Measurement of collective dynamics in small and large systems with the ATLAS detector.

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Puri, 7 February 2023

ATLAS EXPERIMENT

Run: 365512
Event: 110420355
2018-11-09 06:27:05 CEST

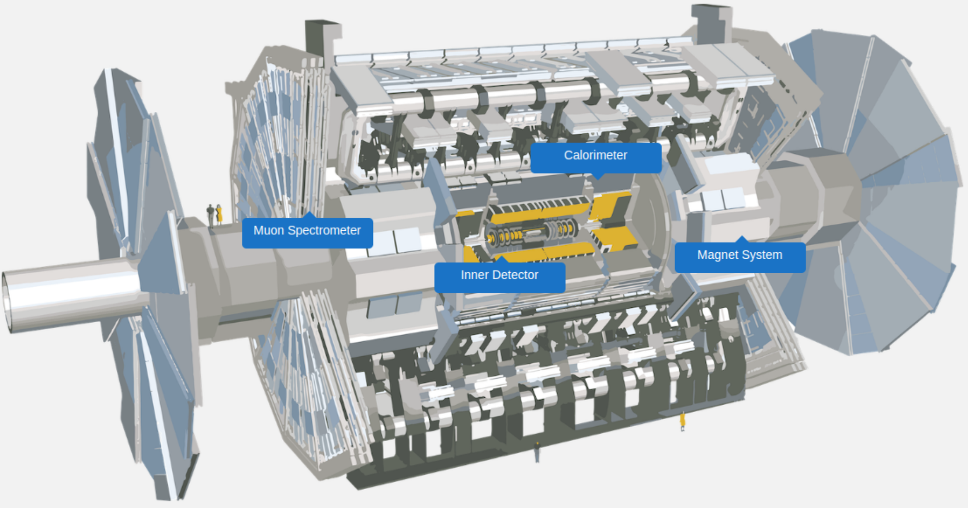
AGH

Content:

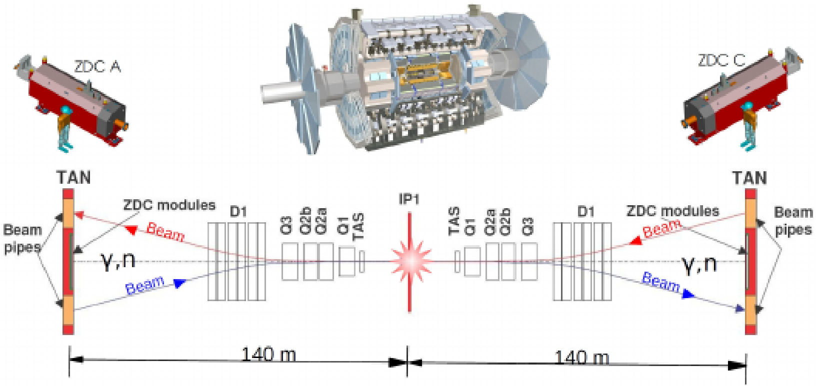
- A (very brief and quick) review of ATLAS detector.

1. Charged-hadron production in *pp*, *p*+Pb, Pb+Pb, and Xe+Xe collisions. (Submitted to JHEP.)
2. Strong constraints on jet quenching in centrality-dependent *p*+Pb collisions. (Submitted to Phys. Rev. Lett.)
3. Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions. (Published in Phys.Rev.C.)
4. Correlations between flow and transverse momentum in Xe+Xe and Pb+Pb collisions: a probe of the heavy-ion initial state and nuclear deformation. (Accepted in Phys.Rev.C.)

ATLAS detector overview



ATLAS ZDC overview

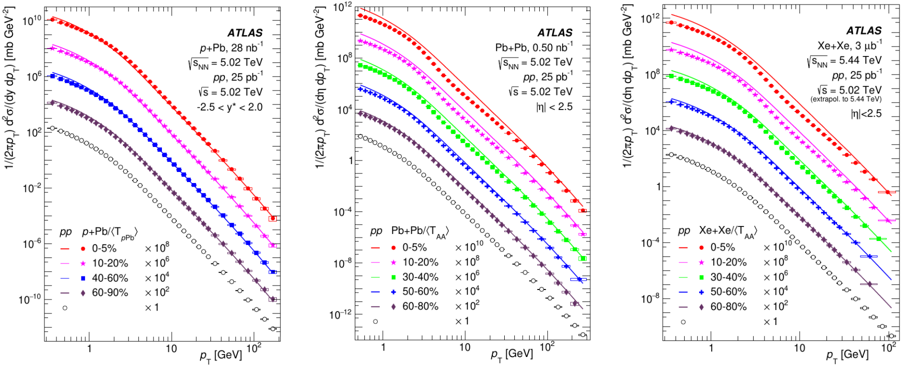


Charged-hadron production in *pp*, *p*+Pb, Pb+Pb, and Xe+Xe collisions

arXiv:2211.15257

Charged-hadron spectra in pp, p+Pb, Pb+Pb, and Xe+Xe

- Comparing the shape of charged-hadron production spectra p+Pb, Pb+Pb, and Xe+Xe with the pp cross-section.



- Mean nuclear thickness function $\langle T_{AA}\rangle = \langle N_{\mathrm{coll}}\rangle / \sigma_{pp}$.

Nuclear modification factor R_{AA}

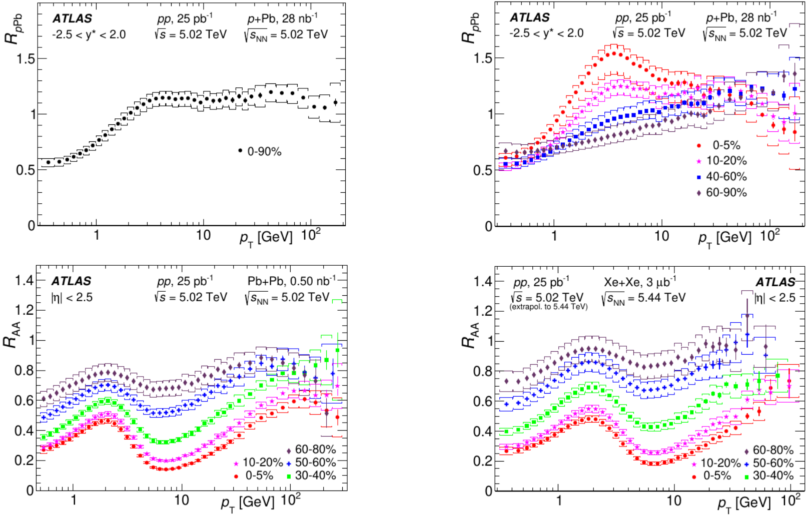
- From the hadron spectra ratio, we can obtain R_{AA}.

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{1/N_{\text{event}}\ d^2 N_{ch}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta} \tag{1}$$

- At high p_T, the production of charged hadrons is mainly from jets and their fragmentation.
- At low p_T, the charged hadrons production is from bulk production of the medium.
- The hadron production per participant pair in AA is fewer than in pp. (Jet quenching.)

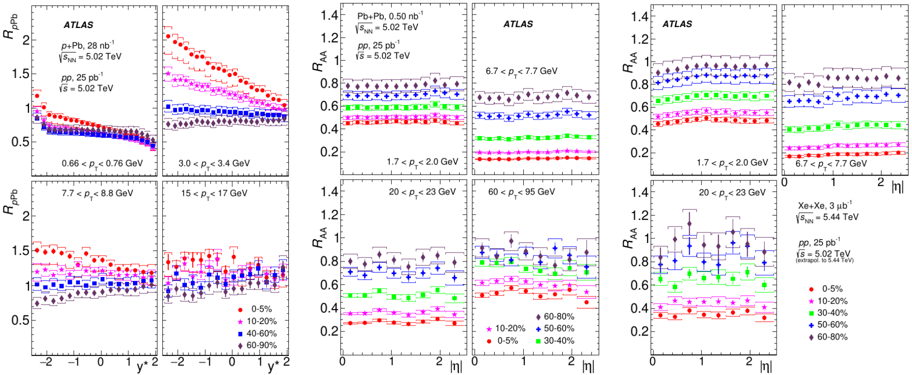
R_{AA} as a function of p_T

- $R_{p\mathrm{Pb}}$ close to 1 at $p_T > 2$ GeV.



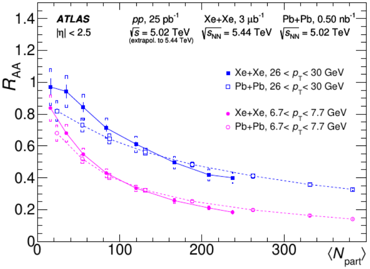
- $R_{AA} < 1$. Suppression of hadron production (jet quenching).

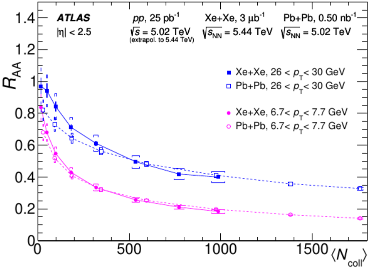
R_{AA} as a function of y^* and $|\eta|$



- Asymmetry on p+Pb with more production in Pb direction.
- The values of R_{AA} for nucleon-nucleon show no strong dependence on $|\eta|$.

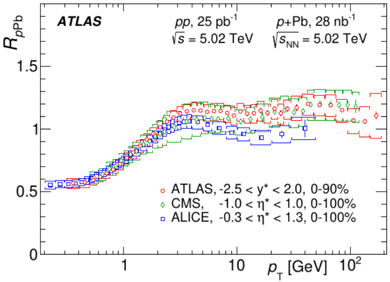
R_{AA} as a function of $\langle N_{\rm coll} \rangle$ and $\langle N_{\rm part} \rangle$

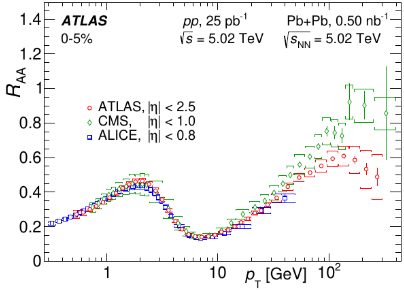


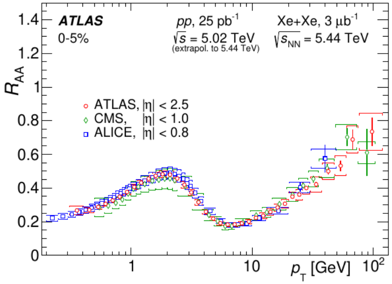


- $\langle N_{\rm coll} \rangle$ and $\langle N_{\rm part} \rangle$ are taken from Glauber model simulation.
- p_T intervals correspond to where R_{AA} has an intermediate value (blue) and the local minimums (magenta).
- R_{AA} decreases in more central collisions. Consistent in both Pb+Pb and Xe+Xe.

Comparison with other experiments

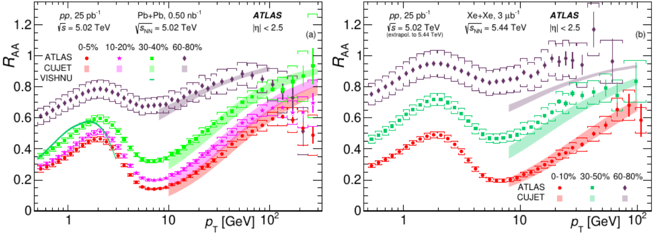




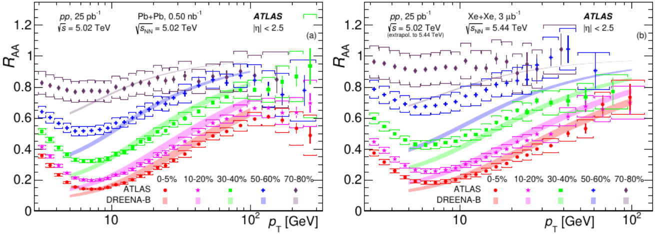


Comparison with theories (More in BACKUP)

- CIBJET framework (VISHNU + CUJET).



- DREENA-B framework



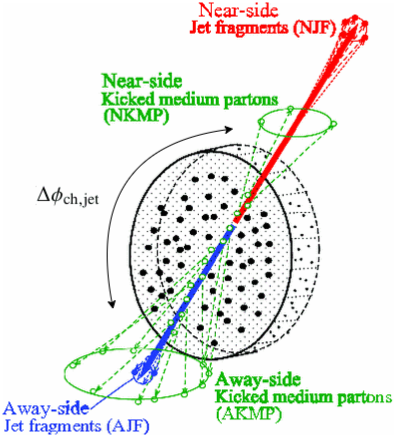
In general, they fit with data, but not in all ranges.

Strong constraints on jet quenching in centrality-dependent p+Pb collisions.

arXiv:2206.01138

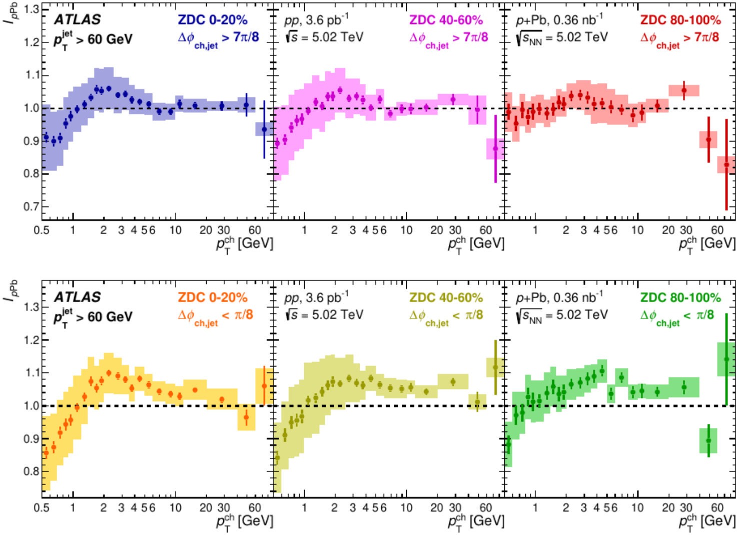
Motivation

- Jet quenching appears in heavy ion collisions due to the jet energy loss as partons traverse the QGP.
- But never observed in small systems despite the presence of harmonic flow there.
- What is the nature of the system created in these collisions?



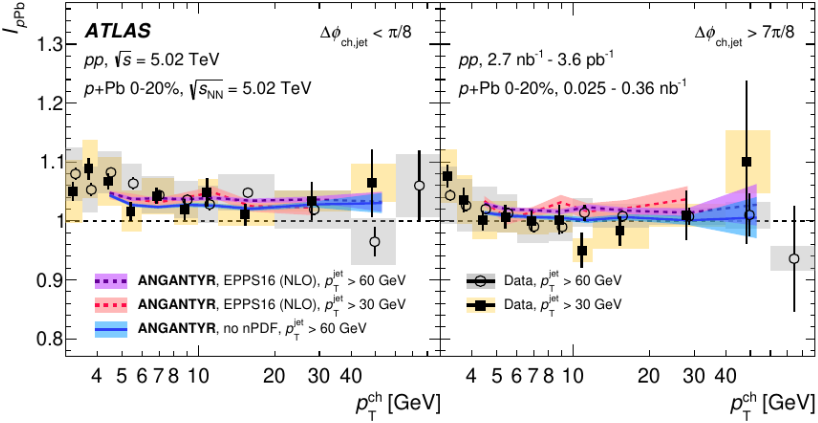
The ratio of per-jet charged-particle yields between p+Pb and pp collisions, dubbed as $I_{p\mathrm{Pb}}$, is measured to check the jet quenching in central p+Pb collisions.

$I_{p\mathrm{Pb}}$ for opposite ($\Delta\phi > 7\pi/8$) and near ($\Delta\phi > \pi/8$) jet



All is close to or above unity so likely no jet quenching. However, the systematic uncertainty is large.

Comparison with MC



- Angantyr is based on Pythia 8 and has no final-state effects producing collectivity or jet quenching.

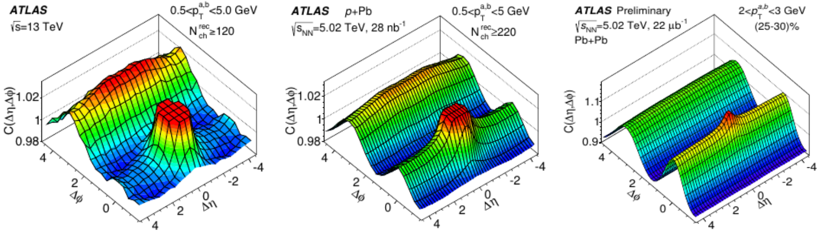
Part 3:

Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions

Phys. Rev. C. 104 (2021) 014903

Motivation

- Heavy ion collisions create quark-gluon plasma.
- Final state particles participate in collective motion of the QGP evolution.
- But in *pp*, *p*+Pb, and even in photonuclear Pb+Pb collisions also exhibit a collective behavior.

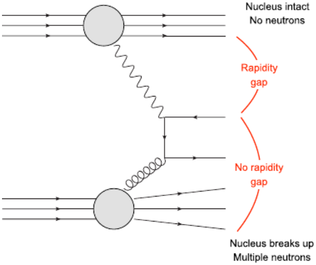


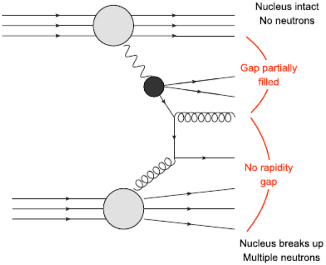
Source: Nuclear Physics A Volume 967, Nov. 2017, p. 59-66.

- Is there any QGP in photonuclear collisions?
- If not, then what is the origin of the harmonic flow?

Photonuclear events

- Photonuclear event (not peripheral hadronic collision) candidates are selected by mapping the distribution of particles in the zero-degree, forward, and barrel calorimeters



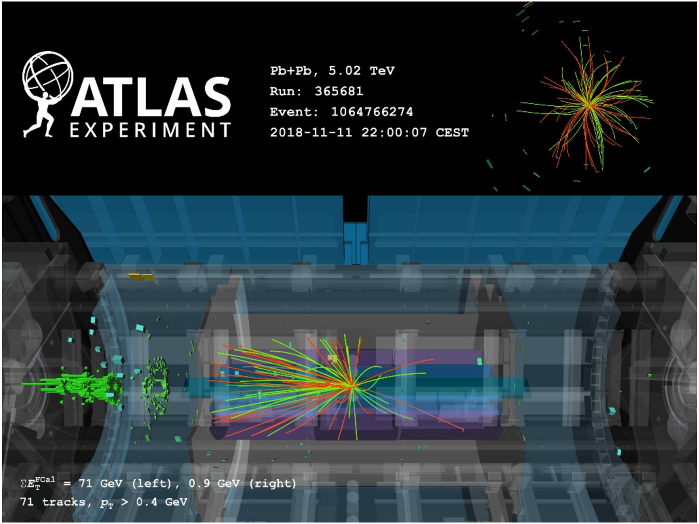


- Photon itself interacts with the nucleus.

- Photon fluctuates into a hadronic state (i.e. ρ & ω).

Photonuclear event display

How those Feynman diagrams before look like in real life:



Two-particle correlation function

- 2D correlation function:

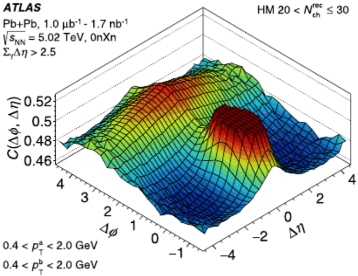
$$Y(\Delta\phi, \Delta\eta) = \frac{1}{N_a}\frac{d^2N_{\mathrm{pair}}}{d\Delta\phi d\Delta\eta} \quad (2)$$

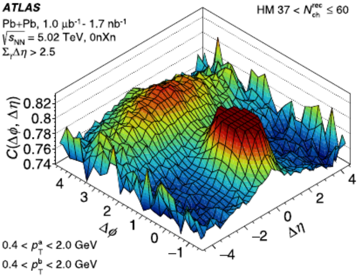
- N_a is the total yield of particles with selection for particle a.
- 2D correlation function corrected for acceptance effects:

$$C(\Delta\phi, \Delta\eta) = Y(\Delta\phi, \Delta\eta) : \left(\frac{1}{N_{\mathrm{pair}}^{\mathrm{mixed}}}\frac{d^2N_{\mathrm{mixed}}}{d\Delta\phi d\Delta\eta}\right) \quad (3)$$

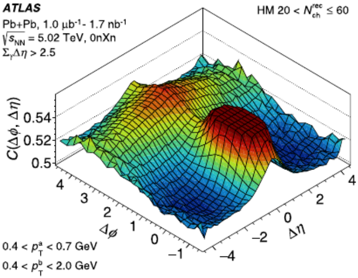
- Correlation functions are constructed for various selections on N_{ch}^{rec} and p_T^a, with the p_T of particle b always in the range $0.4 < p_T^b < 2$ GeV.

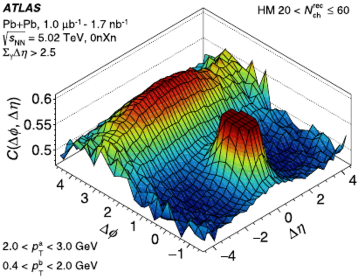
- Different multiplicity range





- Different p_T^a range





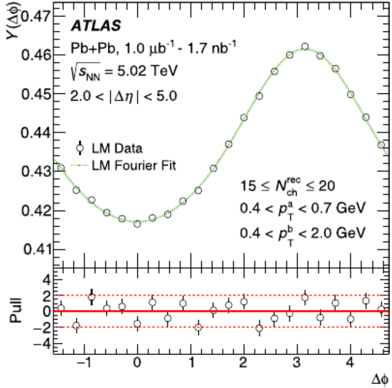
Nonflow template fitting

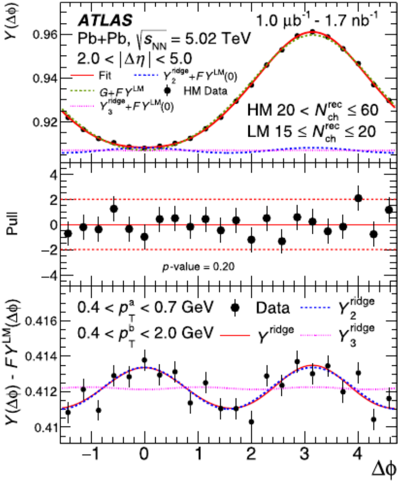
- 1D correlation function (projection to $\Delta\phi$):

$$Y(\Delta\phi) = \int_{|\Delta\eta|=2}^{|\Delta\eta|=5} Y(\Delta\phi, \Delta|\eta|) d\Delta|\eta| \tag{4}$$

- The shape of the nonflow contribution is assumed to be the same in the LM (low-multiplicity) and HM (high) samples.
- LM sample: $15 \leq N_{ch}^{rec} \leq 20$.
- Nonflow subtraction:

$$\begin{aligned} Y^{HM}(\Delta\phi) &= FY^{LM}(\Delta\phi) + G\left\{1 + 2\Sigma_{n=2}^{4} v_{n,n}\cos(n\Delta\phi)\right\} \\ &= FY^{LM}(\Delta\phi) + Y^{\mathrm{ridge}}(\Delta\phi) \\ \therefore Y^{\mathrm{ridge}}(\Delta\phi) &= Y^{HM}(\Delta\phi) - FY^{LM}(\Delta\phi) \end{aligned} \tag{5}$$



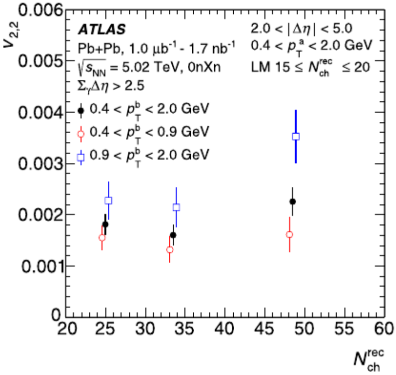


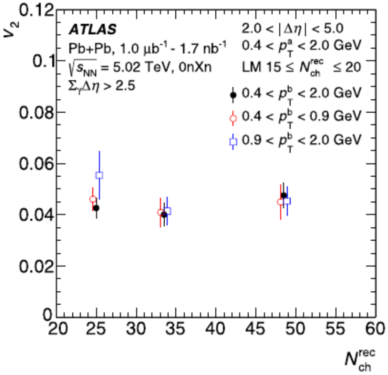
- LM sample of the correlation function.

- Top: HM sample.
- Bottom: HM subtracted by LM giving $Y^{\text{ridge}}(\Delta\phi)$.

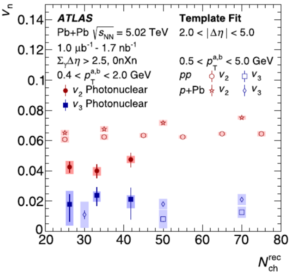
Factorization test

- In hydrodynamic picture, $v_{n,n}$ can be factorized for individual particle $v_{n,n} = v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)v_n(p_T^b)$.
- $v_n(p_T^a) = v_{n,n}(p_T^a, p_T^b)/v_n(p_T^b) = v_{n,n}(p_T^a, p_T^b)/\sqrt{v_{n,n}(p_T^b, p_T^b)}$

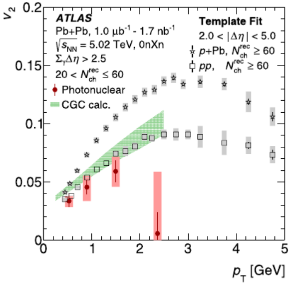




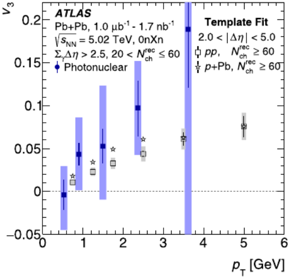
v_n



- No significant N_{ch}^{rec} dependence.



- Comparison of v_2 with other collision systems and some CGC calculation.



- Similar p_T dependence also on v_3.

Part 4:

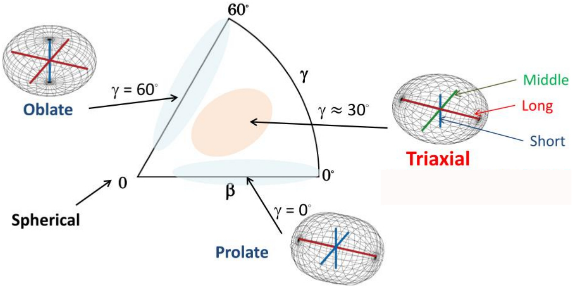
Correlations between flow and transverse momentum in Xe+Xe and Pb+Pb collisions: a probe of the heavy-ion initial state and nuclear deformation.

arXiv:2205.00039

Motivation

- Correlation between the v_n and mean transverse momentum $[p_T]$, dubbed as ρ_n, can serve as qualitative test for initial-state model (e.g. CGC) and hydrodynamic model calculations (Phys Rev C.103, 024909).
- v_n, $[p_T]$, and ρ_n are sensitive to the shape of atomic nuclei.
- The radius of the deformed nucleus at a certain orientation:

$$R(\theta, \phi) = R_0(1 + \beta\,(\cos\gamma\, Y_{2,0} + \sin\gamma\, Y_{2,2})) \tag{6}$$



Observables

$$c_k = \left\langle \frac{1}{N_{\mathrm{pair}}} \sum_i \sum_{i \neq j} \left(p_{T,i} - \langle [p_T] \rangle\right) \left(p_{T,j} - \langle [p_T] \rangle\right) \right\rangle \tag{7}$$

- [...]: average for all particles in one event.
- $\langle ... \rangle$: averaged over all events.

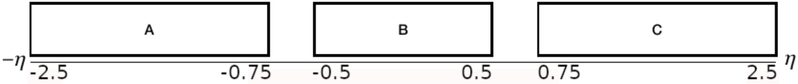
$$\mathrm{Var}\left(v_n\{2\}^2\right) = \langle v_n\{4\} \rangle - \langle v_n\{2\} \rangle^2 \tag{8}$$

- $\langle v_n\{4\} \rangle$ and $\langle v_n\{2\} \rangle$ are $\langle v_n \rangle$ from two- and four-particle cumulants. (More details on Phys. Rev. C 83, 044913.)
- Modified Pearson correlation coefficient:

$$\rho\left(v_n\{2\}^2, [p_T]\right) = \frac{\mathrm{cov}\left(v_n\{2\}^2, [p_T]\right)}{\sqrt{\mathrm{Var}\left(v_n\{2\}^2\right)}\sqrt{c_k}} \tag{9}$$

Subevents

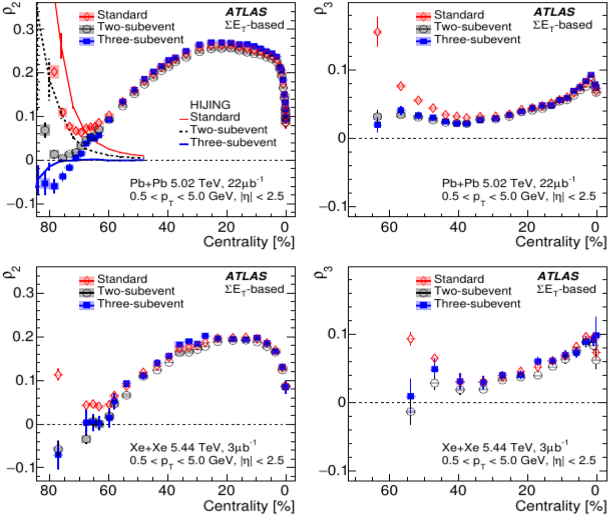
The analysis uses the standard, two-subevent, and three-subevent methods to explore the influence of nonflow correlations.



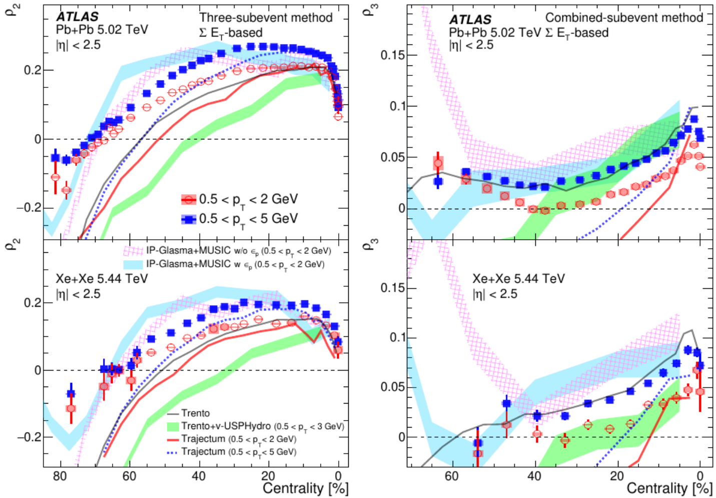
- Standard method: all charged particles within $|\eta| < 2.5$ are used. (Including non-flow effects)
- Two-subevent: The two particles for the v_n are chosen from A and B each. The particle for the p_T is taken from either A or C. (Jets in B won't affect the correlation.)
- Three-subevent: The two particles for v_n are chosen from A and C. the particle for the p_T is taken from B. (Jets in A or C won't affect the correlation.)

Centrality dependence of ρ_n

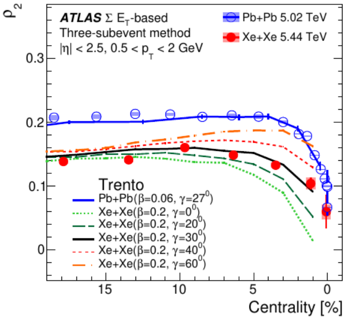
- Non-flow effect is simulated with HIJING.
- Subevent method filters the non-flow contribution.

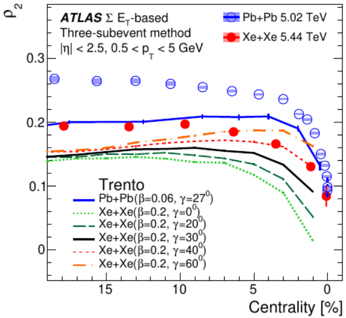


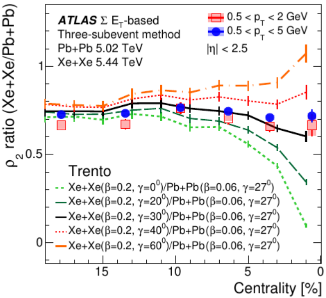
Comparison with theory

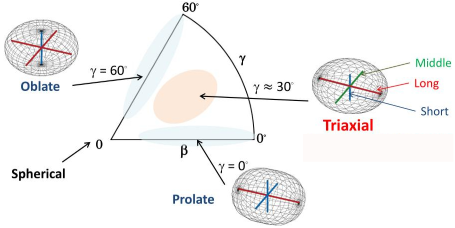


- Trento: based on Glauber model with a "reduced thickness" function.
- v-USPhydro and Trajectum: 2D hydrodynamic models based on Trento initial condition.
- IP-Glasma+MUSIC: 3D hydrodynamic model with gluon saturation initial condition. Can include initial momentum anisotropy (ϵ_p).









- The nuclear shape in this data favours triaxial shape.

Summary

- The R_{AA} for Pb+Pb and Xe+Xe show medium modification.
- Meanwhile, $I_{p\mathrm{Pb}}$ show no sign of jet quenching, and so do with $R_{p\mathrm{Pb}}$ at $p_T > 2$ GeV.
- Non-zero v_2 and v_3 present in photonuclear ultraperipheral Pb+Pb. (Sign of medium formation and expansion?)
- v_n-$\langle p_T \rangle$ correlations analysis can give qualitative test for hydrodynamics and initial state models.
  It is useful for nuclear physics as well, to constrain the quadrupole deformation and triaxiality of the colliding nuclei.

Thank you.

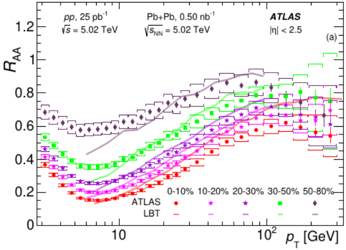
This talk is funded by "Excellence initiative – research university" program for the AGH University of Science and Technology.

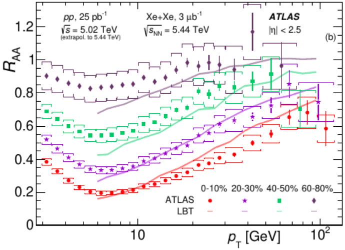
BACKUP

Part 1

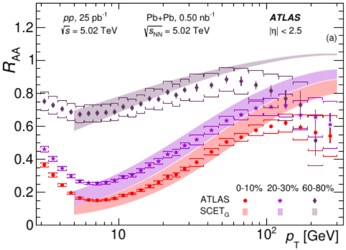
Comparison with theories

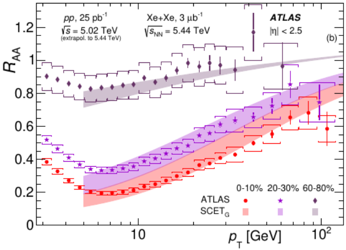
- Linear Boltzmann Transport (LBT) model



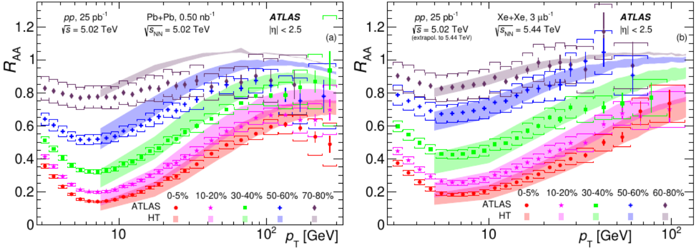


- SCET$_G$ model

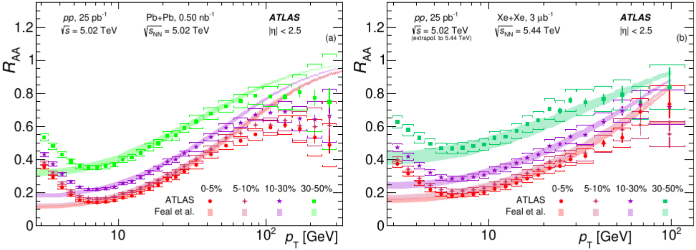




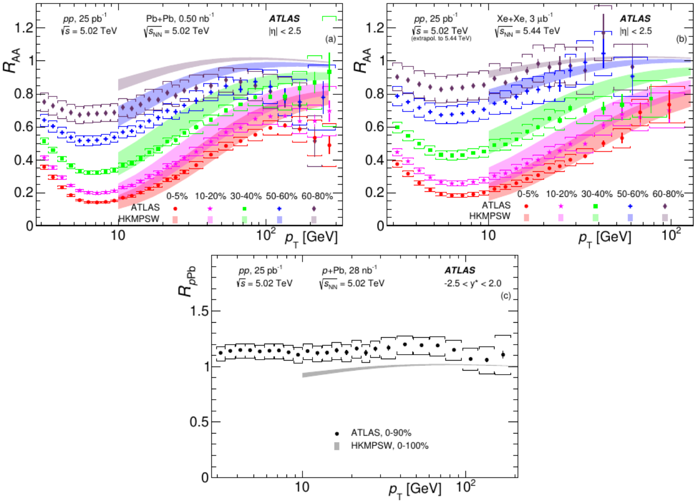
- Higher Twist (HT) model



- The model developed by Feal et al.

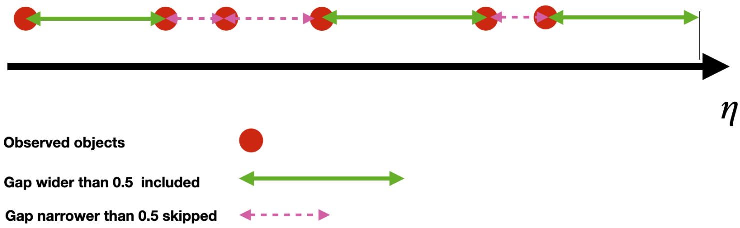


- HKMPSW model



Part 3

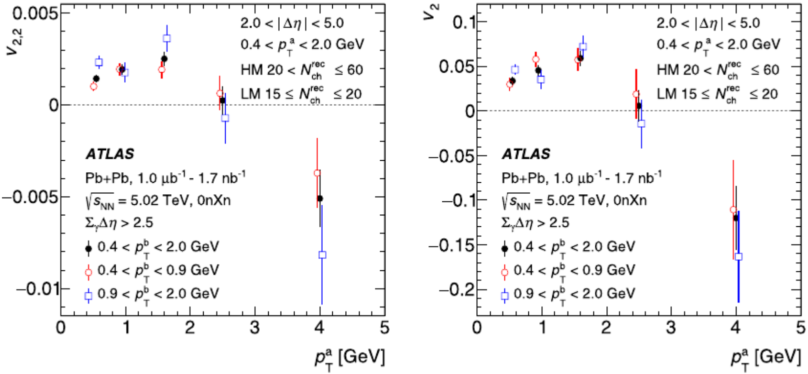
Sum of gap $\Sigma_\gamma \eta$



- $|\Delta\eta| > 0.5$ is chosen to eliminate contribution from jets.

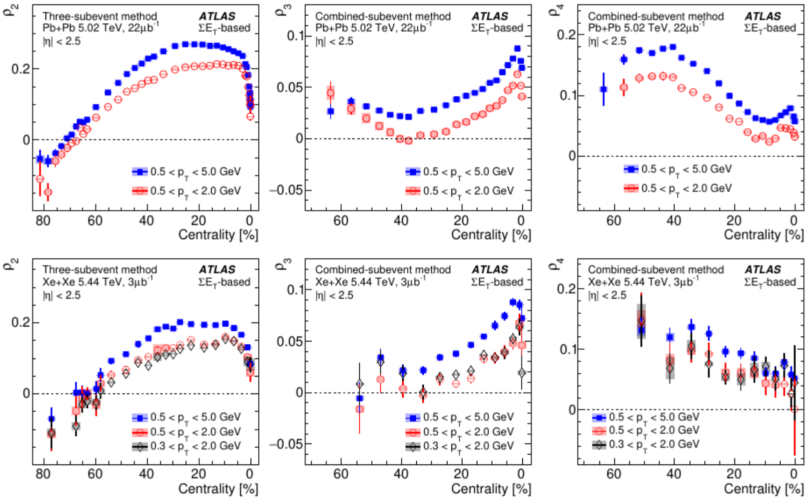
Factorization test

- In hydrodynamic picture, $v_{n,n}$ can be factorized for individual particle $v_{n,n} = v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)v_n(p_T^b)$.
- $-v_{n,n}$ value violates the expected factorization.
- $-v_{n,n}$ at $p_T > 2$ GeV cannot be interpreted as arising from hydrodynamic flow.

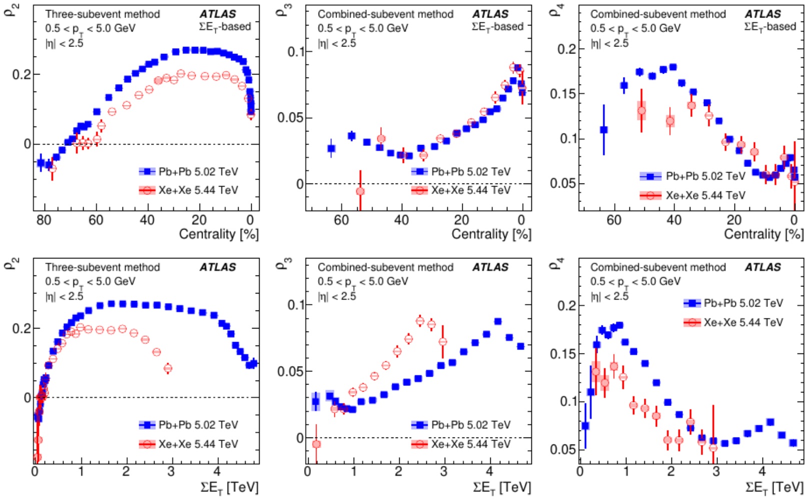


Part 4

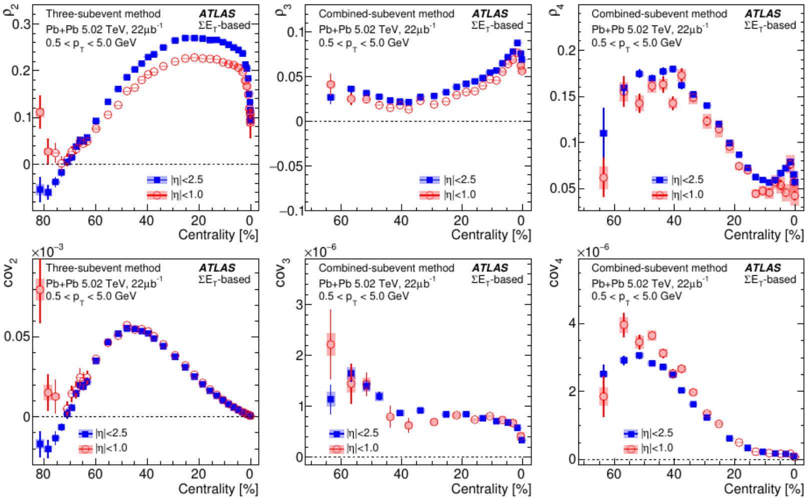
Centrality dependence of ρ_n for different p_T ranges



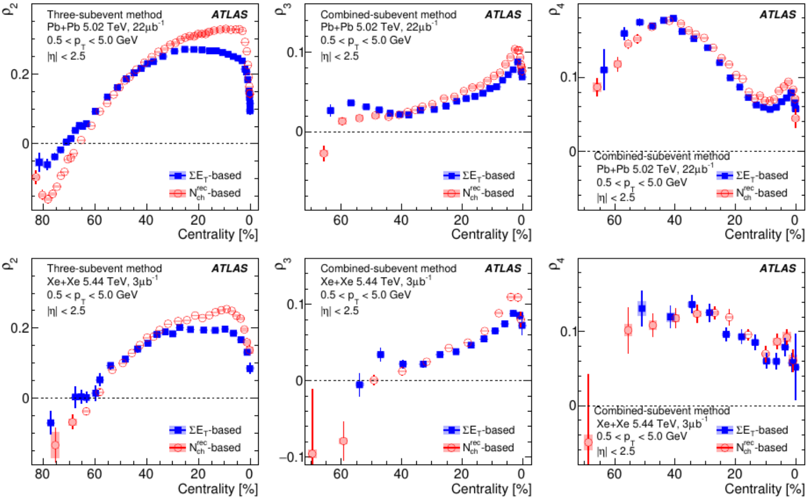
Centrality and ΣE_T dependence of ρ_n for 3-subevent



Effects of centrality fluctuations



Effects of centrality fluctuations (Pt. 2)



Effects of centrality fluctuations (Pt. 3)