

Latest D and Λ_c results in pp and Pb-Pb collisions with ALICE at the LHC

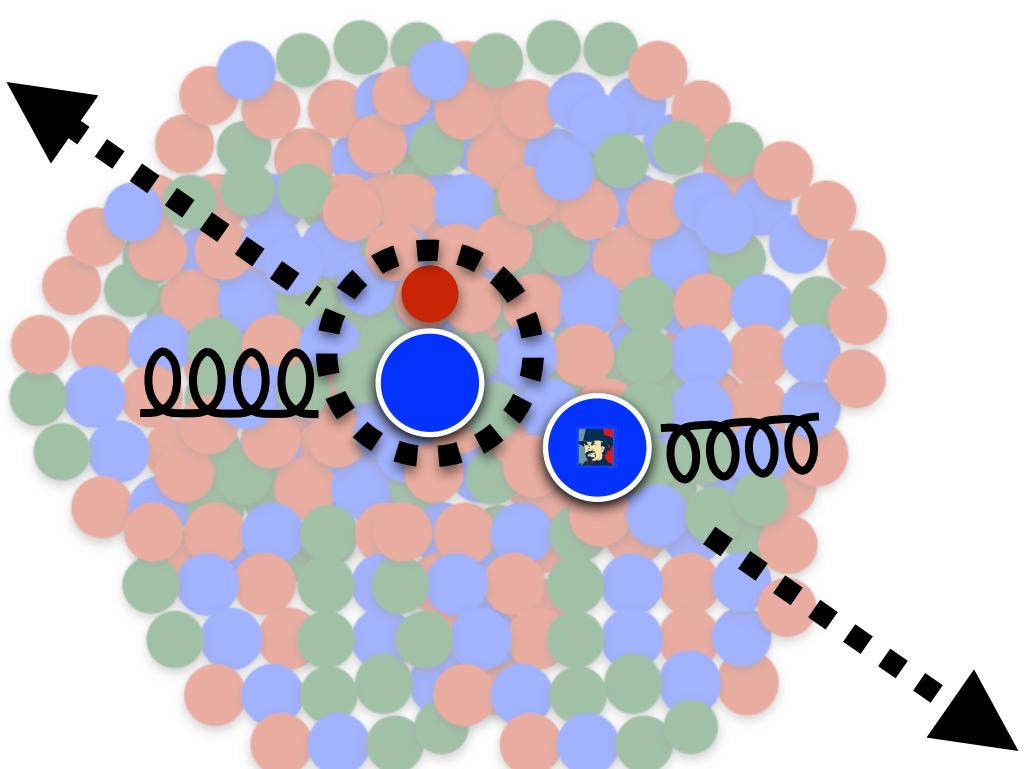
G.M. Innocenti (CERN)
for the ALICE Collaboration

Quark Matter 2019 (Wuhan, China)

Physics motivation

$D^0 R_{AA}$ in AA collisions

- Mechanisms of in-medium E_{loss}
- Test flavour dependence of E_{loss}
 - $E_{\text{loss}} (\text{g}) > E_{\text{loss}} (\text{c}) > E_{\text{loss}} (\text{b})$



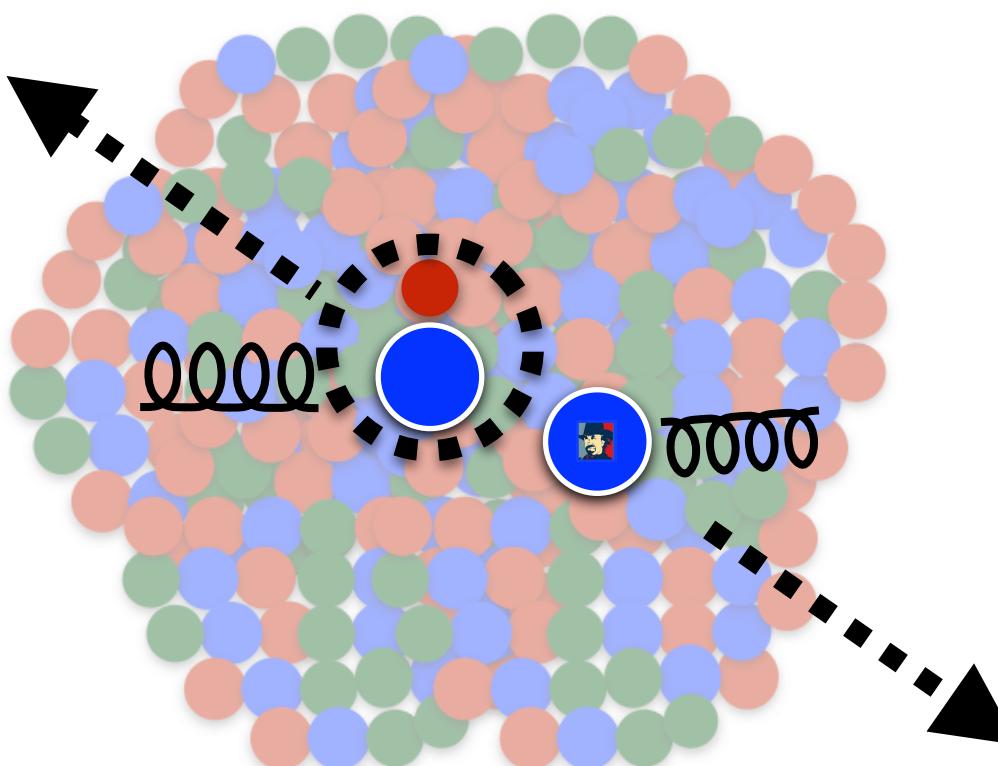
D_s/D^0 and Λ_c/D^0 ratios

- Study the mechanisms of charm recombination inside the medium

Physics motivation

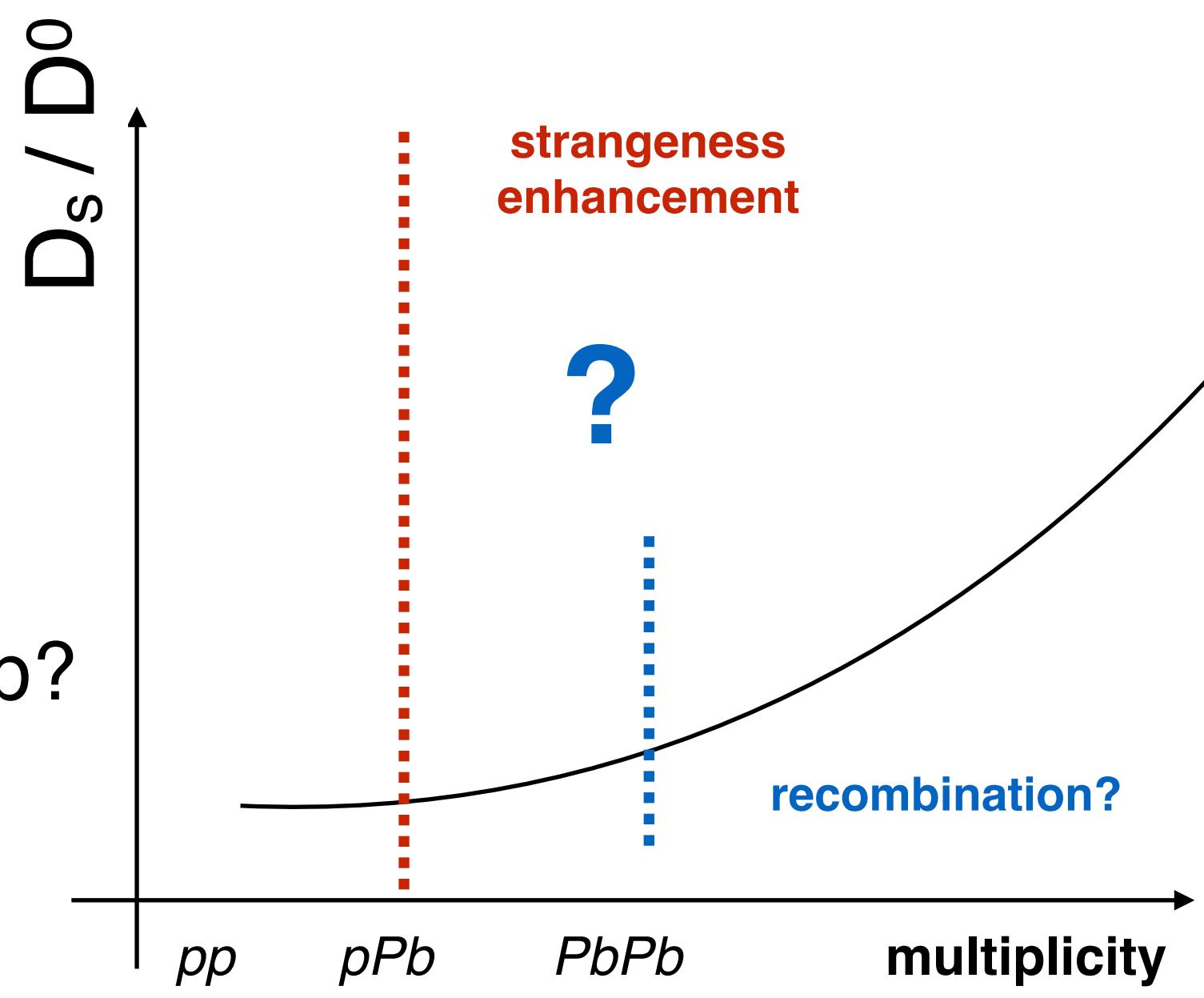
$D^0 R_{AA}$ in AA collisions

- Mechanisms of in-medium E_{loss}
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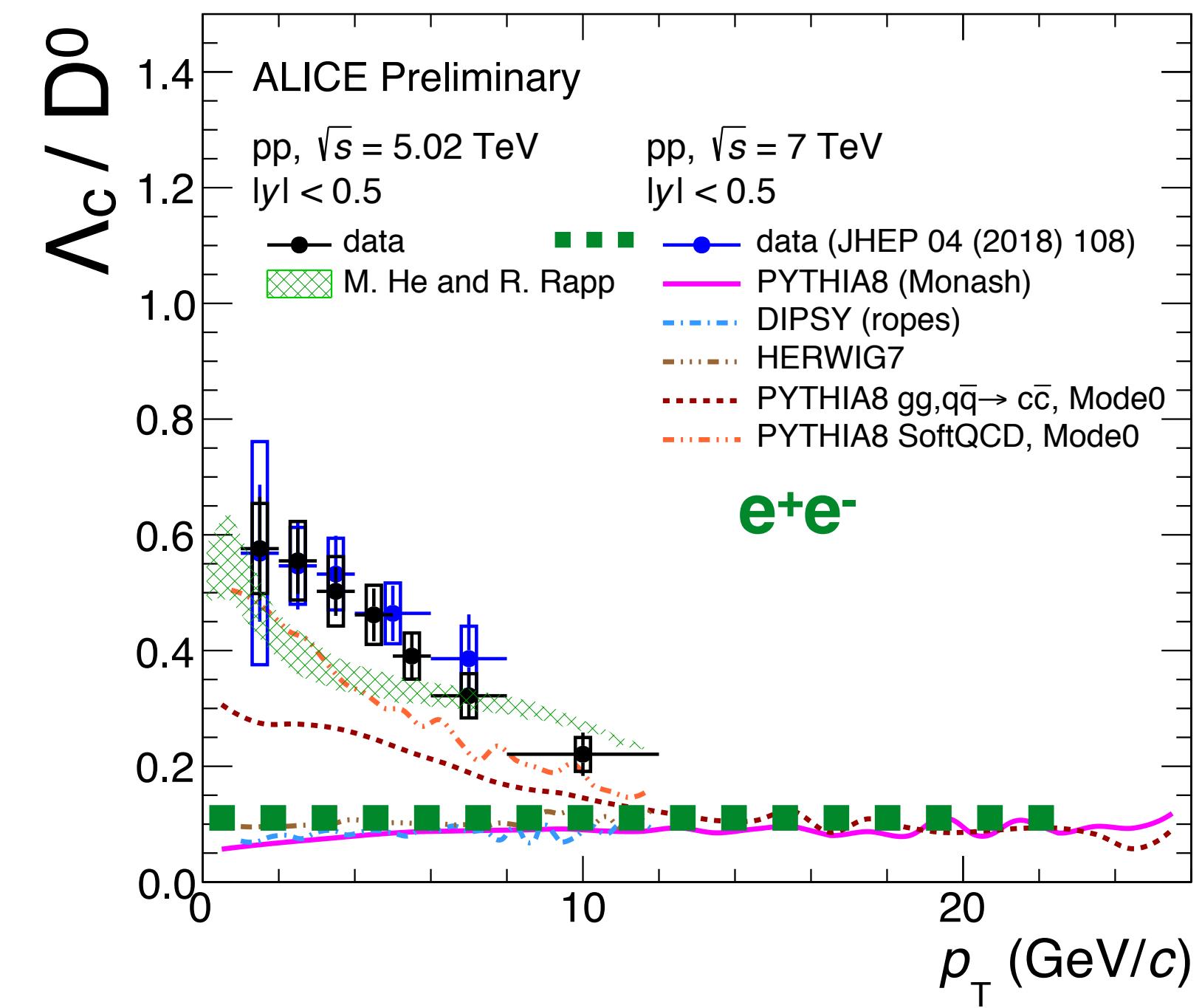
D_s / D^0 and Λ_c / D^0 ratios

- Study the mechanisms of charm recombination inside the medium



D_s / D^0 or Λ_c / D^0 vs multiplicity?

- Can we observe recombination in pp?
- Can this explain the Λ_c / D^0 puzzle?

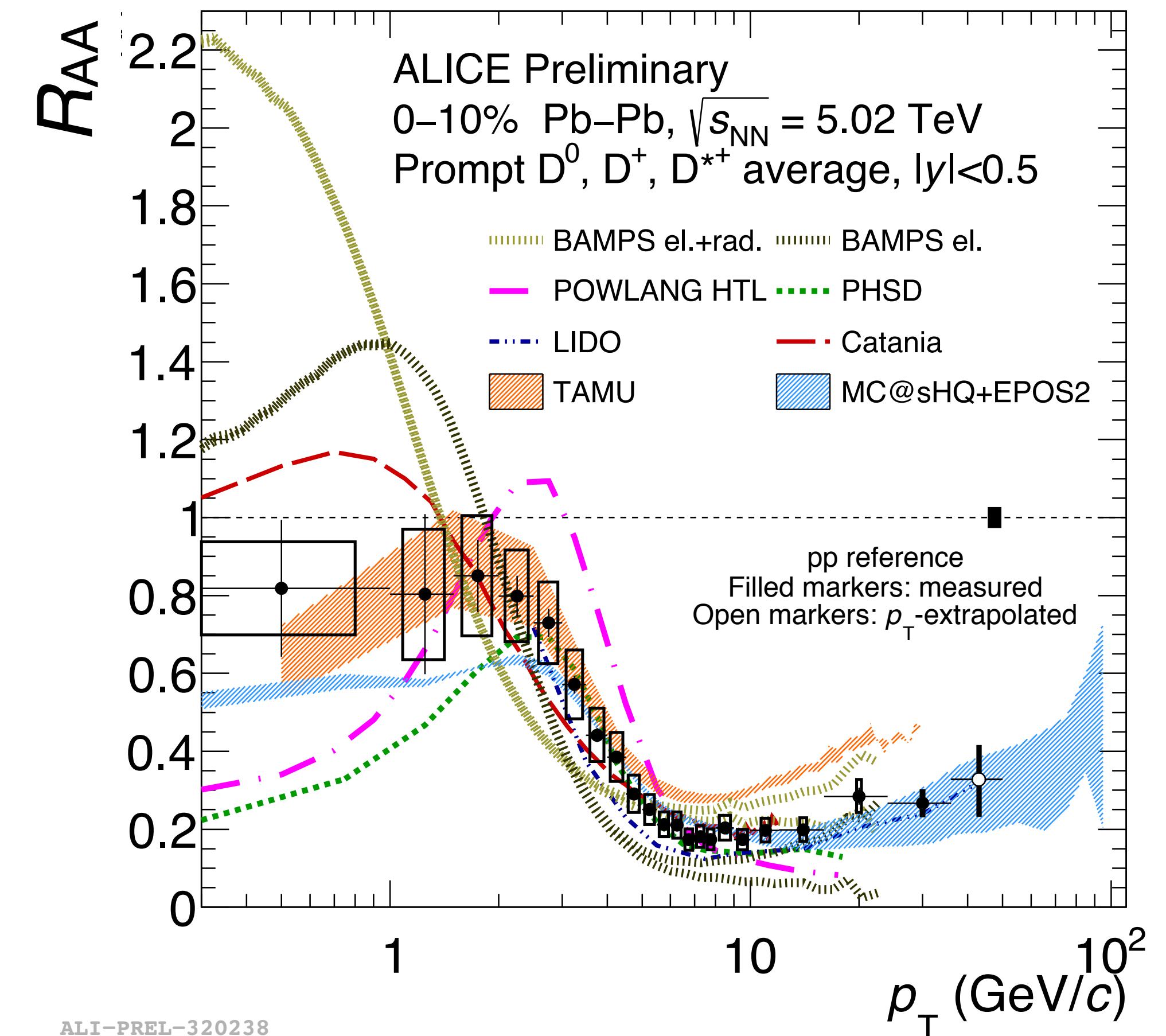


Heavy flavour interactions with the medium

$D^0 R_{AA}$ in central Pb-Pb collisions

Updated for
QM 2019

First measurement of charm production down to 0 GeV/c !

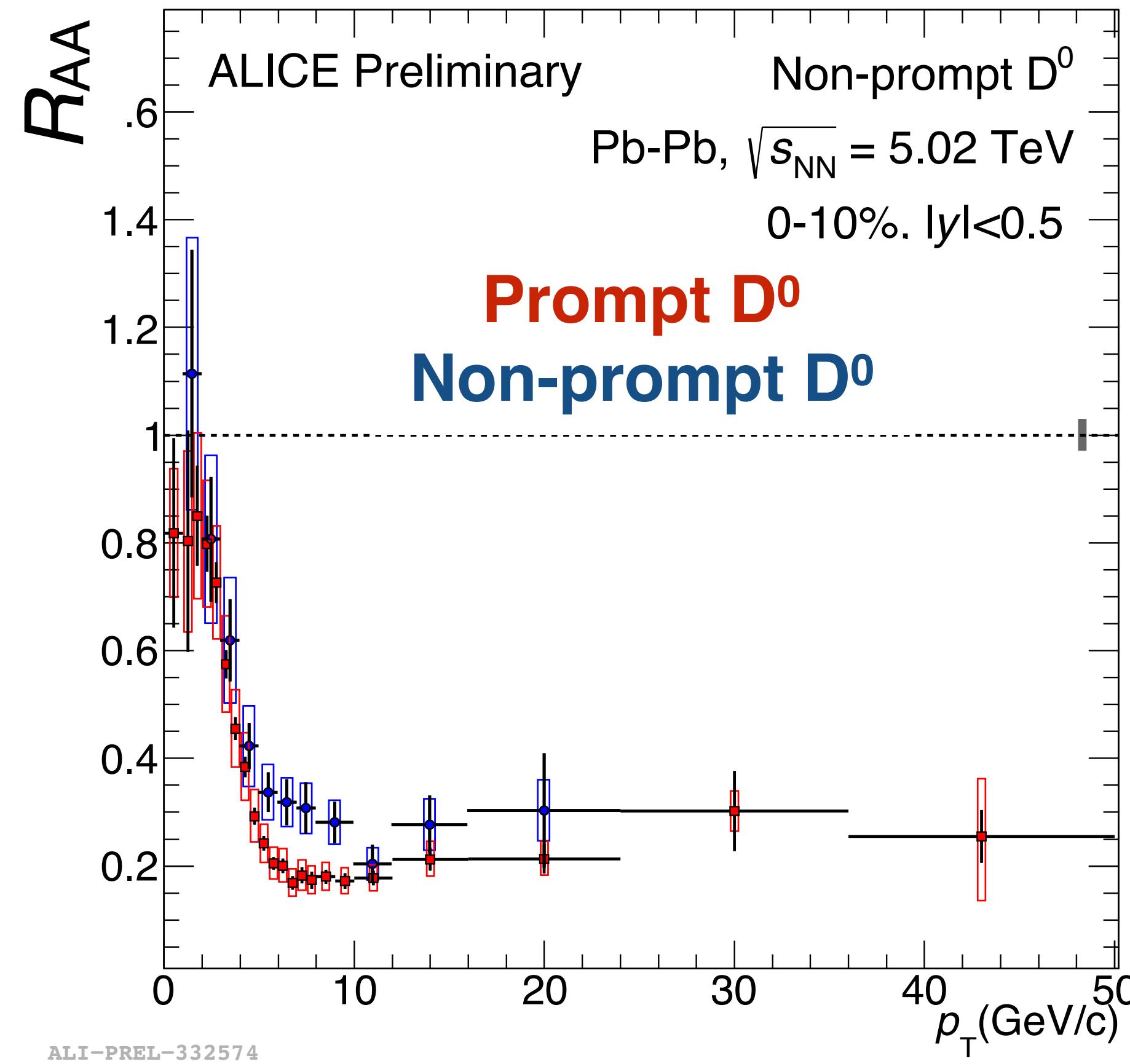


- Strong experimental constraints on charm E_{loss} and initial state effects (e.g. shadowing)
- New constraints on the total charm cross section at the LHC!

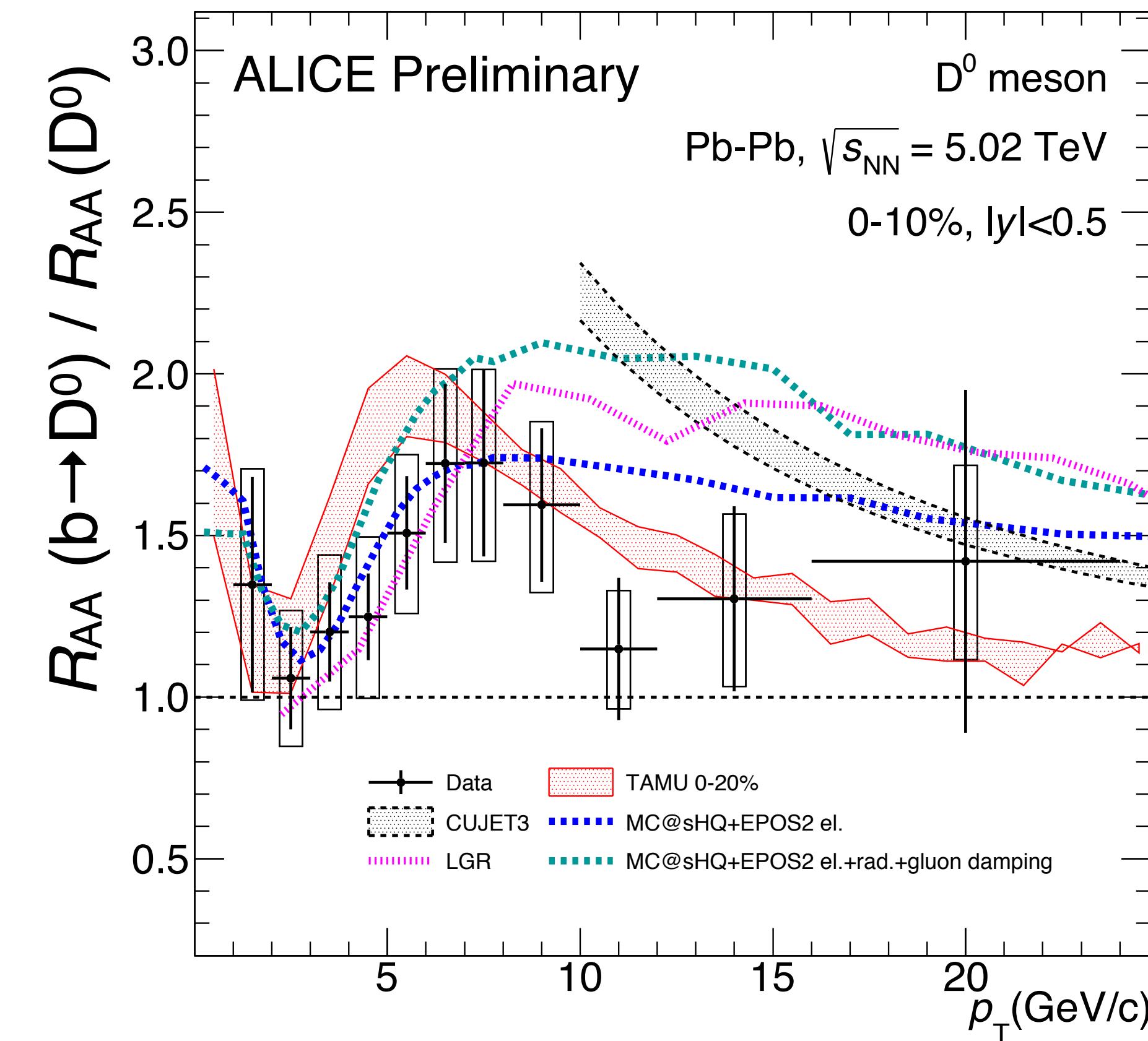
$b \rightarrow D^0 R_{AA}$ in central Pb-Pb collisions

New for
QM 2019

Measurement of **non-prompt D^0 production** in central Pb-Pb collisions provide access to beauty suppression down to very low p_T (2 GeV/c)



- $R_{AA} (b \rightarrow D^0) > R_{AA} (D^0)$ at intermediate p_T

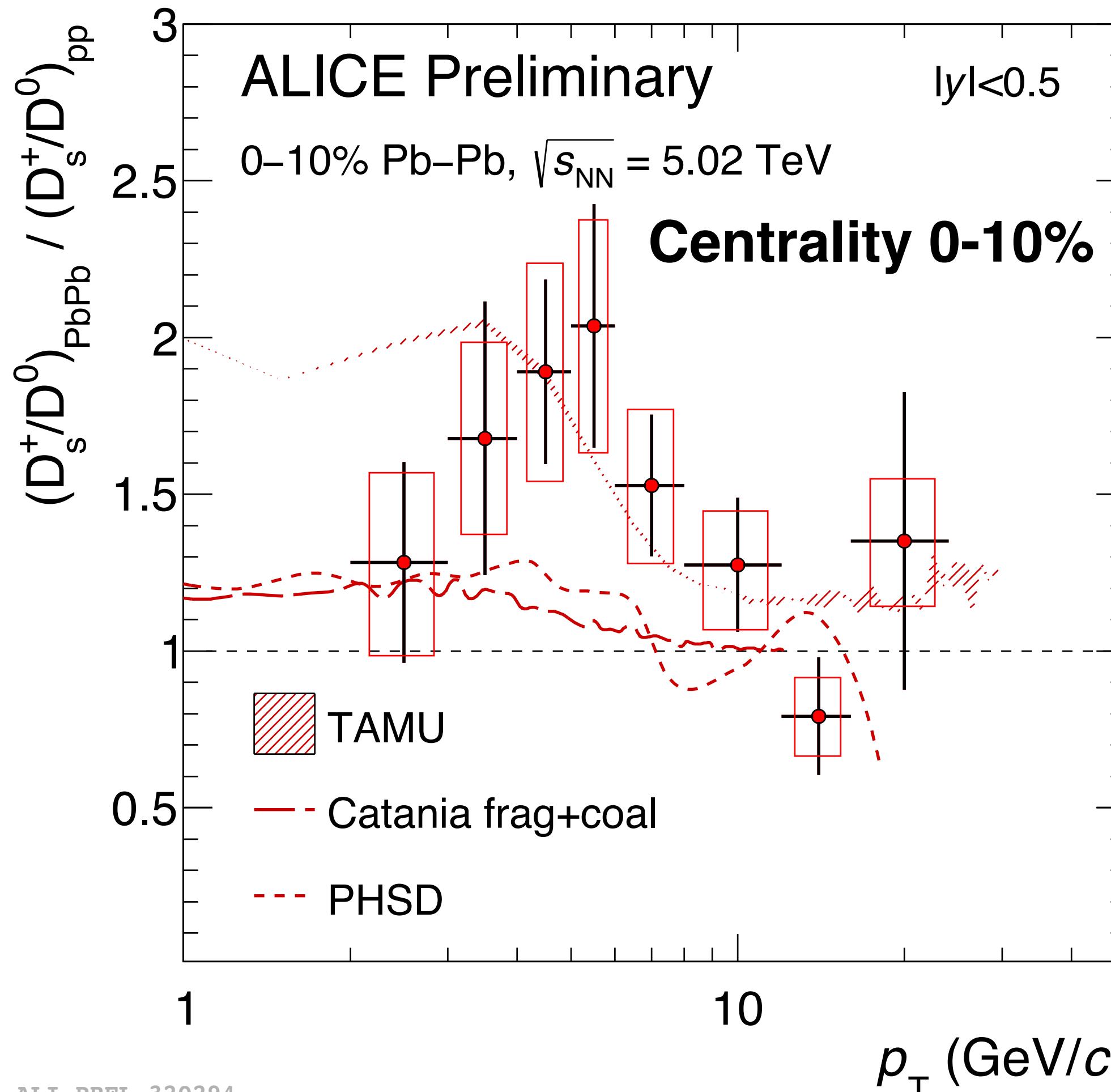


→ From comparison to models, quantitative indication of flavour dependence of E_{loss}

D_s/D^0 ratios in central Pb-Pb

Updated for
QM 2019

D_s/D^0 to be enhanced in Pb-Pb vs pp in presence of charm recombination and strangeness enhancement



- sizable enhancement at intermediate p_T
- Well described by Langevin calculations that include both fragmentation and recombination

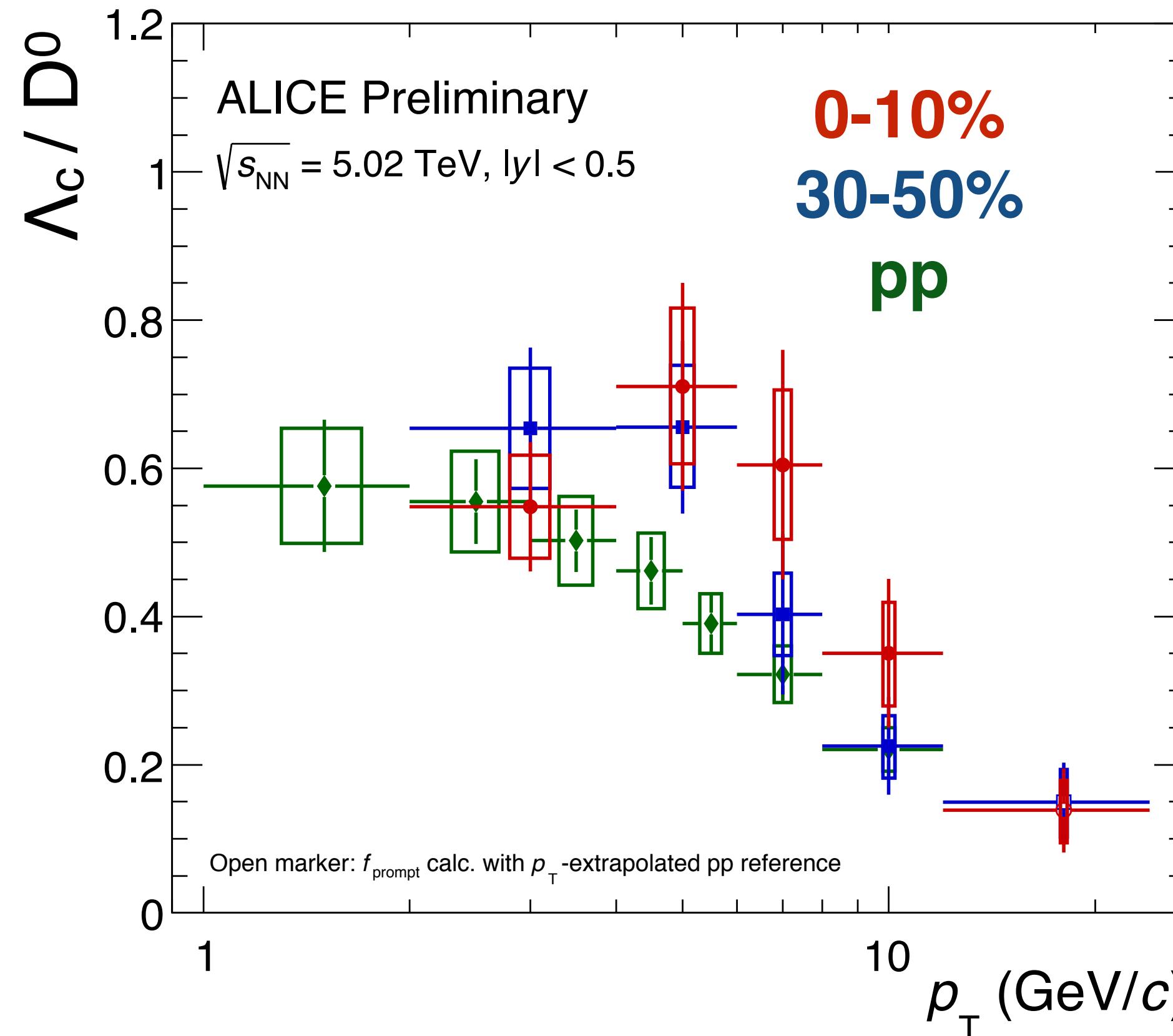
ALI-PREL-320294

→ Supports the hypothesis of a relevant contribution of coalescence in charm hadronization in Pb-Pb

Λ_c/D^0 ratios in Pb-Pb collisions

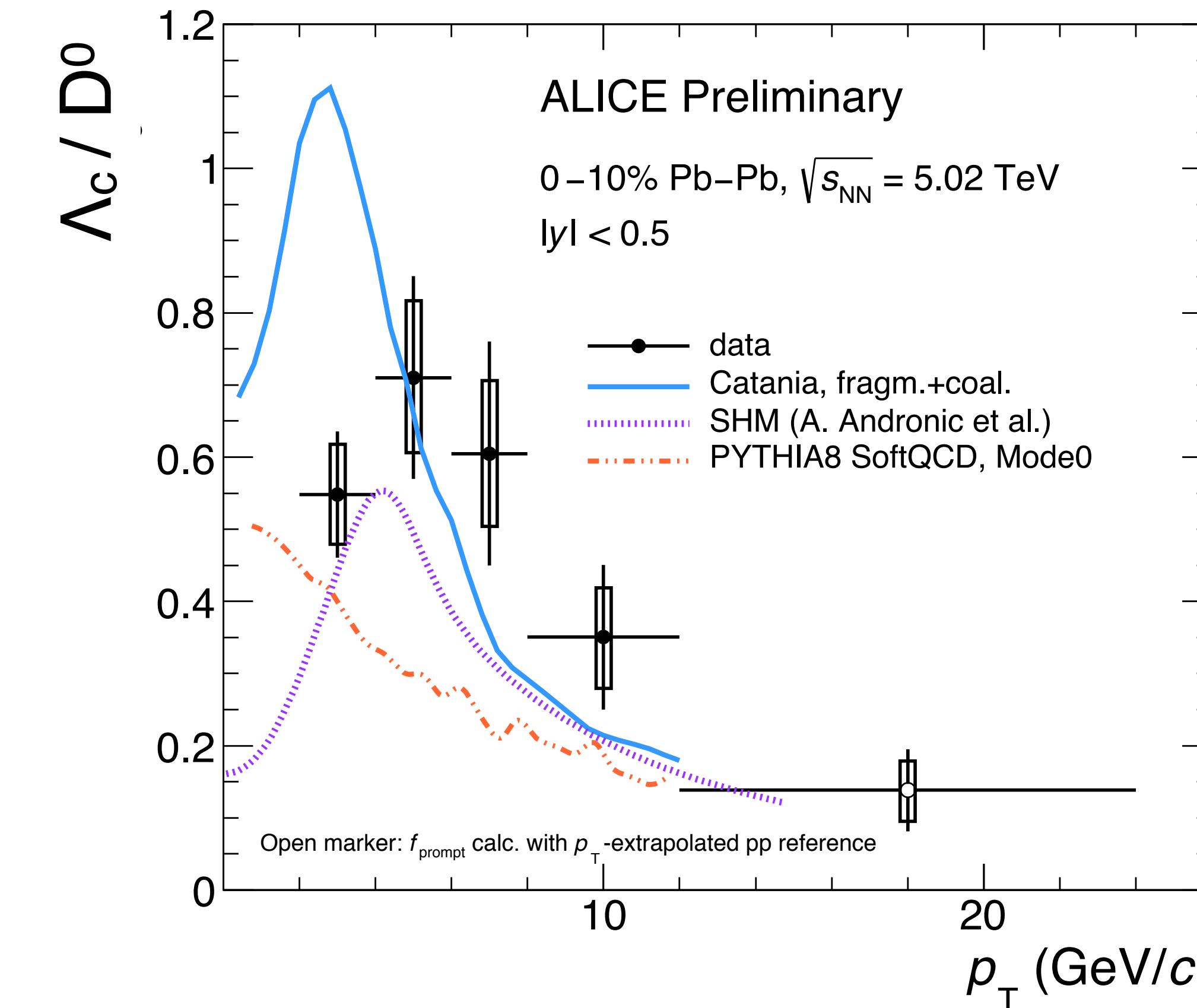
SQM 2019

Λ_c/D^0 (baryon/meson) ratio is also expected to increase in presence of charm recombination in the QGP



ALI-PREL-323761

- Moderate enhancement from pp to Pb-Pb at intermediate p_T within uncertainties
- Hint of baryon/meson enhancement, to be improved with future Run3 data



ALI-PREL-325749

- Compatible with models that include recombination but still not conclusive to discriminate alternative HP

D^0 , D_s and Λ_c production in pp collisions
at 13 TeV vs multiplicity

Can we observe D_s/D^0 enhancement in high multiplicity collisions?

Multiplicity estimator: number of “tracklets”
formed in the Silicon Pixel detector

Classes of barrel multiplicity:

$$\langle dN_{ch}/d\eta \rangle \sim 3.9$$

$$\langle dN_{ch}/d\eta \rangle \sim 6 \text{ (MB)}$$

$$\langle dN_{ch}/d\eta \rangle \sim 13.7$$

$$\langle dN_{ch}/d\eta \rangle \sim 28.1$$

D_s/D^0 in pp collisions vs multiplicity

New for
QM 2019

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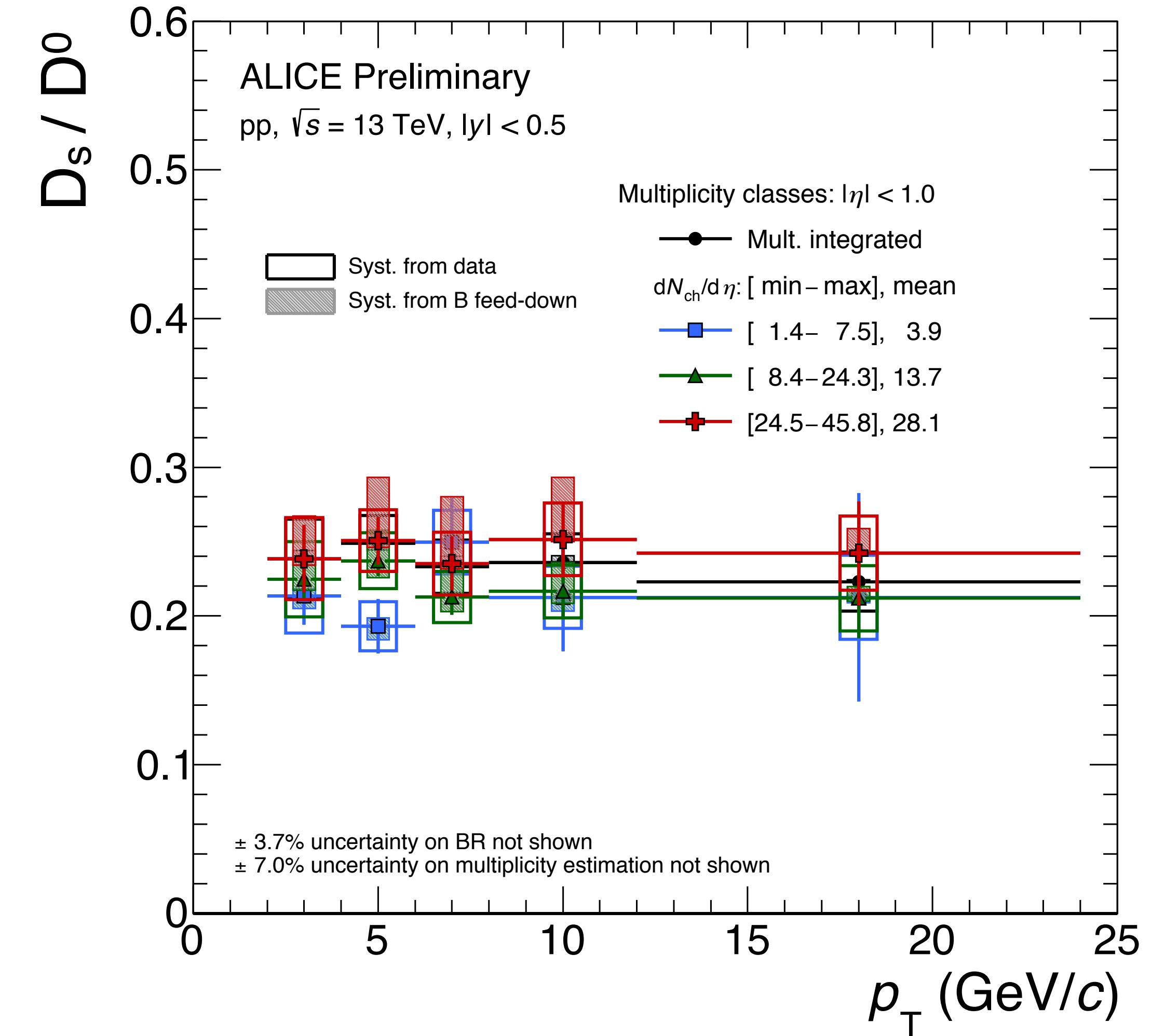
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ALI-PREL-336402

D_s/D^0 in pp collisions vs multiplicity

New for
QM 2019

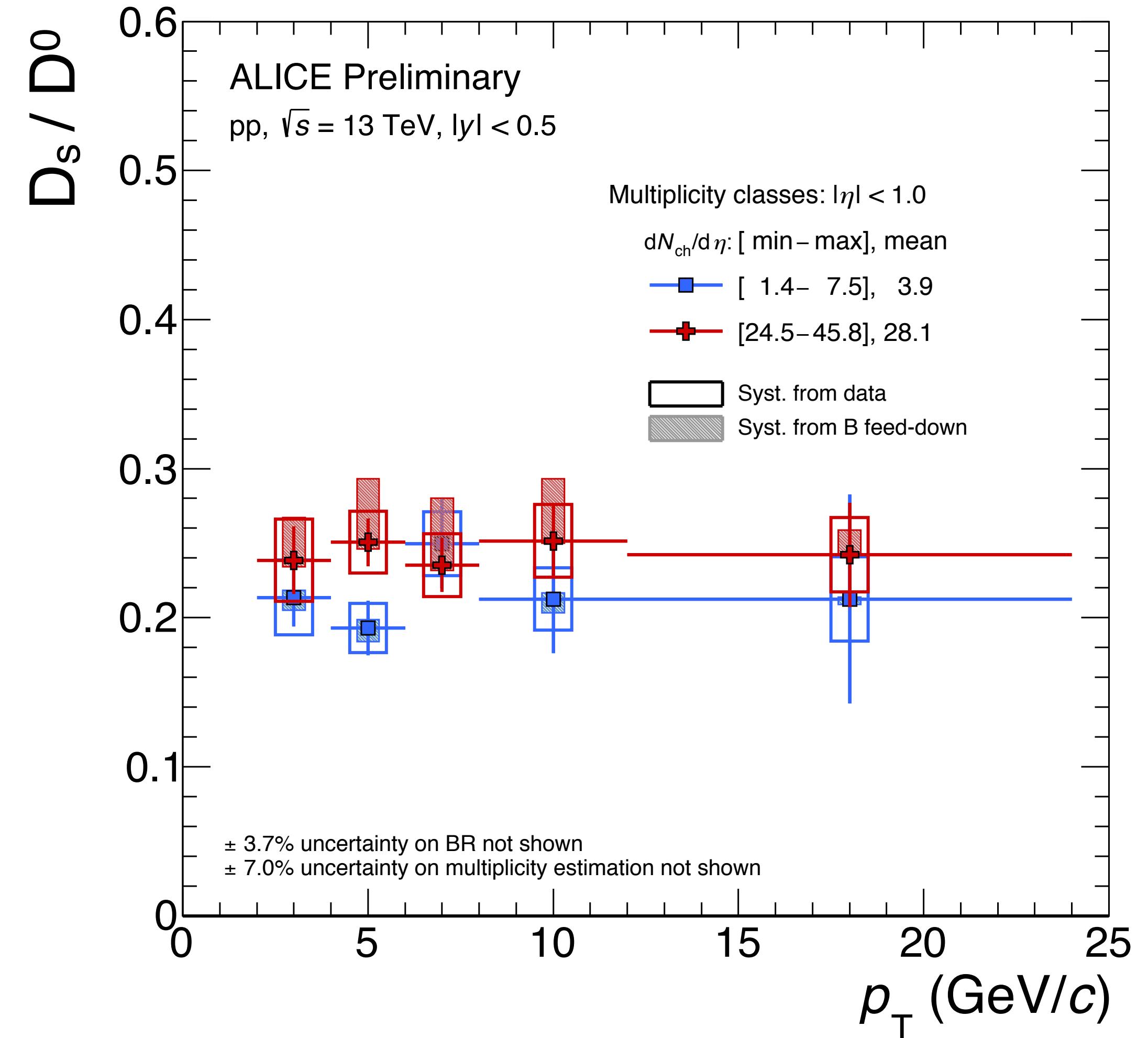
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→ D_s/D^0 shows a hint of enhancement from low to high pp multiplicities

Λ_c/D^0 in pp collisions vs multiplicity

New for
QM 2019

Can we observe Λ_c/D^0 enhancement in high multiplicity collisions?

Multiplicity estimator: number of “tracklets” formed in the Silicon Pixel detector

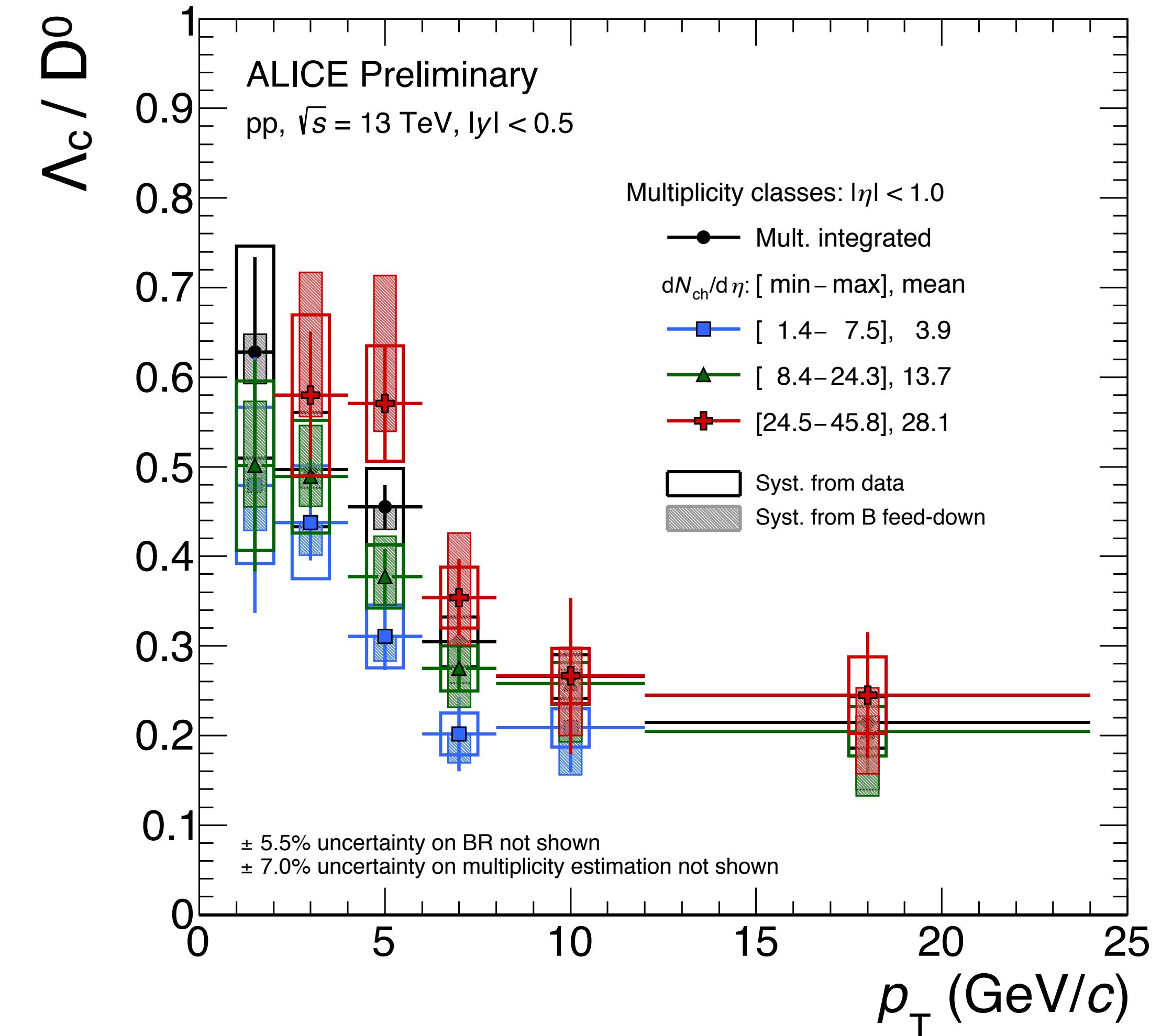
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ALI-PREL-336414

Λ_c/D^0 in pp collisions vs multiplicity

New for
QM 2019

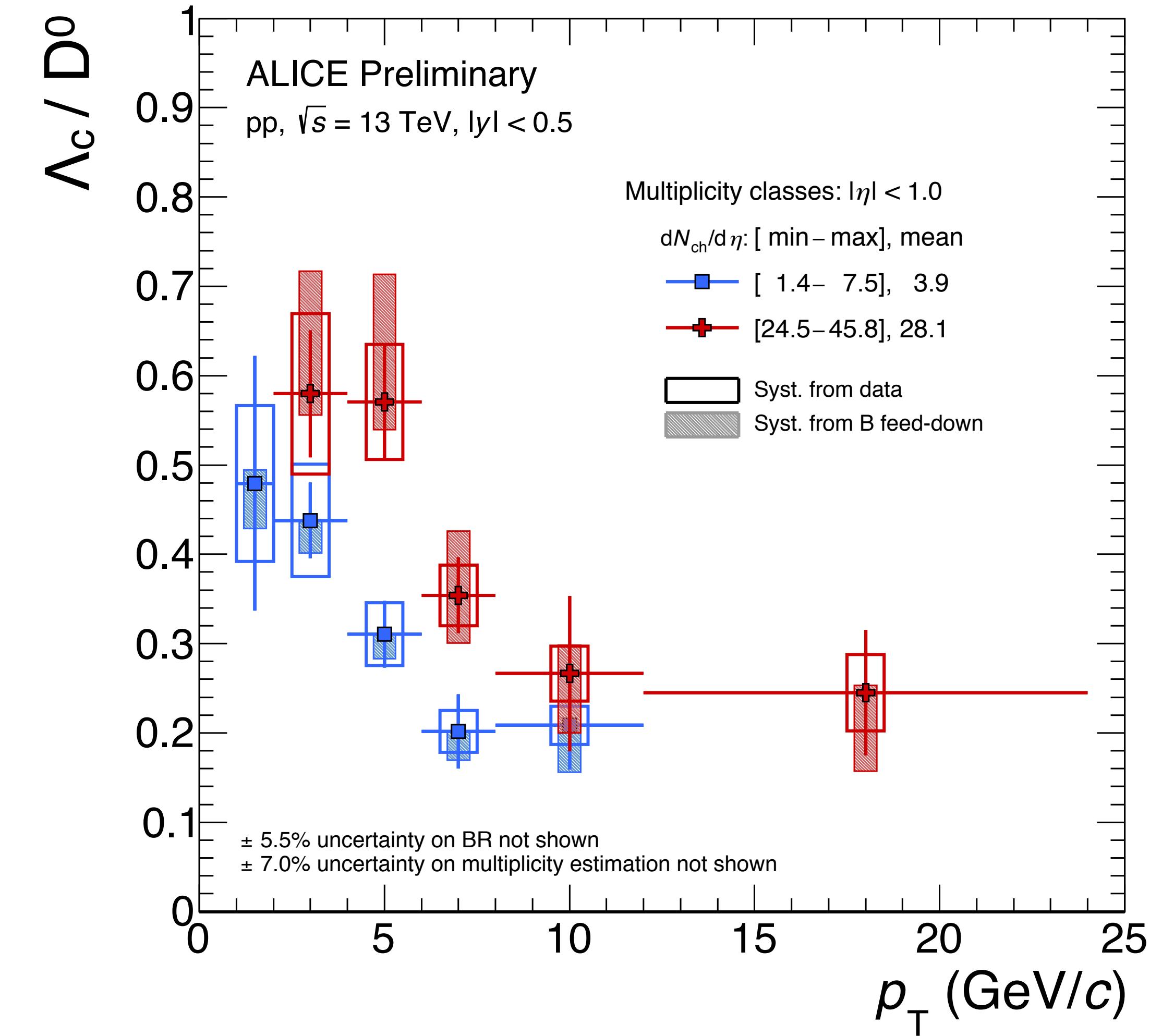
Can we observe Λ_c/D^0 enhancement in high multiplicity collisions?

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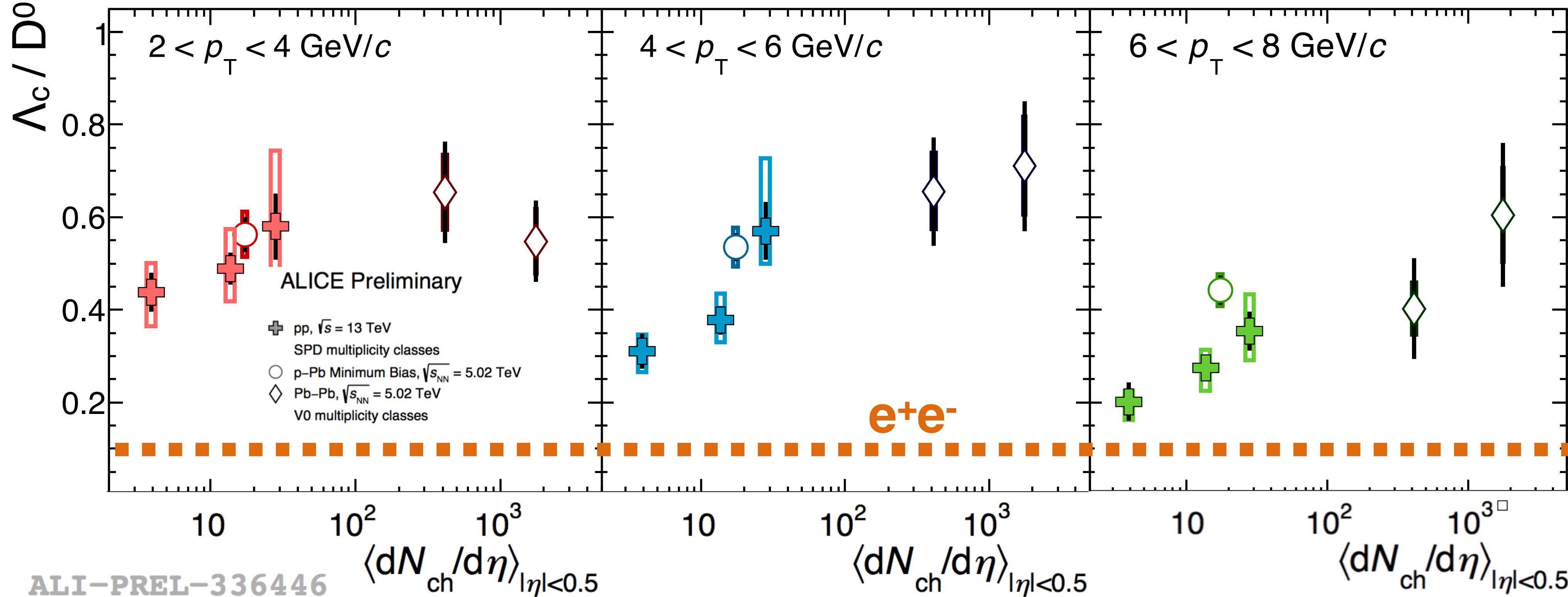
$$\langle dN_{ch}/d\eta \rangle \sim 28.1$$



→ Λ_c/D^0 shows a significant increase for increasing multiplicities

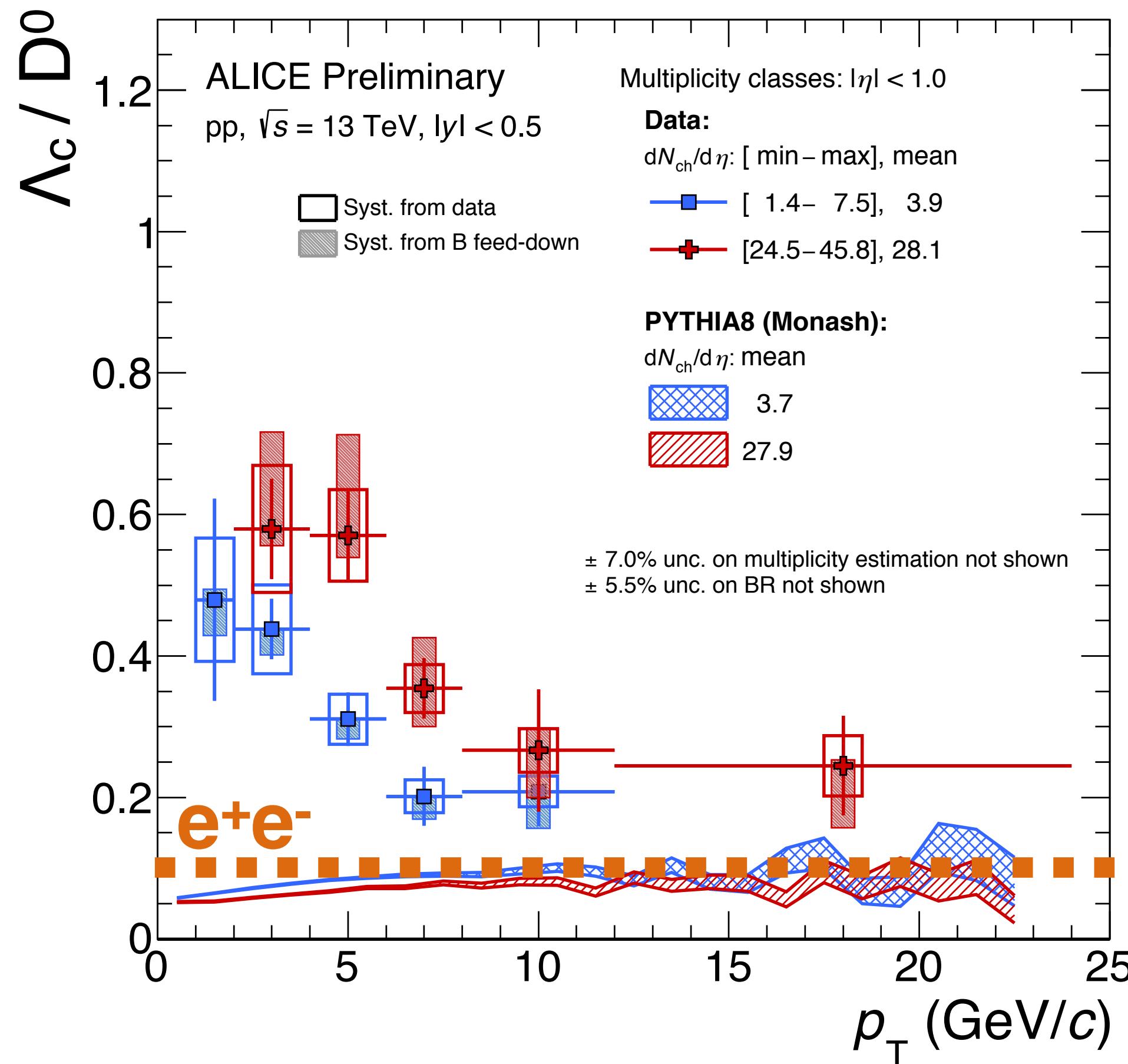
Λ_c/D^0 vs multiplicity across colliding systems

New for
QM 2019



- Smooth increase from pp to p-Pb to Pb-Pb multiplicities
- ratio in low pp multiplicity $> e^+e^-$
- ratio in high pp multiplicity \sim Pb-Pb
- In qualitative agreement with the hypothesis of recombination that “saturates” already in pp!

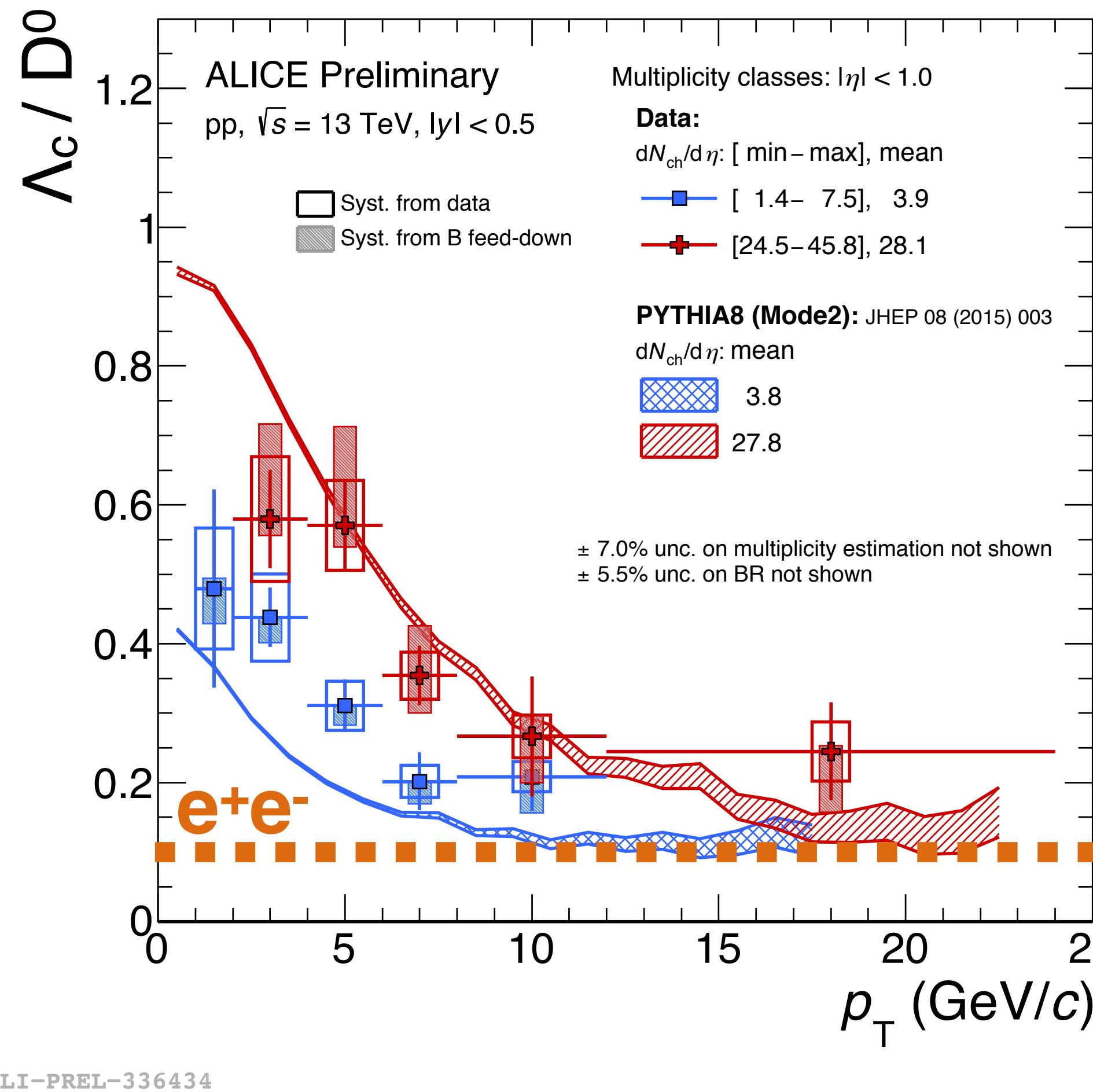
Λ_c/D^0 ratios in PYTHIA



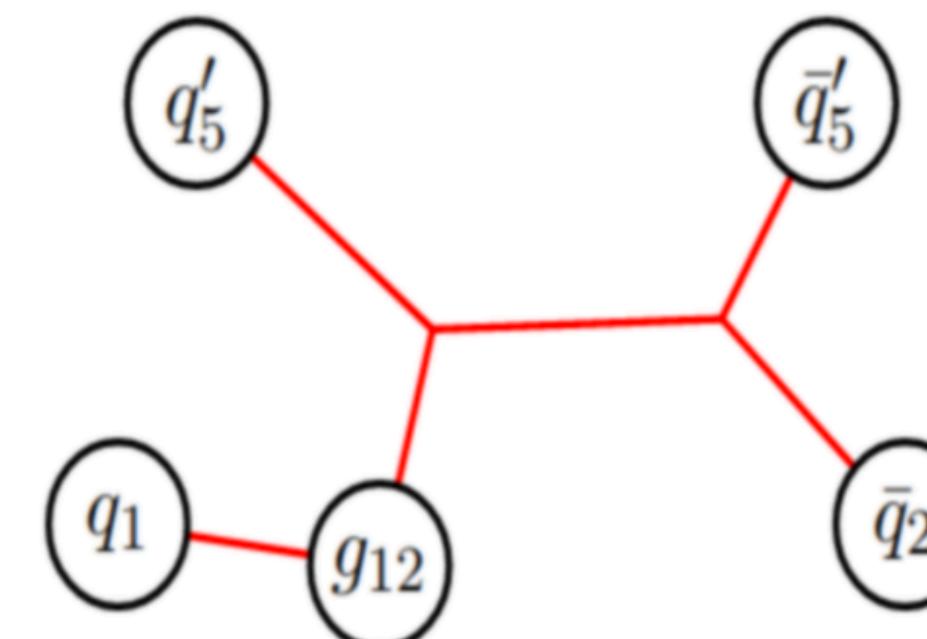
- largely underestimated when comparing to the **default PYTHIA tune (Monash)**

ALI-PREL-336426

Λ_c/D^0 ratios in PYTHIA



- largely underestimated when comparing to the **default PYTHIA tune (Monash)**



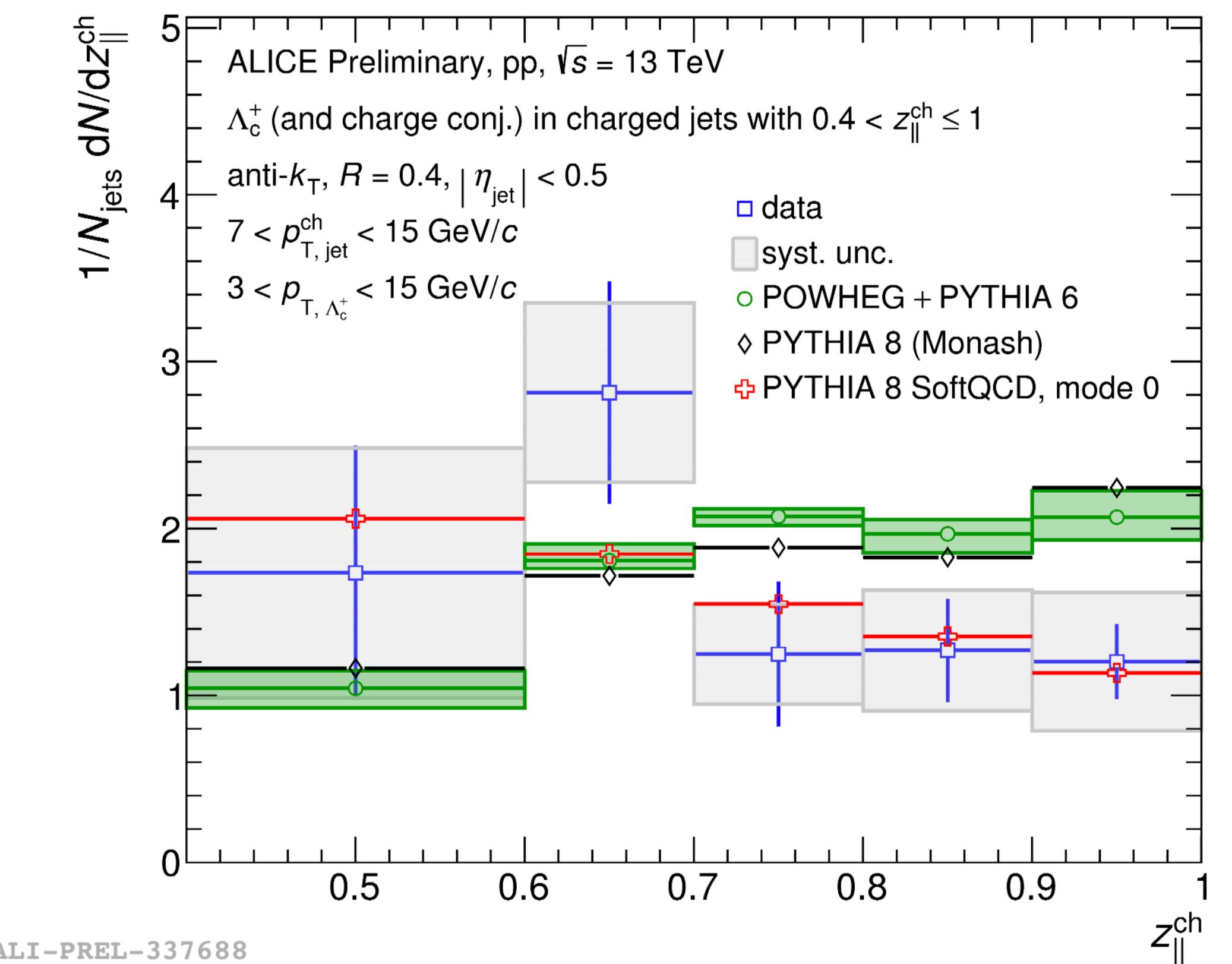
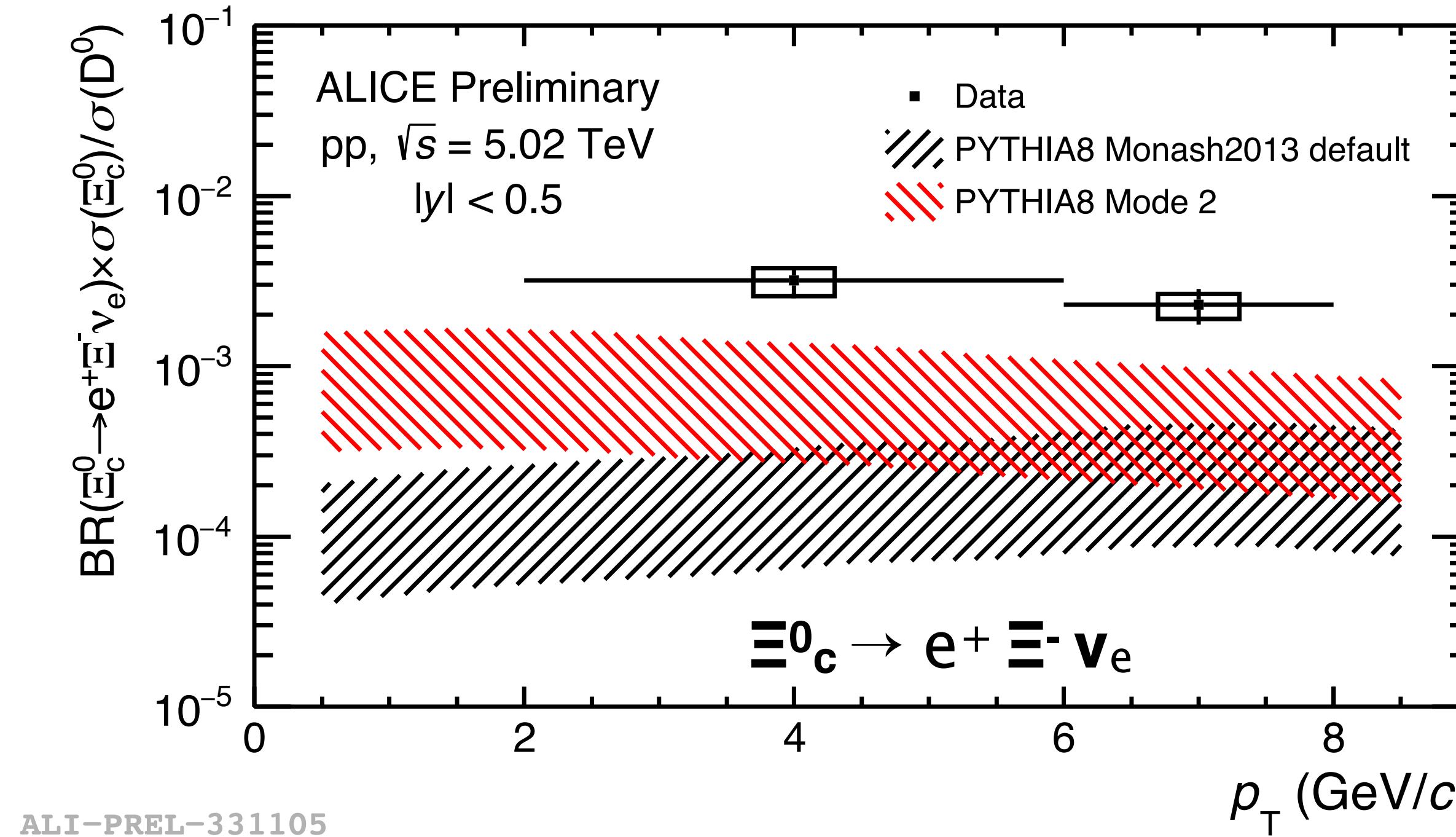
- Good agreement including **color-reconnection processes (e.g. “junctions”) between partons created in different MPIs**
 → “can enhance strange and baryon production!”

Alternative description that does not require the presence of a QGP-like medium!
 → **New experimental constraints on the properties of the proton-proton “medium”!**

New observables for stronger experimental constraints

See T. Cheng's and M. Faggin's poster and J. Kvapil's talk

New for QM 2019



Ratios of with heavier baryons e.g. Ξ_c^0 / D^0 or Σ_c^0 / D^0 :

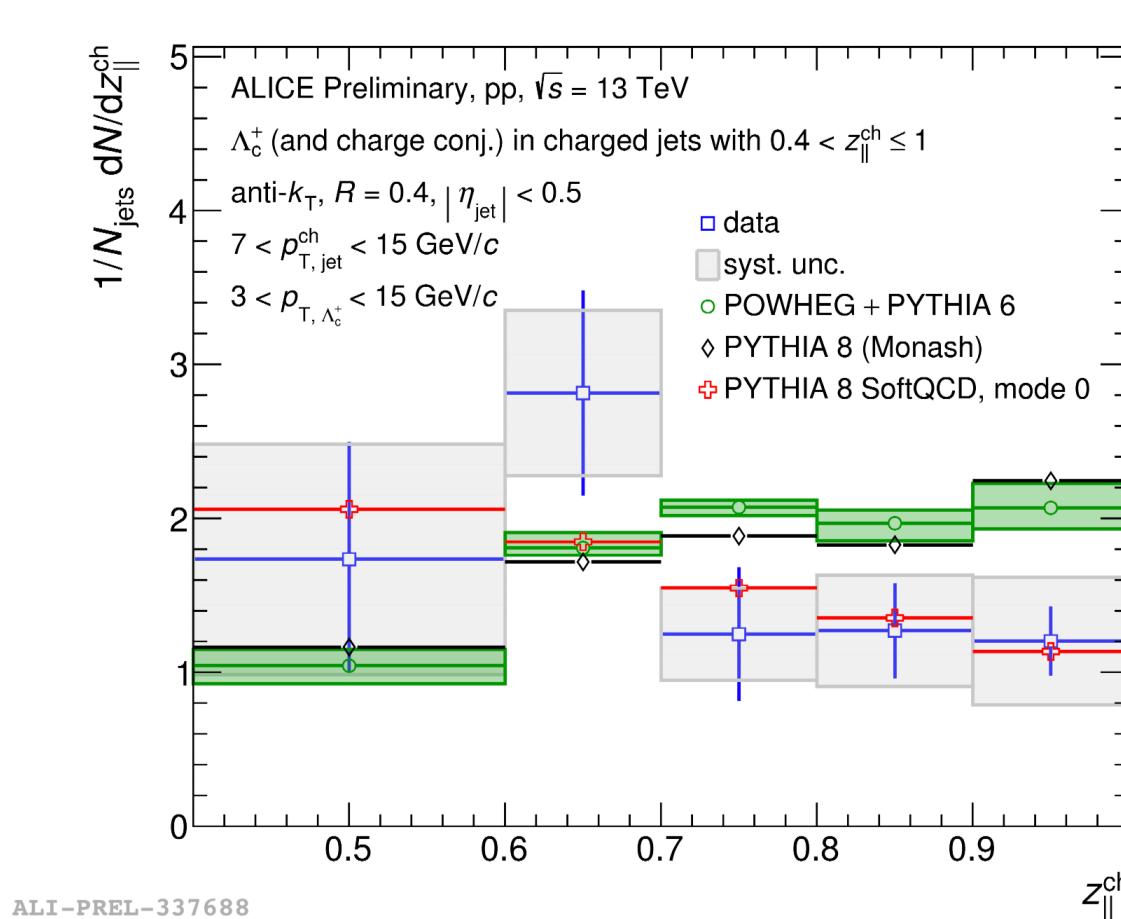
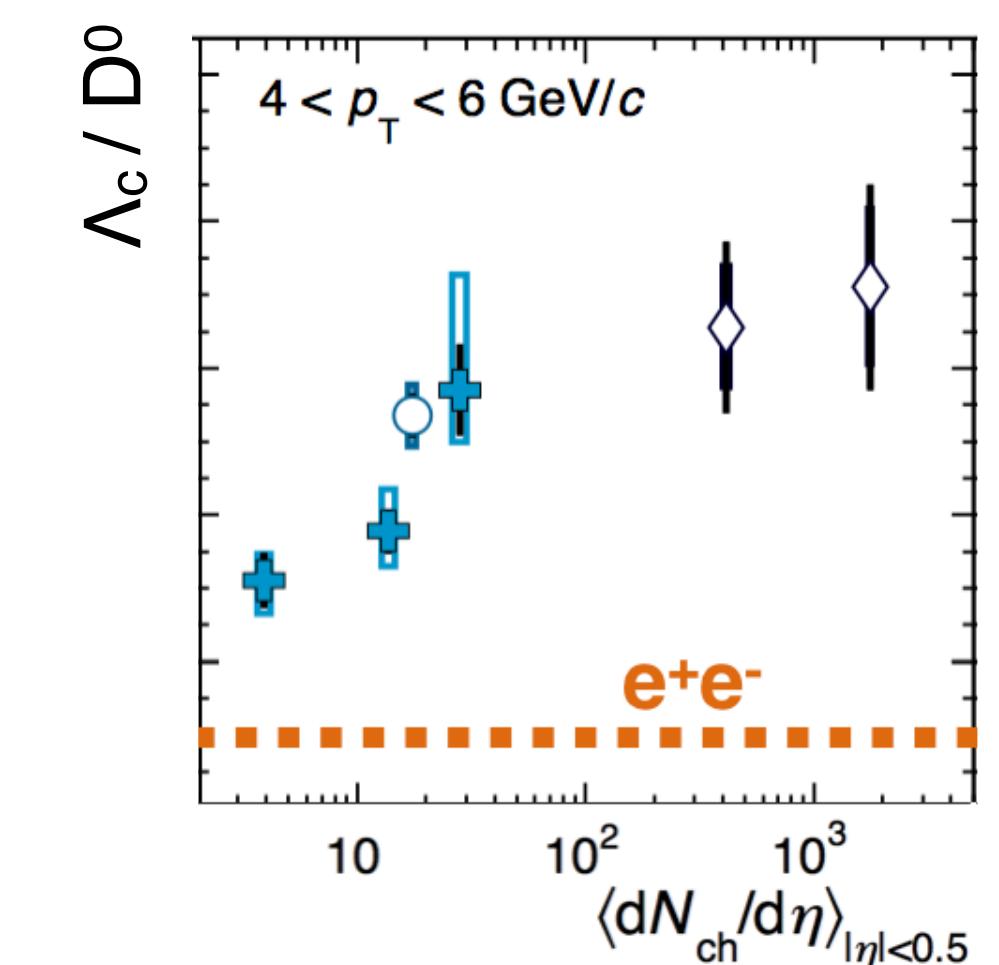
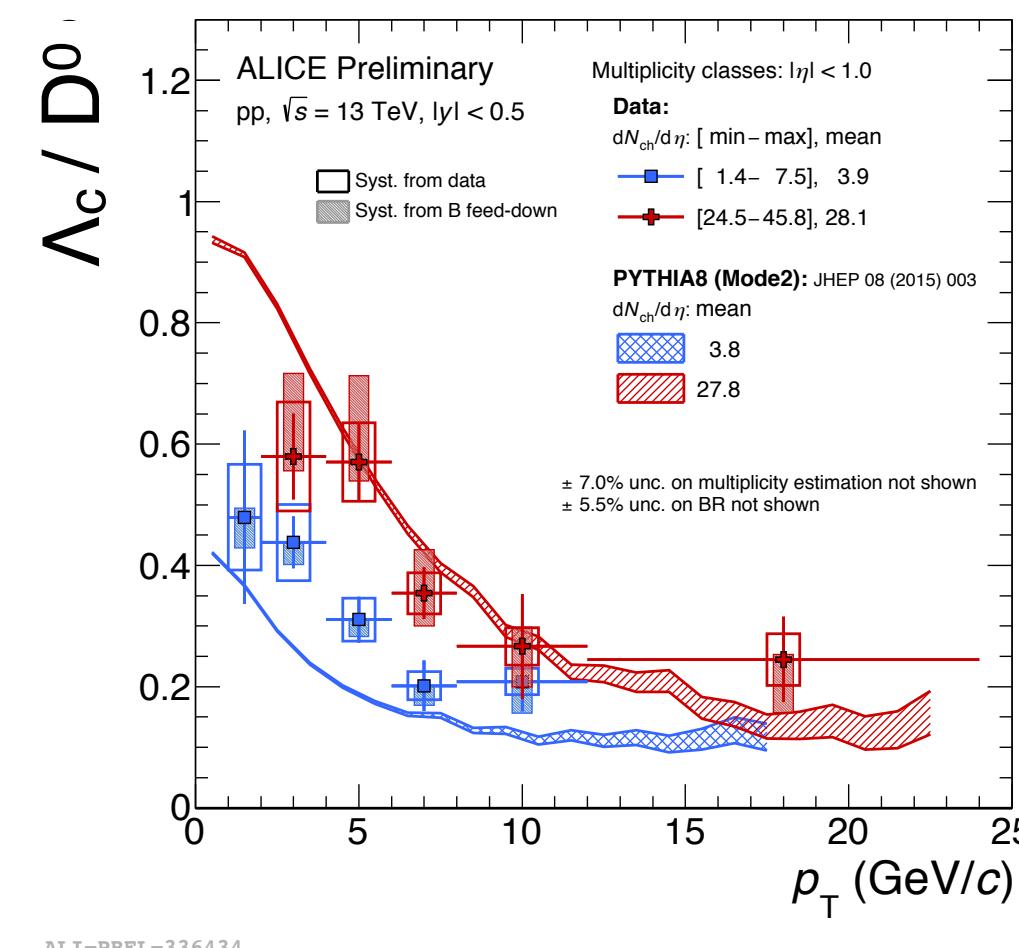
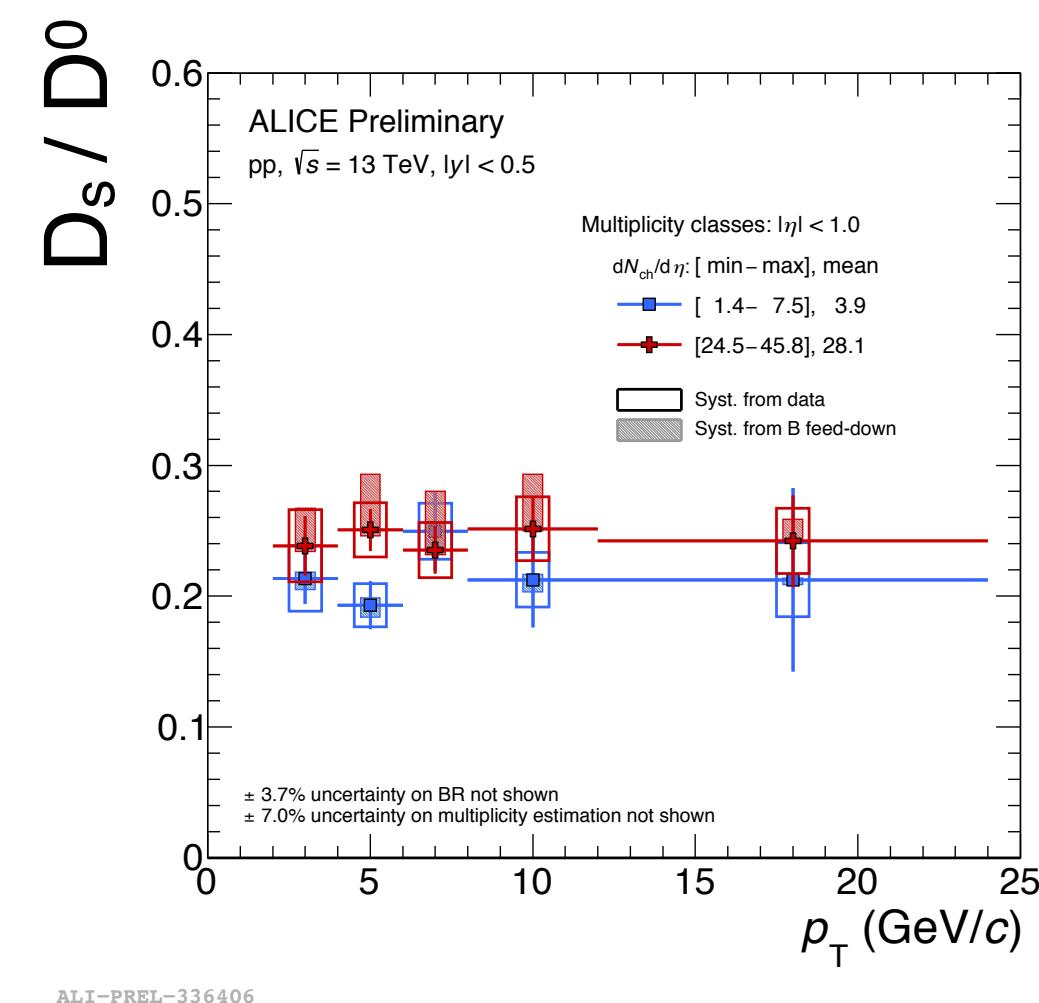
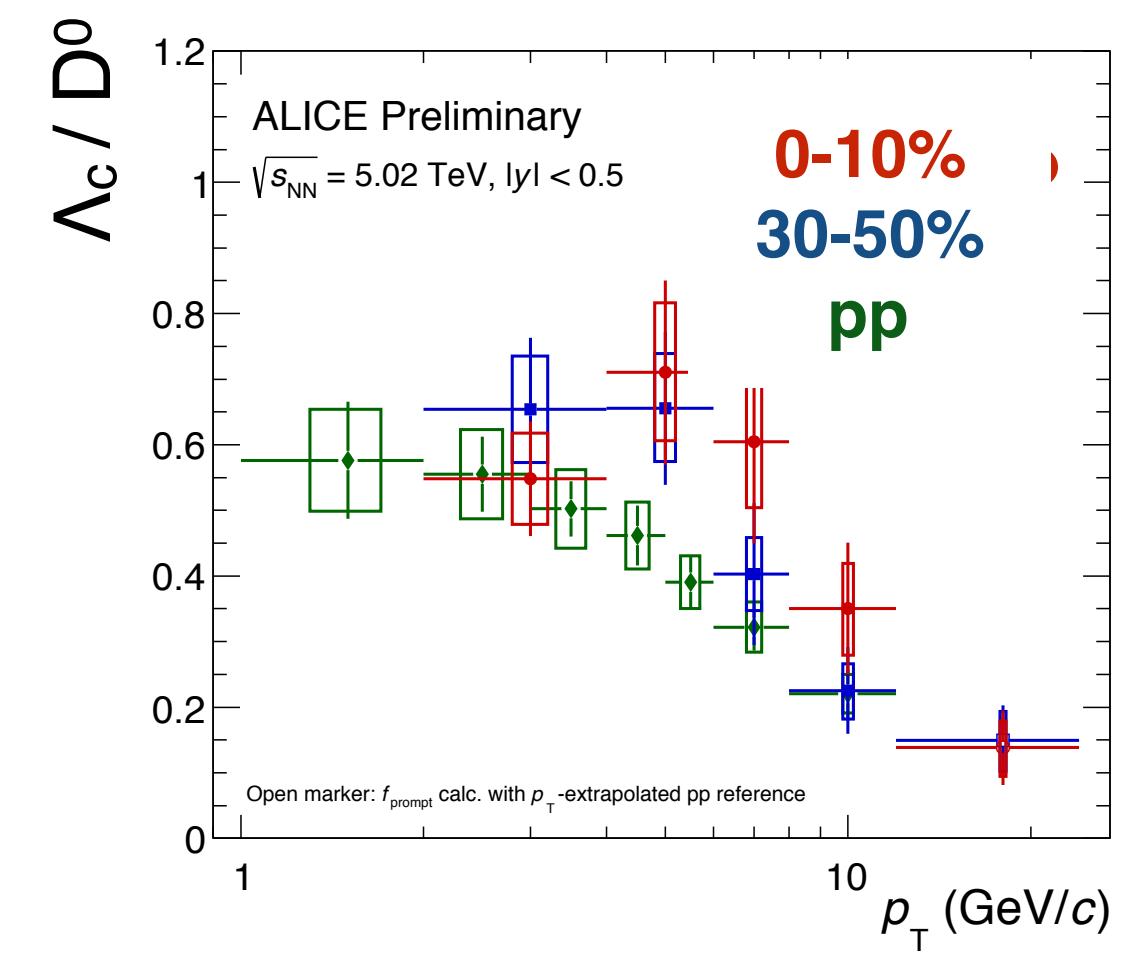
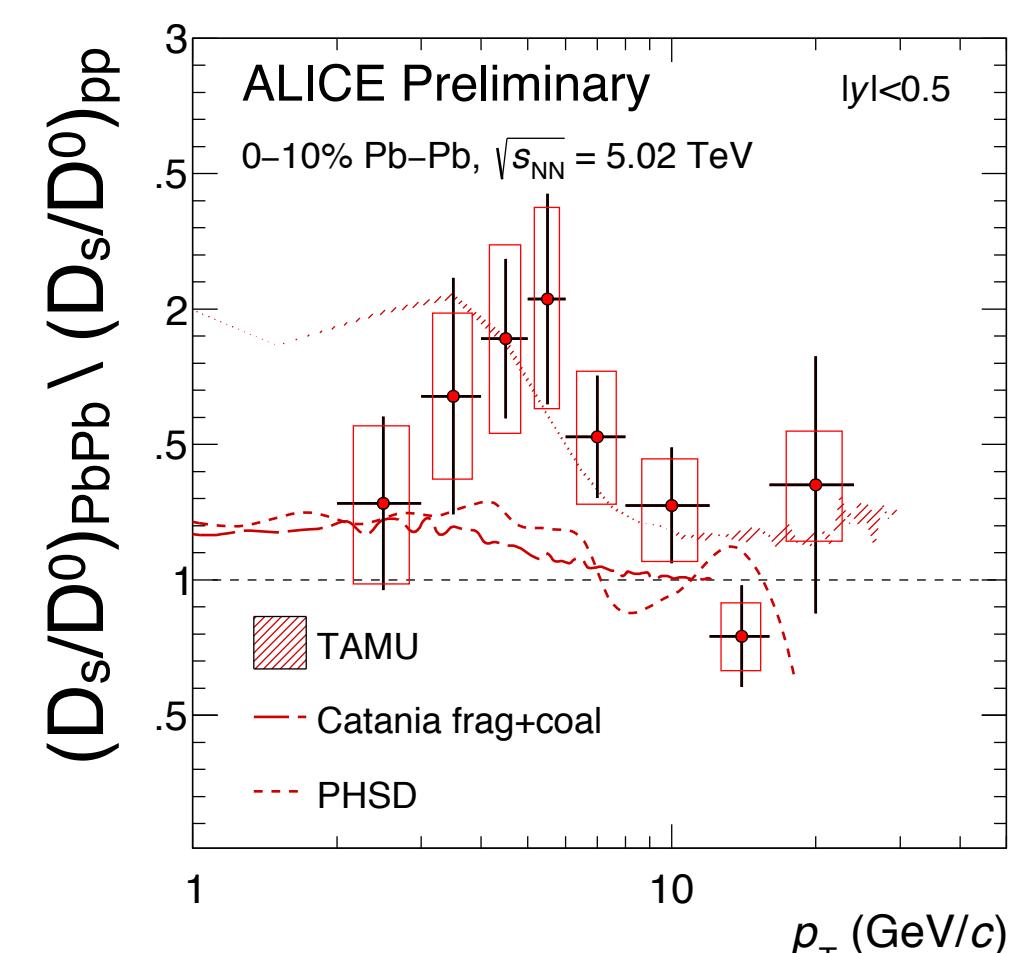
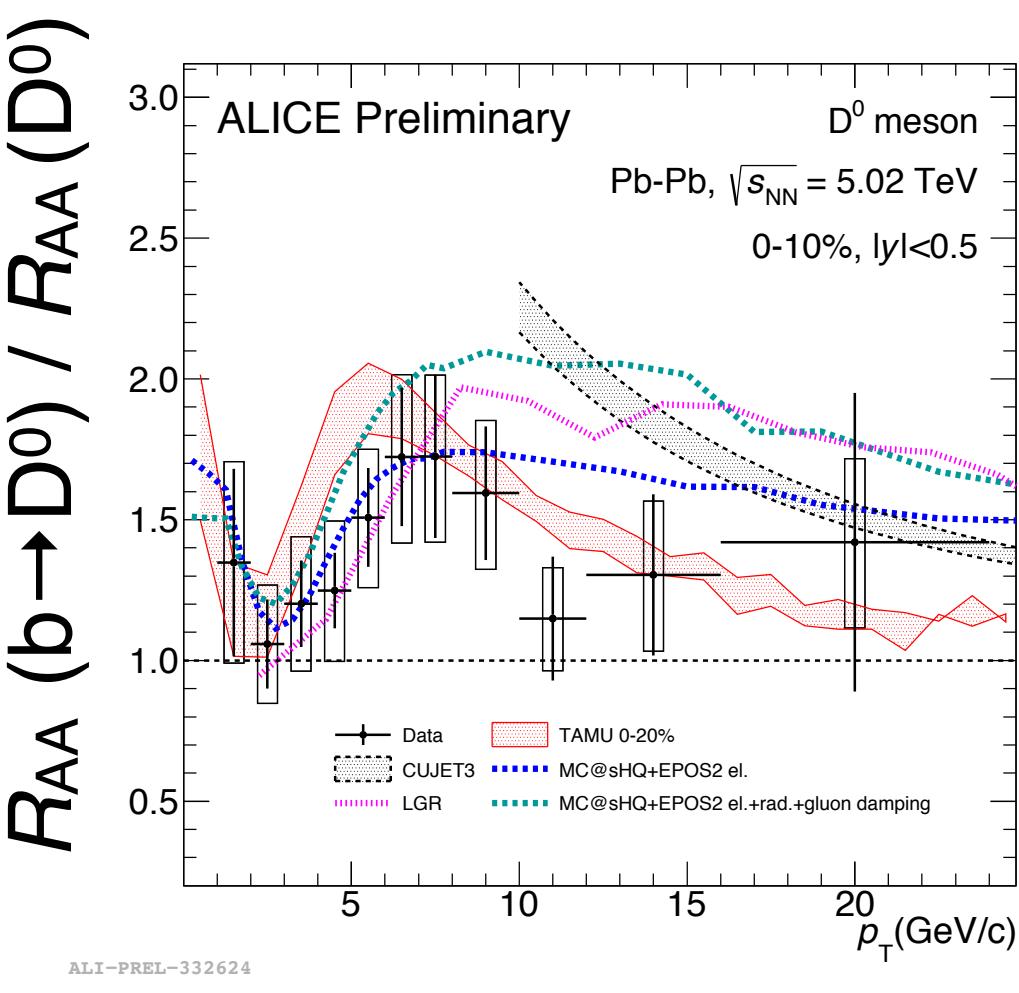
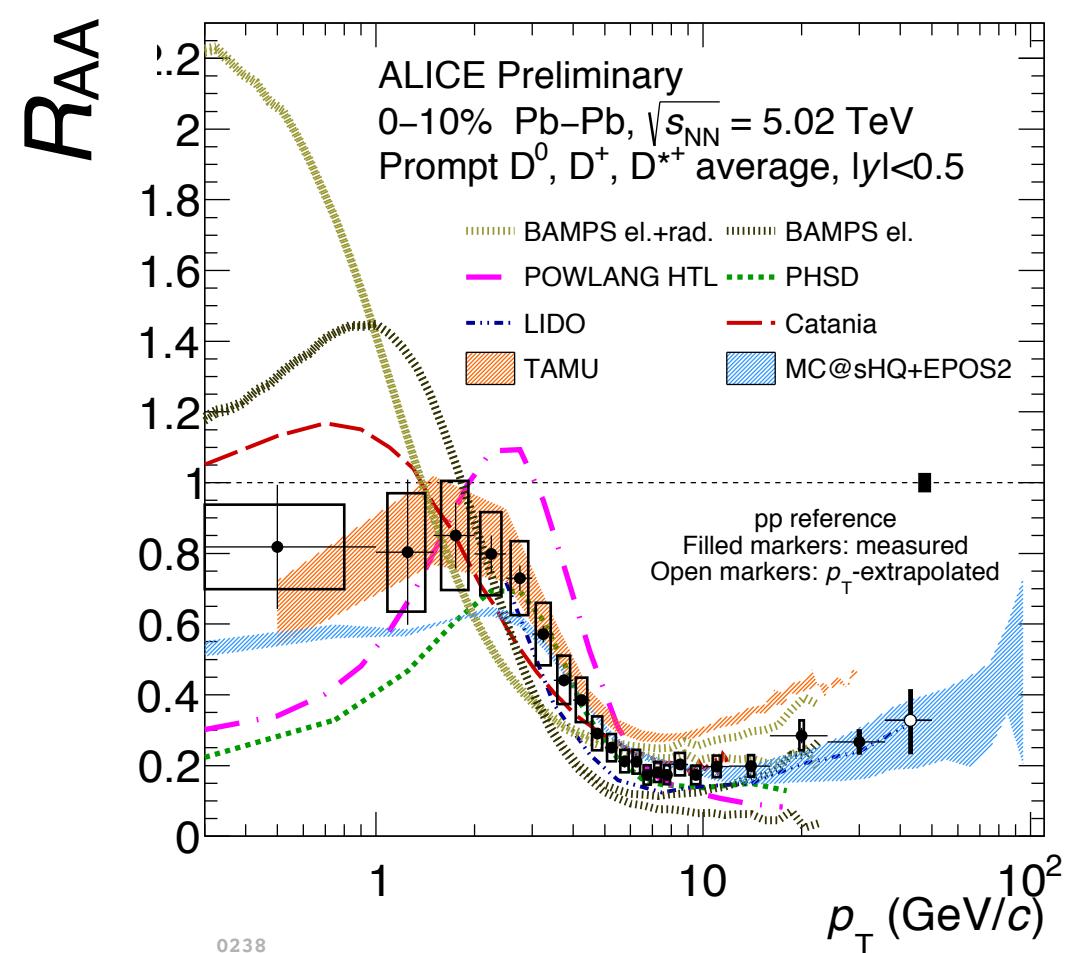
- Expected larger enhancement!

Charmed baryon fragmentation studies:

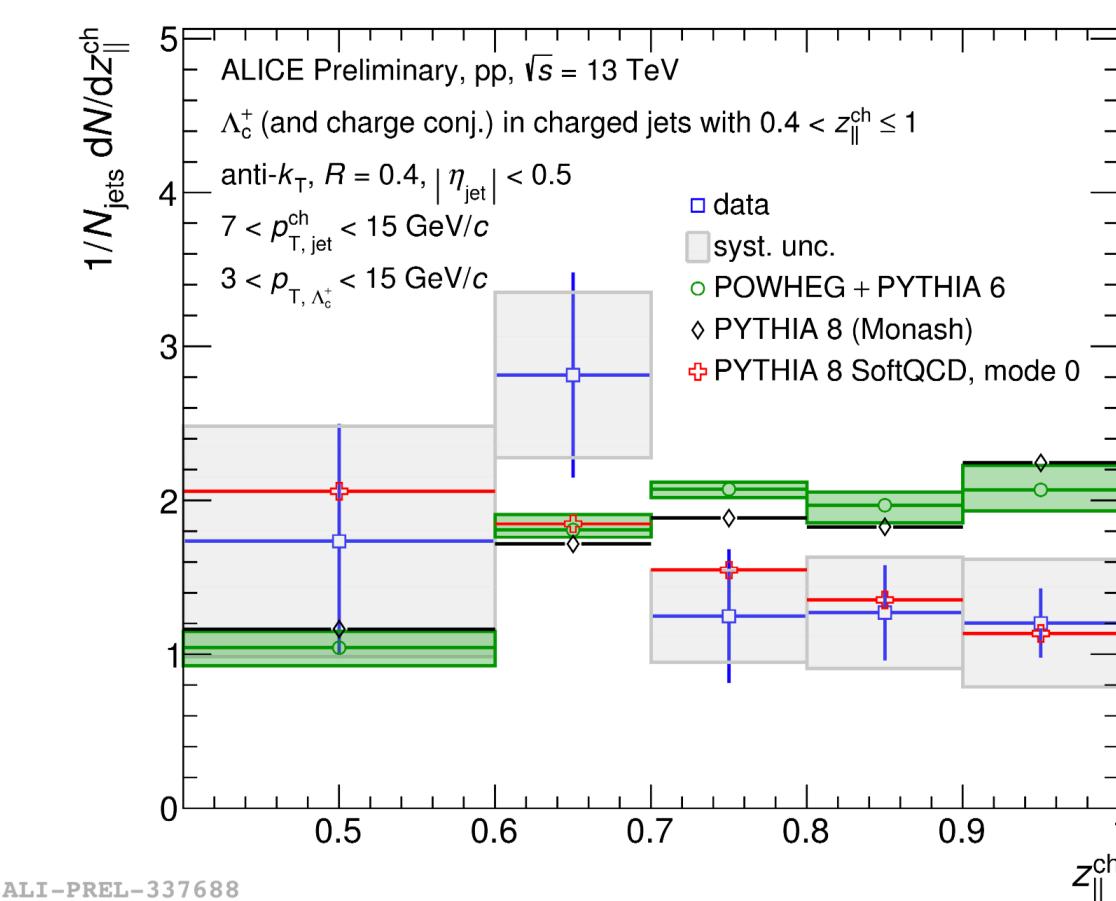
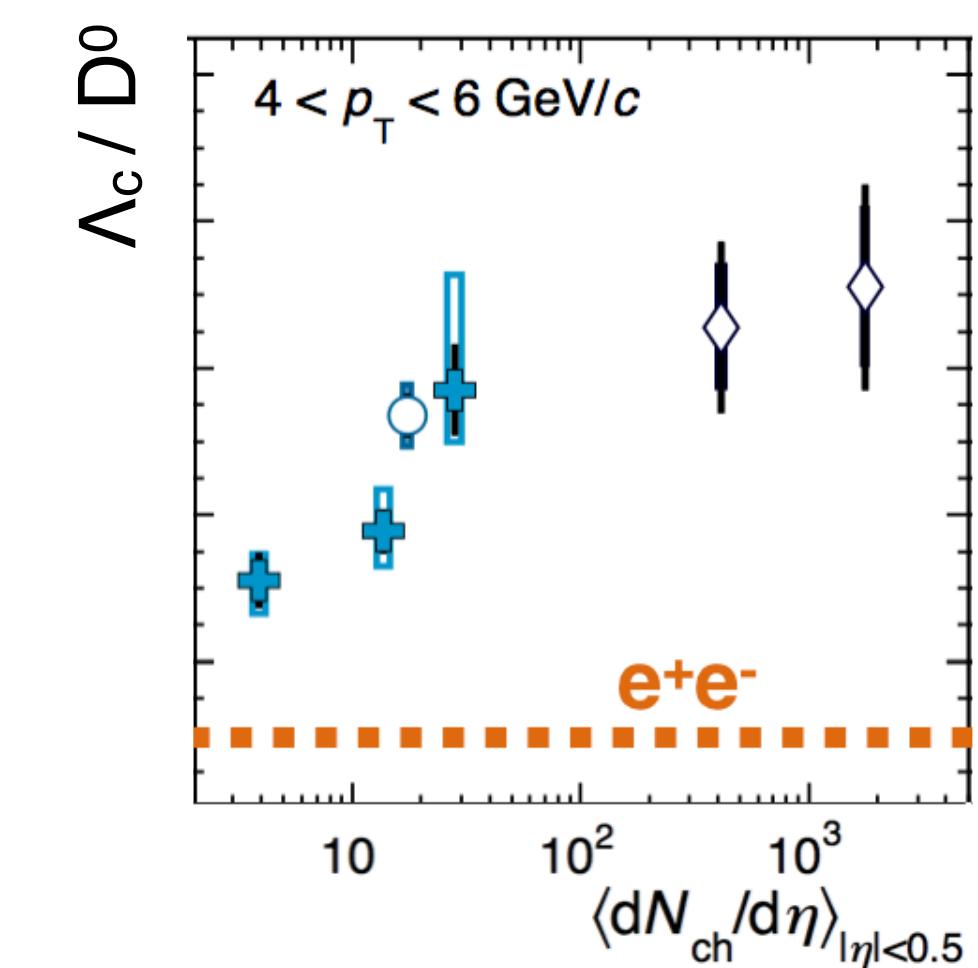
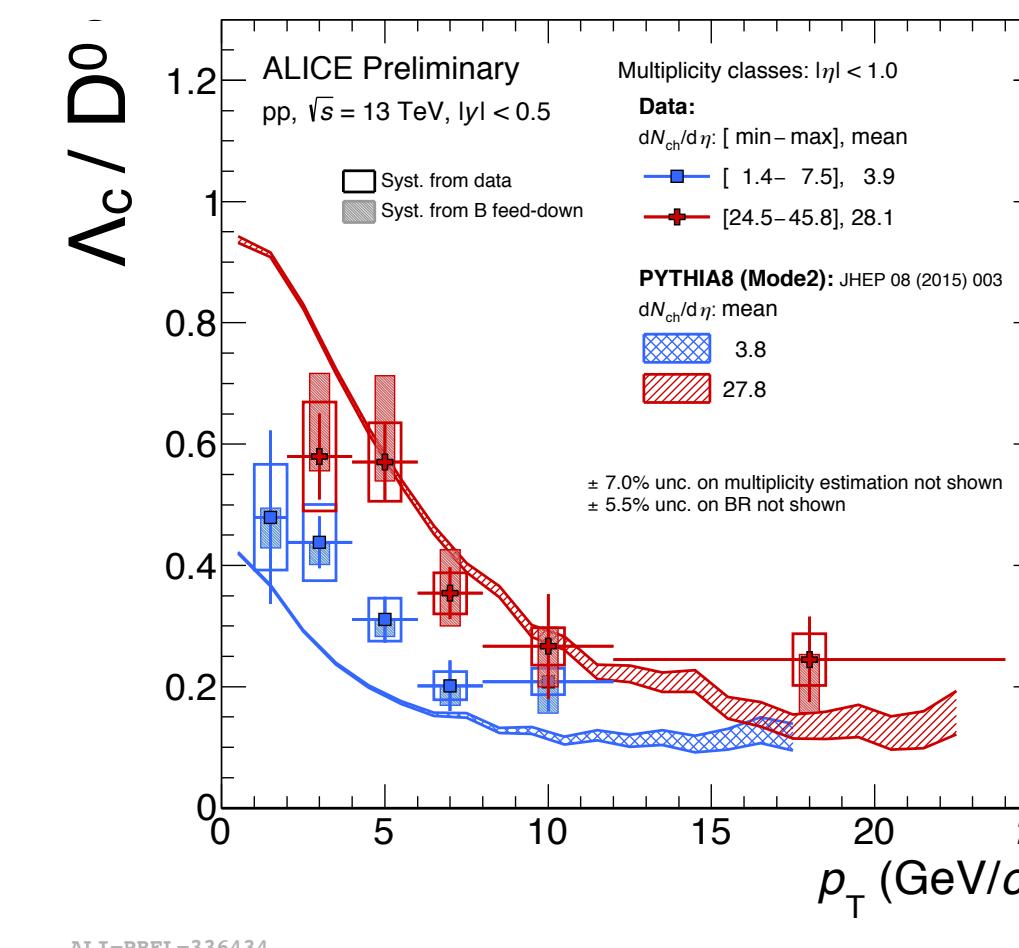
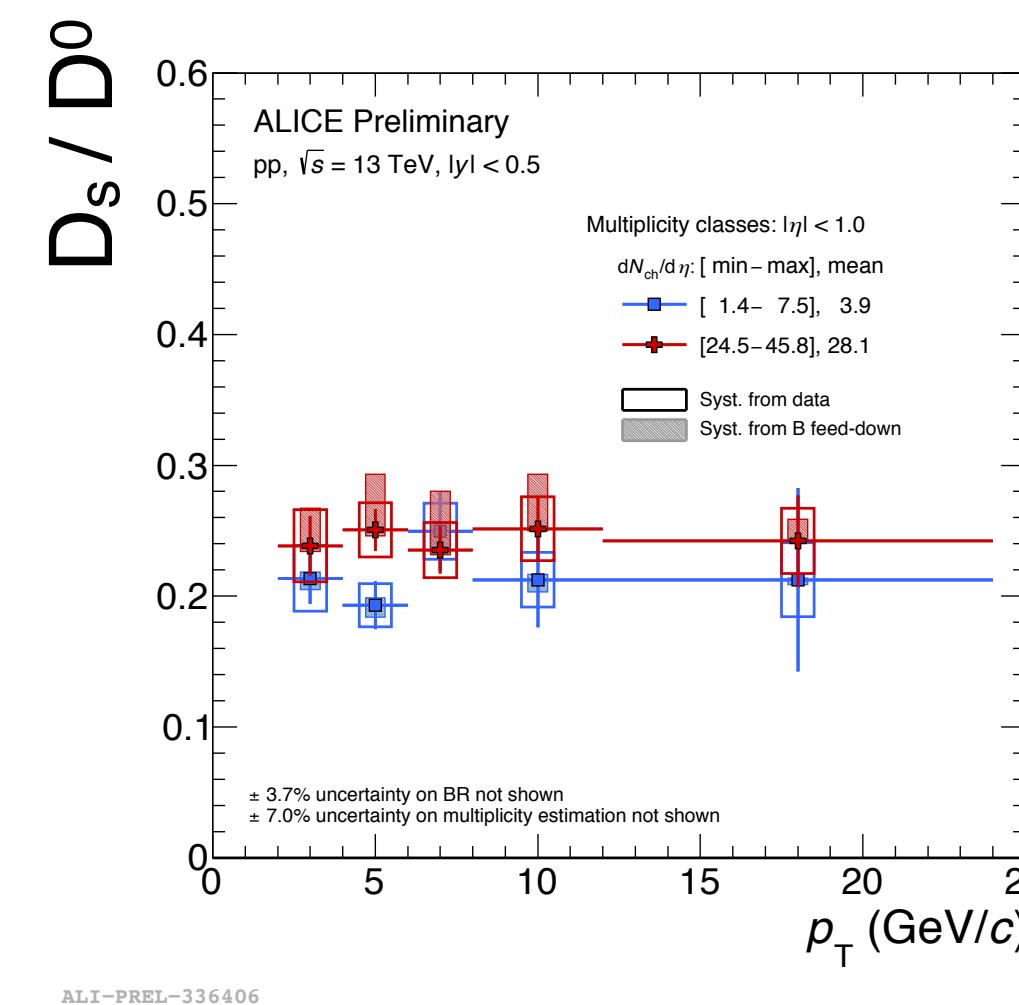
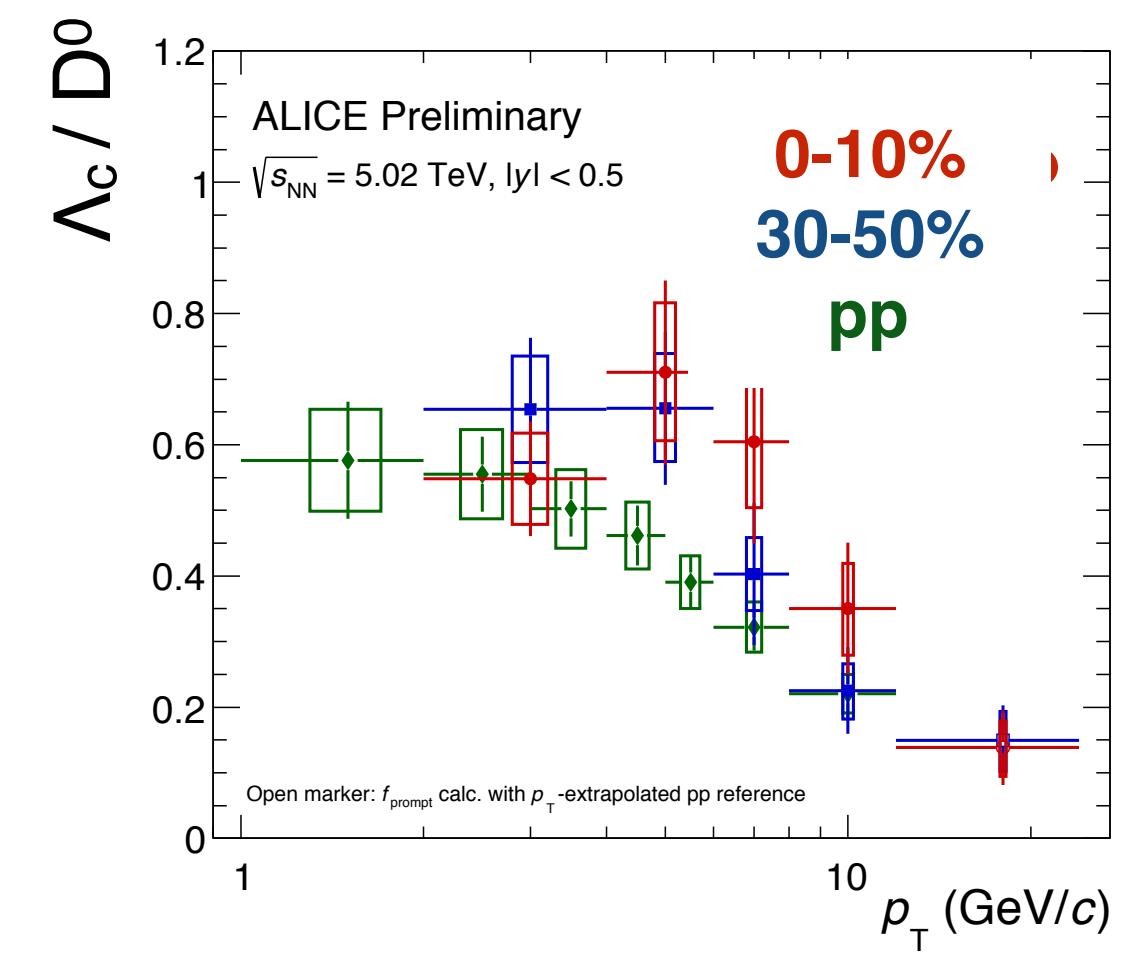
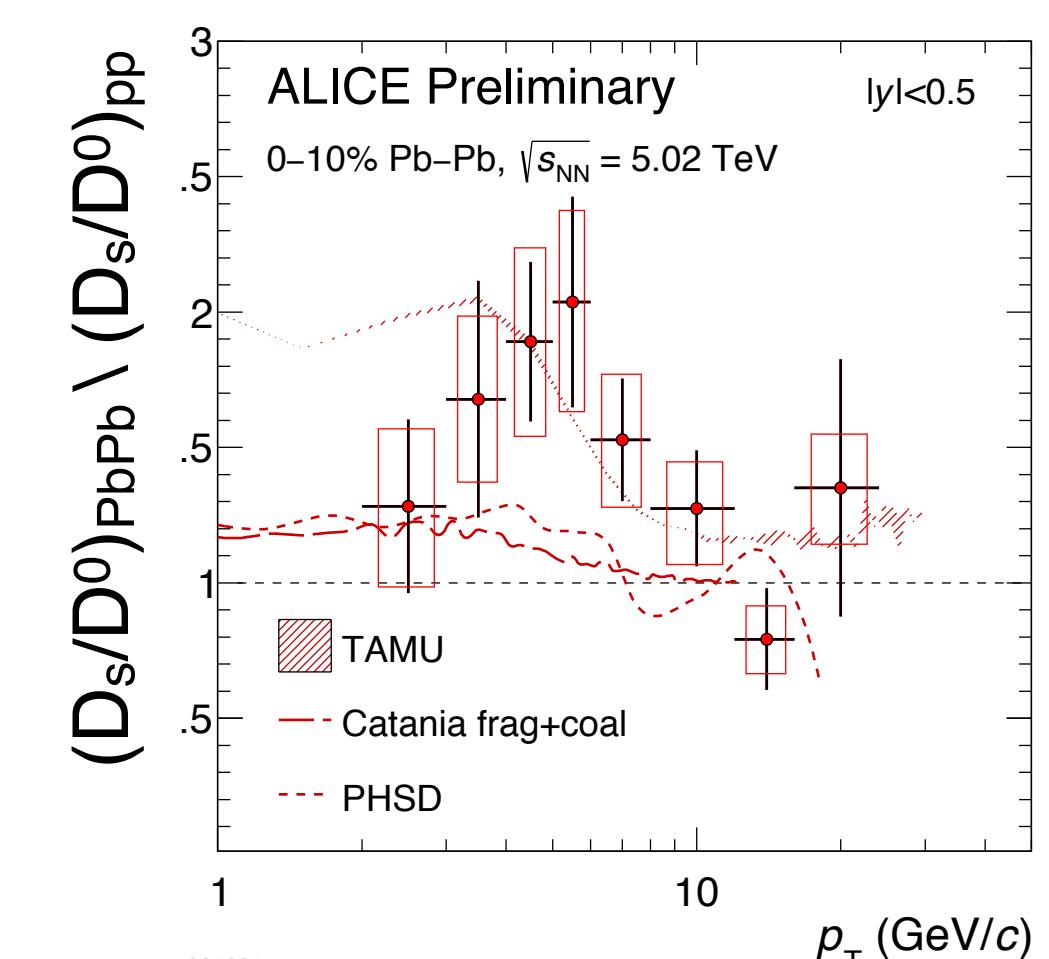
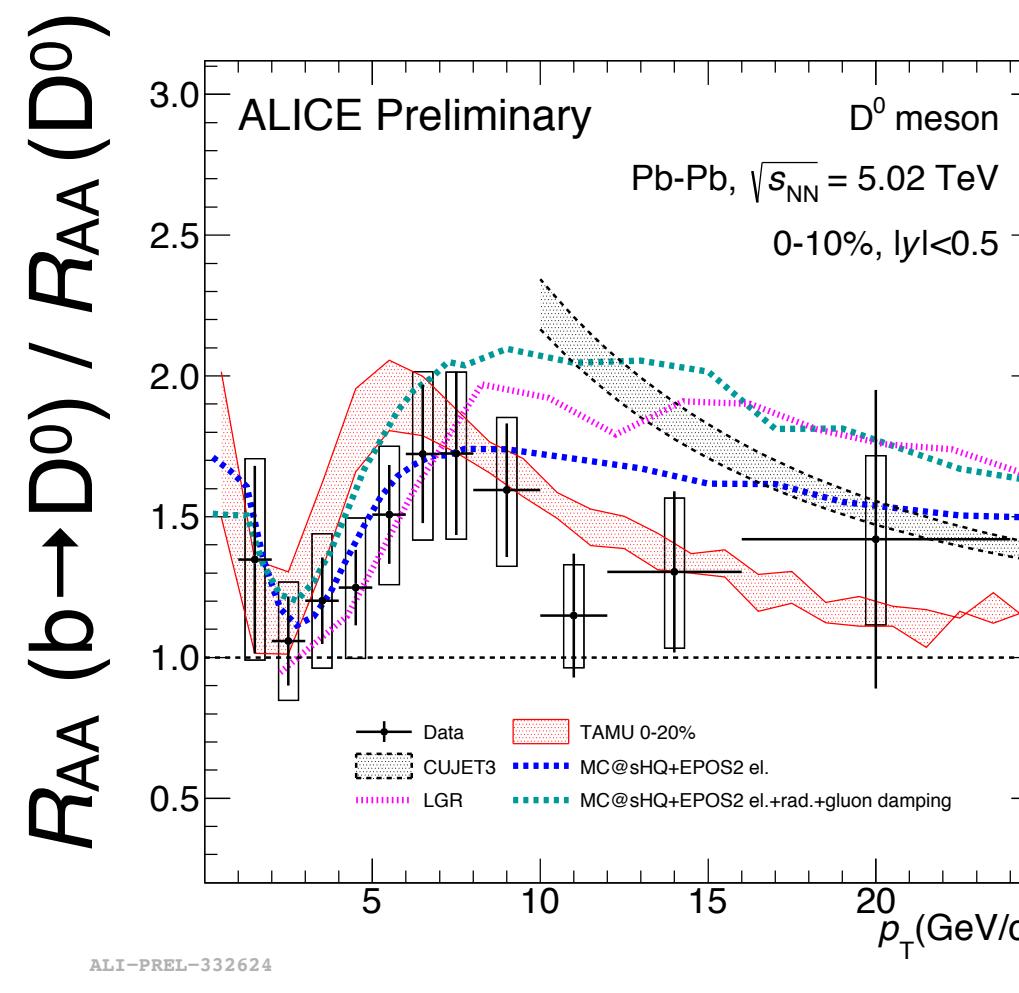
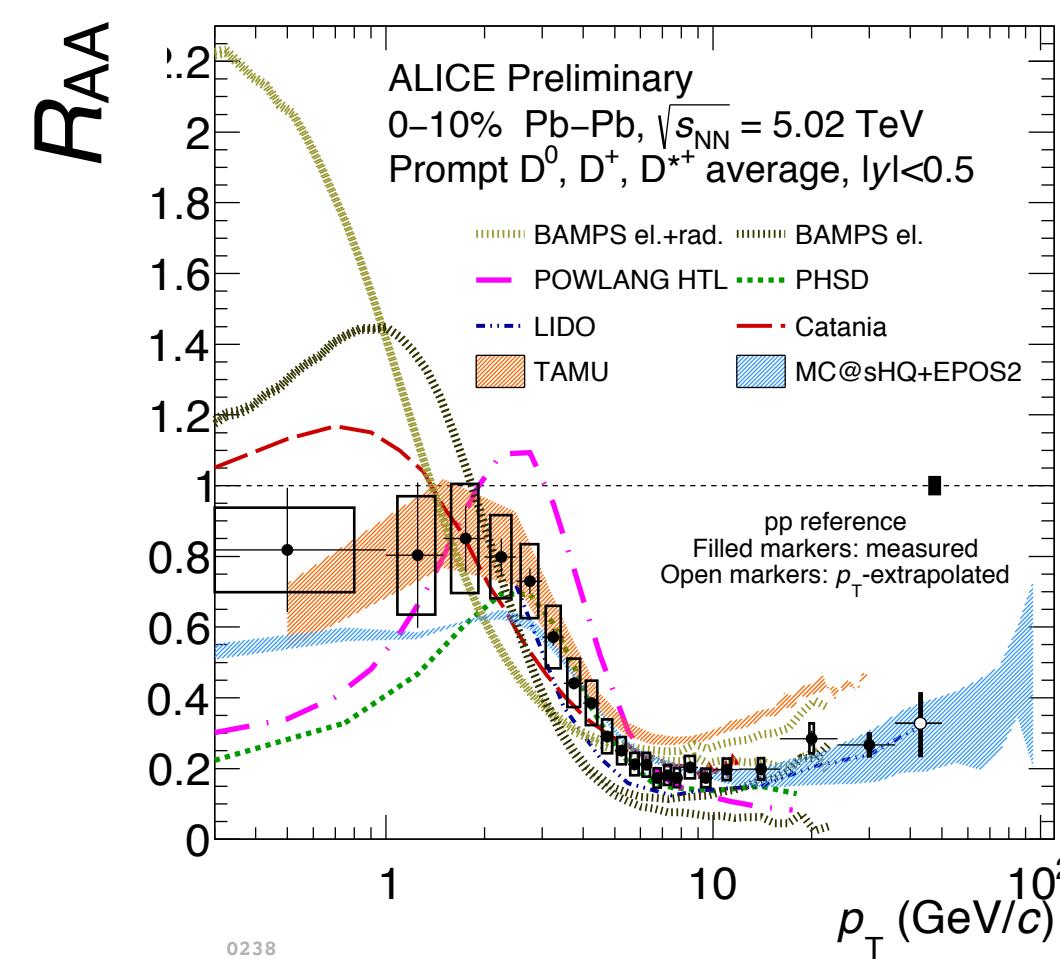
- modifications of the fragmentation that reveal effects of CR mechanisms or recombination
→ First measurement of $\Lambda_c z_{\parallel}$ at LHC!

→ Looking forward to more accurate measurements with high luminosity pp data!

The “heavy” picture!



The “heavy” picture!

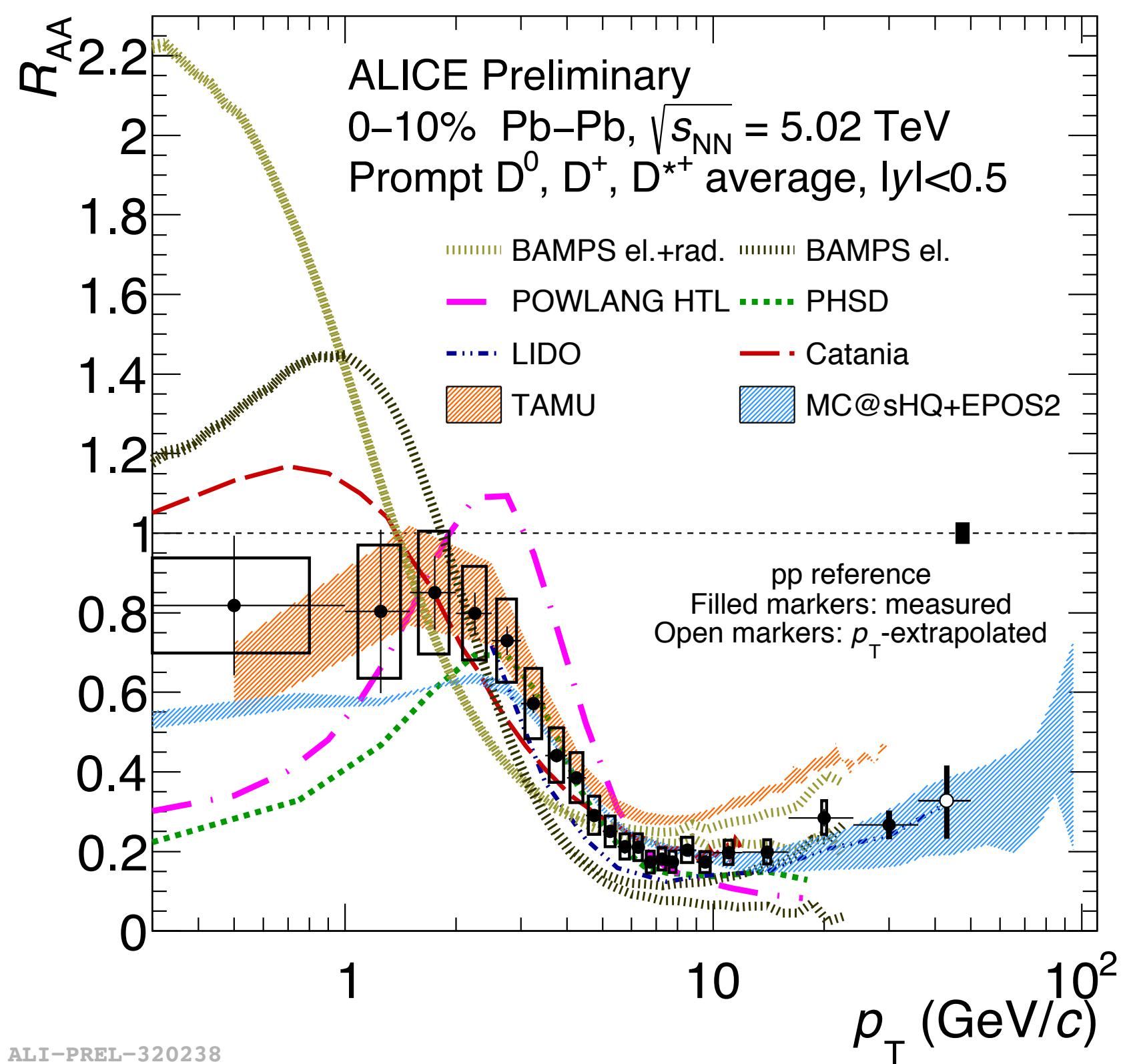


Thank you for your attention!

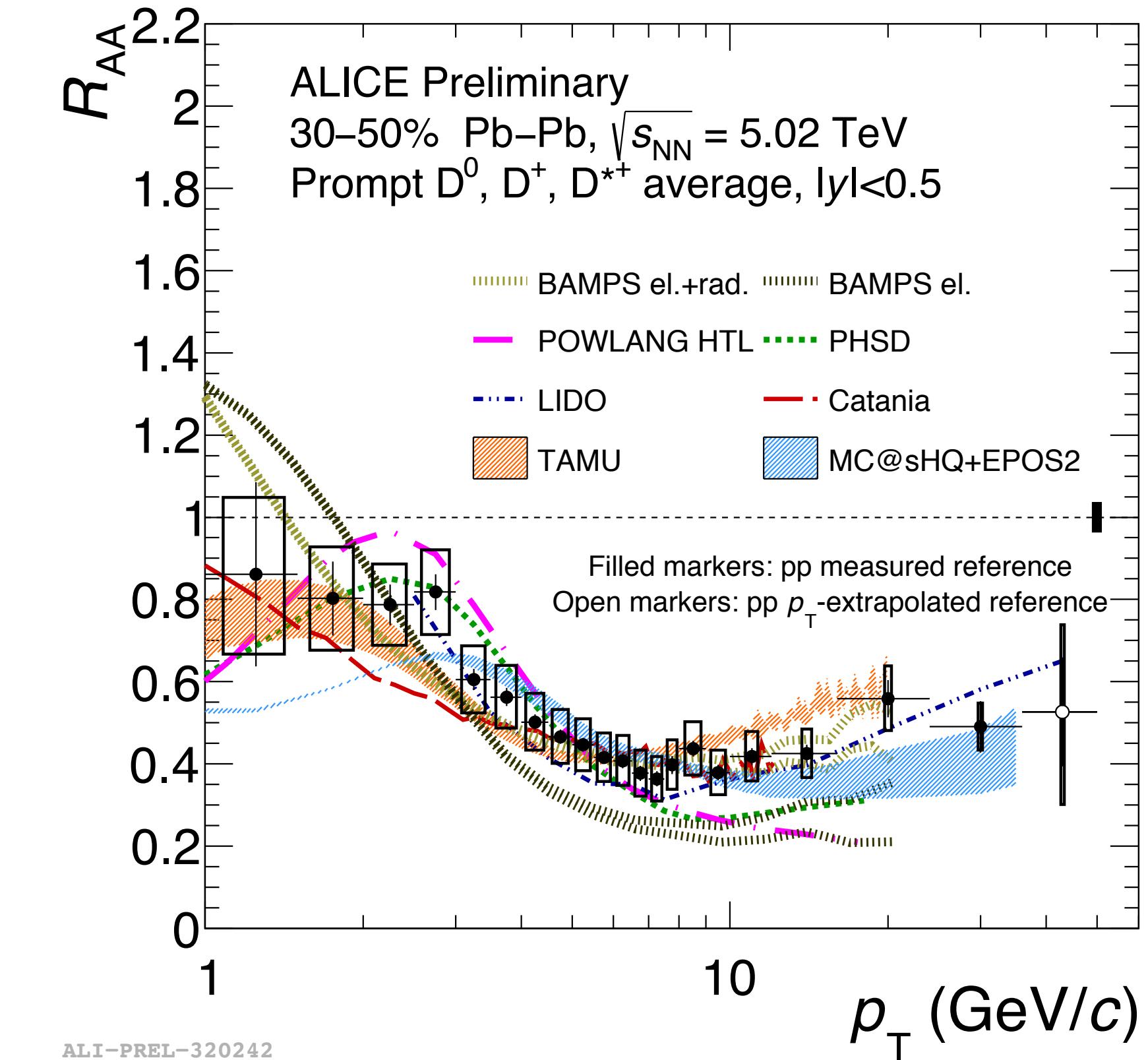
BACKUP

D meson R_{AA} : comparison to models

Centrality 0-10%



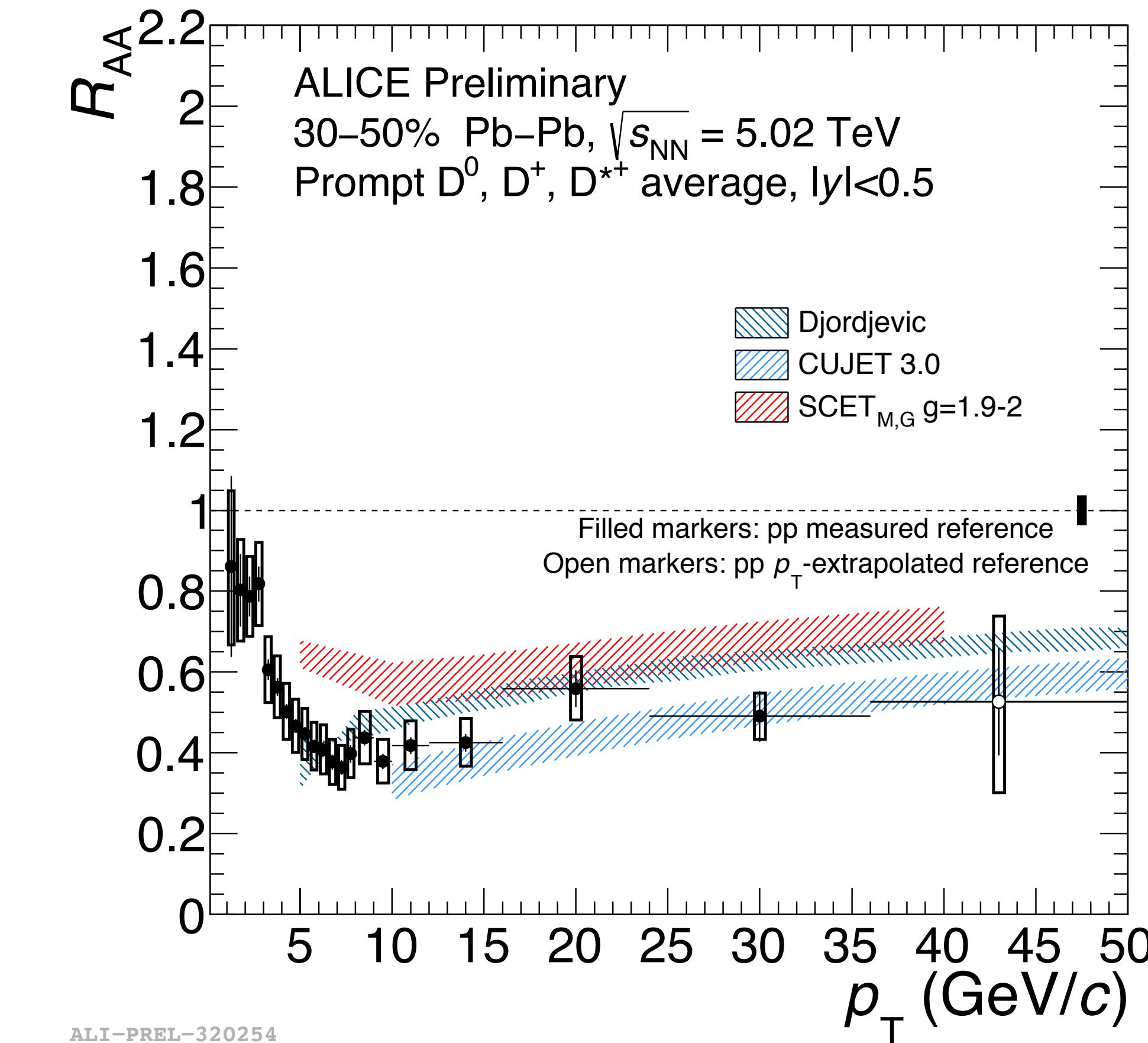
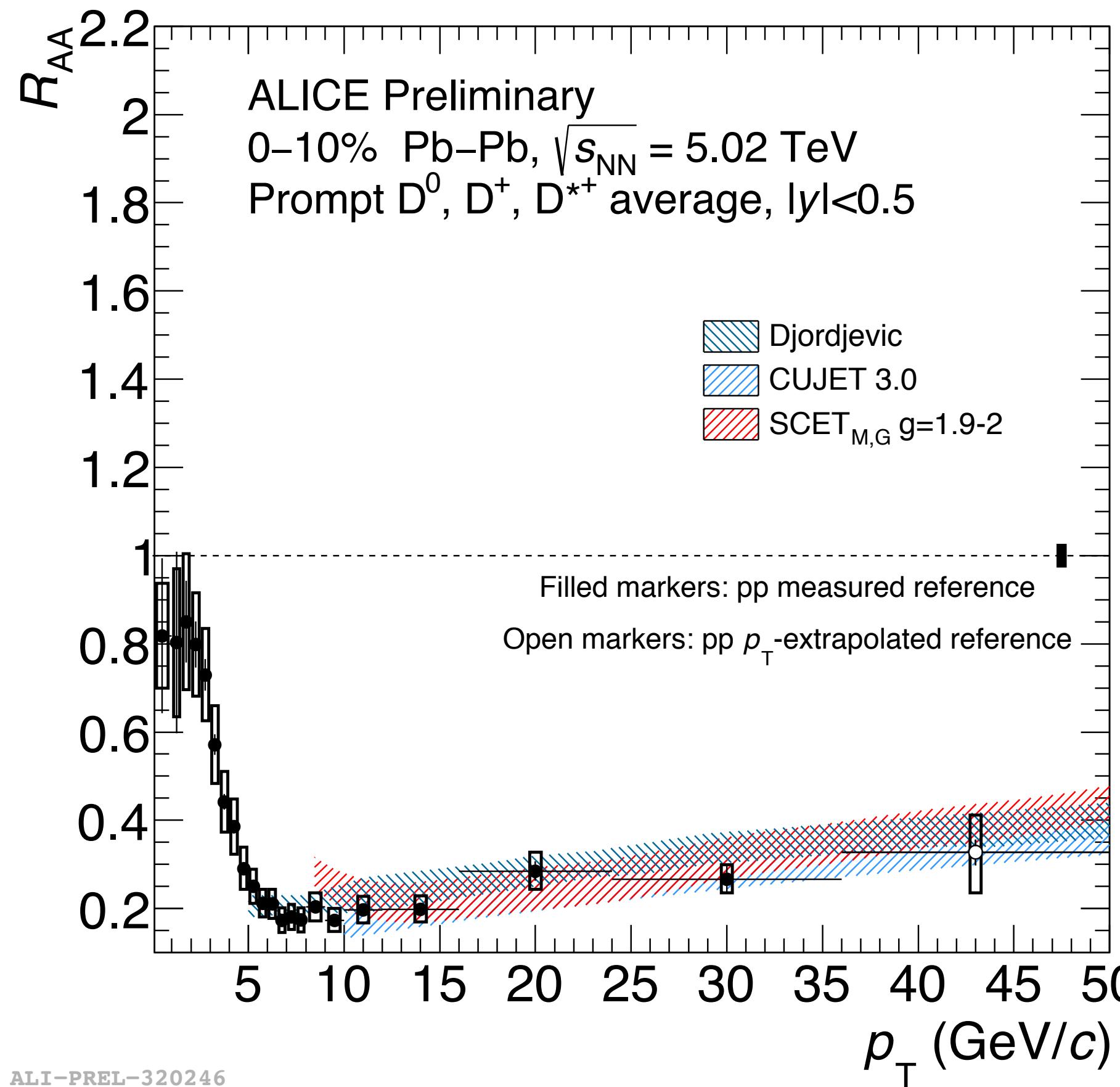
Centrality 30-50%



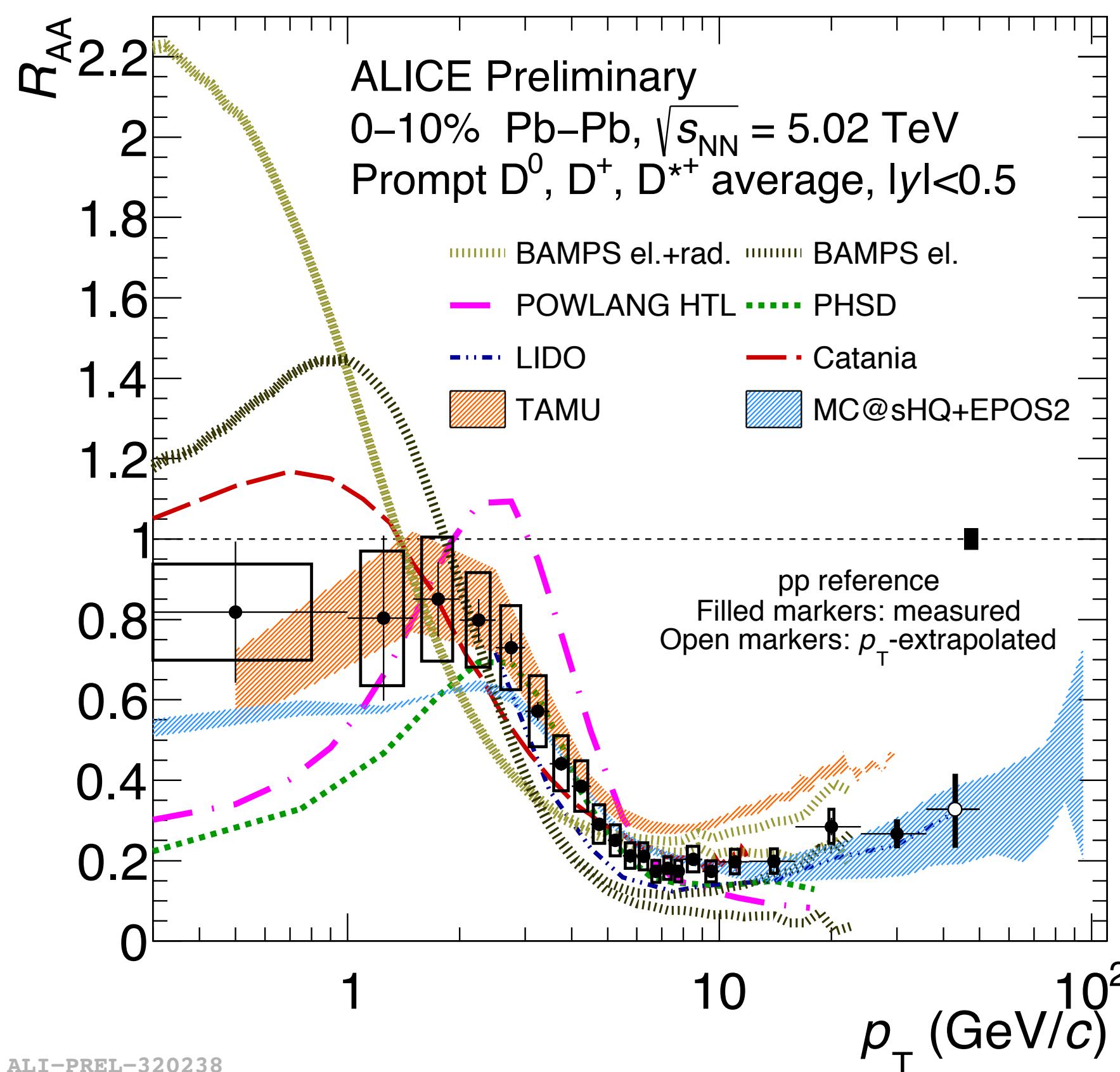
- Strong discrimination power at 0-1 GeV/c
- TAMU (Langevin) well describes the data from low to high p_T

- In semi-peripheral events, most of the models show a good agreement with the data

D meson R_{AA} : comparison to models



D meson R_{AA} : comparison to models



BAMPS el. + rad., BAMPS el.:

- overestimate the low p_T region probably because of absence of PDF modification in nuclei (shadowing)
- In presence of radiative energy loss the Pb–Pb is pushed more at lower momenta and therefore the R_{AA} goes higher

TAMU:

- Good description of the low p_T region including very low p_T intervals thanks to EPS09 + shadowing.
- FONLL as production mechanisms helps having a proper initial p_T shape
- Description at high p_T suffers from missing radiative component

POWLANG:

- The R_{AA} shape is shifted at high p_T . Effect of different HQ production mechanisms?
- The effect of PDF modification is visible at low momenta where the R_{AA} decreases significantly, more than in TAMU
- At high p_T . The R_{AA} is smaller than data, which is surprising given that there is no radiative energy loss

Catania:

- Results similar to TAMU, but with a shift of the p_T spectrum (or R_{AA}) at lower p_T . Effects of the different recombination?

LIDO:

- Results similar to TAMU. Not available for the very low p_T region

MC@sHQ+EPOS2:

- Pretty good agreement at high p_T .
- Underestimate the low p_T region

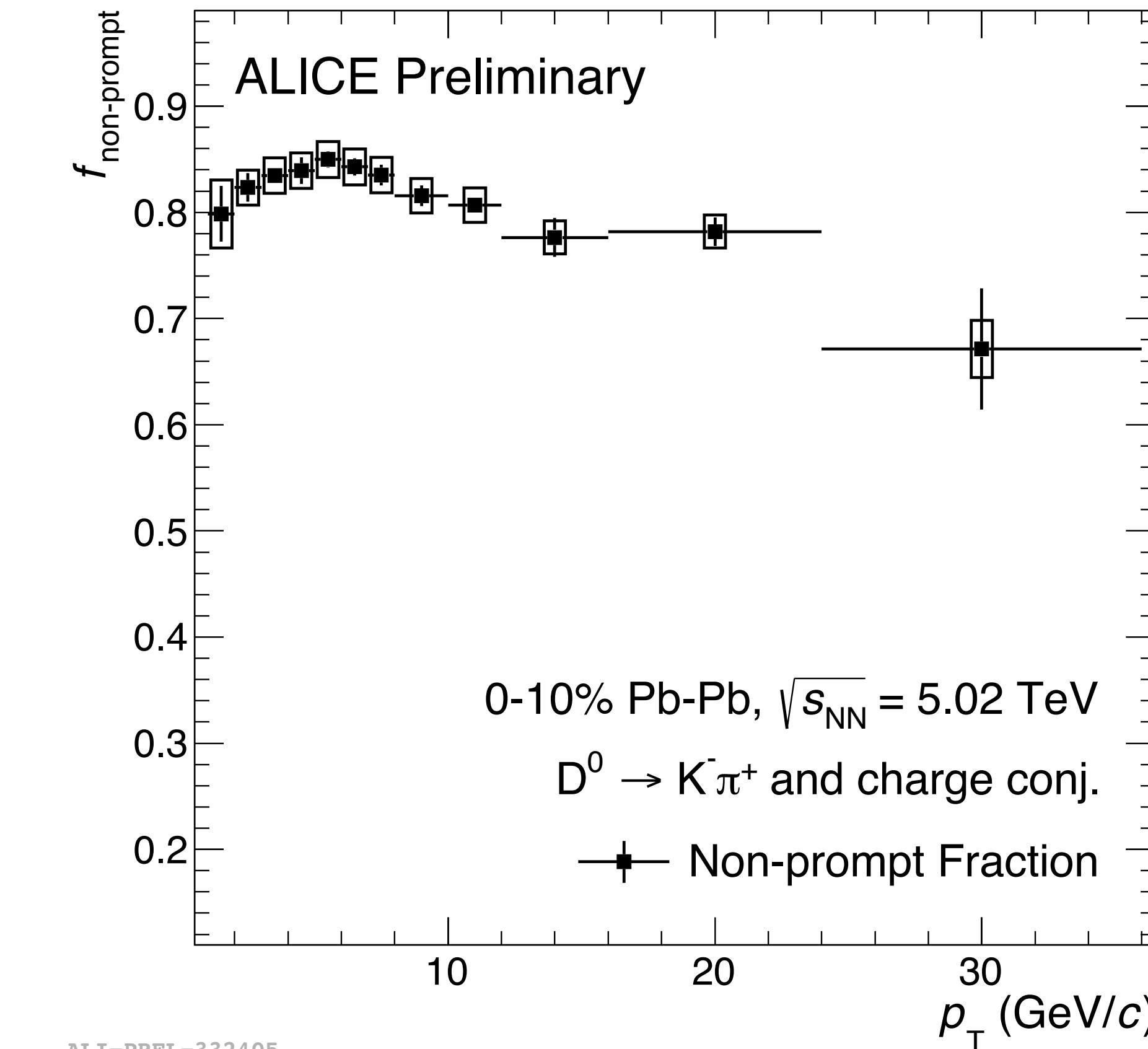
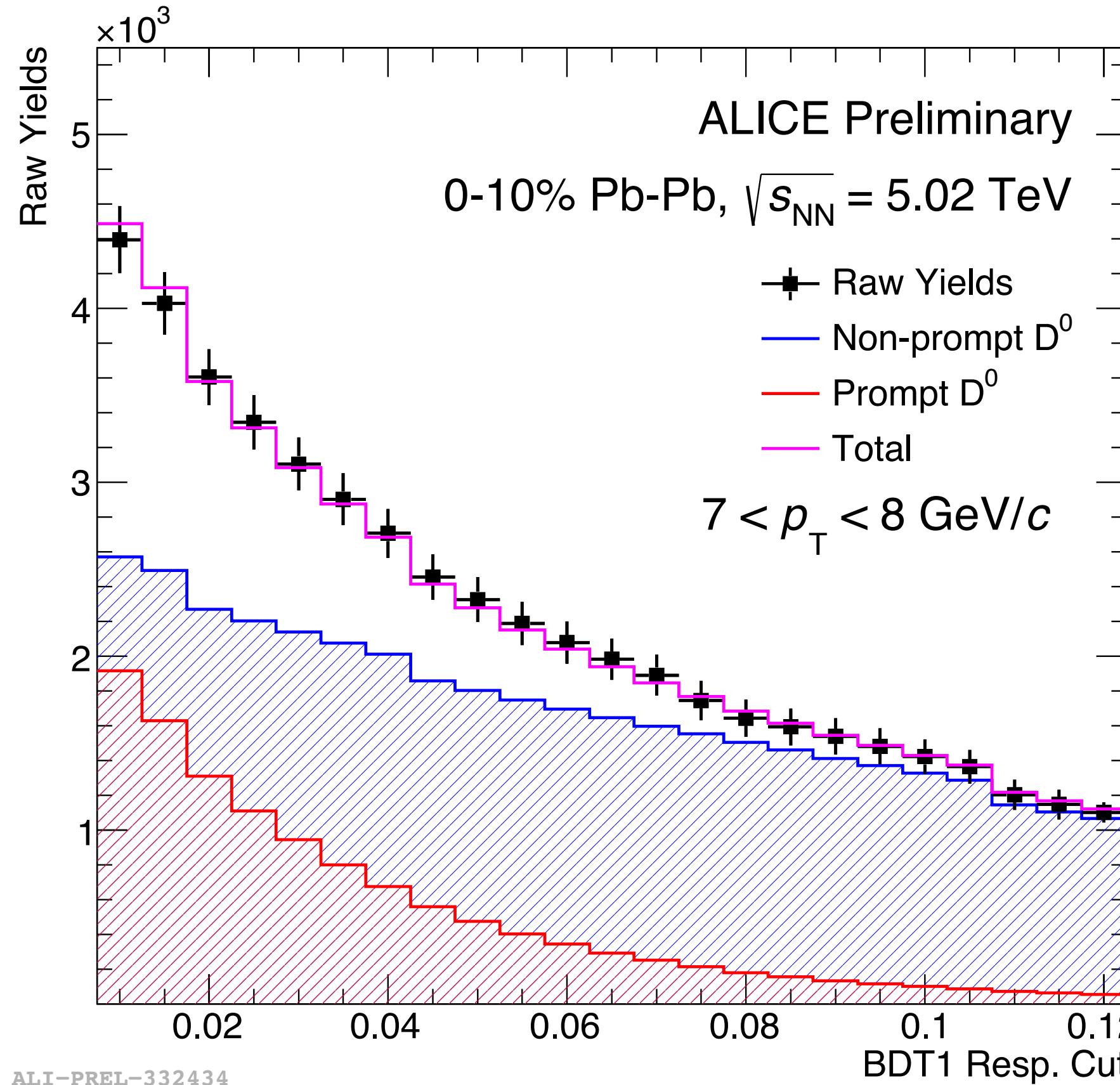
Overview of theoretical calculations

Model	HQ production	Medium modelling	Quark-medium interaction	HQ hadronization	Tuning of medium coupling	References
BAMPS el.	MC@NLO No PDF shadowing	3d+1 expansion parton cascade	Transport with Boltzmann rad. + coll.	Frag.	RHIC (then scaled by $dN/d\eta$)	https://arxiv.org/abs/1408.2964
TAMU	FONLL EPS09 (NLO) PDF shadowing	2d+1 expansion parton cascade	Transport with Langevin coll. only Diffusion in hadronic phase Improved space-mom correlation	Frag. + Rec.	Assume 1-QCD U potential	https://arxiv.org/abs/1401.3817
POWLANG	POWLANG EPS09 (NLO) PDF shadowing	2d+1 expansion with viscous fluido-dyn evolution	Transport with Langevin coll. only	Frag. + Rec.	Assume 1-QCD U potential	https://arxiv.org/abs/1410.6082
Catania	FONLL EPS09 (NLO) PDF shadowing	2d+1 expansion parton cascade	Transport with Langevin coll. only	Frag. + Rec. (different from TAMU?)	Assume 1-QCD U potential	https://arxiv.org/pdf/1712.00730.pdf
LIDO	FONLL EPS09 (NLO) PDF shadowing	2d+1 rel. fluido-dynamics	Transport with Langevin + empirical transport coefficients to capture the non-perturbative part. (Boltzmann)	Frag. + Rec.	Coefficients fixed with Bayesian analysis to LHC D and B results	https://arxiv.org/pdf/1806.08848.pdf

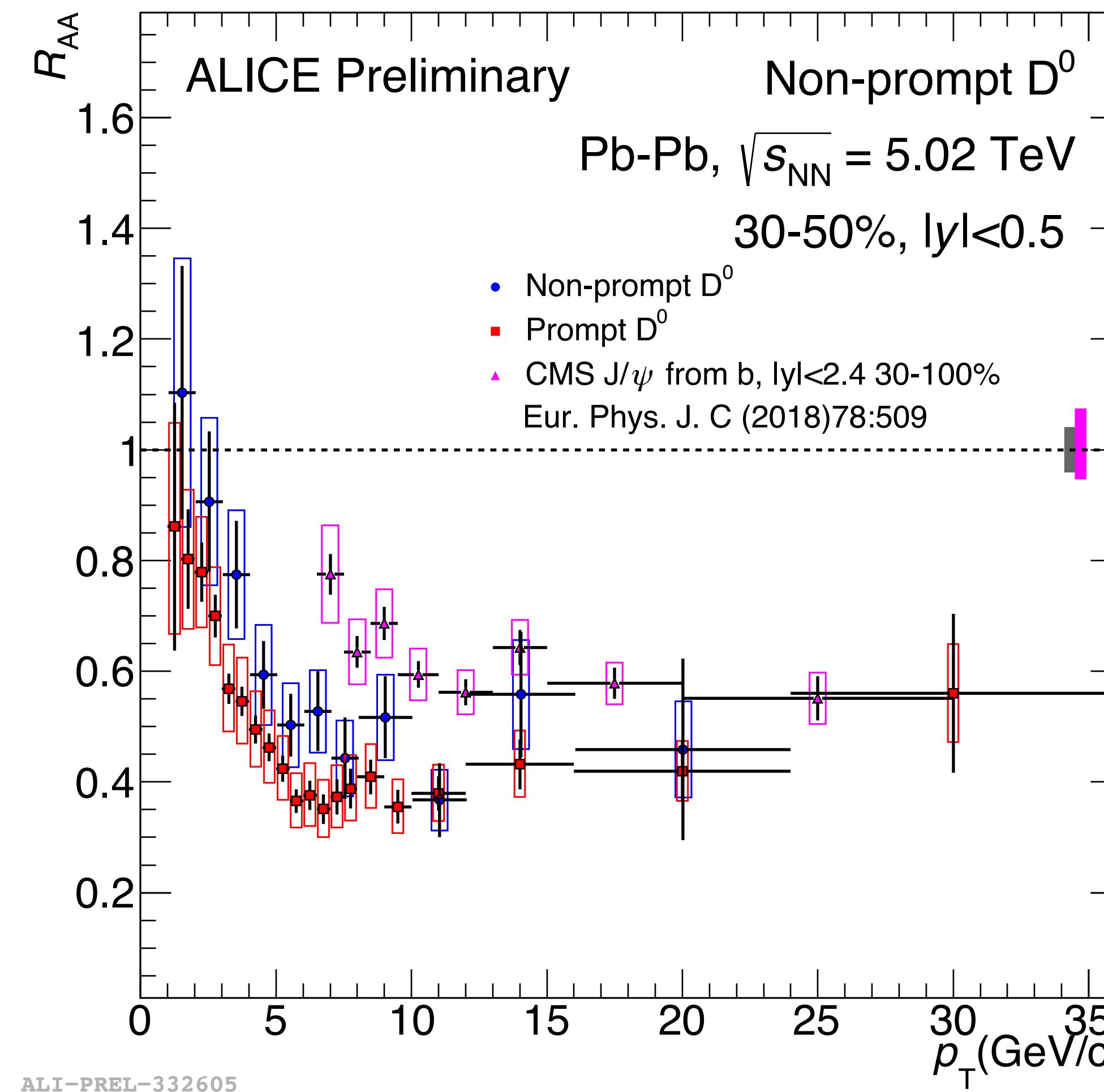
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PHSD	Pythia + string melting		Microscopic covariant transport Dynamical Quasiparticle Model	Local covariant transition rates		https://arxiv.org/pdf/1908.00451.pdf
MC@ sHQ+ EPOS2	FONLL EPS09 (NLO) PDF shadowing	3d+1 expansion (EPOS model)	Transport with Boltzmann coll. (+rad when mentioned)	Frag. + Rec.	QGP transport coefficients fixed at LHC, adapted for RHIC	https://arxiv.org/abs/1305.6544
WHDG	FONLL no PDF shadowing	Glauber model nuclear overlap No fluido-dyn evol.	rad. + coll.	Frag.	RHIC (then scaled by dN/dη)	
Vitev et al.	Non-zero mass VFNS no PDF shadowing	Glauber model nuclear overlap Ideal fluido-dyn Bjorken expansion	rad. + coll. In medium meson dissociation	Frag.	RHIC (then scaled by dN/dη)	
CUJET3		Semi quark gluon monopole plasma	rad.	Frag.	Model parameters tuned on light flavor data	https://arxiv.org/abs/1704.04577

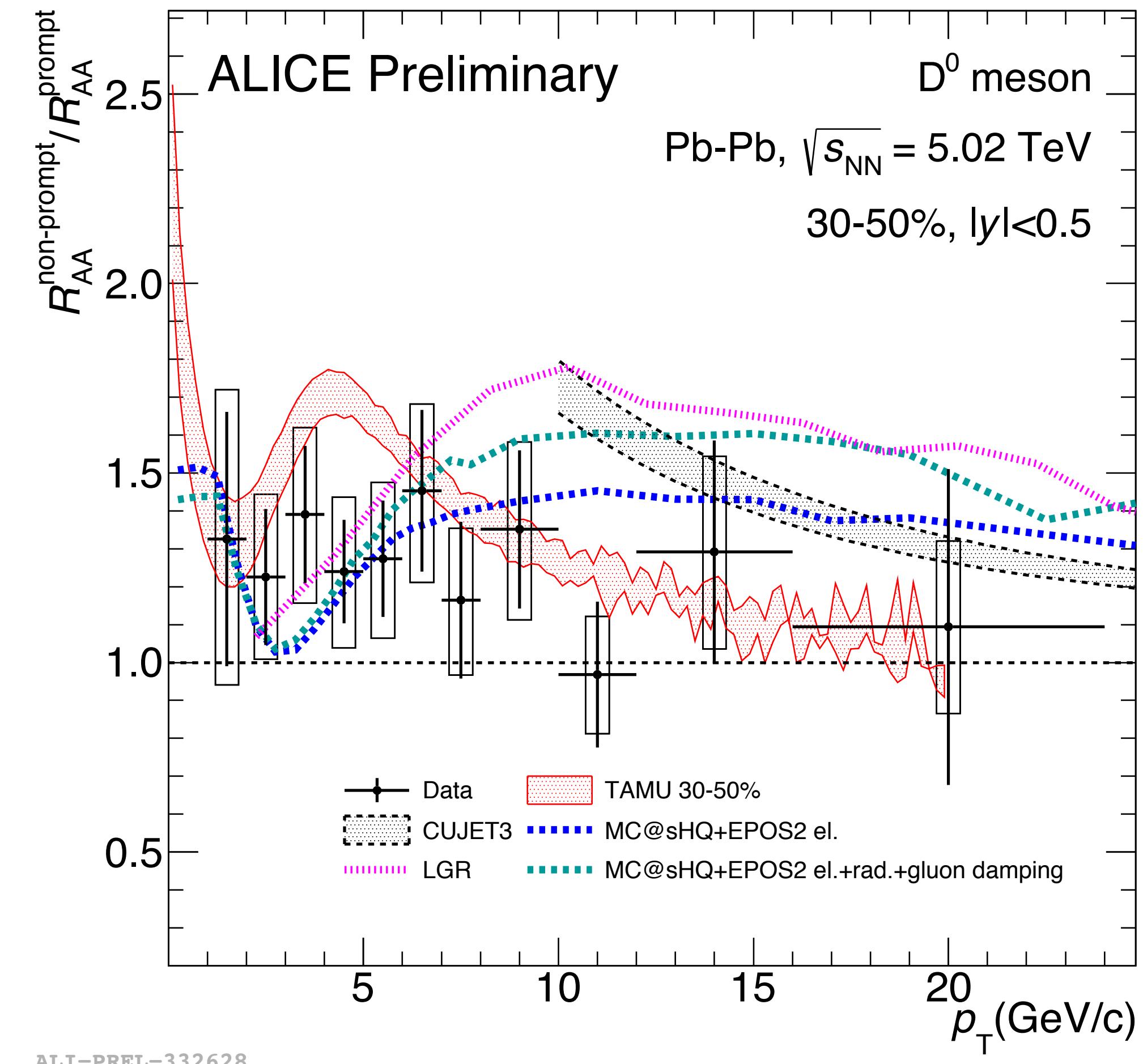
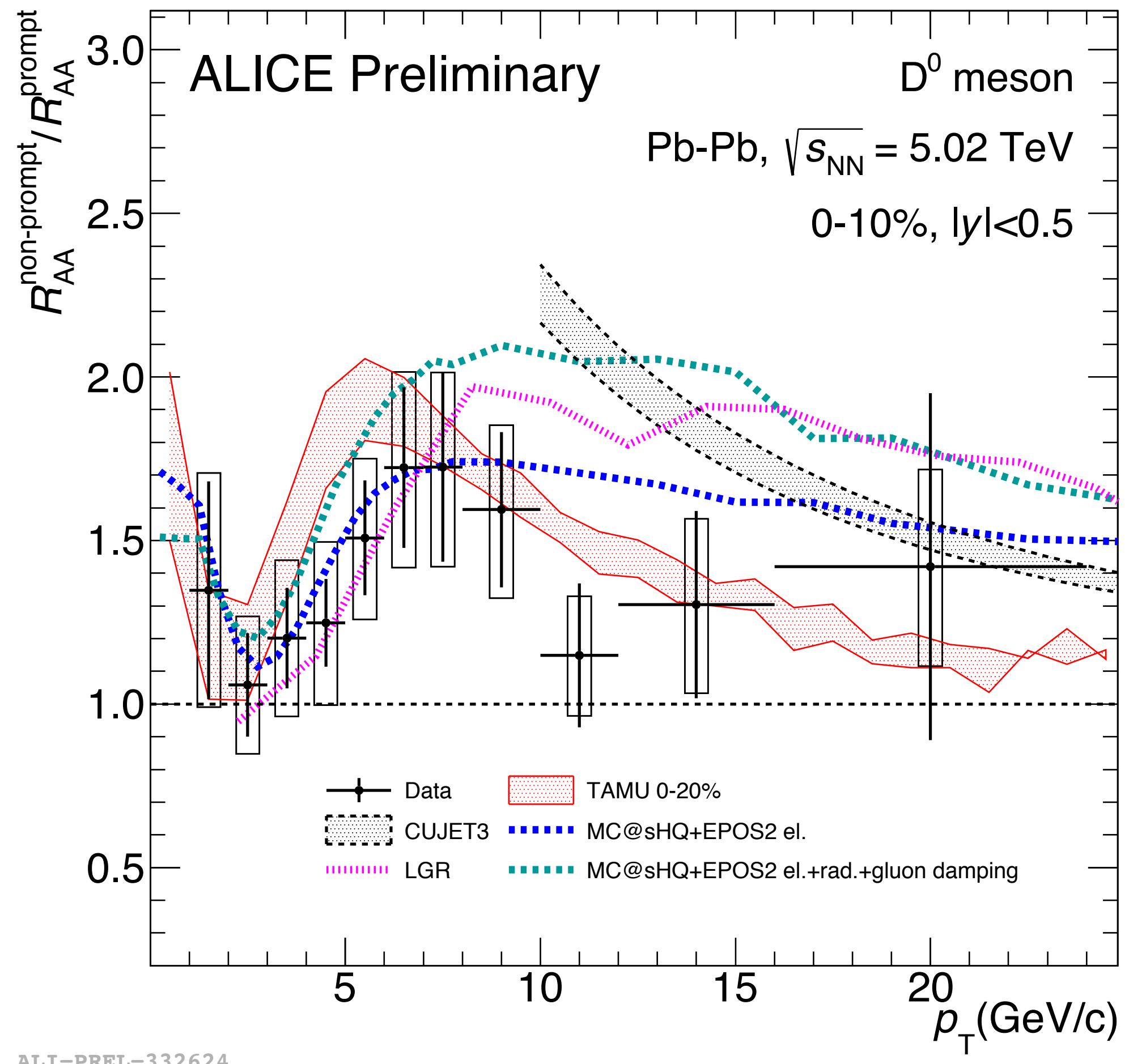
f_{prompt} extraction for non-prompt D^0 R_{AA}



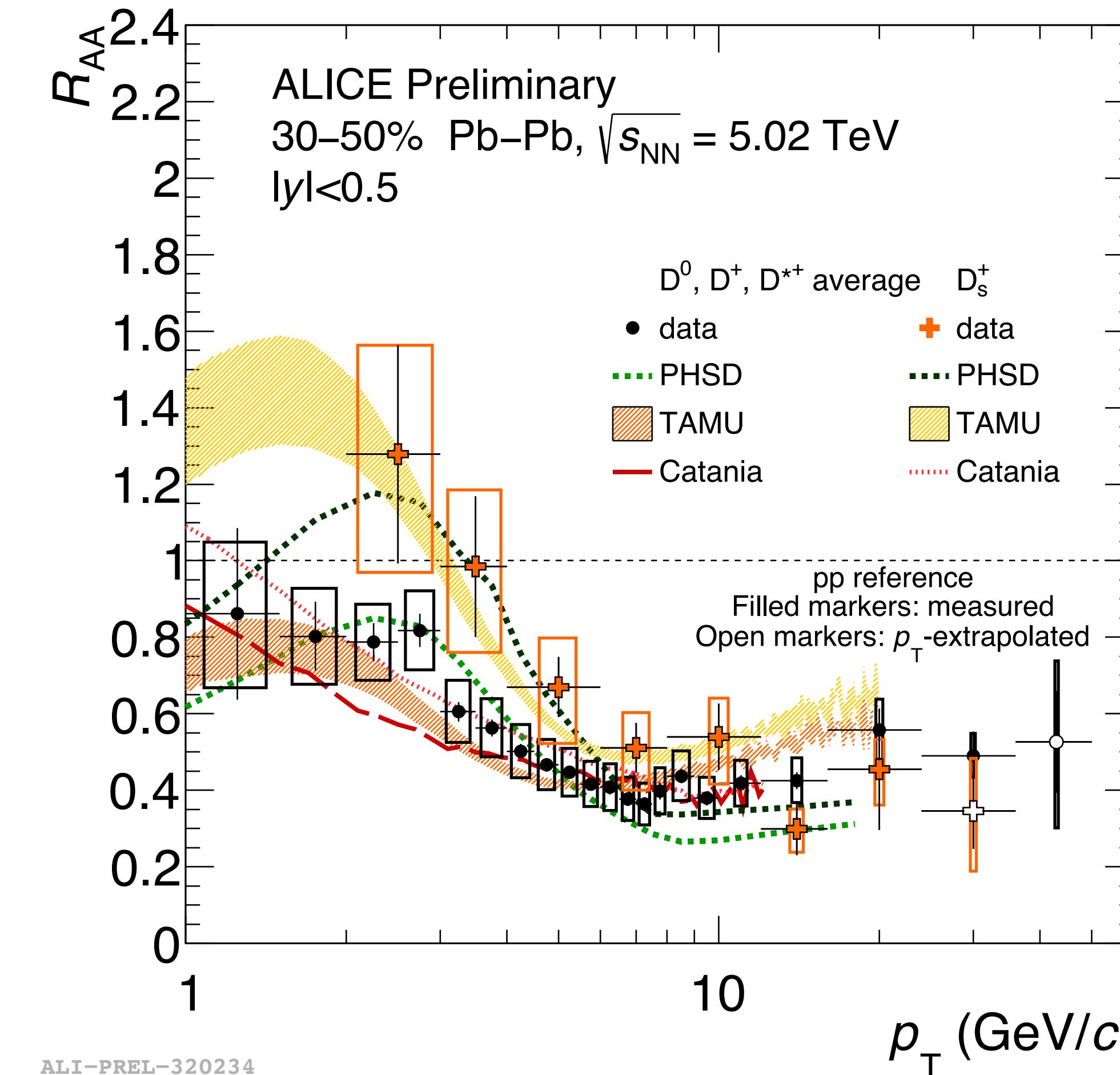
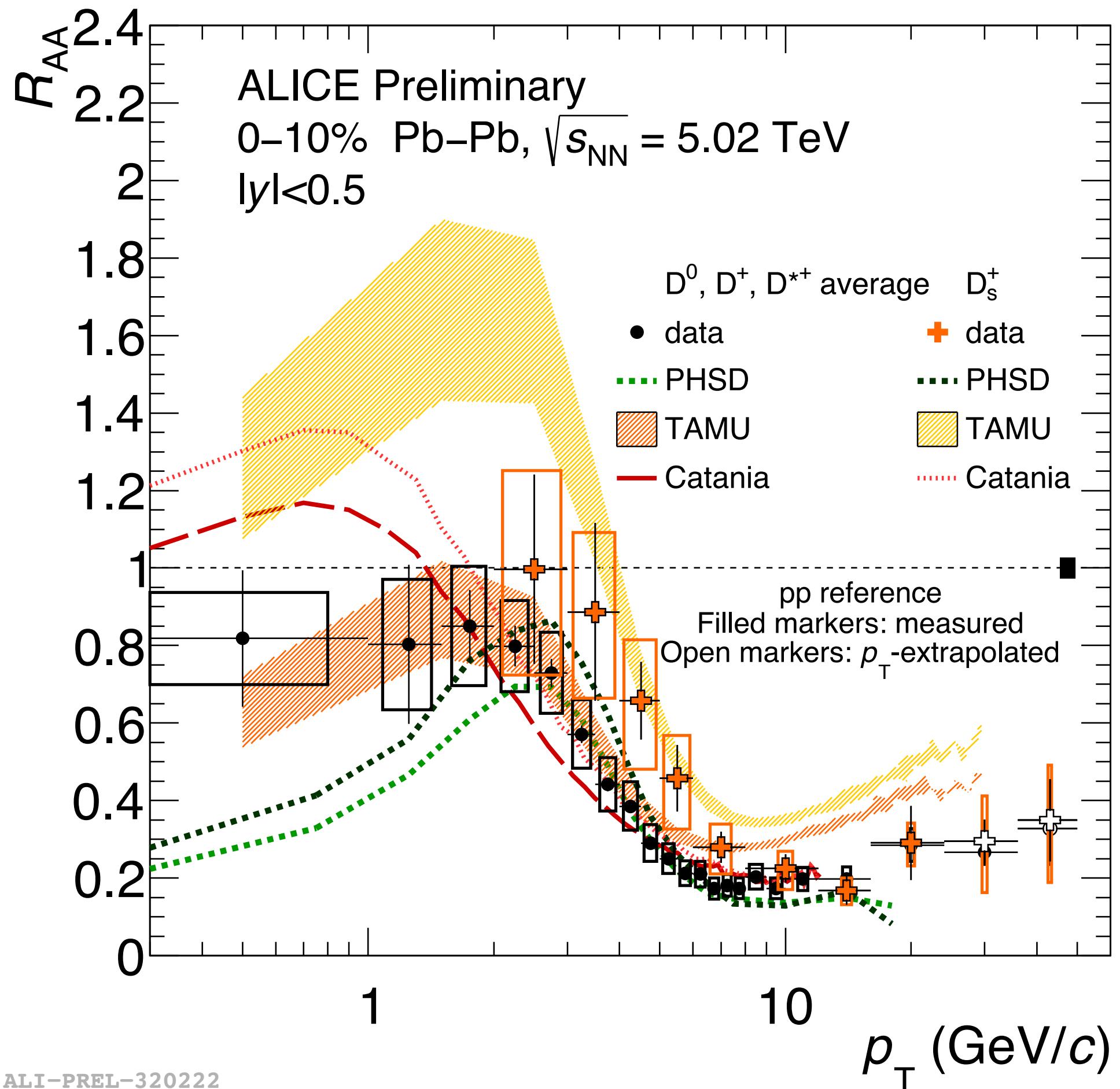
non-prompt D^0 R_{AA} : comparison to CMS $b \rightarrow J/\psi$



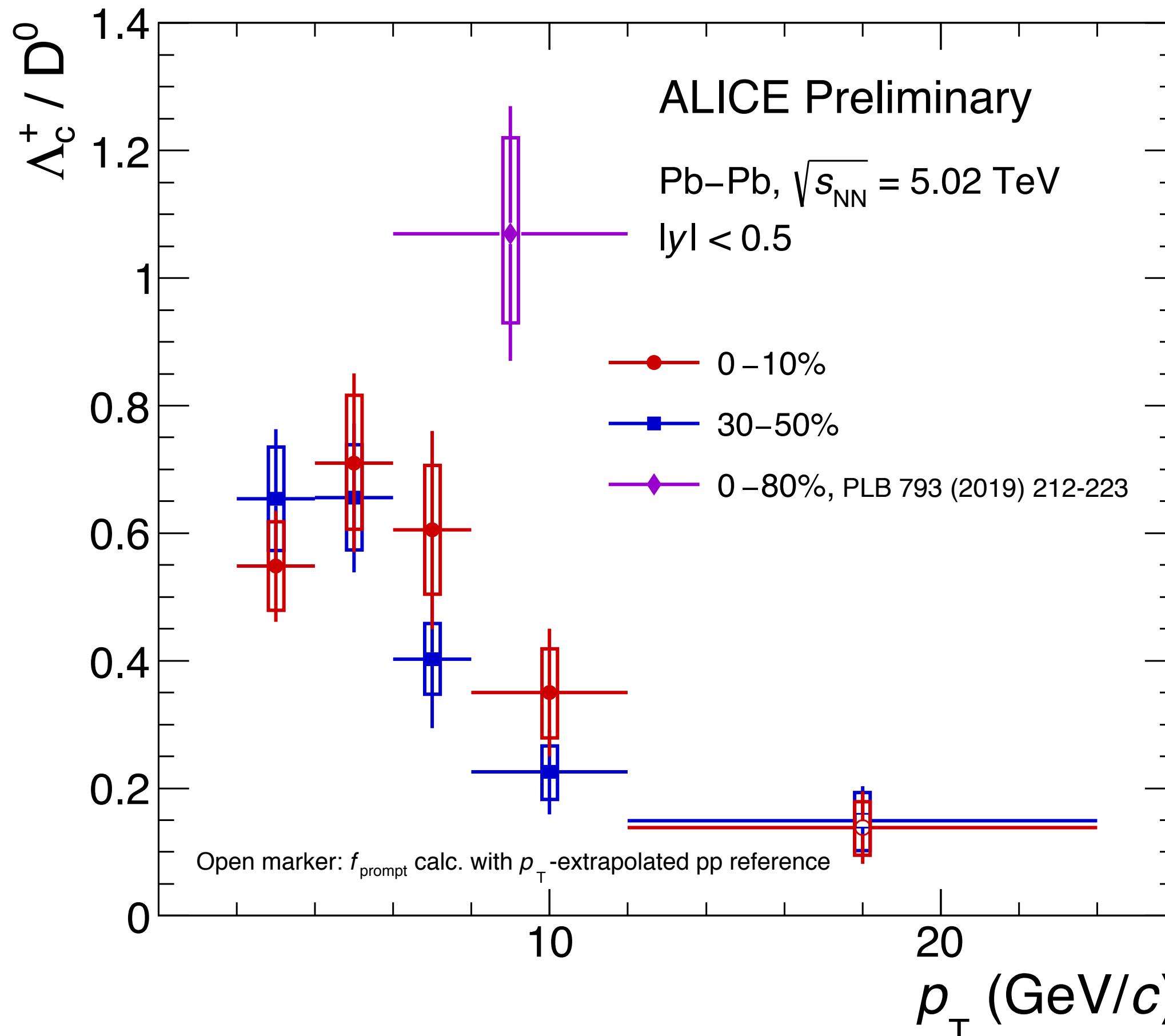
R_{AA} (prompt D⁰) / R_{AA} (non-prompt D⁰)



R_{AA} of D_s vs D^0 in central and peripheral Pb-Pb

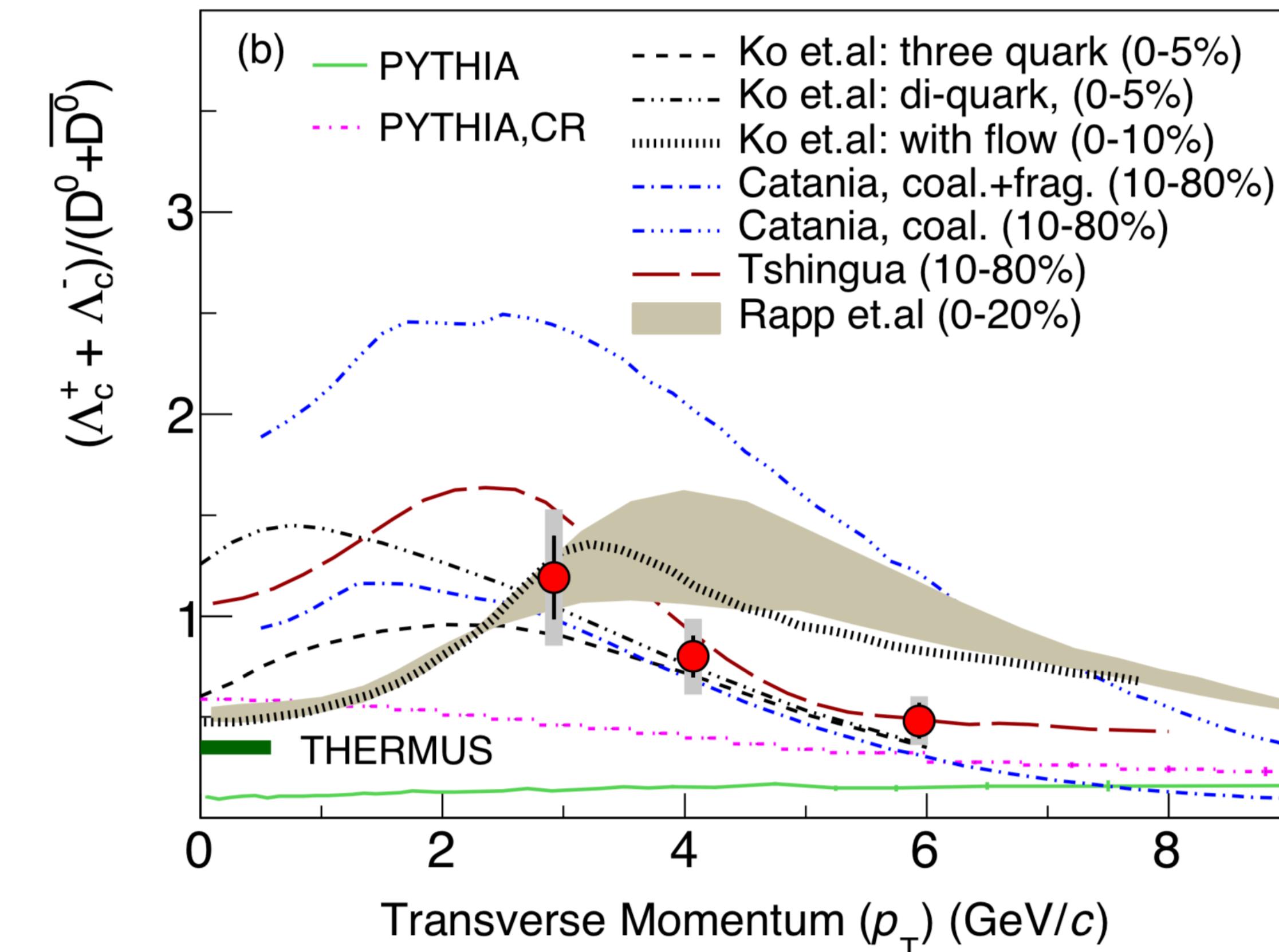
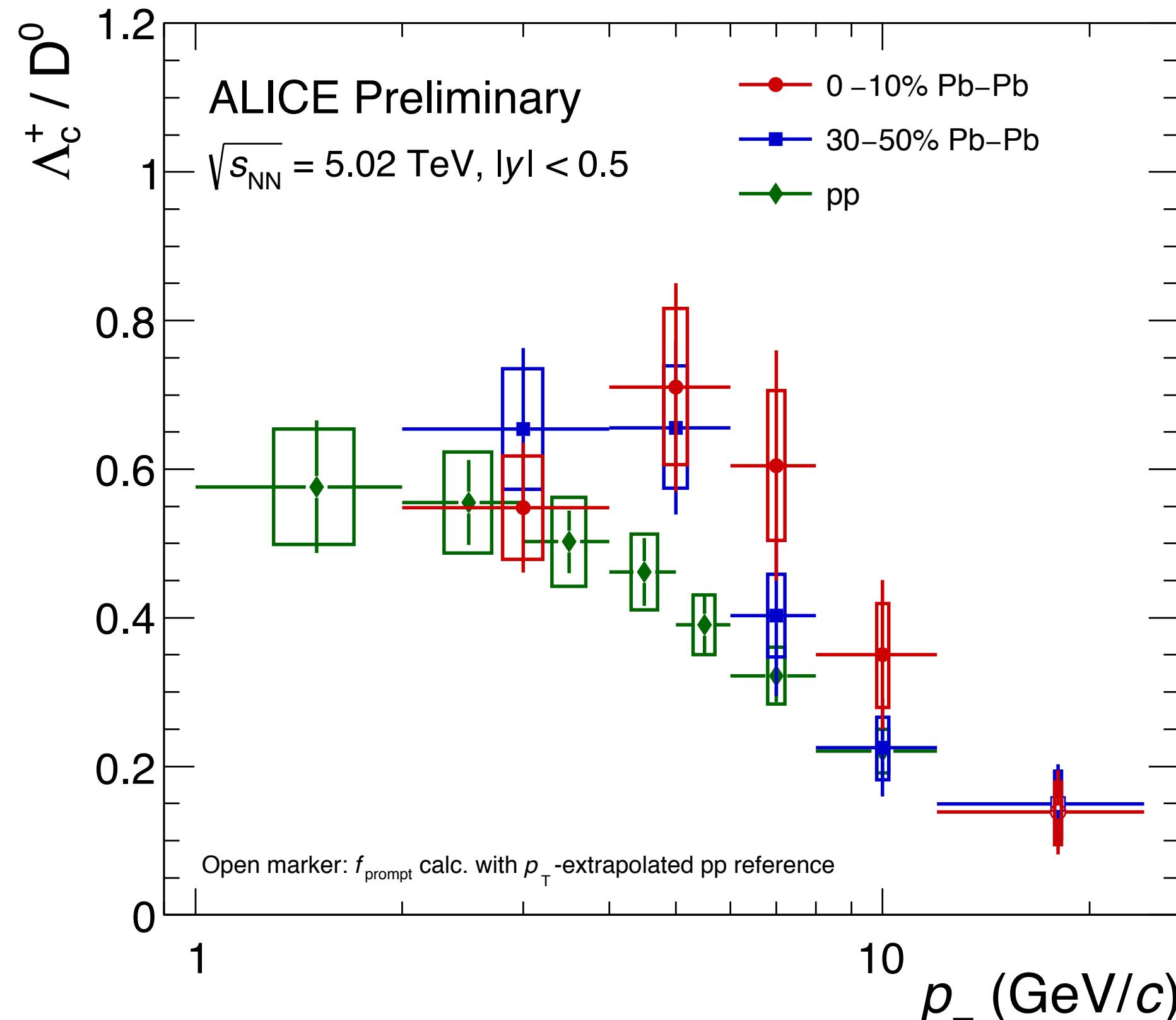


Comparison to 2015 measurement in 0-80%



ALI-PREL-321698

Comparison to Λ_c/D^0 ratio from STAR

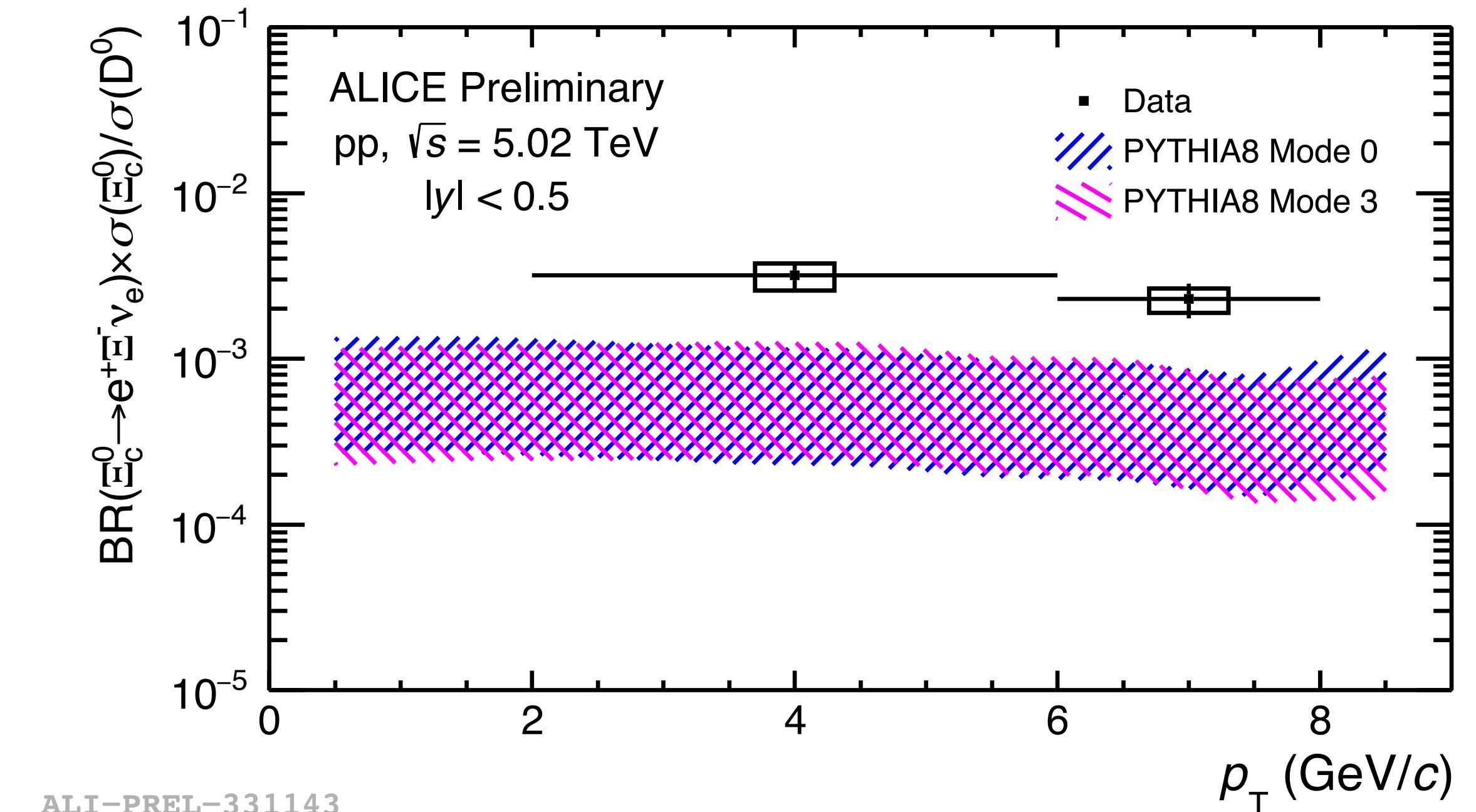
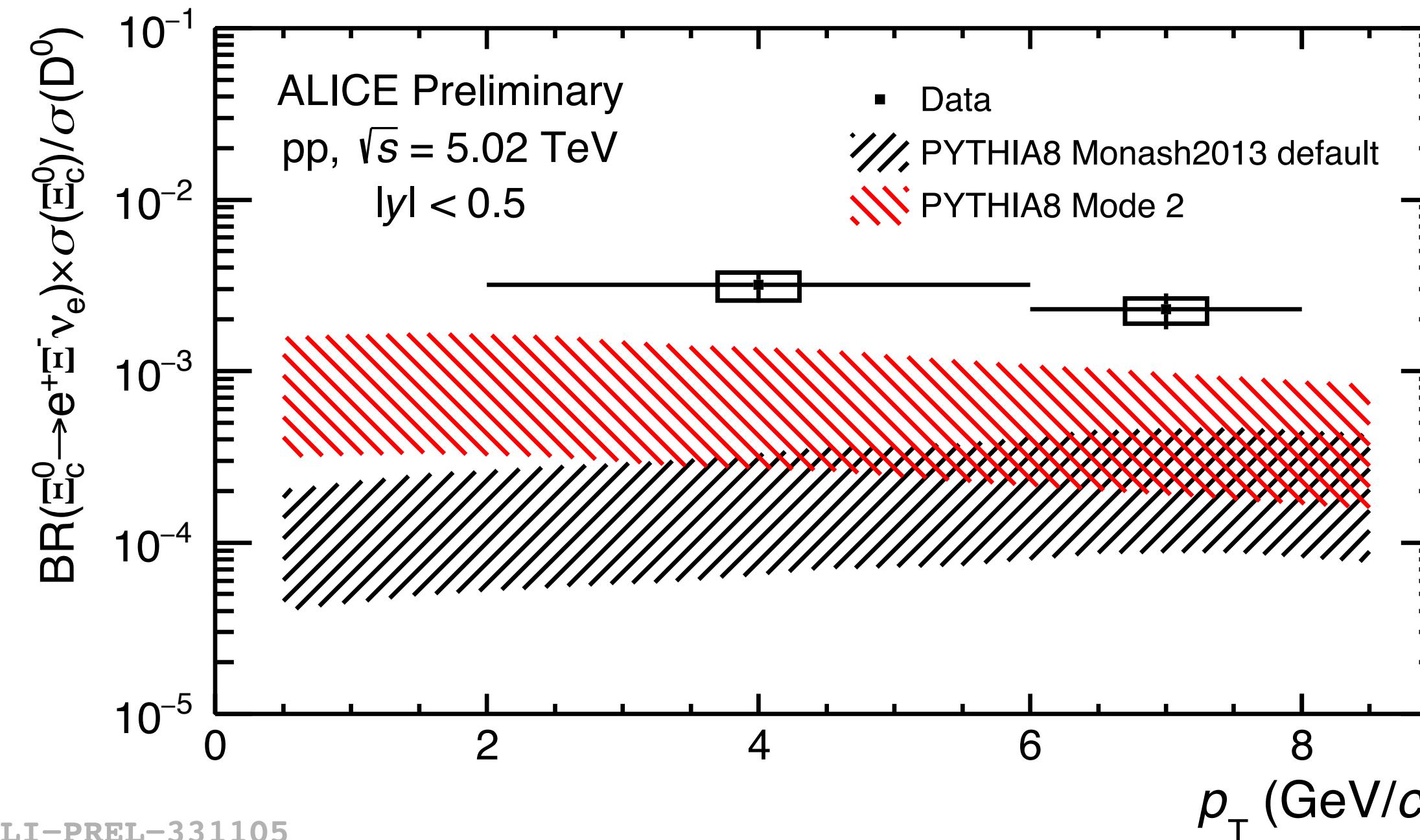


ALI-PREL-323761

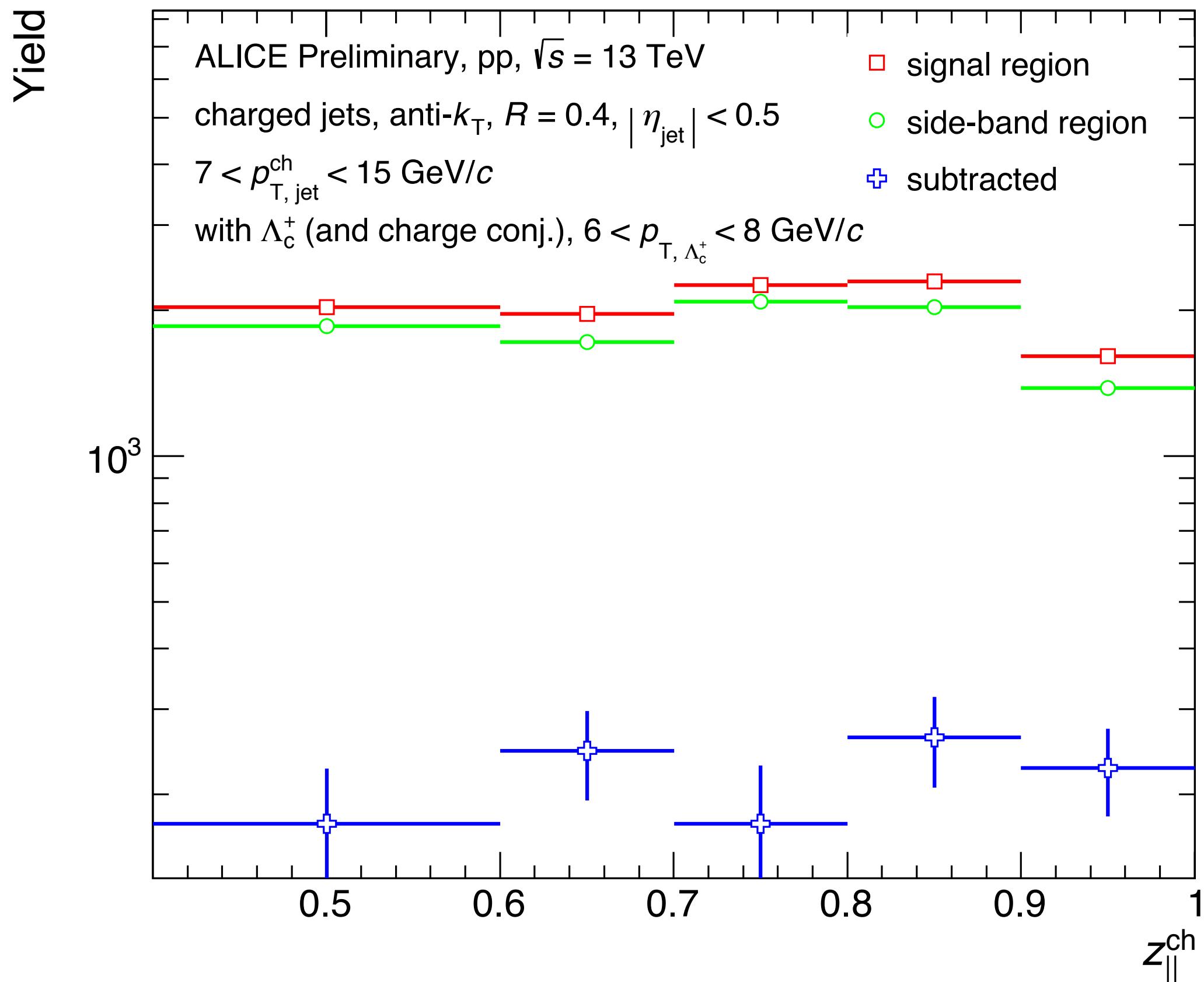
arXiv 1910.14628v1

Ξ^0_c / D^0 cross section ratio compared to PYTHIA

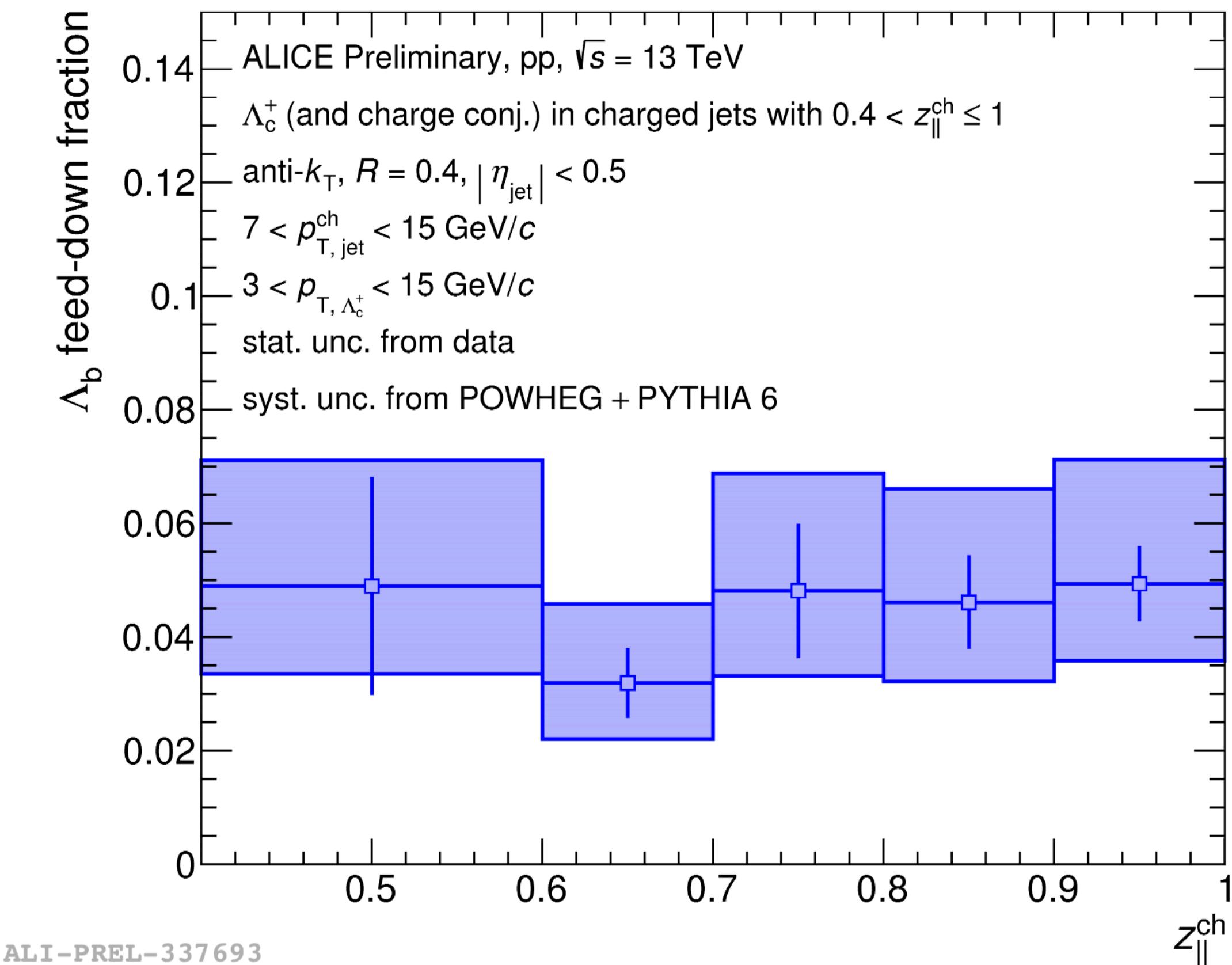
$\Xi^0_c \rightarrow e^+ \Xi^- \bar{\nu}_e$



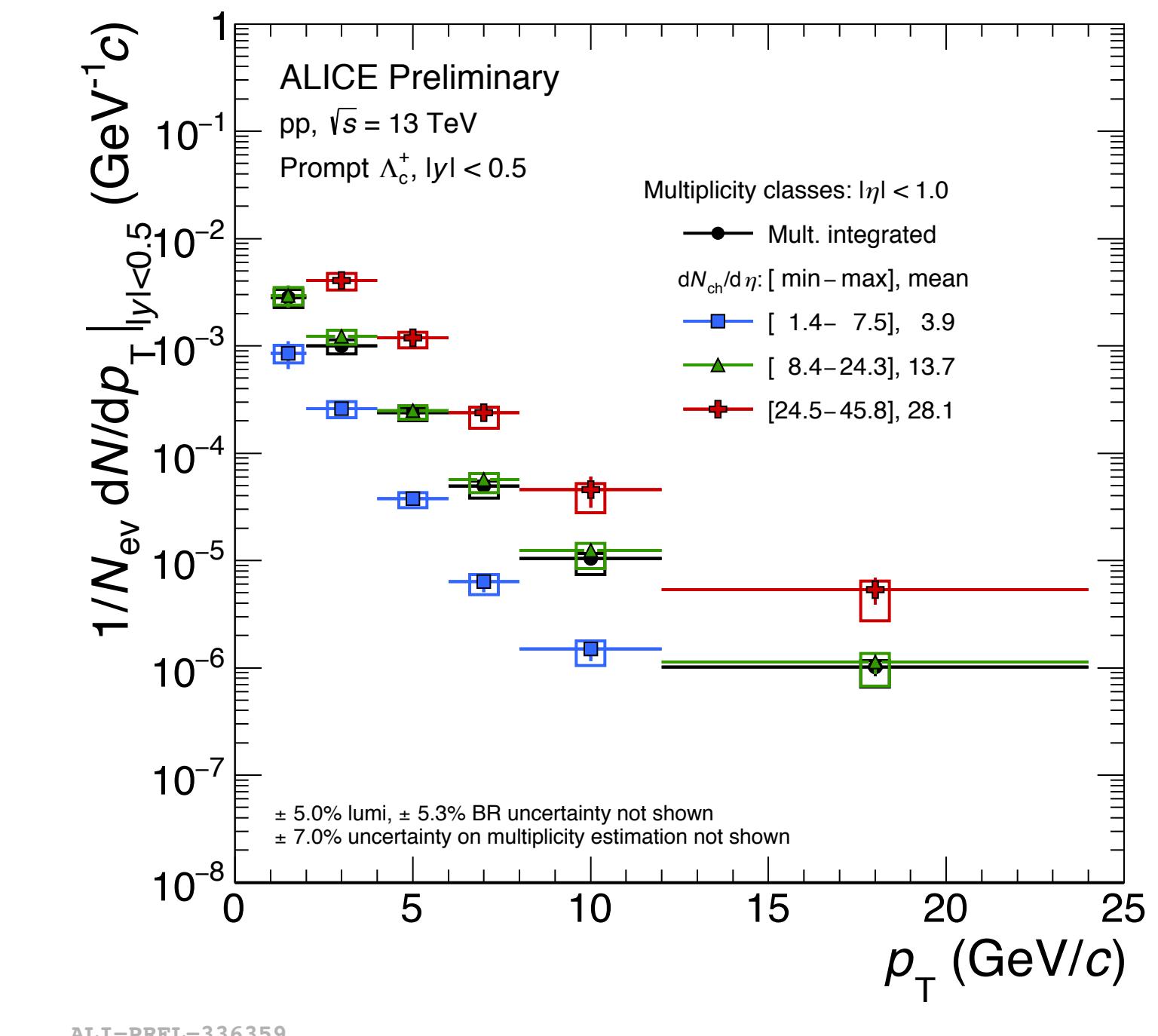
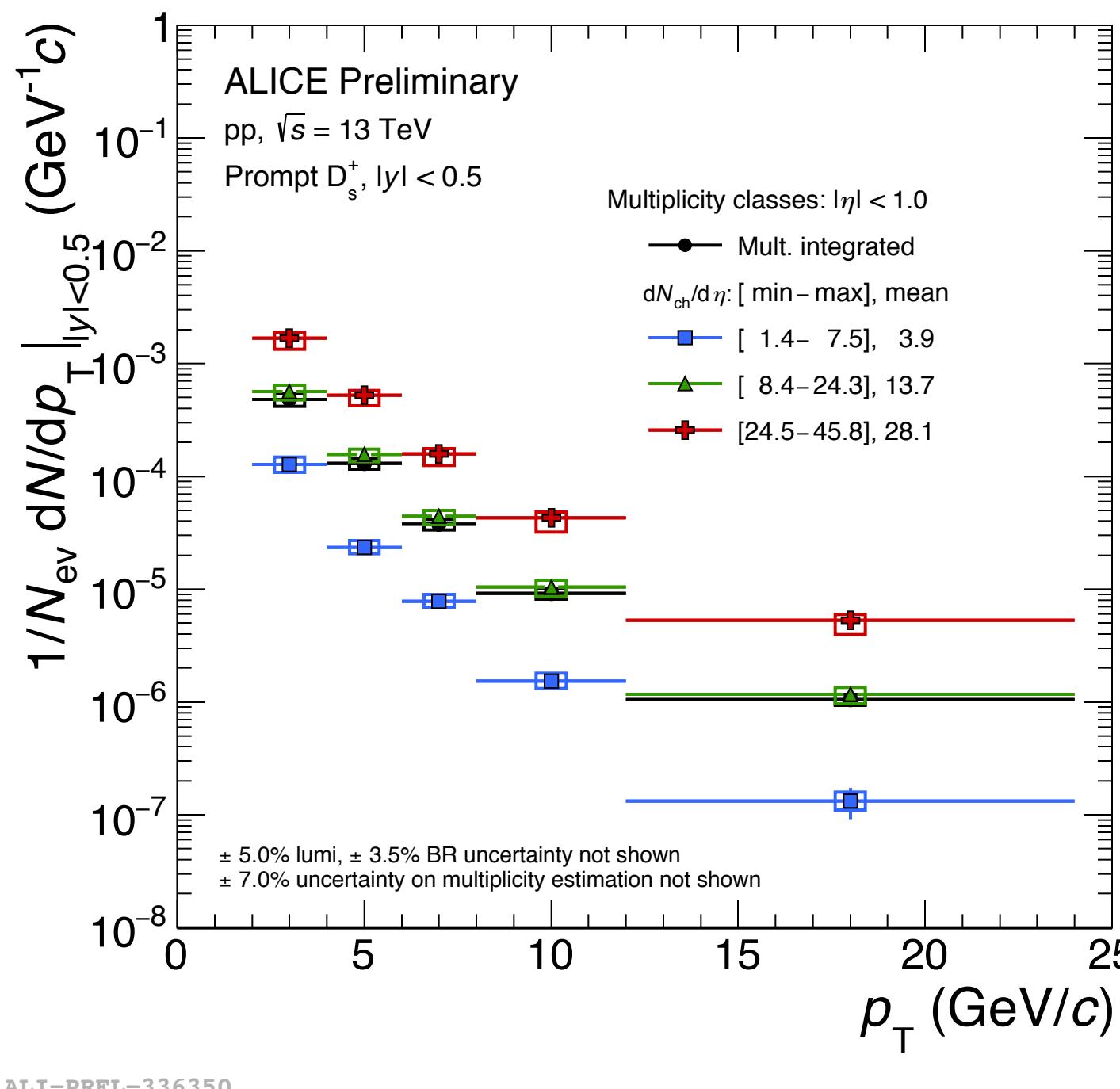
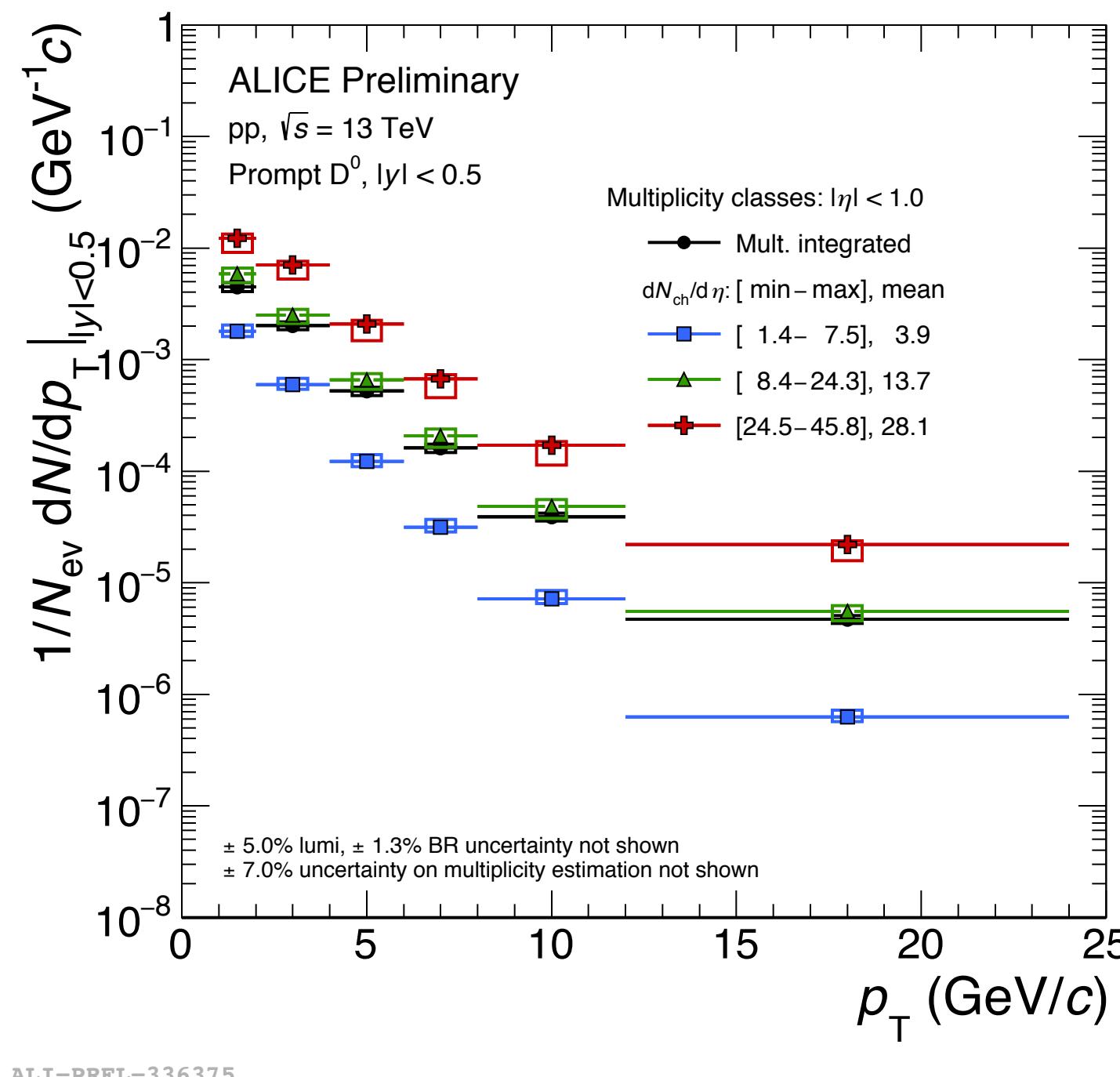
Λ_c longitudinal momentum fraction z_{\parallel} in pp



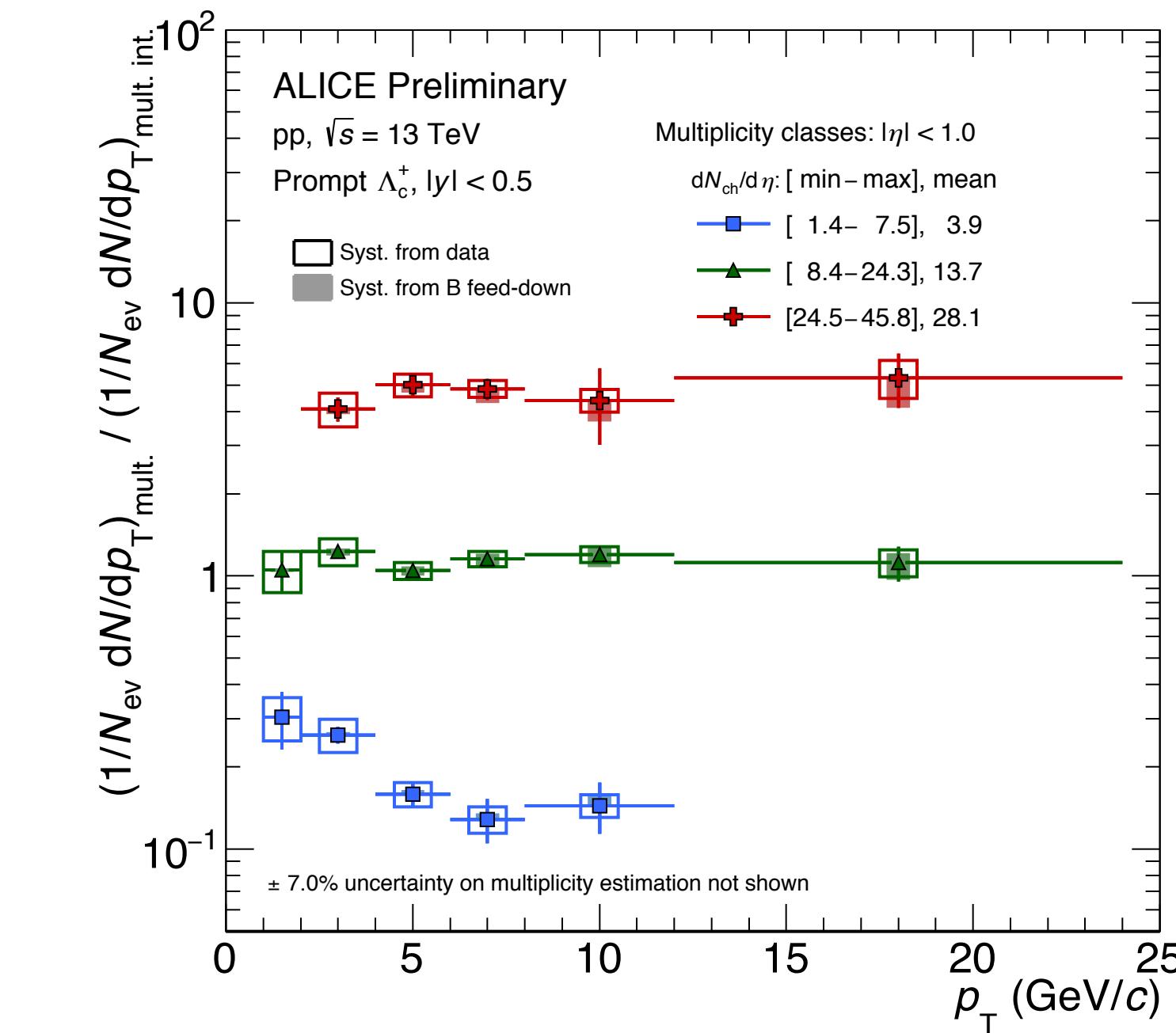
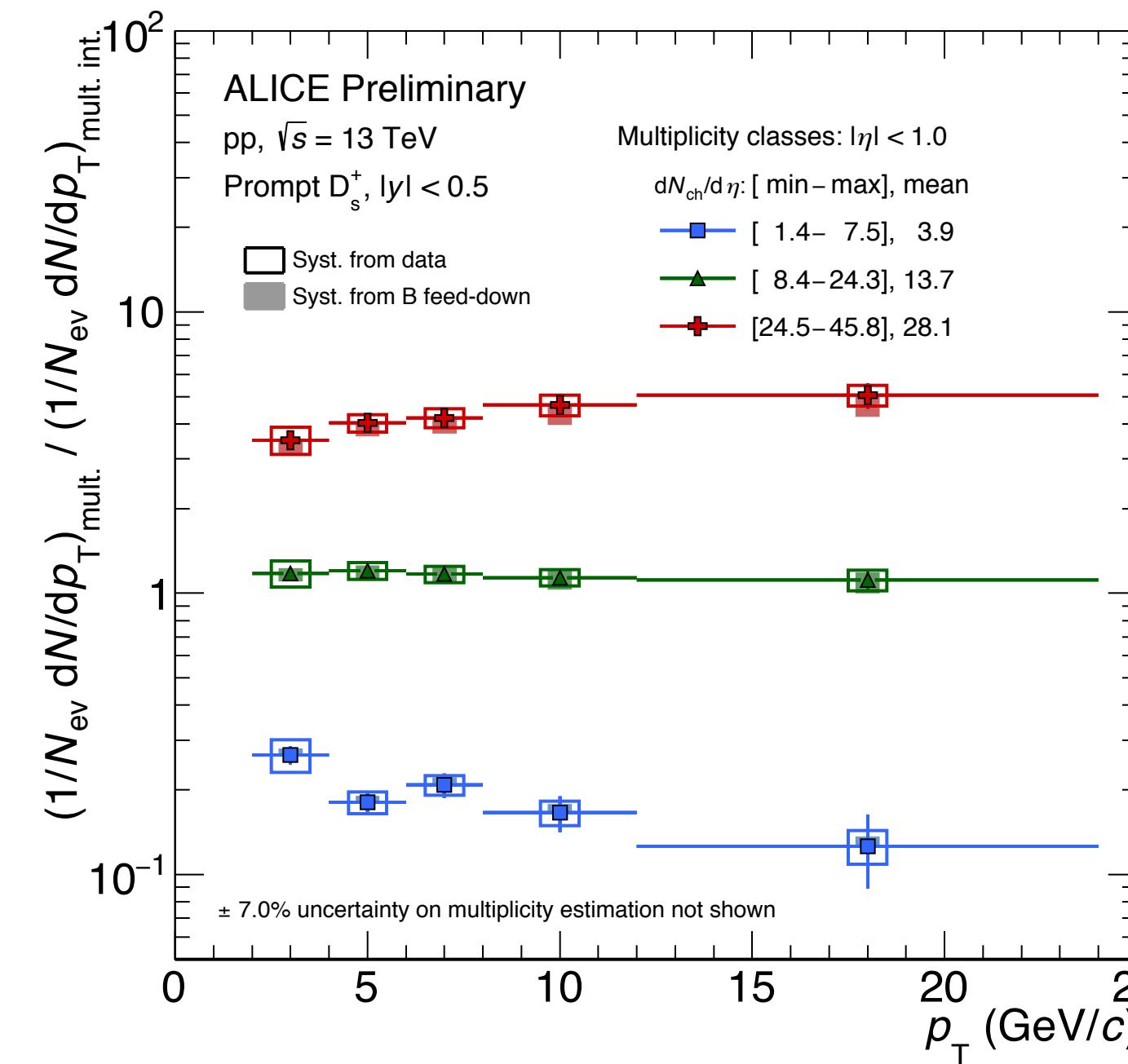
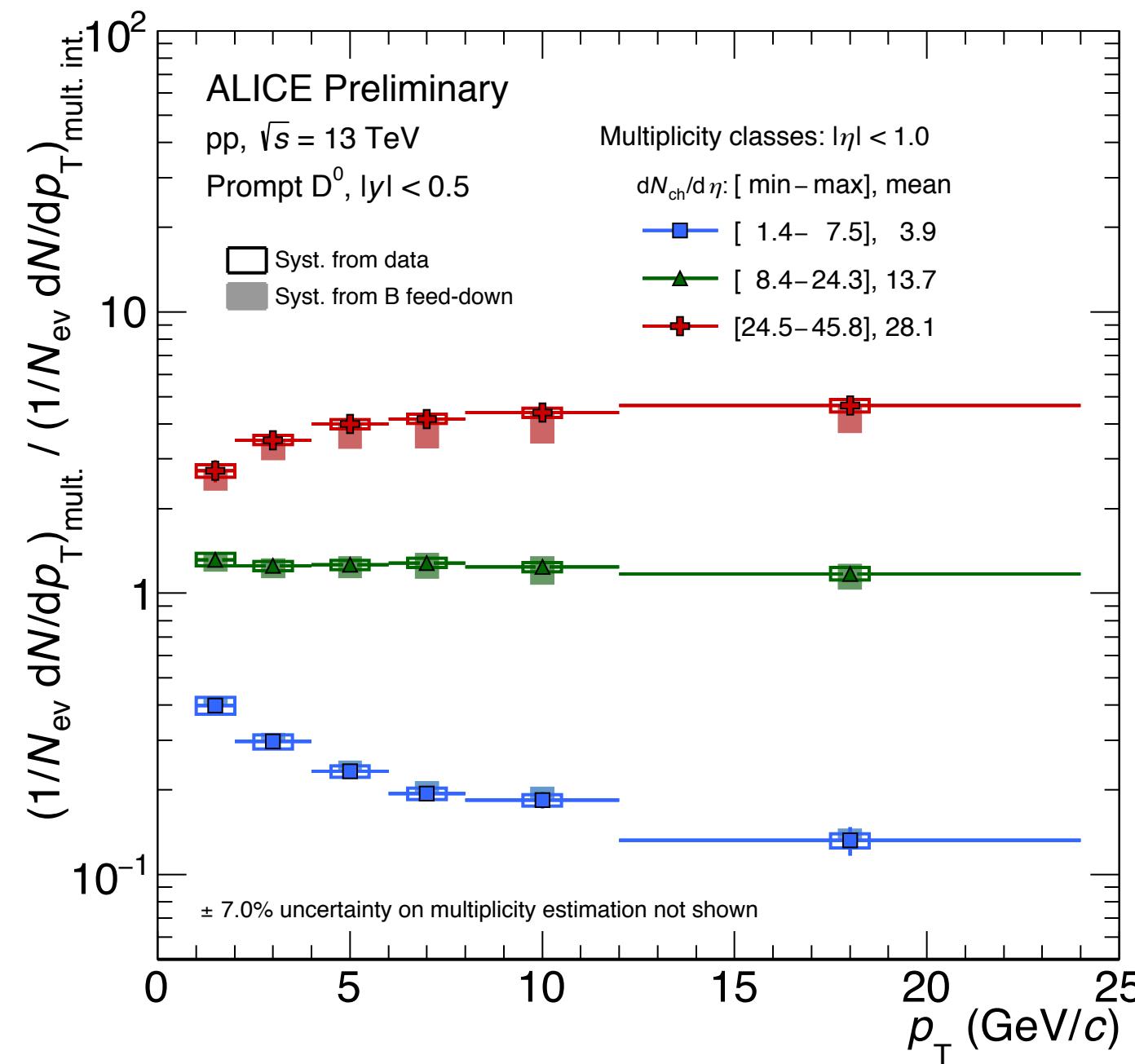
ALI-PREL-337796



D^0 , D_s and Λ_c corrected yields



D⁰, D_s and Λ_c ratios to MB corrected yields

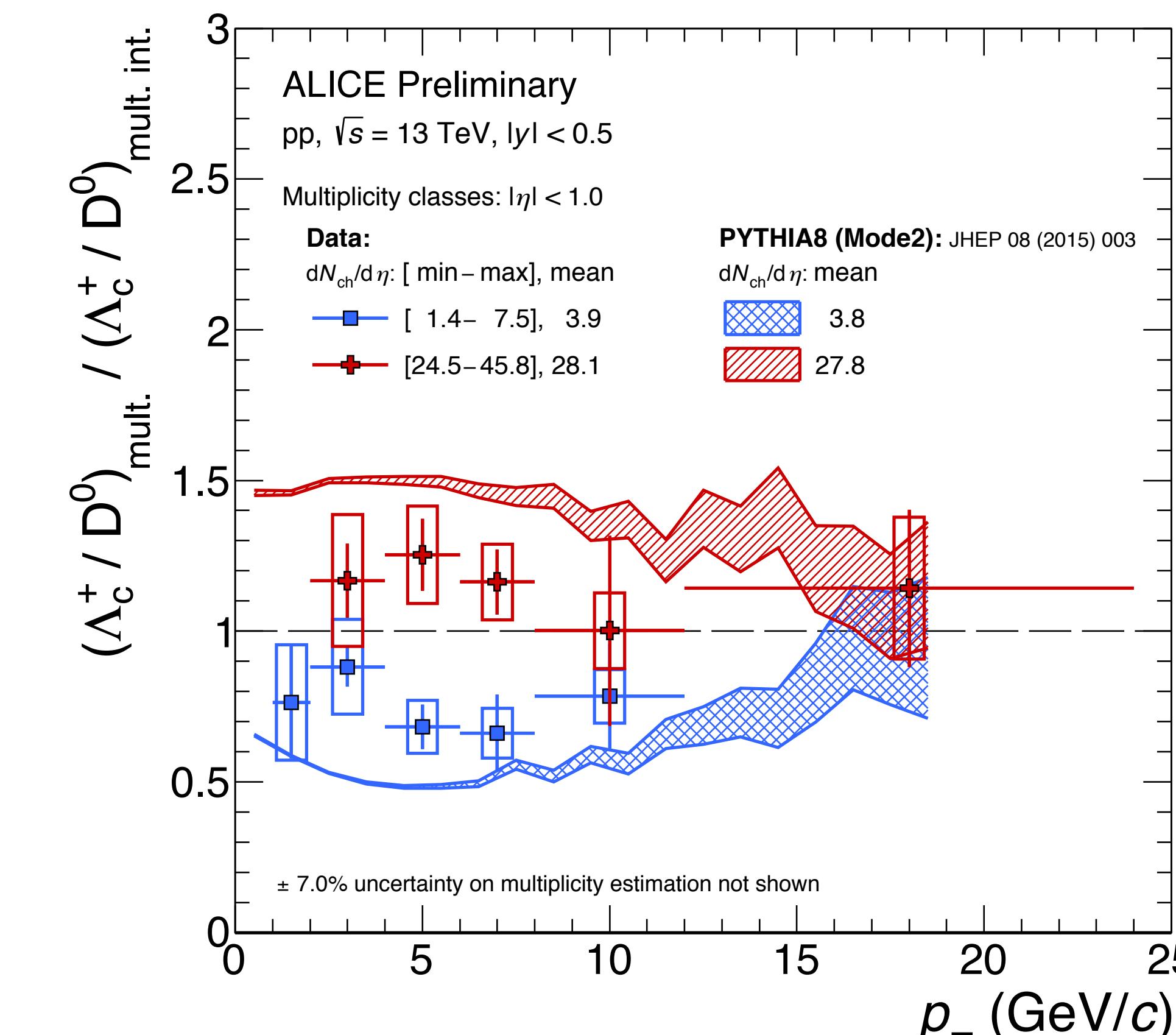
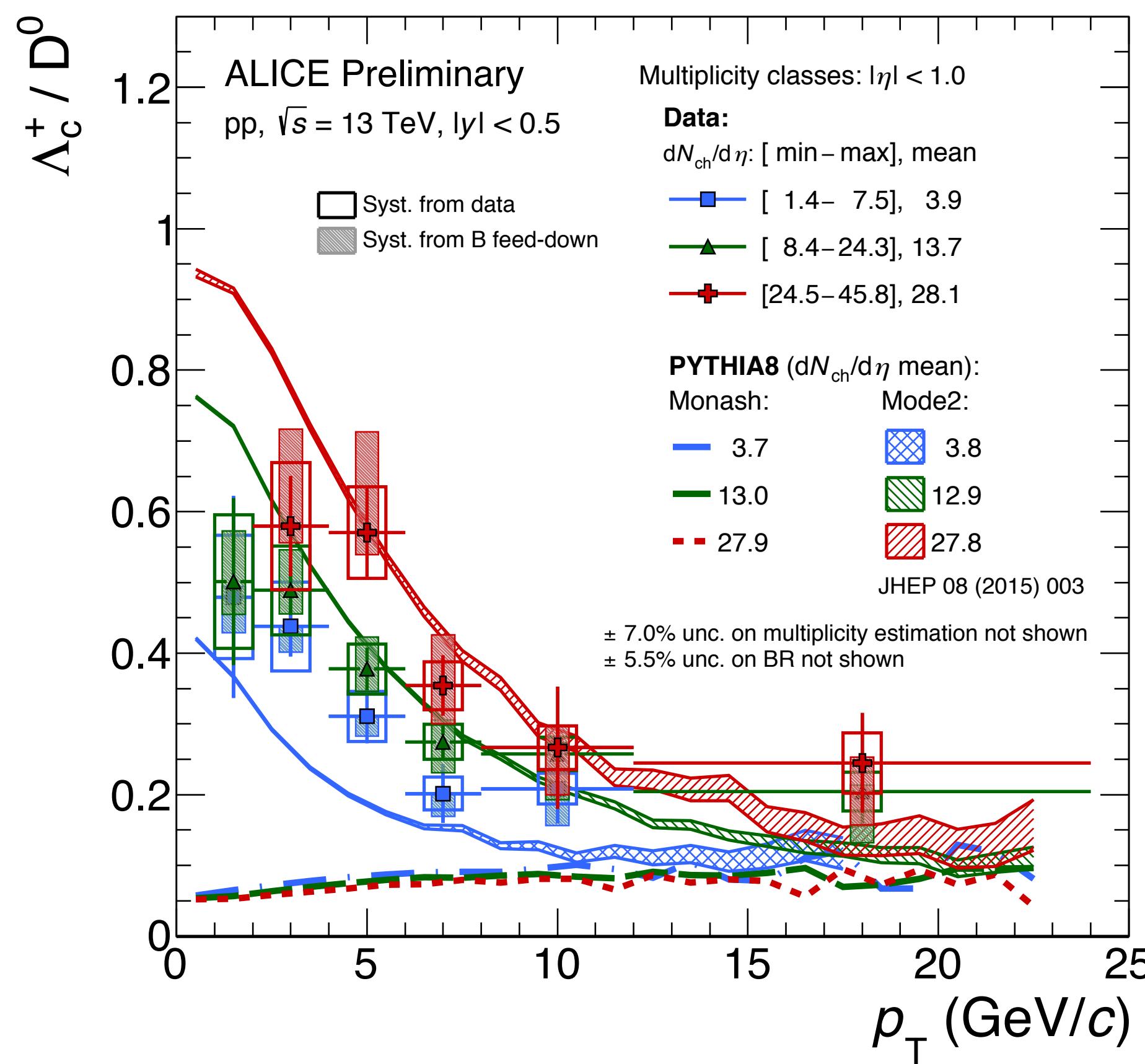


ALI-PREL-336391

ALI-PREL-336382

ALI-PREL-336386

Λ_c / D^0 vs multiplicity: comparison to PYTHIA



ALI-PREL-336438

ALI-PREL-336458

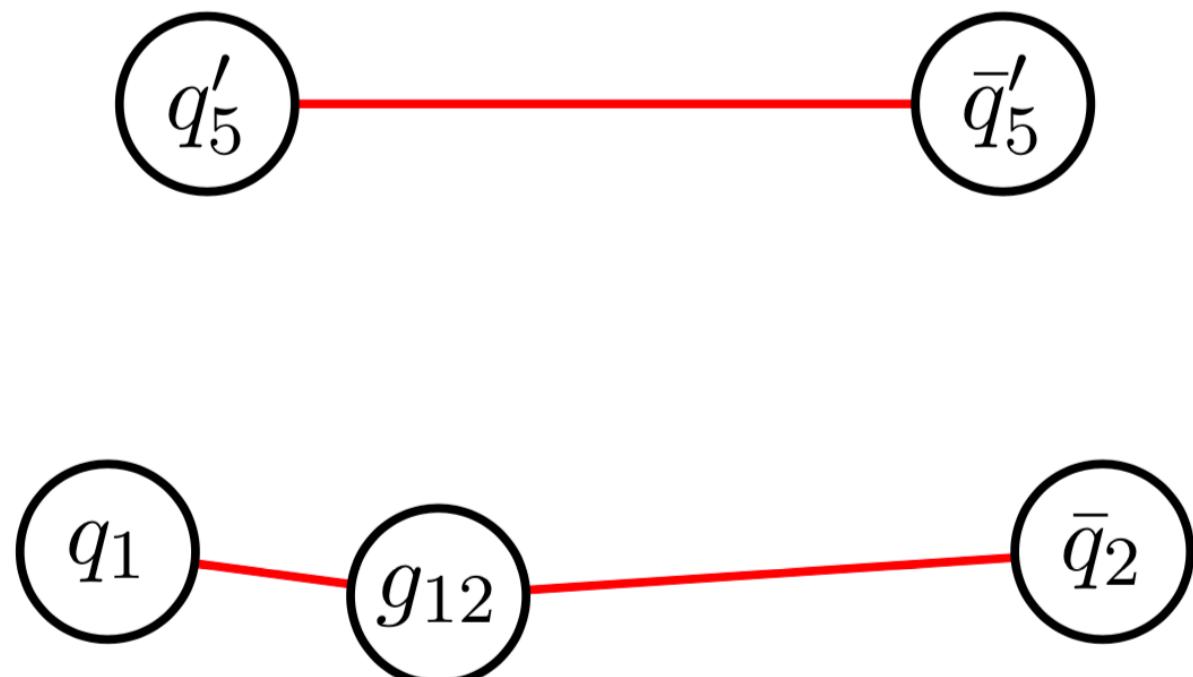
PYTHIA color reconnection parameters

Parameter	Monash	Mode 0	Mode 2	Mode 3
StringPT:sigma	= 0.335	= 0.335	= 0.335	= 0.335
StringZ:aLund	= 0.68	= 0.36	= 0.36	= 0.36
StringZ:bLund	= 0.98	= 0.56	= 0.56	= 0.56
StringFlav:probQQtoQ	= 0.081	= 0.078	= 0.078	= 0.078
StringFlav:ProbStoUD	= 0.217 = 0.5, 0.7, 0.9, 1.0	= 0.2 = 0.0275, 0.0275, 0.0275, 0.0275	= 0.2 = 0.0275, 0.0275, 0.0275, 0.0275	= 0.2 = 0.0275, 0.0275, 0.0275, 0.0275
StringFlav:probQQ1toQQ0join				
MultiPartonInteractions:pT0Ref	= 2.28	= 2.12	= 2.15	= 2.05
BeamRemnants:remnantMode	= 0	= 1	= 1	= 1
BeamRemnants:saturation	-	= 5	= 5	= 5
ColourReconnection:mode	= 0	= 1	= 1	= 1
ColourReconnection:allowDoubleJunRem	= on	= off	= off	= off
ColourReconnection:m0	-	= 2.9	= 0.3	= 0.3
ColourReconnection:allowJunctions	-	= on	= on	= on
ColourReconnection:junctionCorrection	-	= 1.43	= 1.20	= 1.15
ColourReconnection:timeDilationMode	-	= 0	= 2	= 3
ColourReconnection:timeDilationPar	-	-	= 0.18	= 0.073

[JHEP 08 \(2015\) 003, arXiv:1505.01681v1](#)

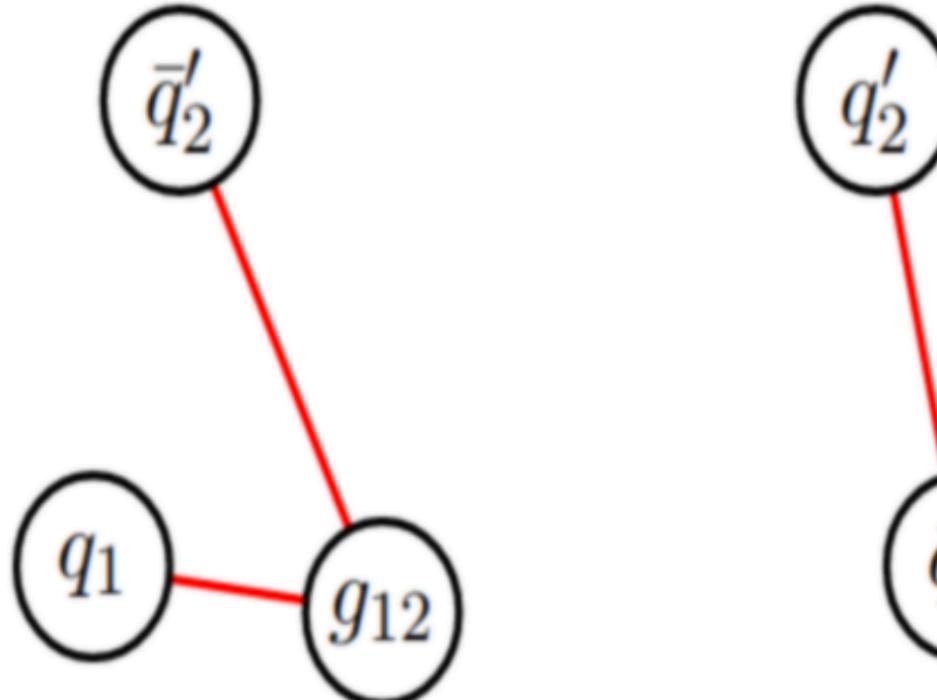
Overview of color reconnection in PYTHIA

No CR



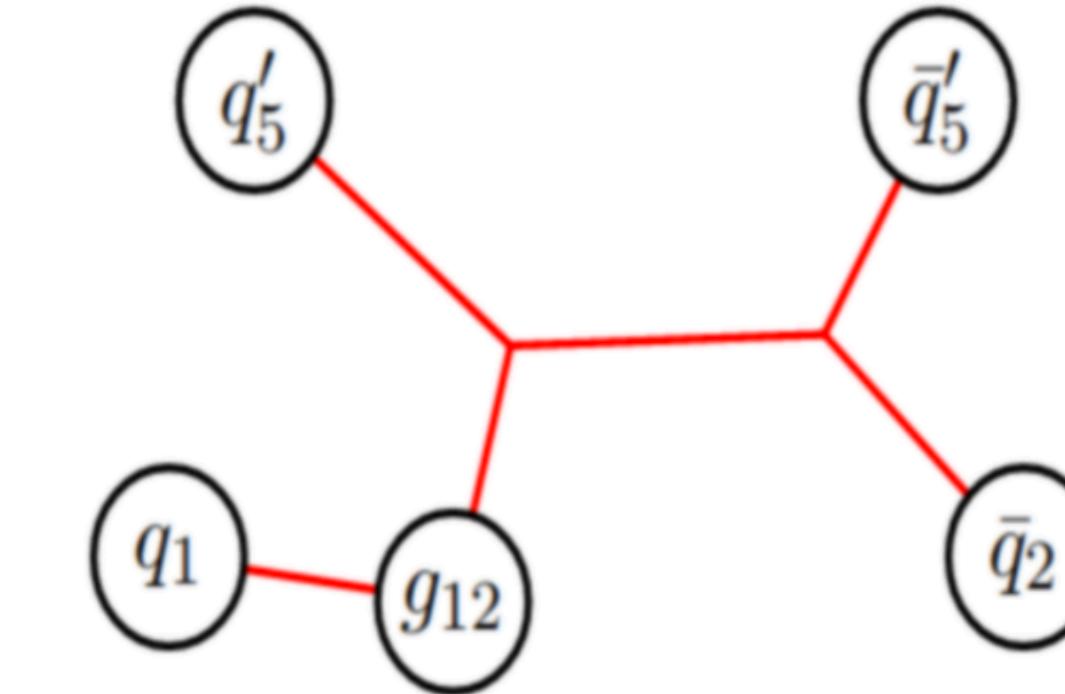
- partons created in different MPIs do not interact

MPI-based CR



- Color reconnection allowed between partons from different MPIs to minimize string length
- As implemented in Monash
- ColorReconnection:mode = 0

More-QCD CR

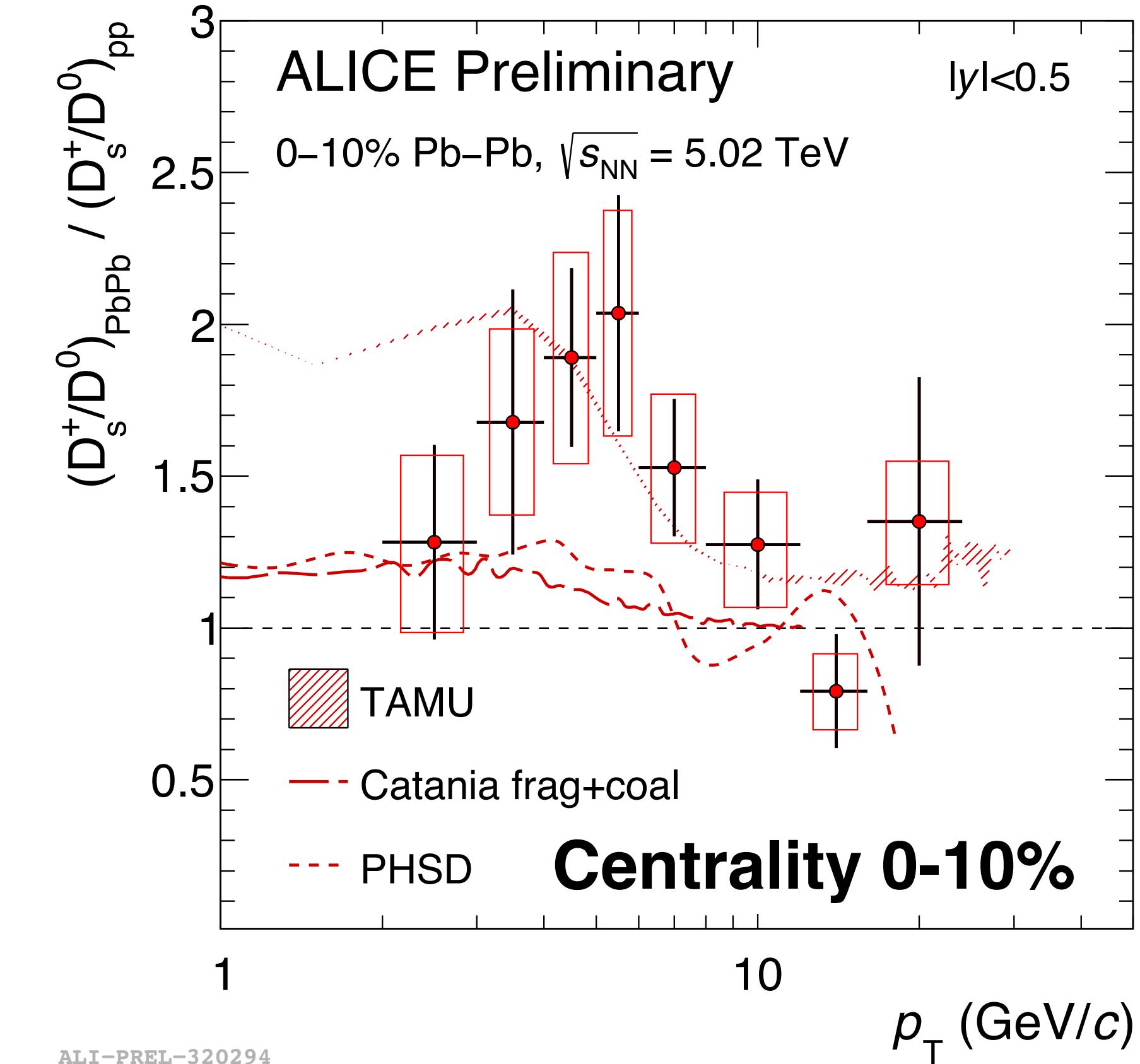
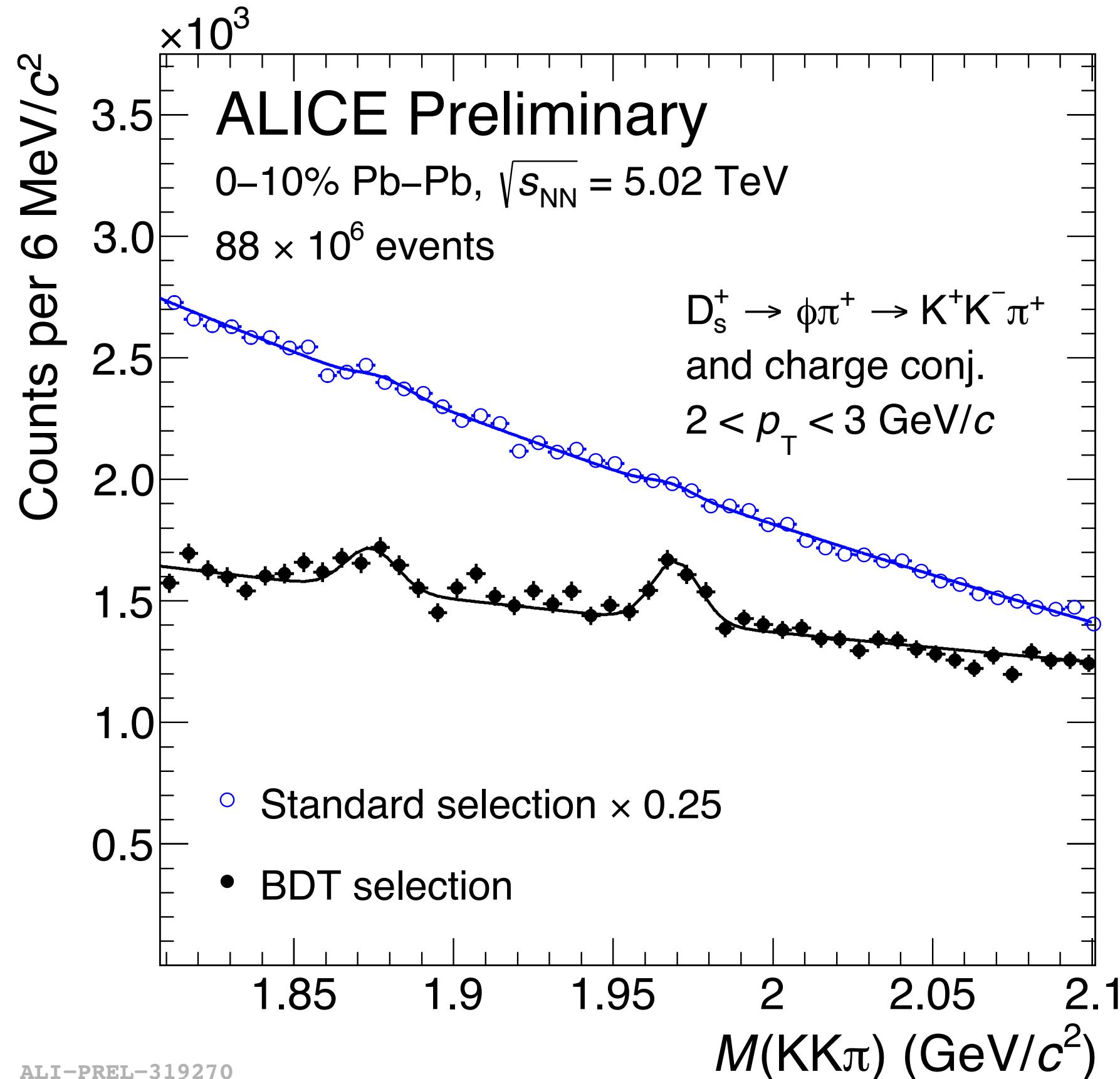


- Uses a simple model of the colour rules of QCD to determine the formation of strings and introduce junctions
- Minimization of the string length over all possible configurations
- Include CR with MPIs and with beam remnants
- ColorReconnection:mode = 1

D_s/D⁰ ratios in central Pb-Pb

Updated for
QM 2019

D_s/D⁰ to be enhanced in PbPb vs pp in presence of charm recombination and strangeness enhancements



- Low p_T interval (2-3 GeV/c) extracted using machine learning techniques

→ Supports the hypothesis of a relevant contribution of coalescence in charm hadronization in Pb-Pb

D_s/D⁰ (PbPb) / D_s/D⁰ (pp):

- sizable enhancement at intermediate p_T
- Well described by Langevin calculations

Heavier charmed baryons

