Assessing the ultra-central flow puzzle in the Bayesian era

arXiv:2203.17011

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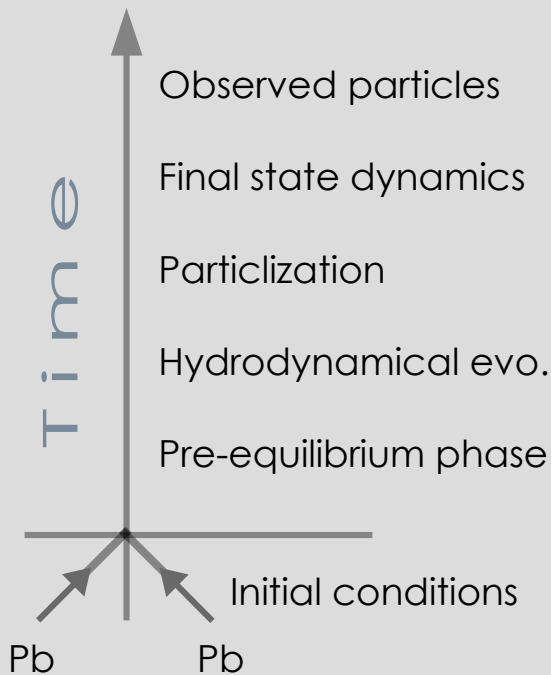Instituto de Fíisica "Gleb Wataghin" – Universidade Estadual de Campinas

In collaboration with: M.N. Ferreira, M. Hippert, D.D. Chinellato, G.S. Denicol, M. Luzum, J. Noronha, T. Nunes da Silva and J. Takahashi

[The ExTrEMe collaboration]

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Ultra-relativistic heavy-ion collisions

Currently best understood via **multi-stage hybrid hydrodynamic simulations**

Time

Observed particles

Final state dynamics

Particlization

Hydrodynamical evo.

Pre-equilibrium phase

Initial conditions

Pb   Pb

Each simulation phase has its own set of input parameters

Potentially **large parameter space constrained** by means of Bayesian analysis

Each Bayesian analysis is **unique**

Different initial conditions, free-streaming time, transport coefficients, out-of-eq. corrections to particlization, collision system(s), collision energie(s) & **exp. data**

Ex: bulk viscosity from Bayesian analysis

Legend:
- Duke
- JETSCAPE Grad
- Trajectum 1
- Trajectum 2

ζ/s vs T [GeV]
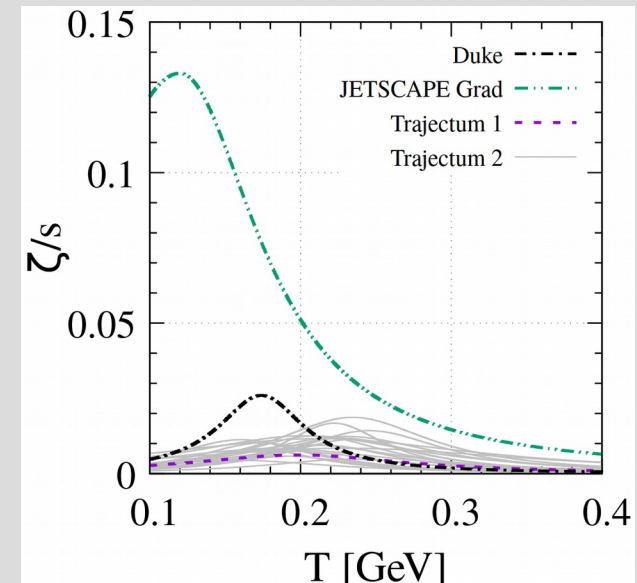
Simulations **fail to explain** anisotropic flow data @ ultra-central collisions **since** ~ 2012 – 2013

CMS PAS HIN-12-011, Luzum, Ollitrault, NPA 904-905 377c (2013); S. Chatrchyan et al. [CMS], JHEP 02, 088 (2014); M. Aaboud et al. [ATLAS], JHEP 01, 051 (2020)

Selected Bayesian analysis & goal

Duke:
p+Pb @ 5.02 TeV
Pb+Pb @ 5.02 TeV
Moreland, Bernhard, Bass, PRC 101, no.2, 024911(2020)
Run using MAP values

JETSCAPE Grad:
Pb+Pb @ 2.76 TeV
Au+Au @ 0.2 TeV
Everett et al.[JETSCAPE], PRL 126, no.24, 242301 (2021) Phys. Rev. C 103, no.5, 054904 (2021)
Run using MAP values

"Trajectum 1":
Pb+Pb @ 2.76 TeV & 5.02 TeV
p+Pb @ 5.02 TeV
Nijs, van der Schee, Gürsoy, Snellings, PRC 103, no.5, 054909 (2021); Phys. Rev. Lett. 126, no.20, 202301 (2021)
Run using MAP values

"Trajectum 2":
Same Pb+Pb data from Trajectum 1
G. Nijs and W. van der Schee, arXiv:2110.13153
Run using 20 random posterior samples

All **data** considered come **from typical centralities**
[0 – 5% centrality bin is the narrower bin included]

Good overall agreement w/ non-ultra-central data for anisotropic flow coefficient + **hint of deviations for $\lesssim$ 1%-2%** →

Decade-long ultra-central flow puzzle: inability of a **simultaneous description of $v_n\{2\}$ @ ulta-central collisions**

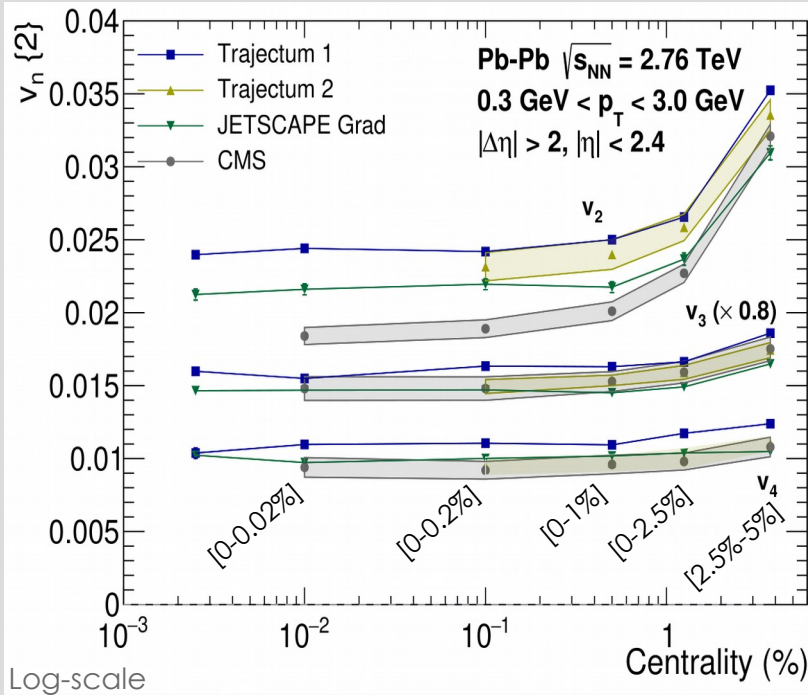[$v_2\{2\}$ ($v_3\{2\}$) too large (small) – or both]

Luzum, Ollitrault, NPA 904-905 377c (2013); S. Chatrchyan et al. [CMS], JHEP 02, 088 (2014); M. Aaboud et al. [ATLAS], JHEP 01, 051 (2020)

Goal: **determine whether modern Bayesian-tuned models have the same pathology as previous models for ultra-central collisions**
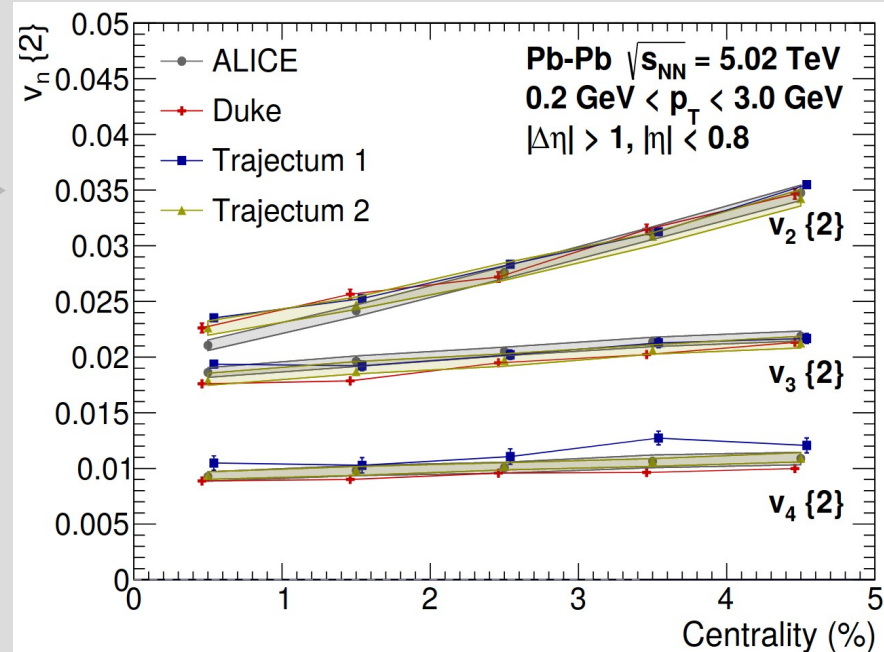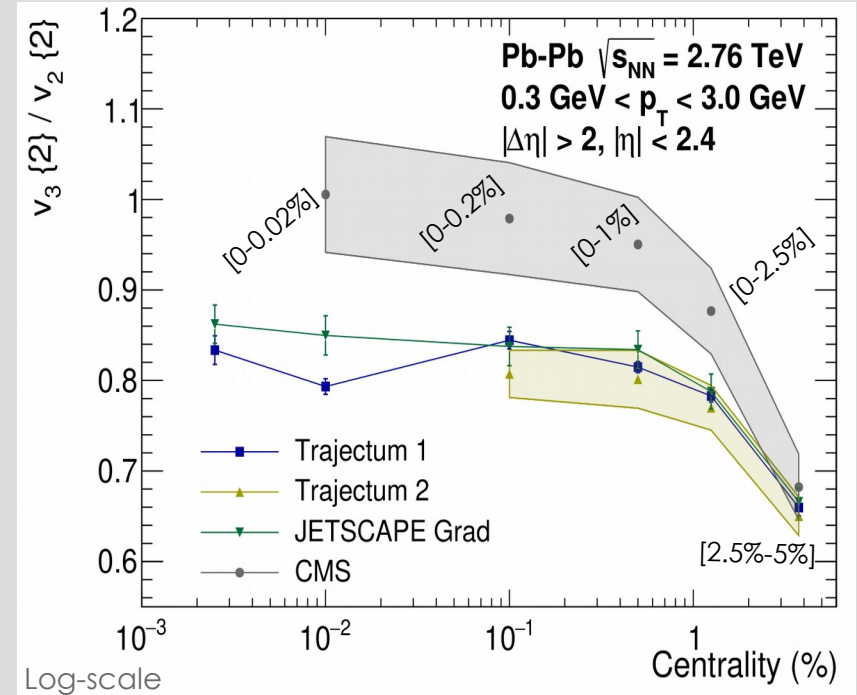
Bayesian analysis meets ultra-central anisotropic flow data

[0-1% of the total cross-section]

Measured **v₂{2} decreases** with centrality while **simulations become ~ constant!**

Similar behavior found in older calculations before "Bayesian era"

All Bayesian constrained models tested fail in the same way even after including the full posterior predictive distribution **[Trajectum 2]**

[Assumed uncorrelated errors for CMS points]

Conclusions

Overall data on anisotropic flow harmonics is **better understood** after Bayesian analysis

Centrality dependence of $v_2\{2\}$: **qualitatively different** trend in models w.r.t. data @ ultra-central regime in all models considered

Same **pathology seen in old calculations is present** in Bayesian constrained models!

Ultra-central flow puzzle: still an open problem!

Unlikely to be solved by another round of fine-tuning of input parameters!

Simultaneous description of ultra-central data + keep current agreement to non-central data? Might not be possible.
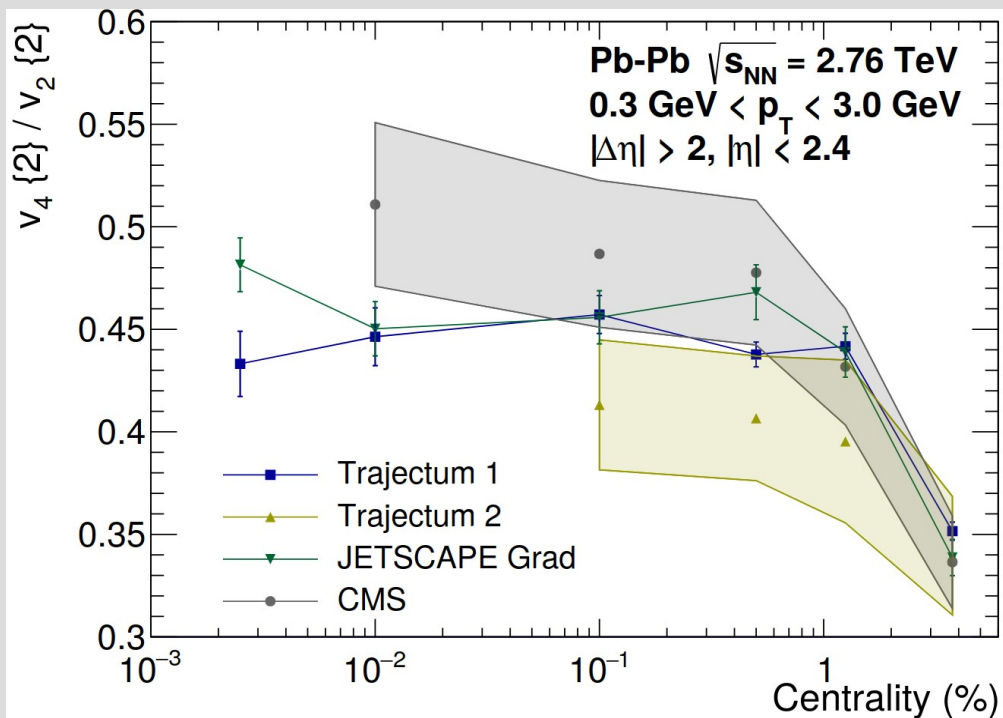
Understanding this puzzle:

Potential physics insight;
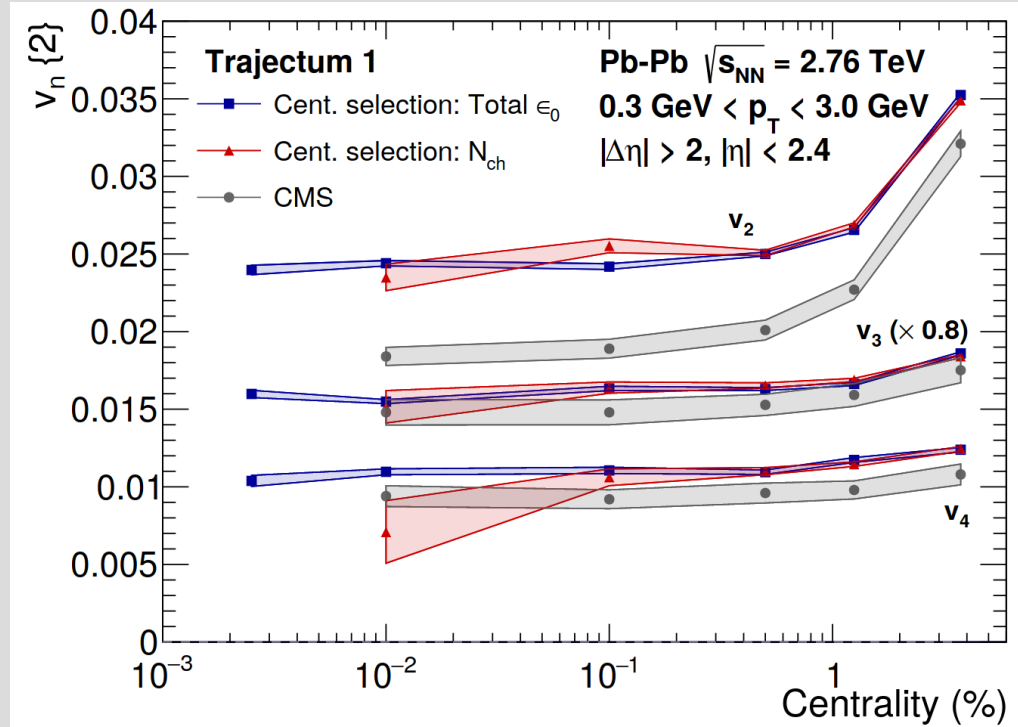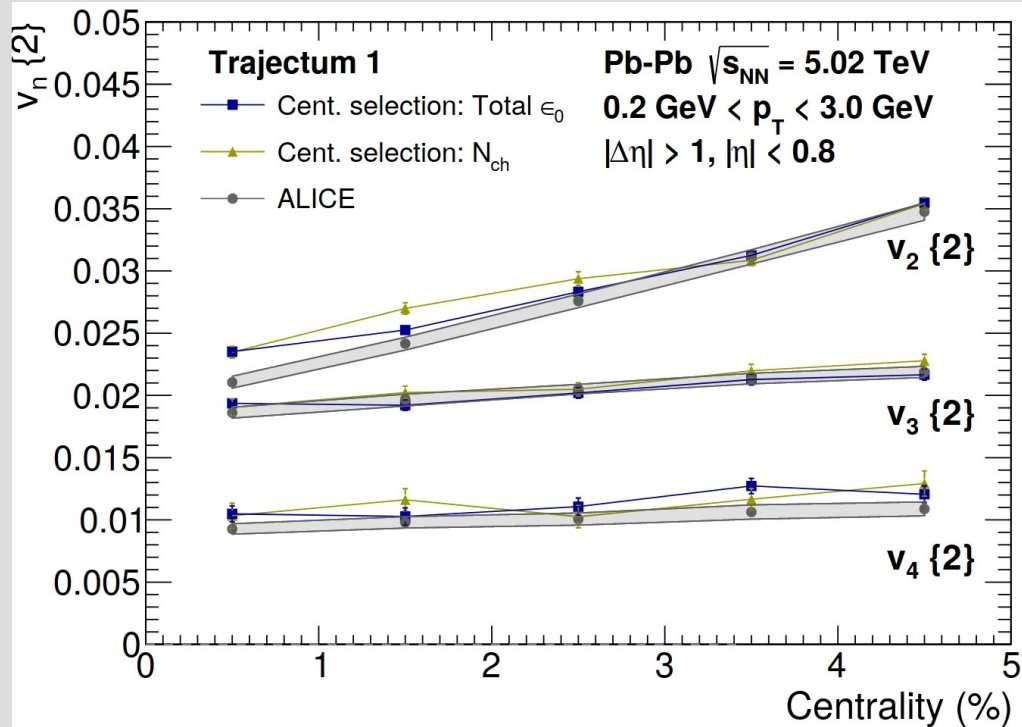
Allow for **more confidence** in simulation results;

Better precise determinations of system properties in future Bayesian analyses.
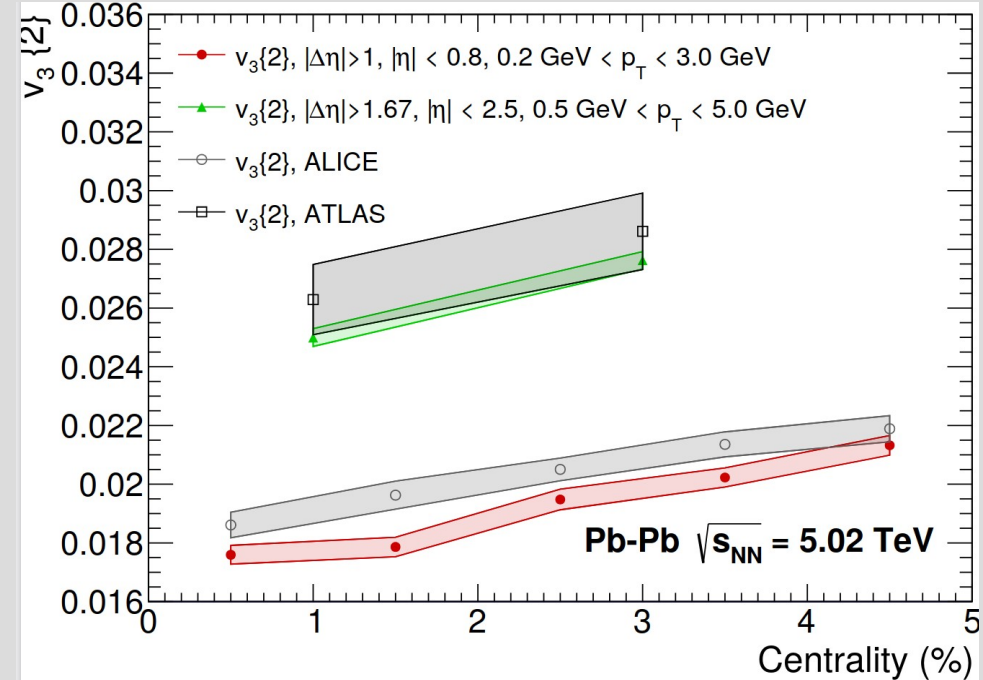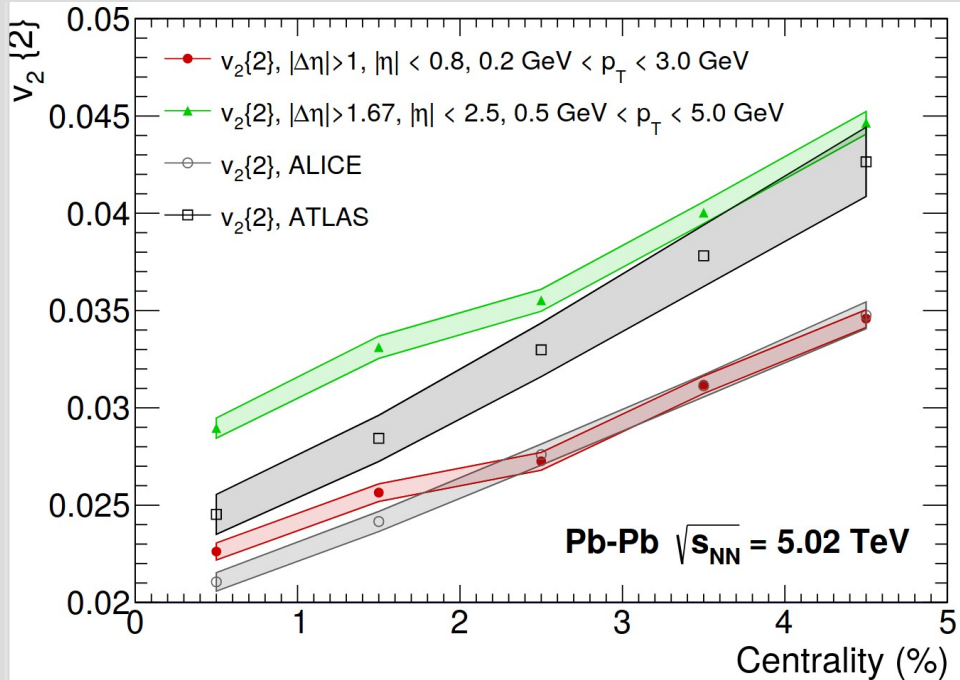
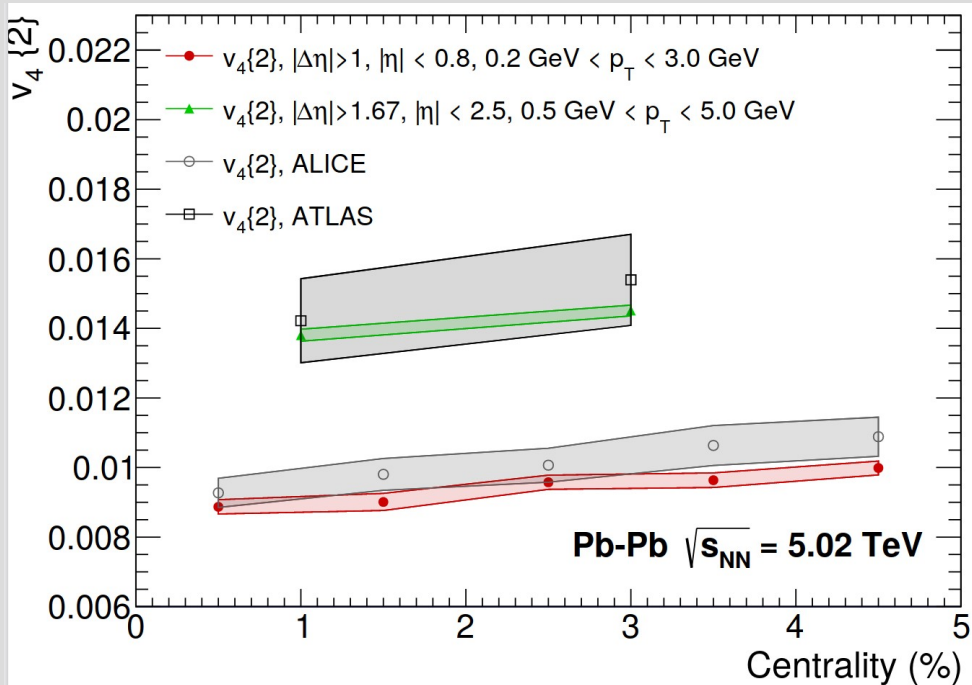# Backup slides

Other $v_n\{2\}/v_m\{2\}$ ratios
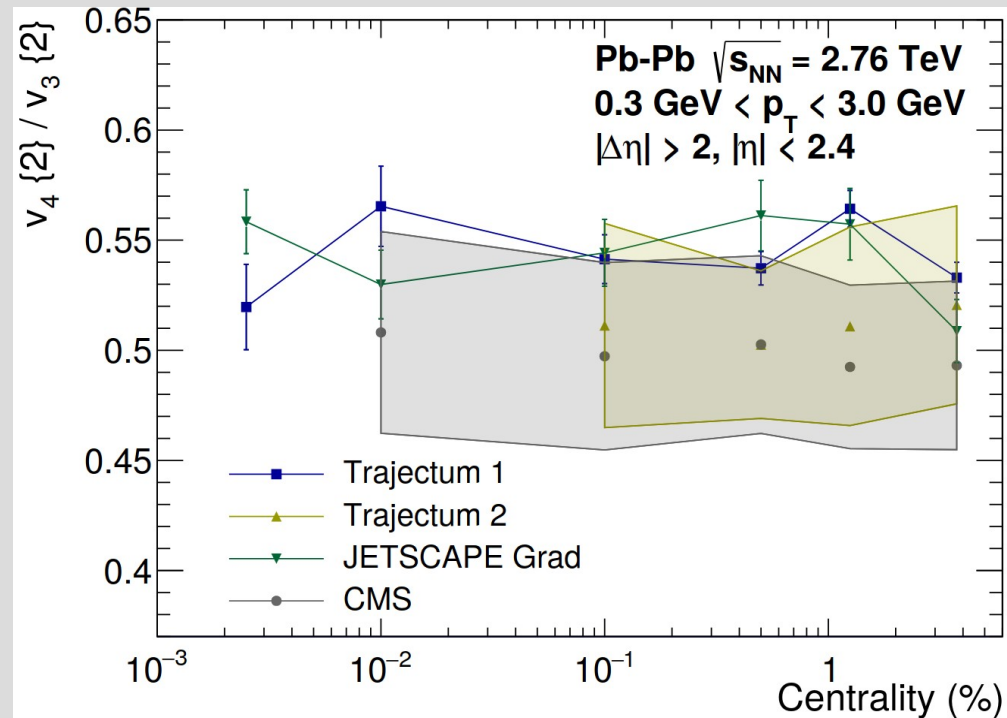
Effect of centrality selection: Total initial energy vs N_{ch}

Other comparisons to anisotropic flow @ 5.02 TeV

Other comparisons to anisotropic flow @ 5.02 TeV

Shear and bulk viscosities from Bayesian analysis