The $v_3^{1/3}/v_2^{1/2}$ ratio in PbAu collisions at sqrt(s_{NN}) = 17.3 GeV

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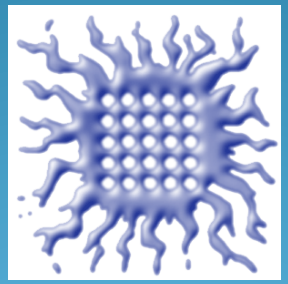
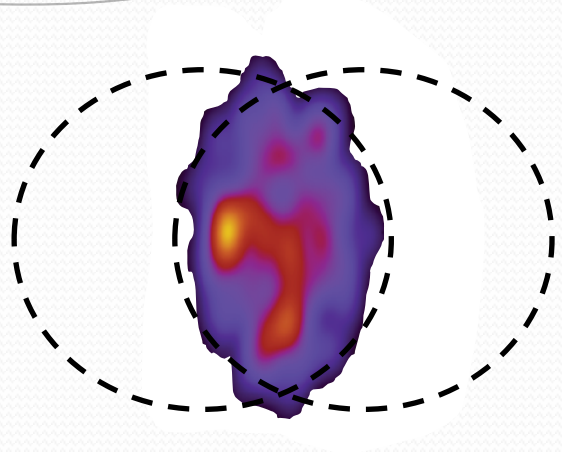


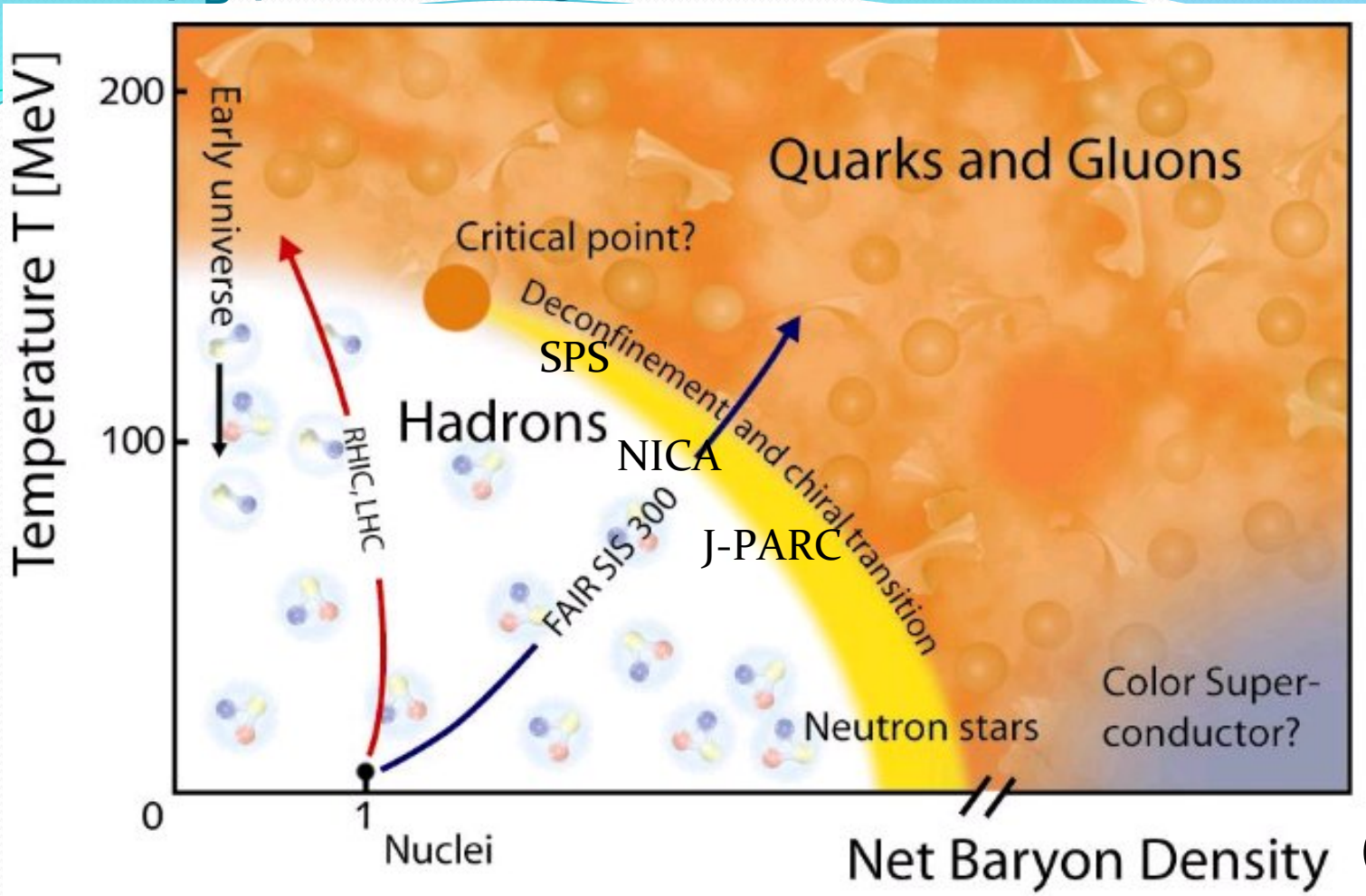
Outline



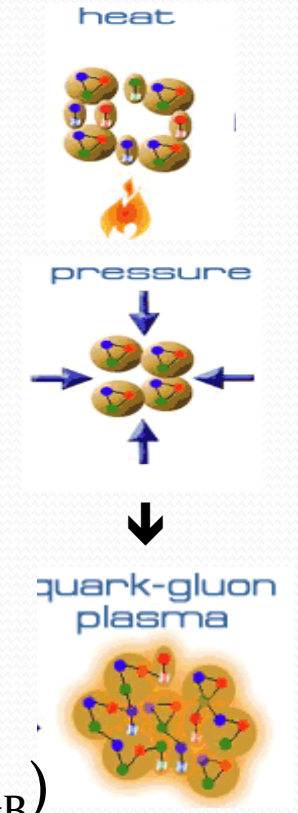
- Motivation
- CERES/NA45 experiment
- v_2 and v_3 magnitudes
- Hydro probes $v_n^{1/n}/v_2^{1/2}$ vs p_T (n=3,4,…)
- Conclusions

Motivation

T-μ_B phase diagram of nuclear matter

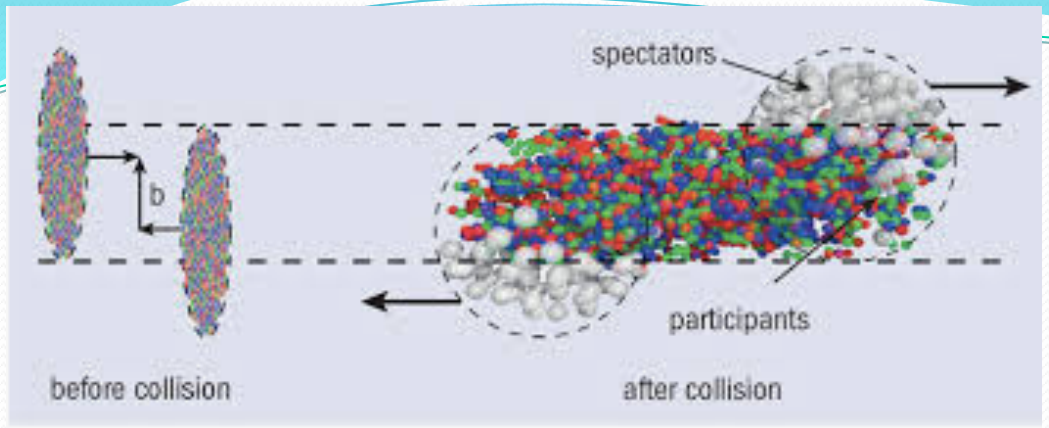


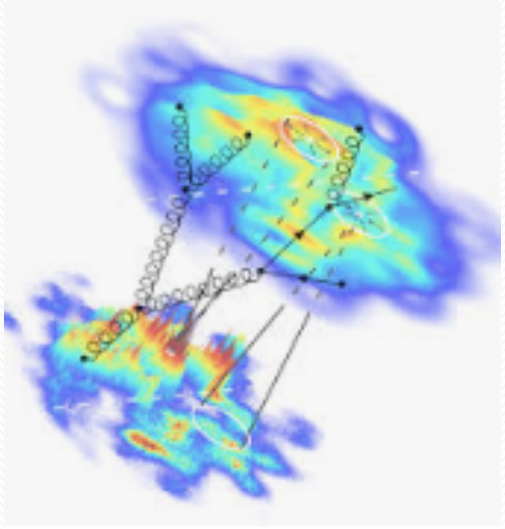
Schematic view



- QGP discovered at high T (~170 MeV) and low μ_B (~0) at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) – corresponds to the early Universe
- QCD phase structures (first-order phase transition, critical point) should exists in high density regime – could correspond to some astrophysical objects and some exotic states

Theoretical models to descibe HI evolution and QGP





Hadronic cascade

- ❖ Ultra relativistic Quantum Molecular Dynamics (**UrQMD**)
- ❖ Quark Gluon String Model (**QGSM**)
- ❖ A Multi Phase Transport Model (**AMPT**)
- ❖ Jet AA Microscopic Transport Model (**JAM**)
- ❖ **…**

Relativistic liquid

- ❖ Hydrodynamics model (**iEBE-VISHNU**)
- ❖ HYDrodynamics plus JETs (**HYDJET++**)
- ❖ **…**

Hybrid models

- ❖ **vHLLE viscous + SMASH**

-Models are not universal. Dependence of different collision energies (range Mev to TeV)

-To check different observables to make possible distinction between different models

-Could something be done independently of the models?

A simple hydrodynamics check

In hydrodynamics, at p_T < 2 GeV/c, the $v_n(p_T)$ behave as power-law functions of p_T [Phys. Rev. C 82 (2010) 034913, arxiv:nucl-th/1007.5469 & Phys. Lett. B 642 (2006) 227, arxiv:nucl-th/0506045].

This can be expressed as $v_n\left(p_T\right) = c_n p_T^{n/m}, n = 2,3,...$

where c_n is a coefficient of proportionality that depends on the order n, and m is a fixed number independent of n.

In this case, the ratio $v_3^{1/3}$ / $v_2^{1/2}$ becomes a p_T independent number $c_3^{1/3}$ / $c_2^{1/2}$

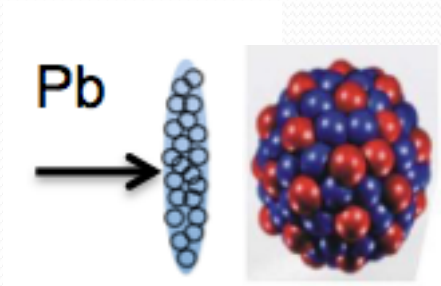
The ratio depends on centrality.

Similar scaling ratios $v_n^{1/n}$ / $v_2^{1/2}$, n>2, as a function of centrality, have been already measured at RHIC and LHC

This is a model independent hydro check!

CERES/NA45 experiment

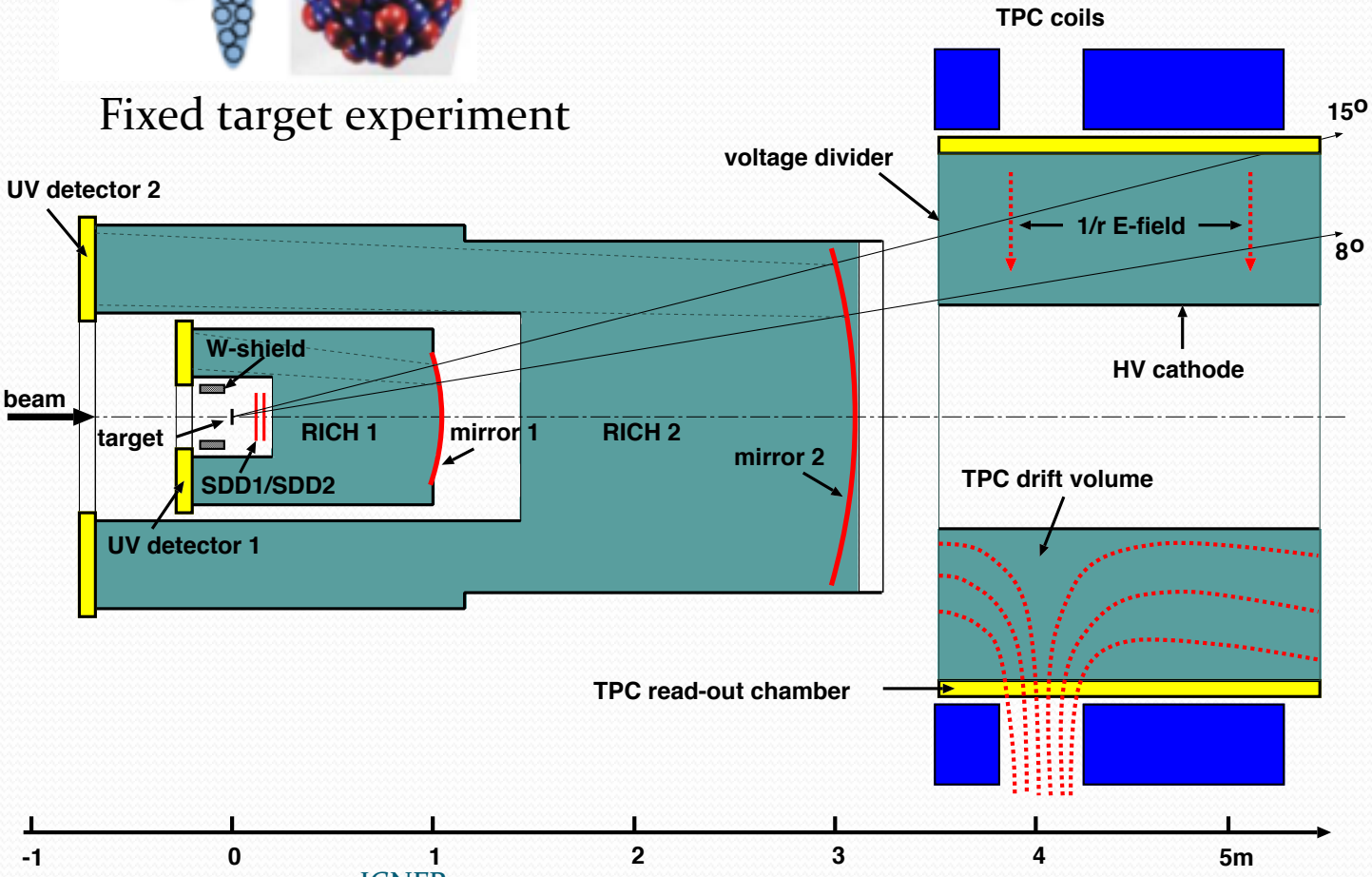
Anisotropies from the CERES/NA45 at the SPS in PbAu collisions



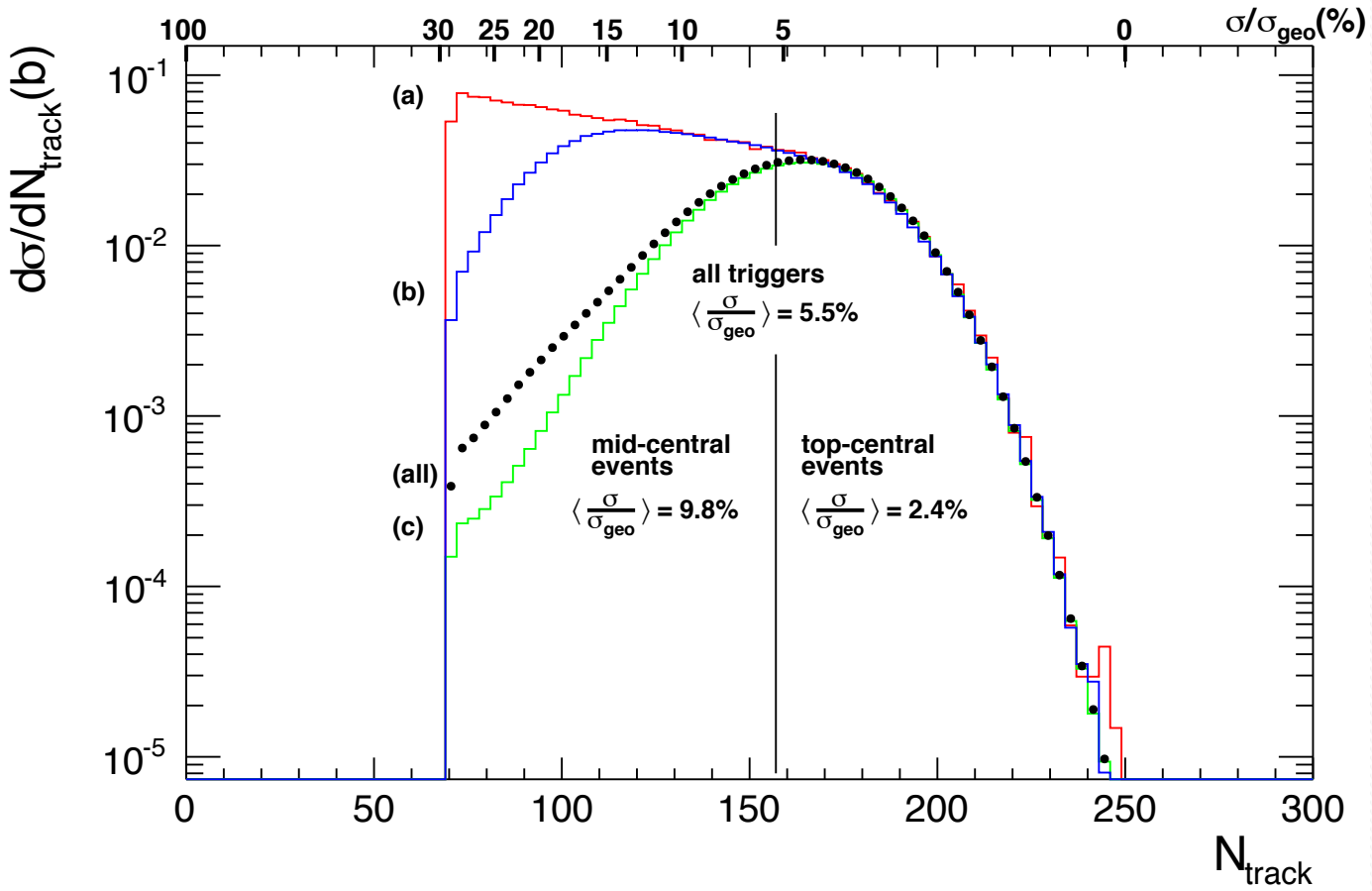
Fixed target experiment

Full azimuthal coverage

PID: π , $2.05<\eta<2.7$,
$0.05 < p_T < 2.2$ GeV/c



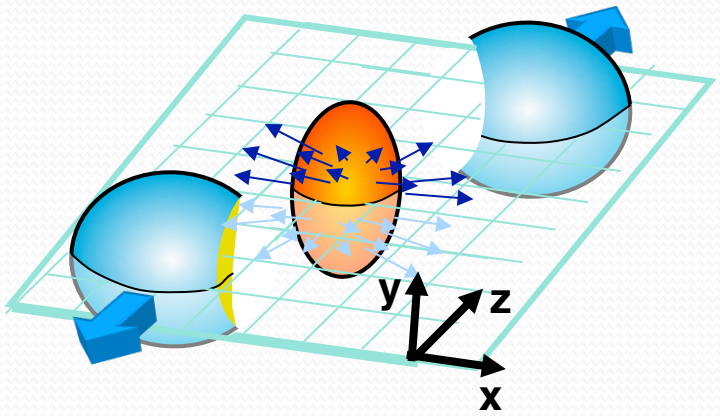
Multiplicity distribution from the CERES/NA45 at the SPS in PbAu collisions



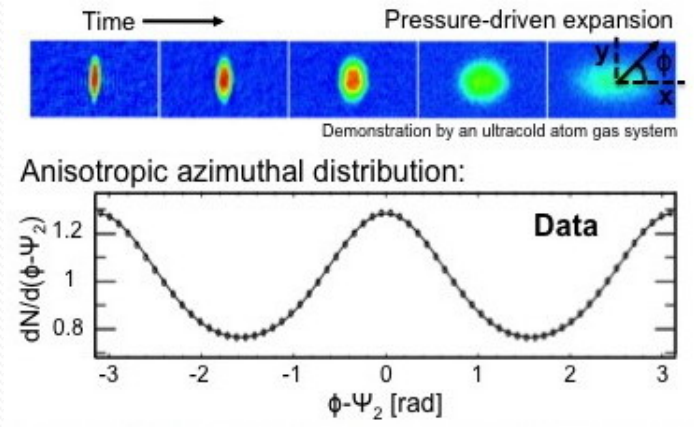
TPC track density for the trigger mix within (0 – 30%) centrality. The mix consists of three components: minimum-bias (0.5%), semicentral (8.3%), and central (91.2%), where the parentheses represent the percentage fractions in the mix.

v_n magnitudes

Azimuthal anisotropy



Ψ_n (angle of nth-order flow symmetry plane)



$$\frac{2\pi}{N}\frac{dN}{d\phi} = 1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n(\phi - \Psi_n)\right]$$

v_n – *Fourier harmonics* depend on

- initial state geometry
- initial state fluctuations
- medium transport properties (e.g. η/s)

$$v_n \equiv \left\langle \cos\left[n(\phi - \Psi_n)\right] \right\rangle$$

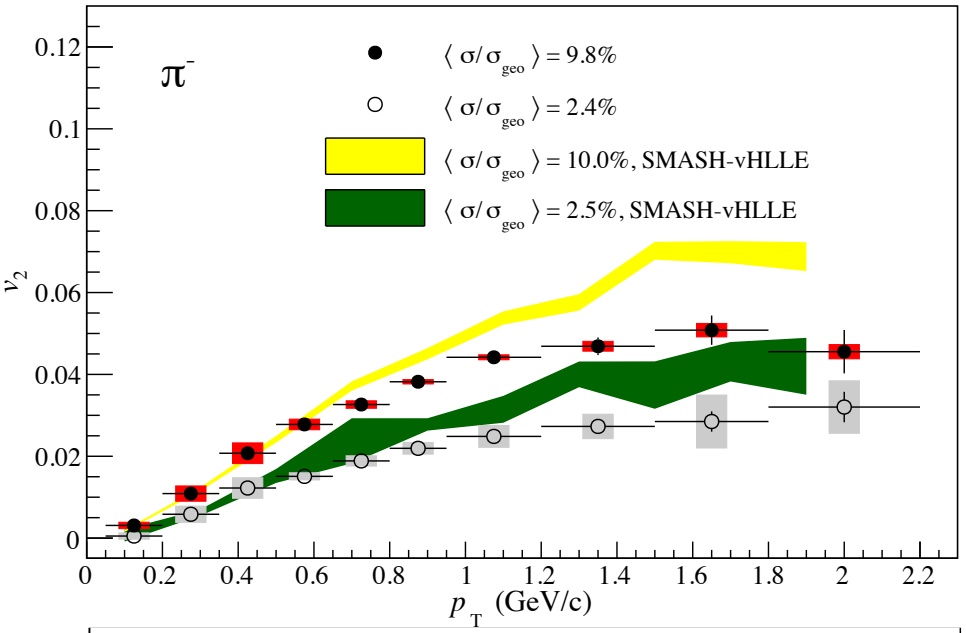
Event-by-event v_n distributions are not Gaussian-like

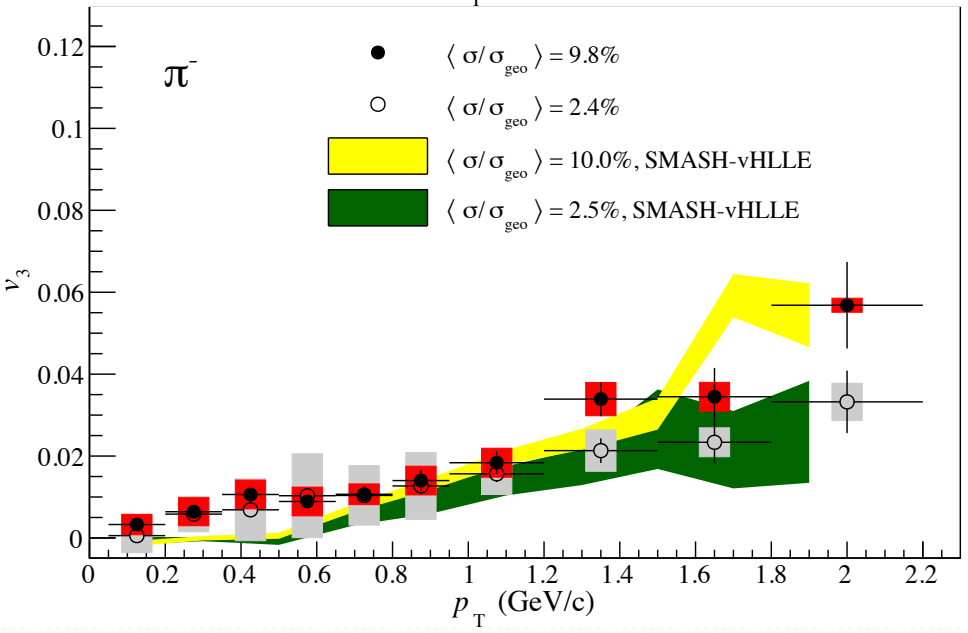
v_2 and v_3 p_T dependence

- **CERES NA/45 experiment**
- **PbAu collisions at 17.3 GeV**
- **Two the most central classes up to 20% centrality**
- **Realistic multiplicity dependence (from vHLLE)**

- **PID: π^- , $2.05<\eta<2.7$, $0.05 < p_T < 2.2$ GeV/c**

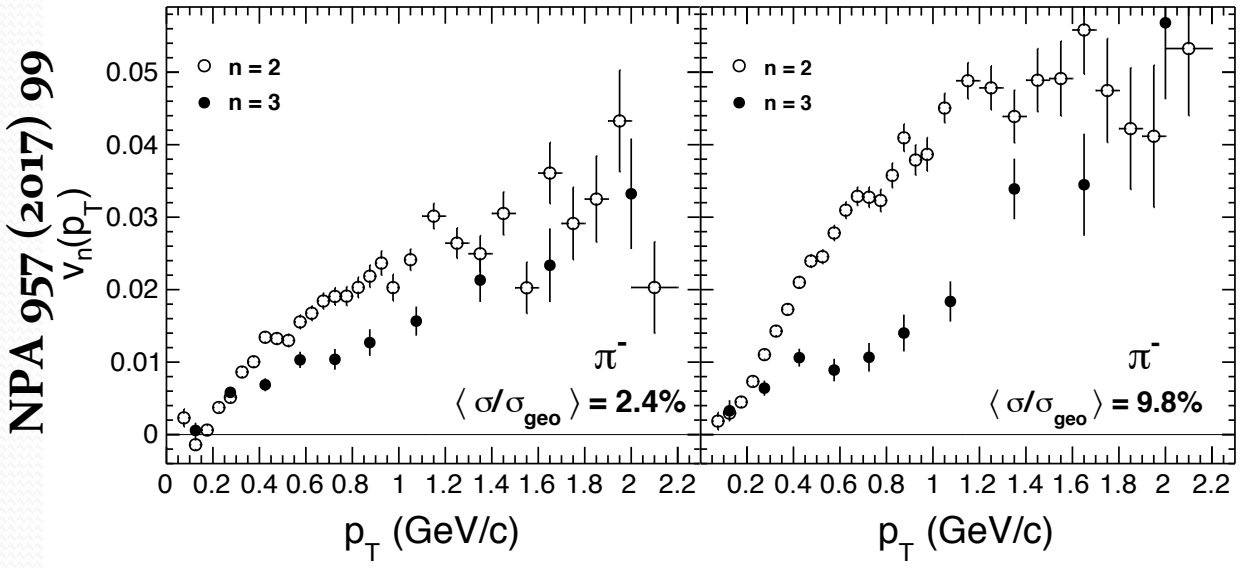
- At low collision energy, v_2 is significantly lower wrt LHC energy
- v_3 is also lower than at the LHC energy
- Multiplicity goes up to 250 tracks of charged particles
- At higher p_T, VHLLE+SMASH overpredicts the v_2 data



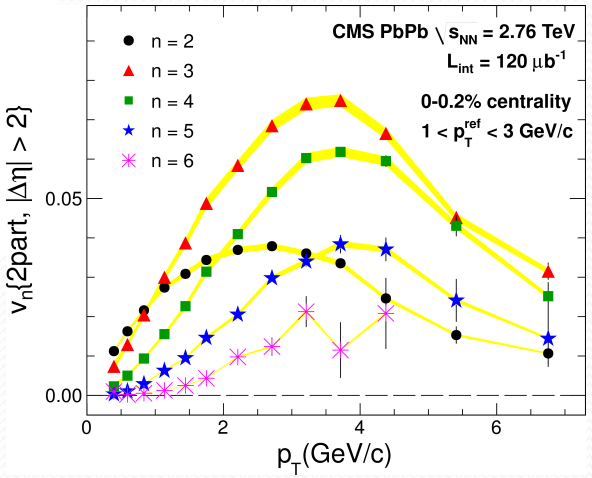


v_3 in comparison with v_2

- Elliptic flow reflects the initial anisotropy and thus depends strongly on centrality
- Triangular flow comes from the Initial State Fluctuations and weakly depends on centrality
- The different centrality behavior between v_2 and v_3 is observed from the corresponding p_T dependencies
- For very central collisions ($\langle \sigma/\sigma_{geo} \rangle = 2.4\%$), v_3 becomes close to the v_2



- Triangular flow is dominant anisotropy for ultra-central collisions at the LHC energies



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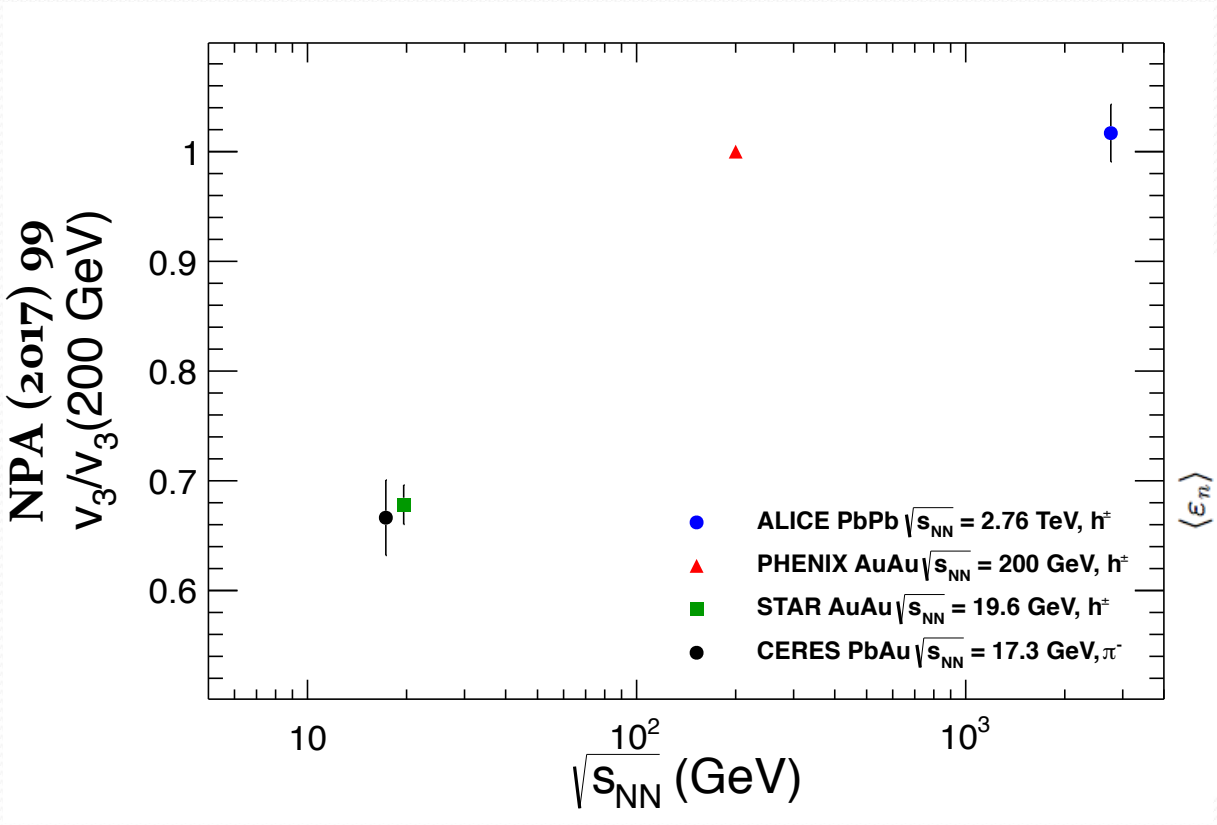
- Systematic errors for the v_3 are very similar to those found for the mean centrality of 5.5%

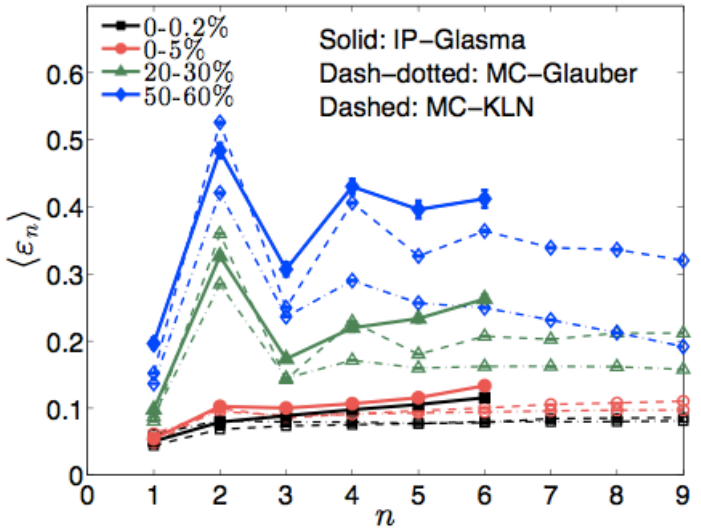
v_3/v_2 *vs* energy

- Relatively good agreement between top SPS and 19.6 GeV RHIC data
- Maximum at the top RHIC energy
- With increasing the energy, due to a faster increase of the elliptic flow wrt the triangular flow, the *v3/v2* decreases



✧ **v_3 and v_2 values integrated over $0.3 < p_T < 2.1$ GeV/c !**

various order of ε_n converge as collision becomes central



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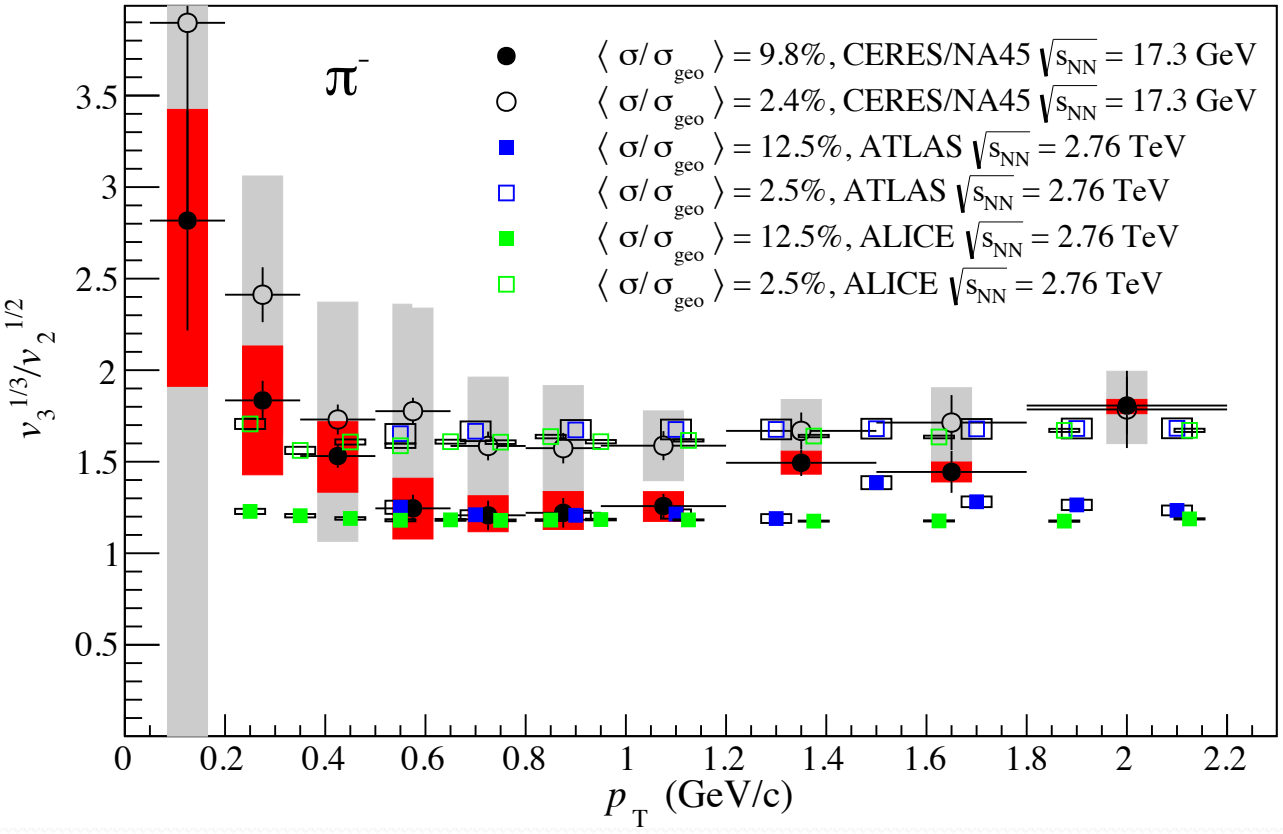
Hydrodynamic prediction

- Ratio $v_3^{1/3}/v_2^{1/2}$ should be p_T independent
- A rather good agreement with ALICE and ATLAS results
- Increase at small p_T probably due to not completely removed HBT contribution
- It shows that even at the SPS energy hydrodynamics works
- Could we expect similar behavior at the NICA top energy too?

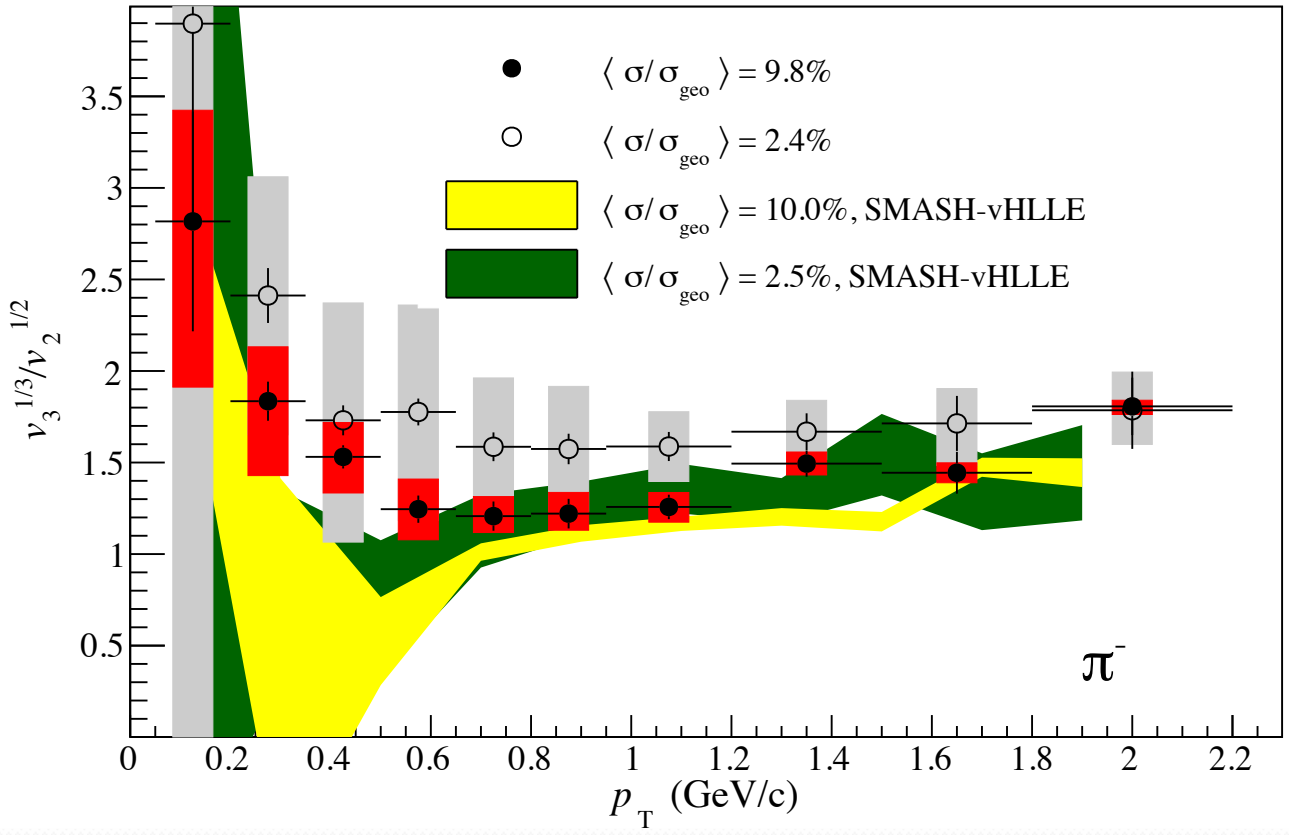
Submitted to EPJC



Hydrodynamic prediction

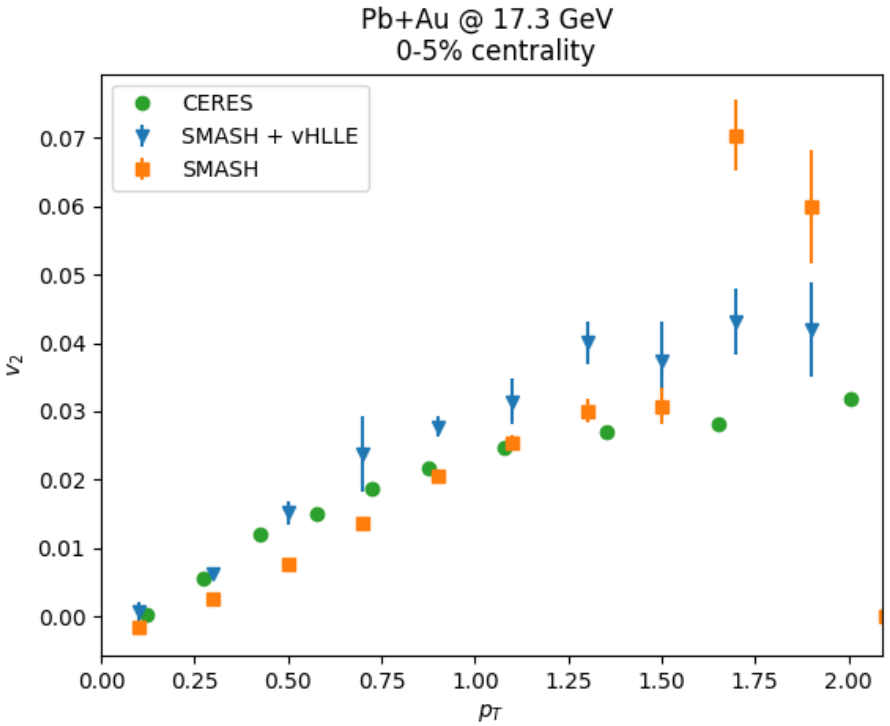
- The SMASH-vHLLE model prediction tends to stay slightly below the experimental data.
- This is due to the fact that the model overestimates the experimentally measured v_2 somewhat for $p_T > 0.7$ GeV/c, while it reproduces v_3 harmonics.
- The choice of initial state and η/s value for hydrodynamic evolution is very important. This measurement could help to better constrain them.

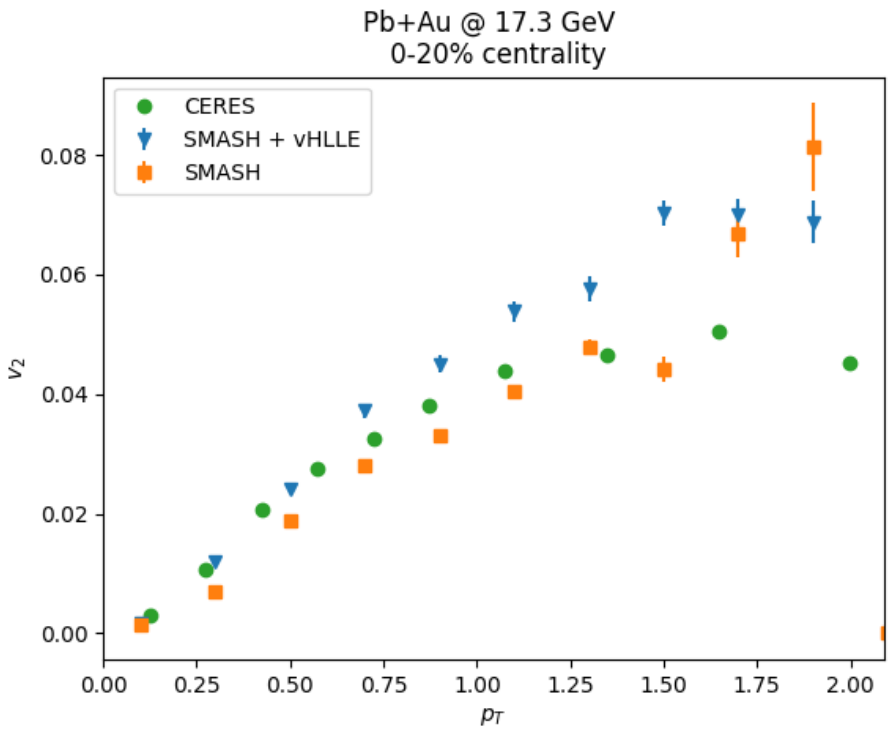
Submitted to EPJC



SMASH only v_2 prediction

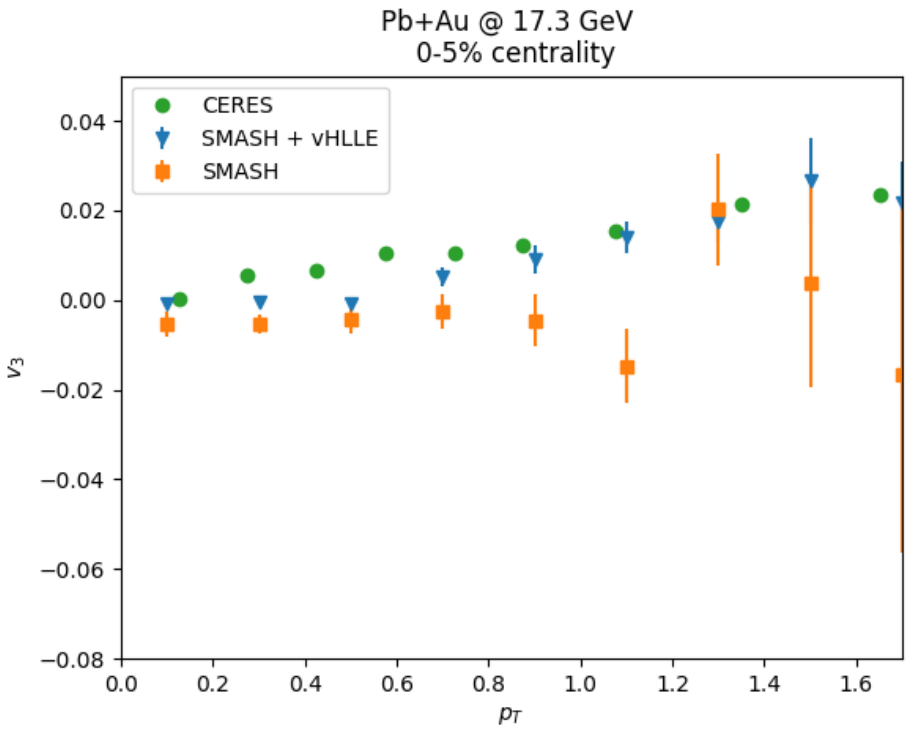
- Up to 1 GeV/c, the SMASH model prediction tends to stay slightly below the experimental data, and even more below the SMASH-vHLLE prediction
- In general, microscopic models have a tendency to be below hydro models

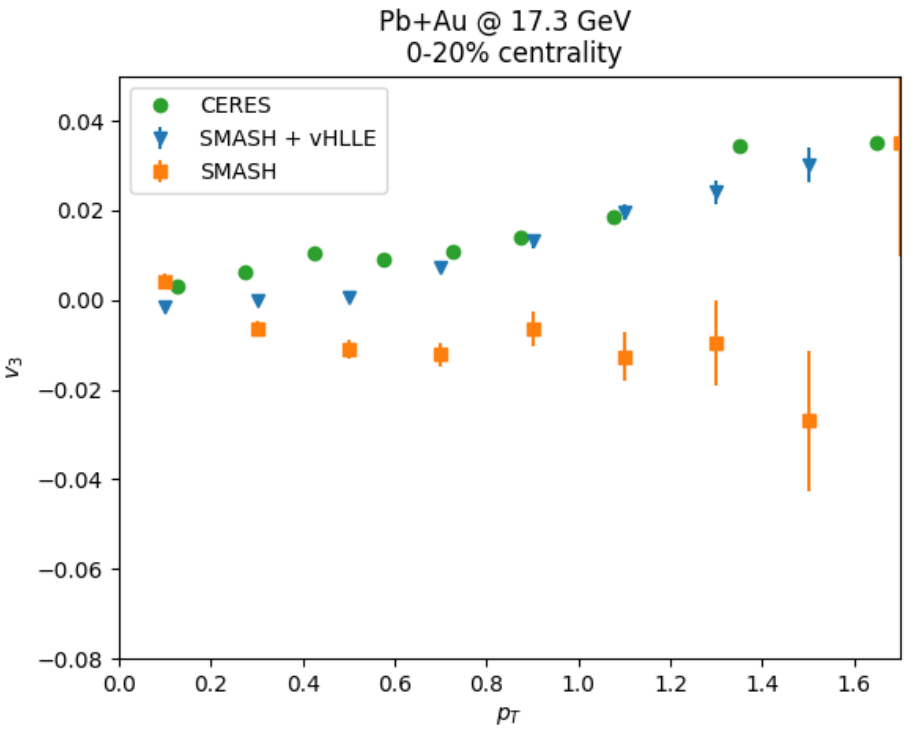




SMASH only v_3 prediction

- The SMASH model alone prediction gives a very small, but negative v_3
- It seems that only with a hydro evolution (as the main part of the evolution), followed by the SMASH model can reproduce the experimental v_3 data
- In this case, the ratio $\mathbf{v_3^{1/3}/v_2^{1/2}}$ cannot be calculated at all





Conclusions

- Hydrodynamics probe as a ratio $\mathbf{v_3^{1/3}/v_2^{1/2}}$ has been performed on PbAu collisions at 17.3 GeV collected by CERES/NA45 Collaboratiion at the SPS
- Different hydrodynamics predictions for the v_2 overpredict the experimental SPS data
- The ratio $\mathbf{v_3^{1/3}/v_2^{1/2}}$ as a hydrodynamics probe is model independent
- The probe shows that matter created at top SPS energy behaves hydrodynamically
- The results could help theoreticians to adjust their models to reproduce the v_2 flow experimental data
- Also, the SMASH model only prediction gives v_2 slightly smaller than the experimental one, while v_3 is quite small, but negative, that makes calculation of the ratio $\mathbf{v_3^{1/3}/v_2^{1/2}}$ impossible

Backup

SMASH only v_3 prediction

- The SMASH model alone prediction gives a very small, but negative v_3
- It seems that only with a hydro evolution (as the main part of the evolution), followed by the SMASH model can reproduce the experimental v_3 data
- In this case, the ratio $\mathbf{v_3^{1/3}/v_2^{1/2}}$ cannot be calculated at all