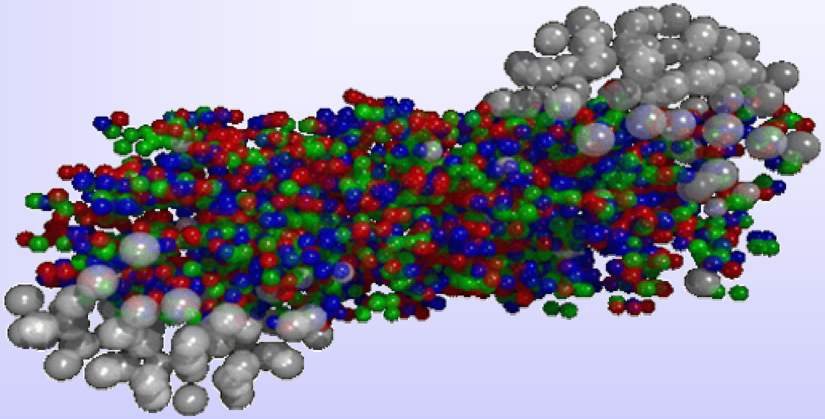
Low mass vector mesons and di-leptons in heavy ion collisions



Marcus Bleicher

Institut für Theoretische Physik

Goethe Universität Frankfurt

Germany

Thanks to the UrQMD group

- Katharina Schmidt
- Sascha Vogel
- Xianglei Zhu
- Daniel Krieg
- Horst Stoecker
- Hannah Petersen
- Diana Schumacher
- Stephane Haussler
- Mohamed Abdel-Aziz
- Qingfeng Li

Special thanks to C. Sturm (HADES)

Outline

- Model properties:
  Space-time evolution / particle production
- Physics expectation
- Technical issues
- Physical issues
- Summary
- Detector?

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

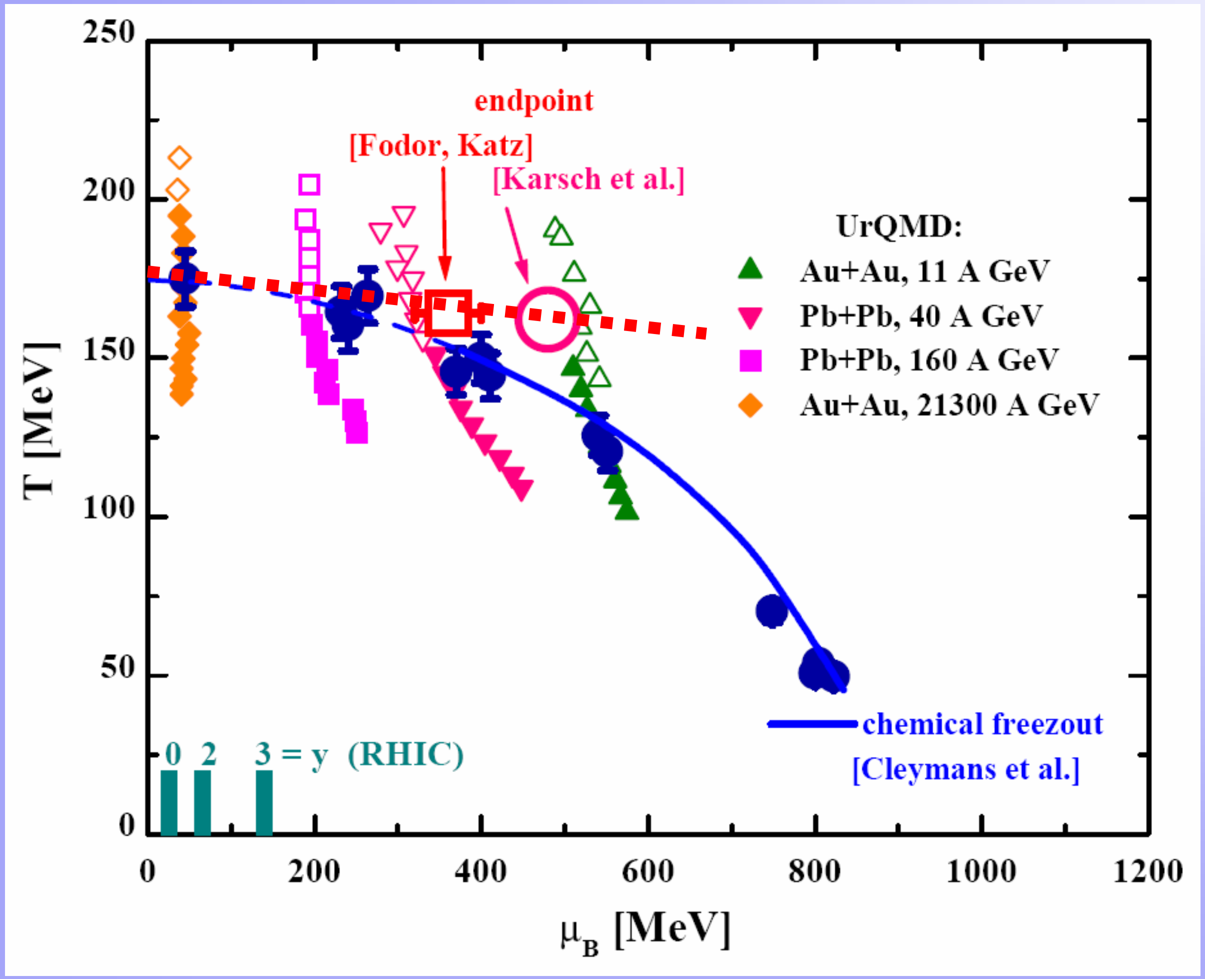
What can transport models do?

- Provide baseline calculations,
  including resonances, jets, flow,…
  Study energy/centrality dependence

- Provide a look “behind the curtain”,
  i.e. what is the origin of the observed effect

- Study acceptance effects,
  i.e. how does limited detector coverage and the trigger conditions influence the results

Motivation

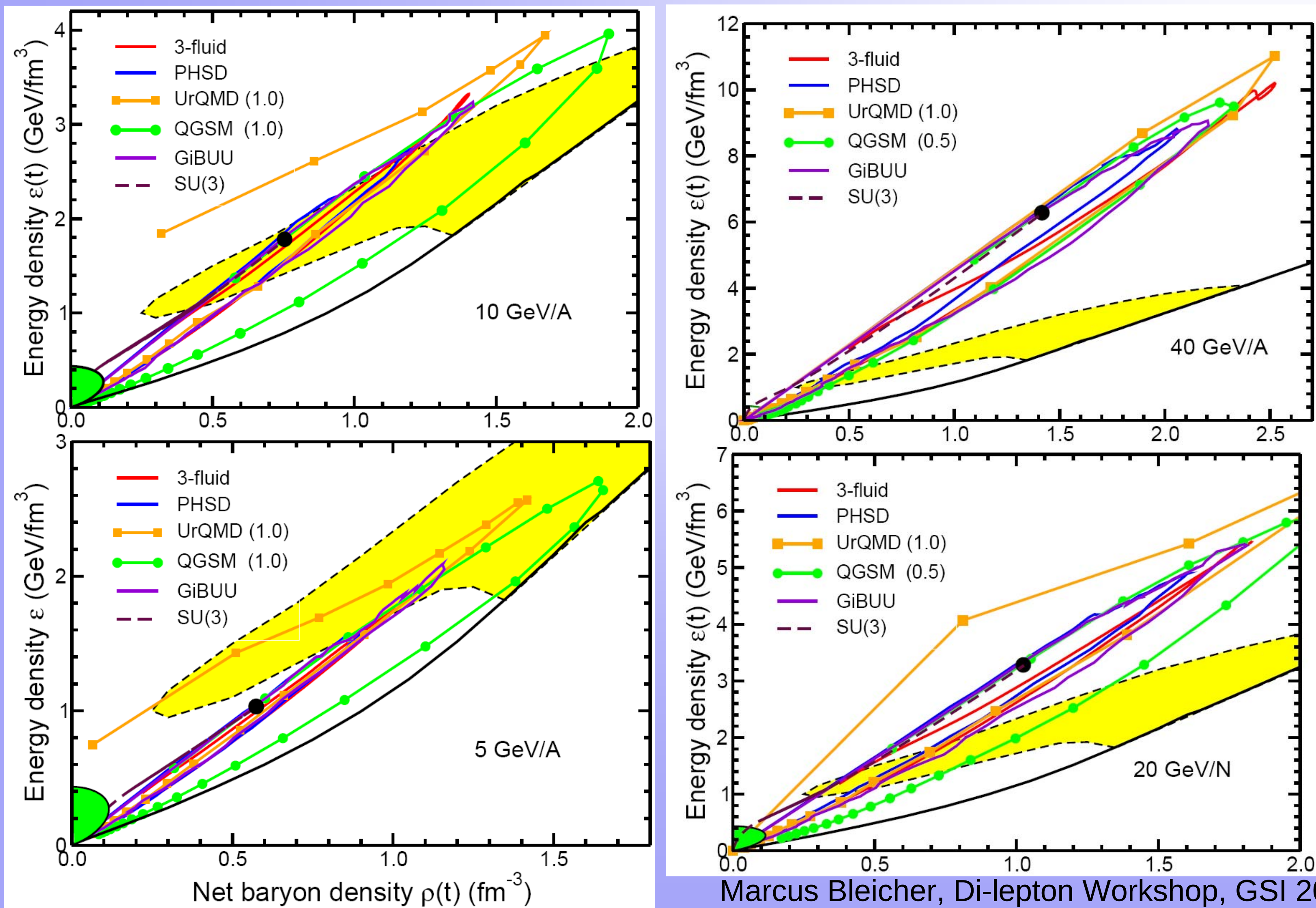


At **RHIC**:
look for signals of freely moving partons.

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

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

Phase trajectories



I. Arsene et al, nucl-th/0609042

Initial state matter: ‘string matter’

String matter dominates the early stages

‘string matter‘ = QGP?

UrQMD, Pb+Pb

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

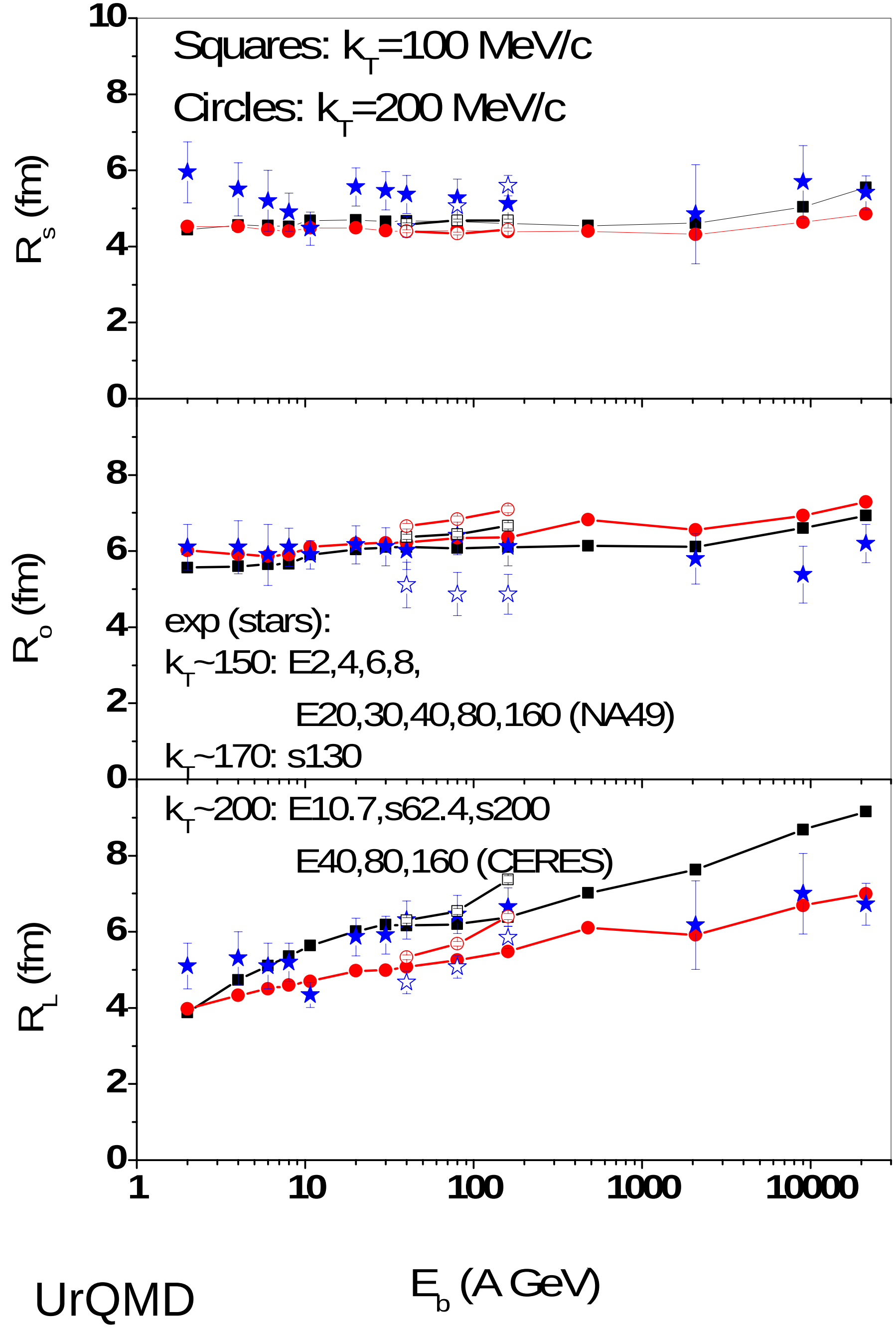
What do we want to see?
→ in-medium spectral functions

- 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

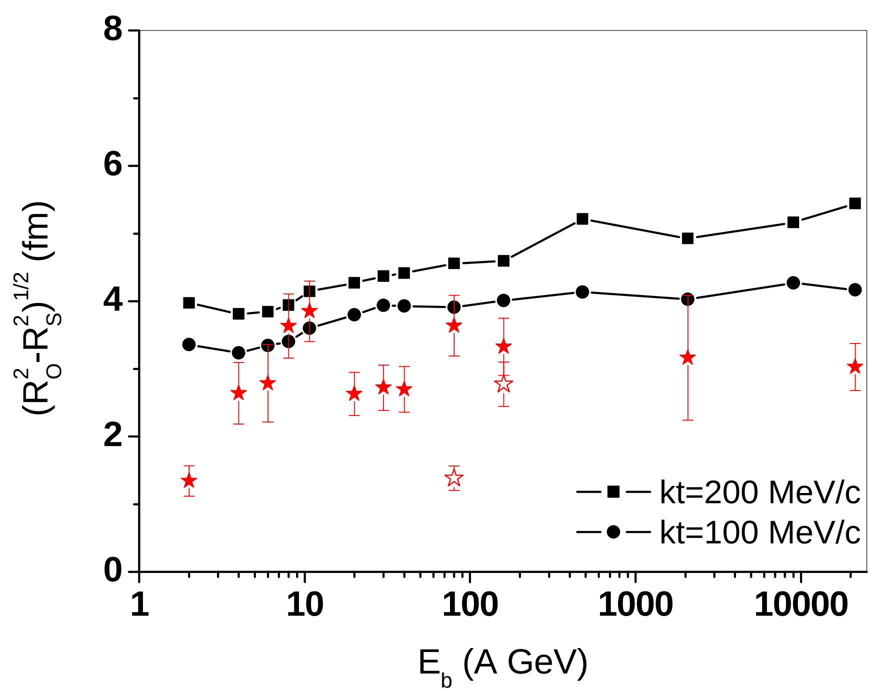
Are the dynamical models good enough?

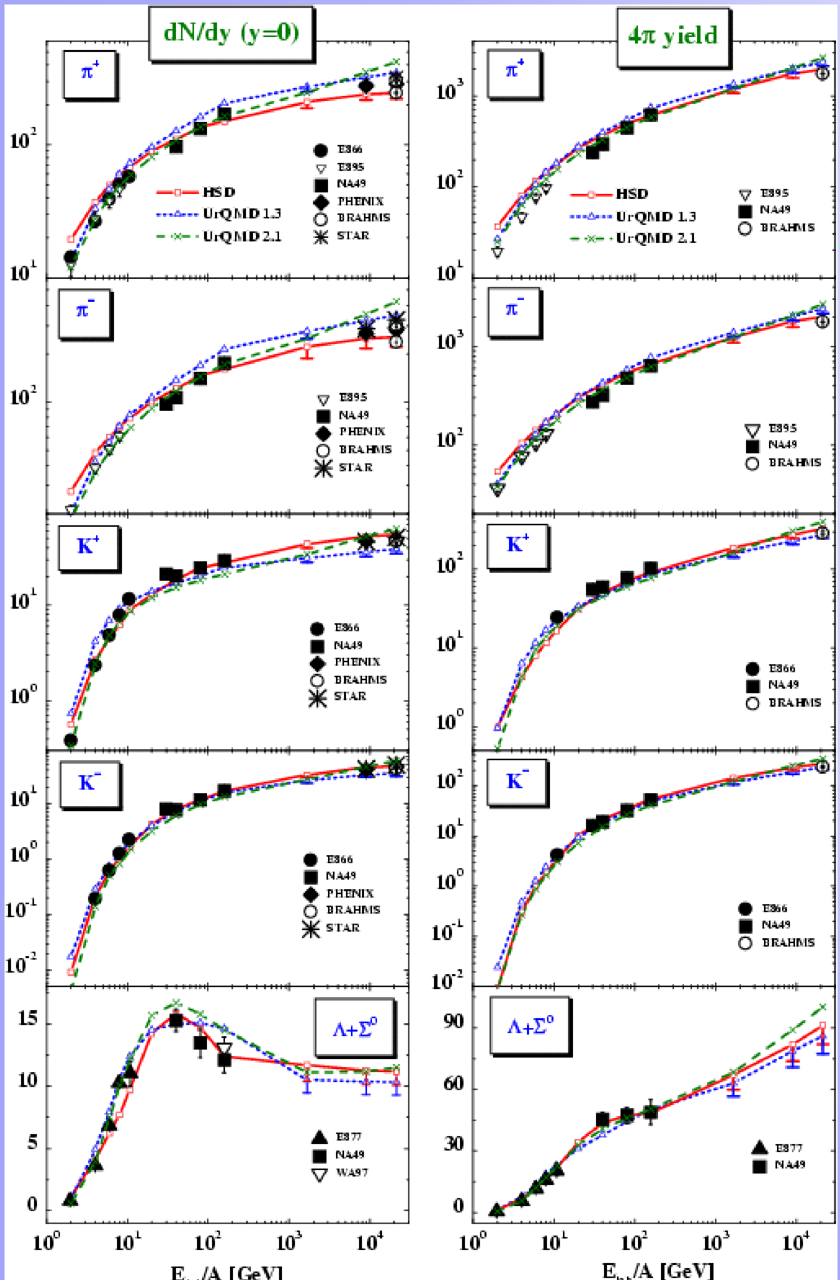
- Check space-time evolution
  ➔HBT correlations
- Check particle production
  ➔Pion production ($\pi\pi$➔ρ !)
  ➔Baryon stopping (Many ρ from decays !)
  ➔Final state ρ from $\pi\pi$ correlations

HBT-Energy dependence



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





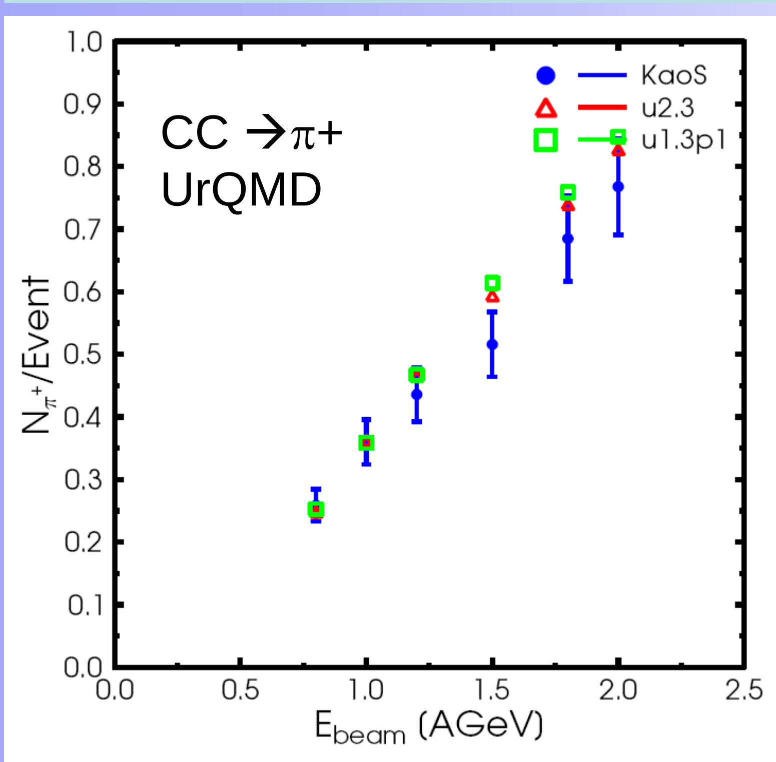
Excitation functions

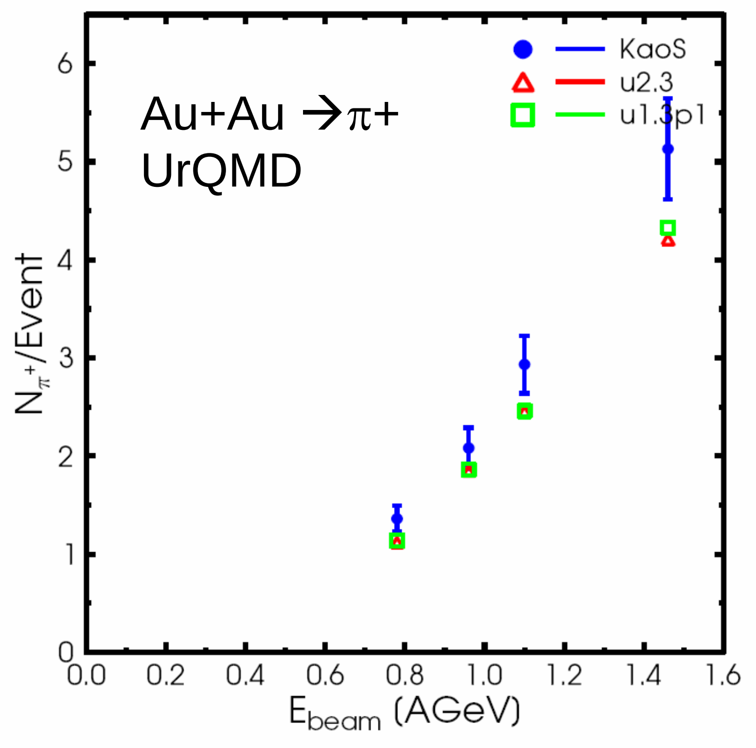
- Good agreement between different transport models (HSD/UrQMD)
- 4 pi and midrapidity abundancies are described on a 10-20% level (systematic error)
- Energy dependence: OK
- Hadron-string models work well

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

Detailed view at low energies

D. Schumacher, H. Petersen





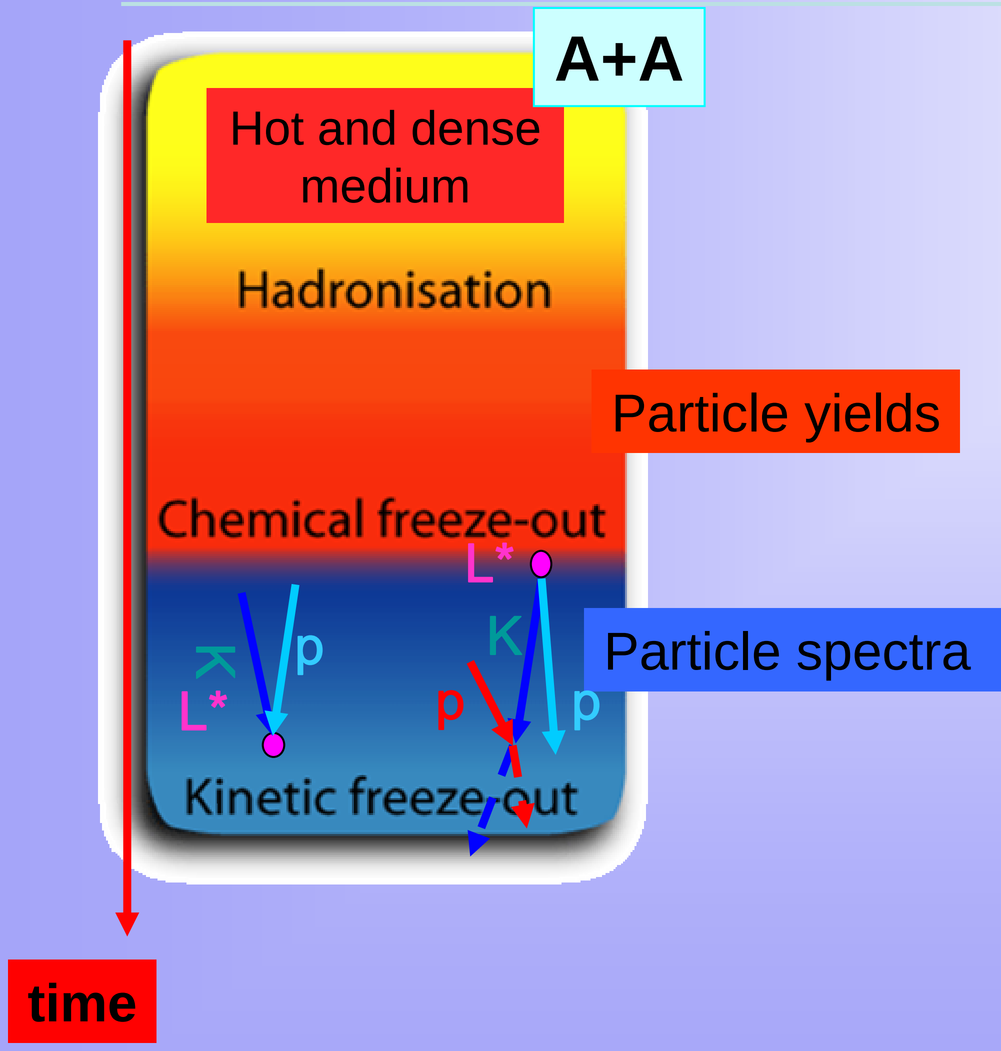
- Comparison to KAOS data
- Reasonable agreement

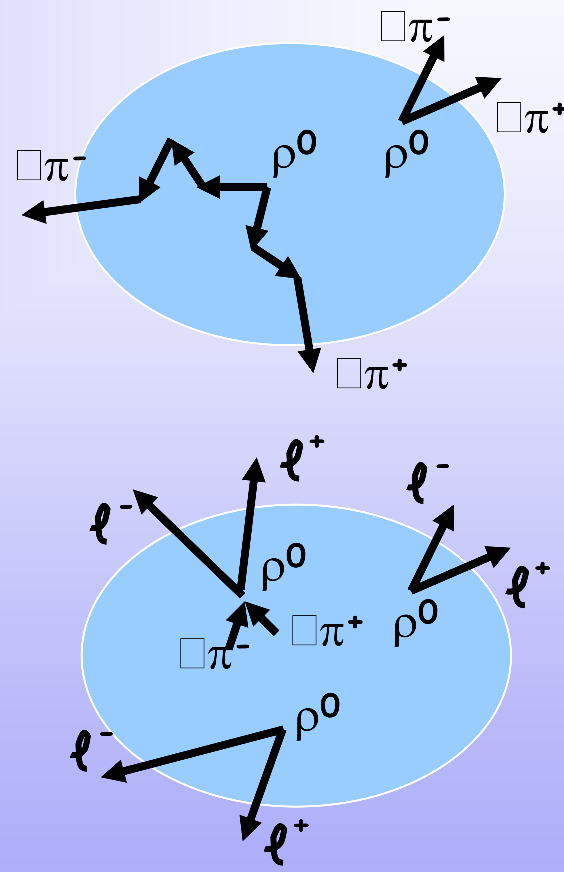
D. Schumacher, s. Vogel, M.B, Acta Phys.Hung.A27:451-458,2006

Why are short lived hadron resonances interesting?

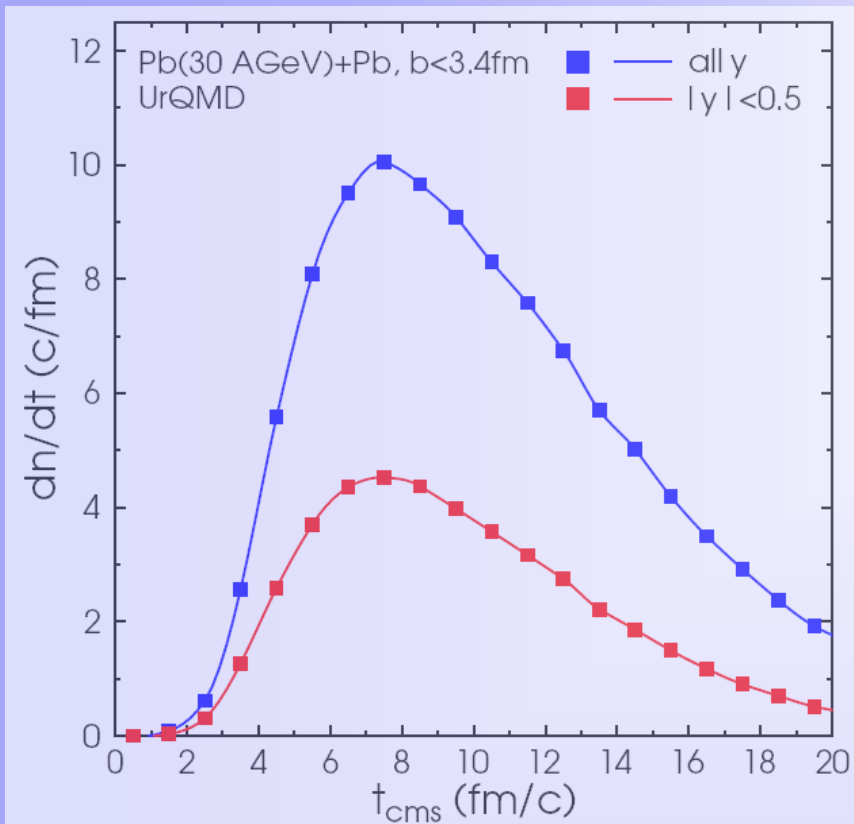
- There is a (long living) hadronic rescattering stage at FAIR and SPS energies
- Lifetime and properties of the hadronic stage are defined and probed by resonance production/absorption/re-feeding/decay
- Use different resonances to explore this stage:
  e.g. mesons: $K^*(892), \rho, f_0, \phi$
  baryons: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

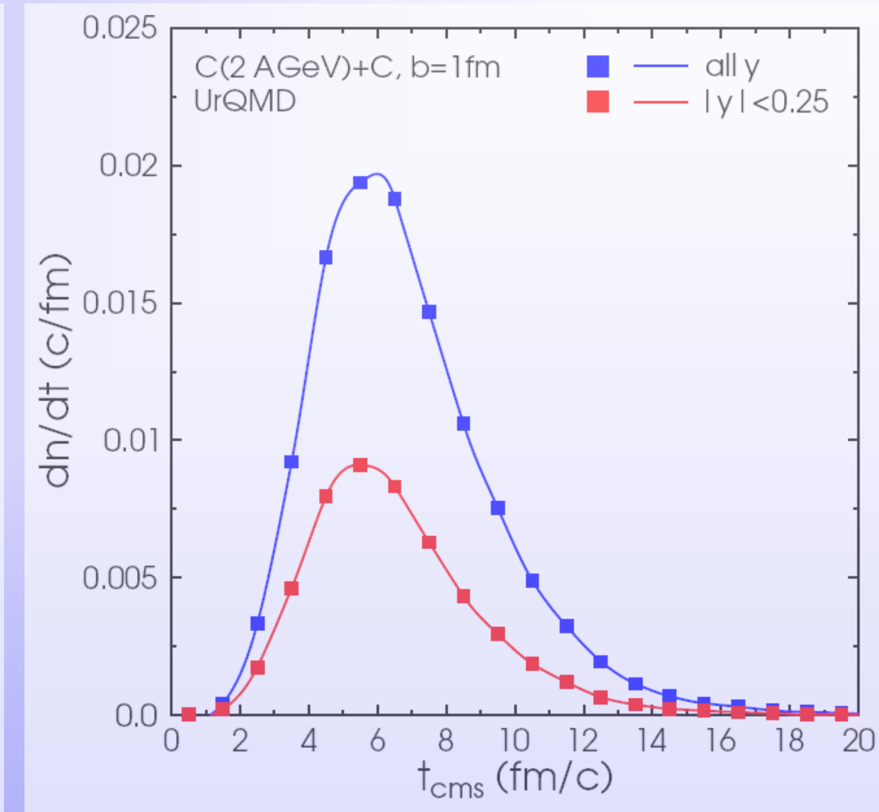
Hadronic vs leptonic channel





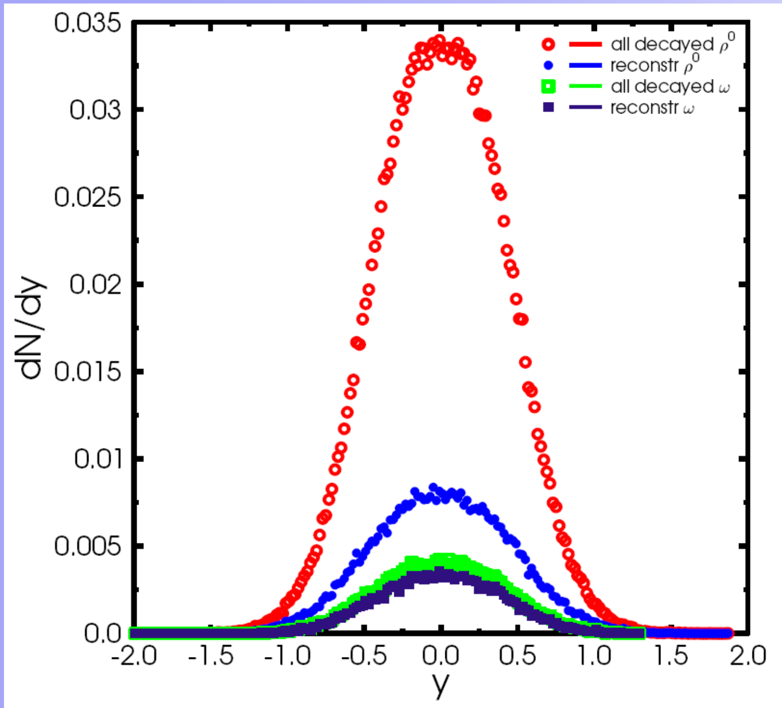
Decay time distribution of ρ mesons

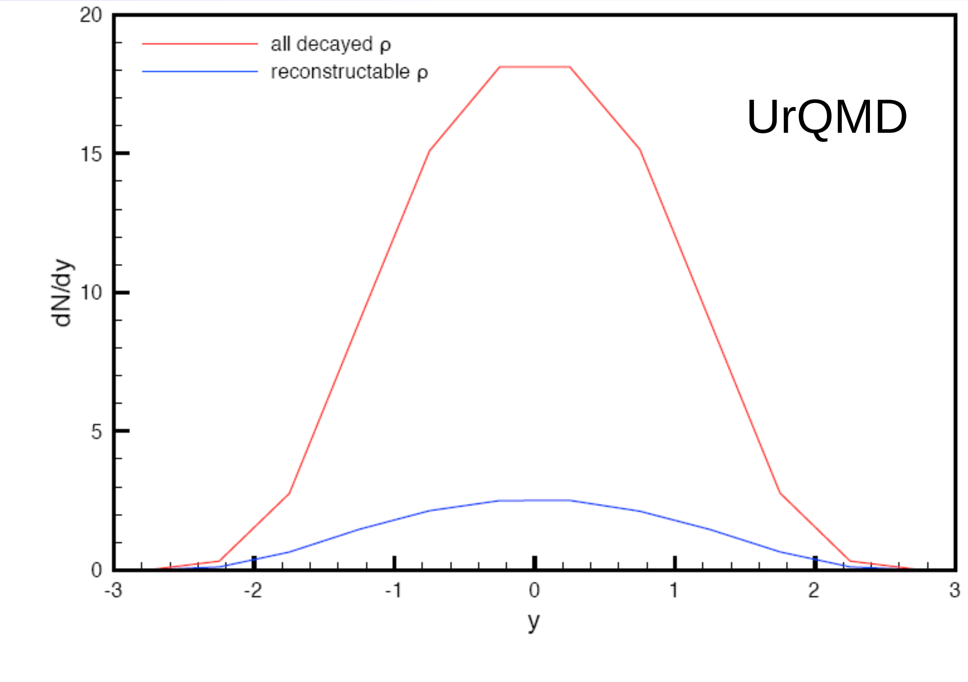




Resonance formation needs time (most ρ from baryon resonances)
➔ even short lived resonances are dominantly from later stages

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

Di-leptons: Some technical issues

- Different di-lepton physics:
  - VMD, EVMD, form factors,
  - collisional broadening, shining,
  - explicit ρ, effective ρ, instant di-leptons
  - ➔ Different result from same input!
  - ➔ Standard / consensus needed
- Bremsstrahlung?!

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

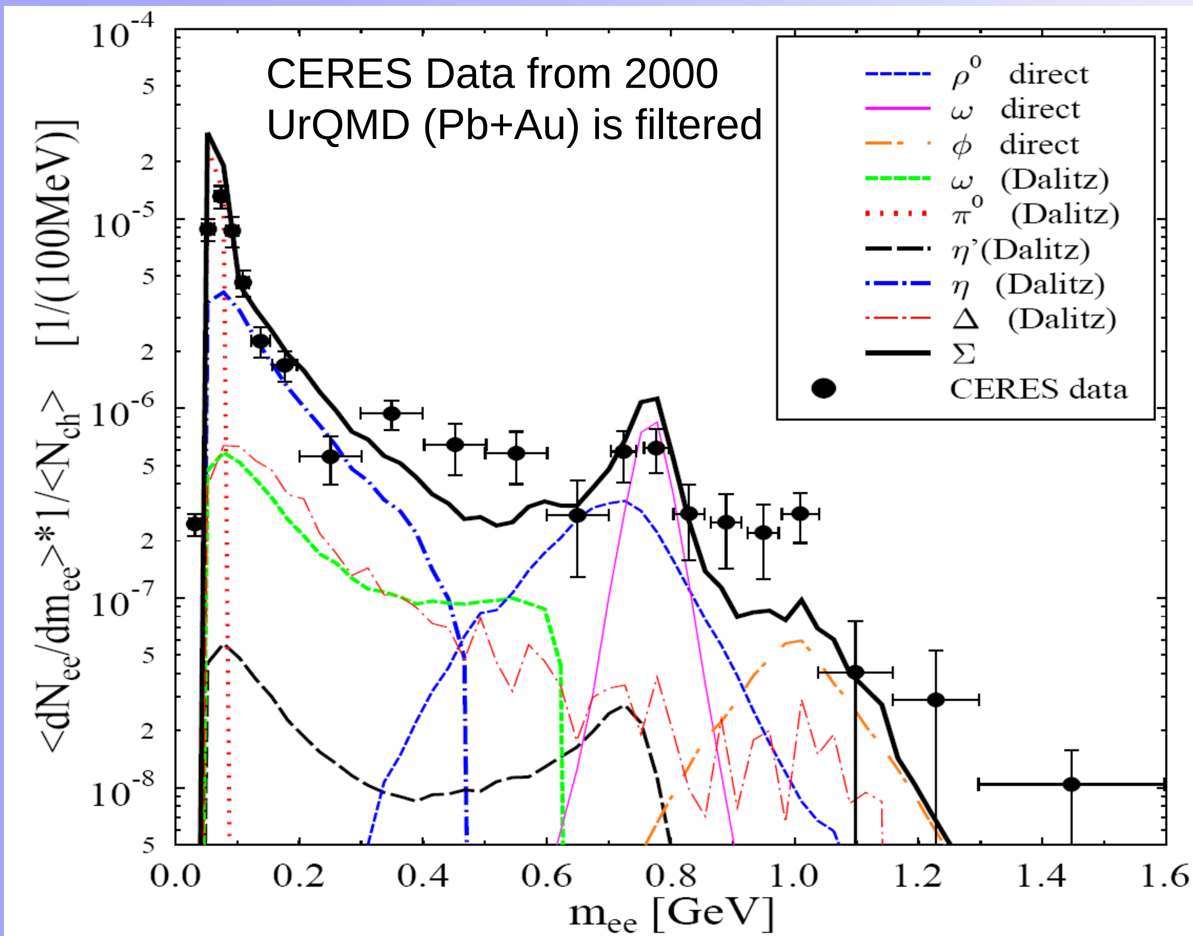
$$\frac{dN_{A\to\gamma e^+e^-}}{dM} = \frac{4\alpha}{3\pi M}\sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)\left(1-\frac{M^2}{m_A^2}\right)^3 \times |F_{AB}(M^2)|^2\frac{\Gamma_{A\to 2\gamma}}{\Gamma_{tot}}\langle N_A\rangle.$$

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

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

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)

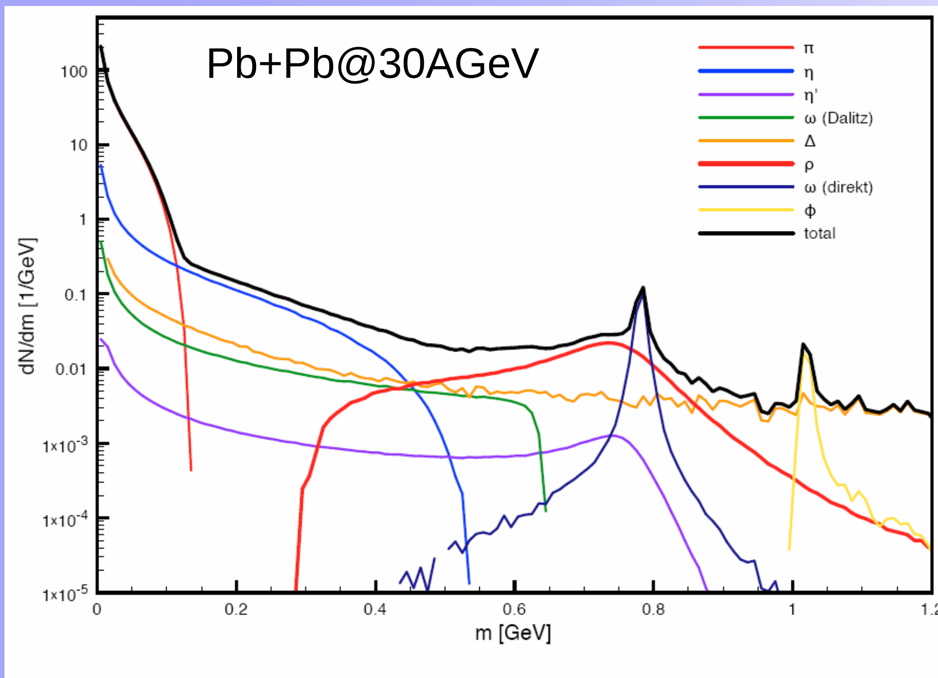
Comparison to CERES @ 160 AGeV

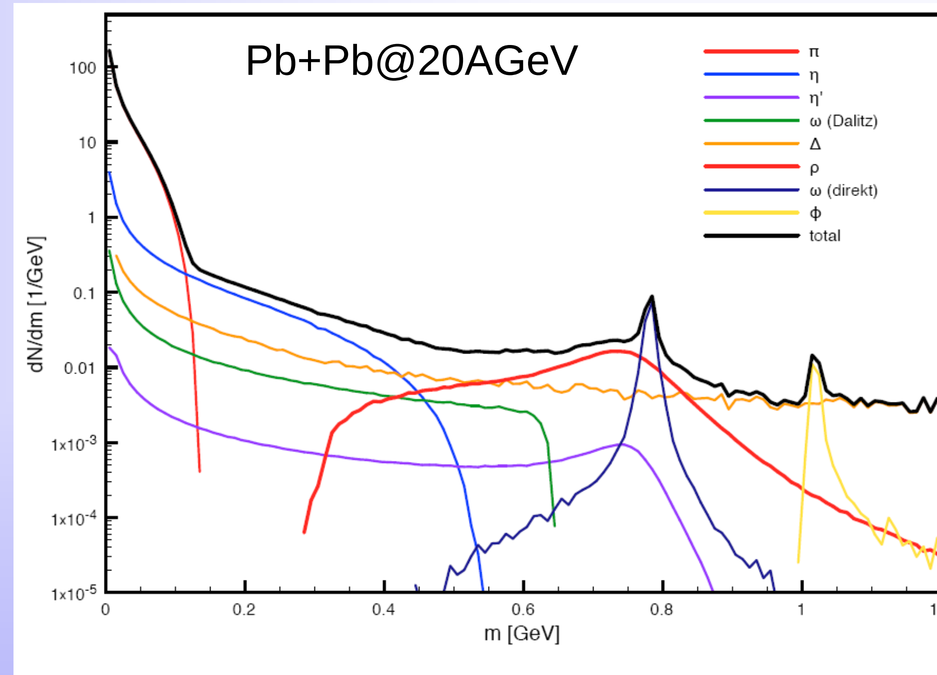


- Well known dip around 500 MeV
- Dip is from low momentum di-lepton pairs

D. Schumacher, M.B., to be published

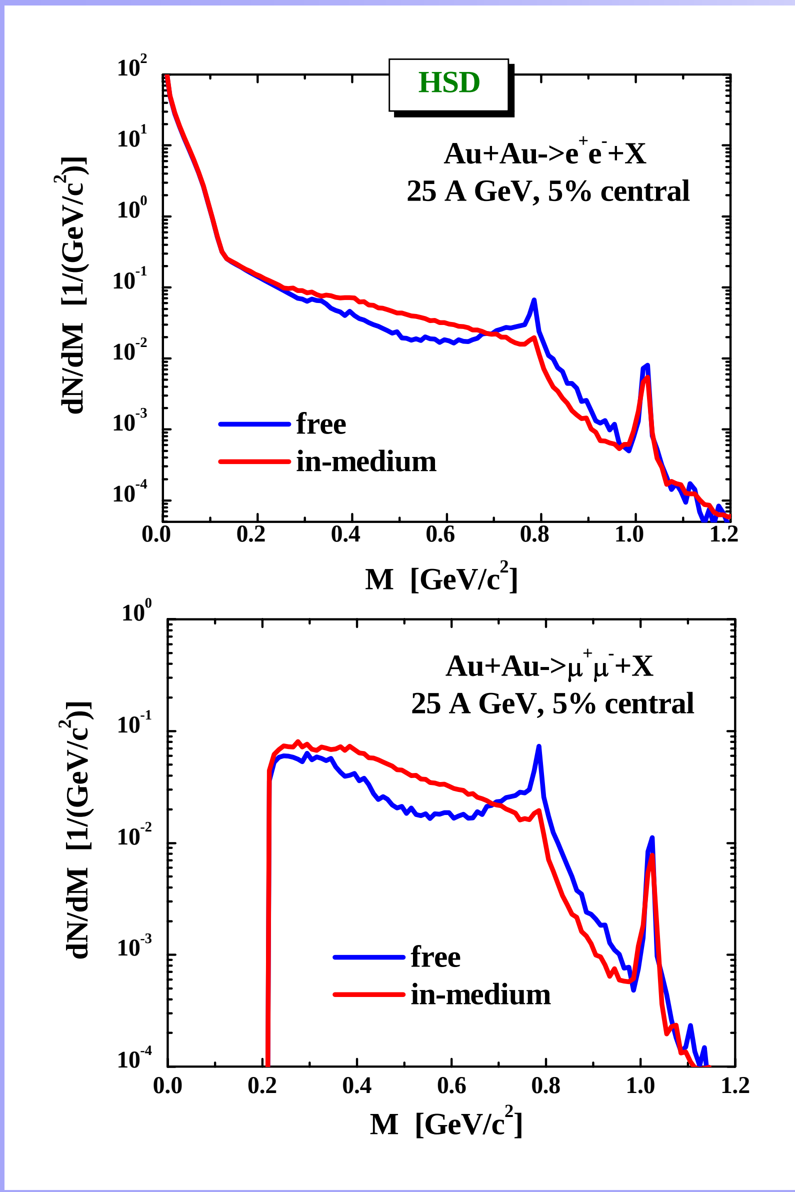
FAIR energy: UrQMD





- Strong contribution from Δ resonances
- Rather broad structure from the ρ meson

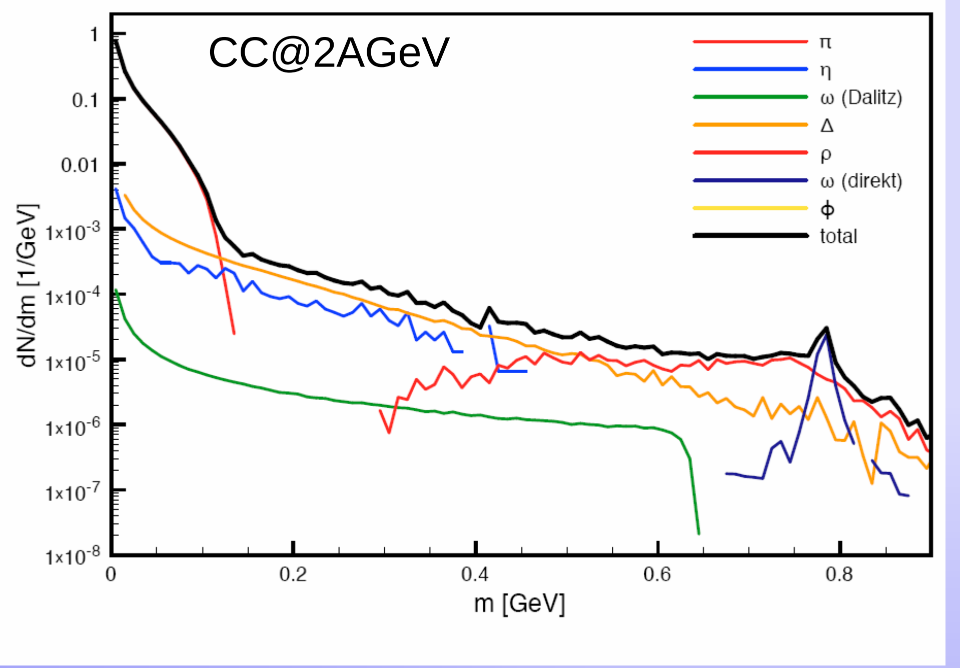
FAIR energy: HSD

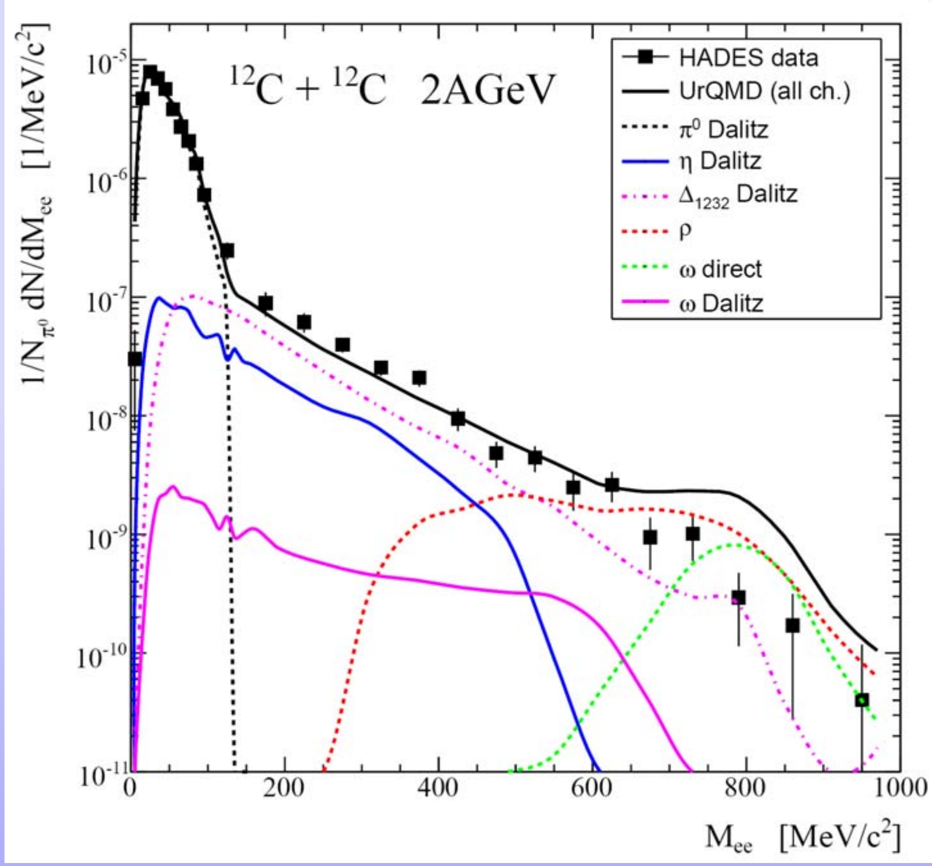


- Independent study assures
  - ➔ Robustness
  - ➔ Theoretical error
- Note difference to UrQMD above the ρ mass (Δ contribution?)

HSD by E. Bratkovskaya, W. Cassing

HADES energies: UrQMD

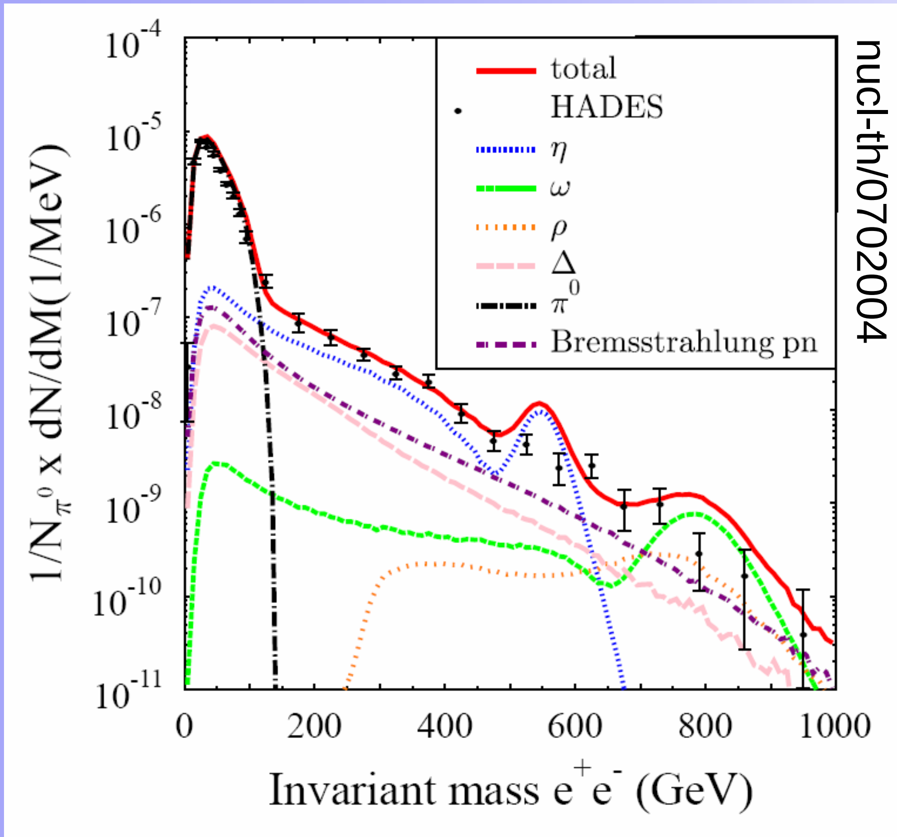


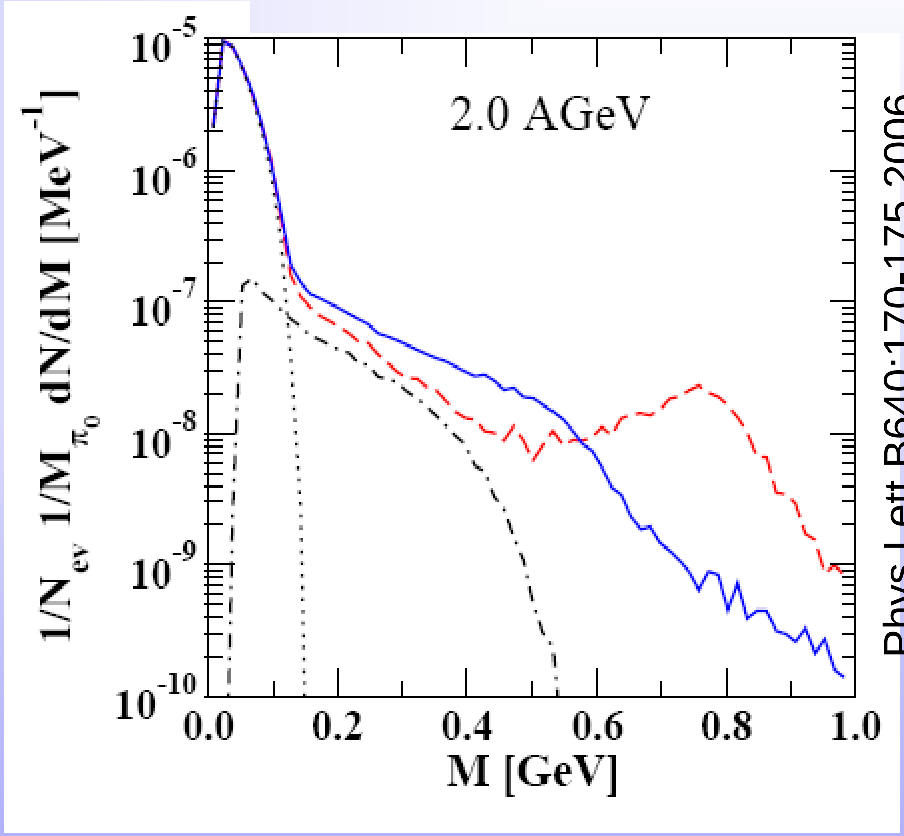


- Note the broad ρ mass distribution

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

HADES energies: IQMD/RQMD

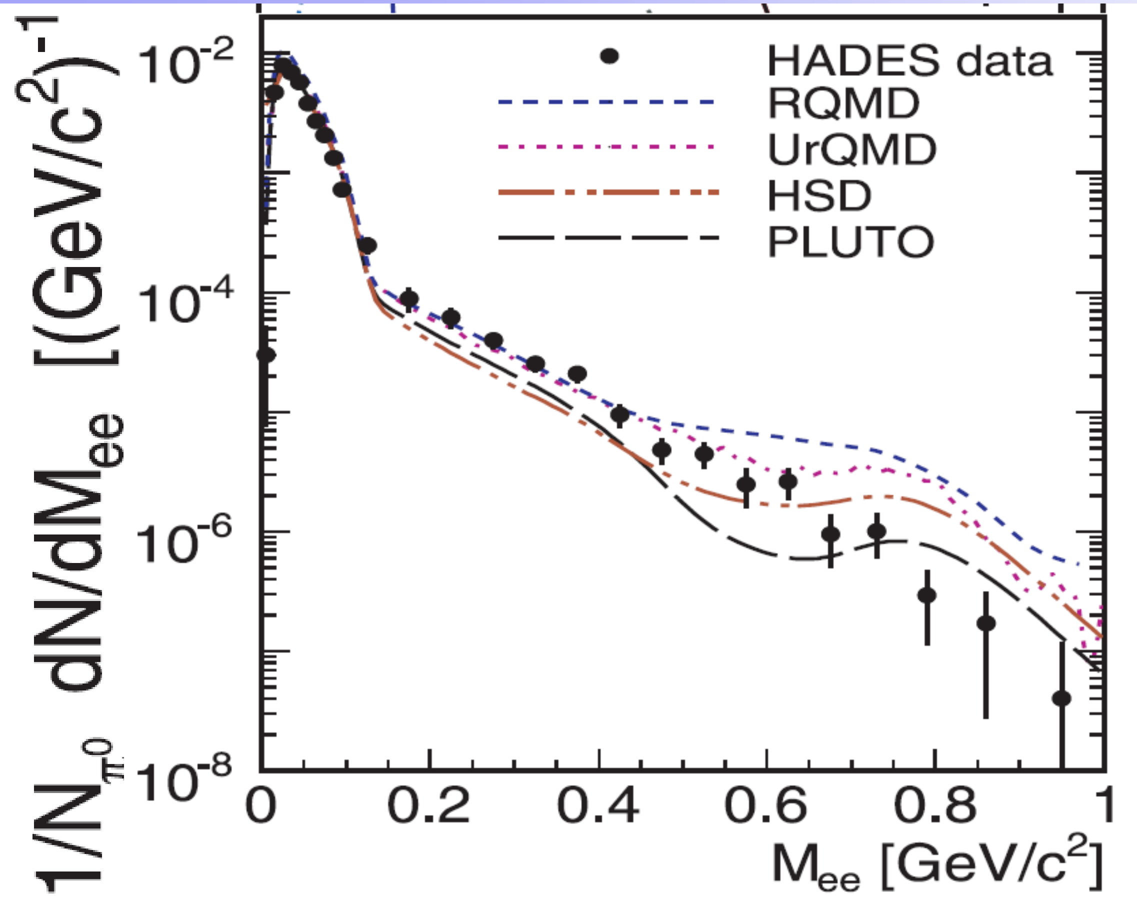




IQMD, CC@2AGeV
(instant di-leptons: no baryon and ρ resonance propagation)

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

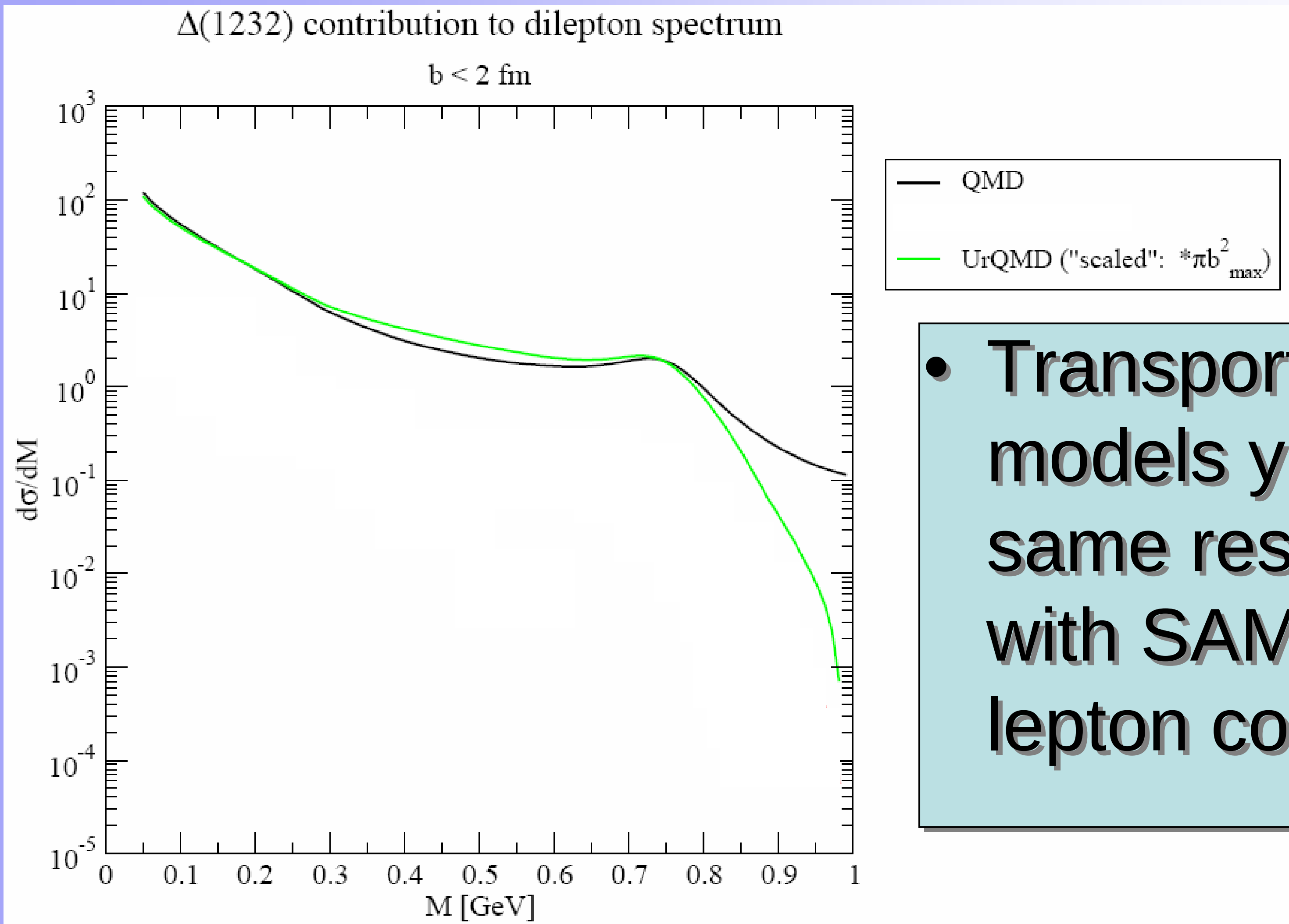
Di-lepton summary



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

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

Comparison:(R)QMD/UrQMD

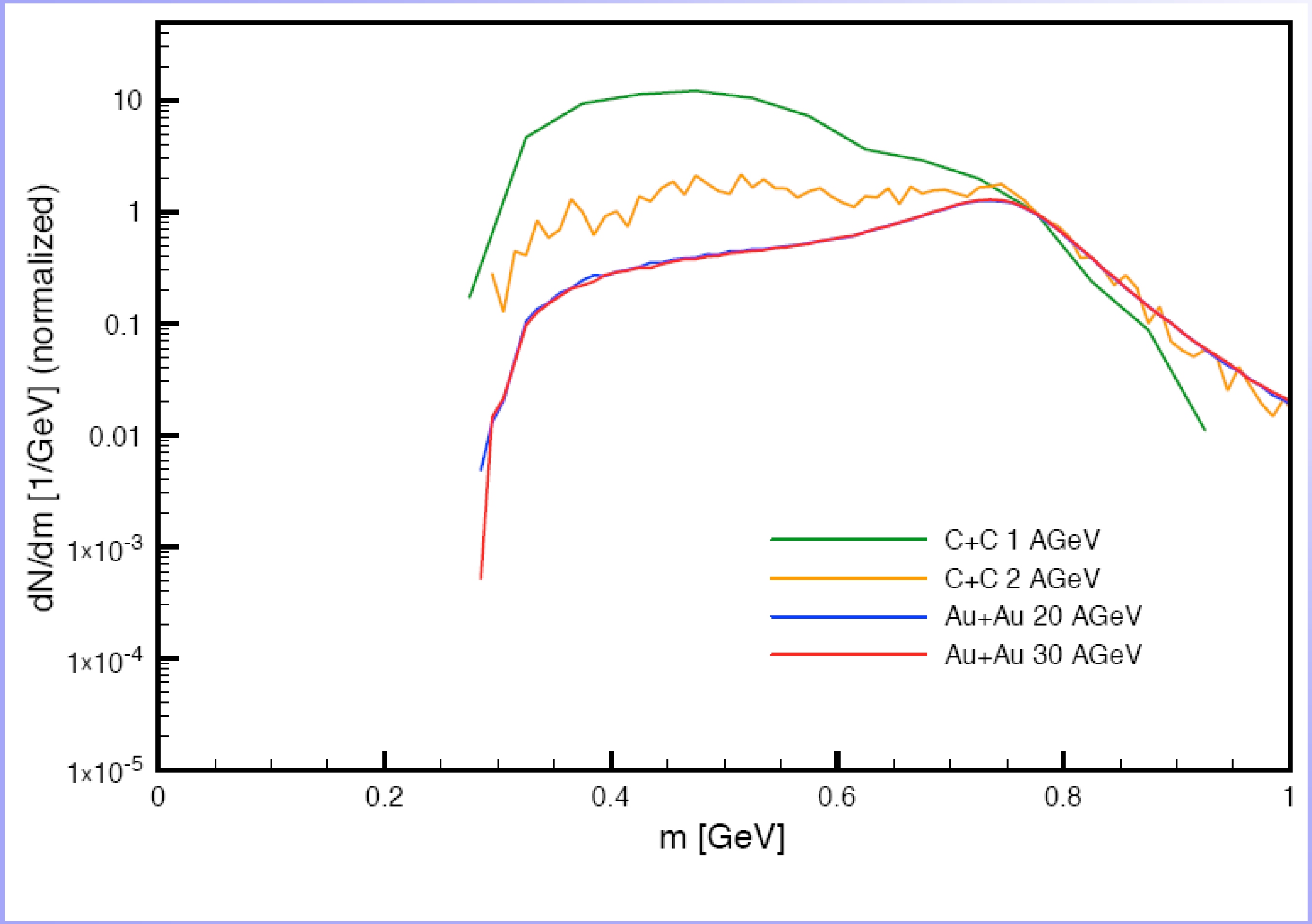


- Transport models yield same results with SAME di-lepton code

‘Trivial’ physics effects

- Even without chiral symmetry restauration and in-medium modifications one expects a modification of the ρ spectral function

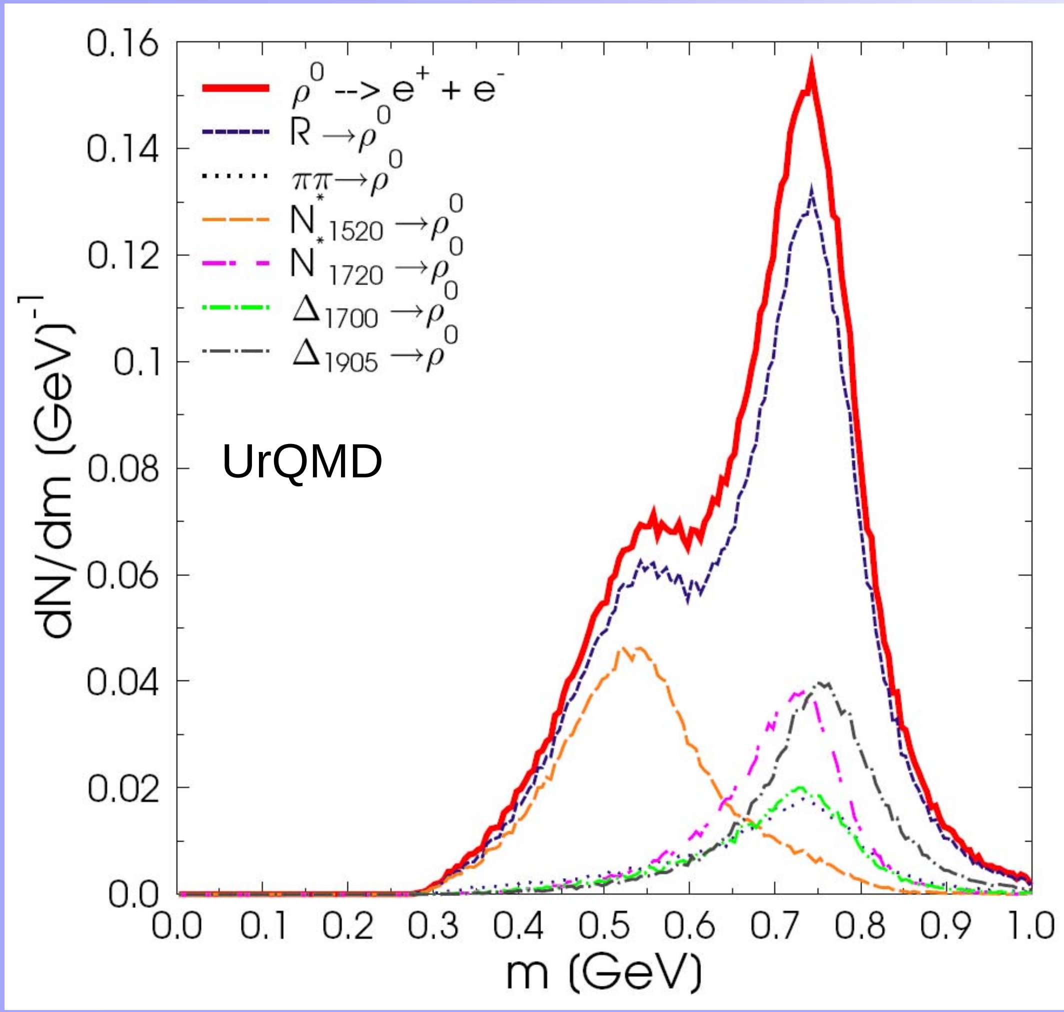
Di-leptons from the ρ



- Broadening and mass shift of the ρ meson
- In-medium modifications increase towards lower energies

UrQMD, S. Vogel

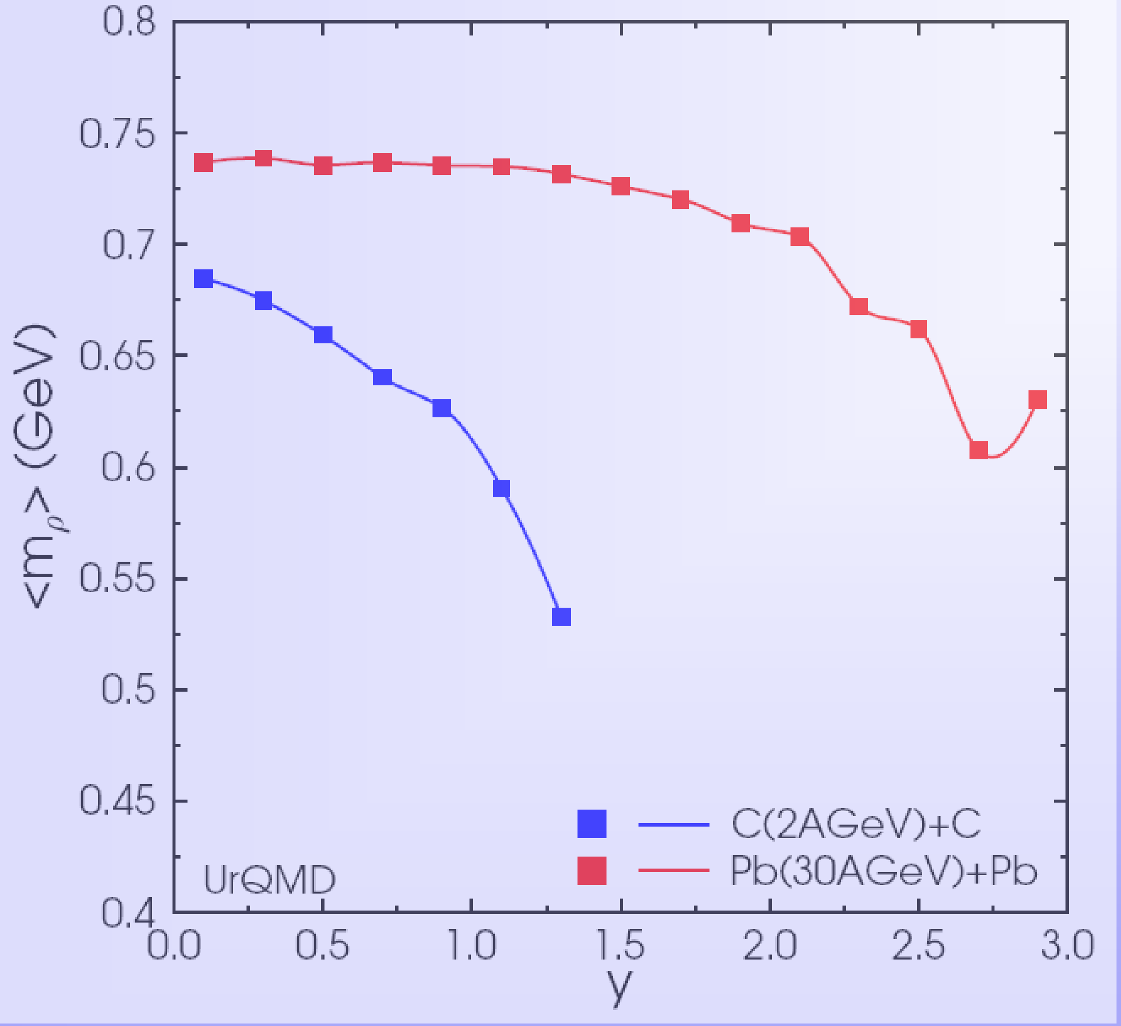
ρ mass distribution in C(2AGeV)+C



- Double hump feature
- Strong contribution to low mass ρ's from N^*_{1520}
- Only small contributions from ππ channel

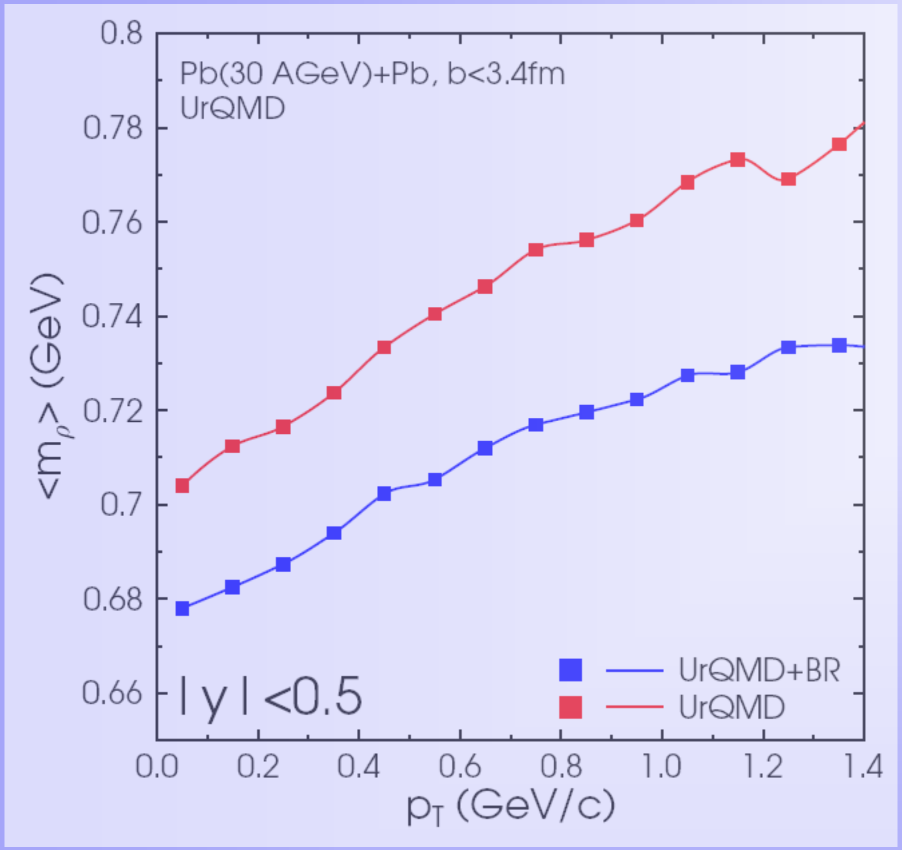
S. Vogel, M. Bleicher, Phys.Rev.C74:014902,2006

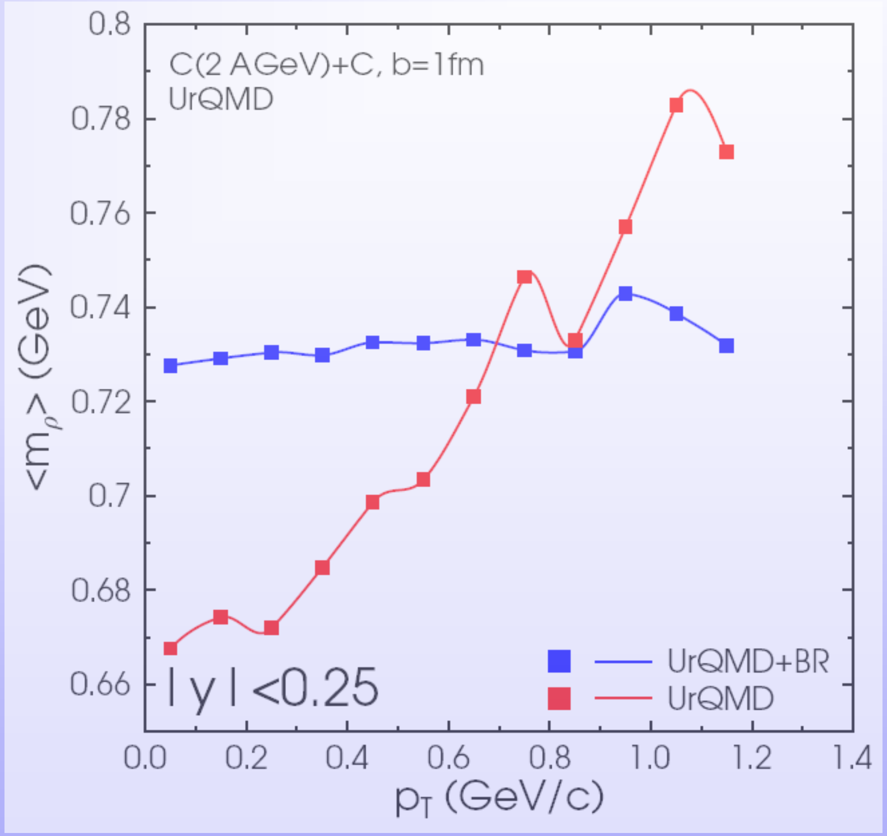
Rapidity dependence of masses



- Test: With increasing rapidity, baryonic contribution outweighs $\pi\pi$ channel
- ρ mass decreases towards forward rapidity

Brown-Rho vs. kinematics





Strong kinematic effects from resonances: $N^*_{1520} \rightarrow$ rho+N

BR means m*=m_rho(1-0.15 rho_b/rho_0)

Summary (I) - Theory

- Theory has to get space-time structure and particle densities right (di-leptons are integrated over fireball lifetime and sensitive to baryon res. and $\pi\pi$ collisions)
- The underlying transport models are mostly consistent with each other, however di-lepton after burners are not
  ➔ Real ρ vs. effective ρ vs. instant leptons
  ➔ Standard' model for hadron to di-lepton conversion needed
- Bremsstrahlung might be important for 1-2 AGeV reactions
- Non-trivial modification of the ρ spectral function due to N*(1520) coupling. Strong effect even in cascade calcs.
  → might blur more interesting effects

Summary (II) - Detector

- Good mass resolution ~10 MeV (should allow subtraction of background to get the ρ mass distibution)
- Same set-up for all energies from E_{lab}=5 AGeV – 40 AGeV
- Good statistics in this energy range
- Allow for complementary information from $\pi\pi$ reconstruction
- No interesting physics below m_{l+l-}<200 MeV (only π Dalitz)
- All mass modifications are around 400 MeV<m_{l+l-}<1100 MeV
- The ‚sweet spot' is at midrapidity and low p_T

➔ muons would be fine
(if bias can be understood/minimized)