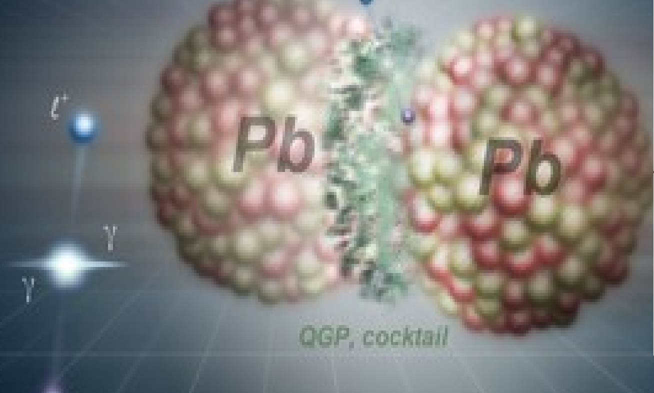
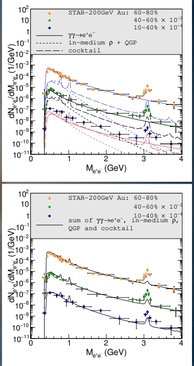
Centrality dependence of dilepton production via photon-photon fusion processes from Wigner functions of photons in nuclei

✓ M. Kłusek-Gawenda, W. Schäfer and A. Szczurek, Phys. Lett. **B814** (2021) 136114
Centrality dependence of dilepton production via $\gamma\gamma$ processes from Wigner distributions of photons in nuclei„

✓ M. K-G, R. Rapp, W. Schäfer and A. Szczurek, Phys. Lett. **B790** (2019) 339
Dilepton Radiation in Heavy-Ion Collisions at Small Transverse Momentum.





- From ultraperipheral to semicentral collisions $\rightarrow$ $\gamma\gamma$ fusion mechanism $\rightarrow$ dilepton sources

➢ Invariant mass
  - ➢ SPS (NA60 data)
  - ➢ RHIC (STAR data)
  - ➢ LHC (ALICE data)

➢ Low-P_T dilepton spectra
  - ➢ RHIC (STAR data)
  - ➢ LHC (ALICE data)

➢ Acoplanarity
  - ➢ LHC (ATLAS data)

DIELECTRON PAIR TRANSVERSE MOMENTUM

EPA in the impact parameter space - the pair transverse momentum $P_T^{\ell^+\ell^-}$ is neglected

$$\sigma_{A_1A_2\to A_1A_2\ell^+\ell^-} = \int N(\omega_1,\mathbf{b_1})\,N(\omega_2,\mathbf{b_2})\,\delta^{(2)}(\mathbf{b}-\mathbf{b}_1-\mathbf{b}_2)\int d^2\mathbf{b}_1 d^2\mathbf{b}_2 d^2\mathbf{b}\, dy_{\ell+}\, dy_{\ell-}\, dp_{t,\ell}^2\,\frac{d\sigma(\gamma\gamma\to\ell^+\ell^-;\hat{s})}{d(-\hat{t})}$$

➩ **k_t-factorization**

$$\frac{dN_{ll}}{d^2\mathbf{P}_T^{\ell^+\ell^-}} = \int \frac{d\omega_1}{\omega_1}\frac{d\omega_2}{\omega_2}d^2\boldsymbol{q}_{1t}d^2\boldsymbol{q}_{2t}\frac{dN(\omega_1,q_{1t}^2)}{d^2\boldsymbol{q}_{1t}}\frac{dN(\omega_2,q_{2t}^2)}{d^2\boldsymbol{q}_{2t}}\delta^{(2)}(\boldsymbol{q}_{1t}+\boldsymbol{q}_{2t}-\mathbf{P}_T^{\ell^+\ell^-})\hat{\sigma}(\gamma\gamma\to\ell^+\ell^-)\Big|_{\rm cuts},$$

➩ **Exact calculation**

$$\frac{d\sigma[\mathcal{C}]}{d^2\mathbf{P}_T^{\ell^+\ell^-}} = \int\frac{d^2\boldsymbol{Q}}{2\pi}w(Q;b_{\rm max},b_{\rm min})\int\frac{d^2\boldsymbol{q}_1}{\pi}\frac{d^2\boldsymbol{q}_2}{\pi}\delta^{(2)}(\mathbf{P}_T^{\ell^+\ell^-}-\boldsymbol{q}_1-\boldsymbol{q}_2)\int\frac{d\omega_1}{\omega_1}\frac{d\omega_2}{\omega_2}$$
$$\times\; E_i\Big(\omega_1,\boldsymbol{q}_1+\frac{\boldsymbol{Q}}{2}\Big)E_j^*\Big(\omega_1,\boldsymbol{q}_1-\frac{\boldsymbol{Q}}{2}\Big)E_k\Big(\omega_2,\boldsymbol{q}_2-\frac{\boldsymbol{Q}}{2}\Big)E_l^*\Big(\omega_2,\boldsymbol{q}_2+\frac{\boldsymbol{Q}}{2}\Big)\frac{1}{2\hat{s}}\sum_{\lambda\bar\lambda}M_{ik}^{\lambda\bar\lambda}M_{jl}^{\lambda\bar\lambda\dagger}\,d\Phi(\ell^+\ell^-)\,.$$

The factorization formula is written in terms of the Wigner function:

$$N_{ij}(\omega,\mathbf{b},\mathbf{q}) = \int\frac{d^2\mathbf{Q}}{(2\pi)^2}\exp[-i\mathbf{bQ}]\,E_i\Big(\omega,\mathbf{q}+\frac{\mathbf{Q}}{2}\Big)E_j^*\Big(\omega,\mathbf{q}-\frac{\mathbf{Q}}{2}\Big) = \int d^2\mathbf{s}\,\exp[i\mathbf{qs}]\,E_i\Big(\omega,\mathbf{b}+\frac{\mathbf{s}}{2}\Big)E_j^*\Big(\omega,\mathbf{b}-\frac{bs}{2}\Big),$$
$$N(\omega,\mathbf{q}) = \delta_{ij}\int d^2\mathbf{b}\,N_{ij}(\omega,\mathbf{b},\mathbf{q}) = \delta_{ij}\,E_i(\omega,\mathbf{q})E_j^*(\omega,\mathbf{q}) = \Big|\boldsymbol{E}(\omega,\mathbf{q})\Big|^2,$$
$$N(\omega,\mathbf{b}) = \delta_{ij}\int\frac{d^2\boldsymbol{q}}{(2\pi)^2}N_{ij}(\omega,\mathbf{b},\mathbf{q}) = \delta_{ij}\,E_i(\omega,\mathbf{b})E_j^*(\omega,\mathbf{b}) = \Big|\mathbf{E}(\omega,\mathbf{b})\Big|^2.$$

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PAIR TRANSVERSE MOMENTUM - RHIC & LHC

$p_t > 0.2$ GeV,
$|\eta_e| < 1$
c=(60-80)%
$|y_{ee}| < 1$

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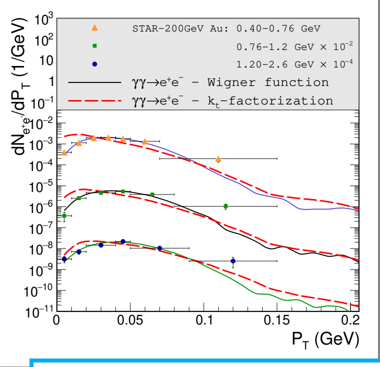
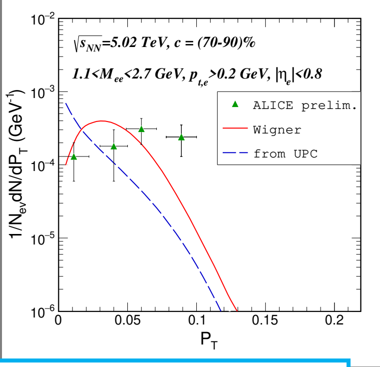
vs.
—— PL**B814** (2021) 136114

$p_t > 0.2$ GeV,
$|\eta_e| < 0.8$
c=(70-90)%
$M_{e^+e^-} = (1.1\text{-}2.7)$ GeV

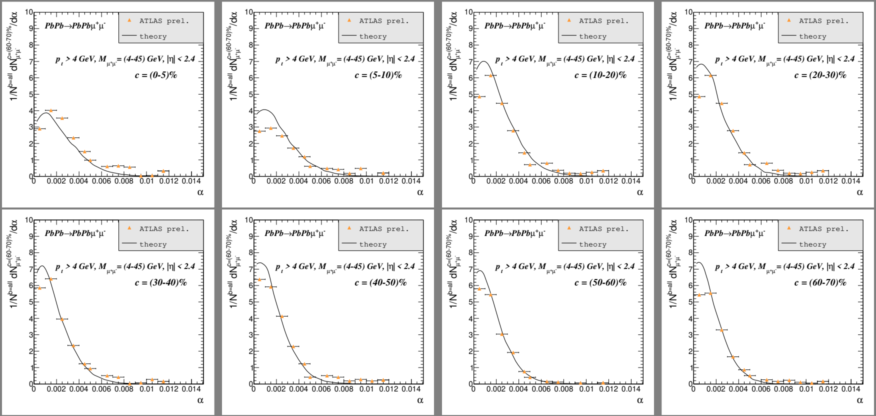




Small correction to the STAR description & much better situation for LHC

ACOPLANARITY - ATLAS DATA

From central to peripheral collisions



A successful description of ATLAS data by $\gamma\gamma$-fusion alone

A correct normalization and shape of the distributions

$p_t > 4$ GeV,

$M_{\mu^+\mu^-} =$(4-45) GeV,

$|\eta_\mu| < 2.4$

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CONCLUSION

- ✓ The interplay of **thermal radiation with the initial photon annihilation process** triggered by the coherent electromagnetic fields of the incoming nuclei was presented.
- ✓ We **first** verify that photon fusion, thermal radiation, and final-state hadron decays give a fair description of the low-P_T dilepton mass spectra and dilepton transverse momentum distribution as measured by the STAR collaboration for different centrality classes, including experimental acceptance cuts.
- ✓ STAR, ALICE and ATLAS experimental data show that **without free parameters**, (but taking into account **Wigner distribution**) excellent agreement with the data is achieved without including of leptons in quark-gluon plasma.
- ✓ Recently the CMS collaboration has measured modification of α distributions correlated with **neutron multiplicity**. A very new ATLAS study also presents the dimuon cross section in the presence of forward and/or backward neutron production. We plan to study it in the future.

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