Flow of the Charm Hadron to Constrain In-medium Hadronisation

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arXiv:2510.16299 2512.07169

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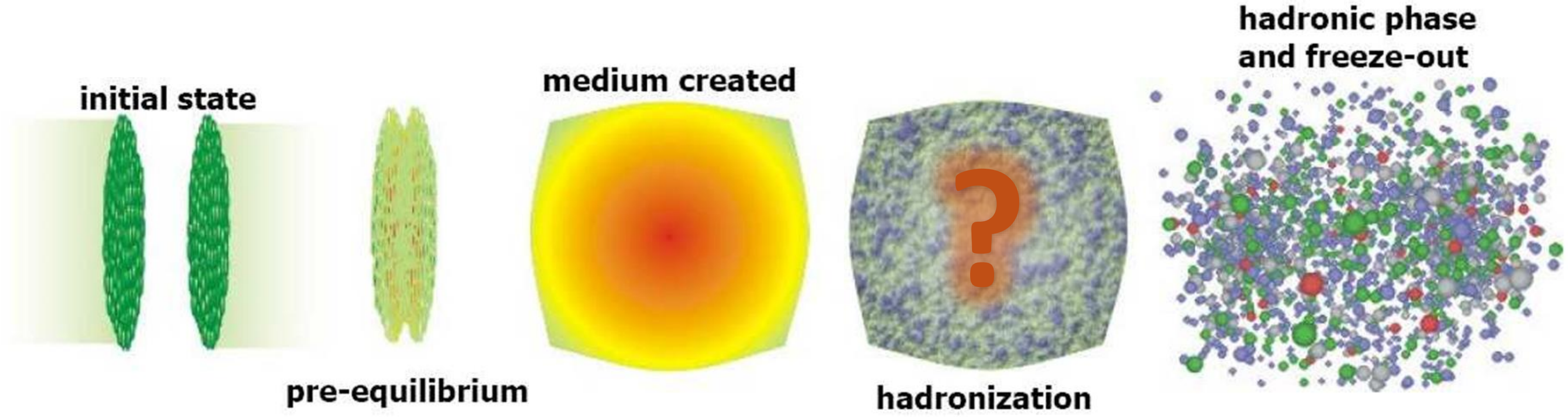
Outline

- Elliptic flow of Ds as evidence of the sequential hadronization mechanism in the hot QCD medium

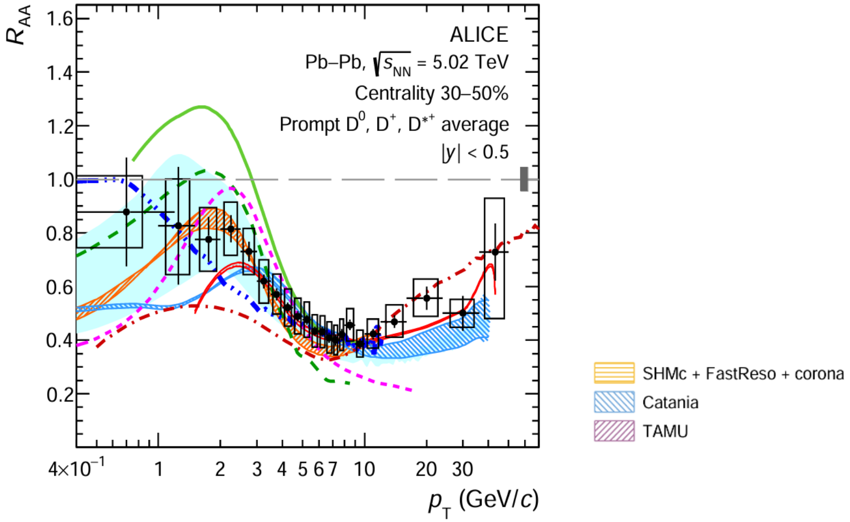
- Bayesian Inference of Heavy-Quark Dissipation and Jet Transport Parameters from D-Meson observables

- Radial flow of Ds as evidence of the sequential hadronization and its NCQ scaling

Intro



All hadronize at the same time !

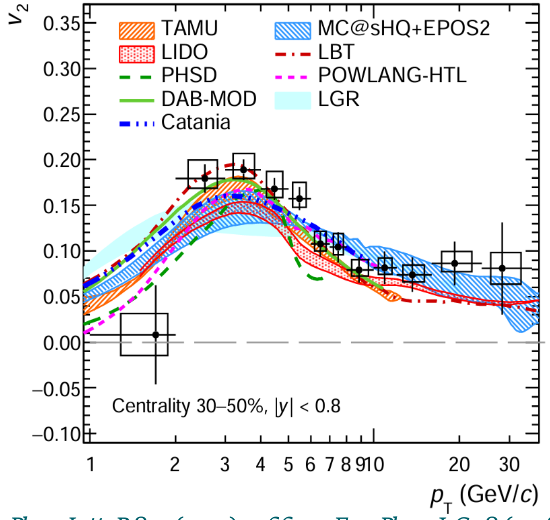


multi-stage， multi-messenger

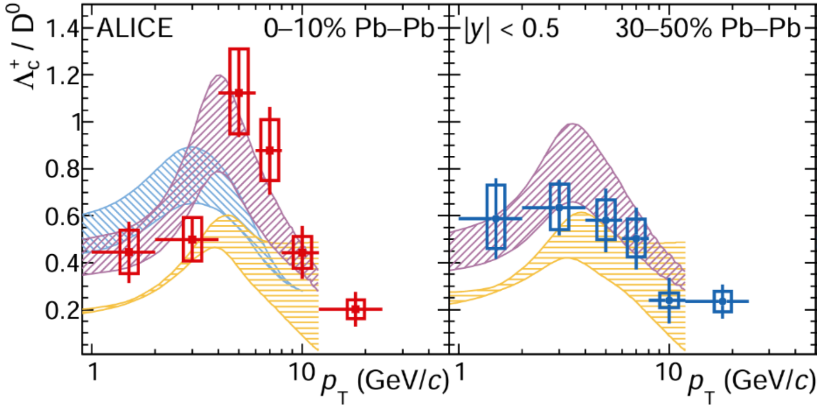
Constraint provided by Data-learning

Heavy flavor can be a nice probe to study hadronization:

- Produced by initial hard scattering
- HQ mass $m_Q \gg T_{QGP}$ number conservation
- Few excited states
- The direct and feed-down contributions can be well separated in experiments



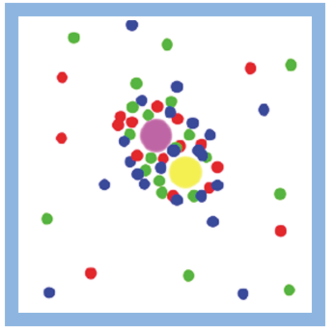
- CATANIA *Phys. Lett. B* 821 (2021), 136622; *Eur. Phys. J. C* 78 (2018) no.4, 348
- Duke *Phys. Rev. C* 92 (2015) no.2, 024907; *Phys. Rev. C* 88 (2013), 044907
- Nantes *Phys. Rev. C* 79 (2009), 044906
- PHSD *Phys. Rev. C* 92 (2015) no.1, 014910; *Phys. Rev. C* 93 (2016) no.3, 034906
- TAMU *Phys. Lett. B* 655 (2007), 126-131; *Phys. Lett. B* 795 (2019), 117-121
- … …

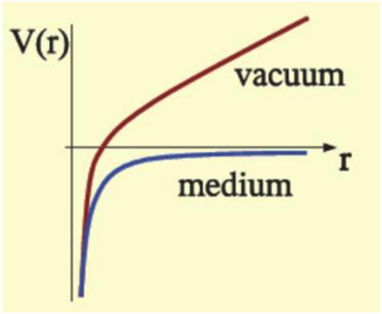


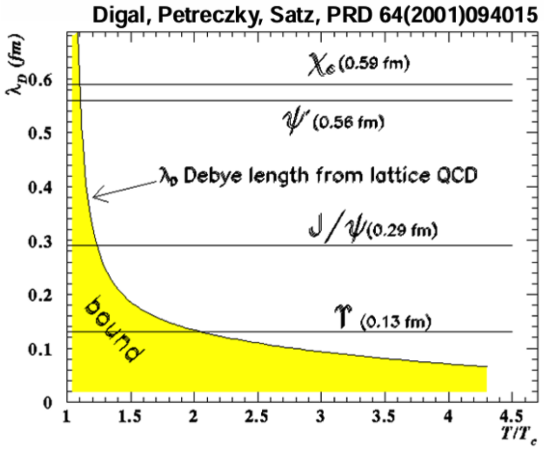
Phys.Lett.B 839 (2023) 137796

◆ Considering a more realistic picture ——

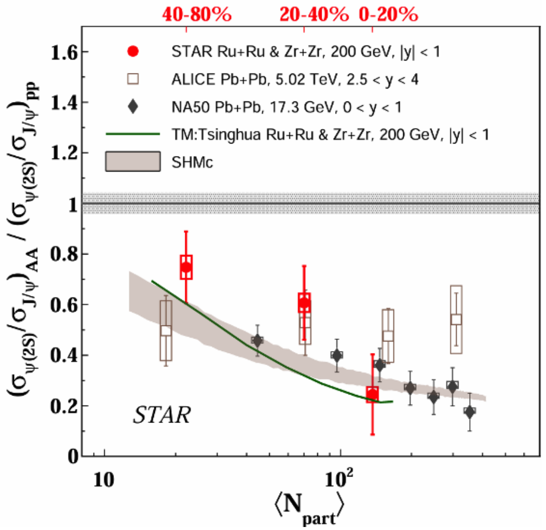
Sequential hadronization inspired by charmonium







R. Averbeck in Quark Matter 2025



In vacuum : $q\bar{q}$ interaction described by Coulomb + linear potential –

$$V(r) = -\frac{\alpha}{r} + kr$$

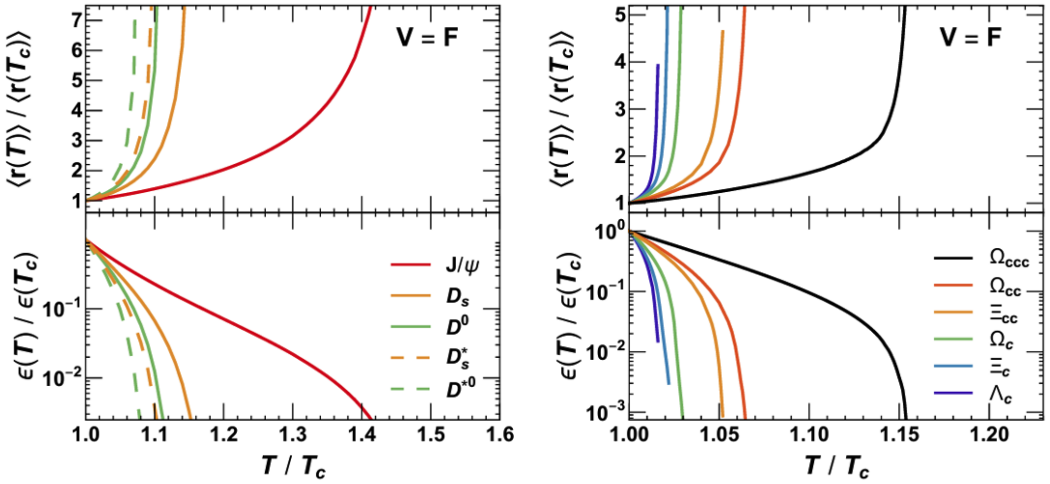
In medium : confinement term vanishes, Coulomb term is color screened beyond a Debye length –

$$V(r) = -\frac{\alpha}{r} e^{-r/\lambda_D}$$

◆ *quarkonia exhibit different binding energies and radii*

hadronization sequence (by *Zhuang et al.*) :

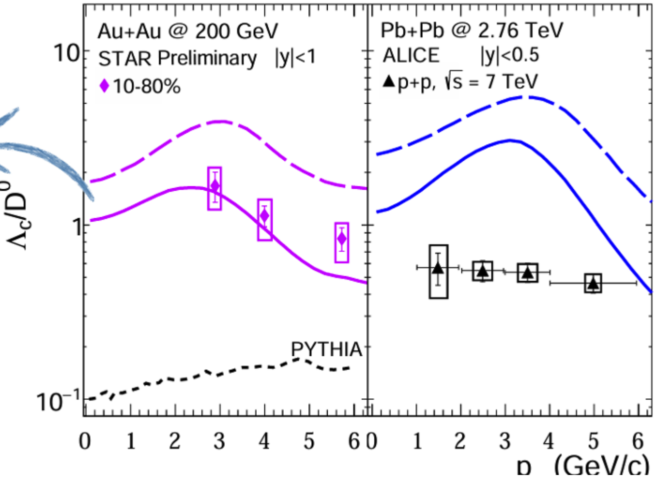
$$T_d^{J/\psi} > T_d^{D_s} > T_d^{\Omega_{ccc}} > T_d^{D^0} > T_d^{\Omega_{cc},\Xi_{cc}} > T_d^{\Omega_c,\Xi_c,\Lambda_c} > T_d^{\pi,K,N} \approx T_c$$



Nucl. Phys. A **1005** (2021), 121898

- *Excited states*
- *Gaussian widths*
- *Coalescence & fragmentation fraction*
- *... ...*

A stronger signal remains to be found.



Coalescence + fragmentation hadronization

- Coalescence: a precise constraint will provide a strong probe of flow !

- Well accepted scenario: → provide good descriptions of available data :
  - CATANIA *Phys. Lett. B* **821** (2021), 136622; *Eur. Phys. J. C* **78** (2018) no.4, 348
  - Duke *Phys. Rev.. C* **92** (2015) no.2, 024907; *Phys. Rev. C* **88** (2013), 044907
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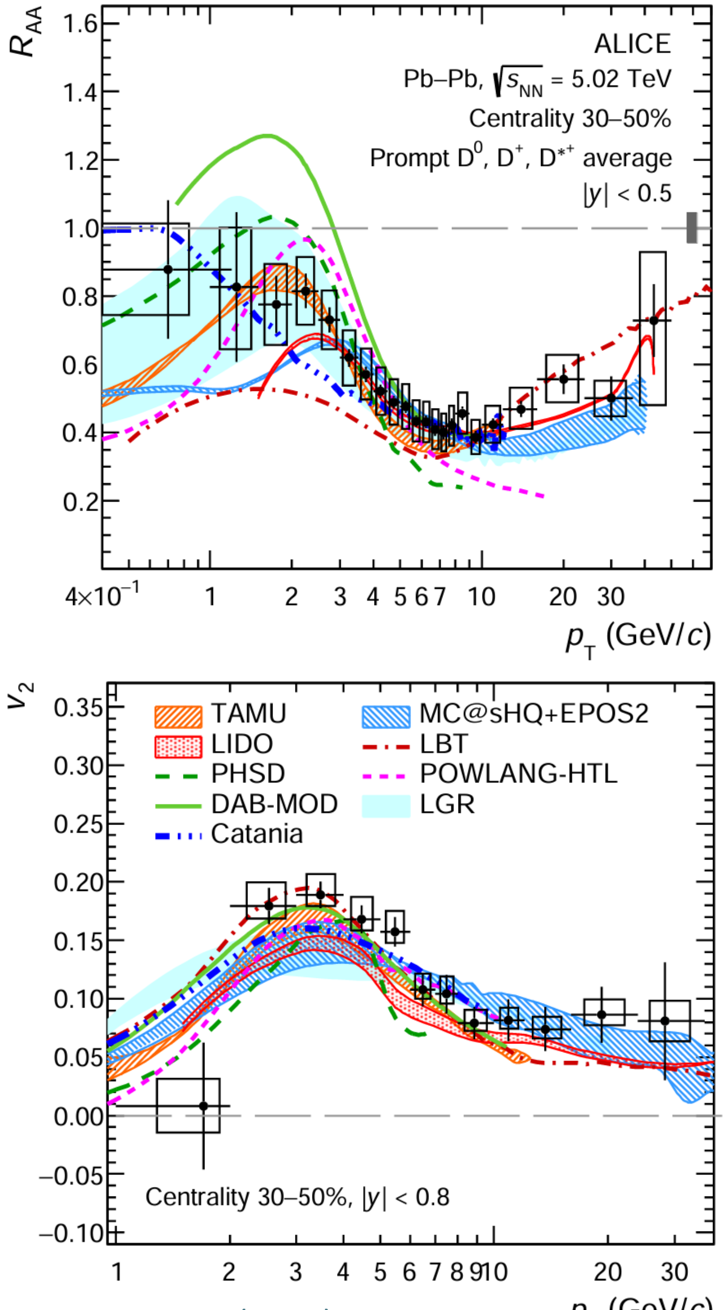
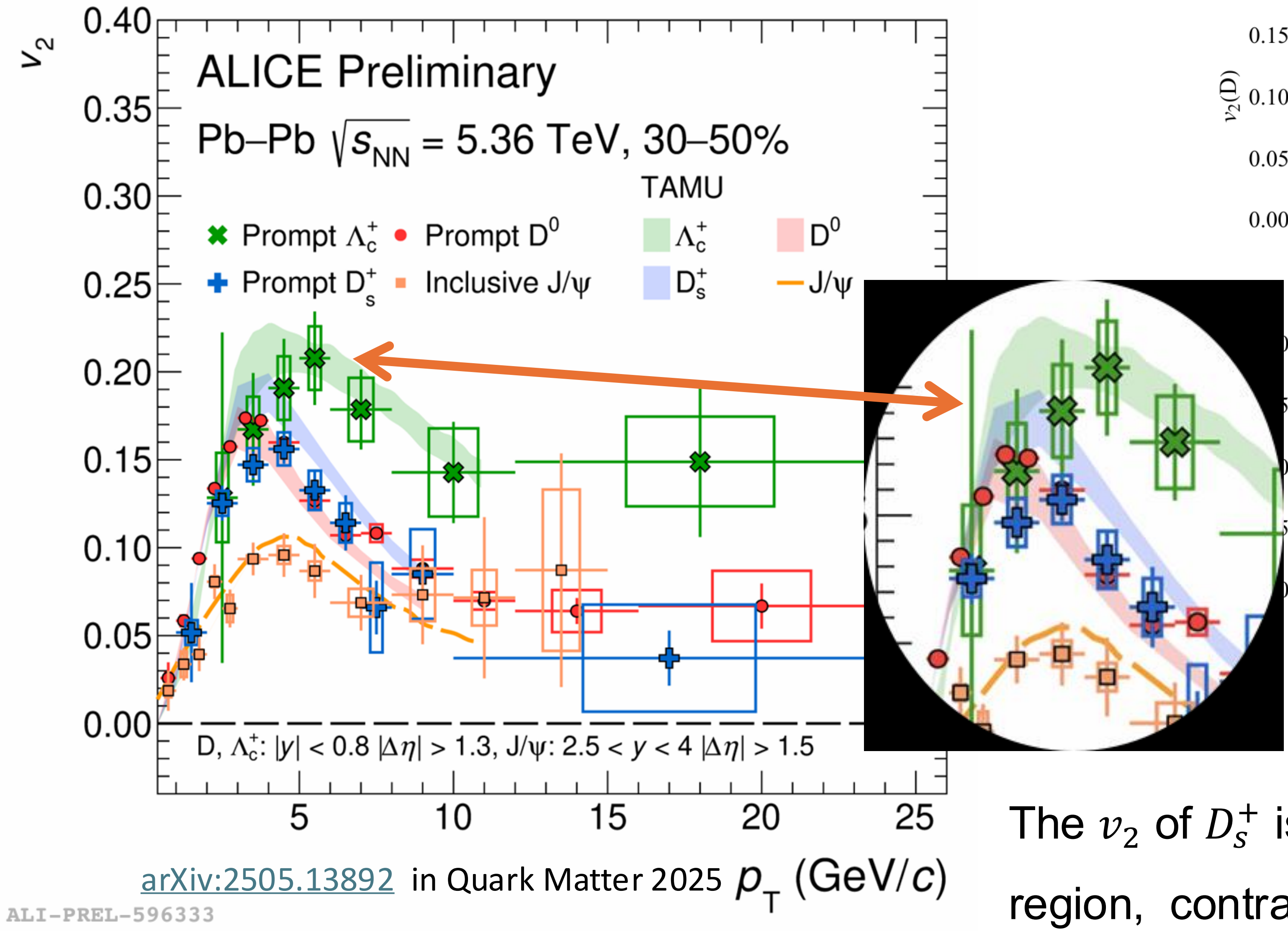
  - TAMU *Phys. Lett. B* **655** (2007), 126-131; *Phys. Lett. B* **795** (2019), 117-121
  - … …

hadronized at the same temperature!

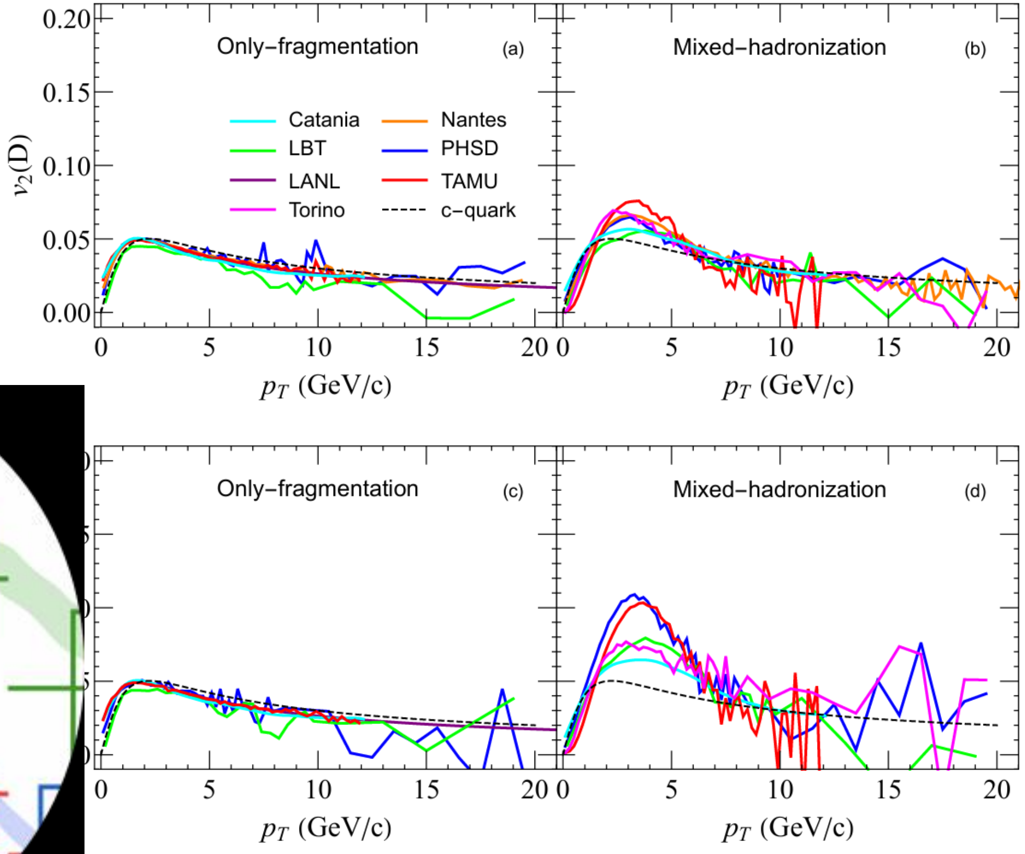


JHEP **01** (2022), 174

v_2 Hierarchy between D^0 and D_s^+ due to conventional Coalescence



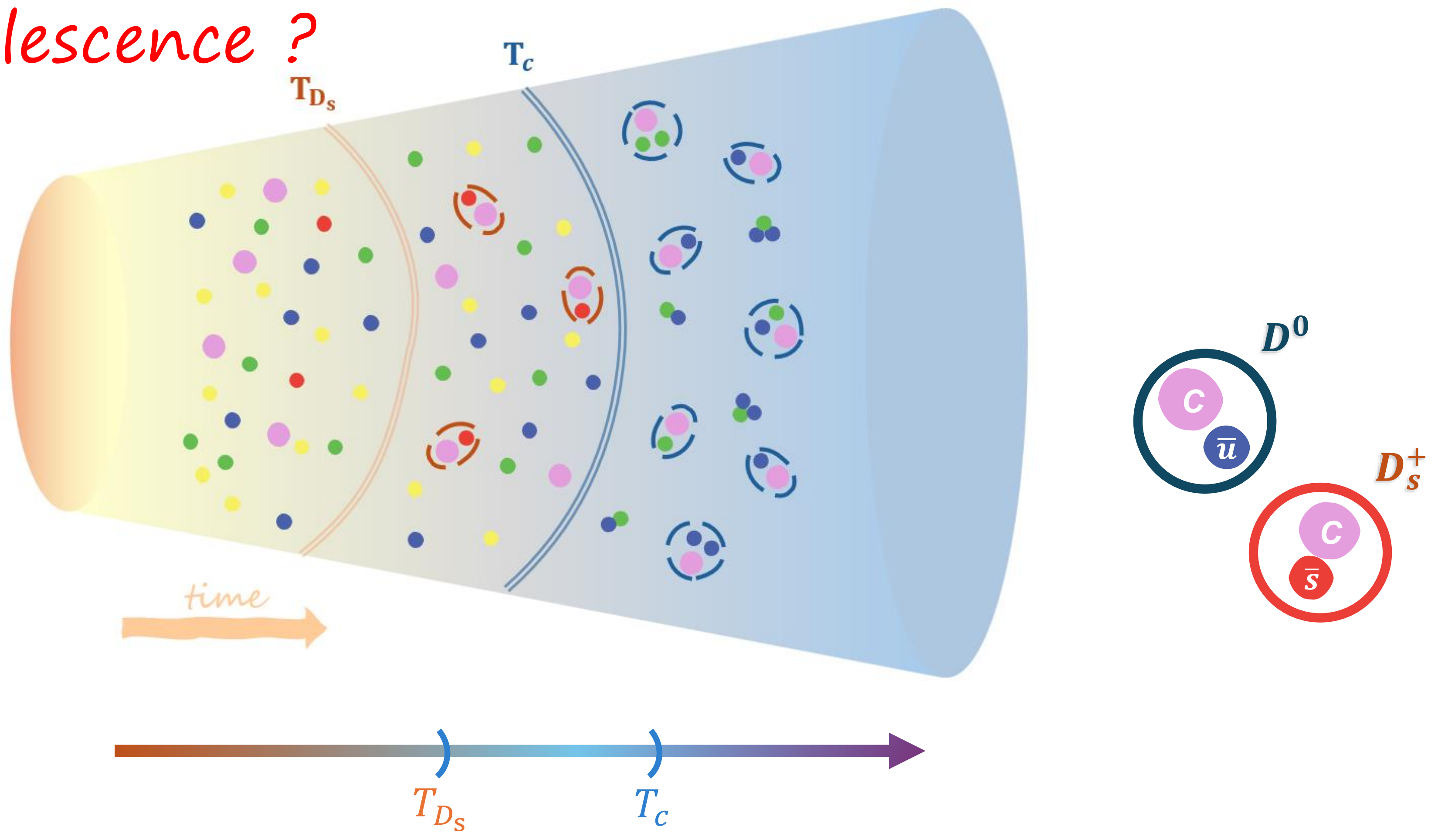
arXiv:2505.13892 in Quark Matter 2025



Phys. Rev. C **109** (2024) no.5, 054912

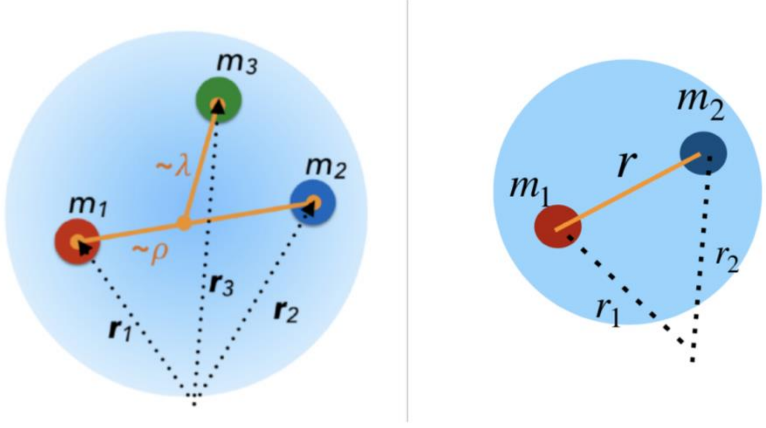
The v_2 of D_s^+ is lower than D^0 in the intermediate-p_T region, contradict to model predictions.

How to consider Sequential Coalescence ?



- D_s coalesce before other hadrons at a temperature $T_{D_s} = 1.2\ T_c$ (By solving Dirac Equation)
- All other heavy-flavor hadrons hadronize on a separate hypersurface at $T = T_c$

How to consider Sequential Coalescence ?



The momentum distribution of hadrons produced from coalescence:

$$P_h = g_h \int \prod_{i=1}^{n} \frac{d^3x_i d^3p_i}{(2\pi)^3} f_i(x_i, p_i) \cdot W_h(x_1, \cdots, x_i, p_1, \cdots, p_i)$$

- Quark distribution function $f_i(x_i, p_i)$

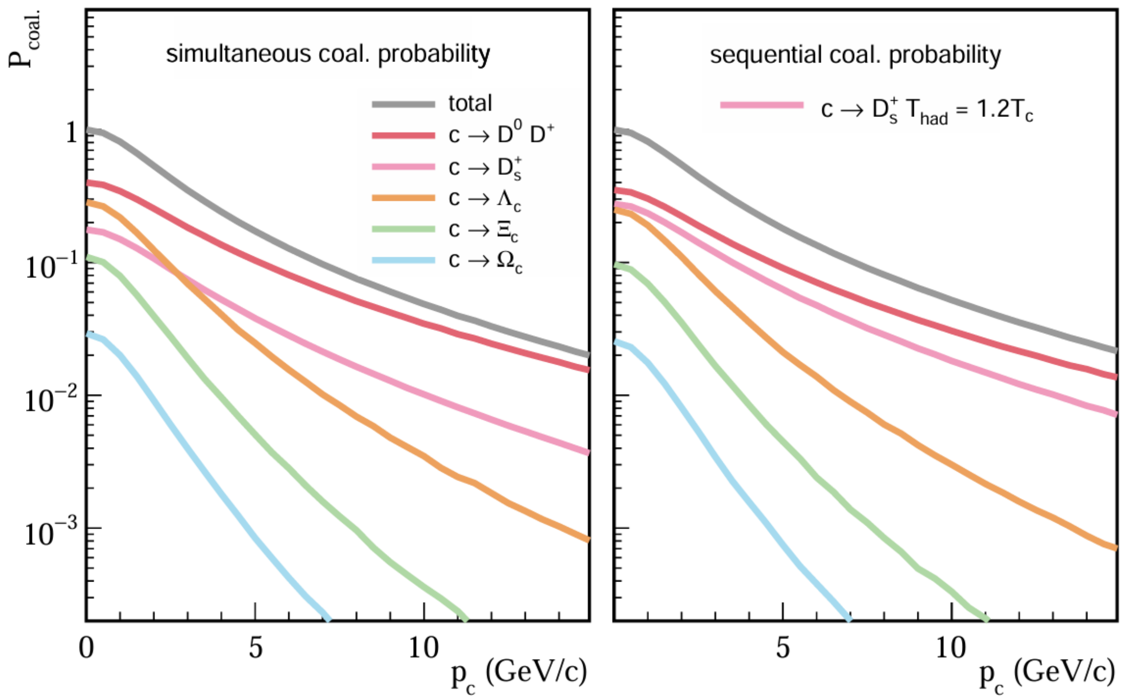
  For light quark $f_i(p_i) = N_i/(e^{u_\mu p_i^\mu/T} + 1)$

- Wigner function $W_h(\boldsymbol{r}, \boldsymbol{p}) = \int d^3\boldsymbol{y} e^{-i\boldsymbol{p}\cdot\boldsymbol{y}} \psi\left(\boldsymbol{r} - \frac{\boldsymbol{y}}{2}\right) \psi^*\left(\boldsymbol{r} - \frac{\boldsymbol{y}}{2}\right)$

The total sequential coalescence probability:

$$P_{coal}(p_c) = C \cdot \left(P_{D_s}(p_c, T_{D_s}) + \sum P_{D^0,\ldots}(p_c, T_c) \right)$$

C normalize the total coalescence probability when $P_c \to 0$



⭐ Sequential mechanism

1. Enhance the earlier-produced hadron yield via coalescence;

2. more coalescence → more v_2 ?

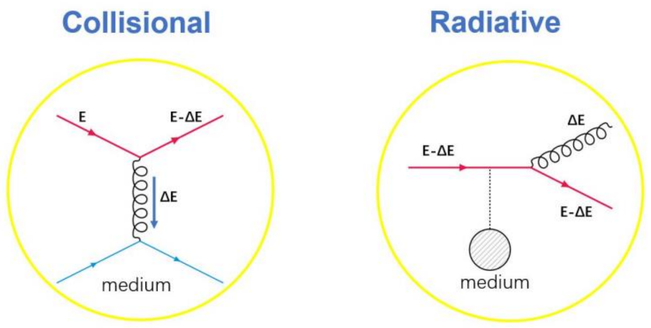
Methodology & Parton-level elliptic flow

Initial momentum and position:

FONLL *JHEP* 10 (2012) 137

Monte Carlo Glauber model *EPJC* 72 (2012) 1896

In-medium evolution:

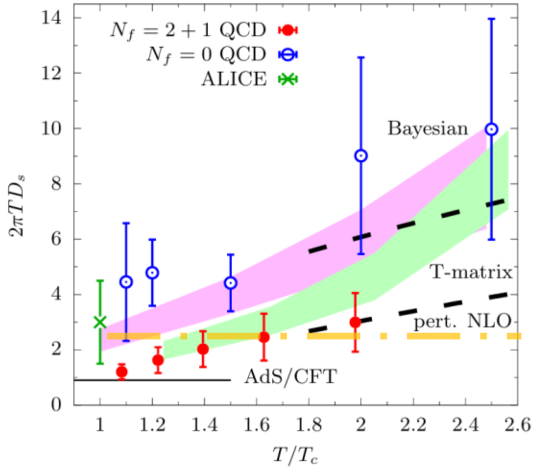


SHELL model *Chin.Phys.C* 44 (2020) 104105

Collisional: Langevin transport equations

$(2\pi T)D_s = 2.5$ based on lattice QCD calculation.

PRL 130 (2023) no.23, 231902



Higher-twist approach is implemented to describe the medium-induced gluon radiation:

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

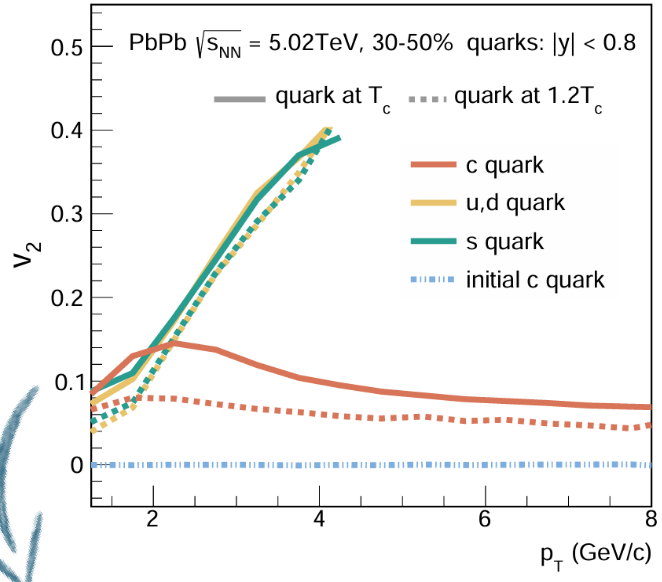
The jet transport coefficient $\hat{q} = \hat{q}_0 (\frac{T}{T_0})^3 \frac{p^\mu u_\mu}{p^0}$

We take $\hat{q}_0 = 1.5\ \mathrm{GeV}^2/\mathrm{fm}$

Hydrodynamic information:

(3+1)D CLVisc hydro

Phys.Rev.C 97 (2018) 6, 064918



Earlier-produced hadron obtain a smaller v_2

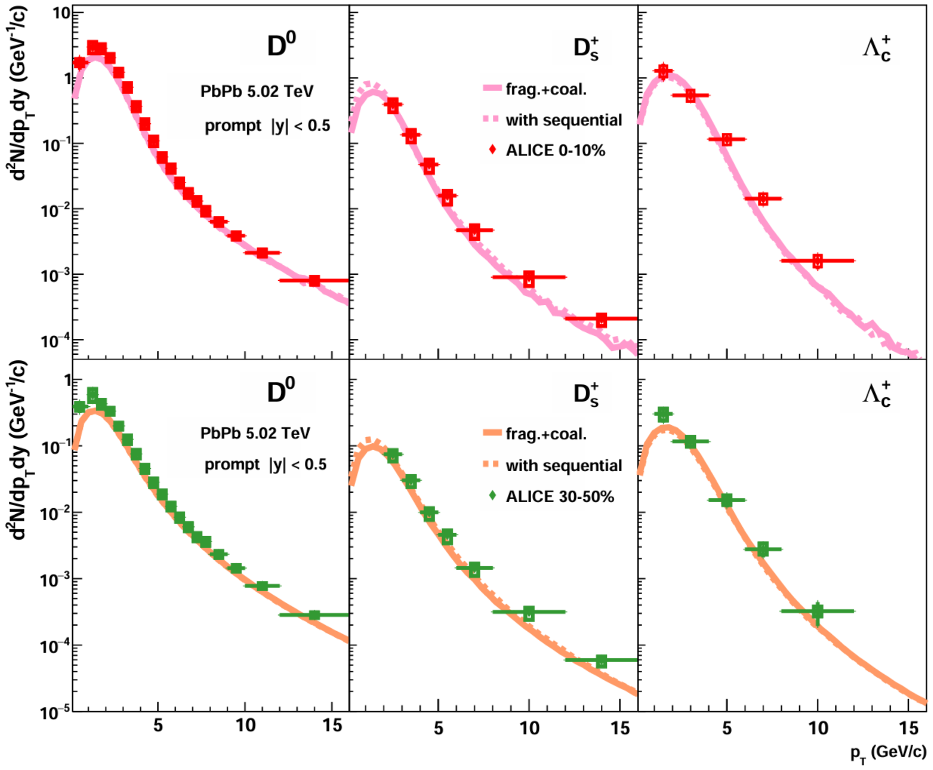
Hadronization:

Simultaneous & sequential coalescence plus Peterson fragmentation function:

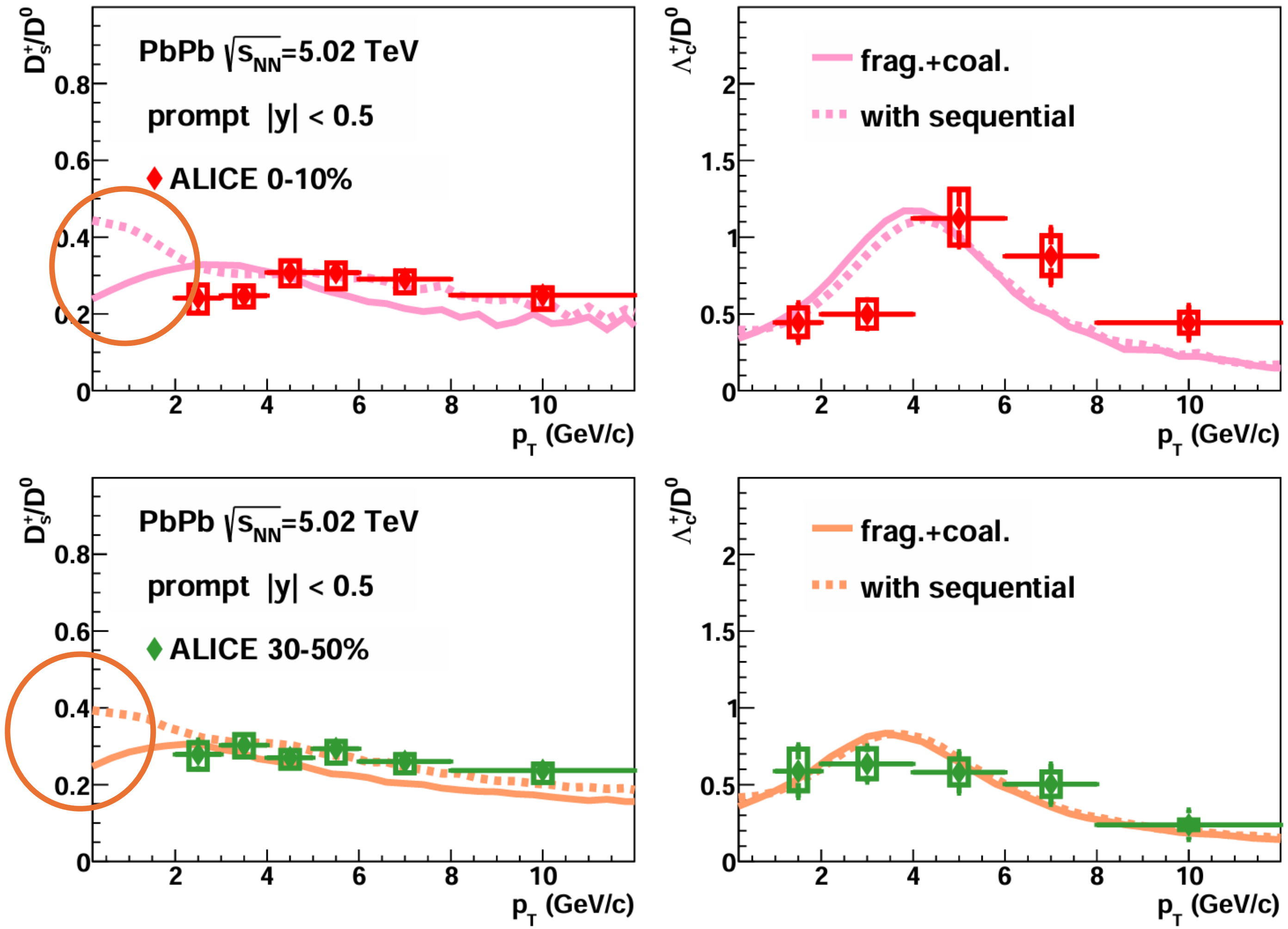
$$\mathcal{D}_{c\to H} \propto \frac{1}{z[1-\frac{1}{z}-\frac{\epsilon}{1-z}]^2}$$

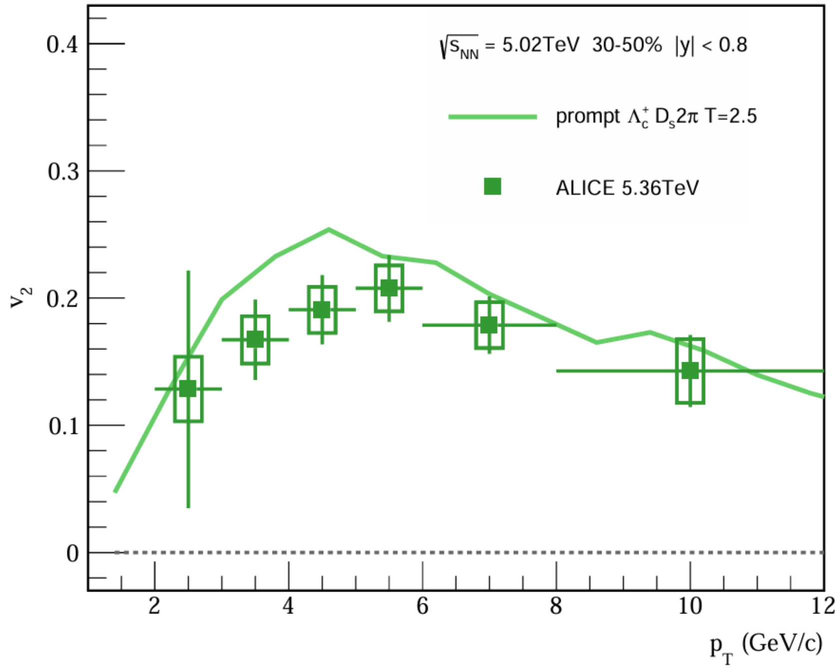
charm-quark fragmentation fraction

Eur.Phys.J.C 76 (2016) 7, 397



Model constraint by spectrum, particle ratios and v_2





Enhancement of D_s/D^0 in the lower p_T might also be evidence for *sequential Coalescence.*
Calculation for different centralities is on the way.

Hadronic re-scattering

Treatment：
Min He, Ralf et al 1204.4442

D-meson hadronic re-scattering is realized in Langevin simulation:

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

$$dp_j = -\Gamma(p)p_j dt + \sqrt{\kappa dt}\rho_j$$

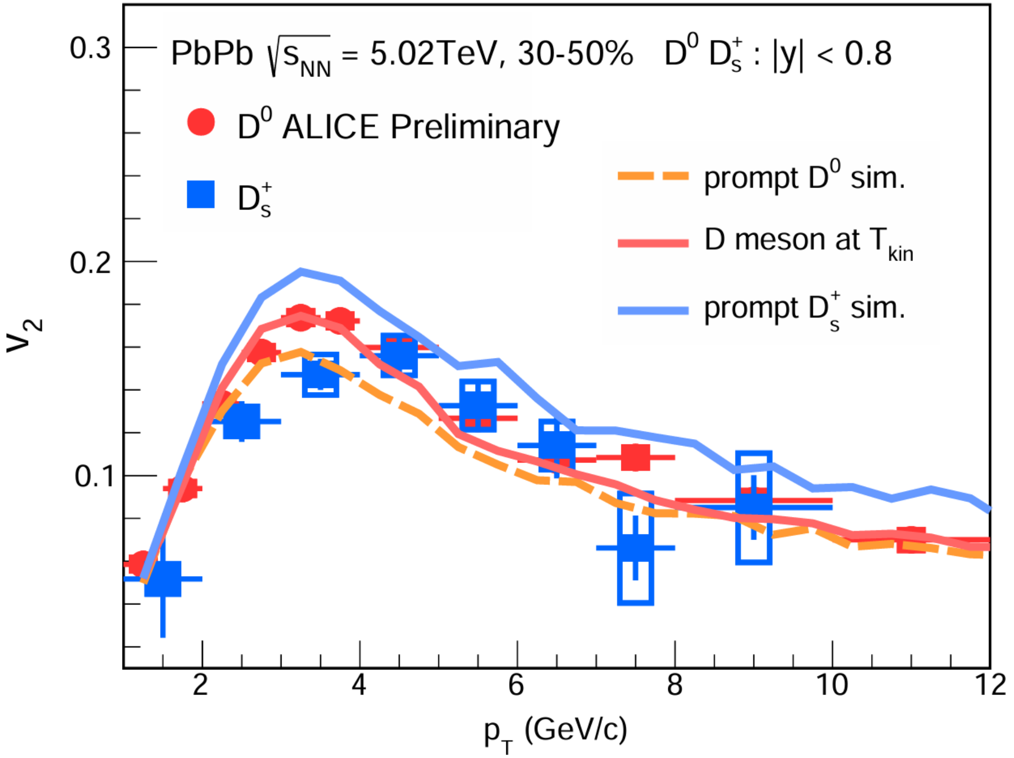
The fluctuation-dissipation relationship:

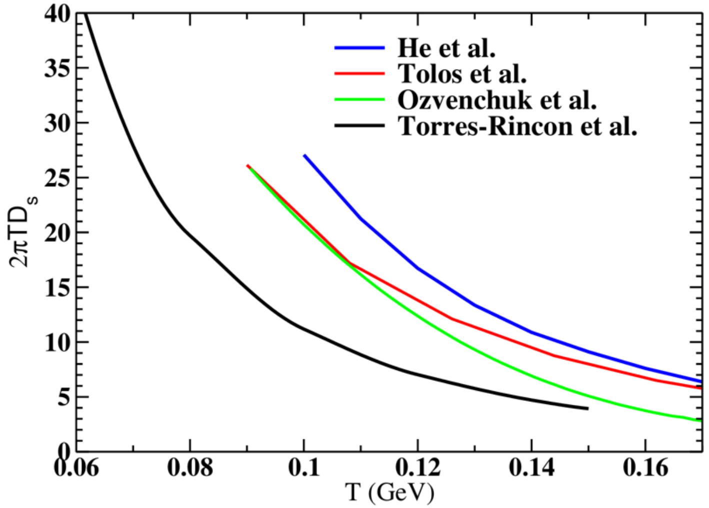
$$\kappa = 2\Gamma ET = \frac{2T^2}{D_s}$$

The spatial diffusion coefficient D_s for D meson is taken from *Torres-Rincon et al.*

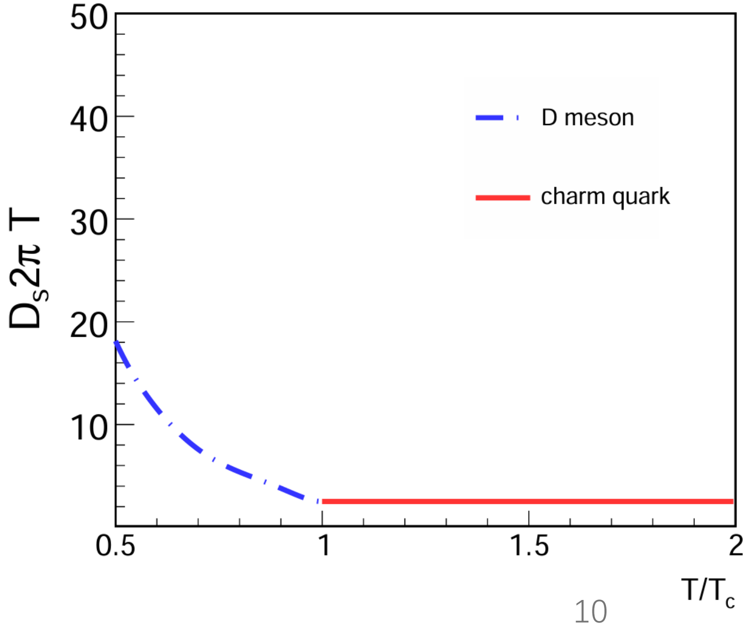
Phys. Rev. C **105** (2022) no.2, 025203

：BREAKING v_2 hierarchy for D^0 and D_s requires a mechanism beyond hadronic scattering ！

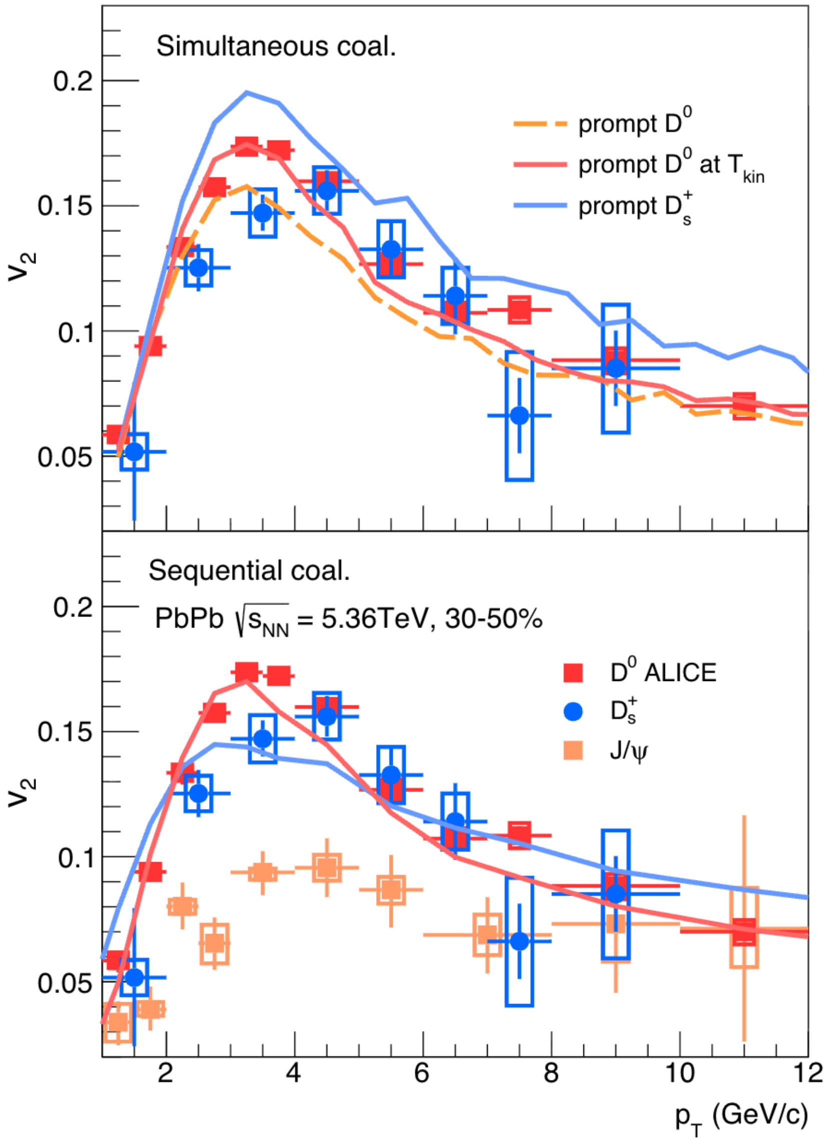




Phys. Rept. **1129-1131** (2025), 1-53



Sequential & simultaneous coalescence + Hadronic phase



- The coalescence mechanism dominates the contribution to the elliptic flow at lower and intermediate-p_T.

Simultaneous coalescence leads to

$$v_2\ (D^0) < v_2\ (D_s)\ .$$

sequential mechanism -

- Sequential coalescence + Hadronic rescattering reproduces the ALICE measurements.
- The reverse of such a v_2 hierarchy is observed

$$v_2\ (D^0)\ >\ v_2\ (D_s)\ .$$

Conclusion 01

- Although the hadronic re-scattering indeed contributes additional elliptic flow to D^0 , it can still not lead to the reversal of the v_2 hierarchy between D^0 and D_s.
- Sequential coalescence effect cause the v_2 of D_s mesons significant suppressed at $p_T \approx 2-5$ GeV/c, the reverse of such a v_2 hierarchy is observed.
- charm quark number conservation --- > a hill rather than a plateau of the ratio D_s/D^0at low p_T
- They provides compelling evidence of the sequential hadronization mechanism and supplies a unique opportunity to further constrain the hadronization processes of charm hadrons.

Backup 01

Meson	M(GeV)	J^P	$\langle r\rangle_{T_c}$(fm)	B.R.
D^+	1.869	0^-(1S)	0.7	-
D^0	1.865	0^-(1S)	0.7	-
$D^{*0}(2007)$	2.007	1^-(1S)	0.77	$100\% \to D^0$
$D^{*+}(2010)$	2.010	1^-(1S)	0.77	$68\% \to D^0$
$D_0^*(2300)$	2.343	0^+(1P)	0.77	$68\% \to D^0$
$D_1(2420)$	2.422	1^+(1P)	0.77	$68\% \to D^0$
$D_1^0(2430)$	2.412	1^+(1P)	0.77	$68\% \to D^0$
$D_2^*(2460)$	2.461	2^+(1P)	0.77	$68\% \to D^0$
$D_0^0(2550)$	2.549	0^-(2S)	0.77	$68\% \to D^0$
D_s^+	1.968	0^-(1S)	0.66	-
D_s^{*+}	2.112	1^-(1S)	0.72	$100\% \to D_s^+$
$D_{s0}^{*\pm}(2317)$	2.318	0^+(1P)	0.72	$100\% \to D_s^+$
$D_{s1}^{\pm}(2460)$	2.460	1^+(1P)	0.72	$100\% \to D_s^+$
$D_{s1}^{\pm}(2536)$	2.535	1^+(1P)	0.72	$79\% \to D^0$,
				$21\% \to D^+$
$D_{s2}^*(2573)$	2.569	2^+(1P)	0.72	$34\% \to D^0$,
				$16\% \to D^+$,
				$50\% \to D_s^+$
$D_{s0}^+(2590)$	2.591	0^-(2S)	0.72	$50\% \to D^+$,
				$50\% \to D_s^+$

Baryon	M	$I(J^P)$	$\langle\rho\rangle_{T_c}$	$\langle\lambda\rangle_{T_c}$	B.R.
	(GeV)		(fm)	(fm)	
Λ_c^+	2.286	$0(\frac{1}{2}^+)$(1S)	0.75	0.75	-
$\Lambda_c(2595)^+$	2.592	$0(\frac{1}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Lambda_c(2625)^+$	2.628	$0(\frac{3}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Lambda_c(2860)^+$	2.856	$0(\frac{3}{2}^+)$(1D)	0.8	0.8	$50\% \to \Lambda_c^+$
$\Lambda_c(2880)^+$	2.881	$0(\frac{5}{2}^+)$(1D)	0.8	0.8	$50\% \to \Lambda_c^+$
$\Lambda_c(2765)^+$	2.766	$0(\frac{1}{2}^+)$(2S)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Lambda_c(2940)^+$	2.939	$0(\frac{3}{2}^-)$(2P)	0.8	0.8	$50\% \to \Lambda_c^+$
$\Sigma_c(2455)^{(++,+,0)}$	2.453	$1(\frac{1}{2}^+)$(1S)	0.75	0.75	$100\% \to \Lambda_c^+$
$\Sigma_c(2520)^{(++,+,0)}$	2.518	$1(\frac{3}{2}^+)$(1S)	0.75	0.75	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	2.713	$1(\frac{1}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	2.799	$1(\frac{1}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	2.773	$1(\frac{3}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c(2800)^{(++,+,0)}$	2.800	$1(\frac{3}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	2.789	$1(\frac{5}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	3.041	$1(\frac{1}{2}^+)$(1D)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	3.040	$1(\frac{3}{2}^+)$(1D)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	3.043	$1(\frac{3}{2}^+)$(1D)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	3.038	$1(\frac{5}{2}^+)$(1D)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	3.023	$1(\frac{5}{2}^+)$(1D)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	3.013	$1(\frac{7}{2}^+)$(1D)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	2.901	$1(\frac{1}{2}^+)$(2S)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Sigma_c^{(++,+,0)}$	2.936	$1(\frac{3}{2}^+)$(2S)	0.8	0.8	$100\% \to \Lambda_c^+$

$\Xi_c^{(+,0)}$	2.469	$\frac{1}{2}(\frac{1}{2}^+)$(1S)	0.75	0.75	-
$\Xi_c'^{(+,0)}$	2.578	$\frac{1}{2}(\frac{1}{2}^+)$(1S)	0.75	0.75	$100\% \to \Xi_c$
$\Xi_c(2645)^{(+,0)}$	2.645	$\frac{1}{2}(\frac{3}{2}^+)$(1S)	0.75	0.75	$100\% \to \Xi_c$
$\Xi_c(2790)^{(+,0)}$	2.792	$\frac{1}{2}(\frac{1}{2}^-)$(1P)	0.8	0.8	$100\% \to \Xi_c$
$\Xi_c(2815)^{(+,0)}$	2.818	$\frac{1}{2}(\frac{3}{2}^-)$(1P)	0.8	0.8	$100\% \to \Xi_c$
$\Xi_c(2923)^{(+,0)}$	2.923	$\frac{1}{2}(\frac{3}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Xi_c(2930)^{(+,0)}$	2.940	$\frac{1}{2}(\frac{5}{2}^-)$(1P)	0.8	0.8	$100\% \to \Lambda_c^+$
$\Xi_c(2970)^{(+,0)}$	2.965	$\frac{1}{2}(\frac{3}{2}^-)$(1P)	0.8	0.8	$50\% \to \Lambda_c^+$
					$50\% \to \Xi_c$
Ω_c^0	2.695	$0(\frac{1}{2}^+)$(1S)	0.75	0.75	-
$\Omega_c(2770)^0$	2.765	$0(\frac{3}{2}^+)$(1S)	0.75	0.75	$100\% \to \Omega_c^0$
$\Omega_c(3000)^0$	3.000	$0(\frac{1}{2}^-)$(1P)	0.8	0.8	$100\% \to \Omega_c^0$
$\Omega_c(3050)^0$	3.050	$0(\frac{1}{2}^-)$(1P)	0.8	0.8	$100\% \to \Omega_c^0$
$\Omega_c(3065)^0$	3.065	$0(\frac{3}{2}^-)$(1P)	0.8	0.8	$100\% \to \Omega_c^0$
$\Omega_c(3090)^0$	3.090	$0(\frac{1}{2}^+)$(2S)	0.8	0.8	$100\% \to \Omega_c^0$
$\Omega_c(3120)^0$	3.119	$0(\frac{3}{2}^+)$(2S)	0.8	0.8	$100\% \to \Omega_c^0$

Backup 01

Model comparison — model description

	Frag.	Recom.	Recom. Form	Charmed hadrons involved
Catania	Peterson	Phase space Wigner function	$W(x,p) = \prod_{i=1}^{N_q-1} A_W \exp\left(-\frac{x_i^2}{\sigma_{ri}^2} - p_i^2\sigma_{ri}^2\right)$	S-wave, D0,Ds, D*+,D*0,D*s,several excited states of \Lambda_c,\Sigma_c
Duke	Pythia 6.4/ Peterson	Momentum space Wigner function	$W(p) = g_h \frac{(2\sqrt{\pi}\sigma)^3}{V} e^{-\sigma^2 p^2},$	S-wave,D,D*
LBT	Pythia 6.4/ Peterson	Momentum space Wigner function	$W_s(p) = g_h \frac{(2\sqrt{\pi}\sigma)^3}{V} e^{-\sigma^2 p^2},$ $W_p(p) = g_h \frac{(2\sqrt{\pi}\sigma)^3}{V} \frac{2}{3}\sigma^2 p^2 e^{-\sigma^2 p^2}.$	S-wave,P-wave,D,Ds,D*, \Lambda_c,\Sigma_c,\Xi_c. \Omega_c
Nantes	**HQET**	Phase space Wigner function	$W(x_Q,x_q,p_Q,p_q) = \exp\left(\frac{(x_q-x_Q)^2 - [(x_q-x_Q)\cdot u_Q]^2}{2R_c^2} - \alpha_d^2(u_Q\cdot u_q - 1)\right)$	S-wave, D0
PHSD	Peterson	Phase space Wigner function	$W_s(r,p) = \frac{8(2S+1)}{36} e^{-\frac{r^2}{\sigma^2} - \sigma^2 p^2},$ $W_p(r,p) = \frac{2S+1}{36}\left(\frac{16}{3}\frac{r^2}{\sigma^2} + \frac{16}{3}\sigma^2 p^2 - 8\right) e^{-\frac{r^2}{\sigma^2} - \sigma^2 p^2},$	S-wave, P-wave D+,D0,Ds, D*+,D*0,D*s
TAMU	thermal density correlated **HQET**	Resonance amplitude	$\frac{\gamma_M}{\Gamma} v_{rel} g_\sigma \frac{4\pi}{k^2} \frac{(\Gamma m)^2}{(s-m^2)^2 + (\Gamma m)^2}$	D+,D0,Ds and few excited states. Charm baryons+missing baryons
Turin	Pythia 6.4/ String fragmentation	Invariant mass criterion	$M_D < M_{Cluster} < M_{max}.$	(prompt) D+,D0,Ds,\Lambda_c, \Xi_c,\Omega_c
Los Alamos	**HQET**	—	—	S-wave, D+,D0,Ds, charm-baryons

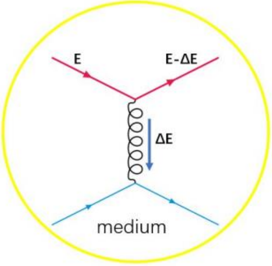
Fixed Hadronization to constrain transport coefficient

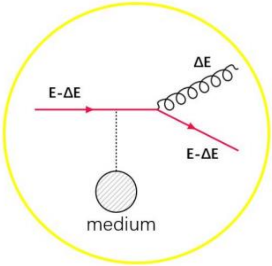
Initial momentum and position:

FONLL *JHEP* 10 (2012) 137
Monte Carlo Glauber model *EPJC* 72 (2012) 1896

In-medium evolution:

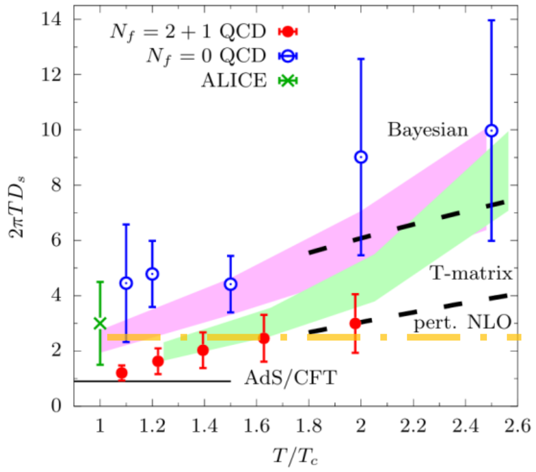
Collisional **Radiative**





SHELL model *Chin.Phys.C* 44 (2020) 104105
Collisional: Langevin transport equations
$(2\pi T)D_s = 2.5$ based on lattice QCD calculation.

PRL **130** (2023) no.23, 231902



Higher-twist approach is implemented to describe the medium-induced gluon radiation:

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

The jet transport coefficient $\hat{q} = \hat{q}_0 \left(\frac{T}{T_0}\right)^3 \frac{p^\mu u_\mu}{p^0}$

We take $\hat{q}_0 = 1.5\ \mathrm{GeV}^2/\mathrm{fm}$

Hydrodynamic information:

(3+1)D CLVisc hydro

Phys.Rev.C 97 (2018) 6, 064918

Hadronization:

Simultaneous & sequential coalescence plus Peterson fragmentation function:

$$\mathcal{D}_{c\to H} \propto \frac{1}{z\left[1-\frac{1}{z}-\frac{\epsilon}{1-z}\right]^2}$$

charm-quark fragmentation fraction

Eur.Phys.J.C 76 (2016) 7, 397 and also 84 (2024) 12, 1286

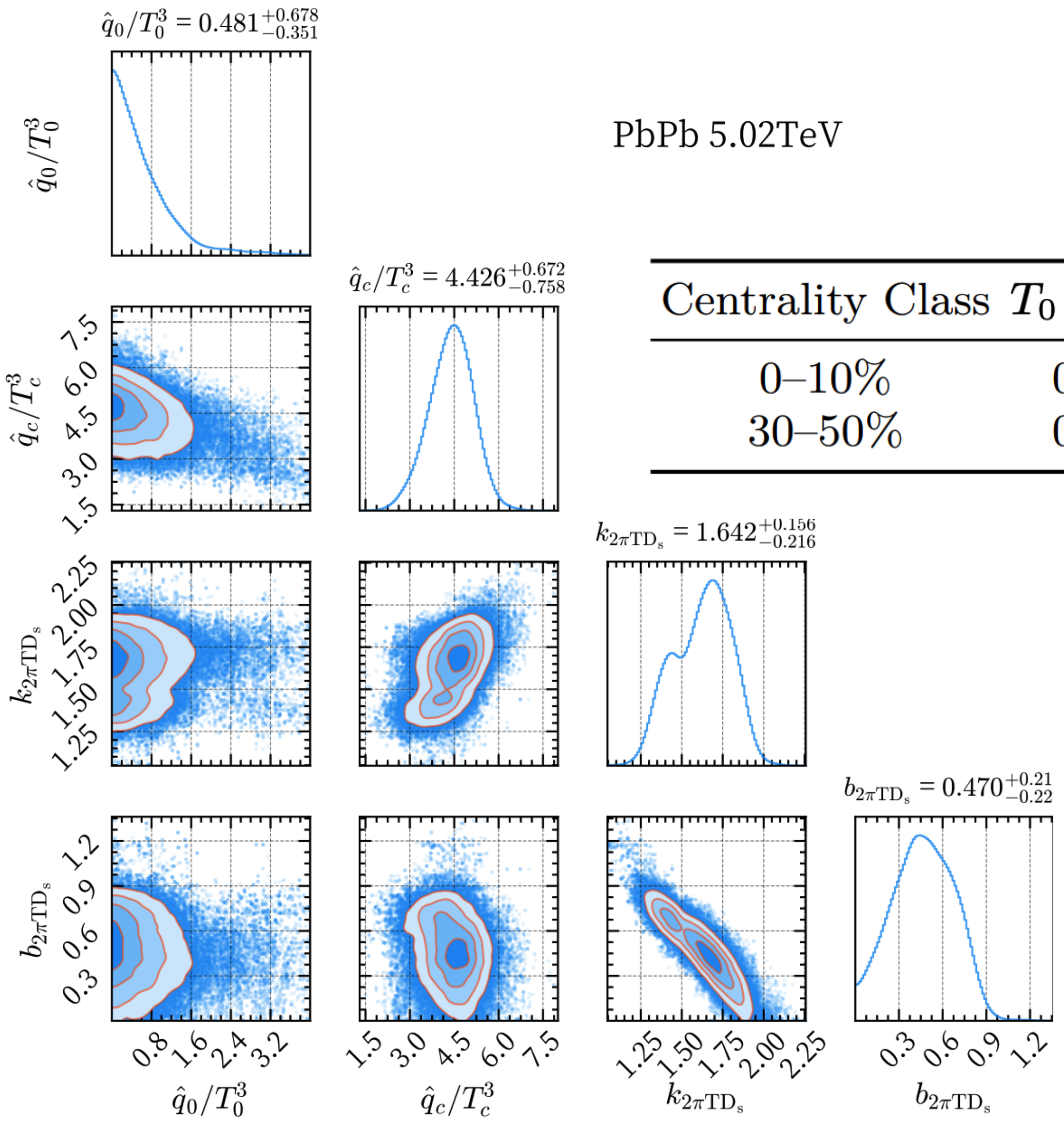
$$2\pi T D_s = k * T/\mathrm{T_c} + b$$

$$\frac{\hat{q}}{T^3} = \left[\left(\frac{\hat{q}_0}{T_0^3} - \frac{\hat{q}_c}{{T_c}^3}\right)\frac{T-T_c}{T_0-T_c} + \frac{\hat{q}_c}{{T_c}^3}\right]\frac{p^\mu \cdot u_\mu}{p_0}. \qquad (10)$$

arXiv:2409.18773

$$\hat{q} = 2\kappa C_A/C_F$$

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



PbPb 5.02TeV

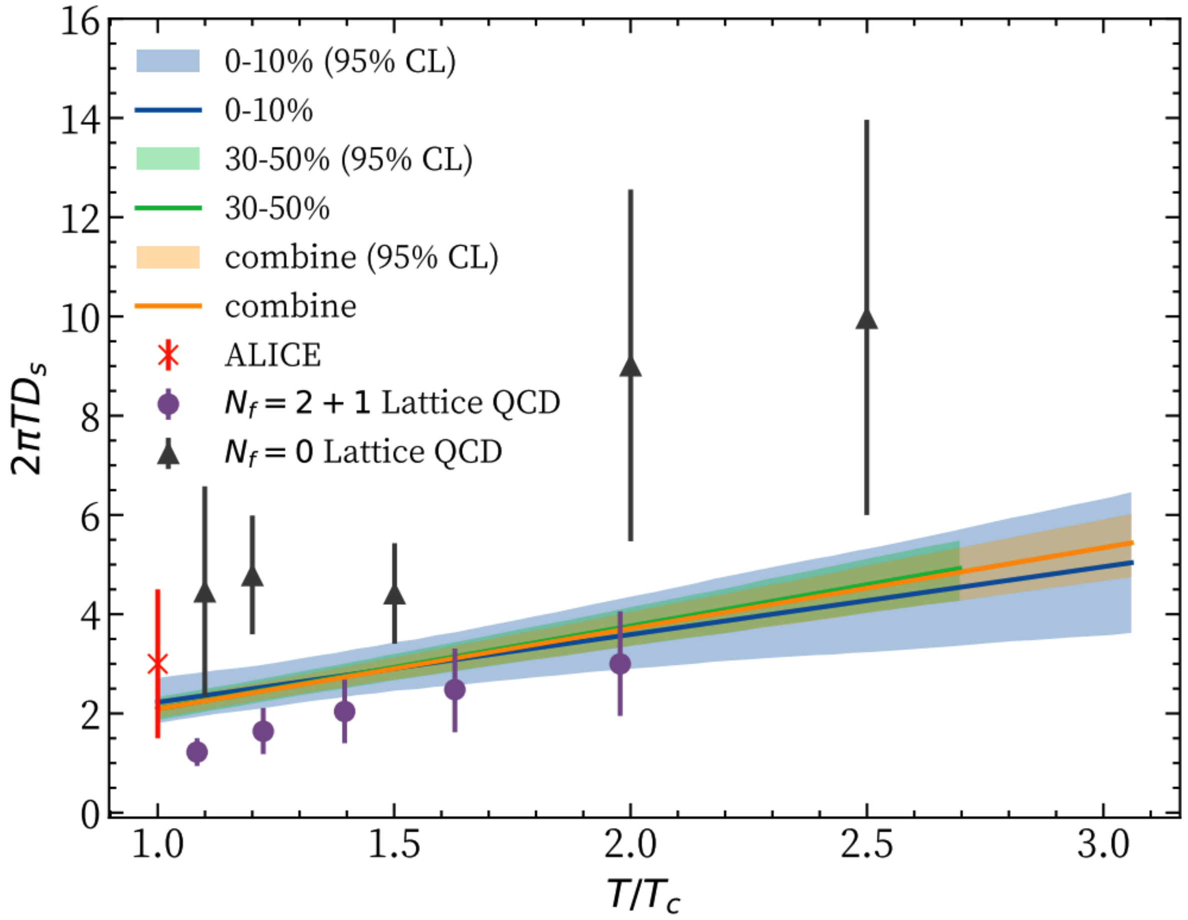
Centrality Class	T_0 (GeV
0–10%	0.505
30–50%	0.445

TABLE III: Experimental observables used in the likelihood function.

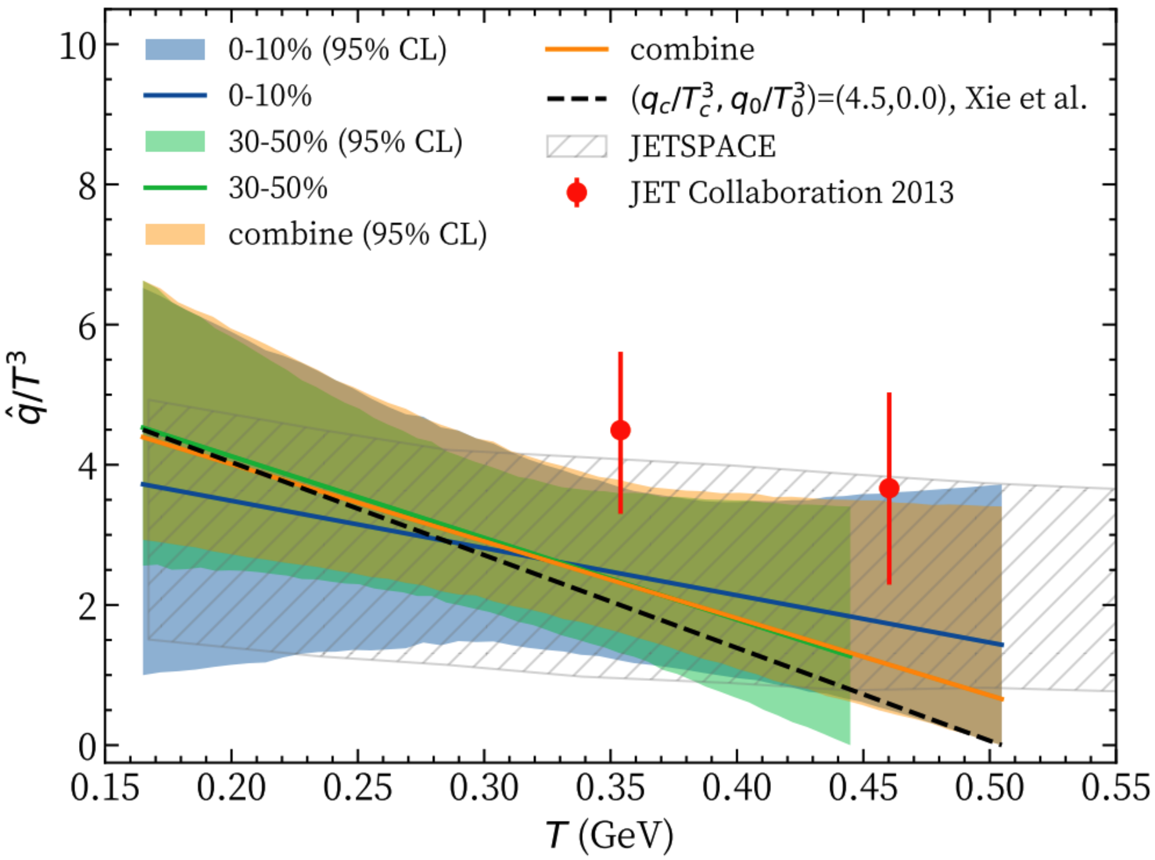
Centrality Class	Observable	Particle	Reference
0–10%	d^2N/dp_Tdy	D^0, D_s^+	ALICE[75, 76]
	R_{AA}	D^0	ALICE[75]
	v_2	D^0	CMS[74]
	D_s^+/D^0	D^0, D_s^+	ALICE[76]
30–50%	d^2N/dp_Tdy	D^0, D_s^+	ALICE[75, 76]
	R_{AA}	D^0	ALICE[75]
	v_2	D^0, D_s^+	CMS[74], ALICE[76]
	D_s^+/D^0	D^0, D_s^+	ALICE[76]

TABLE II: Prior ranges of the model parameters

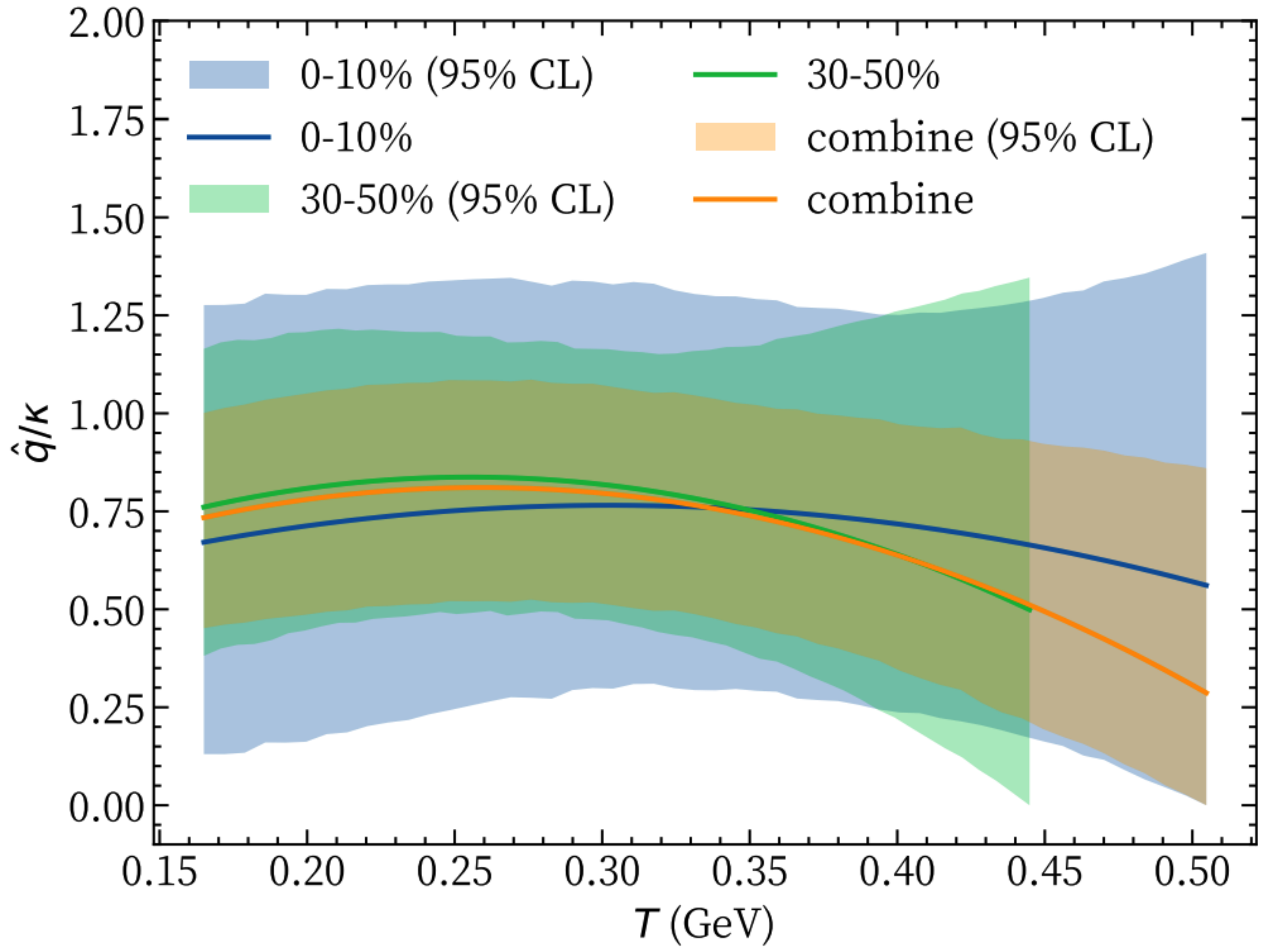
Parameter	Prior Range
$\hat{q}_0/T_0^3$	0–6.0
$\hat{q}_c/T_c^3$	0–9.0
$k_{2\pi T\mathcal{D}_s}$	0.5–3.0
$b_{2\pi T\mathcal{D}_s}$	0–4.5



0-10% (95% CL)
0-10%
30-50% (95% CL)
30-50%
combine (95% CL)
combine
ALICE
$N_f = 2 + 1$ Lattice QCD
$N_f = 0$ Lattice QCD
$2\pi T D_s$
T/T_c



0-10% (95% CL)
0-10%
30-50% (95% CL)
30-50%
combine (95% CL)
combine
$(q_c/T_c^3, q_0/T_0^3)$=(4.5,0.0), Xie et al.
JETSPACE
JET Collaboration 2013
$\hat{q}/T^3$
T (GeV)


2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
$\hat{q}/\kappa$
0-10% (95% CL)
0-10%
30-50% (95% CL)
30-50%
combine (95% CL)
combine
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
T (GeV)

Conclusion 02

1. First time simultaneously extraction of both $2\pi \mathrm{T} D_s$ and $\hat{q}/T^3$

2. It show that the temperature dependence learned from the D-meson experimental data

aligns well with the $2\pi \mathrm{T} D_s$ previously extracted (calculated) by others in the heavy-flavor sector,

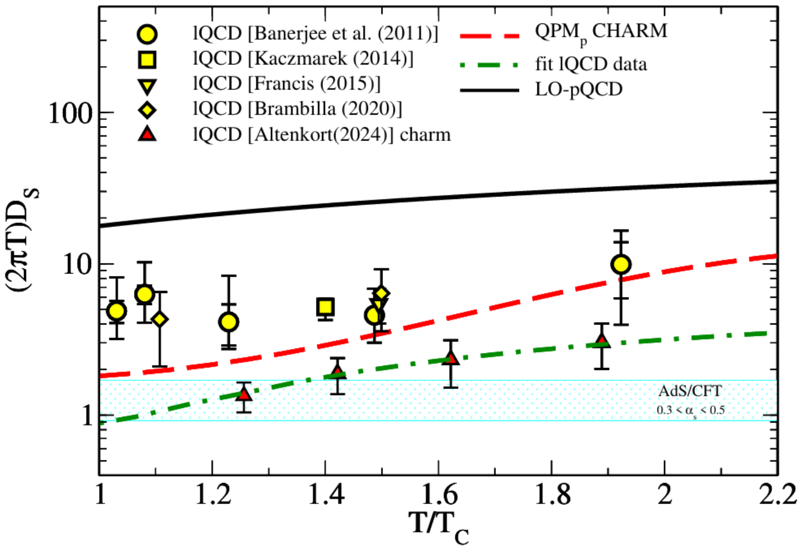
while also being consistent with the $\hat{q}/T^3$ extracted (calculated) in the light-flavor sector.

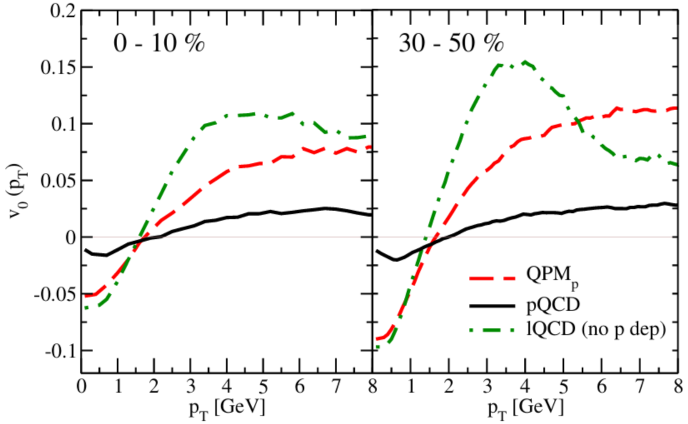
3. the constraints on the direct relationship between these parameters gain stronger physical relevance and can provide valuable guidance

and references for other theoretical studies focusing on these two parameters.

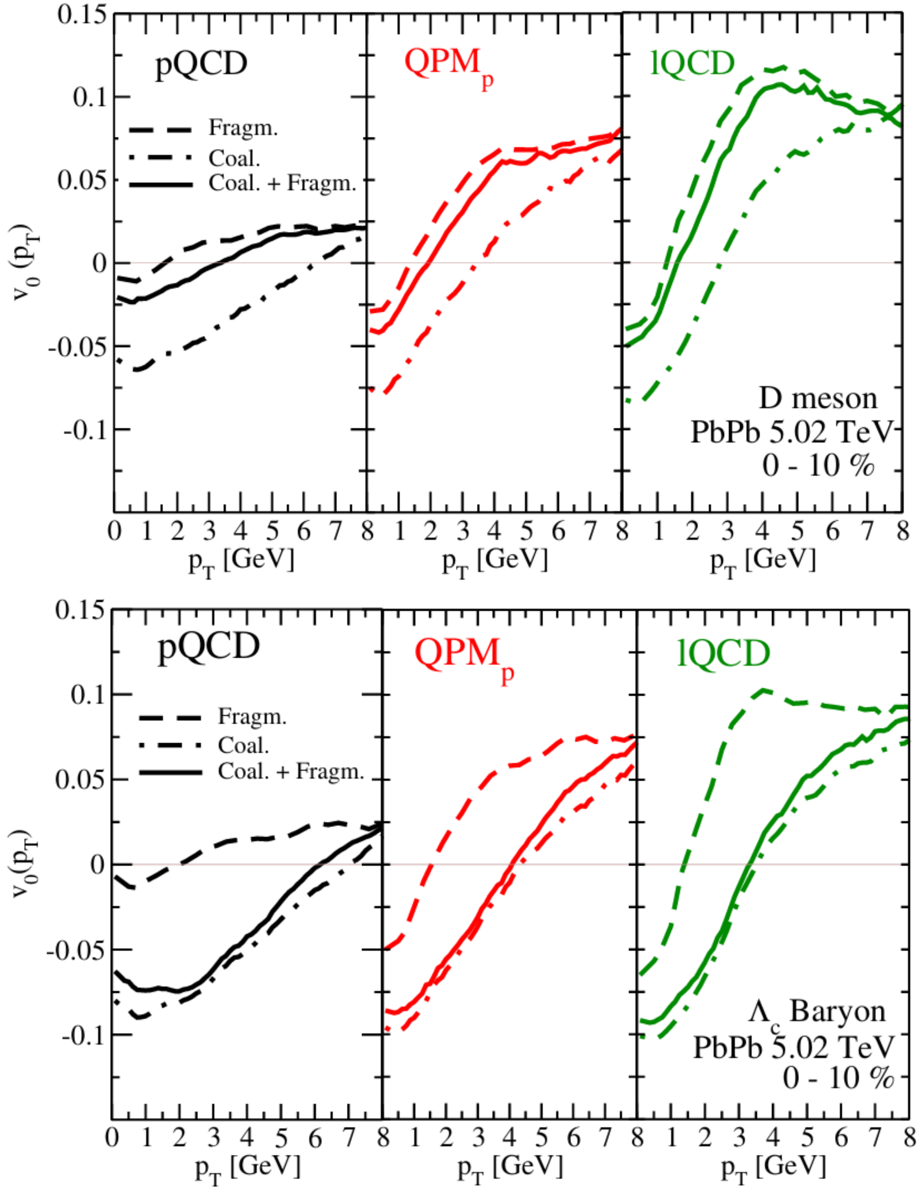
Radial flow in heavy flavor sector

Sambataro, Maria Lucia and Plumari, Salvatore and Das, Santosh K. and Greco, Vincenzo, “Probing the QGP through p_T-differential radial flow of heavy quarks,” *arXiv:* 2510.19448





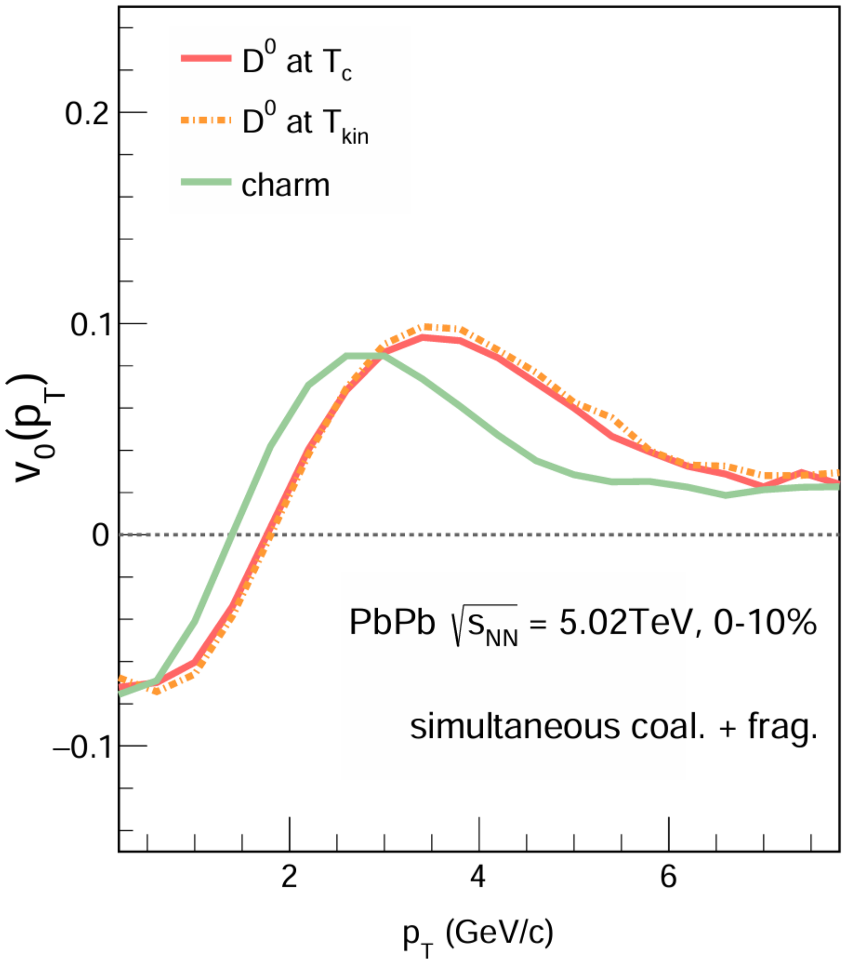
Radial flow for Charm quark



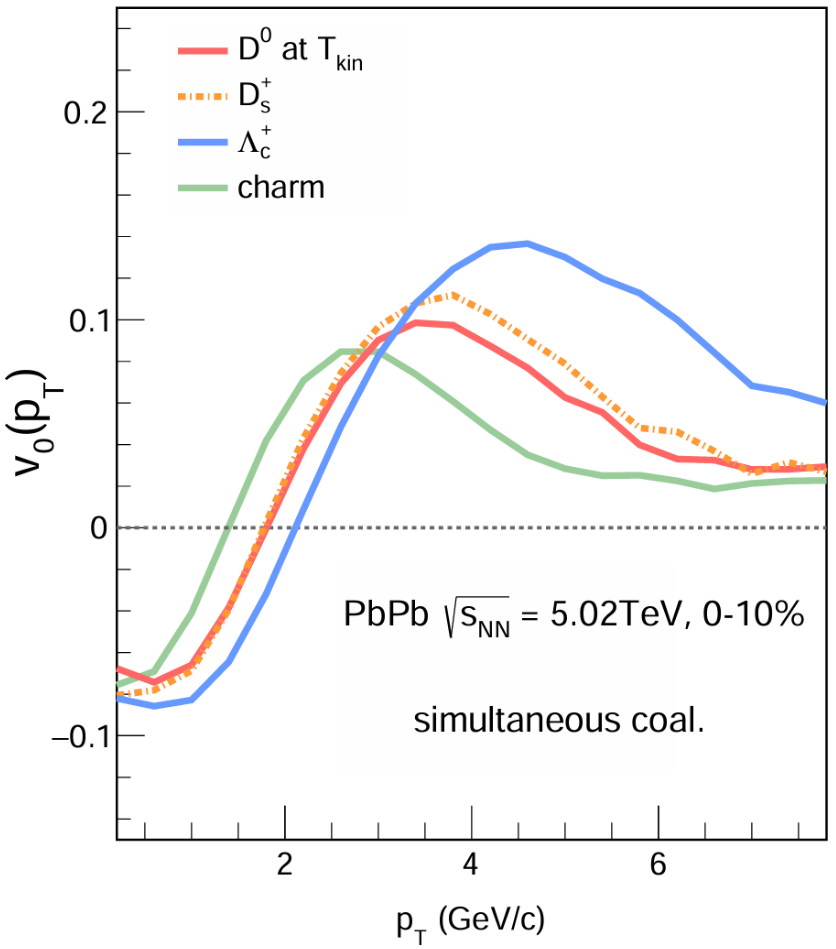
Using p_T-differential radial flow to probe the dynamics of HQ in-medium interactions:

- a weakly coupled regime – pQCD
- a strongly interacting medium – lattice QCD
- Middle scheme - Quasi-Particle model QPM_p

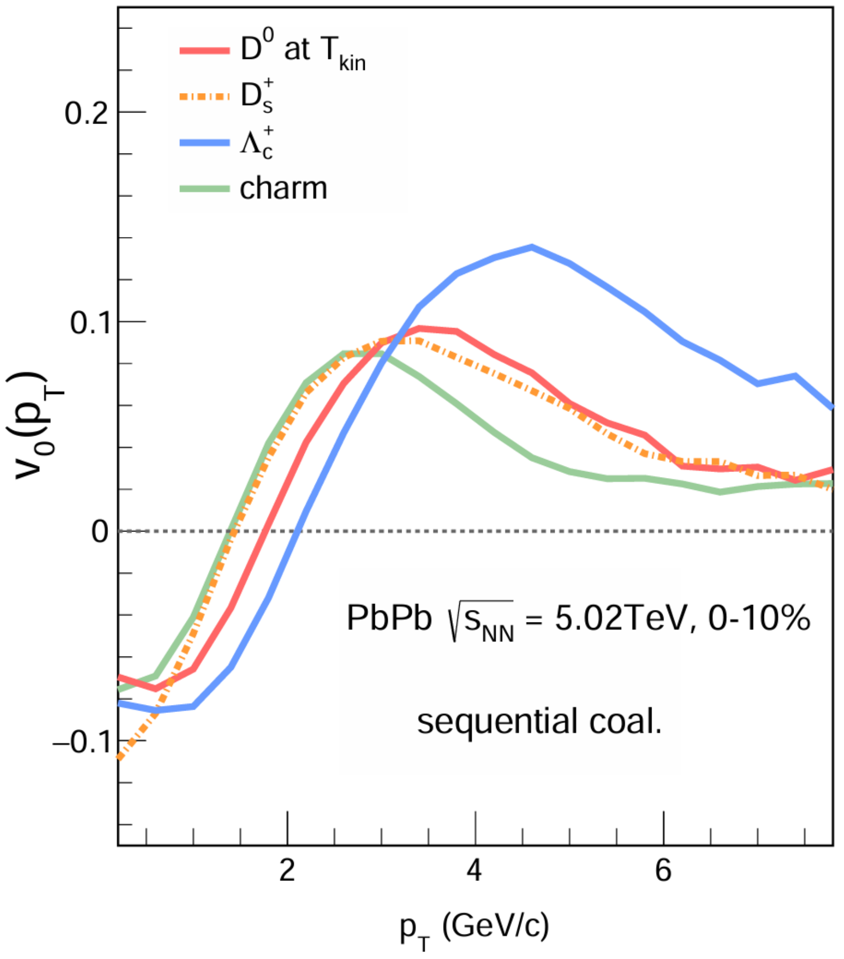
The effect of sequential hadronization revealed in Radial flow?



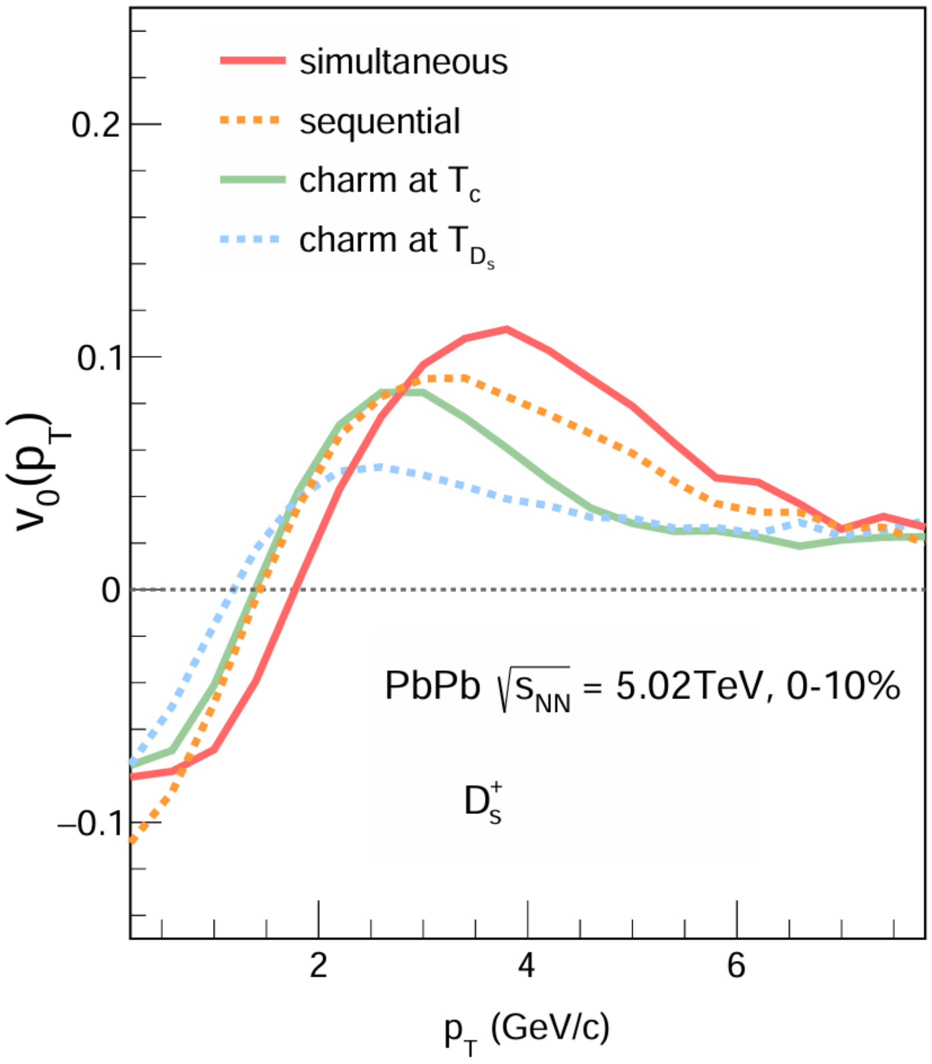
w/o Hadronic phase

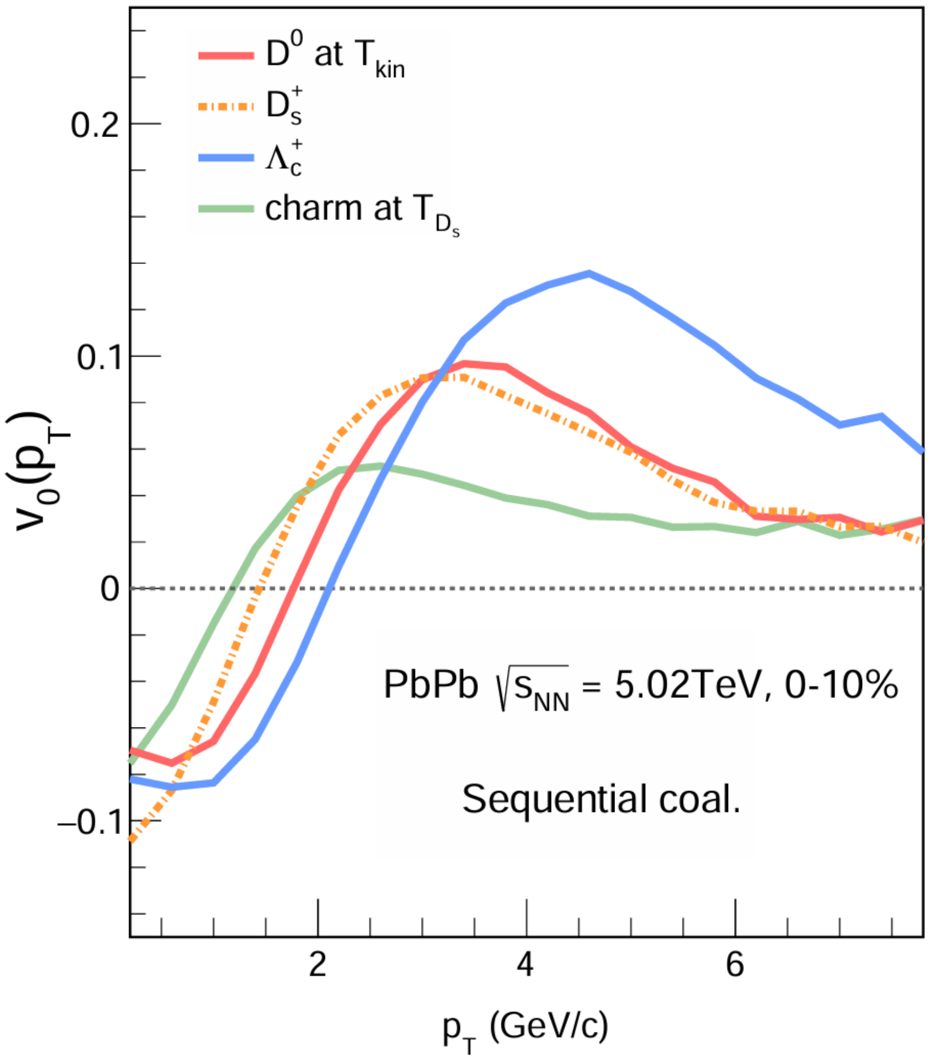


simultaneous

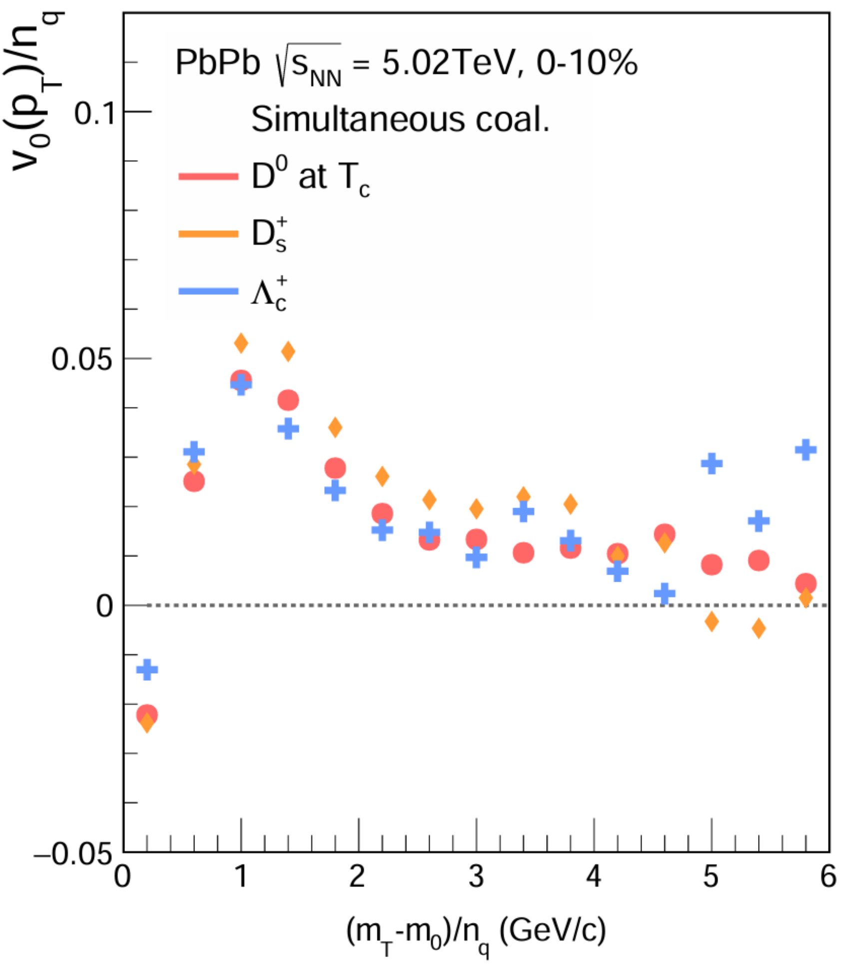


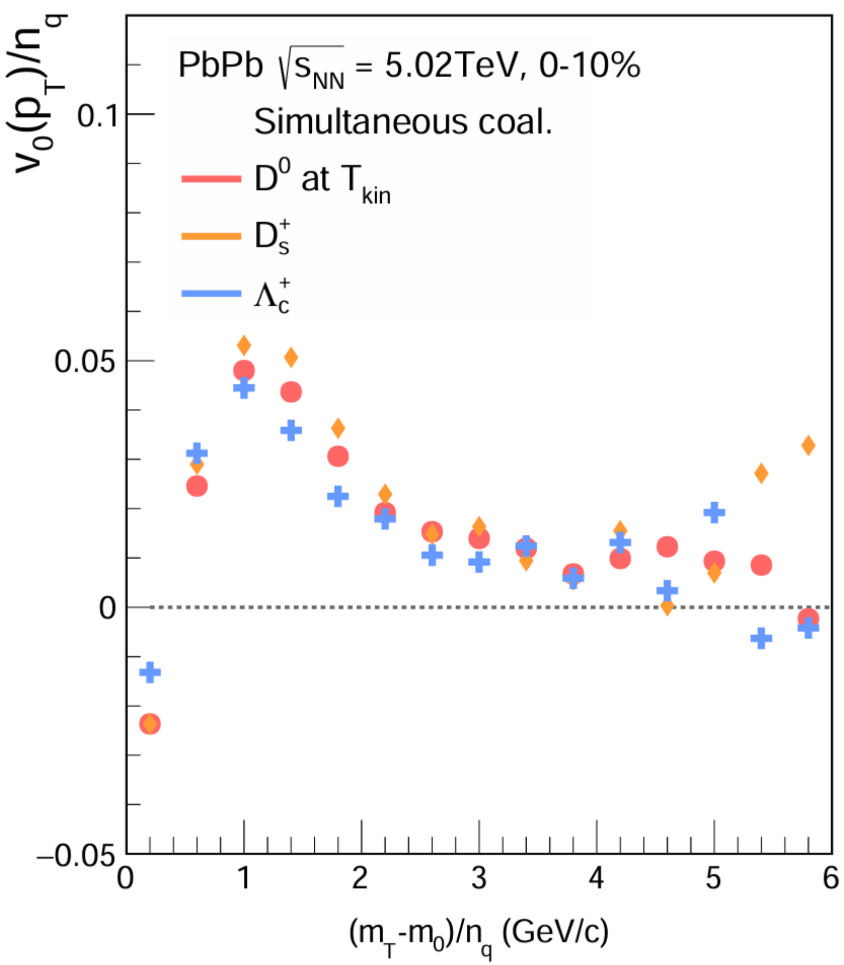
sequential

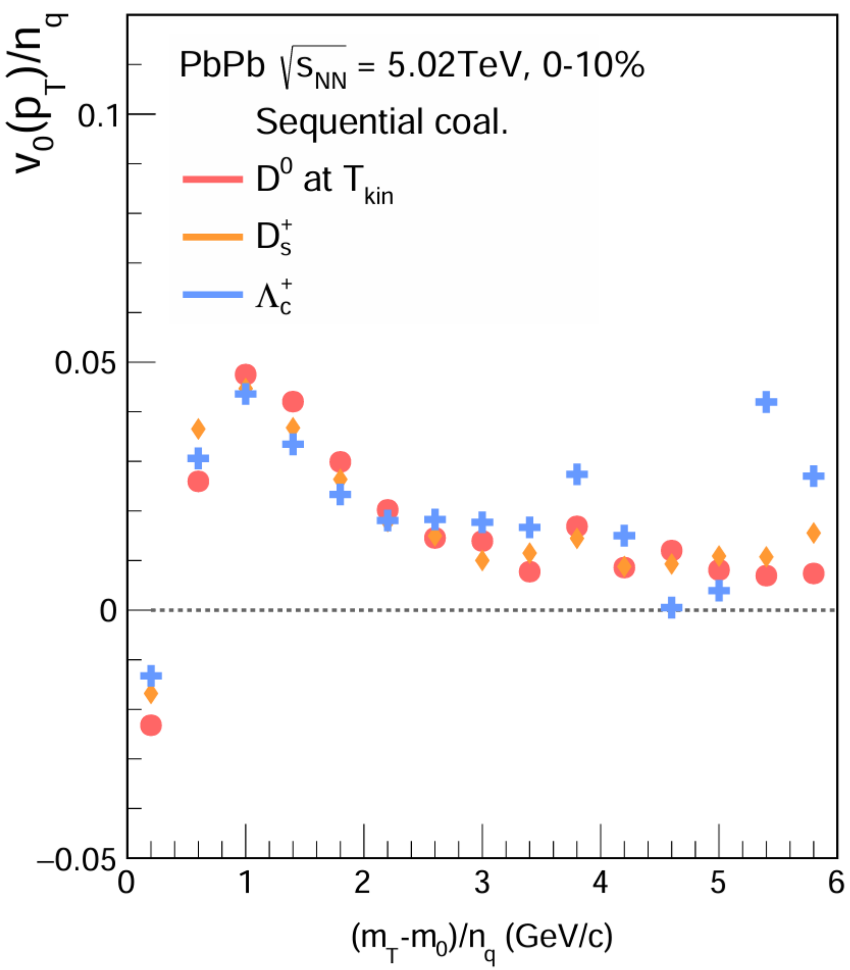

simultaneous
sequential
charm at T_c
charm at T_{D_s}
0.2
0.1
0
−0.1
$v_0(p_T)$
PbPb $\sqrt{s_{NN}}$ = 5.02TeV, 0-10%
D_s^+
2
4
6
p_T (GeV/c)


D^0 at T_{kin}
D_s^+
Λ_c^+
charm at T_{D_s}
0.2
0.1
0
−0.1
$v_0(p_T)$
PbPb $\sqrt{s_{NN}}$ = 5.02TeV, 0-10%
Sequential coal.
2
4
6
p_T (GeV/c)

Heavy flavor v0 NCQ scaling ---- rough tests







Thank you !