INFN LNS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

LHCPhysics
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Theoretical overview of heavy-flavour hadronization

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Belgrade - “11th Edition of the Large Hadron Collider Physics Conference”

Outline

Hadronization:

- Fragmentation
- Recombination models
- Statistical Hadronization

Heavy hadrons in AA collisions:

- Λ_c , D spectra and ratio: RHIC and LHC

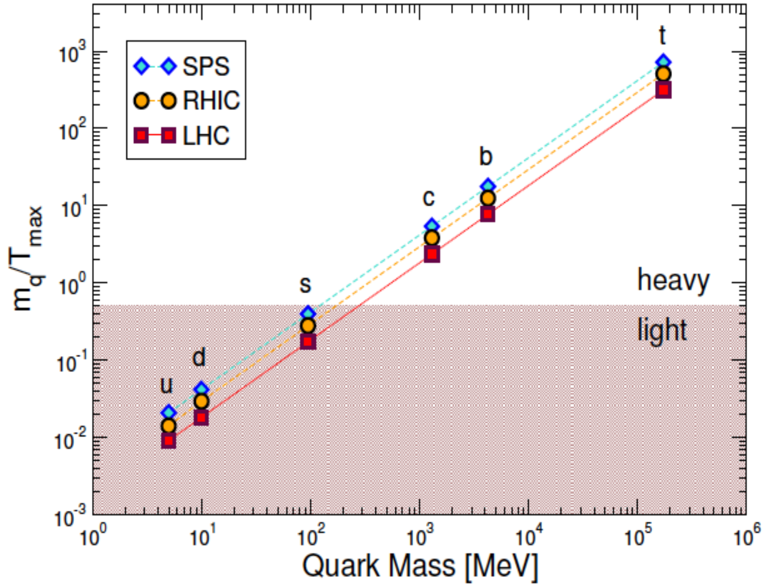
Heavy hadrons in small systems (pp @ 5.02 TeV):

- Λ_c/D^0
- Ξ_c/D^0 , Ω_c/D^0

Specific of Heavy Quarks

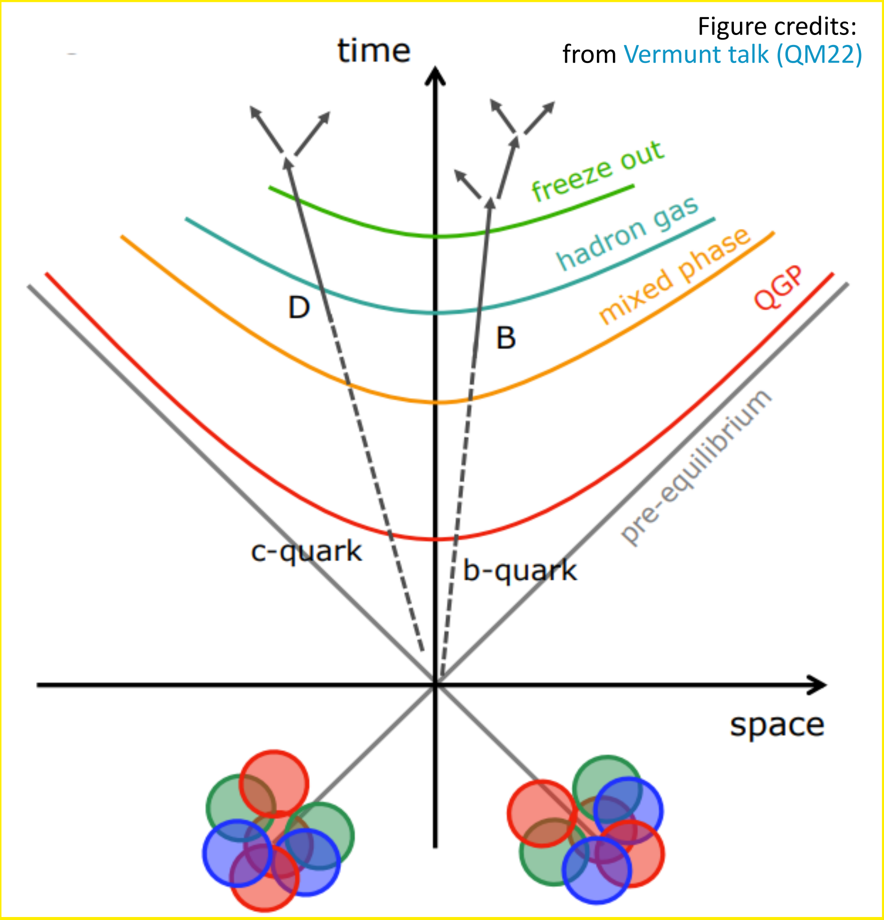
- $m_{c,b} >> \Lambda_{QCD}$
  produced by pQCD process (out of equilibrium)
- $m_{c,b} >> T_0$
  negligible thermal production
- $\tau_0 << \tau_{QGP}$ formation in initial stages of collision
- $\tau_{therm.} \approx \tau_{QGP} >> \tau_{g,q}$ large thermalization time

HQs experience the full QGP evolution
Carry informations about initial stages, more than light quarks



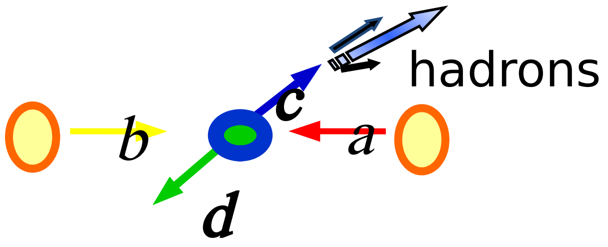
Recent reviews:

1) X.Dong, V. Greco Prog. Part. Nucl. Phys. 104 (2019)
2) A.Andronic Eur.Phys.J.C 76 (2016) 3, 107
3) F.Prino, R.Rapp, J.Phys.G 43 (2016) 9, 093002



Heavy flavour Hadronization

Microscopic approach:



Fragmentation:
production from hard-scattering processes (PDF+pQCD).
Fragmentation functions: data parametrization, assumed "universal"

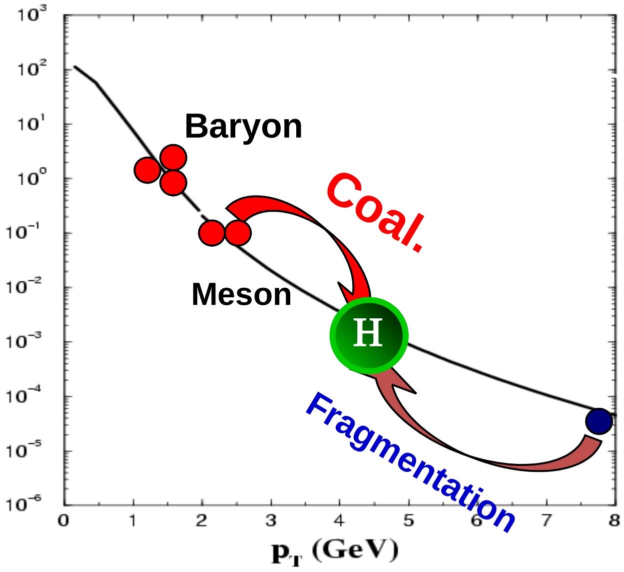
$$\sigma_{pp\to h} = PDF(x_a, Q^2)\, PDF(x_b, Q^2) \otimes \sigma_{ab\to q\bar{q}} \otimes D_{q\to h}(z, Q^2)$$

Parton shower: String fragmentation(Lund model – PYTHIA)
+colour reconnection(interaction from different scattering)
Cluster decay (HERWIG)

Coalescence: recombination of partons in QGP close in phase space

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

Have described first AA observations in light sector for the enhanced baryon/meson ratio and elliptic flow splitting



Catania Model: Coalescence + Fragmentation

Statistical factor colour-spin-isospin

Parton Distribution function

Hadron Wigner function

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

LIGHT

Thermal+flow for **u,d,s** (p_T < 3 GeV)

$$\frac{dN_{q,\bar{q}}}{d^2 p_T} \sim \exp\left(-\frac{\gamma_T - p_T \cdot \beta_T \mp \mu_q}{T}\right)$$

$$\beta(r) = \frac{r}{R} \beta_{max}$$

$$V = \pi R^2 \tau \cosh(y_z), R(\tau_f) = R_0 (1 + \beta_{max} \tau_f)$$

PbPb@5ATeV(0-10%): $\tau_f = 8.4 \frac{fm}{c} \rightarrow V_{|y|<0.5} = 4500\, fm^3$

+quenched minijets for u,d,s (p_T > 3 GeV)

CHARM

In AA collisions charm distribution from the studies of R_{AA} and v_2 of **D-meson** to determine the Space Diffusion coefficient:

parton simulations solving relativistic Boltzmann transport equation

Coalescence simulation in a fireball with radial flow for light quarks → dimension set by experimental constraints

Catania Model: Coalescence + Fragmentation

Statistical factor colour-spin-isospin — **Parton Distribution function** — **Hadron Wigner function**

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

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

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

Wigner function – Wave function

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

$\phi_M(\boldsymbol{r})$ meson wave function

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

$$\mu_1 = \frac{m_1 m_2}{m_1+m_2}$$

$$\sigma_{ri} = 1/\sqrt{(\mu_i \omega)}$$

$$\mu_2 = \frac{(m_1+m_2) m_3}{m_1+m_2+m_3}$$

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

Assuming gaussian wave function

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

only one width coming from $\phi_M(\mathbf{r})$, constraint $\sigma_r \sigma_p = 1$

- Normalization of $f_W(\ldots)$ requiring that $P_{coal}=1$ at $p=0$
- The charm that does not coalesce undergo fragmentation

Heavy flavour: Resonance decay

Meson	Mass(MeV)	I (J)	Decay modes	B.R.
$D^+ = \bar{d}c$	1869	$\frac{1}{2}\,(0)$		
$D^0 = \bar{u}c$	1865	$\frac{1}{2}\,(0)$		
$D_s^+ = \bar{s}c$	2011	$0\,(0)$		
Resonances				
D^{*+}	2010	$\frac{1}{2}\,(1)$	$D^0\pi^+;\ D^+X$	68%,32%
D^{*0}	2007	$\frac{1}{2}\,(1)$	$D^0\pi^0;\ D^0\gamma$	62%,38%
D_s^{*+}	2112	$0\,(1)$	D_s^+X	100%
Baryon				
$\Lambda_c^+ = udc$	2286	$0\,(\frac{1}{2})$		
$\Xi_c^+ = usc$	2467	$\frac{1}{2}\,(\frac{1}{2})$		
$\Xi_c^0 = dsc$	2470	$\frac{1}{2}\,(\frac{1}{2})$		
$\Omega_c^0 = ssc$	2695	$0\,(\frac{1}{2})$		
Resonances				
Λ_c^+	2595	$0\,(\frac{1}{2})$	$\Lambda_c^+\pi^+\pi^-$	100%
Λ_c^+	2625	$0\,(\frac{3}{2})$	$\Lambda_c^+\pi^+\pi^-$	100%
Σ_c^+	2455	$1\,(\frac{1}{2})$	$\Lambda_c^+\pi$	100%
Σ_c^+	2520	$1\,(\frac{3}{2})$	$\Lambda_c^+\pi$	100%
$\Xi_c^{\prime +,0}$	2578	$\frac{1}{2}\,(\frac{1}{2})$	$\Xi_c^{+,0}\gamma$	100%
Ξ_c^+	2645	$\frac{1}{2}\,(\frac{3}{2})$	$\Xi_c^+\pi^-,$	100%
Ξ_c^+	2790	$\frac{1}{2}\,(\frac{1}{2})$	$\Xi_c^{\prime}\pi,$	100%
Ξ_c^+	2815	$\frac{1}{2}\,(\frac{3}{2})$	$\Xi_c^{\prime}\pi,$	100%
Ω_c^0	2770	$0\,(\frac{3}{2})$	$\Omega_c^0\gamma,$	100%

In our calculations we take into account hadronic channels including the ground states + first excited states

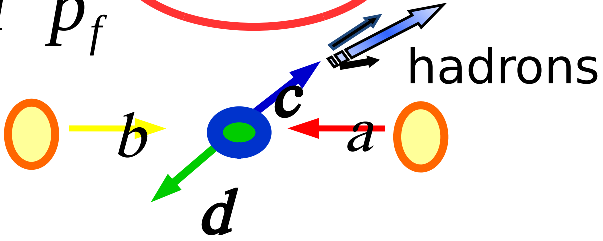
Statistical factor suppression for resonances

$$\frac{[(2J+1)(2I+1)]_{H^*}}{[(2J+1)(2I+1)]_H}\left(\frac{m_{H^*}}{m_H}\right)^{3/2} e^{-(m_{H^*}-m_H)/T}$$

Catania Model: Coalescence + Fragmentation

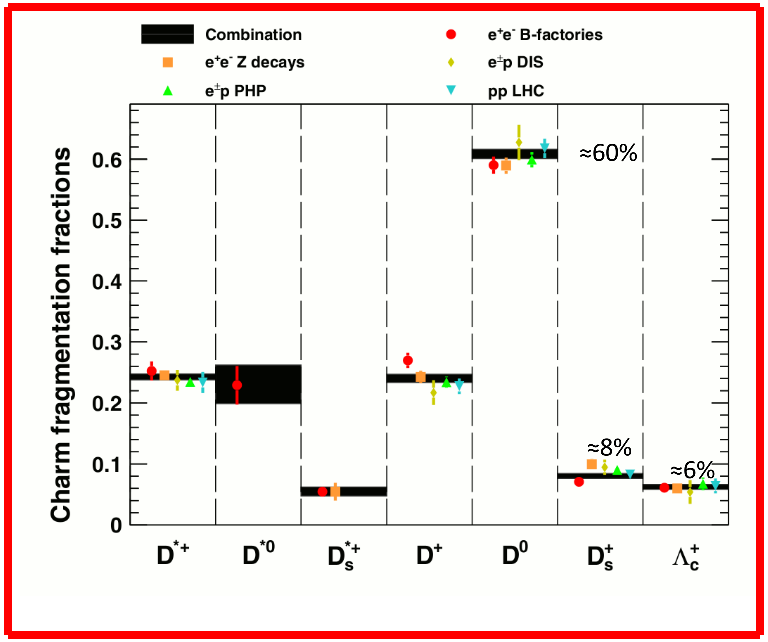
Fragmentation function

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



Fixed-Order plus Next-to-Leading-Log (FONLL) distribution function

M. Cacciari, P. Nason, R. Vogt, PRL 95 (2005) 122001



M. Lisovyi, et al. EPJ C76 (2016) no.7, 397

In AA: bulk+charm evolution with Relativistic Transport Boltzmann Equation

Peterson fragmentation function

C. Peterson, D. Schalatter, I. Schmitt, P.M. Zerwas PRD 27 (1983) 105

$$D_{f\to h}(z) \propto \frac{1}{z\left[1 - \frac{1}{z} - \frac{\epsilon}{1-z}\right]^2}$$

Charm Fragmentation Fraction (c→h)

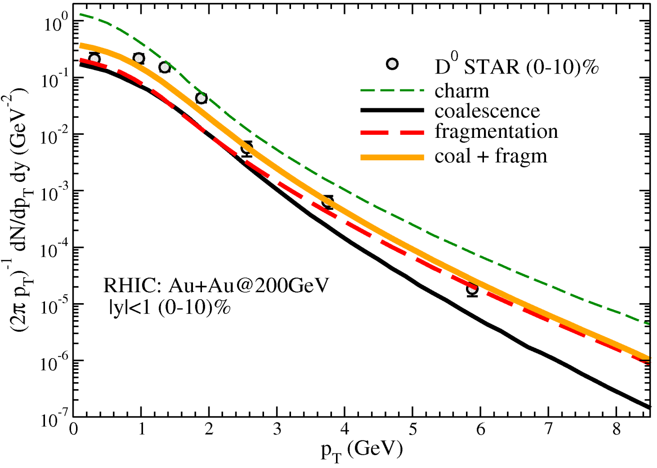
Measurement in $e^{\pm} p$, $e^+ e^-$ *and old pp data*

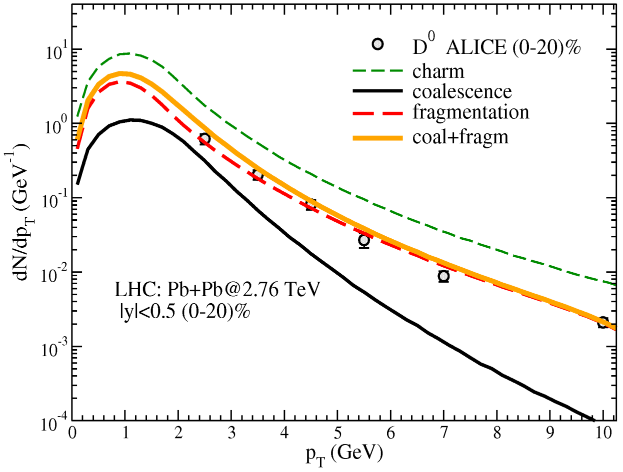
$$\left(\frac{\Lambda_c^+}{D^0}\right)_{e^+e^-,\,pp} \simeq 0.1 \qquad \left(\frac{D_s^+}{D^0}\right)_{e^+e^-,\,pp} \simeq 0.13$$

AA @ RHIC & LHC

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

Data from ALICE Coll. JHEP 09 (2012) 112





D^0

Coalescence contribution is smaller at LHC w.r.t. RHIC:

-effect of the slope in p_T

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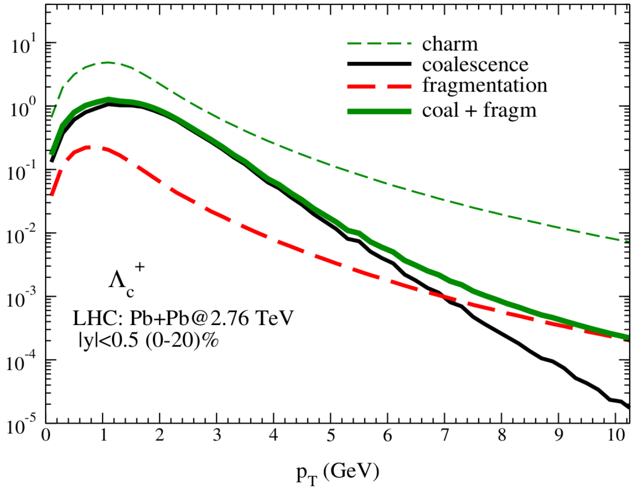

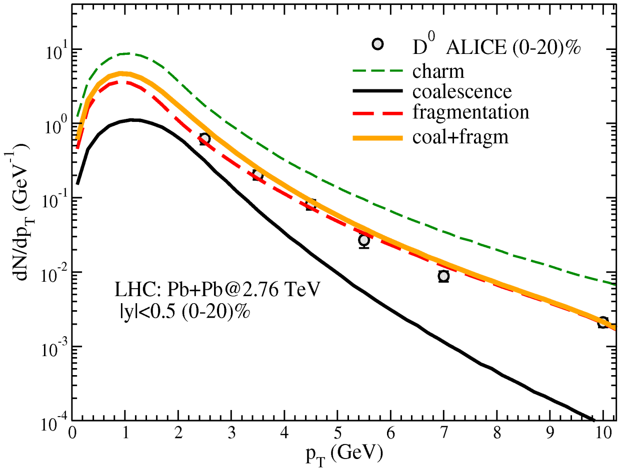

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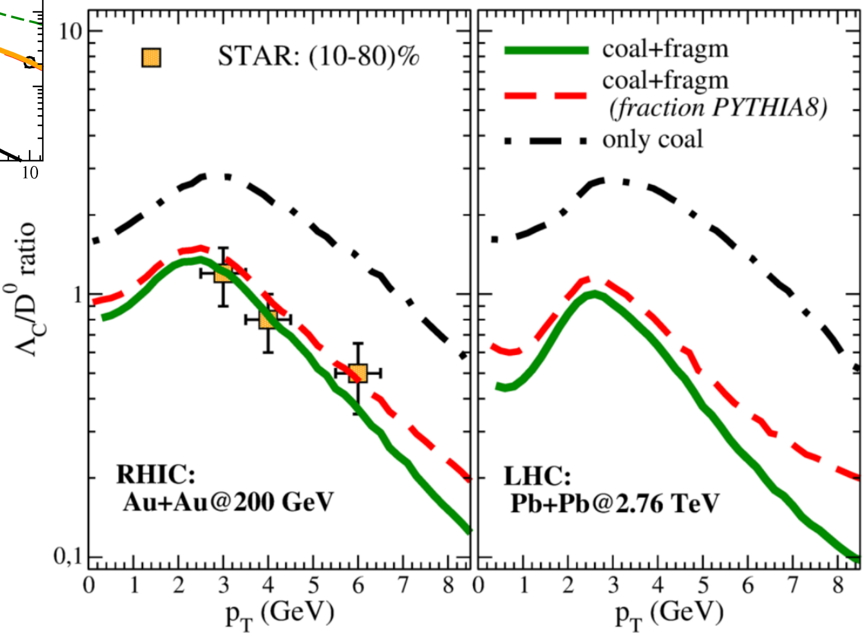


Only Coalescence ratio is similar at both energies.

Λ_c/D^0

Fragmentation ~ 0.1 at both energies.

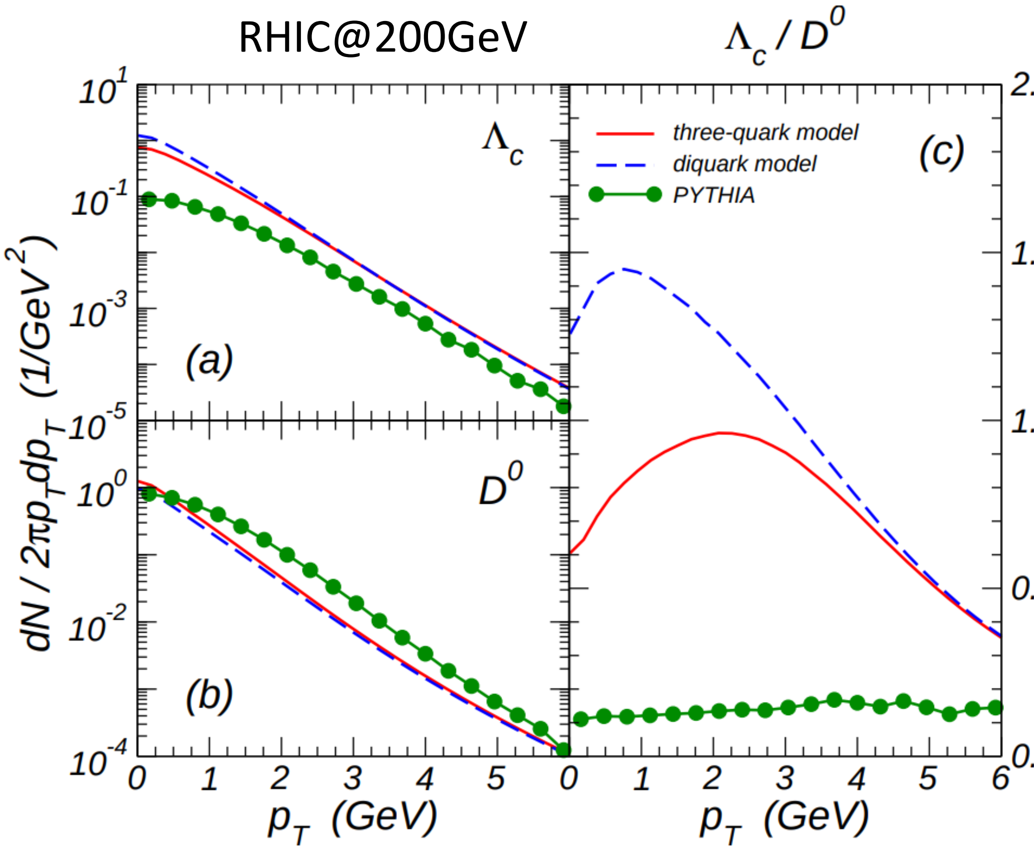
the **combined ratio is different** because the <u>coalescence over fragmentation ratio at LHC is smaller than at RHIC</u>

Therefore at LHC the larger contribution in particle production from fragmentation leads to a final ratio that is smaller than at RHIC.

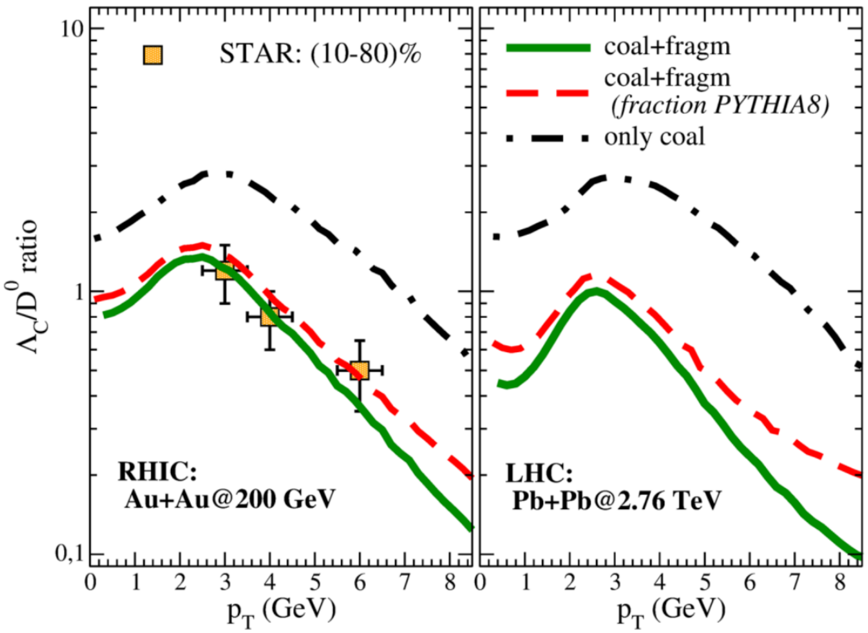
STAR Coll., Phys.Rev.Lett. 124 (2020) 17, 172301

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

AA @ RHIC & LHC



First prediction about baryon over meson ratio in charm sector by Oh,Ko,Lee,Yasui Phys.Rev.C 79 (2009) 044905



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

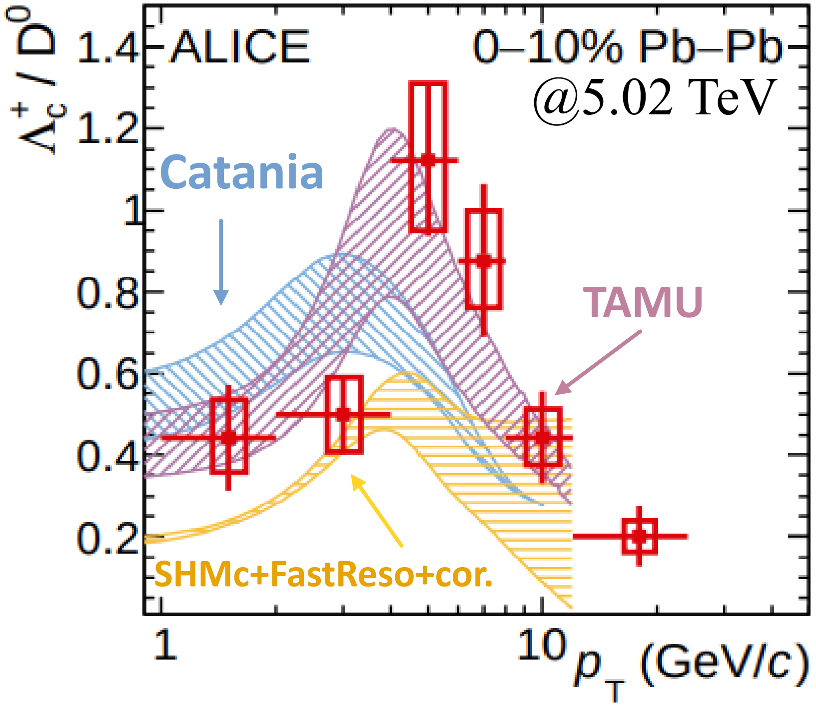
AA @ RHIC & LHC

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

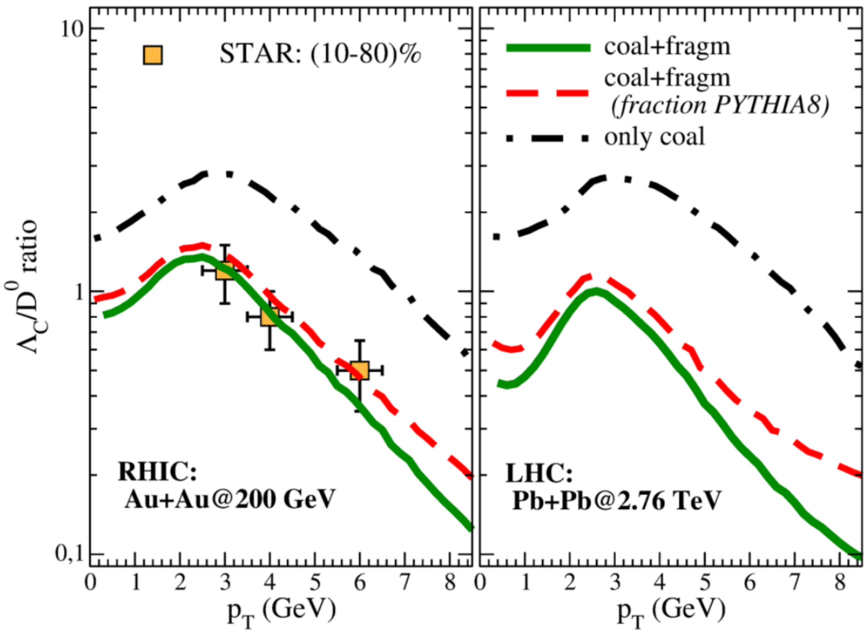
Results for 0-10% in PbPb @5.02TeV:

Consistent with the trend shown at RHIC and LHC @2.76TeV

Available data at low p_T → differences recombination vs SHM



ALICE Coll. arXiv:2112.08156v1



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Baryons in Resonance Recombination Model (RRM - TAMU)

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

STEP 1

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

$q_1(p_1) + q_2(p_2) \rightarrow dq(p_{12})$

The diquark spectrum in analogy to meson formation

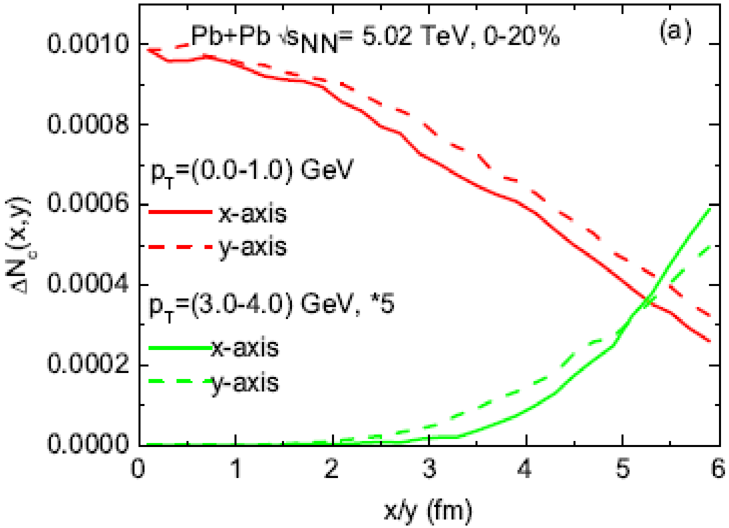
STEP 2

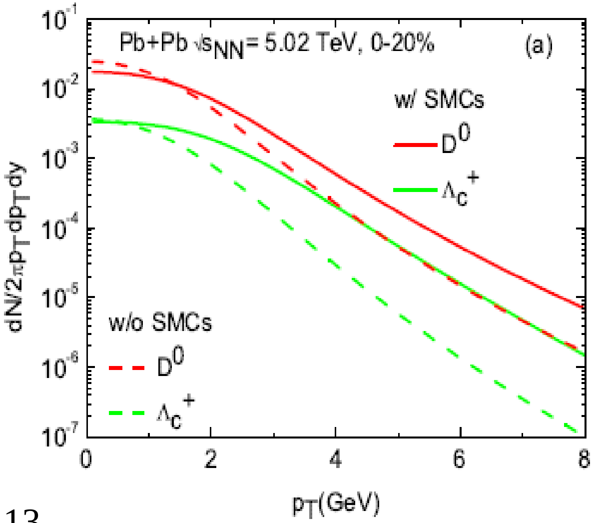
the diquark recombines with quark-3 into a baryon

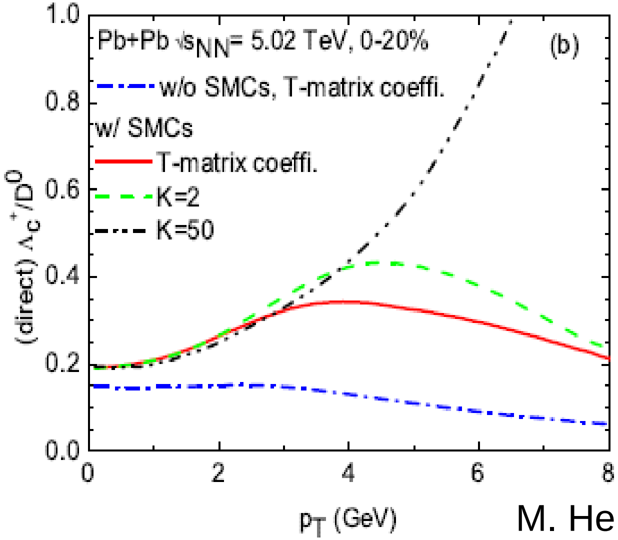
$dq_1(p_{12}) + q_3(p_3) \rightarrow B$

The baryon spectrum in analogy to meson formation

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







Space-momentum correlation

p_T=0-1GeV: c quarks preferentially populate the inner regions of the fireball

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

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The baryon spectrum in analogy to meson formation

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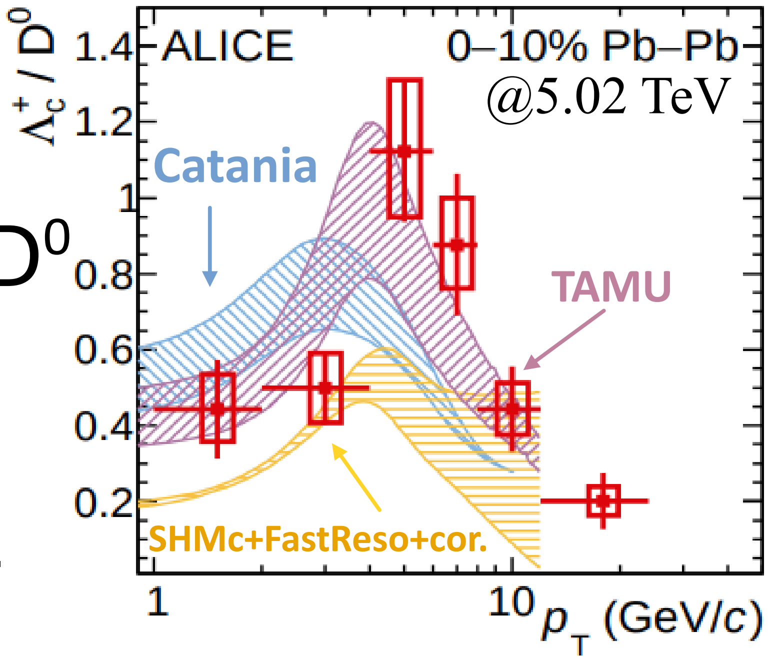
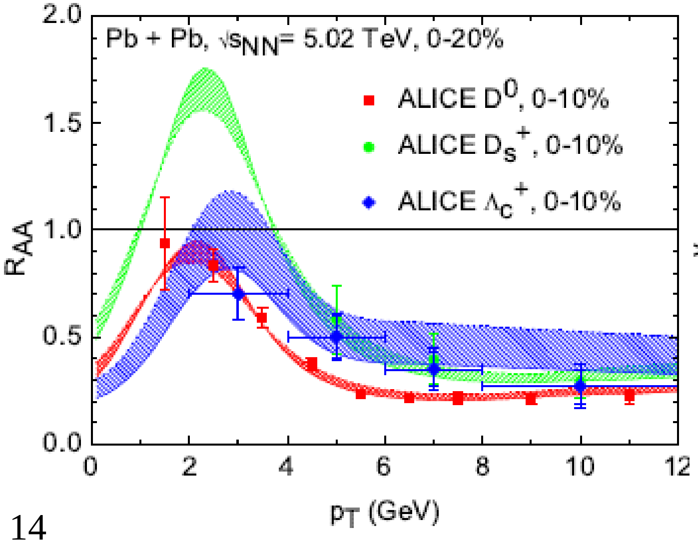
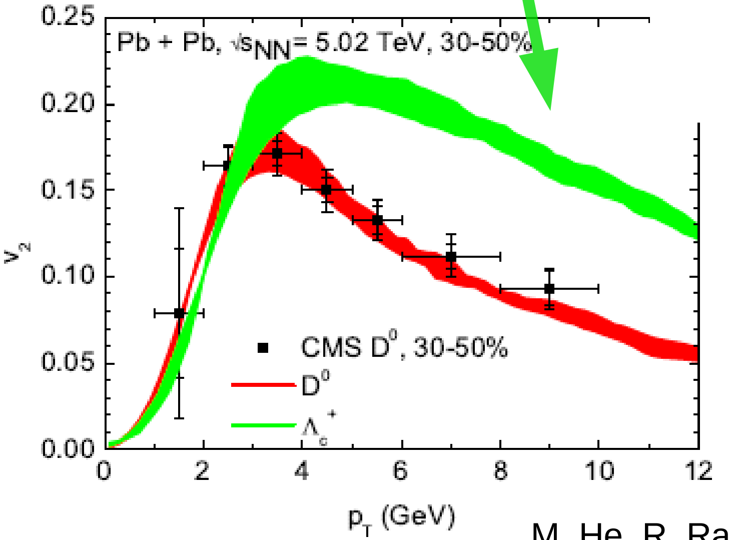
$$\times f_3(\vec{x},\vec{p}_3)\sigma_{dq}(s_{12}) v_{\rm rel}^{12} \sigma_B(s) v_{\rm rel}^{dq3} \delta^3(\vec{p}-\vec{p}_1-\vec{p}_2-\vec{p}_3)$$

Λ_c/D^0



Elliptic flow splitting between baryon and meson





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

PDG: $5\Lambda_c, 3\Sigma_c, 8\ \Xi_c, 2\ \Omega_c$

RQM: $18\ \Lambda_c, 42\ \Sigma_c, 62\ \Xi_c, 34\ \Omega_c$

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

Duke

Y. Xu, S. Cao, M. Nahrgang, W. Ke, G. Qin, J. Auvinen, and S. Bass, Nucl.Part.Phys.Proc. 276 (2016) 225
S. Cao, G. Qin, and S. Bass, PRC92, 024907 (2015)

Instantaneous coalescence model

Mesons

$$\frac{dN_M}{d^3p_M} = \int d^3p_1 d^3p_2 \frac{dN_1}{d^3p_1}\frac{dN_2}{d^3p_2} f_M^W(\vec{p}_1,\vec{p}_2)\delta(\vec{p}_M - \vec{p}_1 - \vec{p}_2)$$

$$f_M^W(q^2) = g_M \frac{(2\sqrt{\pi}\sigma)^3}{V} e^{-q^2\sigma^2}$$

$$\vec{q} \equiv \frac{E_2^{\rm cm}\vec{p}_1^{\,\rm cm} - E_1^{\rm cm}\vec{p}_2^{\,\rm cm}}{E_1^{\rm cm} + E_2^{\rm cm}}$$

Baryons

$$\frac{dN_B}{d^3p_B} = \int d^3p_1 d^3p_2 d^3p_3 \frac{dN_1}{d^3p_1}\frac{dN_2}{d^3p_2}\frac{dN_3}{d^3p_3} f_B^W(\vec{p}_1,\vec{p}_2,\vec{p}_3) \times\delta(\vec{p}_M - \vec{p}_1 - \vec{p}_2 - \vec{p}_3).$$

$$f_B^W(q_1^2,q_2^2) = g_B \frac{(2\sqrt{\pi})^6(\sigma_1\sigma_2)^3}{V^2} e^{-q_1^2\sigma_1^2 - q_2^2\sigma_2^2}$$

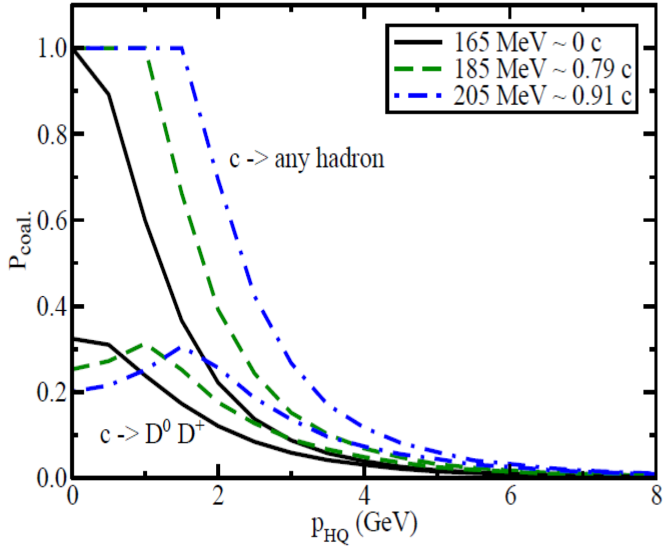
$$\vec{q}_1 \equiv \frac{E_2^{\rm cm}\vec{p}_1^{\,\rm cm} - E_1^{\rm cm}\vec{p}_2^{\,\rm cm}}{E_1^{\rm cm} + E_2^{\rm cm}},$$

$$\vec{q}_2 \equiv \frac{E_3^{\rm cm}(\vec{p}_1^{\,\rm cm} + \vec{p}_2^{\,\rm cm}) - (E_1^{\rm cm} + E_2^{\rm cm})\vec{p}_3^{\,\rm cm}}{E_1^{\rm cm} + E_2^{\rm cm} + E_3^{\rm cm}}$$

Harmonic oscillator relation

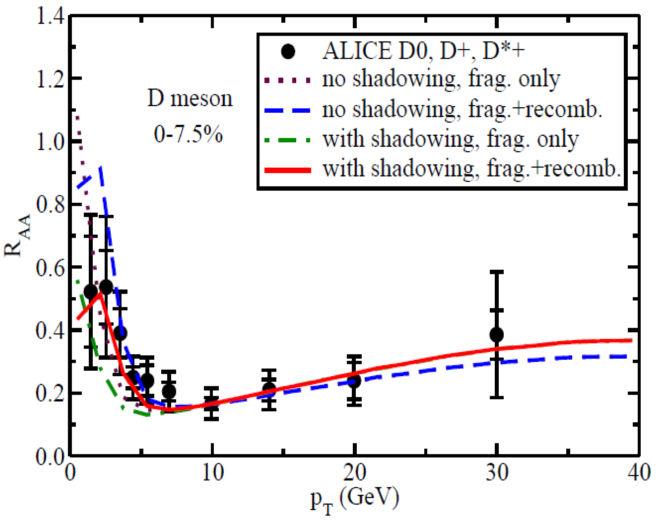
$$\sigma_{ri} = 1/\sqrt{\mu_i\omega}$$

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



Hadron Wigner functions are averaged over the position space

Shadowing in the low momentum region, big effect on R_{AA}



s+p waves resonances

S. Cao, K. Sun, S. Li, S. Liu, W. Xing, G. Qin, and C. Ko, PLB 807 (2020) 135561.
F. Liu, W. Xing, X. Wu, G. Qin, S. Cao, and X. Wang, EPJC 82 (2022) 4, 350.

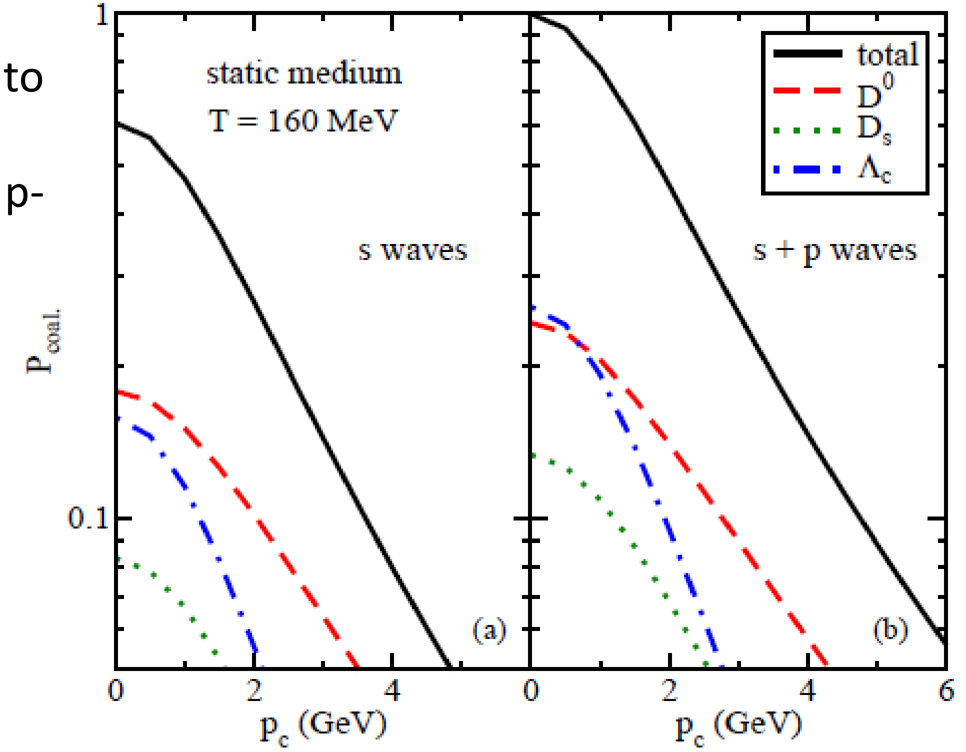
$$f_h(\boldsymbol{p}'_h) = \int \left[\prod_i d\boldsymbol{p}_i f_i(\boldsymbol{p}_i)\right] W(\{\boldsymbol{p}_i\}) \delta(\boldsymbol{p}'_h - \sum_i \boldsymbol{p}_i)$$

- The quark wave functions in the meson is assumed to be those of a harmonic oscillator potential
- The Wigner functions for mesons are in the s and p-wave states

$$W_s = g_h \frac{(2\sqrt{\pi}\sigma)^3}{V} e^{-\sigma^2 \boldsymbol{k}^2},$$

$$W_p = g_h \frac{(2\sqrt{\pi}\sigma)^3}{V} \frac{2}{3} \sigma^2 \boldsymbol{k}^2 e^{-\sigma^2 \boldsymbol{k}^2}$$

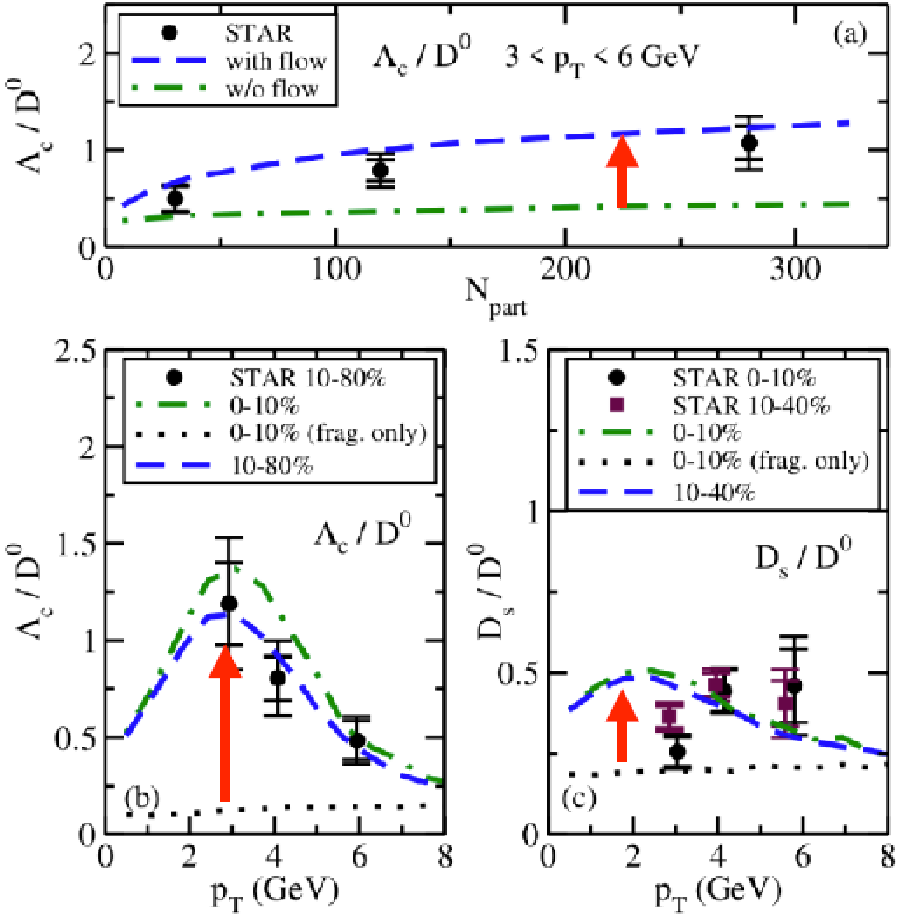
The oscillator frequency is fixed to impose that the total coalescence probability for zero-momentum charm quark is equal to 1 when s and p states are included.



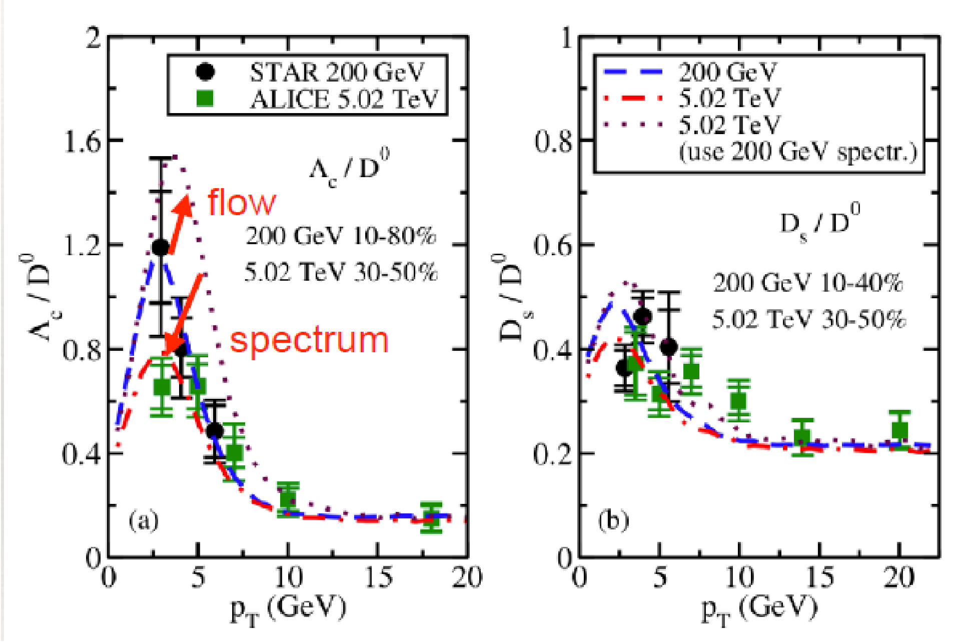
s+p waves resonances

S. Cao, K. Sun, S. Li, S. Liu, W. Xing, G. Qin, and C. Ko, PLB 807 (2020) 135561.
F. Liu, W. Xing, X. Wu, G. Qin, S. Cao, and X. Wang, EPJC 82 (2022) 4, 350.

Stronger QGP flow boost on heavier hadrons
=> increasing Λ_c/D^0 ratio with N_{part}

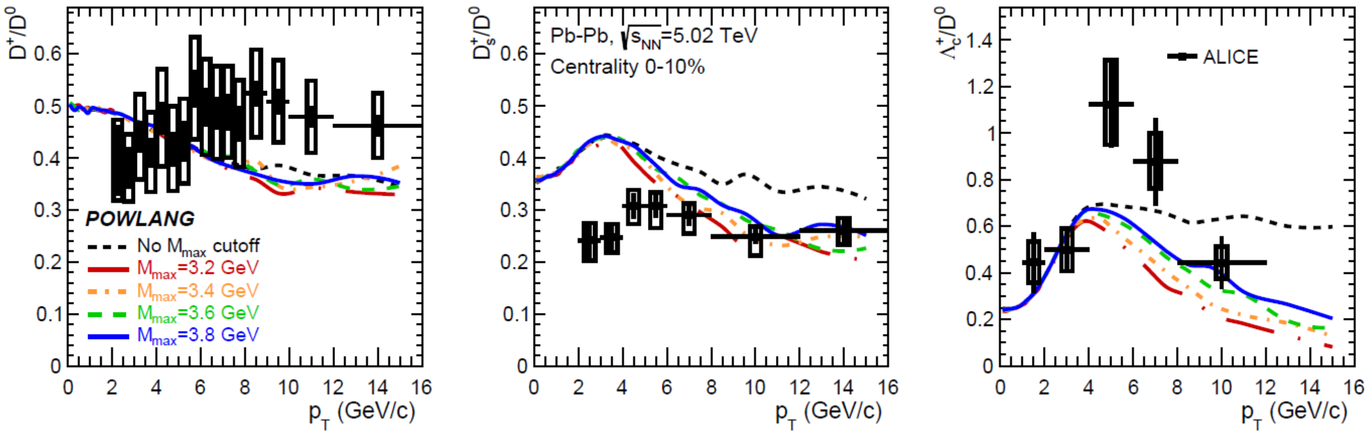


harder initial charm spectra at LHC **reduces** the Λ_c/D^0 ratio



Torino

A. Beraudo et al.,Eur.Phys.J.C 82 (2022) 7, 607



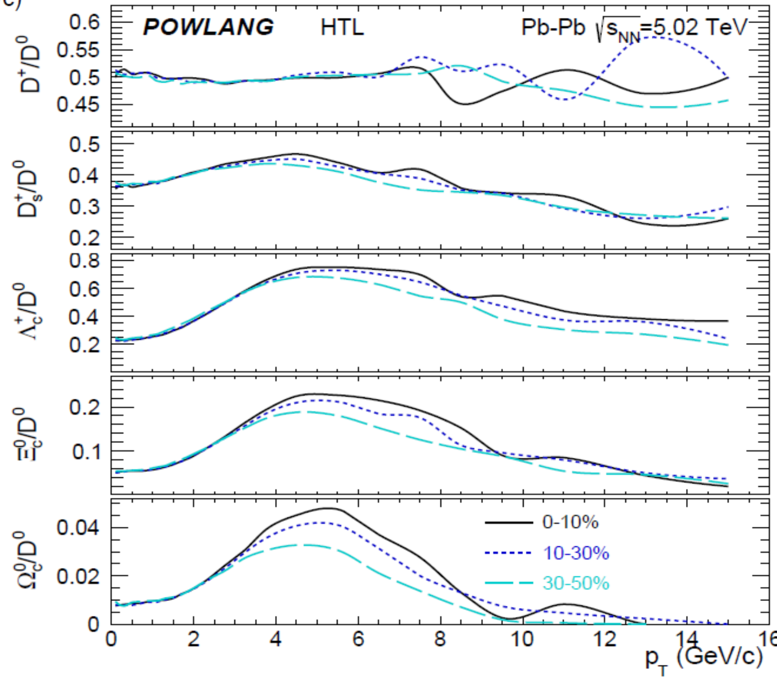
HQ hadronization in the presence of a reservoir of lighter thermal particles:

Recombination of the HQ with light antiquark or <u>diquarks</u>:

- Color-singlet clusters with low invariant mass M (M<4 GeV) are assumed to undergo an isotropic 2-body decay in their local rest-frame.
- Heavier clusters are instead fragmented as Lund strings.

➢ Recombination with light diquarks → enhances the yields of charmed baryons.

➢ The local color neutralization → strong space-momentum correlation → enhancement of the collective flow of the final charmed hadrons



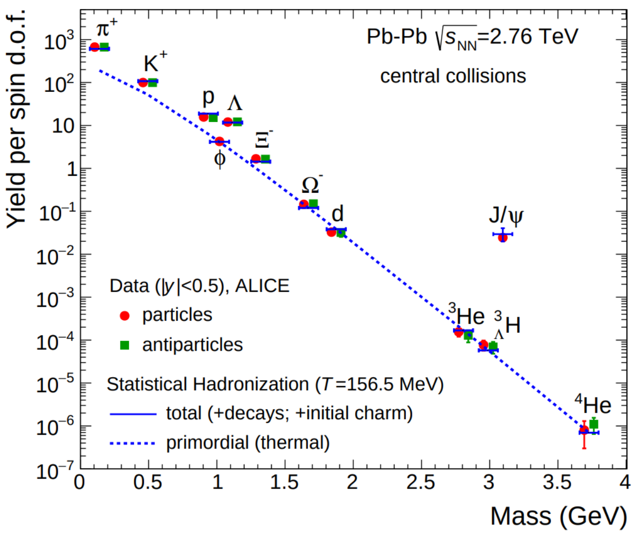
Statistical Thermal Model (SHM) + charm(SHMc)

grand canonical partition function

$$\ln Z_i = \frac{V g_i}{2\pi^2} \int_0^\infty \pm p^2 dp \ln\left[1 \pm \exp\left(-(E_i - \mu_i)/T\right)\right]$$

chemical potential ↔ conservation quantum numbers (N_B, N_s, N_c)

Braun-Munzinger, Stachel, PLB 490 (2000) 196



Equilibrium + hadron-resonance gas + freeze-out temperature.

Production depends on hadron masses and degeneracy, and on system properties.

***Charm hadrons** according to thermal weights*

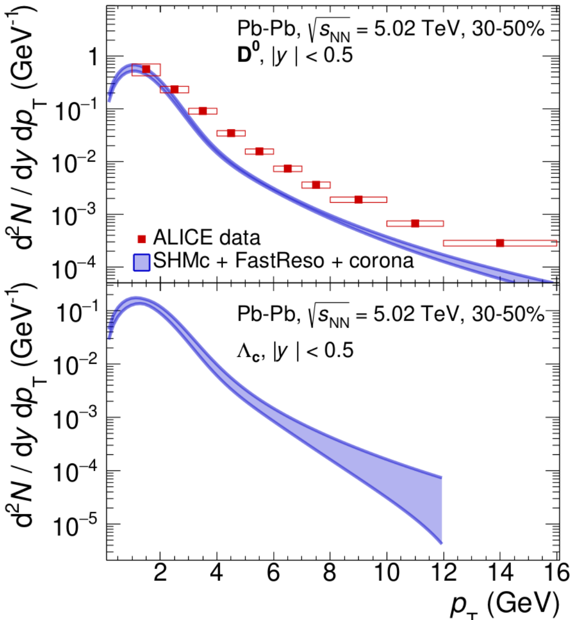
the *total charm content* of the fireball is fixed by the *measured open charm cross section*.

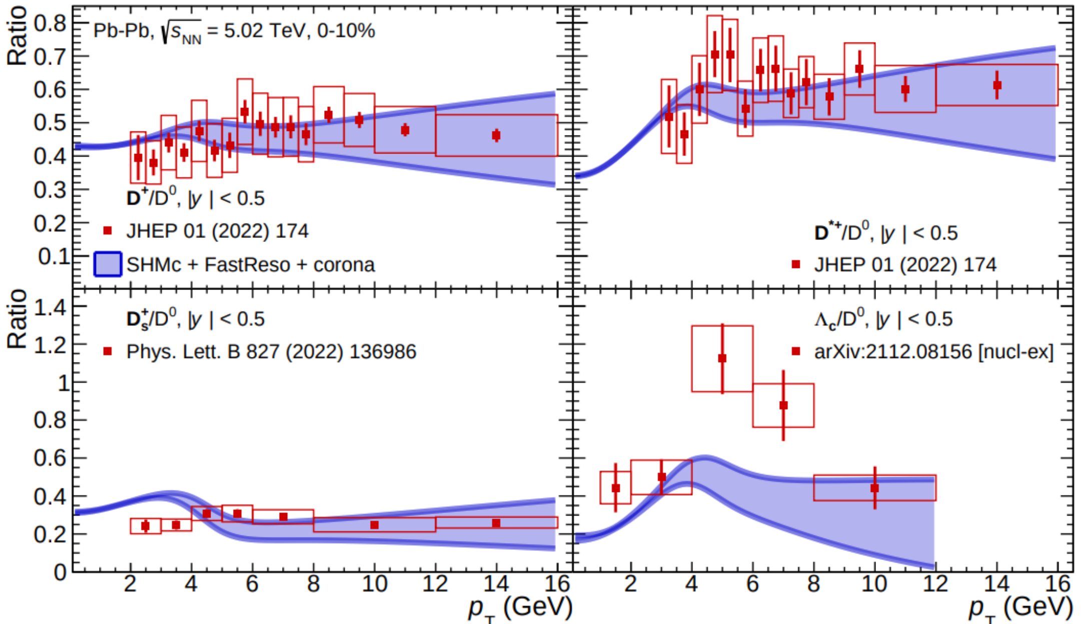
$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c V \left(\sum_i n_{D_i}^{th} + n_{\Lambda_{ci}}^{th} \right) + g_c^2 V \left(\sum_i n_{\psi_i}^{th} + n_{\chi_i}^{th} \right)$$

pQCD production $N_{c,\text{anti-c}}$ = 9.6 → g_c = 30.1 (charm fugacity)

Andronic et al., JHEP 07 (2021) 035

SHMc yields+blast wave →p_T spectra





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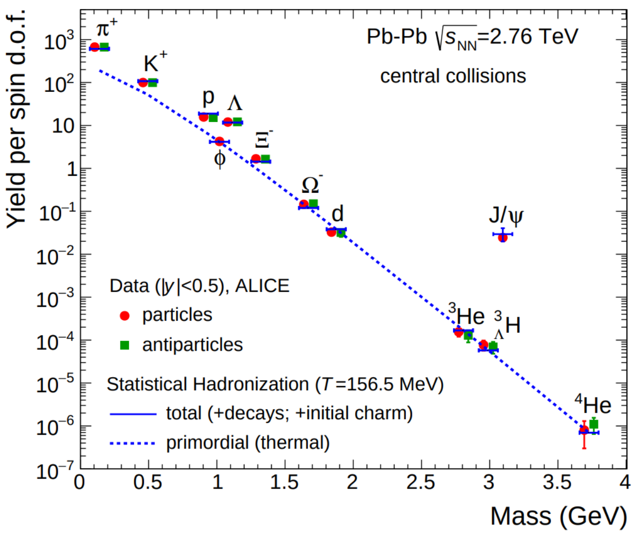
Braun-Munzinger, Stachel, PLB 490 (2000) 196



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Andronic et al., JHEP 07 (2021) 035

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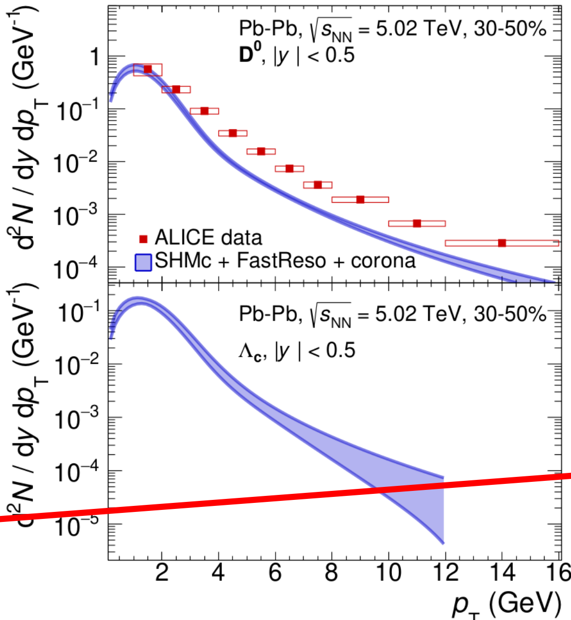
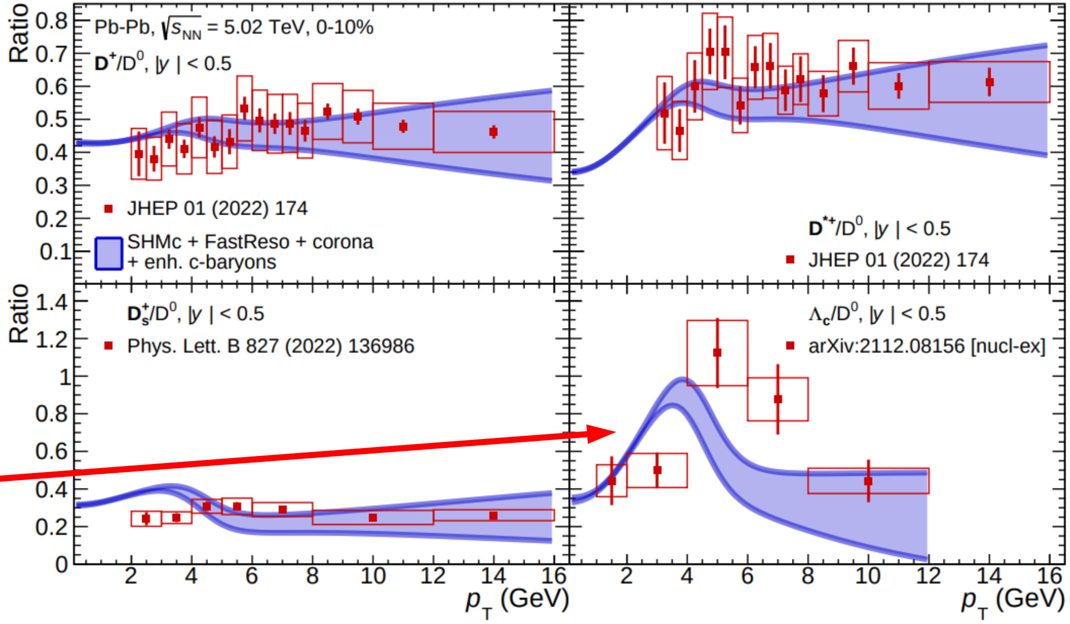
With enhanced set of charmed baryons



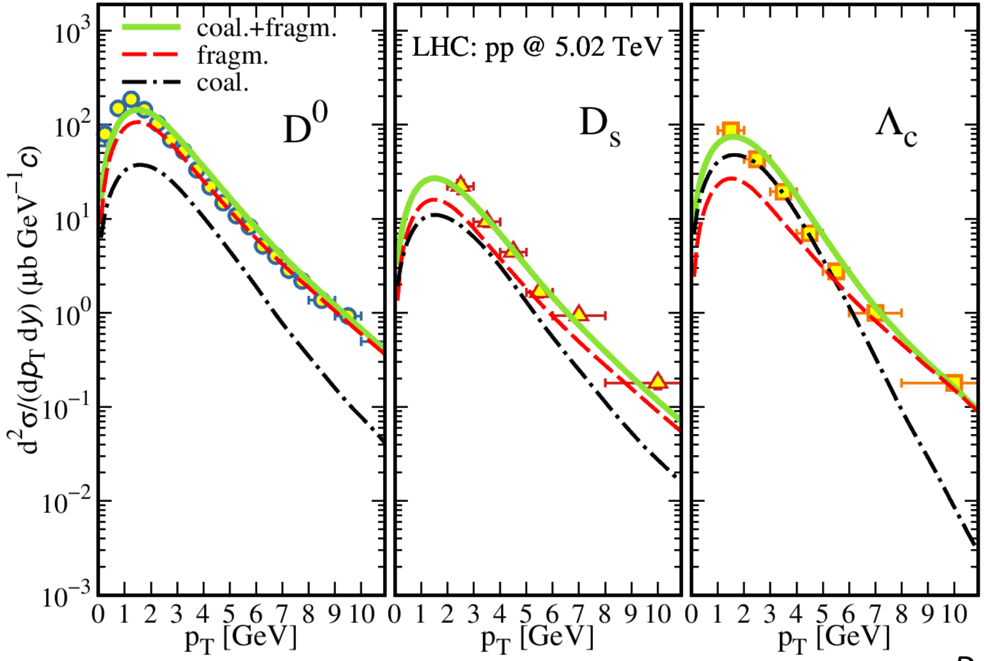


Small systems: Coalescence in pp?

What if:

- **Assuming QGP formation also in pp?**
- **What coalescence+fragmentation predicts in this case?**

V. Minissale, S. Plumari, V. Greco, Physics Letters B 821 (2021) 136622



Data from:
S. Acharya et al. (ALICE), Eur. Phys. J. C 79, 388 (2019)
ALICE Coll., Phys.Rev.Lett. 127 (2021) 20, 202301 - Phys.Rev.C 104 (2021) 5, 054905

If we assume in p+p @ 5 TeV a medium similar to the one simulated in hydro:

p+p @ 5 TeV

- τ_{pp}=2 fm/c
- β_0=0.4
- R=2.5 fm
- V~30 fm^3

LIGHT

- Thermal Distribution (p_T< 2 GeV)

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

- Minijet Distribution (p_T> 2 GeV)
  NO QUENCHING

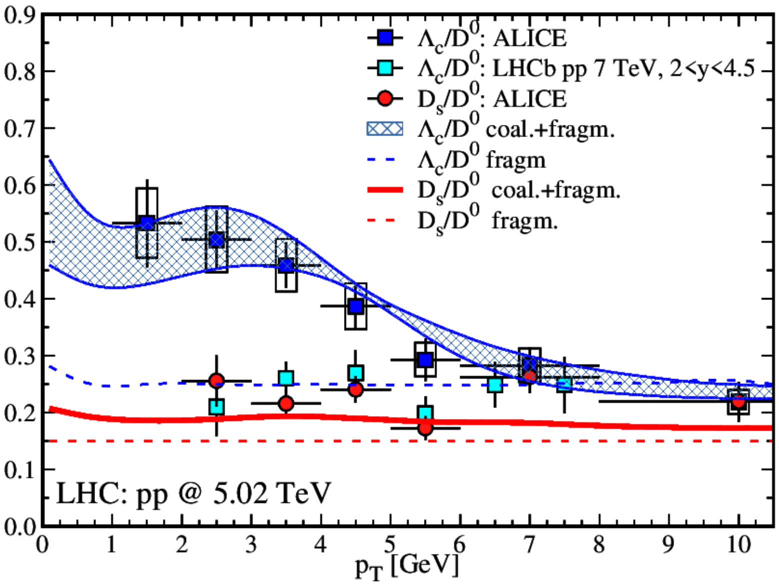
CHARM

FONLL Distribution

wave function widths σ_p of baryon and mesons kept the same from AA to pp

Small systems: Coalescence in pp?

V. Minissale, S. Plumari, V. Greco, Physics Letters B 821 (2021) 136622



Reduction of rise-and-fall behaviour in Λ_c / D^0 ratio:

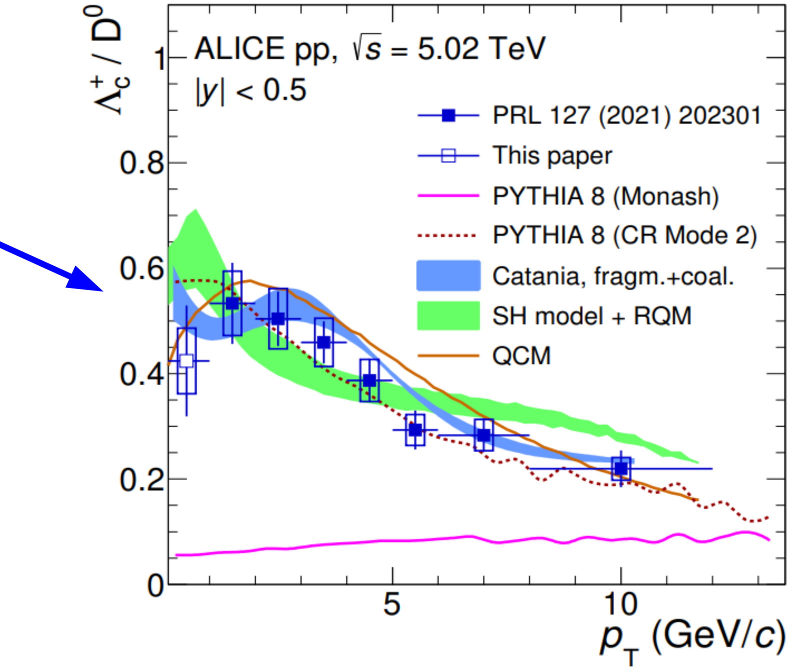
-Confronting with AA: Coal. contribution smaller w.r.t. Fragm.

-FONLL distribution flatter w/o evolution trough QGP

-Volume size effect

ALICE, Phys.Rev.Lett. 127 (2021) 20, 202301
ALICE,CERN-EP-2022-261, arXiv:2211.14032 (sub. to PRC)

new low p_T point



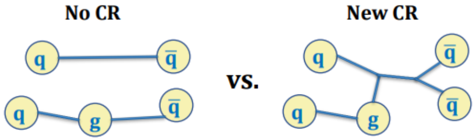
Error band correspond to <r^2> uncertainty in quark model

Other models:

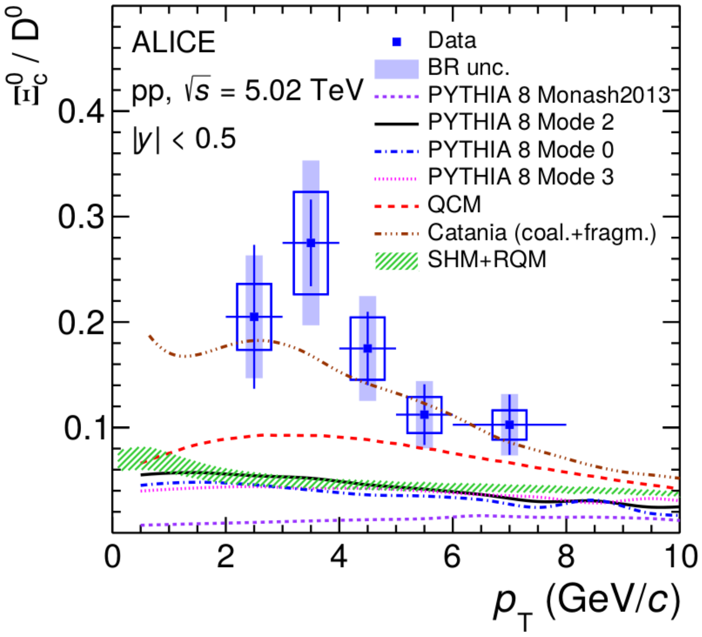
He-Rapp, Phys.Lett.B 795 (2019) 117-121: Increase≈2 to Λ_c production: SHM with resonance not present in PDG

PYTHIA8 + color reconnection

CR with SU(3) weights and string length minimization



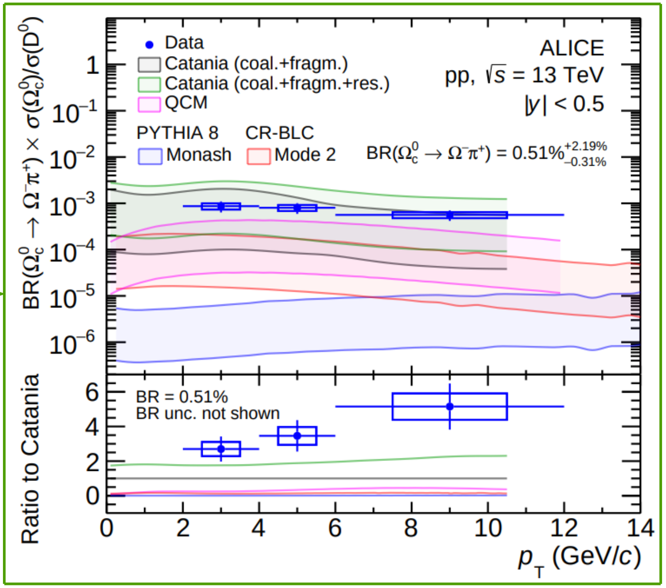
Small systems: Coalescence in pp?

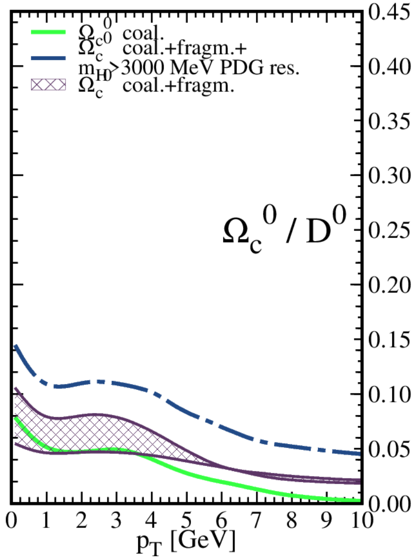


New measurements of heavy hadrons at ALICE:

- Ξ_c/D^0 ratio, same order of Λ_c/D^0: coalescence gives enhancement
- very large Ω_c/D^0 ratio, our model does not get the big enhancement

Uncertainties bands coming from the Branching Ratio error





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 $\langle r^2 \rangle$ uncertainty in quark model

ALICE Coll. JHEP 10 (2021) 159
ALICE Coll. arXiv:2205.13993

V. Minissale, S. Plumari, V. Greco, Physics Letters B 821 (2021) 136622

Thank you