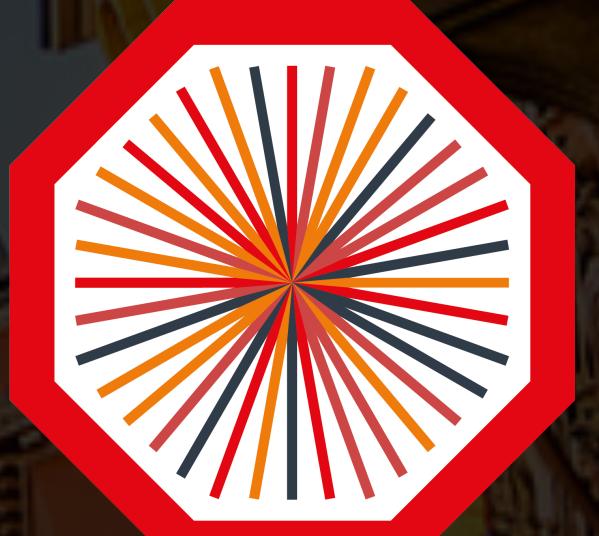


# Beauty production in heavy-ion collisions with ALICE at the LHC

Biao Zhang  
Central China Normal University



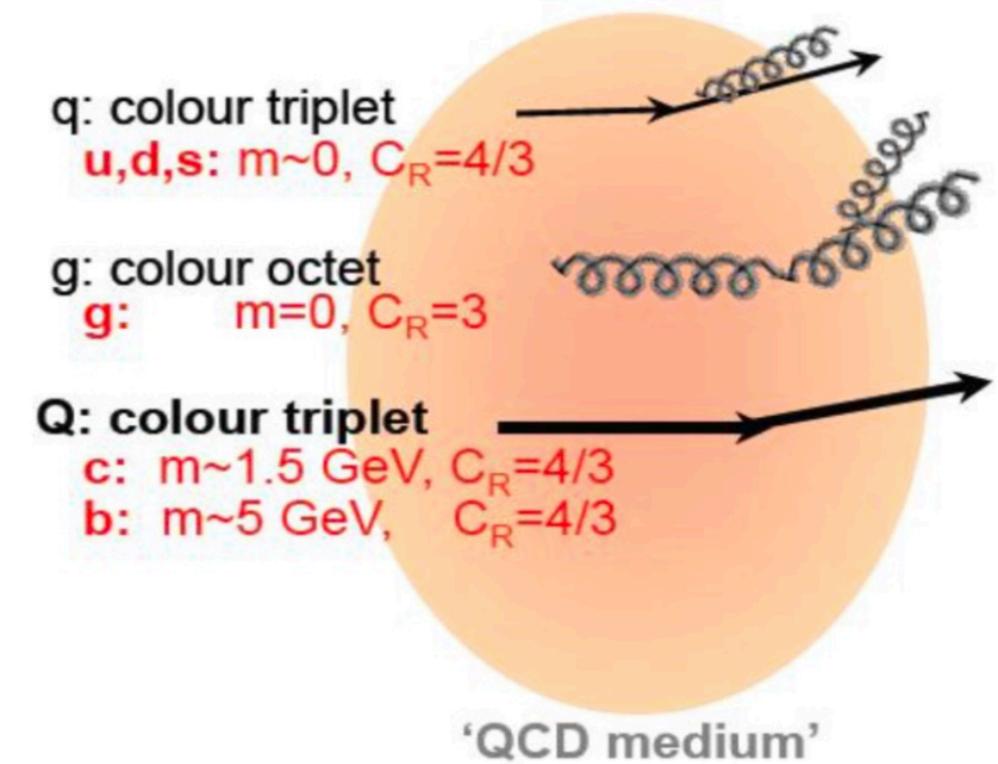
ALICE

# Introduction

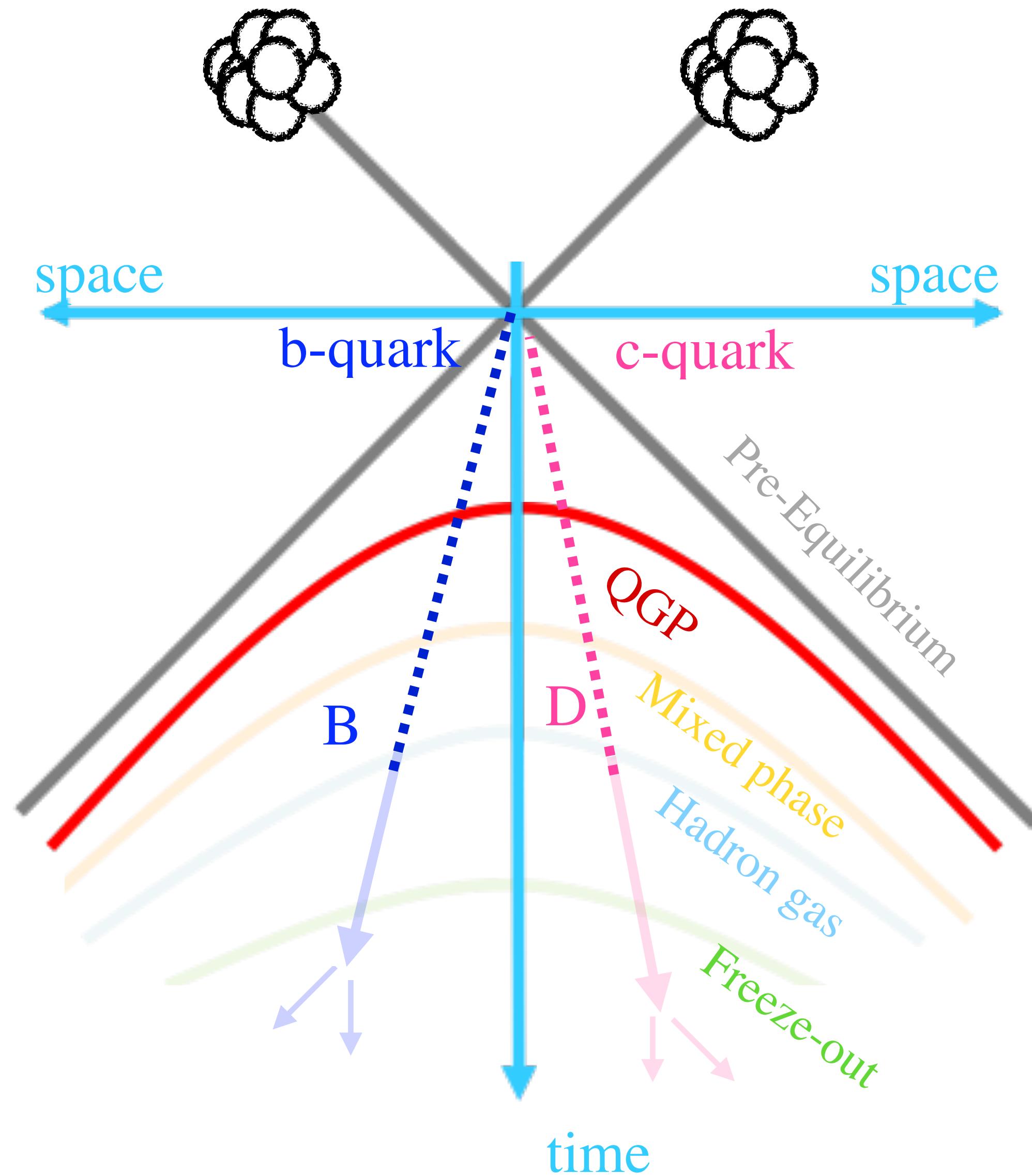
- Heavy-quarks (**charm**, **beauty**) are mainly produced in hard partonic scattering processes, in the early stage of system evolution after the collision:

$$\rightarrow \tau_b \sim 0.02 \text{ fm}/c < \tau_c \sim 0.07 \text{ fm}/c < \tau_{QGP} \sim 1 \text{ fm}/c^{[1][2]}$$

- Heavy-quark interaction in the QGP
  - Energy loss: quantified with nuclear modification factor



$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

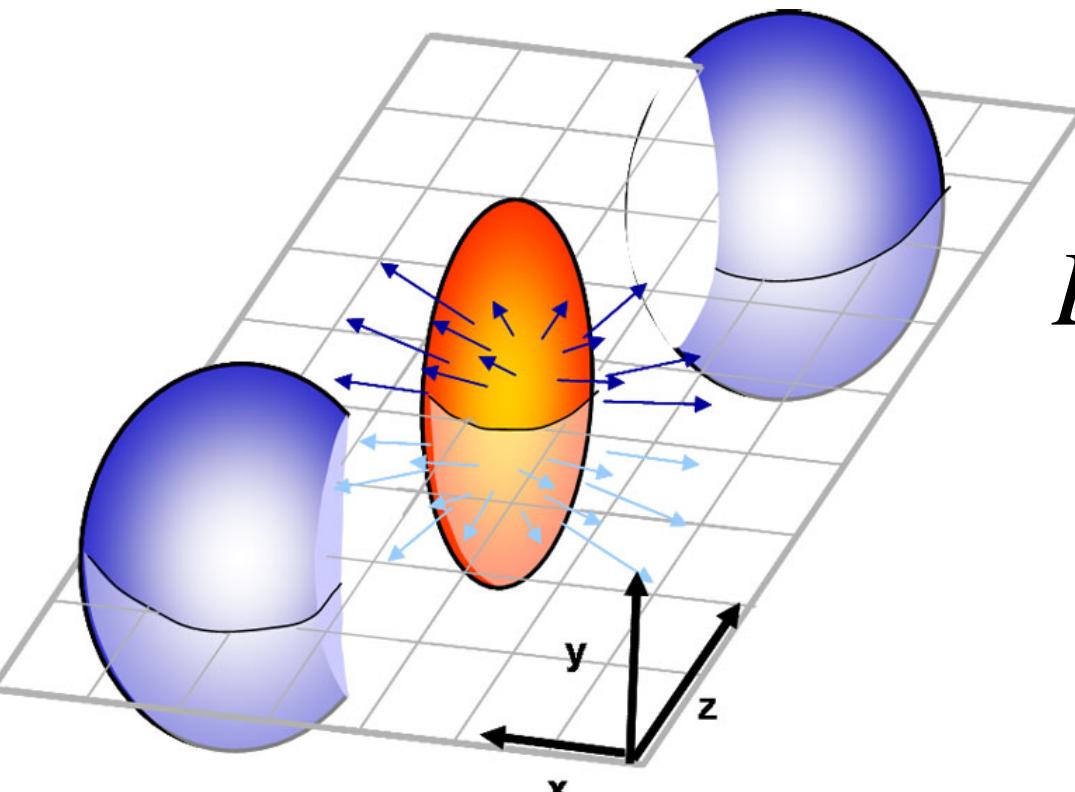


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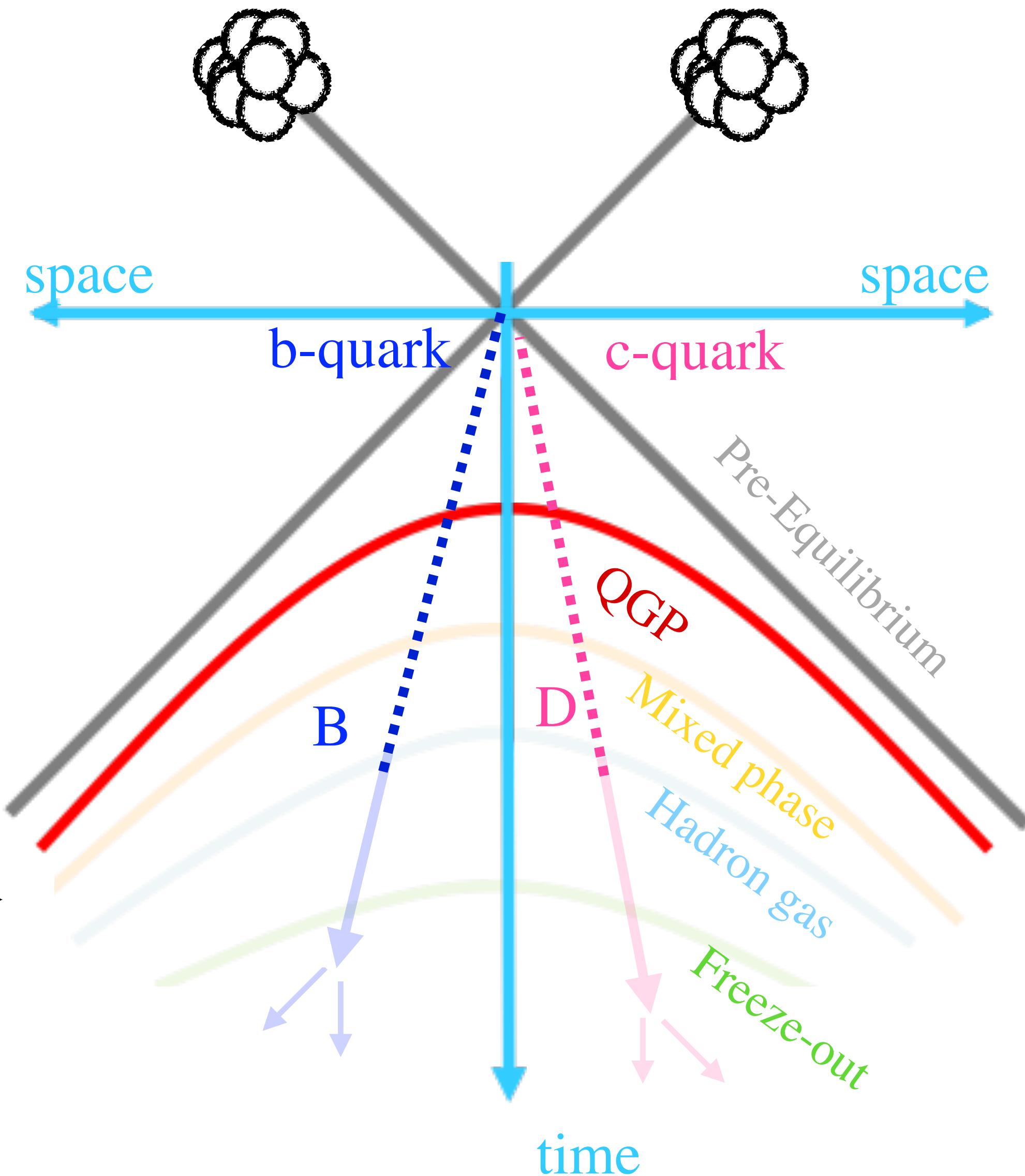
$$\rightarrow \tau_b \sim 0.02 \text{ fm}/c < \tau_c \sim 0.07 \text{ fm}/c < \tau_{QGP} \sim 1 \text{ fm}/c^{[1][2]}$$

- Heavy-quark interaction in the QGP
  - Thermalization, collectivity: quantified with azimuthal anisotropy



$$E \frac{d^3N}{dp_T} = \frac{1}{2\pi} \frac{d^2N}{p_T dp_T dy} \left\{ 1 + \sum_{n=1}^{\infty} v_n \cos[n(\varphi - \psi_n)] \right\}$$

$$v_2 = \langle \cos[2(\varphi - \psi_2)] \rangle$$

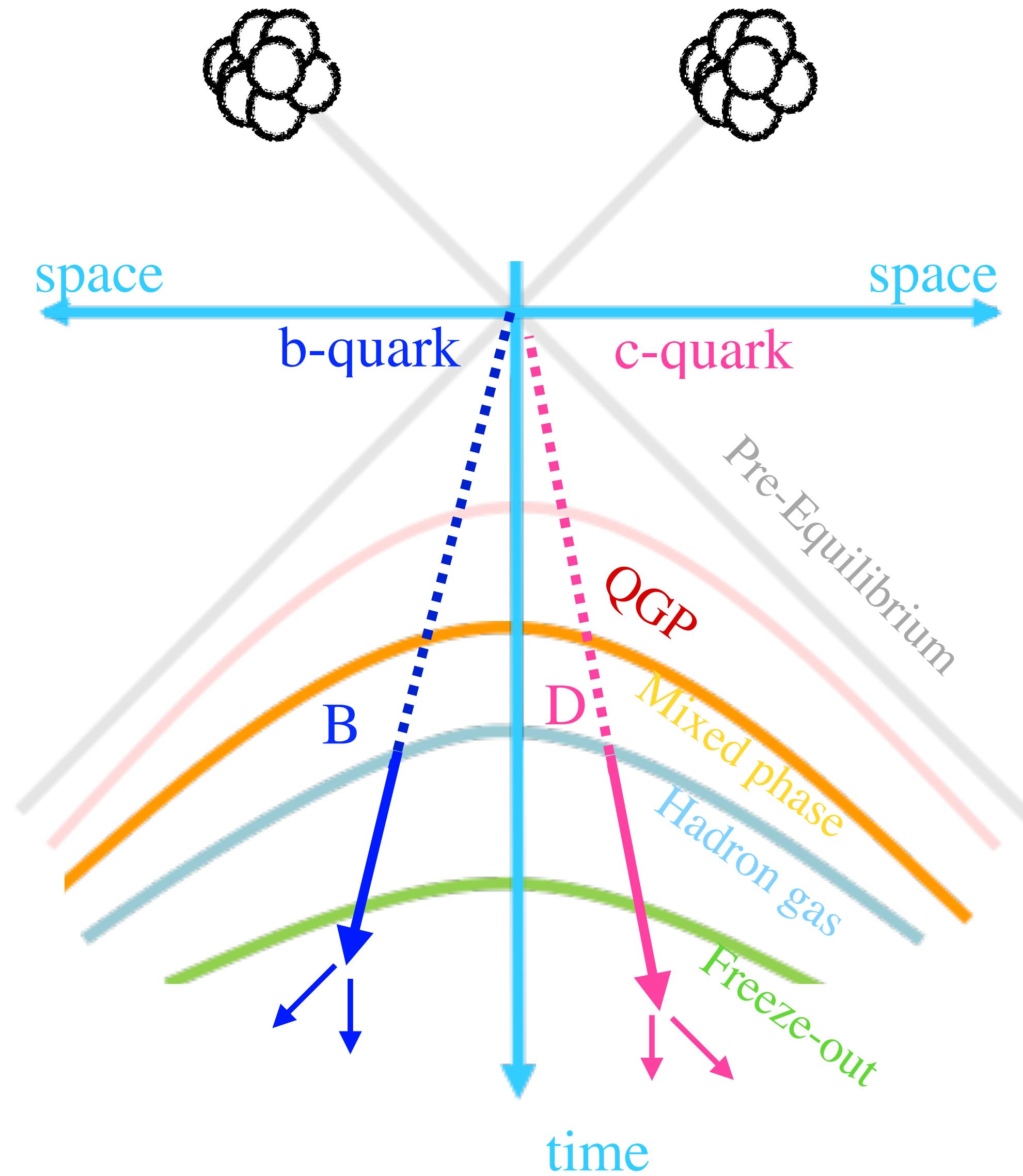
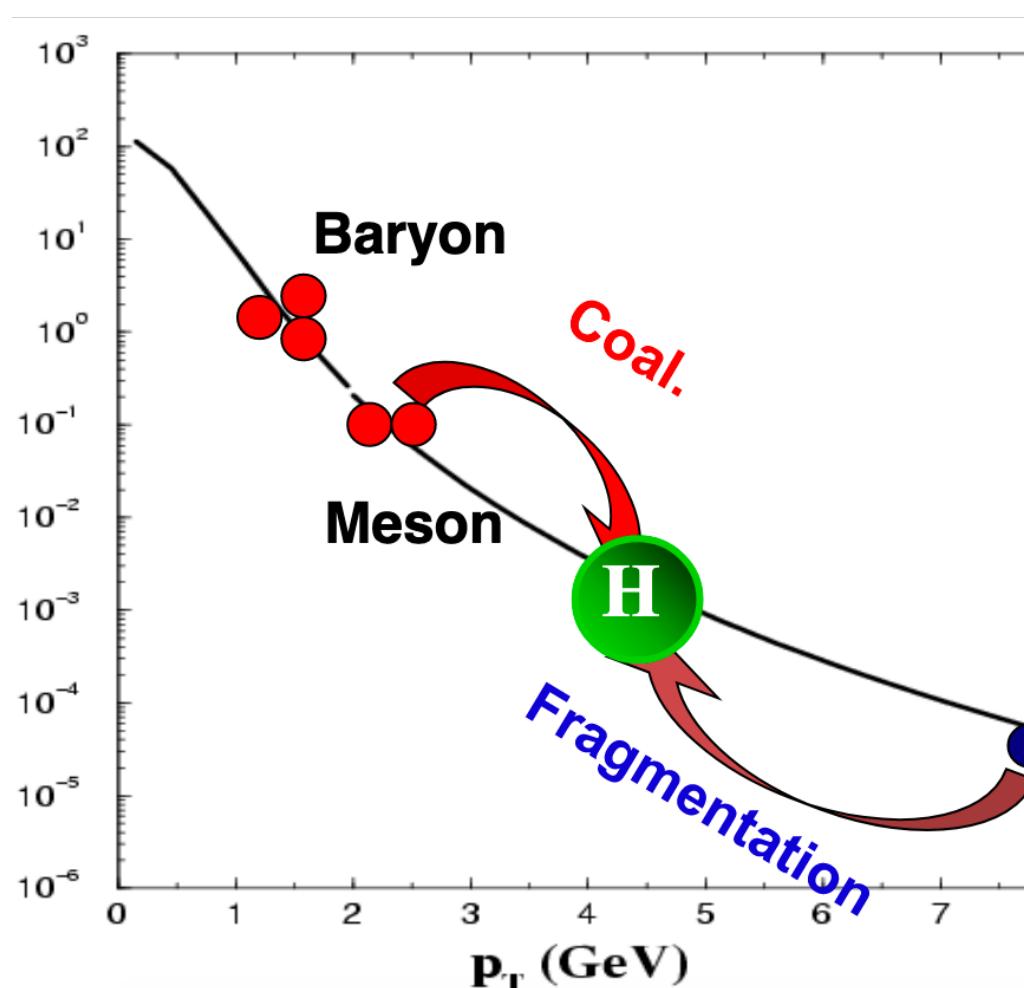
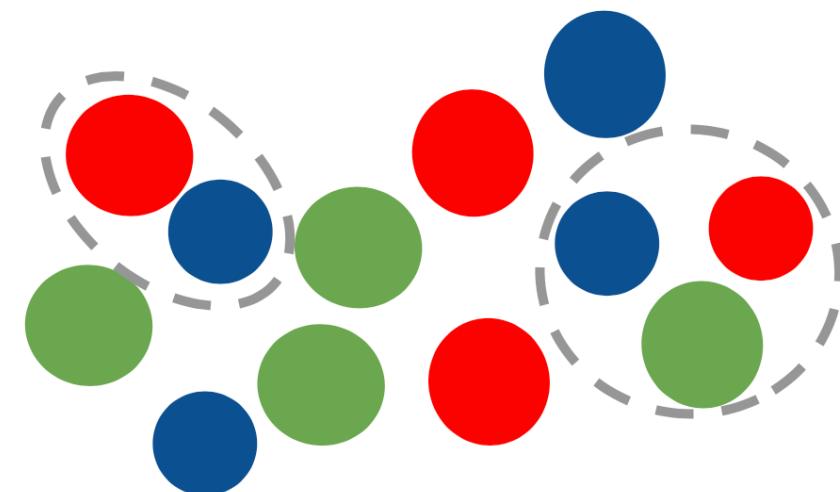


# Introduction

- Heavy quarks (**charm**, **beauty**) are mainly produced in hard partonic scattering processes, in the early stage of system evolution after the collision:

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- Heavy-quarks interaction in the QGP
  - Hadronisation mechanisms: yield ratio measurements of different particle species → **Fragmentation + Coalescence**



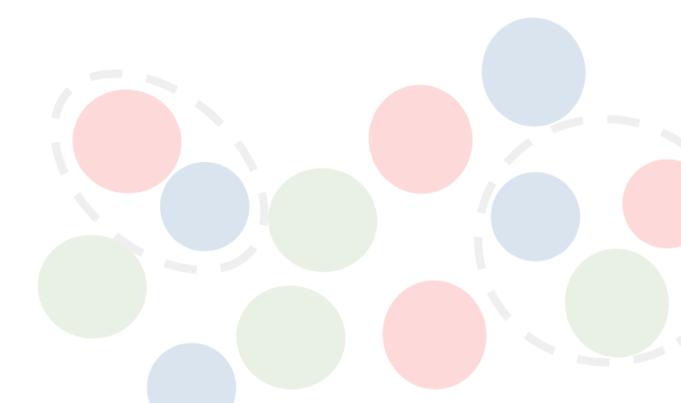
# Introduction

- The heavy-flavor quarks (**charm**, **beauty**) are mainly produced in hard parton-parton interactions at early stage of system evolution

$$\rightarrow \tau_b \sim 0.02 \text{ fm/c} < \tau_c \sim$$

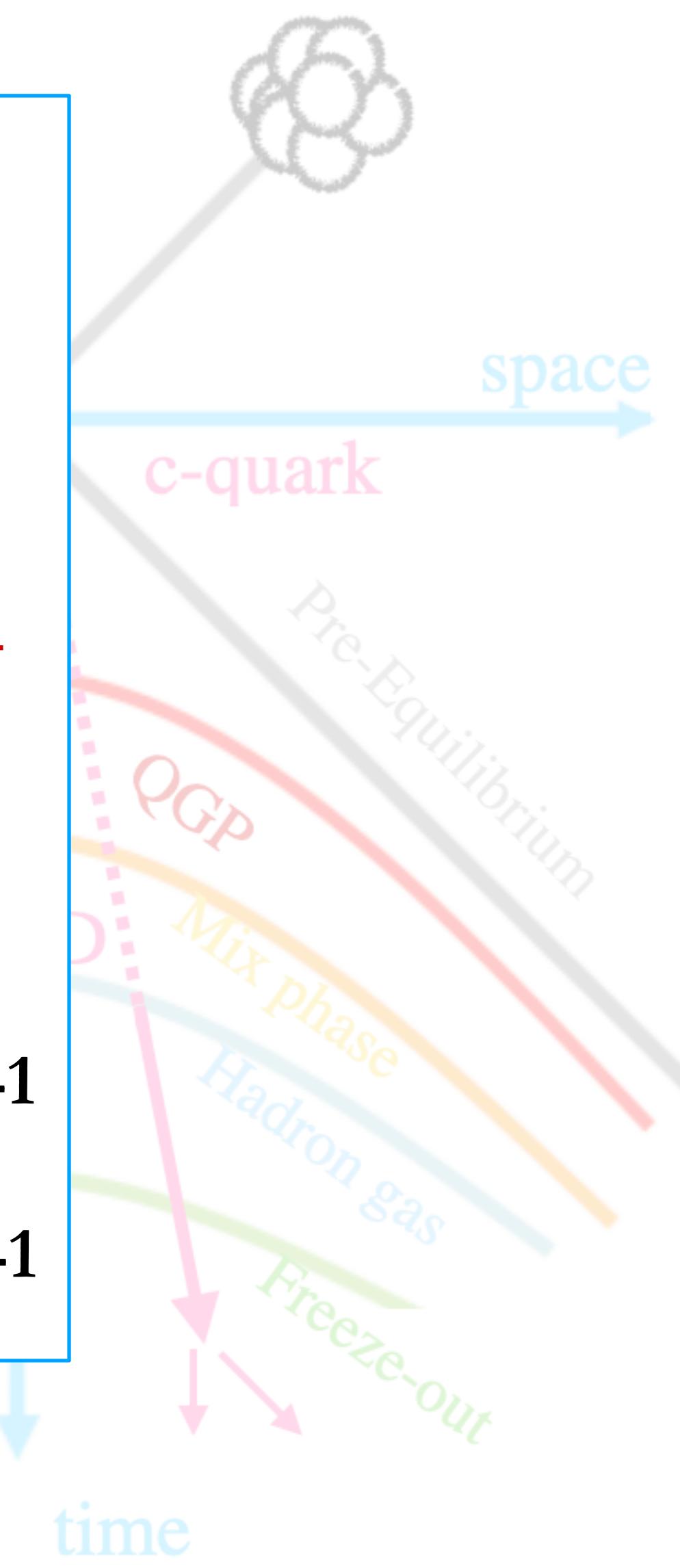
- Heavy-quark interaction
- Hadronisation mechanism among different particles

Coalescence

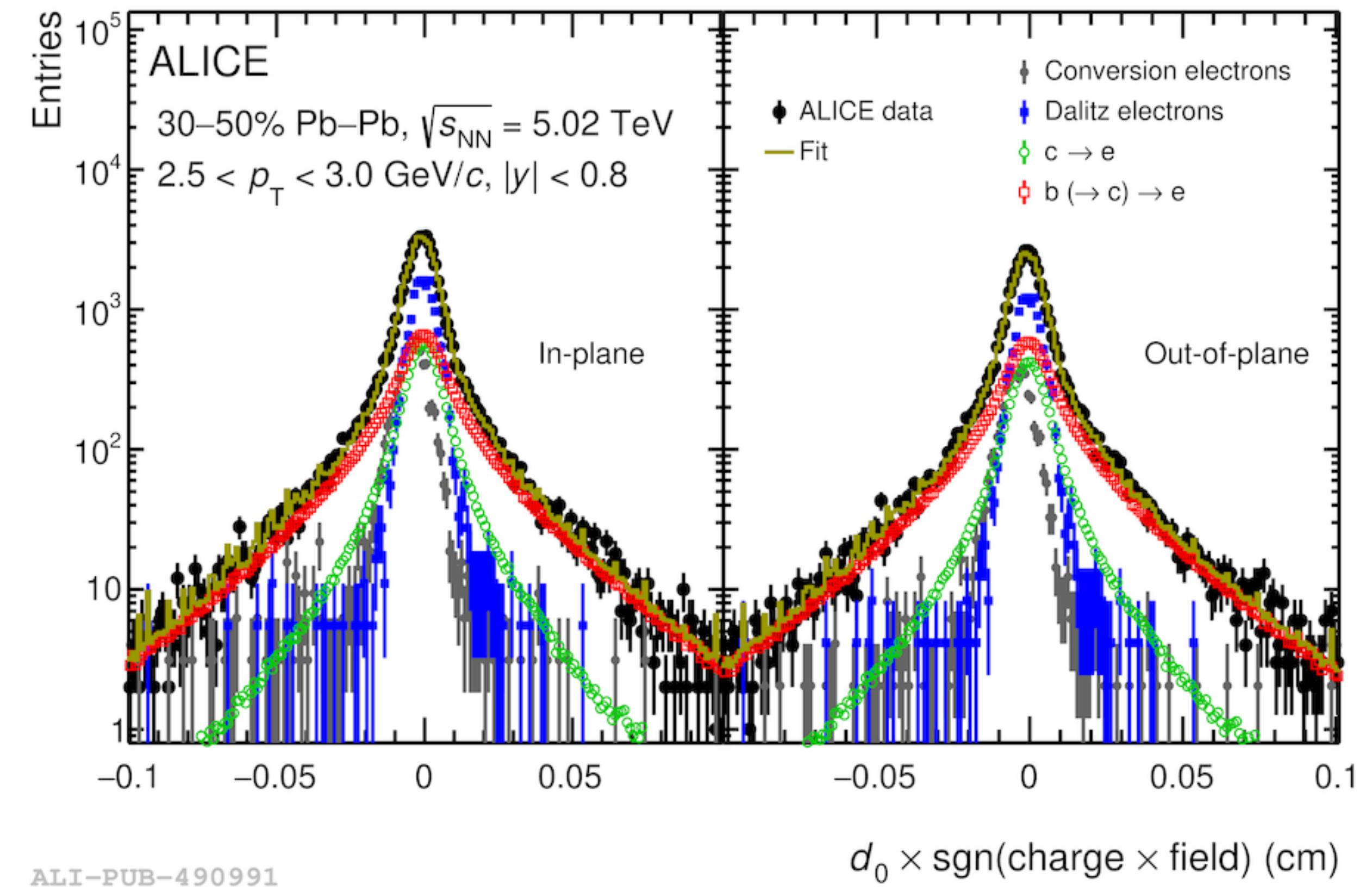
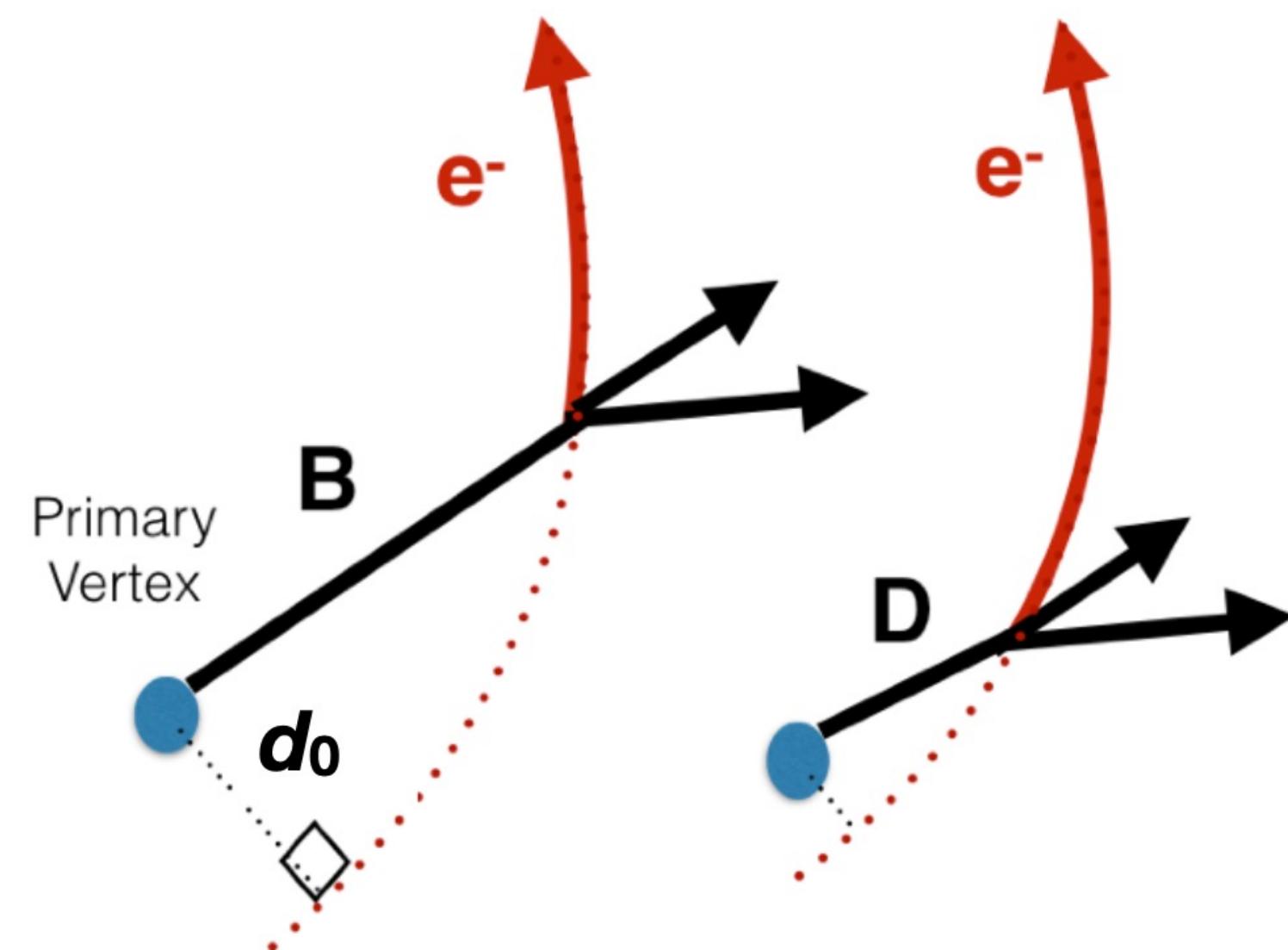


## Beauty measurements in this talk:

- Semileptonic decay:  $b \rightarrow e$
- Hadronic decay:  $b \rightarrow D^0 \rightarrow K^- \pi^+$   
 $b \rightarrow D_s^+ \rightarrow \phi \pi^+ \rightarrow K^- K^+ \pi^+$
- 2015 Pb–Pb 5.02 TeV:  $\mathcal{L}_{\text{int}} \sim 13 \mu\text{b}^{-1}$
- 2018 Pb–Pb 5.02 TeV:  $\mathcal{L}_{\text{int}} (0\text{-}10\%) \sim 130 \mu\text{b}^{-1}$   
 $\mathcal{L}_{\text{int}} (30\text{-}50\%) \sim 56 \mu\text{b}^{-1}$



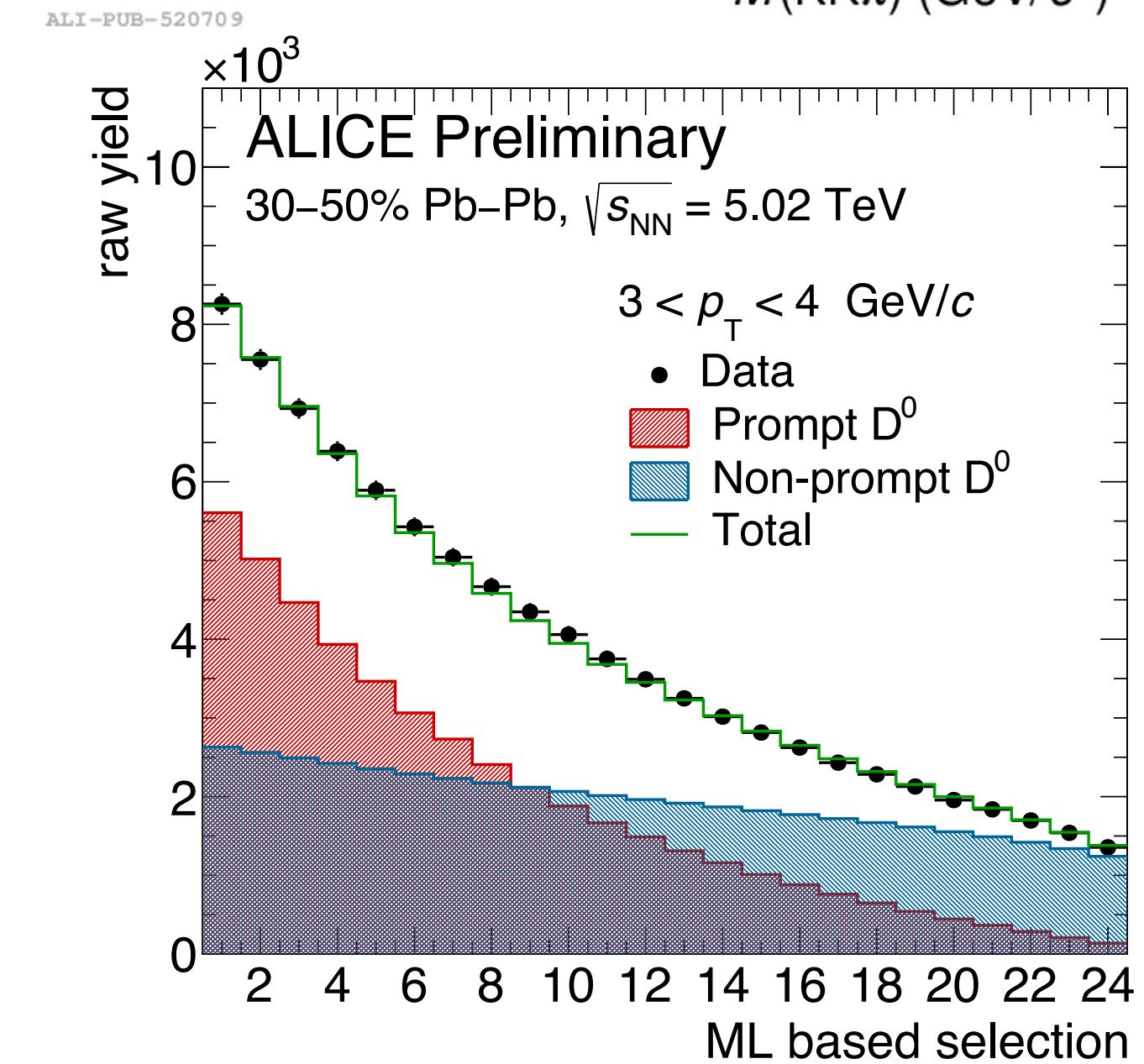
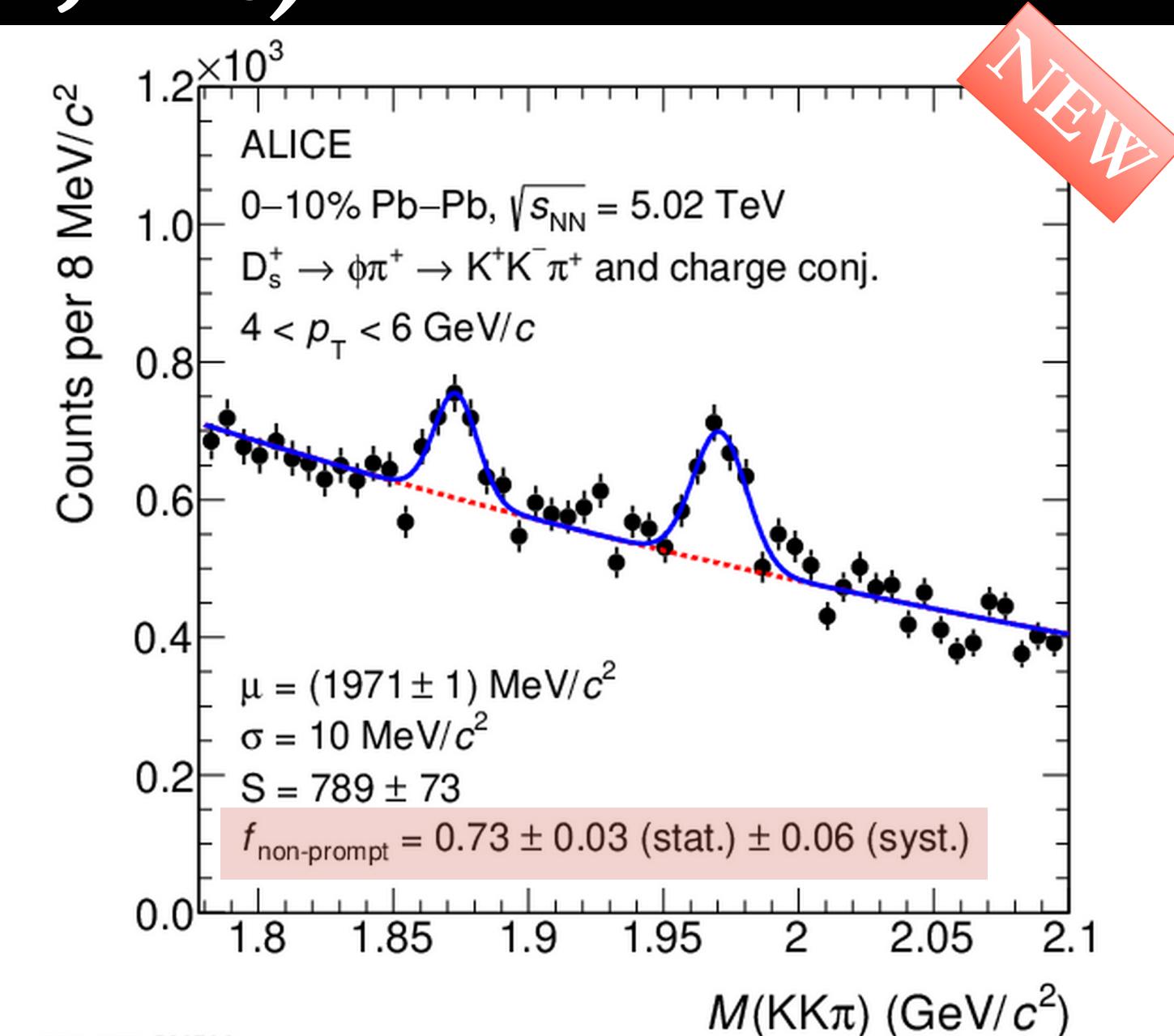
# Analysis strategy: beauty-decay electrons



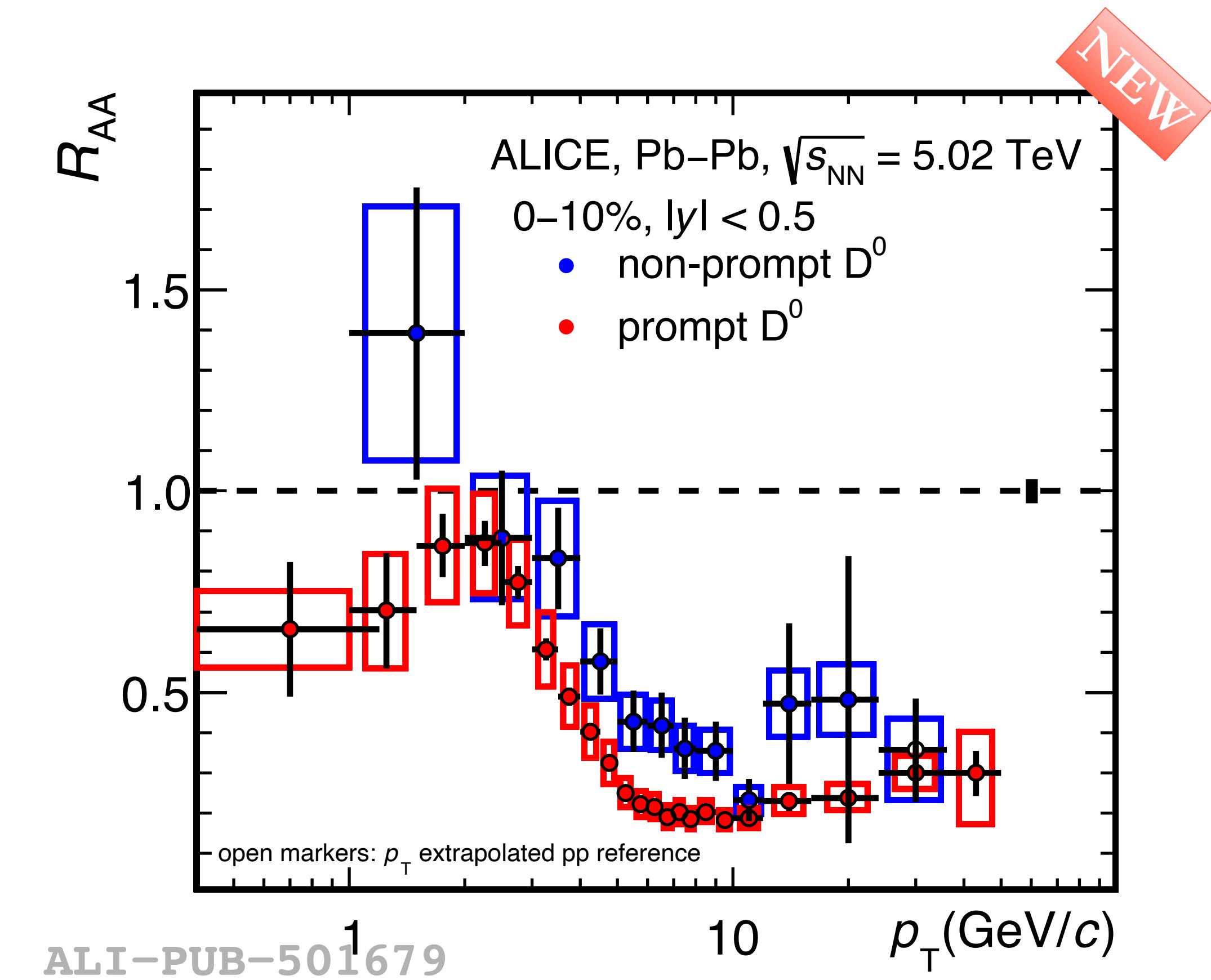
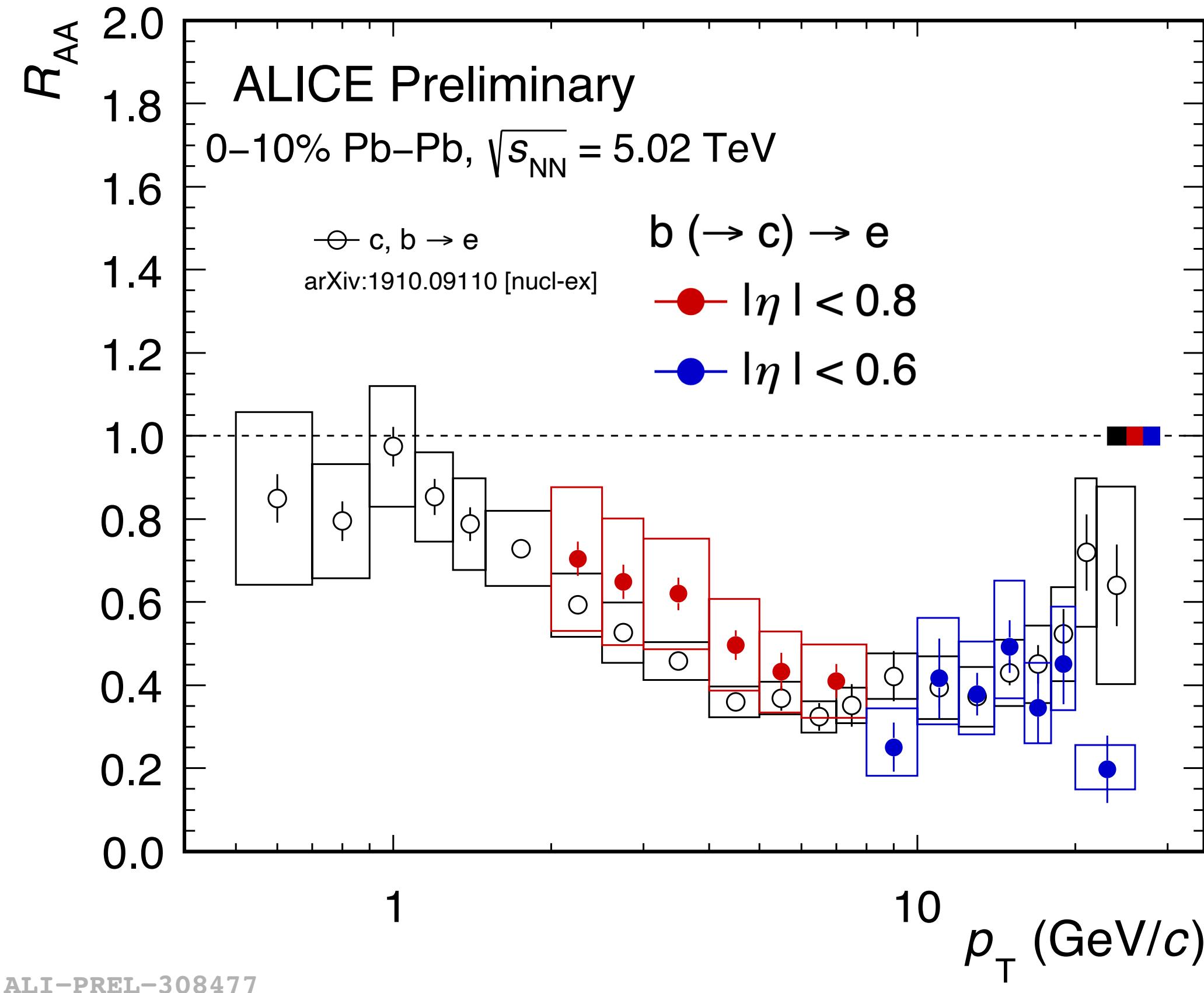
- Large branching ratios via semileptonic decays:  $b \rightarrow e + X$  (~10%) ,  $b \rightarrow c \rightarrow e + X$  (~10%)
- Longer lifetime than c-quark and other electron sources:  $\tau_b \sim 500 \mu\text{m}/c$ ;  $\tau_c \sim 60\text{-}300 \mu\text{m}/c$ 
  - larger impact parameter ( $d_0$ ) w.r.t primary vertex
- $b \rightarrow e$  yield obtained with template fit on impact parameter distributions

# Analysis strategy: Non-prompt D mesons( $D^0$ , $D_s$ )

- Use Machine Learning method with a multi-classification by **BDT** to select candidates, separating prompt D and non-prompt D mesons and combinatorial background<sup>[1]</sup>
- Signal was extracted from invariant mass fit
- Prompt and non-prompt D mesons contributions extracted from  $\chi^2$  minimization of the system of n sets of selections with different prompt and non-prompt D-meson contributions



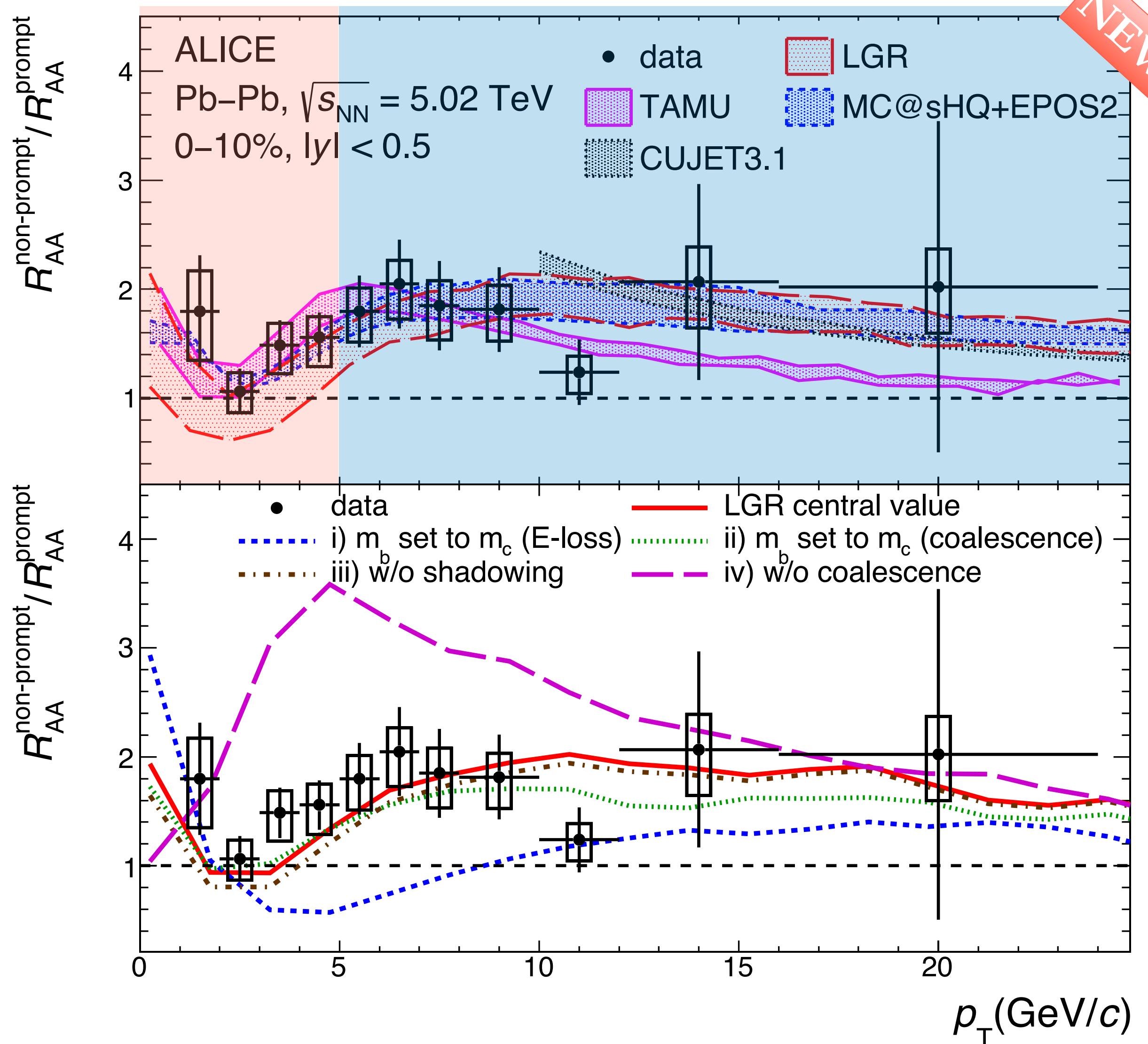
# Nuclear modification factor for beauty



**Beauty quark  $R_{\text{AA}}$  suppression:**

→ Hint of  $R_{\text{AA}}(\text{charm}) < R_{\text{AA}}(\text{beauty})$  at low  $p_{\text{T}}$

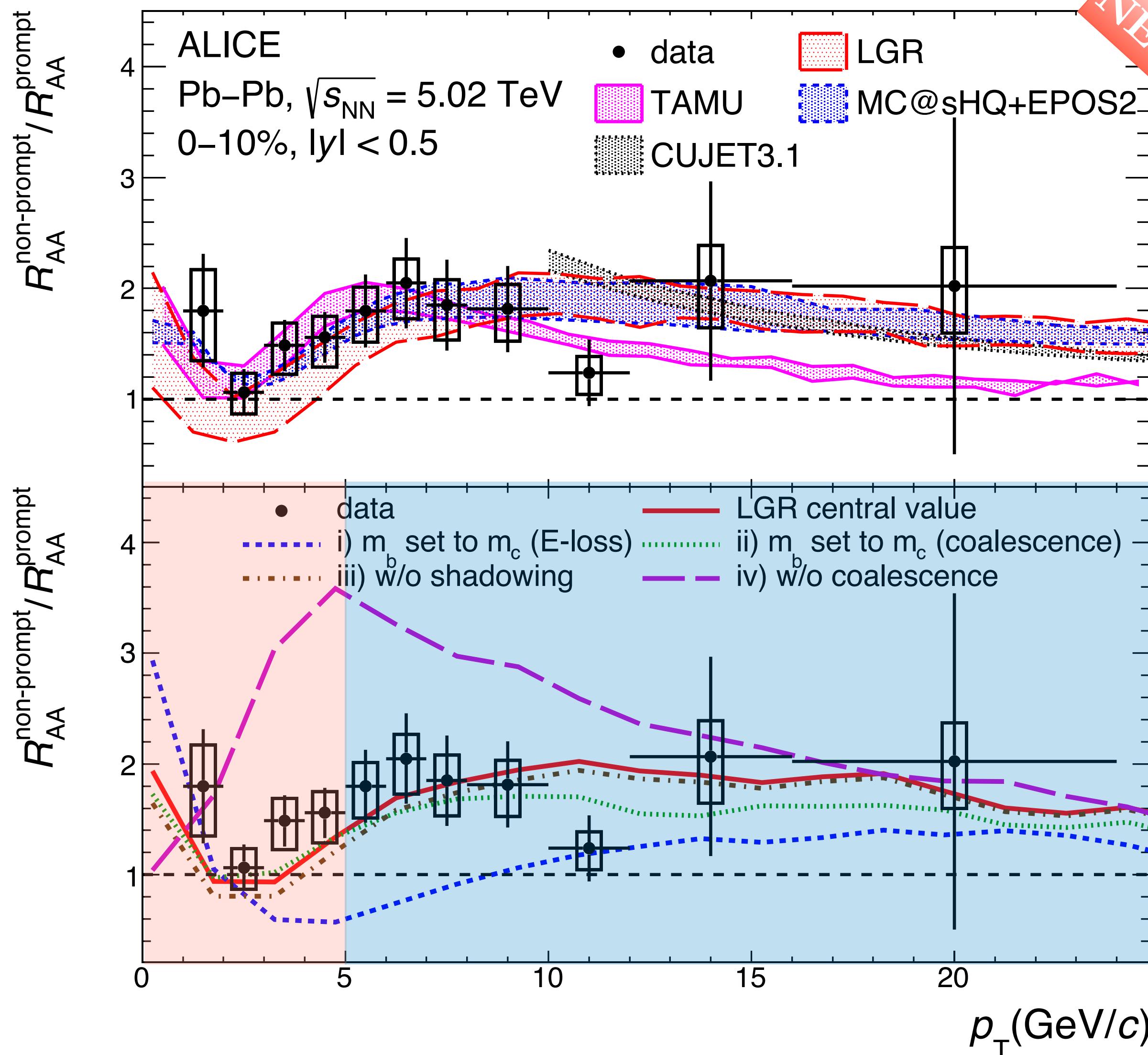
# Ratio of Non-prompt and prompt D<sup>0</sup> R<sub>AA</sub>(beauty over charm)



$R_{AA, b \rightarrow D^0} / R_{AA, c \rightarrow D^0}$  ratio comparison  
with models:

- $p_T < 5 \text{ GeV}/c$  : sensitive to shadowing / flow / decay kinematics for charm and beauty
- $p_T > 5 \text{ GeV}/c$  :  $3.9 \sigma$  above unity  $\rightarrow$  beauty quarks undergo less suppression than charm quarks

# Ratio of Non-prompt and prompt $D^0$ $R_{AA}$ (beauty over charm)



Testing **LGR** ingredients effect:

- $p_T < 5 \text{ GeV}/c$  : The “valley” structure is interpreted as the formation of prompt D-mesons via **charm-quark coalescence (iv)**
- $p_T > 5 \text{ GeV}/c$  : The significant enhancement of double ratio at high  $p_T$  is related to the mass dependent quark in-medium **energy loss effect(i)**

# Nuclear modification factor for beauty (Non-prompt D<sub>s</sub><sup>+</sup>)

NEW

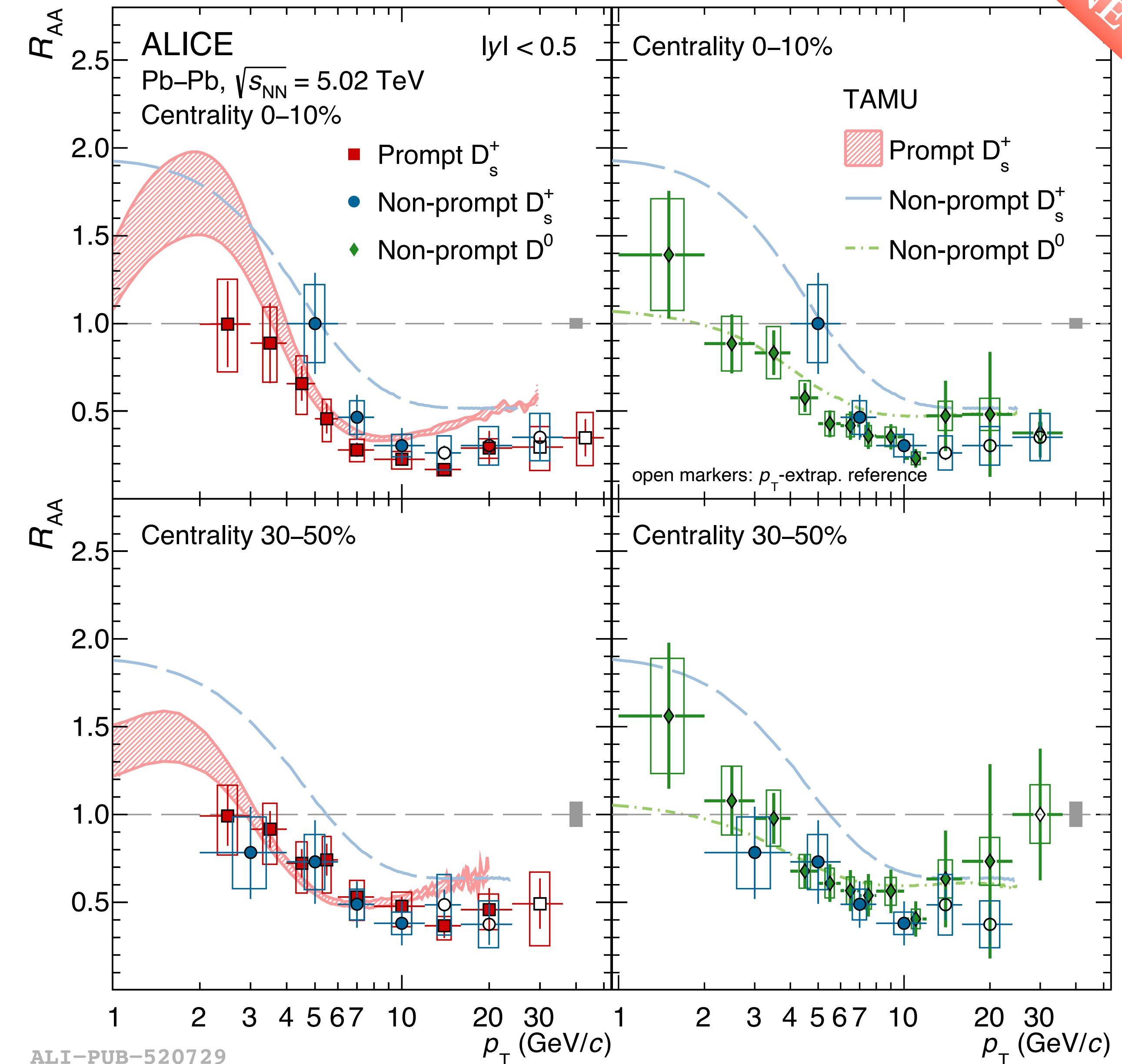
## Central collisions(0-10%):

- $p_T < 6 \text{ GeV}/c$  hint of:
  - $R_{AA}^{\text{non-prompt}}(\text{D}_s^+) > R_{AA}^{\text{prompt}}(\text{D}_s^+)$
  - $R_{AA}^{\text{non-prompt}}(\text{D}_s^+) > R_{AA}^{\text{non-prompt}}(\text{D}^0)$

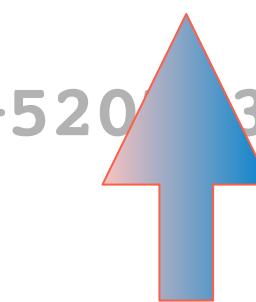
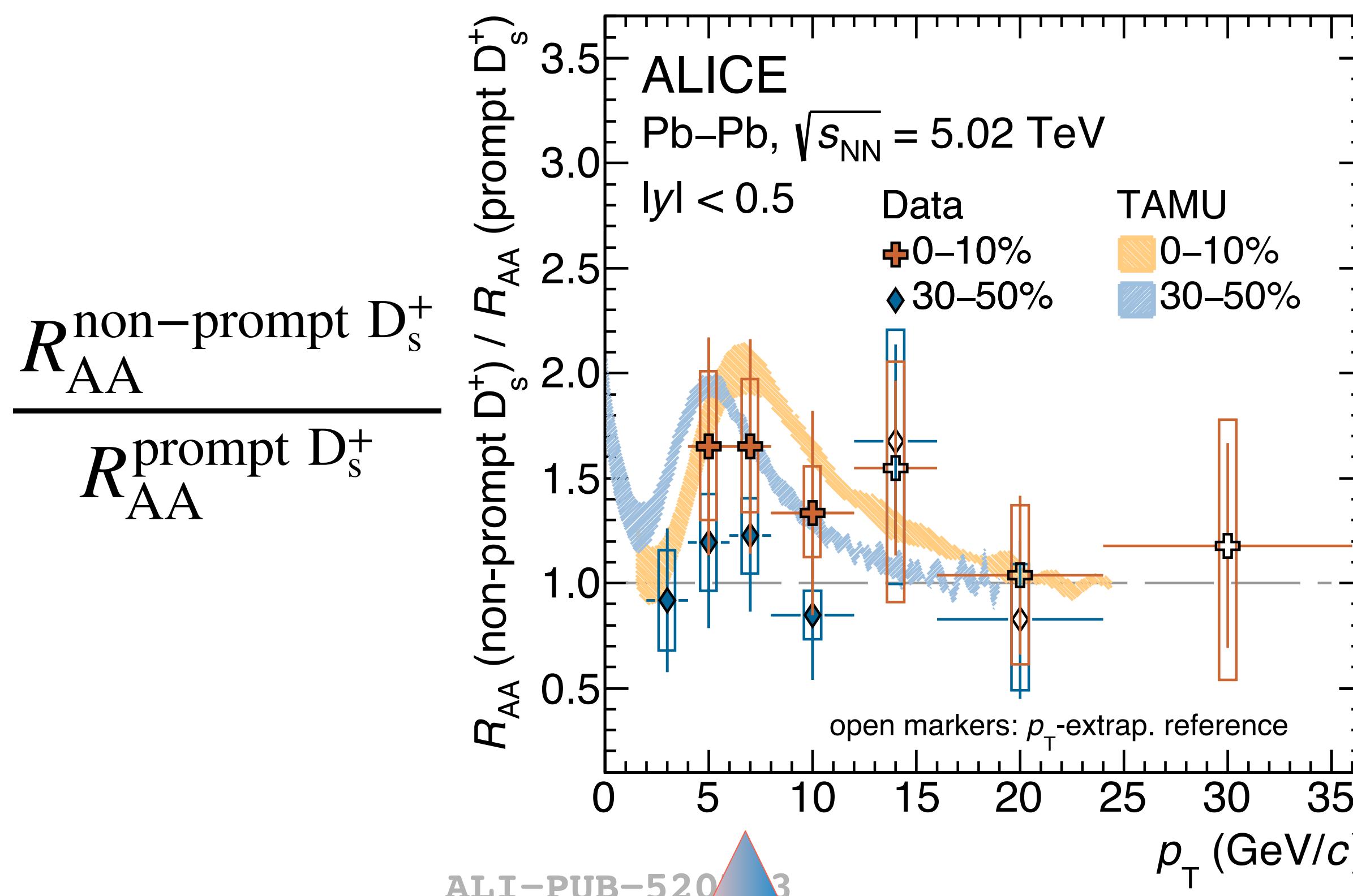
→ interplay of different energy loss and recombination btw. charm and beauty

## Semicentral collisions(30-50%):

→ no sizeable medium-induced effect

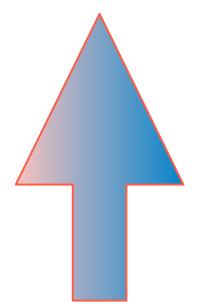
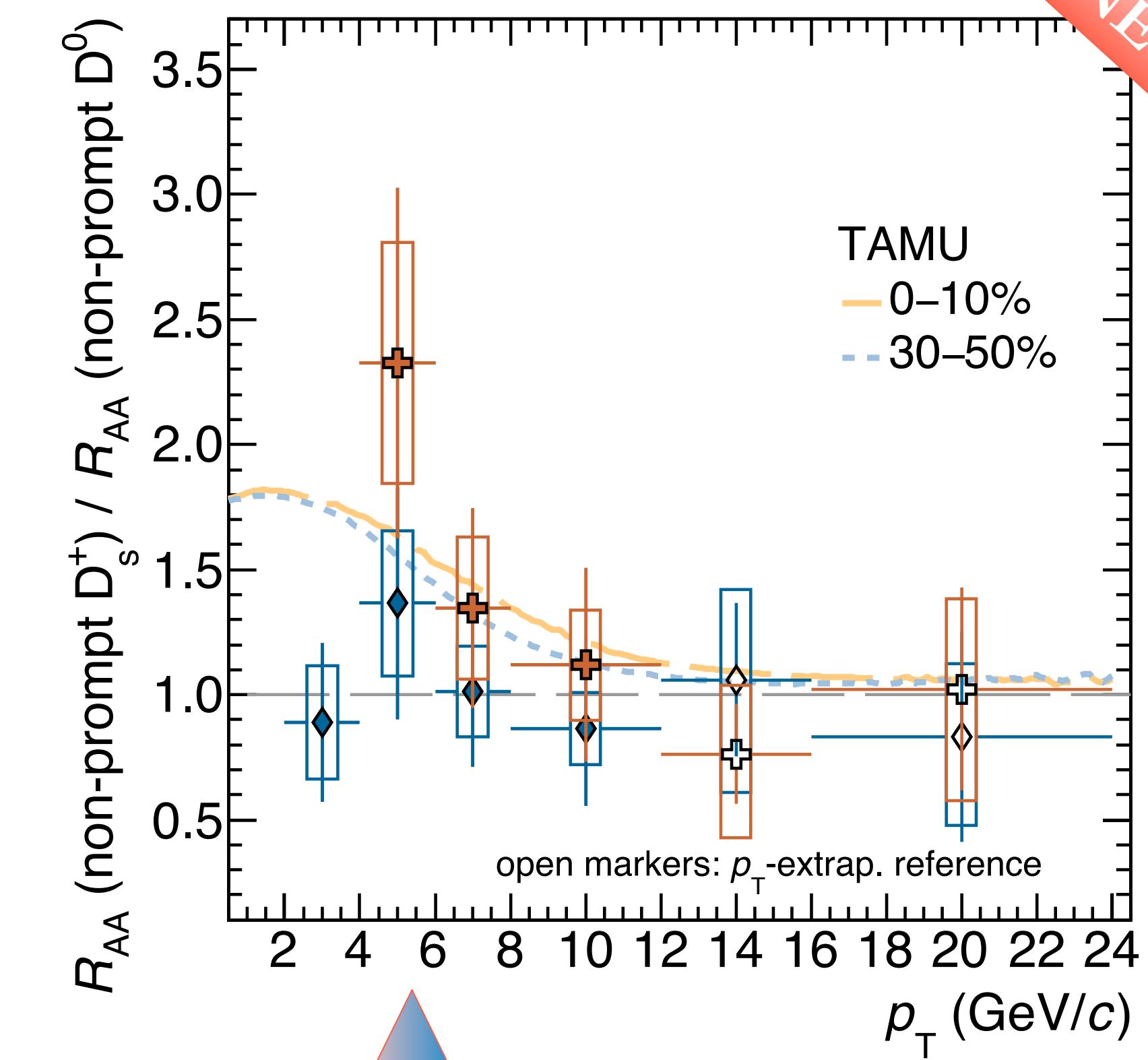


# Ratio of Non-prompt and prompt $D_s^+$ R<sub>AA</sub>(beauty over charm)



ALI-PUB-520

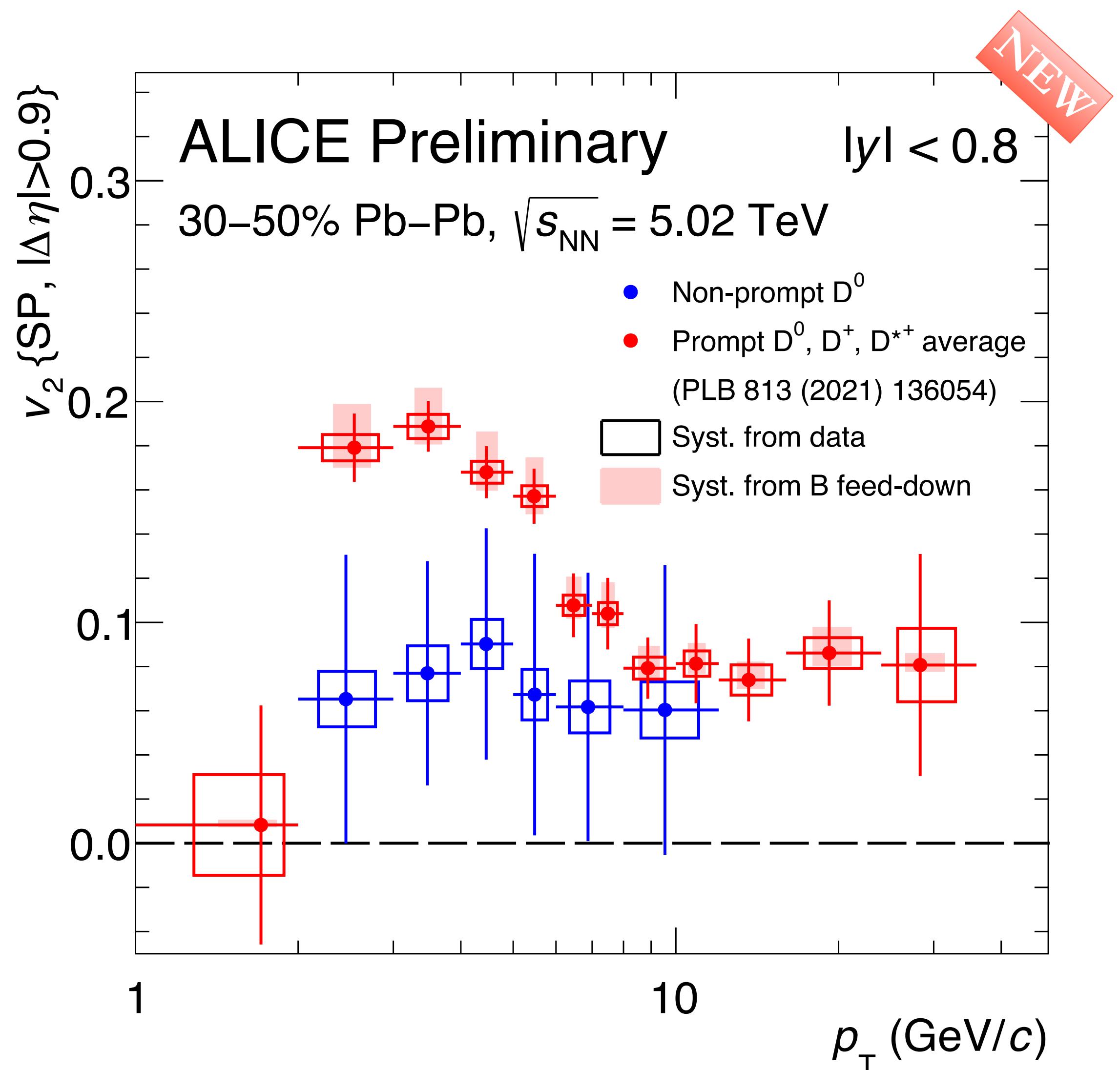
- Hint of enhancement ( $1.6 \sigma$ )
- $\Delta E_c > \Delta E_b$  ?
- TAMU predictions qualitatively describe the result for 0–10%, but overestimate the values for 30–50%



NEW

- Hint of enhancement ( $1.7 \sigma$ )
- consequence of coalescence + strangeness enhancement?

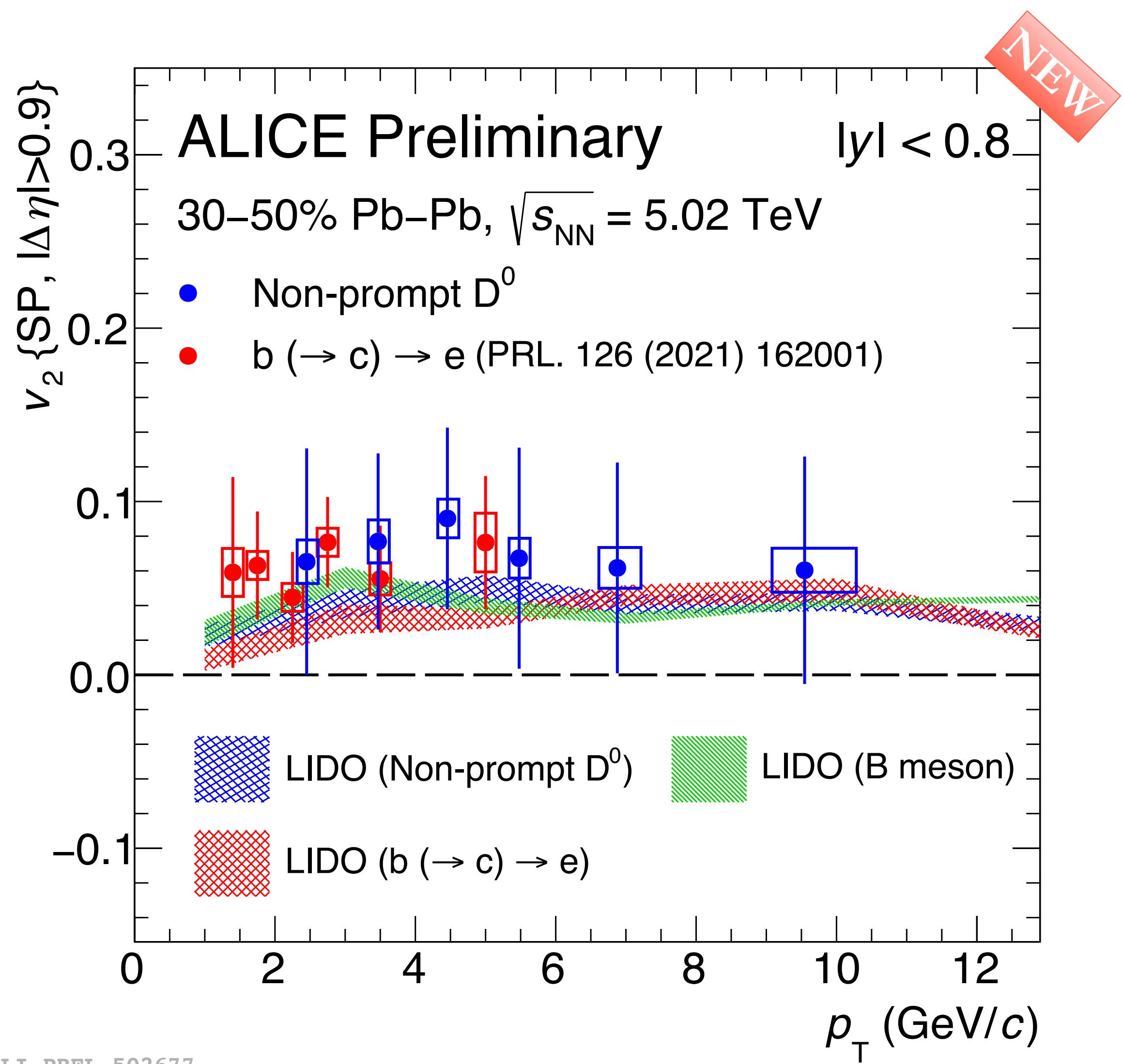
# Elliptic flow $v_2$ for beauty (Non-prompt D<sup>0</sup>)



## Non-prompt D<sup>0</sup> Vs Prompt D $v_2$ :

- $2 < p_T < 12 \text{ GeV}/c$ : Non-zero non-prompt  $v_2$  with  $2.7 \sigma$  significance
  - suggests that beauty quarks partially thermalize in the medium or recombines with light quarks
- $2 < p_T < 8 \text{ GeV}/c$ :  $3.2 \sigma$  for the difference between **non-prompt D<sup>0</sup>** and **prompt non-strange D meson  $v_2$** 
  - charm and beauty quarks participate differently to collective motion

# Elliptic flow $v_2$ for beauty (Non-prompt D<sup>0</sup>)



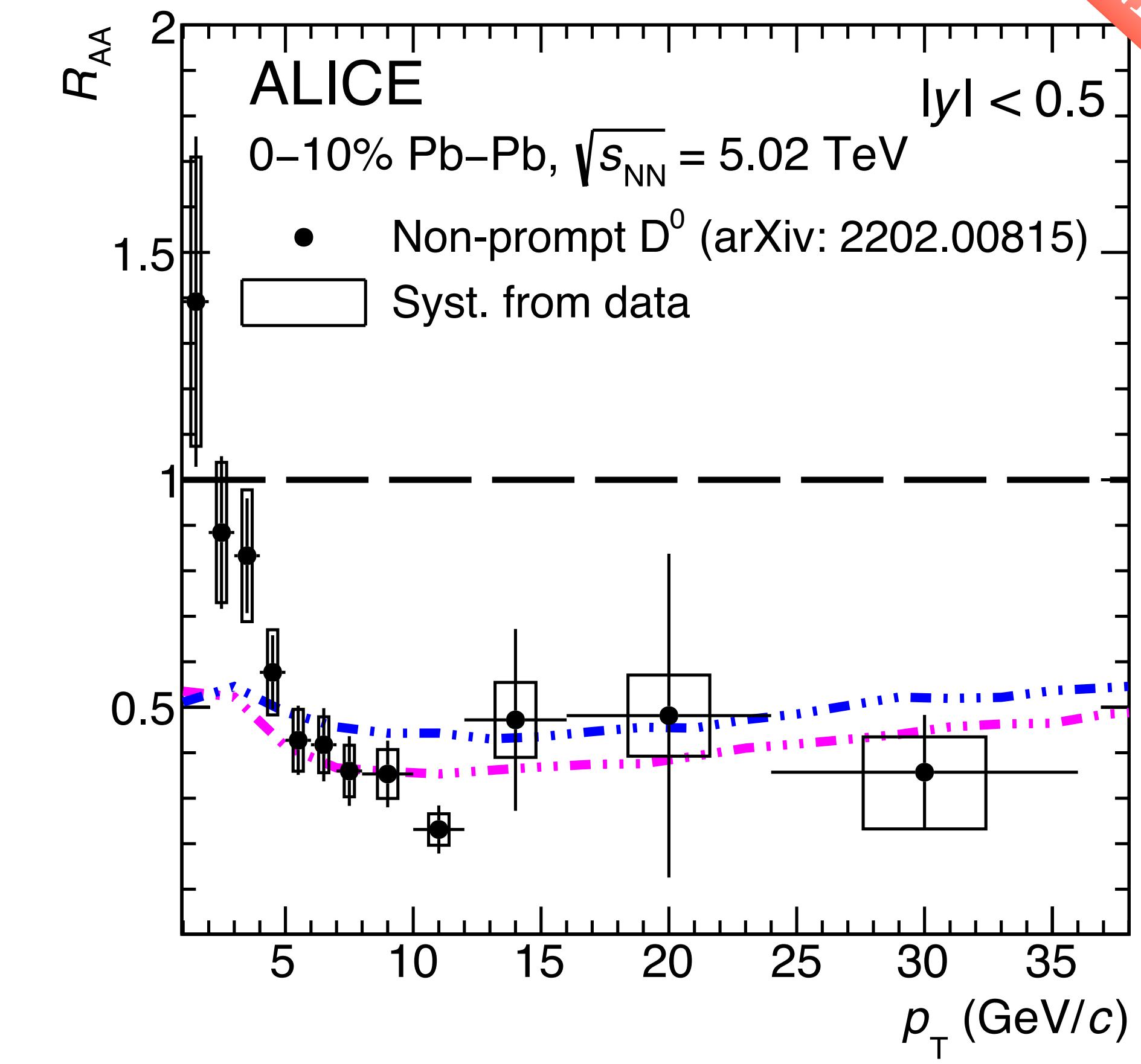
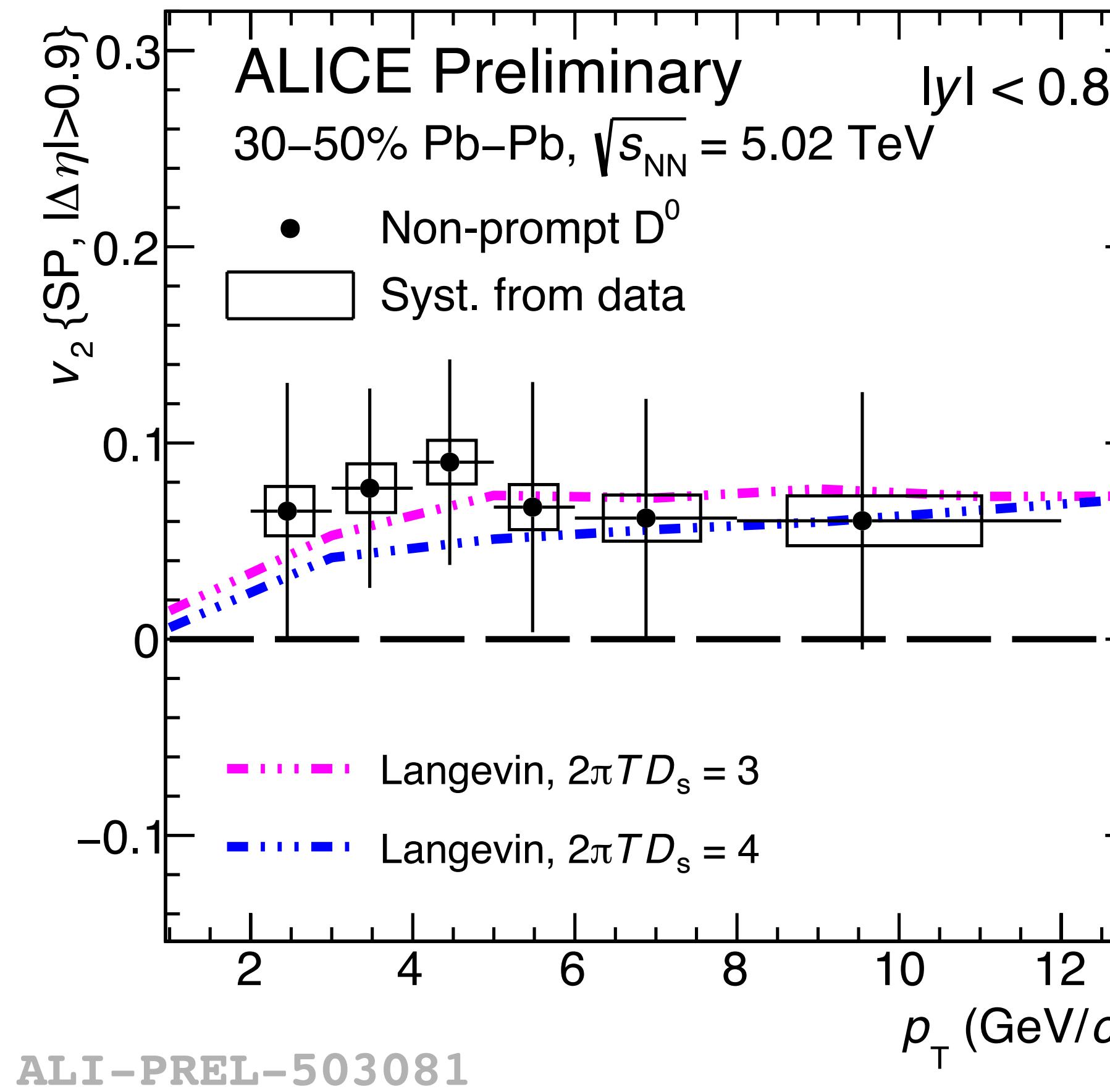
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## Non-prompt D<sup>0</sup> Vs $b \rightarrow e$ $v_2$ :

- Compatible within uncertainties

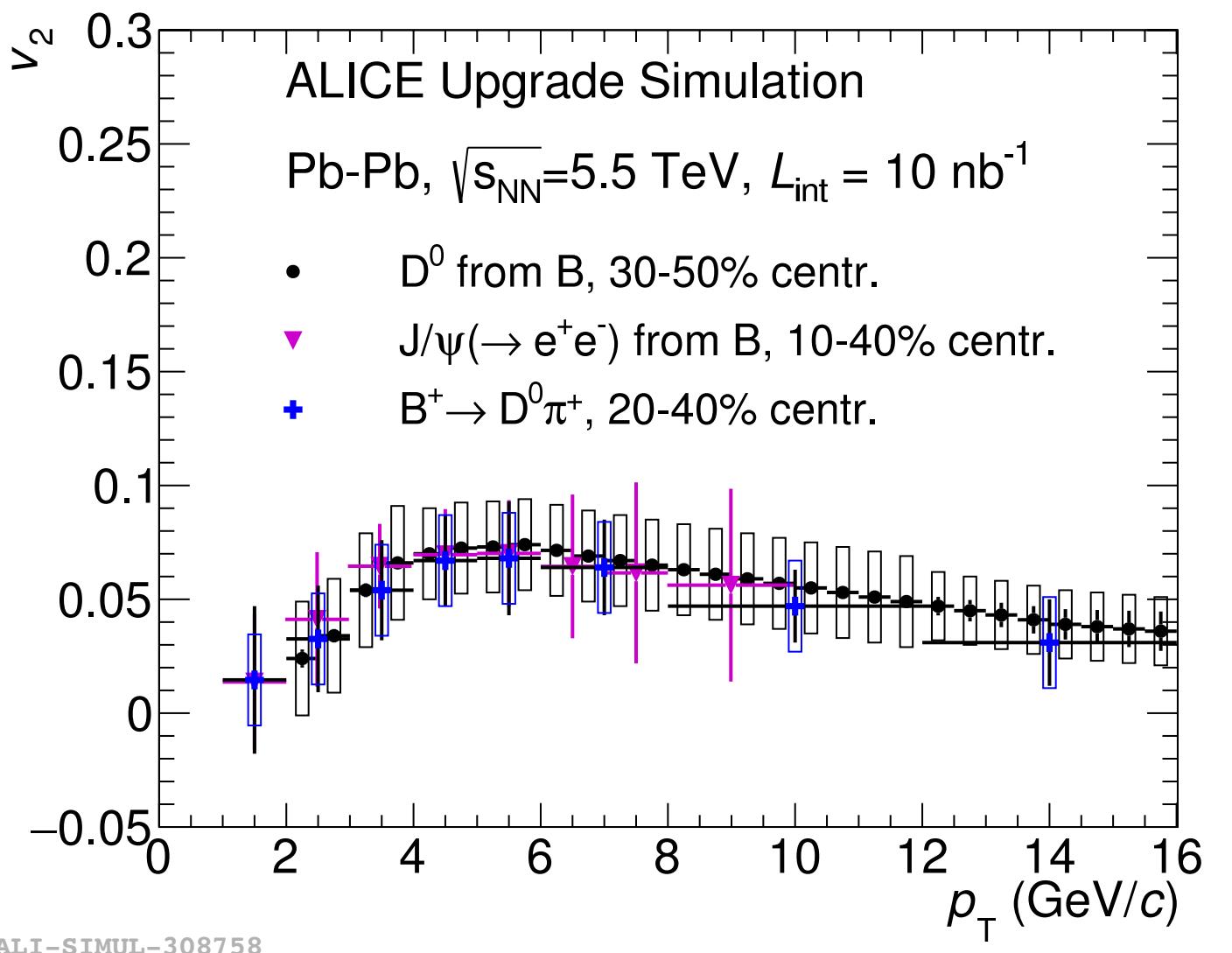
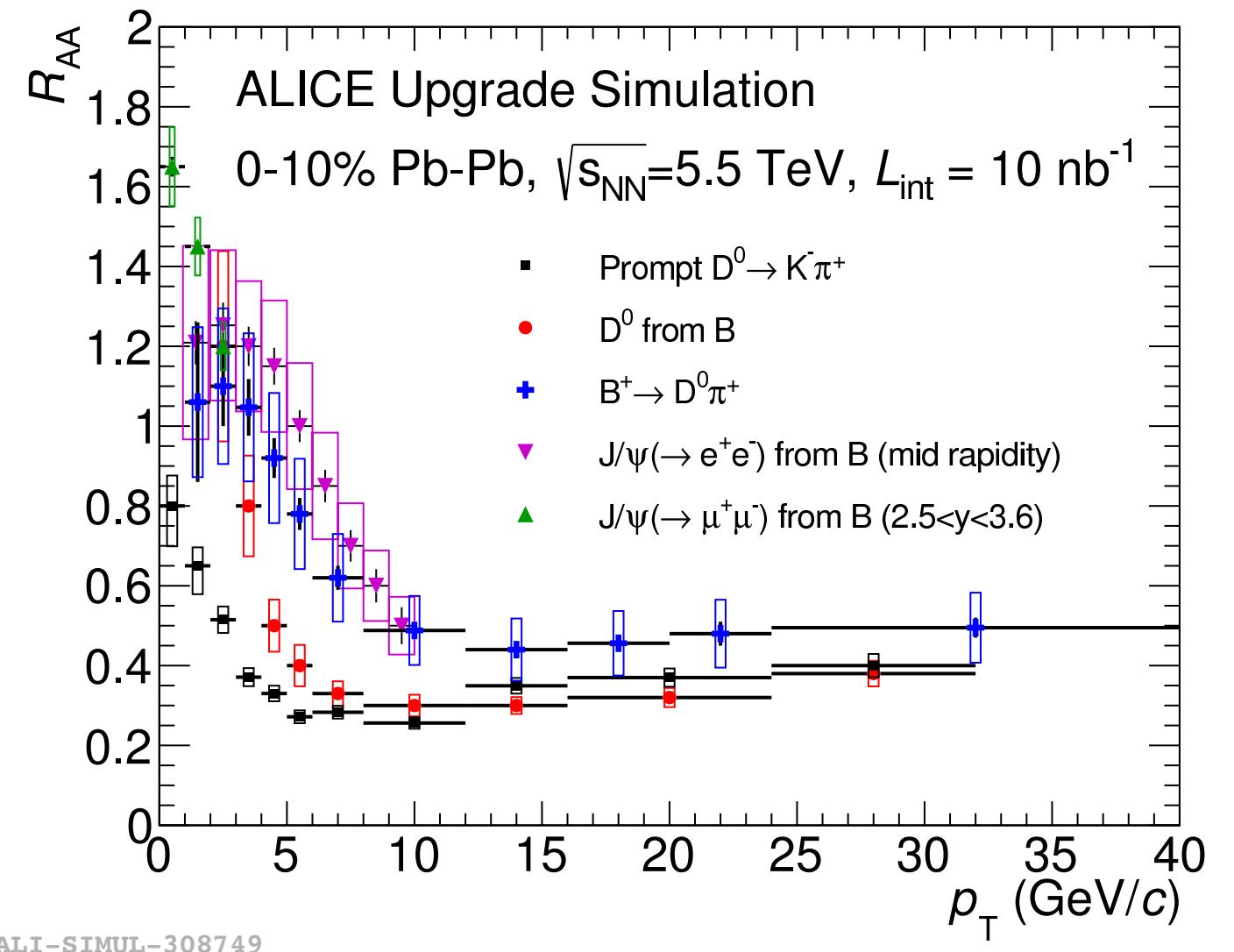
# Constrain of beauty spatial diffusion coefficient



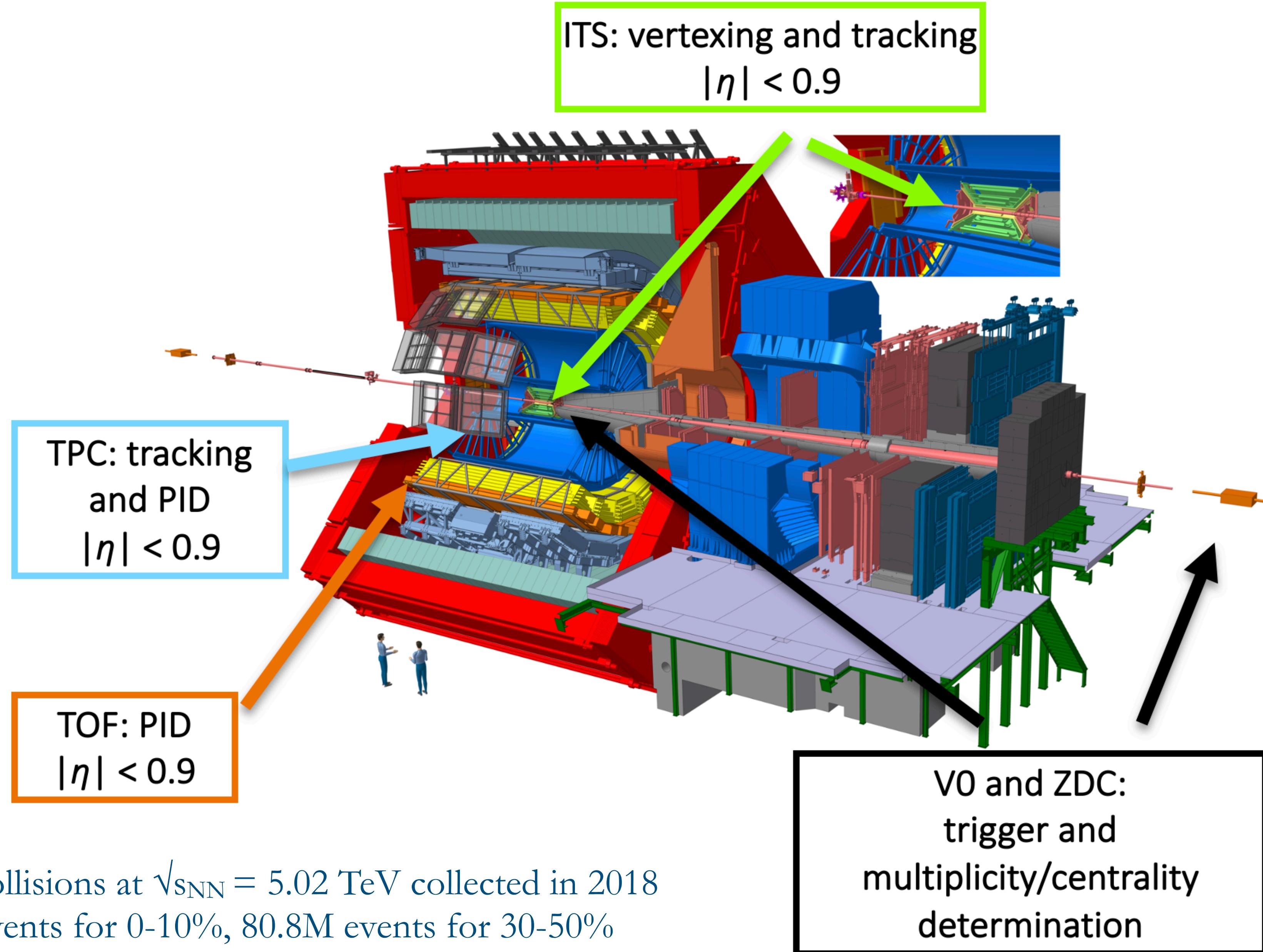
- Constrain spatial diffusion coefficient with b measurements comparing  $v_2$  and  $R_{AA}$  simultaneously
  - ➡ More precise measurements needed (Run3/4)

# Summary

- Beauty quarks undergo energy loss in the medium → important constraint on mass dependence energy loss
  - Strange non-prompt D-meson  $R_{AA}$  provides insights into beauty quarks hadronisation via recombination
  - Different non-prompt and prompt D  $v_2$ 
    - Different degree of participation to collective motion and hadronisation between charm and beauty
- New Inner Track System (ITS) detectors and increased integrated luminosity for LHC Run 3
- Precise measurements of beauty hadrons at midrapidity



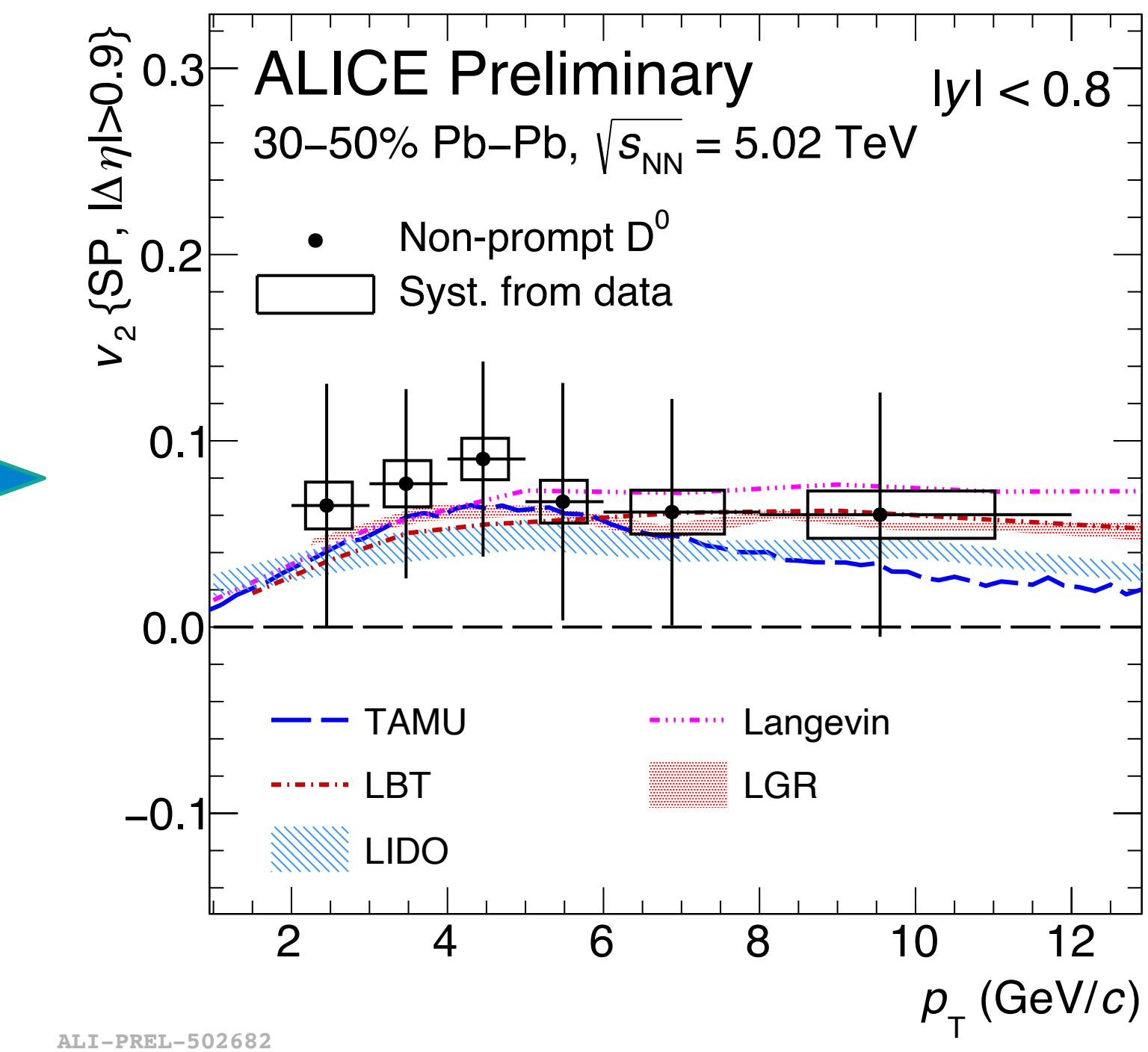
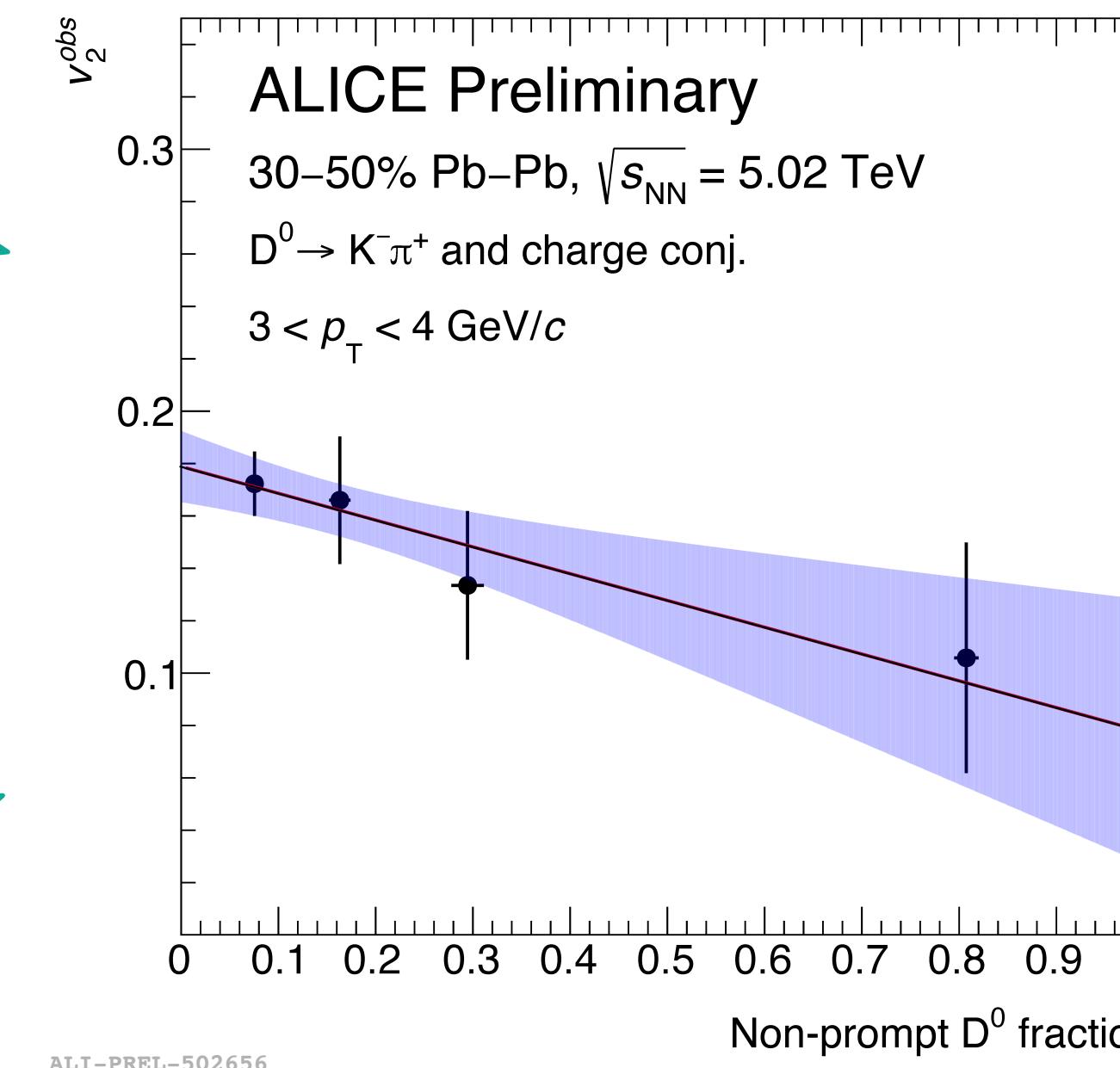
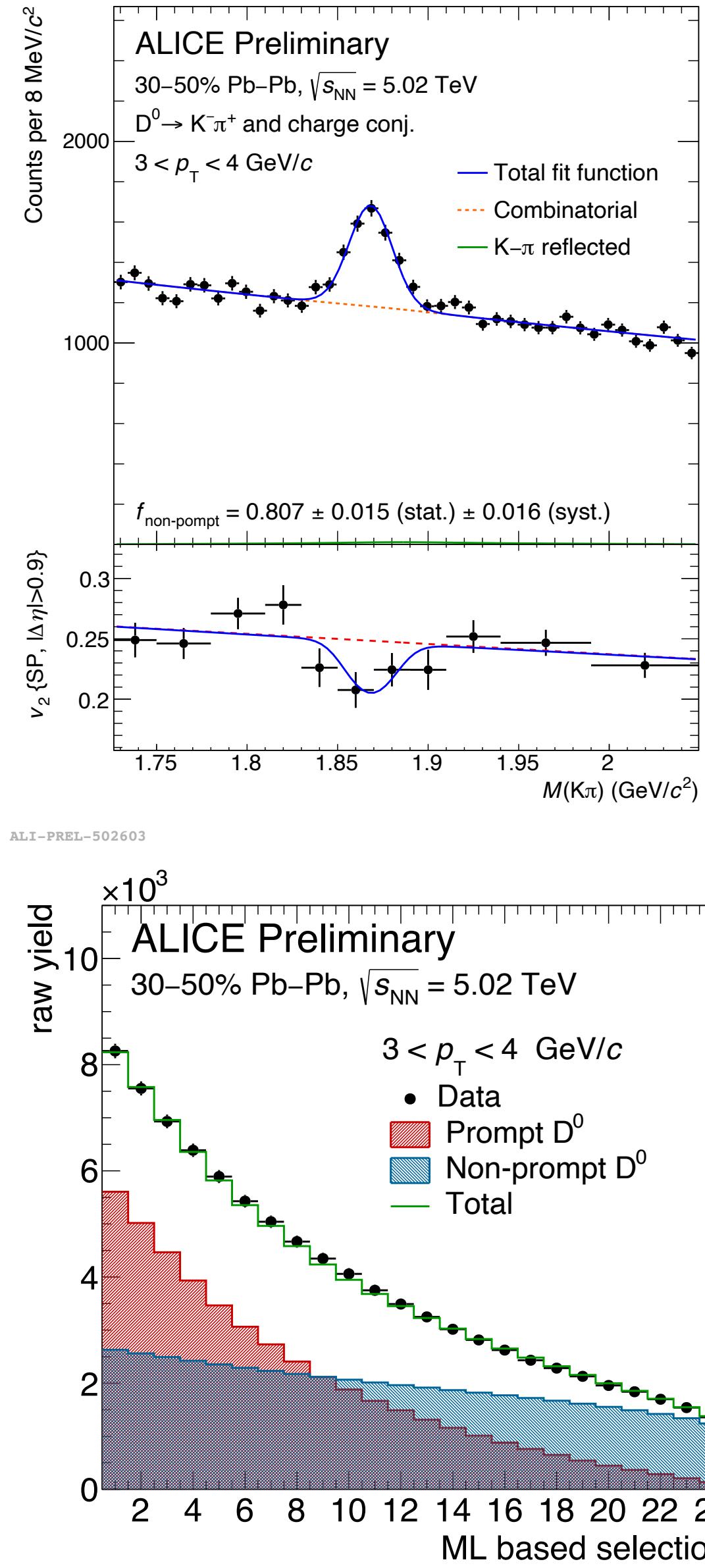
# ALICE detector



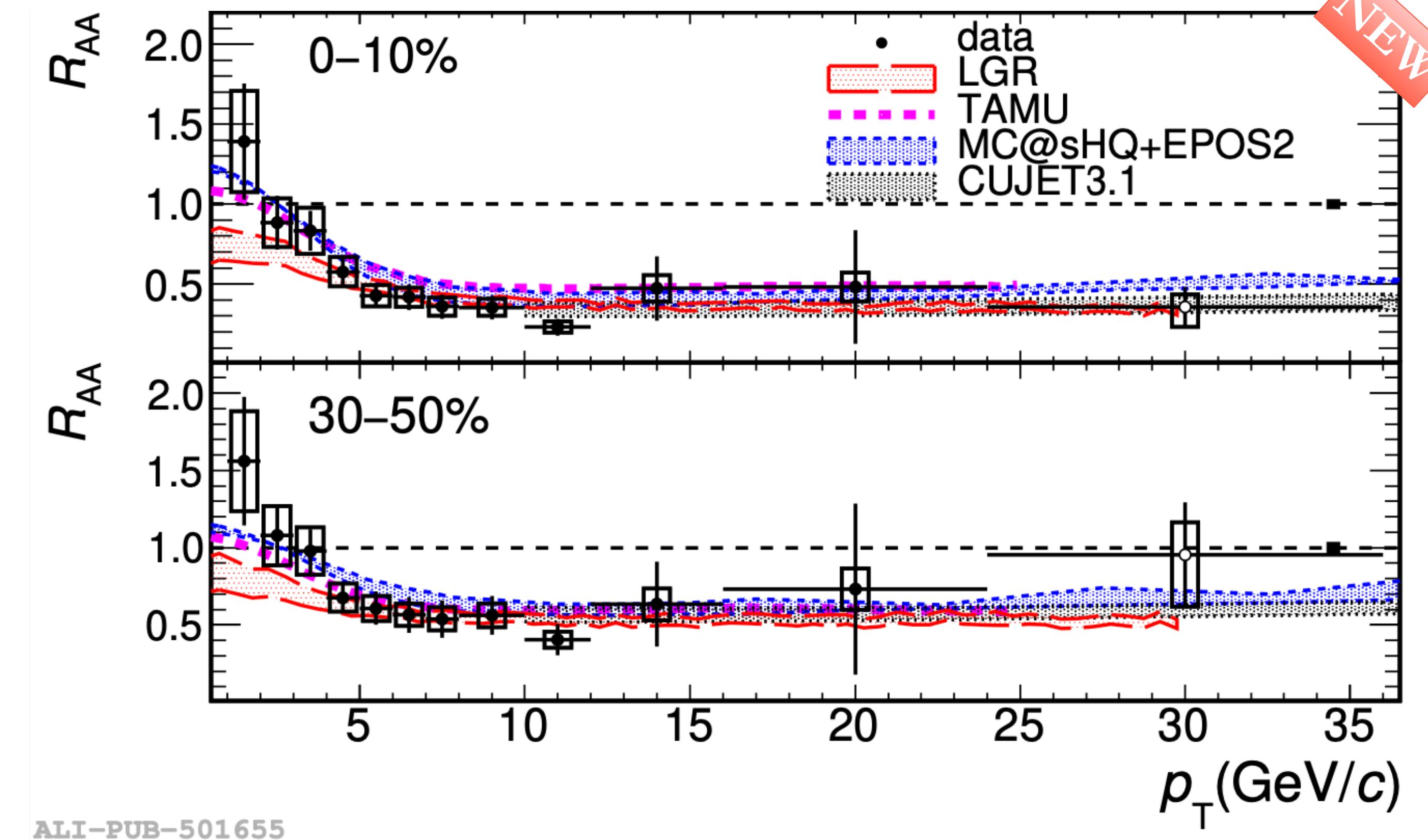
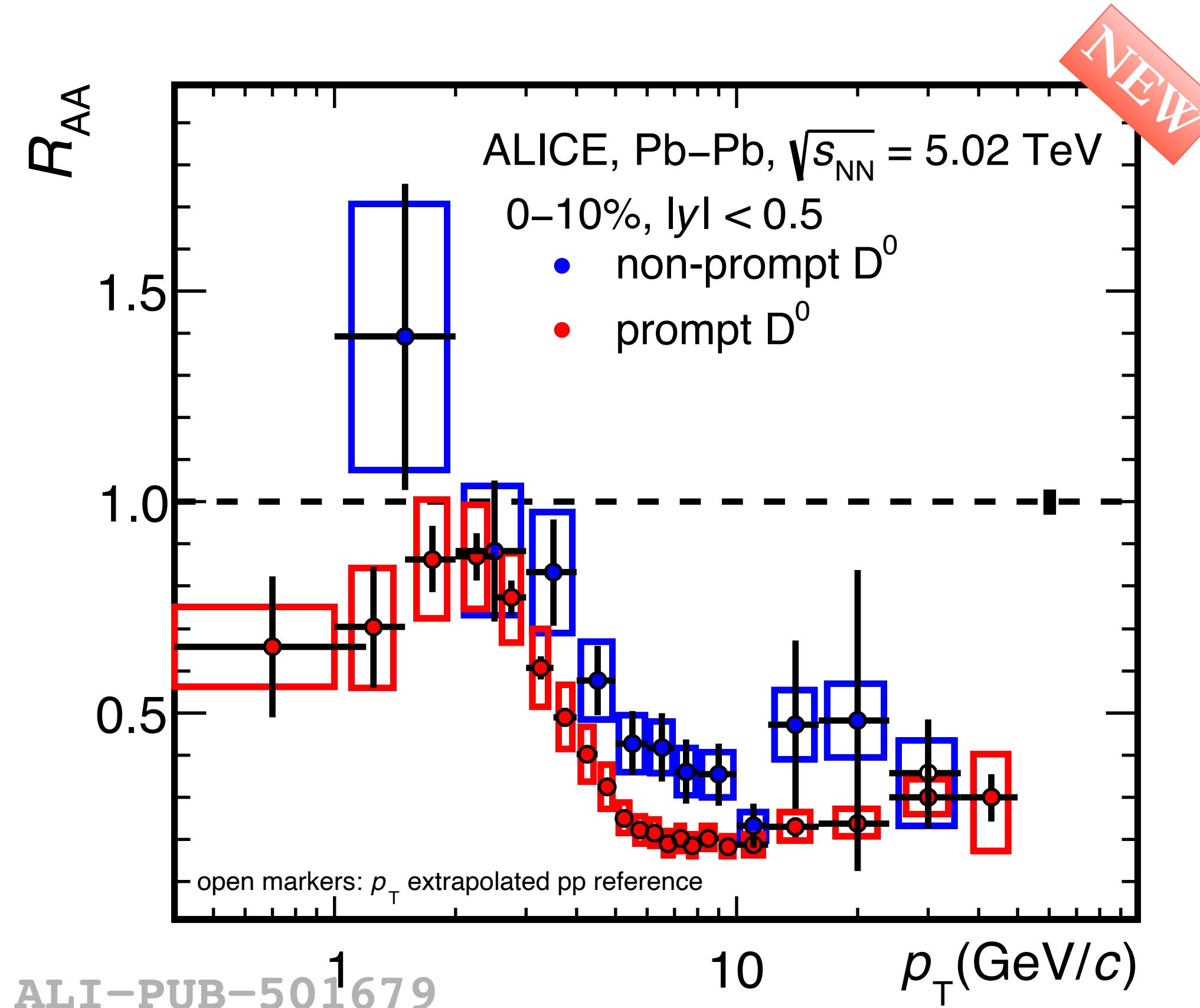
- $D^0 \rightarrow K^-\pi^+$ , BR  $\sim 3.95\%$
- $D_s^+ \rightarrow K^-K^+\pi^+$ , BR  $\sim 5.39\%$
- $D^+ \rightarrow K^-\pi^+\pi^+$ , BR  $\sim 0.38\%$
- $D^* \rightarrow D^0\pi^+$ , BR  $\sim 67.7\%$

- Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV collected in 2018
- 92.5M events for 0-10%, 80.8M events for 30-50%

# Elliptic flow $v_2$ for beauty (Non-prompt D<sup>0</sup>)



# Nuclear modification factor for beauty (Non-prompt $D^0$ )



- ▶  $R_{AA,b \rightarrow D^0} > R_{AA,c \rightarrow D^0}$  at intermediate  $p_T$
- ▶  $R_{AA,b \rightarrow D^0}(0\text{-}10\%) < R_{AA,b \rightarrow D^0}(30\text{-}50\%)$
- ▶ Theoretical models that include collisional and radiative energy loss describe the data within uncertainties