Heavy-flavour jets, correlations and multiplicity dependent heavy-flavour hadrons measurements in small systems with ALICE

Marianna Mazzilli on behalf of the ALICE Collaboration

40th International Conference on High Energy Physics (ICHEP2020)
28/07/2020

Physics Motivations

pp collisions

Heavy quarks (charm and beauty quarks) are produced in hard-scattering processes:

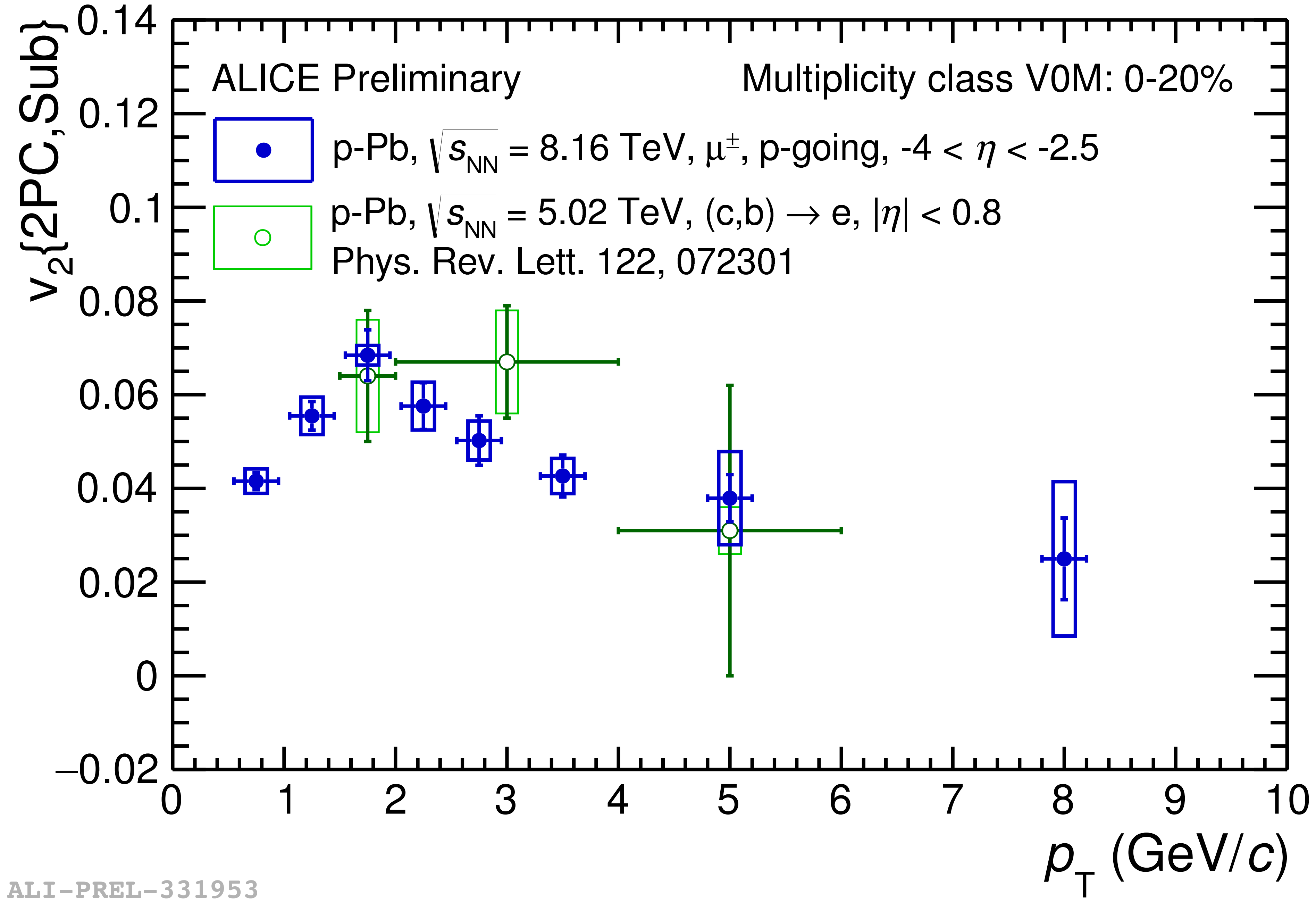
- Test of pQCD calculations
- Benchmark for p-Pb and Pb-Pb systems

Physics Motivations

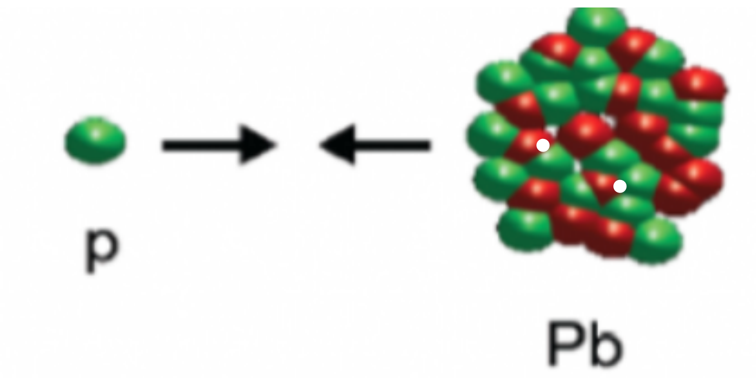
pp collisions

Heavy quarks (charm and beauty quarks) are produced in hard-scattering processes:

- Test of pQCD calculations
- Benchmark for p-Pb and Pb-Pb systems



p-Pb collisions



Study **cold nuclear matter (CNM) effects**

- (anti-)shadowing modifications for nuclear PDFs
- gluon saturation, Colour Glass Condensate
- parton energy loss in the initial or final state
- final state dissociation (absorption, comovers)

Open questions: Collectivity?

Physics Motivations: in particular…

Why HF jets and correlations?

Study heavy-flavour quark production, fragmentation and hadronization
→ Reference for the energy and direction of the initial parton

Heavy-flavour correlations complementary characterize heavy-flavour jet properties
→ Give access to the production mechanisms: LO and NLO

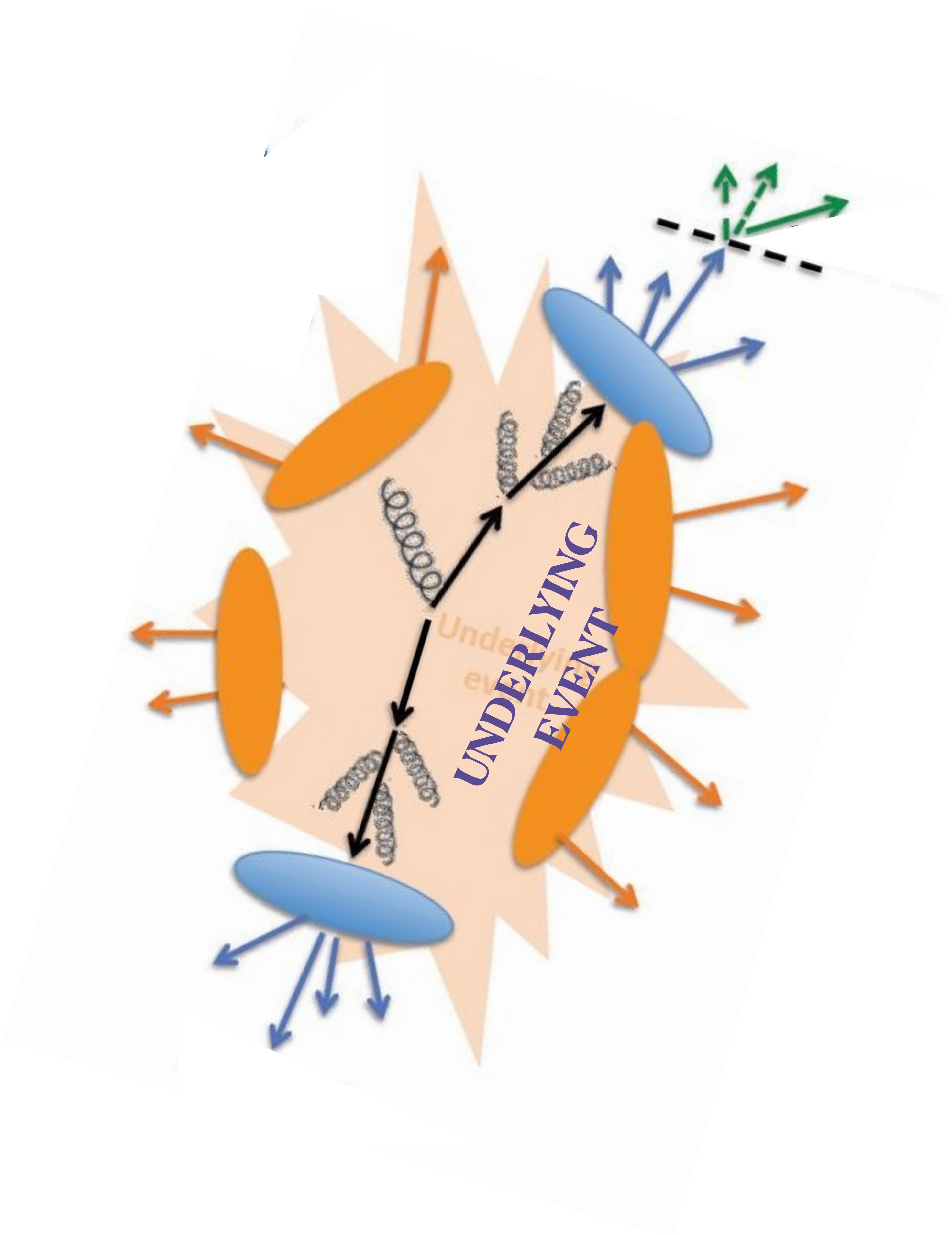
Why multiplicity dependent HF studies?

Investigate the possible influence of mutiparton interactions (MPI) to the particle production

Study the interplay between soft and hard mechanisms

Good observable related to the underlying event associated with the HF production

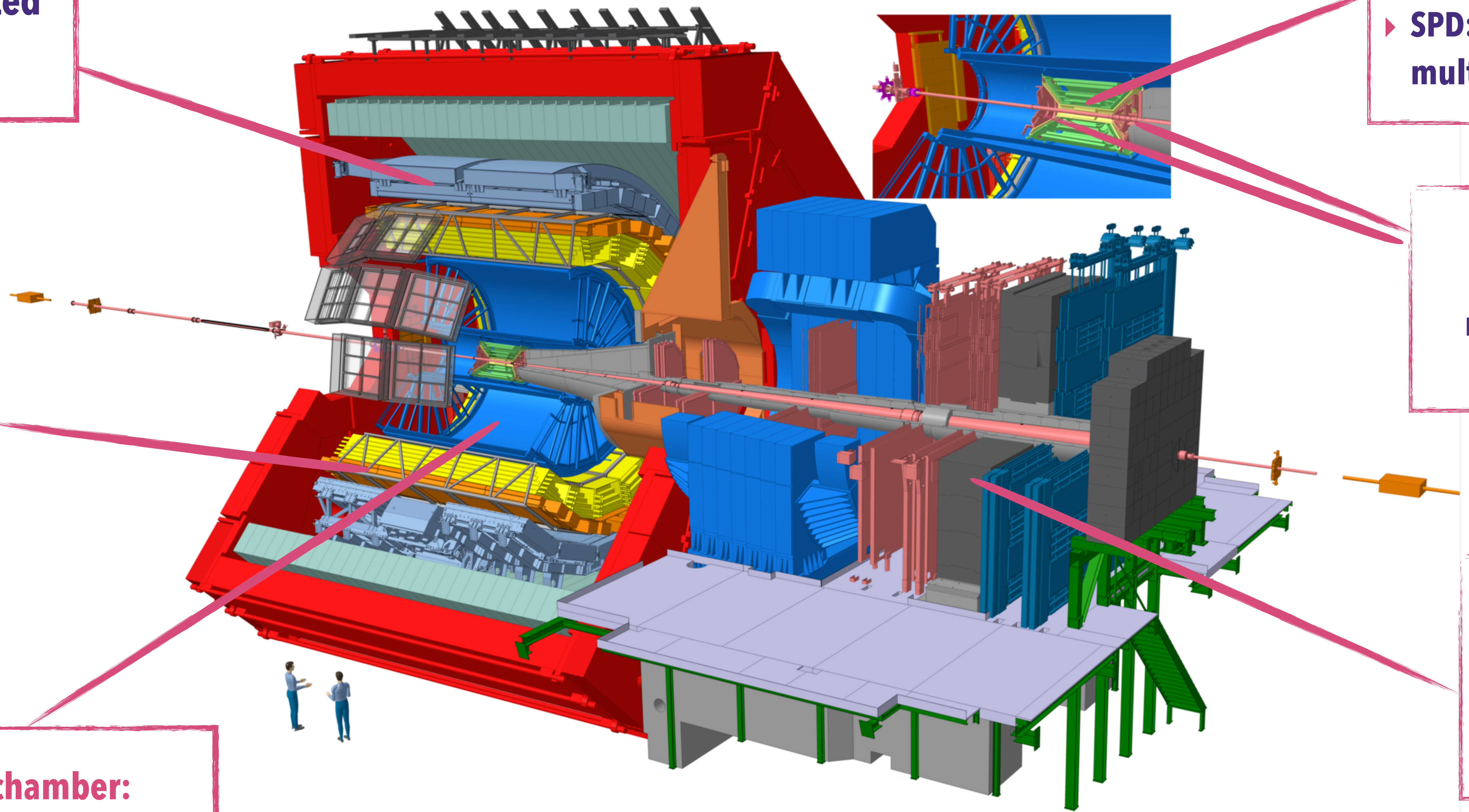
Further insights into the role of Colour Reconnection in the hadronization mechanism



ALICE detector

Electromagnetic calorimeter:
- PID via energy deposited
- Trigger

Inner tracking system:
- Tracking and vertexing
- SPD: minimum bias and high multiplicity trigger (midrapidity)



V0:
Minimum bias and high multiplicity trigger (forward rapidity)

Time of flight:
- PID via time-of-flight

Muon spectrometer:
- Muon trigger
- Muon tracking

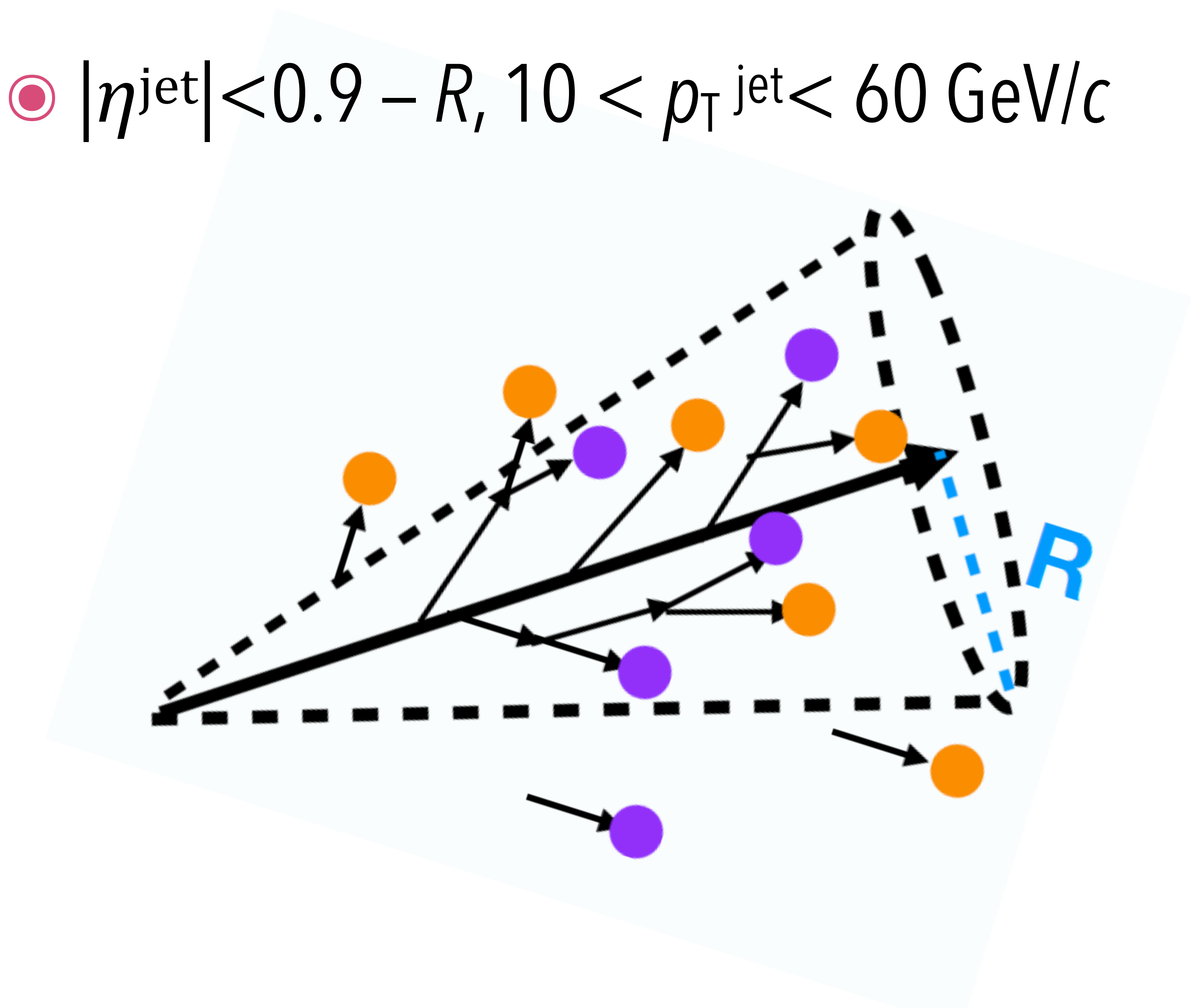
Time projection chamber:
- Tracking
- PID via specific energy loss

Heavy-Flavour jets and correlations

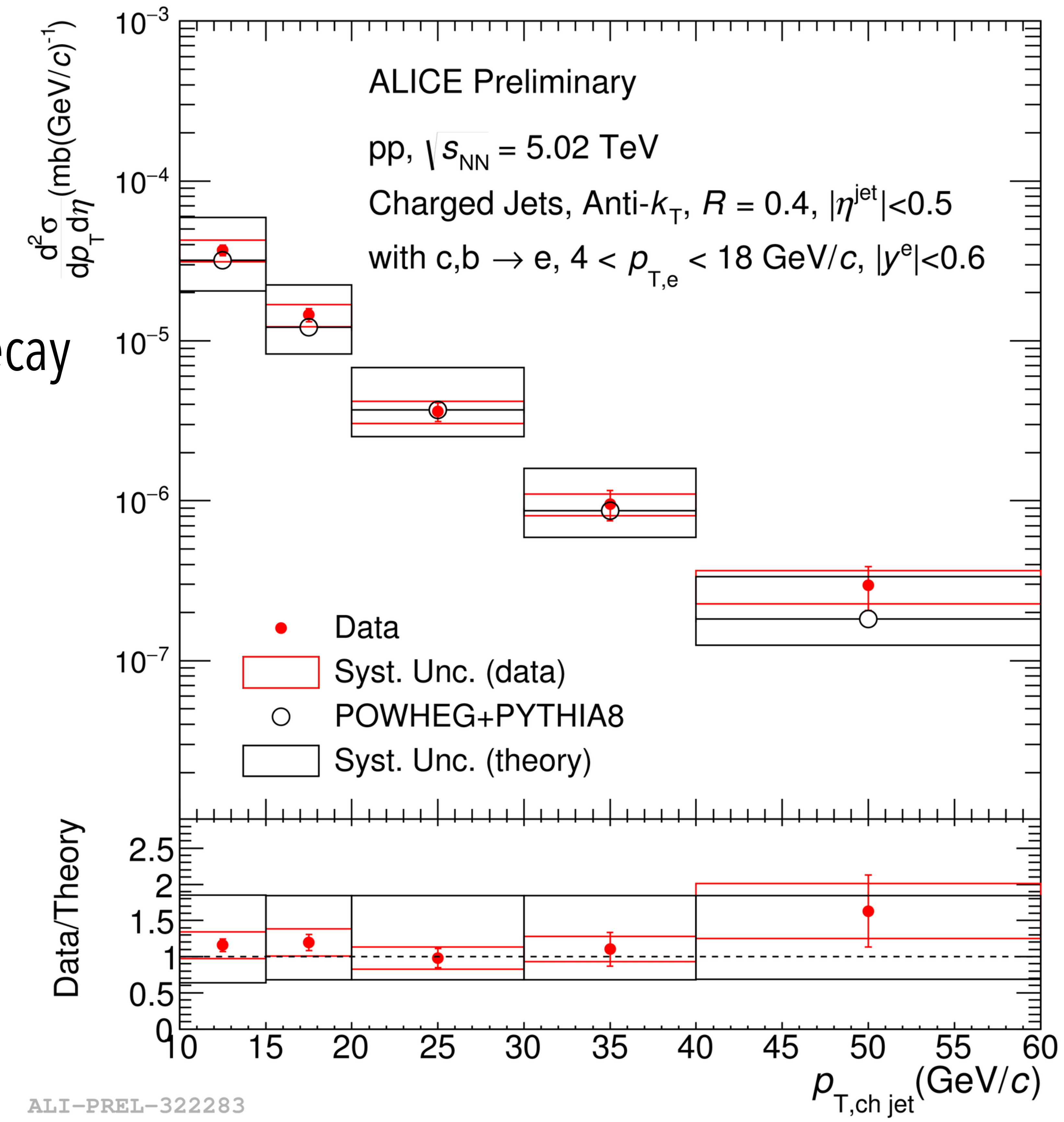
HFe-jets in pp and in p-Pb collisions

Jets are:

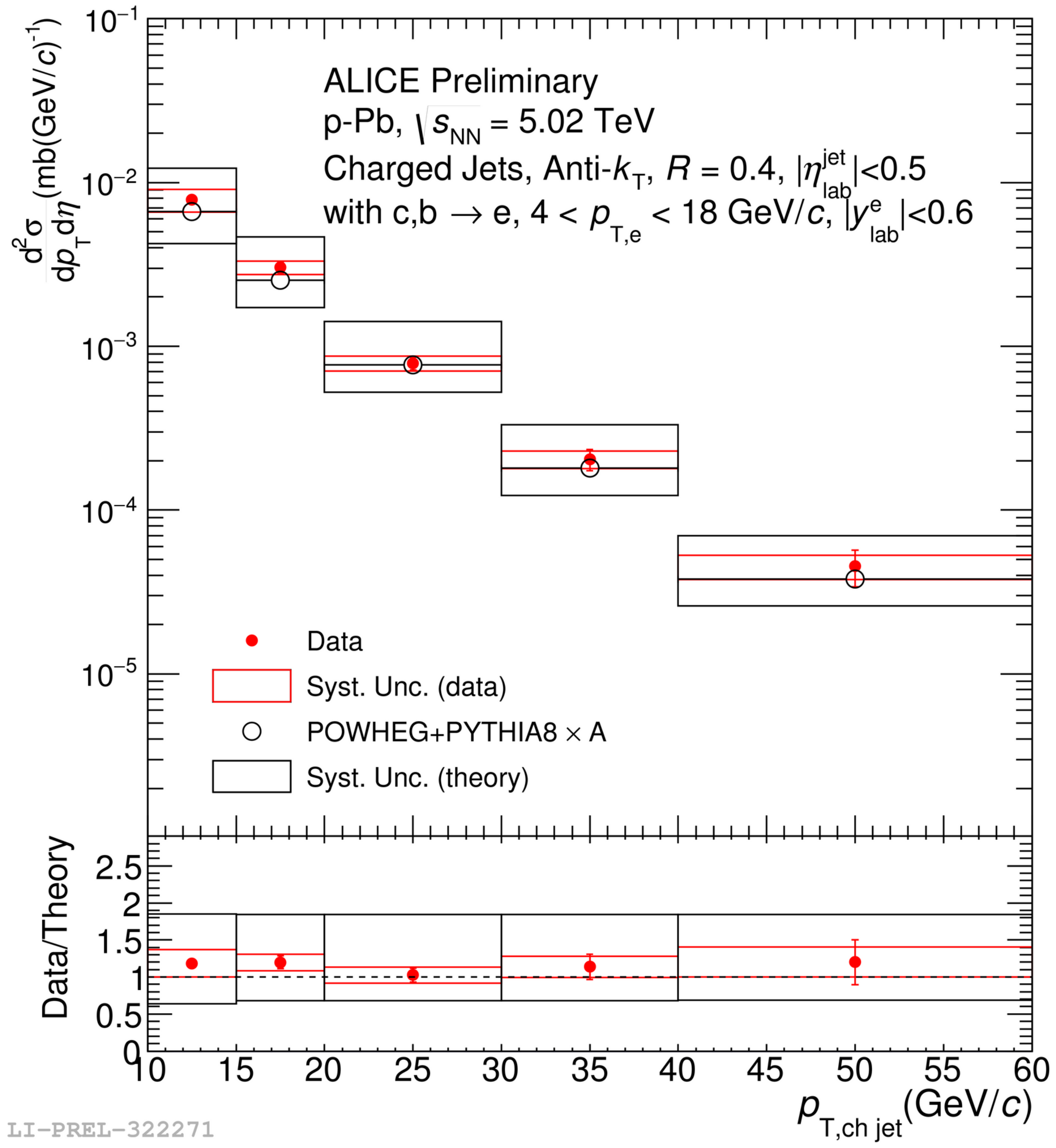
- identified by the presence of heavy flavour decay electrons, $4 < p_T^{e} < 18$ GeV/c
- reconstructed using tracks of charged particle (anti-k_T algorithm)
- $|\eta^{jet}|<0.9 - R$, $10 < p_T^{jet} < 60$ GeV/c



pp@5.02TeV



p-Pb@5.02TeV

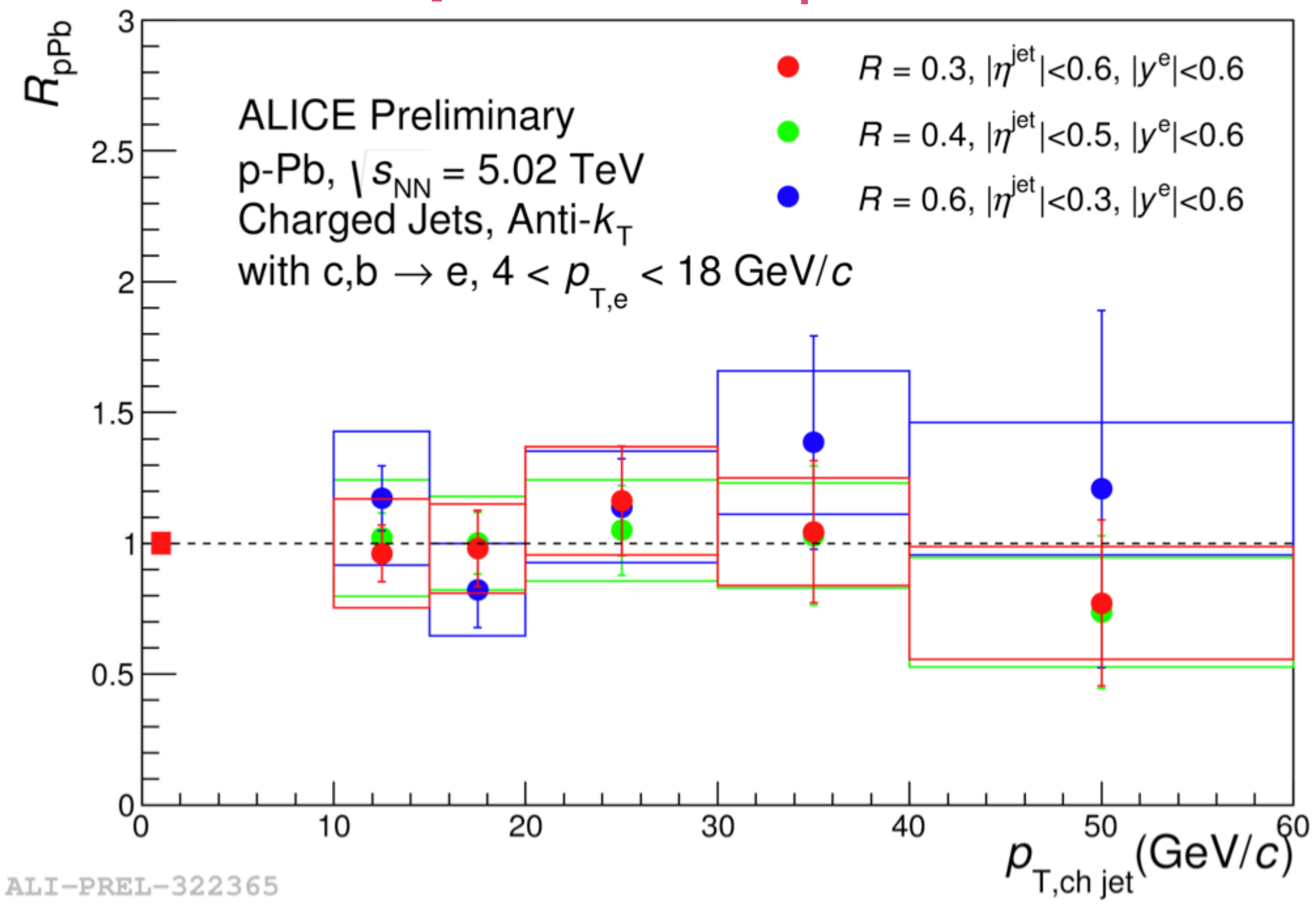


Good **agreement** with NLO pQCD **POWHEG + PYTHIA8** predictions

PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)
POWHEG: JHEP 11, 040 (2004), JHEP 1200 11, 070 (2007)

Final state effects? –> Measurement performed with different R: R=0.2, 0.3, 0.4, 0.6

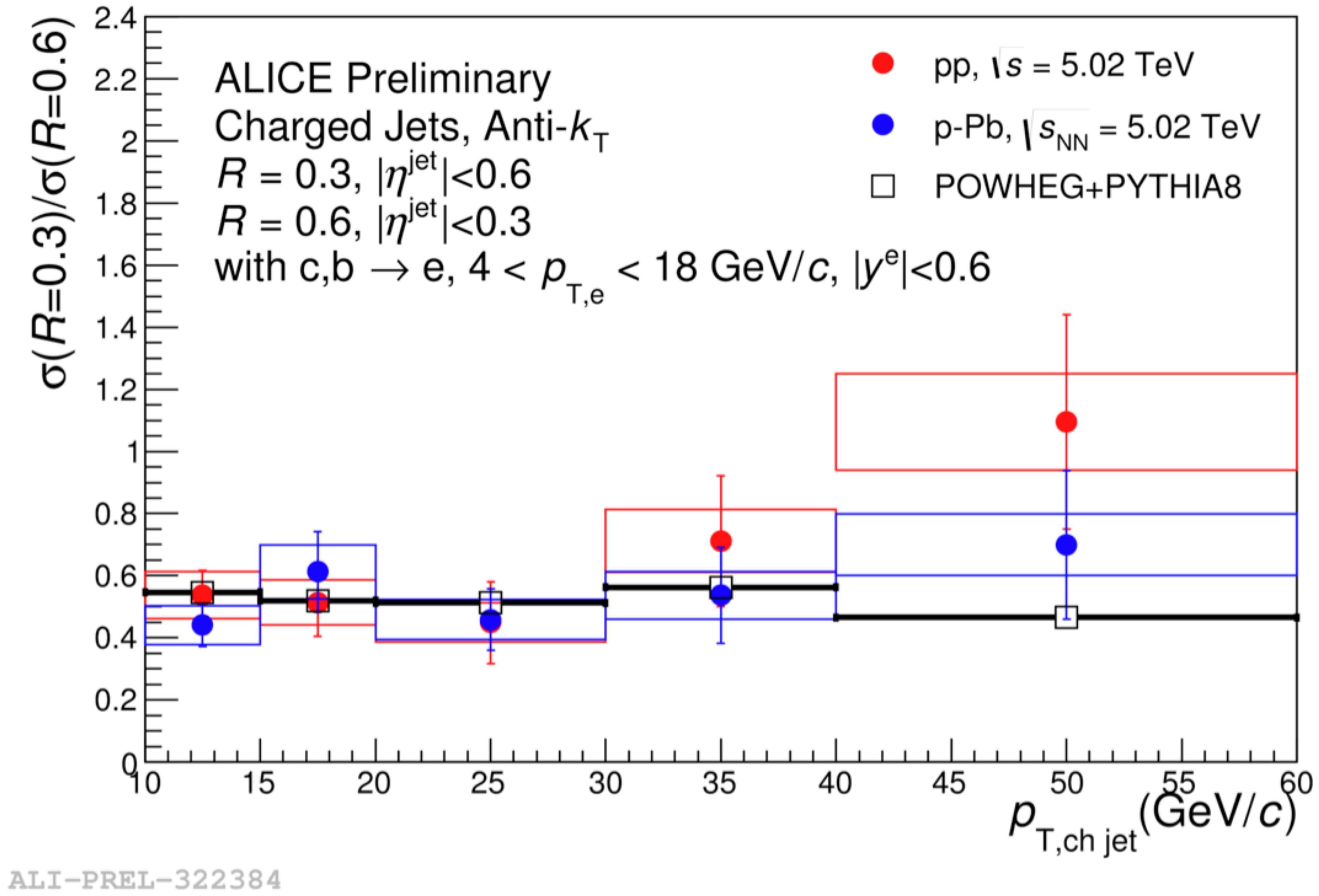
R dependence of R_{pPb}



$$R_{pPb} = \frac{1}{A}\frac{d\sigma_{pPb}/dp_T}{d\sigma_{pp}/dp_T}$$

No evidence of final state effect (energy loss) on heavy-flavour productions in small systems as well as initial state effects

Ratio of cross sections $\sigma(R=0.3)/\sigma(R=0.6)$ in pp and p-Pb



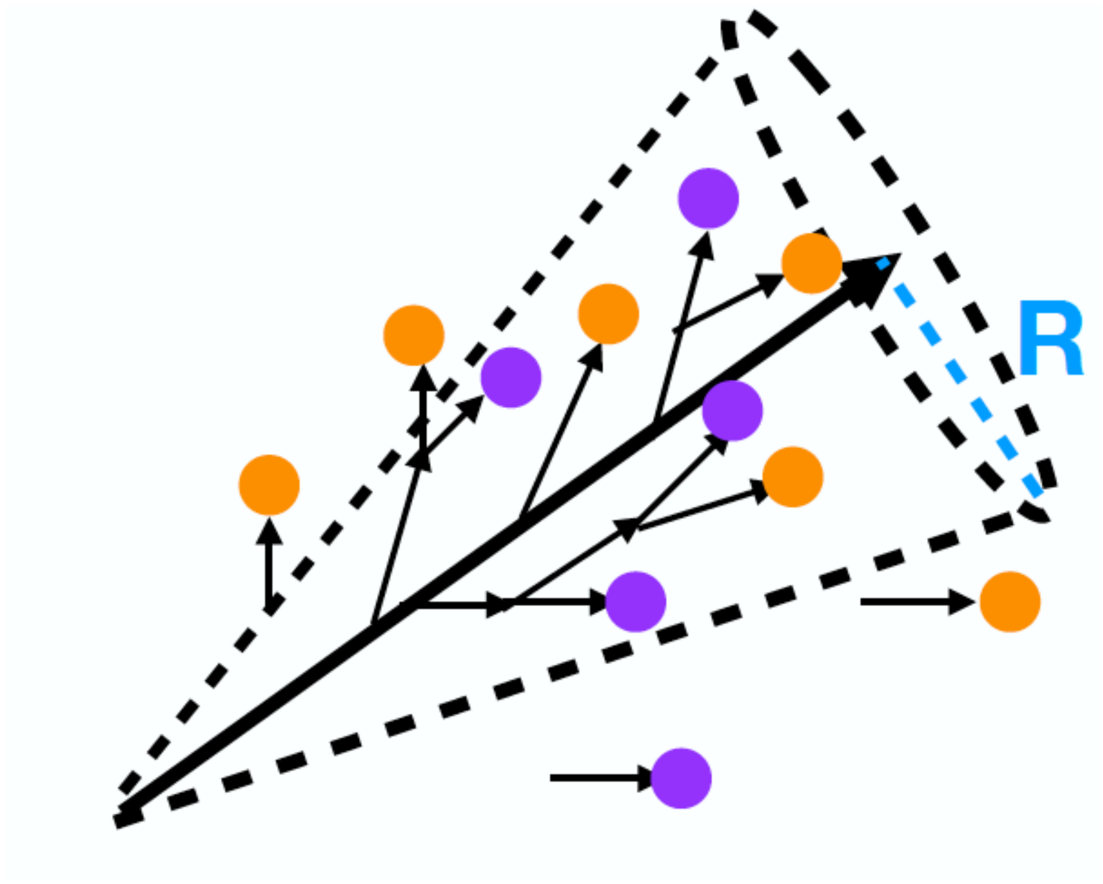
PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)
POWHEG: JHEP 11, 040 (2004), JHEP 1200 11, 070 (2007)

- No modification of the jet spectra in small system
- POWHEG describes also the radial shower development of HFe-jets
- No modification of jet shape of heavy-flavour jets

D^0-tagged charged-particle jets

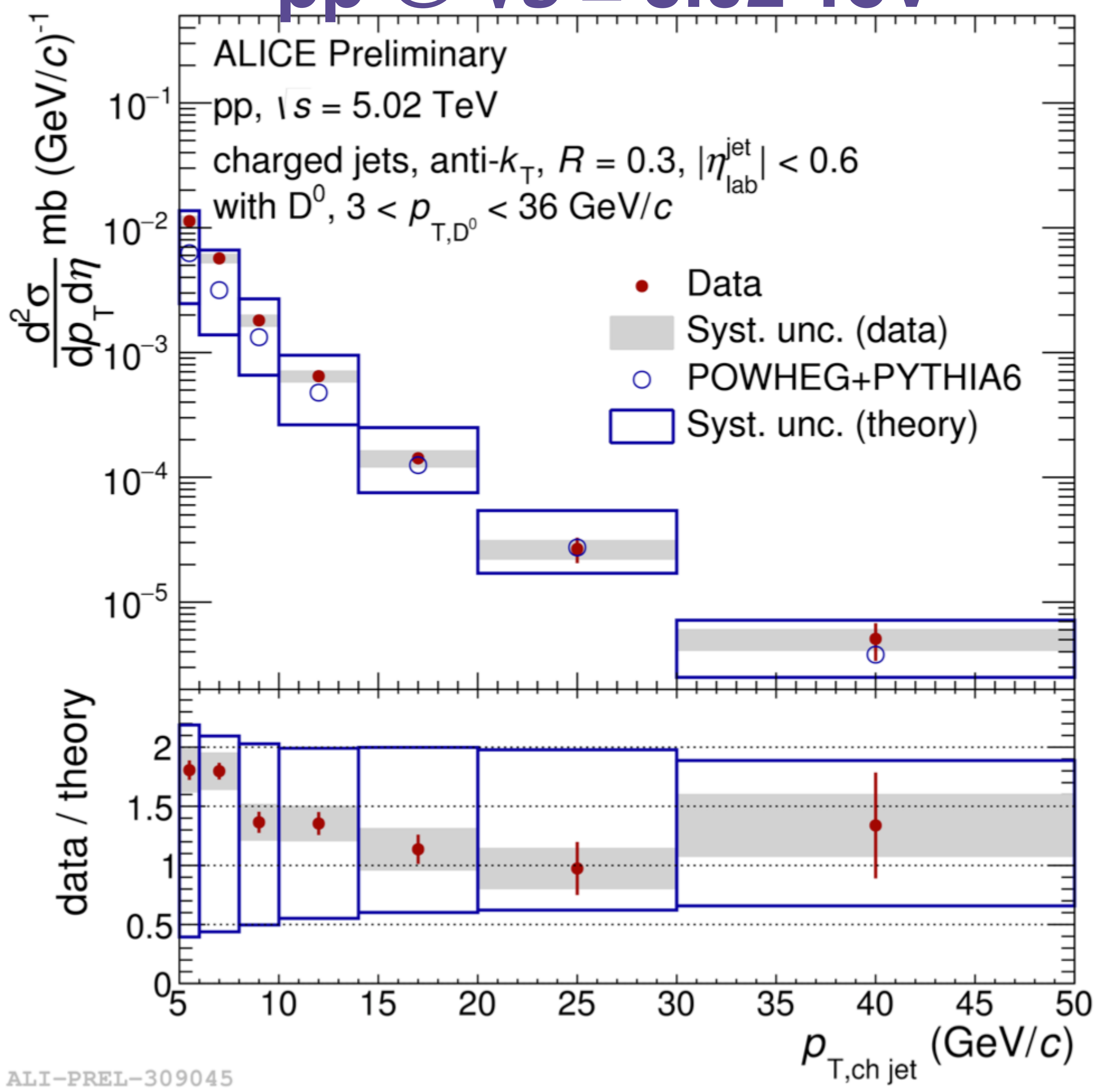
Jets are:

- identified by the presence of D^0 mesons, $2(3) < p_T^{\,D} < 36$ GeV/c
- reconstructed using charged particle (anti-k_T algorithm)
- $|\eta^{jet}|<0.9 - R$, $5 < p_T^{\,jet} < 50$ GeV/c

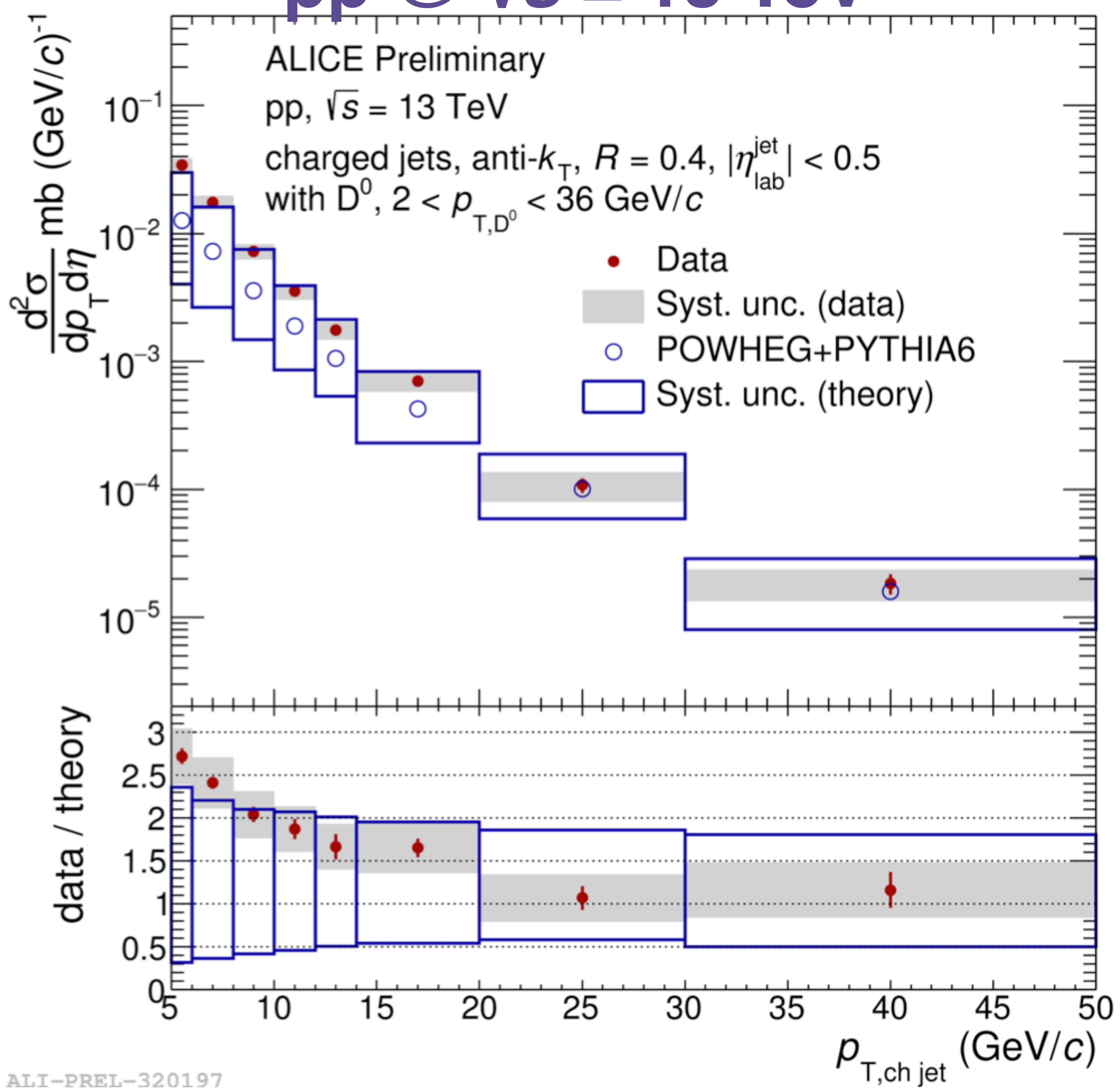


PYTHIA6: JHEP 05, 026 (2006)
POWHEG: JHEP 11, 040 (2004), JHEP 1200 11, 070 (2007)

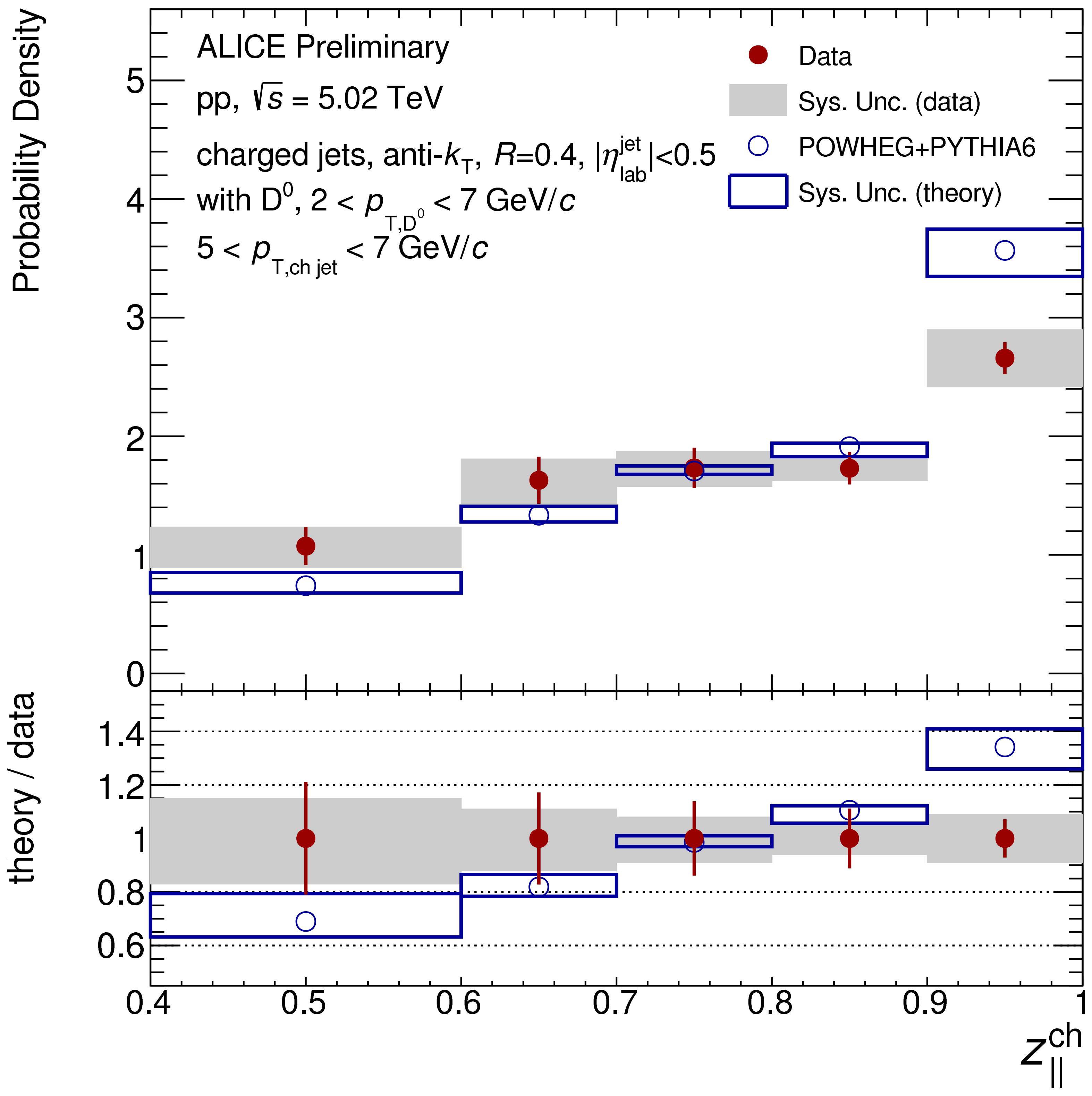
pp @ $\sqrt{s}$ = 5.02 TeV



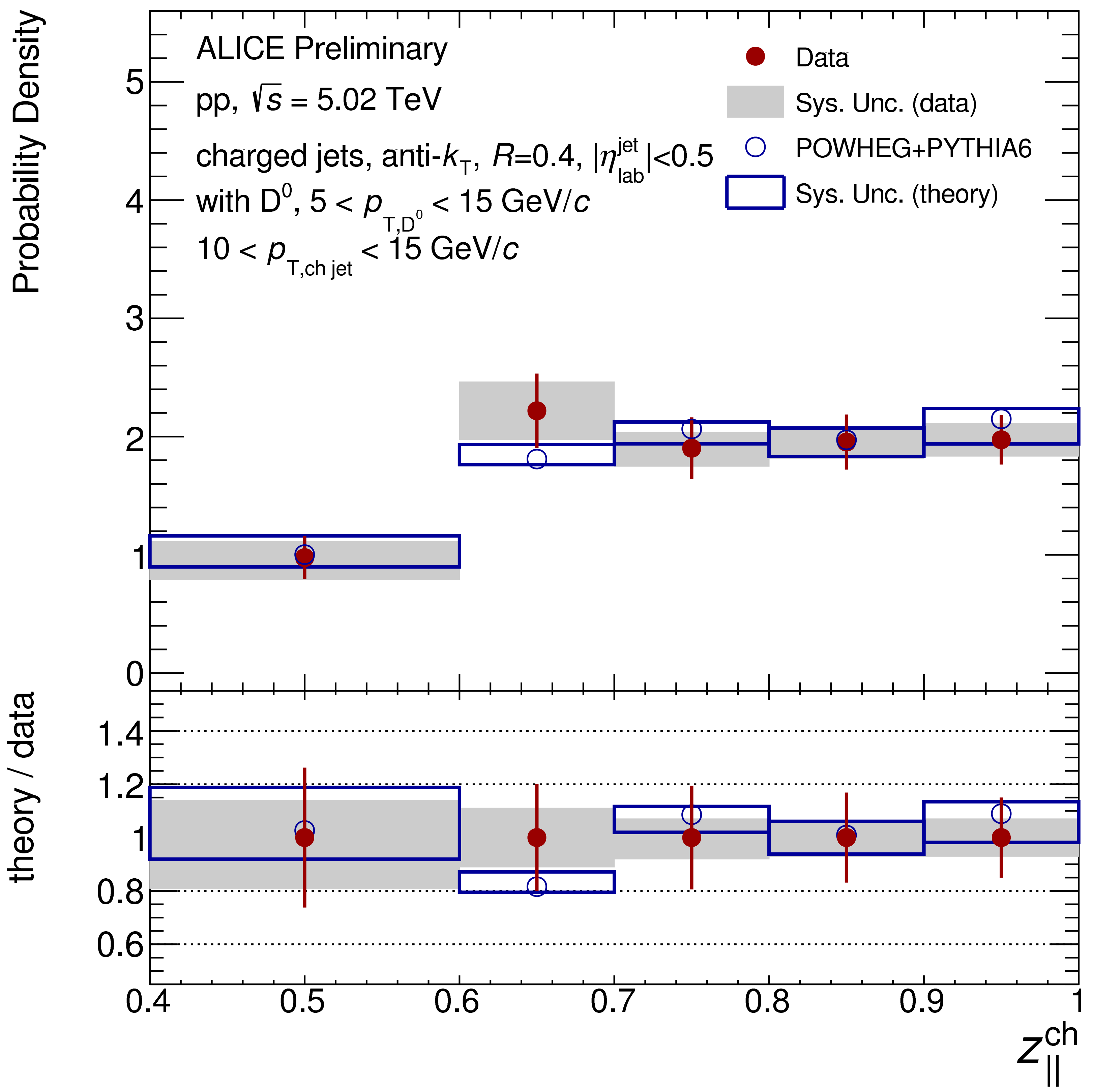
pp @ $\sqrt{s}$ = 13 TeV



- p_T–differential cross section of D^0 jets –> consistent trend between the energies: $\sqrt{s}$ = 5.02 TeV ($p_T^{\,D} > 3$ GeV/c, $R = 0.3$), 13 TeV ($p_T^{\,D} > 2$ GeV/c, $R = 0.3$).
- Consistent with theory predictions (POWHEG+PYTHIA6) decreasing minimum $p_T^{\,jet}$ increased difference from the central POWHEG+PYTHIA6.



ALI-PREL-332972



ALI-PREL-333048

pp @ $\sqrt{s}$ = 5.02 TeV

PYTHIA6: JHEP 05, 026 (2006)
PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)
POWHEG: JHEP 11, 040 (2004), JHEP 1200 11, 070 (2007)

Momentum fraction carried by the D^0 meson in the direction of the jet axis: $z_{||}^{ch} = \frac{\overrightarrow{p_{jet}^{ch}} \cdot \overrightarrow{p_{HF}}}{\overrightarrow{p_{jet}^{ch}} \cdot \overrightarrow{p_{jet}^{ch}}}$

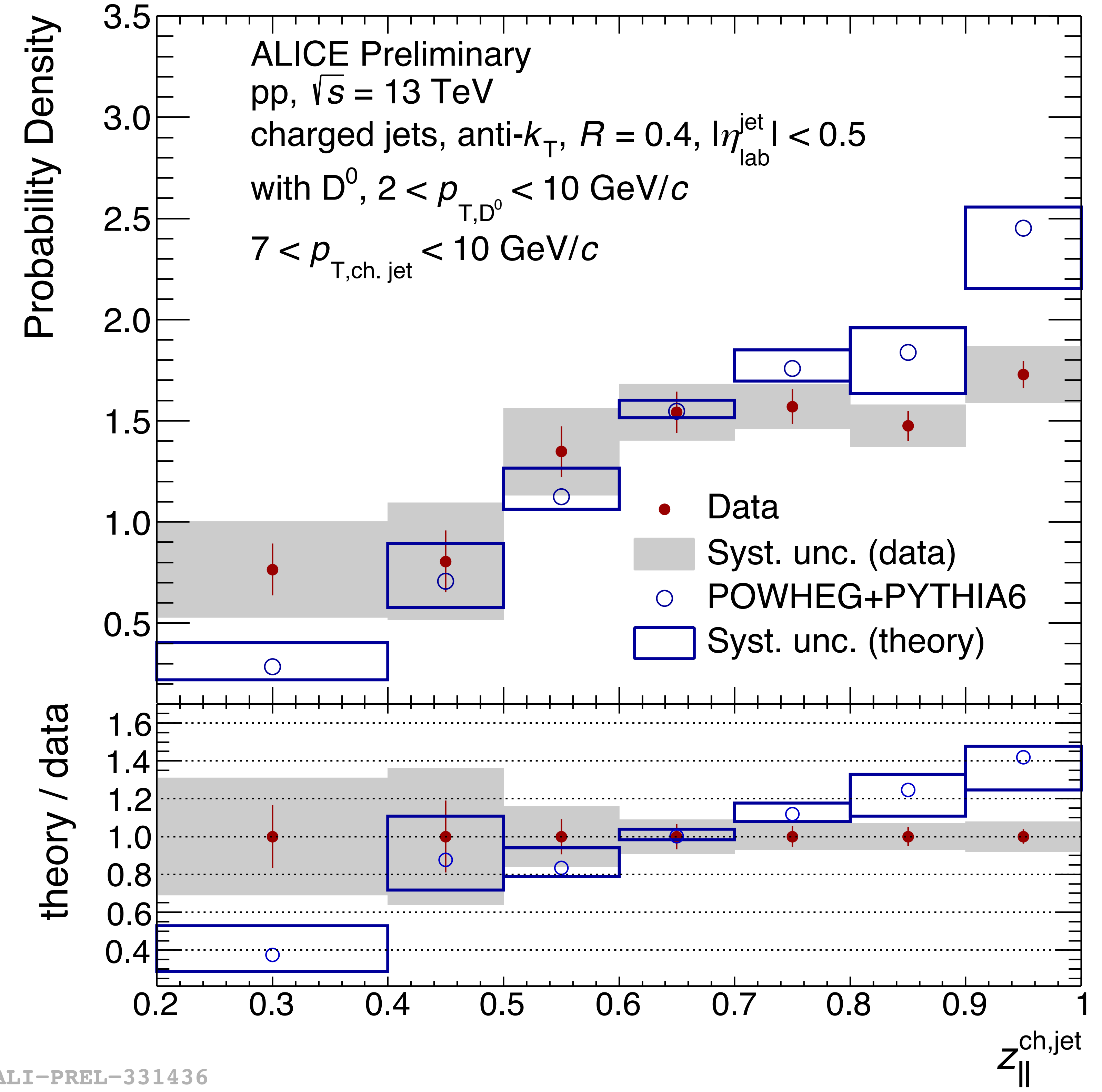
Measurements point towards a softer fragmentation at lower $p_{T,jet}$

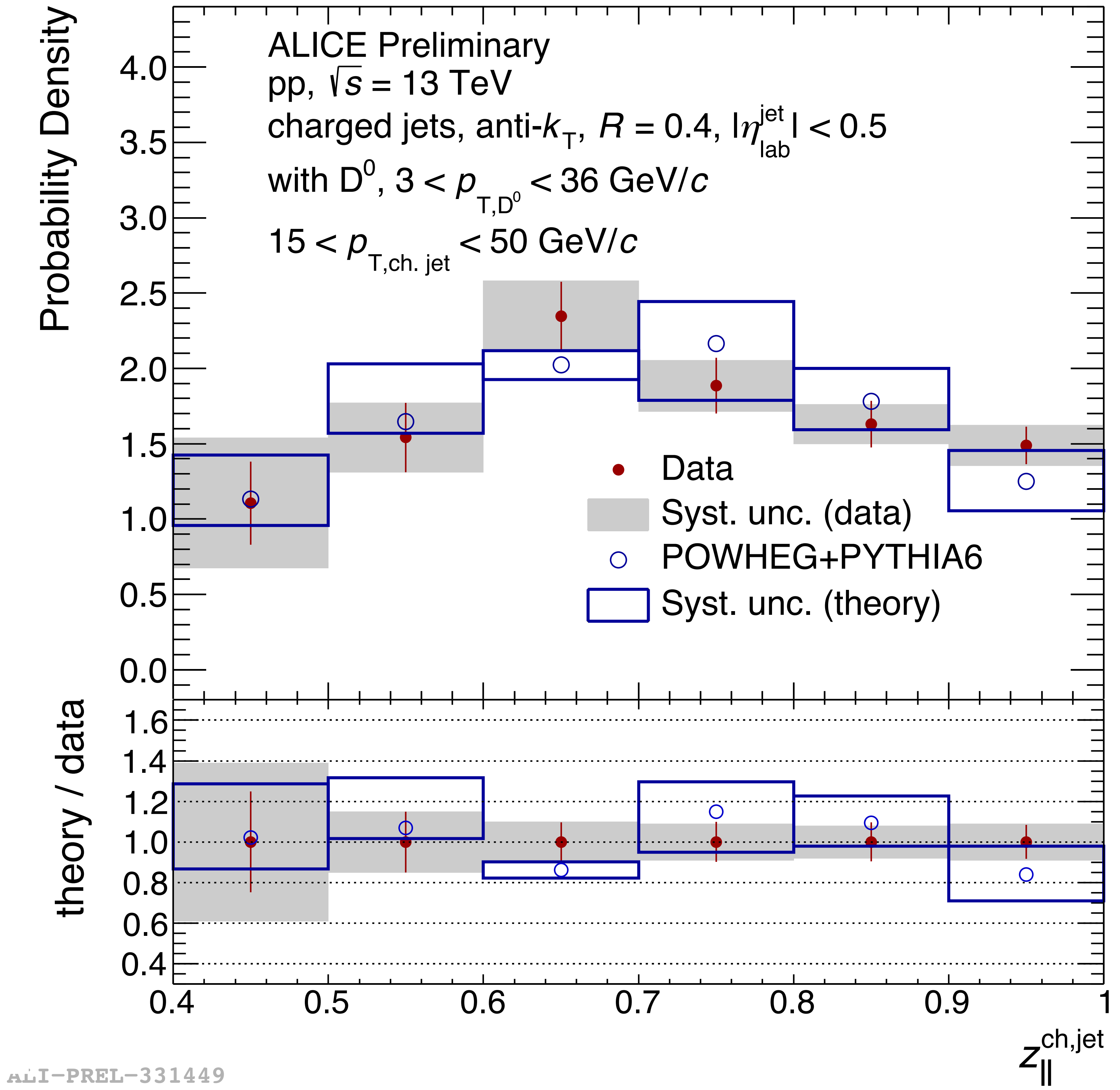
Good agreement with NLO (POWHEG+PYTHIA6) pQCD predictions for higher $p_{T,jet}$

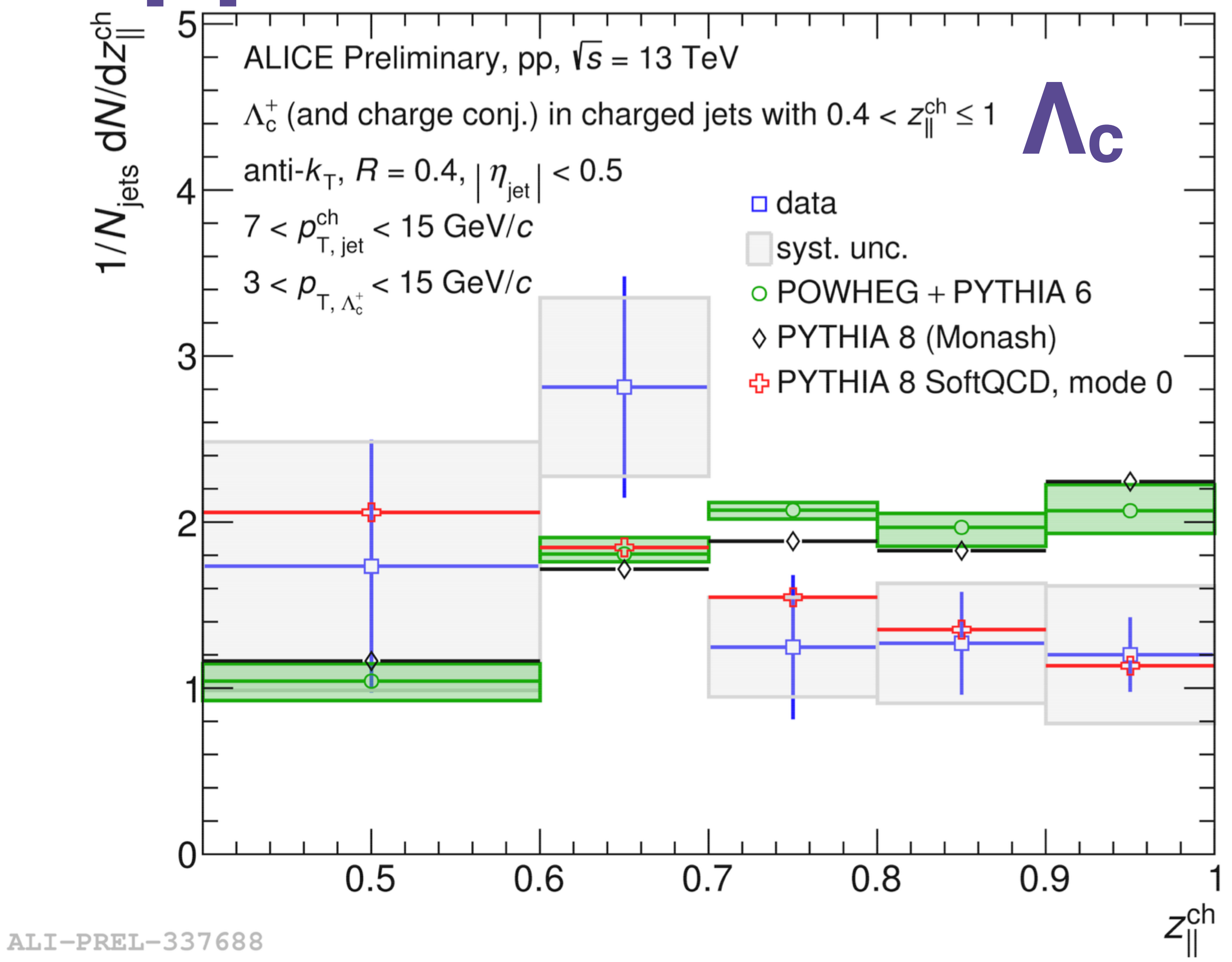
Peak at $z_{||}^{ch} \approx 1$ for **$5 < p_{T,jet} < 7$ GeV/c only D^0 as jet component**

D^0 and Λ_c-tagged charged-particle jets: fragmentation function

pp @ $\sqrt{s}$ = 13 TeV







PYTHIA6: JHEP 05, 026 (2006)
PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)
POWHEG: JHEP 11, 040 (2004), JHEP 1200 11, 070 (2007)

Measurements point towards a softer fragmentation at lower $p_{T,jet}$

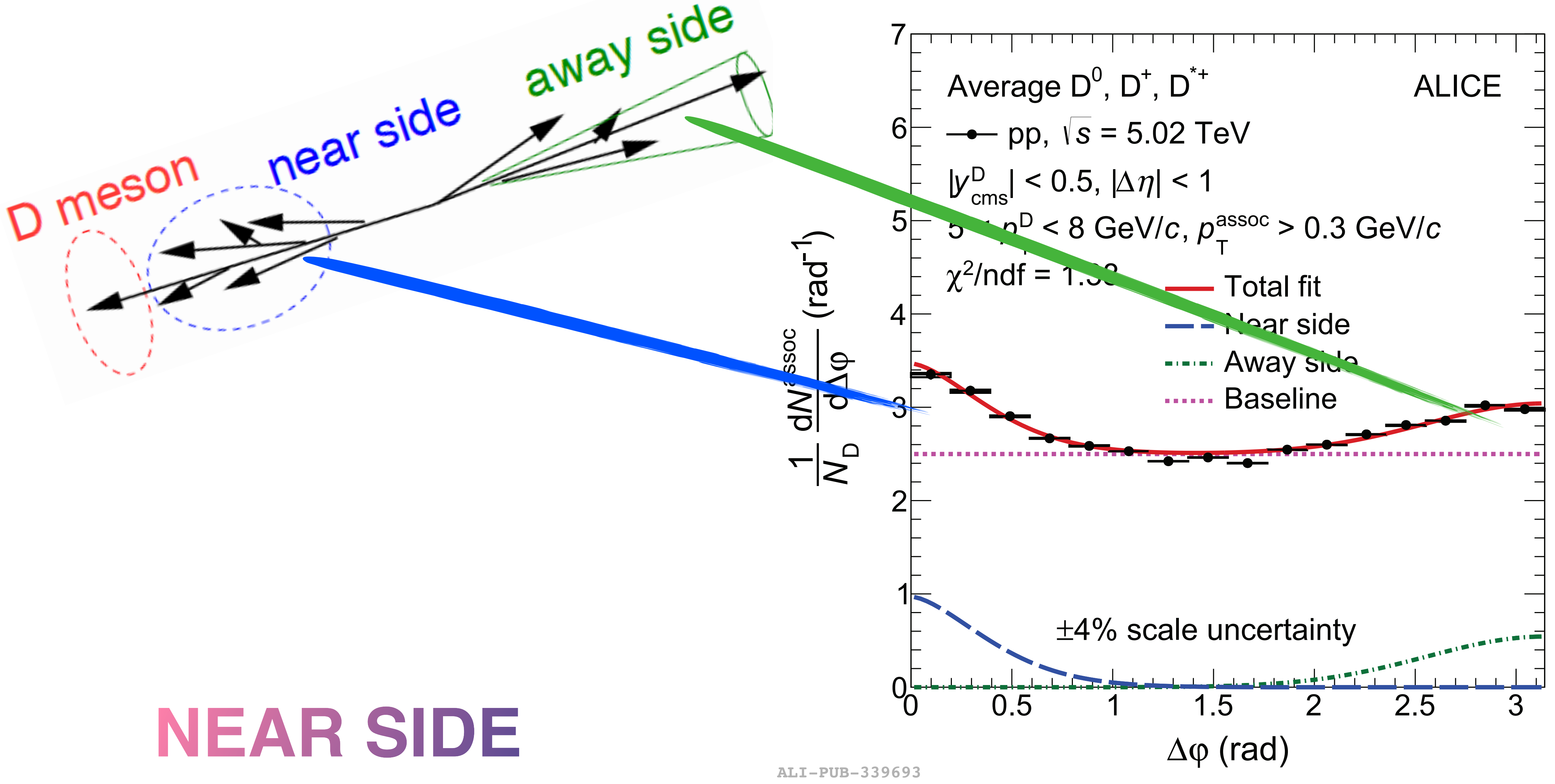
Momentum fraction carried by the D^0 meson in the direction of the jet axis: $z_{||}^{ch} = \dfrac{\vec{p}_{jet}^{\,ch} \cdot \vec{p}_{HF}}{\vec{p}_{jet}^{\,ch} \cdot \vec{p}_{jet}^{\,ch}}$

Good agreement with NLO (POWHEG+PYTHIA6) pQCD predictions for higher $p_{T,jet}$

Peak at $z_{||}^{ch} \approx 1$ for **$7 < p_{T,jet} < 10$ GeV/c only D^0 as jet component**

D-hadron correlations: pp vs. p-Pb collisions

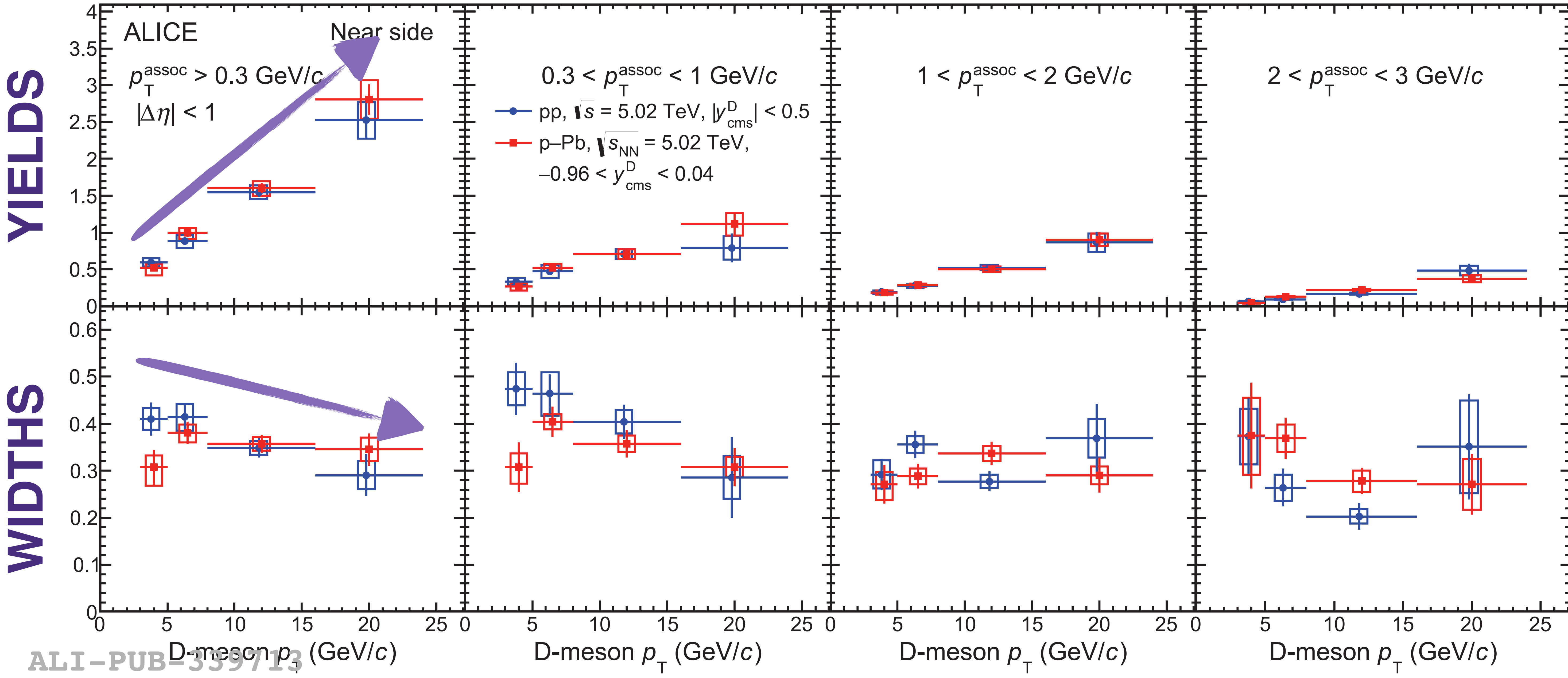
Complementary to jet studies:
internal composition, spatial profile



arXiv:1910.14403

D^0, D^{*+}, D$^+$-meson (trigger particle) correlated with primary charged tracks (associated particles)

NEAR SIDE



NS Yield and width *vs.* p_T(D) describe the charged-particle multiplicity and the spatial profile of the charm jet

Compatibility throughout all kinematic ranges between the two collision systems

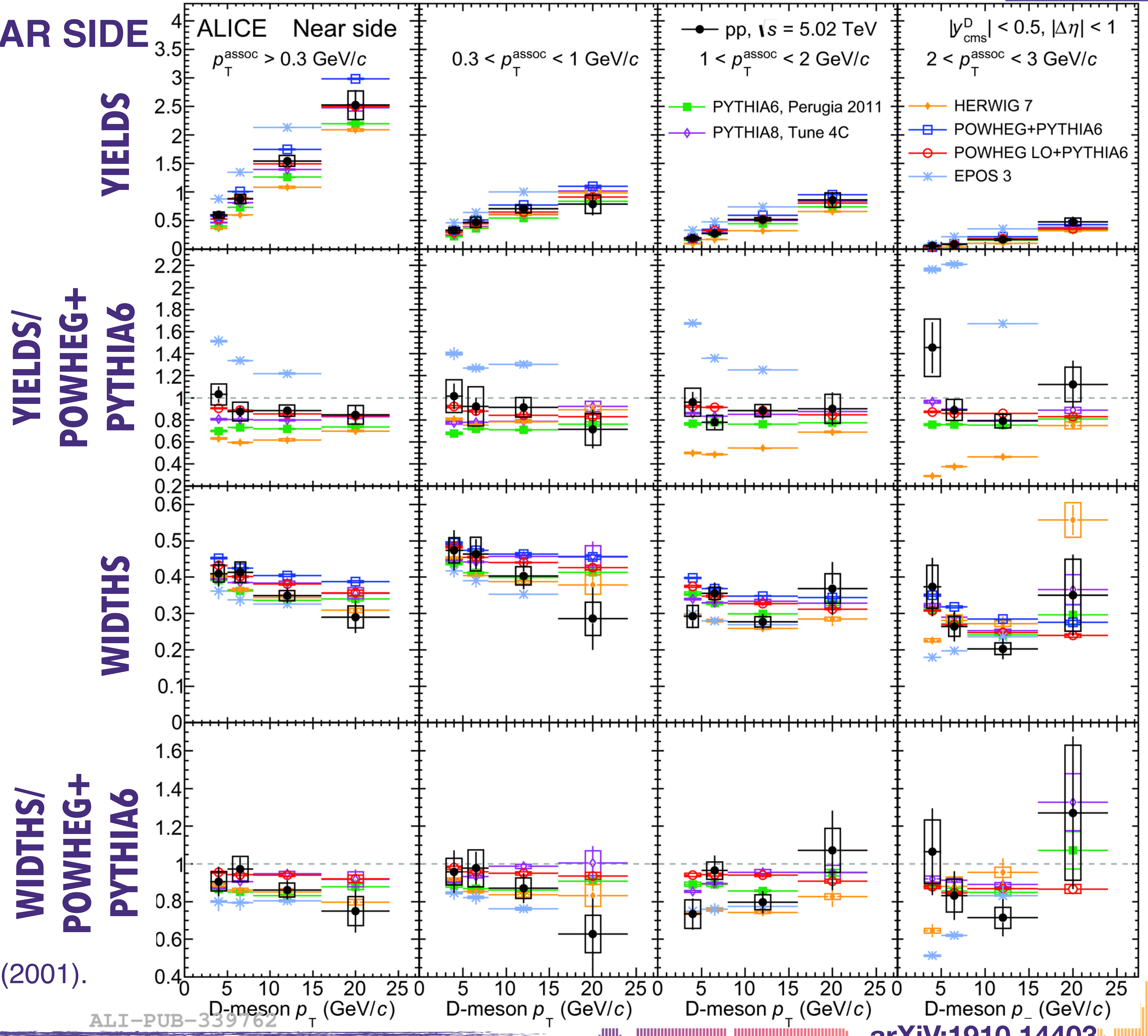
No evidence of CNM effects

D-hadron correlations: comparison with models

NEAR SIDE

Most of the models provide a fair description of the NS correlation peak

- POWHEG+PYTHIA6 and PYTHIA8 provide the best description –> the best candidates for building model references for Pb-Pb studies
- HERWIG misses completely the near-side peak yield at low $p_{T,D}$ and high $p_{T,assoc}$
- EPOS 3 predicts too large near-side yields



PYTHIA6: JHEP 05, 026 (2006)
PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)
POWHEG: JHEP 11, 040 (2004), JHEP 1200 11, 070 (2007)
EPOS 3: Phys. Rev. C 82, 044904 (2010), Phys. Rept. 350, 119 393–289 (2001).
HERWIG: Eur. Phys. J. C 76(4), 196 (2016)

arXiV:1910.14403

Multiplicity dependent heavy-flavour hadrons measurements

J/ψ production vs. multiplicity in pp collisions at 13 TeV (midrapidity)

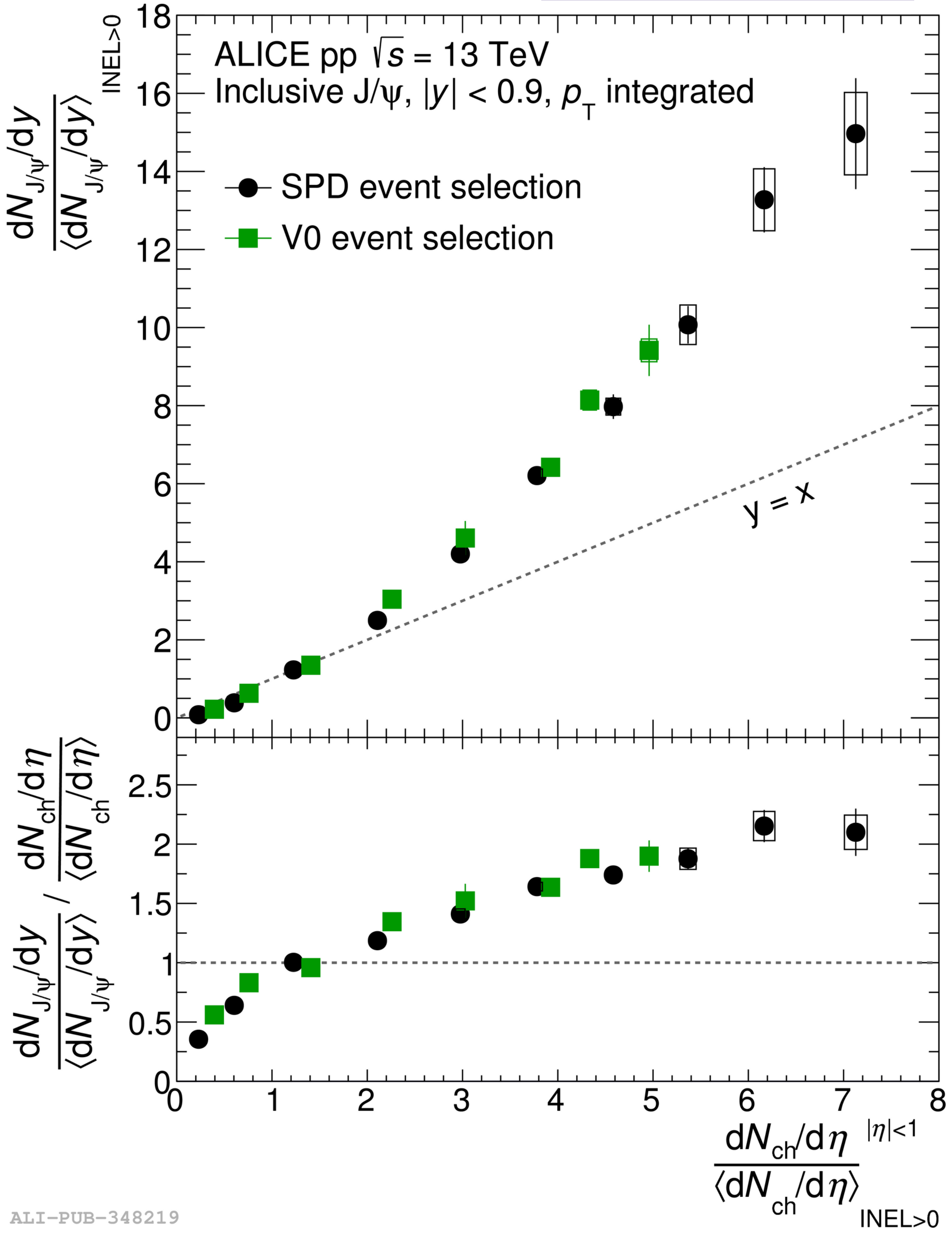
$J/\psi \rightarrow e^+e^-$

Stronger-than-linear increase of the J/ψ self-normalized yield

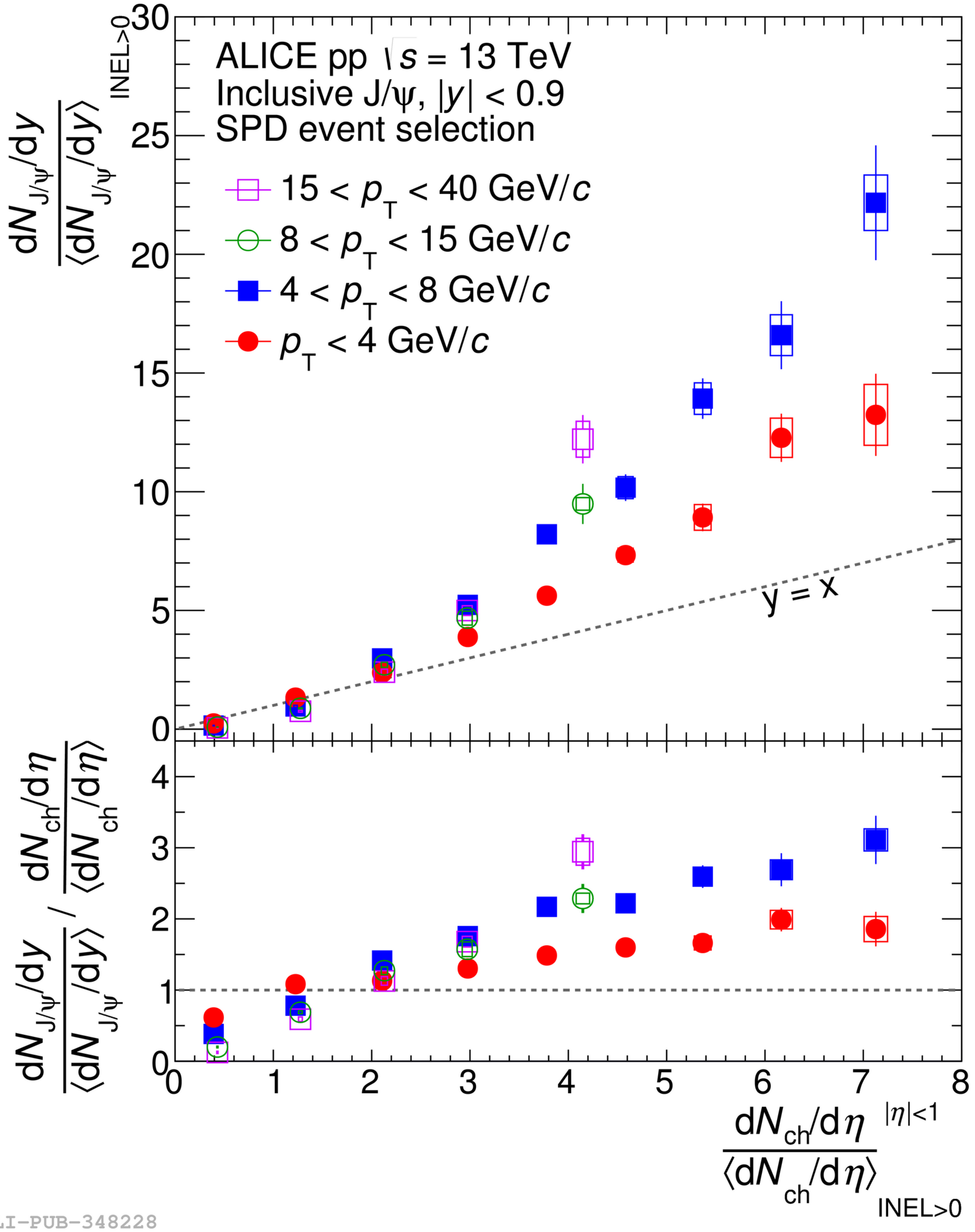
Differentially in p_T: significant increase of the self-normalized J/ψ yield with relative multiplicity between the J/ψ p_T intervals 0-4 and 4-8 GeV/c

- Associated J/ψ production with other hadrons in jet fragmentation
- Beauty-quark fragmentation?

arXiV:1910.14403

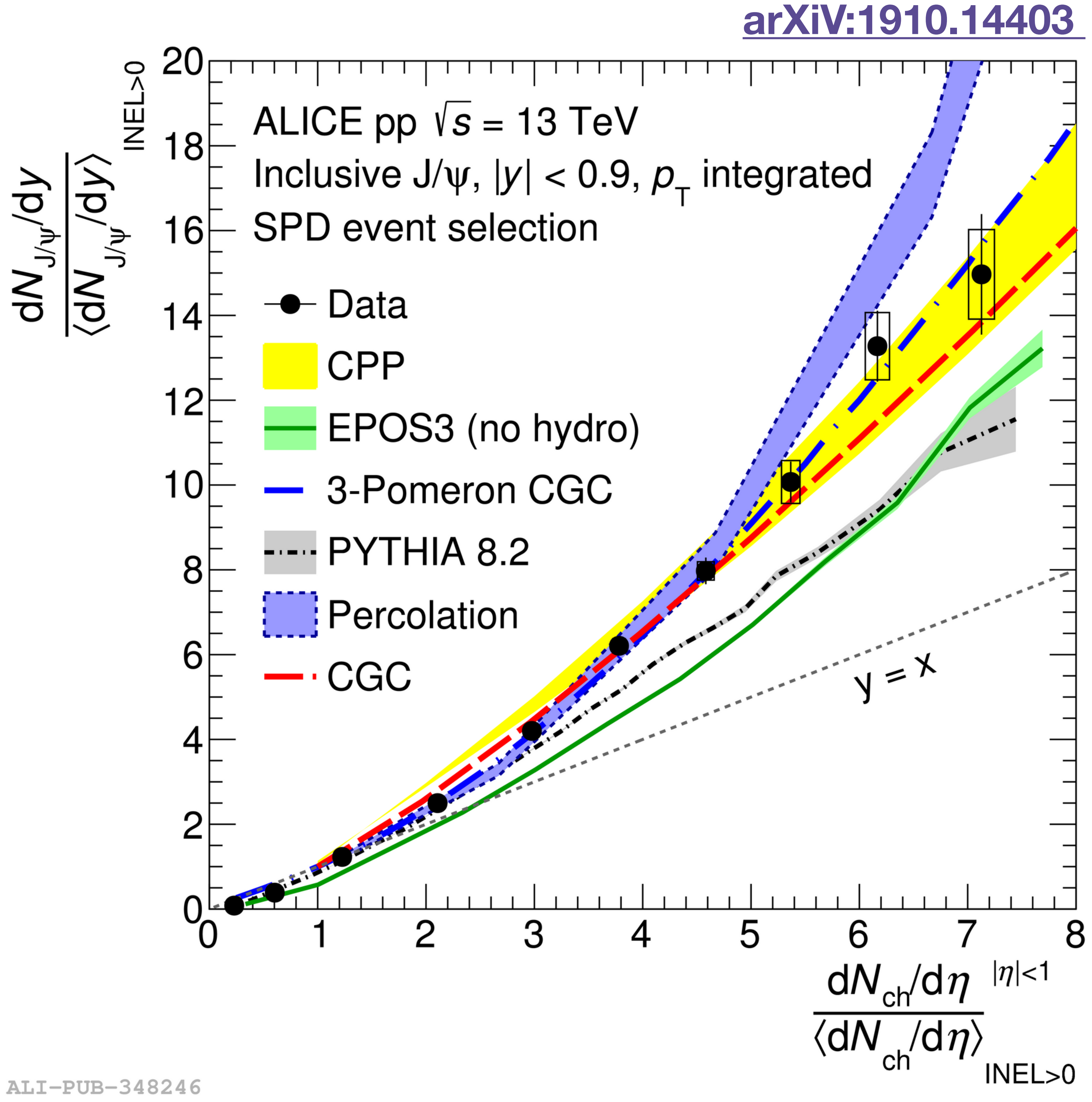


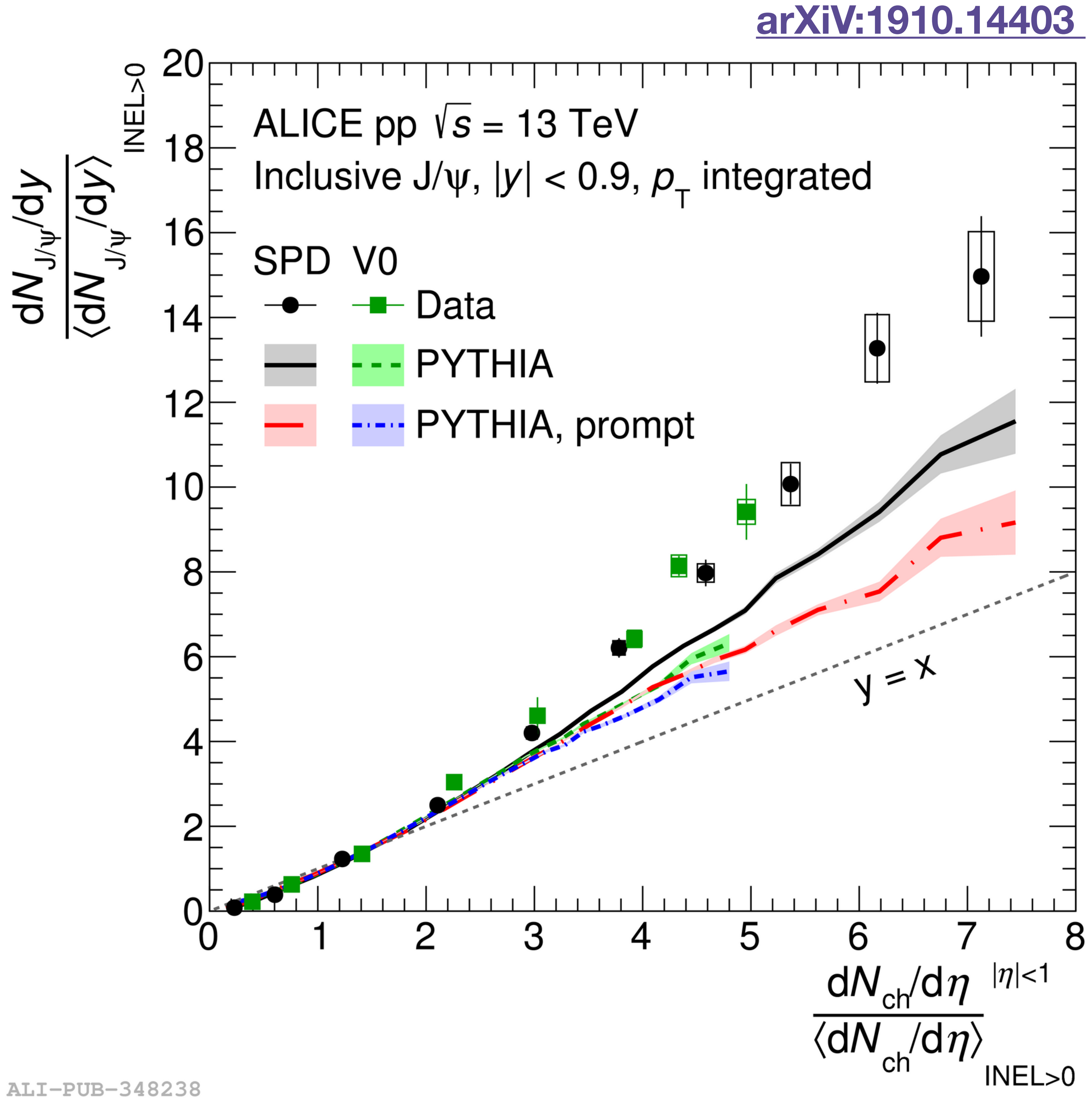
arXiV:1910.14403



J/ψ production vs. multiplicity in pp collisions at 13 TeV (midrapidity)

- Significant reduction of the correlation observed when only including the prompt component in PYTHIA
- Various mechanisms (e.g. CSR, percolation, gluon saturation) responsible for multiplicity-dependent reduction of $dN_{ch}/d\eta$ in all models
- Good agreement with CGC, CPP and 3-Pomeron models
- PYTHIA8 and EPOS3 underestimate the data



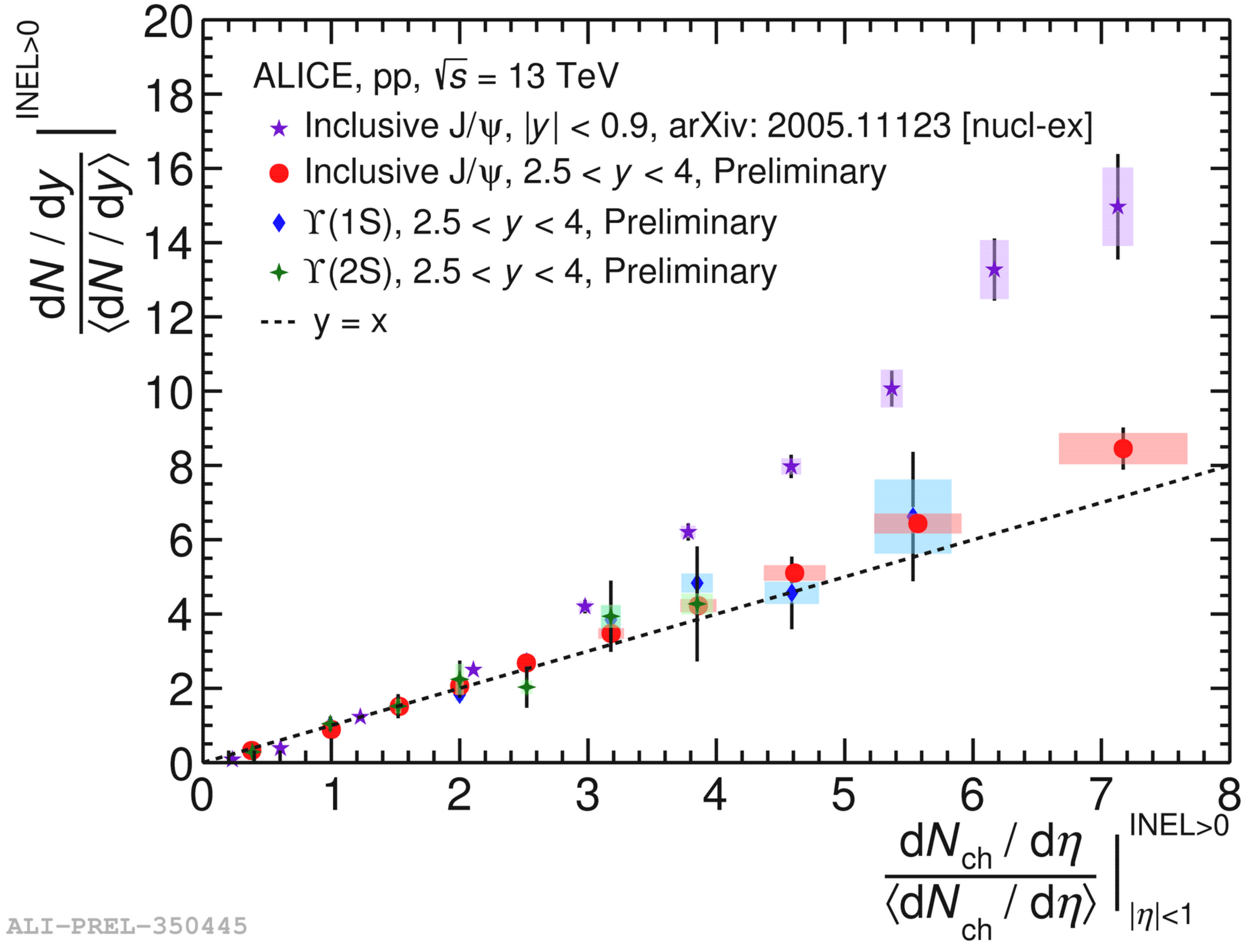


CPP: Phys. Rev. D88 no. 11, (2013)116002,
EPOS 3: Phys. Rev. C 82, 044904 (2010), Phys. Rept. 350, 119 393–289 (2001).
3-Pomeron CGC: arXiv:1910.13579.
PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)
Percolation: Phys. Rev. C86 (2012) 034903
CGC: Phys. Rev. D98 no. 7, (2018) 074025.

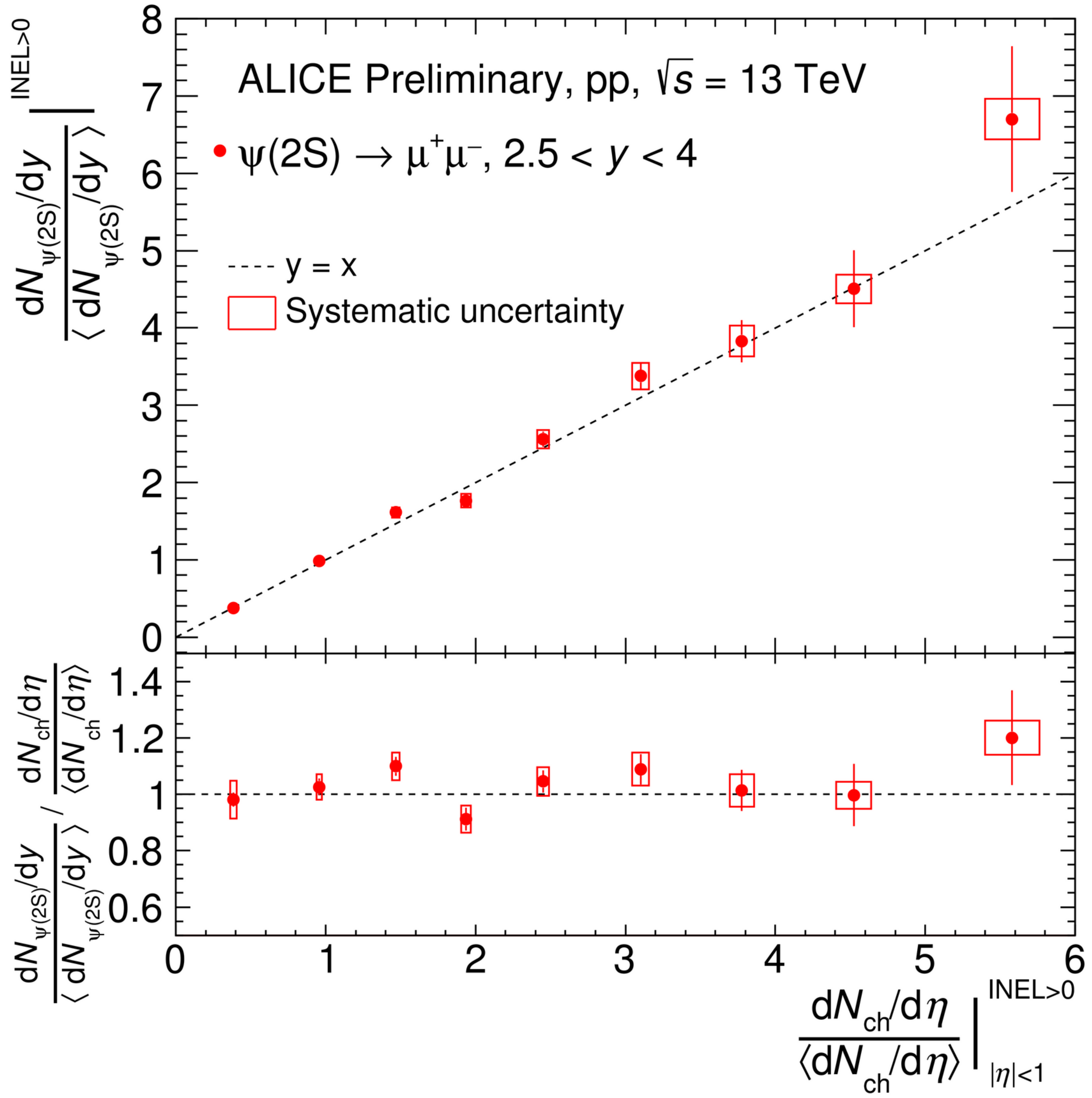
NEW

J/ψ, ψ(2S), ϒ(1S), ϒ(2S) → $\mu^+\mu^-$

- J/ψ, ϒ(1S) and ϒ(2S) relative yields compatible with linear dependence on multiplicity (unlike J/ψ mid-*y* results)
- No energy dependence observed for the J/ψ results
- New ψ(2S) results on the full Run 2 data sample also compatible with linear dependence on multiplicity



ALI-PREL-350445



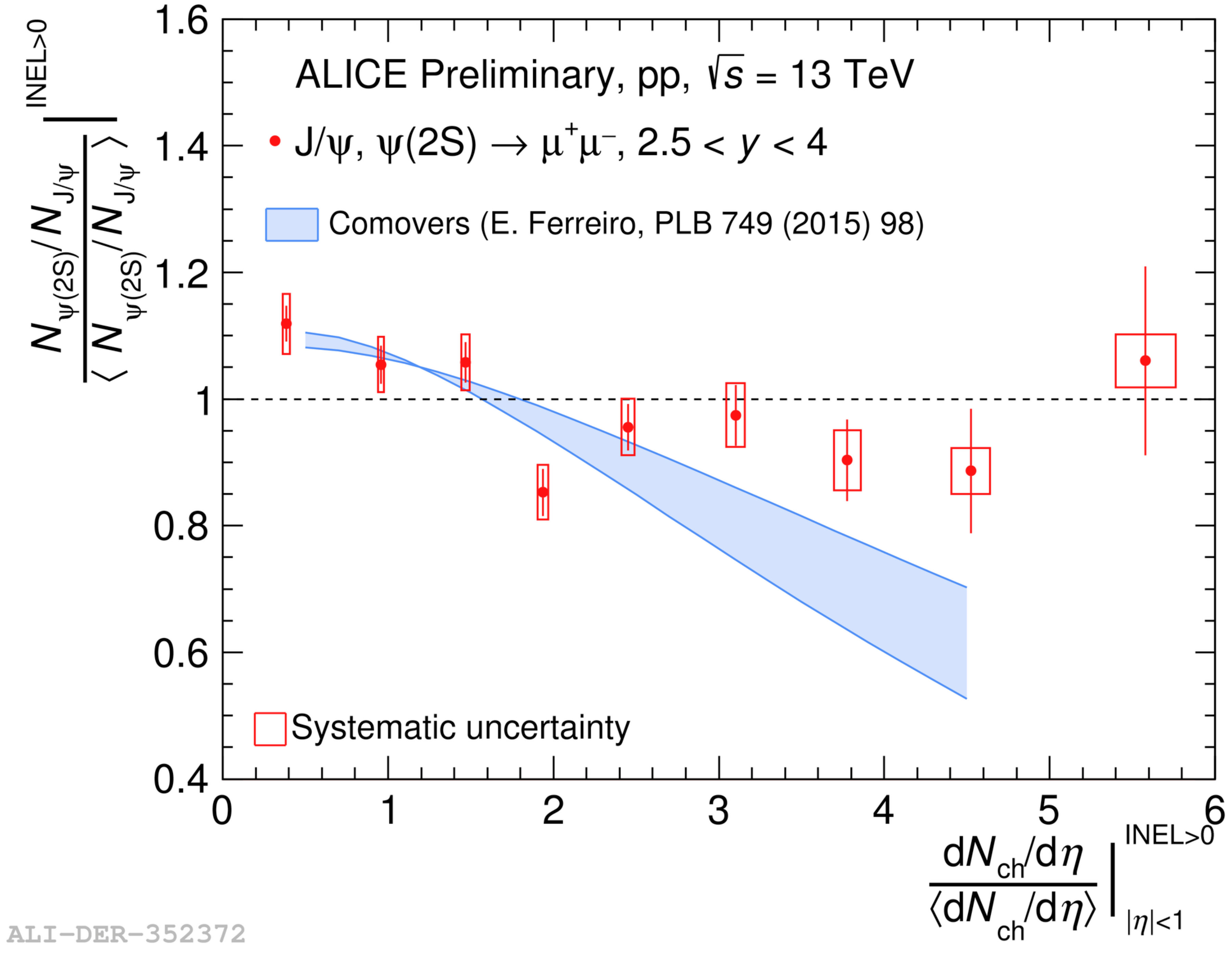
ALI-PREL-346195

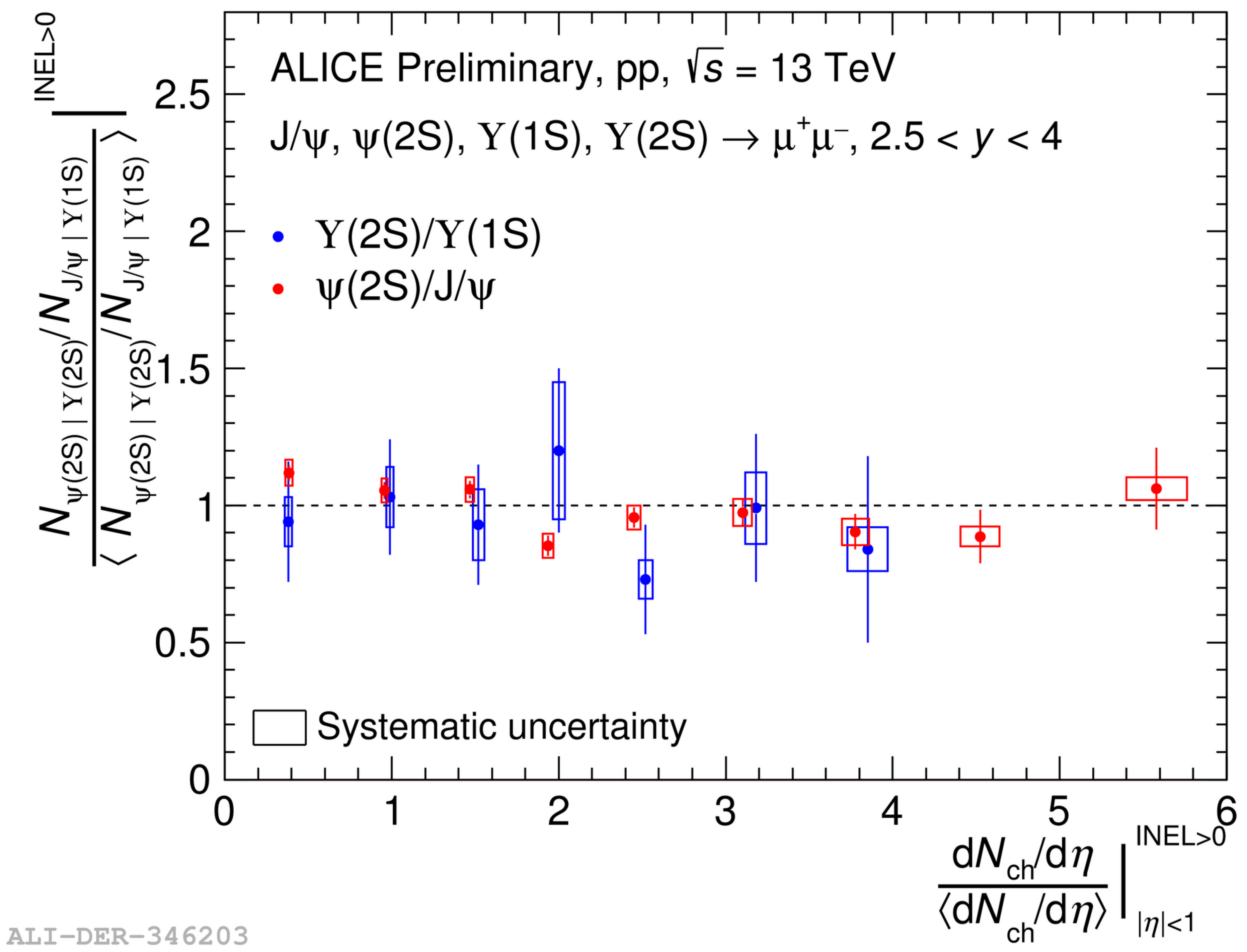
forward rapidity

NEW

- New self-normalized ψ(2S)/J/ψ results (on full Run 2 data sample): maximum deviation from unity ~2.2σ (first bin) → hint of a multiplicity dependence of ψ(2S) suppression w.r.t J/ψ?

- Amplitude of the suppression stronger in the model (comovers approach) than in the measurement at high multiplicity



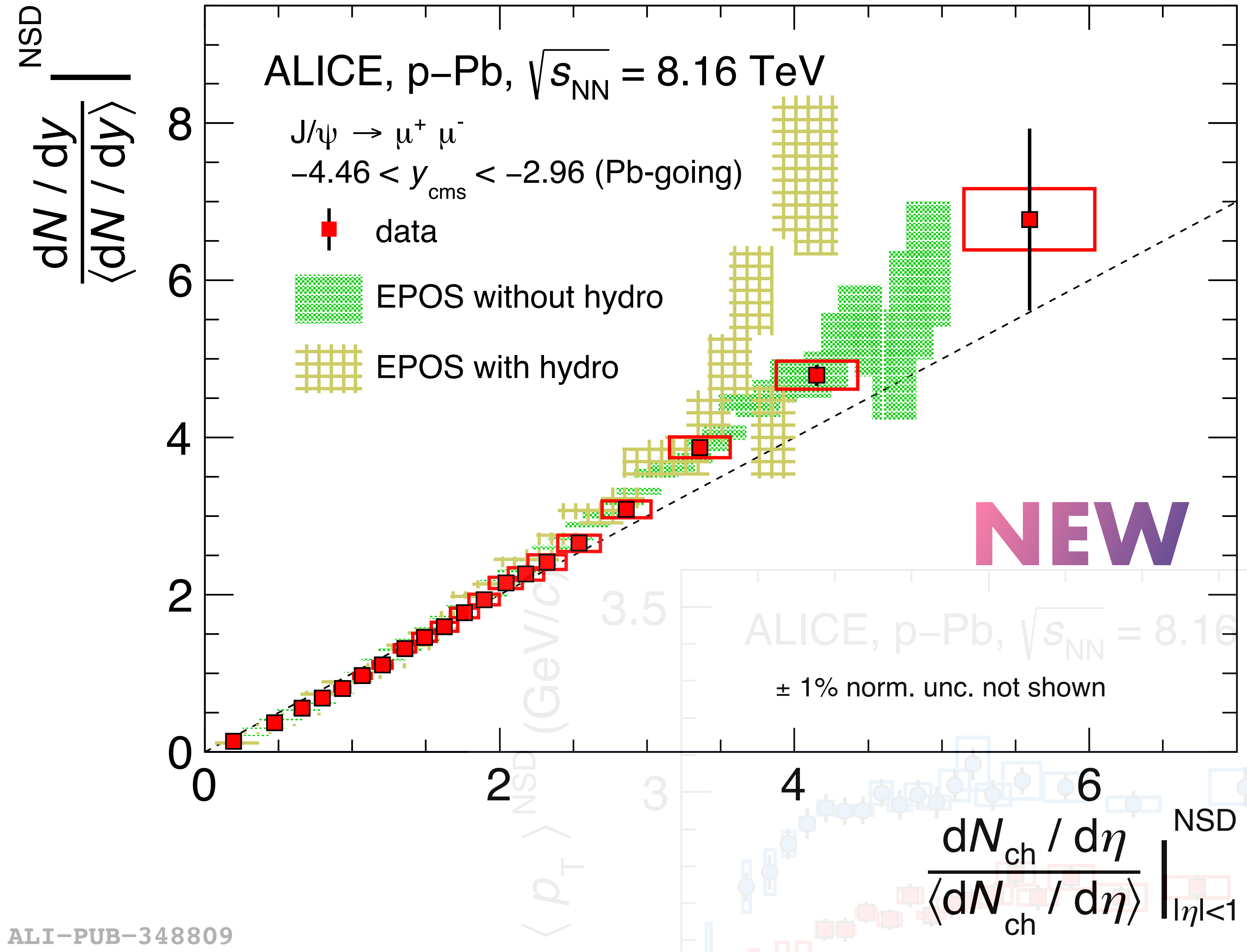


- Charmonium ratio compatible with ϒ(2S)/ϒ(1S) within large statistical and systematic uncertainties

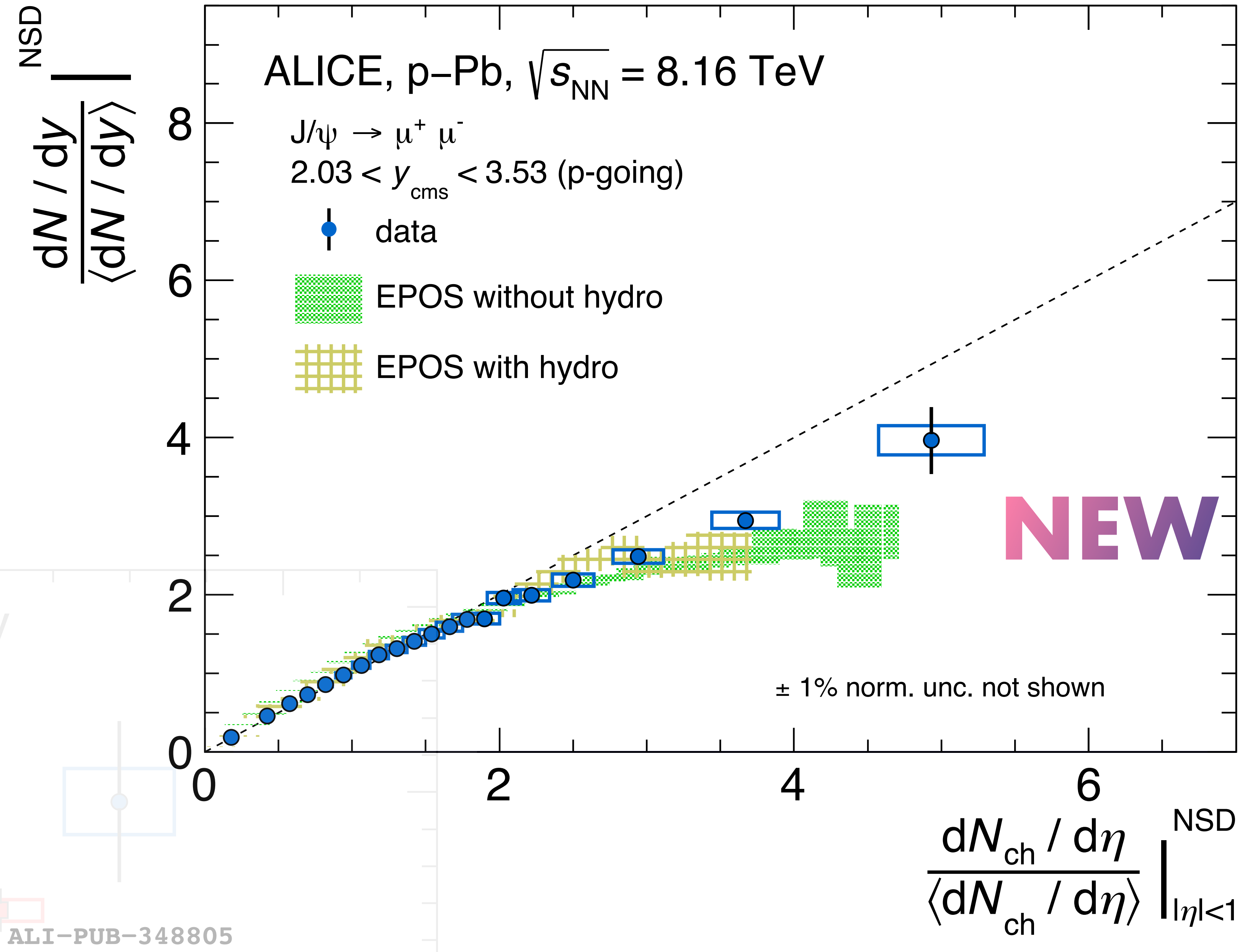
J/ψ production vs. multiplicity in p-Pb collisions

- Slightly faster-than-linear increase of J/ψ relative yield at backward rapidity (Pb-going)
- Slower-than-linear increase at forward rapidity (p-going)
- EPOS3 well reproduces the observed yields at backward/forward rapidity
- Small influence of hydrodynamic evolution

Pb-going



p-going



arXiv:2004.12673

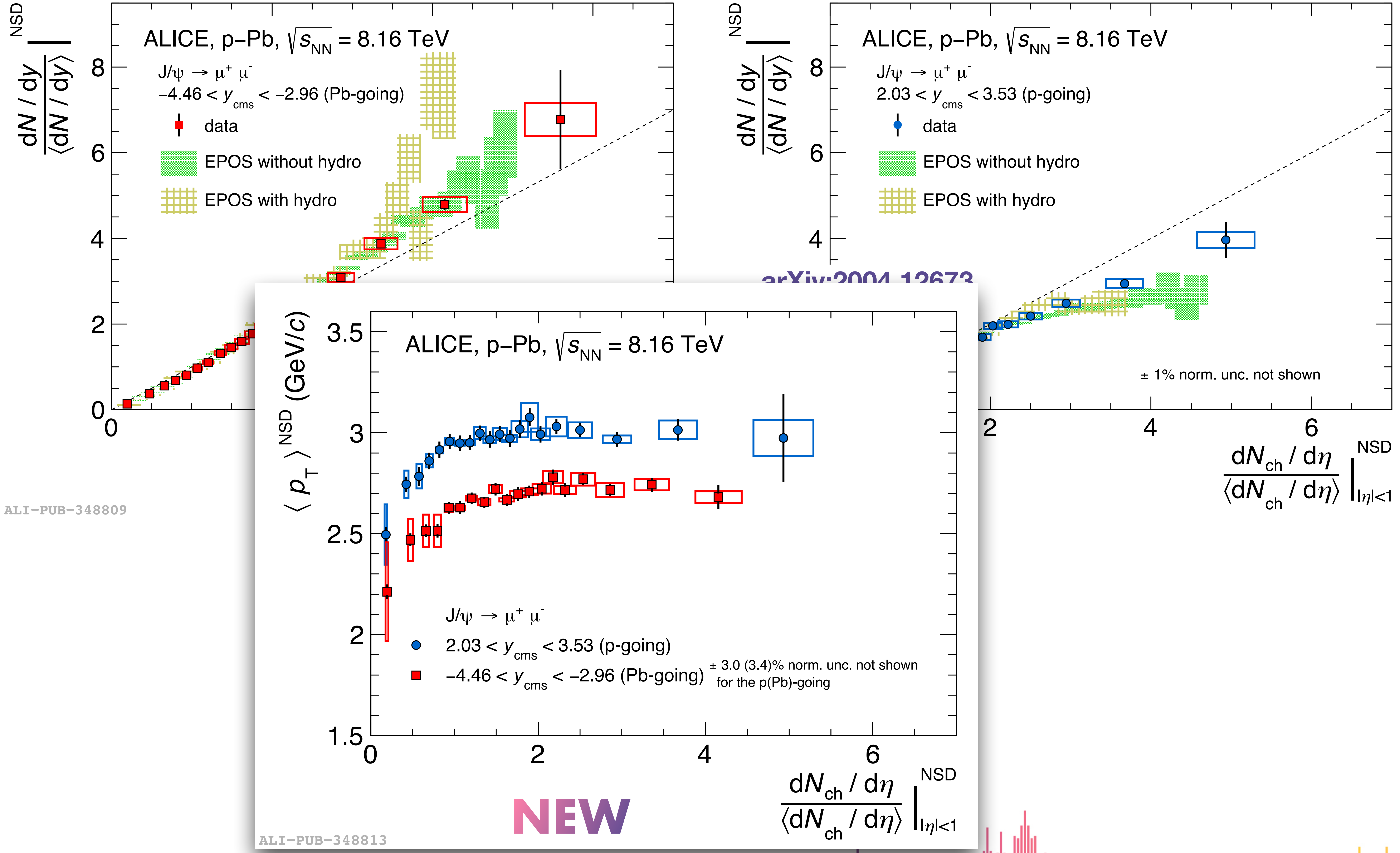
EPOS 3: Phys. Rev. C 82, 044904 (2010), Phys. Rept. 350, 119 393–289 (2001).

J/ψ production vs. multiplicity in p-Pb collisions

- $\langle p_T \rangle$ is smaller at backward than at forward
- $\langle p_T \rangle$increases steadily below the average multiplicities
- Increase of yields + saturation of $\langle p_T \rangle$ point towards an incoherent superposition of parton-parton interaction

Pb-going

p-going

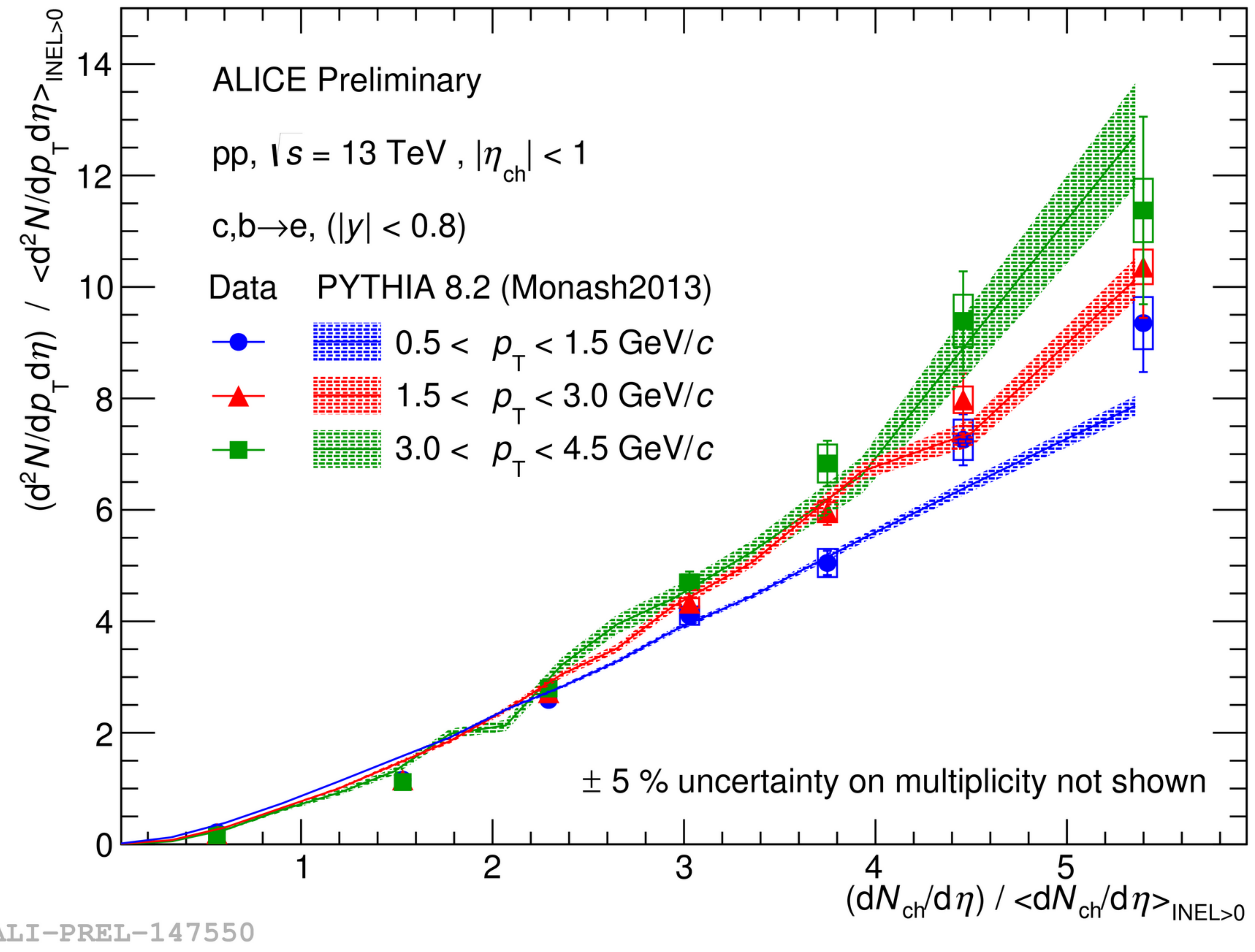


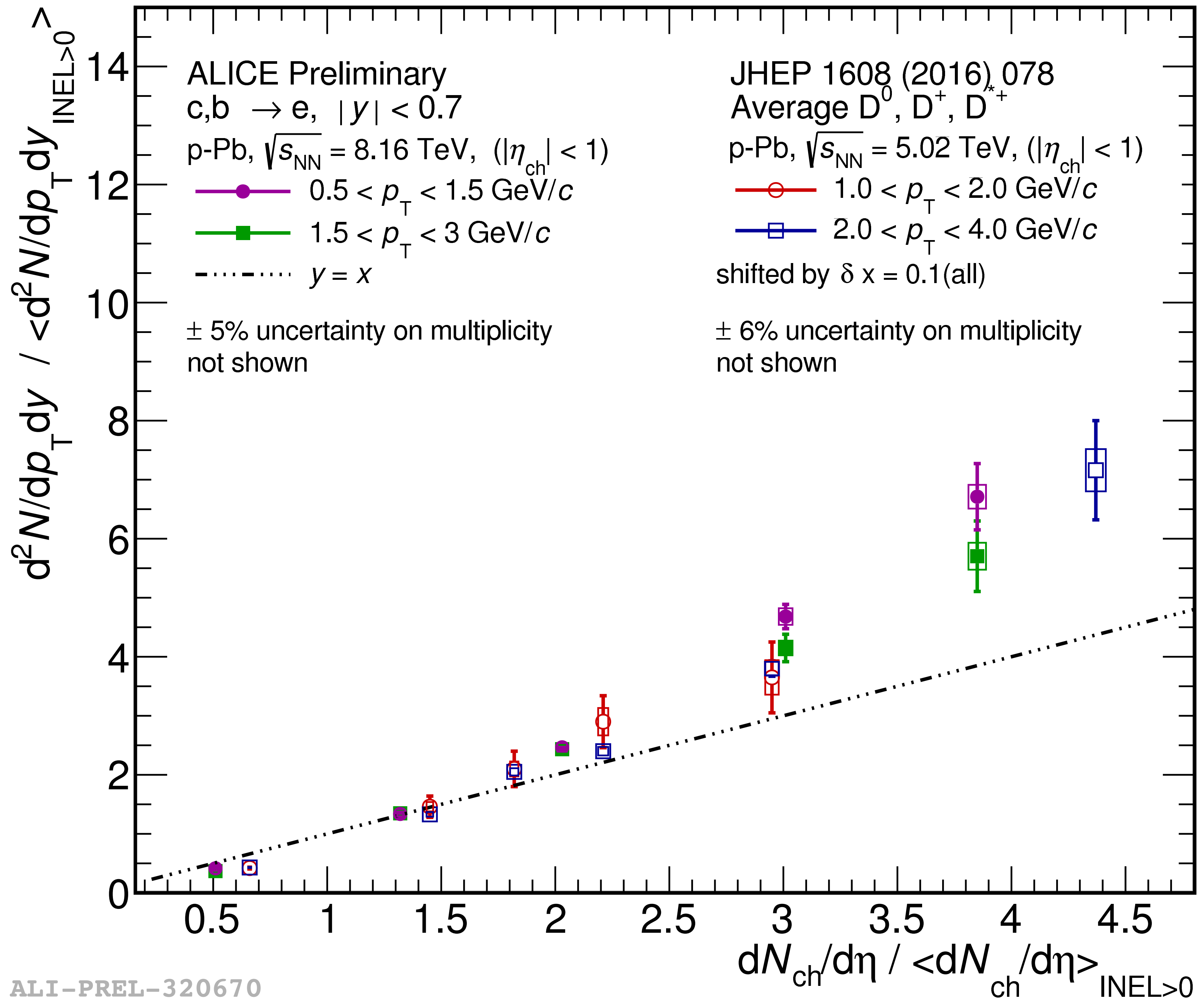
HFe production vs. multiplicity

Stronger than linear increase of heavy-flavour decay electrons self-normalized yield

At higher p_T intervals –> Hint of a steeper increase

PYTHIA8 well reproduces the HFe normalized yields in all the kinematic regions addressed –> Is MPI the main responsible?





Similar trend in both pp and p-Pb collisions.

High-multiplicity p-Pb collisions: MPI (like pp) but also higher number of binary nucleon-nucleon collisions.

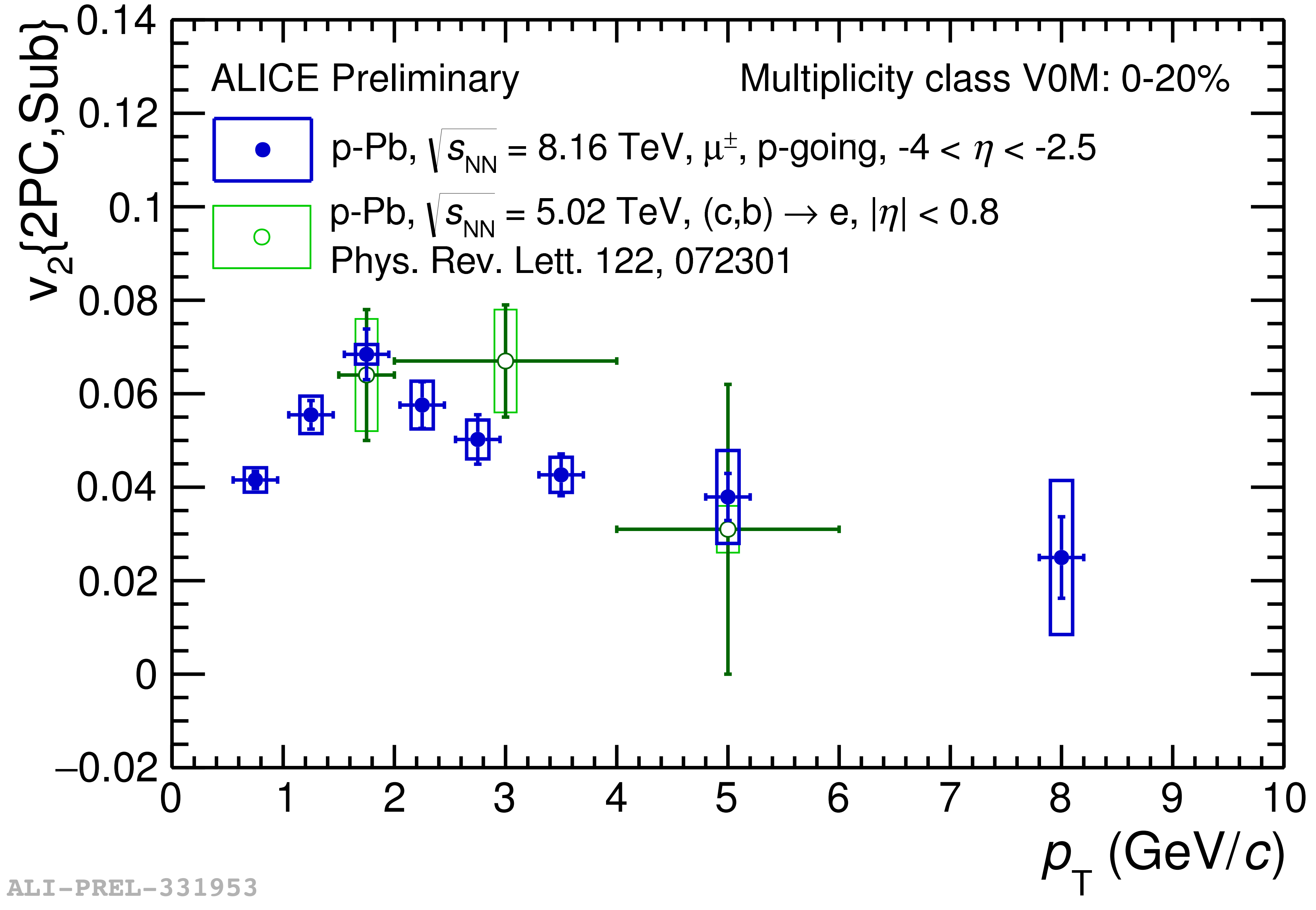
PYTHIA8: Comput. Phys. Commun. 178, 852–867 (2008)

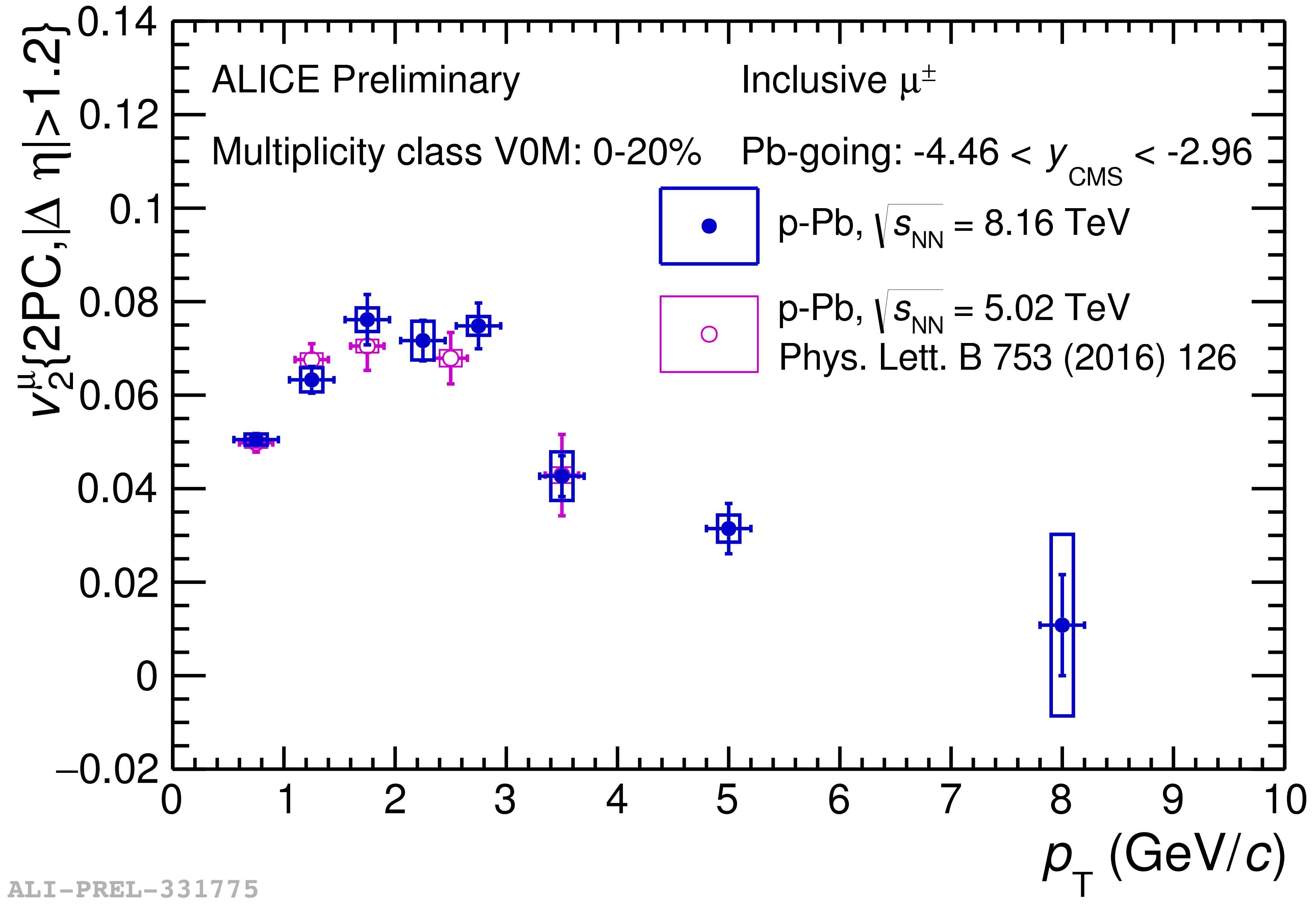
Heavy-flavour jets and correlations measurements:

- Heavy-flavour jets measurements consistent with theory NLO predictions
- D^0 and Λ_c–jet momentum fraction consistent with theory: hint for softer fragmentation in data for low $p_{T,jet}$ –>constrain models?
- No evidence of CNM effects nor final-state effects within current uncertainties

Heavy-flavour production *vs* multiplicity:

- Quarkonium and HFe normalized yields as a function of the normalized charged-particle multiplicity:
  - rapidity dependence behavior in pp collisions
  - evidence of CNM effects in p–Pb collisions
  - several models (based on different physics mechanisms) describe well the trend of data





Positive muon v_2 measured at high multiplicity in p-Pb@8.16 TeV with significance > 5σ for $0.5 < p_T < 6$ GeV/*c*

Compatible with inclusive muons v2 at forward rapidity and HF-e v_2 at midrapidity in p-Pb collisions 5.02 TeV

J/ψ production vs. multiplicity in p-Pb collisions at 5.02 and 8.16 TeV

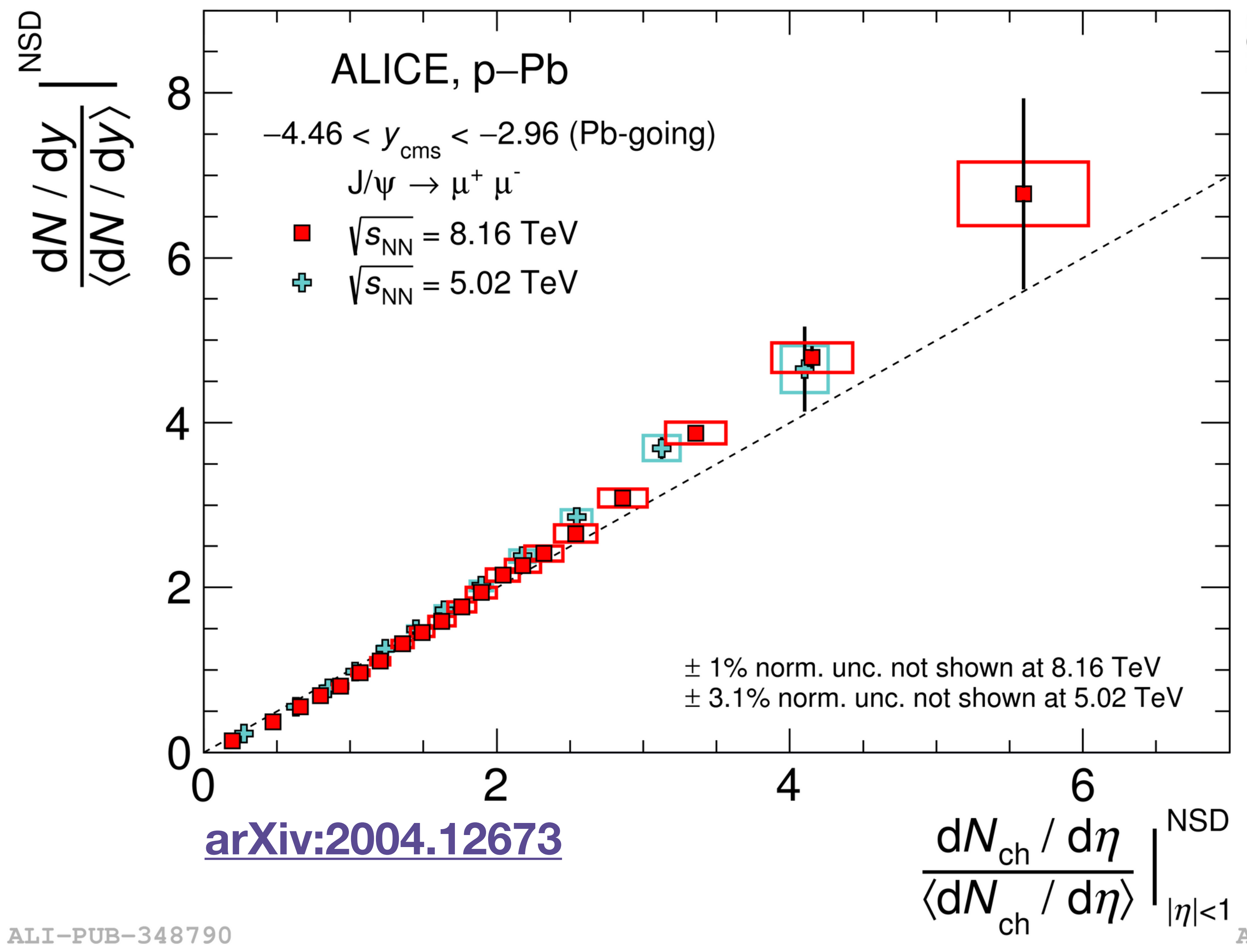
$J/\psi \rightarrow \mu^+\mu^-$

Slightly faster-than-linear increase of J/ψ relative yield at backward rapidity (Pb-going)

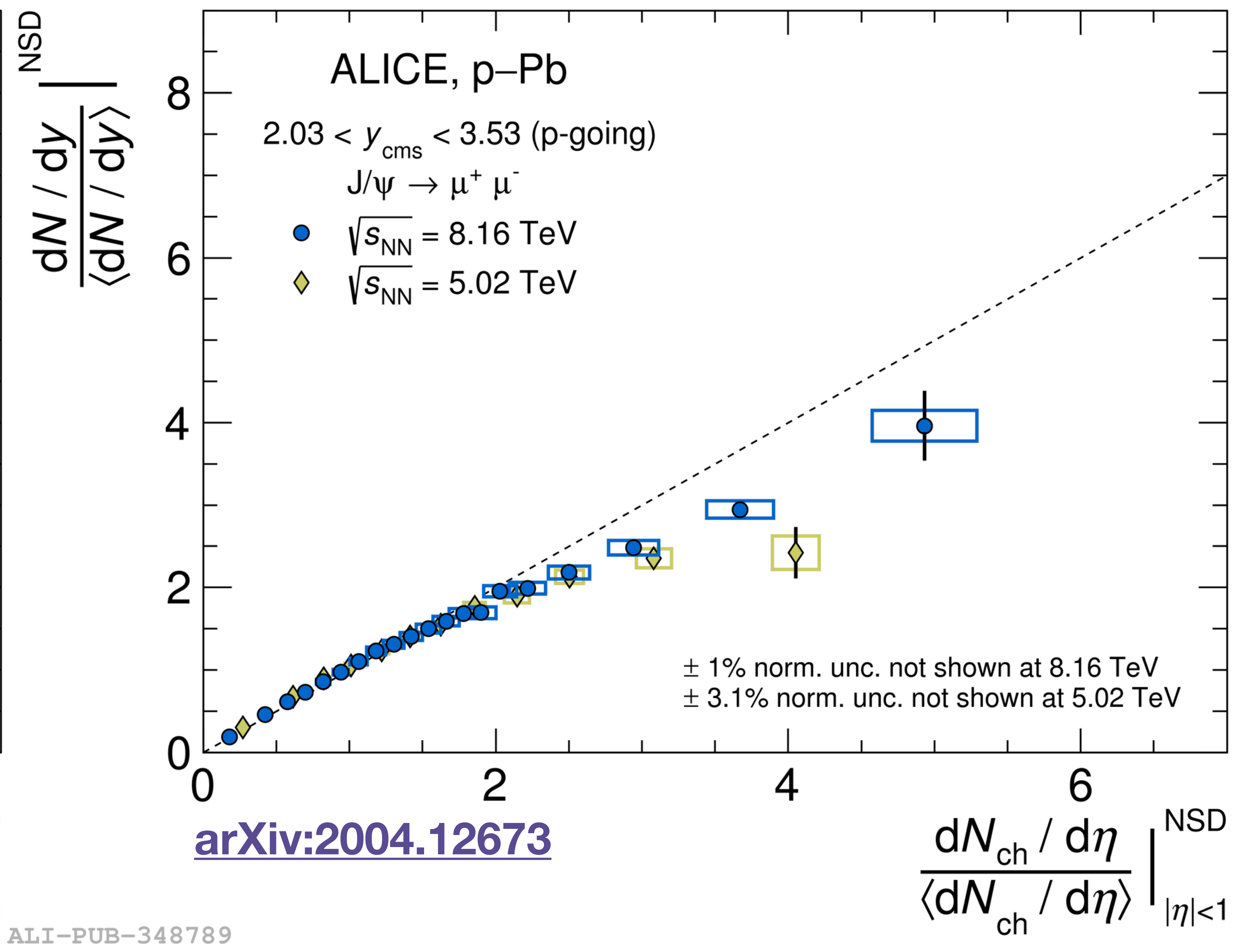
Slower-than-linear increase at forward rapidity (p-going)

New 8.16 TeV results compatible with previous 5.02 TeV ones → no significant energy dependence observed

backward rapidity



forward rapidity

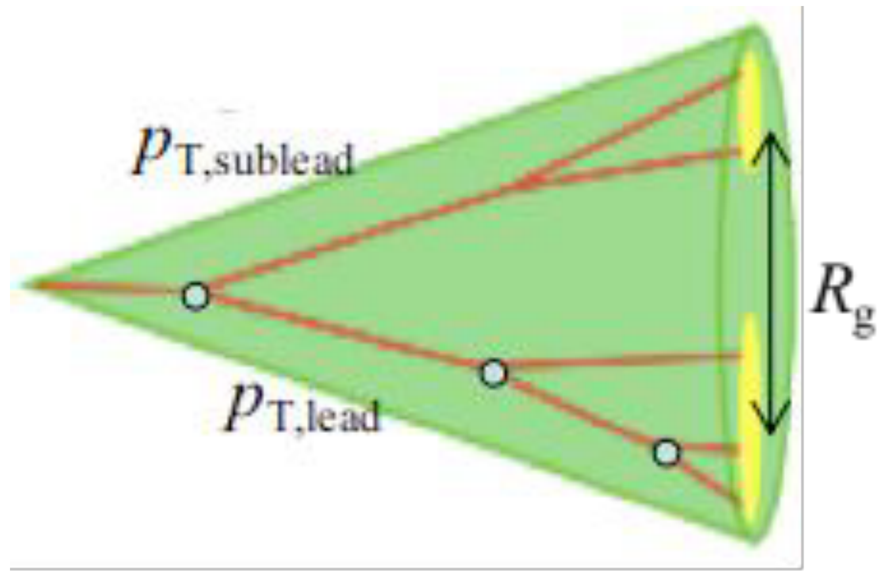


Nucleus in the initial state influences the J/ψ yield in p-Pb (linear in pp results) ?

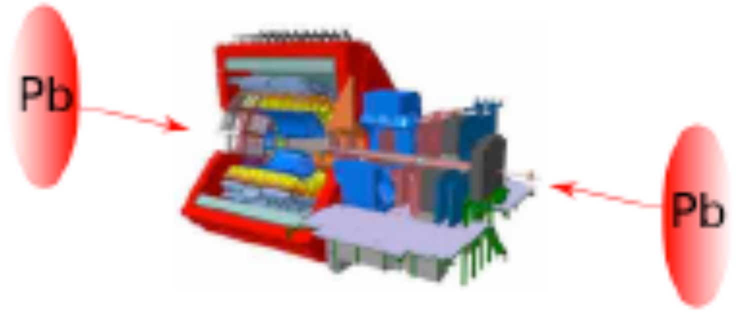
ψ(2S) measurement in p-Pb will provide the possibility to directly compare 2S/1S results to the pp ones

D-jet substructure: z_g, R_g and n_{SD}

- D^0-tagged charged-jet groomed momentum fraction
  pp $\sqrt{s}$=13 TeV, z_{cut}=0.1, β=0
- n_{SD}: charm jets typically have less hard splitting than light jets
  → Consistent with harder heavy-flavor fragmentation (mass and color charge effects)

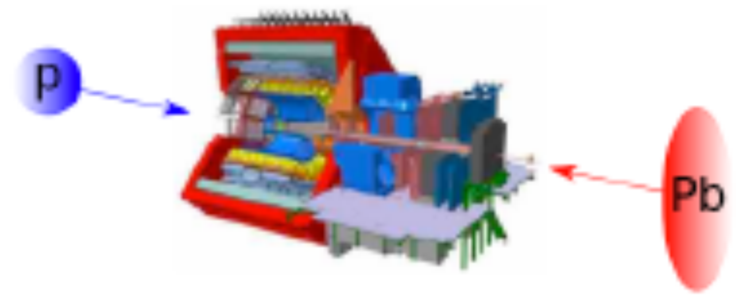


Pb–Pb:



$$2.5 < y_{\mathrm{cms}} < 4$$

p–Pb, p-going:



$$2.03 < y_{\mathrm{cms}} < 3.53$$

p–Pb, Pb-going:

$$-4.46 < y_{\mathrm{cms}} < -2.96$$