



CMS overview



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(for the CMS Collaboration)



Initial Stages 2023
Copenhagen, Jun 19-23



Initial stage – what does it mean?

what are other
words for
initial stages?



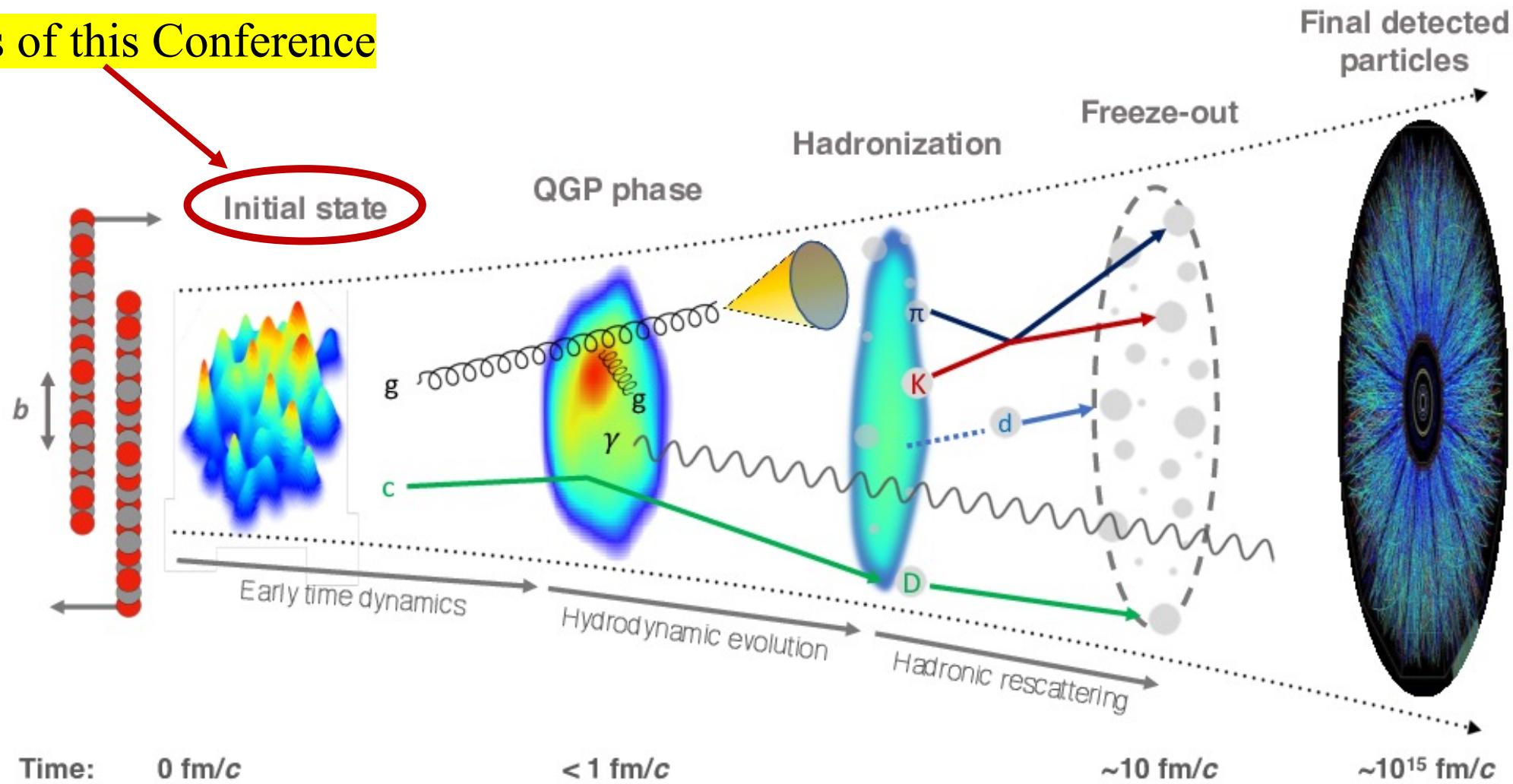
infancy, early stages,
embryonic stage, first phase



 Thesaurus.plus

Initial stage – what does it mean?

Focus of this Conference



[arXiv:2303.17254](https://arxiv.org/abs/2303.17254)

Outline – the probes

□ Early dynamics and nPDFs

- Electroweak bosons
- UPC: J/ψ , dijets, flow

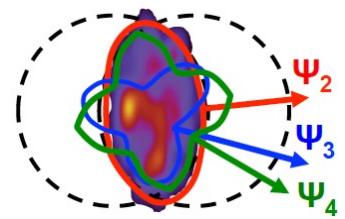
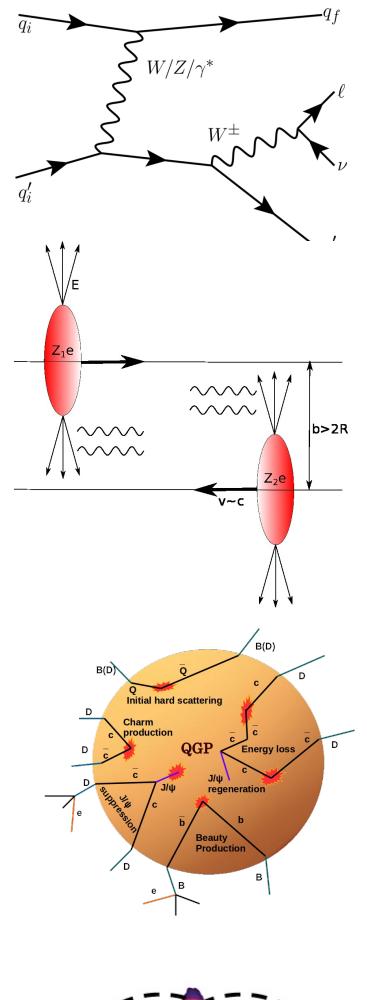
□ Heavy quarks and quarkonia

- Υ (nS), J/ψ , D^0

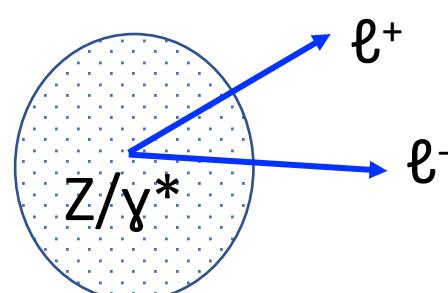
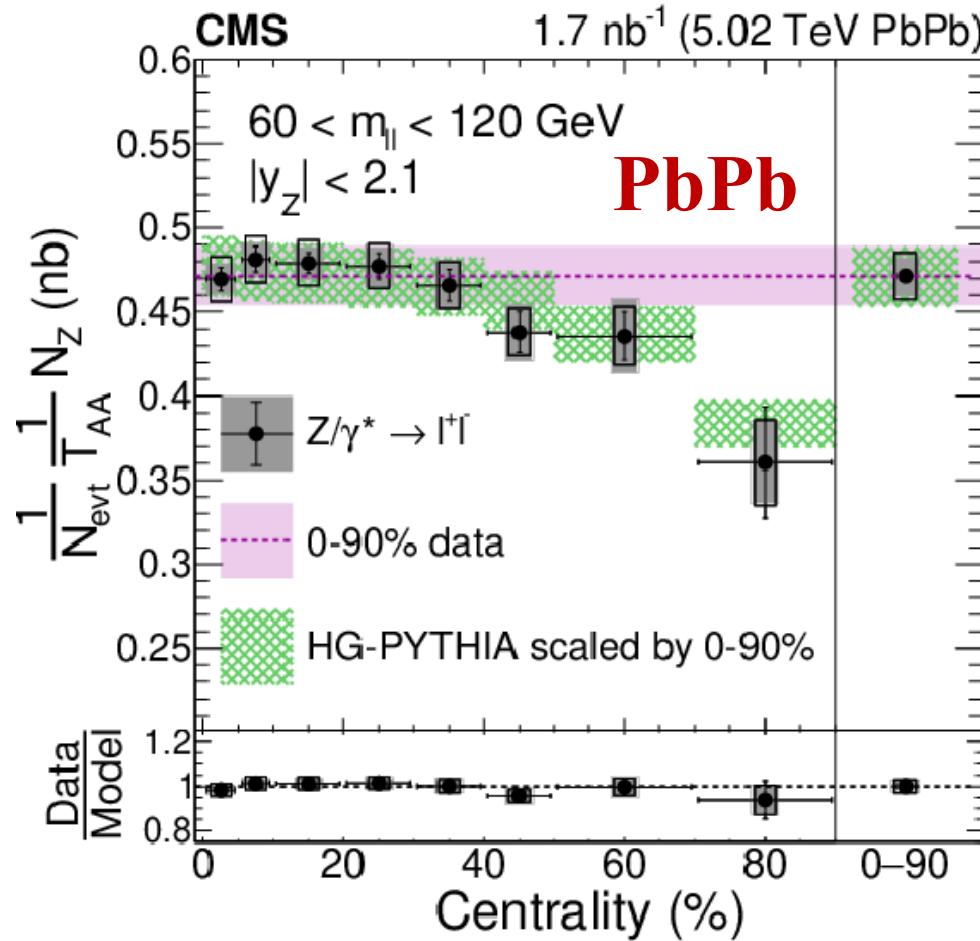
□ Multi-particle correlation

- Single parton in vacuum
- v_n and $[p_T]$ correlation
- Higher-order cumulants
- Charge-balance functions
- Net-charge fluctuations

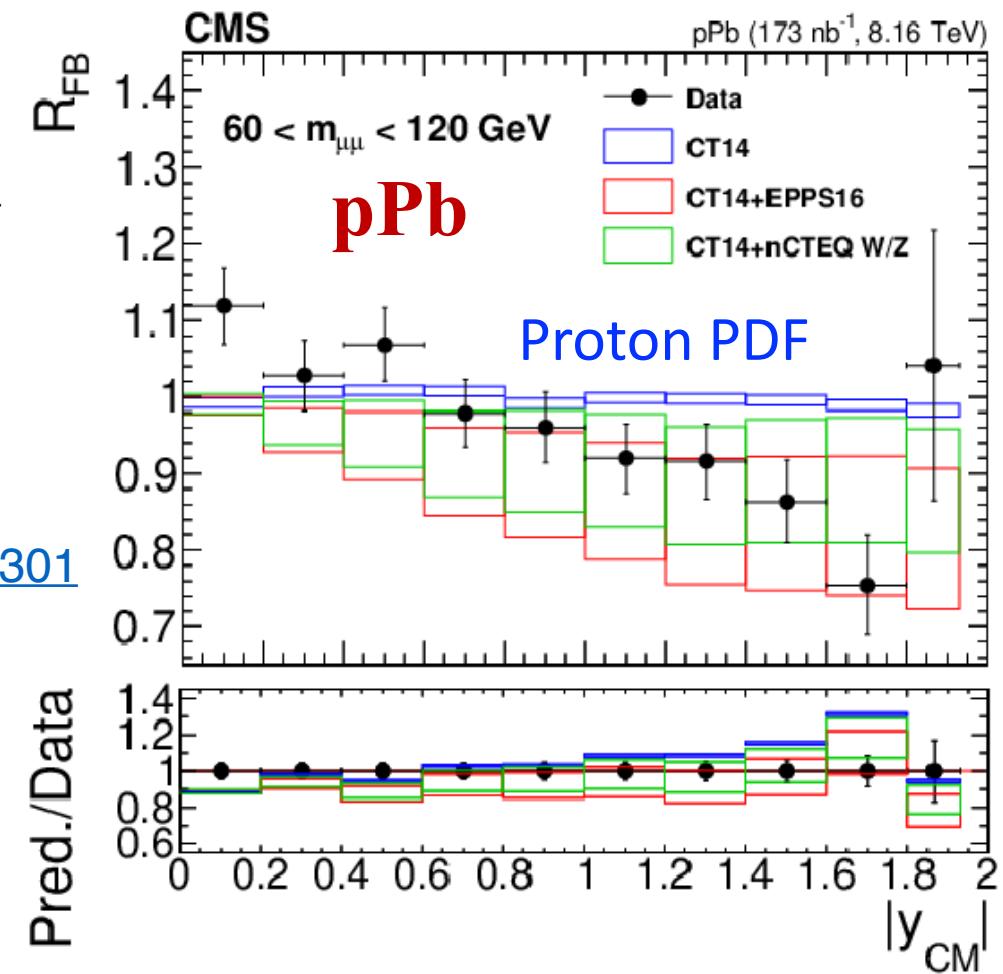
□ CMS in Run 3



Electroweak probe: Z/ γ^* production in Pb-Pb & p-Pb

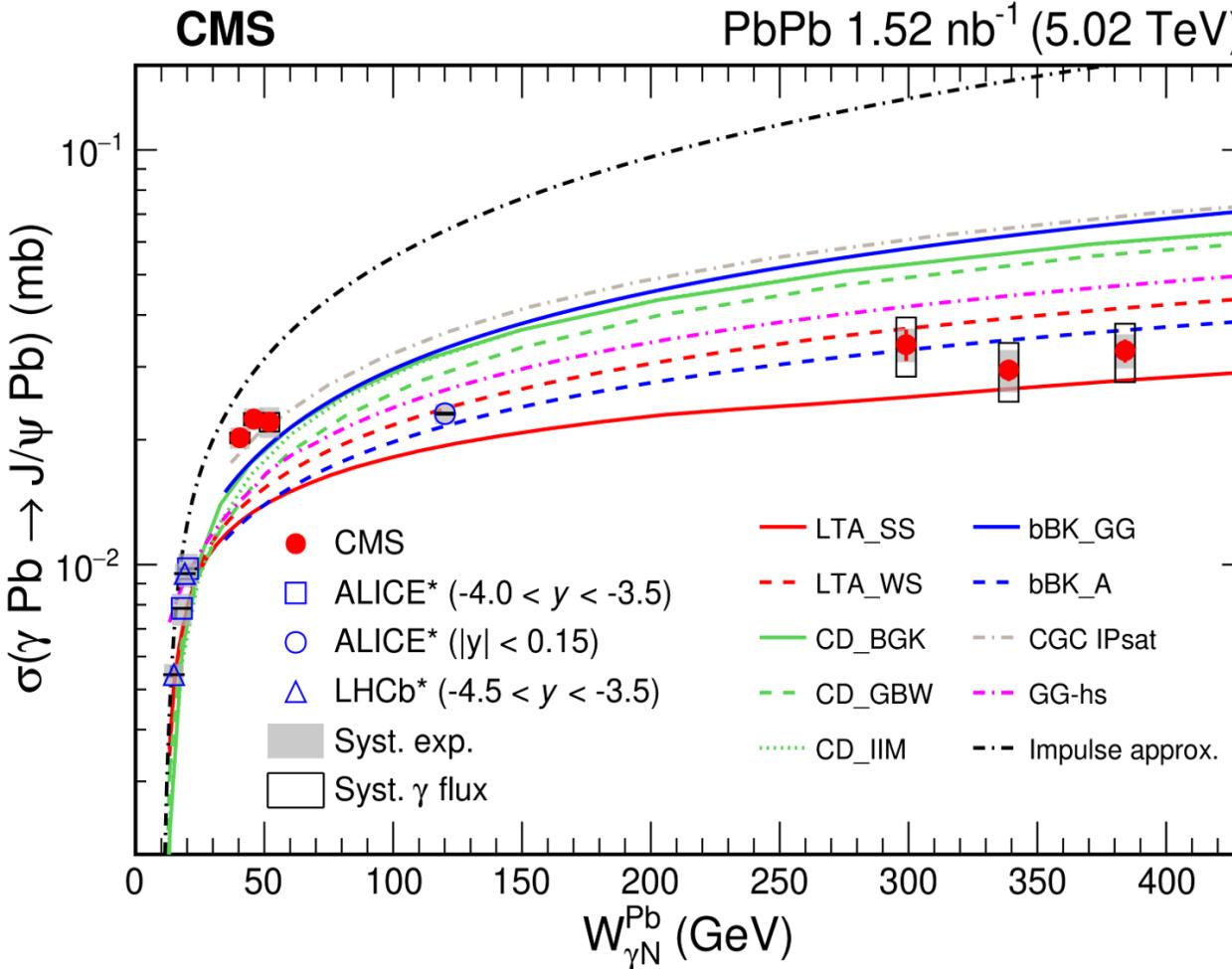


[JHEP05\(2021\)182](#)
[PRL 128 \(2022\) 122301](#)



- HG-PYTHIA grasps centrality evolution → initial geometry & centrality bias in 40-80%
- Forward-backward ratios $R_{\text{FB}} \equiv 1$ in the absence of nuclear effects
- W bosons, dijets, top quarks sensitive to gluons at different x

[arXiv:2303.16984](https://arxiv.org/abs/2303.16984) Submitted to PRL

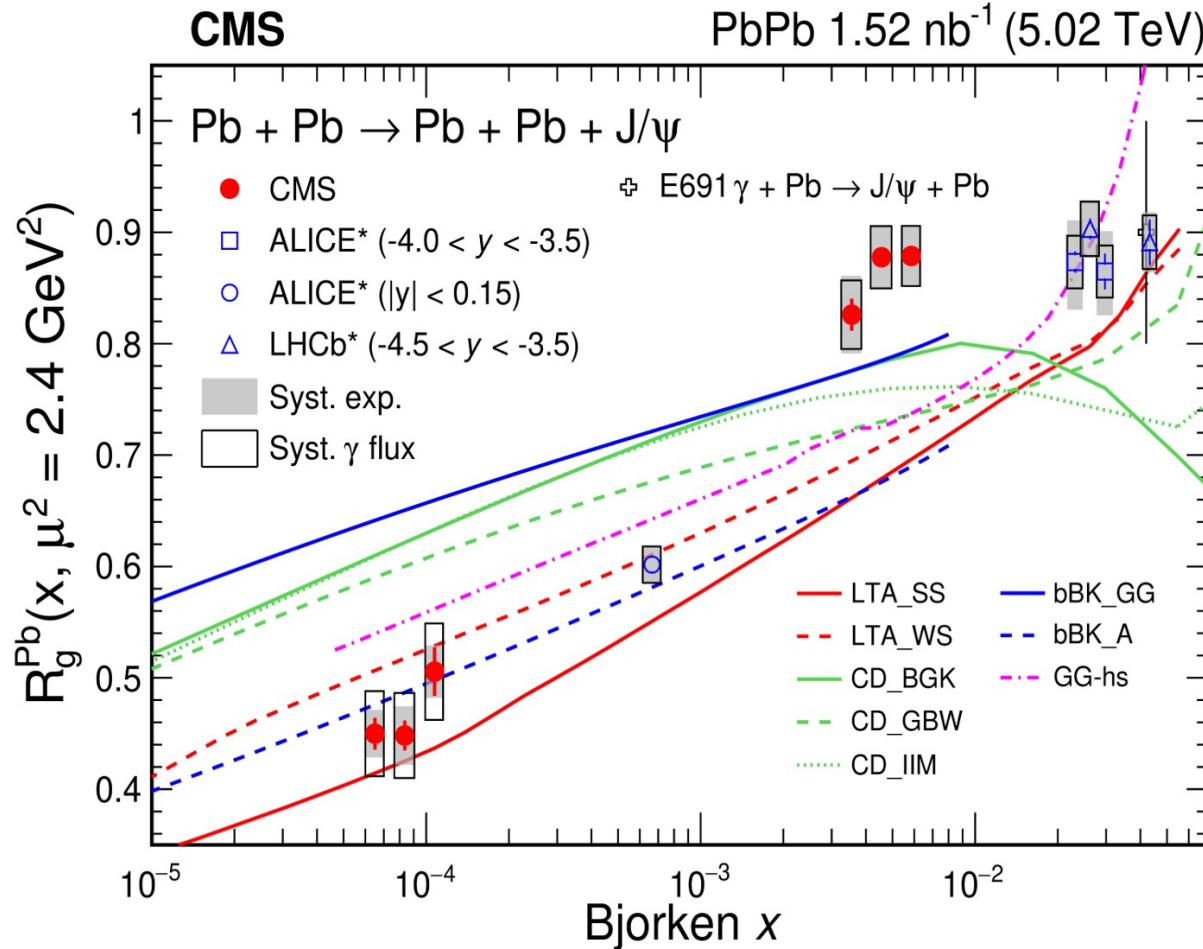


J. Lin@IS2023 Tue 20 (16:30-16:50)

- First measurement of directly disentangled coherence cross section
- CMS measurement up to $W \sim 400 \text{ GeV}$
- No significant change in the range $40 < W < 400 \text{ GeV} \Rightarrow$ evidence for strong gluon saturation
- Probing small- $x \sim 10^{-4} - 10^{-5}$ gluons in nuclei

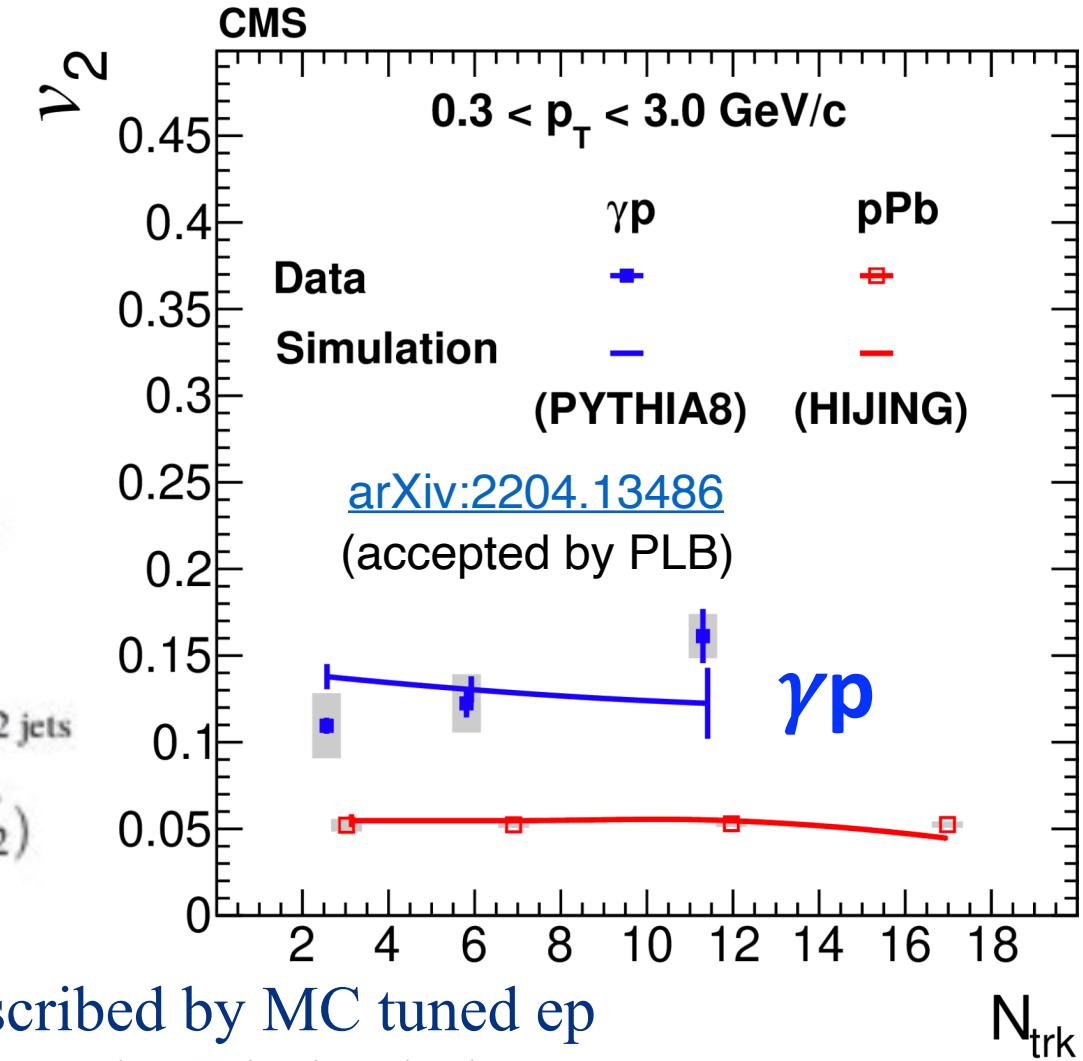
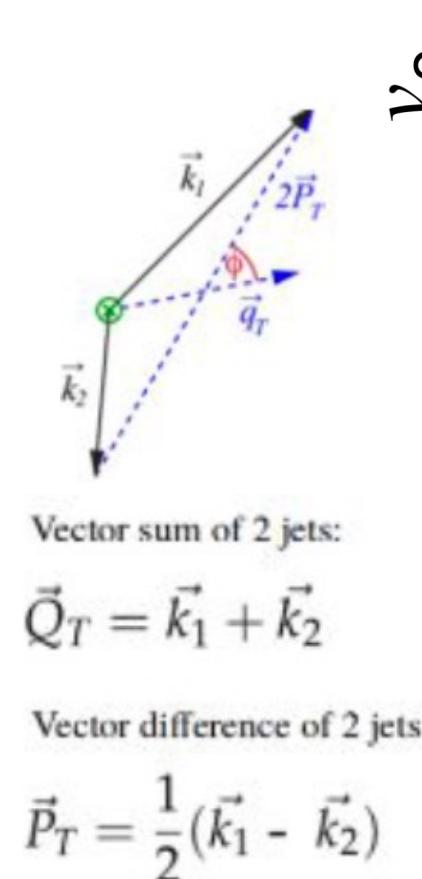
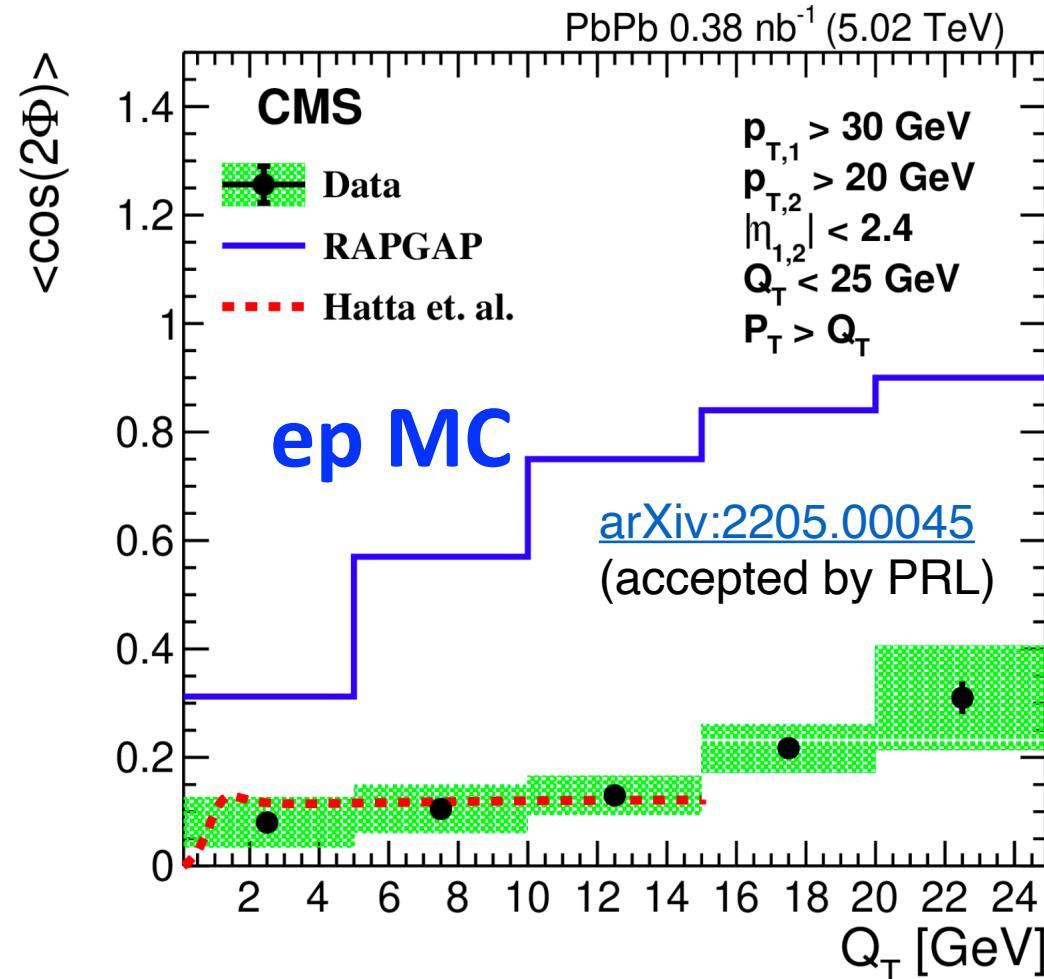
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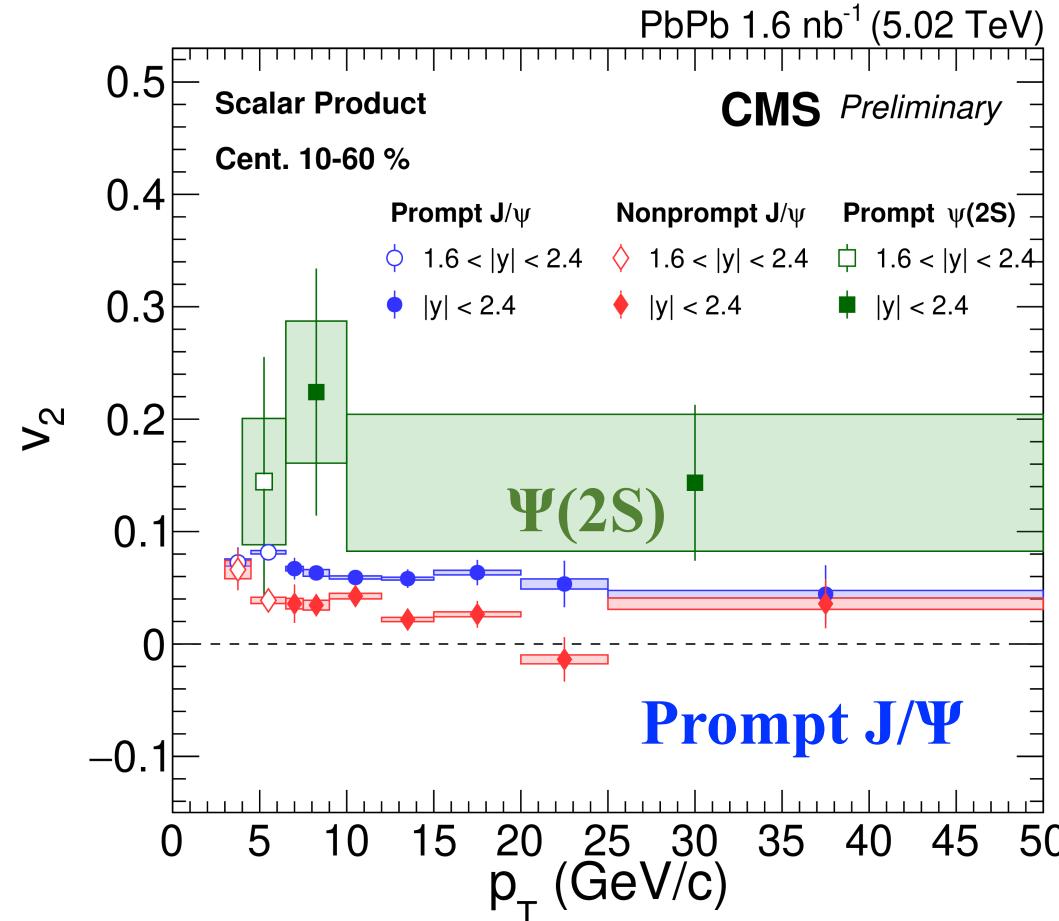


$$R_g^A = \left(\frac{\sigma_{\gamma A \rightarrow J\Psi A}^{\exp}}{\sigma_{\gamma A \rightarrow J\Psi A}^{IA}} \right)^{1/2}$$

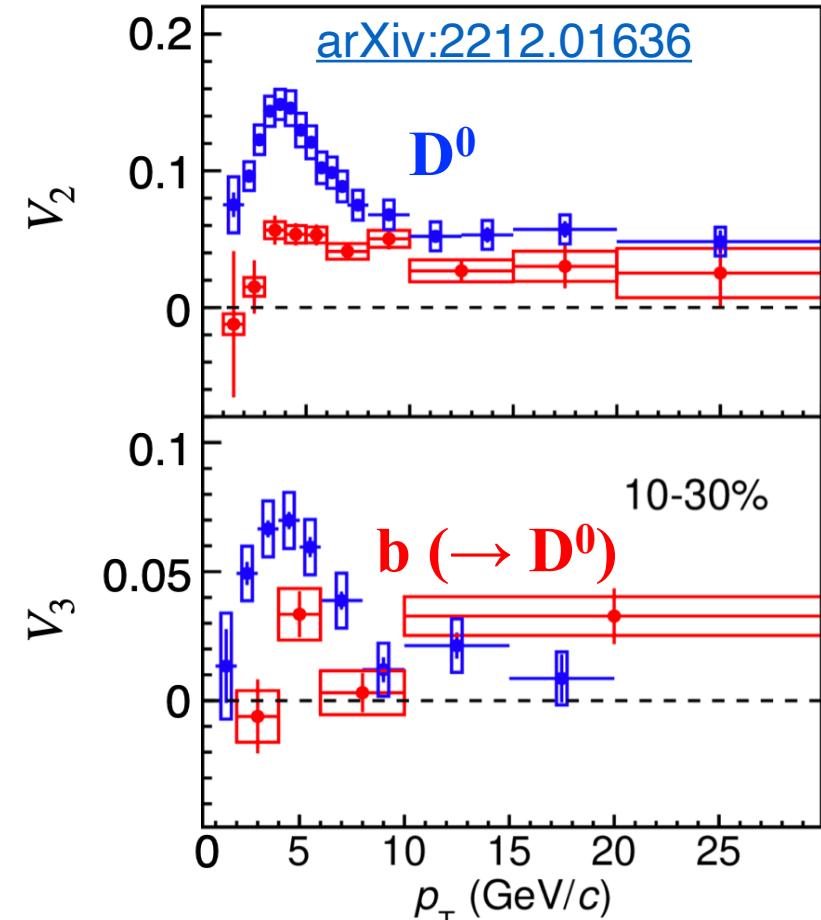
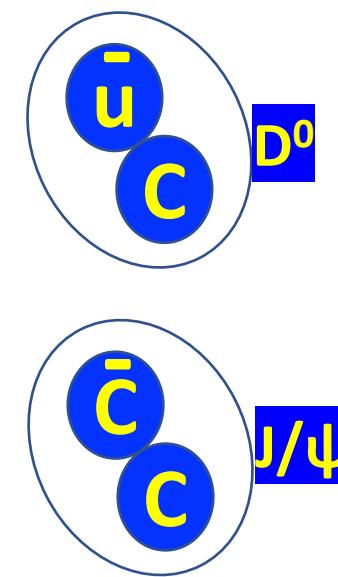
- Flattening of coherent J/ψ at Bjorken $x \sim 10^{-2} - 10^{-3}$
- Rapid decrease towards small x region
 - Not described by the models
- LHC data seem to consistently point to a common x evolution



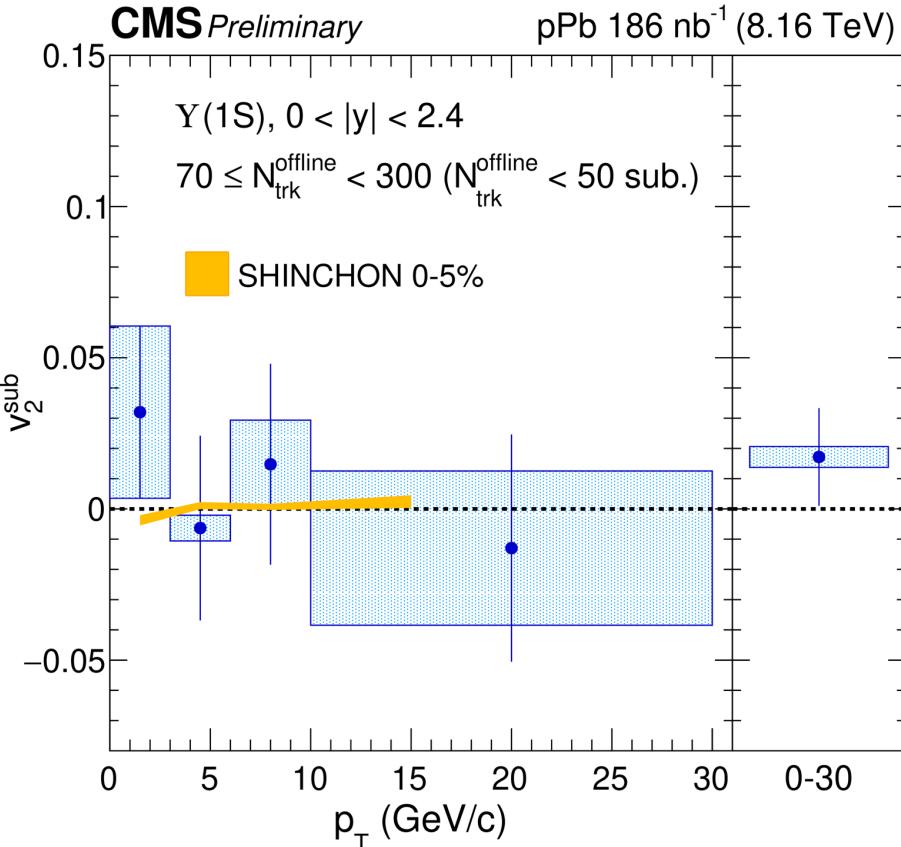
- Average $\cos(2\Phi)$ for exclusive dijets not well described by MC tuned ep
 - sensitive to primordial asymmetry due to the linearly polarized gluons
- Bridging large with exceedingly small systems



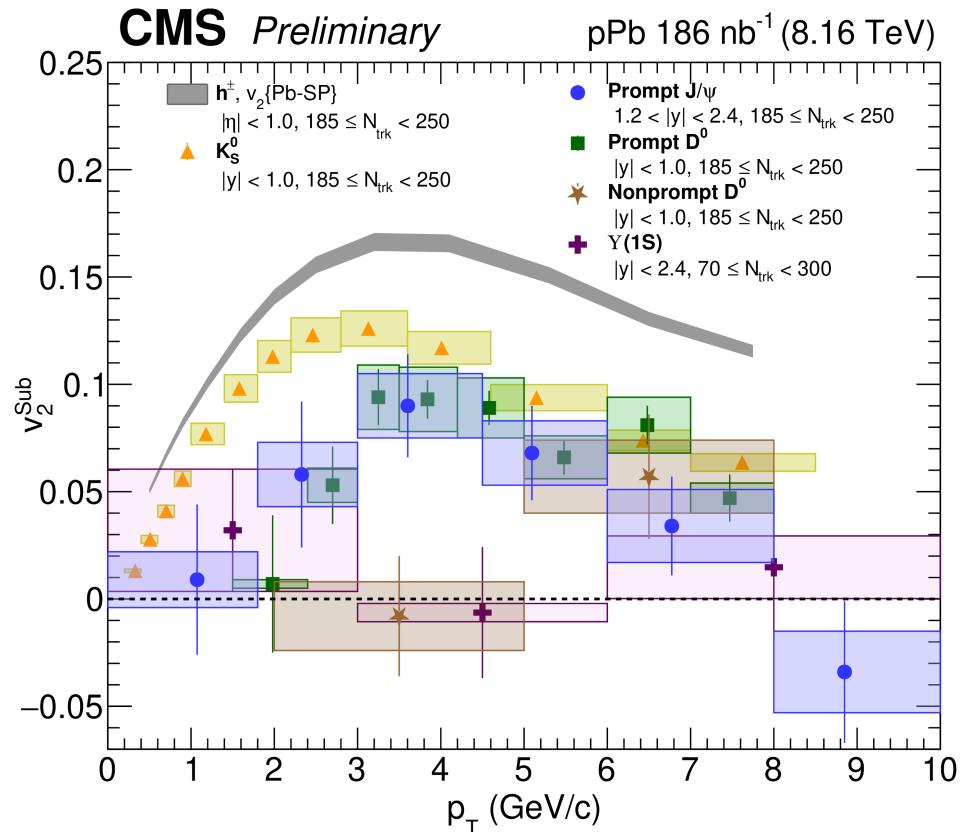
[CMS-PAS-HIN-21-008](#)



- First $v_{2,3}$ measurement for $\Psi(2S) \rightarrow$ indicating recombination at later stage?
- First v_2 for $b (\rightarrow D^0)$; b quark and D^0 meson p_T well correlated
 - v_2 of charm $> b (\rightarrow D^0)$; whereas $\Upsilon(1S), \Upsilon(2S)$ $v_2 \approx 0$
 - Evidence for $b (\rightarrow D^0) v_3 > 0$ at intermediate p_T

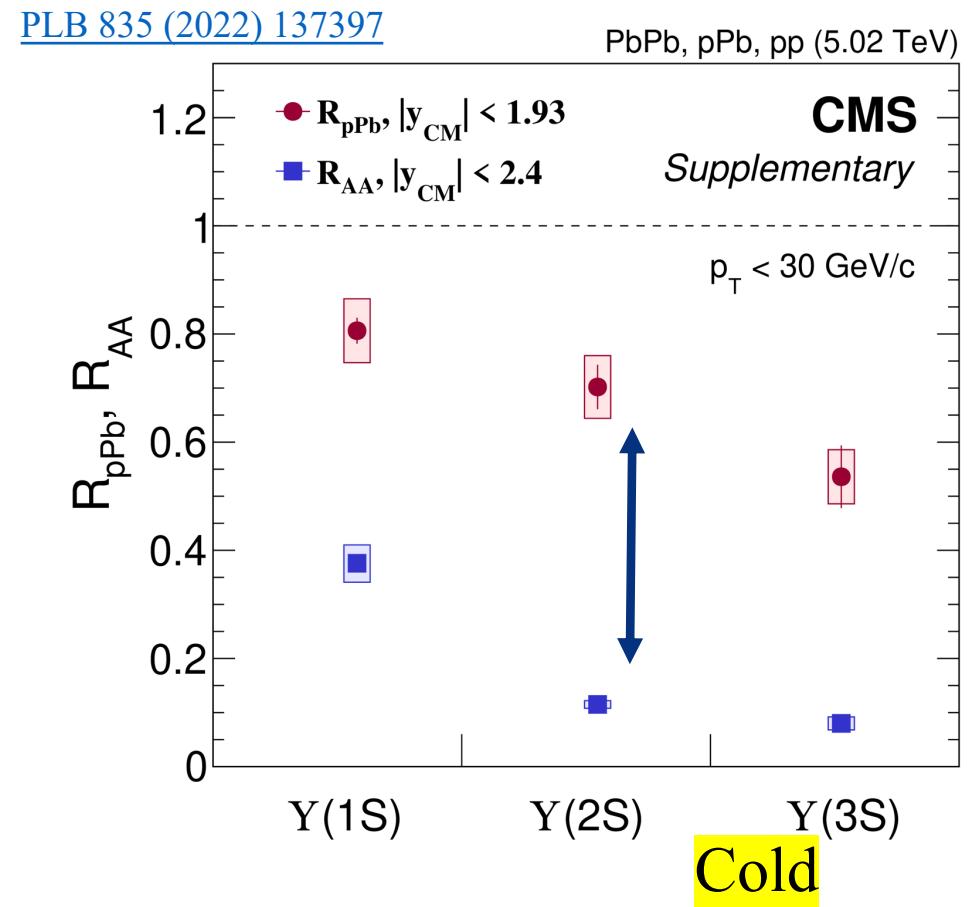
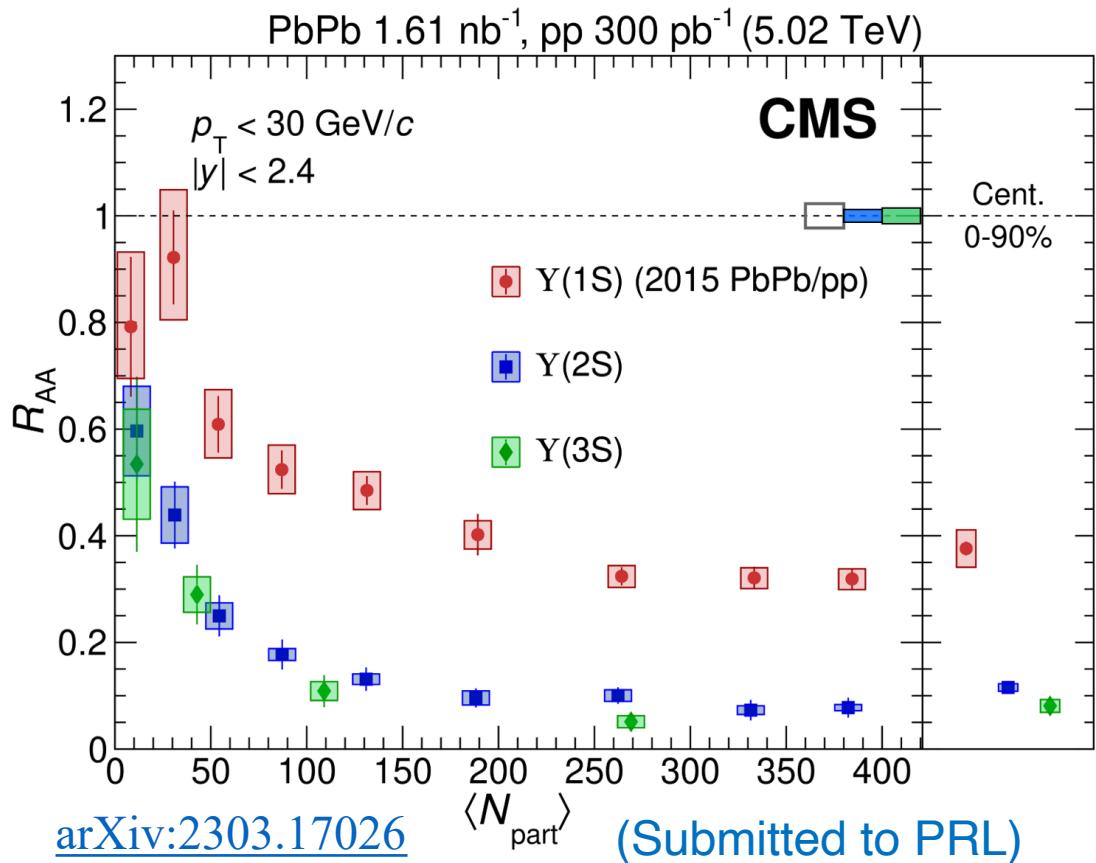


[CMS-PAS-HIN-21-001](#)



- First v_2 measurement of $\Upsilon(1S)$ state in p-Pb
 - $v_2 \approx 0$ up to 30 GeV/c (!), similar to [a model](#) with final-state interactions only
- Bridging HF flow measurement in large and small systems
 - clear mass ordering → heavier particles flow less
 - do open/closed b hadrons flow in p-Pb?

HF: Υ (nS) suppression in Pb-Pb and p-Pb



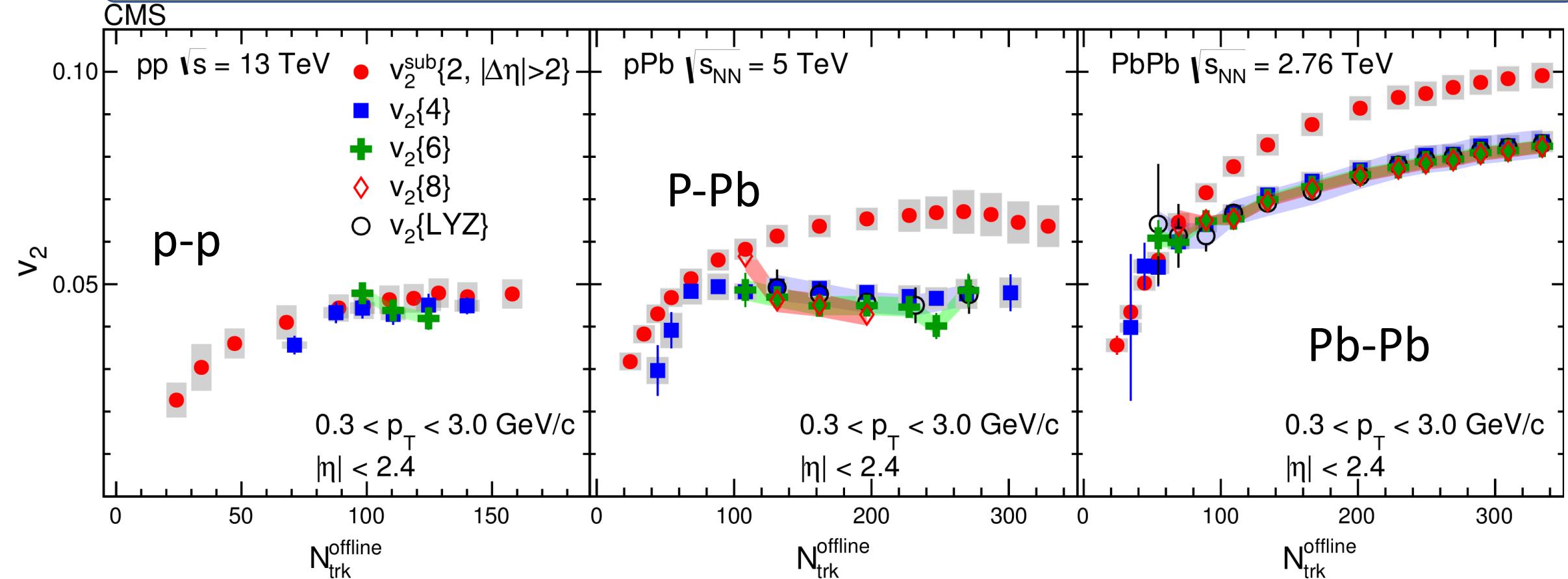
- Υ states are suppressed sequentially: $\Upsilon(3S) \rightarrow \Upsilon(2S) \rightarrow \Upsilon(1S)$
- Suppression observed for both Pb-Pb and p-Pb collisions
 - Suppression magnitude in p-Pb is much smaller compared to Pb-Pb



Is that all what we can learn?

Not yet!

Onset of collectivity from large to small systems



➤ Collectivity: $V_2\{2\} \approx V_2\{4\} \approx V_2\{6\}$

Phys. Lett. B 765 (2017) 193

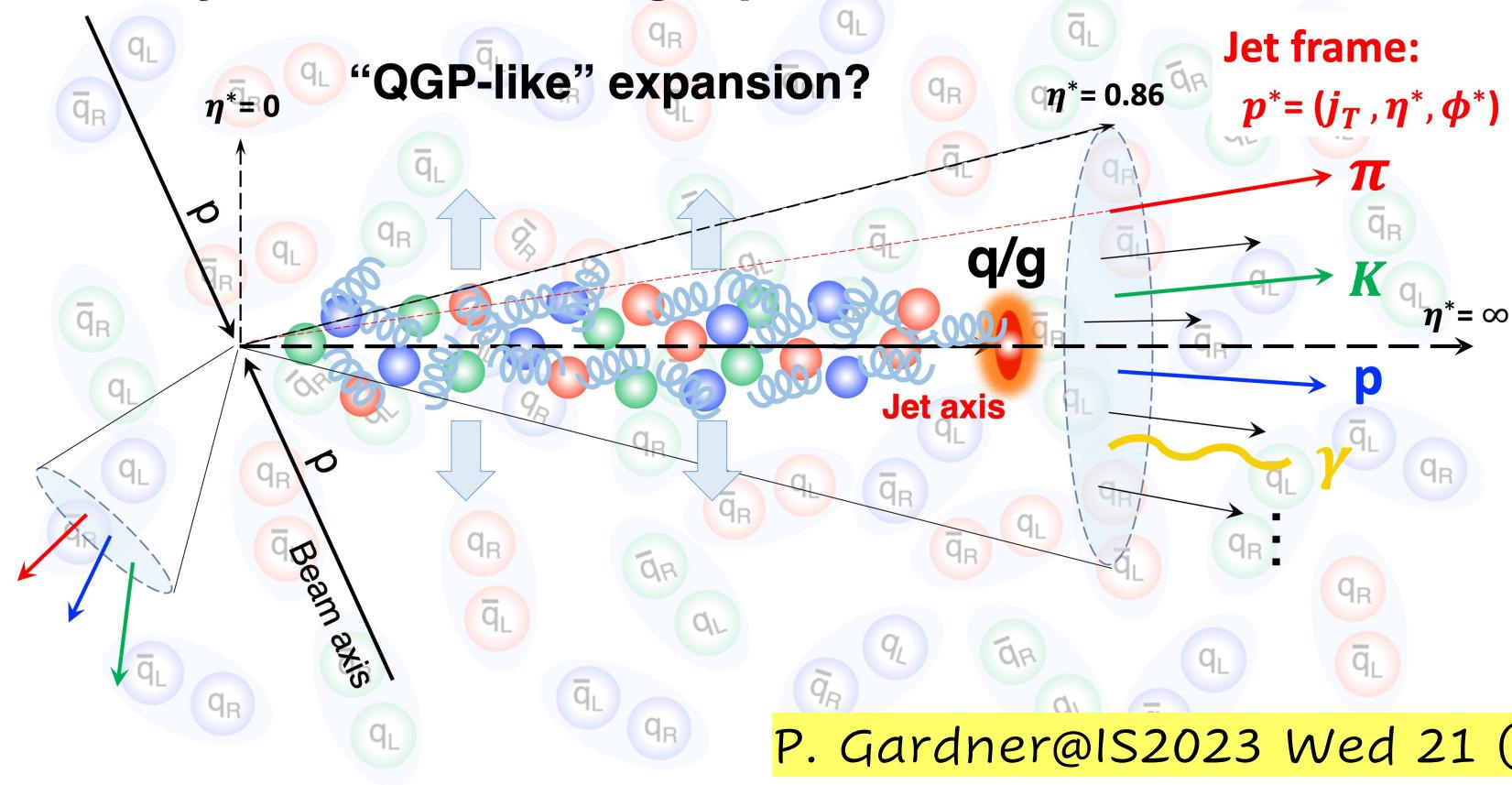
- Similar trend with different magnitude in all 3 systems
- Initial state fluctuations play important role

What is the underlying mechanism driving collectivity?

Strongly interacting QGP-like state can be formed by system initiated by single quark or gluon propagating through QCD vacuum.

arxiv.org/abs/2104.11735

Dynamics of a “single-parton” in the vacuum



Intra-jet correlation in p-p collisions

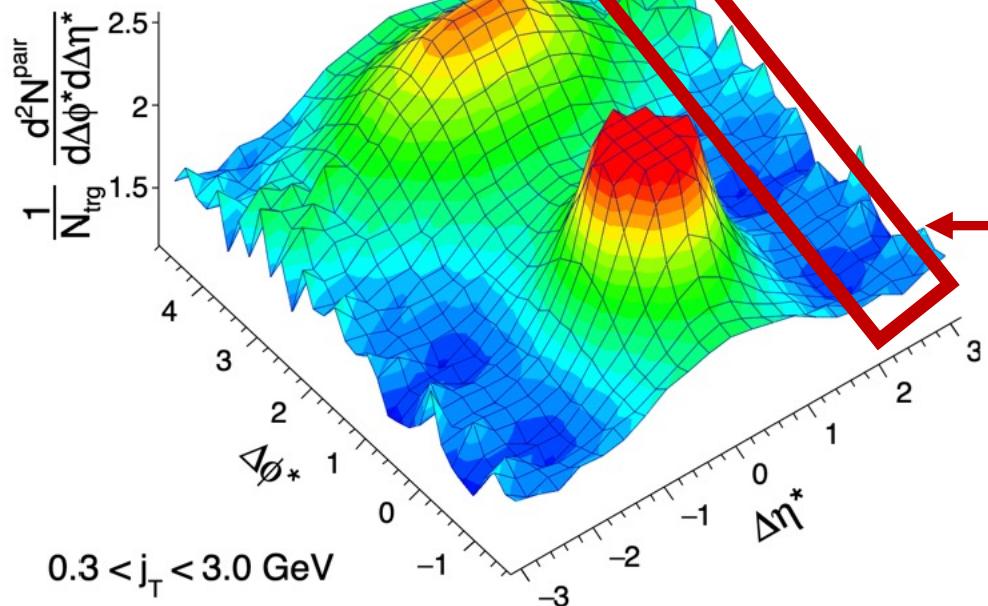
P. Gardner@IS2023 Wed 21 (16:10)

Highest multiplicity jets

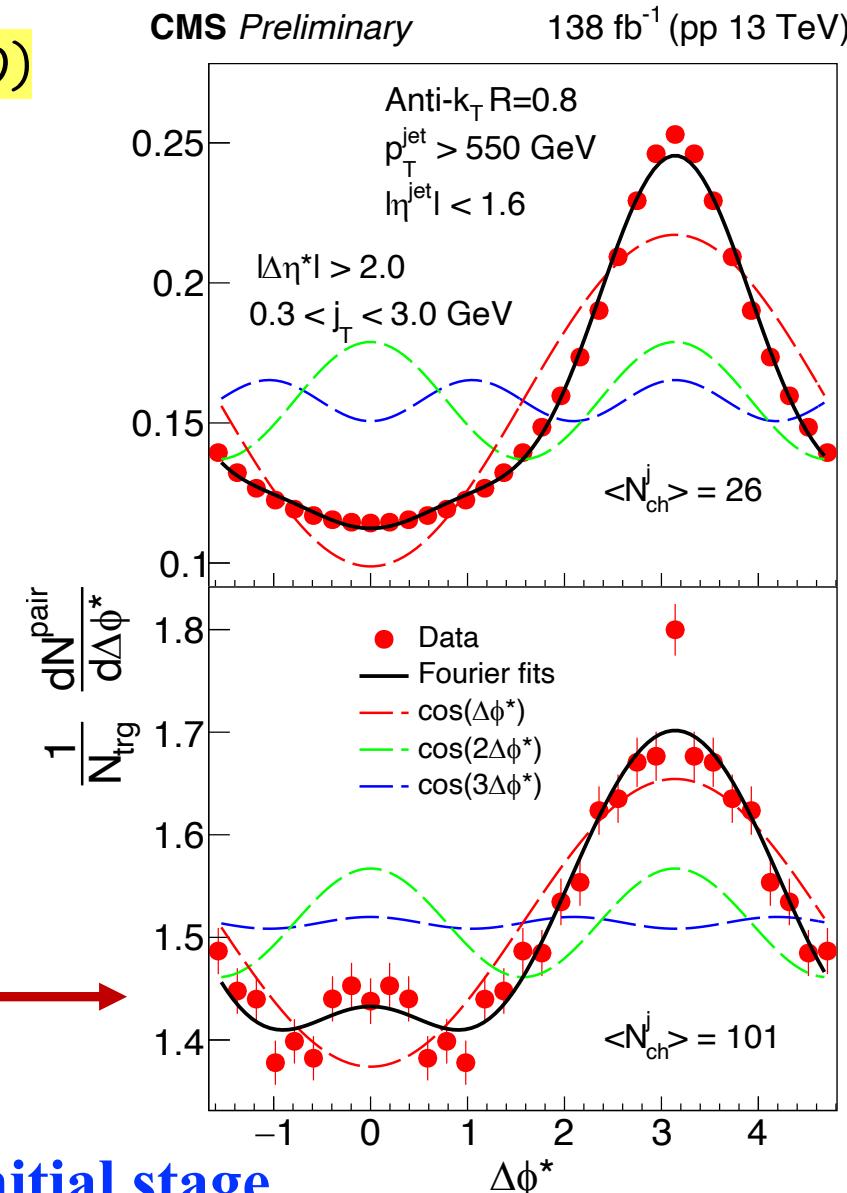
CMS preliminary

$$\langle N_{\text{ch}}^j \rangle = 101$$

Top 0.0023% highest- N_{ch}^j jets

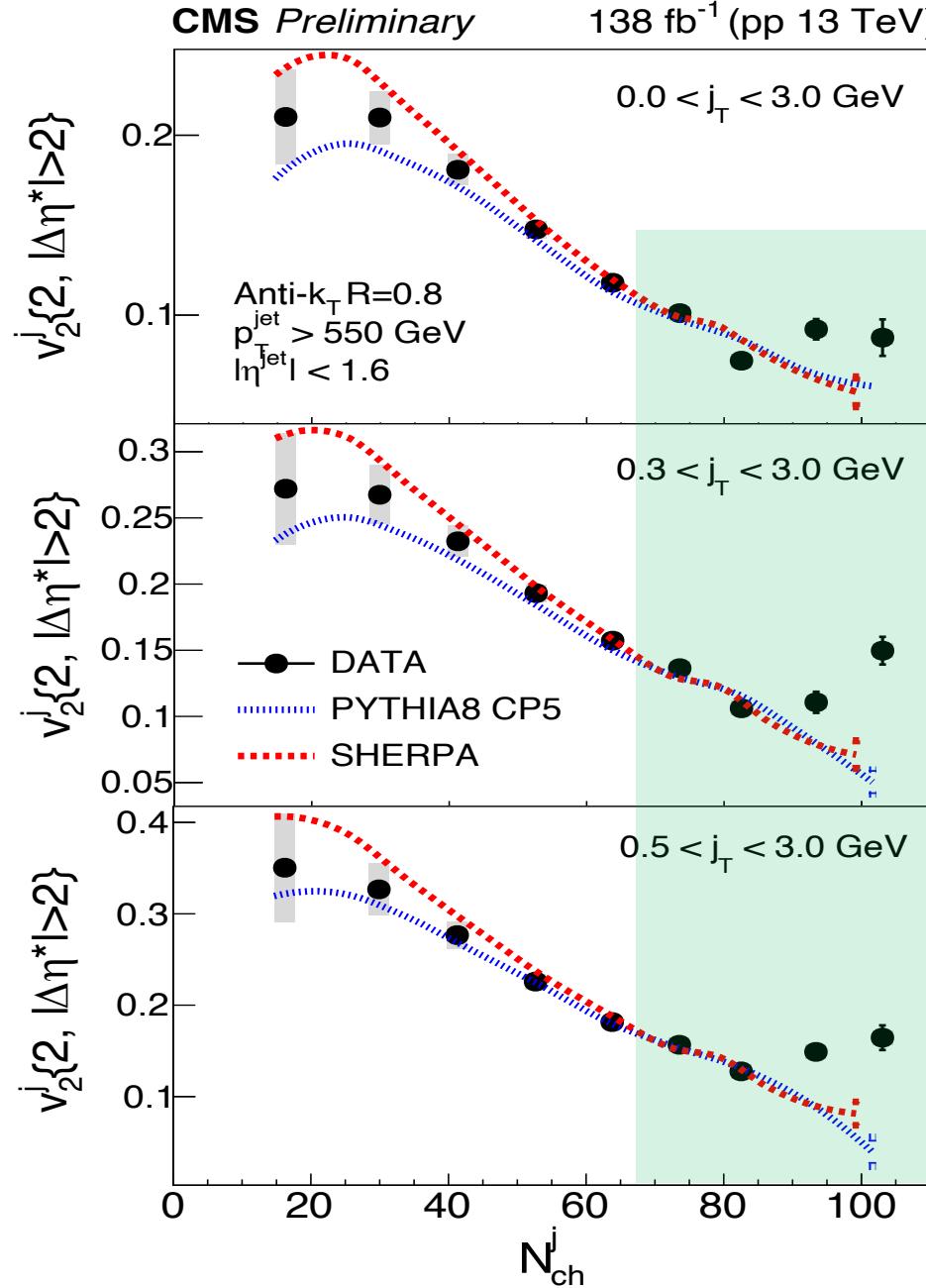


CMS-PAS-HIN-21-013



- Long range $\Delta\eta$ correlation → collectivity → initial stage

Intra-jet correlation in highest multiplicity p-p collisions



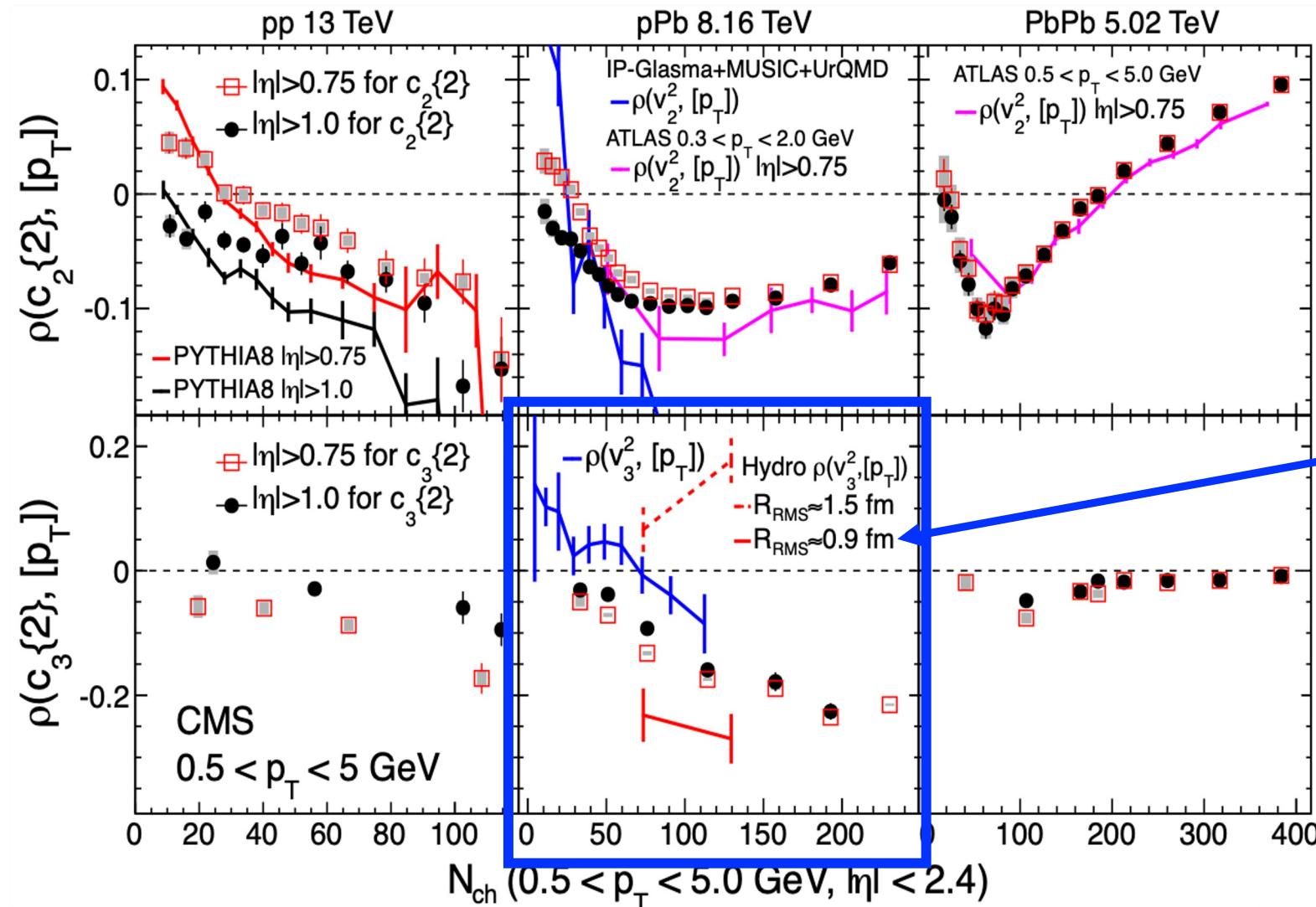
P. Gardner@IS2023 Wed 21 (16:10)

CMS-PAS-HIN-21-013

- In-jet v_2 w.r.t. the jet axis increases in data
- Models show different trend compared to data at higher N_{ch}
- Data indicates collectivity in single parton jets during fragmentation
- Is collectivity an intrinsic nature of nonperturbative QCD?

Cumulant - [p_T] correlations

R. Sing (Poster) @IS2023 Wed 21 (16:10)



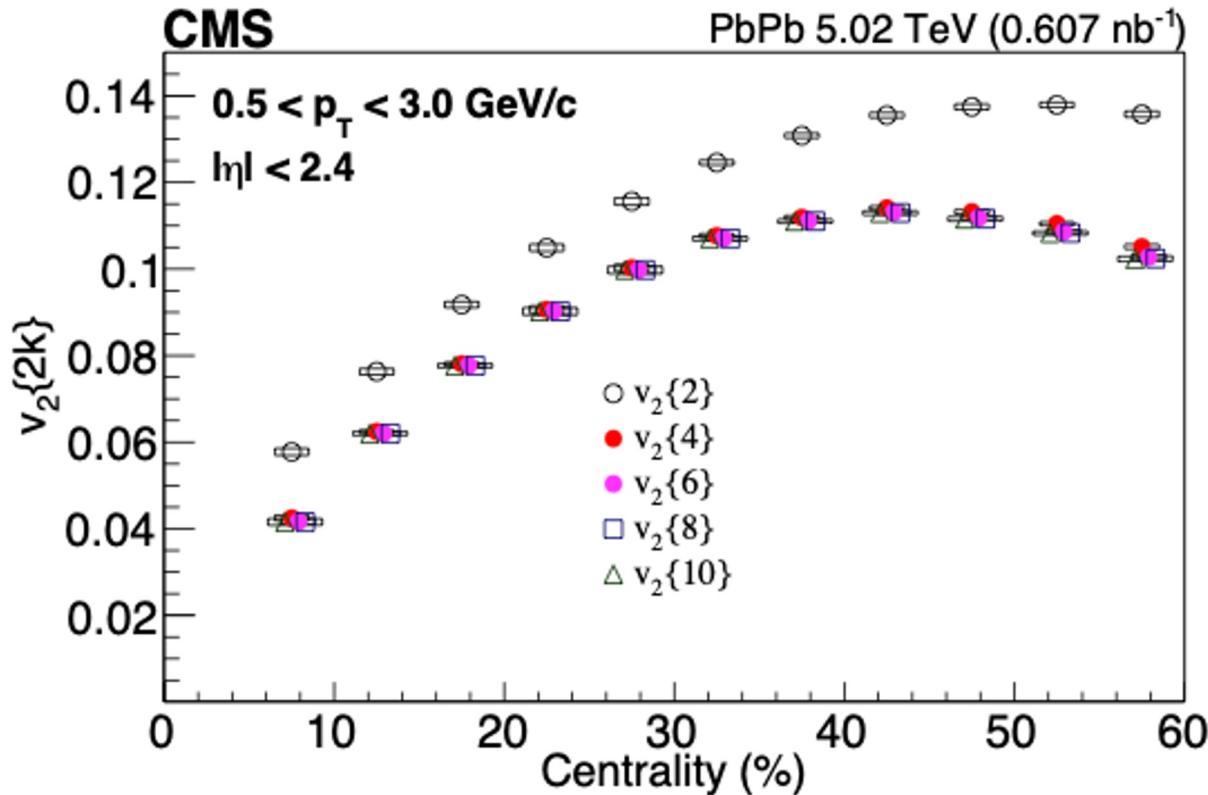
- No sign change with wider η gap in smaller (pp, pA) collisions
- v_2 sensitive to non-flow
- v_3 confirms initial geometry fluctuation

v_3 correlation qualitatively better described by the smaller initial fireball in p-Pb

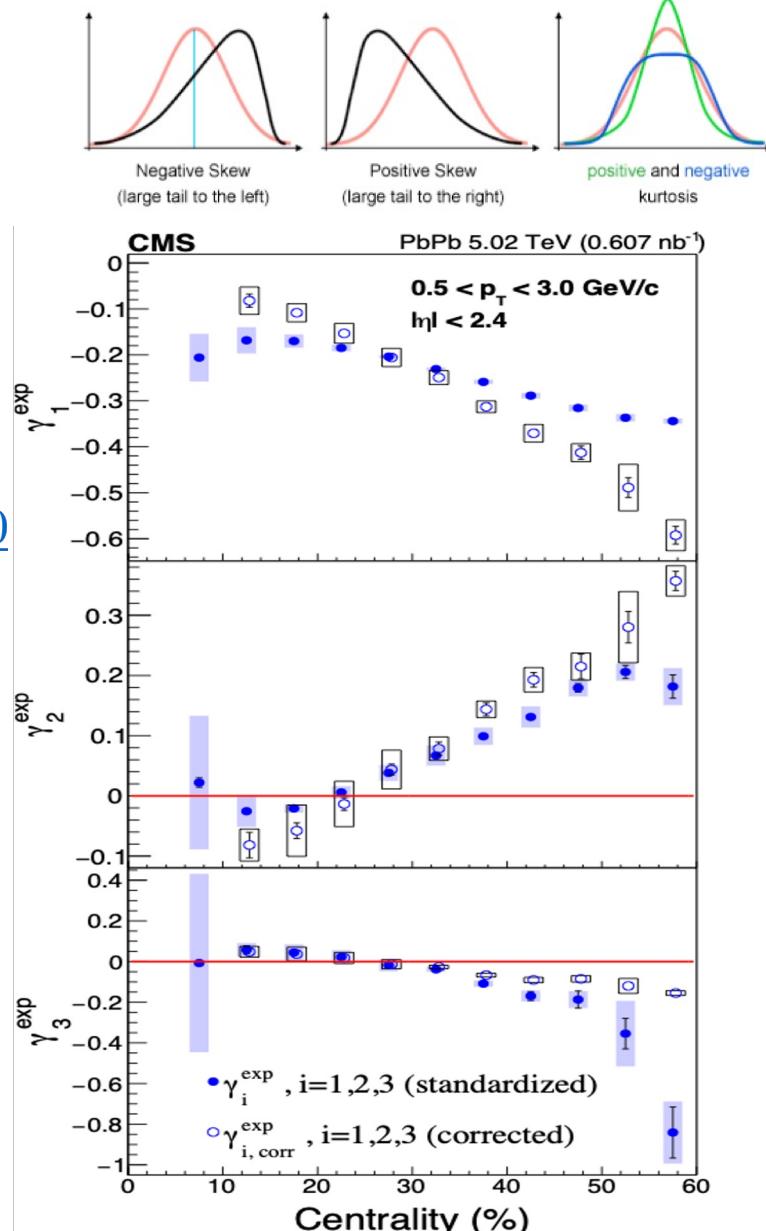
[CMS-PAS-HIN-21-012](#)

Higher-order cumulants $v_2\{2k\}$ in Pb-Pb collisions

- E-by-E fluctuations in anisotropic flow → early state dynamics of the collisions



[CMS-PAS-HIN-21-010](#)



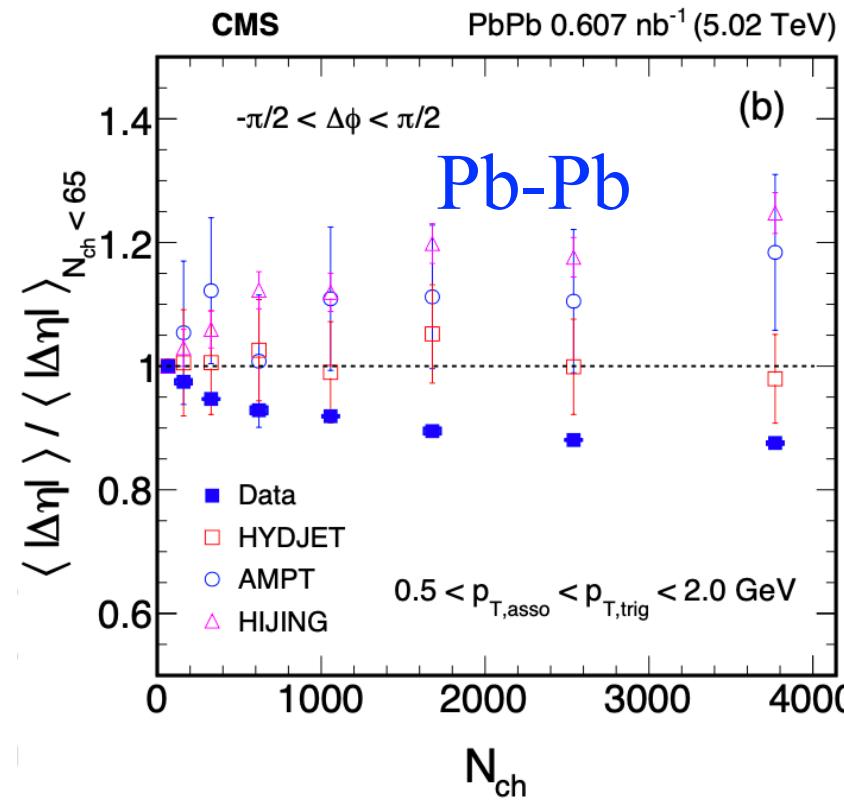
- Fine splitting observed with higher-order cumulants
 - Indication of non-Gaussian behavior of the fluctuations
 - Non-zero values for skewness, kurtosis, and superskewness

Charge balance function in p-Pb and Pb-Pb collisions

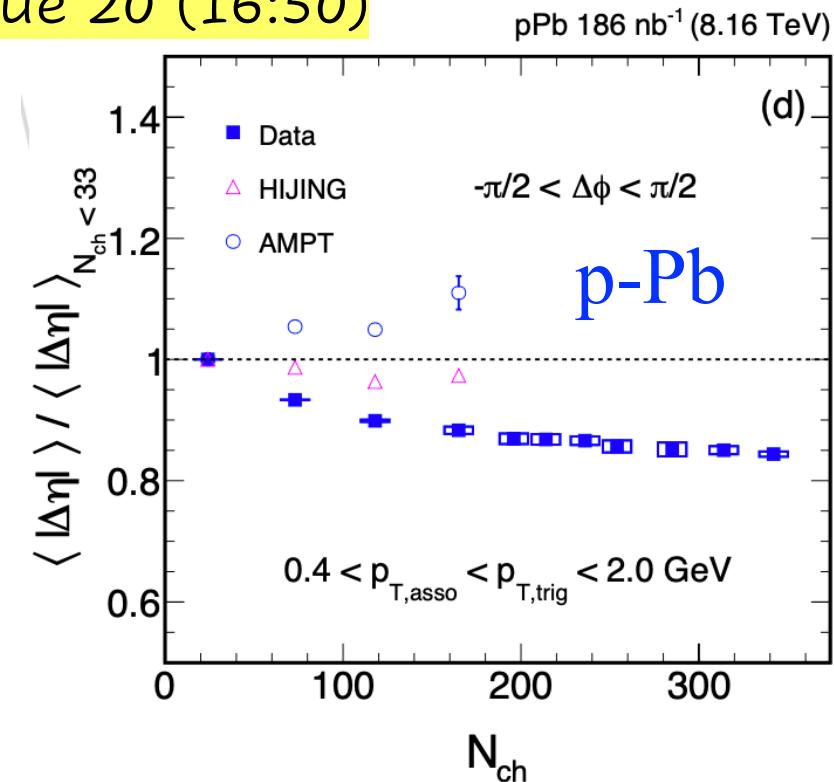
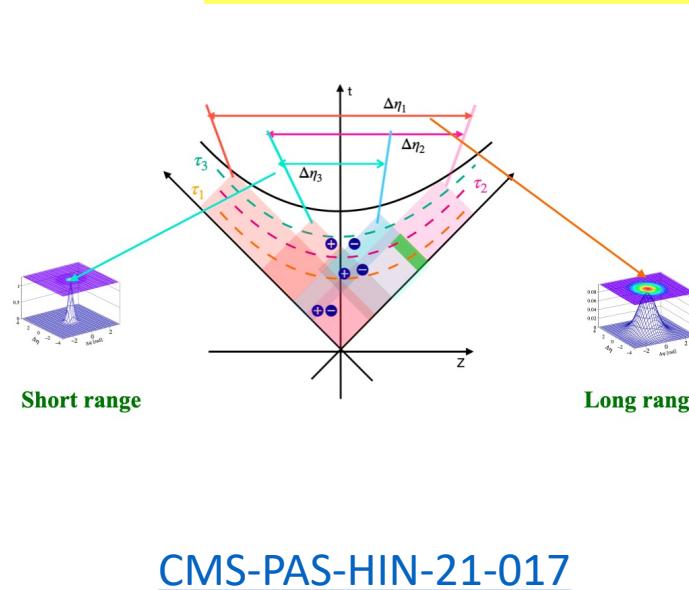
Balance function = $\frac{1}{2} \left[C_2(+,-) + C_2(-,+)^* - C_2(++,)^* - C_2(--)^* \right]$

sensitive to hadronization time & system evolution

LCC & radial flow effect



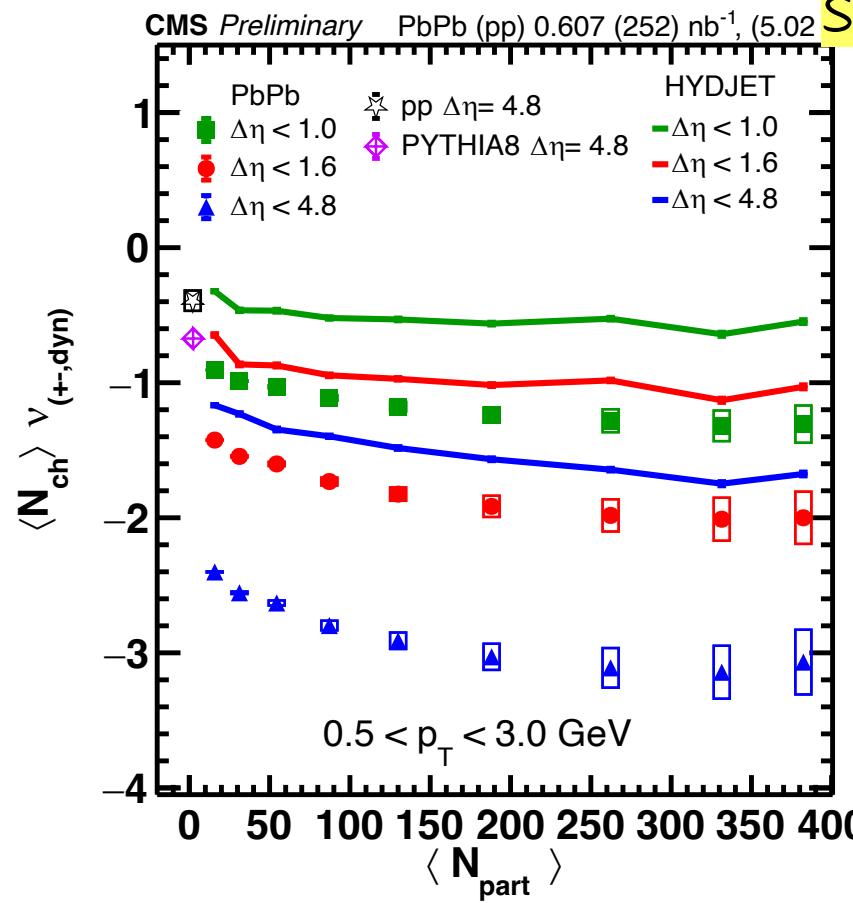
S. Behera@IS2023 Tue 20 (16:50)



- Narrowing of balance function with increasing multiplicity both in p-Pb and Pb-Pb
- Consistent with the delayed hadronization mechanism and radial flow effect in high multiplicity than low multiplicity events

Net-charge fluctuation in Pb-Pb collisions

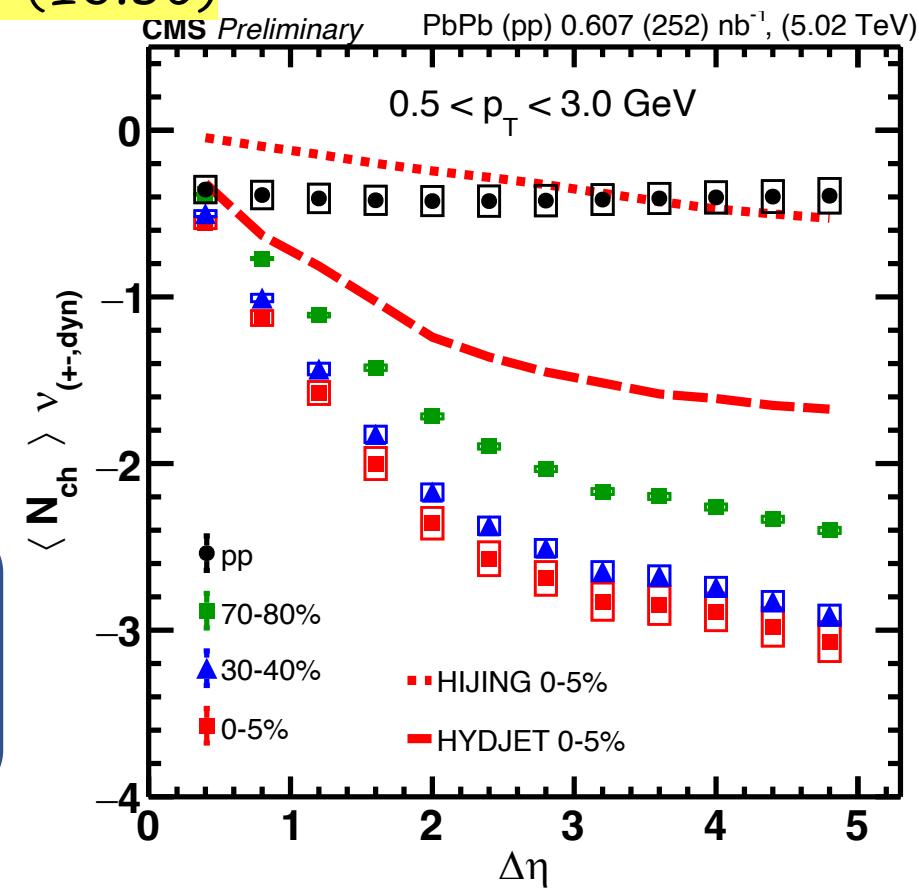
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$$v_{(+,dyn)} = \frac{\langle N_+ (N_+ - 1) \rangle}{\langle N_+ \rangle^2} + \frac{\langle N_- (N_- - 1) \rangle}{\langle N_- \rangle^2} - 2 \frac{\langle N_+ N_- \rangle}{\langle N_+ \rangle \langle N_- \rangle}$$

Hadron Gas: $q = \pm 1, q^2 = 1$

QGP: $q = \pm \frac{1}{3}; \frac{2}{3}, q^2 = \frac{1}{9}; \frac{4}{9}$

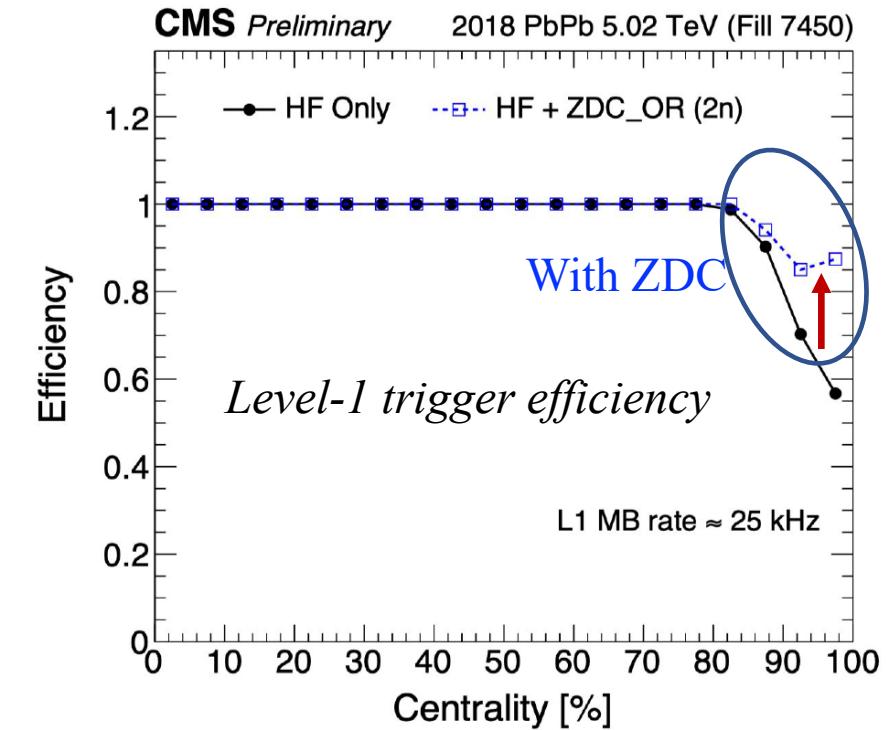
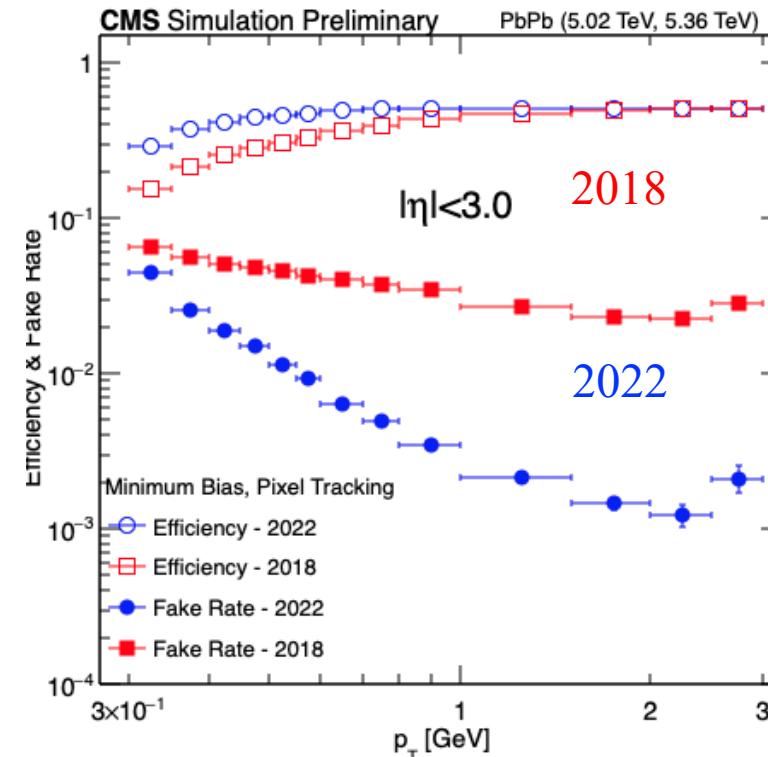
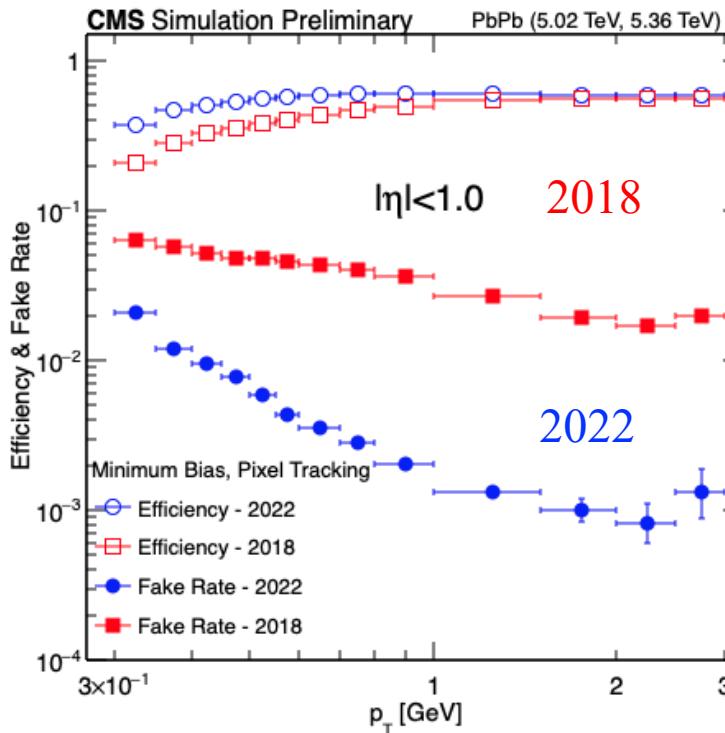


- Net-charge fluctuations differ between QGP and hadron gas phase
 - The less $|v_{dyn}|$ is, the more + and - charges are equilibrated → signature of QGP
- Dilution in rapidity during system evolution (hadronization to kinetic freeze-out) → diluting fluctuation
- Both data and MC approach to Poissonian limit for smaller acceptance
- Charge conservation and resonance contribution coupled with radial flow and/or any other effects?

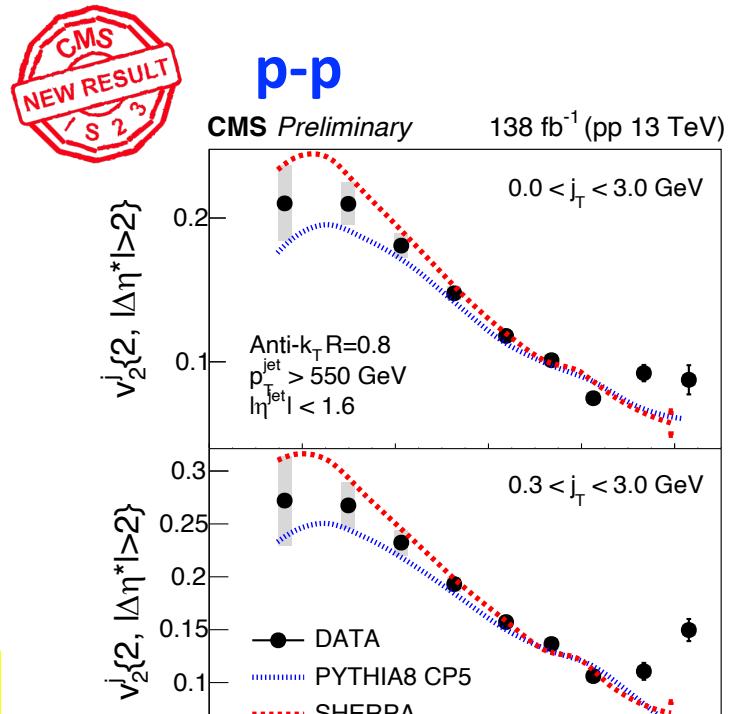
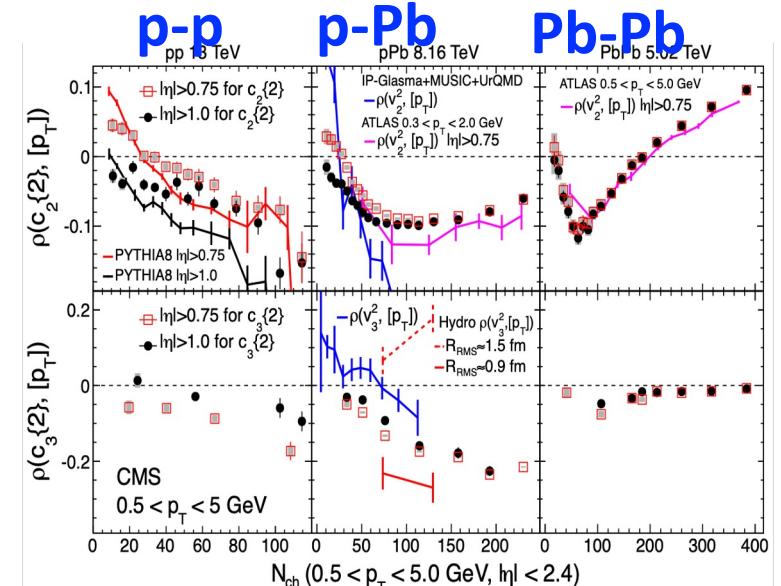
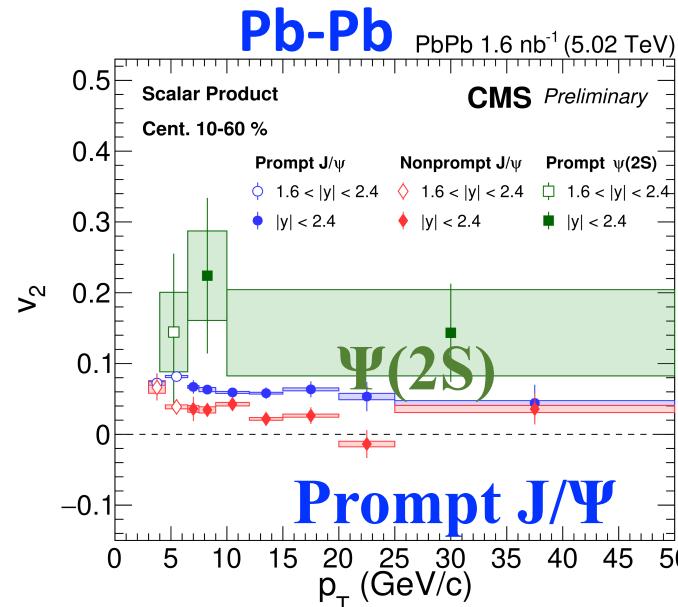
Improvement in tracking efficiency for Run3

Chosen examples

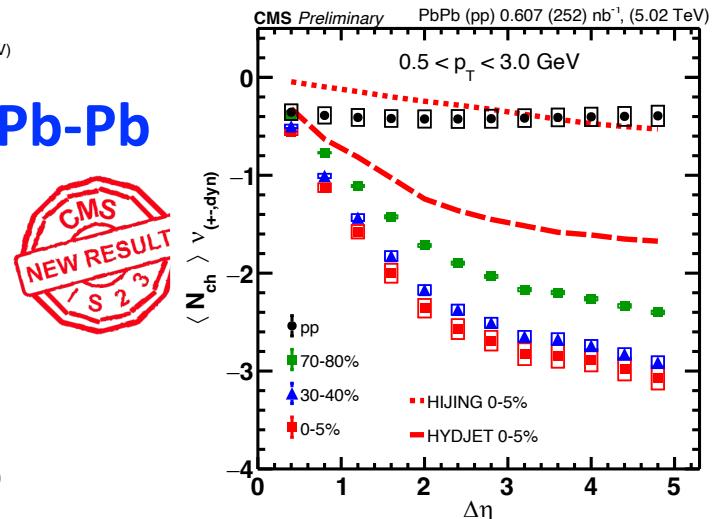
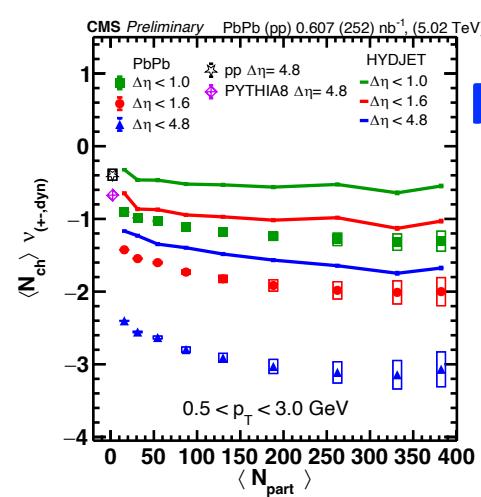
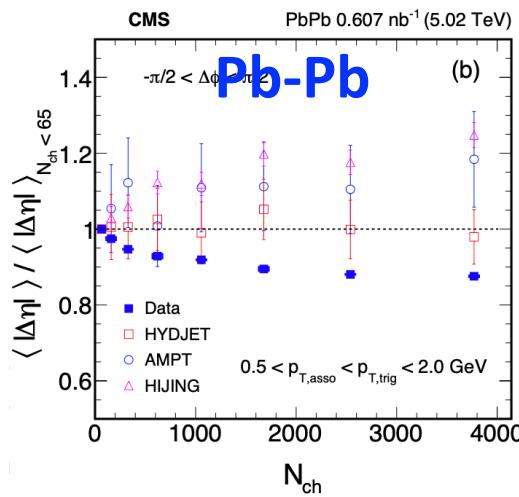
CMS-DP-2023-011



- Expected better tracking performance & lower fake rate for **Run 3!**
 - Online: increased MB trigger efficiency in peripheral events with ZDC
 - Offline: improved low- p_T tracking with the innermost pixel layer
- Expected CMS to record 25kHz of MB Pb-Pb events in **Run3**
 - An increase of ~ 3 times that of 2018



CMS has provided a wealth of very interesting measurements





CMS talk and poster at IS 2023



- ✓ Rohit Singh – Monday **19:00 (Poster)**
 - v_n and $[p_T]$ correlation
- ✓ Subash Behera - Tuesday **16:10 (Oral)**
 - Charge balance function and net-charge fluctuations
- ✓ Jiazhao Lin – Tuesday **16:50 (Oral)**
 - Coherent J/ψ in Pb-Pb UPC
- ✓ Parker Gardner – Wednesday **16:10 (Oral)**
 - Intra-jet correlation in HM p-p collisions



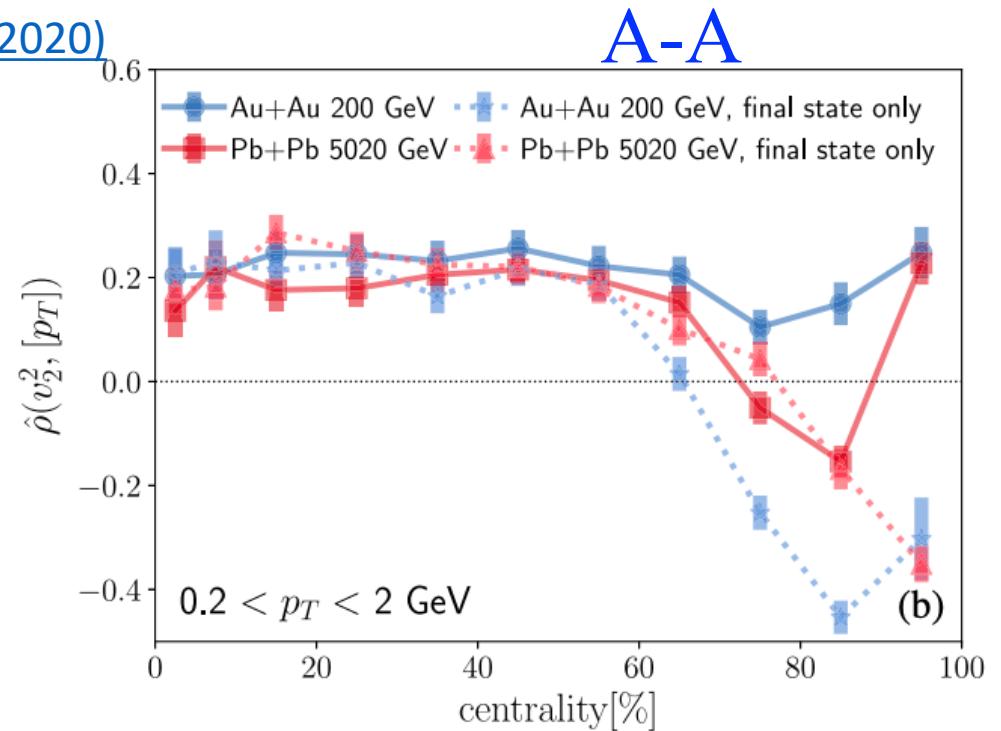
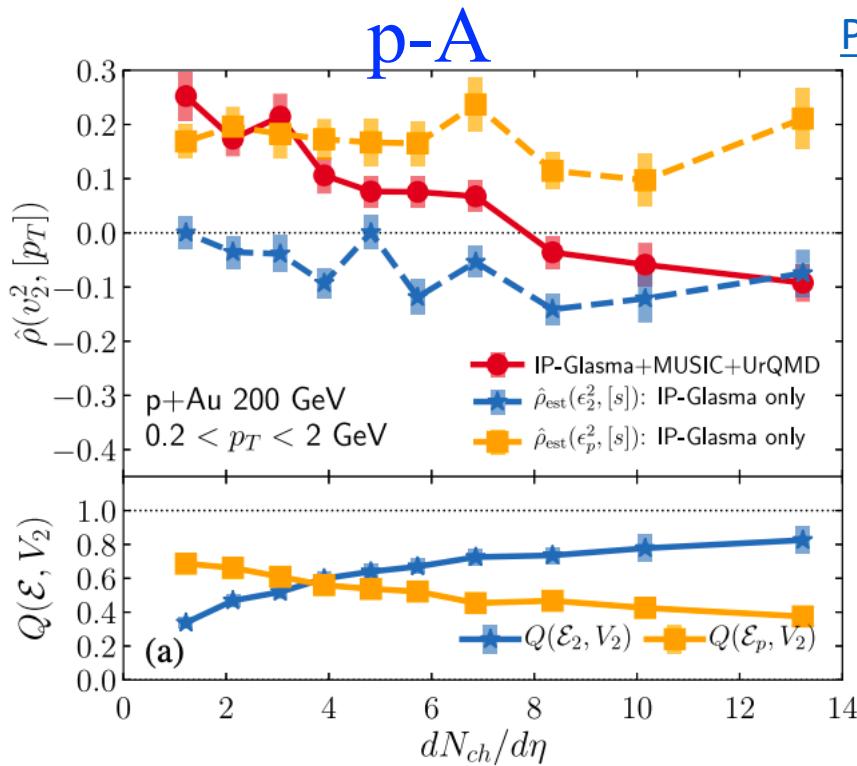
STAY TUNE FOR MORE COMING NEXT!!!

Thank you 🙏

BACK UP

Cumulant - $[p_T]$ correlations

R. Sing (Poster) @IS2023 Wed 21 (16:10)



- Correlation between v_n and $[p_T] \rightarrow$ probes fluctuations of initial density profile
- Sensitive to the degree of sub-nucleonic fluctuations
- Sensitive to the transverse size of the initial fireball
- No sign change at low multiplicity without initial v_2 from CGC