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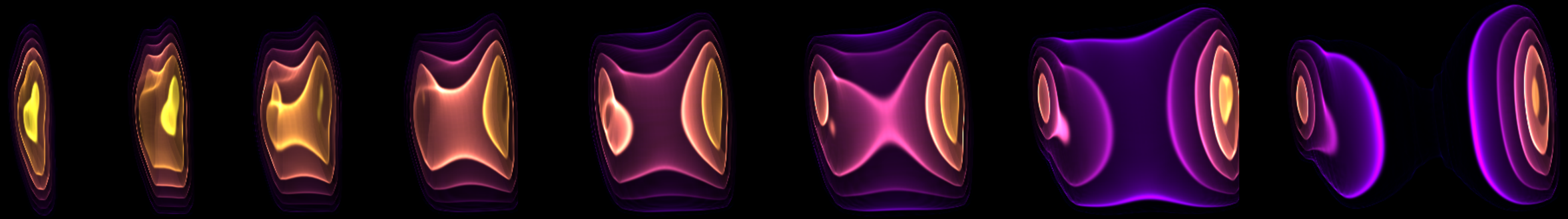
COLLECTIVITY AND BARYON JUNCTIONS IN ULTRA-PERIPHERAL HEAVY-ION COLLISIONS

CHUN SHEN



SQM2022
The 20th International Conference on Strangeness in Quark Matter
13-17 June 2022 Busan, Republic of Korea

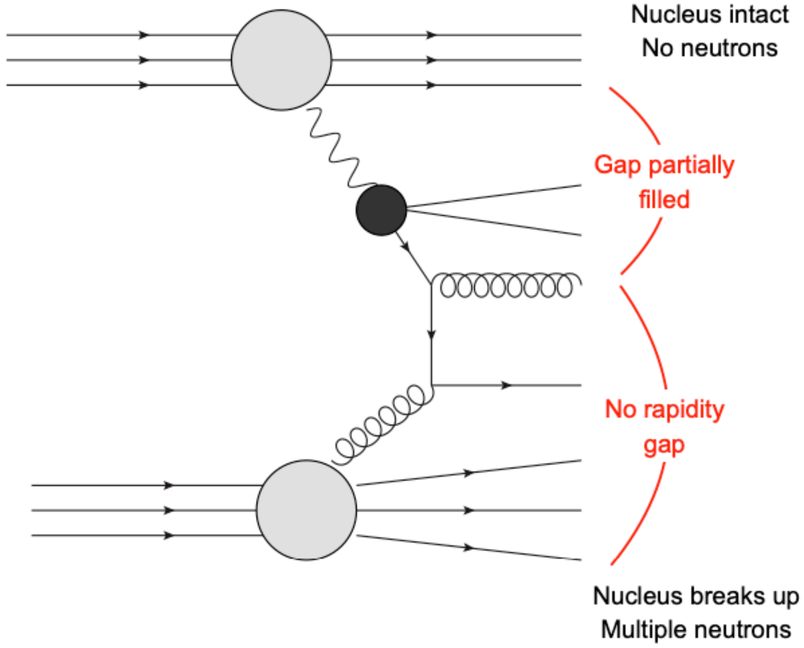
In collaboration with Wenbin Zhao and Björn Schenke

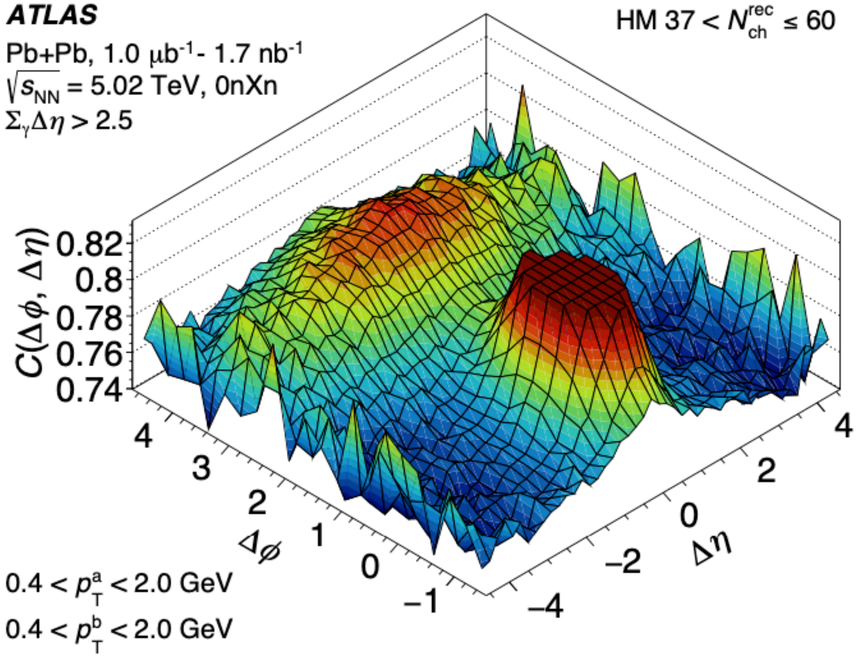
W. Zhao, C. Shen and B. Schenke, arXiv:2203.06094 [nucl-th]

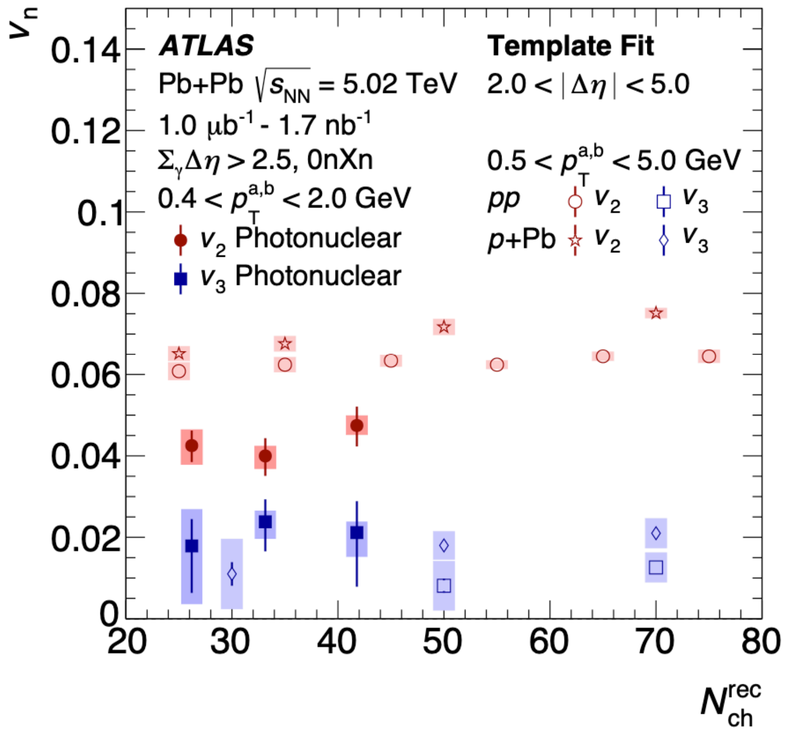
June 14, 2022

COLLECTIVITY IN ULTRA PERIPHERAL COLLISIONS

ATLAS Phys. Rev. C 104, 014903 (2021)



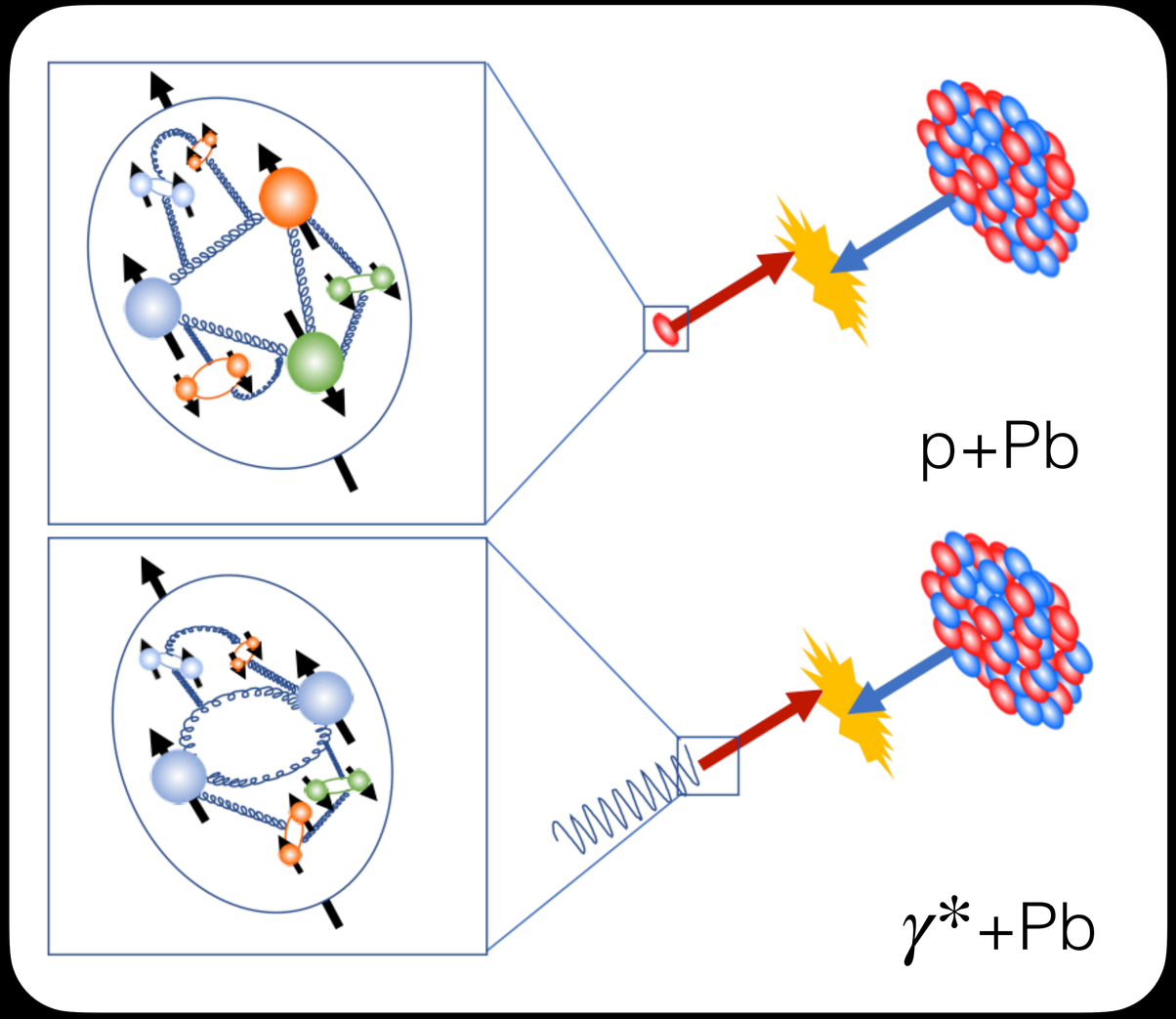




- Collective two-particle correlations were observed in the resolved photo-nuclear processes in ultra peripheral Pb+Pb collisions (UPC) at the LHC
- The magnitudes of v_n in UPC are comparable with those in p+p and p+Pb collisions

ORIGIN OF COLLECTIVITY IN UPC?

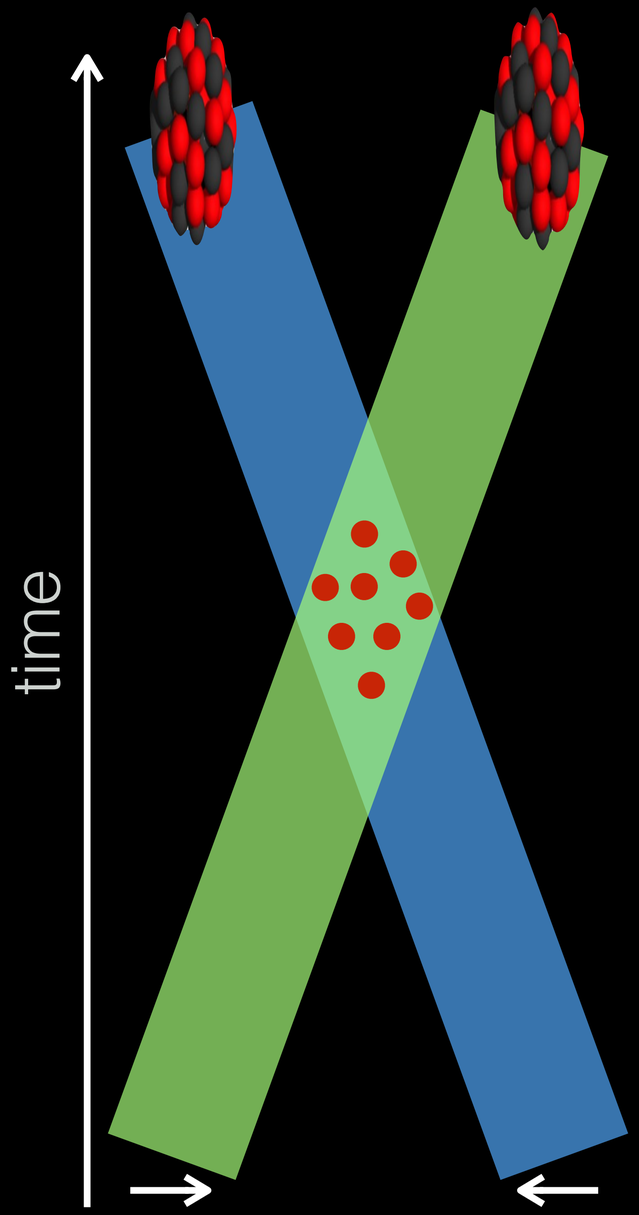
Y. Shi, L. Wang, S. Y. Wei, B. W. Xiao and L. Zheng, Phys. Rev. D 103, 054017 (2021)

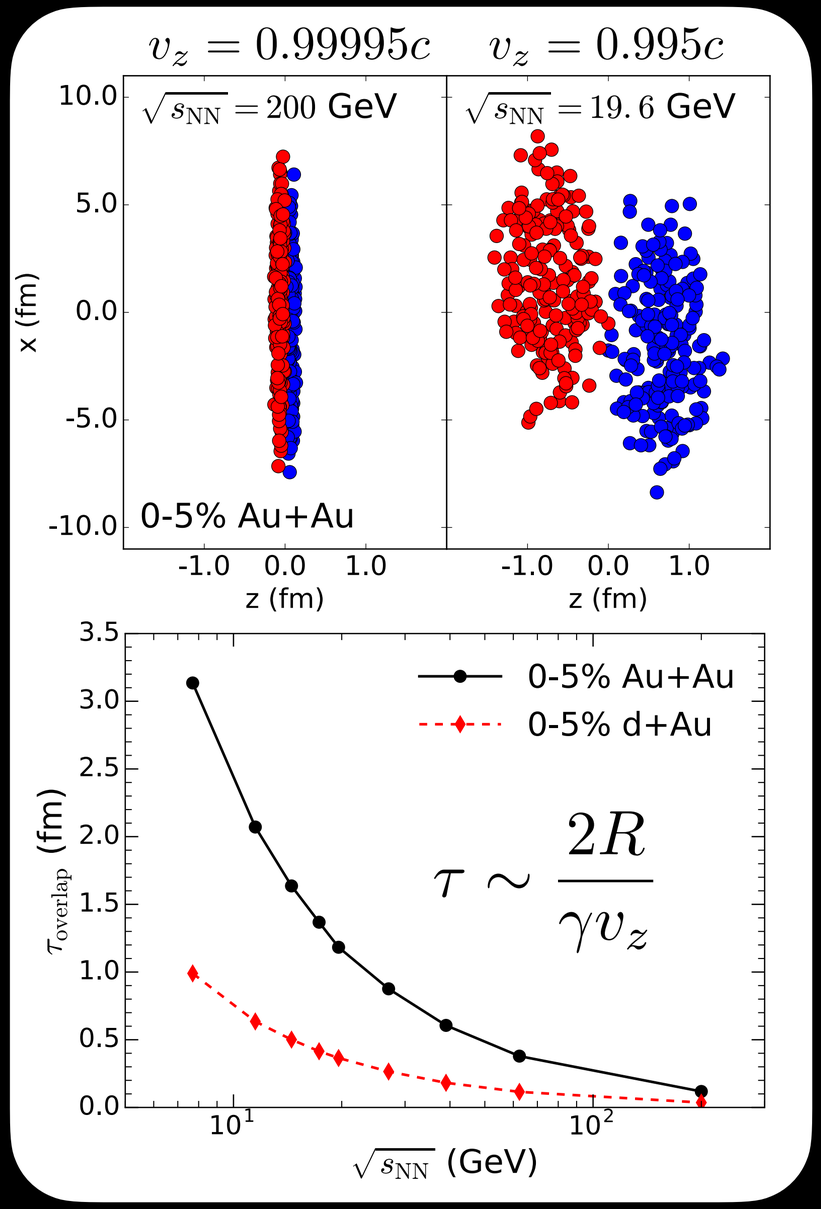


- The quasi-real photon in UPC fluctuates to a vector meson that interacts with the Pb nucleus via QCD interactions
- Similar to high multiplicity p+Pb collisions, the vector meson+Pb collisions could experience strong final-state interactions

Quest for a (3+1)D dynamical framework to quantitatively study γ^*+Pb and p+Pb collisions together

3D DYNAMICS IS ALSO IMPORTANT FOR BES PROGRAMS

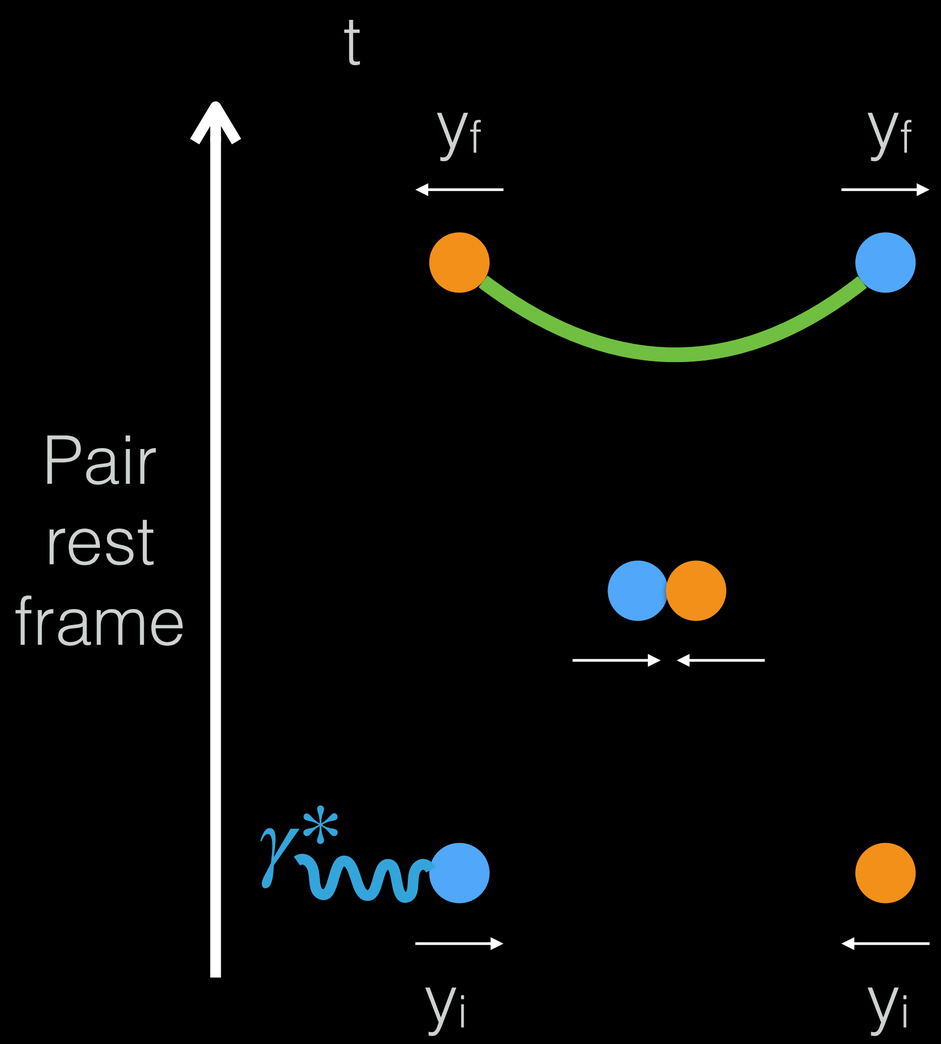




- Geometry-Based initial conditions
  - C. Shen and S. Alzhrani, Phys. Rev. C 102, 014909 (2020)
- Classical string-based initial conditions
  - A. Bialas, A. Bzdak and V. Koch, Acta Phys. Polon. B49 (2018)
  - C. Shen and B. Schenke, Phys.Rev. C97 (2018) 024907
- Transport model based initial conditions
  - I. A. Karpenko, P. Huovinen, H. Petersen and M. Bleicher, Phys. Rev. C91 (2015) 064901
  - L. Du, U. Heinz and G. Vujanovic, Nucl. Phys. A982 (2019) 407-410
- Color Glass Condensate based models
  - M. Li and J. Kapusta, Phys. Rev. C 99, 014906 (2019)
  - L. D. McLerran, S. Schlichting and S. Sen, Phys. Rev. D 99, 074009 (2019)
  - M. Martinez, M. D. Sievert, D. E. Wertepny and J. Noronha-Hostler, arXiv:1911.10272 + arXiv:1911.12454 [nucl-th]
- Holographic approach at intermediate coupling
  - M. Attems, et al., Phys.Rev.Lett. 121 (2018), 261601

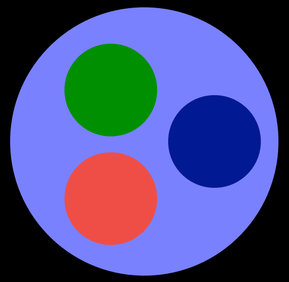
THE 3D MC-GLAUBER + STRING MODEL

C. Shen and B. Schenke, Phys.Rev. C97 (2018) 024907
C. Shen and B. Schenke, arXiv:2203.04685 [nucl-th]

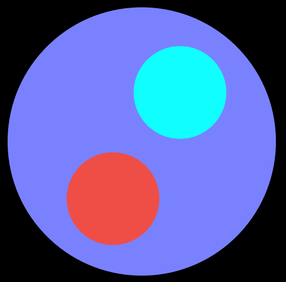


- Collision geometry is determined by MC-Glauber model
- Hot spots associated with valence quarks are sampled from PDF + a soft partonic cloud carrying small x partons
- Hot spots are randomly picked to lose energy during a collision

nucleon



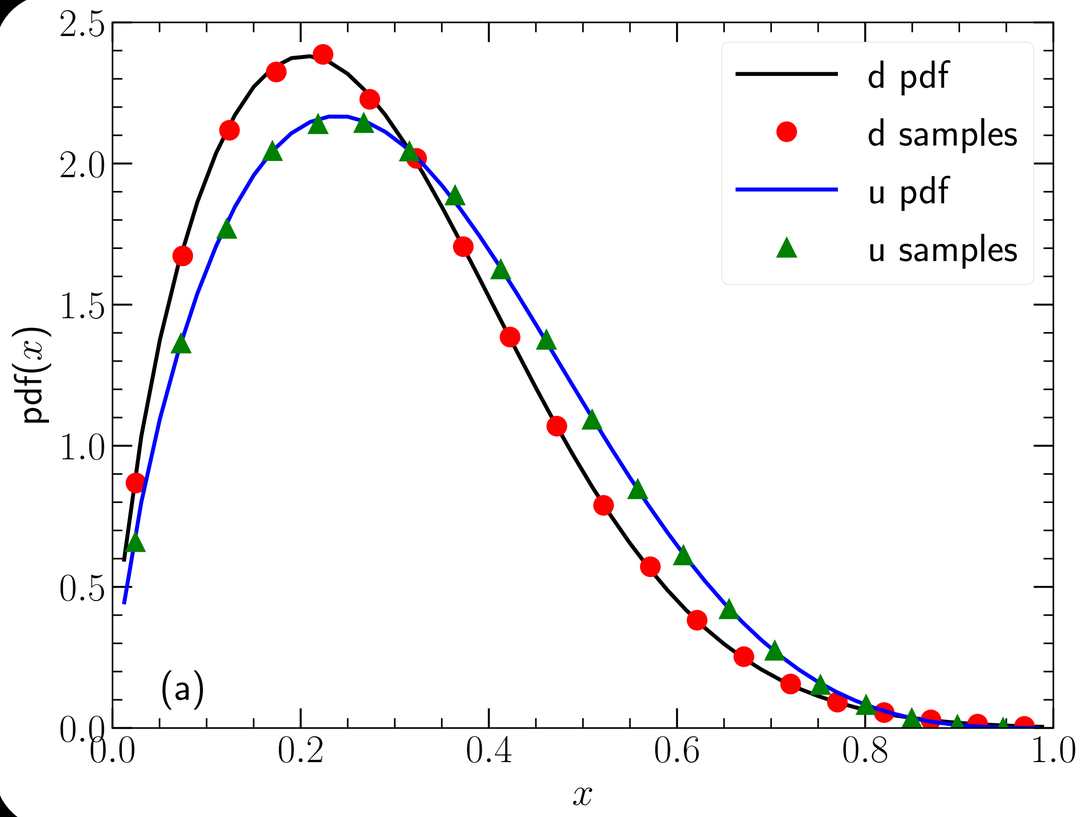
vector meson

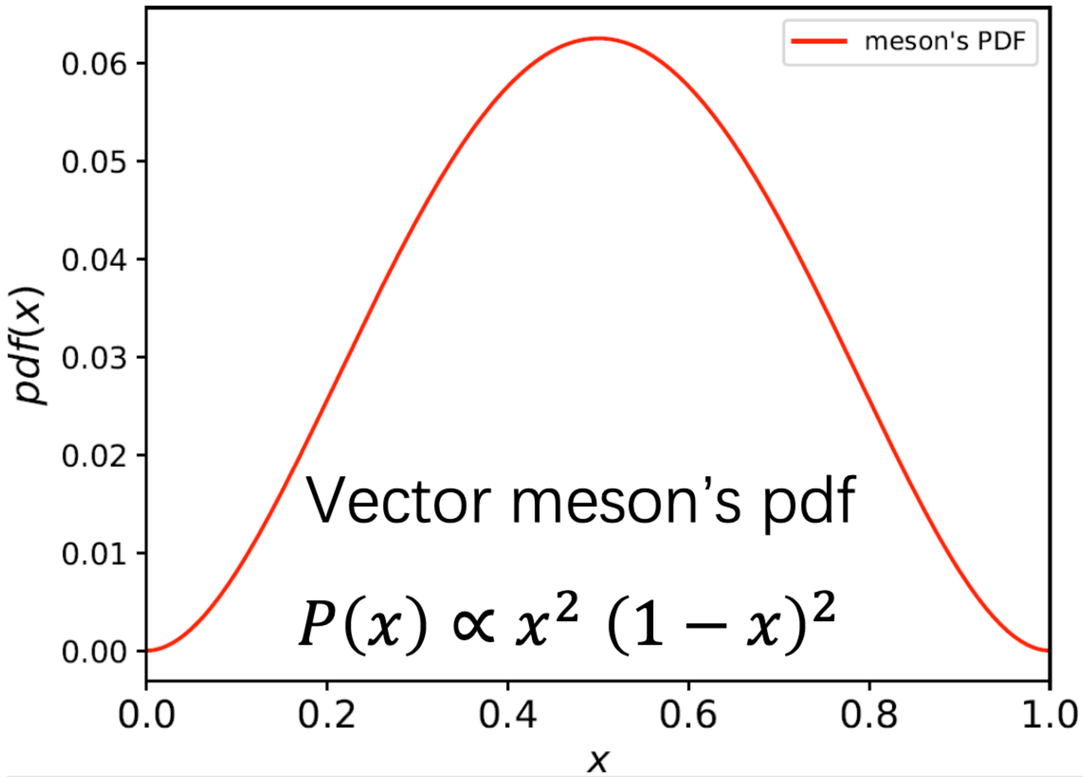


IMPROVED PDF SAMPLING FOR MULTIPLE PARTONS

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

- We develop a Metropolis algorithm to sample multiple partons from PDFs with constraint $\sum_i x_i \leq 1$





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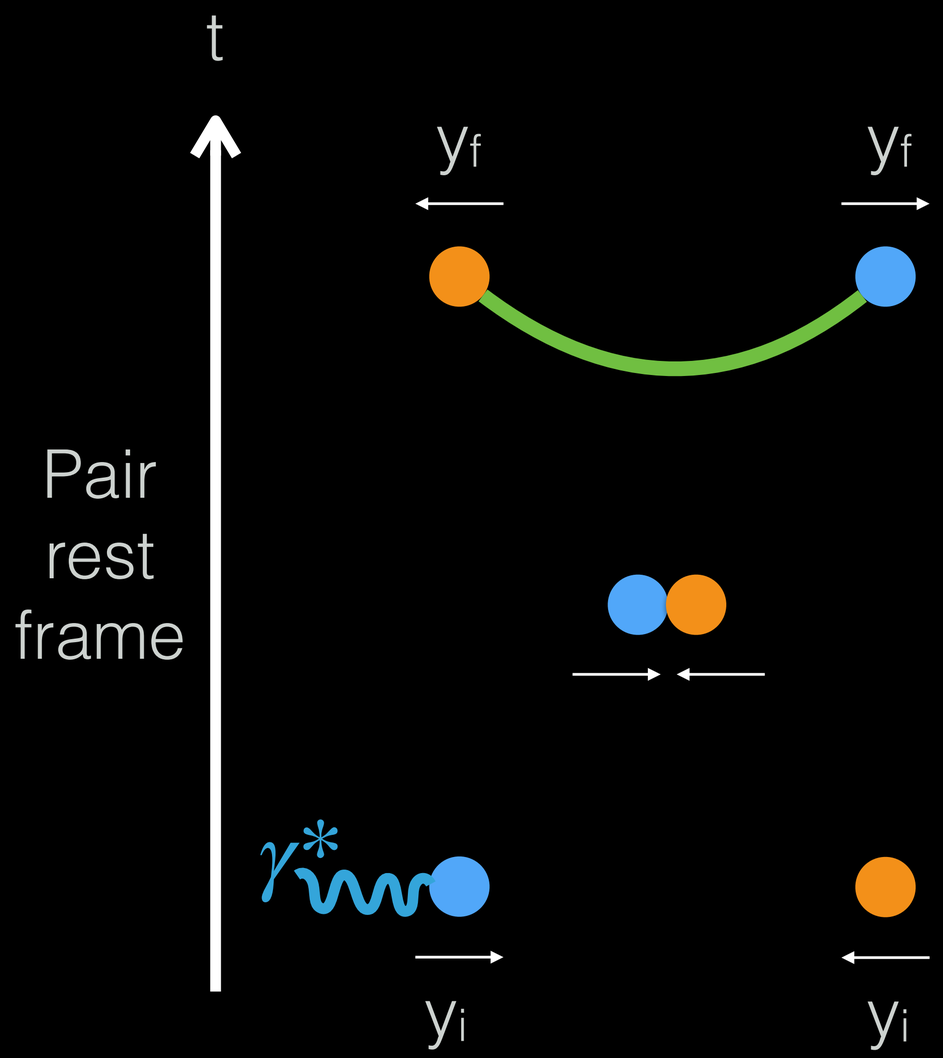

- Collision geometry is determined by MC-Glauber model
- Hot spots are sampled from PDF and randomly picked to lose energy during a collision
- Incoming quarks are decelerated with a classical string tension,

$$dp^\mu = -T^{\mu\nu} d\Sigma_\nu$$

$$T^{\mu\nu} = \begin{pmatrix} \sigma & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\sigma \end{pmatrix} \qquad d\Sigma_\nu = (dz, 0, 0, -dt)$$

THE 3D MC-GLAUBER + STRING MODEL

C. Shen and B. Schenke, Phys.Rev. C97 (2018) 024907
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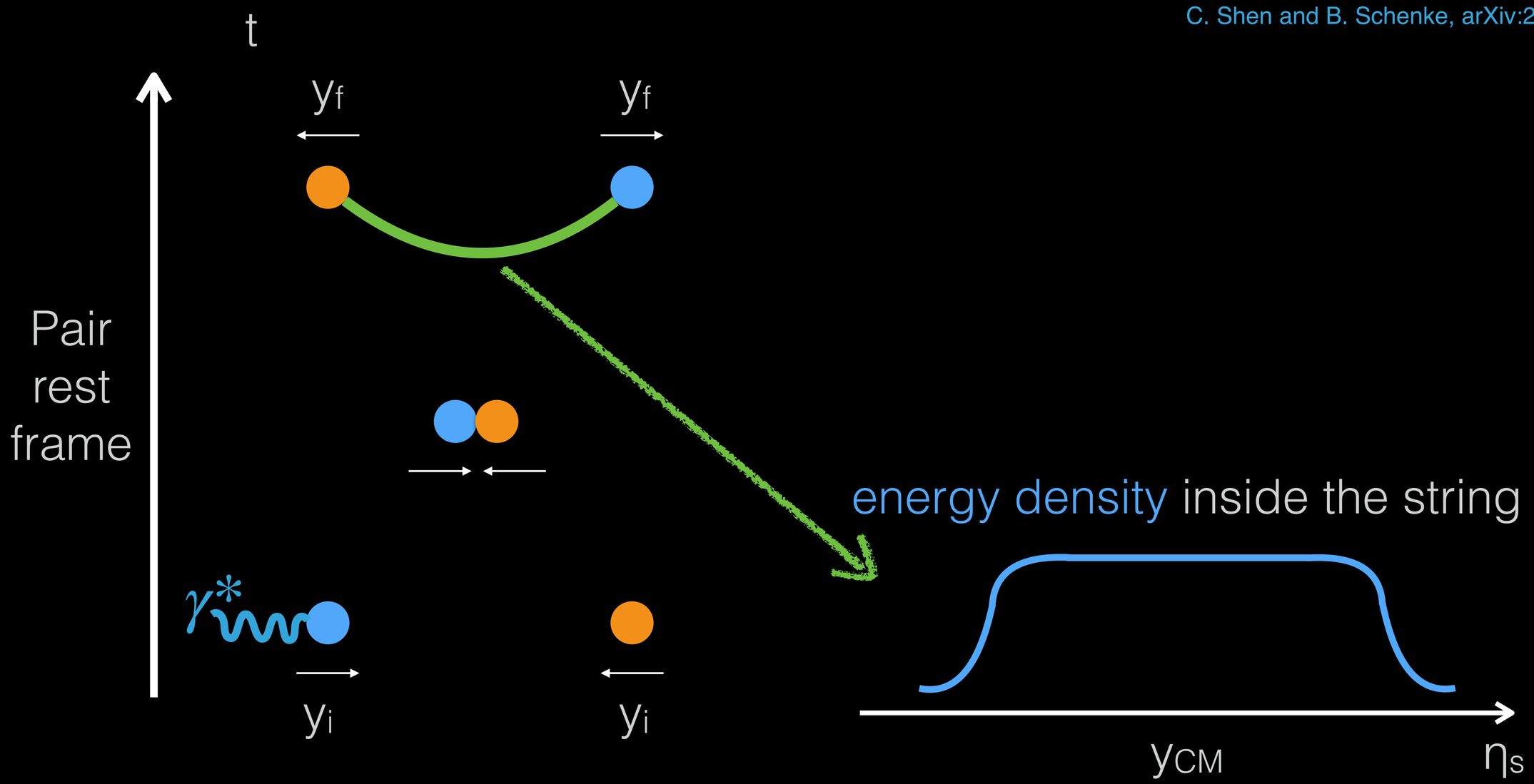

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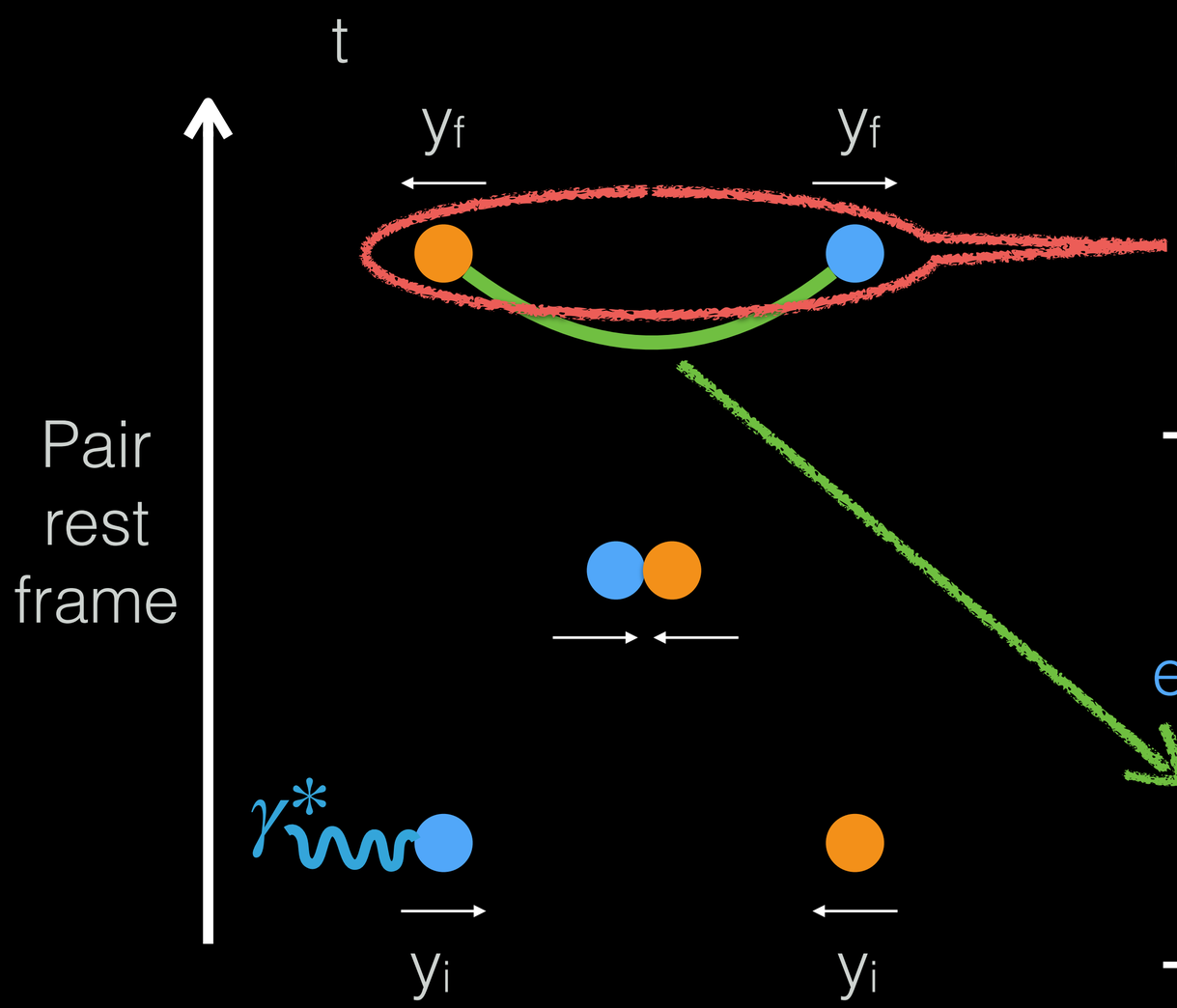
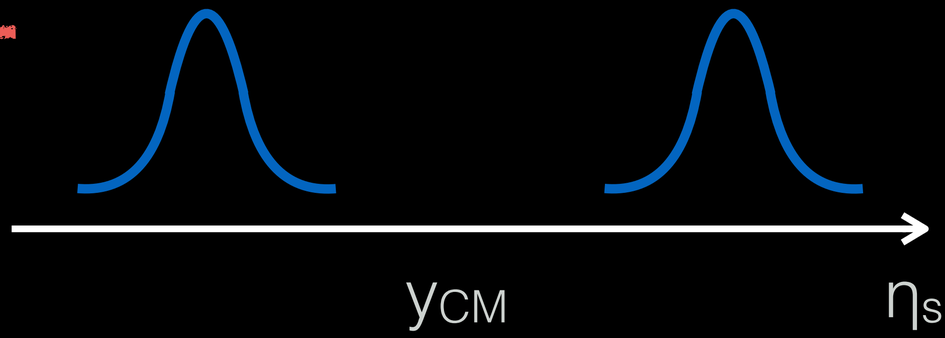


Partons' remaining energies are deposited at the string ends



energy density inside the string

THE 3D MC-GLAUBER + STRING MODEL

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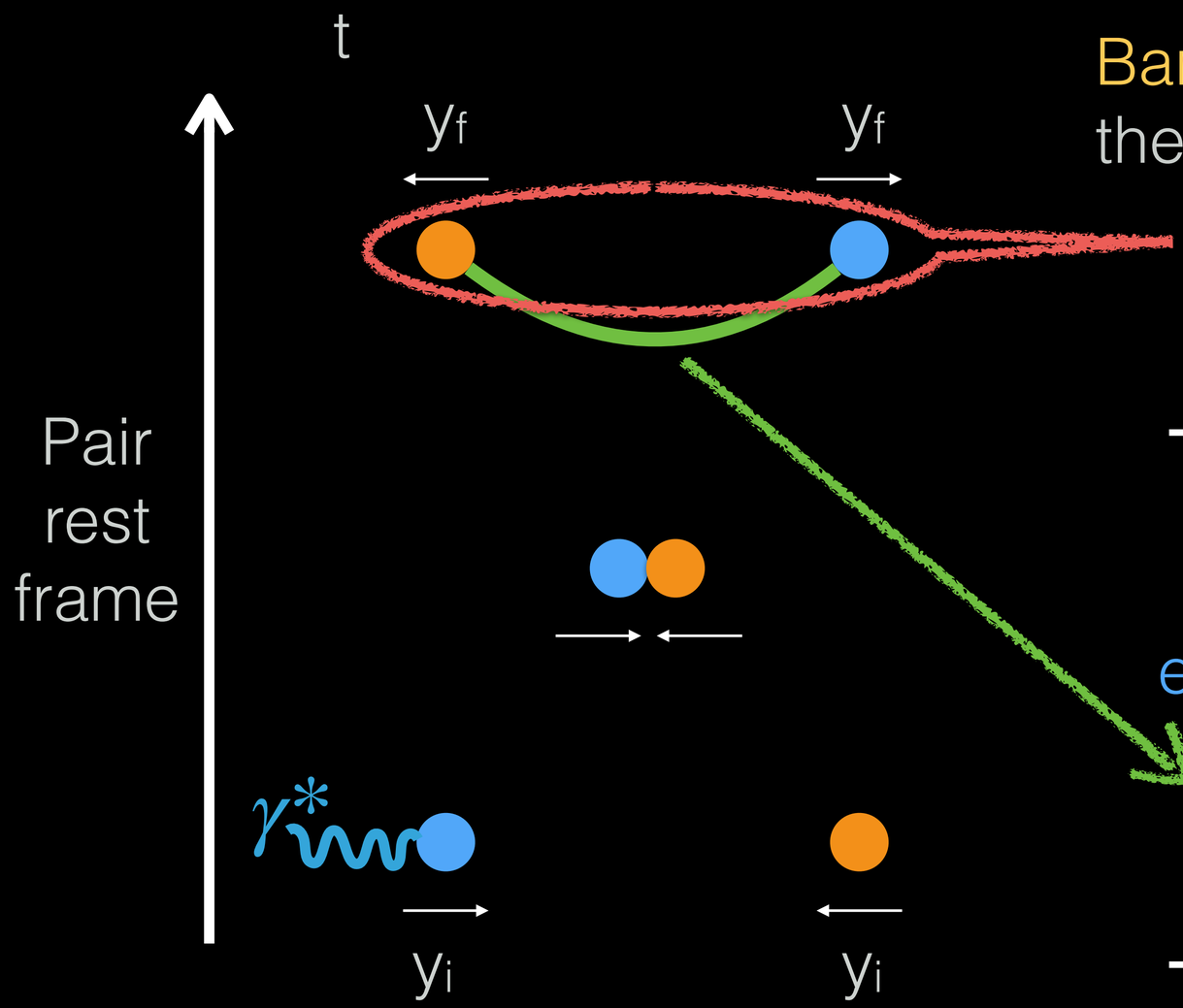
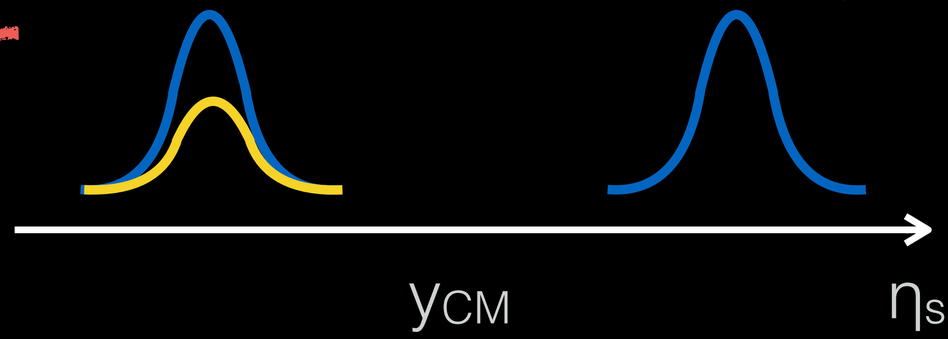
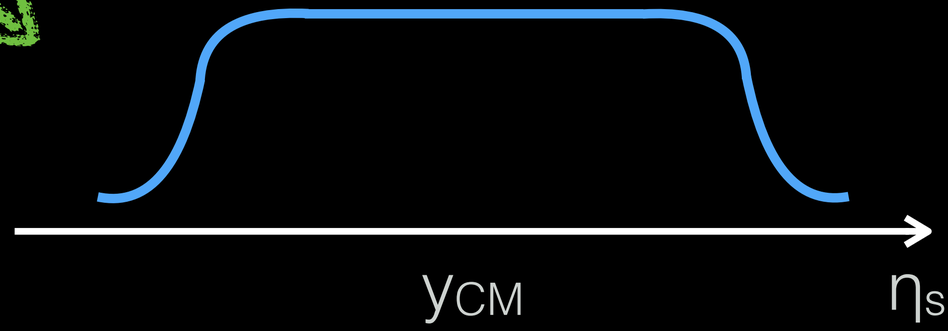


Baryon densities are deposited at the string ends or string junctions

D. Kharzeev, Phys. Lett. B 378, 238 (1996)



energy density inside the string



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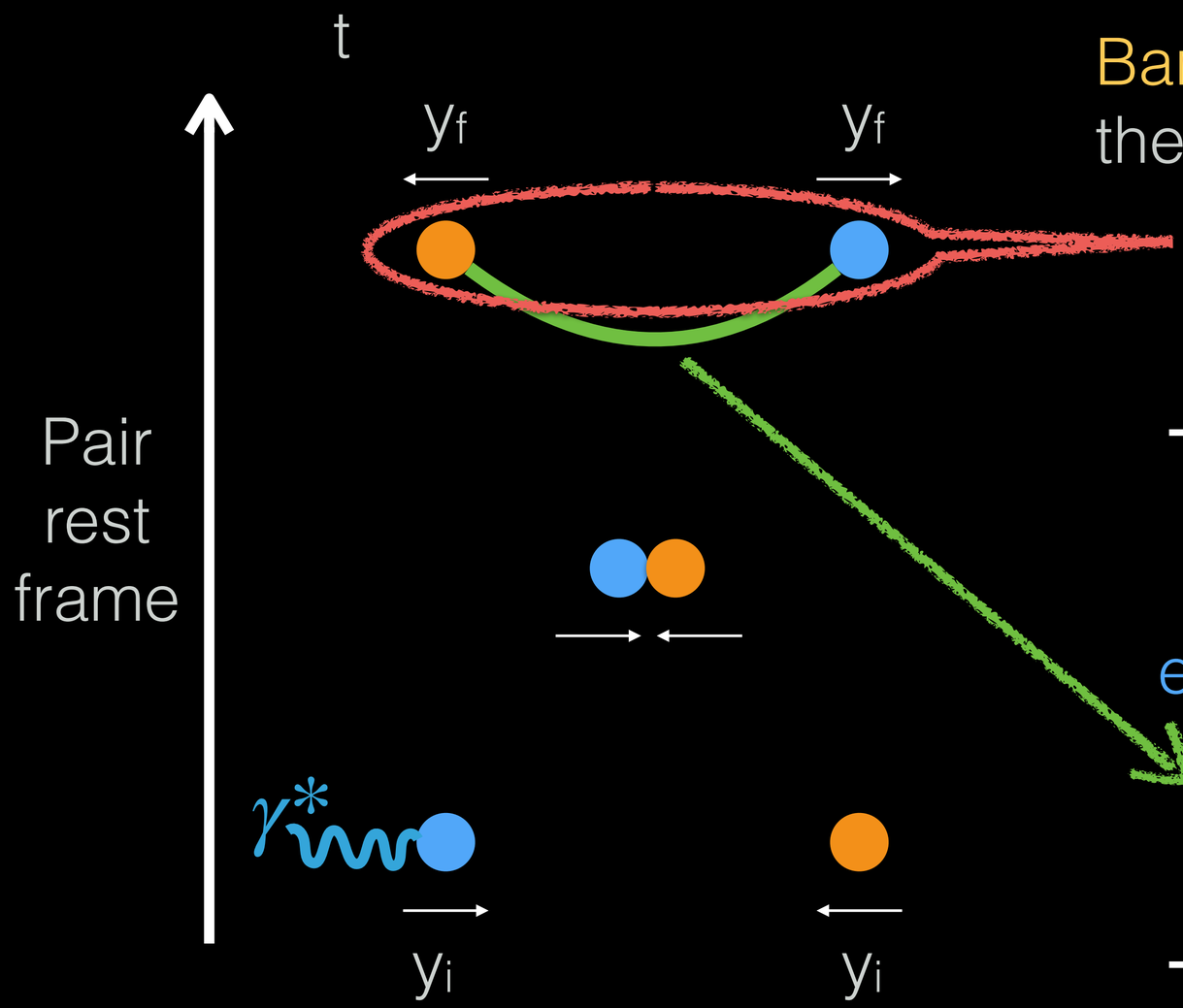

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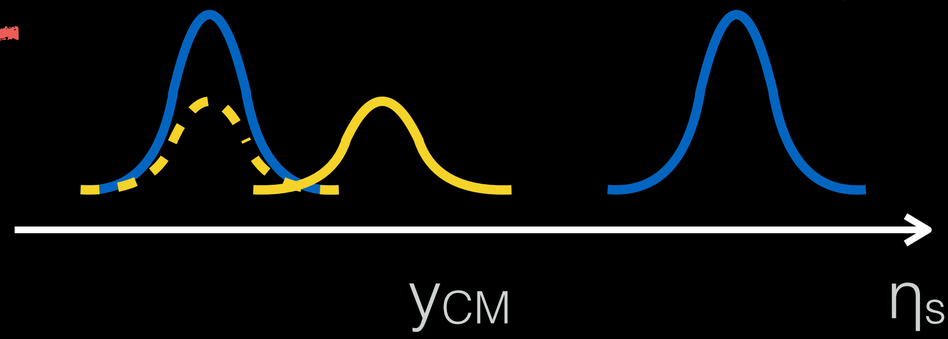

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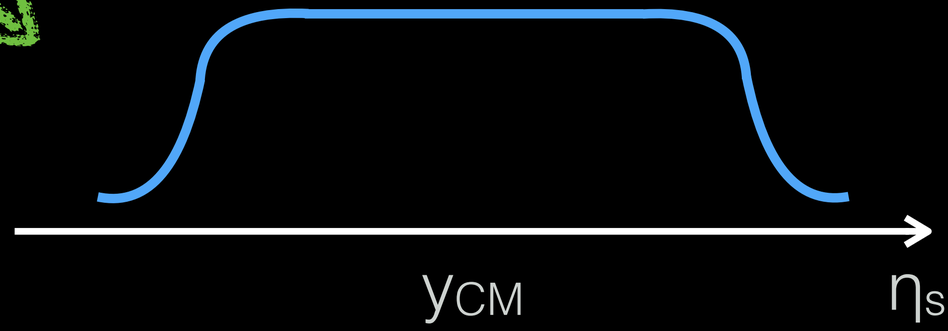

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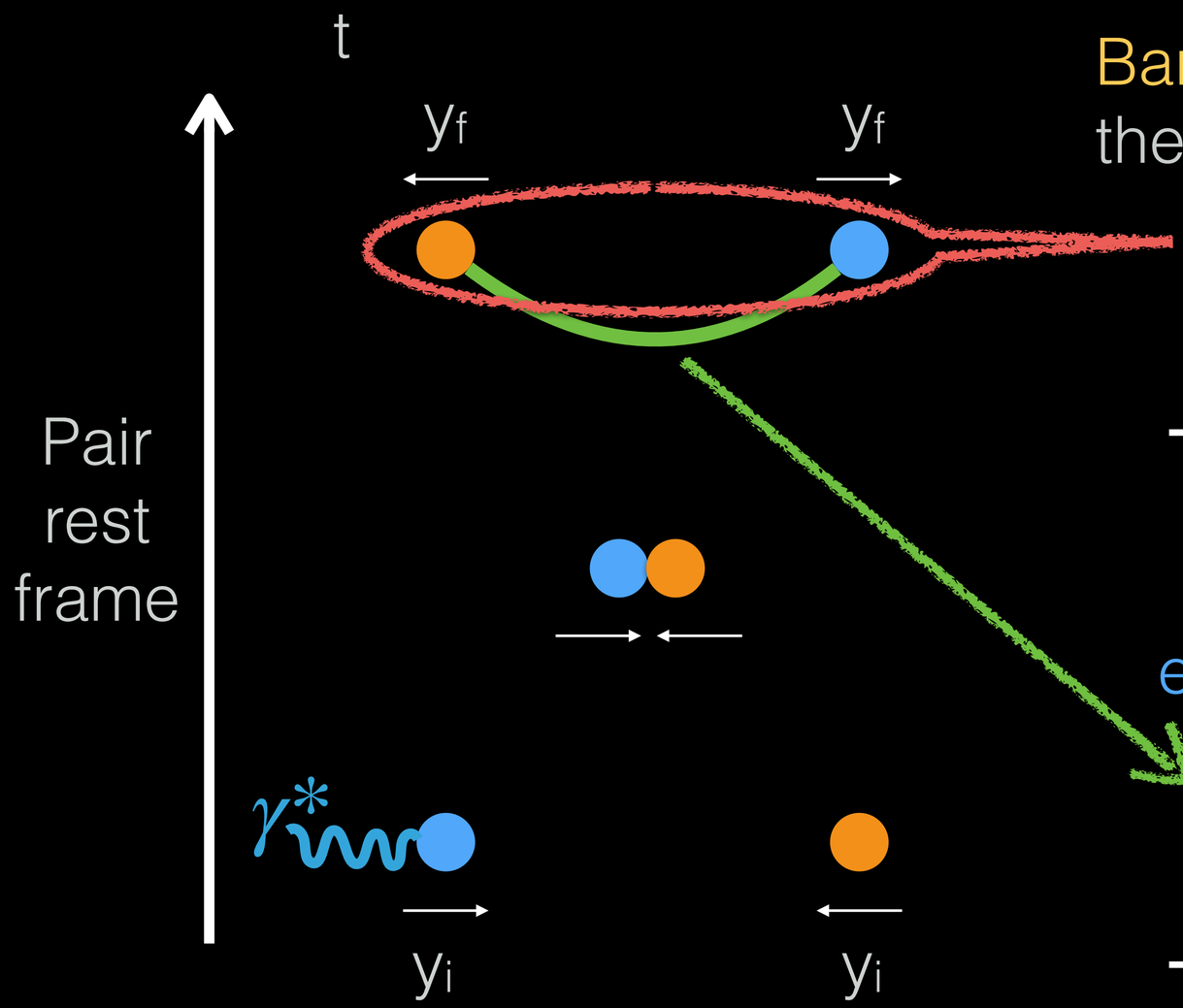

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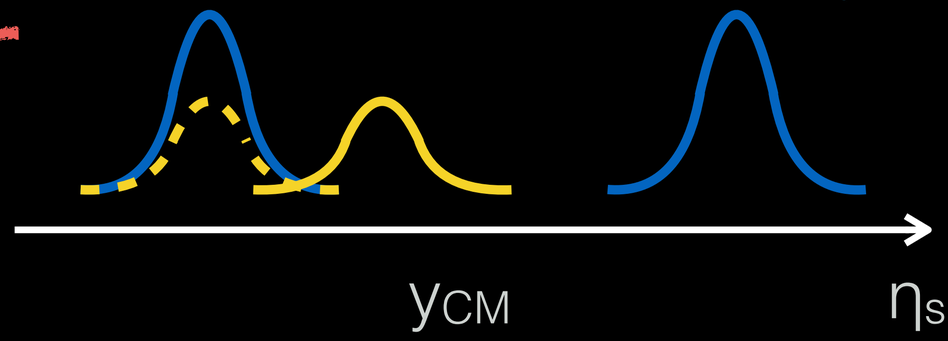
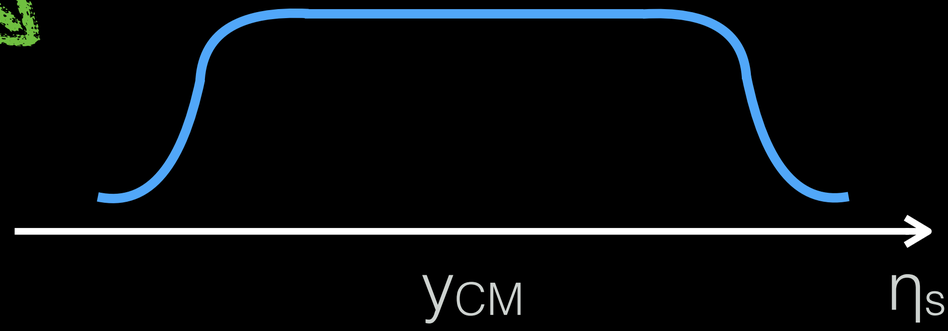


energy density inside the string



Imposed conservation for energy, momentum, and net baryon density

COLLISION KINEMATICS IN UPC

A. J. Baltz *et al.* Phys. Rept. 458, 1-171 (2008)

- The energy of incoming quasi-real photon fluctuates event by event

$$\frac{dN^{\gamma}}{dk_{\gamma}} = \frac{2Z^2\alpha}{\pi k_{\gamma}}\left[w_R^{AA}K_0(w_R^{AA})K_1(w_R^{AA}) - \frac{(w_R^{AA})^2}{2}(K_1^2(w_R^{AA}) - K_0^2(w_R^{AA}))\right]$$

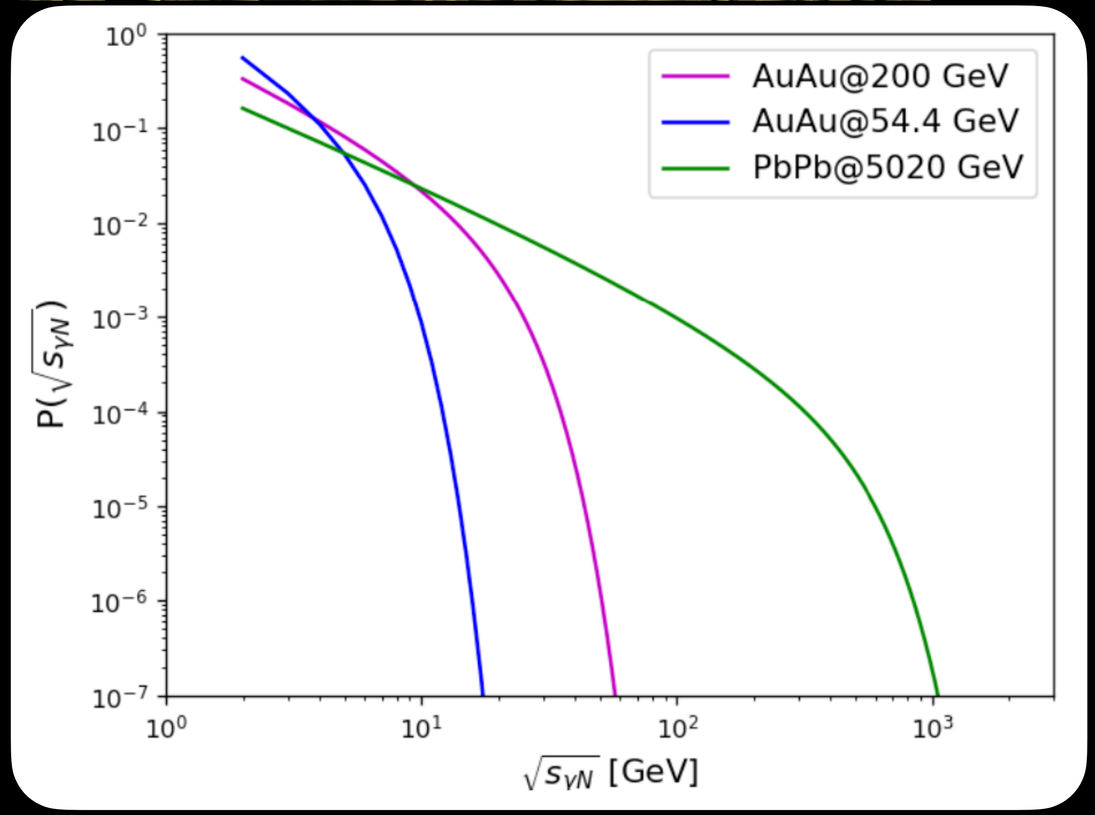
$$w_R^{AA} = 2k_{\gamma}R_A/\gamma_L,\ \gamma_L = \sqrt{s_{\rm NN}}/(2m_N)$$

- The center of mass collision energy for the $\gamma^* + A$ system fluctuates

$$\sqrt{s_{\gamma N}} = (2k_{\gamma}\sqrt{s_{\rm NN}})^{1/2}$$

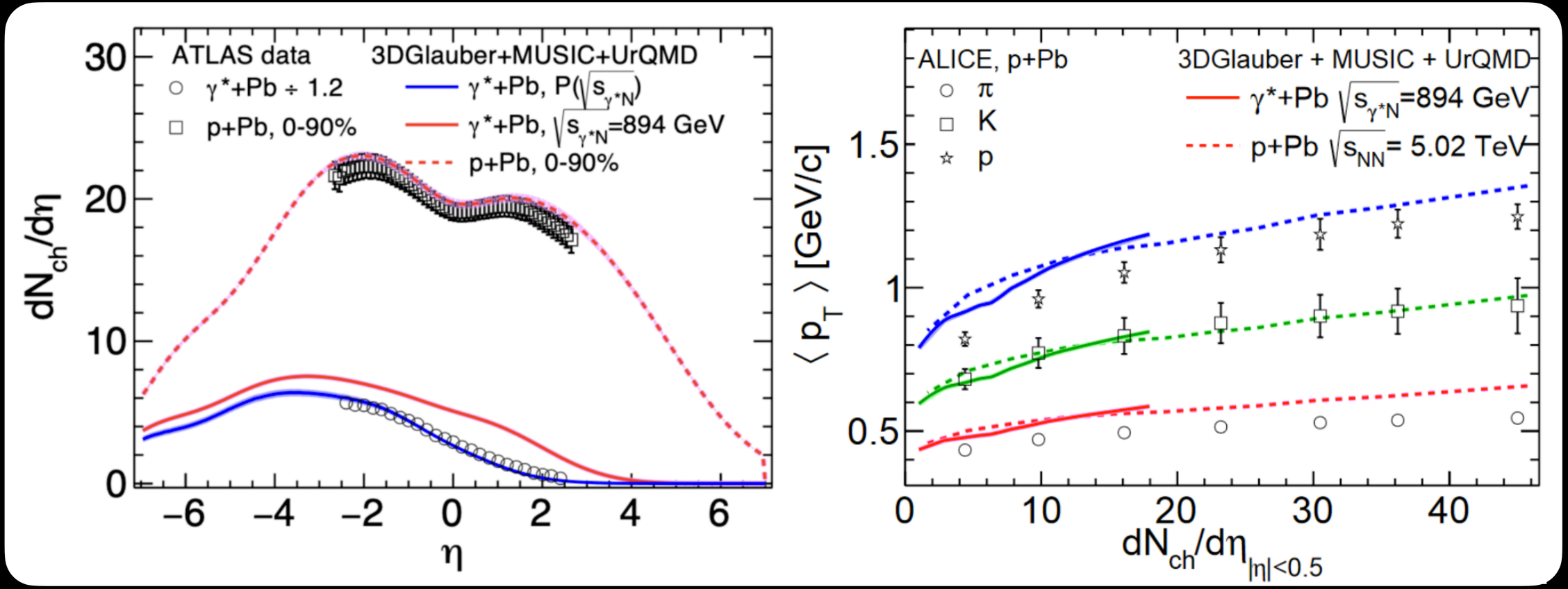
- The center of mass rapidity of $\gamma^* + A$ collision fluctuates in the lab frame

$$\Delta y = y_{\rm beam}(\sqrt{s_{\gamma N}}) - y_{\rm beam}(\sqrt{s_{\rm NN}})$$



MULTIPLICITY AND $\langle p_T \rangle$ IN pA AND γA COLLISIONS

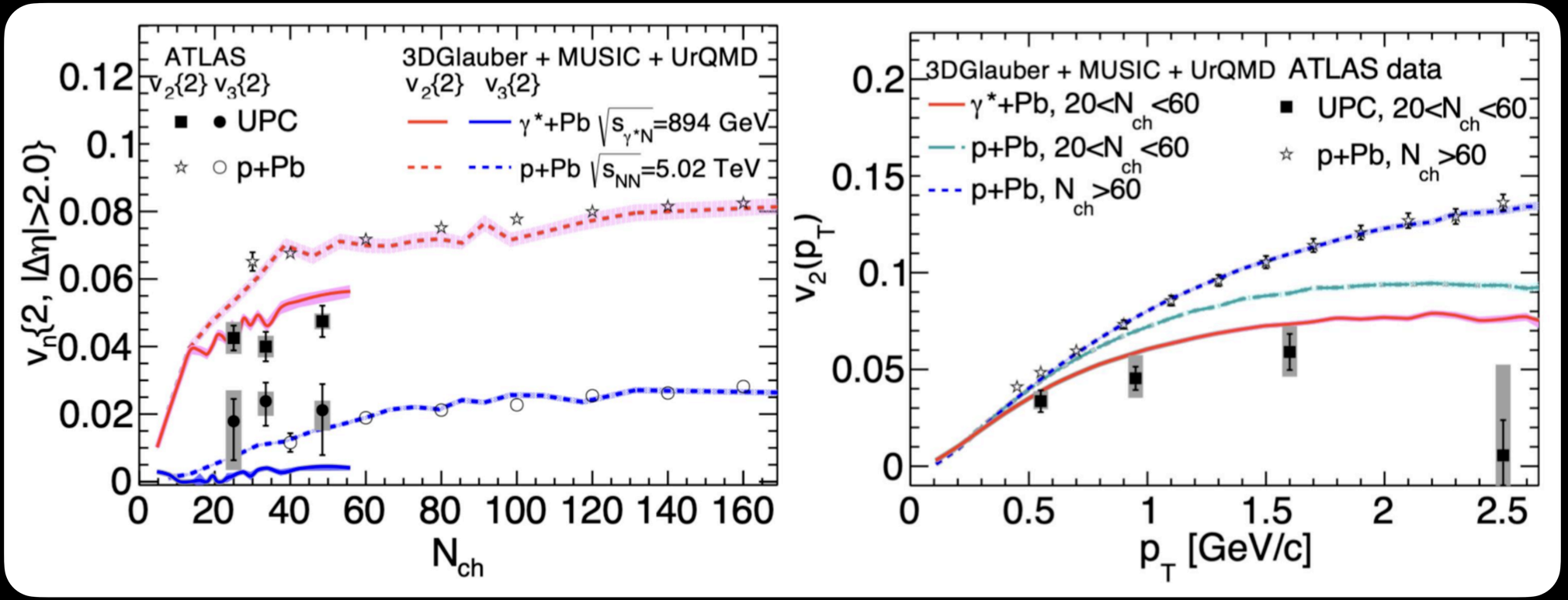
W. Zhao, C. Shen and B. Schenke, arXiv:2203.06094 [nucl-th]



- Our model with fluctuating $\sqrt{s_{\gamma^* N}}$ reproduces the shape of $dN_{ch}/d\eta$ very well
- Hydrodynamic radial flow leads to mass ordering in identified particle $\langle p_T \rangle$

ANISOTROPIC FLOW IN pA AND γA COLLISIONS

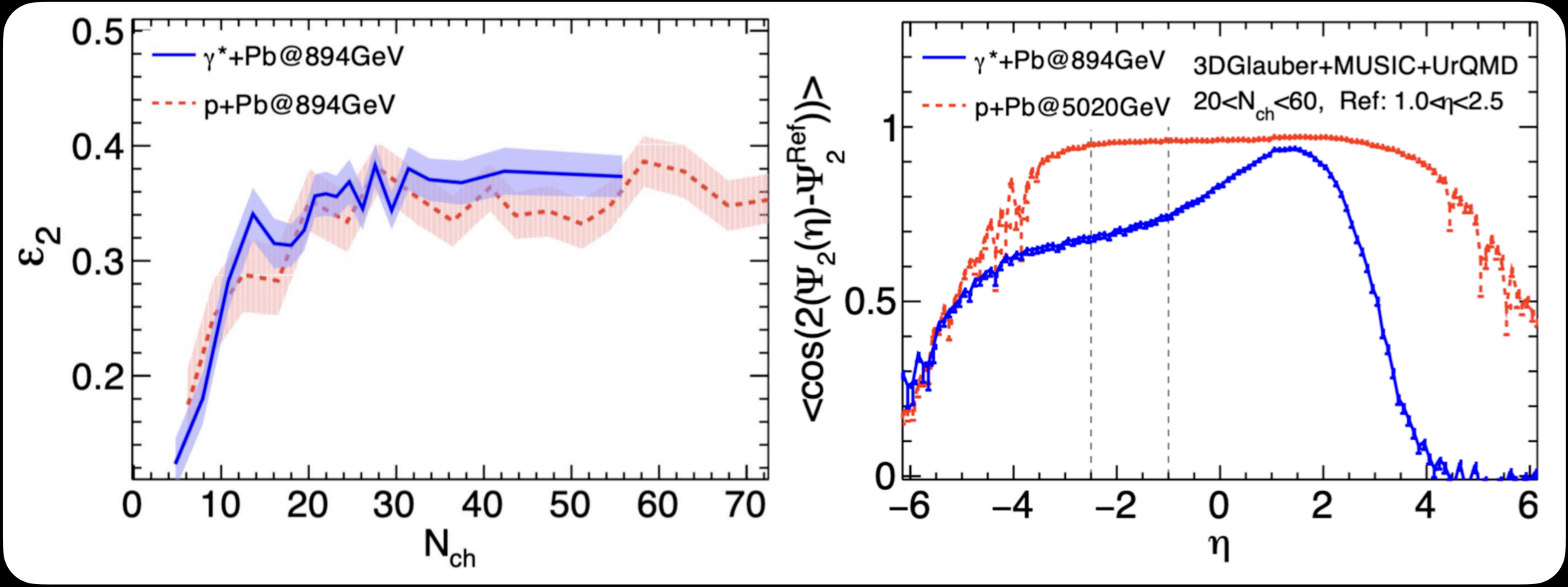
W. Zhao, C. Shen and B. Schenke, arXiv:2203.06094 [nucl-th]



- Our dynamical model reproduces well the hierarchy and values of $v_2\{2\}$ and $v_2(p_T)$ in p+Pb and γ^*+Pb collisions
- The $v_3\{2\}$ in γ^*+Pb collisions are underestimated because of geometry decorrelation

UNDERSTAND THE v_2 HIERARCHY BETWEEN pA AND γ^*A

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

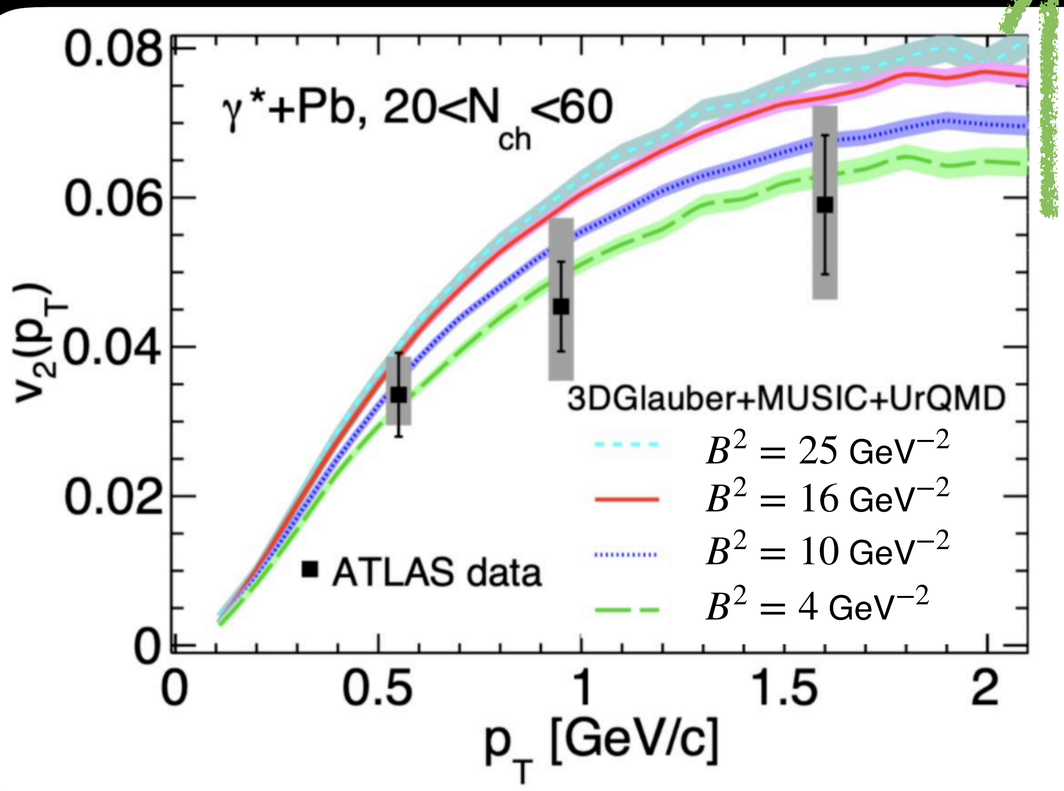


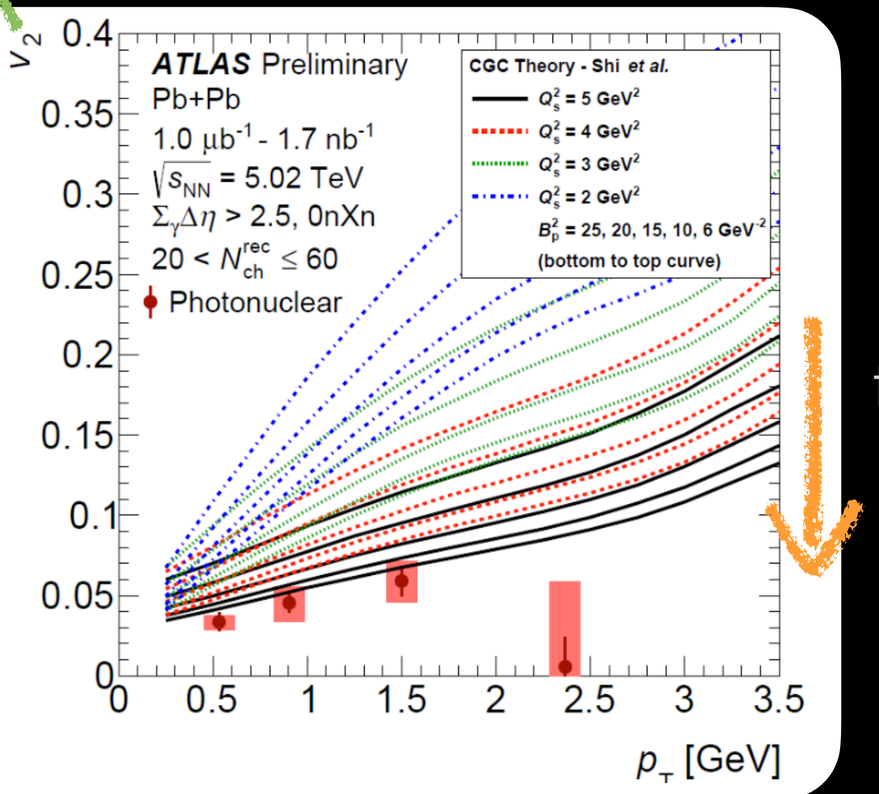
- Initial eccentricities are comparable between p+Pb and γ^*+Pb systems
- The lower $\sqrt{s_{\gamma N}}$ leads to a larger event-plane decorrelation and results in smaller $v_2\{2\}$ than that in p+Pb collisions at the same N_{ch}

TEST GEOMETRY RESPONSE IN eA COLLISIONS AT EIC

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

Y. Shi, L. Wang, S. Y. Wei, B. W. Xiao and L. Zheng, Phys. Rev. D 103, 054017 (2021)





transverse size $\propto B^2$

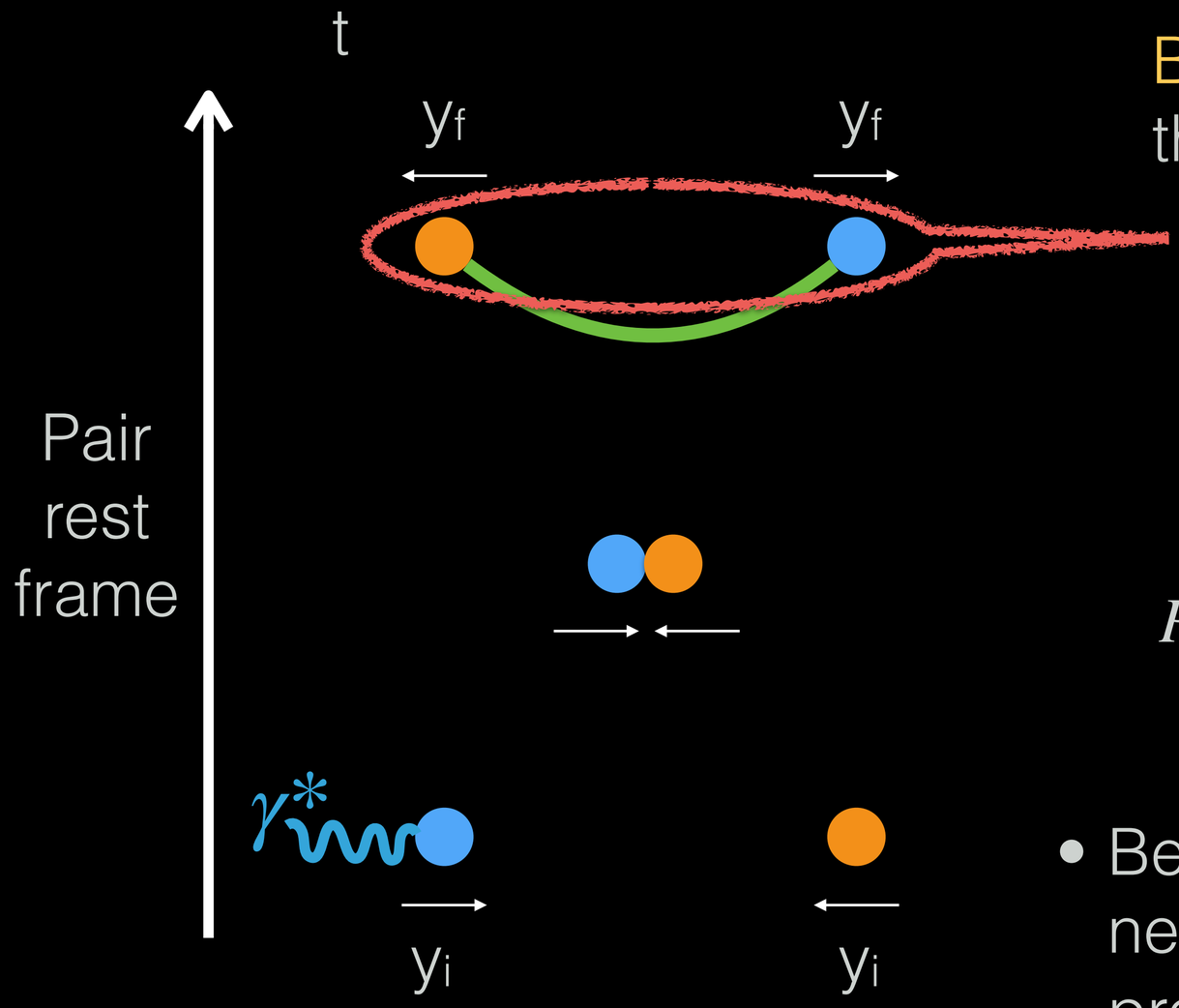
- Hydrodynamics: a larger B^2 allows a larger transverse area for geometry to fluctuates
- CGC: a larger B^2 leads to a larger number of independent domains

$v_2 \propto B^2$

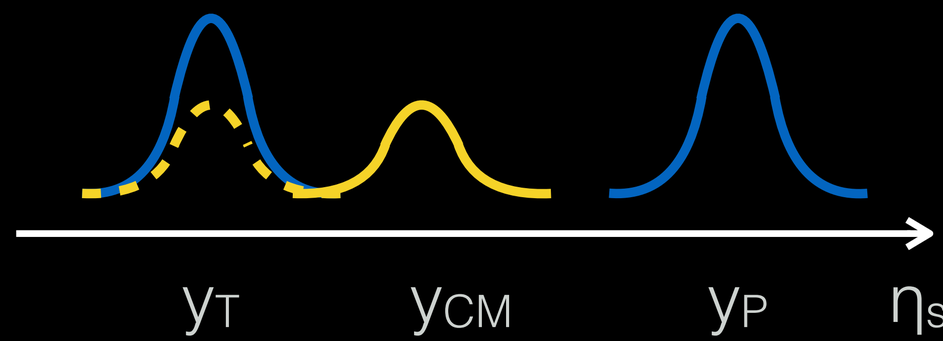
$v_2 \propto 1/B^2$

PROBING BARYON JUNCTION IN γ^*A COLLISIONS

D. Kharzeev, Phys. Lett. B 378, 238 (1996)



Baryon densities are deposited at the string ends or string junctions



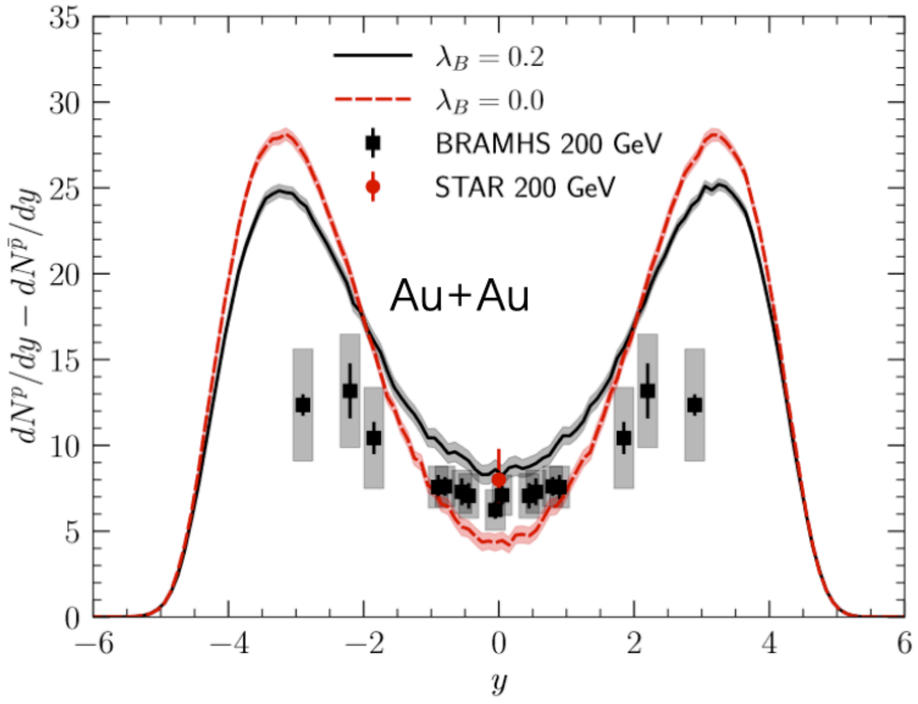
$$P(y_T^B) = (1-\lambda_B)y_T + \lambda_B \frac{e^{(y_T^B-(y_P+y_T)/2)/2}}{4\sinh((y_P-y_T)/4)}$$

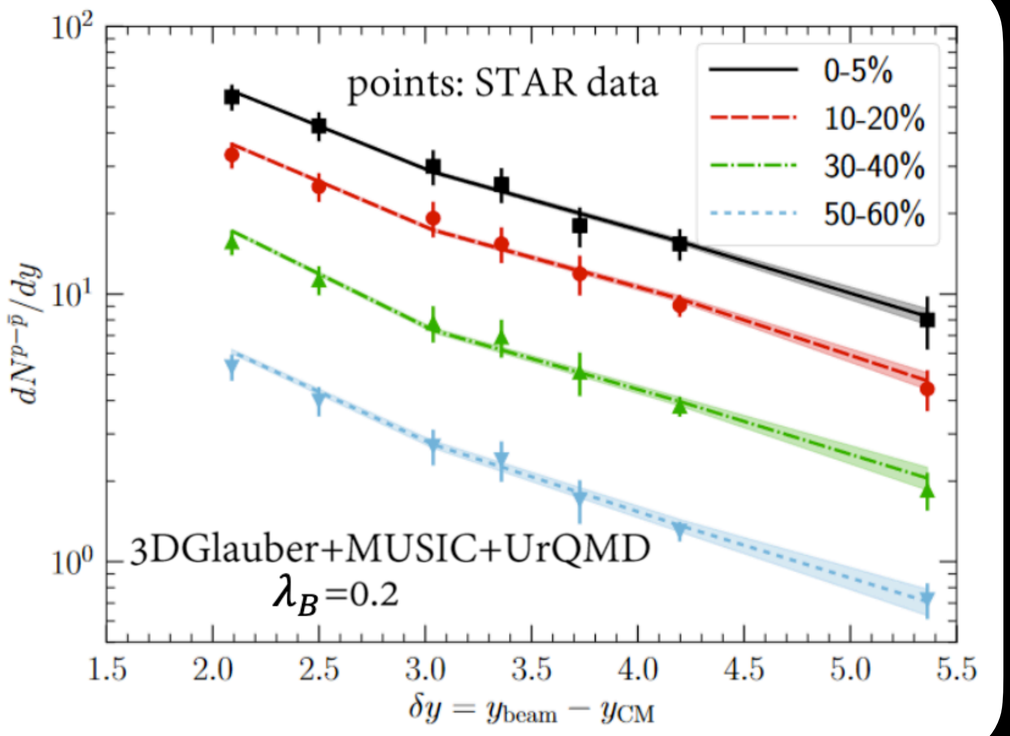
Fragmentation String Junction

- Because the vector meson does not carry net baryon charges, γ^*A collisions can probe the baryon charges at the string junctions more easily

CALIBRATE BARYON JUNCTION IN AA COLLISIONS

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



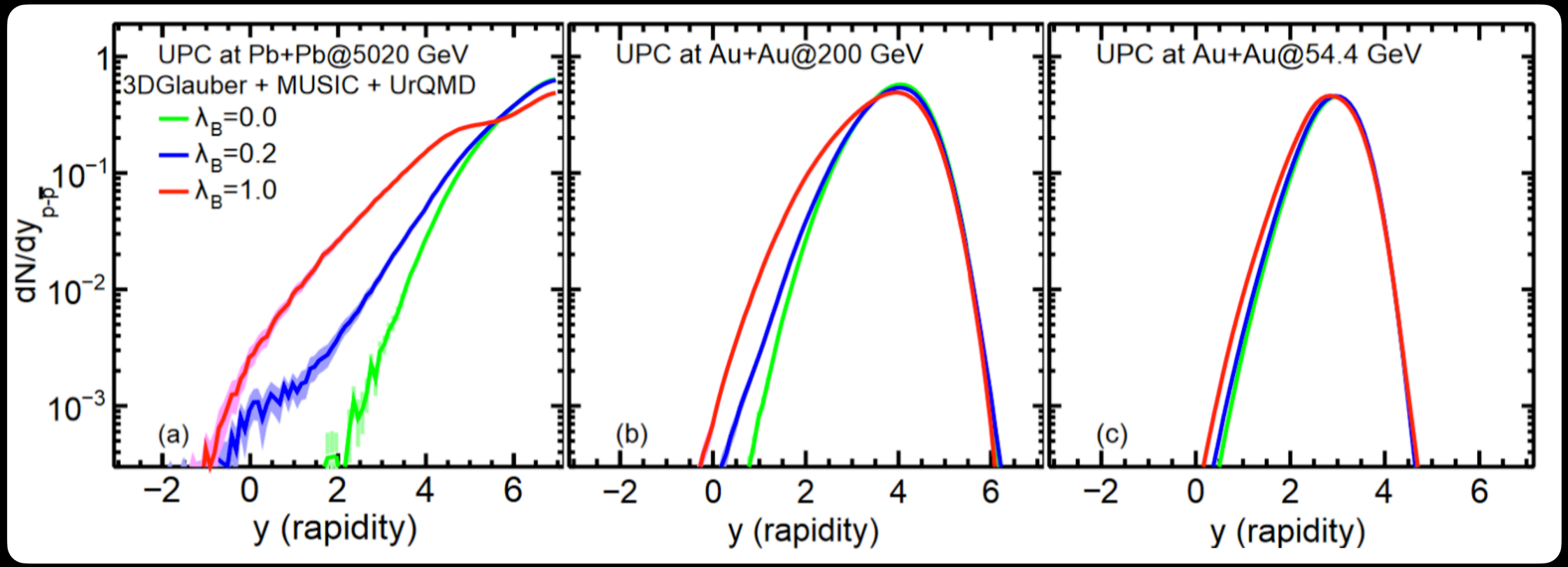


$$P(y^B_{P/T}) = (1-\lambda_B) y_{P/T} + \lambda_B \frac{e^{(y^B_{P/T} - (y_P+y_T)/2)/2}}{4\sinh((y_P - y_T)/4)}$$

- Au+Au collisions at RHIC BES energies prefer 20% of baryon charges ($\lambda_B = 0.2$) to fluctuate to the string junctions in the initial state

PREDICTIONS OF NET PROTON dN/dy IN UPC

W. Zhao, C. Shen and B. Schenke, in preparation



- No net protons from the vector meson's fragmentation region
- The baryons at the string junctions lead to a flatter slope of net proton dN/dy near the mid-rapidity in UPC events at LHC and the top RHIC energies
- The shape of net proton dN/dy at 54.4 GeV is dominated by fragmentations

SUMMARY AND OUTLOOK

- We develop a (3+1)D dynamical model to study the collectivity in highly asymmetric relativistic nuclear collisions, such as p+A collisions and γ^* +A in the ultra-peripheral A+A collisions (UPC) at RHIC and LHC energies
- The elliptic flow hierarchy between p+Pb and γ^*+Pb collisions at the LHC can be explained by the larger geometry decorrelation in the UPC events — (3+1)D simulations are essential!
- The net proton rapidity distributions in UPC provide a clean measurement whether incoming baryon charges are carried by the string junctions
- Our work connects the current studies of small system collectivity and initial-state baryon stopping in heavy-ion collisions with the future $e + A$ collisions at the Electron-Ion Collider