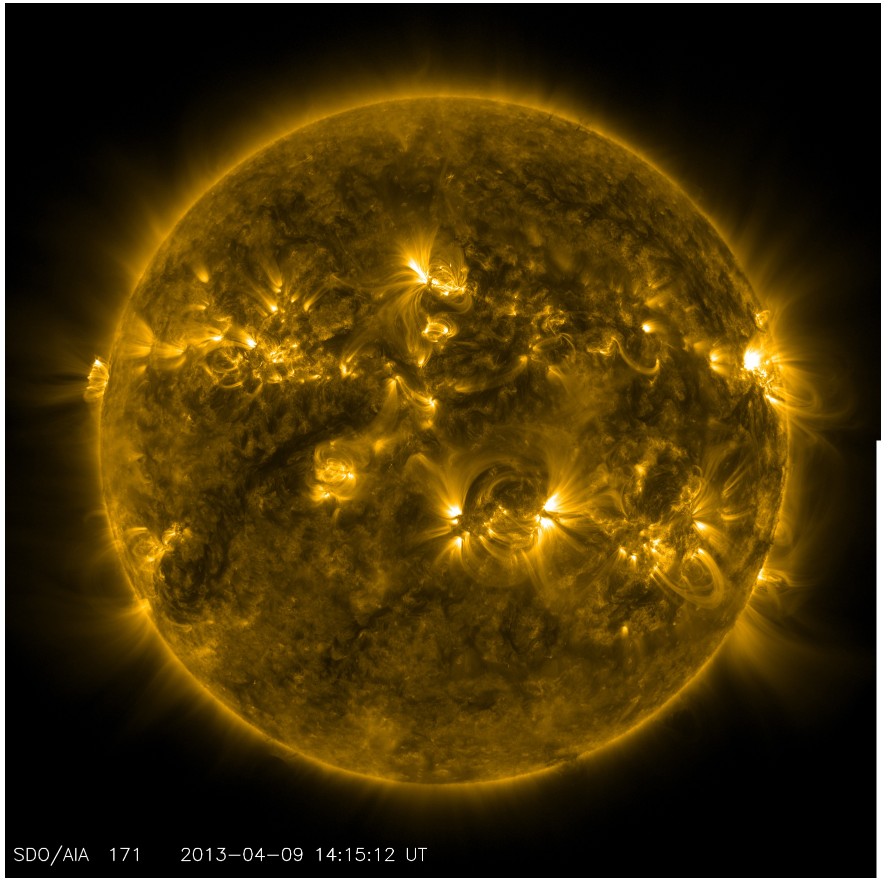
UPC physics in Heavy-ion collisions (EF07)



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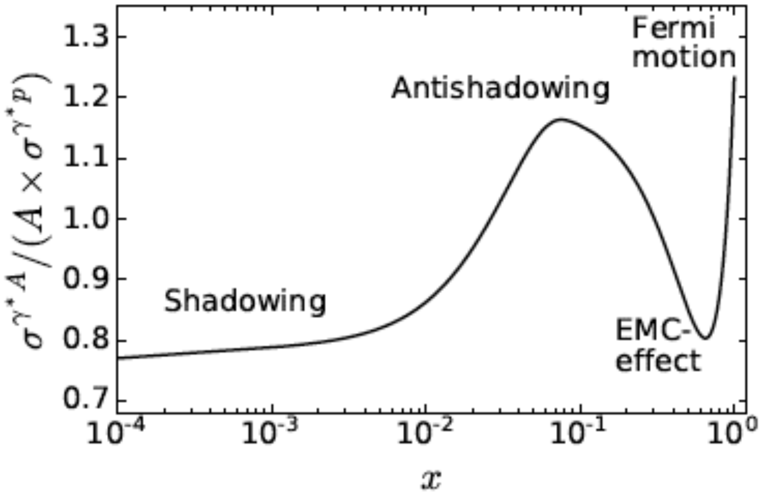

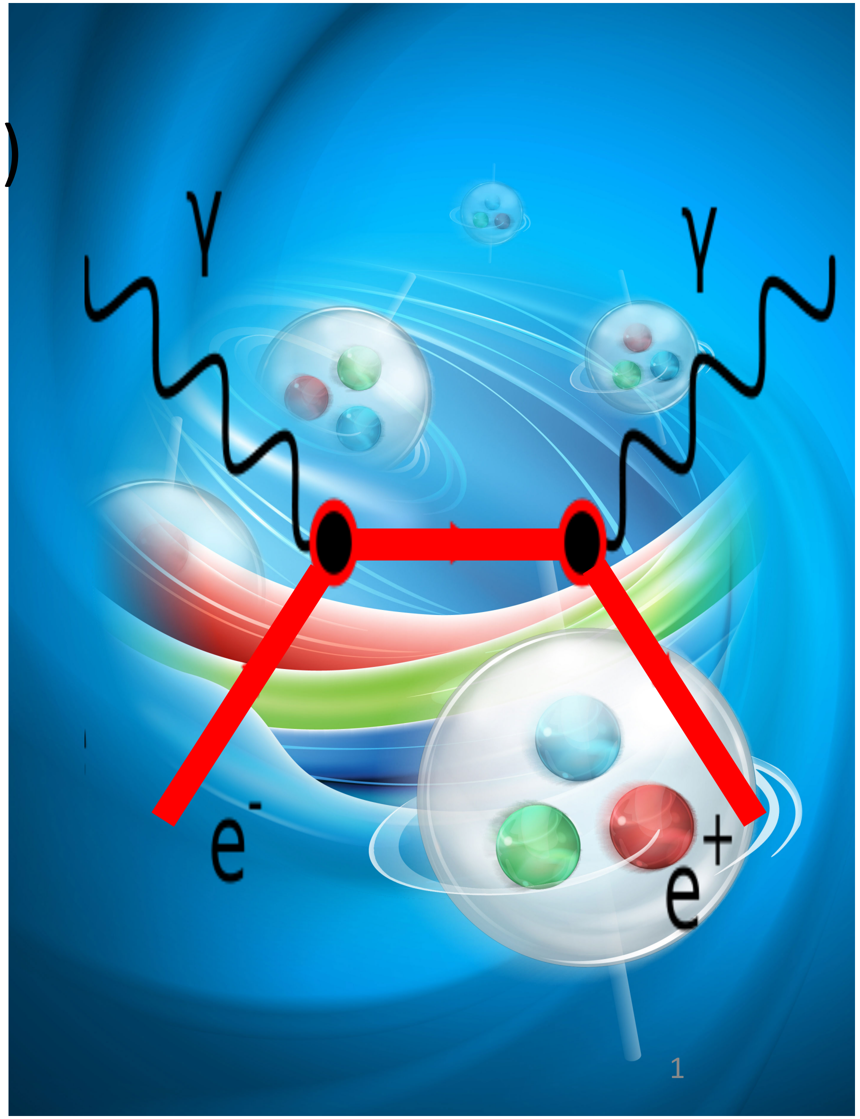

EF07: Ultra-Peripheral Collisions in Heavy-Ion Physics

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ABSTRACT

Ultraperipheral collisions (UPCs) of heavy ions at RHIC and LHC offer great opportunities to study strong field QED, EM/color charge fluctuations, collective phenomenon, electromagnetic properties of QGP, search BSM physics, and explore 3D nuclear structure with high luminosity beams of linearly polarized photons from Lorentz-boosted Coulomb field. Among these exciting directions of UPC studies, we select a few important new developments and emphasize on the polarization dependent effects in photon-photon processes and photon-nuclear interactions, and the processes as an electromagnetic probe of QGP properties.

Sections to be merged with EF06 UPC

- **Photon-nucleus/nucleon interactions**
  - Linearly polarized photon-gluon collisions
    Gluon Shadowing and Imaging,
    azimuthal distribution of polarization
  - Ultraperipheral pA collisions
    Polarized proton (GPD)
  - Photoproduction in non-UPC A+A collisions
    accompanying QGP creation

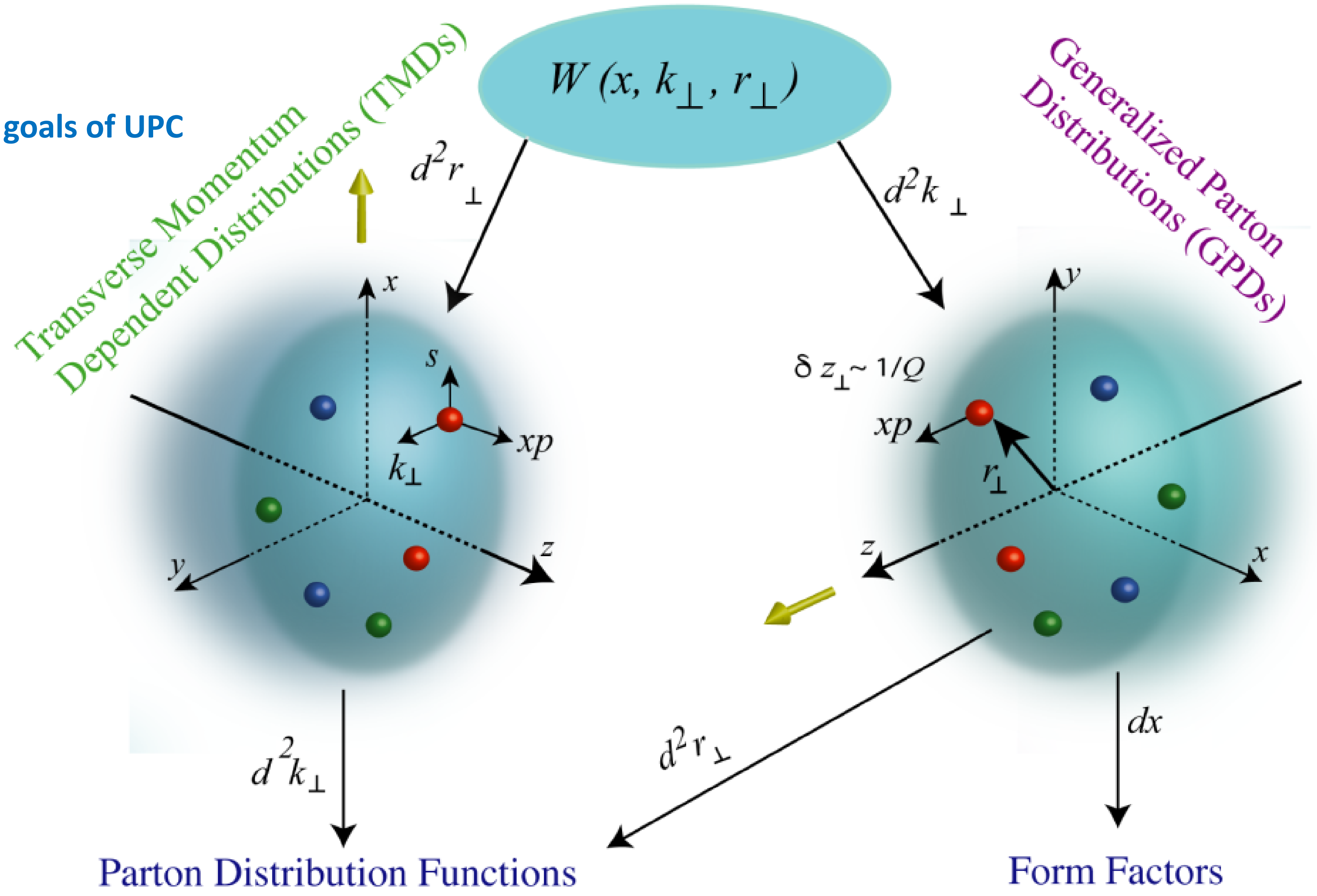
- **Photon-photon to dilepton process**
  - Extreme QED field
    Breit-Wheeler process,
    Wigner function,
    Sudakov effect,
    Coulomb Correction
  - Dilepton as a probe in HI collisions
    Final-state magnetic field,
    Coulomb scattering,
    Azimuthal anisotropy

One of the main hurdles on extracting quantitative information is how we model precisely the QED WW photon source emission and transverse dynamics!

Contact experts and assign section writers

Wigner Distributions

One of the main goals of UPC and also EIC



Y. Hatta

1 Photon-nucleus/nucleon interactions

1.1 Linearly polarized photon-gluon collisions

The diffractive photoproduction of vector mesons at RHIC and LHC can probe the gluon momentum and space distribution inside nuclei and is the closest to the gluon imagining an electron-ion collider will perform in the near future. The diffractive vector meson production in UPCs[1–12] is the dominant channel of photon-nuclear interactions. Recent experimental studies have probed nuclear effects such as gluon shadowing in an unprecedented way, but more systematic studies are needed to address several open questions[13–23]. For example, there are still uncertainties hindering the extraction of the gluon distribution at a quantative level due to the uncertainty of the photon source generated by the heavy-ion Coulomb field, the separation of coherent diffractive production from the incoherent process, and a model with matching precision on the data. One alternative is to address these aspects from a new angle with the polarization dependent observables in UPCs. The significant $\cos 2\phi$ and $\cos 4\phi$ modulations in diffractive ρ^0 production have been reported by STAR collaboration[24]. A recent analysis[25] shows that the $\cos 2\phi$ asymmetry essentially results from the linearly polarization of incident coherent photons. The obtained transverse momentum dependent $\cos 2\phi$ asymmetry has a distinctive diffractive pattern which is sensitive to the nuclear geometry, the quantum interference effect[26–28], and the production mechanism (coherent/incoherent). To reproduce such a diffractive pattern, it is crucial to derive a joint impact parameter and transverse momentum dependent cross sections, which is also important for reliably extracting the transverse spatial distribution of gluons inside a nucleus. Similar measurements of azimuthal harmonic distributions of J/ψ at RHIC and LHC are feasible and will allow more reliable comparison to the QCD calculations. In addition, more experimental measurements and theoretical developments on the Fourier transformation of the gluon distribution with multiple azimuthal harmonics with the linearly polarized photon as a probe are required.

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Imaging the nucleus with high-energy photons

Klein and Mantysaari, Nature Reviews Physics 1 (2019) 662

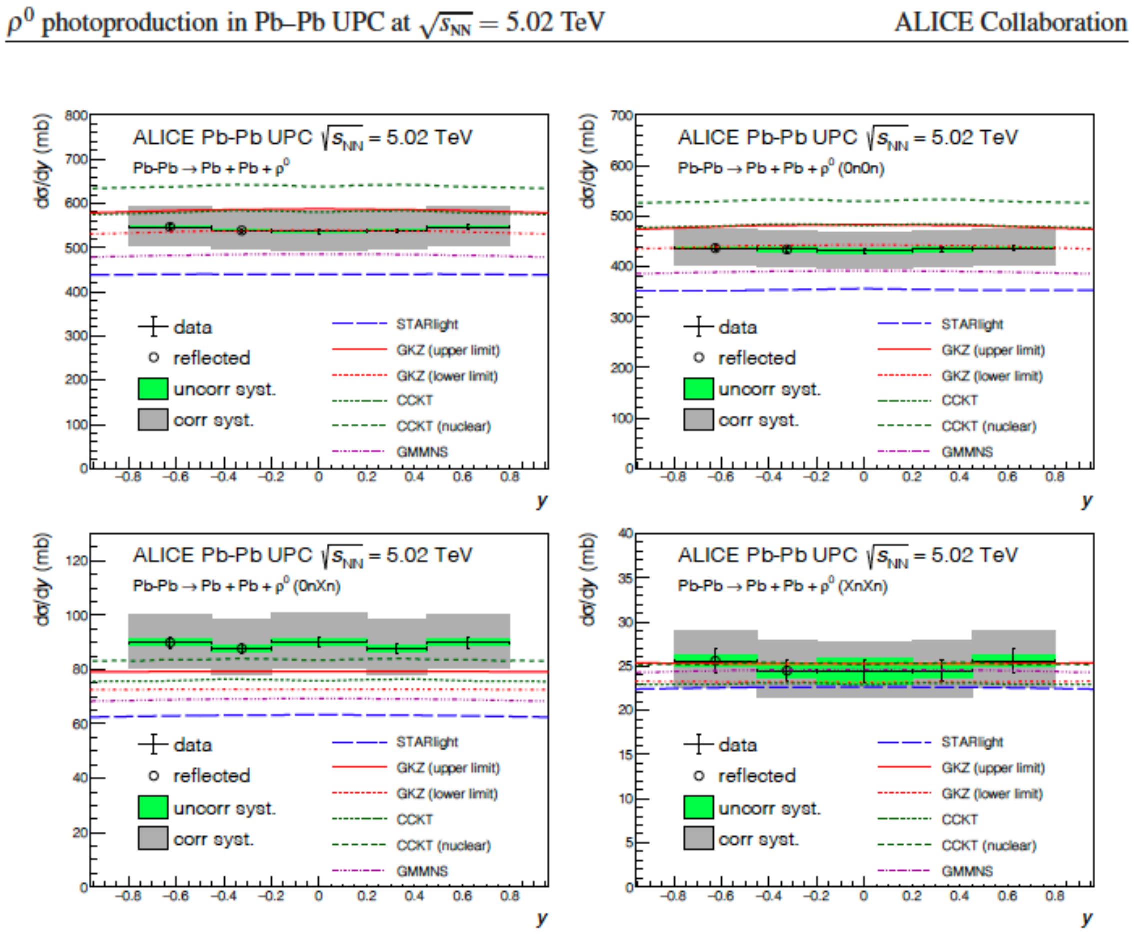


Figure 5: (Colour online). Cross section for the coherent photoproduction of ρ^0 vector mesons in Pb–Pb UPC as a function of rapidity for no forward-neutron selection (top left), and for the 0n0n (top right), 0nXn (bottom left) and XnXn (bottom right) classes. The lines show the predictions of the different models described in the text.

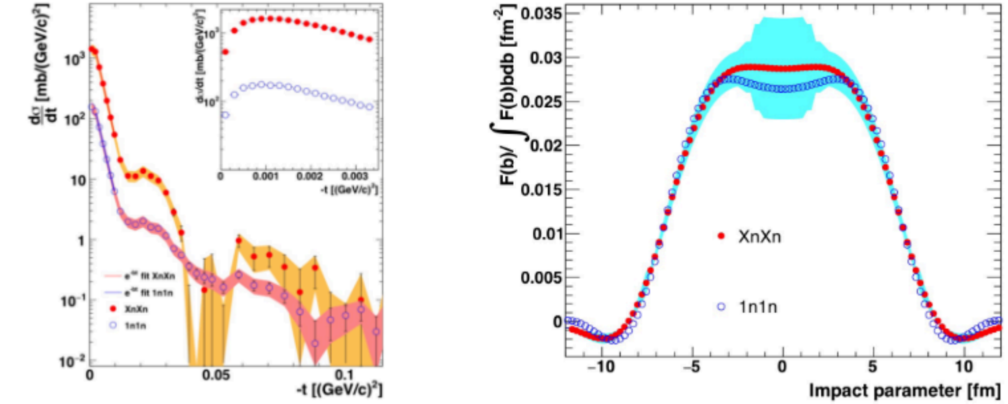
ALICE, JHEP06 (2020) 35

★ **STAR focus: STAR uses photons to probe the structure of gold nuclei**

The STAR Collaboration has recently published "Coherent diffractive photoproduction of ϱ^0 mesons on gold nuclei at 200 GeV/nucleon-pair at the Relativistic Heavy Ion Collider," in Physical Review C 96, 054904 (2017).

This paper reports on a special type of heavy-ion interaction, where the ions do not physically collide, but interact via a long-range electromagnetic interaction, whereby photons emitted by one nucleus probe the structure of the other nucleus. The photons come from the electric and magnetic fields carried by the highly charged nuclei. The electric fields radiate radially outward, while magnetic fields circle the ion's trajectory. The two fields are perpendicular, just like those of a photon, and they can be treated as such.

In the reaction considered here, the photon may be thought of as briefly fluctuating to a quark-antiquark pair, as allowed by the Heisenberg uncertainty principle. Quark-antiquark pairs are mesons; this photon fluctuation acts like a meson with the same quantum numbers (spin one and negative parity) as the photon. These virtual (short-lived) mesons can scatter from the target nucleus, and emerge as real mesons.

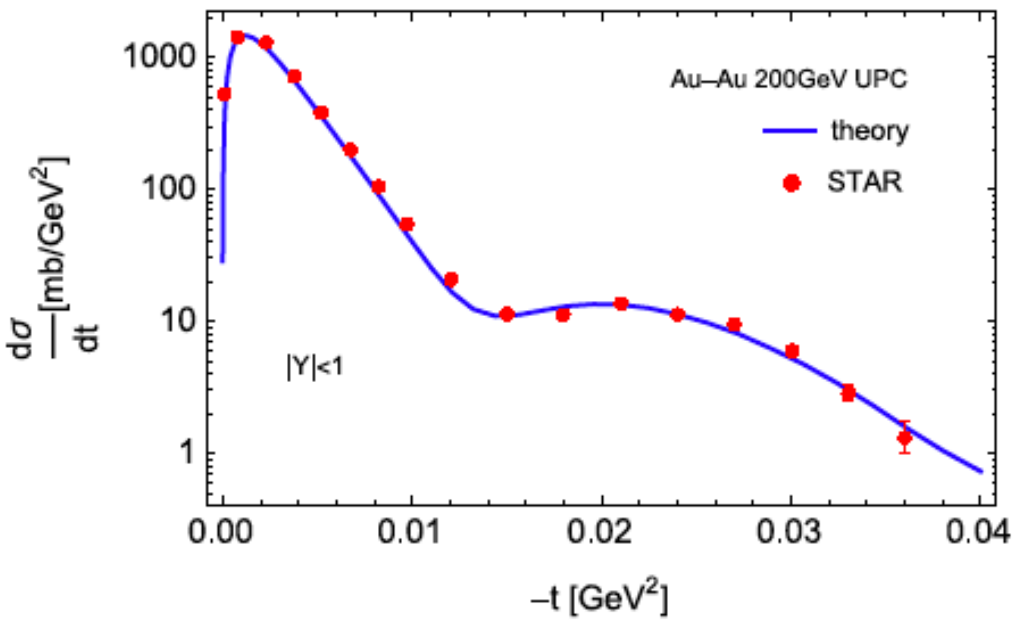


Left: The cross-section as a function of t, the squared momentum transfer to the nucleus. The dips and peaks are a diffraction pattern, akin to the pattern made by a 2-slit interferometer. 'XnXn' and '1n1n' are two different STAR data samples.The inset shows the distribution for very small momentum transfers. **Right:** The two-dimensional Fourier transform of the left panel, showing the density of the interaction sites in the nucleus, as a function of transverse distance from its center. This is a map of where the mesons interacted in the target. Although there is considerable systematic uncertainty (the blue region) near the center of the target, the edges of the nuclei are well defined.

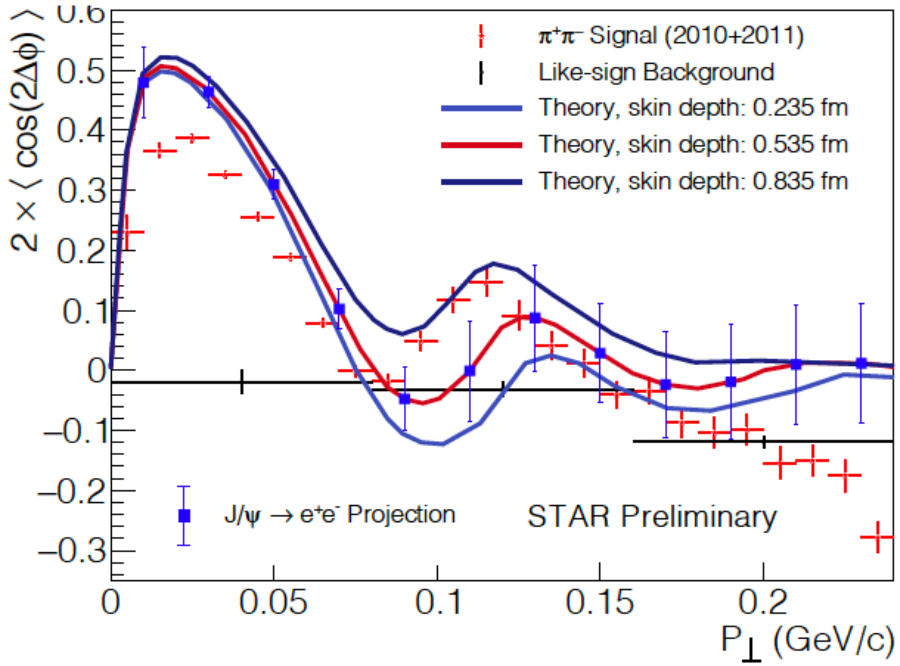
The photons scatter equally from protons and neutrons. But, we can't tell which proton or neutron an individual meson scattered from. In quantum mechanics, we add the amplitudes to scatter from each target meson. The amplitude is a complex number with a phase which depends on the meson momentum and the position of the target nucleon. By studying how the scattering probability varies with the momentum transfer to the nucleus, we can image the matter distribution in the target. The left panel shows the scattering probability as a function of the square of the momentum transfer ('t') for two different STAR data samples. The dips are due to diffraction, like the fringes seen in the classic two-slit diffraction pattern, but with a circular target.

What new and necessary for quantitative Imaging?

- Gluon Shadowing/saturation
- Transverse Momentum Distribution (TMD)
- Photons and Gluons are linearly polarized
- Interference



$$\frac{d\sigma}{d^2q_\perp dY d^2\tilde{b}_\perp} = \frac{1}{(2\pi)^4}\int d^2\Delta_\perp d^2k_\perp d^2k'_\perp \delta^2(k_\perp+\Delta_\perp-q_\perp)(\epsilon_\perp^{V*}\cdot\hat{k}_\perp)(\epsilon_\perp^{V}\cdot\hat{k}'_\perp)\Big\{\int d^2b_\perp$$
$$\times e^{i\tilde{b}_\perp\cdot(k'_\perp-k_\perp)}\left[T_A(b_\perp)\mathcal{A}_{in}(Y,\Delta_\perp)\mathcal{A}^*_{in}(Y,\Delta'_\perp)\mathcal{F}(Y,k_\perp)\mathcal{F}(Y,k'_\perp)+(A\leftrightarrow B)\right]$$
$$+\left[e^{i\tilde{b}_\perp\cdot(k'_\perp-k_\perp)}\mathcal{A}_{co}(Y,\Delta_\perp)\mathcal{A}^*_{co}(Y,\Delta'_\perp)\mathcal{F}(Y,k_\perp)\mathcal{F}(Y,k'_\perp)\right]$$
$$+\left[e^{i\tilde{b}_\perp\cdot(\Delta'_\perp-\Delta_\perp)}\mathcal{A}_{co}(-Y,\Delta_\perp)\mathcal{A}^*_{co}(-Y,\Delta'_\perp)\mathcal{F}(-Y,k_\perp)\mathcal{F}(-Y,k'_\perp)\right]$$
$$+\left[e^{i\tilde{b}_\perp\cdot(\Delta'_\perp-k_\perp)}\mathcal{A}_{co}(Y,\Delta_\perp)\mathcal{A}^*_{co}(-Y,\Delta'_\perp)\mathcal{F}(Y,k_\perp)\mathcal{F}(-Y,k'_\perp)\right]$$
$$+\left[e^{i\tilde{b}_\perp\cdot(k'_\perp-\Delta_\perp)}\mathcal{A}_{co}(-Y,\Delta_\perp)\mathcal{A}^*_{co}(Y,\Delta'_\perp)\mathcal{F}(-Y,k_\perp)\mathcal{F}(Y,k'_\perp)\right]\Big\}, \qquad (2.14)$$



Xing, et al., arXiv: 2006.06206

1.2 Ultraperipheral pA collisions

The 3D gluonic tomography of a nucleon can be studied before the operation of EIC in ultraperipheral pA collisions, where the photons generated from the Lorentz-boosted field from a nucleus interact with the gluons inside the nucleon. It has been proposed to constrain the gluon Wigner distribution in a nucleon by measuring the exclusive diffractive dijet production process in UPCs at RHIC, LHC[29] as well as at EIC[30–33]. In particular, the elliptical gluon Wigner distribution[30] describing the correlation between $b_\perp$ and the gluon transverse momentum can be accessed via a $\cos 2\phi$ azimuthal asymmetry. An unexpectedly large $\cos 2\phi$ asymmetry in diffractive dijet production has been observed in a recent measurement by the CMS collaboration[34] in AA collisions, whose quantitative connection to the elliptic gluon Wigner distribution requires further exploration. In addition to the nucleon 3D imaging, the proton mass decomposition also can be addressed in ultraperipheral pA collisions[35] similar to that in ep collisions[36]. One of the most interesting contributions to the intrinsic proton mass is the trace anomaly, or the gluon condensate contribution which can be probed via diffractive J/ψ production in ultraperipheral pA collisions where the nucleus merely acts as a source of quasi-real photons. The challenge is that one has to detect J/ψ in the very forward, low transverse momentum region. This may be possible after the forward upgrades at RHIC and LHC. A unique capability to probe the generalized gluon distribution function (GPD E_g) with the collider mode at RHIC and the fixed-target mode at the LHC is to use the polarized proton source in ultra-peripheral pA collisions[37–39].

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Polarized target UPCs → Generalized Parton Distributions

Photoproduction w/ polarized protons

Target particle polarized proton p↑,

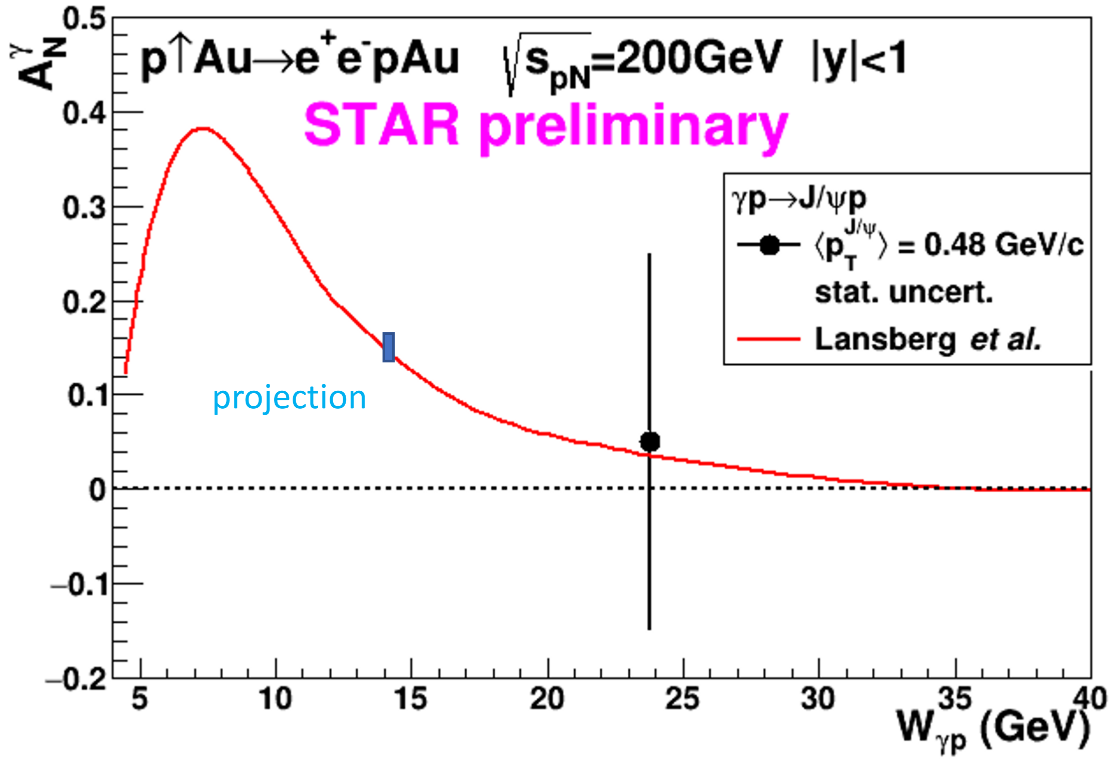
J/ψ photoproduction $d\sigma/d\phi \propto 1 + A^{\gamma}_{N} \cos(\phi)$ (ϕ azimuthal angle)

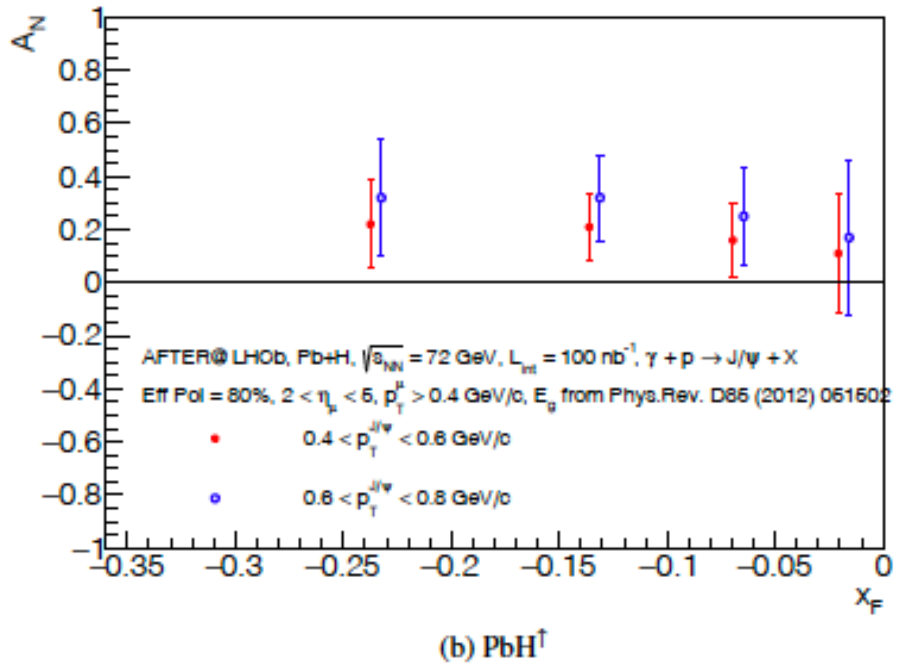
37. Lansberg, J., Massacrier, L., Szymanowski, L. & Wagner, J. Single-Transverse-Spin Asymmetries in Exclusive Photo-production of J/ψ in Ultra-Peripheral Collisions in the Fixed-Target Mode at the LHC and in the Collider Mode at RHIC. *Phys. Lett. B* **793**, 33–40, DOI: https://doi.org/10.1016/j.physletb.2019.03.061 (2019). https://arxiv.org/abs/1812.04553.

A^{γ}_{N} calculable with GPDs: $$A^{\gamma}_{N} \propto p_T \cdot \frac{\mathrm{Im}(H^g \cdot E^{g*})}{|H^g|^2}$$

$A^{\gamma}_{N} \propto E^g \Rightarrow$ sensitive to gluon orbital angular momentum L_g

UPC J/ψ production in p↑Au 2015:





(b) PbH↑

Figure 7: STSAs in the exclusive J/ψ photo-production in UPCs with a proton beam (a) and a lead beam (b) on an transversely polarised hydrogen target.

1.3 Photoproduction in non-UPC heavy-ion collisions

The ALICE Collaboration at the LHC has pioneered the experimental measurements of the photoproduction of J/ψ at low transverse momentum in non-UPC heavy-ion collisions[40], accompanying the more violent hadronic collisions. More detailed study of the diffractive $|t|$ distribution by the STAR Collaboration at RHIC[41] has shown that the $|t|$ distribution is more consistent with the coherent process than the incoherent process. Although models[42,43] incorporating different partial coherent photon and nuclear interactions could explain the yields, it remains unclear how the coherent process happens and whether final-state effects play any role[44]. Resolving this puzzle with high statistics data and detailed $|t|$ distributions at different centralities at RHIC and the LHC may be important for understanding what defines the coherence of the photoproduction and how vector mesons are formed in the process.

40. ALICE Collaboration, J., Adam *et al.* Measurement of an excess in the yield of j/ψ at very low p_T in pb–pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. *Phys. Rev. Lett.* **116**, 222301, DOI: https://doi.org/10.1103/PhysRevLett.116.222301 (2016).

41. STAR Collaboration, J., Adam *et al.* Observation of excess J/ψ yield at very low transverse momenta in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{\rm NN}} = 193$ GeV. *Phys. Rev. Lett.* **123**, 132302, DOI: https://doi.org/10.1103/PhysRevLett.123.132302 (2019). https://arxiv.org/abs/1904.11658.

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J/Psi photoproduction in A+A collisions

ALICE observed J/Psi production at low-pt in non-UPC events;
STAR shows that the t distribution is consistent with photoproduction.
How does this happen?

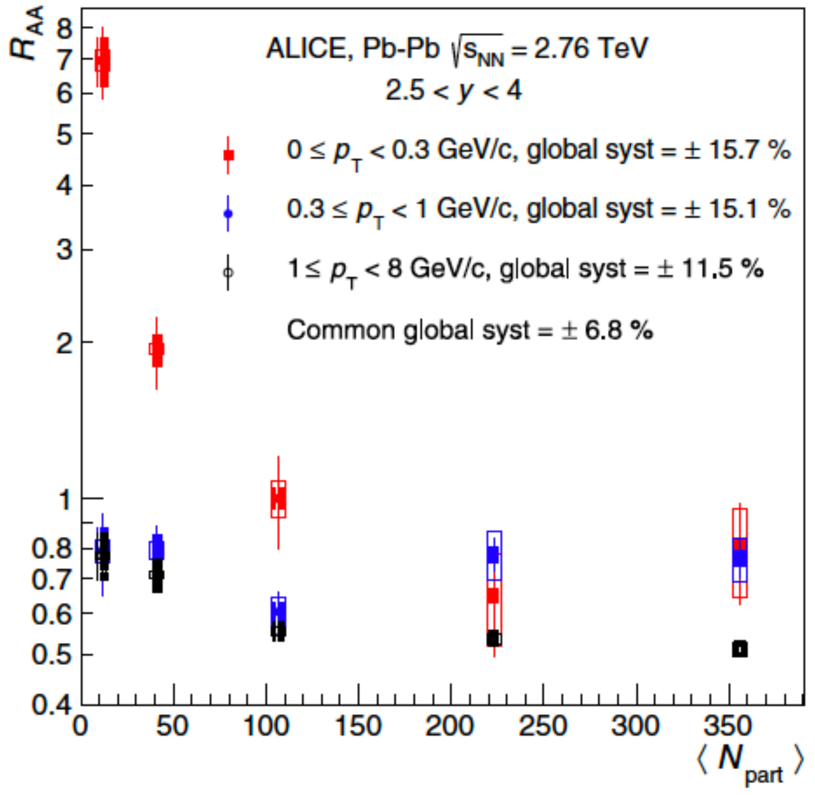
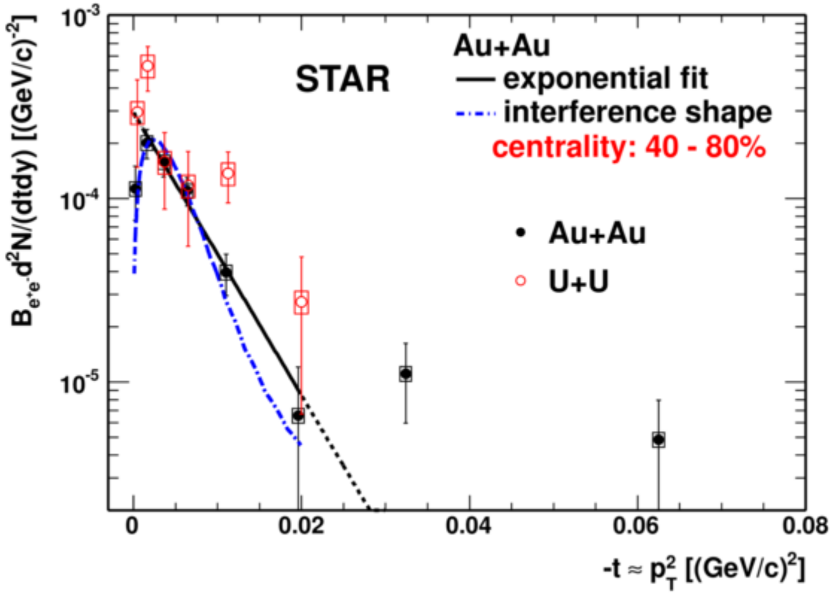


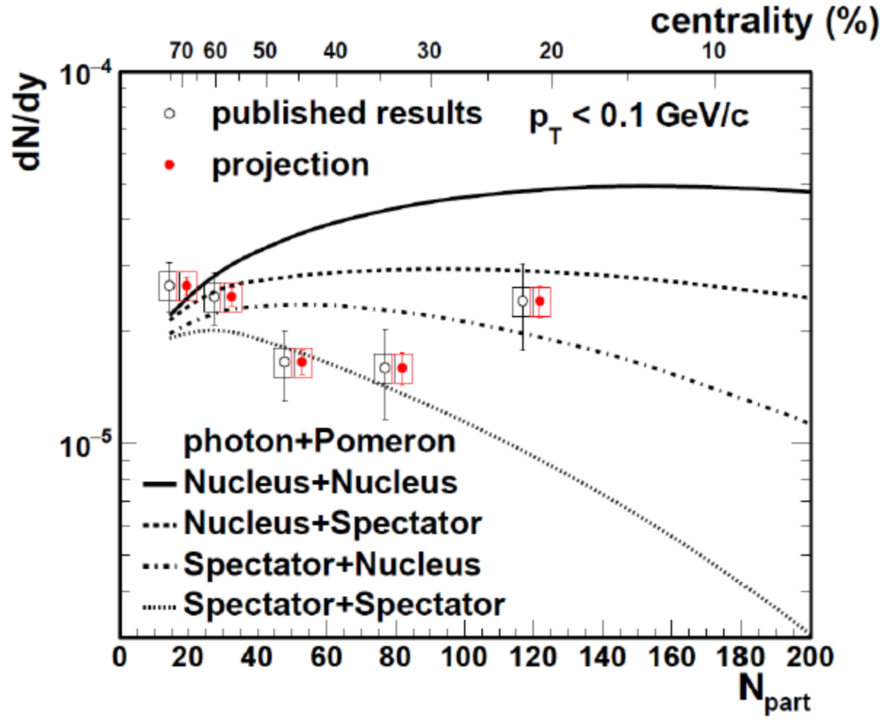
FIG. 3. J/ψ R_{AA} as a function of $\langle N_{part}\rangle$ for 3 p_T ranges in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. See text for details on uncertainties. When assuming full transverse polarization of the J/ψ in Pb-Pb collisions, as expected if J/ψ are coherently photoproduced, the R_{AA} values increase by about 21% in the range $0 < p_T < 0.3$ GeV/c.

Can try to treat the systems in different zones,
but is it correct?

What defines "coherent"?

Are there final-state effects?





2 Photon-photon to dilepton process

2.1 Extreme QED field

It was perceived that photons participating in UPC events are quasi-real with transverse-momentum $k_t = 1/R$ (30 MeV/c) reflecting the virtuality and uncertainty principle of their origin. This led to the assumptions in models employing the equivalent photon approximation (EPA)[45–47] that the dilepton initial transverse momentum does not depend on impact parameter and the transverse space coordinates where the pair are created are randomly distributed based on the same principles. The new measurements of centrality dependence and azimuthal distributions at RHIC[1,48–50] and LHC[3,51–54] have shown that the photons behave like real photons in all observables. The models and theories have demonstrated that the correction to the real photon approximation is suppressed at the order of $1/\gamma^2$ even in the transverse momentum distribution of the pairs. The discovery of the Breit-Wheeler process and the utilization of linearly polarized photons in UPCs are conceptually and experimentally highly nontrivial[50]. With future high statistics data with larger acceptance in UPC at RHIC and LHC, we can explore the phase space of photon collisions in transverse momentum, rapidity and momentum-space-spin correlations in extreme QED fields[55,56]. More importantly, these measurements provide a precision calibration necessary for the photons as sources for the photonuclear processes discussed in the previous section.

The lowest order QED calculation[45–47] of lepton pair production via photon-photon fusion process with the EPA as the input for photon flux can describe the unpolarized cross section measured by RHIC and LHC[49,51,53,54] quite well. It was recently realized that the coherent photons are highly linearly polarized with the polarization vector being parallel to its transverse momentum direction. A sizable $\cos 4\phi$ azimuthal asymmetry induced by linearly polarized coherent photons was observed in a STAR measurement[50]. A remarkable agreement between the computed asymmetry(16.5%)[55,57] and the measured asymmetry(16.8%±2.5%) in UPCs has been reached. With it being experimentally confirmed, the linearly polarized photon beam in UPCs provides us a new tool to estimate the off-shellness of the coherent photons participating in the Breit-Wheeler process and explore novel QCD phenomenology.

The extreme EM field in UPCs also facilitates searches for the elusive Coulomb correction[58–66]. The total cross section of lepton pair production in UPCs is predicted to be reduced by the Coulomb correction. However, there is no clear evidence of the Coulomb correction found in heavy ion collisions so far[65,66]. The multiple coherent Coulomb rescattering is suppressed by the powers of $q_\perp^2/m_{ee}^2$. To maximally enhance the Coulomb correction, pushing the measurement to the lower invariant mass region is required, which should be feasible at RHIC and LHC with forward instrumentation. It would be even more optimal to study Coulomb correction via a polarization dependent observable, for instance $\cos 4\phi$ asymmetry discussed above, which does not depend on the uncertainty of the heavy ion beam luminosity.

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Old Question with new spin

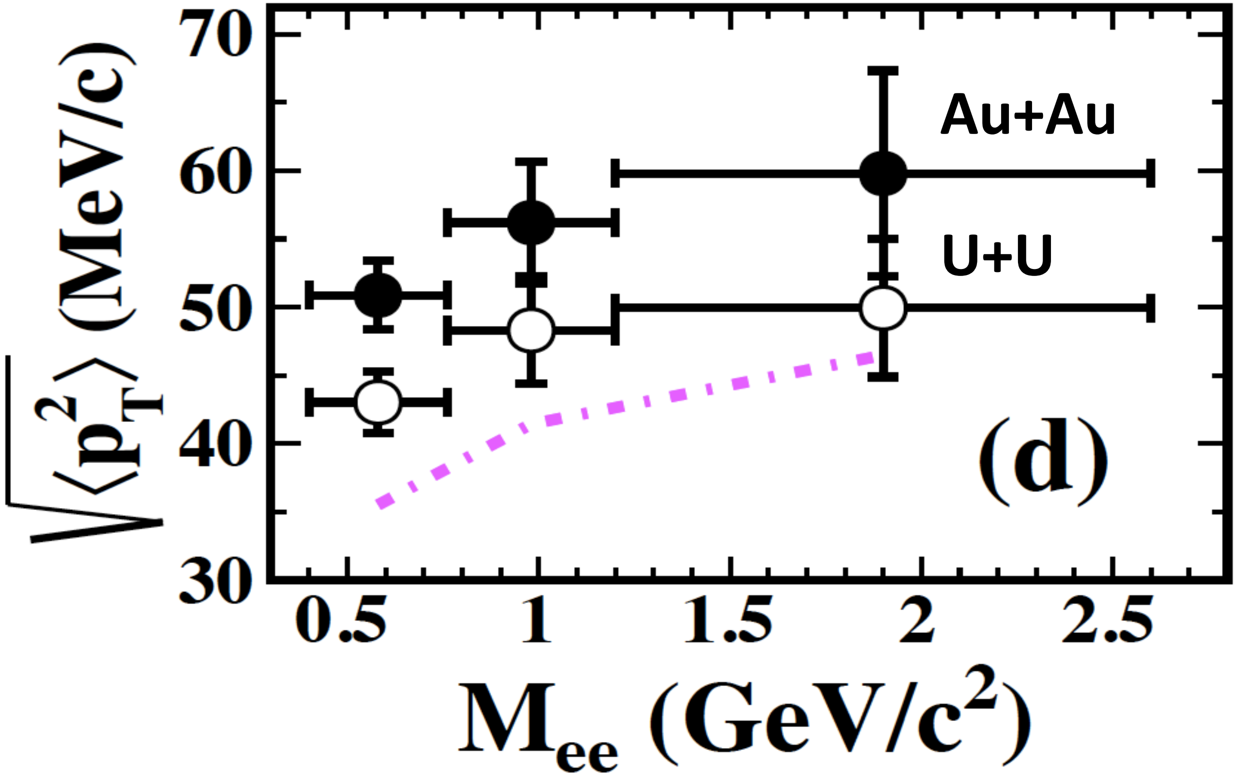
PHYSICAL REVIEW LETTERS 121, 132301 (2018)

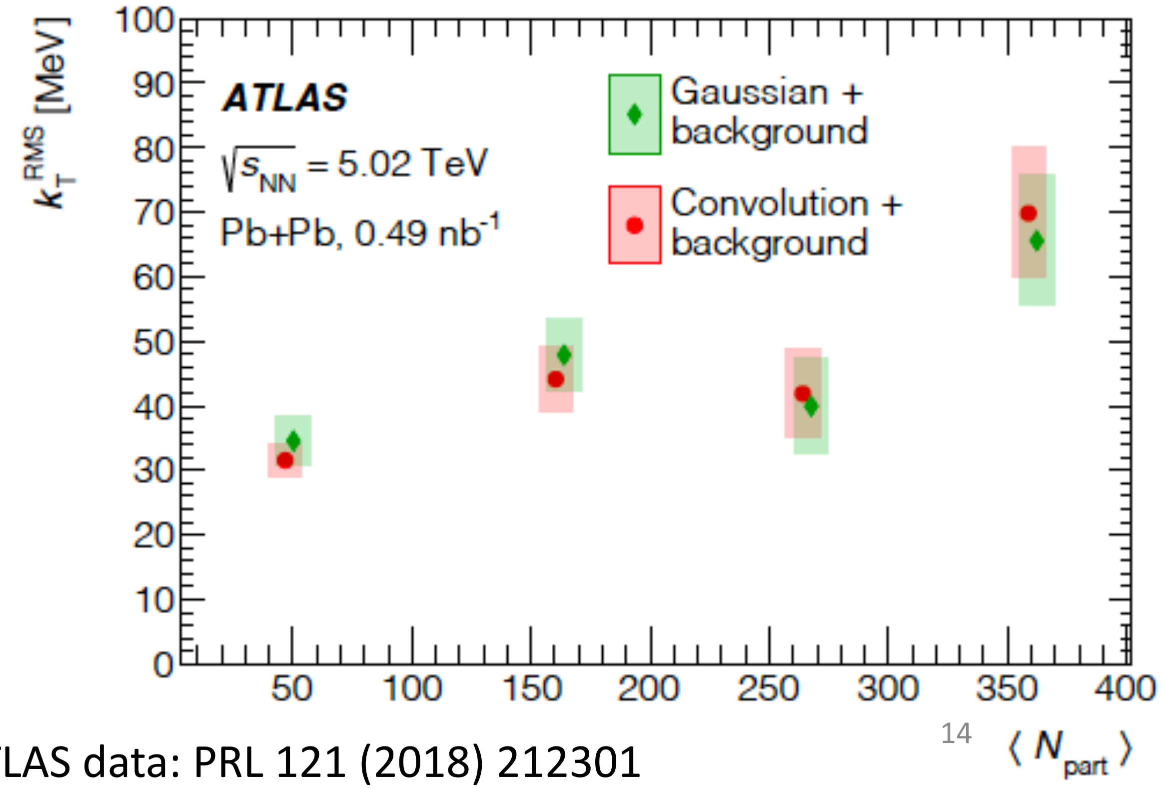
(Received 6 June 2018; revised manuscript received 30 August 2018; published 25 September 2018)

We report first measurements of e^+e^- pair production in the mass region $0.4 < M_{ee} < 2.6$ GeV/c^2 at low transverse momentum ($p_T < 0.15$ GeV/c) in noncentral Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U + U collisions at $\sqrt{s_{NN}} = 193$ GeV. Significant enhancement factors, expressed as ratios of data over known hadronic contributions, are observed in the 40%–80% centrality of these collisions. The excess yields peak distinctly at low p_T with a width ($\sqrt{\langle p_T^2 \rangle}$) between 40 and 60 MeV/$c$. The absolute cross section of the excess depends weakly on centrality, while those from a theoretical model calculation incorporating an in-medium broadened ρ spectral function and radiation from a quark gluon plasma or hadronic cocktail contributions increase dramatically with an increasing number of participant nucleons. Model calculations of photon-photon interactions generated by the initial projectile and target nuclei describe the observed excess yields but fail to reproduce the p_T^2 distributions.

DOI: 10.1103/PhysRevLett.121.132301

This Letter presents a measurement of $\gamma\gamma \to \mu^+\mu^-$ production in Pb+Pb collisions recorded by the ATLAS detector at the Large Hadron Collider at $\sqrt{s_{NN}} = 5.02$ TeV with an integrated luminosity of 0.49 nb^{-1}. The azimuthal angle and transverse momentum correlations between the muons are measured as a function of collision centrality. The muon pairs are produced from $\gamma\gamma$ through the interaction of the large electromagnetic fields of the nuclei. The contribution from background sources of muon pairs is removed using a template fit method. In peripheral collisions, the muons exhibit a strong back-to-back correlation consistent with previous measurements of muon pair production in ultra-peripheral collisions. The angular correlations are observed to broaden significantly in central collisions. The modifications are qualitatively consistent with rescattering of the muons while passing through the hot matter produced in the collision.





ATLAS data: PRL 121 (2018) 212301

Initial Transverse Momentum Broadening

$$\sigma = 16\frac{Z^4e^4}{(4\pi)^2}\int d^2b\int\frac{dw_1}{w_1}\frac{dw_2}{w_2}\frac{d^2k_{1\perp}}{(2\pi)^2}\frac{d^2k_{2\perp}}{(2\pi)^2}\frac{d^2q_\perp}{(2\pi)^2}$$
$$\times\frac{F(-k_1^2)}{k_1^2}\frac{F(-k_2^2)}{k_2^2}\frac{F^*(-k_1'^2)}{k_1'^2}\frac{F^*(-k_2'^2)}{k_2'^2}e^{-i\vec{b}\cdot\vec{q}_\perp} \quad (2)$$
$$\times\left[(\vec{k}_{1\perp}\cdot\vec{k}_{2\perp})(\vec{k}'_{1\perp}\cdot\vec{k}'_{2\perp})\sigma_s(w_1,w_2)\right.$$
$$\left.+(\vec{k}_{1\perp}\times\vec{k}_{2\perp})(\vec{k}'_{1\perp}\times\vec{k}'_{2\perp})\sigma_{ps}(w_1,w_2)\right]$$

Zha, et al., arXiv: 1812.02820
M. Vidovic, et al., Phys.Rev. C47 (1993) 2308

$$dn_i = \frac{Z_i^2\alpha}{\pi^2}\frac{q_{i\perp}^2\left[F\left(q_{i\perp}^2+\frac{w_i^2}{\gamma^2}\right)\right]^2}{\left(q_{i\perp}^2+\frac{w_i^2}{\gamma^2}\right)^2}\frac{d^3q_i}{w_i} \quad (1)$$

arXiv:1005.3531, unpublished

$$\sigma = 16\frac{Z^4e^4}{(4\pi)^2}\int\frac{dw_1}{w_1}\frac{dw_2}{w_2}\frac{d^2k_{1\perp}}{(2\pi)^2}\frac{d^2k_{2\perp}}{(2\pi)^2}\left|\frac{F(-k_1^2)}{k_1^2}\right|^2$$
$$\times\left|\frac{F(-k_2^2)}{k_2^2}\right|^2 k_{1\perp}^2k_{2\perp}^2\sigma(w_1,w_2) \quad (6)$$

Is photon pt really driven by uncertainty principle and independent of position-momentum correlation?

S. Klein, et al. Comput.Phys.Commun. 212 (2017) 258-268

we can afford many mistakes in the search.
The main thing is to make them as fast as possible.
– John Archibald Wheeler
doi:10.1063/1.3120895

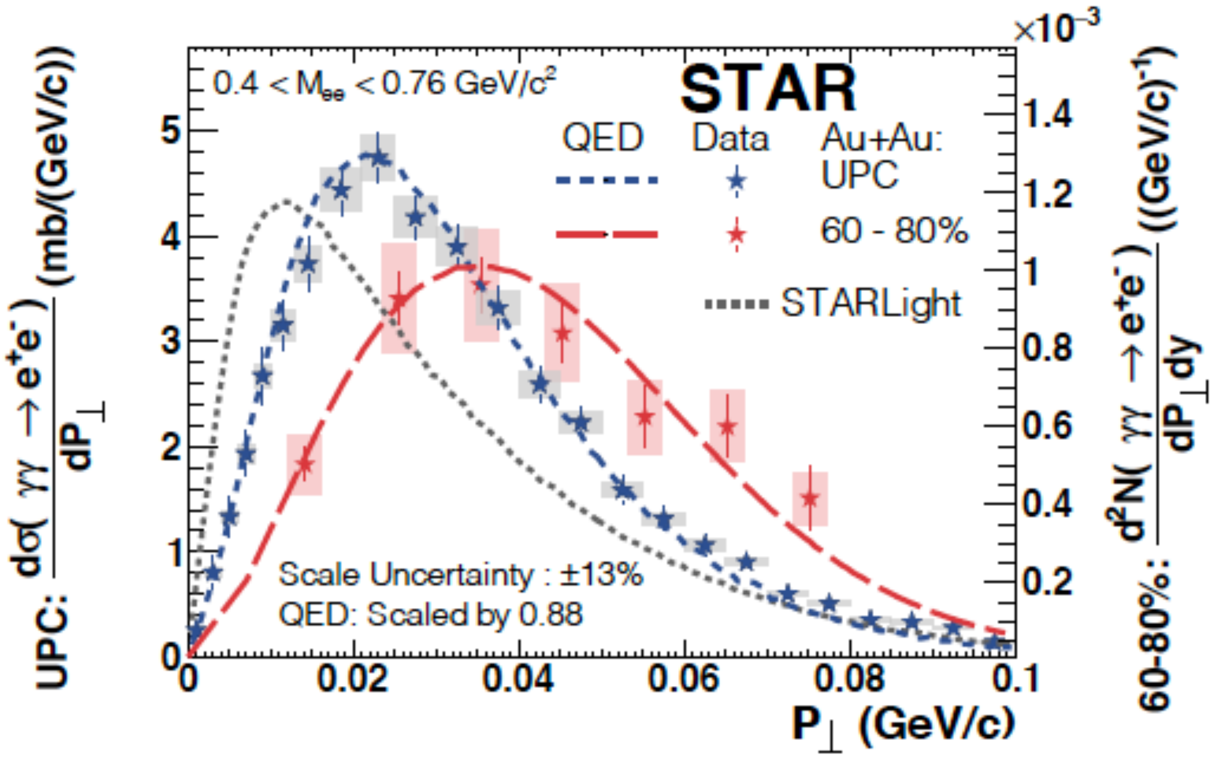
Photon TMD in UPC

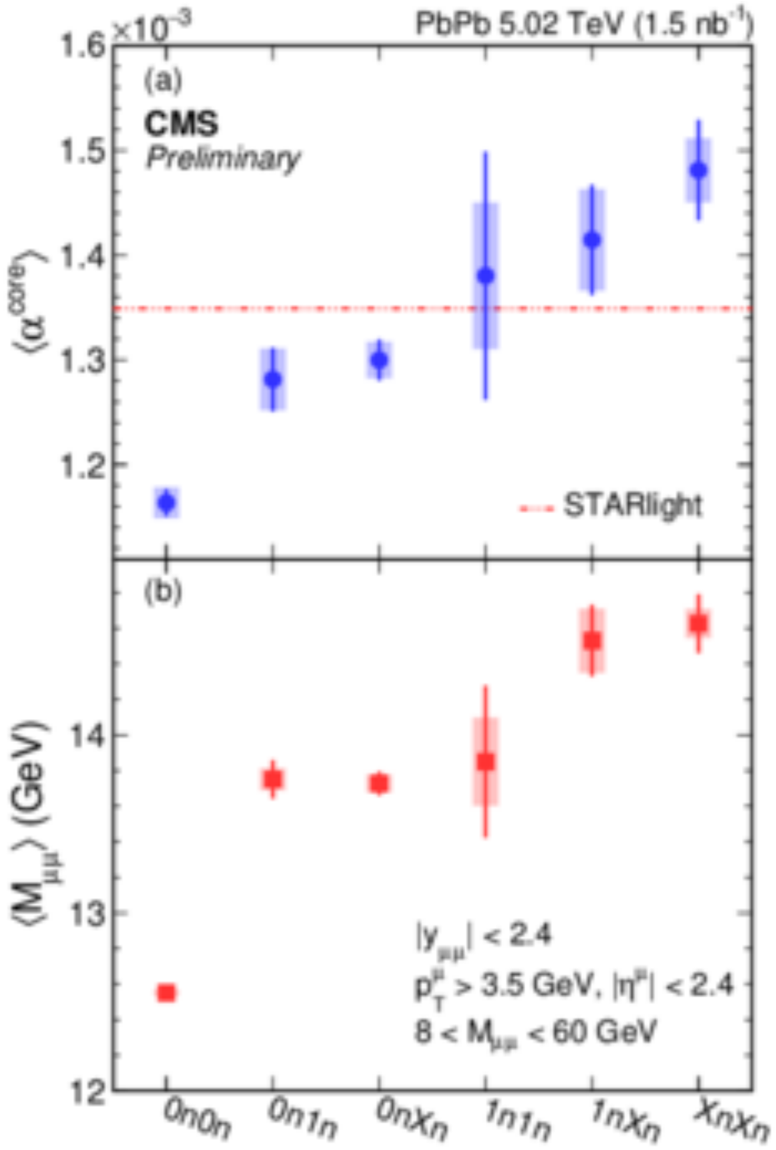
CMS Abstract: "This observation demonstrates the transverse momentum and energy of photons emitted from relativistic ions have impact parameter dependence. These results constrain precision modeling of initial photon-induced interactions in ultra-peripheral collisions. They also provide a controllable baseline to search for possible final-state effects on lepton pairs resulting from the production of quark-gluon plasma in hadronic heavy ion collisions."

50. STAR Collaboration, J., Adam *et al.* Probing Extreme Electromagnetic Fields with the Breit-Wheeler Process. (2019). https://arxiv.org/abs/1910.12400.

51. ATLAS Collaboration. Measurement of non-exclusive dimuon pairs produced via $\gamma\gamma$ scattering in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector. ATLAS-CONF-2019-051. (2019). https://inspirehep.net/literature/1762955.

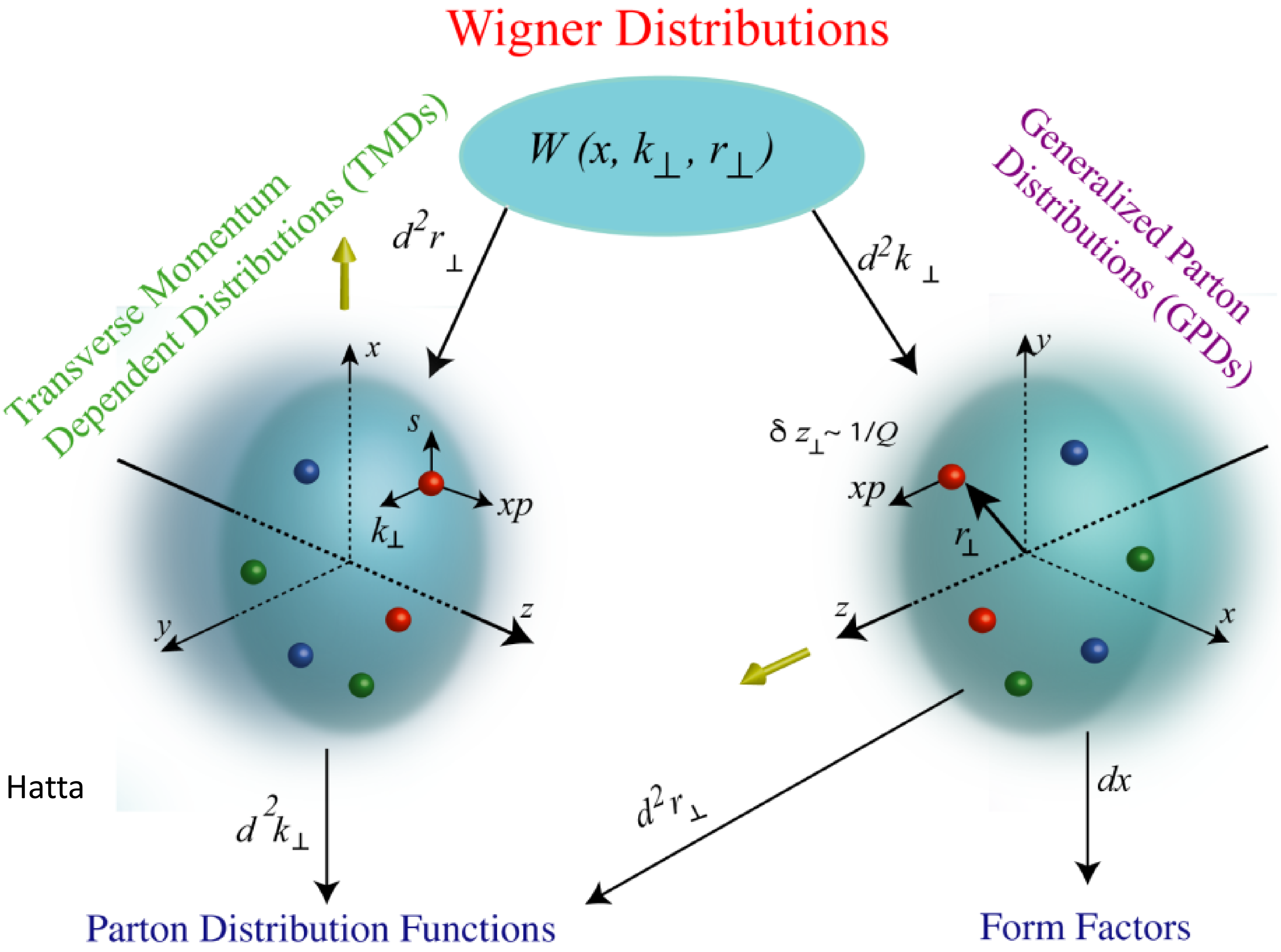
52. CMS Collaboration,. Observation of forward neutron multiplicity dependence of dimuon acoplanarity in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV CMS-PAS-HIN-19-014. (2020). https://inspirehep.net/literature/1798862.





Quite a few techniques used in QCD can be used in strong-field QED as well

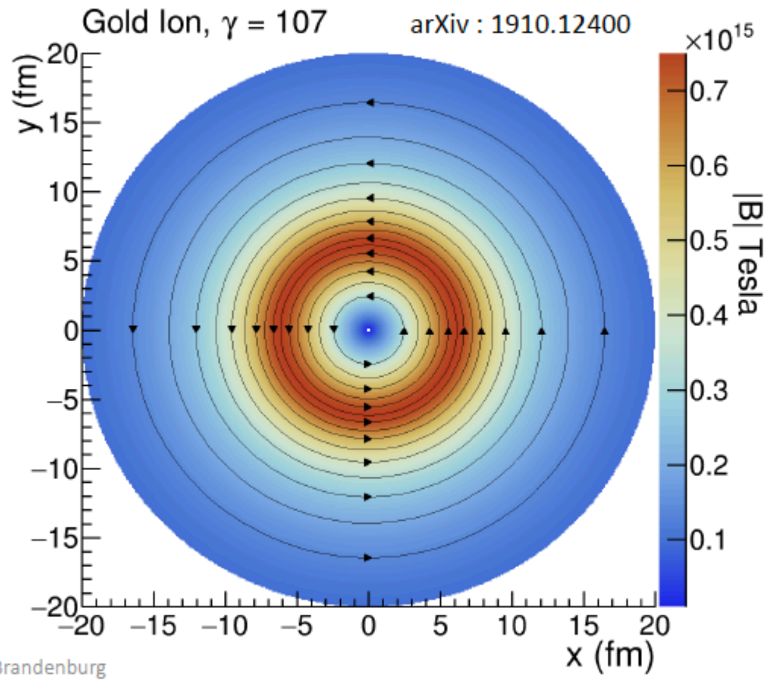
Understanding the QED is also important for quantitative extraction of the photoproduction



Y. Hatta

Observables of photon linear polarization

- Magnetic field generated by the heavy-ions are circular around the nucleus
- Photons are linearly polarized along the transverse radial direction
- There is a significant momentum space correlation of photon field



Birefringence of the QED Vacuum

[1] C. Li, J. Zhou, Y.-j. Zhou, Phys. Lett. B 795, 576 (2019)
QED calculation: arxiv : 1911.00237

Recently realized, $\Delta\sigma = \sigma_{\parallel} - \sigma_{\perp} \neq 0$ leads to **$\cos(n\Delta\phi)$ modulations** in polarized $\gamma\gamma \to e^+e^-$ [1]

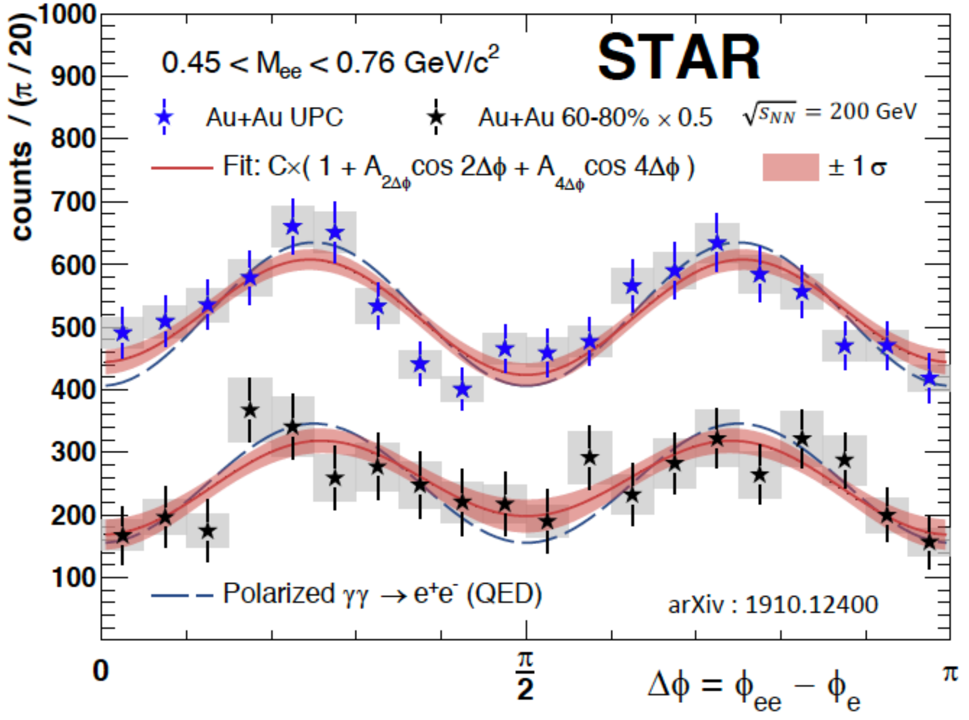
$$\Delta\phi = \Delta\phi[(e^+ + e^-), (e^+ - e^-)] \approx \Delta\phi[(e^+ + e^-), e^+]$$

Ultra-Peripheral

Quantity	Measured	QED	χ^2/ndf
$-A_{4\Delta\phi}(\%)$	16.8 ± 2.5	16	18.8 / 16

Peripheral (60−80%)

Quantity	Measured	QED	χ^2/ndf
$-A_{4\Delta\phi}(\%)$	27±6	34	10.2 / 17



→ **First Earth-based observation (6.7σ level) of vacuum birefringence**

11/05/19 Daniel Brandenburg 13

- **Necessary for observed cos(2phi) in rho photoproduction**

2.2 Dileptons as a probe in heavy ion collisions:

The comprehensive understanding of pure electromagnetic lepton pair production is not only important for probing extreme electromagnetic fields, but also interesting for studying the EM properties of QGP. For example, the significant pair transverse momentum $q_\perp$ broadening effect at different impact parameters found by the STAR[49,50], ATLAS[54] and CMS[52] collaborations has triggered quite an amount of theoretical efforts aimed at understanding if this effect results from the initial QED field strength, or is caused by the final state medium effect. The detailed comparison between theory/model calculations and experimental data appears to be in favor of the initial state effect[46,47,56,67,68], though there is some room left for the final state effect, such as the trapped magnetic field[69] and multiple EM scattering in QGP. Since such an impact-parameter sensitive observable is implicitly dependent on the photon Wigner distribution, it can serve as a clean testing ground for developing the QCD factorization formalism in terms of quark and gluon Wigner functions, which play a central role in exploring the 3D structure of nucleons/nuclei in the forthcoming EIC era. Another interesting development along this line is the prediction of a sizable v_4 anisotropic distribution with respect to the reaction plane [70] in lepton pair production in non-central heavy ion collisions. This EM v_4 anisotropy is purely generated by the initial EM field configuration, while the EM v_2 anisotropy is absent. This unique prediction, if confirmed from the experiments, shall provide a crucial handle on the production mechanism for dileptons in two photon processes in non-UPC collisions.

50. STAR Collaboration, J., Adam *et al.* Probing Extreme Electromagnetic Fields with the Breit-Wheeler Process. (2019). https://arxiv.org/abs/1910.12400.

51. ATLAS Collaboration. Measurement of non-exclusive dimuon pairs produced via $\gamma\gamma$ scattering in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector. ATLAS-CONF-2019-051. (2019). https://inspirehep.net/literature/1762955.

52. CMS Collaboration,. Observation of forward neutron multiplicity dependence of dimuon acoplanarity in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV CMS-PAS-HIN-19-014. (2020). https://inspirehep.net/literature/1798862.

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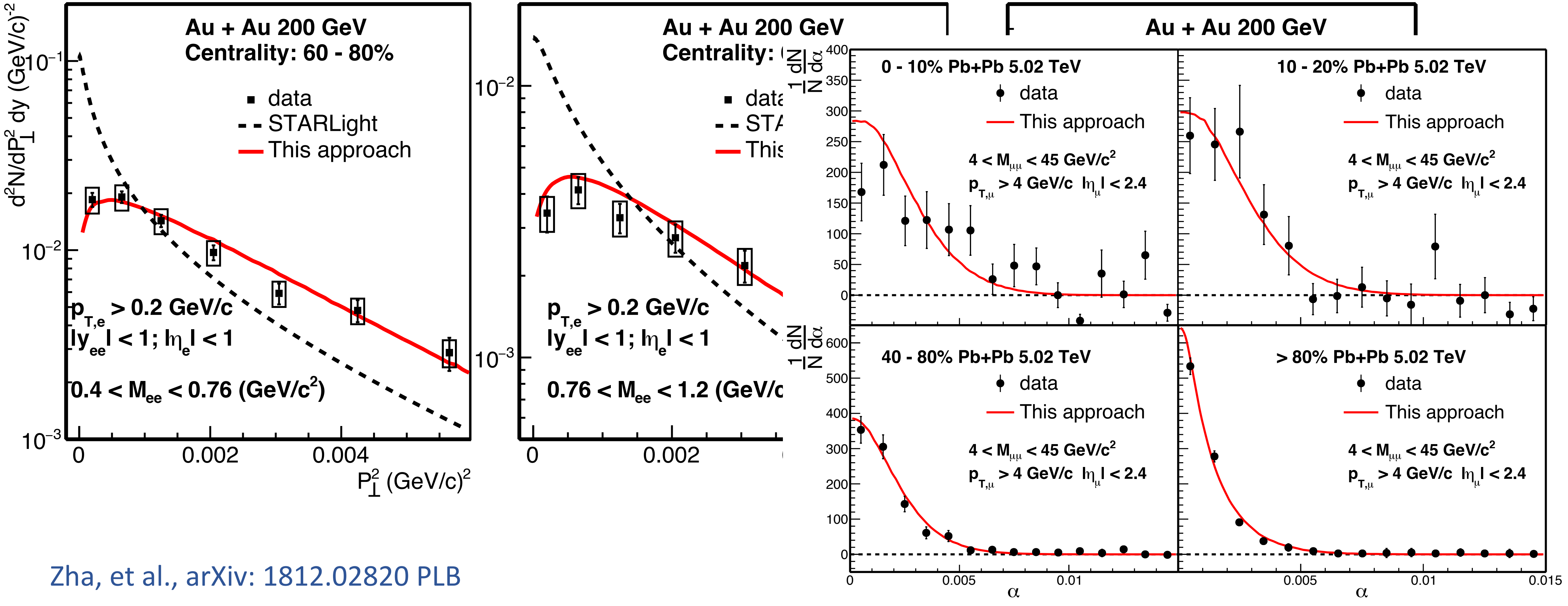
70. Xiao, B.-W., Yuan, F. & Zhou, J. Electromagnetic Flow of Leptons in Heavy Ion Collisions. (2020). https://arxiv.org/abs/2003.06352.

Initial broadening from Breit-Wheeler



Zha, et al., arXiv: 1812.02820 PLB

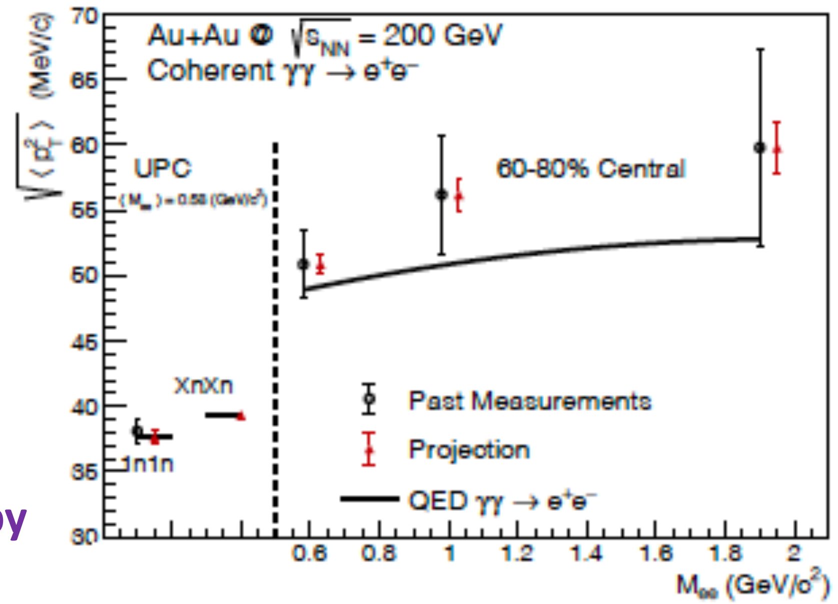
STAR data: PRL 121 (2018) 132301

ATLAS data: PRL 121 (2018) 212301;
New data at QM2019

Are there final-state QED effects?

Precision data with QED theory comparisons: Both on-going at LHC and RHIC

How about azimuthal anisotropy relative to reaction plane?



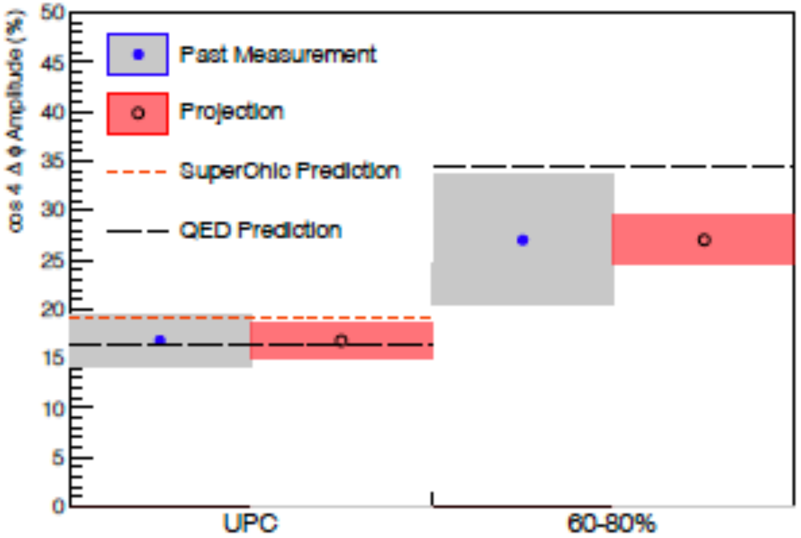


Figure 57: (Color online) Projections for measurements of the $\gamma\gamma \rightarrow e^+e^-$ process in peripheral and ultra-peripheral collisions. Left: The $\sqrt{\langle p_T^2 \rangle}$ of di-electron pairs within the fiducial acceptance as a function of pair mass, M_{ee}, for $60-80\%$ central and ultra-peripheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Right: The projection of the $\cos 4\Delta\phi$ measurement for both peripheral $(60-80\%)$ and ultra-peripheral collisions.

STAR Beam Use Request (2023-2025):

https://drupal.star.bnl.gov/STAR/system/files/BUR2020_final.pdf

p_T broadening and azimuthal correlations of e^+e^- pairs sensitive to electro-magnetic (EM) field;
Impact parameter dependence of transverse momentum distribution of EM production is the key component to describe data.

Is there a sensitivity to final magnetic field in QGP?

Precise measurement of p_T broadening and angular correlation will tell at >3σ for each observable.

Semi-coherent photon collisions

$$dn_i = \frac{Z_i^2\alpha}{\pi^2}\frac{q_{i\perp}^2\left[F\left(q_{i\perp}^2+\frac{w_i^2}{\gamma^2}\right)\right]^2}{\left(q_{i\perp}^2+\frac{w_i^2}{\gamma^2}\right)^2}\frac{d^3q_i}{w_i} \qquad (1)$$

$$\frac{1}{2\pi Q_\perp}\frac{d^2\sigma}{dQ_\perp dy} = \frac{4(Z^2\alpha)^2}{\pi^3}\frac{[F(Q_\perp)]^2}{Q_\perp^2}\frac{1}{2\pi}\int\int\sigma_{\gamma\gamma} \int\frac{q_{1\perp}^3\left[F\left(q_{1\perp}^2+\frac{w_1^2}{\gamma^2}\right)\right]^2}{\left(q_{1\perp}^2+\frac{w_1^2}{\gamma^2}\right)^2}dq_{1\perp}dM\,d\phi_Q \quad (8)$$

$$|F(k)|^2 = \frac{1}{Z^2}\left[Z+2\sum_{m=1}^{Z}\sum_{n=1}^{m-1}\cos\left(k(x_m-x_n)\right)\right] \quad (11)$$

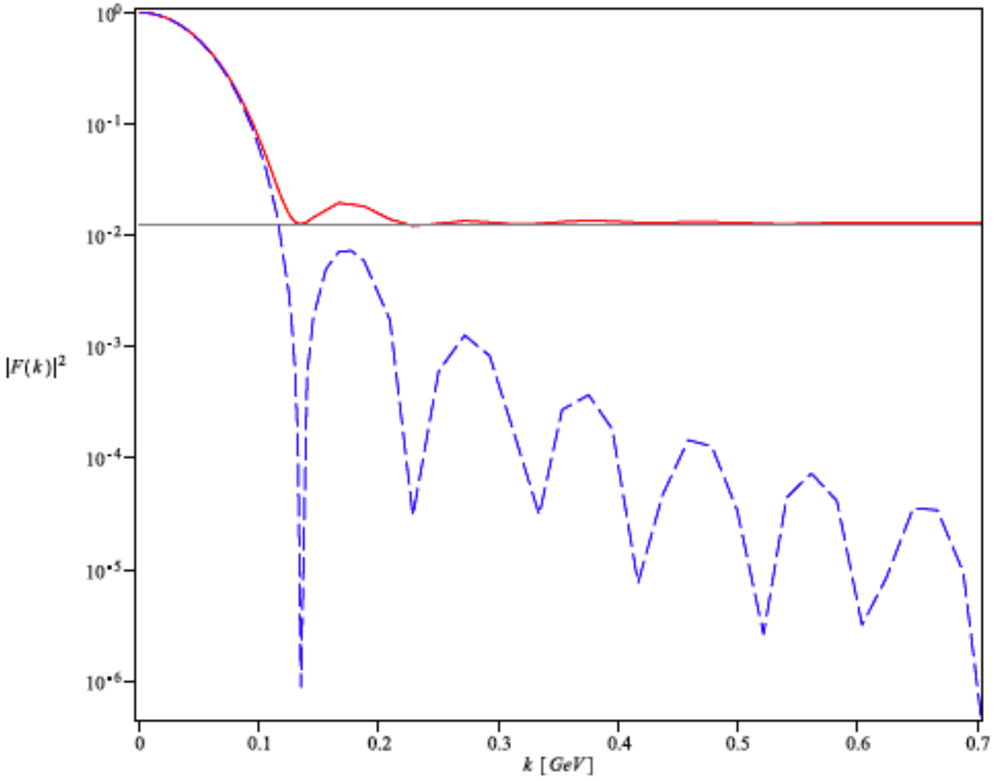


FIG. 3: (Color online)The square of the form factors plotted on a logarithmic scale. The (blue) dashed line corresponds to smooth Woods-Saxon charge distribution, the (red) continuous line corresponds to resolved discrete protons (but not quarks), as explained in the text.)

arXiv:1005.3531, unpublished

LoIs related to UPC in Heavy-ion collisions

- Three LoIs submitted to EF07:
  - Production of Charged BSM Particles at Future Heavy-Ion Colliders Via Photon-Photon Fusion,

    Authors: Laura Jeanty, Jenna Kishinevsky, Lawrance Lee.

    The Authors point out the possibility of the study of the production of ALP and other BSM particles in photon-photon fusion. Their plans include studies of the potential sensitivity of UPCs to higgsino and chargino production in different configurations of HI collisions, together with estimation of backgrounds.
  - New Phenomena Searches in Heavy Ion Collisions,

    Coordinators of this LoI: Marco Drewes, David d'Enterria.

    In the part of the LoI related to UPC, the Authors outline possible measurements of particle production in photon-photon collisions, including new particles.
  - Ultra-Peripheral Collisions in Heavy-IonPhysics,

    Coordinators of the LoI: Mariusz Przybycien, Zhangbu Xu and Jian Zhou.

    To be discussed later.
- ... and one more submitted to EF06:
  - New opportunities at the photon energy frontier,

    Coordinators of the LoI: Spencer Klein and Daniel Tapia Takaki.

    To be discussed later.

Summary

- Exciting new topics at UPC in the last 2 years (Both RHIC and LHC)
- Exploring precision test of strong field QED
- Possible use as probe of QGP electromagnetic properties
- Imaging of nucleus with high-energy photons: precision data and quantitative extraction
- Polarization as a tool: GPD/TMD

- A group discussion in UPC community
- EF07 UPC LoI on overleaf (open to everyone)
- Will expand to a document with writing assignments to experts
- Establish discussion and merging scheme with EF06 UPC
- Expand to include other topics (not too late still)