Status Physics Book:
Observables and Predictions

Convenors:
Elena Bratkovskaya*, Christian Fuchs, Burkhard Kämpfer

*FIAS, J.W. Goethe Universität, Frankfurt am Main

29.05.2006 , CBM Workshop » The Physics of High Baryon Density »

Content of the Chapter: Observables and Predictions

based on dynamical models – transport approaches and hydrodynamics

1. Introduction
2. Excitation function of particle yields and ratios
3. Transverse mass spectra
4. Collective flow
5. Dileptons
6. Open and hidden charm
7. Fluctuations and correlations

Concentrate on FAIR energy range 10-30 A GeV

1. Introduction

FAIR energies are well suited to study dense and hot nuclear matter –

- **a phase transition to QGP ,**
- **chiral symmetry restoration,**
- **in-medium effects**

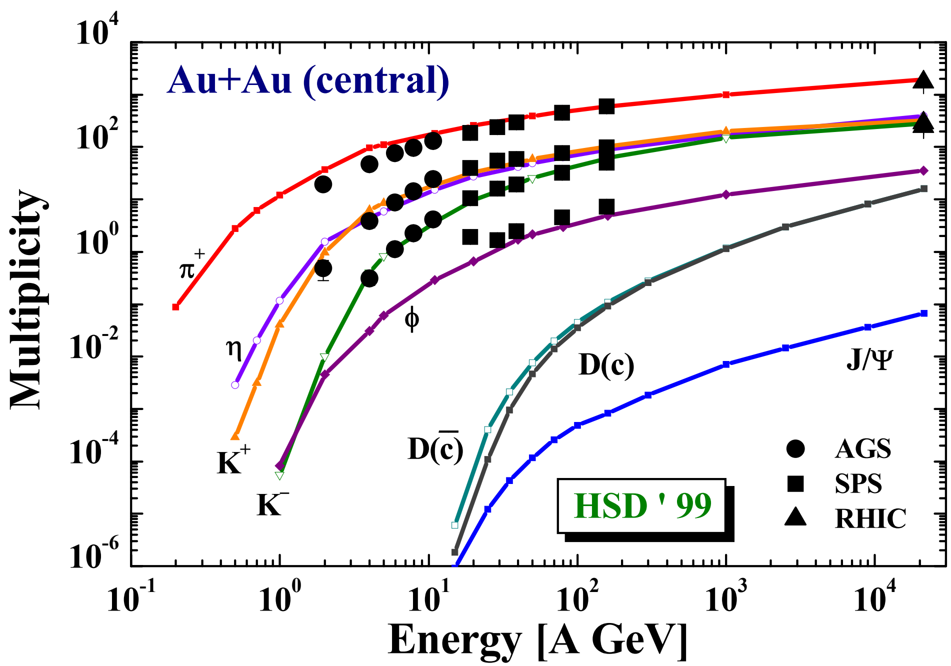
(cf. talk by J. Randrup)

Way to study:

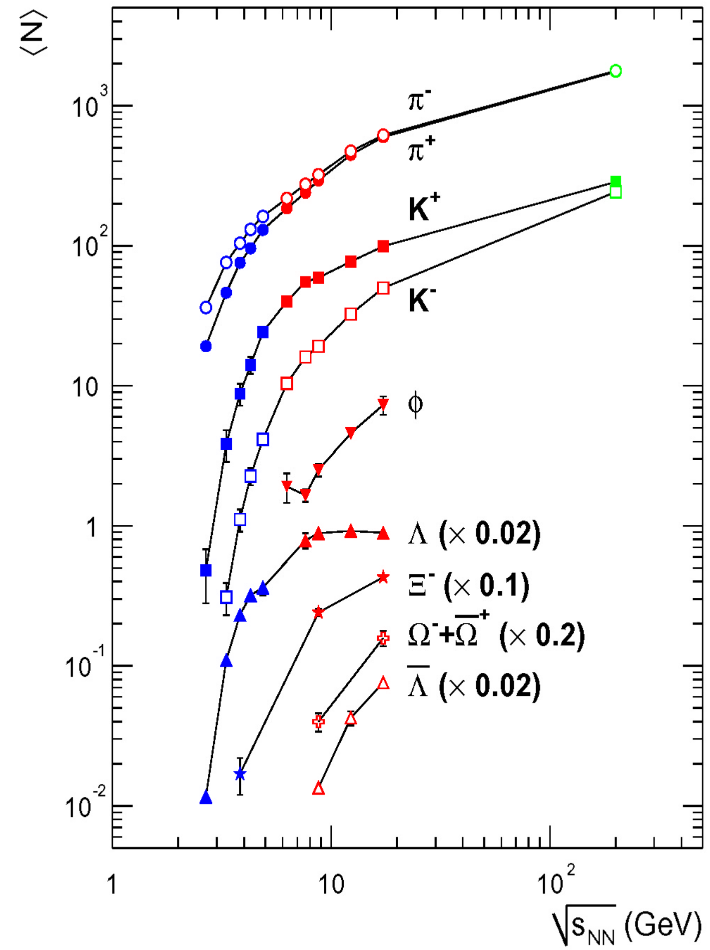
Experimental energy scan of different observables in order to find an ‚anomalous' behavior by comparing with theory

2. Excitation function of particle yields and ratios

Overview on the experimantal meson and strange baryon abundancies from central Au+Au/Pb+Pb collisions versus $s^{1/2}$



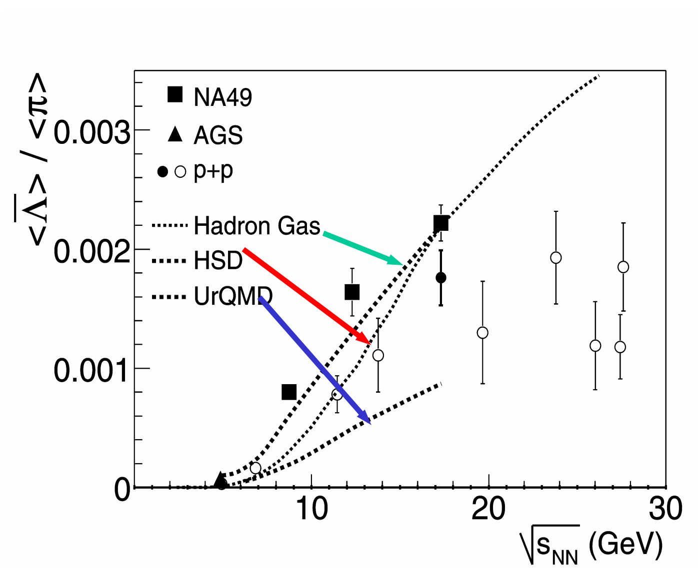
AGS NA49 BRAHMS

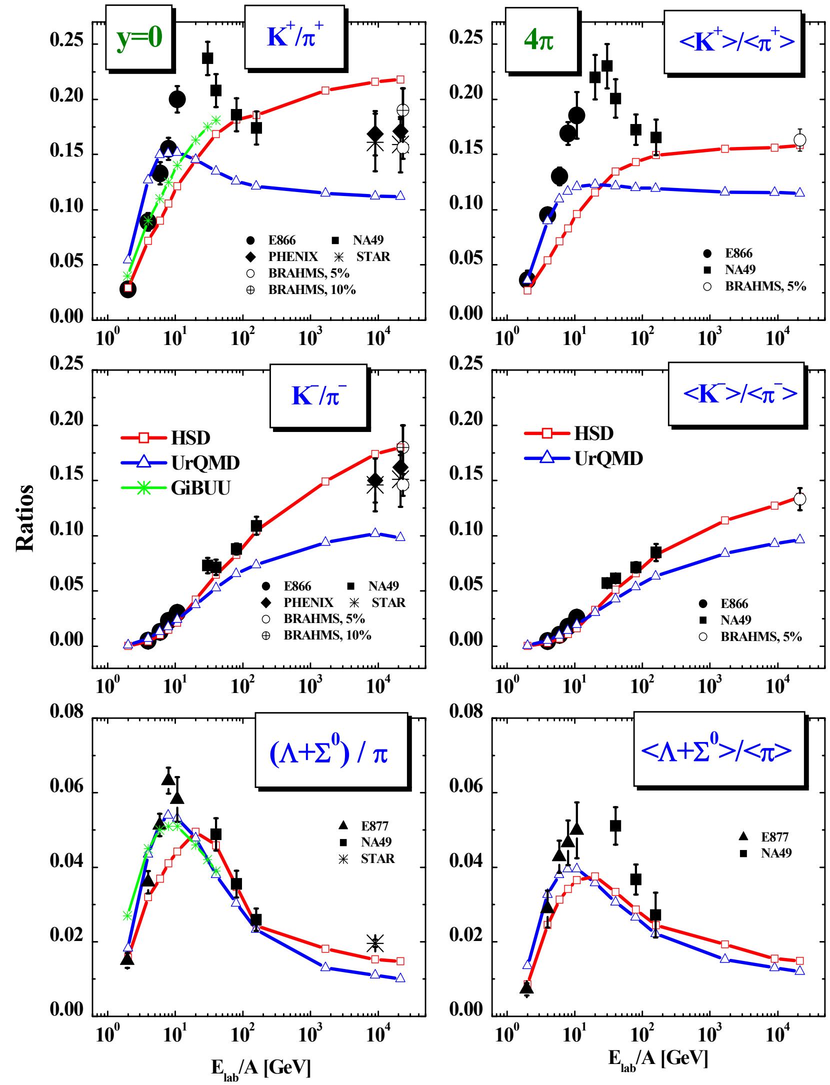


2. Excitation function of particle yields and ratios

Transport models:
HSD, UrQMD, GiBUU

Exp. data are not well reproduced within the hadron-string picture => evidence for nonhadronic degrees of freedom





3. Transverse mass spectra

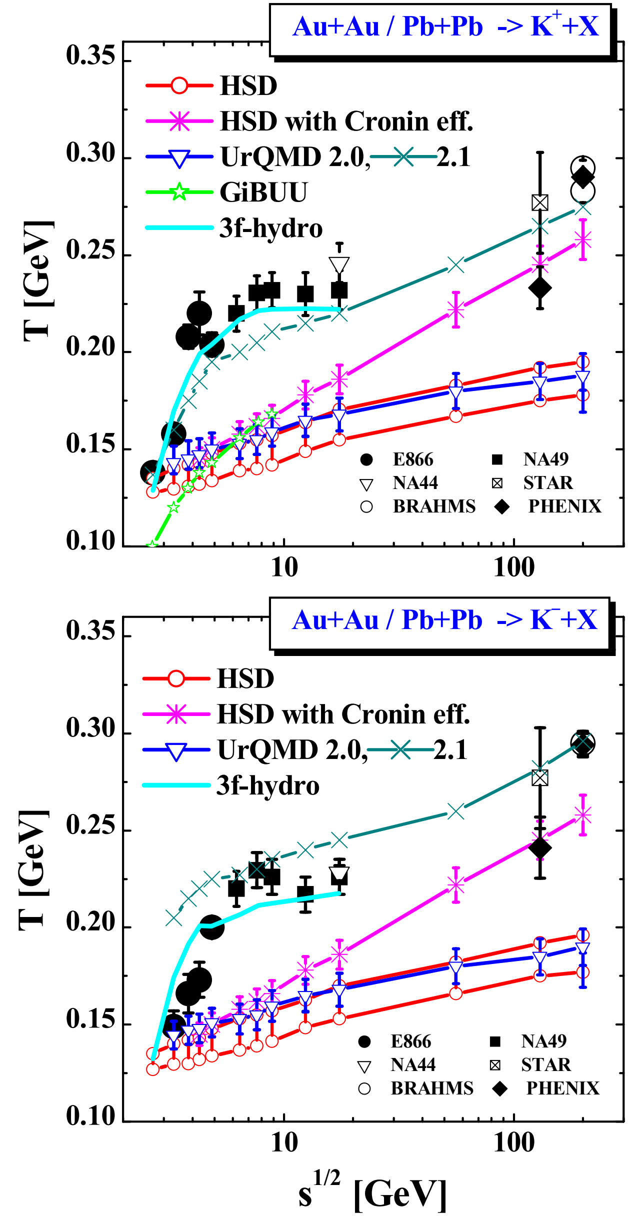
Transport models:

- HSD 2.0 (+ Cronin effect)
- UrQMD 2.0
  UrQMD 2.2 (effective heavy resonances with masses 2 < M < 3 GeV and isotropic decay)
- GiBUU

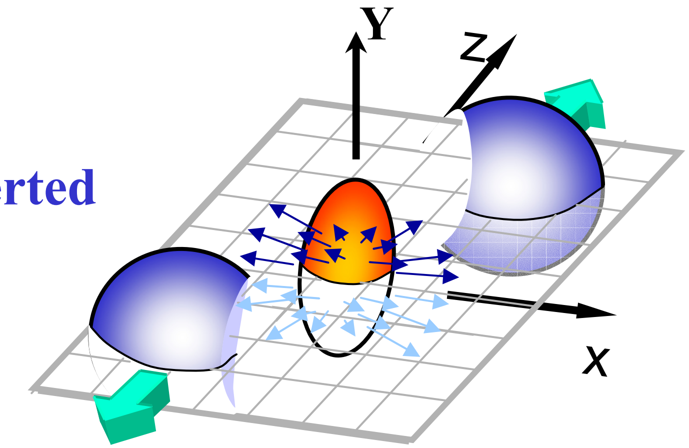
All transport models fail to reproduce the T-slope without introducing special „tricks“ which are, however, inconsistent with other observables!

3D-fluid hydrodynamical model gives the right slope!

Is the matter a parton liquid?



4. Collective flow: general considerations



Non central Au+Au collisions :

interaction between constituents leads to a **pressure gradient** => spatial asymmetry is converted to an asymmetry in momentum space => **collective flow**

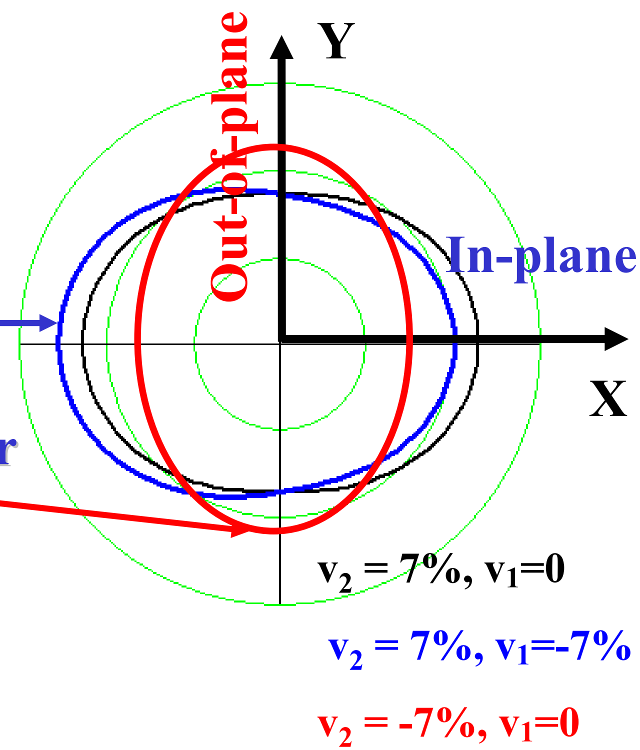
$$\frac{dN}{dy p_T dp_T d\varphi} = \frac{dN}{dy p_T dp_T}\frac{1}{2\pi}\left(1 + 2v_1\cos(\varphi) + 2v_2\cos(2\varphi) + \ldots\right)$$

$v_1 = < \frac{p_x}{p_T} >$ - directed flow

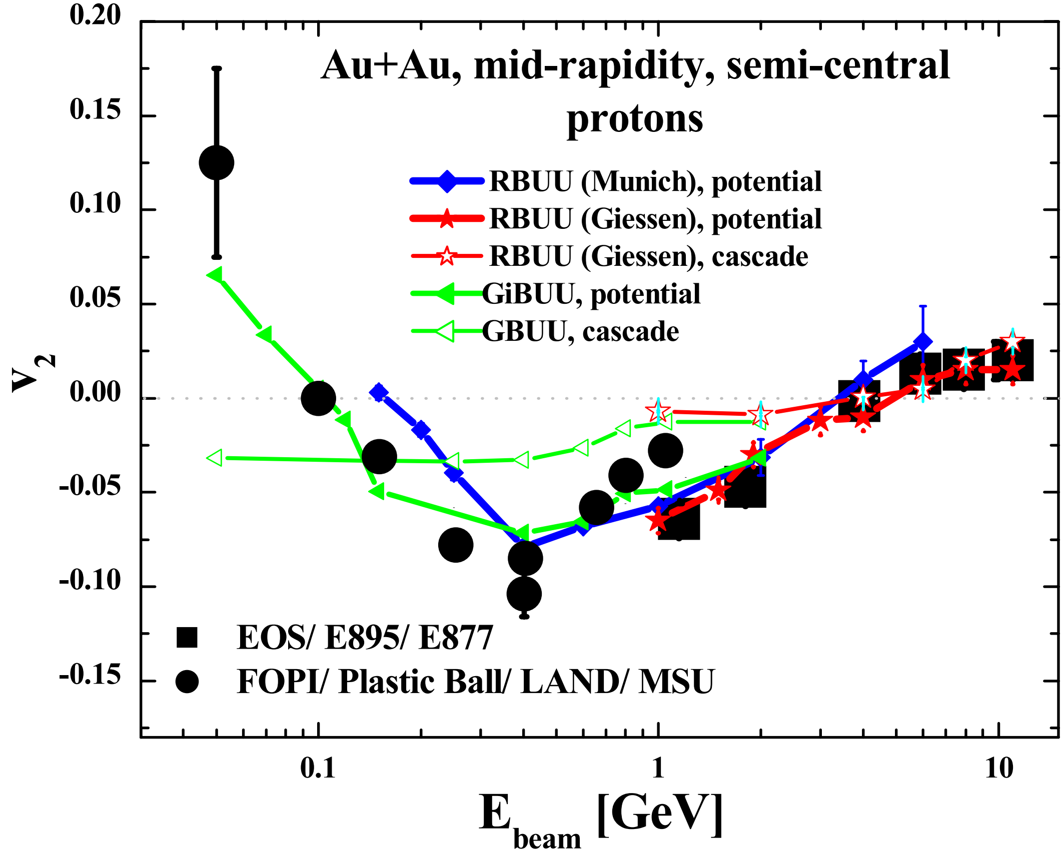
$v_2 = < \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} >$ - elliptic flow

$V_2 > 0$ indicates in-plane emission of particles

$V_2 < 0$ corresponds to a squeeze-out perpendicular to the reaction plane (out-of-plane emission)



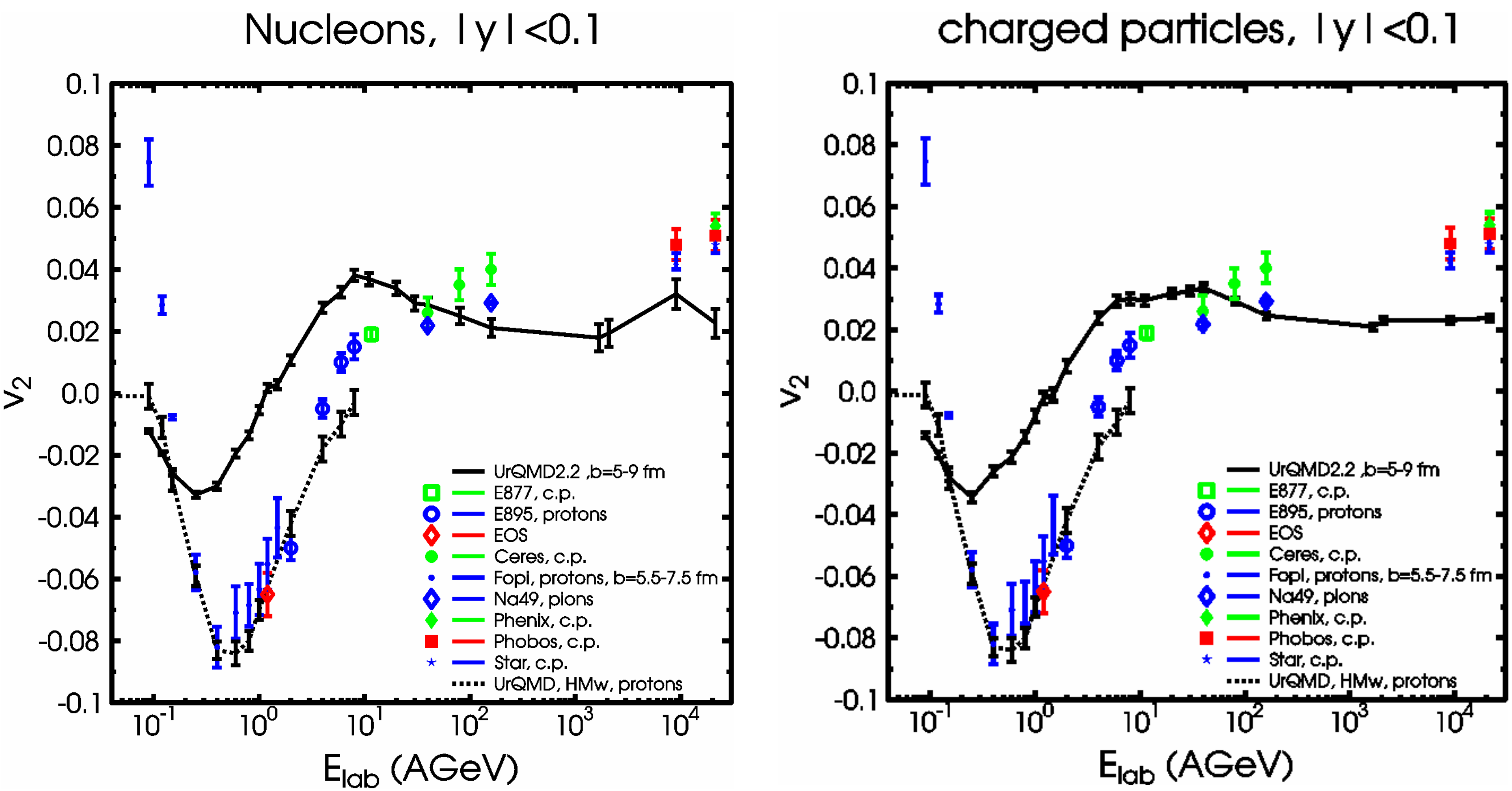
4. Collective flow: v_2 excitation function



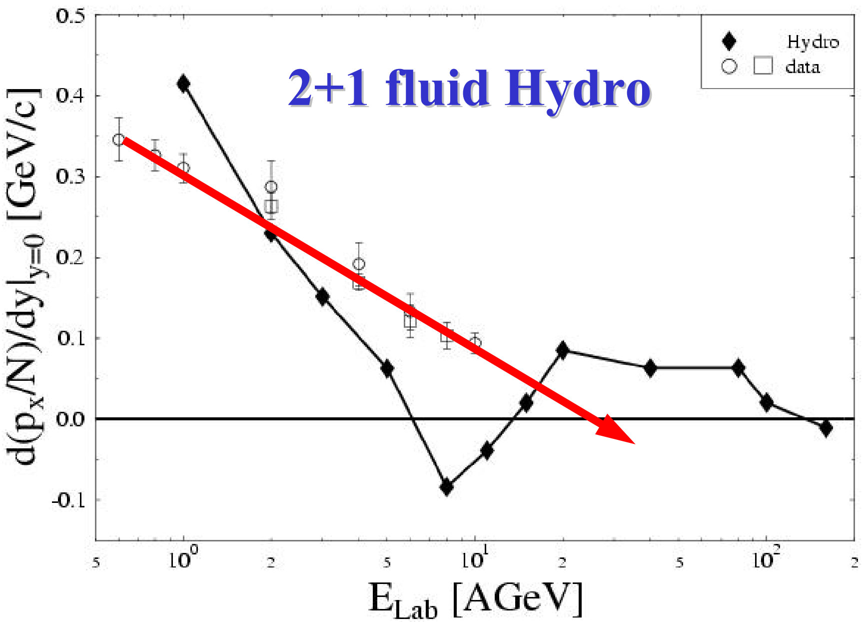
- Proton v_2 at low energy shows sensitivity to the nucleon potential.
- Cascade codes fail to describe the exp. data.
- AGS energies: transition from squeeze-out to in-plane elliptic flow

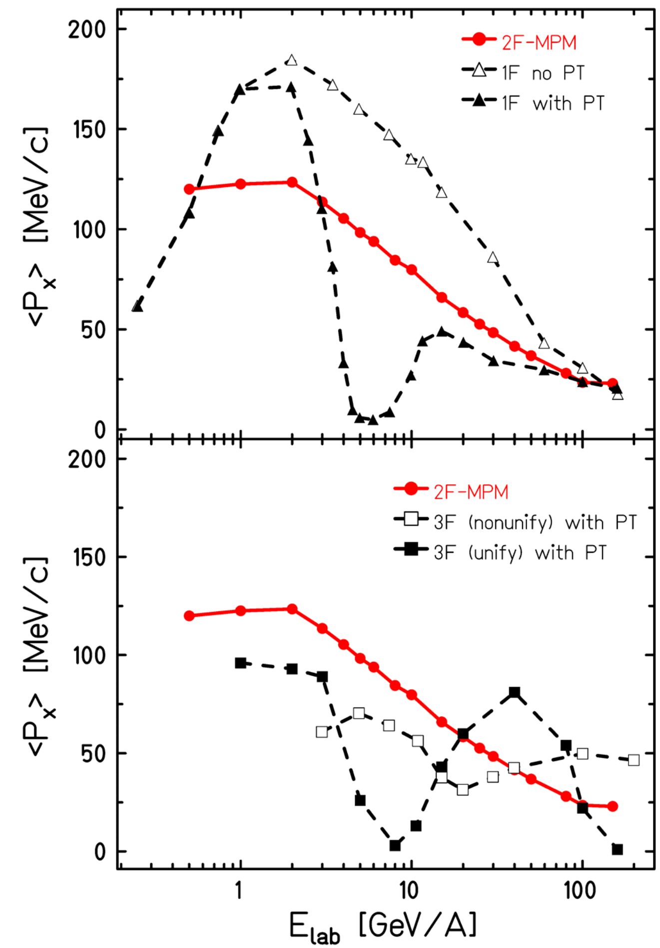
4. Collective flow: v_2 excitation functions

v_2 excitation functions from string-hadronic transport models – UrQMD:



4. Collective flow: v_1 excitation functions



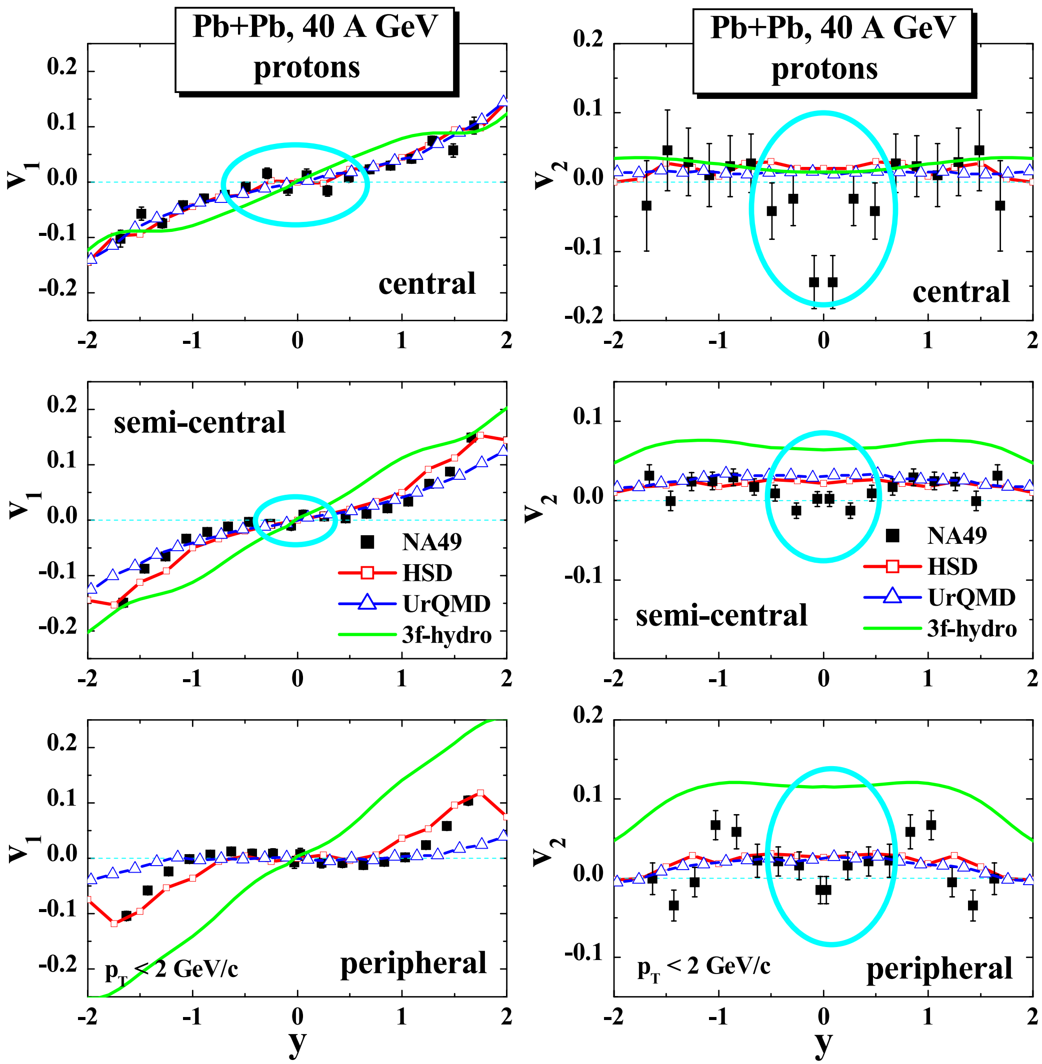


- **2+1 fluid Hydro (Frankfurt) predicts „antiflow“ of protons – if the matter undergoes a 1st order phase transition to the QGP**

- **Warning: other Hydro models don‘t show such „antiflow“ => Hydro results are very sensitive to the initial and „freeze-out“ conditions!**

PT – phase transition
MPM – mixed phase EoS
1F,2F,3F –1,2,3 fluid hydro
(Ivanov et al.)

Directed flow v_1 & elliptic flow v_2 for Pb+Pb at 40 A GeV



- Small wiggle in v_1 at midrapidity not described by HSD, UrQMD and 3-fluid hydro
- Too large elliptic flow v_2 at midrapidity from HSD, UrQMD and 3-fluid hydro for all centralities !

Experimentally: breakdown of v_2 at midrapidity !

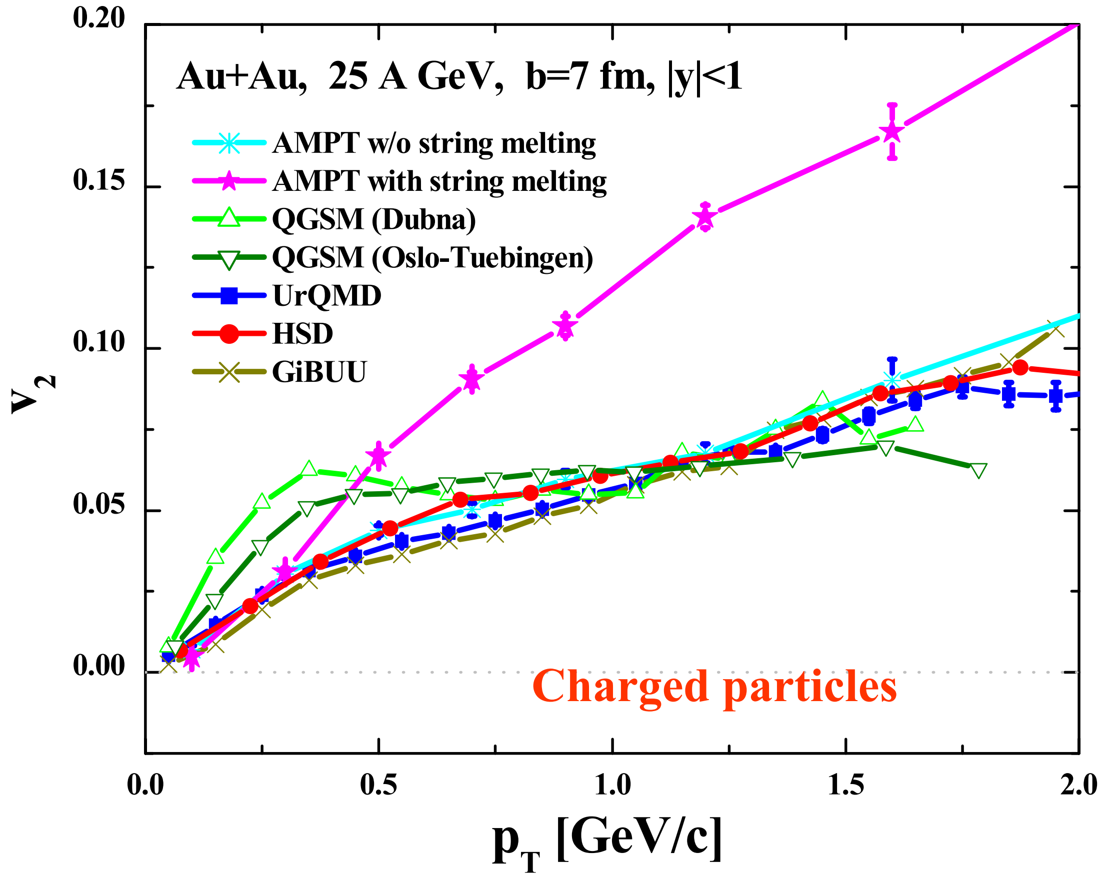
→ Signature for a first order phase transition ?

4. Collective flow: elliptic flow at 25 A GeV – predictions for CBM

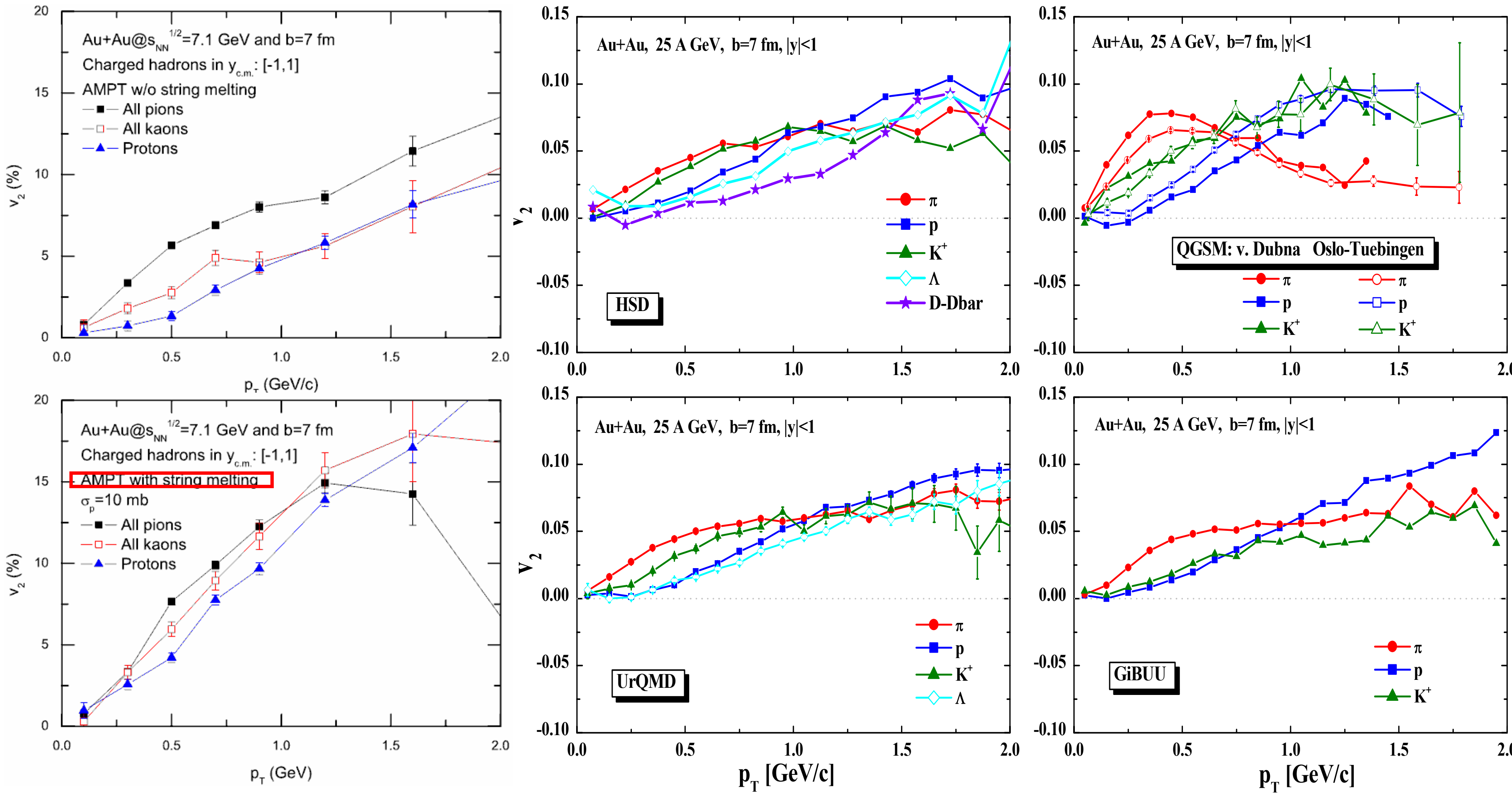
Transport models
- HSD
- UrQMD
- GiBUU
- QGSM (v. Dubna; v. Oslo-Tuebingen)
- AMPT without string melting

predict similar v_2 for charged particles!

AMPT with string melting shows much stronger v_2 for charges particles !



4. Collective flow: elliptic flow at 25 A GeV – predictions for CBM



AMPT with string melting shows v_2 similar for all particles !

5. Dileptons

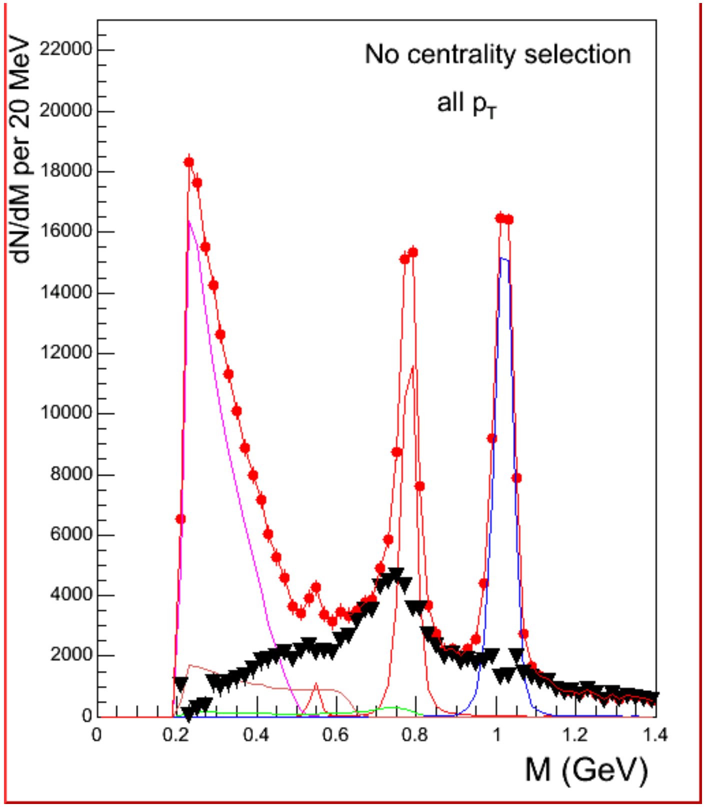
Dileptons are an ideal probe for vector meson spectroscopy in the nuclear medium and for the nuclear dynamics !

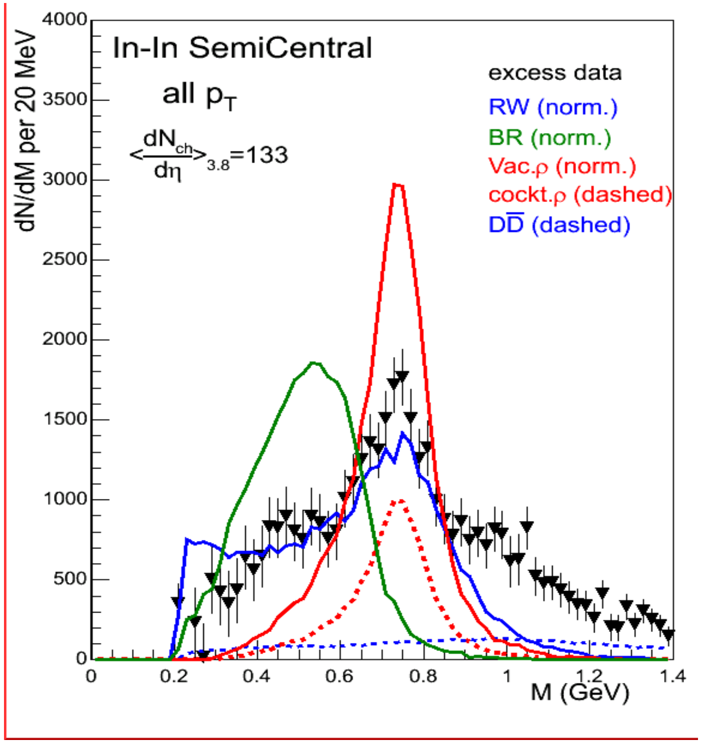
- Study of in-medium effects with dilepton experiments:
  - „Historical“ overview – DLS, SPS (CERES, HELIOS)
  - Novel experiments – HADES, NA50, CERES, PHENIX
  - Future – CBM

- Excitation function for dilepton yields
- Predictions for CBM (e+e- and μ+μ-)

- Direct photons as a possible observable for CBM ?!

5. Dileptons

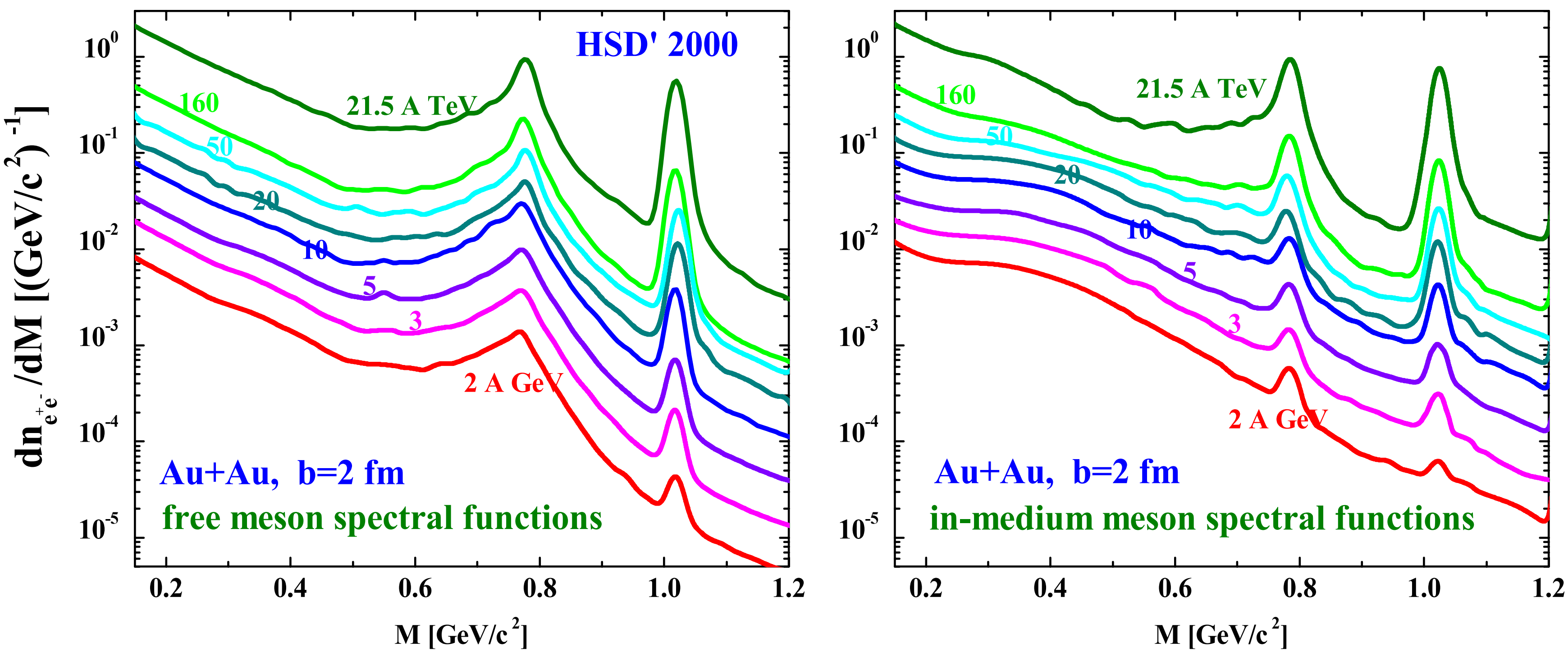




High precision NA60 data allow to distinguish among in-medium models!

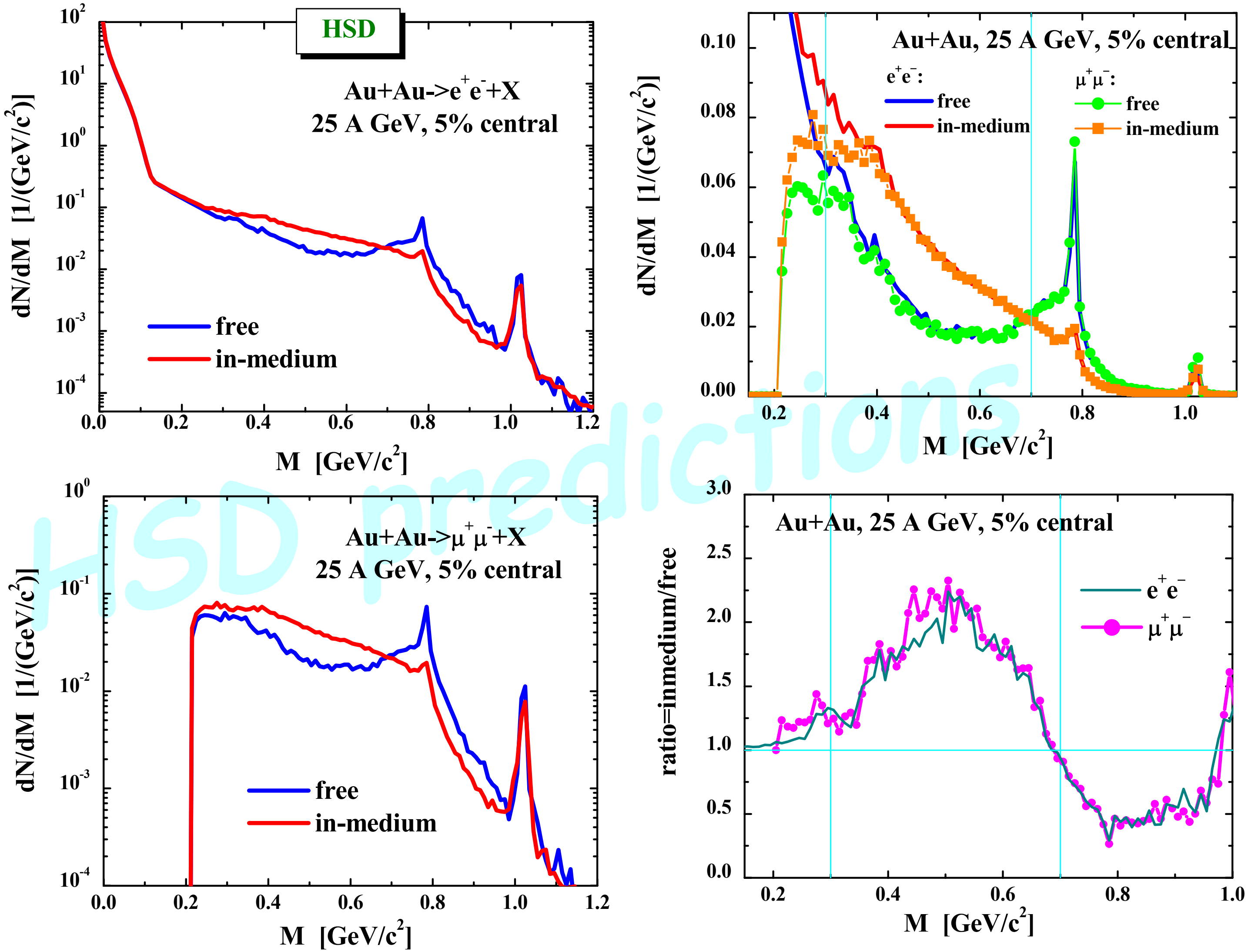
Clear evidence for a broadening of the ρ spectral function!

5. Dileptons



- Dilepton yield increases with energy due to a higher production of mesons
- ρ melts at practically all energies; ω and ϕ show clear peaks on an approx. exponential background in mass!

5. Dileptons – prediction for CBM



In-medium modifications of e+e- and μ+μ- spectra are very similar!

6. Open and hidden charm

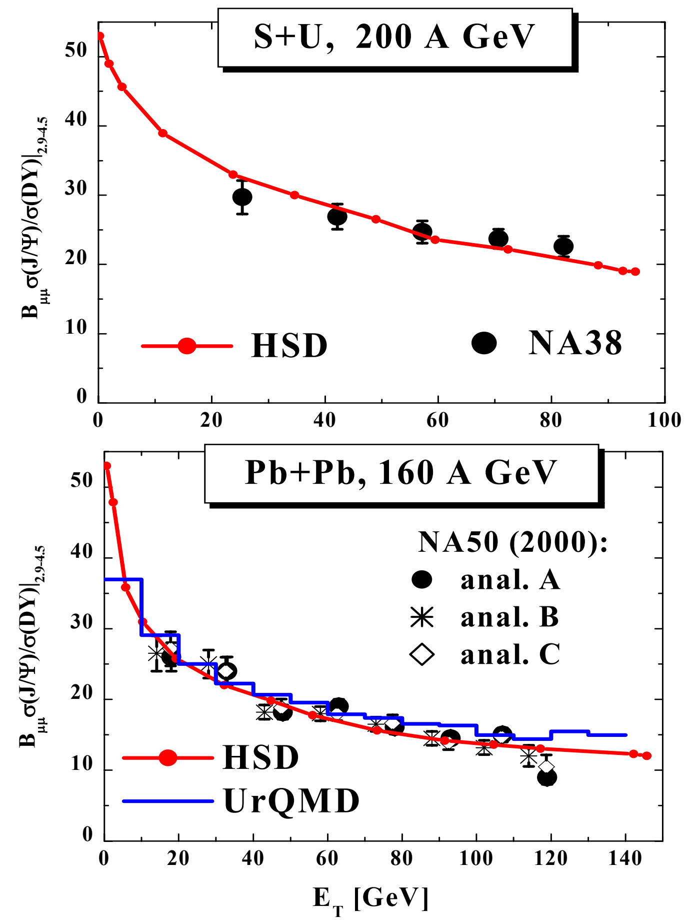
Heavy flavor sector reflects the actual dynamics since heavy hadrons can only be formed in the very early phase of heavy-ion collisions at FAIR/SPS!

- **Hidden charm: J/Ψ , Ψ'**

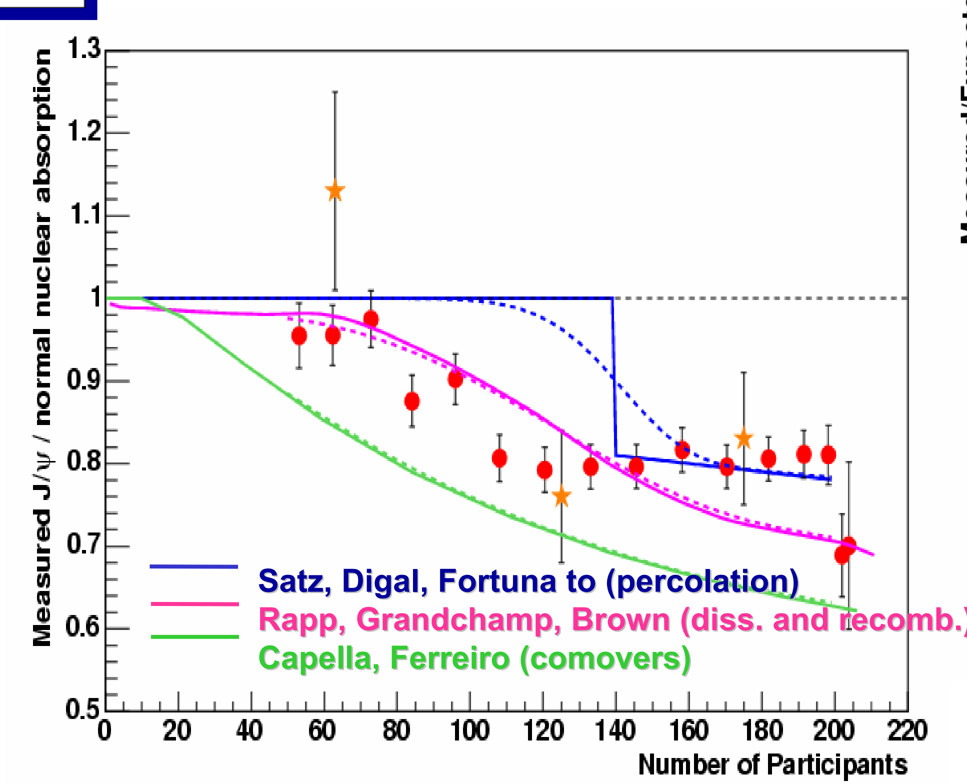
Anomalous J/Ψ suppression in A+A (NA38/NA50)

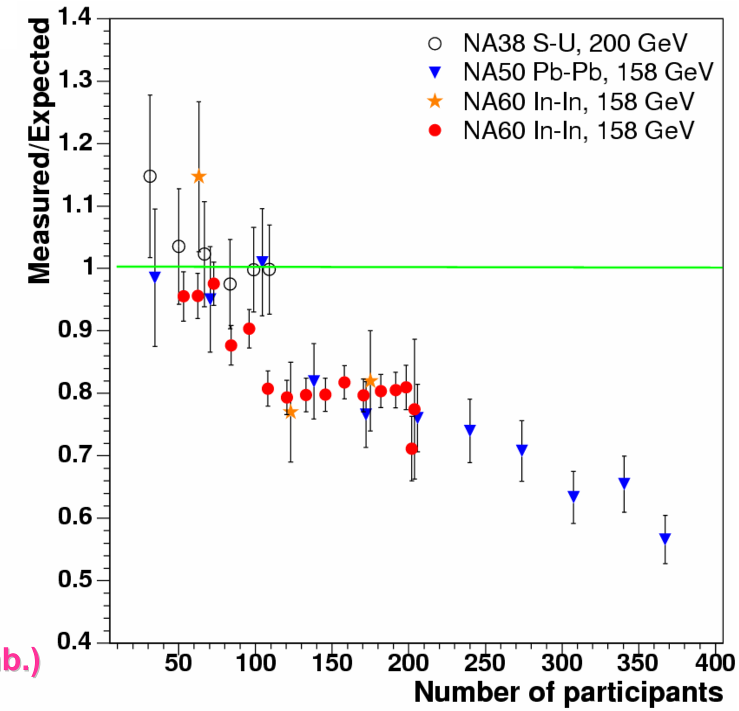
Comover dissociation in the transport approaches – HSD & UrQMD

NA50 data are consistent with comover absorption models



6. Open and hidden charm





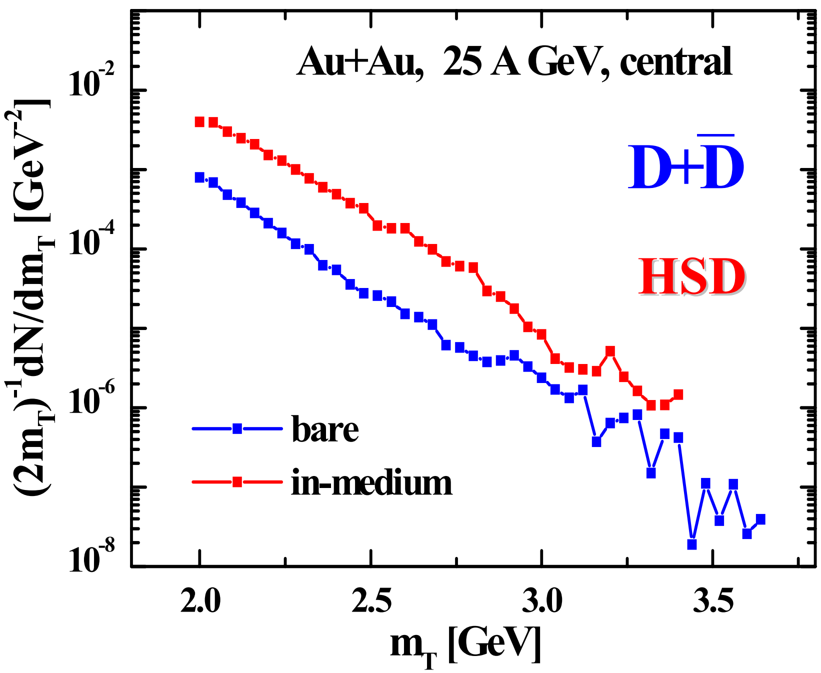
New NA60 data for In+In at 160 A GeV: no consistent description has been found so far with Glauber type comover absorption models

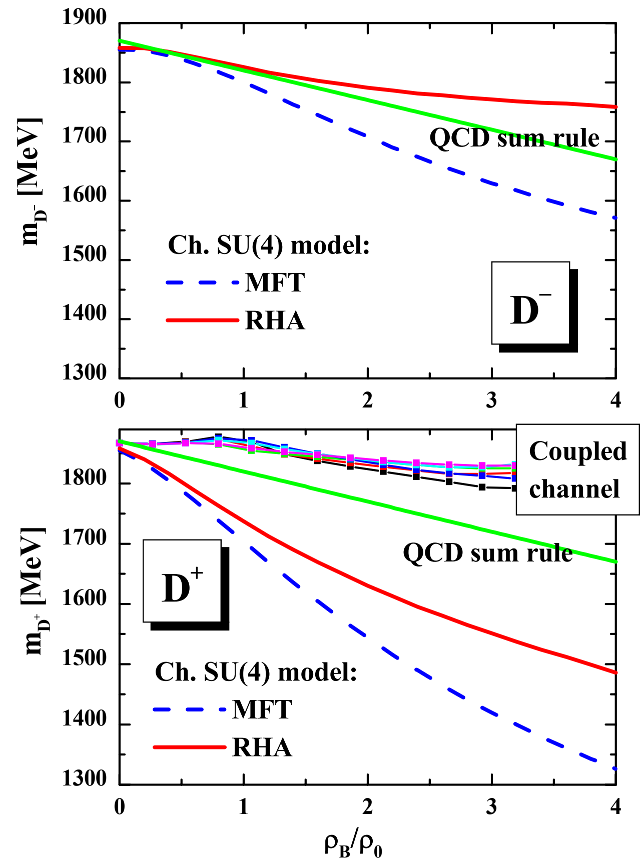
Note: no final transport calculations yet for In+In! (work in progress!)

6. Open and hidden charm

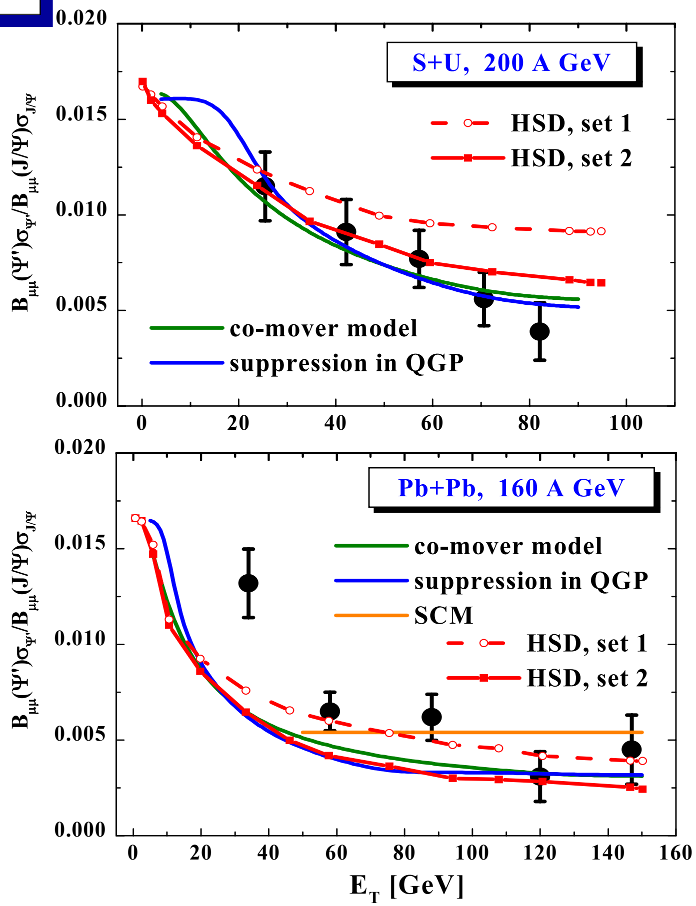
■ Open charm: D-mesons

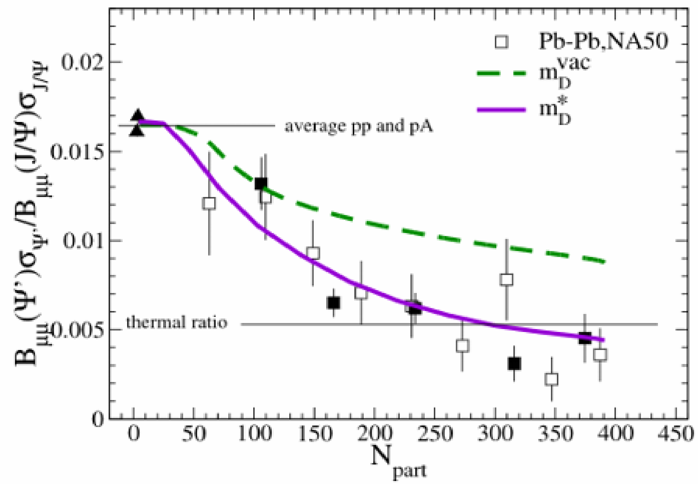
- **Dropping D-meson masses with increasing light quark density might give a large enhancement of the open charm yield at 25 A GeV !**





6. Open and hidden charm

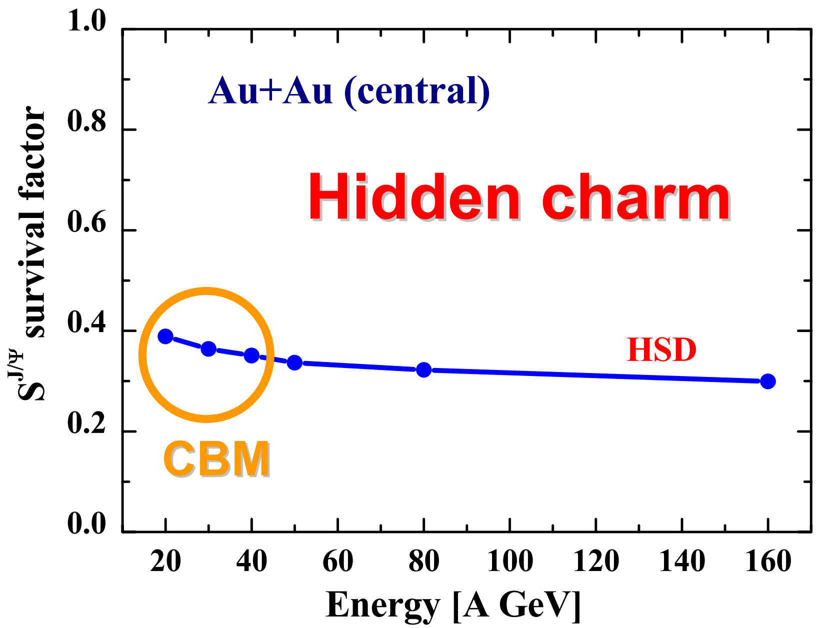


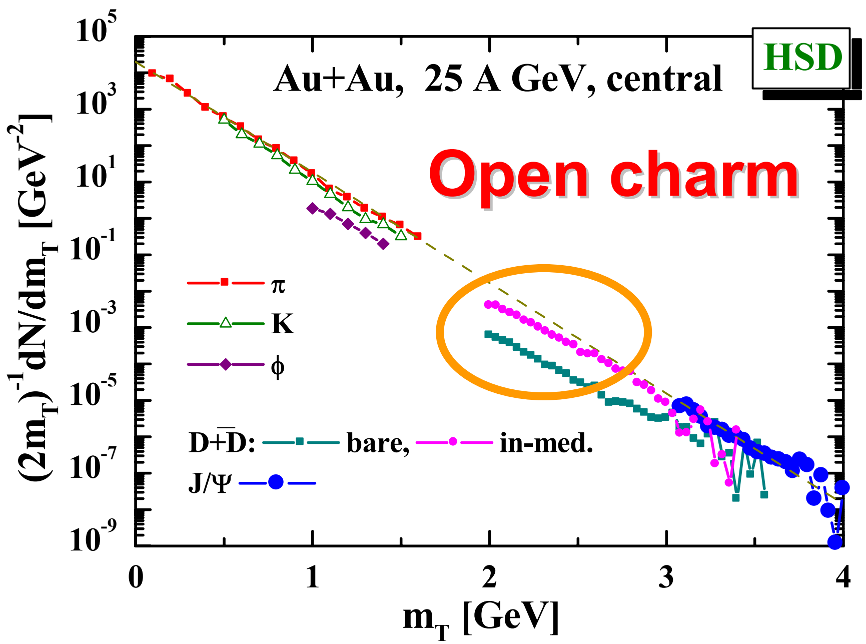


- In-medium reduction of D/Dbar masses might have a strong influence on Ψ‘ suppression due to the opening of the Ψ‘->D Dbar decay channel [Rapp, Brown et al.]

- The Ψ‘/J/Ψ ratio gives information about the approach to chemical equilibration: charm chemical equilibration is not achieved in HSD since the Ψ‘ mesons are more suppressed relative to J/Ψ

6. Open and hidden charm - predictions for CBM





Open charm:

- **without medium effects:** suppression of D-meson spectra by factor ~ 10 relative to the global m_T-scaling
- **with medium effects:** restoration of the global m_T-scaling for the mesons

Hidden charm:

J/Ψ suppression due to comover absorption at FAIR is lower as at SPS

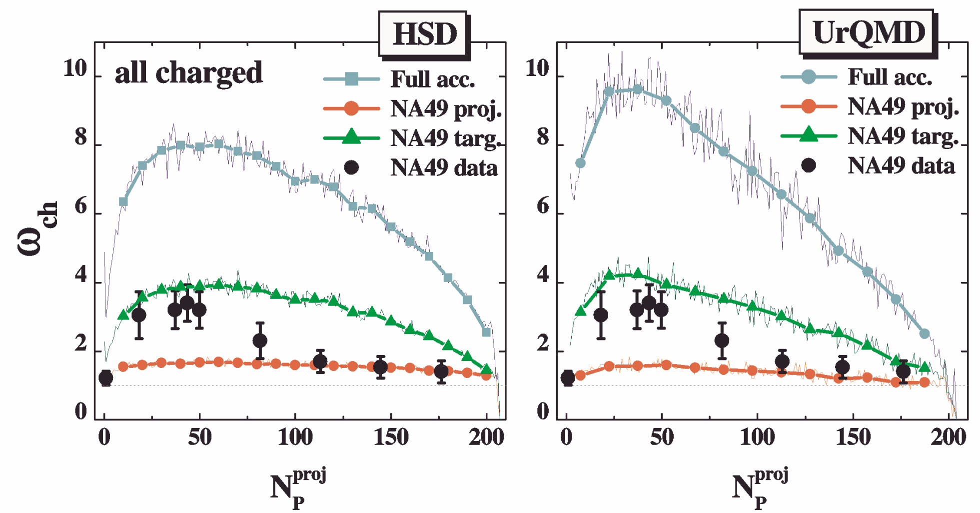
7. Fluctuations and correlations

Fluctuation and correlation measurements provide information on susceptibilities of matter: rapid changes reflect the order of the phase transition

- **Multiplicity fluctuations ω of negatively, positively and all charged particles as a function of the number of projectile participants N_{part}^{proj} :**

$$\omega = \frac{Var(N)}{\langle N \rangle} = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}$$

ω=1 - Poissonian multiplicity distribution with no dynamical correlations

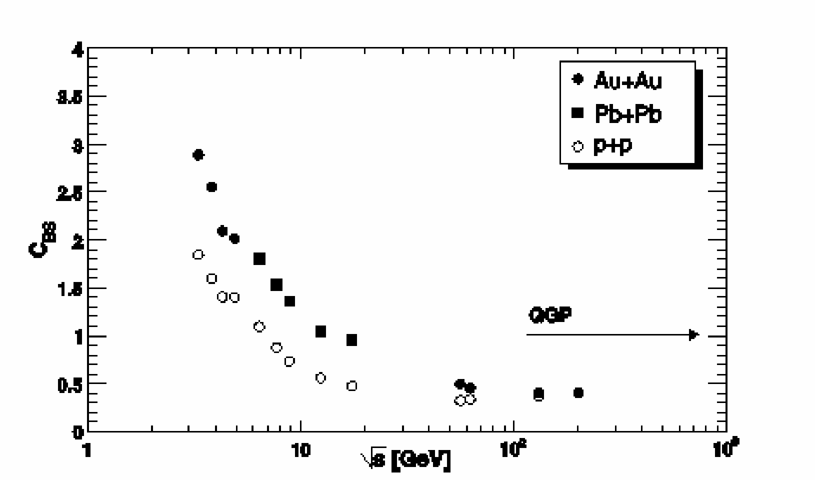


HSD and UrQMD show strong multiplicity fluctuations in 4π ‚full' acceptance, however, the observed (by NA49) non-trivial system size dependence of multiplicity fluctuations is not reproduced by HSD and UrQMD !

7. Fluctuations and correlations

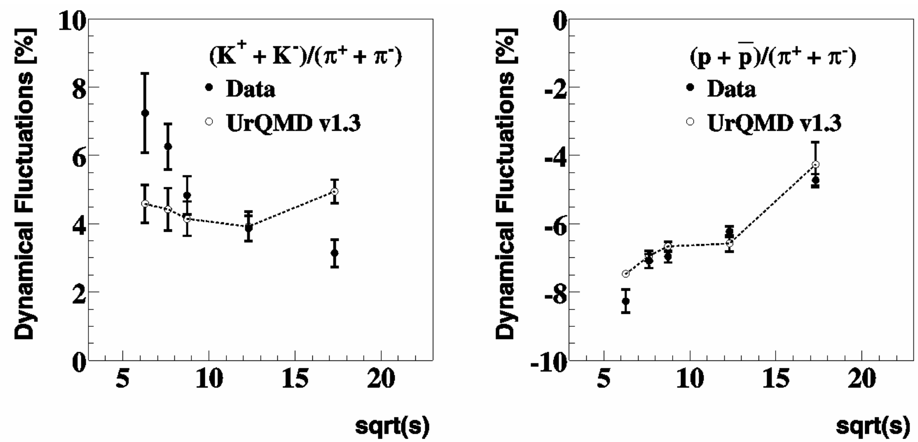
- **Predictions: Excitation function of the correlation coefficient C_{BS} for central Pb+Pb and minimum bias p+p collisions calculated within UrQMD:**

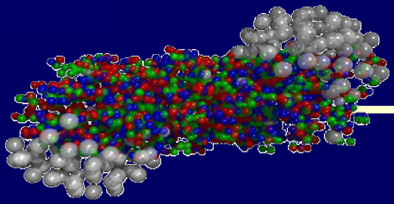
$$C_{BS} = -3\frac{\frac{1}{N}\sum_n B^{(n)}S^{(n)} - \left(\frac{1}{N}\sum_n B^{(n)}\right)\left(\frac{1}{N}\sum_n S^{(n)}\right)}{\frac{1}{N}\sum_n \left(S^{(n)}\right)^2 - \left(\frac{1}{N}\sum_n S^{(n)}\right)^2}$$



$B^{(n)}$, $S^{(n)}$ – baryon number and strangeness in a given event (n)

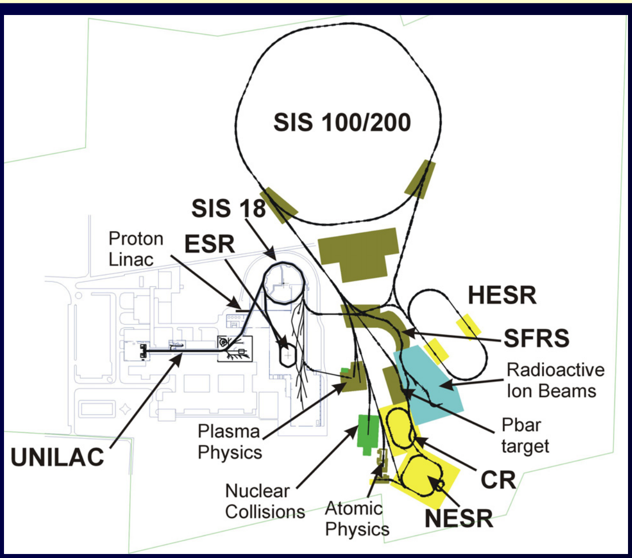
- **Energy dependence of event-by-event fluctuations of the ratios $(K^+ + K^-)/(\pi^+ + \pi^-)$ and $(p+pbar)/(\pi^+ + \pi^-)$ within the UrQMD model:**

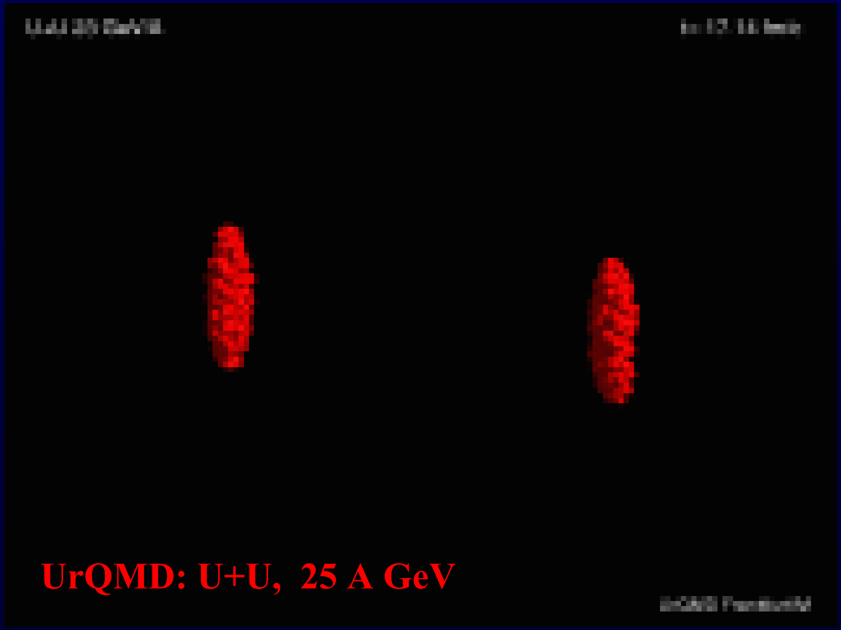




Summary

- **FAIR** is an **excellent facility** to study the properties of sQGP (strongly interacting ‚color liquid') as well as hadronic matter





- **Transport theory** is the **general basis** for an understanding of nuclear dynamics on a microscopic level

How to model a phase transition from hadronic to partonic matter?