Heavy-flavour measurements with the ALICE experiment

László Gyulai, on behalf of the ALICE Collaboration

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Heavy flavour in small systems

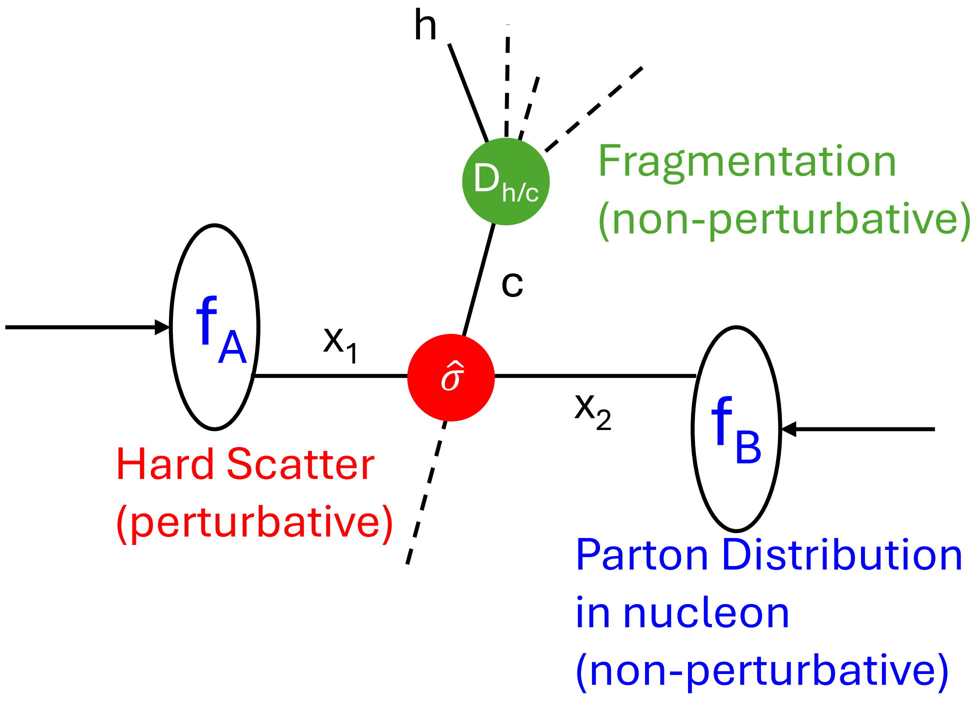
Heavy-flavour (c and b) quarks are produced in the initial stages of hadronic collisions in hard partonic scatterings

Heavy-flavour probes in pp and p–Pb collisions:

- tests of **perturbative QCD** calculations
- testing **factorisation** approach:

$$\sigma_{hh\rightarrow H} = f_a(x_1,Q^2)\otimes f_b(x_2,Q^2)\otimes \sigma_{ab\rightarrow q\bar{q}} \otimes D_{q\rightarrow H}(z_q,Q^2)$$

- studying **collective effects** at high and low multiplicities
- investigation of **cold nuclear matter effects**
- reference for heavy-ion collisions



Heavy flavour in heavy-ion collisions

Heavy flavour quarks are produced **before** quark-gluon plasma (QGP) and survive its **whole evolution**

- ➢ possibility to probe QGP state

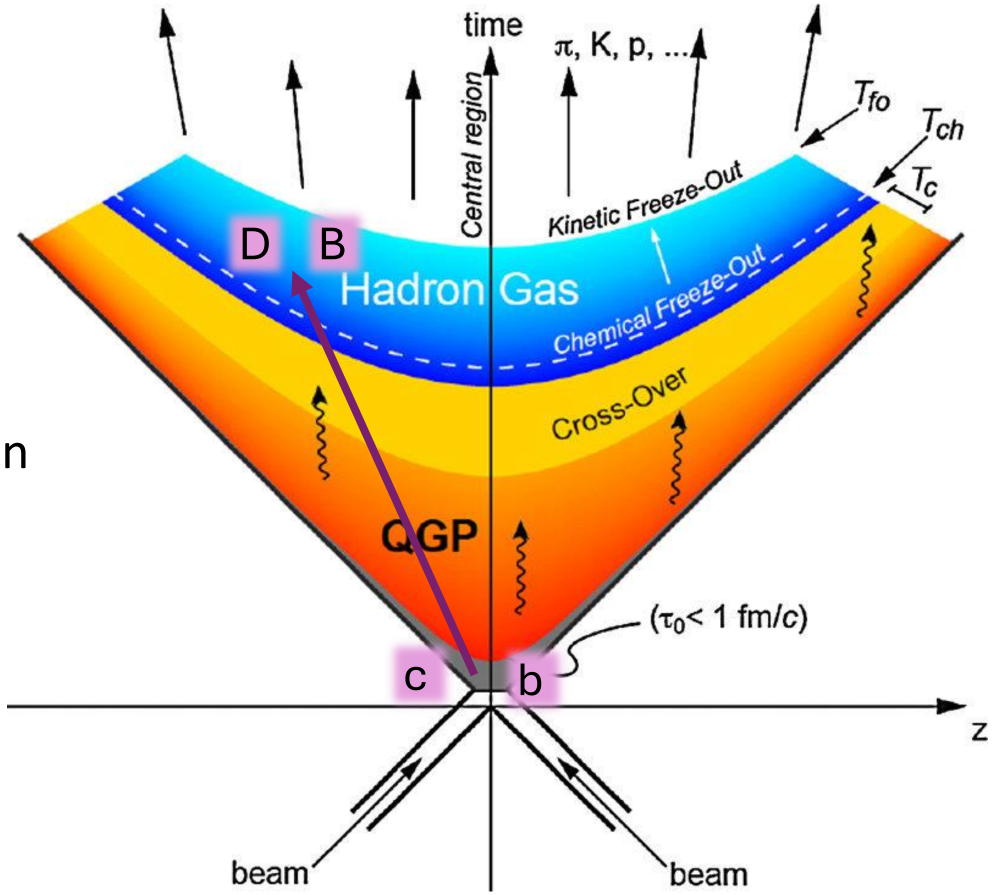
In Pb–Pb collisions heavy flavour serves as probe of:

- **initial state**
- **QGP transport** properties (energy loss, spatial diffusion coefficient)
- **hadronisation mechanisms**: fragmentation, recombination

Energy loss in QGP:

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{< T_{\mathrm{AA}} > \mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- $R_{AA} = 1$: **no modification** compared to pp collisions
- $R_{AA} \neq 1$: effects from **hot (or cold) nuclear matter**



ALICE detector in Run 2

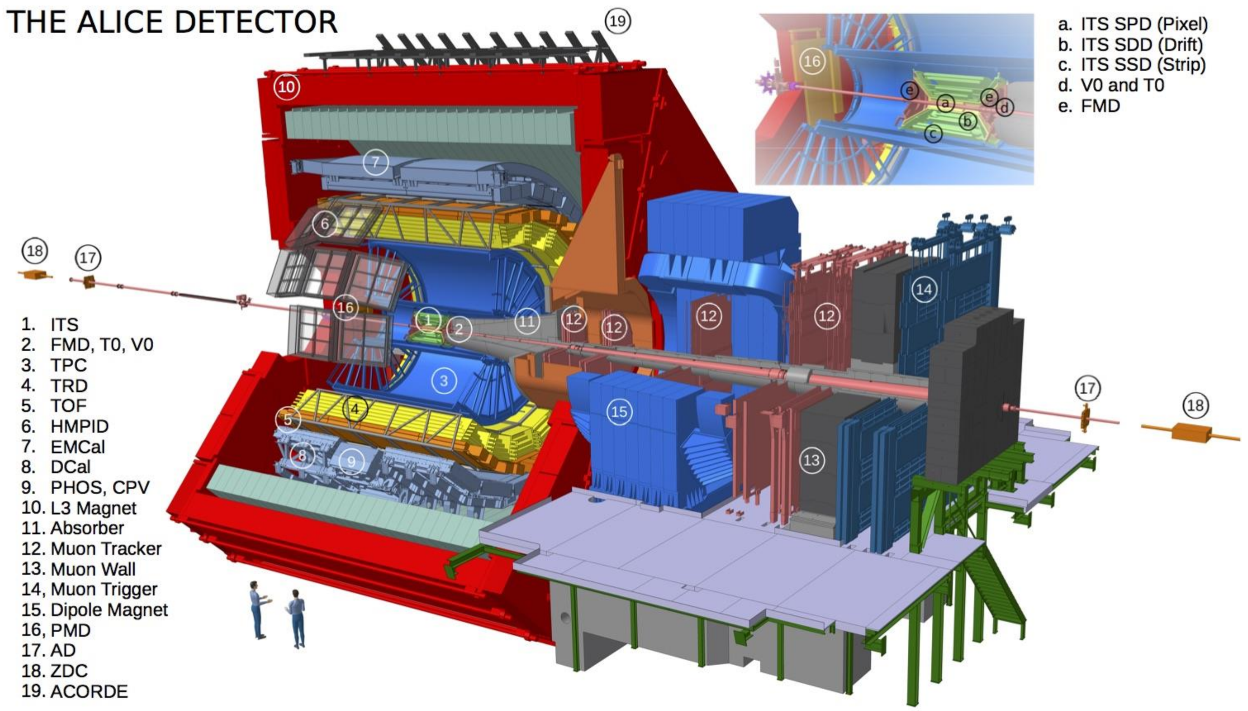
- ➢ The ALICE reconstructs particles over a **broad momentum range**
- ➢ Great reconstruction of **primary** and **secondary** vertices – crucial for heavy flavour!

- **I**nner **T**racking **S**ystem (ITS)
  (vertexing, tracking, $|\eta| < 0.9$)

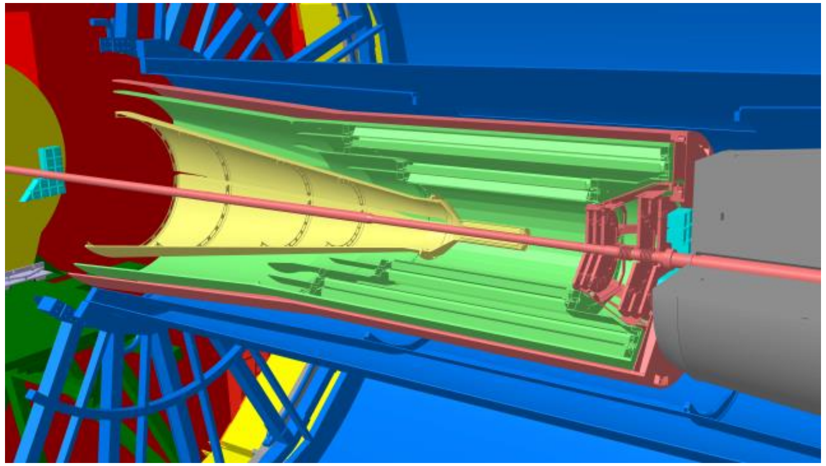
- **T**ime **P**rojection **C**hamber (TPC)
  (tracking, PID, $|\eta| < 0.9$)

- **T**ime-**O**f-**F**light detector (TOF)
  (PID, $|\eta| < 0.9$)

- V0 detectors
  (multiplicity and event activity determination, triggering, $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$)



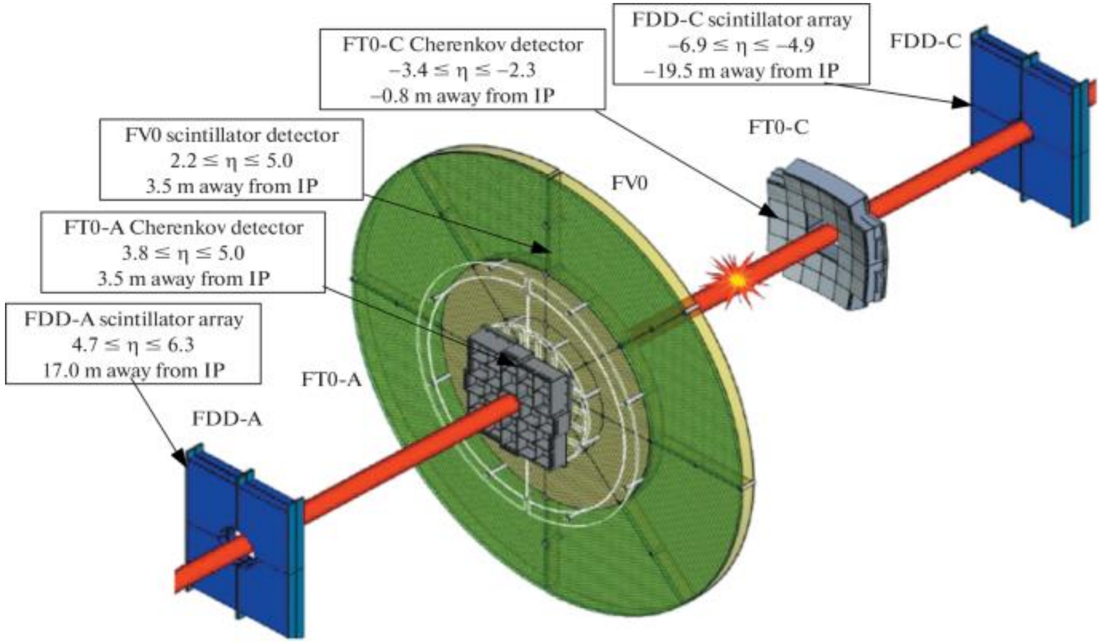
ALICE detector upgrade for Run 3



ITS upgrade:
- readout rate 1kHz→100 kHz
- better secondary vertex resolution, especially at low momenta
- muon forward tracker

TPC upgrade:
- GEM detectors for continuous readout

New **F**ast **I**nteraction **T**rigger:
- Multiplicity, centrality, reaction plane determination



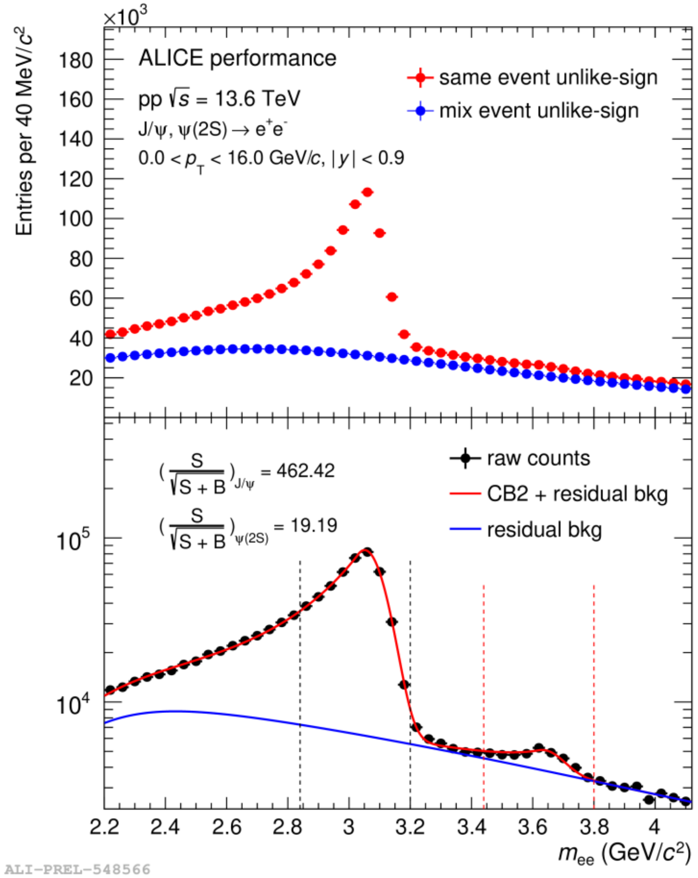
Reconstruction of heavy flavour

Quarkonia:

- reconstruction via **leptonic decays**
- down to **zero** transverse momentum

$\Upsilon(\mathrm{nS}), \psi(\mathrm{nS}) \rightarrow \mu^+\mu^-$

$\psi(\mathrm{nS}) \rightarrow \mathrm{e}^+\mathrm{e}^-$



Open heavy flavour:

- **exclusive** and **inclusive** decays
- wide momentum and rapidity range

$\mathrm{D}^0 \rightarrow \mathrm{K}^-\pi^+$

$\mathrm{D}^+ \rightarrow \mathrm{K}^-\pi^+\pi^+$

$\mathrm{D}^+ \rightarrow \phi\pi^+ \rightarrow \mathrm{K}^-\mathrm{K}^+\pi^+$

$\mathrm{D}_s^+ \rightarrow \phi\pi^+ \rightarrow \mathrm{K}^-\mathrm{K}^+\pi^+$

$\Xi_c^0 \rightarrow \Xi^-\mathrm{e}^+\nu_e$

$\Xi_c^0 \rightarrow \Xi^-\pi^+$

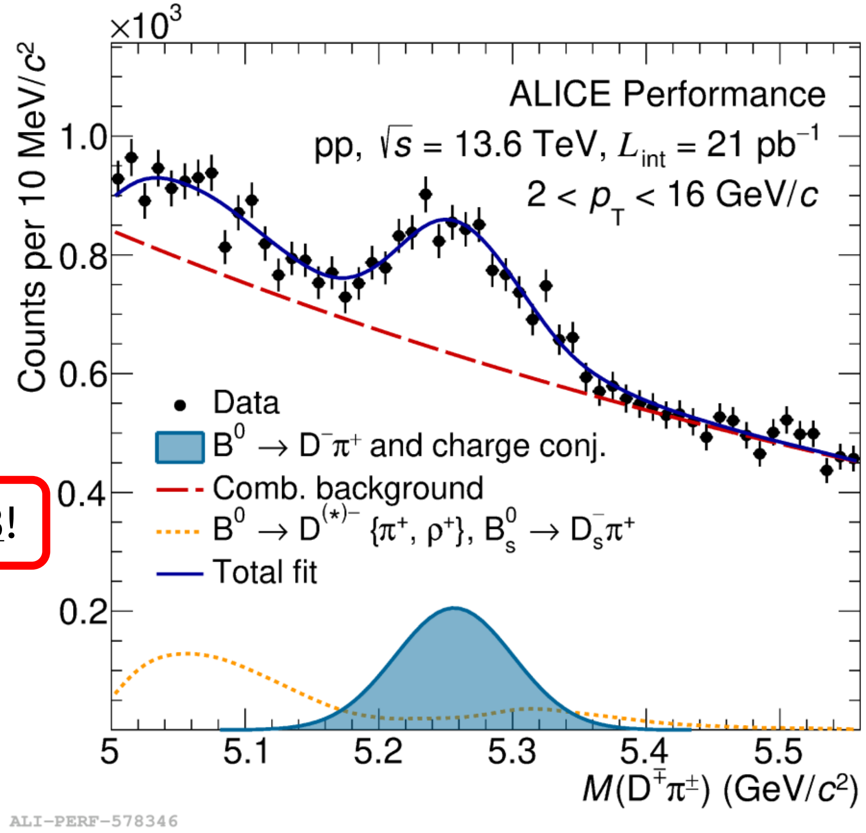
$\mathrm{B} \rightarrow \mathrm{e}(\mu)\mathrm{X}$

$\mathrm{B} \rightarrow \mathrm{J}/\psi(\rightarrow \mathrm{e}^+\mathrm{e}^-)\mathrm{X}$

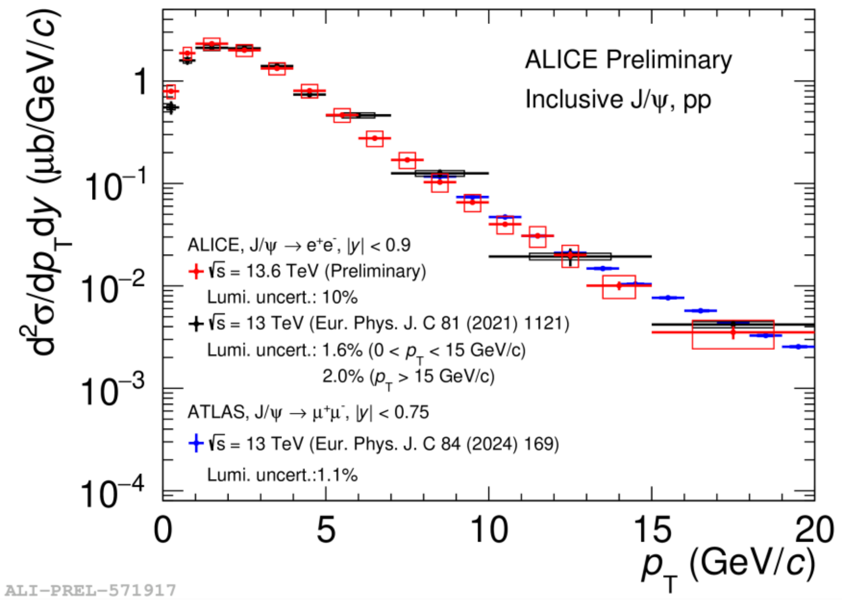
$\mathrm{B} \rightarrow \mathrm{J}/\psi(\rightarrow \mu^+\mu^-)\mathrm{X}$

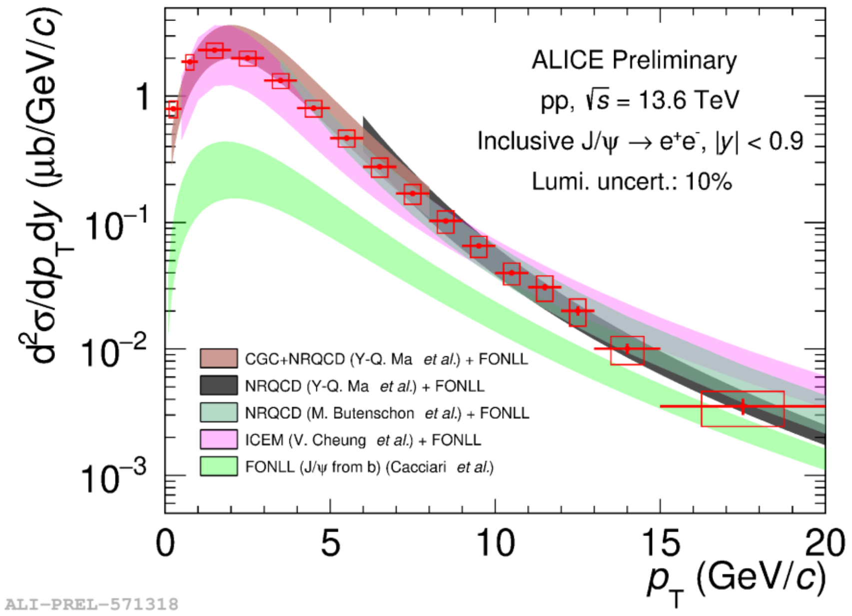
$\mathrm{B} \rightarrow \mathrm{D}\,\mathrm{X}$

$\mathrm{B}^0 \rightarrow \mathrm{D}^-\pi^+$ New in Run 3!



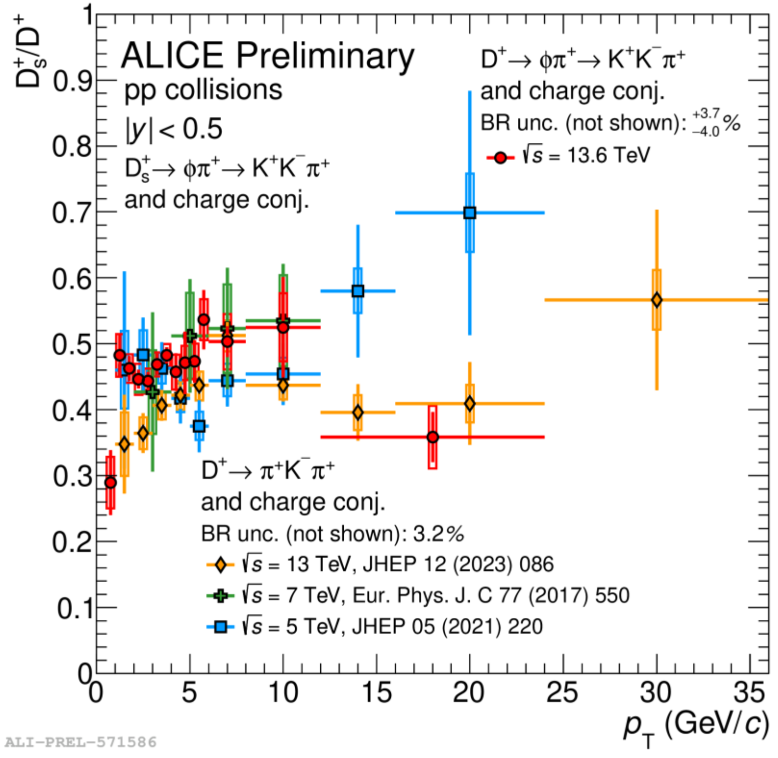
Highlights from pp collisions

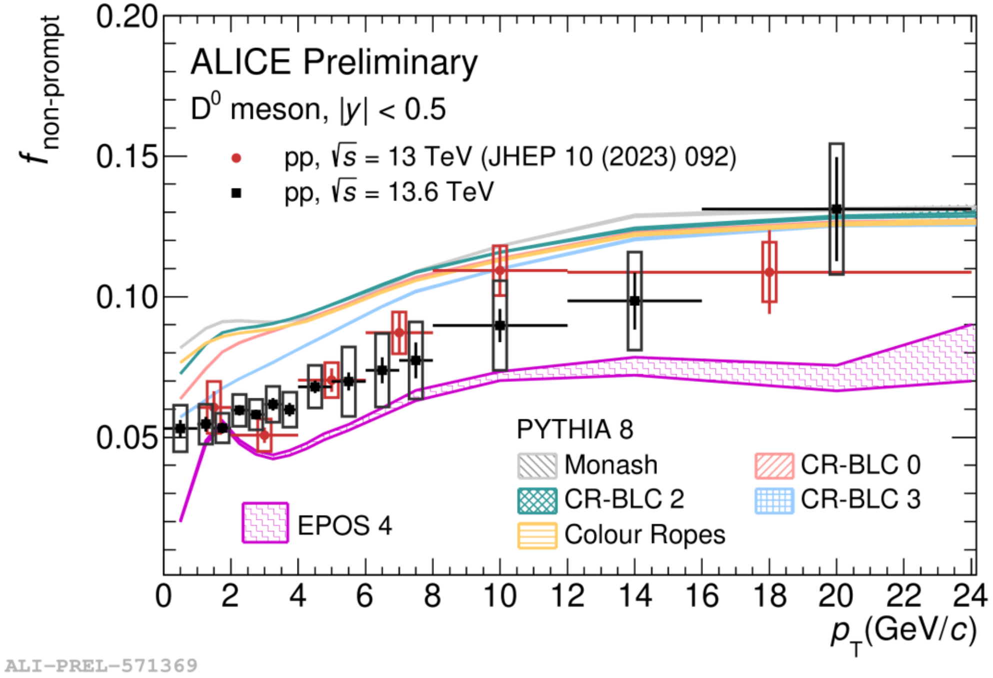




- First J/ψ measurements in pp at $\sqrt{s}$ = 13.6 TeV
- **High granularity** of data due to **increased data sample** of Run 3
- Good agreement with Run 2 data
- Important input for tuning models

Highlights from pp collisions



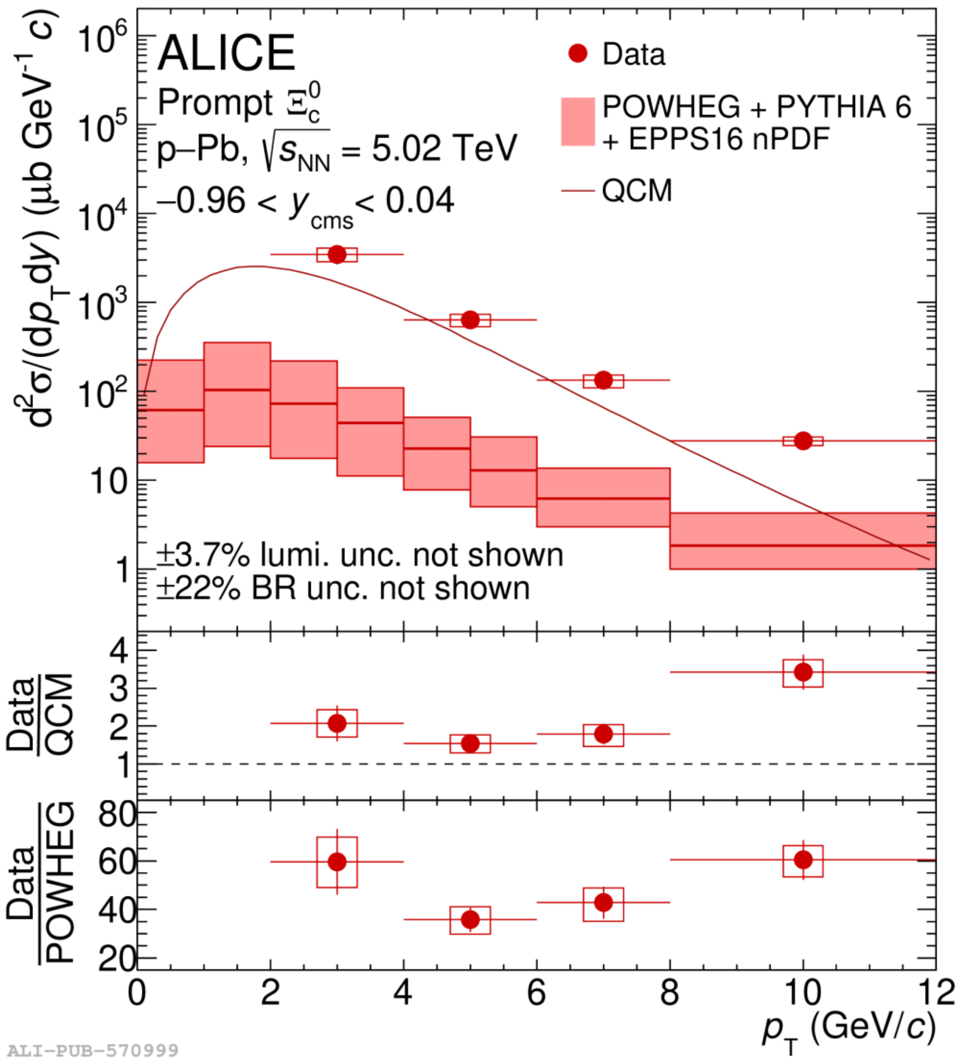


- New measurement of D^{+}_{s}/D^{+} and non-prompt D^0 in pp at $\sqrt{s}$ = 13.6 TeV
- **Finer binning** of data due to increased statistics of Run 3
- Measurements extended down to $\boldsymbol{p_T}$ **= 0.5 GeV/*c*** and $\boldsymbol{p_T}$ **= 0 GeV/*c***, respectively
- Compatible with results at lower energies within uncertainties

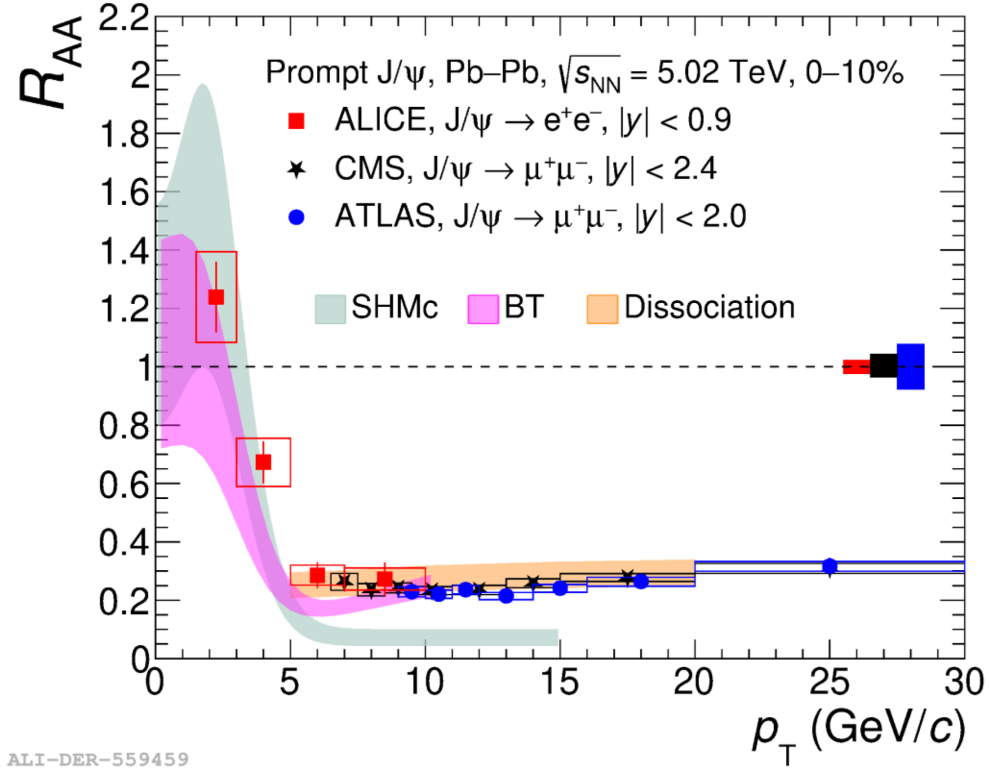
Highlights from p–Pb collisions

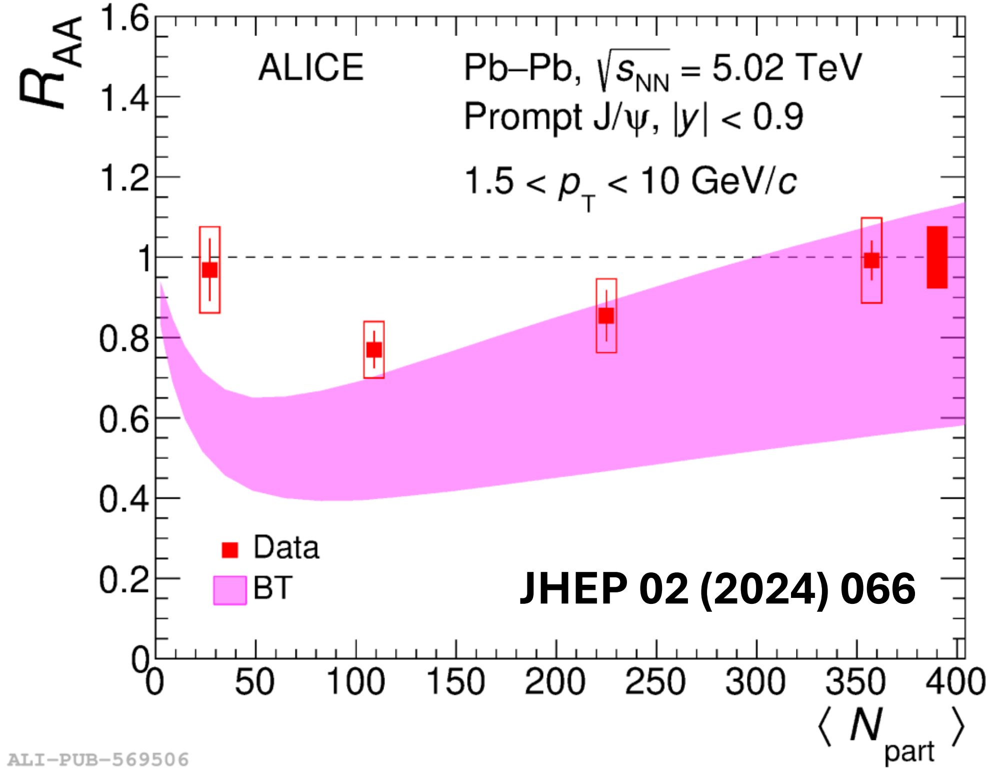
- Measurement of prompt Ξ^0_c production in p–Pb at √*s* = 5.02 TeV
- PYTHIA 6+POWHEG (based on **e^+e^- collisions**) **significantly underestimates** the Ξ^0_c cross section
- Better agreement with quark coalescence model, however still underestimated by a factor of 2

arXiv:2405.14538



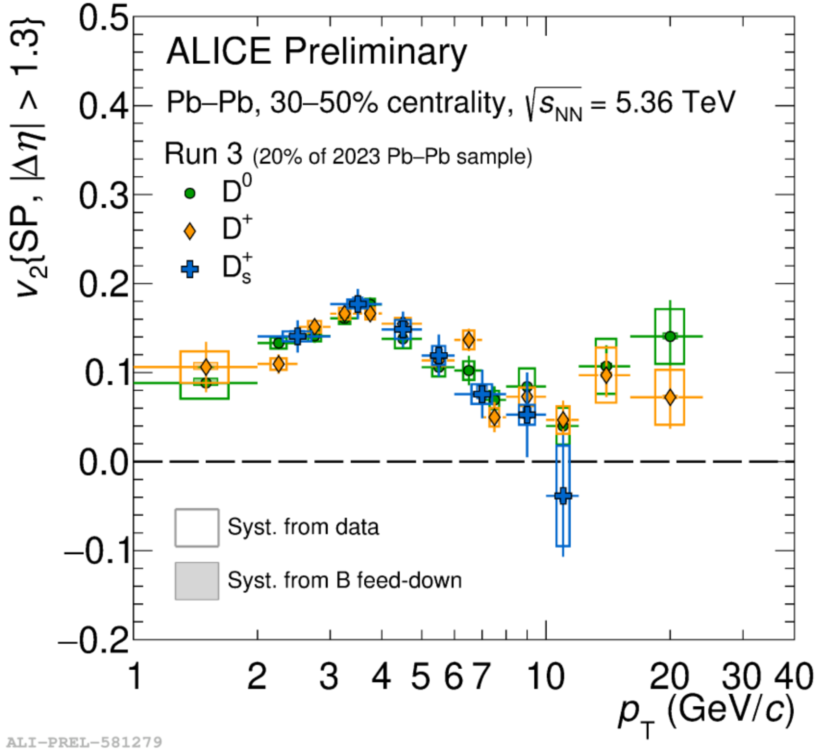
Highlights from Pb–Pb collisions

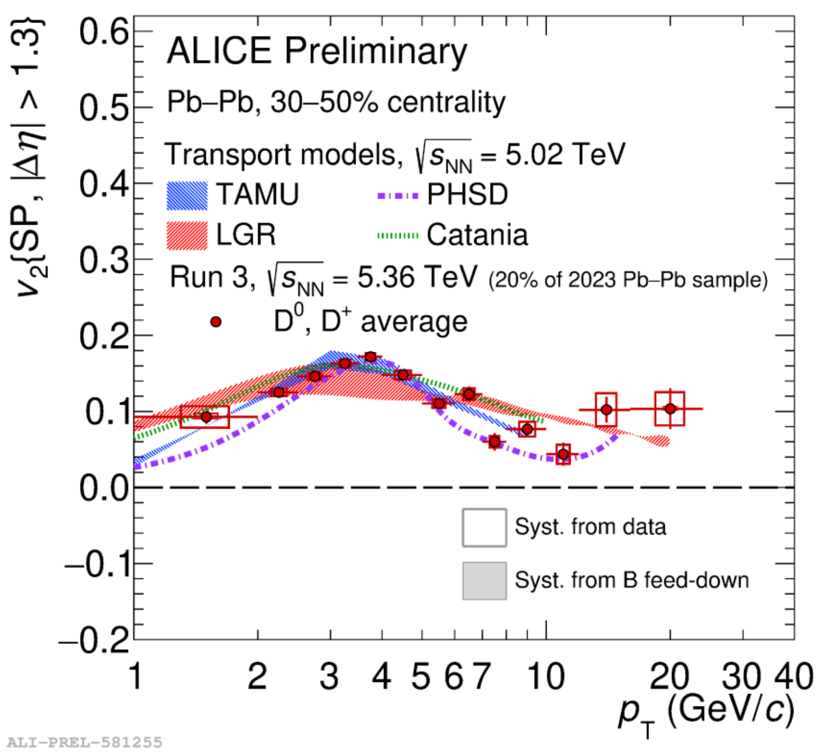




- Measurement of nuclear modification factor R_{AA} for prompt J/ψ in Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- Results are compatible with measurements from ATLAS and CMS in the overlapping p_T region
- Models describe the rising trend towards low p_T and with increasing centrality

Highlights from Pb–Pb collisions





- Measurement of elliptic flow for strange and non-strange D mesons in Pb–Pb at $\sqrt{s_{NN}}$ = 5.36 TeV
- Analysed data sample (20% of available 2023 Pb-Pb data sample) is already **4 times larger than Run 2** sample
- **No significant difference** between strange and non-strange D mesons
- Behaviour of non-strange D mesons is described well by charm transport models that include collisional energy loss and hadronisation through coalescence

Summary and outlook

- Heavy-flavour hadrons in **Pb–Pb** collisions are probes of **initial stages** and **QGP matter**
- Heavy flavour in **pp** and **p–Pb** provides **baseline for Pb–Pb** measurements, allows for testing **perturbative QCD** calculations and investigate **cold nuclear matter effects**
- Upgrades of the ALICE experiment increased the **readout rates** and the **secondary vertex** resolution

- Measurements in pp are extended to **lower p_T** and have **finer binning**. They provide input for **constraining QCD models**
- Measurements of baryons in p–Pb provide **reference for the models** trying to explain the enhanced production in a parton-rich environment
- Measurements of charmonium in Pb–Pb collisions are extended down to **low p_T**, allowing for **verification of models at low p_T**
- Measurements of open heavy flavour in Pb–Pb collisions have **much larger statistics**. The elliptic flow measured for the D mesons **agrees with transport models**