GOETHE UNIVERSITÄT FRANKFURT AM MAIN

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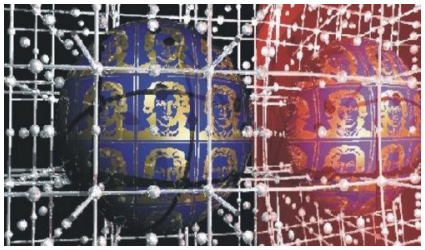

Dynamics of hot and dense nuclear and partonic matter

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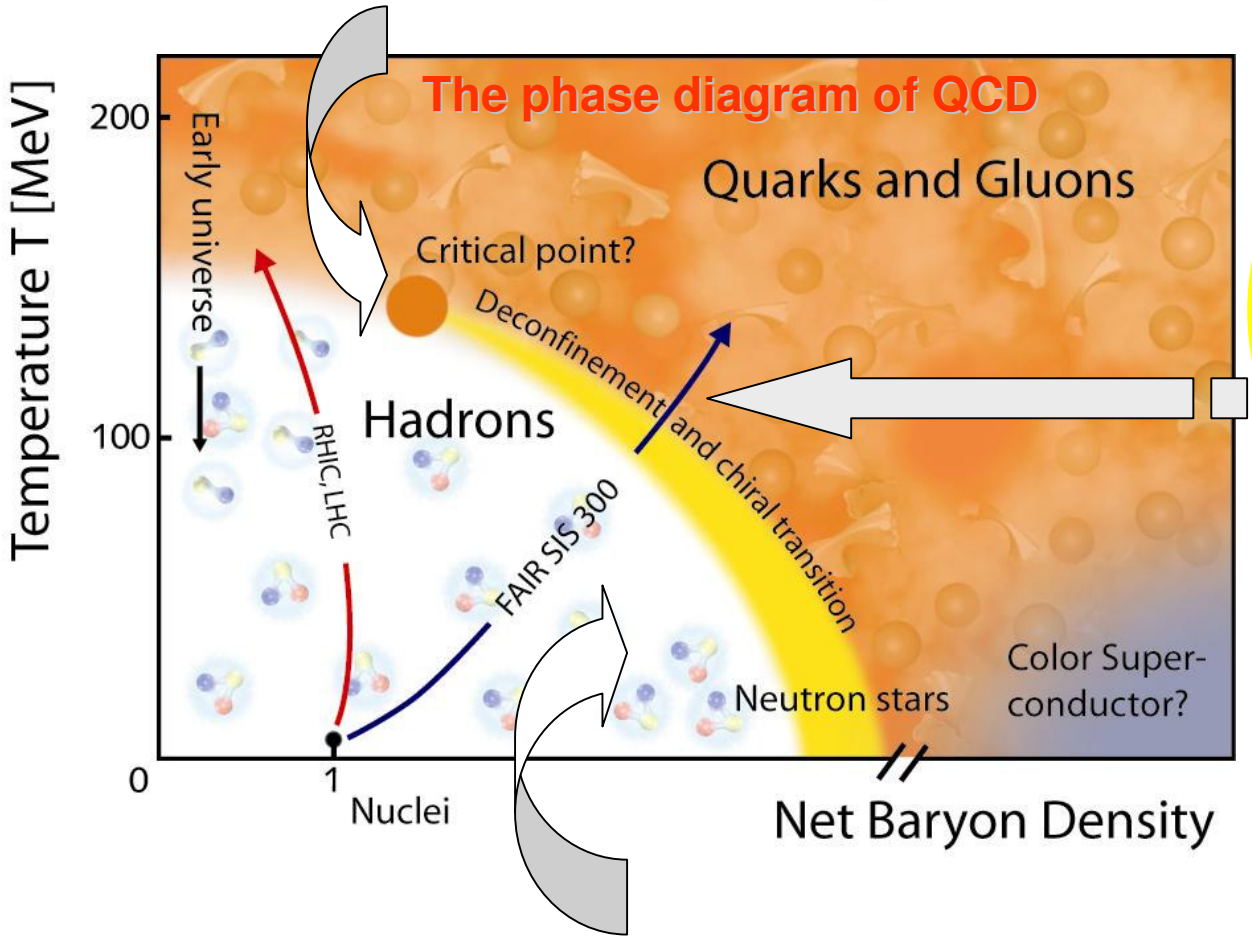
PHSD

Critical Point and Onset of Deconfinement (CPOD)
23 - 29 August 2010, JINR, Dubna

HIC for FAIR
Helmholtz International Center

Our ultimate goals:

- Search for the critical point



- Study of the phase transition from hadronic to partonic matter – Quark-Gluon-Plasma

- Study of the in-medium properties of hadrons at high baryon density and temperature

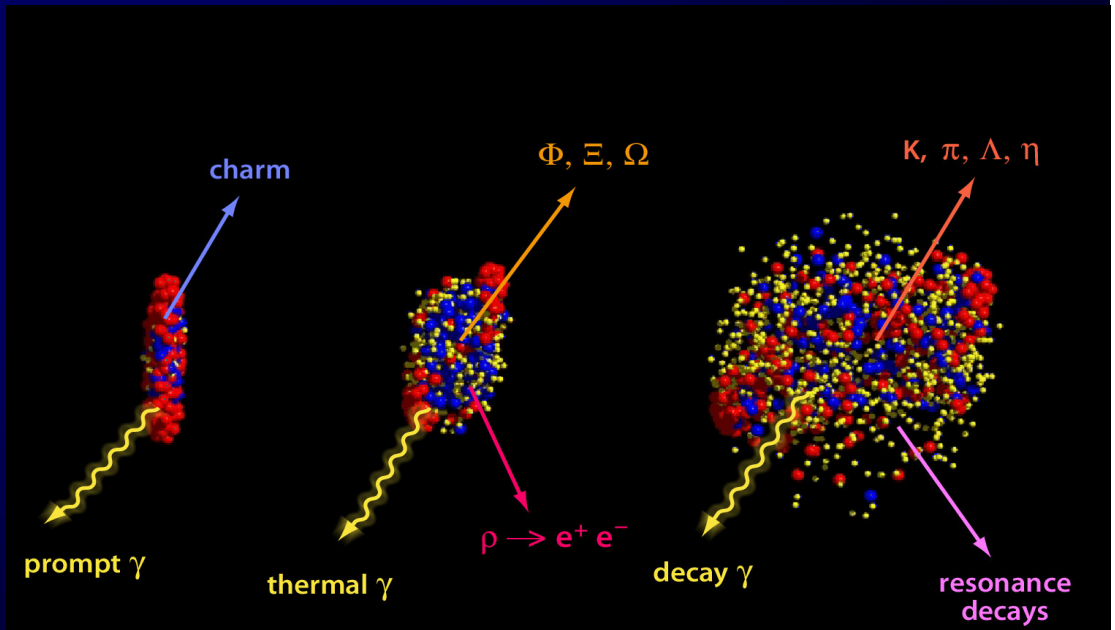
Signals of the phase transition:

- 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

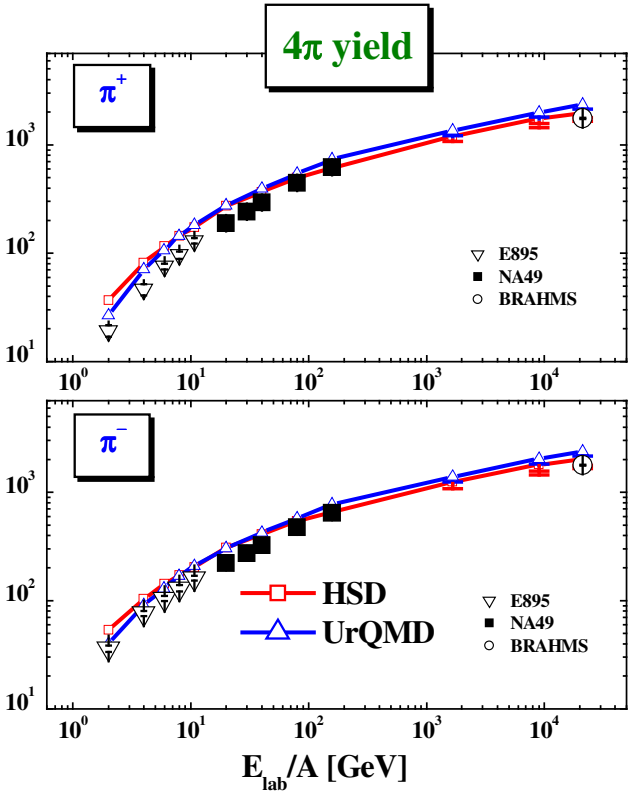
How to learn about physics from data?

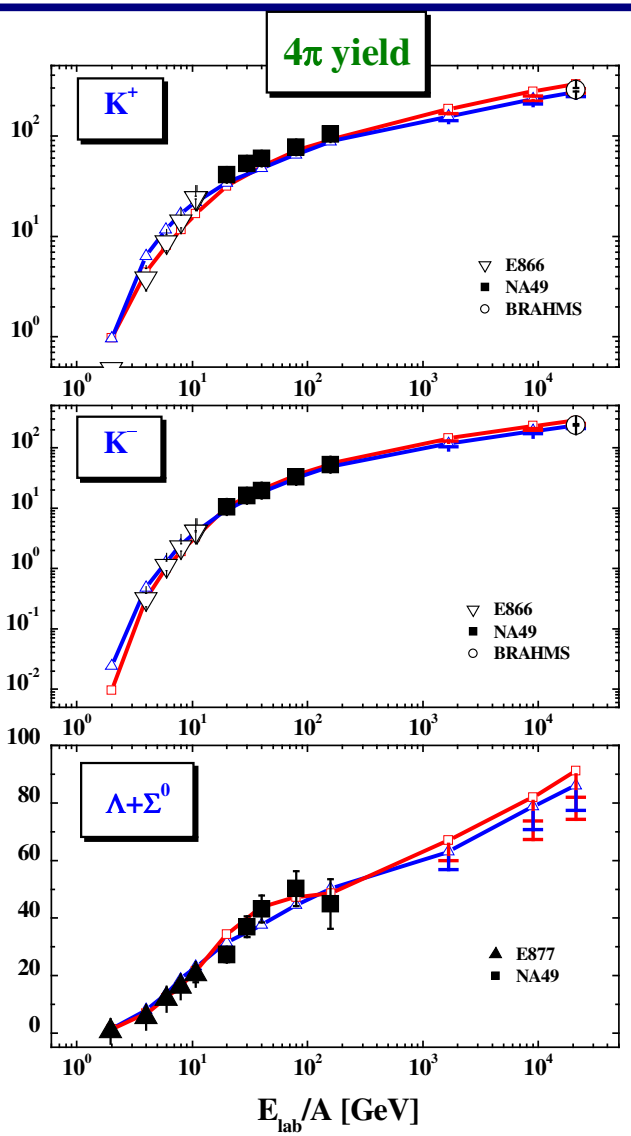
Compare with theory!



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

Hadron-string transport models versus observables





Reasonable description of strangeness by HSD and UrQMD 2.0 (deviations < 20%)

works very well,

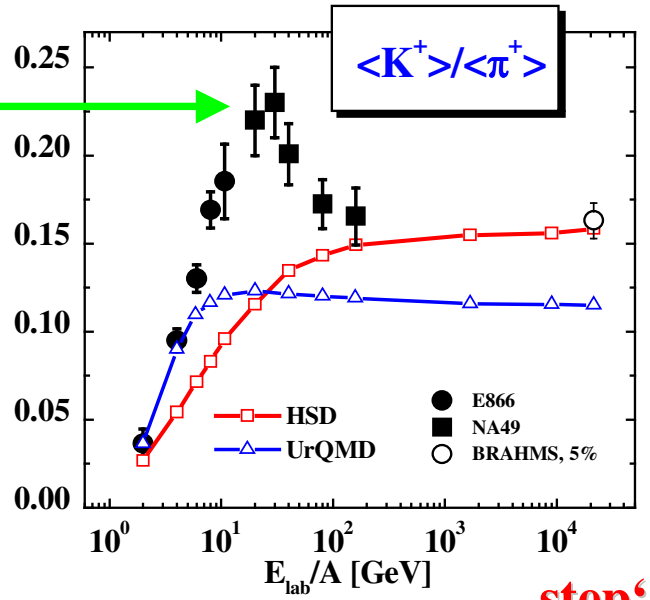
but where do we fail ?

PRC 69 (2004) 032302

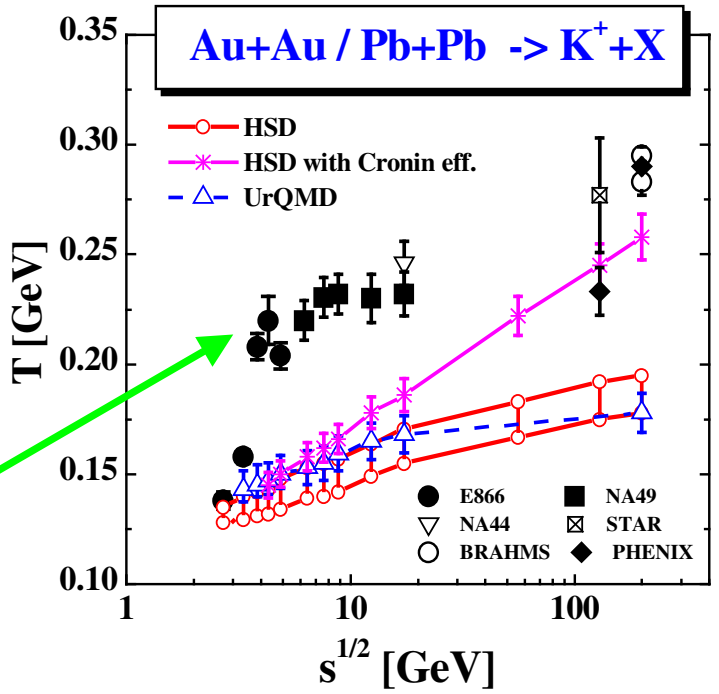
Hadron-string transport models versus observables

- **Strangeness signals of QGP**

‚horn‘
in K^+/π^+



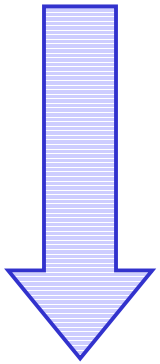
‚step‘
in slope T

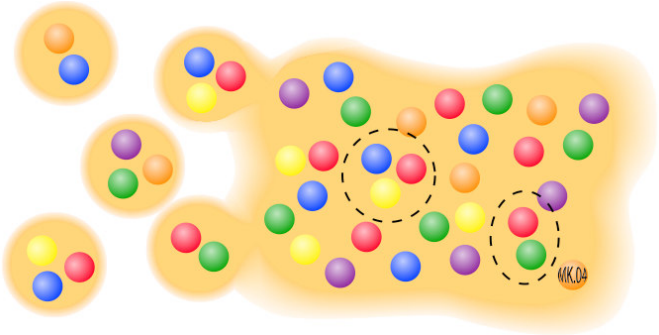


Exp. data are not reproduced in terms of the hadron-string picture
=> evidence for nonhadronic degrees of freedom

PRC 69 (2004) 032302

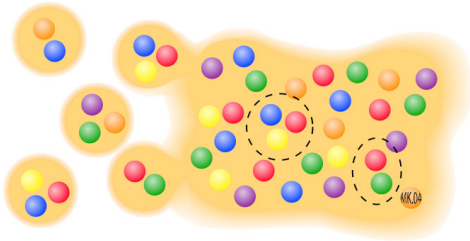
Transport description of the partonic and hadronic phase





Parton-Hadron-String-Dynamics (PHSD)

From hadrons to partons



In order to study of the phase transition from hadronic to partonic matter – Quark-Gluon-Plasma – we need a consistent transport model with

- explicit parton-parton interactions (i.e. between quarks and gluons) beyond strings!
- explicit phase transition from hadronic to partonic degrees of freedom
- lQCD EoS for partonic phase => phase transition is always a cross-over

Transport theory: off-shell Kadanoff-Baym equations for the Green-functions $S^{<}_{h}(x,p)$ in phase-space representation with the partonic and hadronic phase

⇒ **Parton-Hadron-String-Dynamics (PHSD)**

W. Cassing, E. Bratkovskaya, PRC 78 (2008) 034919; NPA831 (2009) 215; W. Cassing, EPJ ST 168 (2009) 3

QGP phase described by input from the

Dynamical QuasiParticle Model (DQPM)

A. Peshier, W. Cassing, PRL 94 (2005) 172301; Cassing, NPA 791 (2007) 365: NPA 793 (2007)

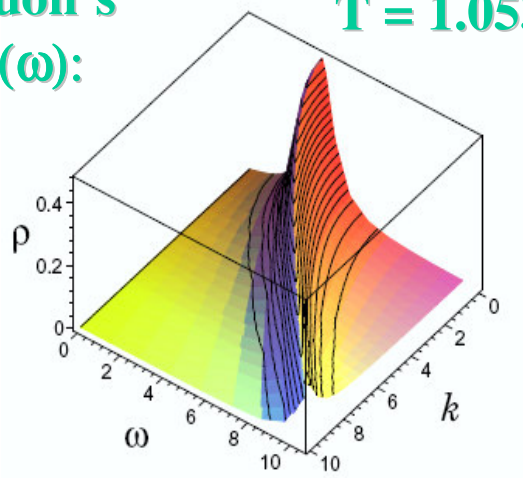
The Dynamical QuasiParticle Model (DQPM)

- **Interacting quasiparticles :**
  massive quarks and gluons
  with spectral functions

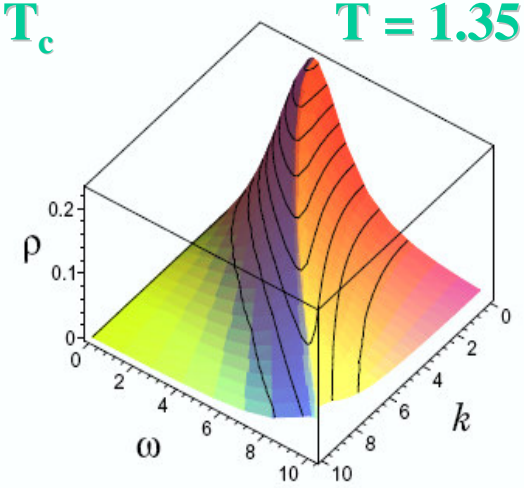
$$\rho(\omega) = \frac{\gamma}{\mathrm{E}} \left(\frac{1}{(\omega - \mathrm{E})^2 + \gamma^2} - \frac{1}{(\omega + \mathrm{E})^2 + \gamma^2} \right)$$

Gluon's ρ(ω):

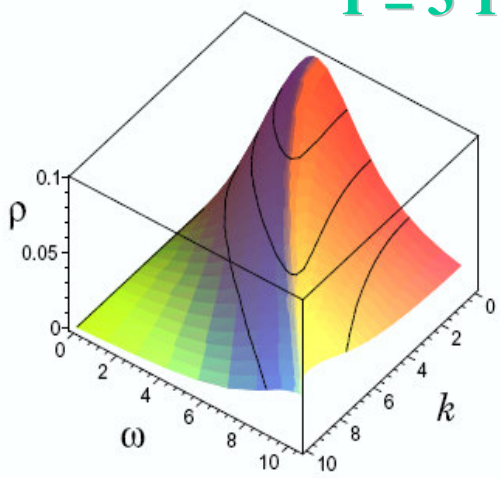
T = 1.053 T_c



T = 1.35 T_c



T = 3 T_c



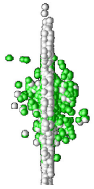
Plot from A. Peshier

- **DQPM well matches lattice QCD**
- **DQPM provides mean-fields for gluons and quarks as well as effective 2-body interactions**

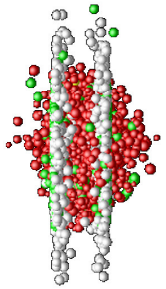
and gives transition rates for the formation of hadrons → PHSD

Peshier, Cassing, PRL 94 (2005) 172301;
Cassing, NPA 791 (2007) 365: NPA 793 (2007)

PHSD - basic concepts



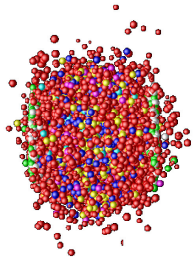
Initial A+A collisions – HSD: string formation and decay to pre-hadrons



Fragmentation of pre-hadrons into quarks: using the quark spectral functions from the Dynamical QuasiParticle Model (DQPM) approximation to QCD

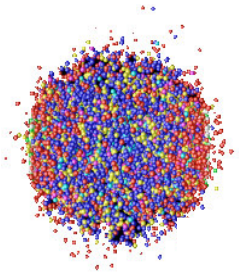
DQPM: Peshier, Cassing, PRL 94 (2005) 172301;
Cassing, NPA 791 (2007) 365: NPA 793 (2007)

Partonic phase: quarks and gluons (= ‚dynamical quasiparticles') with off-shell spectral functions (width, mass) defined by DQPM



elastic and inelastic parton-parton interactions: using the effective cross sections from the DQPM

- ✓ q + qbar (flavor neutral) <=> gluon (colored)
- ✓ gluon + gluon <=> gluon (possible due to large spectral width)
- ✓ q + qbar (color neutral) <=> hadron resonances

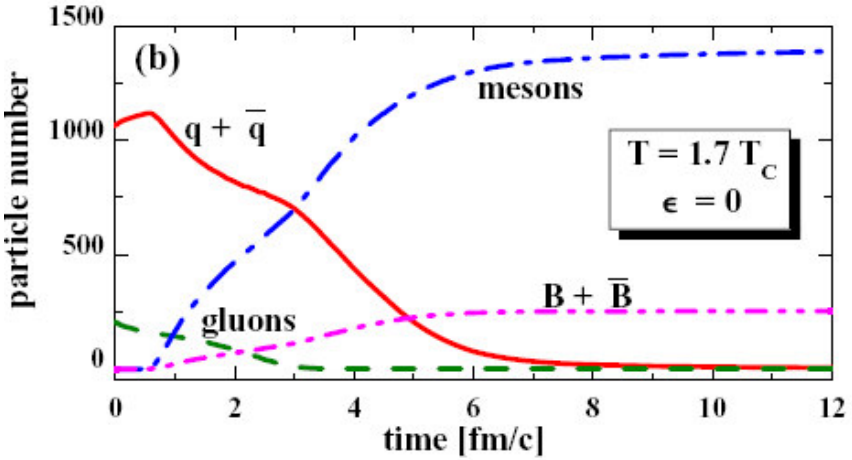


Hadronization: based on DQPM - massive, off-shell quarks and gluons with broad spectral functions hadronize to off-shell mesons and baryons:
gluons → q + qbar; q + qbar → meson (or string);
q + q +q → baryon (or string) (strings act as ‚doorway states' for hadrons)

Hadronic phase: hadron-string interactions – off-shell HSD

PHSD: hadronization

E.g. time evolution of the partonic fireball initialized at temperature 1.7 T_c and μ_q=0



Consequences: ☺

➢Hadronization: $q+q_{bar}$ or 3q or $3q_{bar}$ fuse to color neutral hadrons (or strings) which furtheron decay to hadrons in a microcanonical fashion, i.e. obeying all conservation laws (i.e. 4-momentum conservation, flavor current conservation) in each event

➢ Hadronization yields an increase in total entropy S (i.e. more hadrons in the final state than initial partons) and not a decrease as in the simple recombination model !

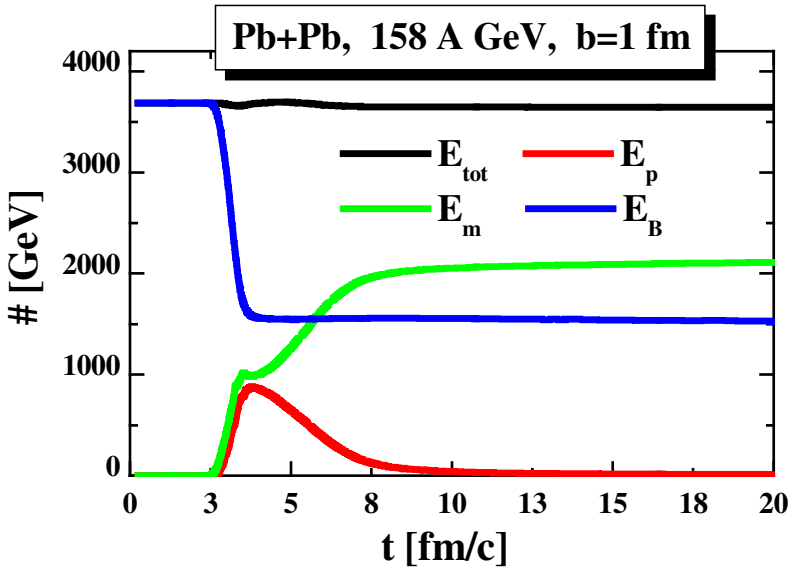
➢Off-shell parton transport roughly leads a hydrodynamic evolution of the partonic system

W. Cassing, E. Bratkovskaya, PRC 78 (2008) 034919;
NPA831 (2009) 215;
W. Cassing, EPJ ST 168 (2009) 3

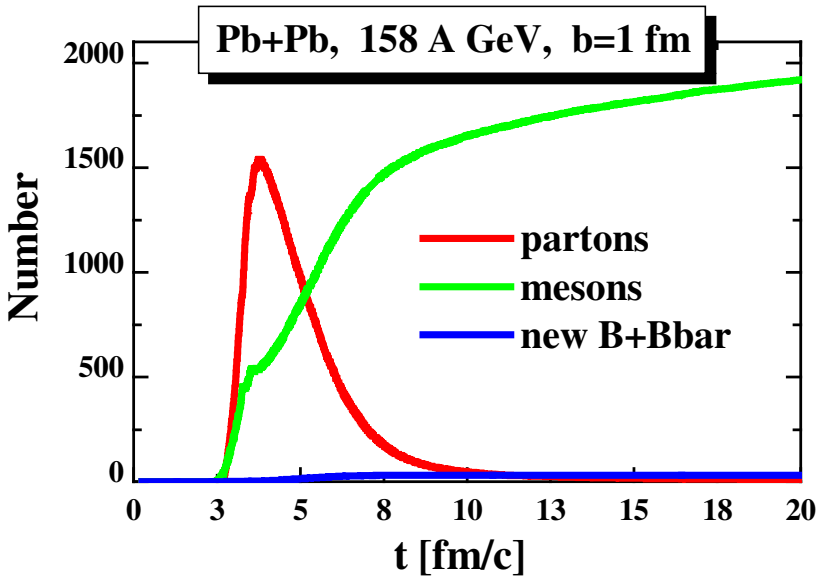
Application to nucleus-nucleus collisions

central Pb + Pb at 158 A GeV

energy balance



particle balance

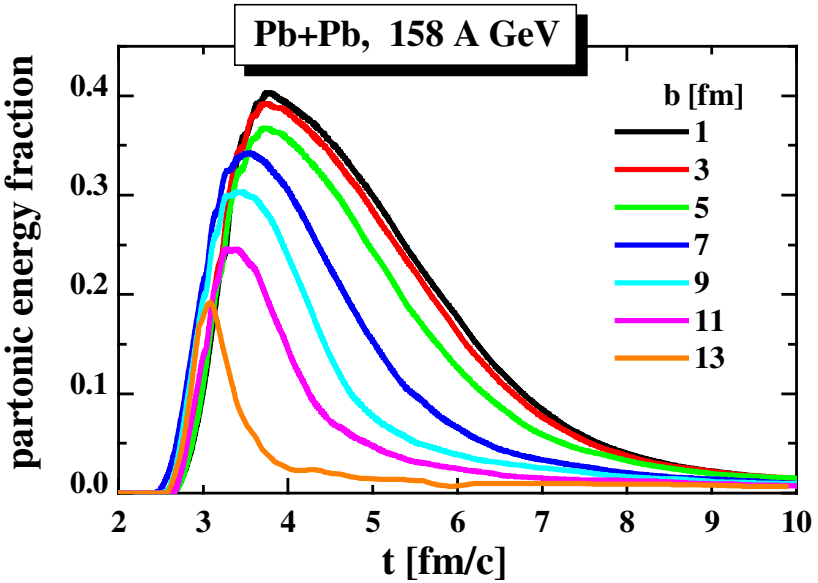


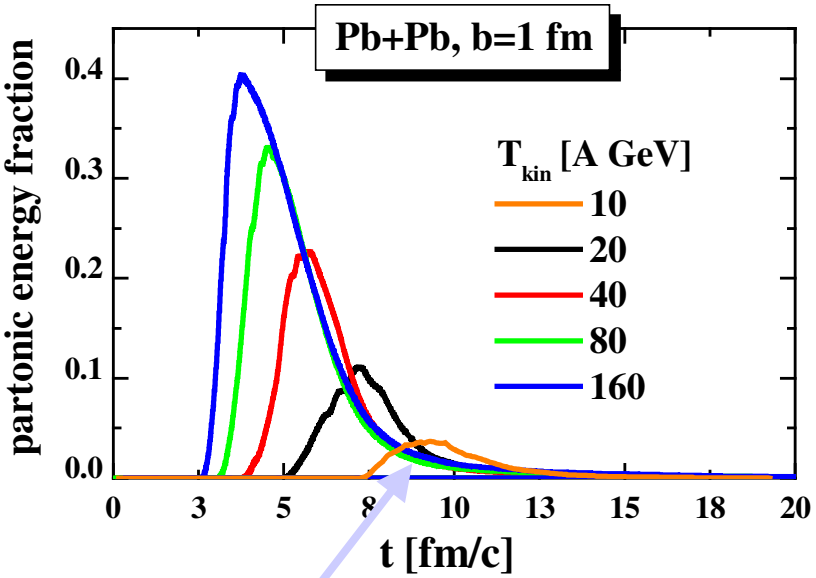
only about 40% of the converted energy goes to partons;
the rest is contained in the ‚large' hadronic corona!

Cassing & Bratkovskaya, NPA 831 (2009) 215

Partonic phase at SPS/FAIR/NICA energies

partonic energy fraction vs centrality and energy





Dramatic decrease of partonic phase with decreasing energy and centrality

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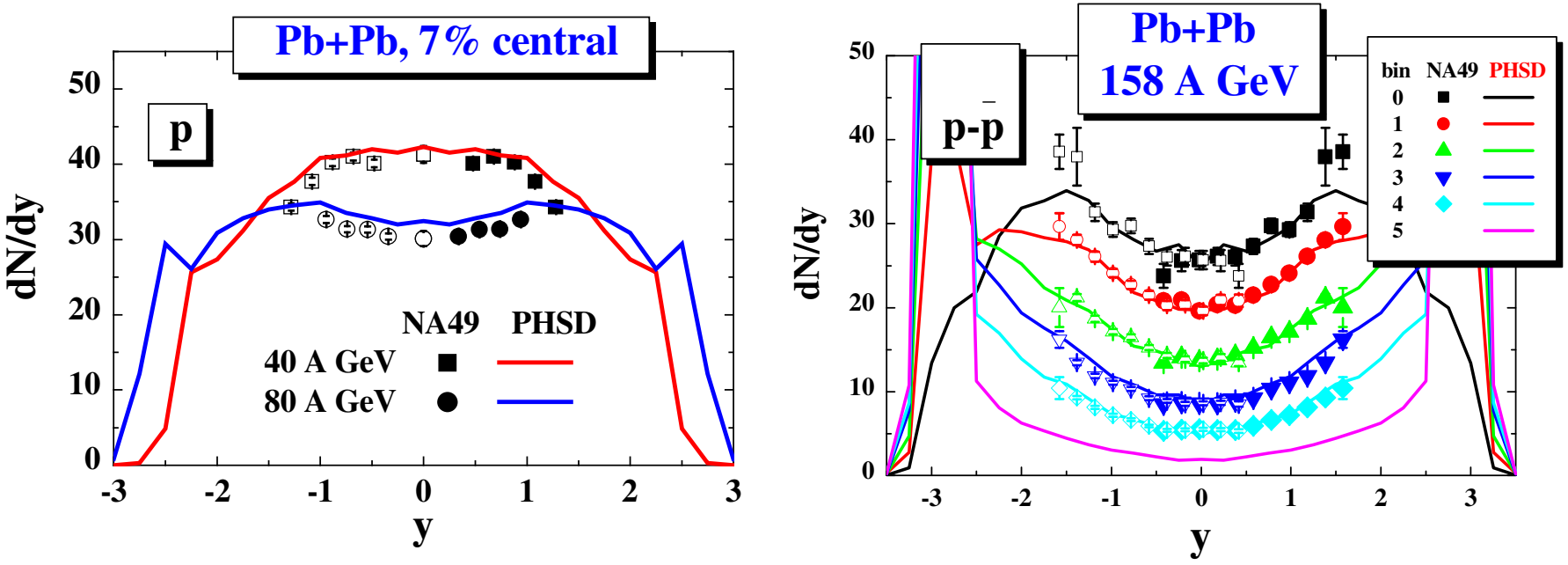
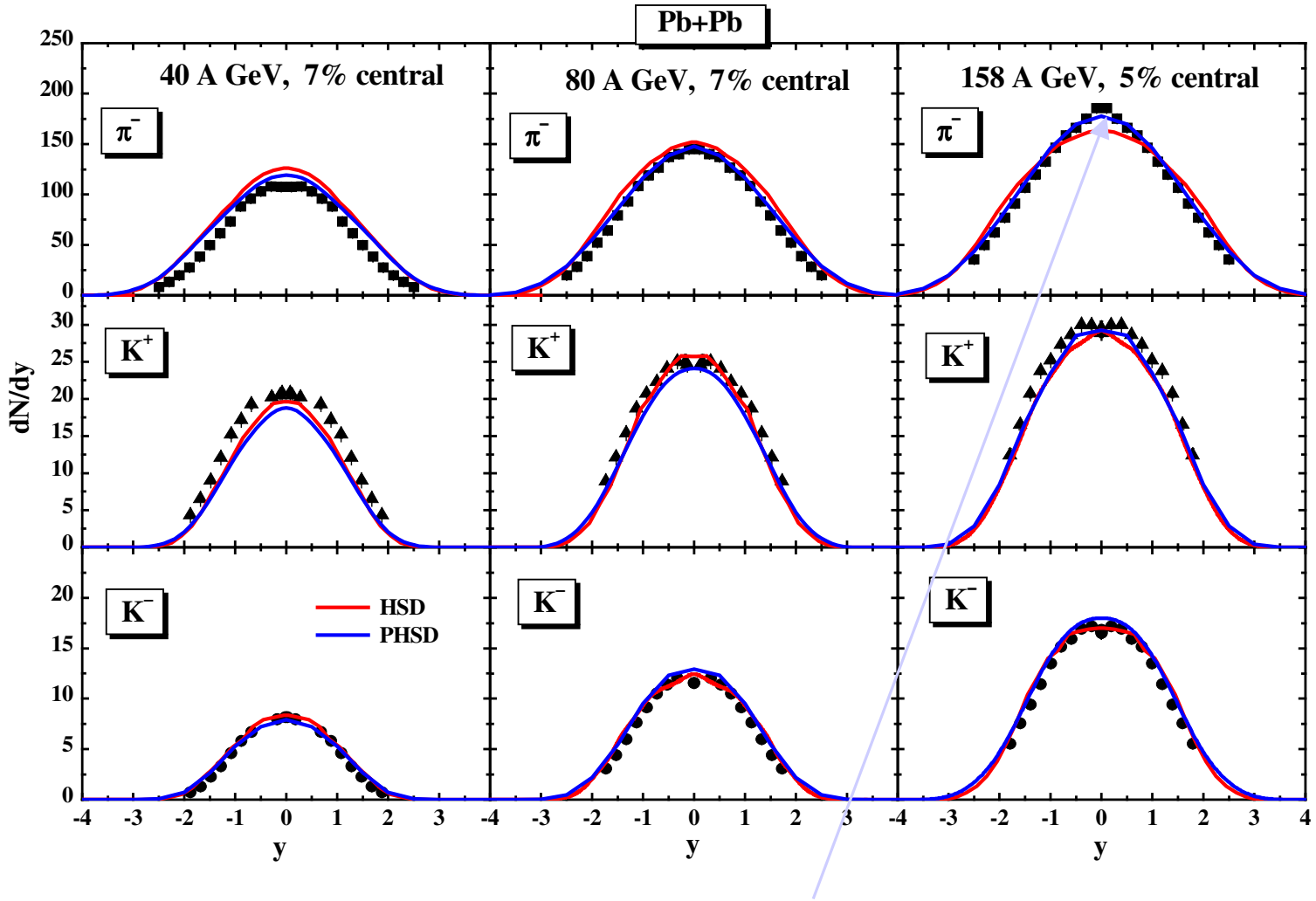
Proton stopping at SPS



➔looks not bad in comparison to NA49 data,
but not sensitive to parton dynamics (PHSD = HSD)!

Cassing & Bratkovskaya, NPA 831 (2009) 215

Rapidity distributions of π, K^+, K^-



➔ pion and kaon rapidity distributions become slightly narrower

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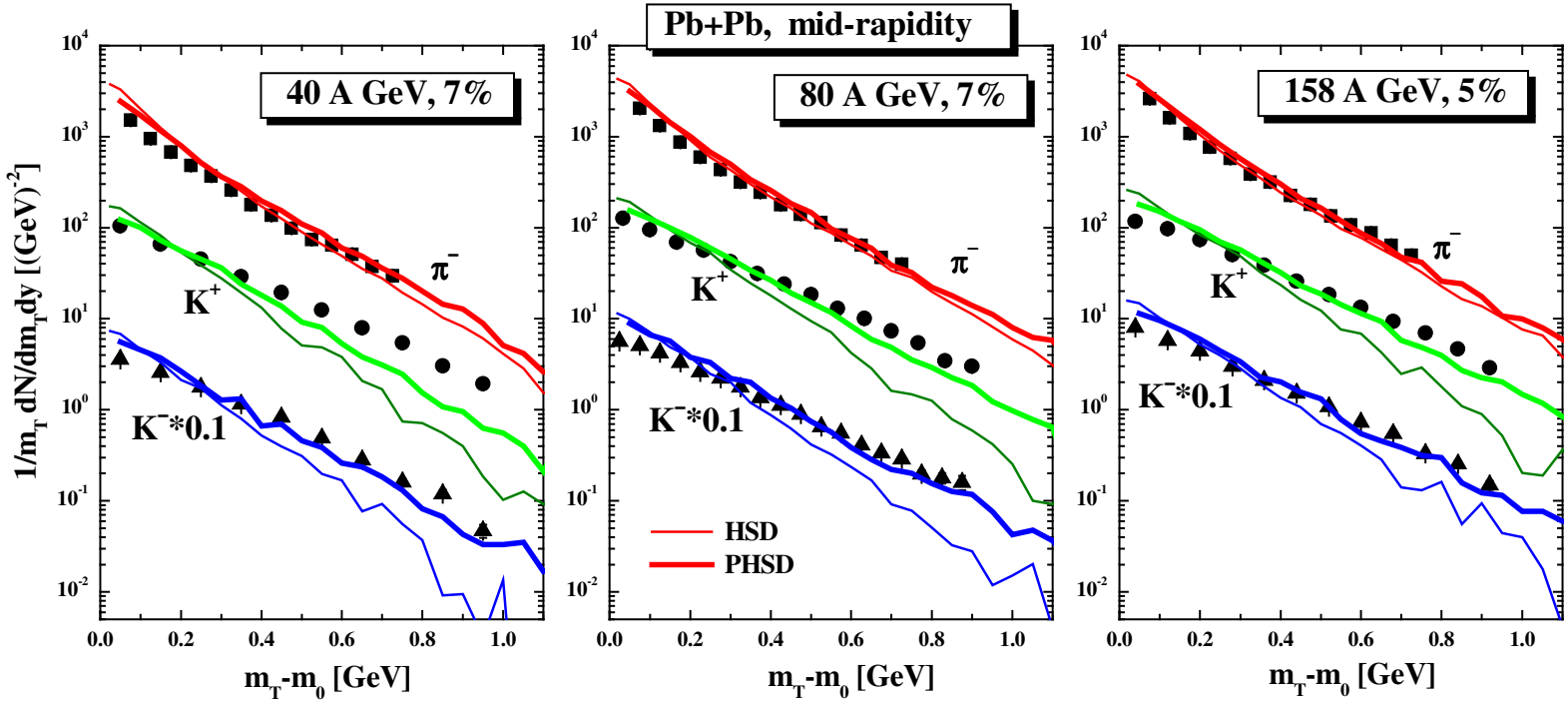
PHSD: Transverse mass spectra at SPS

Central Pb + Pb at SPS energies



☺ PHSD gives harder spectra and works better than HSD at SPS (and top FAIR, NICA) energies

☹ However, at low SPS (and low FAIR, NICA) energies the effect of the partonic phase is NOT seen in rapidity distributions and m_T spectra

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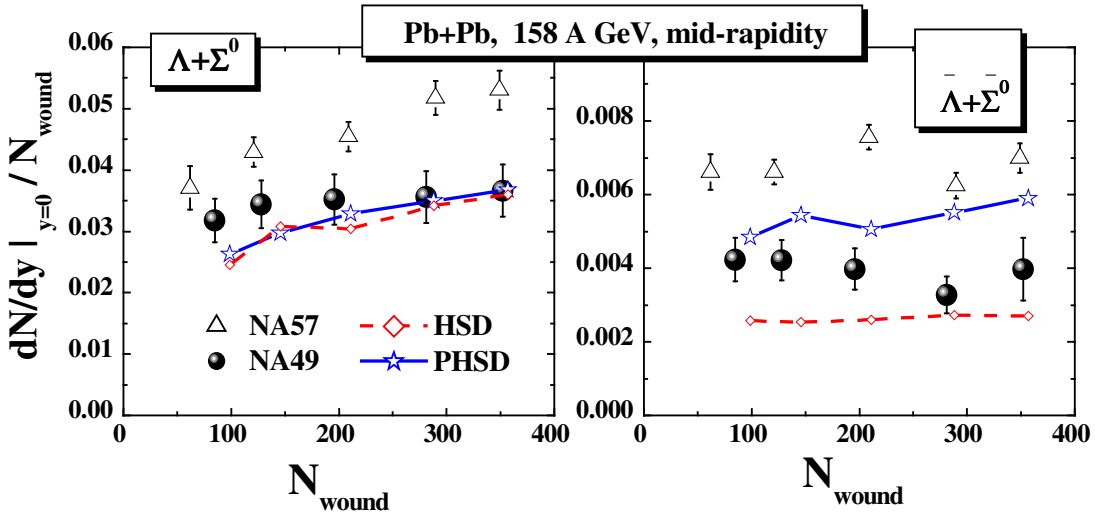
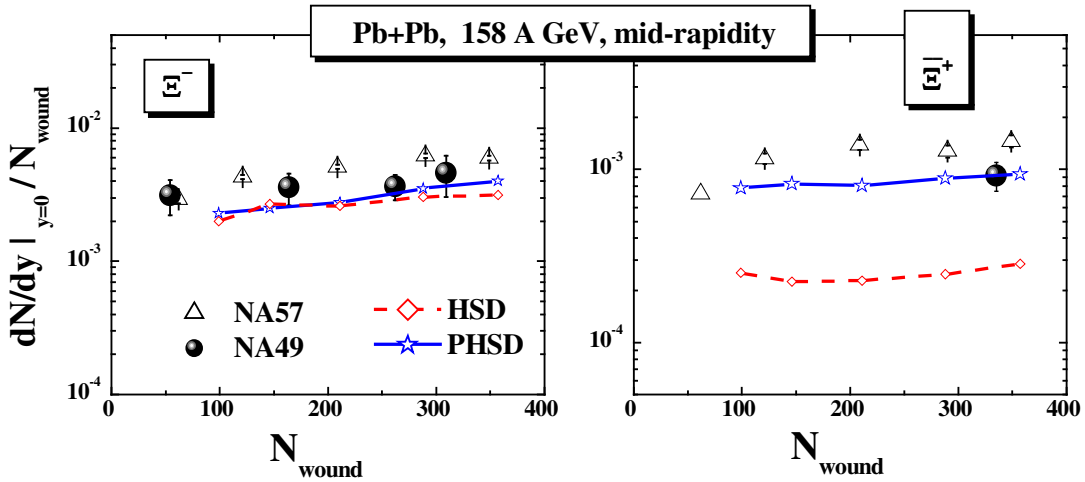
Centrality dependence of (multi-)strange (anti-)baryons

strange baryons $\Lambda+\Sigma^0$



strange antibaryons $\bar{\Lambda}+\bar{\Sigma}^0$

multi-strange baryon Ξ^-



multi-strange antibaryon $\bar{\Xi}^+$

➔ **enhanced production of (multi-) strange antibaryons in PHSD**

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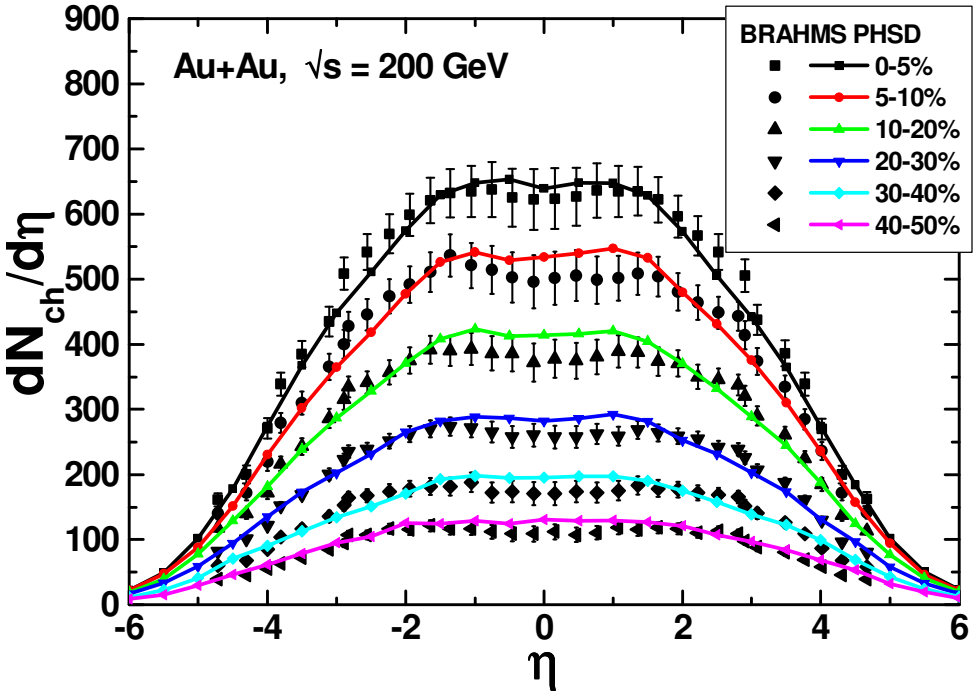
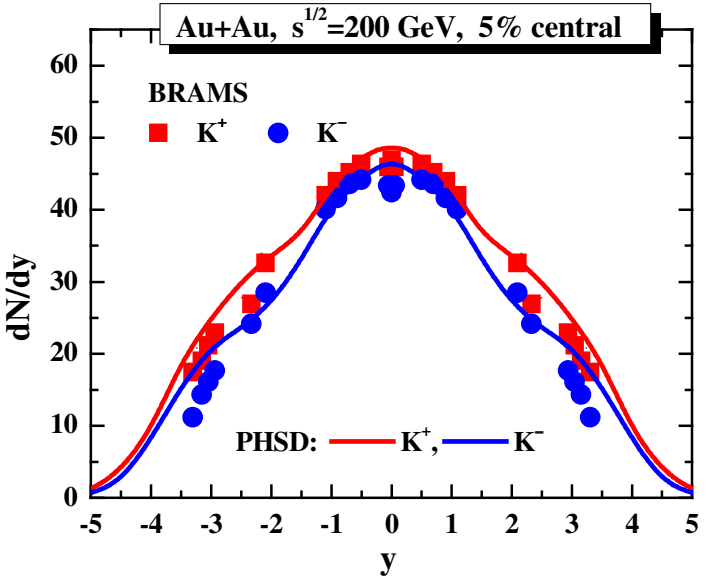
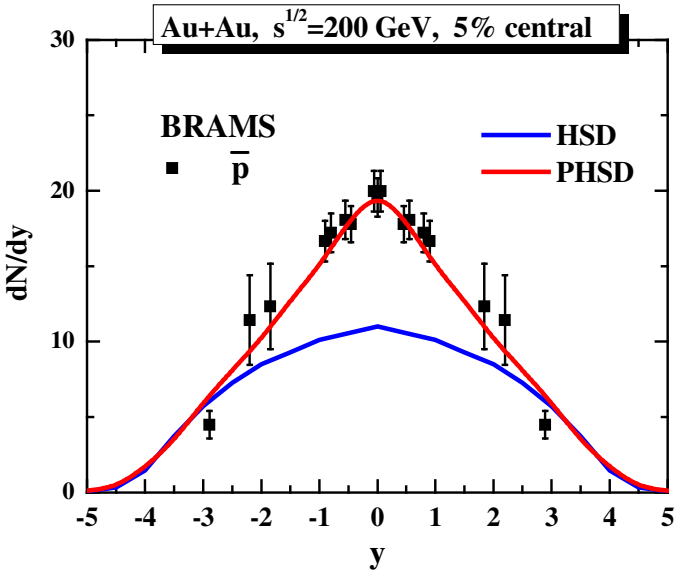
PHSD: rapidity spectra at RHIC



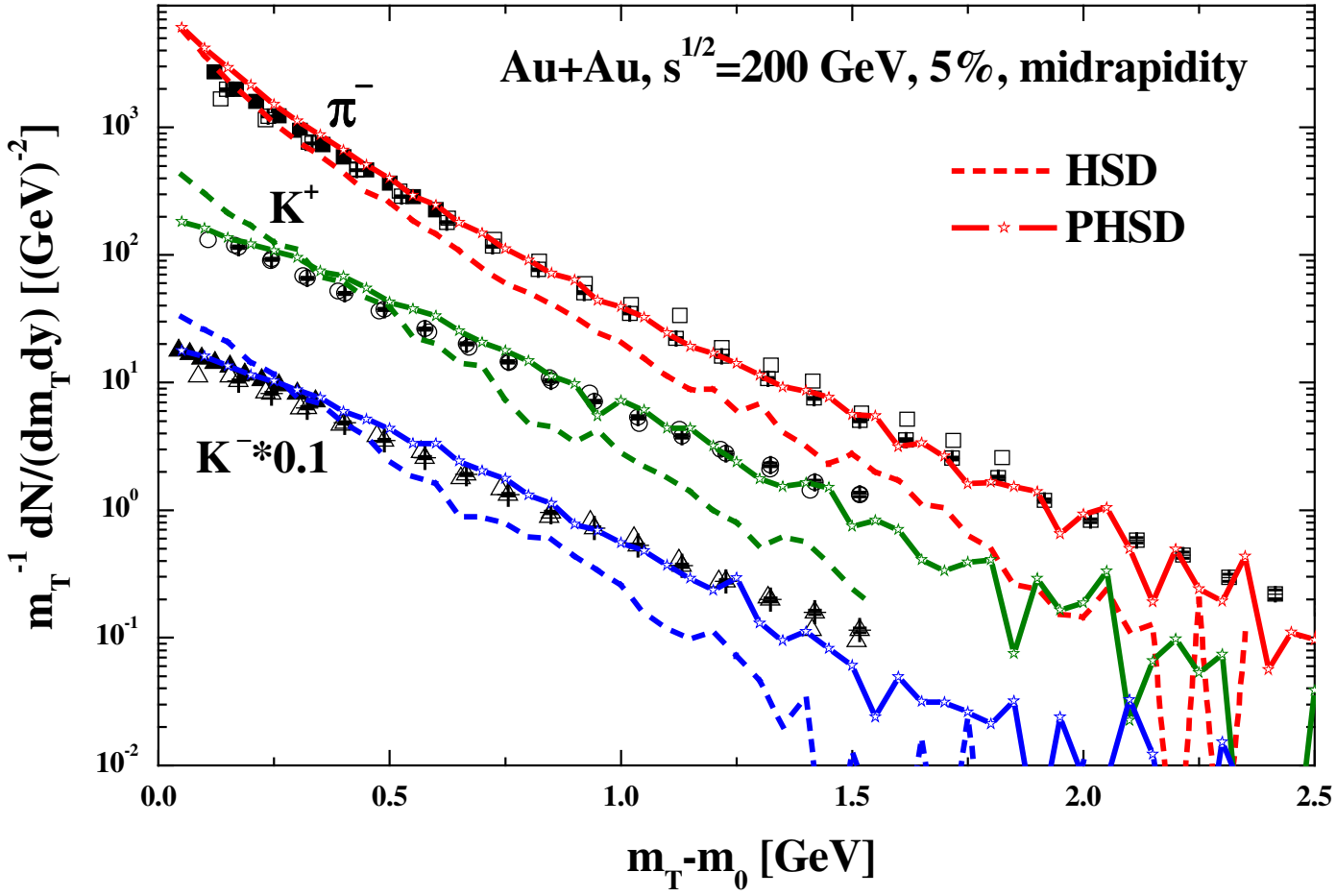




Preliminary

PHSD gives a reasonable description of the rapidity spectra at RHIC

PHSD: Transverse mass spectra at RHIC



PHSD gives harder spectra and works better than HSD at RHIC

Summary

- Some exp. data are not well reproduced in terms of the hadron-string picture => evidence for nonhadronic degrees of freedom

- PHSD provides a consistent description of off-shell parton dynamics in line with a lattice QCD equation of state

- The Pb + Pb data at top SPS energies are rather well described within PHSD including baryon stopping, strange antibaryon enhancement and meson m_T slopes (will be also seen at top FAIR, NICA energies)

- PHSD provides a reasonable description of the rapidity spectra and meson m_T slopes for Au+Au collisions at the top RHIC energy

- At low SPS energies PHSD gives practically the same results as HSD (except for strange antibaryons) when the lQCD EoS (where the phase transition is always a cross-over) is used

➔ Is the matter at low SPS (FAIR, NICA) a ‚mixed phase' of hadrons and partons?

Thanks

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…

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