Identified and strange hadron production and flow in $O + O$ collisions at $\sqrt{s_{NN}} = 7$ TeV using various models

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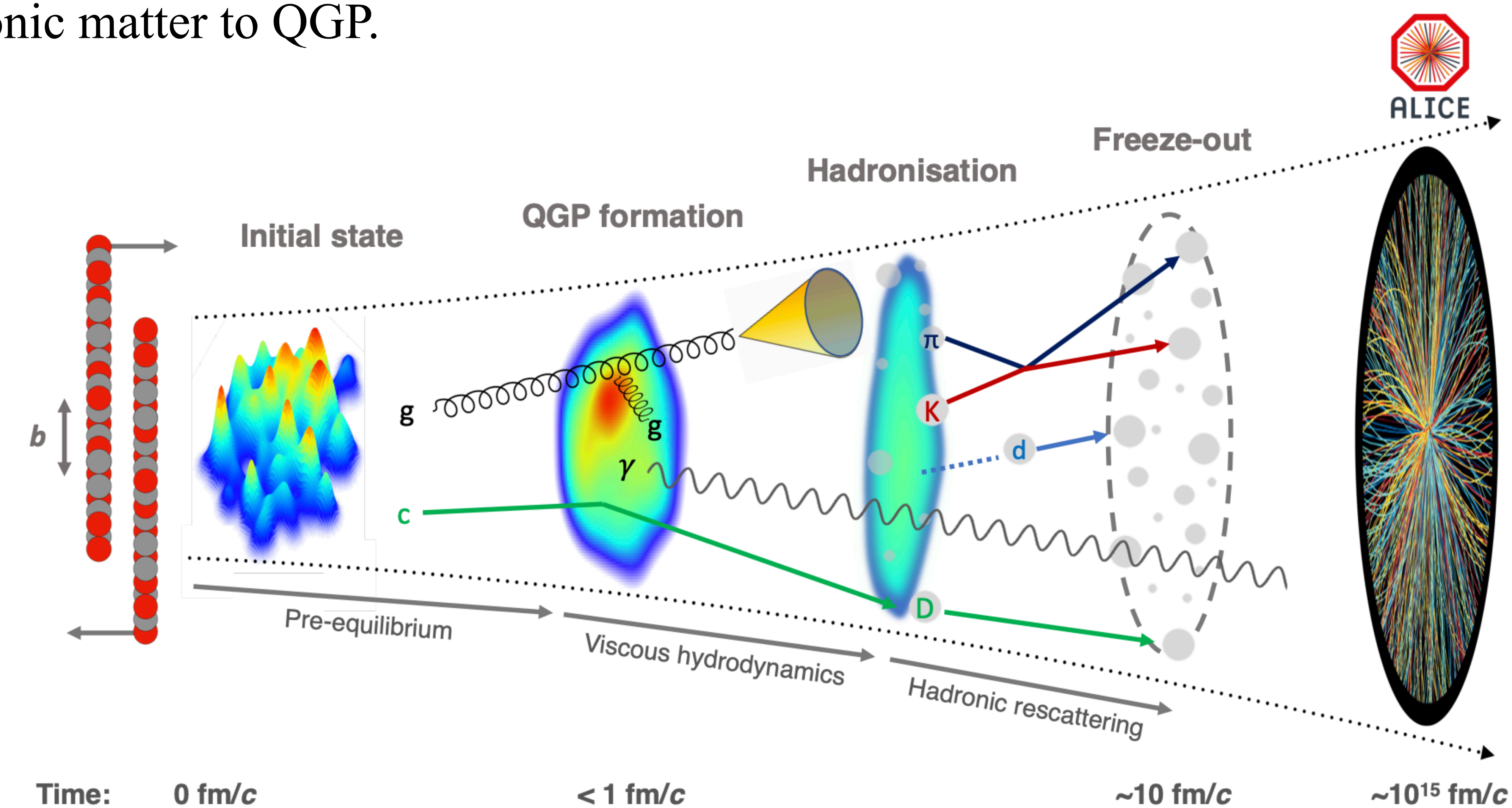
Outline

- Introduction: Heavy-Ion Collisions
- Motivation
- Models: EPOS4 and AMPT
- Results:
    - Charge Particle Multiplicity
    - p_T -Spectra
    - Integrated Yield (dN/dy) and $\langle p_T \rangle$
    - Ratios
    - Anisotropic flow (v_2, v_3 and v_4)
- Summary

Introduction: Heavy Ion Collisions

- ***What are Heavy-Ion Collisions?***
  High-energy collisions between nuclei to create conditions similar to those just after the Big Bang.
- ***Objective*: To study the Quark-Gluon Plasma (QGP), a state of matter where quarks and gluons are deconfined.
- ***Importance*: Helps understand the strong interaction (QCD) and the phase transition from hadronic matter to QGP.



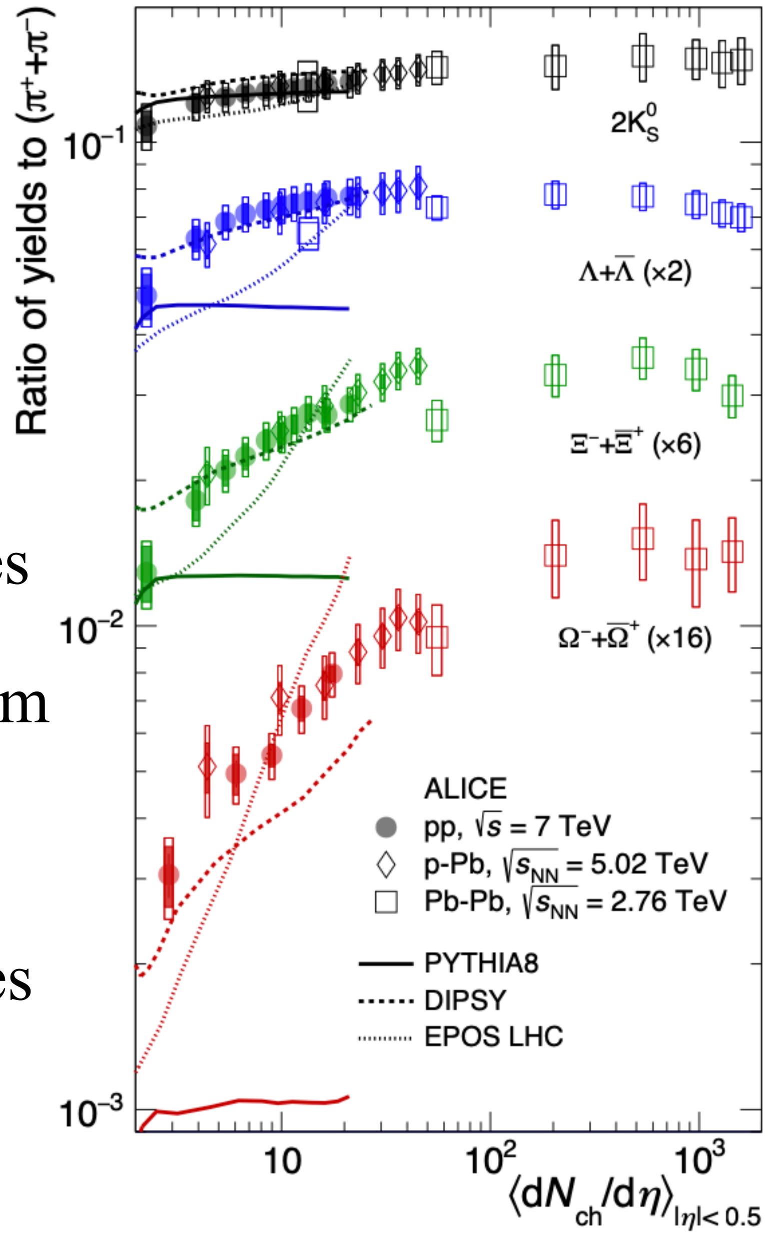
The evolution of a heavy-ion collision at LHC energies

S. Acharya et al., ALICE, Eur. Phys. J. C 84 (2024)

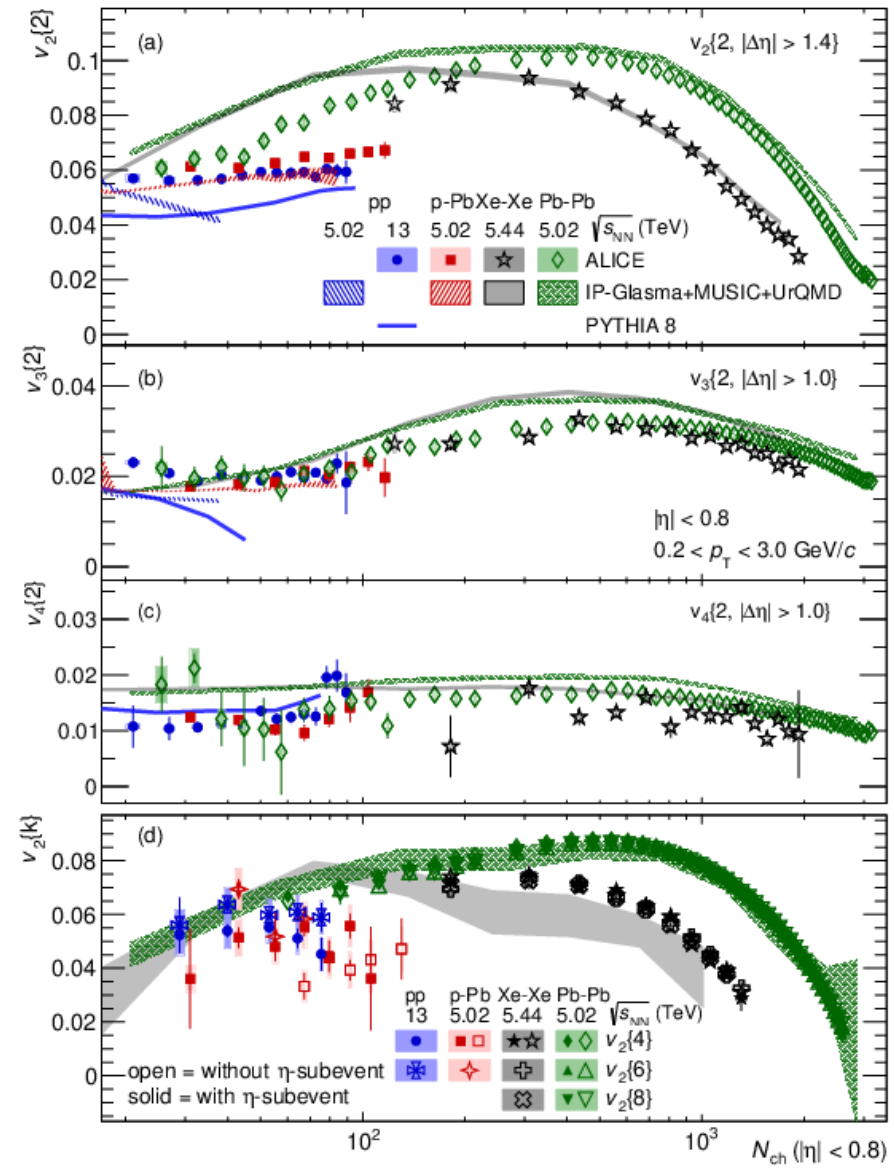
Motivation

- Small systems exhibit similar behavior as that of Large systems at LHC — **collectivity in small systems?**
    - Strangeness enhancement
    - Anisotropic flow

- $O + O$ **Collisions**:
    - Charged particle multiplicities
    - Particle production mechanism
    - Particle ratios
    - Multiplicity range that bridges pp/p–Pb and Pb–Pb/Xe–Xe



Nature Phys **13**, 535–539, ALICE, 2017

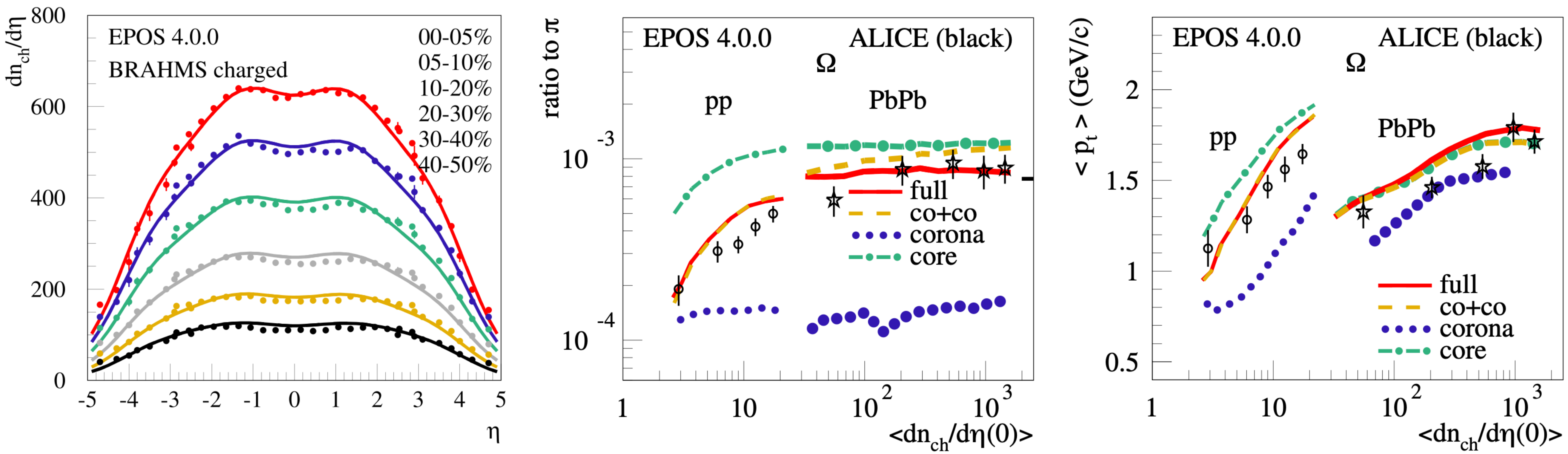


S. Acharya et al., ALICE, Phys. Rev. C, 123, 142301 (2019)

- $O + O$ collisions can provide significant and timely opportunity to explore these effects

Models: EPOS4

- EPOS4: a multi-purpose event generator, based on parton-based Gribov-Regge Theory, using relativistic hydrodynamic simulation to mimic the fluid behaviour of the QGP.
  - uses a unique approach to treat ALL systems ($e^+ + e^-$, $e^- + p$, $p + p$, $p + A$, $A + A$)
  - scattering approach, including parton saturation effects
    - secondary interactions based on a core-corona separation
  - Hadrons and fluid, expands using viscous hydrodynamical, with final-state hadronic cascades
  - Reproduces naturally many flow-like features (even in small systems)
- We generated approximately ~1.5 Millions events using full options of EPOS4

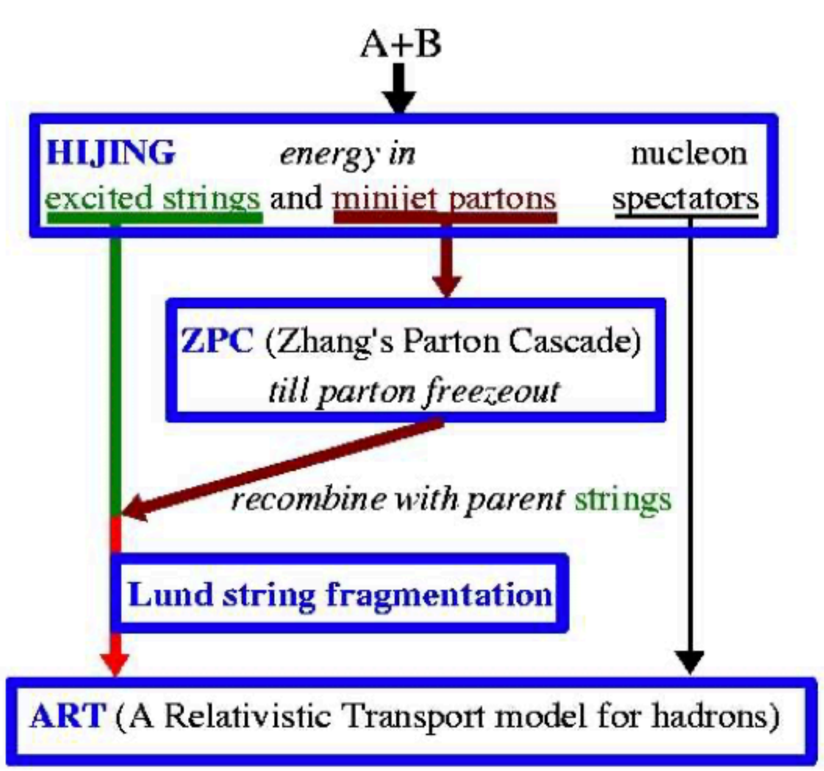


K. Werner et al., Phys. Rep. 350 , 93 (2001)
K. Werner, Phys. Rev. C 108, 064903 (2023)
https://journals.aps.org/prc/pdf/10.1103/PhysRevC.109.034918
https://indico.in2p3.fr/event/26074/contributions/112639/attachments/71952/102635/Tuto_EPOS_RIVET-(HIC_School-2022).pdf

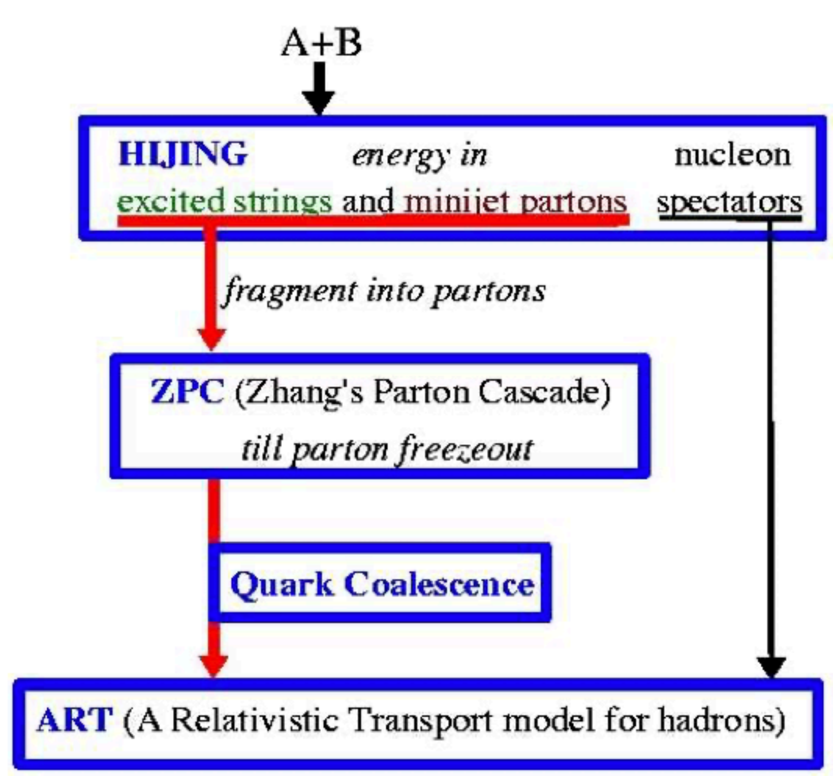
Models: AMPT

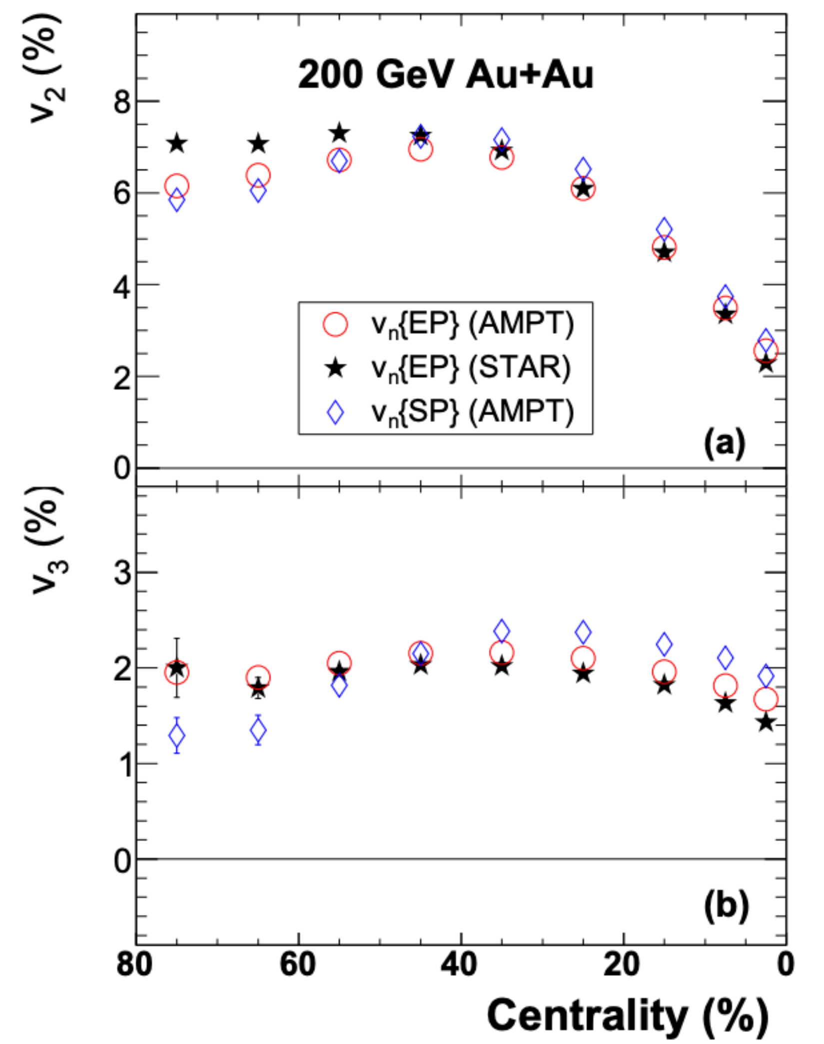
- **AMPT (A Multi-Phase Transport Model)** is a Monte Carlo transport model for pp and heavy ion collisions.
- Includes both initial partonic and final hadronic interactions, and the transition between these two phases of matter.
- We generated approximately 2.5 Millions events for both default and String Melting version of AMPT.

Default



String Melting



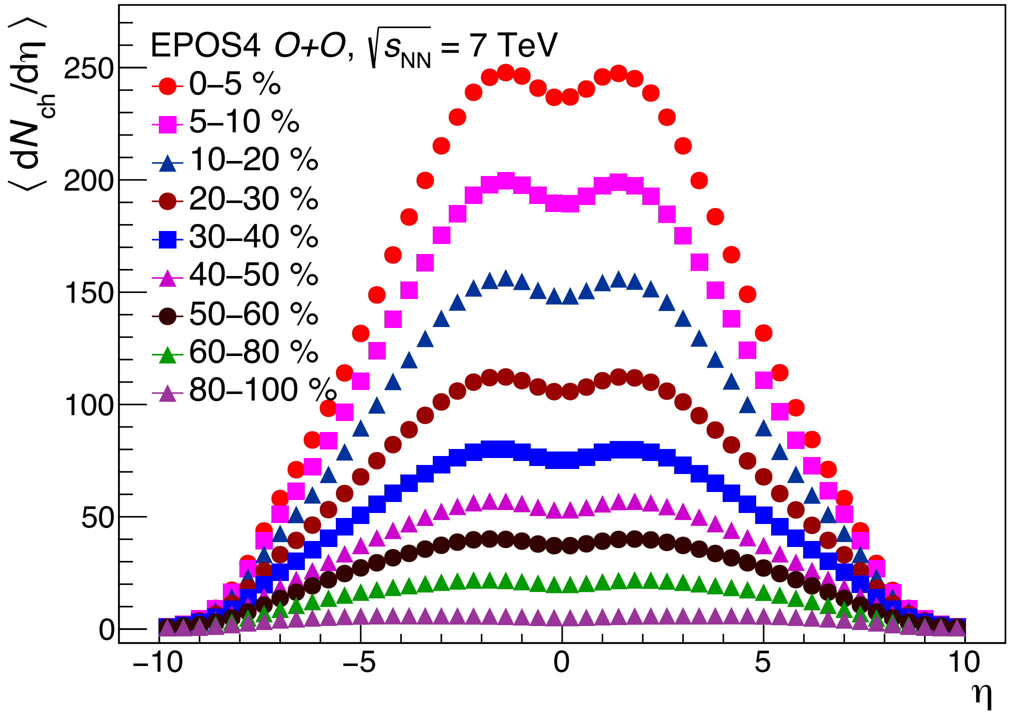


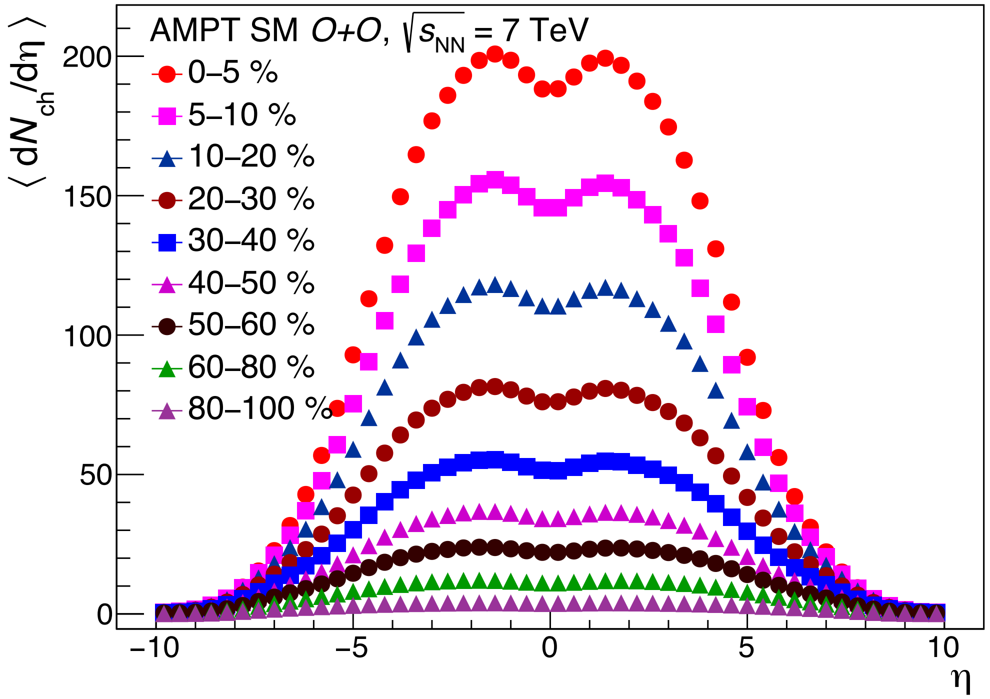
Z. W. Lin et al., Phys. Rev. C 72, 064901, 2005
https://indico.bnl.gov/event/4773/contributions/26332/attachments/21597/29571/AMPT_final.pdf

S. Choudhury et al., , Eur. Phys. J. C 80, 383 (2020)

Results

Charged particle multiplicity distributions for EPOS4 and AMPT





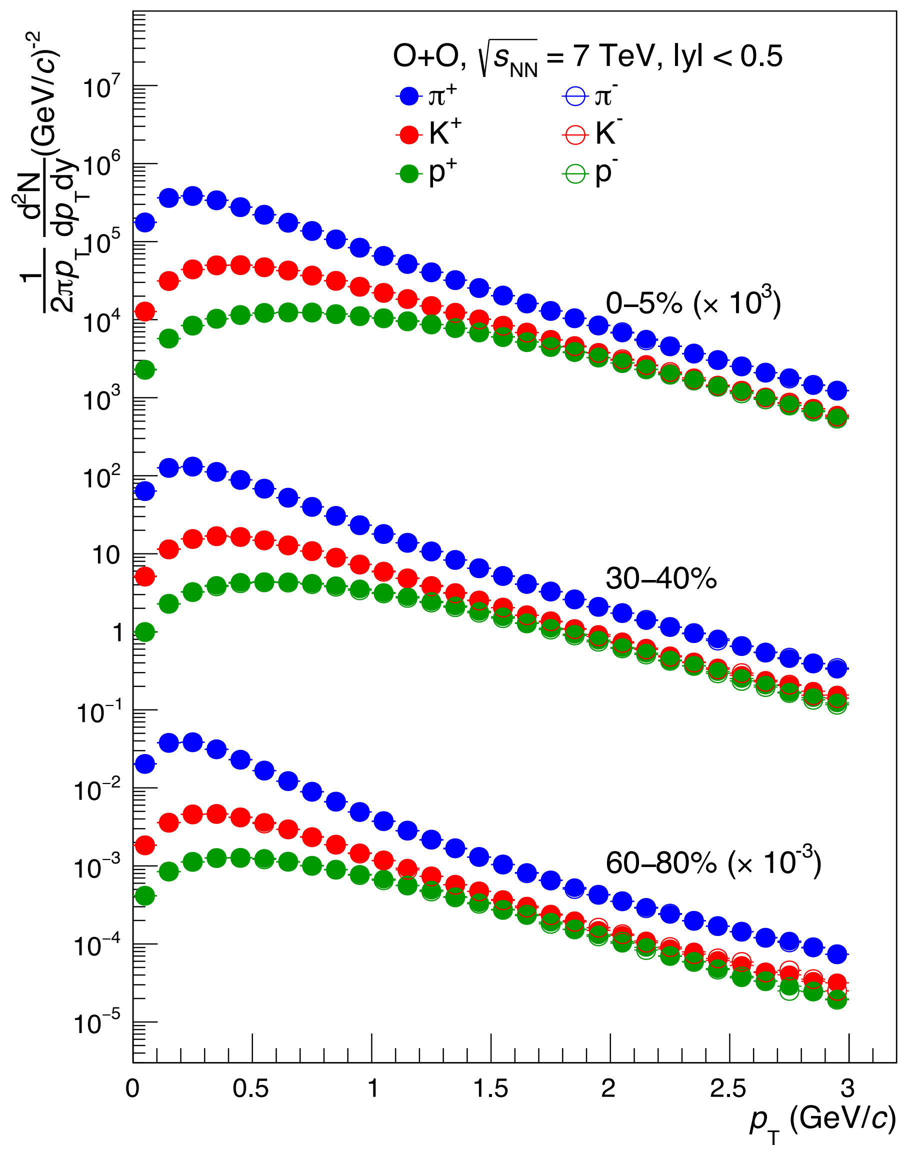
- Pseudorapidity distributions
- Centrality classes: Reference multiplicity ($|\eta| < 0.5$)

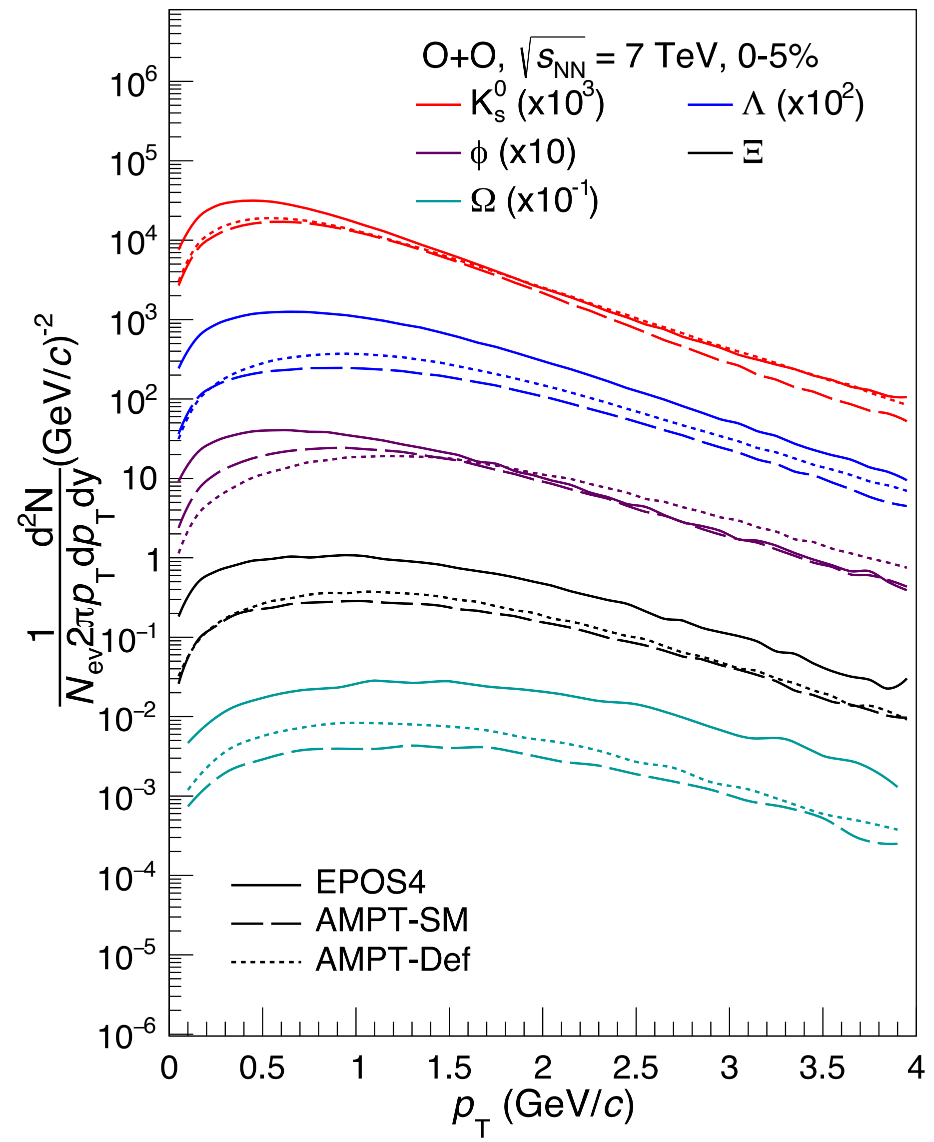
Centrality (%)	EPOS		AMPT SM	
	$dN_{ch}/d\eta$	$\langle N_{part}\rangle \pm$ rms	$dN_{ch}/d\eta$	$\langle N_{part}\rangle \pm$ rms
0 – 5	236.44 ± 0.14	27.86 ± 2.18	188.293 ± 0.043	29.00 ± 2.03
5 – 10	189.801 ± 0.13	25.05 ± 2.33	145.678 ± 0.038	26.78 ± 2.60
10 – 20	148.437 ± 0.08	21.44 ± 3.15	110.442 ± 0.023	23.24 ± 3.24
20 – 30	105.863 ± 0.07	16.87 ± 3.12	76.0851 ± 0.019	18.54 ± 3.26
30 – 40	75.027 ± 0.06	12.44 ± 2.56	51.4713 ± 0.016	14.33 ± 3.05
40 – 50	53.037 ± 0.05	9.60 ± 2.52	34.1878 ± 0.013	10.80 ± 2.75
50 – 60	37.146 ± 0.06	6.98 ± 2.3	22.0823 ± 0.010	7.99 ± 2.40
60 – 80	19.889 ± 0.02	4.49 ± 1.96	11.1169 ± 0.005	4.94 ± 2.00
80 – 100	5.127 ± 0.01	1.89 ± 1.53	3.76107 ± 0.003	2.63 ± 1.03

M. U. Ashraf et al., arXiv:2402.13843, 2024
M. U. Ashraf, J. Singh et al., arXiv:2406.04096, 2024

Transverse momentum (p_T) spectra at mid rapidity

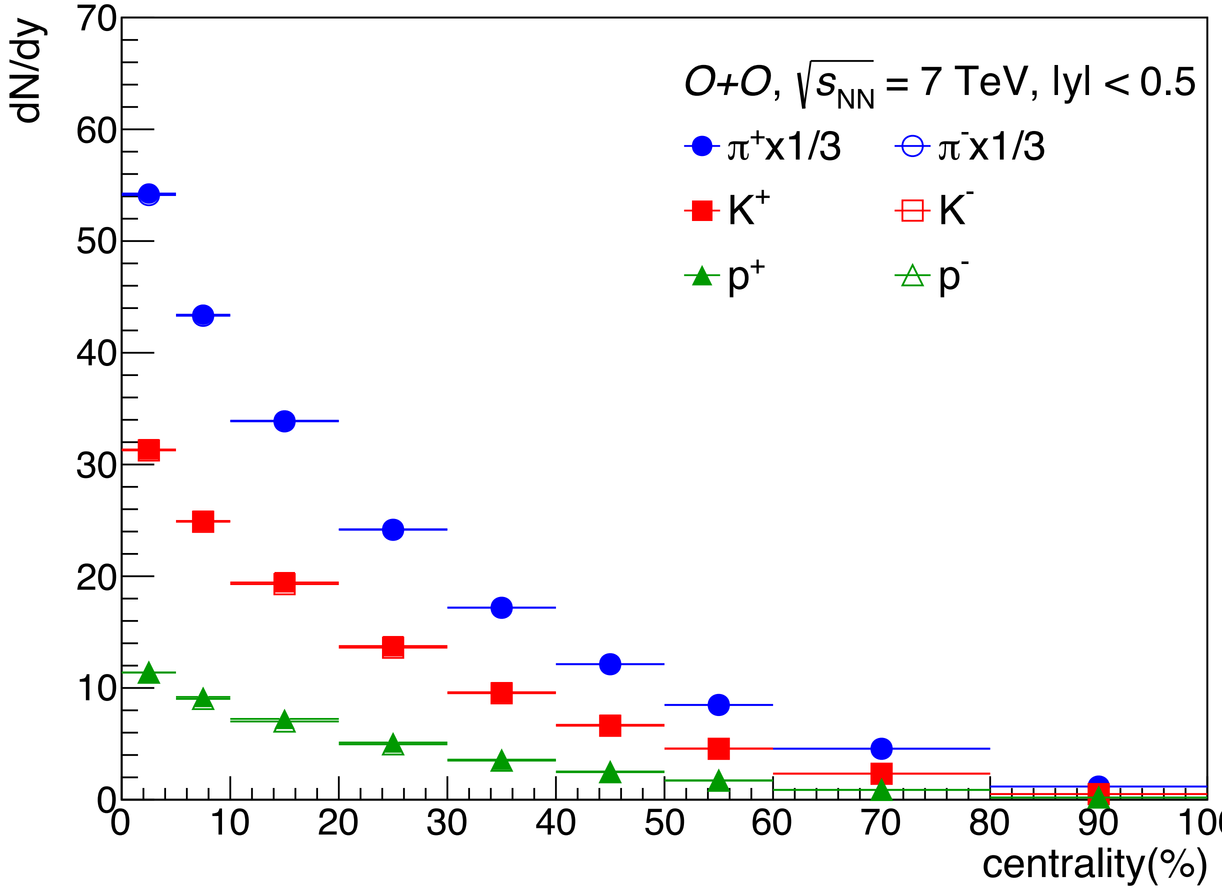
- Pions: lightest hadrons - most abundance
- Low-p_T : Mass-dependent behavior (identified);
- Suppressed production of ϕ compared to Λ, clear violation of mass ordering
- Intermediate-p_T: Spectra converges; due to radial flow effects
- Steeper slope: heavy particles

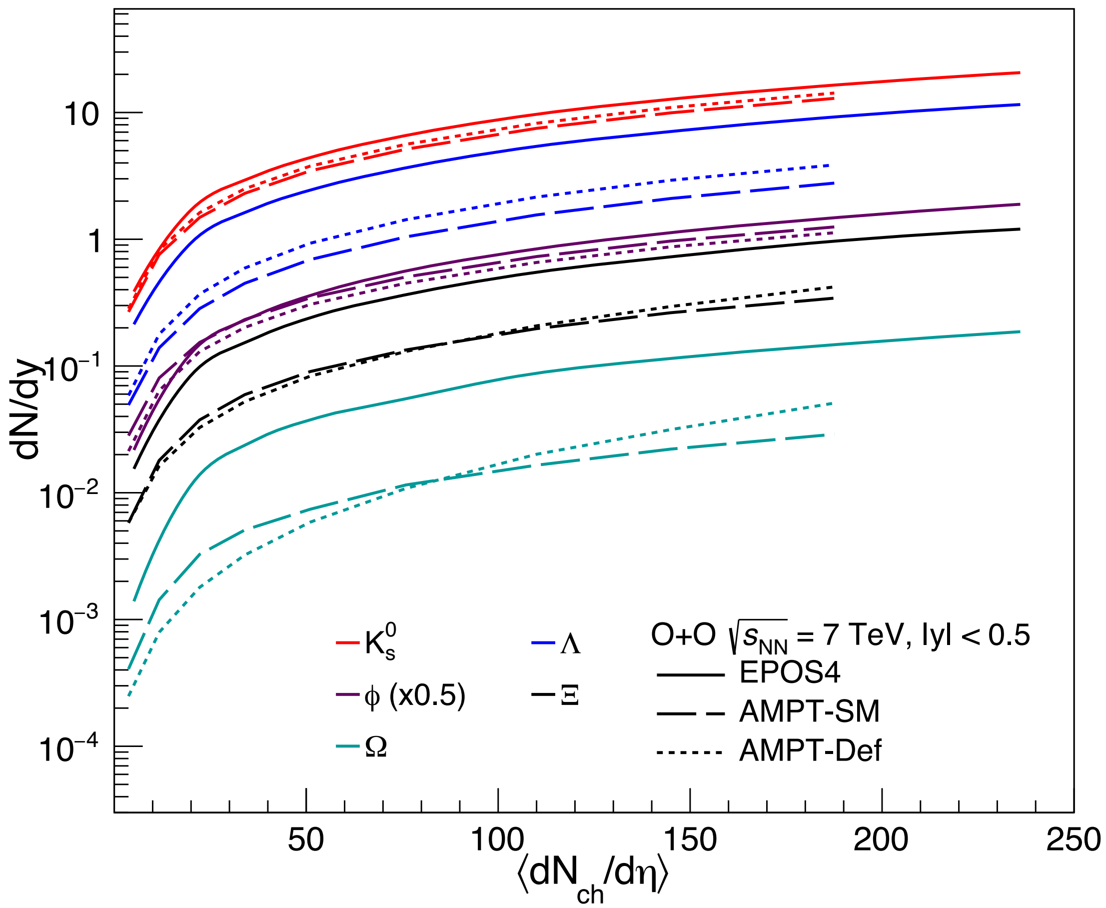




M. U. Ashraf et al., arXiv:2402.13843, 2024
M. U. Ashraf, J. Singh et al., arXiv:2406.04096, 2024

Integrated Yield (dN/dy)

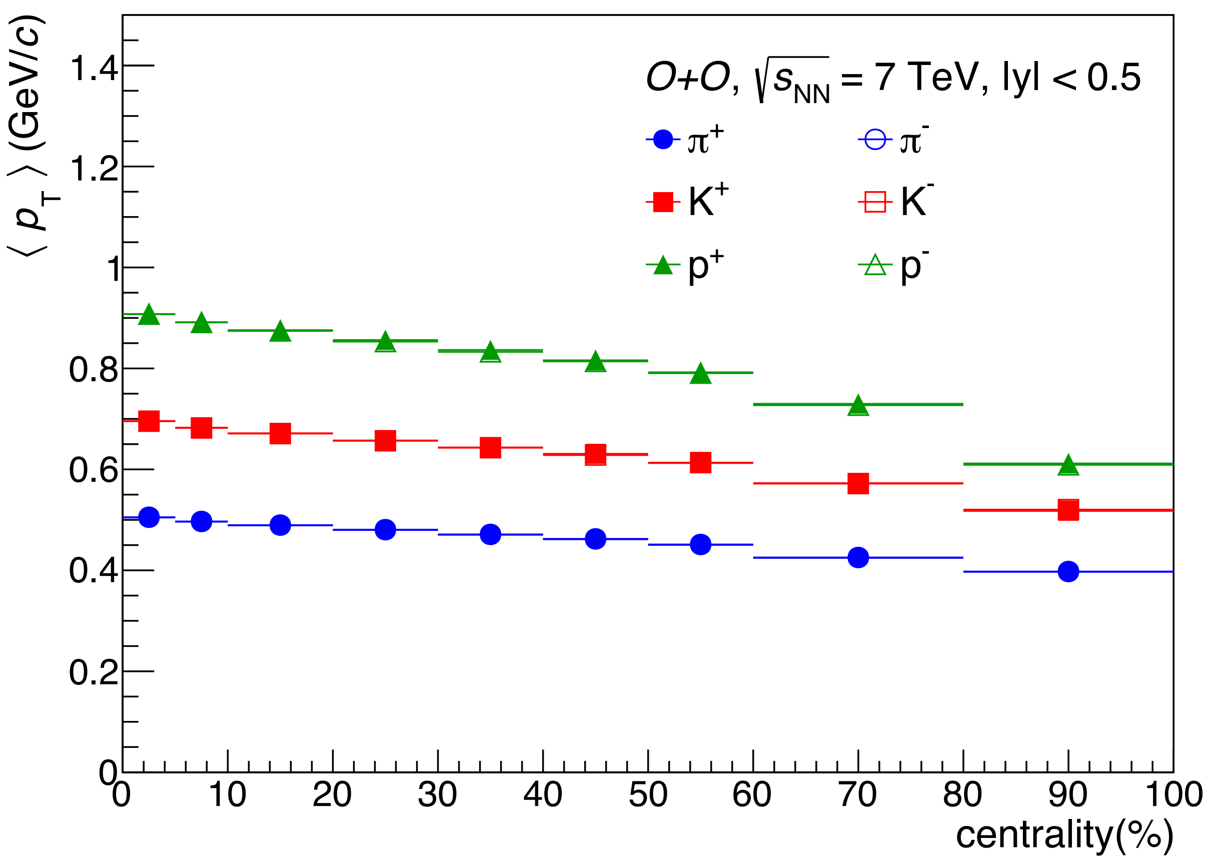


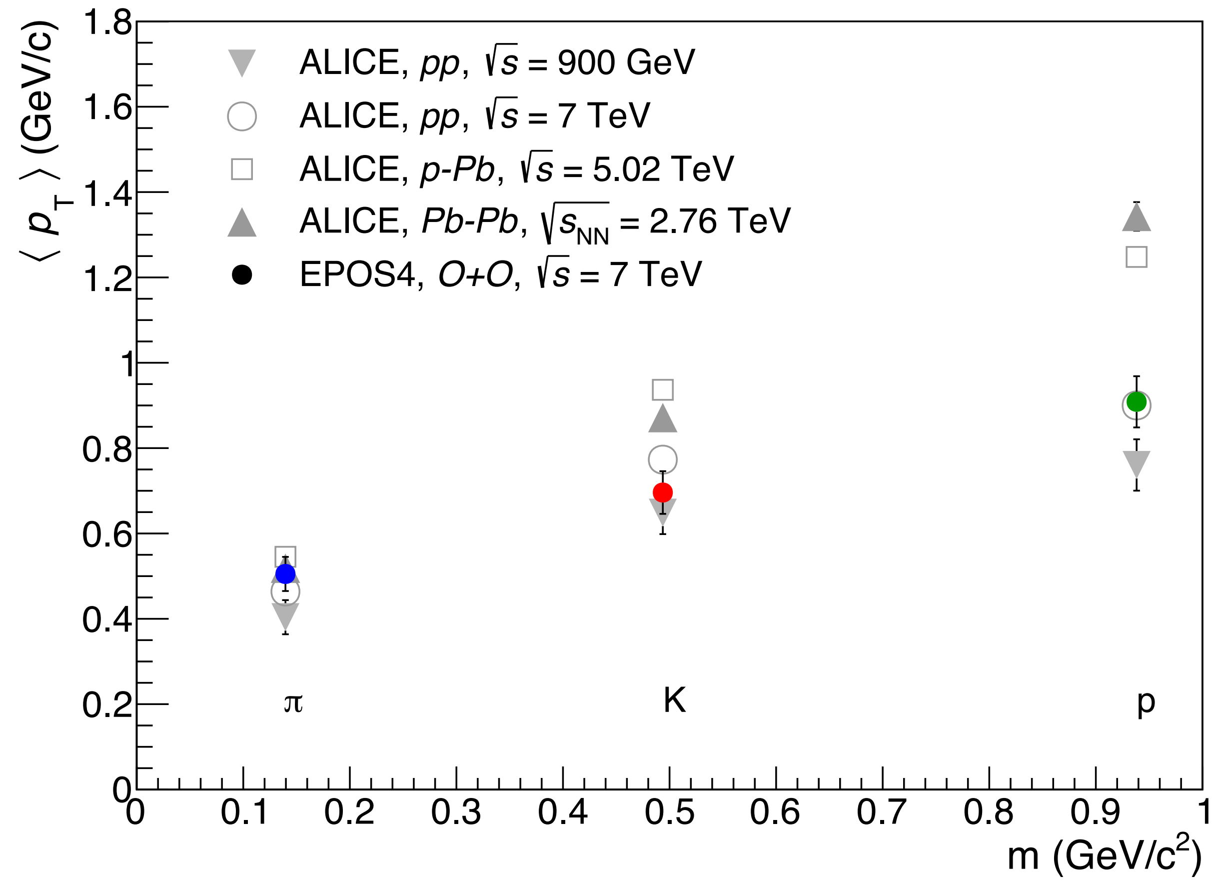


- Integrated Yield (dN/dy): Increasing with increasing $\langle dN_{ch}/d\eta \rangle$
- Abundance of Pions: aligns with the predictions of thermalized Boltzmann production of secondary particles
- Strangeness: Yield decreases with increasing number of strange quark
- EPOS4 > AMPT-SM (AMPT-Def)

M. U. Ashraf et al., arXiv:2402.13843, 2024
M. U. Ashraf, J. Singh et al., arXiv:2406.04096, 2024

Mean transverse momentum ($\langle p_T \rangle$)





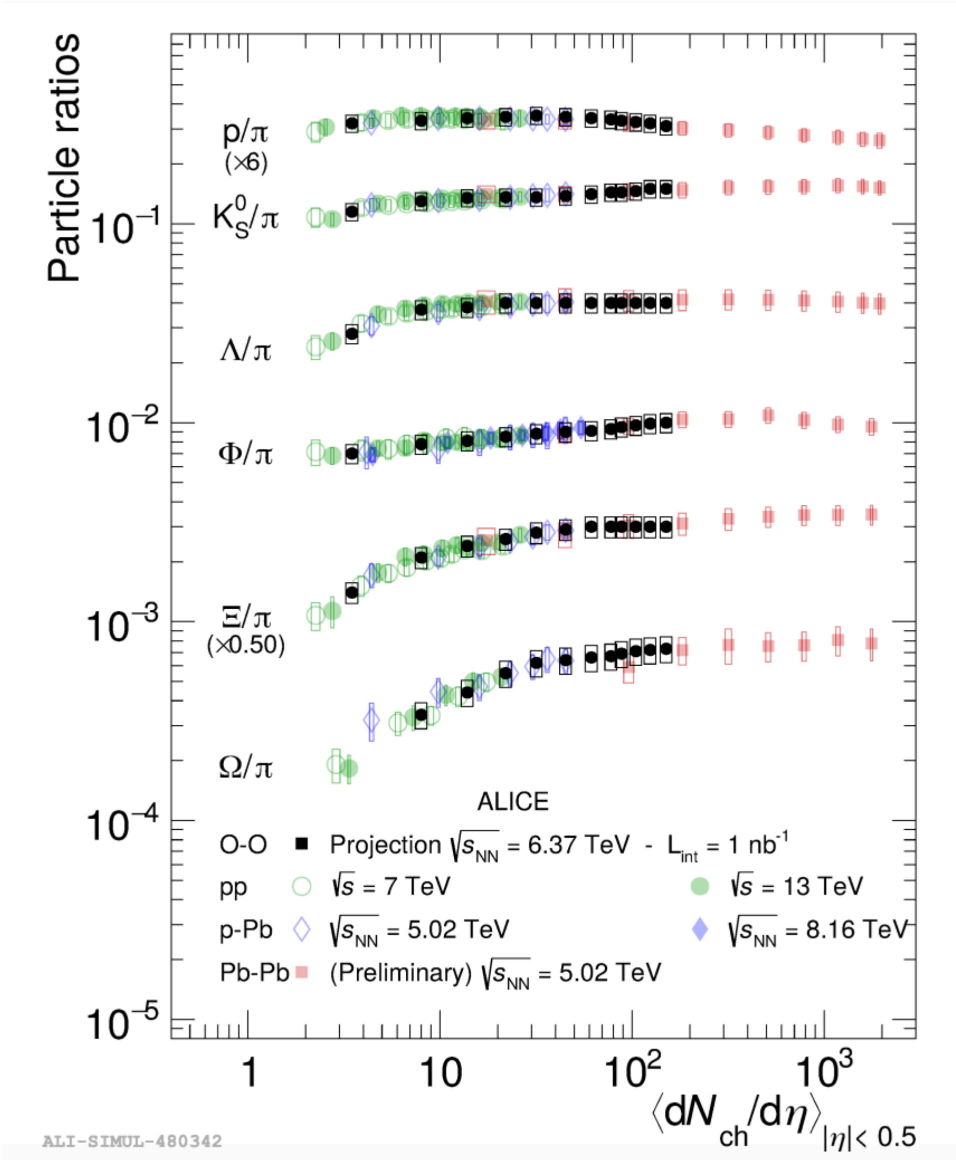
- $\langle p_T \rangle$: Increases with mass

- Increasing trend in $\langle p_T \rangle$
  - peripheral to central
  - increase in radial flow

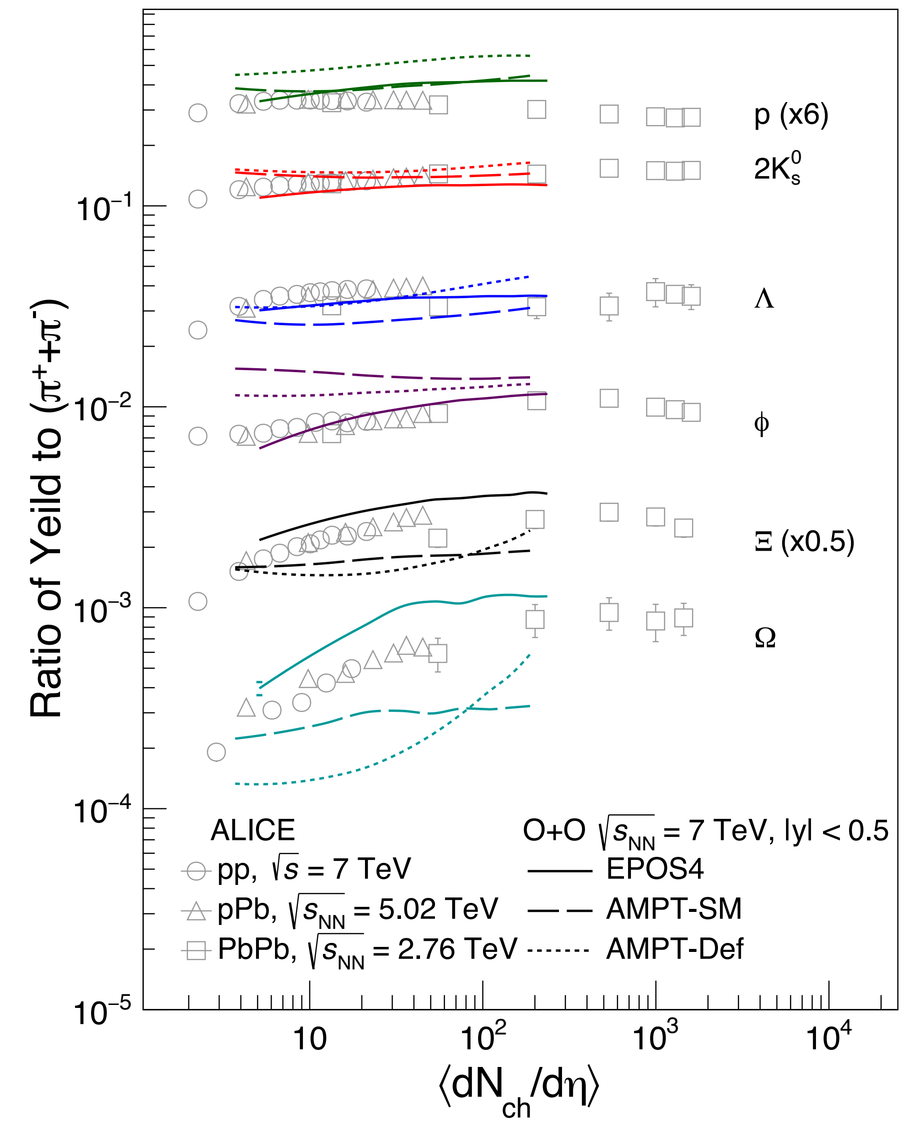
- Increasing $\langle p_T \rangle$ with increasing center-of-mass energy
- $O + O$ collisions follow the trend

M. U. Ashraf et al., arXiv:2402.13843, 2024

Measurements of ratios to pions



ALICE physics projections for a short oxygen-beam run at the LHC, ALICE, 2021



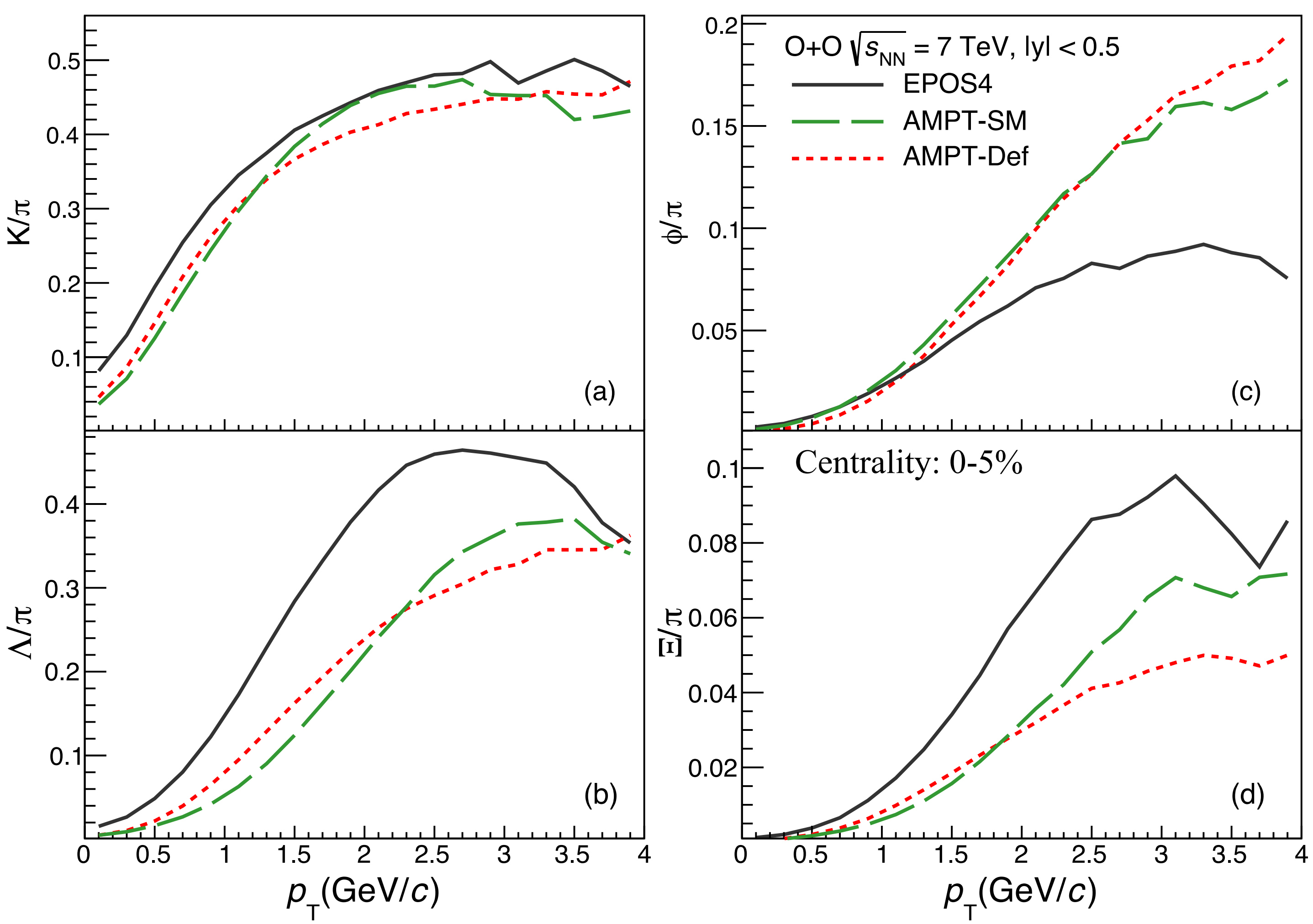
- Projection of ALICE O+O collisions at $\sqrt{s_{NN}}$ = 6.37 TeV compared with pp, p-Pb and Pb-Pb collisions

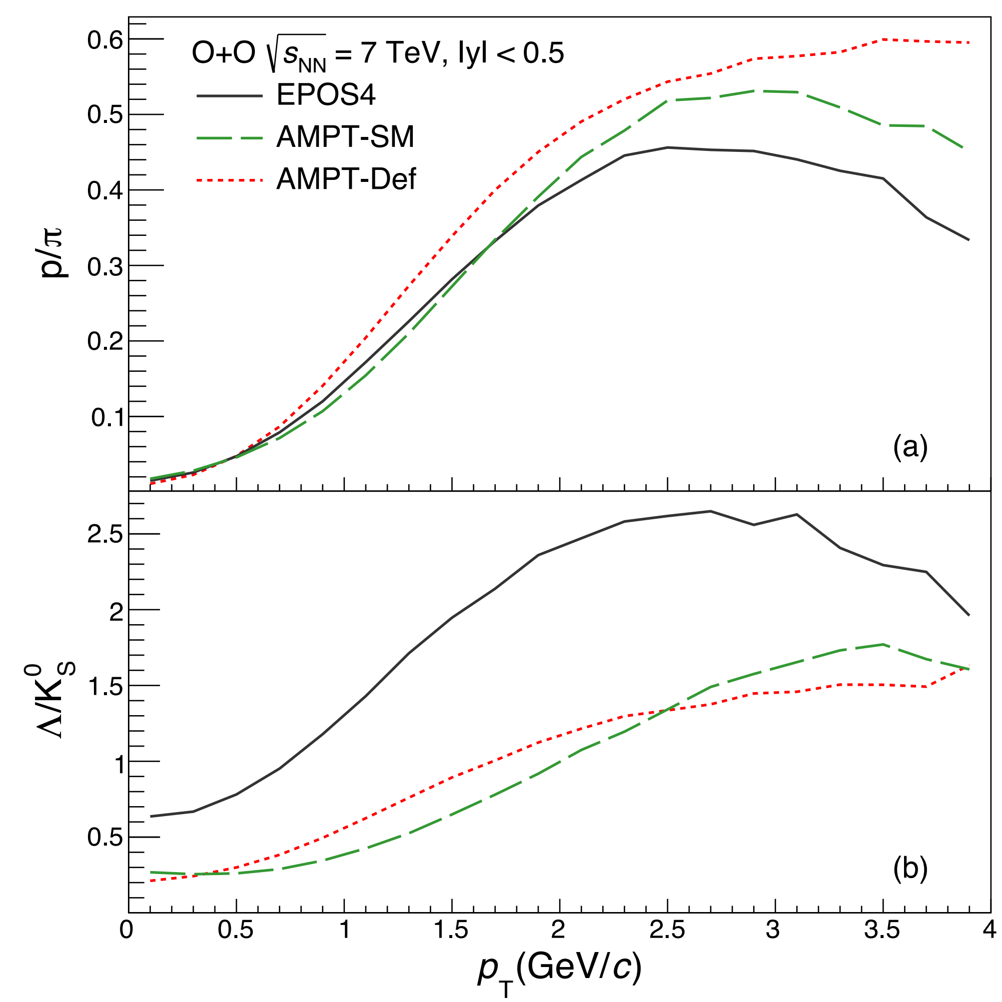
- p_T -integrated ratios relative to pions
- None of the model quantitatively describe this yield ratio
- EPOS4: describe strangeness enhancement

M. U. Ashraf, J. Singh et al., arXiv:2406.04096, 2024

Predictions of p_T -differential particle ratios

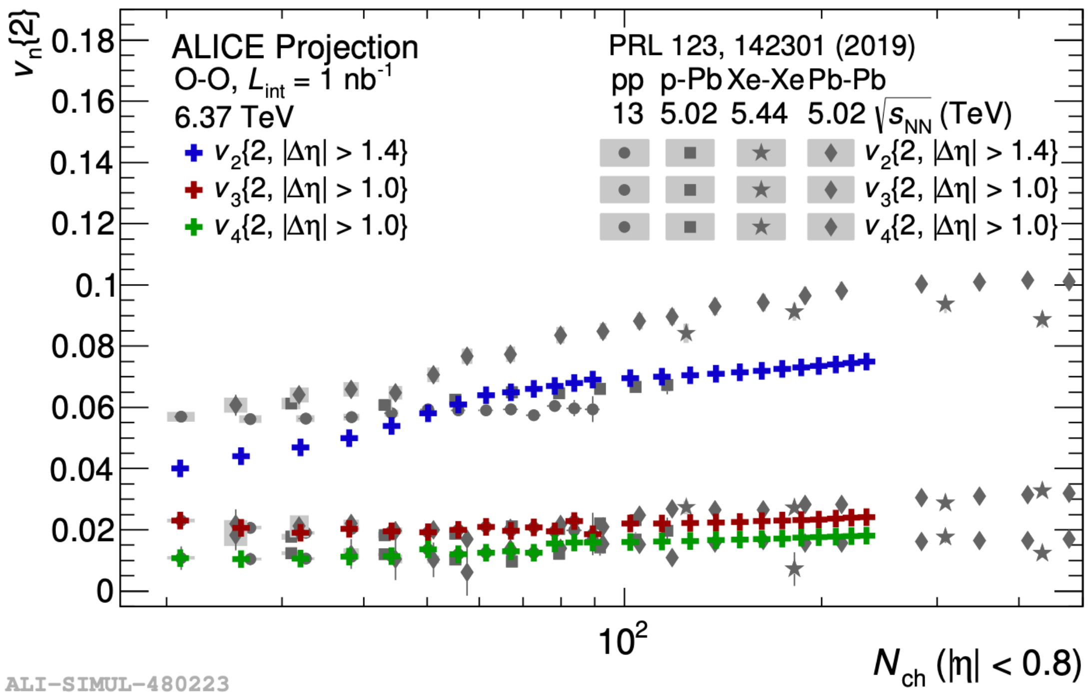
- Particle ratios:
  - direct probe
  - relative abundances
  - dynamics of the underlying quark constituents
- K/π, Λ/π, ϕ/π and Ξ/π: Strangeness enhancement
- p/π (Λ/K_s^0): (higher) relative production of baryons (strange) compared to mesons (strange)
  - Baryon enhancement at intermediate p_T in central collisions— recombination



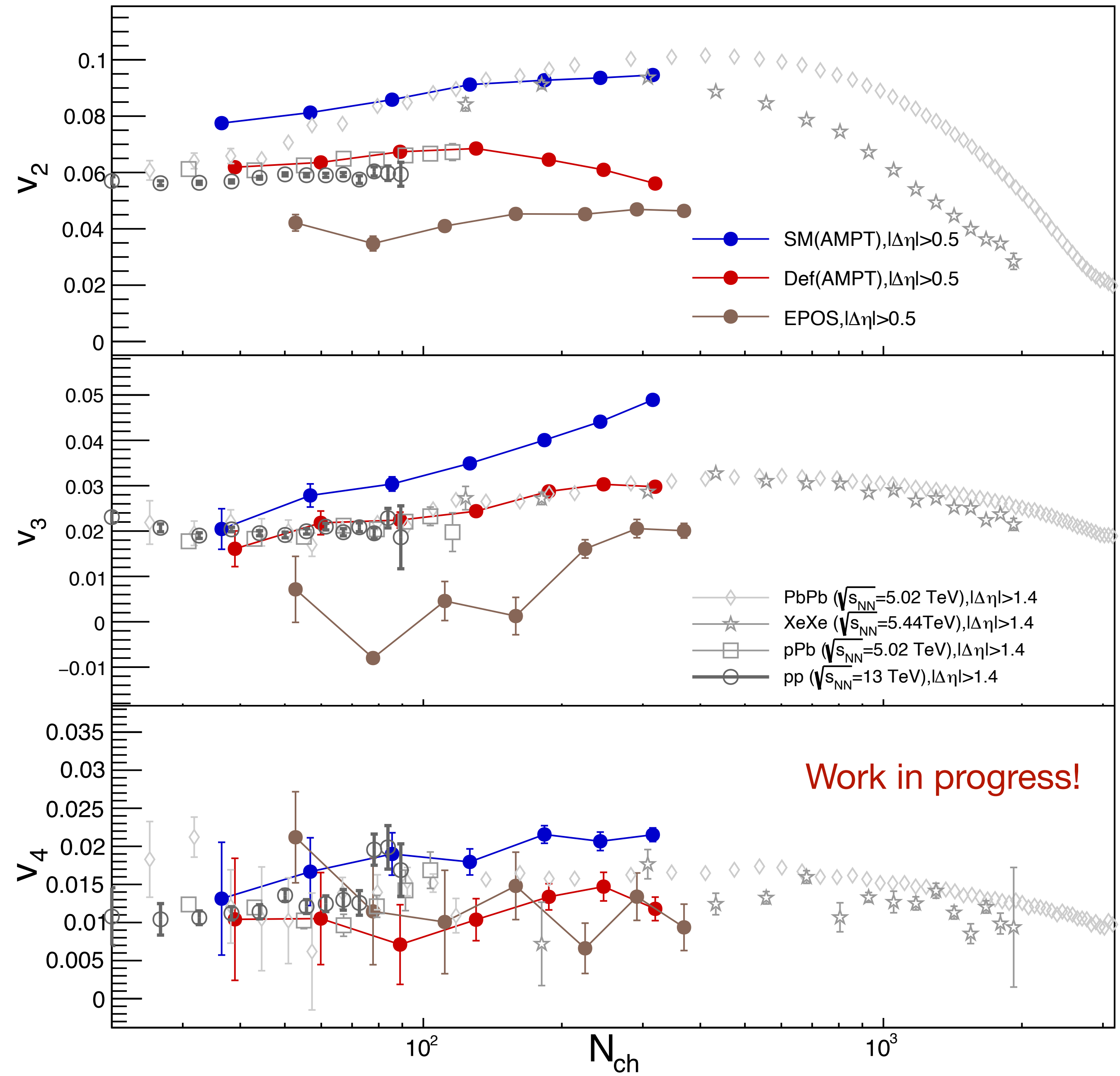


M. U. Ashraf, J. Singh et al., arXiv:2406.04096, 2024

Anisotropic flow (v_2, v_3 and v_4) versus N_{ch}



ALICE physics projections for a short oxygen-beam run at the LHC, ALICE, 2021



- Projection of ALICE for O+O collisions at $\sqrt{s_{NN}}$ = 6.37 TeV compared with pp, p-Pb and Pb-Pb collisions.

- Anisotropic Flow (v_2, v_3 and v_4) vs. N_{ch}
  - Q-Cumulant method
  - multiplicity overlap (bridges between small and large system)

S. Acharya et al., ALICE, Phys. Rev. C, 123, 142301 (2019)
A. Bilandzic et al., Phys. Rev. C **83**, 044913, 2011

Summary

- We present predictions of various observables for identified (π, K, p) and (mutli-)strange hadrons (K_s^0, Λ, $\Xi^-(\Xi^+)$, ϕ, and $\Omega^-(\Omega^+)$) in O + O collisions at $\sqrt{s_{NN}}$ = 7 TeV using the recently updated hydrodynamics-based EPOS4, AMPT-SM and AMPT-Default.
- Yield of identified and (multi-)strange hadrons increase with collision centrality
  - decreases systematically with increasing number of strange quarks
- $\langle p_T \rangle$ increases from peripheral to central collisions:
  - More radial flow in central collisions.
- p_T-integrated ratios:
  - EPOS4 predict relative larger enhancement for (multi-)strange baryons while preforms well for strange hadrons
  - none of the models quantitatively describe the strangeness enhancement
- Anisotropic flow (v_2 , v_3 and v_4) vs N_{ch}
  - AMPT-Def prediction is better and close to pp, p-Pb and Pb-Pb
- Interestingly, final state multiplicity overlap is observed
- It would be interesting to investigate strangeness enhancement with the experimental data and extended AMPT model when available.

Thank you for your attention!!