EPOS4 Model Predictions for Global Observables in Pb–Pb Collisions at $\sqrt{s_{NN}}$ = 5.36 TeV

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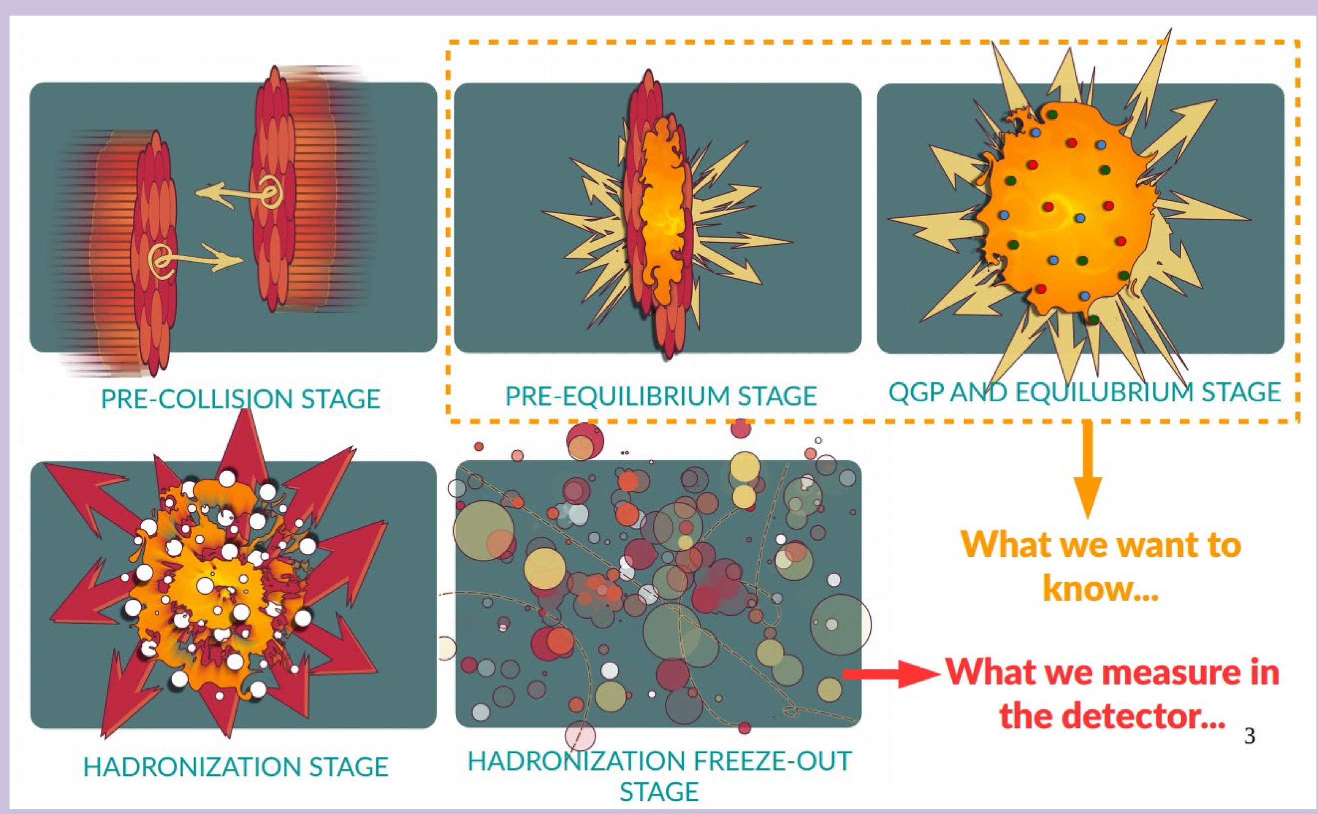
1. Introduction

Study production of π, K, and p in high energy collisions:

- Serve as essential probes for studying the Quark-Gluon Plasma (QGP), where quarks and gluons are not confined within hadrons.
- Crucial for probing the fundamental properties of matter under extreme conditions of density and temperature.
- Partons originating from initial hard scatterings lose their energy in the medium, which results in suppression of high p_T hadrons.
- Light flavor particles are powerful probes to measure the suppression in a wide p_T range with high precision.



Key Role in studying final state charged particles:

- Understanding particle production mechanisms
  - Interplay between soft and hard QCD processes

Hard QCD processes	Soft QCD processes
High p_T	Low p_T
Described by pQCD: precise calculation at high p_T	non-perturbative in nature

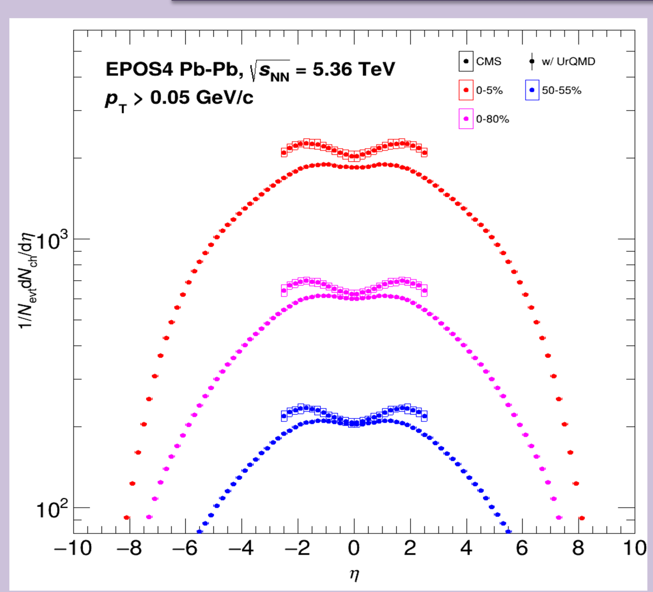
2. EPOS4 Model

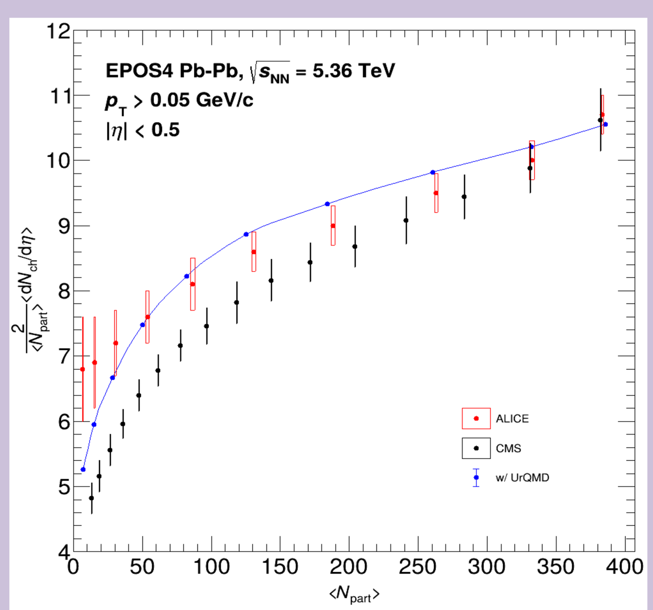
- **Initial Conditions**: Gribov-Regge multiple scattering, Elementary object ➡ Pomeron [1]
- Core-corona approach to separate fluid and jet hadrons
- Core undergoes full collective expansion producing Quark Gluon Plasma ➡ a complete 3+1D viscous hydrodynamic evaluation applied
- **Parton-hadron transition**: Realistic equation-of-state
- **Hadronization**: microcanonical approach with subsequent hadronic cascade (UrQMD)

Event Type: Minimum bias with UrQMD afterburner for Pb-Pb events
Sample Size: 1.5M events
Centre of mass energy: 5.02 and 5.36 TeV

- Centrality determinations for Pb-Pb collisions are done following ALICE V0M conventions

3. Multiplicity as a Tool to Study Particle Production





Charged particle pseudo-rapidity density ($dN_{ch}/d\eta$) gives elementary information on the underlying production dynamics

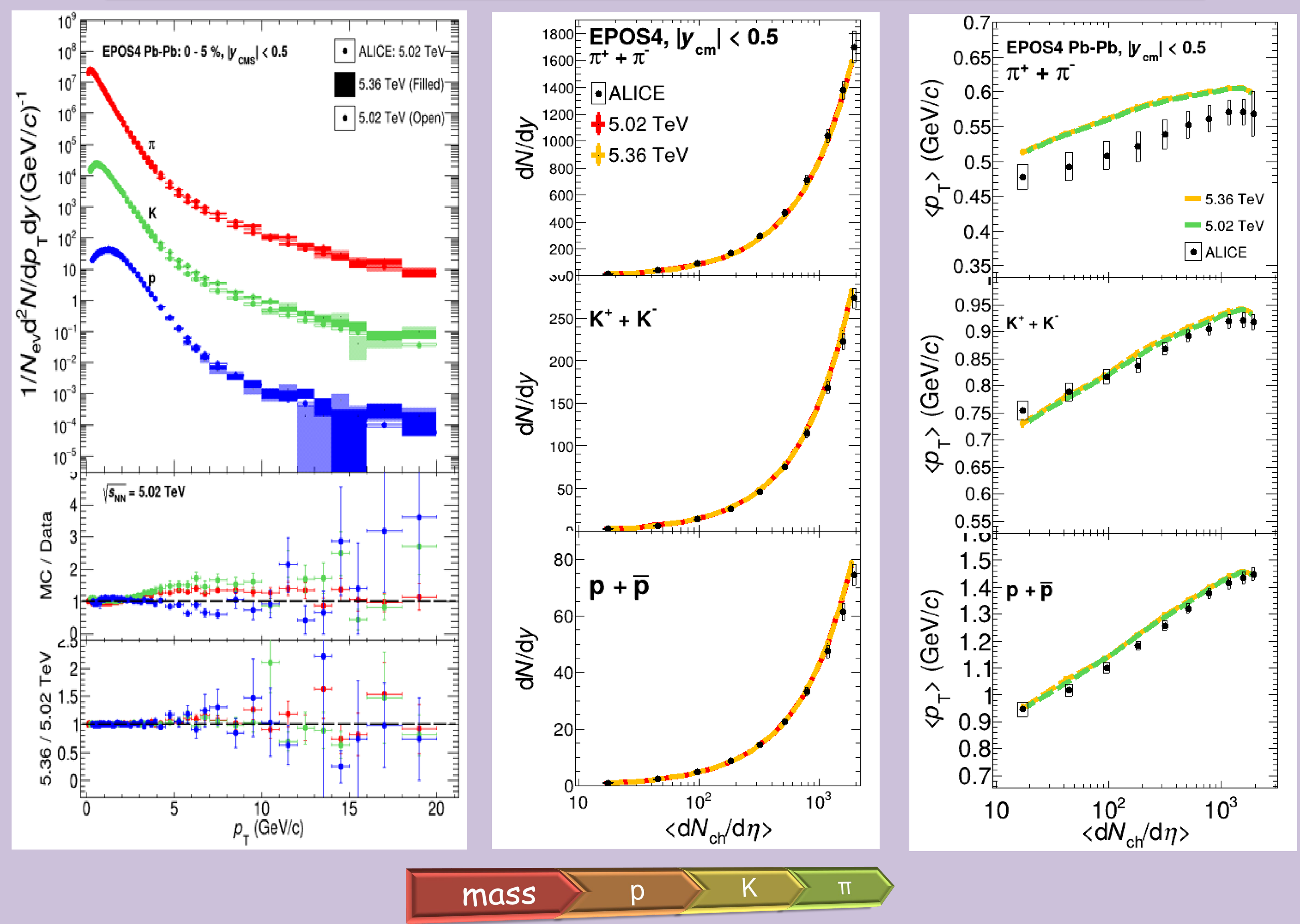
Scales approximately as: $\left.\frac{dN_{ch}}{d\eta}\right|_{AA} = n_{pp}\left[(1-x)\frac{N_{part}}{2} + xN_{coll}\right]$

N_{part}: number of participant nucleons (soft processes)
N_{coll}: number of binary collisions (hard processes)
x: scaling factor for hard process
n_{pp}: average number of produced charged particles per unit pseudo-rapidity in pp collisions

At higher $\sqrt{s_{NN}}$, increased contribution from hard scattering ➡ deviation from pure N_{part} scaling

- **CMS** → Transverse energy based centrality estimator
- **This study** → Multiplicity-based centrality estimator
- Rapid increase of $dN_{ch}/d\eta$ with collision centrality
- **EPOS4**
  ➡ underestimates for most central collision, Good prediction at low multiplicity within |η| < 1
- The $\langle dN_{ch}/d\eta\rangle$ increases from peripheral to central collisions by a factor of ~1.8
- EPOS4 predictions follow similar trend as measurements from ALICE [2] and CMS [3]

4. Light Flavour Spectra: Probing Collective Dynamics



Spectra:

- ✓ **Identified hadrons (π, K, p) spectra are sensitive to medium properties**
- ✓ **Centrality dependence reveals collective effects (e.g., hydrodynamic expansion)**

- **Upper:** 0-5% spectra are compared with ALICE results [4] for 5.02 TeV and predicted for 5.36 TeV with EPOS4
- **Middle:** ratio of MC prediction with the data at low p_T shows agreement, but, differs at high p_T
- **Lower:** ratio of spectra for both energies ➡ it is not clear if there is any deviation at high p_T, given the uncertainty

p_T-integrated Yield:

- dN/dy for identified hadrons increases with multiplicity for both energies
- EPOS4 describes the experimental trends from ALICE reasonably [4]
- No significant change for 5.36 TeV observed w. r. t. 5.02 TeV estimation

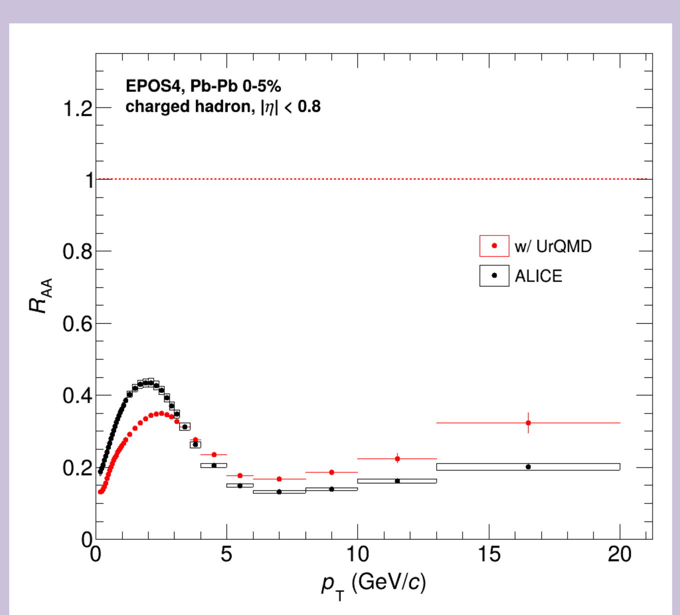
Average Transverse Momentum (<p_T>):

- The common feature of multiplicity dependent <p_T> increases with a steeper trend with higher hadron masses in Pb-Pb collisions
  ➡ Supporting the picture of a collective hydrodynamic evolution similar to radial flow
- EPOS4 describes the ALICE trends qualitatively well [4], but <p_T> for pion is overpredicted

5. Nuclear Modification Factor (R_{AA})

Comparison of particle production in pp and Pb-Pb collisions:

$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle N_{coll}\rangle d^2N^{pp}/dp_T d\eta}$$



<N_{coll}> : average number of binary nucleon-nucleon (NN) collisions for a given centrality class of Pb–Pb collisions, determined from the Glauber model of the nuclear collision geometry

- Hard processes scale with the number of binary NN collisions ➡ scale pp events by <N_{coll}>
- Different centrality corresponds to different system size
- In absence of medium effects: R_{AA} = 1

- Compared R_{AA} of inclusive charged particle for 0-5% with ALICE results
- At low p_T, EPOS4 with hadronic scattering effect shows more suppression than ALICE, whereas at high p_T, this effect is less

6. Conclusion and Outlook

- We have compared the hadron production in Pb-Pb collisions at 5.02 TeV results from EPOS4 with the available ALICE and CMS data, and given prediction for 5.36 TeV LHC Run3 energy.
- Overall, observed good agreement between EPOS4 predictions and available experimental results
- Increase of the global observables like dN/dy, <p_T> is observed for light hadrons with the variation of charged particle multiplicity
- R_{AA} from EPOS4 and data are in agreement

❑ Future measurements of differential observables (e.g., v_2) will help further unravel the role and dynamics of the QGP medium.

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References

[1] **K. Werner**, Phys. Rev. C 108, 064903 (2023)
[2] **arxiv:** 2504.02505v1
[3] **A. Hayrapetyan et al.**, Phys. Lett. B 861, 139279 (2025)
[4] **S. Acharya et al.**, Phys. Rev. C 101, 044907 (2020)
[5] **S. Acharya et al.**, JHEP 1811, 013 (2018)