Elliptic flow of deuterons in heavy ion collisions

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1. Motivation

- Both deuteron and larger cluster yields align well with the statistical model, which is calibrated to hadron yields.
- Universality of Statistical Models: The statistical approach appears broadly applicable across different particle types.
- Given that the temperature exceeds the binding energy of clusters by two orders of magnitude, clusters should not exist under these high temperature
- conditions, suggesting an alternative formation mechanism.
- Coalescence provides a realistic framework for cluster formation, matching observed yields effectively.
- In coalescence, cluster production is influenced by the spatial and temporal proximity of merging nucleons, making it a valuable femtoscopic probe of the fireball's structure.
- The elliptic flow is shaped by the azimuthal variation in homogeneity regions within the fireball.
- Distinguish between thermal production and coalescence mechanisms by analyzing differences in elliptic flow characteristics. [1]

2. Hybrid model

The study uses a **hybrid dynamical model** approach, combining multiple stages of heavy-ion collision simulations to capture different aspects of the evolution and particle production mechanisms. The hybrid model integrates the following components:

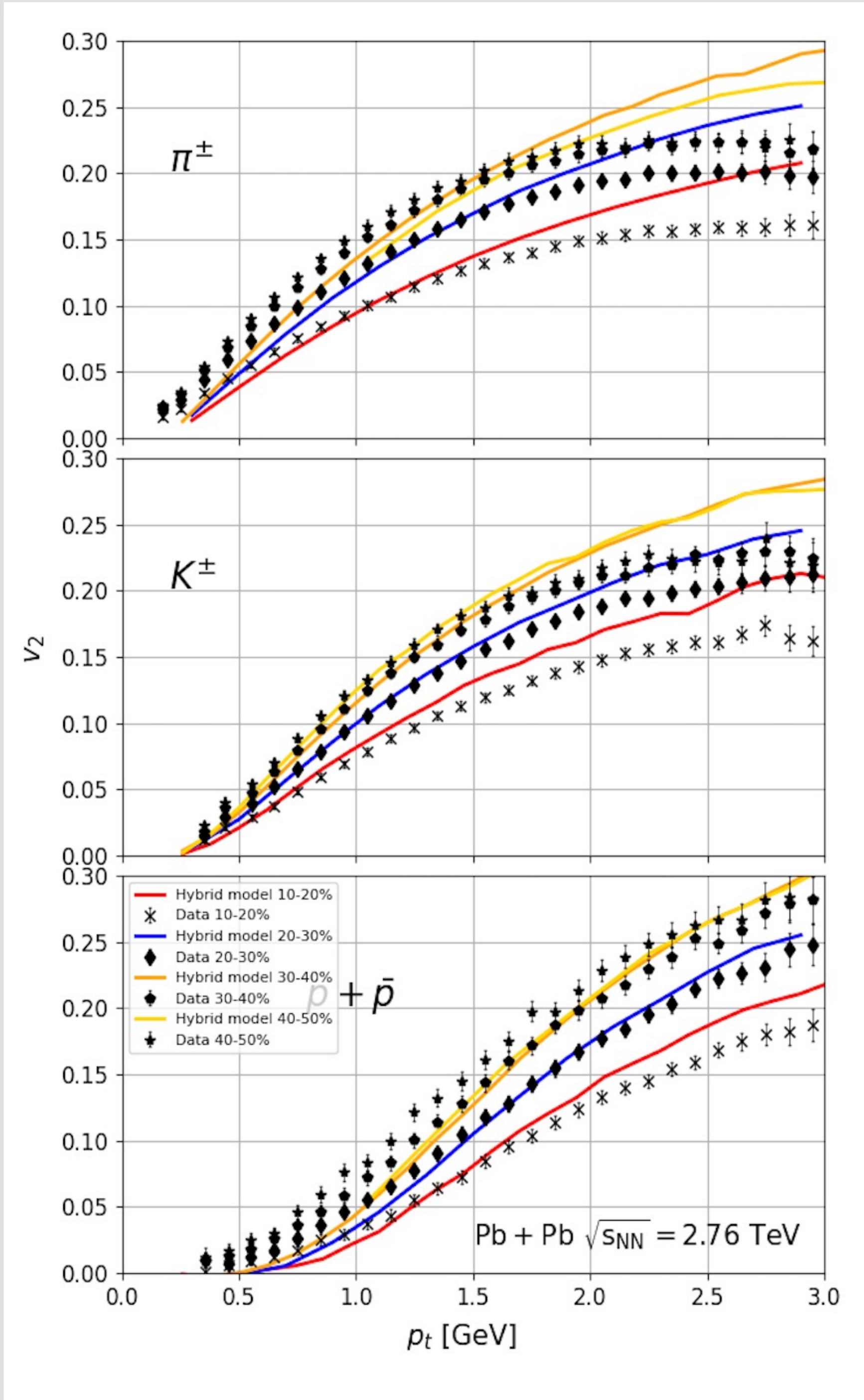
1. **Trento3D** [2]
   - Generates the initial conditions for the simulation.
   - Trento is a parametric initial condition model that calculates the initial energy density distribution in the transverse plane using participant nucleon densities.
   - Provides realistic geometry and fluctuations for the starting point of the hydrodynamic evolution.
2. **vHLLE** [3]
   - Simulates the hydrodynamic evolution of the quark-gluon plasma (QGP).
   - vHLLE is a (3+1)D viscous hydrodynamic code that models the expansion of the QGP.
   - Solves Israel - Stewart hydrodynamic equations with viscosity.
   - Incorporates realistic equations of state based on lattice QCD and hadronic resonance gas models.
   - Outputs a freeze-out hypersurface where hydrodynamics ceases to apply, transitioning to particle-based models.
3. **SMASH** [4]
   - SMASH (Simulating Many Accelerated Strongly-interacting Hadrons) is a hadronic transport model for describing interactions in the dilute phase of the evolution.
   - Simulates the hadronic afterburner phase.
   - Handles the propagation and interaction of hadrons post-freeze-out.
   - Models particle decays, rescatterings, and resonance formations.
   - Assumes **pointlike deuterons**, which contrasts with extended object assumptions in other models.

3. The model – implementation

1. **Collision System**:
   - Pb+Pb collisions at 2.76 TeV are simulated to study quark-gluon plasma (QGP) properties and nuclear matter dynamics at high energy densities.
2. **Event Generation**:
   - The simulation integrates hydrodynamic modeling with SMASH to ensure high-accuracy particle spectra and detailed particle distributions.
   - A total of 1.5 million events per centrality class are generated using a 500×3000 oversampling setup (500 hydrodynamics x 3000 SMASH events)
   - The model is set based on p_T spectra and v_2 of light hadrons, and for deuterons, we examine how well the predictions match the data.
3. **Data Collection and Analysis**:
   - The analysis focuses on transverse momentum p_T spectra and elliptic flow coefficients $v_2(p_T)$ of particles such as deuterons, protons, kaons, and pions
   - These metrics provide insights into momentum distributions, anisotropic flow, and the geometry of the initial collision zone.
4. **Choice of Scattering Model**:
   - In this study, **geometric scattering** is utilized, where deuteron formation is simulated using a d′ resonance at the particlization hypersurface. This method simplifies interaction criteria while maintaining consistency with coalescence predictions, enabling efficient modeling of v_2 and other observables.

4. Results

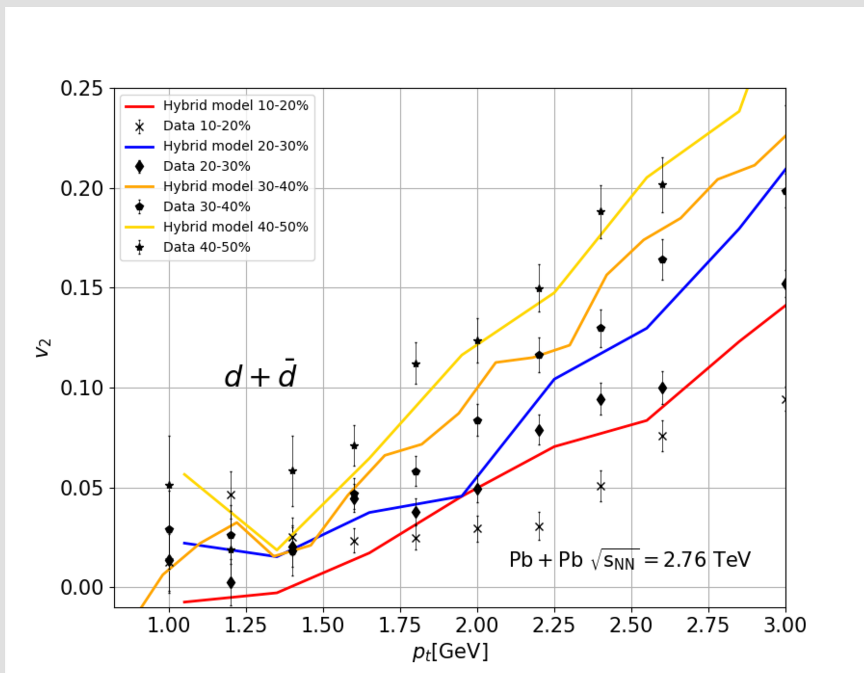
- Protons, kaons, pions and deuterons spectra and the elliptic flow



- Elliptic flow of pions, kaons and protons for four centralities: 10-20 %, 20-30 %, 30-40 % and 40-50% centrality. We used ALICE data for energy 2.76 TeV.
- Elliptic flow of charged hadron is calculated with used of Scalar Product Method (SP) [6]

$$v_n(\eta, p_T) = \frac{< Q_n u_{n,i}^*(\eta, p_T) >}{2\sqrt{< Q_n{}^a Q^{b*}{}_n >}}$$

- The "Hybrid model" results are shown as lines for each centrality, while experimental data points (with error bars) correspond to the actual measurements.
- For all particle species, the hybrid model captures the general trend of $v_2(p_T)$ but shows deviations in some p_T ranges.



- $v_2(p_T)$ of deuterons starts near zero at low p_T and rises to approximately 0.25 for p_T~3 GeV with clear centrality dependence
- The hybrid model matches the data less closely at intermediate p_T values

5. Conclusions

- The comparison of elliptic flow for deuterons, kaons, protons and pions in Pb+Pb collisions at 2.76 TeV with hybrid model simulations (Trento3D-vHLLE-SMASH) shows overall good agreement with data, particularly for kaons, protonos and pions.
- For deuterons, discrepancies at intermediate $v_2(p_T)$ suggest limitations in the current hydrodynamic description
- The centrality dependence of $v_2(p_T)$ is well-reproduced, reflecting the model's ability to capture the system's anisotropic dynamics.
- Outlook:
  - We aim to incorporate explicit coalescence models into the hybrid framework to compare predictions for deuterons..
  - This will involve systematic exploration of coalescence parameters.

References

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