

Beauty production in small systems with ALICE at the LHC

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On behalf of the ALICE collaboration

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Motivation for measuring beauty in small systems

Test perturbative QCD (pQCD)

- heavy-flavours (HFs) are produced in hard processes ($Q^2 \geq m_{\text{HF}}^2$)
- production expected to be described by pQCD

Heavy-quark fragmentation

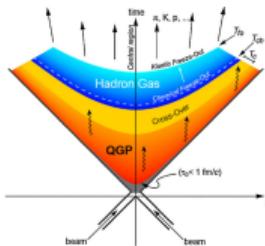
- investigate hadronisation mechanisms and test predictions from different quark-fragmentation models

$$d\sigma^h = \sum_{a,b,n} f_a(x_a, Q^2) \otimes f_b(x_b, Q^2) \otimes d\sigma_{ab \rightarrow n} \otimes D_{n/h}(z, Q^2)$$

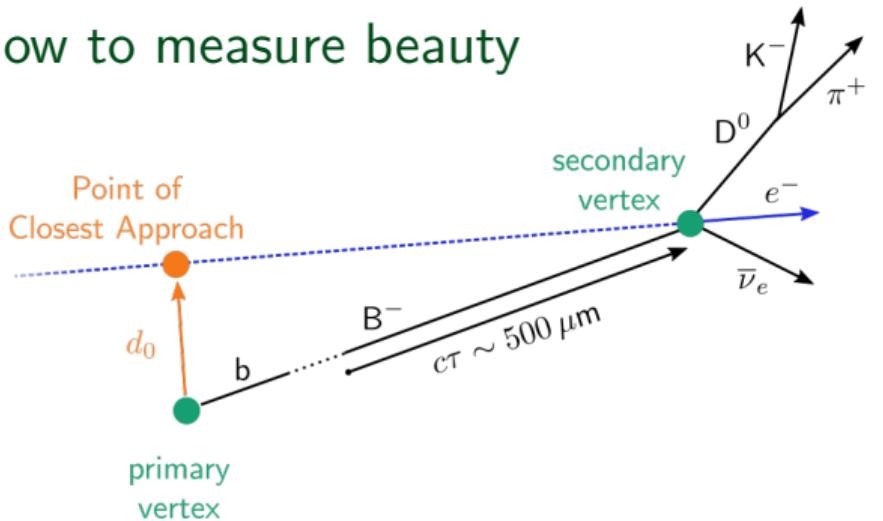
[HIC Figure: P. Braun-Munzinger, B. Dönicus; Nucl.Phys. A 987 (2019)]

Reference for heavy-ion collisions (HIC)

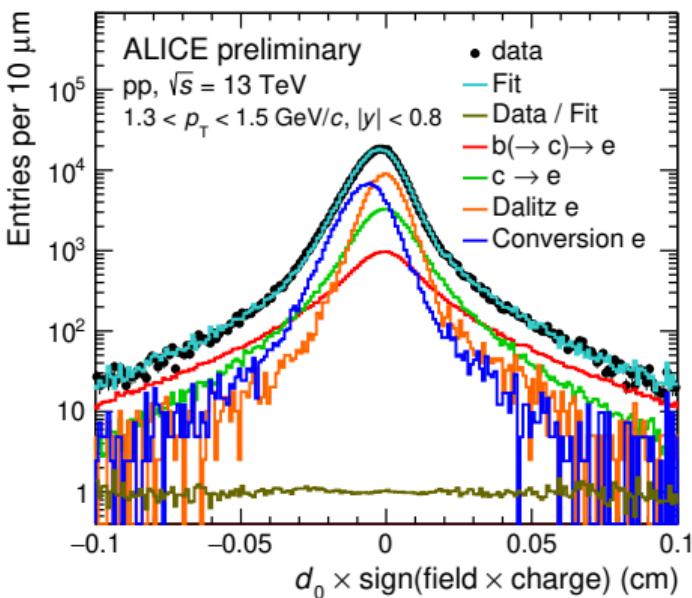
- pp collisions are studied as reference for heavy-ion collisions
- HFs are produced early in HIC
→ their properties provide information on characteristics of the quark-gluon plasma (QGP)
- HF polarisation sheds light on initial conditions right after the collision



How to measure beauty



- weak decays of beauty hadrons exhibit long lifetimes
 → can be identified using displaced secondary vertices
- beauty production is measured via
 - statistical methods (template fits)
 - identification of beauty jets
 - machine-learning based selection of non-prompt charm hadrons

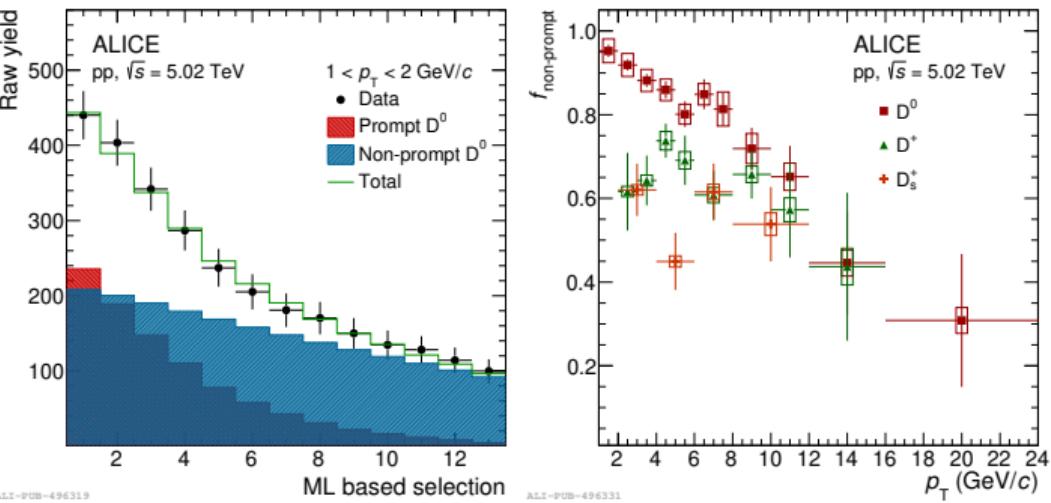


ALI-PREL-503685

Separation of prompt & non-prompt charm hadrons

ALICE, JHEP05 (2021) 220

- Machine Learning (ML) approach:
 - multi-class classification algorithm for Boosted Decision Trees to separate
 - prompt charm hadrons
 - non-prompt charm hadrons
 - combinatorial background
- signal extraction via fits to invariant mass distributions of candidates selected with ML techniques



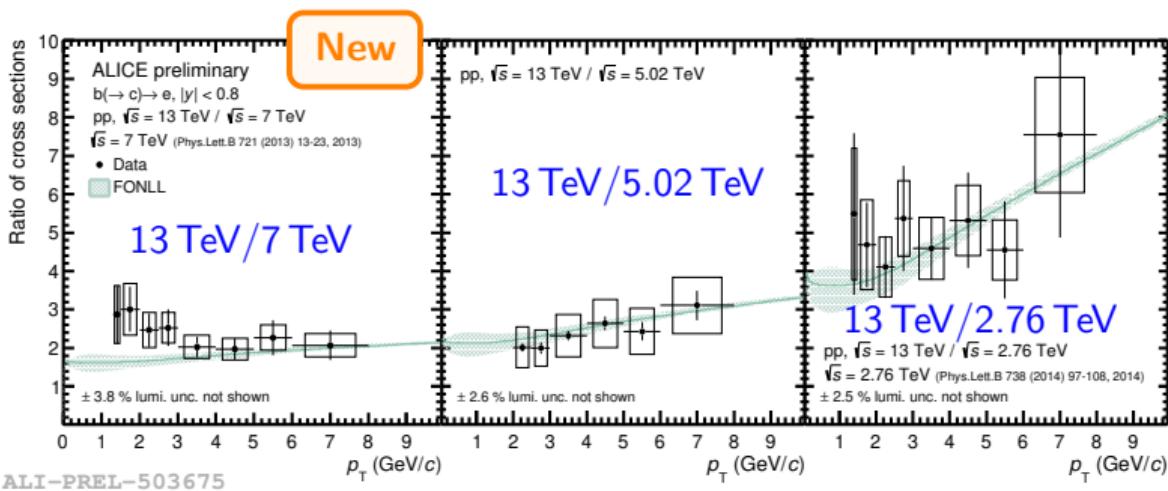
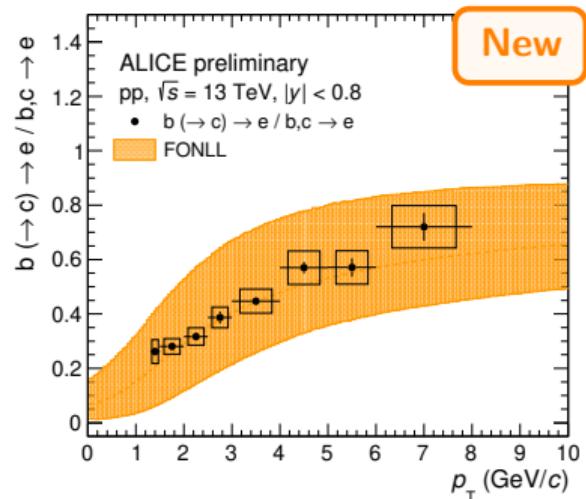
- data-driven procedure to determine raw $f_{\text{non-prompt}}(N^p, N^{np})$
- χ^2 minimisation of equation system for different ML selections i to determine N^p, N^{np}

$$Y_i = \epsilon_i^p N^p + \epsilon_i^{np} N^{np}$$

Yields (from data), Acc \times eff (from MC), True Yields

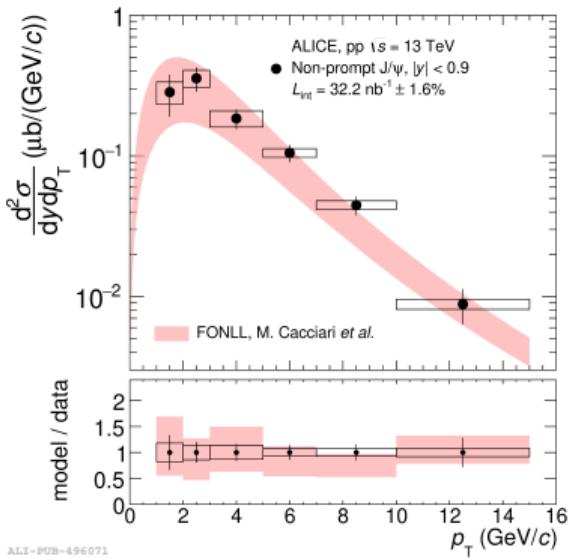
Beauty-electron production in 13 TeV pp collisions

- p_T -dependent beauty-electron fraction and cross section ratios at different centre-of-mass energies compatible with FONLL calculations
- contribution of beauty-decay electrons dominating for $p_T > 5 \text{ GeV}/c$



Non-prompt J/ψ production in 5.02 TeV and 13 TeV pp collisions

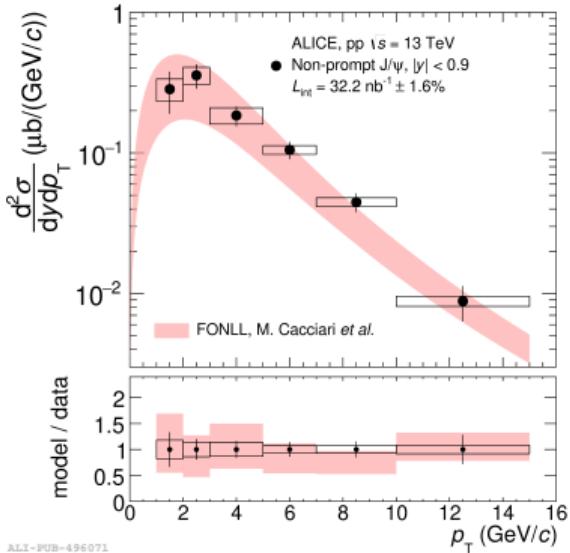
ALICE, JHEP03 (2022) 190



→ p_T -differential non-prompt J/ψ cross section compatible with FONLL

Non-prompt J/ψ production in 5.02 TeV and 13 TeV pp collisions

ALICE, JHEP03 (2022) 190



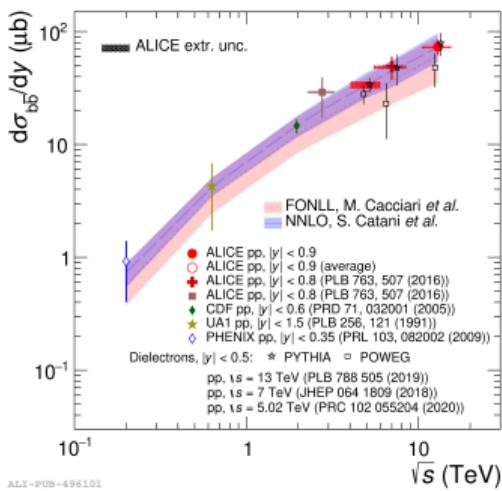
→ p_T -differential non-prompt J/ψ cross section compatible with FONLL

→ σ_{bb^-} calculated using $\text{BR}(h_B \rightarrow J/\psi + X)$ from FONLL

$$\sigma_{bb^-}^{13 \text{ TeV}} = 541 \pm 45(\text{stat.}) \pm 69(\text{syst.})^{+10}_{-12}(\text{extr.}) \mu\text{b} \quad \text{compatible with LHCb}$$

$$\sigma_{bb^-}^{5.02 \text{ TeV}} = 218 \pm 37(\text{stat.}) \pm 32(\text{syst.})^{+8.2}_{-9.1}(\text{extr.}) \mu\text{b}$$

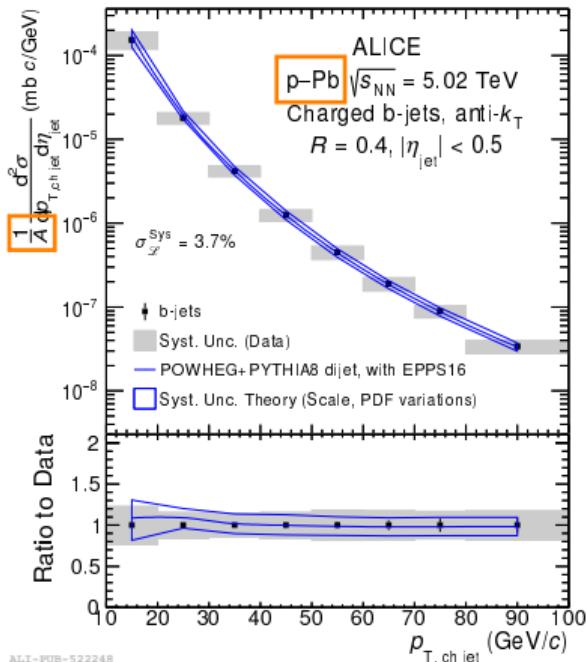
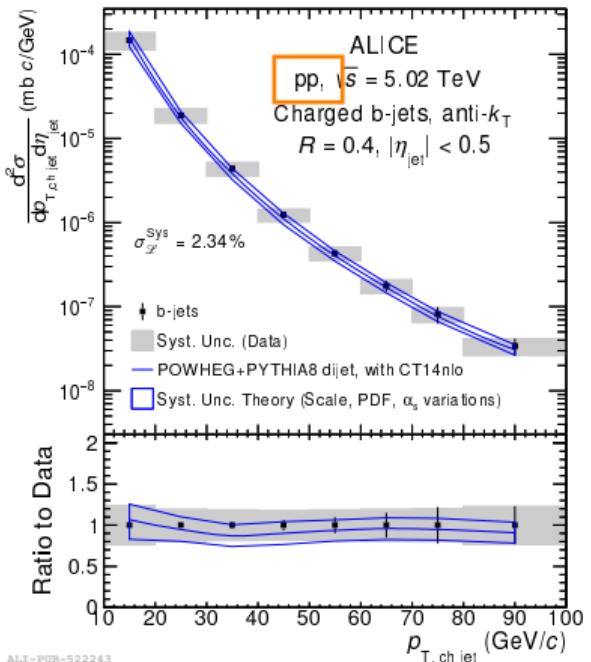
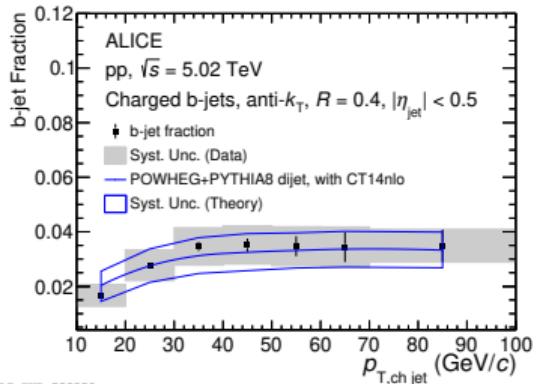
→ σ_{bb^-} and $d\sigma_{bb^-}/dy$ well reproduced by FONLL and NNLO



Beauty-jet production in 5.02 TeV pp and p-Pb collisions

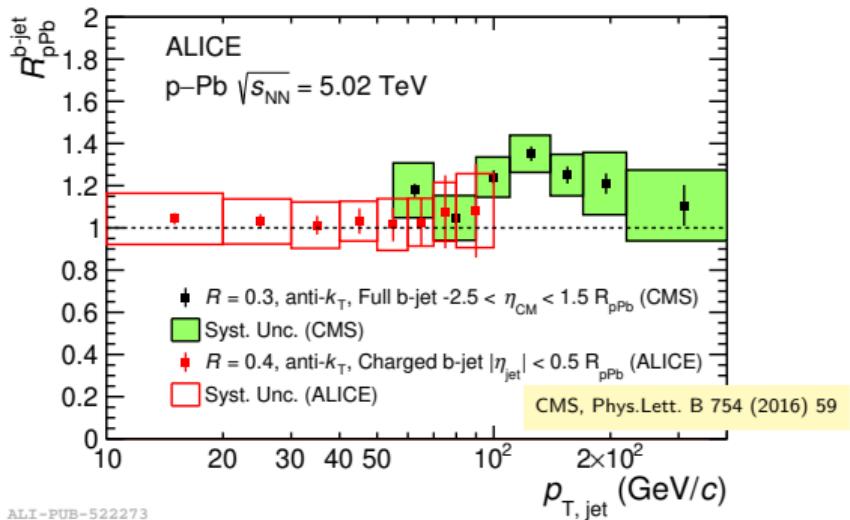
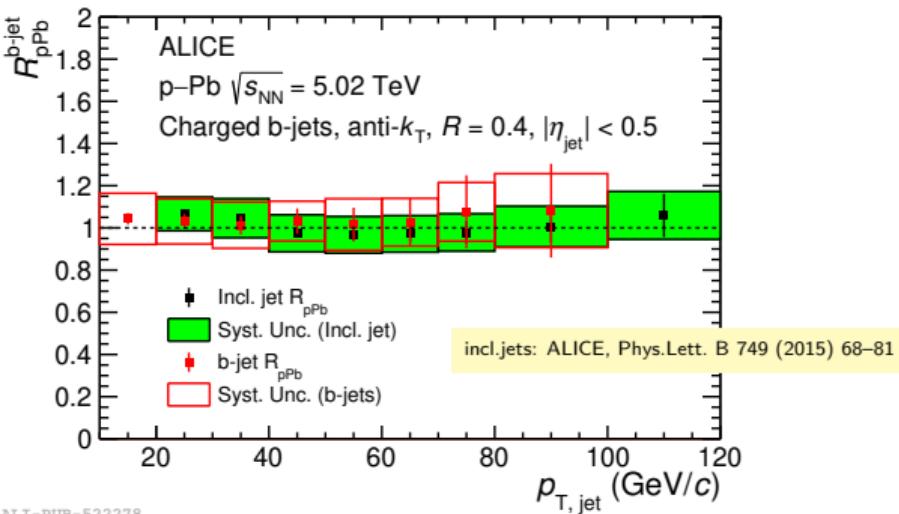
ALICE, JHEP01 (2022) 178

- identification of beauty jets based on track impact parameters and displaced secondary vertices
- b-jet cross sections and b-jet fraction compatible with POWHEG+PYTHIA 8



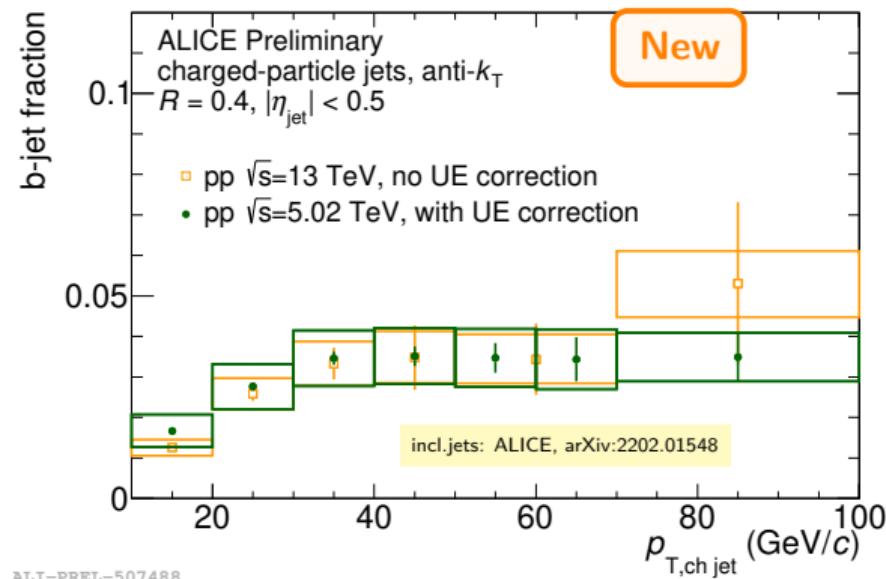
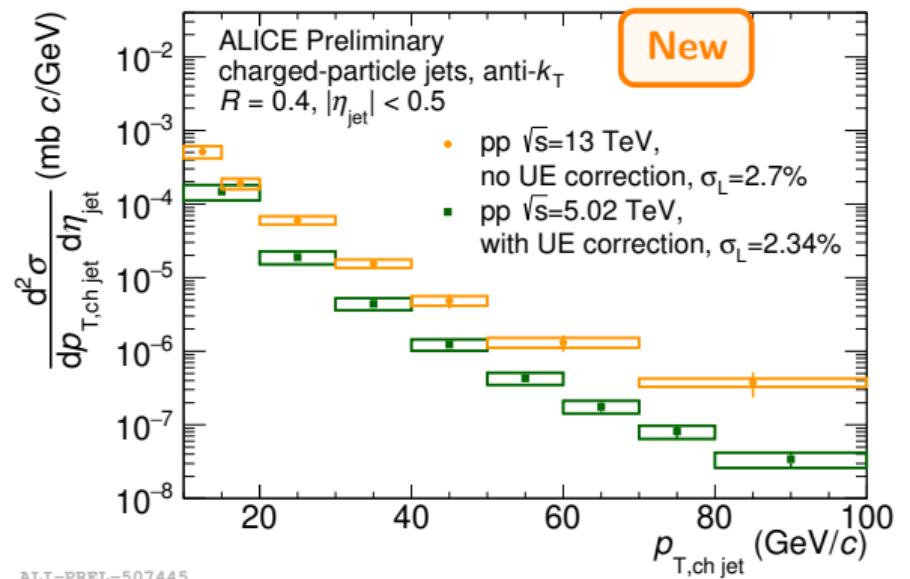
Beauty-jet production in 5.02 TeV pp and p-Pb collisions

ALICE, JHEP01 (2022) 178



- $R_{\text{p-Pb}}$ compatible with unity \rightarrow no significant Cold Nuclear Matter (CNM) effects
- first measurement of b-jet $R_{\text{p-Pb}}$ down to $10 \text{ GeV}/c$

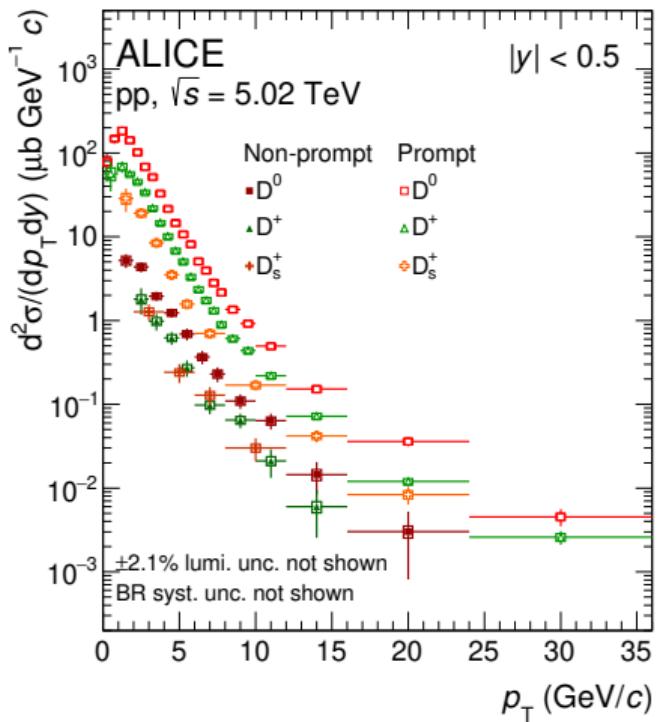
Beauty-jet production in 5.02 TeV and 13 TeV pp collisions



- b-jet production measured at $\sqrt{s} = 13$ TeV larger by about a factor of 2-6 from low to large $p_{T,\text{ch jet}}$
- fraction of b jets over inclusive jets compatible for 13 TeV and 5.02 TeV data
- ALICE can measure b-jet production down to 10 GeV/c with good precision

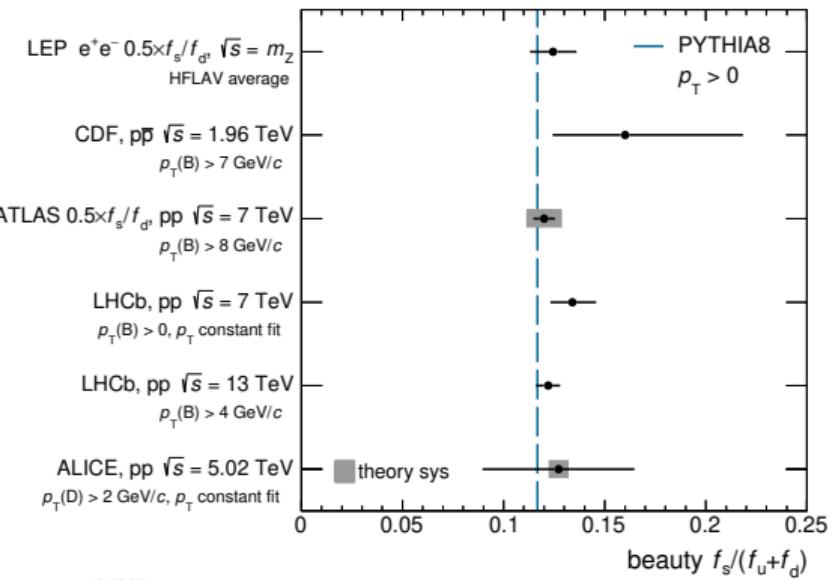
Non-prompt D mesons in 5.02 TeV pp collisions

ALICE, JHEP05 (2021) 220



ALI-PUB-496351

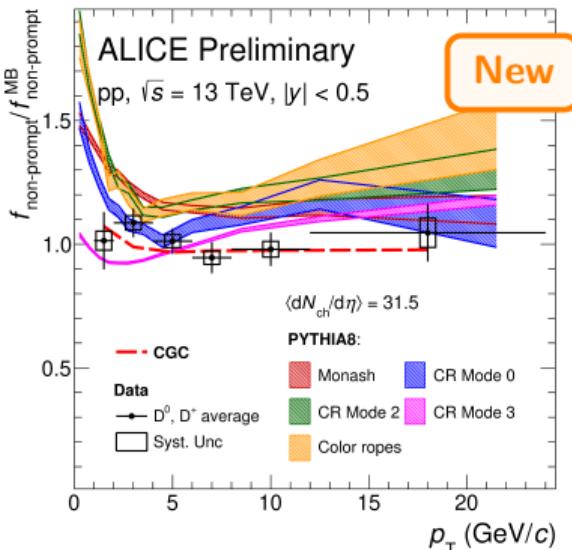
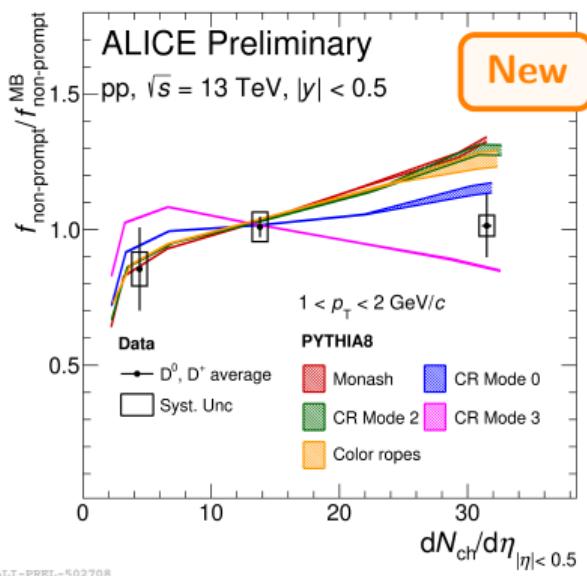
- fragmentation fraction $f_s/(f_u + f_d)$ for charm and beauty compatible with previous measurements and PYTHIA 8



ALI-PUB-496395

Non-Prompt D^0, D^+ mesons vs. multiplicity in 13 TeV pp collisions

- $D^0 \rightarrow K^\mp \pi^\pm$
- $D^+ \rightarrow K^\mp \pi^\pm \pi^\pm$
- no visible multiplicity dependence of non-prompt D mesons
- high-multiplicity D meson production in tension with Pythia tunes (Monash, CR Mode 2 und 3, Color ropes)
- p_T -dependence at high multiplicities captured by CGC predictions



Monash: P. Skands et al., arXiv:1404.5630

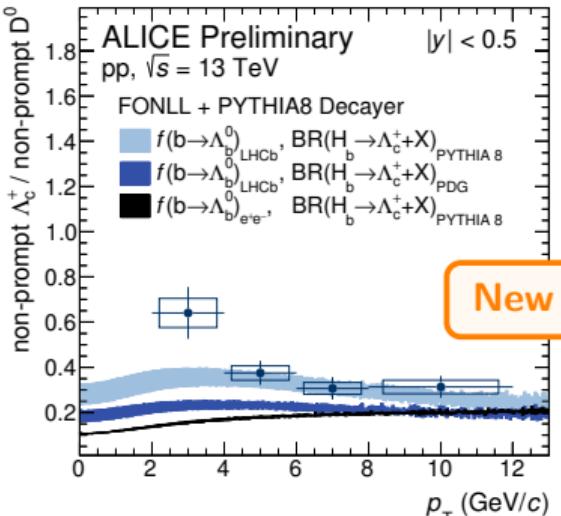
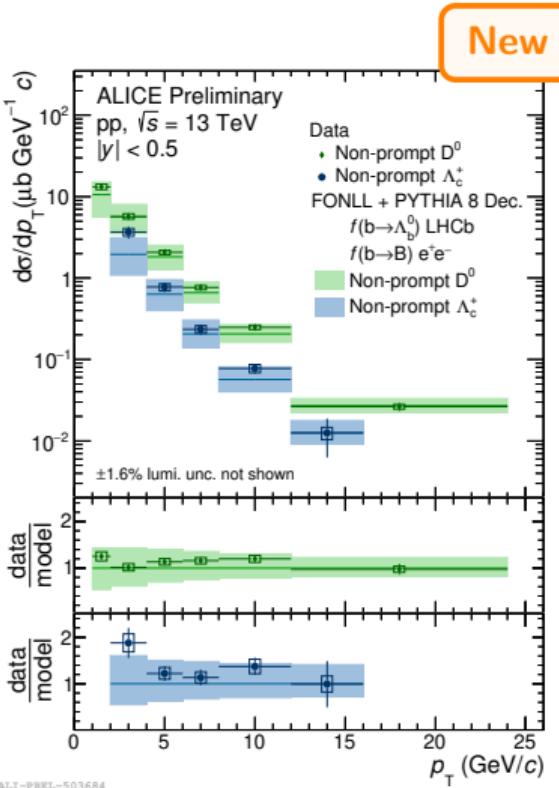
CGC: I. Schmidt and M. Siddikov, PRD 101 (2020) 094020

CR Mode 0,2,3: J. Christiansen & P. Skands, JHEP08 (2015) 003

Color ropes: C. Bierlich et al., JHEP03 (2015) 148

Non-Prompt Λ_c^+ baryons in 13 TeV pp collisions

- $\Lambda_c^+ \rightarrow p K_s^0$, $K_s^0 \rightarrow \pi^+ \pi^-$
- $\Lambda_c^+ \rightarrow p K^- \pi^+$
- Λ_c^+ cross section is described by FONLL+PYTHIA 8 Decayer for $p_T > 4 \text{ GeV}/c$
- Λ_c^+/D^0 underestimated by theoretical models at small p_T
- beauty-baryon production significantly enhanced wrt. e^+e^- collisions (different hadronisation mechanisms in pp wrt. to ee collisions?)



LHCb, Phys.Rev. D 100, 031102

Polarisation of prompt & non-prompt D^{*+} in 13 TeV pp collisions

- observable: element of spin-density matrix ρ_{00}

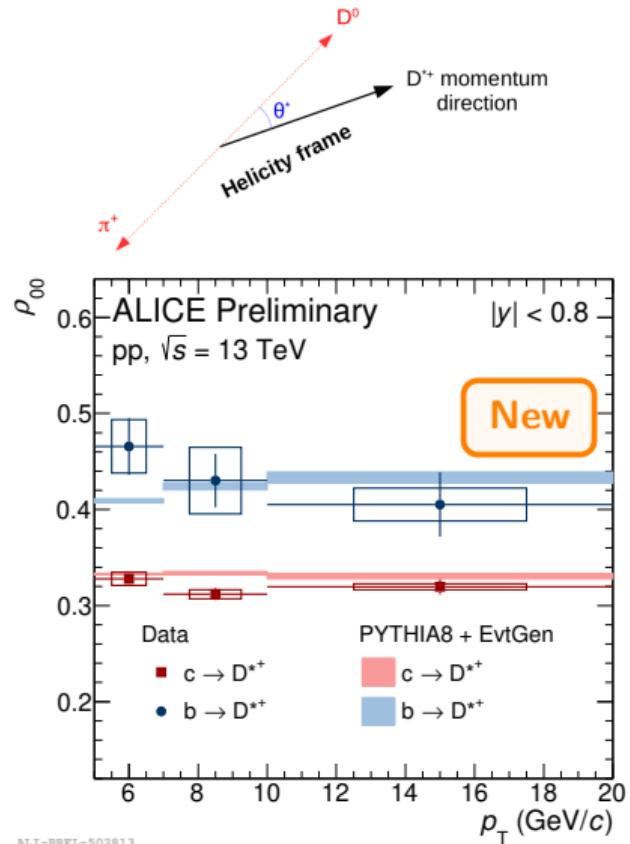
$$\frac{dN}{d \cos \theta^*} = N_0 [(1 - \rho_{00}) + (3\rho_{00} - 1) \cos^2 \theta^*]$$

no

polarisation for $\rho_{00} = \frac{1}{3}$

K. Schilling et al., Nucl.Phys. B15 (1970) 397–412

- depends on initial magnetic field and initial angular momentum in HIC
- no visible polarisation of prompt D^{*+}
- polarisation of non-prompt D^{*+} as expected due to helicity conservation in the decay of scalar beauty to vector mesons
- ρ_{00} for prompt & non-prompt D^{*+} consistent with predictions by PYTHIA+EvtGen



Summary

Conclusions from measurements of beauty-decay electrons, beauty jets and non-prompt charm mesons:

- beauty production in general described by pQCD calculations
 - Λ_c^+/\bar{D}^0 ratio underestimated by theoretical models at low p_T
 - no visible CNM effects for beauty jets in p-Pb collisions down to $p_{T,\text{ch jet}} = 10 \text{ GeV}/c$
 - no polarisation of prompt D^{*+} mesons in pp collisions; polarisation of non-prompt D^{*+} mesons as expected from helicity conservation
 - no significant multiplicity dependence of non-prompt D meson production
- ALICE tests beauty production and fragmentation down to low p_T

Outlook for LHC Run 3:

- higher statistics and improved vertexing capabilities due to major detector upgrades
- boosts HF measurements e.g. via possibility to fully reconstruct beauty hadrons

ALICE heavy-flavour contributions at ICHEP

7th July (Thursday):

- 11:45 Constraining hadronization with prompt and non-prompt charm baryons in small collision systems with ALICE at the LHC, J. Zhu
- 14:30 Charm production: constraint to transport models and charm diffusion coefficient with ALICE, F. Catalano
- 15:20 Beauty production in heavy-ion collisions with ALICE at the LHC, B. Zhang
- 18:25 J/ψ photoproduction and the production of dileptons via photon-photon interactions in hadronic Pb-Pb collisions measured with ALICE, R. Bailhache

8th July (Friday):

- 18:35 Ground and excited quarkonium states as probes of MPI in small systems with ALICE, T. Tork
- 19:05 Poster: D-meson average production analysis as a function of multiplicity in pp collisions at $\sqrt{s} = 13$ TeV with ALICE at the LHC, M. Giacalone

9th July (Saturday):

- 9:35 $\Psi(2S)$ production and nuclear modification factor in nucleus-nucleus collisions with ALICE, B. Paul
- 10:10 Quarkonium polarization in Pb-Pb and pp collisions with ALICE, Y. Ding
- 11:15 Quarkonia production and elliptic flow in small systems measured with ALICE, M. Coquet
- 12:05 Measurement of the inclusive, prompt and non-prompt J/ψ production in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE, H. Sharma

Backup

List of presented measurements

- New: beauty-decay electrons in pp at $\sqrt{s} = 13 \text{ TeV}$
- New: beauty-jets in pp at $\sqrt{s} = 13 \text{ TeV}$
- New: non-prompt D mesons vs. multiplicity in pp at $\sqrt{s} = 13 \text{ TeV}$
- New: non-prompt Λ_c^+ baryons in pp at $\sqrt{s} = 13 \text{ TeV}$
- New: polarisation of prompt and non-prompt D^{*+} mesons in pp at $\sqrt{s} = 13 \text{ TeV}$
- non-prompt J/ψ in $\sqrt{s} = 5.02 \text{ TeV}$ and $\sqrt{s} = 13 \text{ TeV}$
- beauty-jets in pp and p-Pb at $\sqrt{s} = 5.02 \text{ TeV}$
- non-prompt D mesons in pp at $\sqrt{s} = 5.02 \text{ TeV}$

ALICE detectors utilised in beauty analyses

