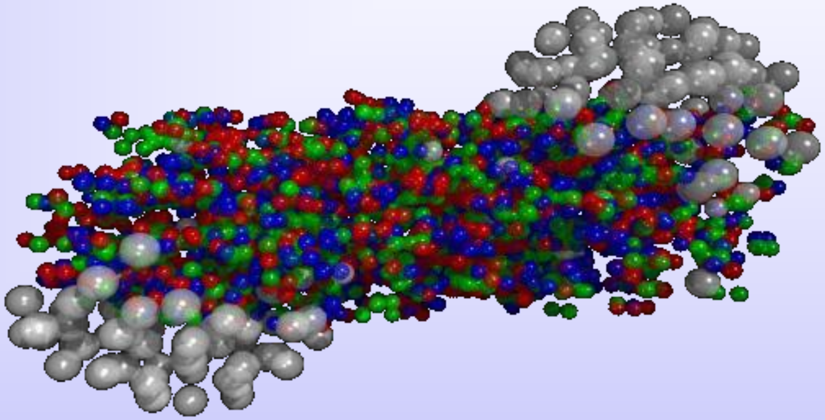
Are di-leptons sensitive messengers from the hot and dense stage?



Marcus Bleicher

Institut für Theoretische Physik

Goethe Universität Frankfurt

Germany

Outline

- Introduction
- Baryon densities: methods, results
- Densities at rho decay
- Model features
- Di-leptons
- Summary

Tools: Transport approaches

UrQMD, IQMD, HSD, RQMD,…

- out-of-equilibrium transport model, (rel. Boltzmann equation)
- Particles interact via :

  - measured and calculated cross sections

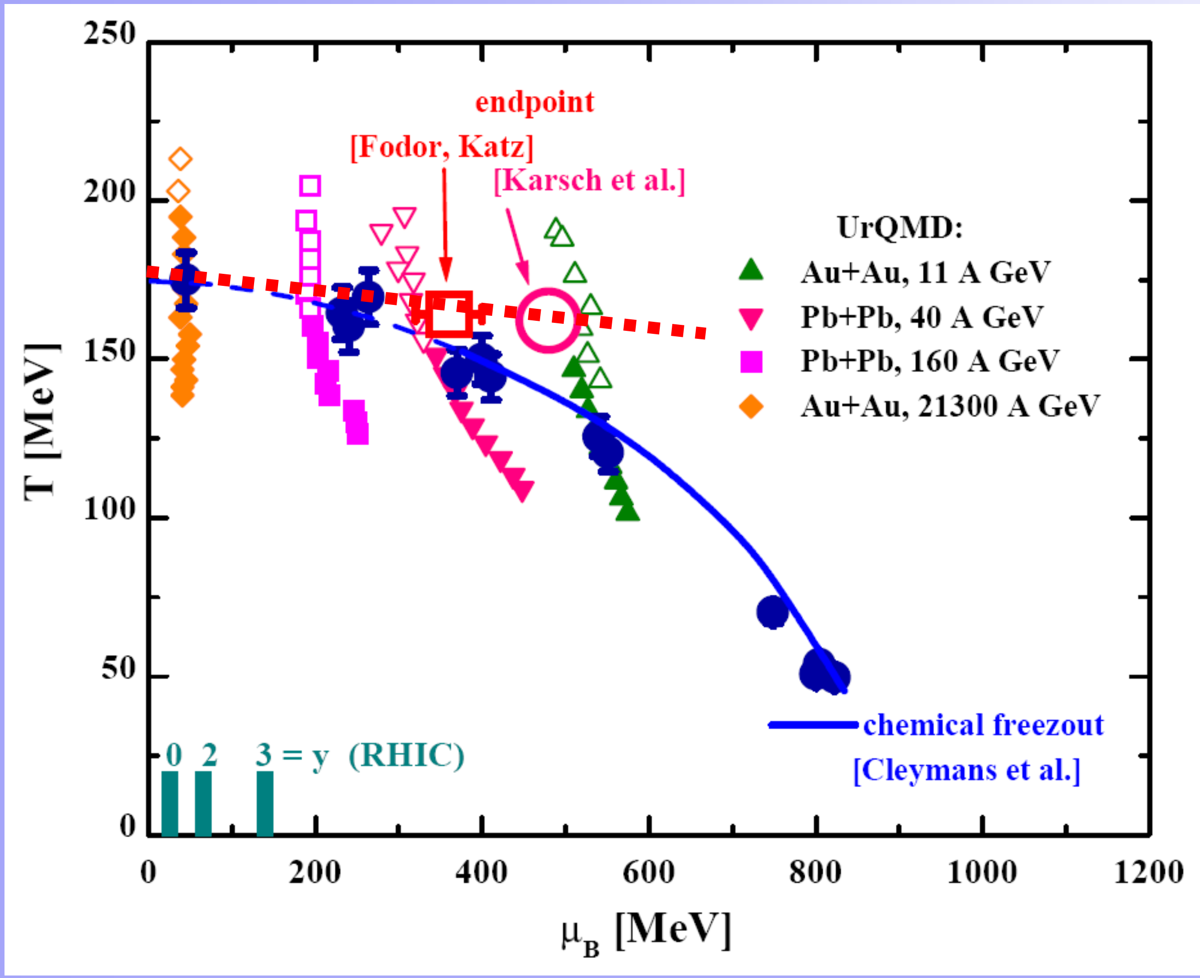
  - string excitation and fragmentation

  - formation and decay of resonances

  - Potentials and in-medium properties

- Provides full space-time dynamics of heavy-ion collisions

Motivation

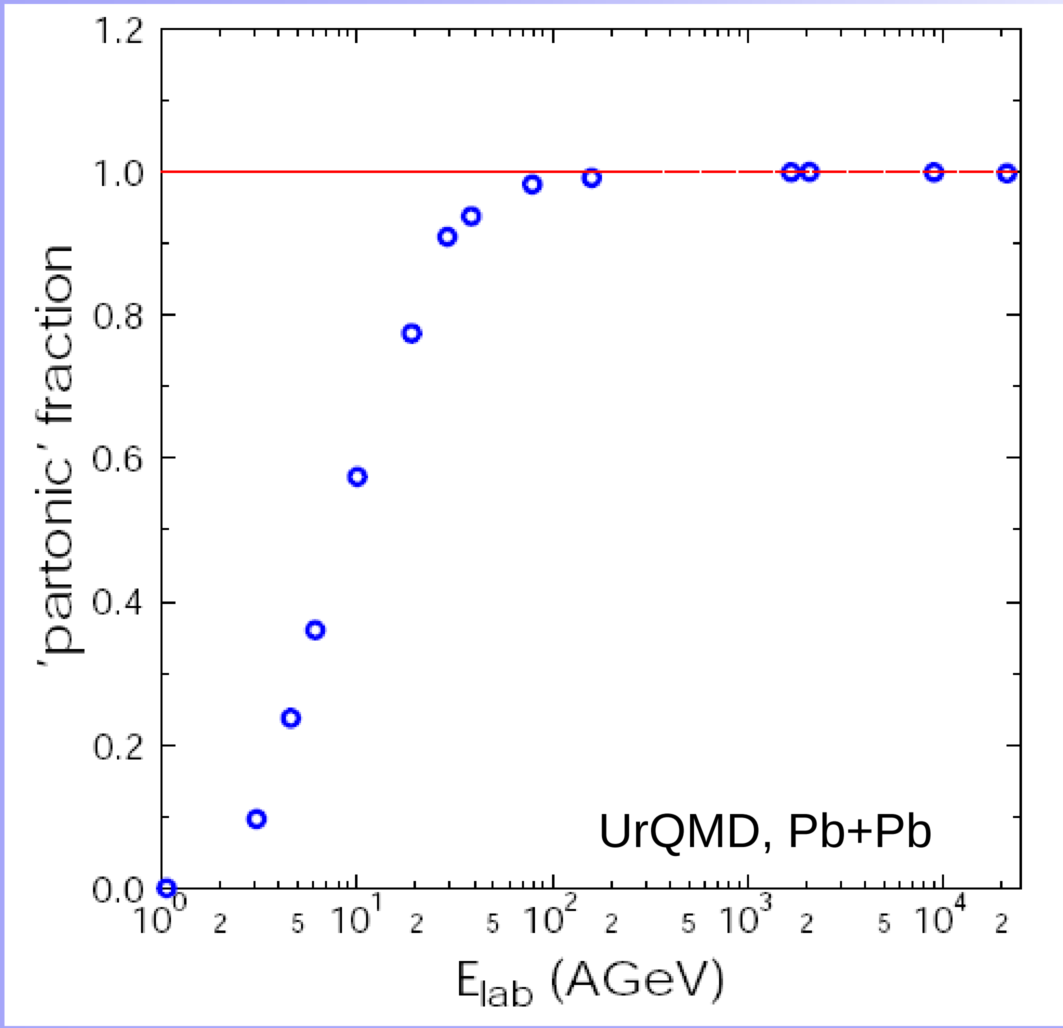


At **RHIC**:
look for signals of freely moving partons.

At **FAIR/SPS**:
look for the mixed phase and the onset of deconfinement

E. Bratkovskaya, M.B. et al., Phys.Rev.C69:054907,2004

Do we understand the interesting stages of the reaction?



String matter dominates the early stages
(t ~ overlap time)

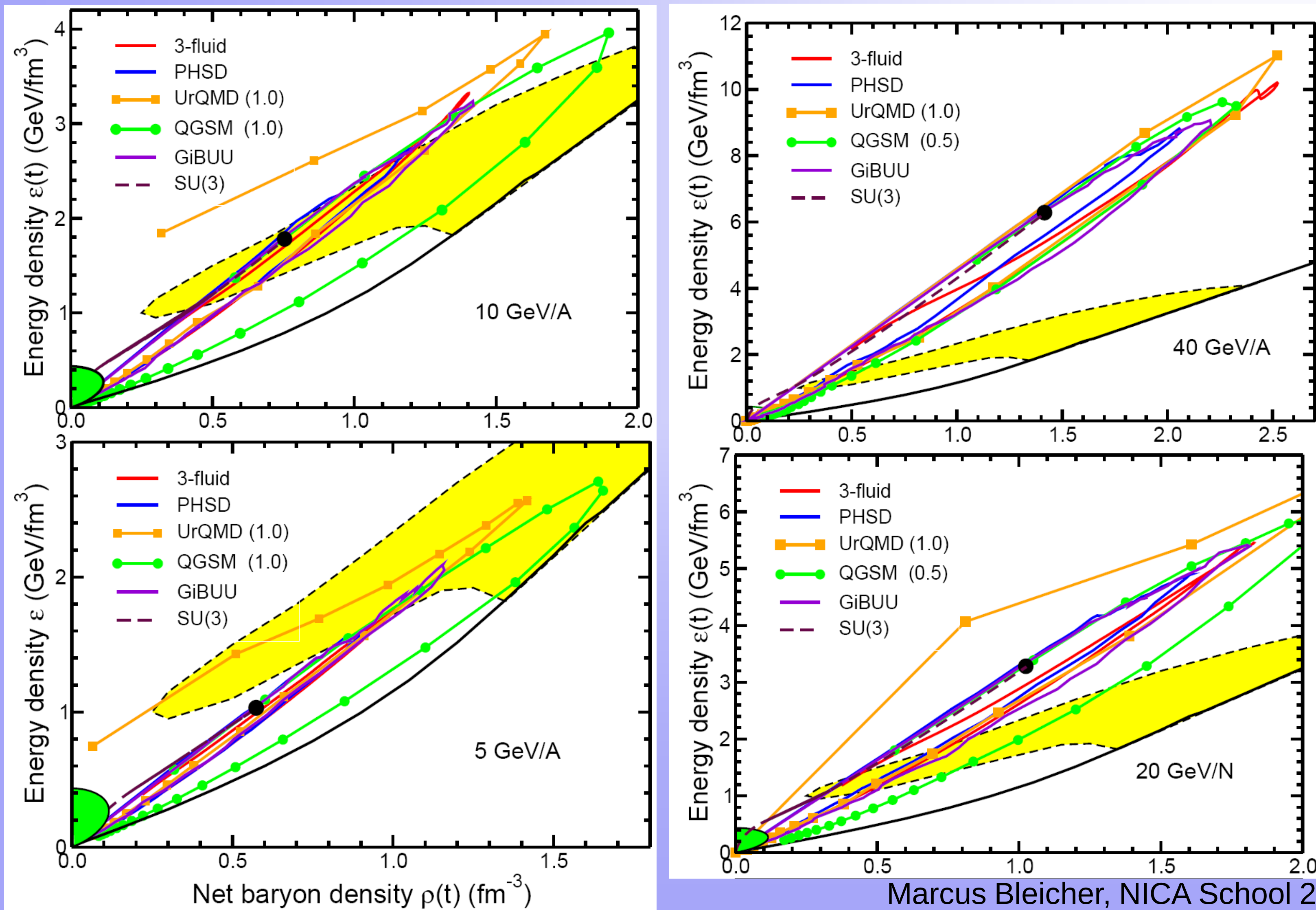
'string matter' = QGP?

However, overall dynamics does not seems to be sensitive to the underlying degrees of freedom

I. Arsene et al, nucl-th/0609042

H. Petersen, M.B., nucl-th/0611001

Phase trajectories

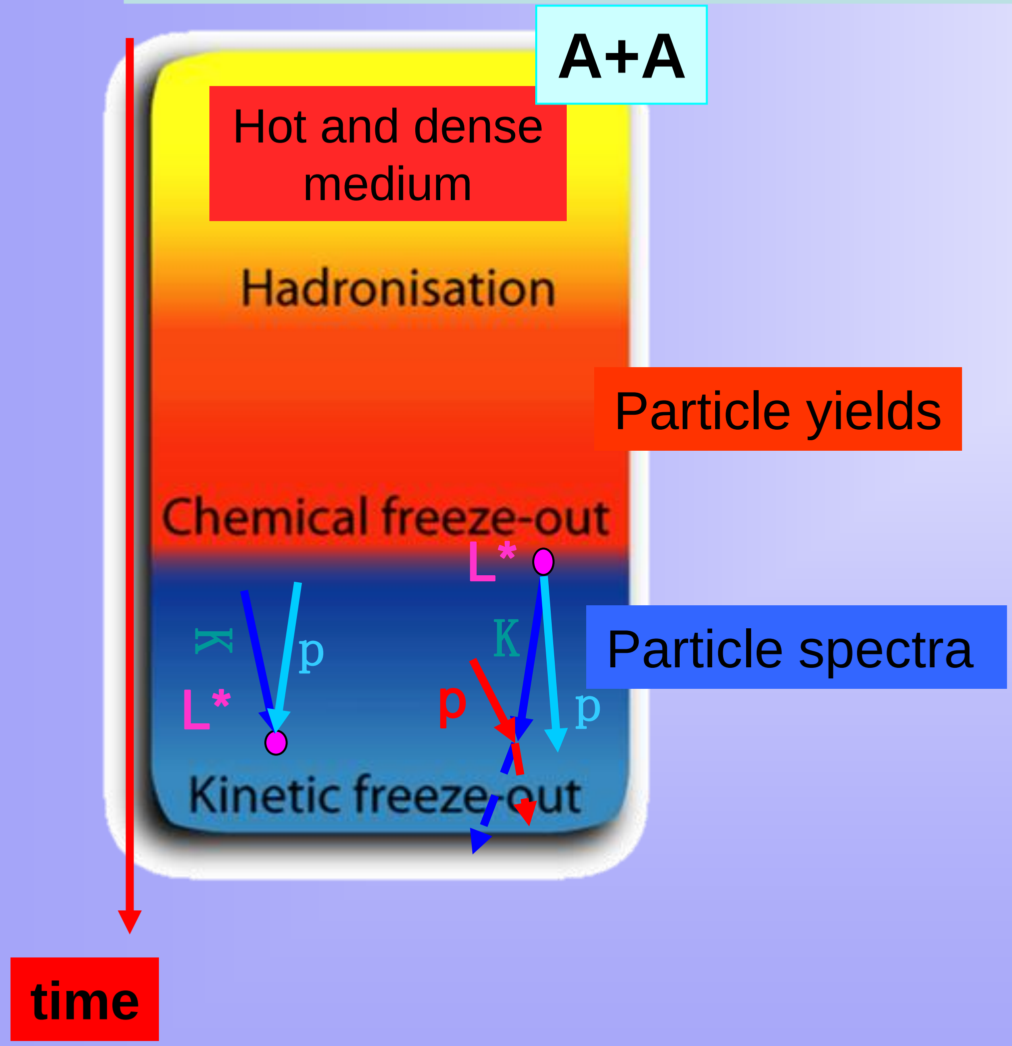


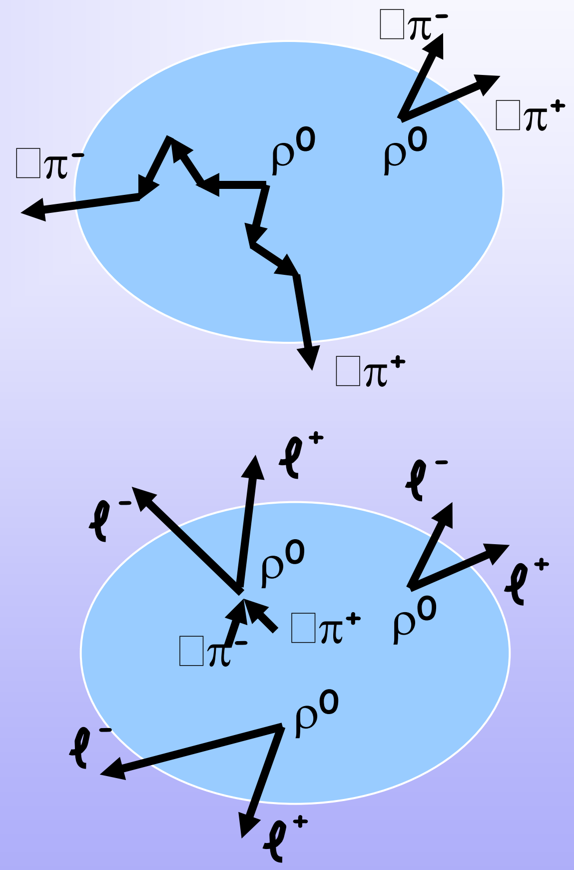
I. Arsene et al, nucl-th/0609042

Why resonances are interesting?

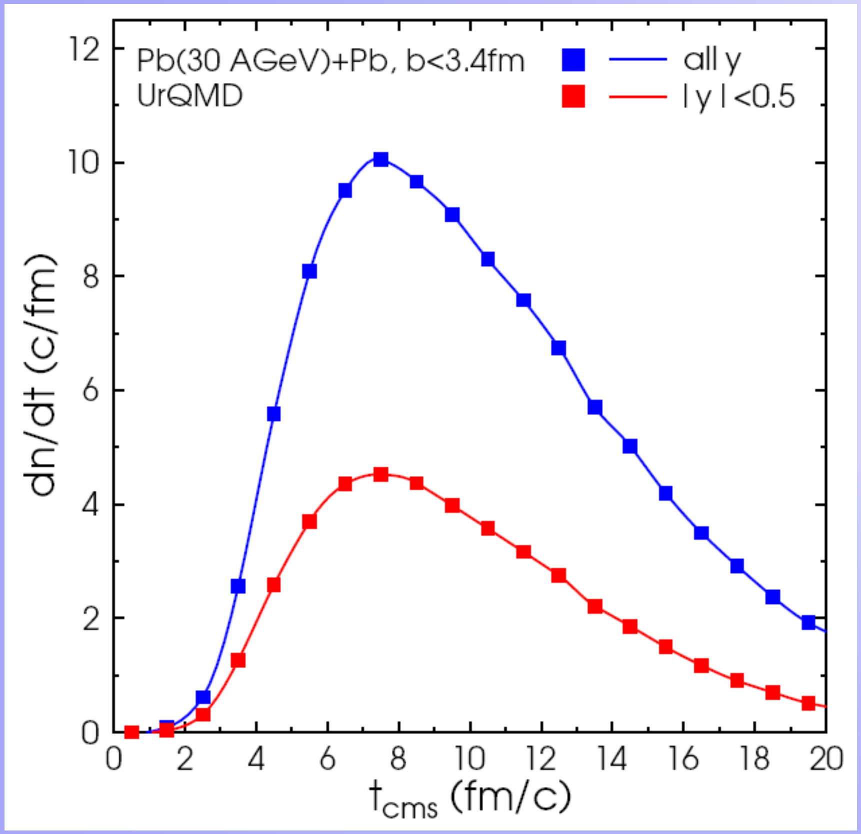
- There is a (long living) hadronic rescattering stage at FAIR and SPS energies
- Lifetime and properties of the hadronic stage are defined and probed by resonance production/absorption/re-feeding/decay
- Use different resonances to explore this stage:
  e.g. mesons: $K^{*}(892), \rho, f_0, \phi$
  baryons: $\Delta(1232), \Lambda(1520), \Sigma(1385)$
- Are resonances dissolved/broadened/shifted in matter?

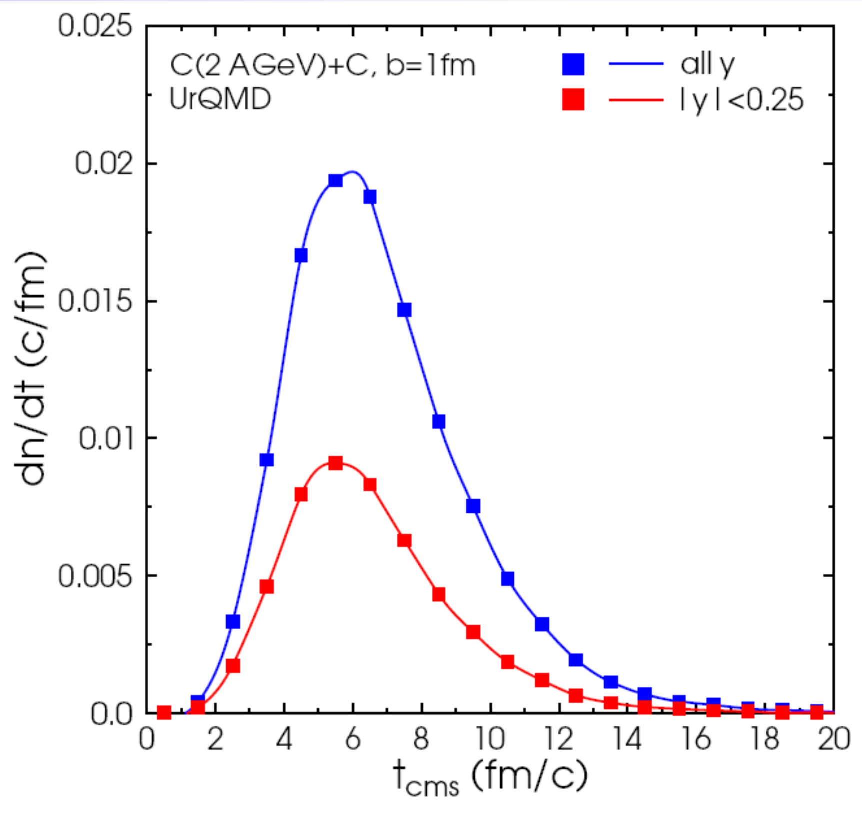
The rho has additional potential: Hadronic vs leptonic channel





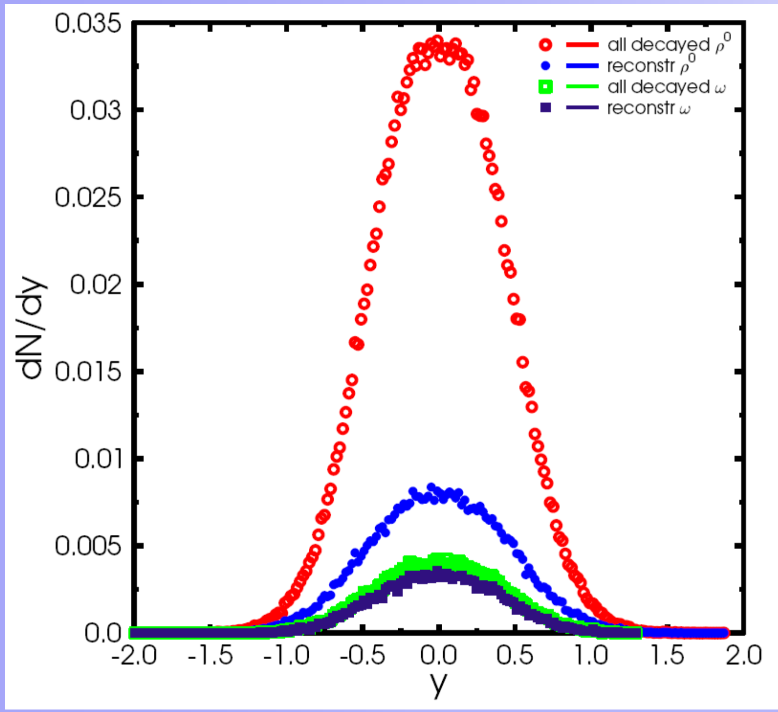
Decay time distribution of ρ mesons

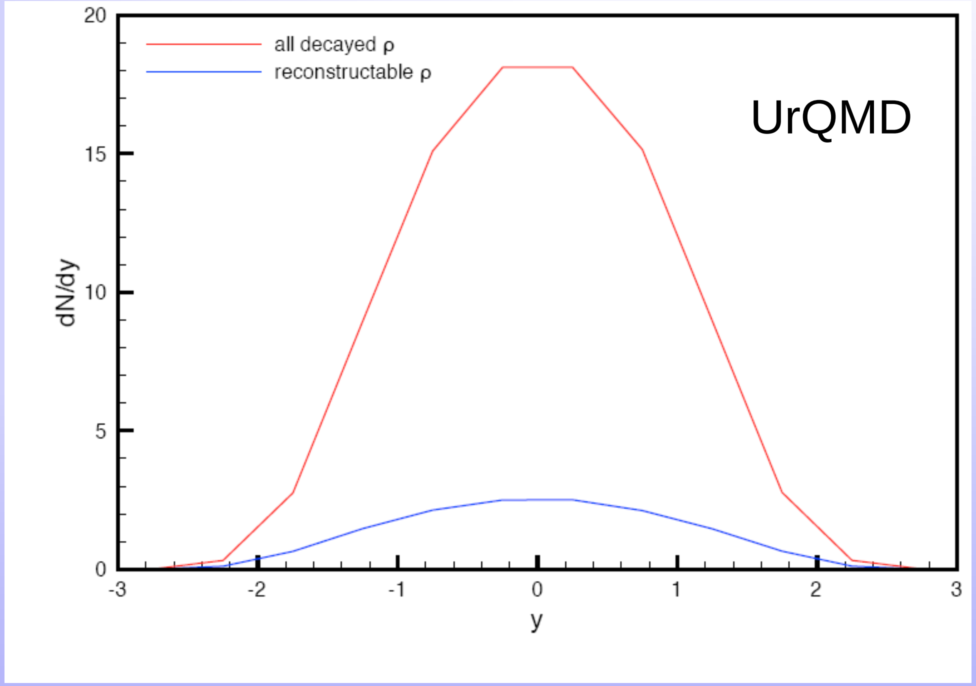




Resonance formation needs time (most ρ from baryon resonances)
➔ even short lived resonances are dominantly from later stages

Expected multiplicities





C+C@2AGeV

Pb+Pb@30AGeV

Pion reconstruction is free from ρ→e+e- model

S. Vogel, M. Bleicher, Phys.Rev.C74:014902,2006

Dileptons and the rho

Gerry Brown

Ralf Rapp

Jochen Wambach

Dileptons – spectral function

$$\frac{\mathrm{d}N_{ll}}{\mathrm{d}^4x\mathrm{d}^4q} = -\frac{\alpha^2}{3\pi^3}\frac{L(M^2)}{M^2}\,\mathrm{Im}\,\Pi^{\mu}_{\mathrm{em},\mu}(M,q;\mu_B,T) \times f^B(q_0;T)\ ,$$

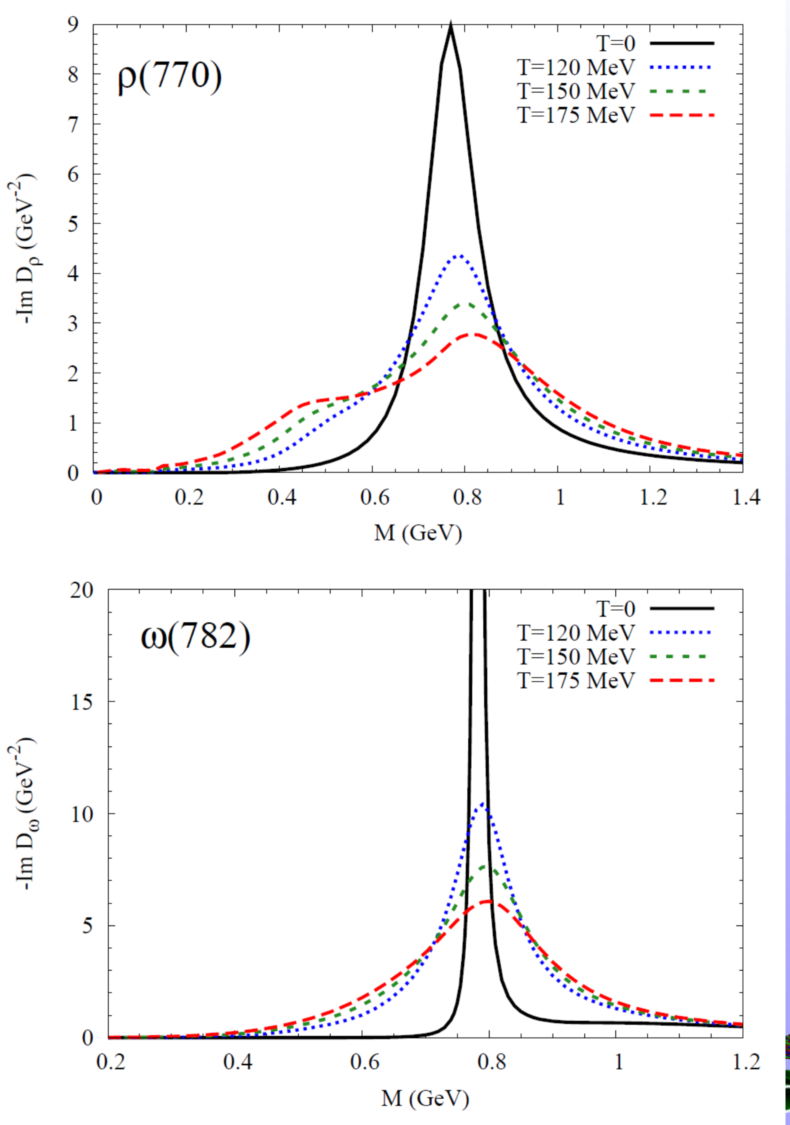
$$\Pi^{\mu\nu}_{\mathrm{em}}(q) = \mathrm{i}\int \mathrm{d}^4x \mathrm{e}^{\mathrm{i}q_\sigma x^\sigma}\Theta(x^0)\left\langle[\mathbf{J}^{\mu}_{\mathrm{em}}(x),\mathbf{J}^{\nu}_{\mathrm{em}}(0)]\right\rangle$$

$$L(M) = \left(1+\frac{2m_l^2}{M^2}\right)\sqrt{1-\frac{4m_l^2}{M^2}}$$

van Hees, Rapp, 2008

Spectral function

$$\mathrm{Im}\,\Pi_{\mathrm{em}} = \begin{cases} \sum\limits_{V=\rho,\omega,\phi} \left(\frac{m_V^2}{g_V}\right)^2 \, \mathrm{Im}\, D_V\,, \; M \lesssim M_{\mathrm{dual}} \\ -\frac{N_c M^2}{12\pi} \left(1 + \frac{\alpha_s}{\pi} + \ldots\right) \sum\limits_i (e_i)^2, \; M \gtrsim M_{\mathrm{dual}} \end{cases} \quad (4)$$



van Hees, Rapp, 2008

Evolution of the medium

- Fix S/A ~ 27

$$V_{\mathrm{FB}}(t) = \pi \left(r_{\perp,0} + \frac{1}{2} a_\perp t^2 \right)^2 \left(z_0 + v_{z,0} t + \frac{1}{2} a_z t^2 \right)$$

$$S = s(t) \cdot V(t)$$

Use hadron gas EoS to obtain T(t) and mu_B(t) from s(t)

van Hees, Rapp, 2008

What do we want to see?
➔in-medium spectral functions

- Mass shift of the ρ meson
  roughly from 770 MeV → 600 MeV
- Modified width of the ρ meson
  roughly from 150 MeV → 300 MeV
- Possibly modifications of ϕ and ω

➔Do we know the densities to the required precision?

Problems

- How are energy density and baryon density defined? (N/V doesn't work!)
  - What frame? Landau? Eckardt?
  - Lorentz contraction? Nucleus? Nucleon?
- Is the system thermalized?
  - Viscous contributions in hydro?
- What are the degrees of freedom?

Baryon density

- Define baryon density at point r in the Eckardt frame (vanishing baryon flow)

→I.e. $\rho_B(r) = j^0_B(r)$ in the frame with $j^\mu=(\rho_{B,}0)$

- Lorentz contraction for the nucleons along the beam axis is taken into account

$$\rho_B(\vec{r}) \sim \sum_i \gamma_{i,z} \exp\left(\frac{(z-z_i)^2}{2\sigma^2/\gamma^2_{i,z}}\right)\exp\left(\frac{(r_T-r_{i,T})^2}{2\sigma^2}\right)$$

Further problem: thermalization

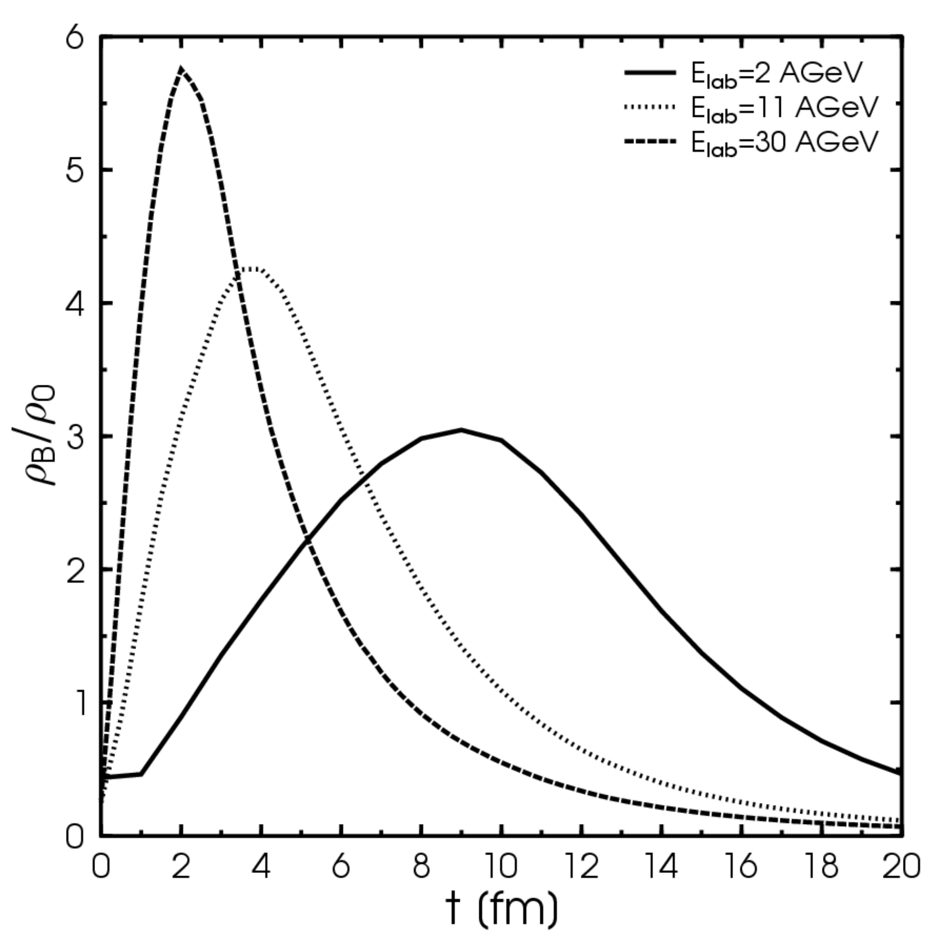
- Sound definition of the baryon current/density is possible

However, free streaming effects are not excluded (the defined baryon density is not necessarily thermal)

→consider only particles that have a velocity around to the thermal velocity (similar to three-fluid approach, Brachmann et al)
not practical for transport…

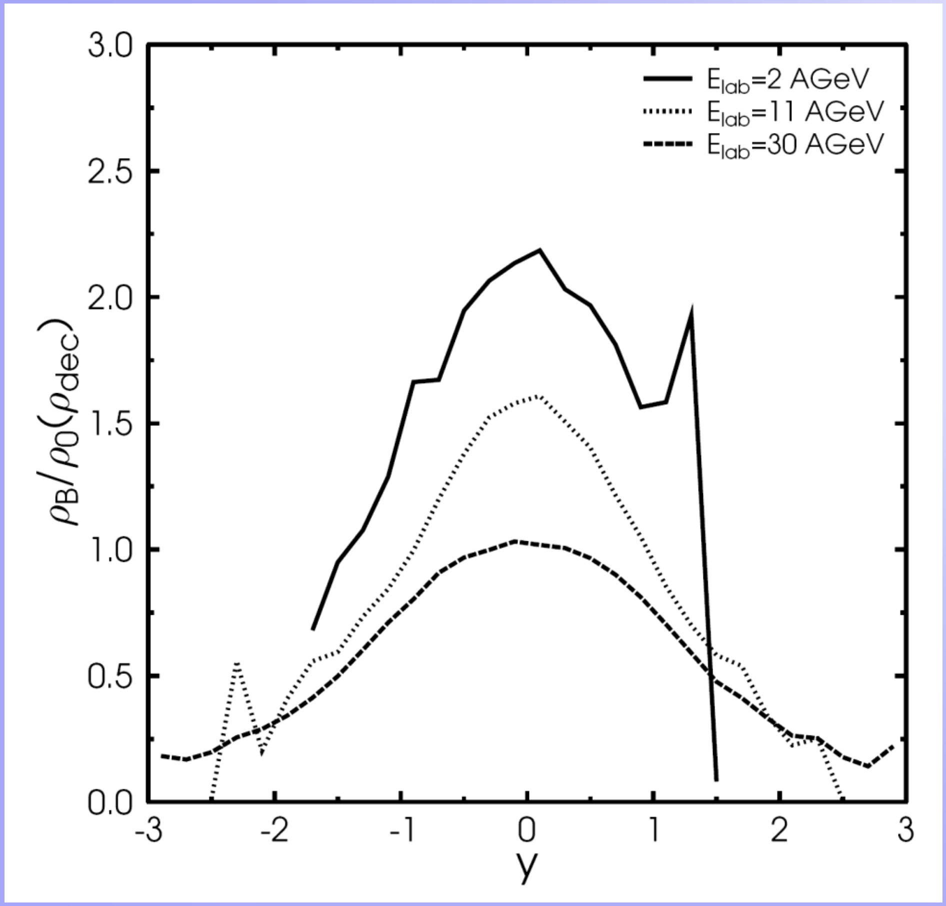
Local baryon densities
(Averaged over the positions of all hadrons)

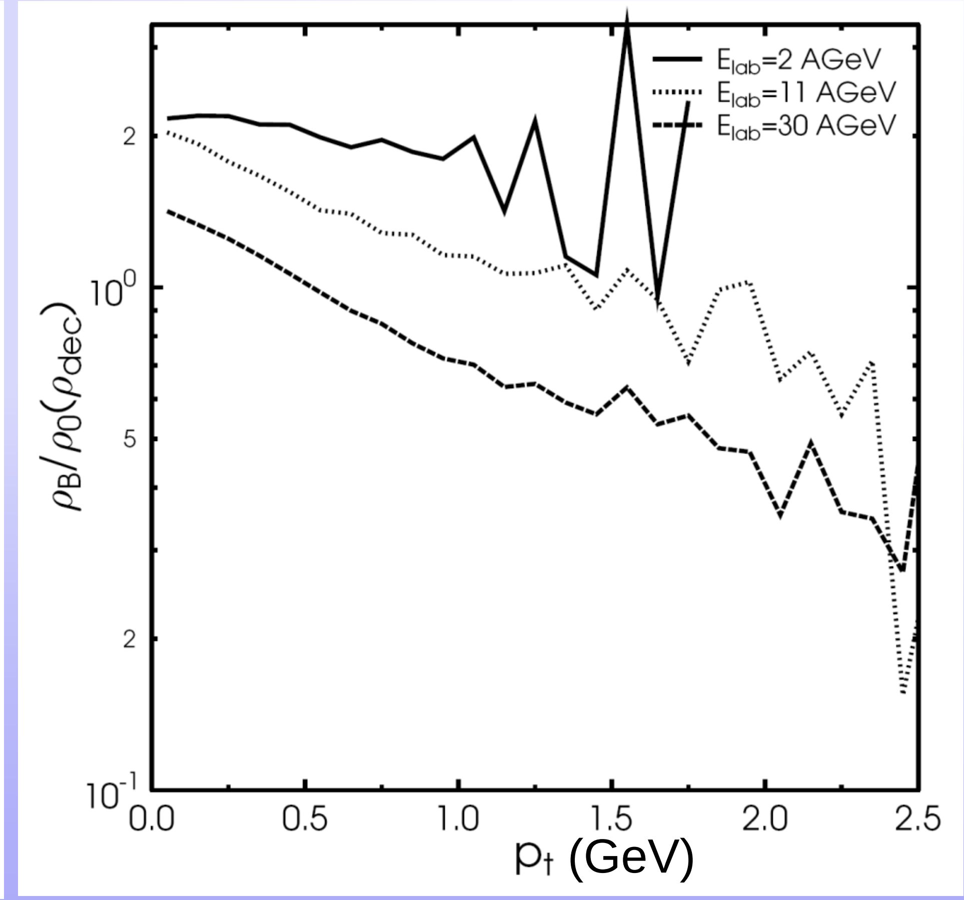
- Are we able to observe unambiguous signals from the most compressed region of the system?



Central Au+Au/Pb+Pb collisions

Baryon densities in momentum space at the point of the rho decay

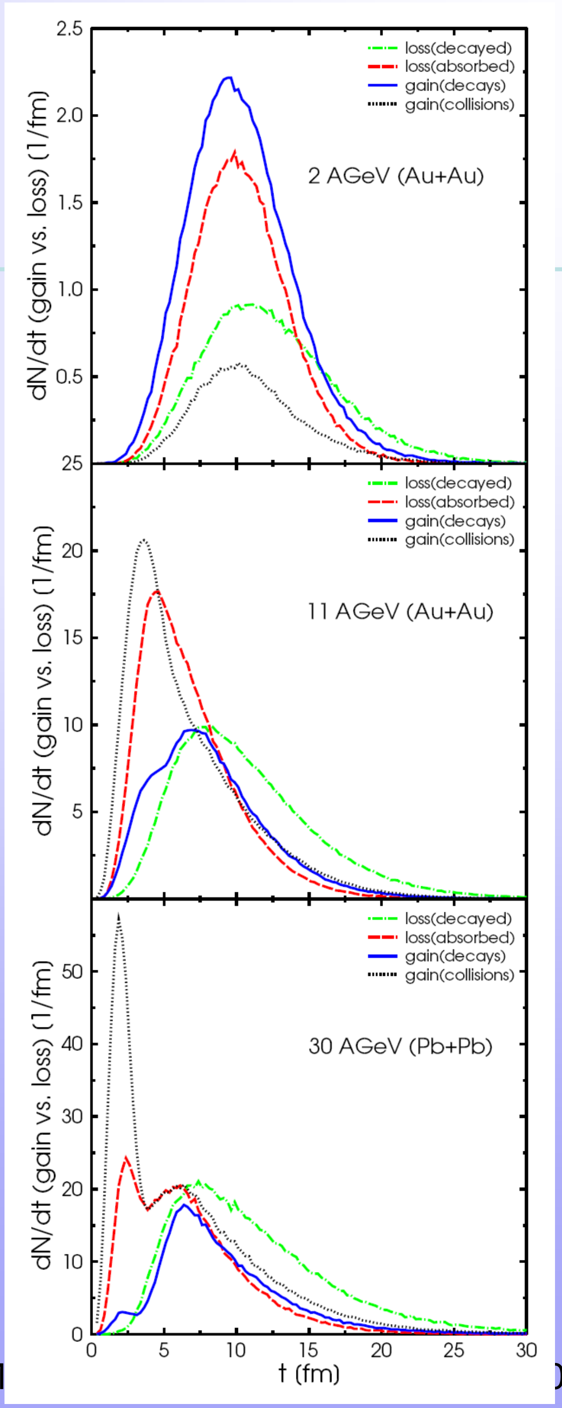




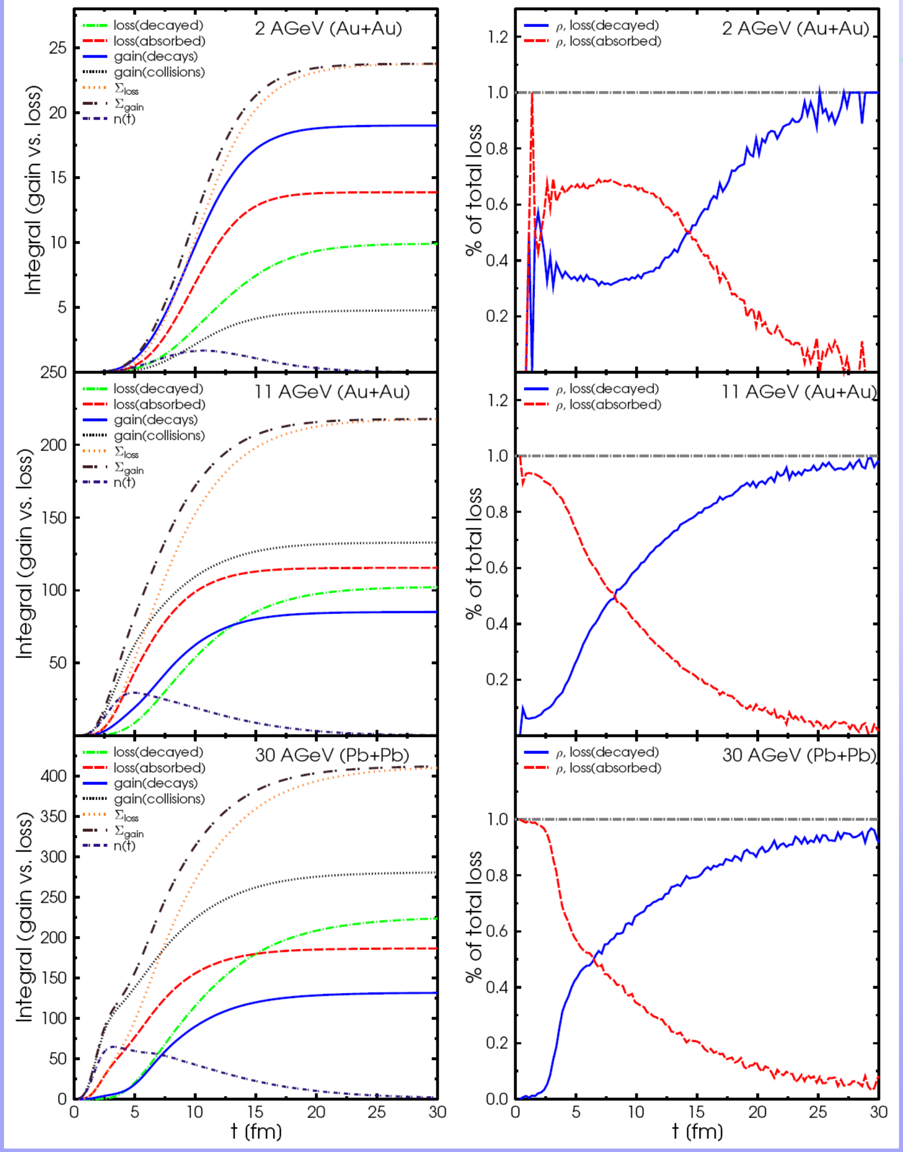
Central Au+Au/Pb+Pb reactions

Gain and loss rates of rho mesons

- Maximal densities reached at t=10,4,2 fm
- rho production at HADES energies driven by baryon resonance decays
- at higher energies: major early stage production, but still sizeable tail from decays in the late stage



Absorption vs decay

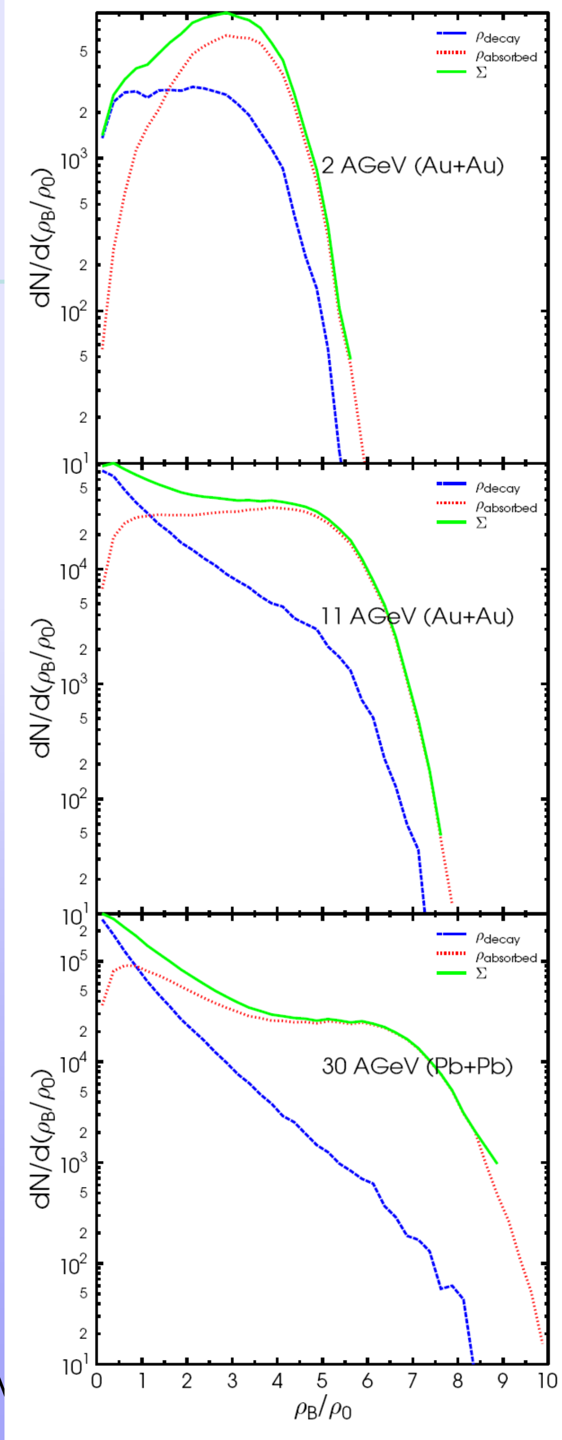


- How are the dileptons calculated?
- Shining vs decay
- Strong absorption in the early stages

Marcus Bleicher, NICA School 2010

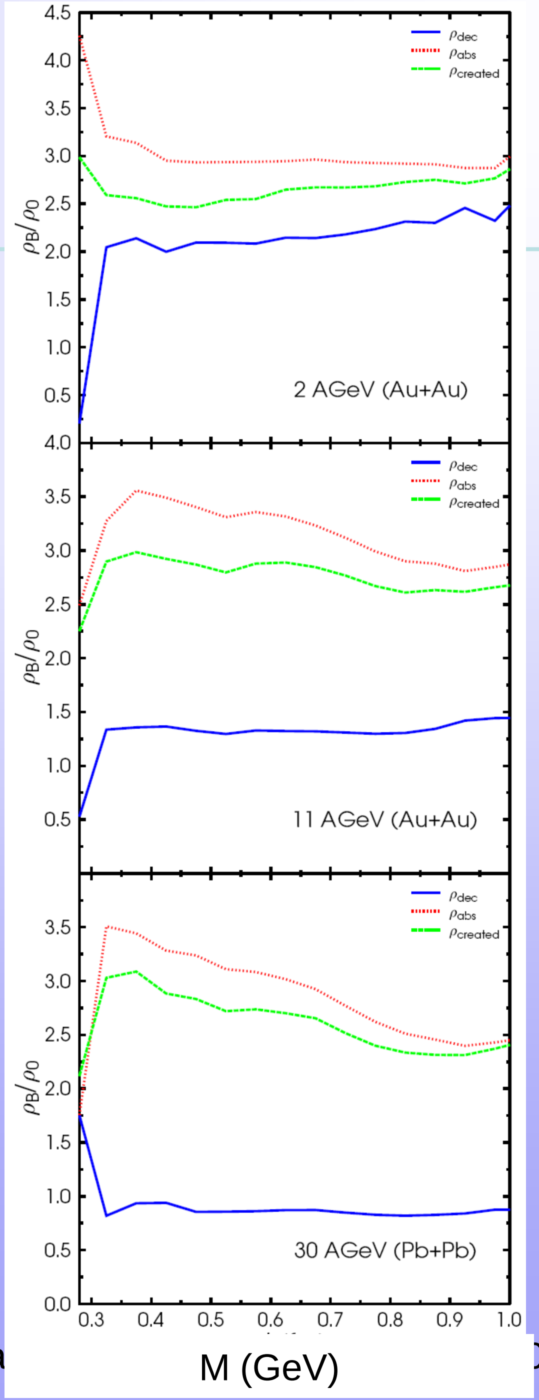
Density distributions

- Distribution baryon density at the point of rho decay or absorption
- Significantly higher reach in density if absorbed rhos are included.
(However, here the integrated rho life times are shorter)



Density vs rho mass

- Absorption has the highest reach in density →shining method necessary?
- Moderate mass dependence
- Final feeding from decays around 1-2 ground state density



- Dalitz decay of the pseudoscalar mesons π^0, η and η' $(m_B = 0)$:

$$\frac{dN_{A\to\gamma e^+e^-}}{dM} = \frac{4\alpha}{3\pi M}\sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)\left(1-\frac{M^2}{m_A^2}\right)^3 \times |F_{AB}(M^2)|^2\frac{\Gamma_{A\to 2\gamma}}{\Gamma_{tot}}\langle N_A\rangle.$$

$$\frac{dN_{A\to Be^+e^-}}{dM} = \frac{2\alpha}{3\pi M}\sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)|F_{AB}(M^2)|^2\frac{\Gamma_{A\to 2\gamma}}{\Gamma_{tot}}\langle N_A\rangle \times \left(\left(1+\frac{M^2}{m_A^2-m_B^2}\right)^2-\left(\frac{2m_AM}{m_A^2-m_B^2}\right)^2\right)^{3/2}. \qquad (3)$$

$$\Gamma_{V\to e^+e^-}(M) = \frac{\Gamma_{V\to e^+e^-}(m_V)}{m_V}\frac{m_V^4}{M^3}\sqrt{1-\frac{4m_e^2}{M^2}}\left(1+2\frac{m_e^2}{M^2}\right)$$

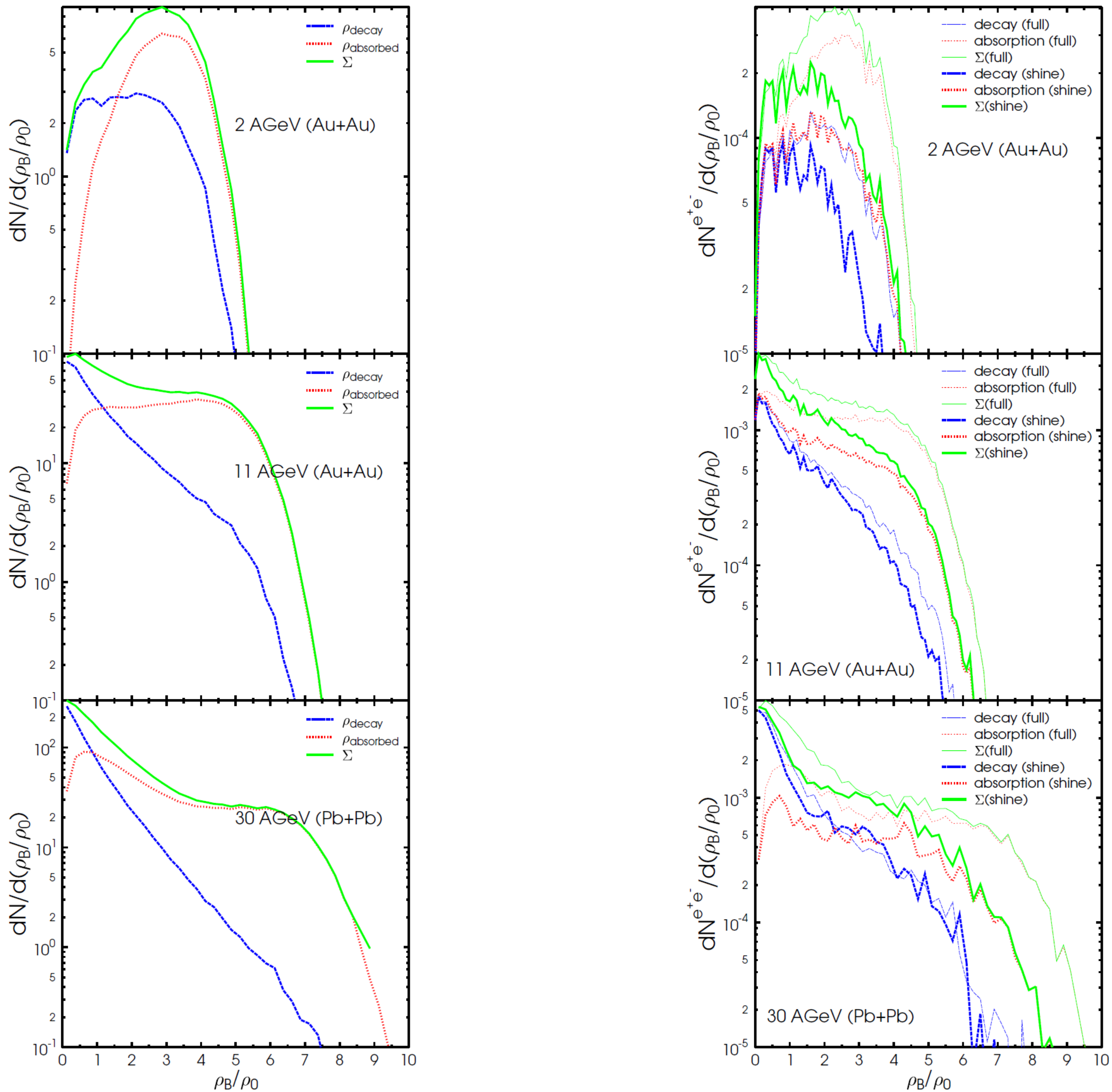
L. G. Landsberg, Phys. Rept. **128**, 301 (1985)
P. Koch, Z. Phys. C **57**, 283 (1993)
G. Wolf, G. Batko, W. Cassing, U. Mosel, K. Niita and M. Schaefer, Nucl. Phys. A **517**, 615 (1990)
C. M. Ko, G. Q. Li, G. E. Brown and H. Sorge, Nucl. Phys. A **610**, 342C (1996)

Shining method

- Continuous emission of dileptons

$$\frac{dN_{e^+e^-}}{dM} = \frac{\Delta N_{e^+e^-}}{\Delta M} = \sum_{j=1}^{N_{\Delta M}} \int_{t_i^j}^{t_f^j} \frac{dt}{\gamma} \frac{\Gamma_{e^+e^-}(M)}{\Delta M}$$

- vs. branching ratio at decay point Gamma(rho→e+e-)/Gamma_tot



Difference between shining and other approaches

Thin lines: 'no absorption'

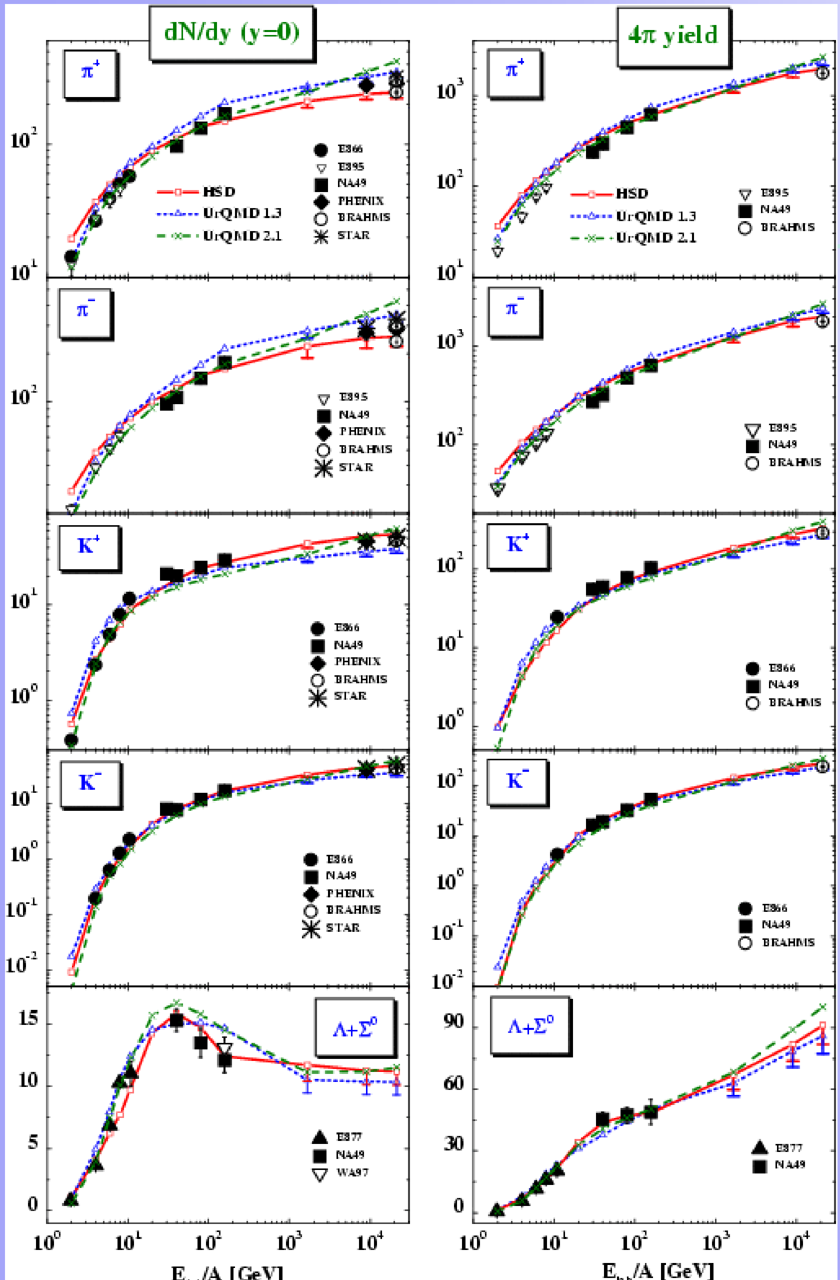
Blue lines: only final decays

Green lines: 'shining'

Are the dynamical models good enough?

- Check space-time evolution
  ➔HBT correlations
- Check particle production
  ➔Pion production ($\pi\pi \rightarrow \rho$!)
  ➔Baryon resonances (ρ from decays !)
  ➔Final state ρ from $\pi\pi$ correlations

Excitation functions

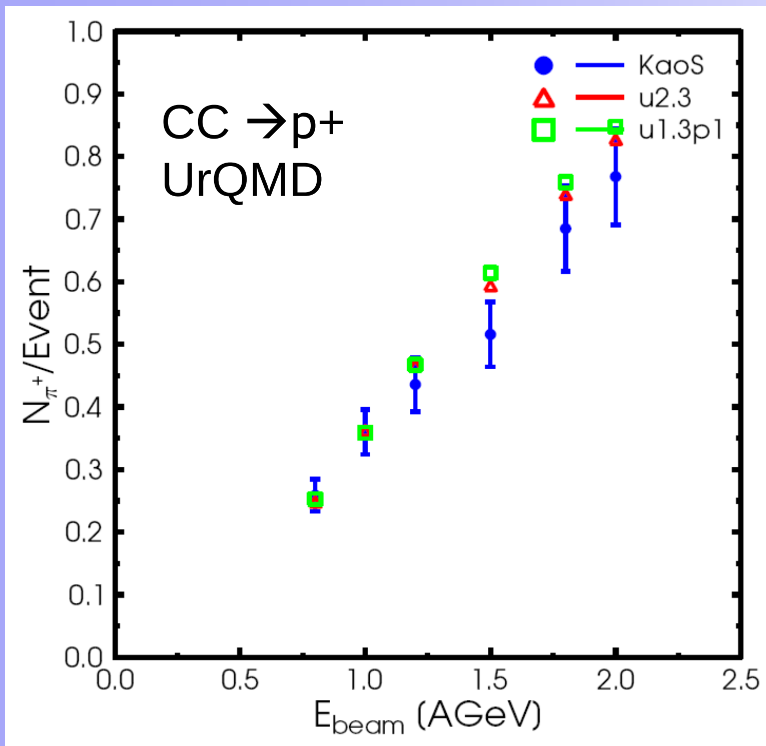


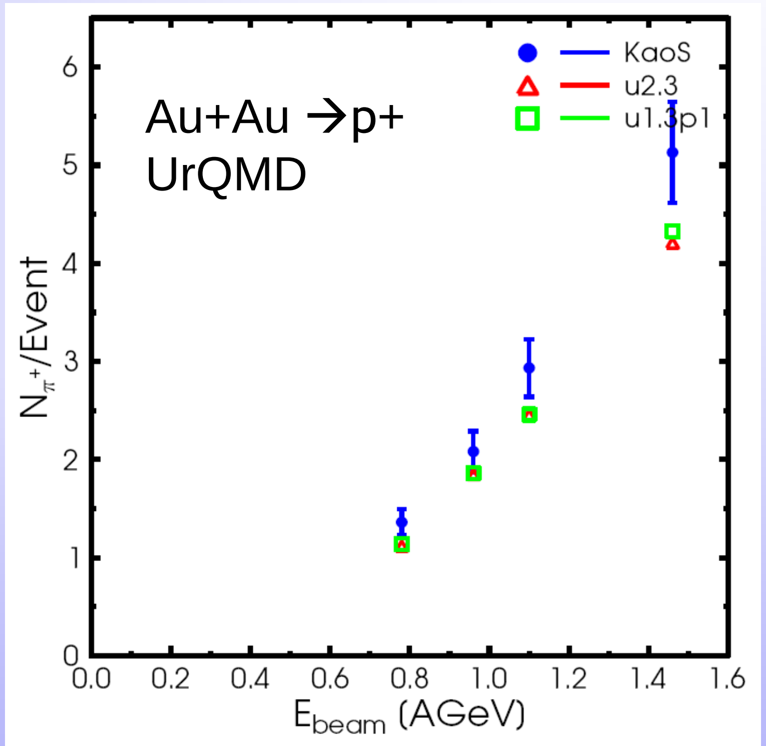
E. L. Bratkovskaya, M.B., et al, Phys. Rev. C 69, 054907 (2004)

- Good agreement between different transport models (HSD/UrQMD)
- 4 pi and midrapidity abundancies are described on a 10-20% level (systematic error)
- Energy dependence: OK
- Hadron-string models work well

Detailed view at low energies

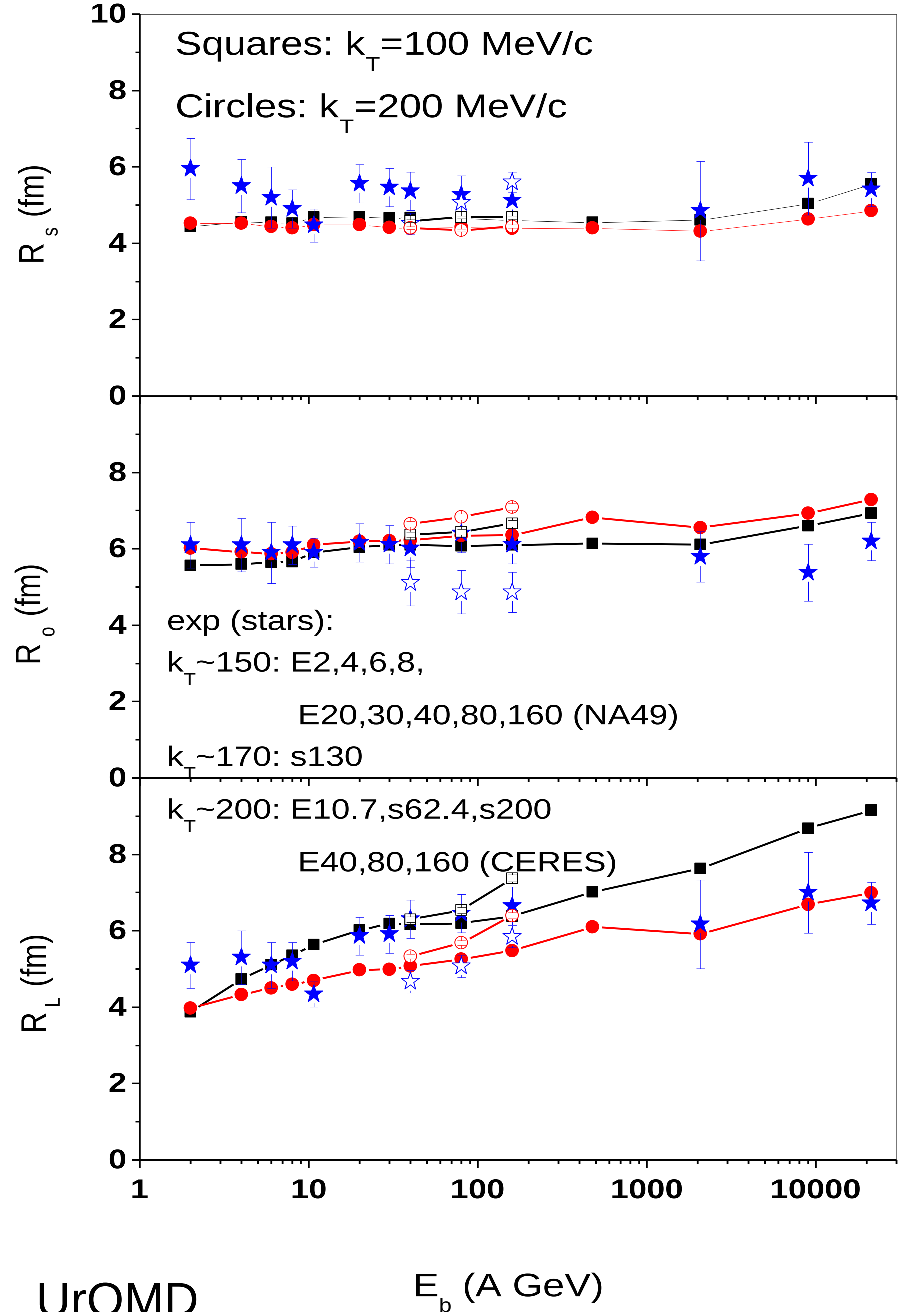
D. Schumacher, H. Petersen





- Comparison to KAOS data
- Reasonable agreement

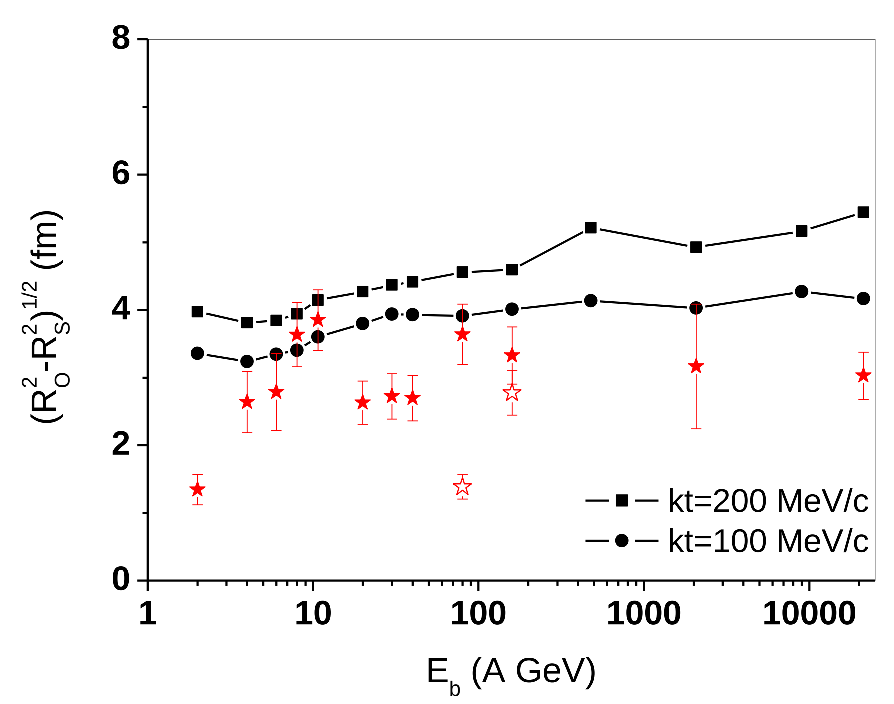
D. Schumacher, s. Vogel, M.B, Acta Phys.Hung.A27:451-458,2006



UrQMD

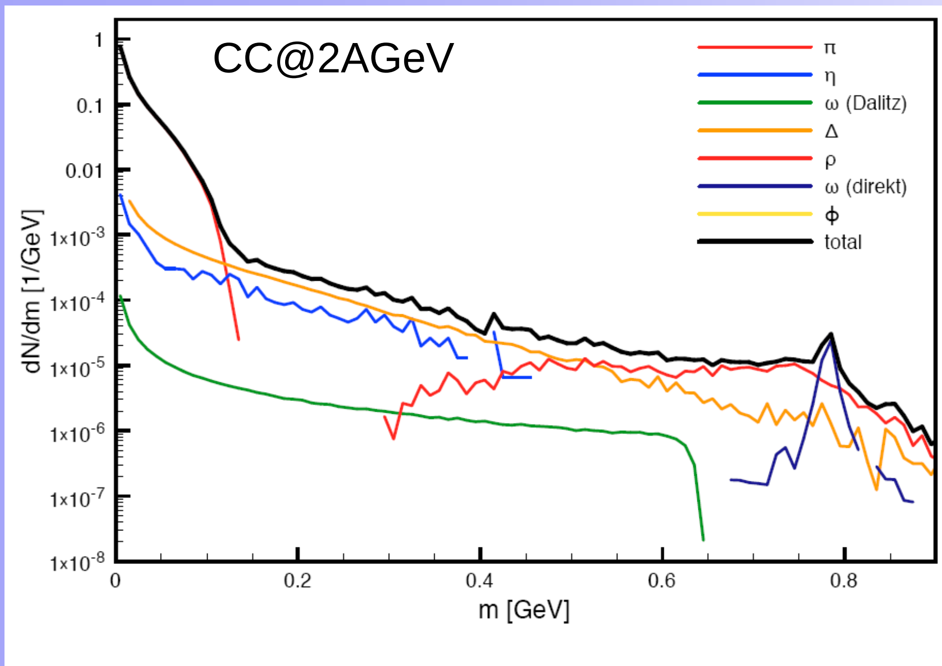
HBT-Energy dependence

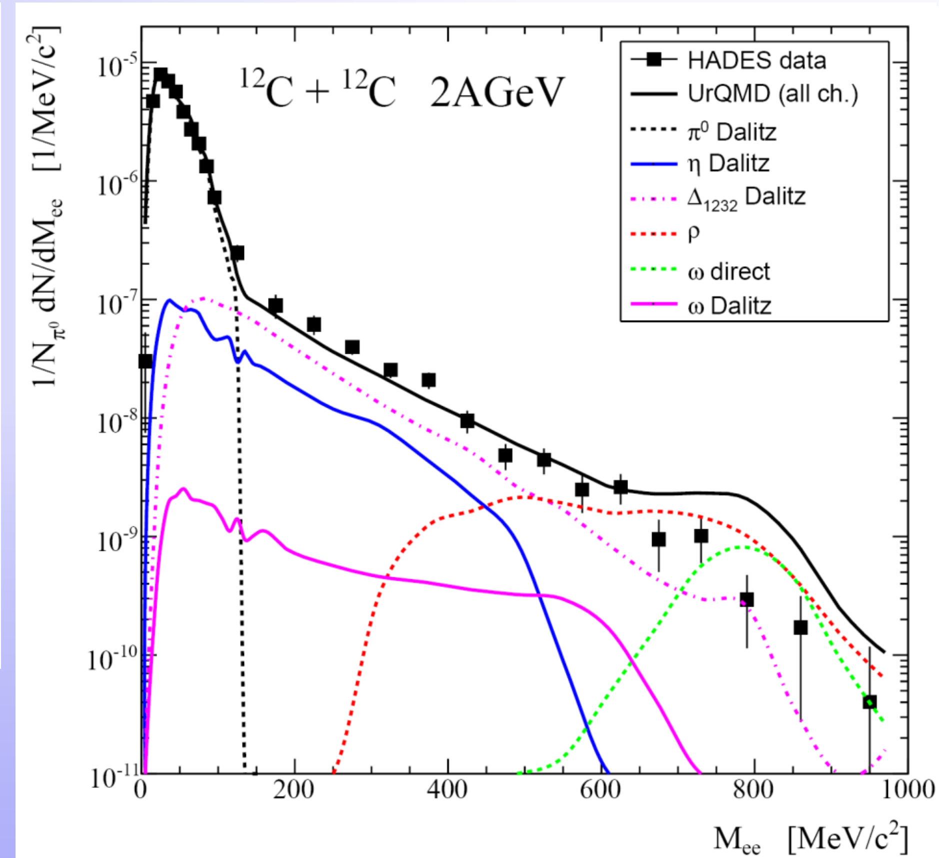
- Data shows no dramatic features
- Expansion and decoupling dynamics ok
- Fireball life time ok



Results SIS energies

HADES energies: UrQMD



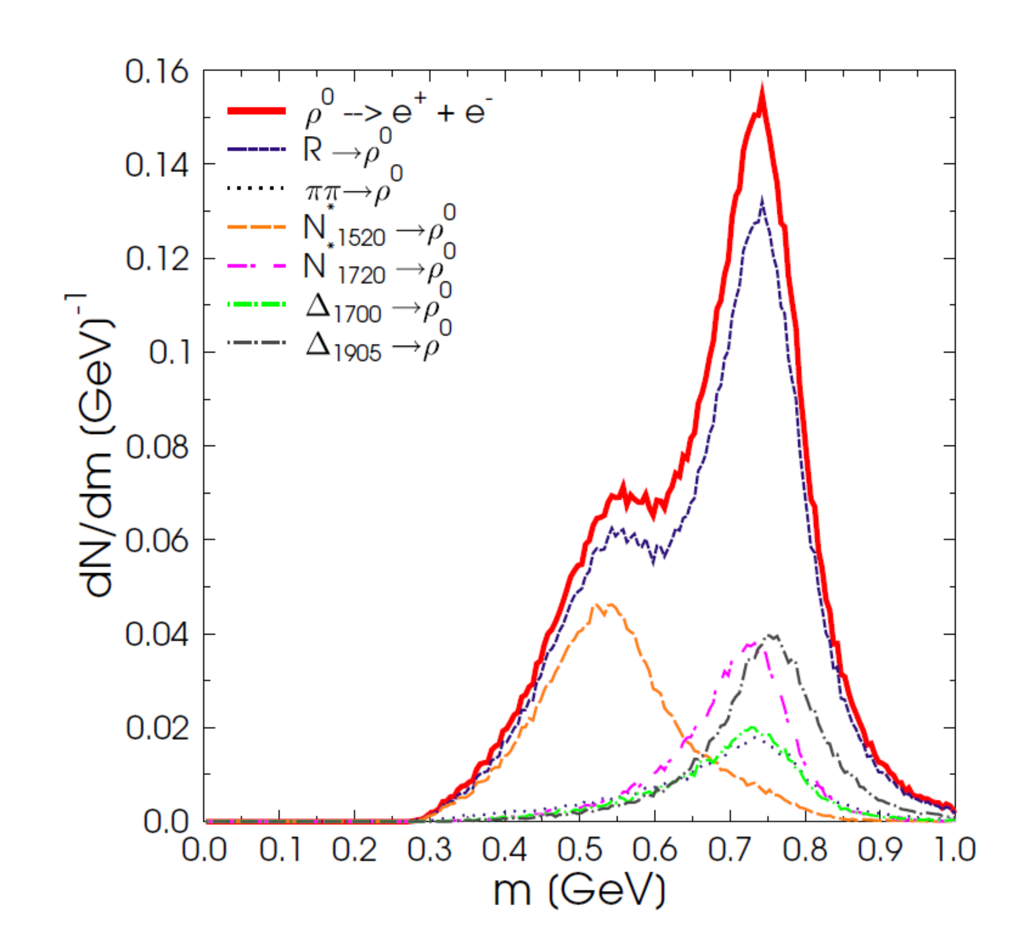


- Note the broad ρ mass distribution

D. Schumacher, s. Vogel, M.B, Acta Phys.Hung.A27:451-458,2006

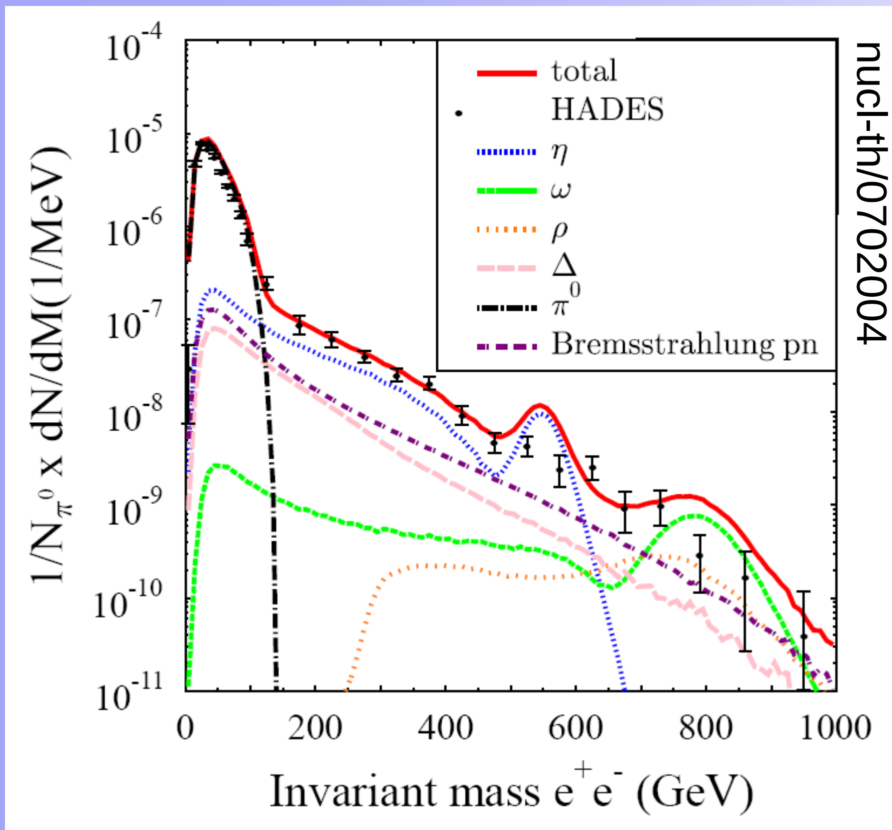
Trivial rho broadening

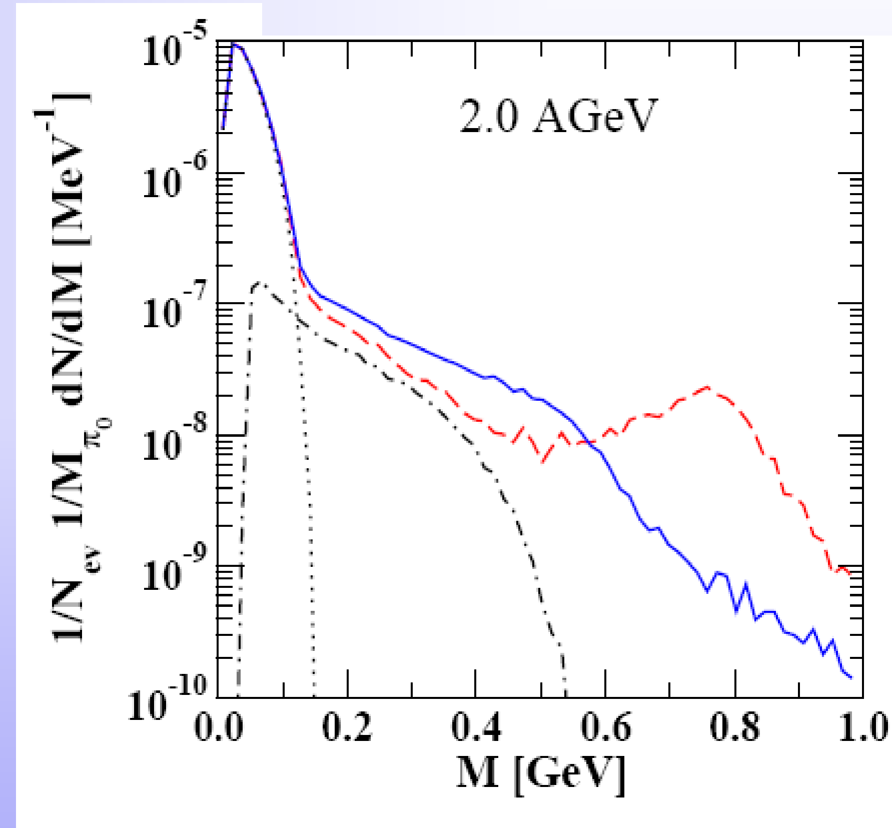
- Coupling to baryon resonances broadens the rho meson mass distribution even without ‘explicit’ medium contribution



Schumacher, Vogel, Bleicher, Acta Phys.Hung.A27:451-458,2006

HADES energies: IQMD/RQMD

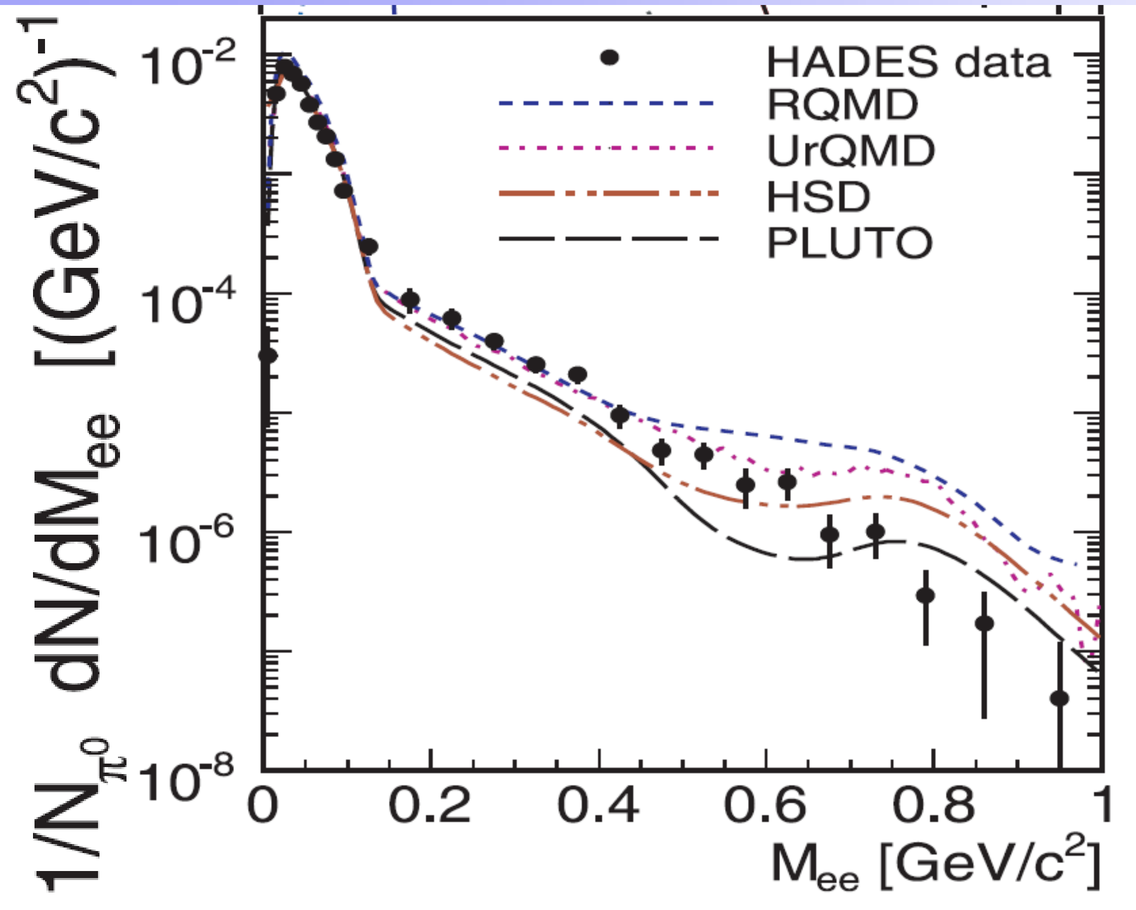




IQMD, CC@2AGeV
(instant di-leptons: no baryon- and ρ resonance propagation)

RQMD, CC@2AGeV
(effective ρ, no ρ and π propagation)

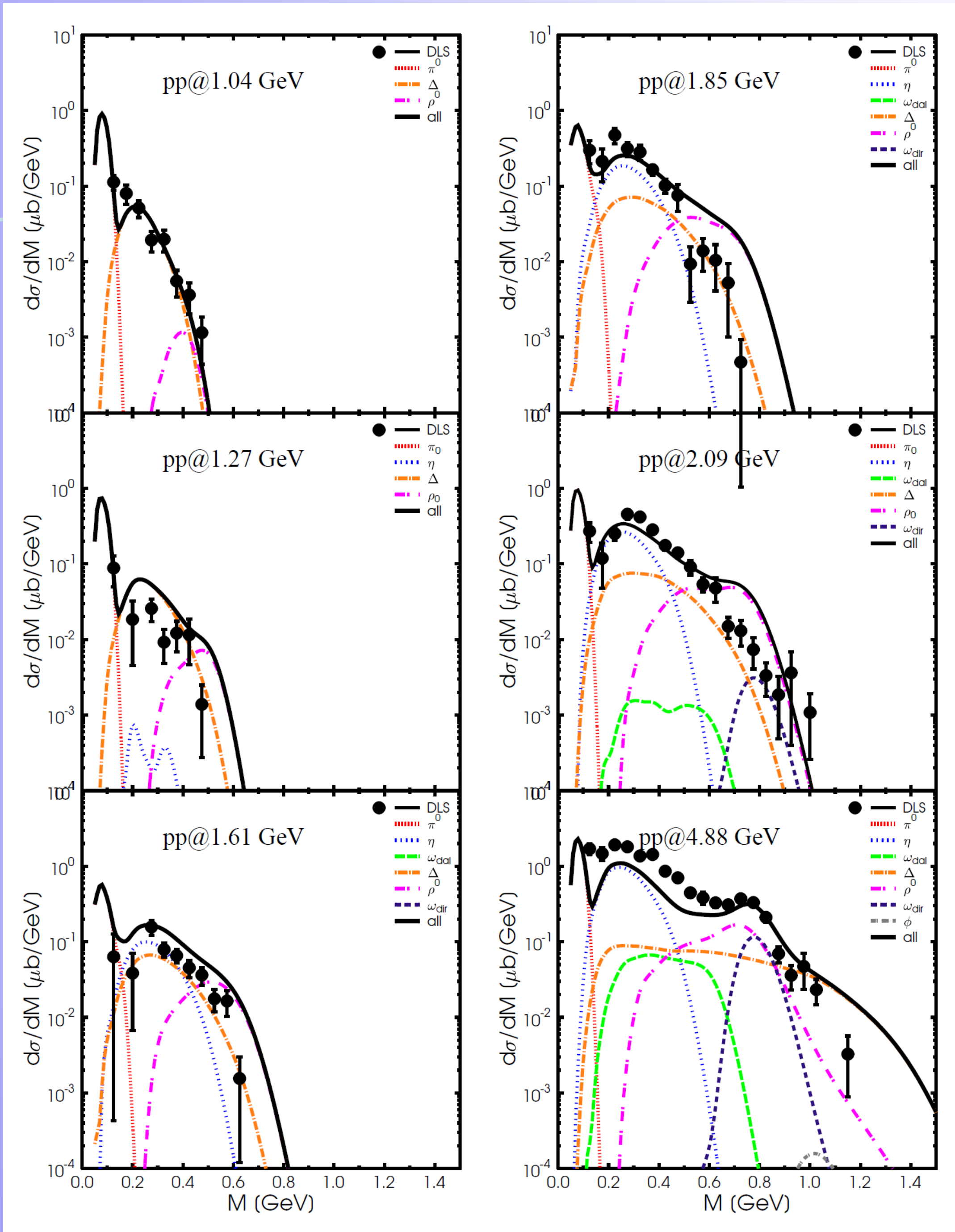
Di-lepton summary



- Model differences due to different di-lepton ‘after burner’!
- Clear hint of non-equilibrium contributions

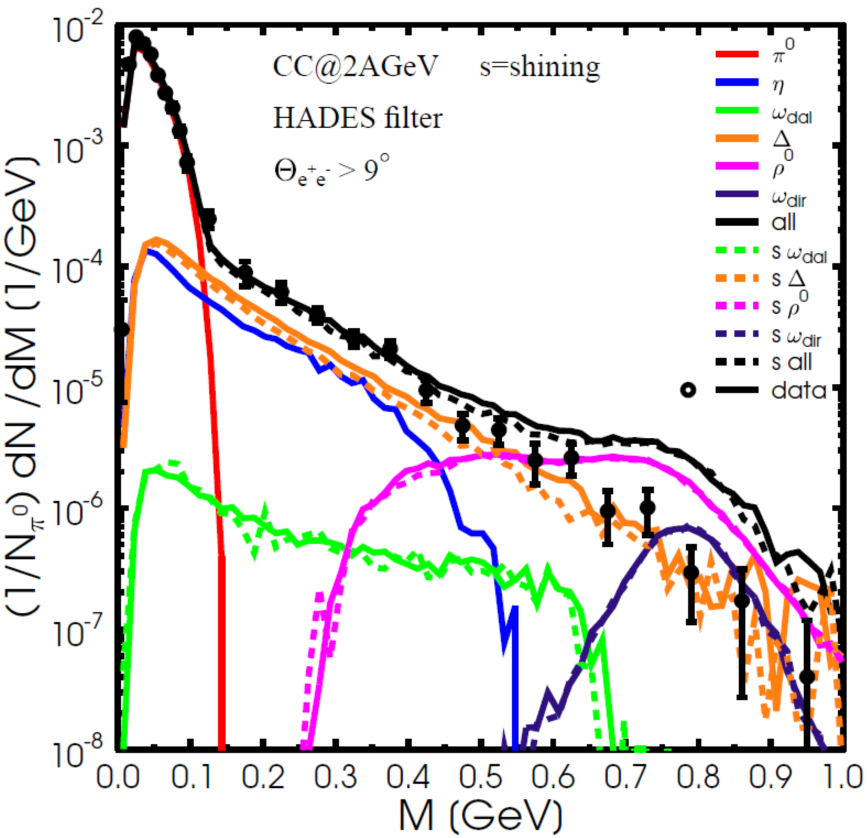
CC@2AGeV, HADES, nucl-ex/0608031

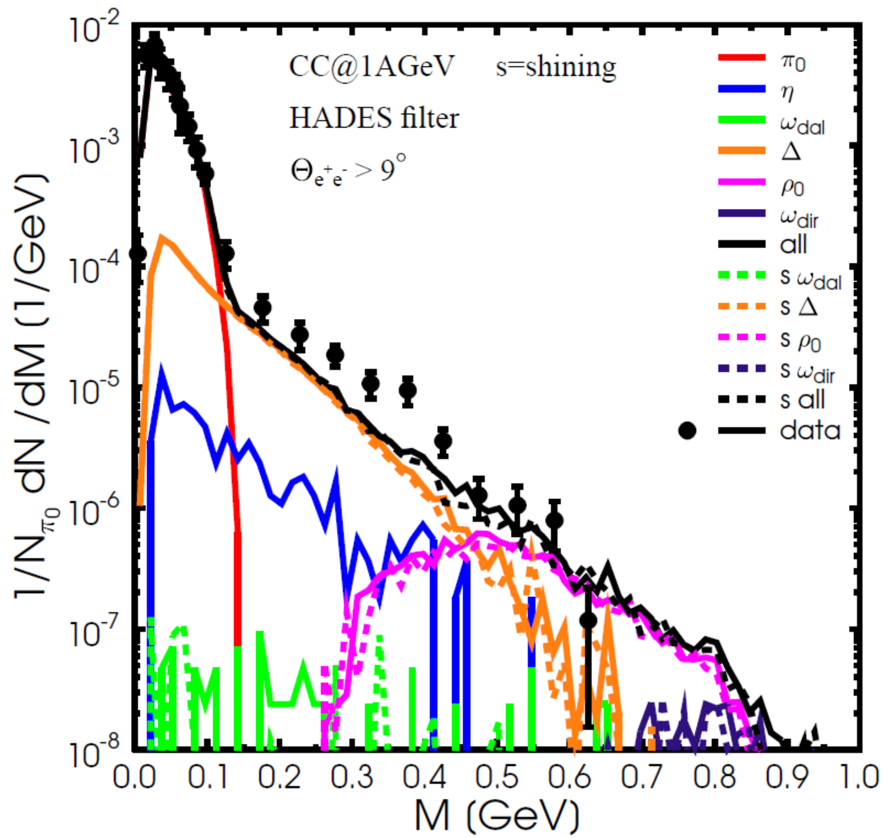
Discussion: SIS



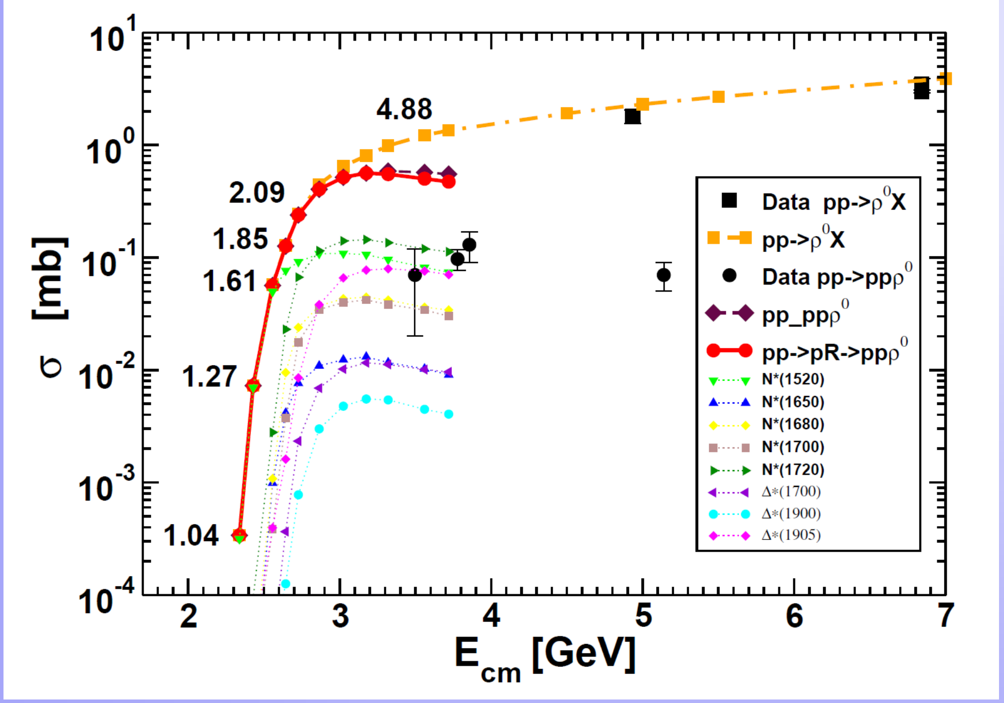
A School 2010

Overestimation at 2 GeV



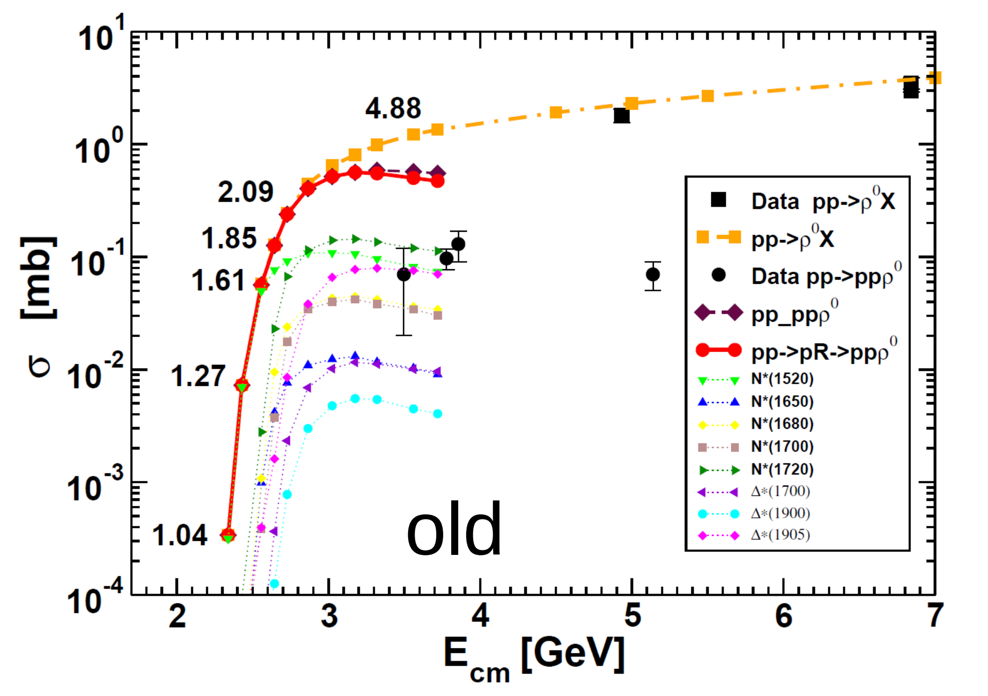


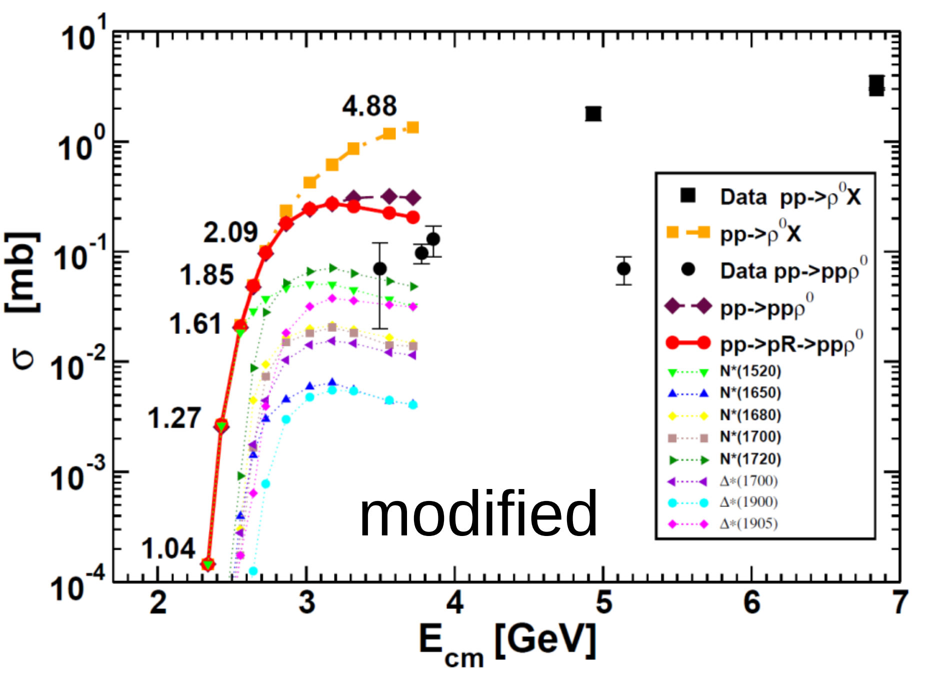
Where do the rhos come from?



Resonance	$\mathrm{Br}(N\rho)$	Resonance	$\mathrm{Br}(N\rho)$
$N^*(1520)$	.15	$\Delta^*(1620)$	.05
$N^*(1650)$	.06	$\Delta^*(1700)$	.25
$N^*(1680)$	.10	$\Delta^*(1900)$	.25
$N^*(1700)$	.20	$\Delta^*(1905)$	.80
$N^*(1710)$	.05	$\Delta^*(1910)$	.10
$N^*(1720)$	.73	$\Delta^*(1930)$	.22
$N^*(1900)$	.15	$\Delta^*(1950)$	.08
$N^*(1990)$	.43		
$N^*(2080)$	.12		
$N^*(2190)$	.24		
$N^*(2220)$	.22		
$N^*(2250)$	.25		

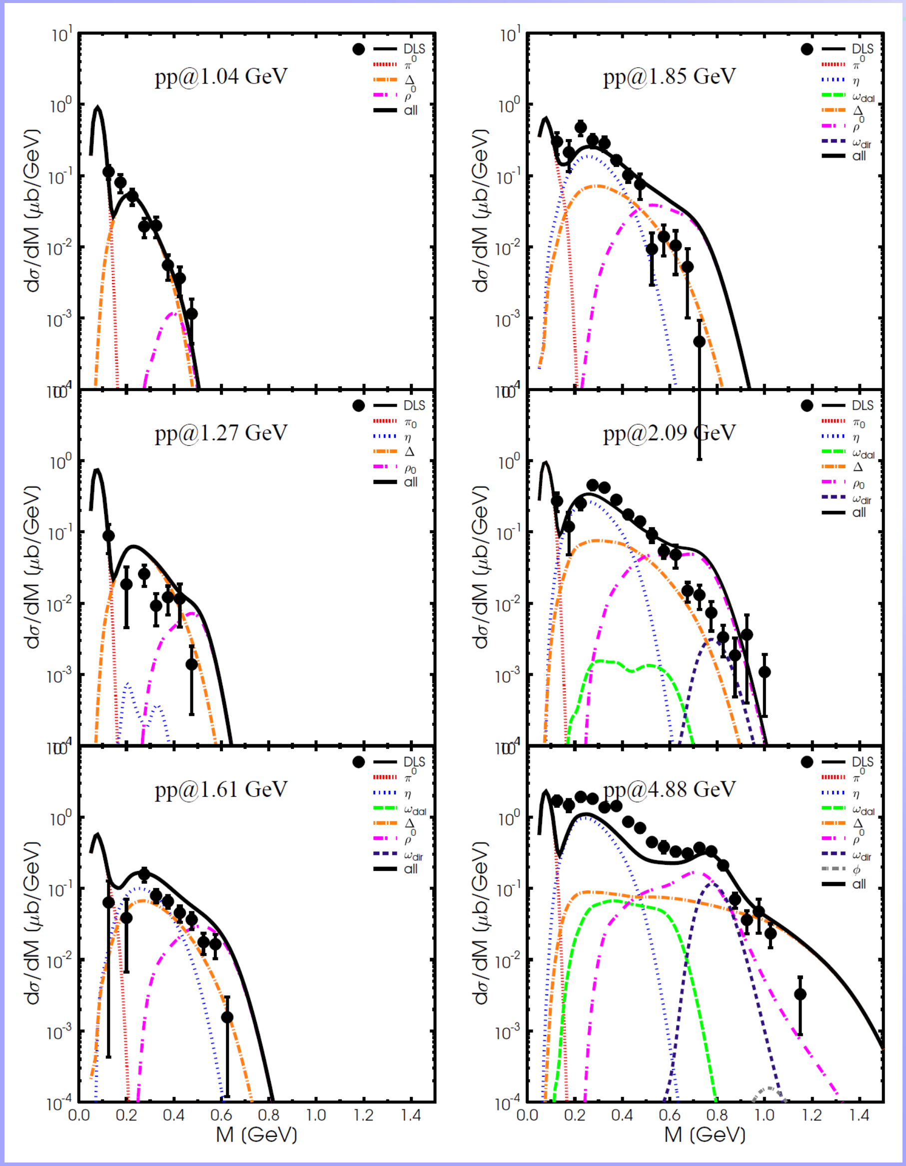
Re-adjustment of the branching ratios

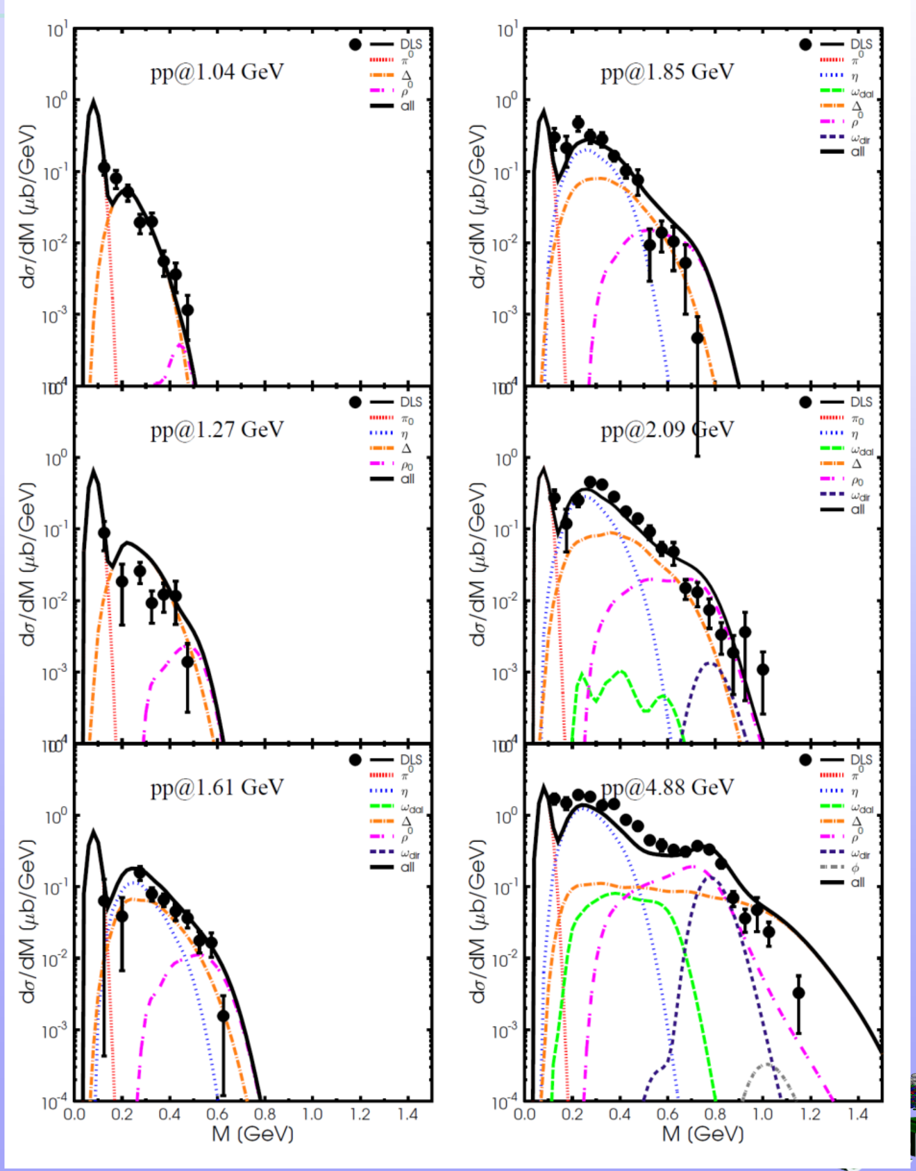




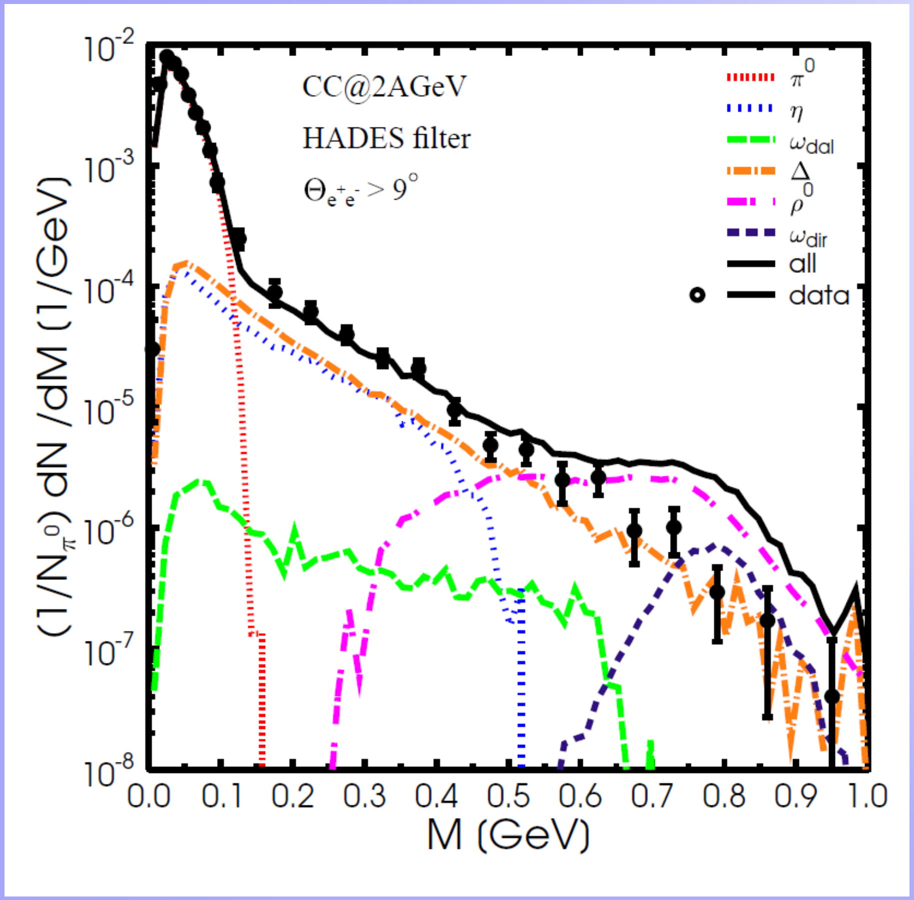
Reduce rho production in pp bei factor 2

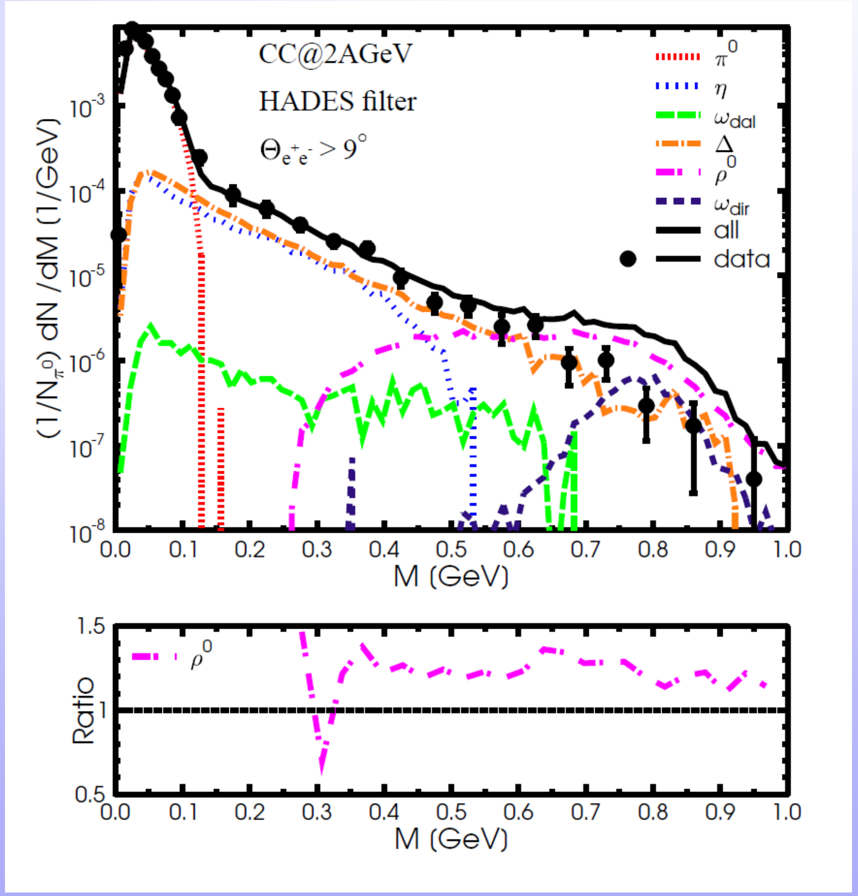
Standard vs. modified





Standard vs modified

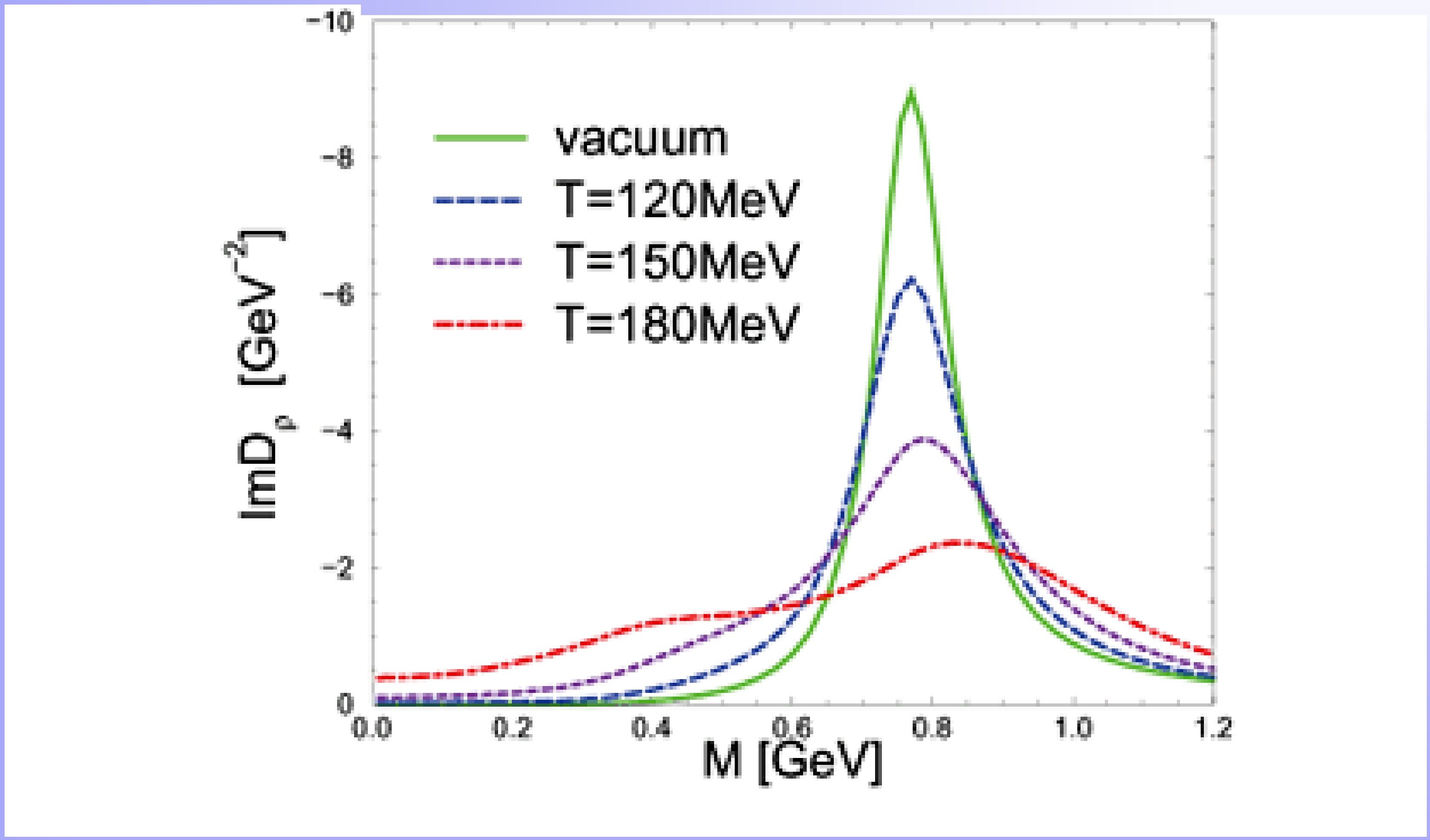




modified pp!

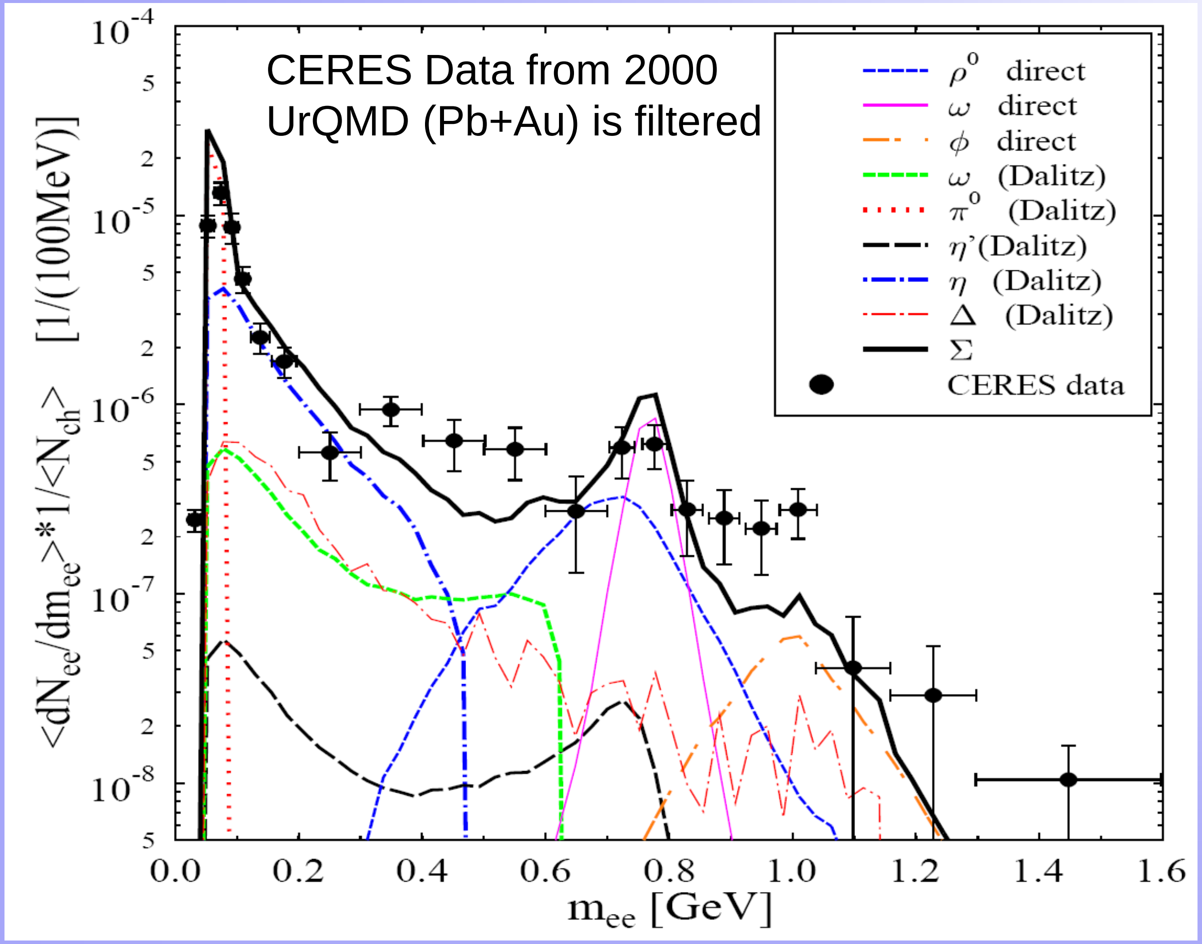
High energies

Rho meson spectral function



From Rapp, Wambach

Comparison to CERES @ 160 AGeV

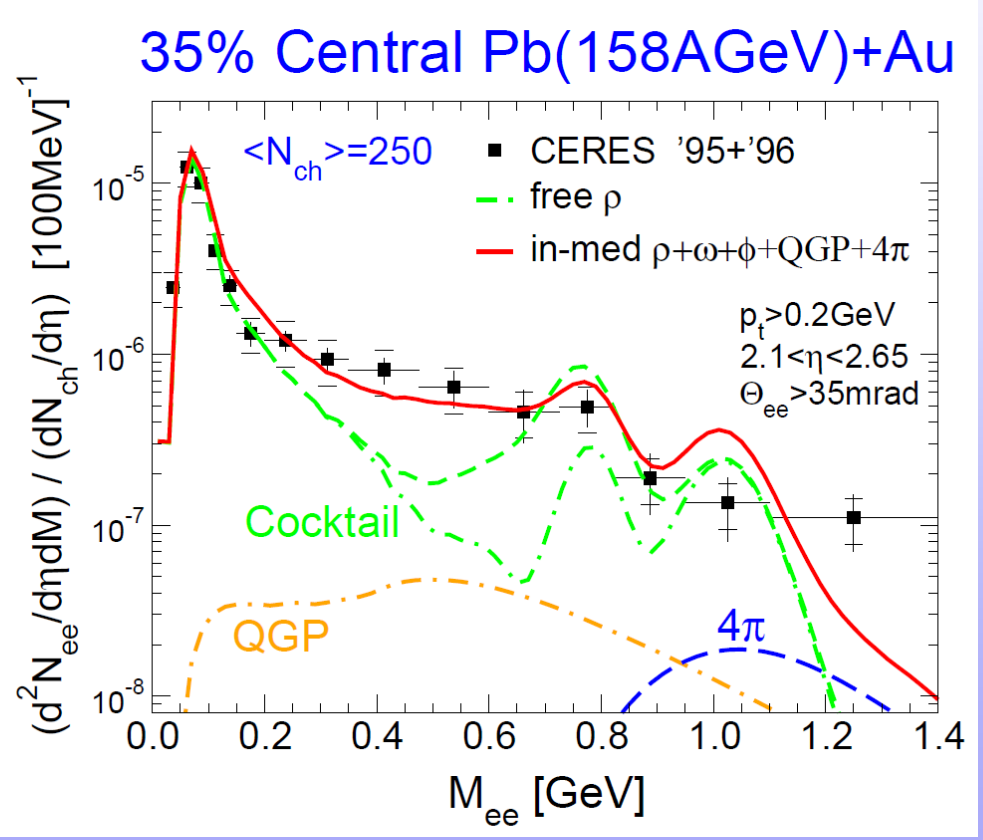


- Well known dip around 500 MeV
- Dip is from low momentum di-lepton pairs

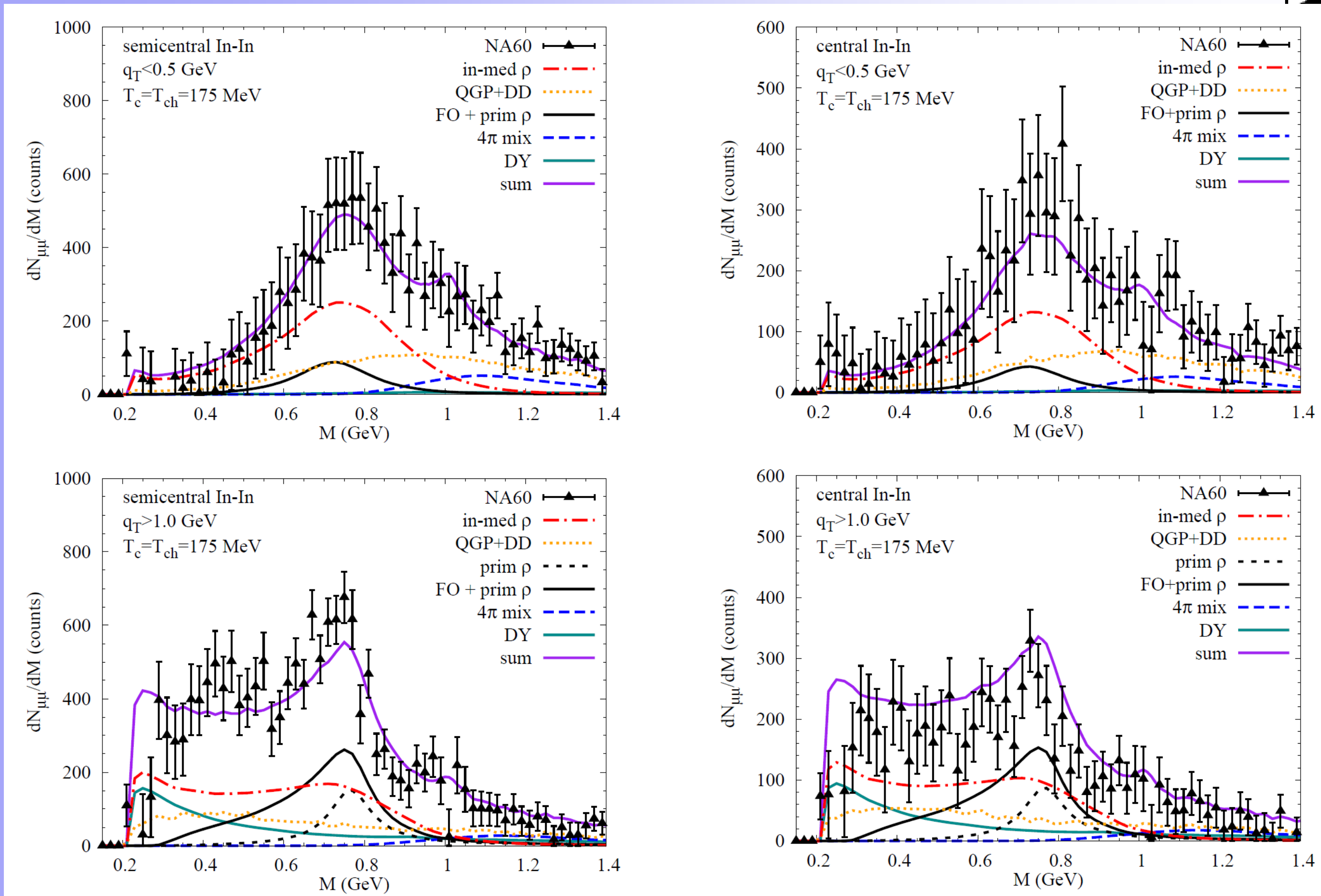
D. Schumacher, M.B.

With spectral function

- Broad spectral function allows for a nice description of the data



Results NA60



Summary

- Theory has to get space-time structure and particle densities right (di-leptons are integrated over fireball lifetime and sensitive to baryon res. and pp collisions)
- Fundamentals, e.g. definition of densities (frames, methods, thermal fraction) have to be fixed
- Bremsstrahlung might be important for 1-2 AGeV reactions, however double counting needs to be avoided
- The underlying transport models are mostly consistent with each other, however di-lepton after burners are not
  - ➔ Real r vs. effective r vs. instant leptons
  - ➔ **Standard‘ model for hadron to di-lepton conversion needed**