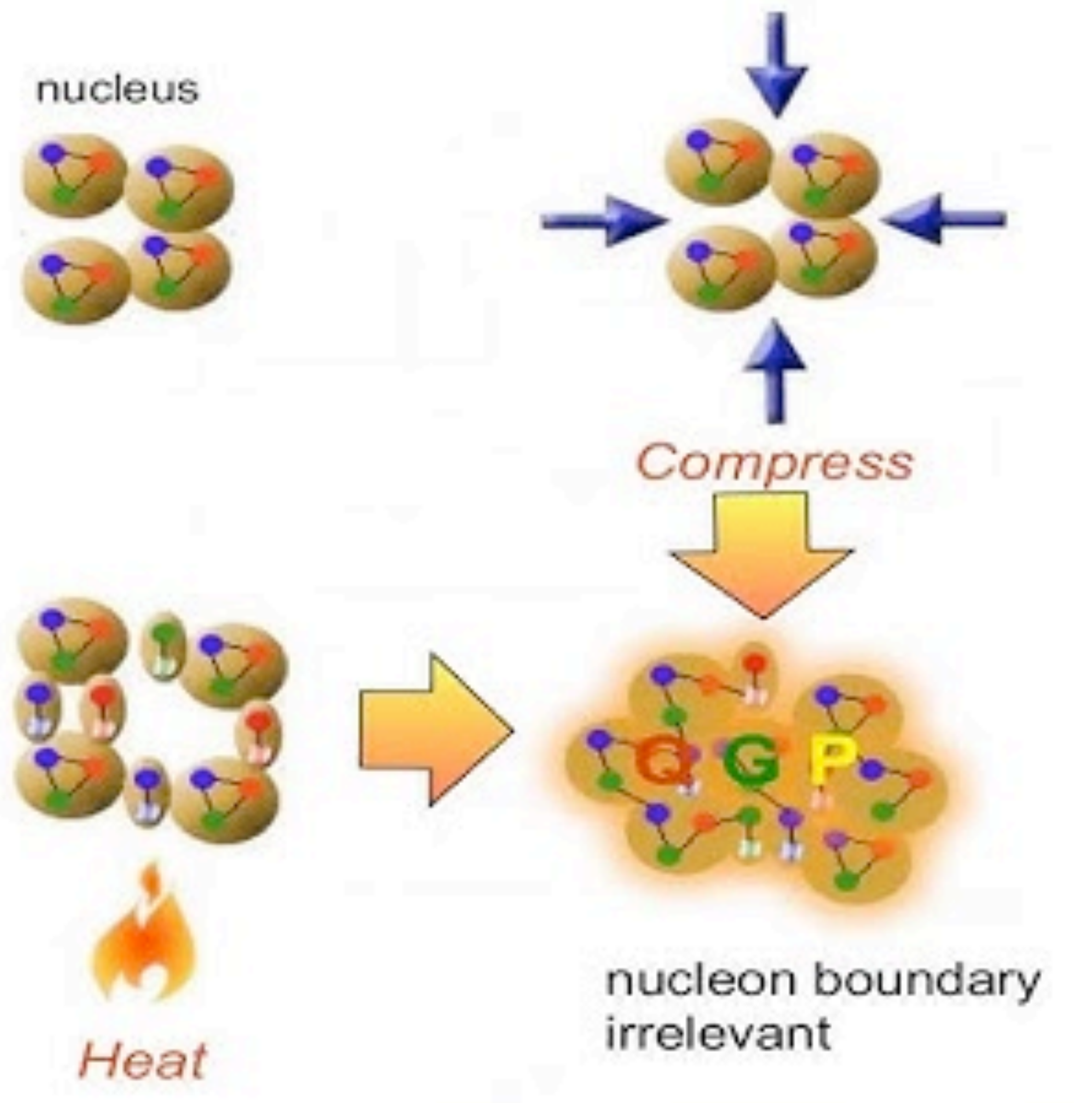
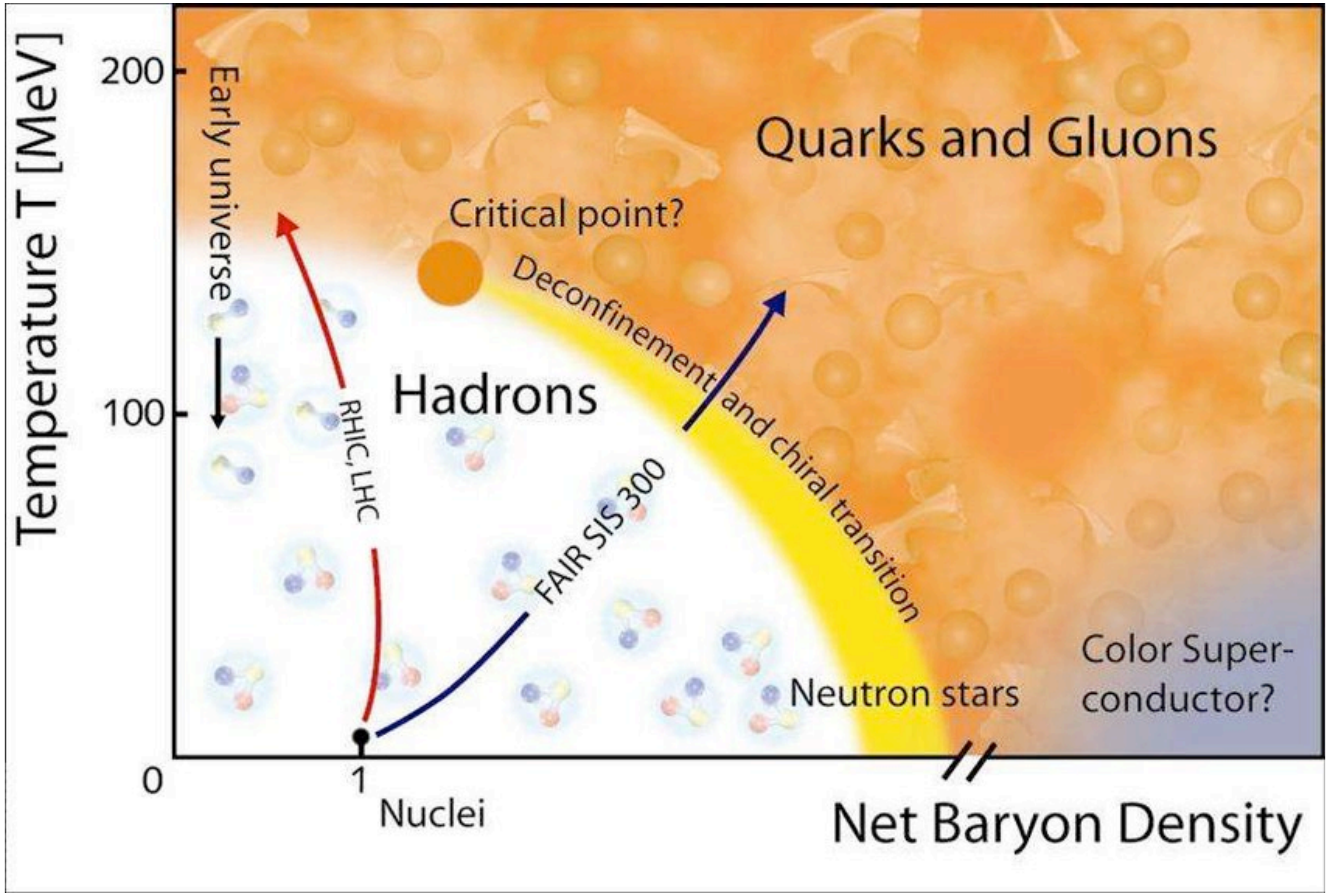
Probing the QGP: Recent Advances in Heavy-Flavour Physics with ALICE at the LHC

Samrangy Sadhu
University of Bonn

What is Quark-Gluon Plasma (QGP) ?

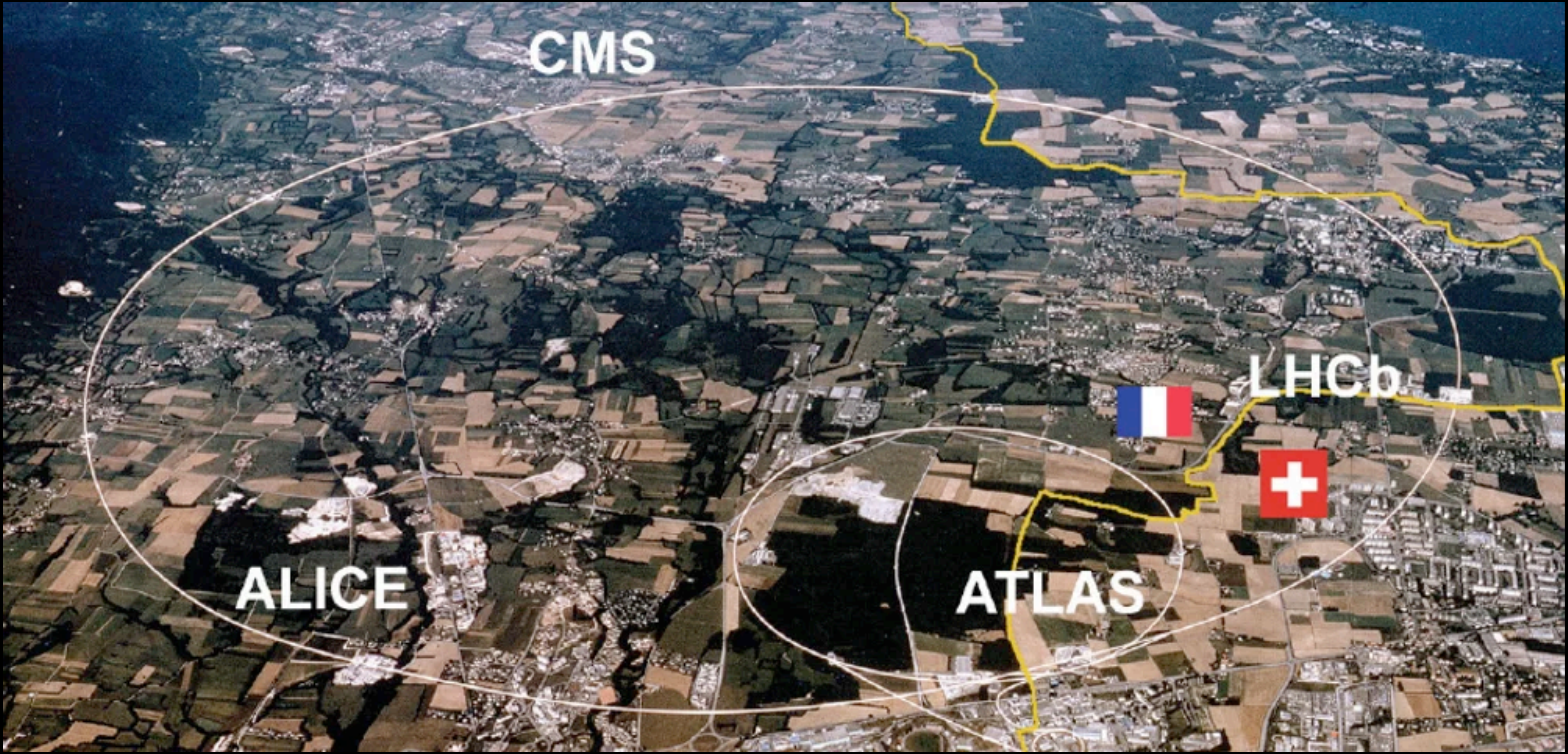
At extreme temperature and energy density, QCD predicts a phase transition from hadronic matter to a deconfined partonic matter, the Quark-Gluon Plasma (QGP)



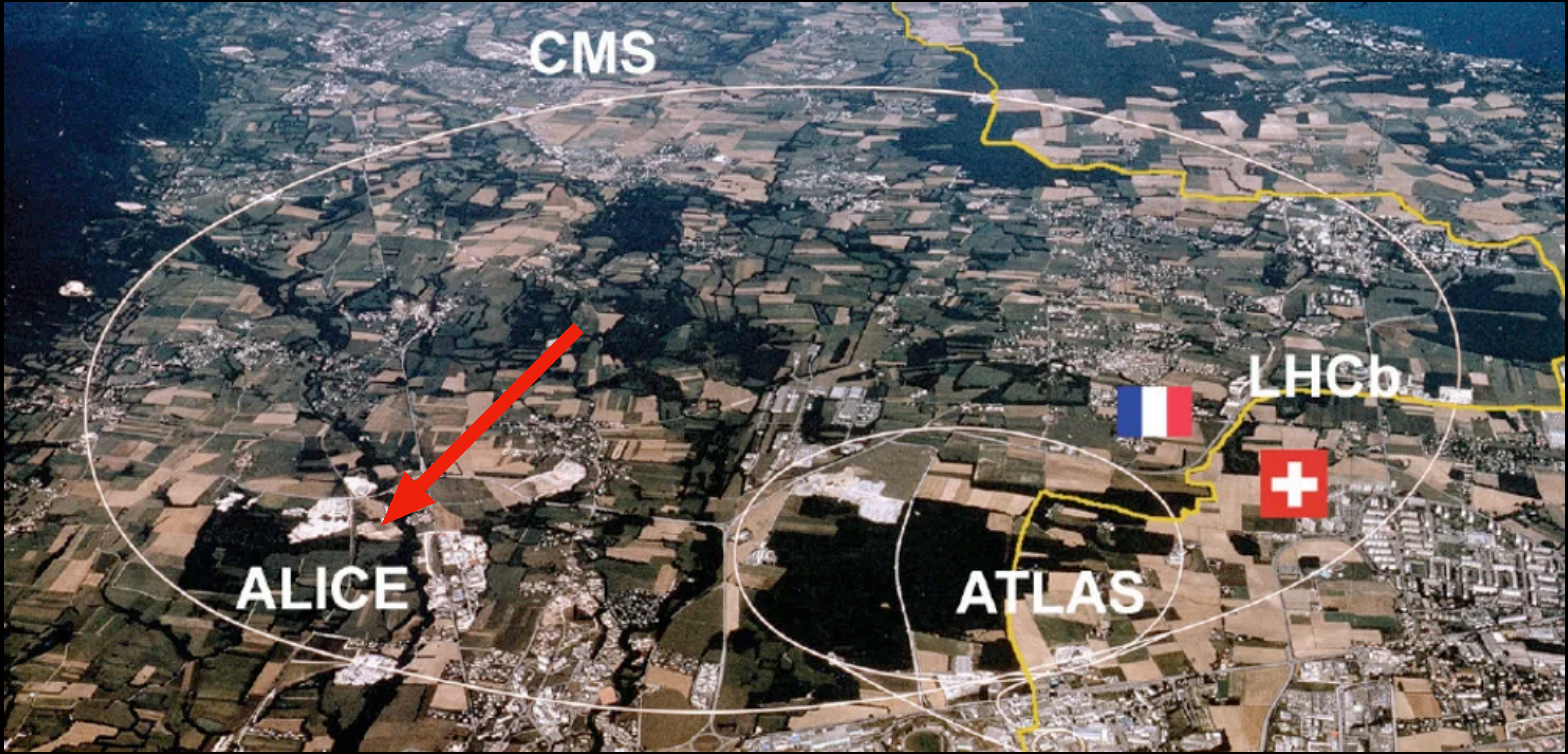


RHIC, LHC : high temperature, low baryon density
FAIR : moderate temperature, high baryon density

The Large Hadron Collider (LHC)



The Large Hadron Collider (LHC)



Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

Initial state effects:
- **Gluon saturation**
- **Modification of PDFs**

Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

Initial state effects:

- **Gluon saturation**
- **Modification of PDFs**

Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

Initial state effects:
- **Gluon saturation**
- **Modification of PDFs**

In medium effects:
- **Energy loss**
- **Collectivity**

Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

Initial state effects:
- **Gluon saturation**
- **Modification of PDFs**

In medium effects:
- **Energy loss**
- **Collectivity**

Heavy-ion collisions: Creating the QGP state

Schematic picture of the time evolution of Heavy-ion collisions :

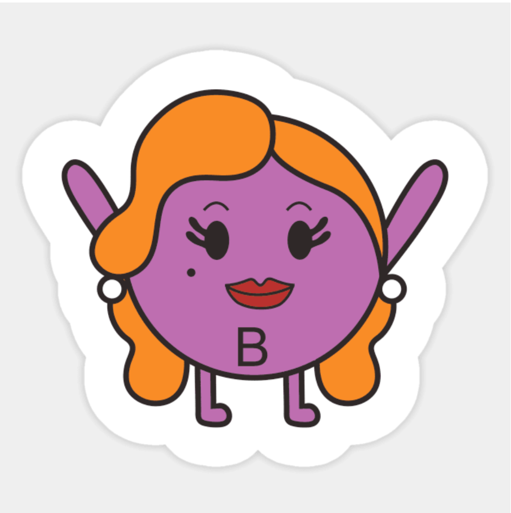
Initial state effects:
- **Gluon saturation**
- **Modification of PDFs**

In medium effects:
- **Energy loss**
- **Collectivity**

- **Coalescence: combination of quarks close in phase space**
- **Fragmentation: break up of colour strings connecting partons**

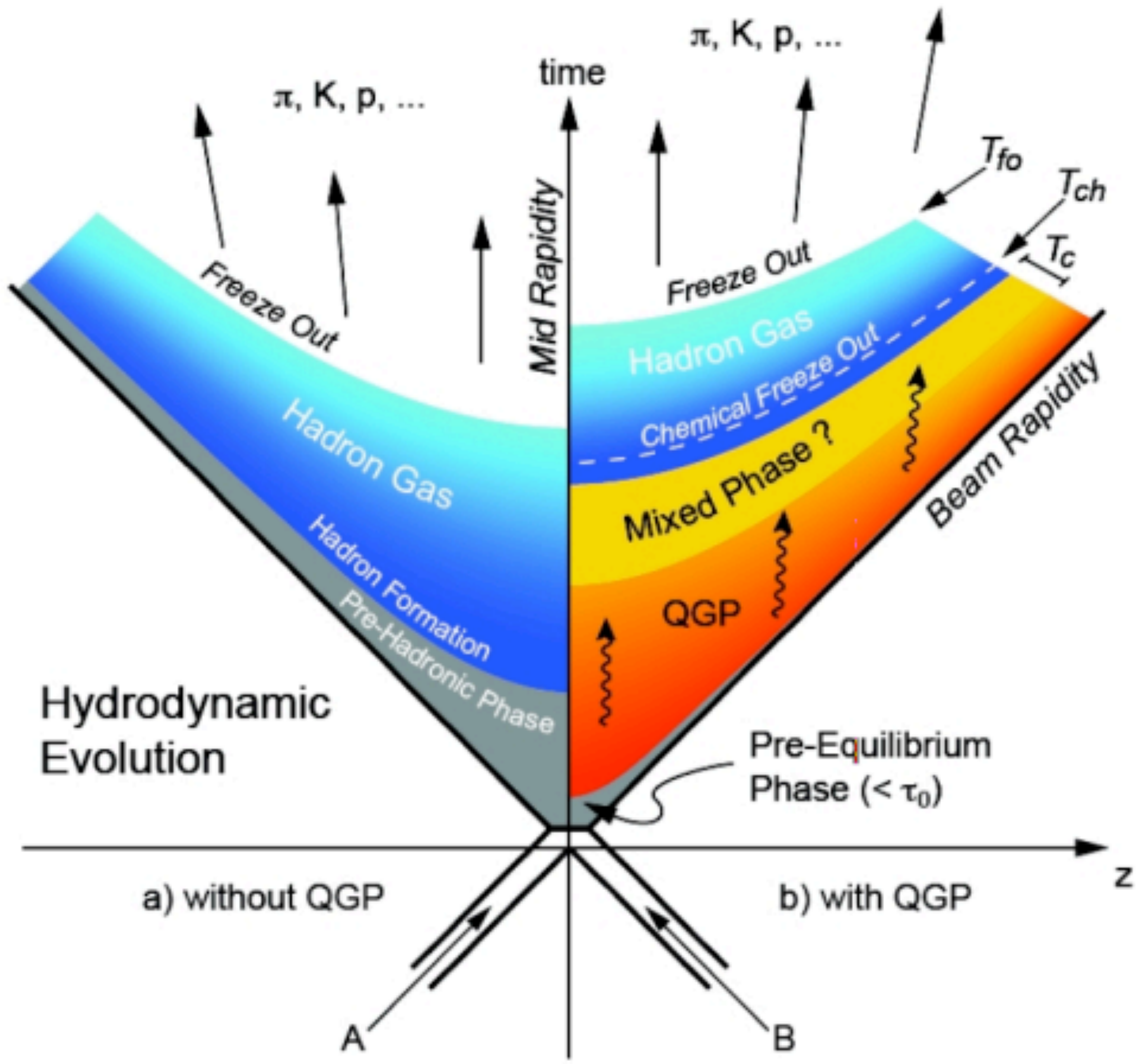
Heavy quarks: a unique probe of QGP

- Heavy quarks: charm and beauty, predominantly produced by the parton-parton hard scattering in heavy-ion collisions -> perturbative QCD can be applied.
- In heavy-ion collisions: a quark-gluon plasma (QGP) state is produced
  - -> Heavy quarks are produced before QGP formation (t_{QGP} ~ 1 fm/c and $t_Q = 1/2m_Q \leq 0.1$ fm/c)
  - -> Identity is preserved while traversing the medium
  - -> Experience the complete evolution of QGP medium



Charm
m_c ~ 1.3 GeV/c^2
t_c ~ 0.08 fm/c

Beauty
m_b ~ 4.2 GeV/c^2
t_b ~ 0.03 fm/c



- Energy loss of partons traversing the QGP is expected to occur via both inelastic (radiative energy loss via medium-induced gluon radiation) and elastic (collisions with the QGP constituents) processes.

★ **Therefore, heavy quarks act as important tools for characterizing the medium formed in heavy-ion collisions.**

Physics motivation: Study of Heavy-Flavour physics

Physics motivation: Study of Heavy-Flavour physics

pp collisions:

- Test pQCD calculations
- Study heavy-flavour quark production, fragmentation and hadronization
- Reference for p—Pb and Pb—Pb systems

Physics motivation: Study of Heavy-Flavour physics

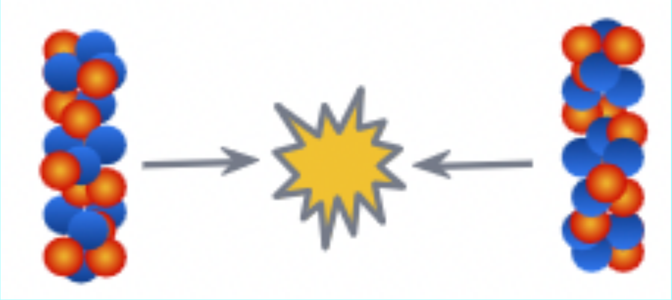
pp collisions:
- Test pQCD calculations
- Study heavy-flavour quark production, fragmentation and hadronization
- Reference for p—Pb and Pb—Pb systems

p—Pb collisions:
- Study cold nuclear matter (CNM) effects
- Possible collective effects ?

Physics motivation: Study of Heavy-Flavour physics

pp collisions:
- Test pQCD calculations
- Study heavy-flavour quark production, fragmentation and hadronization
- Reference for p—Pb and Pb—Pb systems

p—Pb collisions:
- Study cold nuclear matter (CNM) effects
- Possible collective effects ?

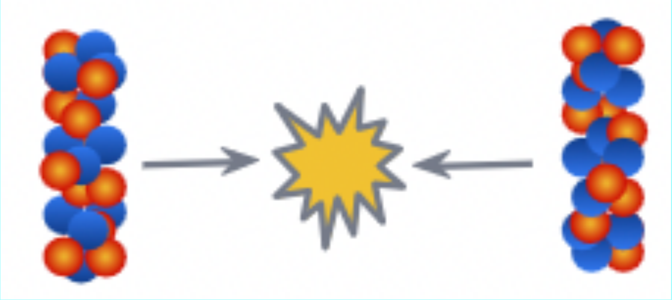


Pb—Pb collisions:
- Sensitivity to the energy-loss mechanism of heavy quarks (collisional and radiative processes)
- Possible modification of the quark hadronization

Physics motivation: Study of Heavy-Flavour physics

pp collisions:
- Test pQCD calculations
- Study heavy-flavour quark production, fragmentation and hadronization
- Reference for p—Pb and Pb—Pb systems

p—Pb collisions:
- Study cold nuclear matter (CNM) effects
- Possible collective effects ?



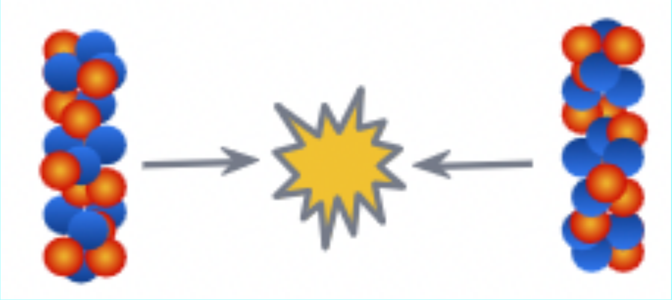
Pb—Pb collisions:
- Sensitivity to the energy-loss mechanism of heavy quarks (collisional and radiative processes)
- Possible modification of the quark hadronization

Production of heavy-quark hadrons can be calculated using the factorization approach:

Physics motivation: Study of Heavy-Flavour physics

pp collisions:
- Test pQCD calculations
- Study heavy-flavour quark production, fragmentation and hadronization
- Reference for p—Pb and Pb—Pb systems

p—Pb collisions:
- Study cold nuclear matter (CNM) effects
- Possible collective effects ?



Pb—Pb collisions:
- Sensitivity to the energy-loss mechanism of heavy quarks (collisional and radiative processes)
- Possible modification of the quark hadronization

Production of heavy-quark hadrons can be calculated using the factorization approach:

$$\frac{\mathrm{d}\sigma^{\mathrm{H_c}}}{\mathrm{d}\sigma^{\mathrm{H_c}}_{p_\mathrm{T}}}(p_\mathrm{T};\mu_F,\mu_R) = \boxed{\mathrm{PDF}(x_1,\mu_F)\cdot\mathrm{PDF}(x_2,\mu_F)} \otimes \boxed{\frac{\mathrm{d}\sigma^c}{\mathrm{d}p^c_\mathrm{T}}(x_1,x_2;\mu_R,\mu_F)} \otimes \boxed{D_{\mathrm{c}\to H_c}\left(z=\frac{p_{\mathrm{H_c}}}{p_\mathrm{c}},\mu_F\right)}$$

Parton distribution functions (PDFs) | Hard scattering cross section (pQCD) | Fragmentation function (hadronisation)

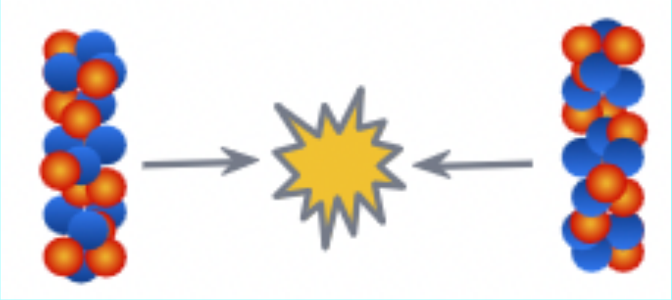
Physics motivation: Study of Heavy-Flavour physics

pp collisions:

- Test pQCD calculations
- Study heavy-flavour quark production, fragmentation and hadronization
- Reference for p—Pb and Pb—Pb systems

p—Pb collisions:

- Study cold nuclear matter (CNM) effects
- Possible collective effects ?



Pb—Pb collisions:

- Sensitivity to the energy-loss mechanism of heavy quarks (collisional and radiative processes)
- Possible modification of the quark hadronization

Production of heavy-quark hadrons can be calculated using the factorization approach:

$$\frac{d\sigma^{H_c}}{d\sigma^{H_c}_{p_T}}(p_T;\mu_F,\mu_R) = \boxed{PDF(x_1,\mu_F)\cdot PDF(x_2,\mu_F)} \otimes \boxed{\frac{d\sigma^c}{dp^c_T}(x_1,x_2;\mu_R,\mu_F)} \otimes \boxed{D_{c\rightarrow H_c}\left(z=\frac{p_{H_c}}{p_c},\mu_F\right)}$$

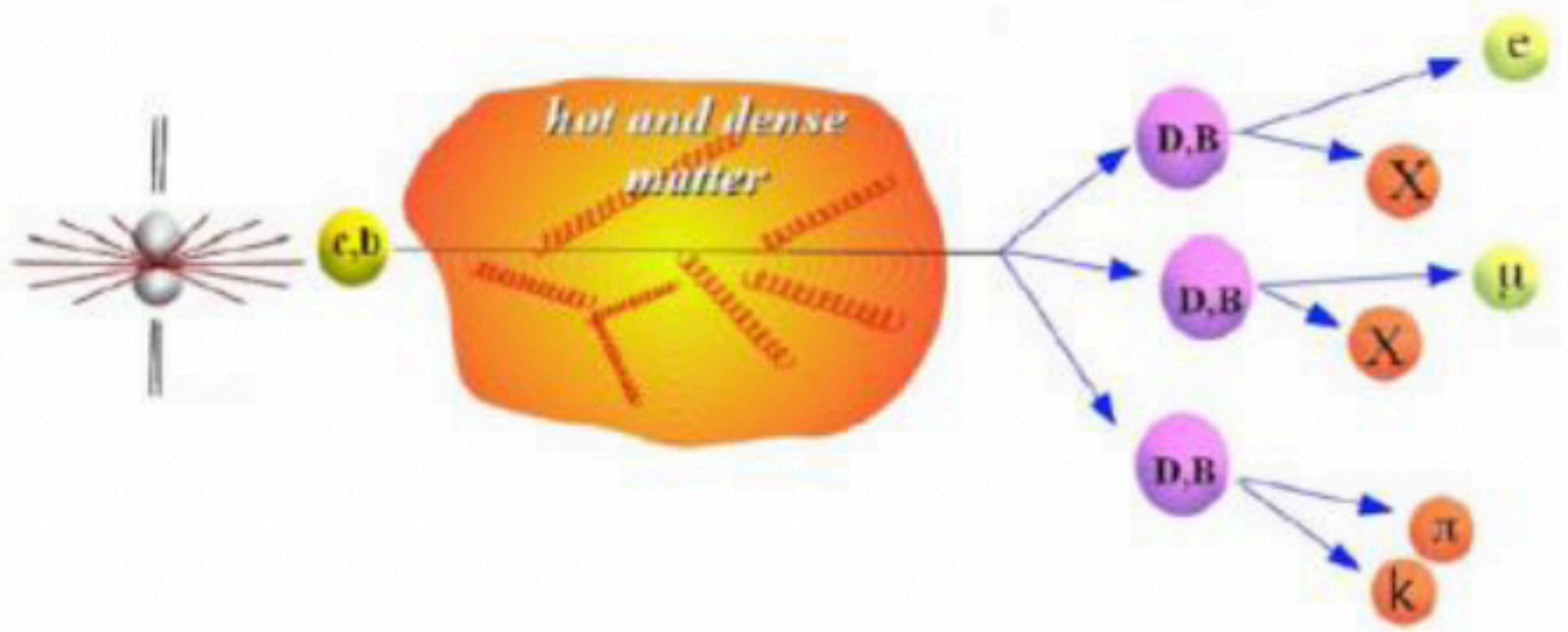
Parton distribution functions (PDFs) | Hard scattering cross section (pQCD) | Fragmentation function (hadronisation)

Assumed to be universal across collision systems

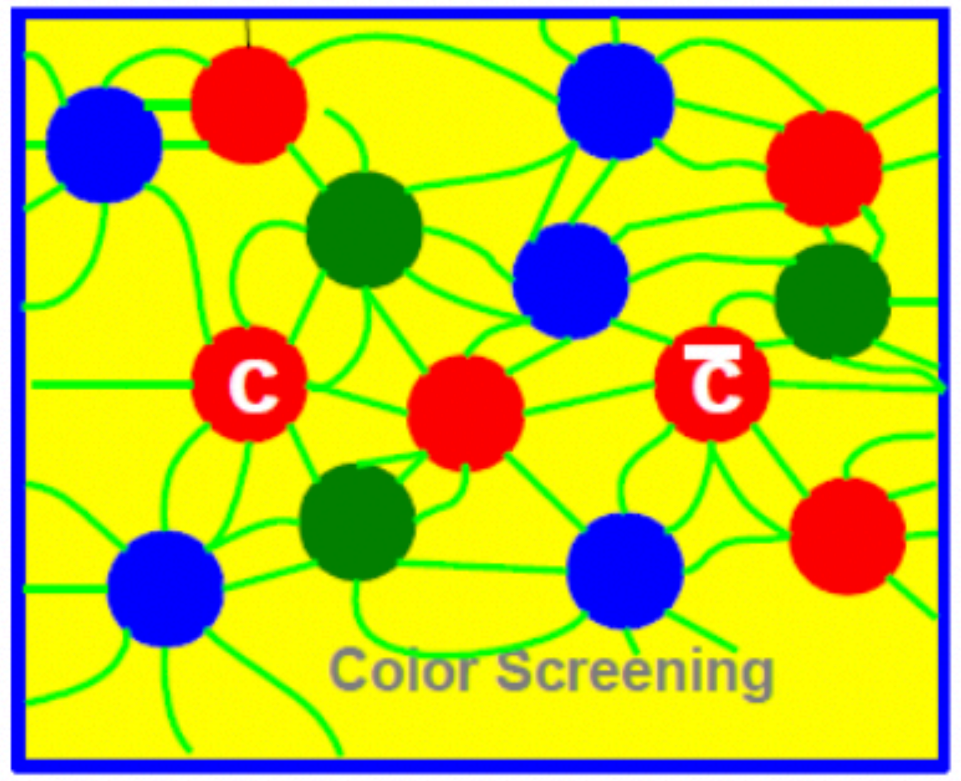
Two important probes

Open heavy flavour: Charm hadrons (D^0, $D^{\pm}$, …), bottom hadrons (B^0, $B^{\pm}$,…)

Quarkonia: charmonium ($c\bar{c}$): J/ψ, ψ',…, bottomonium ($b\bar{b}$): ϒ..



Probe of QCD interaction dynamics in extended systems

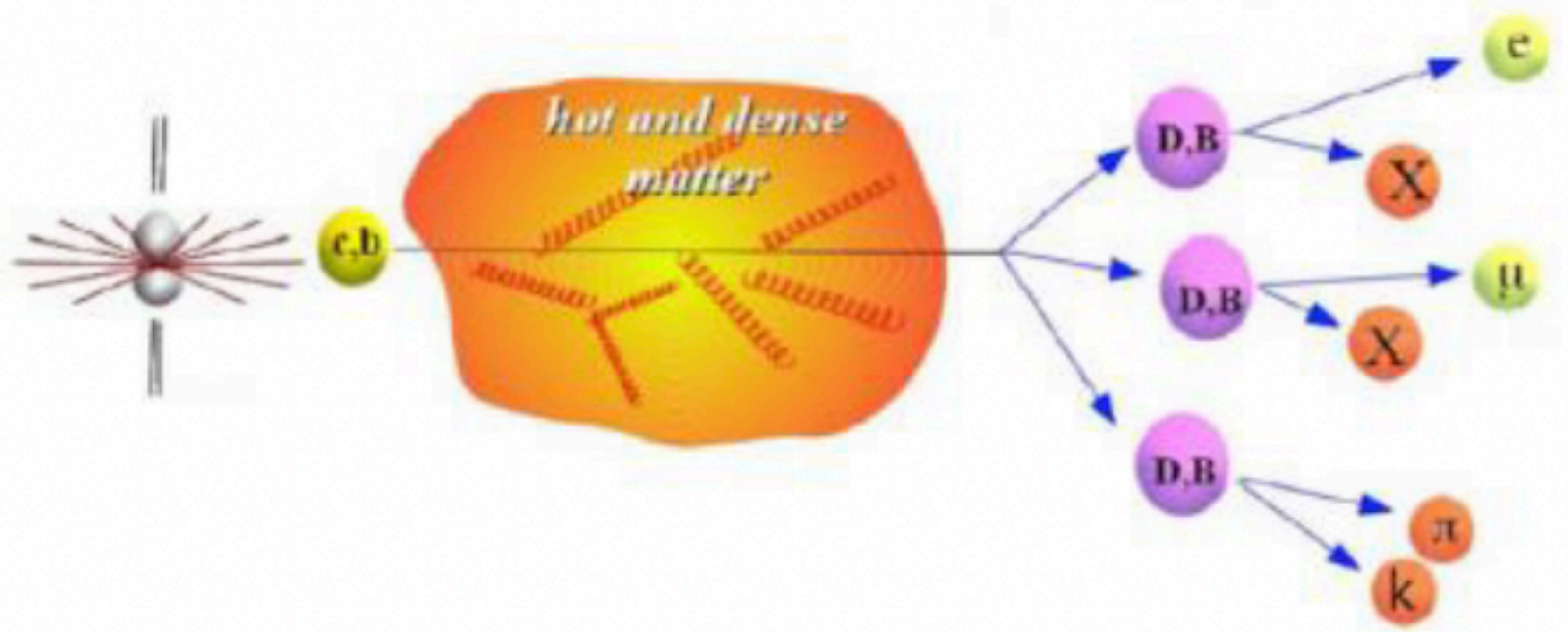


Probe of deconfinement & QGP medium temperature

- **Both probe medium transport properties via, e.g. the collective expansion of the QGP**
- **Both pillars evolved and extended significantly over the years**

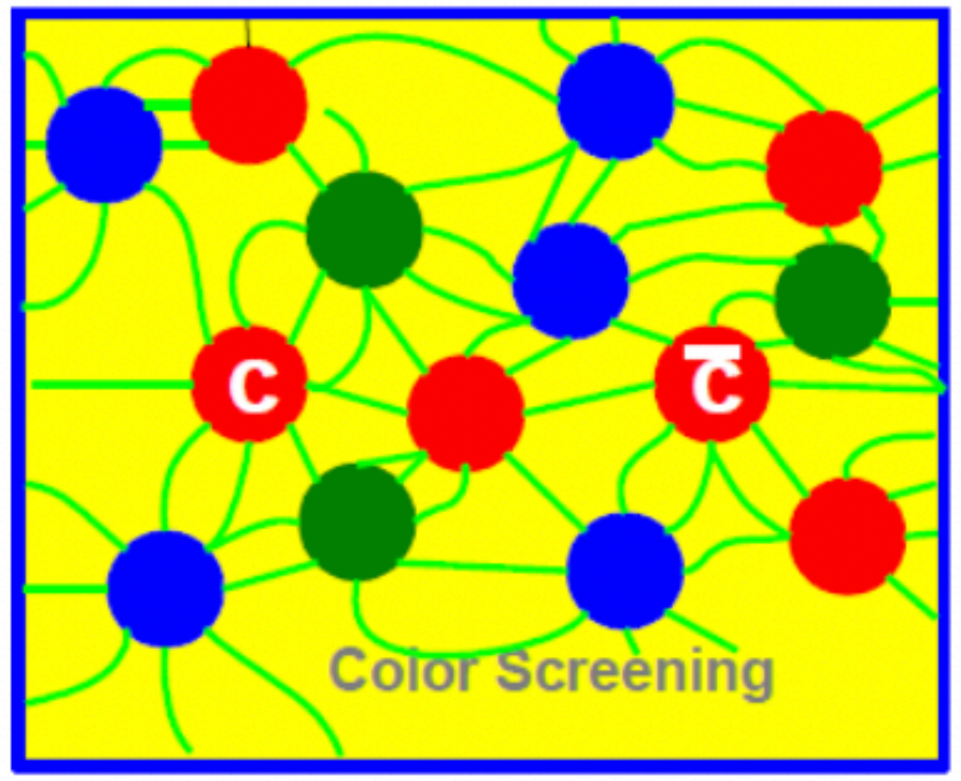
Two important probes

Open heavy flavour: Charm hadrons (D^0, $D^{\pm}$, …), bottom hadrons (B^0, $B^{\pm}$,…)



Probe of QCD interaction dynamics in extended systems

Quarkonia: charmonium ($c\bar{c}$): J/ψ, ψ',…, bottomonium ($b\bar{b}$): ϒ..



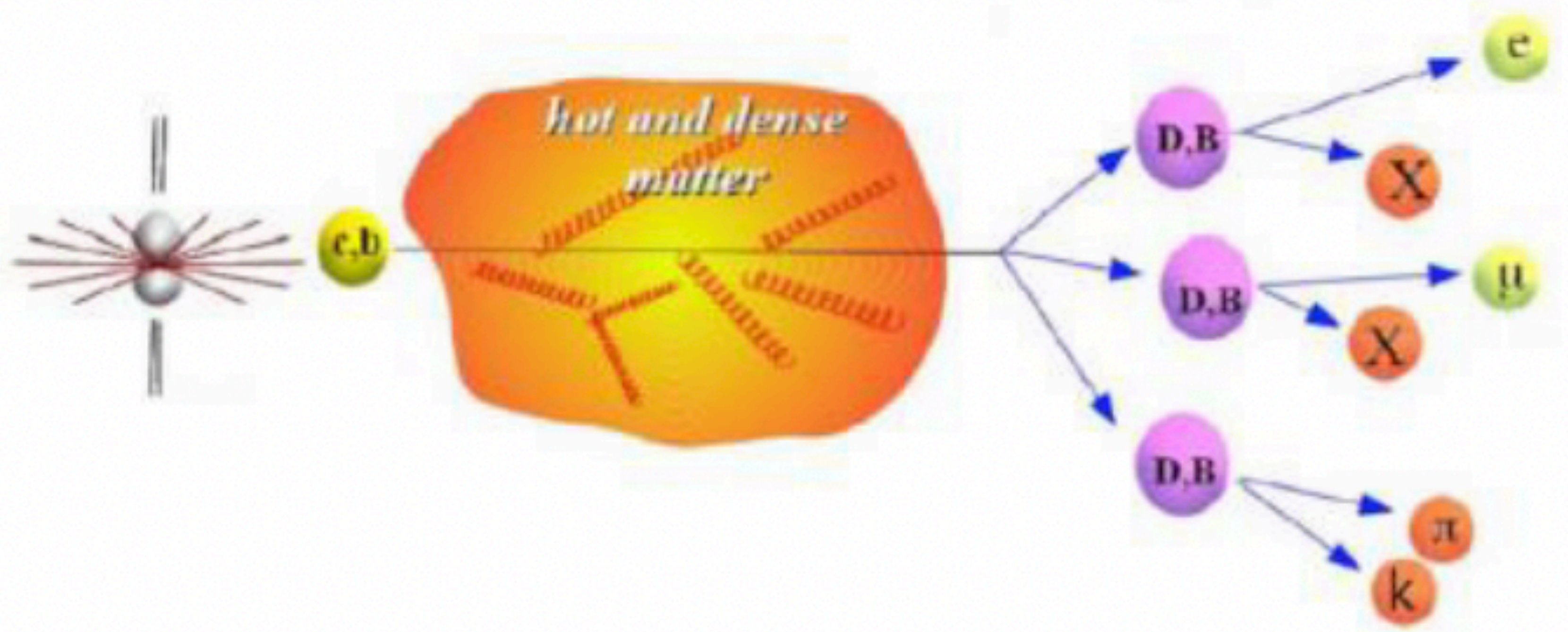
Probe of deconfinement & QGP medium temperature

- **Both probe medium transport properties via, e.g. the collective expansion of the QGP**
- **Both pillars evolved and extended significantly over the years**

Two important probes

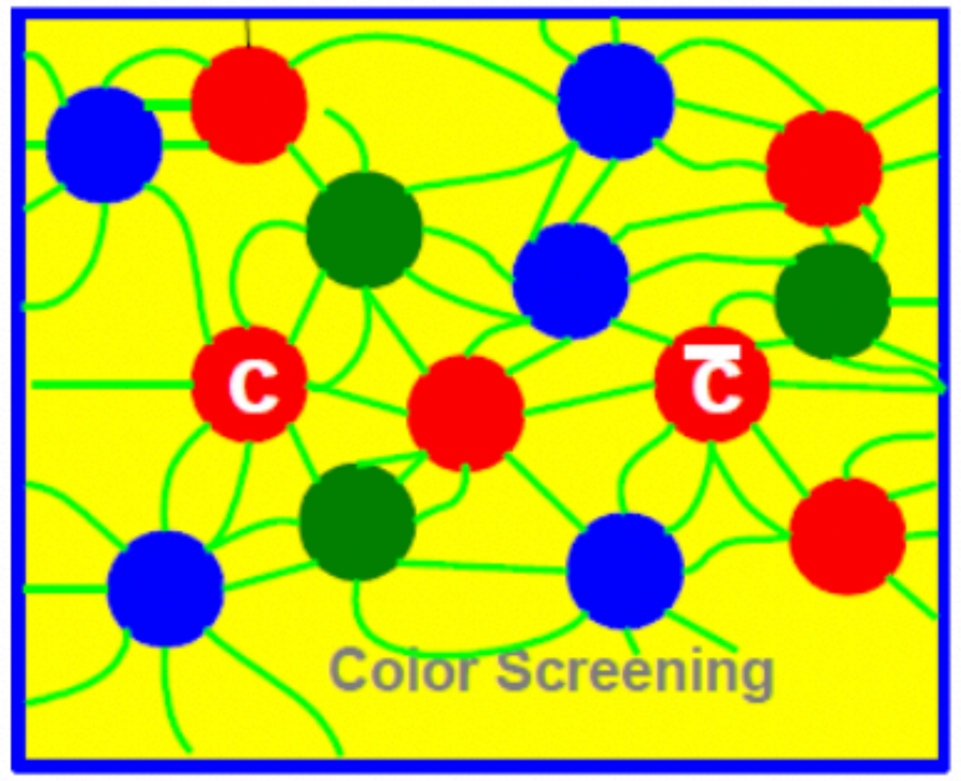
This talk

Open heavy flavour: Charm hadrons (D^0, $D^{\pm}$, …), bottom hadrons (B^0, $B^{\pm}$,…)



Probe of QCD interaction dynamics in extended systems

Quarkonia: charmonium ($c\bar{c}$): J/ψ, ψ',…, bottomonium ($b\bar{b}$): ϒ..



Probe of deconfinement & QGP medium temperature

- **Both probe medium transport properties via, e.g. the collective expansion of the QGP**
- **Both pillars evolved and extended significantly over the years**

The ALICE detector (Run 2)

Time-Of-Flight detector
- particle identification

ElectroMagnetic Calorimeter
- trigger
- particle identification

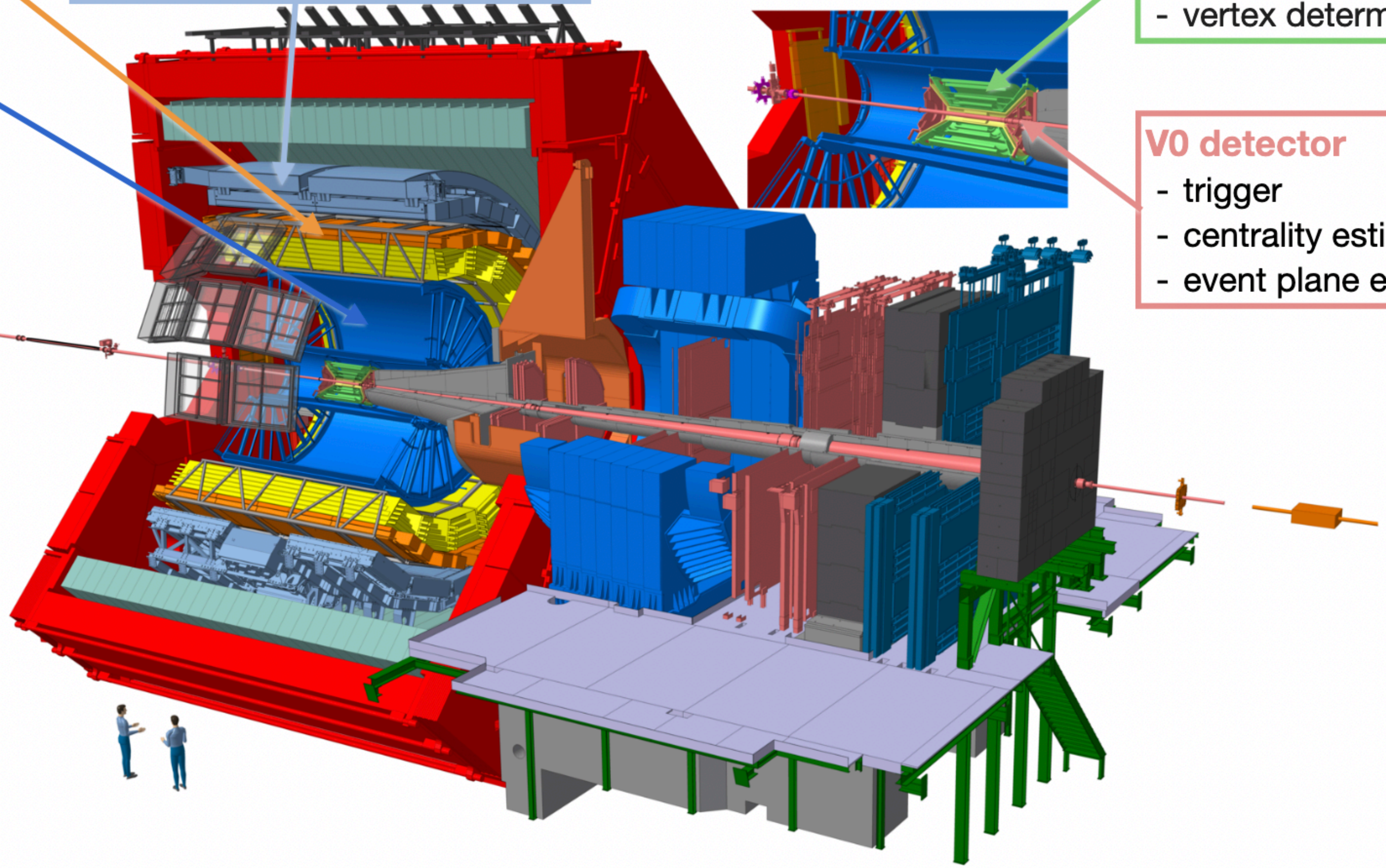
Inner Tracking System
- track reconstruction
- vertex determination

Time Projection Chamber
- track reconstruction
- particle identification

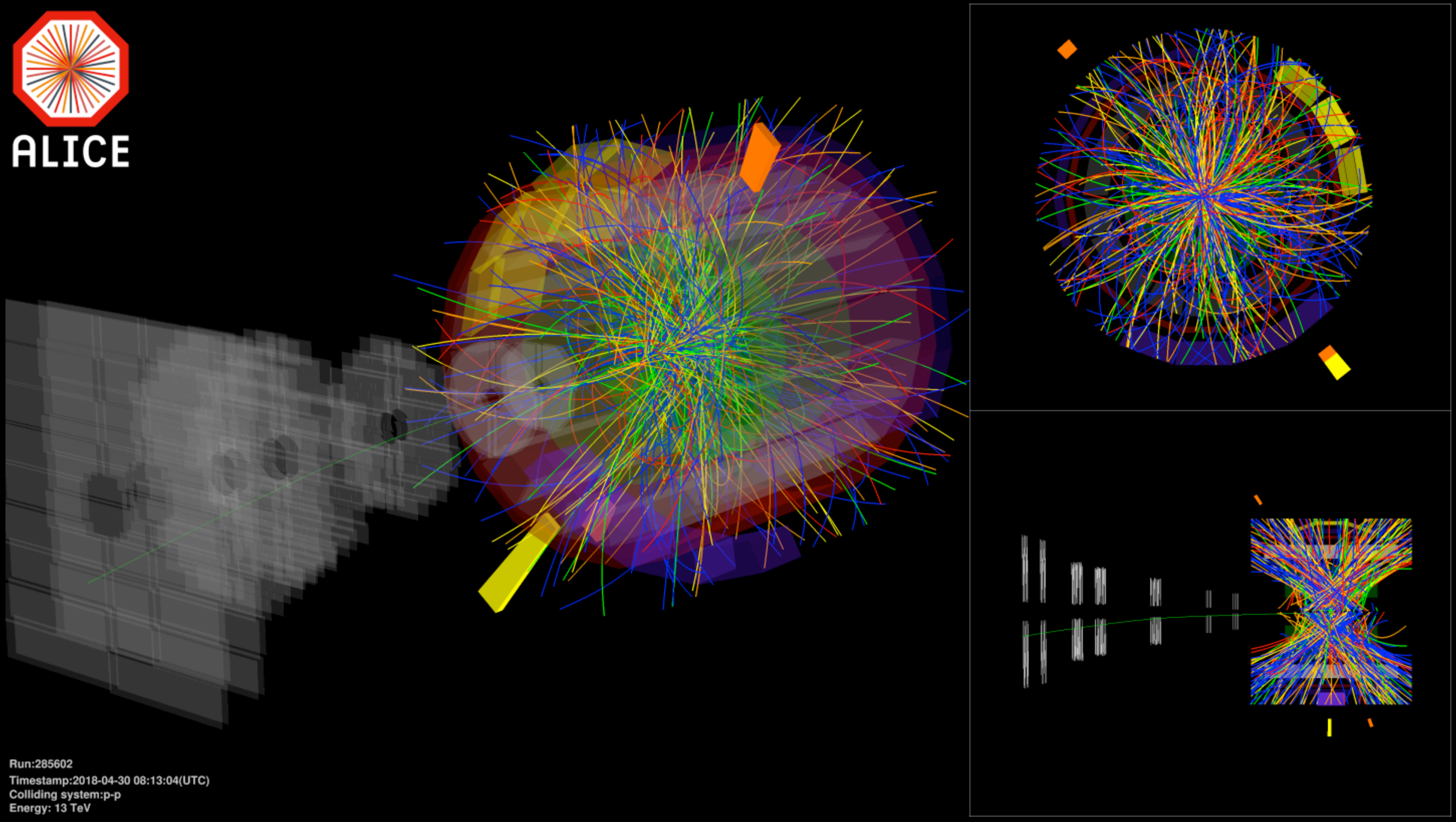
V0 detector
- trigger
- centrality estimation
- event plane estimation

HF hadrons in ALICE

- $D^0 \rightarrow K^-\pi^+$
- $D^+ \rightarrow K^-\pi^+\pi^+$
- $D_s^+ \rightarrow \phi\pi^0 \rightarrow K^+K^-\pi^+$
- $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$
- $\Lambda_c^+ \rightarrow pK^-\pi^+$
- $\Lambda_c^+ \rightarrow pK_S^0 \rightarrow p\pi^+\pi^-$
- $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+ \rightarrow \Lambda\pi^-\pi^+\pi^+$
- $\Xi_c^0 \rightarrow \pi^+\Xi^- \rightarrow \pi^+\pi^-\Lambda$
- $\Omega_c^0 \rightarrow \pi^+\Omega^- \rightarrow \pi^+K^-\Lambda$
- $\Sigma_c^{0,++} \rightarrow \pi^{-,+}\Lambda_c^+ \rightarrow \pi^{-,+}pK_S^0$
- $\Sigma_c^{0,++} \rightarrow \pi^{-,+}\Lambda_c^+ \rightarrow \pi^{-,+}pK^-\pi^+$
- $D_{s1}^+ \rightarrow D^{*+}K_S^0$
- $D_{s2}^{*+} \rightarrow D^+K_S^0$



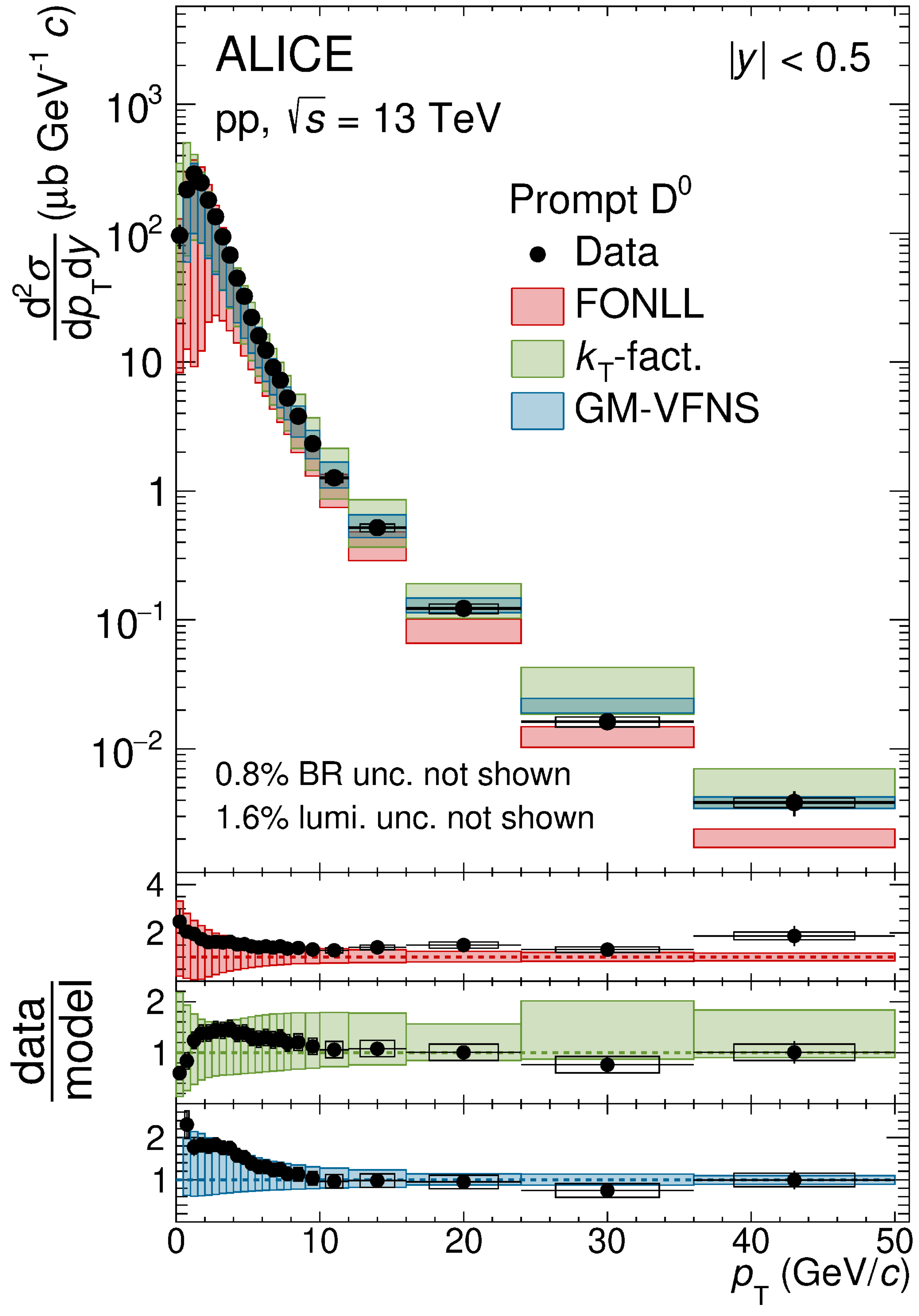
Results in pp collisions

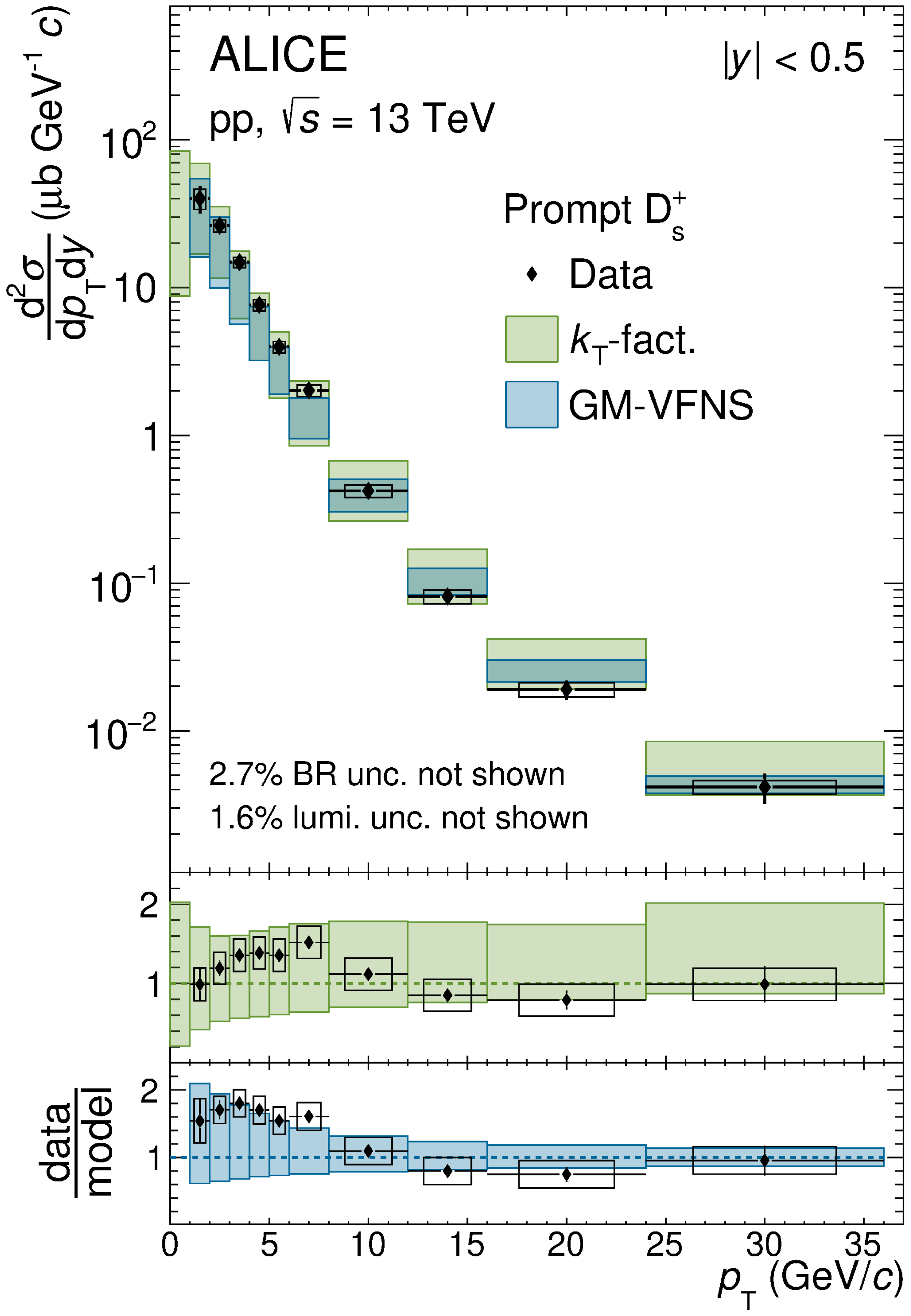


Run:285602
Timestamp:2018-04-30 08:13:04(UTC)
Colliding system:p-p
Energy: 13 TeV

Cross section of D mesons

JHEP 12 (2023) 086





Prompt charm hadron :
hadrons from c-quark hadronisation or from the decay of excited charm hadrons

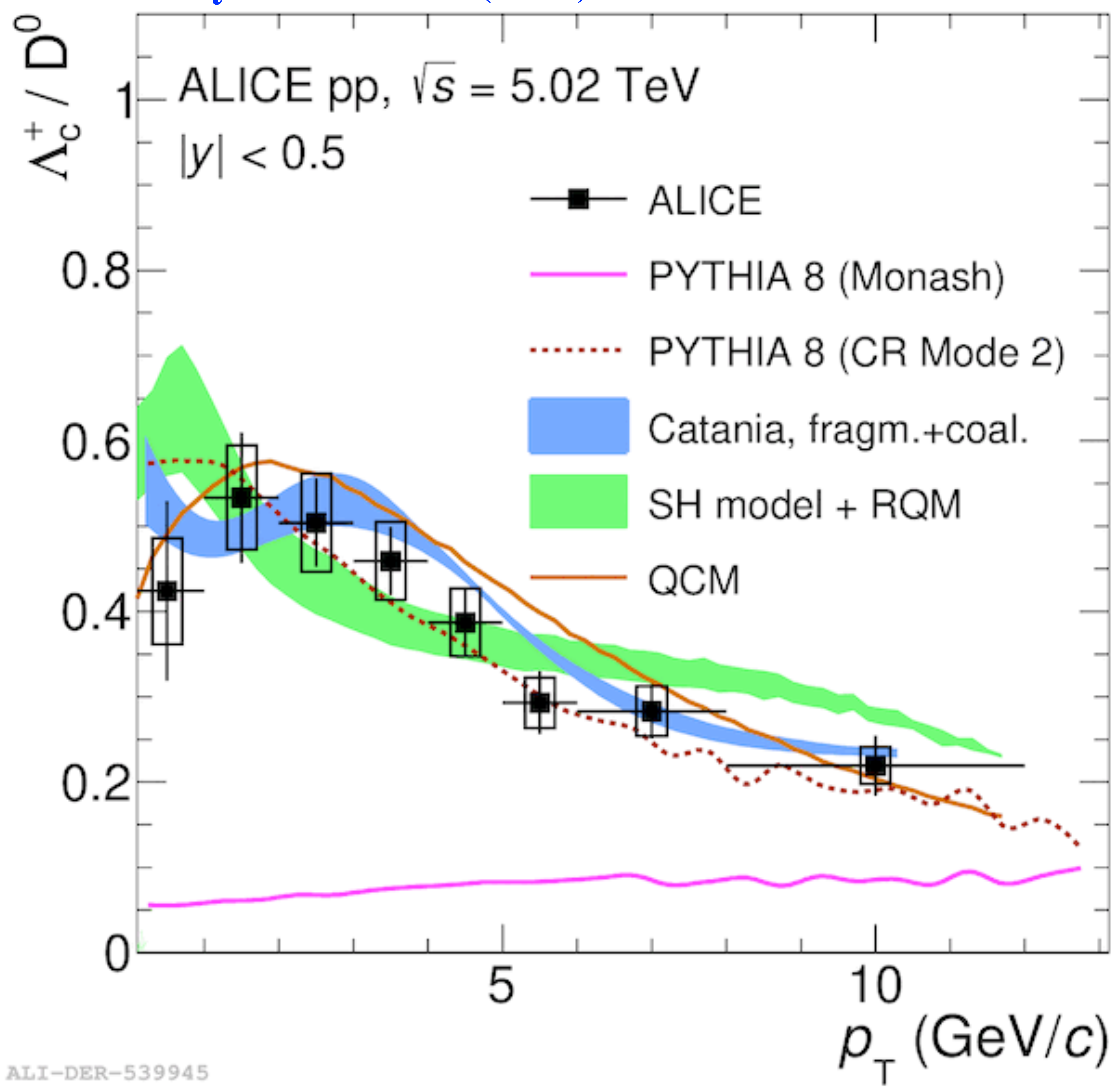
- **p_T-differential cross sections described by pQCD calculations (FONLL, kT-factorization, GM-VFNS) ➡ Good agreement within uncertainties**

FONLL :
JHEP 05 (1998) 007, JHEP 10 (2012) 137
kT-factorization :
Phys. Rev. D 104 (2021) 094038
GM-VFNS :
JHEP 12 (2017) 021, Nucl. Phys. B 925 (2017) 415–430

Prompt Λ_c^+/D⁰ ratio : Questioning the Universality

Measurements of the baryon-to-meson yield ratio -> p_T-dependent enhancement of Λ_c^+/D^0 ratio in pp w.r.t. e^+e^-

Phys. Rev. C 107 (2023) 064901



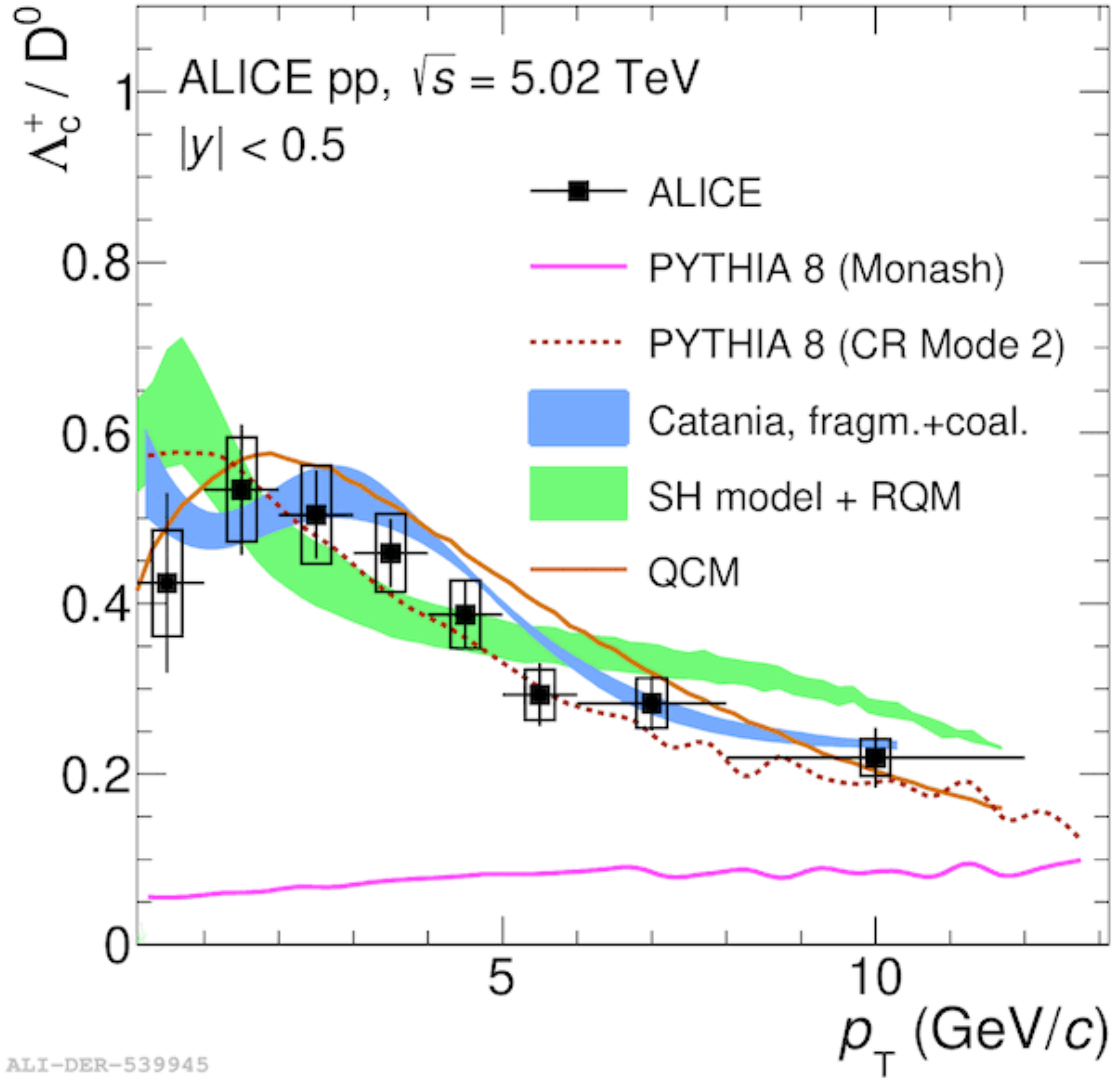
LEP: (0.113 ± 0.013 ± 0.006) EPJC 75 (2015) 19

Prompt Λ_c^+/D⁰ ratio : Questioning the Universality

Measurements of the baryon-to-meson yield ratio -> p_T-dependent enhancement of Λ_c^+/D⁰ ratio in pp w.r.t. e^+e^-

Models based on fragmentation functions evaluated from e^+e^- collisions underestimate the data (PYTHIA 8 Monash)

Phys. Rev. C 107 (2023) 064901



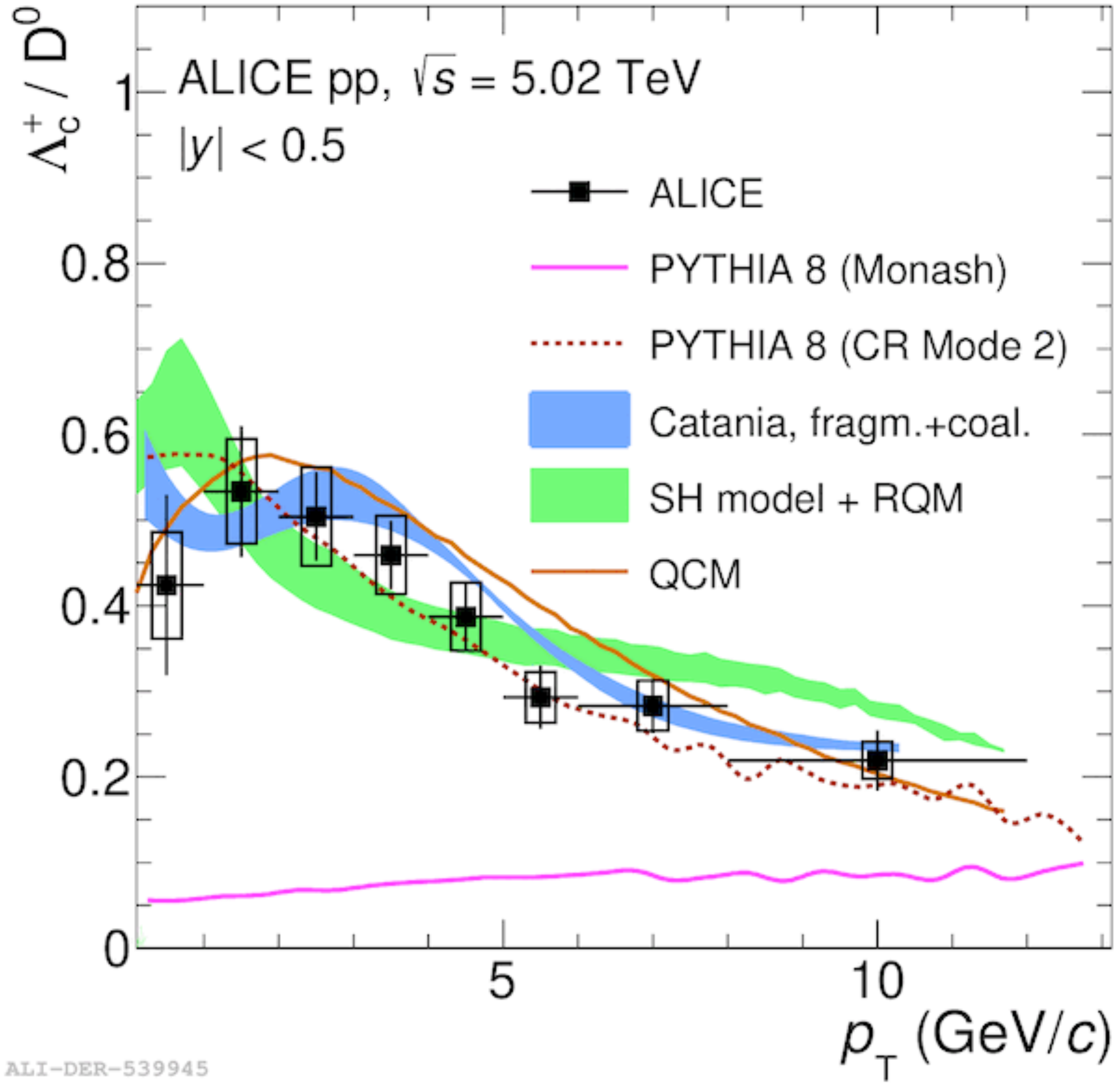
LEP: (0.113 ± 0.013 ± 0.006) **EPJC 75 (2015) 19**

Prompt Λ_c^+/D^0 ratio : Questioning the Universality

Measurements of the baryon-to-meson yield ratio -> p_T-dependent enhancement of Λ_c^+/D^0 ratio in pp w.r.t. e^+e^-

Models based on fragmentation functions evaluated from e^+e^- collisions underestimate the data (PYTHIA 8 Monash)

Phys. Rev. C 107 (2023) 064901



LEP: (0.113 ± 0.013 ± 0.006) EPJC 75 (2015) 19

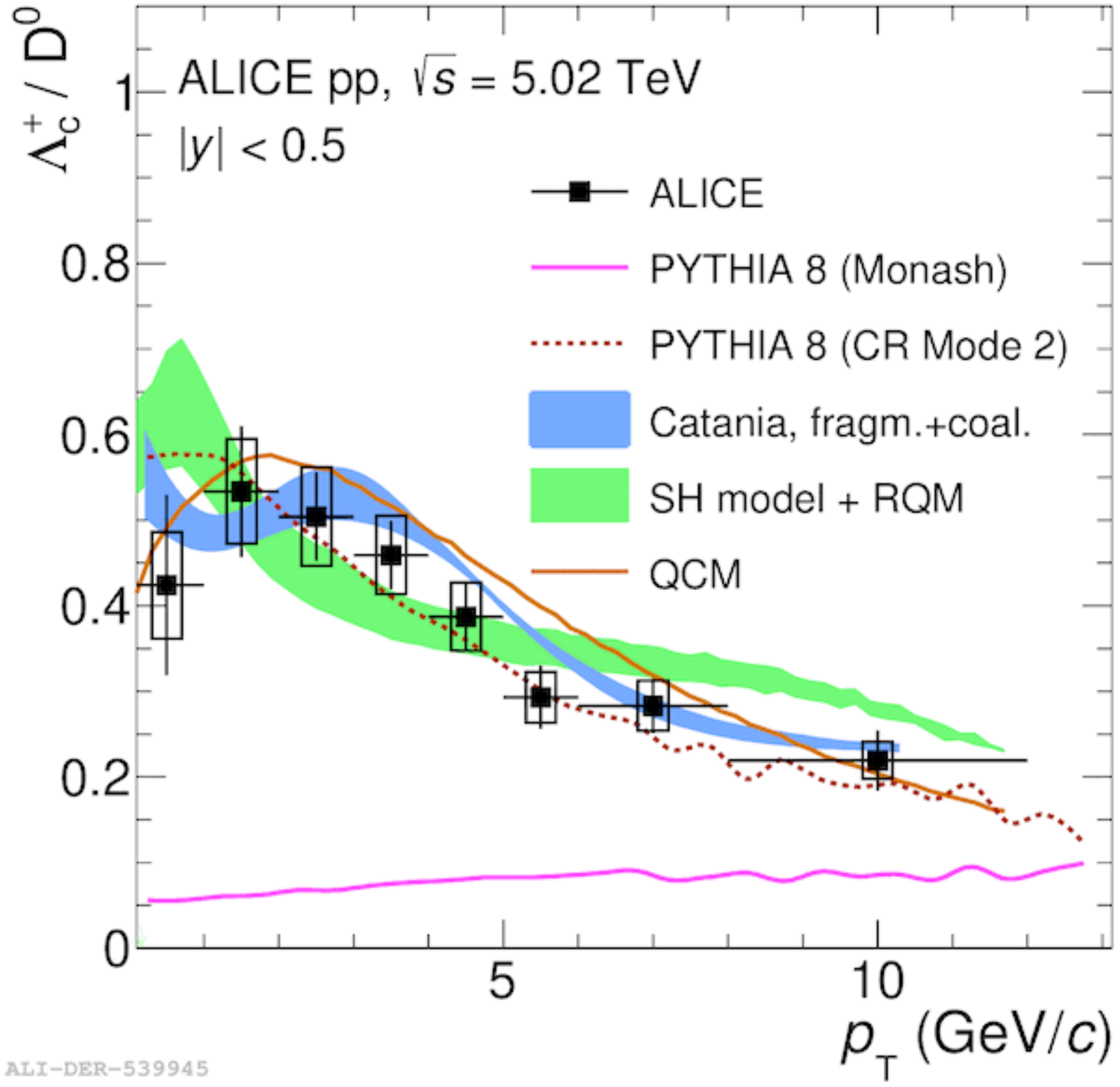
Different hadronization mechanisms proposed:

Prompt Λ_c^+/D^0 ratio : Questioning the Universality

Measurements of the baryon-to-meson yield ratio -> p_T-dependent enhancement of Λ_c^+/D^0 ratio in pp w.r.t. e^+e^-

Models based on fragmentation functions evaluated from e^+e^- collisions underestimate the data (PYTHIA 8 Monash)

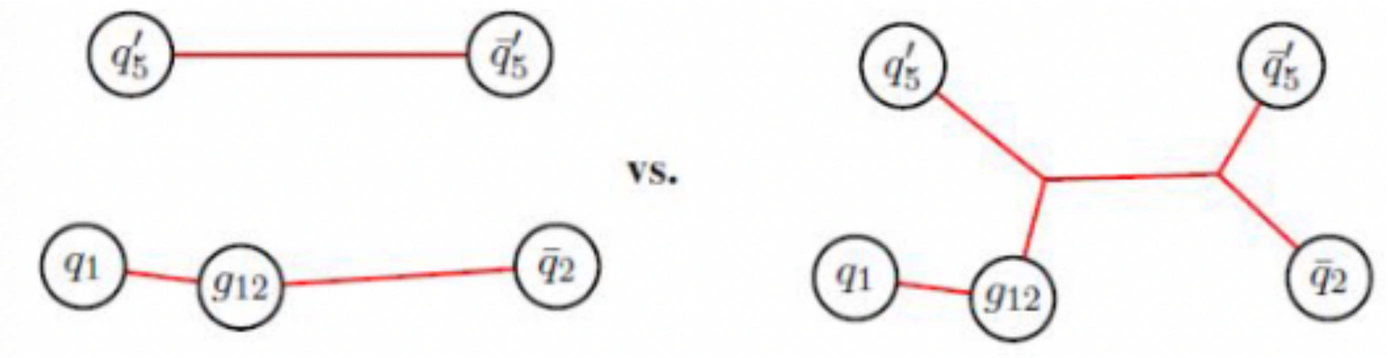
Phys. Rev. C 107 (2023) 064901



LEP: (0.113 ± 0.013 ± 0.006) EPJC 75 (2015) 19

Different hadronization mechanisms proposed:

Color reconnection beyond leading color (PYTHIA 8 CR Mode 2)

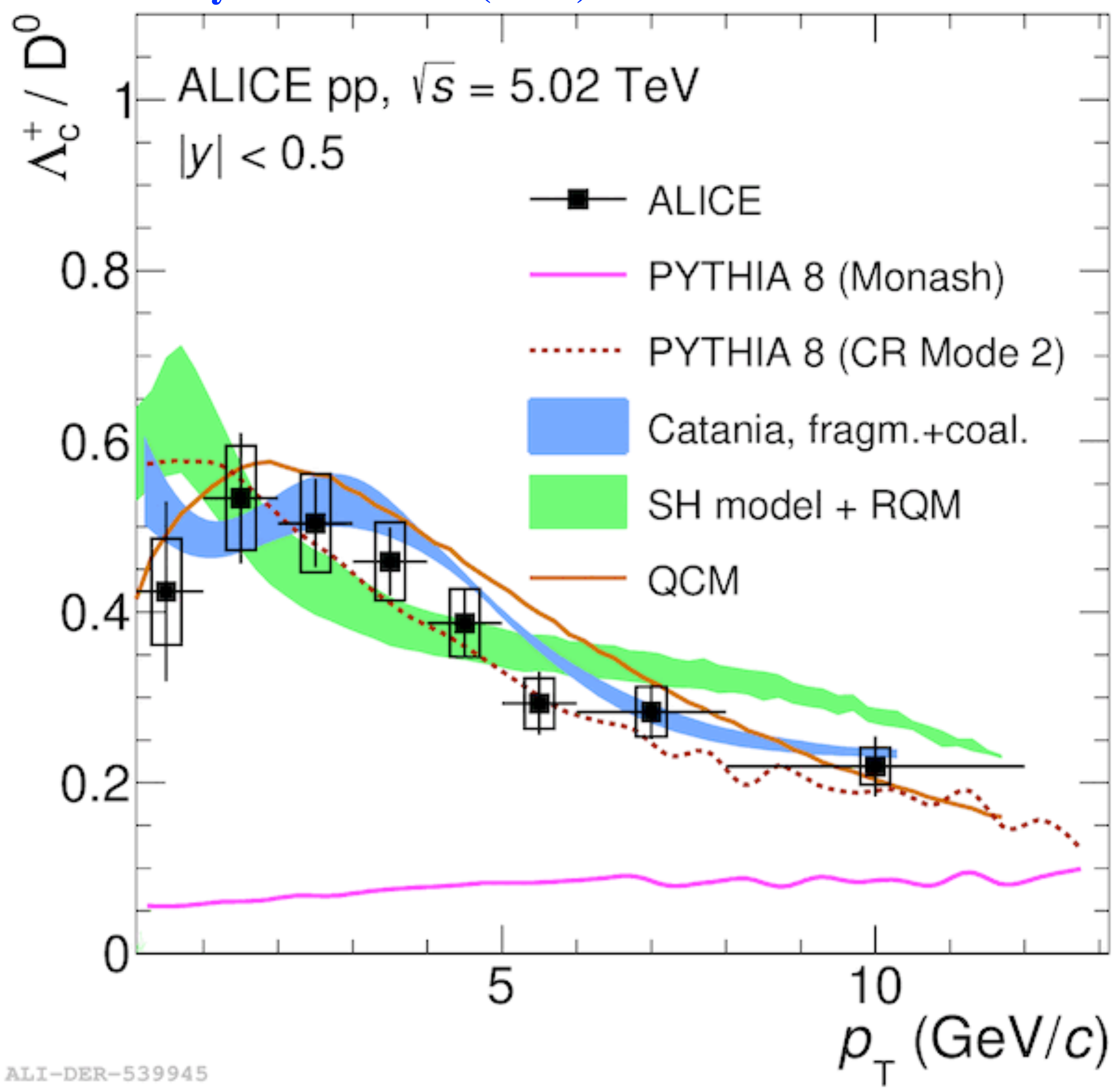


Prompt Λ_c^+/D^0 ratio : Questioning the Universality

Measurements of the baryon-to-meson yield ratio -> p_T-dependent enhancement of Λ_c^+/D^0 ratio in pp w.r.t. e^+e^-

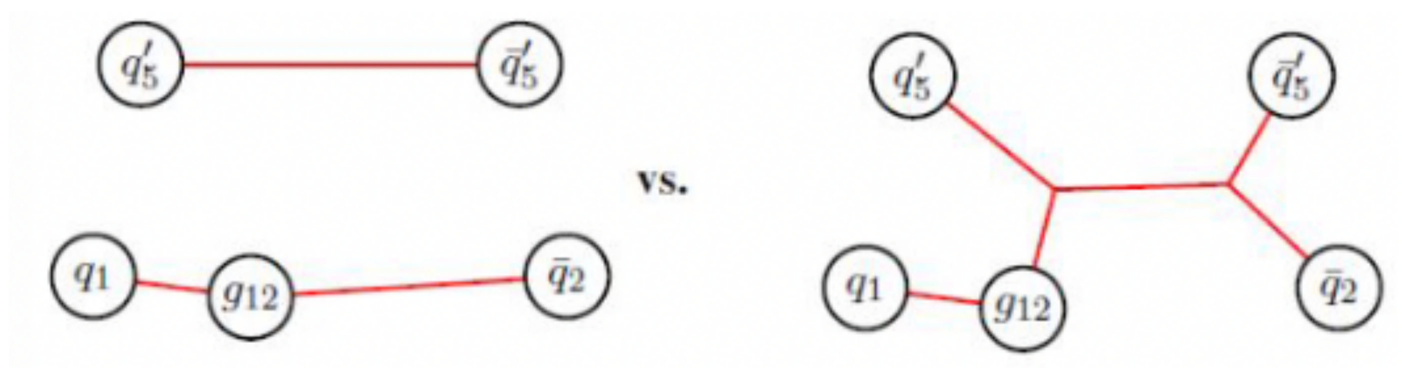
Models based on fragmentation functions evaluated from e^+e^- collisions underestimate the data (PYTHIA 8 Monash)

Phys. Rev. C 107 (2023) 064901



Different hadronization mechanisms proposed:

Color reconnection beyond leading color (PYTHIA 8 CR Mode 2)



Increased feed-down from an augmented set of excited charm baryons (Statistical Hadronisation model + Relativistic Quark model)

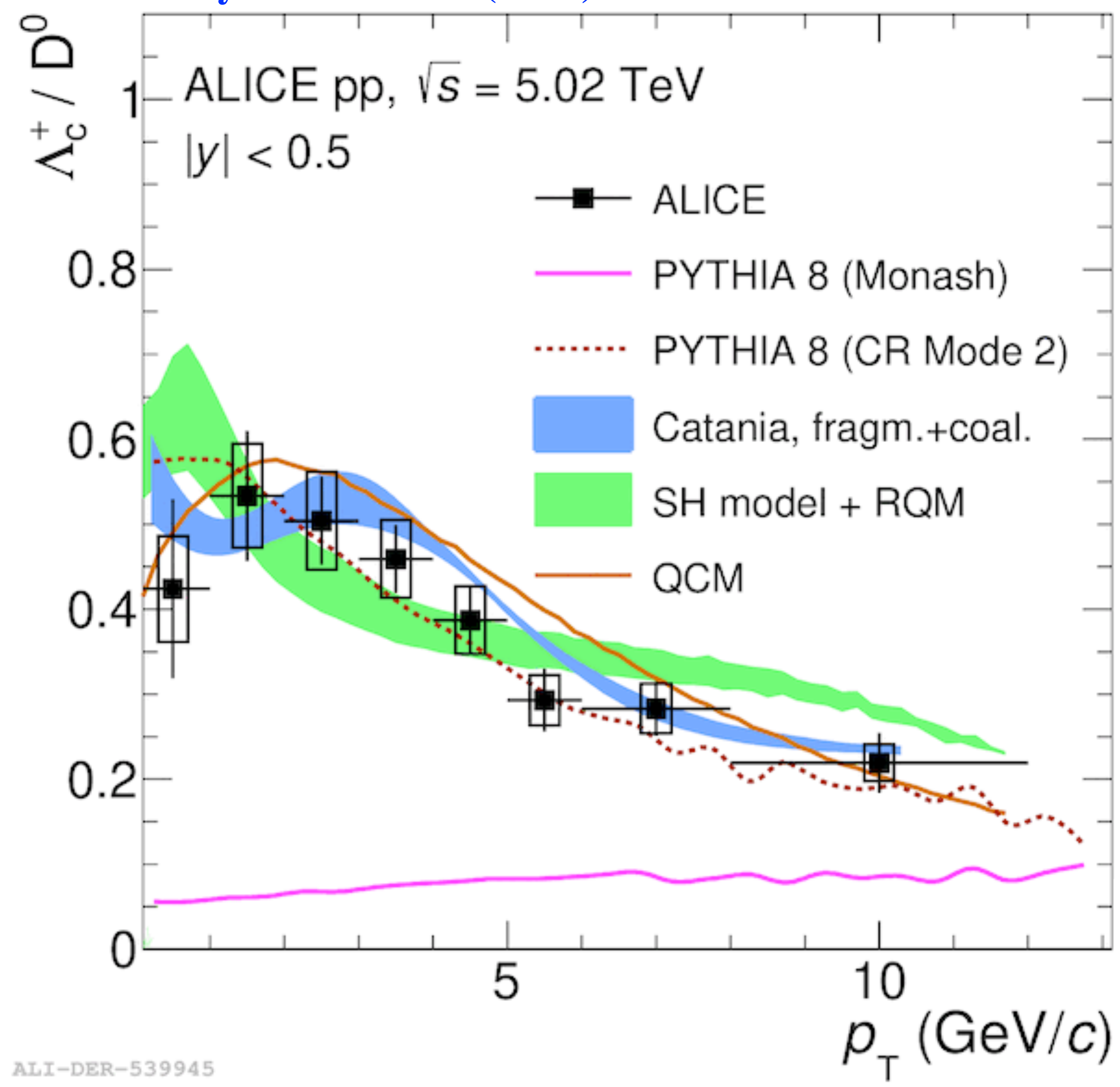
LEP: (0.113 ± 0.013 ± 0.006) **EPJC 75 (2015) 19**

Prompt Λ_c^+/D^0 ratio : Questioning the Universality

Measurements of the baryon-to-meson yield ratio -> p_T-dependent enhancement of Λ_c^+/D^0 ratio in pp w.r.t. e^+e^-

Models based on fragmentation functions evaluated from e^+e^- collisions underestimate the data (PYTHIA 8 Monash)

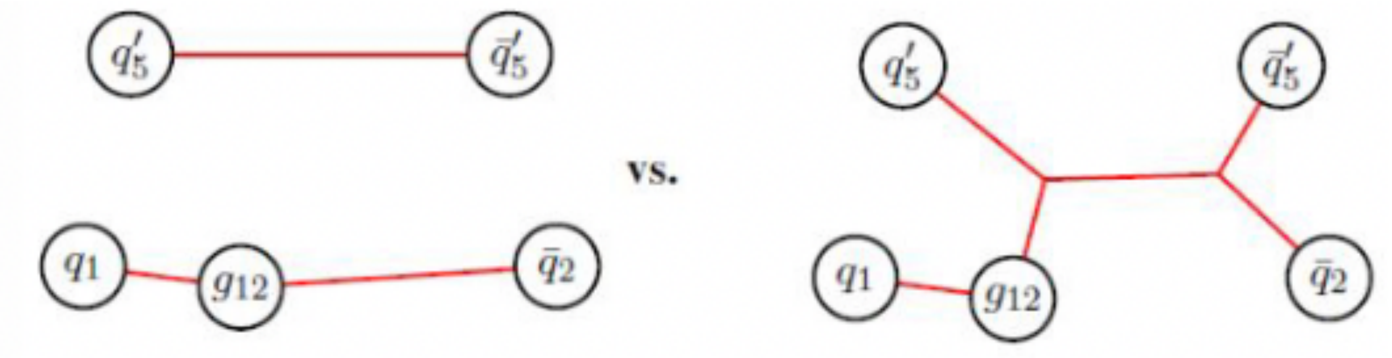
Phys. Rev. C 107 (2023) 064901



LEP: (0.113 ± 0.013 ± 0.006) EPJC 75 (2015) 19

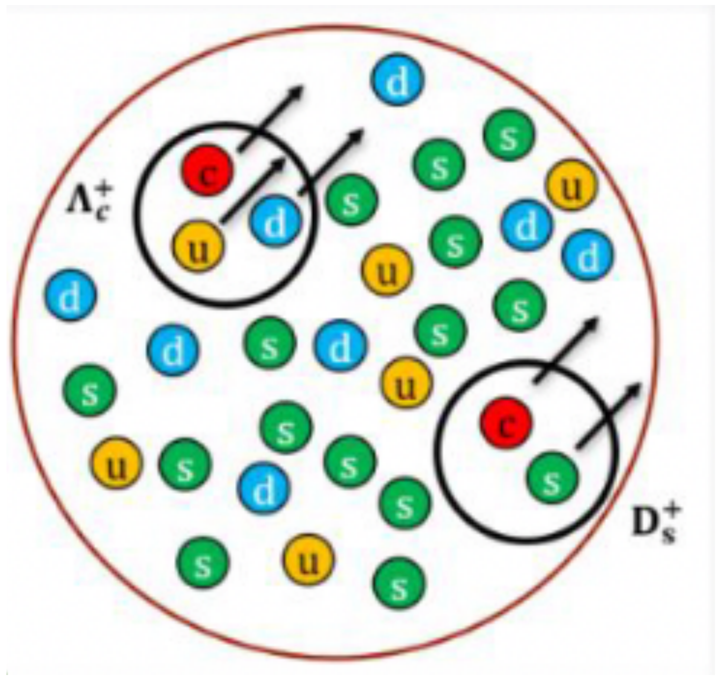
Different hadronization mechanisms proposed:

Color reconnection beyond leading color (PYTHIA 8 CR Mode 2)



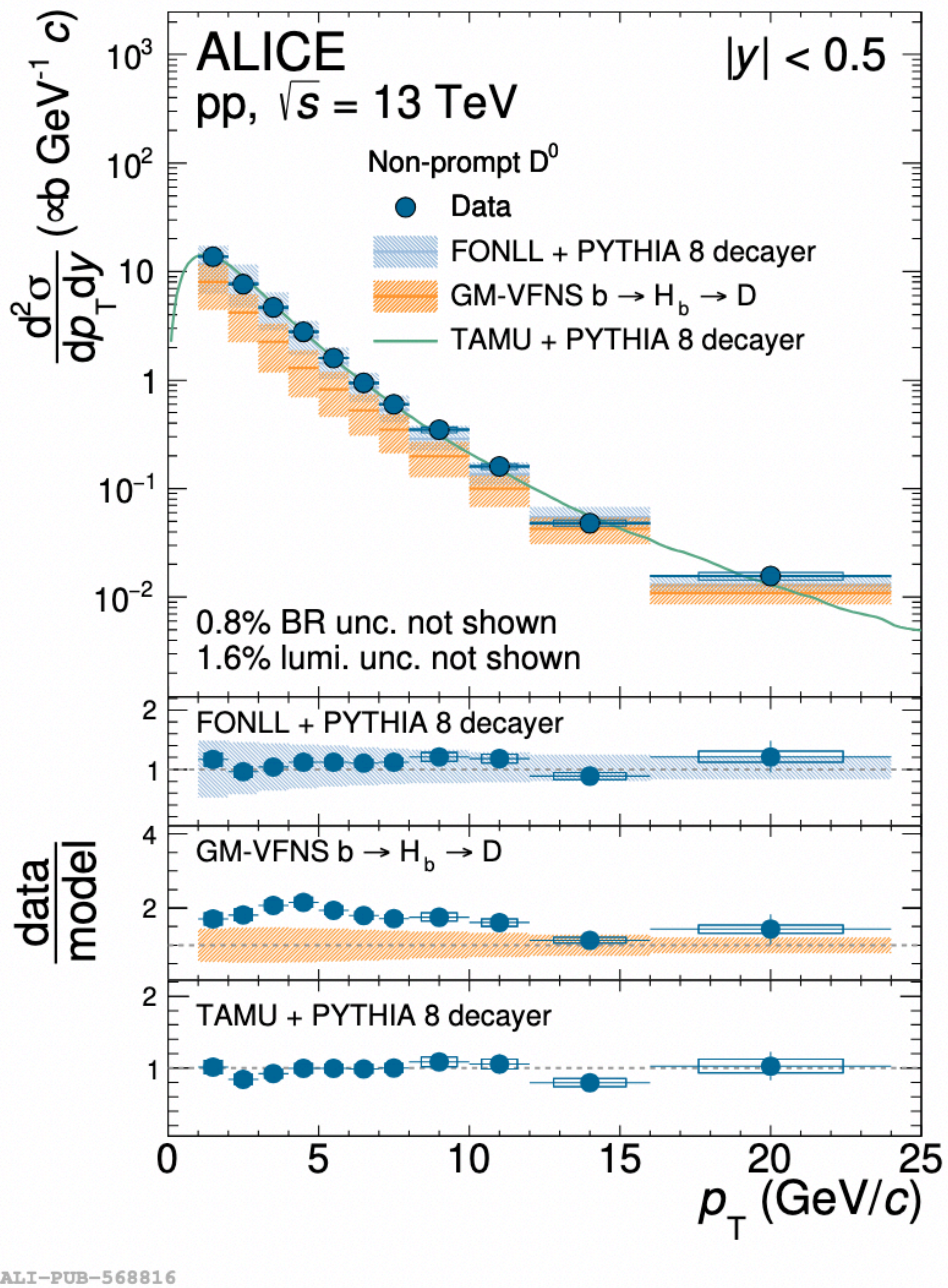
Increased feed-down from an augmented set of excited charm baryons (Statistical Hadronisation model + Relativistic Quark model)

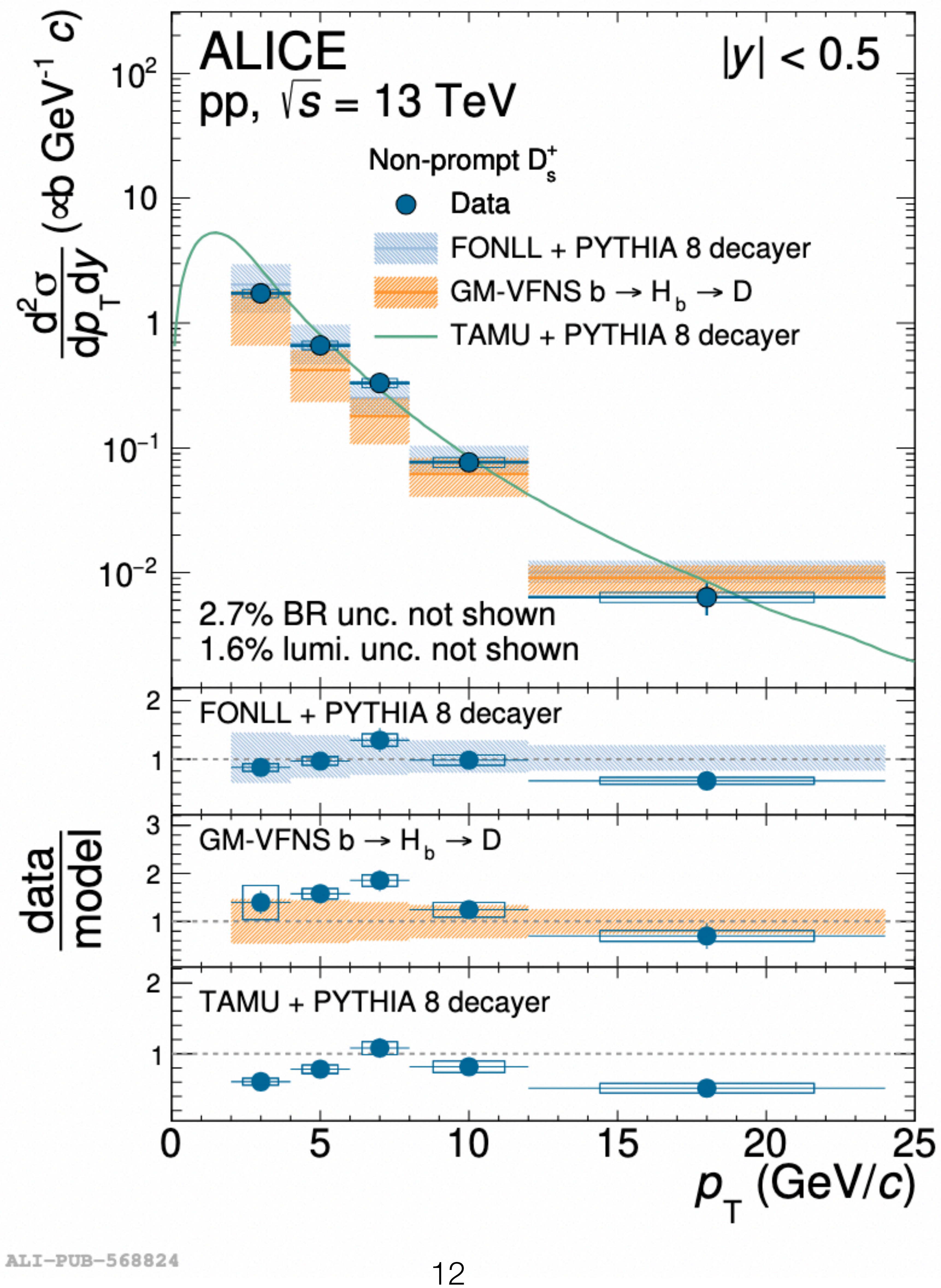
Hadronization via coalescence and fragmentation in a thermalised system of gluons, light quarks and antiquarks (Catania, Quark (re)Combination Model)



Cross section of non-prompt D mesons

arXiv:2402.16417





Non-prompt charm hadron : Charm hadrons from beauty-hadron decays

PYTHIA 8
Comput. Phys. Commun. 191 (2015) 159–177
Eur. Phys. J. C 74 (2014) 3024

FONLL
JHEP 05 (1998) 007
JHEP 10 (2012) 137

- **Consistent with data within uncertainties**

TAMU
Phys. Rev. Lett. 131 (2023) 012301

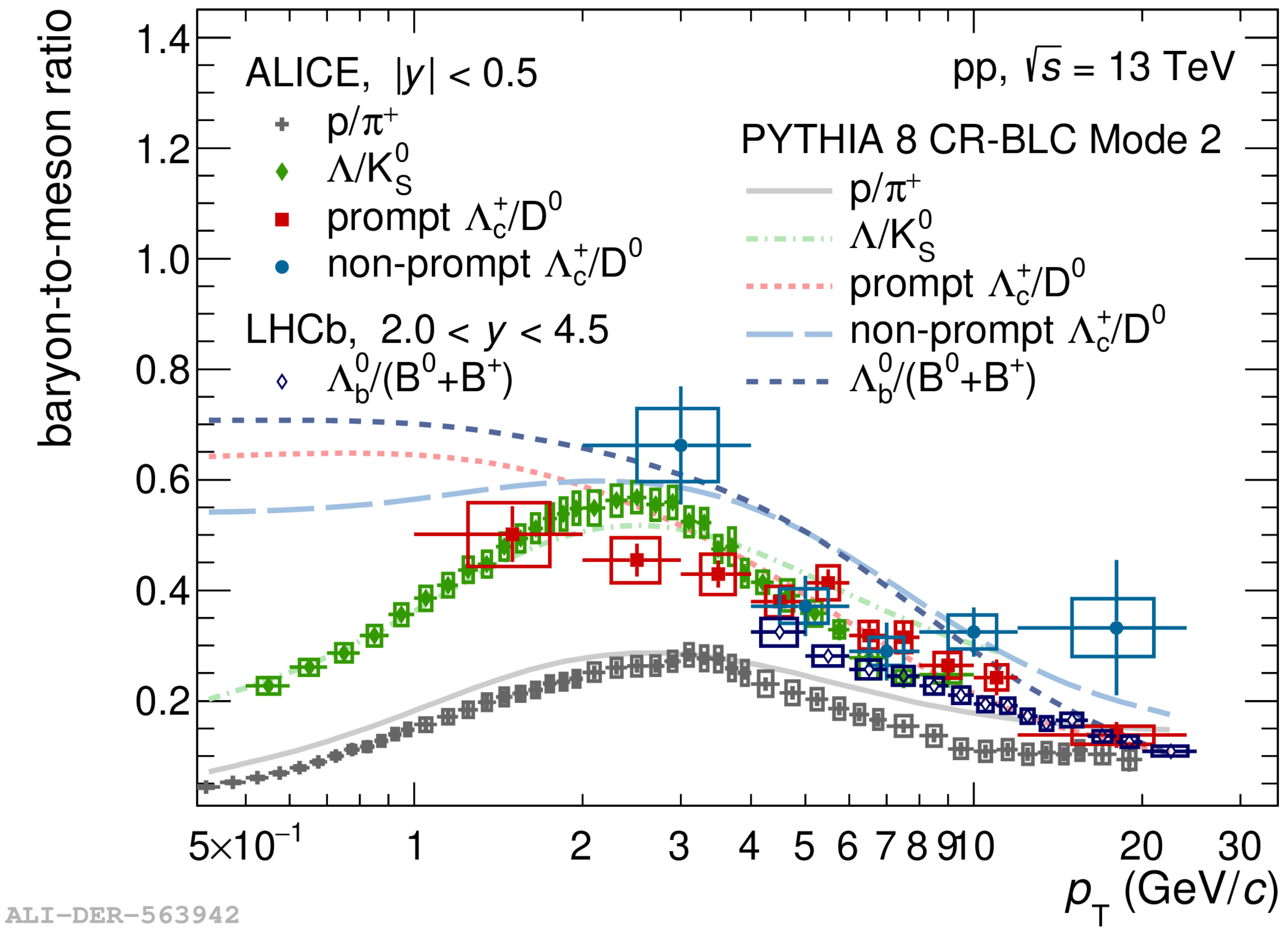
- **Good agreement for D^0**
- **Tend to overestimate the D_s^+**

GM-VFNS
JHEP 12 (2017) 021
Nucl. Phys. B 925 (2017) 415–430
J. Phys. G 41 (2014) 075006

- **Underestimate the data at low p_T, whereas a better description at high p_T**

Non-prompt Λ_c^+/D^0 ratio

Phys. Rev. D 108, 112003

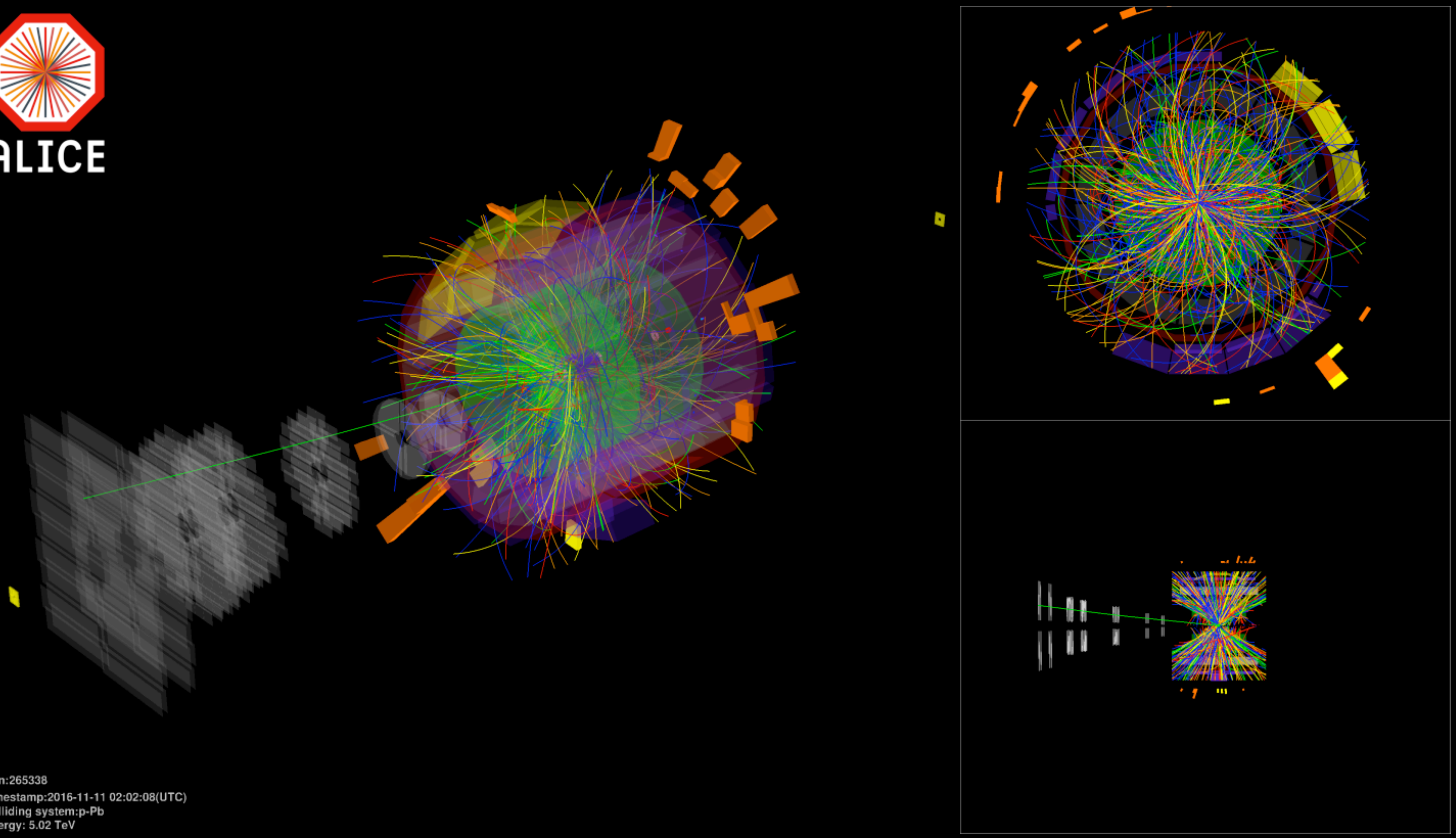


Ratio of p_T-differential production cross section of non-prompt Λ_c^+ and D^0

- ✓ Ratio Λ_b^0/ (B^0+B^+) is a bit lower than non-prompt Λ_c^+/D^0
- ✓ Beauty, charm, and strange hadrons have a similar trend and are compatible within uncertainties
- ✓ PYTHIA with CR-BLC tune describes the data for p_T > 2 GeV/c and significantly higher at low p_T for heavy-flavour hadrons

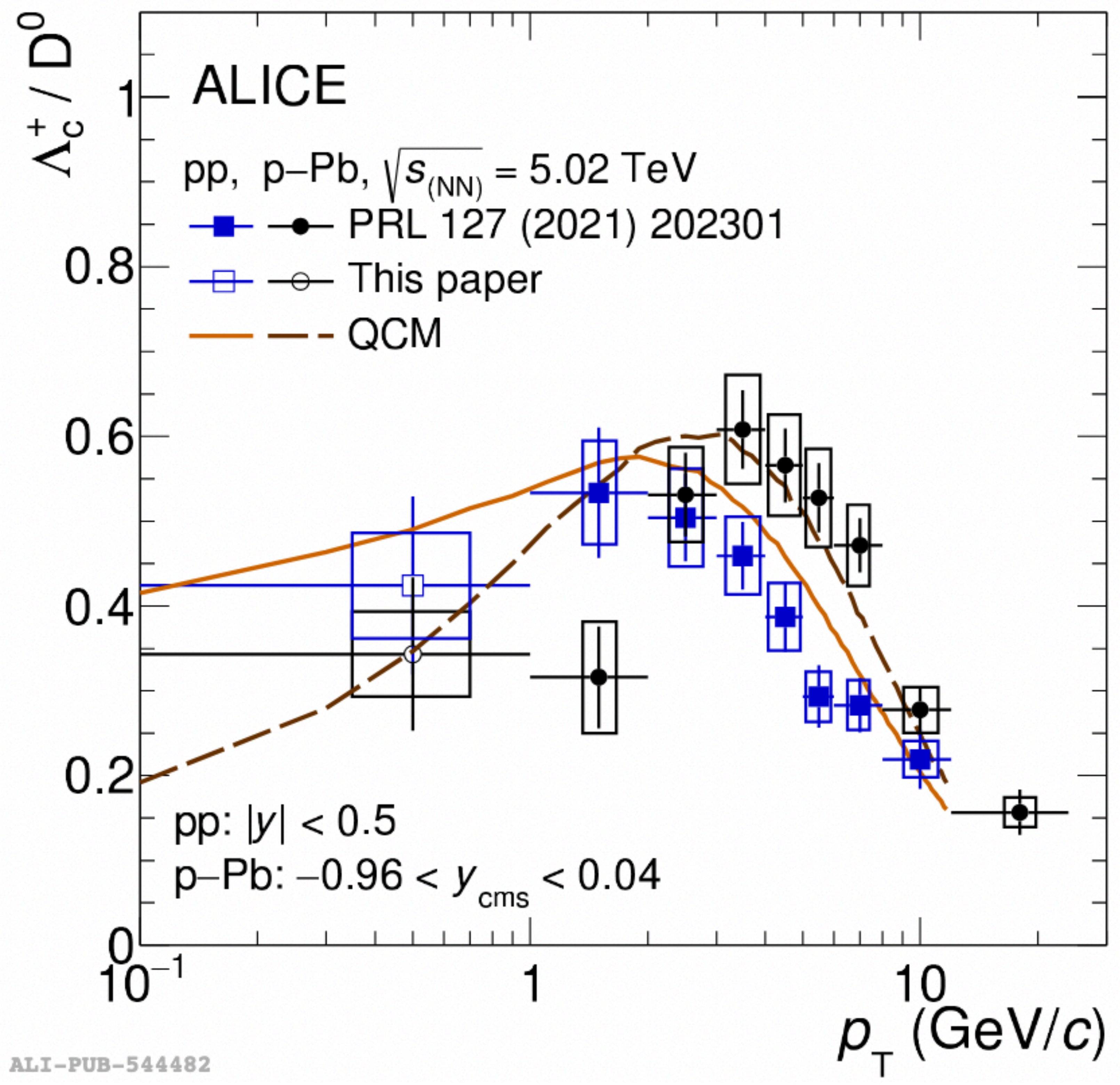
Results in p–Pb collisions

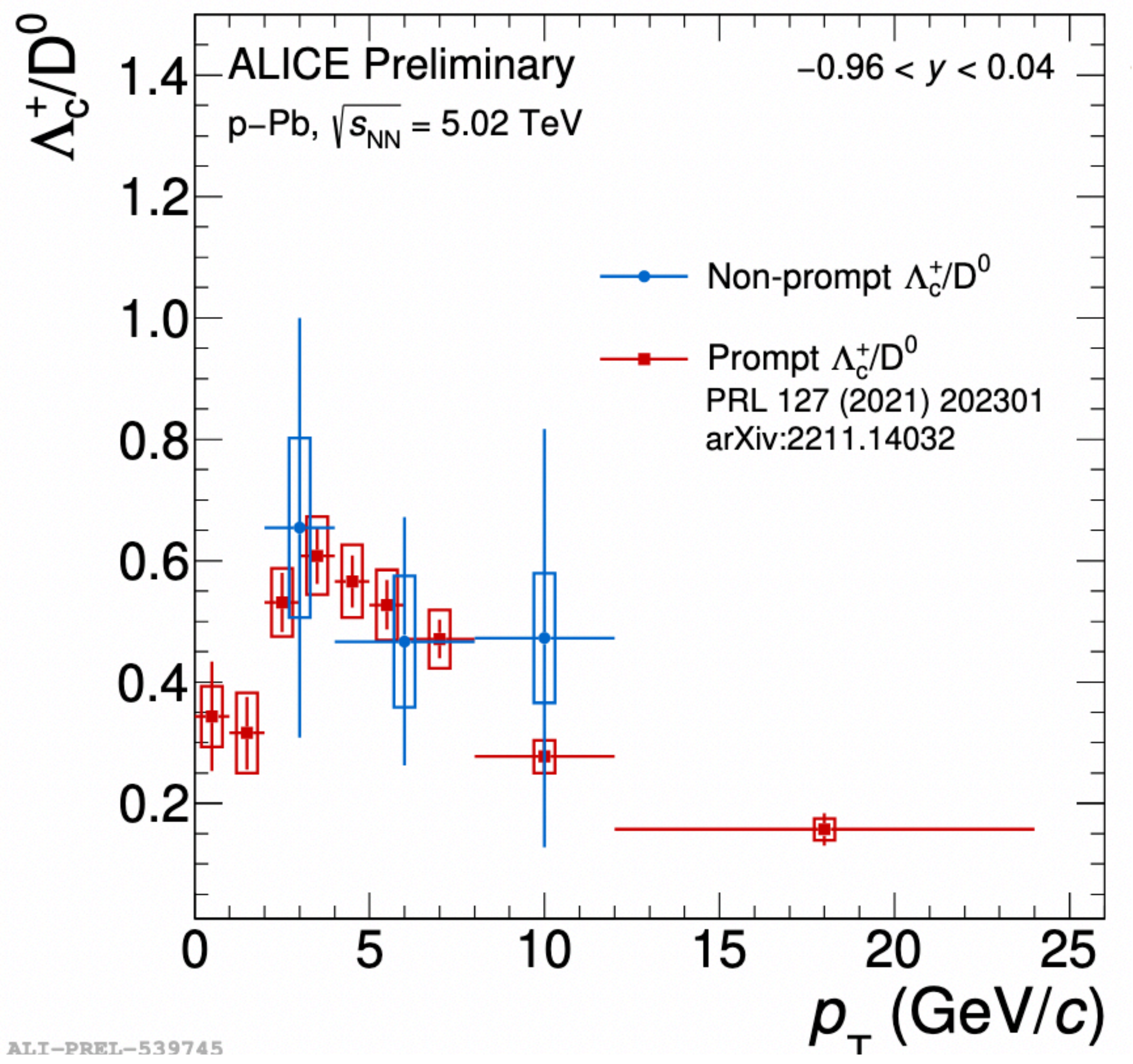
ALICE



Prompt and non-prompt Λ_c^+/D^0 ratio

Phys. Rev. C 107, 064901





Similar trend of in both pp and p–Pb collisions

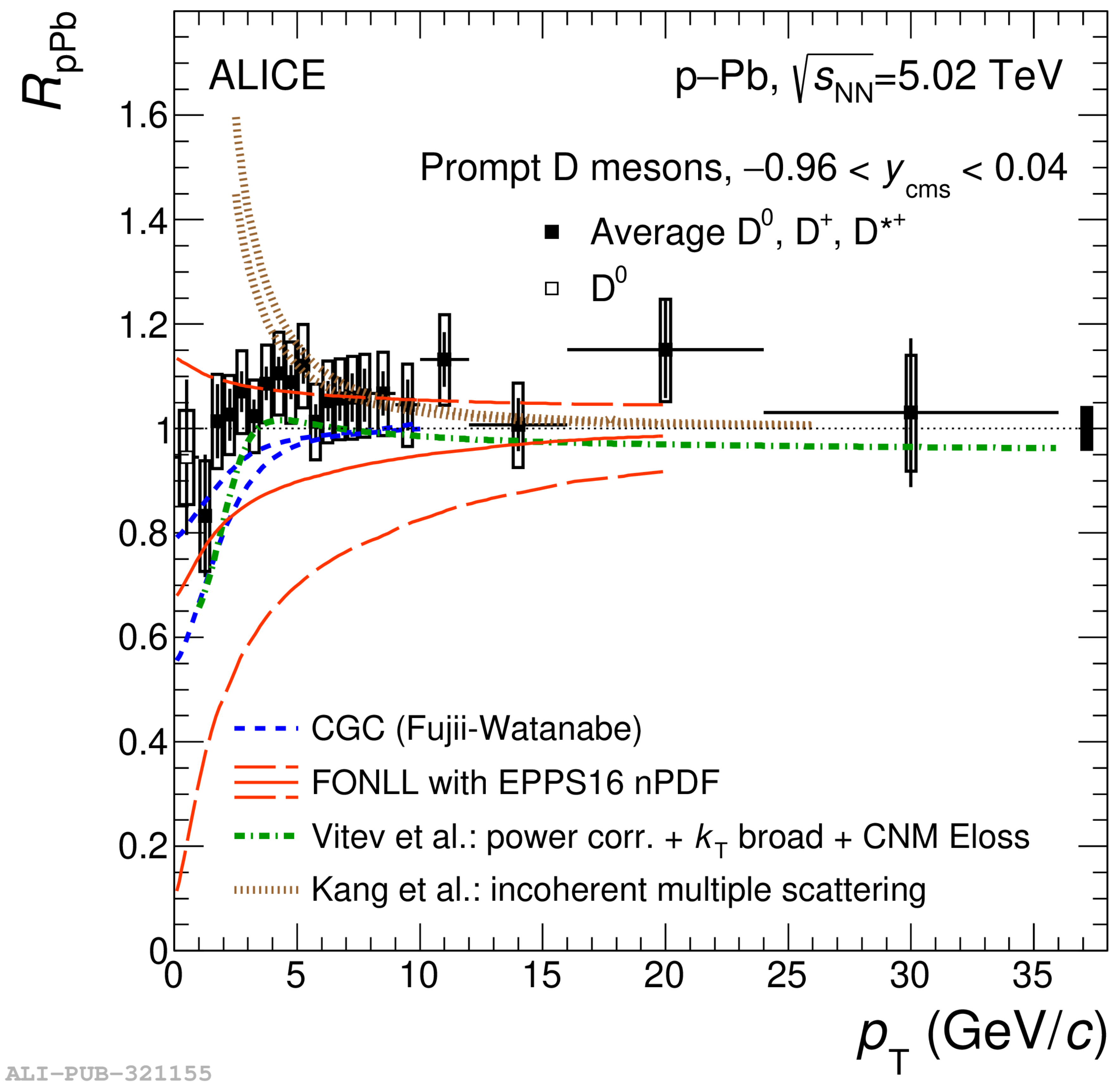
- Shift towards higher p_T in p–Pb collisions attributed to radial flow (described by QCM prediction)

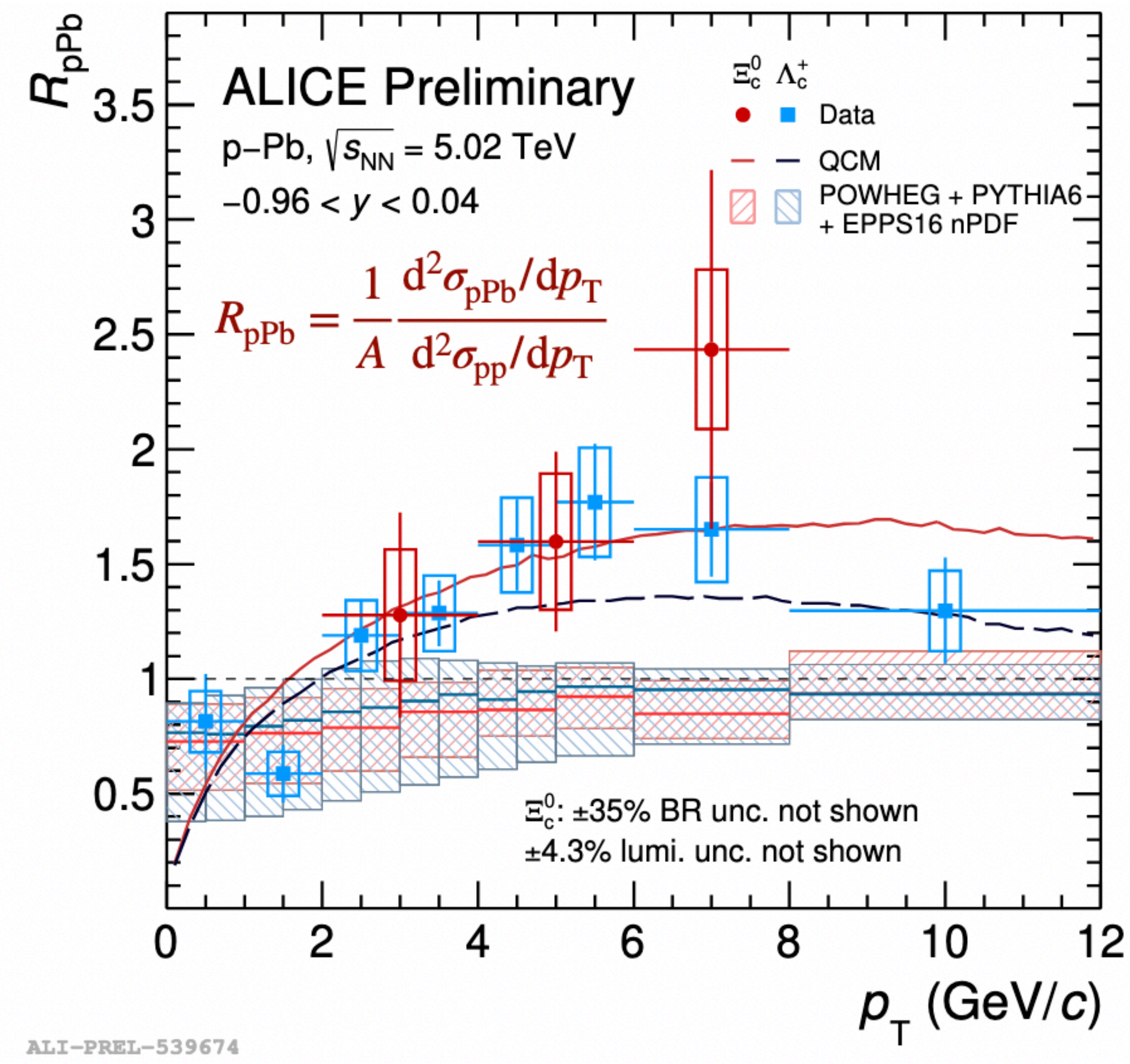
Decreasing trend of non-prompt at midrapidity with increasing p_T

- Baryon enhancement at low p_T → hadronisation effects apart from in-vacuum fragmentation

QCM
pp : Chin. Phys. C 45 (2021) 113105
p-Pb : Phys. Rev. C 97 (2018) 064915

R_{pPb} of prompt charm hadrons in p–Pb collisions





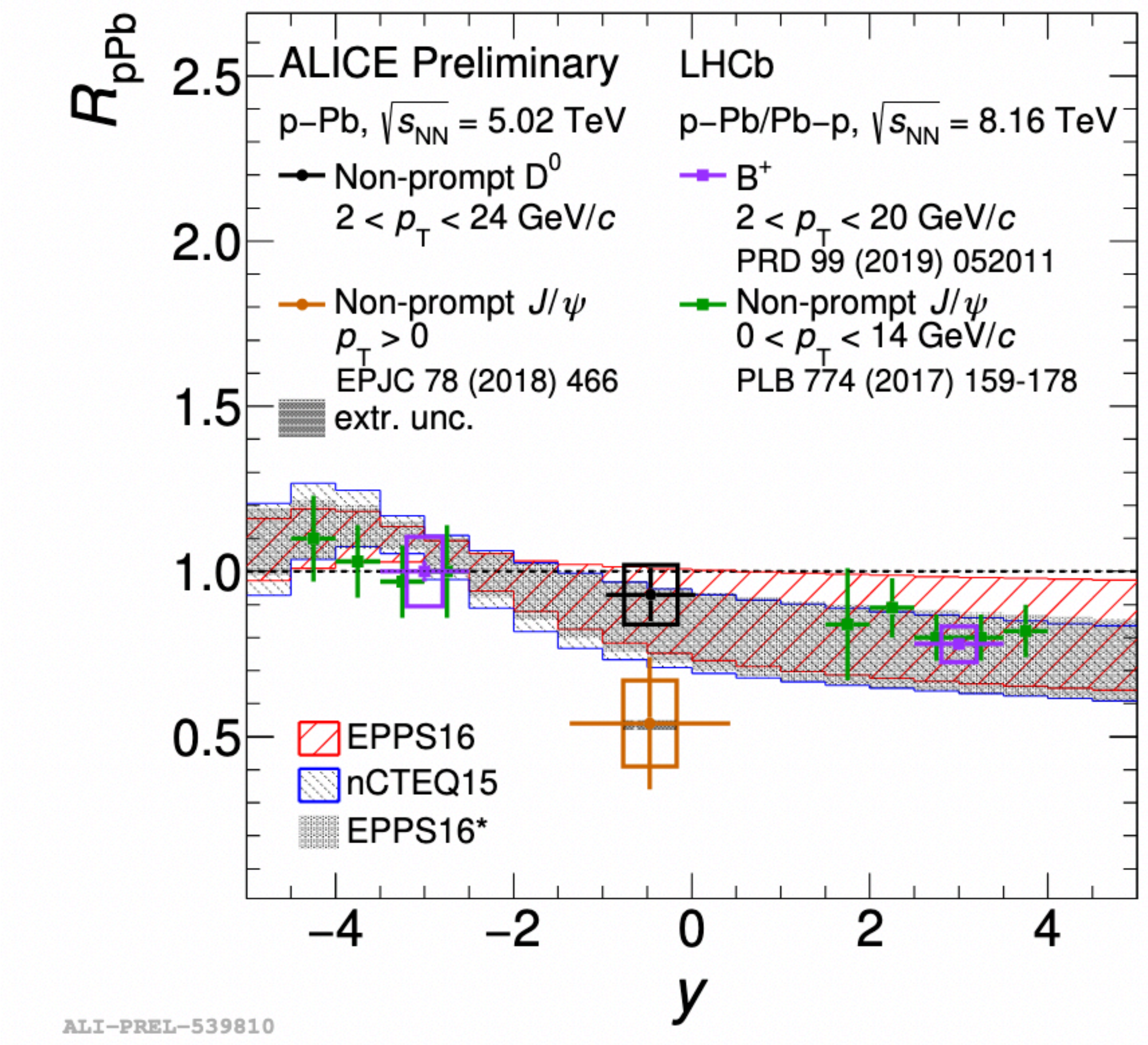
D-meson R_{pPb} is compatible with unity and compared to model predictions including CNM effects

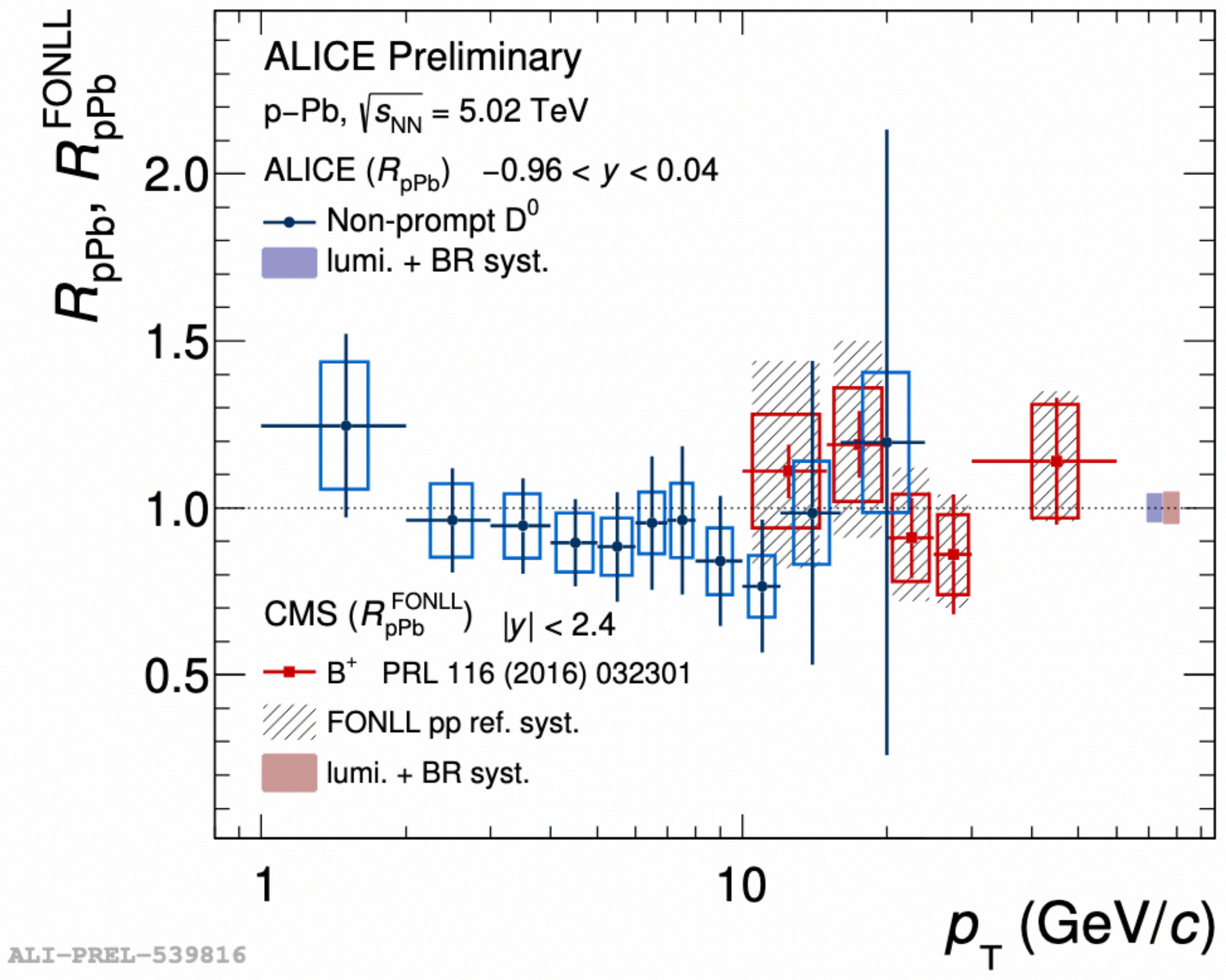
Both Λ_c^+ and Ξ_c^0 R_{pPb} are compatible within uncertainties → similar modification of the production in p–Pb collisions

✓ R_{pPb} of Ξ_c^0 is larger than unity → no conclusion of increasing trend with p_T due to large uncertainties

✓ Models underestimate the data (only Λ_c^+ R_{pPb} is described below 2 GeV/c)

R_{pPb} of non-prompt charm hadrons





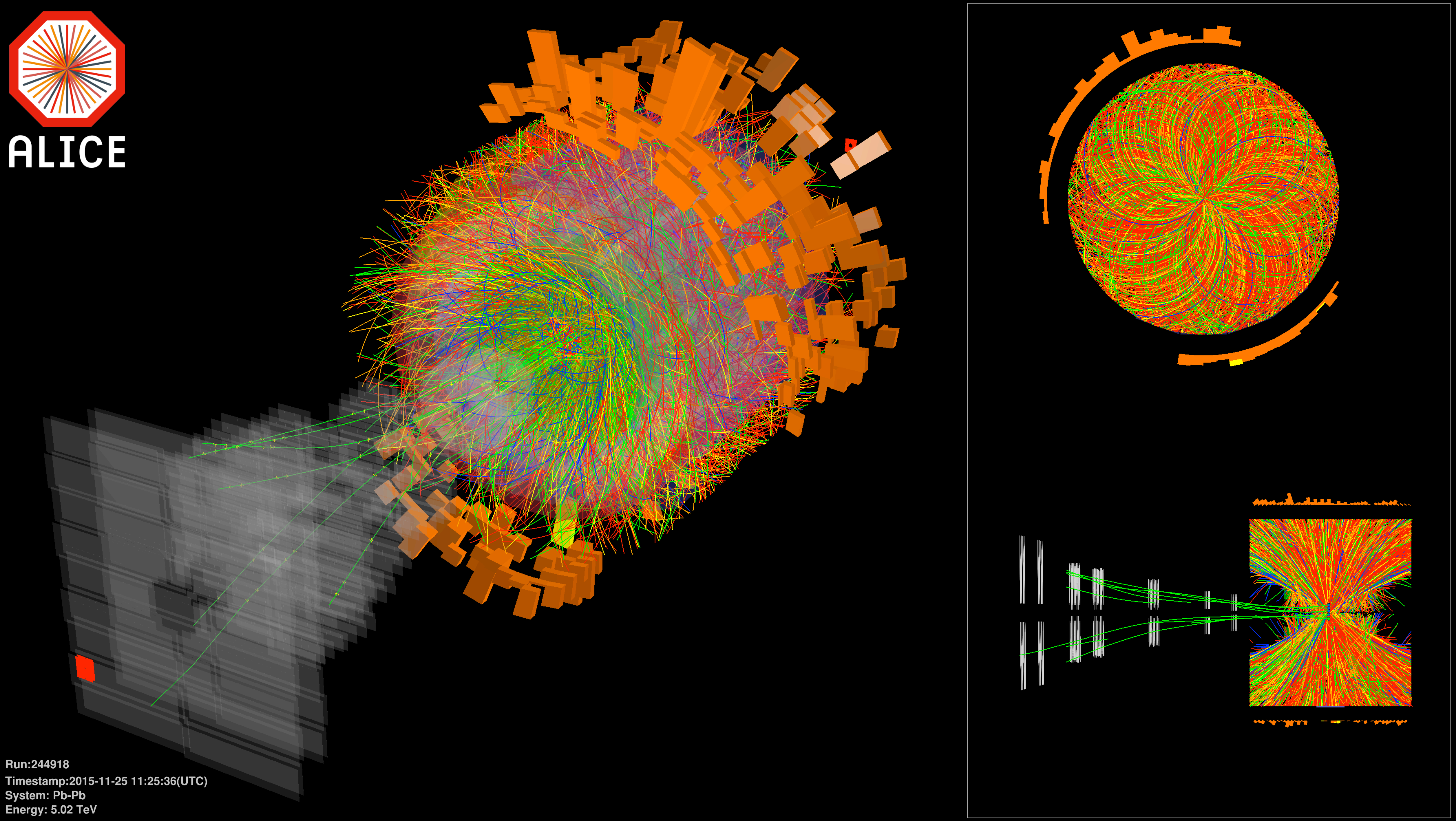
EPPS16
EPJC 77 (2017) 163
nCTEQ15
Phys. Rev. D 93 (2016) 085037
EPPS*
Phys. Rev. Lett. 121 (2018) 052004

- **p_T-integrated R_{pPb} of measured at midrapidity**

✓ Observed a possible suppression for non-prompt J/ψ
✓ Suppression at forward rapidity whereas compatible with unity at backward rapidity
✓ Good agreement with model predictions within uncertainties

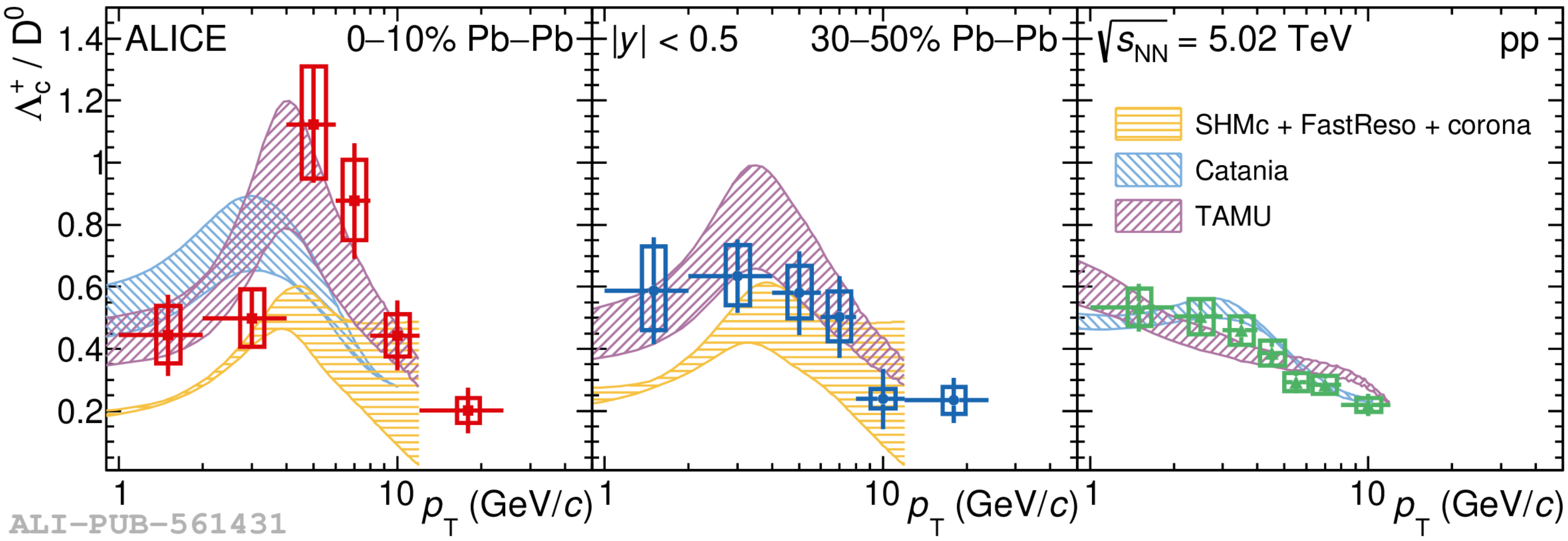
- **Consistent with B meson R_{pPb} result from CMS at high p_T**

Results in Pb–Pb collisions



Λ_c^+/D^0 ratio

SHMc : JHEP 07 (2021) 035
Catania : Phys. Lett. B 821 (2021) 136622 (pp) EPJC 78 (2018) 348 (Pb–Pb)
TAMU : Phys. Lett. B 795 (2019) 117–121 (pp) Phys. Rev. Lett. 124 (2020) 042301 (Pb–Pb)



Ratio increases from pp to semicentral and central Pb–Pb collisions at the intermediate p_T region

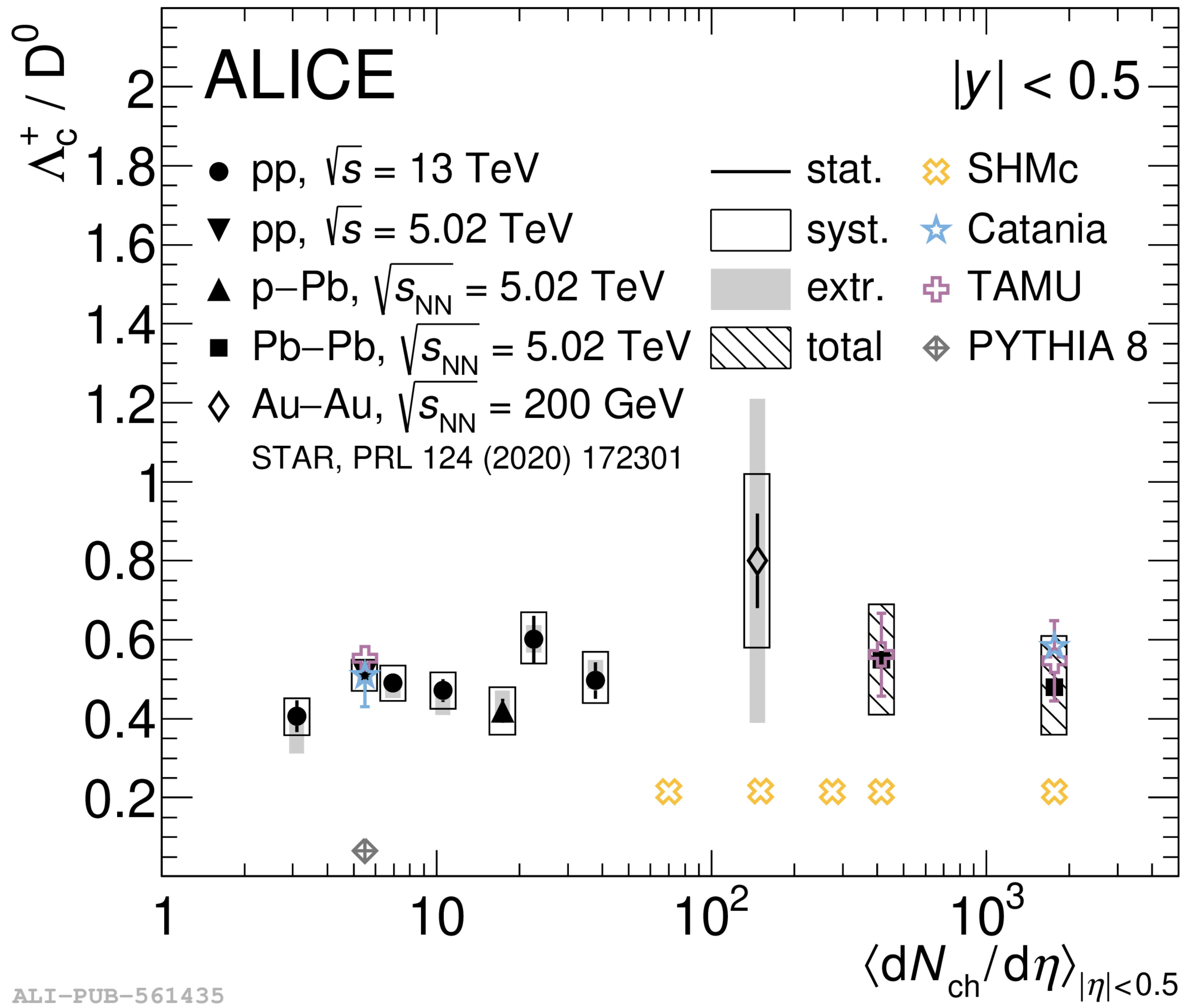
◉ **Compare to different model predictions**

✓ **SHMc : describe the ratio in semicentral collisions and underestimate the data in 4 < p_T < 8 GeV/c in central collisions**

✓ **Catania : underestimate the data in the intermediate p_T region**

✓ **TAMU : reproduce the magnitude and shape of the data, and better description within uncertainties**

Λ_c^+/D⁰ ratio



p_T-integrated ratio vs multiplicity from pp to Pb–Pb

✓No multiplicity dependence observed

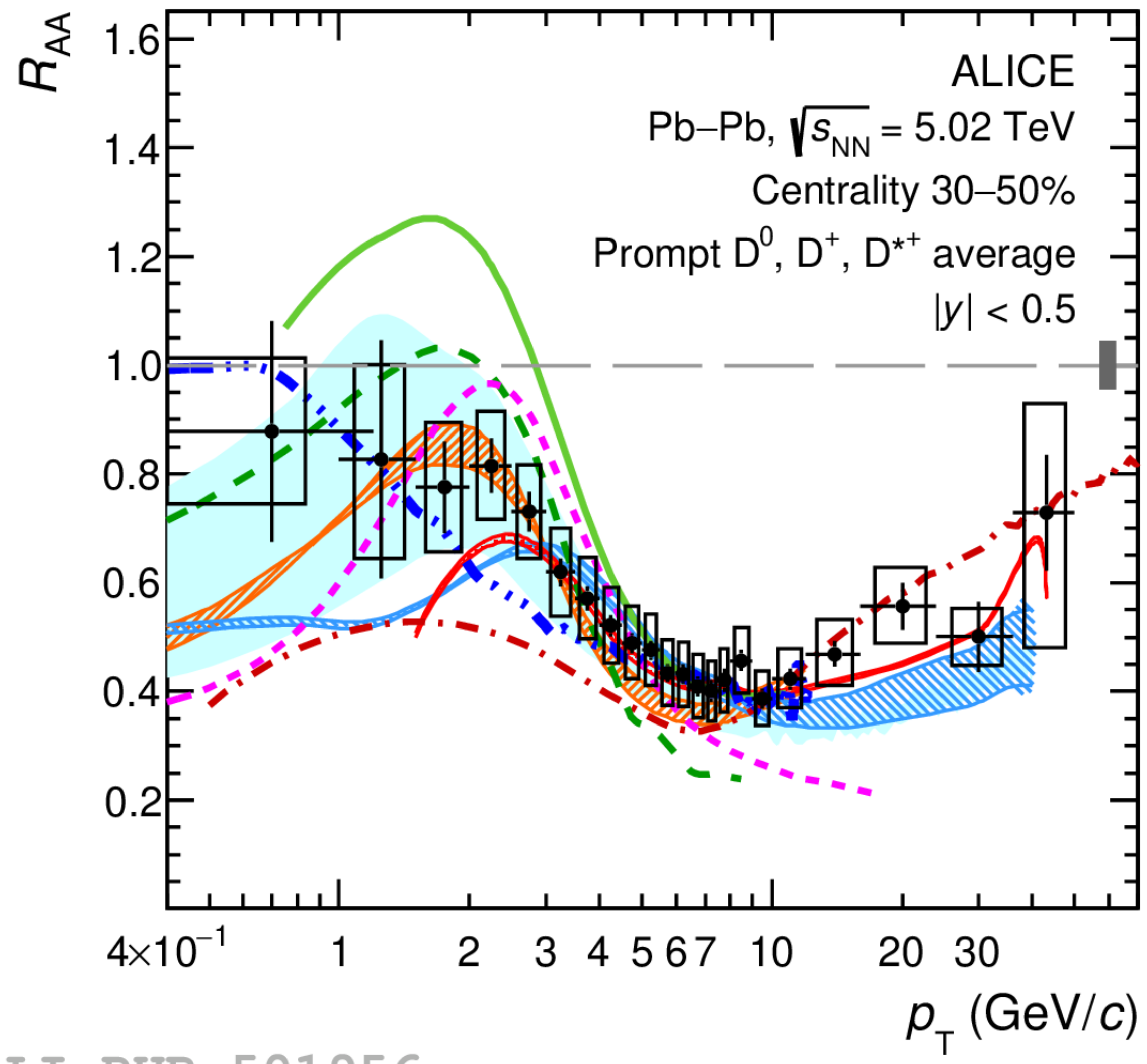
Suggest a modified mechanism of hadronization in all hadronic collisions w.r.t e^+e^- and e-p collisions (PYTHIA 8)

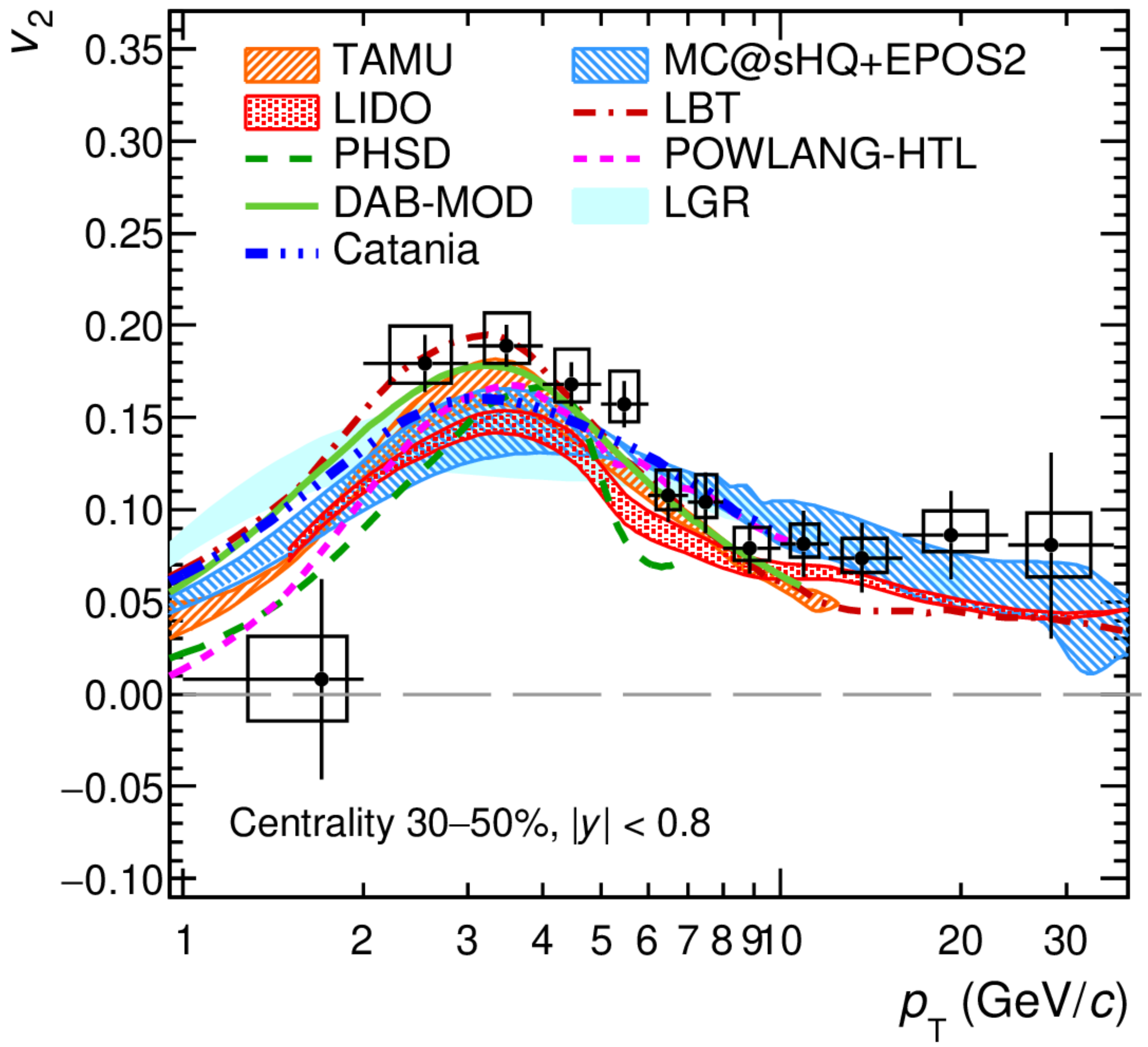
Catania and TAMU describe the data, while SHMc underestimates the data

✓unobserved charm-baryon states need to be assumed in normalisation

SHMc : JHEP 07 (2021) 035
Catania : Phys. Lett. B 821 (2021) 136622 (pp) EPJC 78 (2018) 348 (Pb–Pb)
TAMU : Phys. Lett. B 795 (2019) 117–121 (pp) Phys. Rev. Lett. 124 (2020) 042301 (Pb–Pb)
PYTHIA 8 : Comput. Phys. Commun. 191 (2015) 159–17

R_{AA} and v_2 of non-strange D mesons





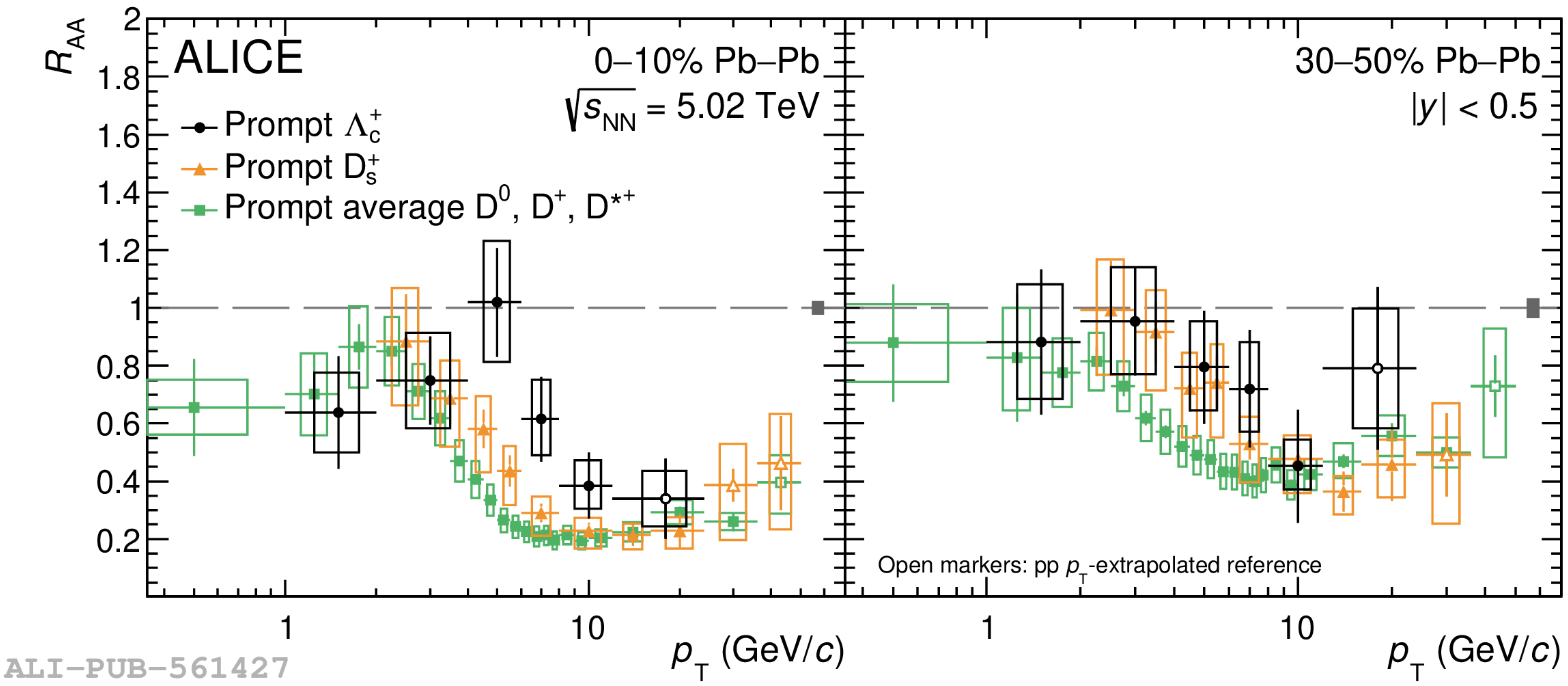
ALI-PUB-501956

TAMU
Phys. Rev. Lett. 124 (2020) 042301
LIDO
Phys. Rev. C 100 (2019) 064911
PHSD
Phys. Rev. C 92 (2015) 014910
DAB-MOD
Phys. Rev. C 102 (2020) 024906
Catania
Phys. Rev. C 96 (2017) 044905
Phys. Lett. B 805 (2020) 135460
MC@sHQ+EPOS2
Phys. Rev. C 89 (2014) 014905
LBT
Phys. Rev. C 94 (2016) 014909
Phys. Lett. B 777 (2018) 255
POWLANG+HLT
EPJC 75 (2015) 121
JHEP 02 (2018) 043
LGR
EPJC 80 (2020) 671

Understanding the heavy-quark interactions with the medium constitutes by comparing R_{AA} and v_2 with models
✓ Models fairly describe the data, but challenging to describe the R_{AA} and v_2 simultaneously
✓ Realistic QGP evolution, collisional/radiative energy loss, and hadronization mechanisms (fragmentation/coalescence) are required to describe the data

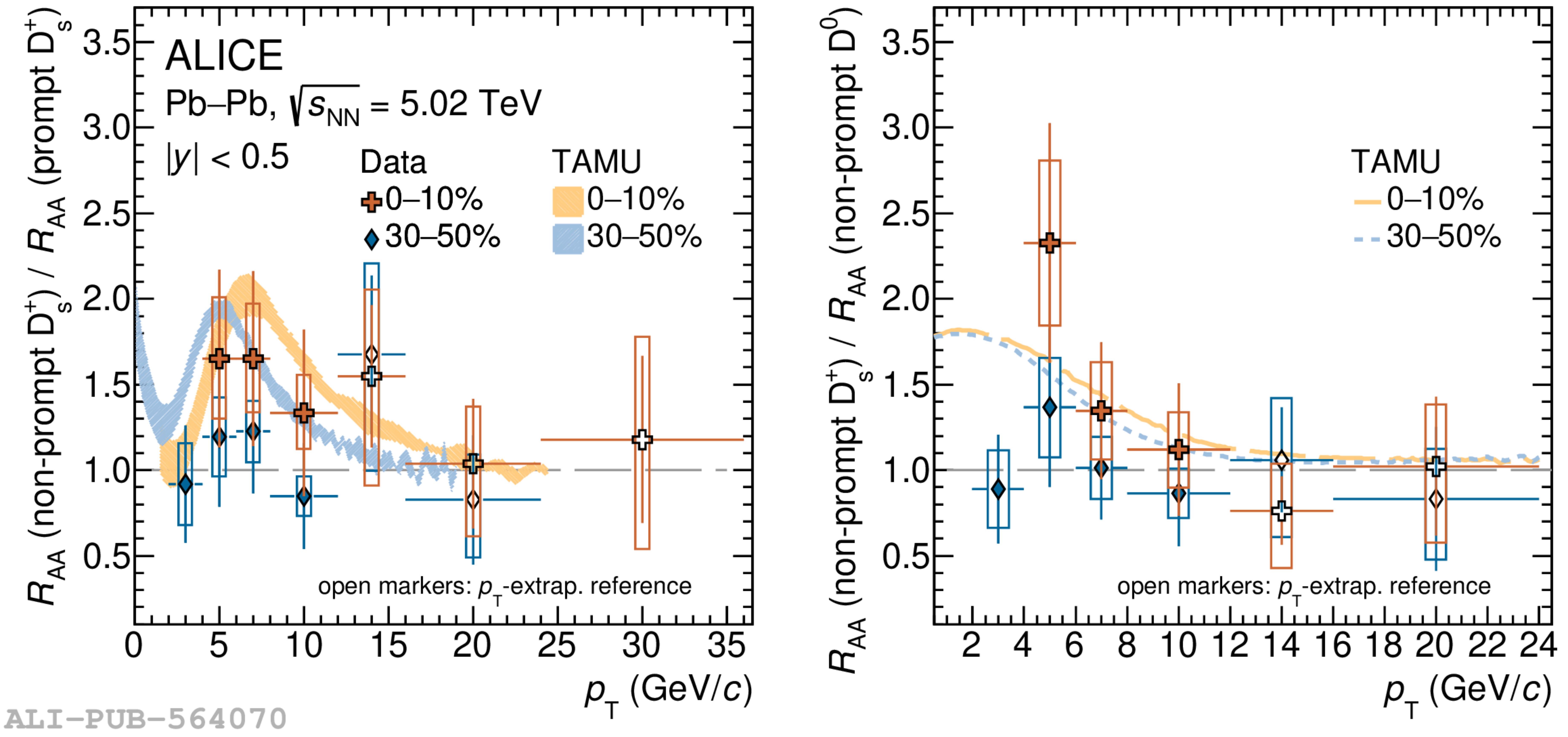
Sensitive to quark diffusion, thermalisation with the medium, and hadronization mechanisms for $2 < p_T < 6$ GeV/c

R_{AA} of charm hadrons



- **Suppression of all charm species from p_T > 6 GeV/c for 0–10% and from p_T > 4 GeV/c for 30–50% -> Interaction of charm quarks with the medium**
- **Hint of a hierarchy $R_{AA}(D^0) < R_{AA}(D_s^+) < R_{AA}(\Lambda_c^+)$ in 4 < p_T < 8 GeV/c in 0–10%, while less pronounced in 30–50%**
- **For p_T > 10 GeV/c, all R_{AA} are compatible within uncertainties**

R_{AA} ratio of non-prompt D mesons



TAMU
Phys. Lett. B 735 (2014) 445

R_{AA} ratio of non-prompt D_s^+ to prompt D_s^+ and non-prompt D^0

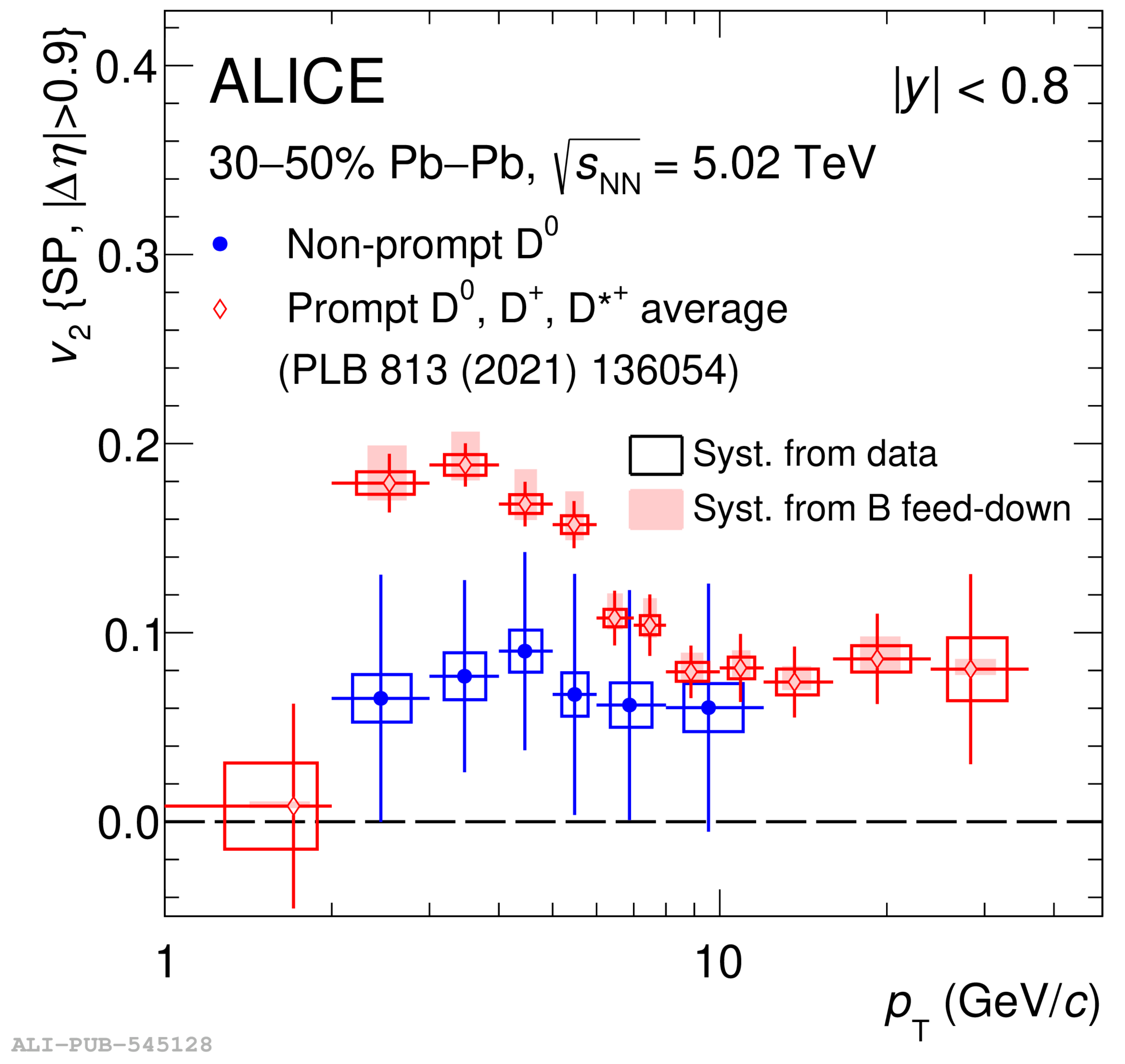
✓ Larger energy loss of charm quark with respect to beauty quark in central collisions

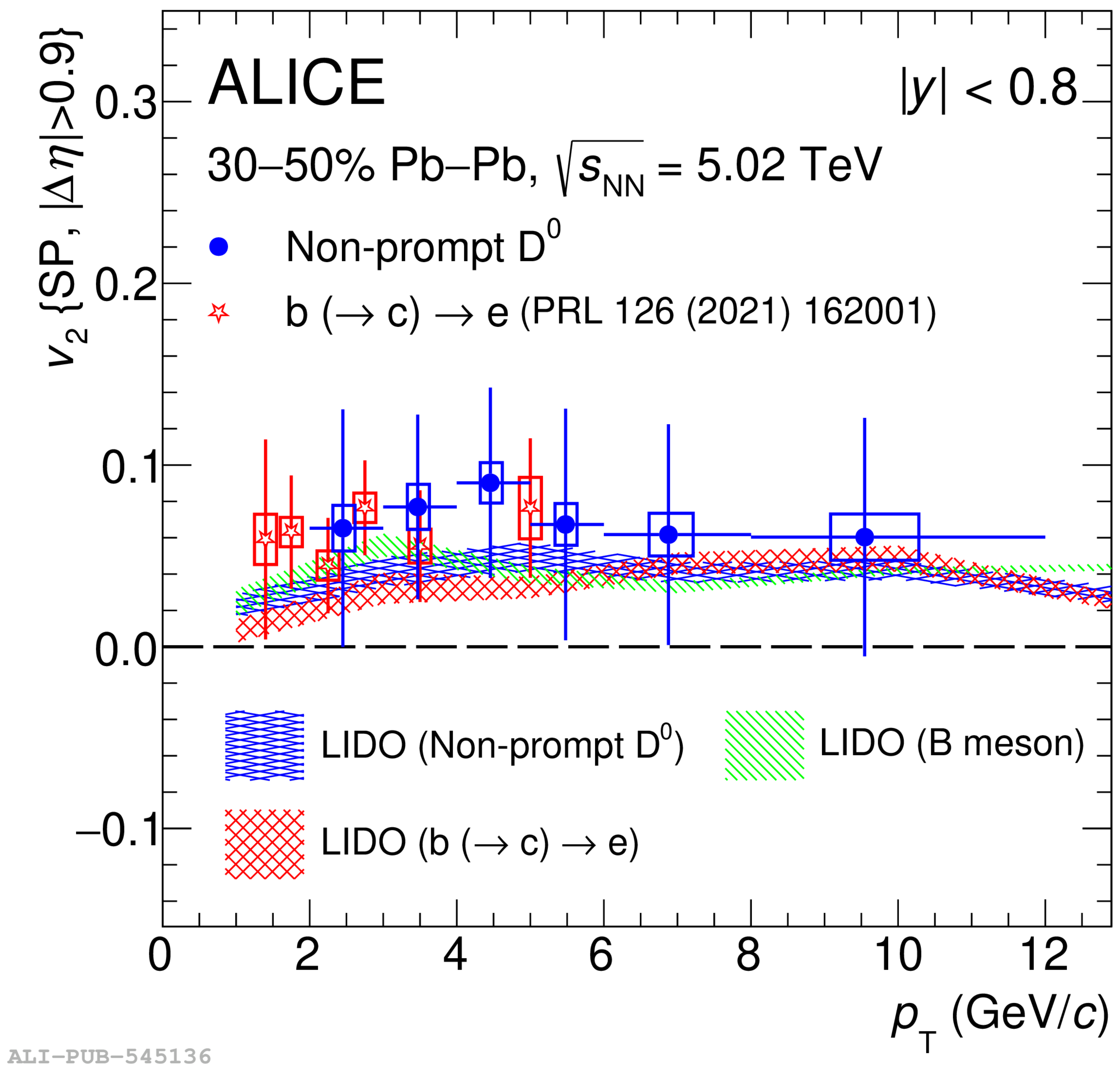
✓ Consistent with unity in semicentral collisions

TAMU model describes the data for central collisions while overestimates for semicentral collisions

✓ Possible enhancement at low pT → the abundance of strange quarks and the hadronisation via recombination

Elliptic flow of non-prompt D mesons





LIDO
Phys. Rev. C 98 (2018) 064901
Phys. Rev. C 100 (2019) 064911
- beauty quark transport
- collisional+radiative
- fragmentation+coalescence

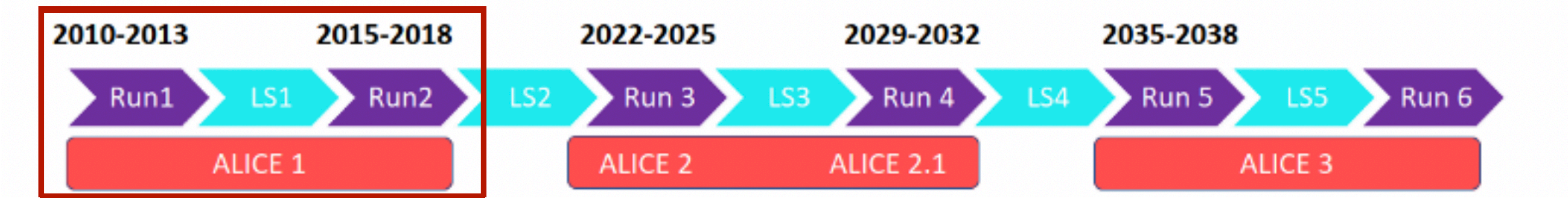
Non-prompt D^0 v2 is lower than that of prompt non-strange D meson v2

✓ Different degree of participation between charm and beauty quarks in the medium expansion Compatible with the v2 of beauty-decay electrons within uncertainties

✓ Good agreement with LIDO predictions

✓ No significant difference of decay kinematics between B meson and non-prompt D^0 meson

Summary



In pp collisions :

◉ Production cross section described by pQCD calculations

◉ Fragmentation function universality is violated in pp collisions

✓ Hadronisation via recombination is dominant at low pT

In p–Pb collisions :

◉ Heavy-quark production is not significantly affected by CNM effects

◉ Enhanced baryon production in p–Pb collisions w.r.t pp collisions in the intermediate pT region

In Pb–Pb collisions :

◉ Baryon enhancement depends on the event multiplicity, while pT-integrated baryon-to-meson ratio is consistent across collision systems

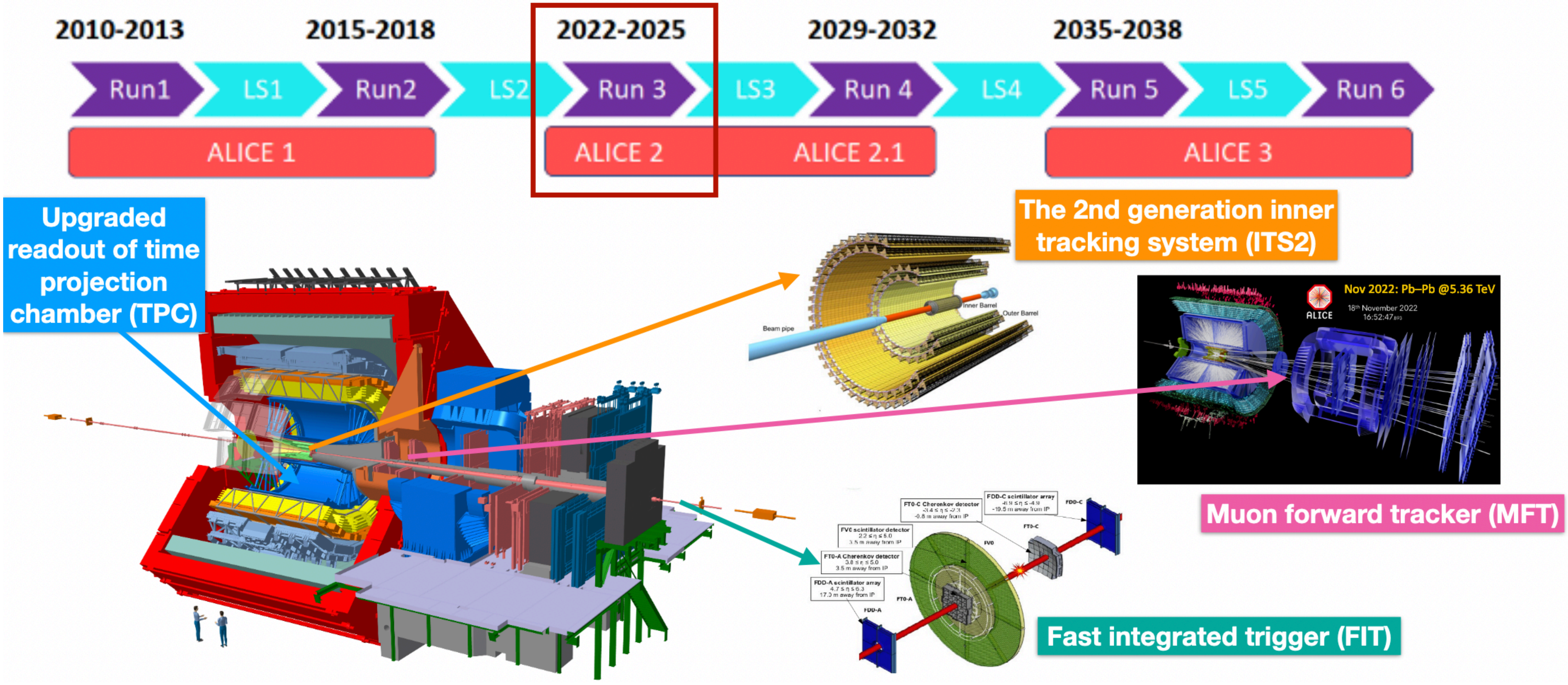
◉ Both charm and beauty quarks lose energy in the medium

✓ Beauty quarks lose less energy than charm quarks

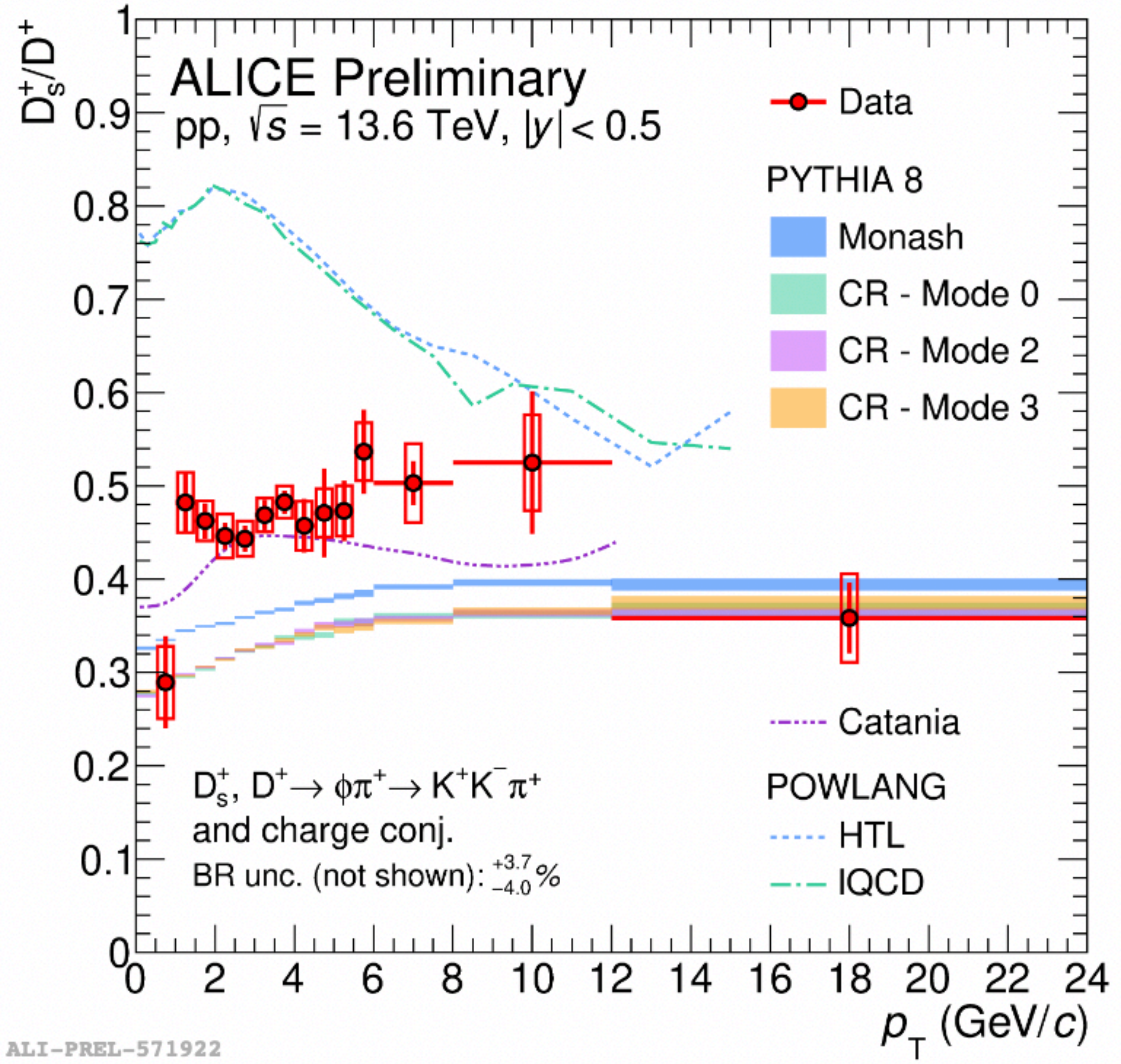
◉ Heavy quarks participate in a hydrodynamically expanding medium, v2(HF) > 0

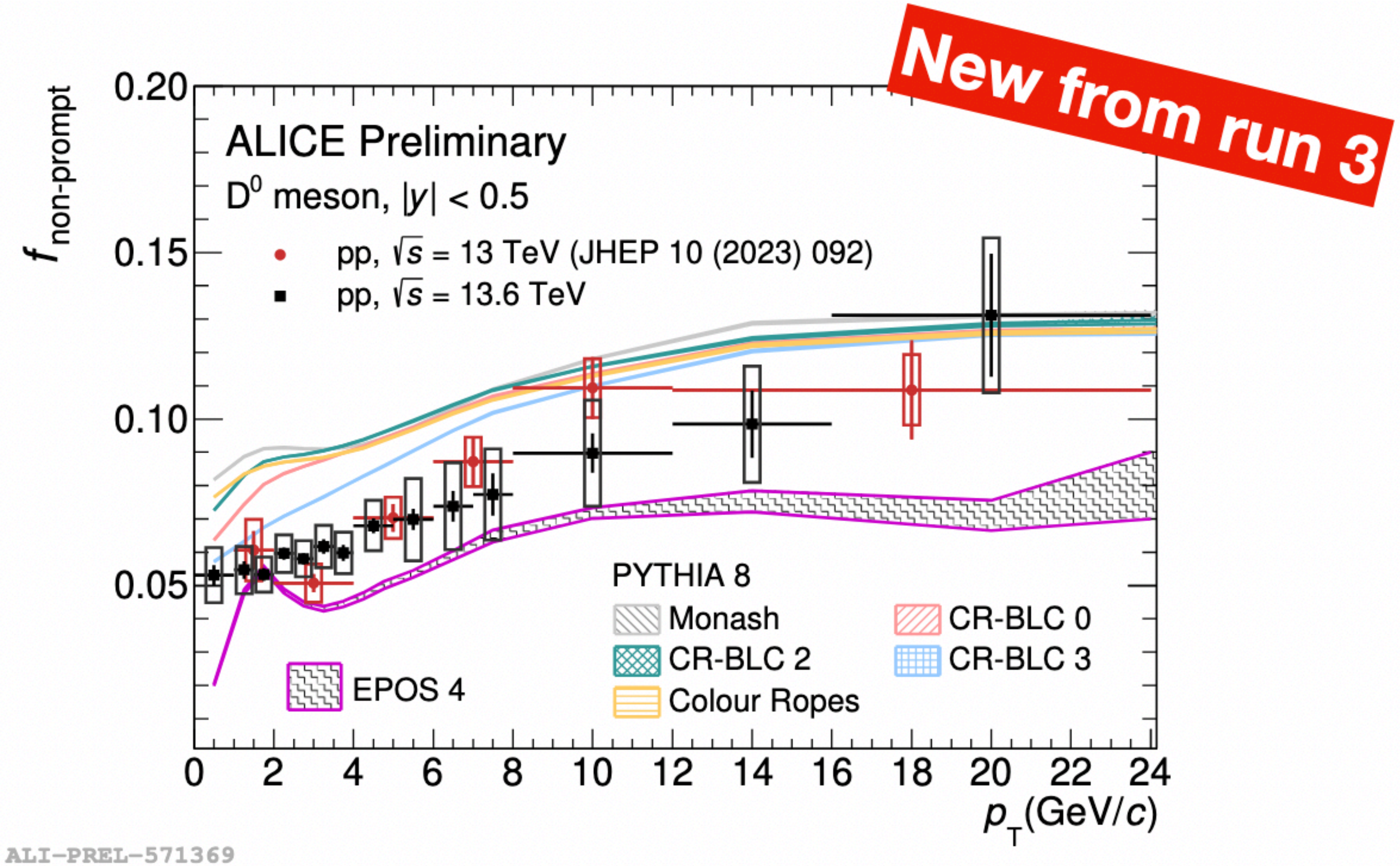
✓ v2(c) > v2(b)

What's going on ?



Recent results from Run3 : D_s^+ and b→D⁰ production

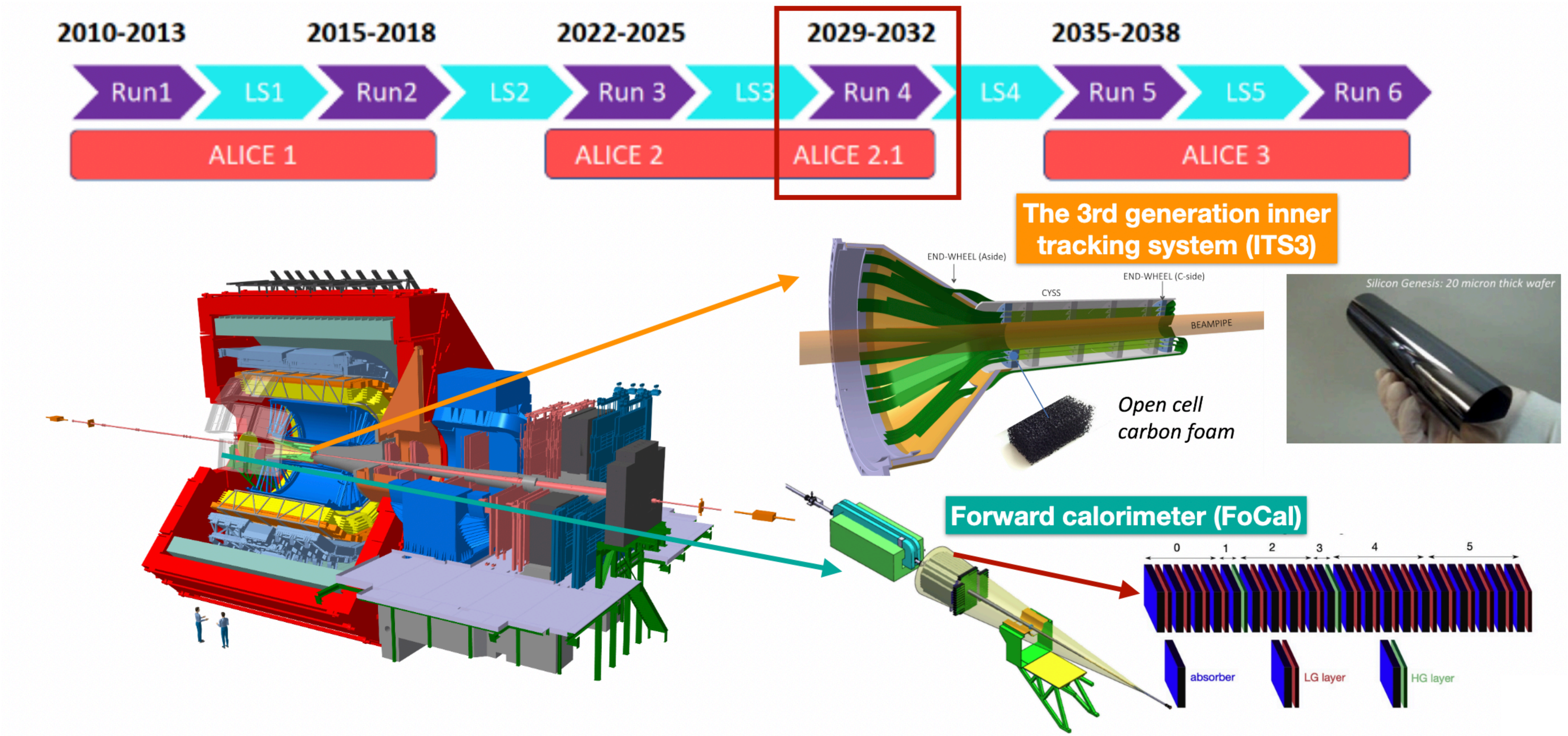




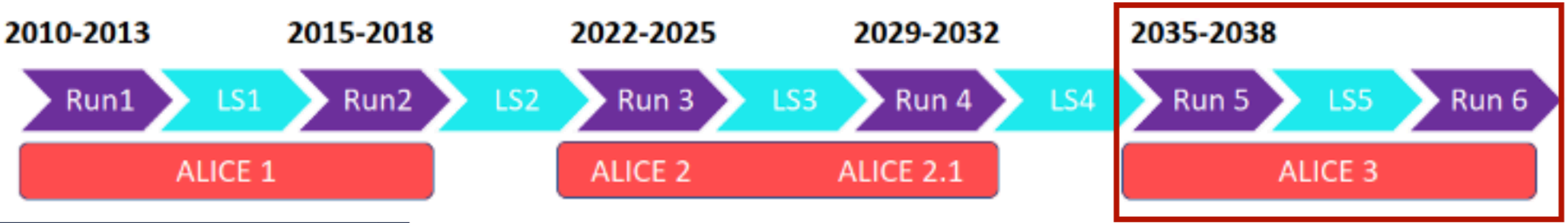
- Measurements are extended to lower p_T and more granular w. r. t. run 2

➡ Stronger constraints on the modelling of charm-quark hadronization

What's next?

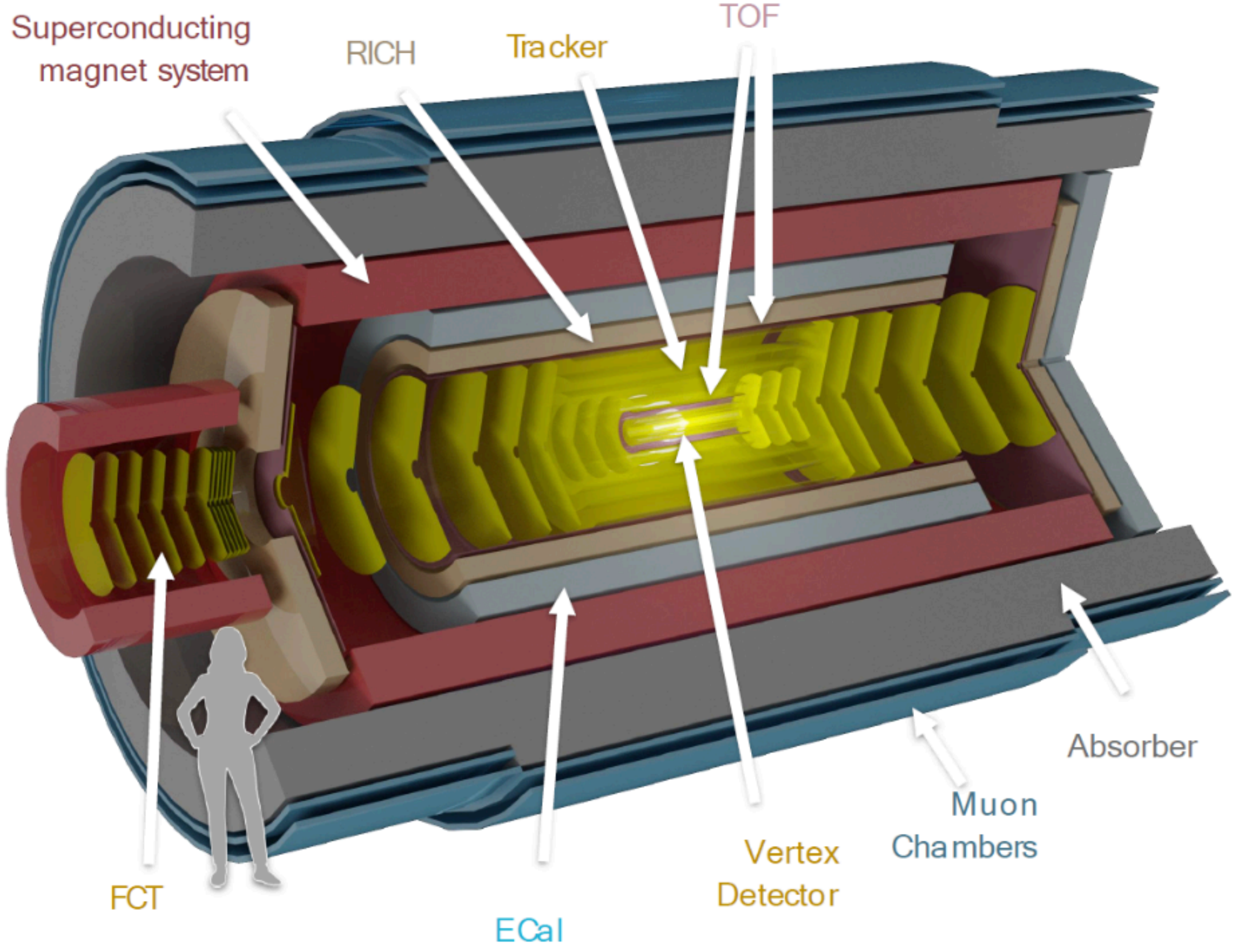

2010-2013
2015-2018
2022-2025
2029-2032
2035-2038
Run1
LS1
Run2
LS2
Run 3
LS3
Run 4
LS4
Run 5
LS5
Run 6
ALICE 1
ALICE 2
ALICE 2.1
ALICE 3
The 3rd generation inner tracking system (ITS3)
END-WHEEL (Aside)
END-WHEEL (C-side)
CYSS
BEAMPIPE
Open cell carbon foam
Silicon Genesis: 20 micron thick wafer
Forward calorimeter (FoCal)
0
1
2
3
4
5
absorber
LG layer
HG layer

What's next?

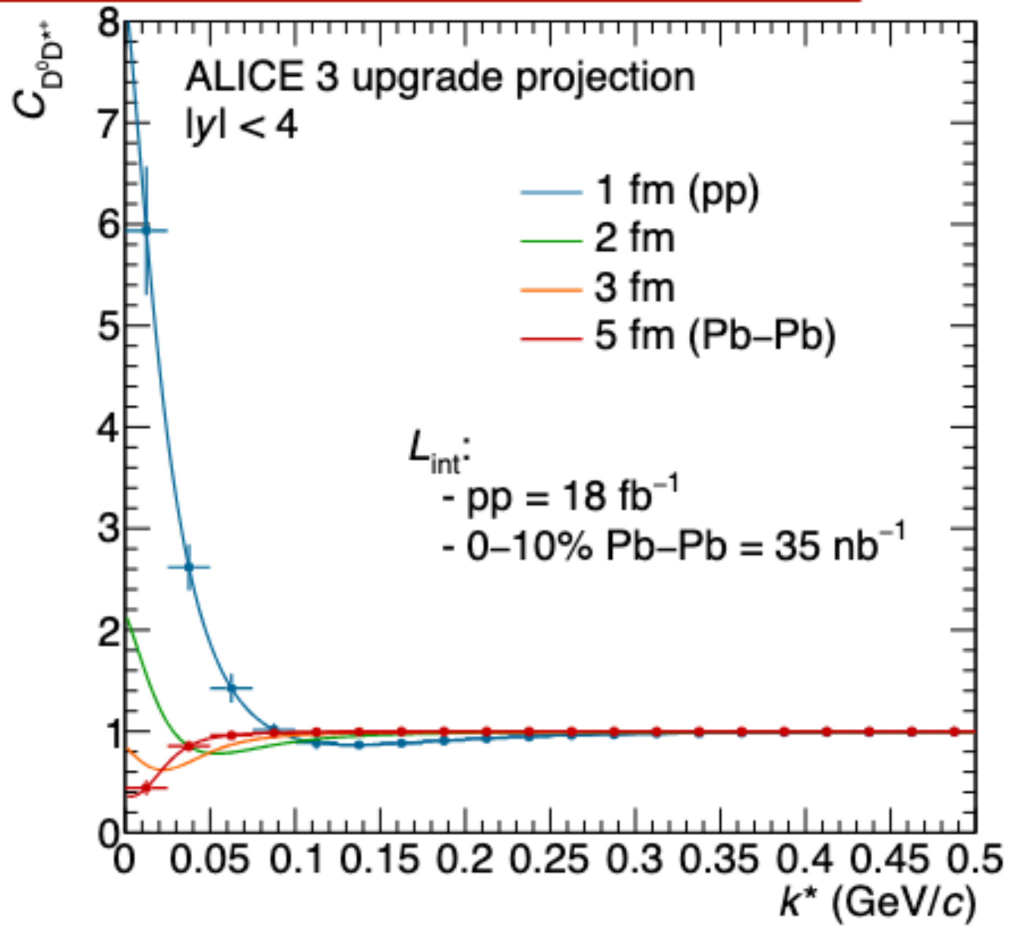


2010-2013
2015-2018
2022-2025
2029-2032
2035-2038
Run1
LS1
Run2
LS2
Run 3
LS3
Run 4
LS4
Run 5
LS5
Run 6
ALICE 1
ALICE 2
ALICE 2.1
ALICE 3

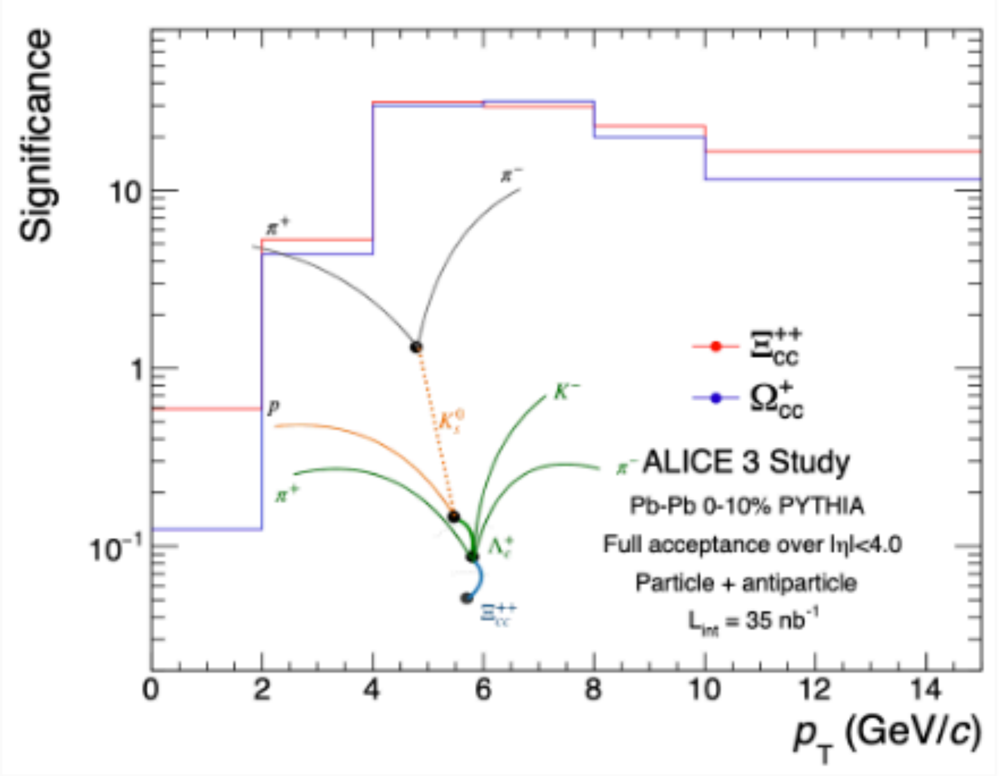
ALICE 3
Letter of intent
CERN-LHCC-2022-009
(LHCC-I-038)
4 November 2022
ALICE
ALICE arXiv:2211.02491
A next-generation heavy-ion experiment at the LHC
VERSION 2



Superconducting magnet system
RICH
Tracker
TOF
Absorber
Muon Chambers
Vertex Detector
ECal
FCT

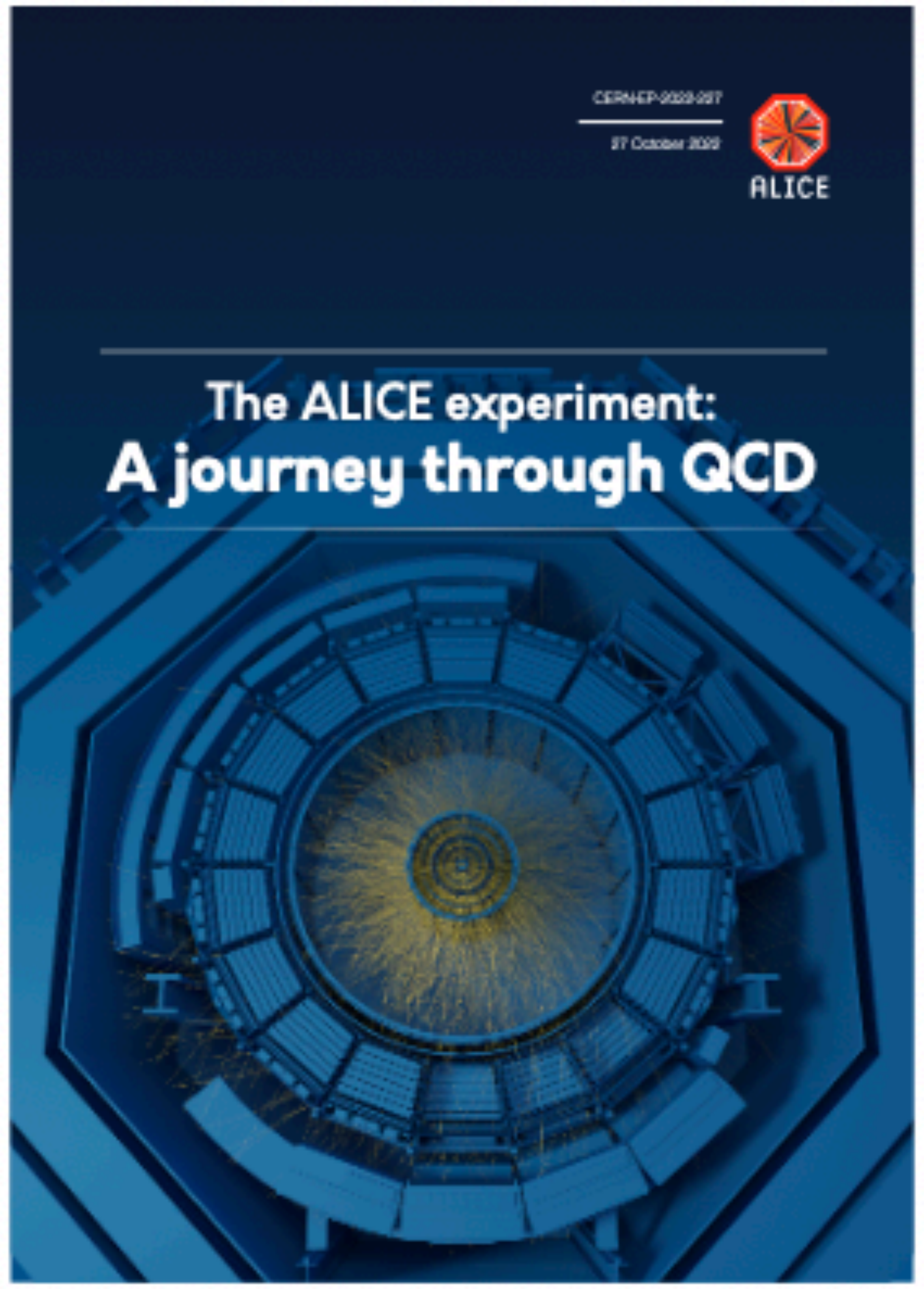


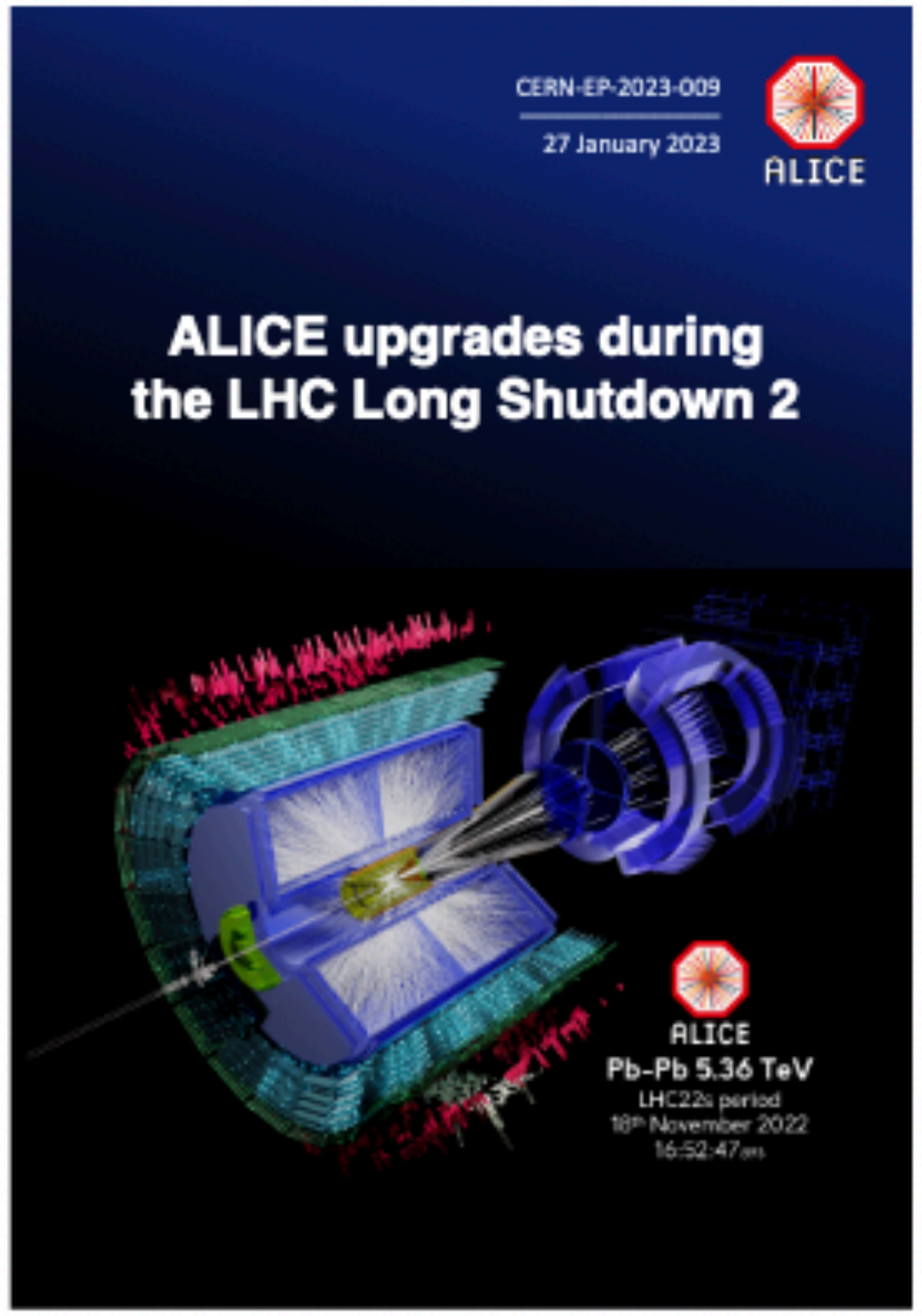
ALICE 3 upgrade projection
|y| < 4
1 fm (pp)
2 fm
3 fm
5 fm (Pb–Pb)
L_int:
- pp = 18 fb^-1
- 0–10% Pb–Pb = 35 nb^-1
k* (GeV/c)

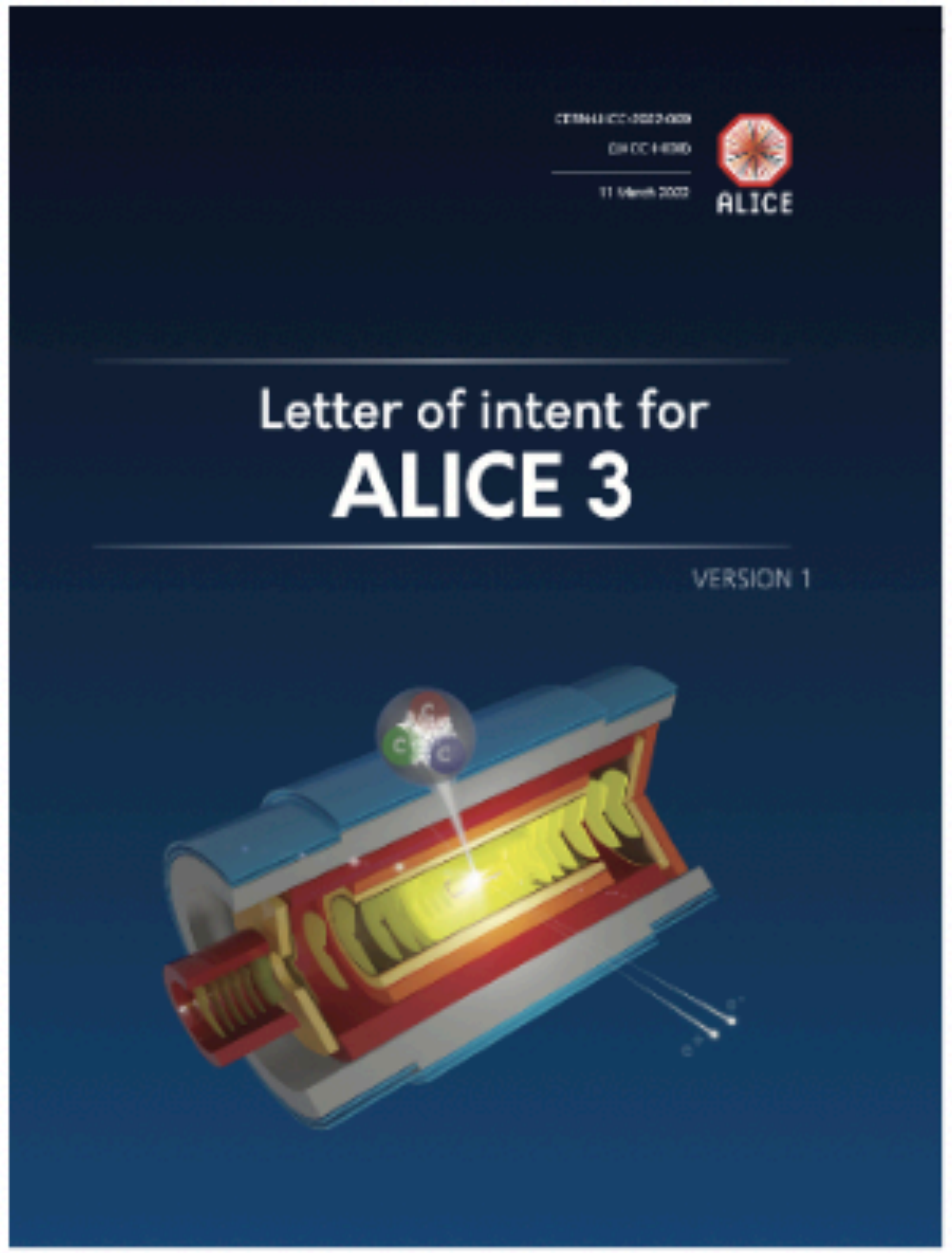


Significance
ALICE 3 Study
Pb-Pb 0-10% PYTHIA
Full acceptance over |η|<4.0
Particle + antiparticle
p_T (GeV/c)

Find out more







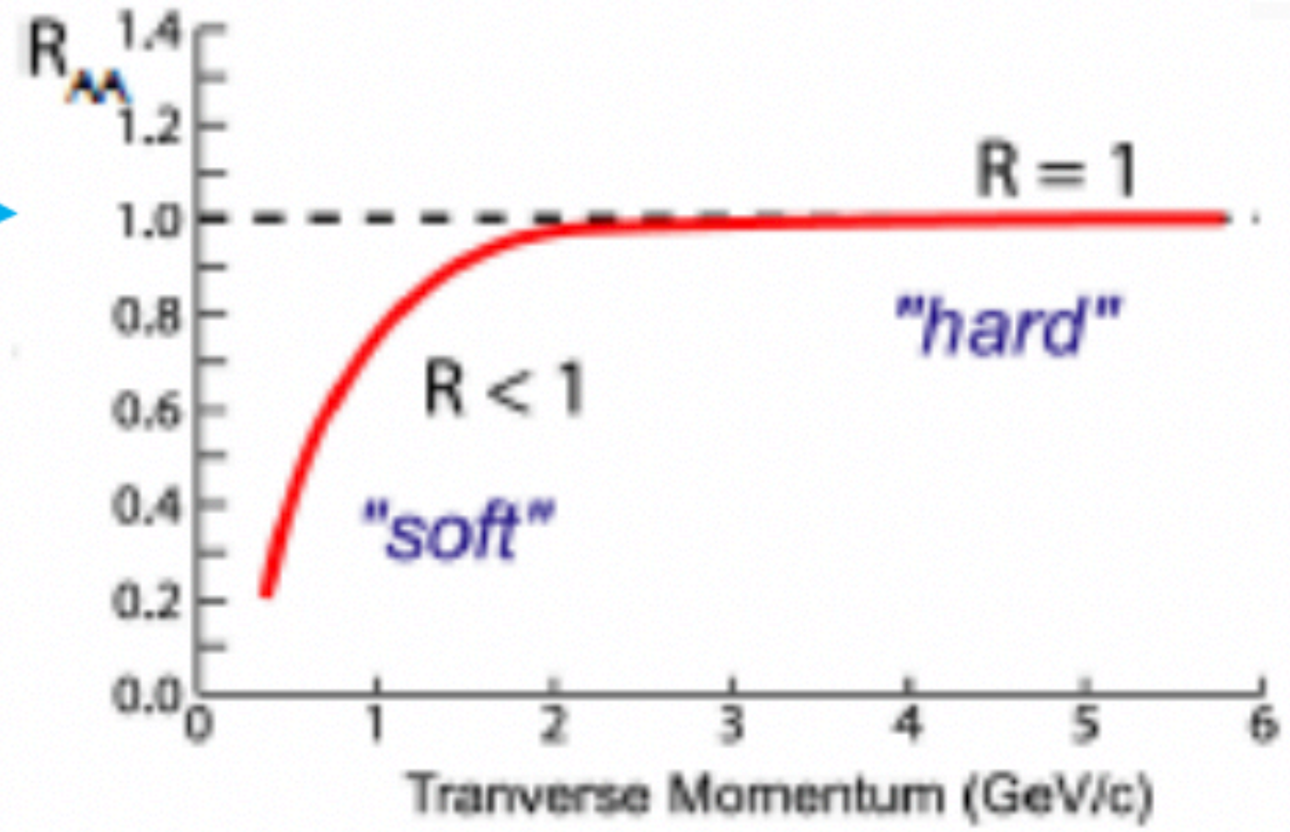
Thank you

Backup

- **Nuclear modification factor:**

$$R_{AA} = \frac{AA}{\text{rescaled } pp} = \frac{d^2N_{AA}/dp_T\,dy}{\langle N_{binary}\rangle\, d^2N_{pp}/dp_T\,dy}$$

R_{AA} = 1 if no medium effects

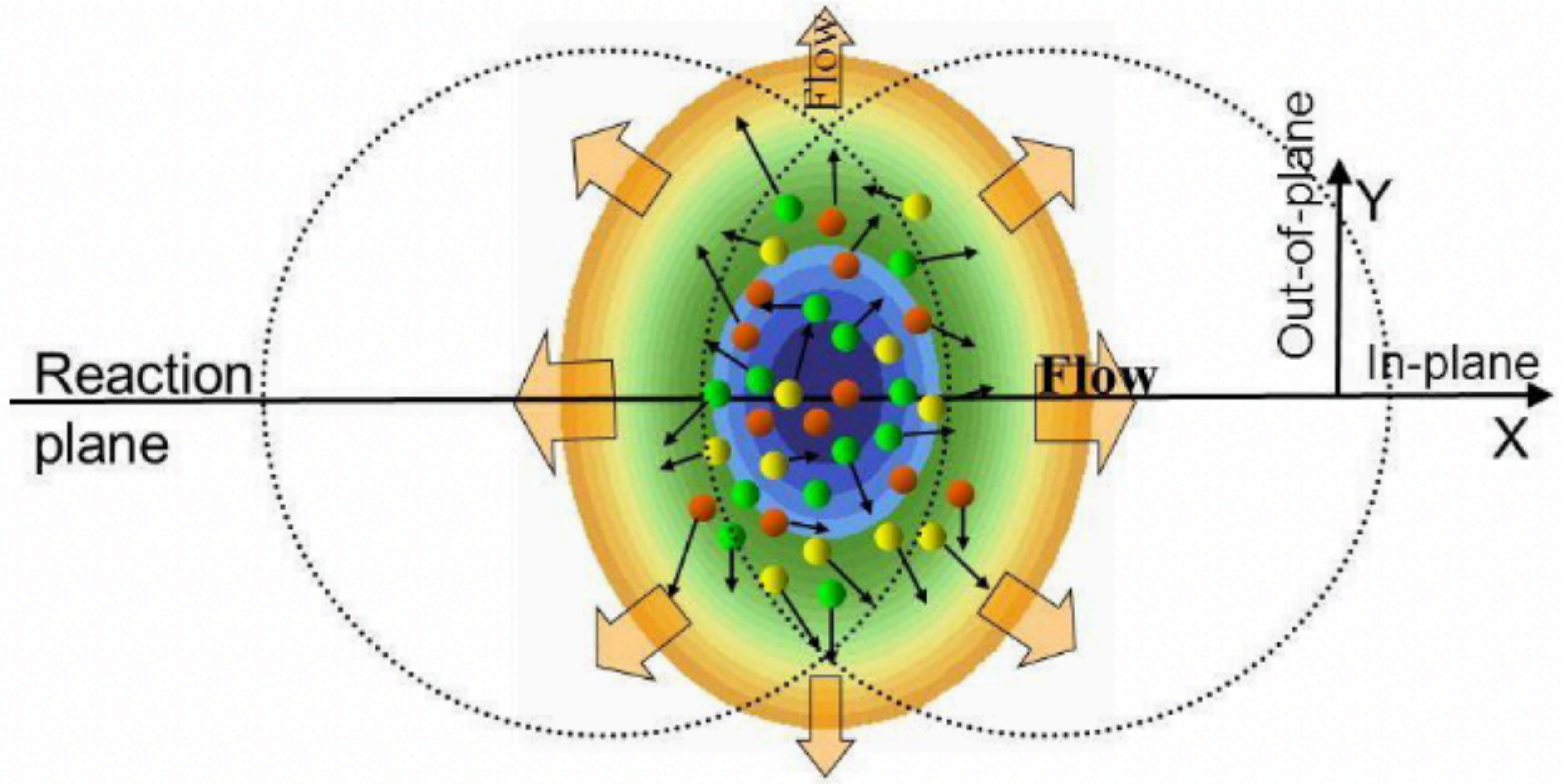


- **Elliptic flow**: initial spatial anisotropy+ hydro = final momentum anisotropy

Quantified by the second Fourier coefficient, v_2

$$\frac{dN}{d\varphi} = \frac{N}{2\pi}\left[1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\varphi - \Psi_R\right)\right)\right]$$

$$v_2 = < cos2(\varphi_{part} - \Psi_{EP}) >$$

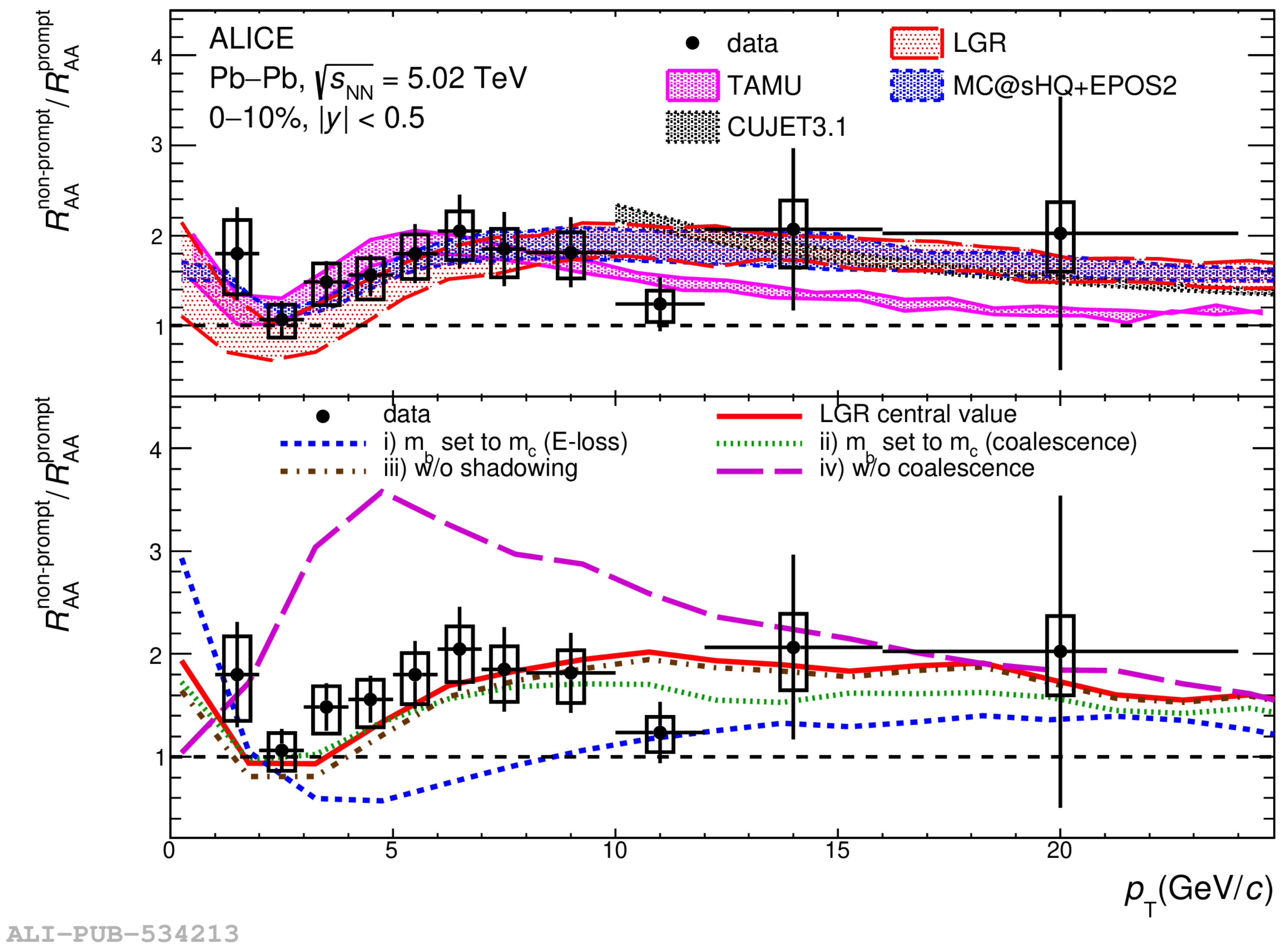


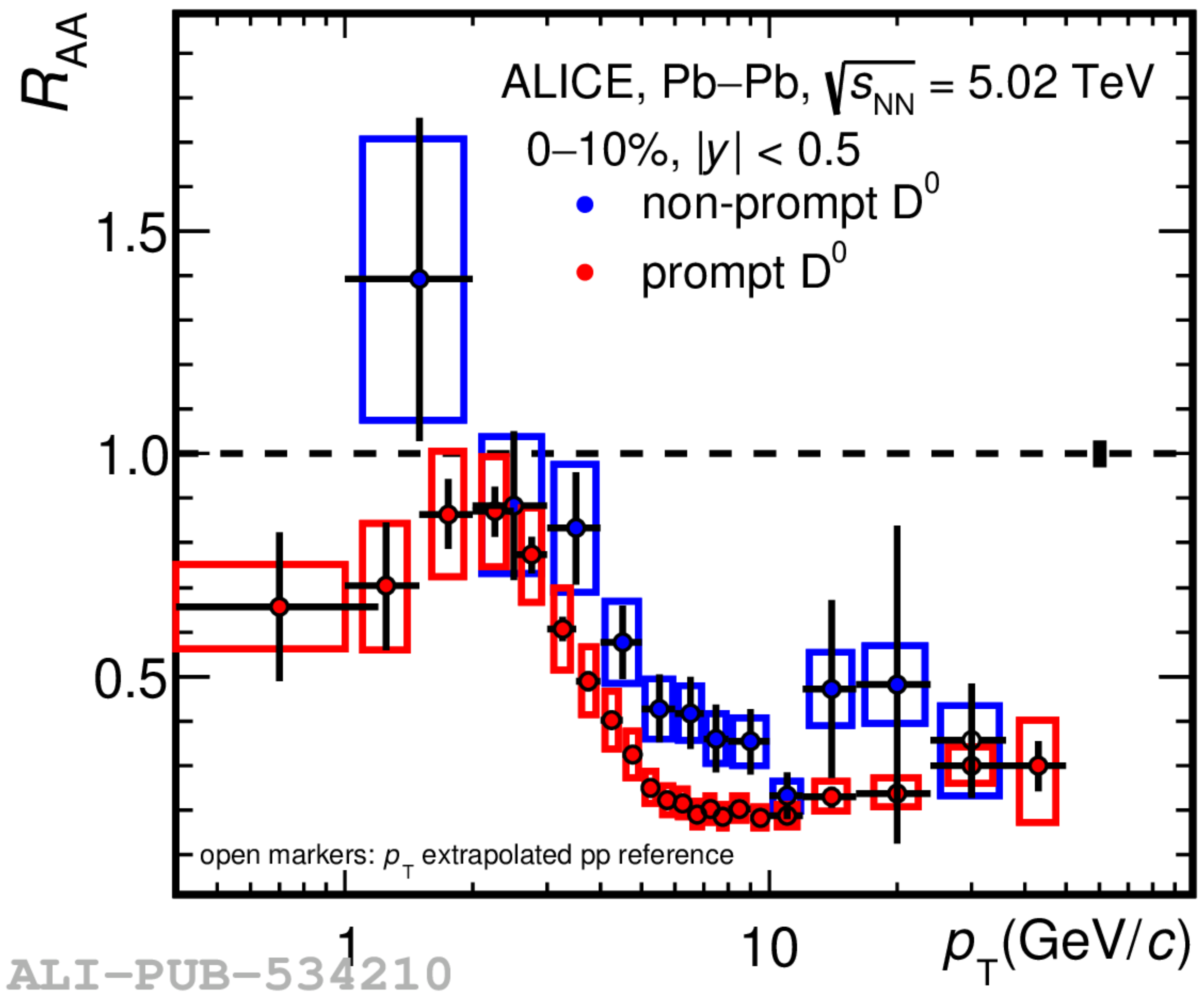
Driven by overlap geometry

→ Related to pressure gradients & shear viscosity to entropy ratio (η/s)

→ Sensitive to thermalization of the system

R_{AA} ratio of prompt D^0





TAMU
Phys. Lett. B 735 (2014) 445
CUJET3.1
Chin. Phys. C 43 (2019) 044101
LGR
EPJC 80 (2020) 671
Phys. J. C 80 (2020) 1113
MC@sHQ+EPOS2
Phys. Rev. C 89 (2014) 014905

Non-prompt D^0 R_{AA} is systematically higher than that of prompt D^0 for p_T > 5 GeV/c in both centrality classes
✓ Hint of a mass dependent in-medium energy loss

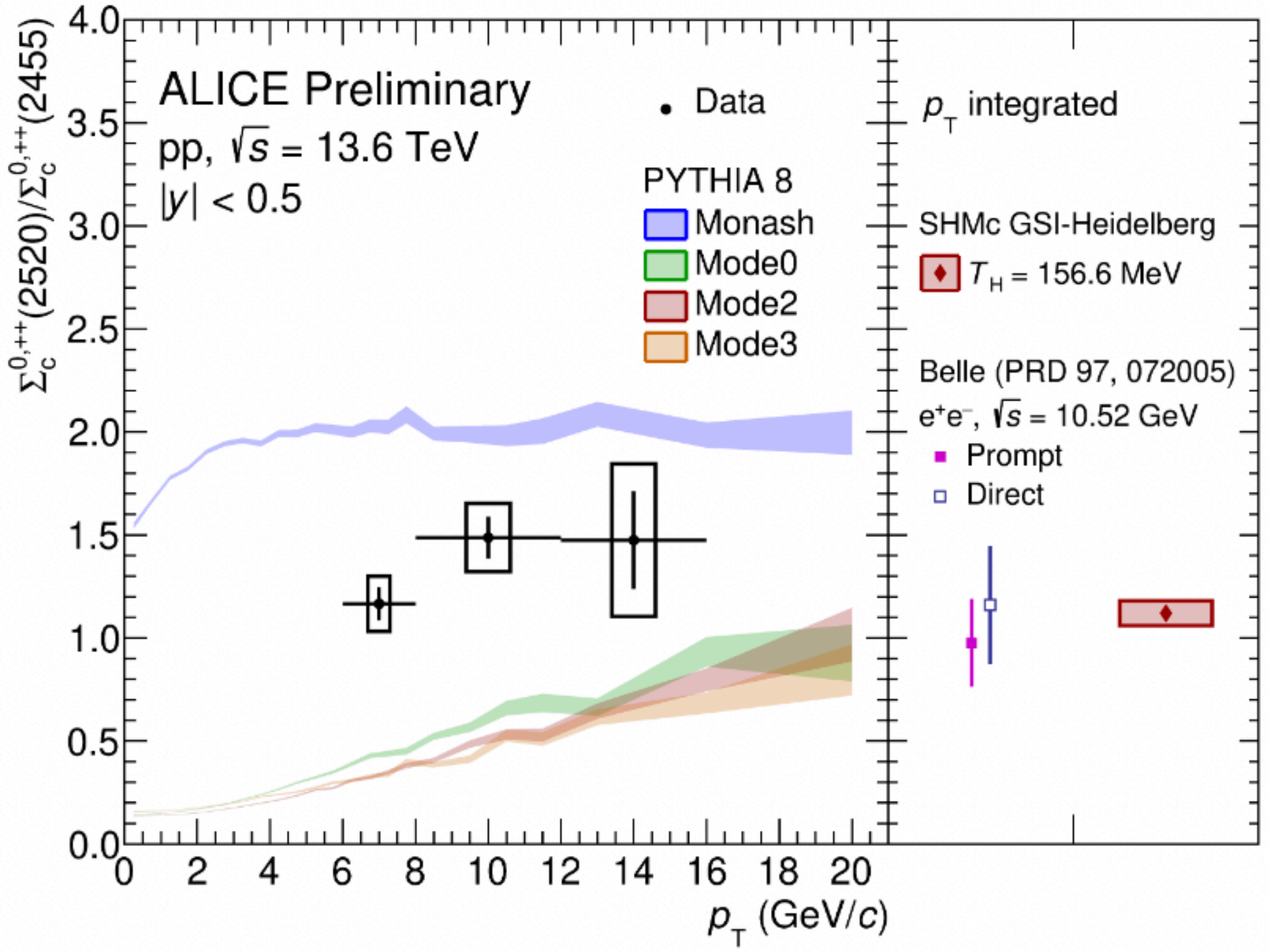
R_{AA} ratio of non-prompt D^0 to prompt D^0 as a function of p_T in 0–10% centrality compared to model predictions
✓ At low pT, formation of D mesons via coalescence makes a hardening of the prompt D^0 meson pT
✓ At hight pT, beauty quarks lose less energy than charm quarks via radiative processes

Recent results from Run3 : $\Sigma_c^{0,++}(2520)/\Sigma_c^{0,++}(2455)$

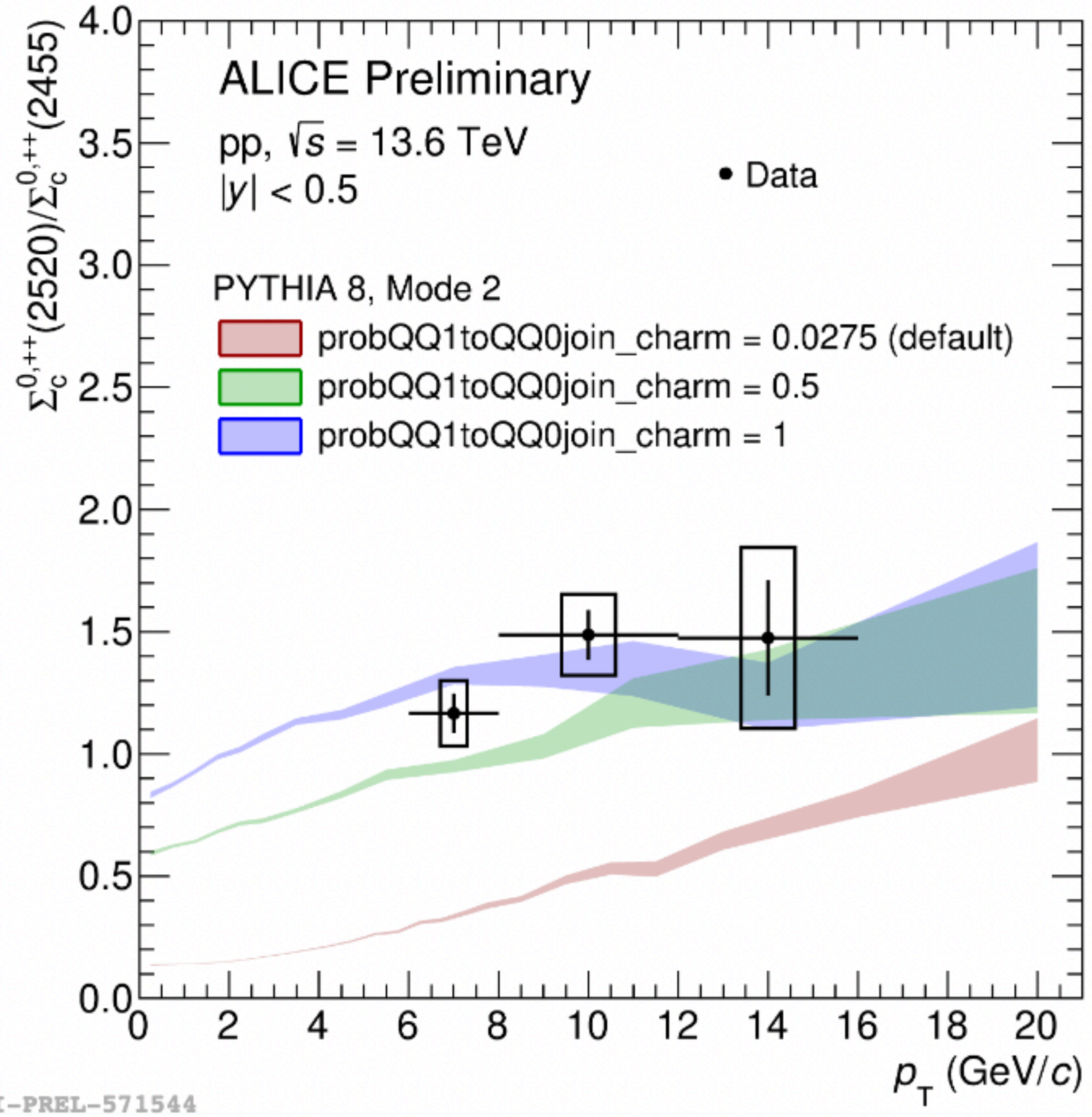
New from run 3

First $\Sigma_c^{0,++}(2520)$ measurement at the LHC

$\Sigma_c^{0,++}(2520)$, J = 3/2
$\Sigma_c^{0,++}(2455)$, J = 1/2



ALI-PREL-571539



ALI-PREL-571544

- SHM agrees with data within uncertainties
- PYTHIA with neither Monash nor CR-BLC reproduces data
- Ratio sensitive to c-diquark spin-1 to spin-0 suppression factor