, Peskin&Schroeder

Sudakov resummation II

◆Call for all order resummation: $$\left[\frac{\alpha}{\pi}\log\left(\frac{-q^2}{\mu^2}\right)\log\left(\frac{-q^2}{m^2}\right)\right]^n$$

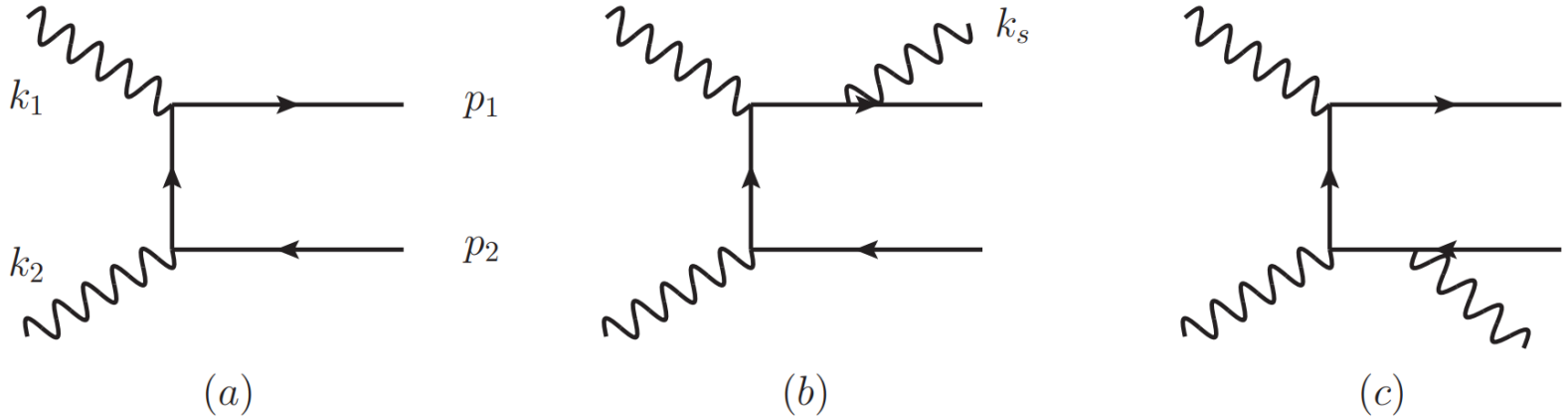


◆Resummed result: $$\left(\frac{d\sigma}{d\Omega}\right)_{\text{meas.}} = \left(\frac{d\sigma}{d\Omega}\right)_0 \times \left|\exp\left[-\frac{\alpha}{2\pi}\log\left(\frac{-q^2}{m^2}\right)\log\left(\frac{-q^2}{E_\ell^2}\right)\right]\right|^2$$

- When E_l →0, the probability →0, the predication from the classical theory recovered

Chapter 6, An introduction to quantum field theory, Peskin&Schroeder

Resummation for qt distribution



◆Primordial coherent photon distribution:

$$e^{-\frac{q_\perp^2}{(30\mathrm{Mev})^2}}$$

◆Perturbative tail from the soft photon reoil effect:

$$\frac{\alpha}{\pi^2}\frac{1}{q_\perp^2}\ln\frac{Q^2}{m^2}$$

Vector summation:bt space

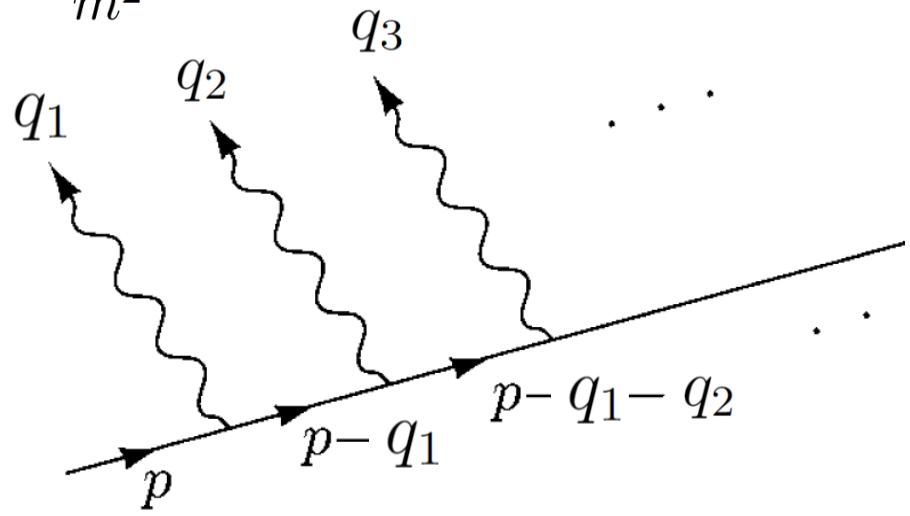
- Electron transvers momentum distribution after multiple soft photon radiations,

$$\sigma_2(p_\perp - q_{1\perp} - q_{2\perp}) = \int d^2q_{1\perp} d^2q_{2\perp} \sigma(p_\perp) S(q_{1\perp}) S(q_{2\perp})$$

$$S_{\text{real}}(q_\perp) = \frac{\alpha}{\pi^2} \frac{1}{q_\perp^2} \ln \frac{Q^2}{m^2}$$

- Fourier transformation:

$$\int \frac{d^2(p_\perp - q_{1\perp} - q_{2\perp})}{(2\pi)^2} e^{ib_\perp \cdot (p_\perp - q_{1\perp} - q_{2\perp})}$$



- One ends up with,

$$\sigma_2(b_\perp) = \sigma(b_\perp) S(b_\perp) S(b_\perp)$$

- Facilitate resuming to all orders,

$$\sigma(b_\perp) - \sigma(b_\perp) S(b_\perp) + \tfrac{1}{2} \sigma(b_\perp) S(b_\perp) S(b_\perp) + ... = \sigma(b_\perp) e^{-S(b_\perp)}$$

Double & Single leading logarithms

➢ The resumed cross section:

$$\frac{d\sigma}{d^2p_{1\perp}d^2p_{2\perp}dy_1dy_2d^2b_\perp} = \int \frac{d^2r_\perp}{(2\pi)^2} e^{ir_\perp\cdot q_\perp} e^{-\mathrm{Sud}(r_\perp)} \int d^2q'_\perp e^{-ir_\perp\cdot q'_\perp} \frac{d\sigma_0(q'_\perp)}{d\mathcal{P}.\mathcal{S}.}$$

Leading double logarithm: $\frac{\alpha_e}{\pi}\ln\frac{M^2}{m^2}\ln\frac{P_\perp^2}{\mu_r^2}$

Hatta-Xiao-Yuan-ZJ, 2021

Born cross section

≈**0.75** for LHC kinematics

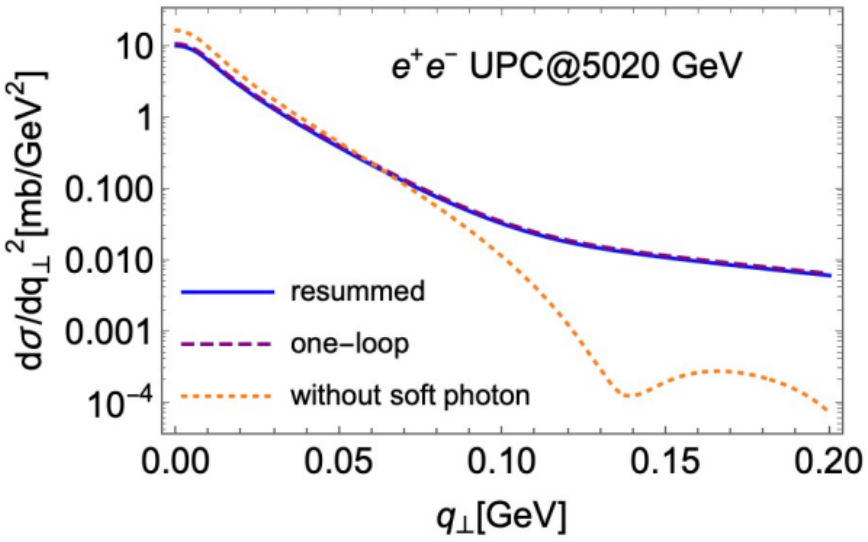
◆ Double+Single leading logarithm:

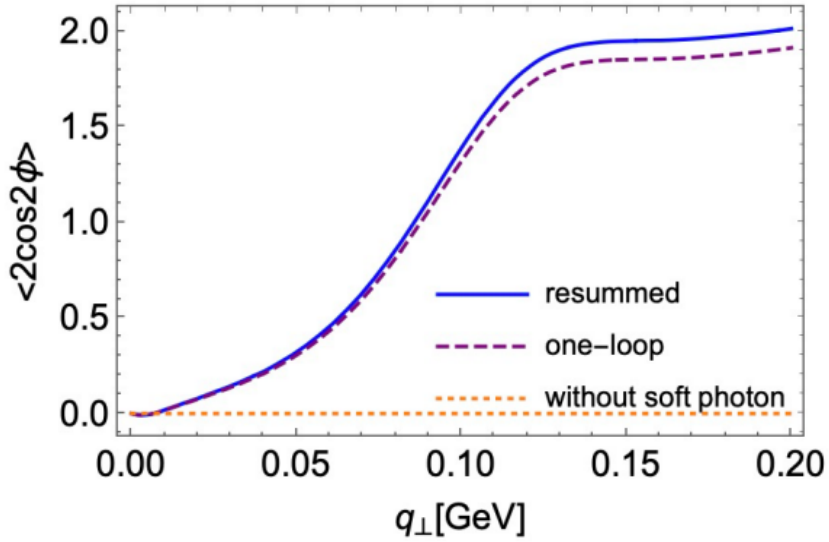
$$\frac{\alpha_e}{\pi}\ln\frac{M^2}{m^2}\ln\frac{P_\perp^2}{\mu_r^2} + \frac{\alpha_e}{\pi}\ln\frac{M^2}{m^2}\ln 4\cos^2\phi_r$$

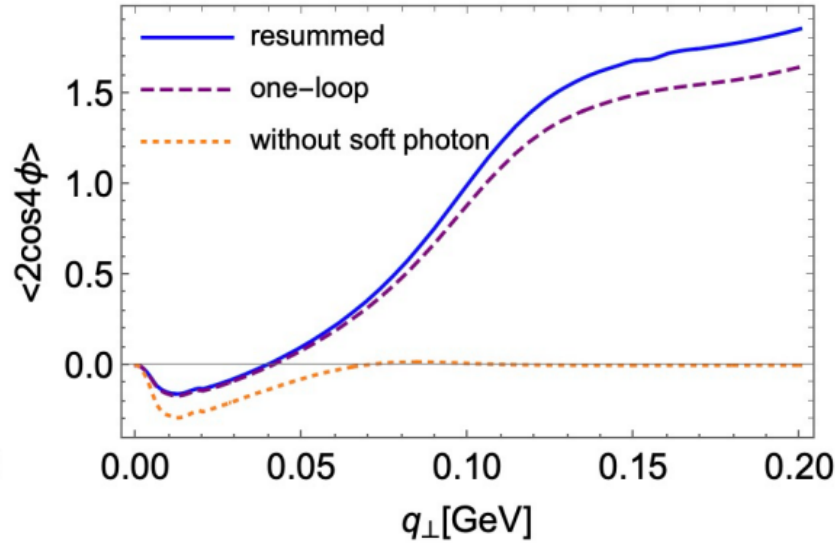
Shao-Zhang-ZJ-Zhou, 2023

Cos2ϕ, Cos4ϕ azimuthal asymmetries

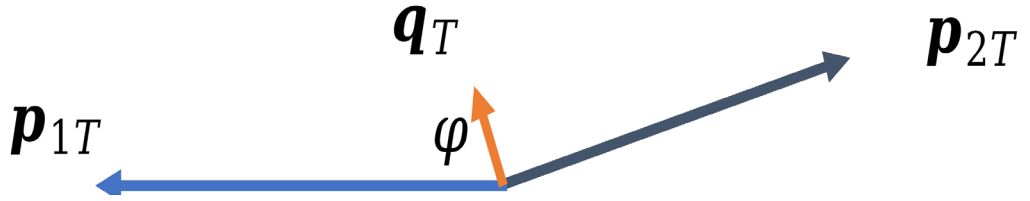
Numerical results



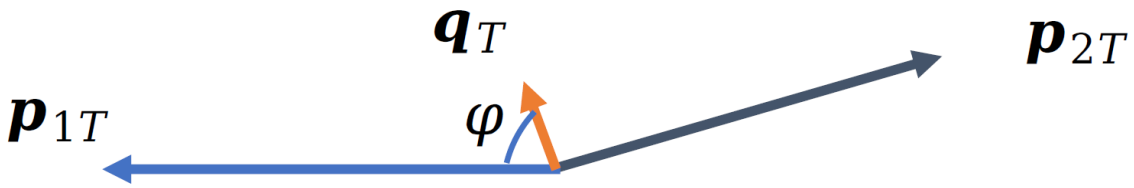


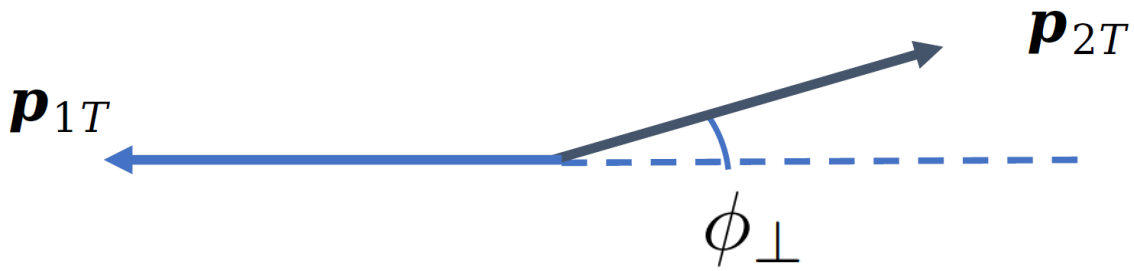


- At high qt, perturbative contribution dominates,
- Soft photon radiations give rise to huge cos2ϕ, cos4ϕ asymmetries
- Leading single logarithm contribution is small



Resummation formular at low α





Acoplanartiy: $\alpha = |\phi_\perp|/\pi$ $\alpha \propto \frac{q_{\perp x}}{P_\perp}$

Can one first derive a resumed qt distribution, and then re-construct α distribution? No!

◆ One dimensional resummation formula:

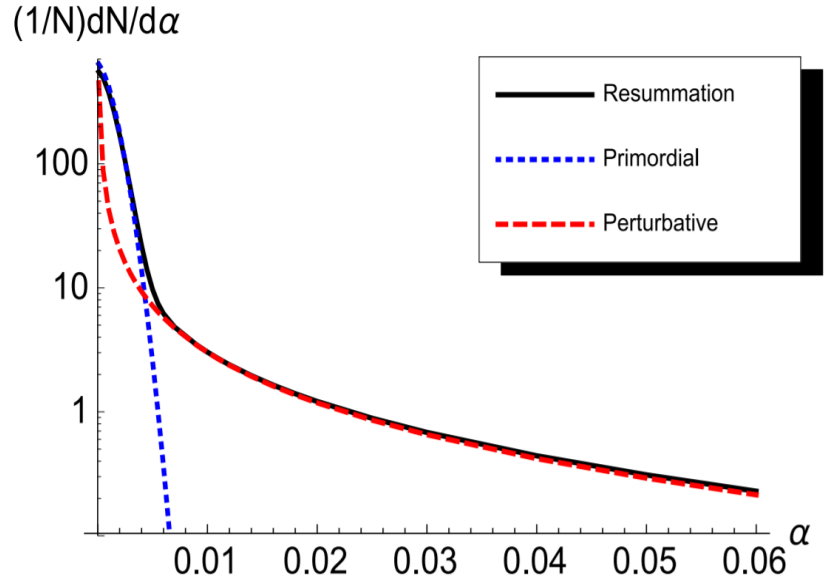
$$\frac{d\sigma}{dq_x d^2P_\perp dy_1 dy_2 d^2b_\perp} = \int \frac{dr_x}{2\pi} e^{ir_x q_x} e^{-\mathrm{Sud_a}(r_x, r_y=0)} \int dq'_x dq'_y \; e^{-ir_x q'_x} \frac{d\sigma_0(q'_\perp)}{d\mathcal{P}.\mathcal{S}.}$$

Double&Single leading logarithm

- Double leading logarithm:

$$\mathrm{Sud_a}(r_x) = \frac{\alpha_e}{2\pi}\left[\ln^2\frac{M^2}{\mu_{rx}^2} - \ln^2\frac{m^2}{\mu_{rx}^2}\theta(m-\mu_{rx})\right]$$

Klein-Mueller-Xiao-Yuan,2018

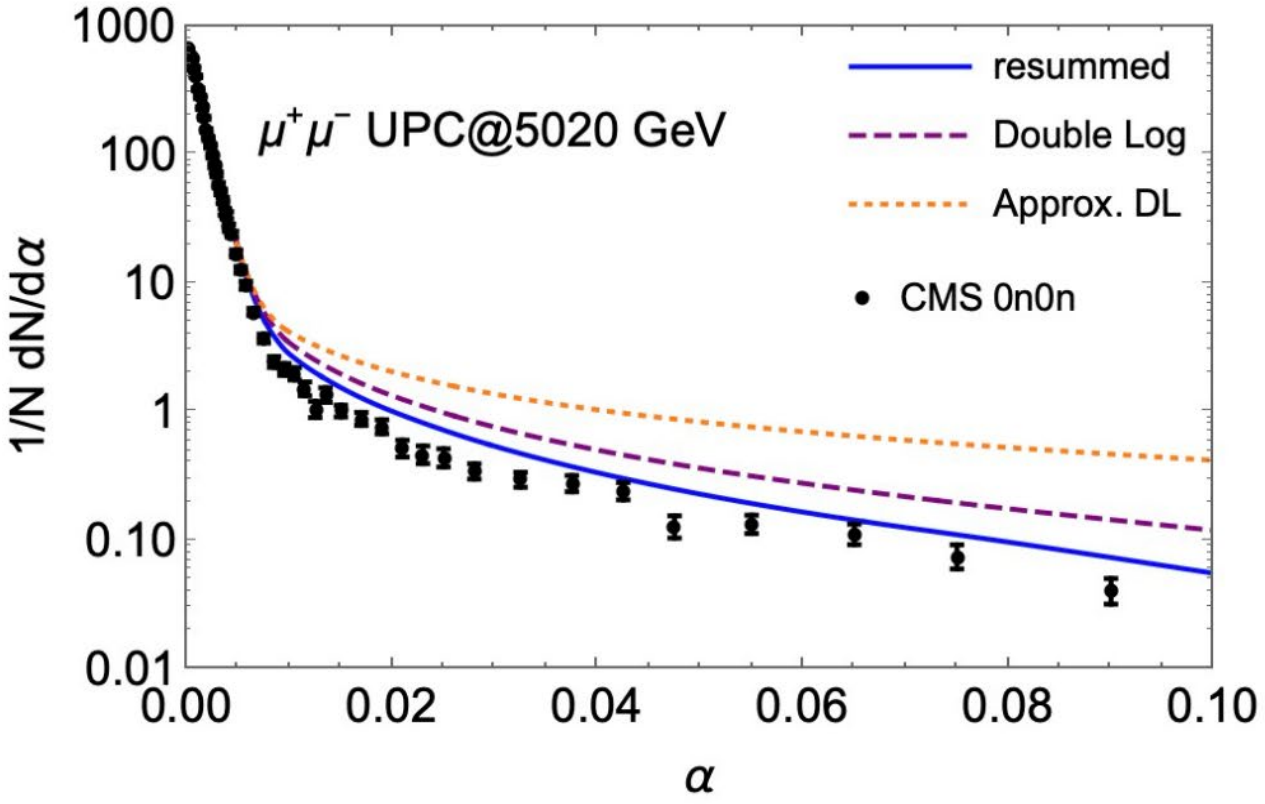


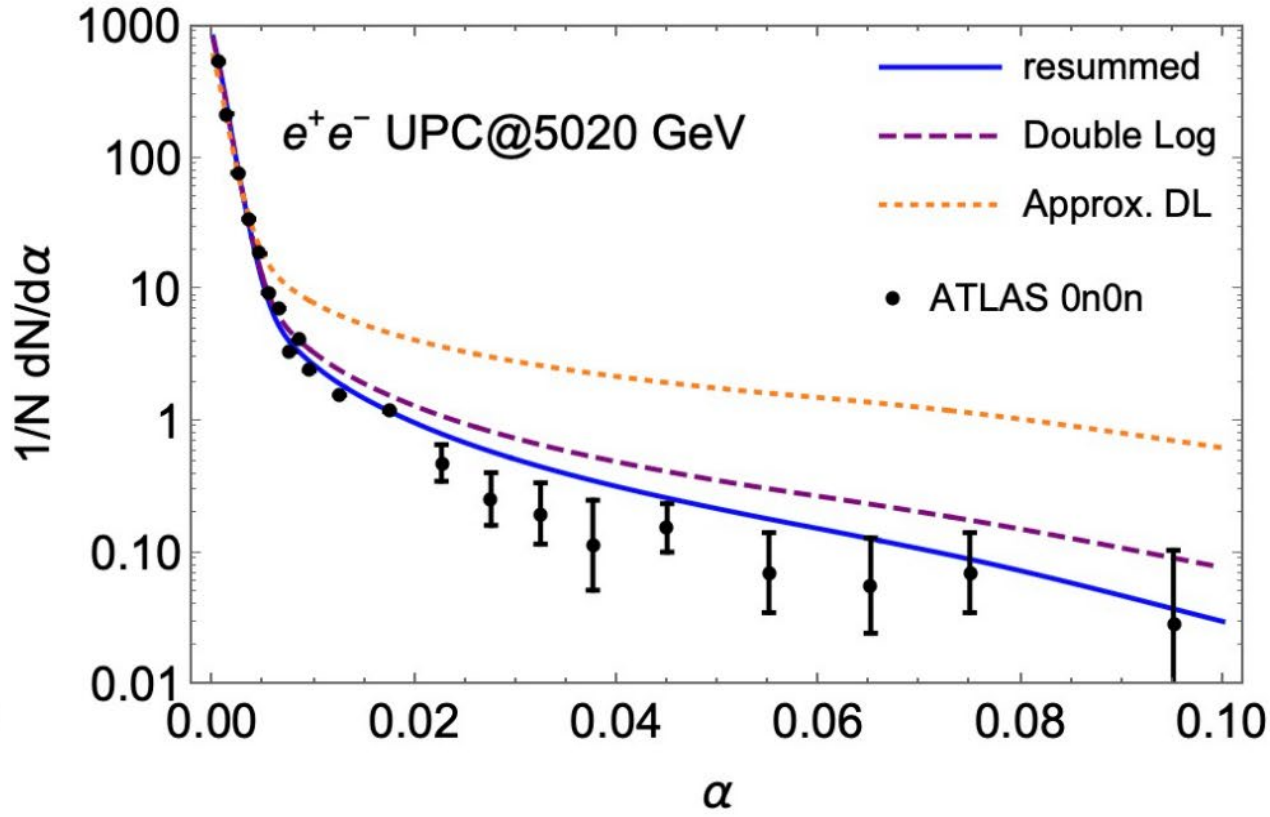
- Double+Single leading logarithm

$$\frac{\alpha_e}{2\pi}\left[\left(\ln^2\frac{M^2}{\mu_{rx}^2} - 3\ln\frac{M^2}{\mu_{rx}^2}\right) - \left(\ln^2\frac{m^2}{\mu_{rx}^2} - \ln\frac{m^2}{\mu_{rx}^2}\right)\theta(m-\mu_{rx})\right]$$

Shao-Zhang-ZJ-Zhou, 2023

Numerical results





- Exclude incoherent events by selecting 0n0n events.
- The difference between qt double log and α double is sizable
- Single log contribution is sizable
- Something missing in our resummation formular?

Summary

- qt and α, two different resummation formula
- Single logarithm is important for large α distribution
- Toward a precision test of resummation formular

Thank you!