

UPC and QED

Jian Zhou (周剑)



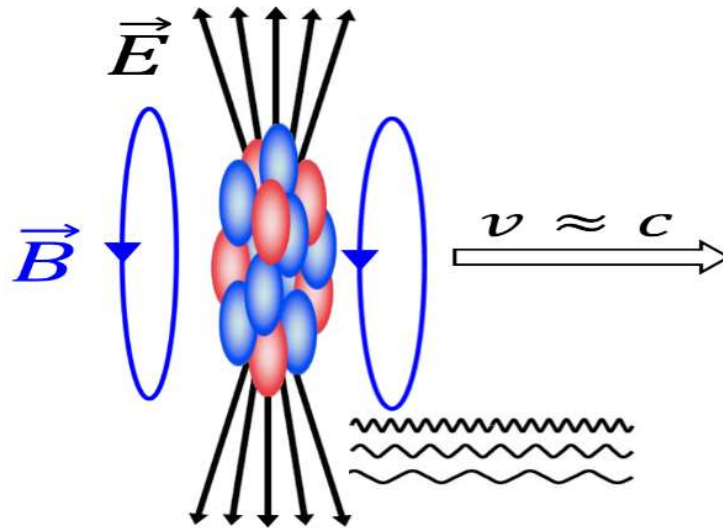
山东大学(青岛)
SHANDONG UNIVERSITY, QINGDAO

Workshop: RHIC Science Programs Informative Toward EIC in the Coming Years, May, 2021

Why study QED in 21th century

- QED under extreme condition: interesting in its own right
(vacuum birefringence, Coulomb correction, Schwinger pair production, light-light scattering...)
- Clean test ground for pQCD theory tools
(factorization in terms of Wigner distribution, multiple scattering formula, Sudakov resummation..)
- Base line & new experimental tool
(EM properties of QGP, accurate bt dependent photon flux, vector meson, BSM, v2, linear polarization of photons...)

Why study QED in UPC



Because relativistic heavy ion is extremely **bright!**

Long history (incomplete list)

Electromagnetic Processes in Relativistic Heavy Ion Collisions

#1

Carlos A. Bertulani (Julich, Forschungszentrum and Rio de Janeiro Federal U.), Gerhard Baur (Julich, Forschungszentrum) (Oct, 1987)

Published in: *Phys.Rept.* 163 (1988) 299

[DOI](#) [cite](#)

[↻](#) 653 citations

Physics of ultra-peripheral nuclear collisions

#1

Carlos A. Bertulani (Arizona U.), Spencer R. Klein (LBL, Berkeley), Joakim Nystrand (Bergen U.) (Feb, 2005)

Published in: *Ann.Rev.Nucl.Part.Sci.* 55 (2005) 271-310 • e-Print: [nucl-ex/0502005](#) [nucl-ex]

[pdf](#) [DOI](#) [cite](#)

[↻](#) 363 citations

The Physics of Ultraperipheral Collisions at the LHC

#23

A.J. Baltz (Brookhaven), G. Baur (Julich, Forschungszentrum)(ed.), D. d'Enterria (CERN)(ed.), L. Frankfurt (Tel Aviv U.)(ed.), F. Gelis (Saclay, SPHT)(ed.) et al. (Jun, 2007)

Published in: *Phys.Rept.* 458 (2008) 1-171 • e-Print: [0706.3356](#) [nucl-ex]

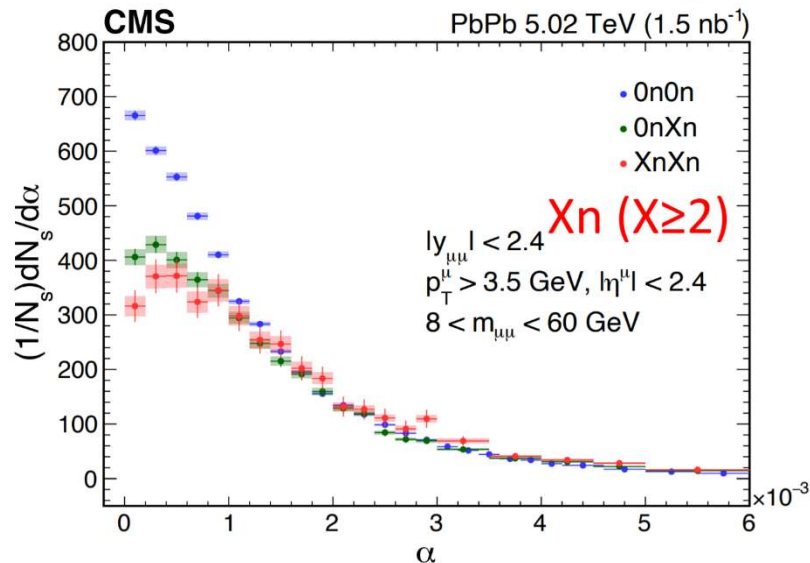
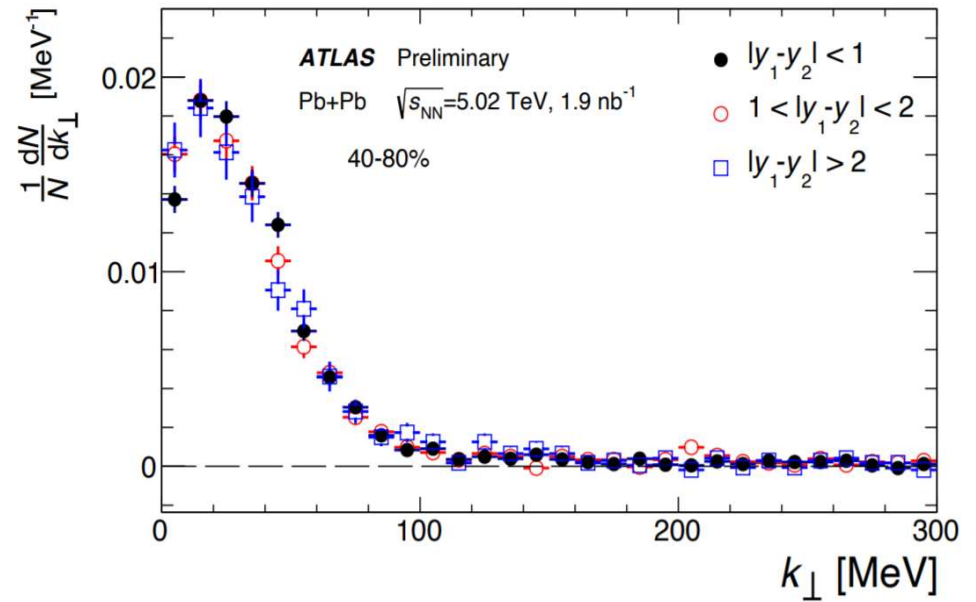
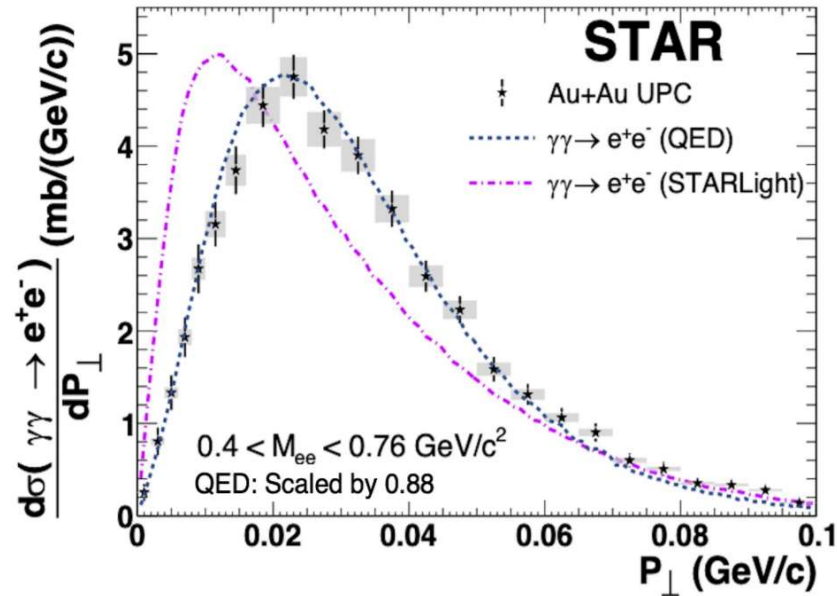
[pdf](#) [DOI](#) [cite](#)

[↻](#) 487 citations

Many more...

qt broadening/acoplanarity of lepton pair

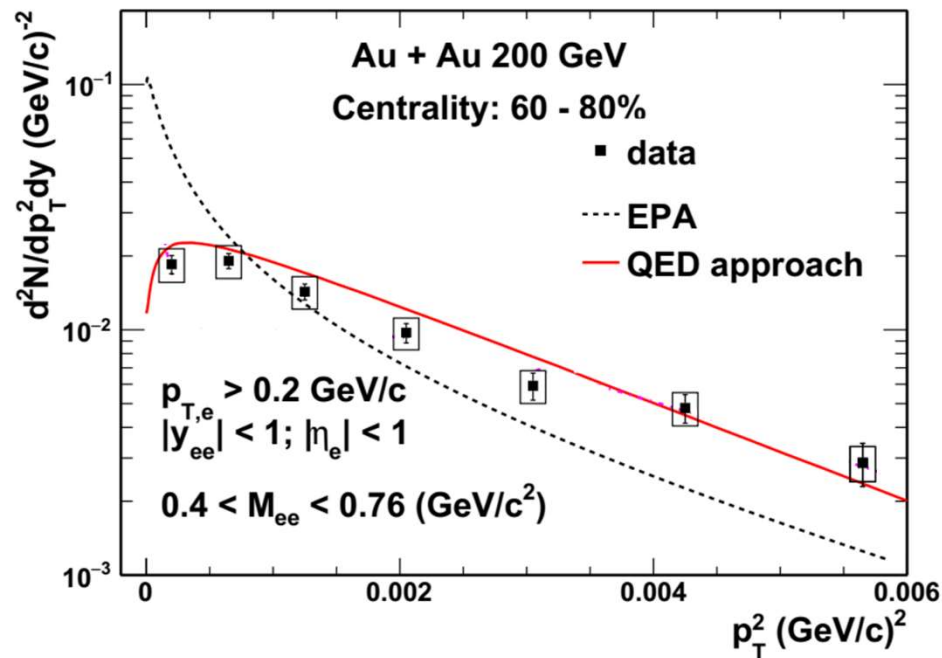
STAR[1806.02295], ATLAS[CONF-2019-051], CMS[PAS-HIN-19-014]



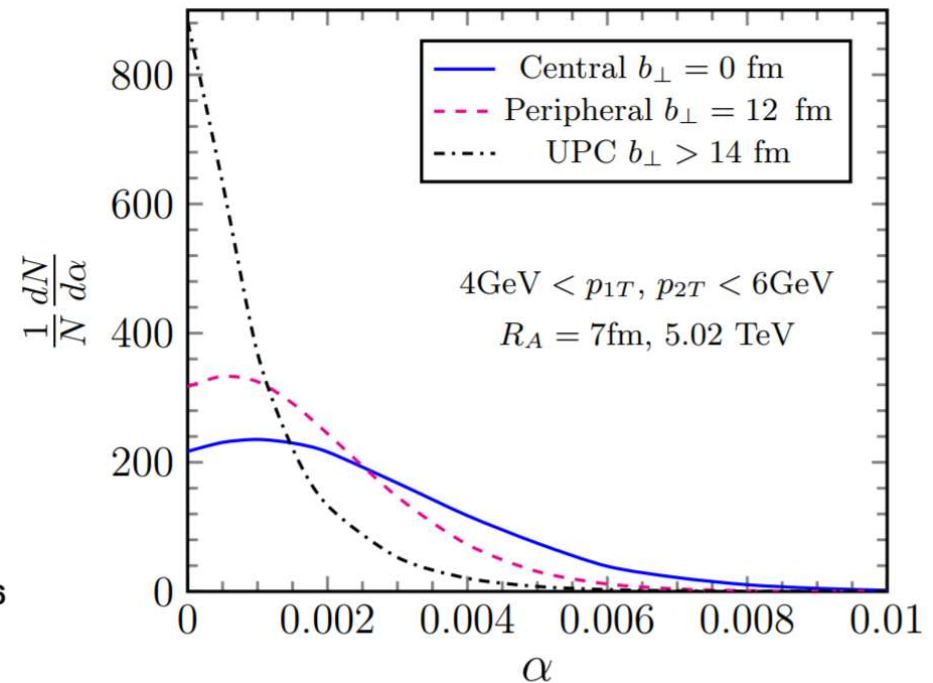
Mysterious dip in more central collisions

New wave of theory and experiment activities!

- STARlight can describe the total pair cross section well but fails to reproduce low q_T shape in central/peripheral collisions .
- b_T dependent photon flux: extension of Fermi and Weizsacker-Williams' idea by M. Vidovic, M. Greiner, C. Best and G. Soff, 1993



W. Zha, Brandenburg, Tang, Xu, 2020



From Bowen's talk; Klein, Mueller, Xiao, Yuan, 20

Also calculation by Klusek-Gawenda, Schafer, and Szczurek, 2020

Dip structure is reproduced!

What do we learn

- Phenomenology point of view:

bt dependent photon flux should be used to compute vector meson production in UPCs, great importance to constrain nuclear geometry.

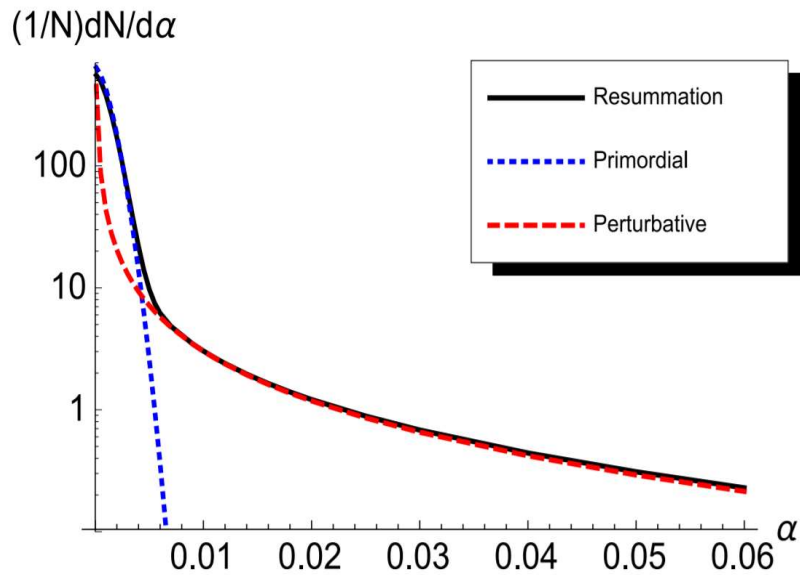
- Formulation in terms of photon Wigner distribution

Klein, Mueller, Xiao, Yuan, 2020; Klusek-Gawenda, Schafer, and Szczurek, 2020

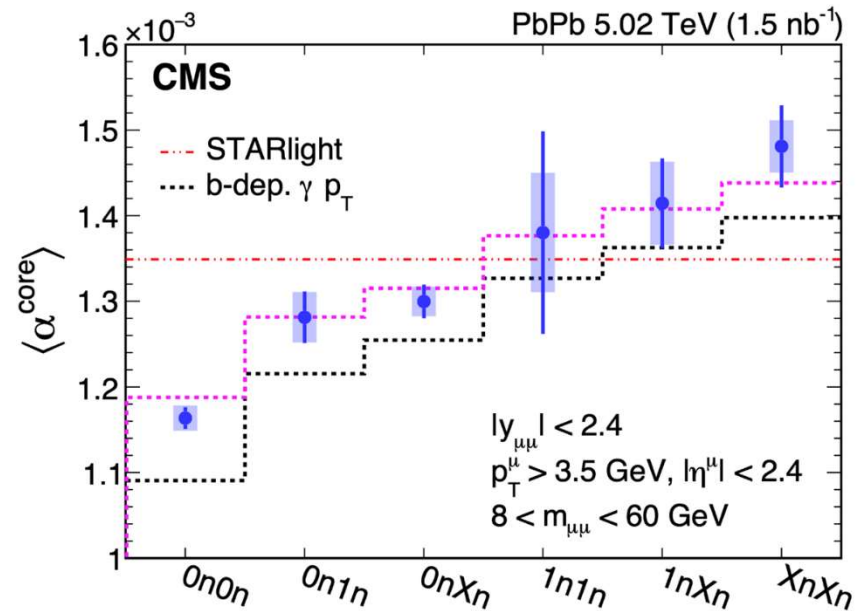
parton Wigner distribution: key element of nucleon 3/5D imaging, test pQCD theory tool.

High qt tail: a return of Sudakov resummation

- STARlight can not describe high qt tail
- Sudakov resummation developed by Sudakov in 1957 in QED context
- Widely used in QCD phenomenology studies



Klein, Mueller, Xiao, Yuan, 2018



Brandenburg, Li, Ruan, Tang, Xu, Yang and Zha, 2020

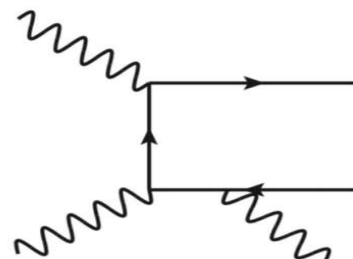
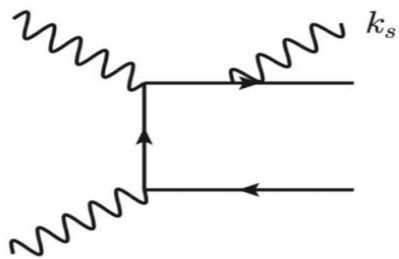
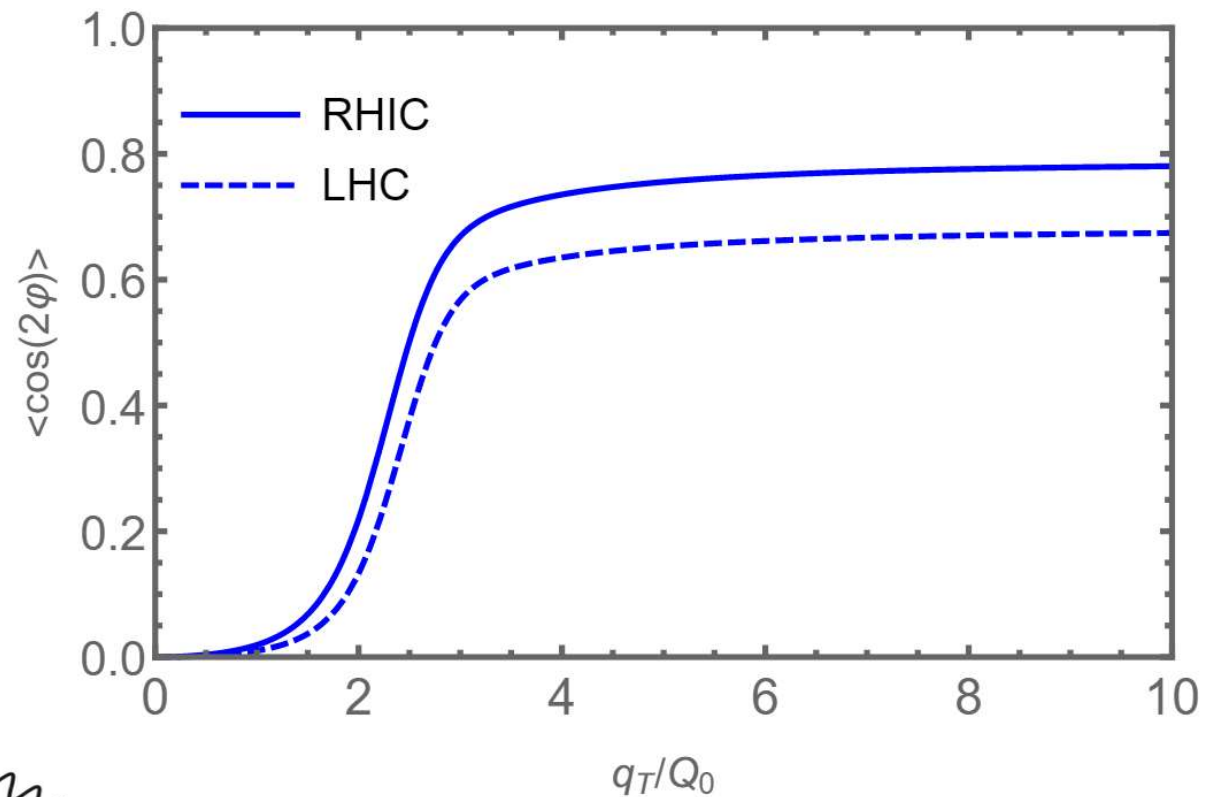
◆ Not Sudakov log exactly, analogy to jet associated log! A new type resummation!

Cos2 ϕ and Cos4 ϕ asymmetries due to final state soft photon radiation

$Q_0=40\text{MeV}$,

LHC kinematics:
 $Q=10\text{GeV}$,
di-muon production.

RHIC kinematics:
 $Q=1\text{GeV}$,
di-electron production

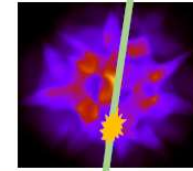


Hatta, Xiao, Yuan, Zhou; to appear

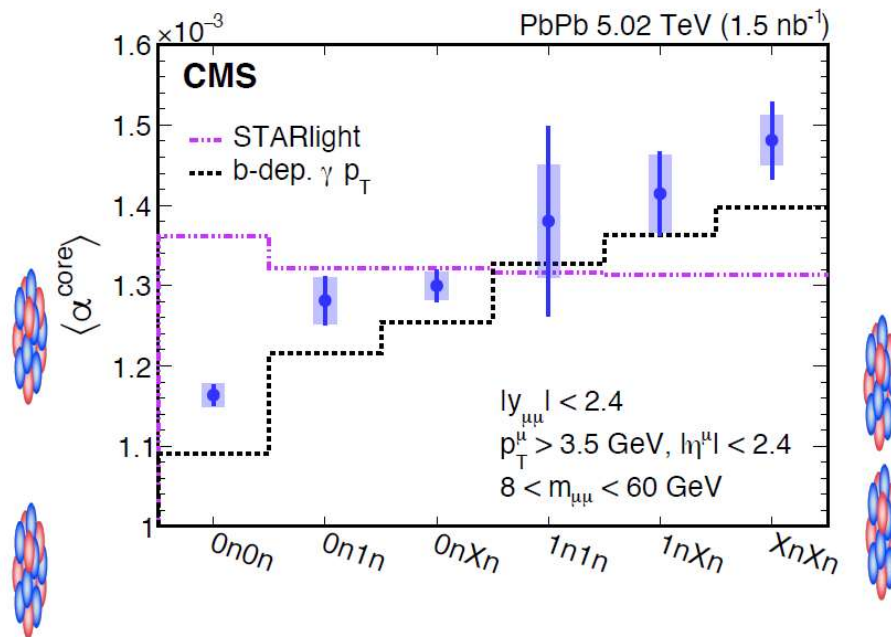
What do we learn and the future plan

- Study new type resummation; hints on jet physics study
lepton+jet correlation at EIC, mixed QCD&QED contribution
- Background for study primordial photon distribution

Exploring QGP EM properties

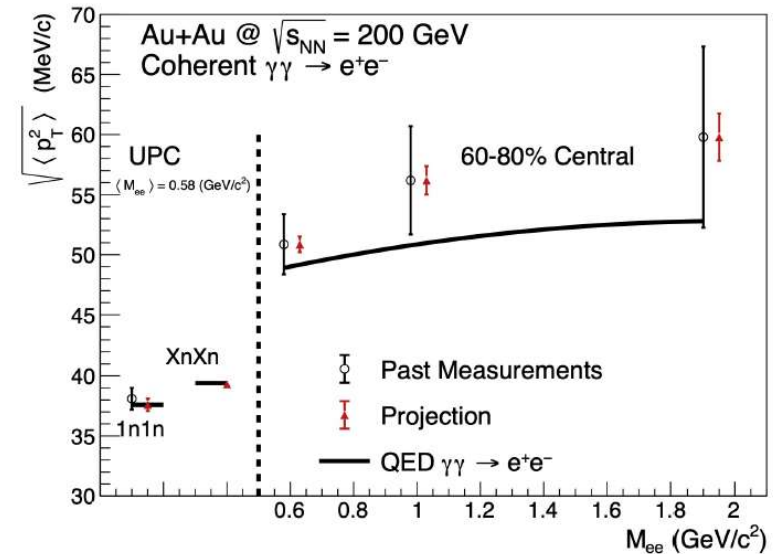


CMS, arXiv:2011.05239



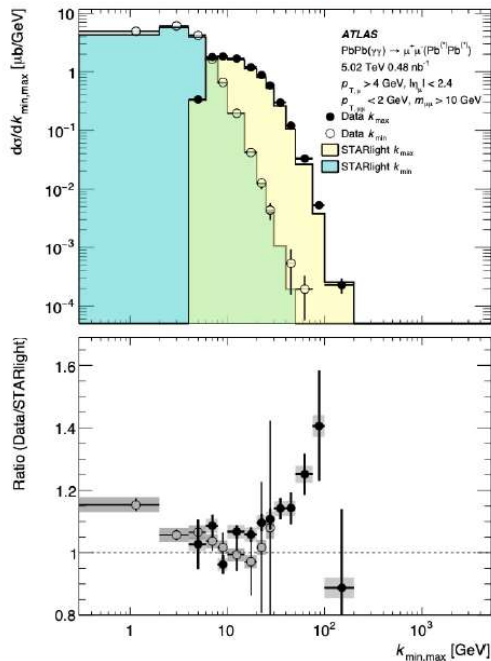
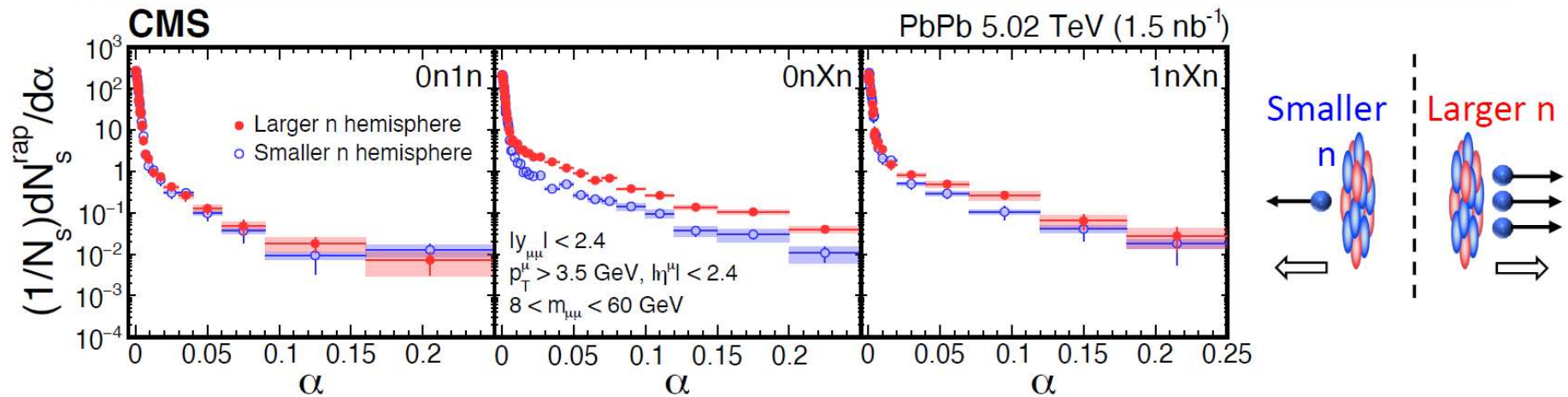
STAR, PRL 121 (2018) 132301, arXiv: 1910.12400

Brandenburg et al., arXiv:2103.16623



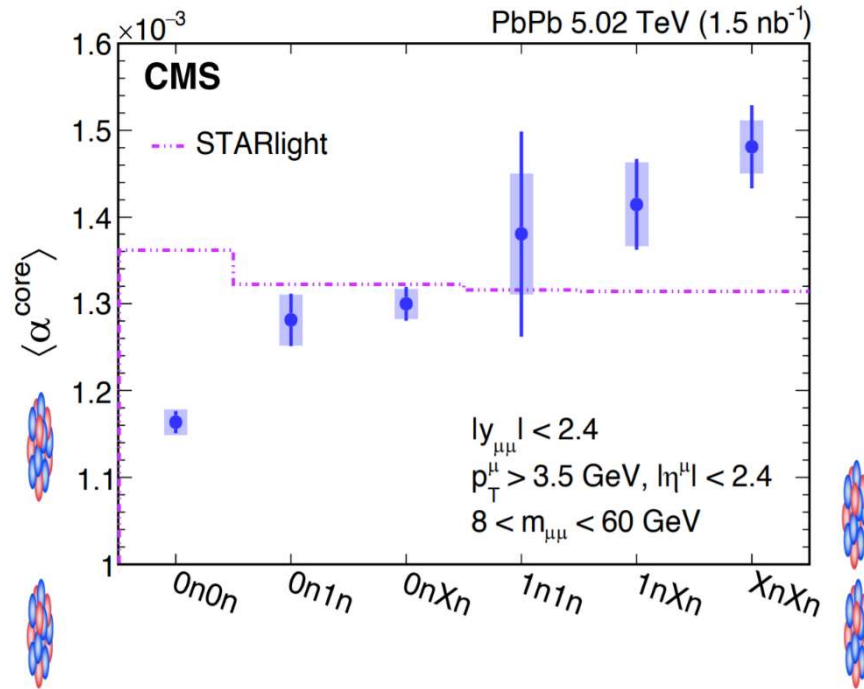
- Experimentally demonstrated **b** dependence of initial photon p_T
- Exploring QGP EM properties benefits from experimental and theoretical developments
 - Precise baseline
 - Excellent detector performance and large statistics in 2023-2025 RHIC runs

Further efforts needed



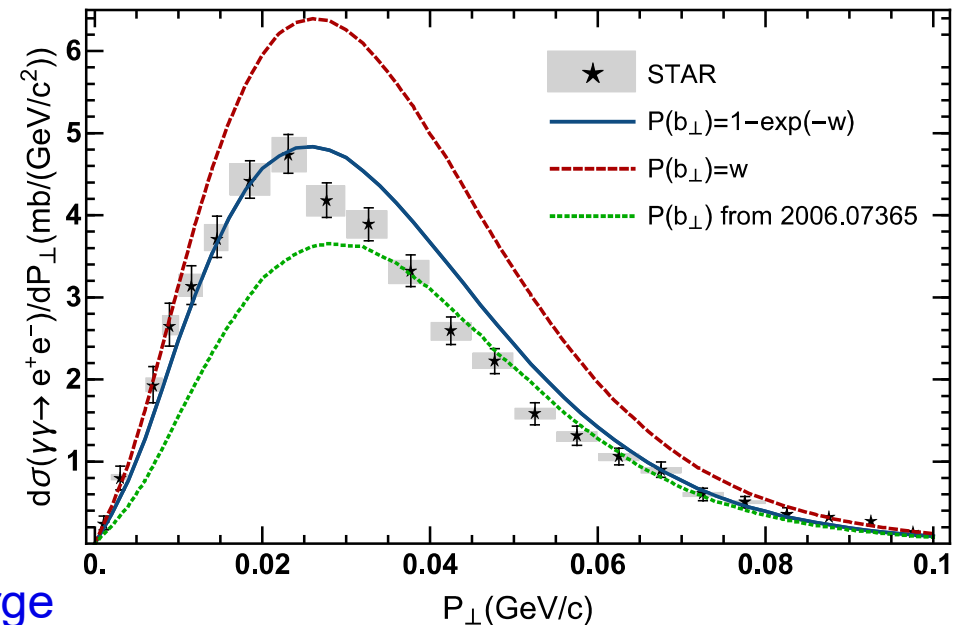
- Photon kinematics (e.g., energy) are not fully understood
 - Charge distribution? HO effects?
 - System size scan (OO, ZrZr, RuRu, AuAu)
- How to understand the rapidity dependence of α tail only happens in 0nXn class?
 - Besides soft photon radiation and dissociative processes, any other HO process(es) contribute to the tail?

Brilliant way to control bt in UPCs



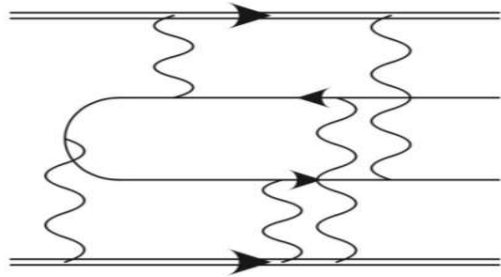
➤ However, uncertainties with $P(b_t)$ is large

From Pushi:



Ren-jie. Wang, Shi Pu, Qun Wang, in preparation

Coulomb correction



H. A. Bethe and L. C. Maximon, Phys. Rev. **93**, 768 (1954); Handel Davies, H. A. Bethe, and L. C. Maximon, Phys. Rev. **93**, 788 (1954).

$Z\alpha \sim 0.6$ for Au and Pb, significant effect?

Evidence for higher order QED in e^+e^- pair production at RHIC

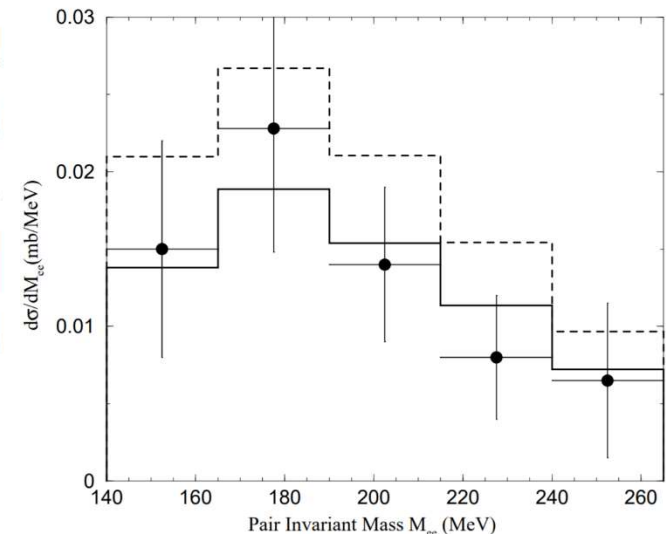
A. J. Baltz

Physics Department, Brookhaven National Laboratory, Upton, New York 11973

(Dated: October 25, 2007)

In the planning stages of RHIC a workshop was held at Brookhaven on the topic “Can RHIC be used to test QED?” [25] A recent paper concluded, “We think that after about 17 years the answer to this question is ‘no’.” [26] The present results indicate that the answer may turn out to be ‘yes’.

17% reduction due to CC



From Wangmei

Higher order QED effect

$Z\alpha \sim 0.6$ for Au and Pb

The effect should be sizeable!

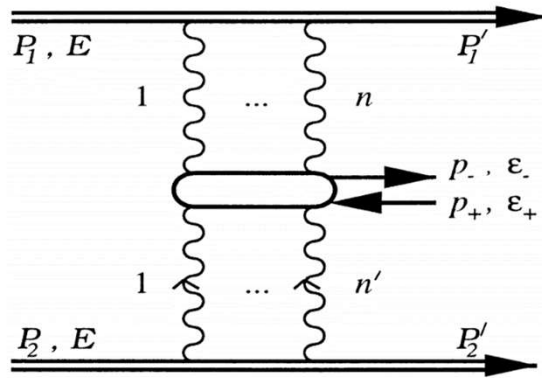
However:

H. A. Bethe and L. C. Maximon, Phys. Rev. **93**, 768 (1954); Handel Davies, H. A. Bethe, and L. C. Maximon, Phys. Rev. **93**, 788 (1954).

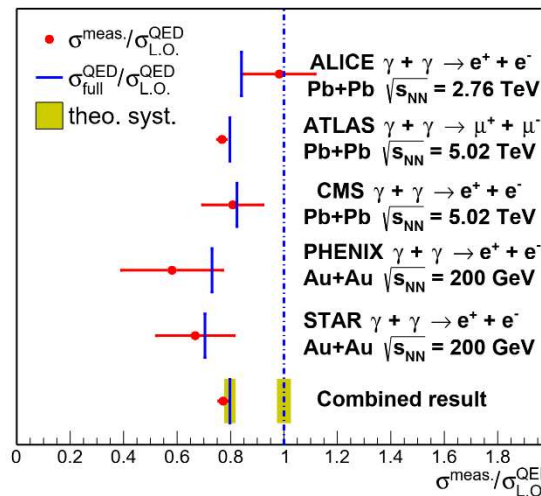
In April 1990 a workshop took place in Brookhaven with the title 'Can RHIC be used to test QED?' [98]. We think that after about 17 years the answer to this question is 'no'. However, many theorists were motivated to deal with this

Phys. Rep. 453, 1 (2007)

M. Fatyga, M. Rhoades-Brown, and M. Tannenbaum, Can RHIC be used to test QED: Workshop summary, Workshop "Can RHIC be used to test QED?", Upton, N.Y., Apr 20-21, 1990, BNL 52247 Formal Report.



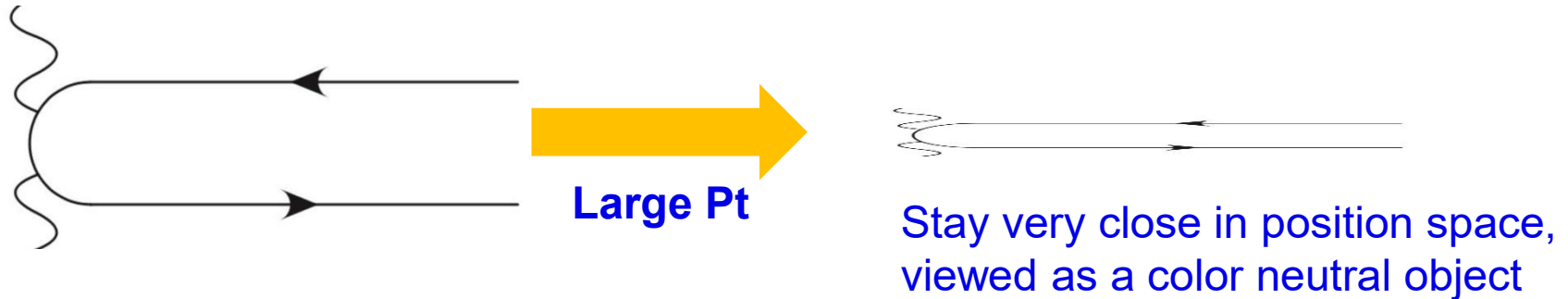
Phys. Lett B454 (1999)
155



7 σ deviation from
Leading order
results
Consistent with
Full order results
From 'No' to 'Yes'

W. Zha and Z. Tang,
arXiv2103.04605
15

Some comments of mine

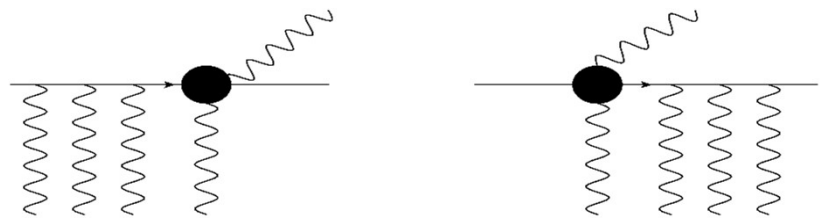


- According to power counting: qt^2/Q^2
- CC in UPCs needs to be better understood
- Pair production inside nuclei should be included;
Tension between theory calculation and data remains:
Why STARlight describes the total CS so well after imposing radius cutoff?

EIC/EicC may offer the better opportunity to search for CC ...

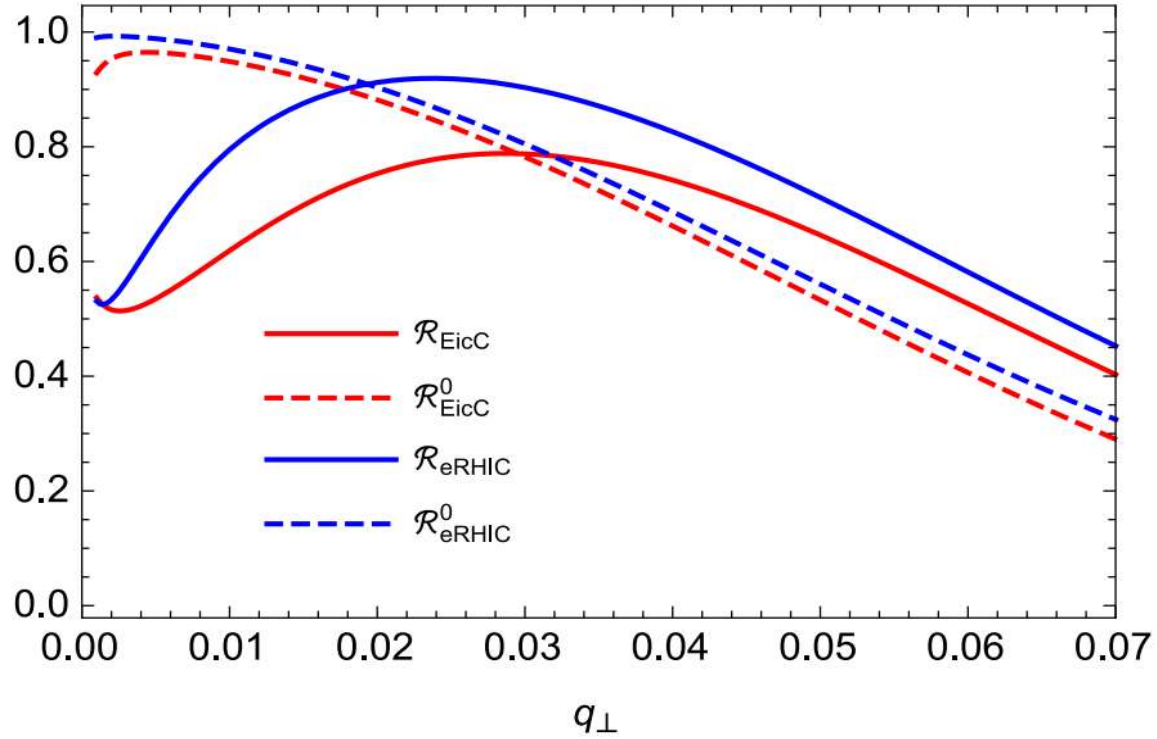
Coulomb correction in the BH process in eA collisions

The ratios between the BH cross sections in ep and eA collisions



$$\mathcal{R}(q_{\perp}) = \frac{d\sigma_{eA}}{Z^2 d\sigma_{ep}}$$

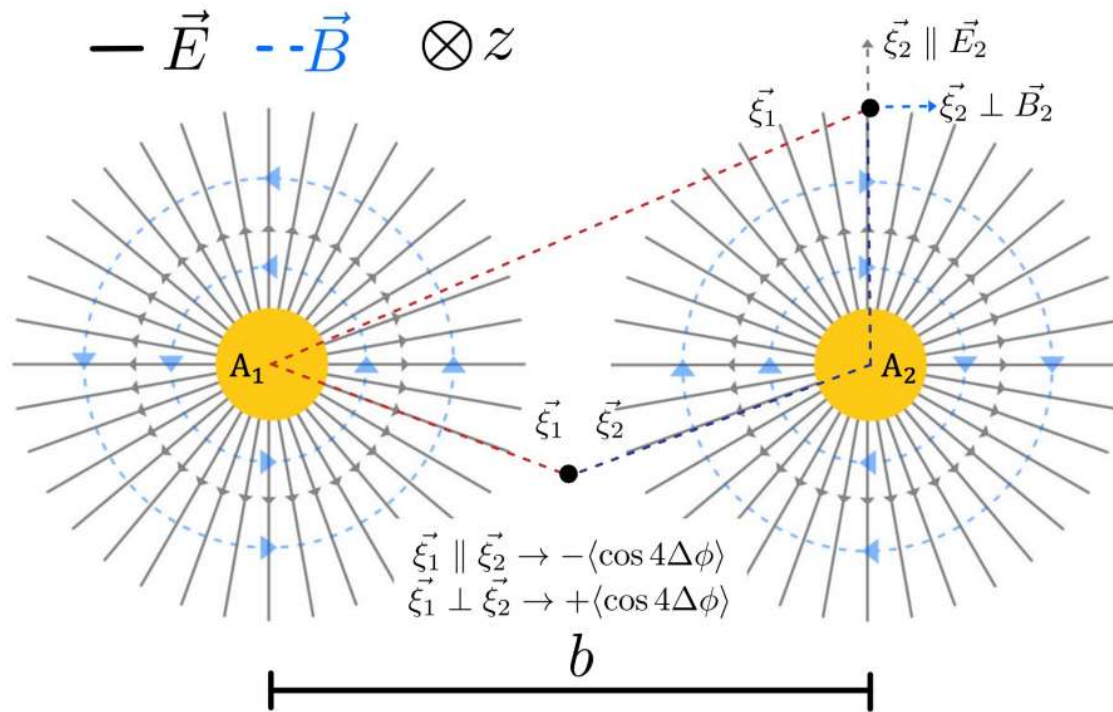
$$\mathcal{R}^0(q_{\perp}) = \frac{d\sigma_{eA}^0}{Z^2 d\sigma_{ep}^0}$$



Z.h. Sun, D.x. Zheng,
J. Zhou, Y.j. Zhou, 2020

- The ratio is suppressed at low q_{\perp} due to CC
- Requires high momentum resolution

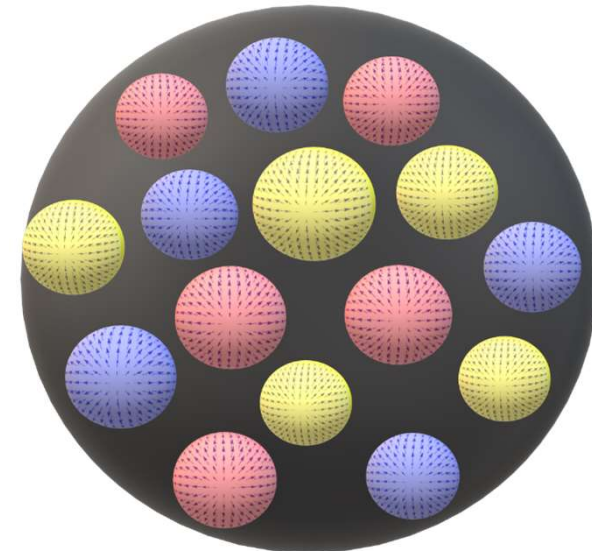
Linear polarization of coherent photons



L. Cong, Y.j. Zhou, ZJ 2019,2020

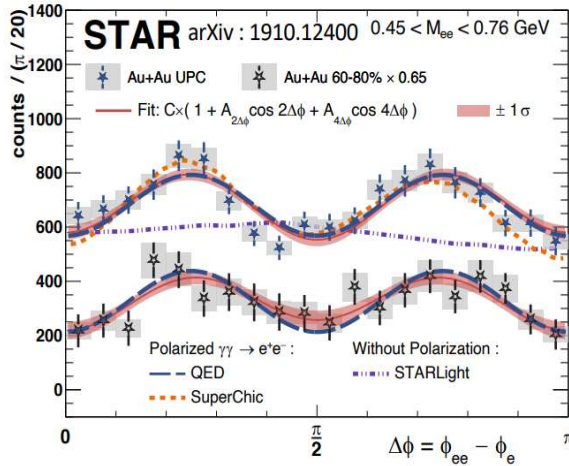
J.D. Brandenburg, CFNS workshop 2021.04

CGC is linearly polarized A. Metz, ZJ; 2011

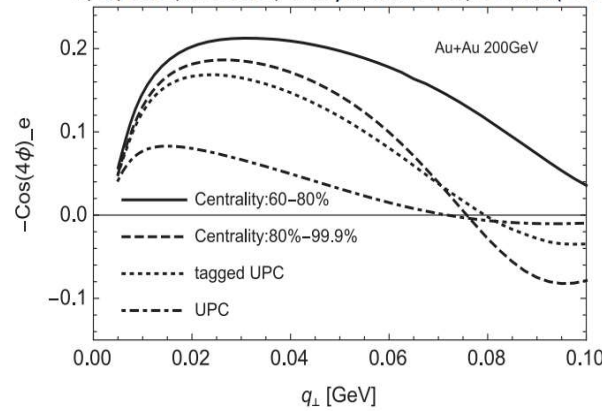


From Daniel Brandenburg

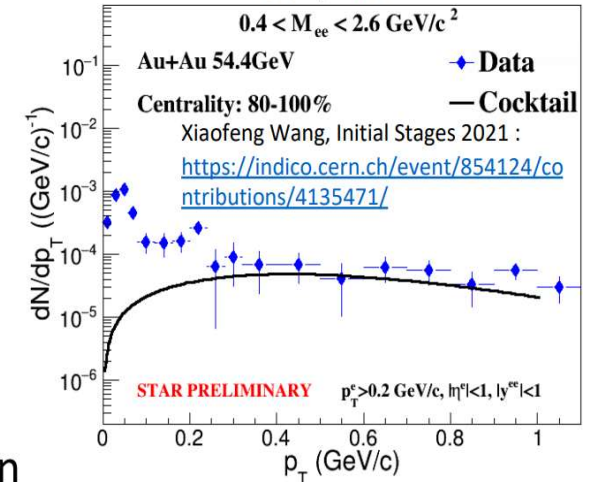
UPC and QED Highlights



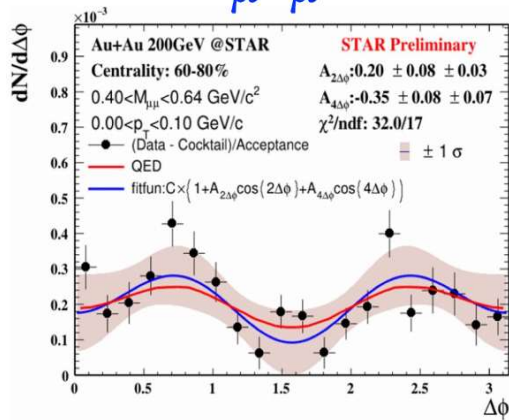
Li, C., Zhou, J. & Zhou, Y. Phys. Rev. D 101, 034015 (2020).



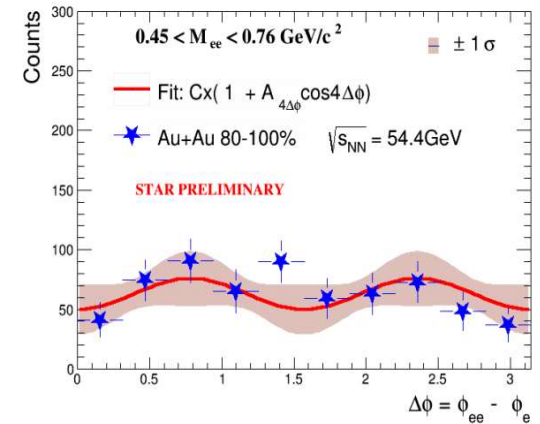
Lower Energy $\sqrt{s_{NN}} = 54.4$ GeV



$\mu^+ \mu^-$ J. Zhou, sQM 2021



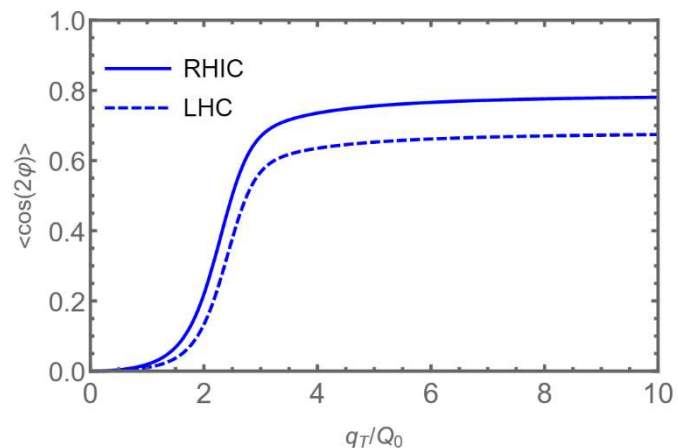
- Now several measurements exist in e^+e^- and $\mu^+\mu^-$
- Need differential measurements of the $\cos 2\Delta\phi$ and $\cos 4\Delta\phi$ to highest P_T possible.
- Measurement in $\sqrt{s_{NN}} = 54.4$ GeV shows hint of 'semi-coherent' interactions or other process
 - Will this contribute to / modify correlations?



Final state collinear photon radiation effect

- Low q_t , linear polarization of photons
- High q_t , perturbative contribution

Combined analysis needed!



Hatta, Xiao, Yuan, ZJ to appear

- ◆ One way to exclude FSI effect:
In DIS experiment, how to reconstruct Q ? the total energy carried by photons and scattered electron is measured.

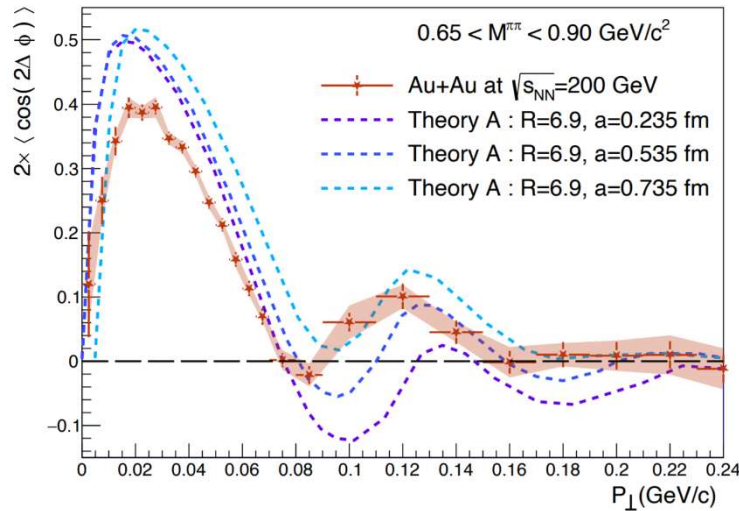
linear polarization of photons firmly established!

As a tool to explore:

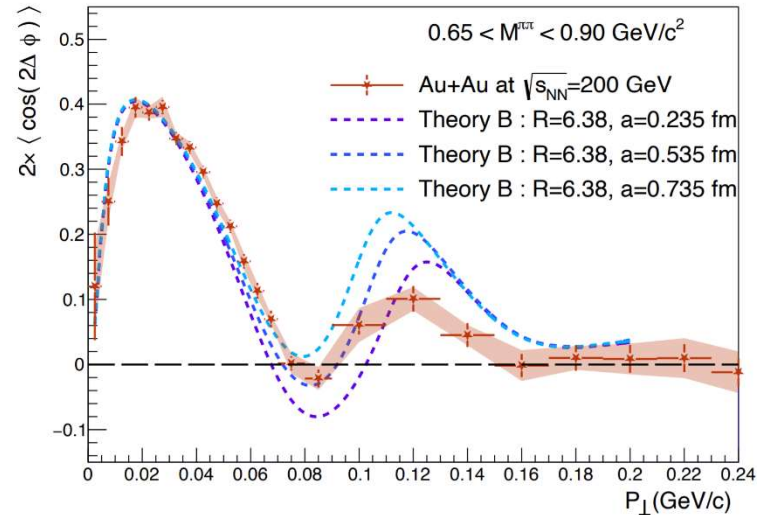
- ◆ QCD phenomenology(vector meson production)
- ◆ BSM physics?

Diffractive pattern at RHIC and EIC

double V.S. single slit interference



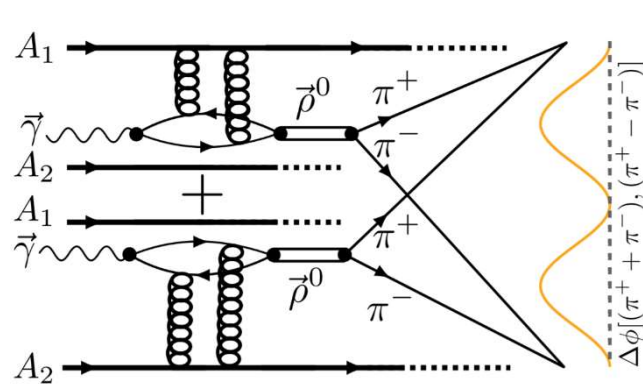
Xing, Zhang, ZJ, Zhou 2020



Zha, Brandenburg, Ruan, Tang, 2021

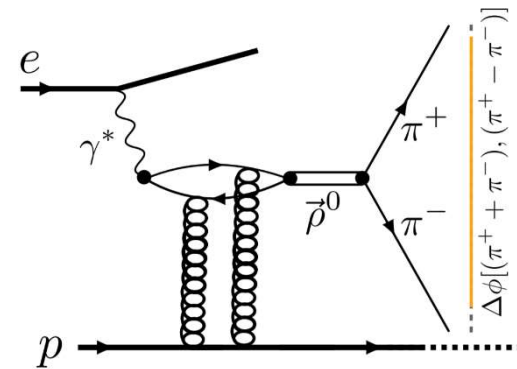
Plots taken from Daniel's talk

- Extremely sensitive to nuclear geometry (spatial gluon distribution)



RHIC

Klein, S. R. & Nystrand, 1999



EIC/EicC

Future plan for RHIC and EIC

- Odd harmonic $\cos\phi$, $\cos 3\phi$ for ρ
- Azimuthal asymmetries in J/Psi.

◆ Azimuthal asymmetries in J/Psi, ρ at EIC

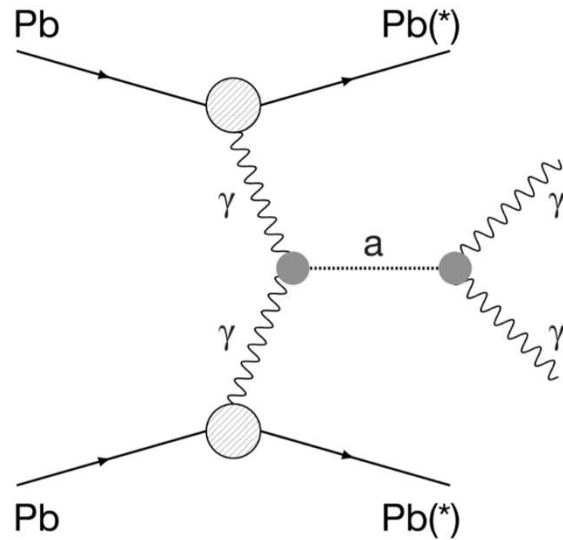
- Complementary ways to constrain gluon spatial distribution

Open question: Vacuum birefringence in UPCs

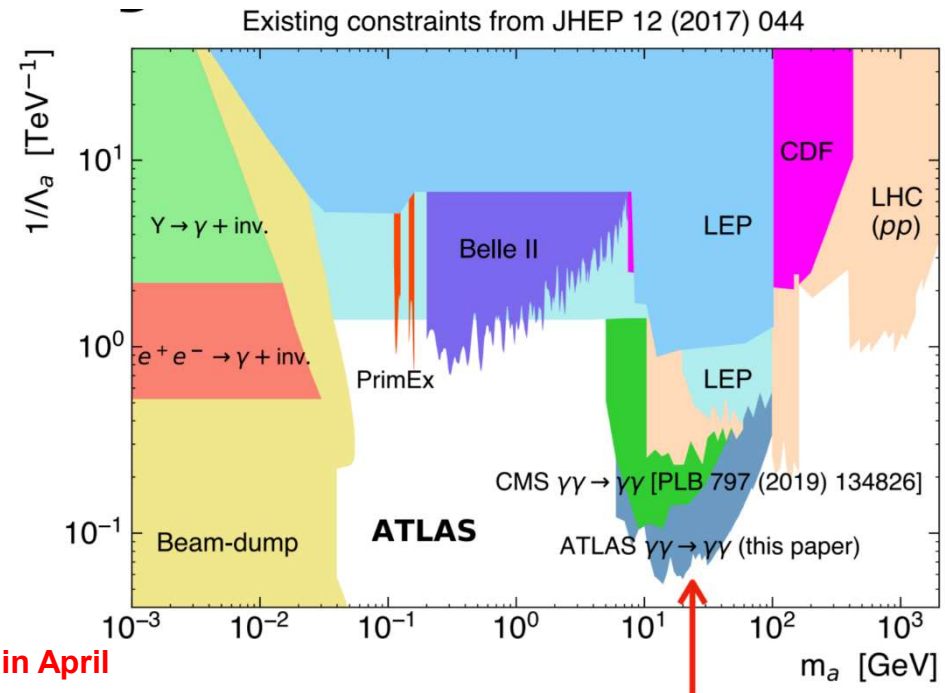


Taken from Koichi Hattori

New physics search in photon-photon collisions



Taken from Peter Steinberg's talk in April



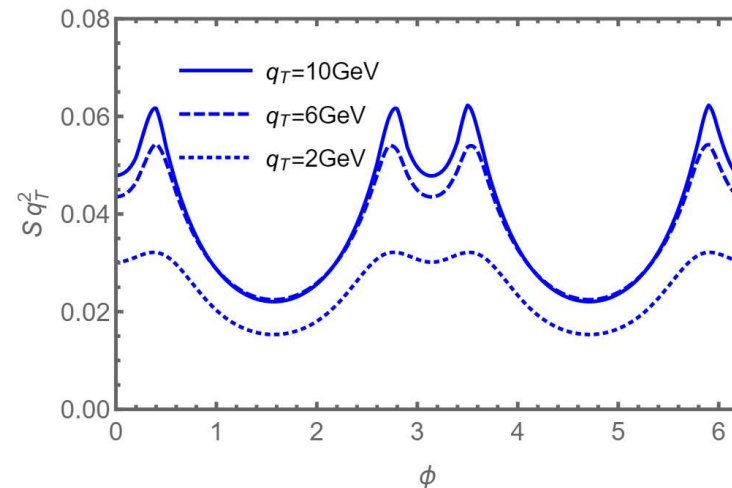
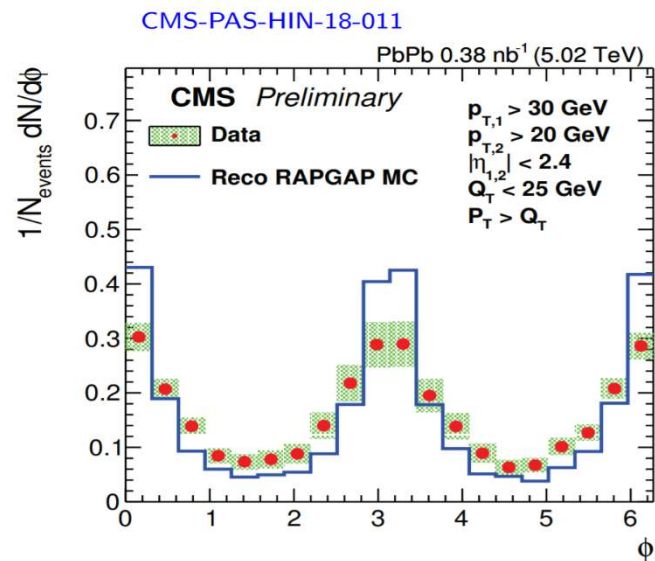
- Great potential to constrain axion-photon coupling
- Constrain axion-gluon coupling in photon-nuclear reaction
- Cleaner background at EIC

work in progress... Hong Zhang, ZJ...

- Overlap with the session: Initial Conditions and Gluon distributions

Some other important topics

- LbyL scatterings: **avenue to BSM**
- (threshold) production of J/psi in pA collisions: **Trace anomaly, E_g**
- Exclusive di-jet production in UPC: **elliptic gluon distribution**
-



Hatta, Xiao, Yuan, ZJ to appear