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Collectivity in photon nuclear collisions from a multiphase transport model

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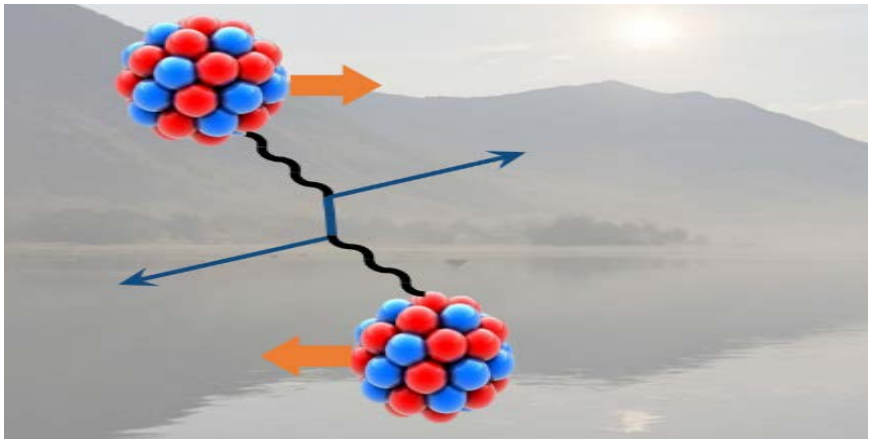


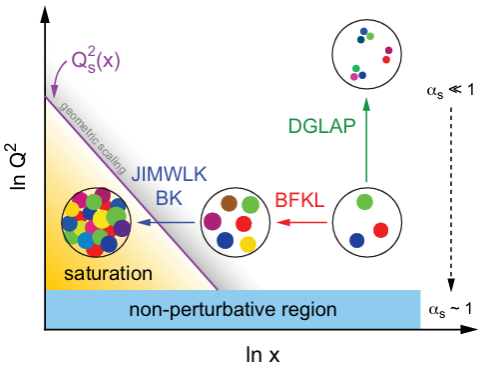
The 2nd Workshop on Ultra-Peripheral Collision Physics:
Strong Electromagnetic fields, UPC and EIC/EicC
Hefei Anhui
2024/4/15

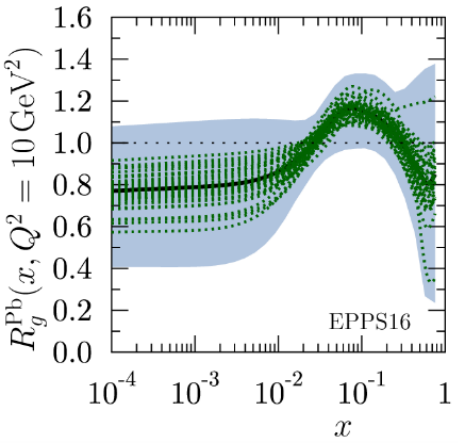
Outline

- Photon nuclear collisions
- Collectivity in photon nuclear collisions (UPC)
- AMPT with PYTHIA8 initial condition and sub-nucleon structures
- Flow in photon nuclear collisions with AMPT

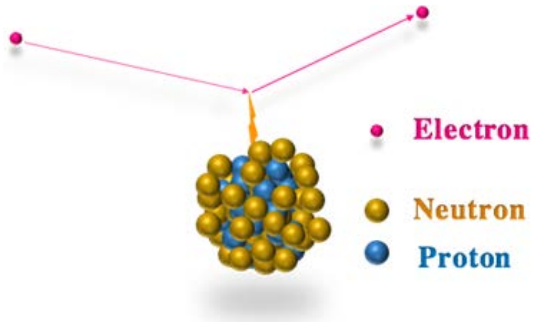
High energy photon nuclear collisions

- Nuclear PDF
- Parton saturation
- Nuclear imaging
- In medium hadronization
- …

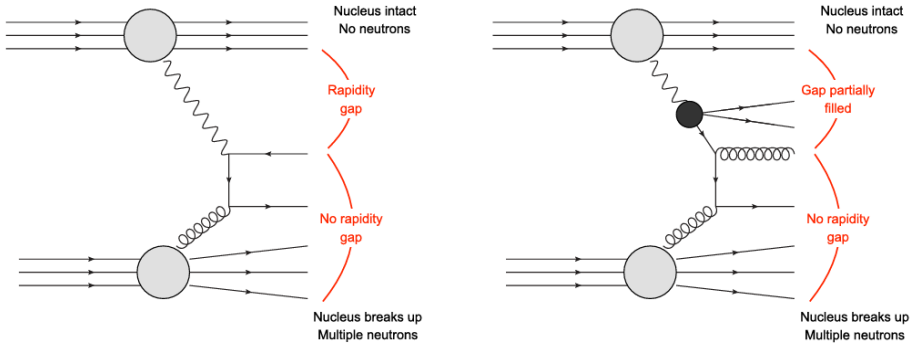




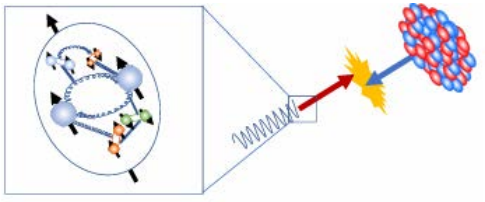
Electron-ion collisions



Ultra-peripheral collisions



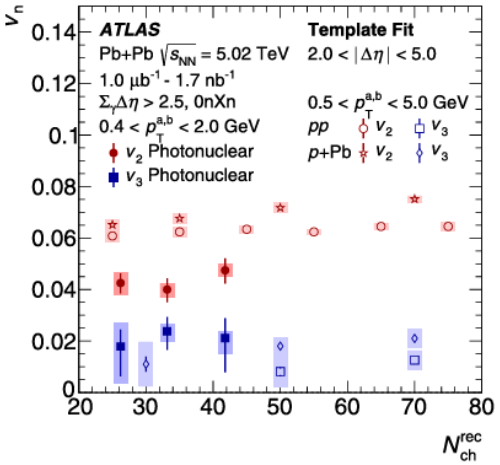
Collectivity in photon nuclear collisions



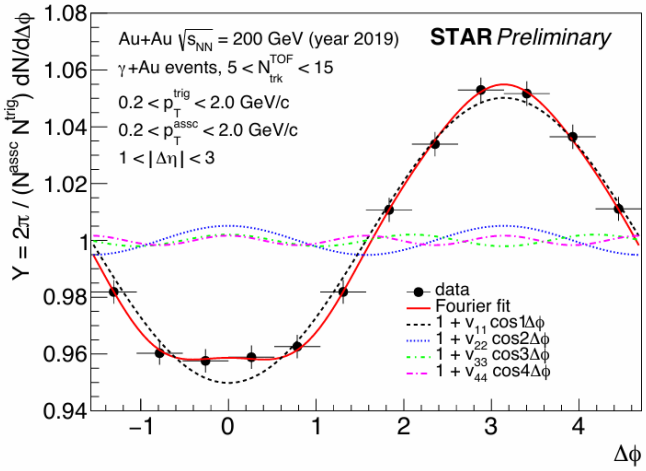
- QCD fluctuations in photon
- Two particle correlation method
- Non-zero v2, v3 in UPC@LHC
- Hierarchy of γ- and p-A flow
- Search in UPC@RHIC ongoing

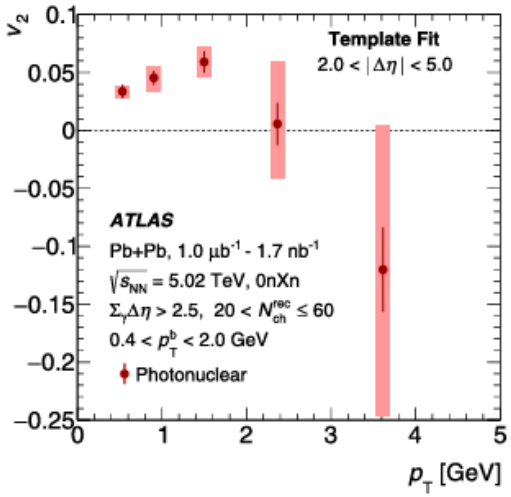
$$|\gamma\rangle = |\gamma_0\rangle + \sum_{m,n} |m\,q\bar{q} + n\,g\rangle + \sum_{\rho,\omega,\cdots} |V\rangle + \cdots$$

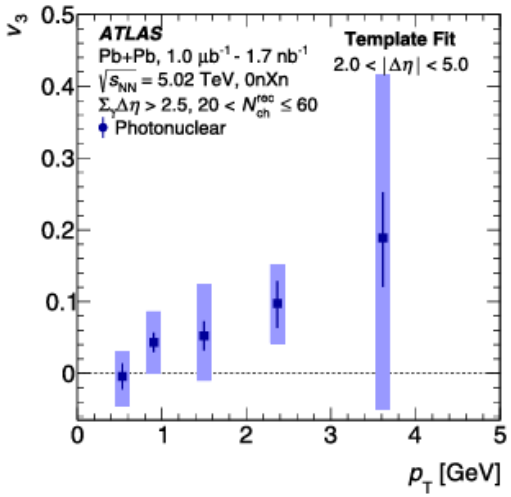
PRC 104 (2021) 014903



Shengli QM23 talk







Collectivity in photon nuclear collisions

- Longitudinal extension of color domains
- Uncorrelated domains randomly oriented
- Initial momentum anisotropy
- Roughly agree with experimental data
- v_2 increases with Q^2

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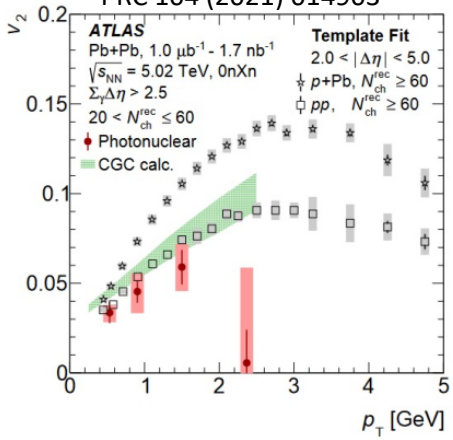

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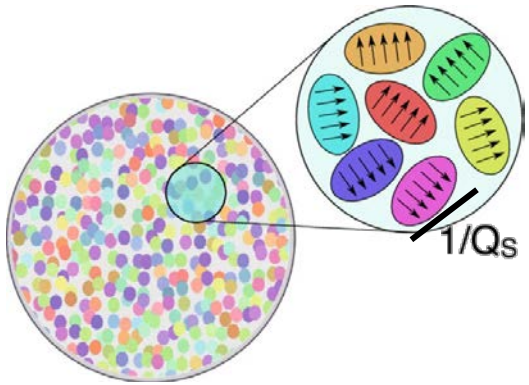
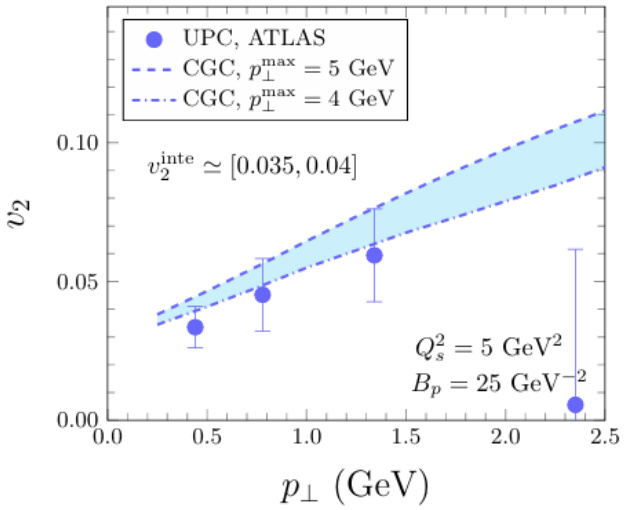
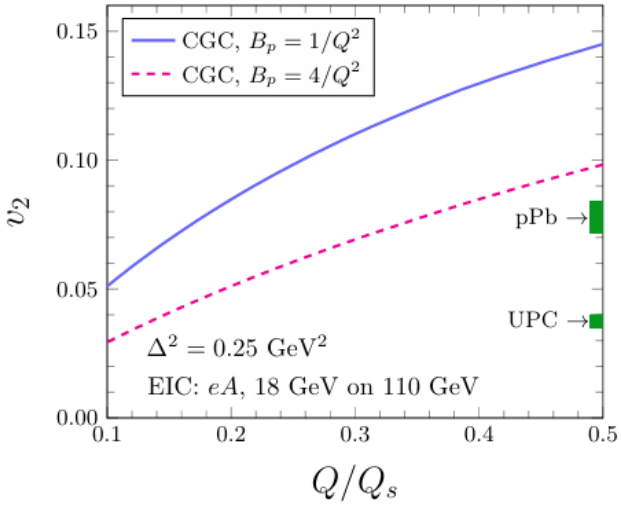


EPJC 81 (2021) 760

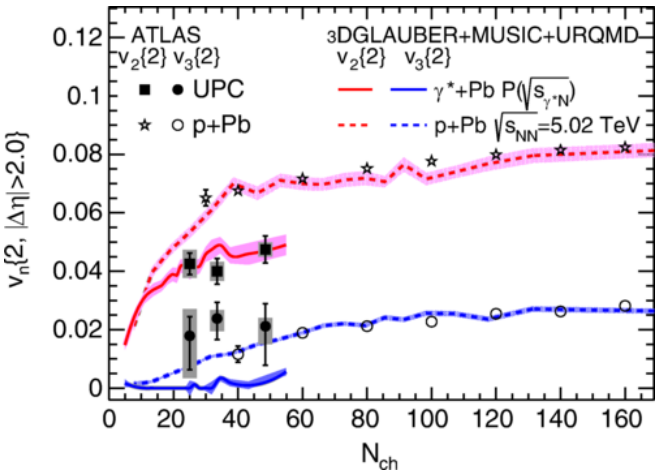


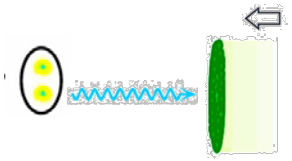


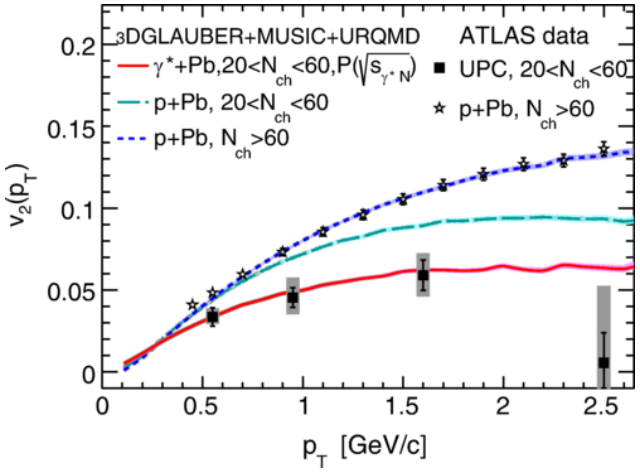
Collectivity in photon nuclear collisions

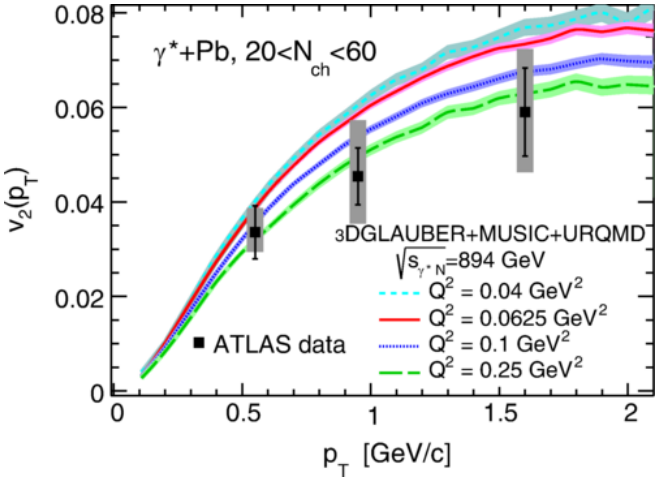
- Hydrodynamic simulation with comprehensive 3+1D framework
- v_2 hierarchy explained with longitudinal decorrelations
- VMD photon structure with sub-hadronic geometry
- Due to photon size dependence, v_2 decreases with Q^2

PRL 129 (2022) 252302

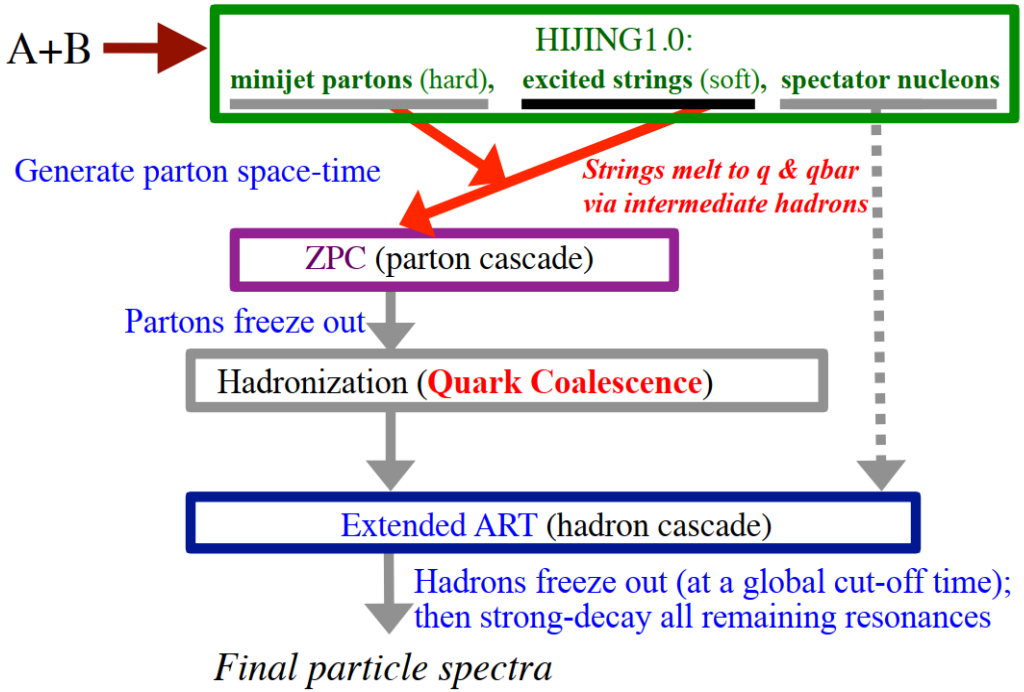








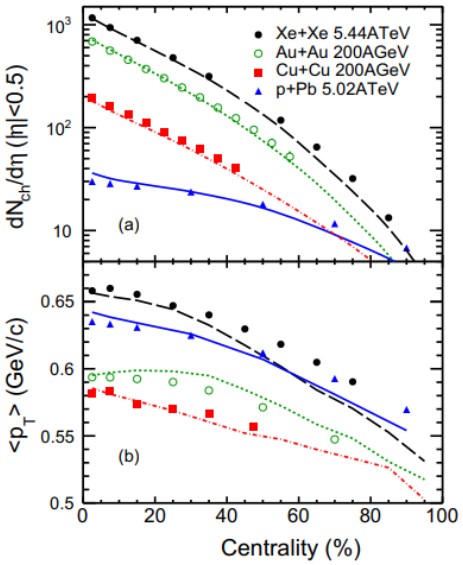
A multi-phase transport model (AMPT)



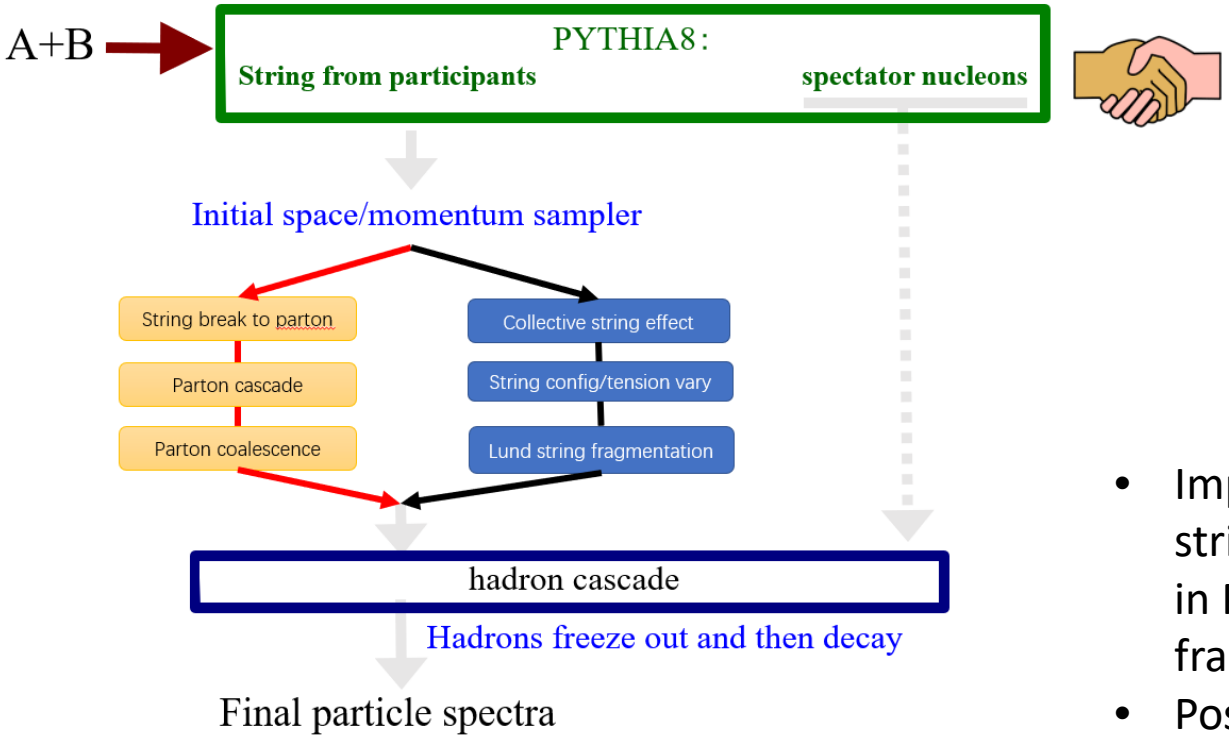
PRC 72 (2005) 064901
Nucl.Sci.Tech. 32 (2021) 113

- AMPT has been extensively applied in collectivity study for large systems
- System size dependence has been improved recently

PRC 104 (2021) 014908



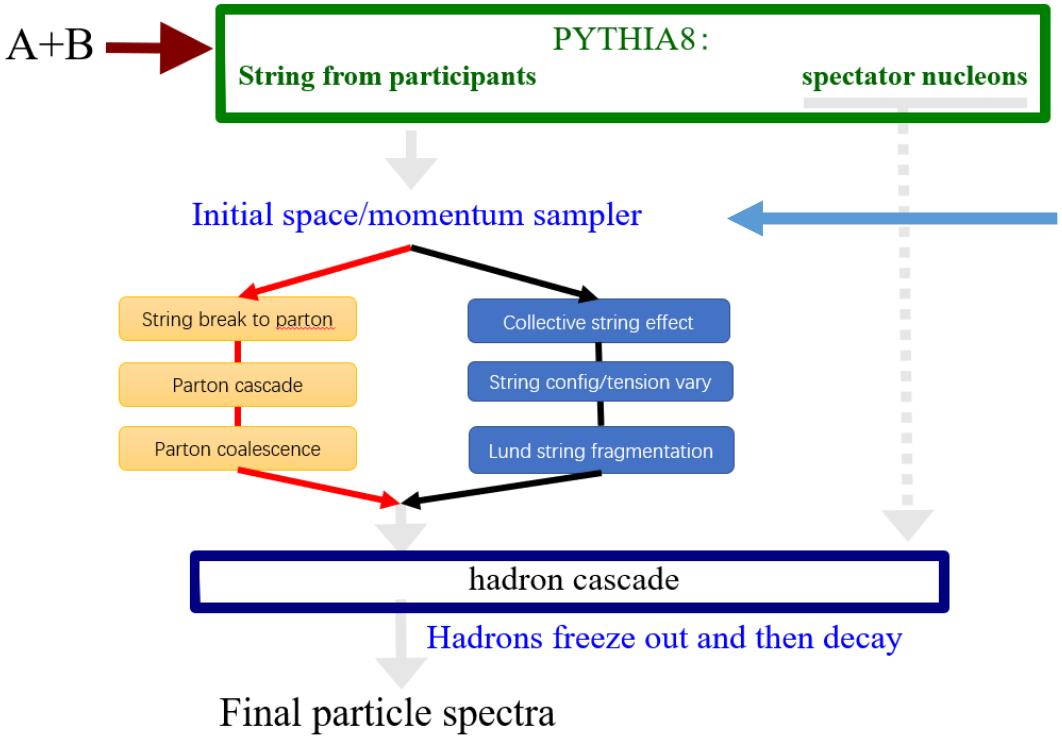
AMPT x PYTHIA8



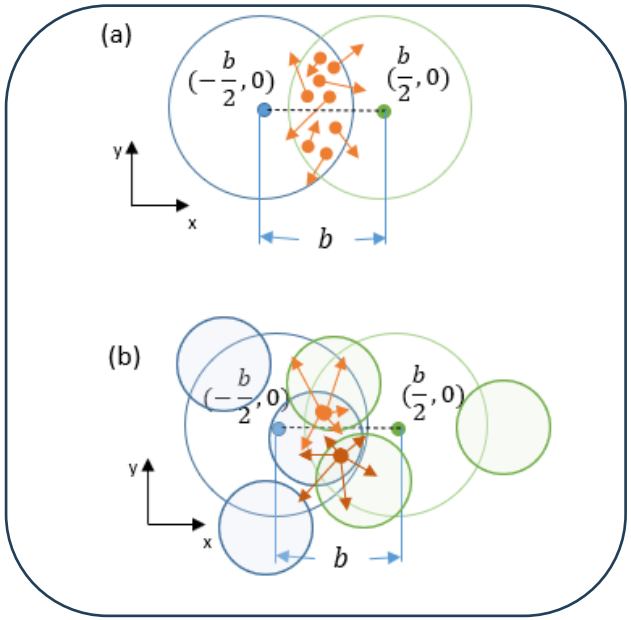
PRC 72 (2005) 064901
Nucl.Sci.Tech. 32 (2021) 113

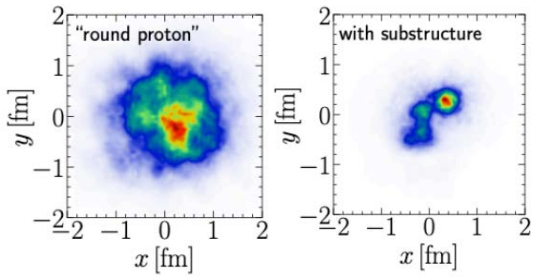
- Impact parameter dependent string system well developed in PYTHIA8/Angantyr framework
- Possible to compare parton transport and inter-string effects on the same basis

Sub-nucleon structure



PRC 72 (2005) 064901
Nucl.Sci.Tech. 32 (2021) 113



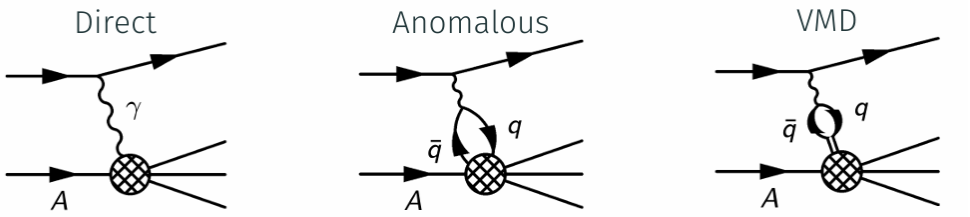


Rept.Prog.Phys. 84 (2021) 082301

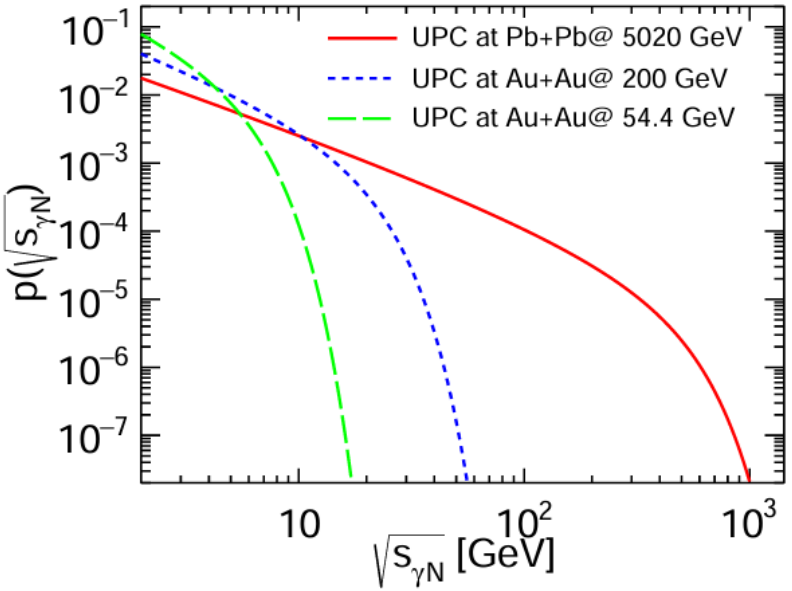
Photon wave function and flux

Linear combination of three components

$$|\gamma\rangle = c_{\text{dir}}|\gamma_{\text{dir}}\rangle + \sum_q c_q|q\bar{q}\rangle + \sum_V c_V|V\rangle$$

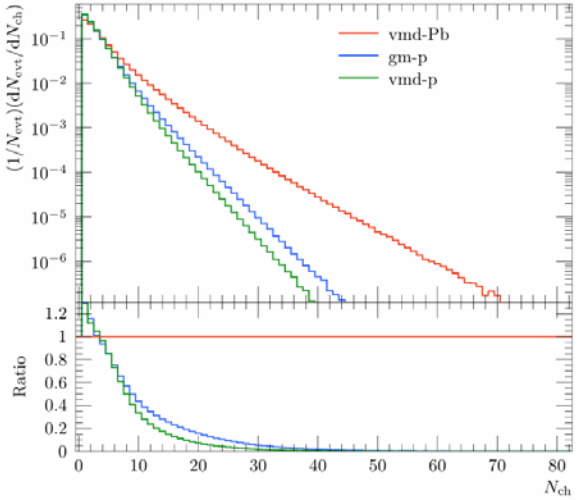


$$\frac{dN^\gamma}{dk_\gamma} = \frac{2Z^2\alpha}{\pi k_\gamma}\left[w_R^{AA}K_0(w_R^{AA})K_1(w_R^{AA}) - \frac{(w_R^{AA})^2}{2}(K_1^2(w_R^{AA}) - K_0^2(w_R^{AA}))\right]$$



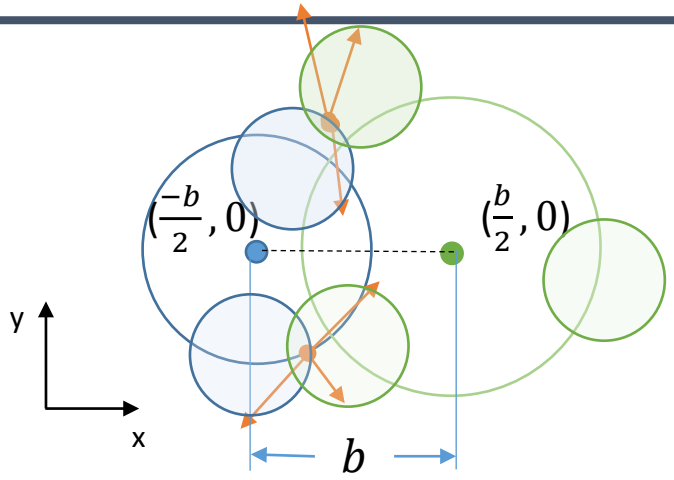
arXiv:2209.15065

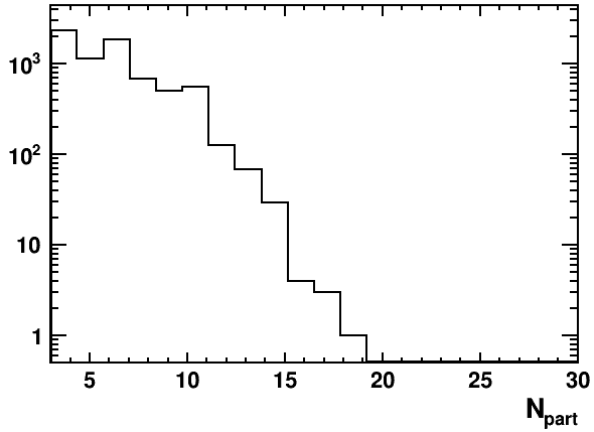
Ilkka UPC23 talk



- High multiplicity dominant by VMD nucleon scatterings

Photon nuclear Glauber model with hot spots

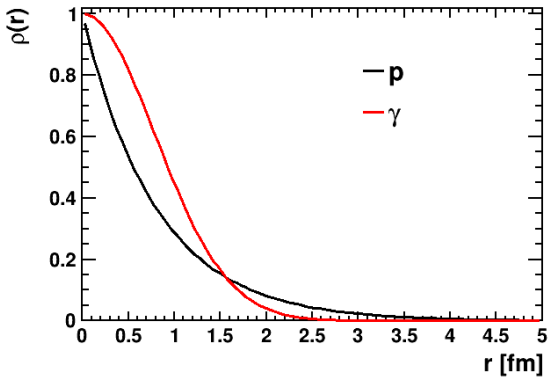


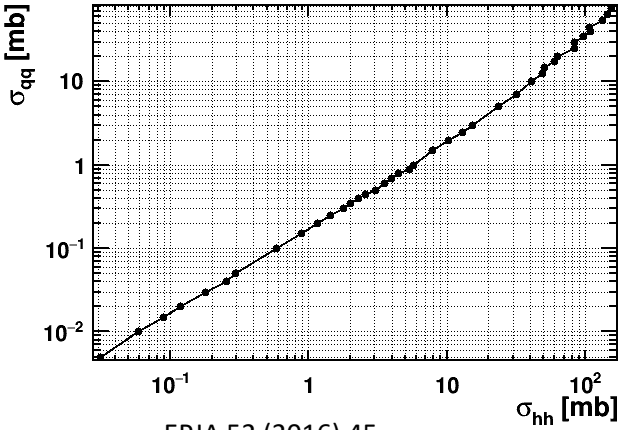


$$\rho(r)_p = \exp\left(-\frac{r}{0.8}\right)$$

$$\rho(r)_\gamma = \exp\left(-\frac{r^2 Q^2}{2}\right), Q^2 = 0.0625\ GeV^2$$

$$\sqrt{s_{\gamma N}} = 894\ GeV, \sigma_{\rho N} = 35\ mb, \sigma_{qq} = 8.14\ mb$$





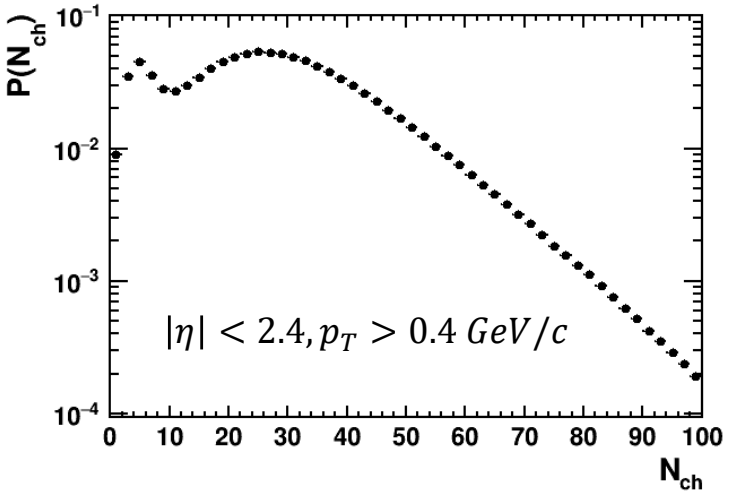
EPJA 52 (2016) 45

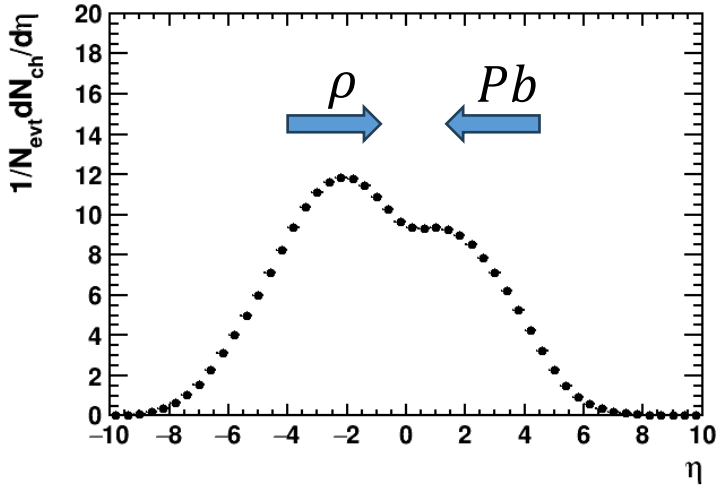
Charged hadron production

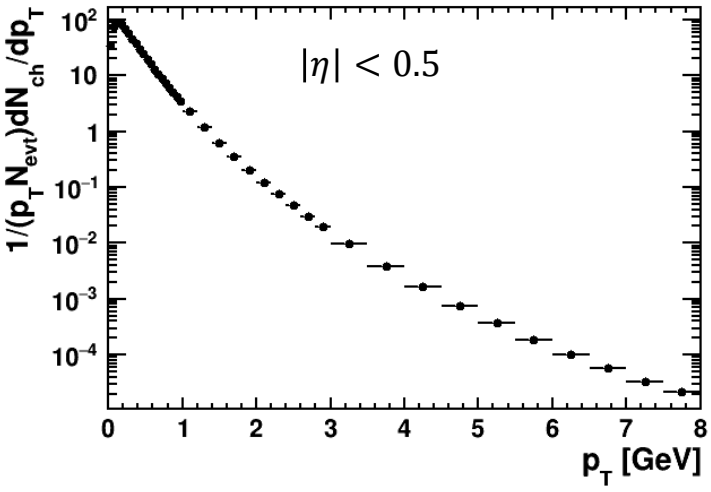
$\sqrt{s_{\gamma N}} = 894\ GeV\ \rho Pb$ collision

$\sigma = 0.15mb, t_{max} = 30\ fm/c$

- Multiplicity can be quite large
- Asymmetric rapidity structure







Dihadron correlations

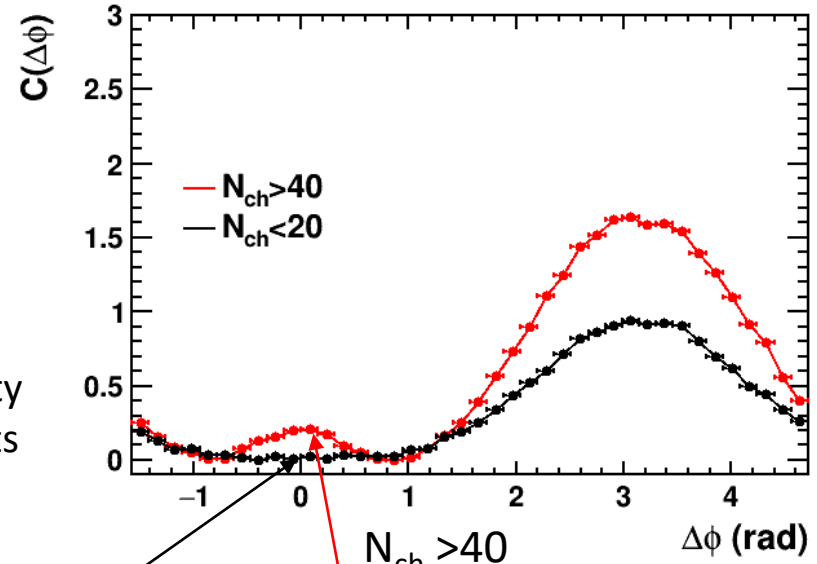
$\sqrt{s_{\gamma N}} = 894\ GeV\ \rho Pb$ collision

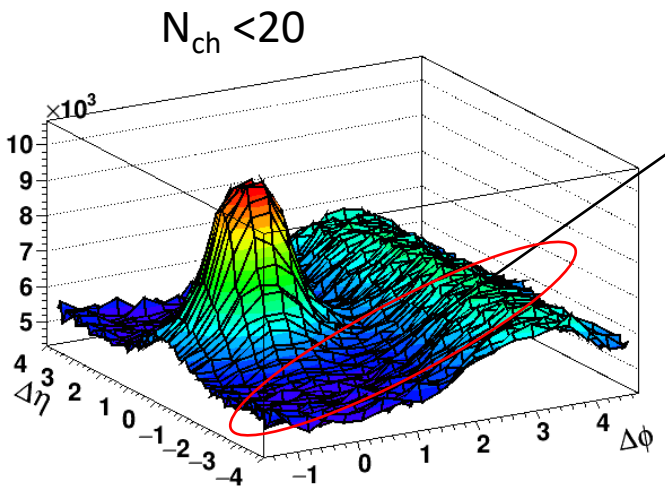
$\sigma = 0.15mb, t_{max} = 30\ fm/c$

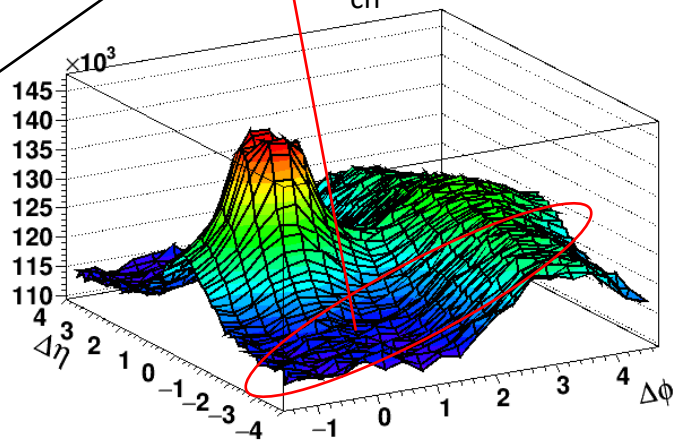
1<p_T<2 GeV/c, $|\triangle\eta|$>2, $|\eta|$<2.4

N_{ch} defined with $|\eta|$<2.4, p_T>0.4 GeV/c

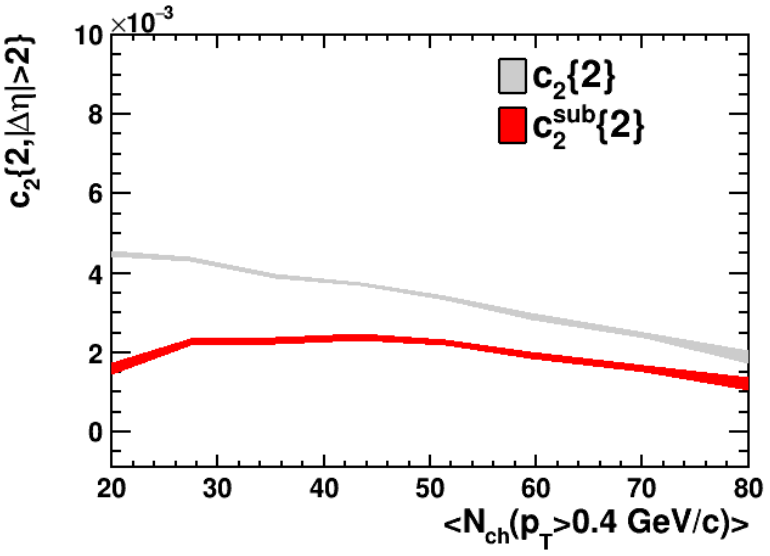
- Charged hadron pairs selected within mid-rapidity
- Near side ridge appears in high multiplicity events







Elliptic flow coefficient



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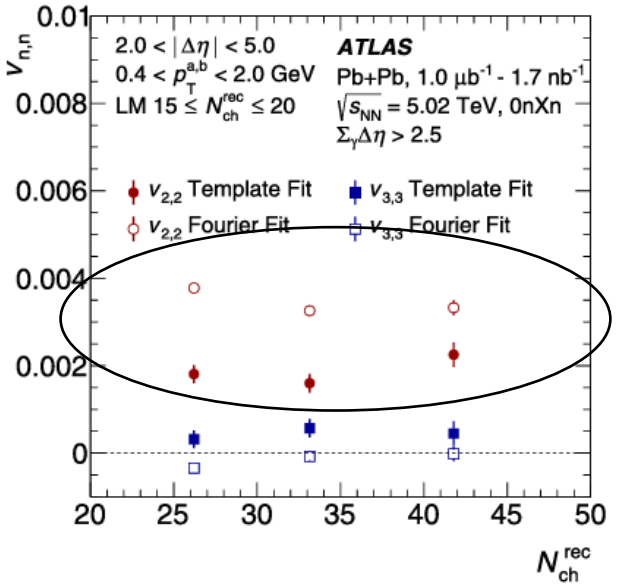


$$Q_n = \sum_{i=1}^{M} e^{in\phi_i} \qquad \langle 2\rangle_{\Delta\eta} = \frac{Q_n^A \cdot Q_n^{B*}}{M_A \cdot M_B}$$

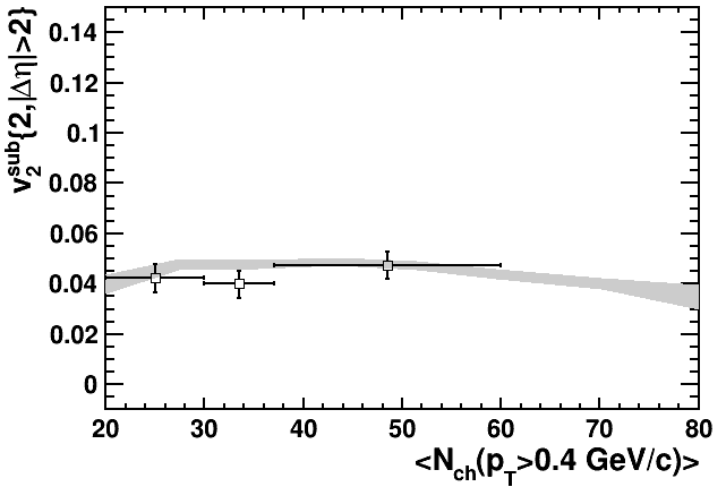
$$c_n\{2,|\Delta\eta|\} = \langle\langle 2\rangle\rangle_{\Delta\eta} \qquad k = \langle M\rangle^{low}/\langle M\rangle$$

$$c_n^{sub}\{2,|\Delta\eta|\} = c_n\{2,|\Delta\eta|\} - k \cdot c_n^{low}\{2,|\Delta\eta|\}$$

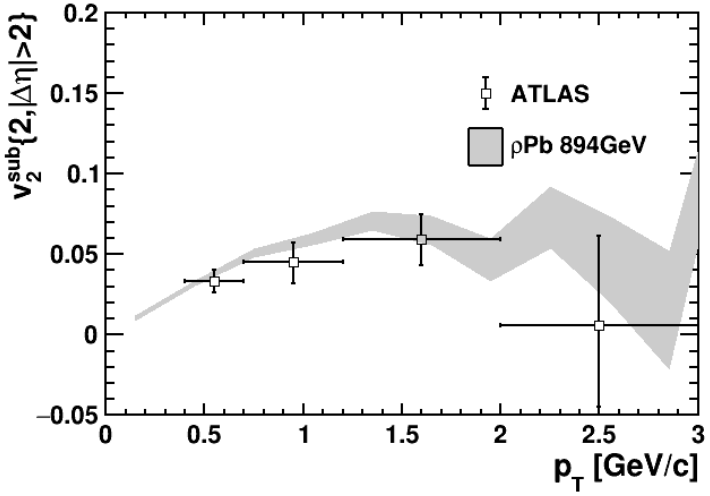
$0.3<p_T<3$ GeV/c, $|\Delta\eta|>2$, $|\eta|<2.4$
N_{ch} defined with $|\eta|<2.4$, $p_T>0.4$ GeV/c

- Flow estimated with Q-cumulant method
- Low multiplicity subtract using $N_{ch}<20$ events
- Similar to the value seen in ATLAS data

Elliptic flow coefficient



30<N_{ch}<50



$$p_n = \sum_{i=1}^{m_p} e^{in\phi_i}$$

$$\langle 2' \rangle_{\Delta\eta} = \frac{p_{n,A} Q^*_{n,B}}{m_{p,A} M_B}$$

$$d_n\{2,|\Delta\eta|\} = \langle\langle 2' \rangle\rangle_{\Delta\eta}$$

$$v_n^{sub}\{2,|\Delta\eta|\} = \frac{d_n\{2,|\Delta\eta|\} - k \cdot d_n^{low}\{2,|\Delta\eta|\}}{\sqrt{c_n\{2,|\Delta\eta|\} - k \cdot c_n^{low}\{2,|\Delta\eta|\}}}$$

- Integrated flow with non-flow subtraction N_{ch} dependence consistent with data
- High multiplicity events selected with (30,50), data for (20, 60)
- p_T differential flow with gap and nonflow subtraction using N_{ch}<20 events

Summary

- Collectivity in photon nuclear collisions has been stimulating for new theoretical and experimental developments in QGP studies.
- The AMPT model based on PYTHIA8/Angantyr initial conditions are expected to deal with different collisions systems.
- Sub-nucleon fluctuations for both proton and photon are considered in the same framework.
- Collectivity in UPC can be potentially explained in this model.
- A new framework to interpret the collectivity in UPC process and disentangle the its final state parton/hadron evolution effects.