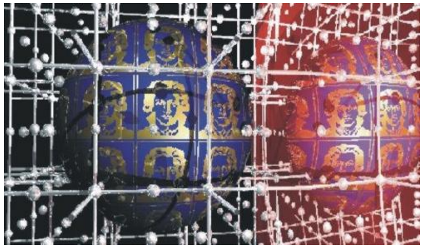
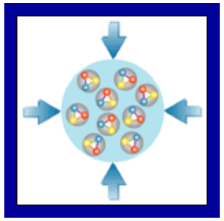


Electromagnetic and strong probes of compressed baryonic matter at SIS100 energies

Elena Bratkovskaya

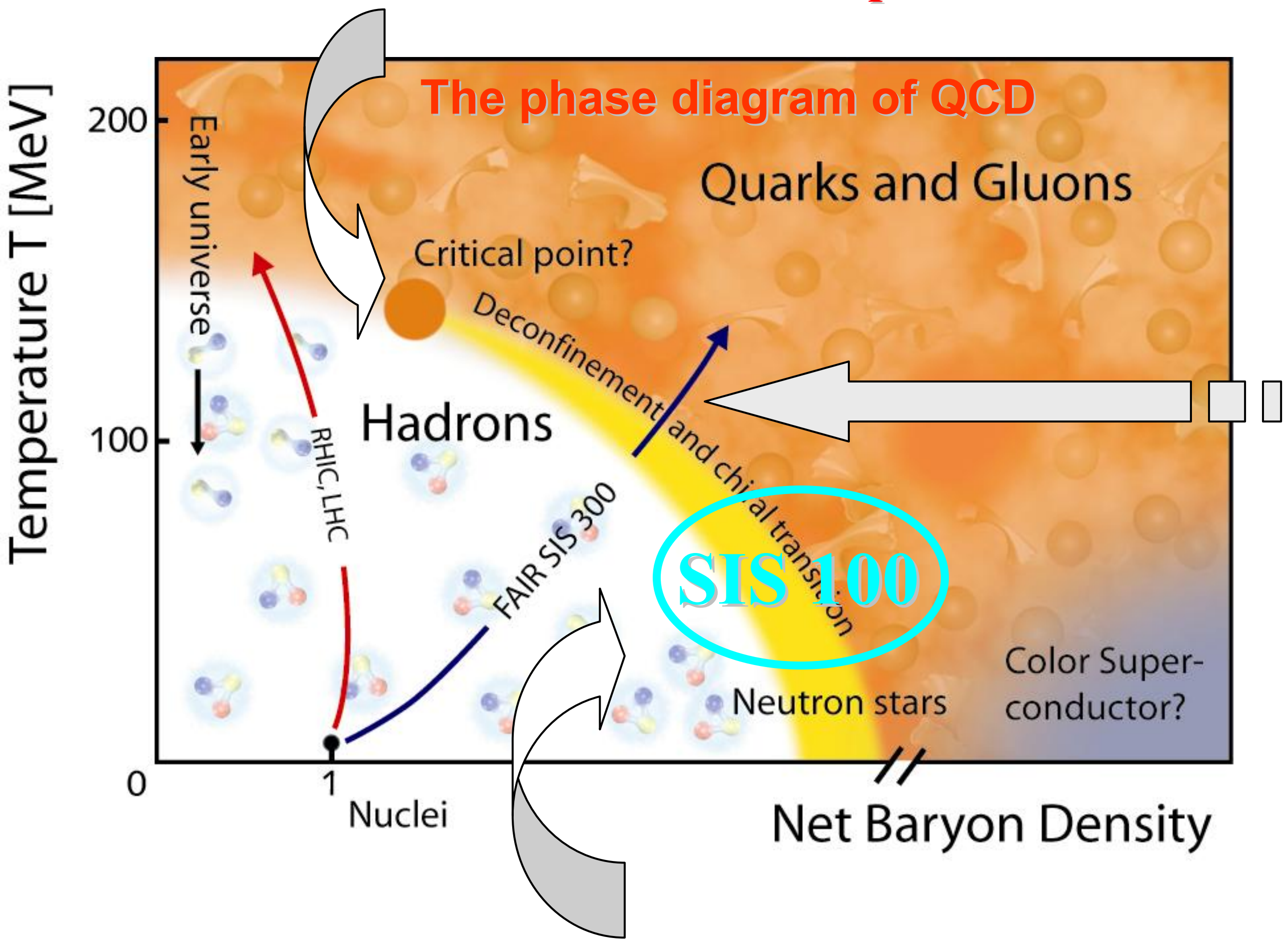
Institut für Theoretische Physik, Uni. Frankfurt



27 April 2009, Meeting on ‘Nuclear Matter Physics at SIS 100‘
GSI, Darmstadt

Our ultimate goals:

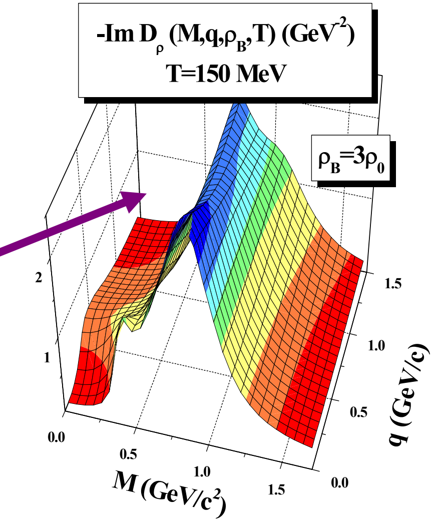
- **Search for the critical point**



- **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**

Aim I. Study of in-medium effects within transport approaches



Models predict changes of the particle properties in the hot and dense medium, e.g. broadening of the spectral function

Accounting for in-medium effects requires off-shell transport models

HSD* off-shell transport approach:

Generalized transport equations on the basis of the Kadanoff-Baym equations for Greens functions accounting for the first order gradient expansion of the Wigner transformed Kadanoff-Baym equations beyond the quasiparticle approximation (i.e. beyond standard on-shell models)

W. Cassing et al., NPA 665 (2000) 377; 672 (2000) 417; 677 (2000) 445

➔ The off-shell spectral functions change their properties dynamically by propagation through the medium and become on-shell in the vacuum

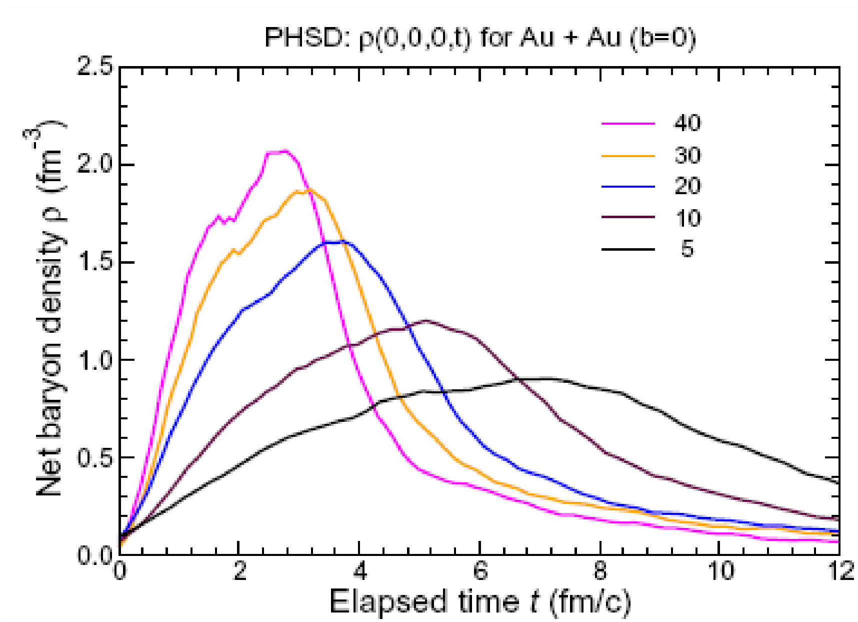
E. Bratkovskaya, NPA 686 (2001), E. Bratkovskaya & W. Cassing, NPA 807 (2008) 214

*HSD=Hadron-String-Dynamics

Dileptons

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

J. Randrup et al., CBM Physics Book; PRC75 (2007) 034902



FAIR energies

- **In-medium effects can be observed at all energies from SIS to RHIC**
- **The shape of the theoretical dilepton yield depends on the actual model for the in-medium spectral function**

=> Energy / system scan will allow to distinguish in-medium scenarios

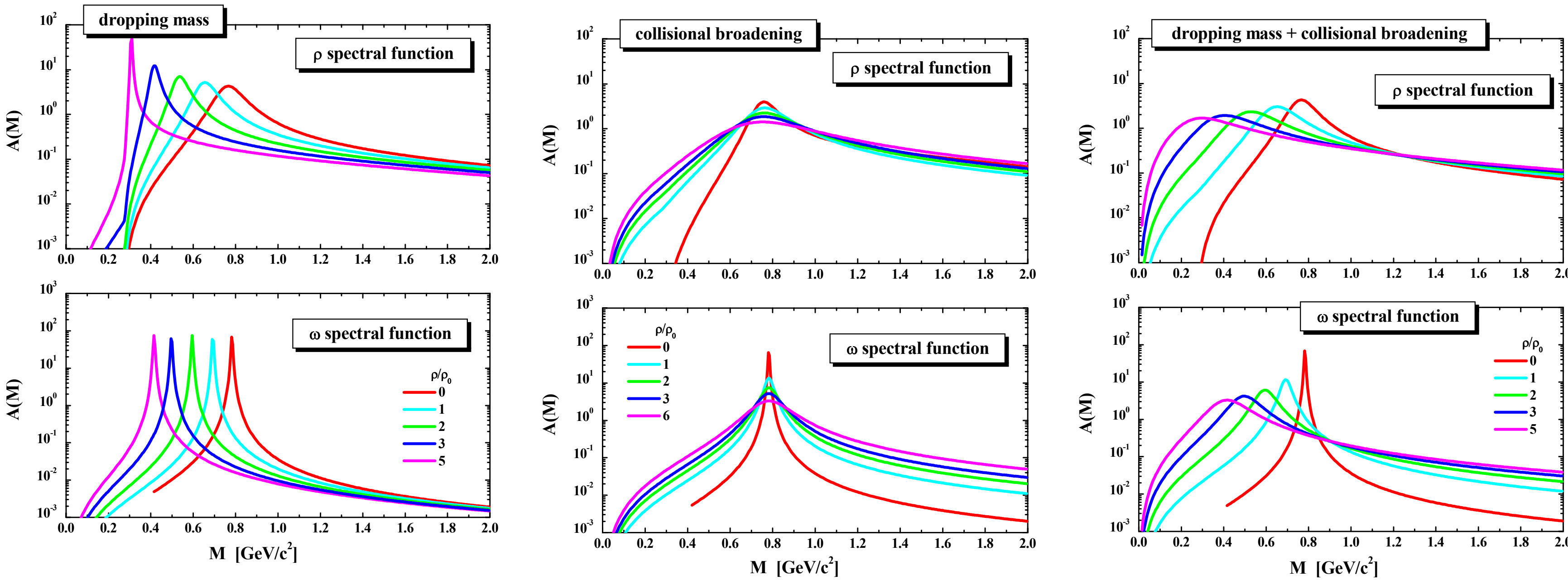
Modelling of in-medium spectral functions for vector mesons

In-medium scenarios:

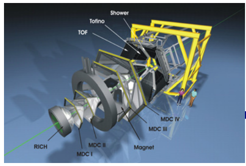
dropping mass — $m^* = m_0(1-\alpha\rho/\rho_0)$

collisional broadening — $\Gamma(M,\rho) = \Gamma_{vac}(M) + \Gamma_{CB}(M,\rho)$

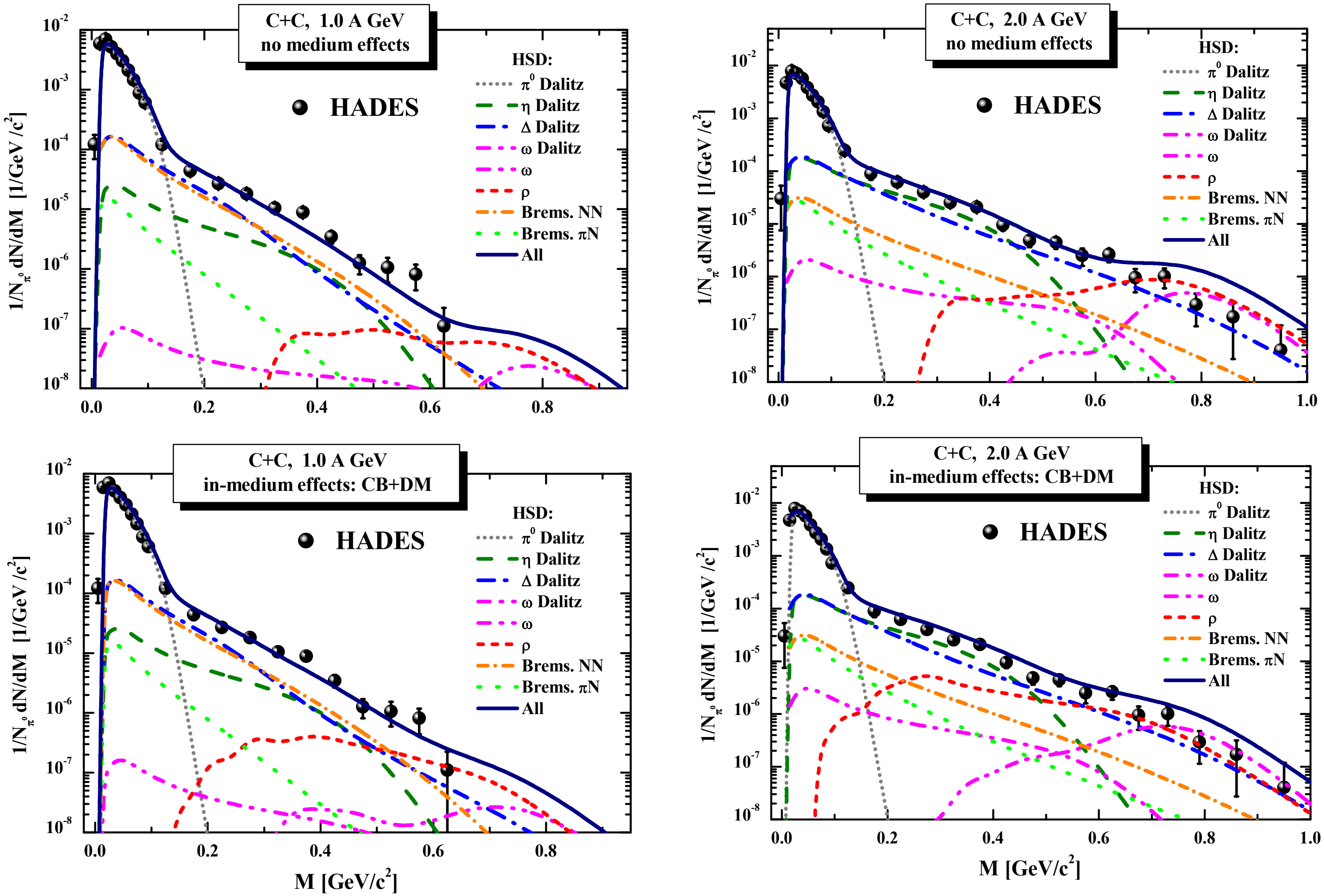
dropping mass + coll. broad.



- **Note:** for a consistent off-shell transport one needs not only in-medium spectral functions but also in-medium transition rates for all channels with vector mesons, i.e. the full knowledge of in-medium off-shell cross sections $\sigma(s,\rho)$



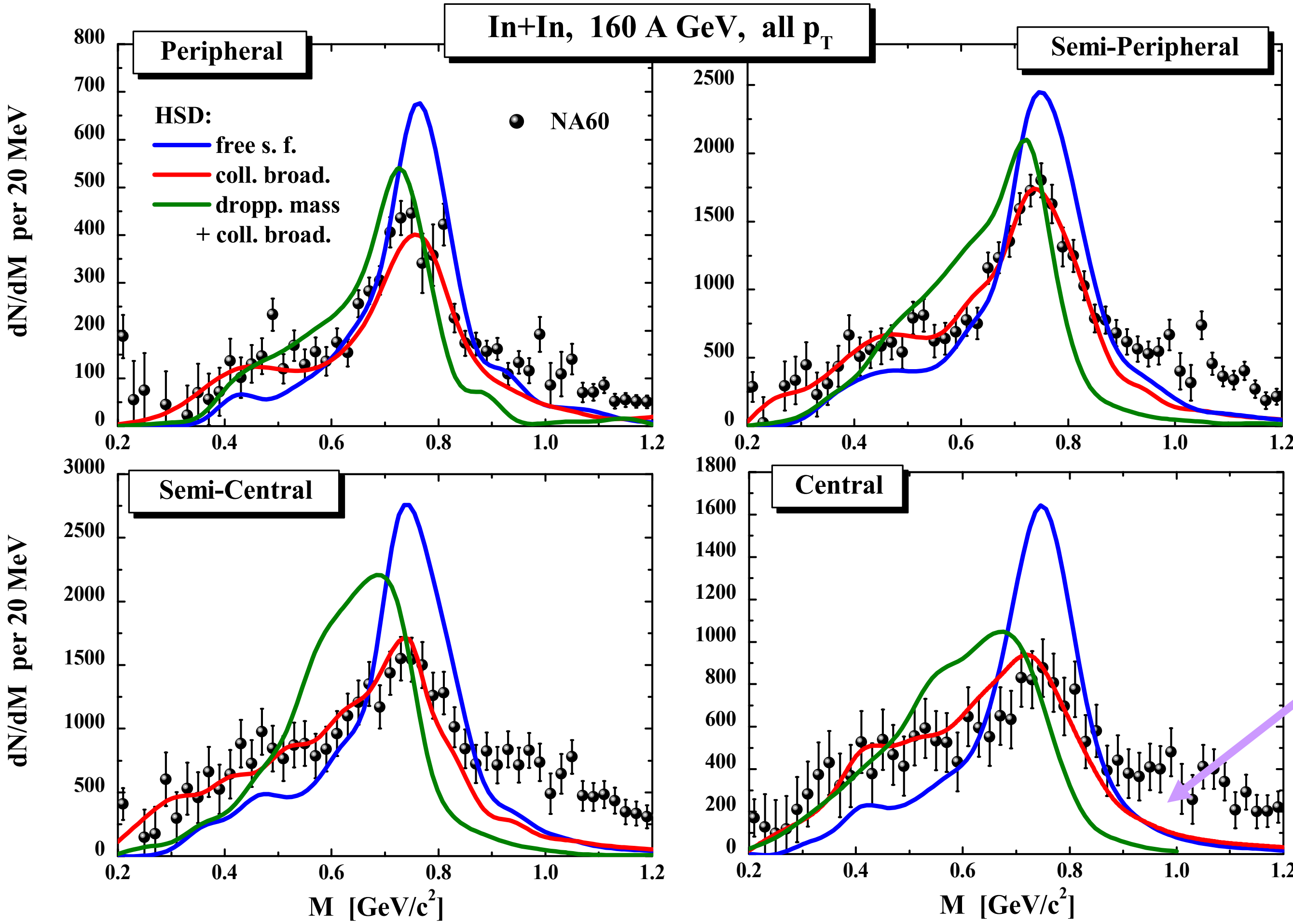
HSD: Dileptons from C+C at 1 and 2 A GeV - HADES



- HADES data show exponentially decreasing mass spectra
- Data are better described by in-medium scenarios with collisional broadening
- In-medium effects are more pronounced for heavy systems such as Au+Au

E.B., Cassing, NPA807 (2008) 214

Dileptons at SPS: NA60

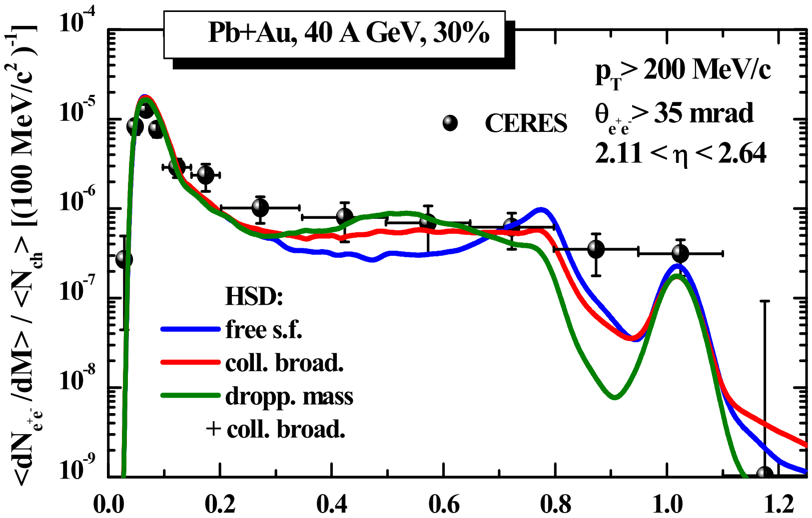


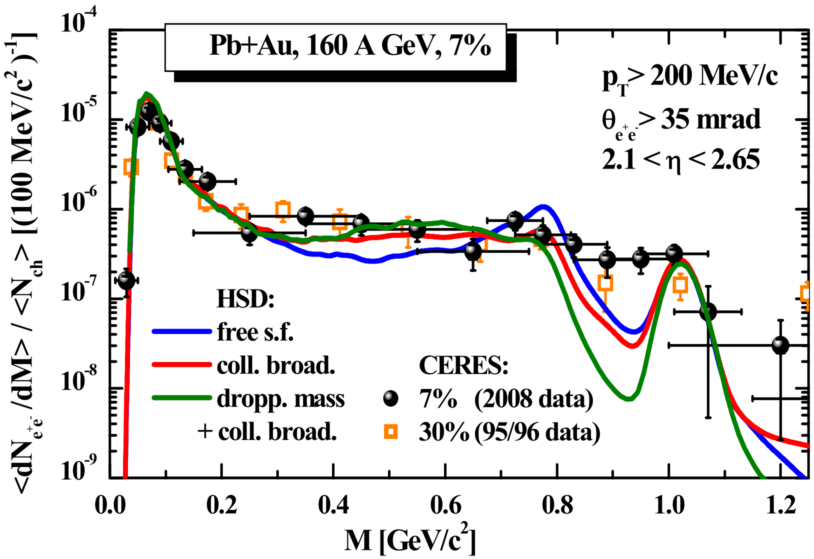
High M tail not reproduced in HSD
||
Non-hadronic origin?

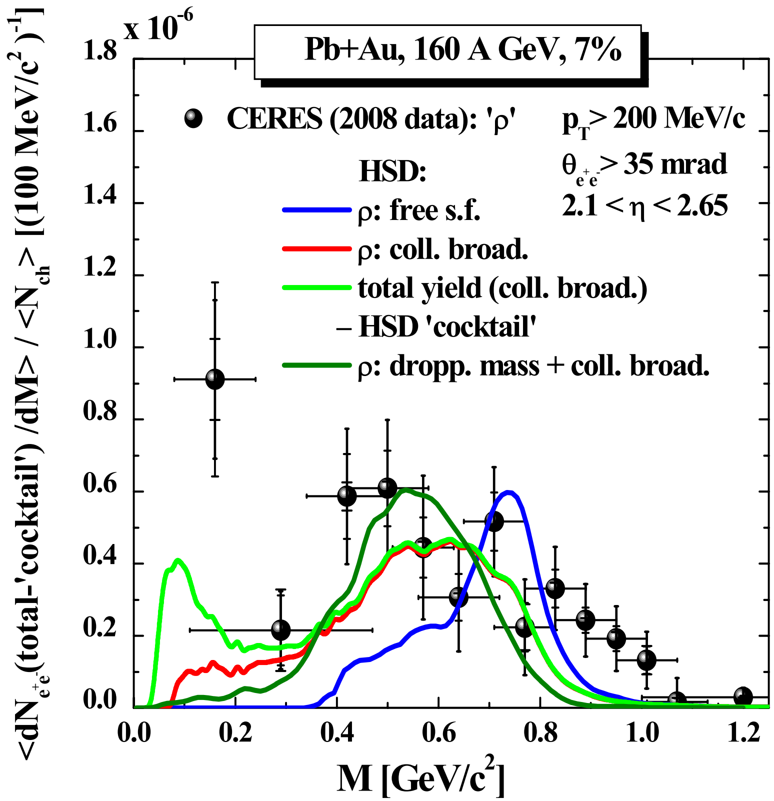
- NA60 data are better described by in-medium scenario with collisional broadening

E. Bratkovskaya, W. Cassing, O. Linnyk, PLB 670 (2009) 428

Dileptons at SPS: CERES



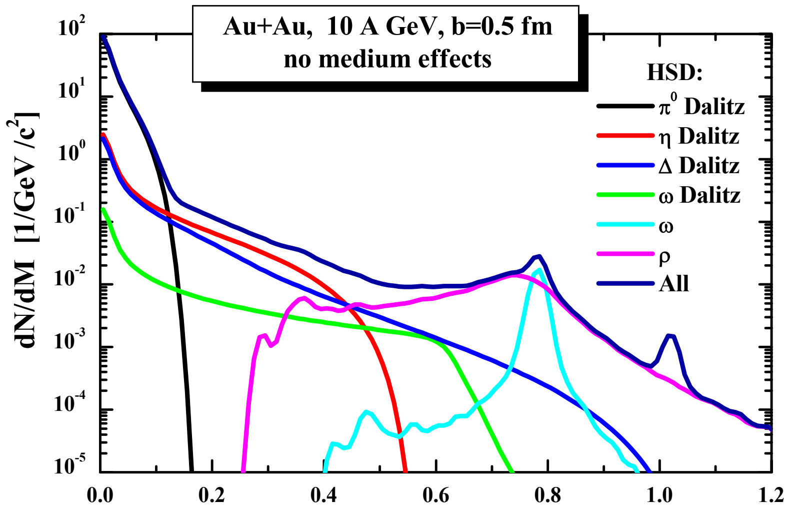




CERES data are better described by an in-medium scenario with collisional broadening

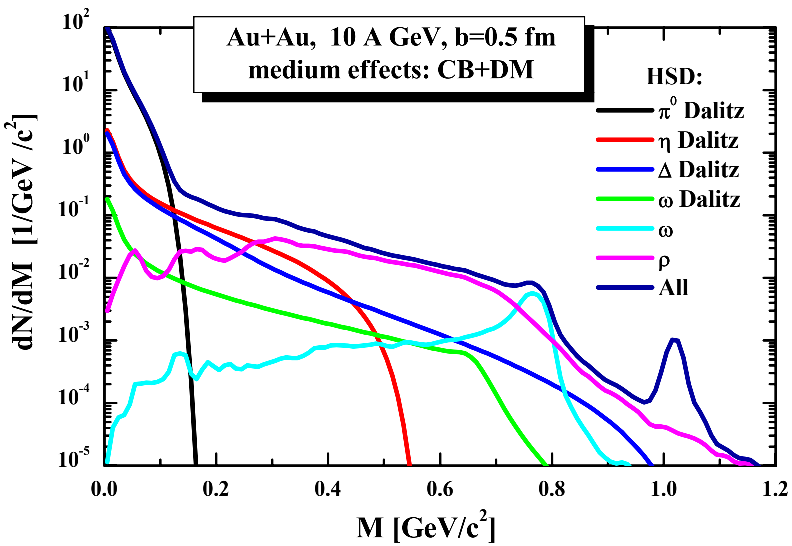
E. Bratkovskaya, W. Cassing, O. Linnyk, PLB 670 (2009) 428

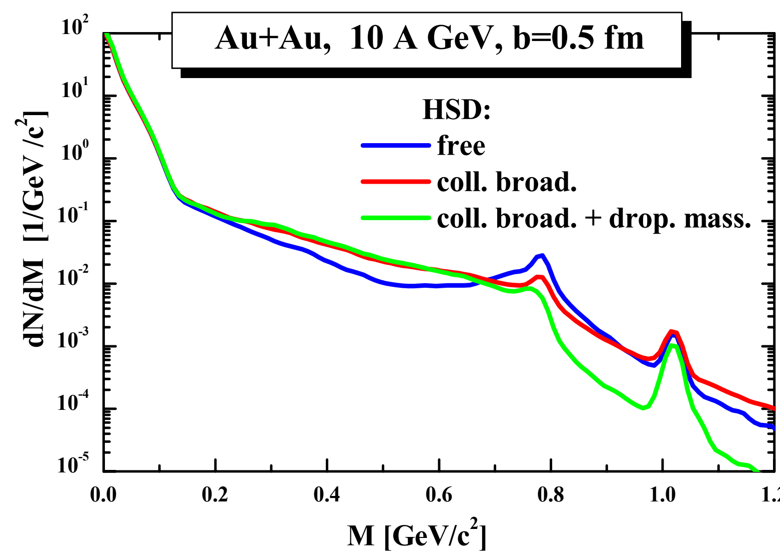
Dileptons at SIS-100



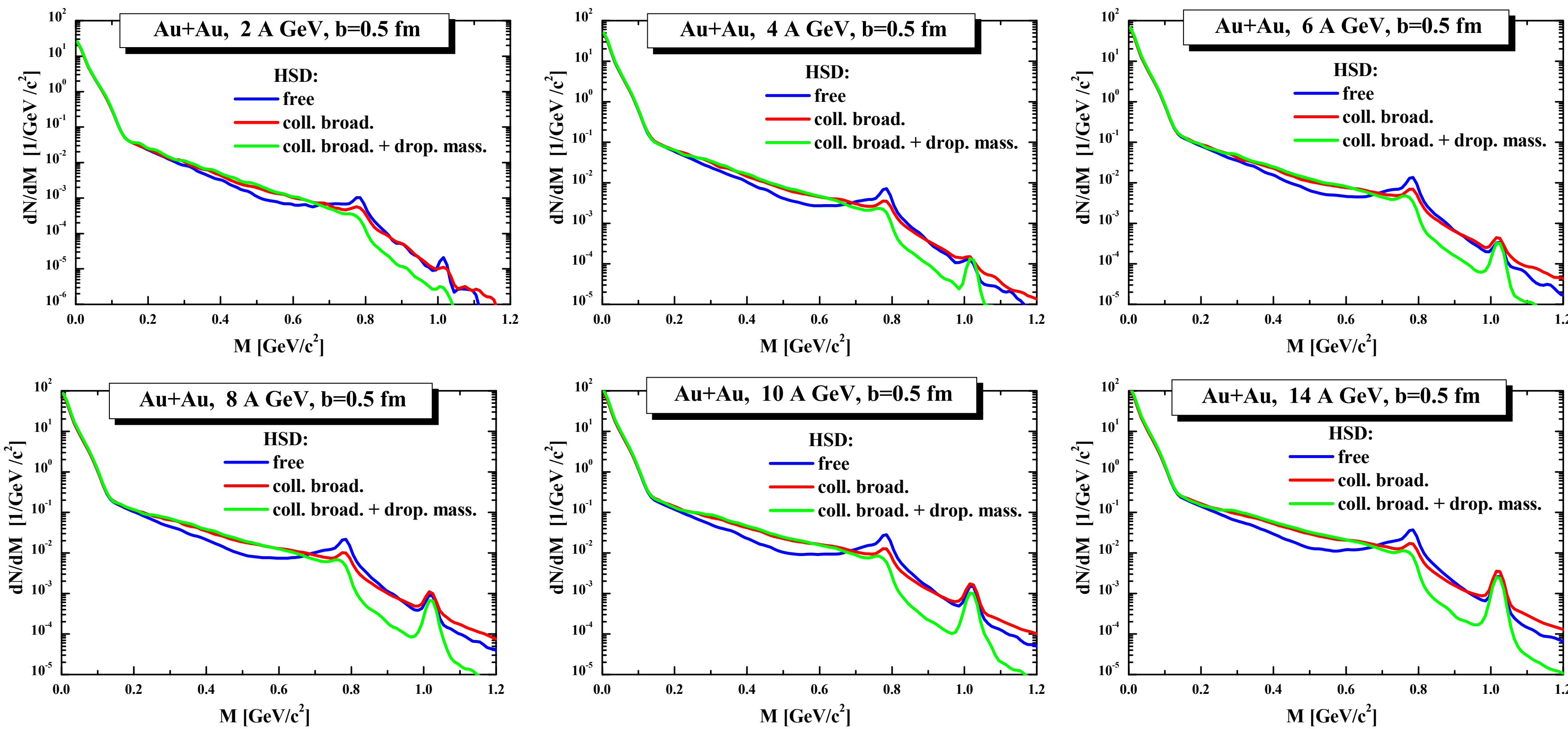
For in-medium scenarios with collisional broadening + dropping mass:

- strong broadening of ρ-meson spectra
- reduction of the yield at the ‚free' pole mass





Dileptons at SIS-100



Dileptons at SIS-100 : ‚free‘ vs. ‚in-medium‘ scenarios (collisional broadening , collisional broadening +dropping mass) for vector mesons (ρ,ω,ϕ)

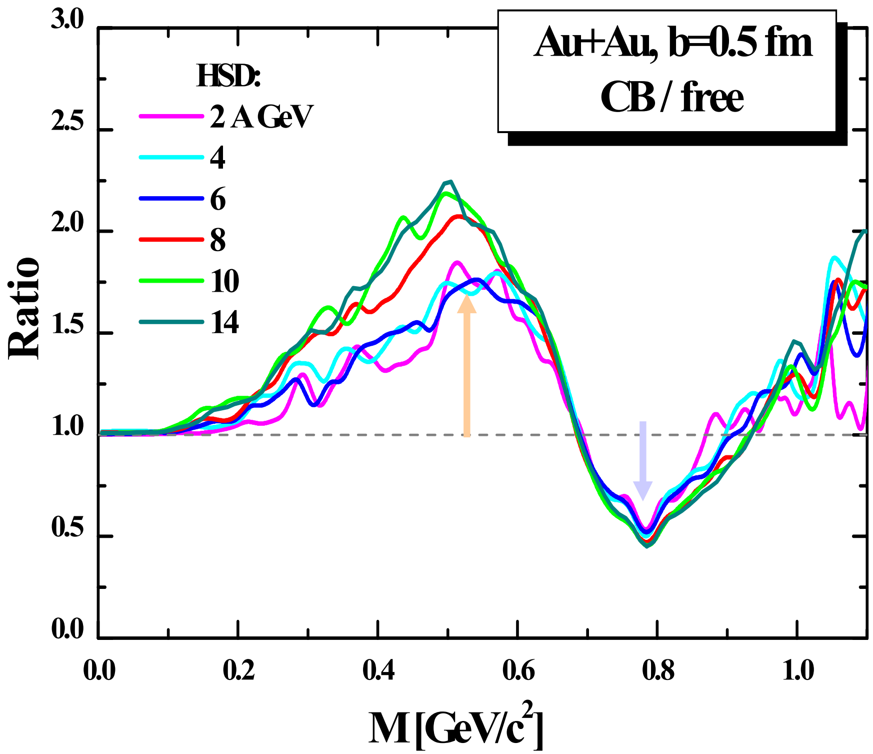
➔ enhancement of dilepton yield for $0.2<M<0.7$ GeV and reduction at $M\sim m_{\rho/\omega}$ for all SIS-100 energies!

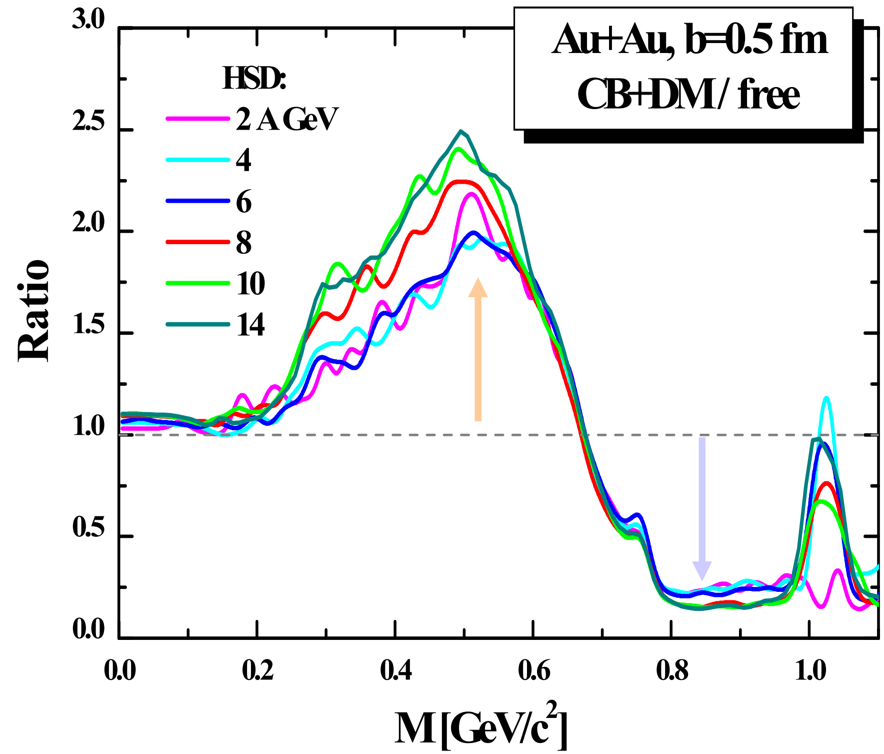
Dileptons at SIS-100

Ratio = dN/dM(in-medium) / dN/dM(free)

• **in-medium scenarios for vector mesons:**

collisional broadening — **collisional broadening + dropping mass**

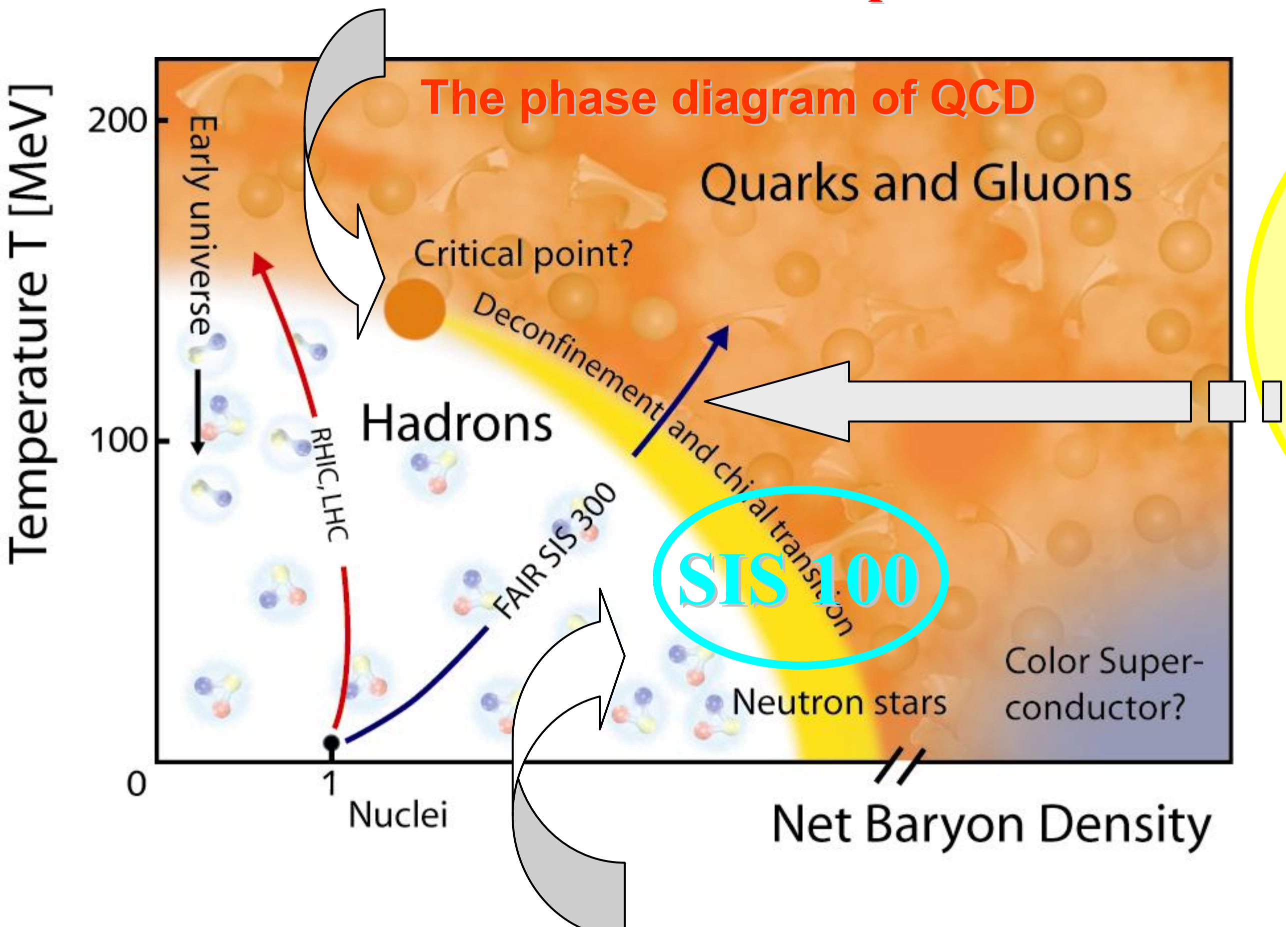




❖ **enhancement of dilepton yield for 0.2<M<0.7 GeV and reduction at $M \sim m_{\rho/\omega}$ for all SIS-100 energies from 2 to 14 A GeV!**

Our ultimate goals:

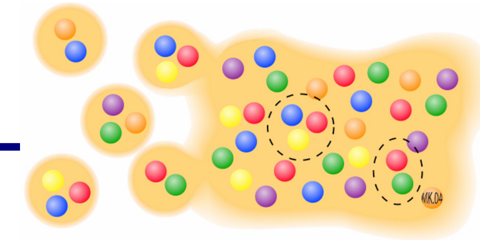
- Search for the critical point



- 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

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) outside 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 $G^{<}_{h}(x,p)$ in phase-space representation; with the partonic and hadronic phase

Parton-Hadron-String-Dynamics (PHSD)

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

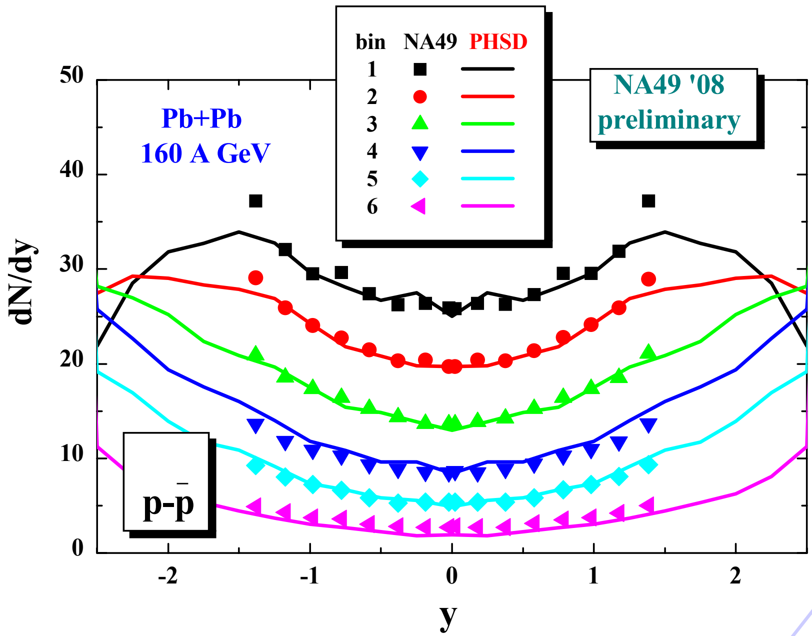
QGP phase described by input from the

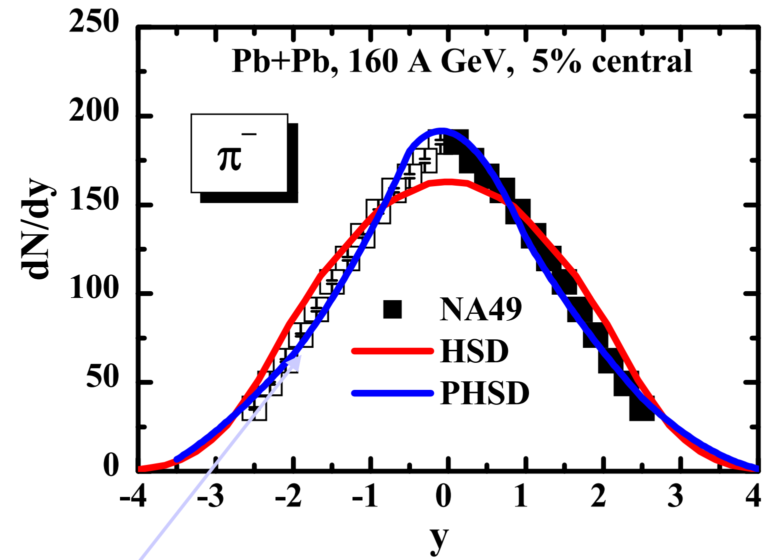
Dynamical QuasiParticle Model (DQPM)

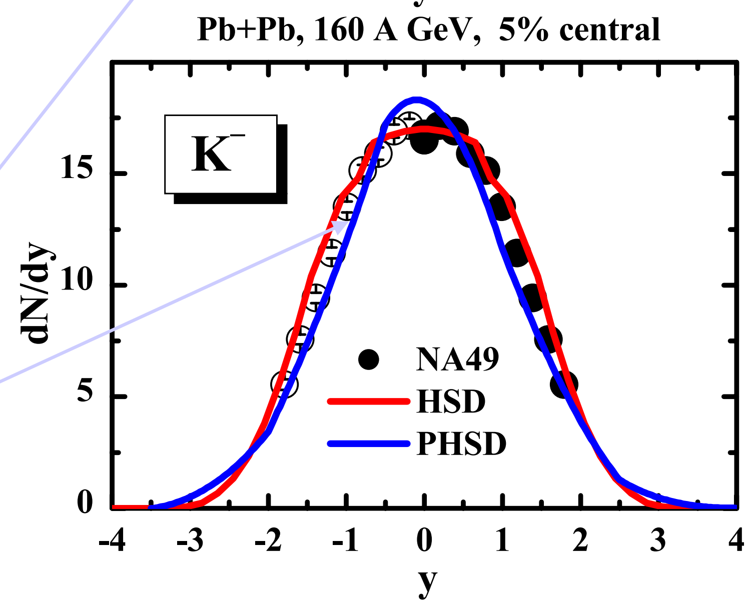
Peshier, Cassing, PRL 94 (2005) 172301;
Cassing, NPA 791 (2007) 365: NPA 793 (2007)

PHSD: Rapidity distributions at top SPS

proton stopping





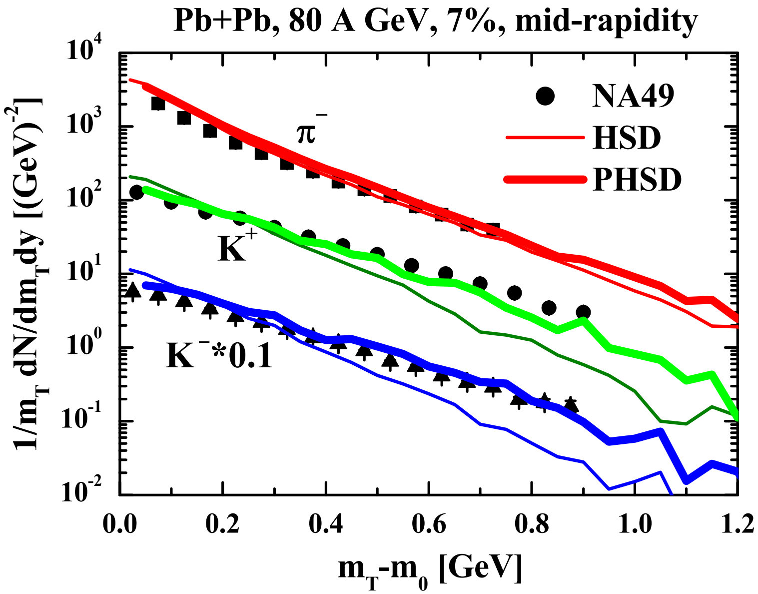


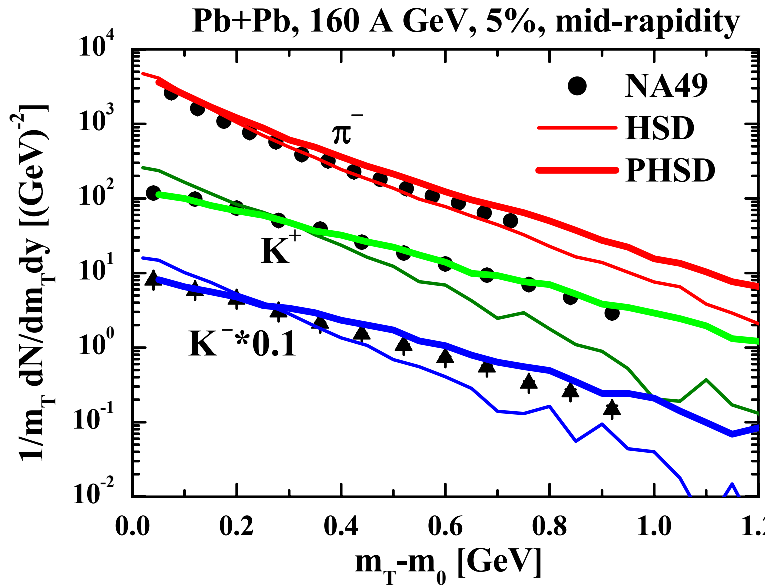
➔ looks not bad !

✓pion and kaon dN/dy
become more narrow !

PHSD: Transverse mass spectra at top SPS

Central Pb + Pb at top SPS energies

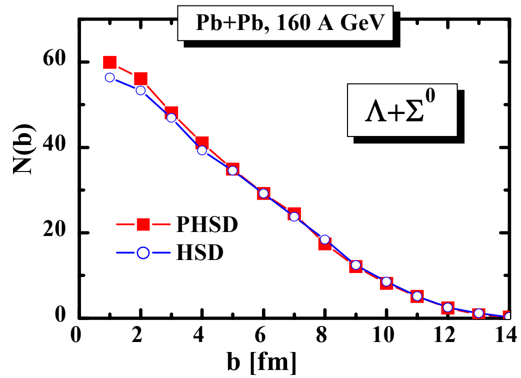


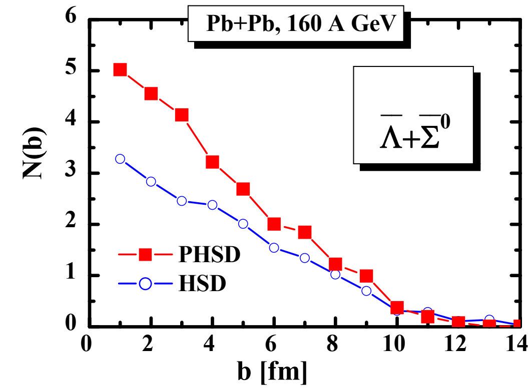


☺ PHSD gives harder spectra and works better than HSD at top SPS energies

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

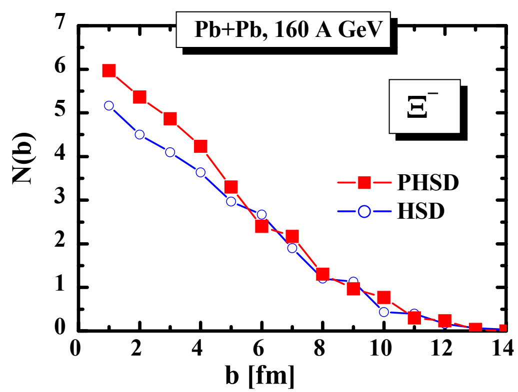
PHSD: Strange and antistrange baryons at 160 A GeV

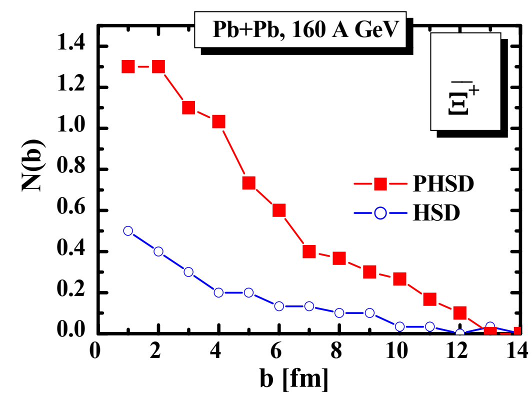




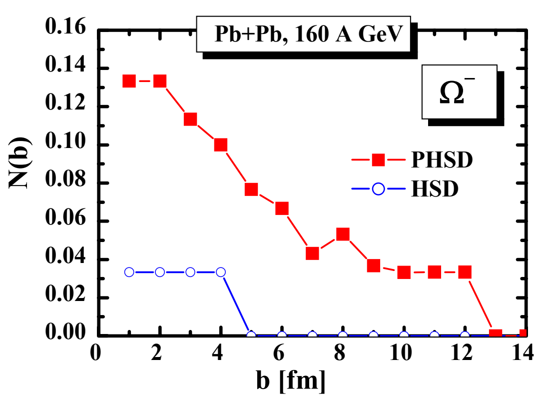
PHSD:

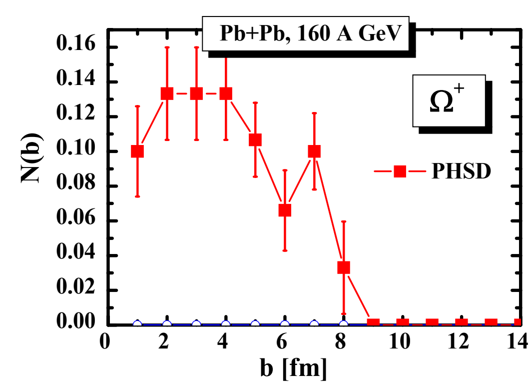
Slightly more Λ and Ξ but much more Ω's !!





Antibaryons (r.h.s,) are substantially enhanced !

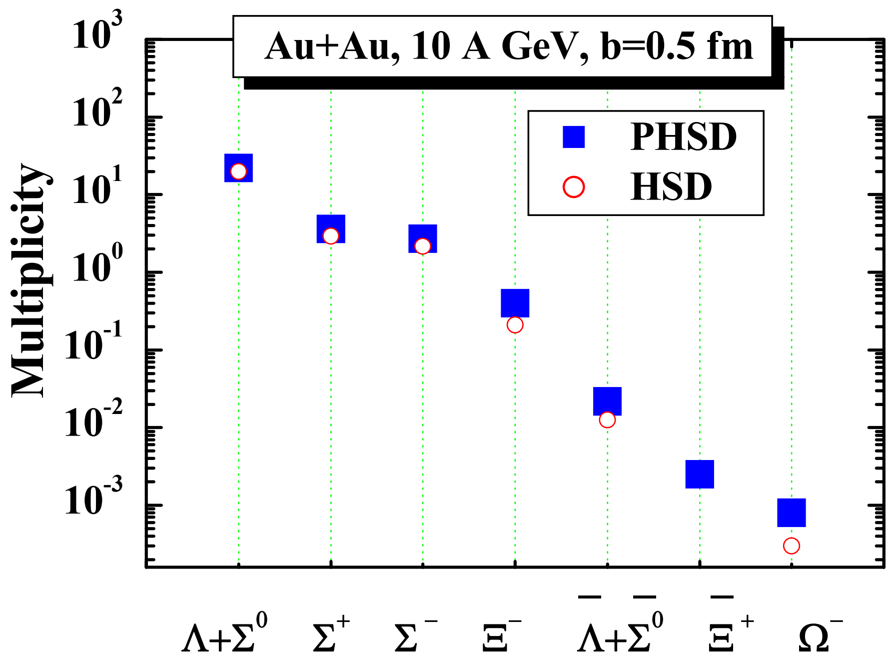




Note:

present statistics drastically need improvement !

Strange and anti-strange baryons at SIS-100



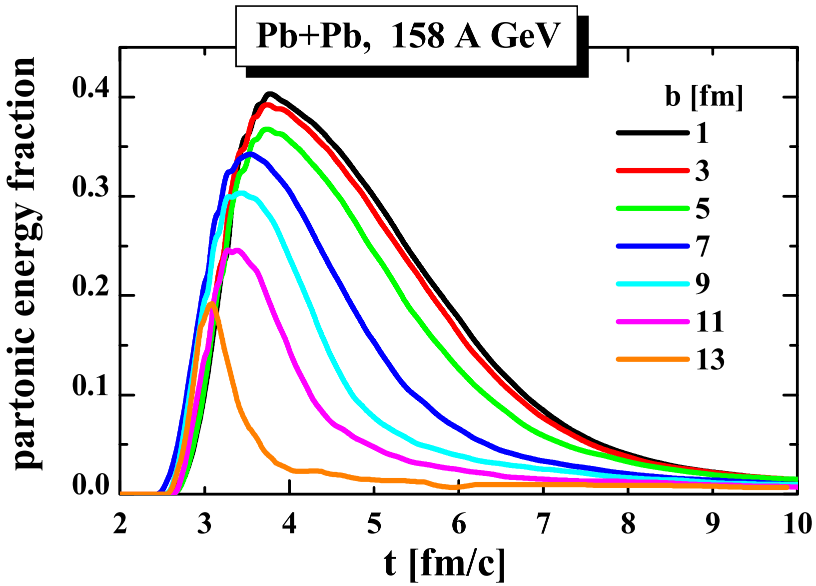
PHSD vs. HSD:

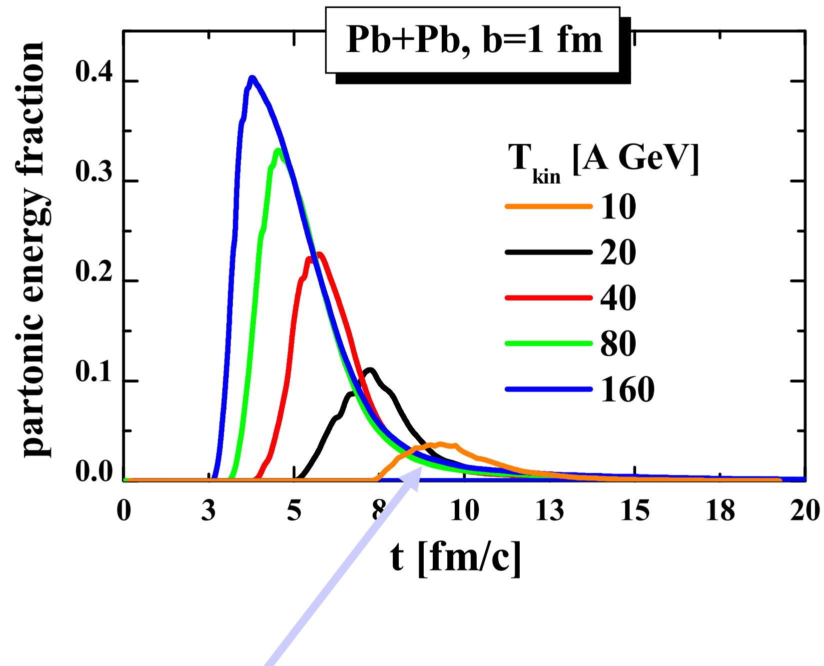
enhancement of strange antibaryons is seen at 10 A GeV

(within present statistics !!!!)

Partonic phase at FAIR energies

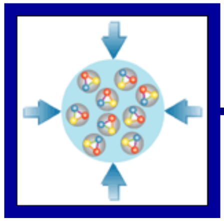
partonic energy fraction vs centrality and energy





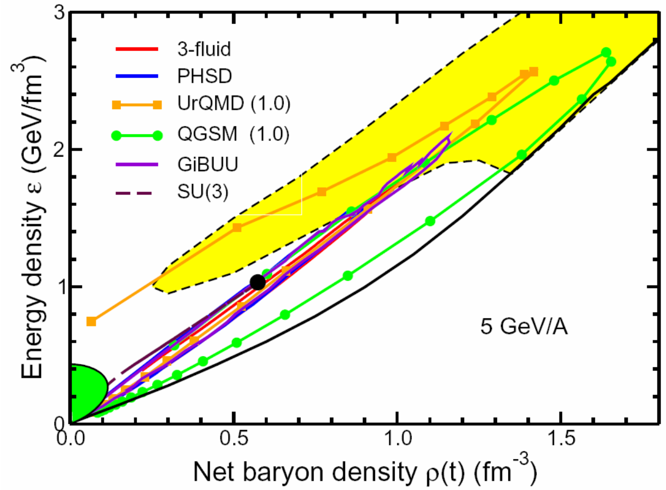
Dramatic decrease of partonic phase with decreasing energy and centrality

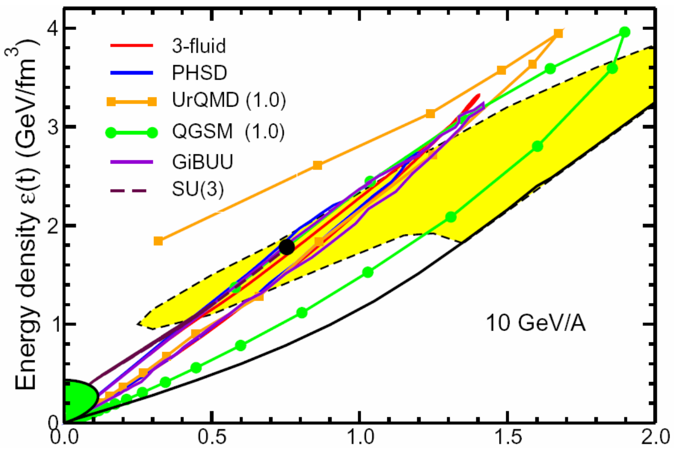
➔ very small effect on pion and kaon observables at FAIR energies!



What is the matter at SIS-100 ?!

The phase trajectories ($\rho(t)$,$\varepsilon(t)$) for central Au+Au collisions:

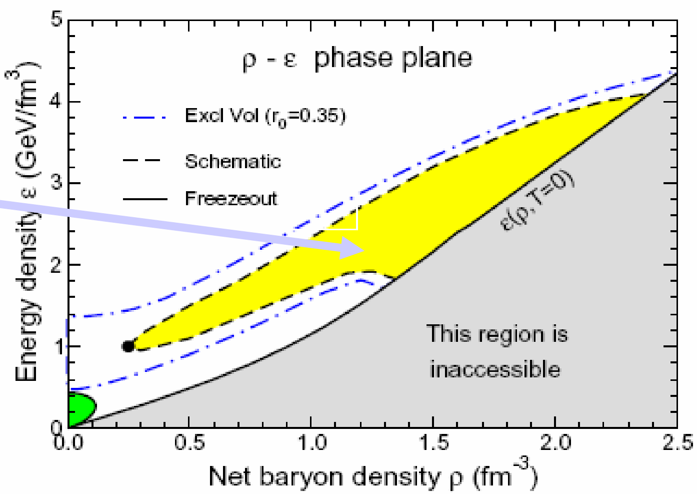




➔huge energy and baryon densities are reached ($\varepsilon > \varepsilon_{crit}$=1 GeV/fm^3) at FAIR energies (> 5 A GeV), however, the phase transition might be NOT a cross-over at FAIR!

- 1st order phase transition with critical point?

⇒ co-existance of partonic and hadronic degrees of freedom (in a mixed phase)



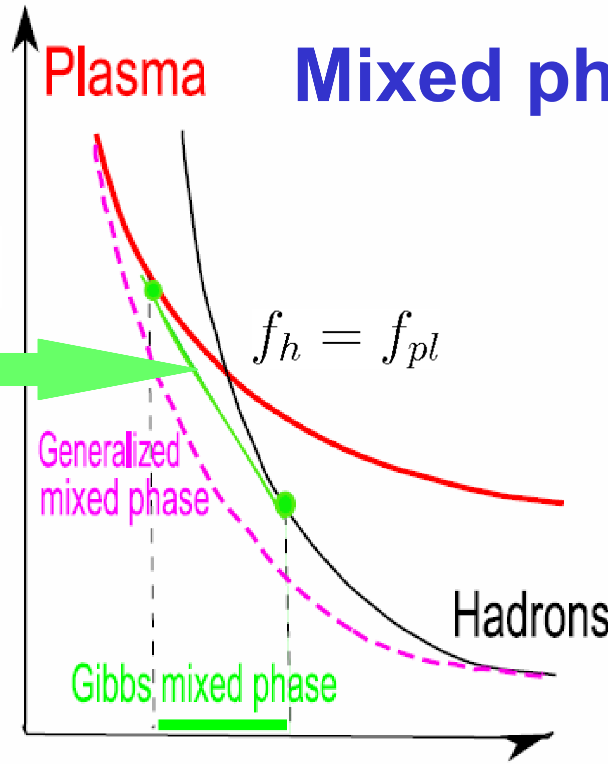
J. Randrup et al., CBM Physics Book; PRC75 (2007) 034902

Mixed phase concept

(Slide from V. Toneev)

reduced free energy

$$f = \frac{F}{N} = -\frac{T \ln \mathcal{Z}}{N}$$



Maxwell construction

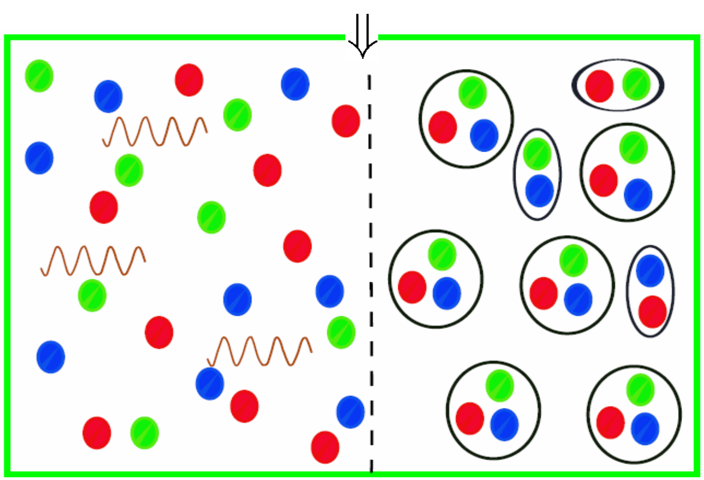
$$\left(\frac{\partial P}{\partial V}\right)_{N,T} < 0$$

$$P = -\left(\frac{\partial F}{\partial V}\right)_{N,T}$$

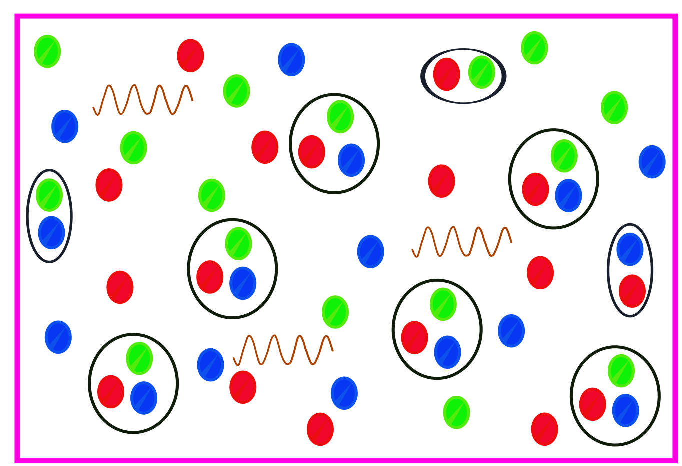
$$\frac{\partial^2 F}{\partial V^2} > 0$$

reduced volume $v = \frac{V}{N} = 1/\rho$

The Gibbs mixed phase (spatially separated domains)

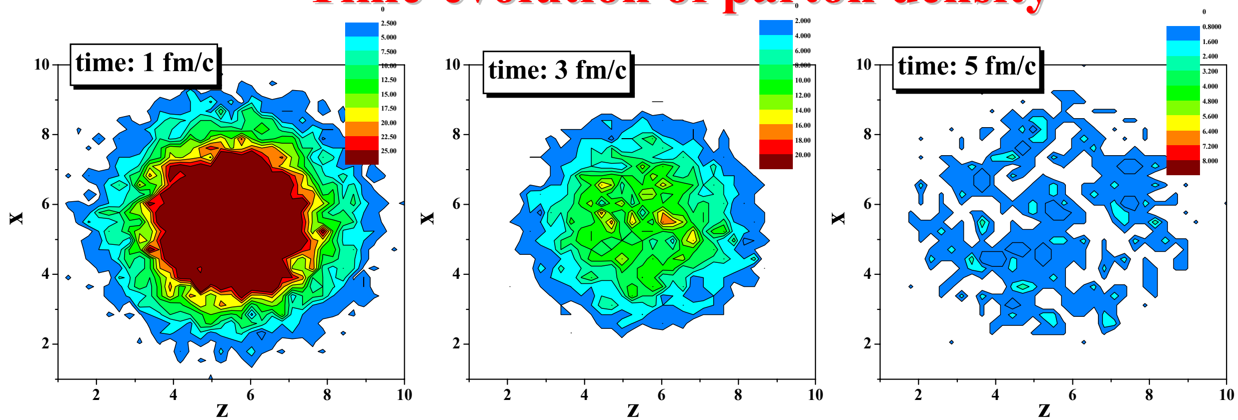


Generalized mixed phase (homogeneous)

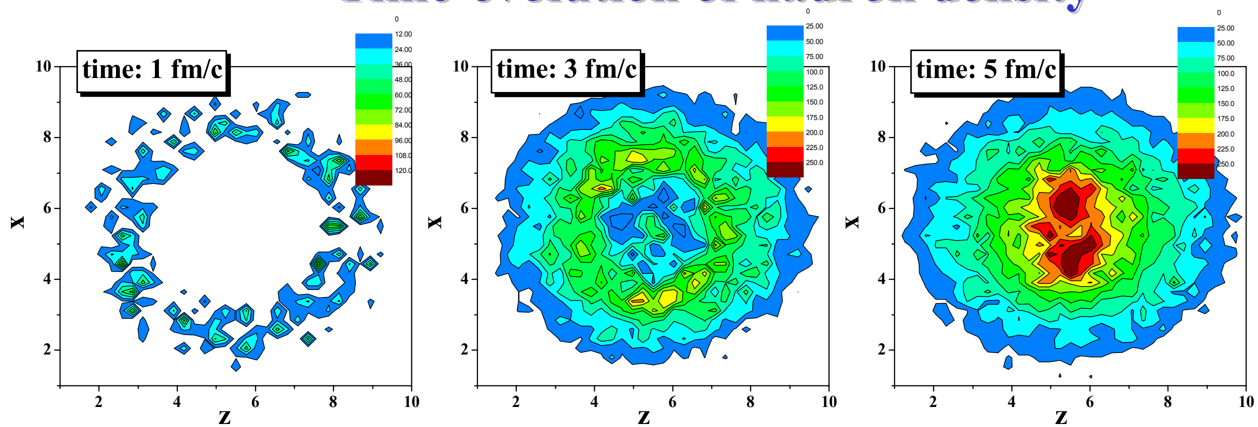


PHSD: Expanding fireball

Time-evolution of parton density



Time-evolution of hadron density



Expanding grid: $\Delta z(t) = \Delta z_0(1+0.75\ t)$!

PHSD: spacial phase ‚co-existence‘ of partons and hadrons, but NO interactions between hadrons and partons (cross-over)

Summary

- SIS-100 is well situated to study in-medium effects due to the high baryon densities and long reaction times

- dilepton spectra - according to the HSD predictions - show sizeable changes due to the different in-medium scenarios (as collisional broadening and dropping mass) which can be observed experimentally

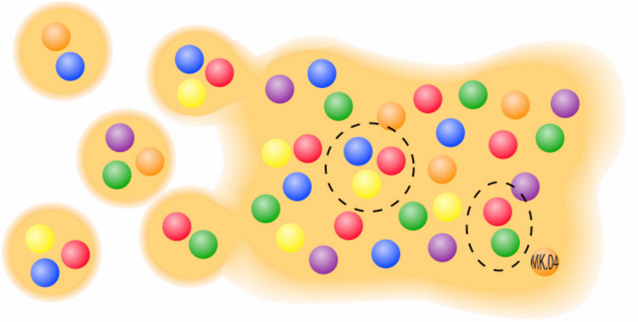
- fraction of the partonic phase is small at FAIR energies => PHSD gives practically the same results as HSD (except for multi-strange antibaryons) when the lQCD EoS (where the phase transition is always a cross-over) is used

- is the matter at SIS-100 a ‚mixed phase' ?

Open problems

- How to describe a first-order phase transition in transport ?

- How to describe parton-hadron interactions in a ‚mixed' phase?



Thanks

Wolfgang Cassing
Olena Linnyk
Volodya Konchakovski

HSD & PHSD Team

Viatcheslav D. Toneev

and the numerous experimental friends and collegues !

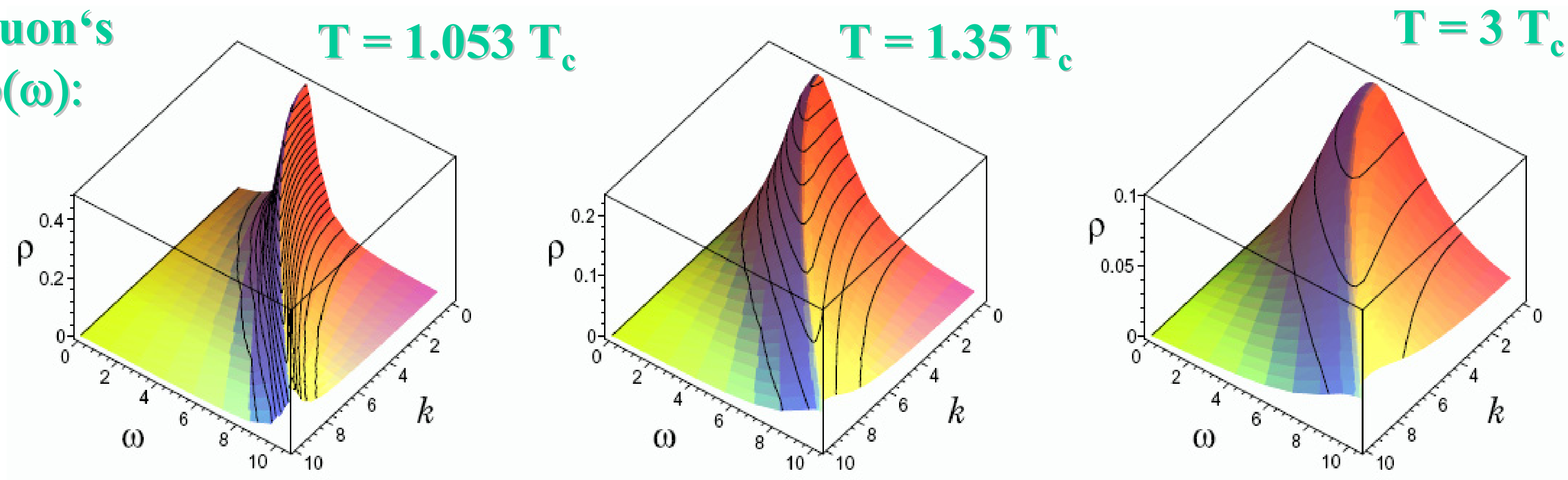
-- END --

The Dynamical QuasiParticle Model (DQPM)

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

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

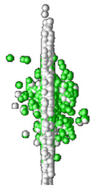
Gluon's $\rho(\omega)$:



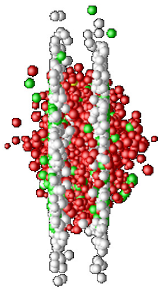
- **DQPM well matches lQCD**
- **DQPM provides mean-fields for gluons and quarks as well as effective 2-body interactions and gives transition rates for the formation of hadrons → PHSD**

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

PHSD - basic concepts



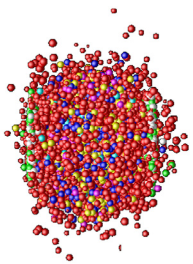
Initial A+A collisions – HSD: string formation and decay to pre-hadrons



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

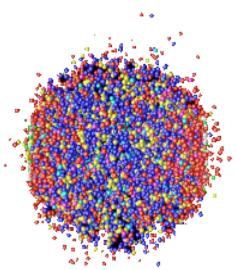
DQPM: Peshier, Cassing, PRL 94 (2005) 172301; Cassing, NPA 791 (2007) 365: NPA 793 (2007)

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

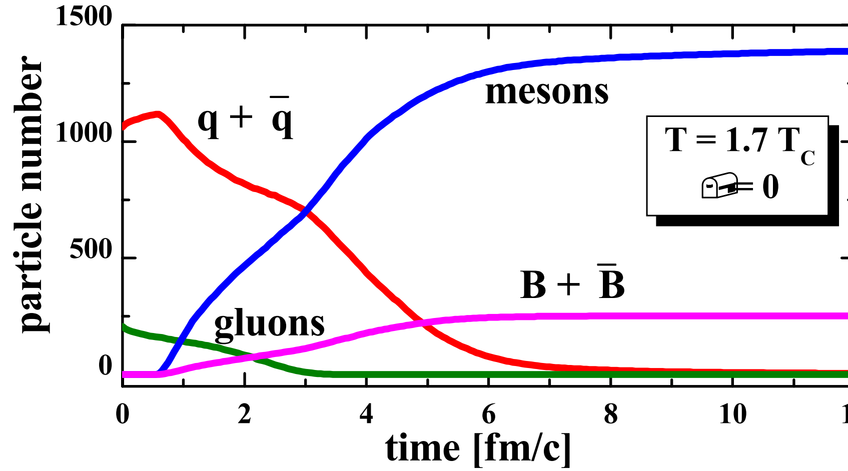


Hadronization: based on DQPM - massive, off-shell quarks and gluons with broad spectral functions hadronize to off-shell mesons and baryons:
gluons → q + qbar; q + qbar → meson (or string);
q + q +q → baryon (or string) (strings act as ‚doorway states' for hadrons)

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

PHSD: hadronization

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



Consequences: ☺

- **Hadronization:** q+qbar or 3q or 3qbar fuse to a 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 and not a decrease as in the simple recombination model !

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

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