Heavy-flavour production and correlations in pp collisions: precision tests of pQCD and hadronisation with ALICE

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IIT BOMBAY

for the ALICE Collaboration

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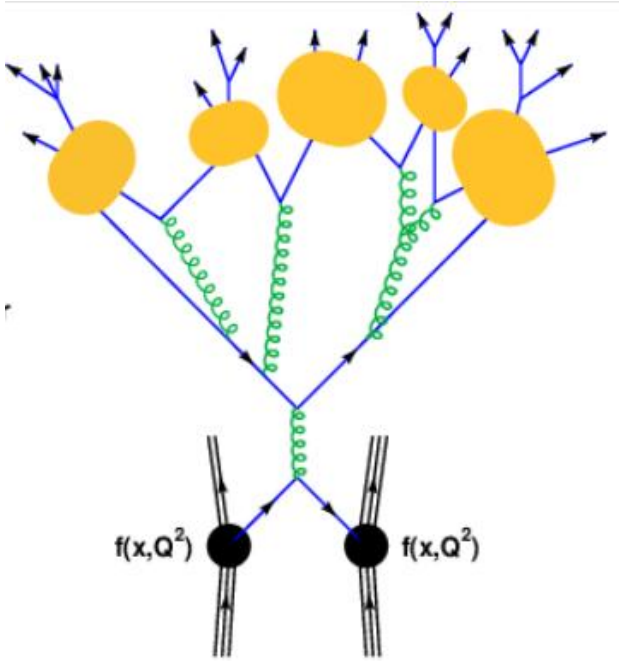
Introduction

- Why heavy quarks are important?
  - $m_{\mathrm{c}} \sim 1.3$ GeV/c^2 and $m_{\mathrm{b}} \sim 4.2$ GeV/c^2
  - Have masses $m_Q \gg \Lambda_{\mathrm{QCD}}$ (~ 200 MeV)
  - Introduce a natural hard scale into the problem
  - Ensure coupling is small: $\alpha_{\mathrm{s}}(m_{\mathrm{Q}}) \ll 1$



- Heavy-flavour hadron production can be calculated with factorization approach

$$d\sigma_{\mathrm{p_1p_2}\to\mathrm{H}+X} = \sum_{i,j,k} \int dx_1 dx_2\, dz\, f_{i\mathrm{p}_1}(x_1,\mu_F) \times f_{j\mathrm{p}_2}(x_2,\mu_F) \times \hat{\sigma}_{ij\to k}(x_1,x_2,\mu_F,\mu_R) \times D_{q\to\mathrm{H}}(z,Q^2)$$

Parton distribution functions (initial state hadronic structure)

Partonic cross section (calculated within pQCD framework)

Hadronisation function (Non-perturbative, tuned using e^+e^- data, assumed universal across collision system)

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- In this talk :
  - D^0-meson and B^0-meson production to test pQCD predictions
  - Associated production of D^0 and J/ψ to assess the role of Multiple Parton Interactions

- Heavy-flavour hadron production can be calculated with factorization approach

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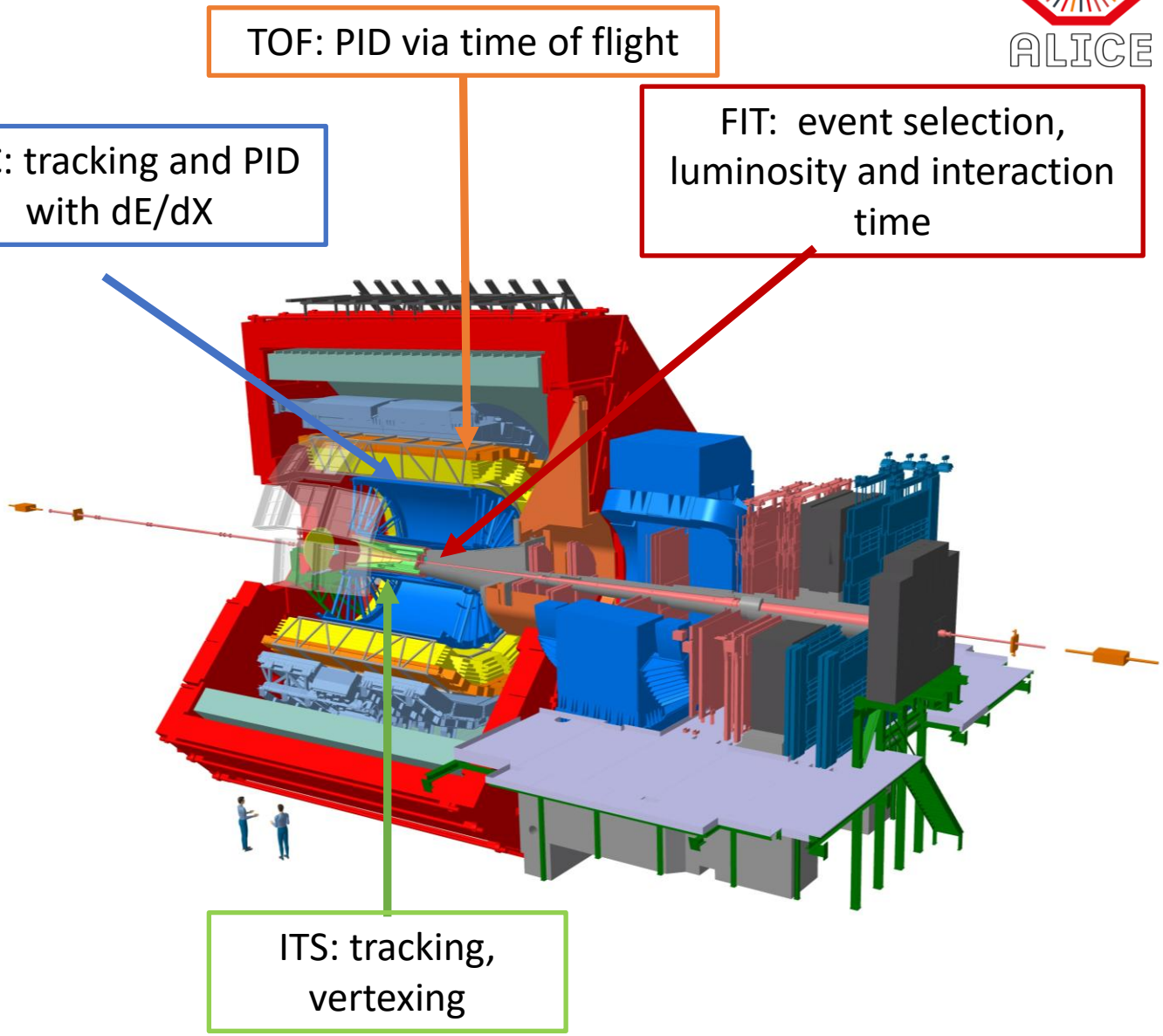
The ALICE apparatus

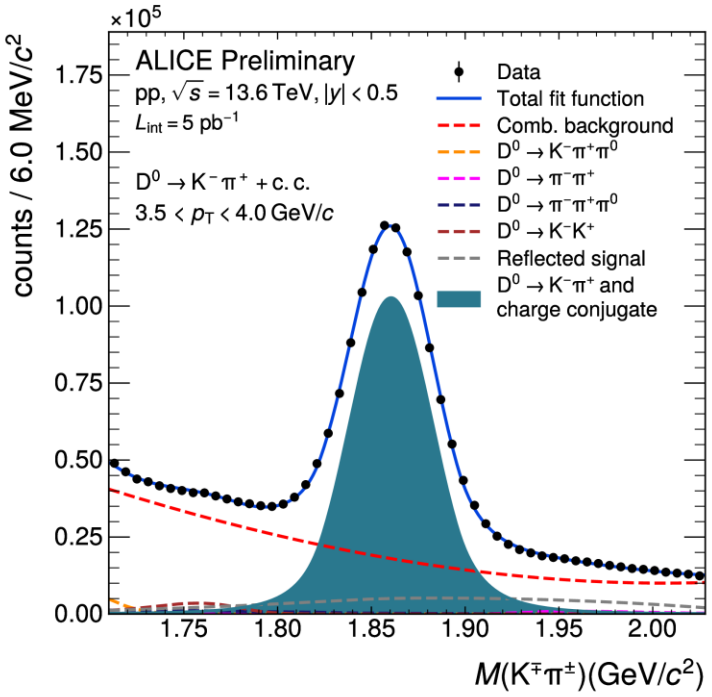
- c-hadron $c\tau$: 45−313 μm and b-hadron $c\tau$: 450 − 500 μm → require high resolution for identification of decay vertices displaced from collision point

- Continuous readout at high interaction rates, up to 750 kHz in pp collisions, allows collection of a large data sample: $L_{\mathrm{int}} \sim 50\ \mathrm{pb}^{-1}$



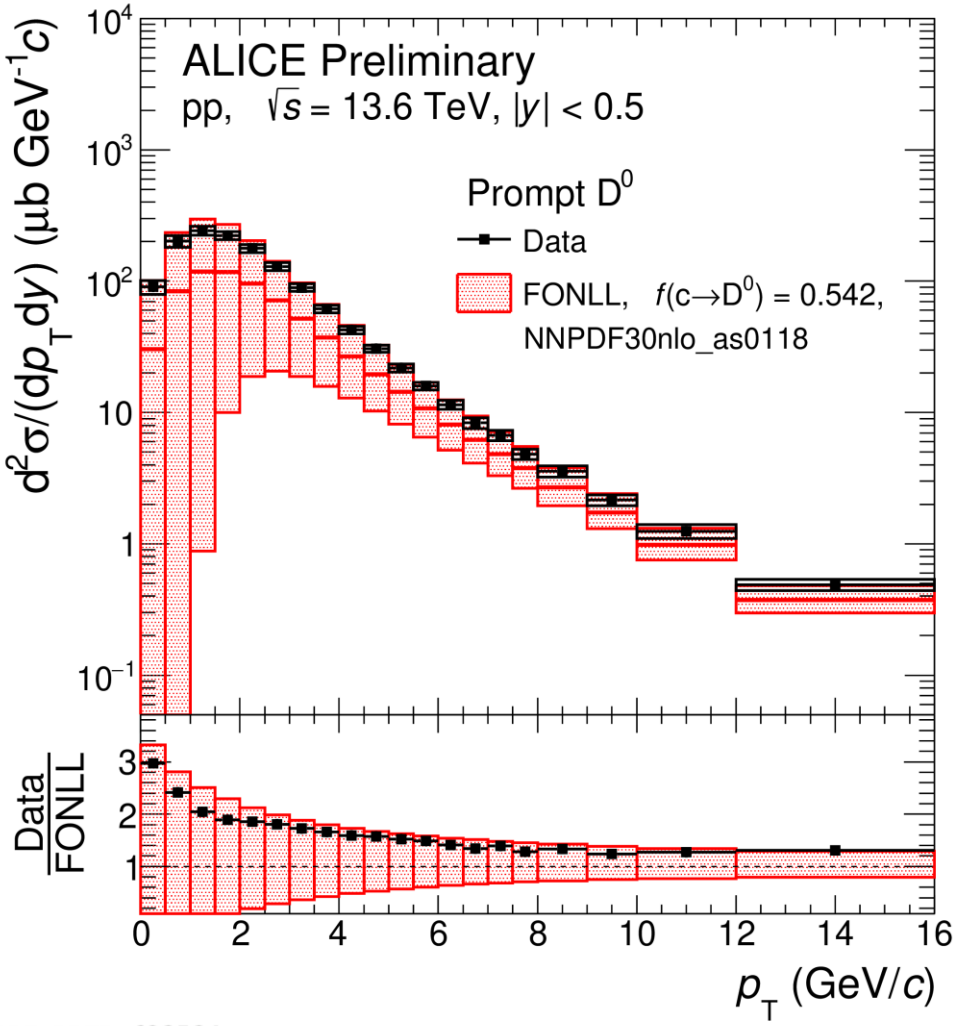
Prompt D^0-meson production

- Prompt D^0-meson production measured with high precision in the interval $0 < p_T < 16$ GeV/c



ALI-PREL-623550

New



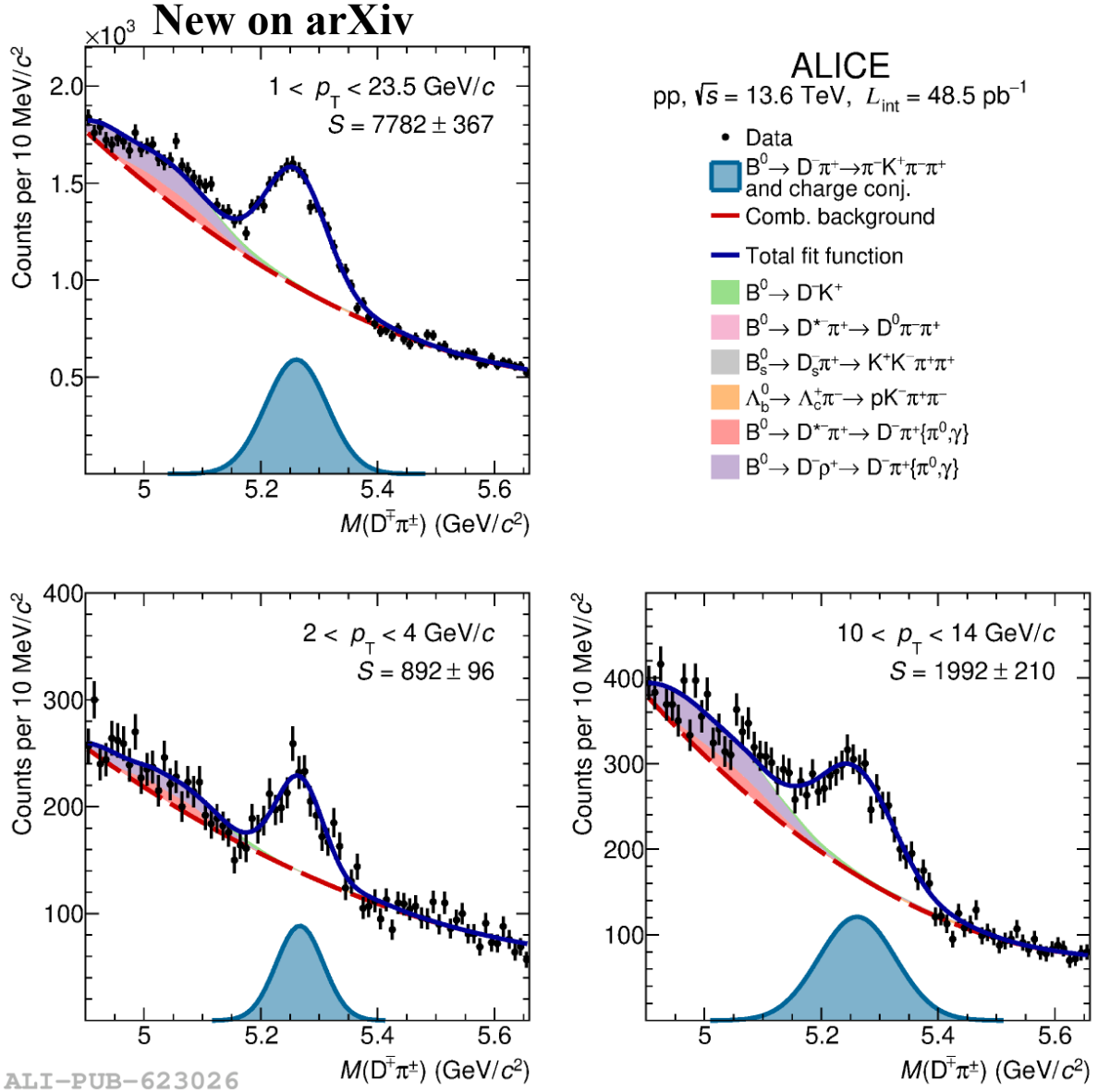
ALI-PREL-623534

- FONLL describes the data, with data on upper edge of the theoretical calculations
- Experimental uncertainties much smaller than theoretical uncertainties → can constrain theoretical models

❑ FONLL: M. Cacciari et al., JHEP05(1998)007

B^0-meson production

❑ ALICE, arXiv:2603.18904v1



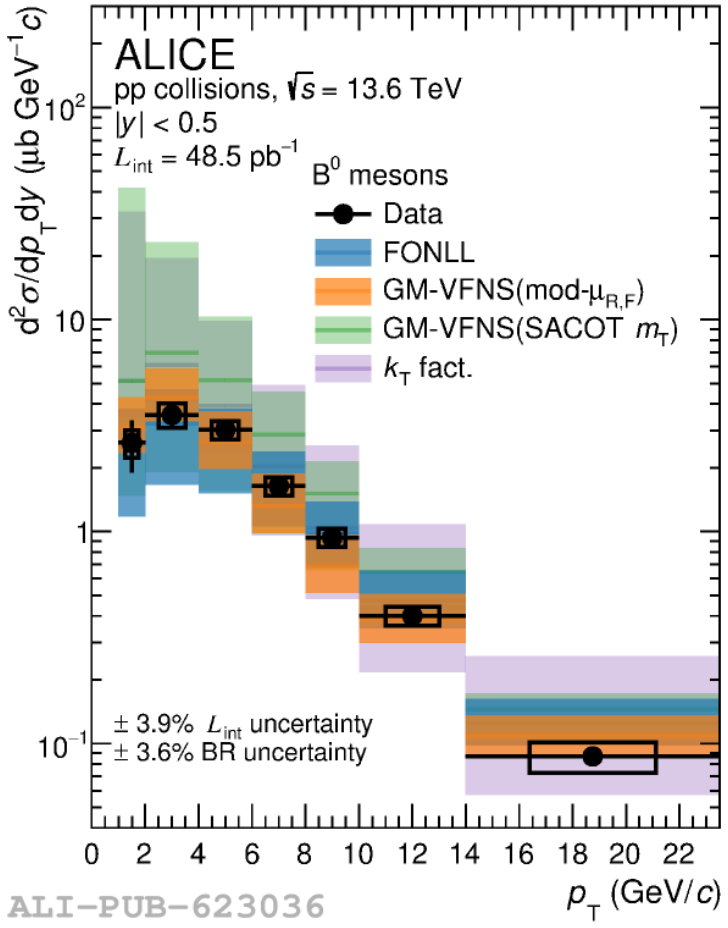
- Beauty-quark has larger mass w.r.t. to charm quark, resulting in smaller uncertainties in theoretical calculations
- First measurement of B^0-meson production at midrapidity down to low $p_T = 1$ GeV/c in pp collisions at $\sqrt{s} = 13.6$ TeV by ALICE
- Offline software trigger used for B^0 meson reconstruction via

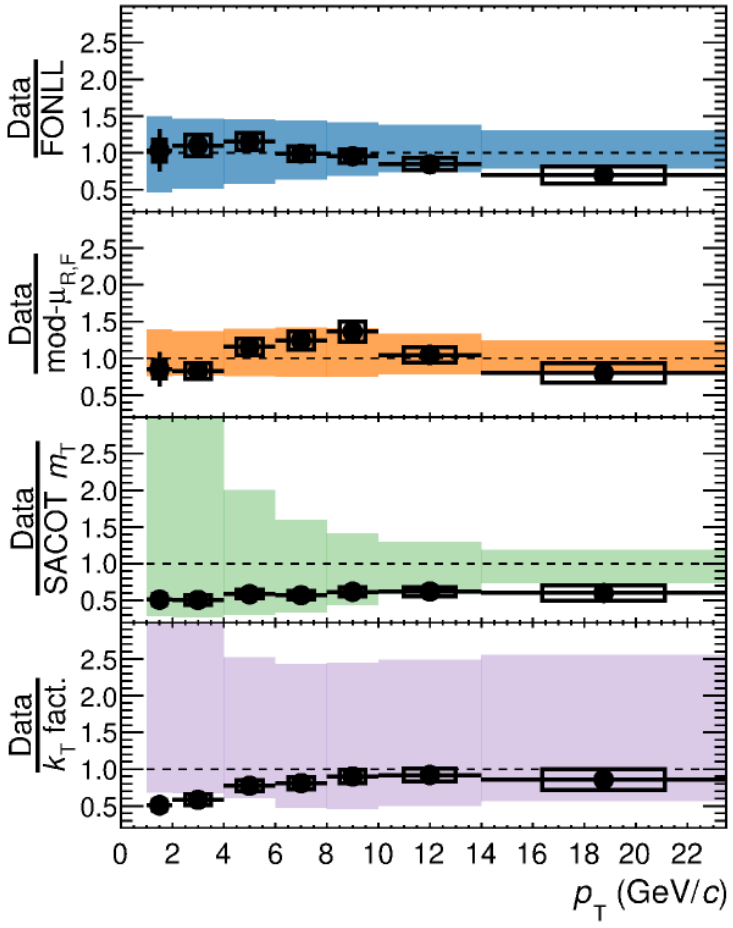
  $B^0 \to D^- \pi^+ \to \pi^- K^+\pi^- \pi^+$
- Correlated background due to misidentified kaons/protons and/or partially reconstructed decays modelled with MC templates

B^0-meson production

❑ ALICE, arXiv:2603.18904v1

New on arXiv





- B^0-meson production cross section in agreement with various pQCD calculations
- FONLL describes the data within uncertainties
- GM-VFNS (mod-$\mu_{R,F}$: uses tuning in factorisation and fragmentation scale to overcome divergence at low p_T) describe data within uncertainties
- GM-VFNS (SACOT m_T: uses finite mass to overcome divergence at low p_T). Central values overestimate the data in entire p_T range
- k_T fact. considers k_T-dependent factorisation, describes the data for $p_T > 4$ GeV/c

❑ FONLL: M. Cacciari et al., JHEP05(1998)007
❑ mod-$\mu_{R,F}$: M. Benzke et al., EPJC 79, 814 (2019)
❑ SACOT m_T: I. Helenius et al., JHEP 07 (2023) 054
❑ k_T fact: F. Barattini et al., JHEP 05 (202) 115

B^0-meson production

❑ ALICE, arXiv:2603.18904v1

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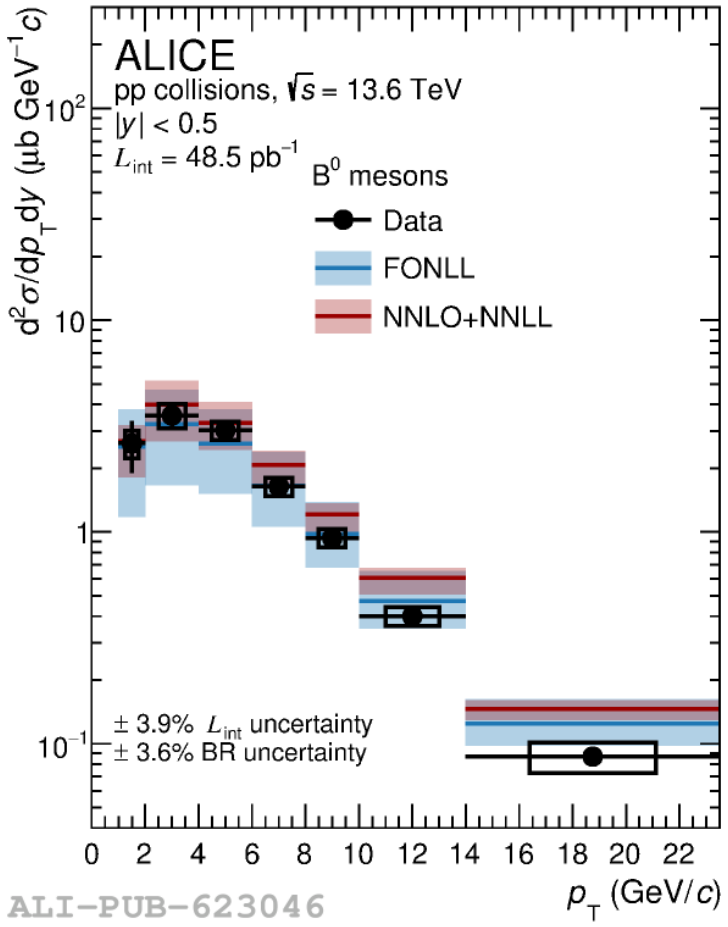

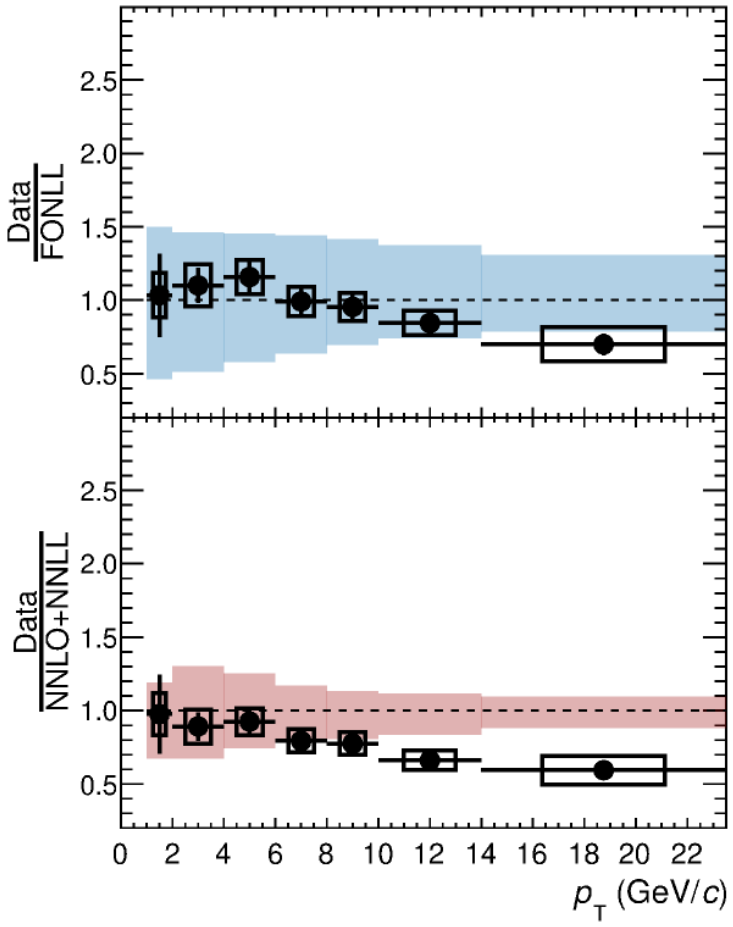

NNLO+NNLL calculations are also available:

- Improved theoretical precision
- Reduced scale dependence

B^0-meson production cross section:

- Well described by both NLLO+NNLL and FONLL predictions within uncertainties at $p_T < 10$ GeV/c
- NNLO+NNLL predictions lie toward the upper part of FONLL uncertainty band

❑ FONLL: M. Cacciari et al., JHEP05(1998)007

❑ NLLO+NNLL: M. Czakon et al., PRL 135, 161903

B^0-meson production

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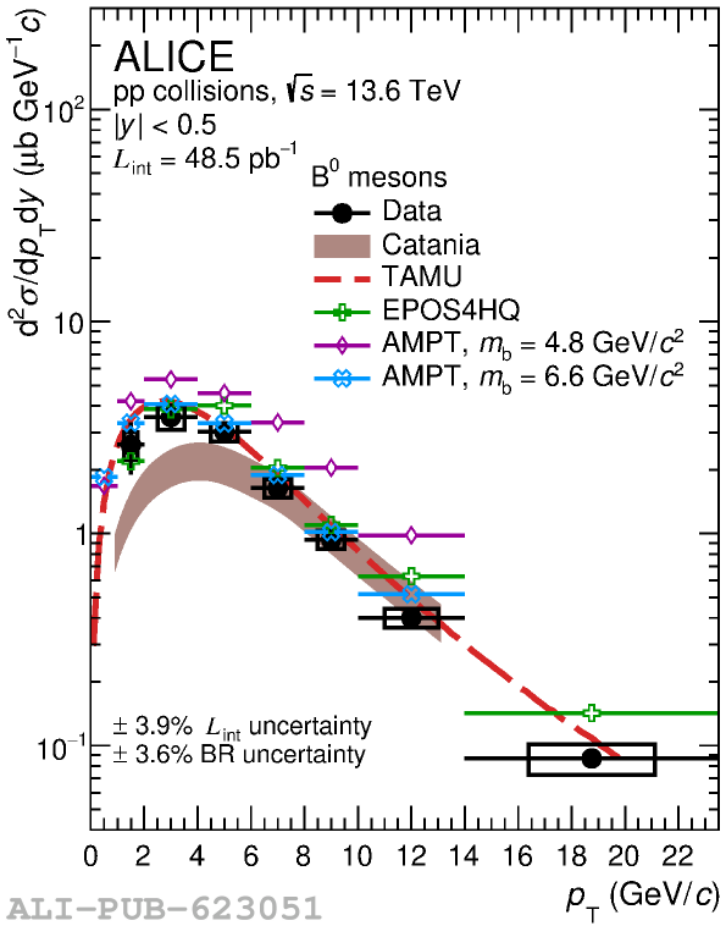

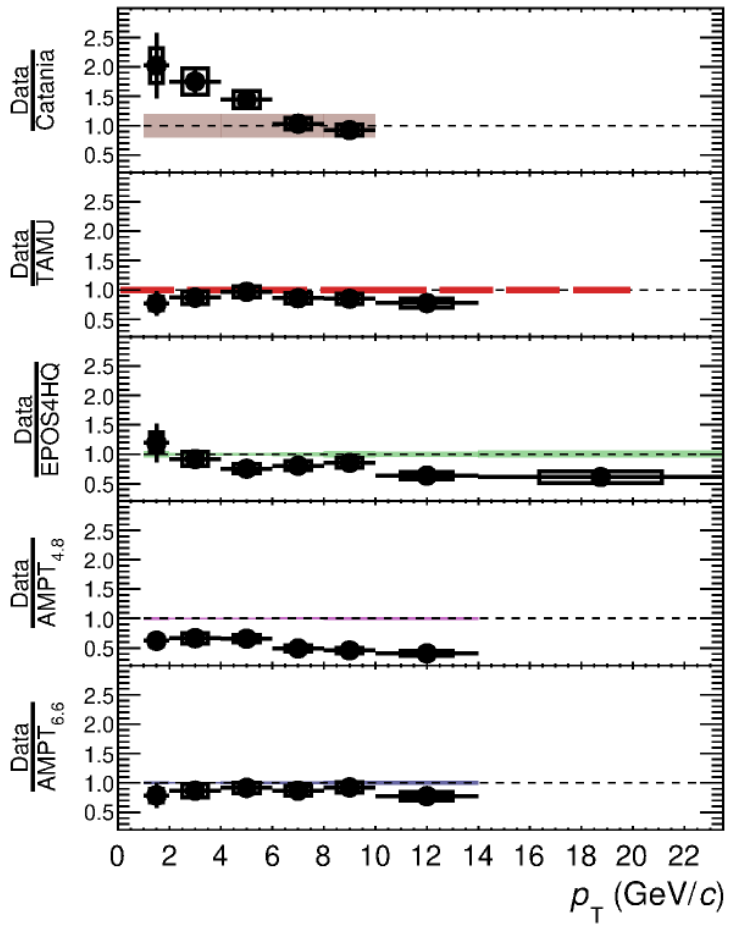

Comparison with transport models:

- Catania
  - FONNL b-quark spectra
  - In medium heavy-quark diffusion
  - Hadronisation via fragmentation and coalescence
  - Underestimates the data at low p_T
- TAMU
  - LHCb $b\bar{b}$ + FONLL b-quark spectra
  - Non-perturbative T-matrix interactions
  - ($b \rightarrow H_b$) from statistical hadronisation model
  - Better describes data

❑ Catania: V. Minissale et al., PLB 2021 136622

❑ TAMU: M. He et al., PRL 131 (2023) 1, 012301

B^0-meson production

❑ ALICE, arXiv:2603.18904v1

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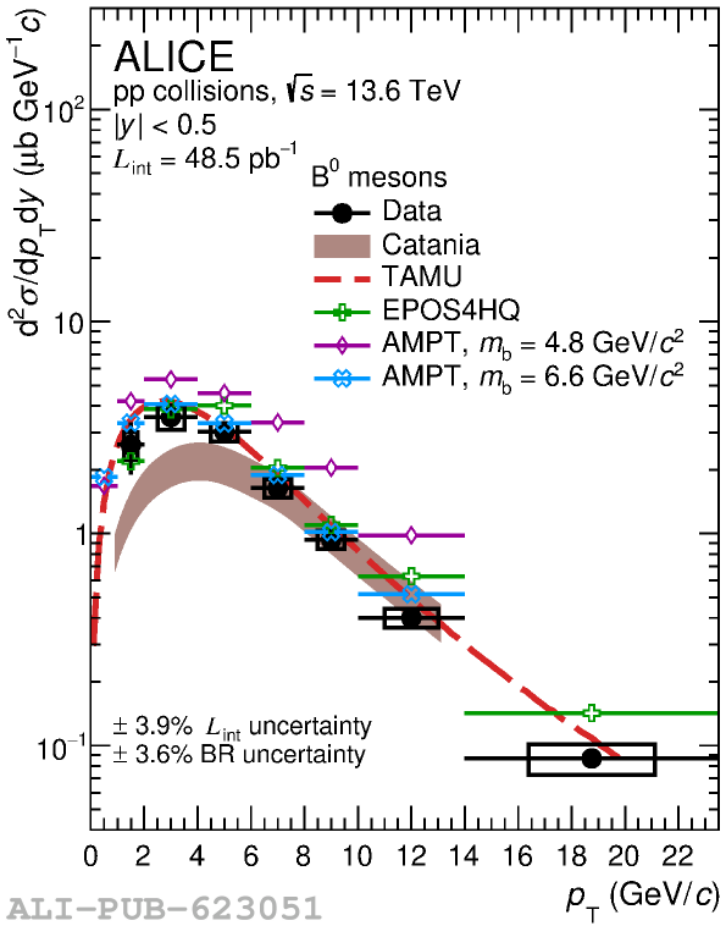
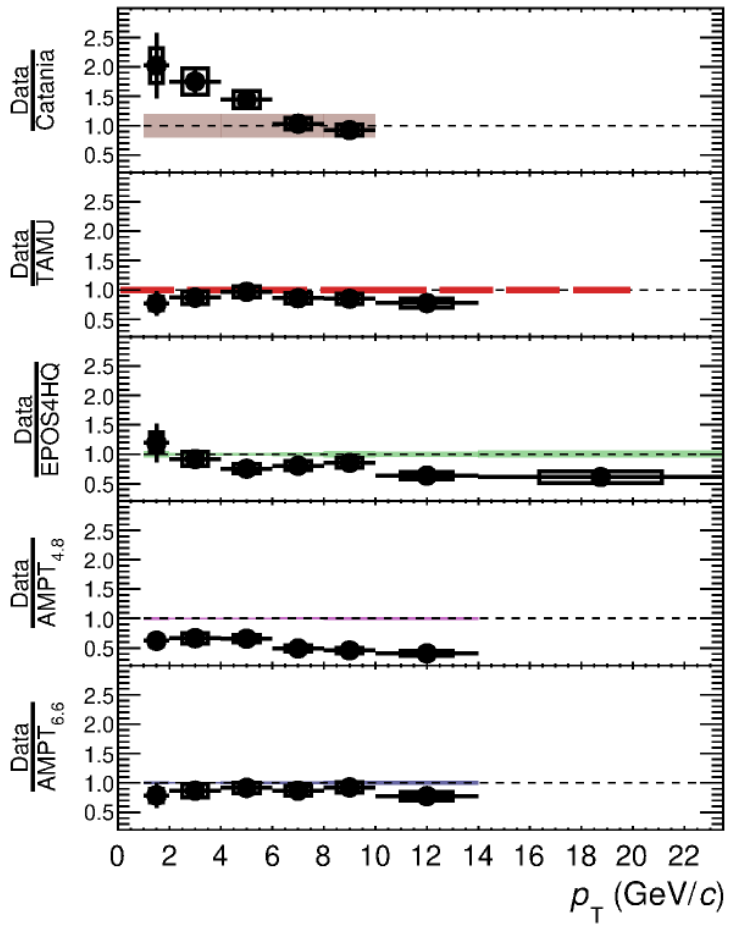




Comparison with transport models:

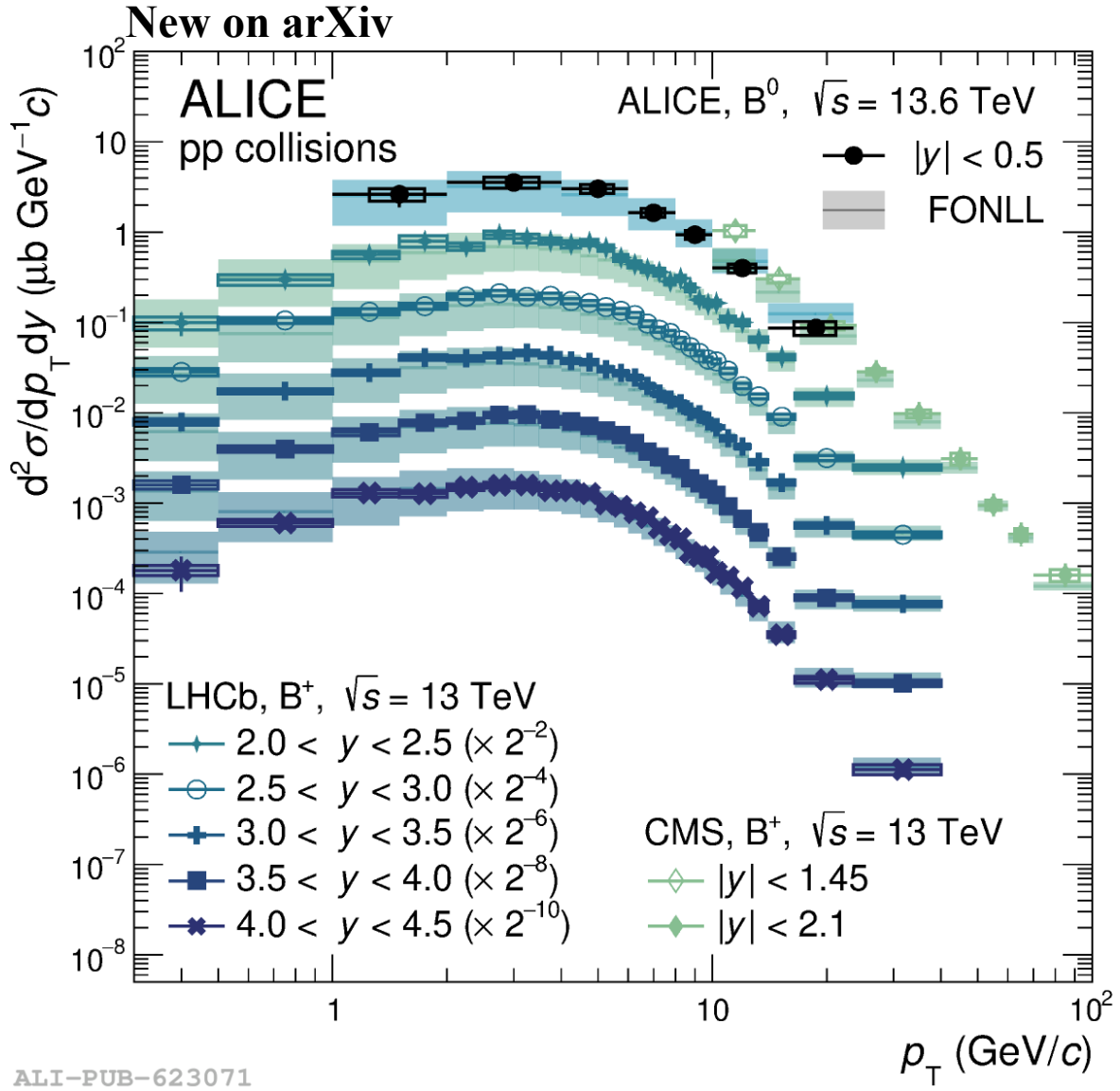
- EPOS4HQ
  - Hydrodynamic evolution with heavy-quark propagation
  - Hadronisation via fragmentation and coalescence
  - Describes data well up to 10 GeV/c only
- AMPT
  - Multi-phase partonic and hadronic interactions
  - Hadronisation via fragmentation and coalescence
  - Overestimates data for $m_b = 4.8$ GeV/c^2

❑ EPOS4HQ: J. Zhao et al., PRC 110 (2024) 2. 024909

❑ AMPT: J. He et al., PRD 113(2026), 034008

B^0-meson production

❑ ALICE, arXiv:2603.18904v1



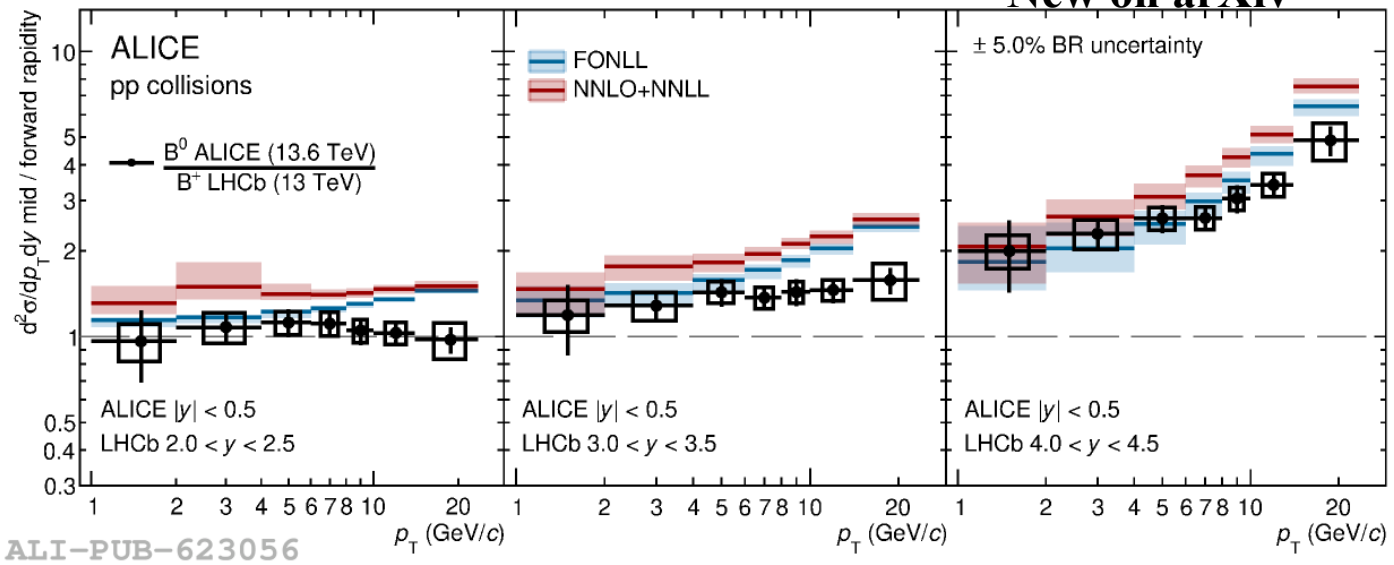
- Together with LHCb and CMS B^+ results, B-meson cross section measured over a wide kinematic interval

- ALICE complements CMS and LHCb previous B^+ measurements by covering low p_T at midrapidity, down to 1 GeV/c

B^0-meson production

❑ ALICE, arXiv:2603.18904v1

New on arXiv



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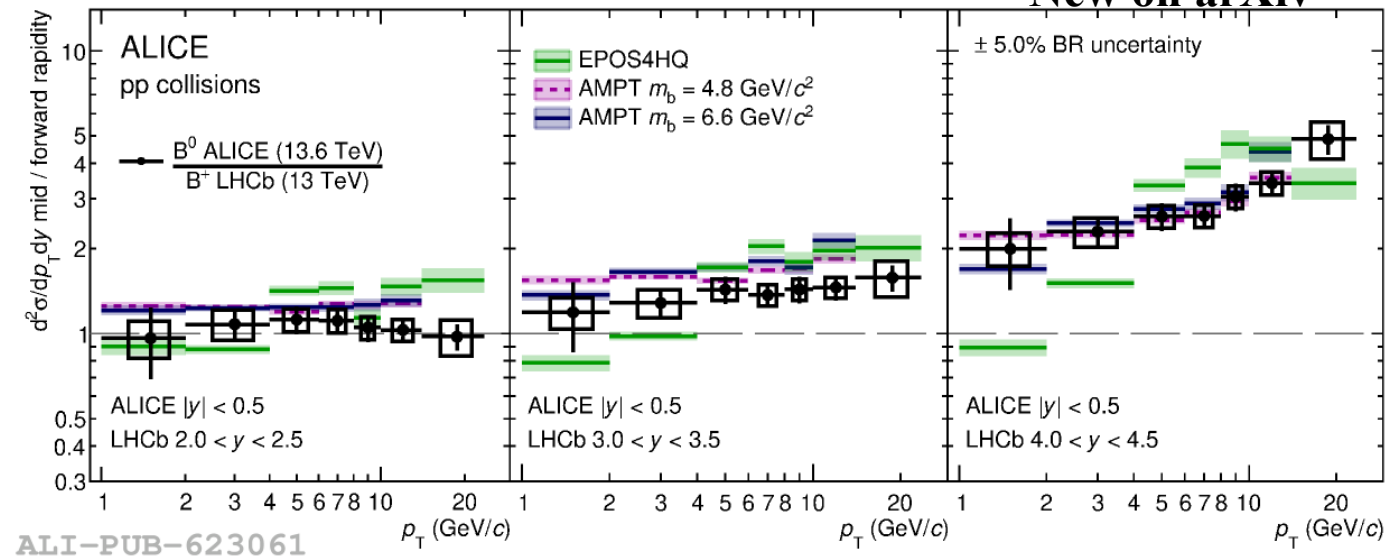
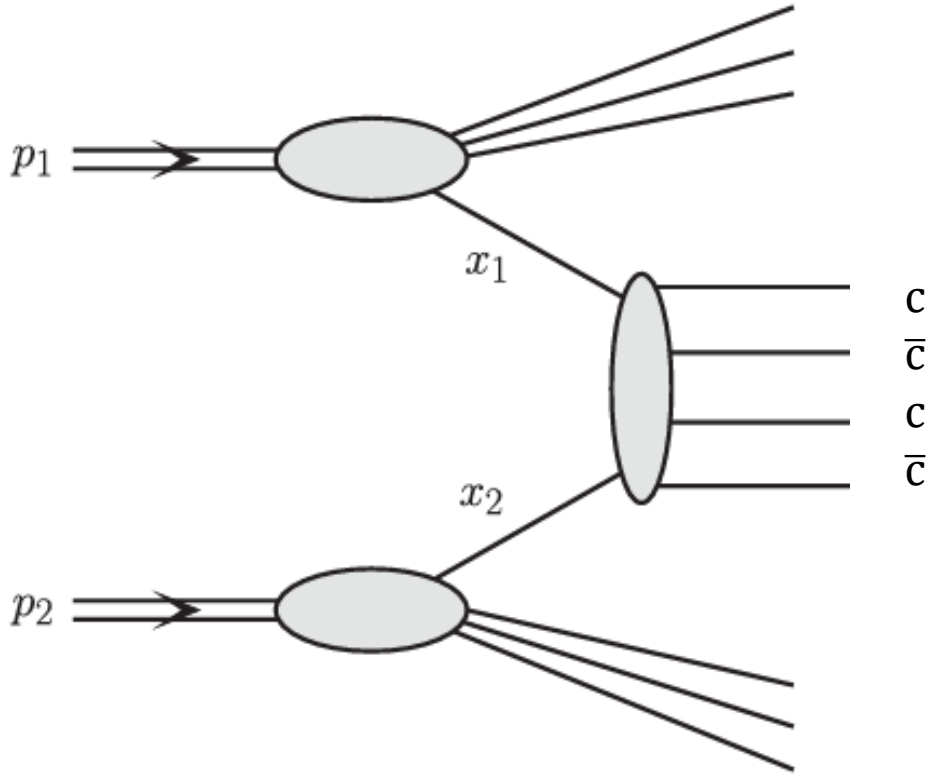


- Ratio of B^0-meson production at midrapidity by ALICE and B^+-meson production at forward rapidity by LHCb
- As expected, harder p_T-spectrum and larger production towards midrapidty
- Comparison with models:
  - FONLL and NNLO+NNLL qualitatively describe the data, with NNLO+NNLL calculations systematically higher than FONLL
    - ❑ FONLL: M. Cacciari et al., JHEP05(1998)007
    - ❑ NLLO+NNLL: M. Czakon et al., PRL 135, 161903
  - AMPT with two hypotheses for beauty-quark mass describes data
  - EPOS4HQ underestimates the ratio at low p_T
    - ❑ EPOS4HQ: J. Zhao et al., PRC 110 (2024) 2. 024909
    - ❑ AMPT: J. He et al., PRD 113(2026), 034008

Associated production cross section (SPS +DPS)

- Production of two specified particles in the same collision : σ (X + Y)
- Particle production can occur through independent MPI
- Single Parton Scattering (SPS) and Double Parton Scattering (DPS) can be two of these processes …
  - SPS: A single hard scattering between partons

SPS



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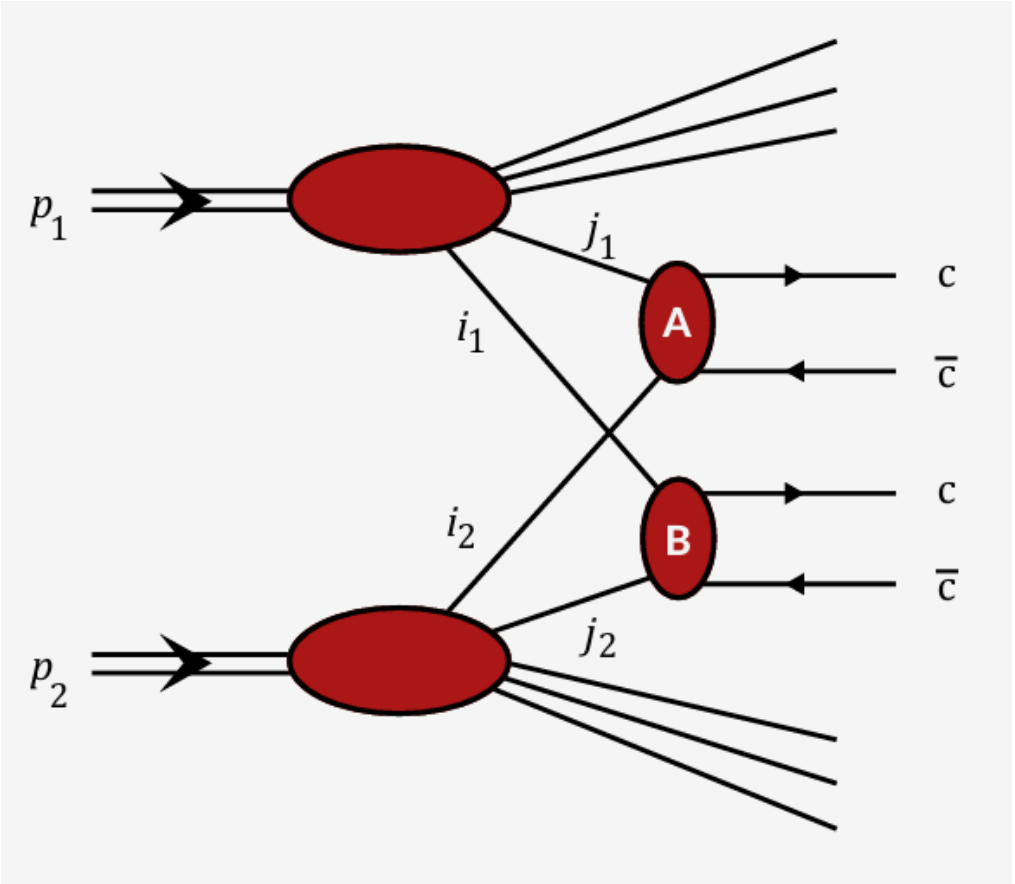
- Single Parton Scattering (SPS) and Double Parton Scattering (DPS) can be two of these processes …
  - SPS: A single hard scattering between partons
  - DPS: Two hard scatterings among partons
- Simplest form of MPI: Double parton scattering (DPS)

DPS



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$$\sigma\ (\mathrm{X}+\mathrm{Y}) = \sigma_{\mathrm{DPS}}(\mathrm{X}+\mathrm{Y}) + \sigma_{\mathrm{SPS}}(\mathrm{X}+\mathrm{Y})$$

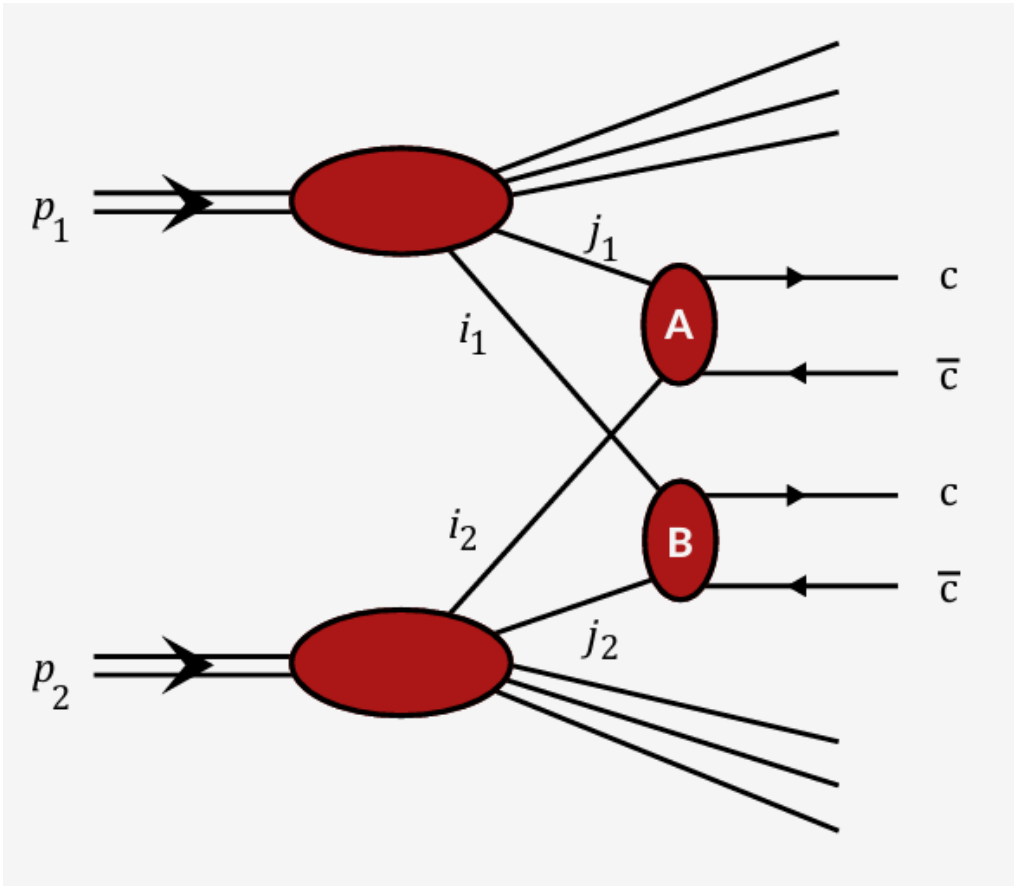
$$\sigma_{\mathrm{DPS}}(\mathrm{X}+\mathrm{Y}) = \frac{1}{1+\delta_{\mathrm{XY}}}\frac{\sigma(\mathrm{X})\sigma(\mathrm{Y})}{\sigma_{\mathrm{eff}}}$$

$\delta_{\mathrm{XY}} = 1$ if X =Y
$\delta_{\mathrm{XY}} = 0$ otherwise

σ_{eff} : **effective cross section**

- Considered independent of process, scale and collision energy
- Measurements in different channels and kinematic regimes can help shed light on its nature

DPS



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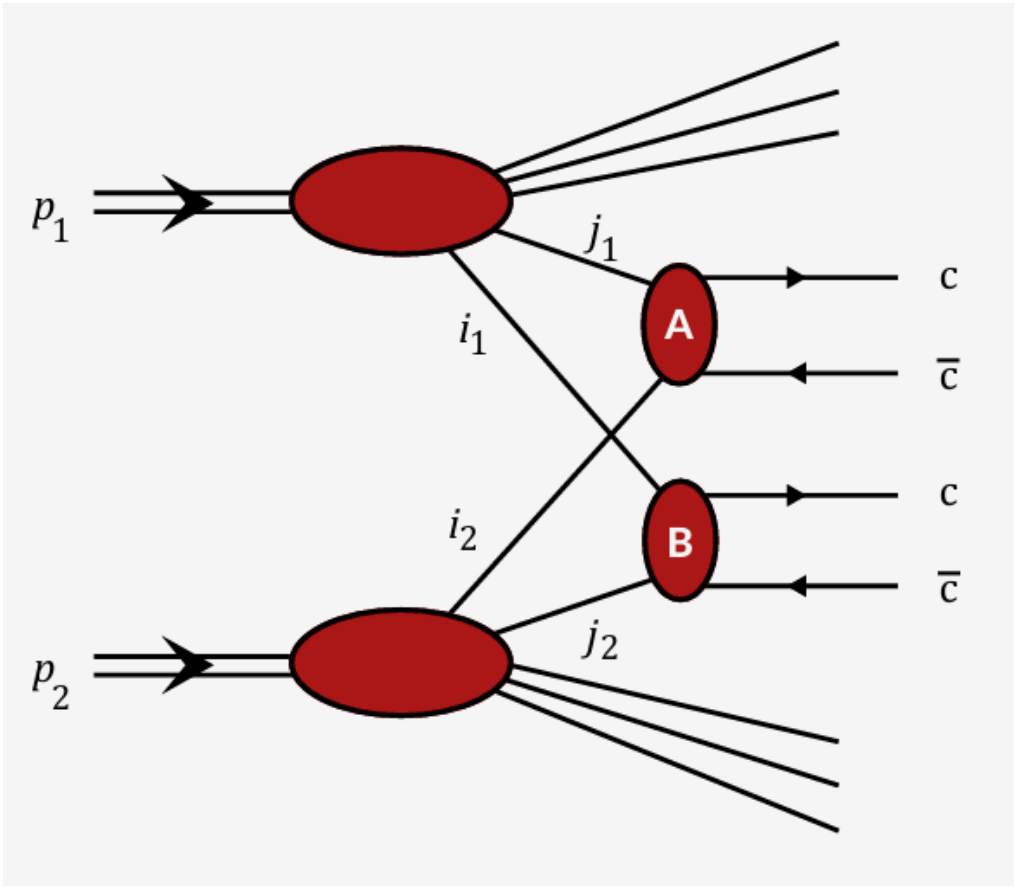
$$\sigma_{\mathrm{DPS}}(\mathrm{X}+\mathrm{Y}) = \frac{1}{1+\delta_{\mathrm{XY}}}\frac{\sigma(\mathrm{X})\sigma(\mathrm{Y})}{\sigma_{\mathrm{eff}}}$$

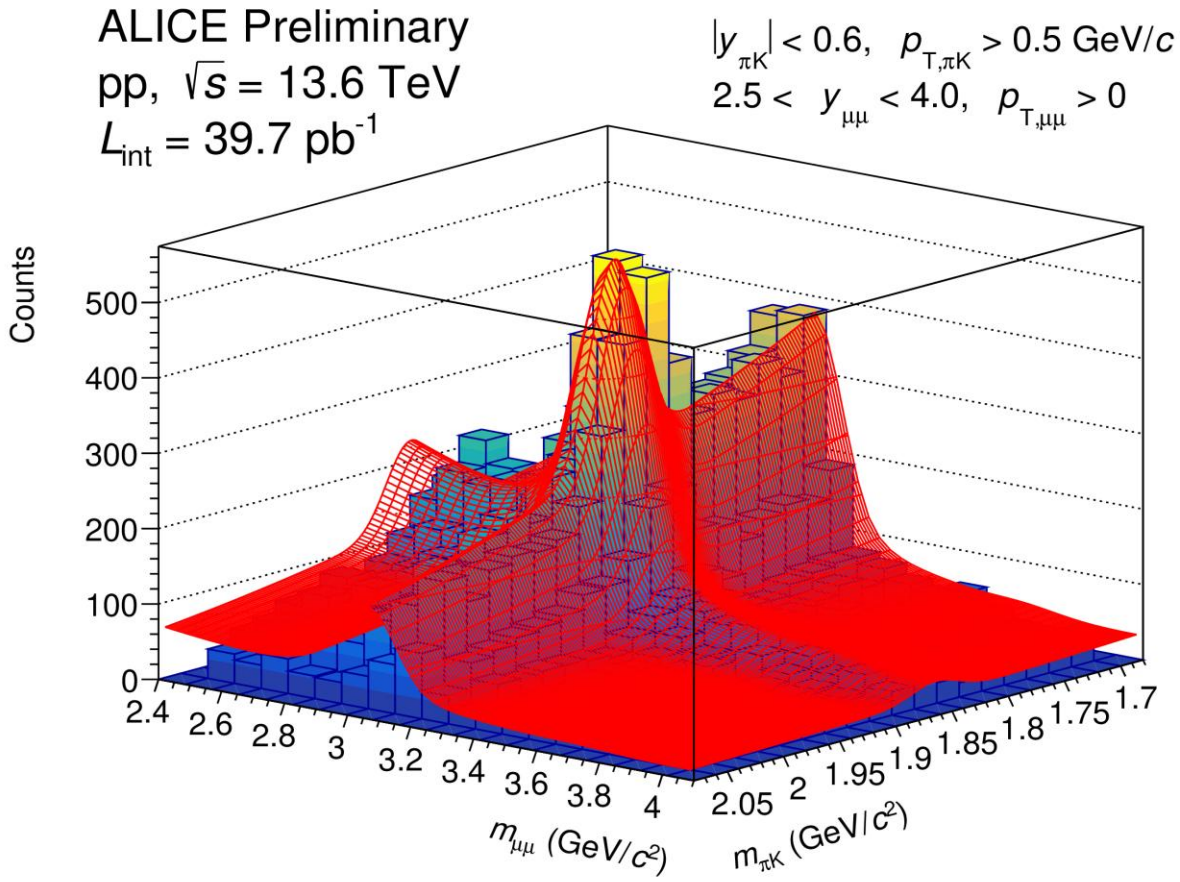
$\delta_{\mathrm{XY}} = 1$ if X =Y
$\delta_{\mathrm{XY}} = 0$ otherwise

- At LHC energies, DPS cross section can be significant
- Provides input to tune Monte Carlo (MC) generators

DPS



Associated production cross section of prompt D^0 and J/ψ



ALI-PREL-609889

- J/ψ reconstructed in forward rapidity using offline trigger selection
- Paired with D^0-mesons reconstructed at midrapidity
- Raw yield extracted using a 2-dimensional invariant-mass fit

Associated production cross section of prompt D^0 and J/ψ

❑ P. Skands et al., Eur. Phys. J. C (2014) 74:3024

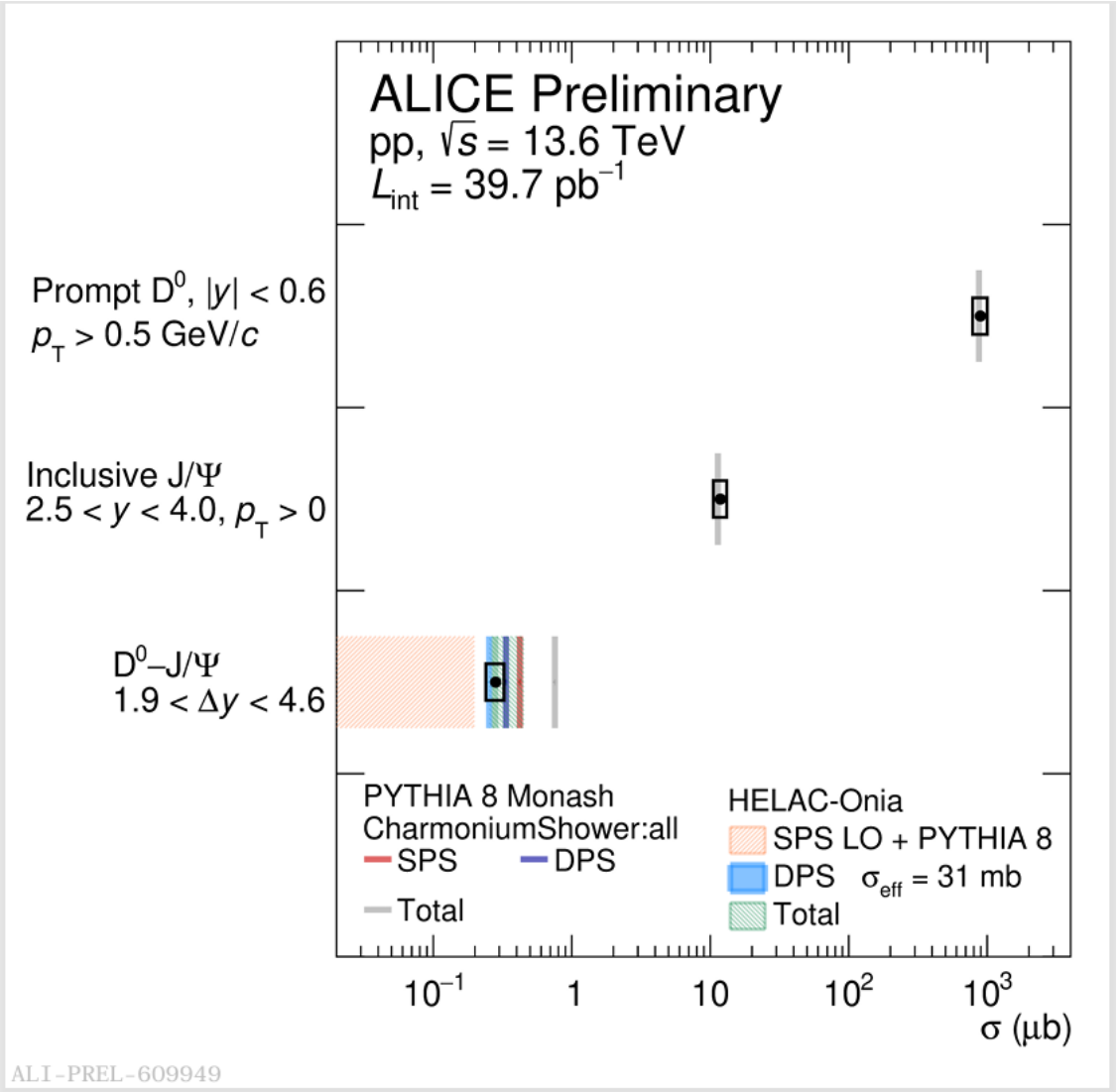
PYTHIA 8 simulations (Monash tune + CharmoniumShower:all) :

- Compatible with single prompt D^0 and inclusive J/ψ production cross section
- Overestimates the associated J/ψ – D^0 production cross section

❑ Hua-Sheng et al., Comput.Phys.Commun. 184 (2013) 2562-2570

HELAC-Onia:

- Reproduces the associated J/ψ – D^0 production cross section considering $\sigma_{\mathrm{eff}} = 31$ mb.
- Large uncertainties on SPS LO+PYTHIA8 component could be reduced using NLO calculation

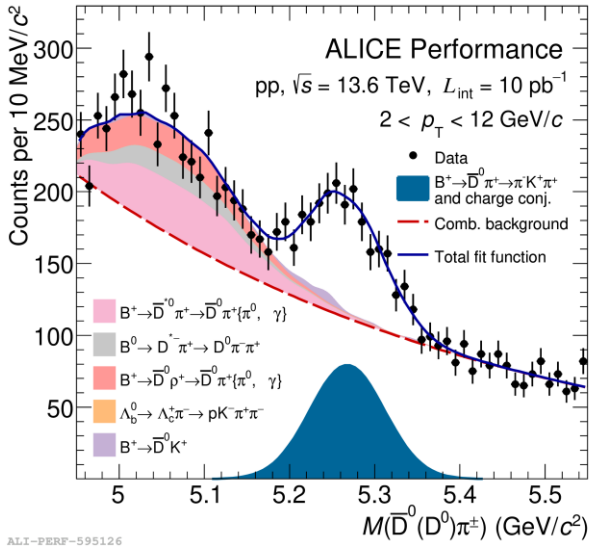


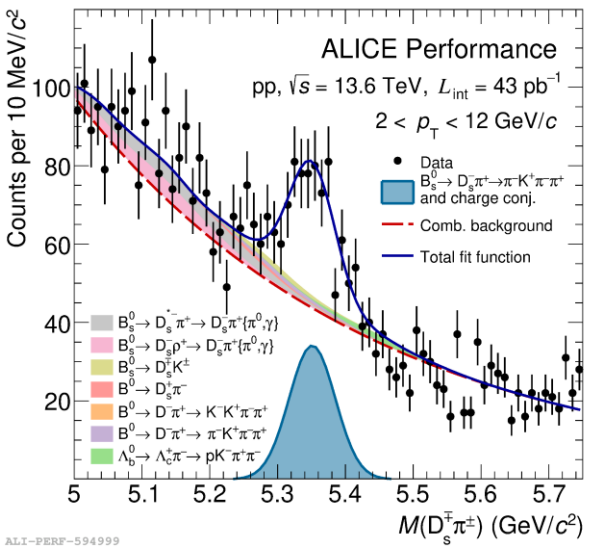
New measurements coming soon …

Direct reconstruction of B-meson signals in other decay channels

- $B \rightarrow D + X$
- $B \rightarrow J/\psi(\rightarrow \mu^+\mu^-) + X$

These measurements will enable direct studies of beauty-quark hadronisation in ALICE





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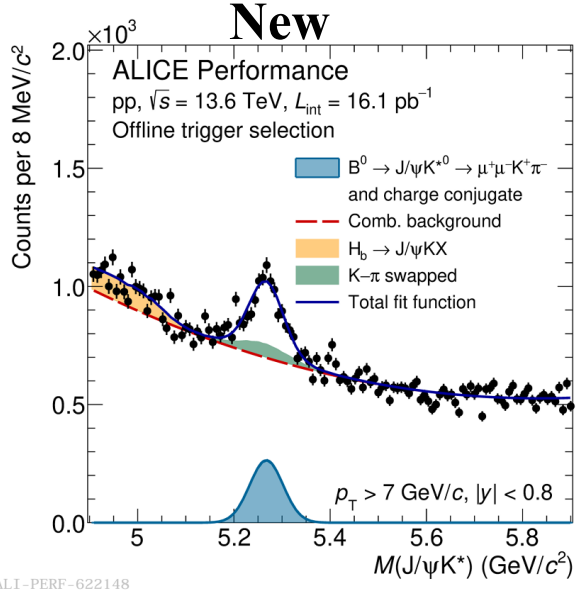

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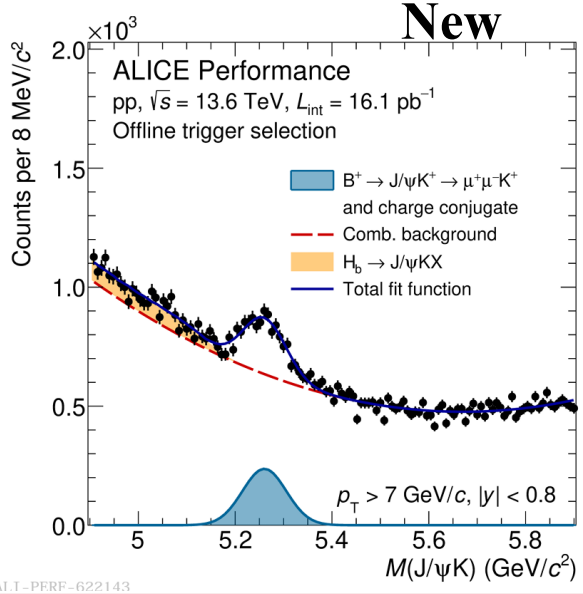

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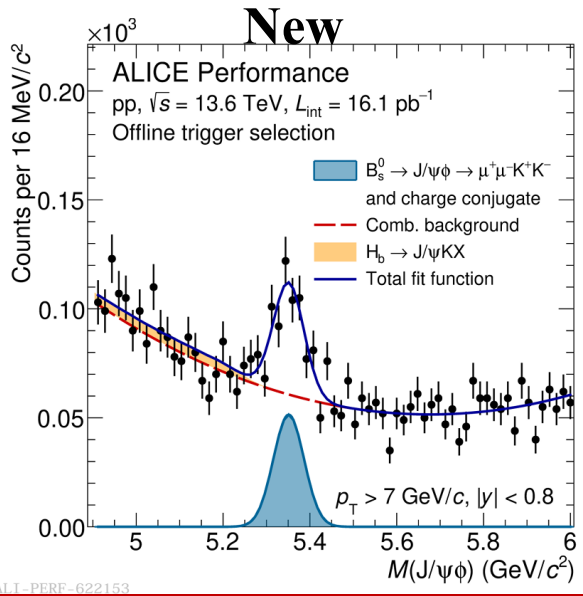
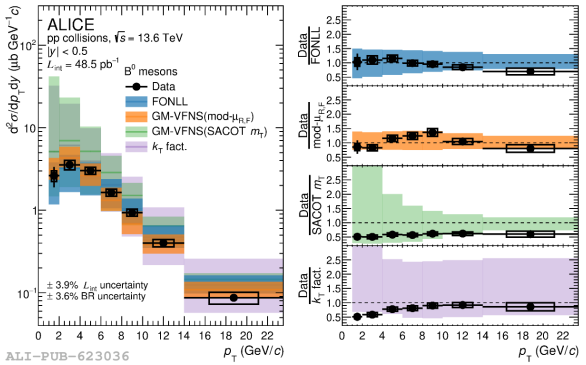
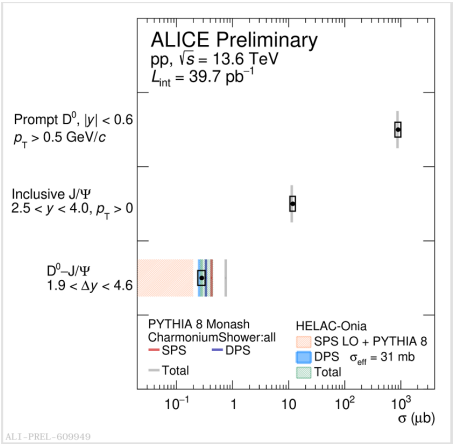


Summary

- Prompt D^0-meson and B^0-meson production measured in pp collisions at $\sqrt{s}$ = 13.6 TeV by ALICE
- Compared with large set of theoretical models, set constrains to pQCD calculations and transport models



- Double Parton Scattering studied by measuring associated production of J/ψ and D^0



Talk by **Ida Storehaug** on 25 Mar 2026, 09:05
Beauty production studies via quarkonia measurements with ALICE

Talk by **Jesper Karlsson Gumprecht** on 25 25 Mar 2026, 12:15
ALICE 3: a next-generation heavy-ion detector for LHC Run 5 · Indico Global

Thank you

Backup