Dilepton production from Relativistic Heavy Ion Collisions

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FIAS

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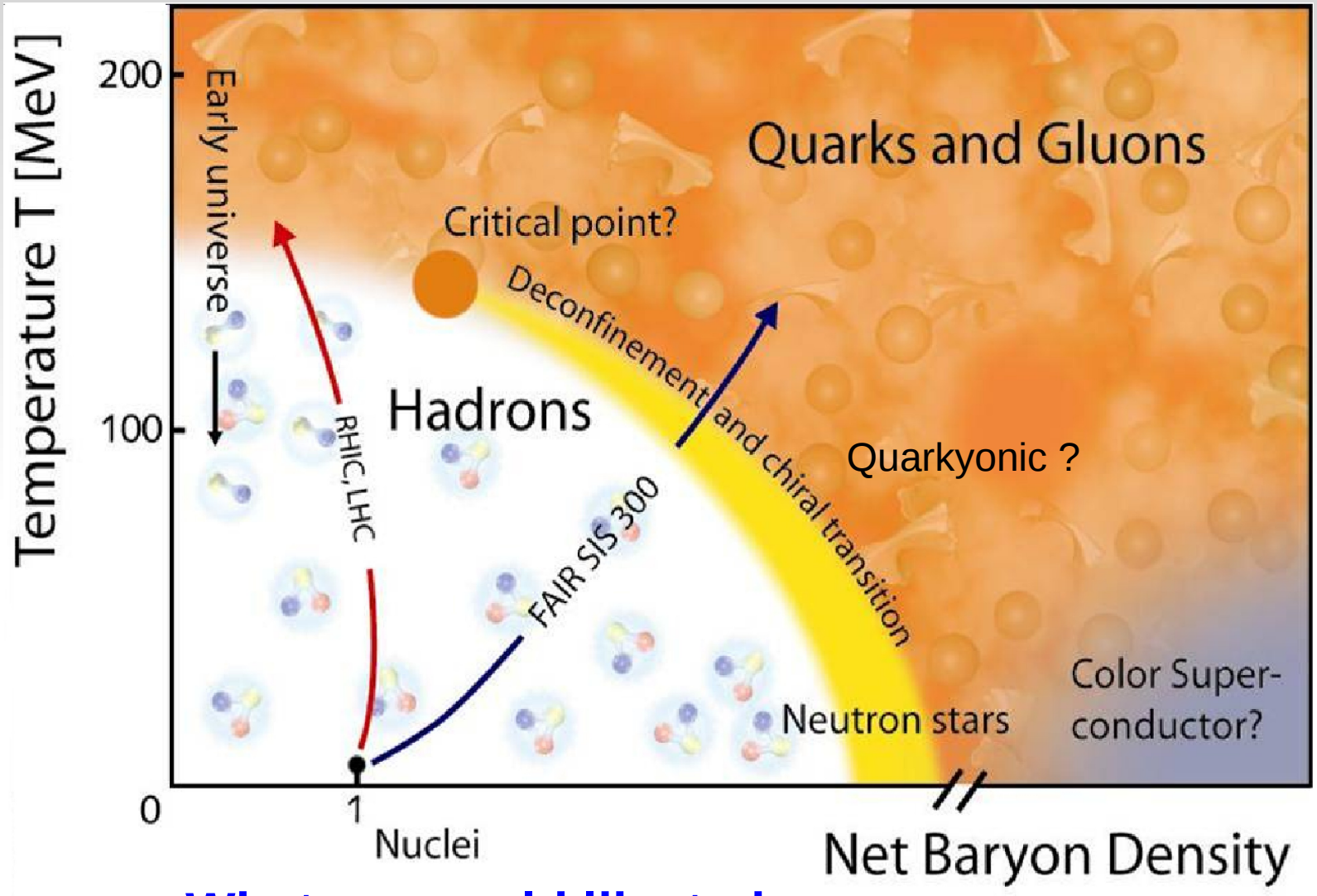
Les Houches, France

FIAS Frankfurt Institute for Advanced Studies

HIC for FAIR

Helmholtz International Center

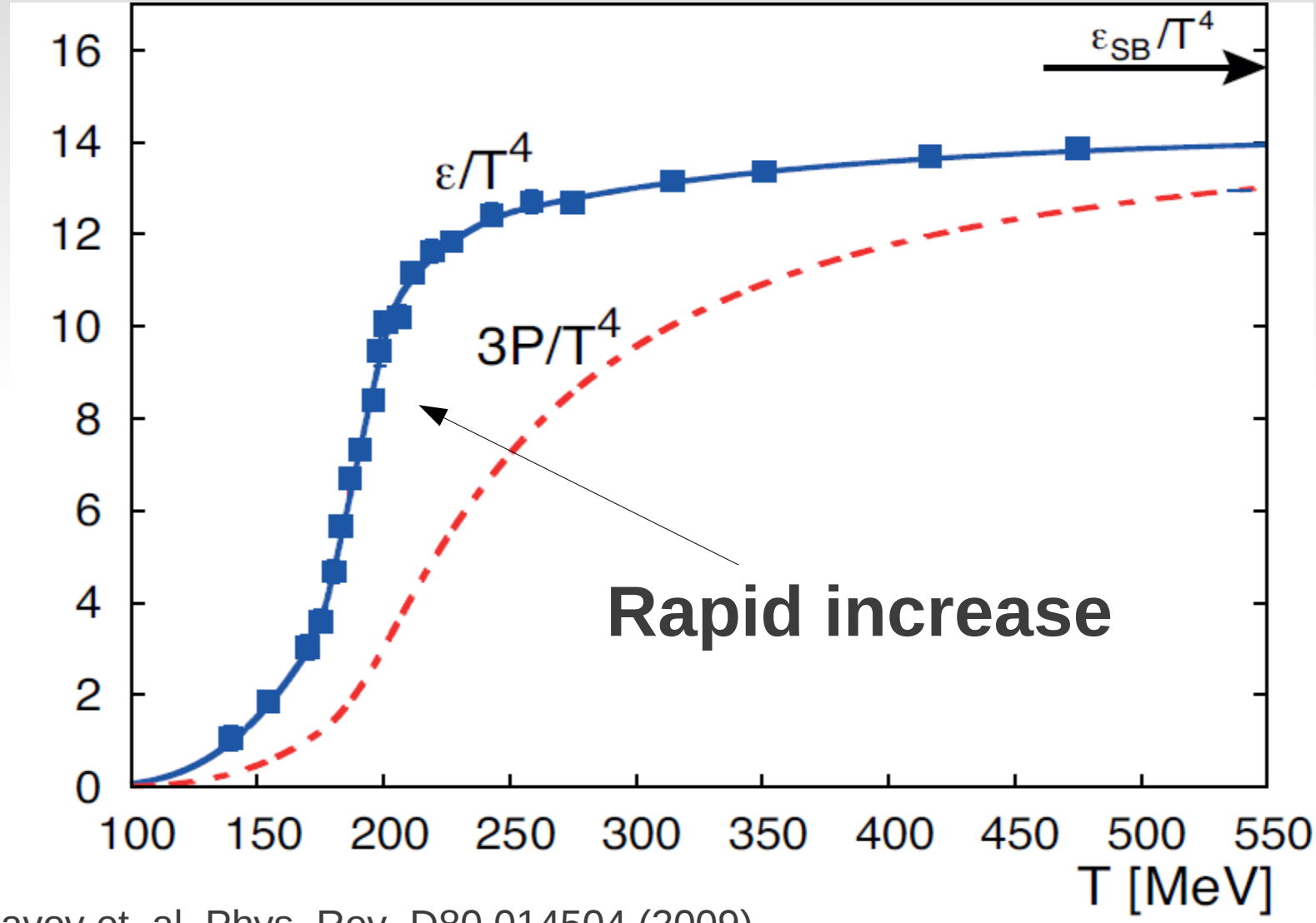
QCD Phase Diagram



What we would like to know:

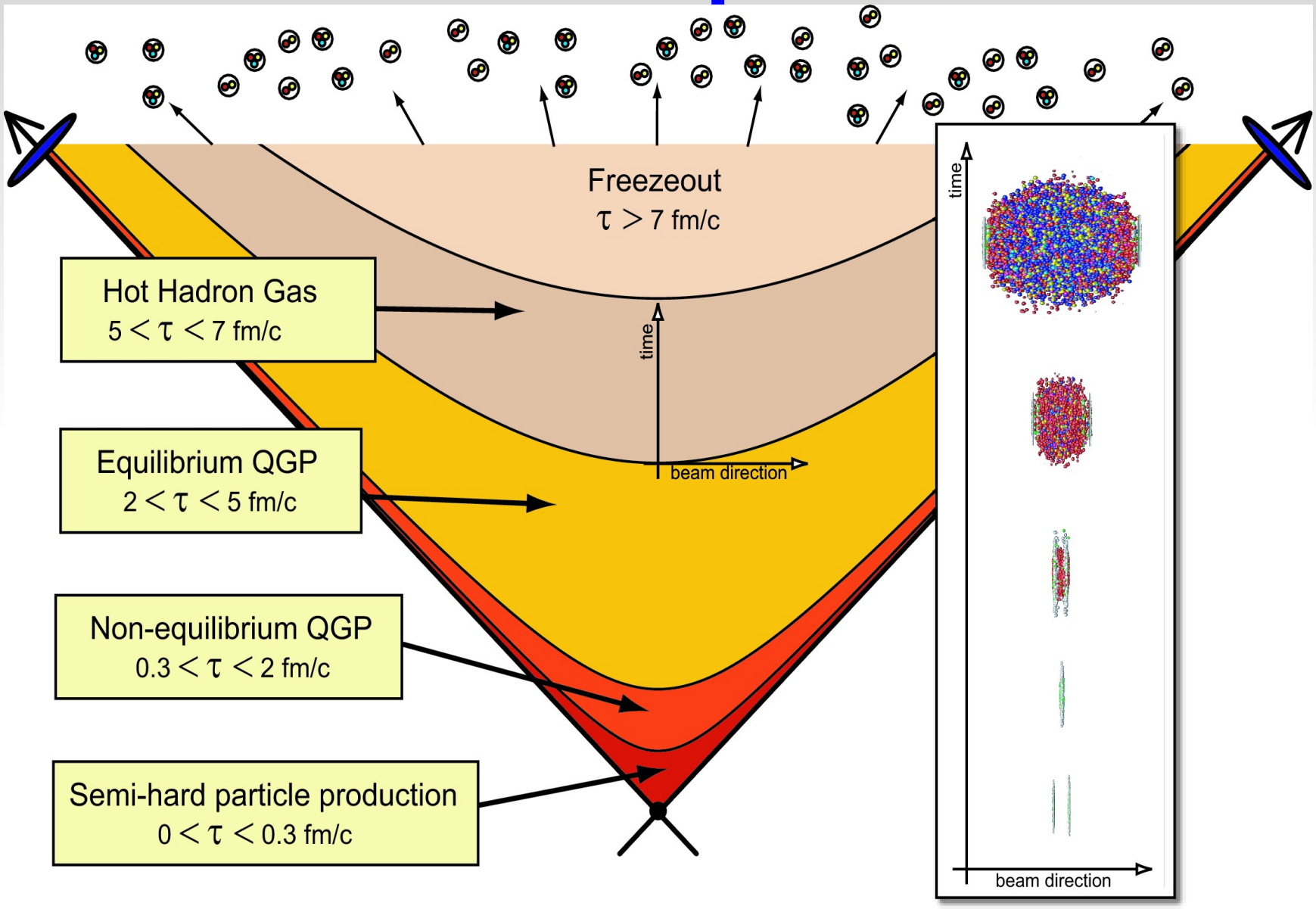
- **QCD matter at extreme conditions.**
- **Transport and thermal properties.**
- **Predictions and comparison with data.**

Lattice QCD: high T and low μ



A. Bazavov et. al, Phys. Rev. D80,014504 (2009).

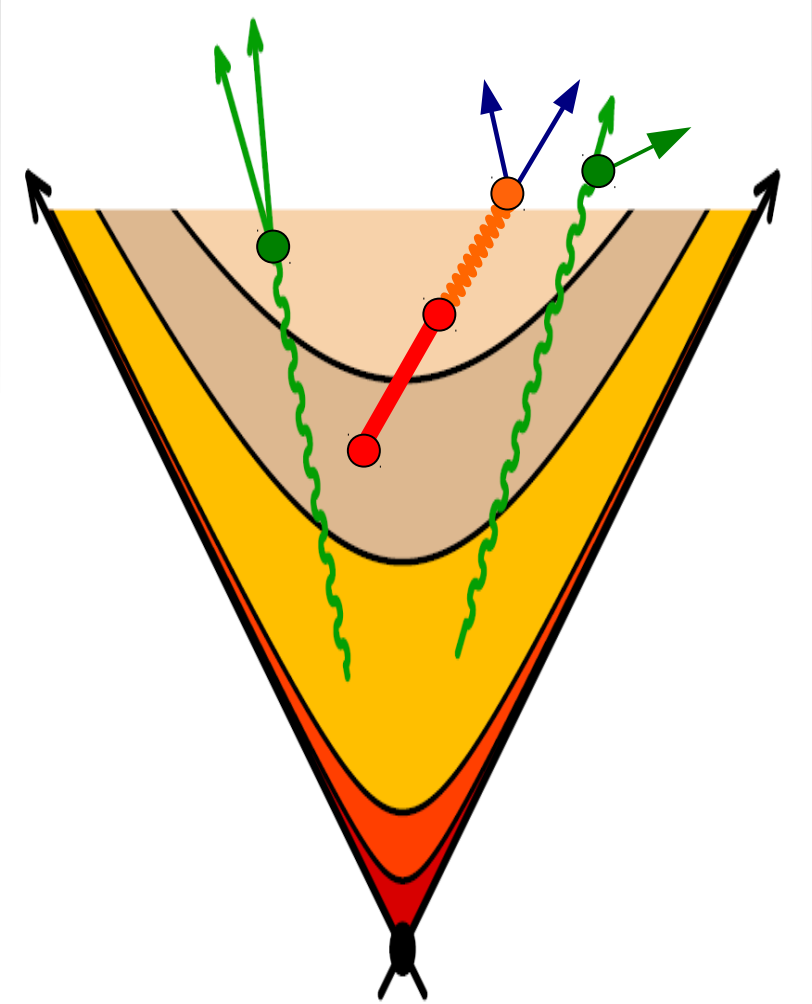
Space-Time picture of the fireball expansion



How to measure the QGP ??

- It is difficult to have an **unique measurement** that determines the QGP.
- Instead, take a look to a **different set of data:** characterize the new state of matter.
- Different observables have been proposed: collective flow effects (e.g. v_2,v_4), jet quenching, HBT, J/ψ suppresion, photons, etc.
- In this talk: **dileptons.**

Dileptons in Heavy Ion Collisions



- are emmited in each and every stage of the fireball,
- do not interact with the hot and dense medium ($\lambda_{mfp} >> L$),
- provide information about Q, $\bar{Q}$ parton distr. functions.
- produced at high energy (p_T, $M \geqslant 1$ GeV) are sensitive at $\tau \leqslant 2$ fm,
- differentiate between both hadronic and partonic sources.

Dilepton spectrum

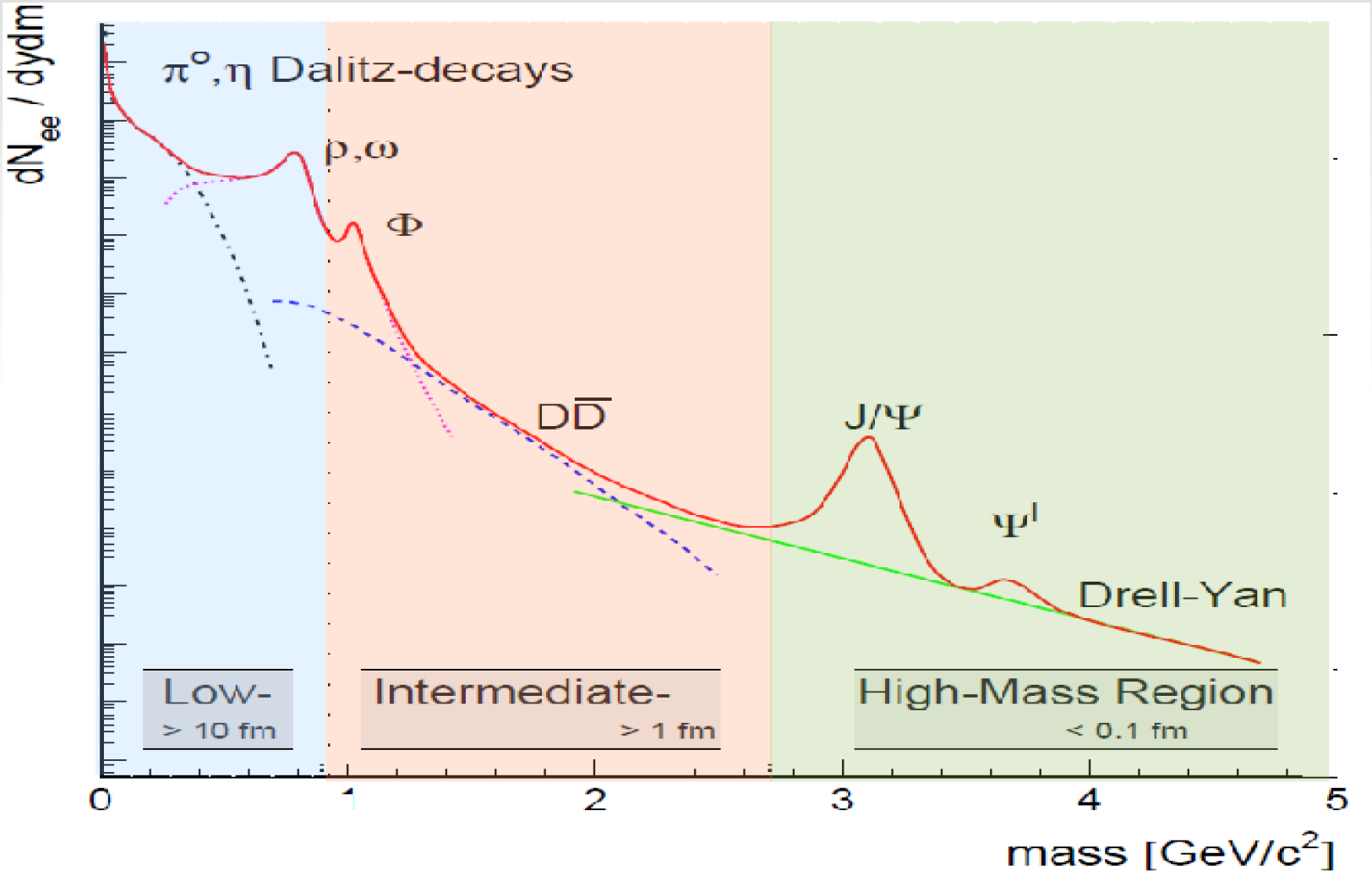


Figure from R. Rapp and J. Wambach, Adv. Nucl. Phys. 25: 1, 2000.

Dilepton spectrum: LMR

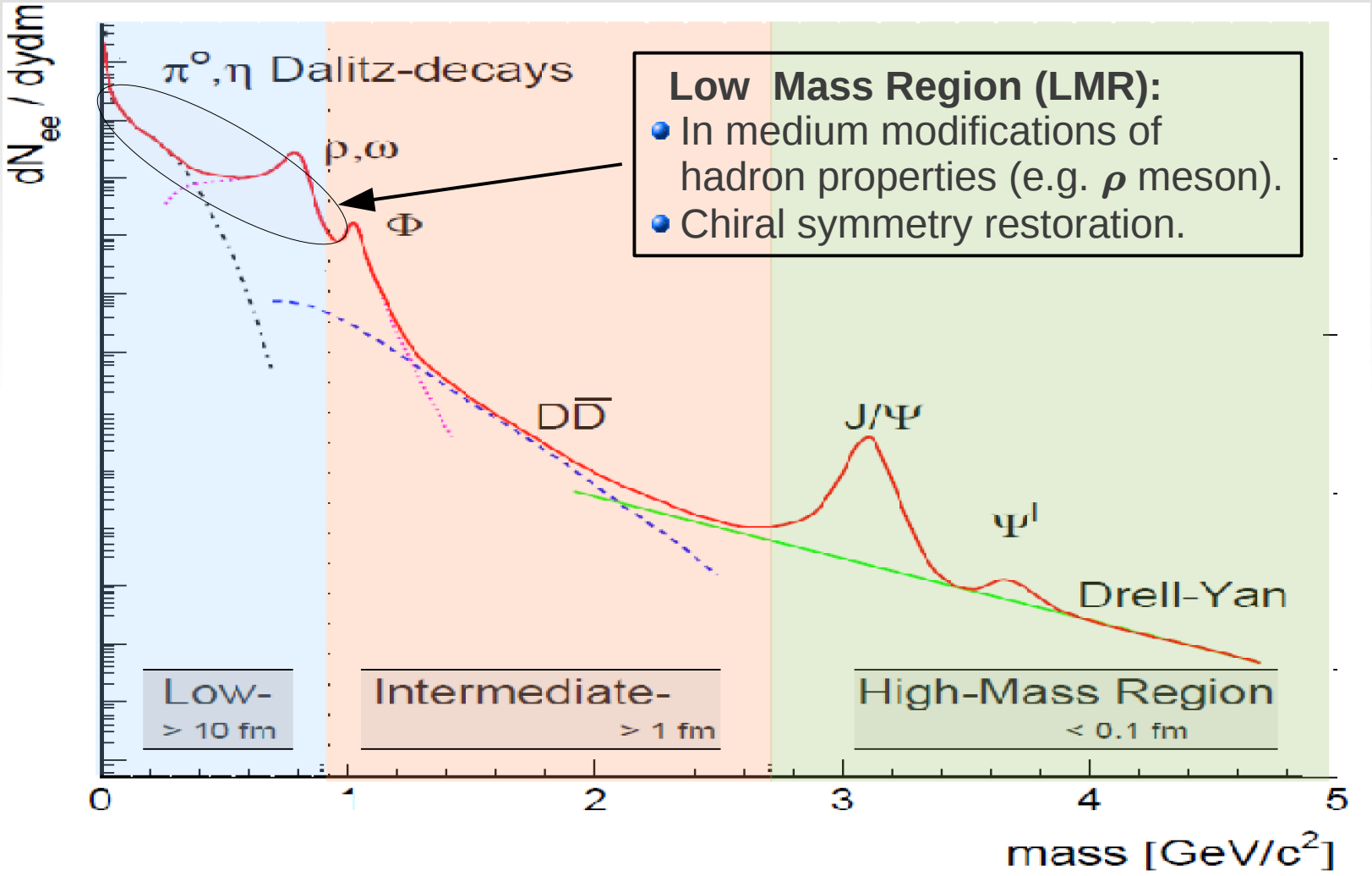


Figure from R. Rapp and J. Wambach, Adv. Nucl. Phys. 25: 1, 2000.

Dilepton spectrum: IMR

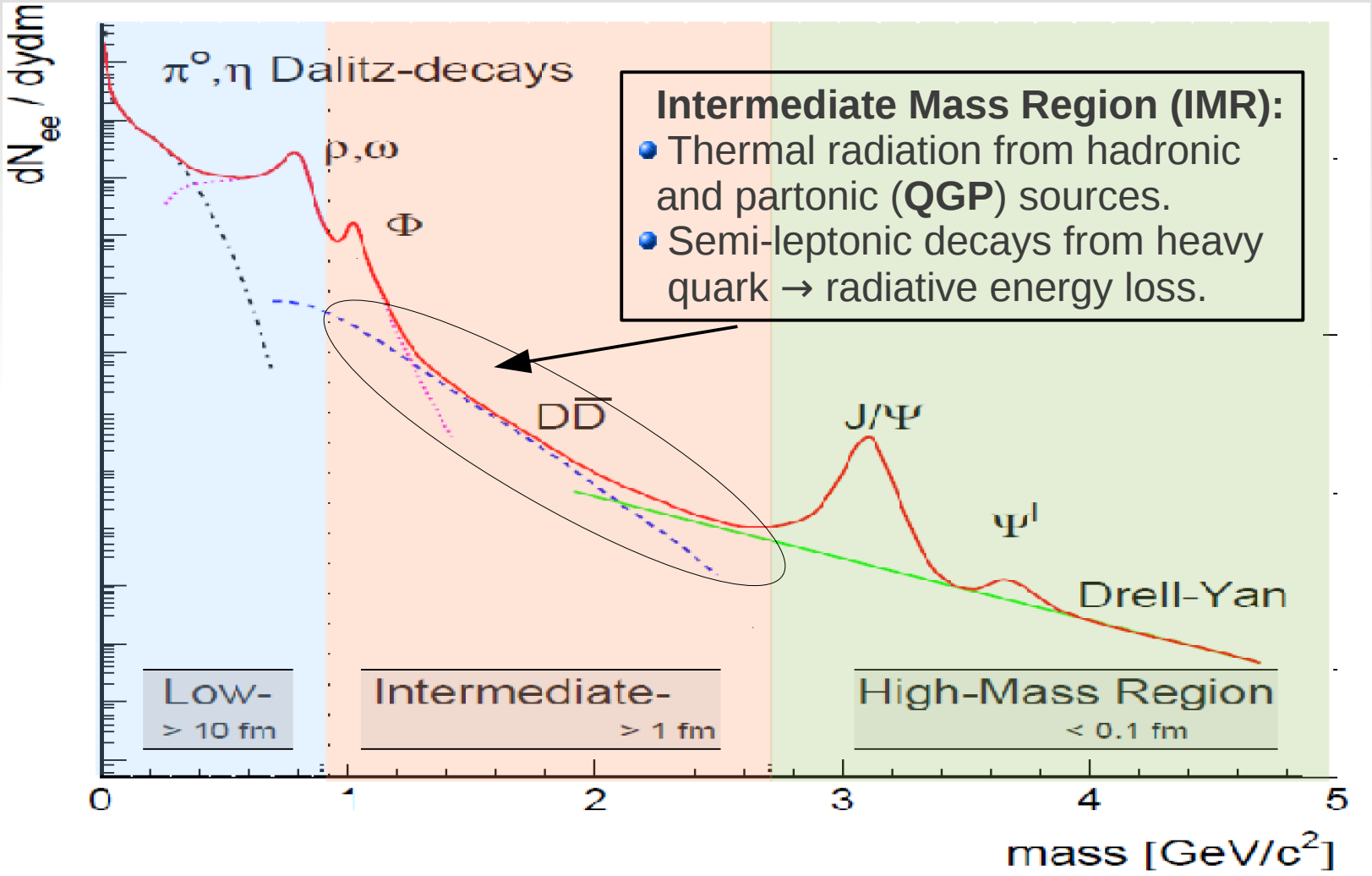


Figure from R. Rapp and J. Wambach, Adv. Nucl. Phys. 25: 1, 2000.

Dilepton spectrum: HMR

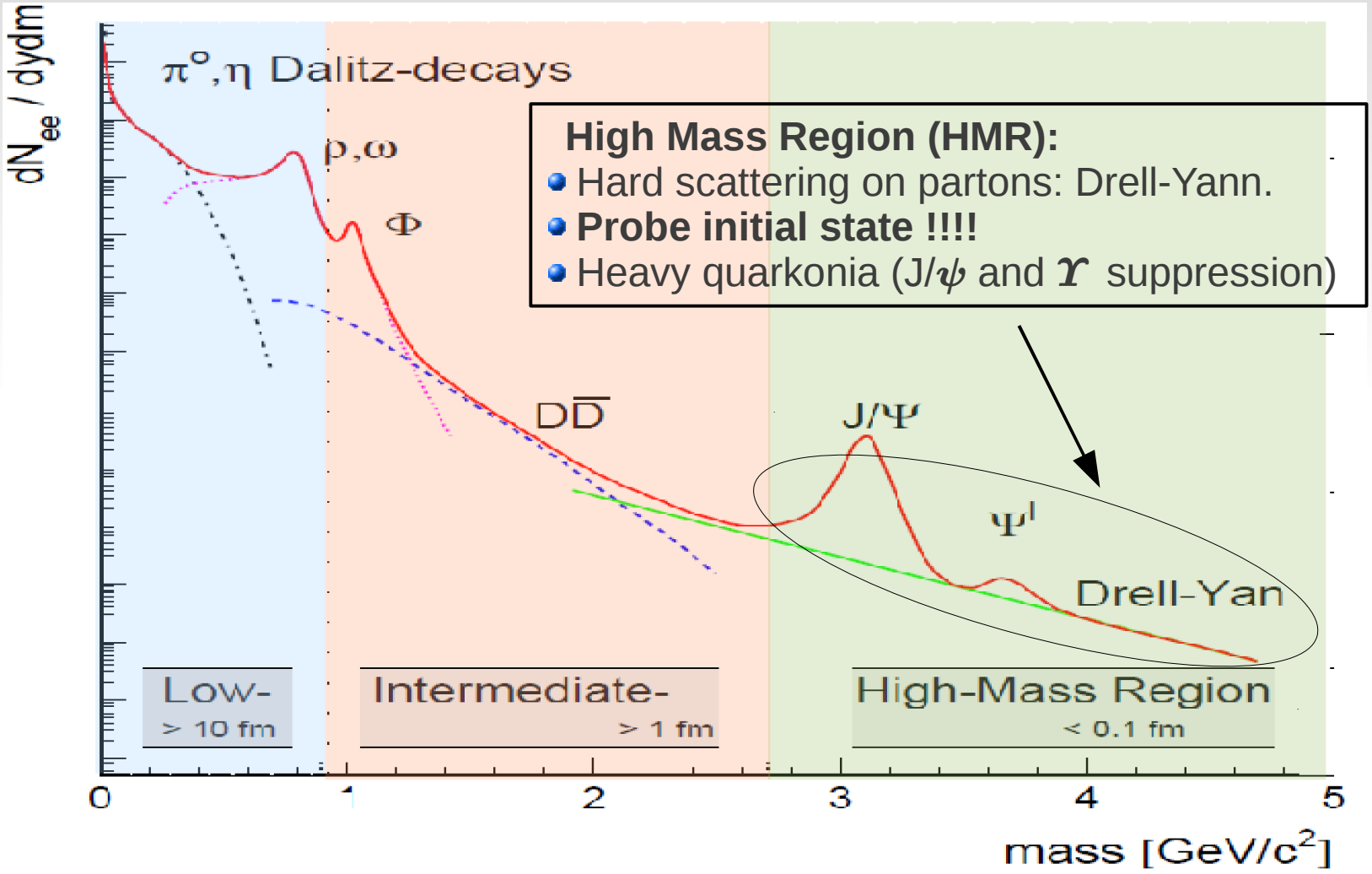
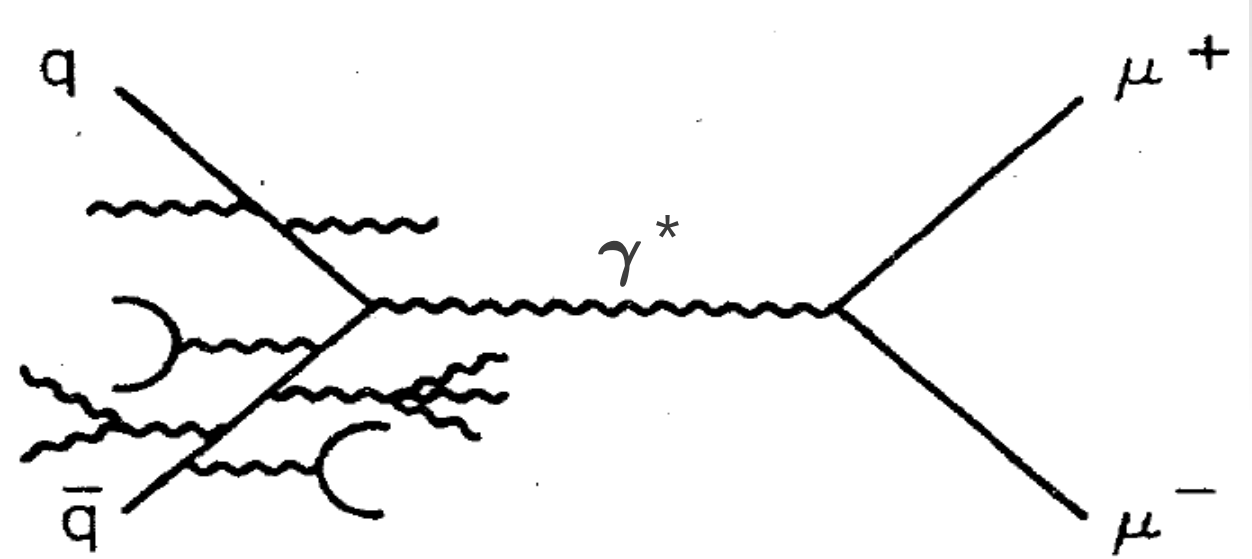


Figure from R. Rapp and J. Wambach, Adv. Nucl. Phys. 25: 1, 2000.

Dilepton emission rate

McLerran, Toimela (1986), Weldon (1990), Gale, Kapusta (1991)

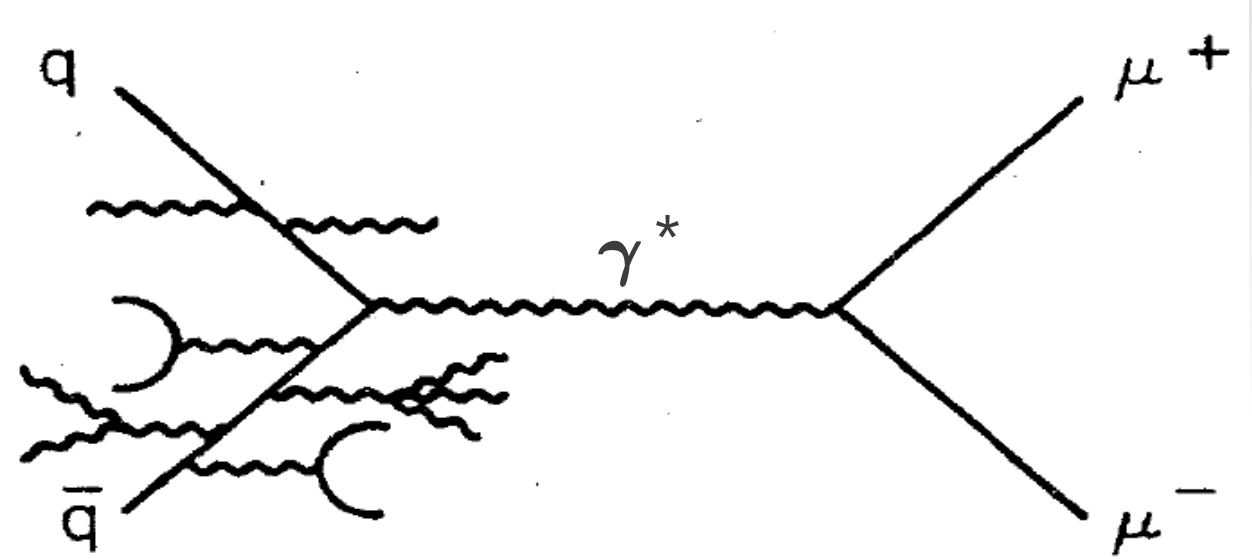


Thermal ensamble average of the current-current correlator:

$$dR = -\frac{g^{\mu\nu}}{2\omega}\frac{d^3k}{(2\pi)^3}\frac{1}{Z}\sum_i e^{-\beta K_i}\sum_f (2\pi)^4\delta(p_i - p_f - k)$$
$$\times\langle j\,|\,J_\mu\,|\,i\rangle\langle i\,|\,J_\nu\,|\,j\rangle$$

Dilepton emission rate

McLerran, Toimela (1986), Weldon (1990), Gale, Kapusta (1991)



Dilepton emission rate:

$$E_+ E_- \frac{d^6 R}{d^3 p_+ d^3 p_-} = \frac{2e^2}{(2\pi)^6} \frac{1}{k^4} L^{\mu\nu} \, \mathrm{Im}\, \Pi^R_{\mu\nu}(\omega, k) \frac{1}{e^{\beta\omega} - 1}$$

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Thermal sources:	**Relevance**
• **Quark-Gluon Plasma:**	
$q\,\bar{q} \rightarrow e^+ e^-$,	$T > T_c$
jet conversion, …...	
• **Hot + Dense Hadron Gas:**	
$\pi^+ \pi^- \rightarrow e^+ e^-$, ….	$T \leqslant T_c$

But....

… just knowing the dilepton emission rate is not enough.

→ Need to incorporate space-time evolution to compare with data (be careful with the experiment acceptance):

- Microscopic transport models (e.g. URQMD, HSD).
- Hydrodynamical models (ideal, viscous).
- Thermal fireball models...

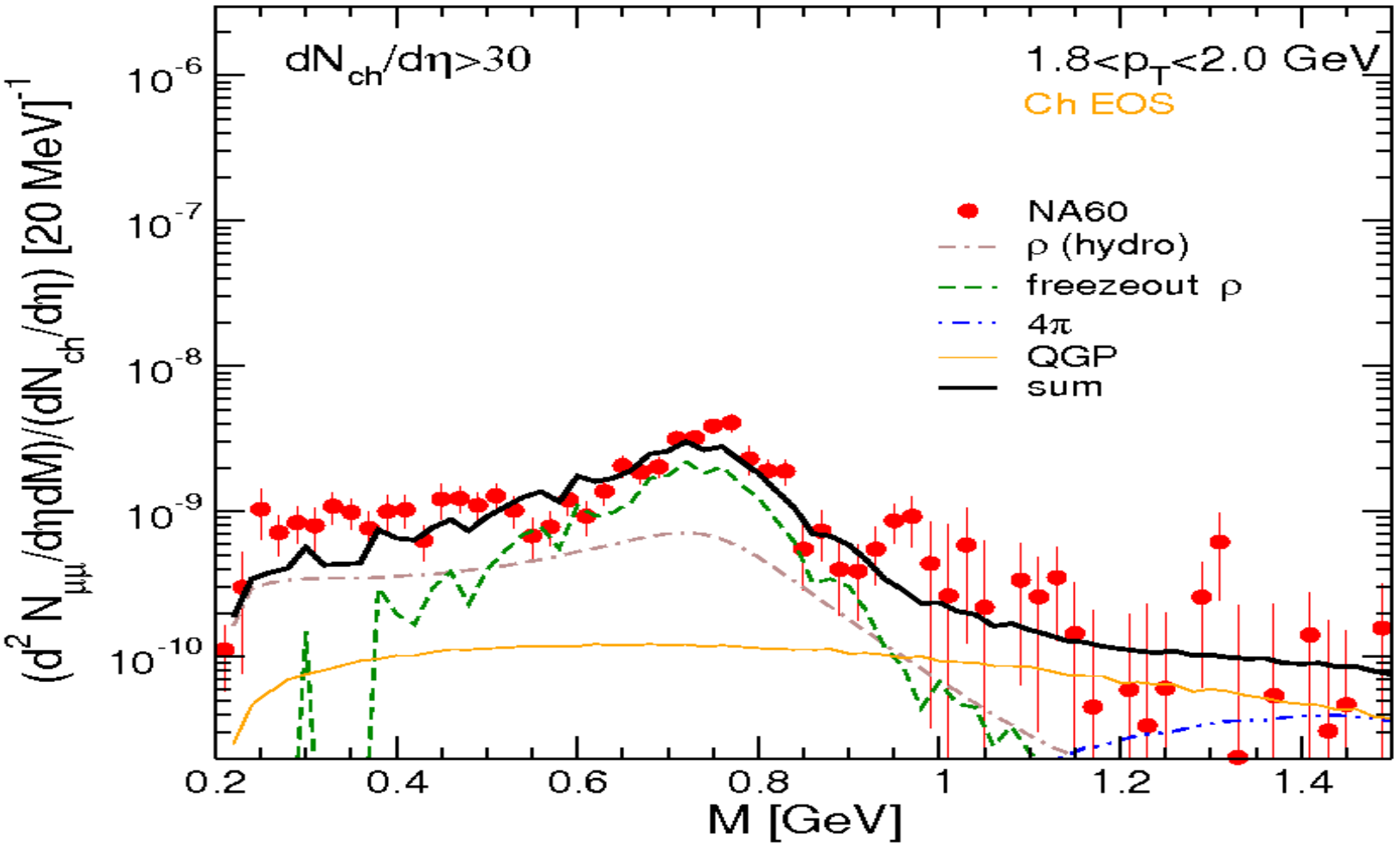
- Those models **differ** to each other in their assumptions (chemical potentials, freeze out conditions, etc).

  See P. Gossiaux et. al., The influence of bulk evolution models on heavy quark phenomenology, arXiV: 1102.1114.

- Need to be **constrain** by hadronic observables.

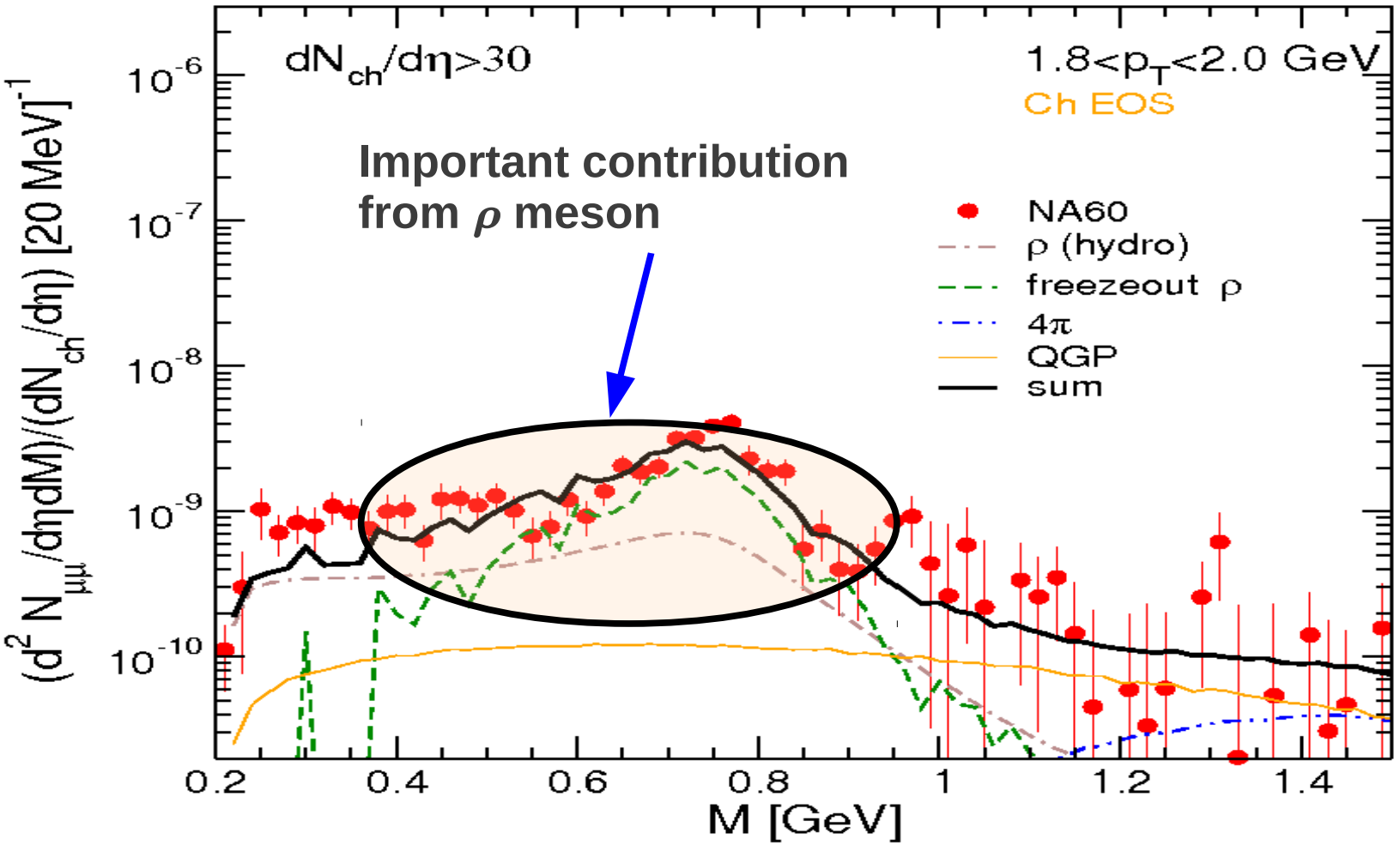
In addition, it is necessary to estimate properly the background related with non thermal sources (e.g. Drell-Yann, heavy flavour Decays, etc).

Dileptons @ NA60



E. Santini et. Al, URQMD collaboration, forthcoming.

Dileptons @ NA60



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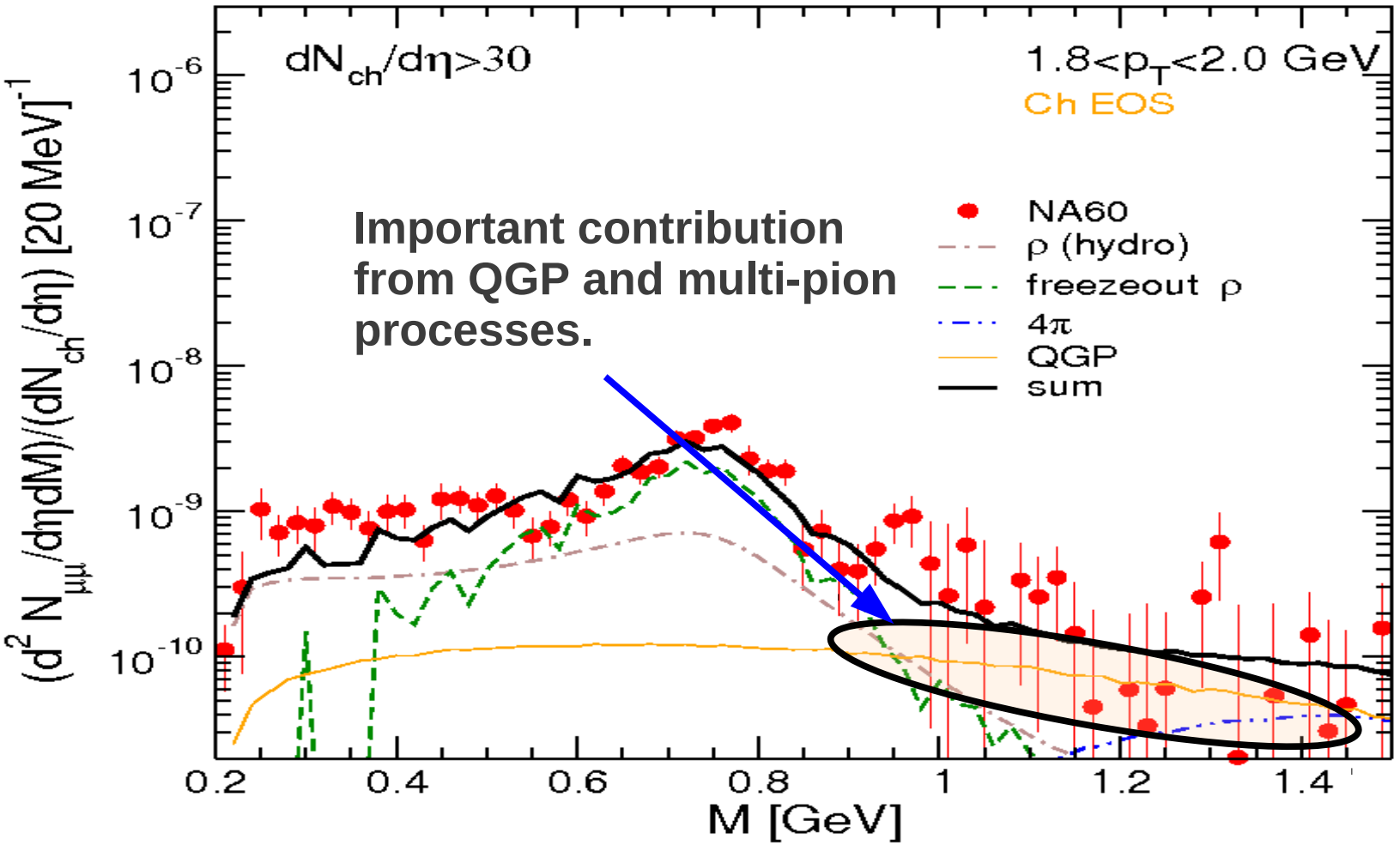

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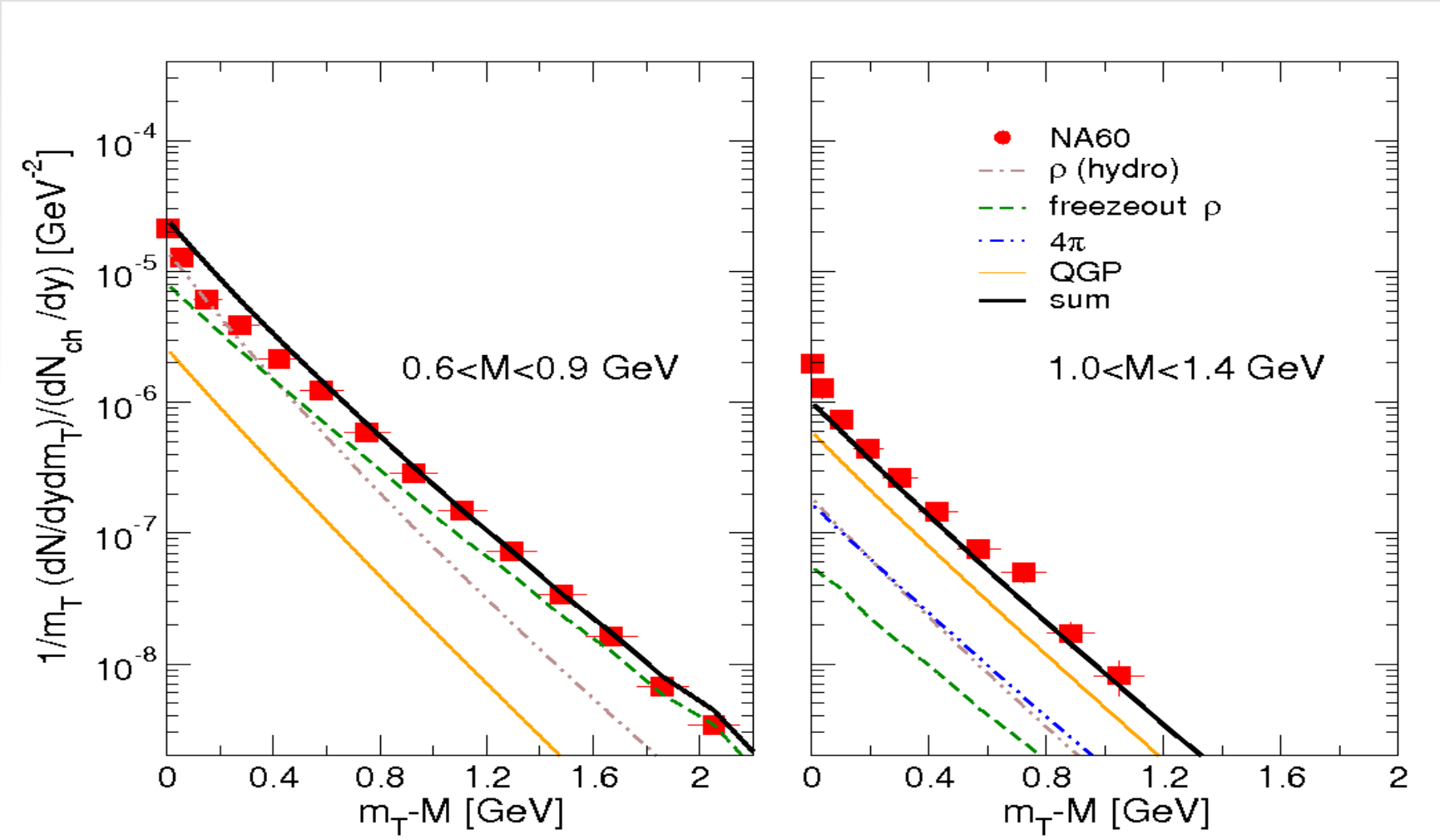

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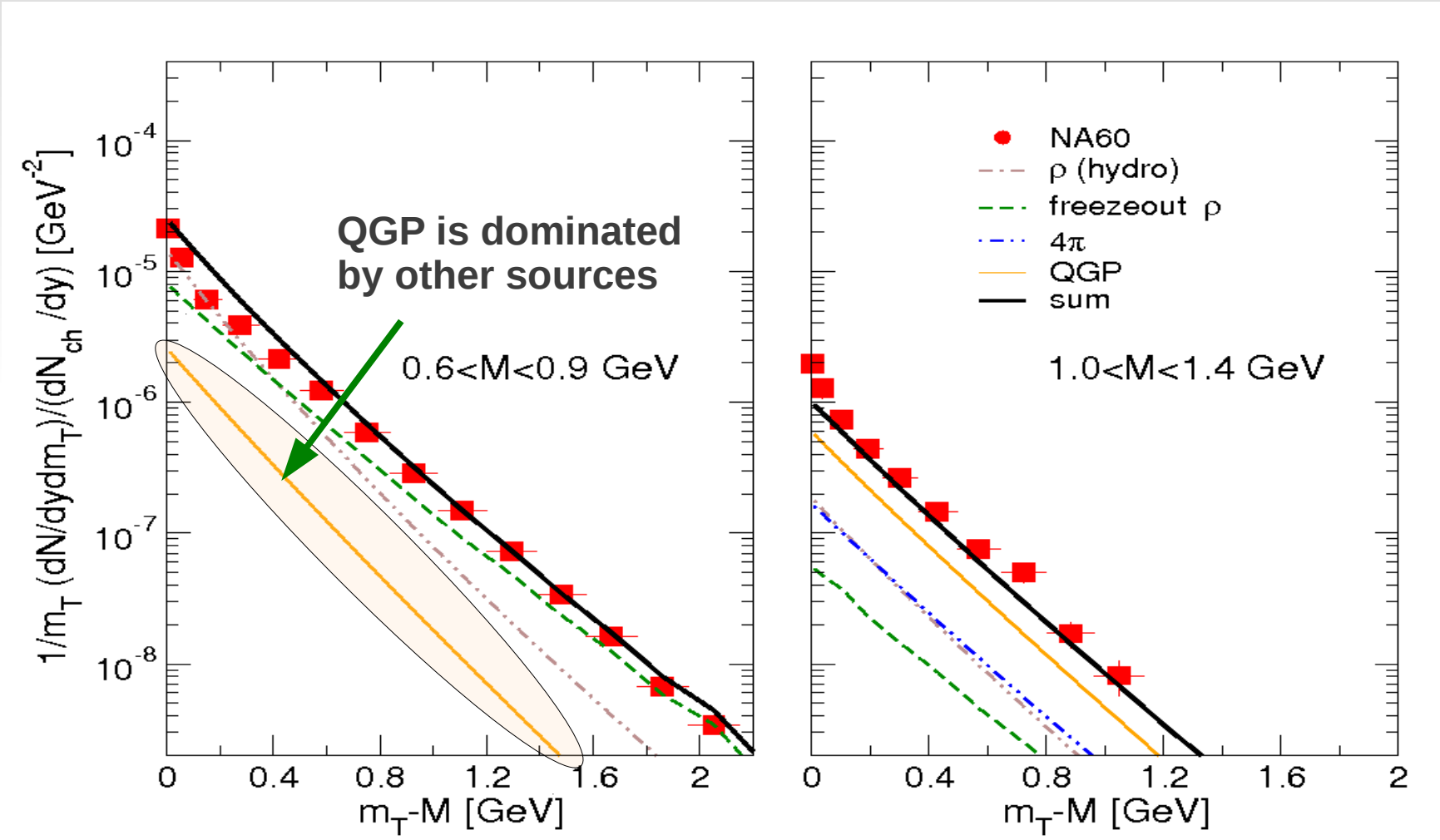

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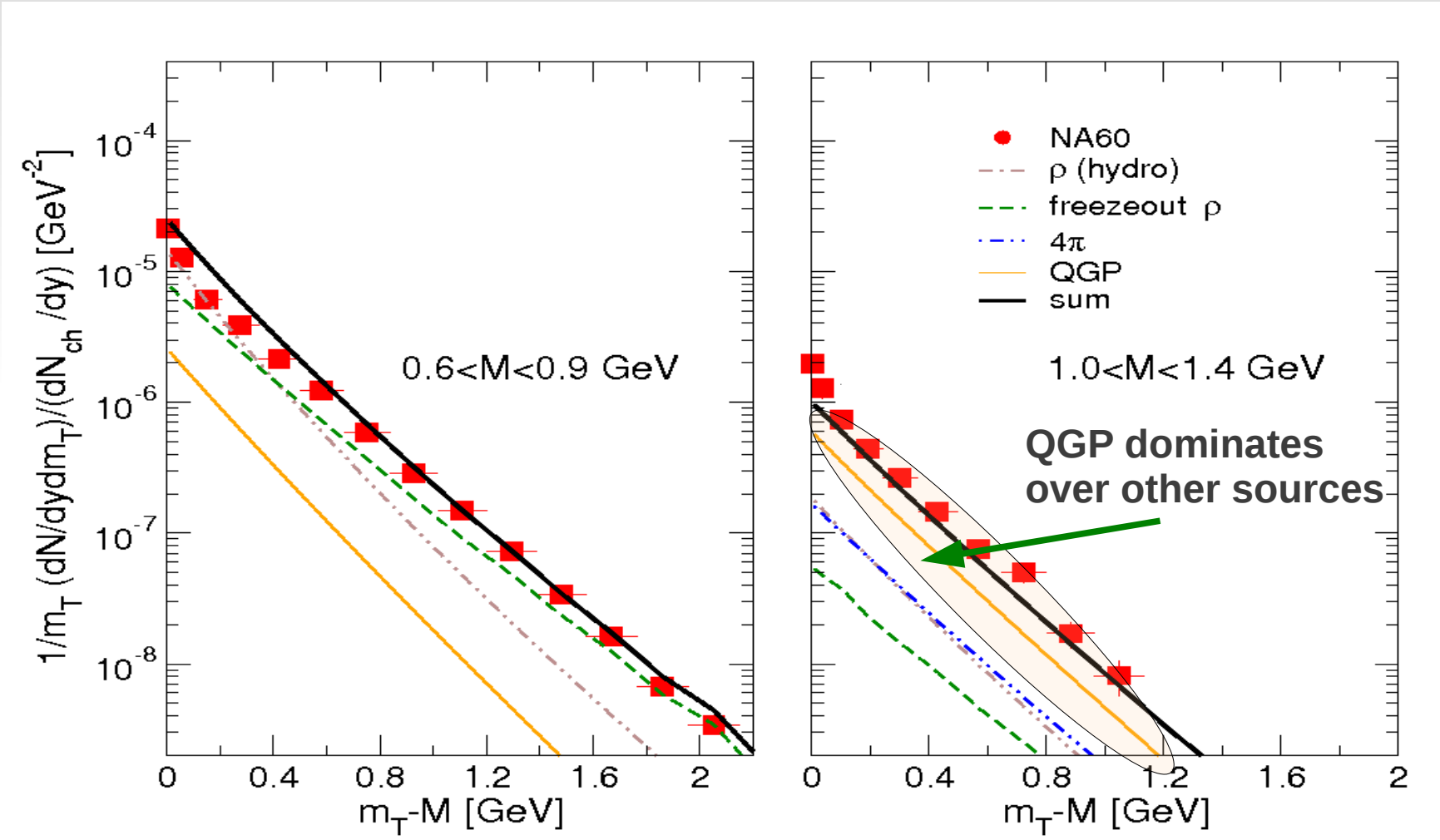

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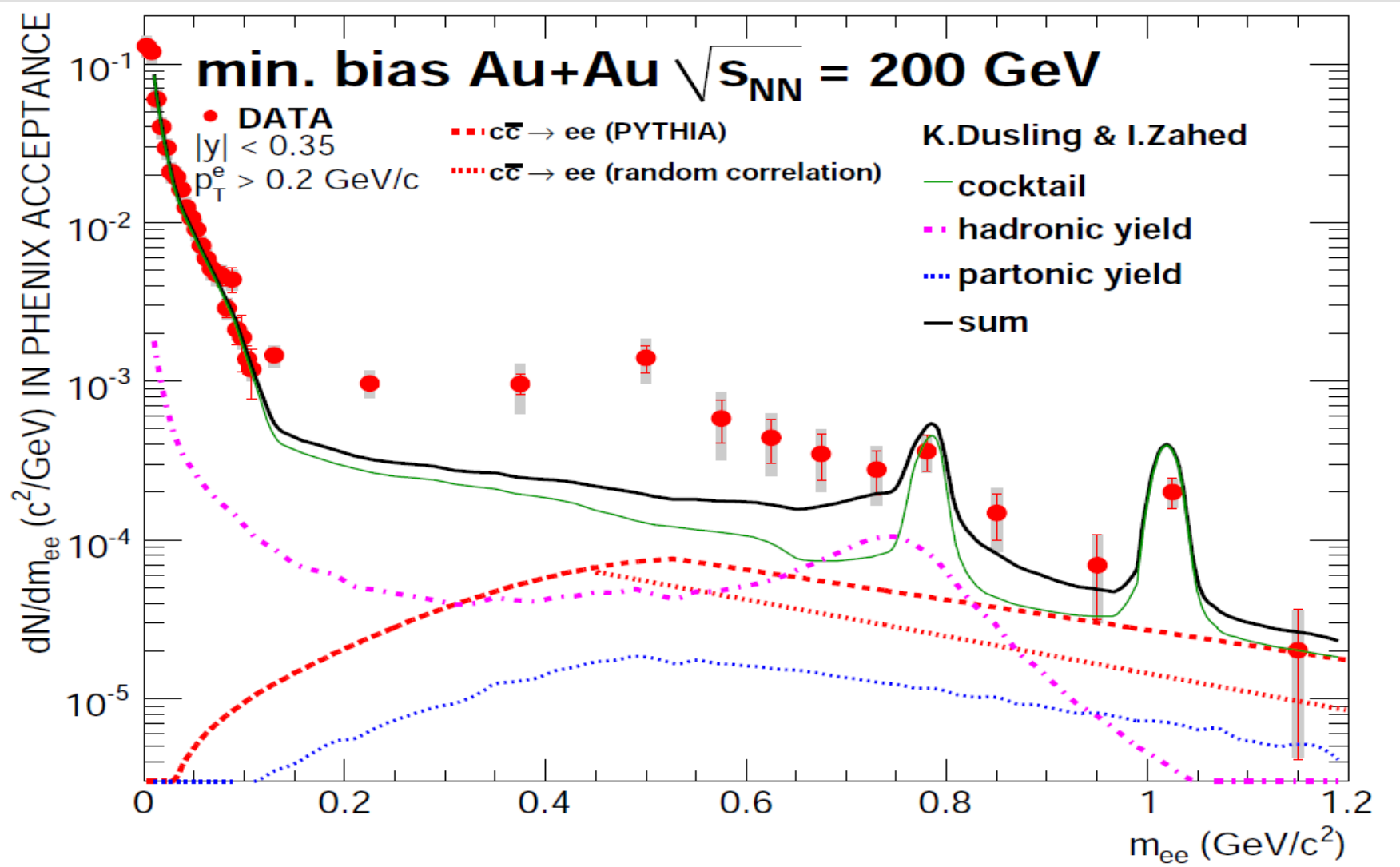
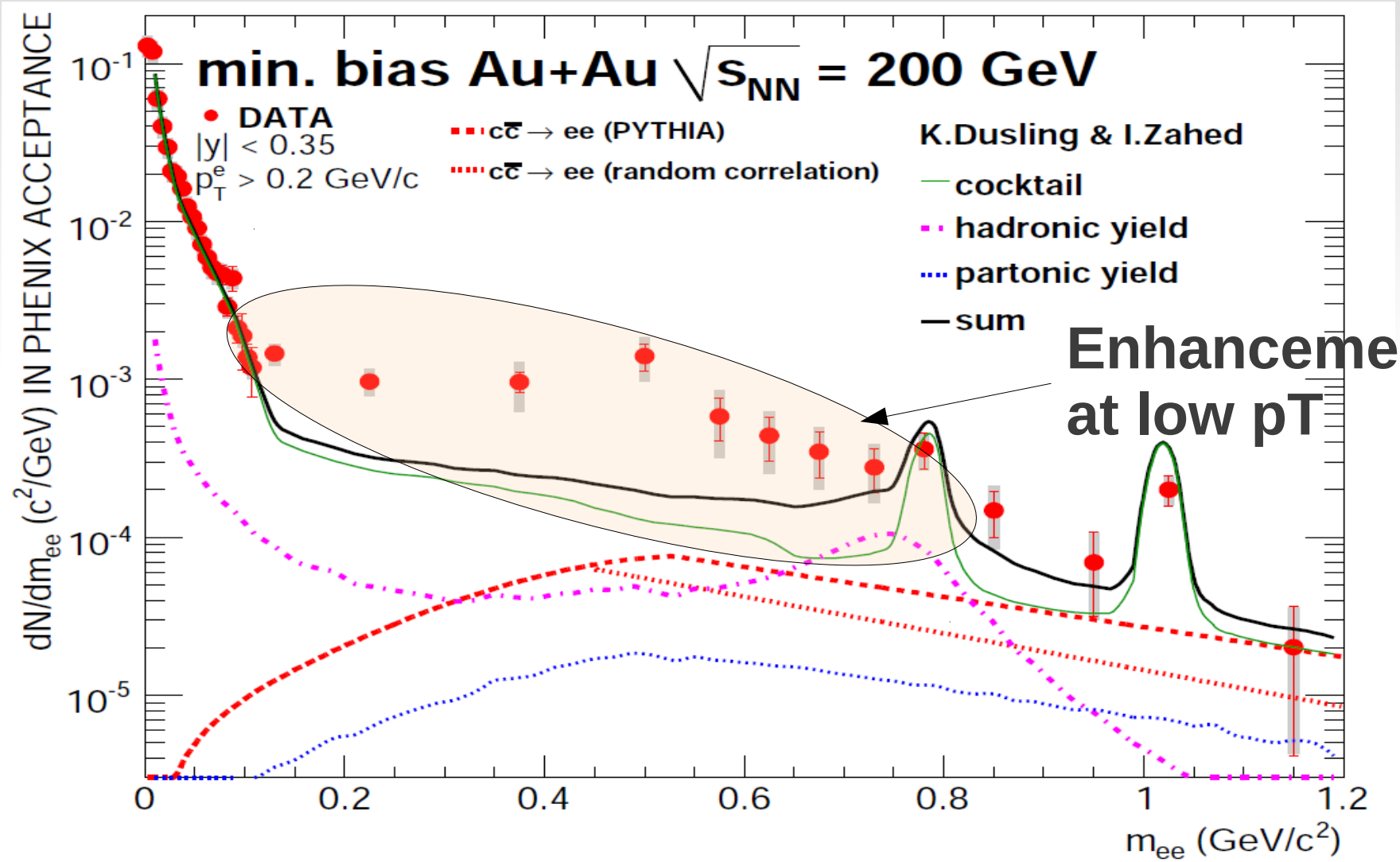
Dileptons @ RHIC: Puzzle

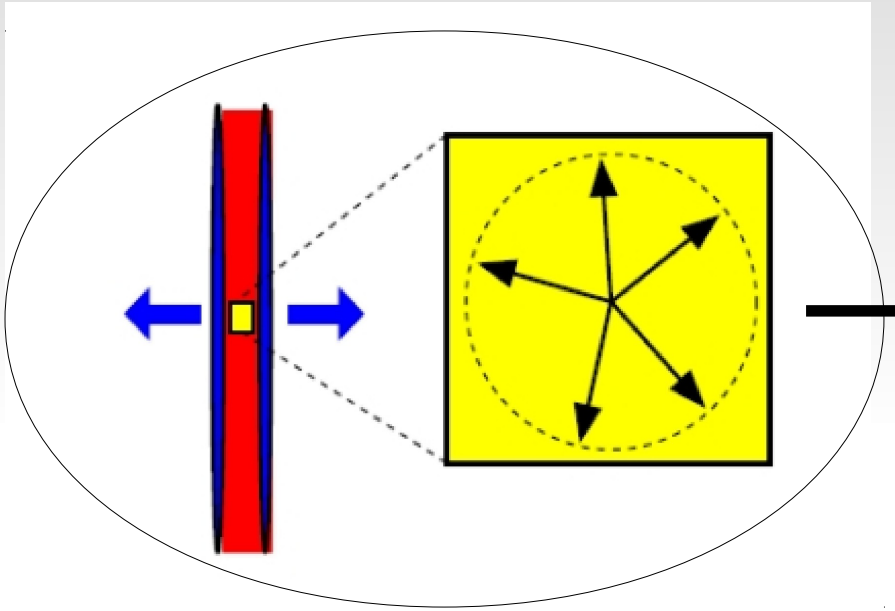


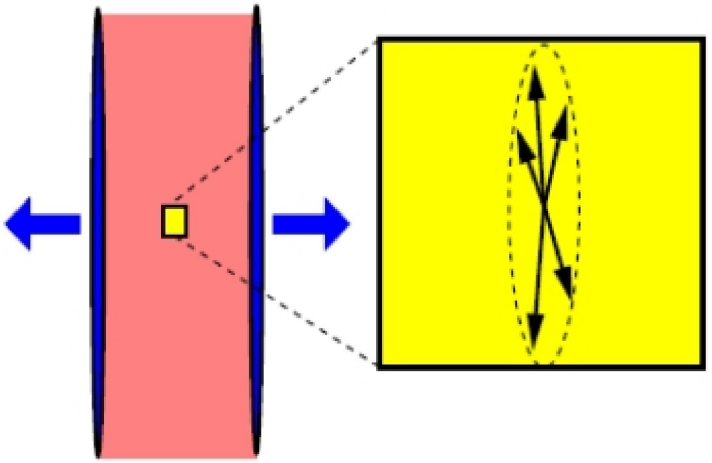
Dileptons @ RHIC: Puzzle



PHENIX Collaboration, Phys. Rev. C81:034911,2010.

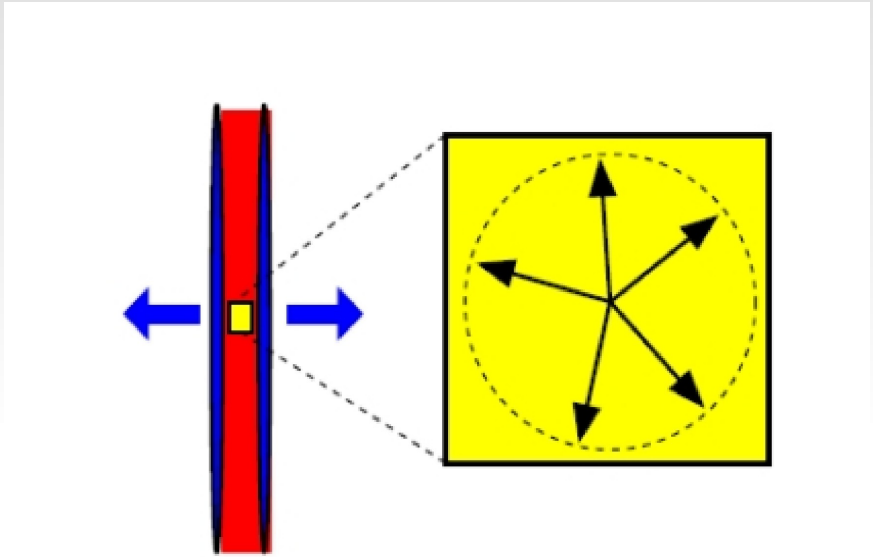
Dileptons as a tool of pre-equilibrium stage

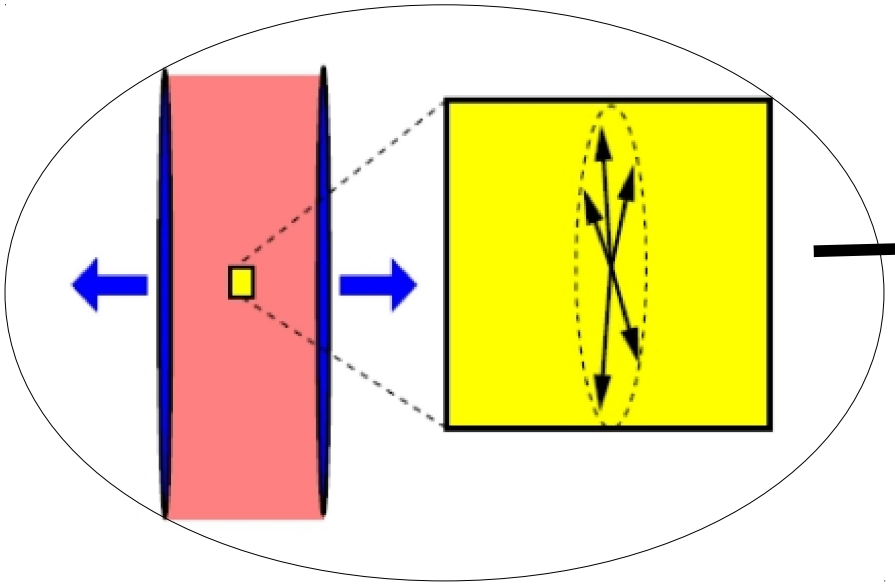




Around $\tau \sim Q_s^{-1}$ it is assumed an instantaneous isotropic state in momentum space.

Dileptons as a tool of pre-equilibrium stage

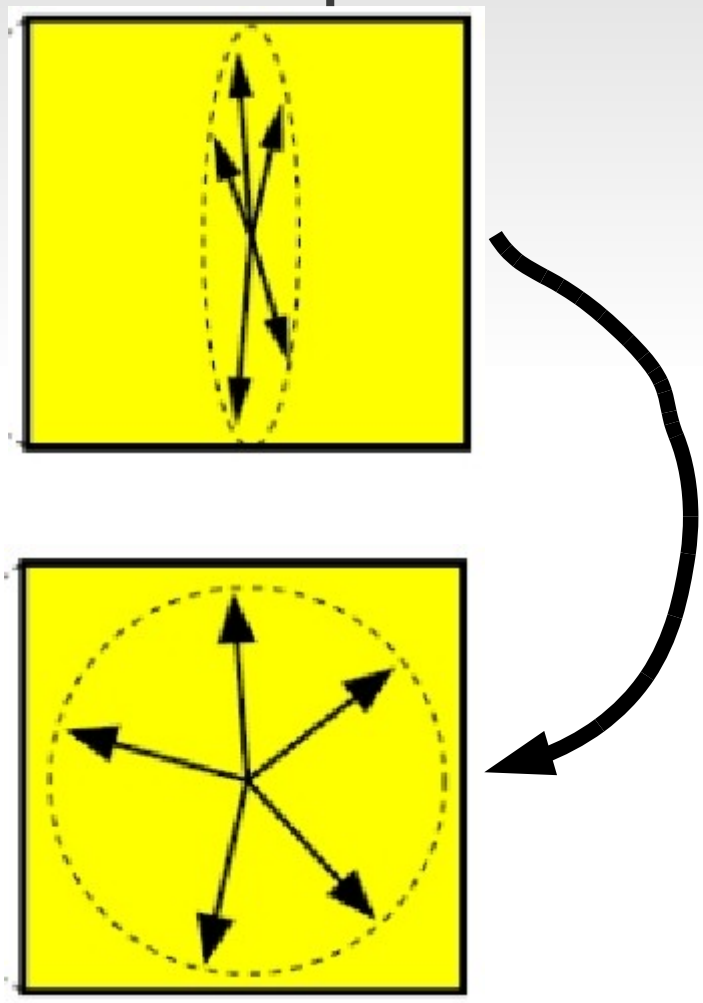




However, longitudinal expansion is faster than the transverse one. **System is anisotropic in momentum-space at early-times.**

Dileptons as a tool of pre-equilibrium stage

Anisotropic

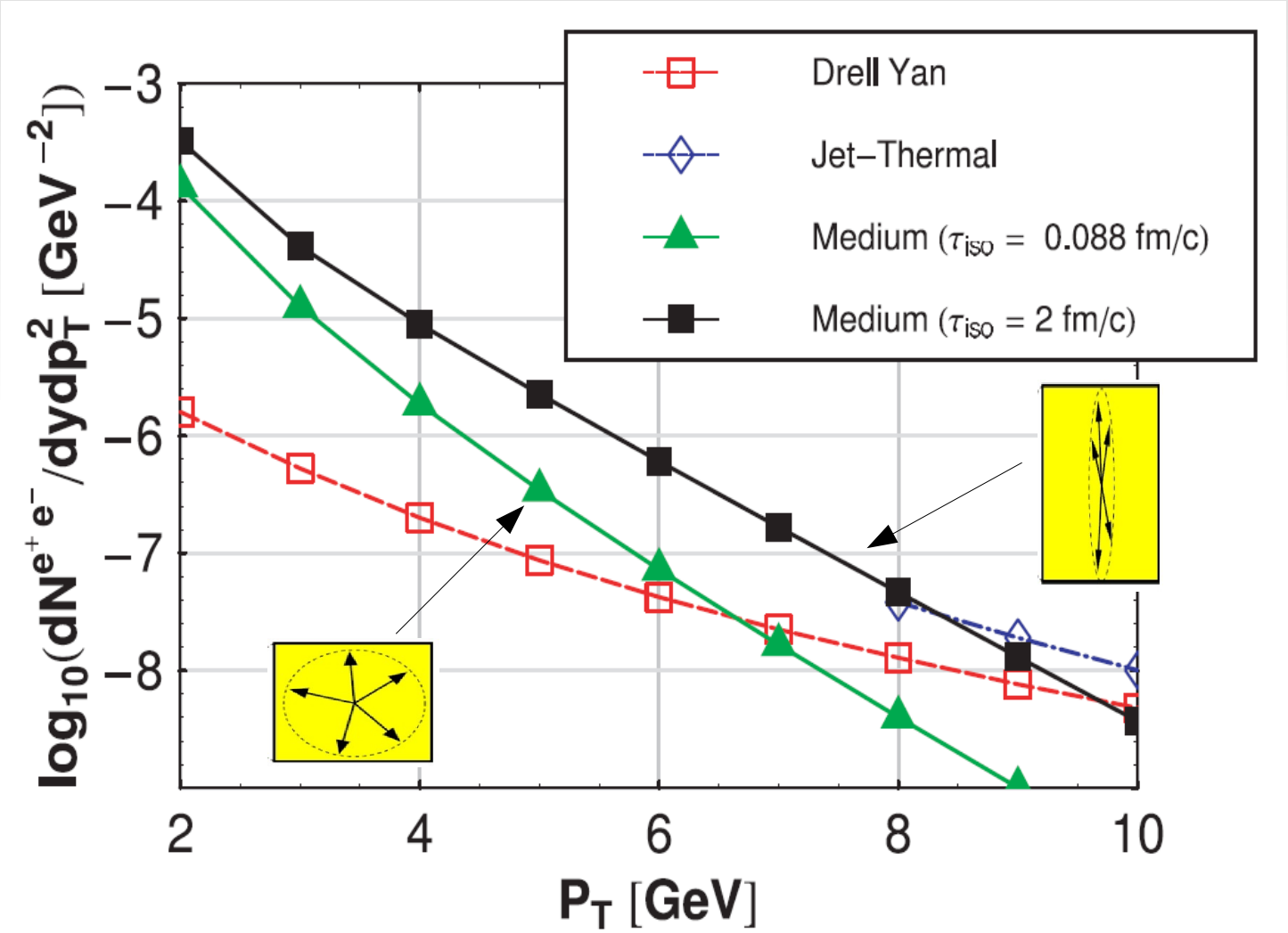


Isotropic (Near to equilibrium)

Can we learn about early-time momentum-space anisotropies from dileptons?

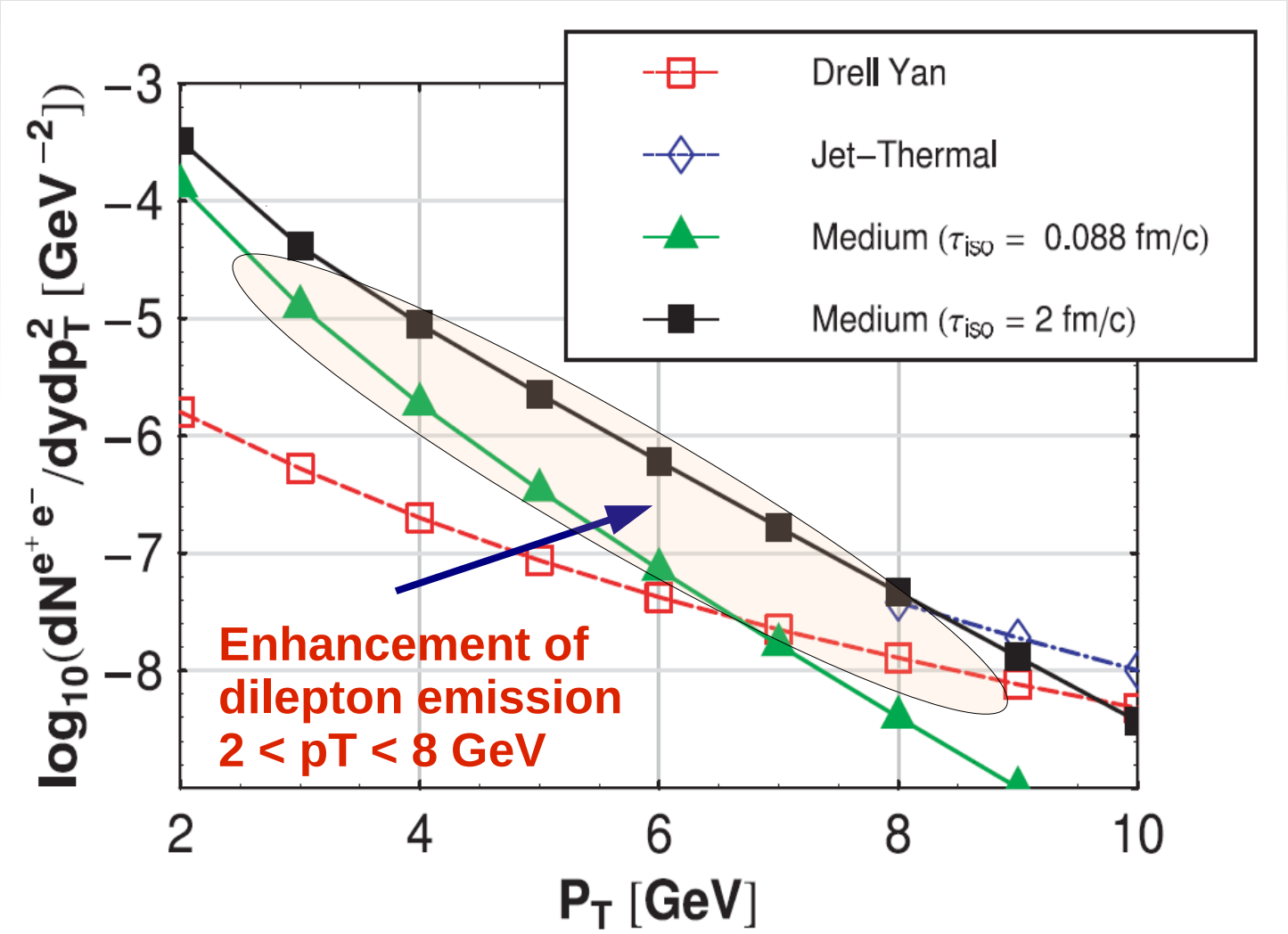
Constrain the initial time of the onset of hydrodynamics.

Dileptons as a tool of pre-equilibrium stage



M. Martinez and M. Strickland, Phys. Rev. Lett. 100, 102301 (2008).
Phys. Rev. C 78, 034917 (2008)

Dileptons as a tool of pre-equilibrium stage



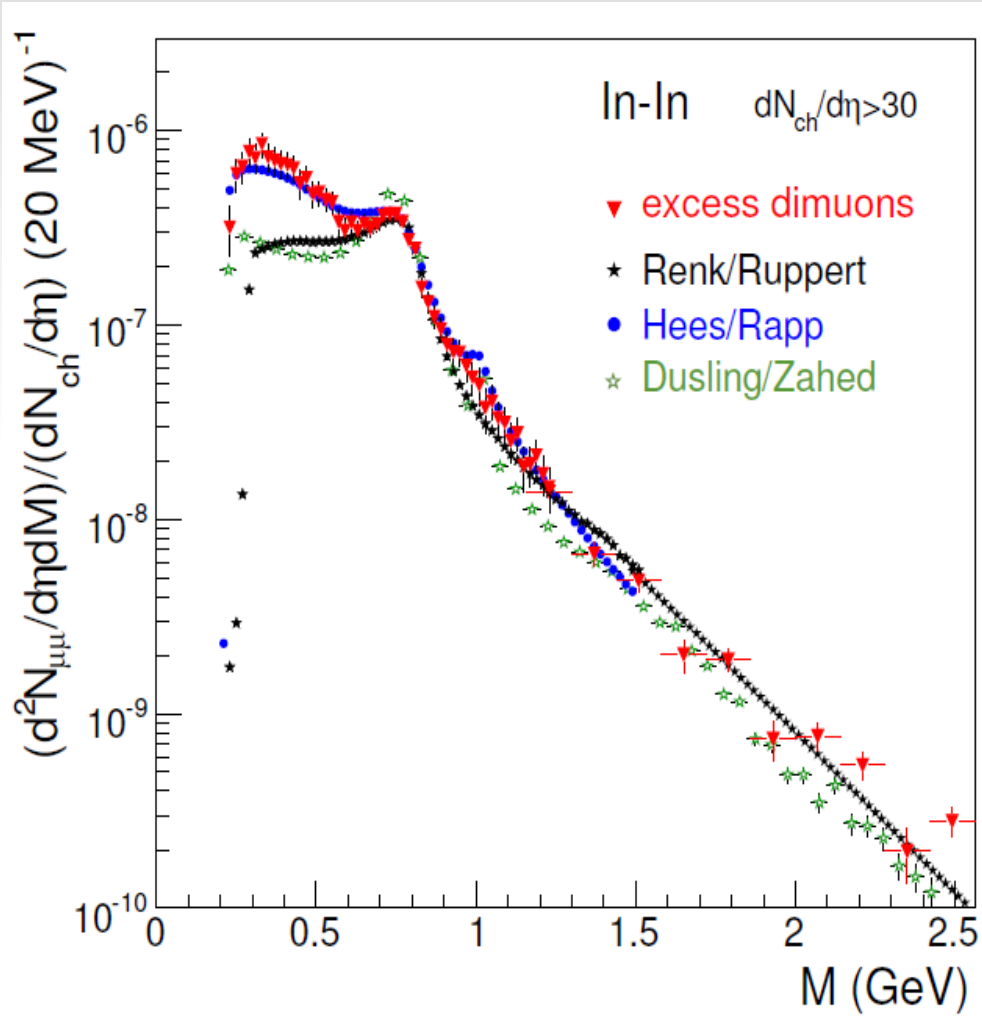
M. Martinez and M. Strickland, Phys. Rev. Lett. 100, 102301 (2008).
Phys. Rev. C 78, 034917 (2008)

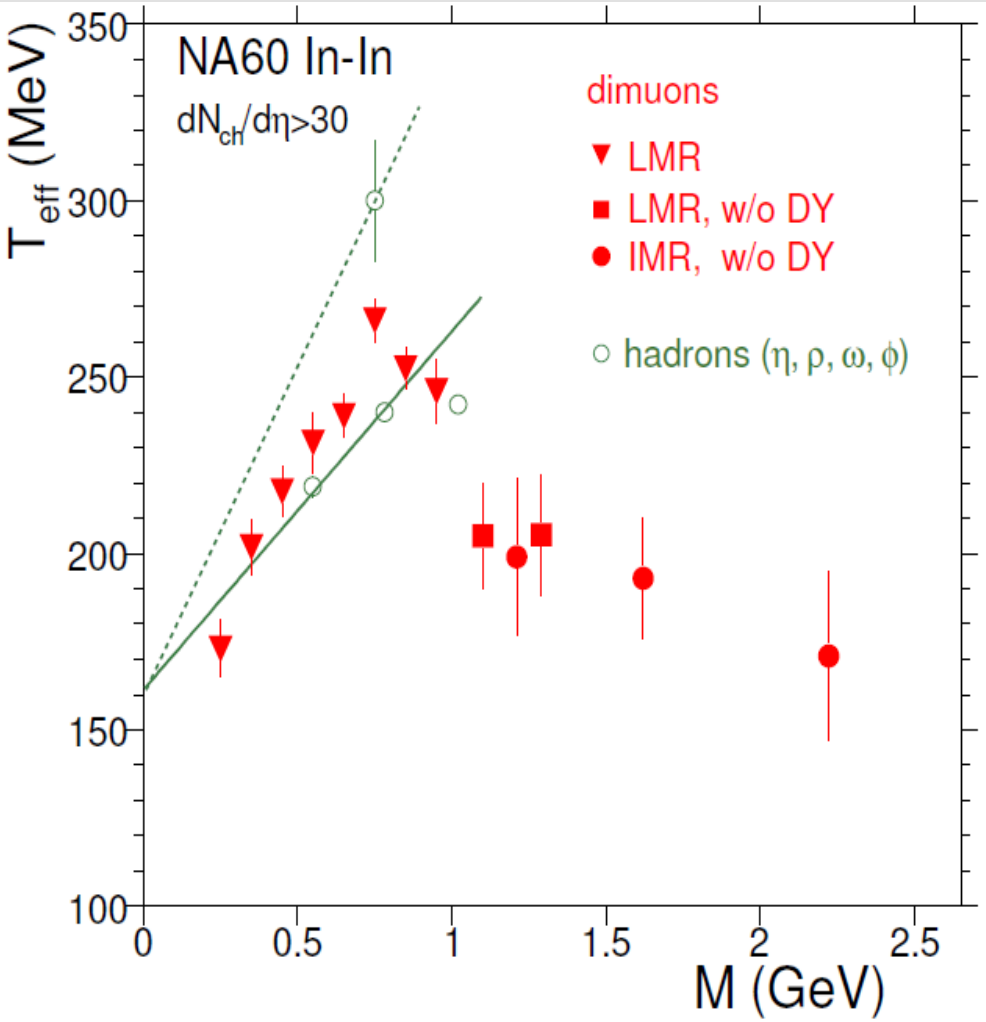
Conclusions

- Dileptons provide important information of the dynamics of the fireball:
  - → in medium hadronic properties,
  - → thermal radiation of QGP,
  - → pre- equilibrium stage: further constrains on the onset of hydrodynamics !!!
- Dilepton data from NA60 and CERES at SPS are well described by different models (Why??).
  - → Low mass region is dominated by ρ meson.
  - → In the intermediate mass region QGP thermal ratiation becomes important.
- Neither the incorporated hadronic nor partonic sources can describe the enhancement observed by PHENIX in $0.2 < M < 0.5$ GeV in Au+Au collisions.

Back up slides

More NA60 results





Dilepton emission from kinetic theory

The differential dilepton rate for $q\bar{q} \to l^+l^-$ is:

$$\frac{dR}{d^4P} = \int \frac{d^3\mathbf{p_1}}{(2\pi)^3}\frac{d^3\mathbf{p_2}}{(2\pi)^3} \underbrace{v_{rel}\, f_q(p_1,T(\tau)) f_{\bar{q}}(p_2,T(\tau))}_{\text{Phase space}} \underbrace{\sigma^{LO}_{q\bar{q}\to l^+l^-}}_{\text{pQCD}} \underbrace{\delta^4(P-p_1-p_2)}_{\text{En.-mom. conservation}}$$

The dynamics of the fireball expansion is taken into account by integrating over the space-time volume:

$$\left.\frac{dN}{dM^2dy}\right|_{y=0} = \int d^4x \int d^2P_T \frac{dR}{d^4P}$$

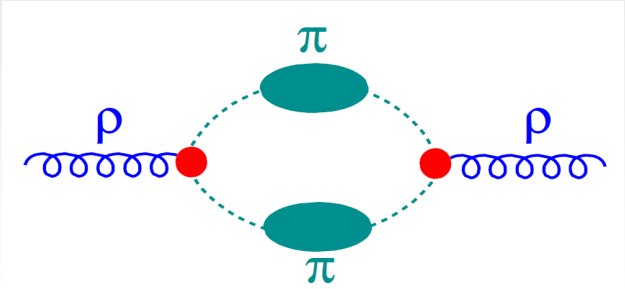
$$\left.\frac{dN}{d^2p_Tdy}\right|_{y=0} = \int d^4x \int dM^2 \frac{dR}{d^4P}$$

The evolution is encoded in the phase space distribution $f(x,p,T)$

ρ meson in Hadronic Medium

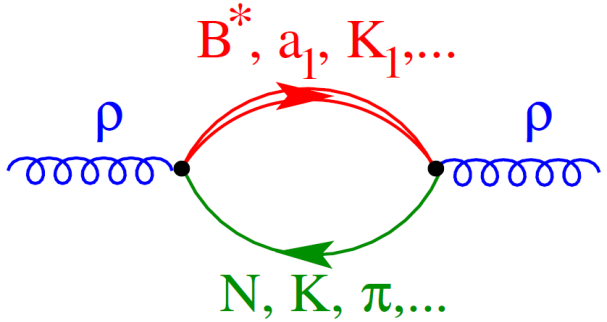
ρ-Propagator: $D_\rho(M,q;\mu_B,T) = [M^2 - m_\rho^2 - \Sigma_{\rho\pi\pi} - \Sigma_{\rho B} - \Sigma_{\rho M}]^{-1}$

$\Sigma_{\rho\pi\pi} =$



Selfenergies:

$\Sigma_{\rho B,\rho M} =$



Constraints: decays: $B,M \rightarrow \rho N, \rho\pi, \ldots$;

scattering: $\pi N \rightarrow \rho N, \gamma A, \ldots$

Chanfray et al, Herrmann et al, Asakawa et al, RR et al, Koch et al, Klingl et al, Post et al, Eletsky et al, Harada et al …

In medium spectral functions

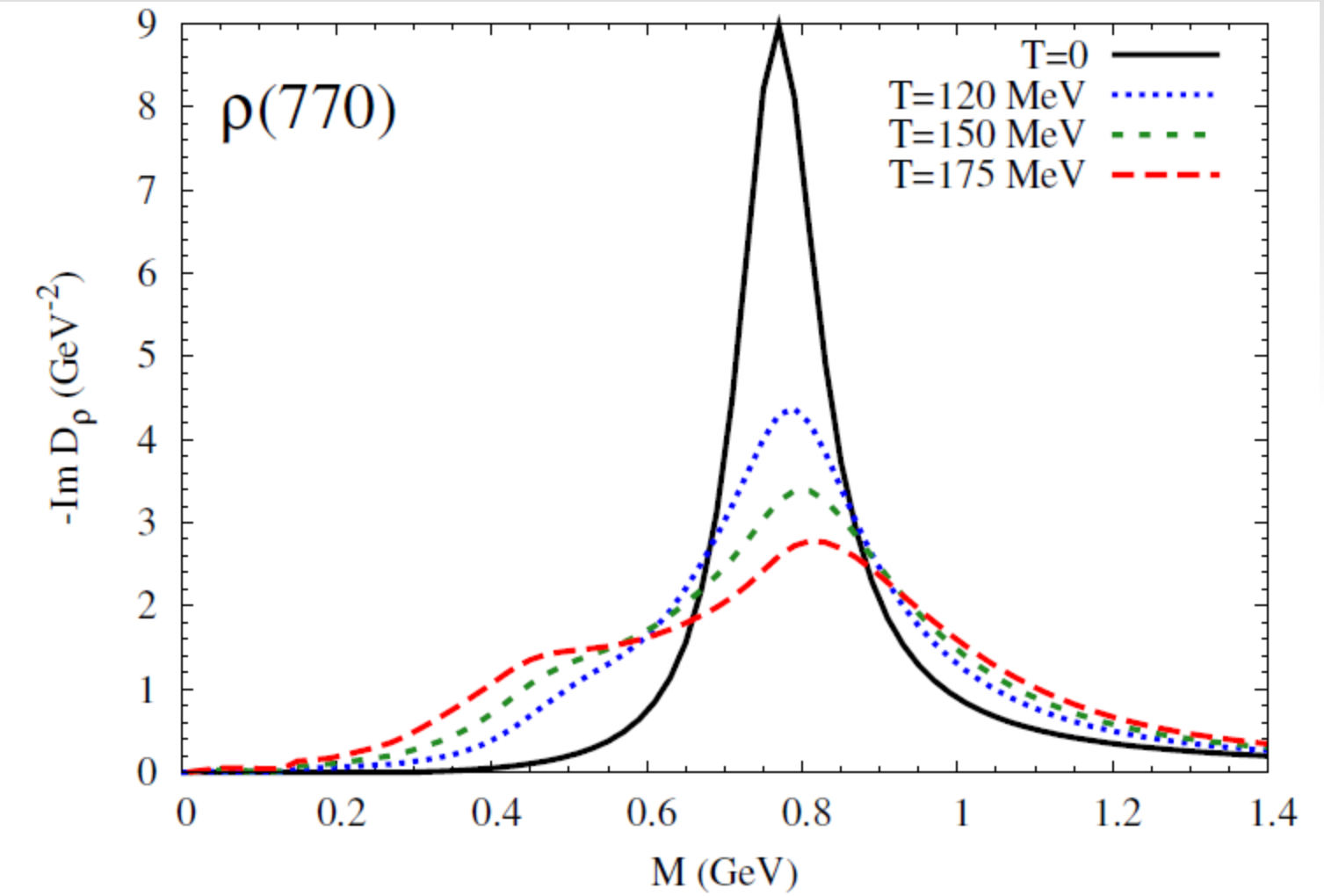
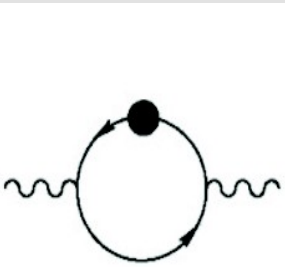


Figure from R. Rapp and J. Wambach, Adv. Nucl. Phys. 25: 1, 2000.

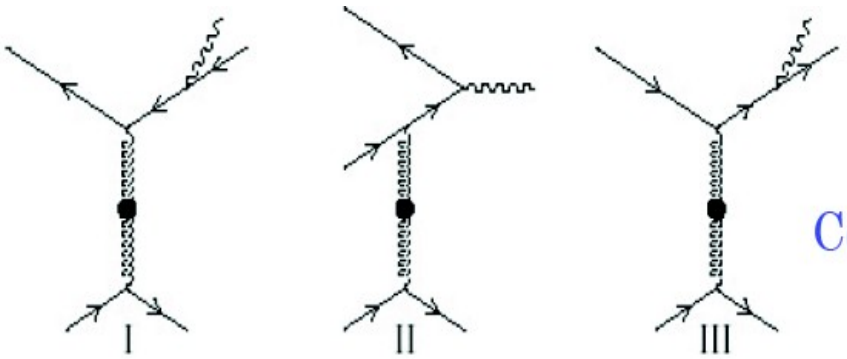
QGP medium radiation



$$\mathrm{Im}\,\Pi^{\mu}_{R\mu} \sim \ln\left(\frac{\varpi T}{\left(m_{th}\left(\sim gT\right)\right)^2}\right)$$

Kapusta et. al (1991)
Baier et. al. (1992)

At two loops: Aurenche et. al. (1996)
Aurenche et. al. (1998)



Co-linear singularities: $\alpha_s^2\left(\frac{T^2}{m_{th}^2}\right) \sim \alpha_s$

Complete results at O (α_s), AMY (2001):
LPM included, Treatment of collinear enhancement, photon and gluon emission.

Hadron vs. QGP emission rates

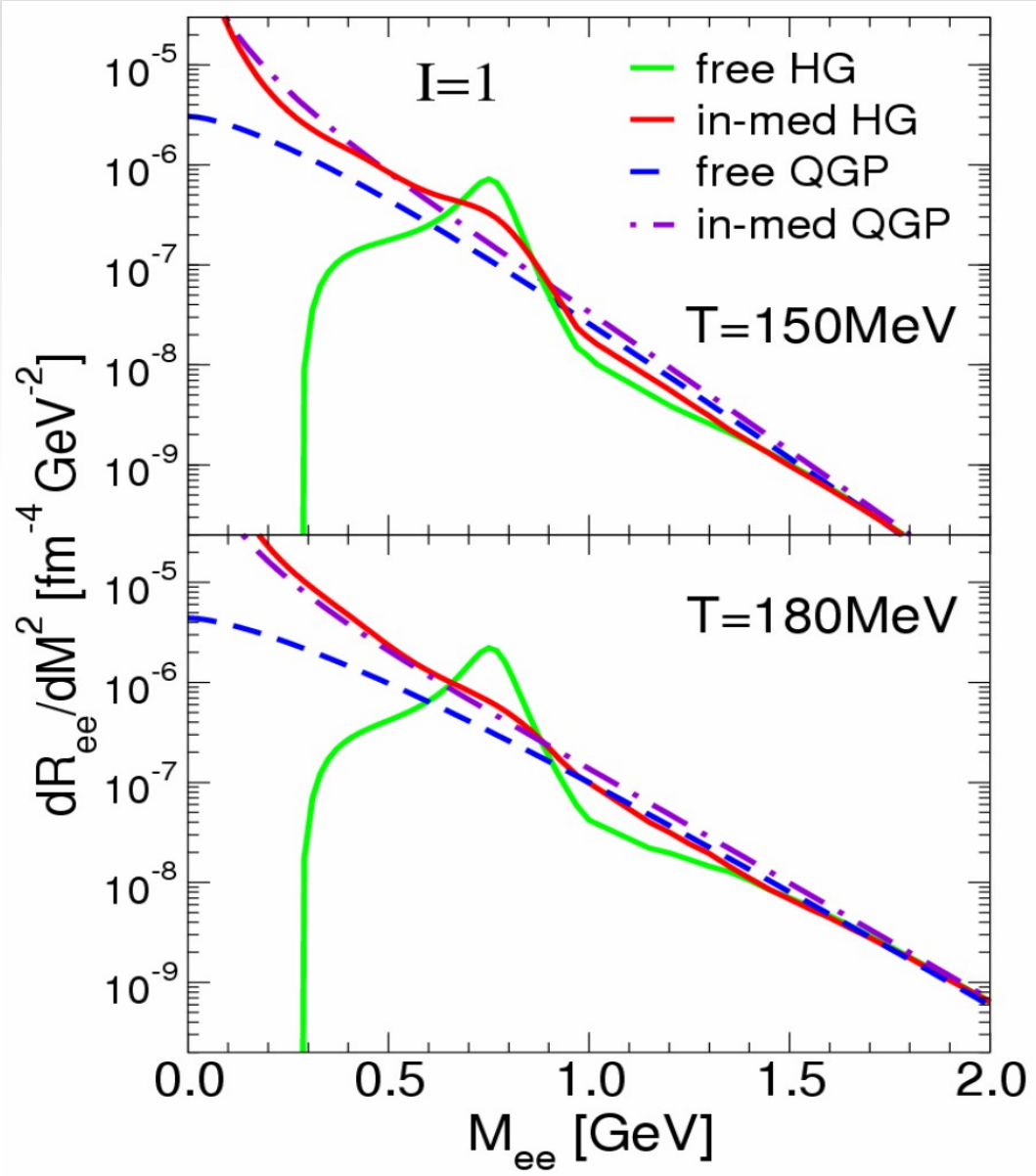


Figure from R. Rapp and J. Wambach, Adv. Nucl. Phys. 25: 1, 2000.