Recent results from the LHC

Focus on heavy flavour and jets measurements

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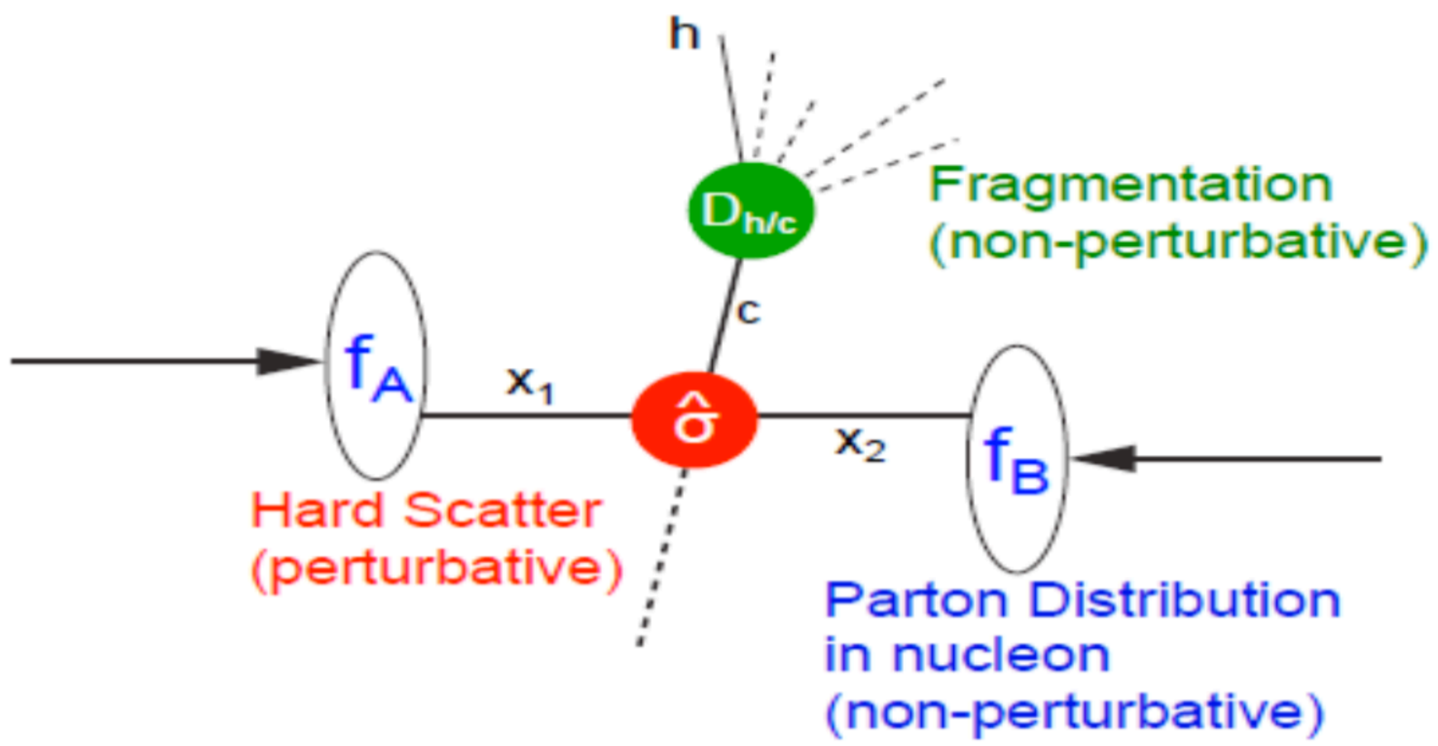
16/03/19

Workshop on Novel Probes of the Nucleon Structure in SIDIS, e+e- and pp (FF2019)

Physics motivation

- Heavy quarks are produced in hard scattering processes
  - $m_{c,b} >> \Lambda_{QCD}$ -> perturbative QCD (pQCD) applicable



- Open heavy-flavour production measurements in pp collisions

➡ Important test of pQCD-based calculations

- Study of charmed and beauty hadrons ratio and baryon-to-meson ratio

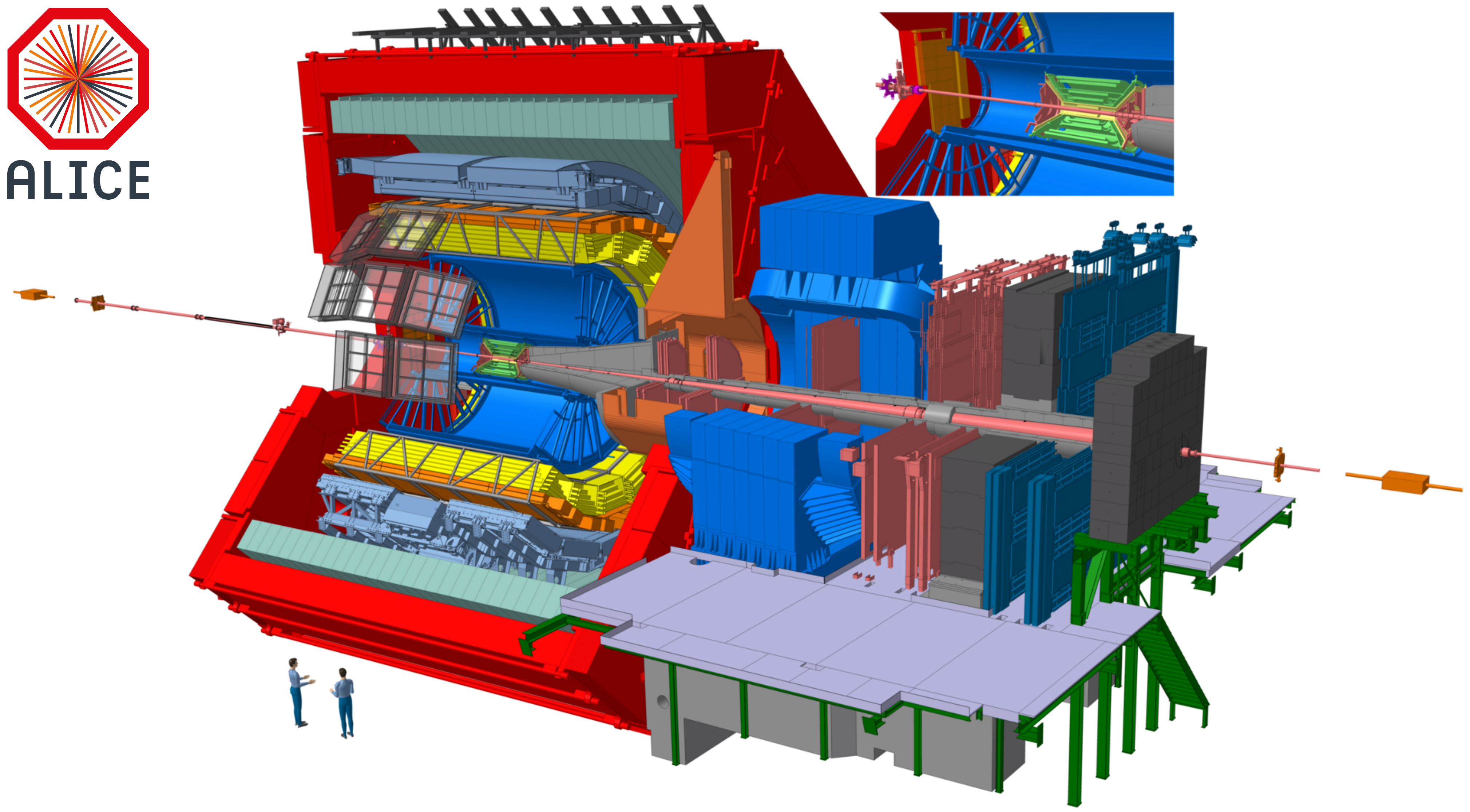
➡ Sensitive to fragmentation functions

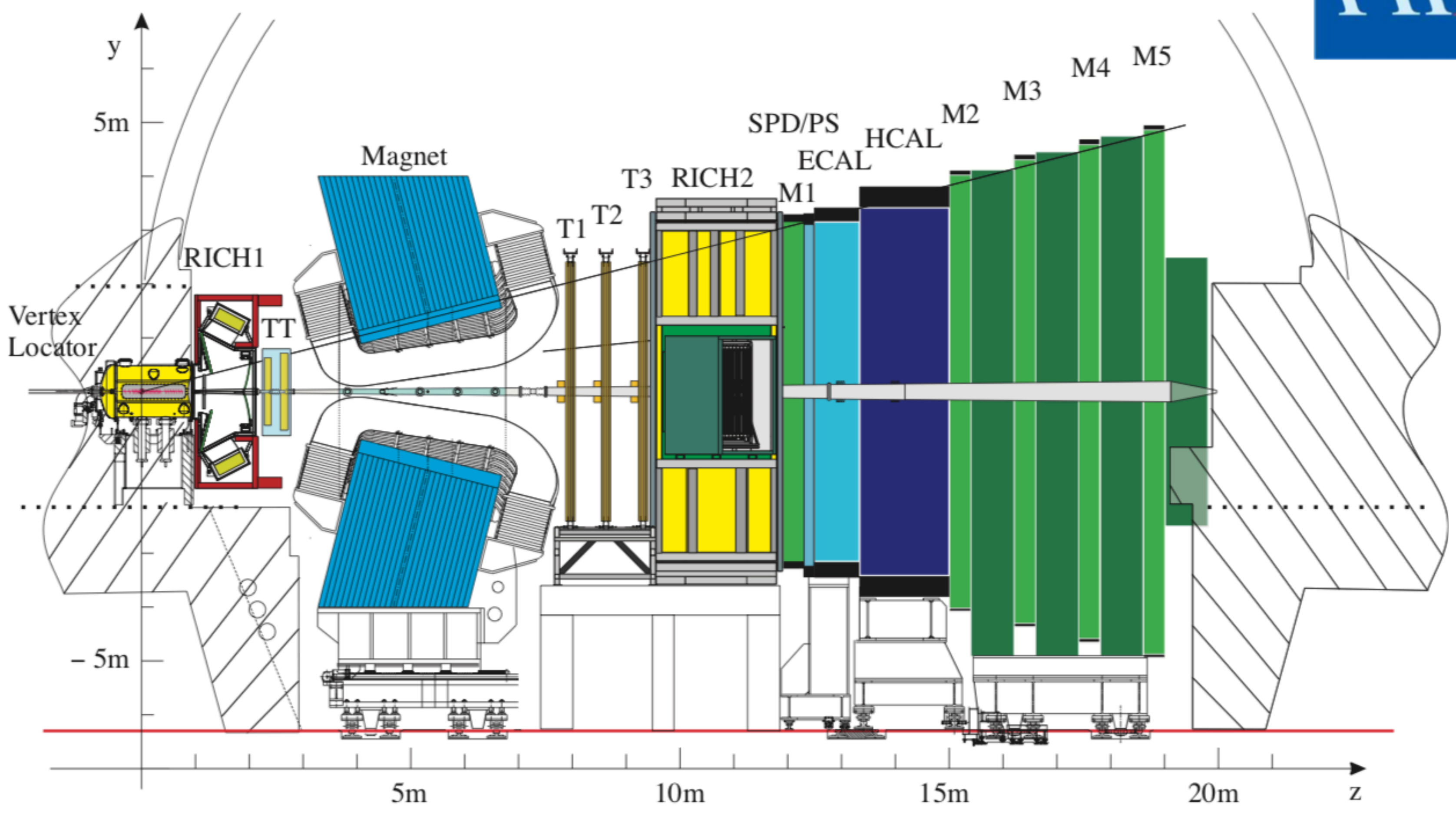
➡ Relate the *qq* production cross-section from pQCD to the observed hadrons

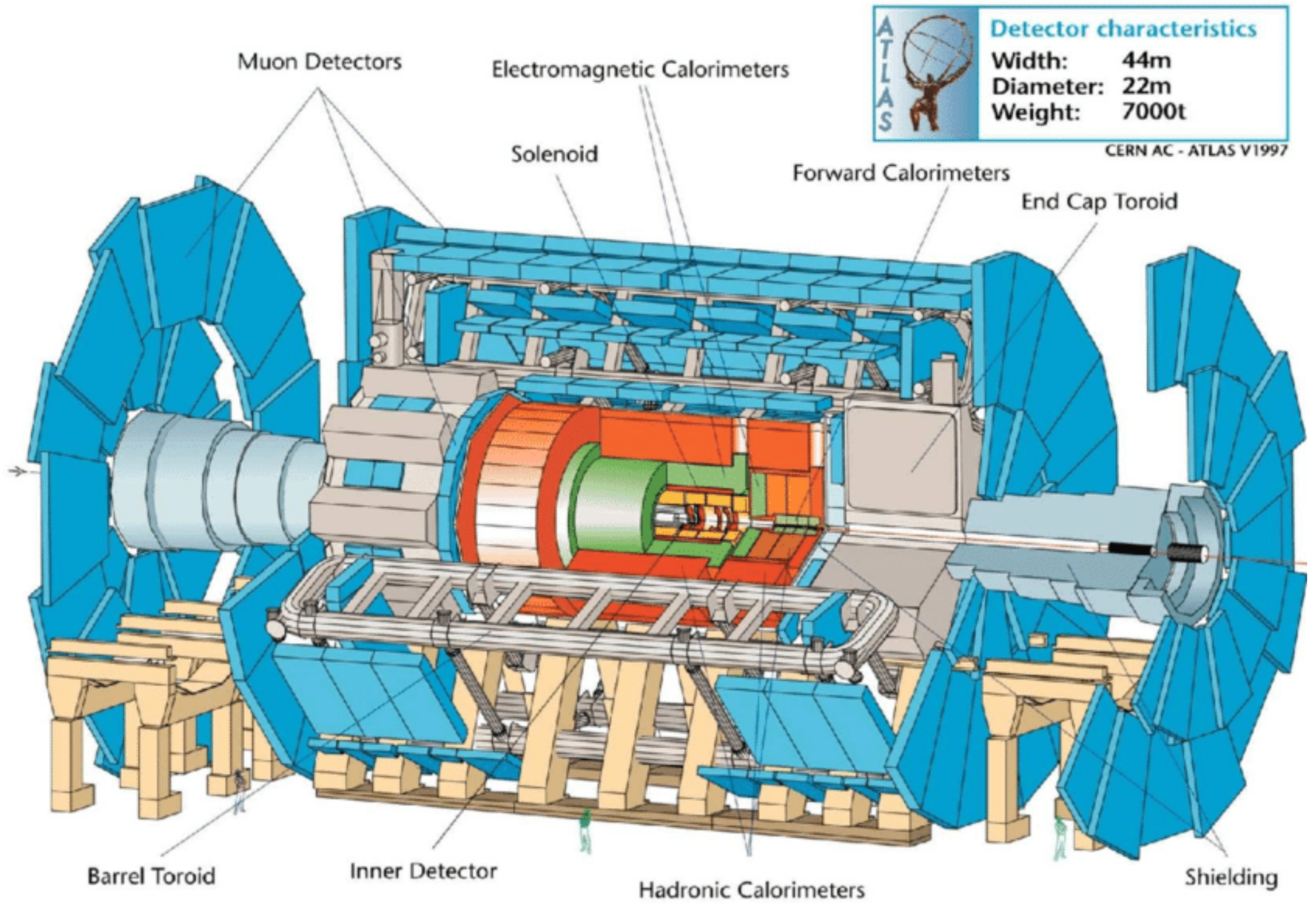
- HF tagged jets

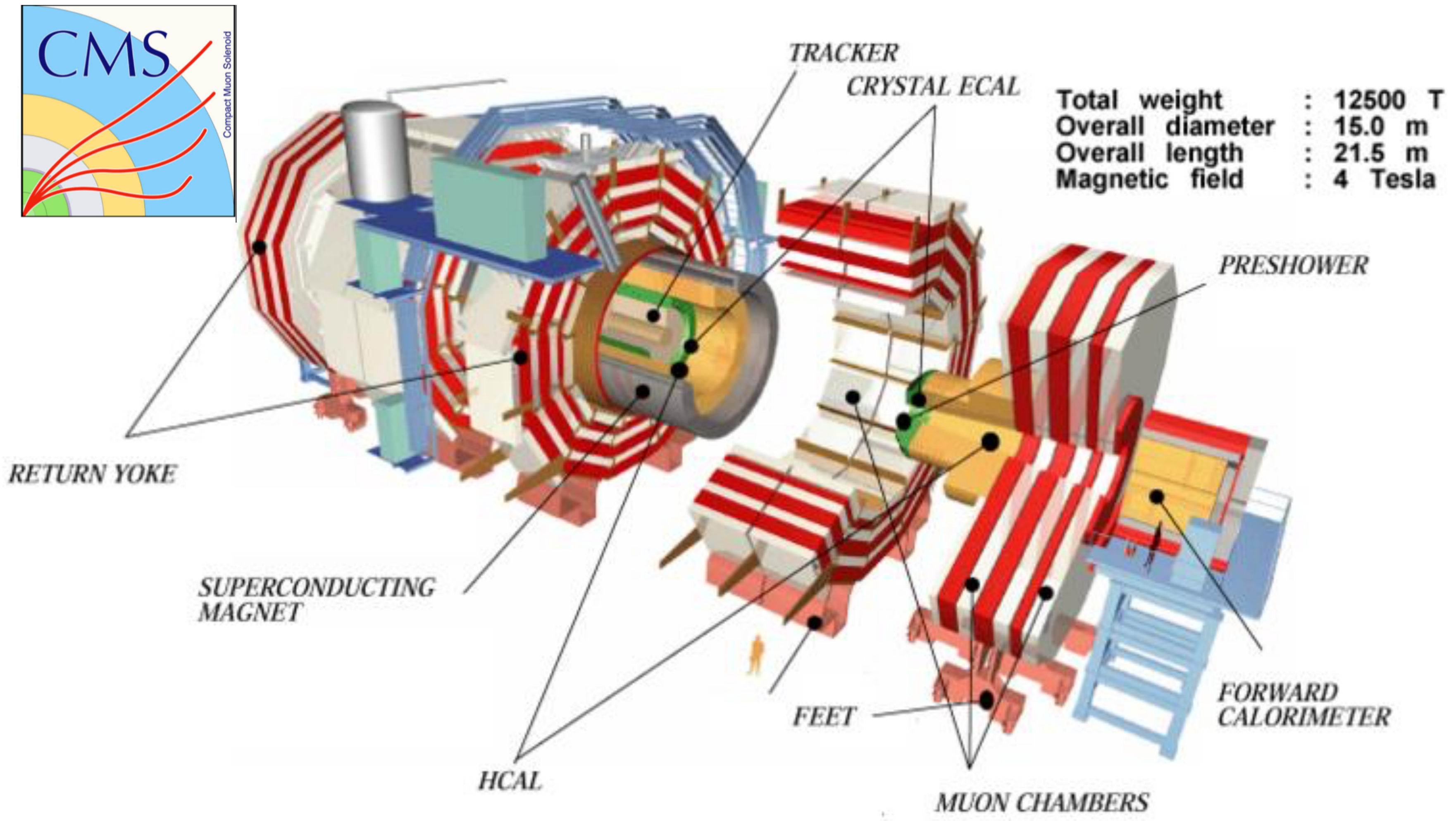
➡ Explore the inner structure of jets

LHC experiments

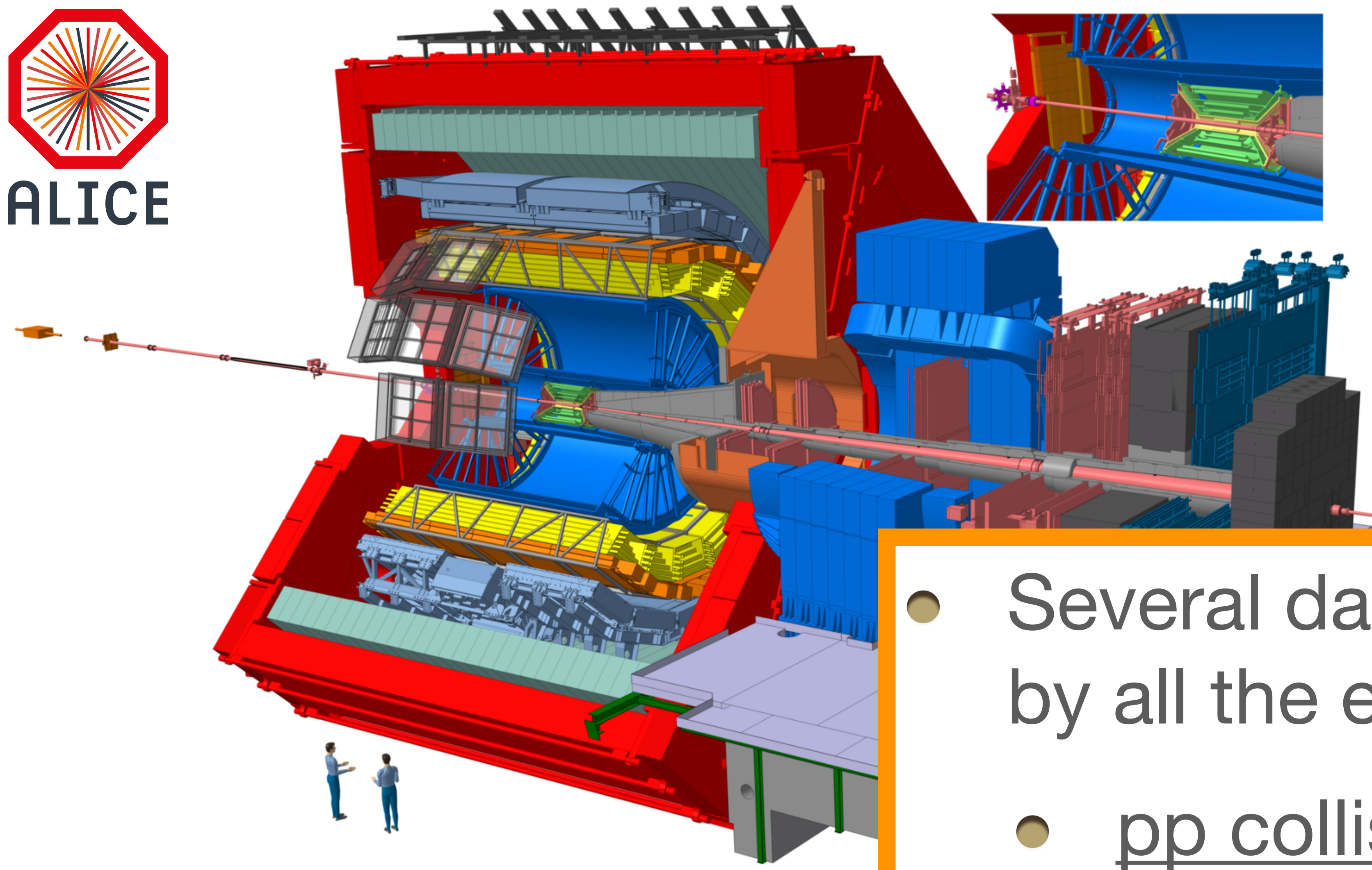


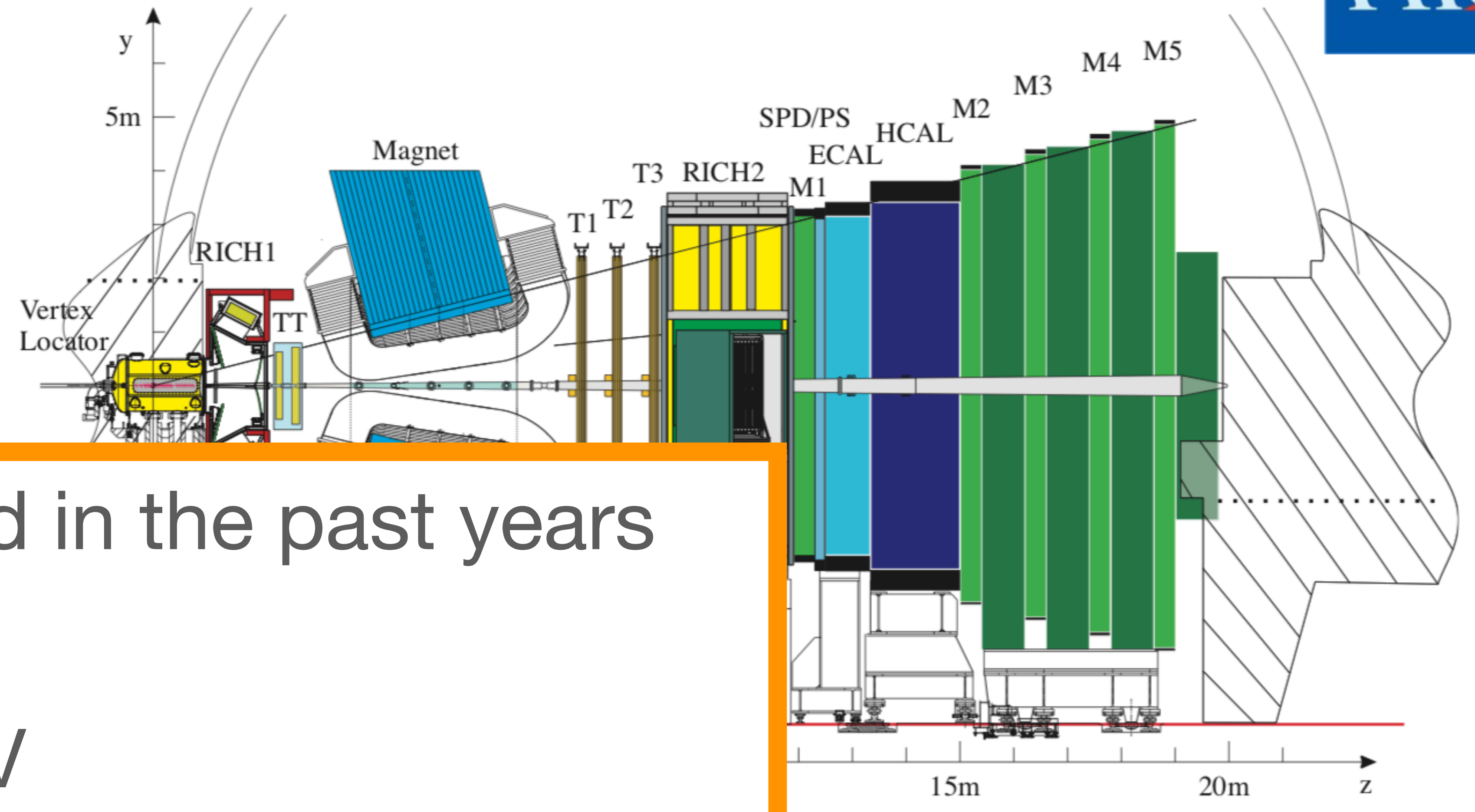






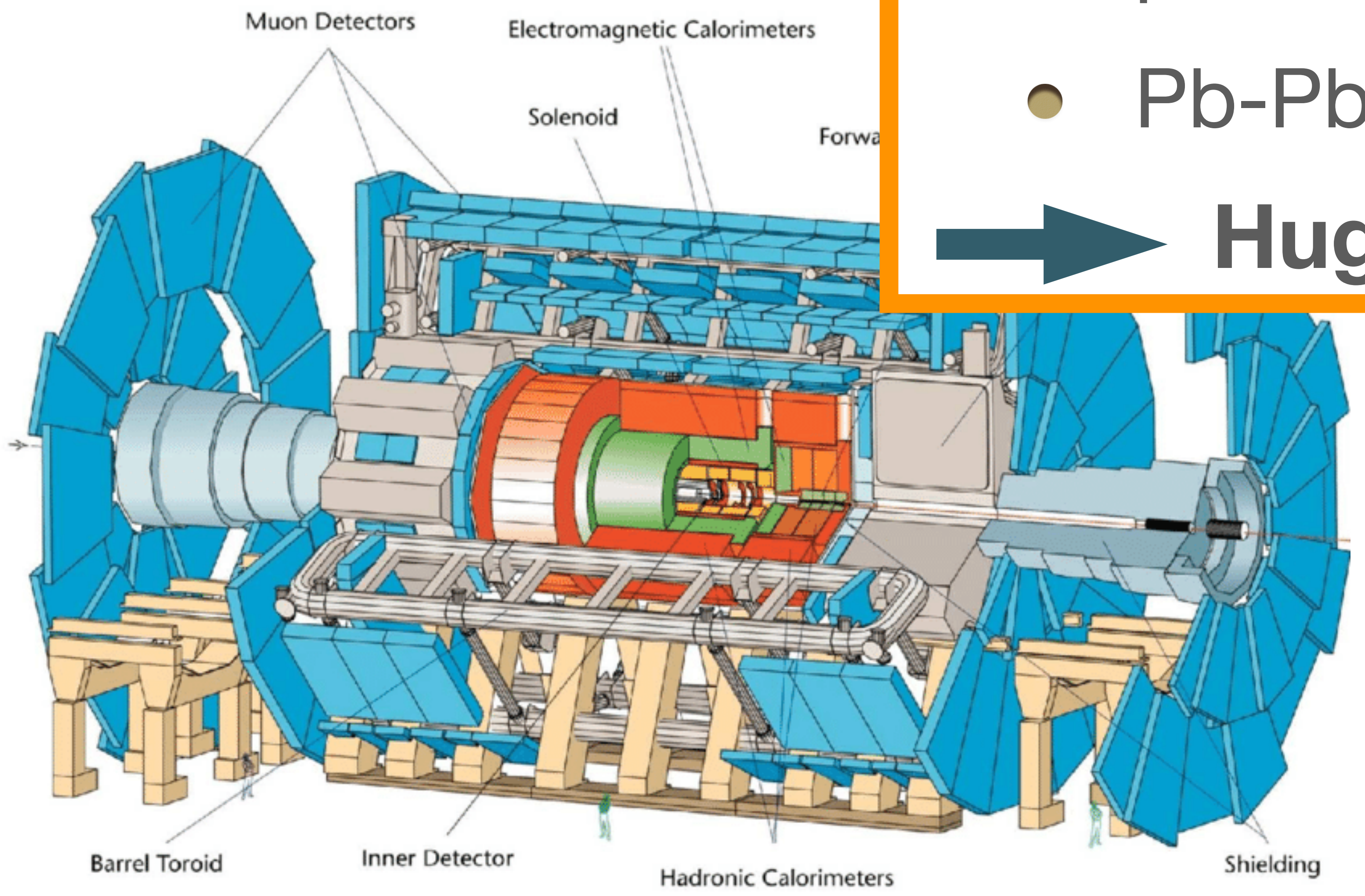
LHC experiments

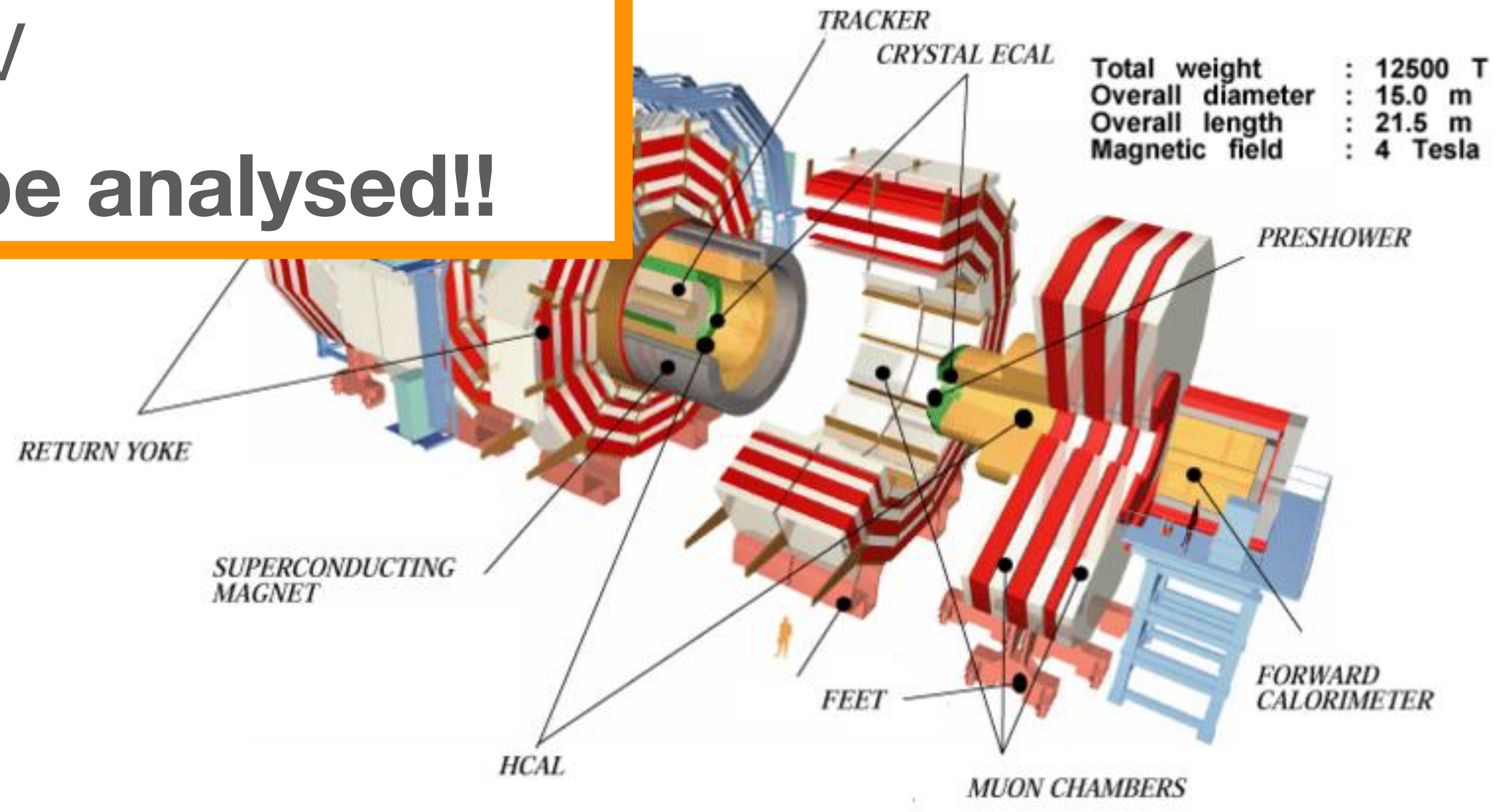




- Several data samples collected in the past years by all the experiments:
  - pp collisions: 5, 7, 8, 13 TeV
  - p-Pb collisions: 5.02, 8.16 TeV
  - Pb-Pb collisions: 2.76, 5.02 TeV

➡ **Huge amount of data to be analysed!!**





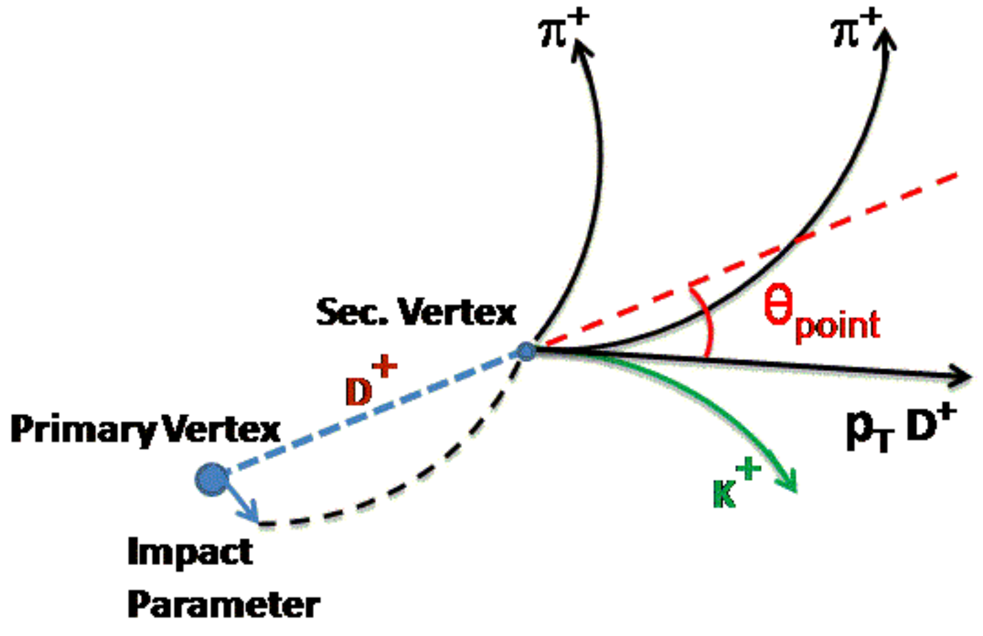
Charm

- D meson production in ALICE
- Λ_c baryon production in ALICE and LHCb
  - Λ_c /D baryon-to-meson ratio
- Ξ_c^0 baryon production and baryon-to-meson ratio in ALICE

D meson production

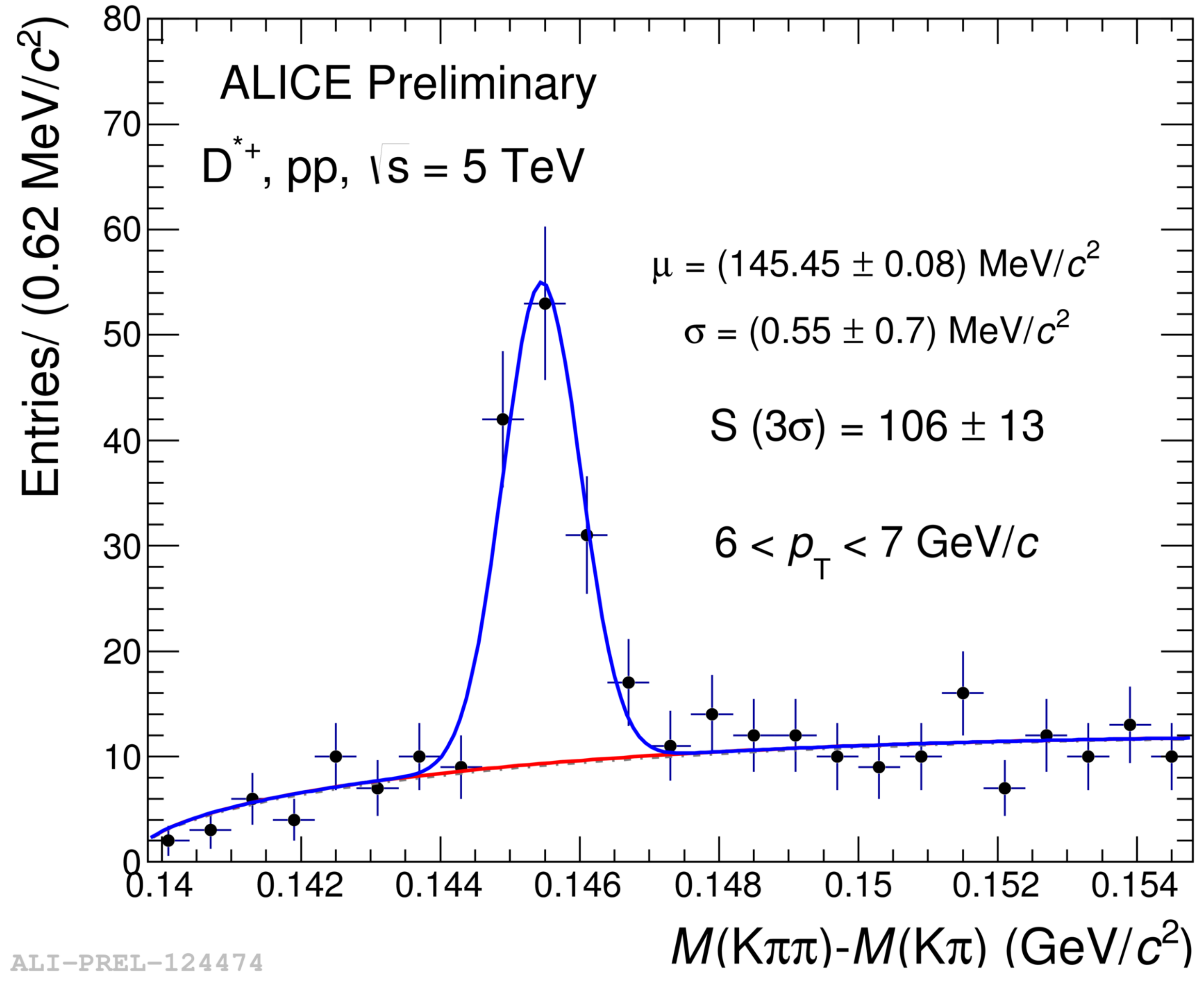
- Focus on D-meson hadronic decay channels:

meson	M (GeV/c^2)	$c\tau$ (μm)	decay	BR (%)
D^0 ($c\bar{u}$)	1.865	123	$K^-\pi^+$	3.93
D^+ ($c\bar{d}$)	1.870	312	$K^-\pi^+\pi^+$	9.46
D^{*+} ($c\bar{d}$)	2.010	Γ = 83.3 KeV	$D^0(K^-\pi^+)\pi^+$	67.7 x 3.93
D^+_s ($c\bar{s}$)	1.968	150	$\Phi(K^-K^+)\pi^+$	2.27



arXiv:1901.07979
submitted to EPJC

- Reconstruction based on identification of displaced secondary vertices by few hundreds μm
- Background reduction via topological selections and Particle IDentification (PID)
- Invariant mass analysis
- FONLL-based method to subtract feed-down from b hadrons



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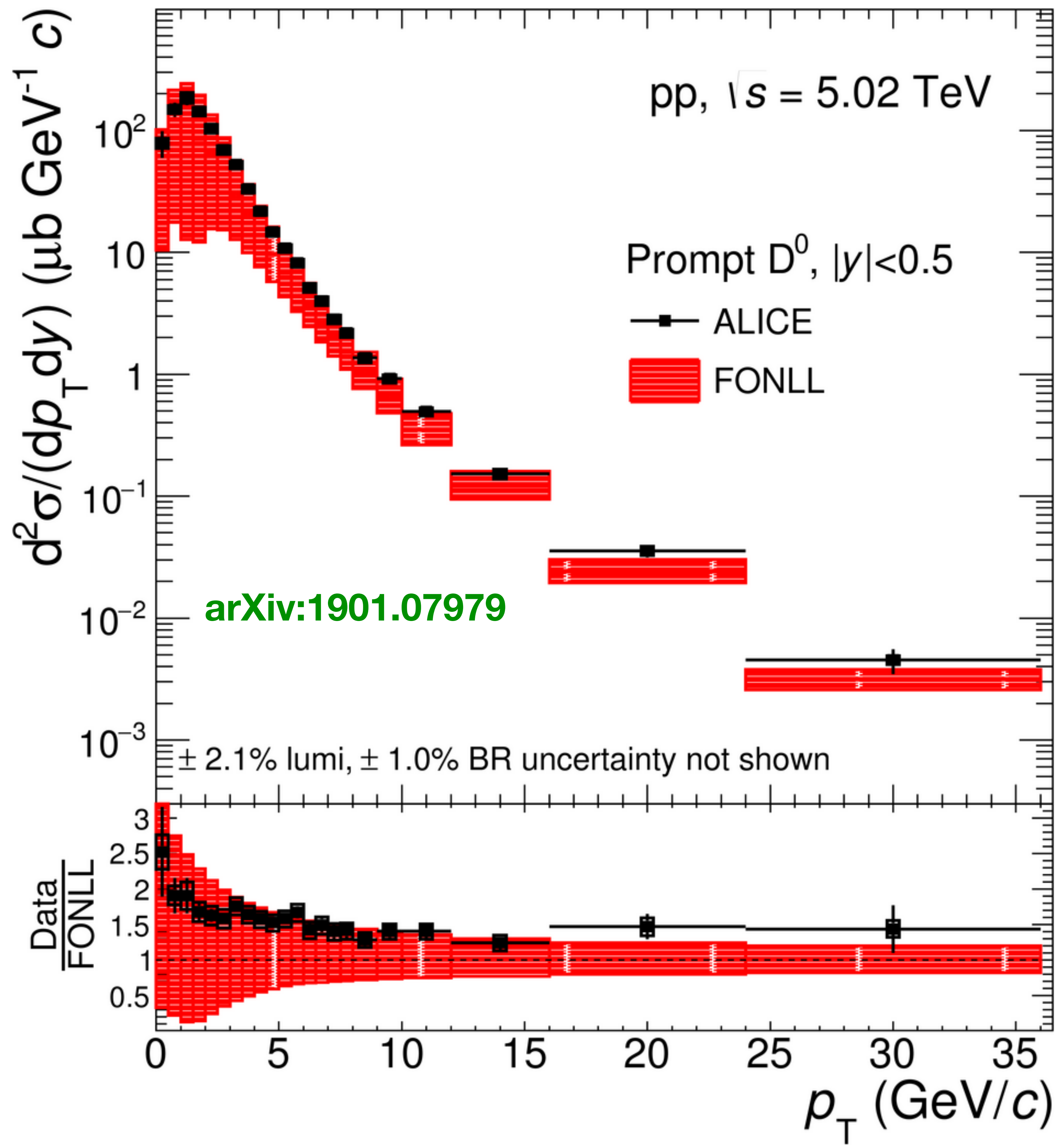
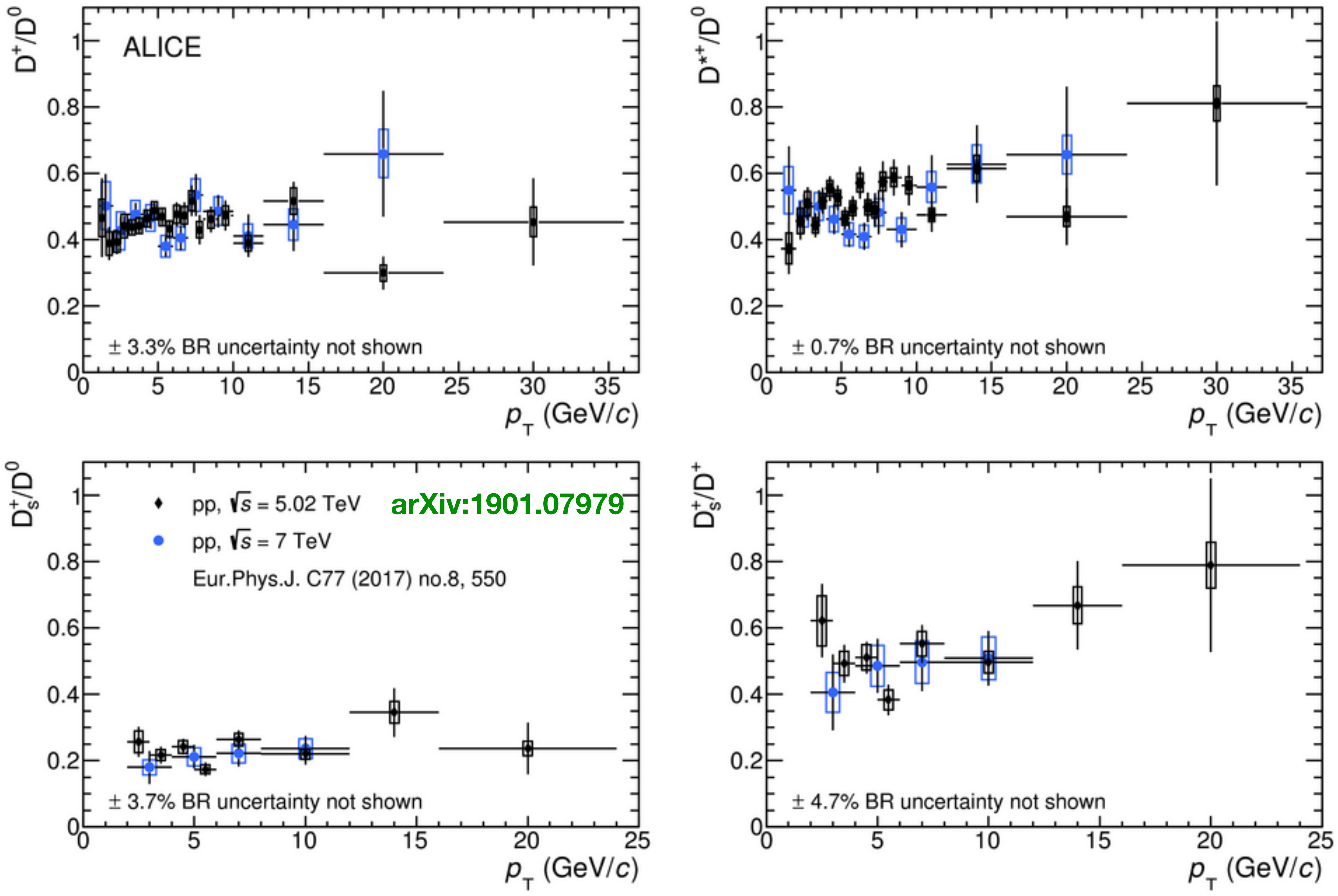
→ p_T-differential cross section of D mesons down to p_T~0

- Compatible with pQCD calculations

New reference for D mesons at 5 TeV

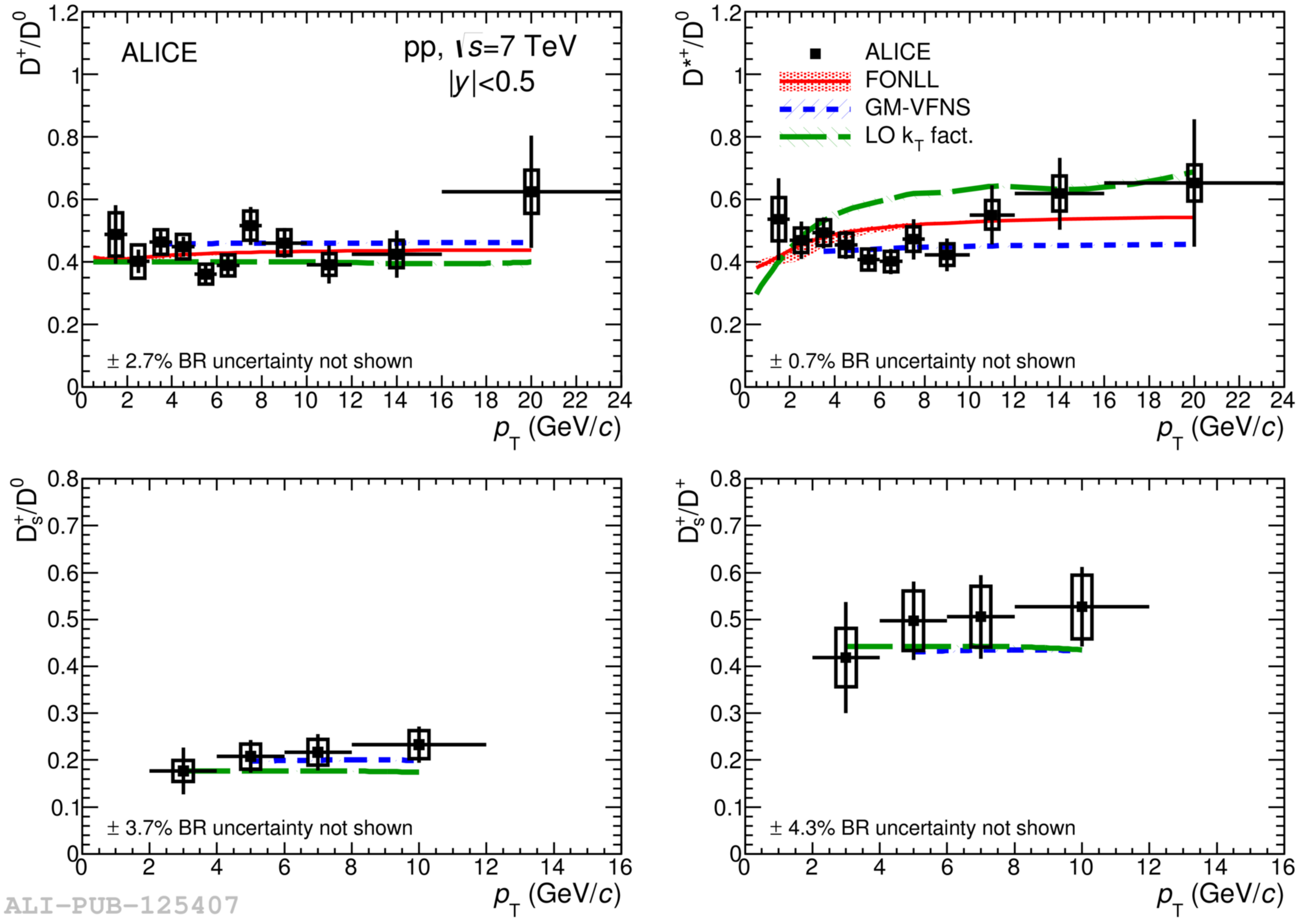


D-meson particle ratios



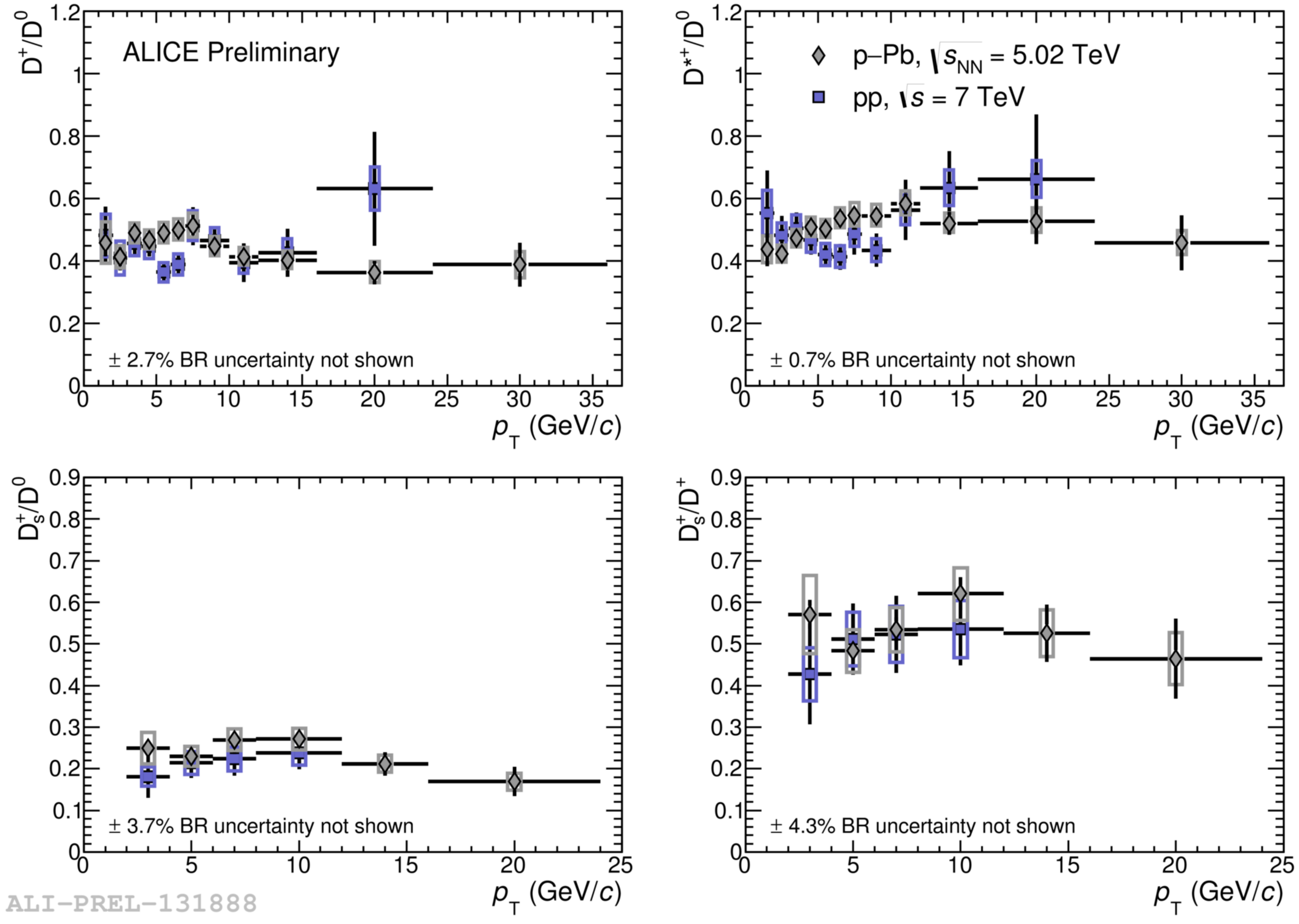
- The relative abundances of the four species are **unmodified** in pp collisions going from **5** to **7** TeV within uncertainties.

D-meson particle ratios



- The relative abundances of the four species are **unmodified** in pp collisions going from **5** to **7** TeV within uncertainties.
- The measurement are well reproduced by theoretical calculations

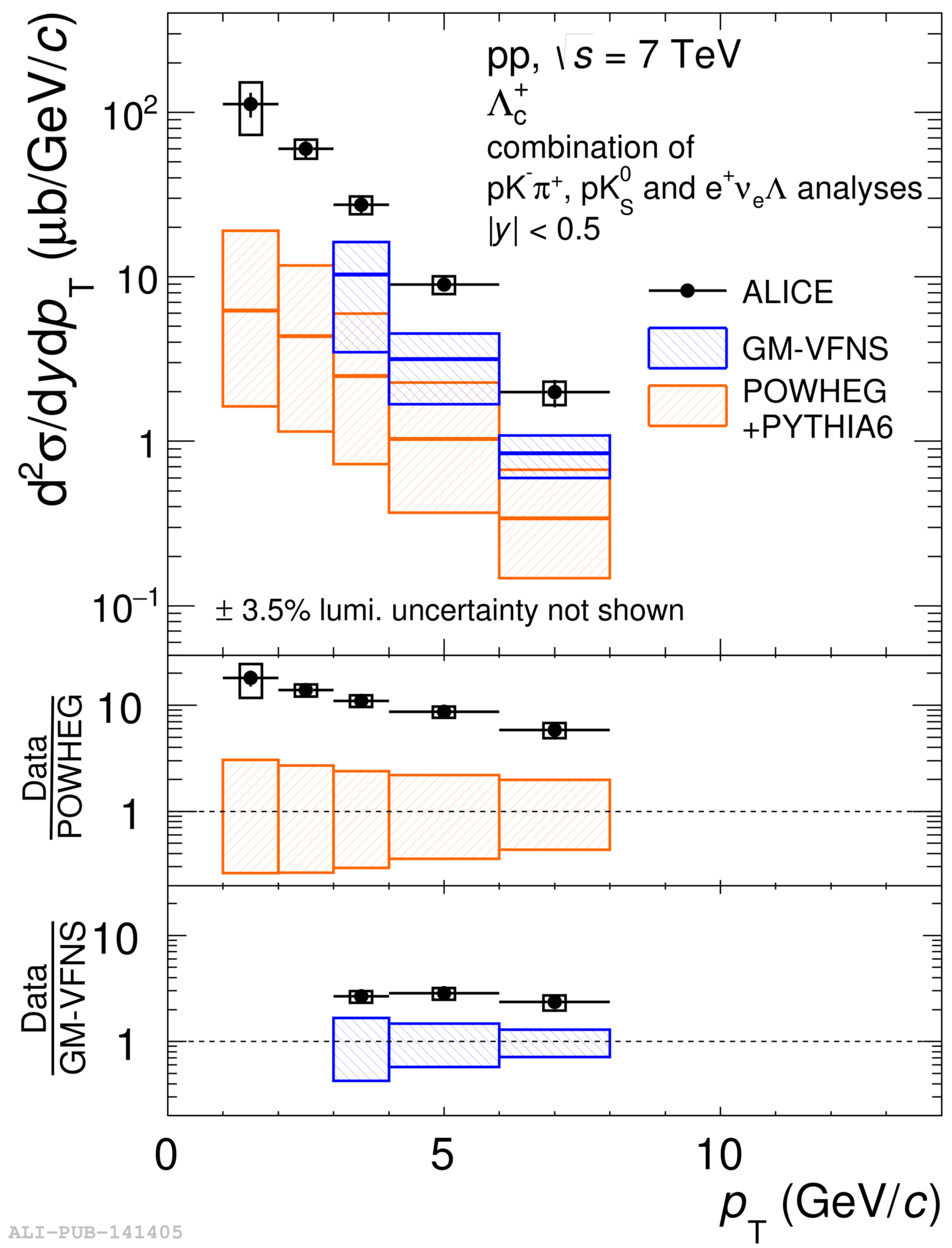
D-meson particle ratios



- The relative abundances of the four species are **unmodified** in **p-Pb** collisions with respect to **pp** collisions within uncertainties.

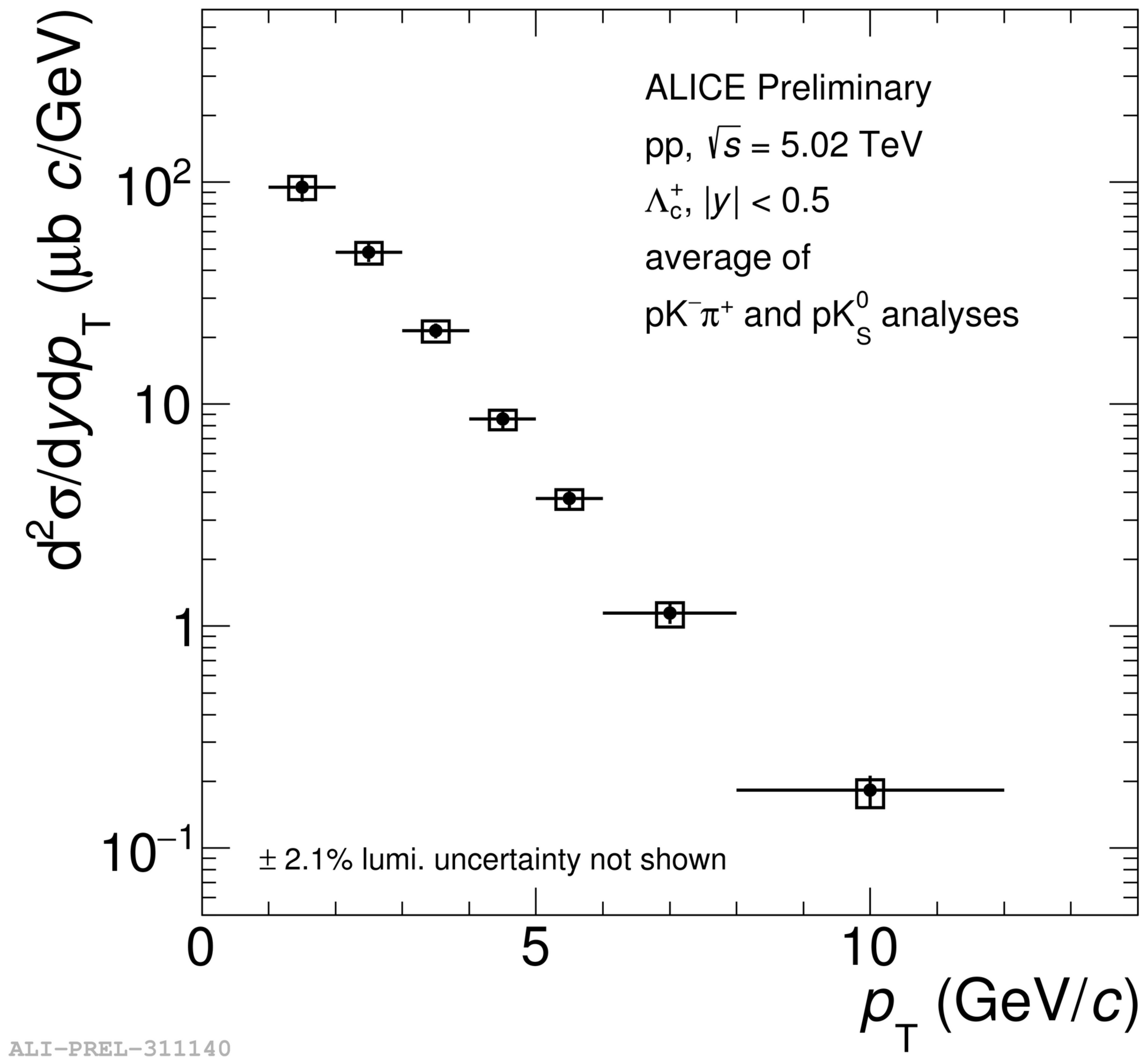
Λ_c p_T-differential cross section

JHEP 1804 (2018) 108



GM-VFNS: B.A. Kniehl et al. Eur. Phys. J. C 72 (2012) 2082

POWHEG: S. Frixione et al.: JHEP 09 (2007) 126

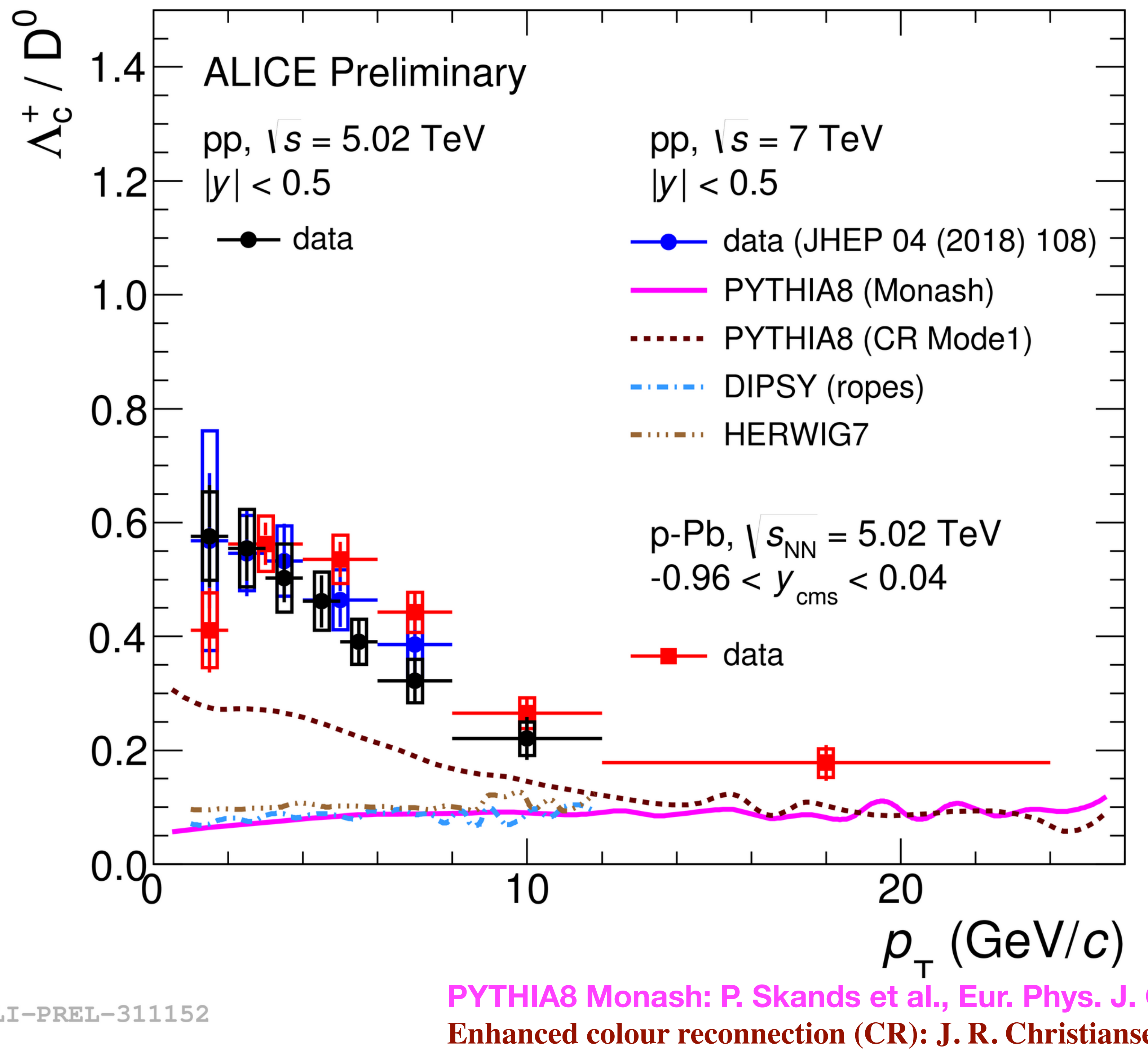


New result from pp @ 5TeV

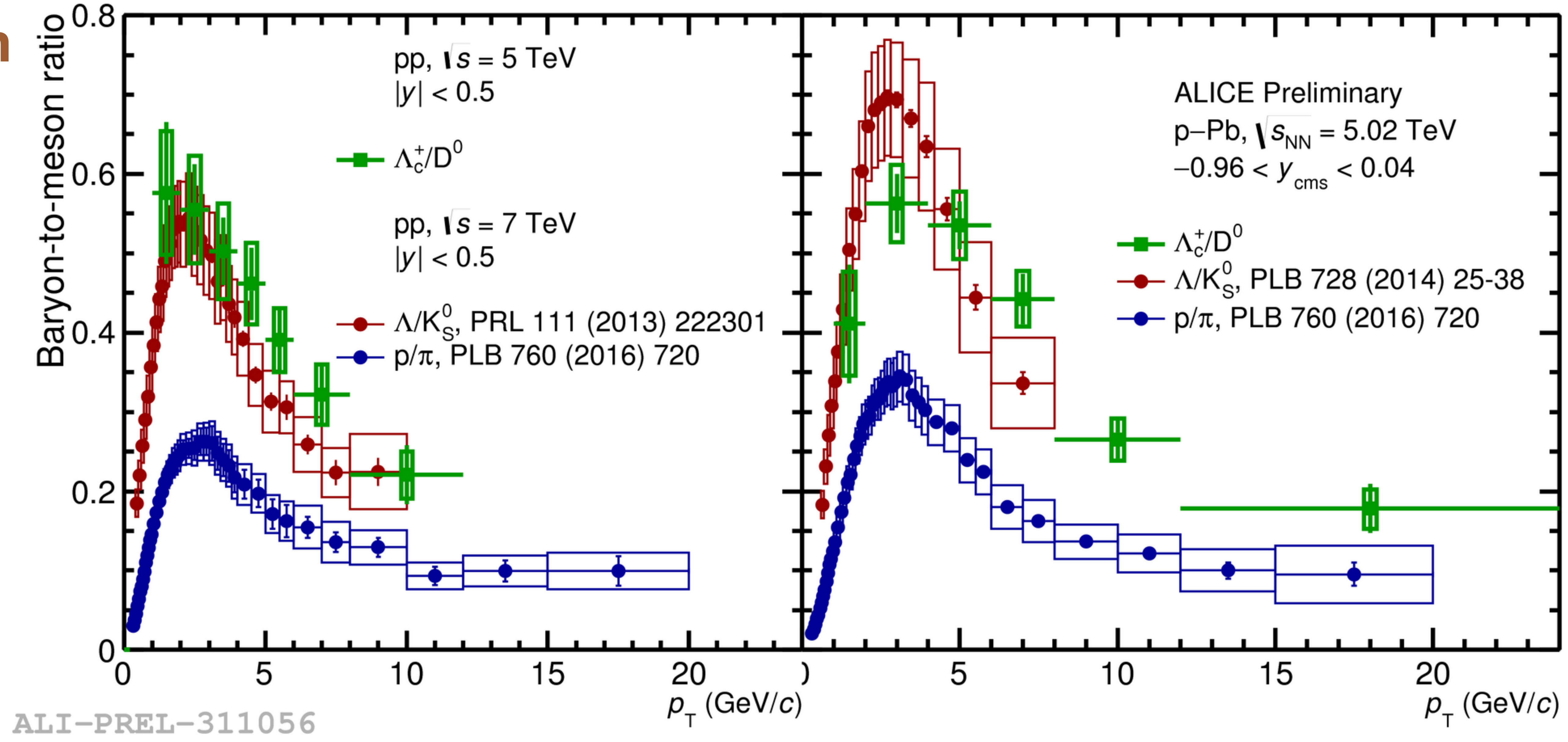
higher p_T reach and precision

- Combination of 3 decay channels in pp collisions at 7 TeV and 2 decay channels in pp collisions at 5 TeV
- **Theoretical predictions underestimate Λ_c p_T-differential cross section**
- In **GM-VFNS** and **POWHEG** the fragmentation function is tuned to reproduce the results from lower energy e^+e^- collisions

Λ_c/D^0 baryon-to-meson ratio



New results from pp @ 5 TeV



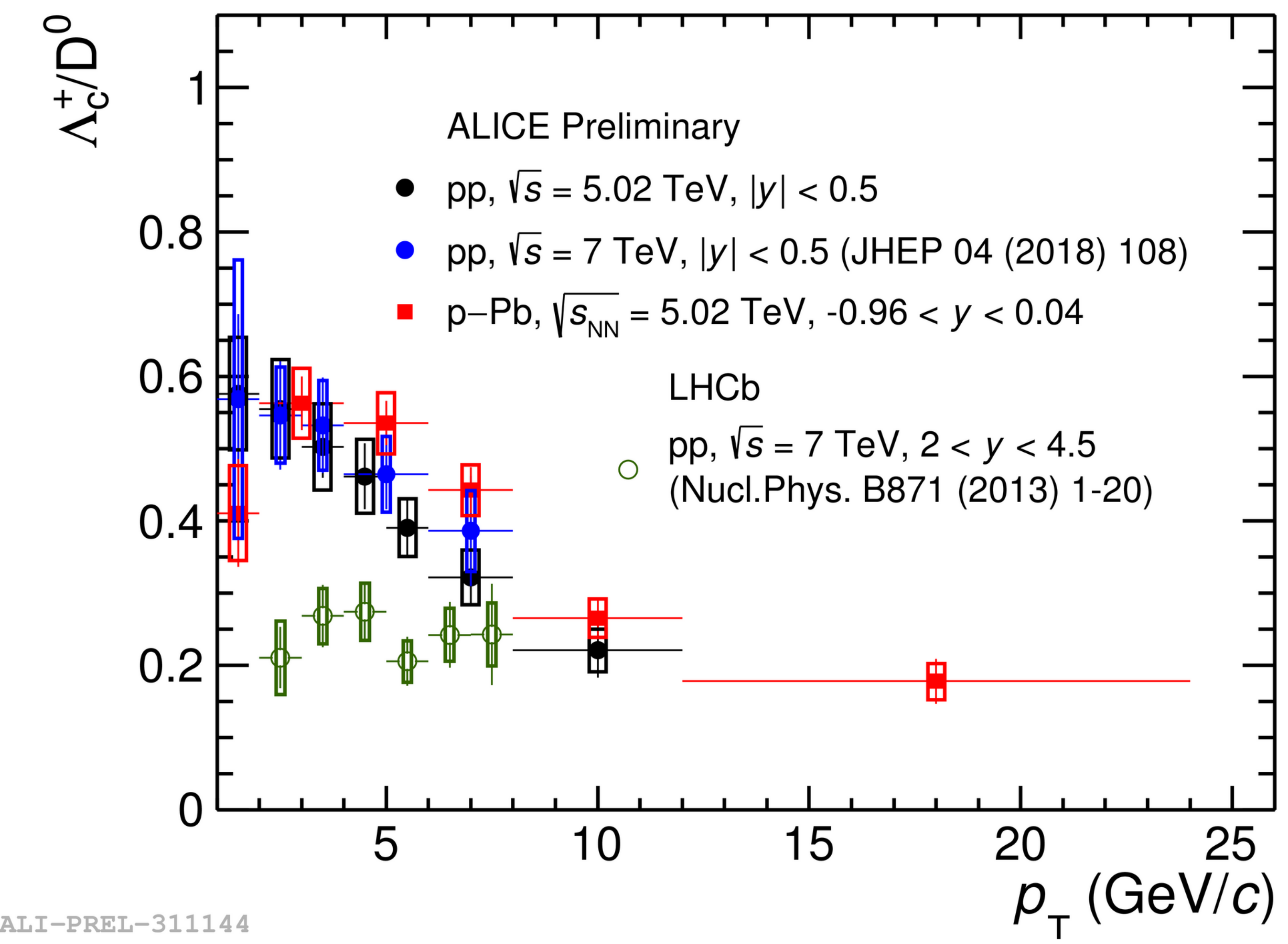
PYTHIA8 Monash: P. Skands et al., Eur. Phys. J. C (2014) 74:3024
Enhanced colour reconnection (CR): J. R. Christiansen and P. Skands, JHEP 08 (2015) 003
DIPSY: JHEP 08 (2011) 103
HERWIG7: Eur. Phys. J. C58 (2008) 639-707

- Λ_c/D^0 ratios in pp and p-Pb collisions are compatible within uncertainties
- All theoretical predictions underestimate our measurements, PYTHIA8 with enhanced colour reconnection closer to data
- Similar trend as a function of p_T as the baryon-to-meson ratio in the light-flavour sector

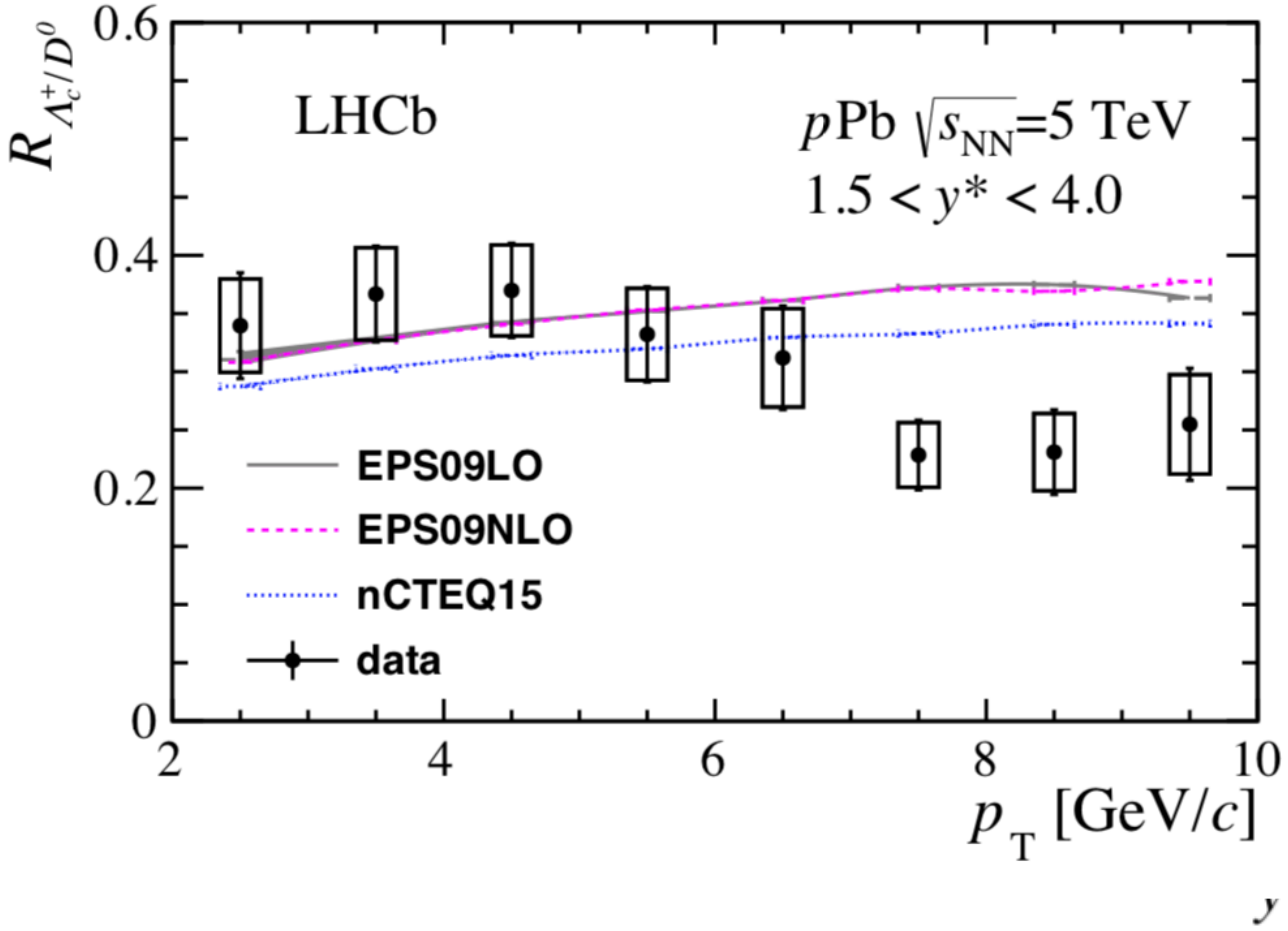
→ ***Is it a baryon/meson effect independent of quark content?***

Λ_c/D^0 in different experiments and collision systems

JHEP 1804 (2018) 108



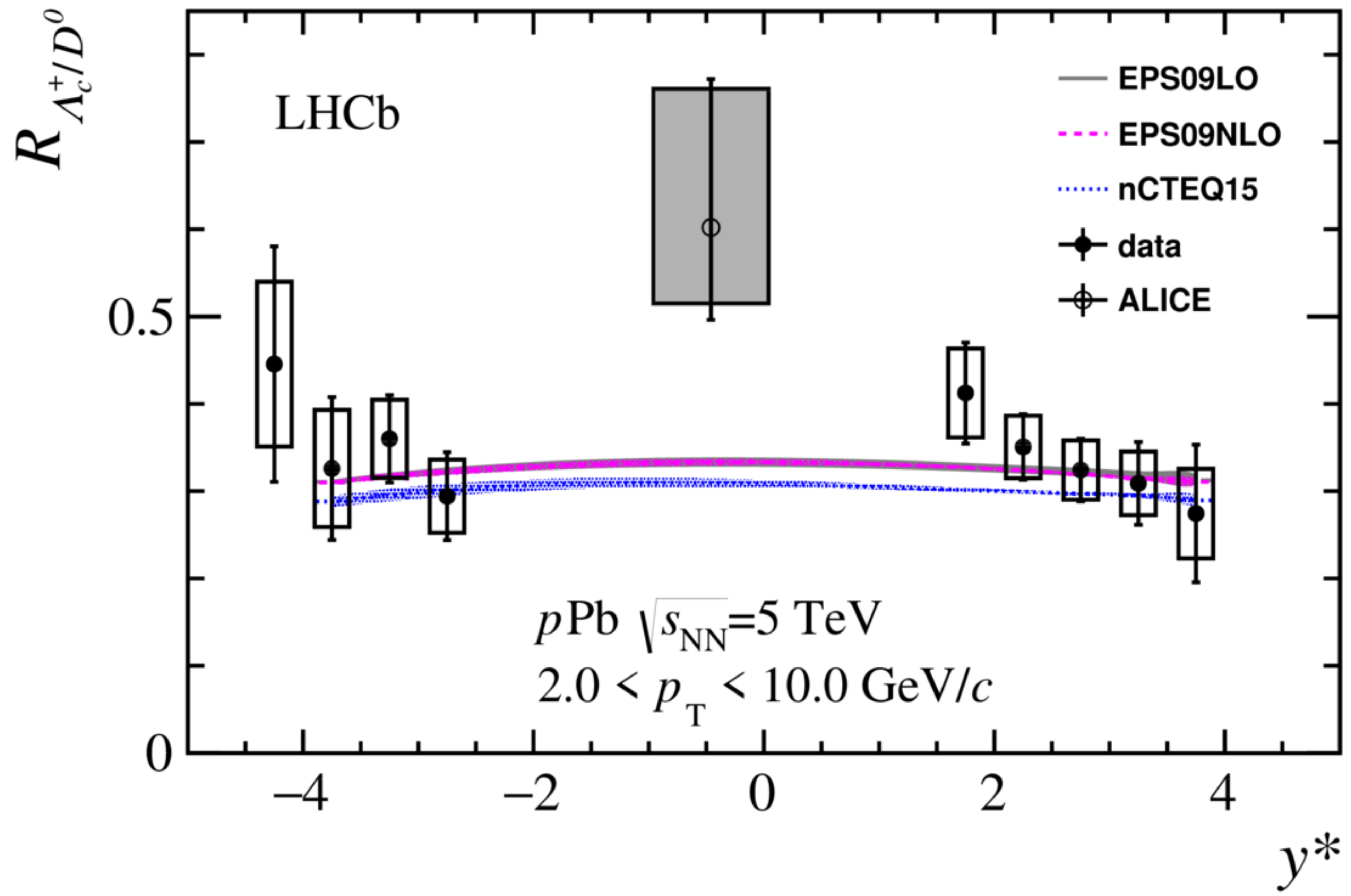
arXiv:1809.01404



- Λ_c/D^0 ratio in pp and p-Pb collisions from ALICE higher than LHCb measurements for $2<p_T<6$ GeV/*c* in pp and pPb collisions
- LHCb results in pPb collisions consistent with theoretical calculations

Λ_c/D^0 in different experiments and collision systems

arXiv:1809.01404



	$\Lambda_c^+/D^0 \pm$ stat. $\pm$ syst.	System	$\sqrt{s}$ (GeV)	Notes
CLEO [43]	$0.119 \pm 0.021 \pm 0.019$	ee	10.55	
ARGUS [42, 98]	0.127 ± 0.031	ee	10.55	
LEP average [80]	$0.113 \pm 0.013 \pm 0.006$	ee	91.2	
ZEUS DIS [51]	$0.124 \pm 0.034^{+0.025}_{-0.022}$	ep	320	$1 < Q^2 < 1000$ GeV^2, $0 < p_T < 10$ GeV/c, $0.02 < y < 0.7$
ZEUS γp, HERA I [49]	$0.220 \pm 0.035^{+0.027}_{-0.037}$	ep	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$
ZEUS γp, HERA II [50]	$0.107 \pm 0.018^{+0.009}_{-0.014}$	ep	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$

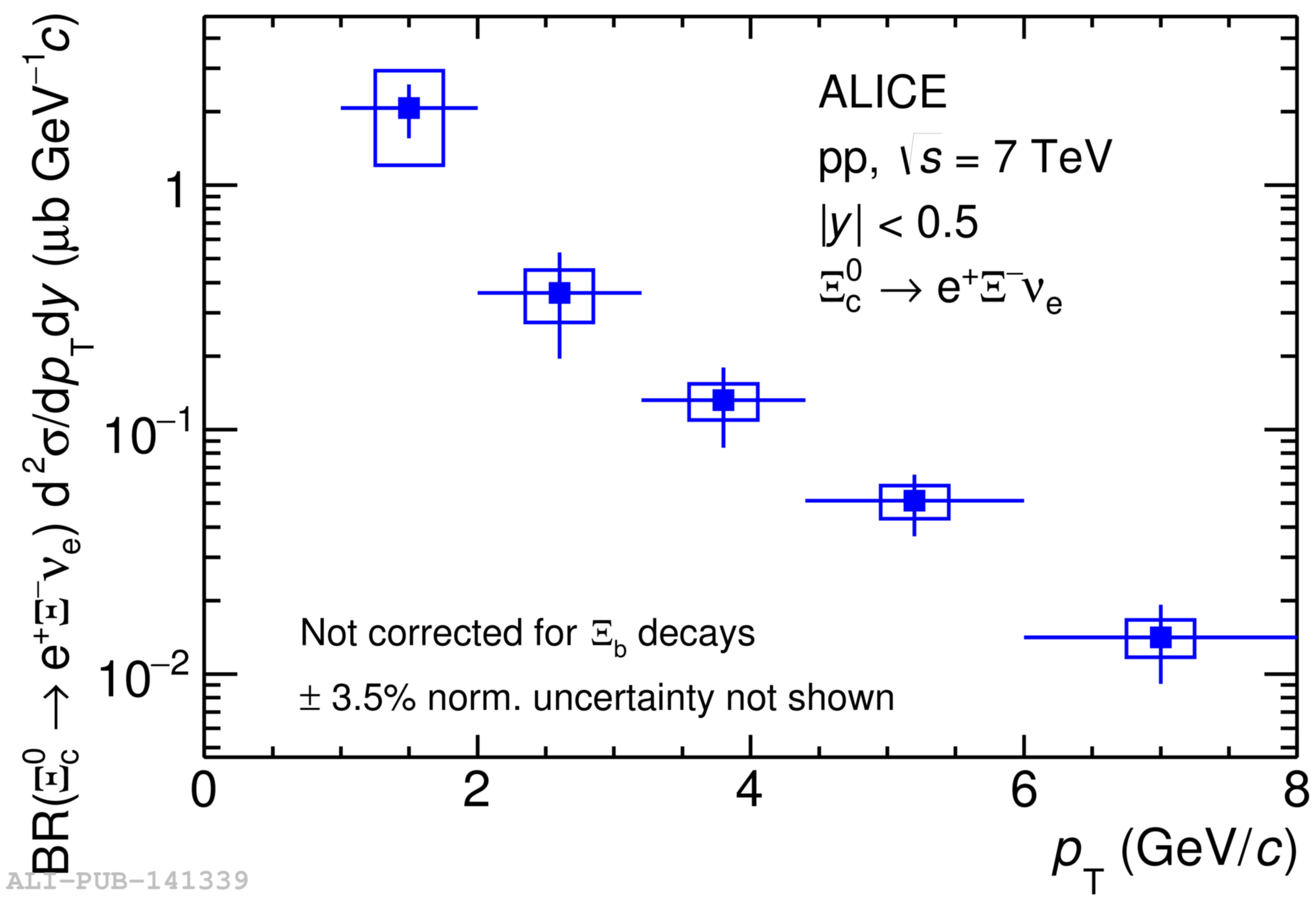
- LHCb and ALICE results in pPb collisions suggest a trend of Λ_c/D^0 ratio towards mid-rapidity, not reproduced by the relatively flat theoretical curves
- Results from LHC in p-Pb collisions higher than previous measurements in e^+e^- and ep collisions at lower centre-of-mass energy
- In the beauty sector, a larger fraction f(b->Λ_b) was measured in pp and p$\bar{p}$ collisions at LHC and Tevatron with respect to e^+e^- at the LEP

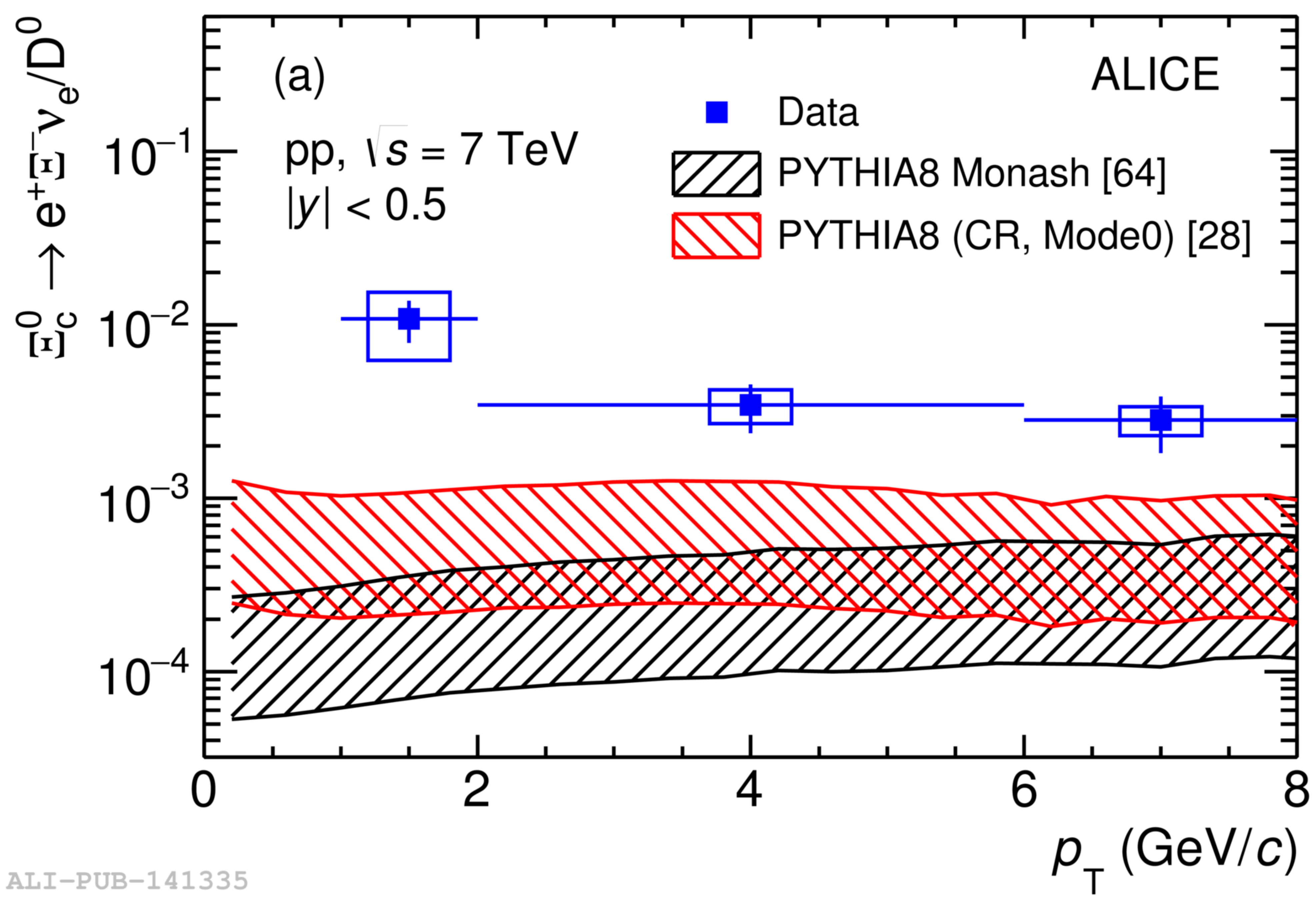
→ ***Violation of the universality of the fragmentation functions?***

arXiv:1612.07233

Ξ_c^0 p_T-differential cross section and baryon-to-meson ratio

Phys. Lett. B 781 (2018) 8-19





D^0 from Eur. Phys. J. C77 (2017) 550

PYTHIA 8 Monash: P. Skands, S. Carrazza, and J. Rojo, Eur. Phys. J. C74 (2014) 3024

Enhanced colour reconnection: J. R. Christiansen and P. Z. Skands JHEP 08 (2015) 003

- First Ξ_c^0 production measurement at the LHC (BR unknown)
- Not feed-down corrected, includes $\Xi_b \rightarrow \Xi_c X \rightarrow e^+\Xi^-\nu_e$
- Baryon-to-meson ratio $\Xi_c^0 \rightarrow e^+\Xi^-\nu_e/D^0$ larger than model predictions (0.83-4.2%: range of the BR in prediction bands)

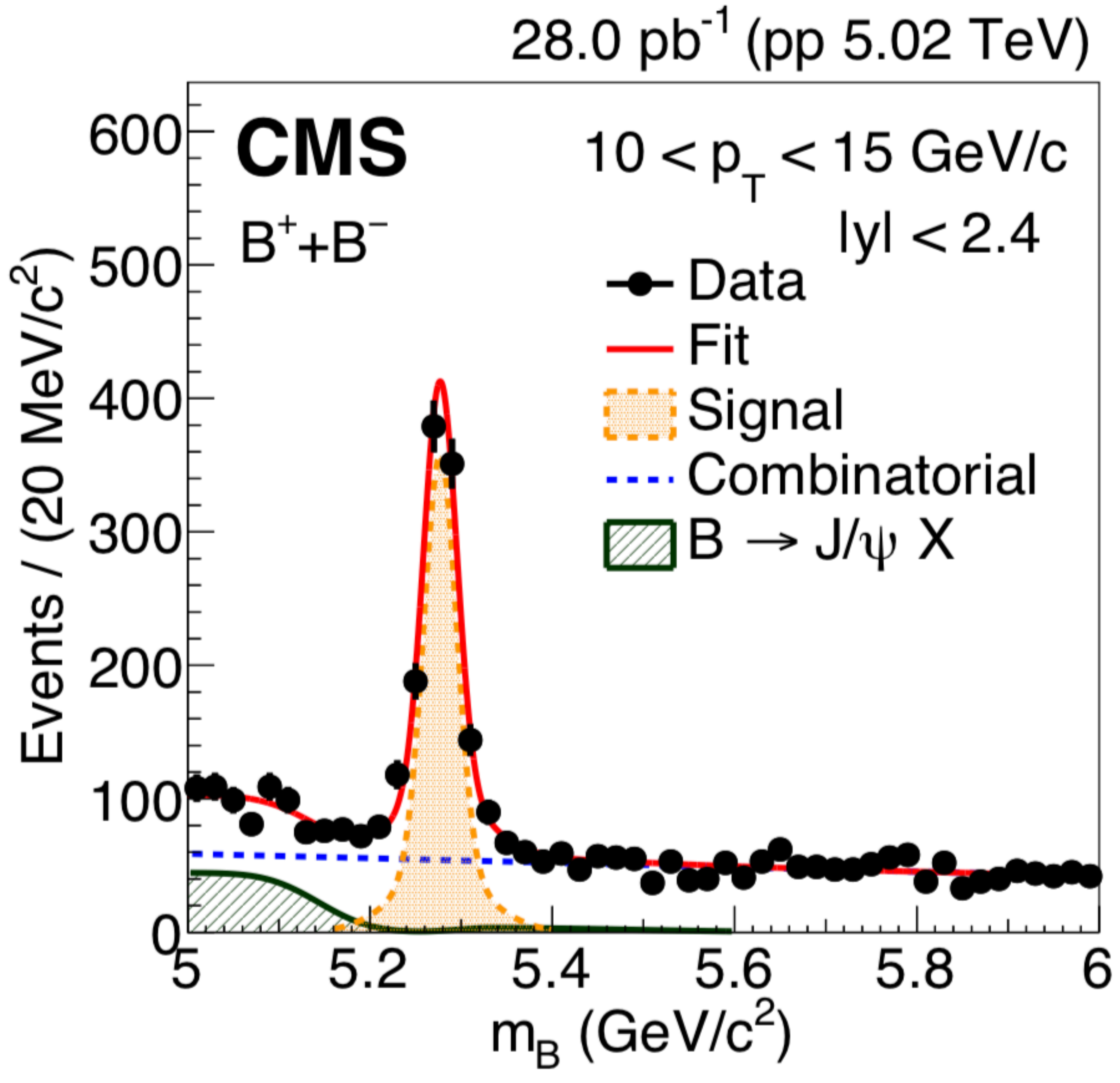
PYTHIA8 with enhanced colour reconnection closer to data

Beauty

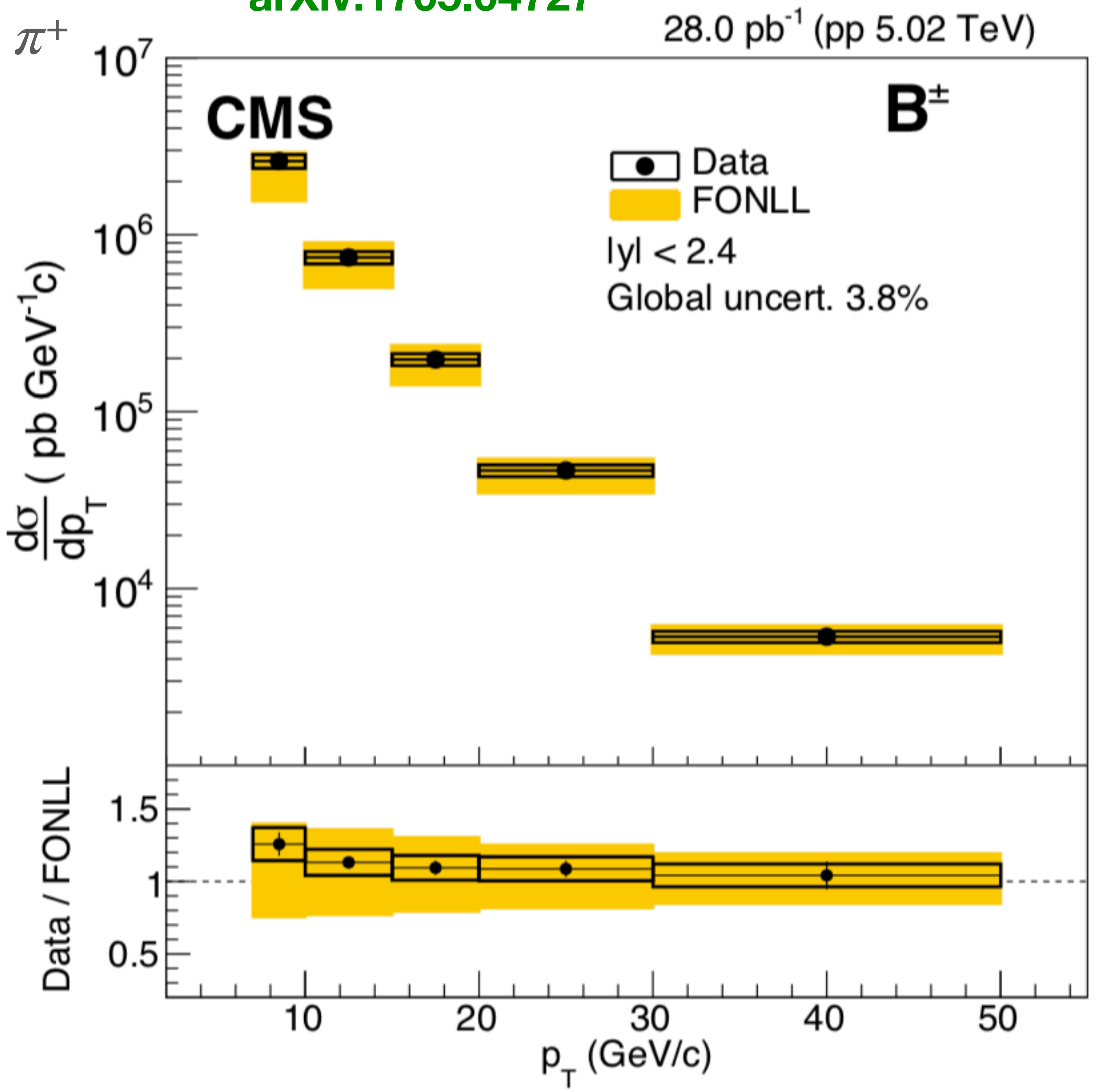
- B meson production in CMS
- b-hadron fractions in LHCb
- Ξ_b^- production ratio in LHCb
- Λ_b^0 polarisation in CMS

B meson production in CMS

- Full reconstruction of B^+ mesons hadronic decay: $B^+ \to J/\varphi\ \pi^+$
- Reconstruction based on identification of displaced secondary vertices by few hundreds μm
- Background reduction via topological selections
- Invariant mass analysis



arXiv:1705.04727

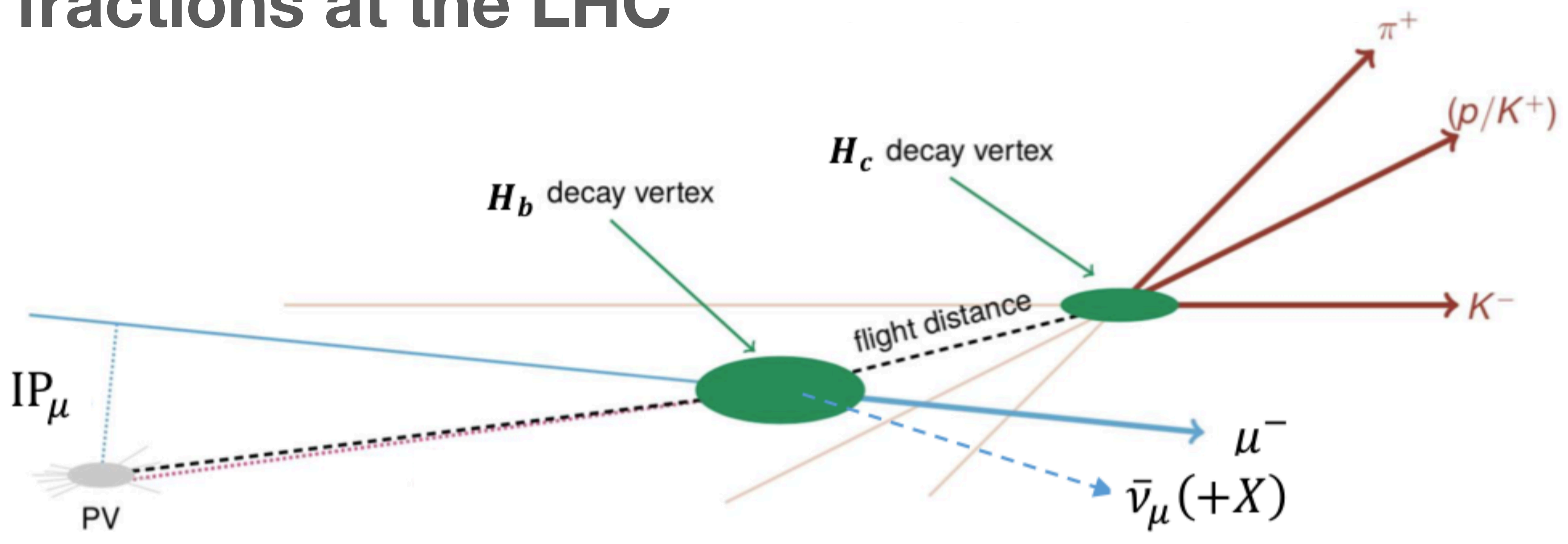


p_T-differential cross section of B^+ mesons

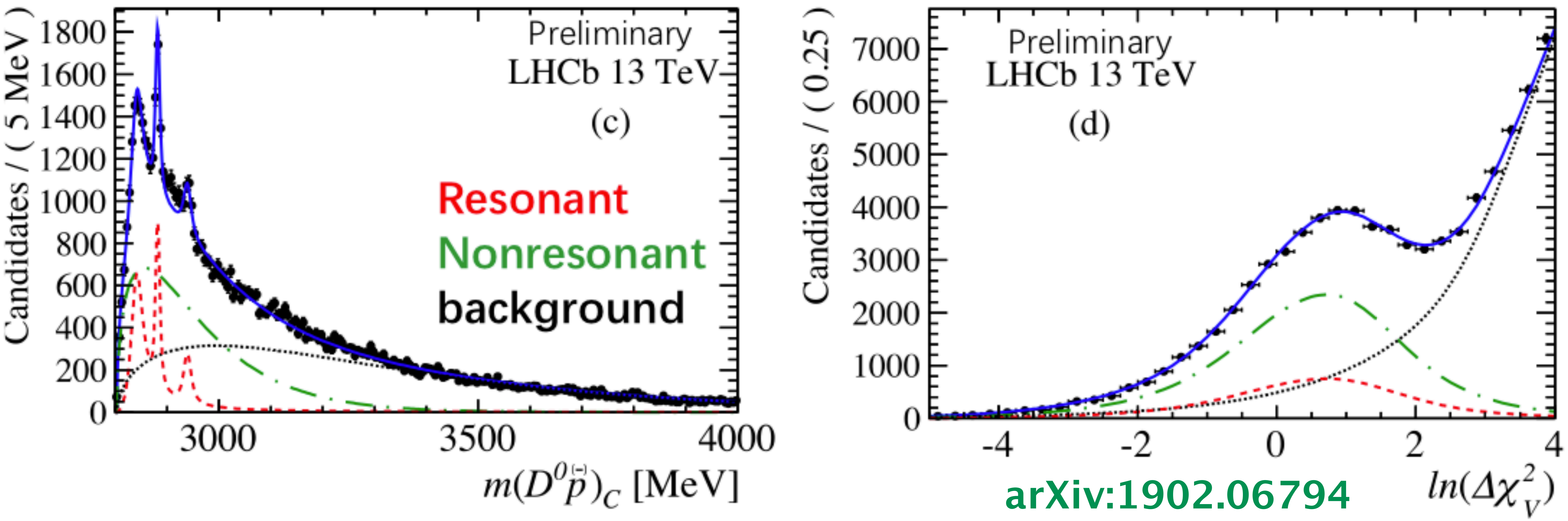
- Compatible with pQCD calculations

b-hadron fractions

- **Goal: complete measurements of b-hadron production fractions at the LHC**
- Inclusive semileptonic decay channels: $H_b \to H_c \mu^- \bar{\nu}_\mu$
- Same strategy for the study of B^0_s and Λ^0_b
- Removal of prompt charmed hadrons through lifetime related requirements
- Non resonant contributions are subtracted



$$\Lambda^0_b \to D^0 p \mu^- \bar{\nu}_\mu X$$



arXiv:1902.06794

b-hadron fractions

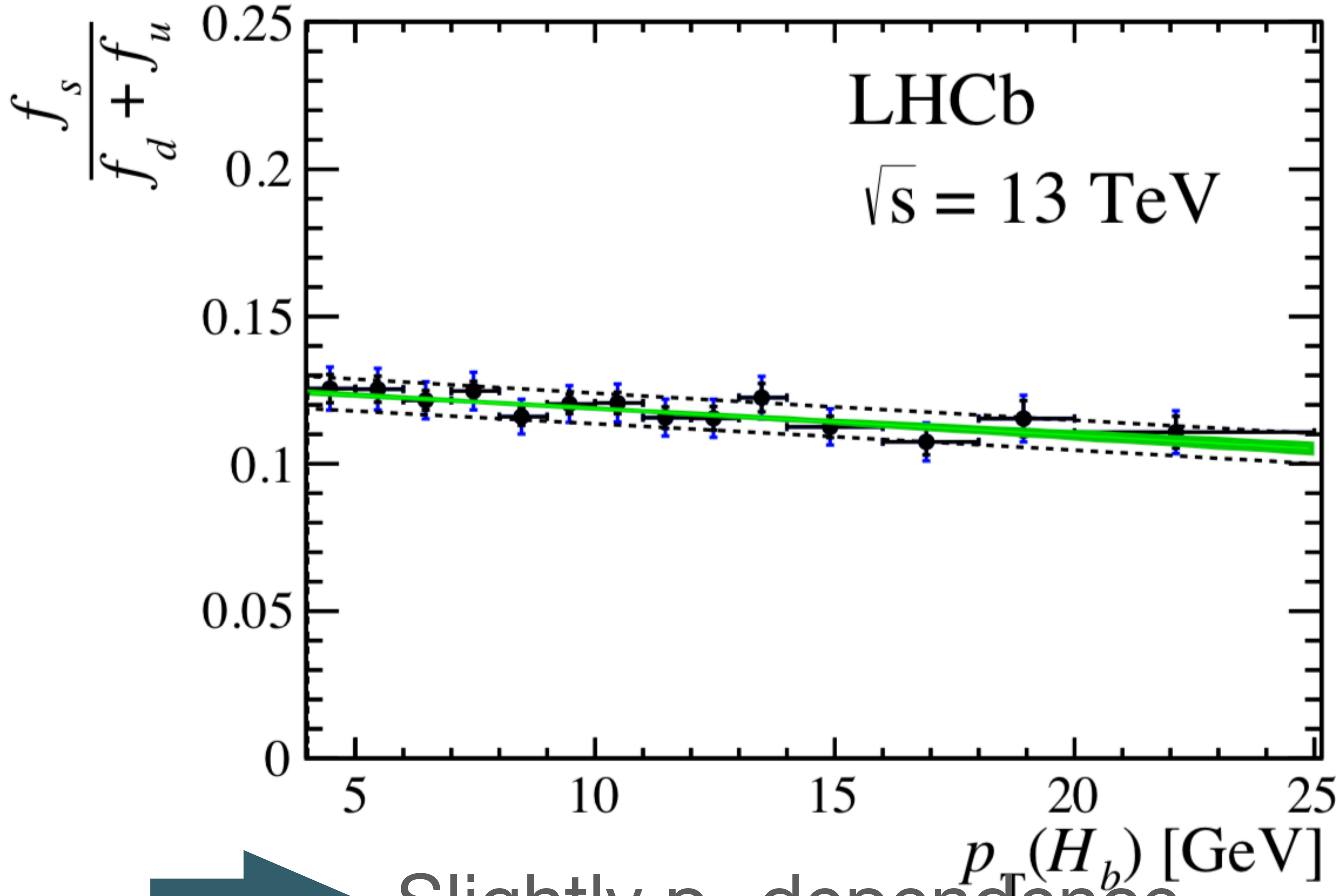
- Assumptions:
  - semileptonic widths almost equal for all hadrons
  - well measured lifetime for B^0_s and branching ratio for B^0 and B^-

$$\frac{f_s}{f_u+f_d} = \frac{n_{\rm corr}(\bar{B}^0_s \to D_s\mu)}{n_{\rm corr}(B \to D^0\mu) + n_{\rm corr}(B \to D^+\mu)} \frac{\tau_{B^-}+\tau_{\bar{B}^0}}{2\tau_{\bar{B}^0_s}}(1-\xi_s) - \frac{\mathcal{B}(B \to D_s K\mu)}{\langle \mathcal{B}_{SL} \rangle} \frac{\epsilon(\bar{B} \to D_s^+)}{\epsilon(\bar{B}^0_s \to D_s^+)}$$

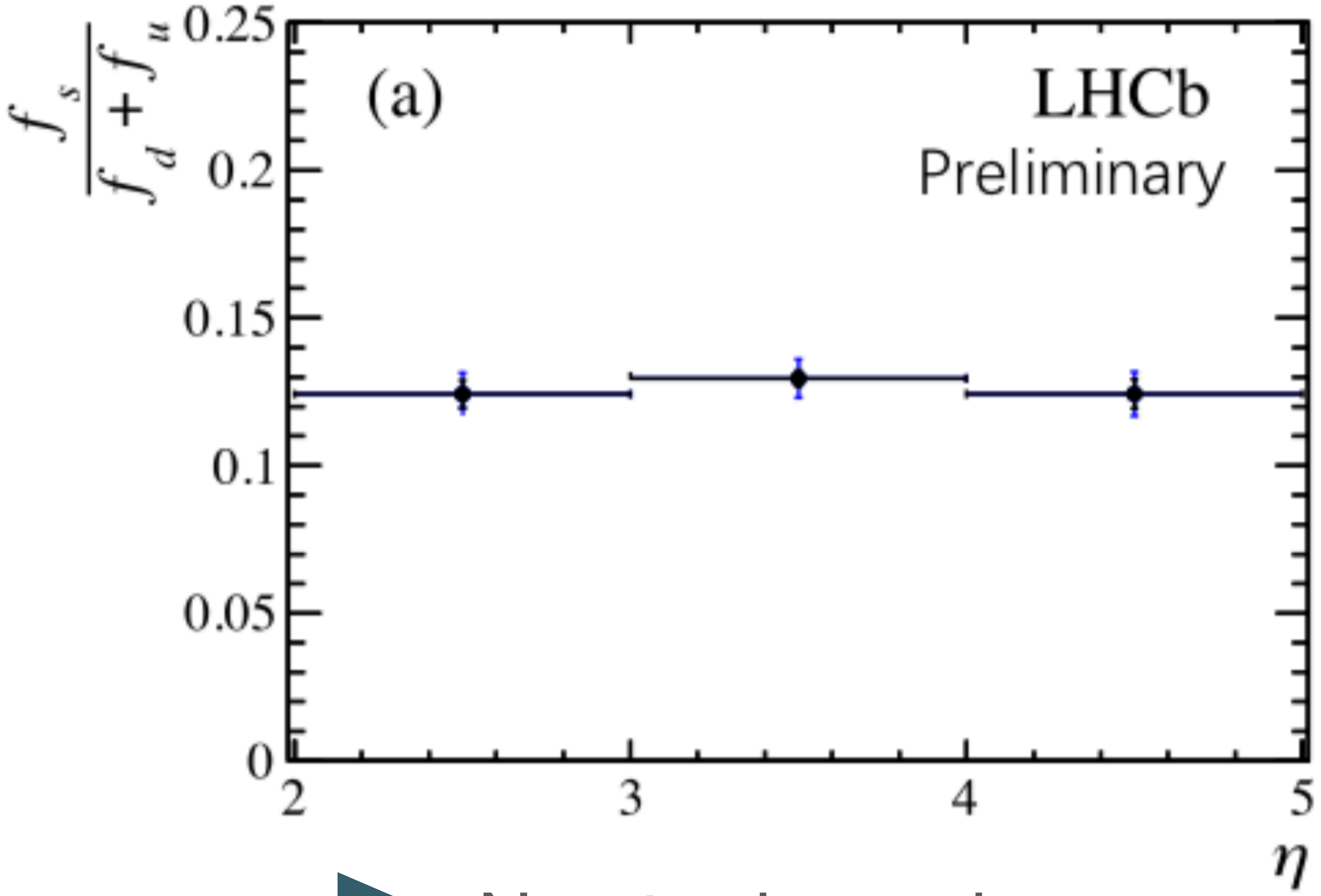
SU(3) breaking correction $\xi_s = (-1 \pm 0.5)\%$

Corrected yields of $\bar{B}^0_s$, $\bar{B}^0$, B^-

Subtraction of $\bar{B}^0(B^-) \to D_s^+ K \mu^- \bar{\nu}_\mu X$ contributions in $\bar{B}^0_s$ signals



Slightly p_T dependence



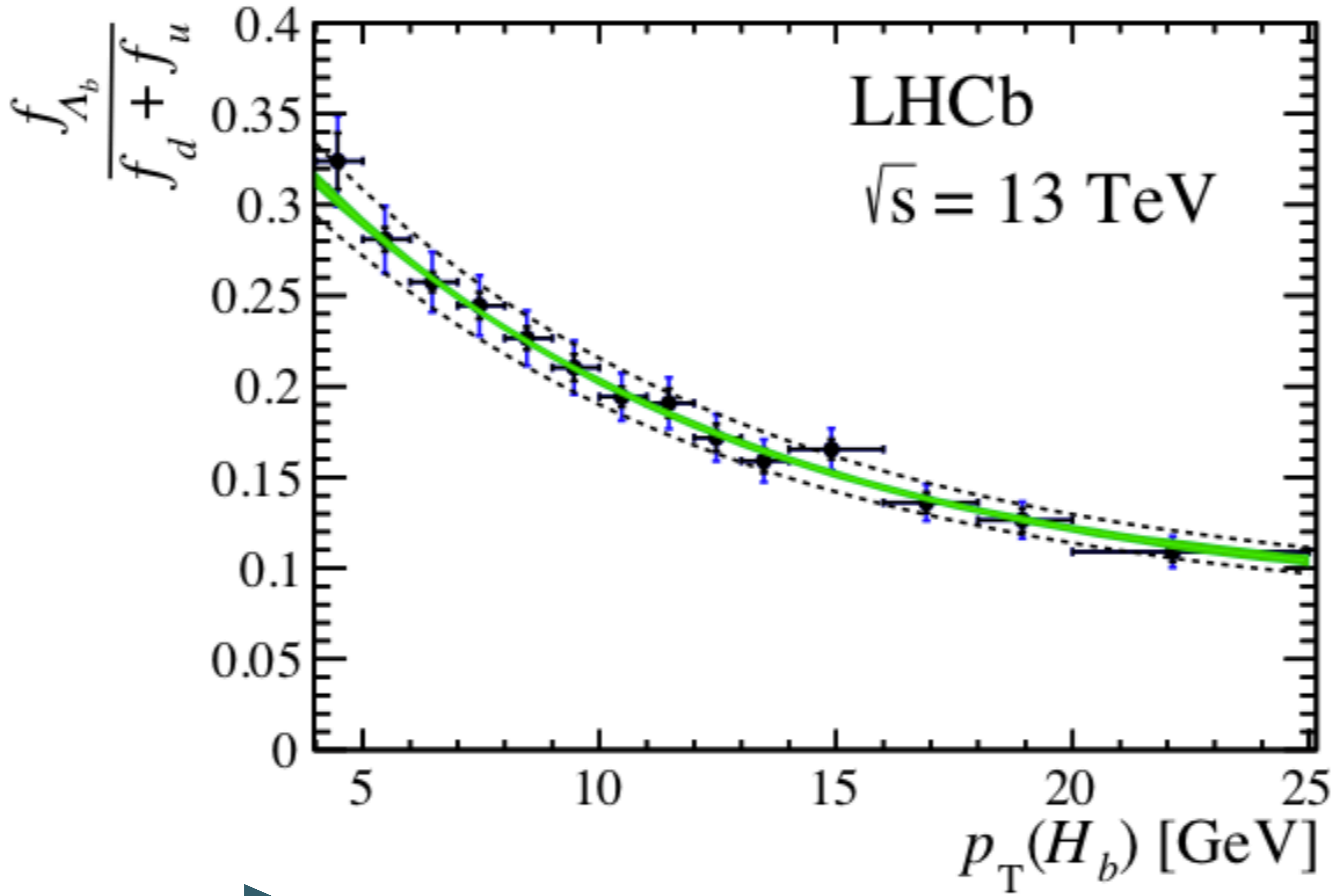
No eta dependence

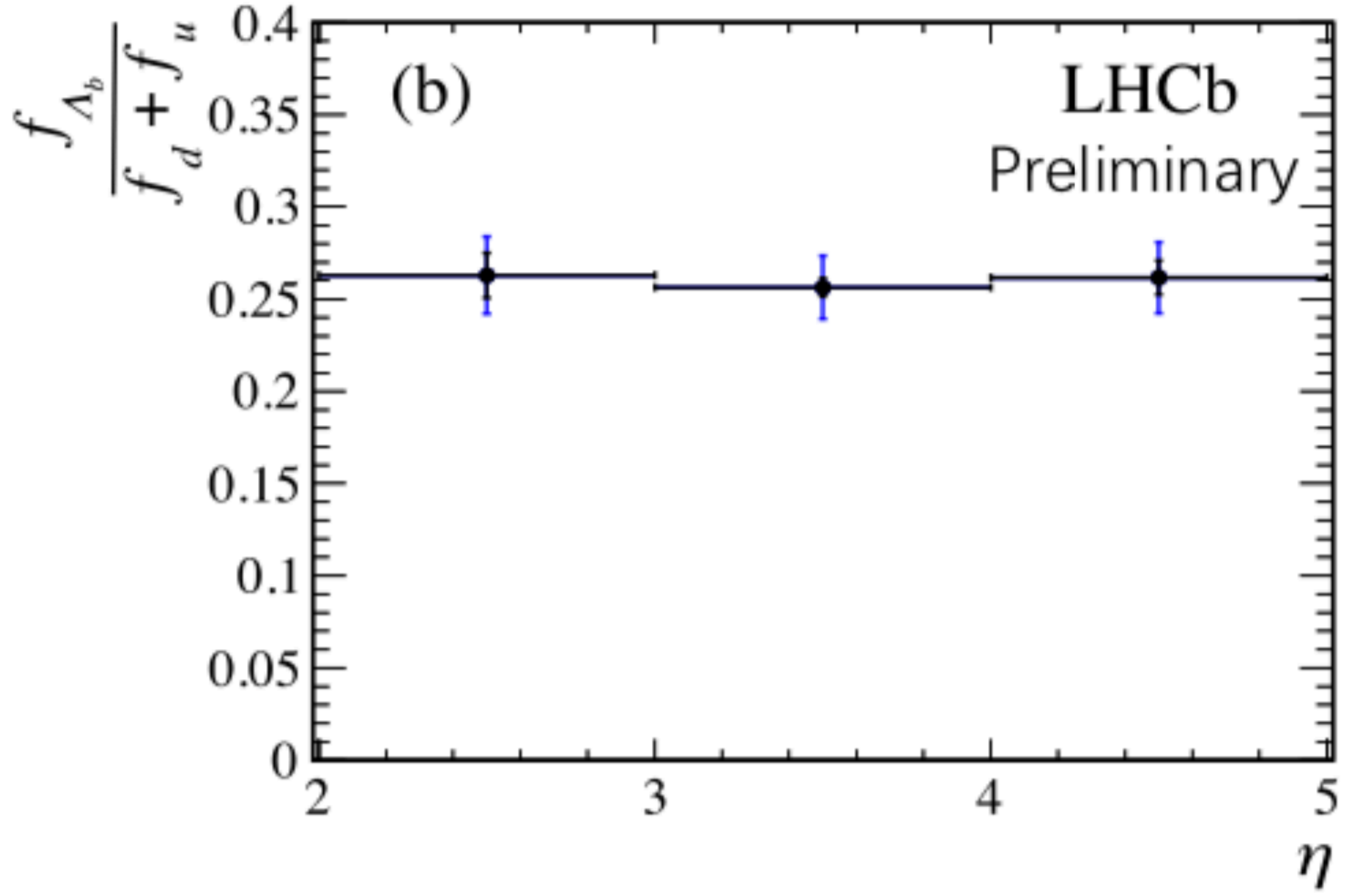
b-hadron fractions

$$\frac{f_{\Lambda_b^0}}{f_u+f_d} = \frac{n_{\mathrm{corr}}(\Lambda_b^0 \to H_c\mu^-)}{n_{\mathrm{corr}}(B \to D^0\mu^-) + n_{\mathrm{corr}}(B \to D^+\mu^-)} \frac{\tau_{B^-}+\tau_{\bar{B}^0}}{2\tau_{\Lambda_b^0}}(1-\xi_{\Lambda_b^0})$$

Corrected yields of Λ_b^0, $\bar{B}^0$, B^-

Chromomagnetic correction $\xi_{\Lambda_b^0} = (3 \pm 1.5)\%$





- Strong p_T dependence
- No eta dependence

b-hadron fractions

- From pp @ 13 TeV (1.67 fb^{-1})

$$\frac{f_s}{f_u + f_d} = 0.122 \pm 0.006$$

$$\frac{f_{\Lambda_b^0}}{f_u + f_d} = 0.259 \pm 0.018$$

- Kinematic region 4<$p_T(H_b)$ <25 GeV/c and 2<η<5
- Statistical and systematic uncertainties combined (systematic dominates)

➡ Consistent with previous results

LHCb 7 TeV result:

$$\frac{f_s}{f_u + f_d} = 0.128 \pm 0.010$$

LHCb, JHEP 04 (2013) 001

b-hadron fractions and Ξ_b^- production ratio

- **Goal: complete measurements of b-hadron production fractions at the LHC**

$$f_{\text{baryon}} = f_{\Lambda_b^0} + f_{\Xi_b^0} + f_{\Xi_b^-} + f_{\Omega_b^-} = f_{\Lambda_b^0}\left(1 + 2\boxed{\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}}} + \boxed{\frac{f_{\Omega_b^-}}{f_{\Lambda_b^0}}}\right)$$

Measurement of $f_{\Xi_b^-}/f_{\Lambda_b^0}$ through the SU(3) relative decays

$\Xi_b^- \to J/\varphi\ \Xi^-$ and $\Lambda_b^0 \to J/\varphi\ \Lambda$

$$\frac{\Gamma(\Xi_b^- \to J/\psi \Xi^-)}{\Gamma(\Lambda_b^0 \to J/\psi \Lambda)} = \frac{3}{2}$$

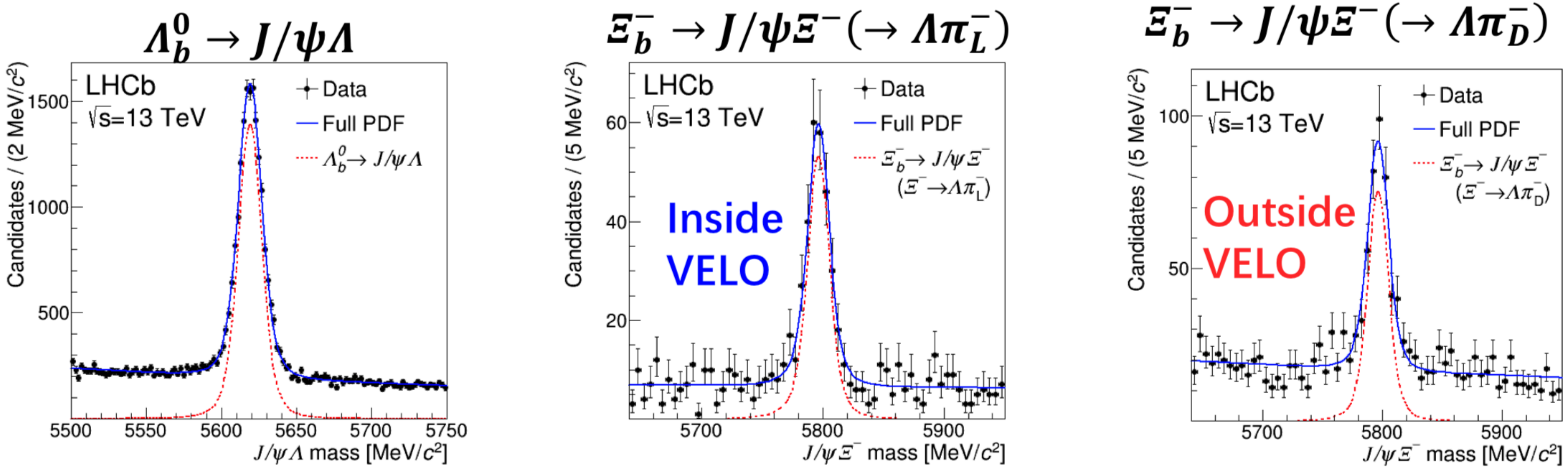
M. Savage et al, NPB326 (1989) 15
M. Voloshin, arXiv:1510.05568
Y. Hsiao et al, PLB751(2015) 127

b-hadron fractions and Ξ_b^- production ratio

- **Goal: complete measurements of b-hadron production fractions at the LHC**

$$R \equiv \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\mathcal{B}(\Xi_b^- \to J/\psi\, \Xi^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\, \Lambda)} = \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\Gamma(\Xi_b^- \to J/\psi\, \Xi^-)}{\Gamma(\Lambda_b^0 \to J/\psi\, \Lambda)} \frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}} = \frac{N(\Xi_b^- \to J/\psi\, \Xi^-)}{N(\Lambda_b^0 \to J/\psi\, \Lambda)} \frac{\epsilon_{\Lambda_b^0}}{\epsilon_{\Xi_b^-}}$$

Known (theo. + exp.) — Measurable



arXiv:1901.07075

b-hadron fractions and Ξ_b^- production ratio

arXiv:1901.07075

- Three different results from pp @ 7,8 and 13 TeV:
  - Most precise determination of the Ξ_b^- mass

$$\delta m = 177.30 \pm 0.39 \pm 0.15\,\mathrm{MeV}/c^2,$$
$$m(\Xi_b^-) = 5796.70 \pm 0.39 \pm 0.15 \pm 0.17\,\mathrm{MeV}/c^2$$

  - Production asymmetry splitting into baryon and anti-baryon

→ consistent with zero

$$A_{\mathrm{prod}}(\Xi_b^-) = (\ \ 1.1 \pm 5.6 \pm 1.9)\% \quad [\sqrt{s} = 7, 8\,\mathrm{TeV}],$$
$$A_{\mathrm{prod}}(\Xi_b^-) = (-3.9 \pm 4.9 \pm 2.5)\% \quad [\sqrt{s} = 13\,\mathrm{TeV}].$$

  - Fragmentation function

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = (6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2} \quad [\sqrt{s} = 7, 8\,\mathrm{TeV}],$$
$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = (8.2 \pm 0.7 \pm 0.6 \pm 2.4) \times 10^{-2} \quad [\sqrt{s} = 13\,\mathrm{TeV}].$$

(stat.) (syst.) (SU(3) breaking)

→ Consistent with existing theoretical predictions:

$(5.4 \pm 2.0)\mathrm{x}10^{-2}$

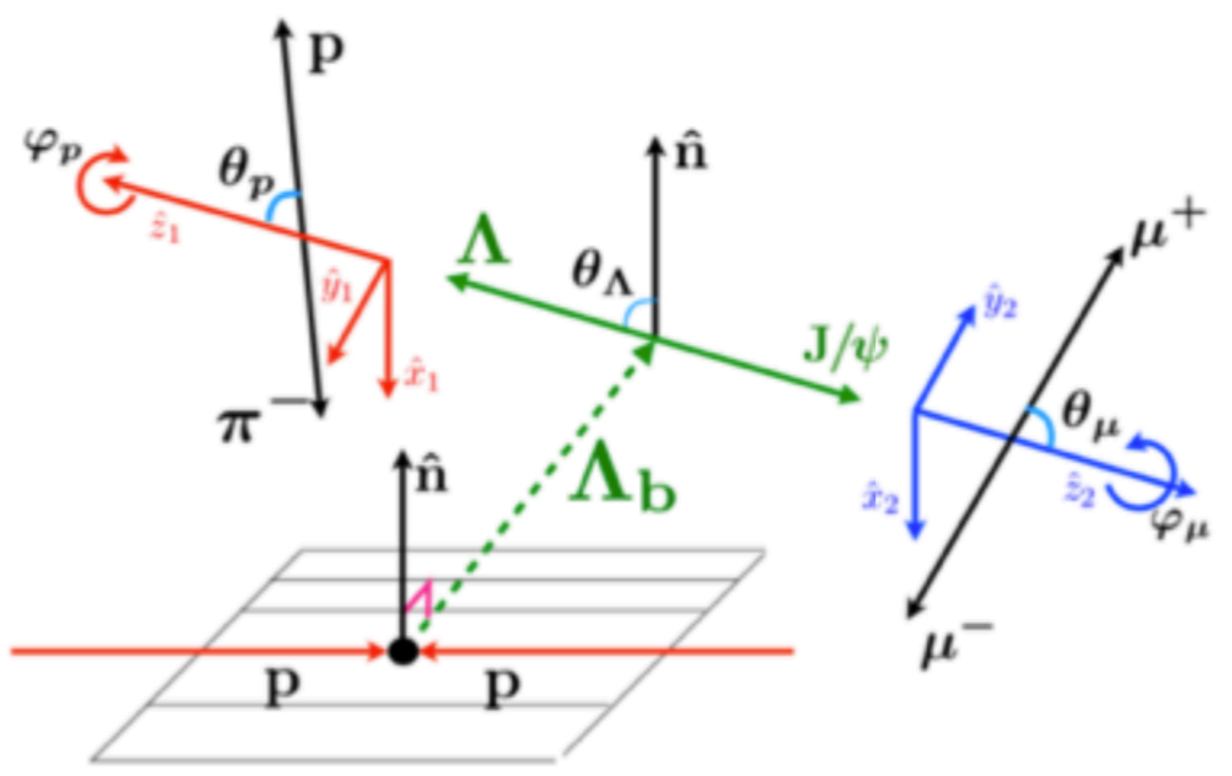
H.-Y. Jiang et al, EPJC78 (2018) 224

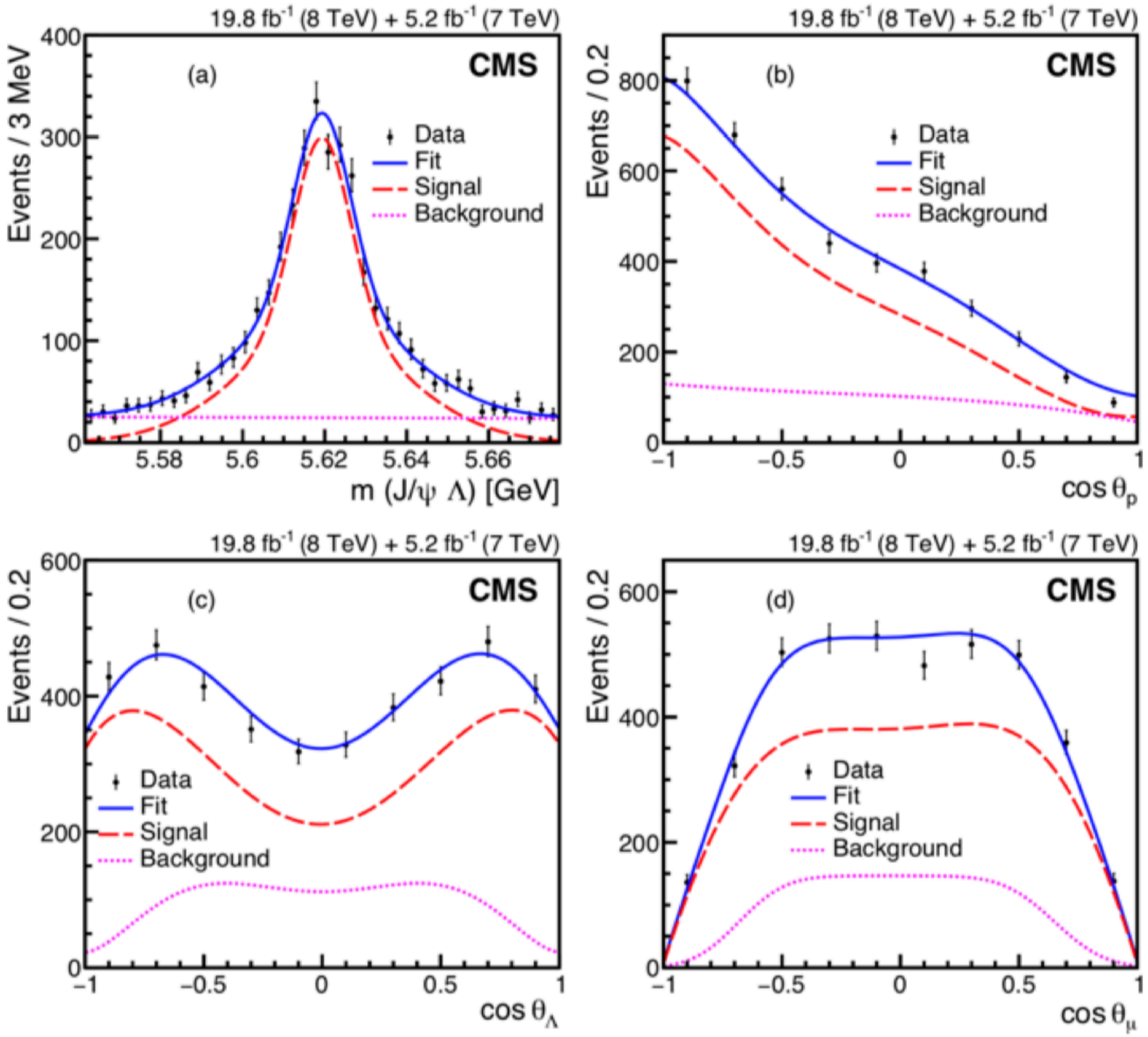
$(6.5 \pm 2.0)\ \mathrm{x}10^{-2}$

D. Wang, arXiv:1901.01776

Λ_b^0 polarisation

PRD 97 (2018) 072010





- Study of the angular distributions in the decay Λ_b^0->J/φ Λ ->$\mu\mu$pπ
  - Λ_b^0 polarisation **P=0.00±0.06(stat)±0.06(syst)**
  - Parity-violating decay asimmetry α

    α_1 **=0.14±0.14(stat)±0.10(syst)**

→ Results are in agreement with LHCb and ATLAS

Jets

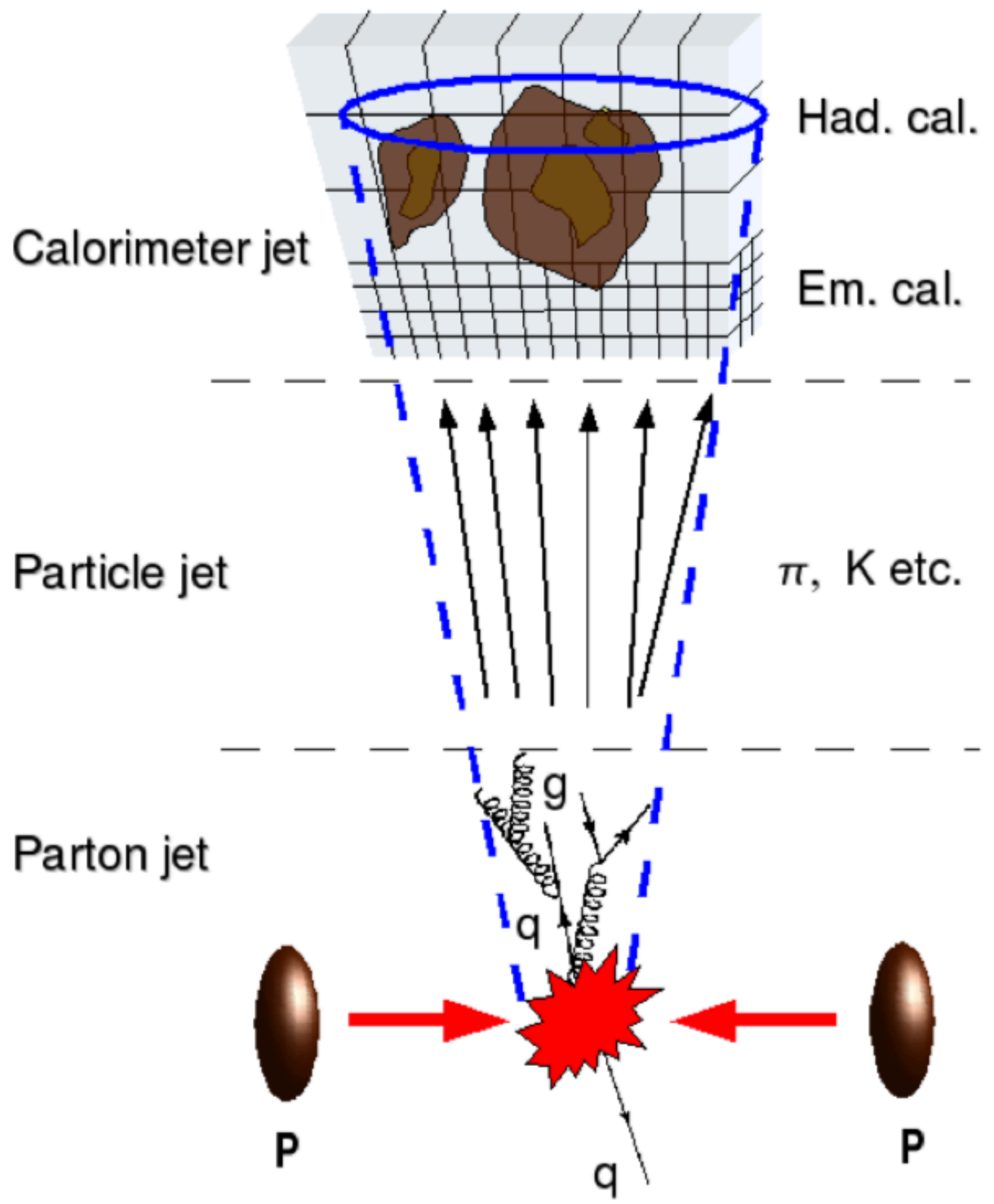
- Jets measurements in ATLAS and ALICE
- D-meson tagged jets in ALICE
- Other approaches to heavy-flavour tagging

Jets

- Anti-k_T clustering algorithm used in all the experiment

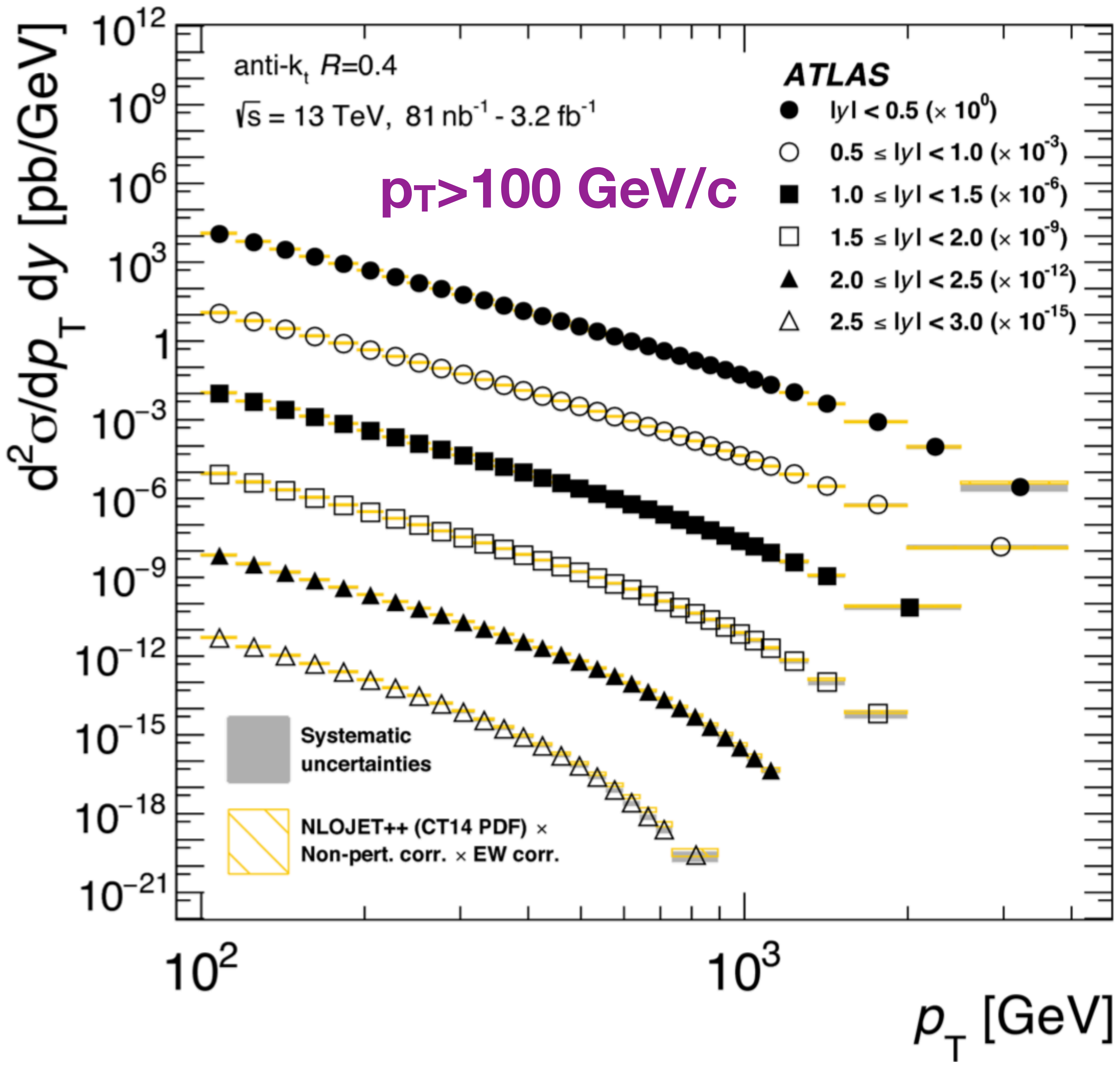
- ATLAS: topological calorimeter-cell clusters
  - jet energy corrected for pile-up, jet flavour composition, absolute/relative scale

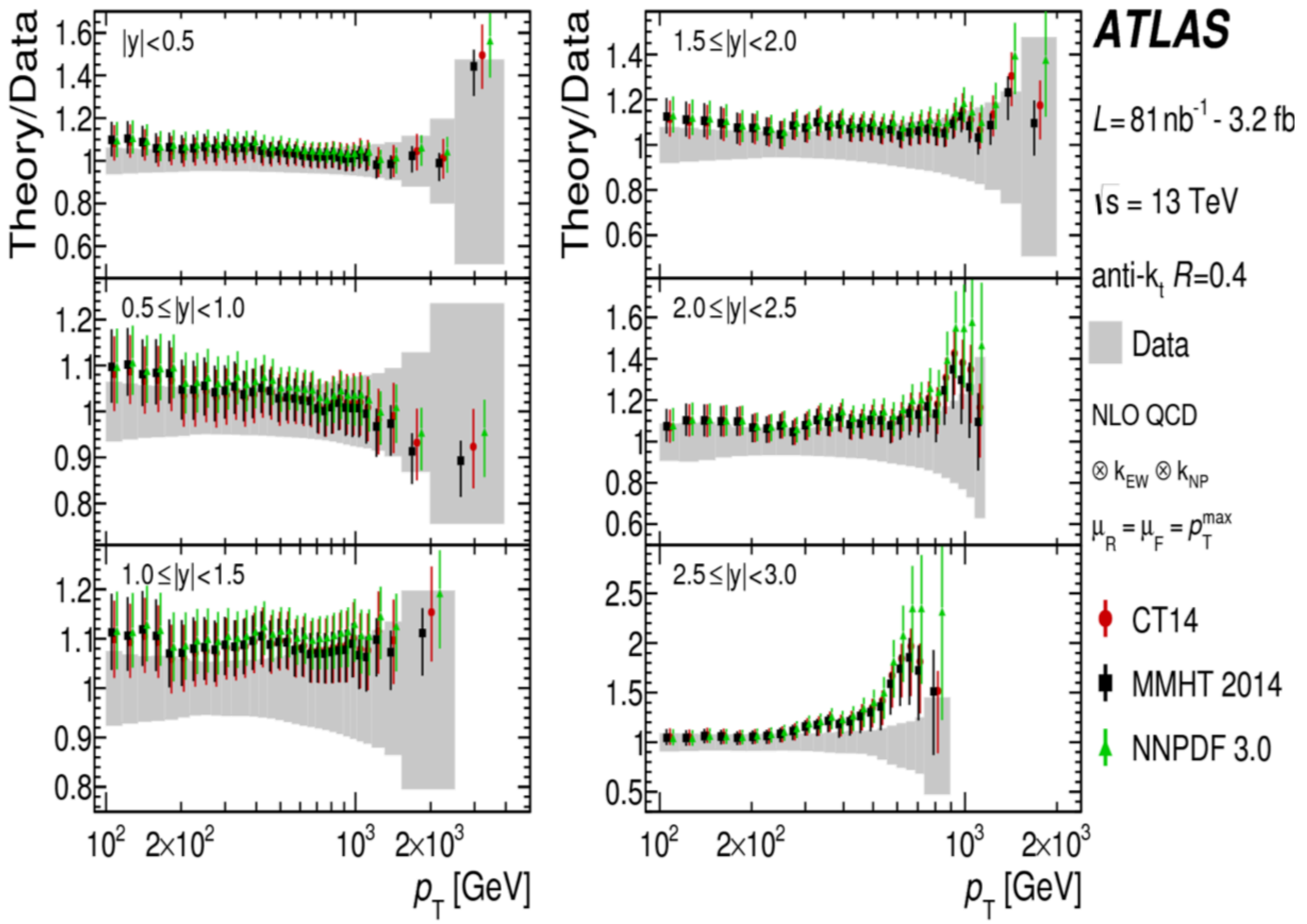
- ALICE: jet trigger based on neutral energy in the EMCal and charged constituent reconstruct in the central barrel



Jets

- ATLAS: jet cross-section in pp collisions at 13 TeV

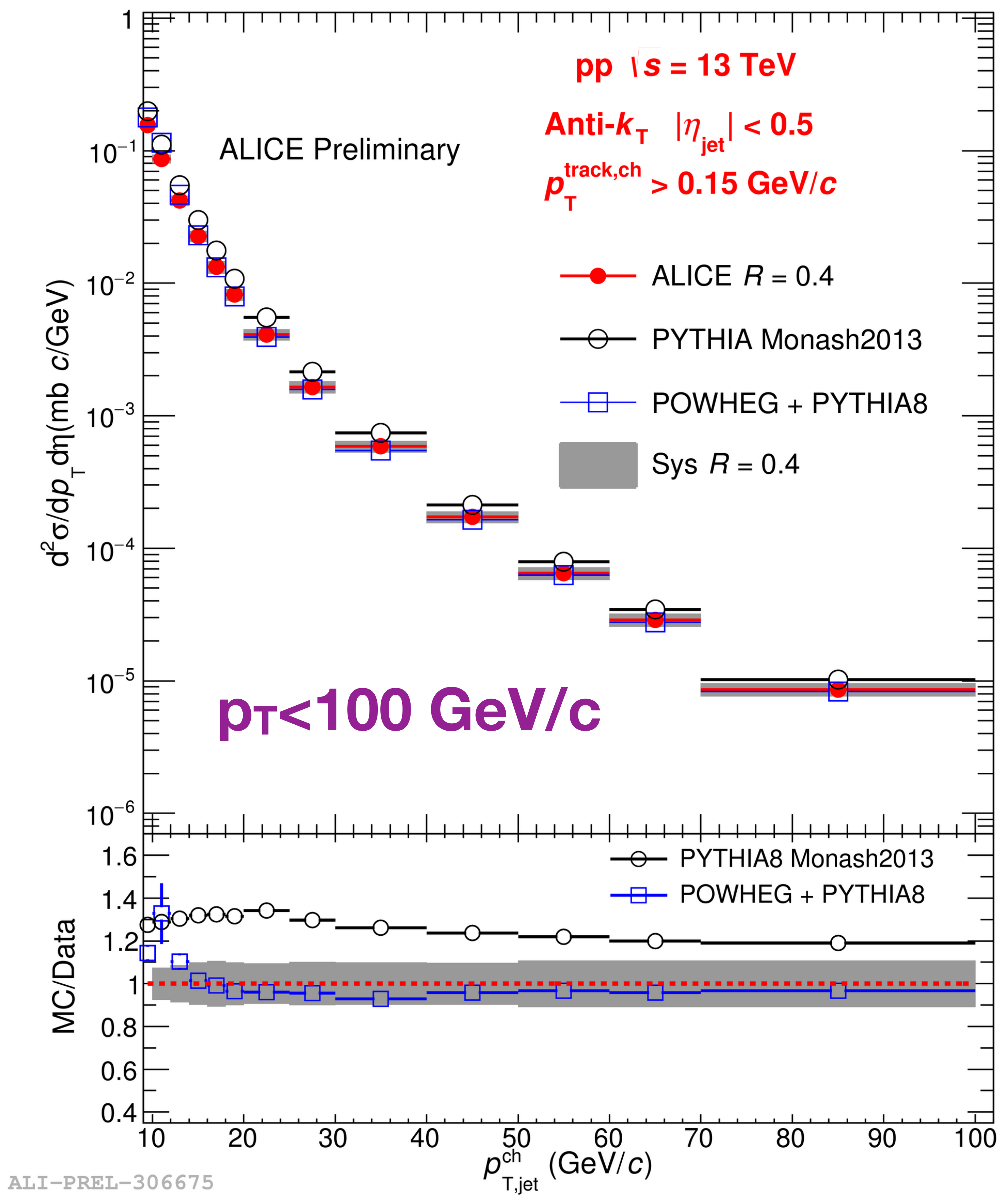


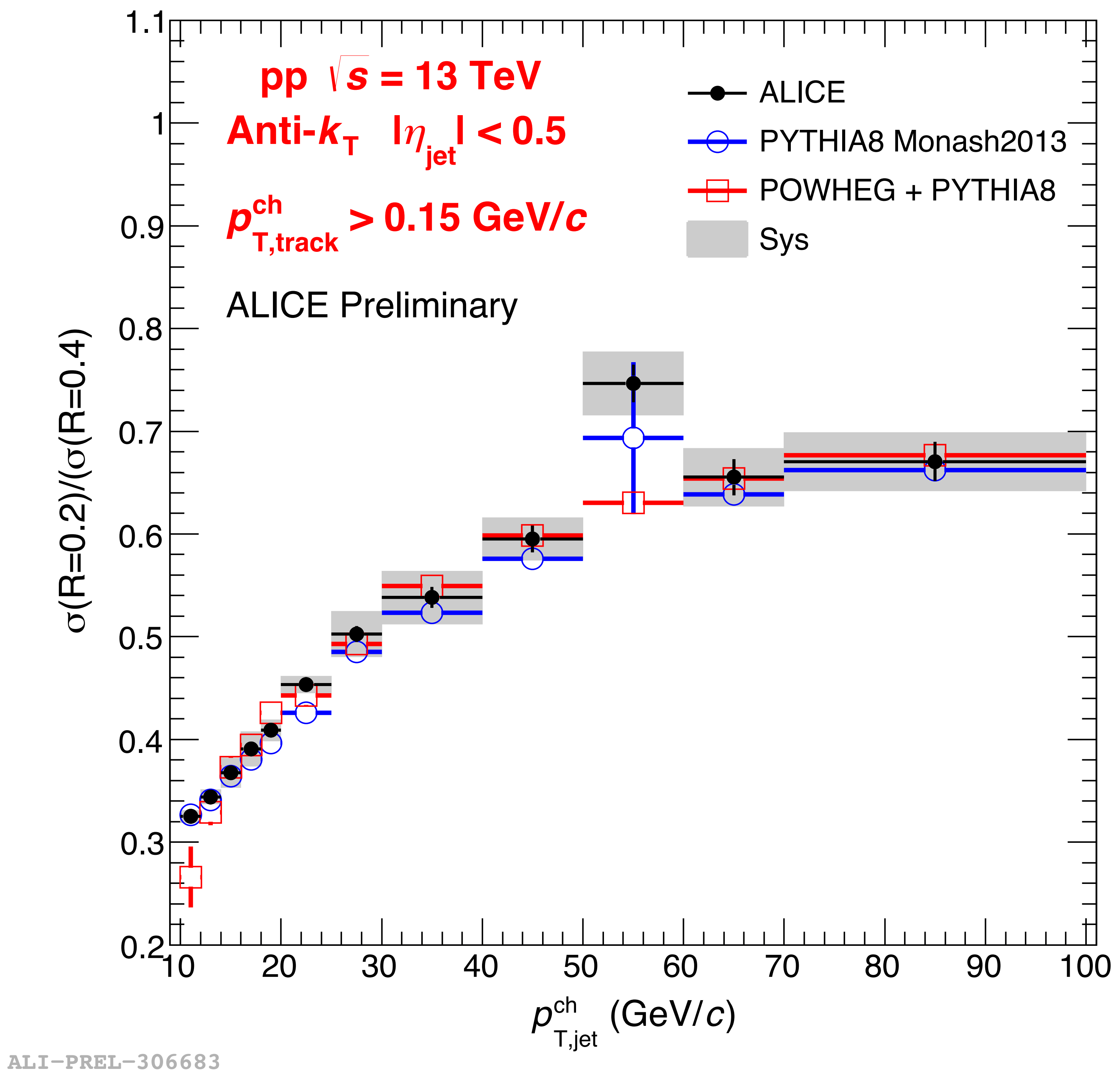


→ Good agreement with NLO predictions within the uncertainties

Jets

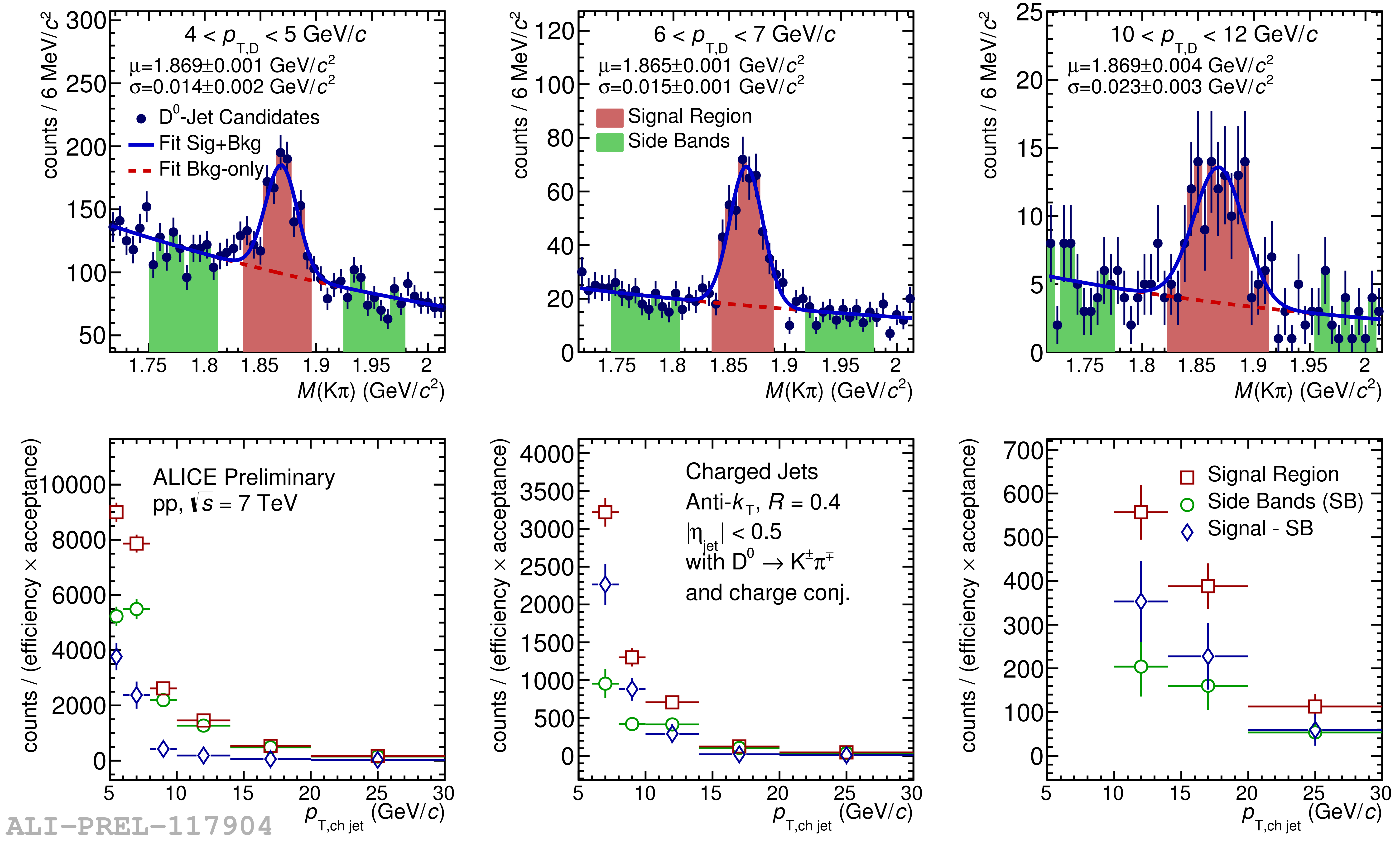
- ALICE: jet cross-section in pp collisions at 13 TeV





- Ratios of jet cross sections with different R are sensitive to intra-jet broadening
- Good agreement with PYTHIA and POWHEG

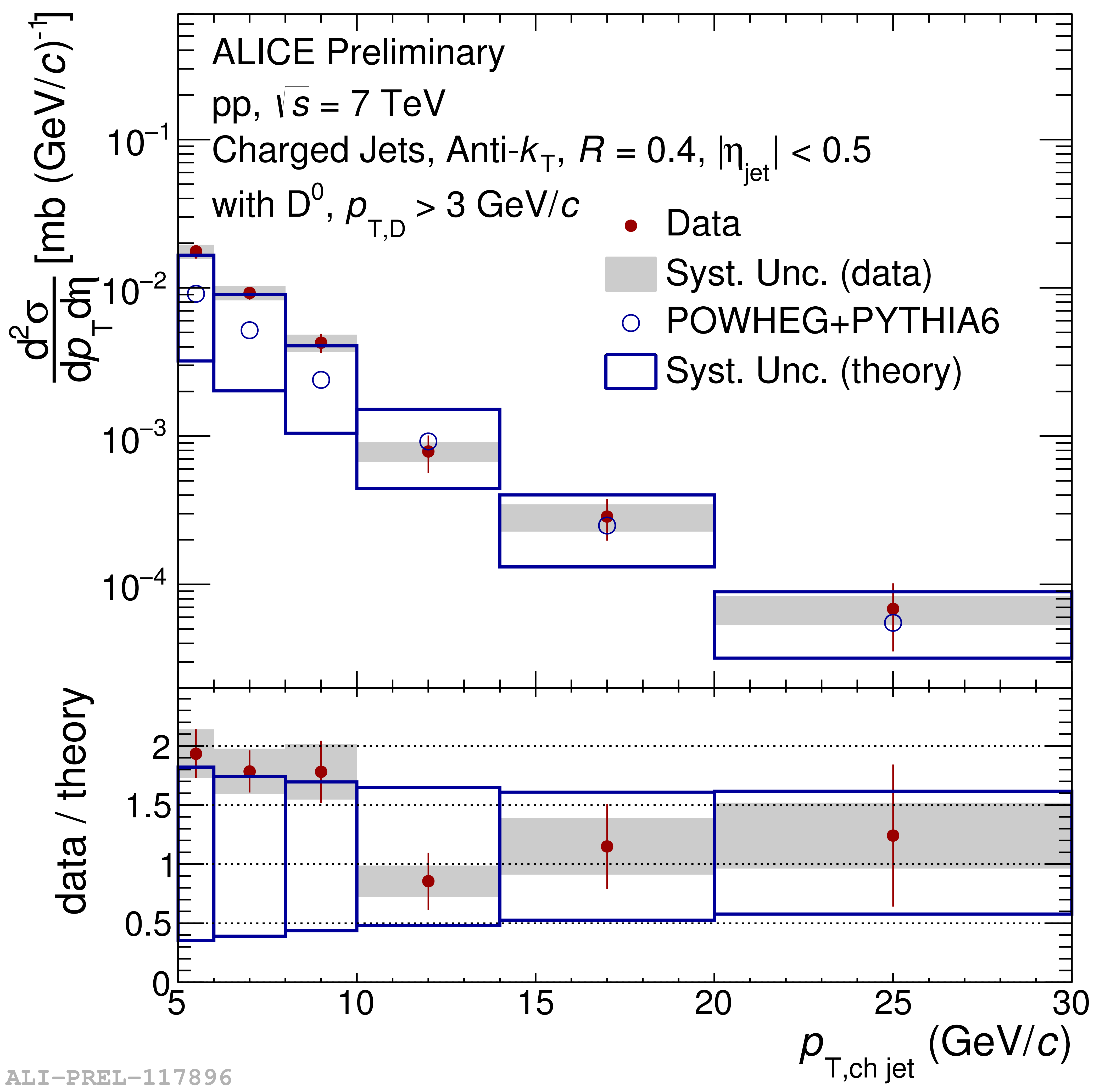
HF Jets - D tagging



- Invariant mass analysis to extract D-jet raw spectrum
- Background subtraction from side-bands
- Correction for the D-jet efficiency and feed-down from beauty
- Corrected jet p_T spectra unfolded for detector

- D-meson p_T>3 GeV/c
- Charged jets, anti-kT with R=0.4
- Jet p_T>5 GeV/c

HF Jets - D tagging

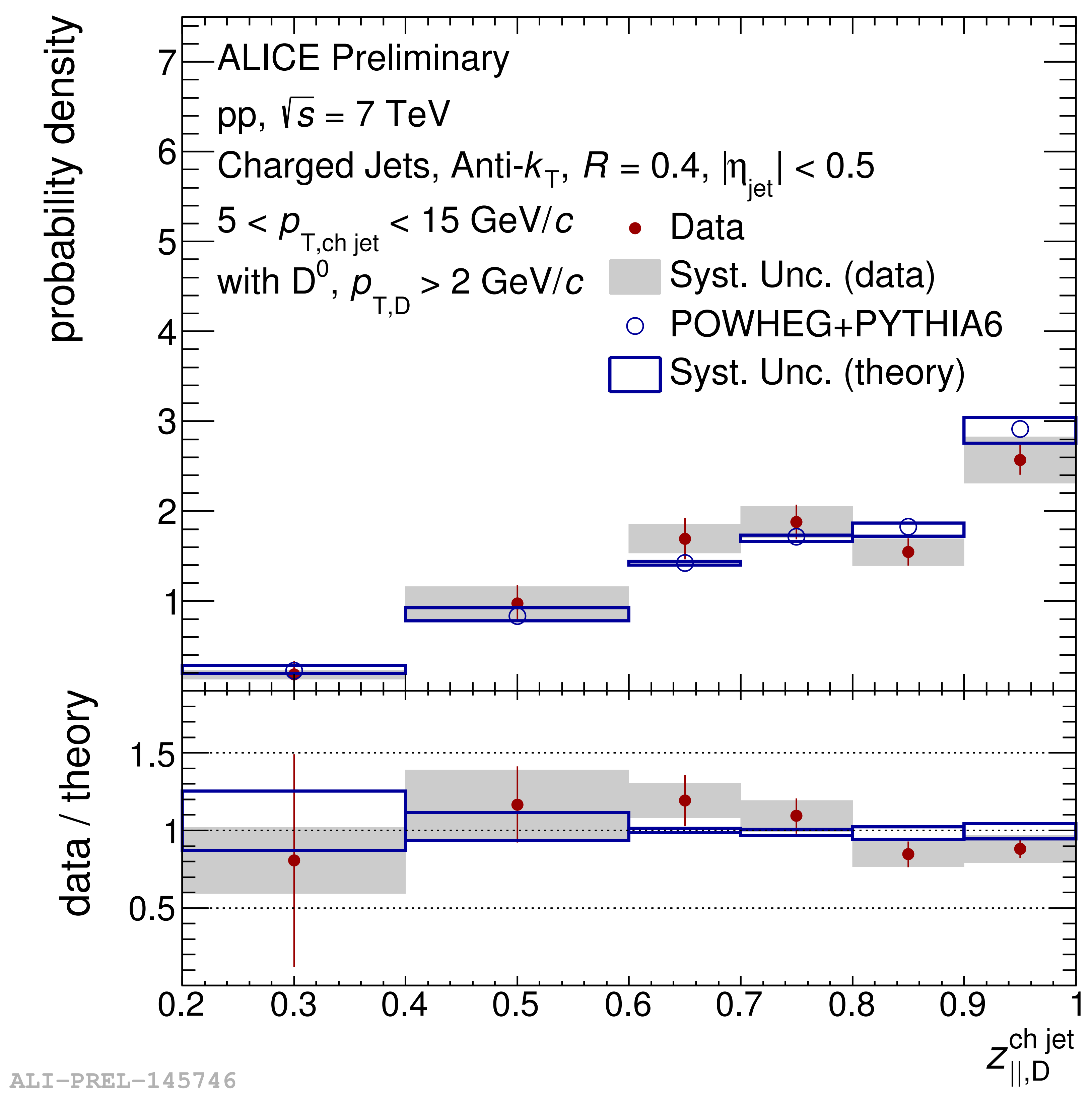


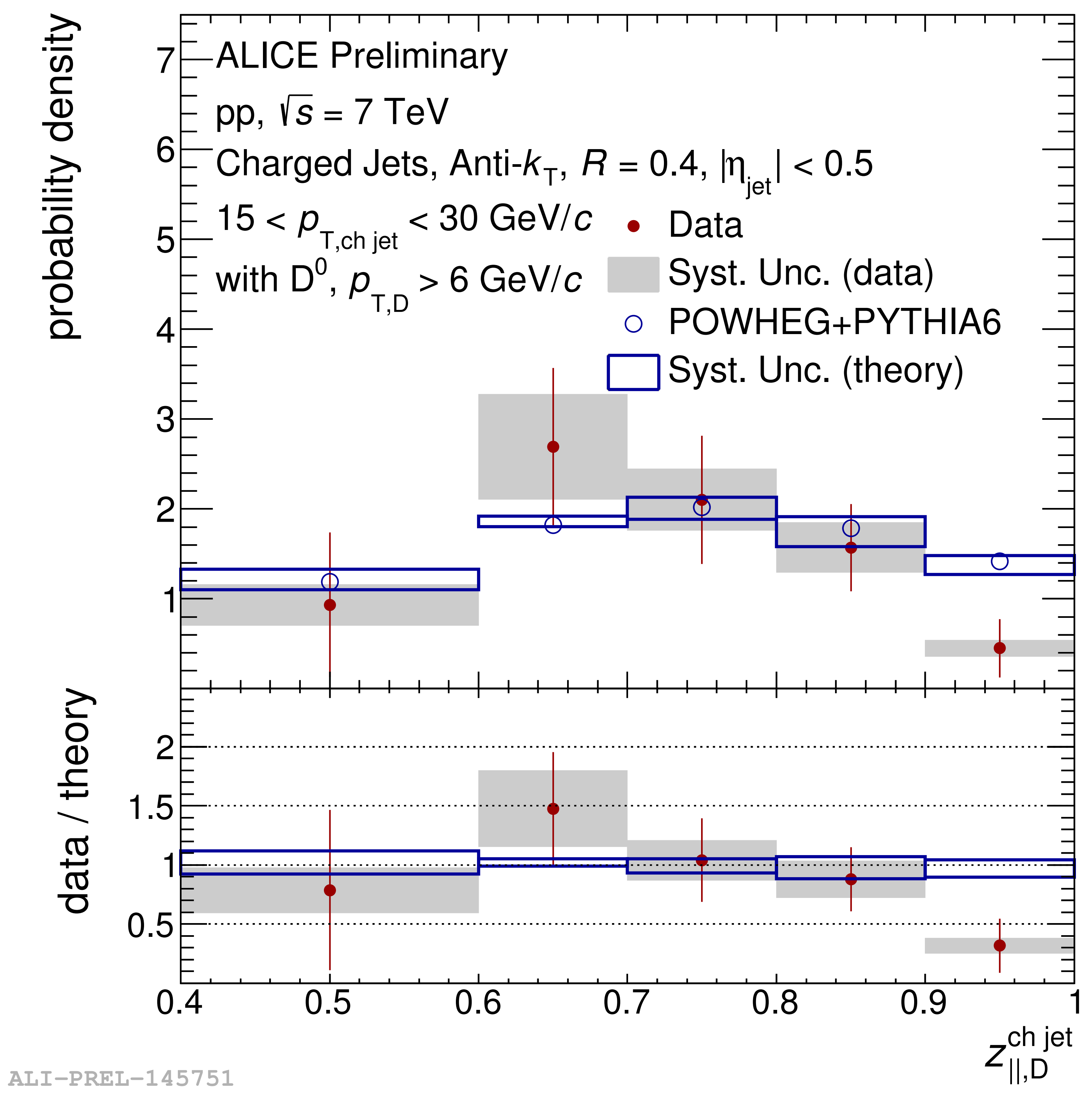
- Good agreement with NLO pQCD POWHEG+PYTHIA predictions
  - New results with pp collisions with the larger data sample are available at 5 TeV (backup)

HF Jets - D tagging

Charged jet momentum fraction carried by D⁰ momentum

$$z_{||} = \frac{\vec{p}_{\mathrm{ch\,jet}} \cdot \vec{p}_{\mathrm{D}}}{\vec{p}_{\mathrm{ch\,jet}} \cdot \vec{p}_{\mathrm{ch\,jet}}}$$



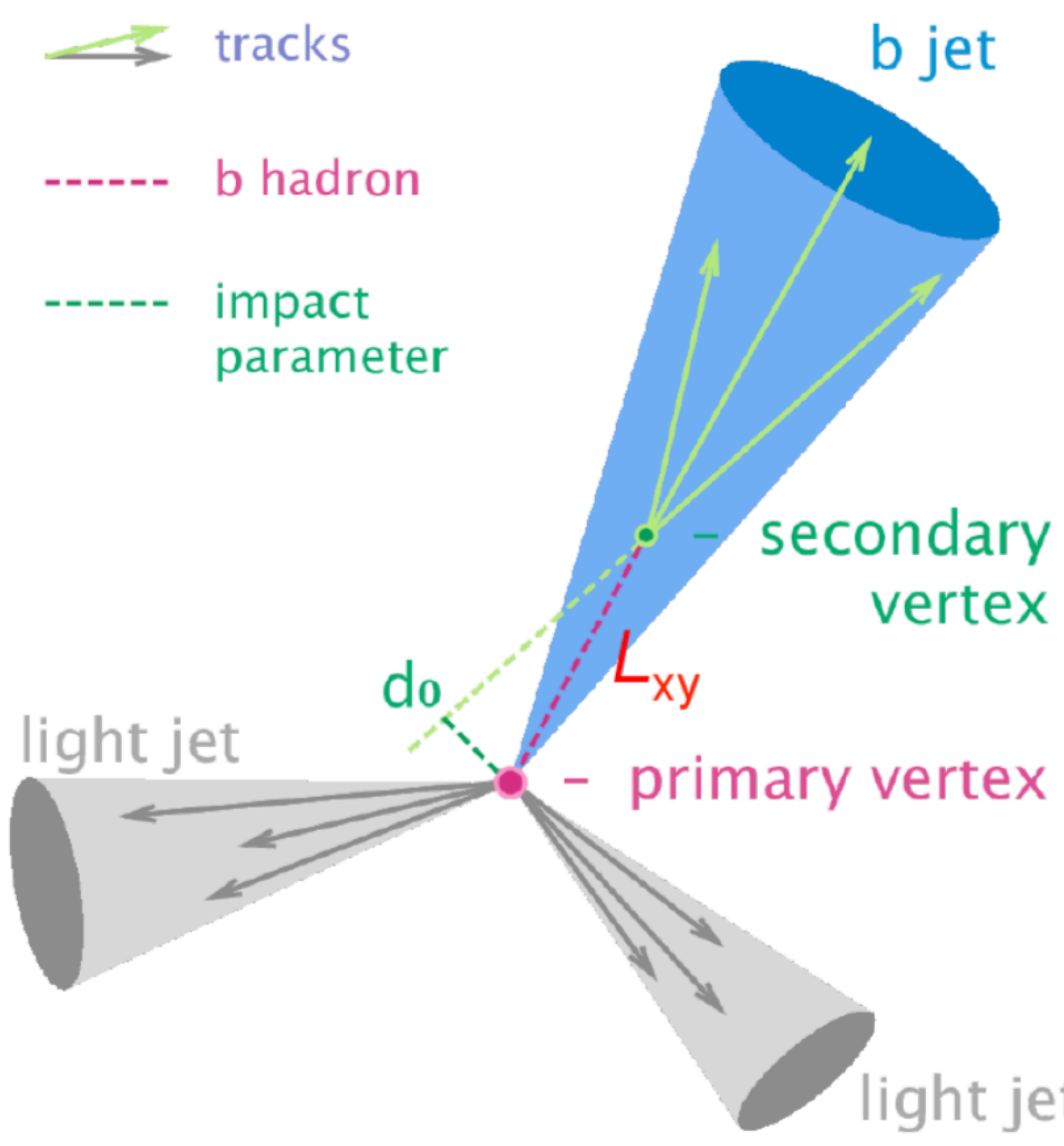


- Good agreement with NLO pQCD POWHEG+PYTHIA predictions
  - New results with pp collisions with the **larger data sample at 5 TeV and 13 TeV will be available soon**

HF Jets - c/b tagging

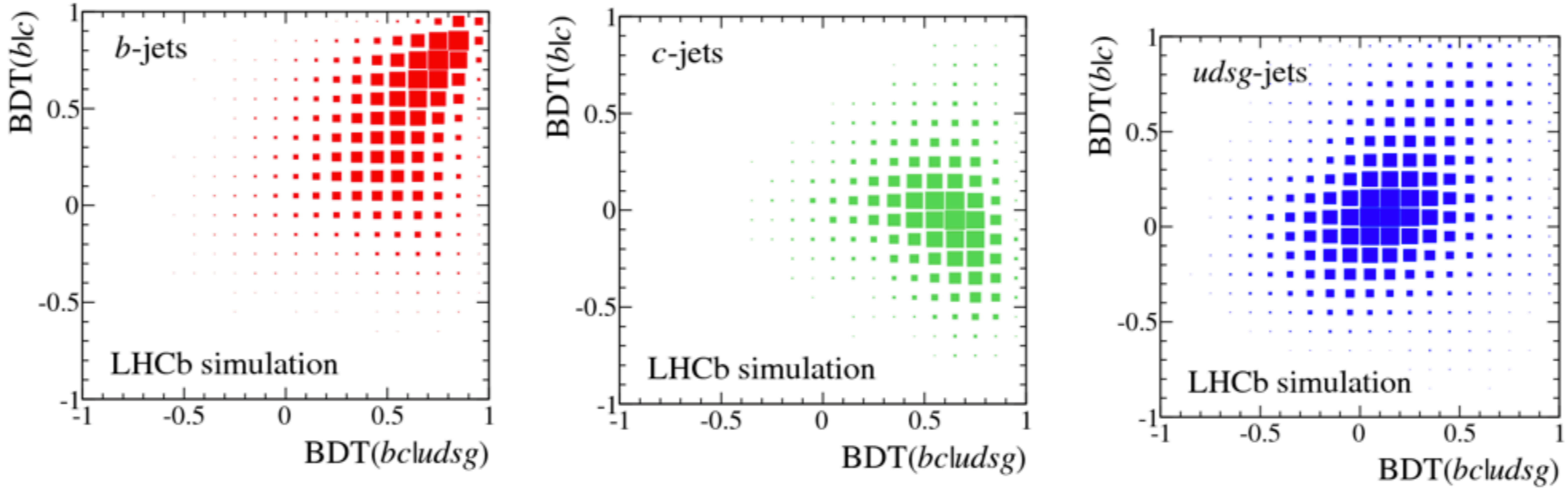
- Different approaches to tag b/c jets:
  - track based (impact parameter tag)
  - soft muon (discriminate μ from b decays)
  - vertex based

➡ BDT or Deep Learning Neural Network to maximise tag performance



http://bartosik.pp.ua/hep_sketches/btagging

Es. LHCb based on vertices reconstruction inside the jet cone



light-jet mistag rate < 1% for b-tag efficiency of 65% and c-tag efficiency of 25%

JINST 10 (2015) P06013

HF Jets - c/b tagging

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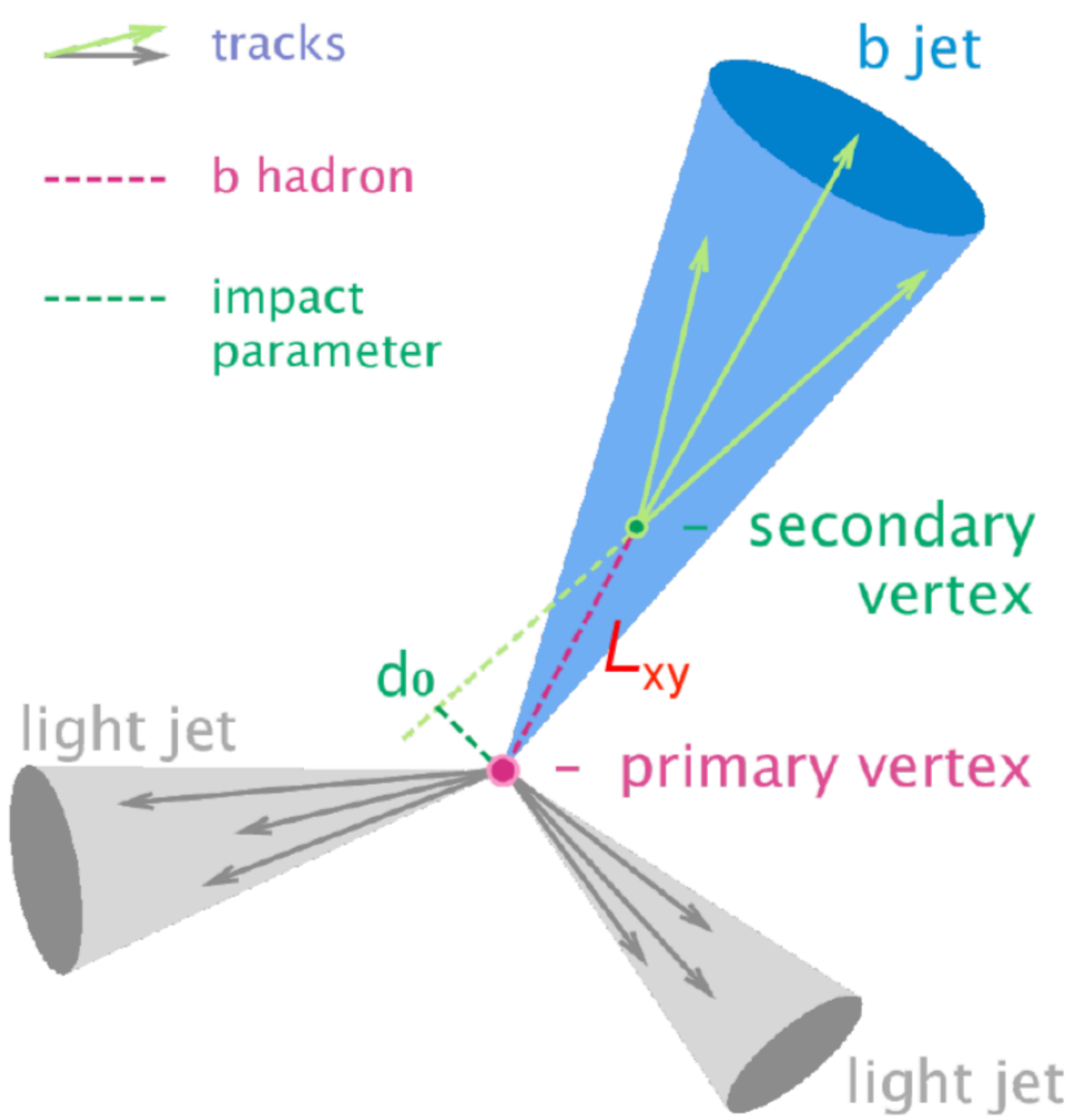
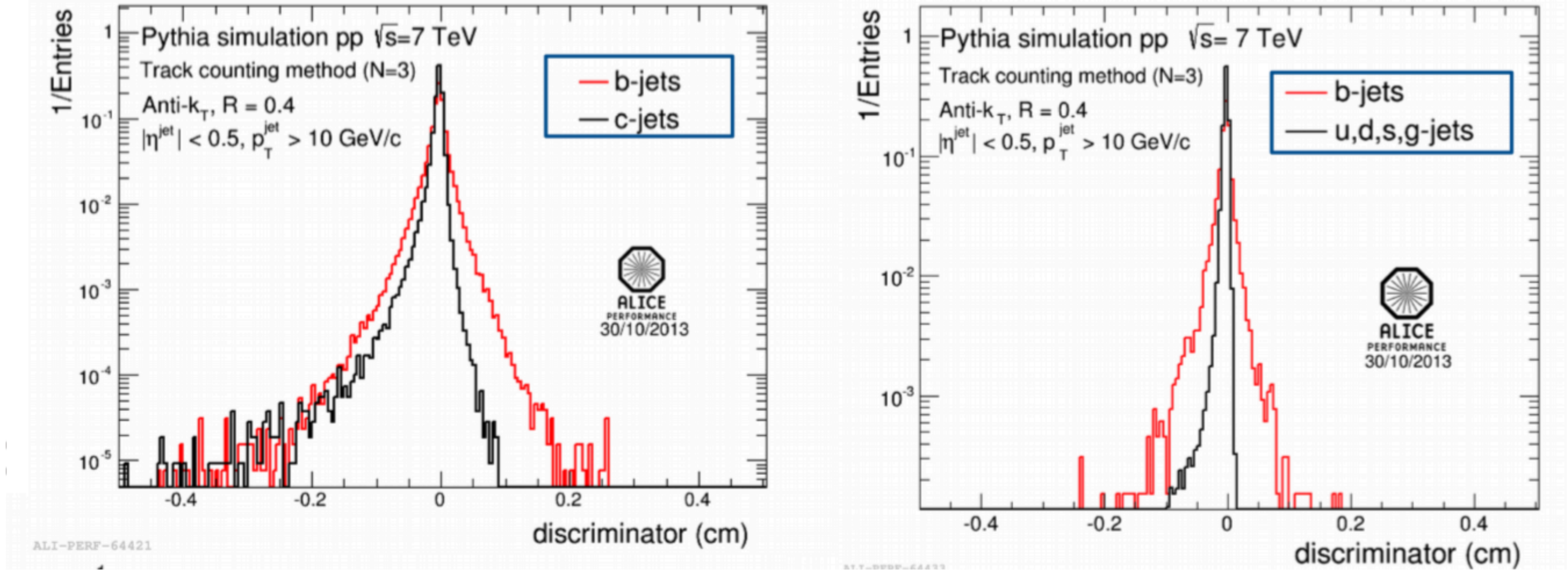
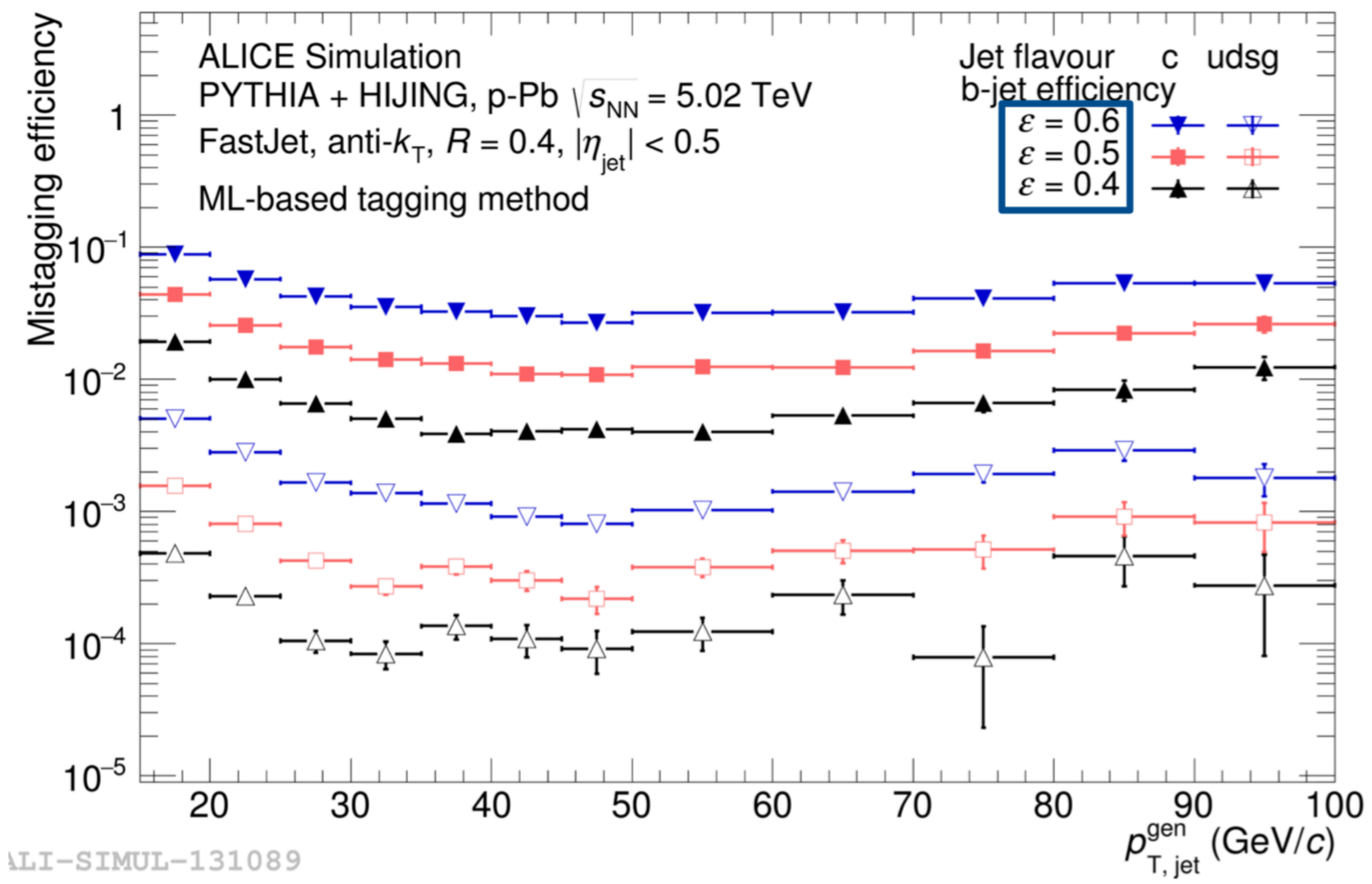


http://bartosik.pp.ua/hep_sketches/btagging

Es. ALICE impact parameter for each track within a jet + ML-based tagging method

N=3



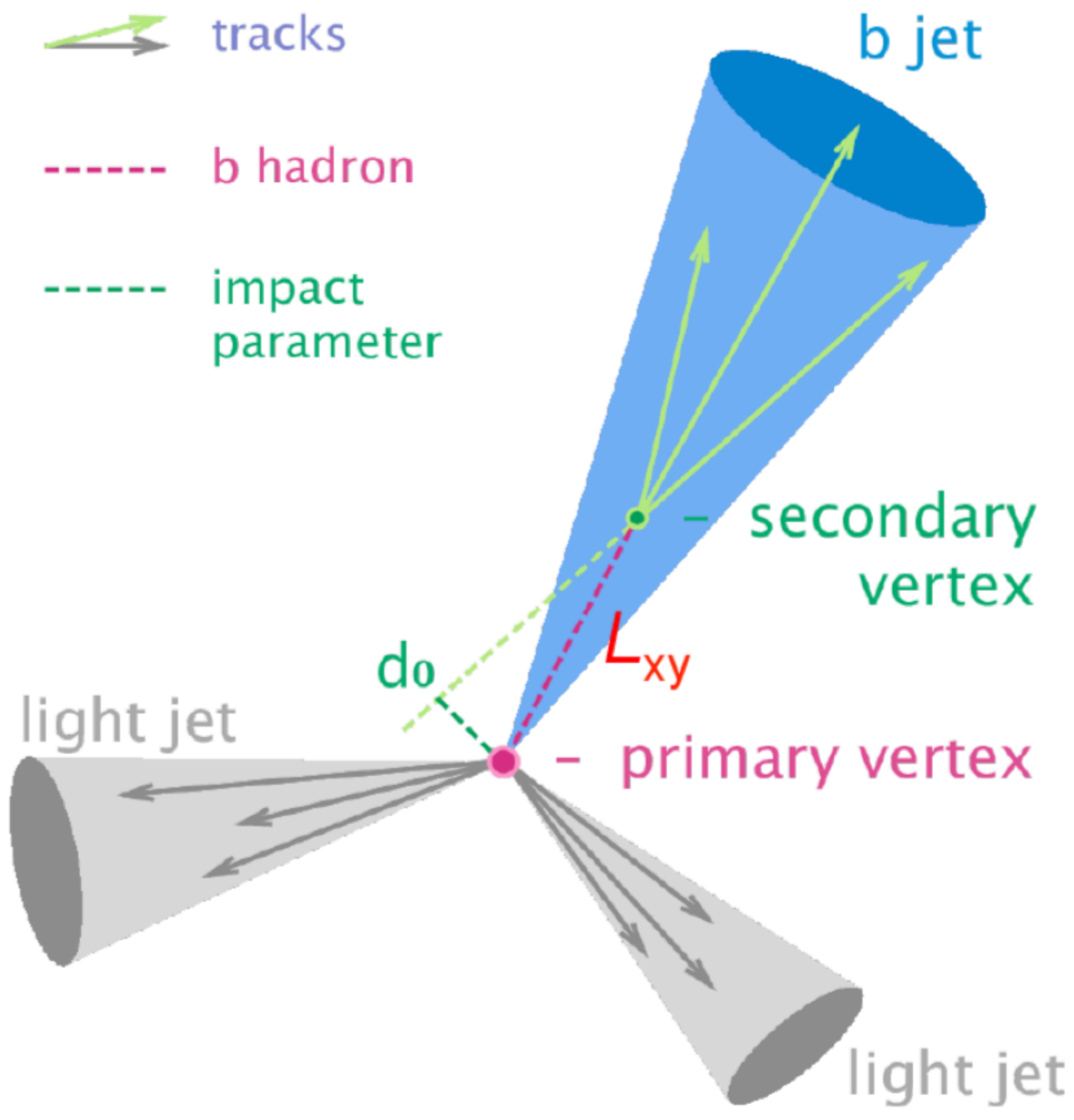


Cristina Bedda

HF Jets - c/b tagging

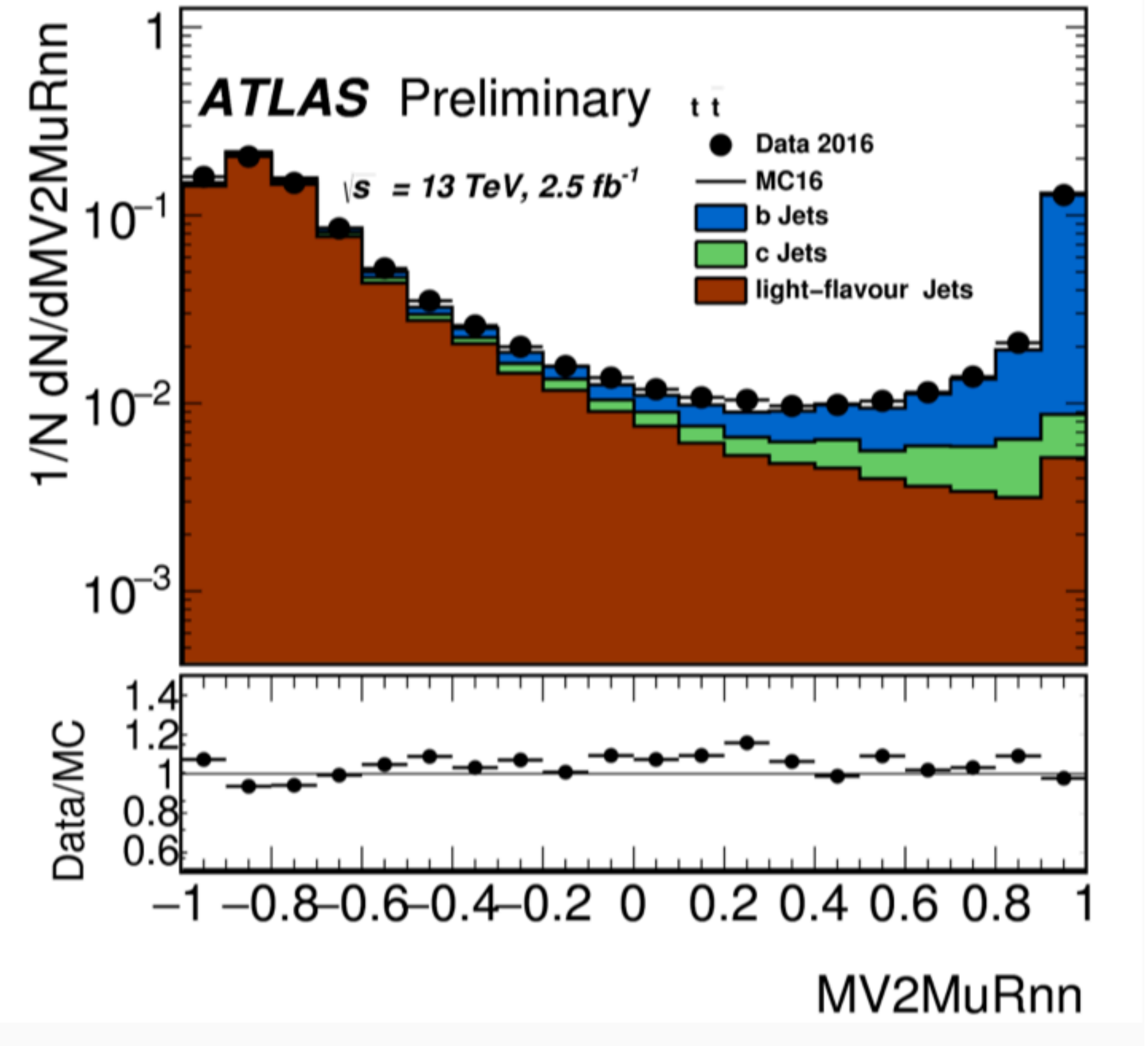
- Different approaches to tag b/c jets:
  - track based (impact parameter tag)
  - soft muon (discriminate μ from b decays)
  - vertex based

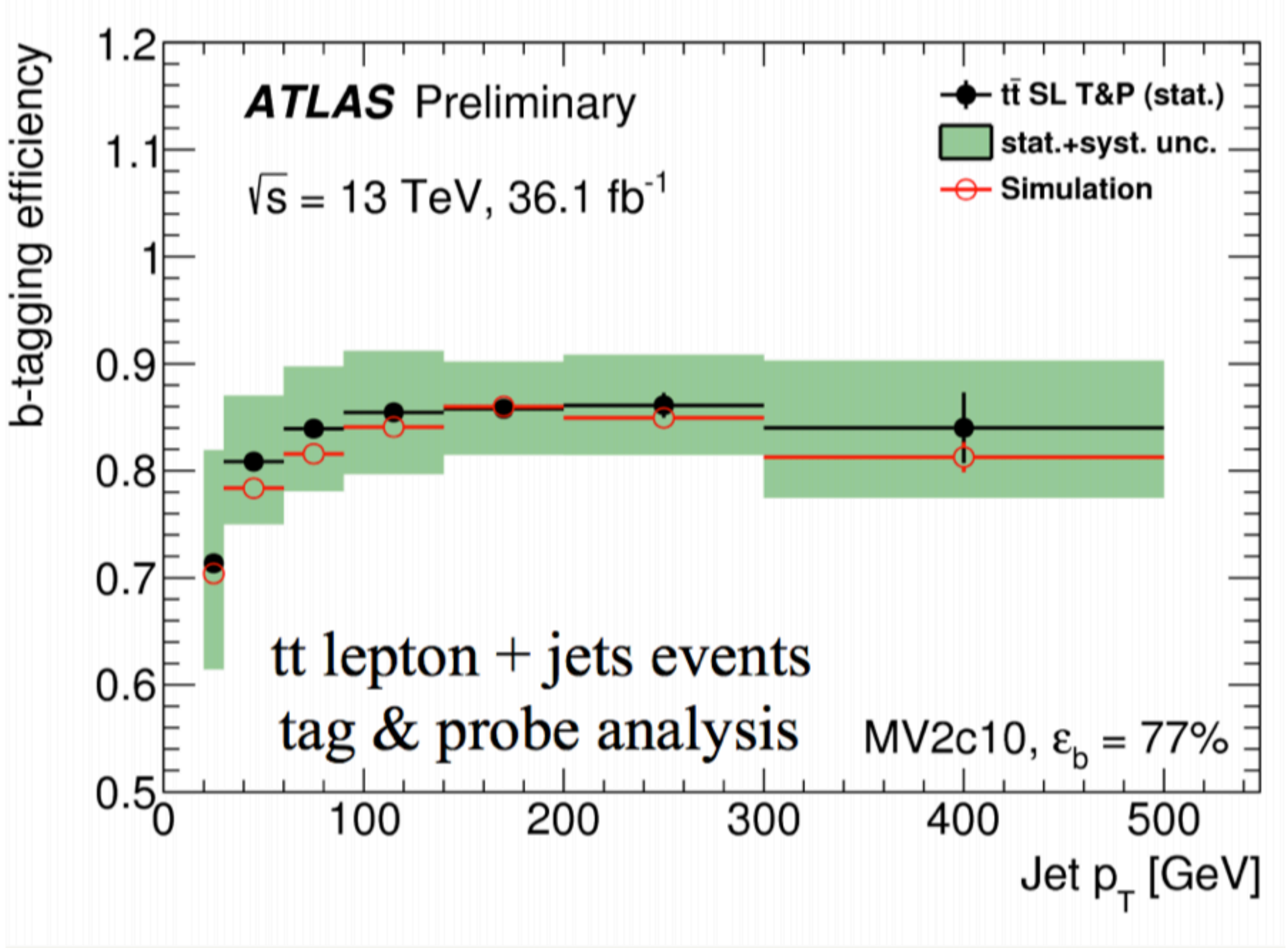
➡ BDT or Deep Learning Neural Network to maximise tag performance



http://bartosik.pp.ua/hep_sketches/btagging

Es. ATLAS multivariate classifier combining track, particle and vertex-base





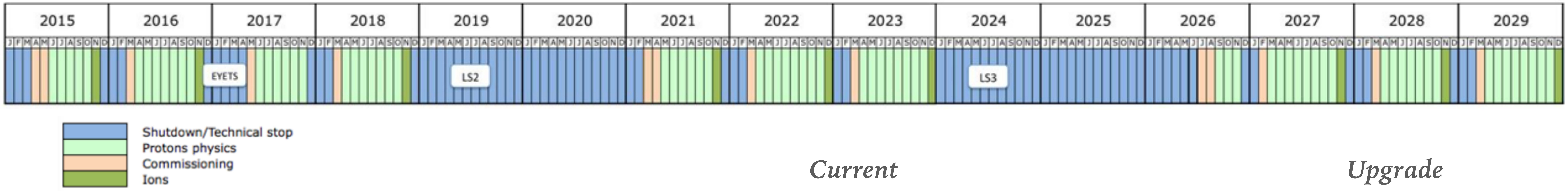
b-tag efficiency of 77% and c-tag efficiency of 25%

ATL-PHYS-PUB-2017-013

Future prospect

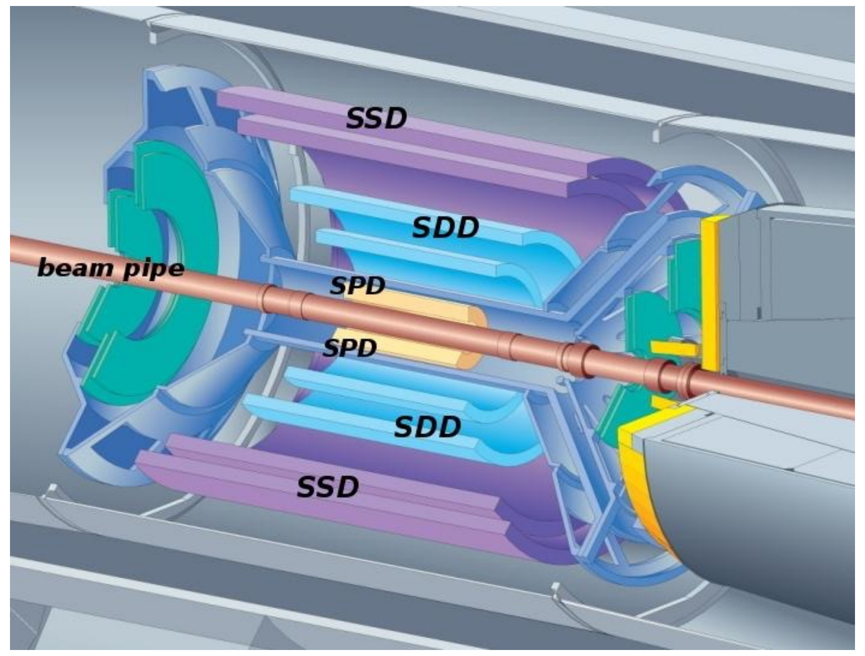
- A lot of data are still waiting to be analysed, more differential analysis will be possible with the large statistics available
- Full exploitation of machine learning techniques
- Update of several detectors ongoing and huge amount of new data to be collected in Run3 and 4

Run 3 **Run 4**

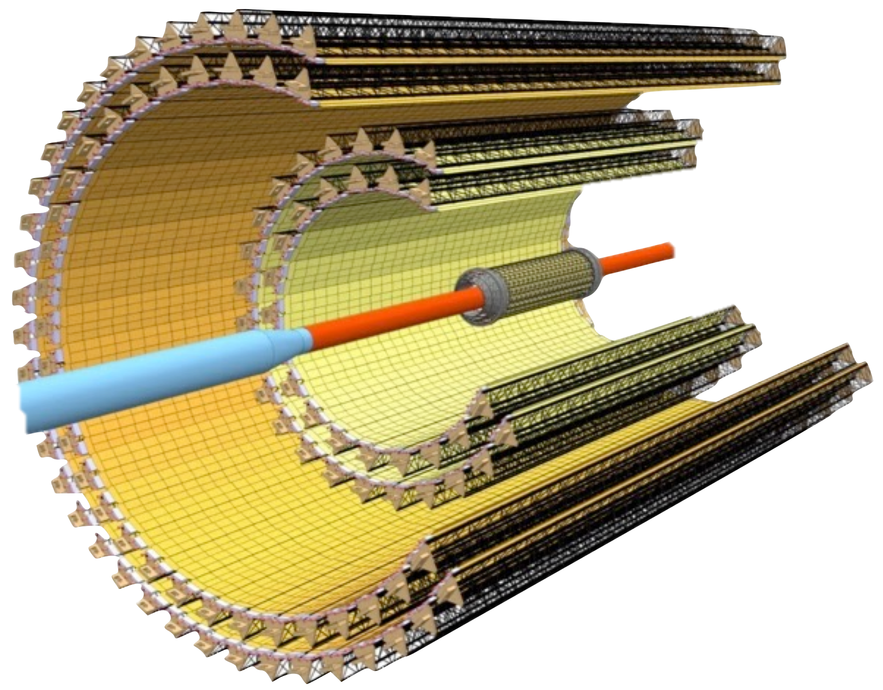


- Es. ALICE new Inner Tracking System designed to enhance heavy flavour reconstruction

Current

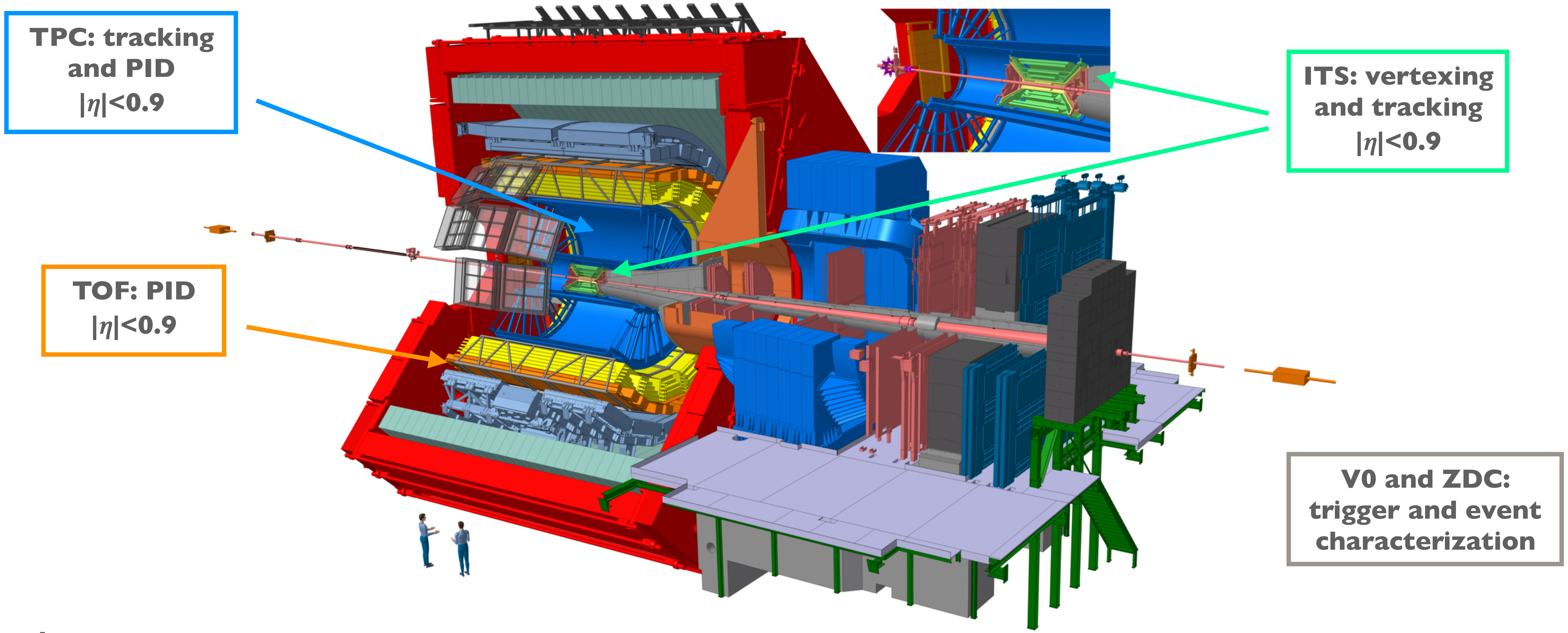


Upgrade



Backup

The ALICE detector



Data samples:

- **pp** collisions (Run 2) at $\sqrt{s}$**=5.02 TeV:** 990 M minimum-bias events, L_{int}=19 nb^{-1}
- **pp** collisions (Run 1) at $\sqrt{s}$**=7 TeV**: 370 M minimum-bias events, L_{int}=6 nb^{-1}
- **p-Pb** collisions (Run 2) at $\sqrt{s_{NN}}$**=5.02 TeV**: 600 M minimum-bias events, L_{int}=292 ub^{-1}
- **p-Pb** collisions (Run 1) at $\sqrt{s_{NN}}$**=5.02 TeV:** 160 M minimum-bias events, L_{int}=49 ub^{-1}

D-meson nuclear modification factor (R_{pPb})

RUN 2

higher p_{T} reach and precision
and new pp reference at 5 TeV

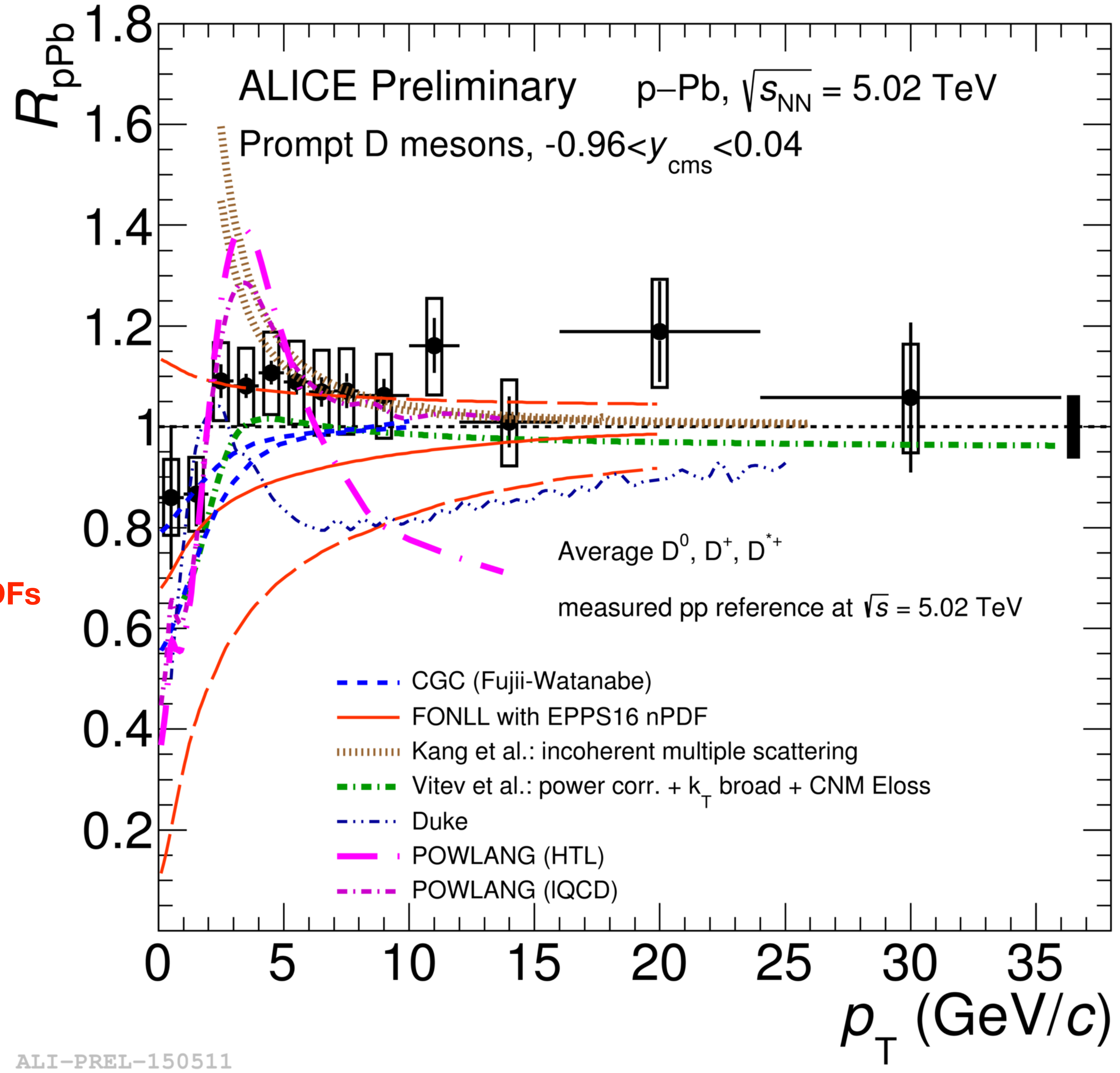
$$R_{\mathrm{pPb}} = \frac{\left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{pPb}}}{A \times \left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{pp}}}$$

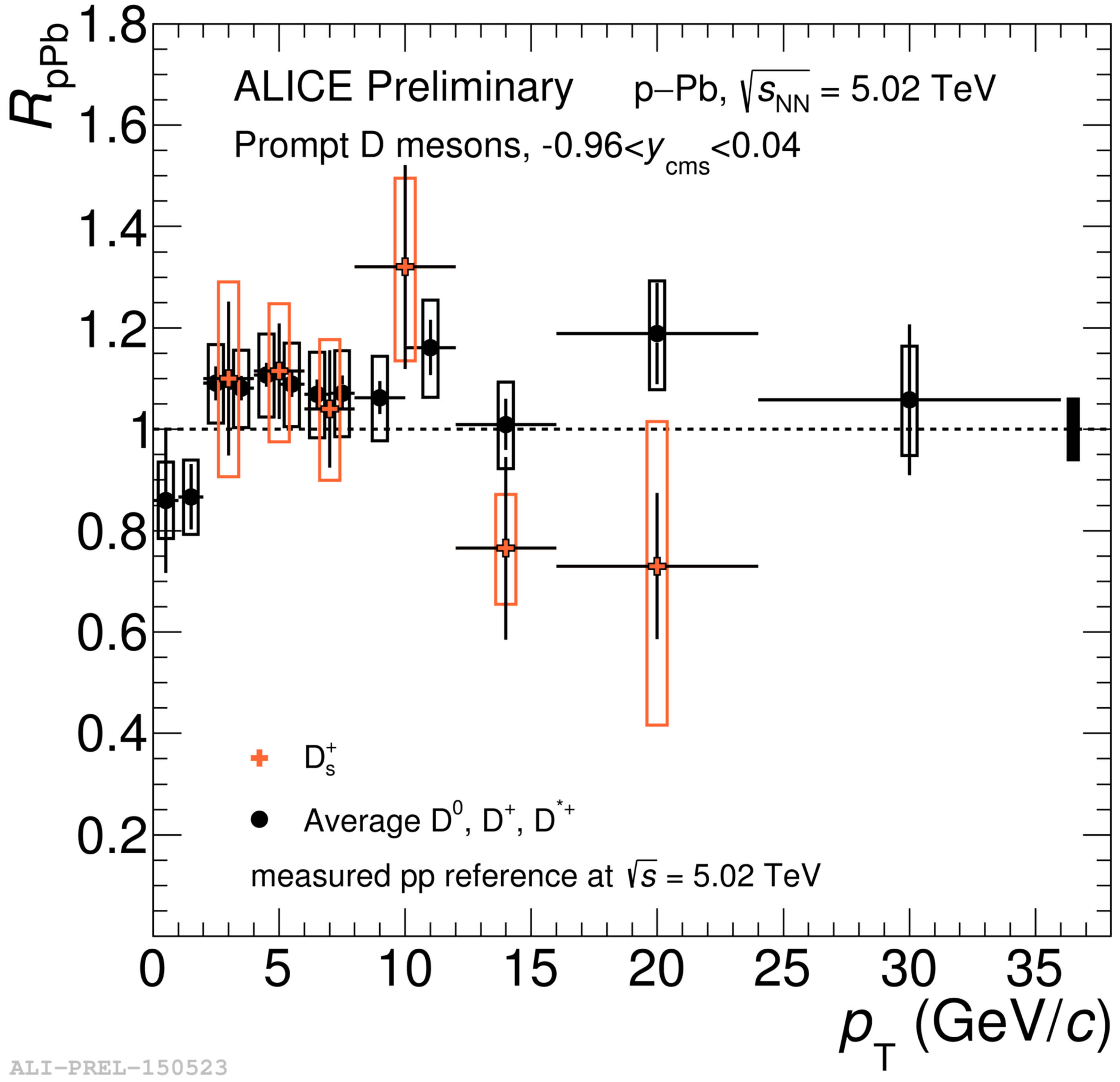
Models including CNM effects:

- CGC: arXiv:1706.06728
- FONLL (JHEP 1210 (2012) 137, arXiv:1205.6344) with EPPS16 nPDFs (Eur. Phys. J. C77 no. 3, (2017) 163, arXiv:1612.05741)
- Vitev et al: Phys.Rev. C80 (2009) 054902, arXiv:0904.0032.
- Kang et al.: Phys. Lett. B740 (2015) 23–29, arXiv:1409.2494.

Models including the QGP formation:

- Duke: Nucl. xPart. Phys. Proc. 276-278 (2016) 225–228, arXiv:1510.07520.
- POWLANG JHEP 03 (2016) 123, arXiv:1512.05186.

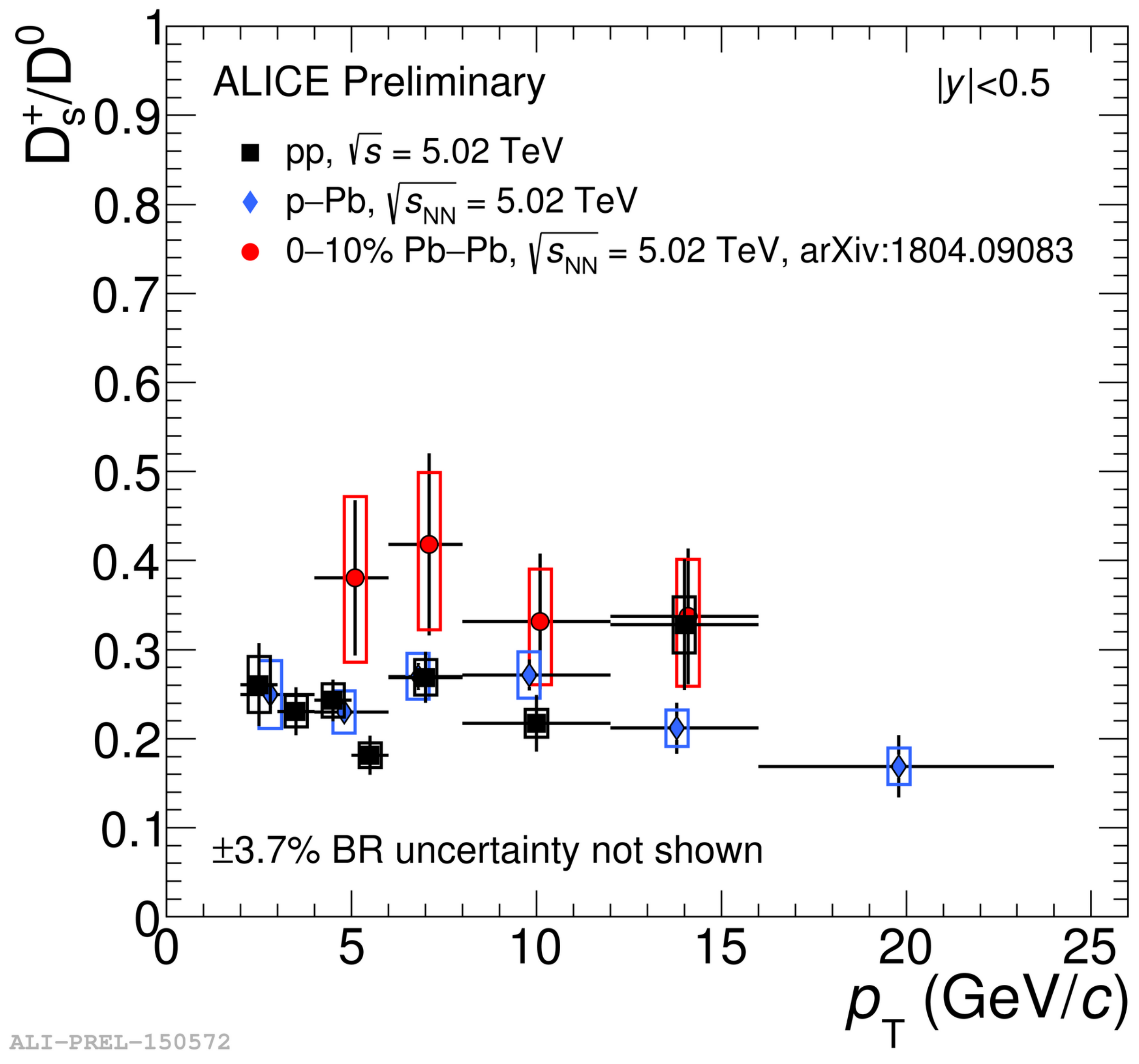




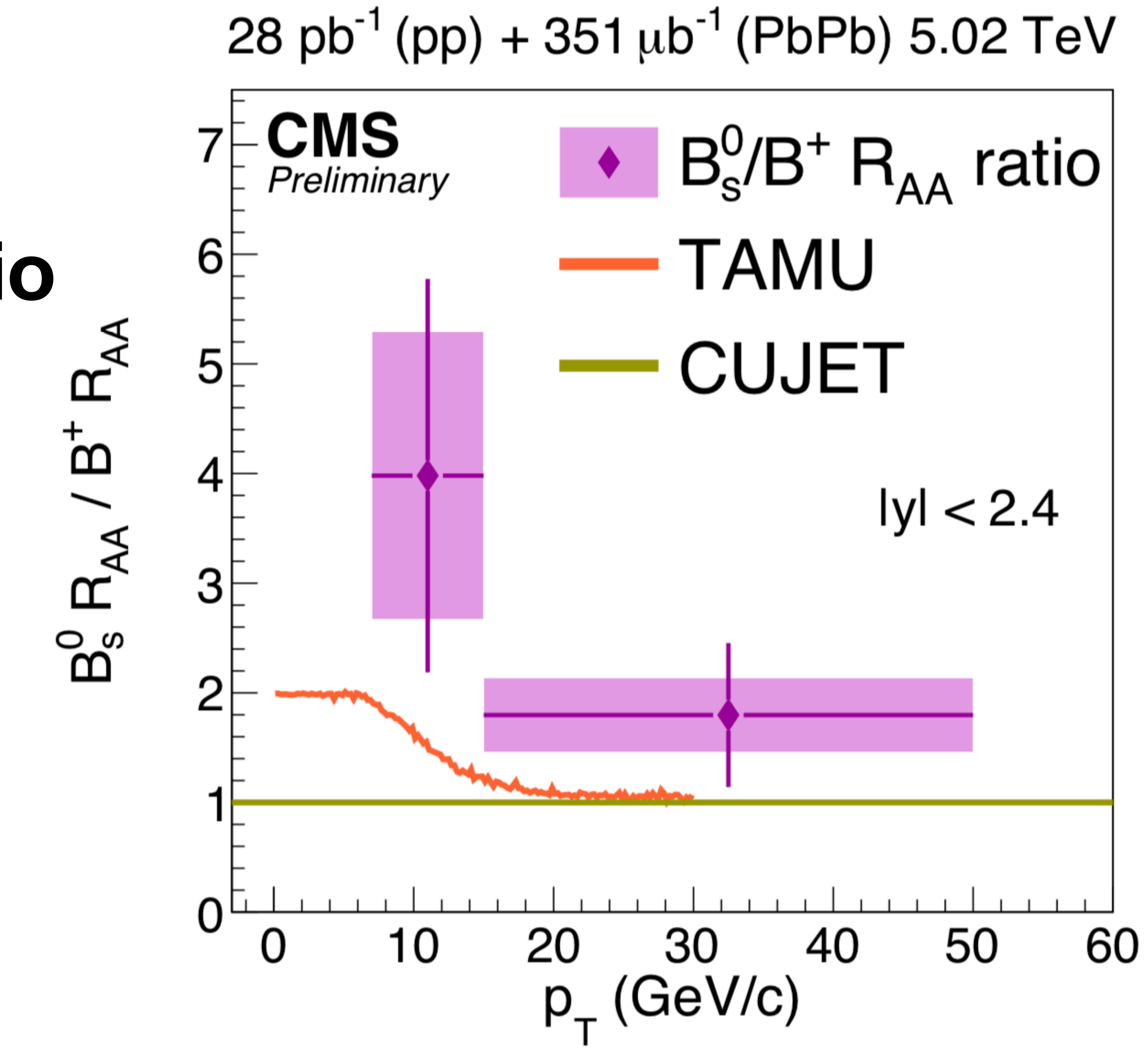
- D-meson R_{pPb} compatible with unity
- Data described by models including Cold Nuclear Matter effects, as well as effects deriving from the formation of QGP in p-Pb collisions
  - data disfavour a suppression larger than 10-15% at high p_{T}
- **D_s R_{pPb} compatible with non-strange D mesons** within uncertainties

Pb-Pb collisions

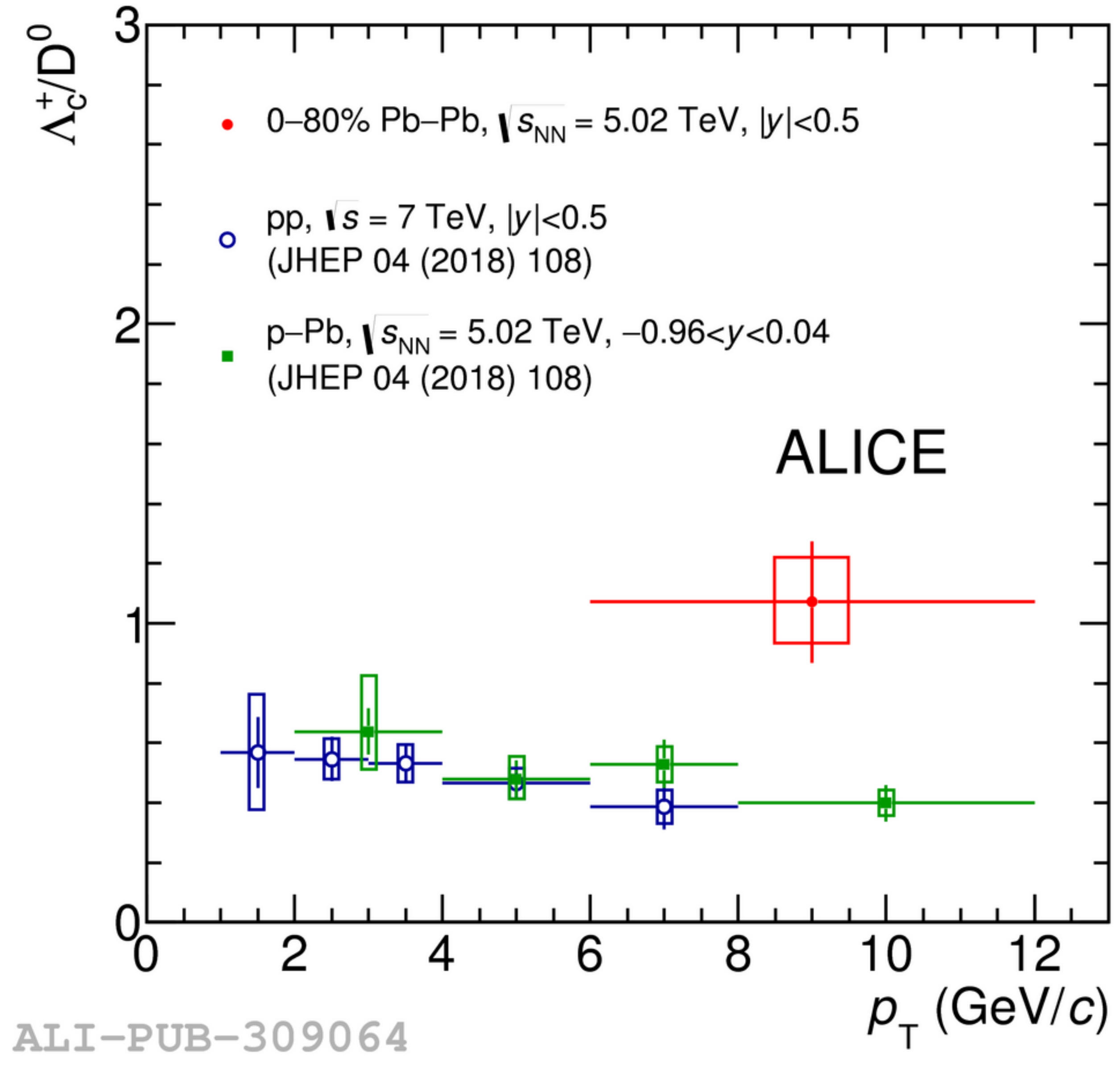
D species ratio

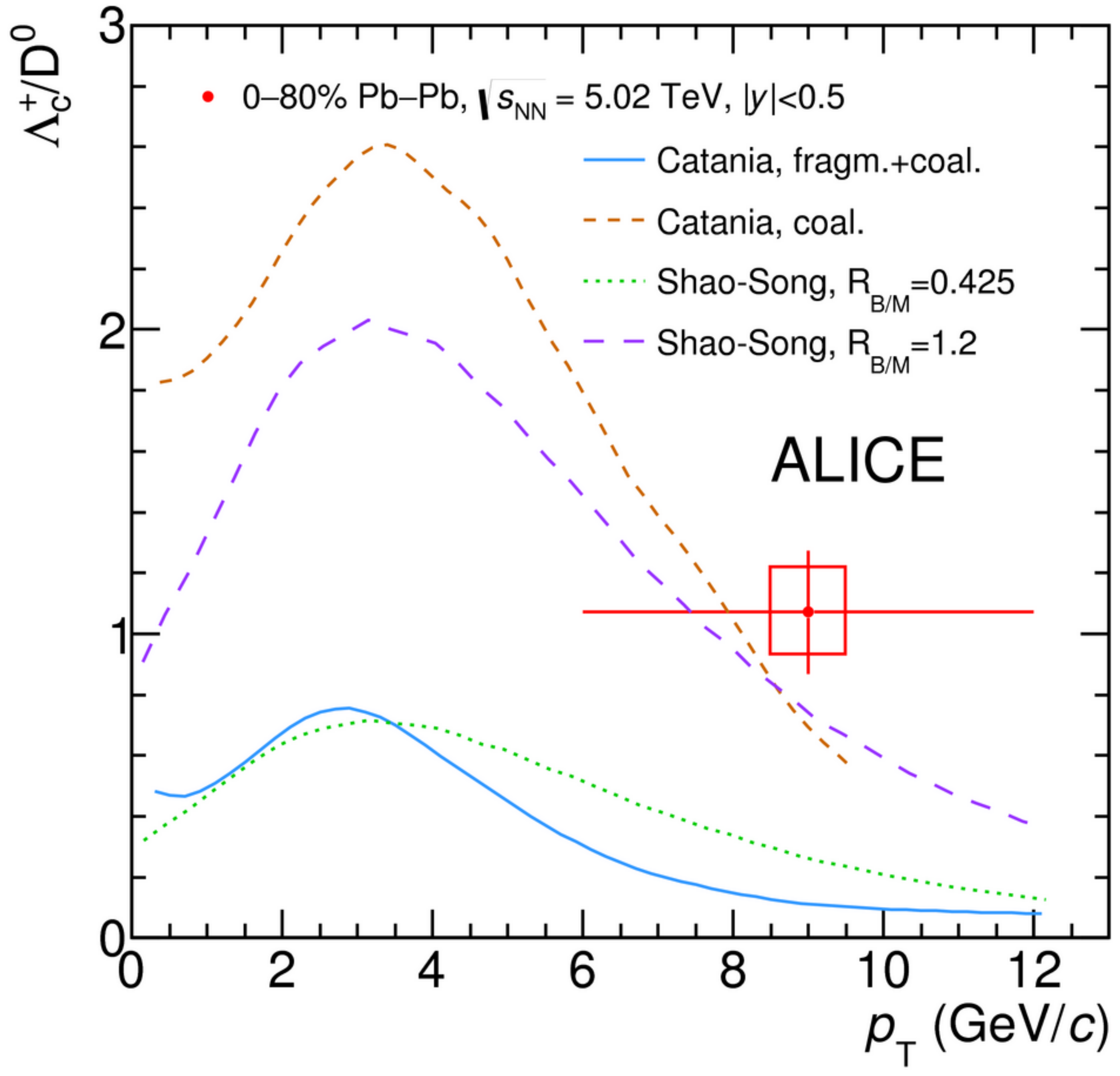


B species ratio



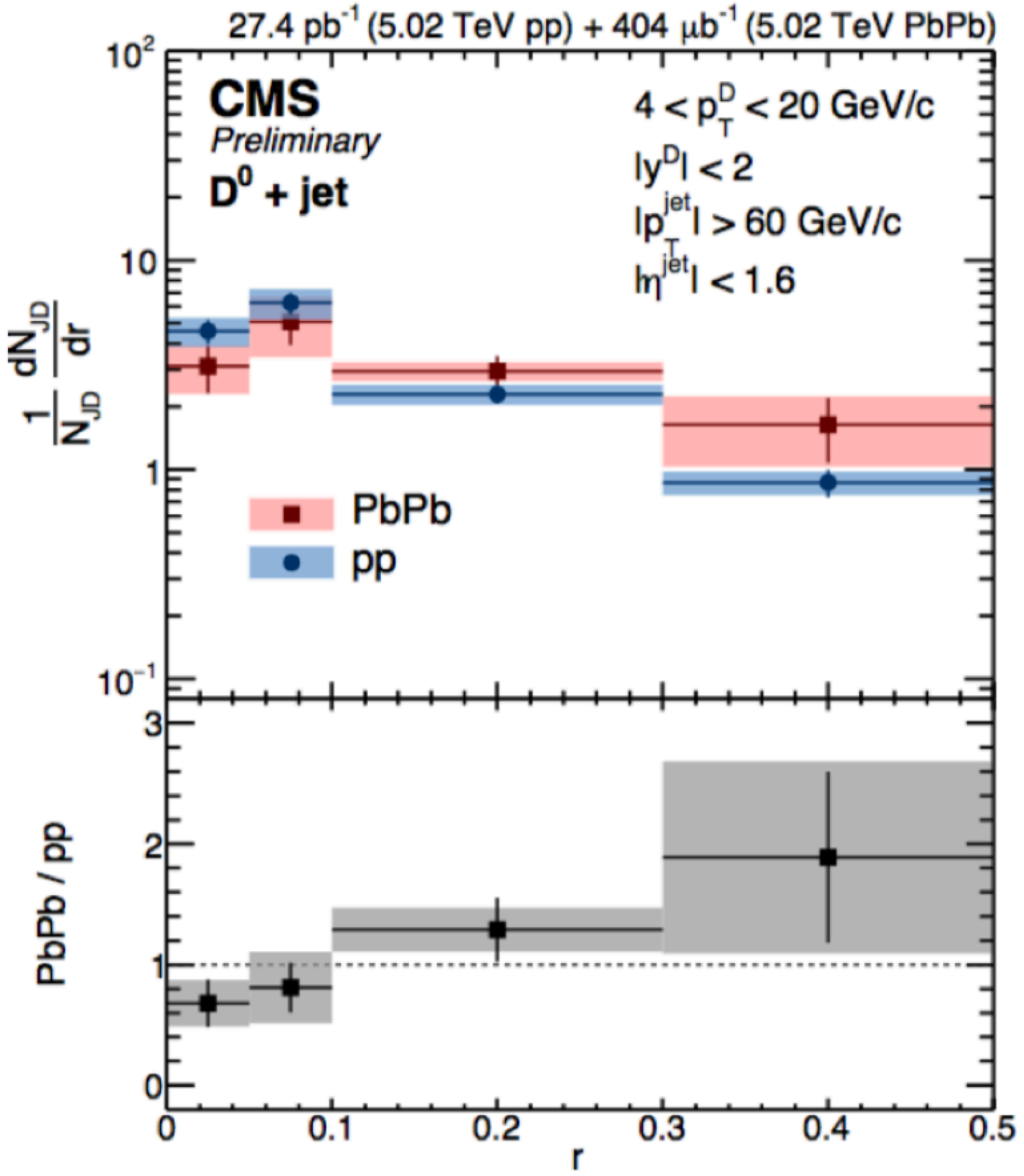
Λ_c/D^0



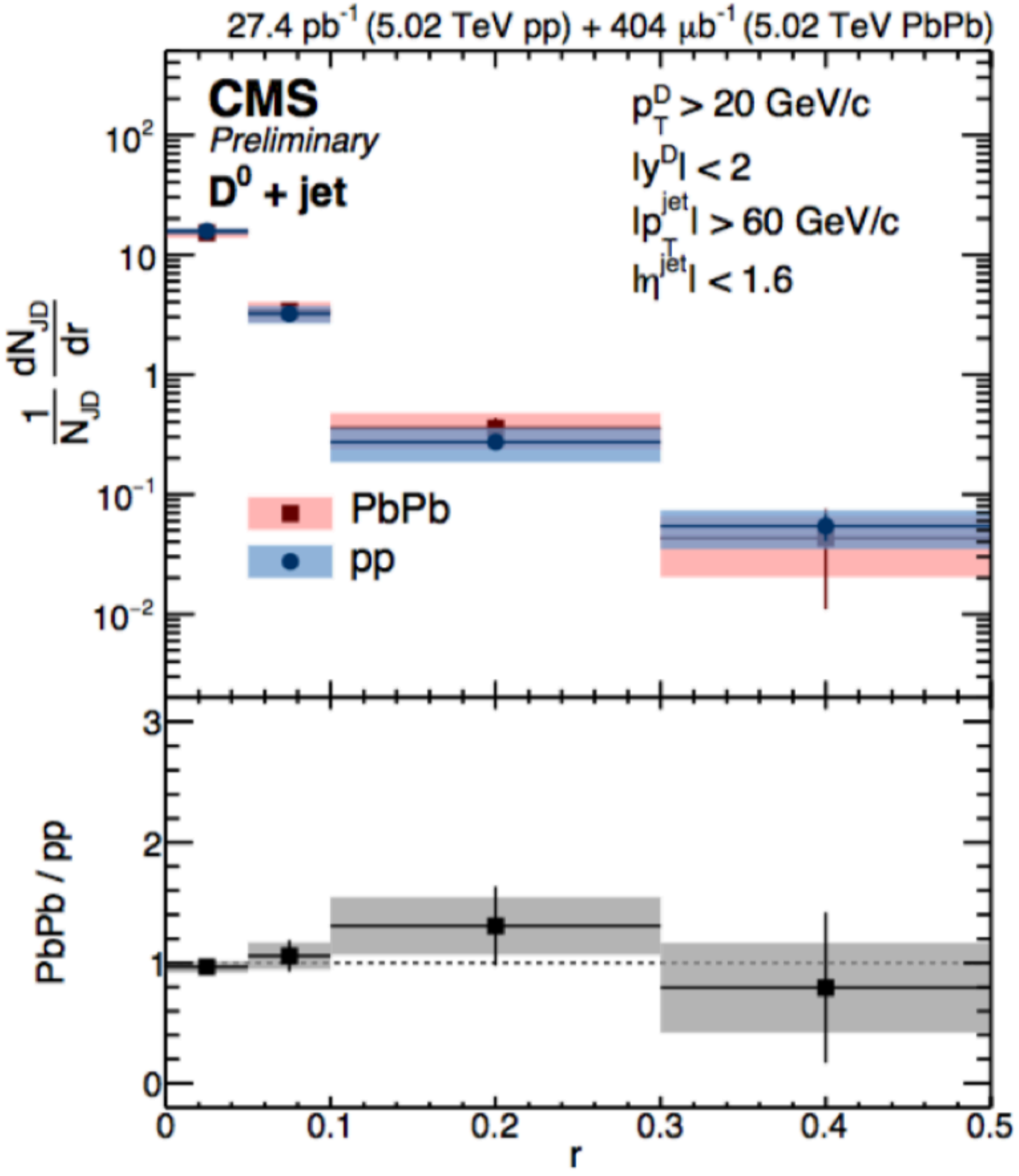


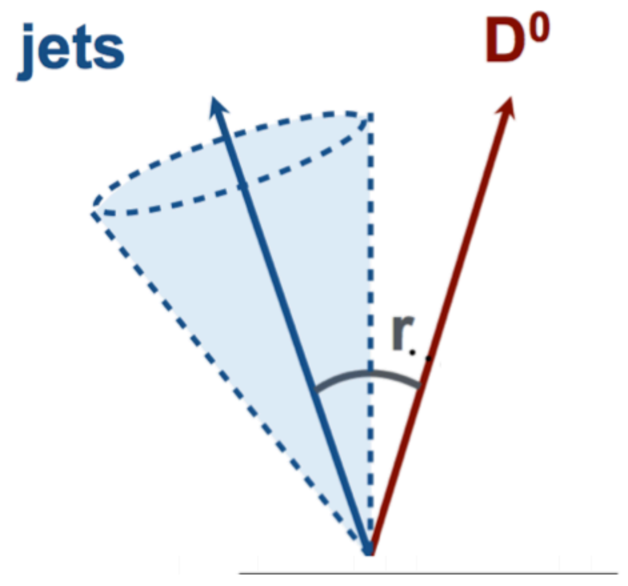
D inside jets by CMS

$4 < p_T^{D0} < 20$ GeV/c

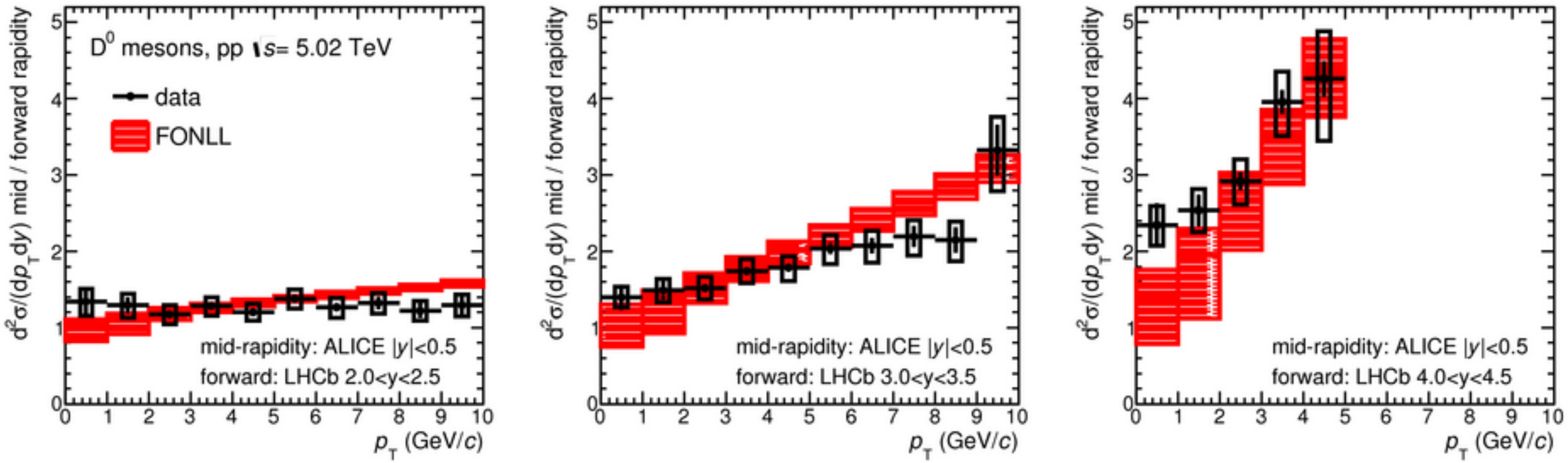


$p_T^{D0} > 20$ GeV/c



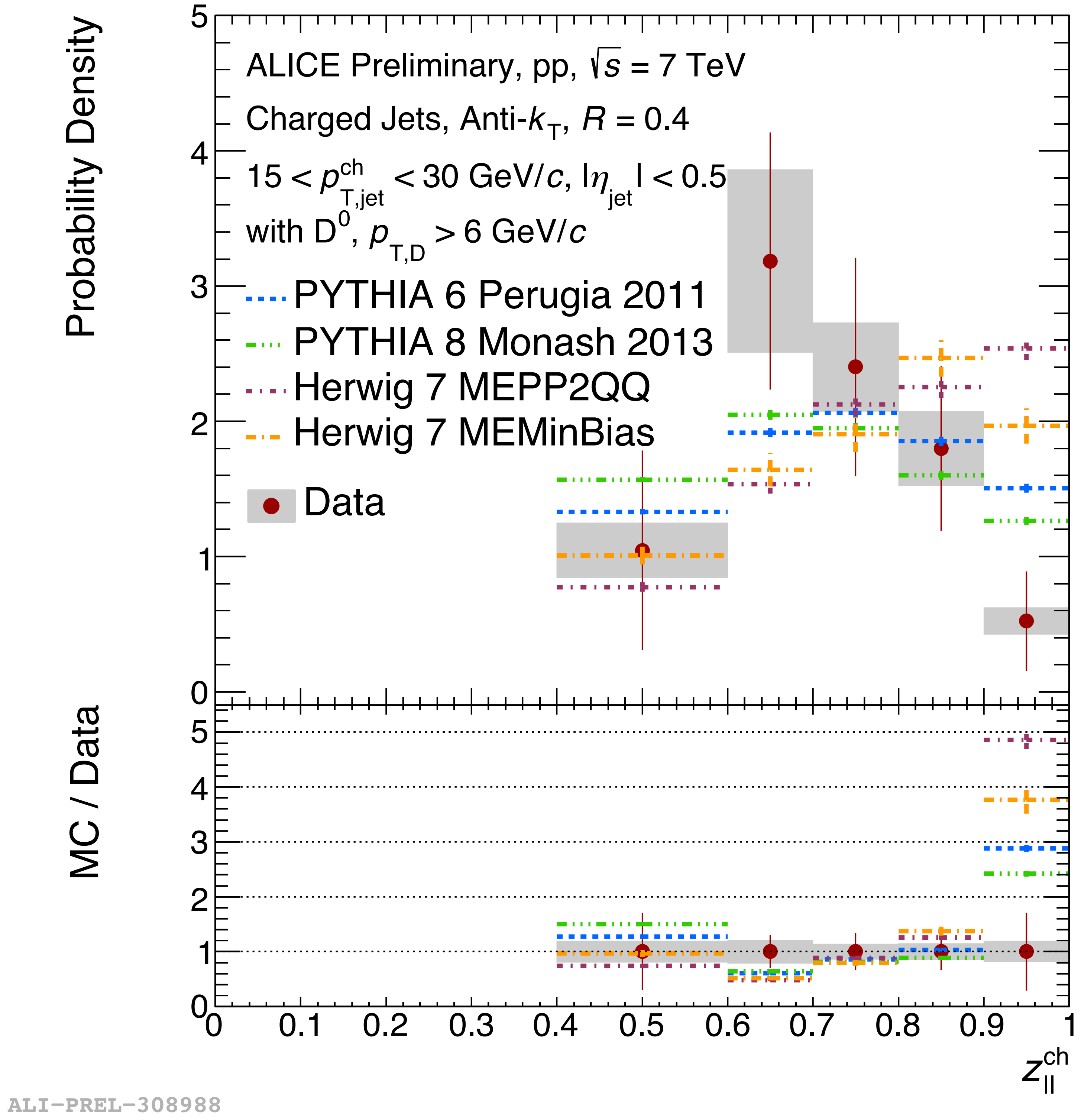


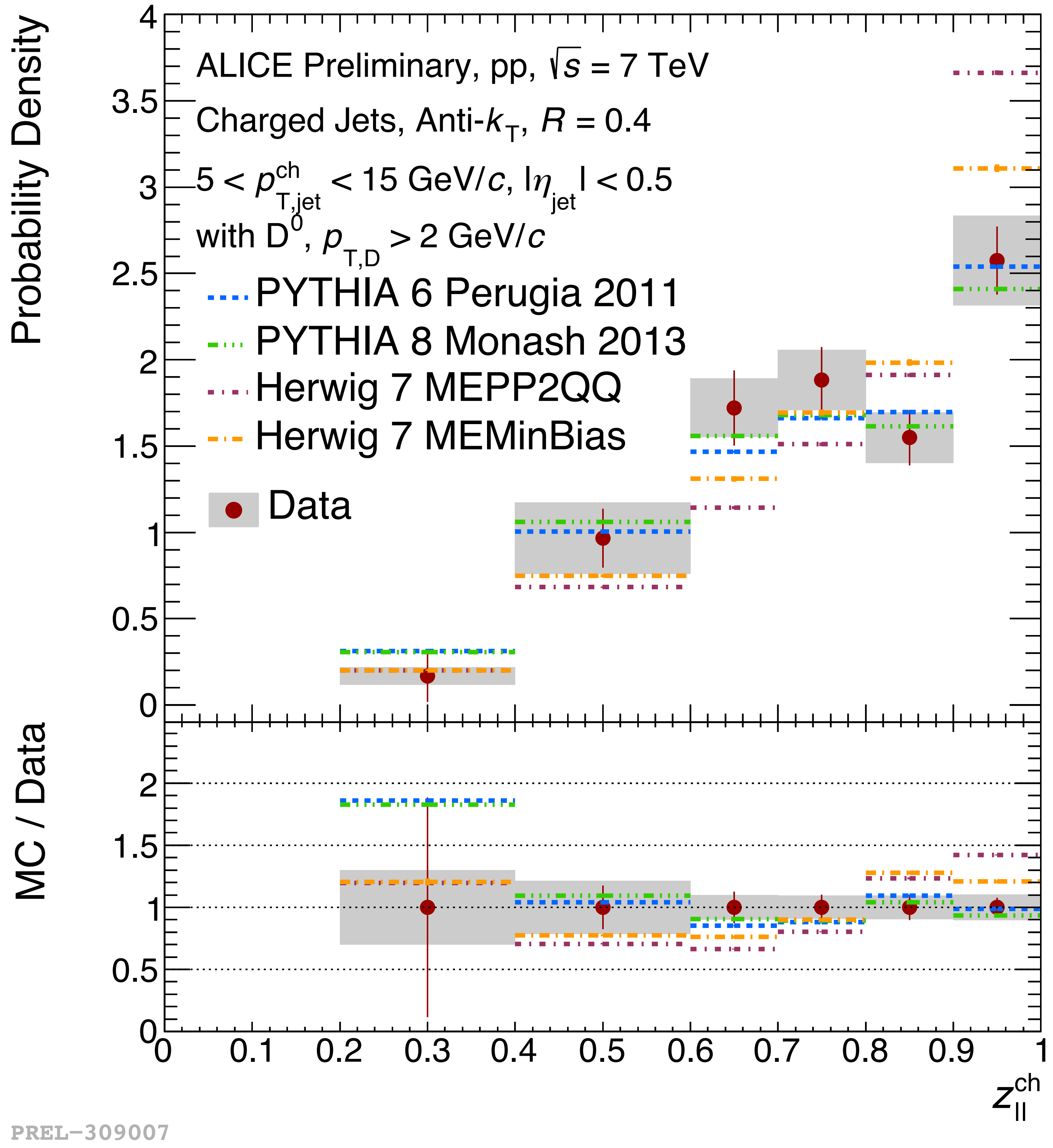
Open charm-meson reconstruction
Mid/forward production



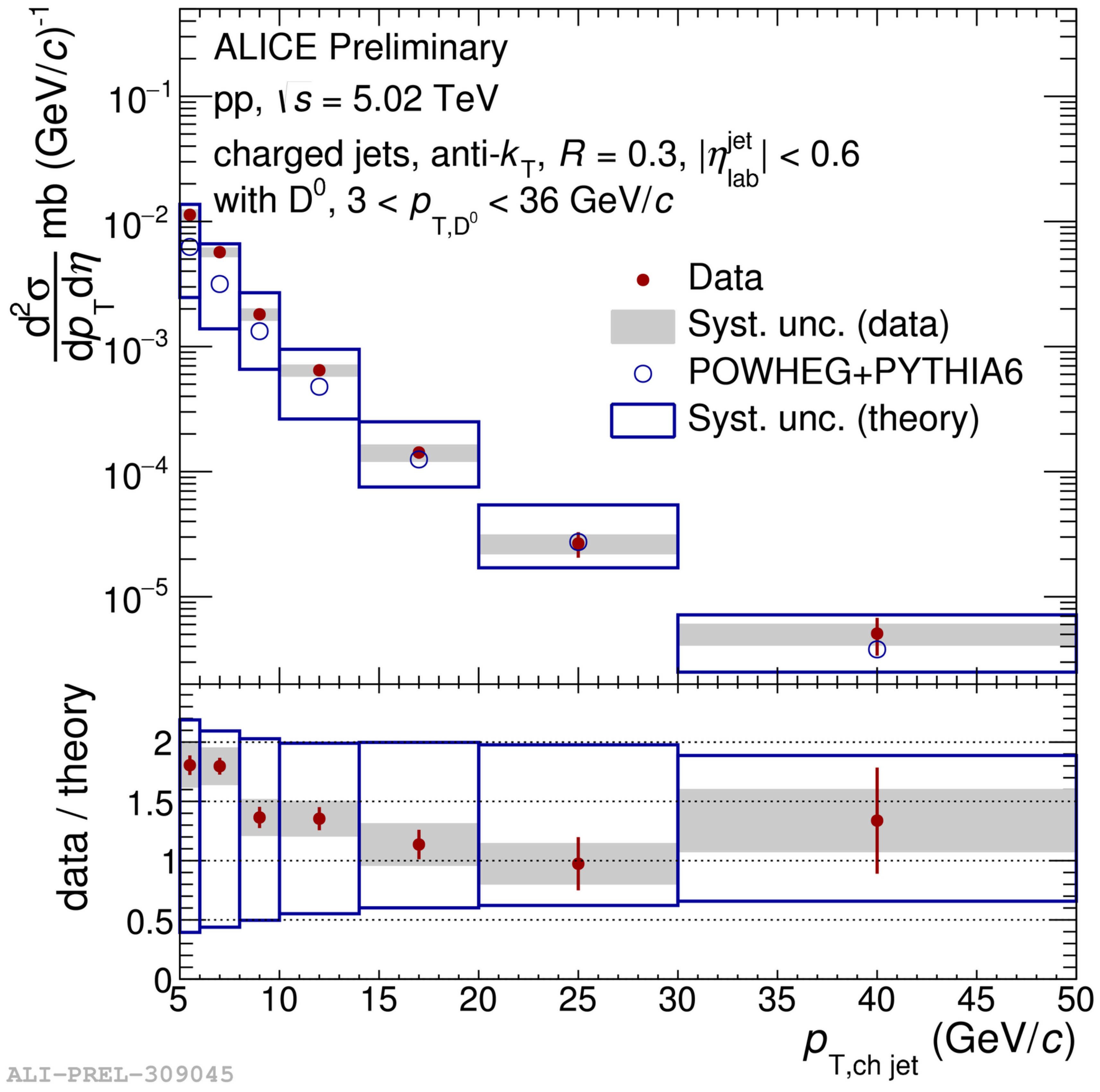
D^0 tagged jets

Other comparisons

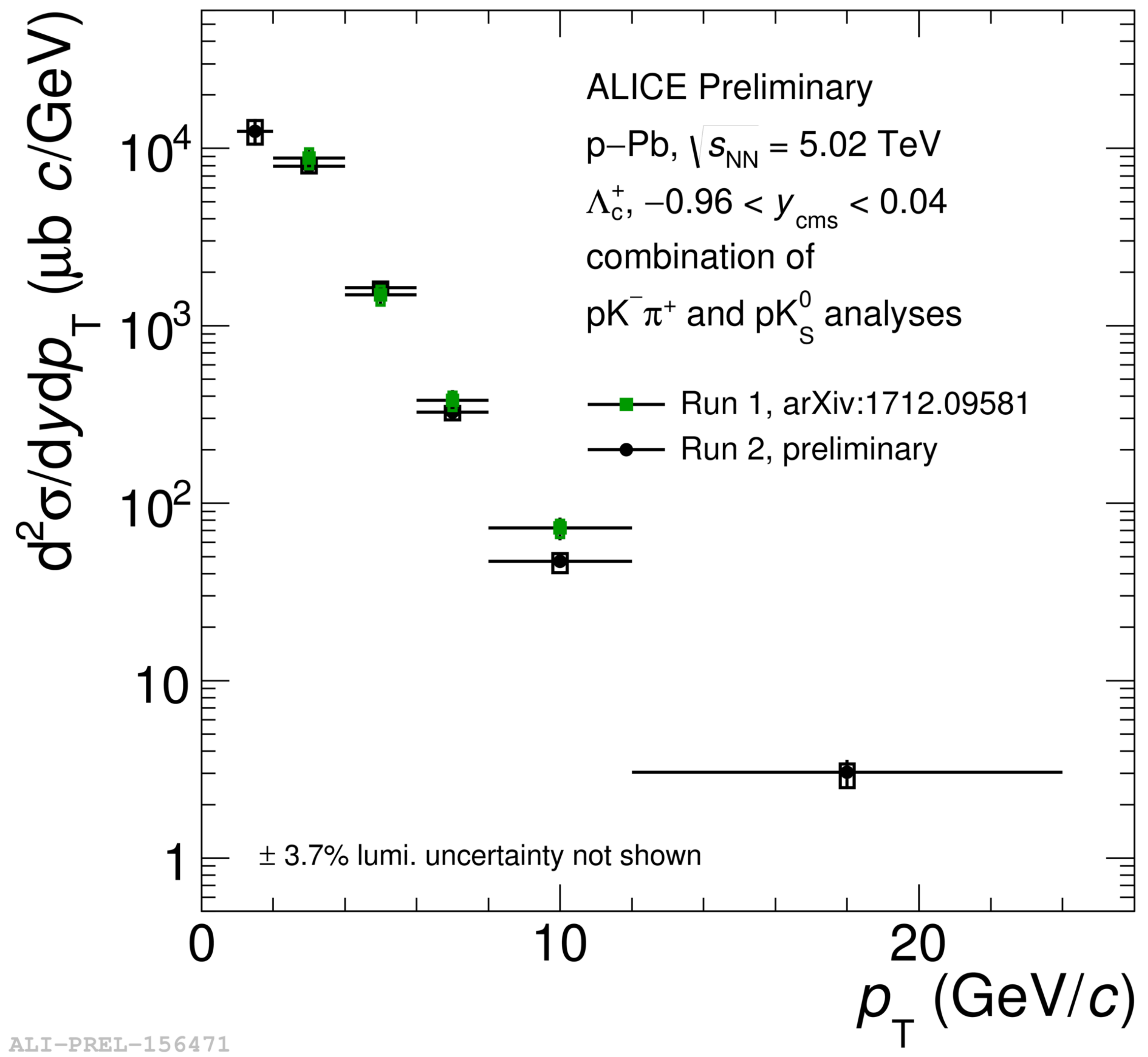




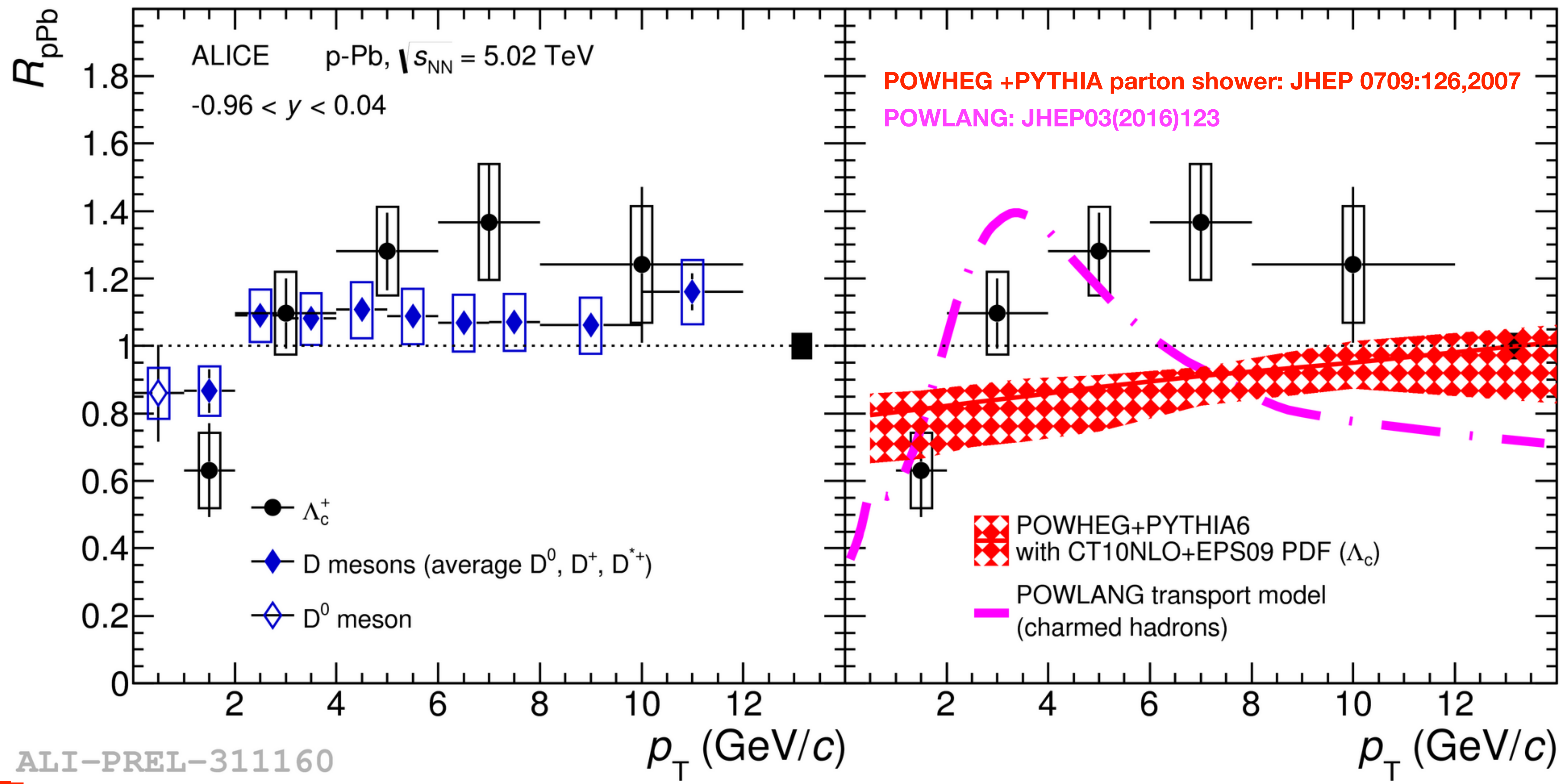
pp @ 5TeV



Λ_c nuclear modification factor (R_{pPb})



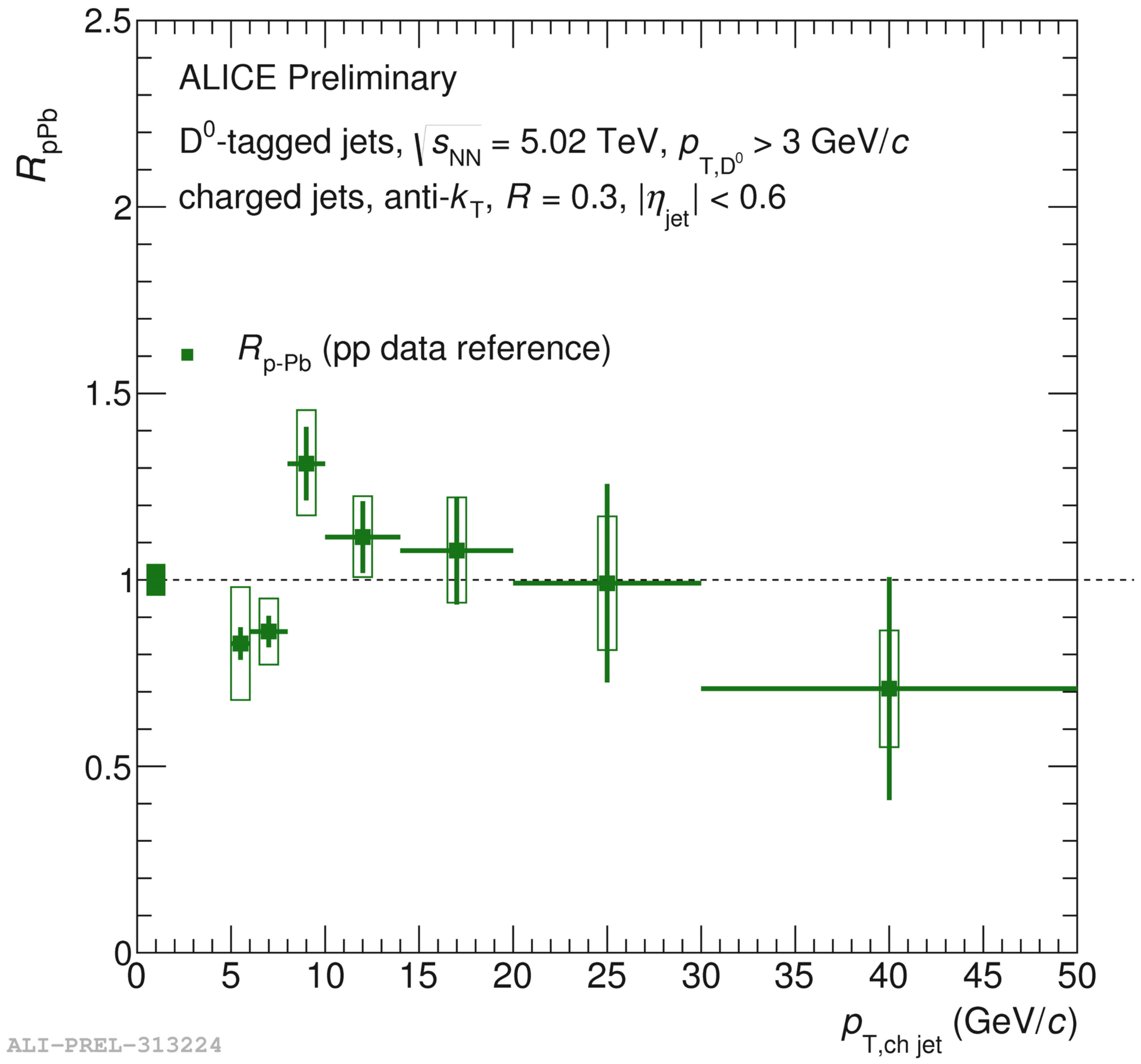
$$R_{pPb} = \frac{\left(\frac{d\sigma}{dp_T}\right)_{pPb}}{A \times \left(\frac{d\sigma}{dp_T}\right)_{pp}}$$



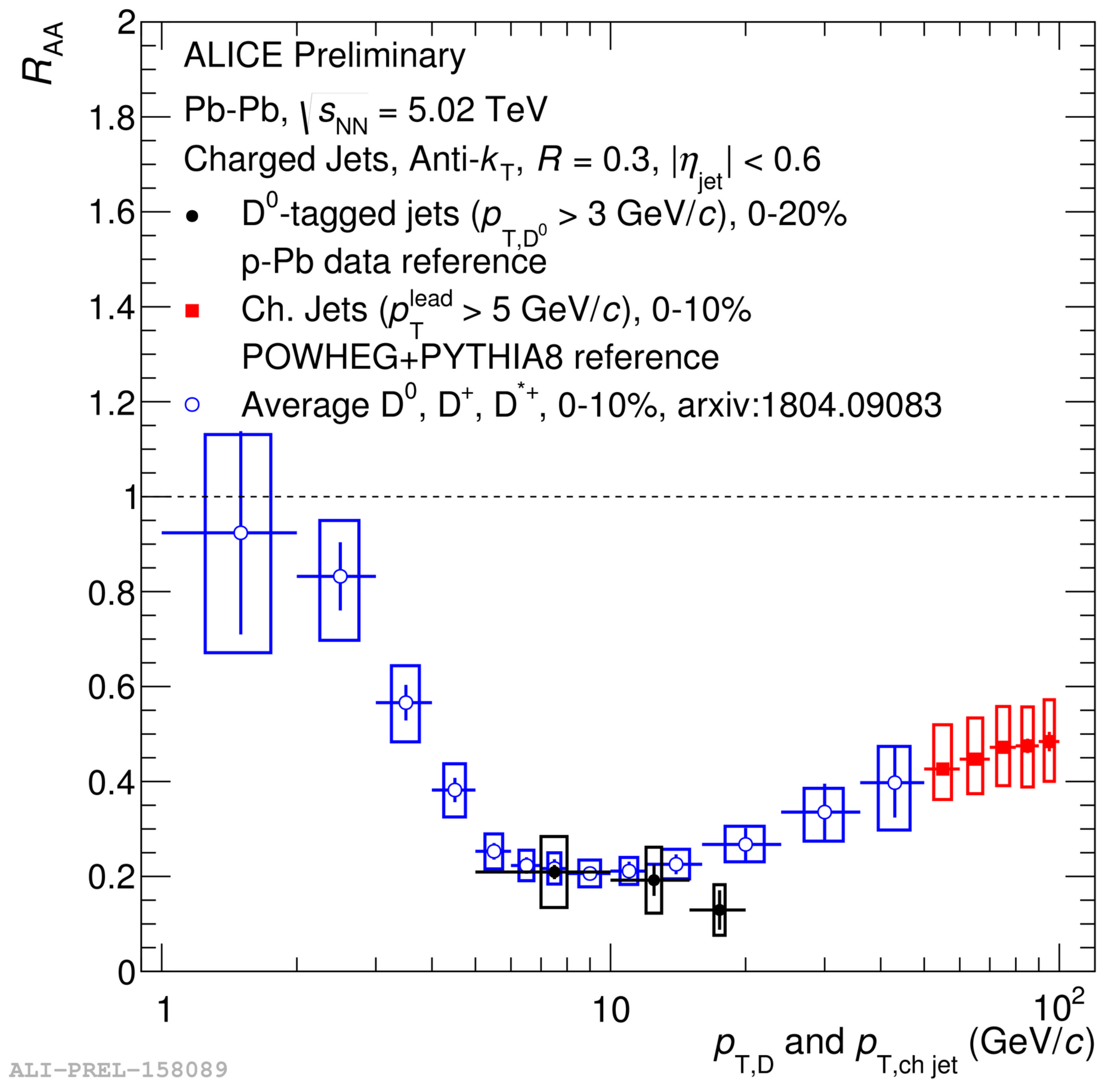
- Λ_c R_{pPb} **is consistent with unity** as D-meson R_{pPb} and with model predictions within uncertainties:
  - POWHEG+PYTHIA6 with CT10NLO+EPS09 PDF: Cold Nuclear Matter effects
  - POWLANG with “small-size” QGP formation: hot medium effects, collisional energy loss

D^0 tagged jets

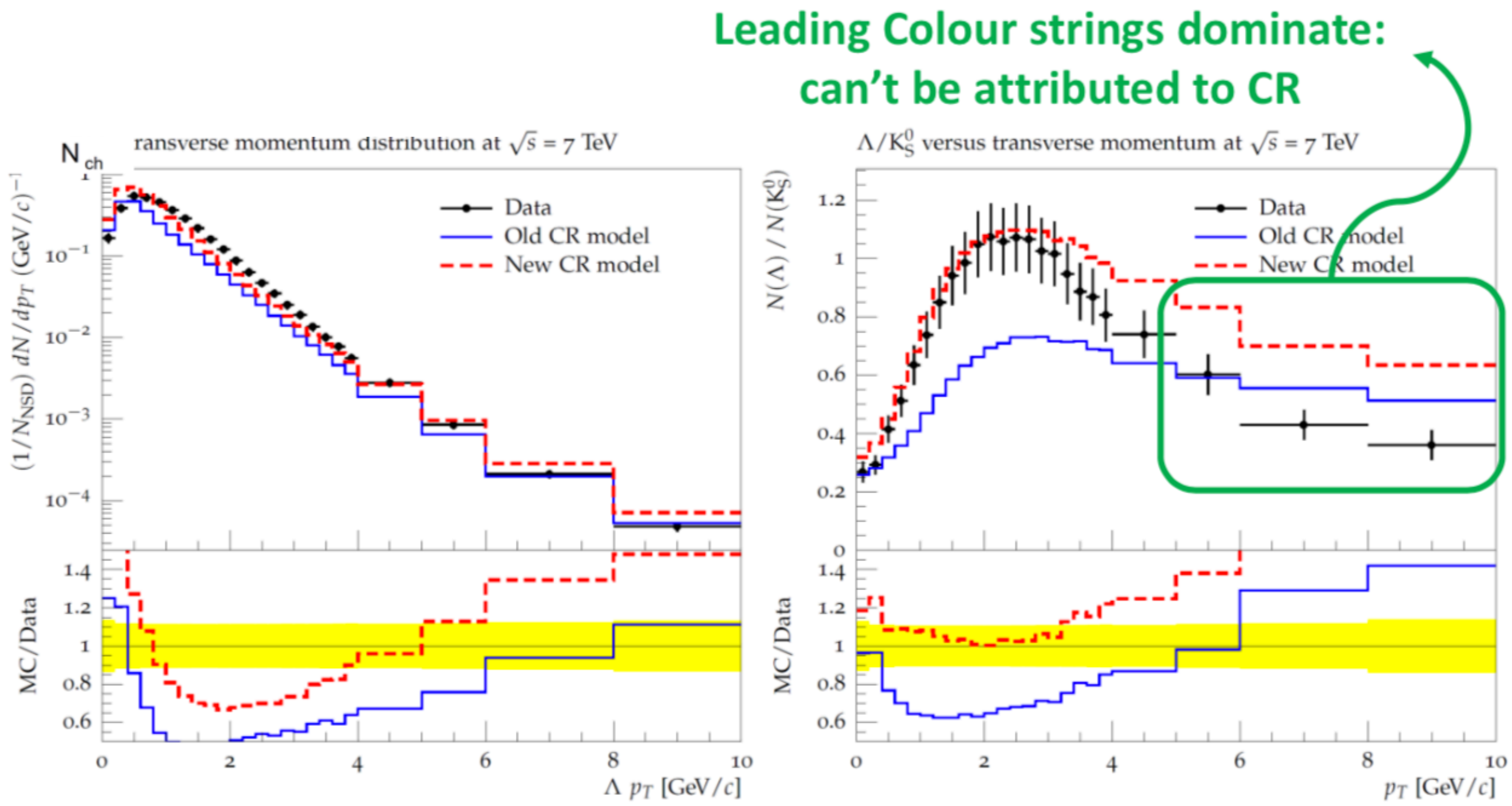
p-Pb collisions



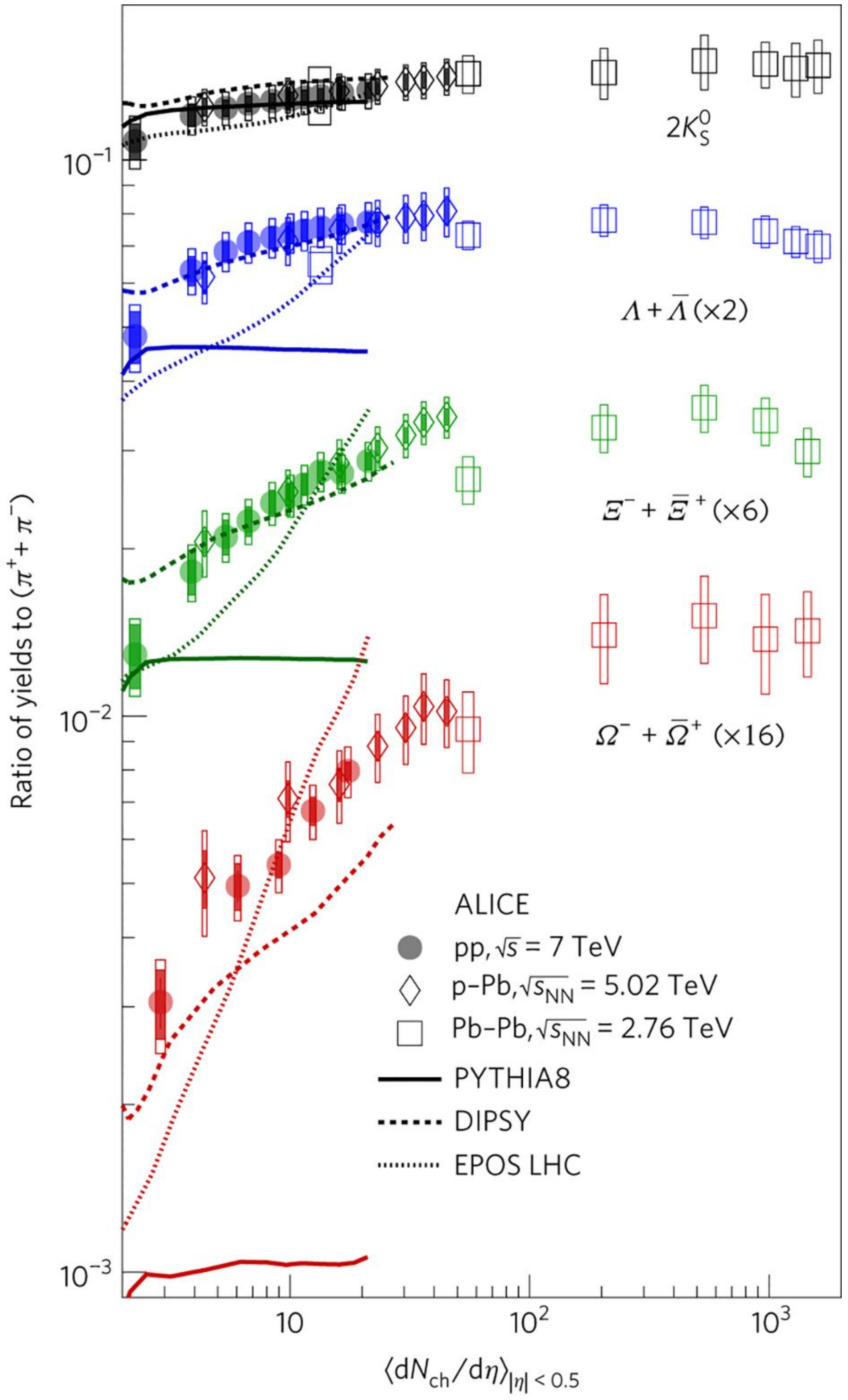
Pp-Pb collisions

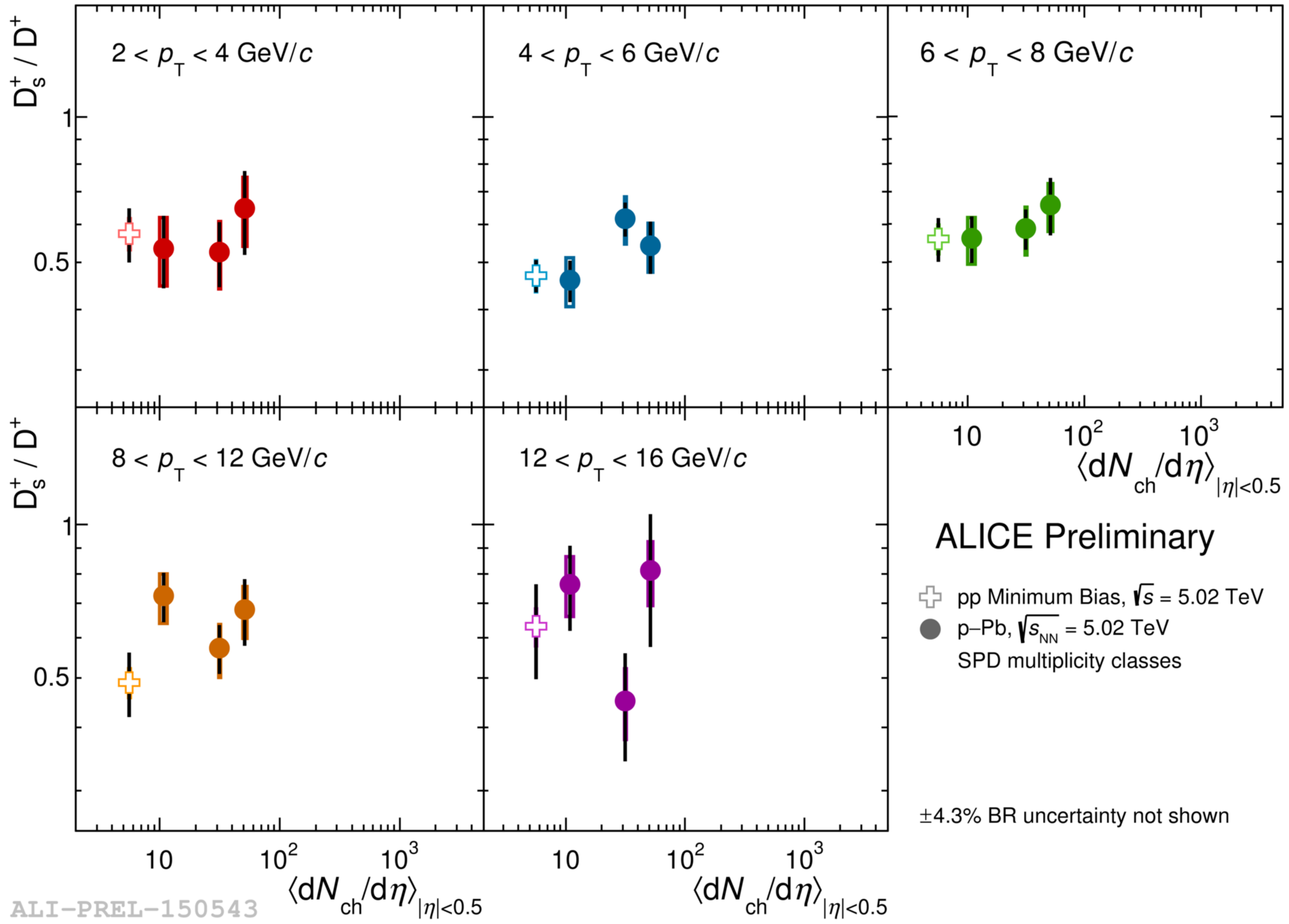


Light flavour CR



- Multiple strings are close in space-time. Dynamical interaction is not implemented in this model, but colour re-arrangement can happen: Colour Reconnection (CR)
- Takes place after parton shower and takes into account all SU(3) permitted configurations. Selection parameter: minimum total string length
- After re-arrangement of the strings, hadronization takes place
- Correctly takes into account the colour re-arrangement in the remnant


Ratio of yields to $(\pi^+ + \pi^-)$
10^{-1}
10^{-2}
10^{-3}
10
10^2
10^3
$\langle dN_{ch}/d\eta \rangle_{|\eta| < 0.5}$
$2K^0_S$
$\Lambda + \bar{\Lambda}$ (×2)
$\Xi^- + \bar{\Xi}^+$ (×6)
$\Omega^- + \bar{\Omega}^+$ (×16)
ALICE
pp, $\sqrt{s}$ = 7 TeV
p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
PYTHIA8
DIPSY
EPOS LHC


D_s^+ / D^+
$2 < p_T < 4$ GeV/c
$4 < p_T < 6$ GeV/c
$6 < p_T < 8$ GeV/c
$8 < p_T < 12$ GeV/c
$12 < p_T < 16$ GeV/c
1
0.5
10
10^2
10^3
$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$
ALICE Preliminary
pp Minimum Bias, $\sqrt{s}$ = 5.02 TeV
p–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
SPD multiplicity classes
±4.3% BR uncertainty not shown
ALI-PREL-150543