Dimuon radiation from a hybrid evolution model

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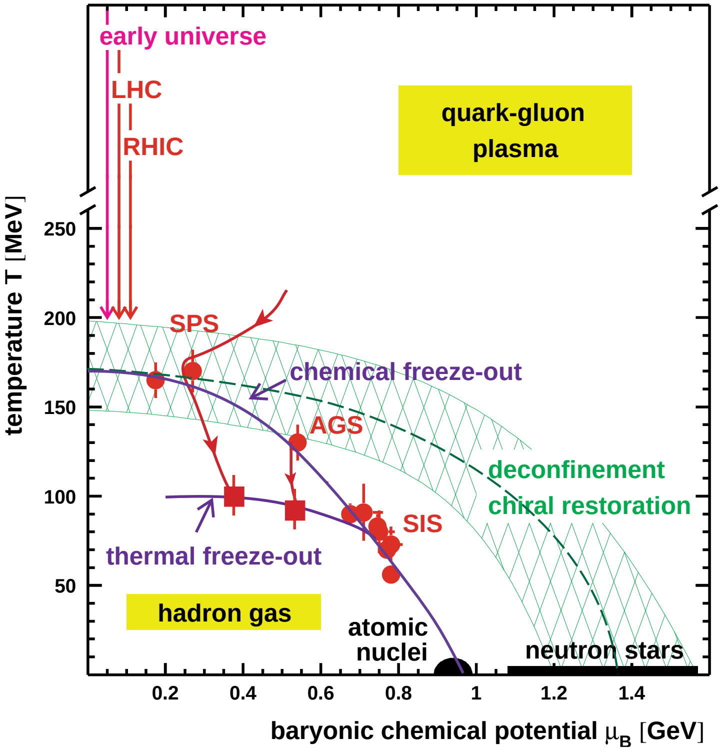
FIAS Frankfurt Institute for Advanced Studies

HIC for FAIR Helmholtz International Center

St. Goar, March 18th, 2011

Dileptons: The ideal probe



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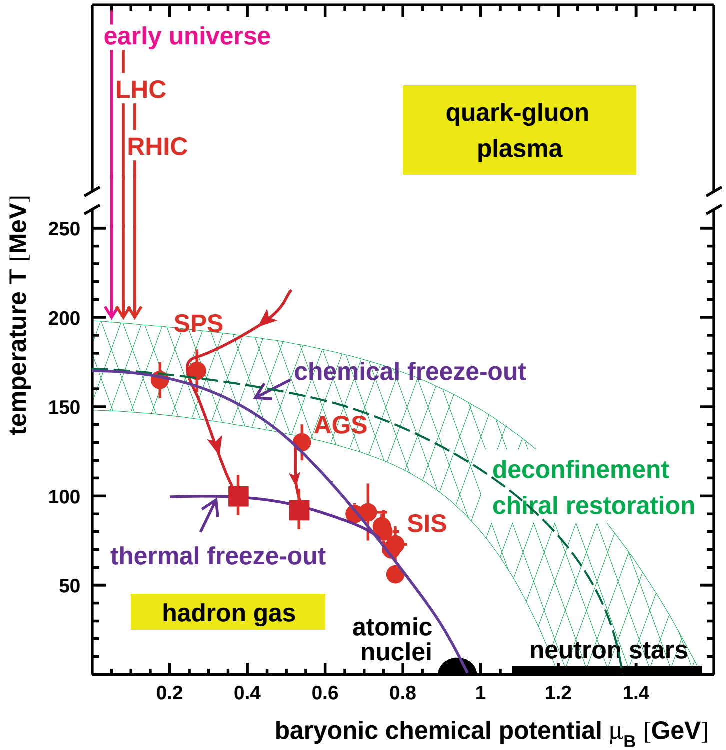
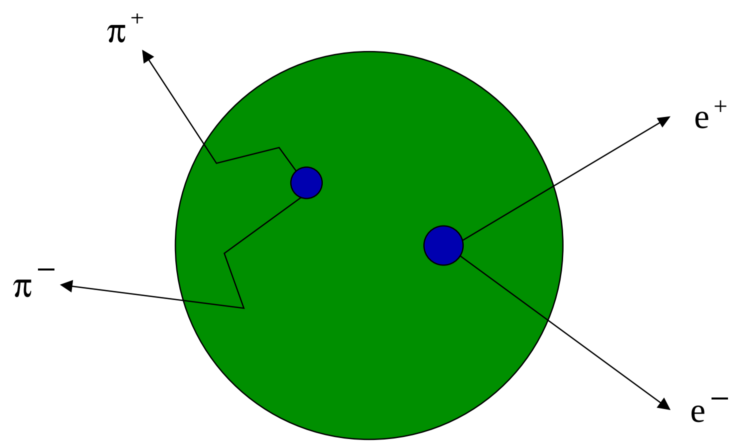
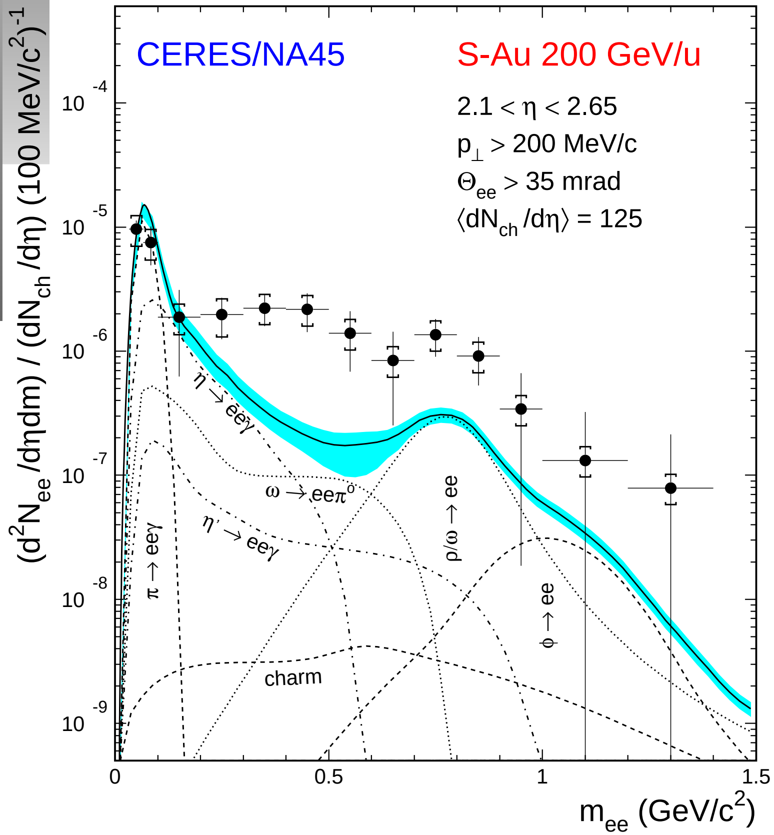


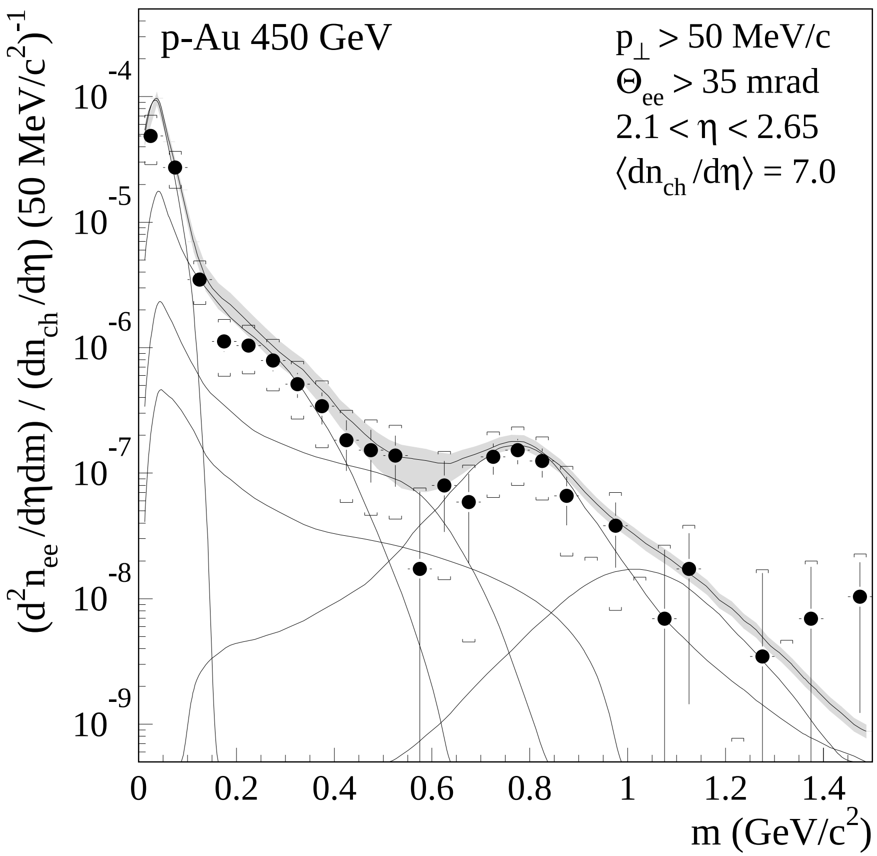


- l^+l^- are **messangers of the hot and dense phase** of the collision
- l^+l^- allow to investigate **medium effects** on hadron properties

Experimental evidence

CERES Coll.@CERN `[G.Agakichiev` *et al.*, **PRL75**(1995)1272]





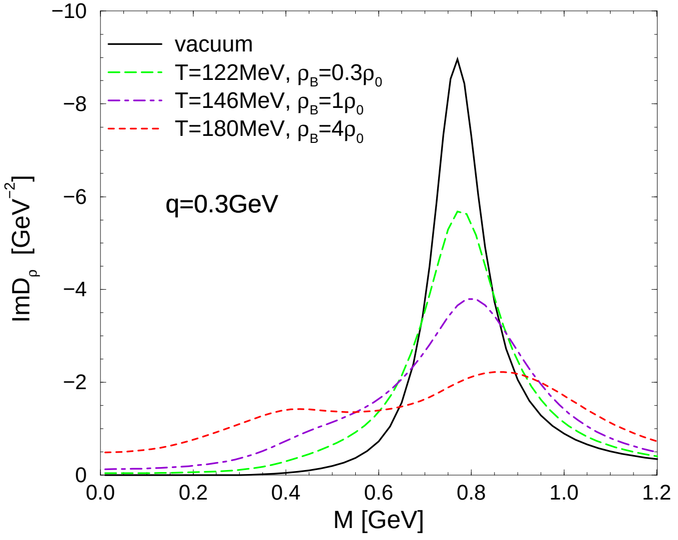
HELIOS-3 Coll.: similar enhancement of low-mass dilepton over the cocktail `[M.Masera` *et al.*,**NPA590**(1995)93c]

In-medium ρ

- **ρ spectral function is modified in the medium.**
  Collisions with sourrounding hadrons lead to a general broadening and specific "structures" may appear

$$D_\rho^{L,T} = [M^2 - (m_\rho^{(0)})^2 - \Sigma_{\rho\pi\pi}^{L,T} - \Sigma_{\rho M}^{L,T} - \Sigma_{\rho B}^{L,T}]^{-1}$$

[R.Rapp,J.Wambach, **ANP25**(2000)1]



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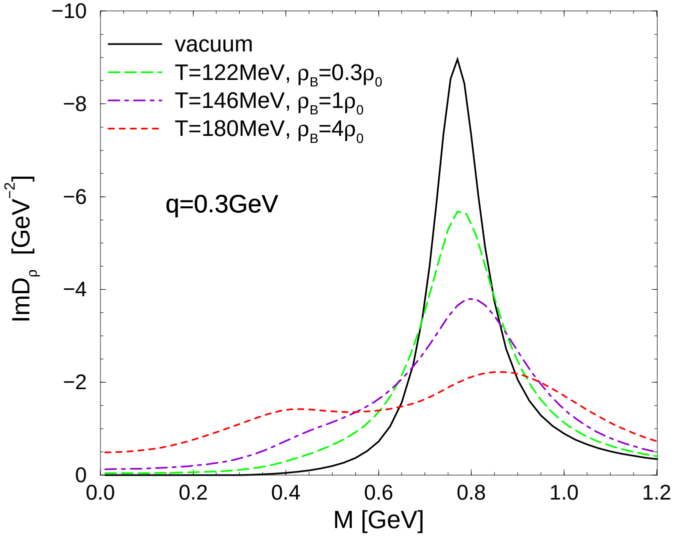

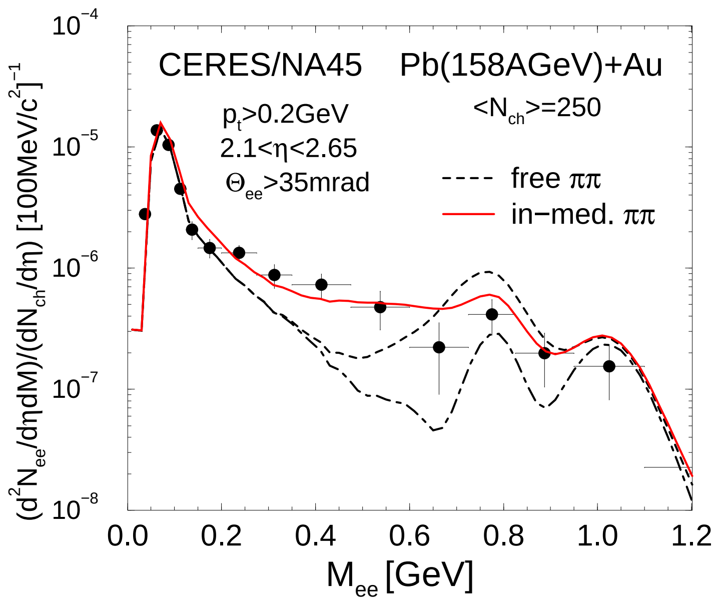

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NA60@CERN:

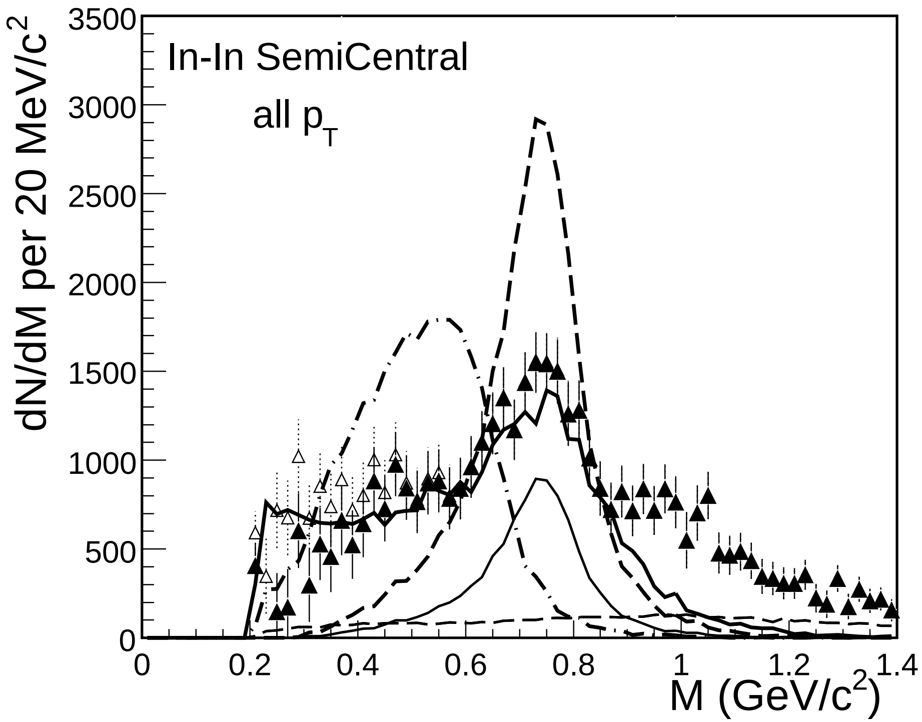
- evidence for no mass shift of the ρ in In+In@158 AGeV
  `[R. Arnaldi et al.,`**`PRL96`**`(2006)162302]`
- data in favour of “complex” spectral functions

dashed : vacuum

thick solid : R.Rapp spf

dash-dotted : Brown-Rho scaling

“The ρ spf shows a strong broadening
but essentially no mass shift.
This may rule out theoretical models
linking hadron masses
directly to the chiral condensate.”



At present

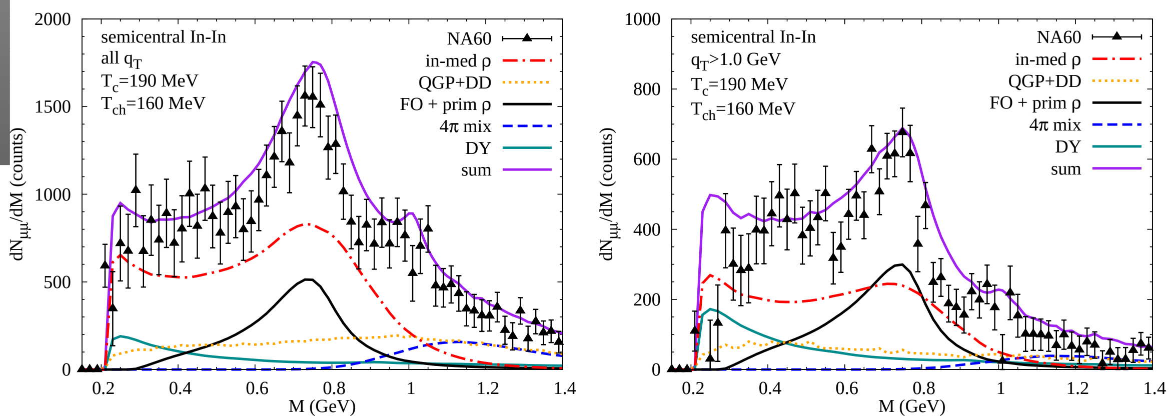
SPS data on excess currently explained as thermal ll emission:

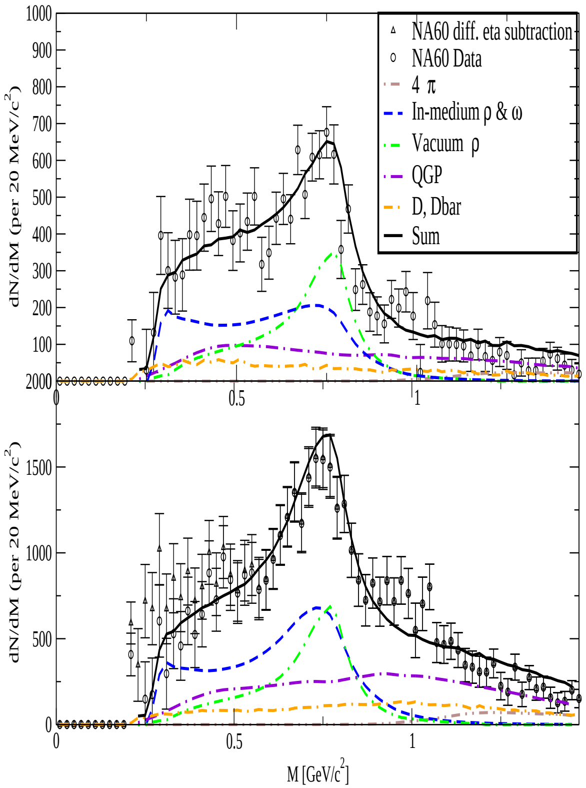
$$\frac{d^8 N_{ll}}{d^4x d^4q} = -\frac{\alpha^2 m_\rho^4}{\pi^3 g_\rho^2}\frac{L(M^2)}{M^2} f_B(q_0;T)\mathrm{Im}\, D_\rho(M,q;T,\mu_B)$$

with ρ spectral function in-medium modified

[J.Ruppert,et al., **PRL100**(2008)162301]

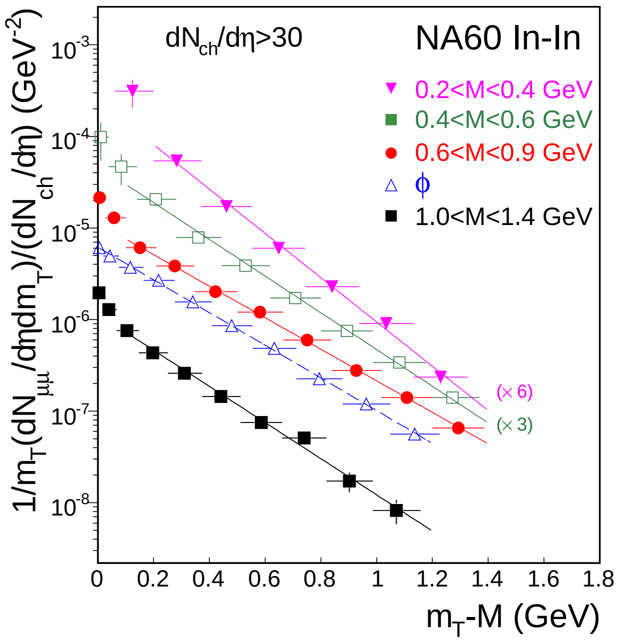
[H.van Hess,R.Rapp,**NPA806**(2008)339]

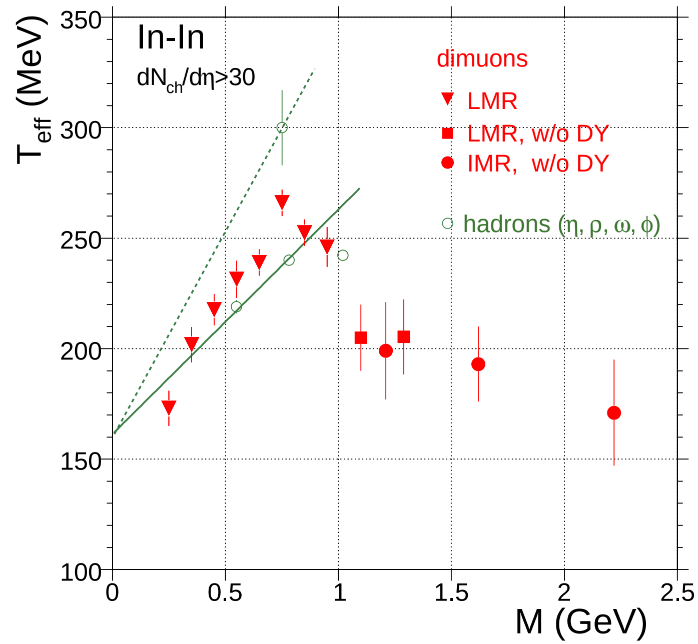




See also K.Dusling et al.,**PRC75**(2007);**PRC80**(2009)

The dropping of T_{eff}





[R.Arnaldi,et al.,**EPJ61**(2009)711]

- **Sudden steepening** of the m_T spectra above the ρ

  $\Rightarrow$ interpred as emission from **early times** at which radial flow has not yet copiously build up

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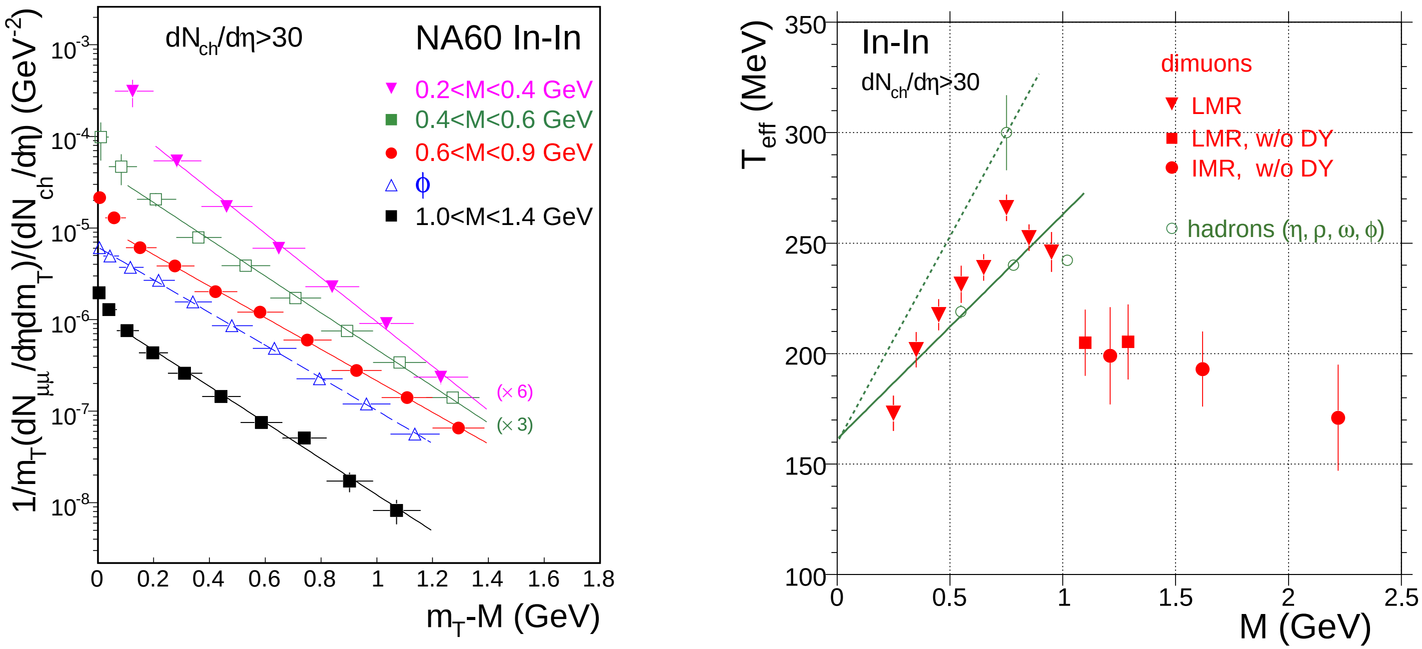

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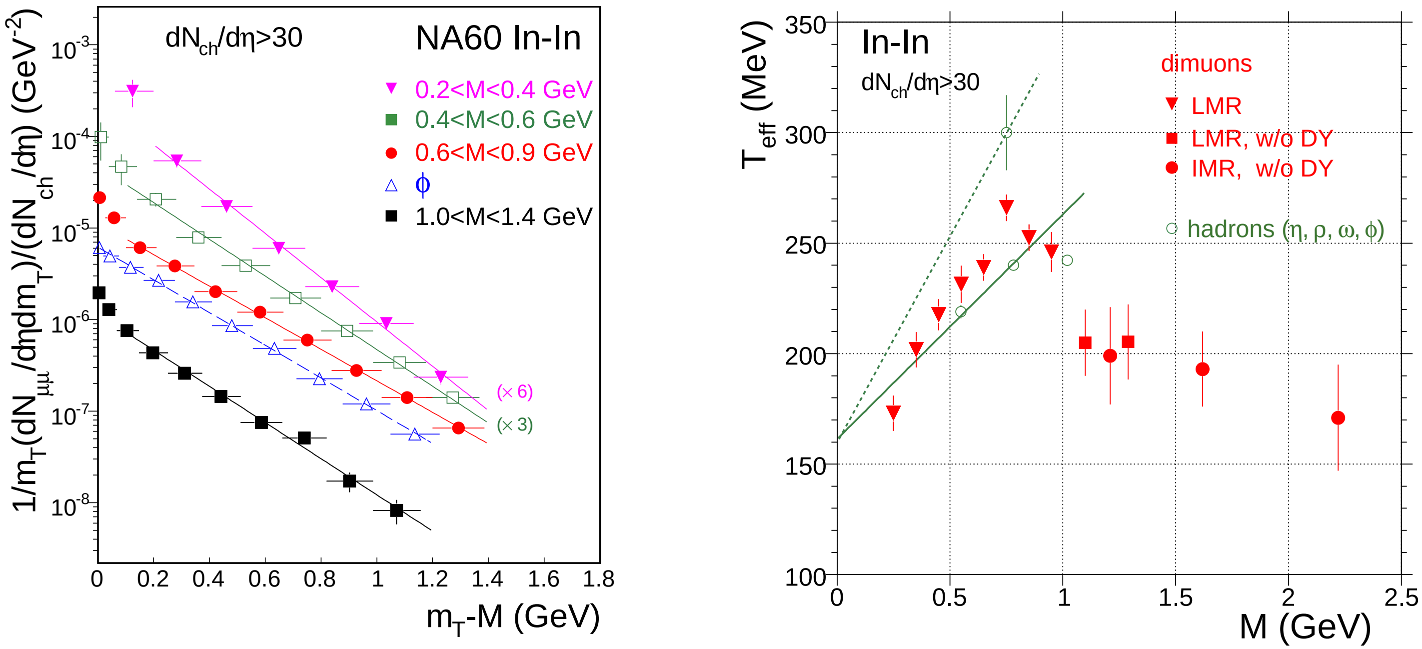

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Realistic transverse dynamics mandatory

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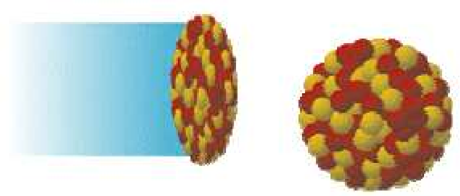
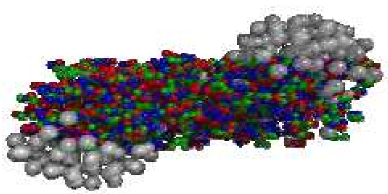
- **Getting ready for FAIR** (in the spirit of HIC for FAIR)

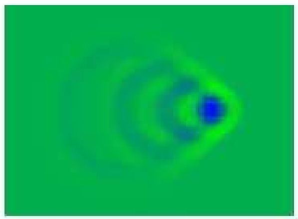
A hybrid model for the dynamics of the HIC

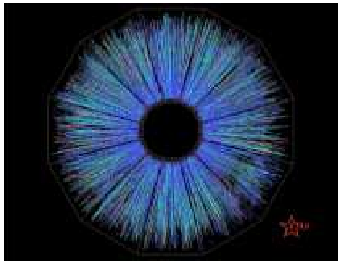
UrQMD $\rightarrow$ SHASTA $\rightarrow$ UrQMD

Embeds a 3+1 ideal hydrodynamical evolution for the hot and dense stage of the reaction. Hydrodynamical grid is mapped into UrQMD according to Cooper-Frye prescription
`[H.Petersen et al.,`**`PRC78`**`(2008)044901]`









Non-equilibrium initial condition via UrQMD

Hydrodynamics (or transport) evolution

Final decoupling via hadronic cascade (UrQMD)

Now available as UrQMD version 3.3. Visit **http://urqmd.org/**

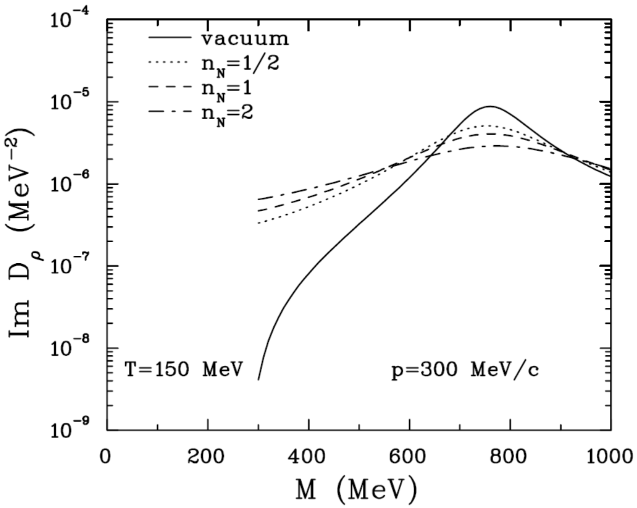
Emission rates – in-medium ρ (LMR)

- $\rho^* \to ll$

$$\frac{d^8 N_{\rho^* \to ll}}{d^4x d^4q} = -\frac{\alpha^2 m_\rho^4}{\pi^3 g_\rho^2} \frac{L(M^2)}{M^2} f_B(q_0;T) \mathrm{Im}\, D_\rho(M,q;T,\mu_B)$$

$$D_\rho(M,q;T,\mu_B) = \left[M^2 - m_\rho^2 - \Sigma_\rho(M,q;T,\mu_B)\right]^{-1}$$

Spectral density for the ρ meson in a heat bath of N and π re-derived from Eletsky,et al.**PRC64** (2001) 035202] and tabelled



- Authors give $f_{\rho a}$ as free to download*
  $\Rightarrow$ close the loop $\Rightarrow \Sigma_\rho$

$$\Sigma_{\rho a}(p) = -\frac{m_\rho m_a T}{\pi p} \int_{m_a}^{\infty} d\omega \ln\left[\frac{1-\exp(-\omega_+/T)}{1-\exp(-\omega_-/T)}\right] f_{\rho a}\left(\frac{m_\rho \omega}{m_a}\right)$$

*http://groups.physics.umn.edu/nucth/archive10.03/index.html

Emission rates – 4π and $q\bar{q}$ (IMR)

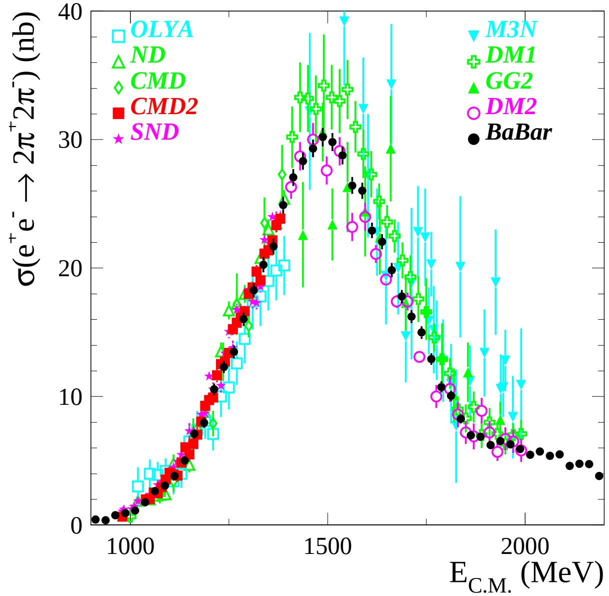
- $4\pi \to ll$ rate from the reverse process measured in e^+e^- annihilation

$$\frac{d^8 N_{4\pi\to ll}}{d^4x d^4q} = \frac{4\alpha^2}{(2\pi)^2} e^{-q_0/T} \frac{M^2}{16\pi^3\alpha^2} \sigma(e^+e^- \to 4\pi)$$

$\sigma(e^+e^- \to 4\pi)$ from BaBar data

$e^+e^- \to 2\pi^+2\pi^-$
[B.Aubert et al.,**PRD71**(2005),052001]

$e^+e^- \to \pi^+\pi^-2\pi^0$
[Druzhinin:2007cs]



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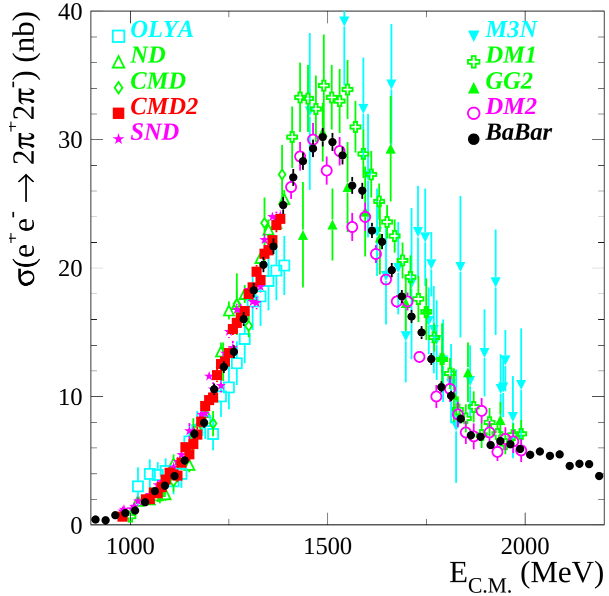

- $q\bar{q} \to ll$ in LO

[J.Cleymans,et al., **PRD35**(1987),2153]

$$\frac{dN_{q\bar{q}\to ll}}{d^4x d^4q} = \frac{\alpha^2}{4\pi^4} \frac{T}{q} f_B(q_0;T) \sum_q e_q^2 \ln \frac{(x_- + \exp[-(q_0+\mu_q)/T])\,(x_+ + \exp[-\mu_q/T])}{(x_+ + \exp[-(q_0+\mu_q)/T])\,(x_- + \exp[-\mu_q/T])}$$

EoS

[J.Steinheimer and S.Schramm, **JPG38**(2011)035001]

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- Obtained from coupling the Polyakov loop to a chiral hadronic flavor-SU(3) model, adding quark d.o.f.
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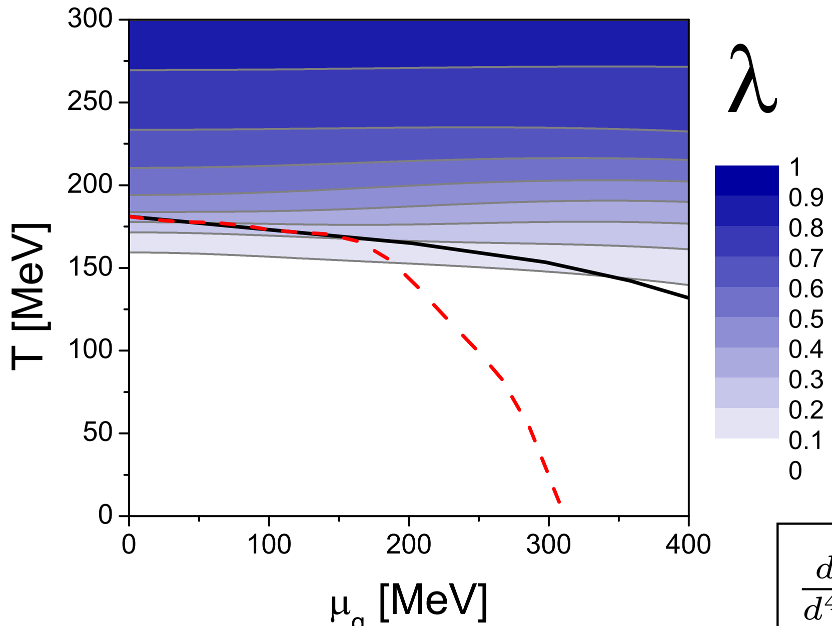


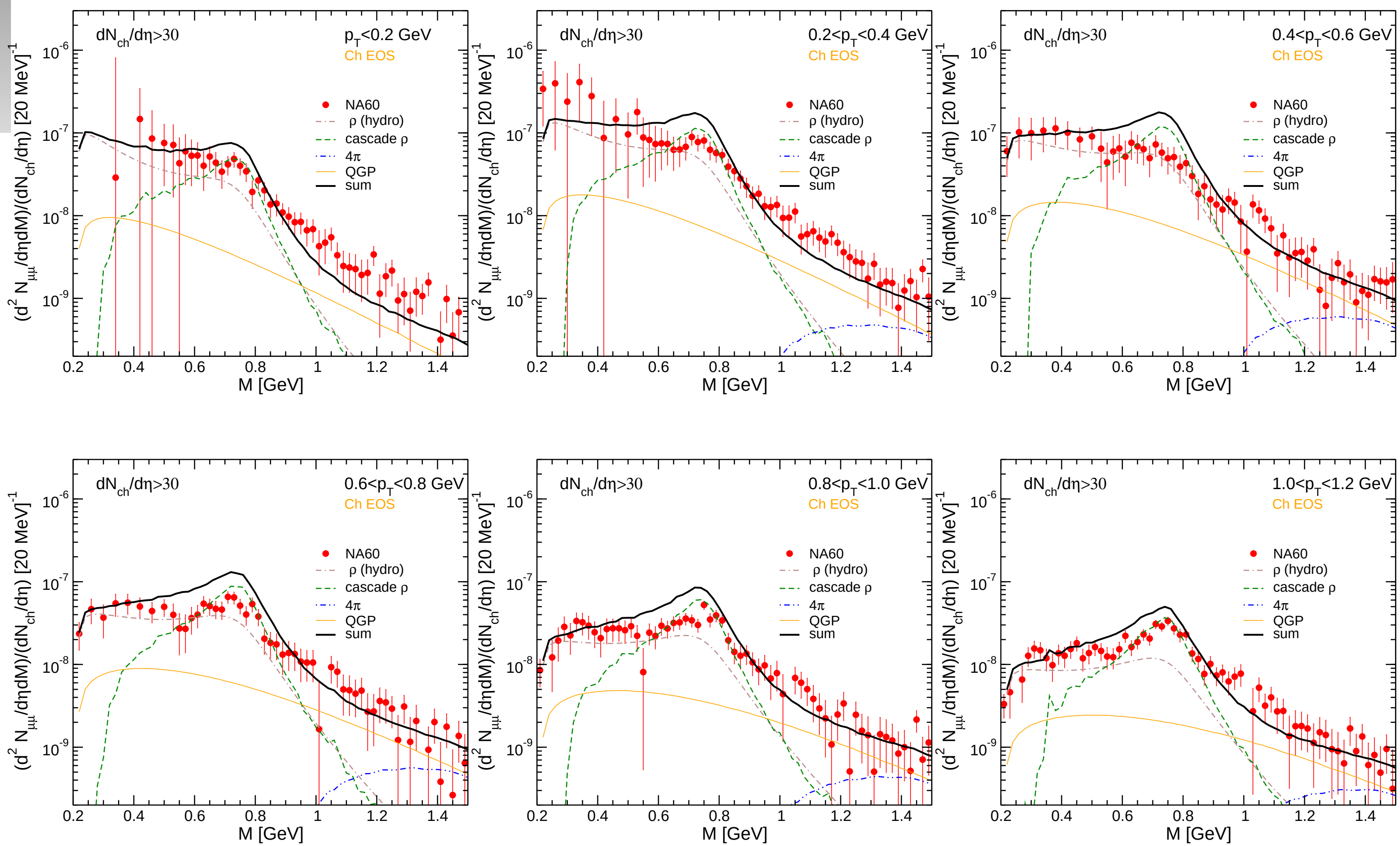
λ : **fraction of QGP**

- λ increases with increasing T
- large coexistence phase
- "weight" hadronic and QGP rates with λ

$$\frac{d^8 N_{ll}}{d^4x d^4q} = [1-\lambda]\left(\frac{d^8 N_{4\pi\to ll}}{d^4x d^4q} + \frac{d^8 N_{\rho\to ll}}{d^4x d^4q}\right) + \lambda \frac{dN_{q\bar{q}\to ll}}{d^4x d^4q}$$

Comparison to NA60 – M spectra

- invariant mass spectra of the excess analysed for **12 p_T bins**



[E.S.,J.Steinheimer,M.Bleicher and S.Schramm, arXiv:1102.4574]

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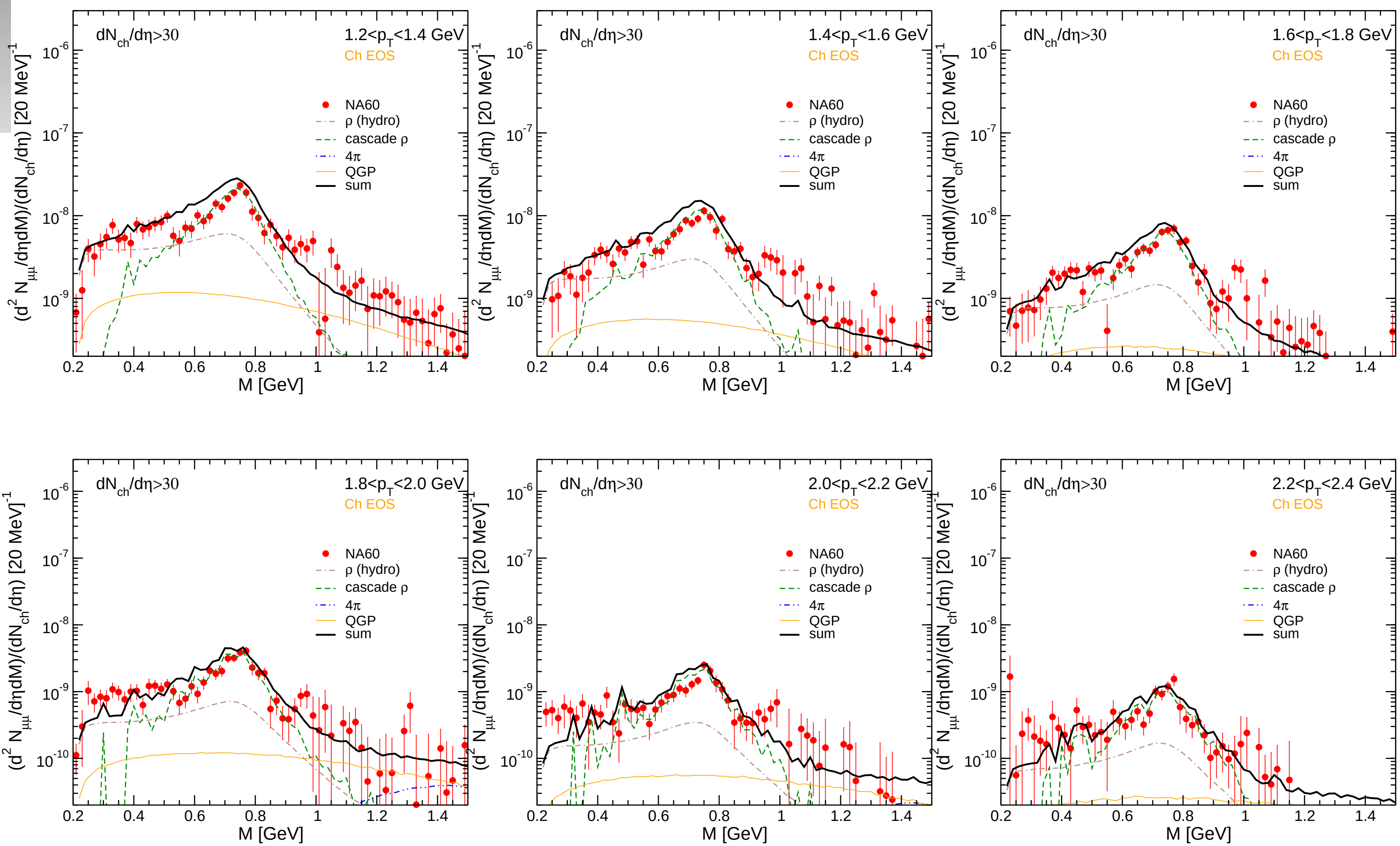

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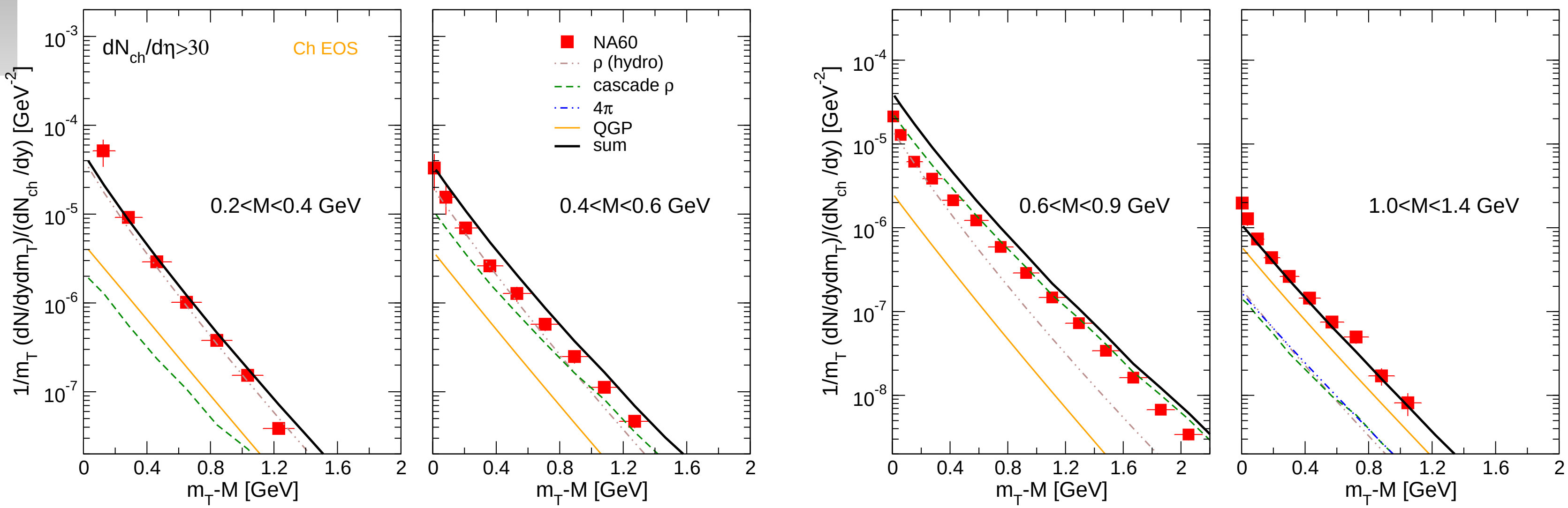
- $M > 1$ GeV
  - emission from QGP accounts for about half of the yield
  - reasonable p_T scaling

Comparison to NA60 – m_T spectra

- transverse mass spectra of the excess analysed for **4 M bins**



- Hardest contribution from non-thermal sources
  (max coupling to flow at transition hydro$\rightarrow$UrQMD)
- agreement for 0.2<M<0.4 GeV and 1<M<1.4 GeV, discrepancies for 0.4<M<0.9 GeV

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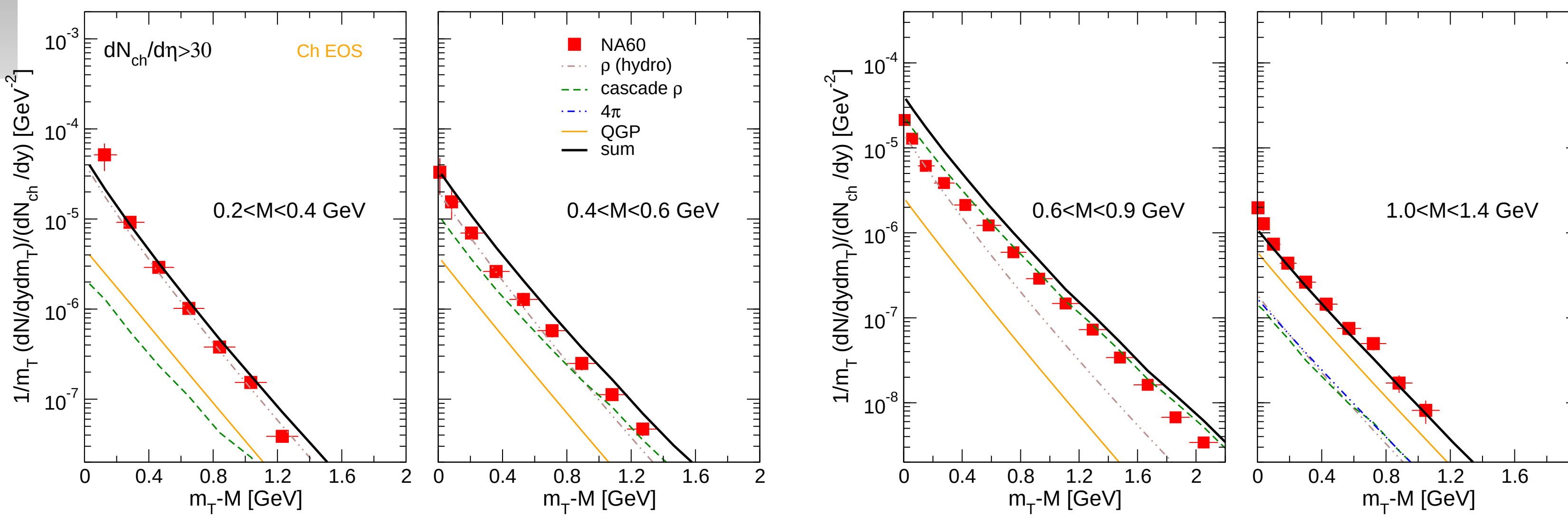

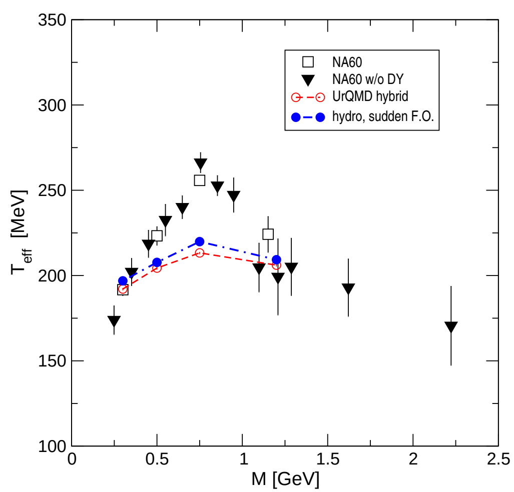

- increase of T_{eff} up to m_ρ followed by drop found qualitatively
- T_{eff} underestimated in $0.4 < M < 0.9$ GeV

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Thanks to: J.Steinheimer and S. Schramm (EoS), D.Rischke (hydro code), B.Bäuchle, G.Gräf, T.Lang, M.Mitrovski, M.Nahrang, H.Petersen

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Thanks for your attention!

BACKUP

Our next step

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- MC routine already written up. First full-run perfomed with success.

SHASTA is shining the in-medium e.m. correlator!!

In-medium scenarios

- 'dropping' mass scenario

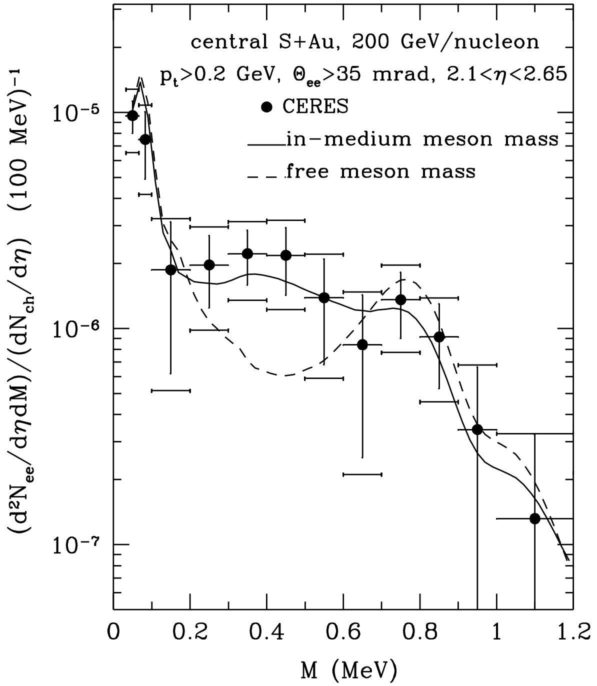
Effective Lagrangian+mean field:

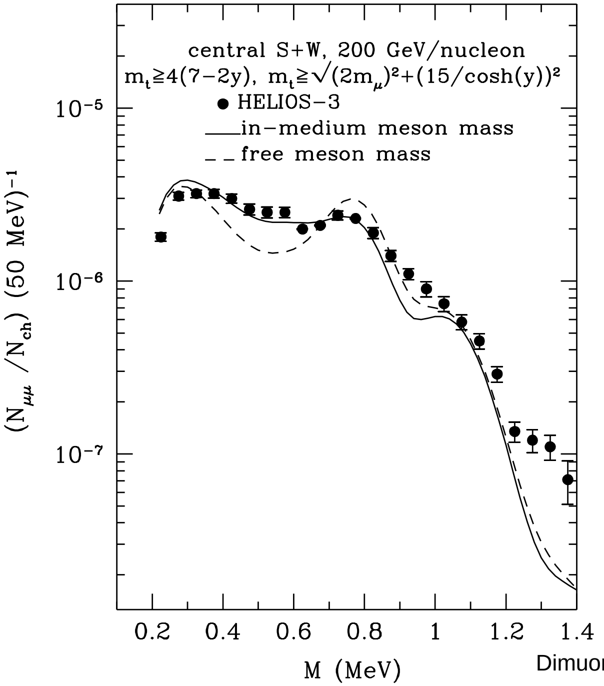
[Brown,Rho,**PRL66** (1991) 2720]

$$\frac{m_V^\star}{m_V} = \frac{m_N^\star}{m_N} = \frac{f_\pi^\star}{f_\pi} \sim 0.8 \text{ at } \rho_0$$

QCD sum rules:
[Hatsuda,Lee, **PRC46** (1992) R34]

$$\frac{m_V^\star}{m_V} = 1 - \alpha\frac{\rho_B}{\rho_0} \quad \alpha \sim 0.16 \pm 0.06$$





G.Q.Li,C.M.Ko,
G.E.Brown,H.Sorge,
NPA611 (1996) 539