Heavy flavour hadron production in a coalescence plus fragmentation approach from AA to pp

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COALESCENCE INTEGRAL

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

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

Fireball Parameters

Constraints from Experiment

RHIC →LHC

$dE_T/dy \sim 740$ GeV→2100 GeV

$dN_{ch}/dy \approx 670 \rightarrow 1600$

$T_c \sim 165$ MeV

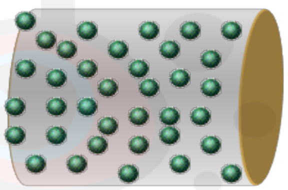
Lifetime and Volume

$\tau \sim 4.5$ fm/c → 7.8 fm/c

$\beta_0 = 0.37 \rightarrow 0.63$

V ~ 1100 fm³ → 2500 fm³

In agreement with HBT



LIGHT QUARK

- Thermal Distr.(p_T<2 GeV) w/Collective flow

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

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

- Minijet Distr.(p_T>2 GeV)

HEAVY QUARK (initial state)

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

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

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

A_W fixed to have all charm hadronizing at $p_T \rightarrow 0$

σ_r width parameter related to the oscillator frequency ω with reduced mass and linked to the hadron size

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

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

$\langle r^2 \rangle_{ch}^{D^0} = 0.184\ fm^2$ $\quad \sigma_p^{D^0} = \sigma_r^{-1\,D^0} = 0.283\ GeV$ $\quad \sigma_{p2}^{\Lambda_c} = 0.342\ GeV$

$\langle r^2 \rangle_{ch}^{\Lambda_c} = 0.15\ fm^2$ $\quad \sigma_{p1}^{\Lambda_c} = 0.18\ GeV$

References

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

Y. Oh, C.M. Ko, S.H. Lee, S. Yasui, **Phys. Rev. C79,044905 (2009)**

F. Scardina, S.K. Das, V. Minissale, S. Plumari, V. Greco, **Phys.Rev. C96 (2017) no.4, 044905**

V.Minissale, F. Scardina,V.Greco**, Phys.Rev.C 92 (2015)**

V.Greco, C.M. Ko, P. Levai, **Phys.Rev.C 68 (2003) 034904**

Fragmentation function

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

Peterson fragmentation function
C. Peterson, et al. PRD **27** (1983) 105

The distribution function is evaluated at the Fixed-Order plus Next-to-Leading-Log (FONLL)
M. Cacciari, P. Nason, R. Vogt, PRL 95 (2005) 122001

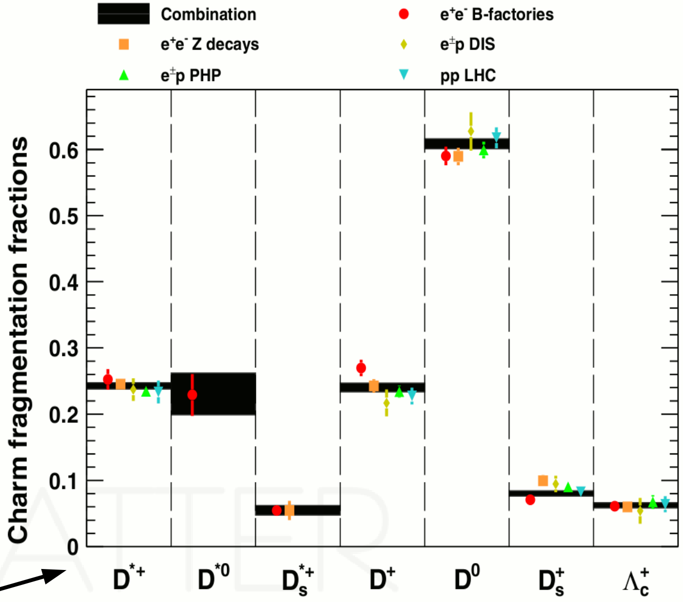
In AA: bulk+charm evolution with Relativistic Transport Boltzmann Equation

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

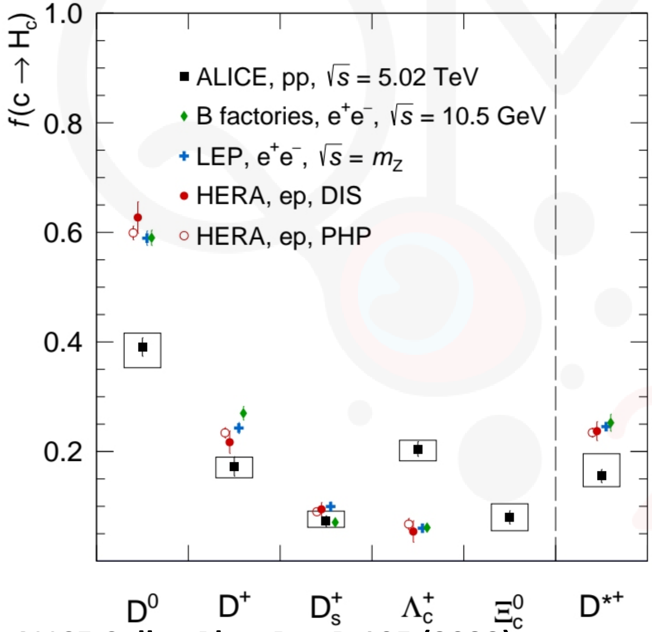
ε set to reproduce tail of the Λ_c and D^0 spectra

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

Charm fragmentation fractions come from analysis of charm hadrons production in elementary collisions systems



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

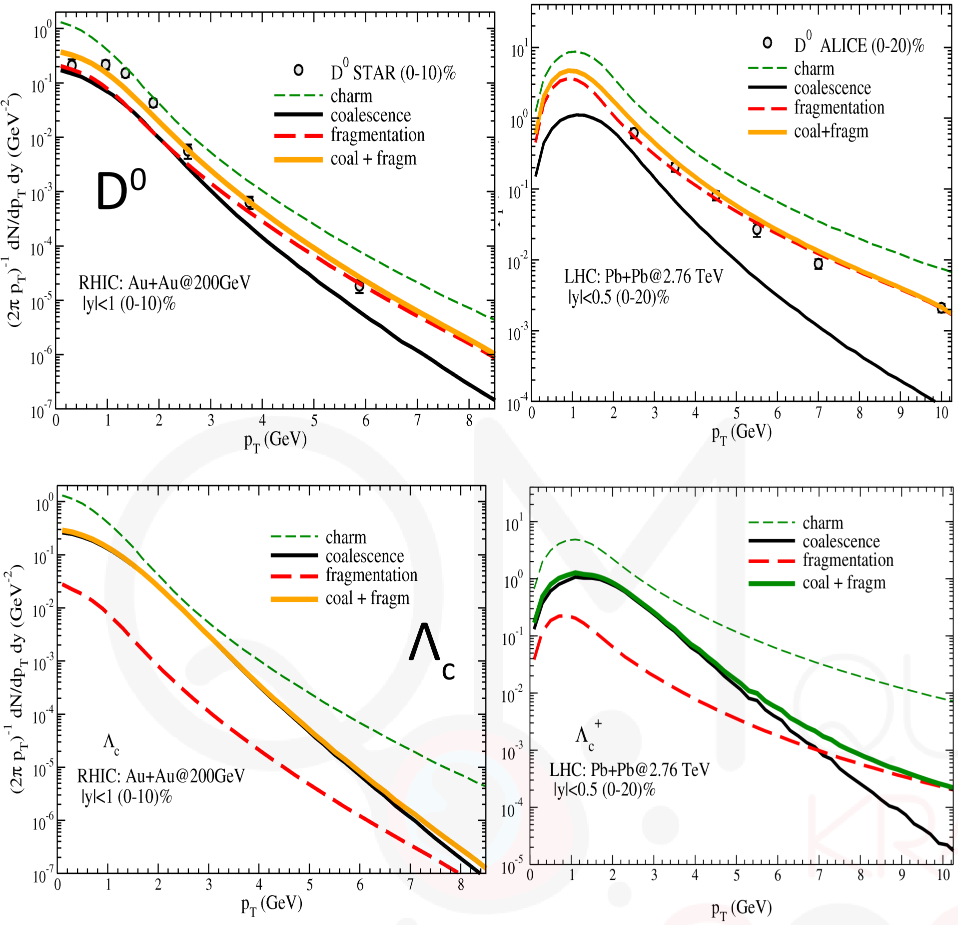


ALICE Coll. ; Phys.Rev.D 105 (2022)

Updated fractions after experimental evidence in pp@5TeV:

Fragmentation fractions ($c\to h$) depends on collision system...*and QGP presence*?

No more Universality?



Coalescence lower at LHC than at RHIC

For D^0 main contribution from Fragmentation

For Λ_c main contribution from Coalescence

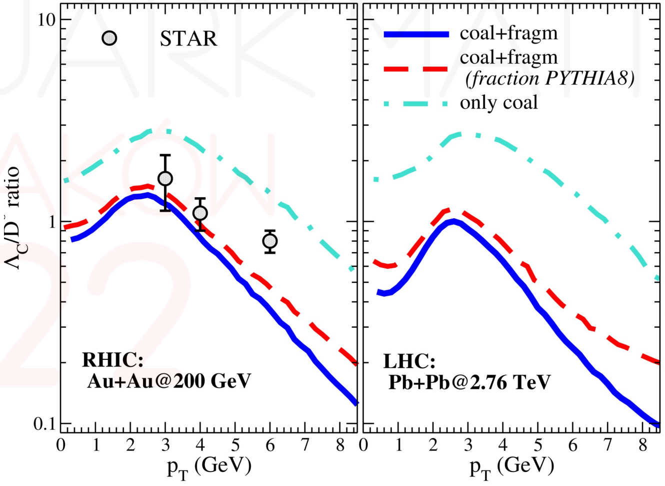
S. Plumari, V. Minissale et al., Eur. Phys. J. ***C78*** *no. 4, (2018) 348*

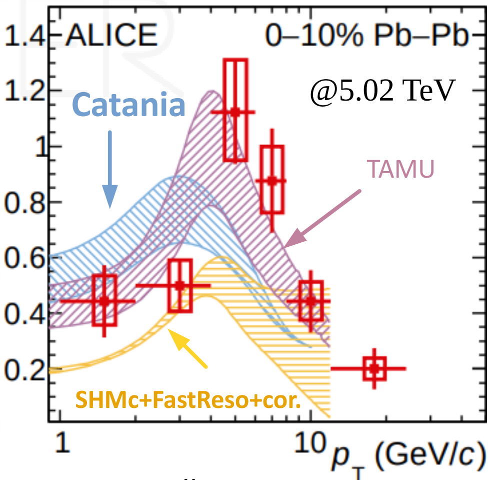
In AA collisions:

Only Coalescence ratio is similar at both energies.
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.





ALICE Coll. arXiv:2112.08156v1

pp collisions

Possible presence of QGP in smaller system.
Assuming QGP formation what coal.+fragm. predicts?

CHARM

FONLL Distribution

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

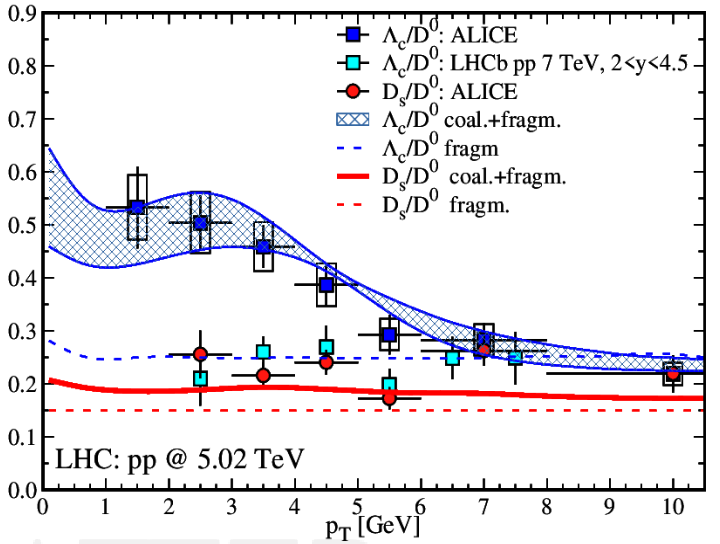
V. Minissale, S. Plumari, V. Greco, Phys.Lett.B821 (2021) 136622

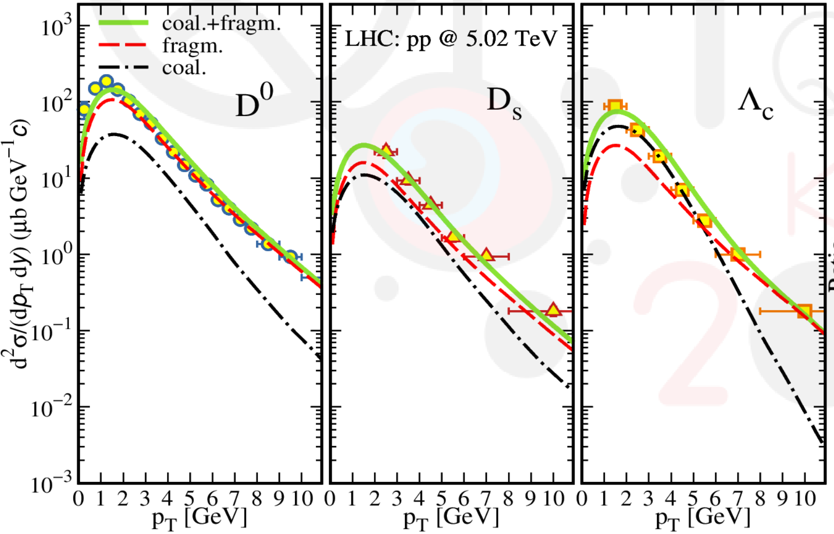
Reduction of rise-and-fall behaviour in Λ_c / D^0 ratio:

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

-FONLL distribution flatter w/o evolution in QGP

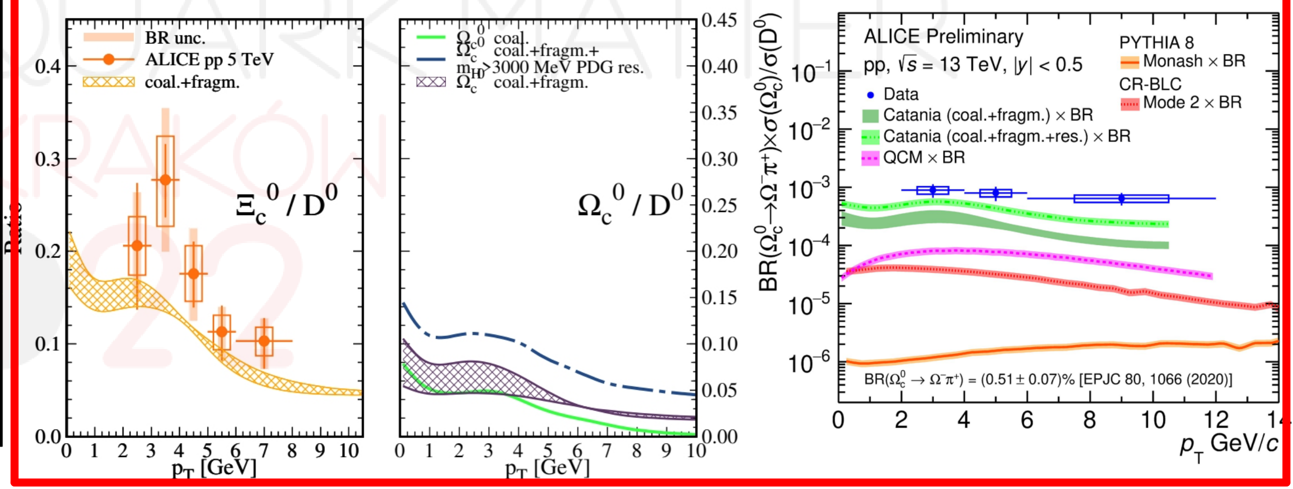
-Volume size effect





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



Implications, developments and outlooks:

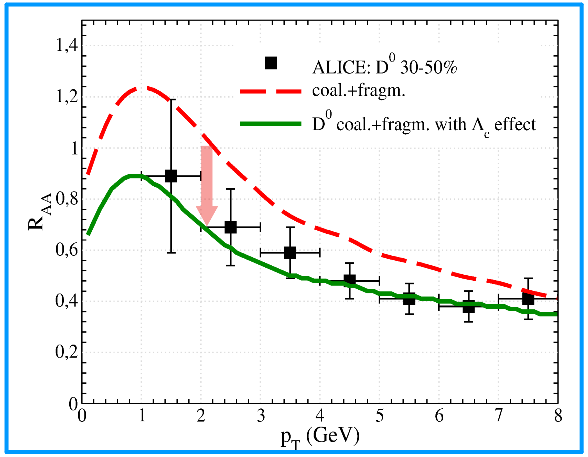
Bulk evolution

$$\underbrace{p^{\mu}\partial_{\mu}f_{q,g}(x,p)}_{\text{free-streaming}} + \underbrace{M(x)\,\partial_{\mu}^{x}M(x)\,\partial_{p}^{\mu}f_{q,g}(x,p)}_{\text{field interaction } \varepsilon-3p\neq 0} = \underbrace{C_{22}[f_{q,g}]}_{\text{collisions } \eta\neq 0}$$

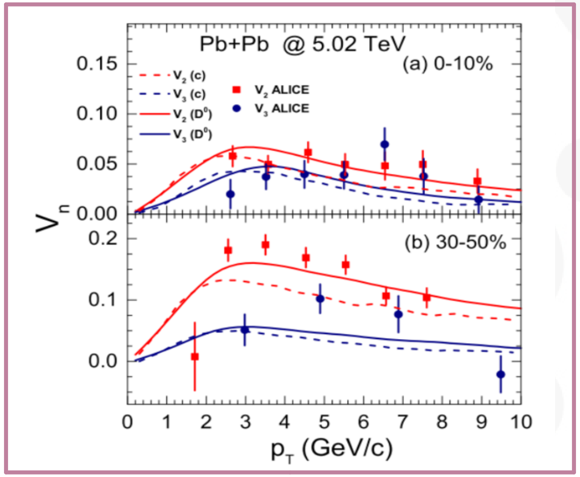
Heavy quark evolution

$$p^{\mu}\partial_{\mu}f_{Q}(x,p)=C[f_{q},f_{g},f_{Q}]$$

The Relativistic Boltzmann transport eq. simulations give us the parton distribution of charm and bottom, and allow us to extend the study of the impact of hadronization.

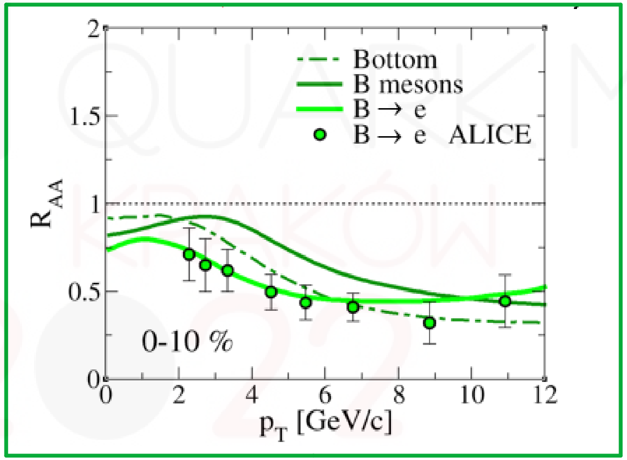


The large Λ_c production has effects on the R_{AA} of D^0, because of the charm conservation



Coalescence give an enhancement to the $v_n(p_T)$ of final hadrons compared to the charm $v_n(p_T)$.

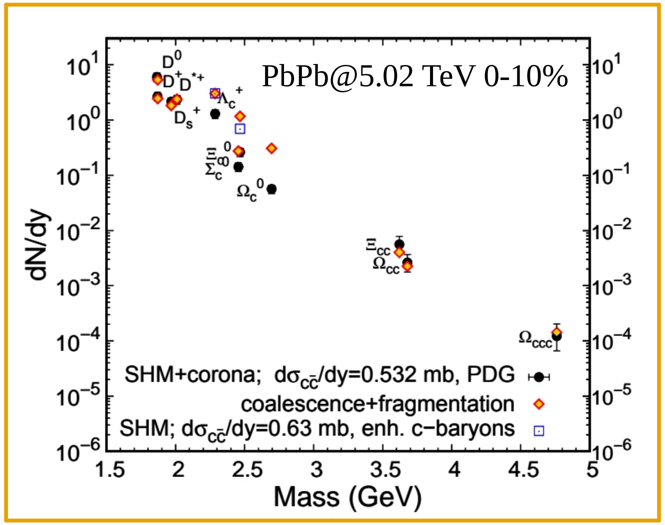
Sambataro,Sun,Minissale,Plumari,Greco(in preparation)



Electrons from semileptonic B meson decay with a coal + fragm model for B meson production

Sambataro, Minissale et al.(in preparation)

MULTICHARM



Yields of multicharm hadrons similar to SHM in PbPb, possible effects with system size and on the distribution vs p_T are under investigation.

A baryon like Ω_{ccc} formed only by heavy quarks can give insights on the baryon wave function and the potential $V_{cc}(r,T)$ between quarks.

Enhancement for single charmed baryons as seen in pp collisions.

Minissale, Plumari, Greco (in preparation)