Di-lepton Production in HI Collisions and the QCD Phase Diagram

Outline:

- ✧ Introduction.
- ✧ Di-lepton sources.
- ✧ Di-lepton production at RHIC energies.
- ✧ Energy dependence, m_T, v_2 …
- ✧ Summary.

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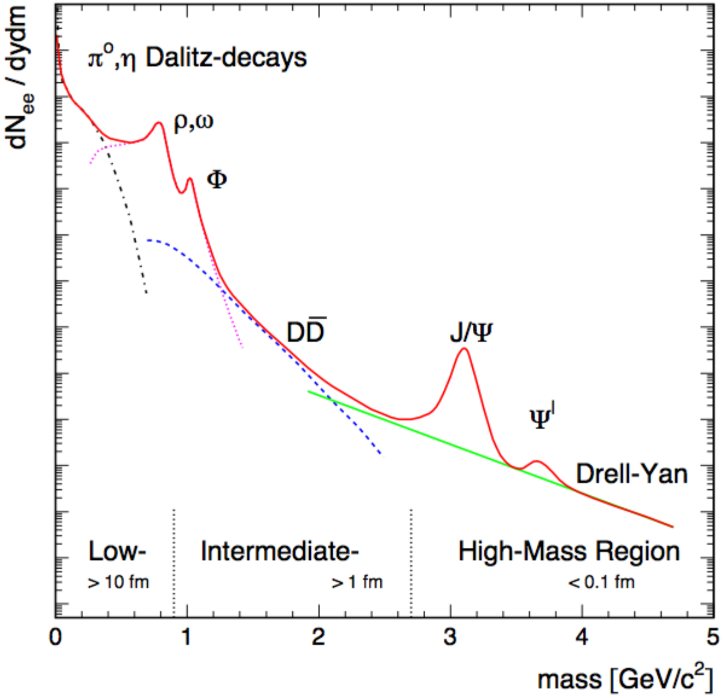
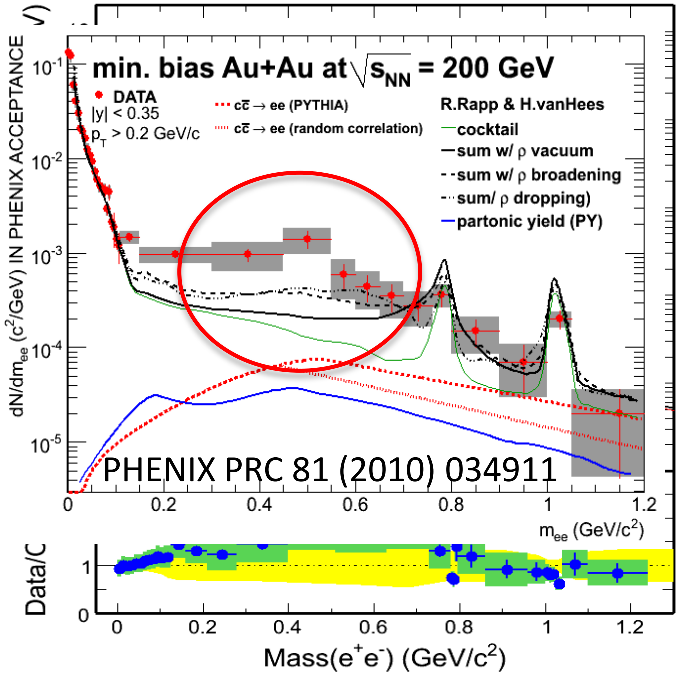
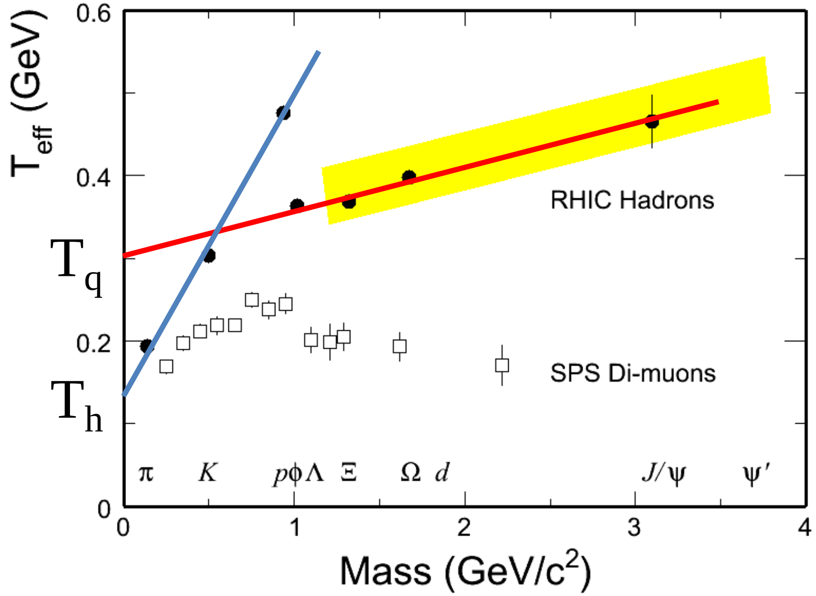
Introduction - I







SPS 17 GeV, PRL 100, 022302 (2008)

RHIC 200 GeV, NPA 757,102 (2005)

$$T_{\text{eff}} = T_0 + M v_T^2$$

LMR Chiral symmetry restoration
Vector meson production: in-medium effect

IMR Heavy quark correlation
QGP thermal radiation

HMR Heavy quarkonian production
Drell-Yan

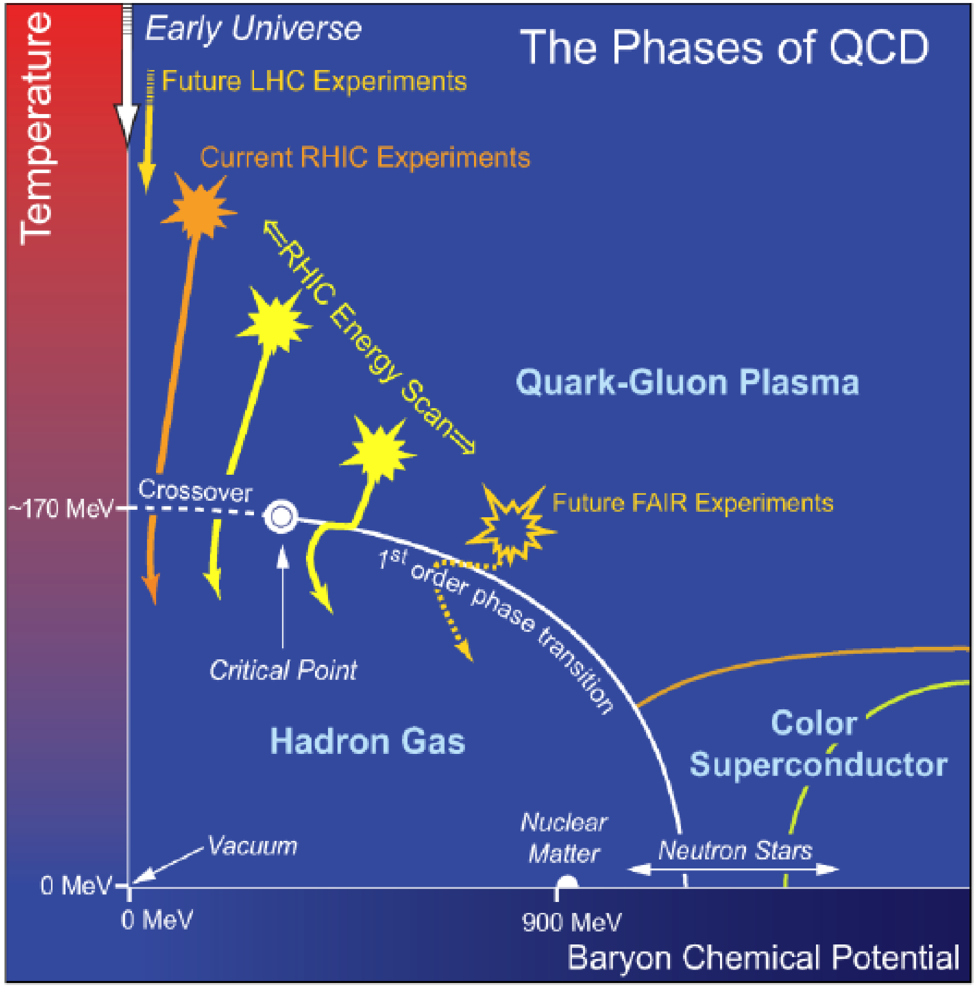
Electromagnetic probes =>

Do not participate in strong interactions.

Bring undistorted information of early production.

Penetrate medium properties.

Introduction - II



RHIC Energy Scan Program:

- Mapping QCD phase boundary.
- Search for QCD critical point.

Observables: fluctuations, flow, correlations …

What about "di-lepton"?

- Mass spectra
- m_T slope
- v_2

How are the behaviors in HG/QGP phase:

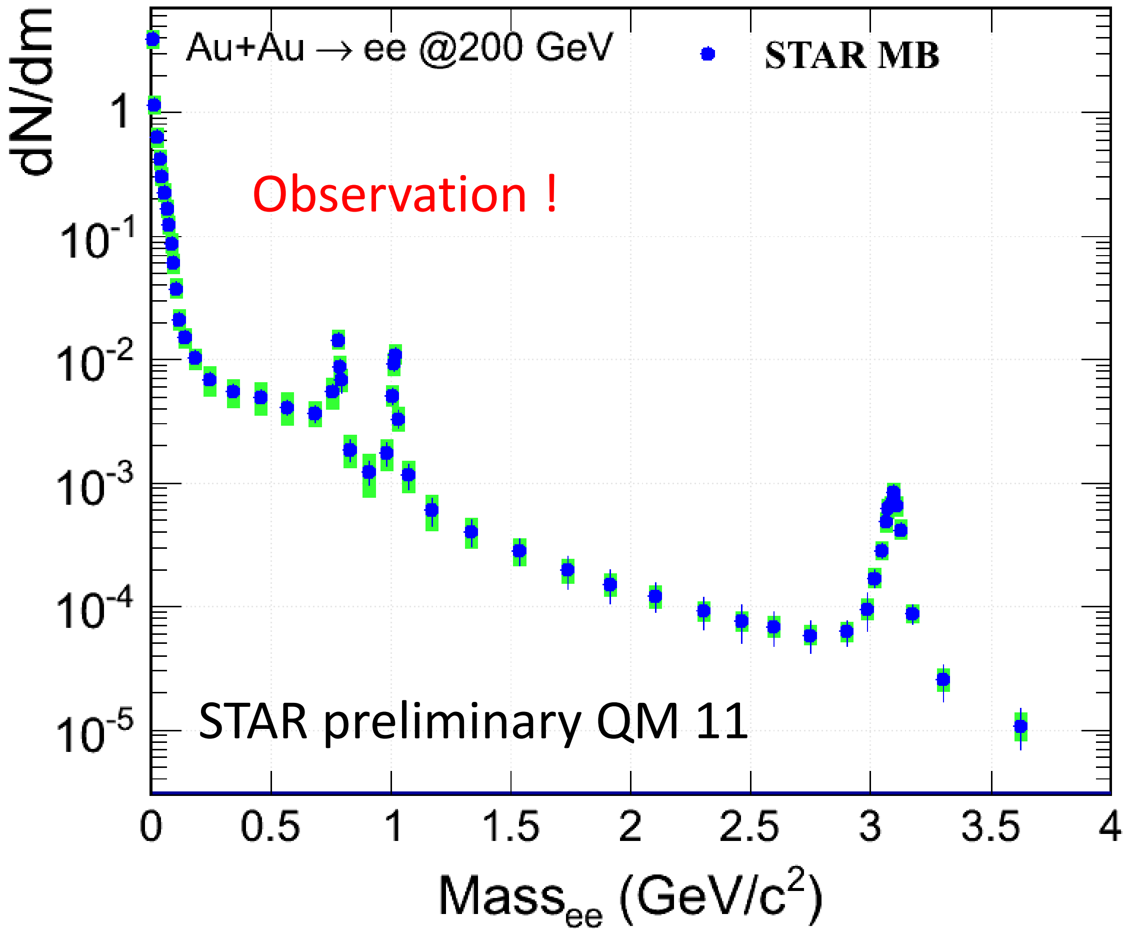
- light meson freeze-out
- ρ meson
- charm correlation
- thermal di-leptons

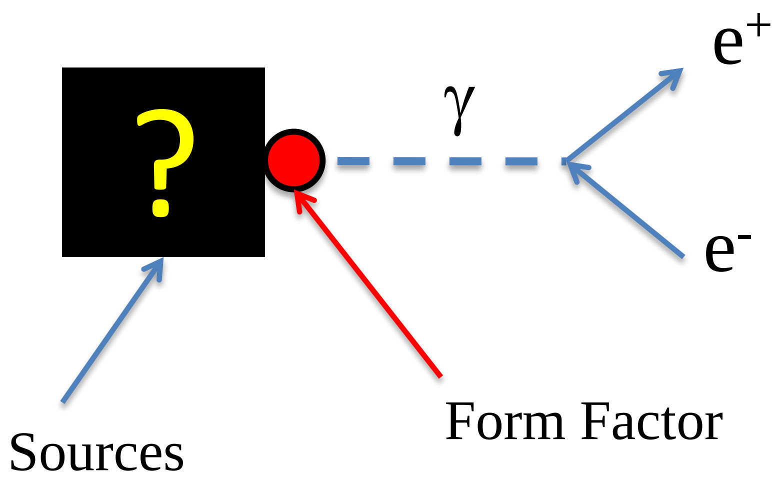
Di-lepton sources

What 's a "di-lepton"? – see Volker Koch 's lecture and Qun Wang 's talk.

Where does di-lepton come from? – A complicated mess, containing many uncertainties.

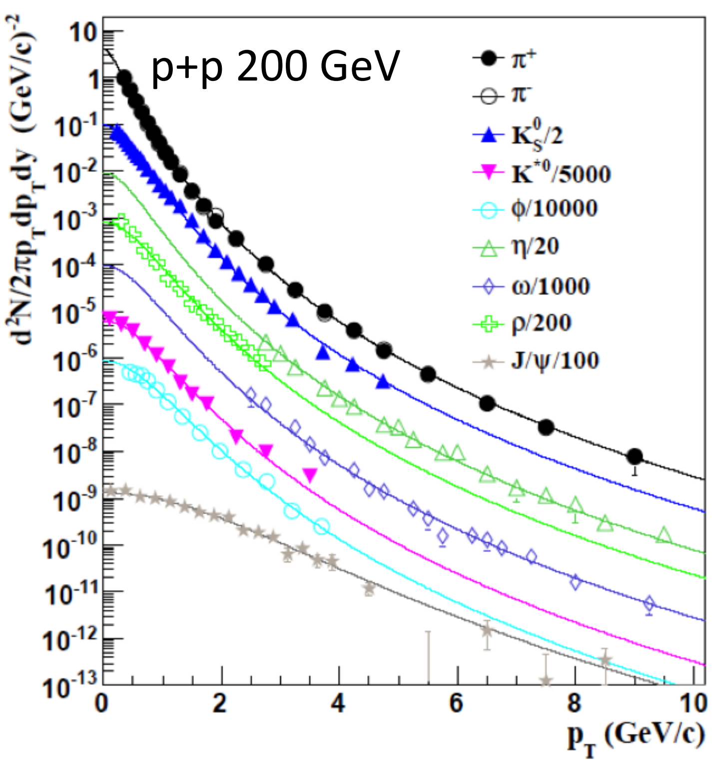
We study the di-lepton sources – A simulation based on constraints from measurements.

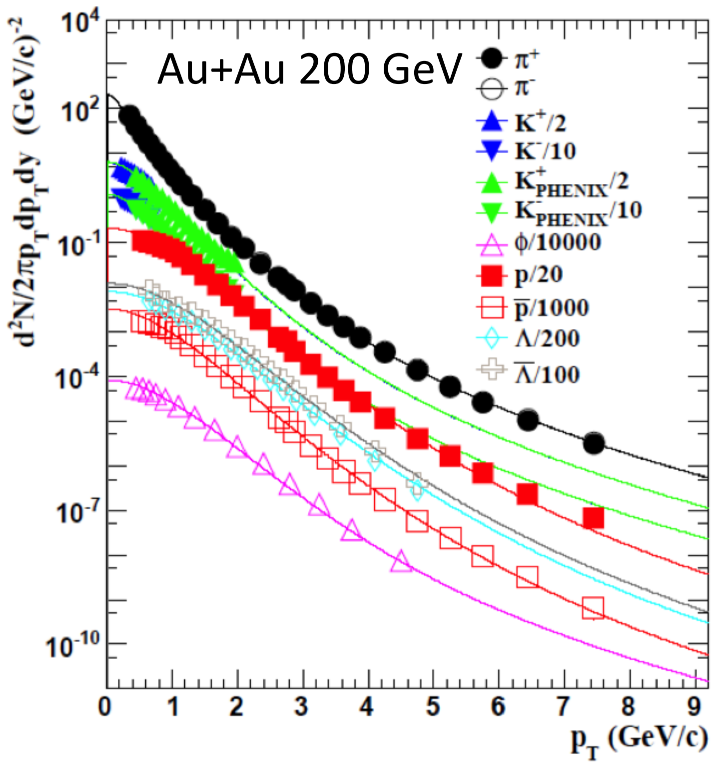




Mesons p_T distributions

Input meson p_T spectra --- Tsallis Blast-Wave(TBW) fit to measurements.





$$\frac{dN}{m_T dm_T} \propto m_T \int_{-Y}^{+Y} cosh(y)dy \int_{-\pi}^{+\pi} d\phi \int_0^R rdr$$
$$\times (1 + \frac{q-1}{T}(m_T cosh(y) cosh(\rho) - p_T sinh(\rho) cos(\phi)))^{-1/(q-1)}$$

ρ is related to average flow velocity.
$q-1$ is the degree of non-equilibrium.
T is the freeze-out temperature.

Z. Tang, et.al., PRC79 051901 (R).

Decays

Kroll-Wada Formula:

$$\frac{dN}{dm_{ee}} \propto \sqrt{1-\frac{4m_e^2}{m_{ee}^2}} \cdot \left(1+\frac{2m_e^2}{m_{ee}^2}\right) \cdot \frac{1}{m_{ee}} \cdot \left(1-\frac{m_{ee}^2}{M_h^2}\right)^3 |F(m_{ee}^2)|^2$$

QED | Phase Space | Form Factor

N.M. Kroll, et al., Phys Rev, 98 (1955) 5.

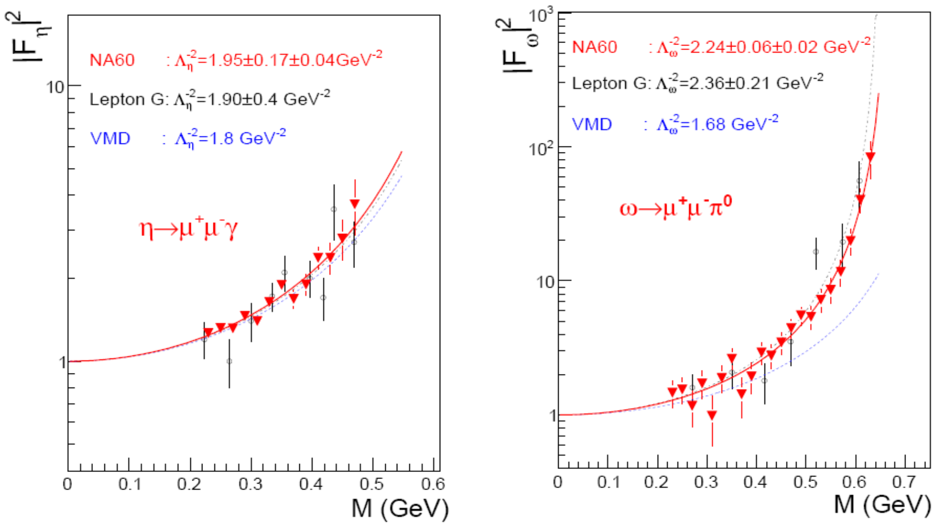
Towbody: Breit-Wigner

Dalitz: Kroll-Wada

FF: parameterized from measurement.

Phase Space term for ω, ϕ:

$$(1-\frac{m_{ee}^2}{m_h^2})^3 \Rightarrow ((1+\frac{m_{ee}^2}{m_\omega^2-m_{\pi^0}^2})^2-\frac{4m_\omega^2 m_{ee}^2}{(m_\omega^2-m_{\pi^0}^2)^2})^{\frac{3}{2}}$$



NA60: PLB677 (2009) 260.

$$|F(m_{ee}^2)|^2=\frac{1}{(1-m_{ee}^2\cdot\Lambda^{-2})^2+\Gamma_0^2\cdot\Lambda^{-2}}$$

$$\frac{dN}{dm_{ee}dp_T} \propto \frac{m_{ee}M_\rho\Gamma_{ee}}{(M_\rho^2-m_{ee}^2)^2+M_\rho^2(\Gamma_{\pi\pi}+\Gamma_{ee}\Gamma_2)^2} \times PS,$$

ρ line shape:

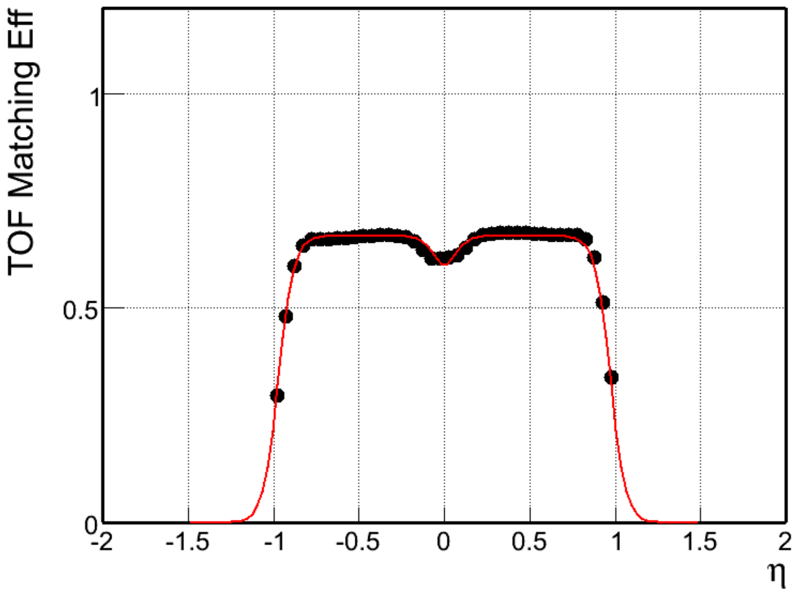
P-wave of ππ channel: $\Gamma_{\pi\pi}=\Gamma_0\frac{M_\rho}{m_{ee}}(\frac{m_{ee}^2-4M_\pi^2}{M_\rho^2-4M_\pi^2})^{3/2},$

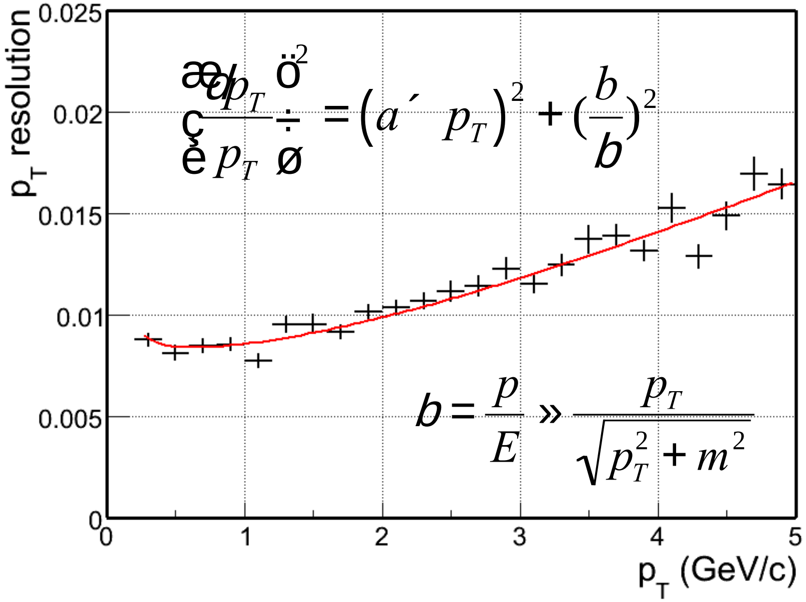
S-wave of ee channel: $\Gamma_{ee}=\Gamma_0\frac{M_\rho}{m_{ee}}(\frac{m_{ee}^2-4m_e^2}{M_\rho^2-4m_e^2})^{1/2},$

$$PS=\frac{m_{ee}}{\sqrt{m_{ee}^2+p_T^2}}e^{-\frac{\sqrt{m_{ee}^2+p_T^2}}{T}}.$$

PRC 78, 044906 (2008)

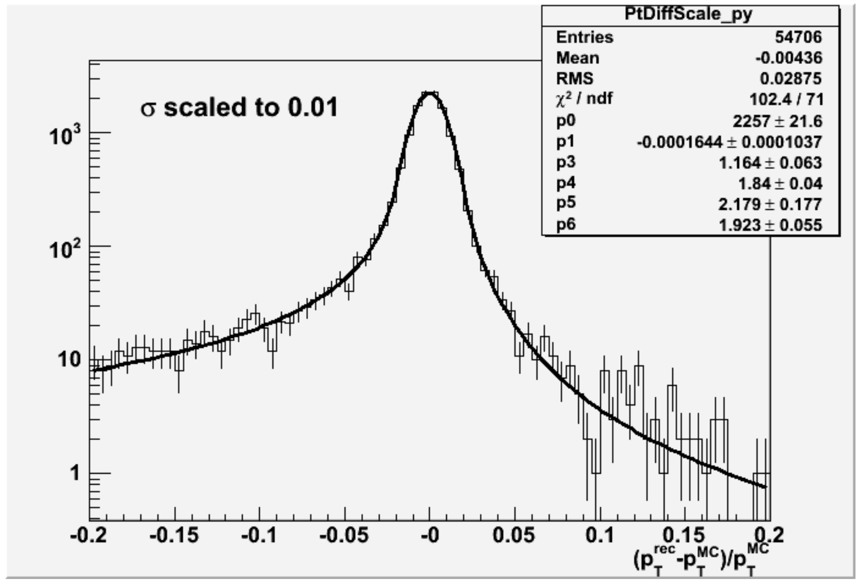
Detector acceptance and response





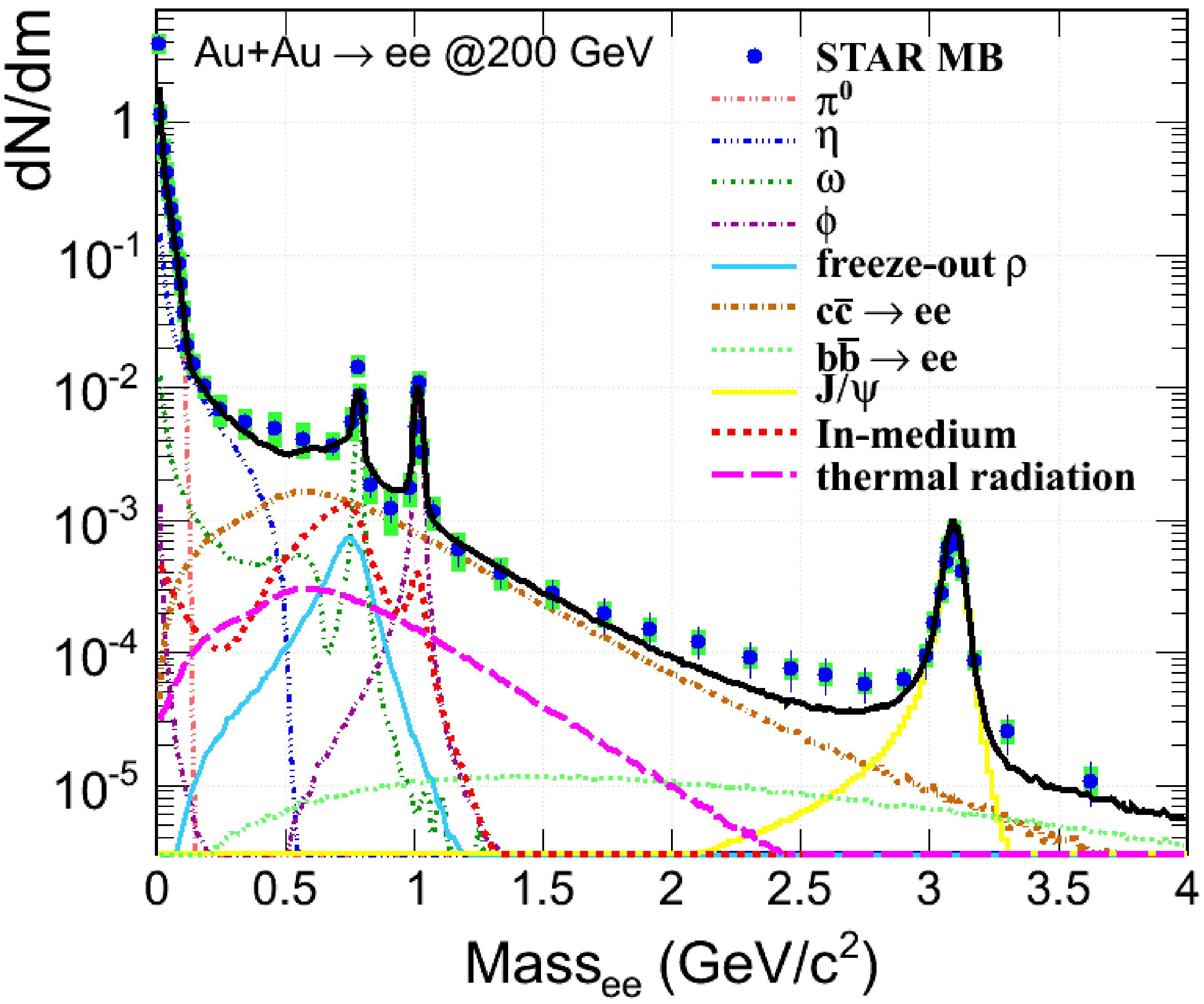
To compare the calculation with measurement, we have to also consider:

- Detector acceptance
- Mass/momentum resolution
- Electron bremsstrahlung.



Double-crystal-ball function for energy loss

Di-electron production at RHIC top energy 200 GeV

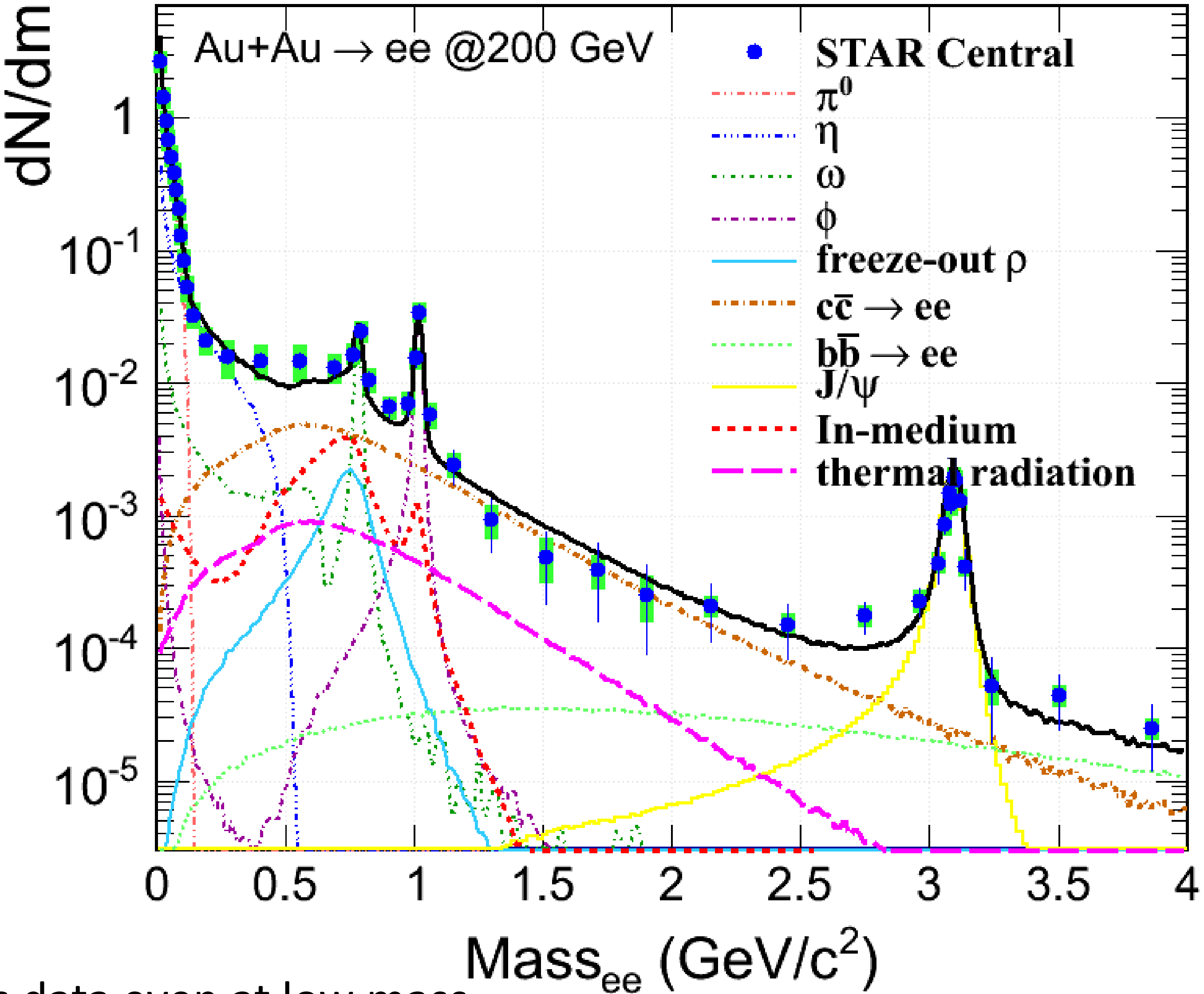


Data from
STAR prel. QM 11

Reproduces data even at low mass, except mass 2-3 GeV.
Charm X-sec: 0.71 mb

In-medium & thermal rad:
H. Xu, et. al, arXiv: 1110.4825 [nucl-th]

Au+Au 200 GeV central collisions



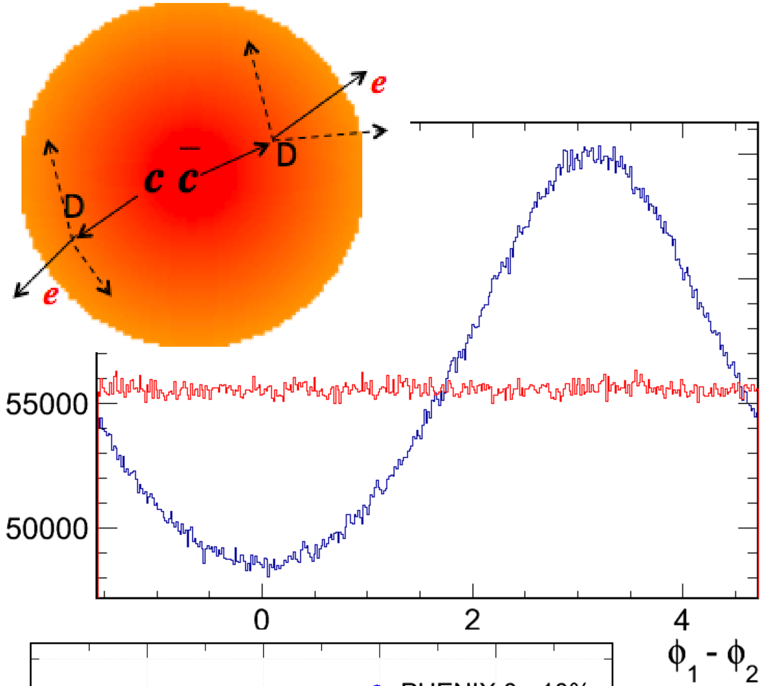
Data from
STAR prel. QM 11

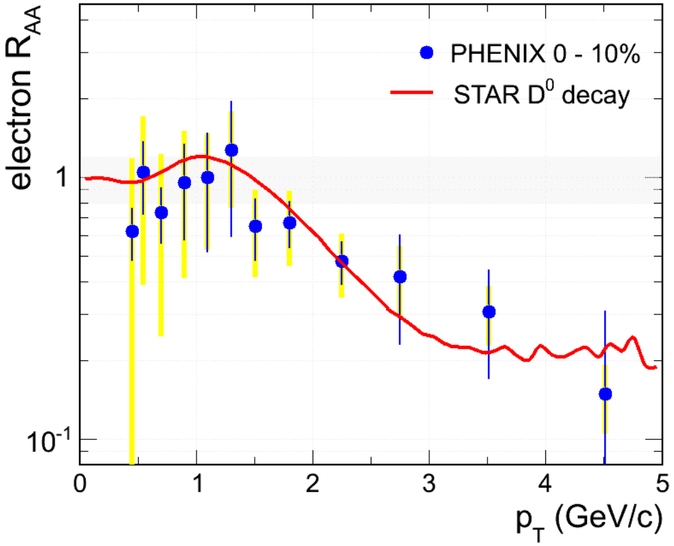
Reproduces data even at low mass.
Enhancement due to In-medium ρ.
Possible charm medium-modification?

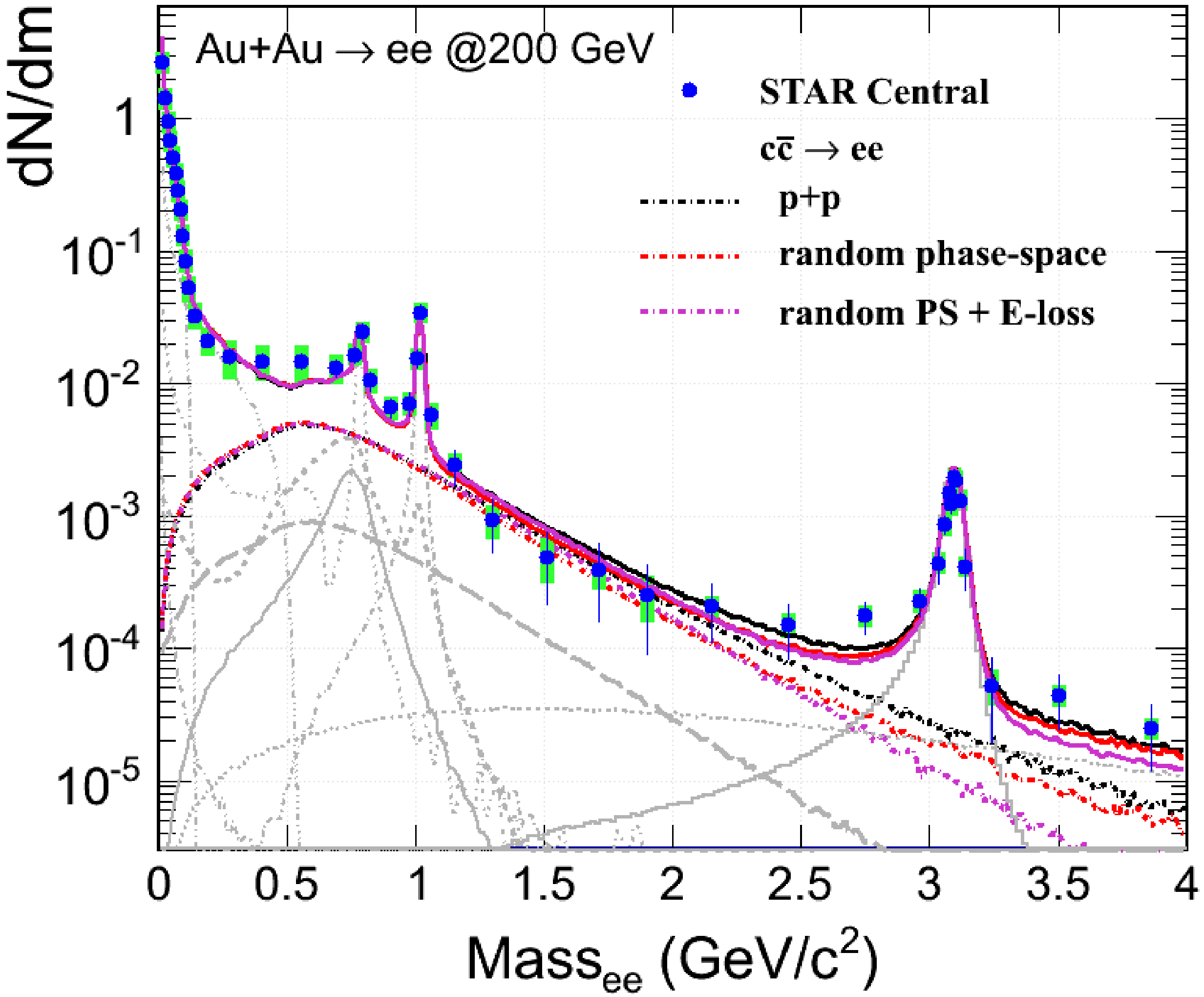
In-medium & thermal rad:
H. Xu, et. al, arXiv: 1110.4825 [nucl-th]

Charm medium-modification

Two naïve approach:
1) Random angular correlation.
2) Energy loss (still on going).



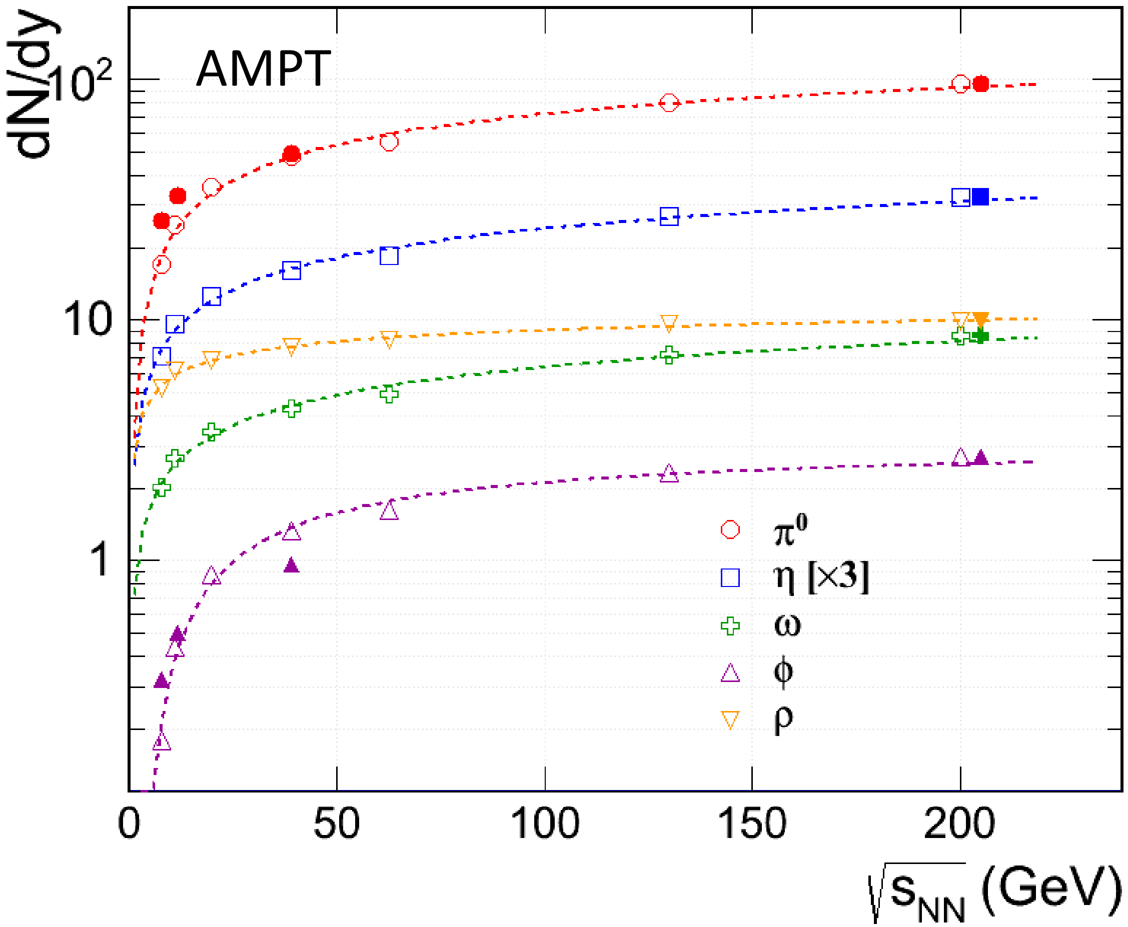


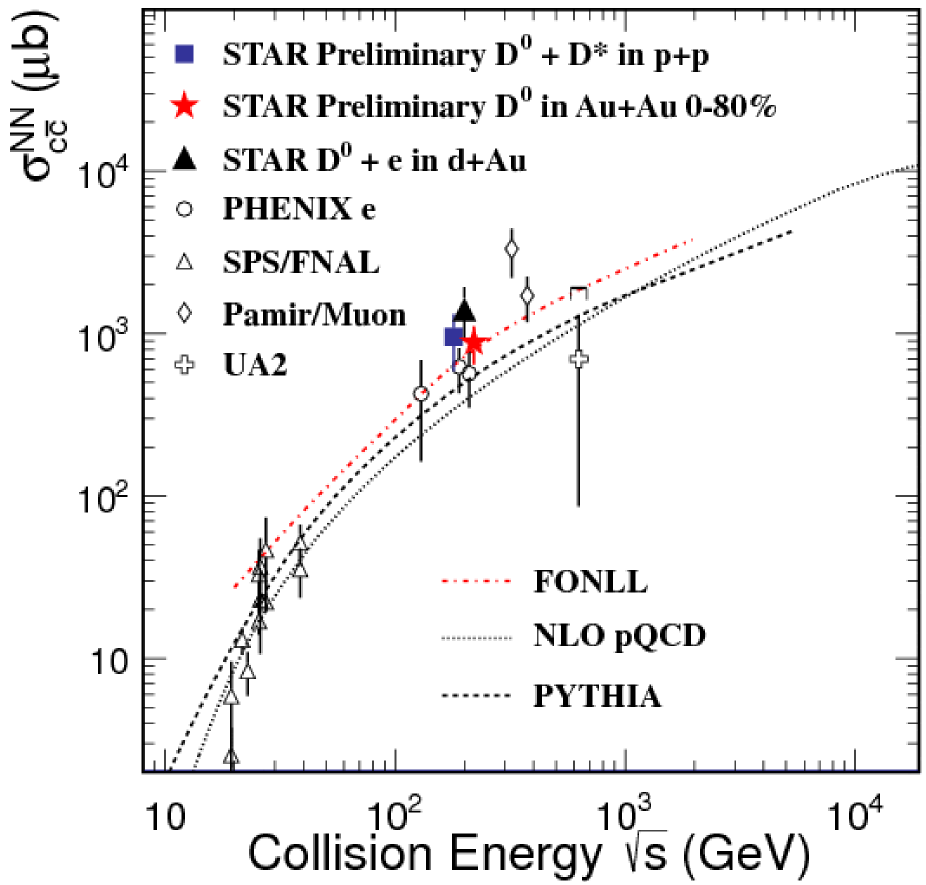


No significant changes for mass spectrum.
But how is the effect on m_T slope?

Extrapolation to lower energies

dN/dy and p_T distributions from AMPT calculations.
Charm cross section: NLO calculation for low energies.



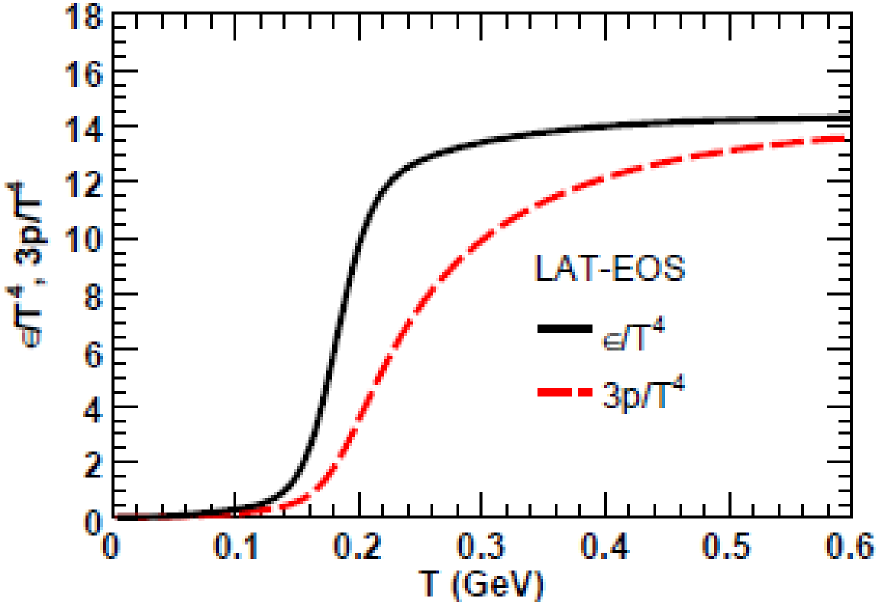


Scale to measurements at 200 GeV (solid symbols), some difference at lower energy.

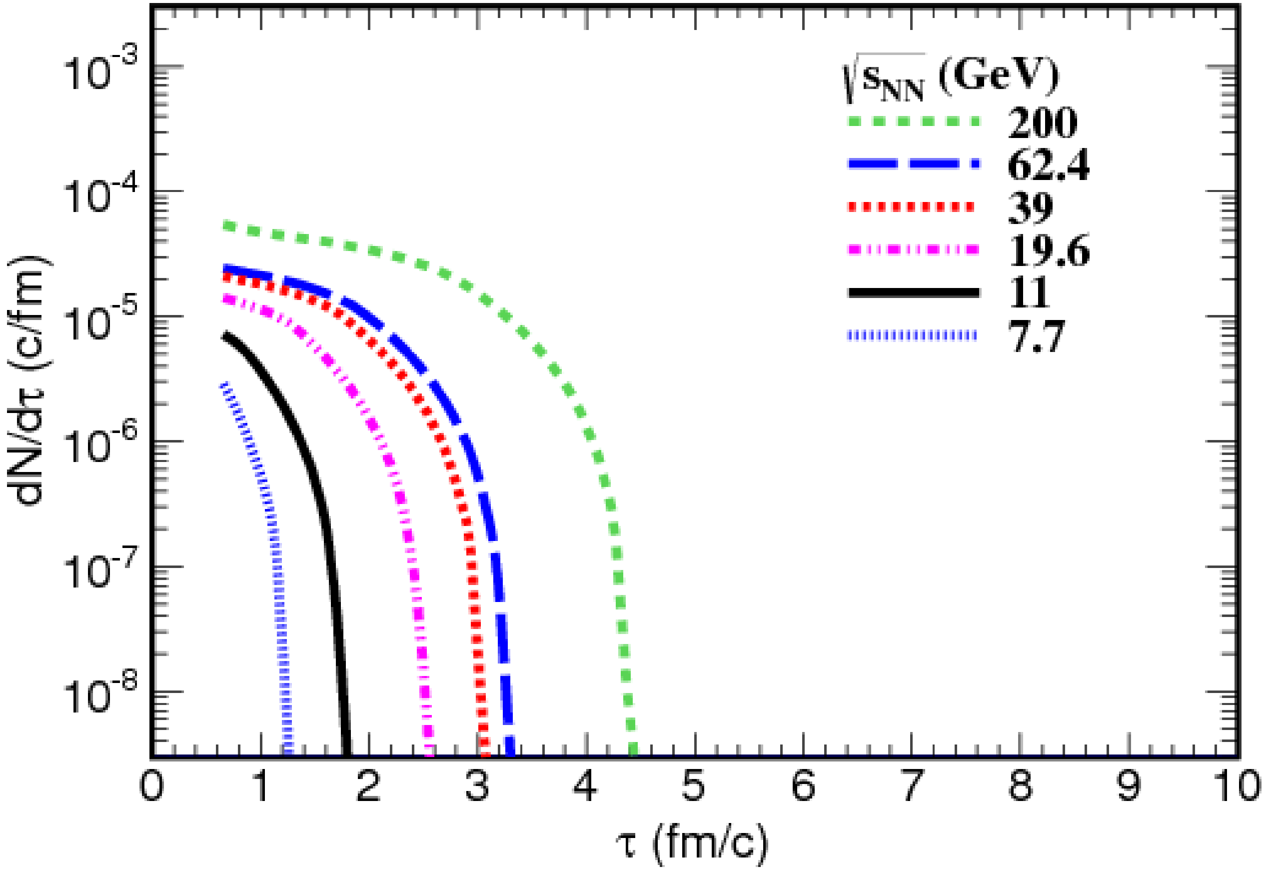
Space-time evolution

B. Schenke, et. al., PRC82, 014903 (2010)

Thermal dileptons:
(2+1)D ideal hydrodynamics
Lattice EOS
Parameters: S95-PCE

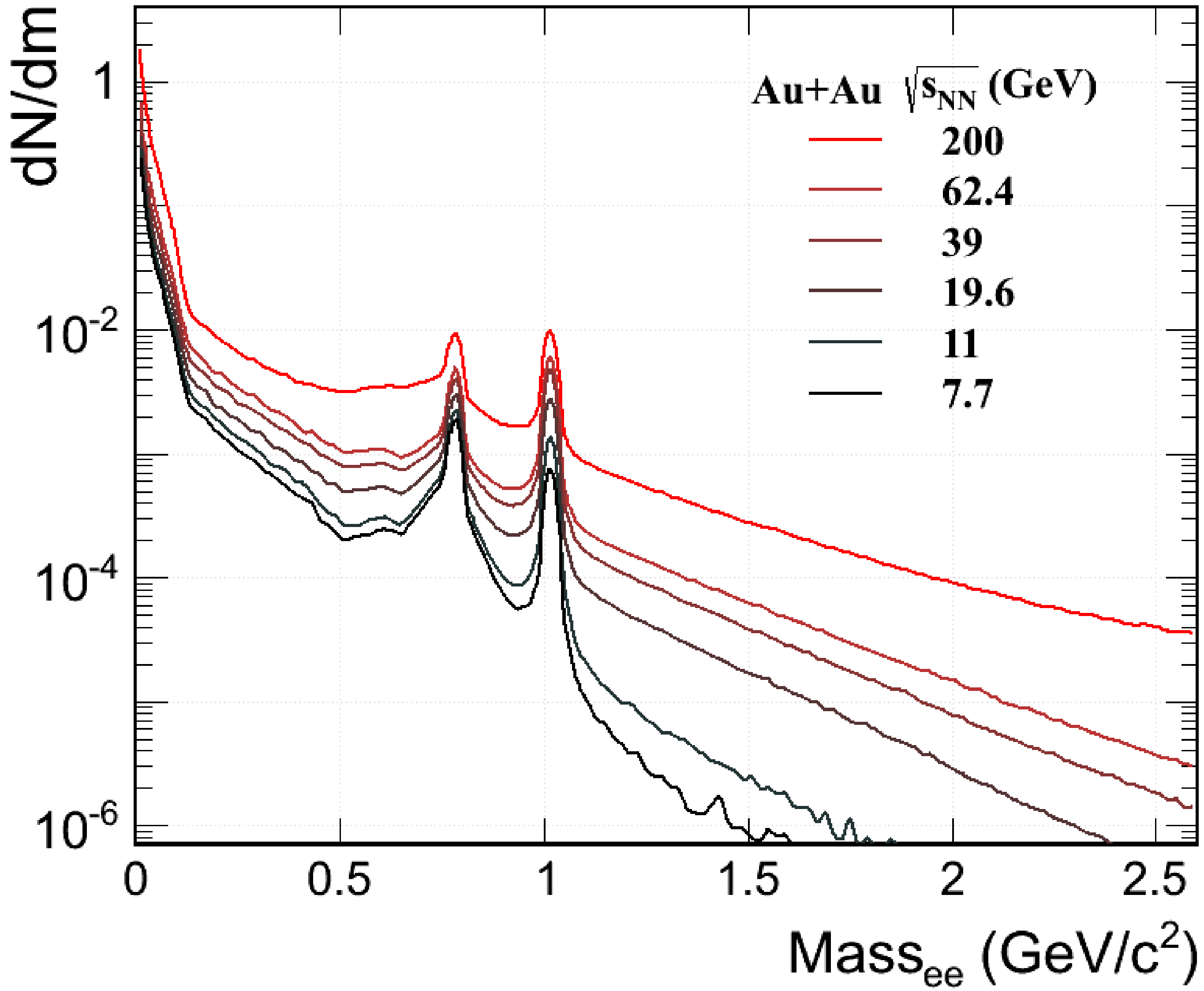


P. Huovinen and P. Petreczky, NPA837 (2010) 26.



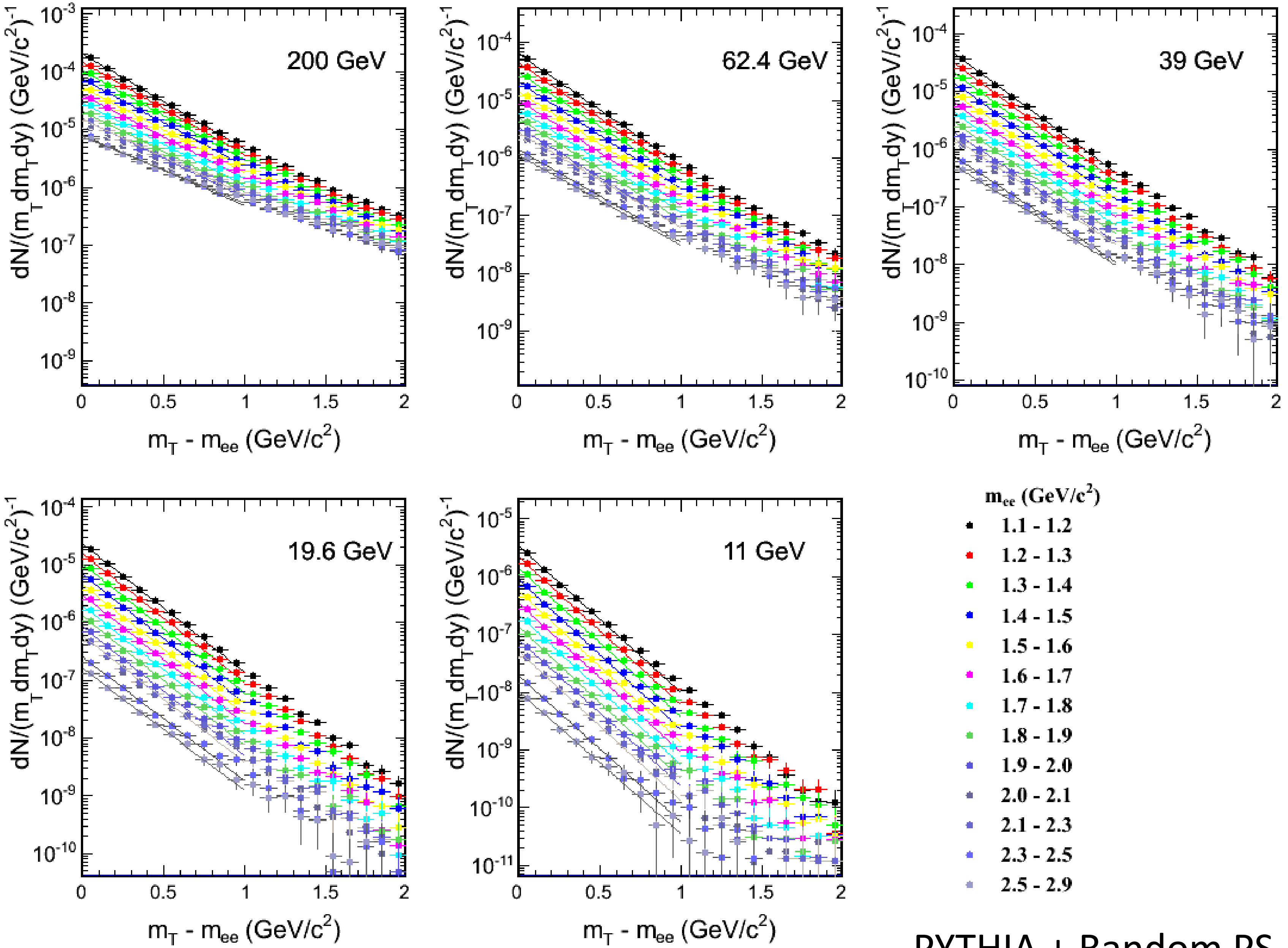
Higher energy =>
larger initial temperature
longer evolution time.

Extrapolation to lower energies



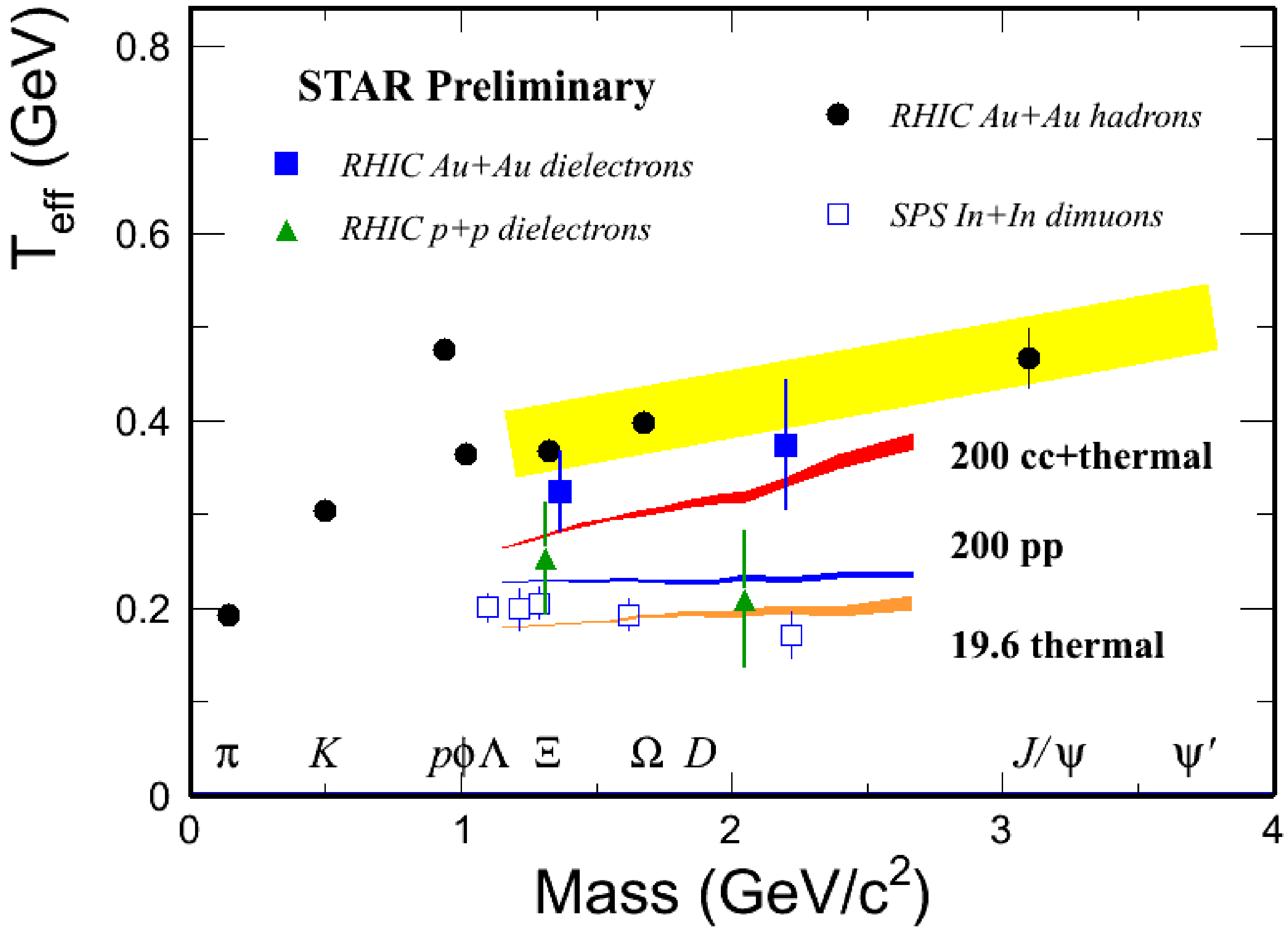
Strong energy dependence, softer in lower energy.
Charm and partonic contributions become smaller when energy decreasing.

m_T slope in the IMR



PYTHIA + Random PS + thermal

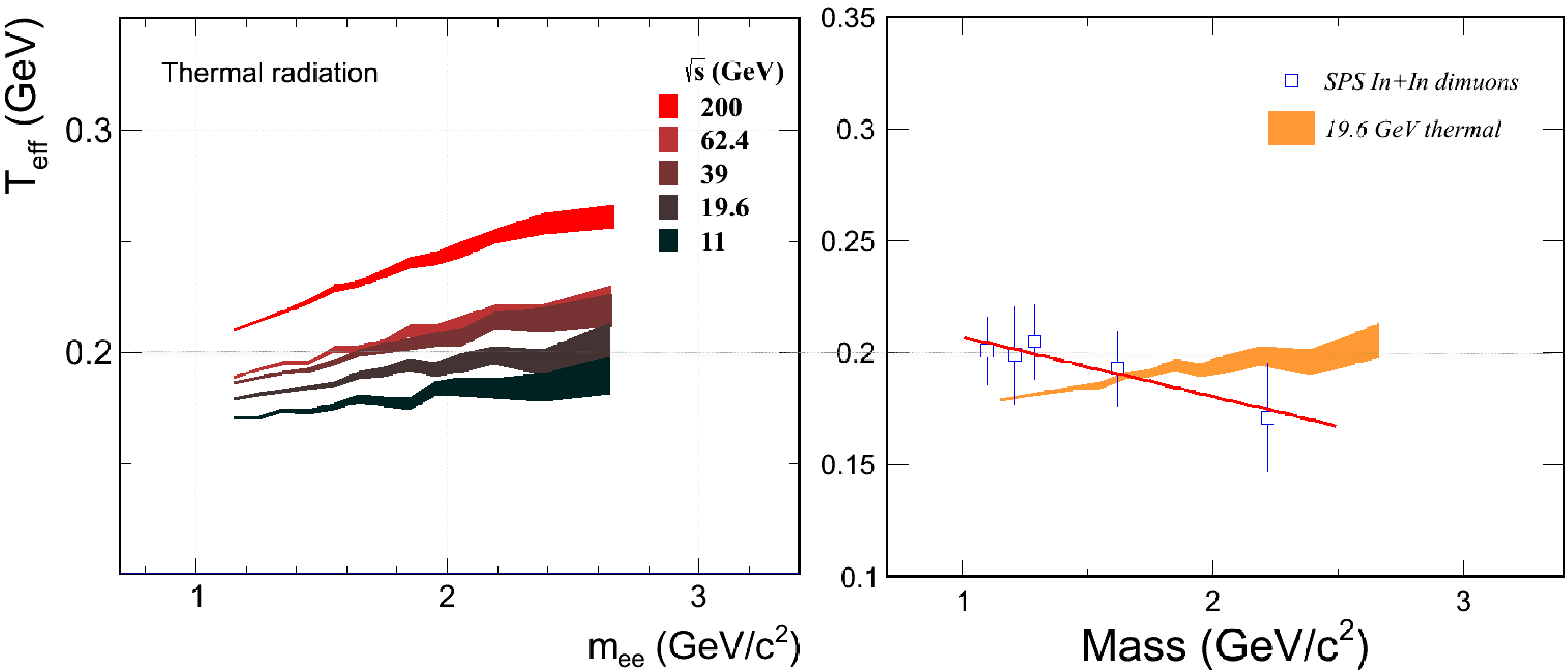
m_T slope in the IMR



Thermal radiation shows slightly increasing trend, which seems different from NA60.
Thermal only is lower than STAR data that with charm contribution.

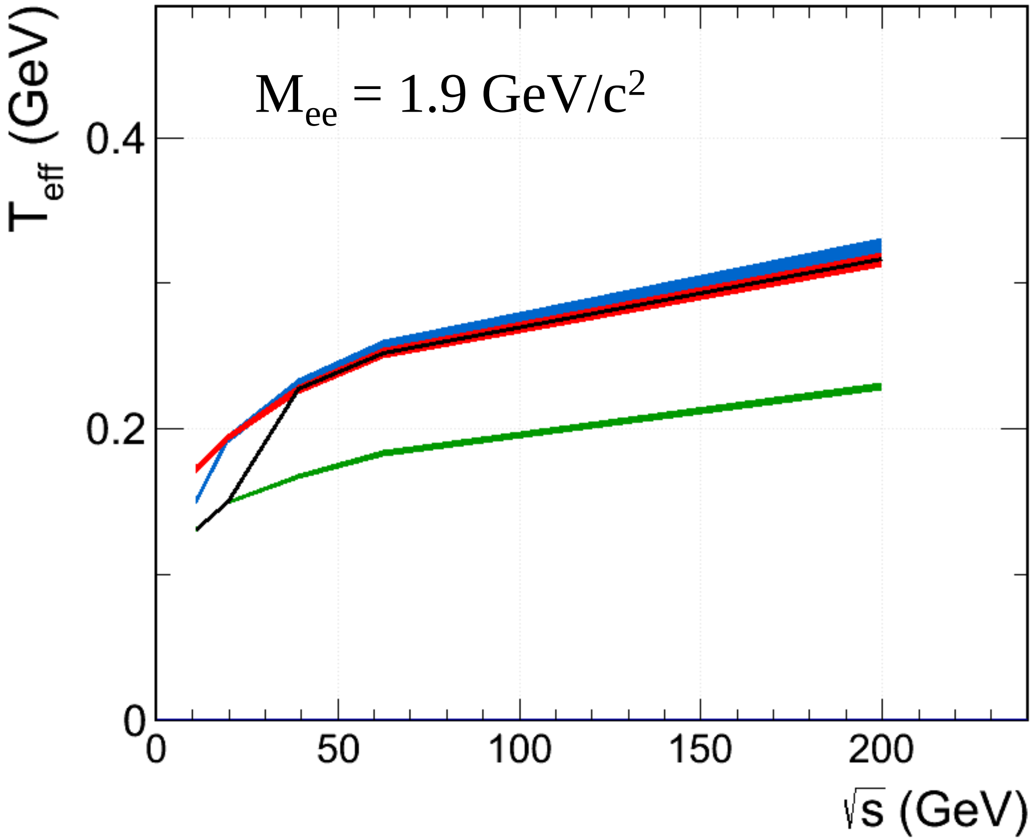
Within errors 19.6 GeV agrees with NA60 (~17 GeV).
Charm correlation in p+p is consistent with STAR p+p data (QM11).
Charm correlation modified by medium. Thermal + charm reproduce STAR Au+Au data well.

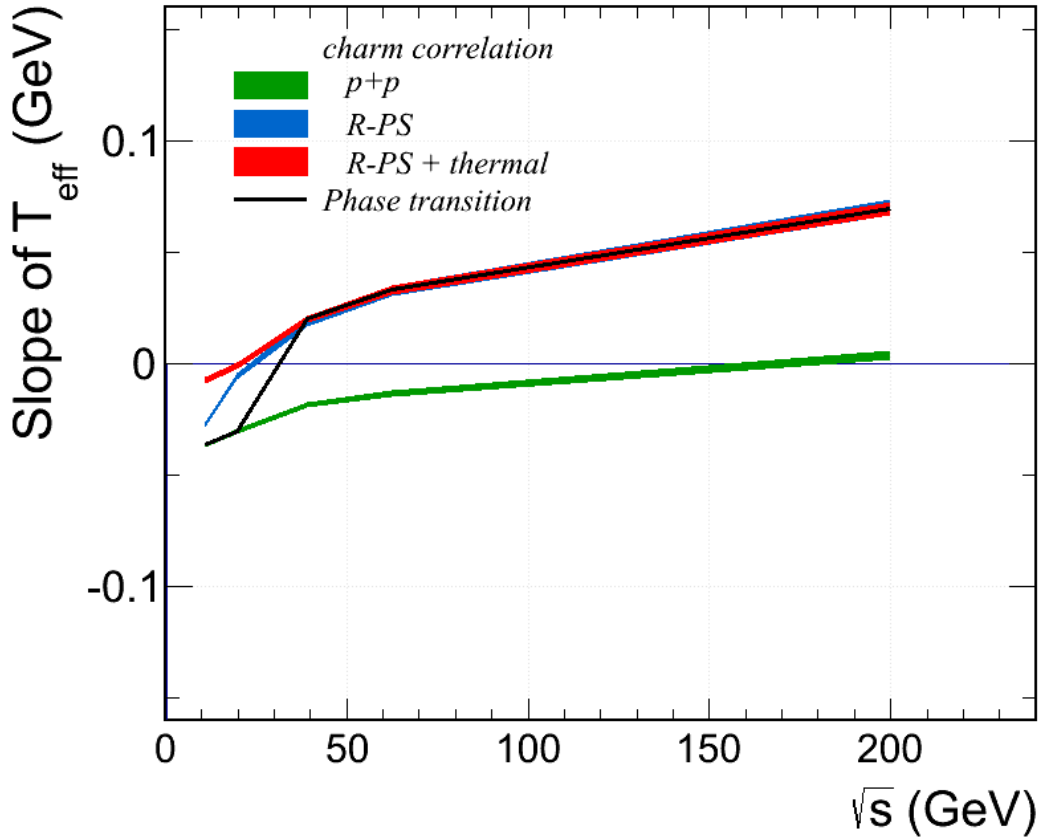
Compare with NA60



Small energy dependence for the T_{eff} of thermal di-leptons.
Thermal radiation shows slightly increasing trend, which seems different from NA60. Average temperature is similar.

Possible observation at phase transition?





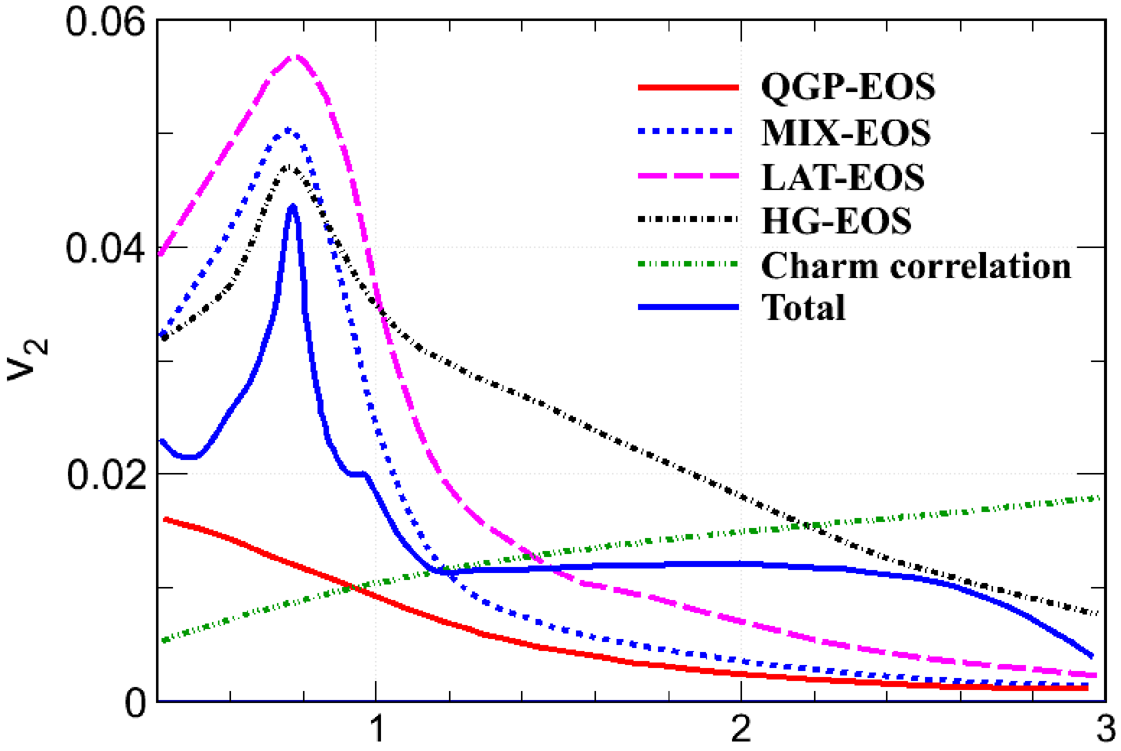
High energy dominant by charm correlation, lower energy charm and thermal contributions are comparable.

Both T_{eff} and its slope in medium are significant higher than the system w/o medium.

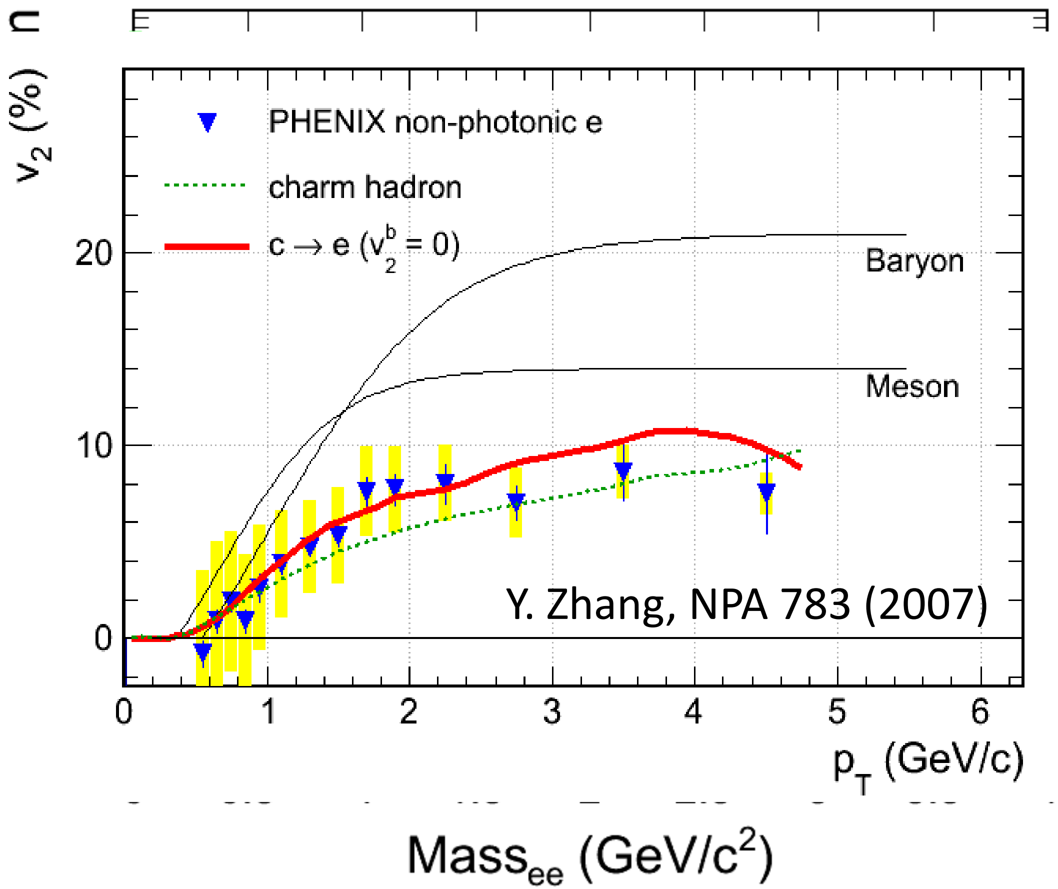
Phase transition could happen if the T_{eff} increases dramatically or the sign of its slope changes from negative to positive.

Di-lepton v_2

J.Deng, QW, N.Xu, P.-f. Zhuang, PLB701,581(2010)



Qun Wang 's talk



It 's very difficult to measure thermal di-lepton v_2 (red).

Charm correlation v_2 (green) is estimated by implementing electron v_2 in the decay kinematics.

But di-lepton v_2 with a combination of thermal and charm correlation (blue solid) is measurable, which is still significantly smaller than the v_2 from hadronic process.

Freeze-out meson v_2 is not include, which is even larger.

Summary

◆ Cocktail simulations reproduce STAR data well. Including In-medium ρ and thermal di-lepton, we can explain the "enhancement" of data at low mass region.

◆ Extrapolation to lower energies based on AMPT model (vector mesons), (2+1)D hydro (thermal) and charm correlation (PYTHIA).

1) Predict the cocktails for STAR BES, expect data coming soon for comparison.

2) m_T slope of charm correlation from PYTHIA (pp) agrees with STAR p+p result.

3) m_T slope of charm correlation with medium modification + thermal di-lepton reproduces STAR Au+Au result.

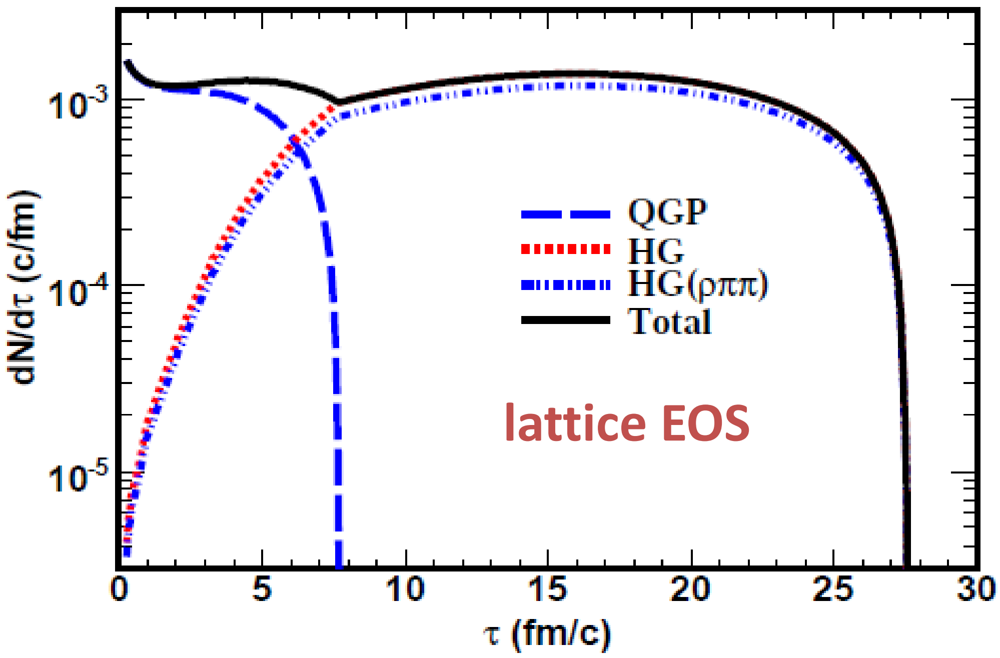
4) m_T slope of thermal di-lepton never drops, which seems different from NA60. But within errors they are consistent.

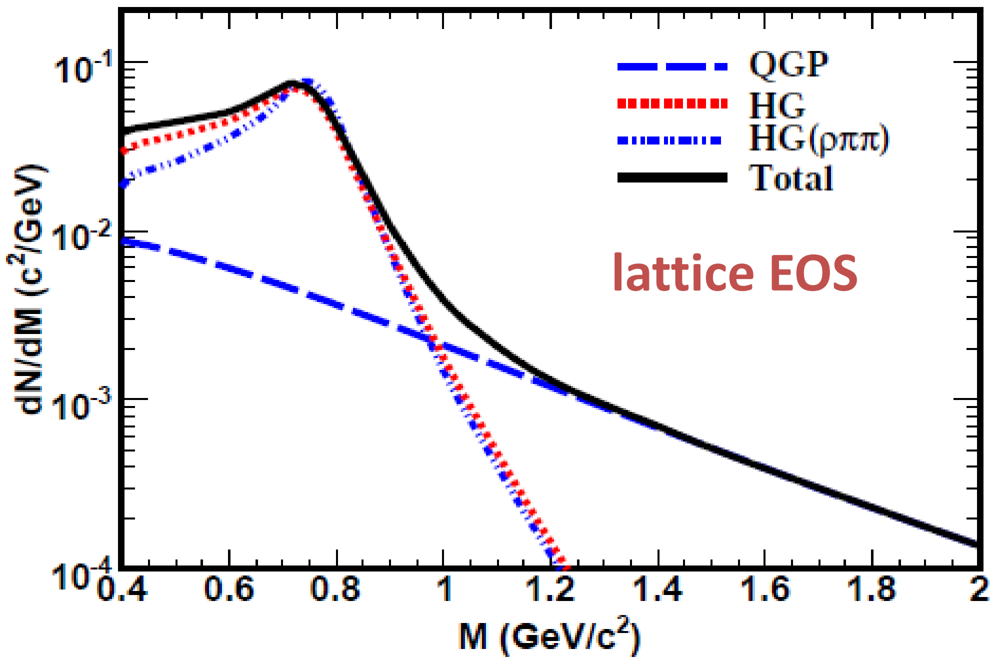
5) Phase transition could happen if the T_{eff} increases dramatically or the sign of its slope changes from negative to positive.

◆ Inclusive v_2 in the IMR still much lower than that from hadronic phase/freeze-out, which is crucial for understanding partonic/hadronic phase in the HI collisions.

Backups

Qun Wang ‘s talk

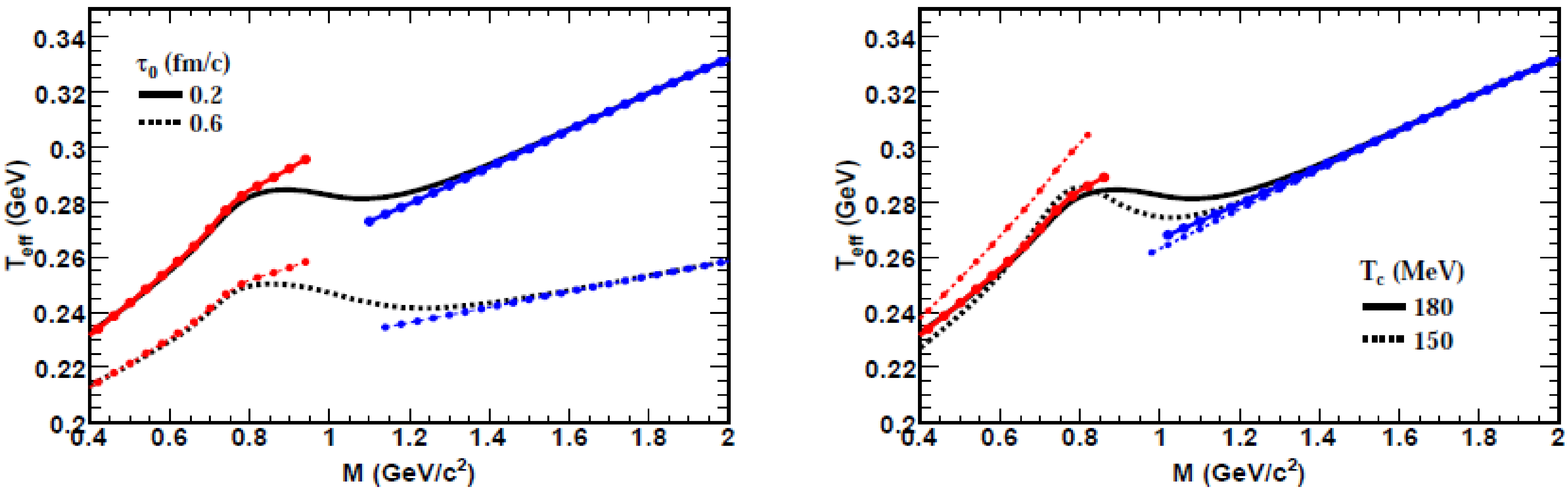




Differential multiplicity as functions of the dilepton invariant mass and proper time. The lattice EOS is used. The unit is arbitrary.

The contributions from QGP and HG are shown in dashed and dotted lines.

Qun Wang 's talk



Parameter dependences of the slope parameter with the lattice EOS.
Left panel: the initial time for the hydrodynamic evolution
τ0= 0.2*;* 0.6 fm/c. Right panel: the phase transition temperature
Tc = 180*,* 150 MeV.