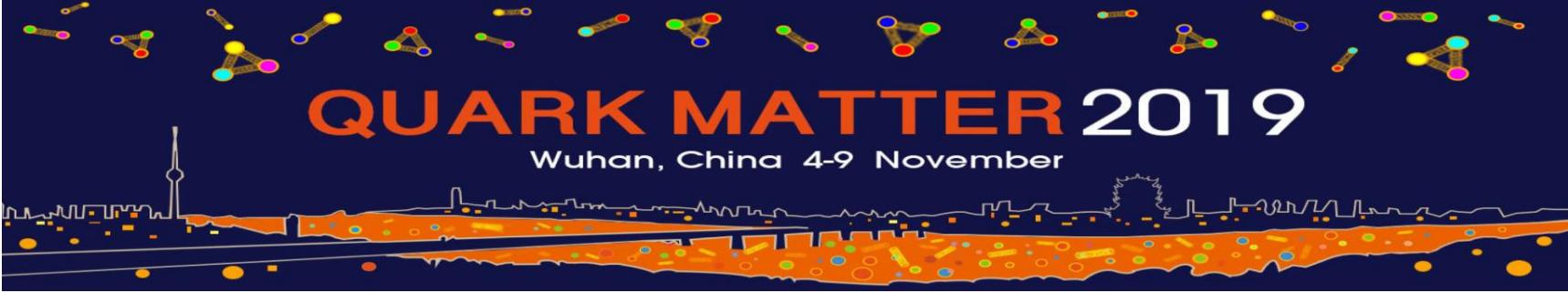


TOPP



# Diffusion of Charm Quarks in Jets in High-energy Heavy-ion Collisions

Sa Wang (CCNU)

Collaborators : Wei Dai (CUG), Ben-Wei Zhang (CCNU), Enke Wang (SCNU)

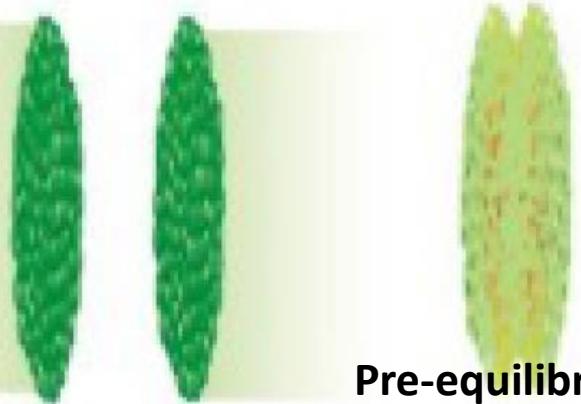
Based on [Eur.Phys.J. C79 \(2019\) no.9, 789](#)

**Quark Matter 2019, Wuhan**

# Introduction

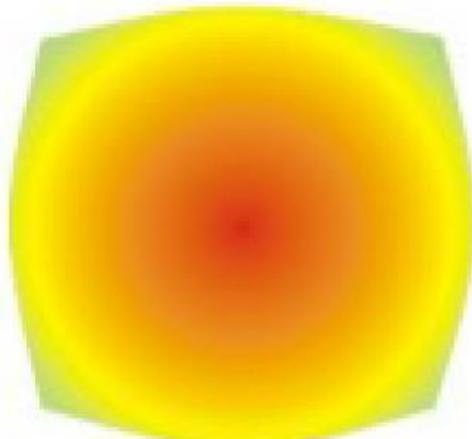
## High-energy heavy-ion collisions (HIC)

Initial state



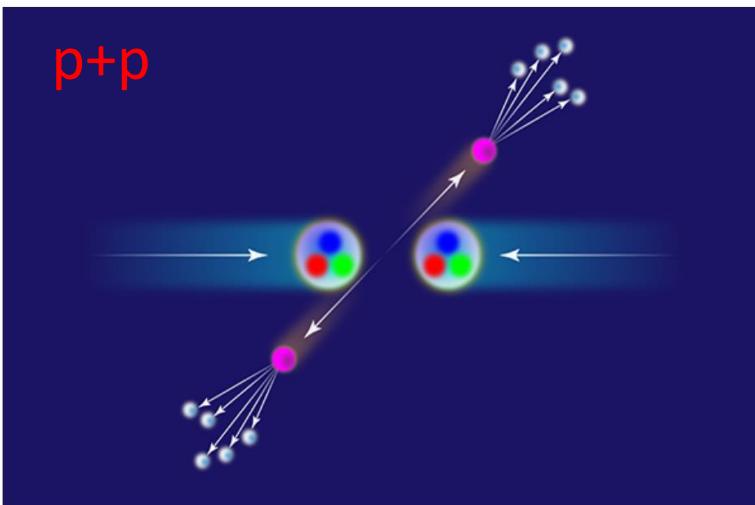
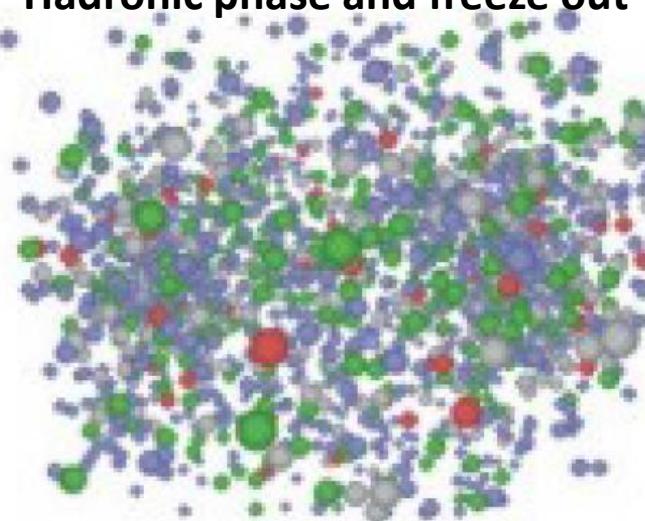
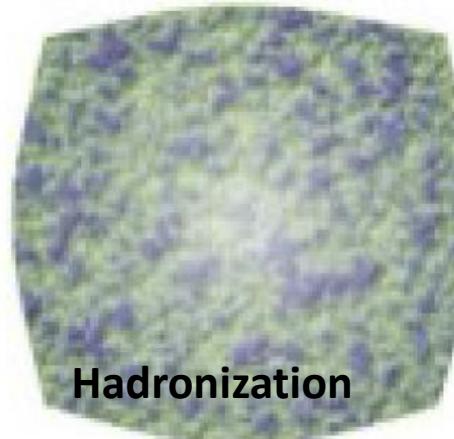
Pre-equilibrium

Quark-Gluon Plasma (QGP)

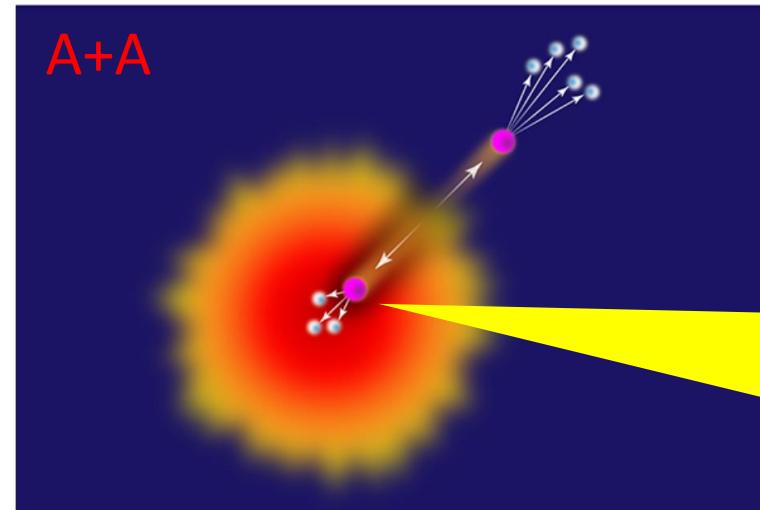


Hadronization

Hadronic phase and freeze out



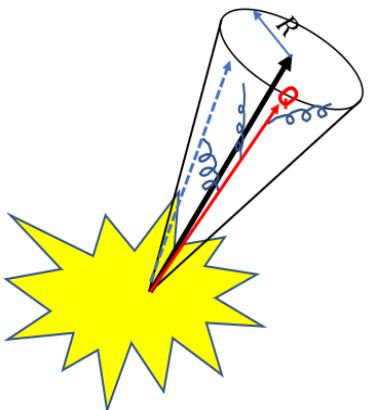
2019/11/5



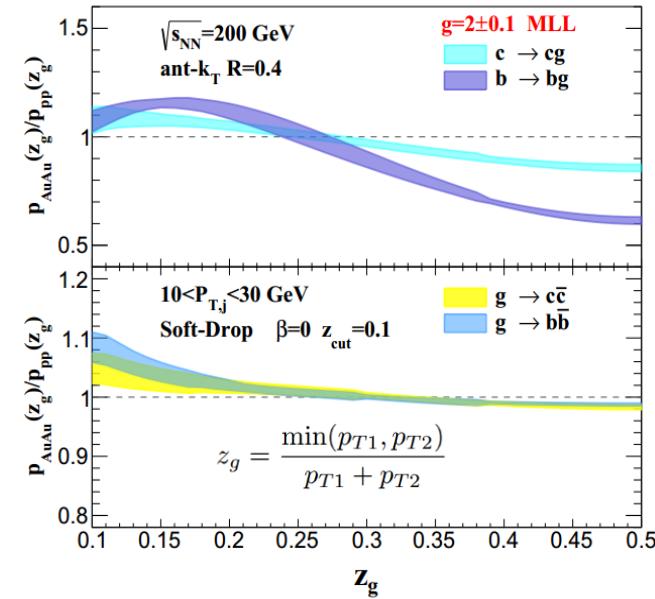
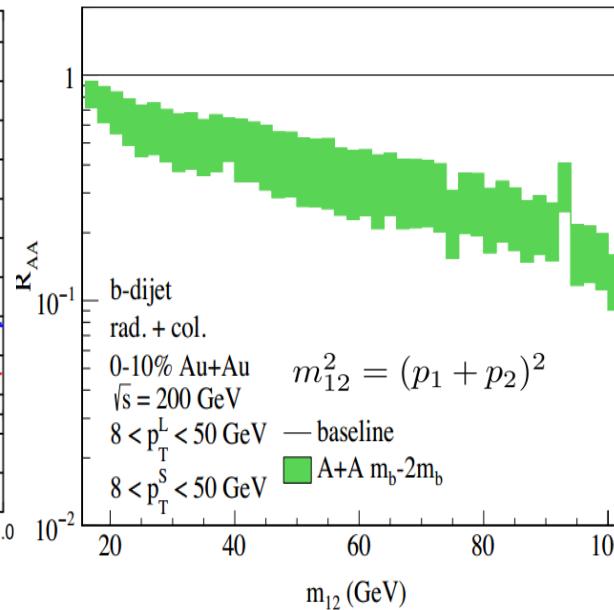
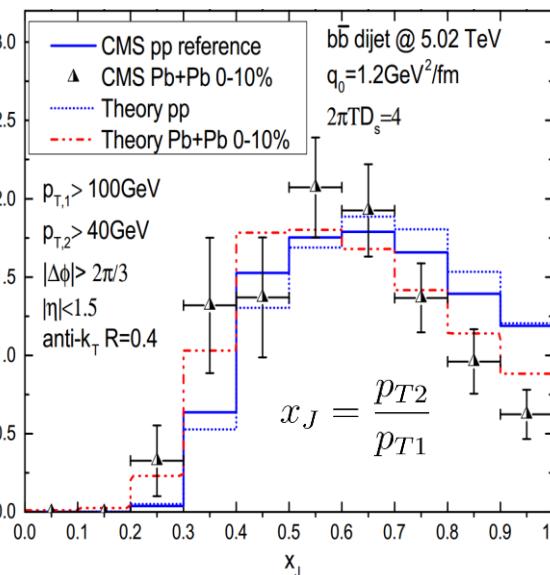
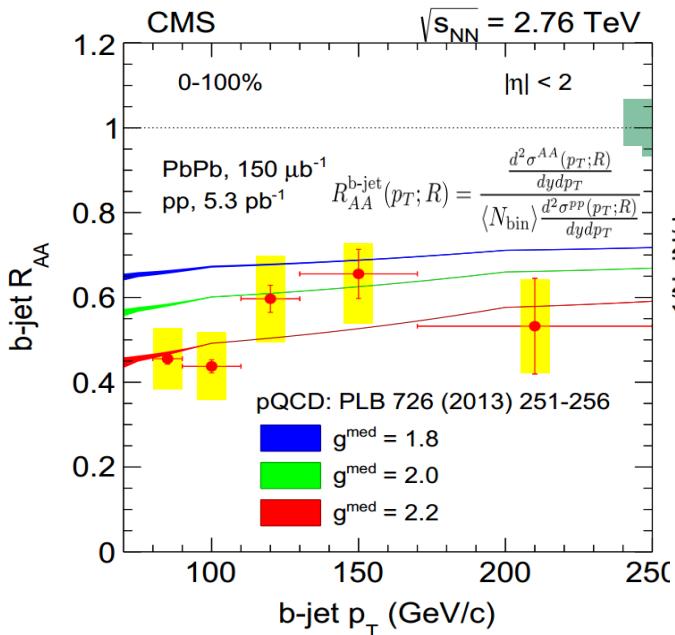
Quark Matter 2019, S. Wang

**Jet Quenching:**  
Strong interaction between  
high  $p_T$  jet and medium.

# Motivation



**Heavy flavor jet—heavy quark (HQ) tagged jet , HQ inside the jet cone.**



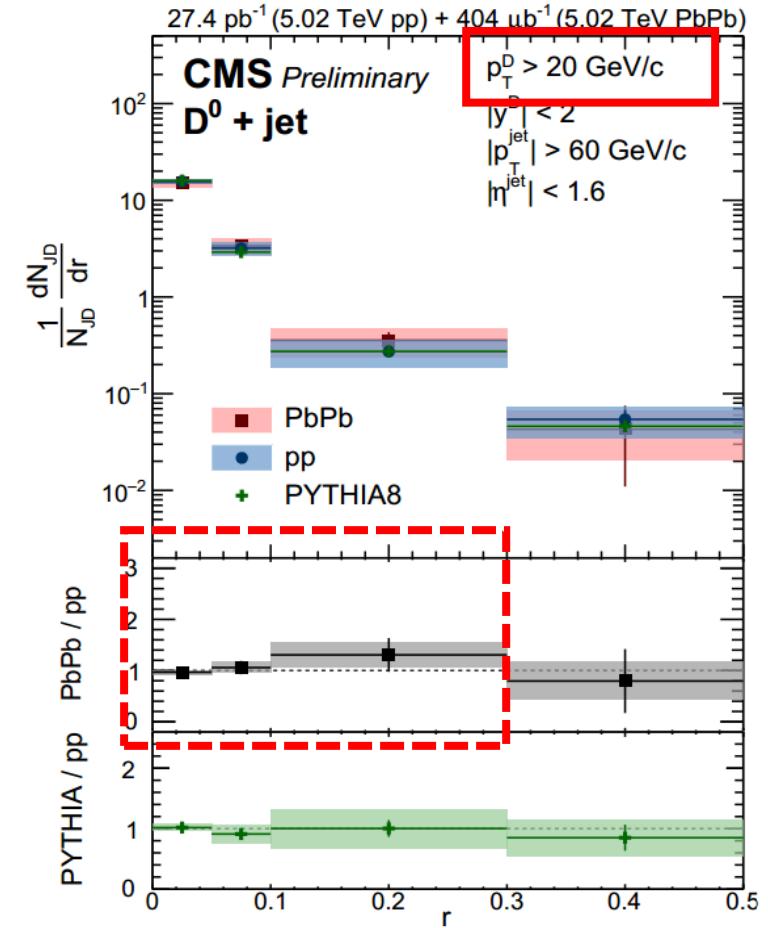
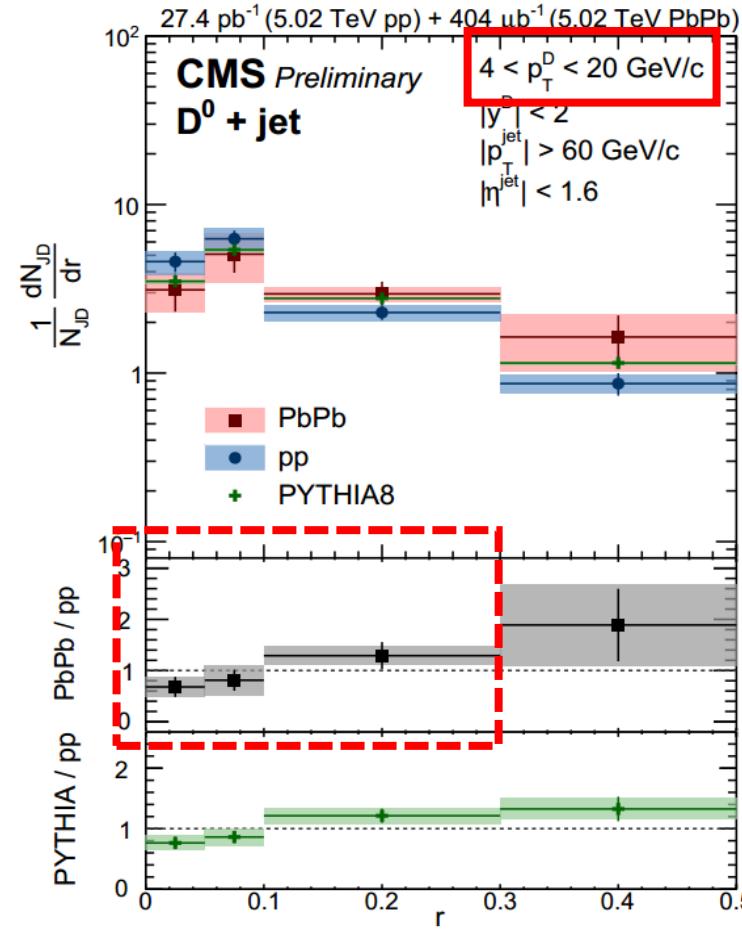
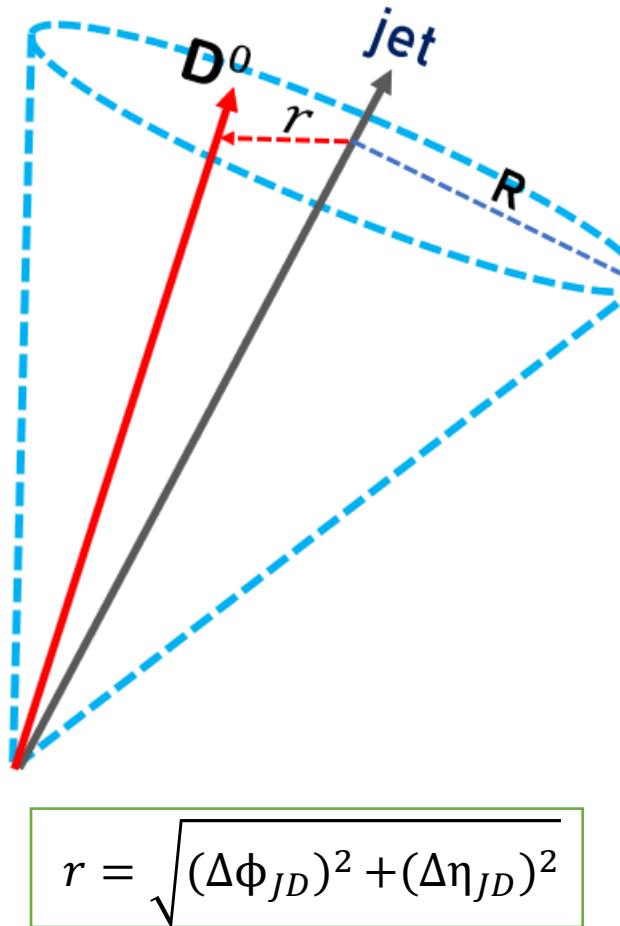
CMS collaboration ,  
**PRL 113(2014)132301;**  
J. Huang, Z. B. Kang and I. Vitev  
**Phys.Lett. B726 (2013) 251-256**

CMS collaboration ,  
**JHEP 1803 (2018) 181;**  
W. Dai S. Wang B-W. Zhang E. Wang,  
arXiv: **1806.06332**

Z.B. Kang, J.Reiten, I. Vitev and B.Yoon  
**Phys.Rev. D99 (2019) no.3, 034006**

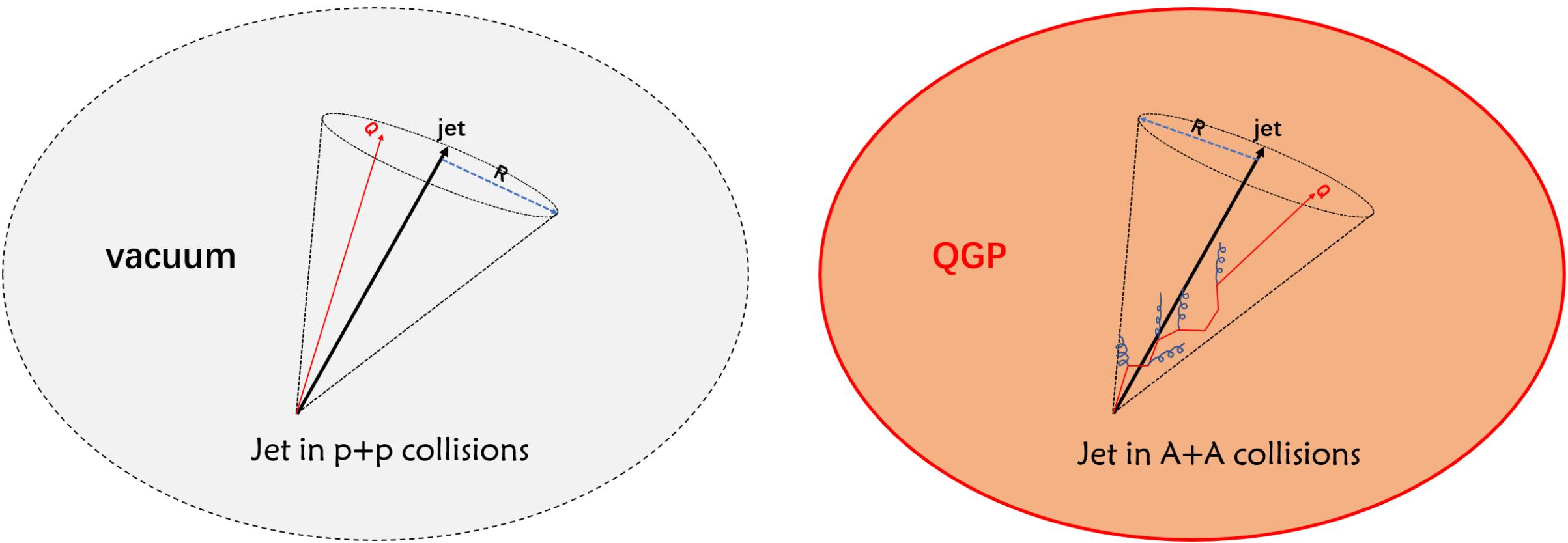
H.T. Li and I. Vitev  
**Phys.Lett. B793 (2019) 259-264**

# Motivation



CMS-PAS-HIN-18-007

# Motivation



- The high  $p_T$  jet can be viewed as a reference to probe the radial diffusion of lower  $p_T$  charm quark in A+A collisions.
- Diffusion of charm in jets provides a new perspective to study the interaction mechanisms between heavy quarks and the medium.

# pp baseline: NLO+PS SHERPA

## SHERPA framework

JHEP 0902 (2009) 007

- Initial state parton shower (QCD)
- Underlying event
- Signal process
- Final state parton shower (QCD)
- Fragmentation
- Hadron decays
- QED radiation

## Parton distribution function (PDF)

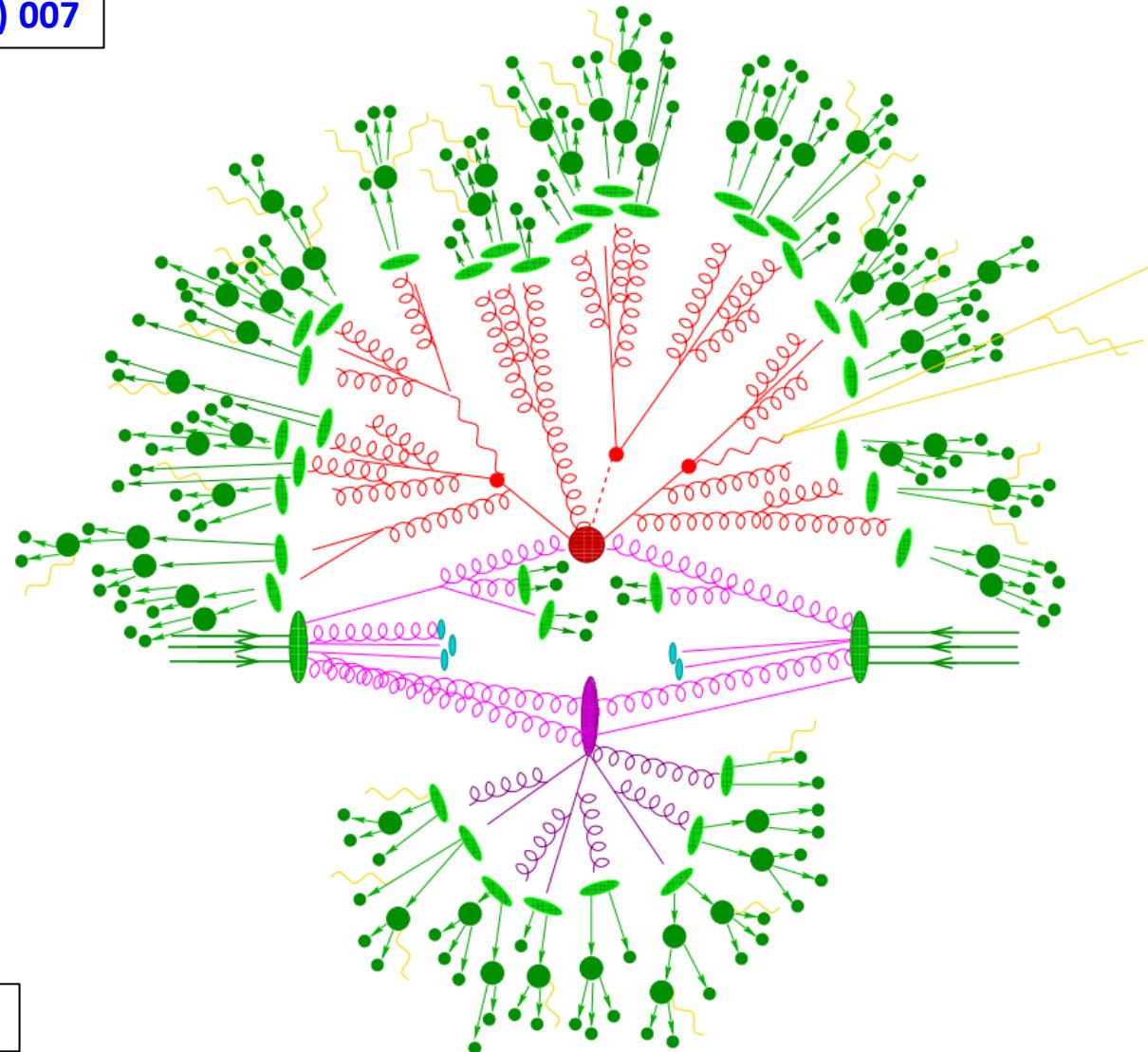
- NNPDF3.0 NLO

JHEP 1504 (2015) 040

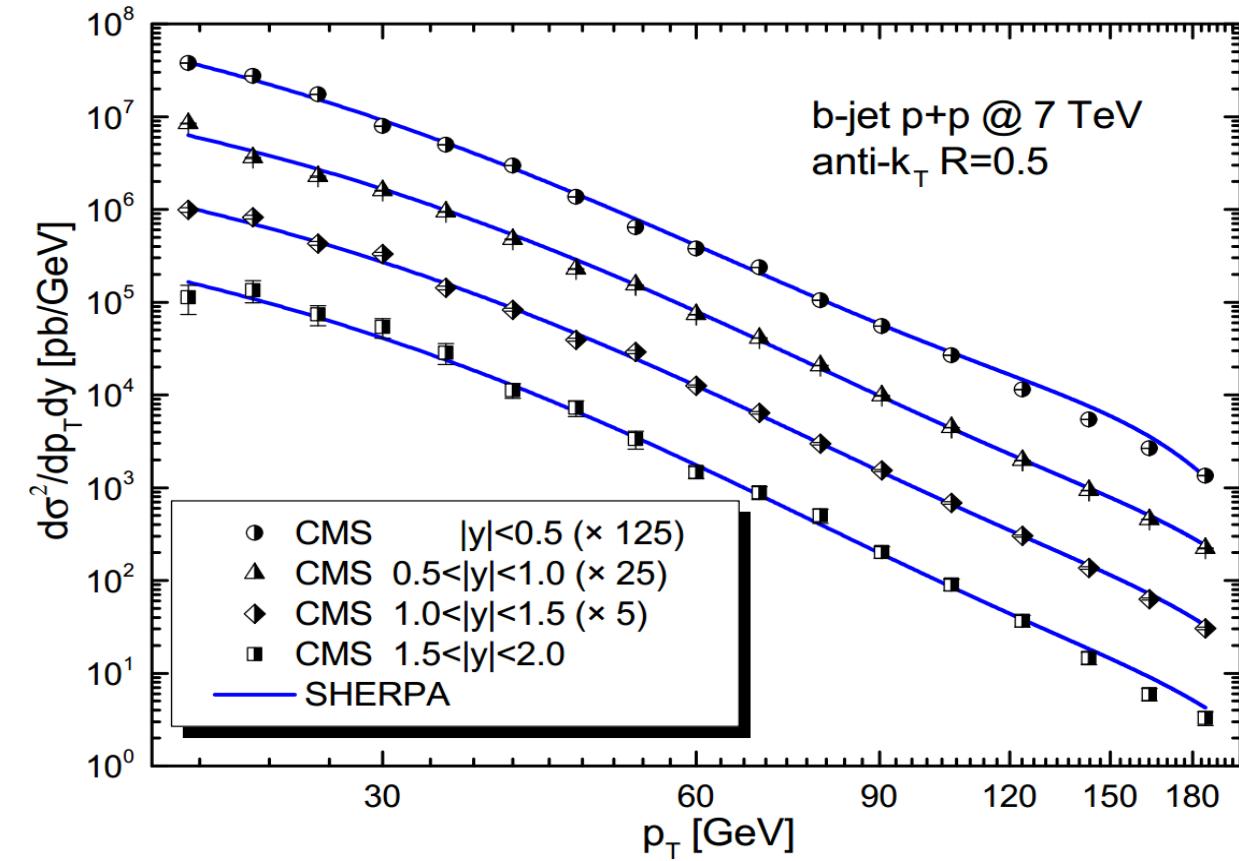
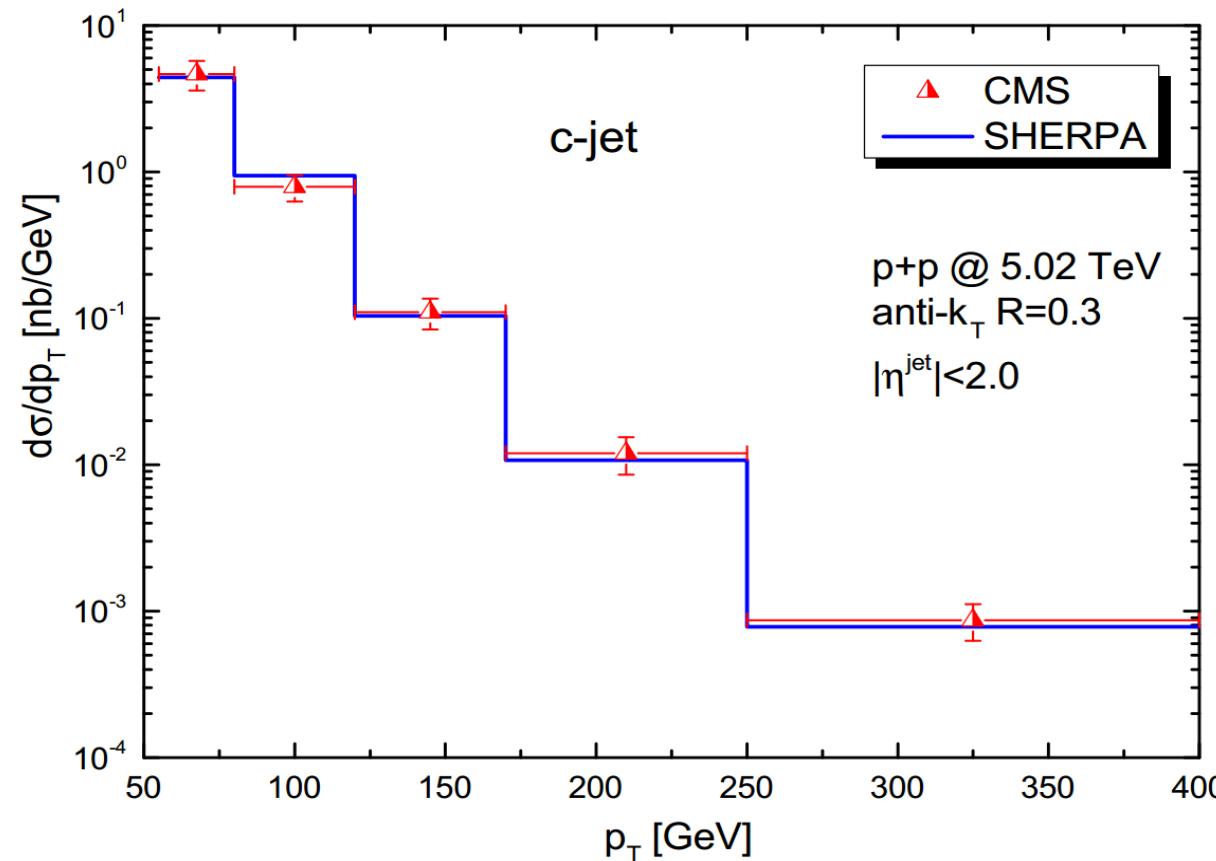
## Jet reconstruction

- FastJet-3.3.0

Eur.Phys.J.C 72 (2012) 1896



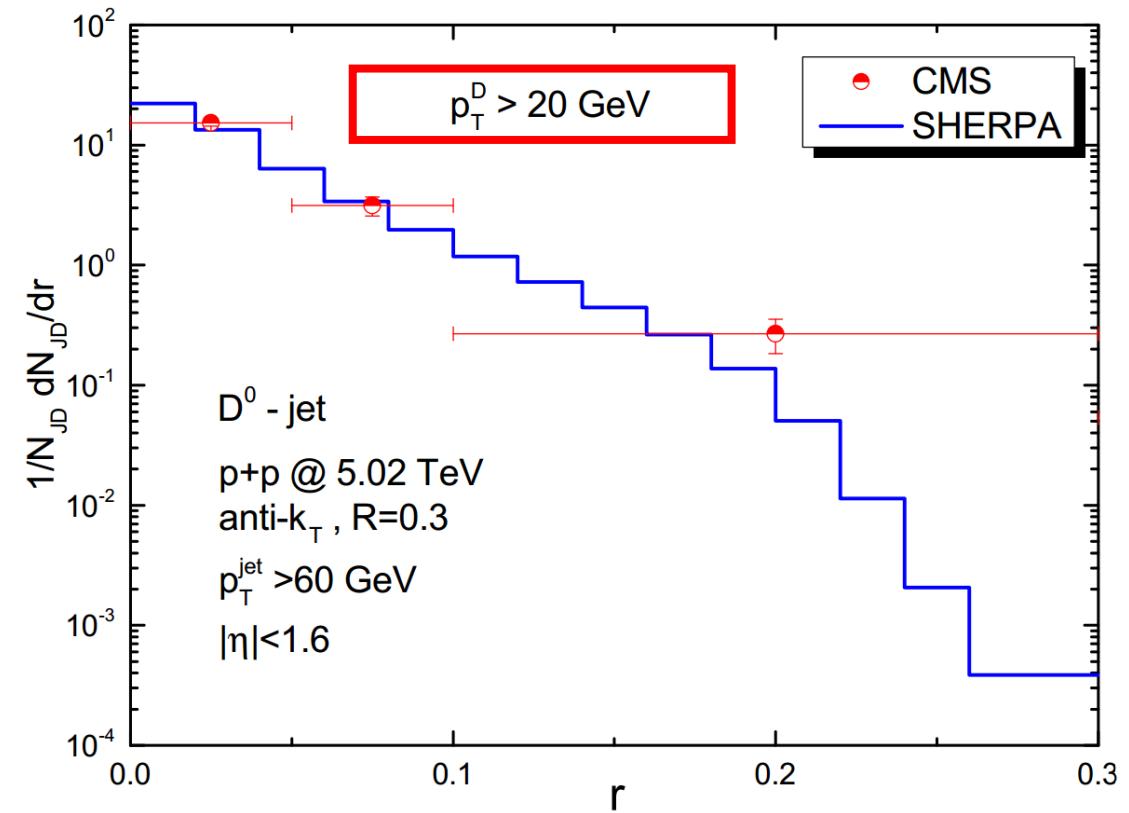
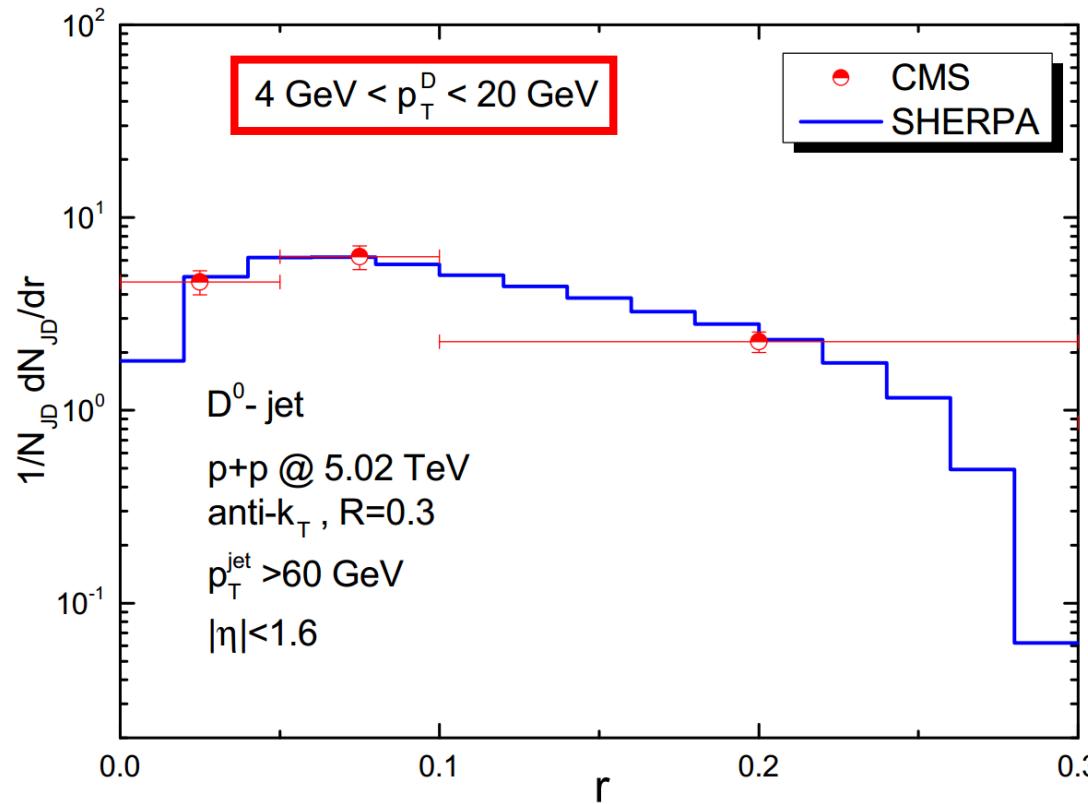
# pp baseline: heavy flavor jet production



S. Wang,W. Dai,B.W Zhang,E. Wang Eur.Phys.J. C79 (2019) no.9, 789

S. Wang, W. Dai,B.W Zhang,E. Wang arXiv:1812.00391

# pp baseline: charm radial distribution in jets



$$r = \sqrt{(\Delta\phi_{JD})^2 + (\Delta\eta_{JD})^2}$$

S. Wang,W. Dai,B.W Zhang,E. Wang Eur.Phys.J. C79 (2019) no.9, 789

# In-medium E-loss: Collisional

- ◆ For heavy quark, the discrete Langevin transport equations are used to describe the propagating of HQ in the QGP .

$$\vec{x}(t + \Delta t) = \vec{x}(t) + \frac{\vec{p}(t)}{E} \Delta t$$

$$\vec{p}(t + \Delta t) = \vec{p}(t) - \Gamma(p) \vec{p} \Delta t + \vec{\xi}(t) \Delta t - \vec{p}_g$$

G.D. Moore and D. Teaney PRC 71 (2005) 064904;  
S. Cao, G.Y. Qin and S.A. Bass Phys.Rev. C88 (2013) 044907

$$\langle \xi_i(t) \rangle = 0$$
$$\langle \xi_i(t) \xi_j(t') \rangle = \kappa \delta_{ij}(t - t')$$

The fluctuation-dissipation relation  $\kappa = 2ET\Gamma = \frac{2T^2}{D_s}$ .

Based on the LQCD calculation ,  $D_s$  is fixed at  $2\pi TD_s = 4$  .

A. Francis, O. Kaczmarek, M. Laine, T. Neuhaus and H. Ohno Phys.Rev. D92 (2015) no.11, 116003

- ◆ For light parton, the collisional energy loss is described by the calculation at Hard Thermal Loop (HTL) approximation .

$$\frac{dE}{dz} = \frac{\alpha_s C_i m_D^2}{2} \ln \frac{\sqrt{ET}}{m_D}$$

R.B. Neufeld, Phys.Rev. D83 (2011) 065012;  
J. Huang, Z.B. Kang and I. Vitev, Phys.Lett. B726 (2013) 251-256

- ◆ Evolution of the bulk medium is produced by the iEBE-VISHNU hydro model .

C. Shen, Z. Qiu, H. Song, J. Bernhard, S. Bass and U. Heinz, Comput.Phys.Commun. 199 (2016) 61-85

# In-medium E-loss: Radiative

- ◆ For both heavy and light parton, the medium-induced gluon radiation is implemented based on the higher-twist approach.

$$\frac{dN_g}{dx dk_{\perp}^2 dt} = \frac{2\alpha_s C_A P(x) \hat{q}}{\pi k_{\perp}^4} \sin^2\left(\frac{t - t_i}{2\tau_f}\right) \left(\frac{k_{\perp}^2}{k_{\perp}^2 + x^2 M^2}\right)^4$$

X.f. Guo and X.N. Wang, Phys.Rev.Lett. 85 (2000) 3591-3594 ;  
B.W. Zhang, E. Wang and X. N. Wang, Phys.Rev.Lett. 93 (2004) 072301;  
A. Majumder, Phys.Rev. D85 (2012) 014023

- ◆  $\hat{q}$  is the jet transport coefficient in QGP.

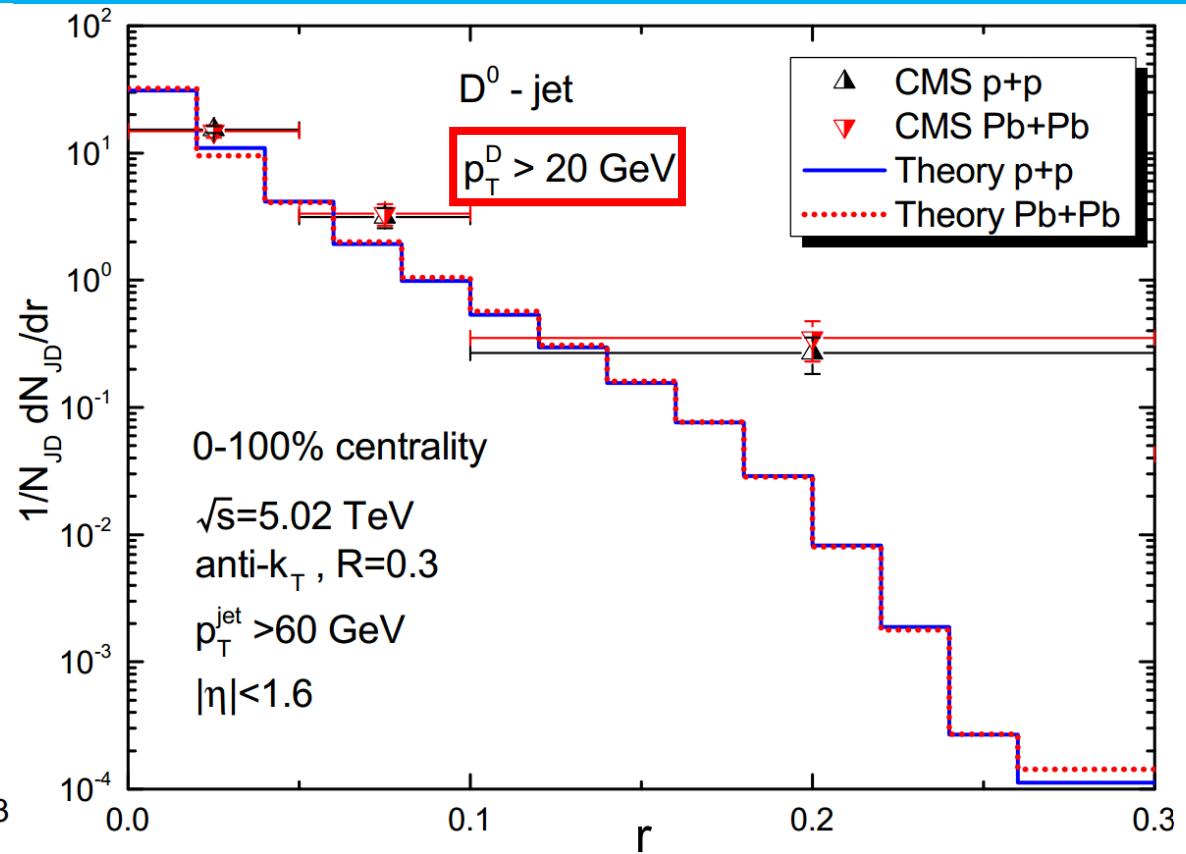
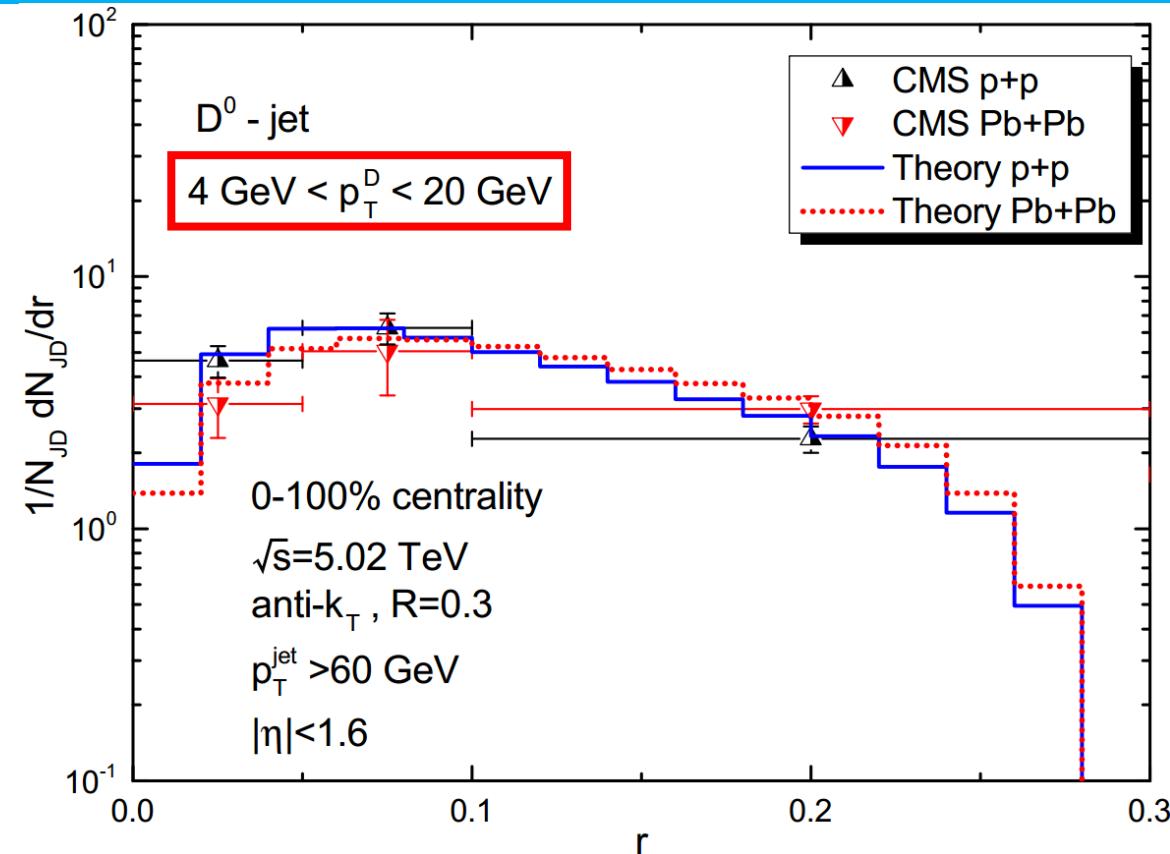
$$\hat{q}(\tau, r) = q_0 \frac{\rho^{QGP}(\tau, r)}{\rho^{QGP}(\tau_0, 0)} \frac{p^\mu u_\mu}{p^0}$$

X. F. Chen, C. Greiner, E. Wang, X.N. Wang and Z. Xu, Phys.Rev. C81 (2010) 064908

- ◆  $q_0 = 1.2 \text{ GeV}^2/\text{fm}$  at LHC energy,  $q_0 = 0.6 \text{ GeV}^2/\text{fm}$  at RHIC energy .

G.Y. Ma, W. Dai, B.W. Zhang and E.K. Wang, Eur.Phys.J. C79 (2019) no.6, 518

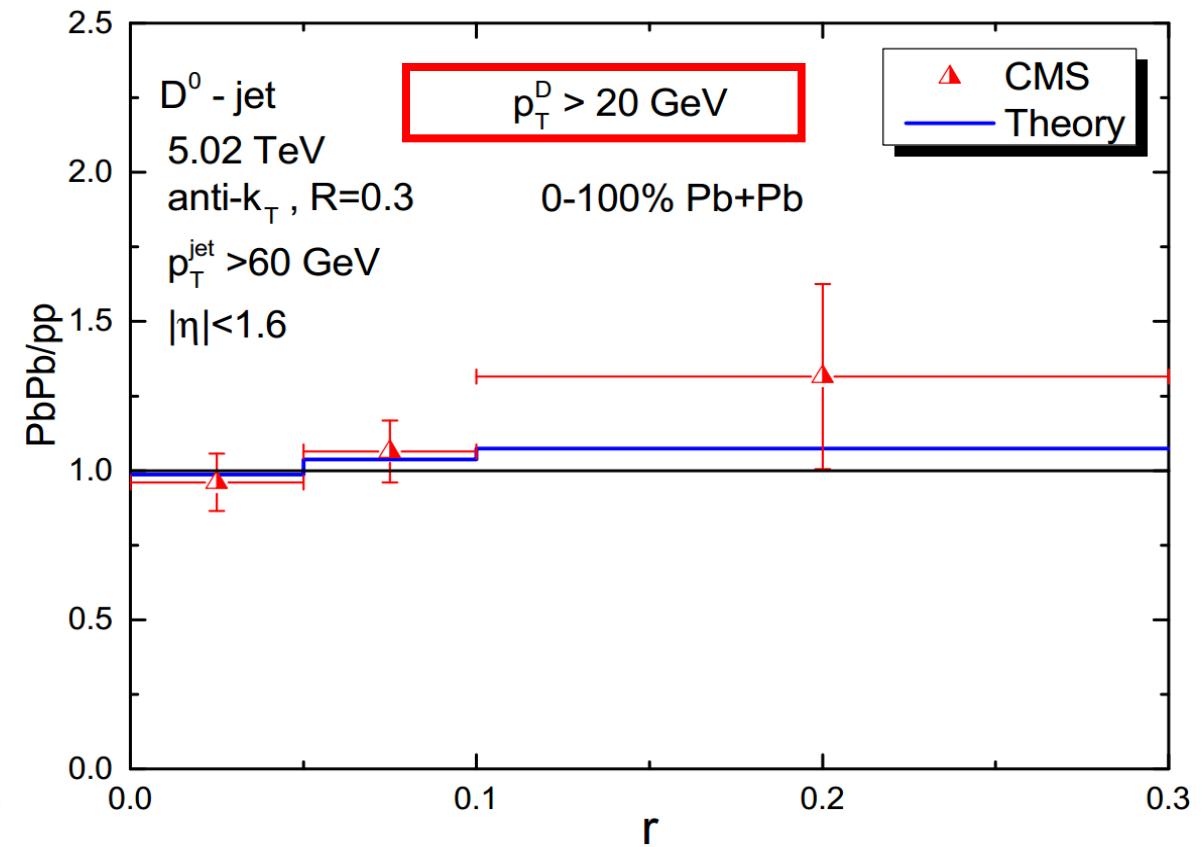
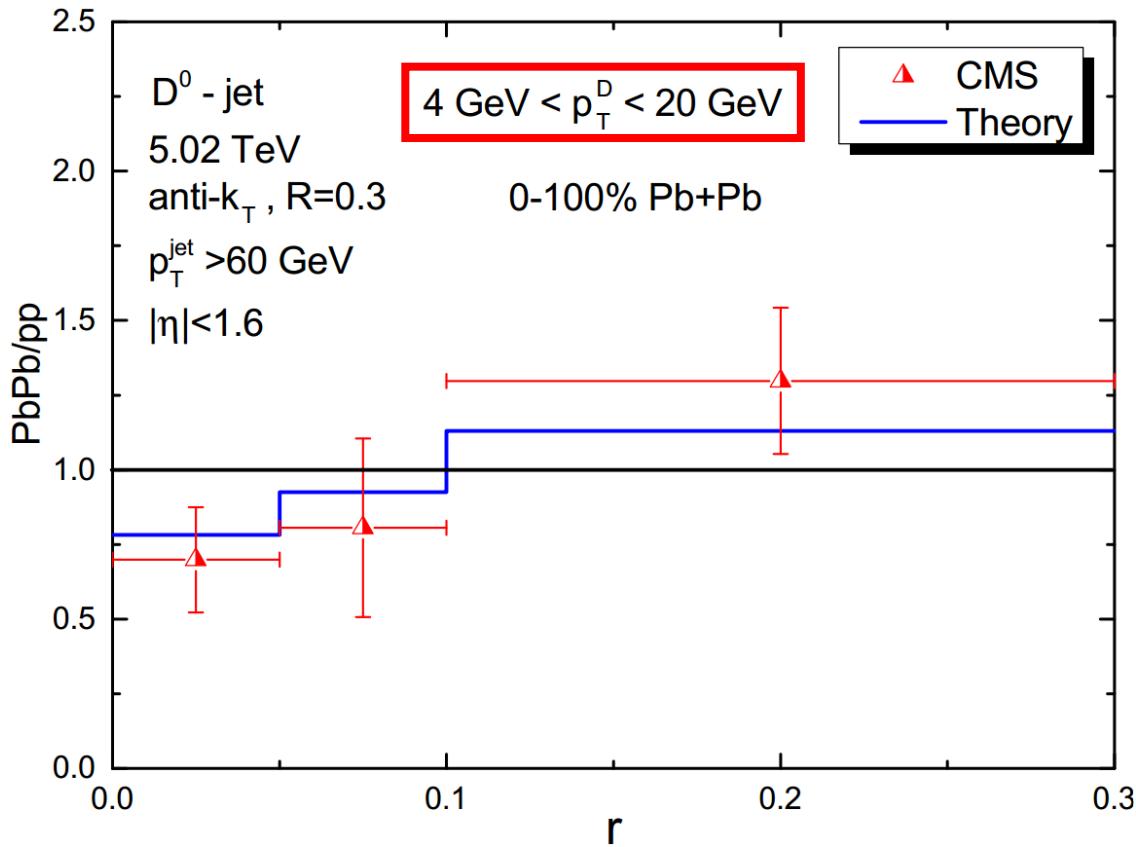
# Results : $D^0$ radial profile in jets



S. Wang,W. Dai,B.W Zhang,E. Wang Eur.Phys.J. C79 (2019) no.9, 789

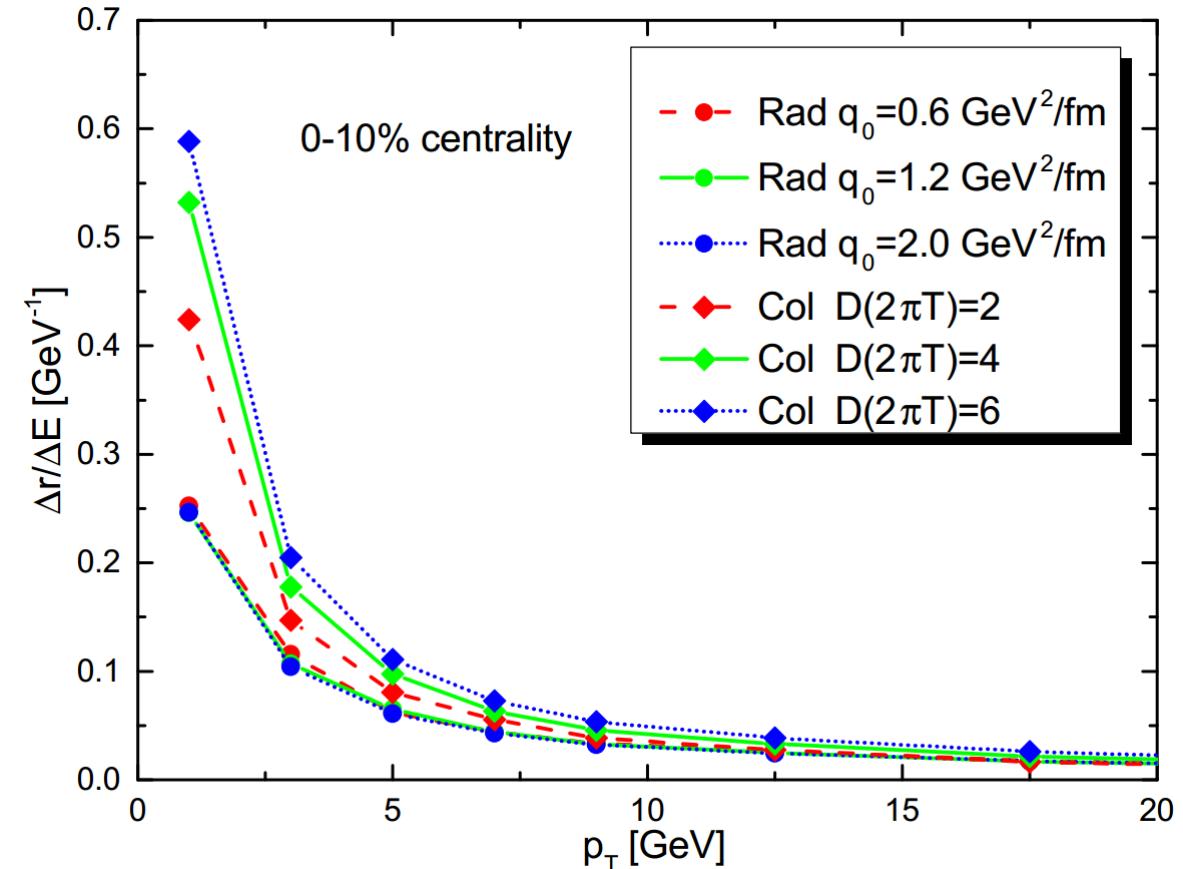
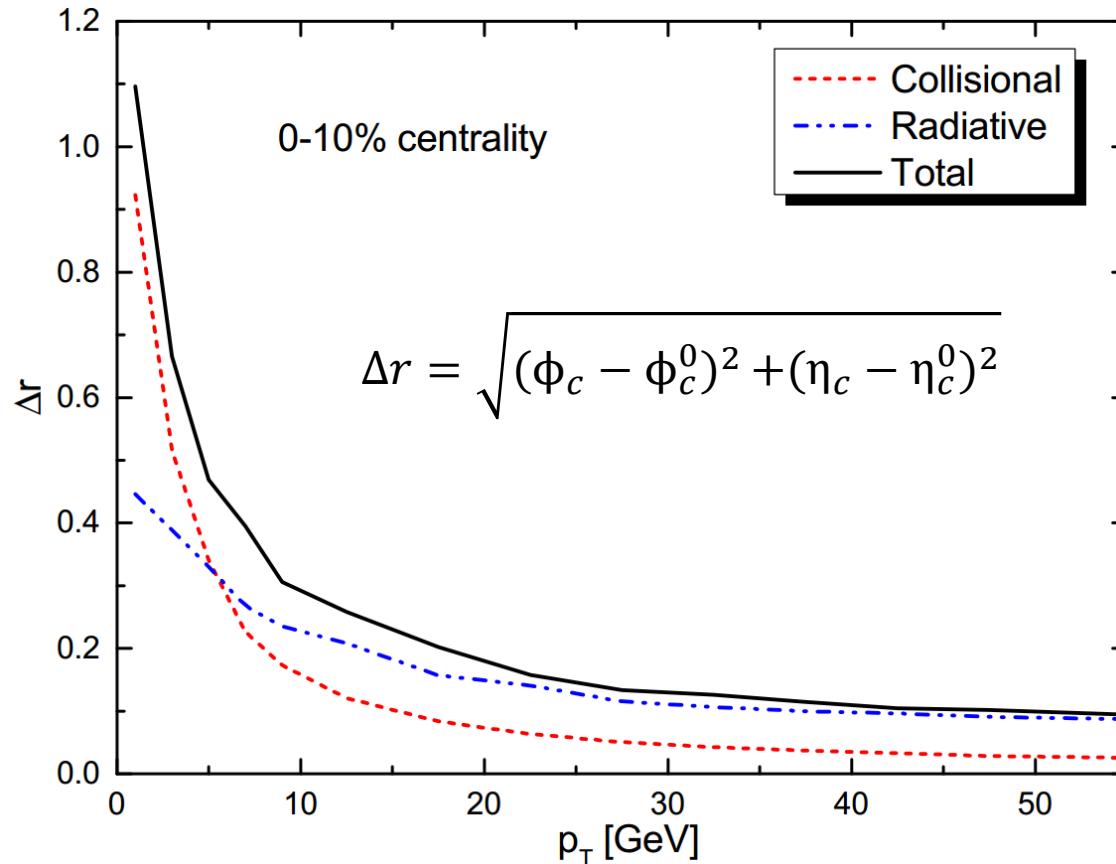
➤ For low  $p_T$   $D$  meson, a significant modification was observed in Pb+Pb collisions relative to the pp baseline.

# Results : $D^0$ radial profile in jets



➤ Low  $p_T$   $D$  mesons diffuse to larger radius region due to the in-medium interactions.

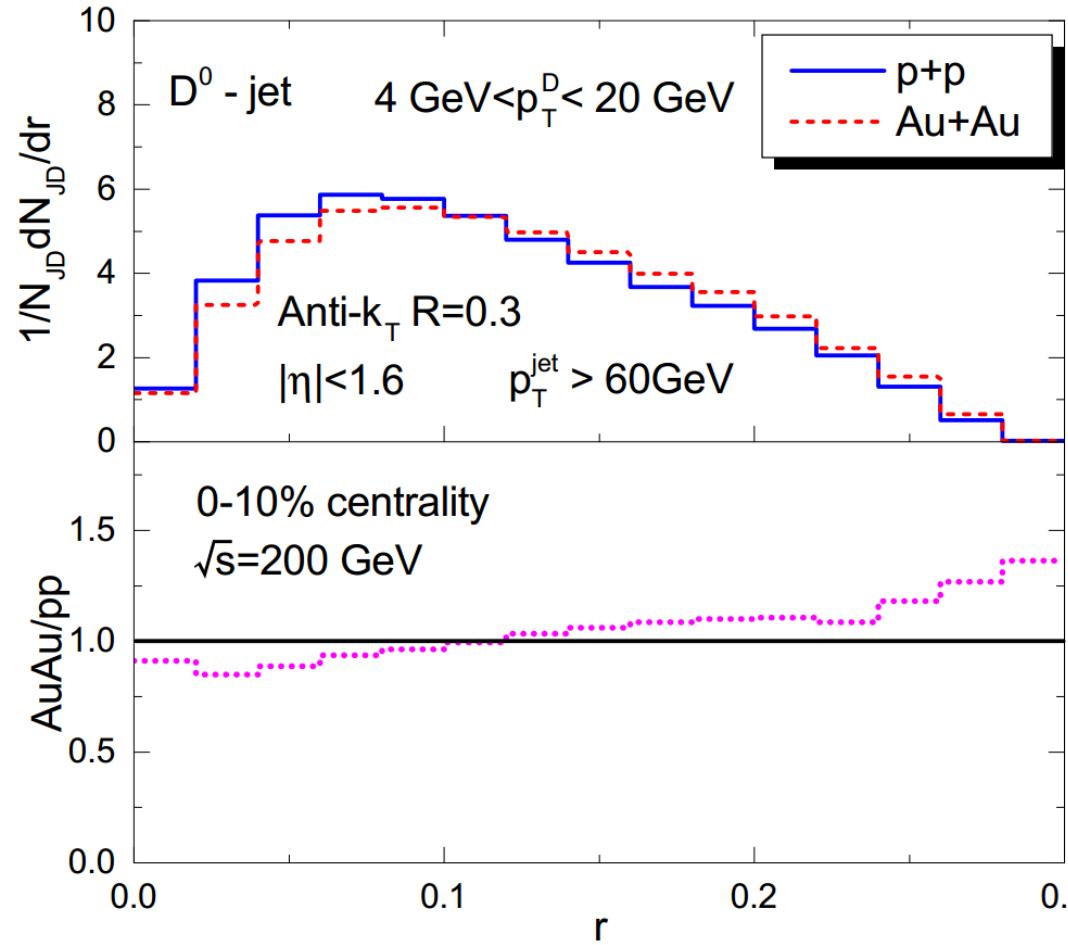
# Discussion : Radiative & Collisional



S. Wang,W. Dai,B.W Zhang,E. Wang Eur.Phys.J. C79 (2019) no.9, 789

- The total diffusion effects decrease with increasing  $p_T$
- The ratio  $\Delta r/\Delta E$  is sensitive to D but not  $q_0$

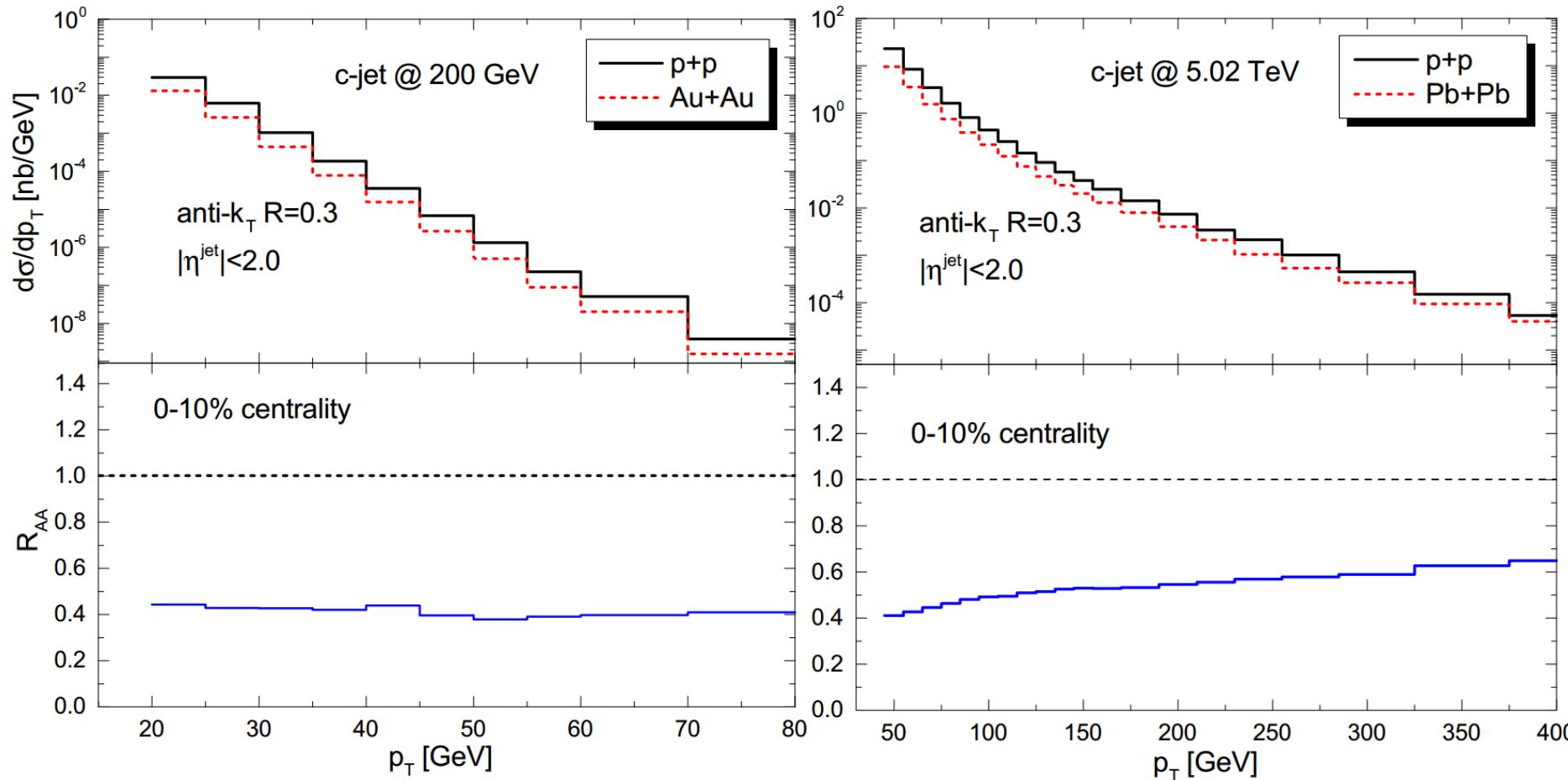
# Prediction : $D^0$ radial diffusion at RHIC energy



S. Wang, W. Dai, B.W Zhang, E. Wang,  
Eur.Phys.J. C79 (2019) no.9, 789

➤ Weaker modification, due to the lower temperature of the QGP at RHIC than LHC.

# Prediction : Nuclear modification factor RAA



$$R_{AA}(p_T) = \frac{1}{N_{coll}} \frac{d^2 N_{AA}/(dp_T dy)}{d^2 N_{pp}/(dp_T dy)}$$

S. Wang, W. Dai, B.W Zhang, E. Wang,  
 Eur.Phys.J. C79 (2019) no.9, 789

# Summary

- We present the first theoretical calculation of the radial distribution of a D meson in jets .
- We estimate the net effect on the charm diffusion from collisional and radiative mechanisms and demonstrate the  $p_T$  dependence of diffusion effect.
- We find the ratio  $\Delta r/\Delta E$  is sensitive to  $D_S$  but not  $\hat{q}$  , which provides extra constrain on the strength of elastic and inelastic interaction.
- The nuclear modification factor  $R_{AA}$  of charm jet both at the RHIC and the LHC are predicted.

Thanks for your attention !

## SHERPA configuration

- The tree-level matrix elements---**Amegic** and **Comix**.
- The one-loop virtual corrections ---**BlackHat**.
- Parton Shower---**Catani-Seymour subtraction method** .
- Matching of NLO+PS: **MC@NLO**.
- **NNPDF3.0** NLO-5FS PDF .
- **Fastjet** ---jet reconstruction.

# Backup 2

$$\vec{x}(t + \Delta t) = \vec{x}(t) + \frac{\vec{p}(t)}{E} \Delta t$$

$$\vec{p}(t + \Delta t) = \vec{p}(t) - \Gamma(p) \vec{p} \Delta t + \vec{\xi}(t) \Delta t - \vec{p}_g$$

$$\kappa = 2ET\Gamma = \frac{2T^2}{D_s}$$

$$\langle \xi_i(t) \rangle = 0$$
$$\langle \xi_i(t) \xi_j(t') \rangle = \kappa \delta_{ij}(t - t')$$

Radiative:

$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2\alpha_s C_A P(x) \hat{q}}{\pi k_\perp^4} \sin^2\left(\frac{t - t_i}{2\tau_f}\right) \left(\frac{k_\perp^2}{k_\perp^2 + x^2 M^2}\right)^4$$

$$\frac{\Delta r}{\Delta E} \propto \frac{\int \frac{k_\perp}{E} \frac{dN}{dx dk_\perp^2 dt} dx dk_\perp^2 dt}{\int x E \frac{dN}{dx dk_\perp^2 dt} dx dk_\perp^2 dt}$$

Collisional:

$$\Delta r \propto \int \frac{|\vec{\xi}(t)|}{E} dt \propto \int \frac{\sqrt{\kappa}}{E} dt \propto \int \frac{T}{E \sqrt{D_s}} dt$$

$$\Delta E \sim \int E \Gamma dt = \int \frac{T}{D_s} dt$$



$$\frac{\Delta r}{\Delta E} \propto \sqrt{D_s}$$