Study of beauty quark production via non-prompt D mesons with ALICE

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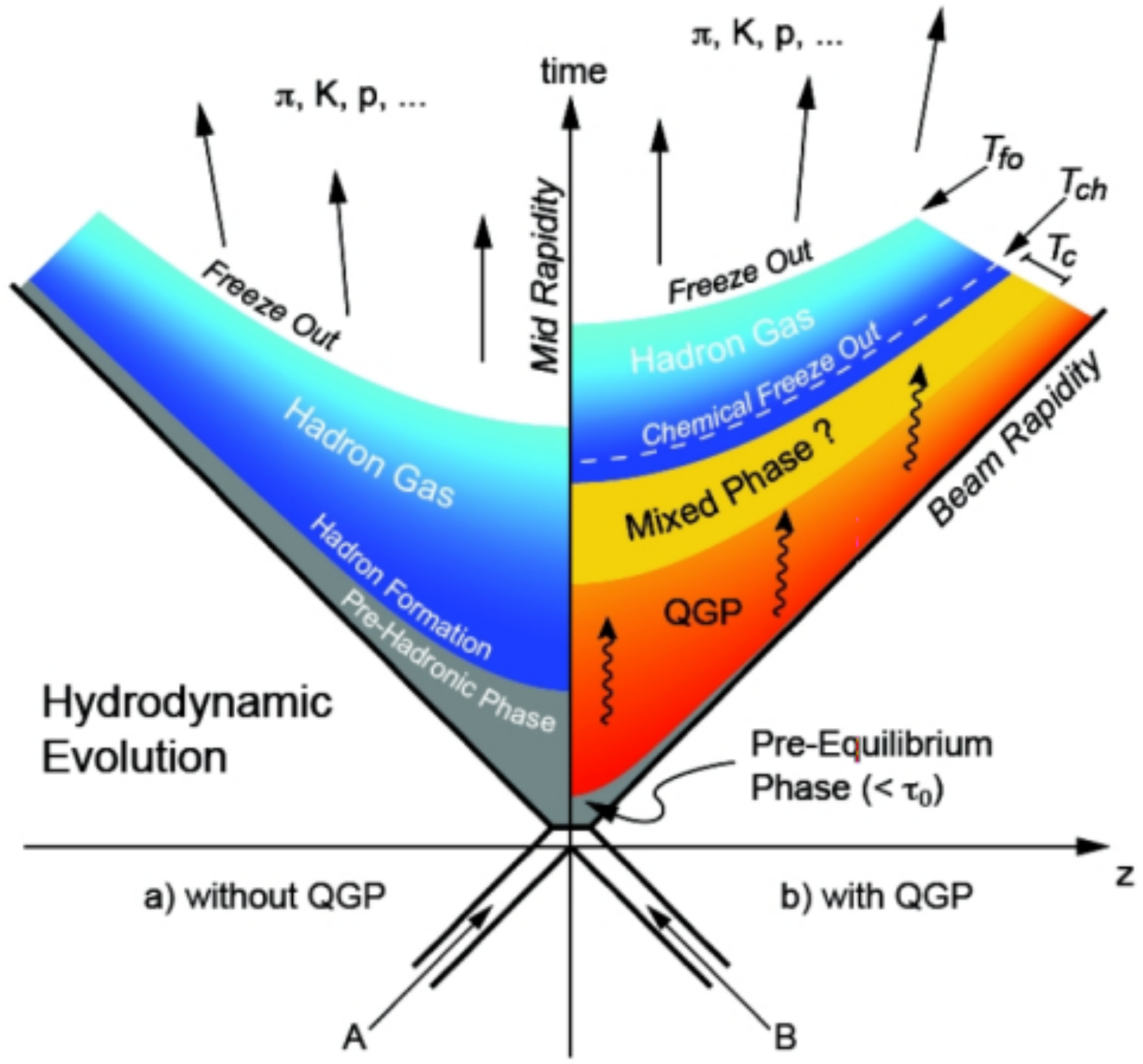
Introduction: heavy flavor

Heavy quarks (charm and beauty):

- Produced in hard scattering processes at the early stage of the collision before the QGP creation ($T_b < T_c < T_{QGP} \sim 0.3$ fm/c)
- Experience the full evolution of the system
- Cross section of charm- and beauty-hadron production is typically calculated in factorization approach:

Phys. Rev. C 89, 034906

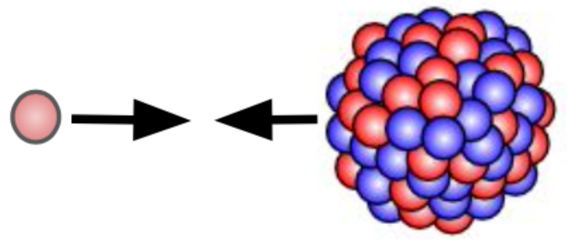


$$\frac{d\sigma^{AB\to H_q}}{dp_T} = f_i(x_1,\mu_f^2) f_j(x_2,\mu_f^2) \times \frac{d\sigma^{ij\to q}}{dp_T}(x_1,x_2,\mu_f^2) \times D_{q\to H_q}\left(z_q = \frac{p_{H_q}}{p_q}, \mu_f^2\right)$$

parton distribution functions (PDFs) | hard scattering cross section (pQCD) | fragmentation function (hadronization)

pp collisions

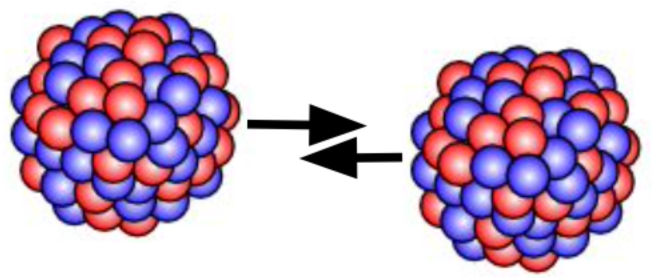
- Test of pQCD calculations (FF assumed to be universal across collision systems)
- Reference for Pb–Pb collisions



p–Pb collisions

Cold nuclear matter effects

- Modification of parton distribution functions (PDFs) in bound nuclei



Pb–Pb collisions

Hot nuclear matter effects

- Energy loss in QGP
- Collectivity in QGP
- Hadronization modified in QGP

A Large Ion Collider Experiment

D meson measurements conducted in the central barrel, using:

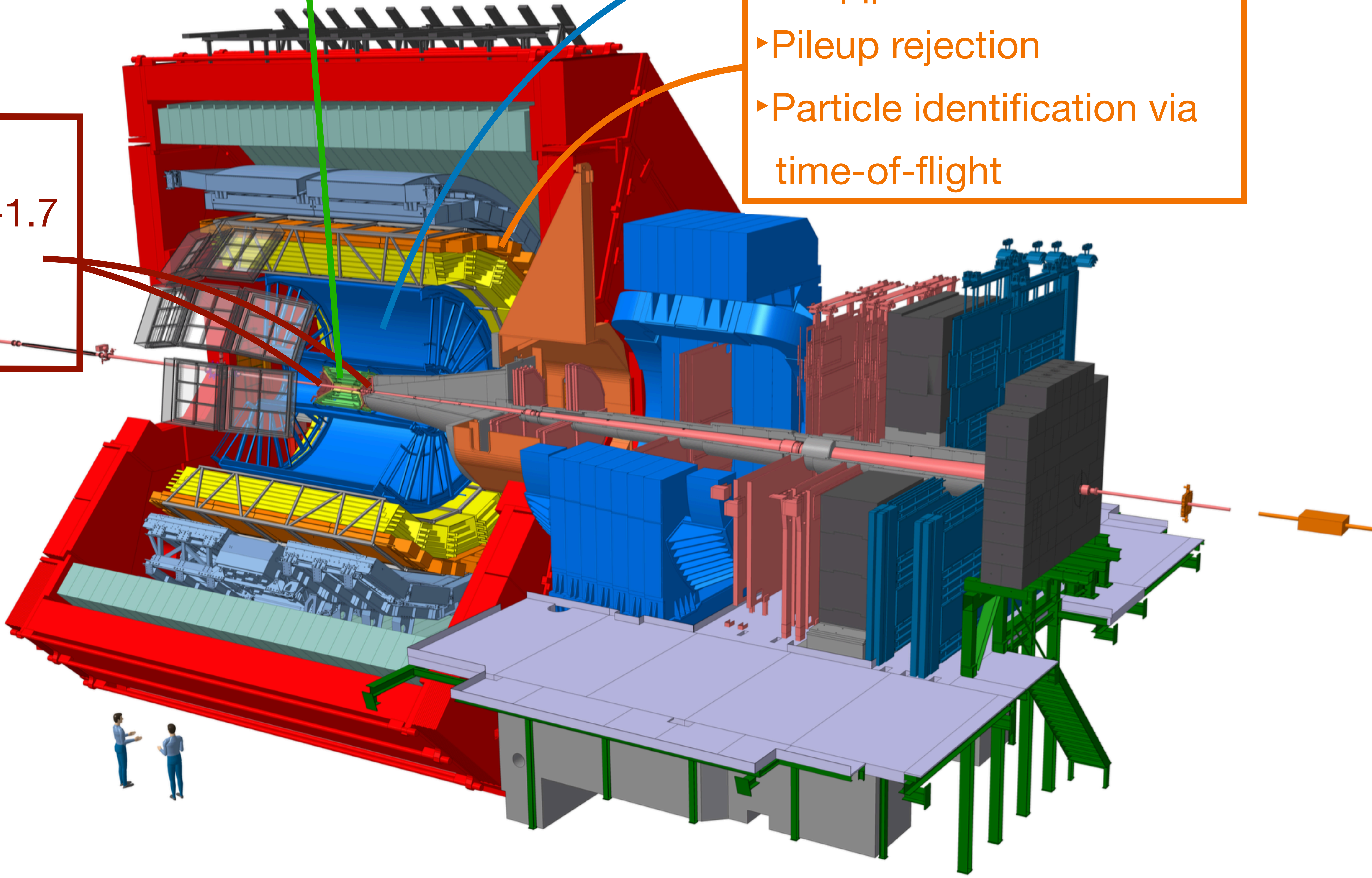
- Inner Tracking System
- Time Projection Chamber
- Time-of-Flight detector
- V0 detectors

V0
V0A: 2.8 < η < 5.1, V0C: -3.7 < η < -1.7
- Trigger
- Centrality determination

ITS |η|<0.9
- Track reconstruction
- Primary and decay vertex reconstruction

TPC |η|<0.9
- Charged track reconstruction
- Particle identification via energy loss

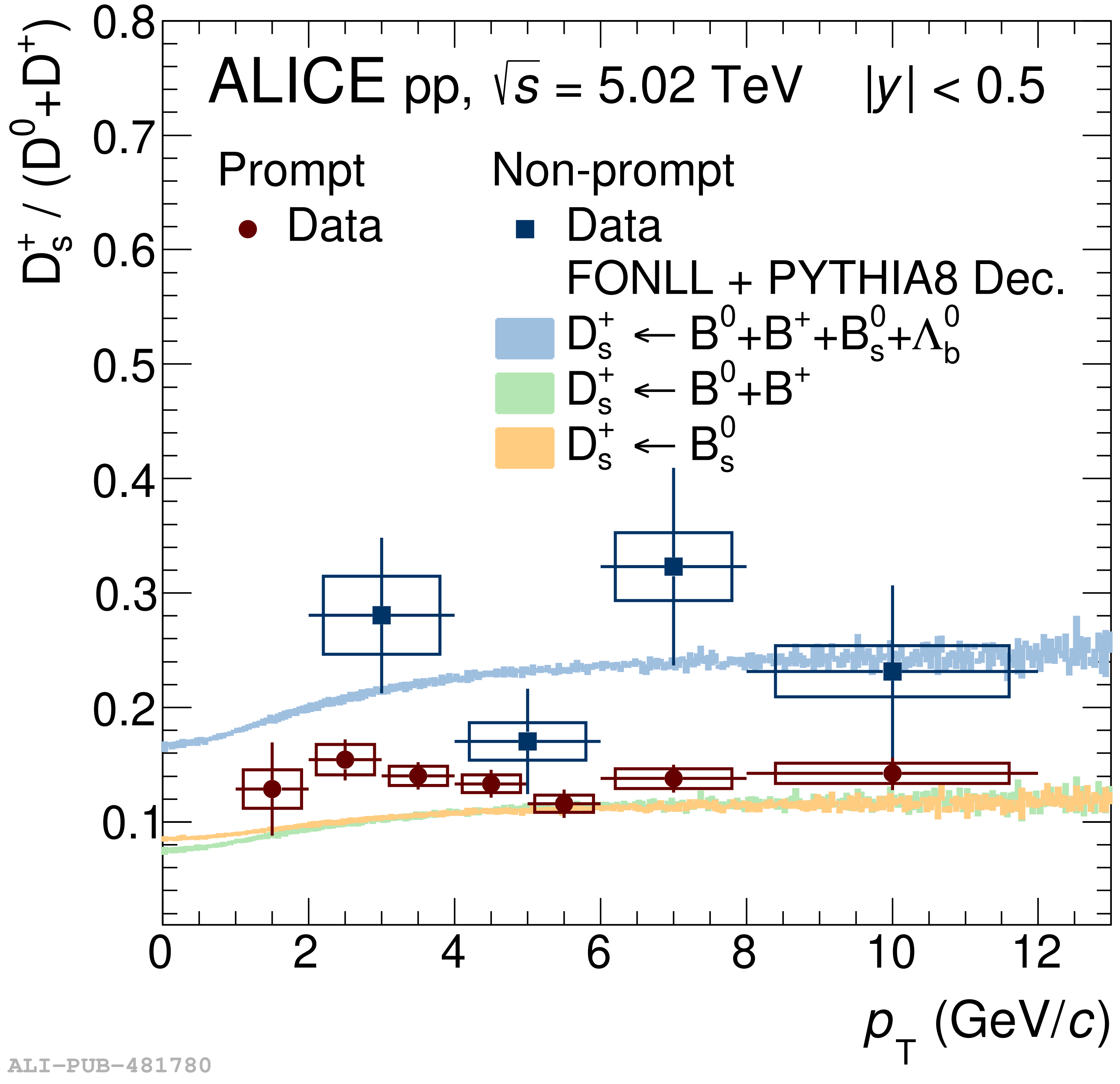
TOF |η|<0.9
- Pileup rejection
- Particle identification via time-of-flight

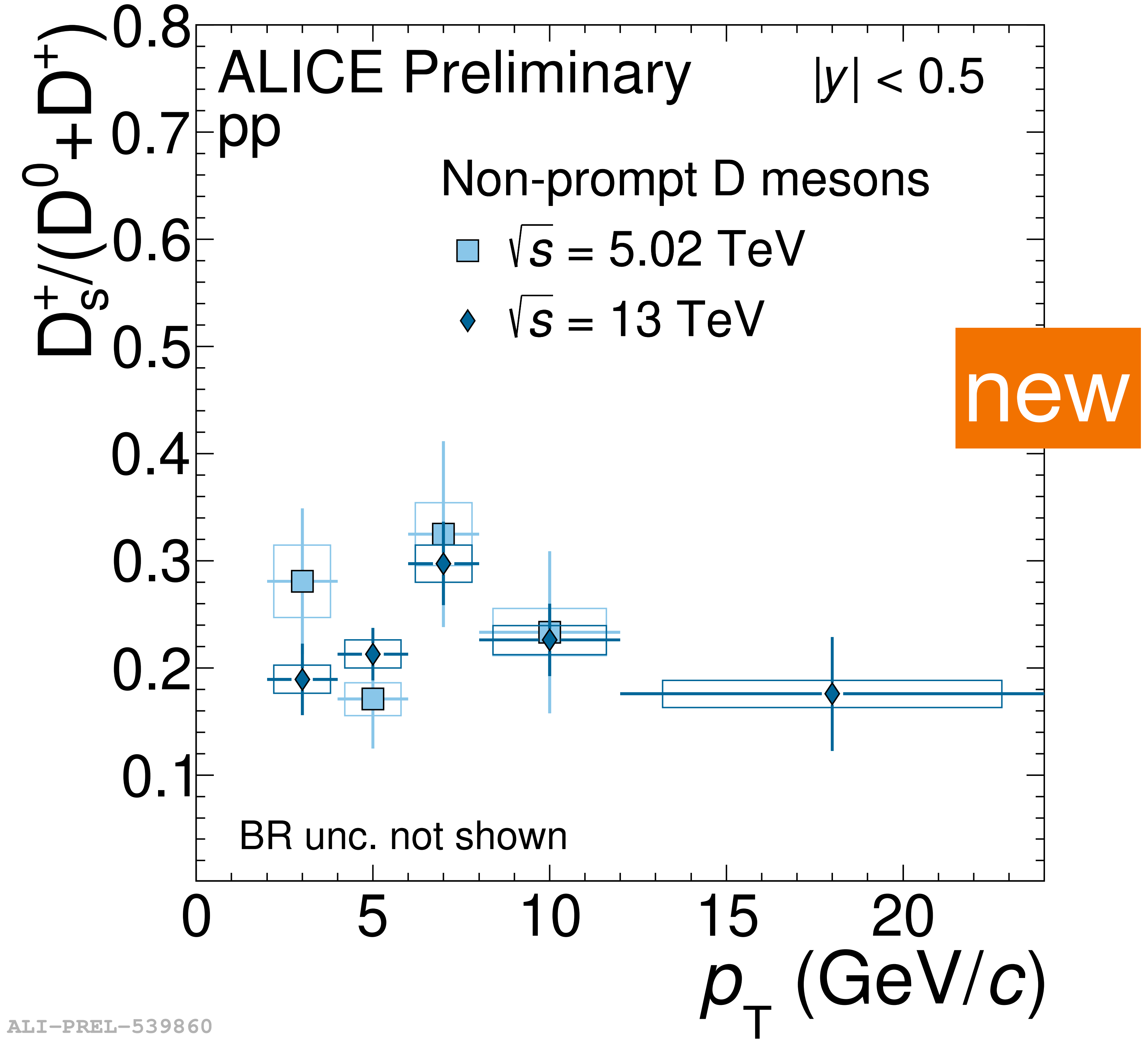


Non-prompt D meson (from beauty hadron decay) measurements in this talk:

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

Non-prompt D meson production in pp



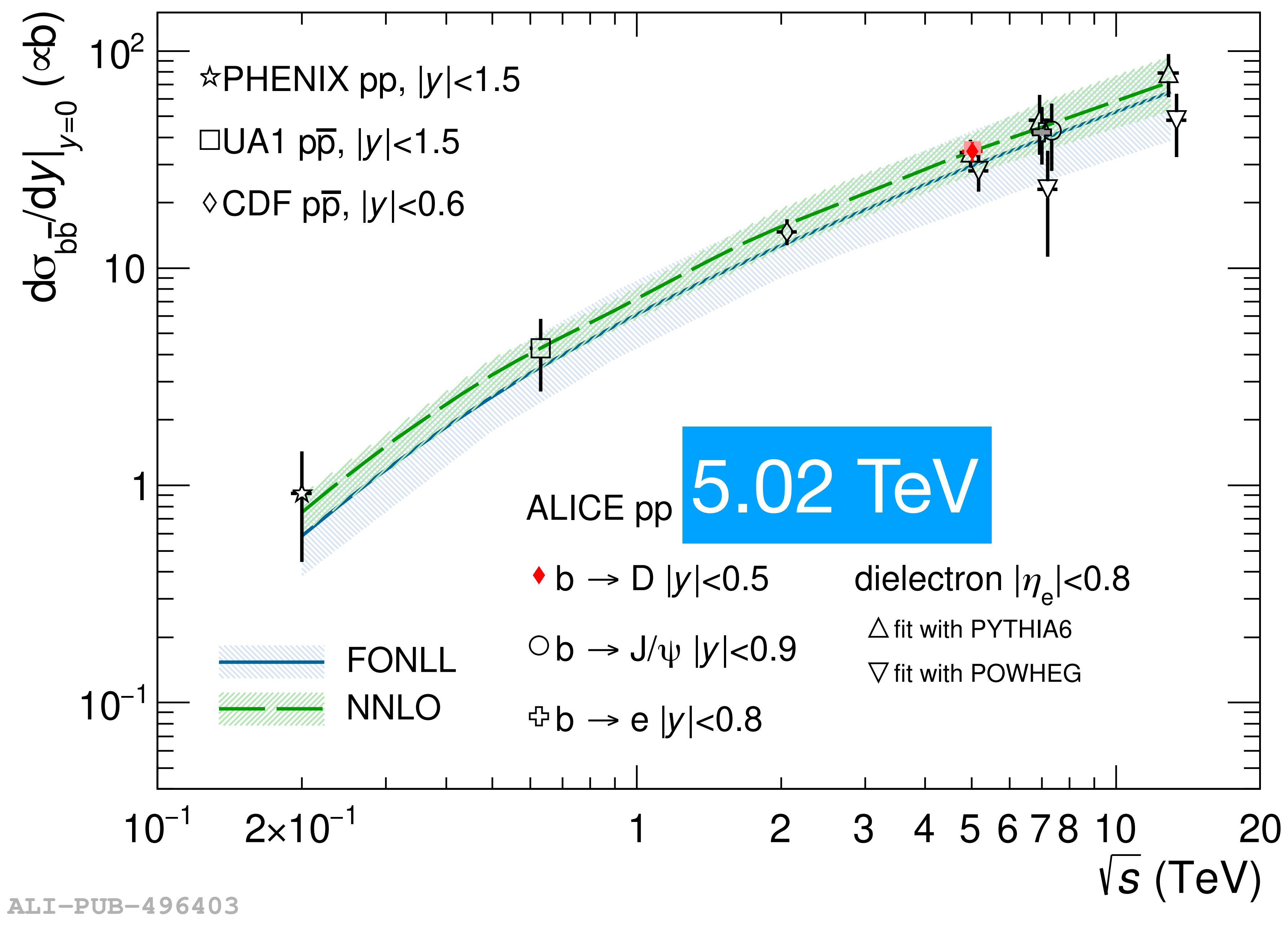


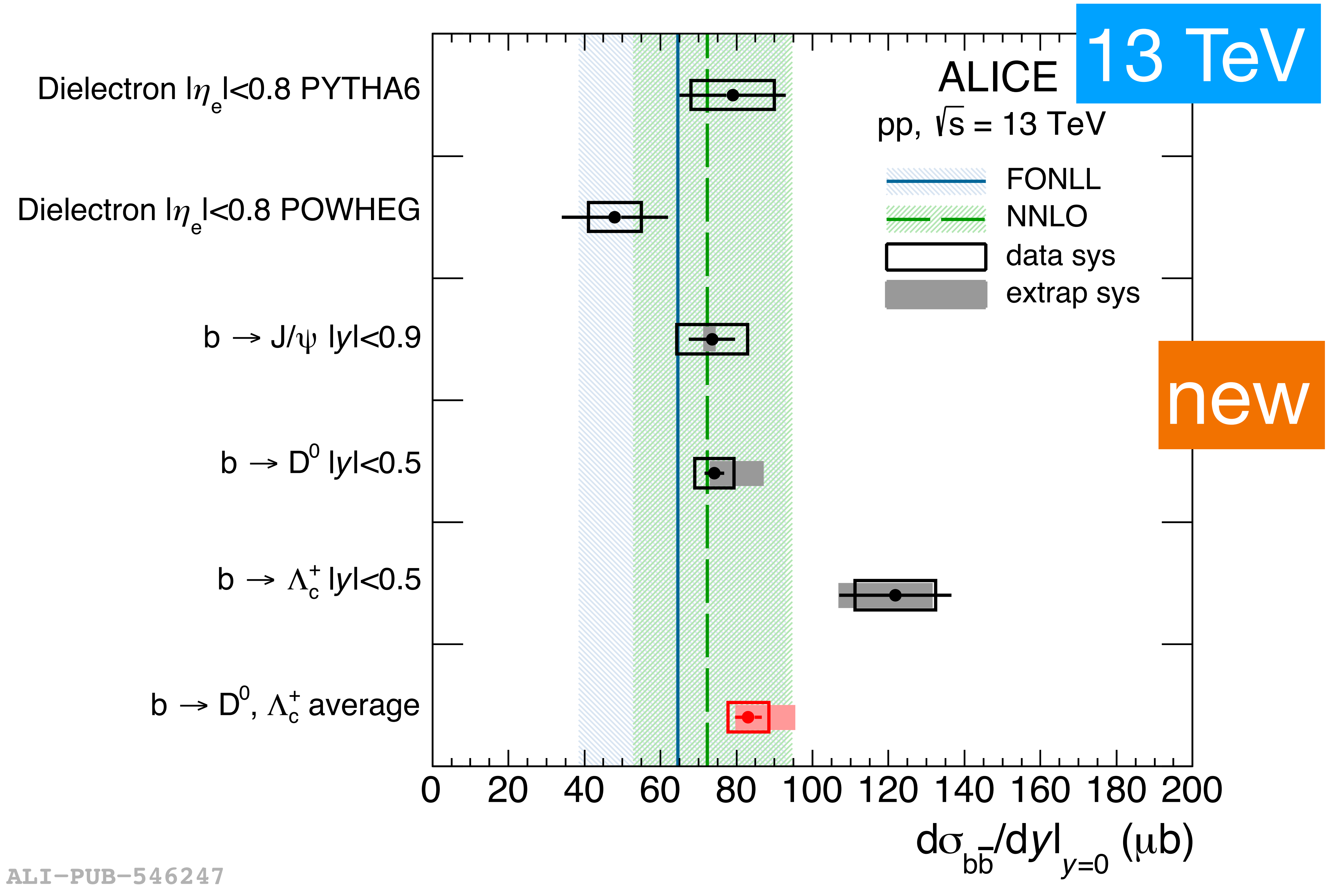
- The measured D meson ratios are p_T-independent within the current experimental precision
- FONLL+PYTHIA 8 predictions are compatible with the measurements
- Latest measurement in pp 13 TeV is compatible with the measurement in 5 TeV

Total $b\bar{b}$ cross section

FONLL: JHEP 05 (1998) 007, JHEP 03 (2001) 006, JHEP 10 (2012) 137

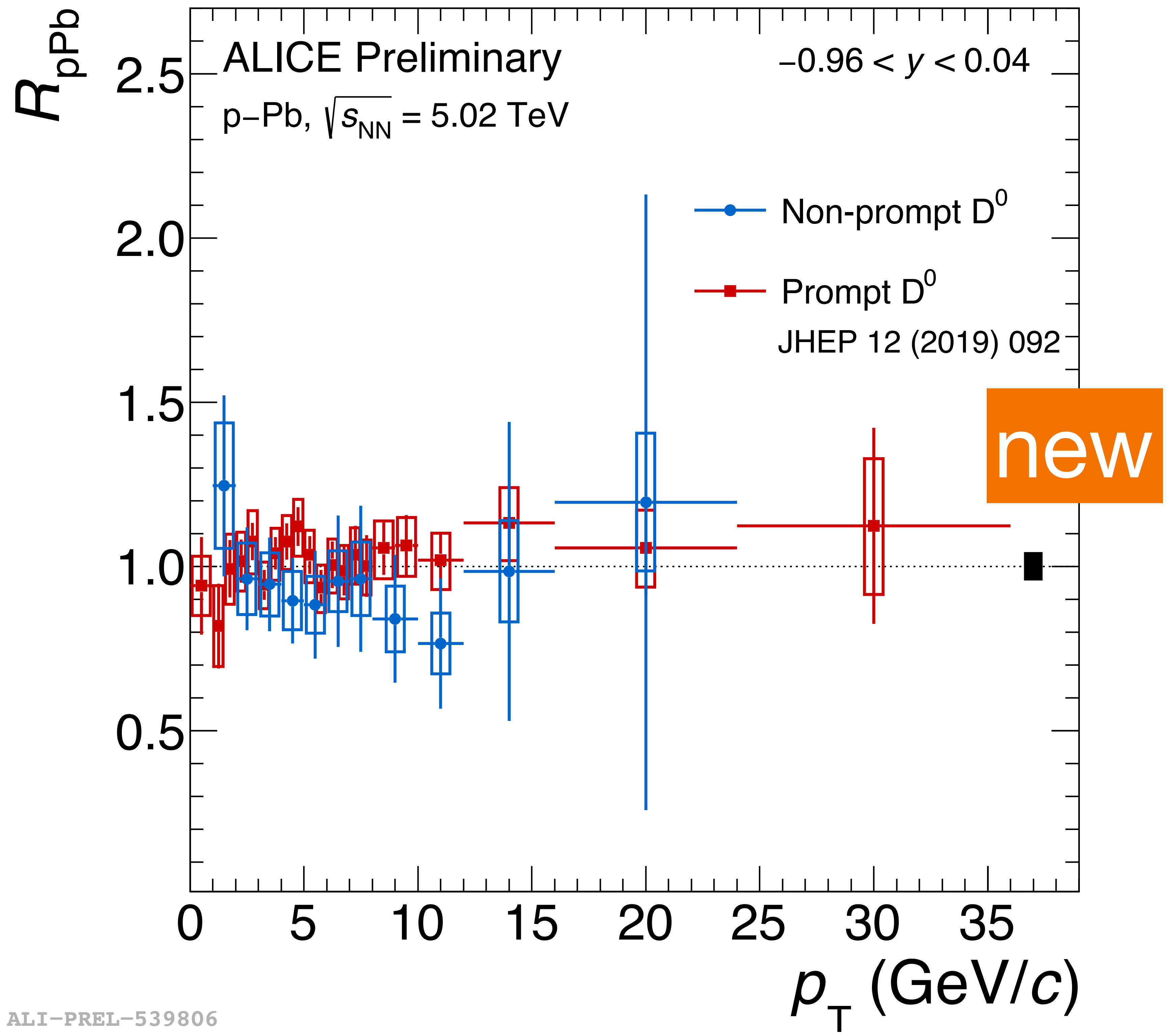
NNLO:JHEP 03 (2021) 029

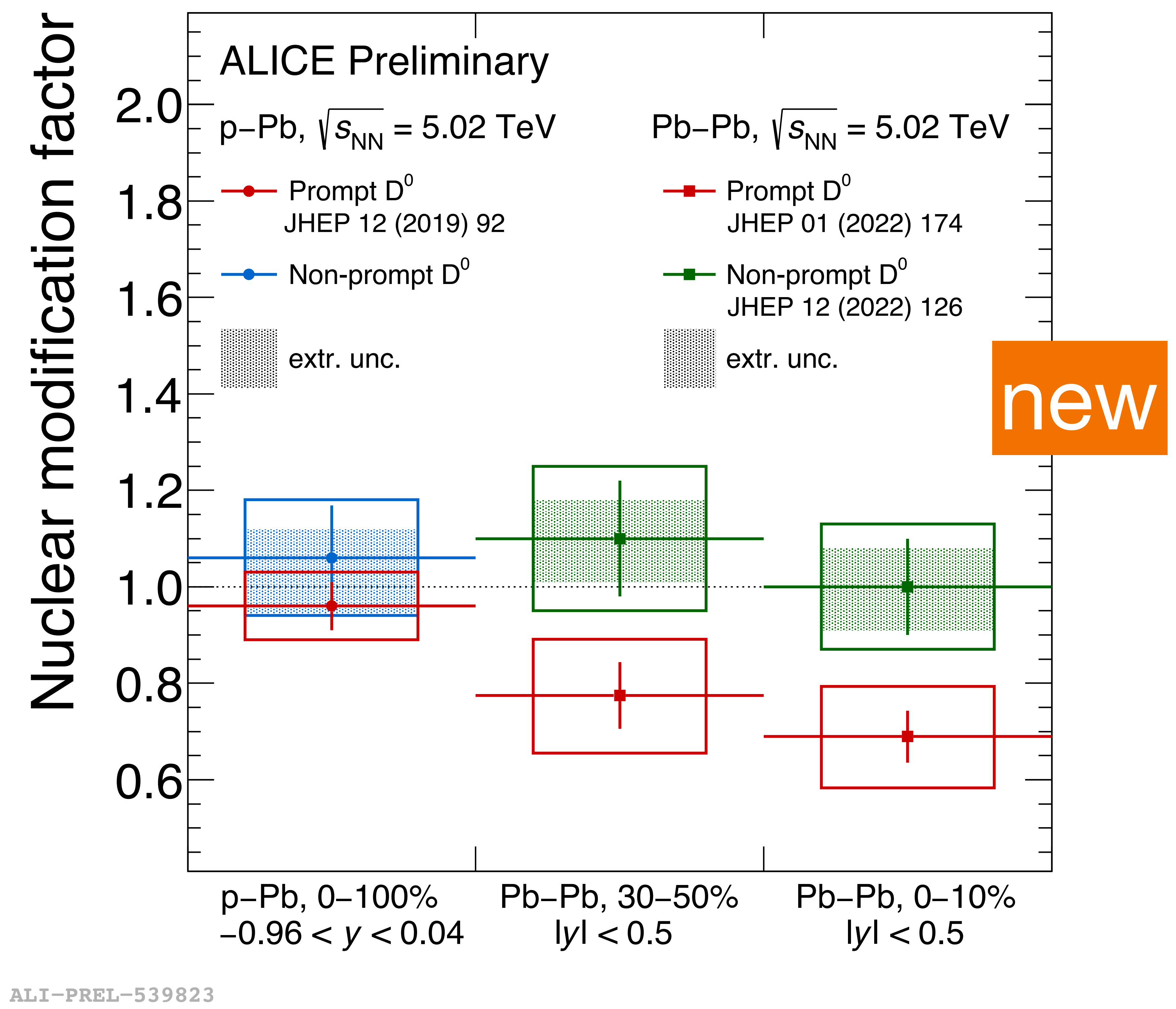




- $b\bar{b}$ production cross section measured at midrapidity at 5.02 TeV and 13 TeV by ALICE is compatible with FONLL and NNLO calculation upper limits

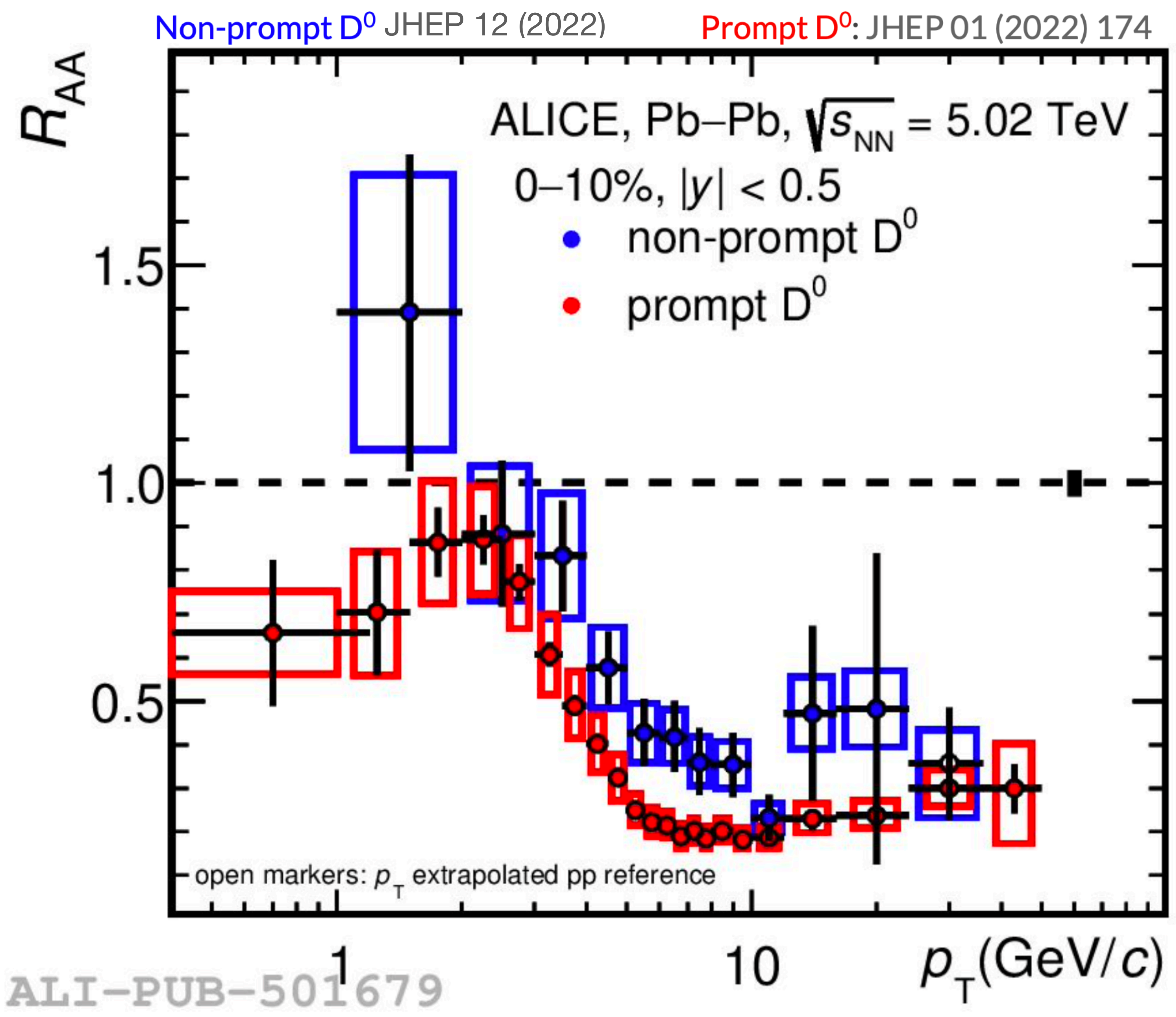
Non-prompt D^0 in p–Pb

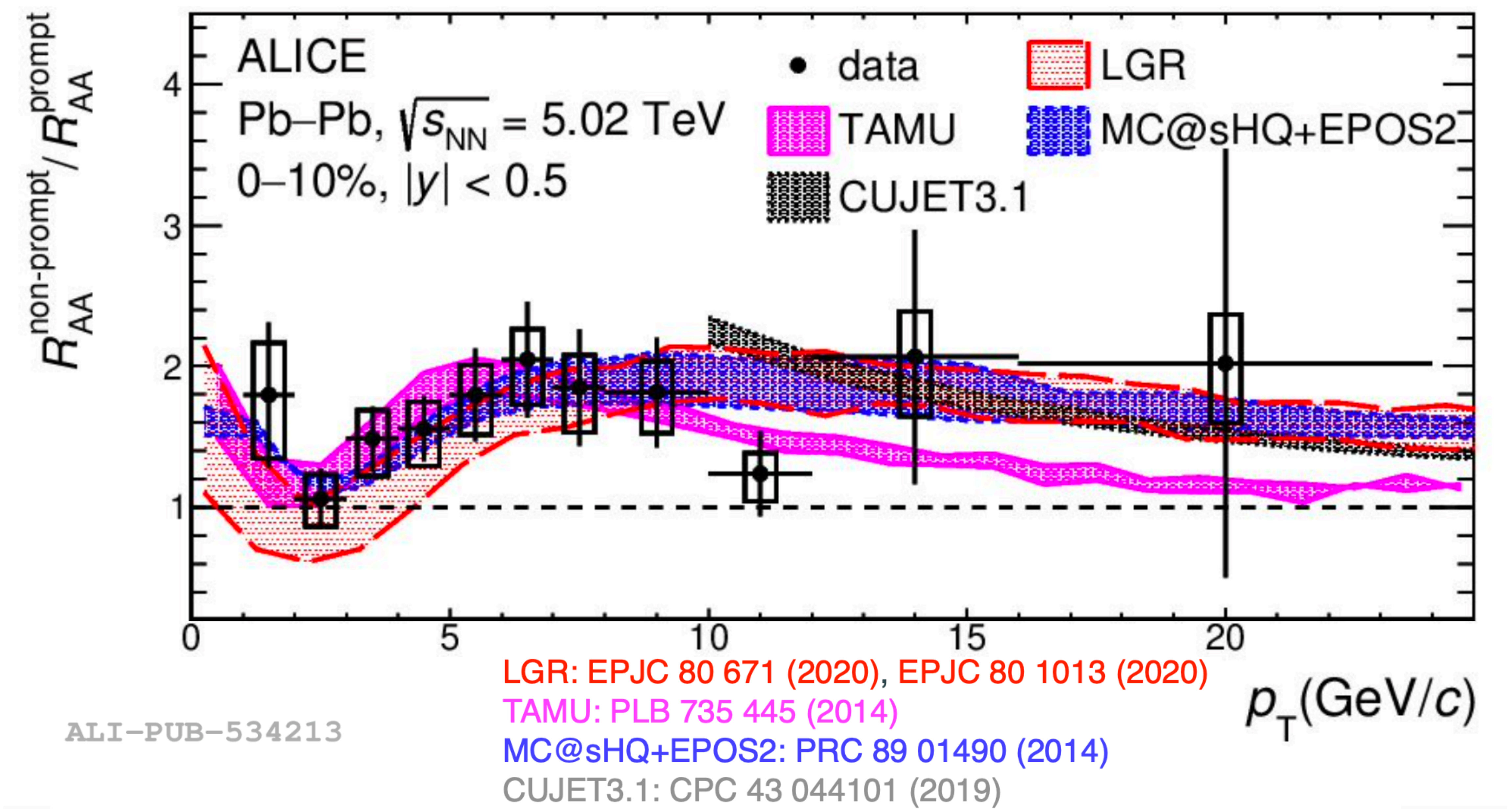


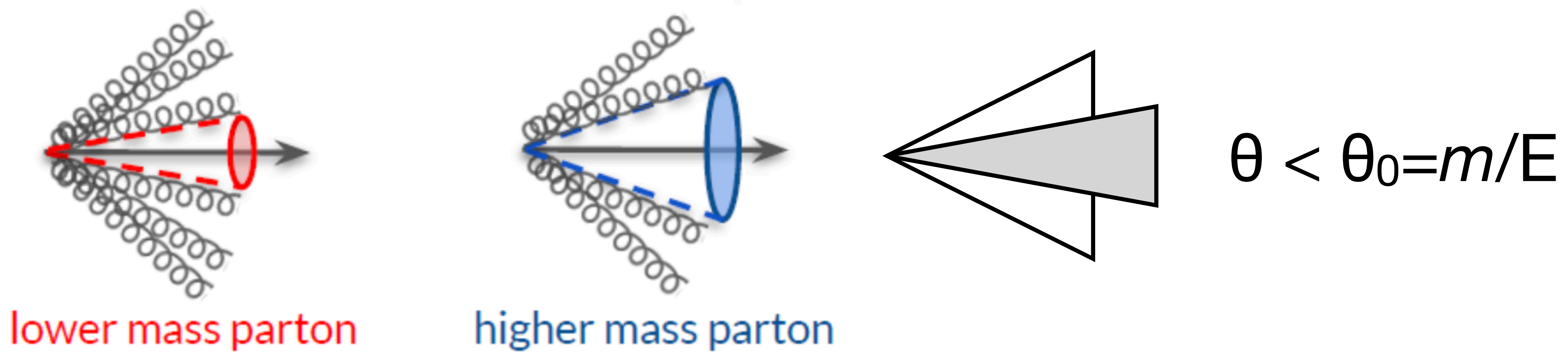


- p_T-differential and p_T-integrated non-prompt D^0 R_{pPb} is compatible with unity and in agreement with prompt D^0
  - ➡ Suggesting a mild cold nuclear matter effect for beauty

Beauty quark in medium energy loss - non-prompt D^0

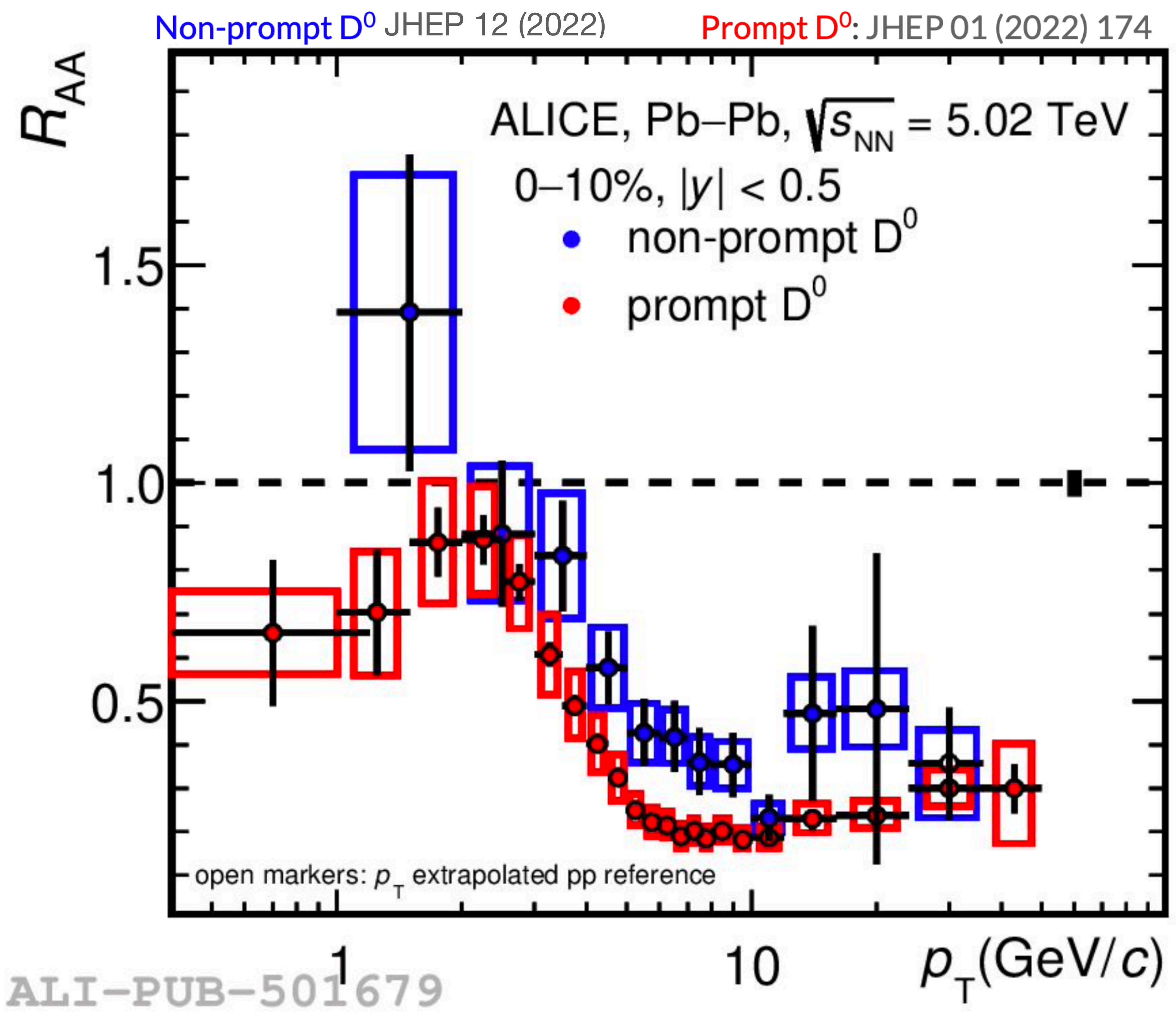




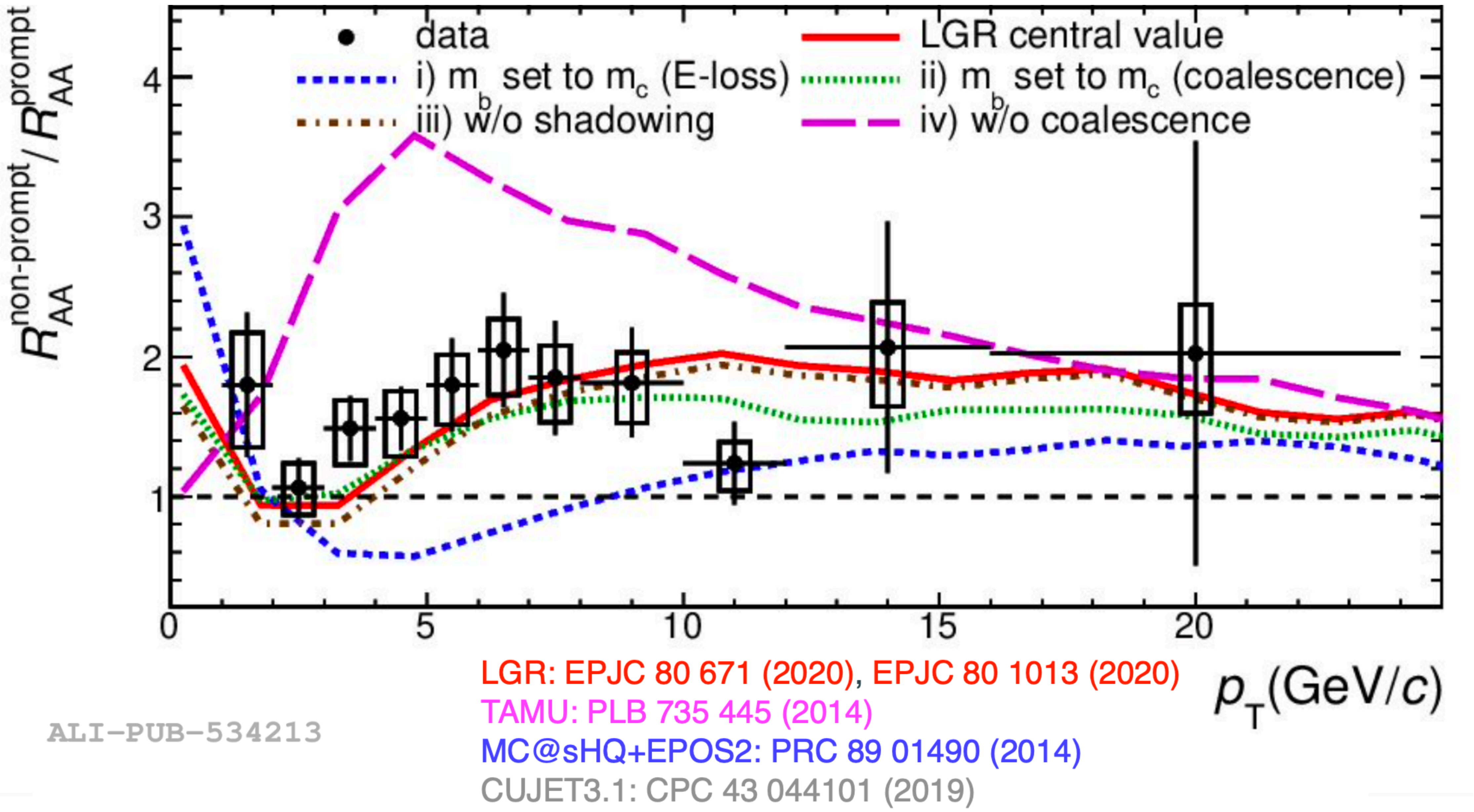


- Hint of hierarchy: R_{AA}(b–>D^0) > R_{AA}(c–>D^0)
  ➡ In-medium energy loss **mass dependence** (dead cone effect)
- Data described by models that include **collisional + radiative** energy loss and hadronization via **fragmentation+coalescence**

Beauty quark in medium energy loss - non-prompt D^0



$$\frac{R_{AA}^{non-prompt}}{R_{AA}^{prompt}}$$



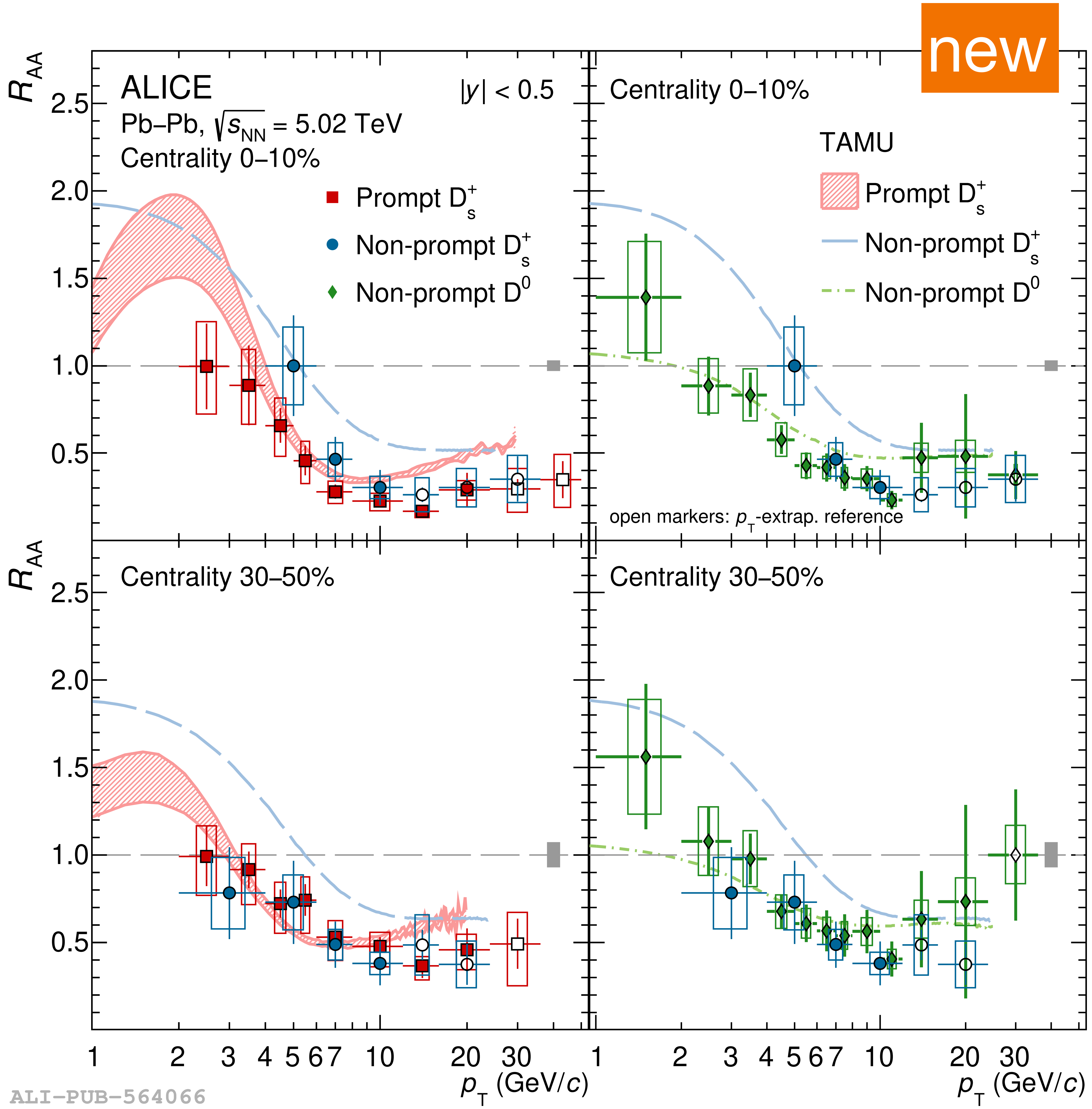
Testing different assumptions with **LGR** model**:**

- **Prompt D^0 hadronisation via coalescence** explains the minimum at 2-3 GeV/*c*
- Ratio close to unity if using m_{charm} for b quarks E-loss calculation

—> mass dependent quark **in-medium energy loss**

—> **Relevant role of dead-cone effect**

Beauty quark in medium energy loss - non-prompt D_s^+



Central collisions (0-10%):

- Higher non-prompt D_s^+ R_{AA} at p_T < 6 GeV/c hint of:

  ➡ $R_{AA}^{non-prompt}(D_s^+) > R_{AA}^{prompt}(D_s^+)$

  ‣ consistent with different E-loss by charm and beauty

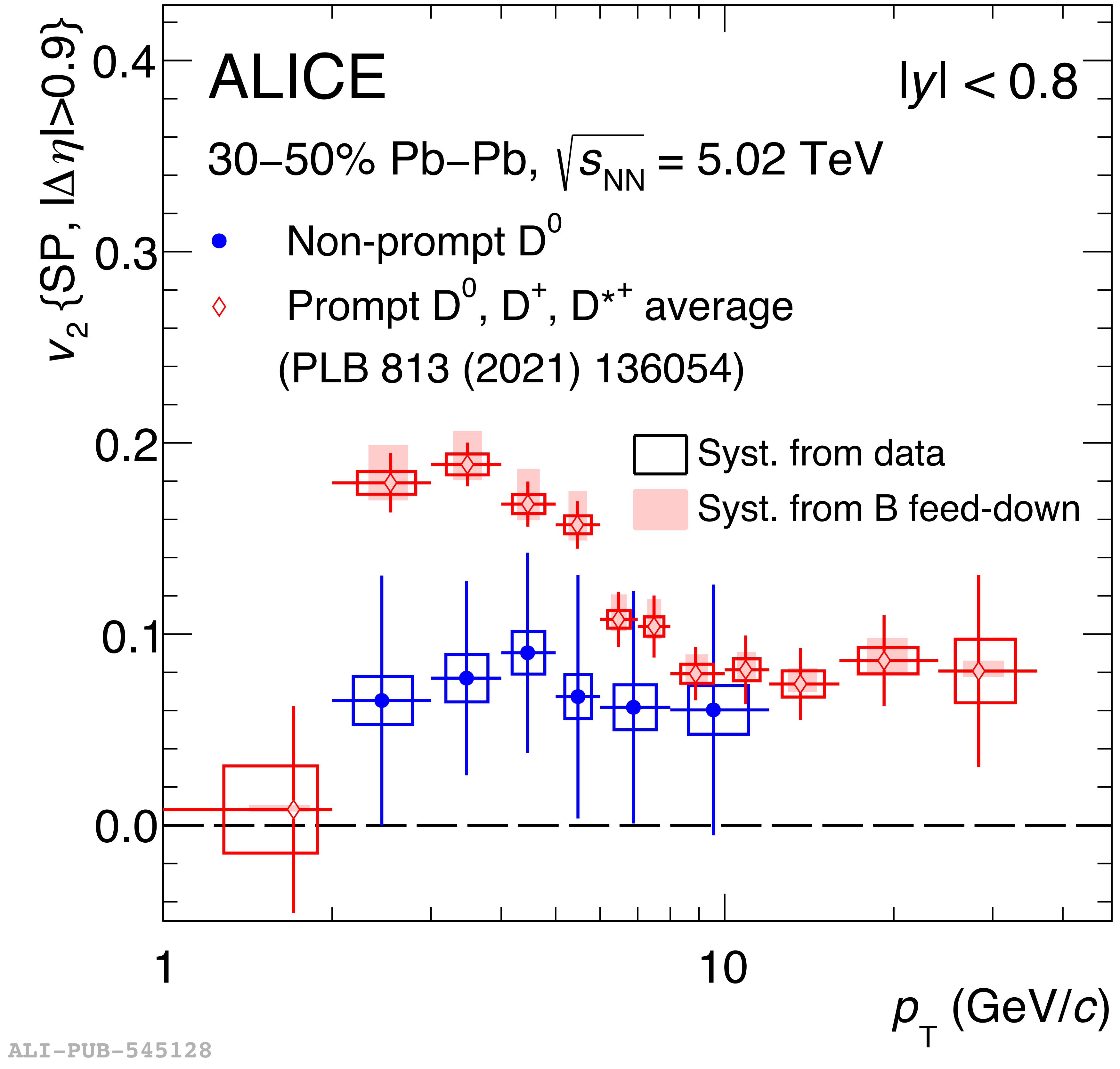
  ➡ $R_{AA}^{non-prompt}(D_s^+) > R_{AA}^{non-prompt}(D^0)$

  ‣ Interplay of hadronization via recombination and strangeness-rich environment

Semicentral collisions (30-50%):

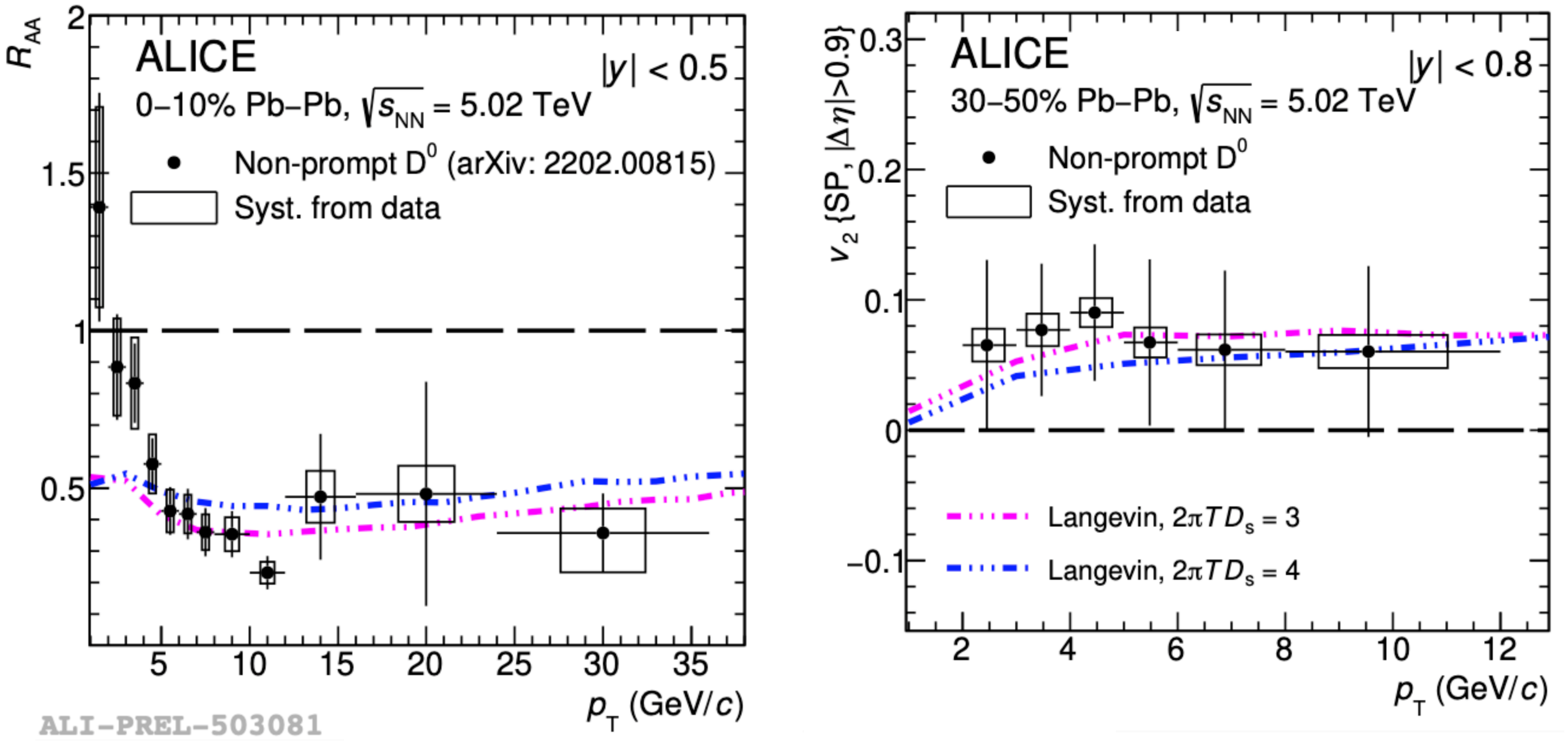
- No sizable separation

Beauty-hadron flow from non-prompt D^0 $v2$



- Significant flow for non-prompt D^0 mesons (2.7σ)
  ➡ Indication of strong interaction of b-quark with the QGP
- v_2 lower than that of prompt D mesons (3.2σ)
  ➡ Different degree of participation to the QGP collective motion between charm and beauty quarks

Beauty-hadron flow from non-prompt D⁰ v2

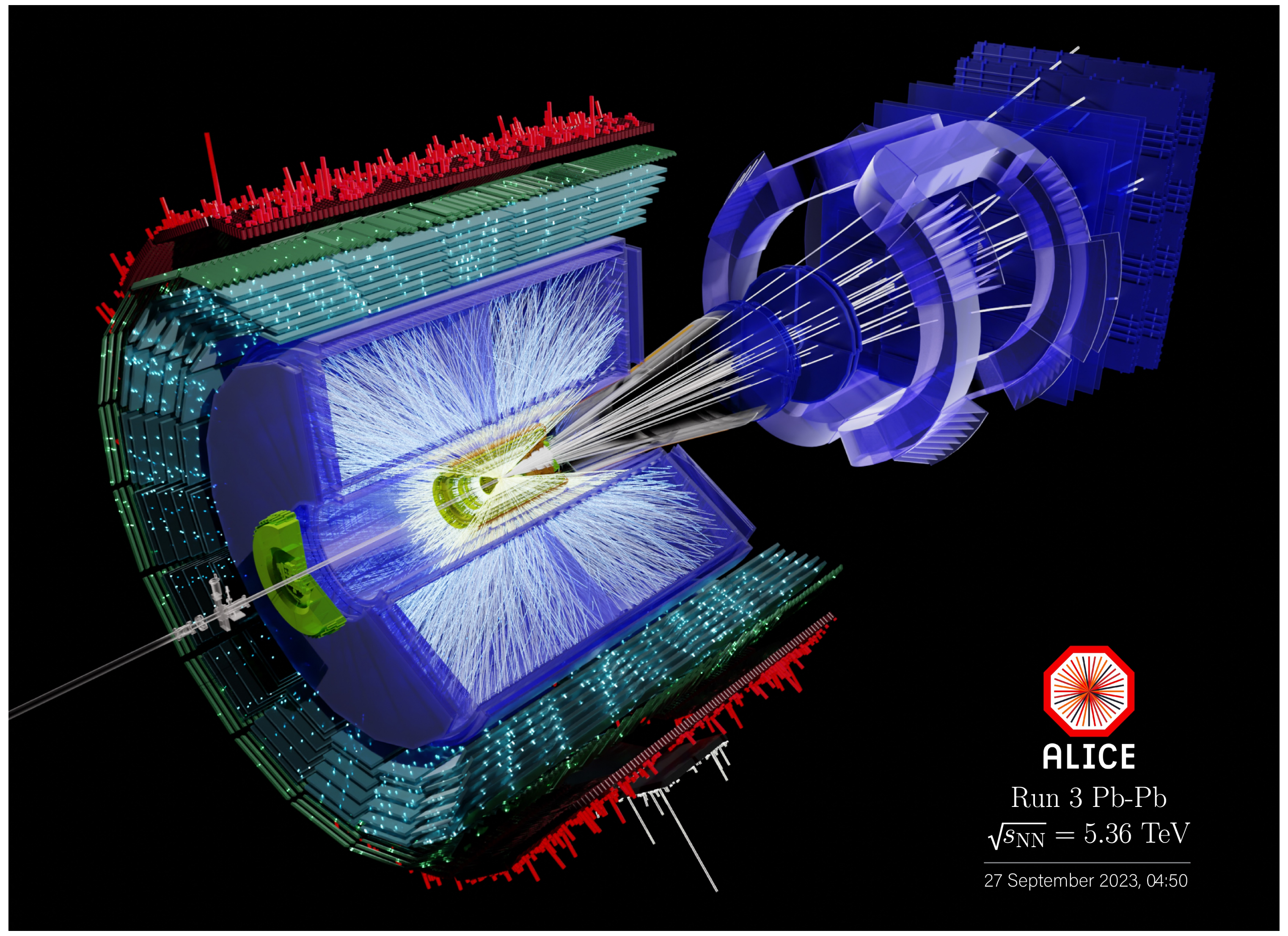


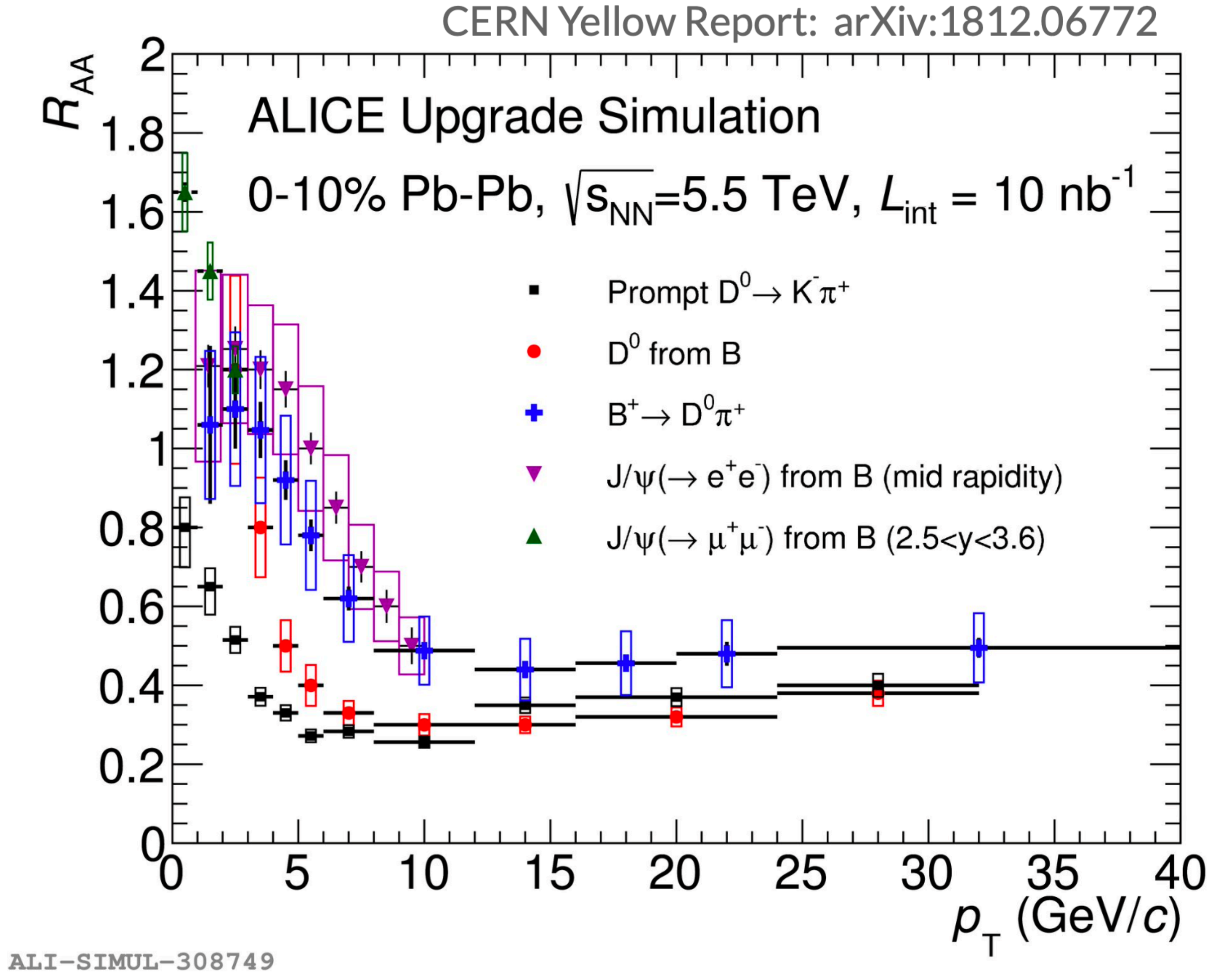
- Rough calculation of D_s in beauty sector is similar to that in charm sector ($2\pi D_s \approx 1.5$-4.5 for charm)
  - ➡ Indicating $\tau_{\text{beauty}} \propto m_{\text{beauty}} D_s \gtrsim \tau_{\text{QGP lifetime}} \approx 10$ fm/c ($m_{\text{beauty}} \approx 3m_{\text{charm}}$, $\tau_{\text{charm}} = 3$-8 fm/c)
  - ➡ Different thermalisation of beauty than charm?
  - ➡ More precise measurements needed

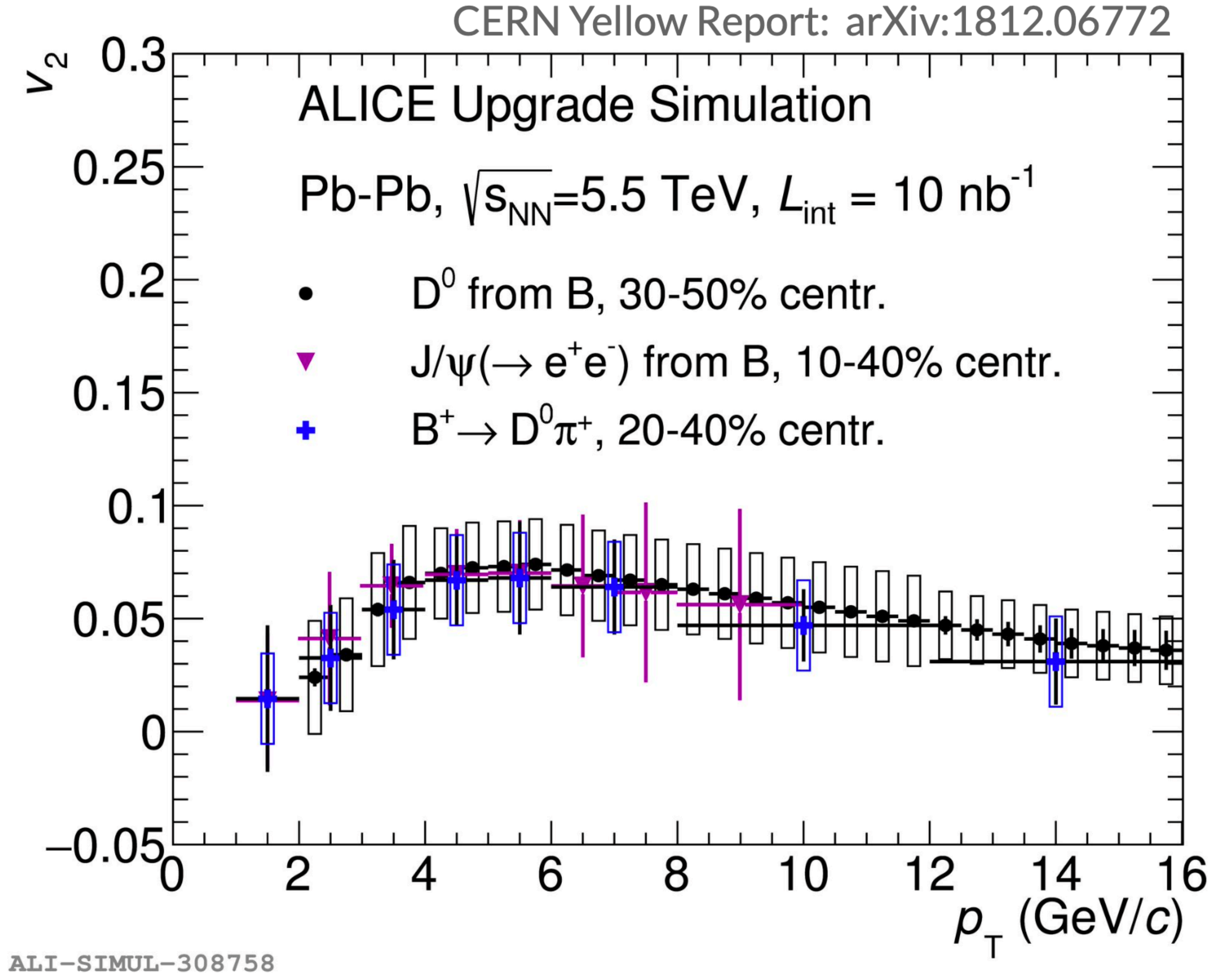
Summary

- Total beauty-quark cross section in pp well described by pQCD calculations
- Heavy flavor hadron production in small system:
  - ➡ D mesons described using FF from e^+e^- measurements
- Heavy flavor in heavy-ion collisions:
  - ➡ Beauty quarks undergo energy loss in QGP (mass dependent)
  - ➡ Heavy quarks hadronise via fragmentation + coalescence
  - ➡ Different degree of participation to collective motion between charm and beauty quarks

- **Next step**? **Run 3**!

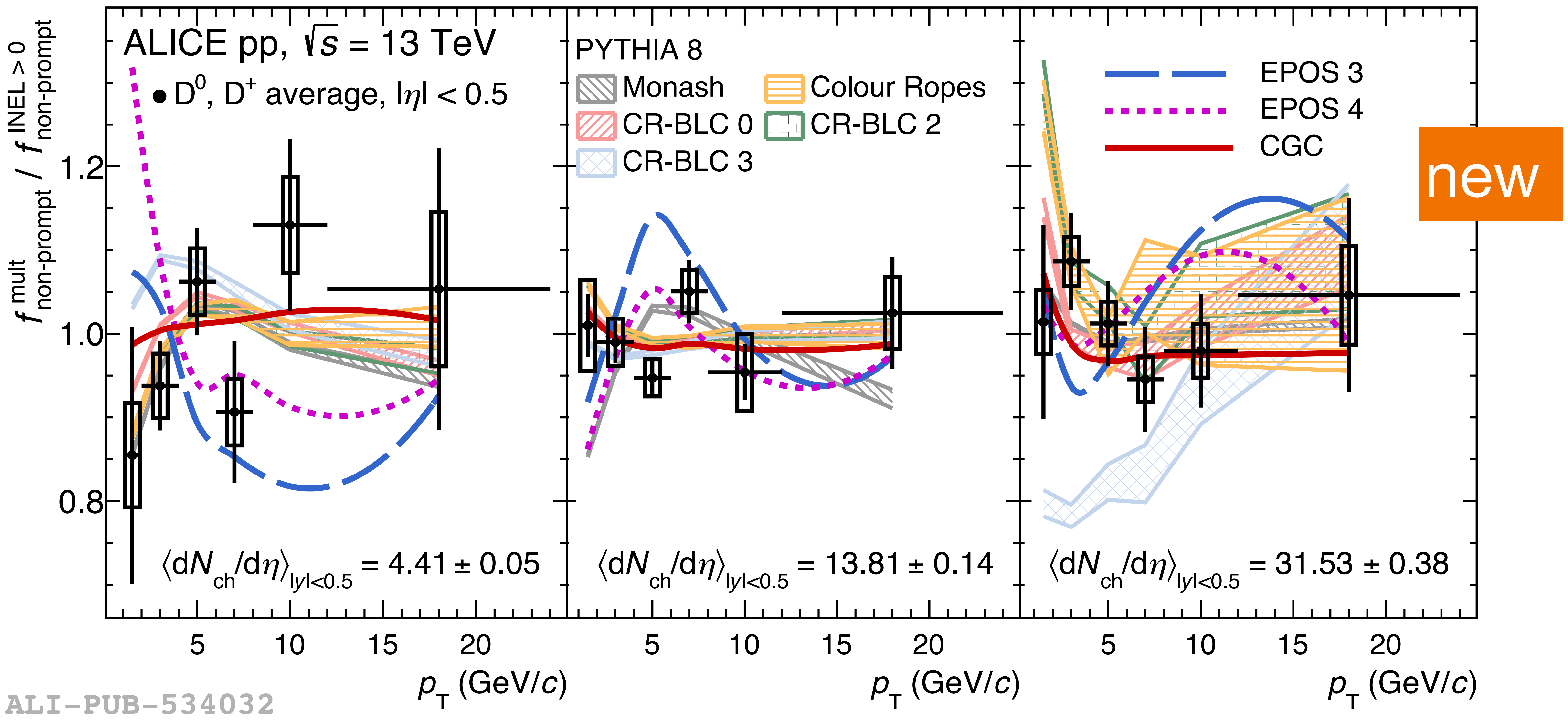






Backup sildes

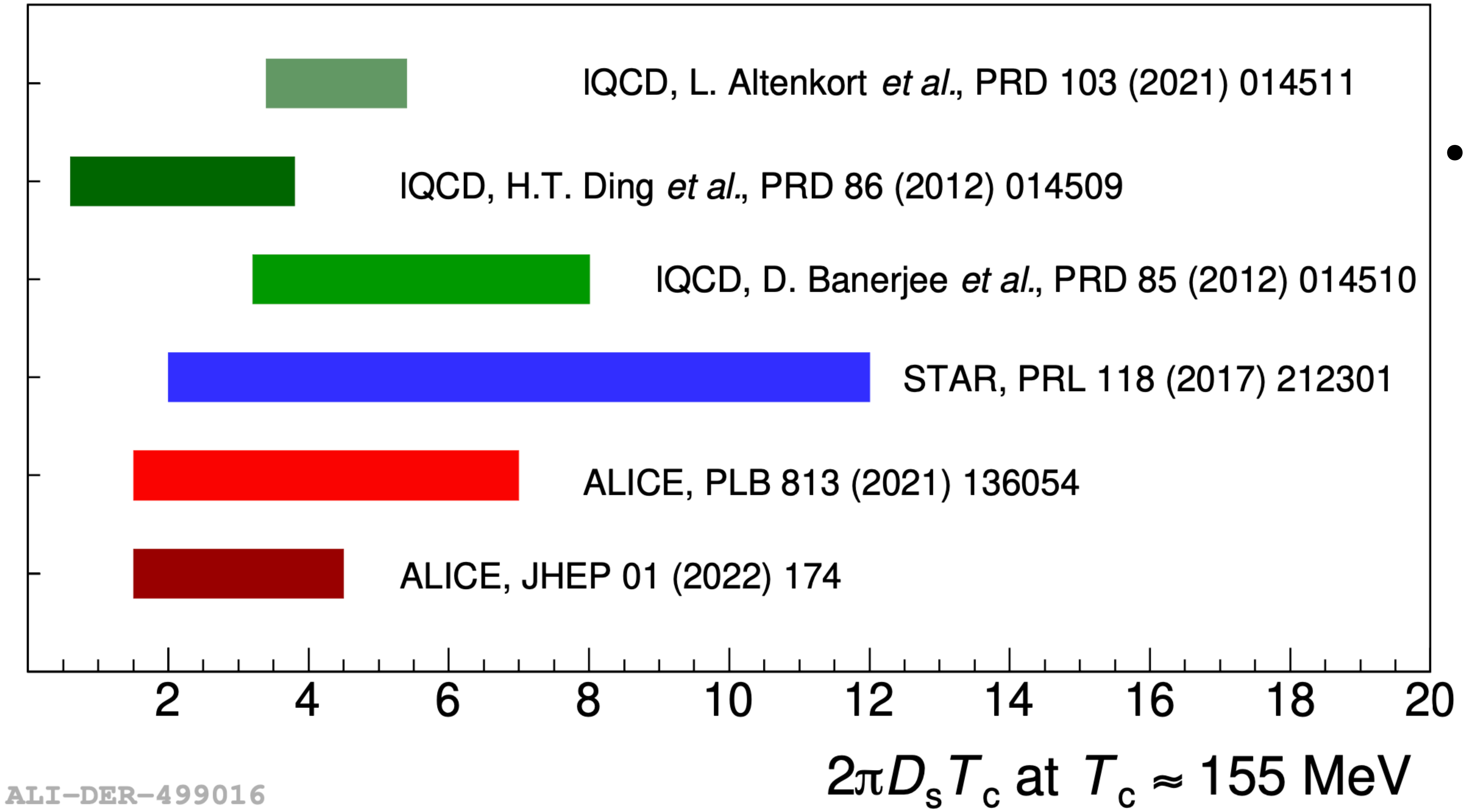
Non-prompt D meson fraction in pp



- Ratio are compatible with unity
  - ➡ Suggesting mild or no multiplicity dependence
  - ➡ Indication of a similar production mechanism of charm and beauty quarks as a function of multiplicity

Charm quark transport

- **Spatial diffusion coefficient D_s** constrained from model-to-data comparison (χ^2 analysis) for both the R_{AA} and v_2



- TAMU, MC@sHQ, LIDO, LGR and Catania provide reasonable description

- $1.5 < 2\pi D_s(T) < 4.5$ corresponds to
  $\tau_{charm} = (m_{charm} / T)D_s(T) \approx 3\text{-}8$ fm/c < $\tau_{QGP\ lifetime} \approx 10$ fm/c

➡ Charm thermalisation happens within the QGP lifetime