Electromagnetic radiation from correlated charm/bottom

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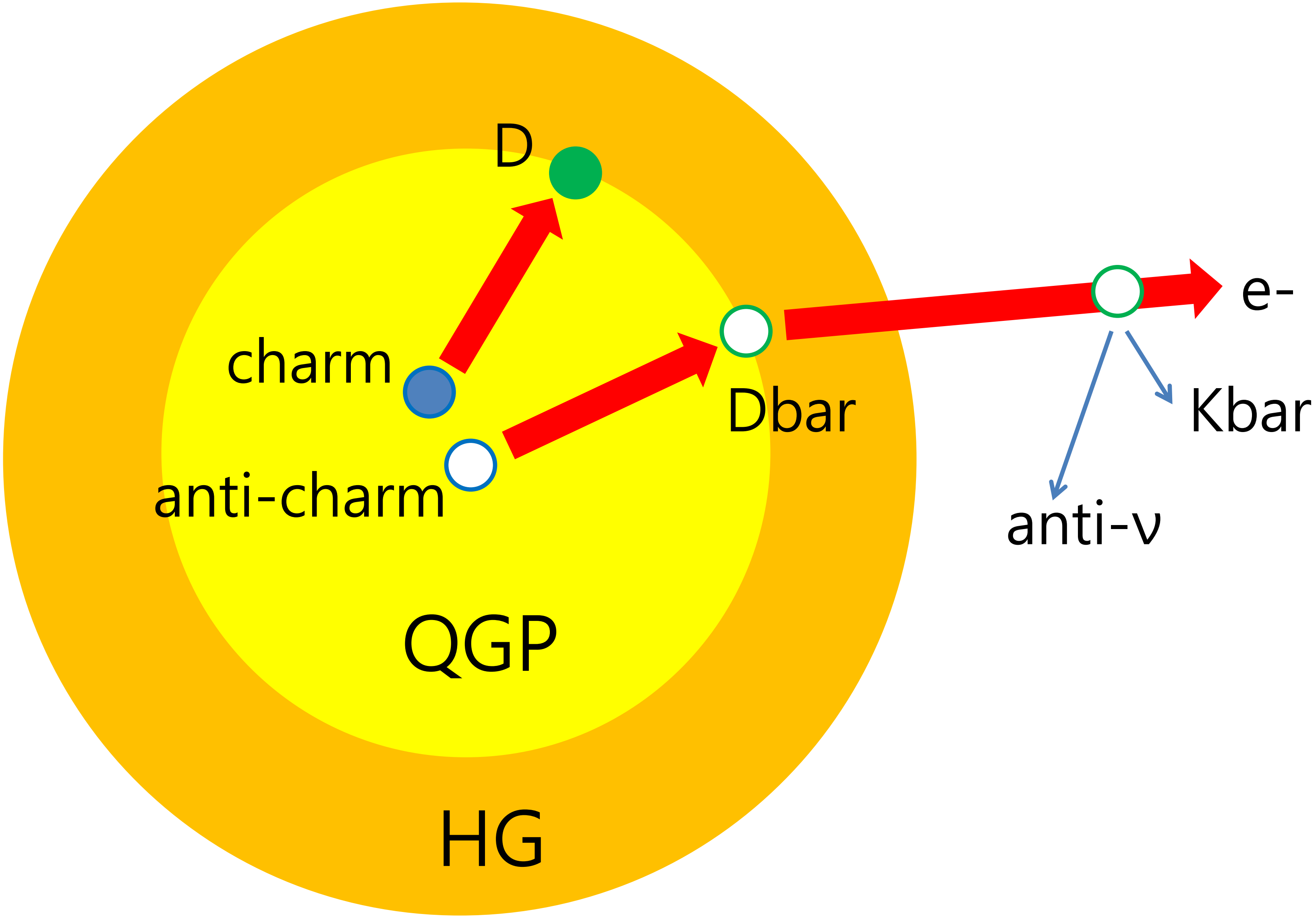
outline

- Introduction
- Single electron from heavy flavor in PHSD
- Dielectron from heavy quark pair in PHSD
- Summary

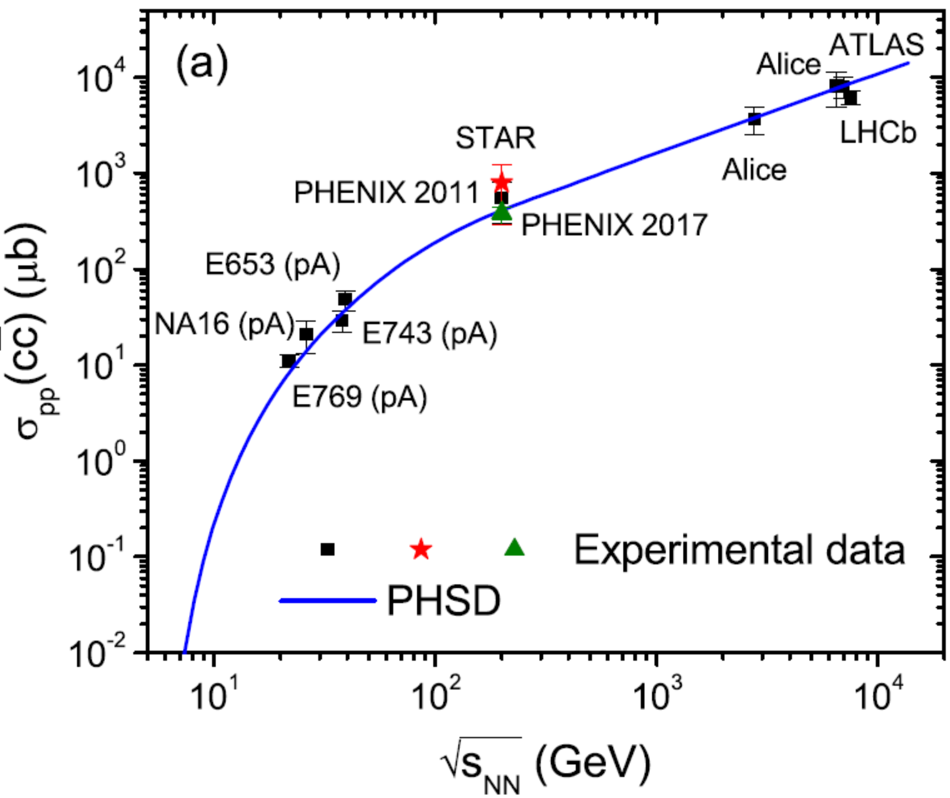
1. Introduction

- Advantages of heavy flavor as a probe particle
- Large energy momentum transfer is needed for the production
- → pQCD is applicable and model-independent
- → early produced, so it probes the matter from the initial stage of heavy-ion collisions
- Less thermalized than light flavors, so the memory time is longer & the information of the initial matter is not completely washed out
- and so on
- Single lepton & part of dilepton are produced through weak decays of heavy flavors

2. Single electron from heavy flavor in PHSD

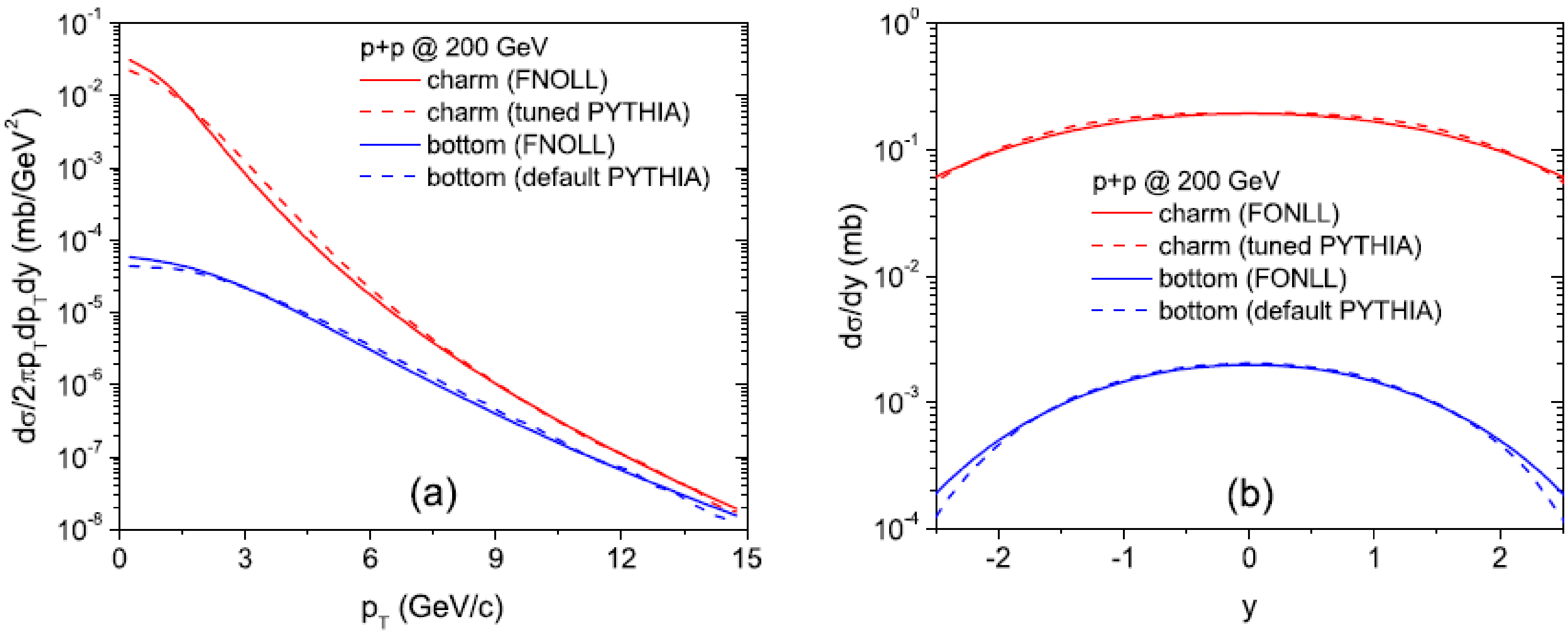

D
charm
anti-charm
Dbar
e-
Kbar
anti-ν
QGP
HG

Cross section for charm production in p+p



Multiplying by **the number of binary collisions**
and dividing by **NN inelastic scattering cross section**,
one obtains the number of charm pairs produced in heavy-ion collisions

Initial charm & bottom quarks from the PYTHIA tuned for FNOLL



Charm/bottom p_T spectra and y-distribution are obtained from PYTHIA, rescaling p_T and y such that they are similar to those from FONLL calculations

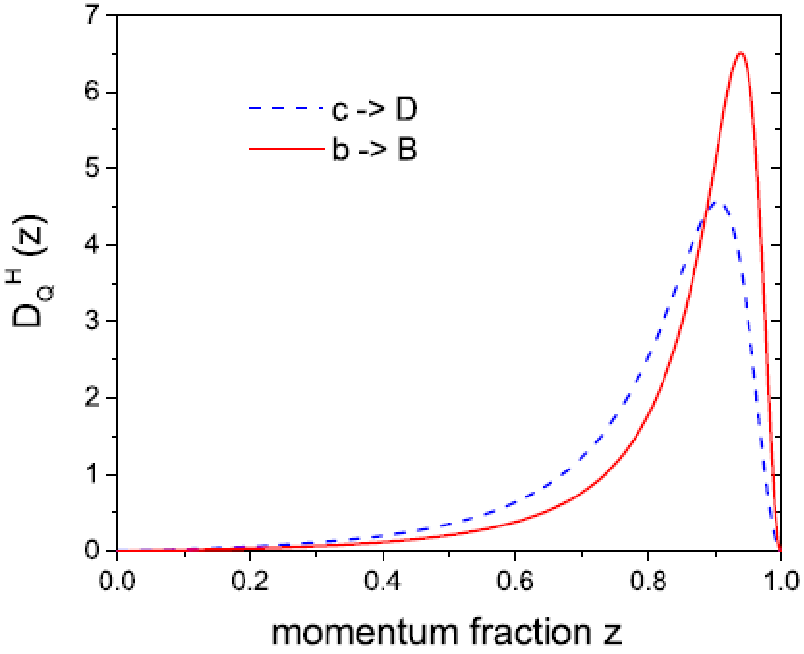
Peterson's fragmentation function

$$D_Q^H(z) \sim \frac{1}{z[1 - 1/z - \epsilon_Q/(1-z)]^2},$$

z: momentum fraction of H to Q

ε_Q=0.01 for charm

=0.004 for bottom



- Chemical fractions

$c \rightarrow D^+$: 14.9 %

$c \rightarrow D^0$: 15.3 %

$c \rightarrow D^{+*}$: 23.8 %

$c \rightarrow D^{0*}$: 24.3 %

$c \rightarrow D_s$: 10.1 %

$c \rightarrow \Lambda_c$: 8.7 %

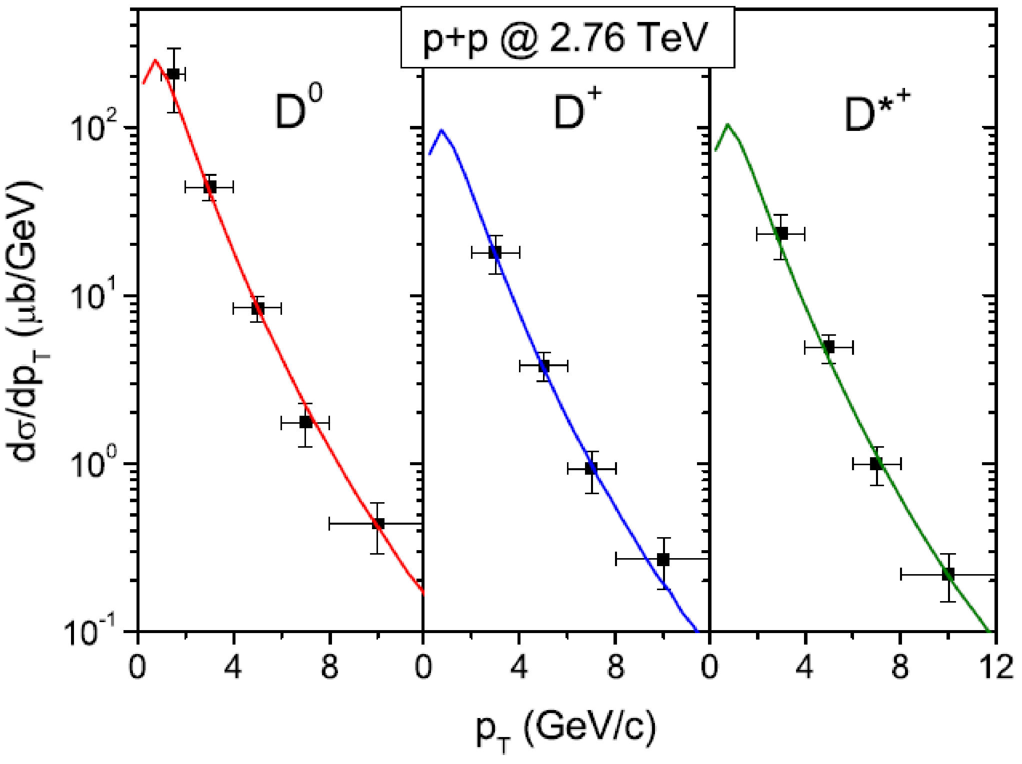
$b \rightarrow B^-$: 39.9 %

$b \rightarrow Bbar^0$: 39.9 %

$b \rightarrow Bbar^0{}_s$: 11 %

$b \rightarrow \Lambda_b$: 9.2 %

comparison with exp. in p+p



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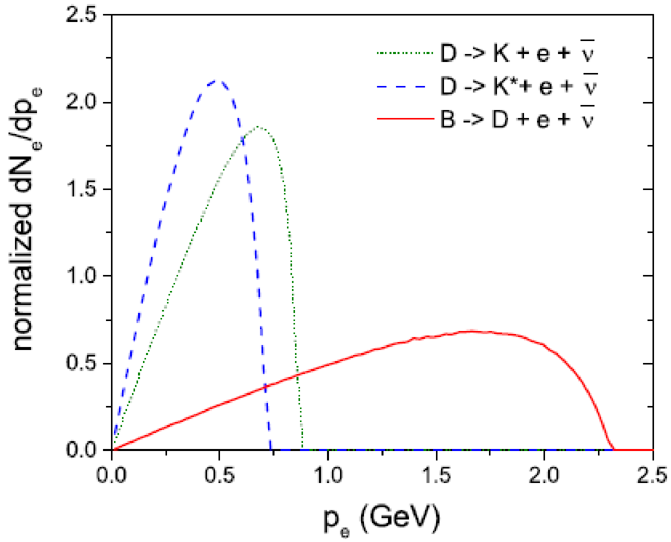
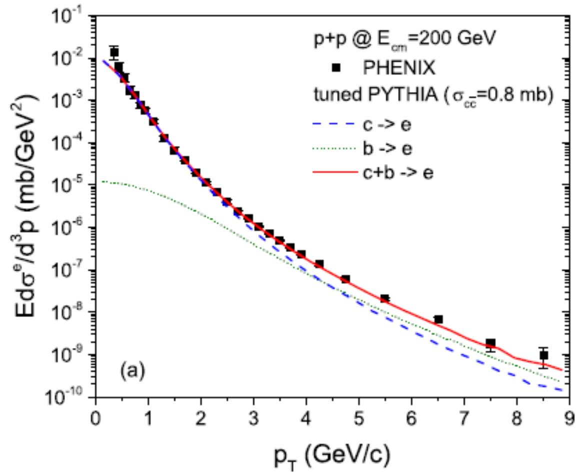
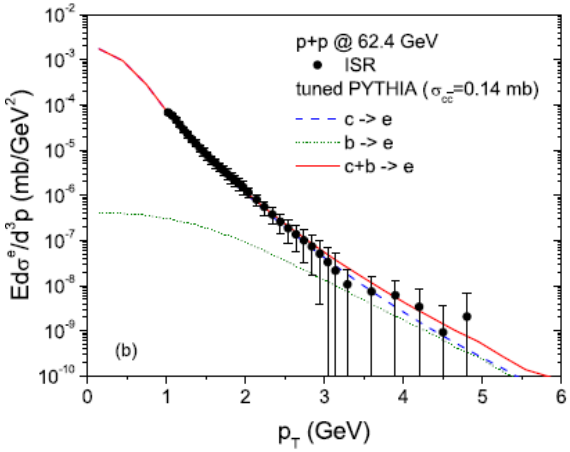
Weak decay of heavy flavor to single electron

Momentum distribution of single e from D/B meson weak decay







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Cold nuclear matter effects

1. Shadowing

: Parton distribution function (PDF) modified in nucleus, for which EPS09 is used.

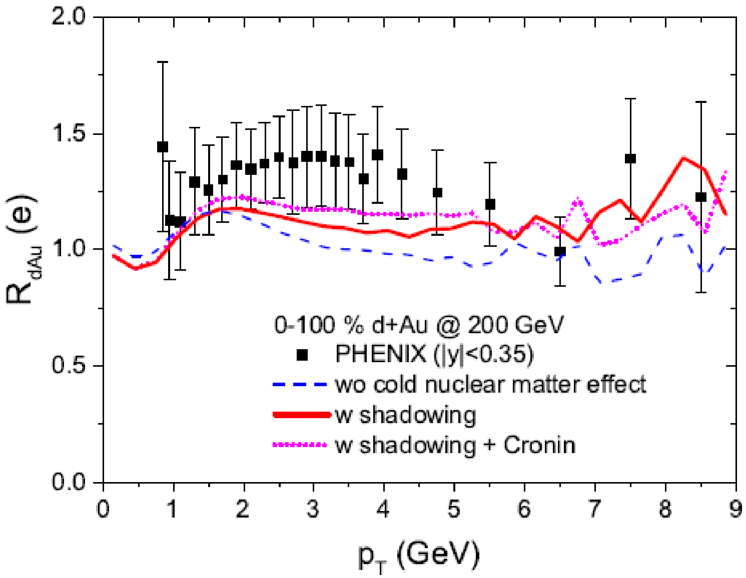
$$g + g \to h + \bar{h}, \qquad q + \bar{q} \to h + \bar{h}$$

2. Cronin effect

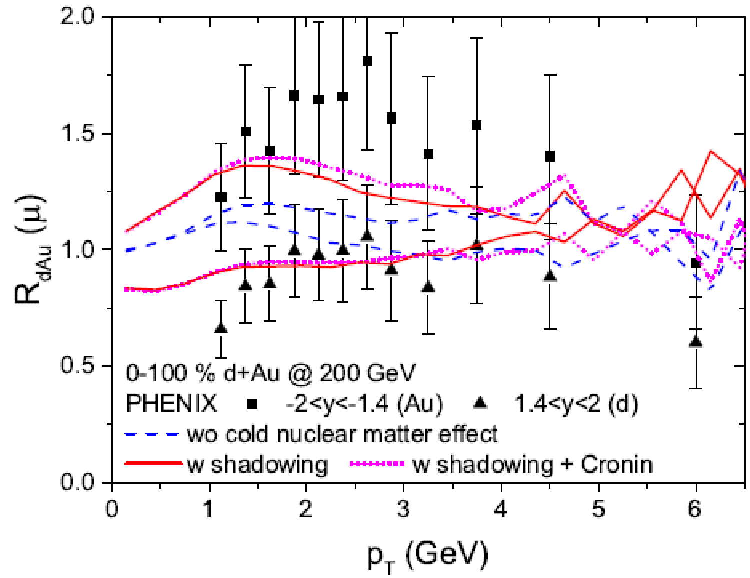
: Because of parton+N scattering in A(p)+A collisions, p_T of the produced heavy quark pair is enhanced.

R_{dAu} @ 200 GeV

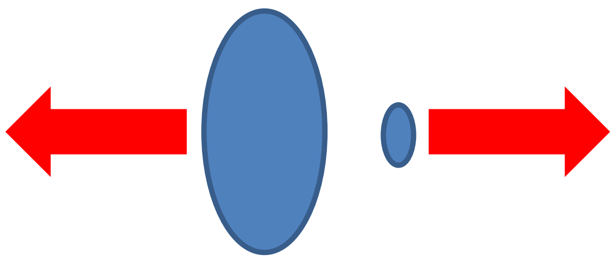
Mid-rapidity (e)



Forward/backward-rapidites (μ)



backward-y (large x)
charm is enhanced



forward-y (small x)
charm is suppressed

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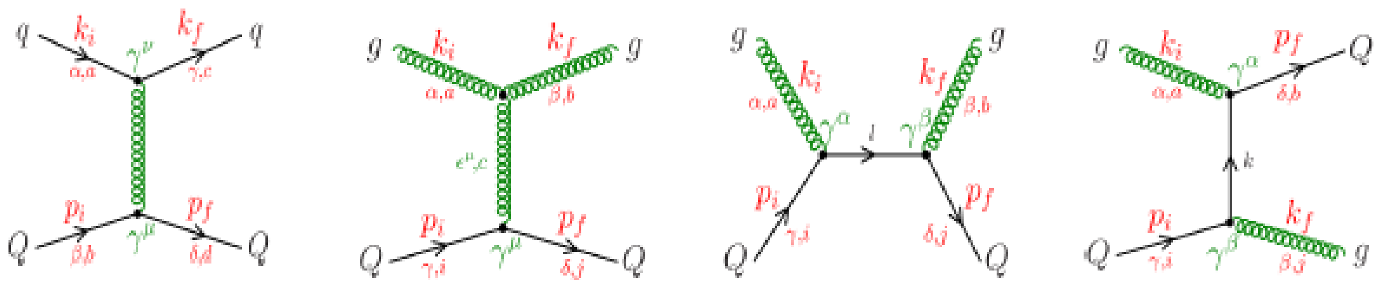
Hot nuclear matter effects

1. Partonic interactions

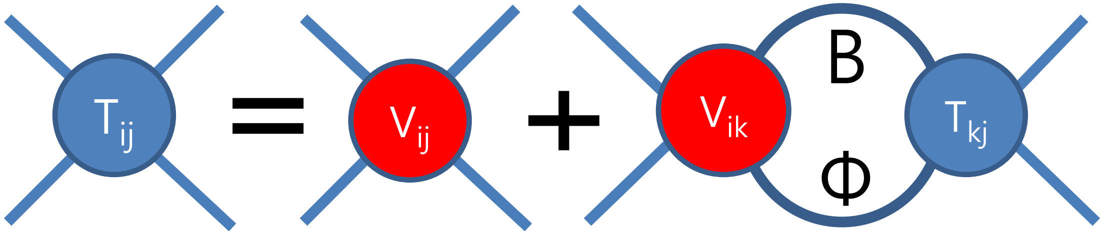
: based on Dynamical Quasi-Particle Model (DQPM)



2. Hadronization (one of issues of this workshop)

3. Hadronic interactions

: T-matrix method from effective Chiral Lagrangian



Coalescence in PHSD

- Wigner function for S-wave coalescence probability

$$\Phi(\mathbf{r},\mathbf{p}) = 8\exp\left[-\frac{r^2}{\sigma^2} - \sigma^2 p^2\right],$$

$$\mathbf{r} = \mathbf{r}_1 - \mathbf{r}_2,$$

$$\mathbf{p} = (m_2\mathbf{p}_1 - m_1\mathbf{p}_2)/(m_1 + m_2).$$

in center-of-mass frame

0.9 fm

$$\langle r_M^2 \rangle = \frac{1}{2}\langle(\mathbf{R}-\mathbf{r}_1)^2 + (\mathbf{R}-\mathbf{r}_2)^2\rangle$$

$$= \frac{1}{2}\frac{m_1^2+m_2^2}{(m_1+m_2)^2}\langle r^2\rangle = \frac{3}{4}\frac{m_1^2+m_2^2}{(m_1+m_2)^2}\sigma^2,$$

multiplied by 4 (=1+3) to include D*
and divided by 36(=6*6)

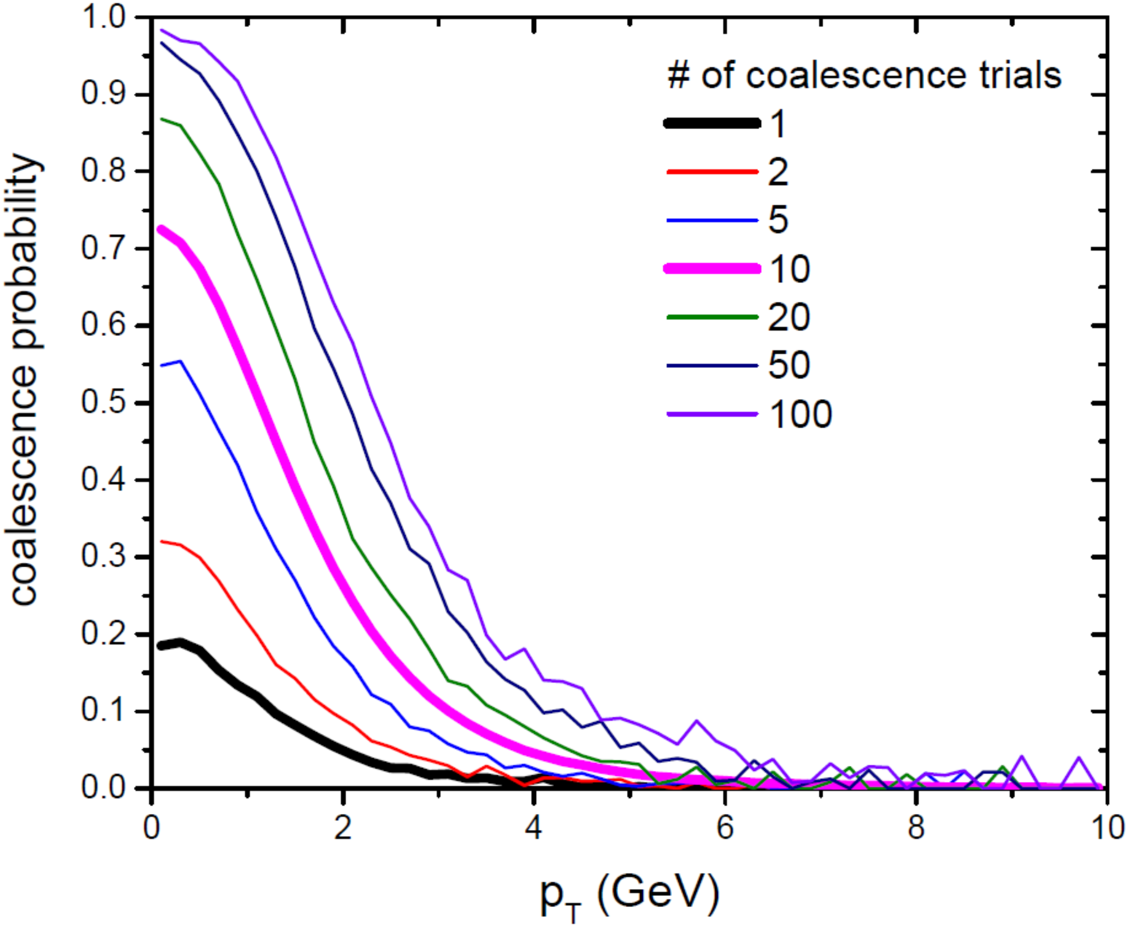
- Wigner function for P-wave coalescence probability

$$\left(\frac{16}{3}\frac{y_i^2}{\sigma_i^2} - 8 + \frac{16}{3}\sigma_i^2 k_i^2\right)\exp\left(-\frac{y_i^2}{\sigma_i^2} - k_i^2\sigma_i^2\right)$$

multiplied by 8 (=3+5)
to include $J^p=1^+$, 2^+
and divided by 36(=6*6)

1. We assume P states decay to D(D*) + π as soon as hadronized
2. D_s is similarly treated

Total coalescence probability is low



Hadronization of heavy quarks in A+A

❑ PHSD: if the local energy density $\varepsilon \rightarrow \varepsilon_C \rightarrow$ hadronization of heavy quarks to hadrons

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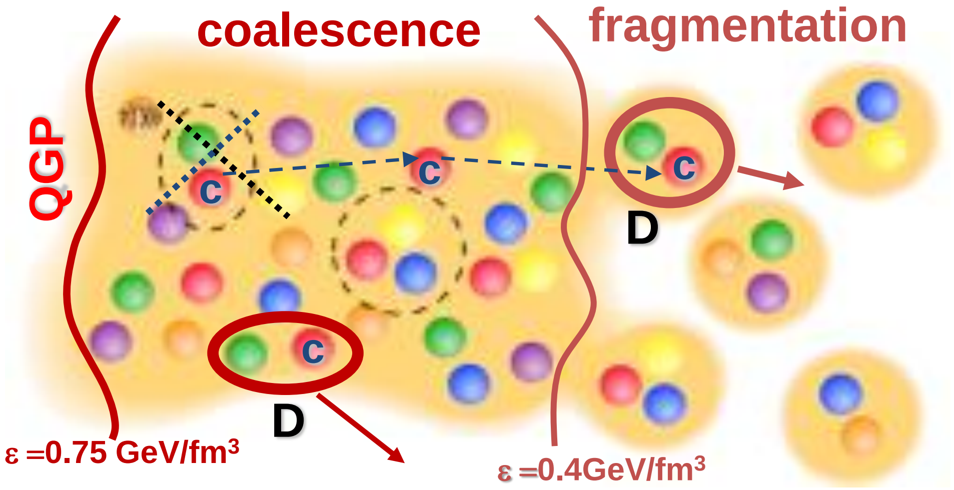
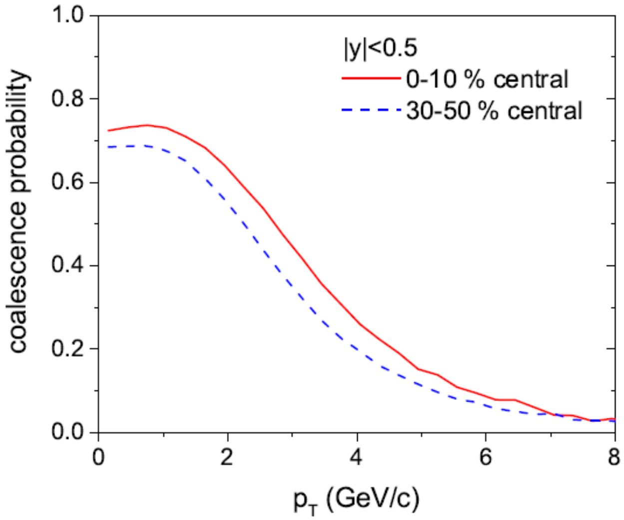
Dynamical hadronization scenario for heavy quarks :

coalescence with <r>=0.9 fm & fragmentation

$0.4 < \varepsilon < 0.75$ GeV/fm^3 $\varepsilon < 0.4$ GeV/fm^3



Coalescence probability in Pb+Pb at LHC



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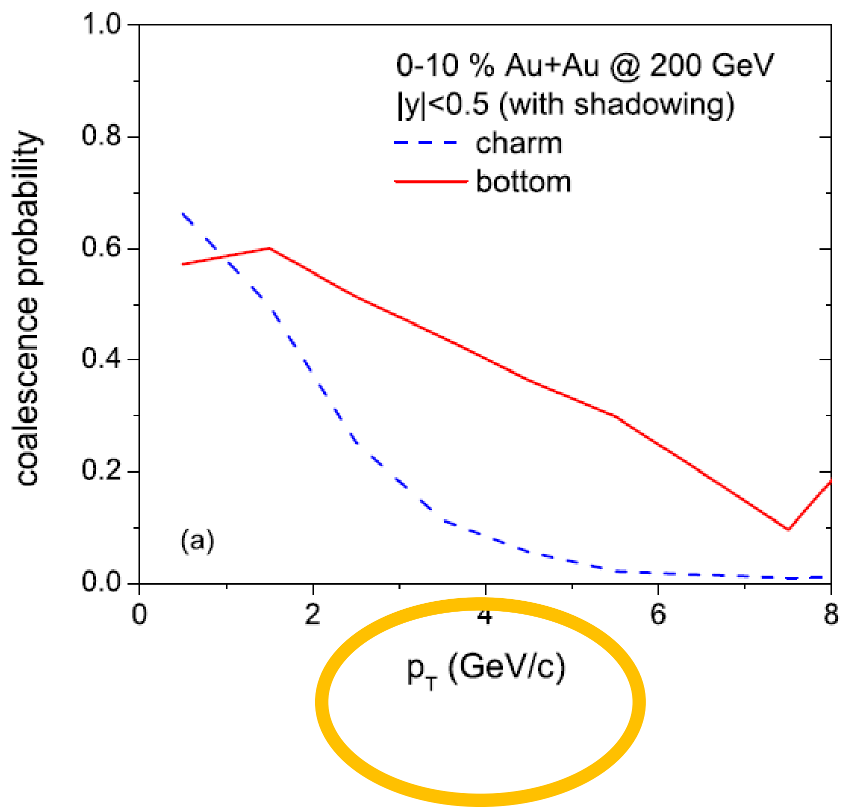
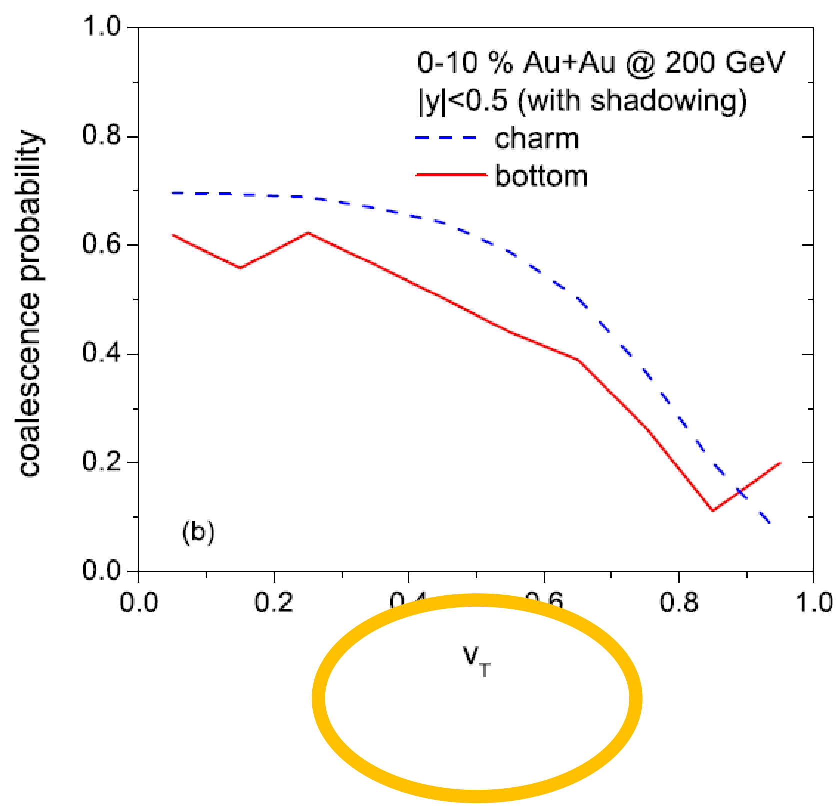
Coalescence probabilites of charm/bottom in Au+Au collisions at 200 GeV





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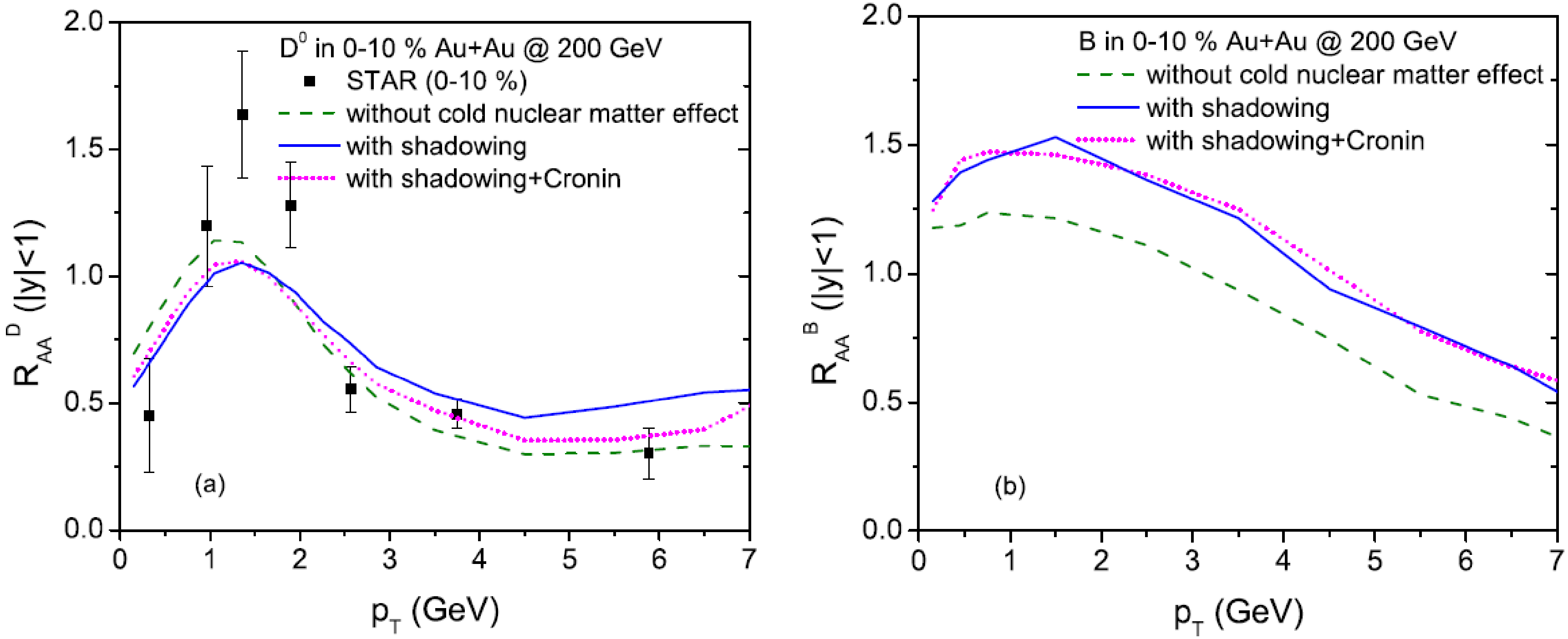
R_{AA} of D/B mesons



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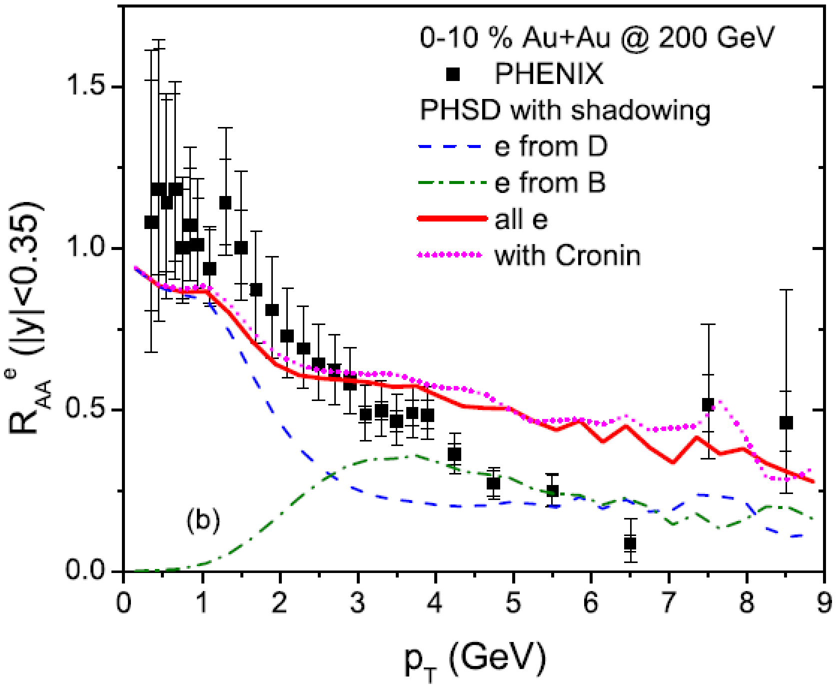
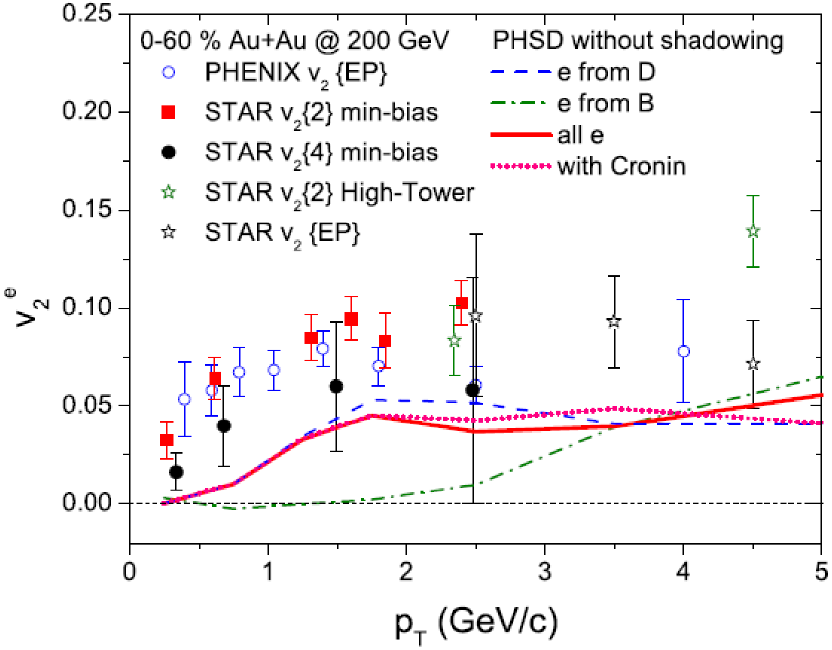
R_{AA} & v_2 of single e





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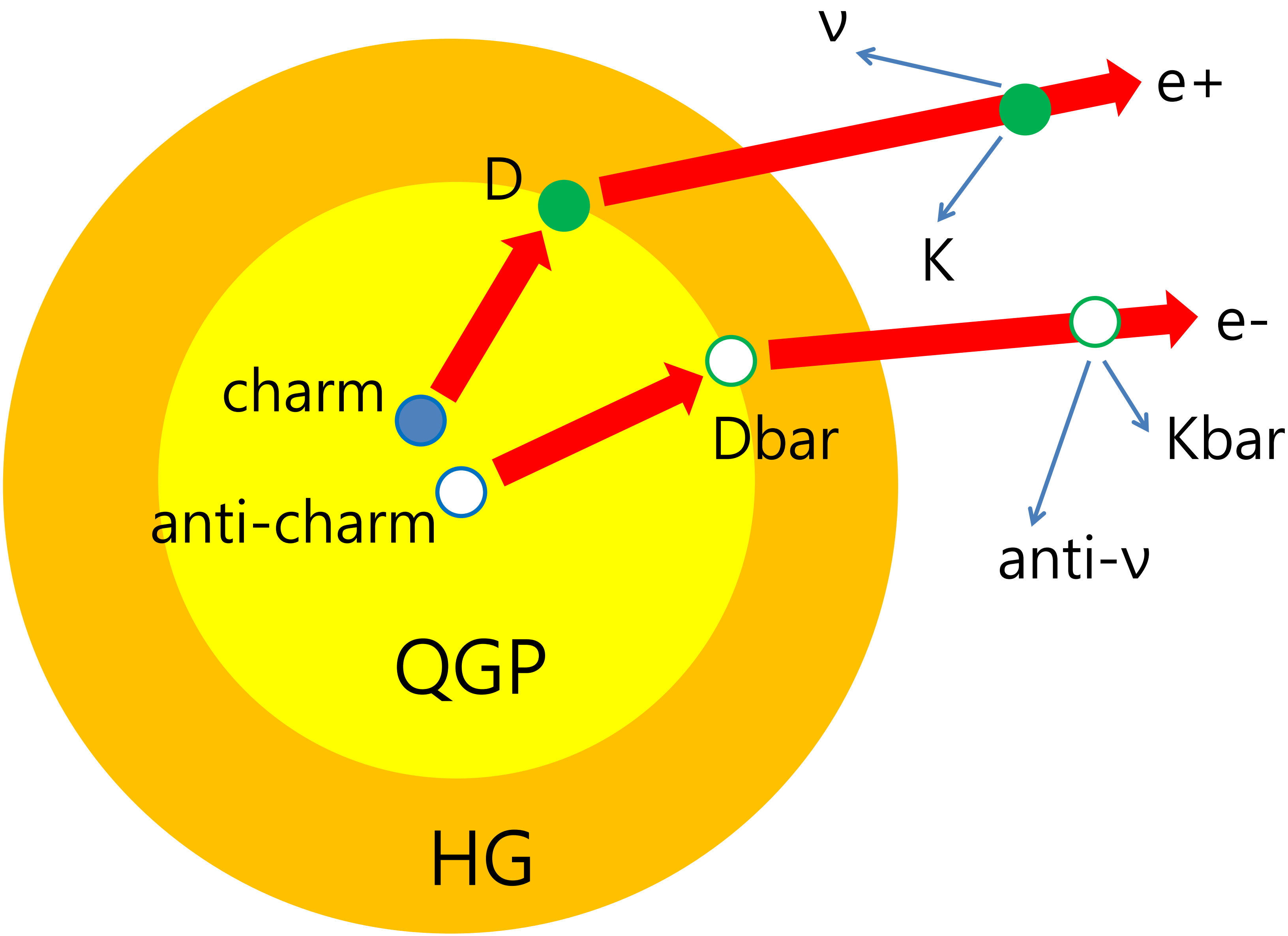
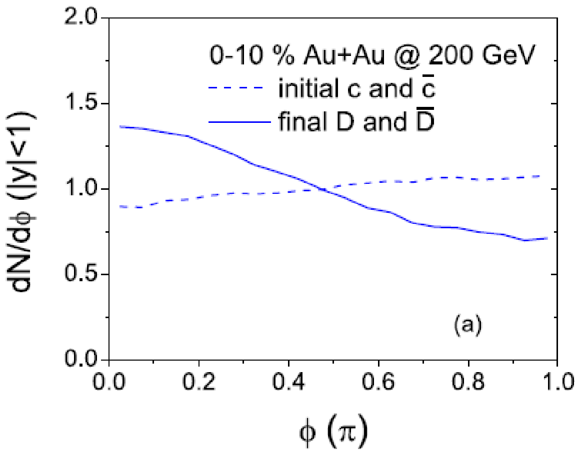
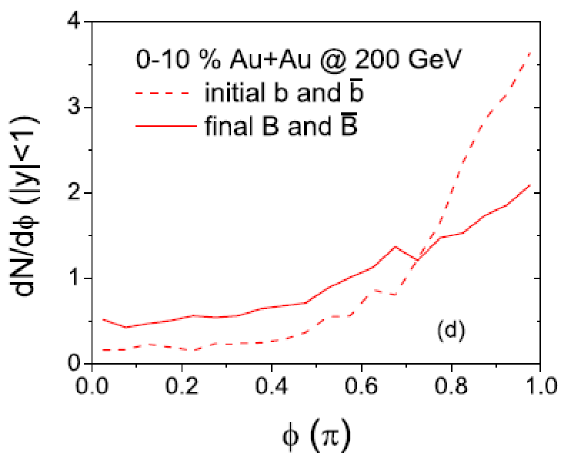
3. dielectron from heavy quark pair in PHSD


ν
e+
D
K
e-
charm
Dbar
Kbar
anti-charm
anti-ν
QGP
HG

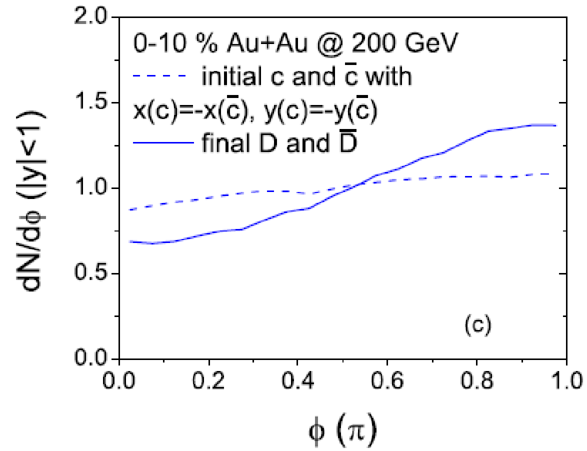
Azimuthal angle correlations (flow effects)

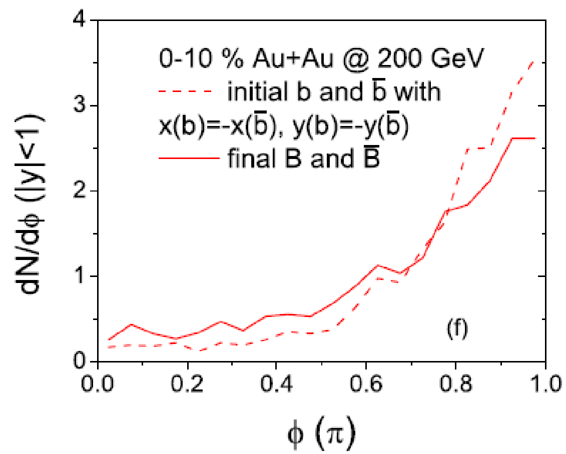
PHSD (PYTHIA)



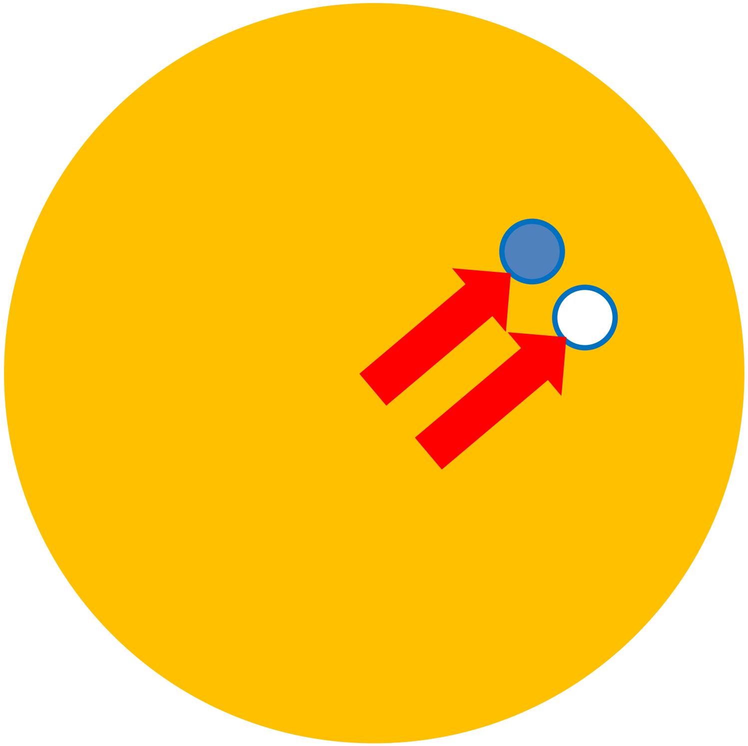


PHSD (opposite position)



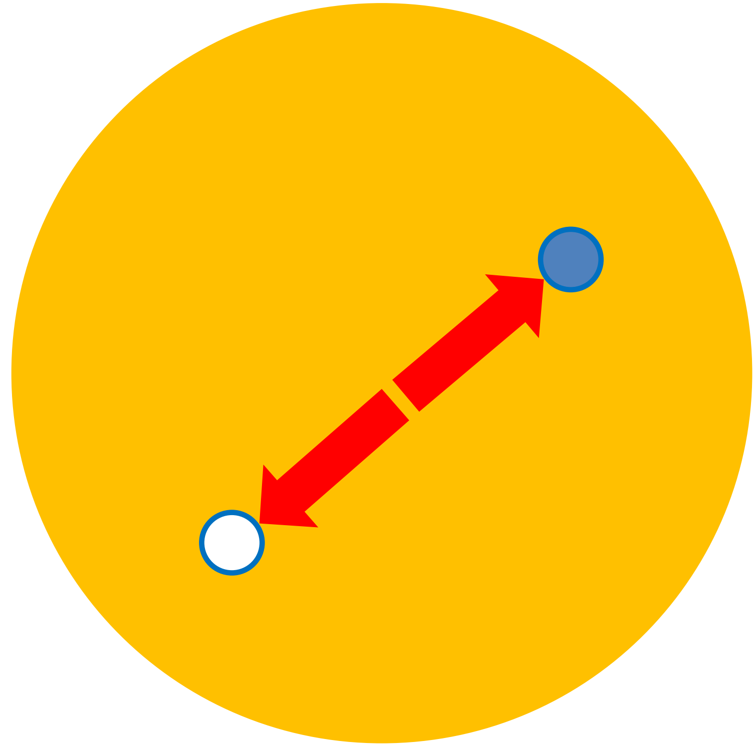


PHSD (PYTHIA)



Boosted by the same direction of flows
→ correlation is enhanced around Φ=0

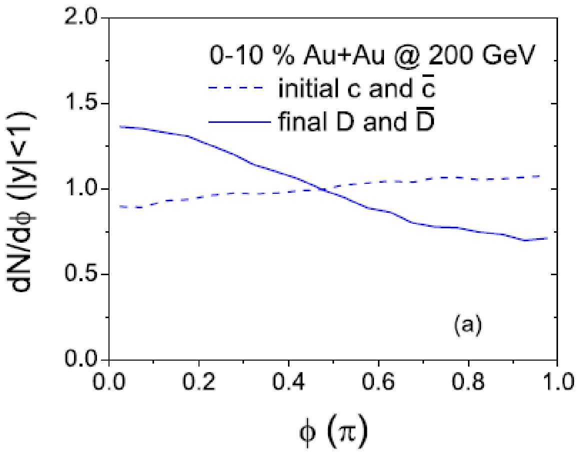
PHSD (opposite position)

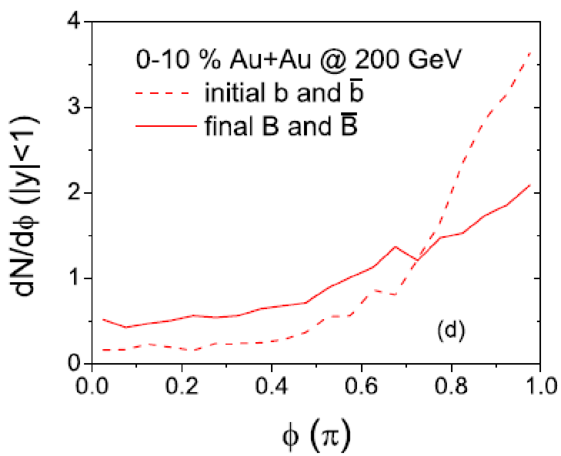


Boosted by the opposite direction of flows
→ correlation is enhanced around Φ=π

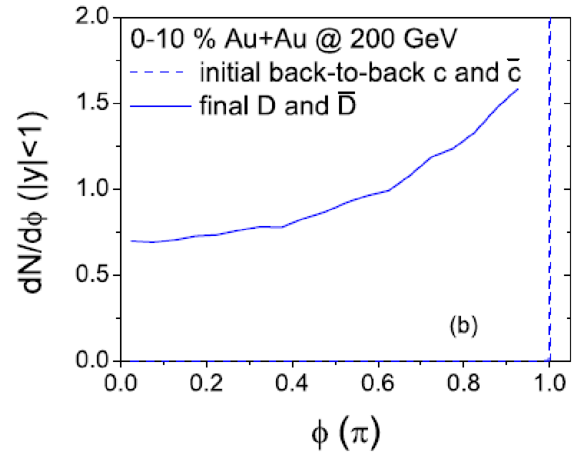
Initial angle correlations are important

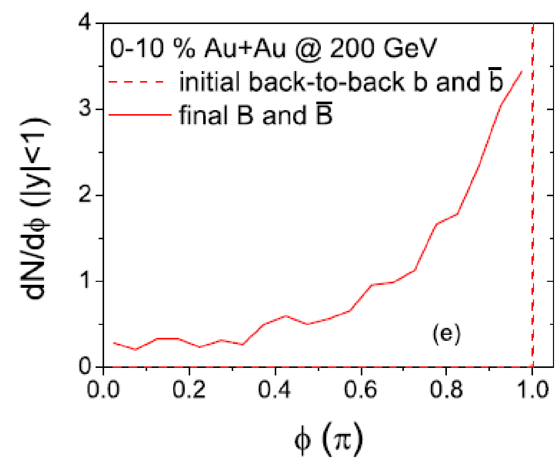
PHSD (PYTHIA)



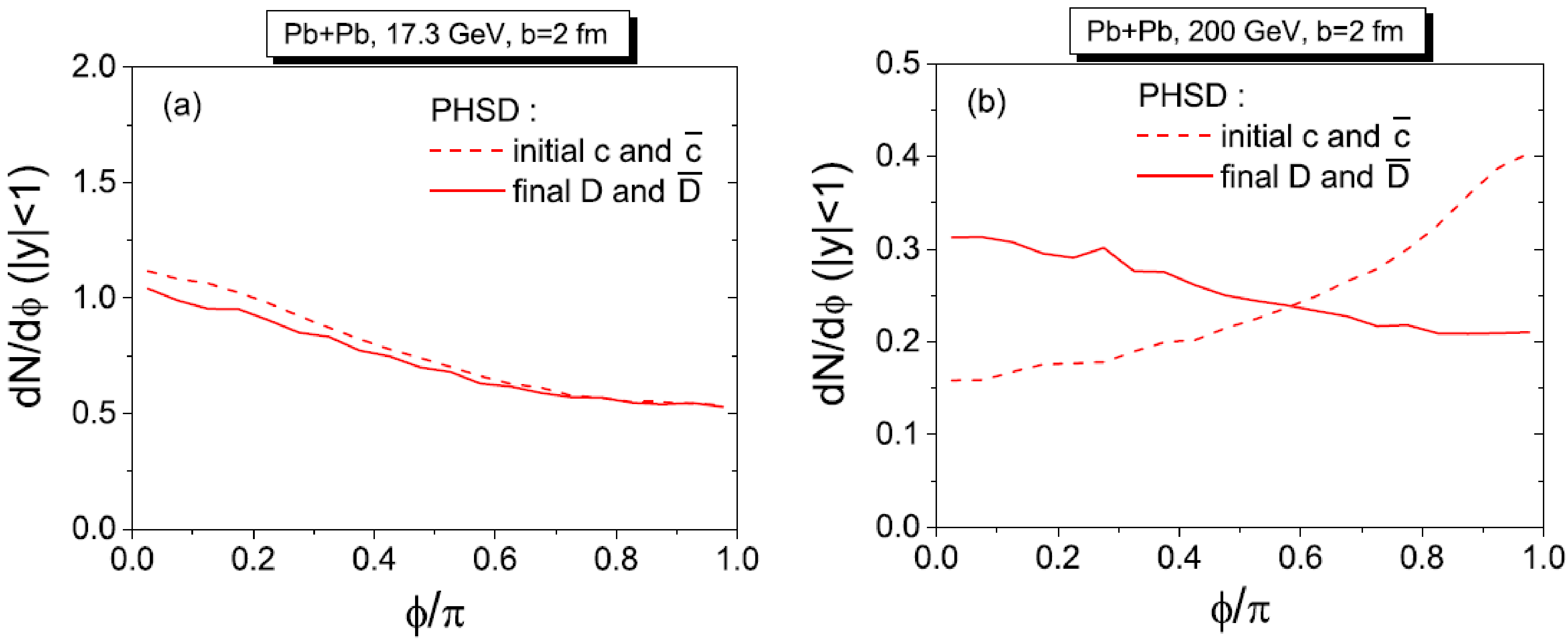


PHSD (back-to-back)





Azimuthal angle correlations (collision energy dependence)



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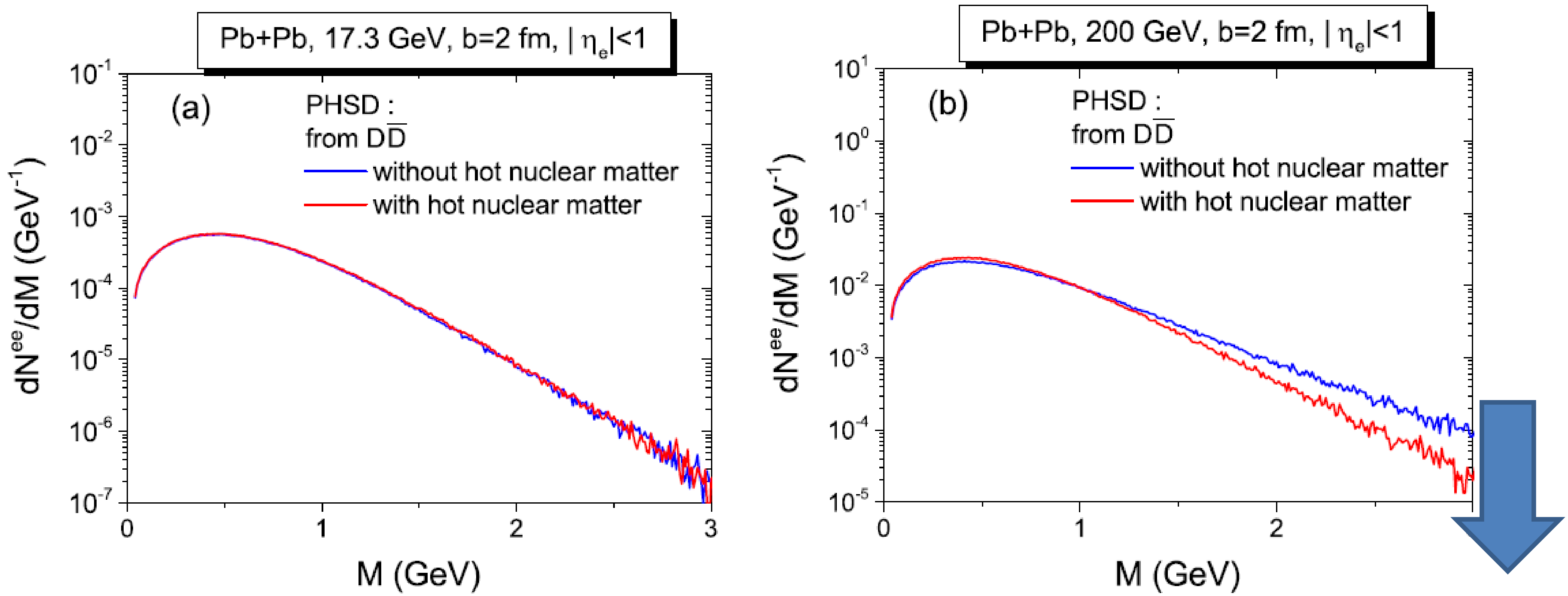
Invariant mass spectra of dielectron from heavy flavor pairs at SPS/RHIC energies



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What we have found

- (random) scattering dissipates the azimuthal angle correlations, that it makes azimuthal angle distribution flat
- However, collective flow enhances azimuthal angle correlations at $\Phi=0$ (same direction) and suppresses them at $\Phi=\pi$ (opposite direction)
- Initial azimuthal angle correlation is important for dilepton study
- Azimuthal angle correlations are more changed in higher energy collisions

4. Summary

- In the PHSD, initial charm spectrum & rapidity distribution from PYTHIA are tuned (rescaled) such that they are similar to those from the FONLL calculations
- Peterson's fragmentation function is used for the hadronization of heavy quark in p+p collisions
- The (anti)shadowing effects are implemented by EPS09
- Partonic interactions of heavy quark are realized by the DQPM, its hadronization through either coalescence or fragmentation, and the hadronic interactions by T-matrix method
- Experimental data on single electron can be explained within the PHSD
- Extended to dielectron, the azimuthal angle distributions are very important and need to be carefully treated