Dileptons in Heavy-Ion Collisions

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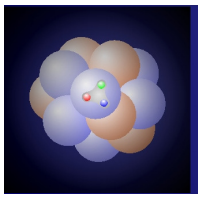

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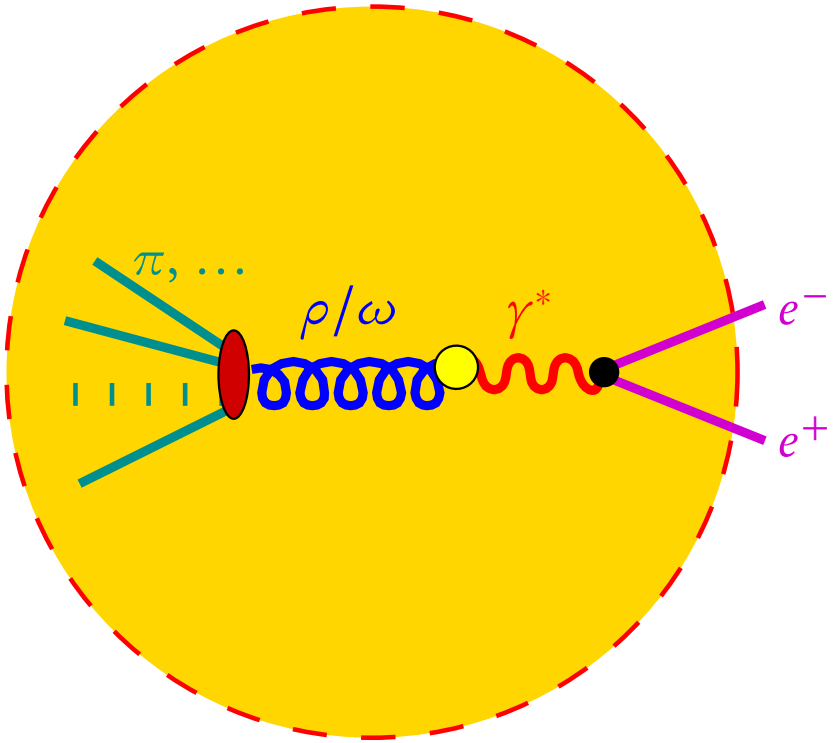
Electromagnetic probes in heavy-ion collisions

- $\gamma, \ell^{\pm}$: no strong interactions
- reflect whole "history" of collision:
  - from pre-equilibrium phase
  - from thermalized medium
    QGP and hot hadron gas
  - from VM decays after thermal freezeout



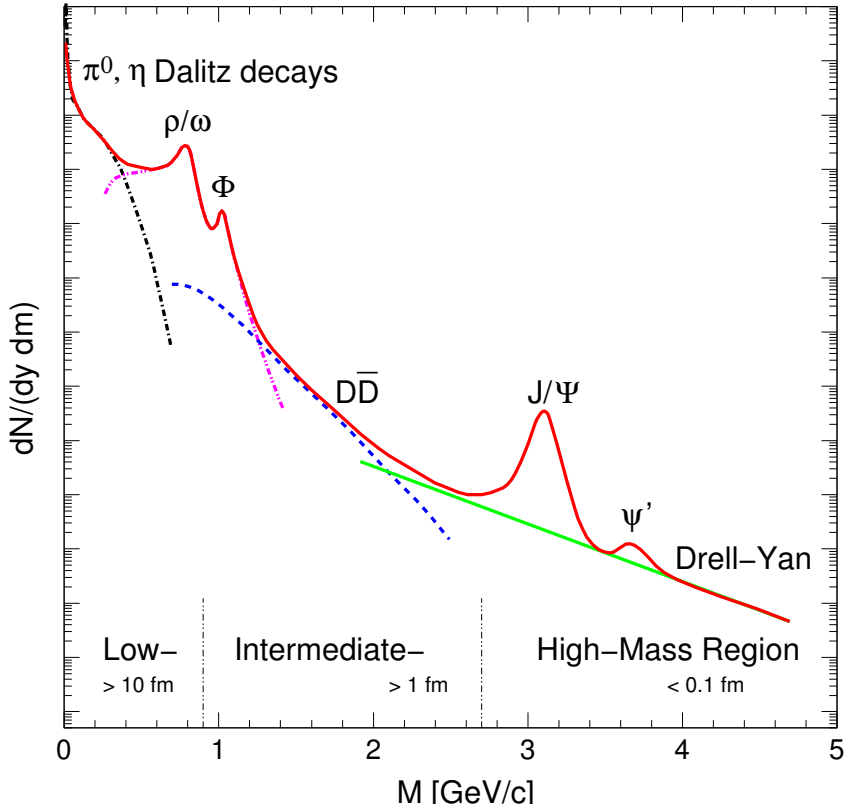


Fig. by A. Drees

Vector Mesons and electromagnetic Probes

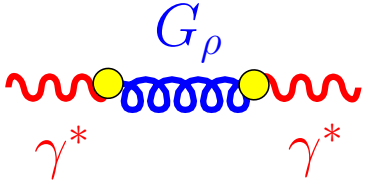
- $\ell^+\ell^-$ thermal emission rates $\Leftrightarrow$ em. current-correlation function, $\Pi_{\mu\nu}$

  [L. McLerran, T. Toimela 85, H. A. Weldon 90, C. Gale, J.I. Kapusta 91]

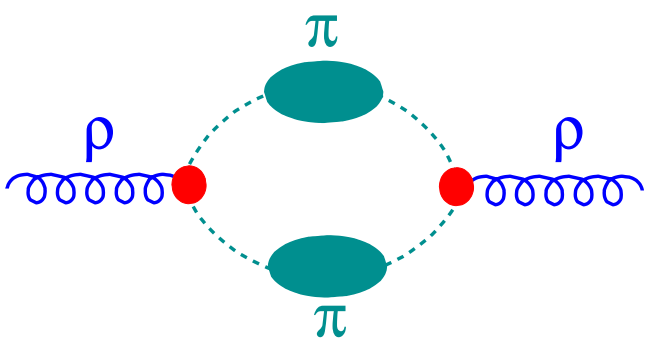
$$\frac{\mathrm{d}N_{e^+e^-}}{\mathrm{d}^4x\mathrm{d}^4q} = -g^{\mu\nu}\frac{\alpha^2}{3q^2\pi^3}\,\mathrm{Im}\,\Pi^{(\mathrm{ret})}_{\mu\nu}(q)\Big|_{q^2=M^2_{e^+e^-}} f_B(q_0)$$

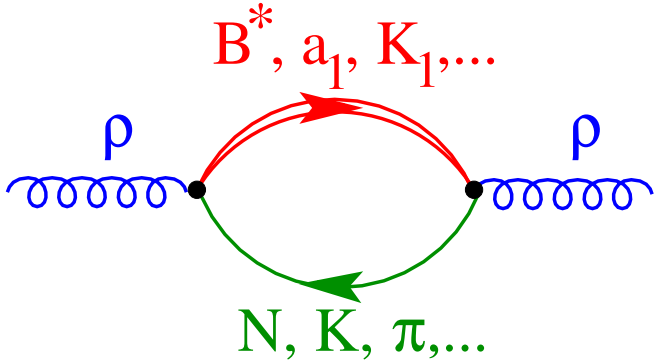
- vector-meson dominance model:

$$\Pi_{\mu\nu} =$$

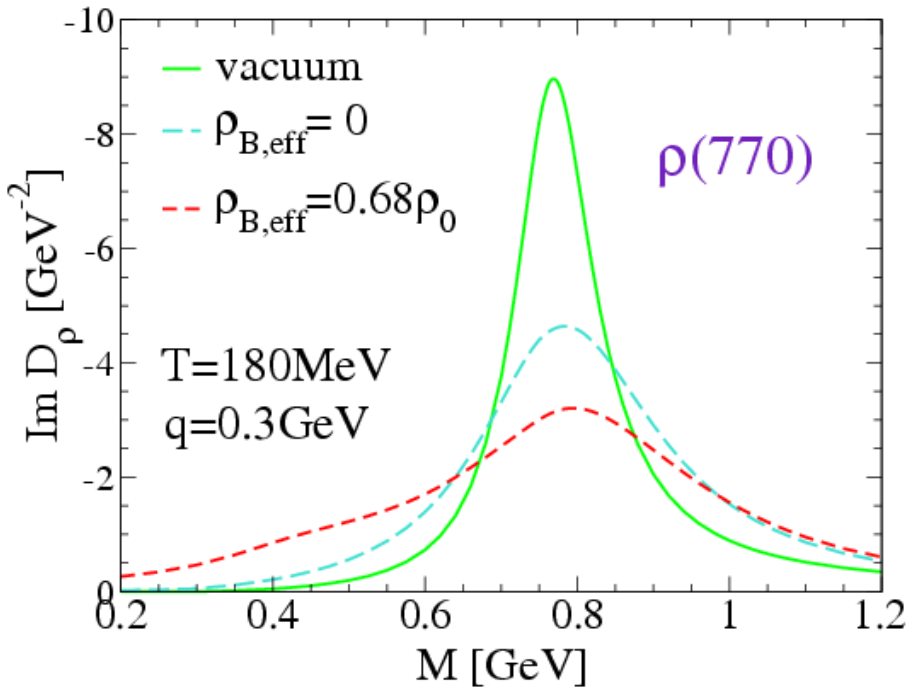


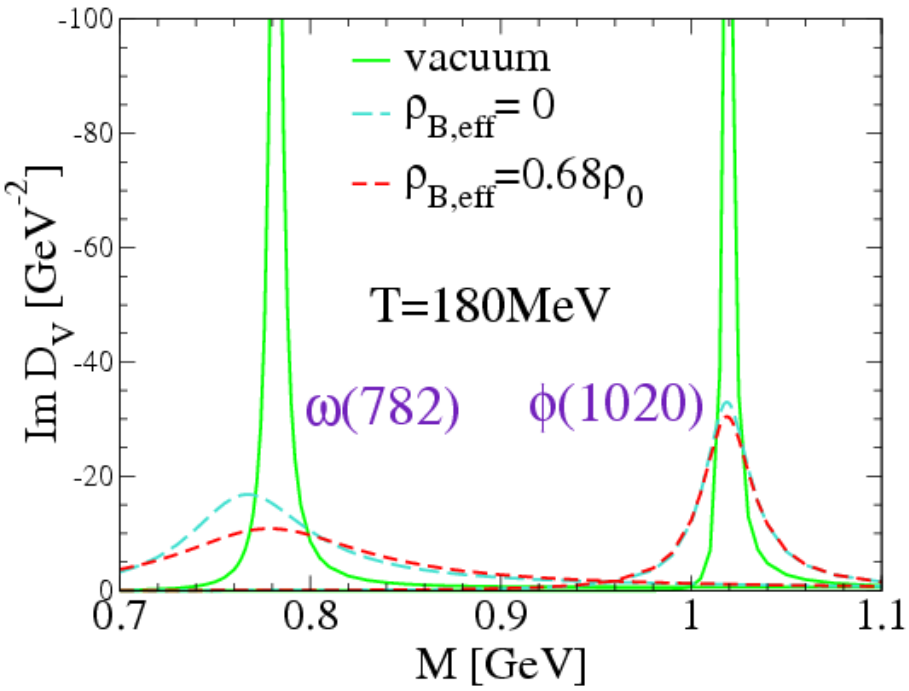
- hadronic many-body theory for vector mesons





In-medium spectral functions and baryon effects

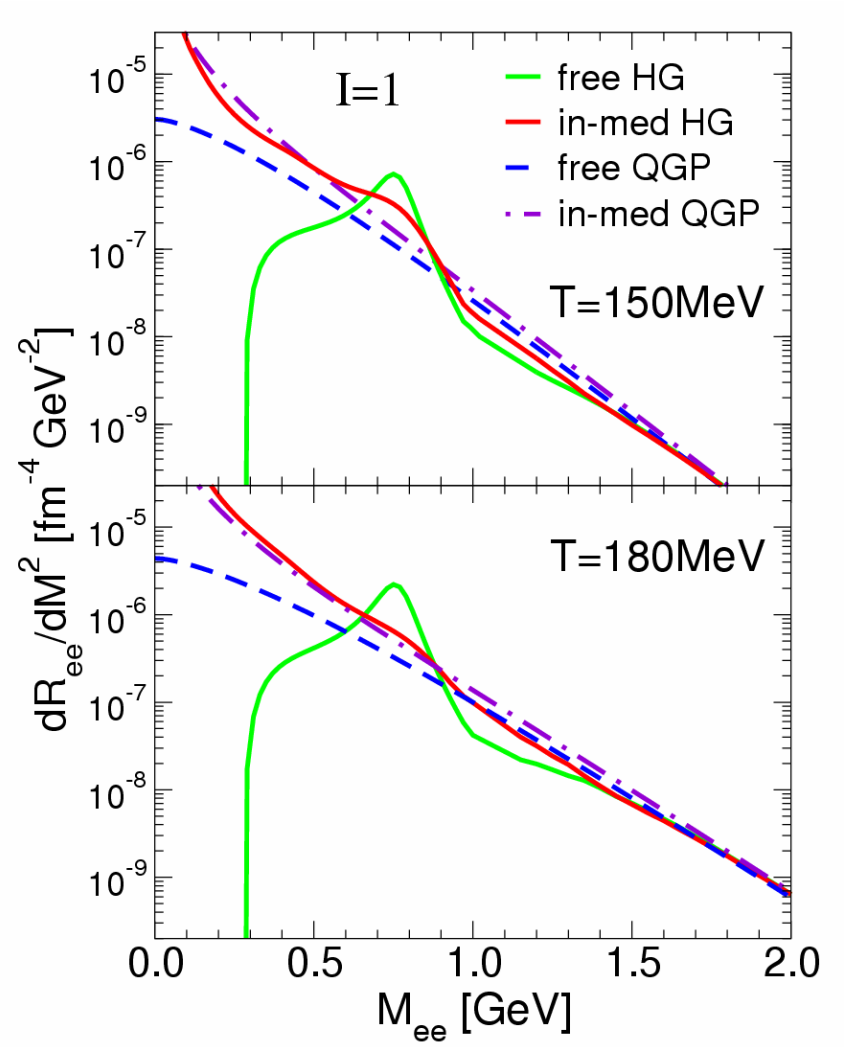




[R. Rapp, J. Wambach 99]

- baryon effects important
  - large contribution to peak broadening
  - responsible for most of the yield at small M
  - reason: not net-baryon density $n_B - n_{\bar{B}}$ but total baryon density $n_B + n_{\bar{B}}$ relevant!

Dilepton rates: Hadron gas $\leftrightarrow$ QGP



- in-medium hadron gas matches with QGP
- similar results also for γ rates
- "quark-hadron duality"!?
- consistent with chiral-symmetry restoration
- "resonance melting" rather than "dropping masses"

Sources of dilepton emission in heavy-ion collisions

1. initial hard processes: Drell Yan
2. "core" $\Leftrightarrow$ emission from thermal source [McLerran, Toimela 1985]

$$\frac{1}{q_T}\frac{\mathrm{d}N^{(\text{thermal})}}{\mathrm{d}M\mathrm{d}q_T} = \int \mathrm{d}^4x \int \mathrm{d}y \int M\mathrm{d}\varphi \frac{\mathrm{d}N^{(\text{thermal})}}{\mathrm{d}^4x\mathrm{d}^4q}\mathrm{Acc}(M, q_T, y)$$

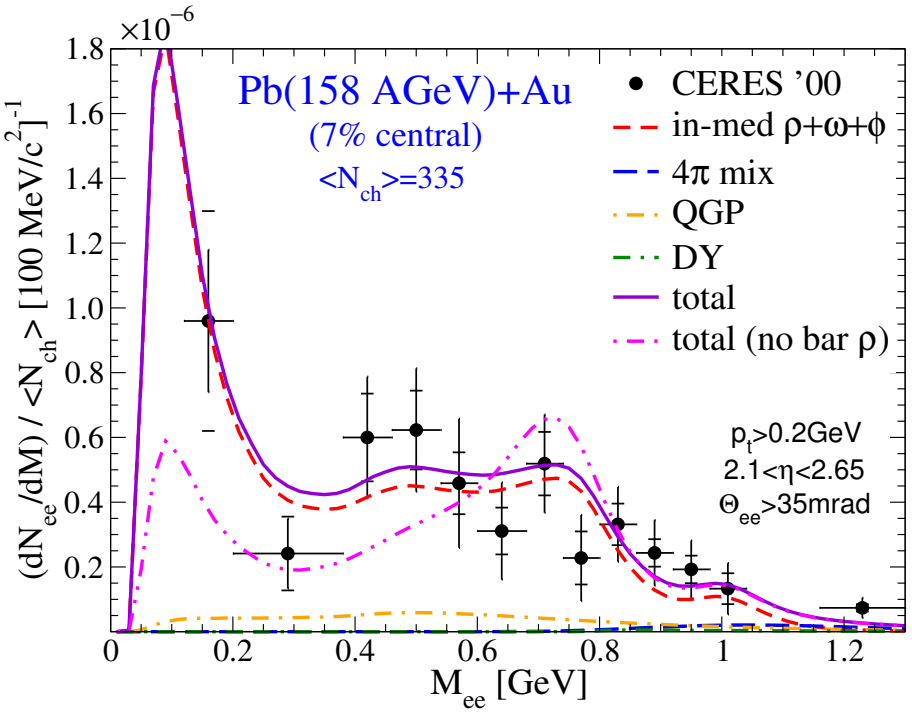
   use cylindrical thermal fireball with QGP, mixed and hadronic phase
3. "corona" $\Leftrightarrow$ emission from "primordial" mesons (jet-quenching)
4. after thermal freeze-out $\Leftrightarrow$ emission from "freeze-out" mesons

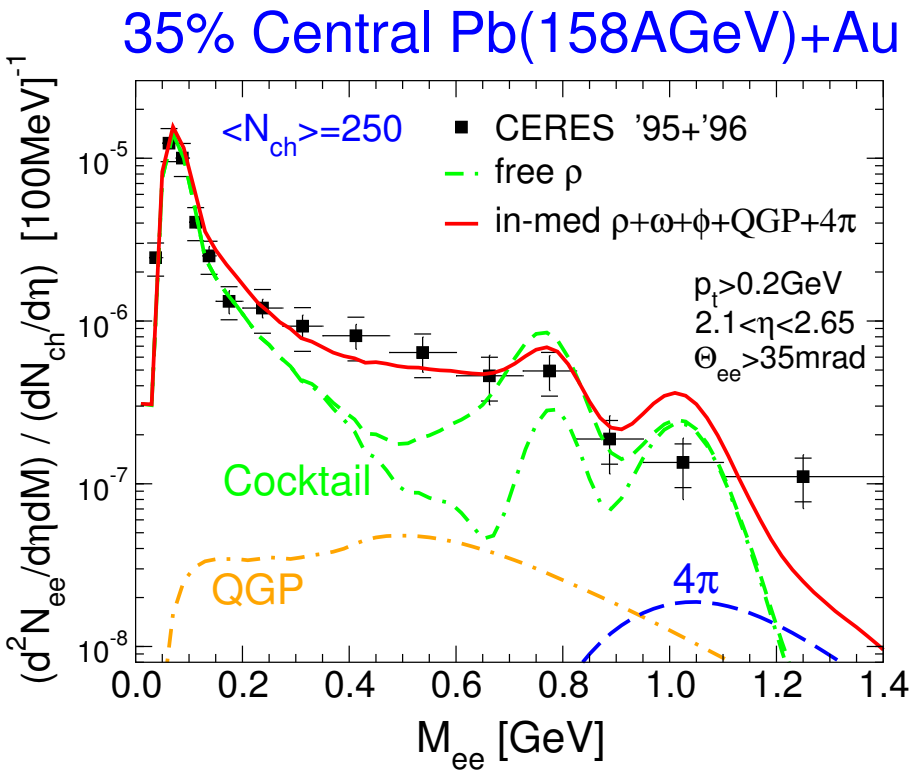
   [Cooper, Frye 1975]

$$N^{(\text{fo})} = \int \frac{\mathrm{d}^3q}{q_0} \int q_\mu \mathrm{d}\sigma^\mu f_B(u_\mu q^\mu/T) \frac{\Gamma_{\text{meson}\to\ell^+\ell^-}}{\Gamma_{\text{meson}}}\mathrm{Acc}$$

CERES/NA45 dielectron spectra

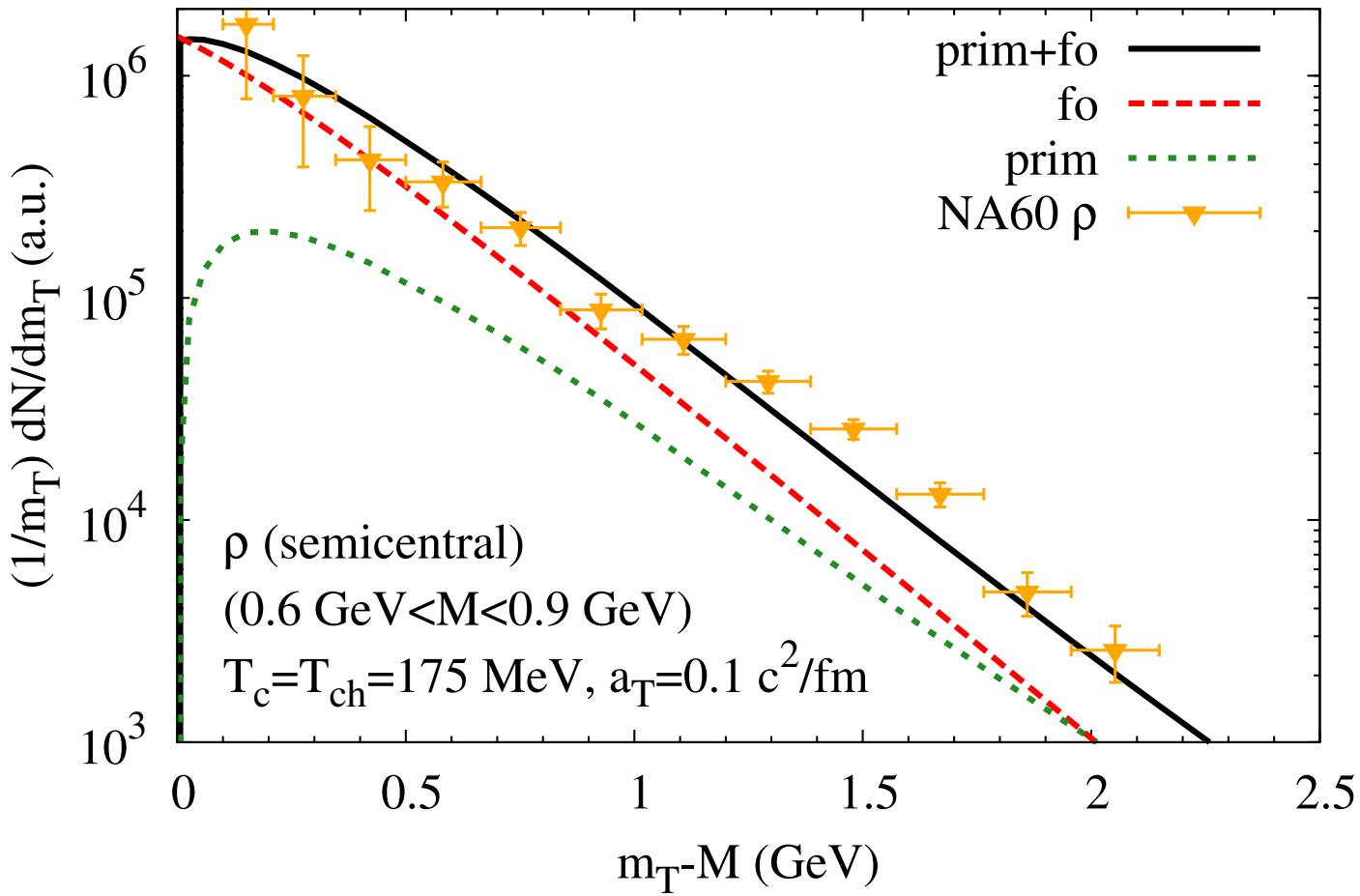
- good agreement also for dielectron spectra in $158\ \mathrm{GeV}$ Pb-Au
- low-mass tail from baryon effects





Hadron spectra

- NA60: Extracted hadronic p_T spectra from $\mu^+\mu^-$ "cocktail"
- analysis of "cocktail": hadron-m_T spectra
- comparison to fireball evolution $\Leftrightarrow$ fixes radial acceleration
- "sequential freeze-out" due to different coupling strength



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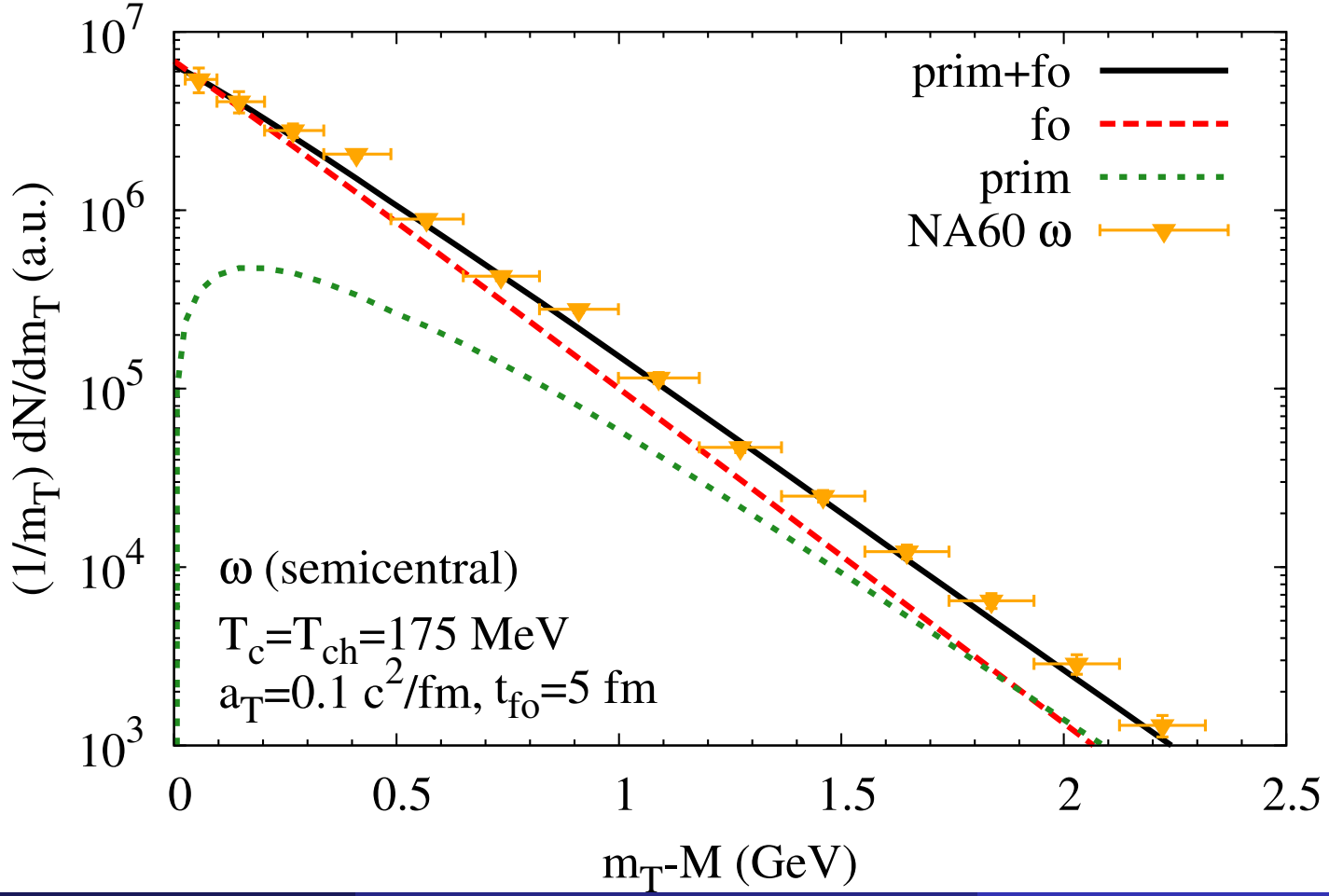

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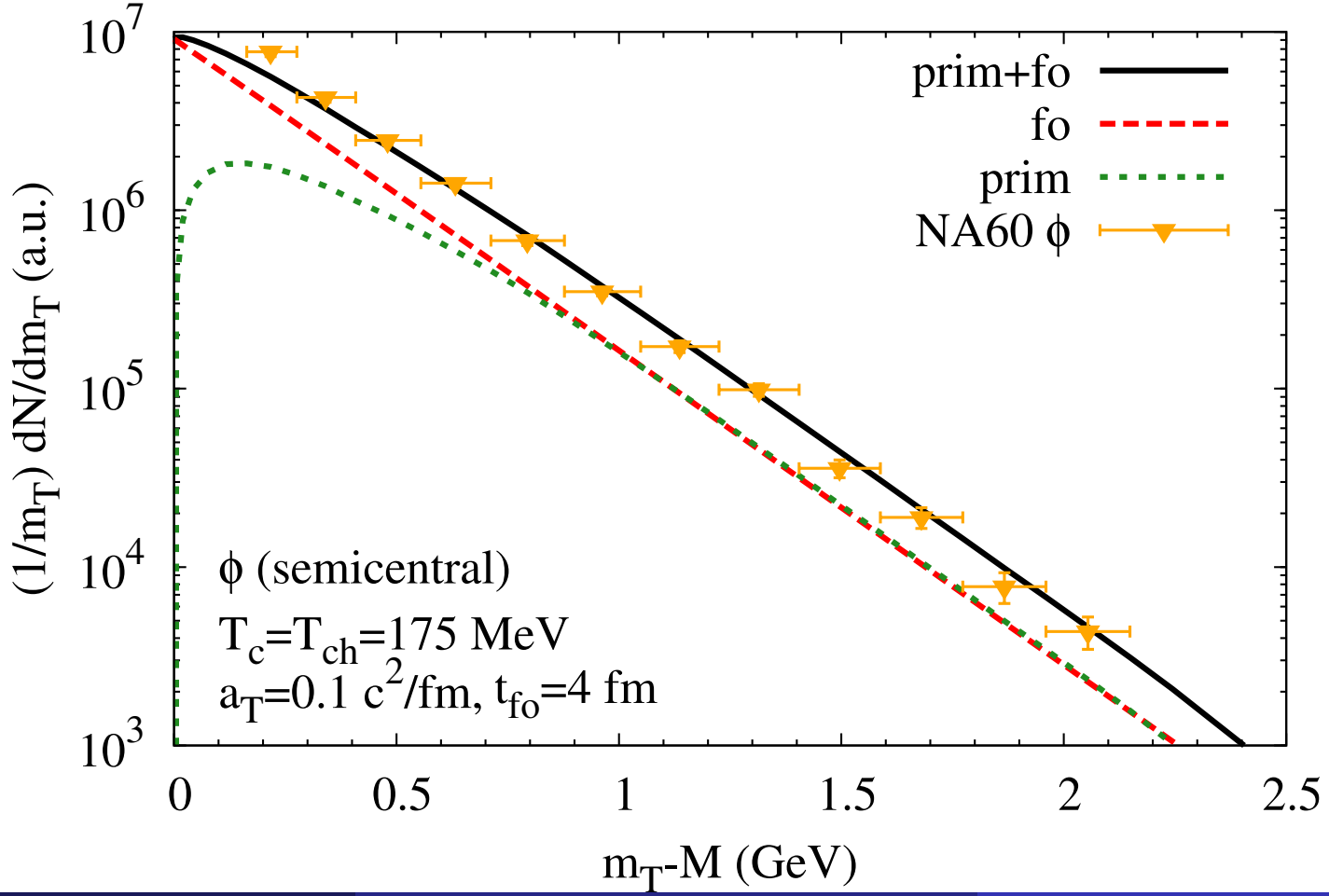
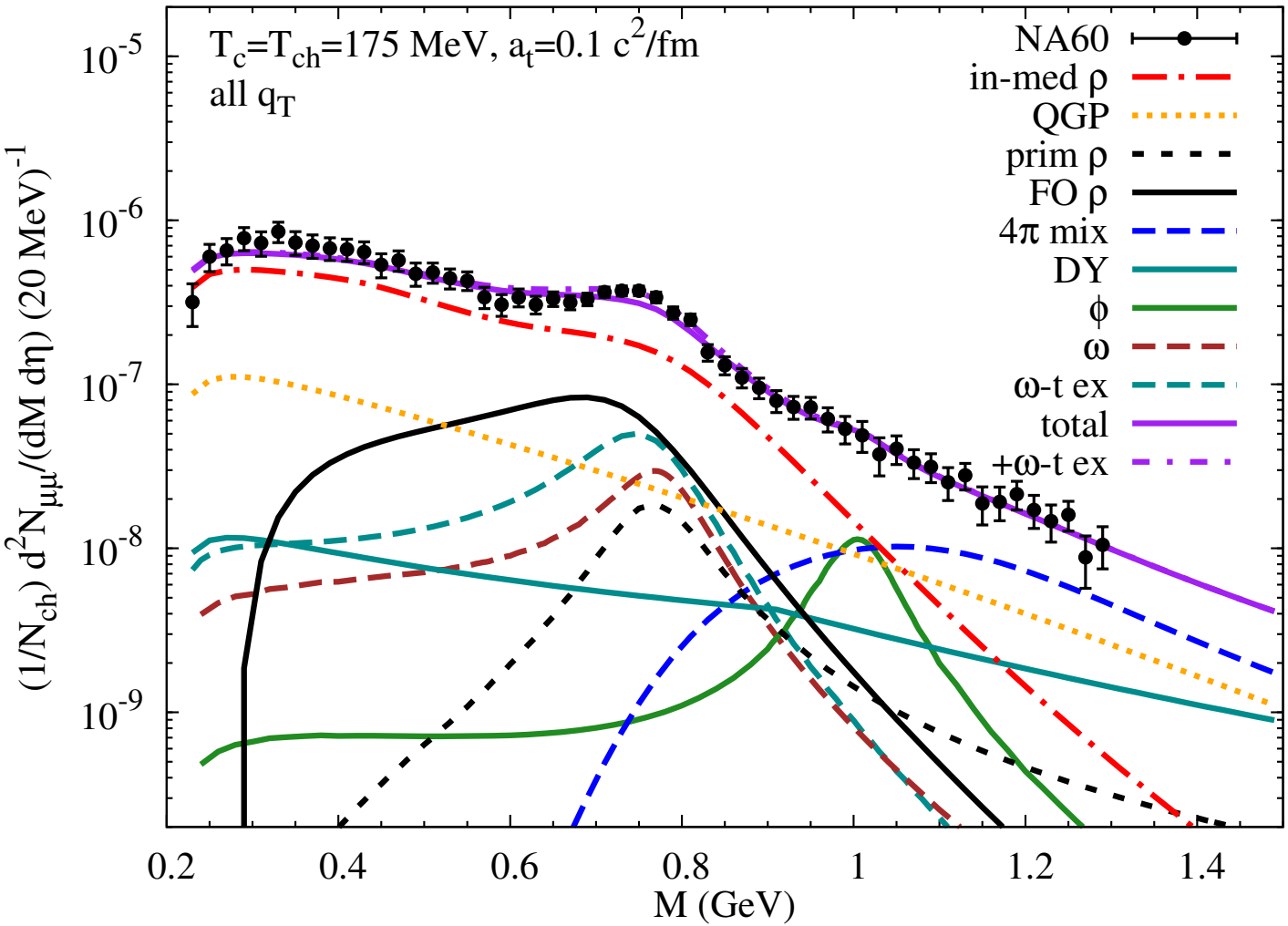


M spectra (in p_T slices)

- norm corrected by $\sim 3\%$ due to centrality correction (min-bias data: $\langle N_{\rm ch} \rangle = 120$, calculation $N_{\rm ch} = 140$)



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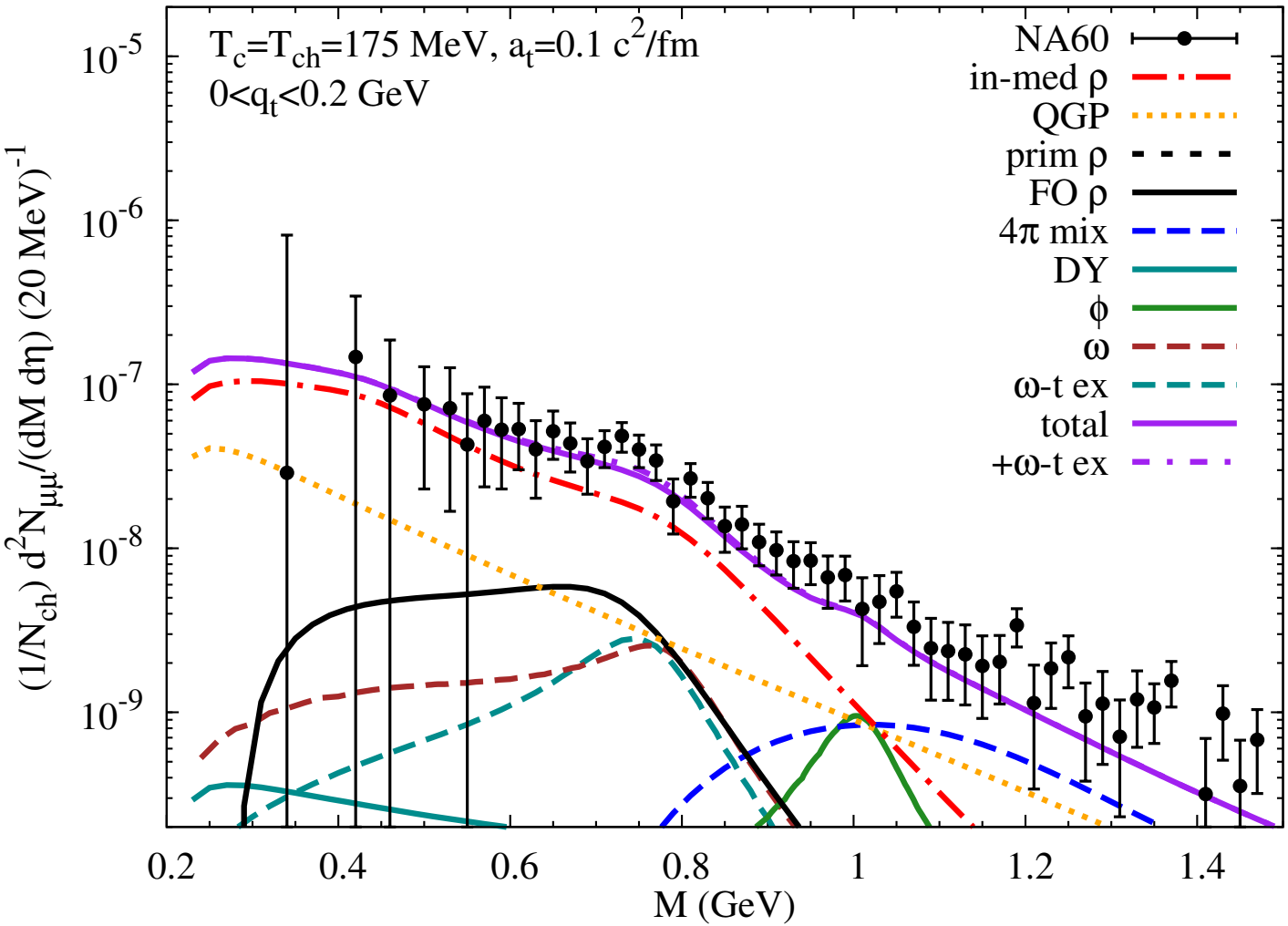

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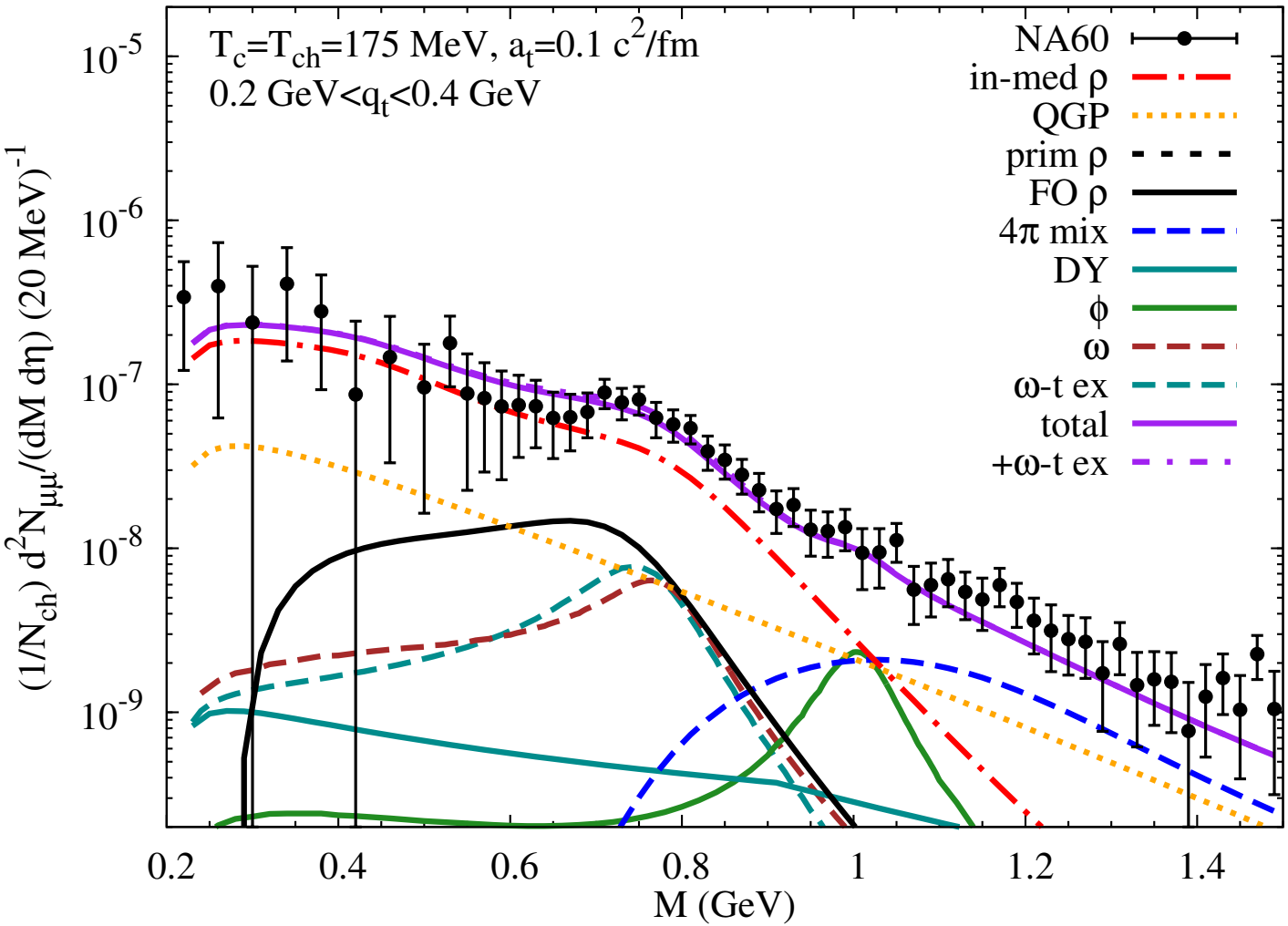

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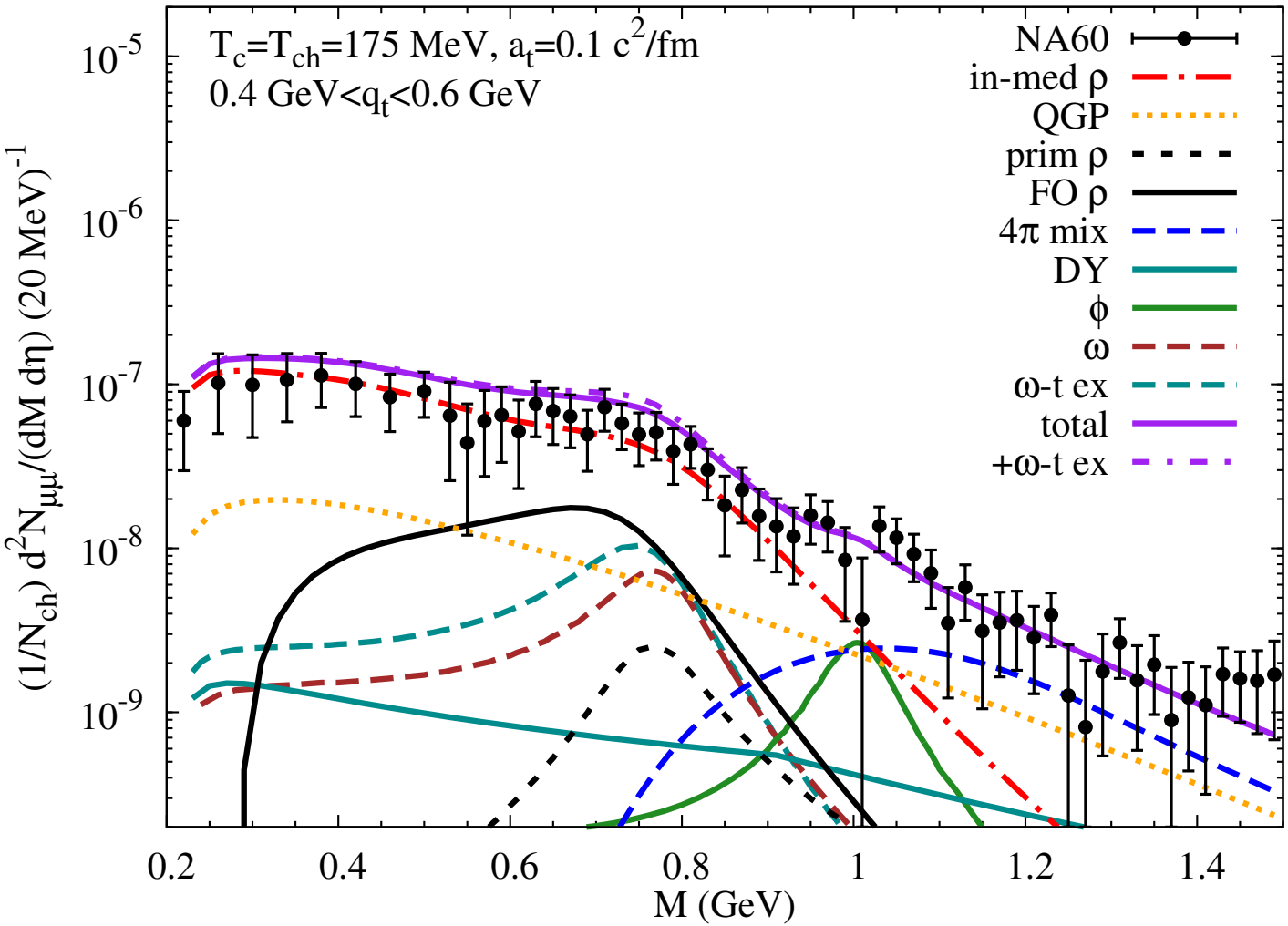

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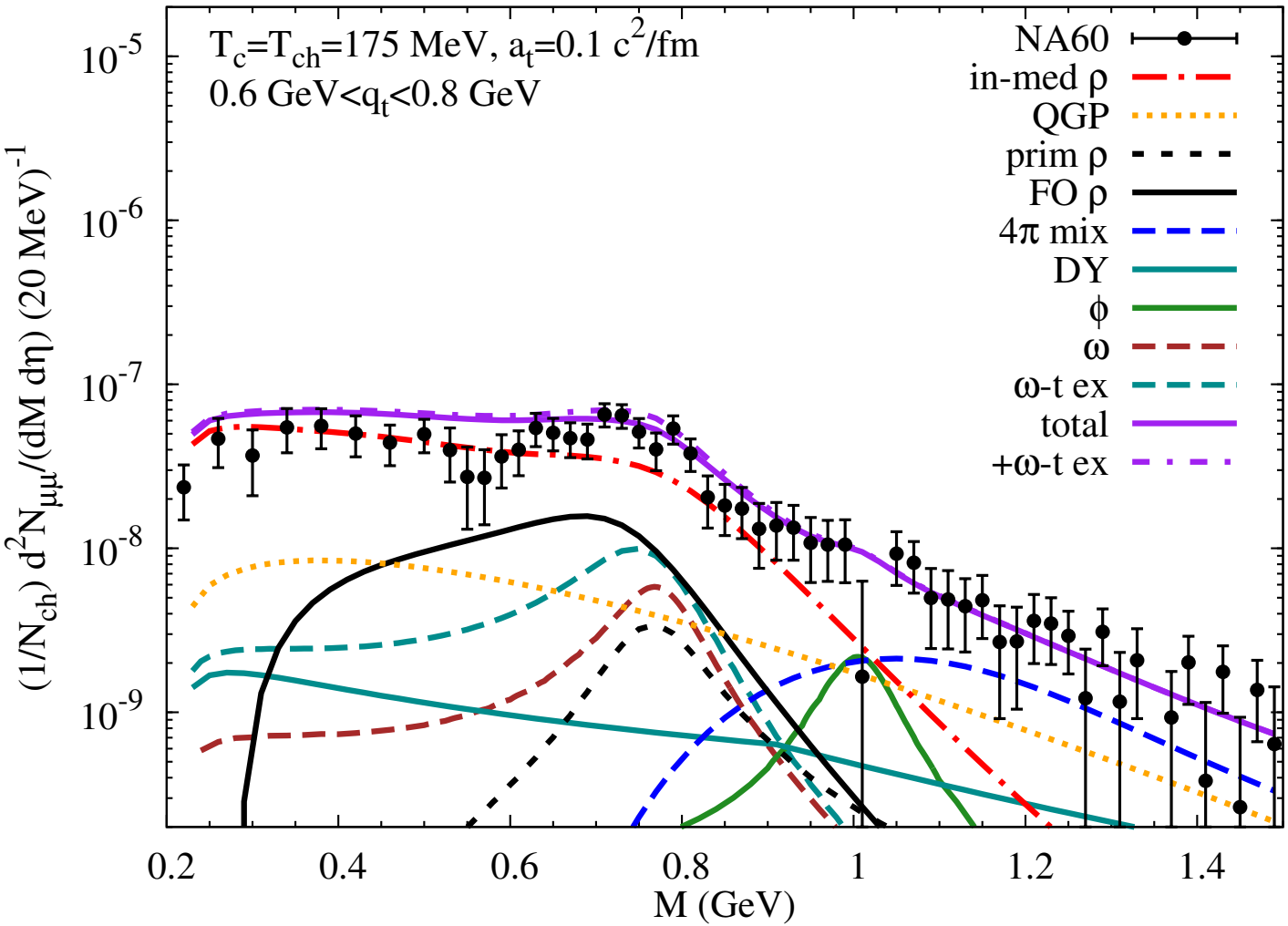

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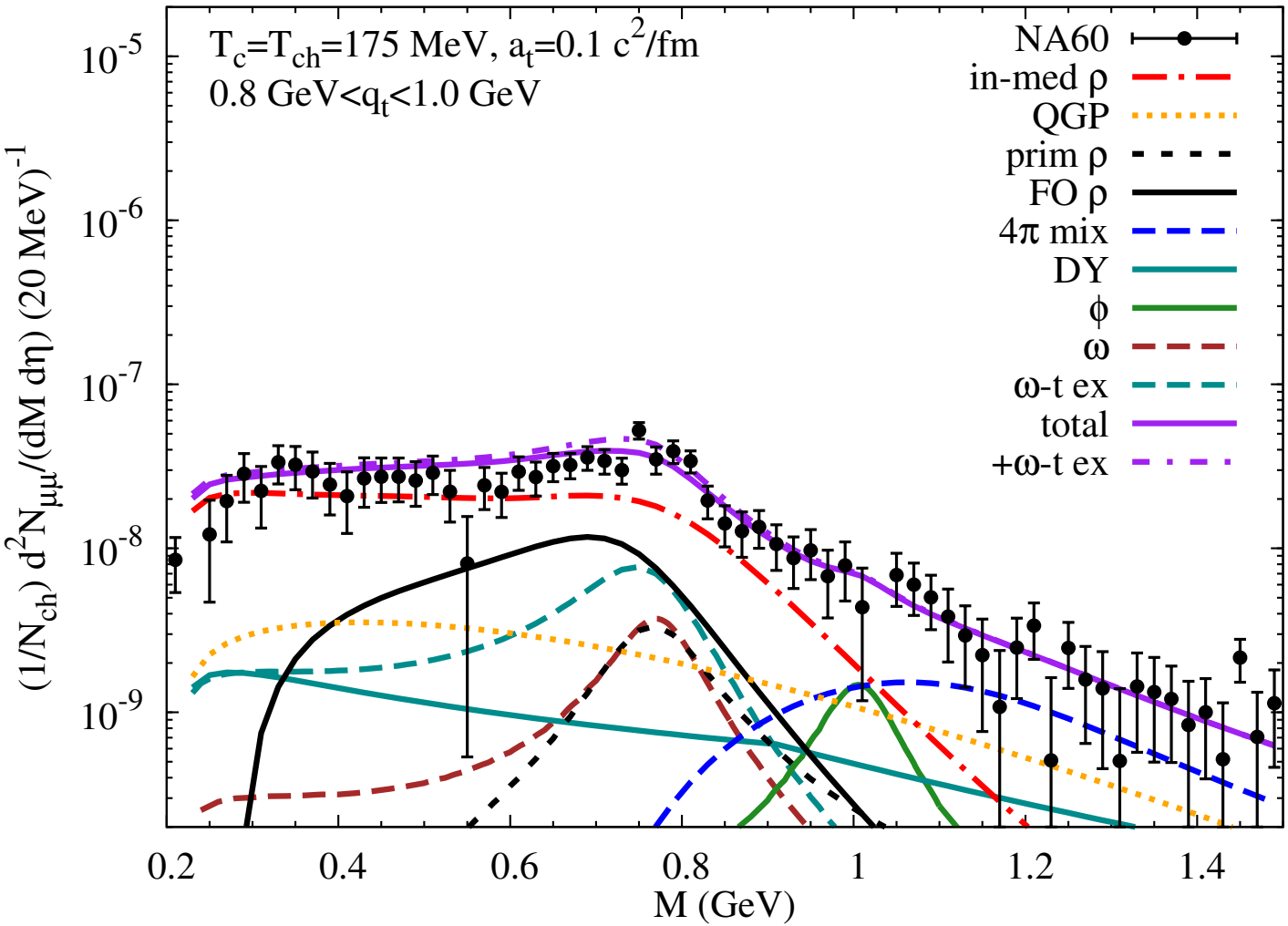

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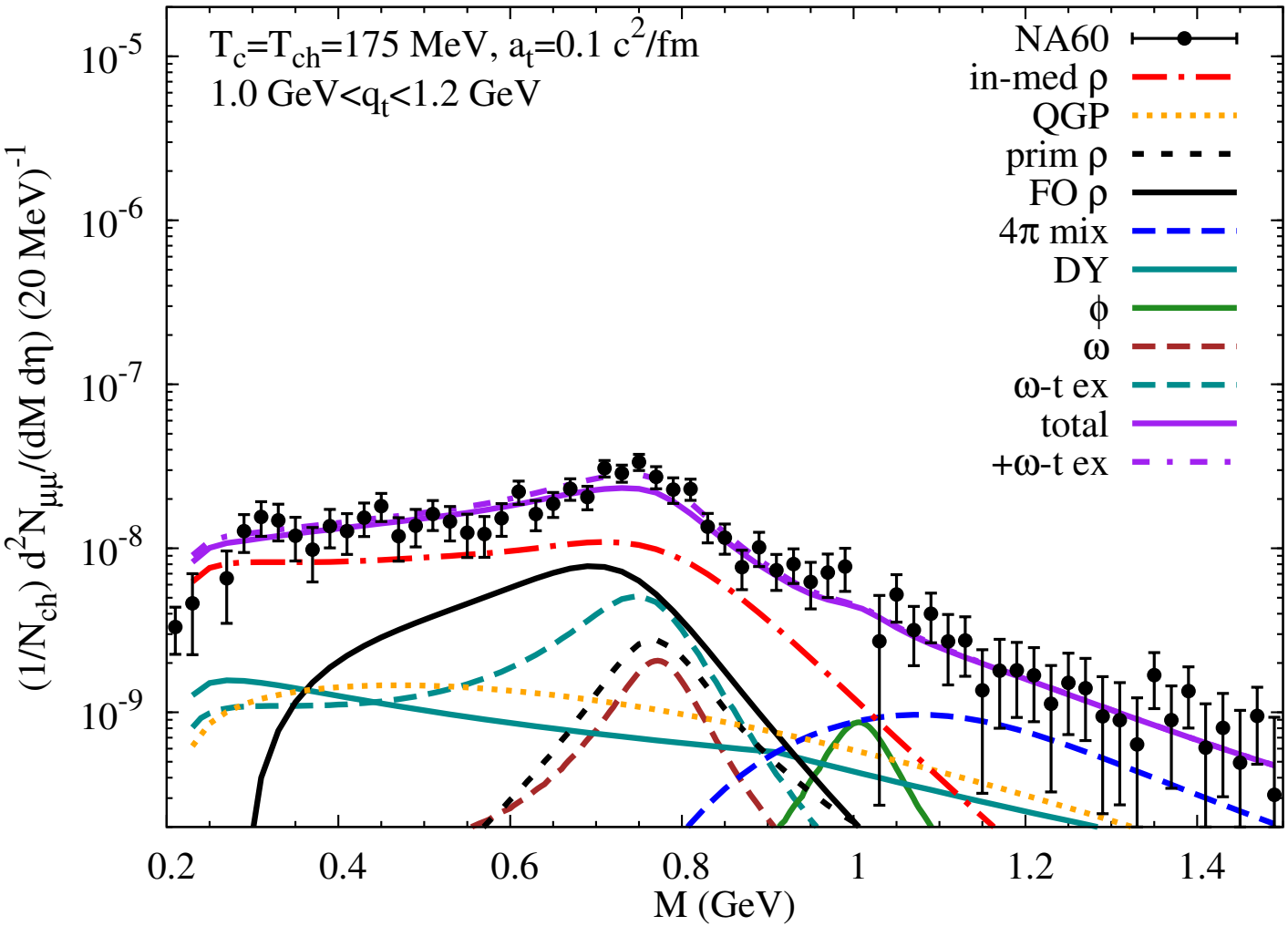

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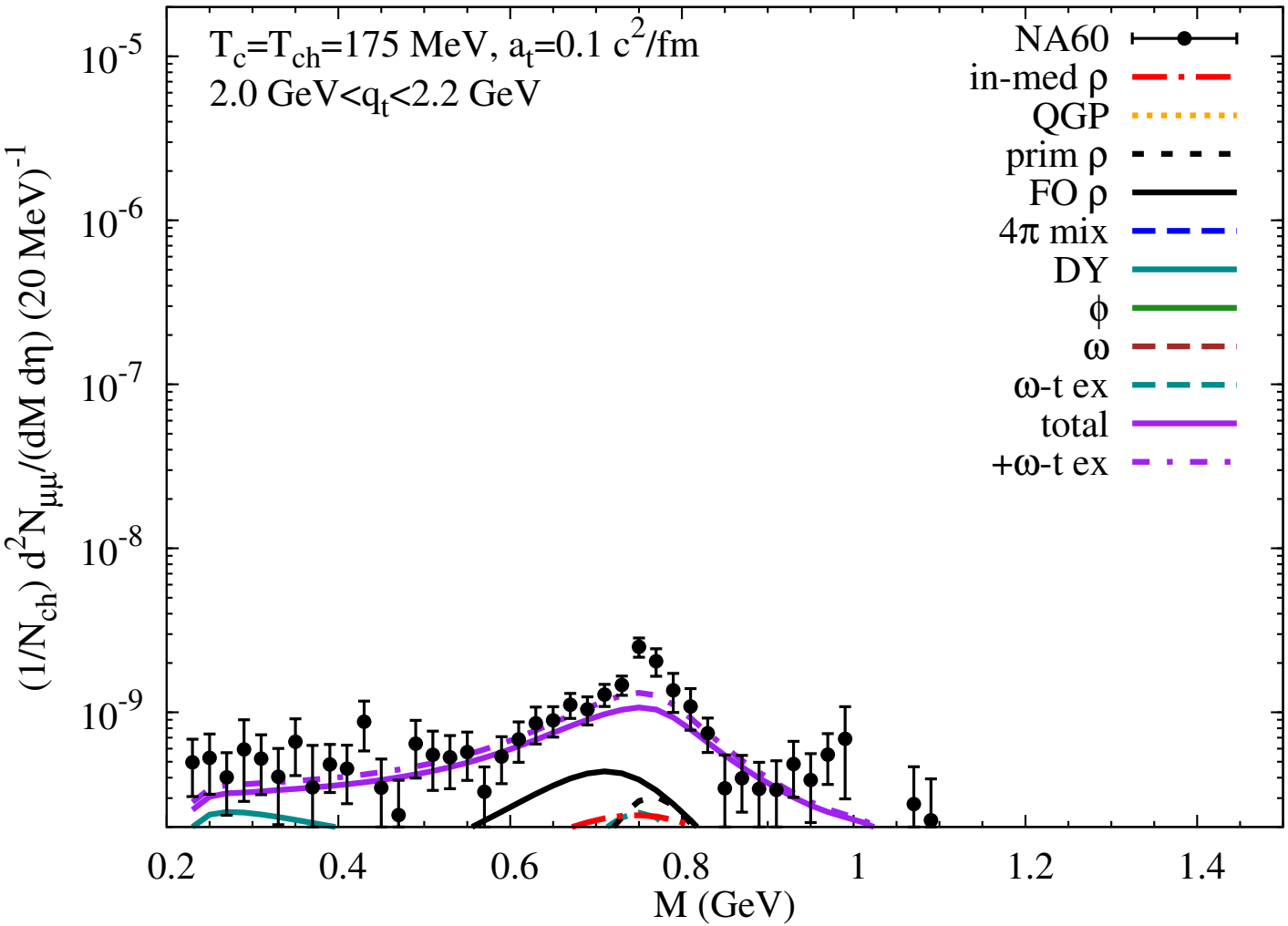

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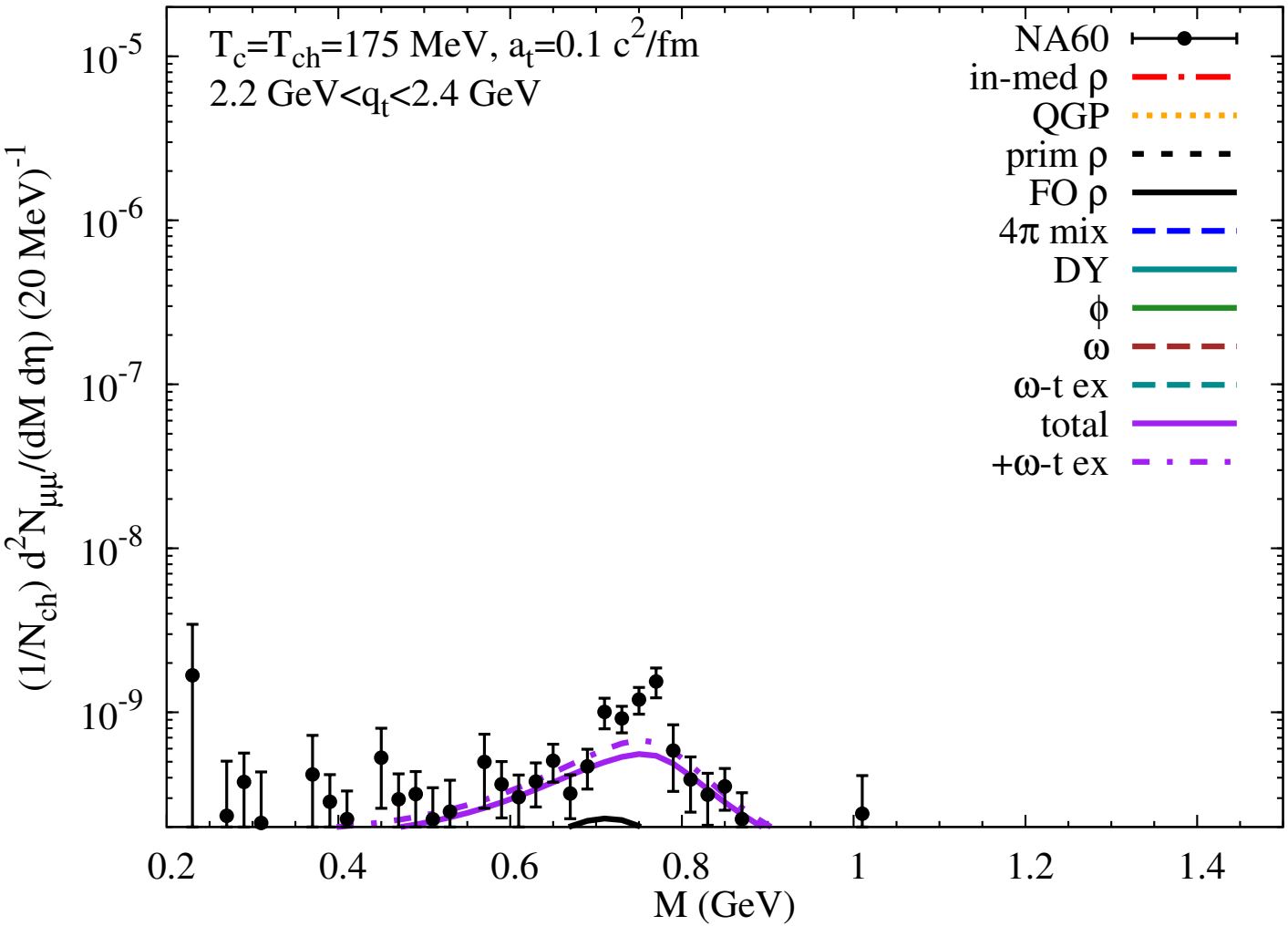
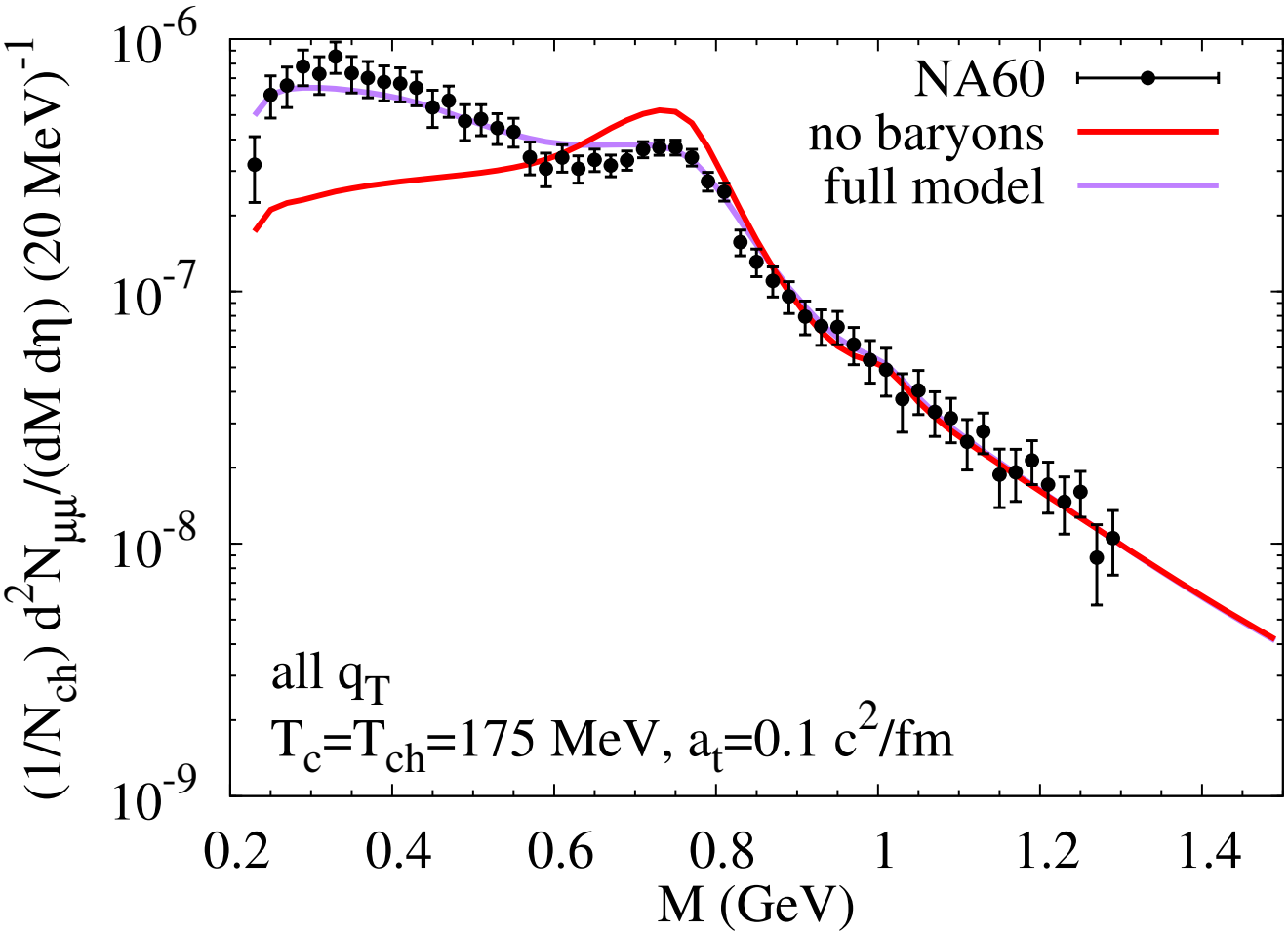
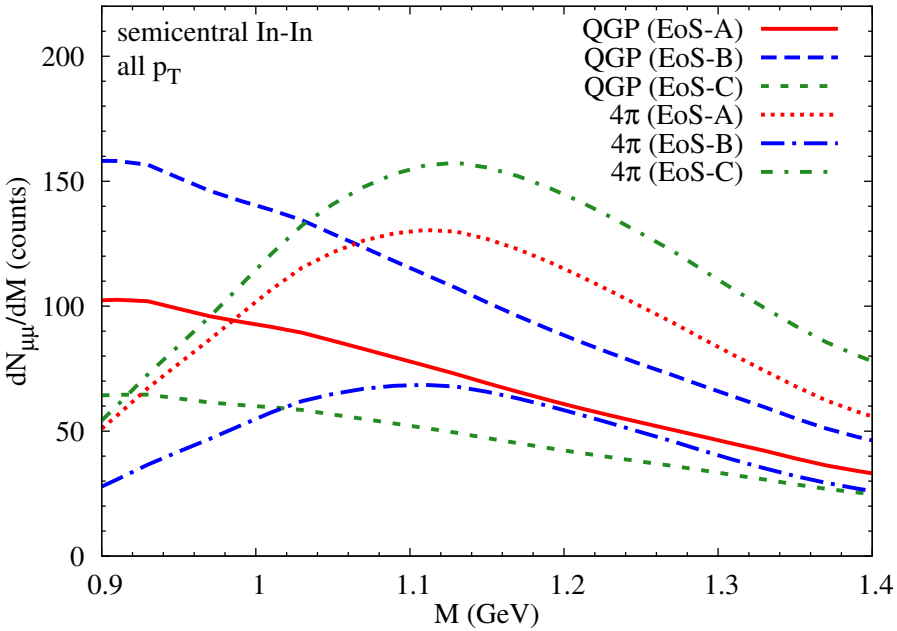


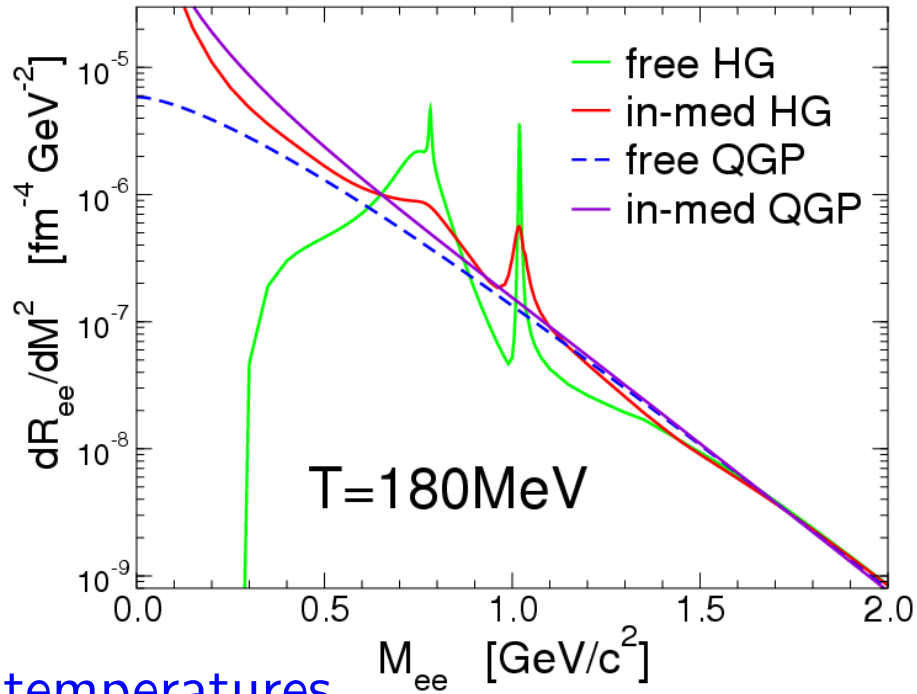
Importance of baryon effects

- baryonic interactions important!
- in-medium broadening
- low-mass tail!



IMR: QGP vs. multi-pion radiation

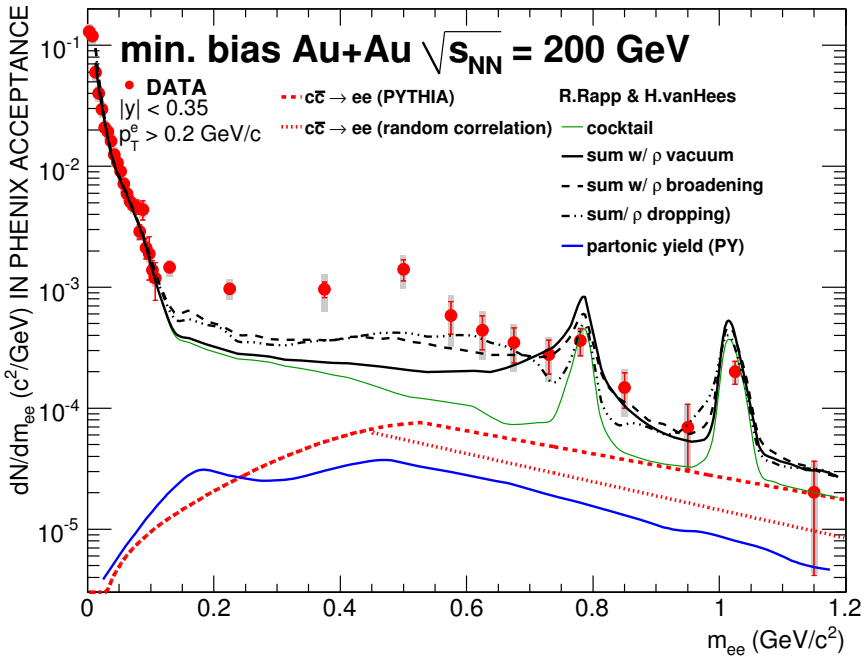




- different critical and freeze-out temperatures
  $T_c = 160 \ldots 190$ MeV, $T_{\mathrm{chem}} = 160 \ldots 175$ MeV
- M- and p_T spectra comparably well described!
- reason: T vs. volume $\Rightarrow$ maximal l^+l^- emission for
  $T = T_{\mathrm{max}} = M/5.5$
- hadronic and partonic radiation "dual" for $T \sim T_c$
  compatible with chiral-symmetry restoration!
- inconclusive whether hadronic or partonic emission in IMR!

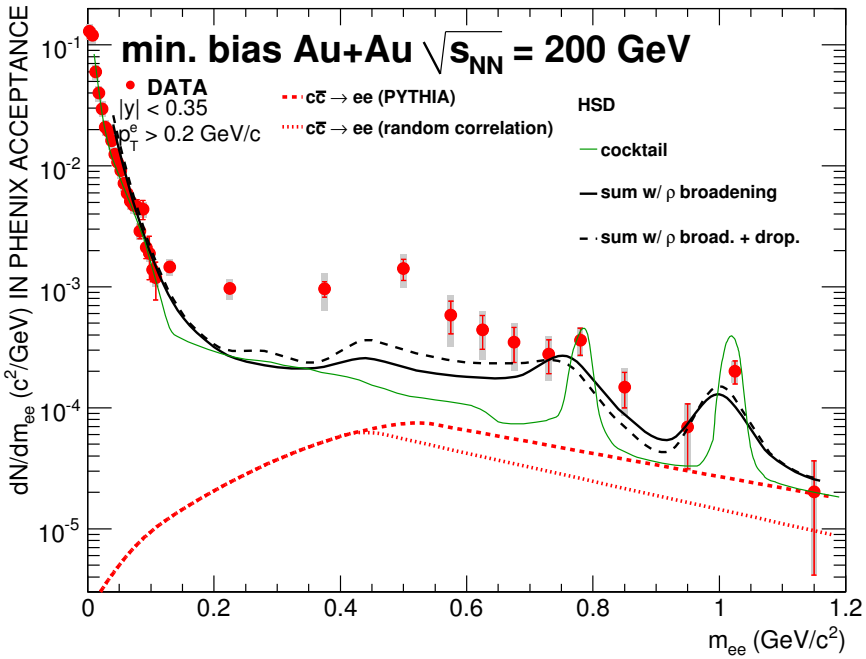
Dileptons@RHIC: New Puzzle?

- huge enhancement in the LMR unexplained yet!



model: Rapp, HvH

[A. Adare et al (PHENIX), arXiv:0912.0244 [nucl-ex]]



model: HSD Bratkovskaya, Cassing

[A. Adare et al (PHENIX), arXiv:0912.0244 [nucl-ex]]

- more on dileptons@RHIC: earlier talk by J. Manninen (HK 2.3)

Conclusions and Outlook

- dilepton spectra $\Leftrightarrow$ in-medium em. current correlator
- excess yield dominated by radiation from thermal sources
- baryons essential for in-medium properties of vector mesons
- melting vector mesons with little mass shift
- IMR well described by scenarios with radiation dominated either by QGP or multi-pion processes (depending on EoS)
- "quark-hadron duality" of $\ell^+\ell^-$ rates around T_c
- compatible with chiral symmetry restoration!
- model describes dileptons in In-In (NA60), Pb-Au (CERES/NA45) (and γ in Pb-Pb (WA98)!)
- new puzzle @ RHIC?!?
- recent review:
  R. Rapp, J. Wambach, HvH, Landolt-Börnstein, 1-23A
  arXiv: 0901.3289 [hep-ph]