Theoretical overview:
Hadronization and coalescence

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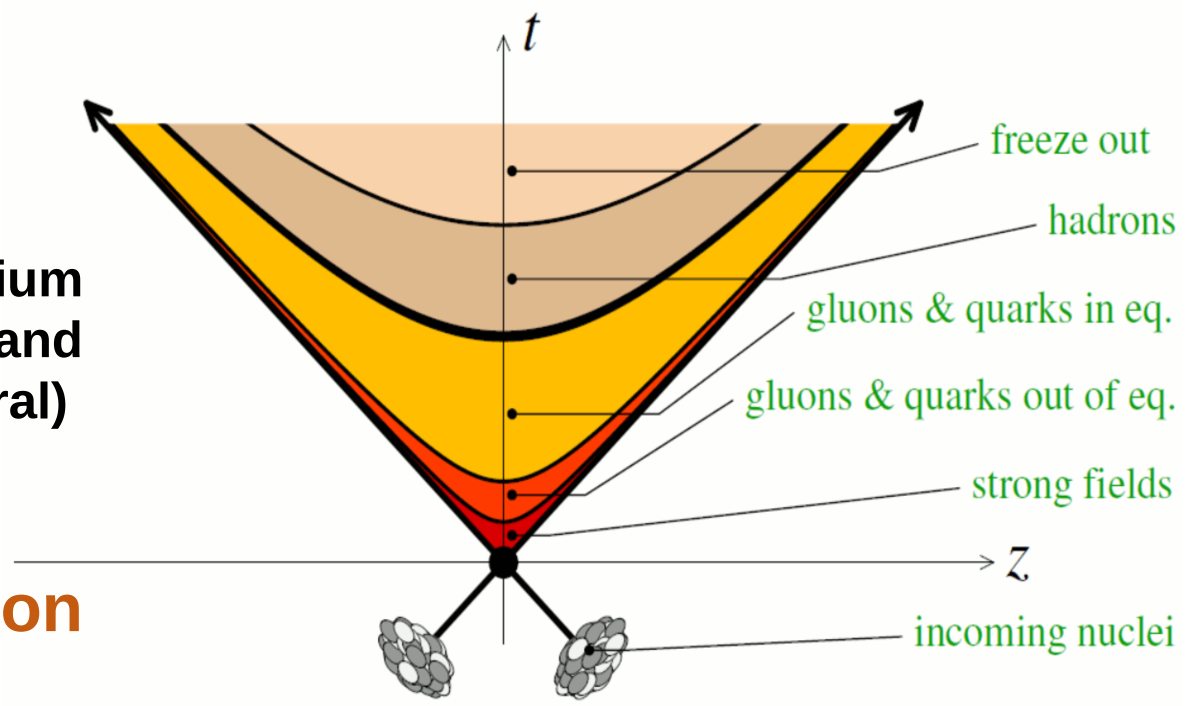
Many thanks to
V. Minissale, S. K. Das, Y. Sun, M.L. Sambataro, V. Greco

Ultra-relativistic heavy ion collisions

Hadronization of the QGP:

Transition from a deconfined medium composed of quarks, antiquarks and gluons to hadronic matter (color-neutral)



No first-principle description of hadron formation:

Non-perturbative problem

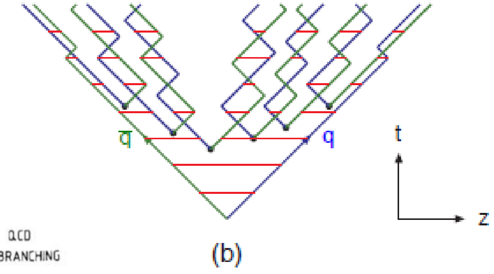
Hadronization schemes

- Independent fragmentation

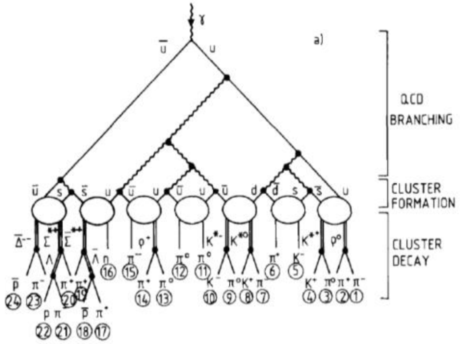
$q \rightarrow \pi, K, p, \Lambda$ ..

$c \rightarrow D, D_s, \Lambda_c$, ...

- **String fragmentation** (PYTHIA)

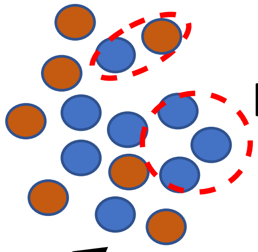


- **Cluster decay** (HERWIG)



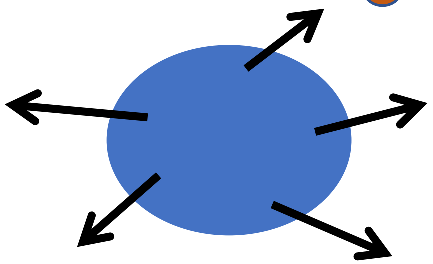
- **Coalescence/recombination**
  Resonance Recombination model

π, K, D, ...



p, Λ, Λ_c, ...

- **Statistical hadronization model (SHM)**



Indipendent fragmentation

Inclusive hadron production from hard-scattering processes (large Q^2):

Factorization of: PDFs, partonic cross section (pQCD), fragmentation function

$$\frac{dN_h}{d^2p_h} = \sum_f \int dz \frac{dN_f}{d^2p_f} D_{f\to h}(z)$$

$q \to \pi, K, p, \Lambda$ ..

$c \to D, D_s, \Lambda_c$, ...

Fragmentation function

Fragmentation functions $D_{f\to h}$ are phenomenological functions

to parameterize the *non-perturbative parton-to-hadron transition*

z = fraction of the parton momentum taken by the hadron h

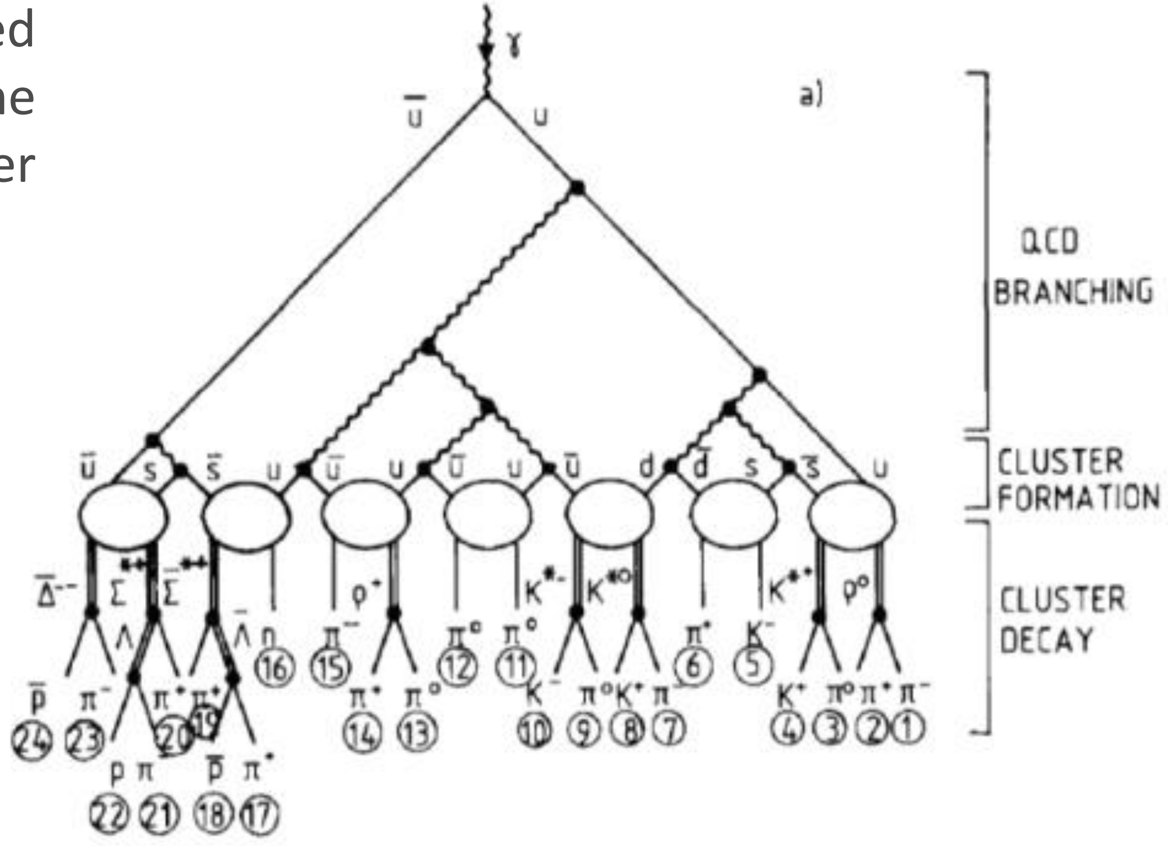
Fragmentation functions assumed **universal** among energy

and collision systems and constrained from e^+e^- and ep

Cluster Fragmentation (HERWIG)

Initially developed for e^+e^- collisions
(B.R. Webber, NPB 238 (1984), 492)

- Parton shower of both the initial partons involved in the collision and the particle produced in the collision are evolved perturbative down to a softer scale Q_0
- Multiple scattering
- Non-perturbative gluon splitting in into qq pairs
- Identify colour-singlet clusters of partons
- Final Clusters decay into hadrons



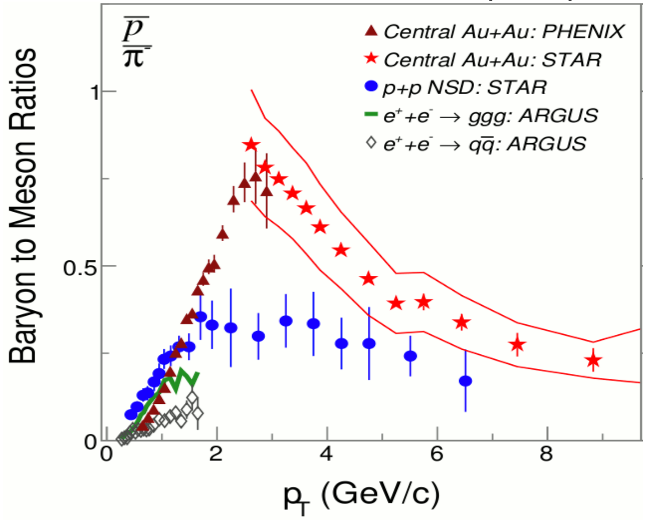
Hadronization: fragmentation and coalescence

Proton to pion ratio Enhancement:

In vacuum from fragmentation functions the ratio is small

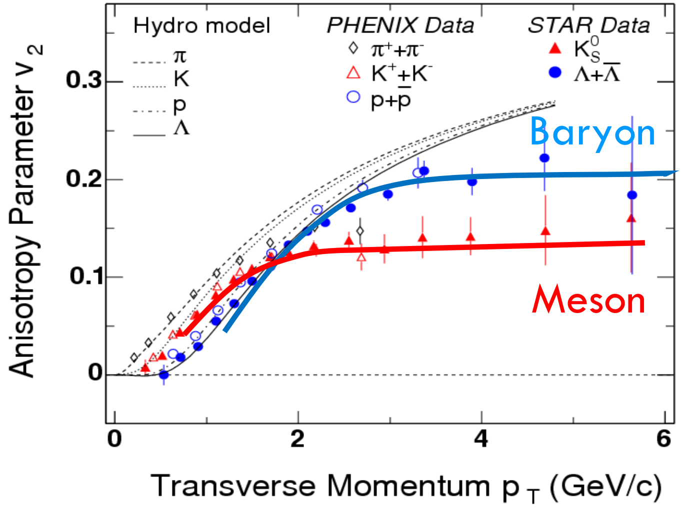
$$\frac{D_{q\to p}(z)}{D_{q\to\pi}(z)} < 0.25$$

R. J. Fries, V. Greco, P. Sorensen
Ann.Rev.Nucl.Part.Sci. 58 (2008) 177



Elliptic flow splitting:

For p_T>2 GeV Both hydro and fragmentation predicts similar v_2 for pions and protons



Another hadronization mechanism is by coalescence:

Formalism originally developed for light-nuclei production from coalescence of nucleons on a freeze-out hypersurface.

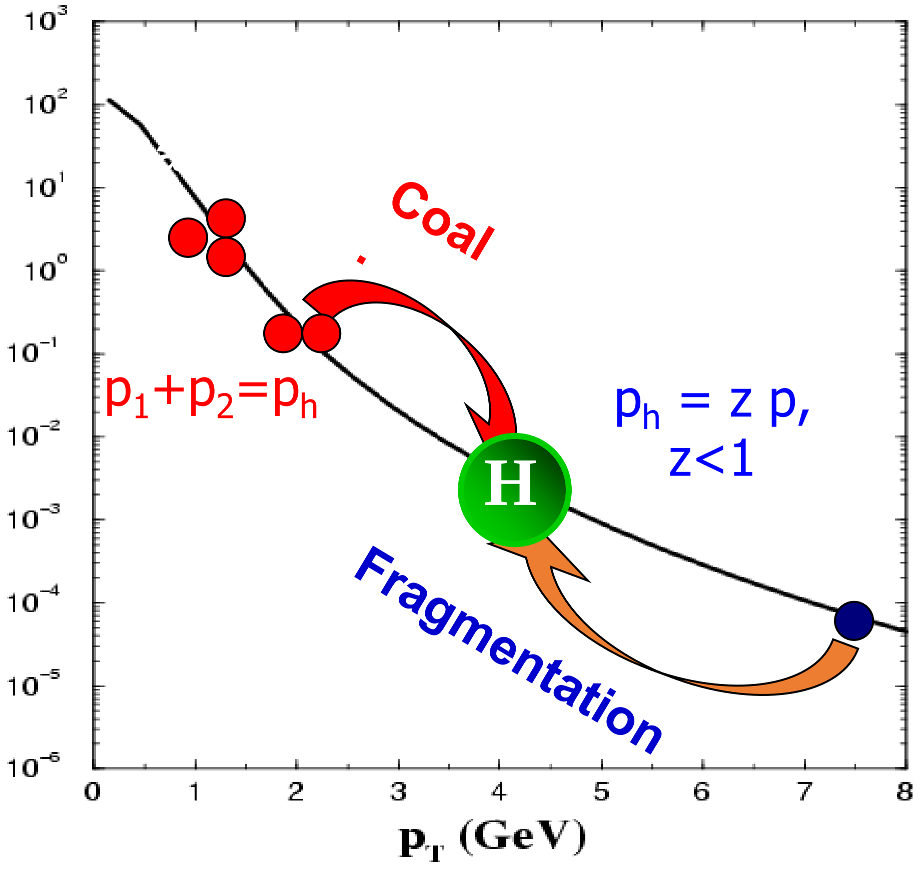
Extended to describe meson and baryon formation in AA collisions from the quarks of QGP through 2→1 and 3→1 processes

V. Greco, C.M. Ko, P. Levai PRL 90, 202302 (2003).
V. Greco, C.M. Ko, P. Levai PRC 68, 034904 (2003).
R.J. Fries, B. Muller, C. Nonaka, S.A. Bass PRL 90, 202303 (2003).
R.J. Fries, B. Muller, C. Nonaka, S.A. Bass PRC 68,044902 (2003).

Hadronization in medium: Coalescence

Phase space at the hadronization is filled with partons

- No partons in the vacuum but a thermal ensemble of partons
- No need to create qq pairs via splitting or string breaking
- Partons that are "close" to each other in phase space (position and momentum) can simply recombine into hadrons



Coalescence

- partons are already there to be close in phase space
- $p_h = n\, p_T$, $n = 2, 3$

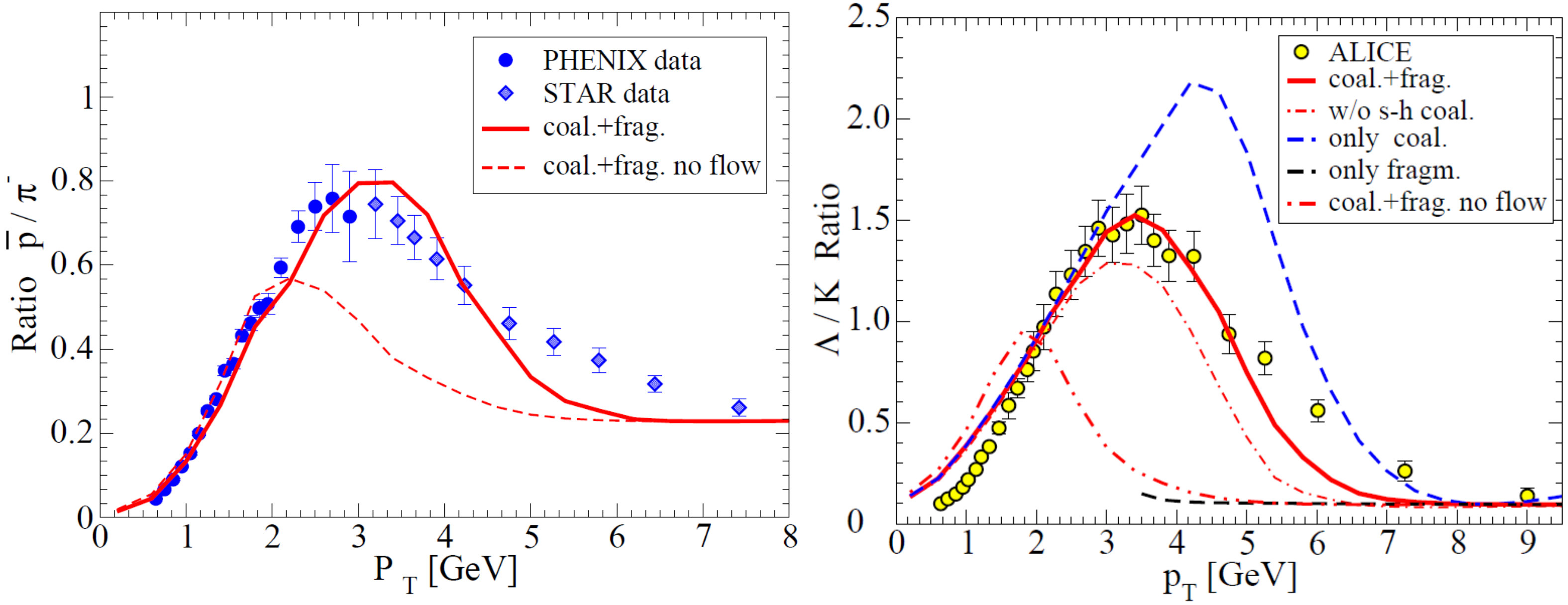
baryons from lower p_T (denser)

Fragmentation

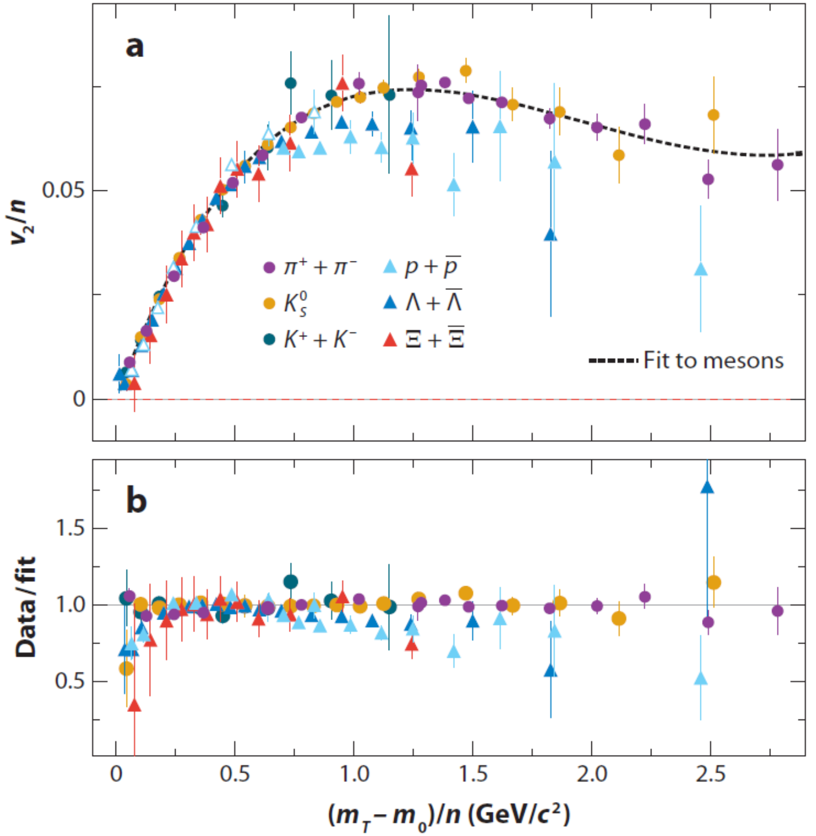
- energy to create quarks from vacuum
- hadrons from higher p_T

Hadronization in medium: Coalescence

Minissale et al., PRC92 (2015) 054904



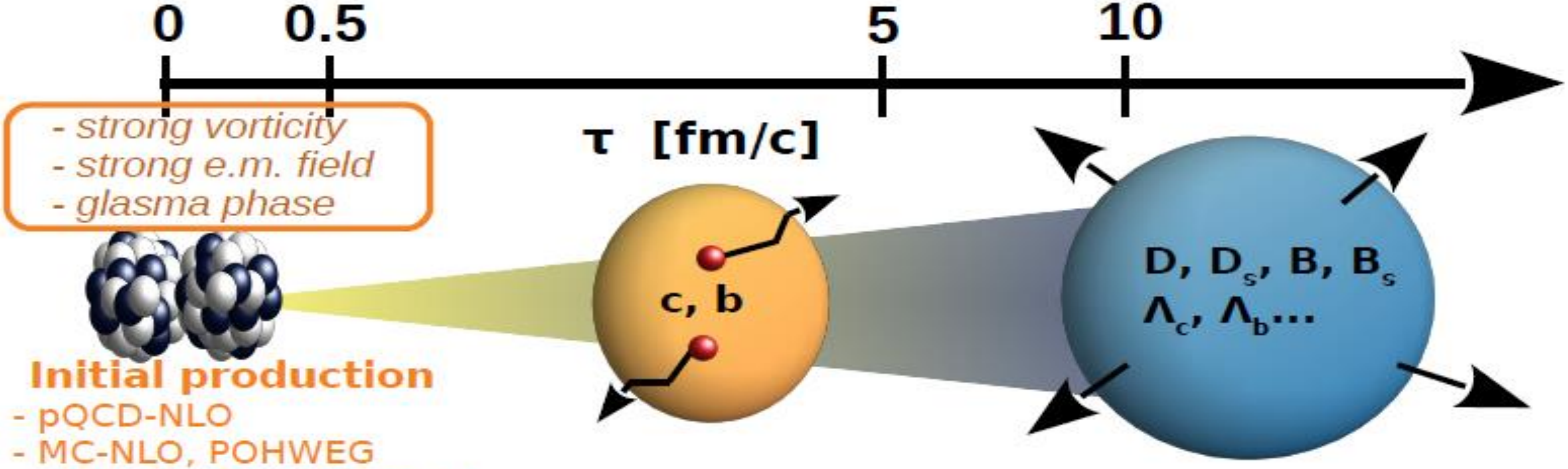
R. Fries et al., Annu. Rev. Nucl. Part. Sci. 2008.58:177-205.



Recombination of soft partons (thermal) with mini-jet partons
Inclusion of contribution of resonance decays

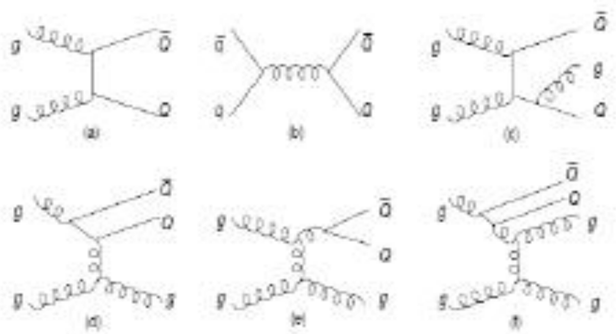
- Coalescence is dominant at low p_T
- Fragmentation is dominant at high p_T
- Radial flow of partons (from blast-wave) needed to describe the data

Heavy quarks in uRHIC



Initial production
- pQCD-NLO
- MC-NLO, POHWEG
- CNM effect[pp,pA exp.]

$$\sigma_{pp\to c\bar{c}} = \int_0^1 dx_1 dx_2 \sum_{i,j} f_i(x_1, Q^2) f_j(x_2, Q^2) \sigma_{ij\to c\bar{c}}(x_1, x_2, Q^2),$$



Dynamics in QGP
- Transport approaches: Boltzmann/Fokker-Planck
- Themalization
- Transp. Coeff. of QCD matter $D_s(T)$
- Jet Quenching

Hadronization
- SHM/coalescence and/or fragm. D, D_s, B, B_s, Λ_c, Λ_b, Ξ_c, Ω_c...
- Λ_c/D in pp,pA,AA
- R_{AA}, collective flow harmonics

Transport approaches

Two main approaches:

1) Fokker-Planck (T<<m_q soft scattering)

[*TAMU, Duke, Nantes, Torino, Catania, ...*]

$$\frac{\partial}{\partial t} f_Q = \gamma \frac{\partial}{\partial p_i}[p_i f_Q] + D_p \nabla_p^2 [f_Q]$$

Background:
Hydro/transport expanding bulk

Drag coeff. *(thermalization rate)*

momentum diffusion coeff.

- **Fluctuation dissipation theorem** $D_p = E T \gamma$
- **Spatial diffusion coefficient** $D_s = \frac{T}{M\gamma} = \frac{T^2}{D_p} = \frac{T}{M}\tau_{th}$ $\quad \langle x^2 \rangle - \langle x \rangle^2 = 6 D_s t$
  a measure of thermalization time

D_s from lQCD

2) Boltzman kinetic transport

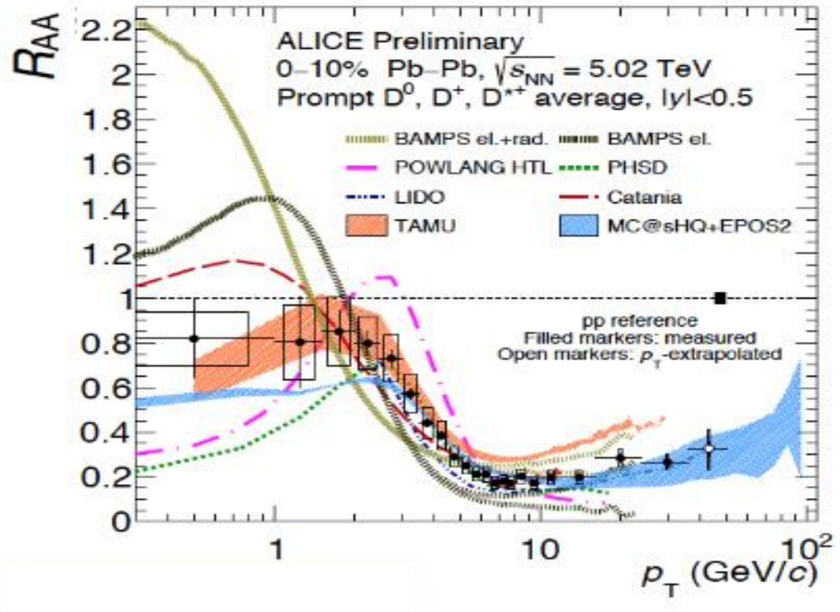
(...Kadanoff-Baym-PHSD)

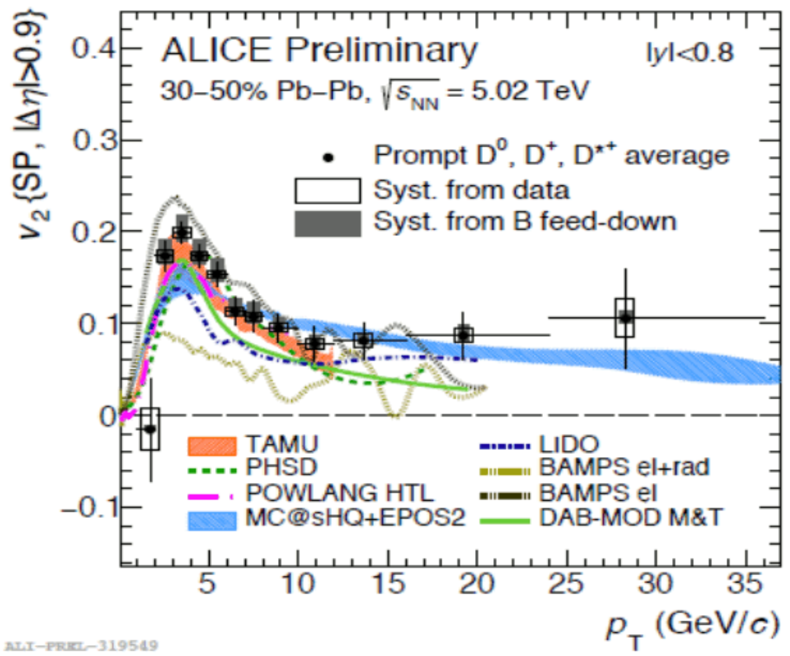
[*Catania, Nantes, Frankfurt, LBL,...*]

$$p^\mu \partial_\mu f_Q(x,p) = C[f_q, f_g, f_Q]$$

$$C[f_q, f_g, f_Q] = \frac{1}{2E_1} \int \frac{d^3 p_2}{2E_2 (2\pi)^3} \int \frac{d^3 p_1'}{2E_1'(2\pi)^3}$$
$$\times [f_Q(p_1') f_{q,g}(p_2') - f_Q(p_1) f_{q,g}(p_2)]$$
$$\times |M_{(q,g)\to Q}(p_1 p_2 \to p_1' p_2')|$$
$$\times (2\pi)^4 \delta^4(p_1 + p_2 - p_1' - p_2')$$

Transport coefficient





Models not really tested at p→0
The new data → determine $D_s(T)$ more properly,
i.e. p→0 where it is defined and computed in lQCD

	Catania	Duke	Frankfurt(PHSD)	LBL	Nantes	TAMU
Initial HQ (p)	FONLL	FONLL	pQCD	pQCD	FONLL	
Initial HQ (x)	binary coll.	binaryy coll.	binary coll.	binary coll.		binary coll.
Initial QGP	Glauber	Trento	Lund		EPOS	
QGP	Boltzm.	Vishnu	Boltzm.	Vishnu	EPOS	2d ideal hydro
partons	mass	m=0	m(T)	m=0	m=0	m=0
formation time QGP	0.3 fm/c	0.6 fm/c	0.6 fm/c (early coll.)	0.6 fm/c	0.3 fm/c	0.4 fm/c
interactions in between	HQ-glasma	no	HQ-preformed plasma	no		no

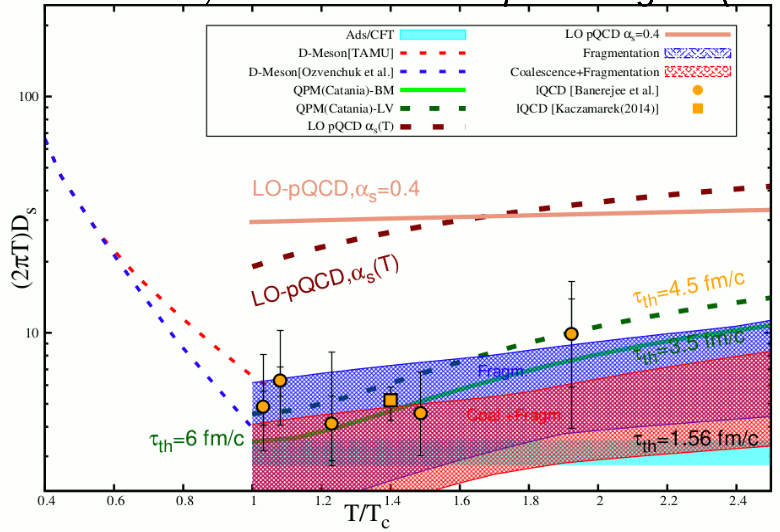
2018-2019

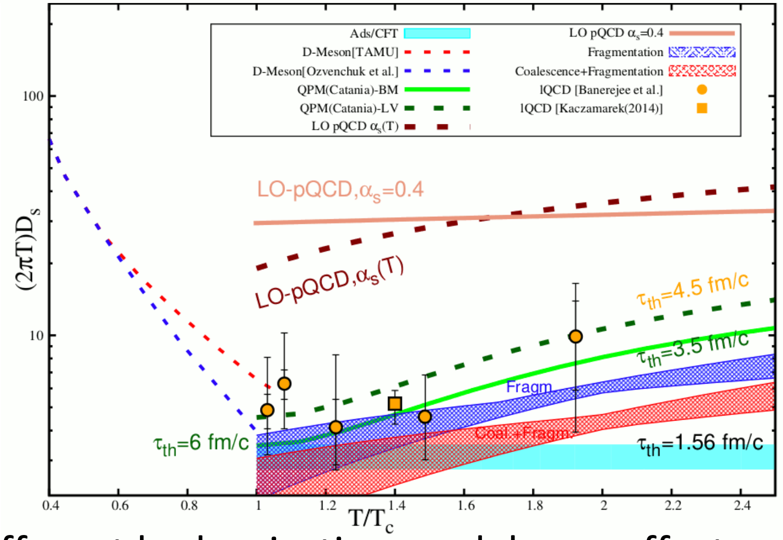
Several Collab. in joint activities:

- EMMI-RRTF:
  R. Rapp et al., Nucl. Phys. A 979 (2018)
- HQ-JETS:
  S. Cao et al.,Phys. Rev. C 99 (2019)
- Y. Xu et al., Phys. Rev. C 99 (2019)

Transport coefficient

Z. Citron et al., CERN Yellow Rep. Monogr. 7 (2019) 1159

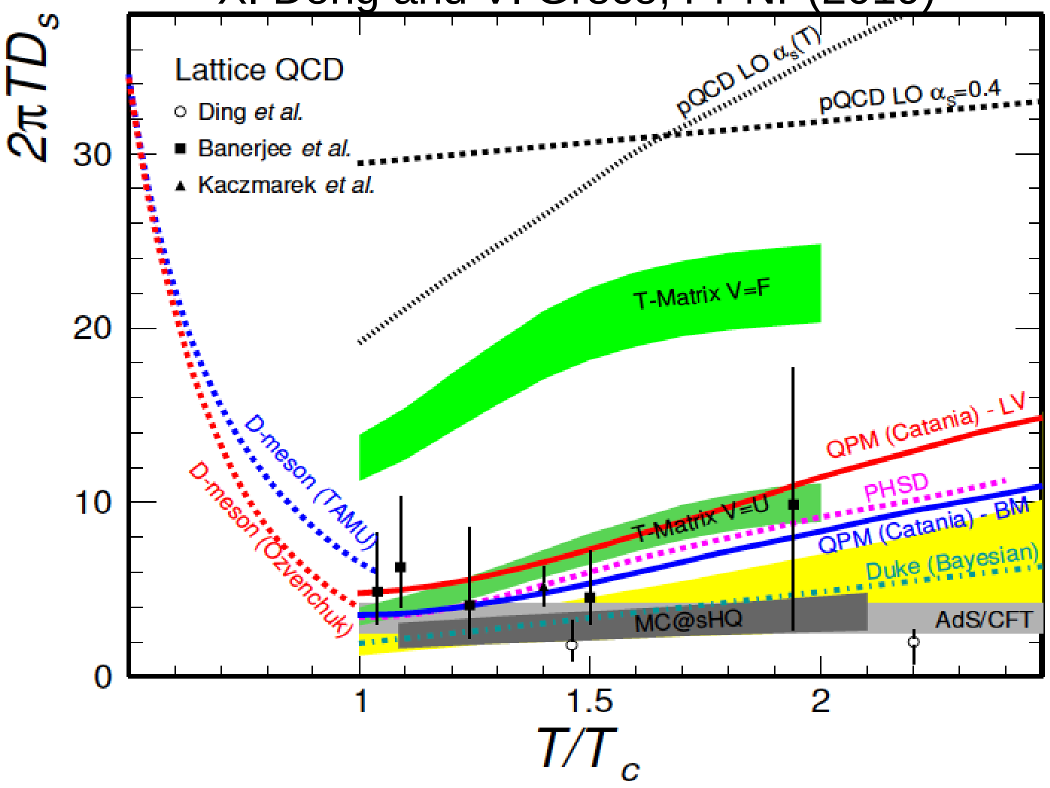




Different hadronization models can affect the extraction of the charm quark diffusion coefficient

New joint activity needed

X. Dong and V. Greco, PPNP(2019)



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Coalescence approach in phase space for HQ

Statistical factor colour-spin-isospin

Parton Distribution function

Hadron Wigner function

$$\frac{dN_{Hadron}}{d^2p_T} = g_H \int \prod_{i=1}^{n} p_i \cdot d\sigma_i \frac{d^3p_i}{(2\pi)^3} f_q(x_i, p_i) f_W(x_1, \ldots, x_n; p_1, \ldots, p_n) \delta\left(p_T - \sum_i p_{iT}\right)$$

Wigner function <-> Wave function

$$\Phi_M^W(\mathbf{r}, \mathbf{q}) = \int d^3r' e^{-i\mathbf{q}\cdot\mathbf{r}'} \varphi_M\left(\mathbf{r} + \frac{\mathbf{r}'}{2}\right) \varphi_M^*\left(\mathbf{r} - \frac{\mathbf{r}'}{2}\right)$$

$\varphi_M(\boldsymbol{r})$ *meson wave function*

Assuming gaussian wave function

$$f_M(x_1, x_2; p_1, p_2) = A_W \exp\left(-\frac{x_{r1}^2}{\sigma_r^2} - p_{r1}^2\sigma_r^2\right)$$

For baryon N_q=3

$$f_H(\ldots) = \prod_{i=1}^{N_q-1} A_W \exp\left(-\frac{x_{ri}^2}{\sigma_{ri}^2} - p_{ri}^2\sigma_{ri}^2\right)$$

Note: only σ_r coming from $\varphi_M(\boldsymbol{r})$ or $\sigma_r*\sigma_p$=1
valid for harmonic oscillator with V(r) $\sigma_r*\sigma_p$>1

Wigner function **width** fixed by root-mean-square charge radius from **quark model**

Meson	$\langle r^2\rangle_{ch}$	σ_{p1}	σ_{p2}
$D^+ = [c\bar{d}]$	0.184	0.282	—
$D_s^+ = [\bar{s}c]$	0.083	0.404	—
Baryon	$\langle r^2\rangle_{ch}$	σ_{p1}	σ_{p2}
$\Lambda_c^+ = [udc]$	0.15	0.251	0.424
$\Xi_c^+ = [usc]$	0.2	0.242	0.406
$\Omega_c^0 = [ssc]$	-0.12	0.337	0.53

C.-W. Hwang, EPJ C23, 585 (2002);
C. Albertus et al., NPA 740, 333 (2004)

$$\langle r^2\rangle_{ch} = \frac{3}{2}\frac{m_2^2Q_1 + m_1^2Q_2}{(m_1+m_2)^2}\sigma_{r1}^2 + \frac{3}{2}\frac{m_3^2(Q_1+Q_2) + (m_1+m_2)^2Q_3}{(m_1+m_2+m_3)^2}\sigma_{r2}^2 \quad (8)$$

$\sigma_{ri} = 1/\sqrt{\mu_i\omega}$ Harmonic oscillator relation

$$\mu_1 = \frac{m_1m_2}{m_1+m_2}, \quad \mu_2 = \frac{(m_1+m_2)m_3}{m_1+m_2+m_3}.$$

Normalization $f_H(\ldots)$ *fixed by requiring* P_{coal}(p->0)=1 which fixes A_w , additional assumption wrt standard coalescence which does not have confinement

Coalescence approach in phase space for HQ

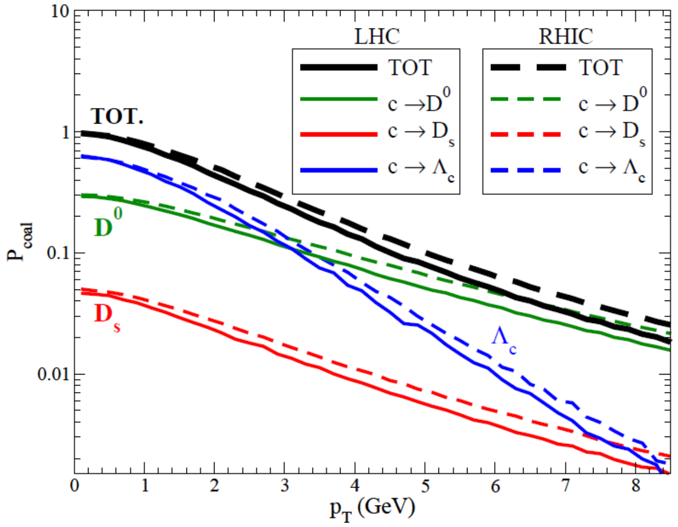
Statistical factor colour-spin-isospin

Parton Distribution function

Hadron Wigner function

$$\frac{dN_{Hadron}}{d^2p_T} = g_H \int \prod_{i=1}^{n} p_i \cdot d\sigma_i \frac{d^3p_i}{(2\pi)^3} f_q(x_i, p_i) f_W(x_1, \ldots, x_n; p_1, \ldots, p_n) \delta\left(p_T - \sum_i p_{iT}\right)$$

$$f_H(\ldots) = \prod_{i=1}^{N_q-1} A_W \exp\left(-\frac{x_{ri}^2}{\sigma_{ri}^2} - p_{ri}^2\sigma_{ri}^2\right)$$



S. Plumari, V. Minissale et al., Eur. Phys. J. **C78** no. 4, (2018) 348

- Normalization in f_W*(...) fixed by requiring* P_{coal}(p->0)=1 : ....others modify by hand σ_r to enforce confinement for a charm at rest in the medium

- The charm not "coalescencing" undergo fragmentation:

$$\frac{dN_{had}}{d^2p_T\,dy} = \sum \int dz \frac{dN_{fragm}}{d^2p_T\,dy} \frac{D_{had/c}(z, Q^2)}{z^2}$$

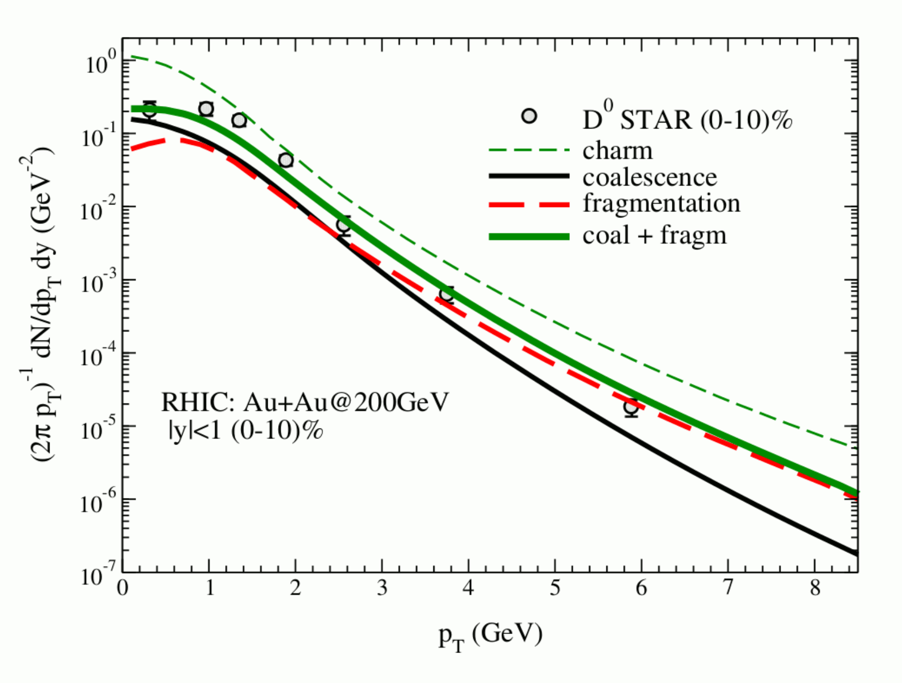
charm number conserved at each p_T,

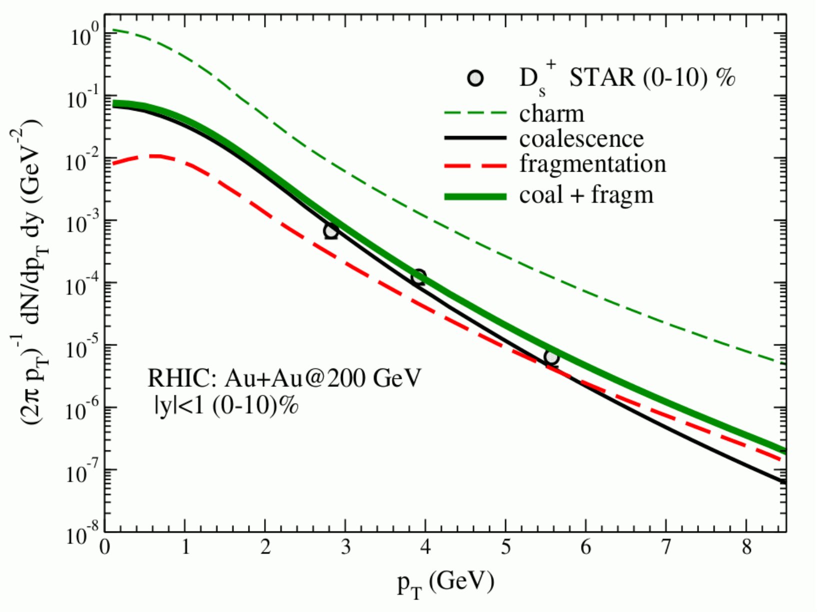
we have employed e^+e^- FF now PYTHIA

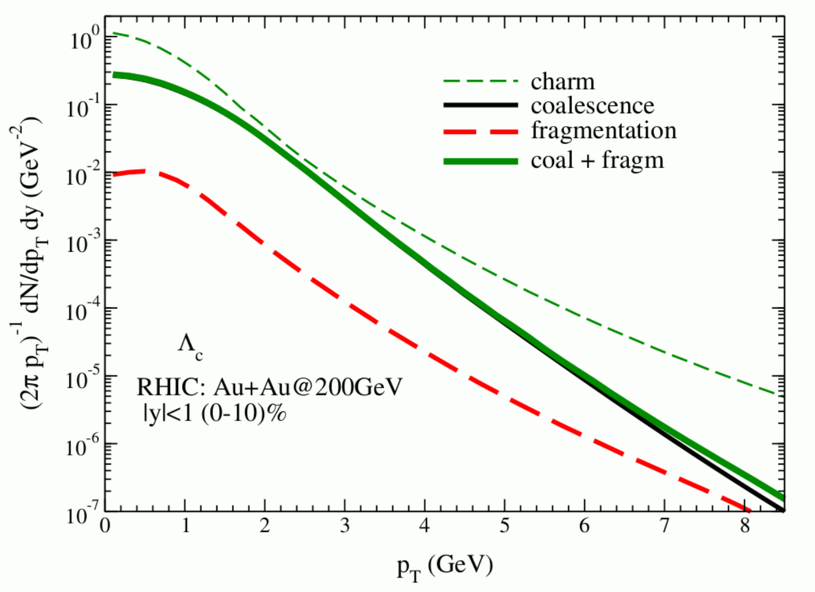
RHIC: results

Data from STAR Coll., arXiv:1704.04364 [nucl-ex].

Data from STAR Coll. PRL **113** (2014) no.14, 142301







*S. Plumari, et al., Eur. Phys. J. **C78** no. 4, (2018) 348*

RHIC: Baryon/meson

S. Plumari, et al., Eur. Phys. J. ***C78*** *no. 4, (2018) 348*

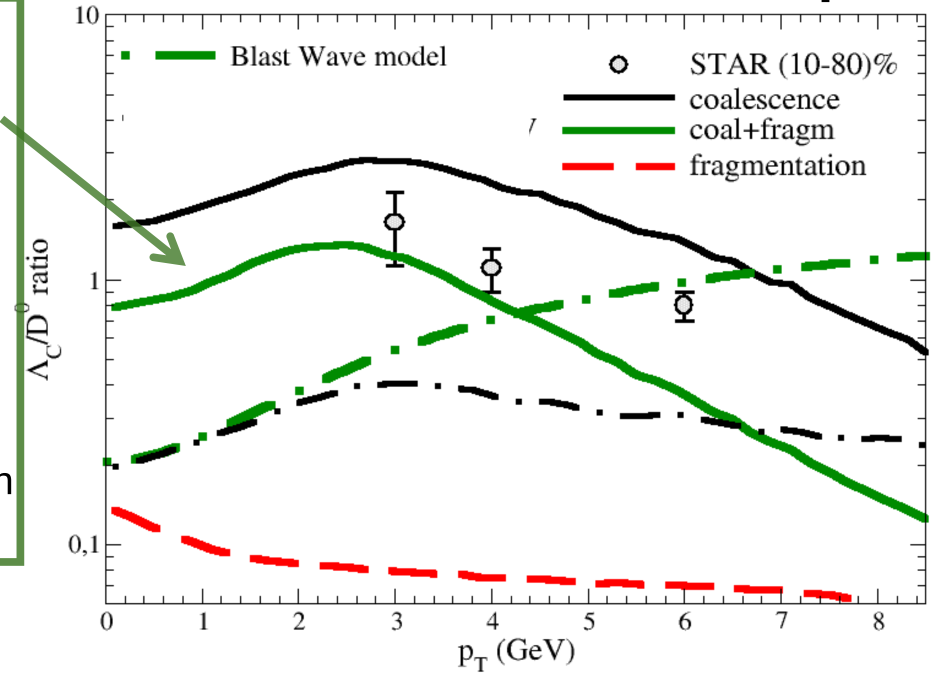
Coalescence

Following: L.W.Chen, C.M. Ko, W. Liu, M. Nielsen, PRC 76, 014906 (2007).
K.-J. Sun, L.-W. Chen, PRC 95, 044905 (2017).
For hypersurface of proper time τ and non relativistic limit:

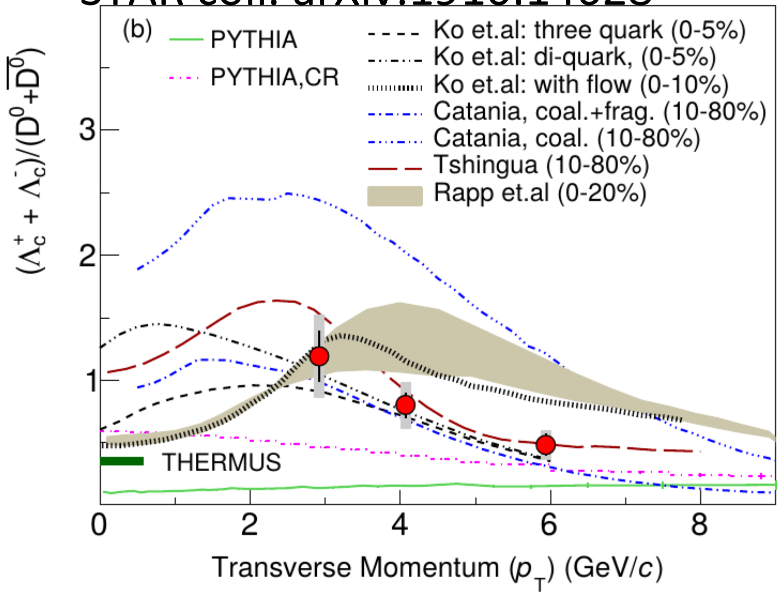
for $p_T << m$ $$\frac{\Lambda_c^+}{D^0} \propto \frac{g_\Lambda}{g_D}\left(\frac{m_T^\Lambda}{m_T^D}\right) e^{-(m^\Lambda - m^D)/T_C}\,\tau\mu_2$$

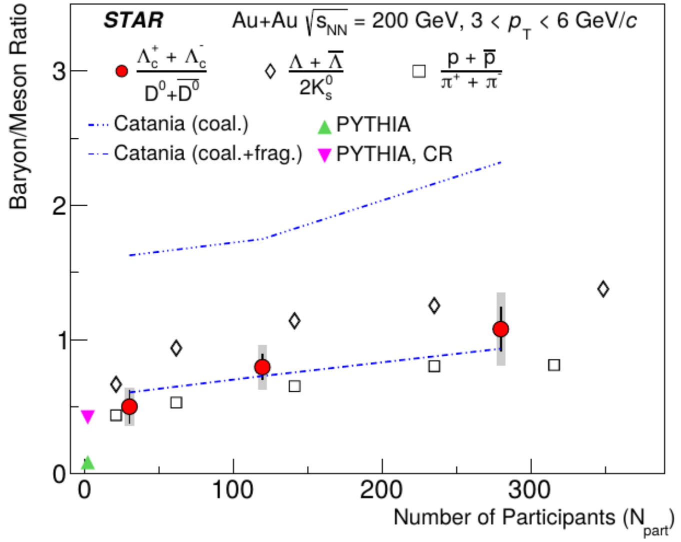
$$\mu_2 = \frac{m_3(m_1+m_2)}{m_1+m_2+m_3}$$ Is the reduced mass of the baryon

Data from STAR Coll., arXiv:1704.04364 [nucl-ex].



STAR coll. arXiv:1910.14628



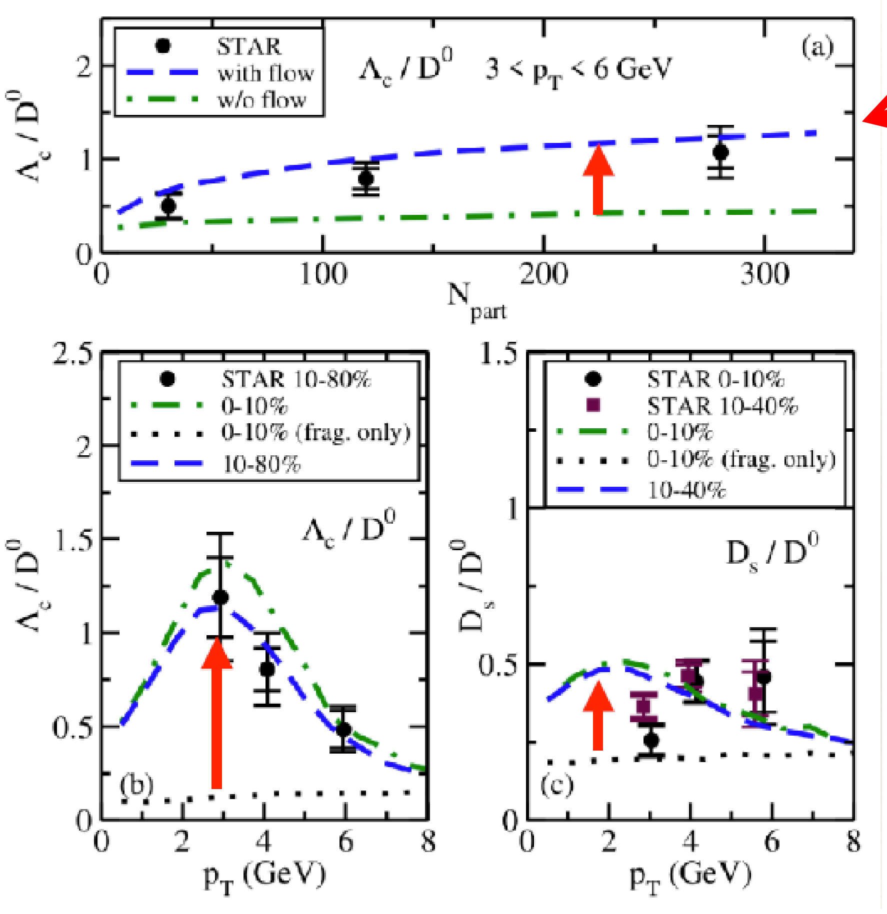


RHIC: Baryon/meson

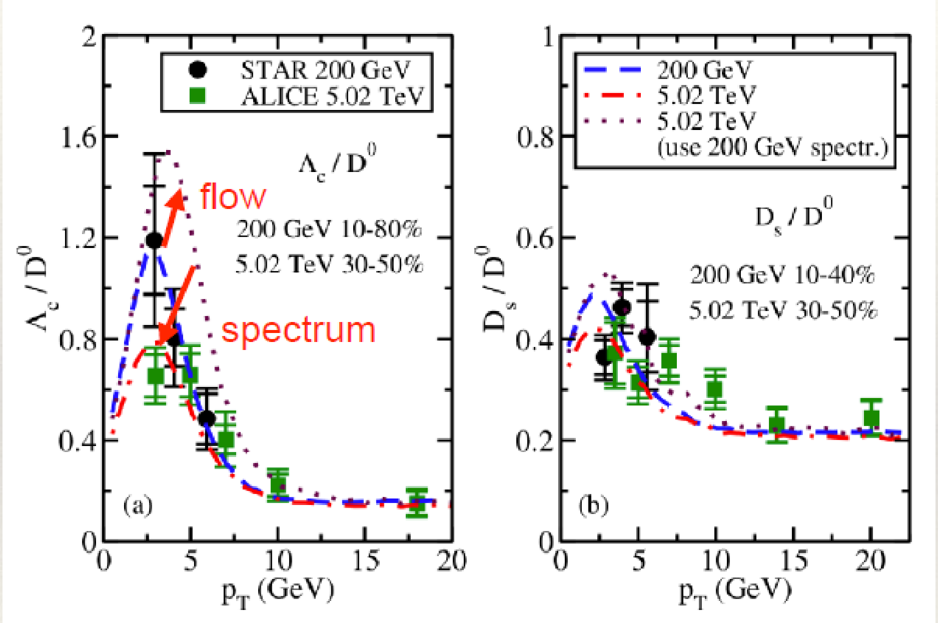
Recent improvements of the coalescence model Wigner function modified including both s and p wave states

Cao et al. , Phys. Lett. B 807 (2020) 135561

Stronger QGP flow boost on heavier hadrons => increasing Λ_c/D^0 ratio with *N*part

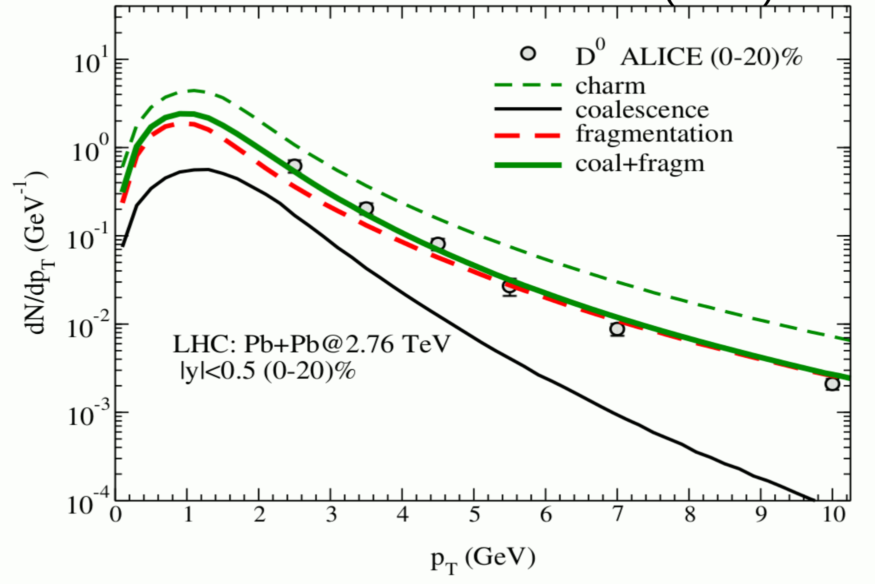


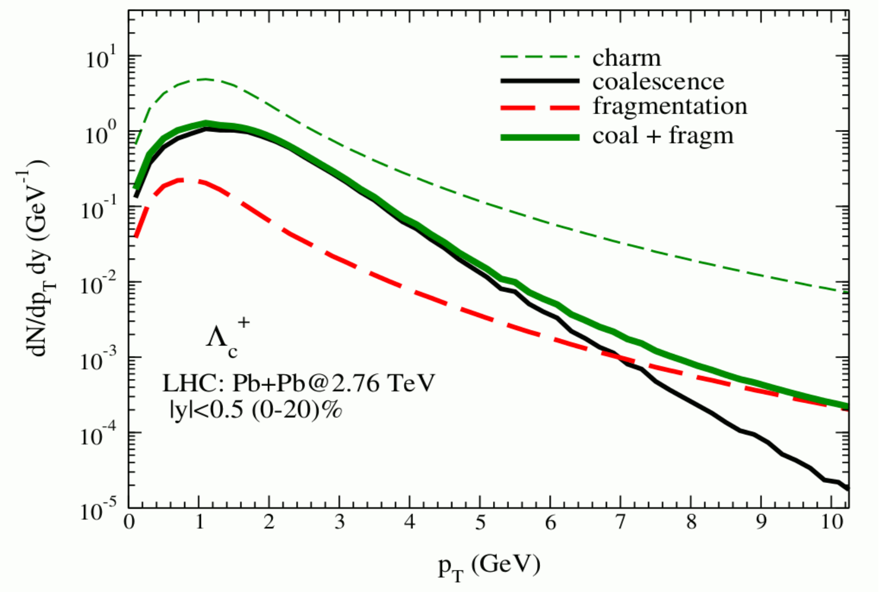
harder initial charm spectra at LHC reduces the Λ_c/D^0 ratio



LHC: results

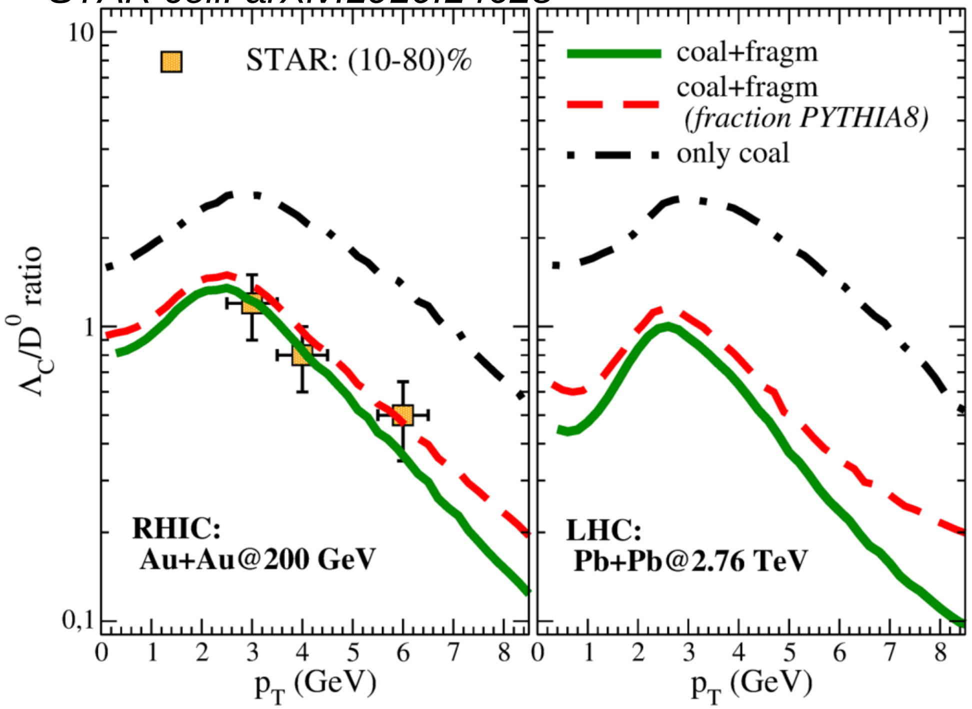
Data from ALICE Coll. JHEP 1209 (2012) 112





wave function widths σ_p of baryon and mesons kept the same at RHIC and LHC!

STAR coll. arXiv:1910.14628



The Λ_c/D^0 ratio is smaller at LHC energies: fragmentation play a role at intermediate p_T

S. Plumari, et al., Eur. Phys. J. ***C78*** *no. 4, (2018) 348*

Resonance Recombination Model (RRM)

Alternative dynamical realization of the coalescence approach

Hadronization proceeds via formation of resonant states when approaching the critical temperature

Starting point is the Boltzmann equation for the **meson**

$$\left(\frac{\partial}{\partial t} + \vec{v}\cdot\vec{\nabla}\right) F_M(t,\vec{x},\vec{p}) = -\frac{\Gamma}{\gamma_p} F_M(t,\vec{x},\vec{p}) + \beta(\vec{x},\vec{p})$$

Γ width attributed to 2-body decays M → q + ¯q,

The gain term

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

The cross section (**q+q → M**) is approximated by a relativistic Breit-Wigner

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

By imposing the stationarity condition at the equilibrium

$$f_M(\vec{x},\vec{p}) = \frac{\gamma_M(p)}{\Gamma_M} \int \frac{d^3\vec{p}_1 d^3\vec{p}_2}{(2\pi)^3} f_q(\vec{x},\vec{p}_1) f_{\bar{q}}(\vec{x},\vec{p}_2) \; \sigma_M(s) v_{\mathrm{rel}}(\vec{p}_1,\vec{p}_2) \delta^3(\vec{p}-\vec{p}_1-\vec{p}_2)$$

L. Ravagli and R. Rapp, Phys. Lett. B 655, 126 (2007).
L. Ravagli, H. van Hees and R. Rapp, Phys. Rev. C 79, 064902 (2009).

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Hadronization proceeds via formation of resonant states when approaching the critical temperature

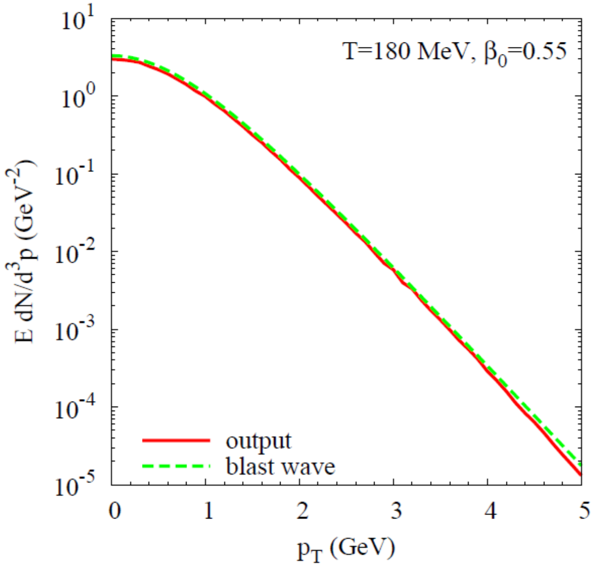
Starting point is the Boltzmann equation for the **meson**

$$\left(\frac{\partial}{\partial t} + \vec{v}\cdot\vec{\nabla}\right) F_M(t,\vec{x},\vec{p}) = -\frac{\Gamma}{\gamma_p} F_M(t,\vec{x},\vec{p}) + \beta(\vec{x},\vec{p})$$

The gain term

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

The cross section (**q+q → M**) is approximated by a relativistic Breit-Wigner



Conserve energy in the hadron formation process

Recover the equilibrium limit of hadron distributions

By imposing the stationarity condition at the equilibrium

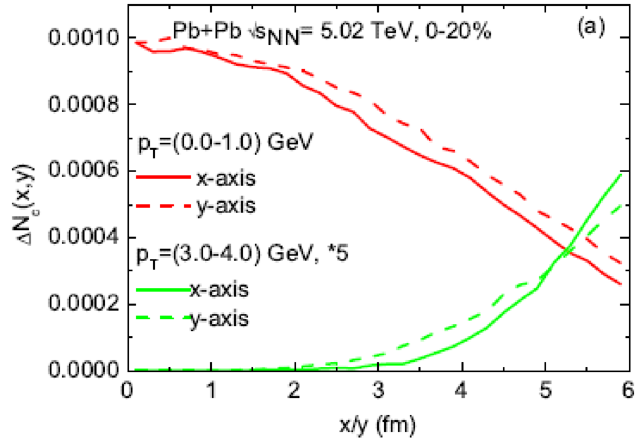
$$f_M(\vec{x},\vec{p}) = \frac{\gamma_M(p)}{\Gamma_M} \int \frac{d^3\vec{p}_1 d^3\vec{p}_2}{(2\pi)^3} f_q(\vec{x},\vec{p}_1) f_{\bar{q}}(\vec{x},\vec{p}_2)\; \sigma_M(s) v_{\mathrm{rel}}(\vec{p}_1,\vec{p}_2)\delta^3(\vec{p}-\vec{p}_1-\vec{p}_2)$$

L. Ravagli and R. Rapp, Phys. Lett. B 655, 126 (2007).
L. Ravagli, H. van Hees and R. Rapp, Phys. Rev. C 79, 064902 (2009).

Baryons in Resonance Recombination Model (RRM)

The 3-body hadronization process in RRM are conducted in 2 steps

Space-momentum correlations included



- **STEP 1**

quark-1 and quark-2 recombine into a diquark,

q1(p1) + q2(p2) → dq(p12)

The diquark spectrum in analogy to meson formation

- **STEP 2**

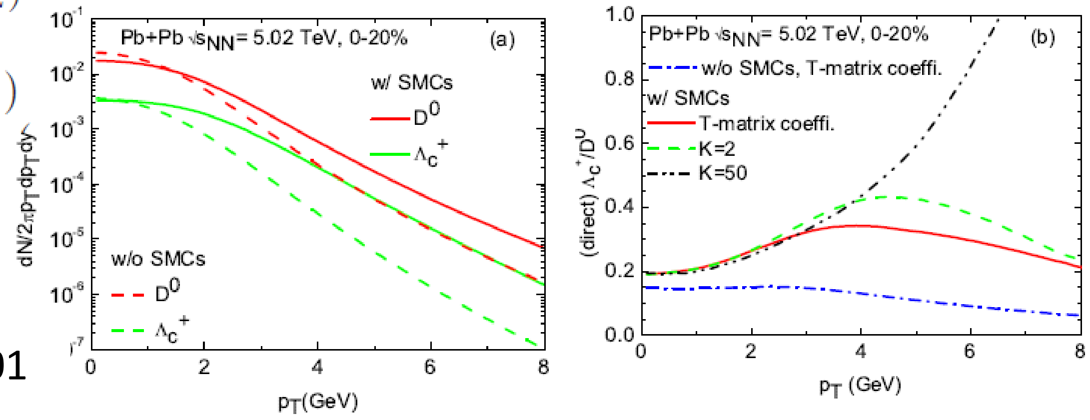
the diquark recombines with quark-3 into a baryon

dq1(p12) + q3(p3) → B

The baryon spectrum in analogy to meson formation

$$f_B(\vec{x},\vec{p}) = \frac{\gamma_B}{\Gamma_B}\int \frac{d^3\vec{p}_1 d^3\vec{p}_2 d^3\vec{p}_3}{(2\pi)^6}\frac{\gamma_{dq}}{\Gamma_{dq}} f_1(\vec{x},\vec{p}_1) f_2(\vec{x},\vec{p}_2) \times f_3(\vec{x},\vec{p}_3)\sigma_{dq}(s_{12})v_{\rm rel}^{12}\sigma_B(s)v_{\rm rel}^{dq3}\delta^3(\vec{p}-\vec{p}_1-\vec{p}_2-\vec{p}_3)$$

- low-p_T (0-1GeV) c quarks preferentially populate the inner regions of the fireball
- higher-p_T (3-4GeV) c quarks populate the outer regions of the fireball



M. He, R. Rapp, Phys. Rev. Lett. **124** (2020) no.4, 042301

Baryons in Resonance Recombination Model (RRM)

The 3-body hadronization process in RRM are conducted in 2 steps

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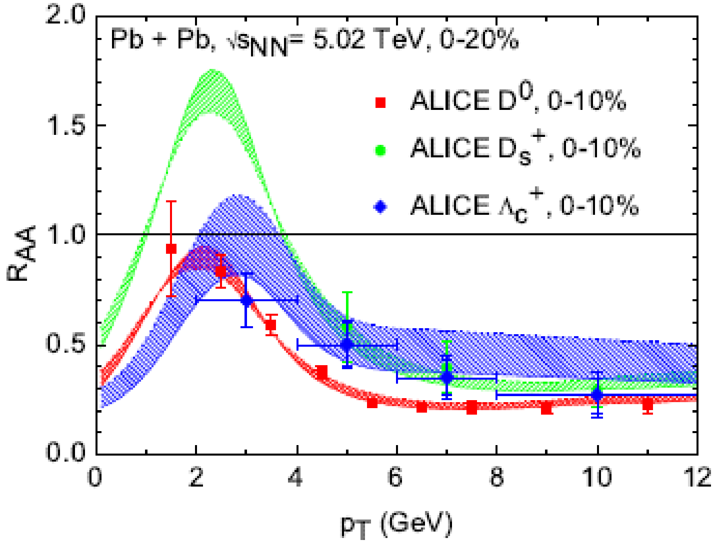
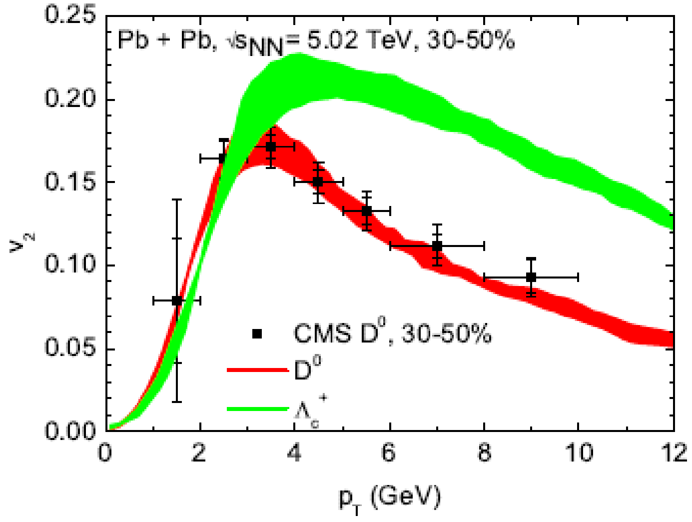
HF hadro-chemistry improved by employing a large set of "missing" HF baryon states not listed by PDG, but predicted by the relativistic-quark model

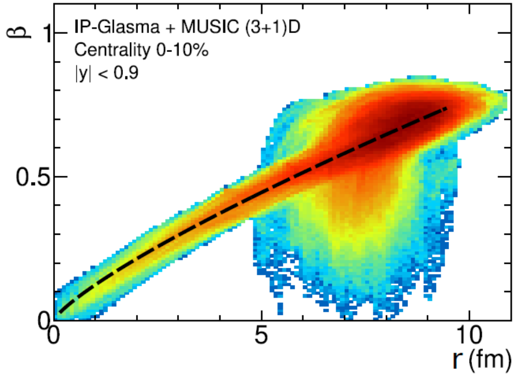




M. He, R. Rapp, Phys. Rev. Lett. **124** (2020) no.4, 042301

Hadronization: SHMc (Baryon/meson)

charmed hadrons included into the SHM with thermal distributions, while the total charm content of the fireball is fixed by the measured open charm cross section.



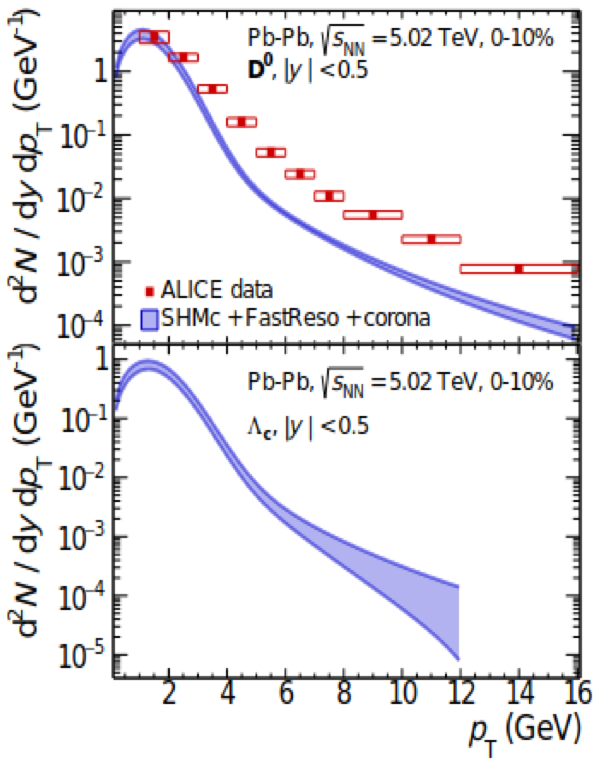
SHMc yields + blast wave →p_T spectra

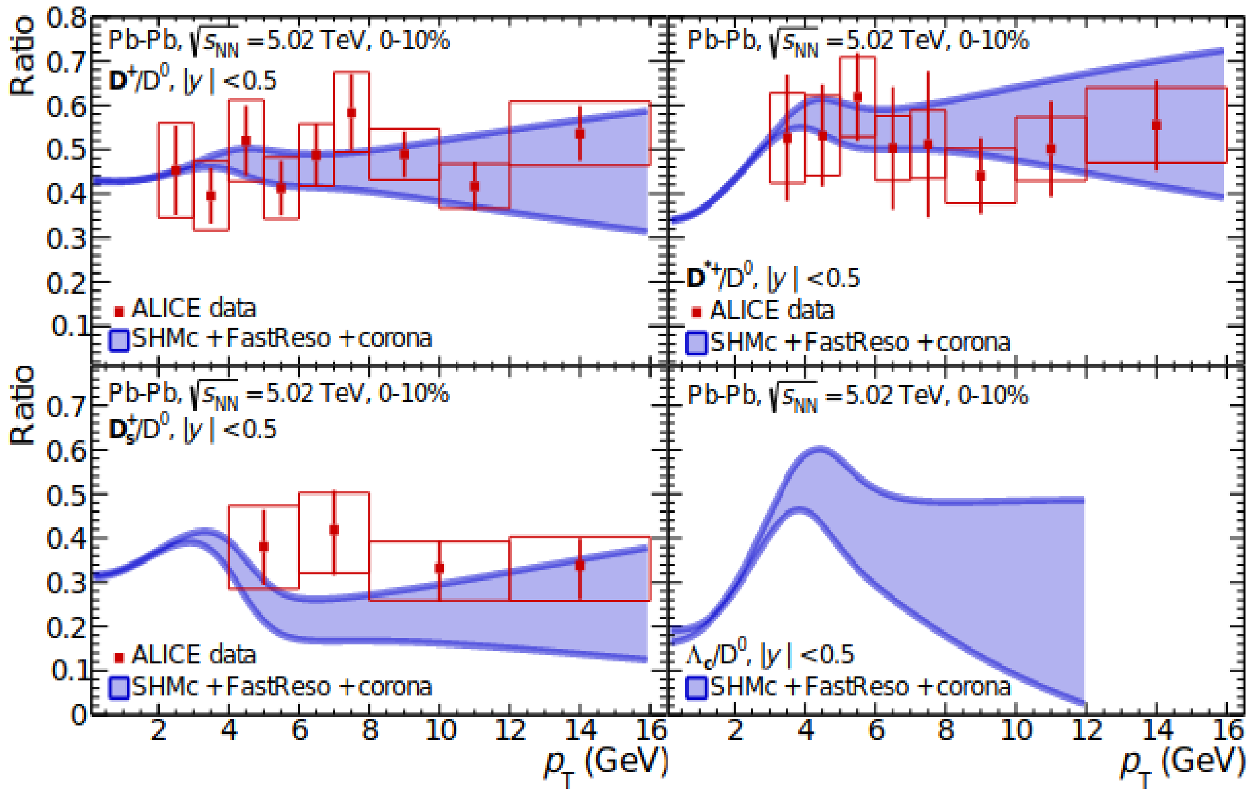
-low pT near fully thermalized

A. Andronic et al, JHEP 07 (2021) 035

$$\frac{d^2N}{2\pi p_T dp_T dy} = \frac{2J+1}{(2\pi)^3}\int d\sigma_\mu p^\mu f(p)$$

$$= \frac{2J+1}{(2\pi)^3}\int_0^{r_{\max}} dr\, \tau(r) r \left[K_1^{eq}(p_T, u^r) - \frac{\partial \tau}{\partial r} K_2^{eq}(p_T, u^r)\right]$$

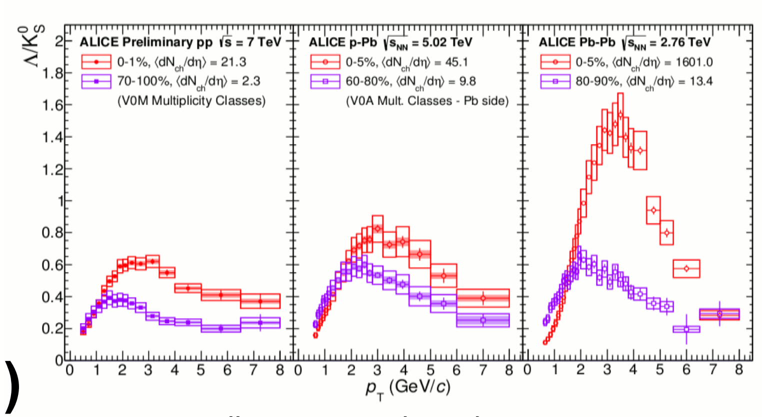




Small systems

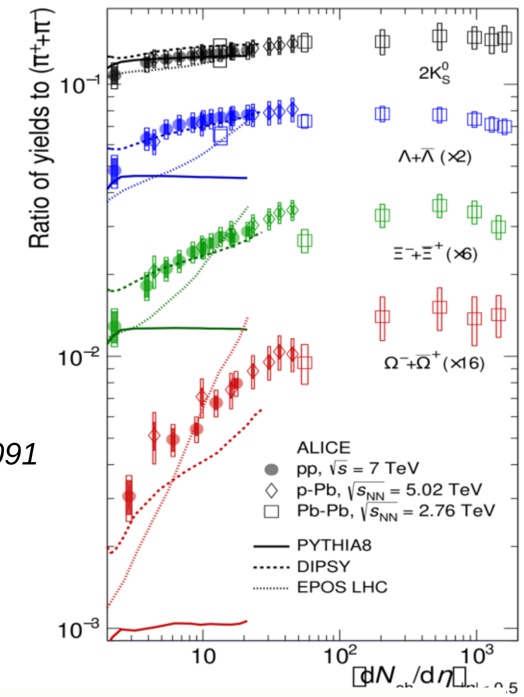
Traditional view:

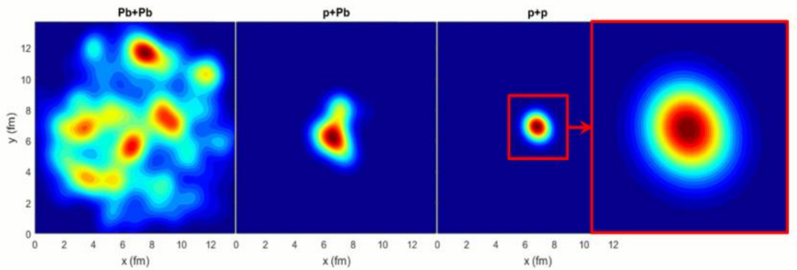
- QGP in Pb+Pb
- no QGP in p+p ("baseline")



ALICE Coll., PRL 111 (2013) 222301
ALICE Coll., J. Phys.: Conf. Ser. 509 (2014) 012091
ALICE Coll. NPA 956 (2016) 777-780.

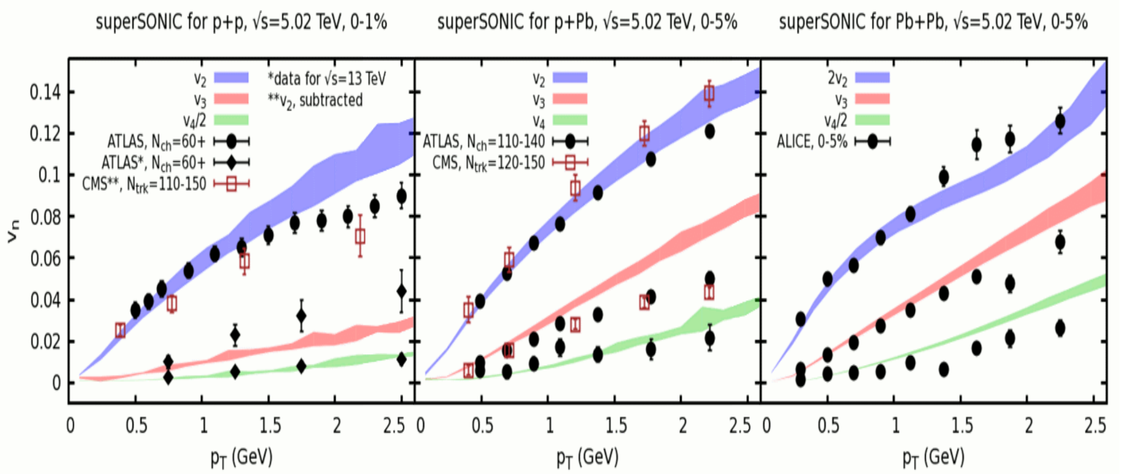
ALICE coll. Nature Phys. 13 (2017) 535





Objections to applying hydro in pp

- Too few particles, cannot be collective
- System not in equilibrium



R. D. Weller, P. Romatschke Phys.Lett. B774 (2017) 351-356

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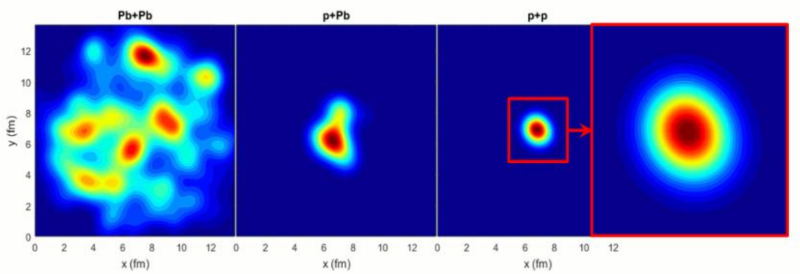

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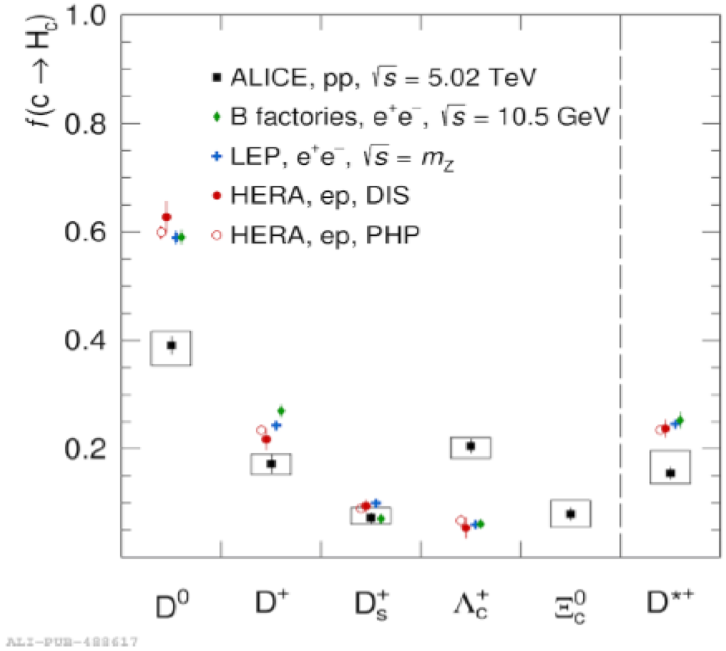
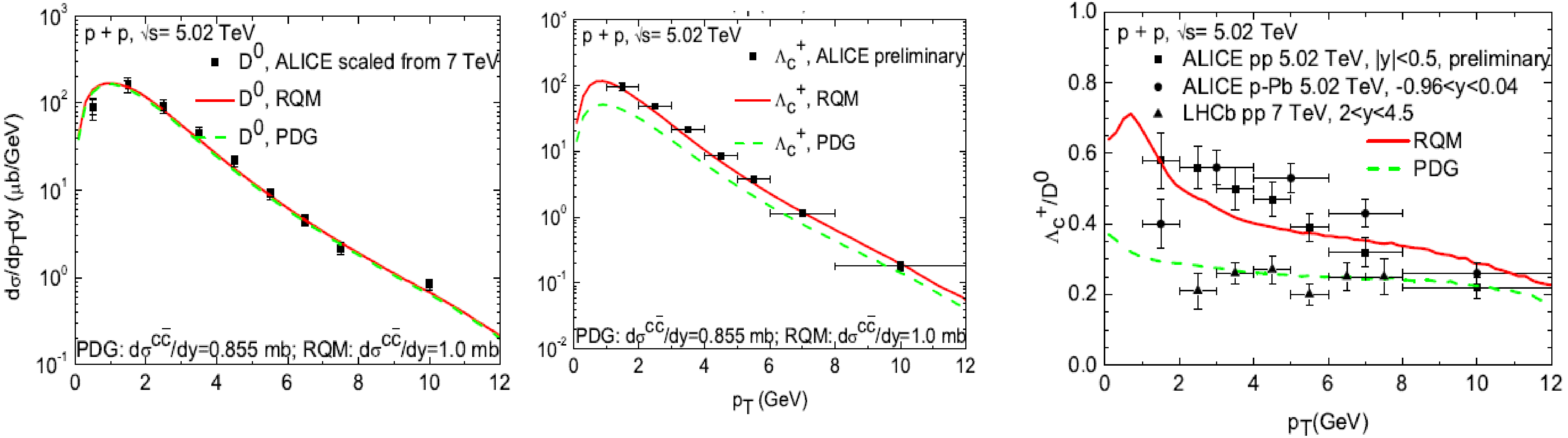
ALICE coll, arXiv:2105.06335



- Indication that fragmentation depends on the collision system
- Assumption of their universality not supported by the measured cross sections

Grand canonical SHM + fragmentation

M. He & R. Rapp, PLB795(2019)117-121



assuming independent fragmentation of charm quarks but with the hadronic ratios fixed by the SHM, and then excited states decayed into ground state charm-hadrons

$$n_i = \frac{d_i}{2\pi^2} m_i^2 T_H K_2\left(\frac{m_i}{T_H}\right)$$

the enhanced feeddown from excited charm baryons can account for the Λc /D ratio measured

n_i $(\cdot 10^{-4}\ \mathrm{fm}^{-3})$	D^0	D^+	D^{*+}	D_s^+	Λ_c^+	$\Xi_c^{+,0}$	Ω_c^0
PDG(170)	1.161	0.5098	0.5010	0.3165	0.3310	0.0874	0.0064
PDG(160)	0.4996	0.2223	0.2113	0.1311	0.1201	0.0304	0.0021
RQM(170)	1.161	0.5098	0.5010	0.3165	0.6613	0.1173	0.0144
RQM(160)	0.4996	0.2223	0.2113	0.1311	0.2203	0.0391	0.0044

Small systems: Coalescence in pp?

- Thermal Distribution (p_T< 2 GeV)

$$\frac{dN_q}{d^2 r_T d^2 p_T} = \frac{g_g \tau m_T}{(2\pi)^3} \exp\left(-\frac{\gamma_T (m_T - p_T \cdot \beta_T)}{T}\right)$$

- Collective flow $\beta_T = \beta_0 \frac{r}{R}$
- Fireball radius+radial flow constraints dN_{ch}/dy and dE_T/dy
- Minijet Distribution (p_T> 2 GeV)
- NO QUENCHING

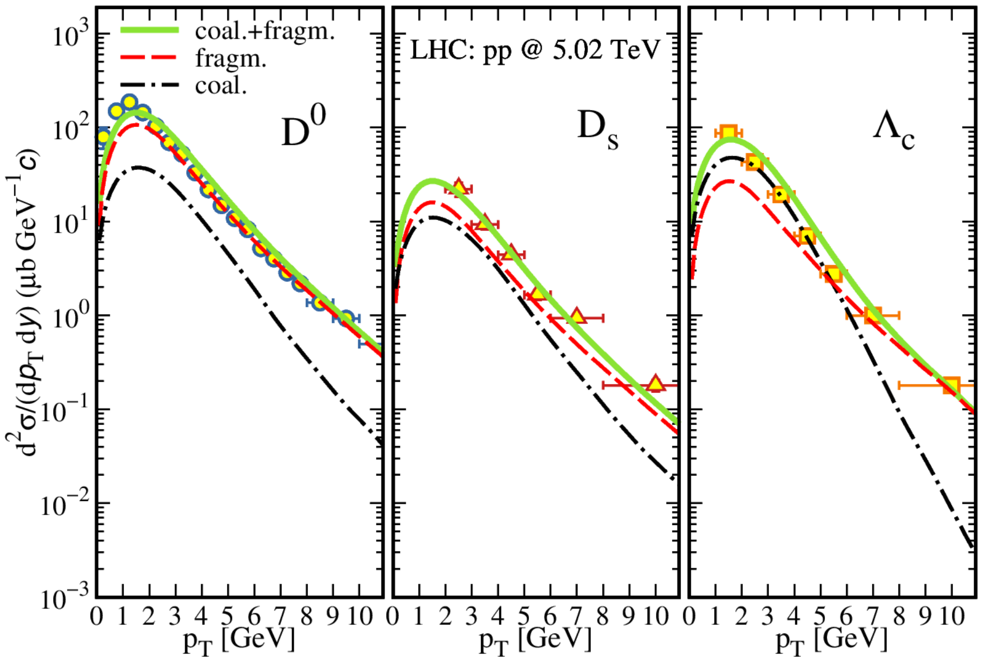
p+p @ 5 TeV

- t_{pp}=1.7 fm/c
- β_0=0.4
- R=2.5 fm
- V~30 fm^3

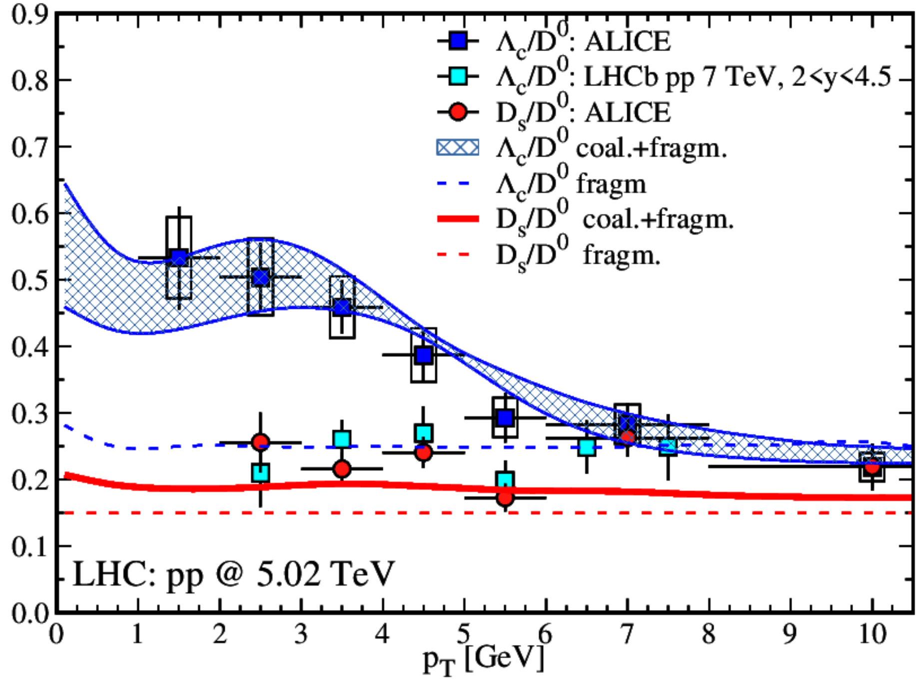
wave function widths σ_p of baryon and mesons kept the same at RHIC and LHC!

V. Minissale et al., *Phys.Lett.B* 821 (2021) 136622

Data from: ALICE coll. EPJ C79 (2019) no.5, 388
ALICE coll. Meninno Hard Probes 2018



Data taken from: ALICE coll. JHEP 04 (2018) 108



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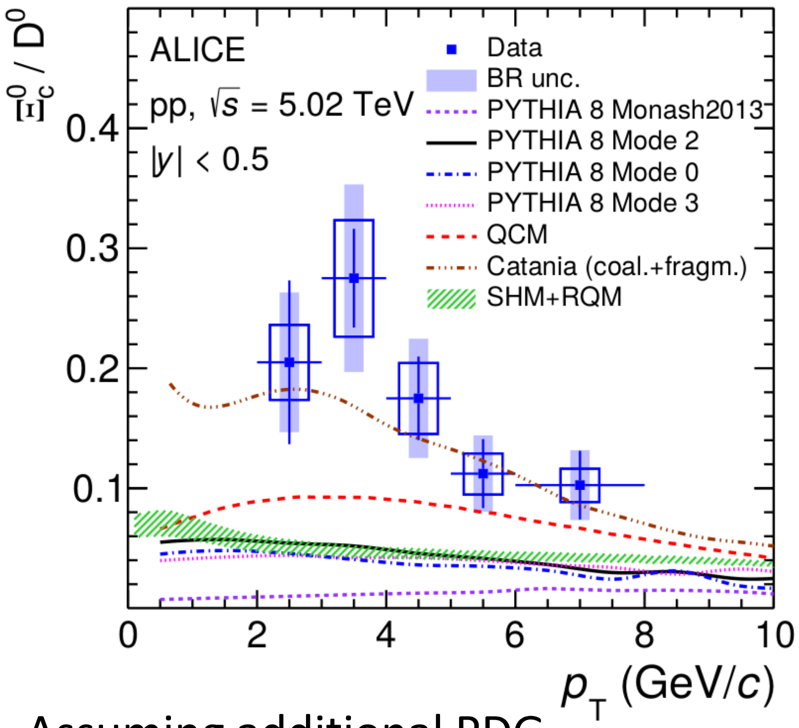
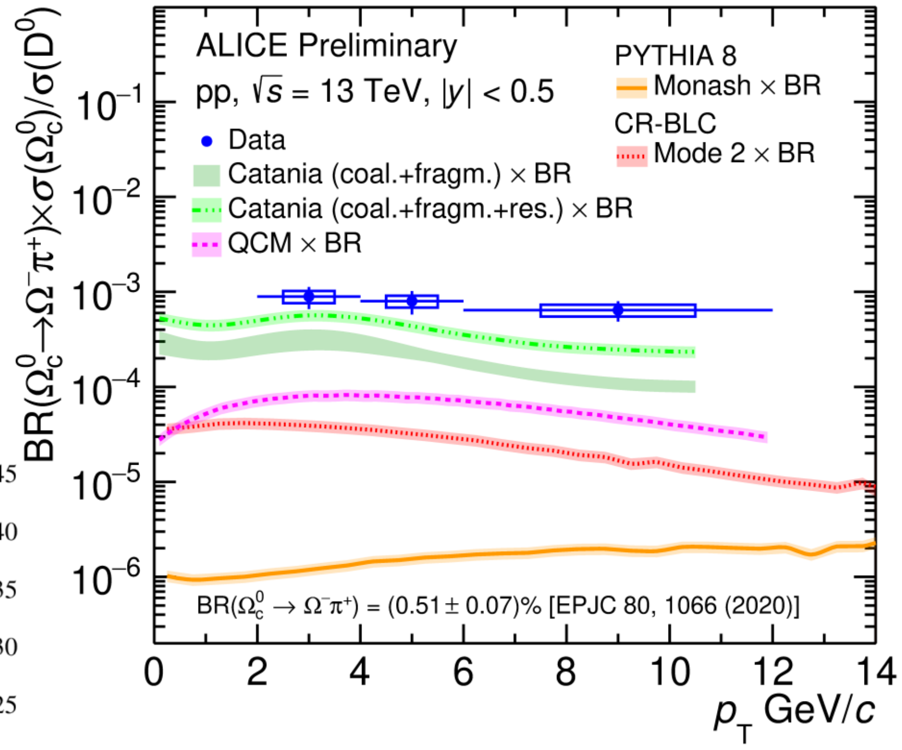


New measurements of heavy hadrons at ALICE:

- Ξ_c/D^0 ratio, same order of Λ_c/D^0: coalescence gives enhancement

- very large Ω_c/D^0 ratio



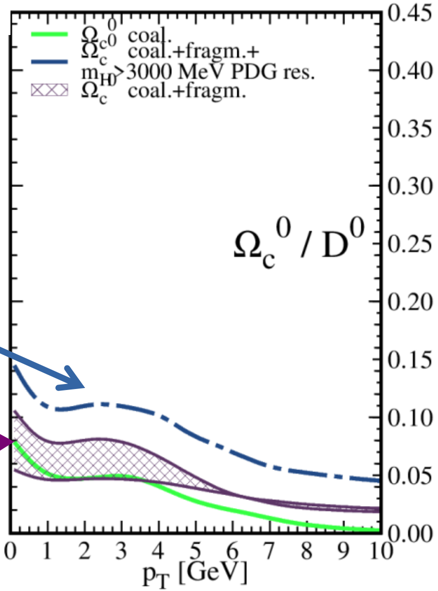
ALICE Collaboration, e-Print: 2109.04326 [hep-ex]
V. Minissale et al., *Phys.Lett.B* 821 (2021) 136622

Assuming additional PDG resonances with J=3/2 and decay to Ω_c additional to $\Omega_c^0(2770)$

$\Omega_c^0(3000), \Omega_c^0(3005), \Omega_c^0(3065),$
$\Omega_c^0(3090), \Omega_c^0(3120)$

supply an idea of how these states may affect the ratio

Error band correspond to <r^2> uncertainty in quark model



Conclusion

- **Light flavour production at intermediate p_T**

  Intermediate p_T sensitive to hadronization via recombination

  baryon/meson enhancement described by coalescence+fragmentation

- **Charm hadronization in AA different than in e^+e^- and ep collisions**

  -Coalescence+fragmentation/Resonance Recombination Model enhancement of Λ_c production at intermediate p_T -> Λ_c/D^0 ~1 for p_T ~ 3 GeV

  -SHM with charm provide information on charm quark thermalization at low p_T

- ***In p+p assuming a medium:***

  - Coal.+fragm. good description of heavy baryon/meson ratio (closer to the data for Λ_c/D^0 , Ξ_c/D^0, Ω_c/D^0)

  - SHM+fragmentation able to capture the Λ_c production