2022 RHIC/AGS ANNUAL USERS' MEETING
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This meeting will be held virtually.
June 7–10, 2022

Investigations on Collectivity and Baryon Junction Conjecture in Ultra-Peripheral Heavy-Ion Collisions

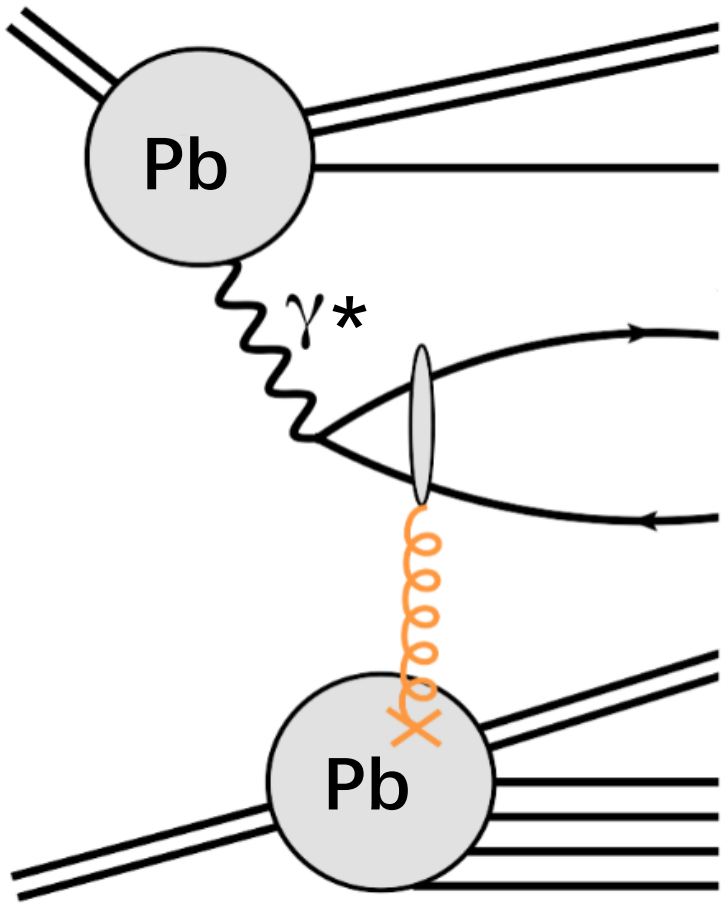
Wenbin Zhao

Wayne State University

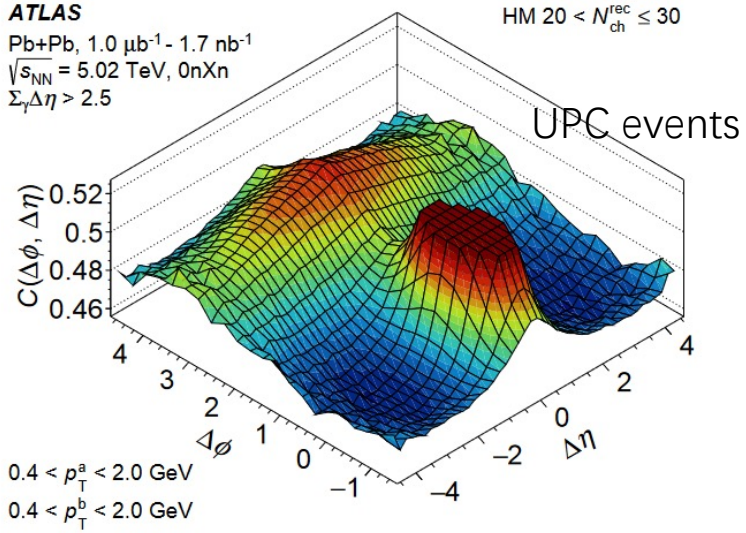
Collaborator: Chun Shen and Björn Schenke

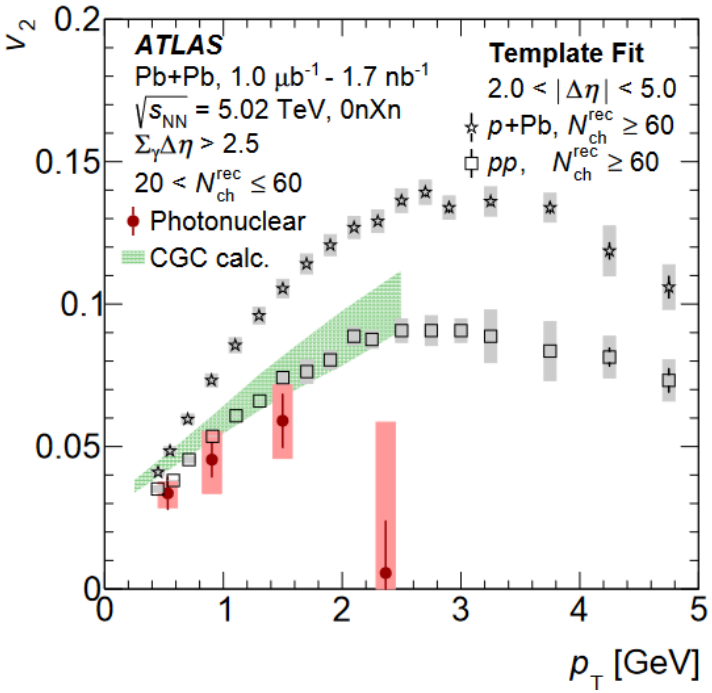
June 7, 2022 RHIC/AGS

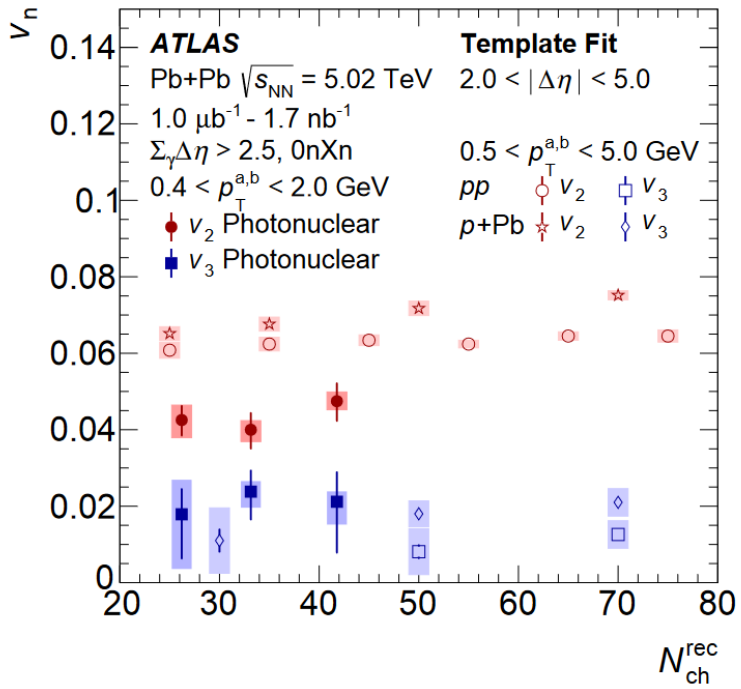
“Collectivity” in UPC



Taken from Nicole Lewis’s slide



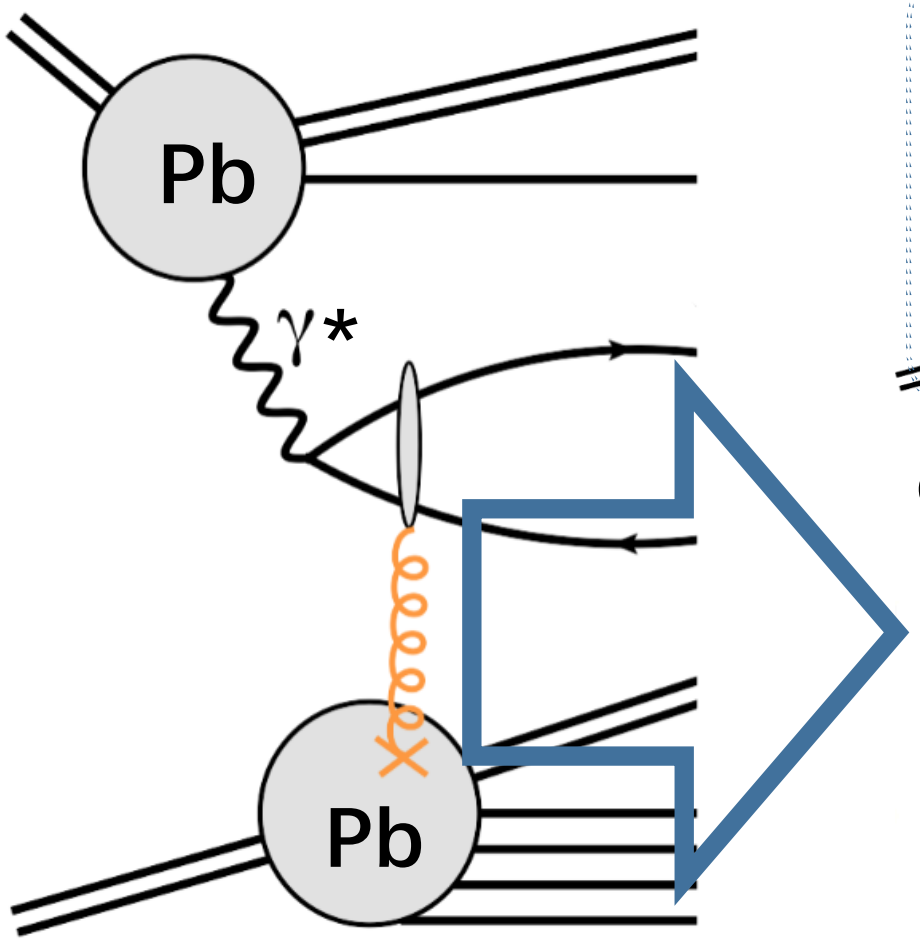




- UPCs have a similar order of magnitude and trends of collectivity as other previously measured hadronic systems

ATLAS Phys. Rev. C 104, 014903 (2021).
Y. Shi, etc.al,Phys. Rev. D 103, 054017 (2021).

Hydrodynamic simulation of UPC



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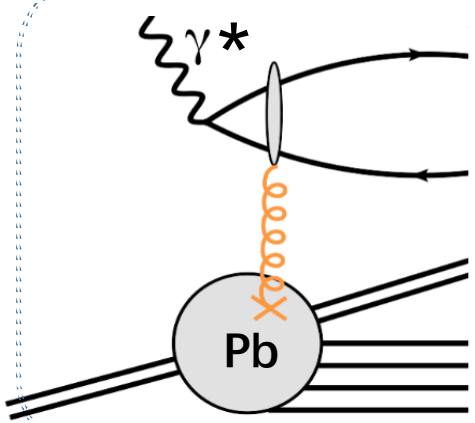
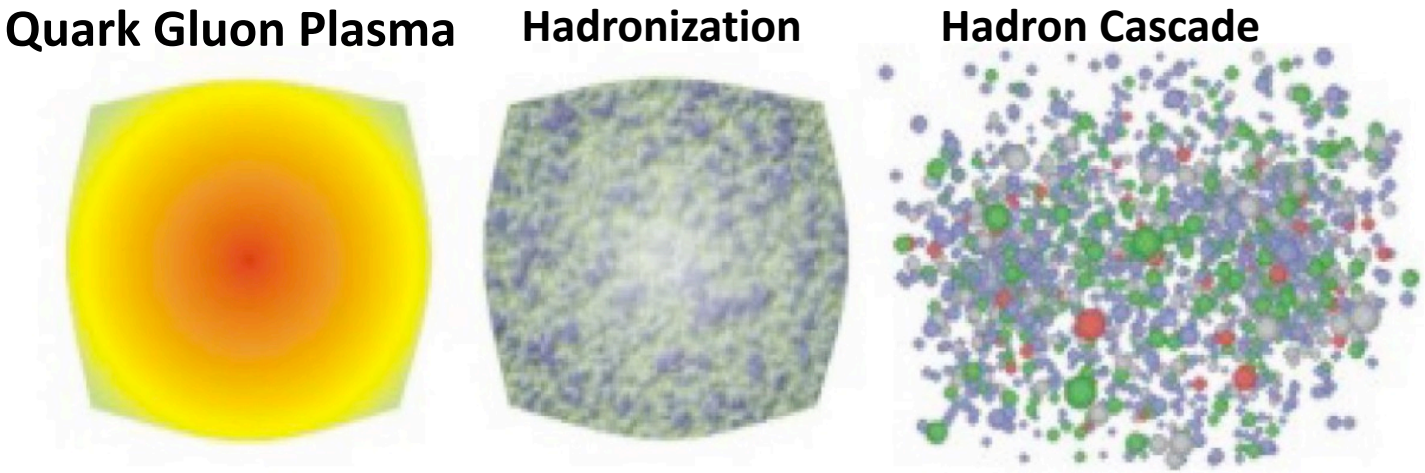


The transverse positions of the partonic participants are sampled from a 2D Gaussian

$$P(x,y) \propto exp[-\frac{x^2+y^2}{2} Q^2]$$

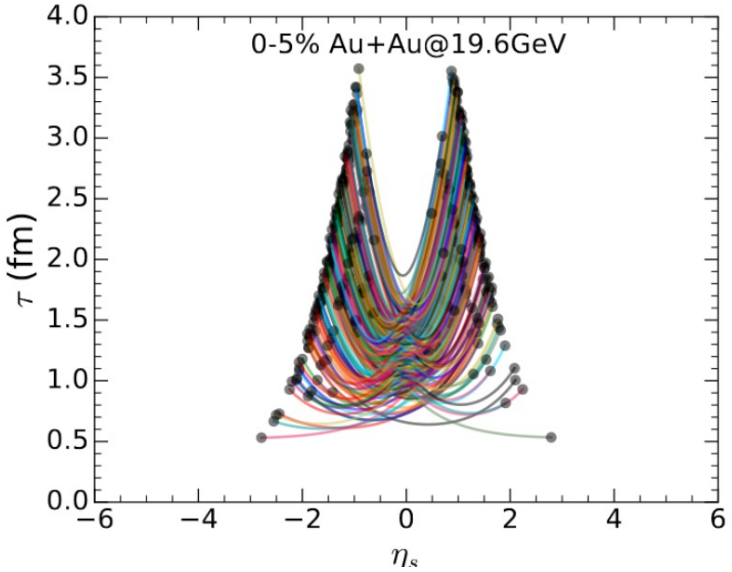
Q: the virtuality of virtual photon.

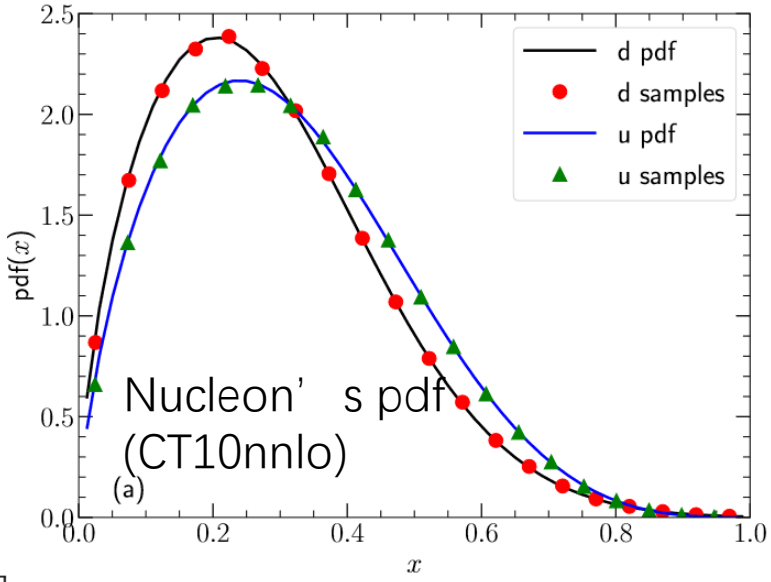


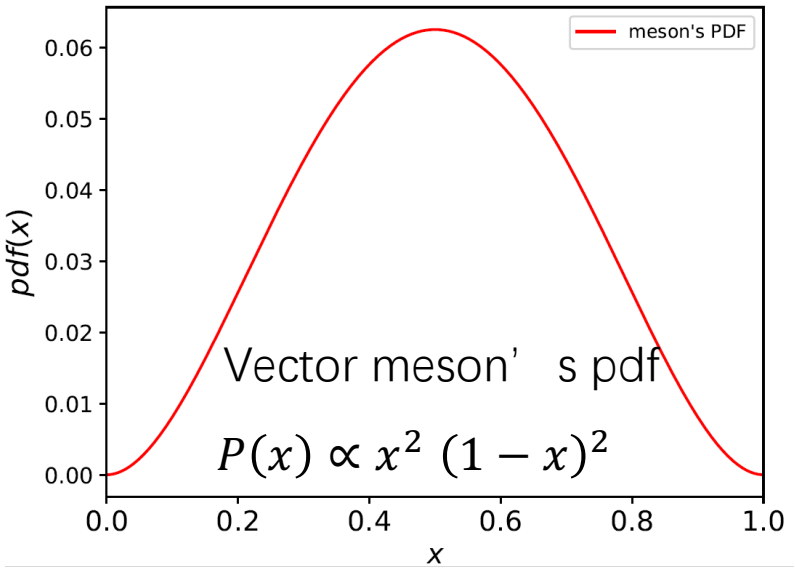
3DGlauber + MUSIC + UrQMD

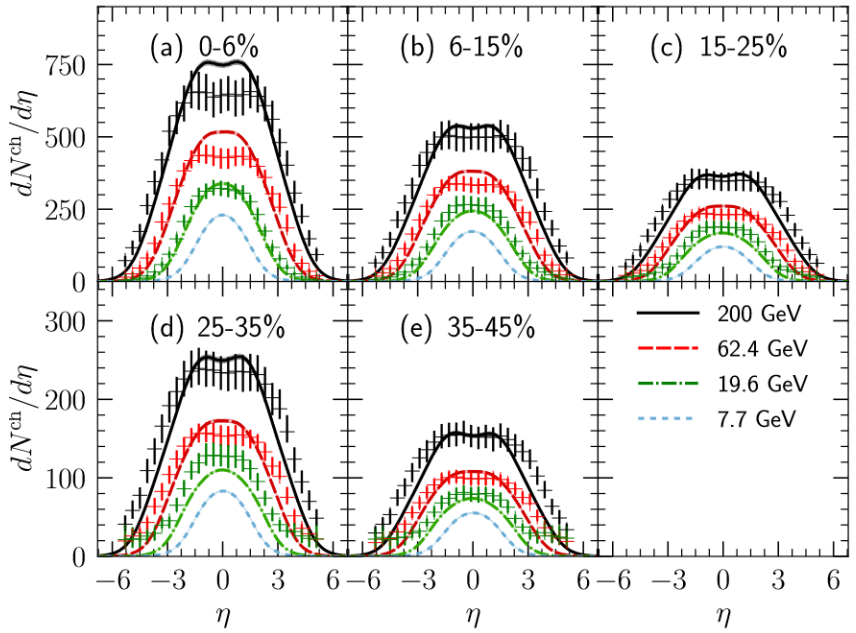
C. Shen and B. Schenke, [arXiv:2203.04685 [nucl-th]].
C. Shen and B. Schenke Phys. Rev. C 97, 024907 (2018).
W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].

3DGlauber + MUSIC + UrQMD









- 3D-Glauber + MUSIC + UrQMD works well in describing various soft observables from low energies to high energies.
- Nucleon's pdf peaks around x~0.33, vector meson's pdf peaks at x~0.5.

C. Shen and B. Schenke, [arXiv:2203.04685 [nucl-th]].
C. Shen and B. Schenke Phys. Rev. C 97, 024907 (2018).
W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].

Kinematics

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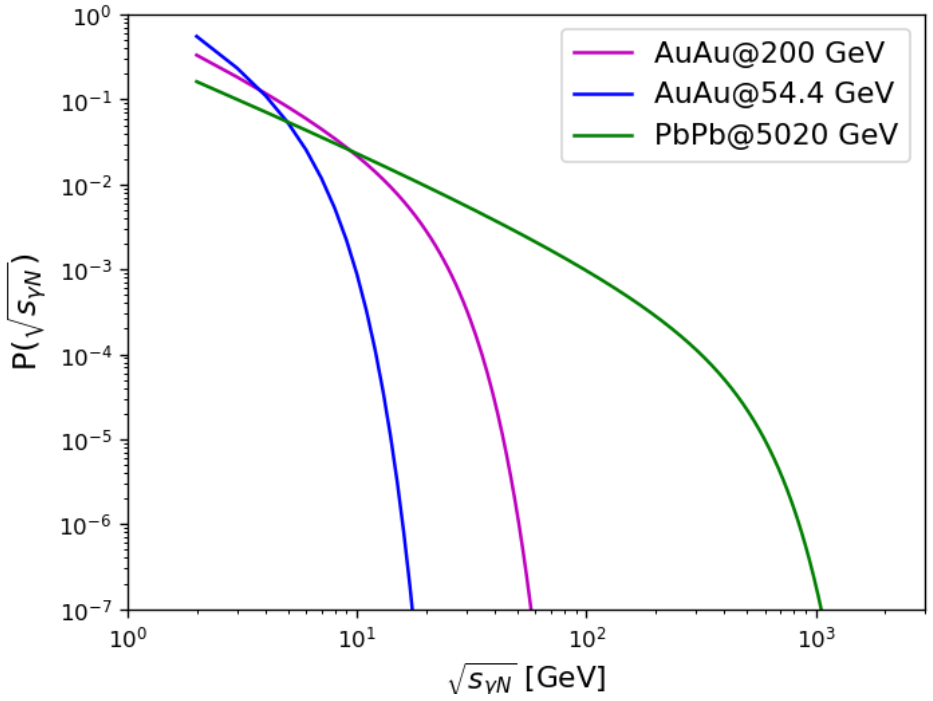
The physics of ultraperipheral collisions at the LHC

A.J. Baltz[a], G. Baur[b], D. d'Enterria[c], L. Frankfurt[d], F. Gelis[e], V. Guzey[f,w], K. Hencken[g,h,1], Yu. Kharlov[i], M. Klasen[j], S.R. Klein[k], V. Nikulin[l], J. Nystrand[m], I.A. Pshenichnov[n,o], S. Sadovsky[i], E. Scapparone[p], J. Seger[q], M. Strikman[r,*,1], M. Tverskoy[l], R. Vogt[k,s,t,1], S.N. White[a], U.A. Wiedemann[u], P. Yepes[v,1], M. Zhalov[l]



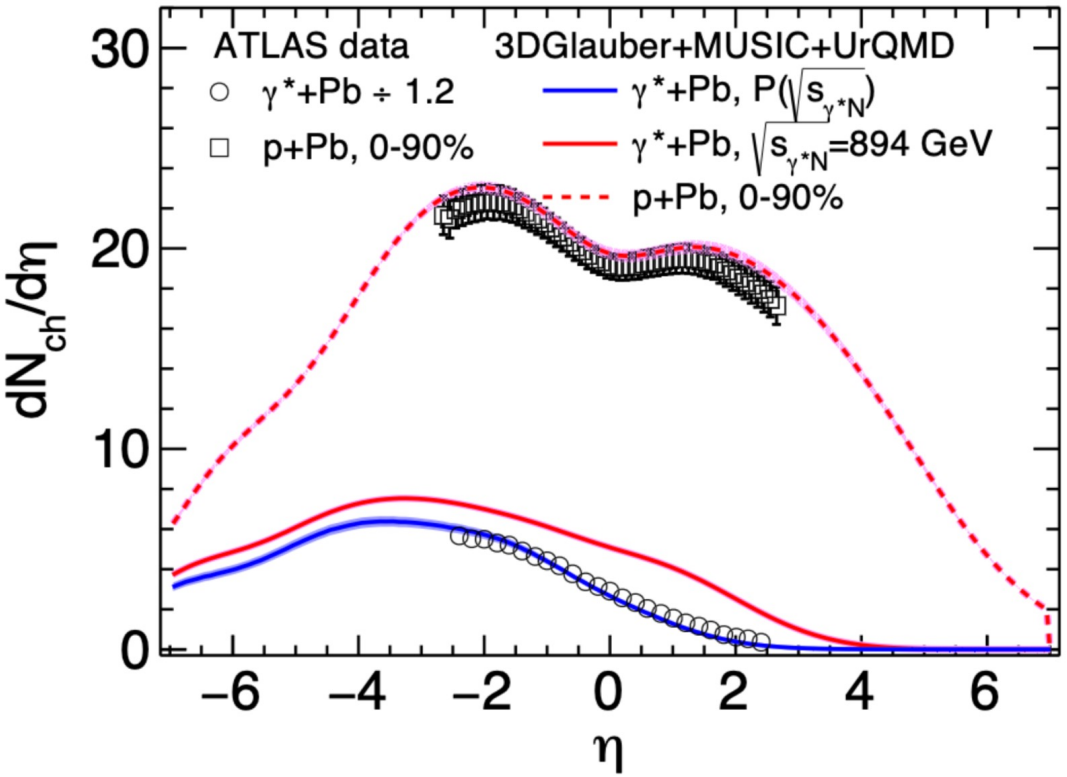
- Based on the photon flux distribution, we get the distribution of center-of-mass energies of γ^*+nucleus collisions.
- Because of the unequal energies of incoming nucleus and γ^*in the lab frame, we need to do a global rapidity shift from center-of-mass frame to lab. frame.

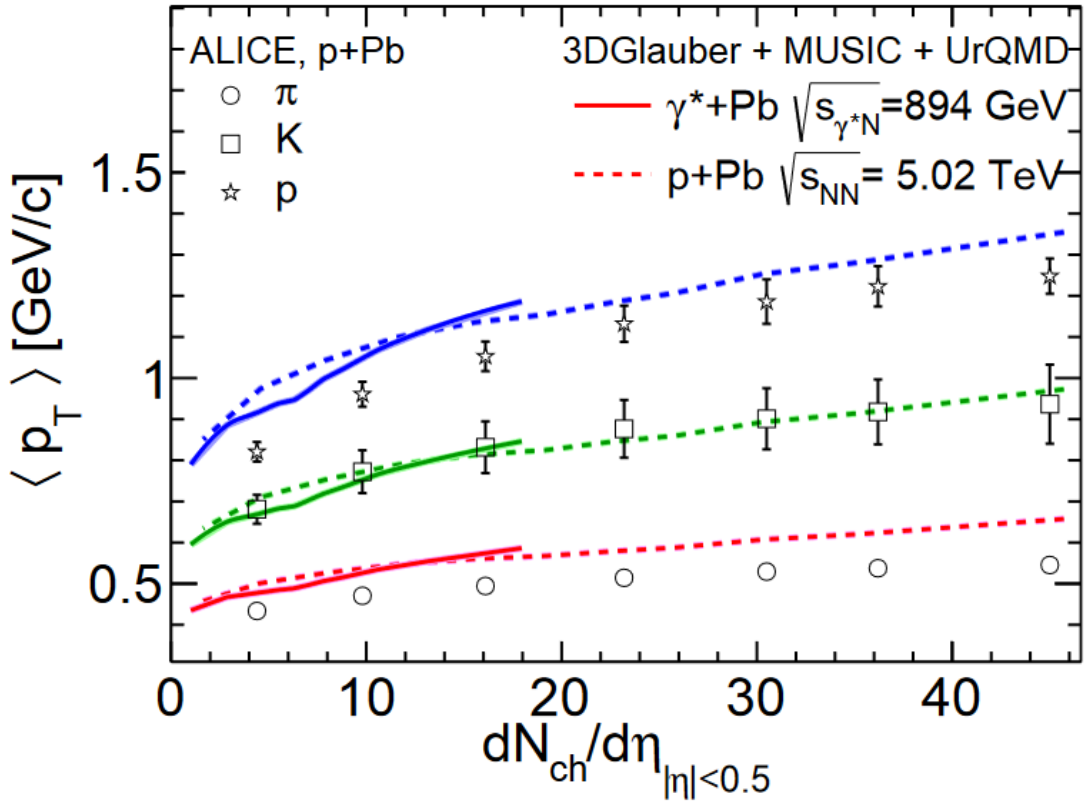
$$\Delta y = y_{\text{beam},\sqrt{s_{\gamma^* N}}} - y_{\text{beam},\sqrt{s_{NN}}}$$

For example, in $\gamma^* + Pb$ with $\sqrt{s_{\gamma^* N}} = 894$ GeV, $\Delta y = 1.756$ in the Pb-going direction;

A. J. Baltz, Phys. Rept. 458, 1 (2008). W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].

Multiplicity and mean p_T

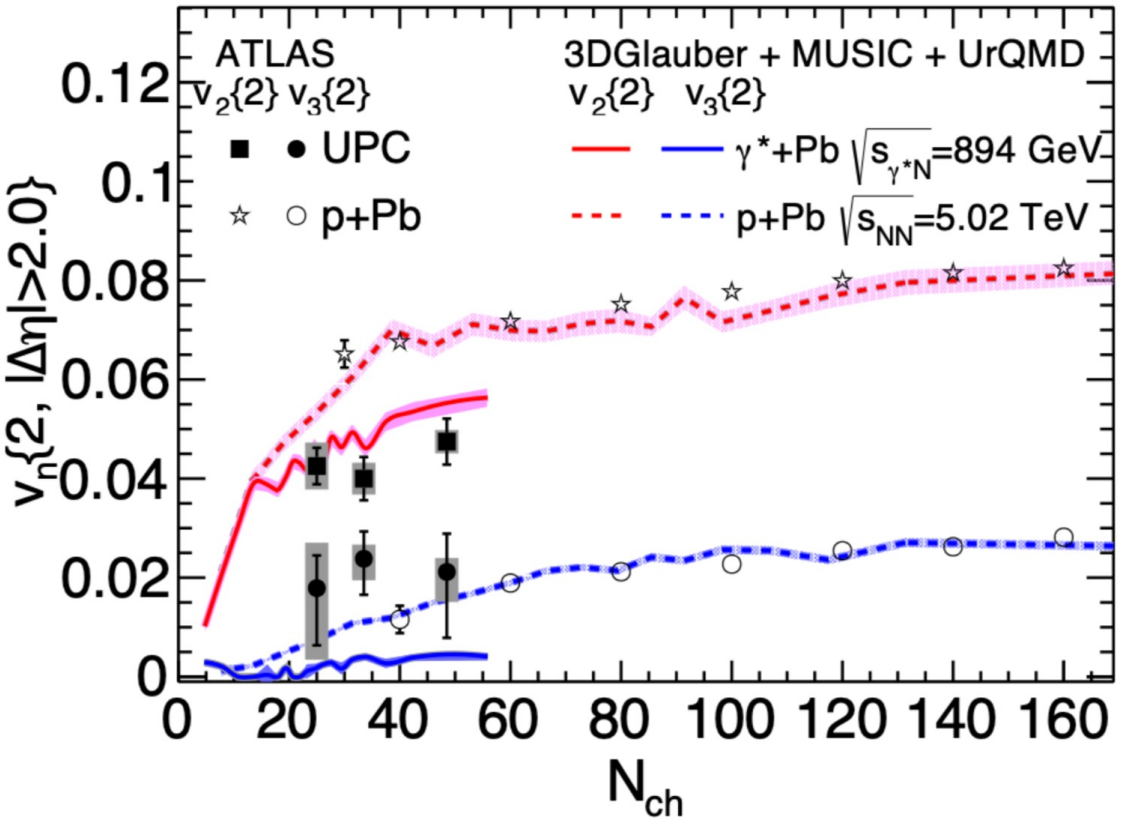


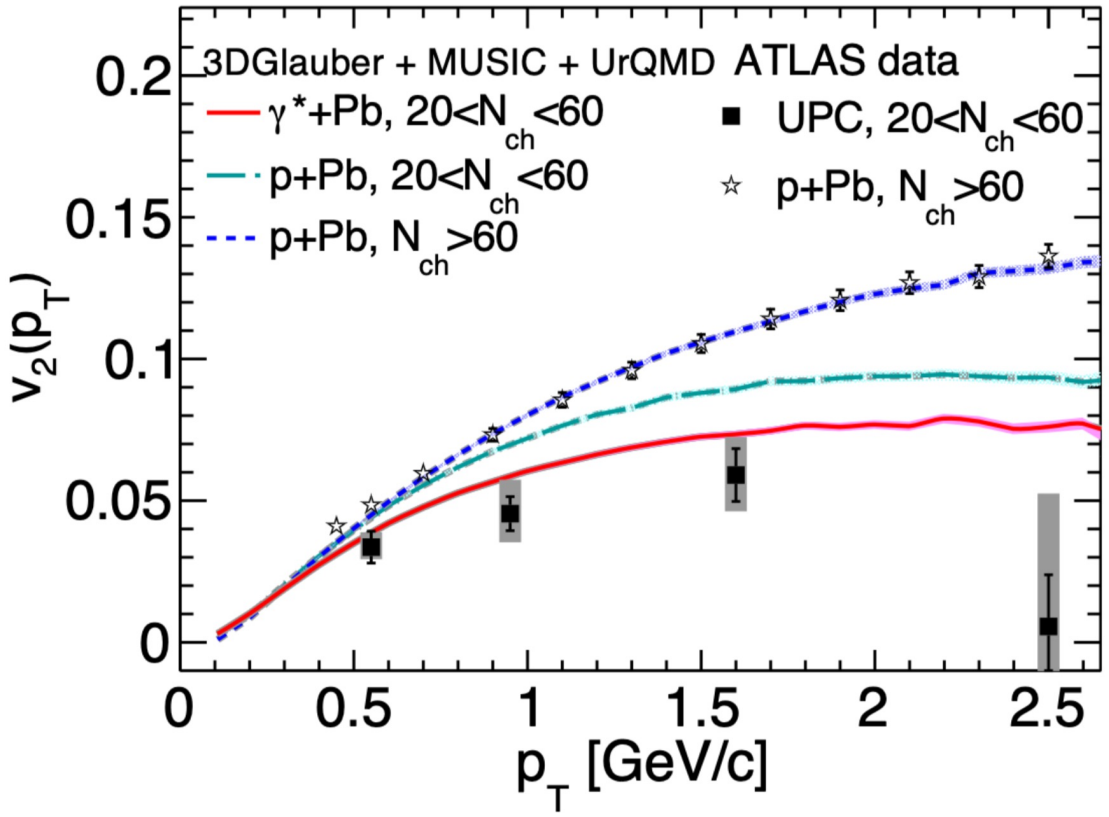


- 3D-Glauber + MUSIC + UrQMD with fluctuating $\sqrt{s_{\gamma^* N}}$ describes the shape of $dN_{ch}/d\eta$ in γ^*+Pb.
- The $dN_{ch}/d\eta$ of γ^*+Pb shows strong violation of longitudinal boost-invariance.
- Clear mass hierarchy of the $<p_T>$ of π, K and P is calculated in γ^*+Pb and p+Pb.

W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094]. C. Shen and B. Schenke, [arXiv:2203.04685 [nucl-th]].

$v_n\{2\}$ in γ^*+Pb and p+Pb

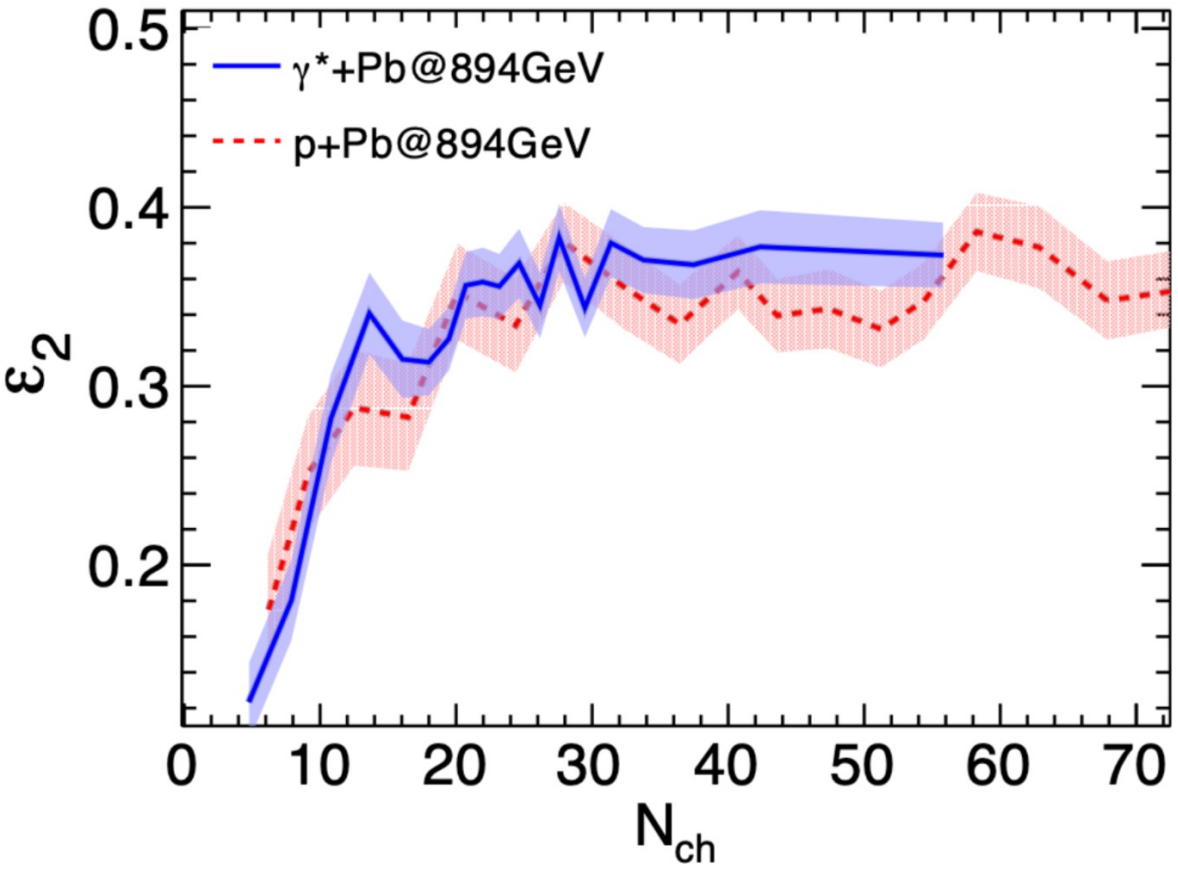


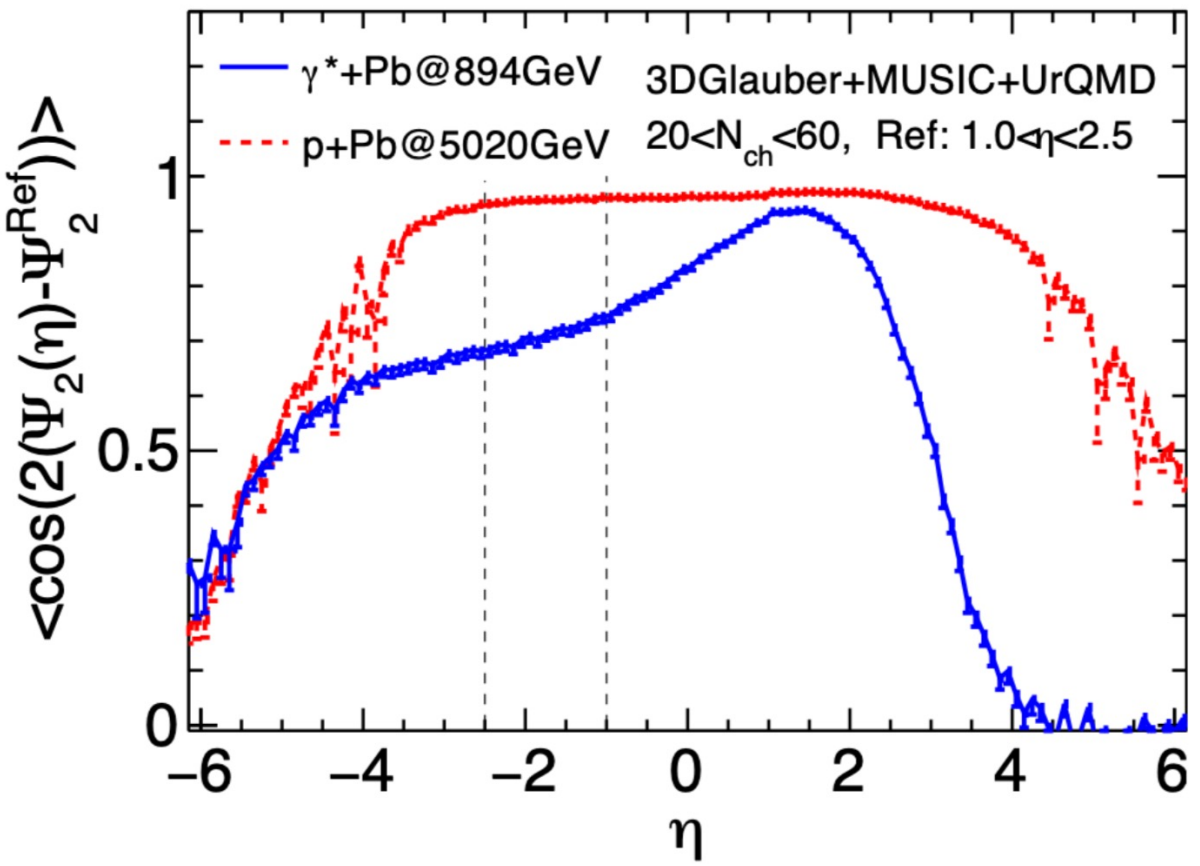


- 3D-Glauber + MUSIC + UrQMD describes the $v_2\{2\}$ and $v_2(p_T)$ in γ^*+Pb and p+Pb well.
- The v_2 hierarchy between p+Pb and γ∗+Pb is reproduced by our model calculations.
- v_3 is not well described in γ^*+Pb.

W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].
C. Shen and B. Schenke, [arXiv:2203.04685 [nucl-th]].

v_2 hierarchy between γ*+Pb and p+Pb

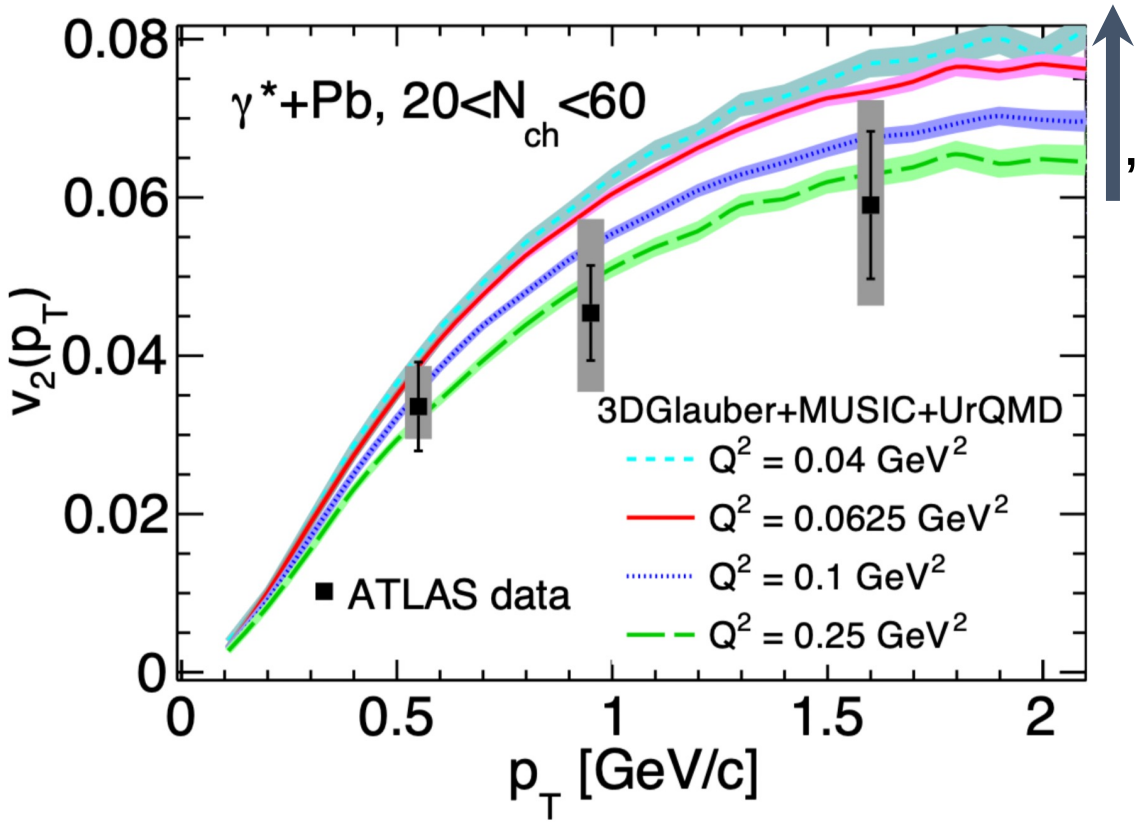




W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].

- ε_2 are very similar between $\boldsymbol{\gamma}$*+Pb and p+Pb.
- The longitudinal flow decorrelation is stronger in the $\boldsymbol{\gamma}$*+Pb than p+Pb, resulting in the v_2 hierarchy between γ*+Pb and p+Pb .

Photon virtuality dependence of flow



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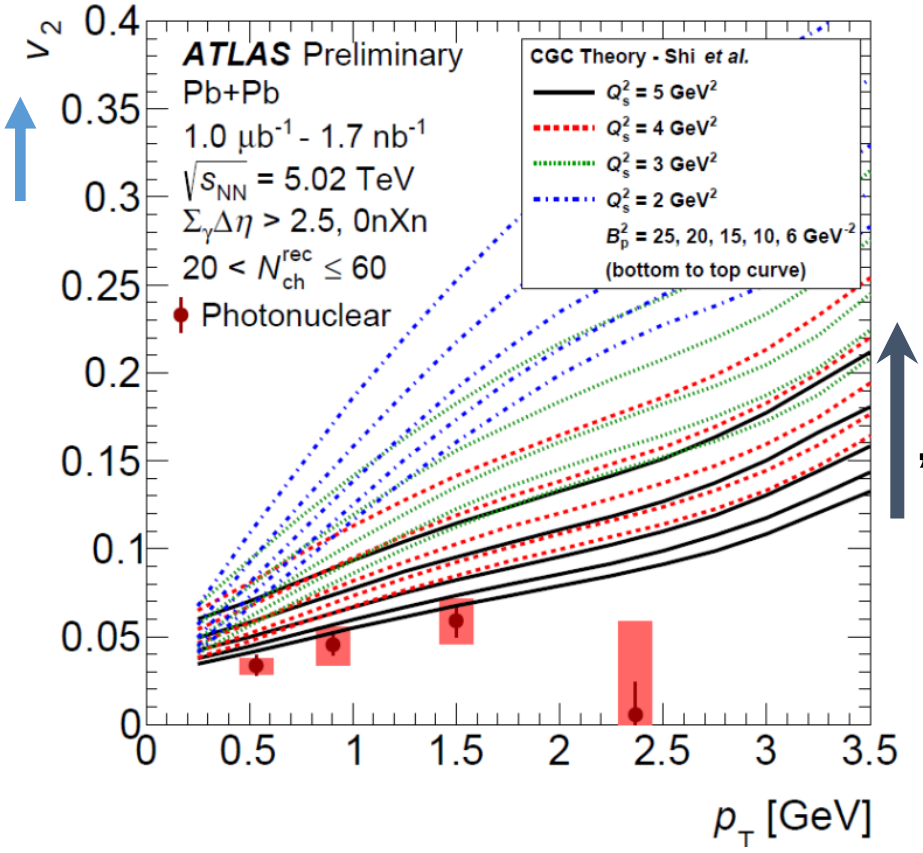

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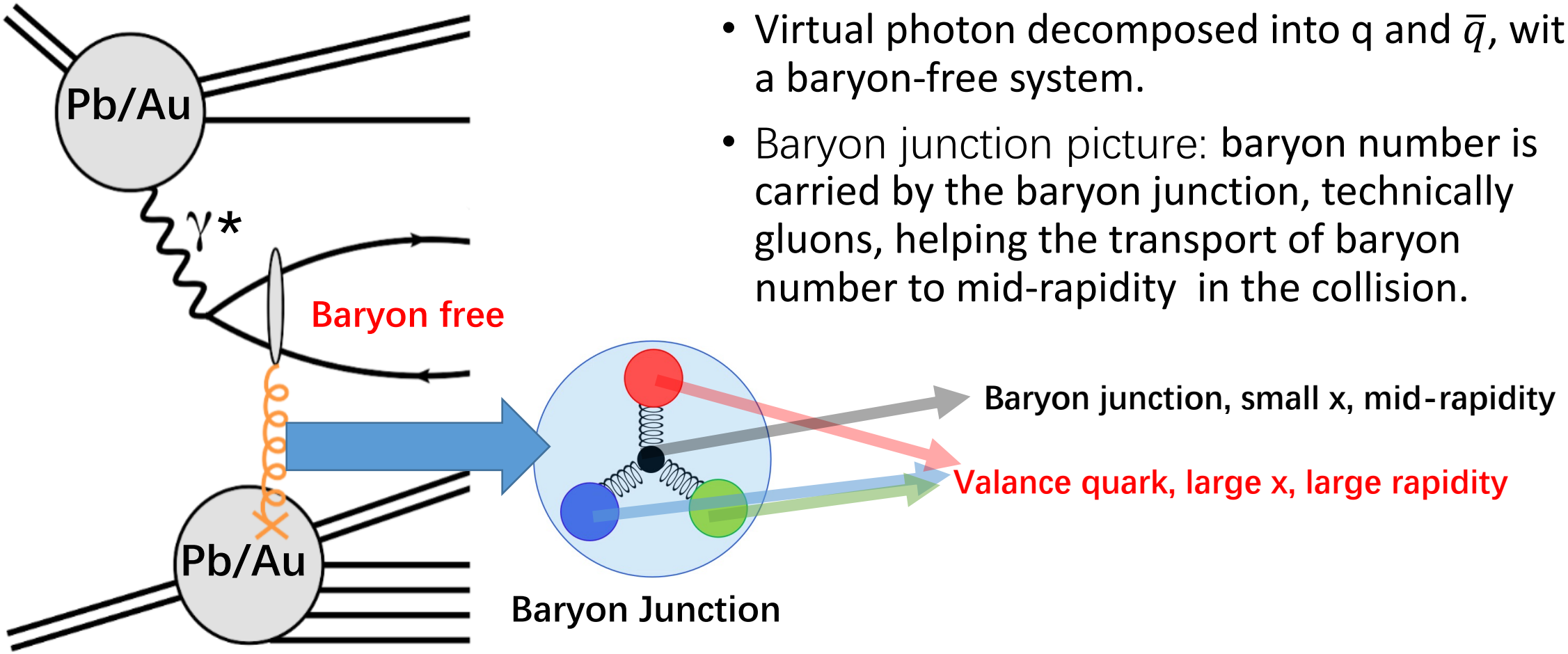
The transverse positions of the partonic participants are sampled from a 2D Gaussian $\boldsymbol{P(x,y) \propto exp[-\frac{x^2+y^2}{2} Q^2]}$

- Hydro: larger transverse space for the geometry allows more fluctuations and the v_2 are larger.
- CGC: Larger number of independent domains leads to lower v_2.
- Hydro predicts the opposite trend with Q^2 than the CGC

W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094]. Y. Shi, etc.al,Phys. Rev. D 103, 054017 (2021). B. D. Seidlitz. QM2019.

Probing Baryon Junction Structure

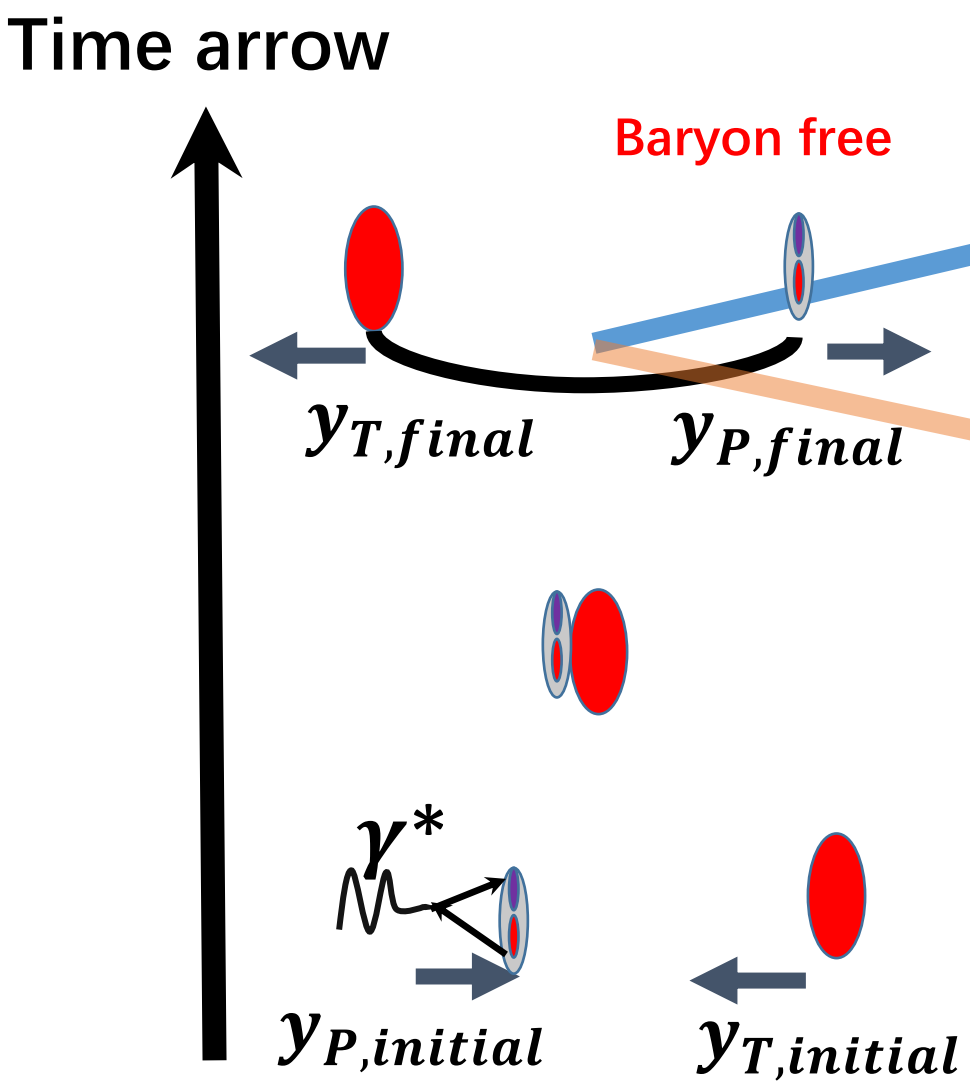
Baryon Junction Structure picture

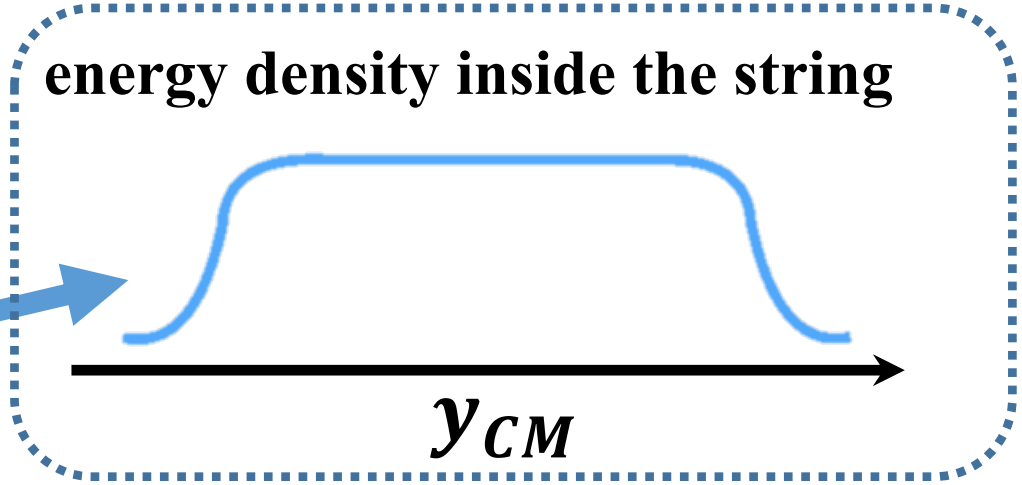


- Virtual photon decomposed into q and $\bar{q}$, with a baryon-free system.
- Baryon junction picture: baryon number is carried by the baryon junction, technically gluons, helping the transport of baryon number to mid-rapidity in the collision.

D. Kharzeev, Phys.Lett. B 378, 238–246 (1996). J. D. Brandenburg, eta. al [arXiv:2205.05685 [hep-ph]].
C. Shen and B. Schenke, [arXiv:2203.04685]. W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].

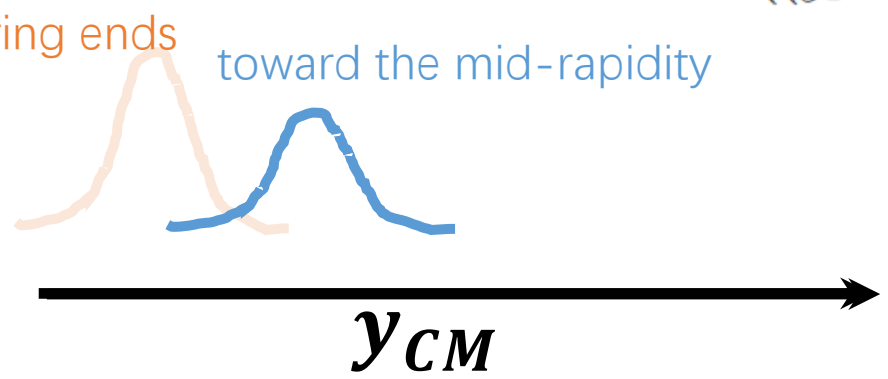
Baryon junction in 3DGlauber





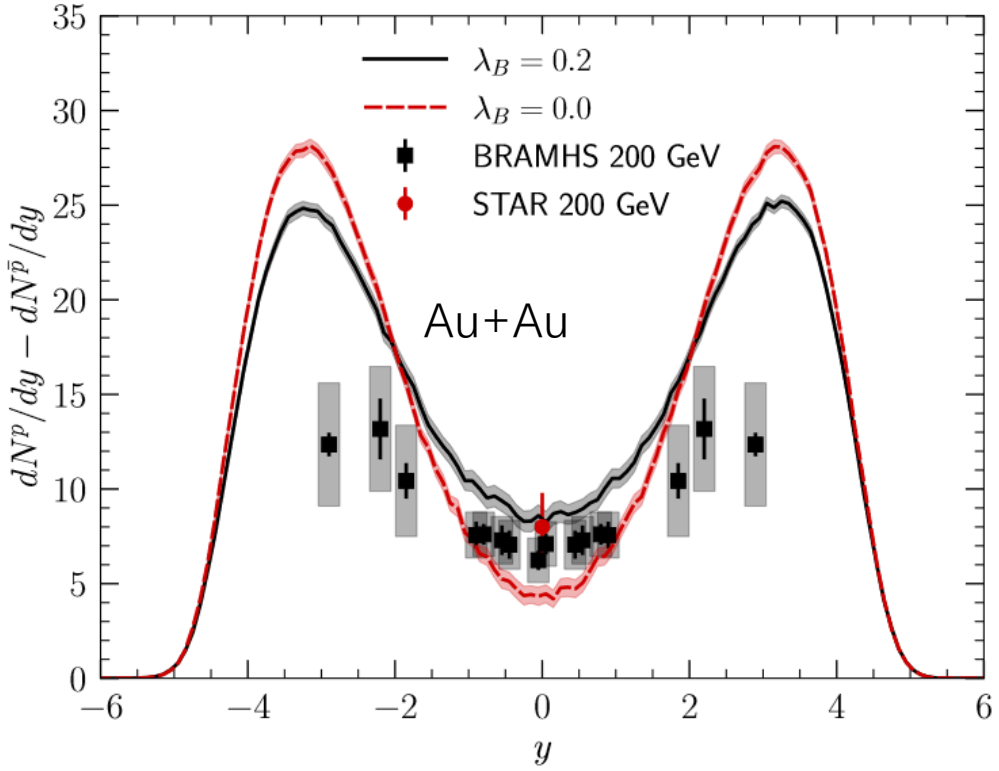
Initial baryon charge distributes towards center of the strings, instead at the string ends

$$P(y^B_{P/T}) = (1-\lambda_B)y_{P/T} + \lambda_B \frac{e^{(y^B_{P/T}-(y_P+y_T)/2)/2}}{4\sinh((y_P-y_T)/4)}.$$

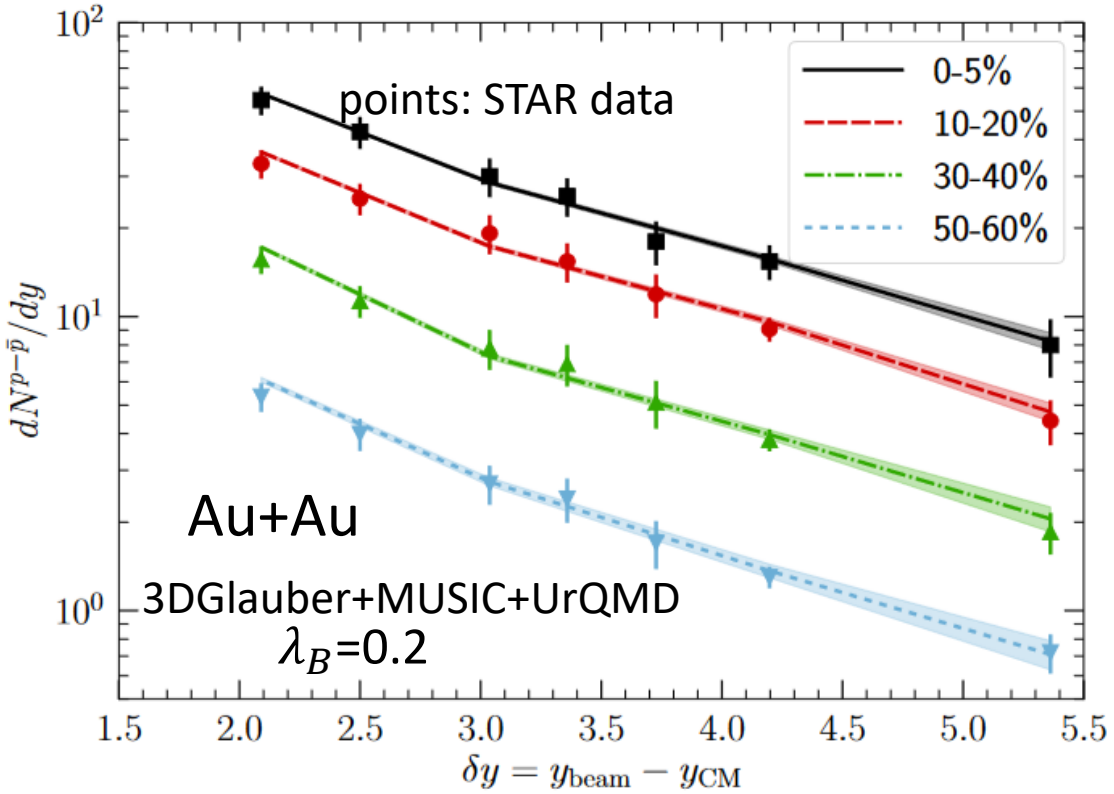


C. Shen and B. Schenke, [arXiv:2203.04685]. D. Kharzeev, Phys.Lett. B 378, 238–246 (1996).
W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094].

dN/dy of net-proton in Au+Au



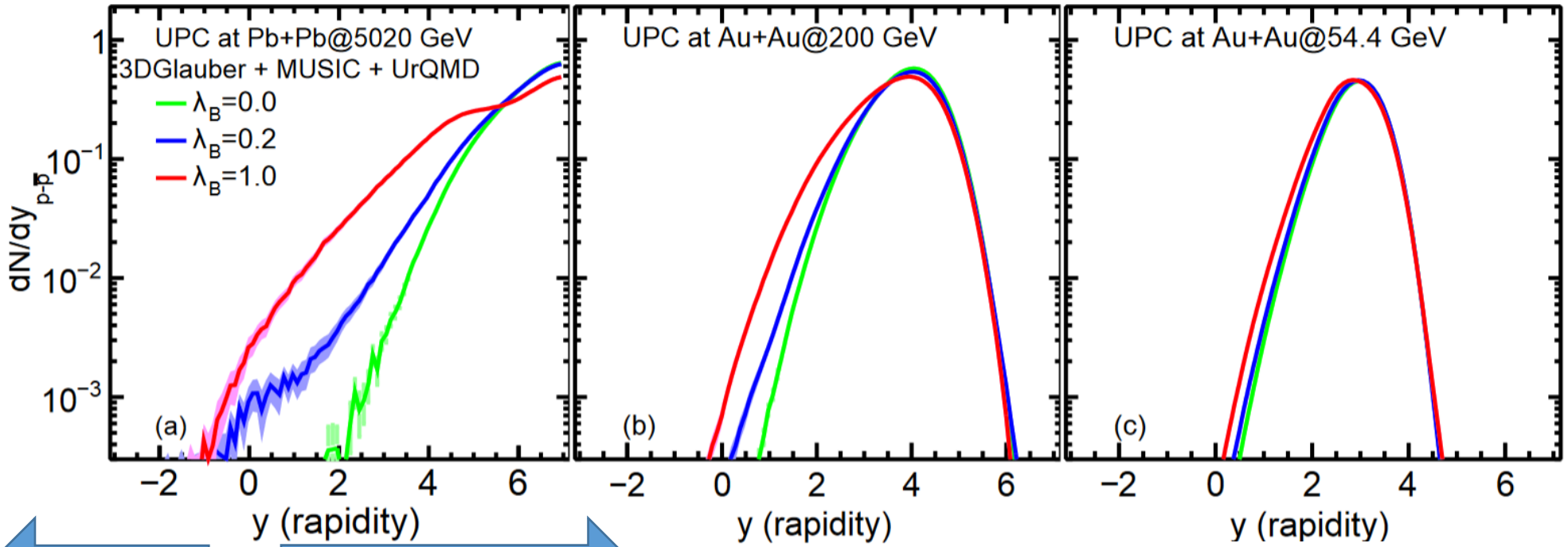
$$P(y^B_{P/T}) = (1-\lambda_B)y_{P/T} + \lambda_B \frac{e^{(y^B_{P/T}-(y_P+y_T)/2)/2}}{4\sinh((y_P-y_T)/4)}.$$



C. Shen and B. Schenke, [arXiv:2203.04685].

- Baryon junction is essential for dN/dy of net-p at mid-rapidity in Au+Au.
- 3DGlauber+MUSIC+UrQMD with λ_B=0.2 well reproduce the dN/dy of net-protons in Au+Au at RHIC.

dN/dy of net-proton in UPCs



$$P(y^B_{P/T}) = (1-\lambda_B)y_{P/T} + \lambda_B \frac{e^{(y^B_{P/T}-(y_P+y_T)/2)/2}}{4\sinh((y_P-y_T)/4)}.$$

- Larger λ_B generates larger dN/dy of net-proton at γ^* side.
- At high energy collisions, dN/dy of net-p is sensitive to λ_B. For UPC in Pb+Pb at $\sqrt{s_{NN}}$=5.02 TeV, dN/dy of λ_B=1.0 is two orders larger than that of λ_B=0.0 at y=2.0.
- λ_B=0.0, dN/dy of net-proton are from nucleus fragmentation only.

C. Shen and B. Schenke, [arXiv:2203.04685]. W. Zhao, C. Shen and B. Schenke [arXiv:2203.06094] and in preparation.

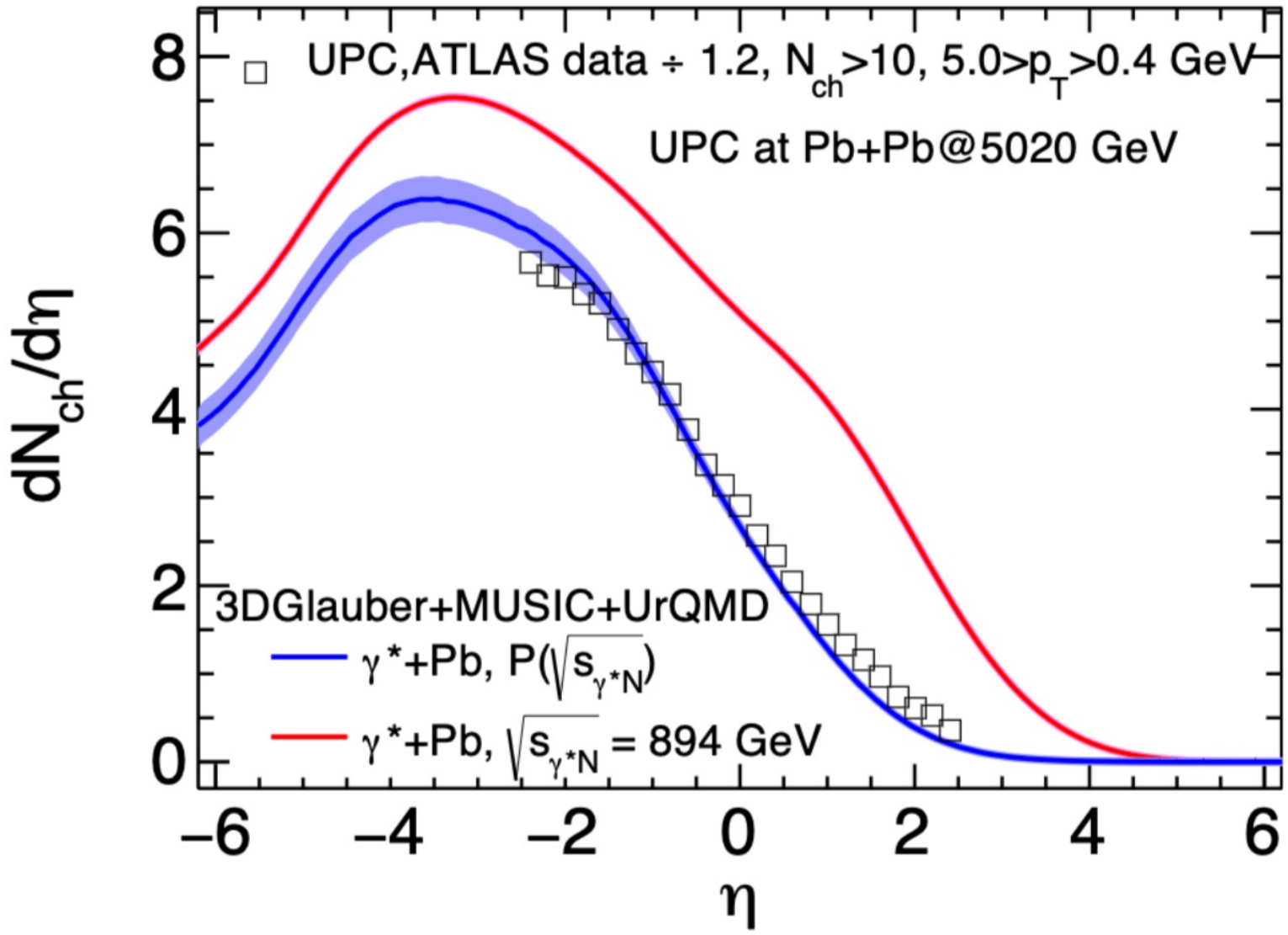
Summary

- We carried out the first dynamical (3+1)D hydro simulations that quantitatively study the collectivity in p+Pb and ultra-peripheral Pb+Pb collisions at LHC energies
- Different longitudinal flow decorrelation results in smaller v_2 in γ∗+Pb collisions compared to p+Pb collisions in a given multiplicity bin.
- The v_2 of γ∗+Pb collisions increases with the decreasing virtualities of photons in the hydro framework, which is qualitatively different with results from the CGC.
- UPCs provide the golden probe to baryon junction structure. At LHC energies, dN/dy of net-p in γ∗ side is very sensitive to the initial baryon charge generation mechanism.
- Our work bridges the phenomenological studies of collectivity and baryon production in relativistic heavy-ion collisions with future electron+nucleus collisions.

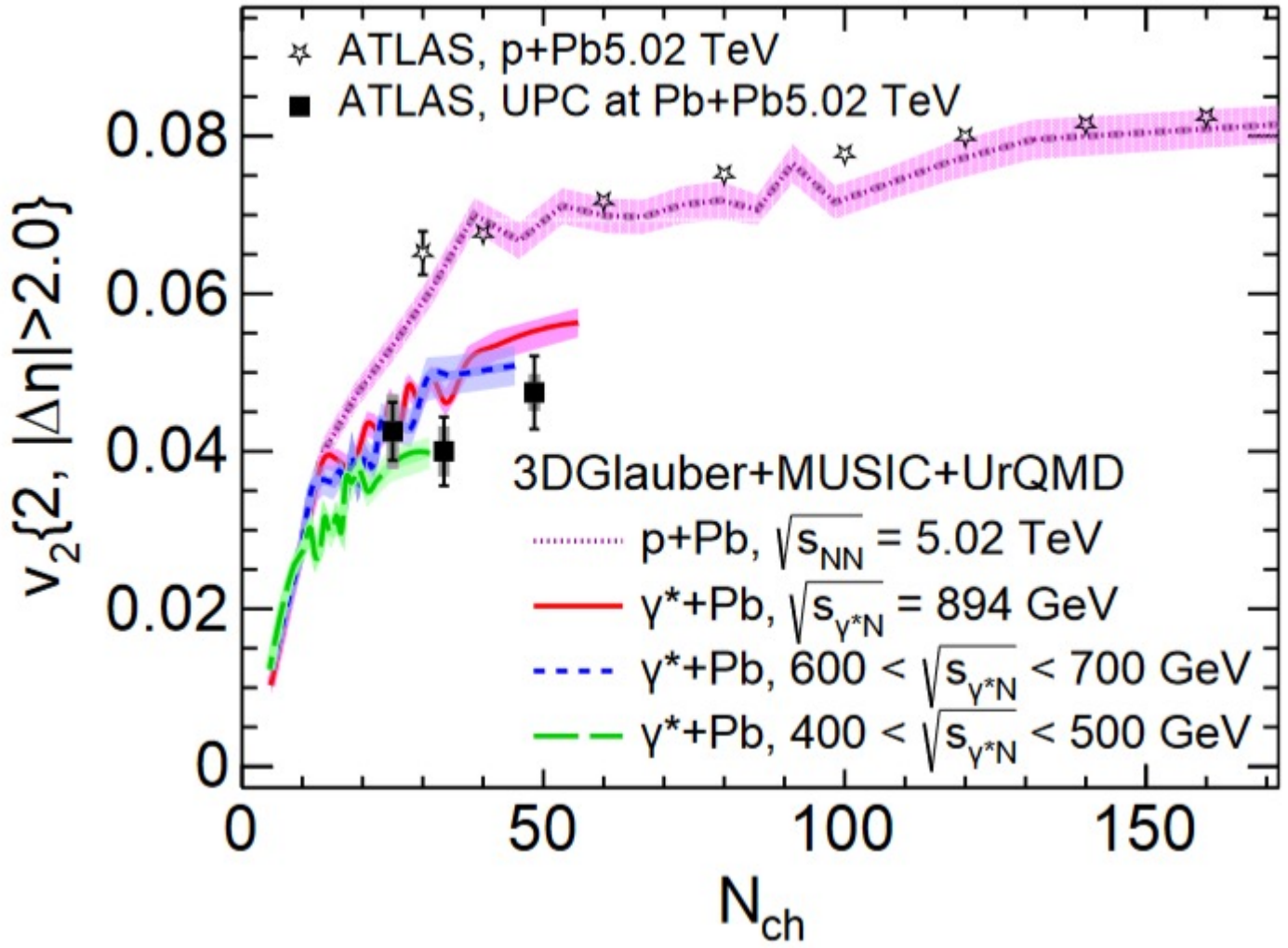
Thanks for Your Attention!

Back Up

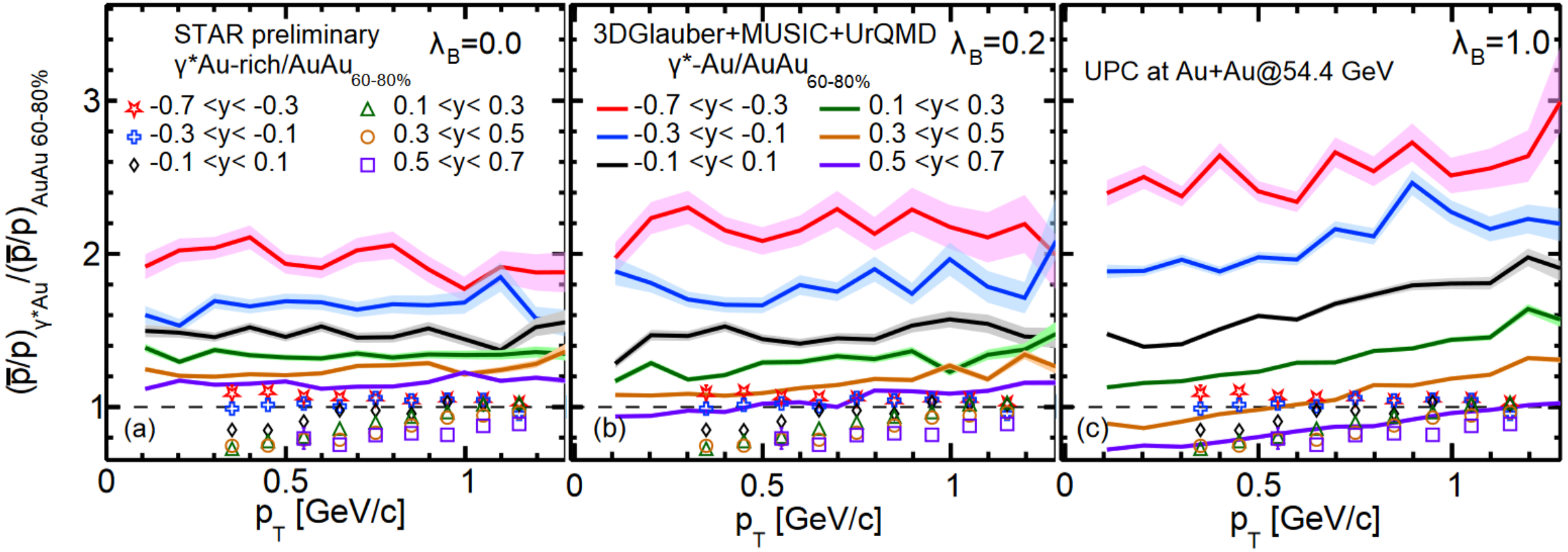
$dN_{ch}/d\eta$


UPC,ATLAS data ÷ 1.2, N_ch>10, 5.0>p_T>0.4 GeV
UPC at Pb+Pb@5020 GeV
3DGlauber+MUSIC+UrQMD
γ*+Pb, P(√s_γ*N)
γ*+Pb, √s_γ*N = 894 GeV
dN_ch/dη
η
8
6
4
2
0
−6
−4
−2
0
2
4
6

$v_n\{2\}$ at different $\sqrt{s_{\gamma^* N}}$



Double ratio of net-protons



$\sqrt{s_{\gamma N}}$ for UPC

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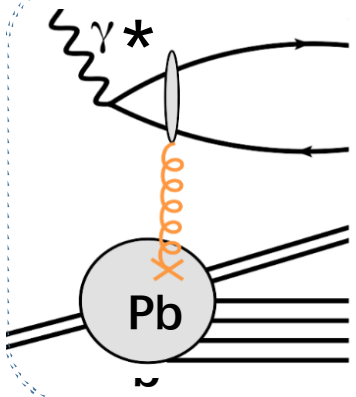
The physics of ultraperipheral collisions at the LHC

A.J. Baltz[a], G. Baur[b], D. d'Enterria[c], L. Frankfurt[d], F. Gelis[e], V. Guzey[f,w], K. Hencken[g,h,1], Yu. Kharlov[i], M. Klasen[j], S.R. Klein[k], V. Nikulin[l], J. Nystrand[m], I.A. Pshenichnov[n,o], S. Sadovsky[i], E. Scapparone[p], J. Seger[q], M. Strikman[r,*,1], M. Tverskoy[l], R. Vogt[k,s,t,1], S.N. White[a], U.A. Wiedemann[u], P. Yepes[v,1], M. Zhalov[l]



In the lab frame, photon flux decreases exponentially above

$$k_{max} \approx \gamma \hbar c / R_A$$

In the lab frame, the four momentum vectors of γ and nucleon, $P_\gamma^\mu = (k_{\max}, 0, 0, k_{\max})$ and $P_N^\mu = (\frac{\sqrt{s_{NN}}}{2}, 0, 0, -\frac{\sqrt{s_{NN}}}{2})$, the central of mass energy per nucleon of γ - nucleon collisions is,

$$s_{\gamma N} = (k_{\max} + \sqrt{s_{NN}}/2)^2 - (k_{\max} - \sqrt{s_{NN}}/2)^2 = 2k_{\max}\sqrt{s_{NN}}. \quad (1)$$

On the other hand, according to the paper [1] the $k_{\max} \approx \gamma\hbar c/R_A$, with the $\gamma = \sqrt{s_{NN}}/2m_p$, we can get the $\sqrt{s_{\gamma N}} = 894$ GeV for Pb-Pb collisions at $\sqrt{s_{NN}}$=5020 GeV.

Virtuality dependent PDF

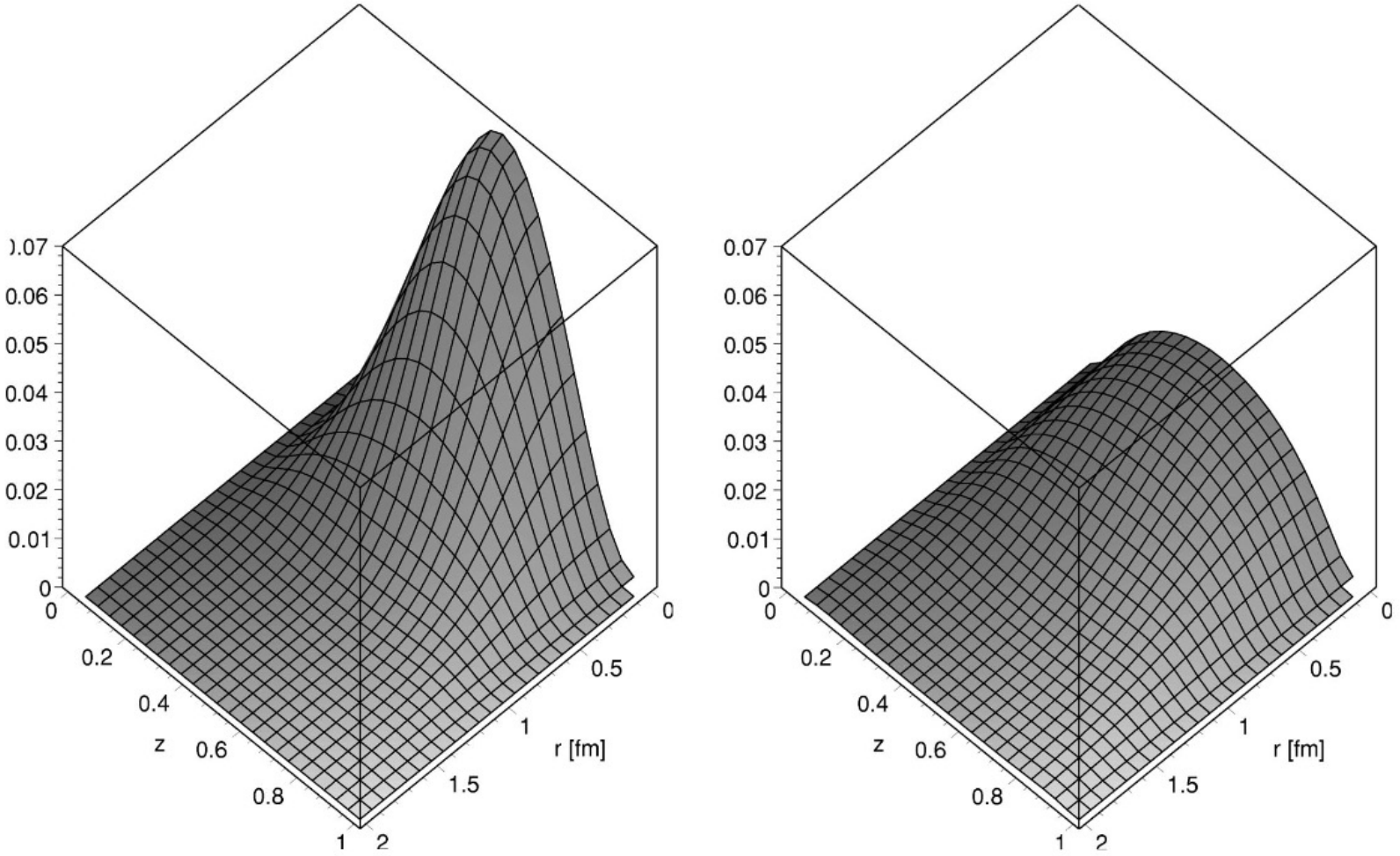


FIG. 6. The ρ wave functions $|\Psi^L|^2$ (left) and $|\Psi^T|^2$ (right) in the boosted Gaussian model with the quark mass used in the FKS dipole model.

J. R. Forshaw, R. Sandapen and G. Shaw, Phys. Rev. D 69, 094013 (2004).