DIS2022: XXIX International Workshop on Deep-Inelastic Scattering and Related Subjects

Beauty production in small systems with ALICE at the LHC

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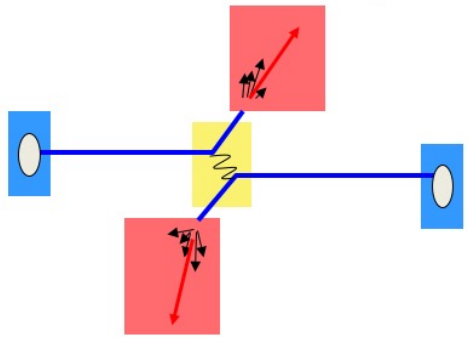
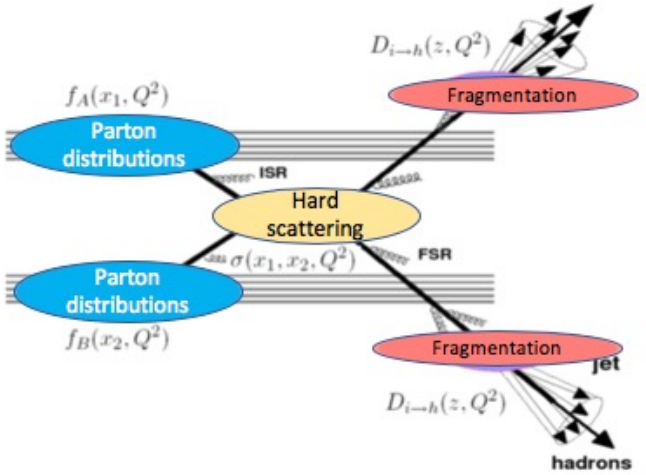
for the ALICE Collaboration

Beauty in small systems: why?

The heavy-flavour production is a test of pQCD

- large quark mass provides hard scale
- pQCD can calculate cross sections down to low p_T



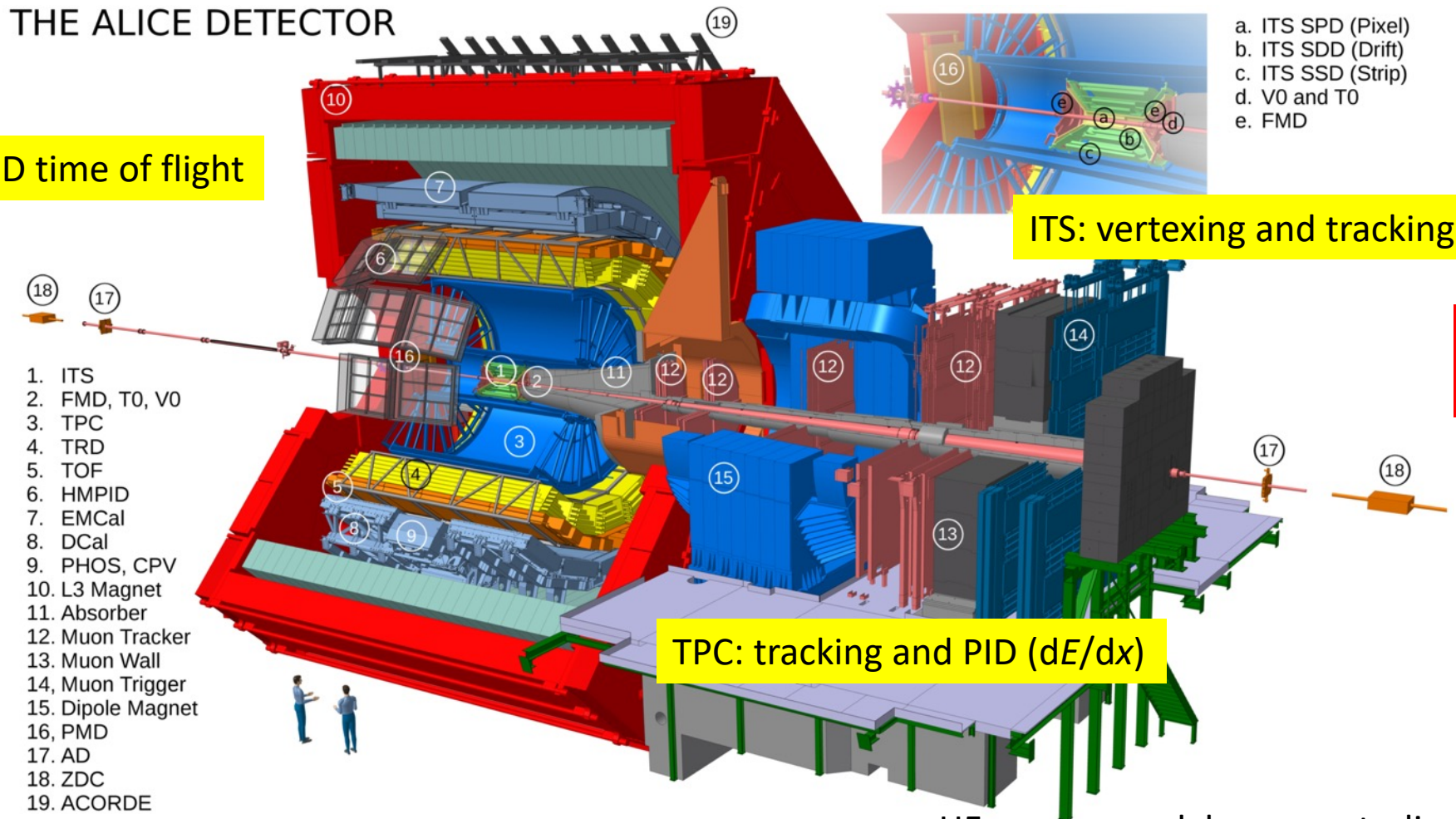


$$\frac{d\sigma^h_{pp}}{dyd^2p_T} = K\sum_{abcd}\int dx_a dx_b f_a(x_a,Q^2) f_b(x_b,Q^2) \frac{d\sigma}{d\hat{t}}(ab\to cd) \frac{D^0_{h/c}}{\pi z_c}$$

- ✓ for an experiment as ALICE (devoted to QGP studies) pp is a "reference" system
- ✓ surprising results on the **charm sector** (especially c-baryons) at the LHC showed fragmentation is not well understood
  - → b as heavier candle to check mass-dependent QCD mechanisms (dead-cone)
  - → check & test hadronization in the b-sector too

ALICE results on charm@DIS2022: Annalena's talk
https://indico.cern.ch/event/1072533/contributions/4778077/

ALICE detector complements HF studies at the LHC



TOF: PID time of flight

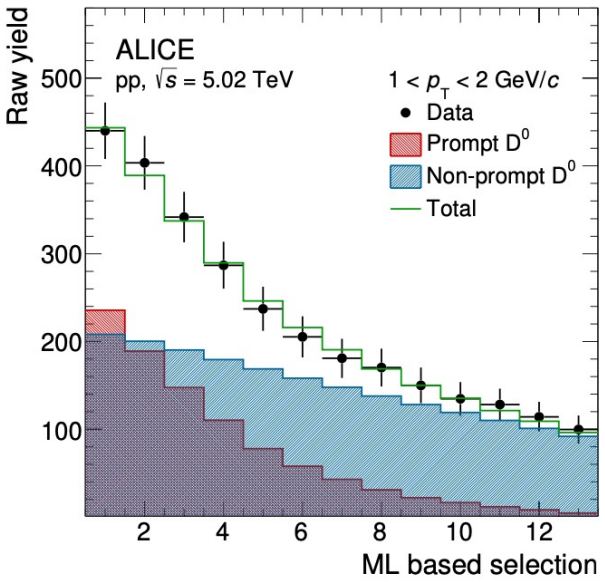
ITS: vertexing and tracking

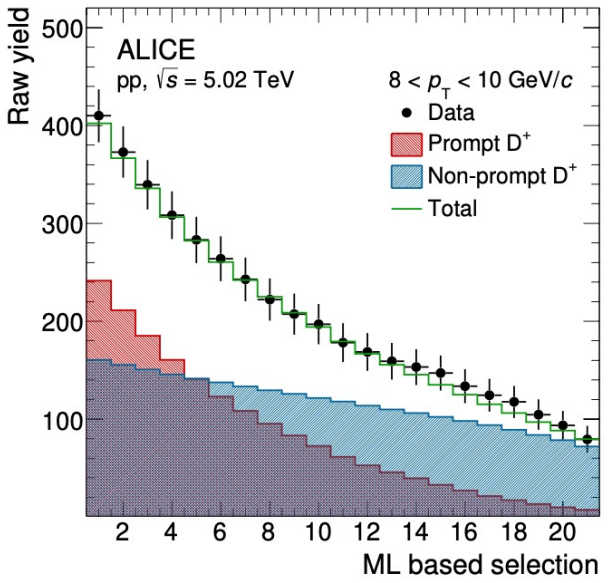
PID capabilities
low p_T reach

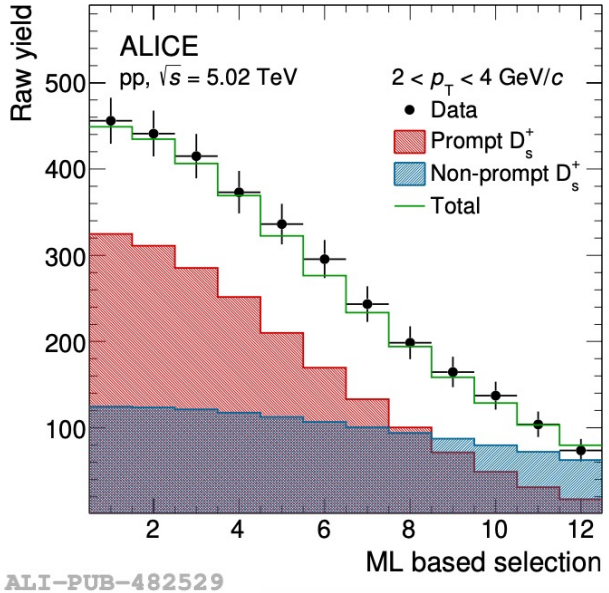
TPC: tracking and PID (dE/dx)

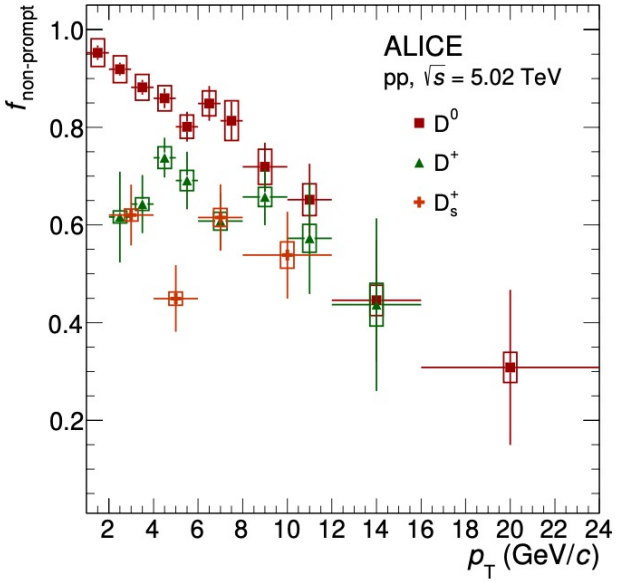
- HF mesons and baryons studied in the central barrel $|y|<0.5$ in pp, as well as HF-electrons
- low p_T reach at LHC: uniqueness of ALICE
- complementary to LHCb in rapidity

Find beauty: how?









ALI-PUB-482529

$$D^0 \rightarrow K^-\pi^+$$
$$D^+ \rightarrow K^-\pi^+\pi^+$$
$$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^-K^+\pi^+$$

- ML algorithms (based on Boosted Decision Trees) used to separate prompt and non-prompt D-mesons: D^0, D^+ and D^+_s (Multi-classification algorithm: prompt, non-prompt, combinatorial background)

Main BDT input:

- displacements of tracks from primary vertex
- D-meson decay length
- D-meson impact parameter
- cosine of the pointing angle

JHEP 05 (2021) 220

non-prompt D-mesons in pp at $\sqrt{s}$ =5.02 TeV

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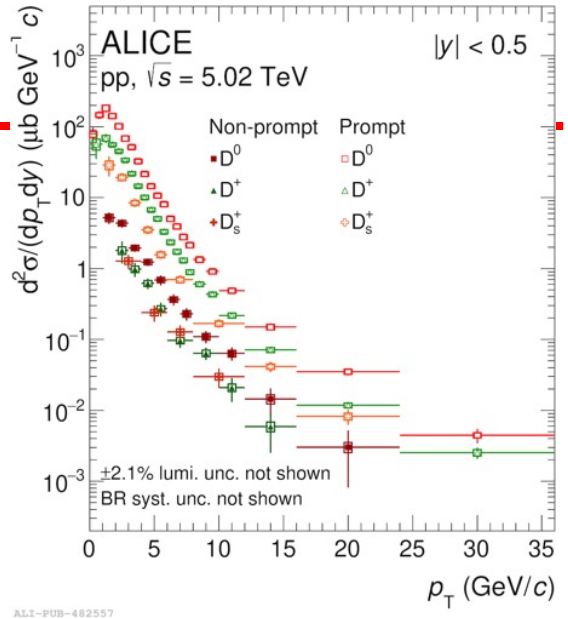
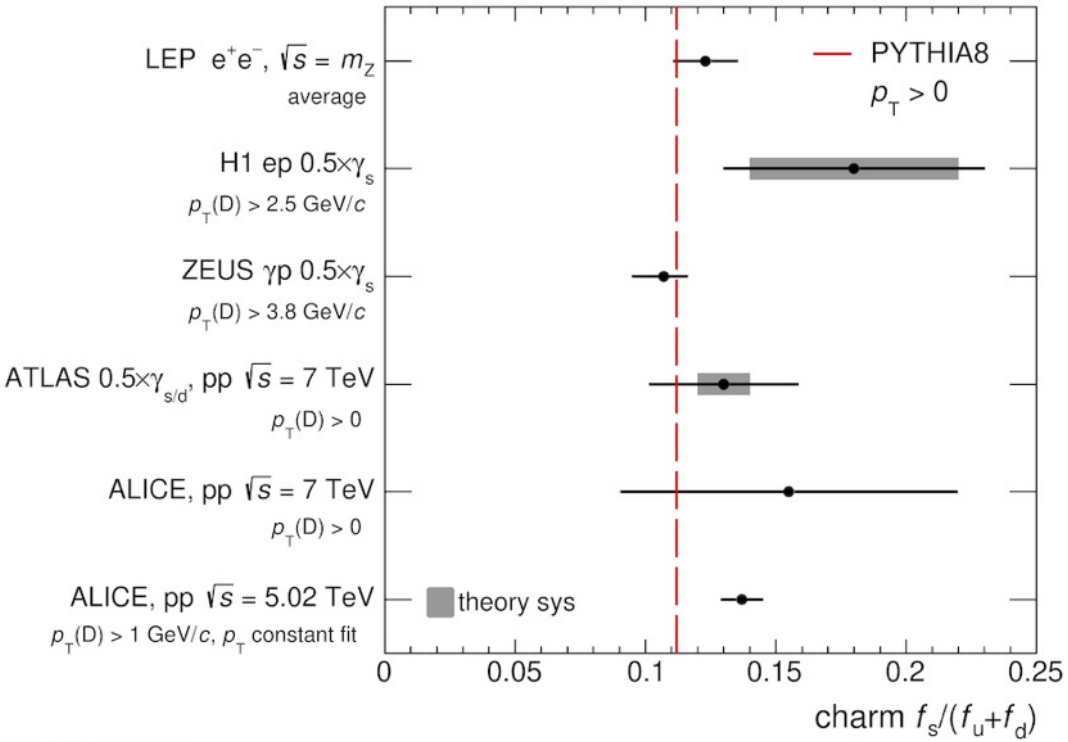
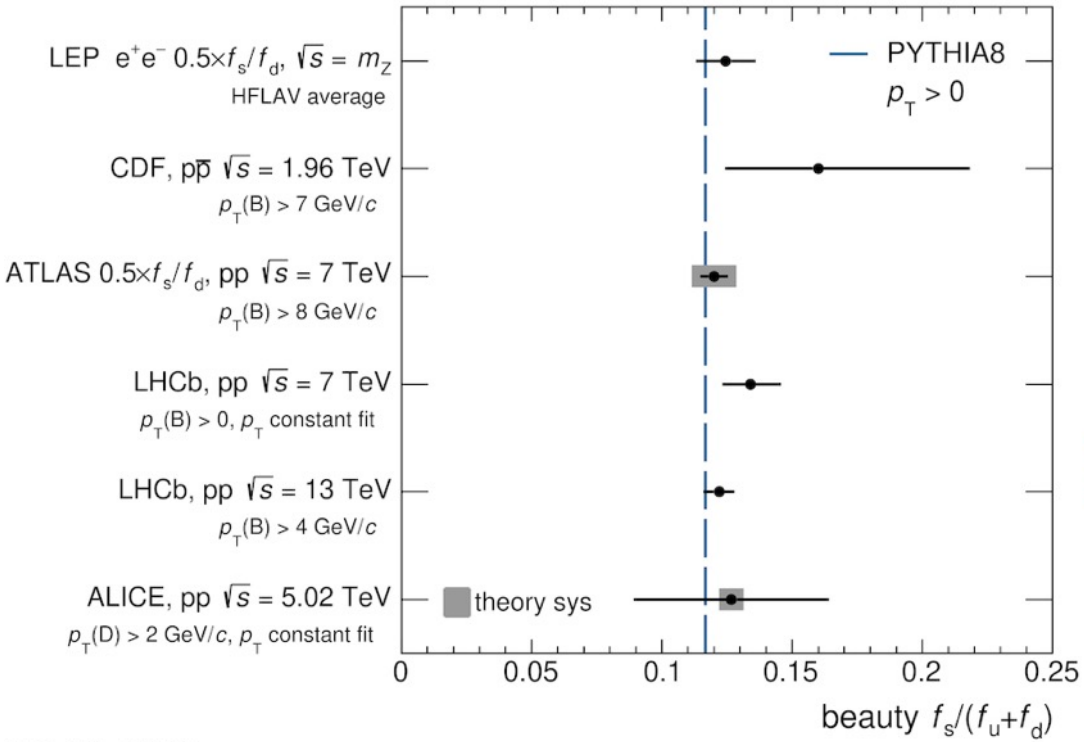
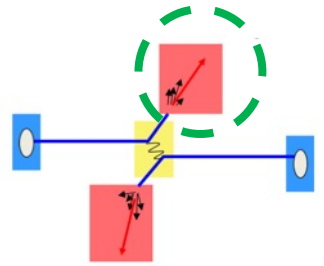
- f_s / (f_u+f_d) fragmentation fractions of HQ to strange/non-strange mesons compatible with previous measurements (different $\sqrt{s}$ and collision system)
- General agreement with pQCD calculations (FONLL/GM-VFNS)









Beauty@ALICE: what's new?

A rich set of new measurements!

- ✓ Non-prompt D^{*+} polarization in pp at $\sqrt{s}$ =13 TeV
- ✓ Multiplicity dependence of non-prompt D production
- ✓ Beauty hadron to electron decay in pp
- ✓ Non-prompt Λ_c production in small systems: pp and p–Pb
- ✓ Non-prompt and prompt Λ_c/D^0 in pp
- ✓ b-tagged jets in pp and p–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- ✓ $b\bar{b}$ production cross-section
- ✓ non-prompt J/Ψ

These results from data samples mainly from LHC RUN 2

ALICE results on Υ-polarization@DIS2022: Yanchun's talk https://indico.cern.ch/event/1072533/contributions/4778125/

System	Year(s)	$\sqrt{s_{NN}}$(TeV)	L_{int}
Pb—Pb	2010,2011	2.76	~75 μb^{-1}
	2015	5.02	~0.25 nb^{-1}
	2018	5.02	~0.55 nb^{-1}
Xe—Xe	2017	5.44	~0.3 μb^{-1}
p—Pb	2013	5.02	~15 nb^{-1}
	2016	5.02, 8.16	~3 nb^{-1}; ~25 nb^{-1}
pp	2009-2013	0.9, 2.76, 7, 8	~200 μb^{-1}; ~100 nb^{-1}; ~1.5 pb^{-1}; ~2.5 pb^{-1}
	2015,2017	5.02	~1.3 pb^{-1}
	2015-2018	13	~36 pb^{-1}

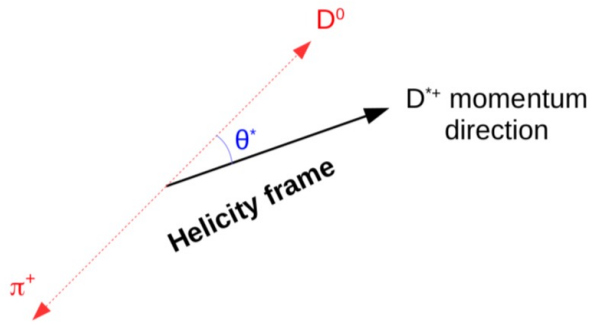
D^{*+} polarization in pp @ √s = 13 TeV

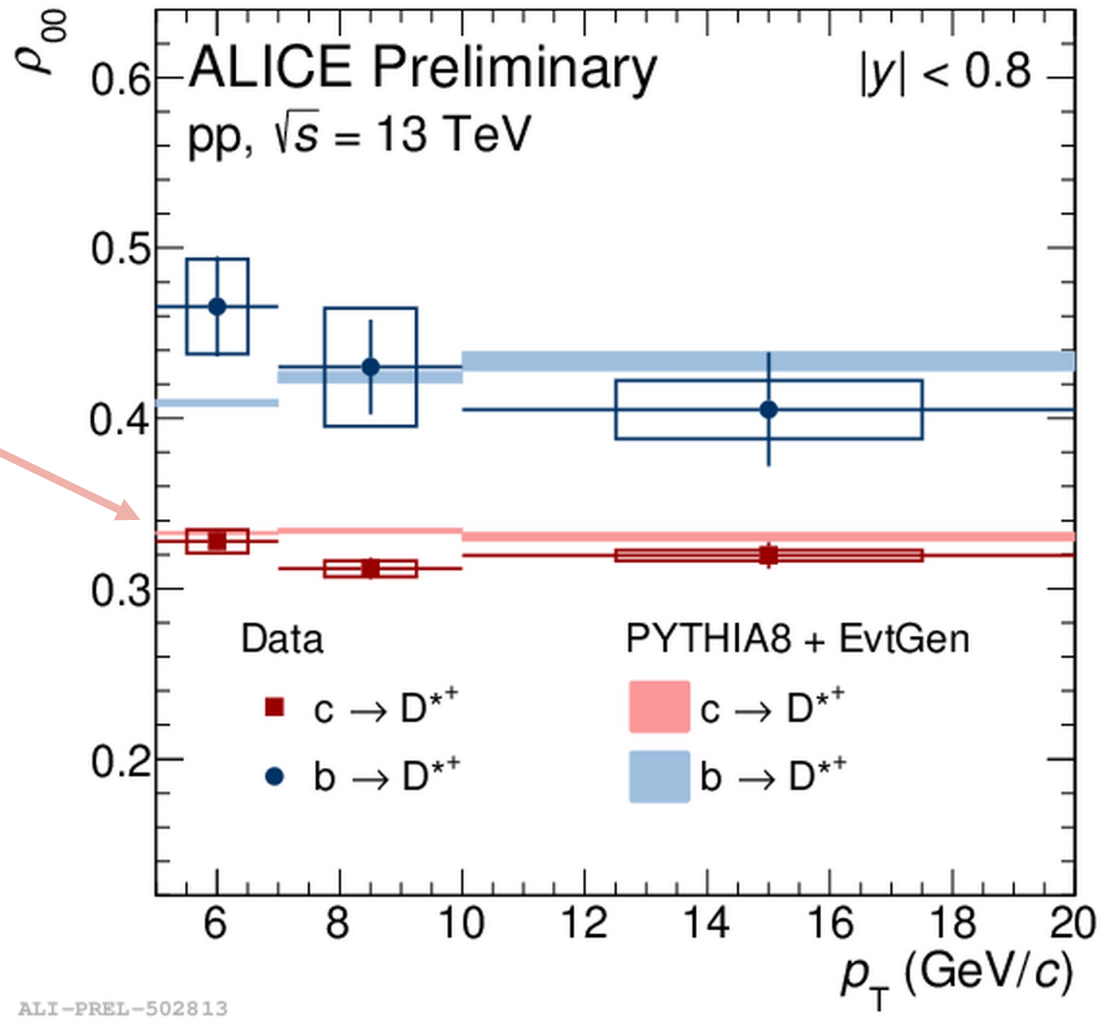
$D^{*+} \rightarrow D^0\pi^+$ (BR 67.7%) $\quad D^0 \rightarrow K^-\pi^+$

$c\tau$ = 120 μm (prompt) / 500 μm (non-prompt)

ρ_{00} = spin matrix element (no polarization → 1/3)

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





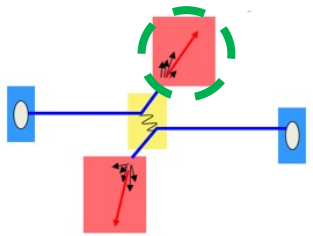
non-zero polarization for non-prompt
prompt D*+ unpolarized

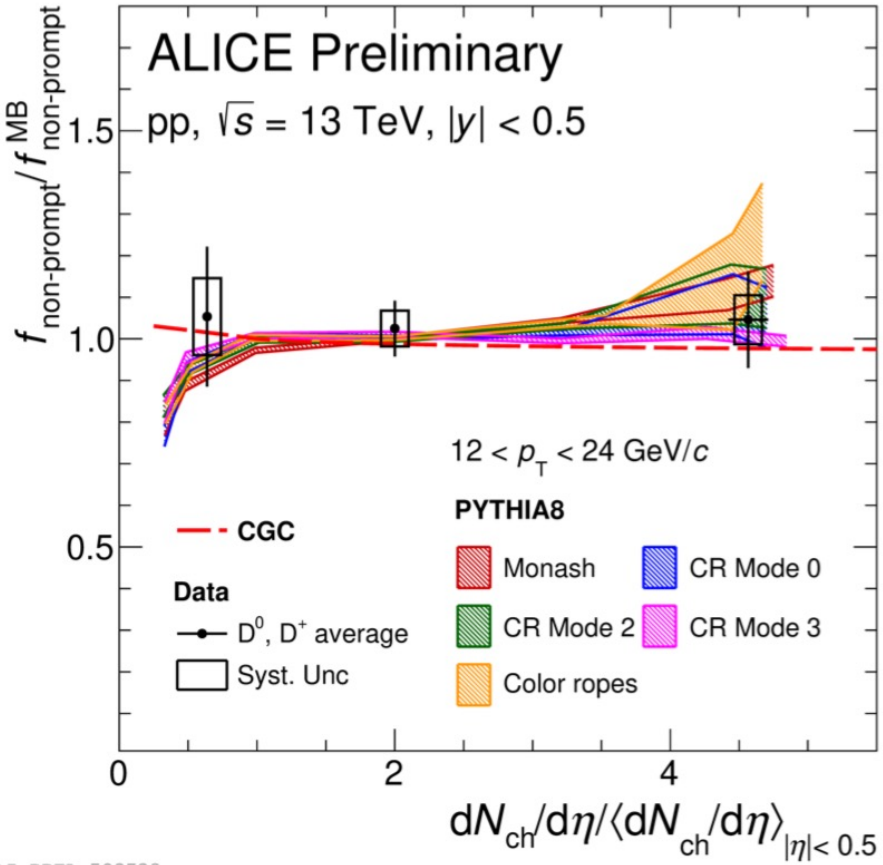
} as expected by PHYTHIA8+EvtGen

"validation" of prompt /non-prompt separation! → looking forward for Pb–Pb studies (role of high *B* fields)

Multiplicity dependence of non-prompt D production

- A tool to study **hadronization**: comparison with models
- $f_{\text{non-prompt}} / f^{\text{MB}}_{\text{non-prompt}}$ = no significant dependence with multiplicity expected (and measured)
- D^0 and D^+ average

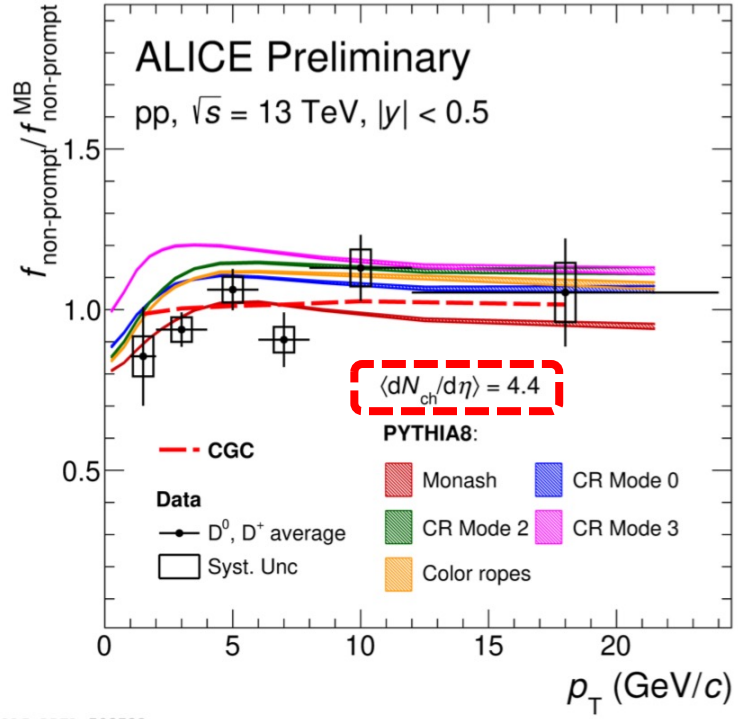




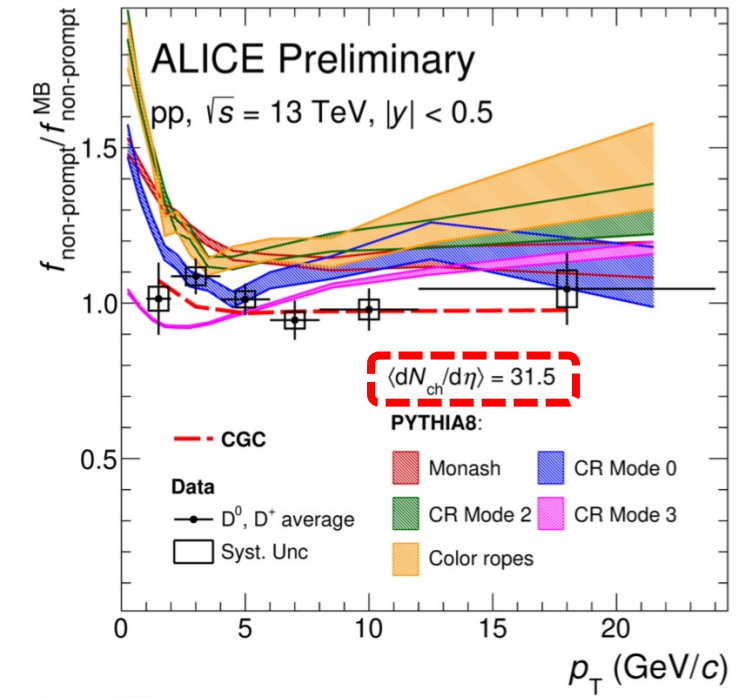
ALI-PREL-502723

- CGC describes data
- PYTHIA tunes (ropes and enhanced CR) show some tensions with data at high mult

Monash: P. Skands et al., arXiv:1404.5630
CR Mode 0,2,3: J. Christiansen and P. Skands, JHEP08 (2015) 003
CGC: I. Schmidt and M. Siddikov, PRD 101 (2020) 094020
Color ropes: C. Bierlich et al., JHEP03 (2015) 148



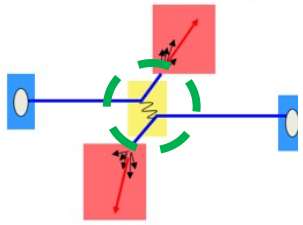
ALI-PREL-502783

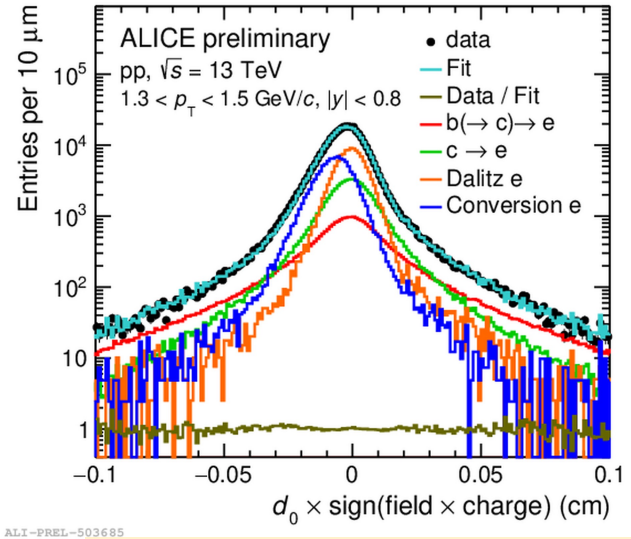


ALI-PREL-502800

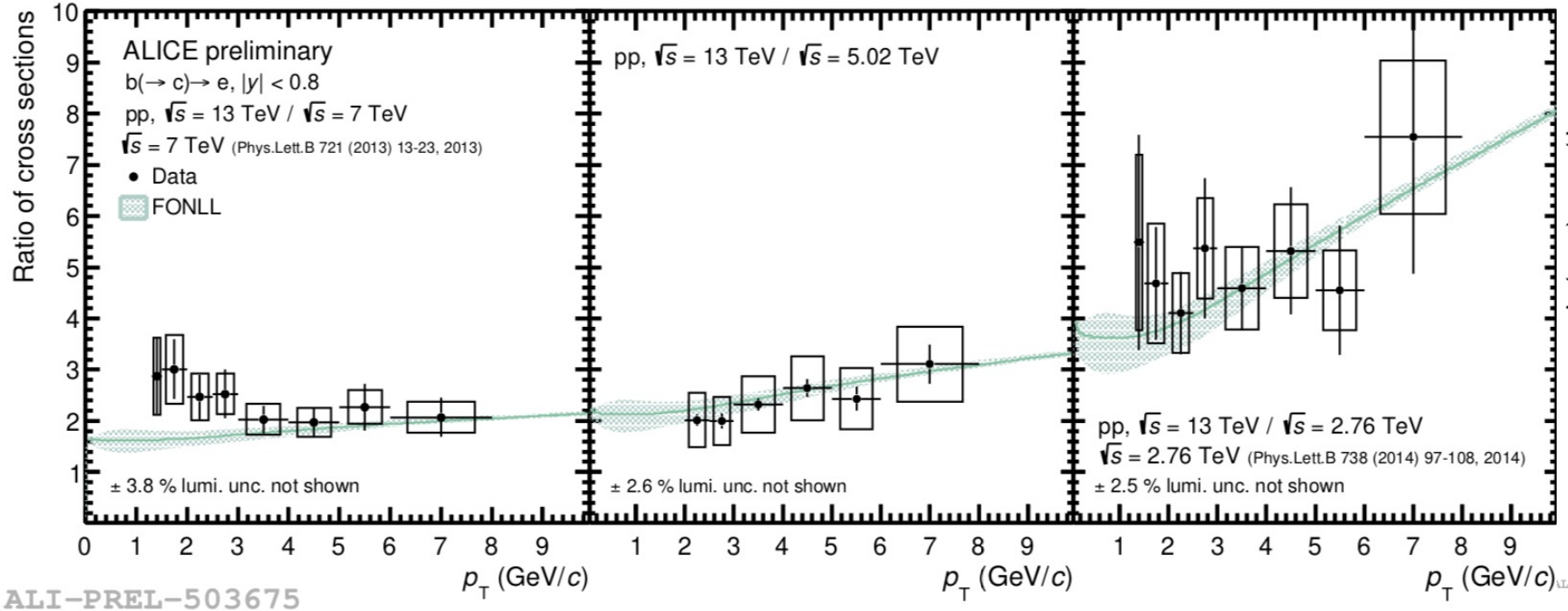
Electrons from beauty-hadron decays in pp @ √s = 13 TeV

- ✓ $H_b \rightarrow l + \nu_l + X$ have BR ≈ 10%
- ✓ e identification via TPC+TOF
- ✓ beauty hadrons decays identified via track impact parameter
- ✓ Sizable decay length (cτ ≈ 450 μm) of beauty hadrons

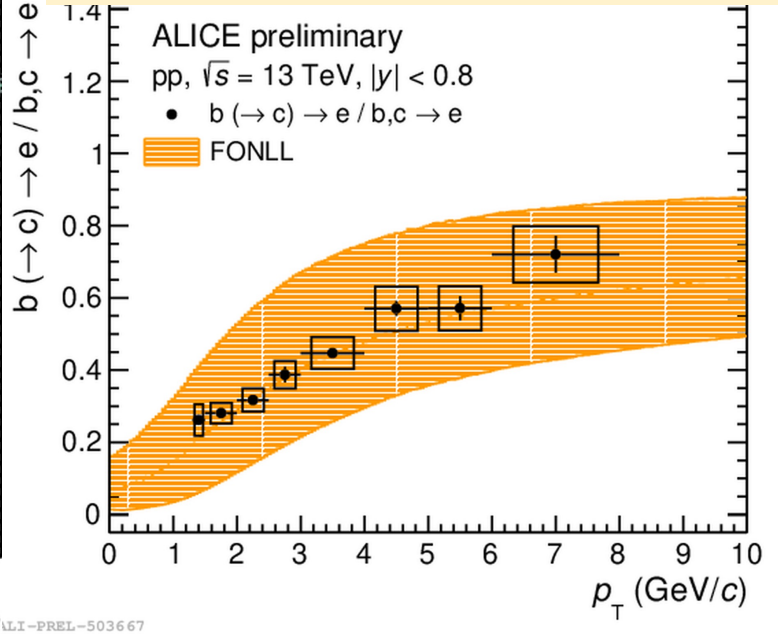




- cross section ratios at different √s: good agreement with FONLL

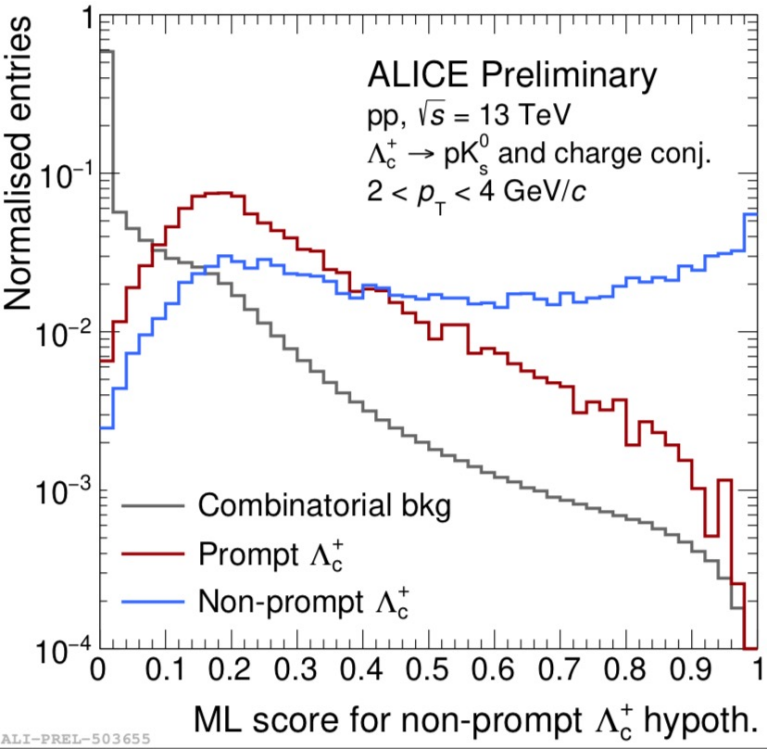


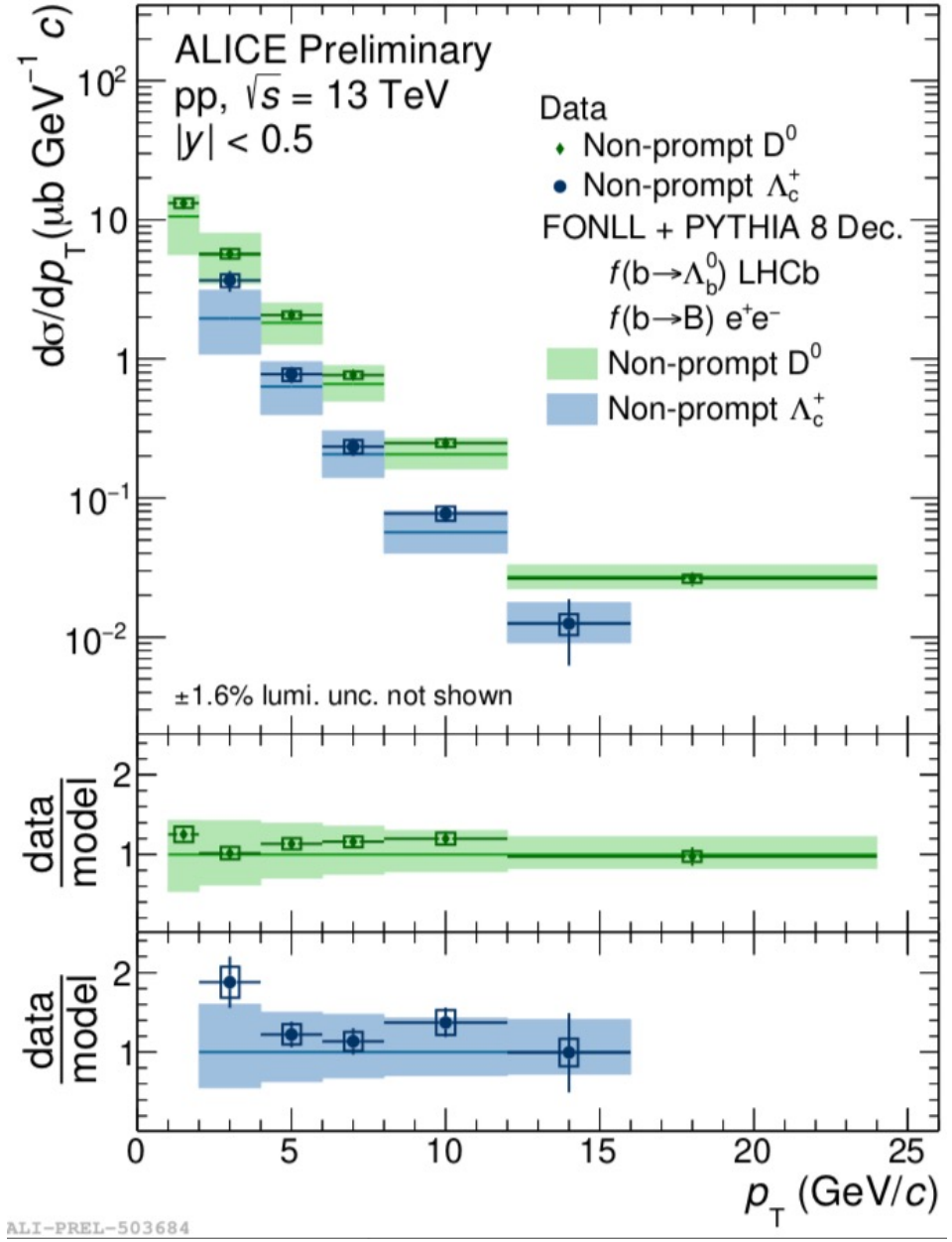
beauty contribution dominant at p_T> 5 GeV/c



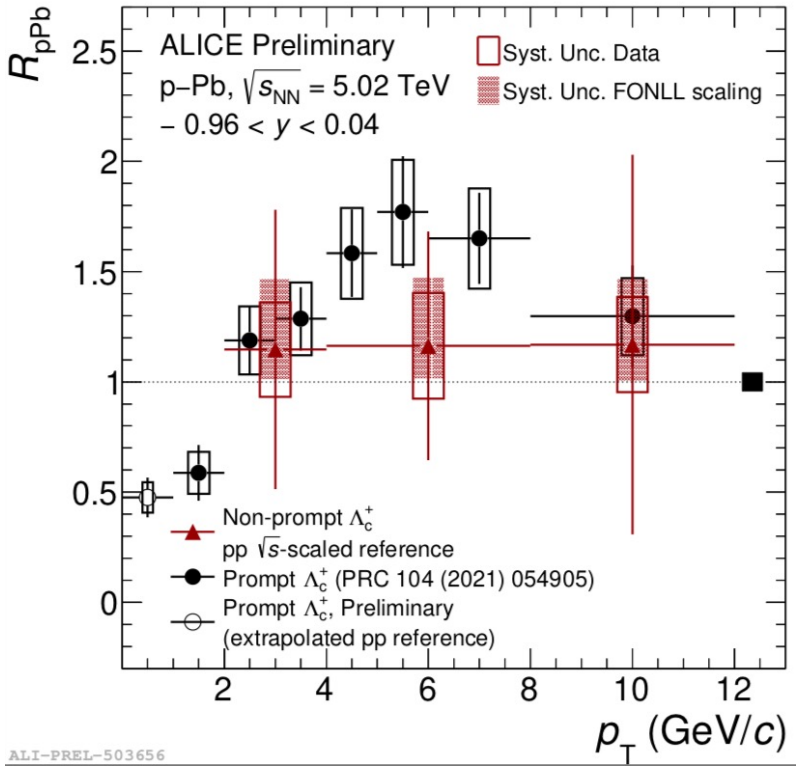
Non-prompt Λ_c production in small systems: pp and p-Pb

- ML method to extract non-prompt component applied to Λ_c
- $\Lambda_c \rightarrow pK^0_s$ and $\Lambda_c \rightarrow pK^-\pi^+$
- FONLL predictions in agreement include use of $f(b \rightarrow \Lambda^0_b)$ from LHCb

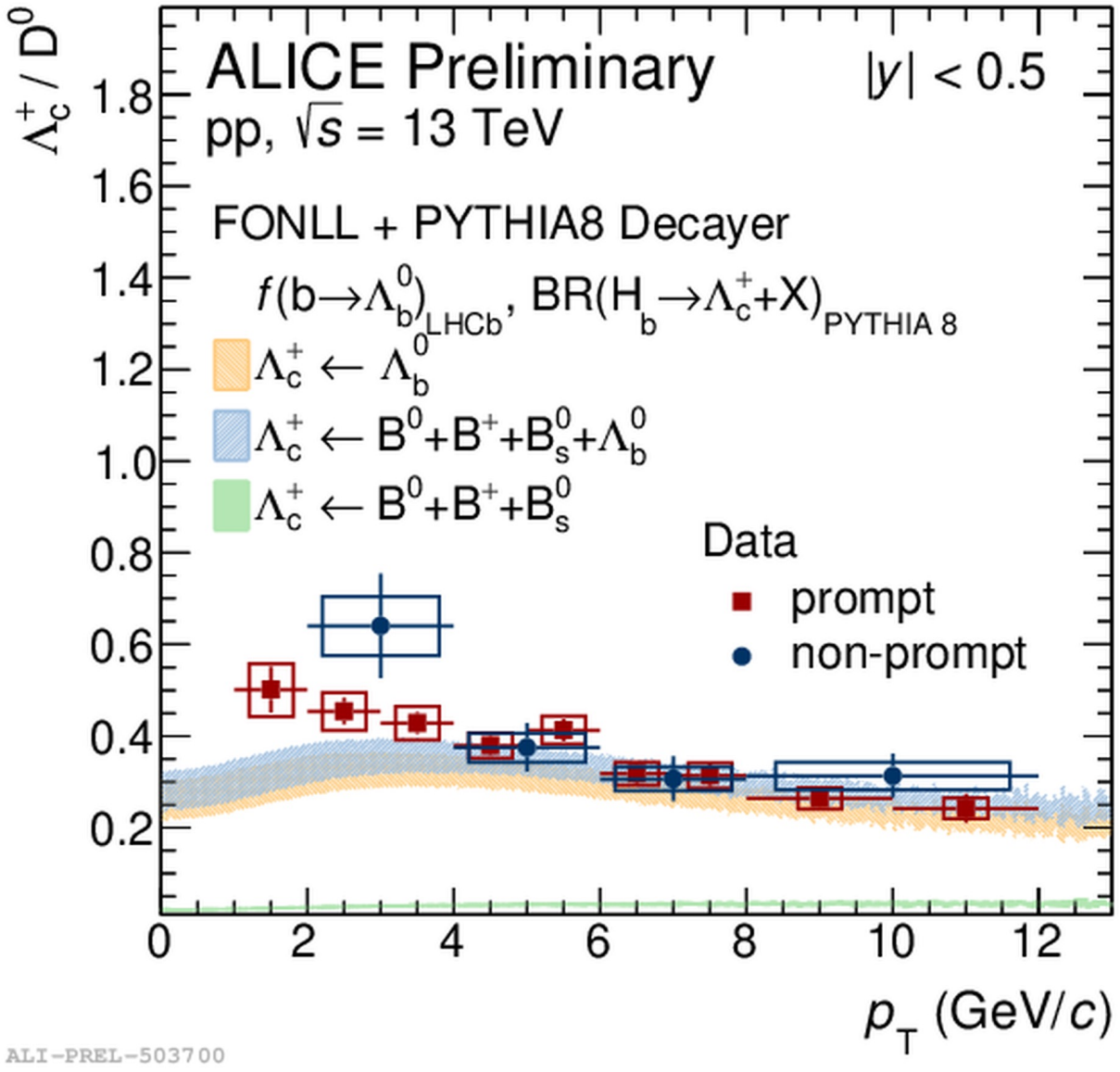




- non-prompt Λ_c also in p–Pb!
- R_{pPb} non-prompt compatible with unity (and with R_{pPb} prompt)
- large uncertainties → Run3

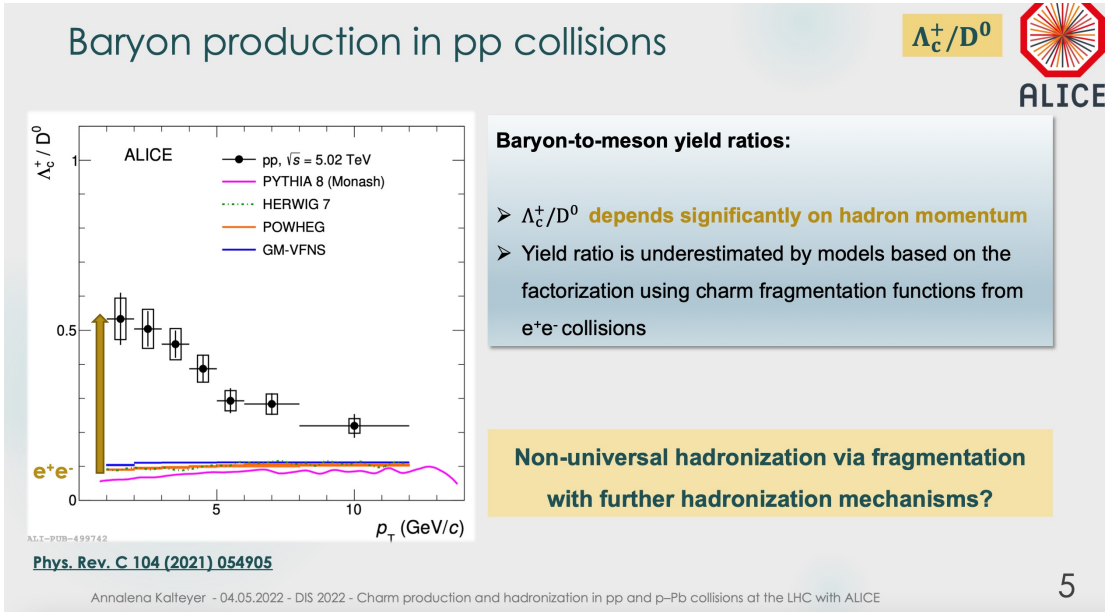


Baryon-to-meson ratio (Λ_c/D^0) for prompt and non-prompt components



- non-prompt Λ_c gives access to Λ_b (and B-mesons)
- main discrepancies between data and pQCD estimates at low (< 4 GeV/c) p_T (as for prompt component)
- hint of higher tension for non-prompt

from Annalena's talk this morning:



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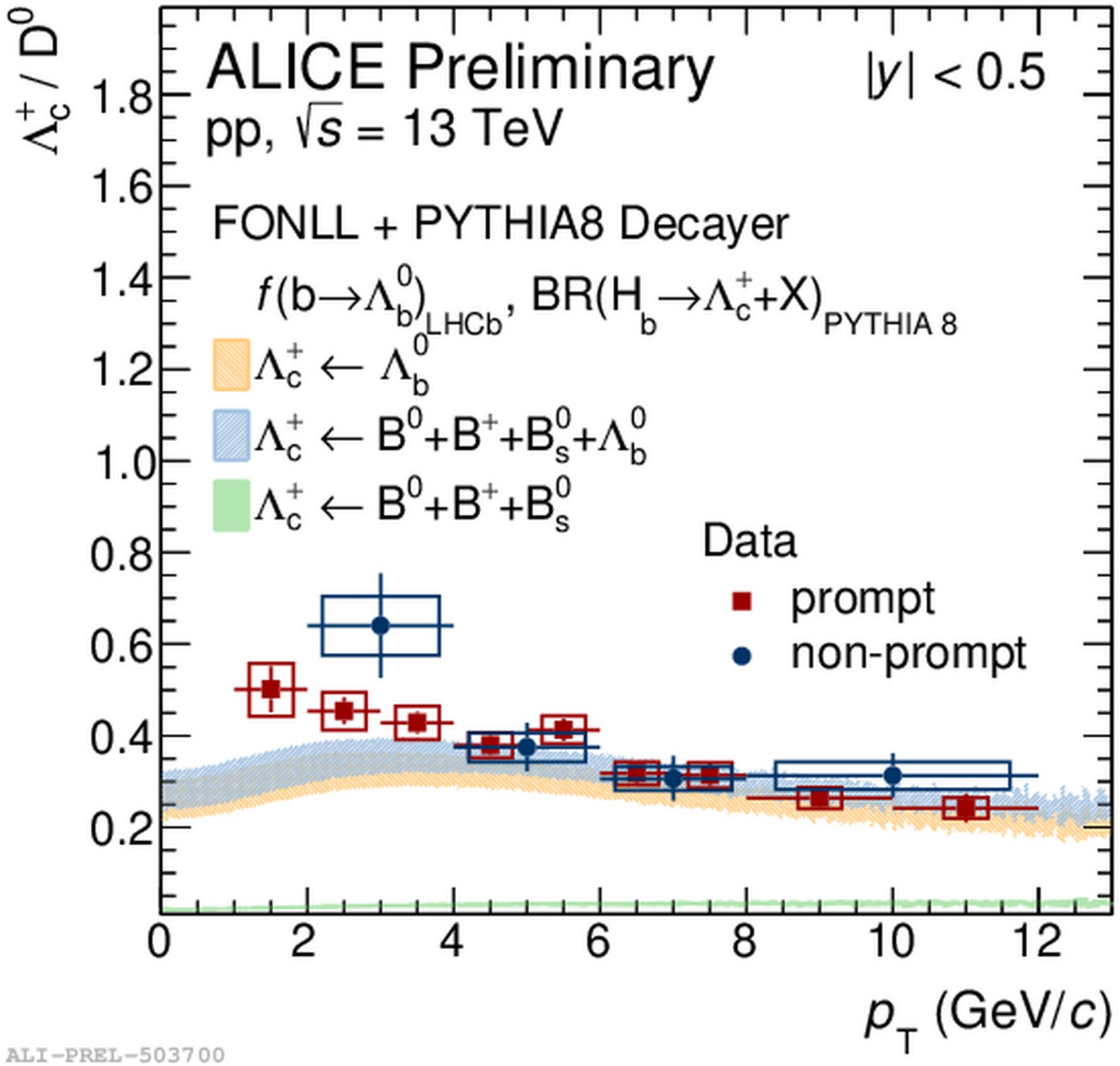
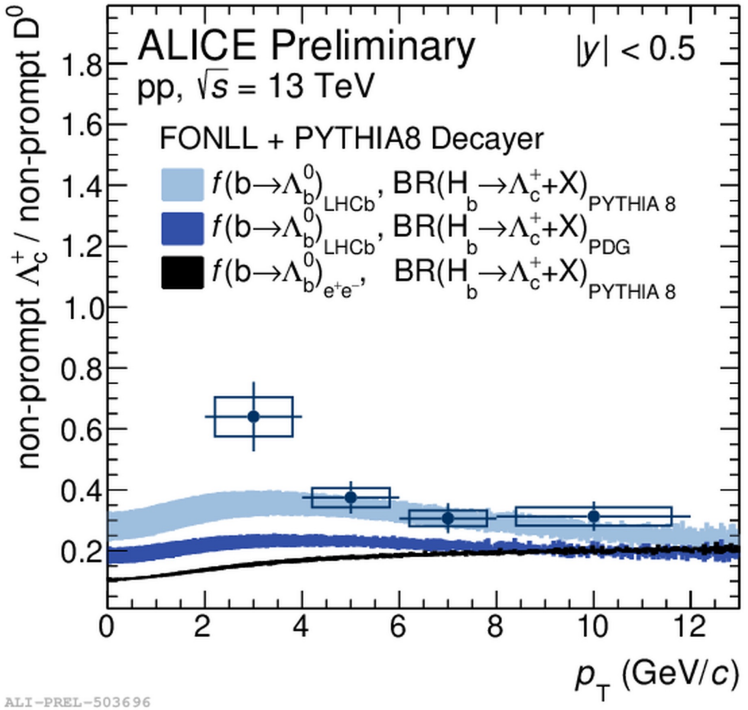
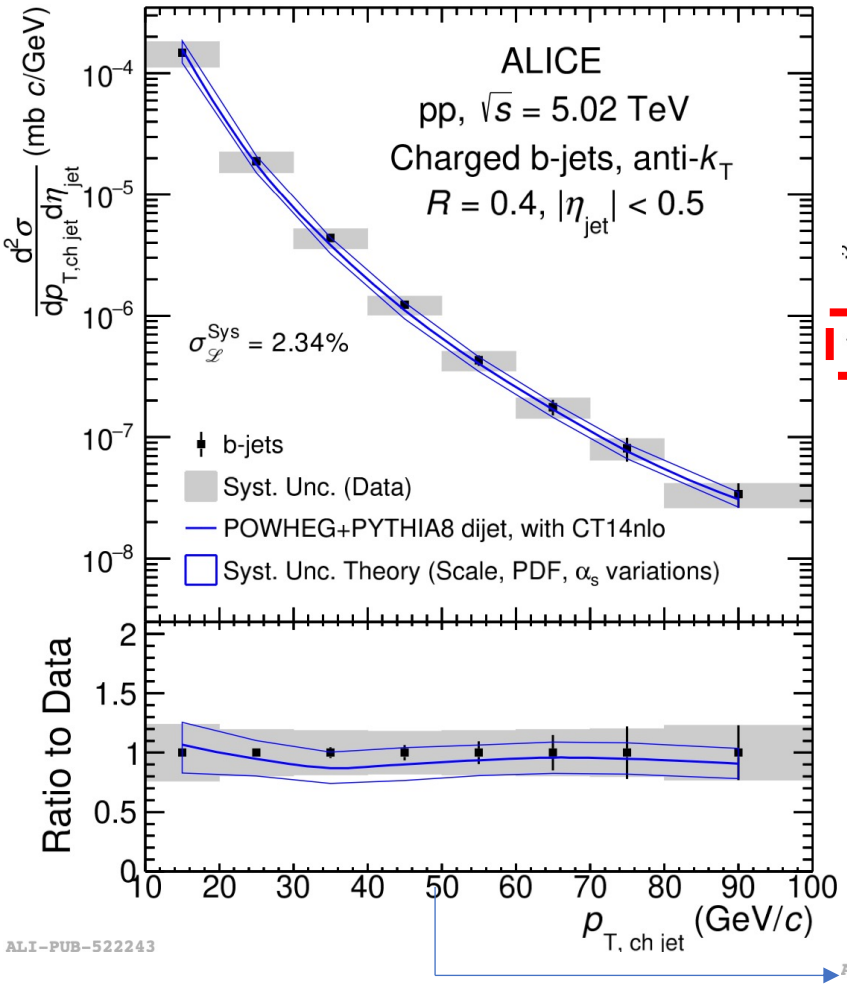


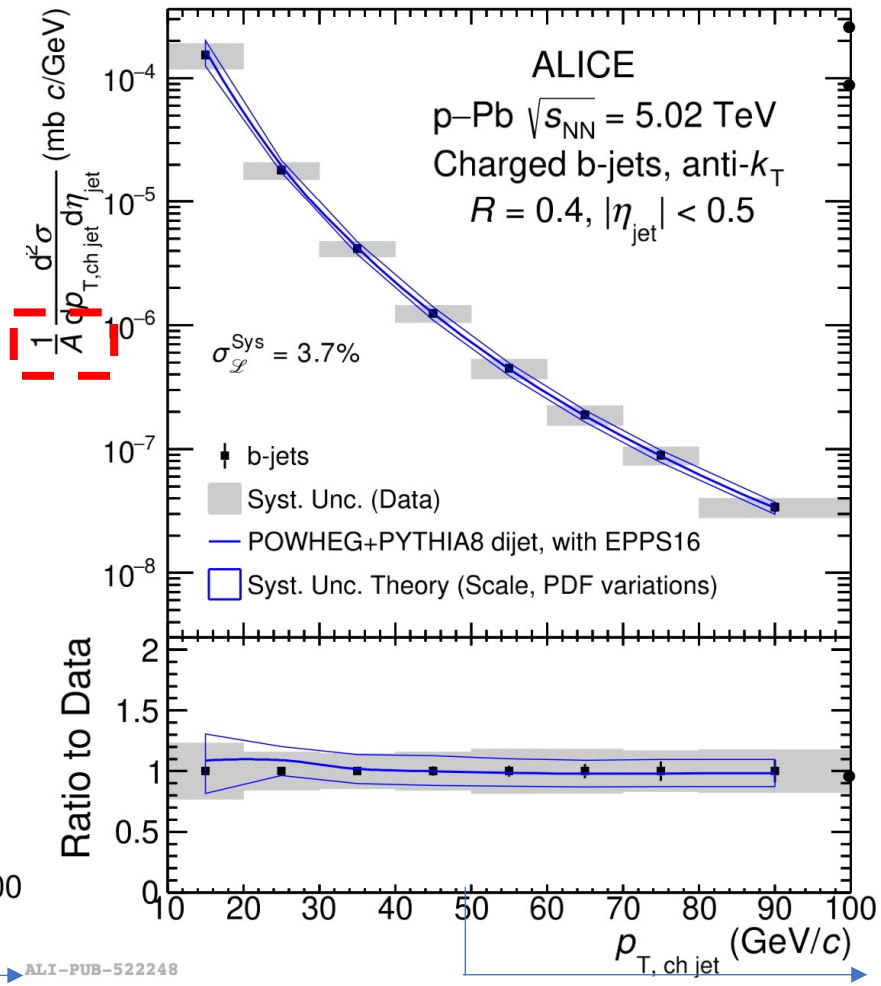
- non-prompt Λ_c gives access to Λ_b (and B-mesons)
- main discrepancies between data and pQCD estimates at low (< 4 GeV/c) p_T (as for prompt component)
- hint of higher tension for non-prompt
- BR & fragmentation fractions uncertainties play a role



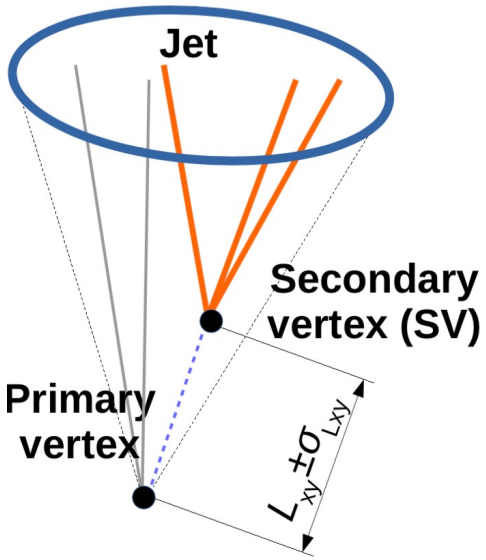
b-tagged jets in pp and p–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

JHEP01(2022)178





- tagging HF jets allow one to study production and fragmentation separately
  CNM effects can differ in LF/HF sectors
  ALICE has access to low p_T b-jets

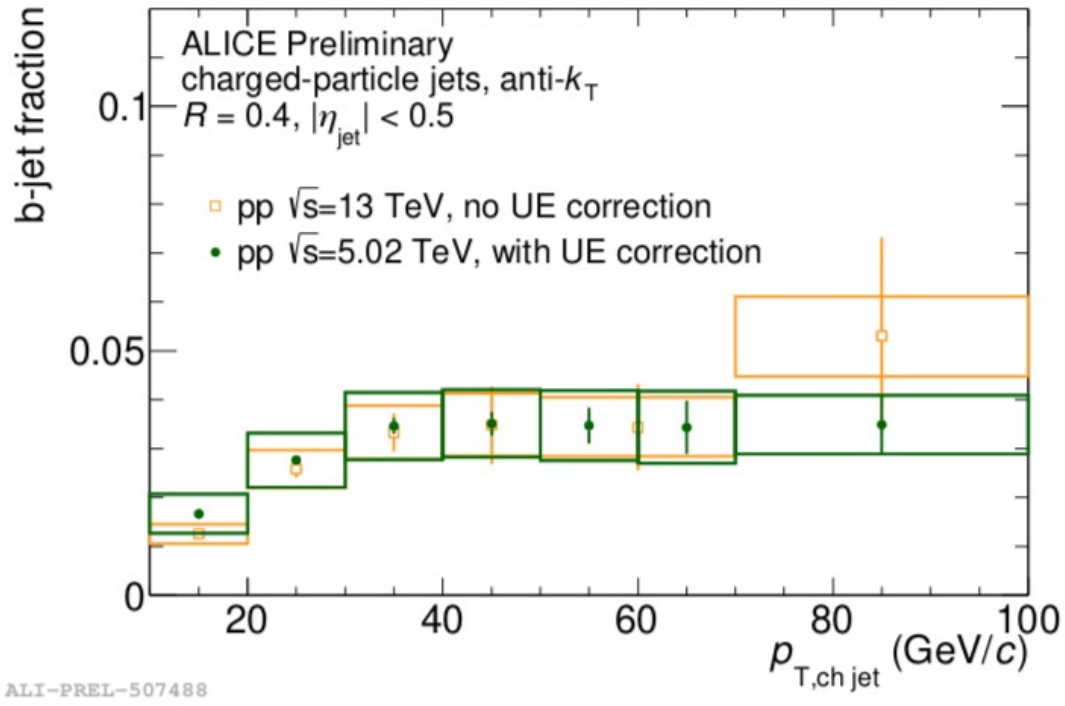


two methods for tagging: impact parameter (IP) and distance of most displaced 3-prong secondary vertex (SV)

b-jet CMS measurement for $p_{T,jet} > 50$ GeV/c (PLB 754 (2016) 59)

NLO calculations describe the data

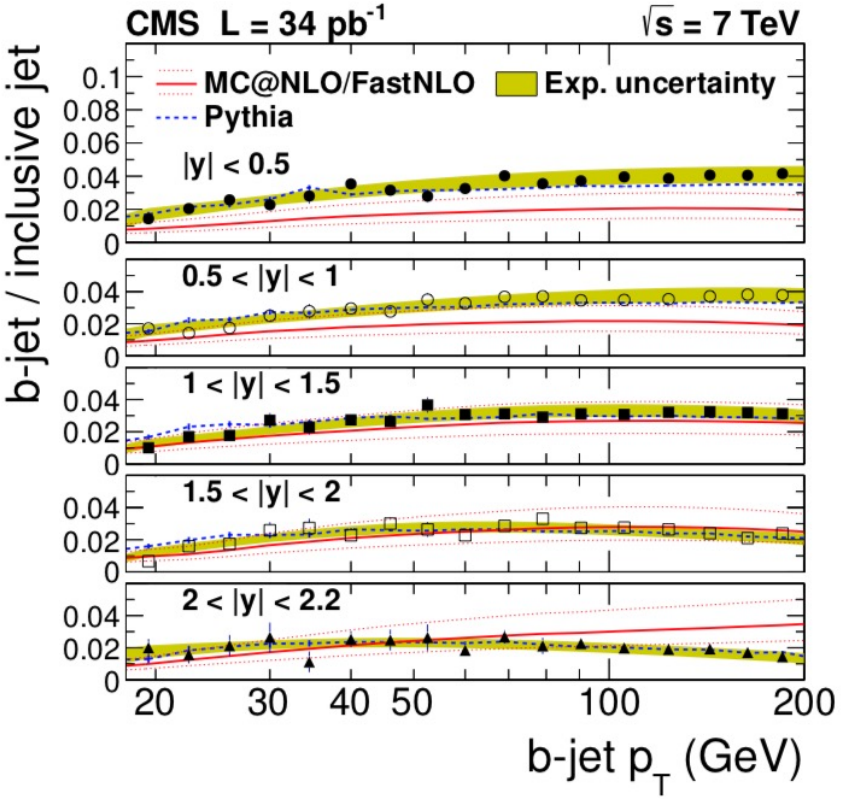
b-jet fraction comparison at $\sqrt{s}$ = 5.02 TeV and $\sqrt{s}$ = 13 TeV



spectrum for inclusive jets from arXiv:2202.01548
b-jet spectrum at 5.02 TeV from JHEP01(2022)178

Note b-jet fraction measured at p_T=10 GeV/c is a lower value than in previous measurements at LHC!

CMS JHEP04(2012)084

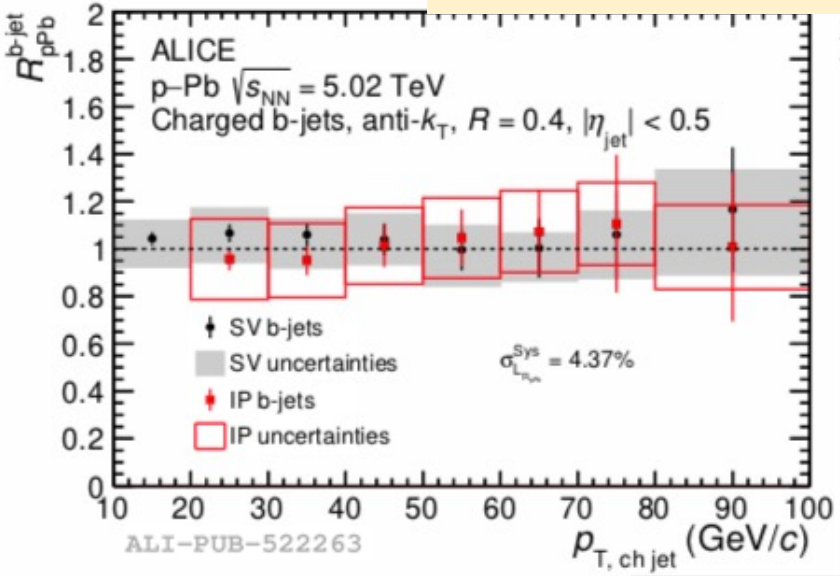


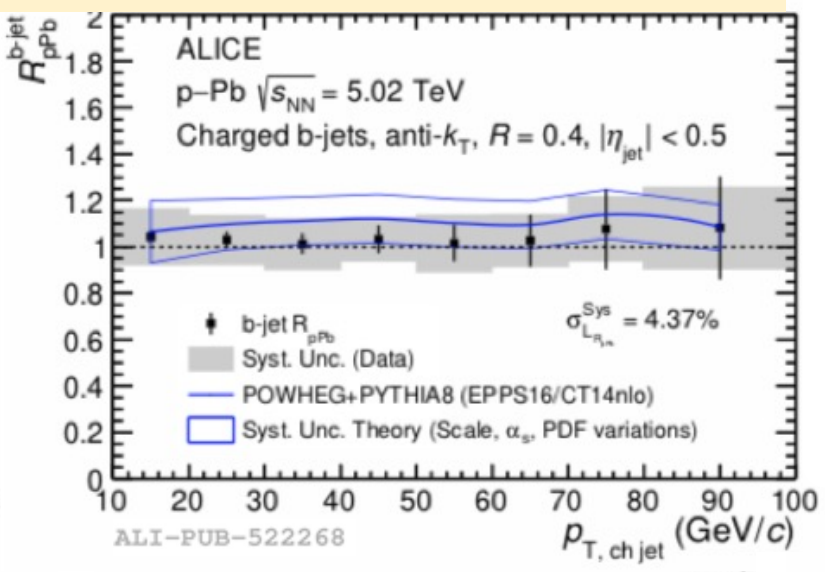
(ATLAS Eur. Phys. J. C (2011) 71:1846)

b-tagged jets in pp and p–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

JHEP01(2022)178

no strong nuclear effects in b-jet production at midrapidity

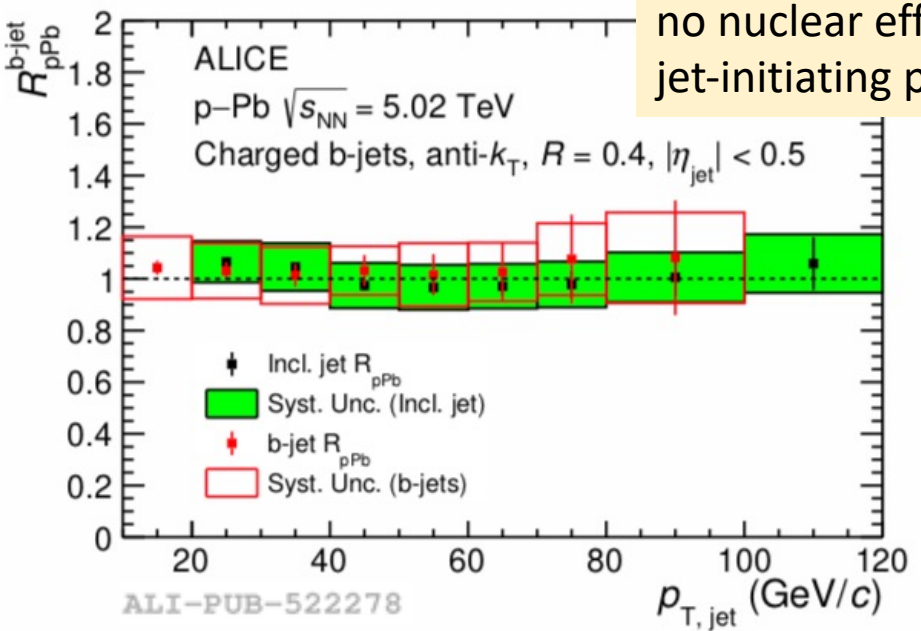




$R^{\text{b-jet}}_{\text{pPb}}$

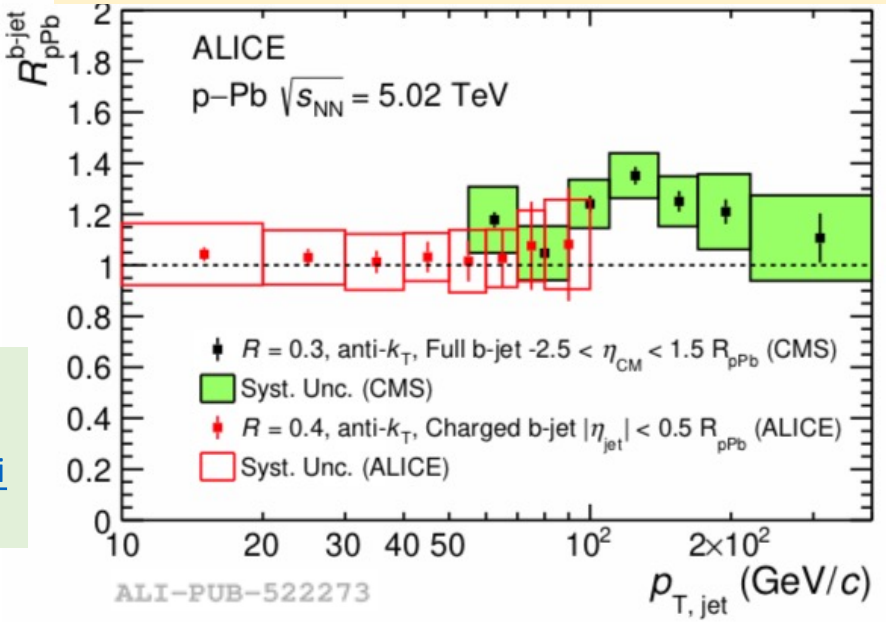
- consistent within uncertainties for IP/SV methods
- consistent within uncertainties with unity (and with a 1.1 valued predicted by a mild nPDF modification due to antishadowing)

no nuclear effects depending on the jet-initiating parton



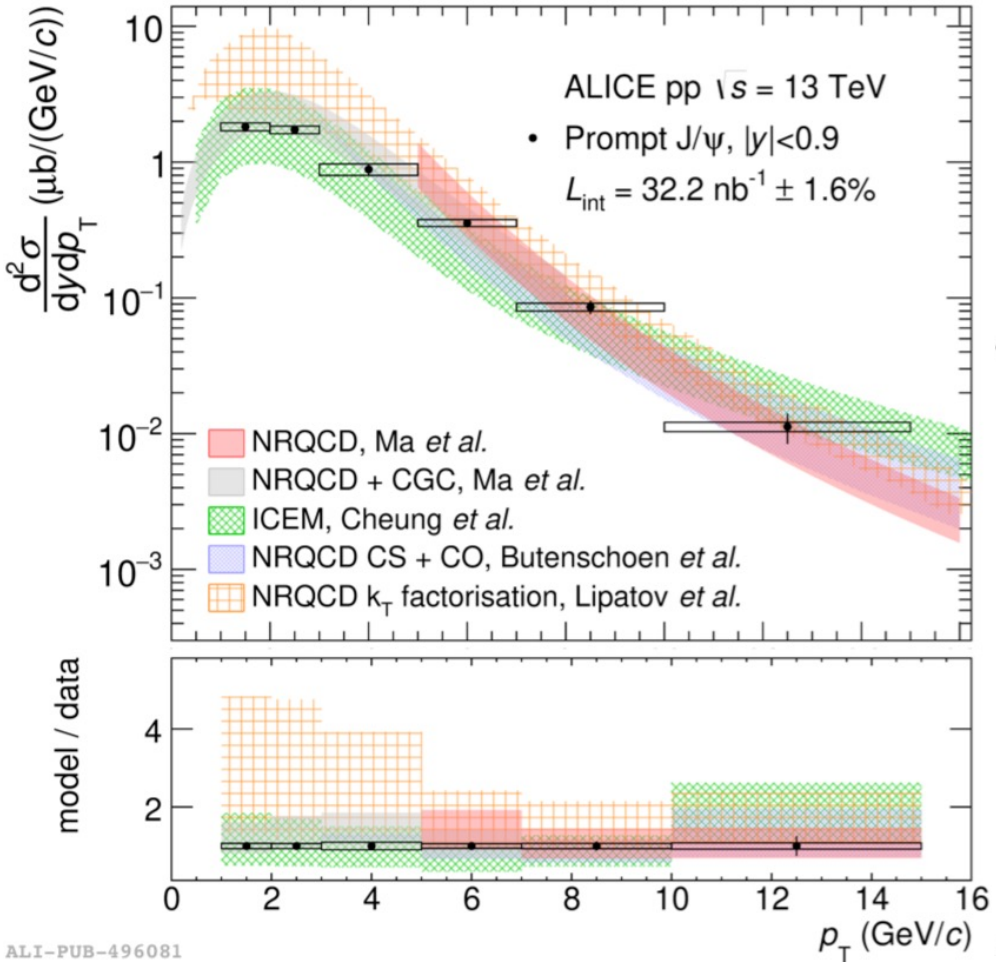
ALICE results on HF-jets@DIS2022:
Ravindra's talk
https://indico.cern.ch/event/1072533/contributions/4778077/

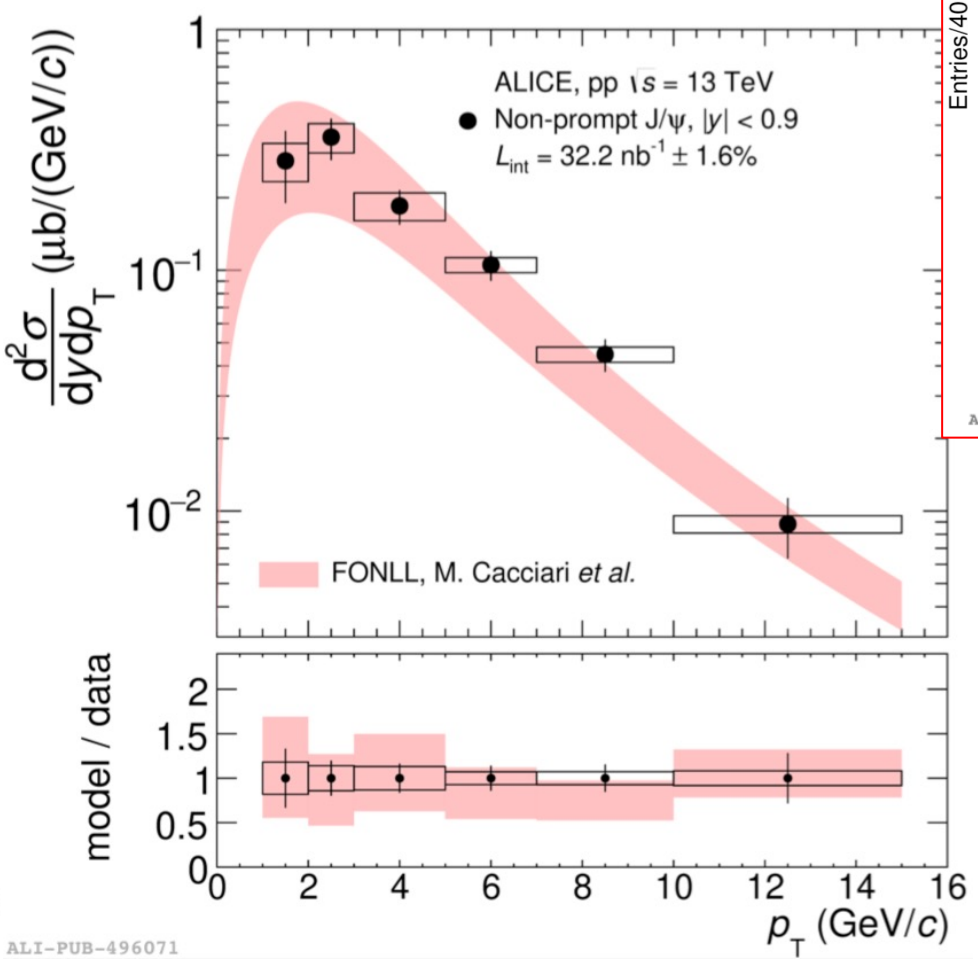
CMS-ALICE complementarity "at a glance"

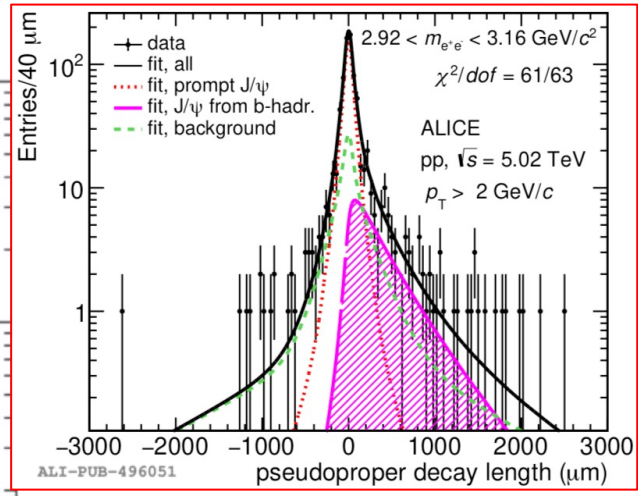


non-prompt J/Ψ in pp

arXiv:2108.02523 (results at $\sqrt{s}$ = 5.02 TeV and $\sqrt{s}$ = 13 TeV)





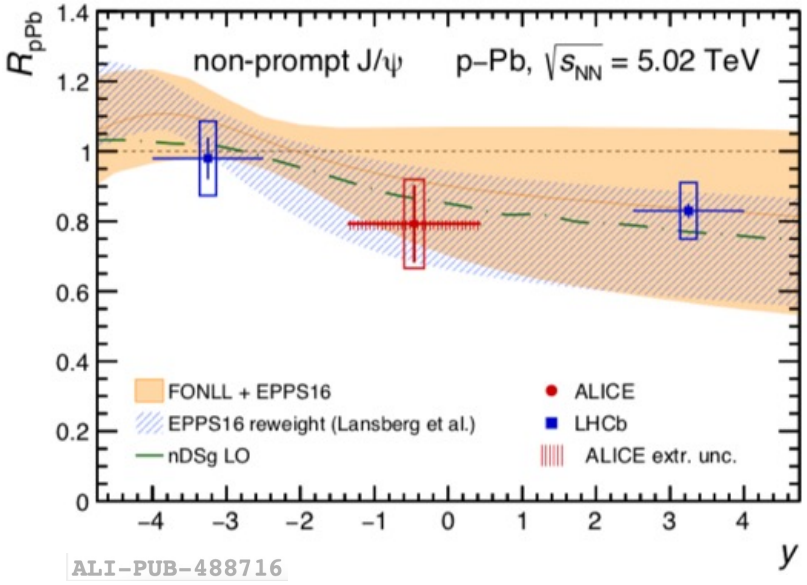


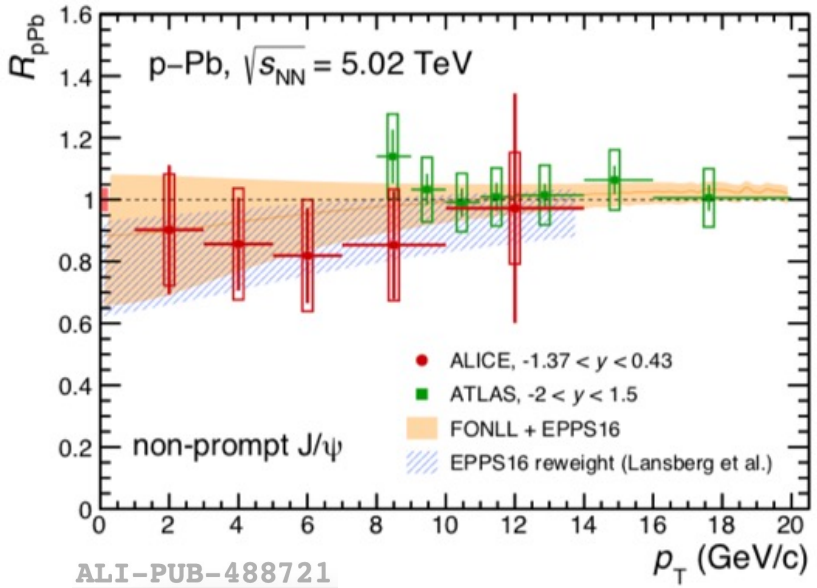
- selection based on three-component fit of the pseudoproper decay length

Prompt component well described by models, FONLL fits well non-prompt J/Ψ
Similar agreement at $\sqrt{s}$ = 5.02 TeV

non-prompt J/Ψ in p–Pb

arXiv:2105.04957 (results at $\sqrt{s}$ = 5.02 TeV)





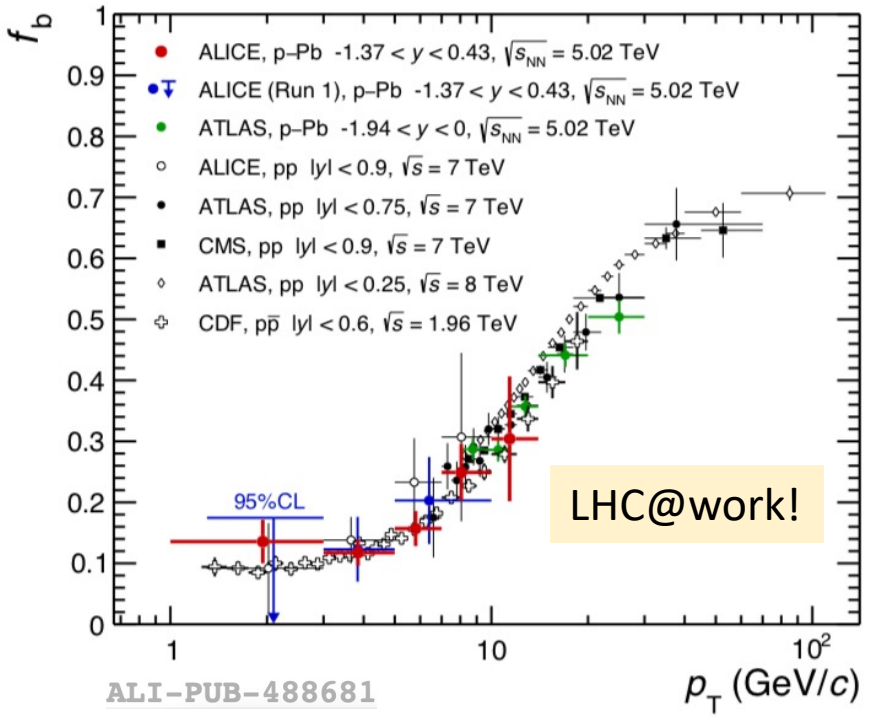
$$\sigma(\mathrm{p+Pb} \to \mathrm{b\bar{b}} + X) = 35.5 \pm 5.0\ (\mathrm{stat.}) \pm 4.8\ (\mathrm{syst.})\ ^{+1.2}_{-1.0}\ (\mathrm{extr.})\ \mathrm{mb}.$$

(total c.s. consistent with previous measurements with total uncertainty reduced by a factor 2)

But we can do better putting together LHC experiments (and visible regions):

$$\sigma(\mathrm{p+Pb} \to \mathrm{b\bar{b}} + X) = 33.8 \pm 2.0\ (\mathrm{stat.}) \pm 3.4\ (\mathrm{syst.})\ ^{+0.4}_{-0.5}\ (\mathrm{extr.})\ \mathrm{mb} \quad (\mathrm{ALICE\ and\ LHCb}).$$

Hint of less pronounced suppression at p_T< 3 GeV/c for non-prompt component with respect to prompt



Conclusions

Direct measurement of prompt / non-prompt component in charmed mesons, baryons and quarkonia allow ALICE to study bb production in small systems

- Since first publication last year for D-meson production, the technique to select non-prompt component used for a rich set of observables in small systems
- FONLL and pQCD calculations describe generally well data with some tension for the baryons (as for prompt), testing fragmentation and hadronization
- QCD-inspired generators show some tensions to describe production as a function of multiplicity
- Key reference for Pb−Pb collisions analyses established, CNM effects b-dependent not visible
- We expect to find & study more beauty in Run 3 (ITS upgrade + continuous readout).

BACKUP