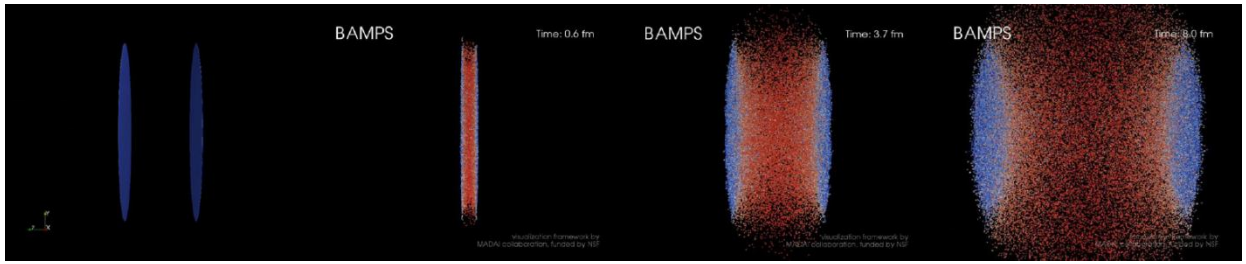
D mesons and non-prompt J/Psi at LHC within a transport model

Jan Uphoff

with O. Fochler, Z. Xu and C. Greiner

Based on arXiv:1104.2295 and 1112.1559



H-QM | Helmholtz Research School Quark Matter Studies

„High p_T physics at LHC“, Frankfurt

26 March 2012

Motivation

Large heavy quark mass

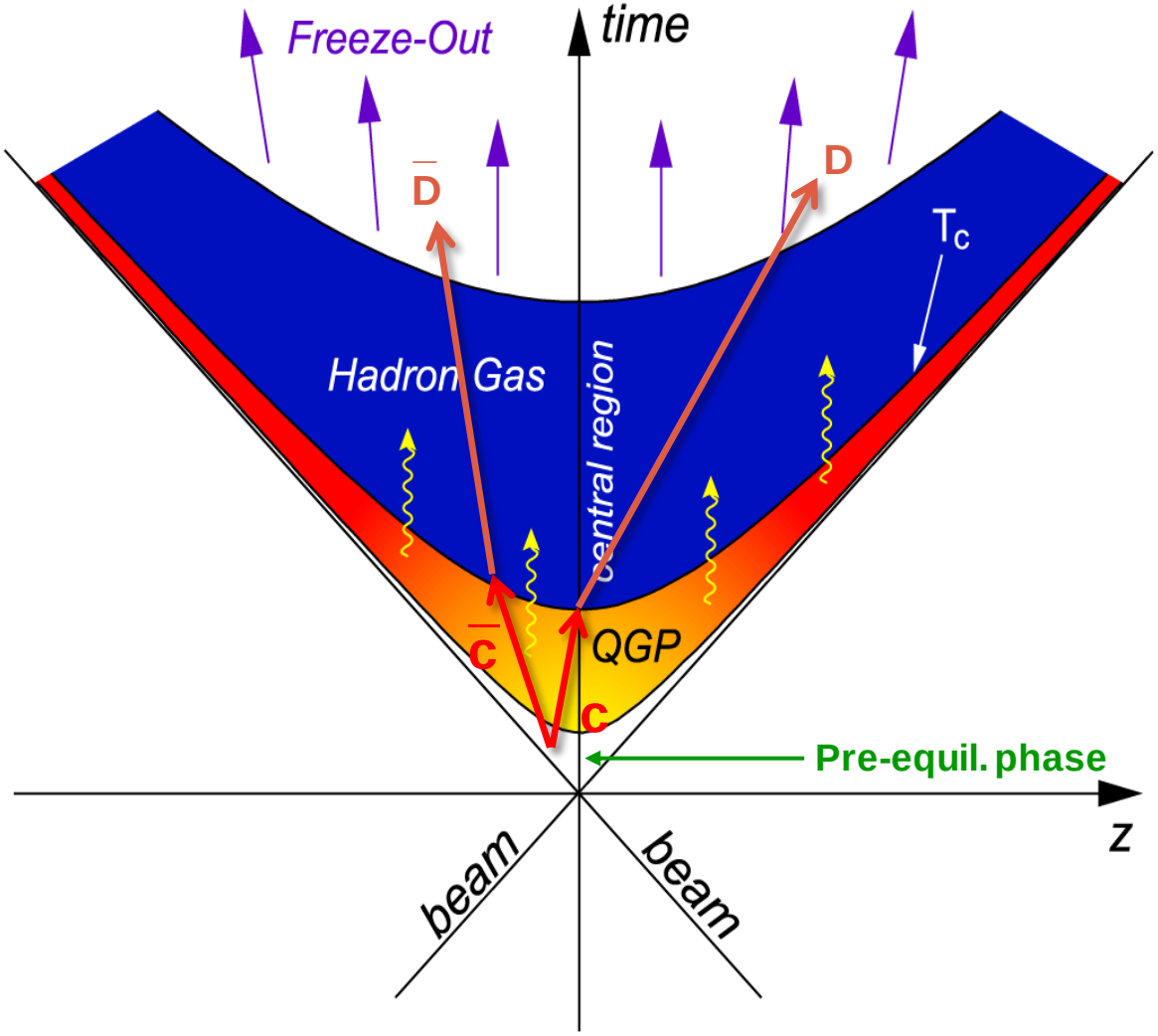
>> Λ_{QCD}

Charm: $M_c \approx 1.5$ GeV

Bottom: $M_b \approx 4.75$ GeV

Heavy quark production at early stage of collision

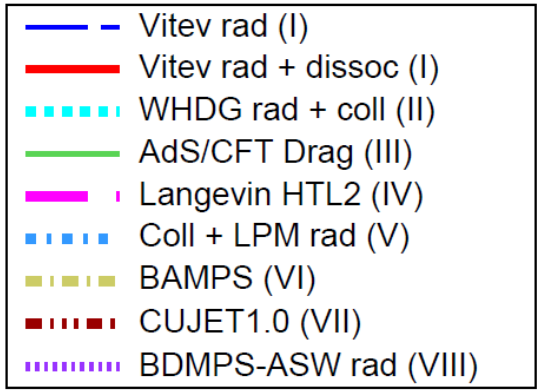
ideal probe for this stage



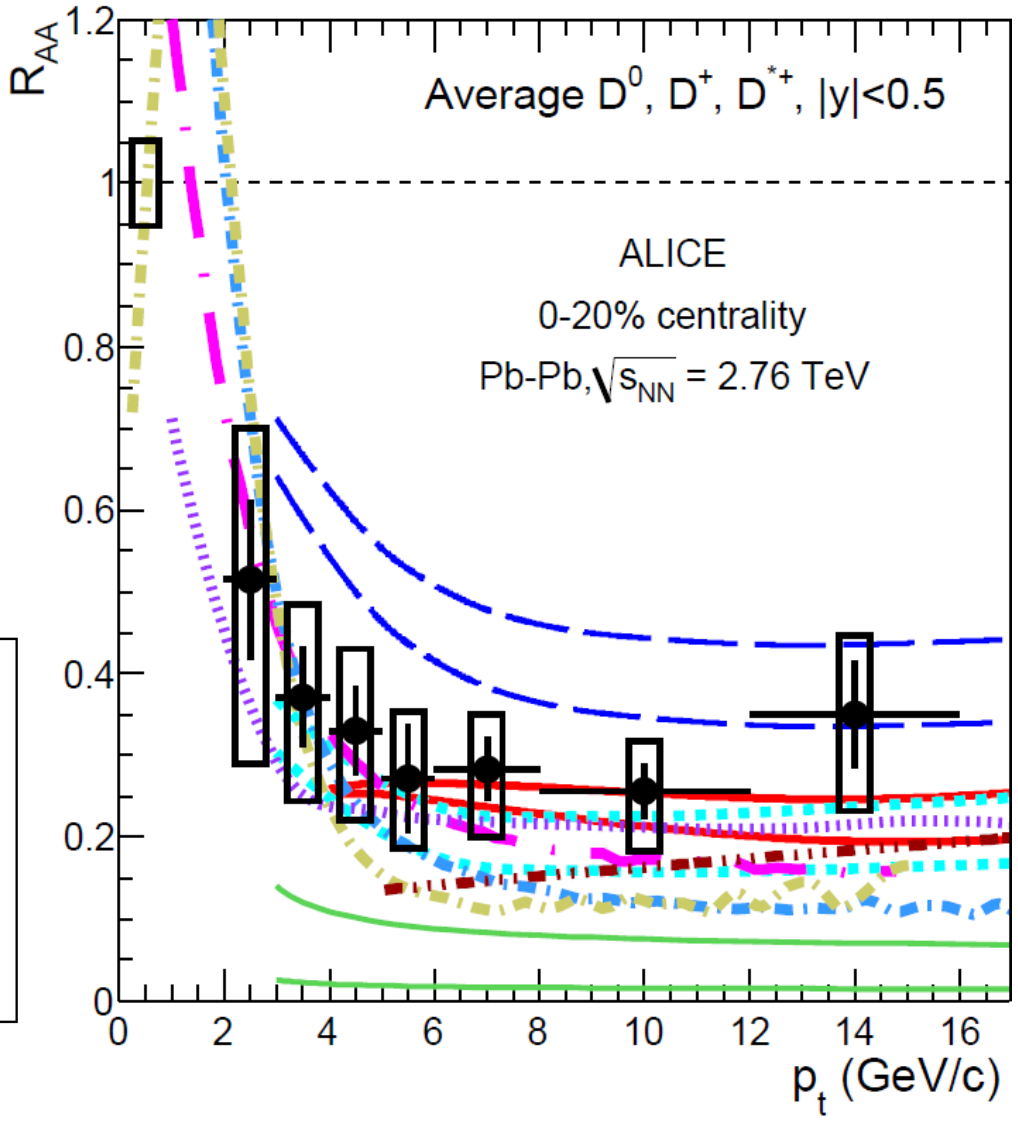
Motivation

Nuclear modification factor

$$R_{AA} = \frac{\mathrm{d}N/\mathrm{d}p_T\mathrm{d}y|_{A+A}}{N_{\mathrm{bin}}\,\mathrm{d}N/\mathrm{d}p_T\mathrm{d}y|_{p+p}}$$



ALICE, arXiv:1203.2160

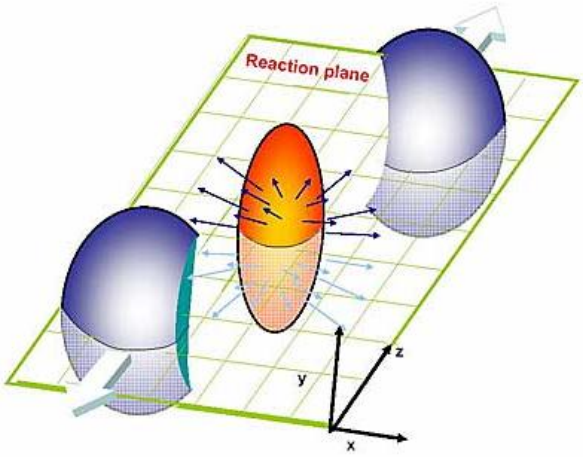


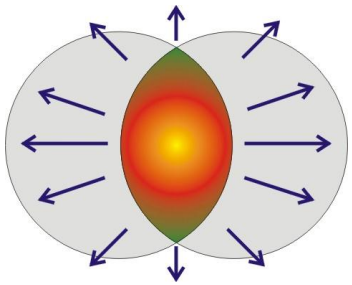
Motivation

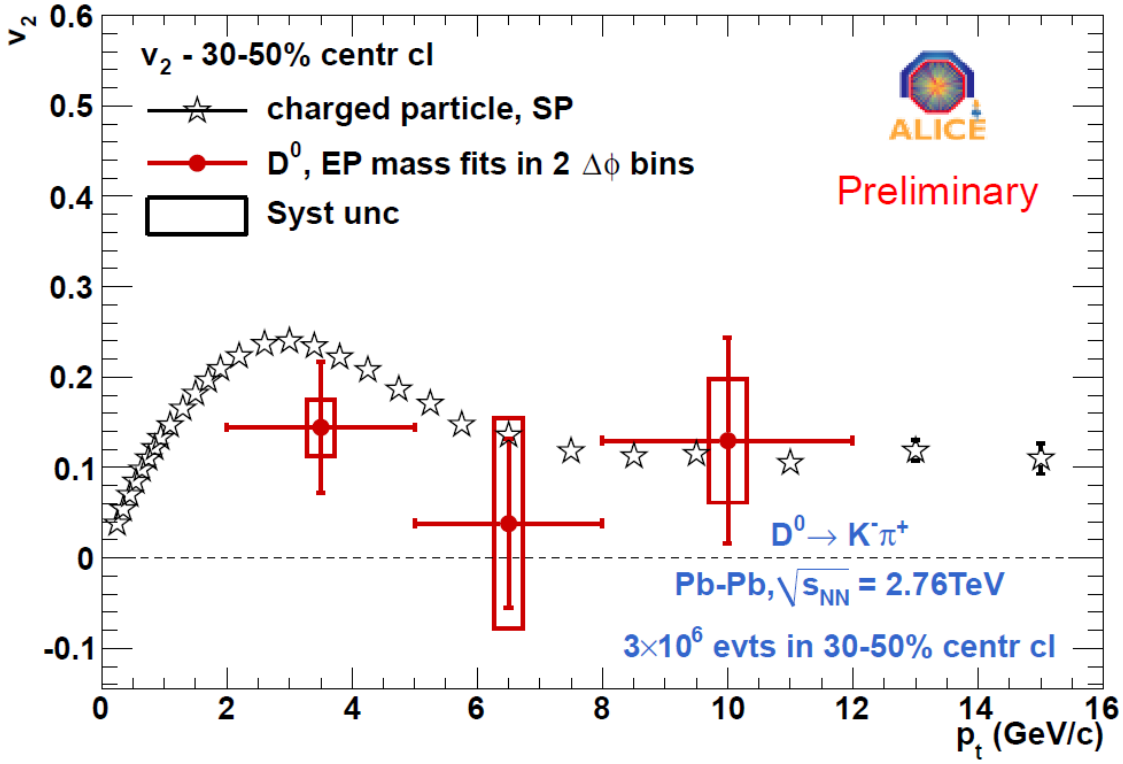
Elliptic flow

$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_T^2} \right\rangle$$

$$\frac{\mathrm{d}^3N}{p_T \mathrm{d}p_T \mathrm{d}y \mathrm{d}\phi}(p_T, y, \phi) = \frac{1}{2\pi} \frac{\mathrm{d}^2N}{p_T \mathrm{d}p_T \mathrm{d}y} \left[1 + 2v_2(p_T, y)\cos(2\phi) + \ldots\right]$$







BAMPS

BAMPS: Boltzmann Approach of MultiParton Scatterings

- **3+1 dimensional, fully dynamic parton transport model**
- **solves the Boltzmann equations for on-shell partons with pQCD interactions**

$$\left(\frac{\partial}{\partial t}+\frac{\mathbf{p}_i}{E_i}\frac{\partial}{\partial \mathbf{r}}\right) f_i(\mathbf{r},\mathbf{p}_i,t) = \mathcal{C}_i^{2\to 2} + \mathcal{C}_i^{2\leftrightarrow 3} + \dots$$

Z. Xu & C. Greiner,
Phys. Rev. C71 (2005)
Phys. Rev. C76 (2007)

Implemented processes:

$$g+g \to g+g$$
$$g+g \to g+g+g$$
$$g+g+g \to g+g$$

Light quarks have been implemented but are not included in all presented calculations

$$g+g \to Q+\bar{Q}$$
$$Q+\bar{Q} \to g+g$$
$$g+Q \to g+Q$$
$$g+\bar{Q} \to g+\bar{Q}$$
$$g+J/\psi \to c+\bar{c}$$
$$c+\bar{c} \to g+J/\psi$$

Heavy-ion collision at LHC

BAMPS simulation of QGP phase at LHC at $\sqrt{s_{NN}}$ = 2.76 TeV

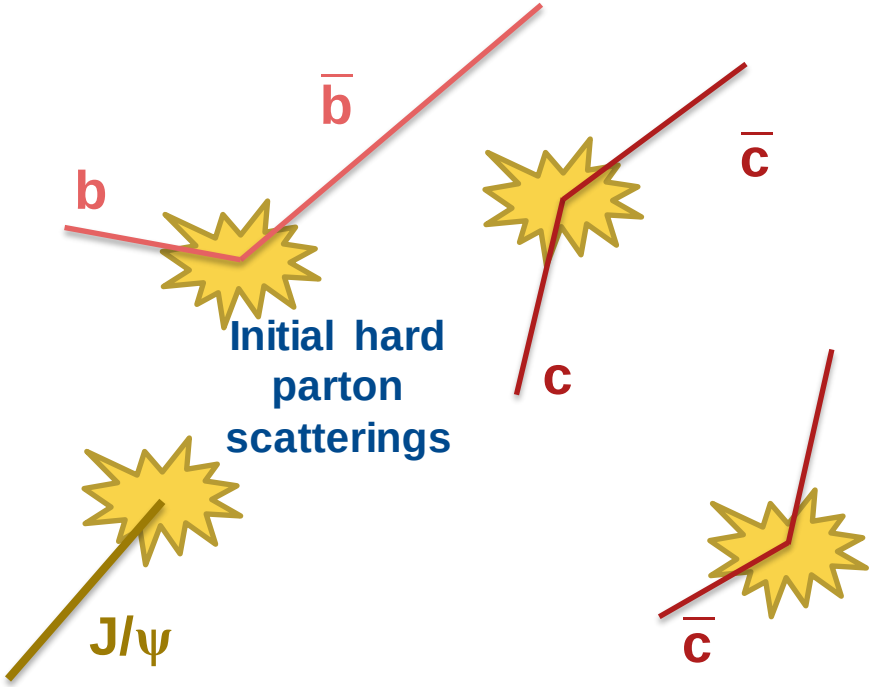
Visualization framework courtesy MADAI collaboration, funded by the NSF under grant# NSF-PHY-09-41373

Sketch of heavy-ion collision in BAMPS

Heavy flavor in BAMPS

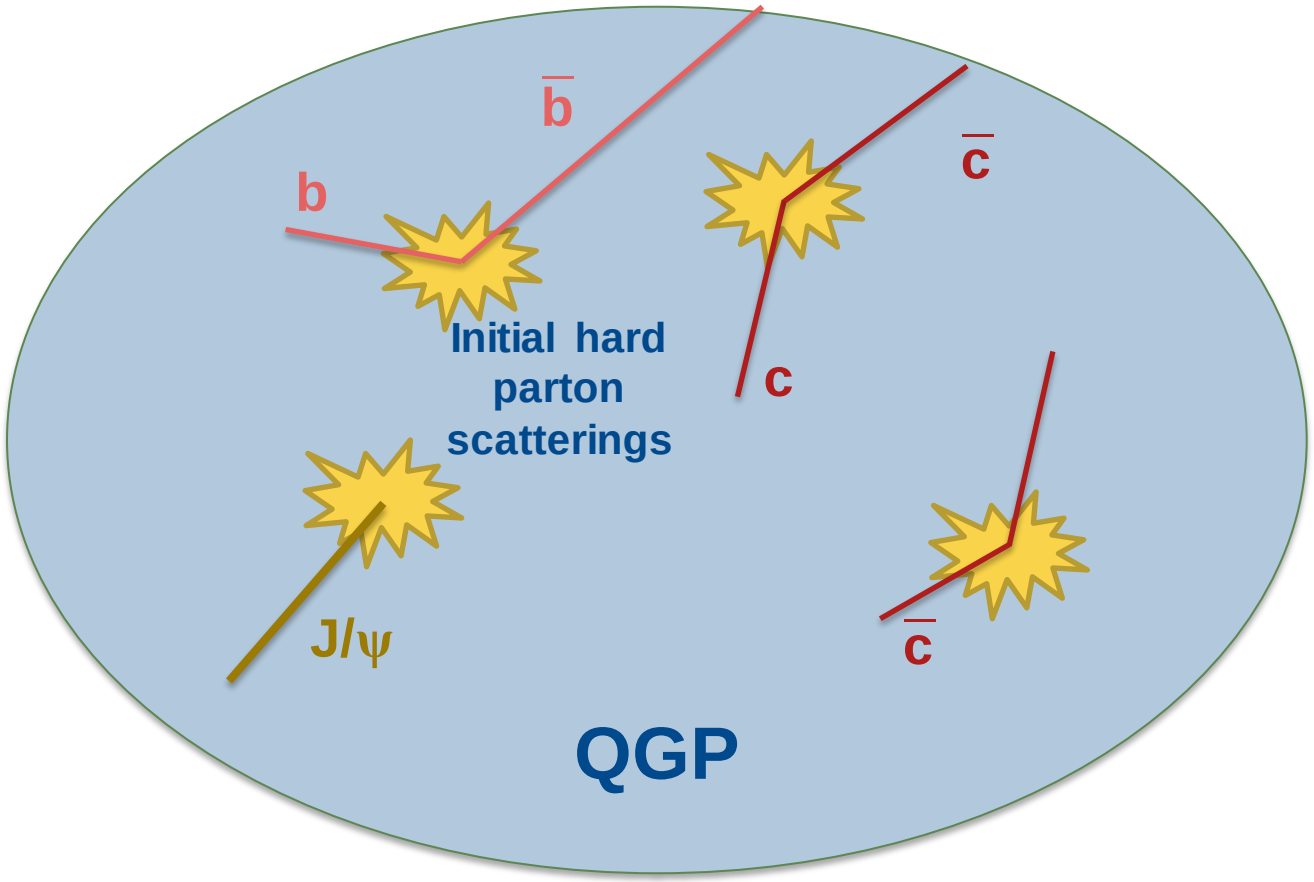
Sketch of heavy-ion collision in BAMPS

Heavy flavor in BAMPS



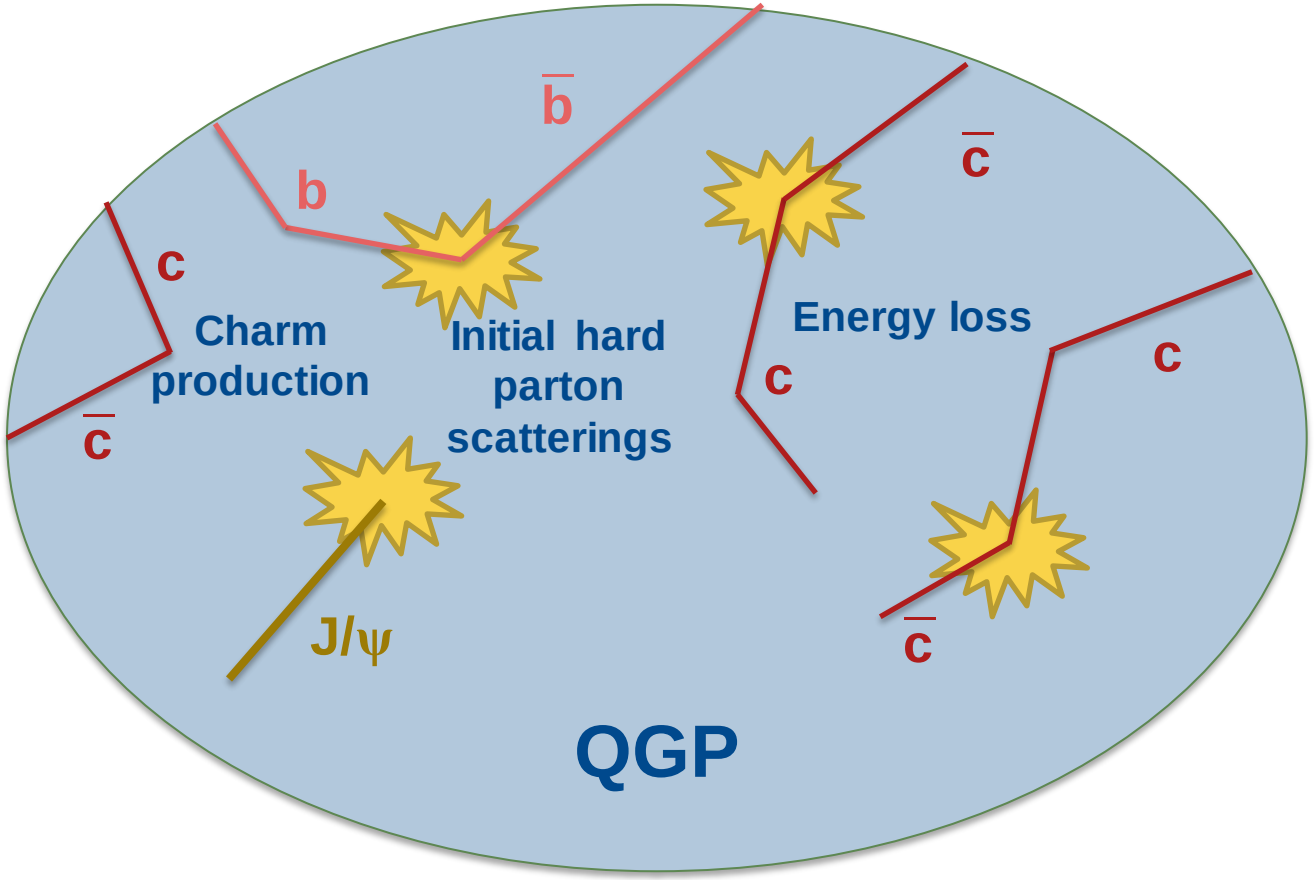
Sketch of heavy-ion collision in BAMPS

Heavy flavor in BAMPS



Sketch of heavy-ion collision in BAMPS

Heavy flavor in BAMPS



Sketch of heavy-ion collision in BAMPS

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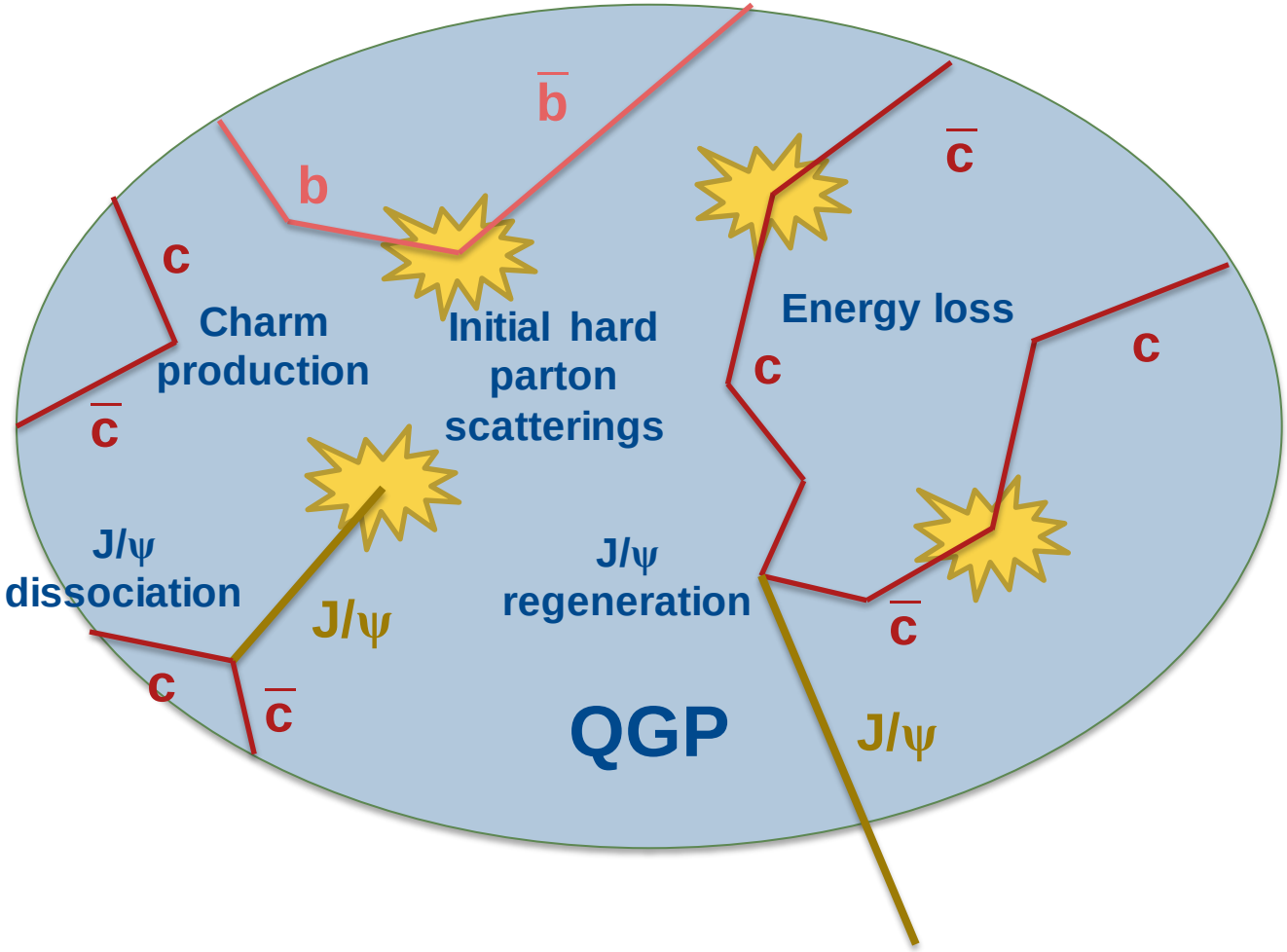
Heavy flavor in BAMPS



Sketch of heavy-ion collision in BAMPS

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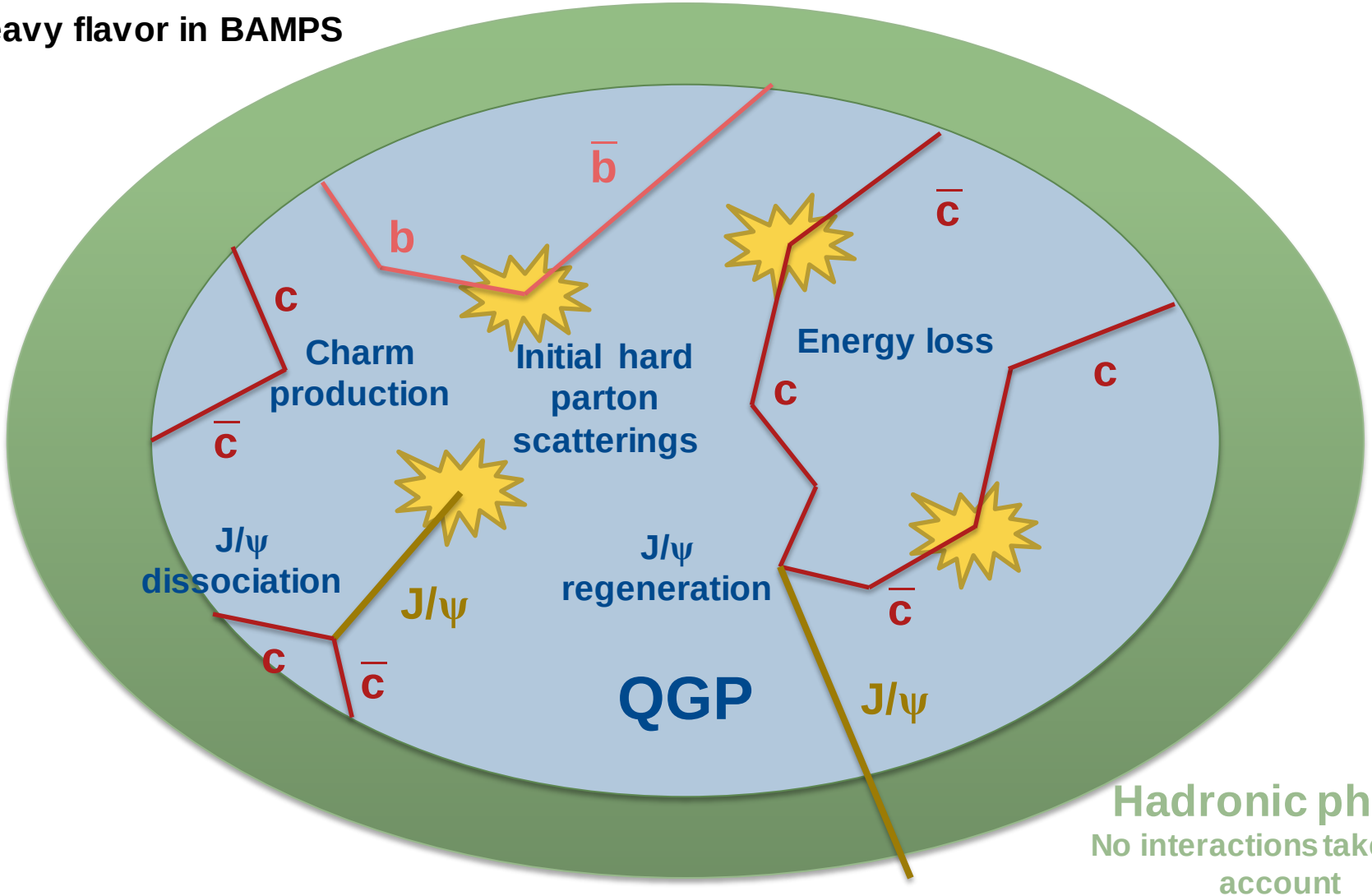
Heavy flavor in BAMPS



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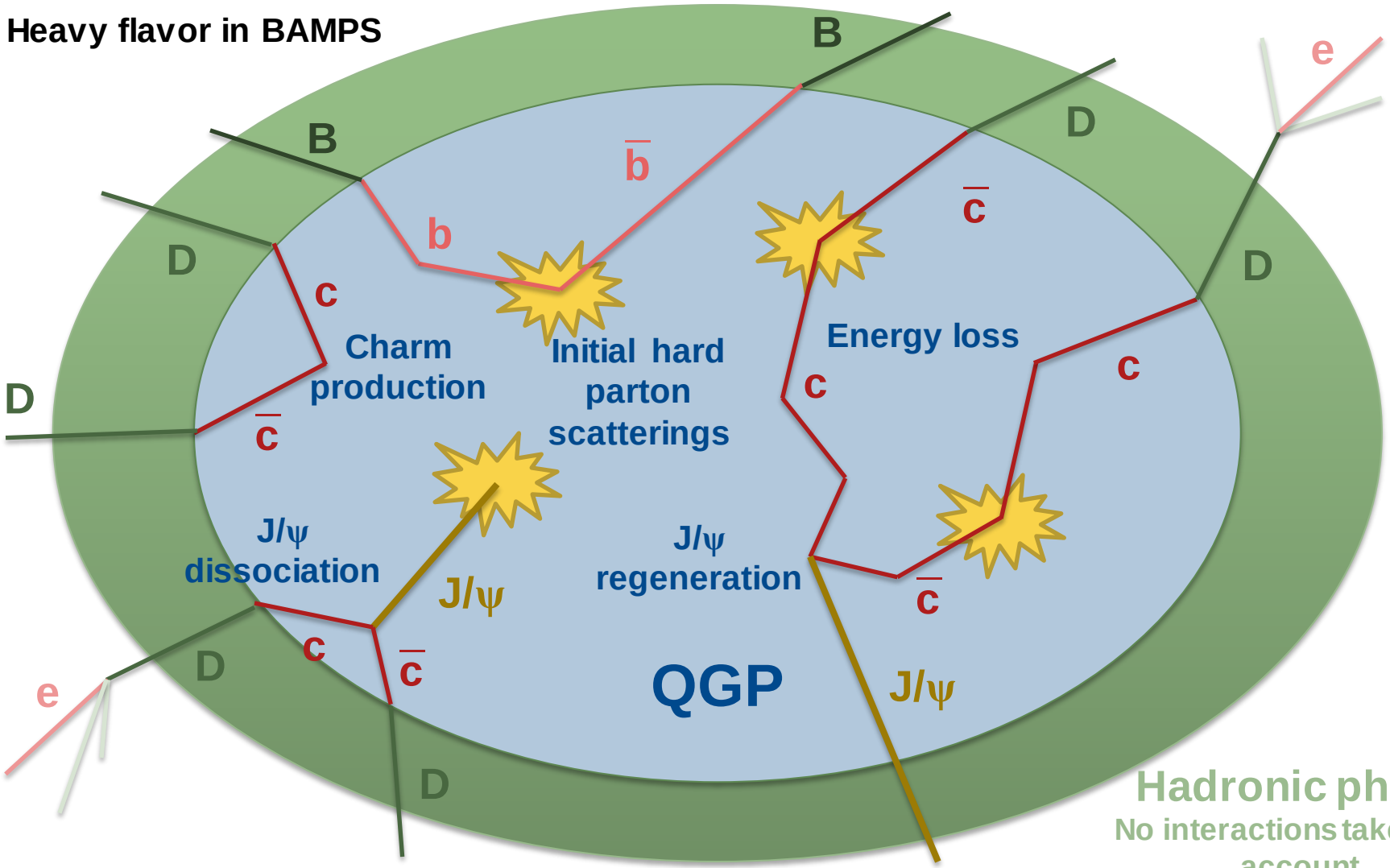
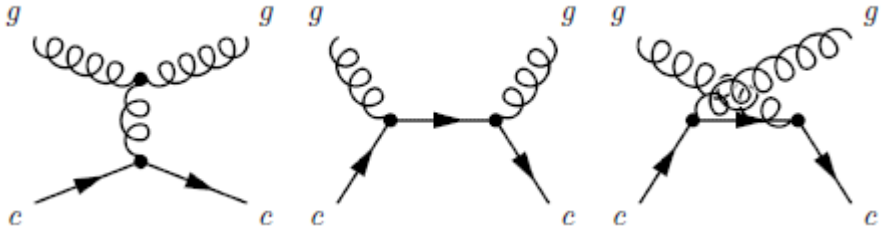


Heavy quark scattering

Leading order perturbative QCD:

$$g + Q \to g + Q$$
$$g + \bar{Q} \to g + \bar{Q}$$



t channel is divergent for small t

$$\frac{1}{t} \to \frac{1}{t - \kappa\, m_D^2}$$

κ **can be fixed to**

$$\kappa = \frac{1}{2e} \approx 0.184$$

by comparing dE/dx to HTL result beyond logarithmic accuracy

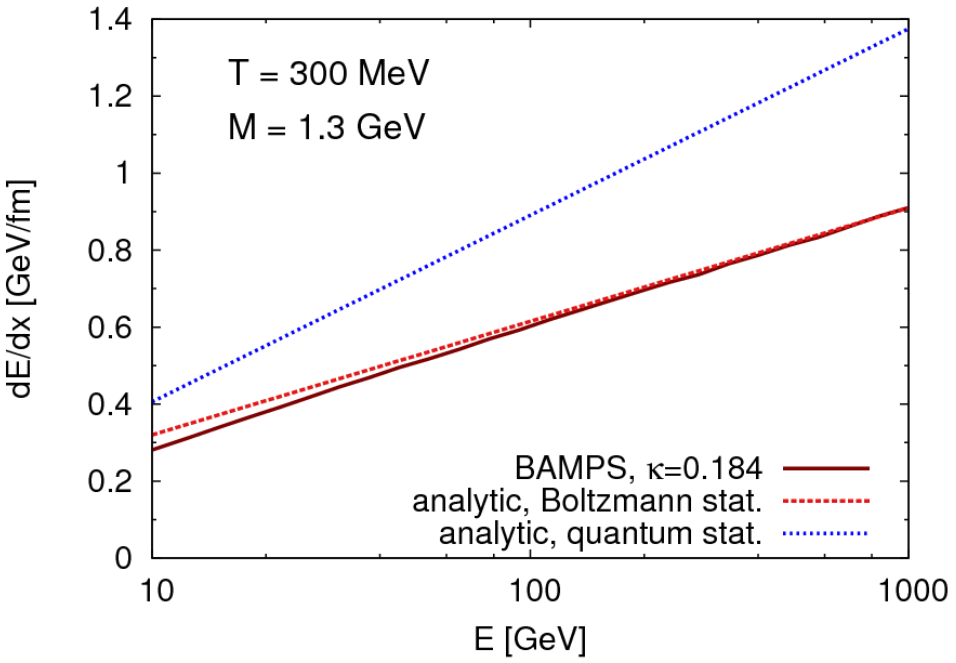
A. Peshier,
arXiv:0801.0595
[hep-ph]

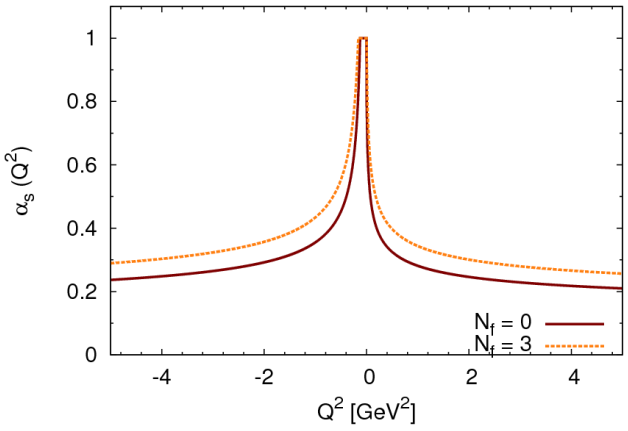
P.B. Gossiaux,
J. Aichelin,
Phys.Rev.C78 (2008)

Heavy quark scattering

Compare to analytic formula

$$\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{8\alpha_s^2 T^2}{\pi}\left[\left(1+\frac{n_f}{3}\right)\ln\frac{ET}{m_D^2} + \frac{2}{9}\ln\frac{ET}{M^2} + \left(\ln 2 - \frac{1}{4} - \frac{\gamma}{3}\right)n_f + \frac{31}{9}\ln 2 - \frac{101}{108} - \frac{11\gamma}{9}\right]$$



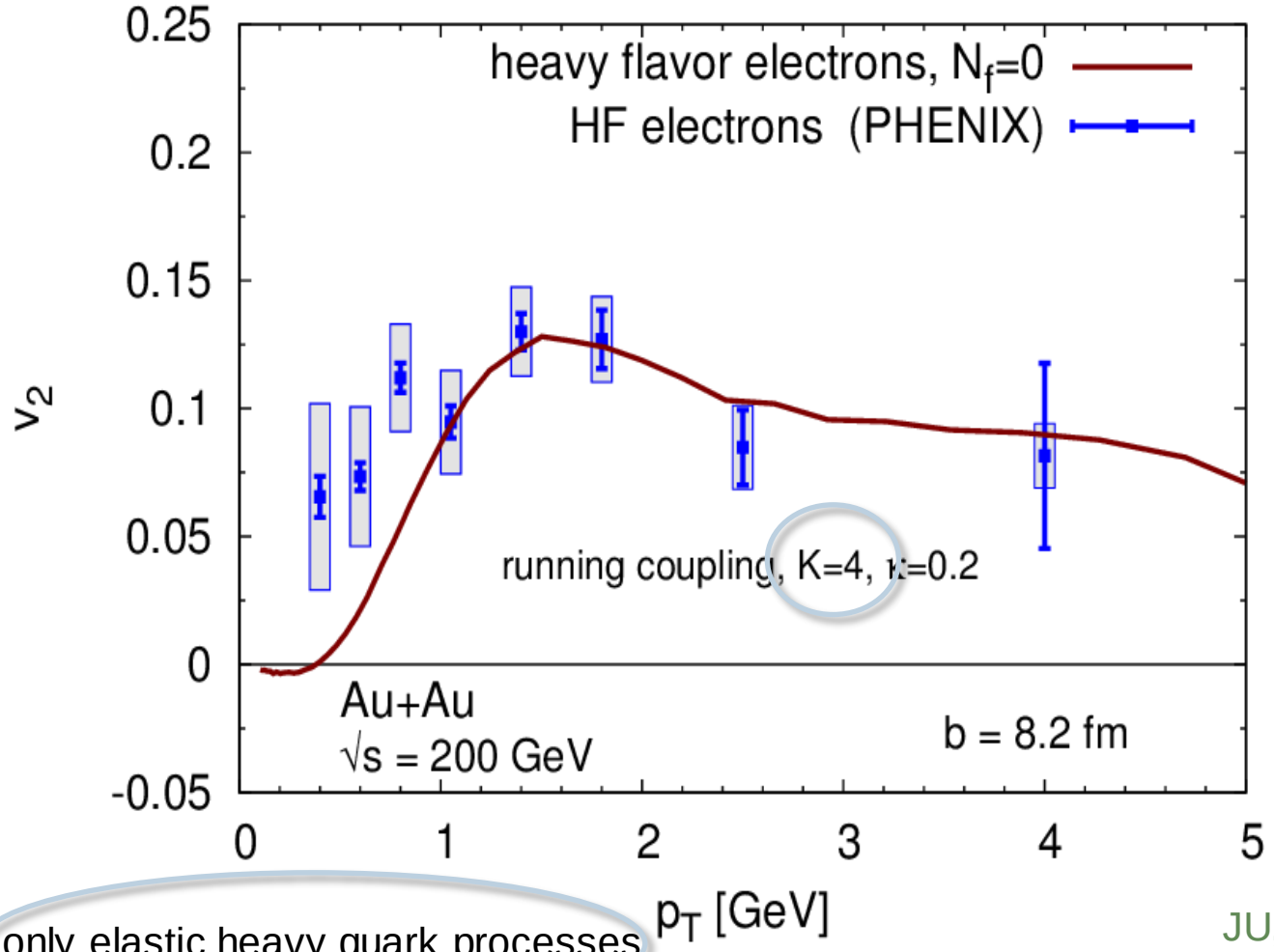


Introduce a running coupling constant for all channels

P.B. Gossiaux, J. Aichelin, Phys.Rev.C78 (2008)

Heavy quark elliptic flow v_2 at RHIC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



RHIC

What is missing:

- **Radiative contributions**
- **Quantum statistics**

PHENIX, arXiv:1005.1627

only elastic heavy quark processes

JU, Fochler, Xu, Greiner
Phys. Rev. C 84 (2011)

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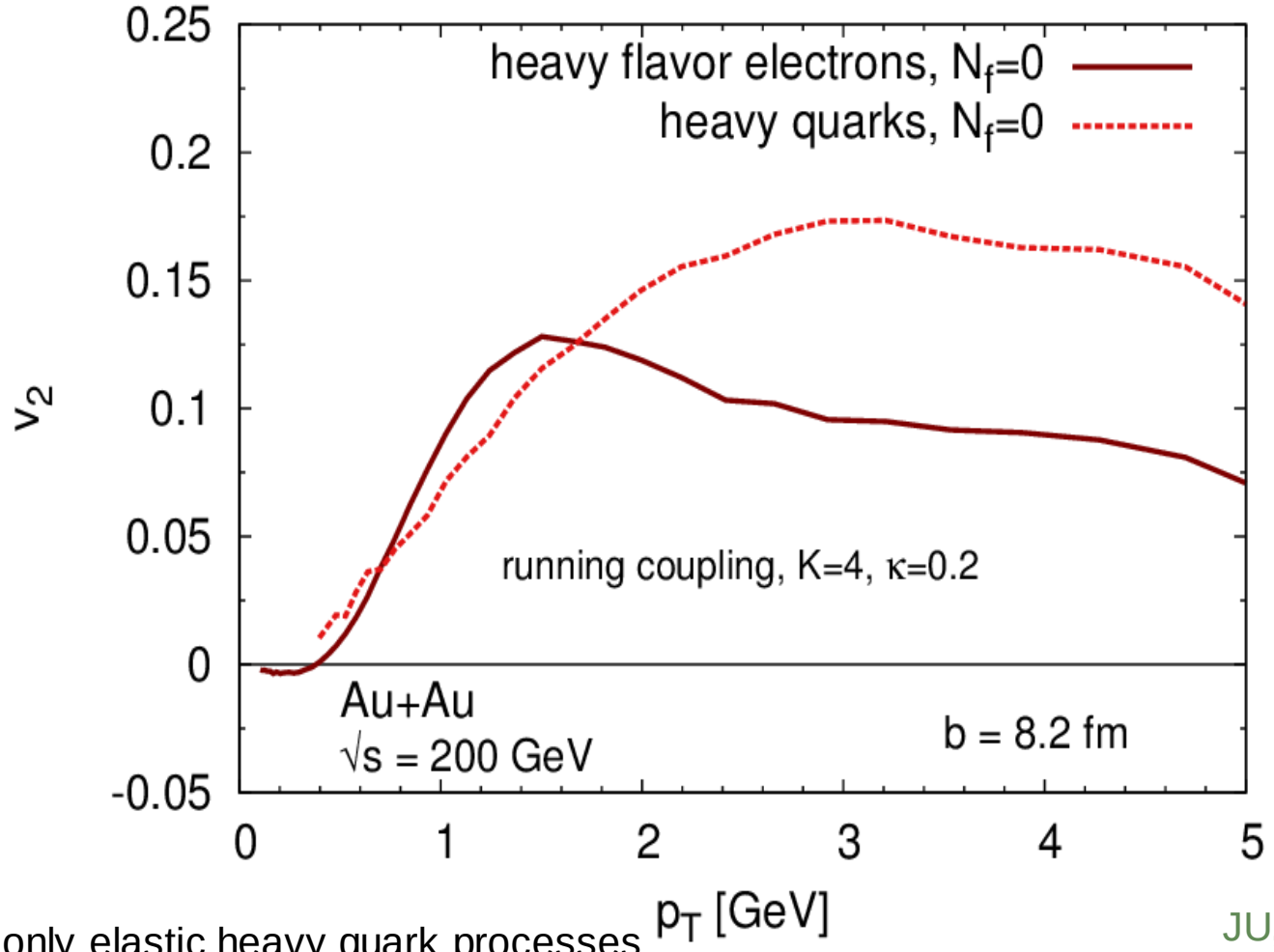

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JU, Fochler, Xu, Greiner
Phys. Rev. C 84 (2011)

BAMPS with N_{flavor} = 3+2

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Implemented processes

Heavy Flavor

$$g + g \to Q + \bar{Q}$$
$$Q + \bar{Q} \to g + g$$
$$q + \bar{q} \to Q + \bar{Q}$$
$$Q + \bar{Q} \to q + \bar{q}$$
$$g + Q \to g + Q$$
$$g + \bar{Q} \to g + \bar{Q}$$
$$q + Q \to q + Q$$
$$q + \bar{Q} \to q + \bar{Q}$$
$$g + J/\psi \to c + \bar{c}$$
$$c + \bar{c} \to g + J/\psi$$

$2 \to 2$

$g\,g \to g\,g$		
$g\,g \to q\,\bar{q}$		
$q\,\bar{q} \to g\,g$	and	$q\,\bar{q} \to q'\,\bar{q}'$
$q\,g \to q\,g$	and	$\bar{q}\,g \to \bar{q}\,g$
$q\,\bar{q} \to q\,\bar{q}$		
$q\,q \to q\,q$	and	$\bar{q}\,\bar{q} \to \bar{q}\,\bar{q}$
$q\,q' \to q\,q'$	and	$q\,\bar{q}' \to q\,\bar{q}'$

$2 \leftrightarrow 3$

$g\,g \leftrightarrow g\,g\,g$		
$q\,g \leftrightarrow q\,g\,g$	and	$\bar{q}\,g \leftrightarrow \bar{q}\,g\,g$
$q\,\bar{q} \leftrightarrow q\,\bar{q}\,g$		
$q\,q \leftrightarrow q\,q\,g$	and	$\bar{q}\,\bar{q} \leftrightarrow \bar{q}\,\bar{q}\,g$
$q\,q' \leftrightarrow q\,q'\,g$	and	$q\,\bar{q}' \leftrightarrow q\,\bar{q}'\,g$

Heavy quark elliptic flow v_2 at RHIC

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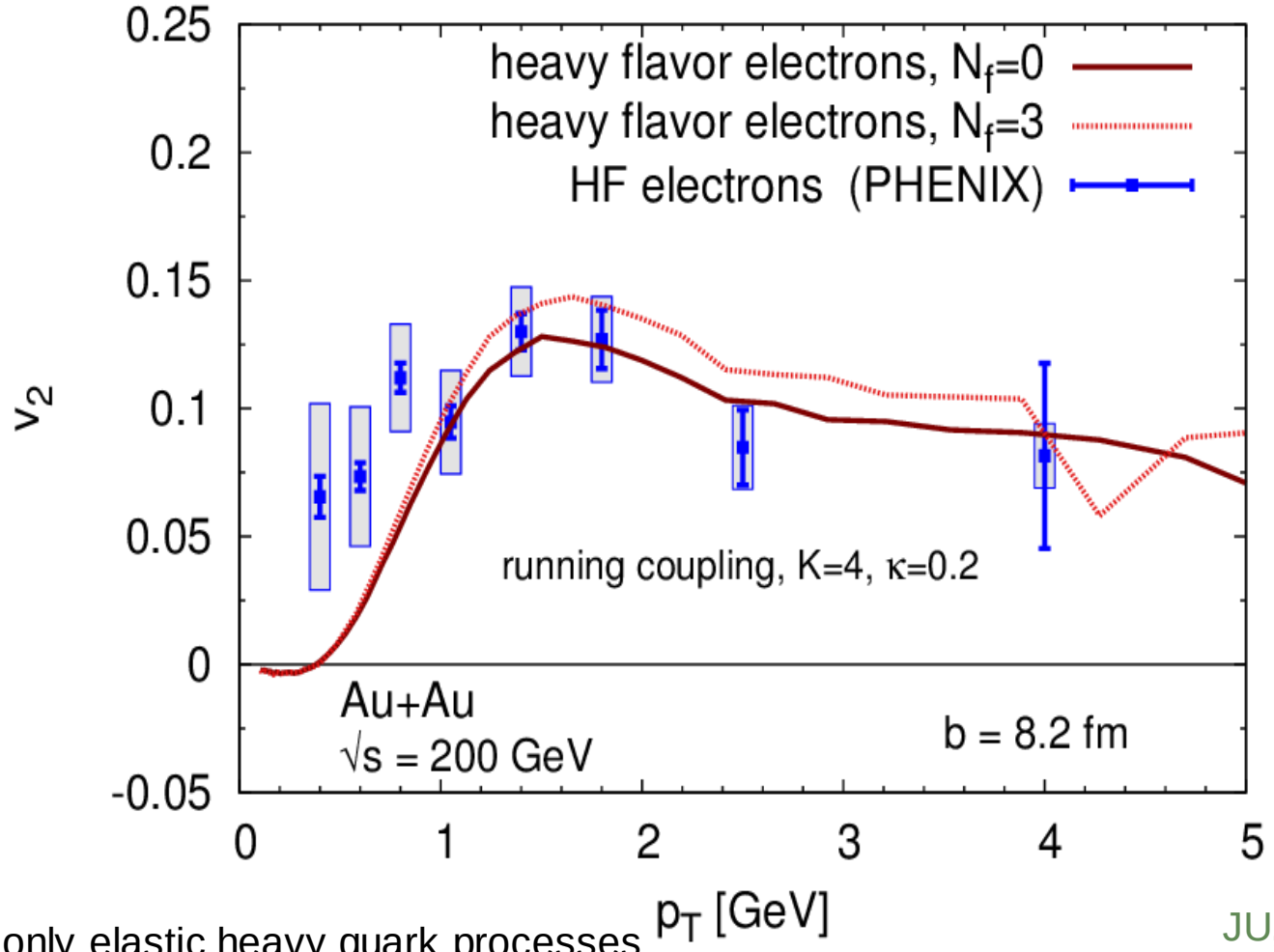

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Heavy quark R_{AA} at RHIC

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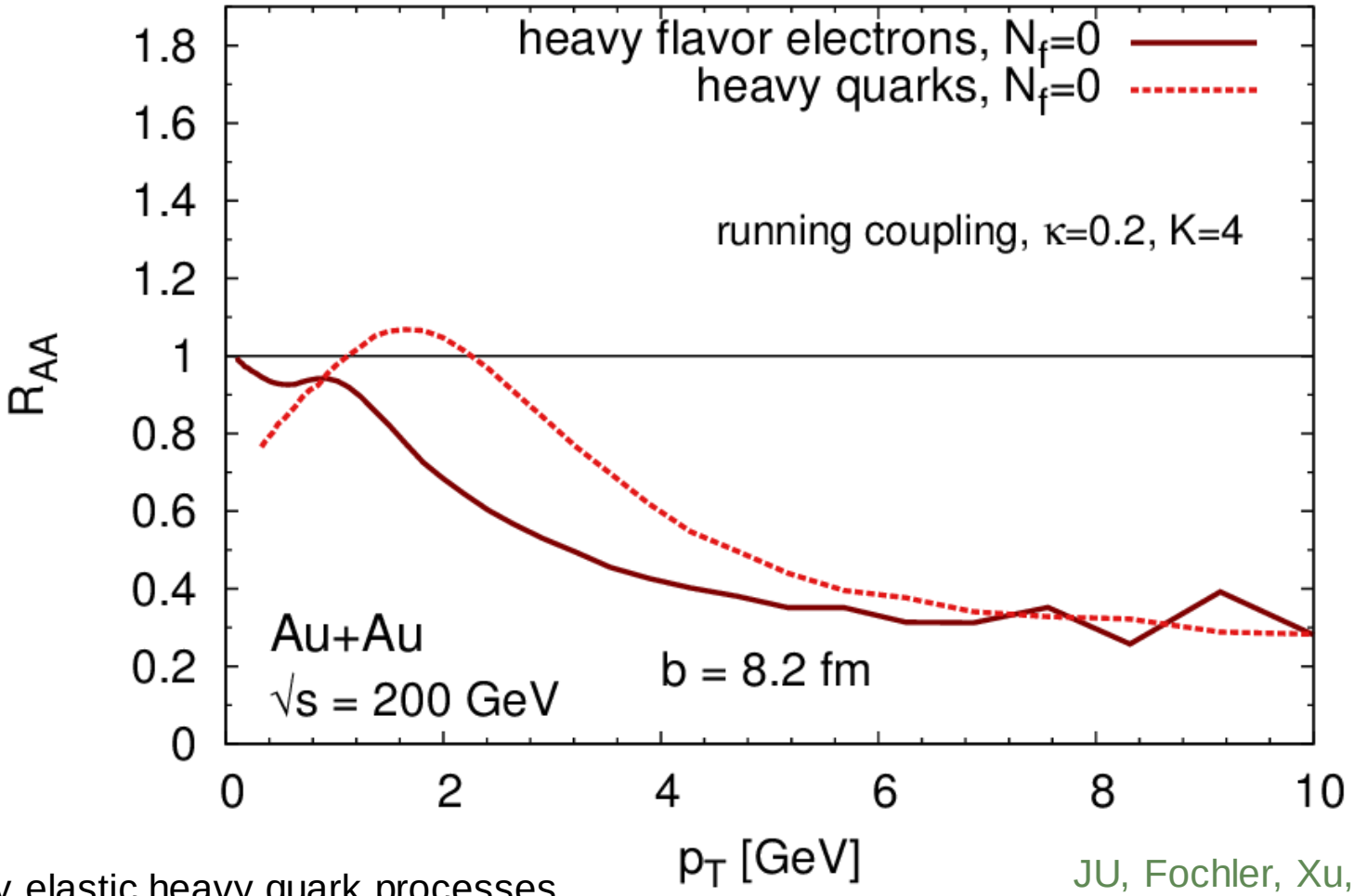

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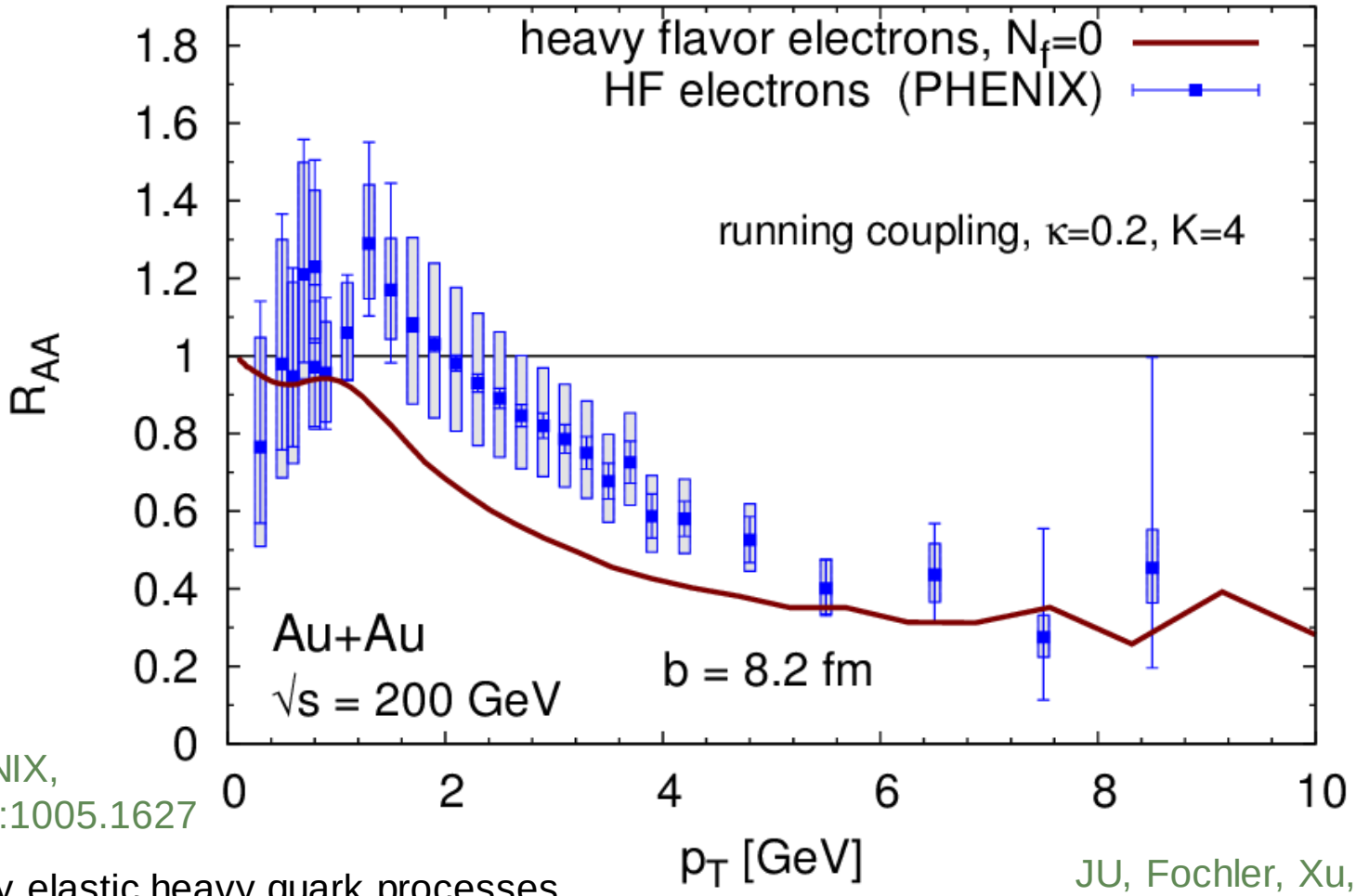

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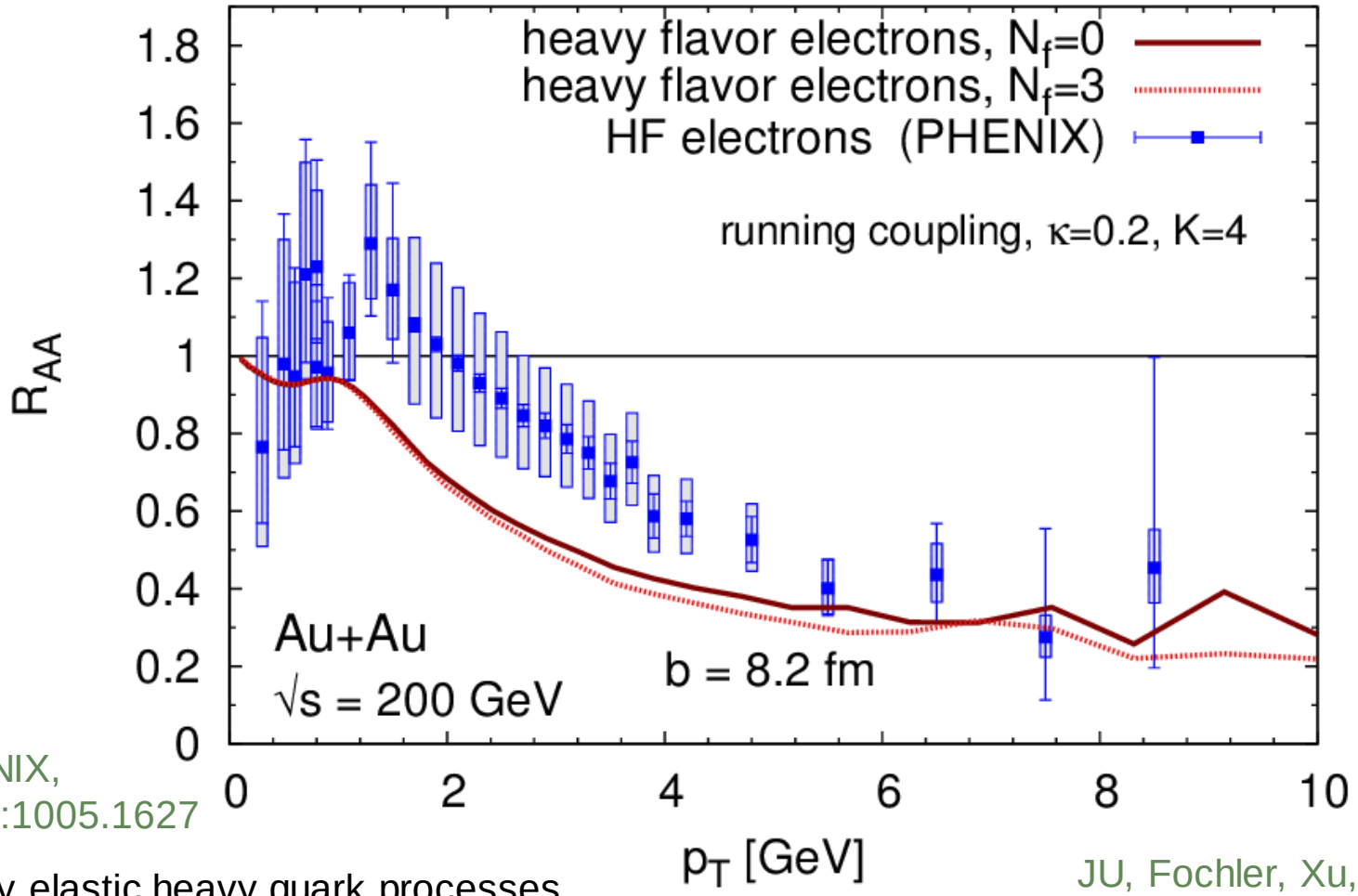

RHIC

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Phys. Rev. C 84 (2011)

Heavy quark v_2 at LHC

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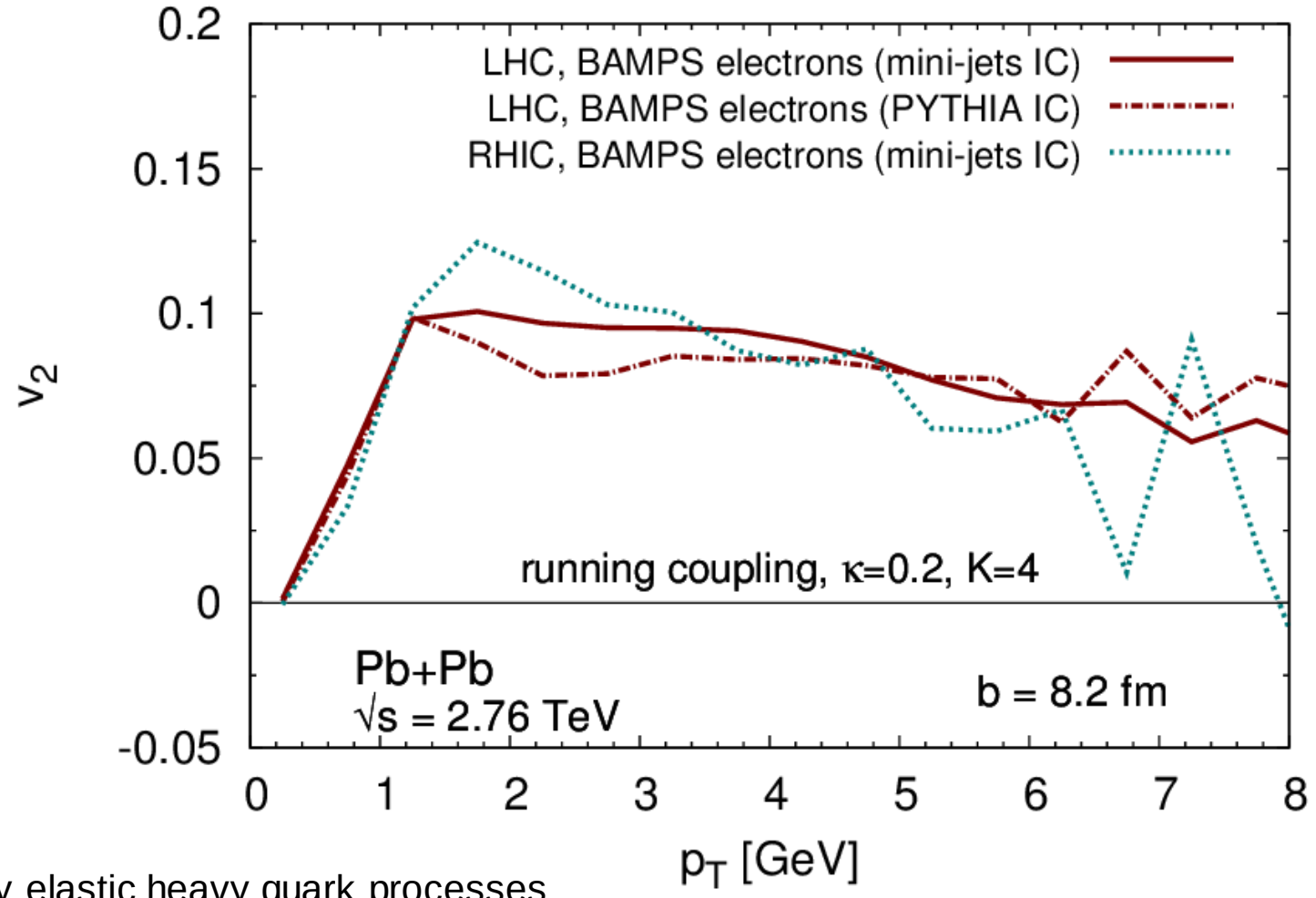
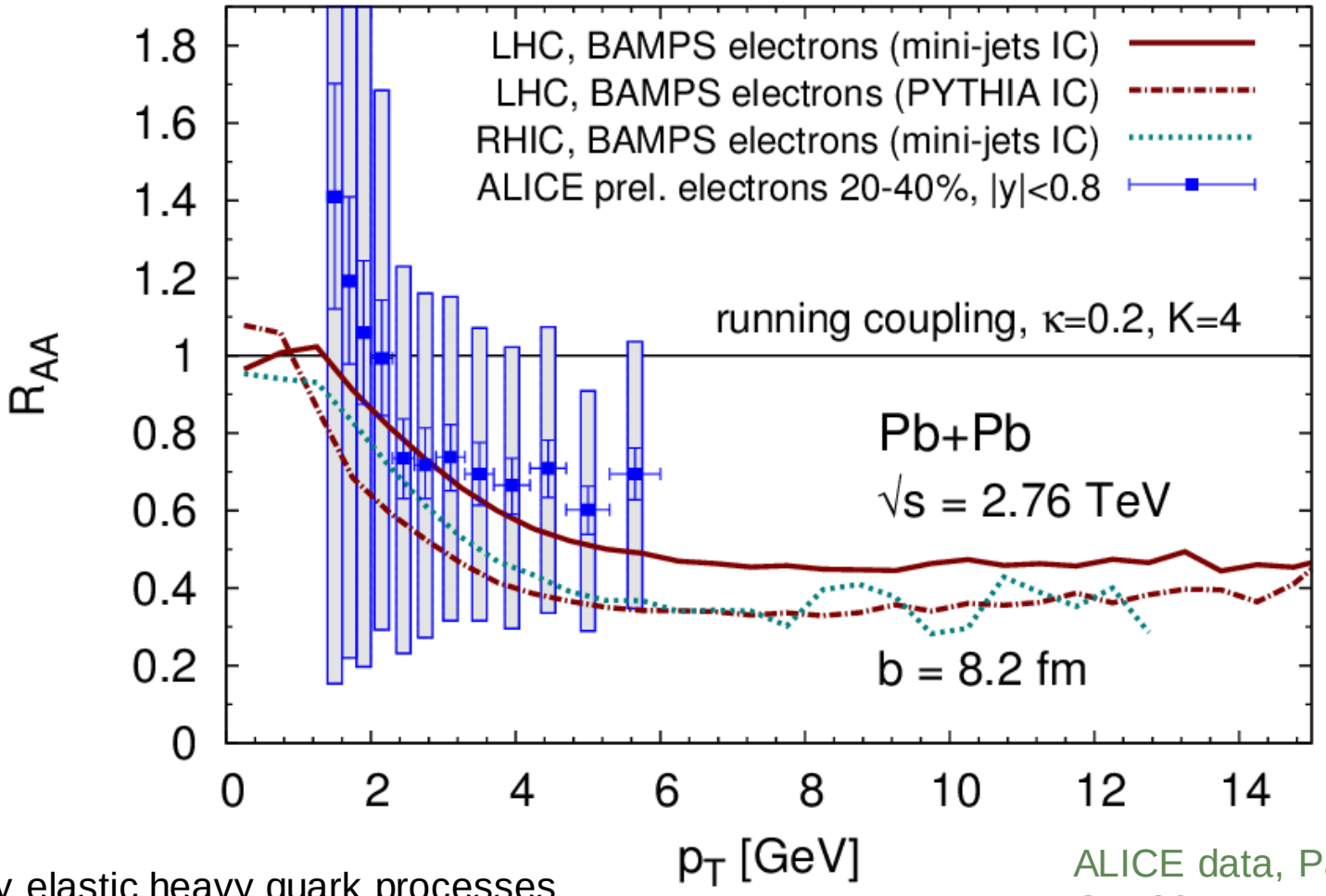


LHC

only elastic heavy quark processes

Heavy quark R_{AA} at LHC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



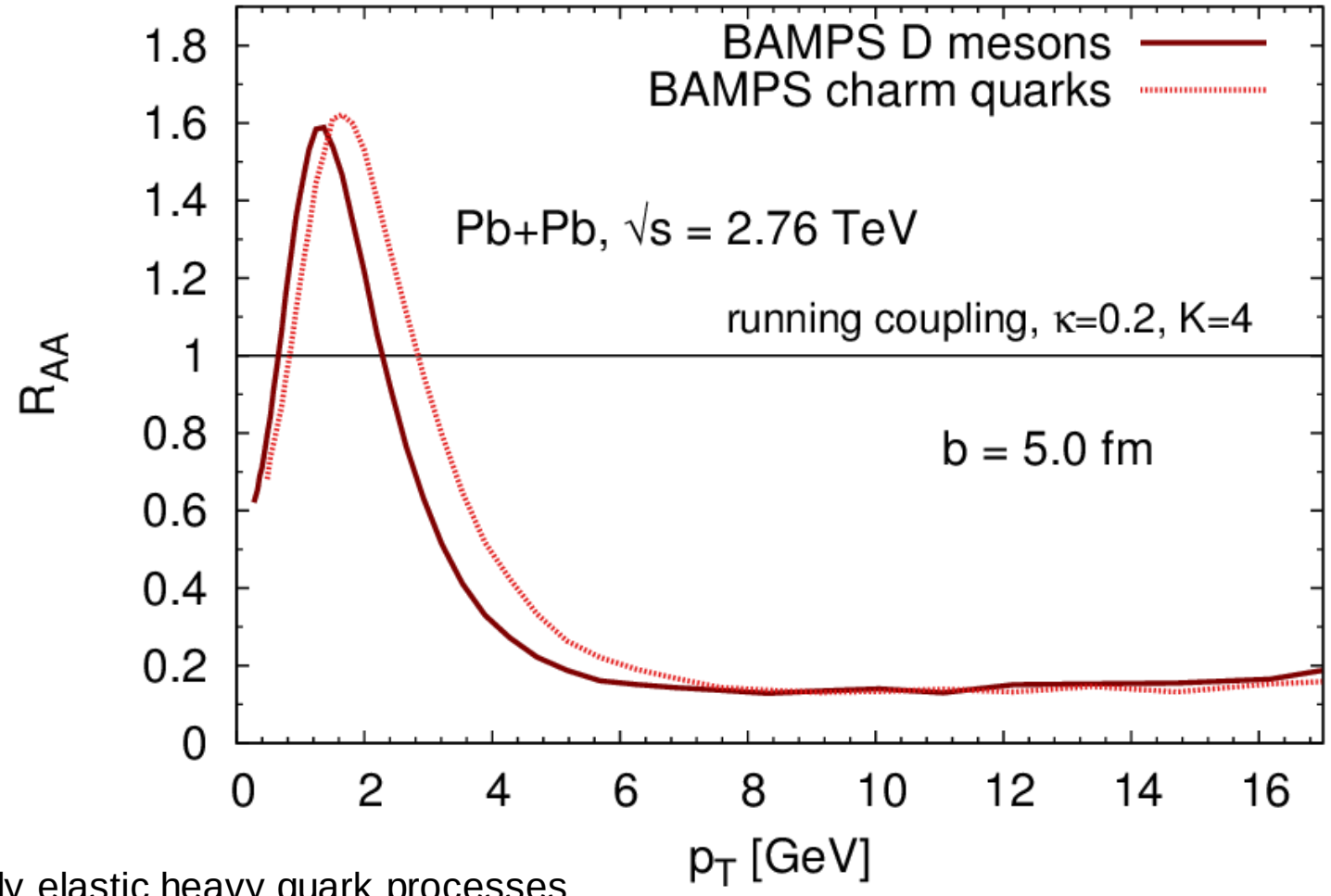
LHC

only elastic heavy quark processes

ALICE data, Pachmayer, QM 2011

D meson R_{AA} at LHC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



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only elastic heavy quark processes

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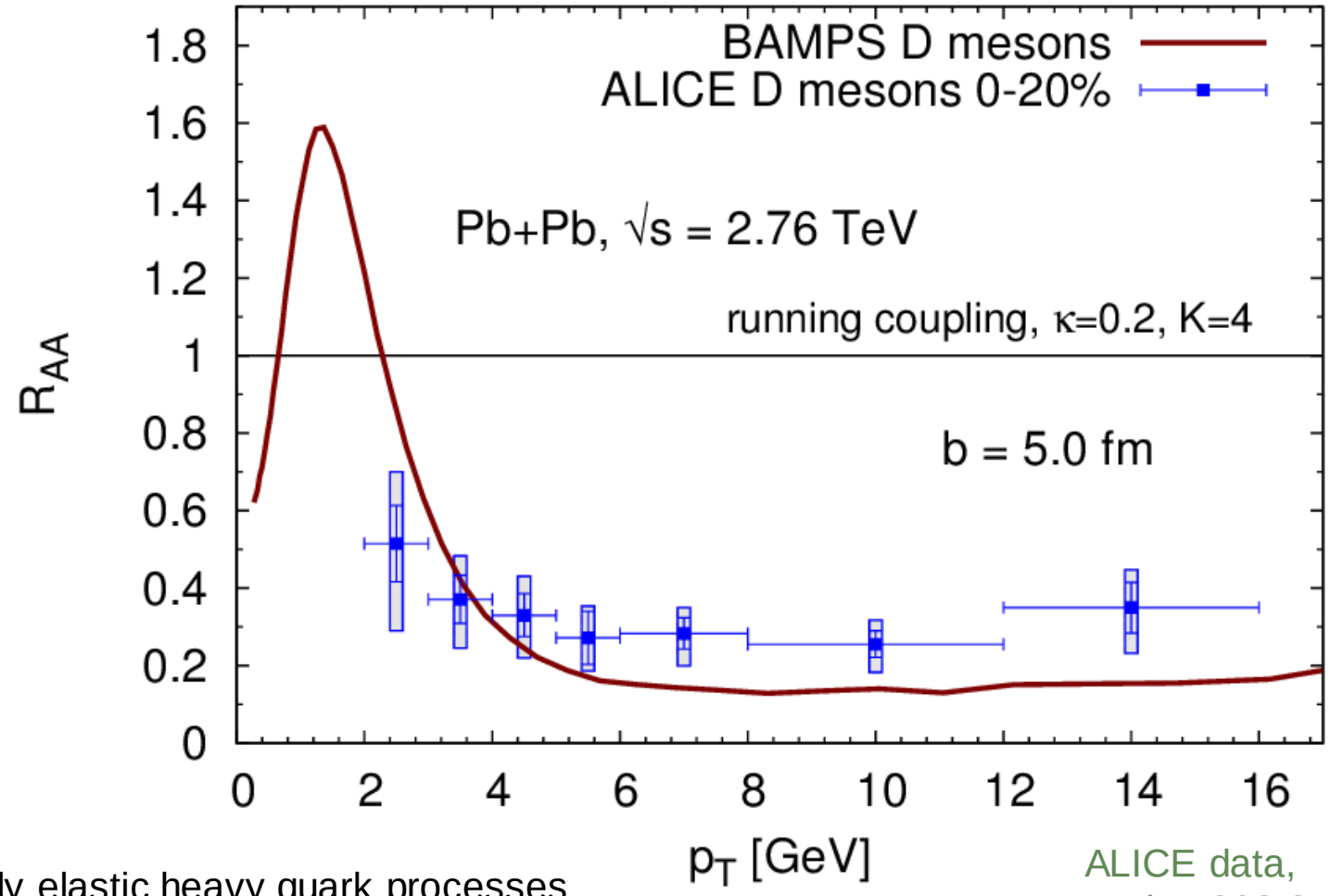


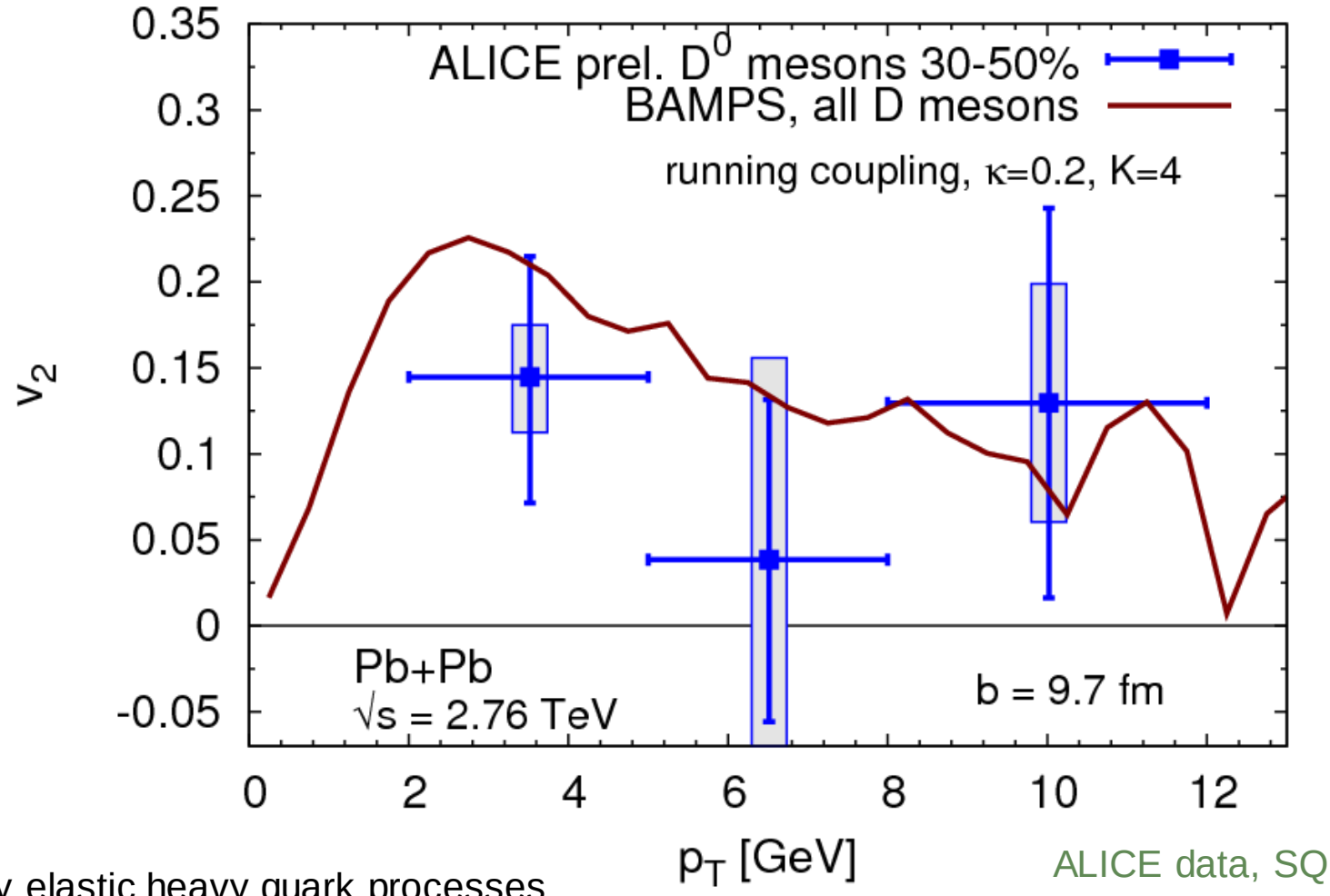
LHC

only elastic heavy quark processes

ALICE data, arXiv:1203.2160

D meson v_2 at LHC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



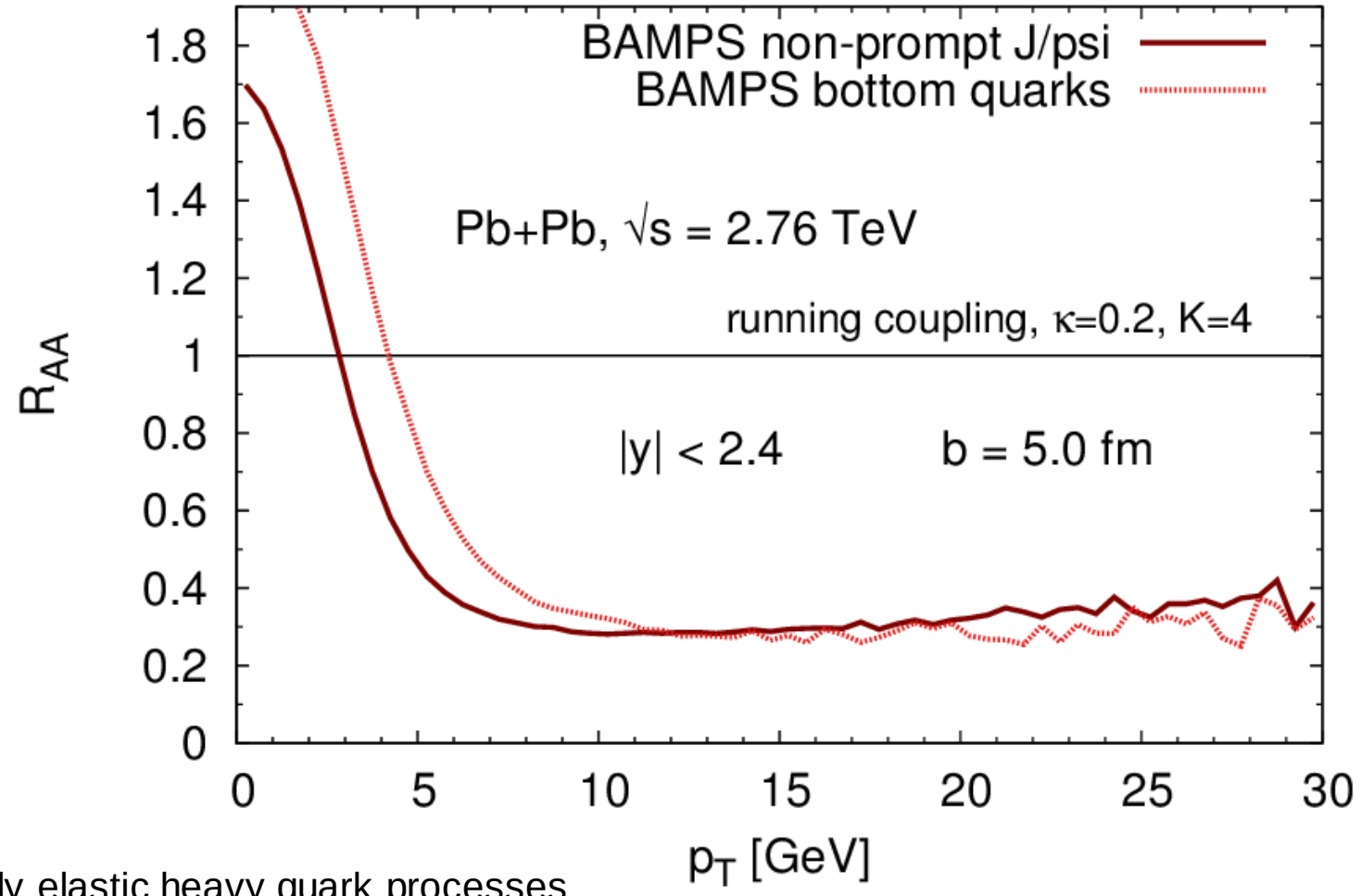
LHC

only elastic heavy quark processes

ALICE data, SQM 2011

Non-prompt J/psi R_{AA} at LHC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



LHC

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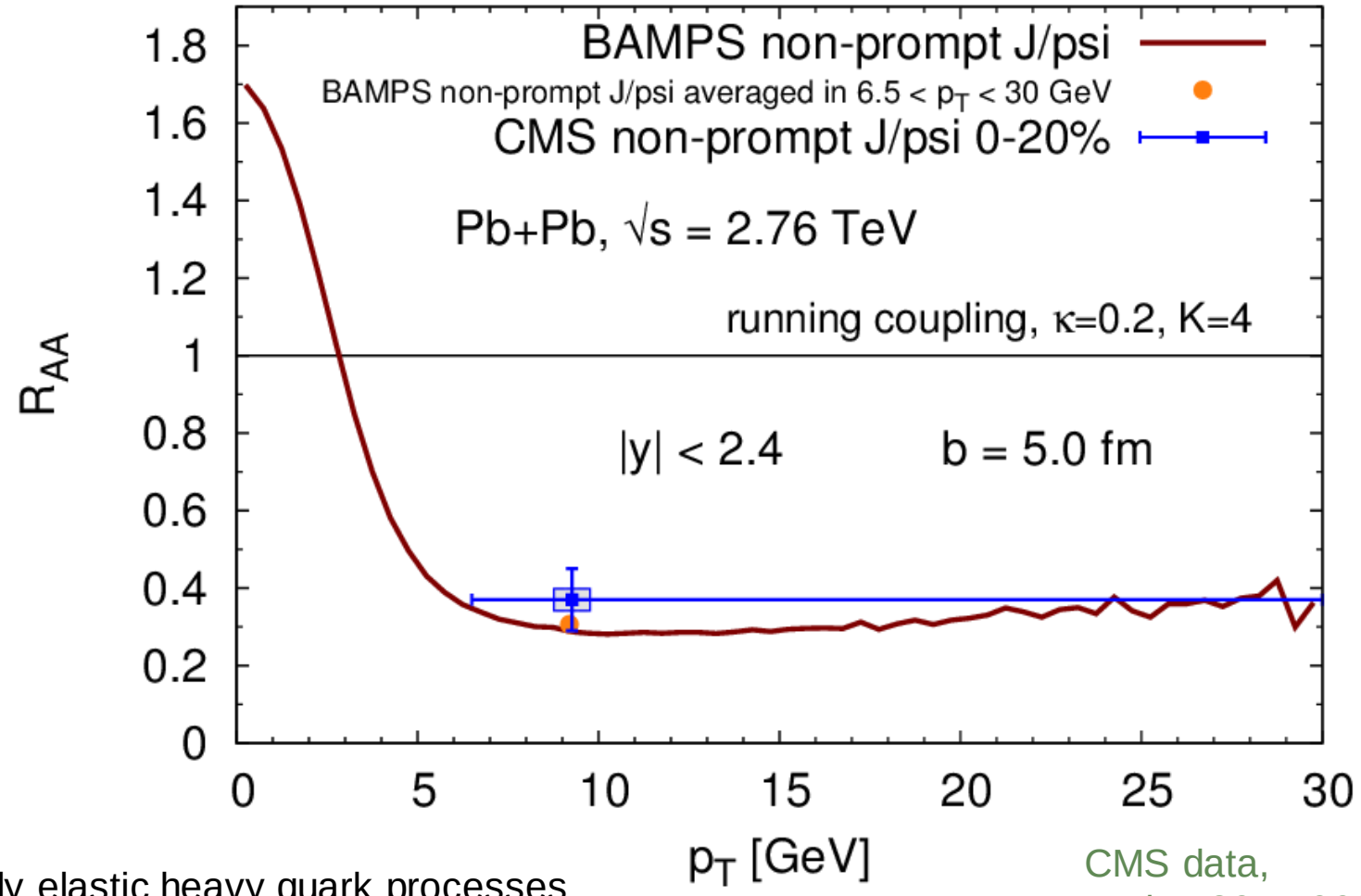
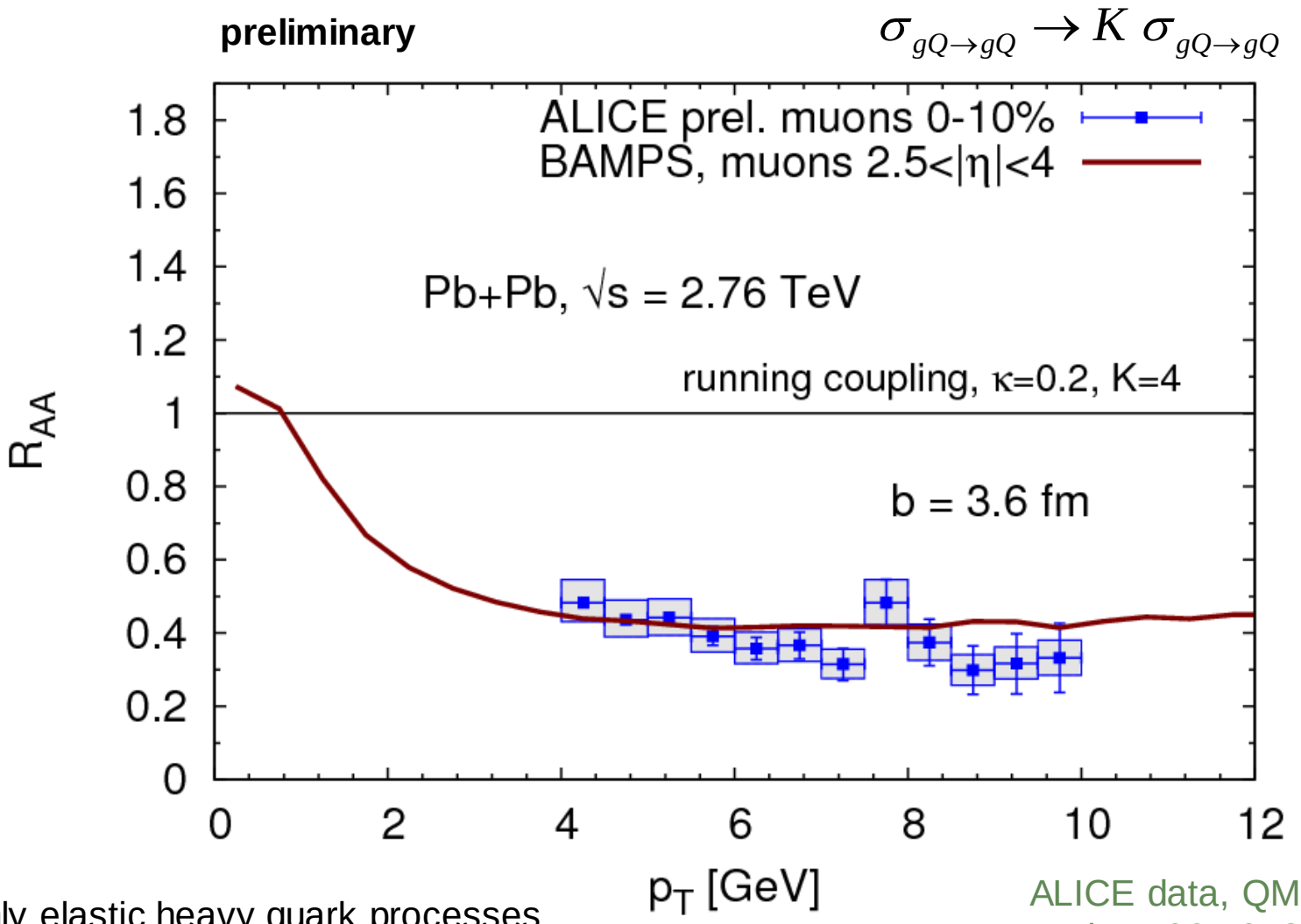


LHC

only elastic heavy quark processes

CMS data, arXiv:1201.5069

Muon R_{AA} at forward rapidity at LHC

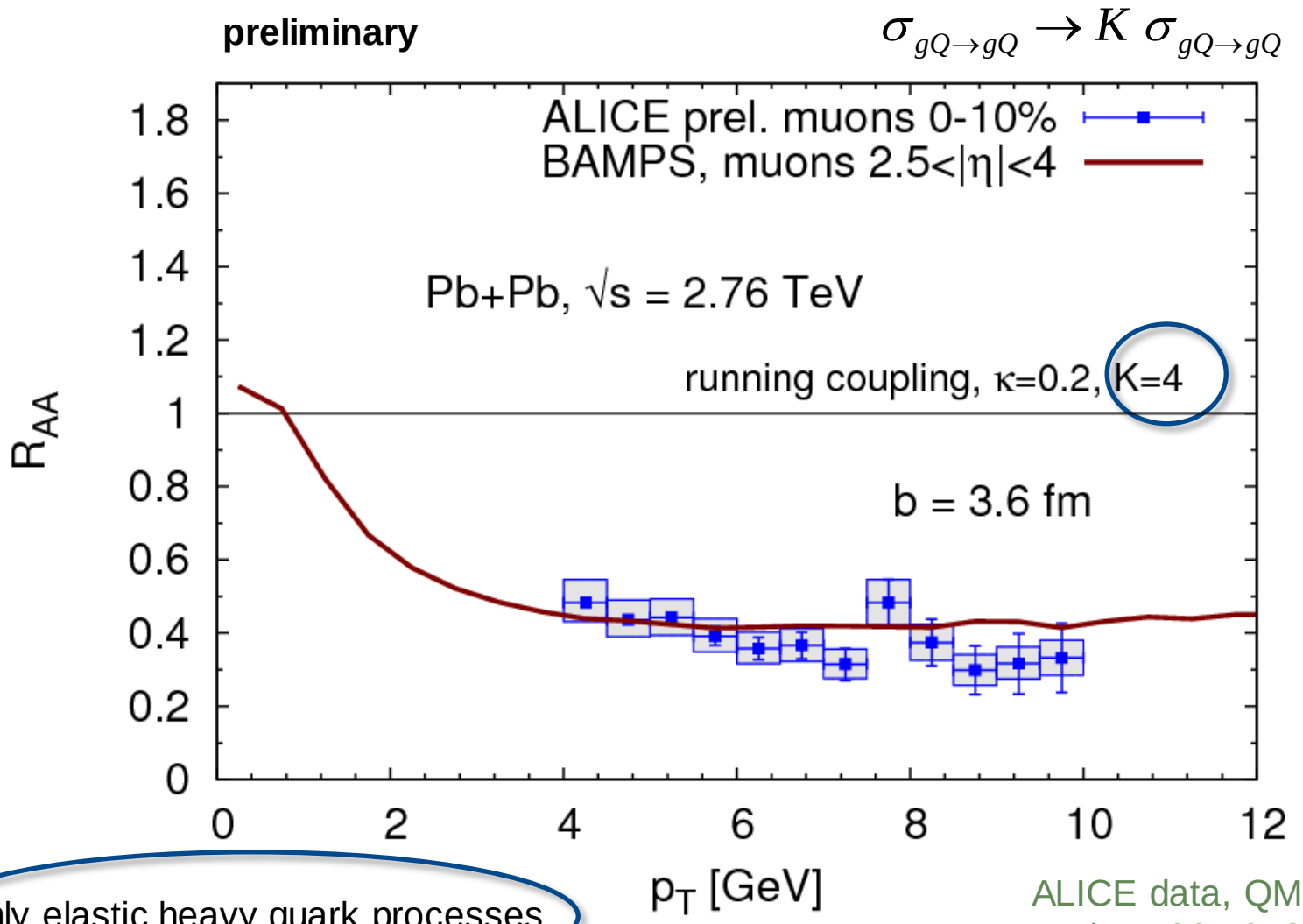


LHC

only elastic heavy quark processes

ALICE data, QM 2011, arXiv:1106.4042

Muon R_{AA} at forward rapidity at LHC



LHC

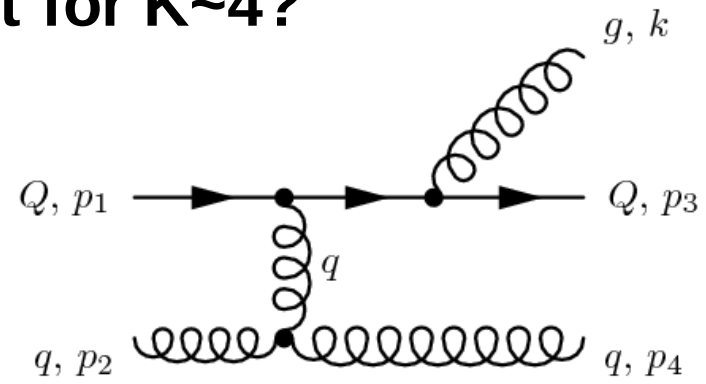
only elastic heavy quark processes

ALICE data, QM 2011, arXiv:1106.4042

Radiative processes

Can radiative processes account for K~4?

$$g + Q \to g + Q + g$$

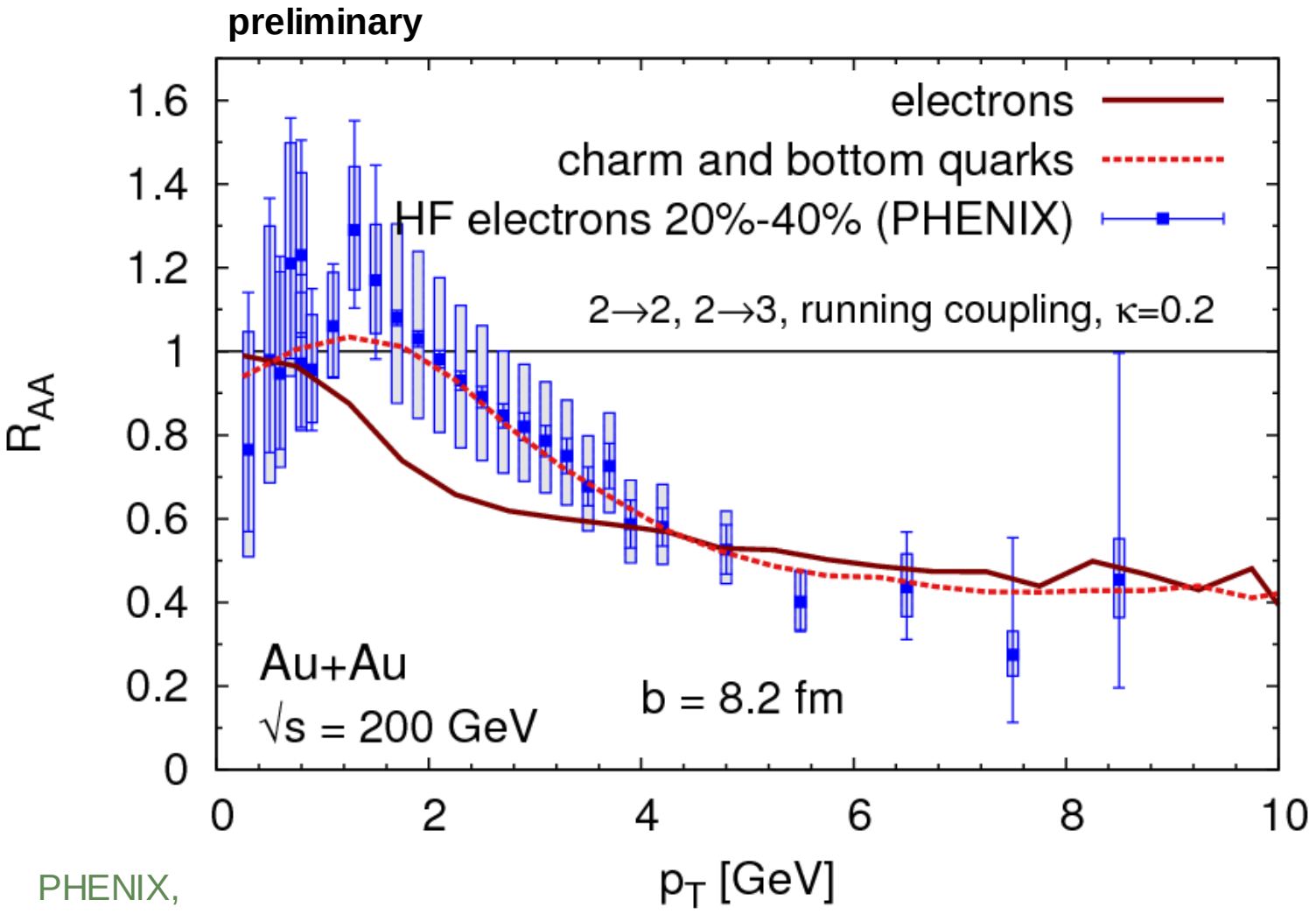


Gunion-Bertsch matrix element generalized to heavy quarks:

$$\left|\overline{\mathcal{M}}_{gQ\to gQg}\right|^2 = 12g^2 \left|\overline{\mathcal{M}}_0^{gQ}\right|^2 \left[\frac{\mathbf{k}_\perp}{k_\perp^2 + x^2M^2} + \frac{\mathbf{q}_\perp - \mathbf{k}_\perp}{(\mathbf{q}_\perp - \mathbf{k}_\perp)^2 + x^2M^2}\right]^2$$

In accordance to scalar QCD result from
Gossiaux, Aichelin, Gousset, Guiho, J.Phys.G37 (2010)

Heavy quark R_{AA} at RHIC with 2->3



RHIC

PHENIX, arXiv:1005.1627

Conclusions & outlook

Full space-time evolution of QGP with charm and bottom quarks

- **Running coupling and improved Debye screening yield results that can explain experimental v_2 and R_{AA} at RHIC if K=4 is introduced**
- **Good agreement with D meson v_2 and R_{AA} at LHC**
- **Good agreement with non-prompt J/psi and muon R_{AA} at LHC**
- **Preliminary results with $2 \rightarrow 3$ in full cascade are promising**

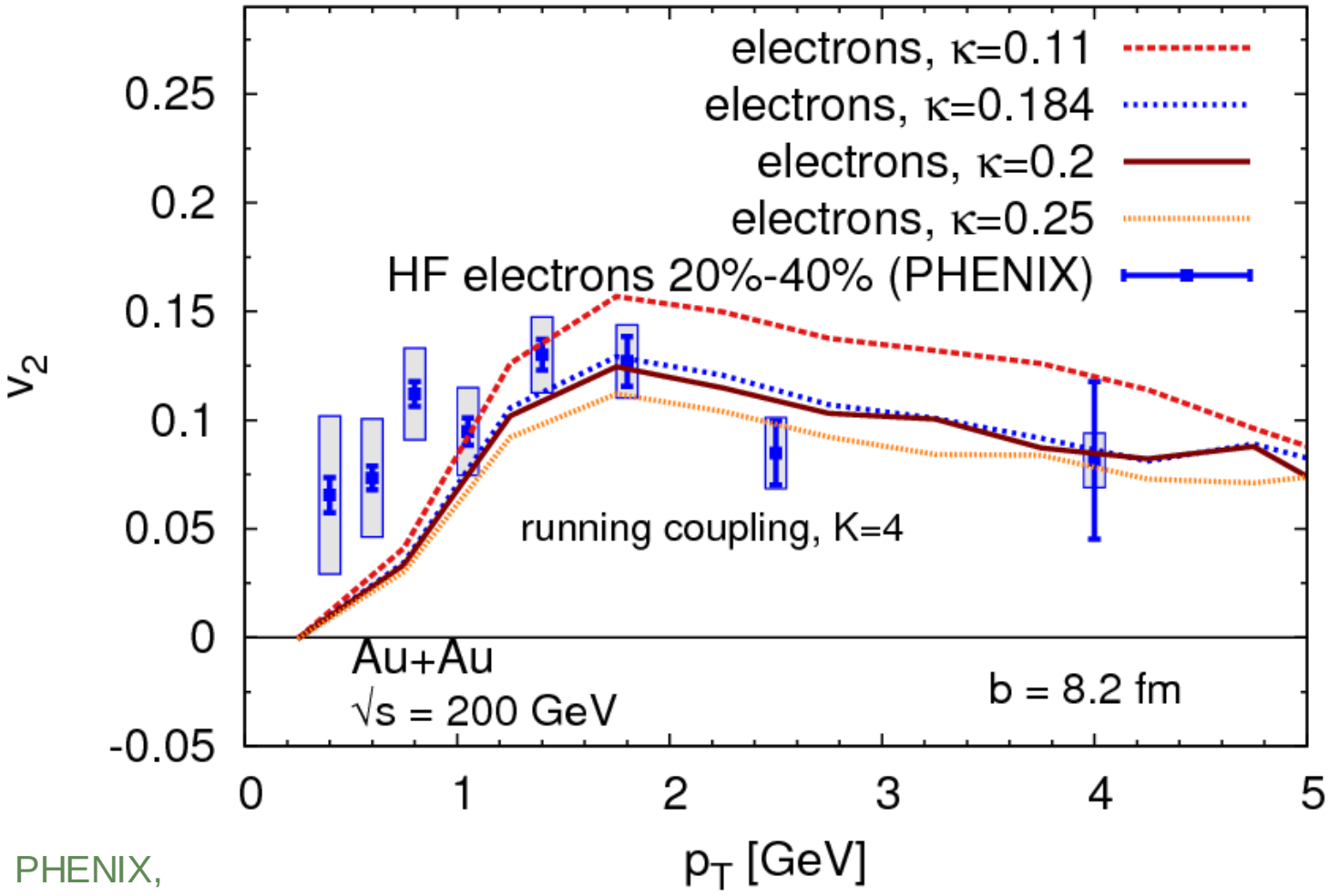
Further details on arXiv:1104.2295 and 1112.1559

Future tasks:

- **Further study of radiative heavy quark scattering in full cascade**
- **Light quark interactions with heavy quarks**

Thank you for your attention.

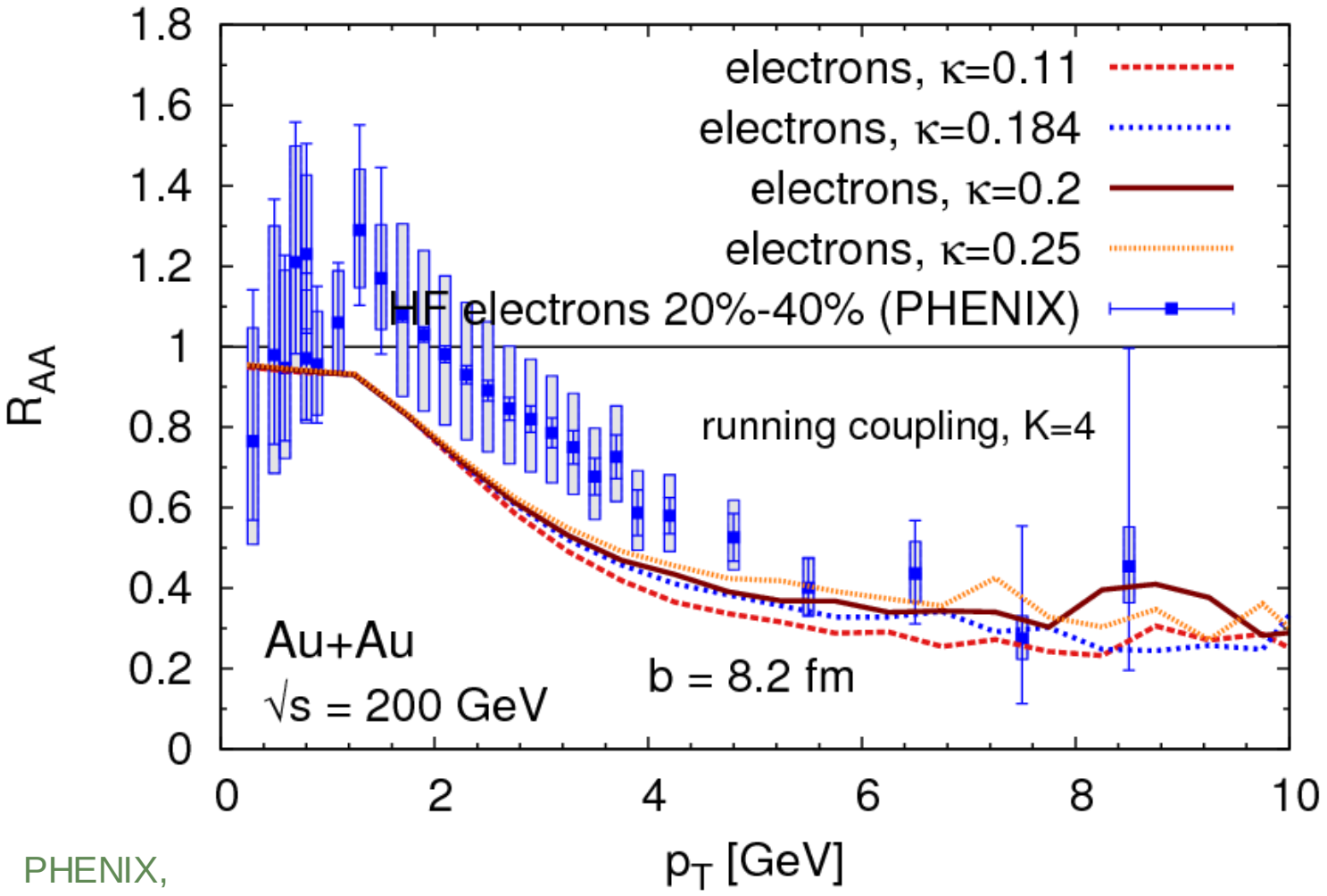
Heavy quark elliptic flow v_2 at RHIC



RHIC

PHENIX, arXiv:1005.1627

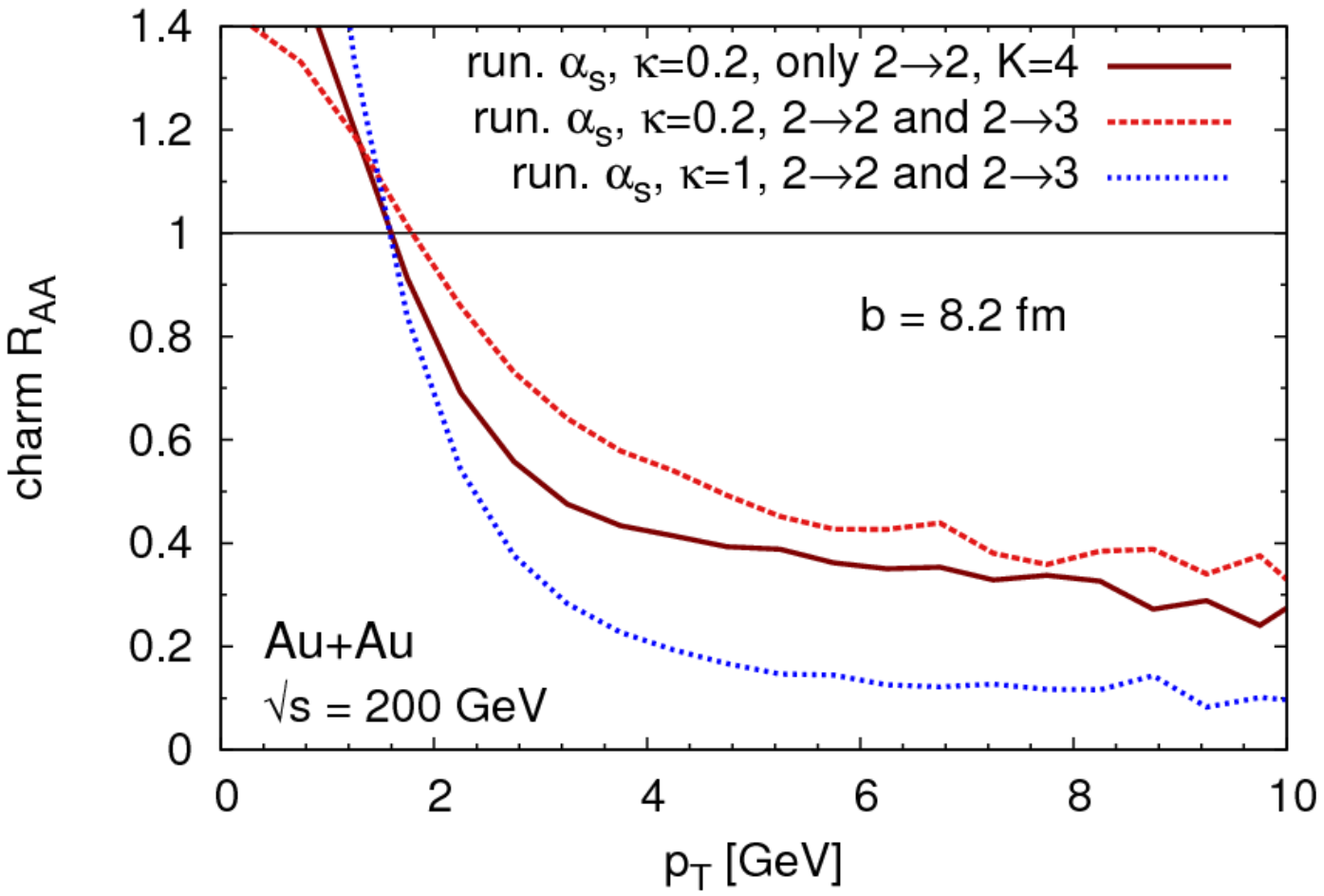
Heavy quark elliptic flow v_2 at RHIC



RHIC

PHENIX, arXiv:1005.1627

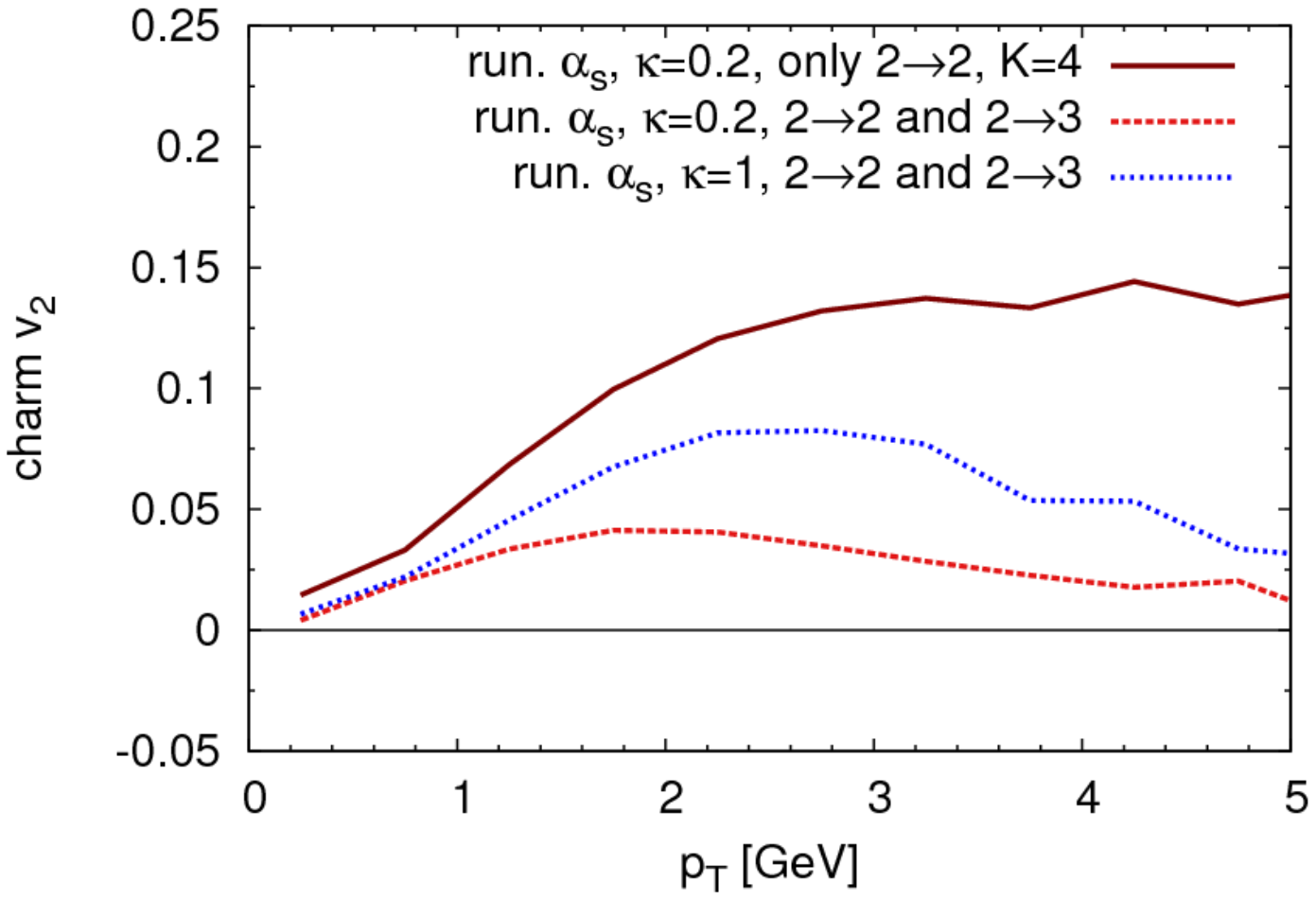
Charm R_{AA} at RHIC



For R_{AA} 2→3 processes can indeed account for K=4

Only charm quarks (no heavy flavor electrons!) for better comparison

Charm elliptic flow v_2 at RHIC



For v_2 2→3 processes cannot explain missing factor K=4

Different impact of 2→3 processes on v_2 and R_{AA}

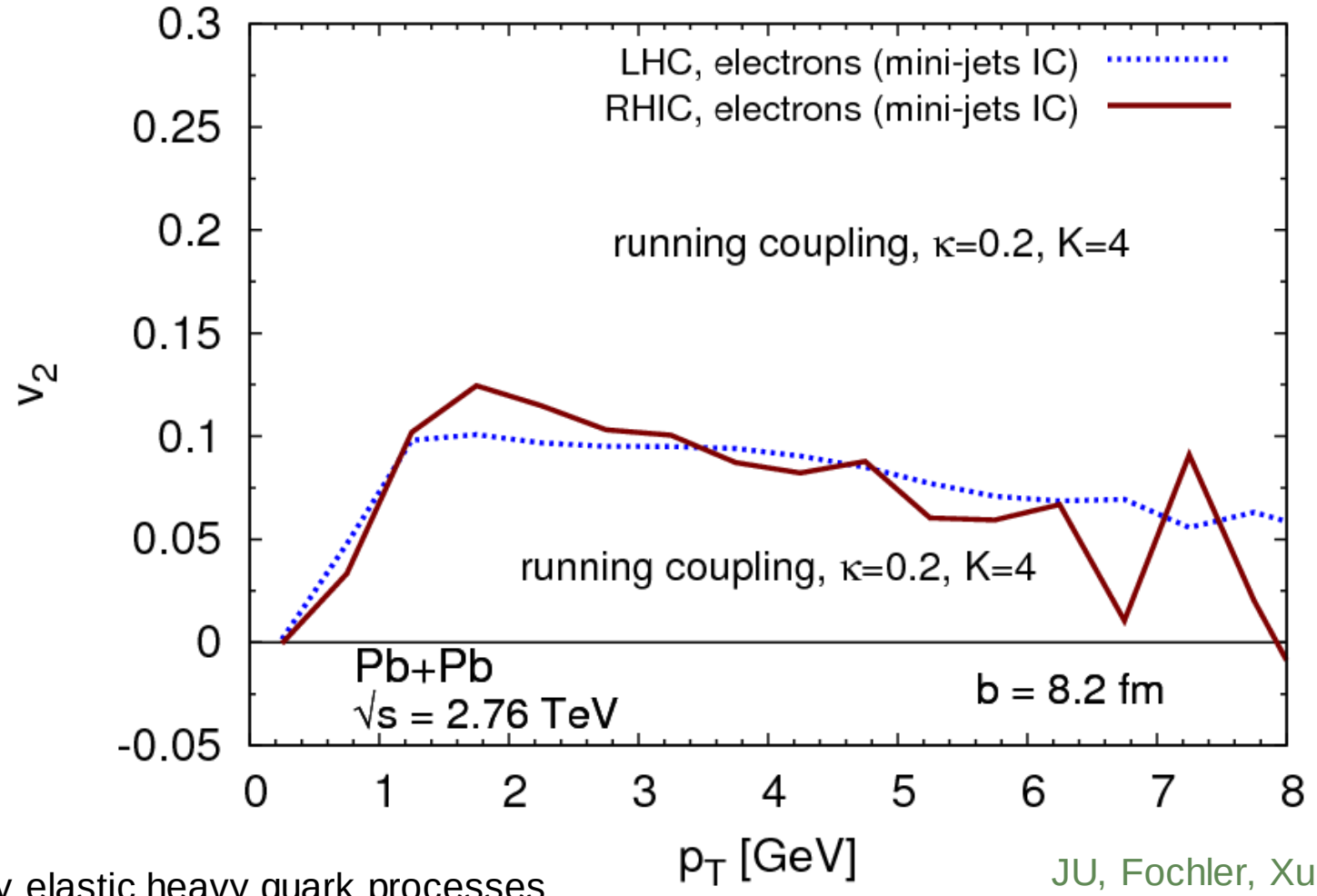
Reason: LPM effect

kappa=1 is even better since 2→3 processes more important due to LPM effect

Only charm quarks (no heavy flavor electrons!) for better comparison

Heavy quark elliptic flow v_2 at LHC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



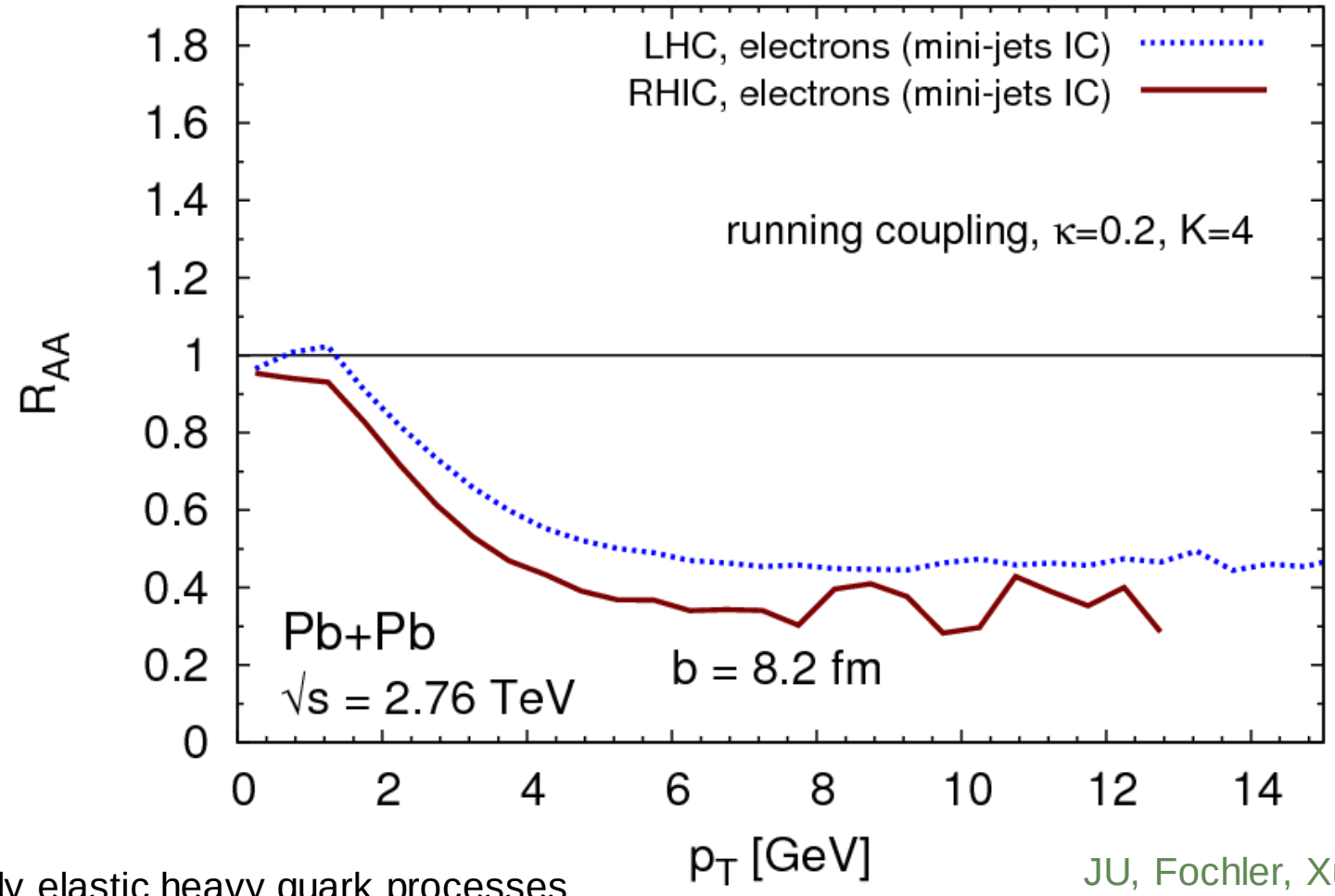
LHC

only elastic heavy quark processes

JU, Fochler, Xu, Greiner
Phys. Rev. C 84 (2011)

Heavy quark R_{AA} at LHC

$$\sigma_{gQ\to gQ} \to K\,\sigma_{gQ\to gQ}$$



LHC

only elastic heavy quark processes

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Heavy quark R_{AA} at RHIC

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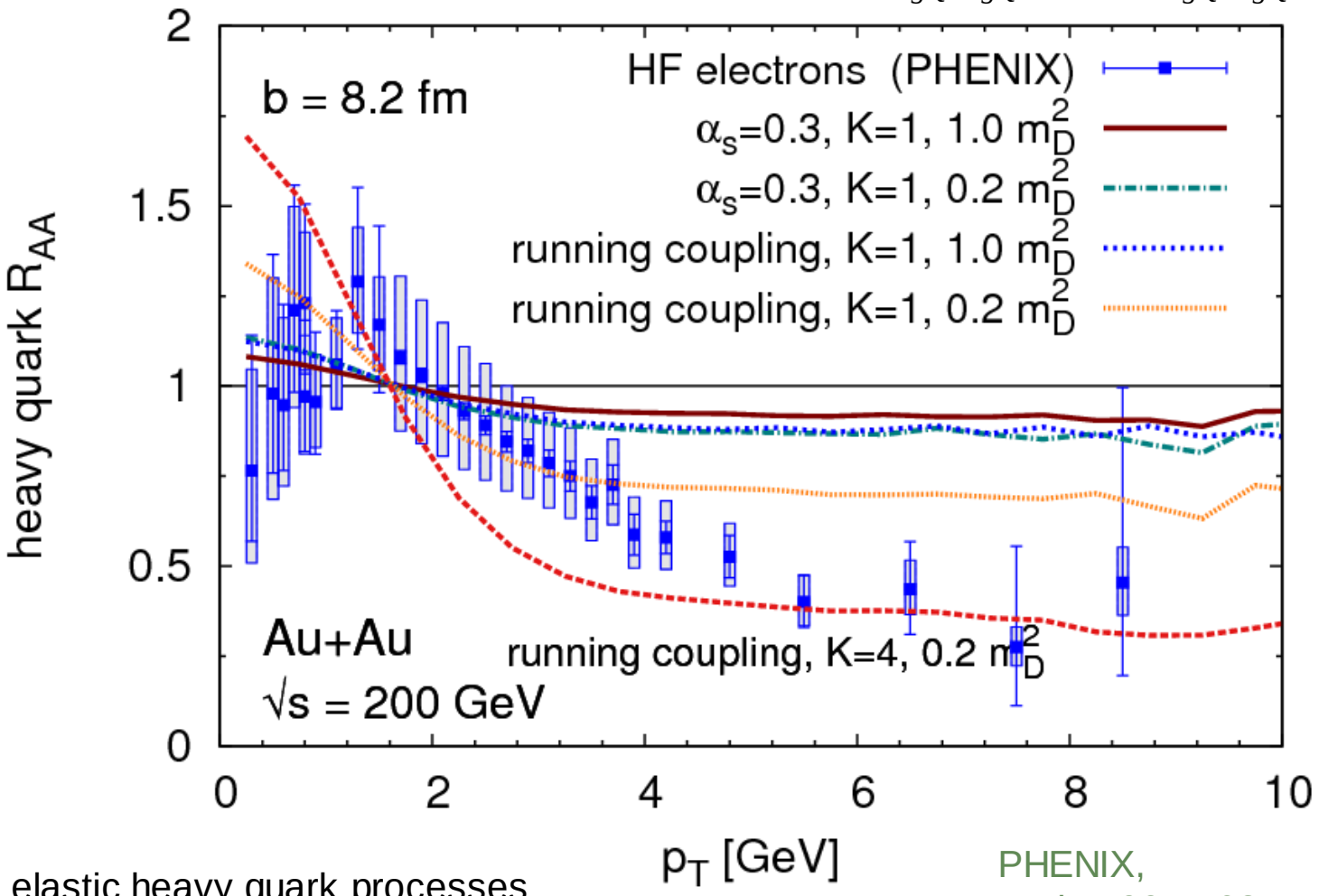
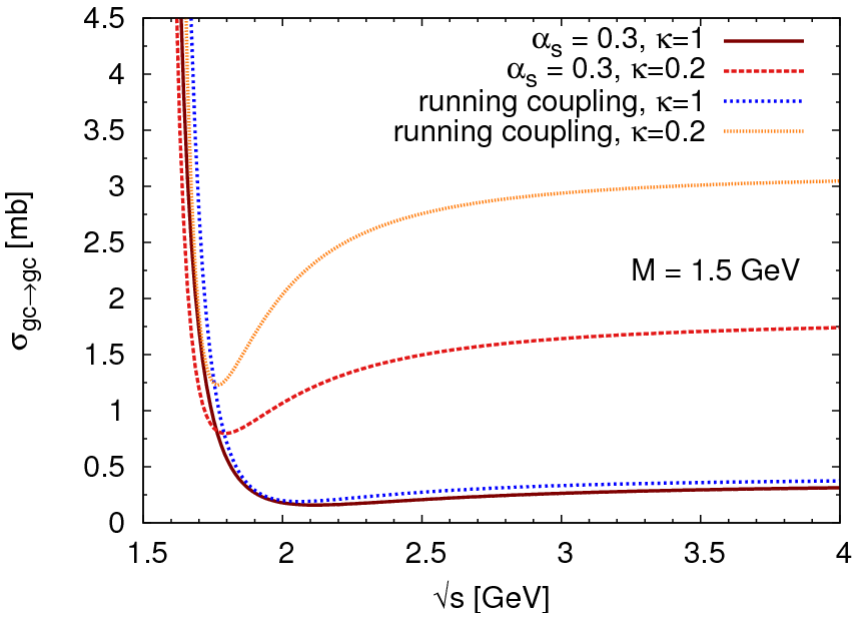
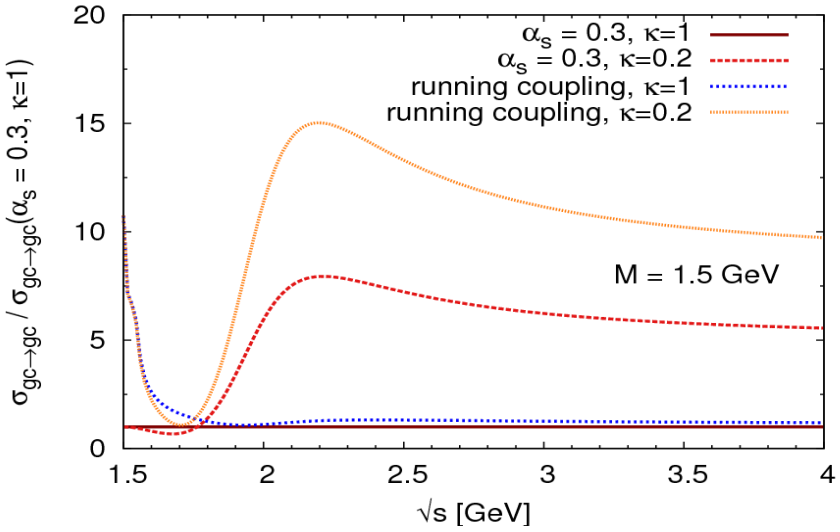


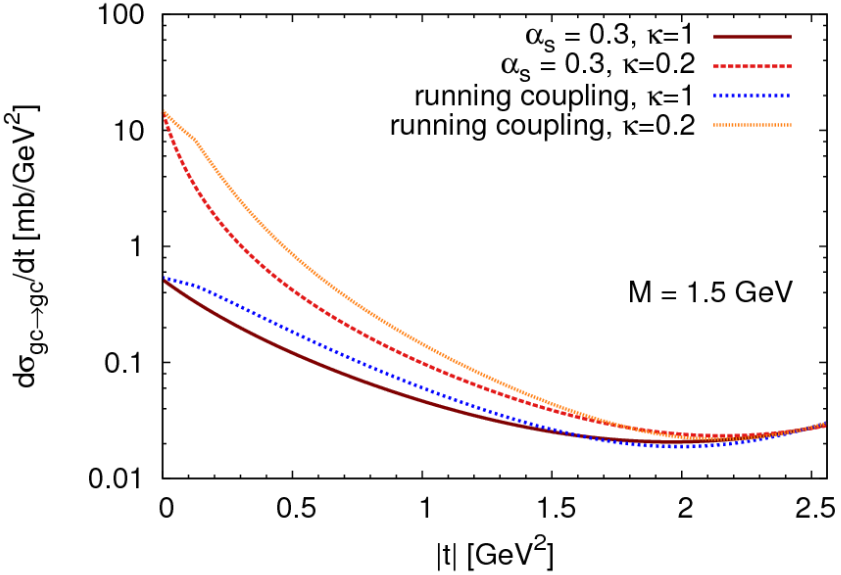
only elastic heavy quark processes

PHENIX, arXiv:1005.1627

Heavy quark scattering cross section



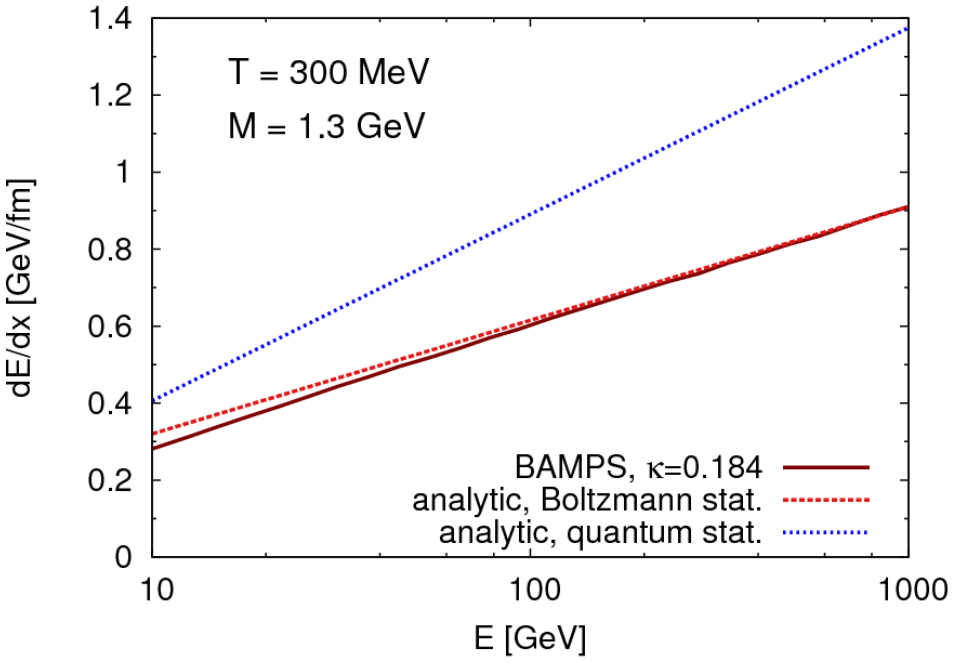




Heavy quark scattering

Compare to analytic formula

$$\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{8\alpha_s^2 T^2}{\pi}\left[\left(1+\frac{n_f}{3}\right)\ln\frac{ET}{m_D^2} + \frac{2}{9}\ln\frac{ET}{M^2} + \left(\ln 2 - \frac{1}{4} - \frac{\gamma}{3}\right)n_f + \frac{31}{9}\ln 2 - \frac{101}{108} - \frac{11\gamma}{9}\right]$$



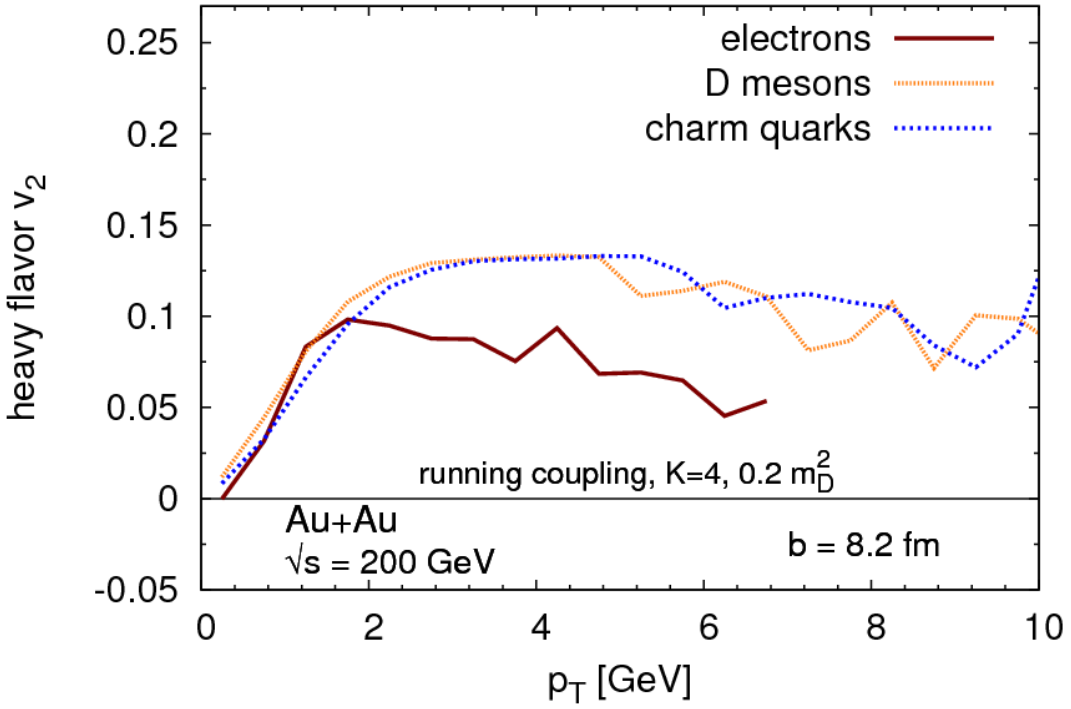
Fragmentation and Decay

- **Peterson fragmentation**

Peterson et al., Phys. Rev. D27 (1983)

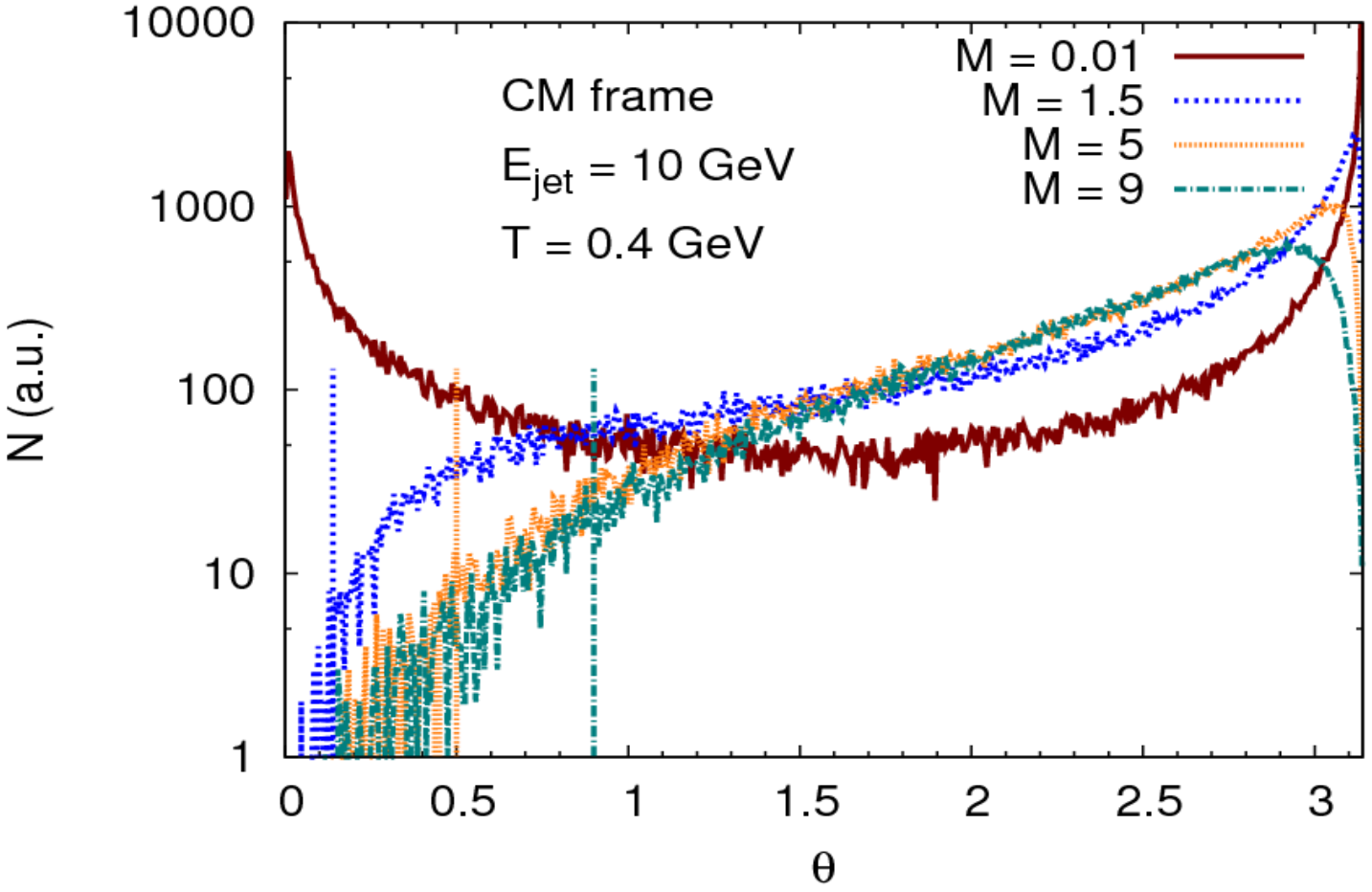
$$D_{H/Q}(z) = \frac{N}{z\left(1 - \frac{1}{z} - \frac{\epsilon_Q}{1-z}\right)^2} \qquad z = \frac{|\vec{p}_H|}{|\vec{p}_Q|} \qquad \epsilon_c = 0.05 \quad \epsilon_b = 0.005$$

- **Decay to electrons with PYTHIA**



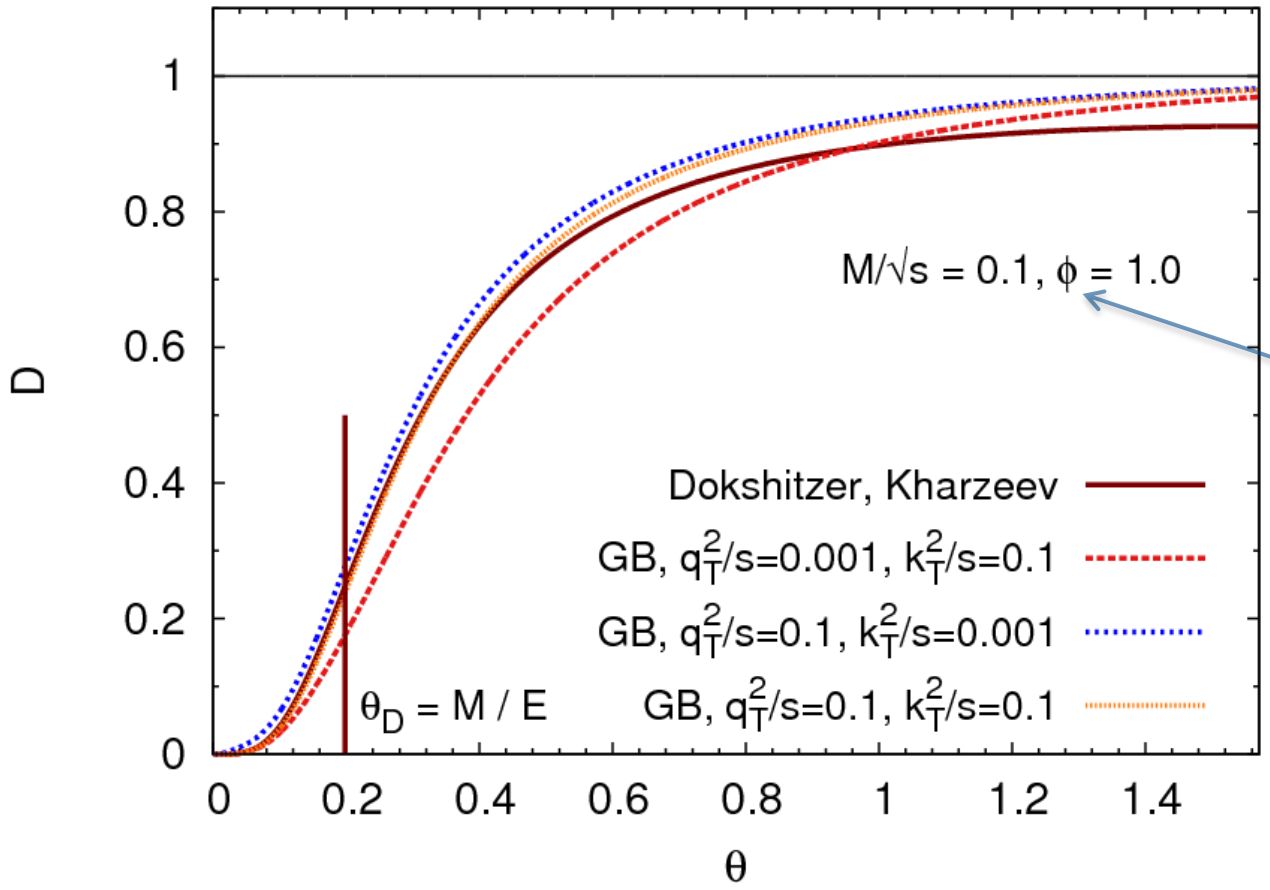
Impact of hadronization and decay small

Θ dependence in static medium



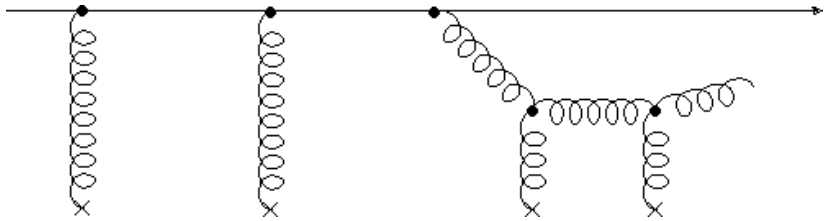
Dead cone effect

$$\left|\overline{\mathcal{M}}_{gQ\to gQg}\right|^2 = 12g^2 \left|\overline{\mathcal{M}}_0^{gQ}\right|^2 \left[\frac{\mathbf{k}_\perp}{k_\perp^2 + x^2M^2} + \frac{\mathbf{q}_\perp - \mathbf{k}_\perp}{(\mathbf{q}_\perp - \mathbf{k}_\perp)^2 + x^2M^2}\right]^2$$



Angle between q_T^2 & k_T^2

LPM effect

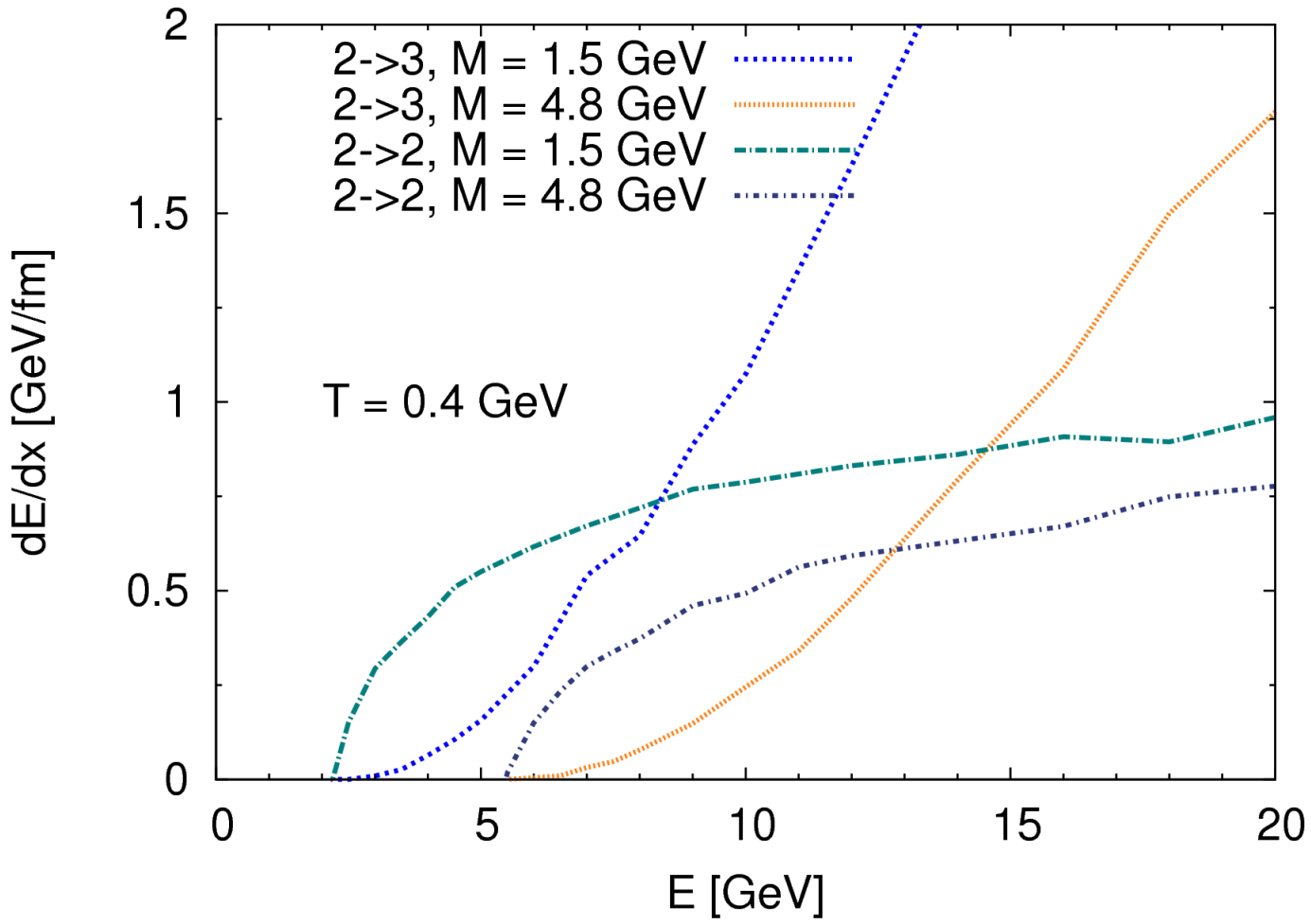


$$\lambda > \tau$$

$2 \rightarrow 3$ only allowed if mean free path of jet larger than formation time of radiated gluon

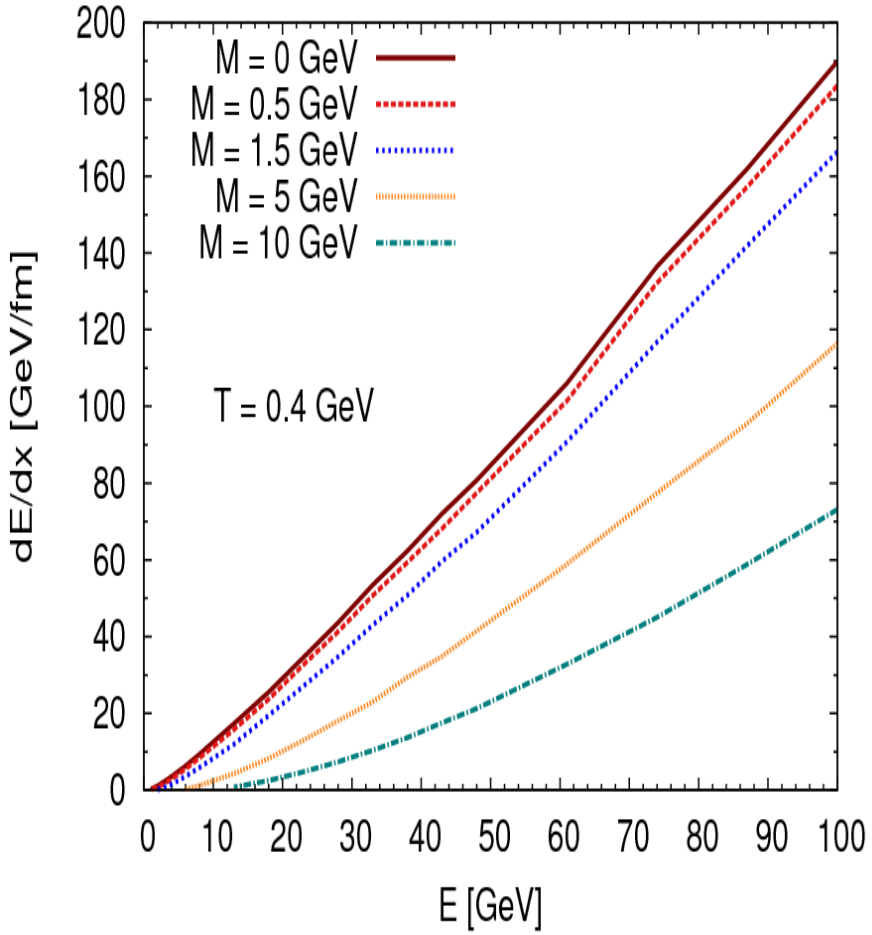
➡ Bethe-Heitler regime, independent scatterings

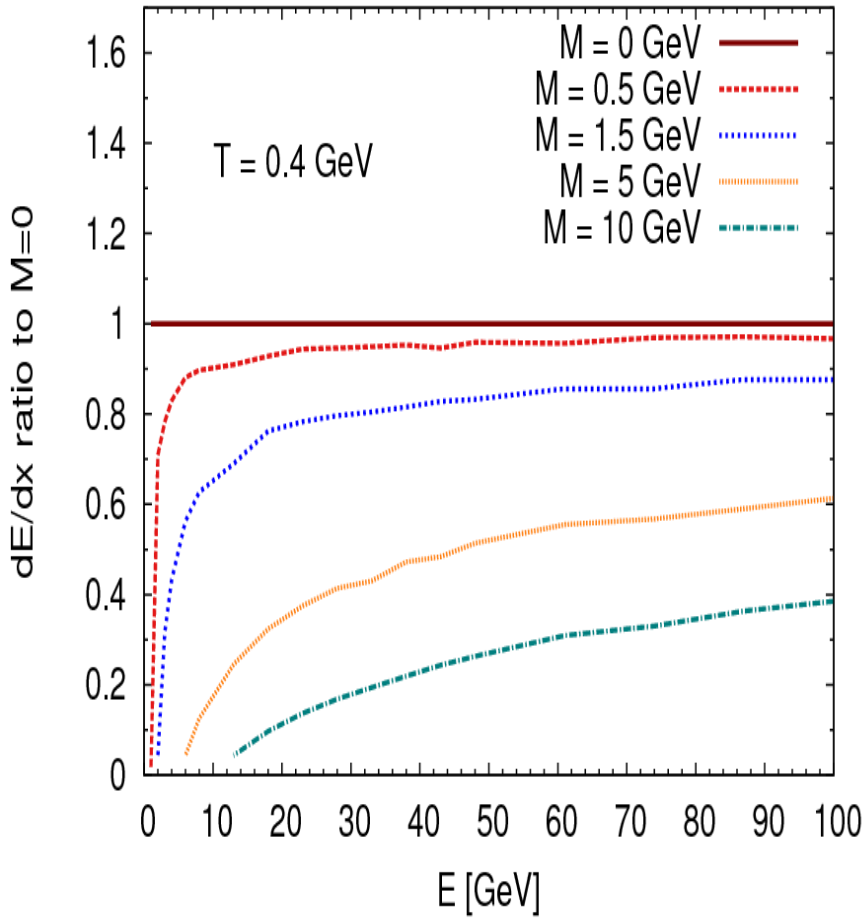
Energy loss in static medium



Running coupling, with LPM effect

Energy loss in static medium





Fixed coupling, without LPM effect

Initial conditions

Gluons:

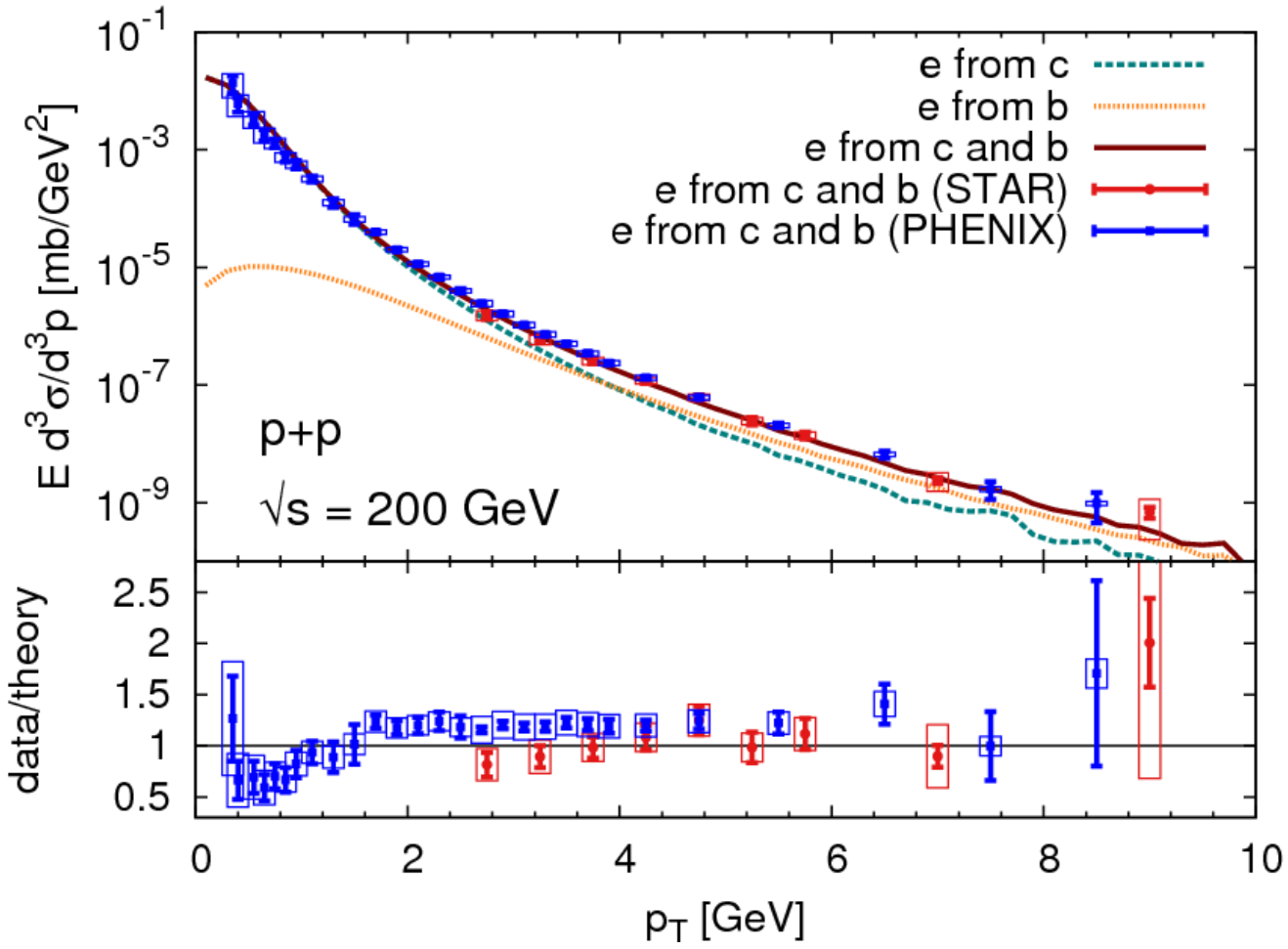
- **PYTHIA**
  scaling to heavy-ion collisions with Glauber model (considering shadowing) and energy conservation
- **Minijets**
  (low p_T cut-off at 1.4 GeV)
- **Color glass condensate**
  H.J. Drescher & Y. Nara, Phys. Rev. C75 (2007)

Heavy quarks:

- **PYTHIA**
  Monte Carlo Event Generator for nucleon-nucleon collisions

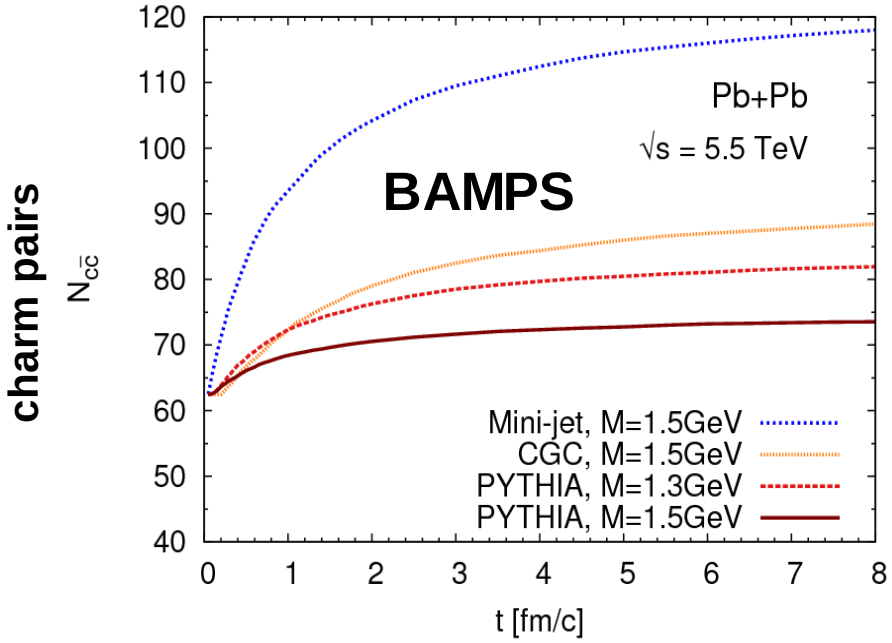
- **NLO pQCD**
  Distributions from R. Vogt
- **MC@NLO**
  Next-to-leading order matrix elements

Initial heavy quark distribution



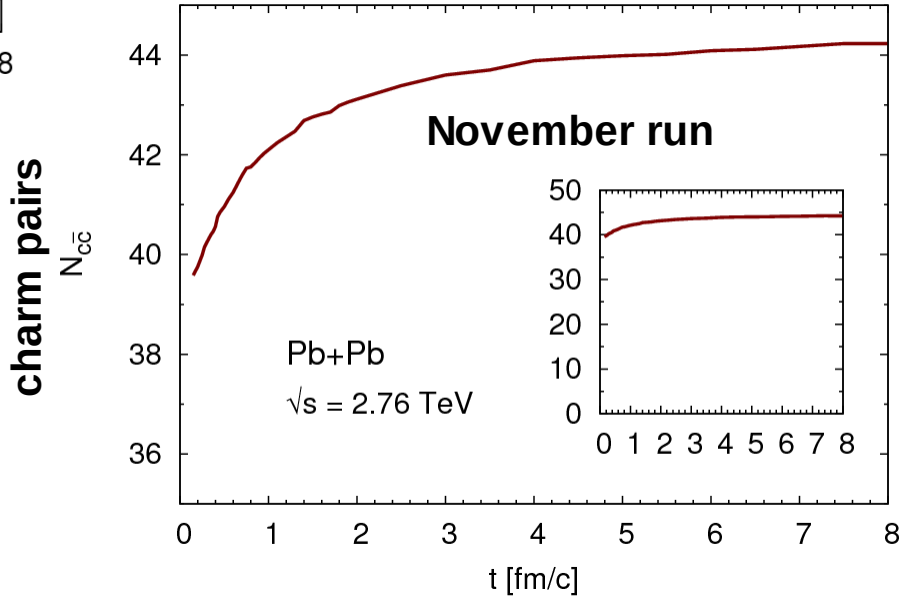
$\mu_F = \mu_R = 0.65\,\sqrt{p_T^2 + M_c^2}$ for charm $(M_c = 1.3\,\mathrm{GeV})$
$\mu_F = \mu_R = 0.4\,\sqrt{p_T^2 + M_b^2}$ for bottom quarks $(M_b = 4.6\,\mathrm{GeV})$

Charm production in the QGP at LHC



LHC

Large secondary production → Can even be comparable to initial production



JU, Fochler, Xu, Greiner
Phys. Rev. C 82 (2010)