Nonperturbative Open Heavy Flavor Transport in QCD Matter

Part Ⅳ

5*LO-pQCD Langevin & RRM vs instantaneous coalescence

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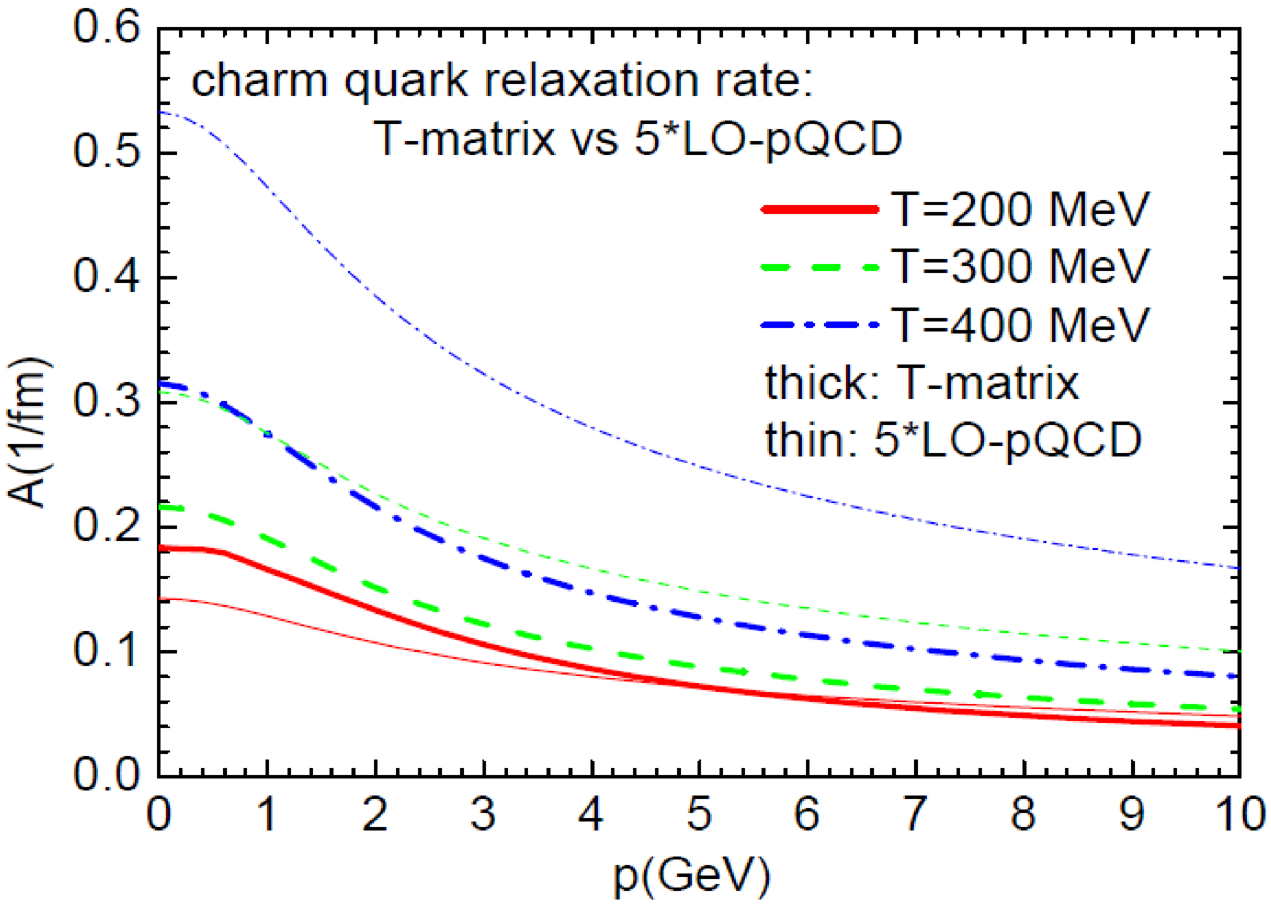
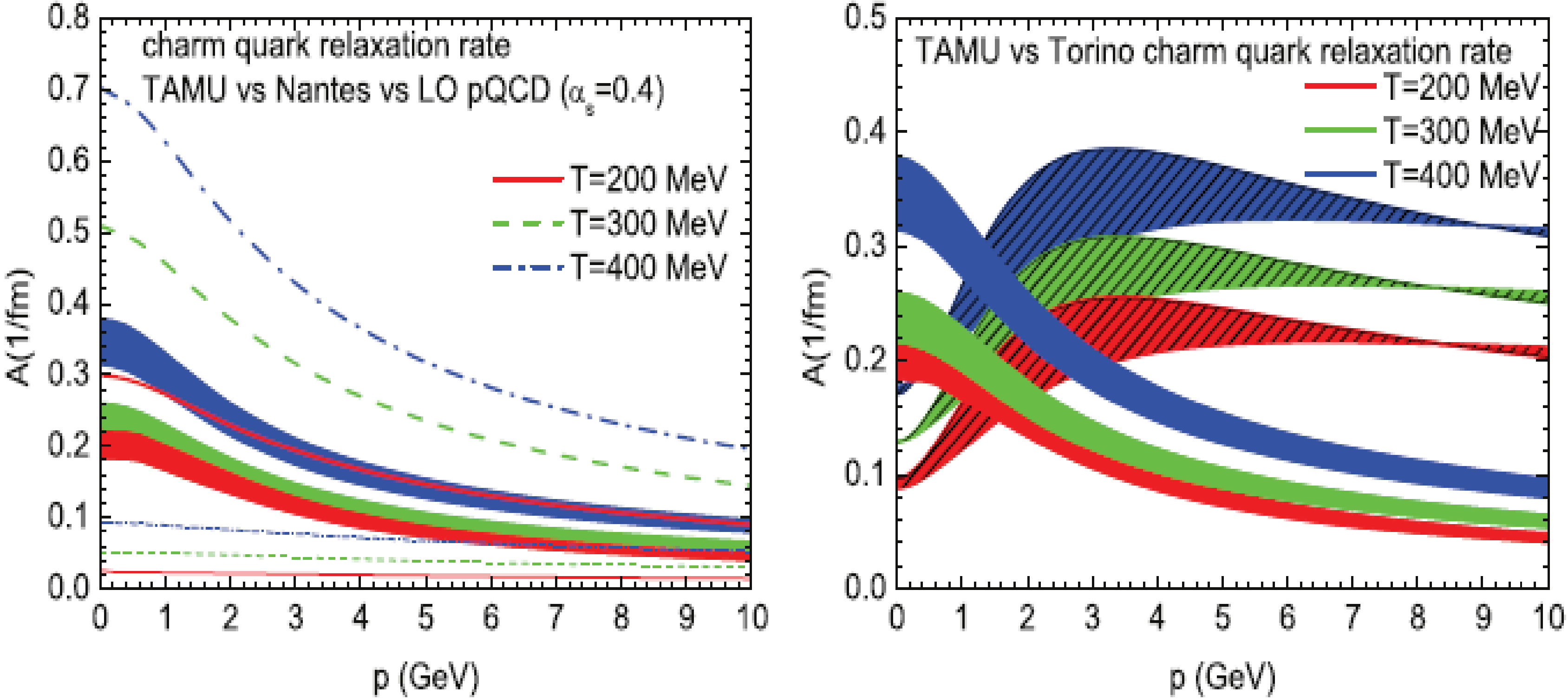
Charm quark relaxation rate: 5*LO-pQCD



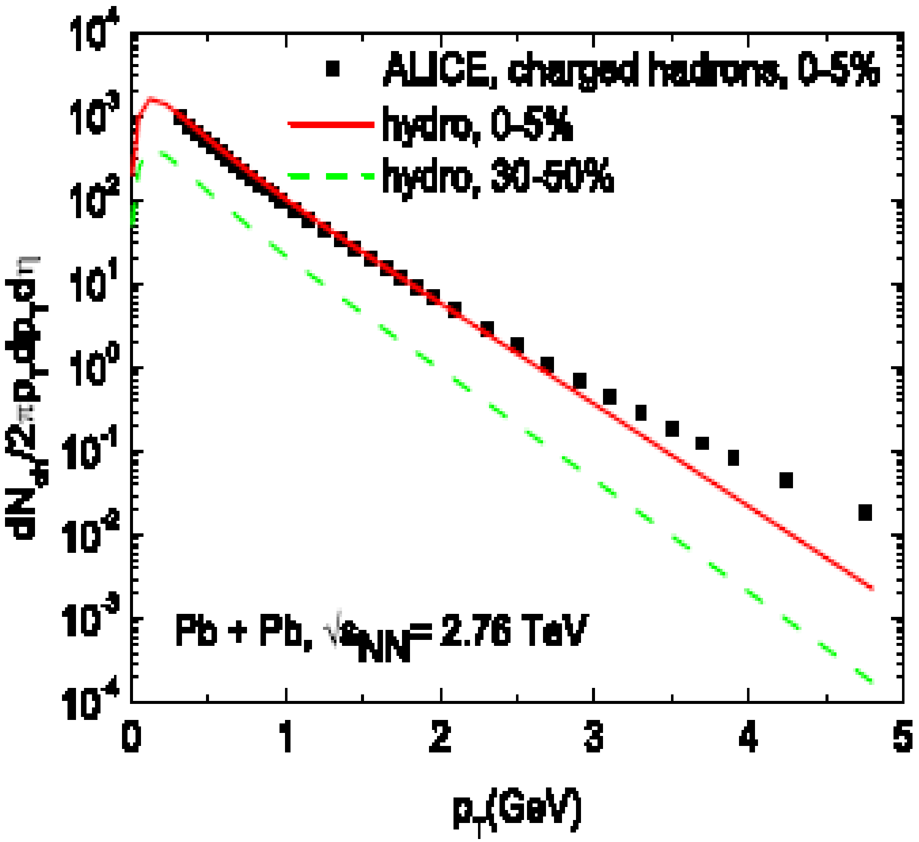
- **low T: T-matrix > 5*LO-pQCD, high T: T-matrix < 5*LO-pQCD**
- **very similar momentum dependence**

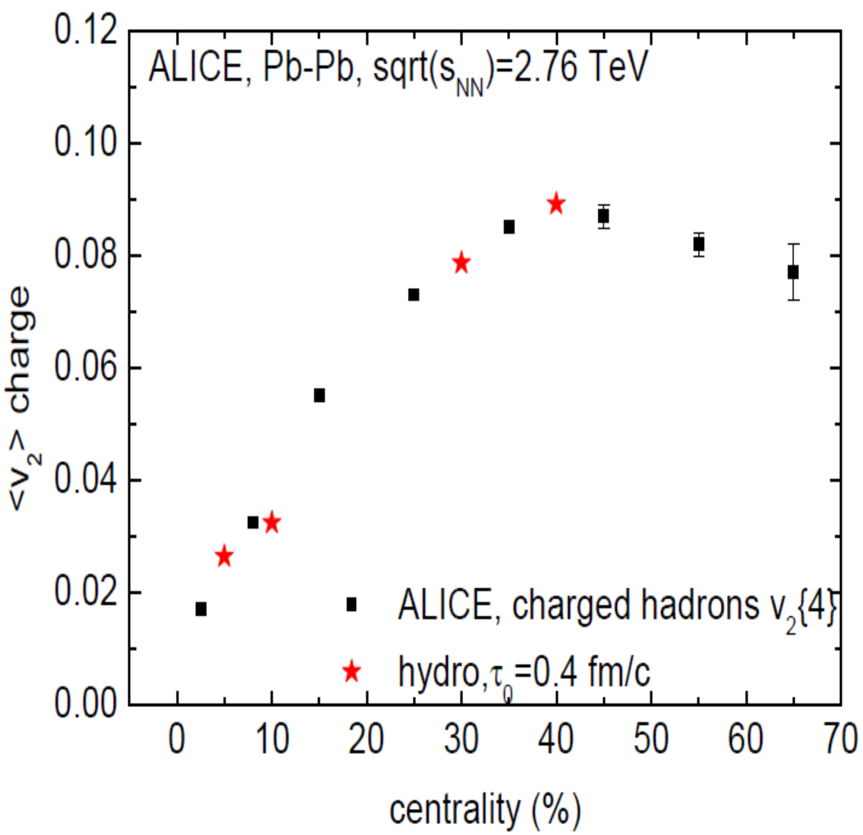
Charm quark relaxation rate: comparison



- **bands: T-matrix, 20% uncertainty due to different lQCD input potential**
- **thin lines: LO-pQCD with alpha_s=0.4**
- **thick lines: Nantes (pQCD Born with reduced screening mass & running coupling**

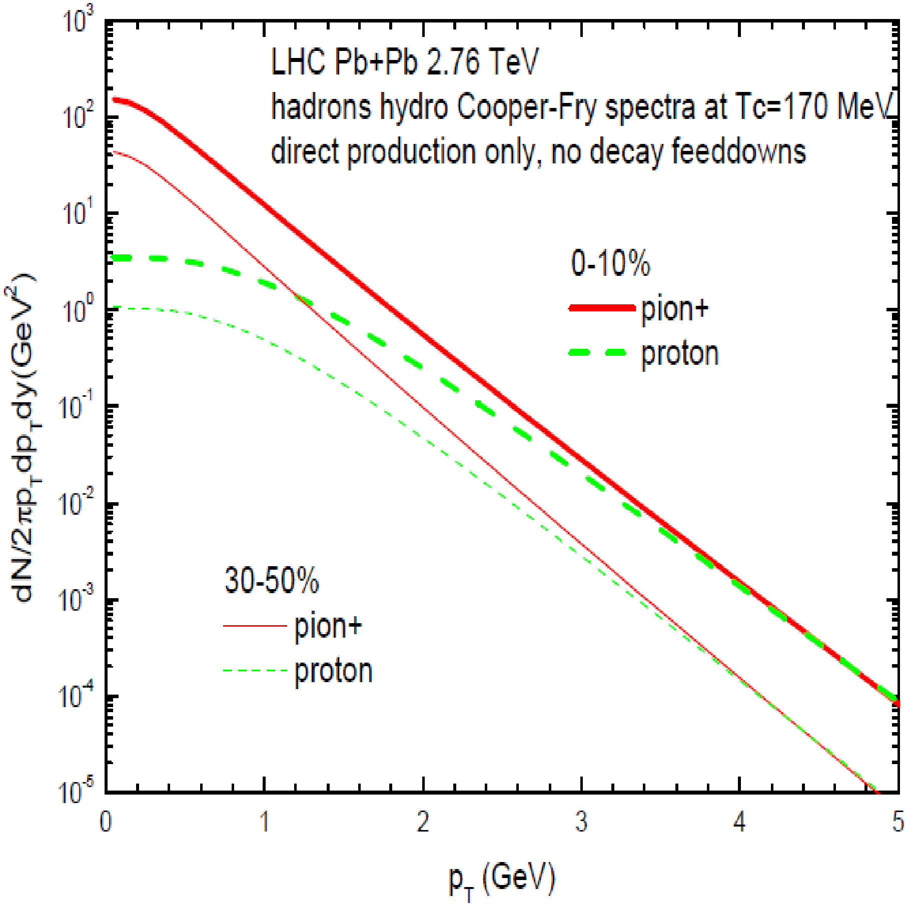
Calibrating bulk medium

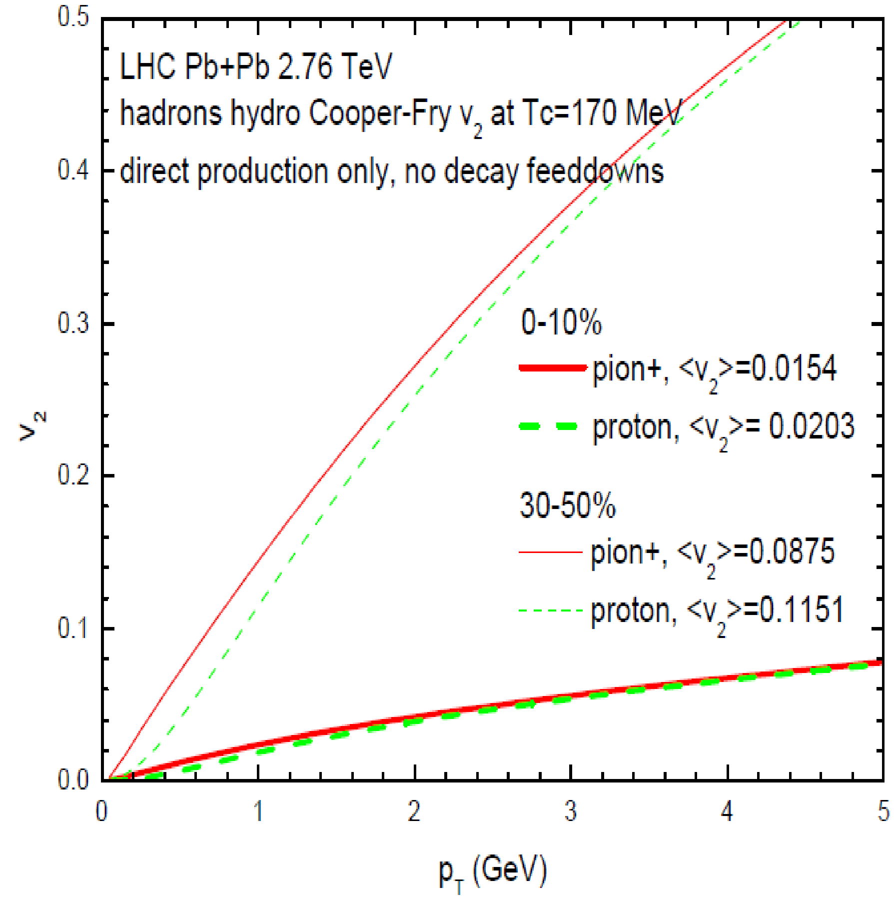




- p_T spectra & integrated $\langle v_2 \rangle$ of charged particles fitted at thermal freezeout T_{kin}=110 MeV

Bulk hadrons spectra vs v_2 at Tc=170 MeV





Post-point Langevin scheme

- **Langevin equation**

$$dx_j = \frac{p_j}{E} dt,$$

$$dp_j = -\Gamma(p,T) p_j dt + \sqrt{dt}\, C_{jk}(\boldsymbol{p} + \xi d\,\boldsymbol{p}, T) \rho_k,$$

with $$C_{jk}(\boldsymbol{p}) = \sqrt{2B_0(p)} P^{\perp}_{jk}(\boldsymbol{p}) + \sqrt{2B_1(p)} P^{\parallel}_{jk}(\boldsymbol{p})$$

- **use 5*LO-pQCD transport coefficient:**

$$\Gamma(p;T) = A(p;T) + \frac{1}{E(p)} \frac{\partial D(p;T)}{\partial E(p)}$$

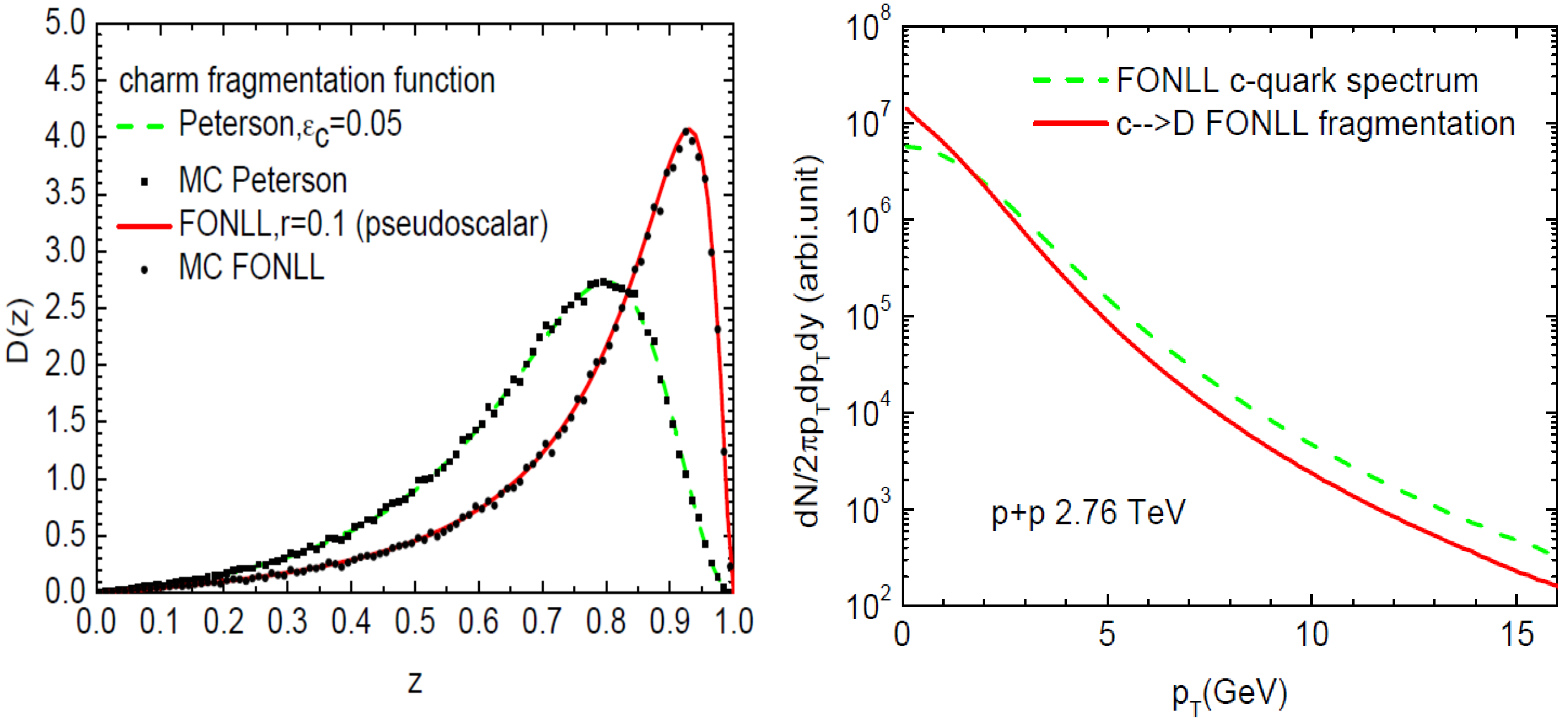
$$= A(p) + \mathcal{O}(T/m_Q)$$

--- Einstein relation between A(p,T) and longitudinal diffusion

$$B_1(p,T) = A(p,T) E(p) T$$

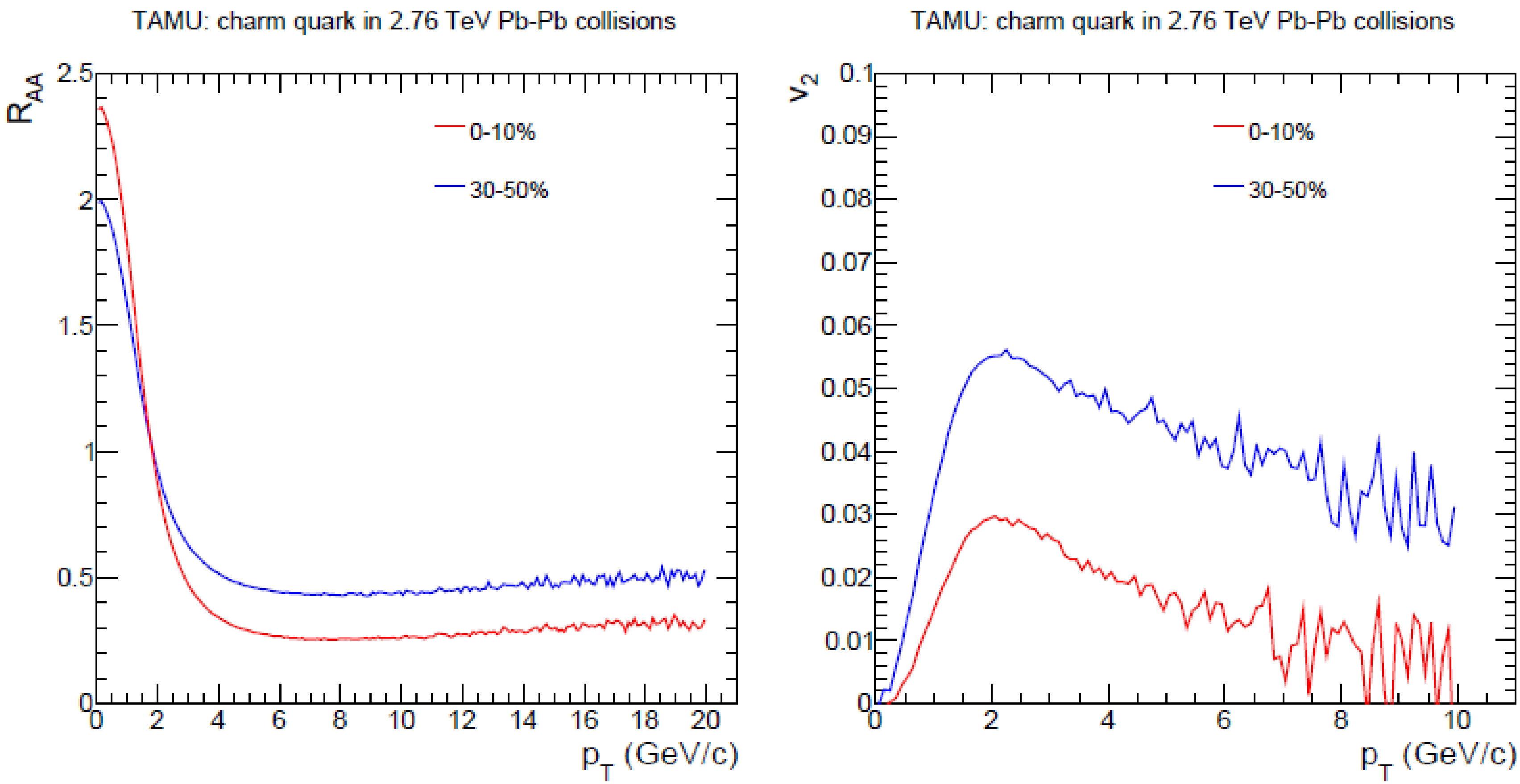
--- A(p,T) & B_0(p,T) taken from LO-pQCD calculations

Charm quark FONLL fragmentation



- **initial charm quark spectrum taken from FONLL**
- **hadronization other than recombination also consistently by FONLL frag. func.**

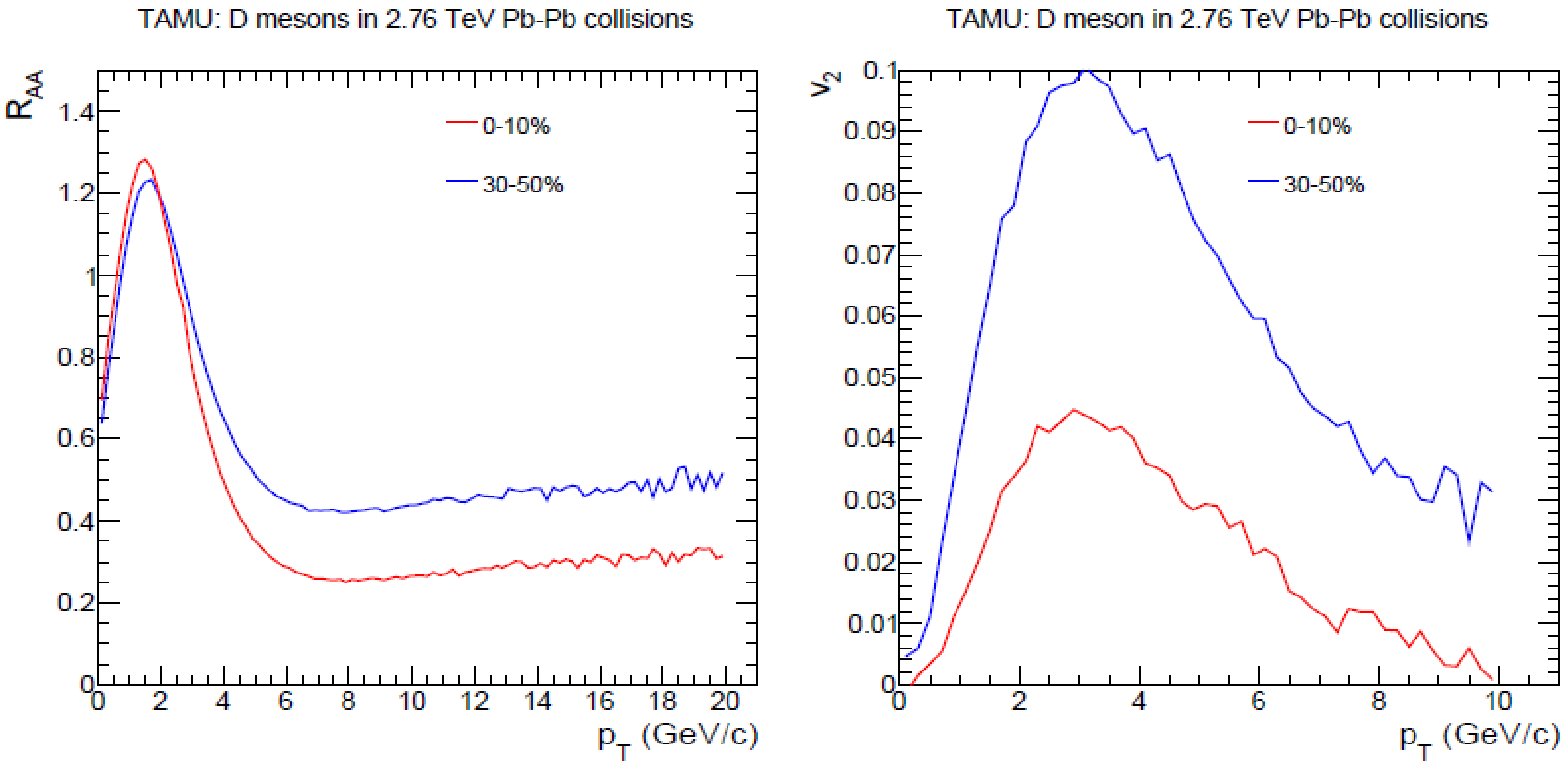
Charm quark R_{AA} vs v_2



- R_{AA} –- slight increase toward high p_T
- v_2 --- drop down toward high p_T
- all similar to previous T-matrix results --- recall similar p-dependence in their A(p,T)

D-meson R_{AA} vs v_2

- **low p_T, Resonance Recombination/RRM dominates; high p_T, fragmentation takes over**



- **R_{AA} –- very low p_T depletion and shoulder due to RRM interaction + different c/D baselines➔ flow bump at ~2 GeV**
- **v_2 --- at p_T=2-5 GeV, much enhanced ➔ fast drop toward high p_T**

RRM vs instantaneous coalescence

- **Resonance Recombination** — Ravagli & Rapp, 2007

$$p^\mu \partial_\mu f_M(t,\vec{x},\vec{p}) = -m\Gamma f_M(t,\vec{x},\vec{p}) + p^0 \beta(\vec{x},\vec{p})$$

gain term

$$\beta(\vec{x},\vec{p}) = \int \frac{d^3p_1 d^3p_2}{(2\pi)^6} f_q(\vec{x},\vec{p}_1) f_{\bar{q}}(\vec{x},\vec{p}_2) \times \sigma(s) v_{\rm rel}(\vec{p}_1,\vec{p}_2)\delta^3(\vec{p}-\vec{p}_1-\vec{p}_2)$$

Breit-Wigner

$$\sigma(s) = g_\sigma \frac{4\pi}{k^2}\frac{(\Gamma m)^2}{(s-m^2)+(\Gamma m)^2}$$

➔ **resonance formation in the equilibrium limit (width from T-matrix)**

$$f_M^{\rm eq}(\vec{p}) = \frac{E_M(\vec{p})}{m\Gamma}\int d^3x\, \beta(\vec{x},\vec{p})$$

- **Instantaneous coalescence** — Ko et al., 2003 & 2009

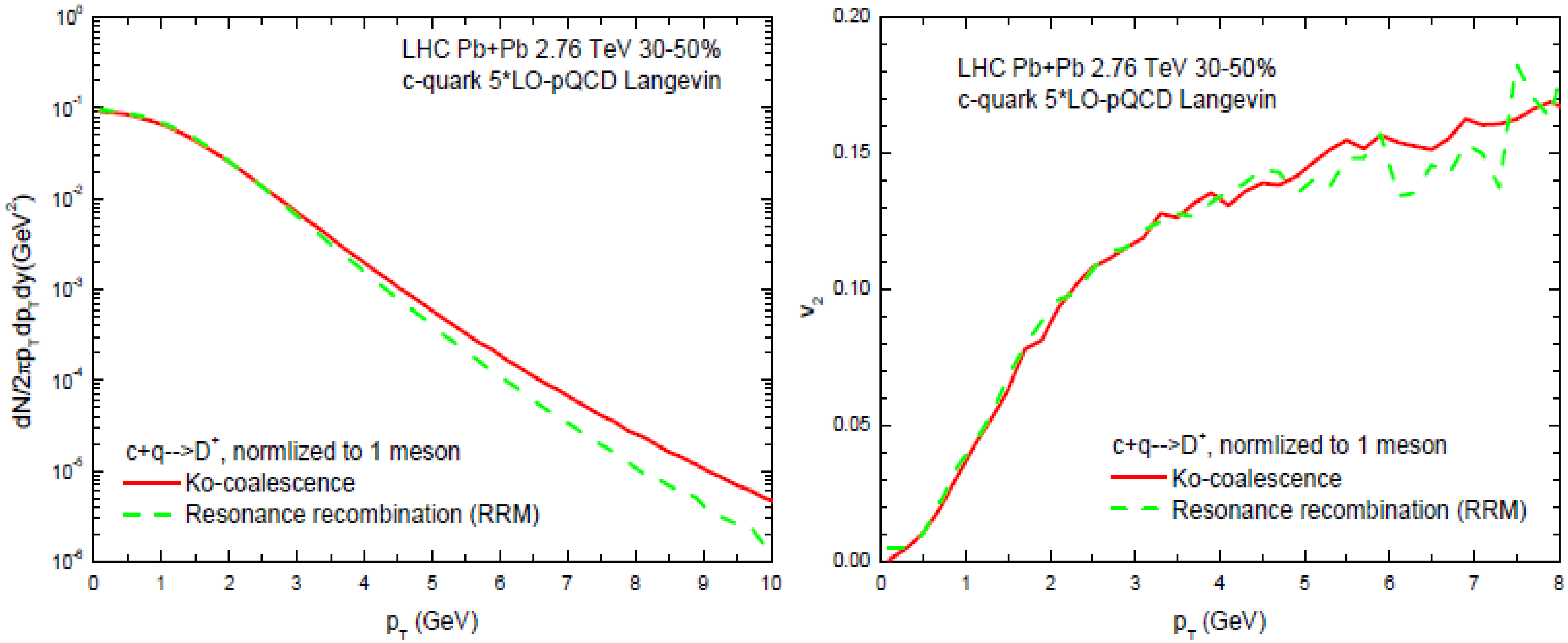
$$\frac{dN_M}{d^2\vec{p}_T} = g_M \frac{(2\sqrt{\pi}\sigma)^3}{V}\int d^2\vec{p}_{T1} d^2\vec{p}_{T2} \frac{dN_1}{d^2\vec{p}_{T1}}\frac{dN_2}{d^2\vec{p}_{T2}} e^{-\vec{k}_T^2\sigma^2}\delta^2(\vec{p}_T-\vec{p}_{T1}-\vec{p}_{T2})$$

where $k = \frac{1}{m_1+m_2}(m_2 p_1' - m_1 p_2')$

with a Gaussian Wigner function fitted to meson rms charge radius

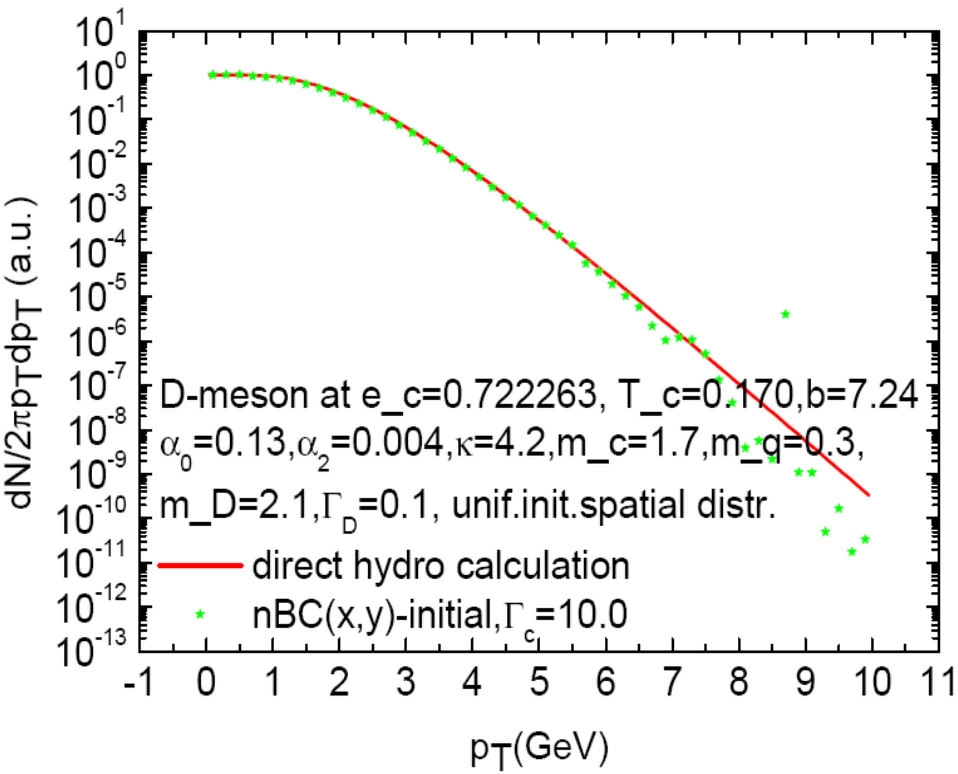
D-meson: RRM vs Ko-coalescence

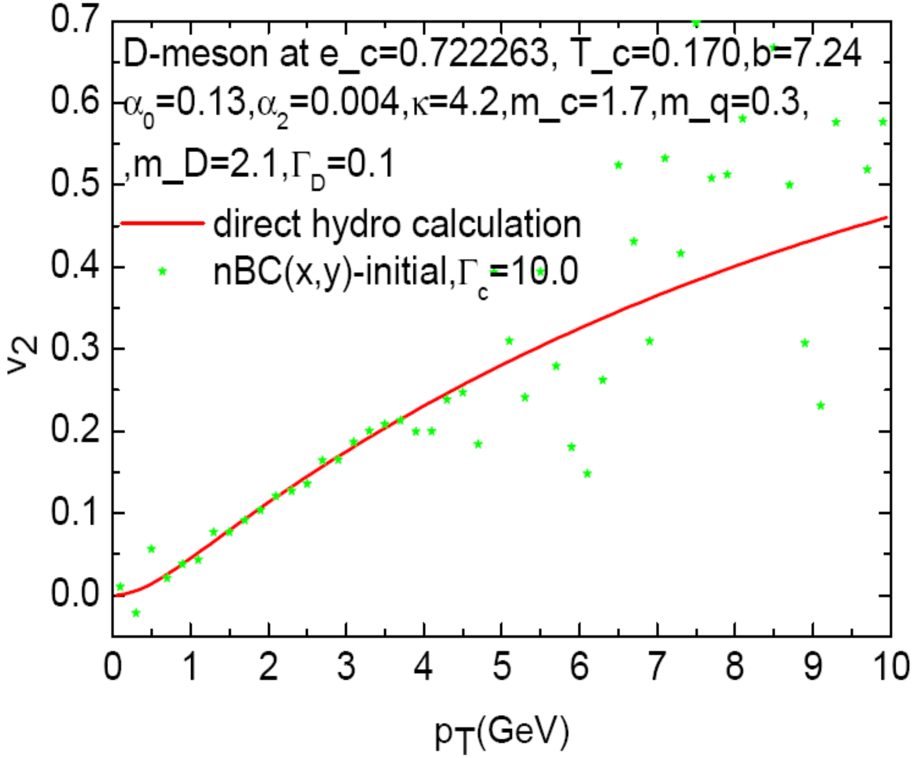
- **different implementations:**
  --- RRM: event-by-event coupled to Langevin, with full space-momentum correlation on the hydro freezeout hypersurface
  --- Ko-coalescence: done in momentum space only with "averaged" quark momentum distribution, thus no space-momentum correlation



- **spectrum --- RRM softer due to correct equilibrium limit**
- **v_2 --- surprisingly similar**

Back-up: D-meson RRM equilibrium





- charm quark Langevin with huge thermalization rate ➔ reaching equilibrium
- then recombine them with hydro light quarks ➔ equilibrium D-meson spectrum