Particle production in transport approaches

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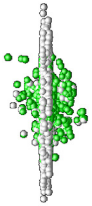
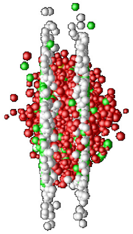
15.12.2005



What can we learn from heavy-ion collisions ?



Low **Intermediate** **High** **Ultra-High** **energy [A GeV]**

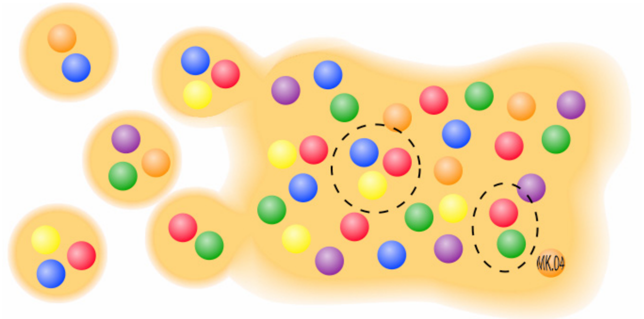
0.1 1 10 100 1000 10000 100000

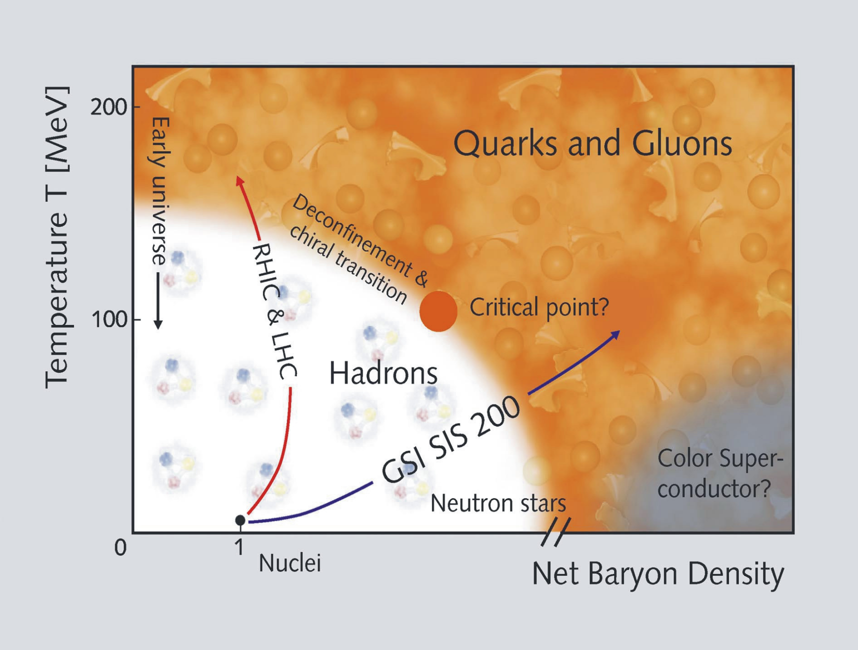
SIS **AGS, FAIR** **SPS** **RHIC** **LHC ->**

Baryonic matter
||
In-medium effects

Mixed phase:
hadrons (baryons, mesons) +
quarks and gluons
||
In-medium effects
Chiral symmetry restoration
Phase transition to sQGP

QGP: quarks and gluons
||
Properties of sQGP





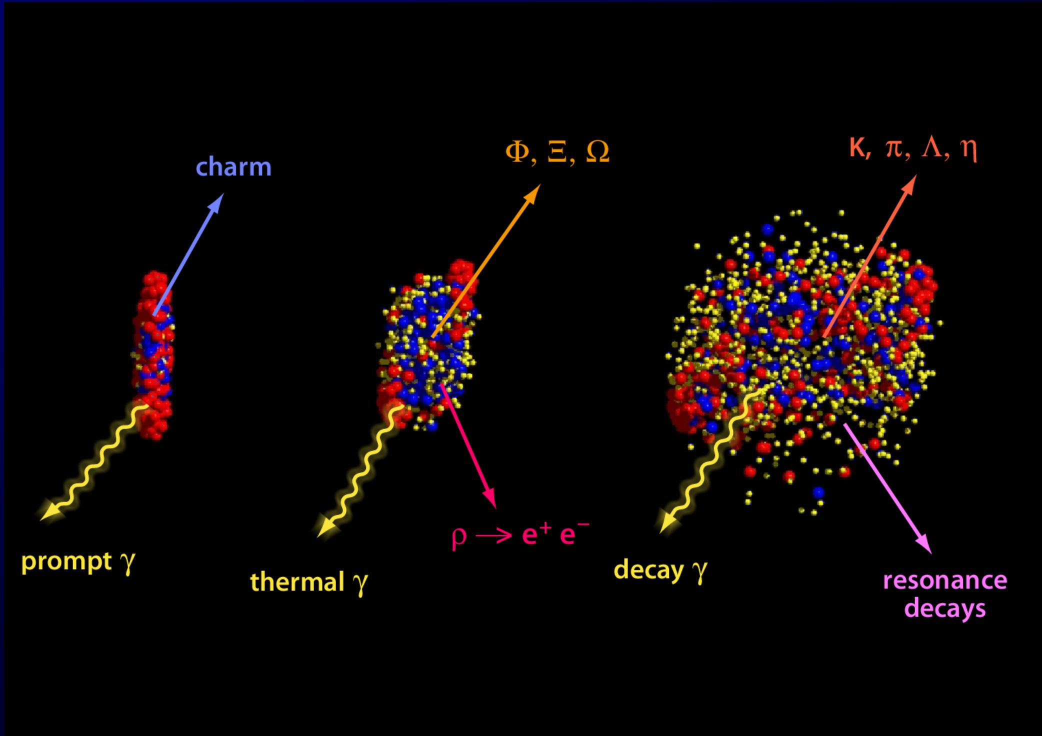
Signals of the phase transition:

- Strangeness enhancement
- Multi-strange particle enhancement in A+A
- Charm suppression
- Collective flow (v_1, v_2)
- Thermal dileptons
- Jet quenching and angular correlations
- High p_T suppression of hadrons
- Nonstatistical event by event fluctuations and correlations
- ...

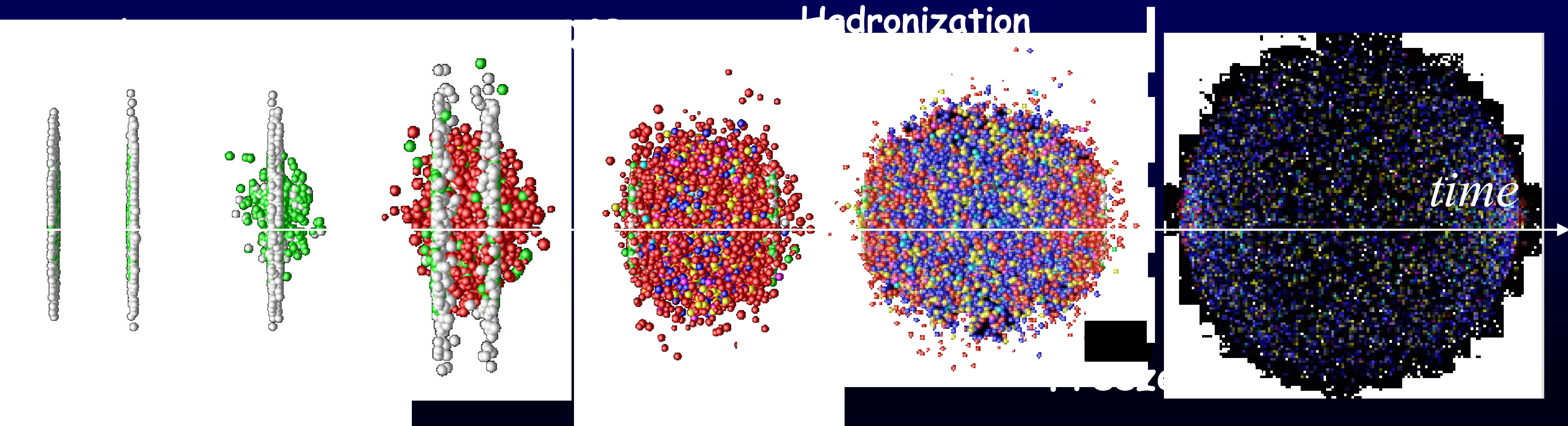
Experiment: measures final hadrons and leptons

How to learn about physics from data?

Compare with theory!



Models for heavy-ion collisions



Thermal models

Hydro models (local equilibrium)

Transport models

Microscopical transport models provide a unique dynamical description of nonequilibrium effects in heavy-ion collisions

Basic concept of HSD & UrQMD

HSD – Hadron-String-Dynamics transport approach

UrQMD – Ultra-relativistic-Quantum-Molecular-Dynamics

- **for each particle species *i* (*i* = *N*, *R*, *Y*, π, ρ, K, …) the phase-space density f_i follows the transport equations**

$$\left(\frac{\partial}{\partial t} + \left(\nabla_{\vec{p}} H\right) \nabla_{\vec{r}} - \left(\nabla_{\vec{r}} H\right) \nabla_{\vec{p}} \right) f_i(\vec{r},\vec{p},t) = I_{coll}(f_1, f_2, \ldots, f_M)$$

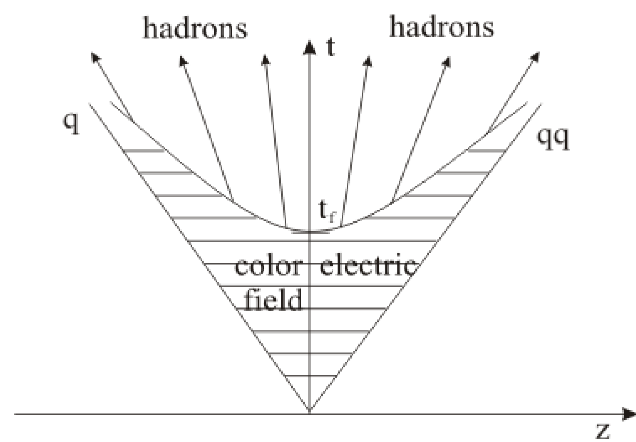
with collision terms I_{coll} describing:

- **elastic and inelastic hadronic reactions:**
- **baryon-baryon, meson-baryon, meson-meson**
- **formation and decay of baryonic and mesonic resonances**
- **string formation and decay**

- **Implementation of detailed balance on the level of 1<–>2 and 2<–>2 reactions (+ 2<–>n multi-meson fusion reactions in HSD)**

Degrees of freedom in HSD & UrQMD

- **hadrons - baryons and mesons including excited states (resonances)**
- **strings – excited color singlet states (qq - q) or (q – qbar)**
  Based on the LUND string model
  & perturbative QCD via PYTHIA
- **leading quarks (q, qbar) & diquarks**
  (q-q, qbar-qbar)



NOT included in the transport models presented here :

- **no explicit parton-parton interactions (i.e. between quarks and gluons) outside strings!**
- **no explicit phase transition from hadronic to partonic degrees of freedom**
- **QCD EoS for partonic phase**

Description of elementary reactions in HSD & UrQMD

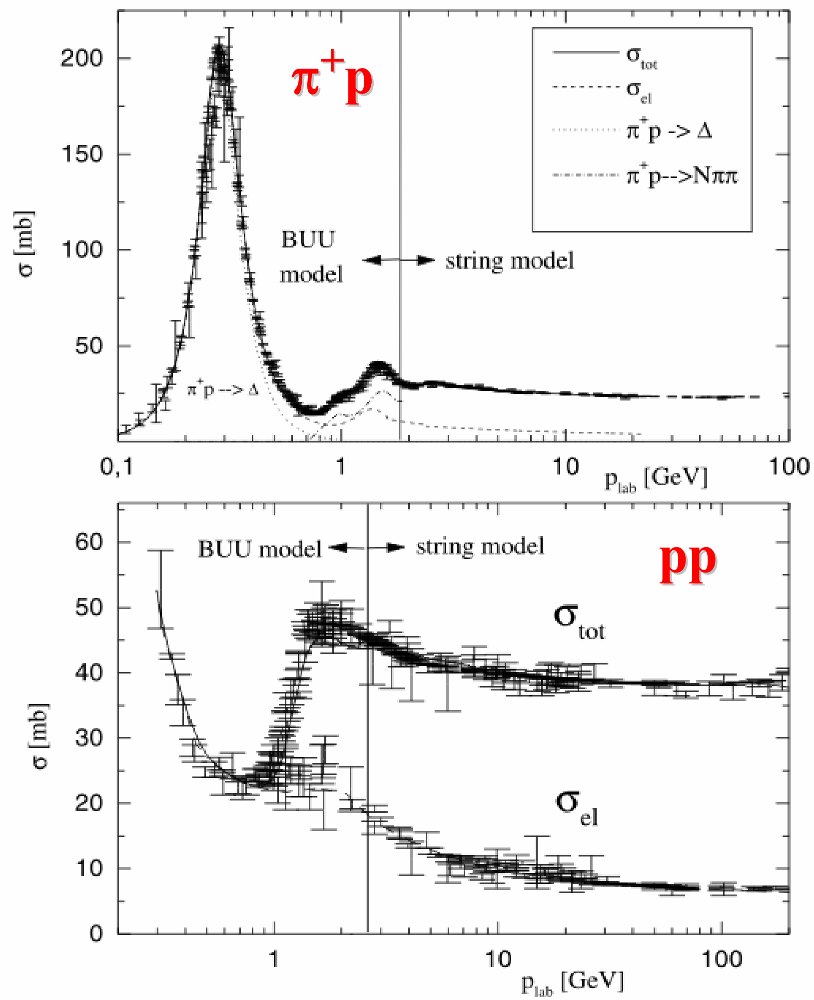
Low energy collisions:

- binary 2<–>2 and 2<–>3 reactions
- formation and decay of baryonic and mesonic resonances

BB <–> B´B´
BB <–> B´B´m

mB <–> m´B´
mB <–> B´

Baryons:
B=(p, n, Δ(1232), N(1440), N(1535), ...)
Mesons:
m=(π, η, ρ, ω, φ, ...)



High energy collisions:
(above $s^{1/2}$~2.5 GeV)

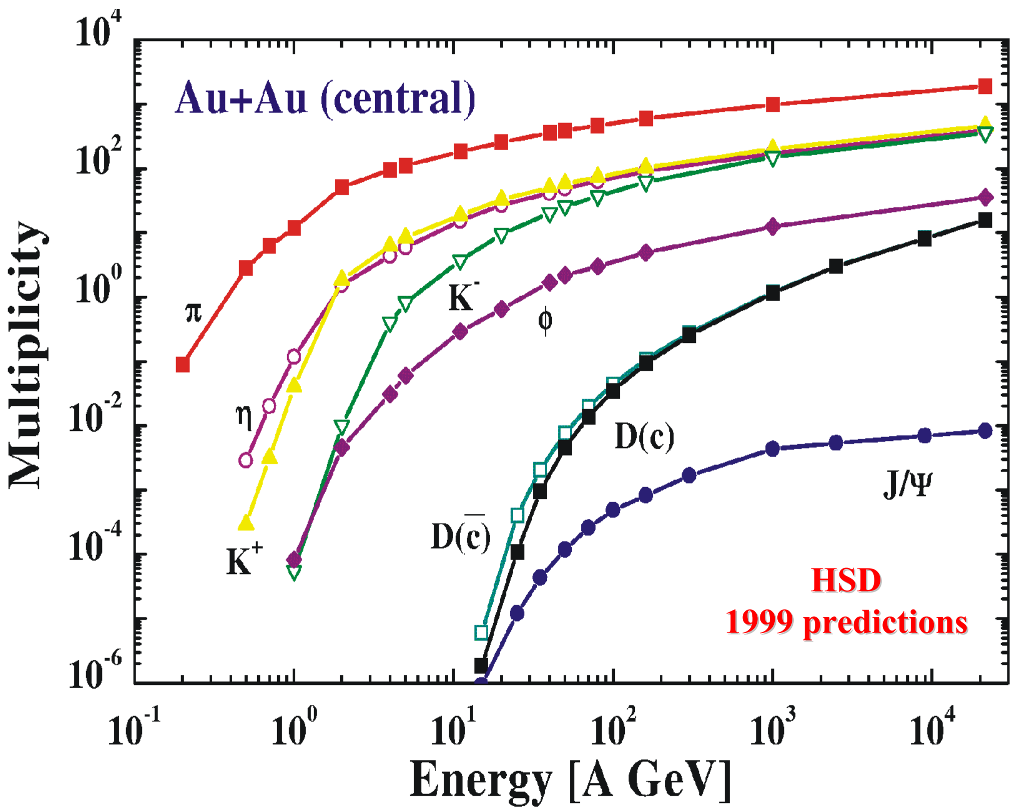
Inclusive particle production:

BB –> X , mB –>X
X =many particles

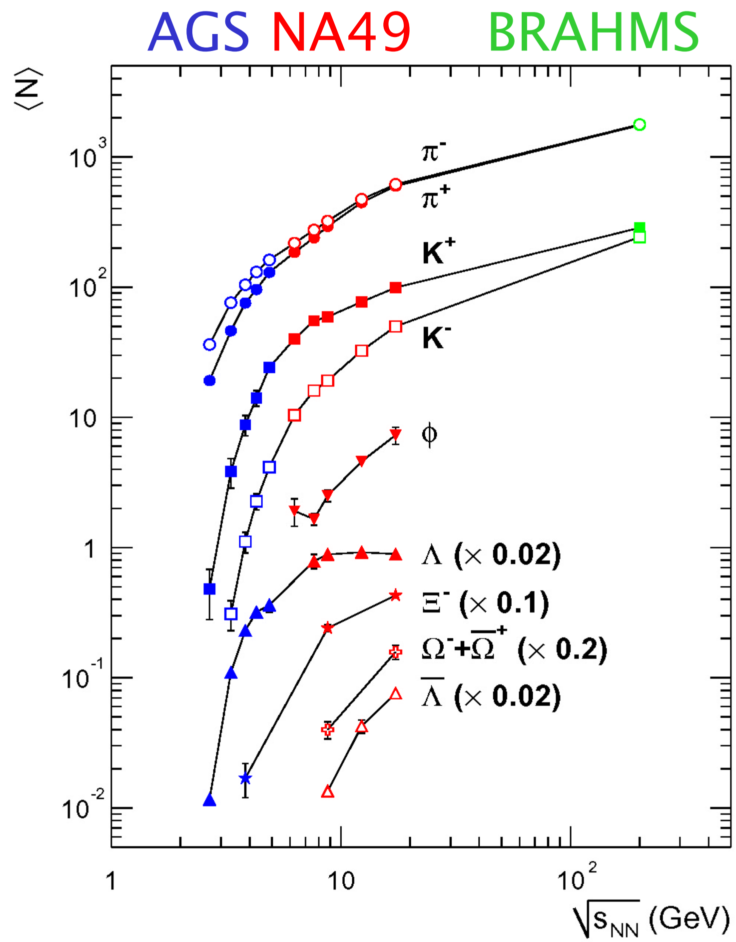
described by string formation and decay

HSD & UrQMD – microscopic models for heavy-ion reactions

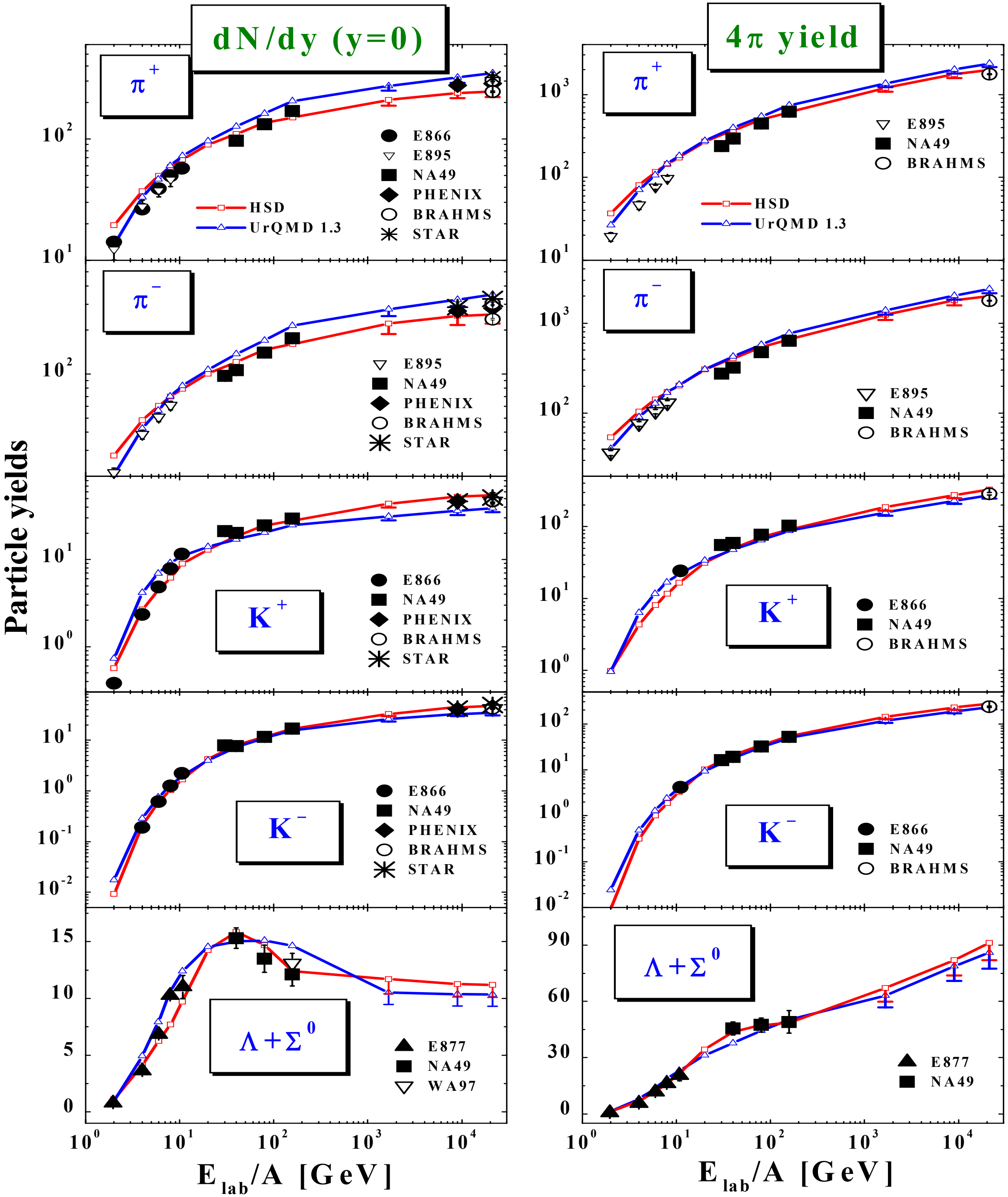
- very good description of particle production in pp, pA reactions
- unique description of nuclear dynamics from low (~100 MeV) to ultrarelativistic (~100 TeV) energies



FAIR



Strangeness

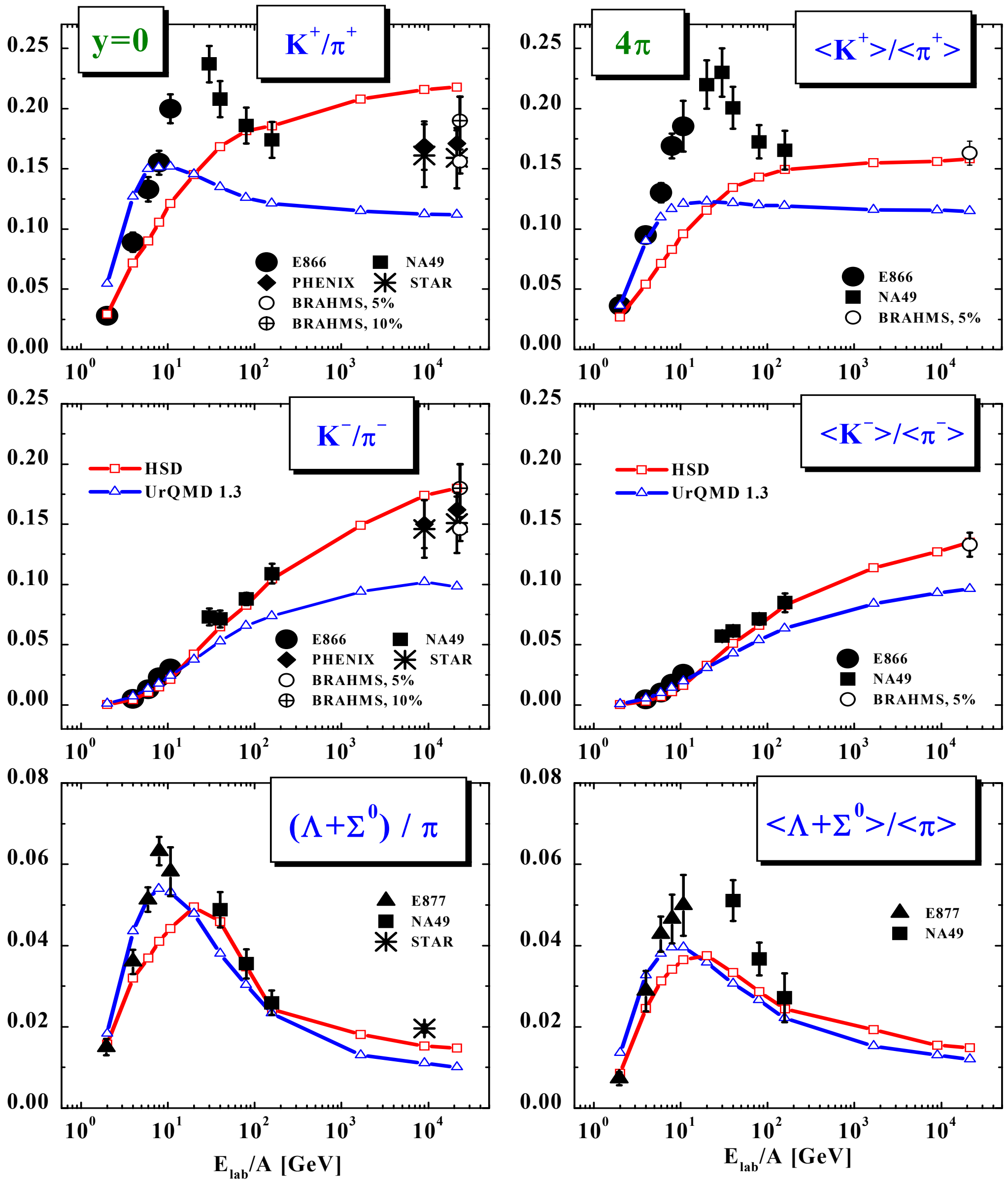


Excitation function of $\pi^{\pm}$, $K^{\pm}$, $(\Lambda+\Sigma^0)$ yields

- Reasonable description of **strangeness** by HSD and UrQMD
- HSD overestimates **pions** at low AGS
- UrQMD overestimates **pions** at top AGS and above

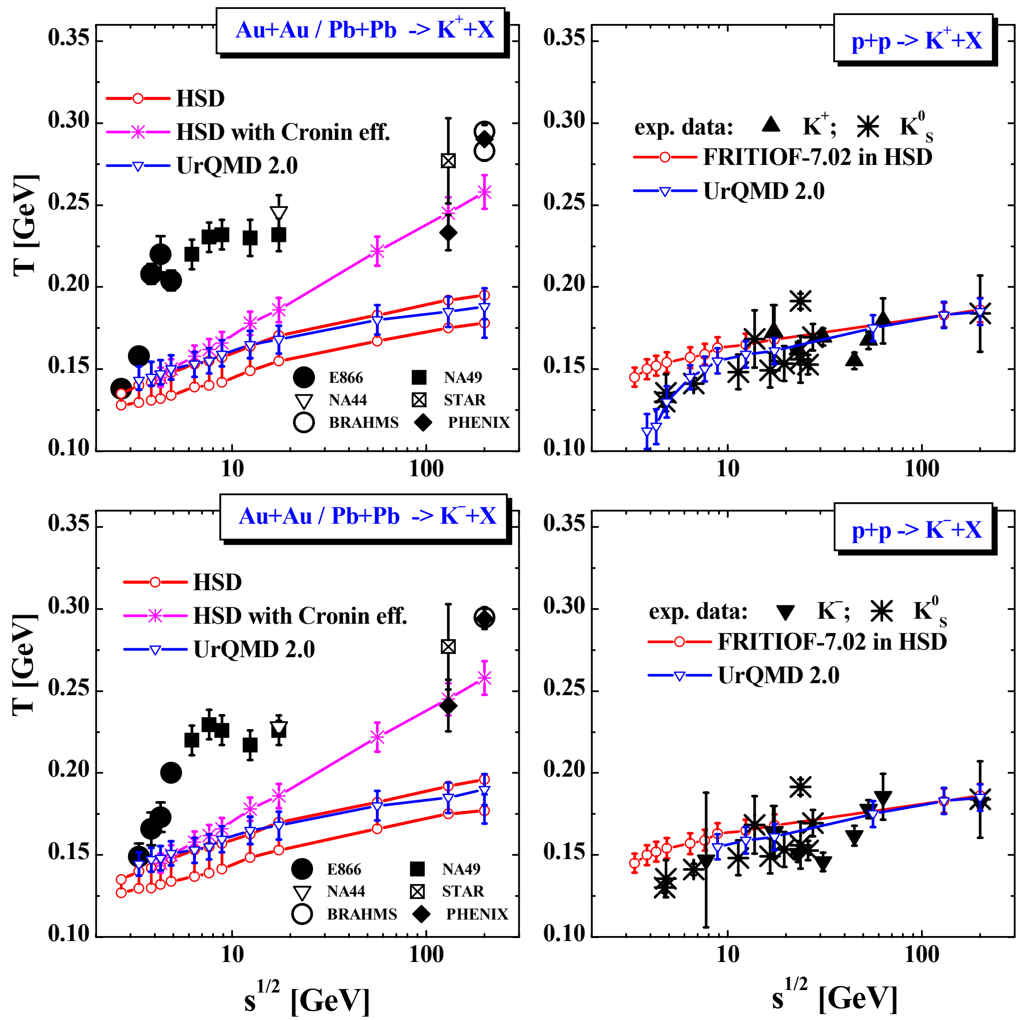
(deviations < 20%)

Excitation function of K^+/π^+, K^-/π^-, $(\Lambda+\Sigma^0)/\pi$ ratios



Experimental K^+/π^+ ratios show a peak at ~30 A GeV (‚horn'), which is not reproduced by the transport approaches HSD and UrQMD !

Inverse slopes T for K^+ and K^-



- Transverse mass spectra of $\pi^{\pm}$, $K^{\pm}$ from p+p and p+A collisions are well reproduced at all energies as well as for light systems C+C and Si+Si at 160 A GeV
- In UrQMD and HSD hadronic rescattering has only a small impact on the kaon slope
- Cronin effect - initial state semi-hard gluon radiation- leads to a substantial hardening of the m_T spectra at RHIC, however, has a very small effect at low energies

||

- The hadron-string picture fails?

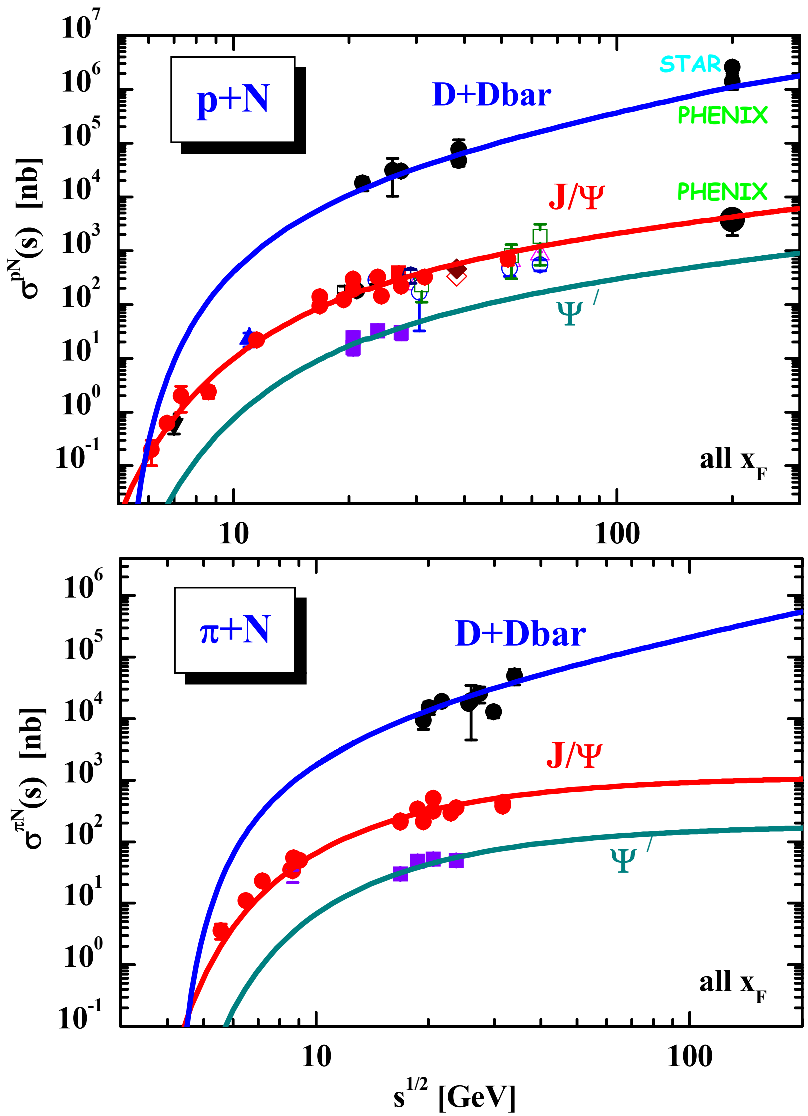
=> New degrees of freedom (colored partons – q^C, g^a) are missing ?!

PRL 92 (2004) 032302

PRC 69 (2004) 015202

Open and hidden charm

D/Dbar, J/Ψ and Ψ' production cross sections in pN and πN



σ(D/Dbar): parametrization of **PYTHIA** ($s^{1/2} > 10$ GeV) scaled by factor **K** to the available exp. data + threshold extrapolation

D/Dbar ‚chemistry' (i.e. flavor decomposition: D^0, D^+, D^-,...) – from PYTHIA

σ(J/Ψ) and σ(Ψ'): parametrization of the available experimental data

But data close to threshold are still needed !

FAIR

Scenarios for charmonium suppression in A+A

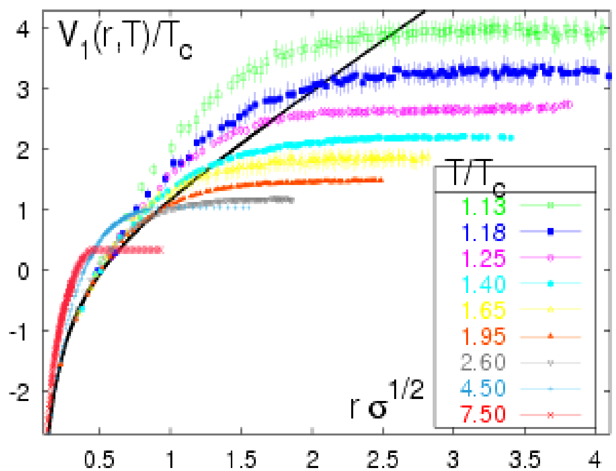
- **QGP color screening**

[Matsui and Satz ’86]

but (!)

Lattice QCD predicts (2004):

J/Ψ can exist up to ~2 T_C !



Regeneration of J/Ψ in QGP at T_C:

[Braun-Munzinger, Thews, Ko et al. `01]

J/Ψ+g <–> c+cbar+g

- **Comover absorption**

[Gavin & Vogt, Capella et al.`97]:

charmonium absorption by low energy inelastic scattering with ‚comoving‘ mesons (m=π,η,ρ,...)

+ regeneration:

J/Ψ+m <–> D+Dbar

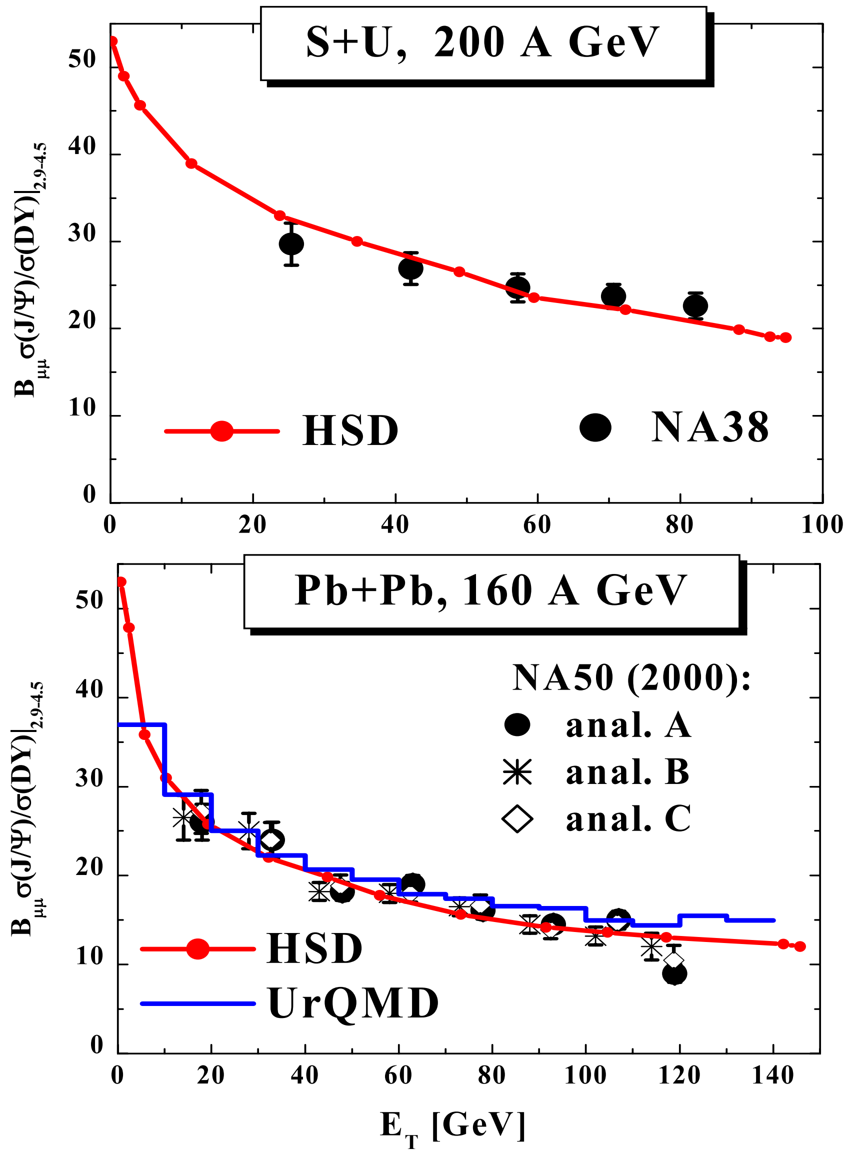
Ψ‘+m <–> D+Dbar

χ_C+m <–> D+Dbar

Meson absorption cross section – strongly model dependent

σ_{abs}^{mesons} ~1-10 mb

J/Ψ suppression in S+U and Pb+Pb at SPS

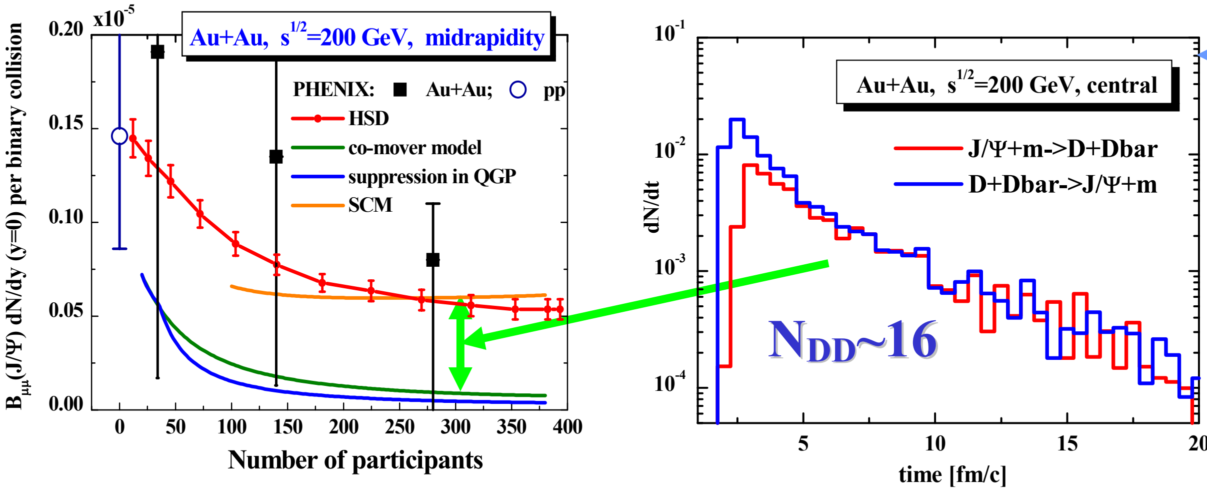


Comover model in the transport approaches – HSD & UrQMD

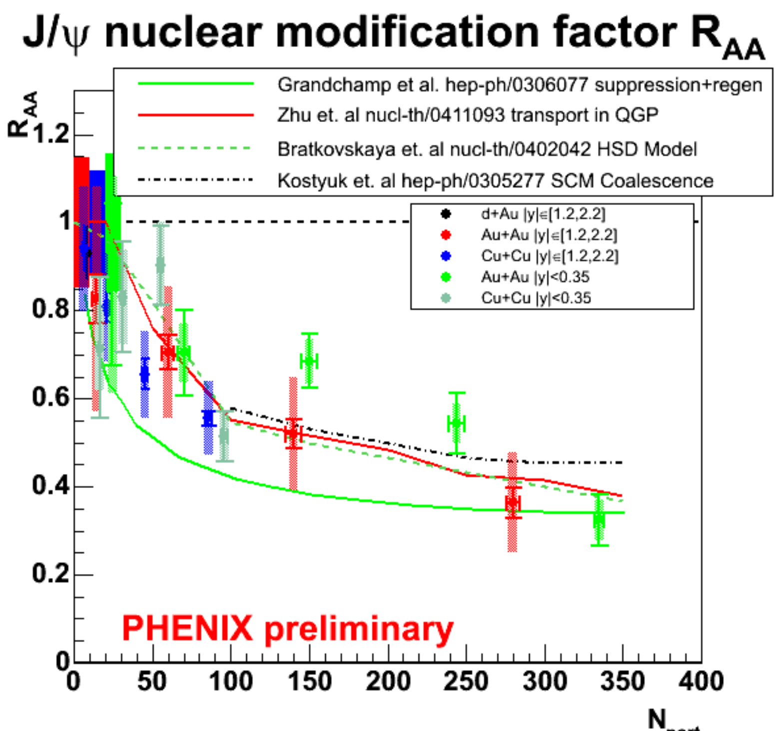
Existing exp. data at SPS (NA50 Collaboration) are consistent with comover absorption models

PRC 69 (2004) 054903

J/Ψ suppression in Au+Au at RHIC



Time dependence of the rate of **J/Ψ absorption by mesons** and recreation by D+Dbar annihilation

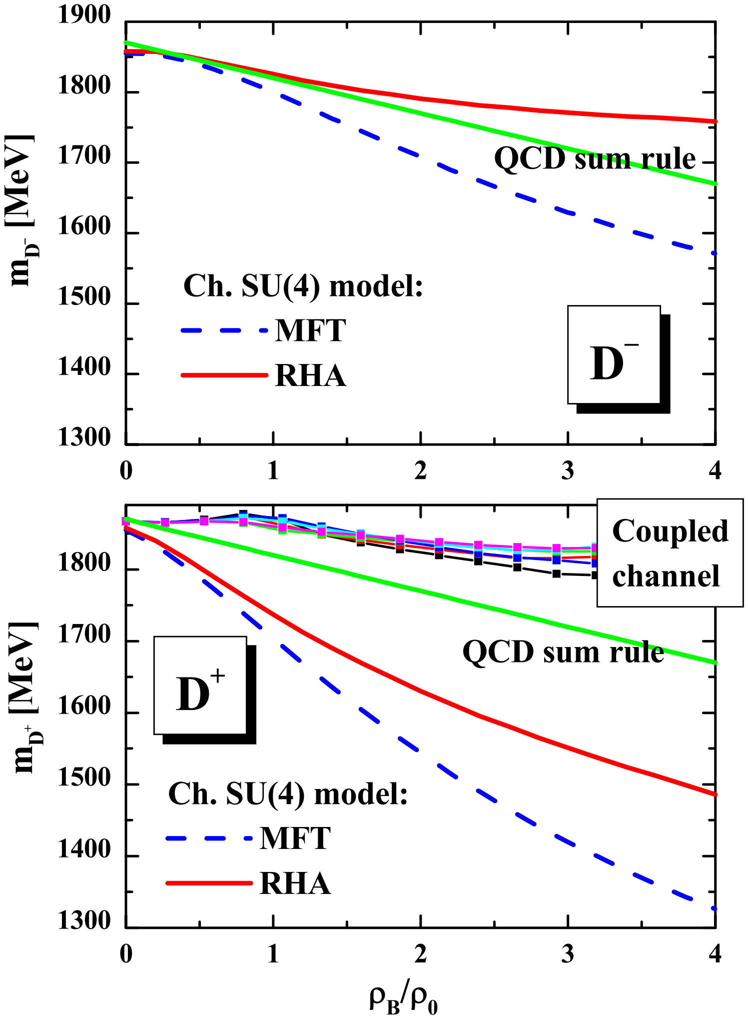


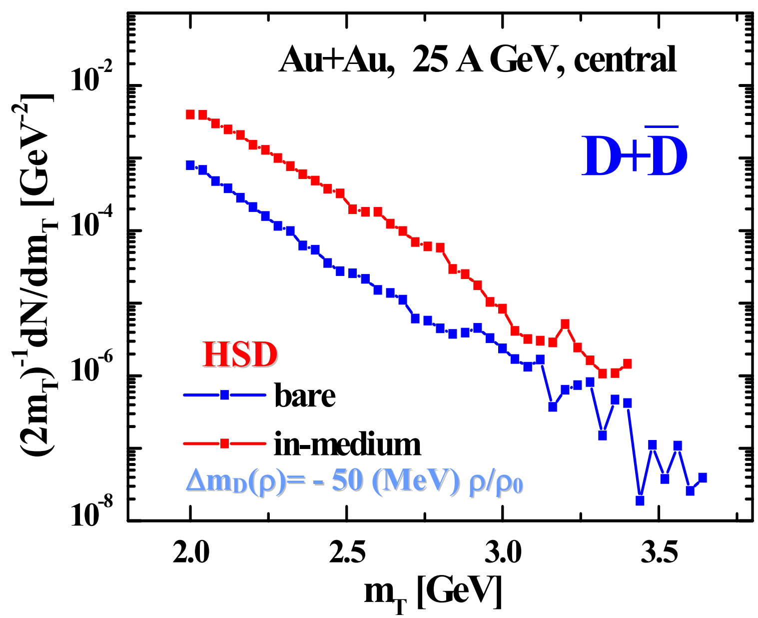
At RHIC the recreation of J/Ψ by D+Dbar annihilation **is important !**

New data with higher statistics are needed to clarify the nature of J/Ψ suppression!

HSD: PRC 69 (2004) 054903

D/Dbar-mesons: in-medium effects





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

Ch. SU(4): A. Mishra et al., PRC69 (2004) 015202
QCD sum rule: Hayashigaki, PLB487 (2000) 96
Coupled channel: Tolos et al., EPJ C43 (2005) 761

HSD: NPA691 (2001) 761

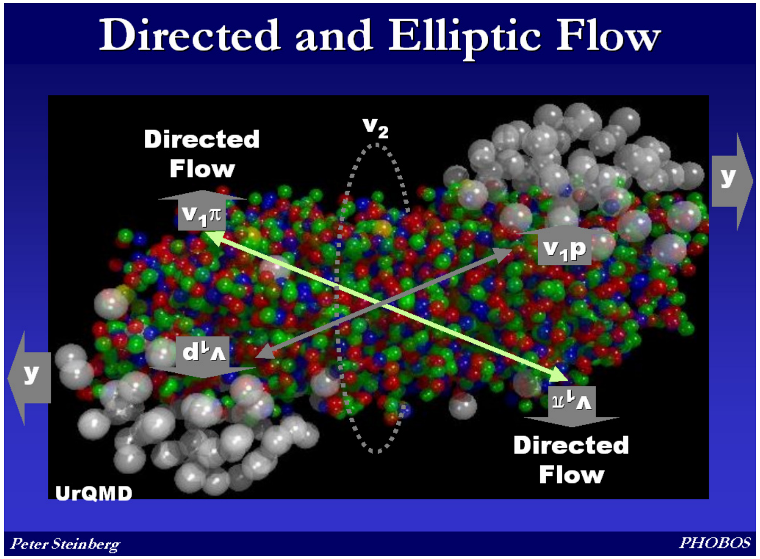
Collective flow (v_1, v_2)

Directed flow v_1 & elliptic flow v_2

Flow is a pressure barometer

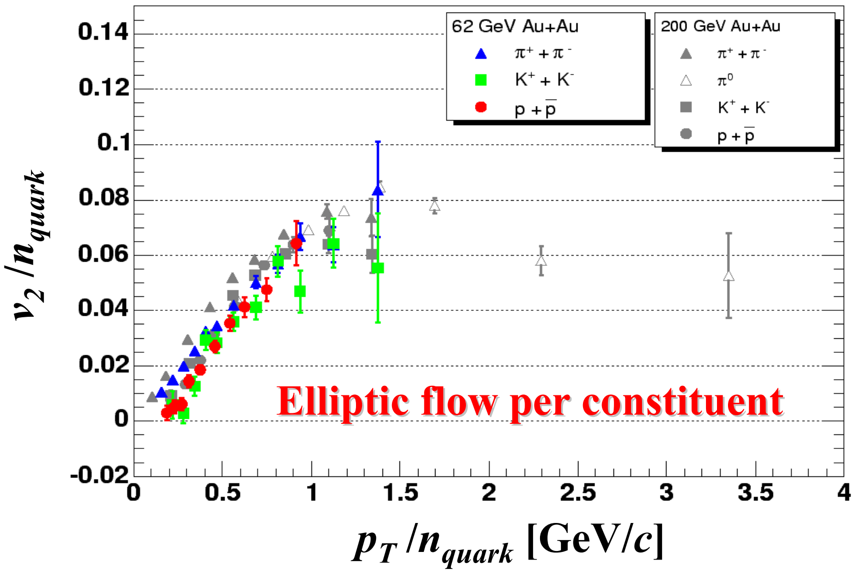
Collective flow provides information on

- properties of the medium – EoS, viscosity etc.
- transverse dynamics
- thermalization
- phase transition

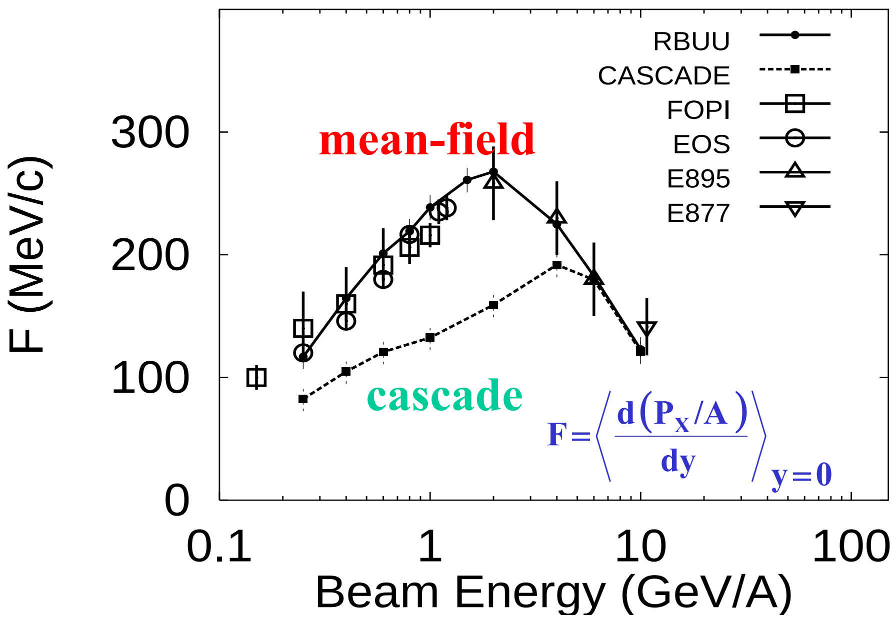


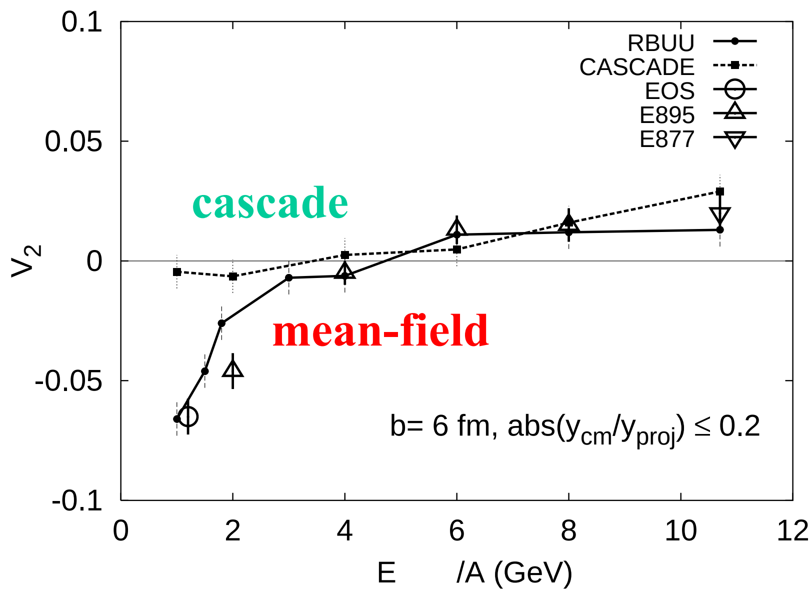
Elliptic flow at RHIC shows an ideal hydro behaviour for all particles =>

flow developed at partonic level ?!



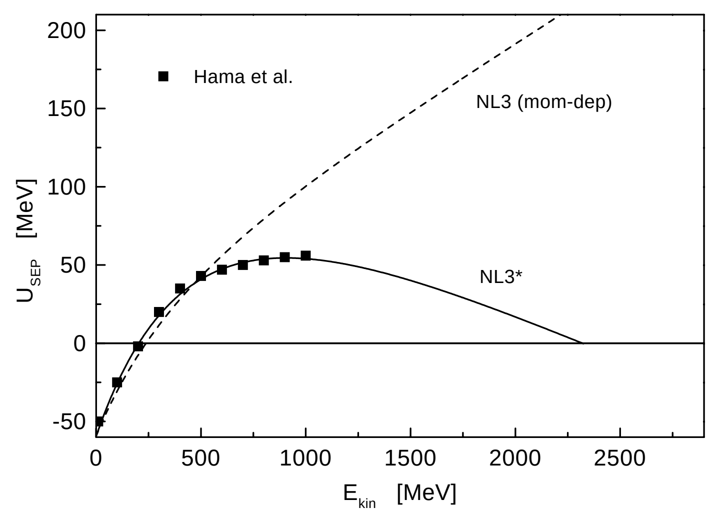
Nucleon flow in Au+Au collisions





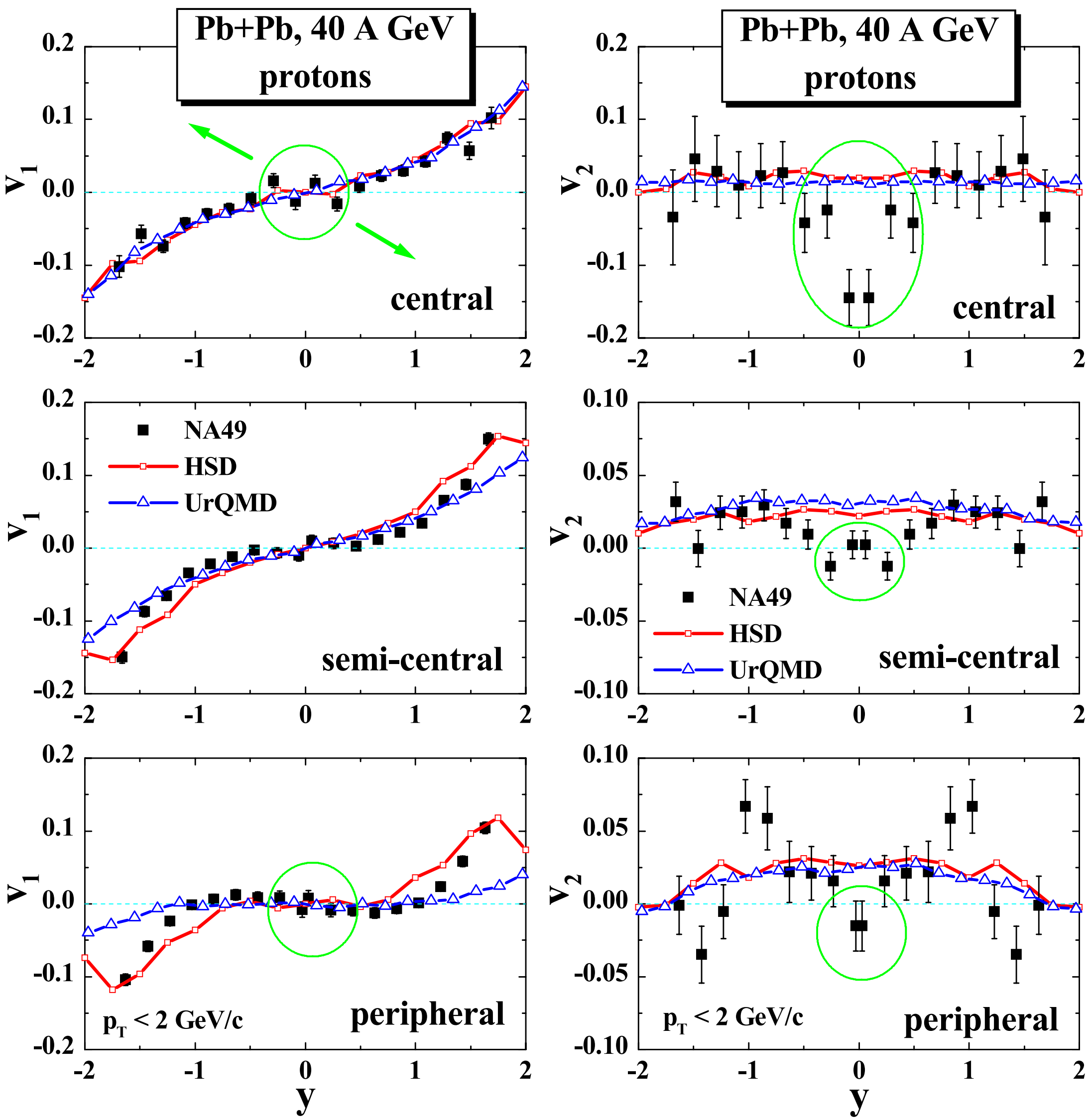
The nuclear mean-field
is attractive at low energy,
repulsive above 250 MeV
and vanishes for energies
above 2-3 GeV

mean-field at saturation density



P. K. Sahu et al., NPA 672 (2000) 376

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



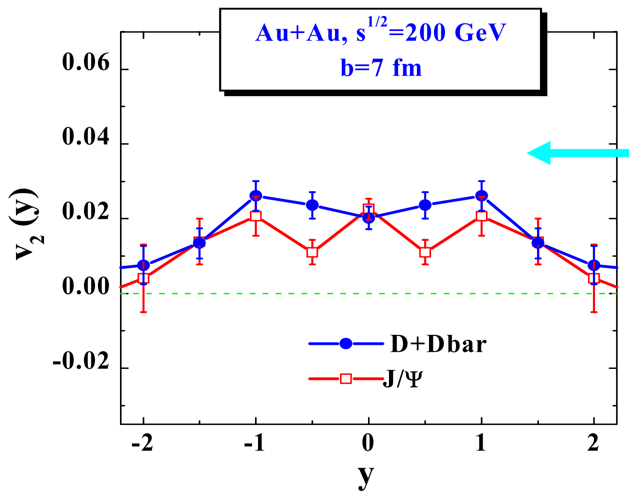
Too large **elliptic flow v_2** at midrapidity from HSD and UrQMD for all centralities !

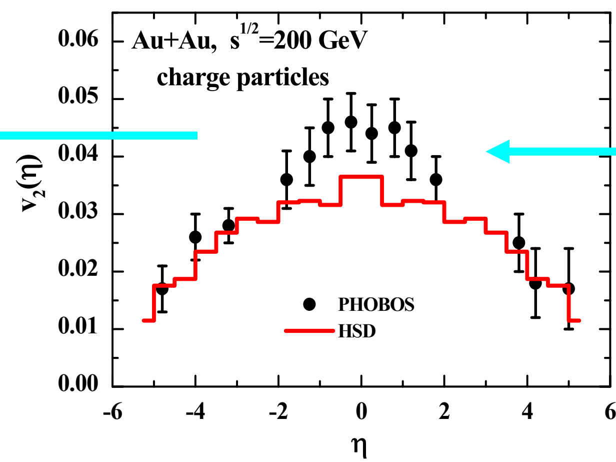
Experimentally: **breakdown of v_2 at midrapidity**

→ Possible signature for a first order phase transition !

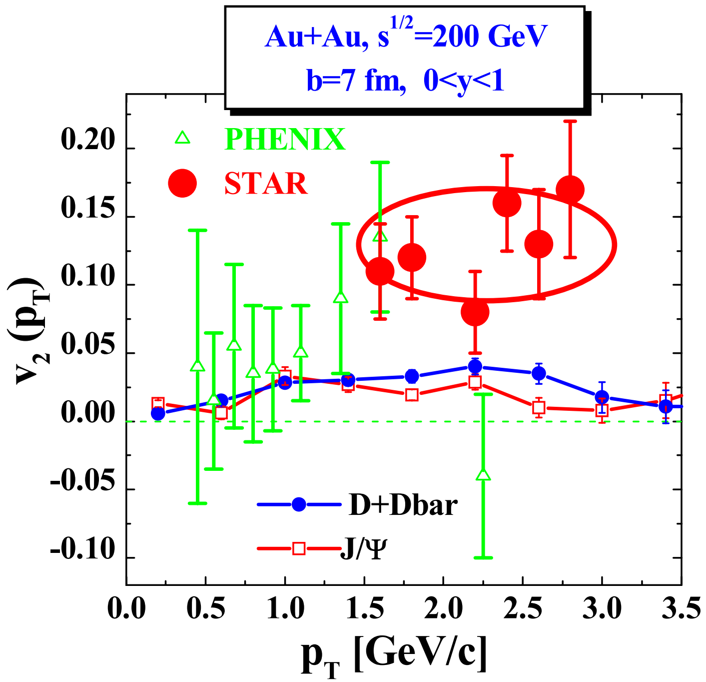
H. Stöcker, NPA 750 (2005)
E.B. et al., JPG 31 (2005)

Elliptic flow v_2 in Au+Au at RHIC





Collective flow from hadronic interactions is too low at midrapidity !



- HSD: D-mesons and J/Ψ follow the charged particle flow => small v_2 < 3%
- STAR data show very large collective flow of D-mesons at high p_T : v_2~15%!

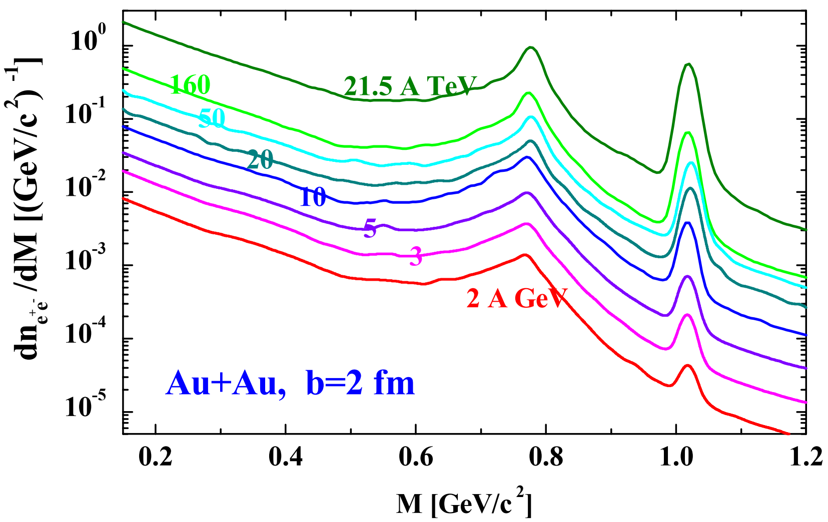
=> strong initial flow of non-hadronic nature!

PRC 71 (2005) 044901

Dileptons

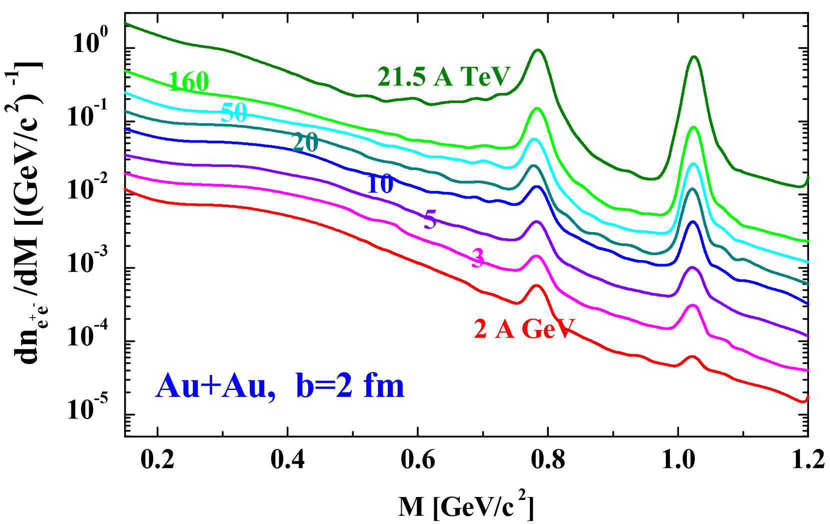
Exitation function of dilepton spectra in central Au+Au

free meson spectral functions



Dilepton yield **increases** with energy due to a **higher production of mesons**

in-medium meson spectral functions

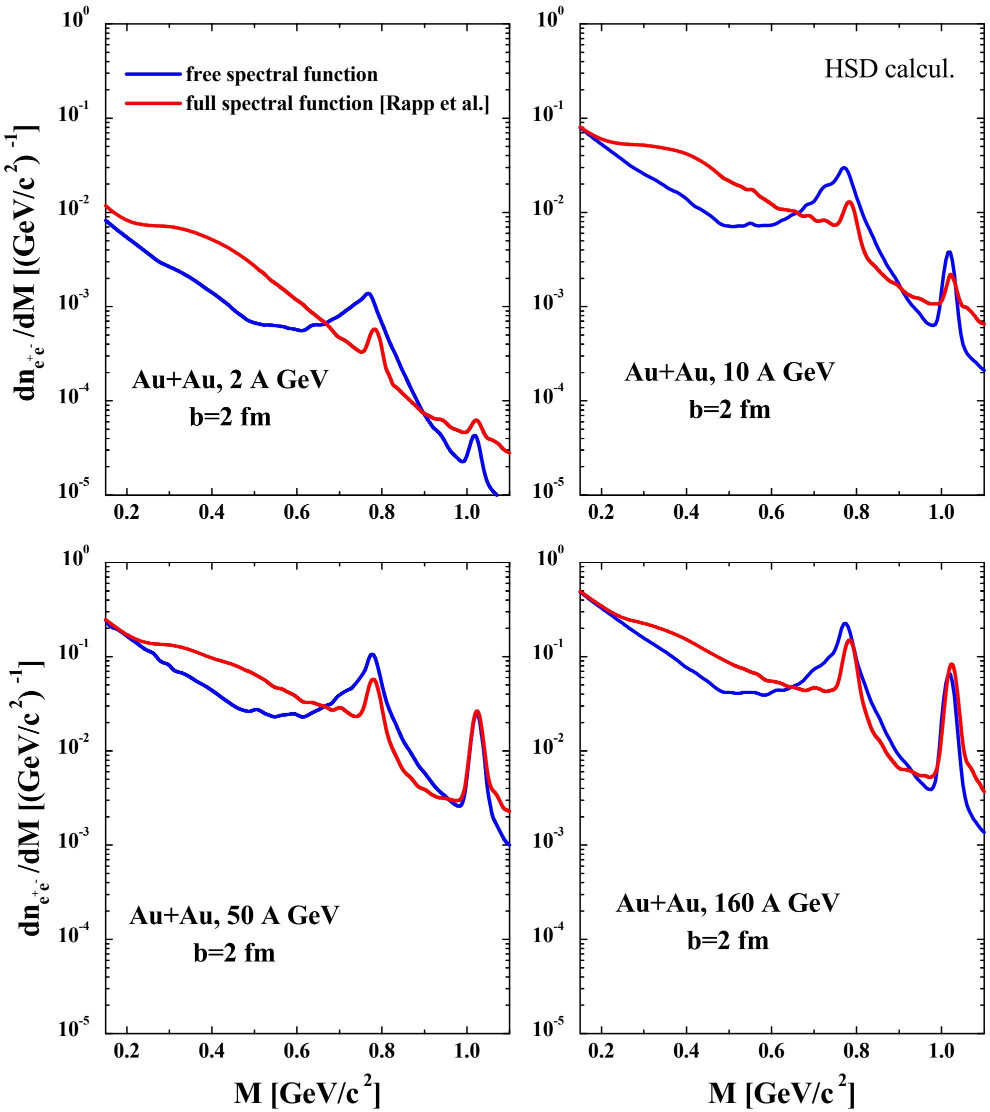


ρ melts practically at all energies

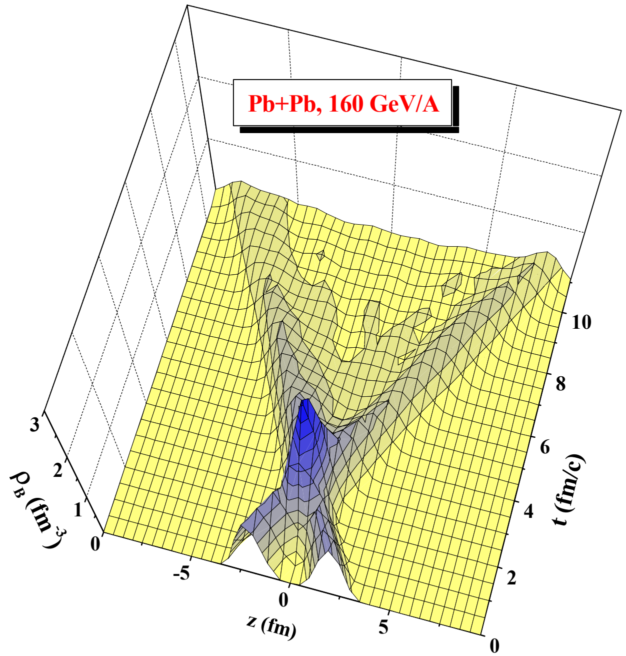
ω and φ show clear **peaks** on an approximately exponential background in mass

NPA 674 (2000) 249

Enhancement of dilepton spectra (in-medium scenario) at different energies

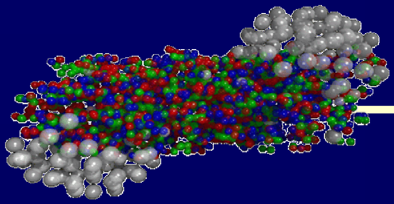


In-medium effects most pronounced at intermediate energies due to higher baryon density and long reaction time

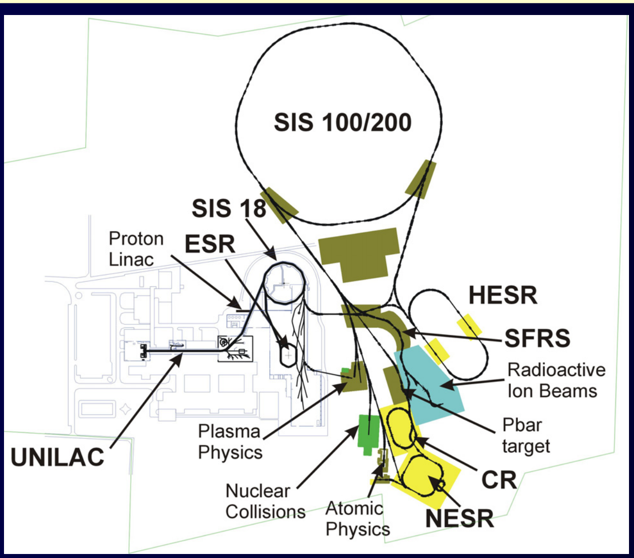


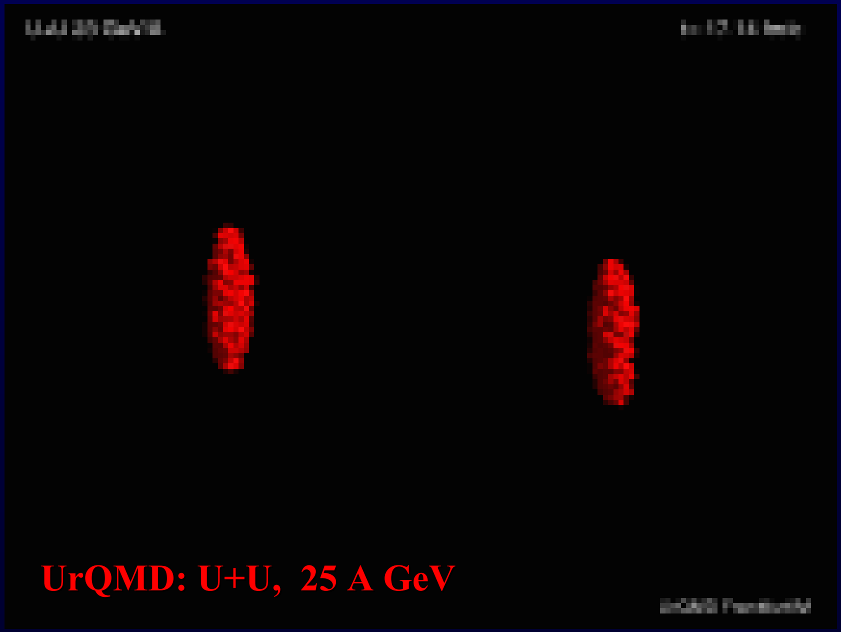
NPA 619 (1997) 413
NPA 674 (2000) 249

Summary



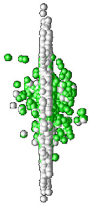
- **FAIR** is an **excellent facility** to study the properties of sQGP (strongly interacting ‚color liquid‘) as well as hadronic matter



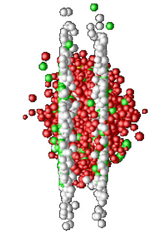


- **Transport theory** is the **general basis** for an understanding of nuclear dynamics on a microscopic level

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



Outlook



Transport description of the partonic phase

Parton-Hadron-String Dynamics

1. Dissolve all new produced secondary hadrons to partons (and attribute a random color c) using the spectral functions from the Quasiparticle approximation to LQCD

Include:

2. parton-parton elastic scattering using the effective cross sections from the QP approximation to LQCD
3. quark+antiquark (flavor neutral) <-> gluon (colored)
4. gluon + gluon <-> gluon (possible due to large spectral width)
5. quark + antiquark (color neutral) <-> hadron resonances

All partonic interactions are constraint to energy densities above 1 GeV/fm !

Reactions 3-5 : Breit-Wigner cross sections determined by the spectral properties of constituents !

slide taken from the talk by W. Cassing at the Workshop „Parton propagation through strongly interacting matter‘, 26 Sep.-7 Okt. 2005, Trento

Thanks to my coauthors

Steffen Bass

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Marco van Leeuwen

Manuel Reiter

Sven Soff

Horst Stöcker

Henning Weber

Nu Xu

HSD & UrQMD Collaboration

HSD, UrQMD - open codes:

http://www.th.physik.uni-frankfurt.de/~brat/hsd.html

http://www.th.physik.uni-frankfurt.de/~urqmd.html