Heavy Flavour Jets and Correlations

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on behalf of the ALICE collaboration

Quark Matter 2019, Wuhan

Physics motivation

- HF mesons
  - Heavy quarks (b,c) are mostly produced in hard scatterings at the initial stage of the collision
  - measurement down to $p_{\mathrm{T,D}} \approx 0$
  - Production cross section can be calculated within pQCD

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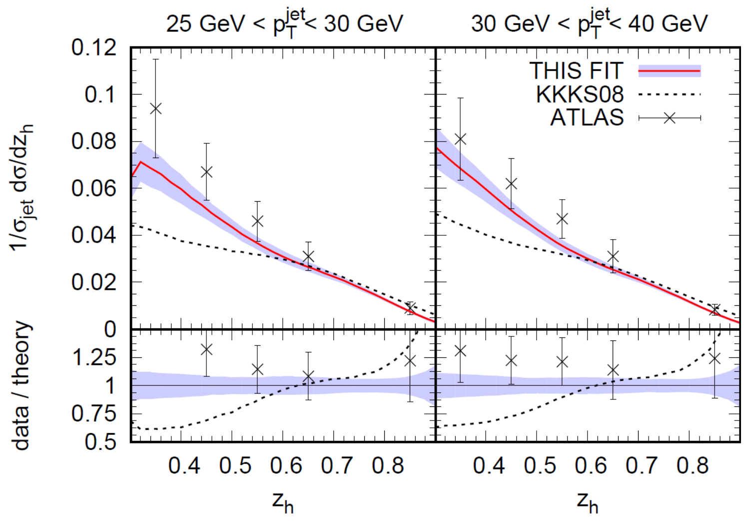
- HF-tagged jets
  - Measurement of jets from hard scattering down to very low $p_{\mathrm{T,jet}}$
    - which helps in constraining the jet background (even in large systems)
  - Experimental input for gluon-to-hadron Fragmentation Function ($g \rightarrow D^0$) and gluon PDF at low x
  - Quark-enhanced jet sample (w.r.t inclusive jets $\Leftarrow$ gluon-induced showers)



Phys. Rev. D96 (2017) 034028

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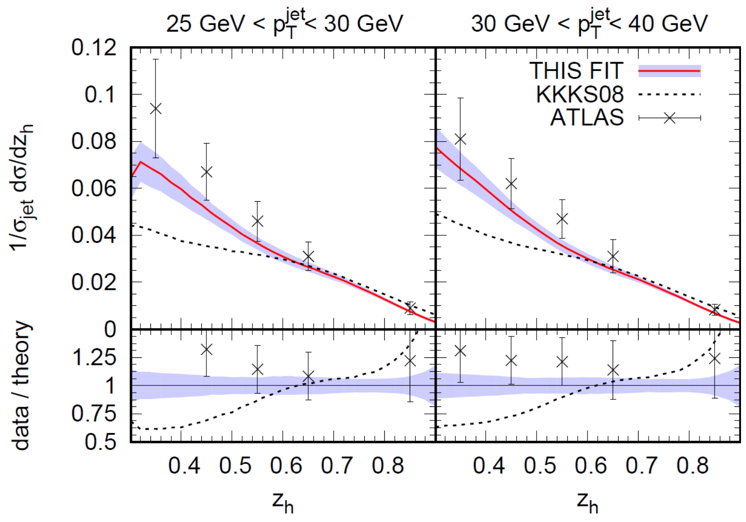
- **pp:** pQCD test
- **pA**: Cold-Nuclear-Matter effects
- **AA**: Probe of Quark-Gluon Plasma
  - Flavour and mass dependence of jet quenching
    - Redistribution of the lost energy
  - Collisional energy loss might be important! (JHEP 1907 (2019) 148)
  - Measurement of radiative energy loss at low $p_{\mathrm{T,jet}}$
    - dead cone effect
  - Modification of the fragmentation and HF jet structure in the medium
  - Additional information, complementary to R_{AA} and v_2

Talk By N. Zardoshti
Tue. 9:20



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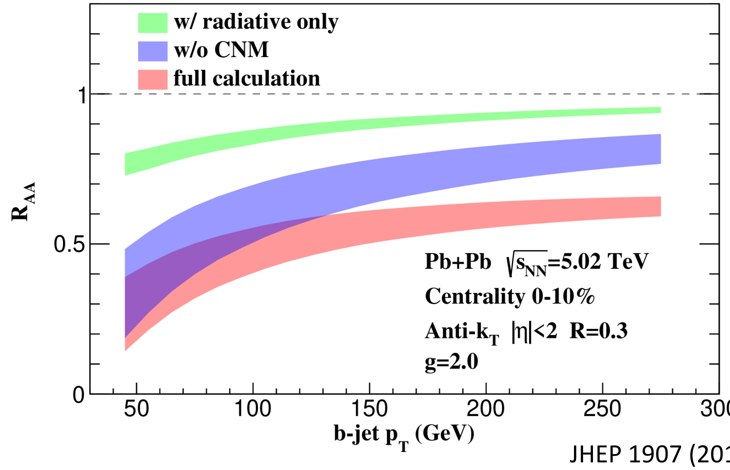
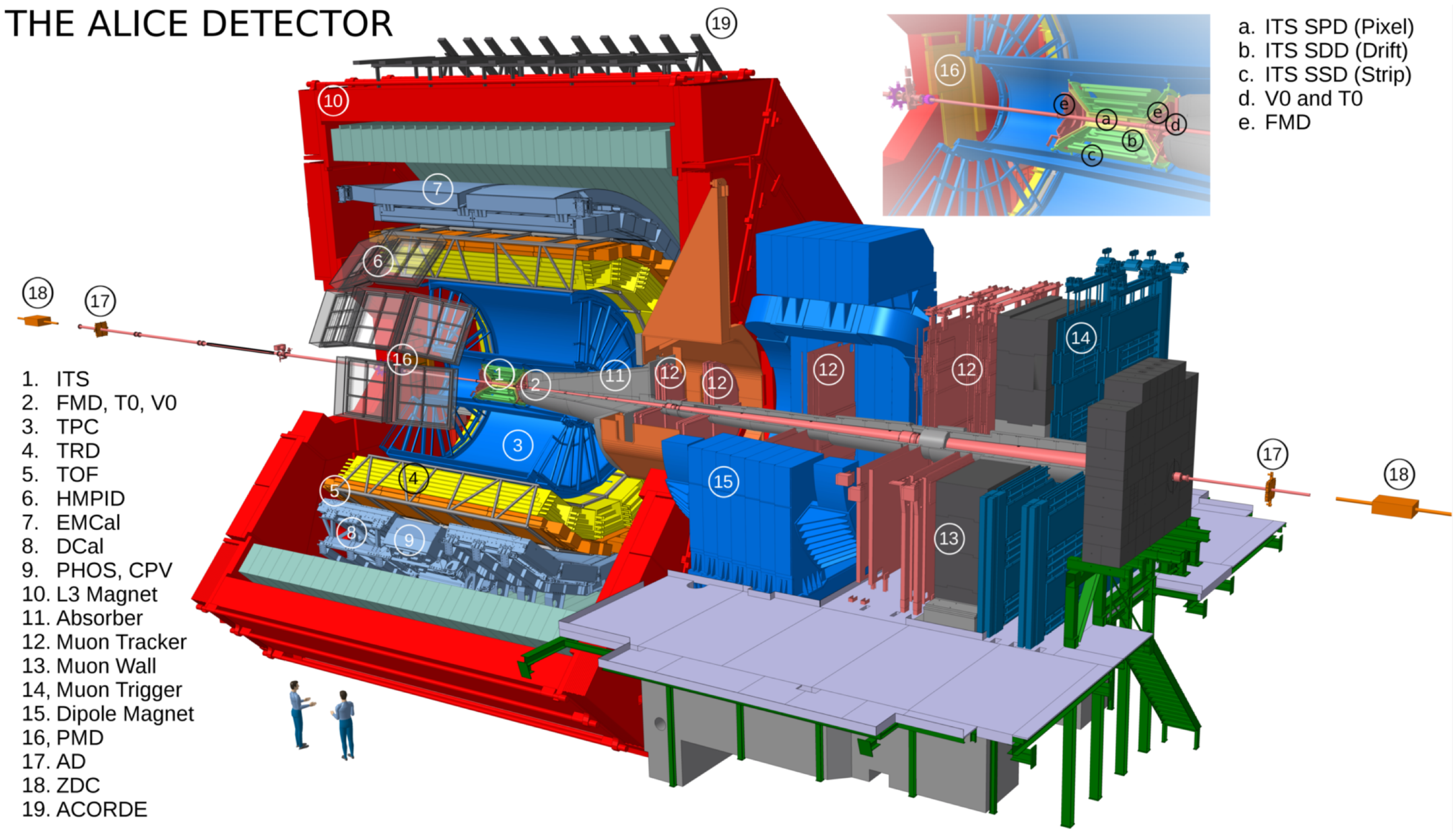


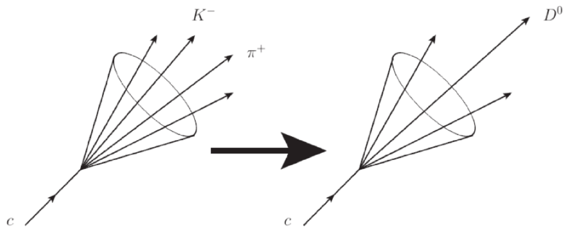
JHEP 1907 (2019) 148

The ALICE DETECTOR

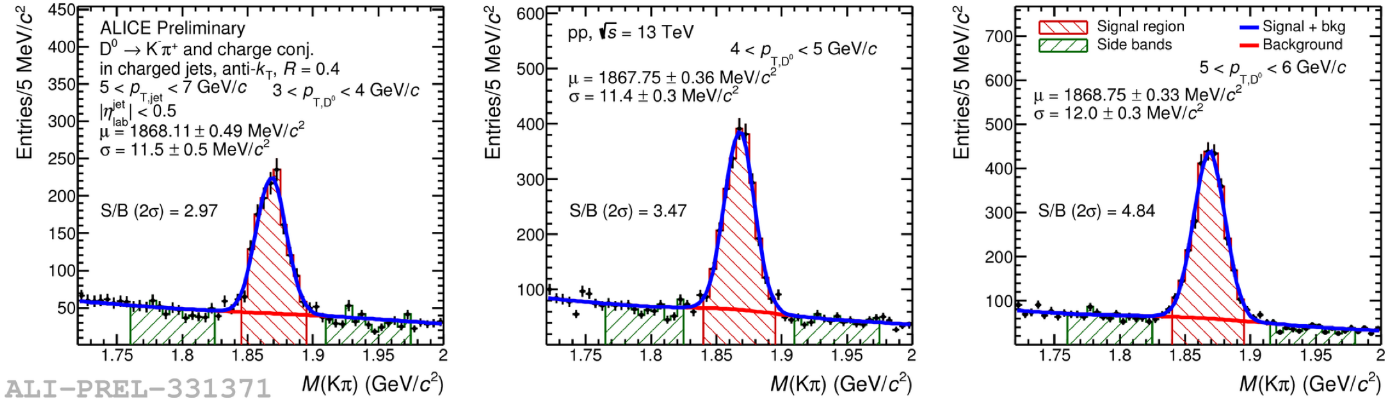


- Detectors
  - ITS $|\eta| < 0.9$
    - Vertexing and tracking
  - TPC $|\eta| < 0.9$
    - Tracking and PID
  - TOF $|\eta| < 0.9$
    - PID
  - EMCAL $|\eta| < 0.7$
    - ePID and trigger
  - V0 $-3.7 < \eta < -1.7$
    $2.8 < \eta < 5.1$
    - Trigger and background rejection

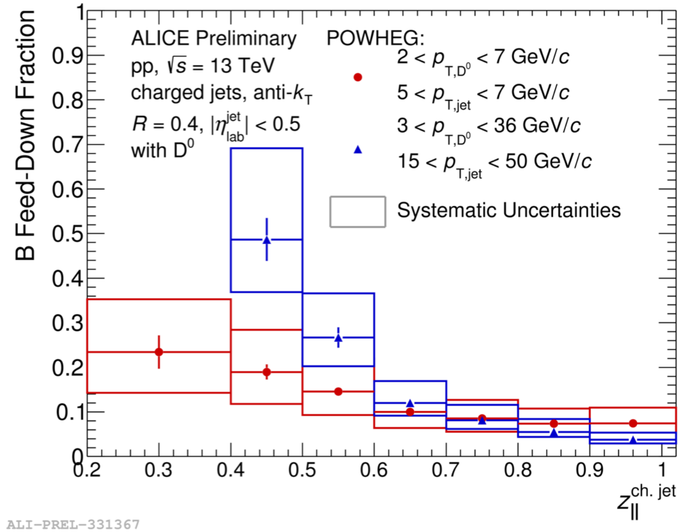
Λ_c^+/D^0-tagged charged jets

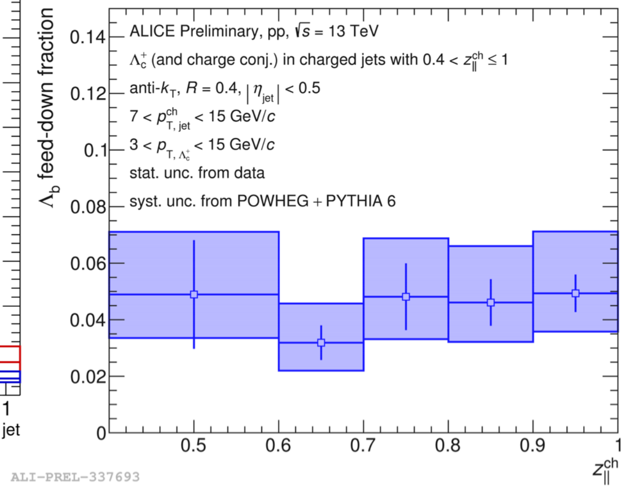


- Λ_c^+/D^0-tagged charged jet reconstruction:
  - Λ_c^+/D^0 daughters in event replaced with Λ_c^+/D^0 candidate
    - One Λ_c^+/D^0 baryon/meson is replaced at one time
    - All charged tracks are clustered into jets -> every Λ_c^+/D^0 meson is in a jet
    - $D^0 \rightarrow K^-\pi^+$+ conj. (B.R. 3.89%)
    - $\Lambda_c^+ \rightarrow pK_S^0$+ conj. (B.R. 1.59%)



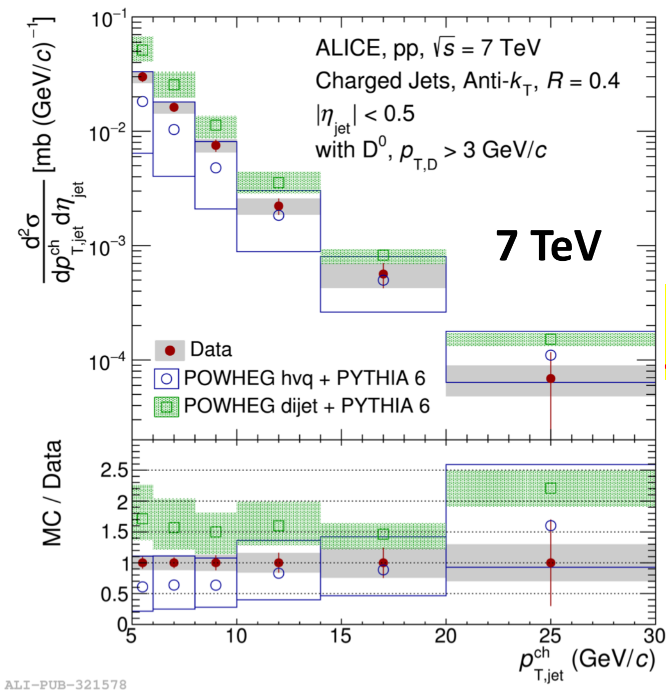
- Invariant mass analysis to extract Λ_c^+/D^0 -jet raw spectrum
  - Side band method for background subtraction
  - Correction on Λ_c^+/D^0 -jet efficiency and beauty feed down
  - 2D unfolding ($z_{\parallel}^{ch}$, $p_{T,jet}$) for detector effects
  - Anti-k_T , charged jets with R=0.4 (R=0.6)





D^0-tagged jets: cross-section

- **POWHEG HVQ CT10NLO + PYTHIA6**
  - Data above central POWHEG value
- **POWHEG Dijet CT10NLO + PYTHIA6**
  - Data below central POWHEG value
- Consistent trend between energies
  - Note: 5.02 TeV ($p_{\mathrm{T,D^0}} > 3\ \mathrm{GeV}/c$, $R = 0.3$)
    7 TeV ($p_{\mathrm{T,D^0}} > 3\ \mathrm{GeV}/c$, $R = 0.4$)
    13 TeV ($p_{\mathrm{T,D^0}} > 2\ \mathrm{GeV}/c$, $R = 0.4$)
  - Decreasing minimum $p_{\mathrm{T,D^0}}$ increased difference from the central POWHEG
- Consistent with theory comparison



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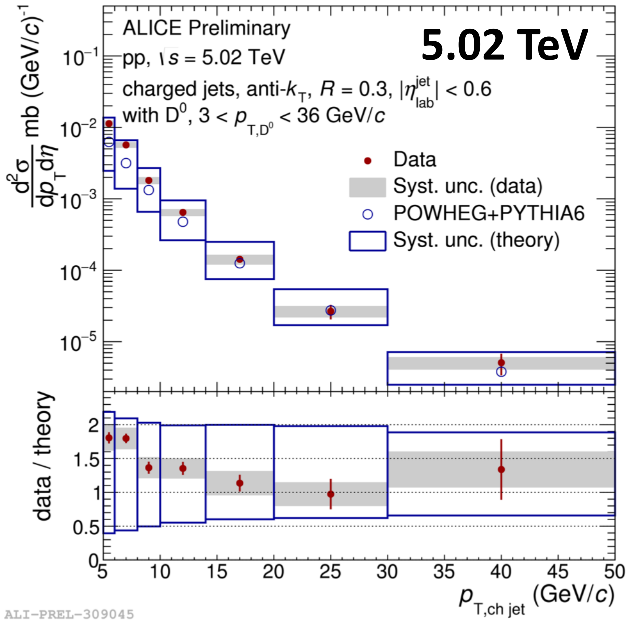
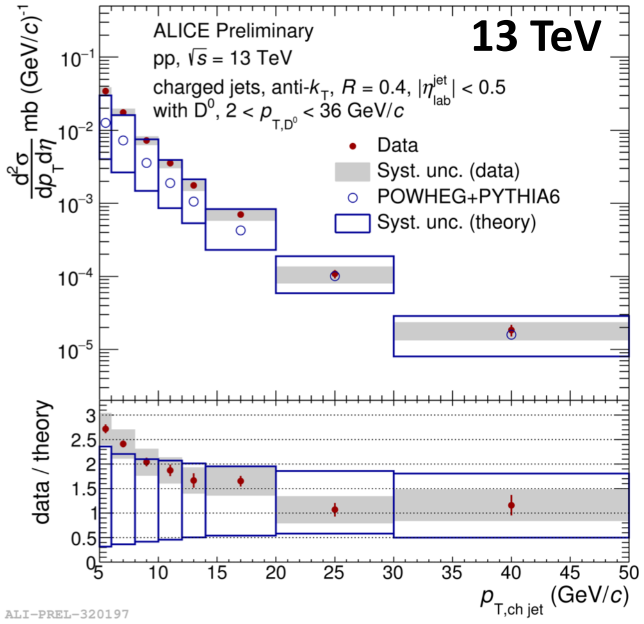




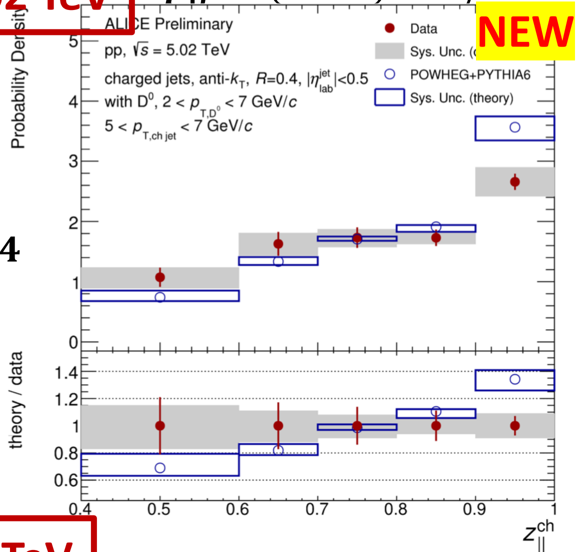
D0-tagged jets: $z_{\parallel}^{ch}$ probability density

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

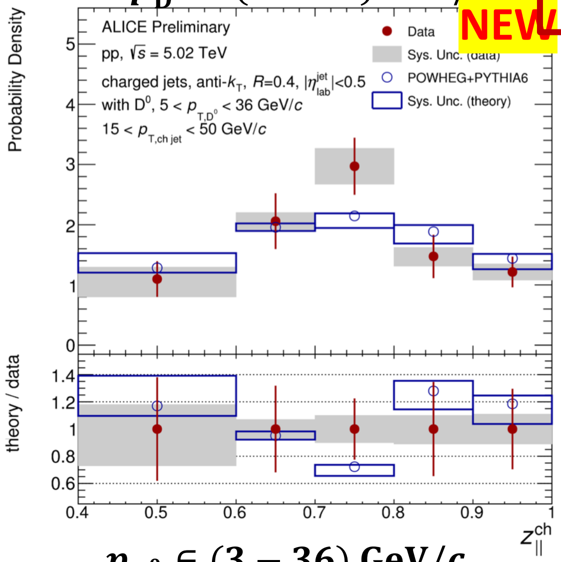
5.02 TeV

$R = 0.4$

$p_{\mathrm{T,jet}} \in (5-7)$ GeV/c, $p_{\mathrm{D^0}} \in (2-7)$ GeV/c **NEW**



$p_{\mathrm{T,jet}} \in (15-50)$ GeV/c, $p_{\mathrm{D^0}} \in (5-36)$ GeV/c **NEW**



5.02 TeV

$R = 0.6$

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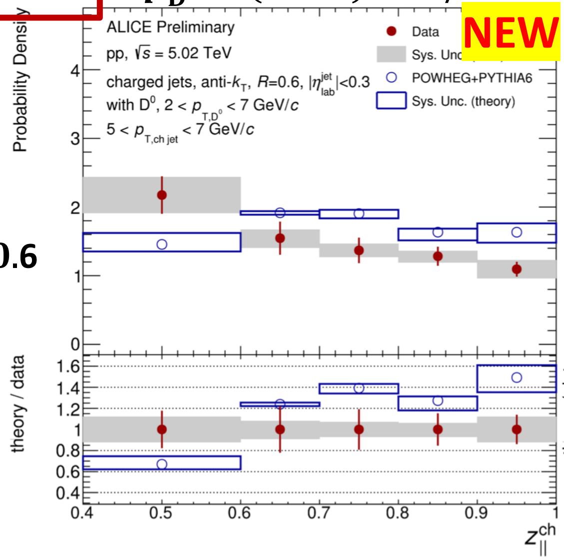

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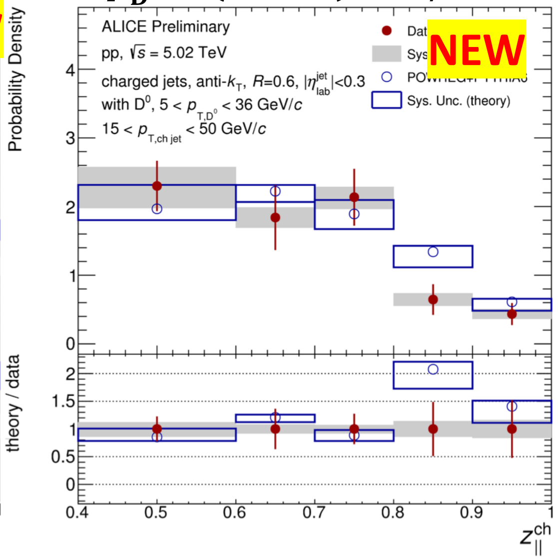
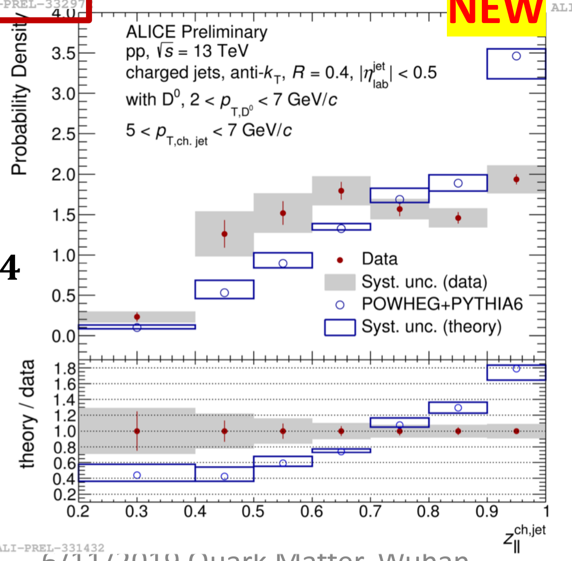


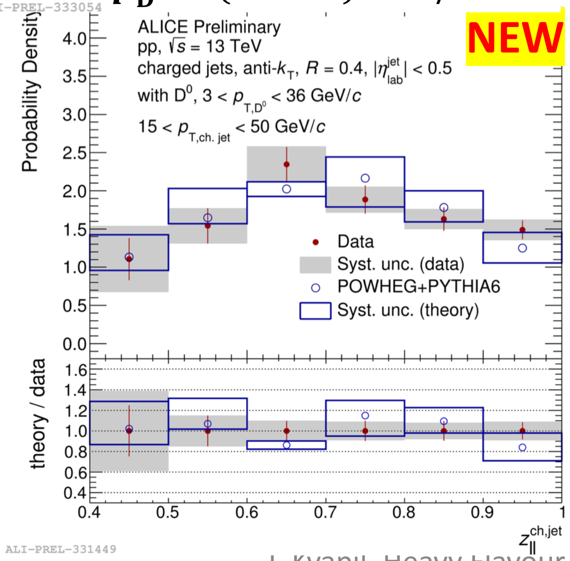
13 TeV

$R = 0.4$

NEW



$p_{\mathrm{D^0}} \in (3-36)$ GeV/c **NEW**



- **Comparison to model**
  - **POWHEG hvq CT10NLO + PYTHIA6**
  - Consistent within uncertainty for high $p_{\mathrm{T,jet}}$
  - Softer fragmentation in data for low $p_{\mathrm{T,jet}}$

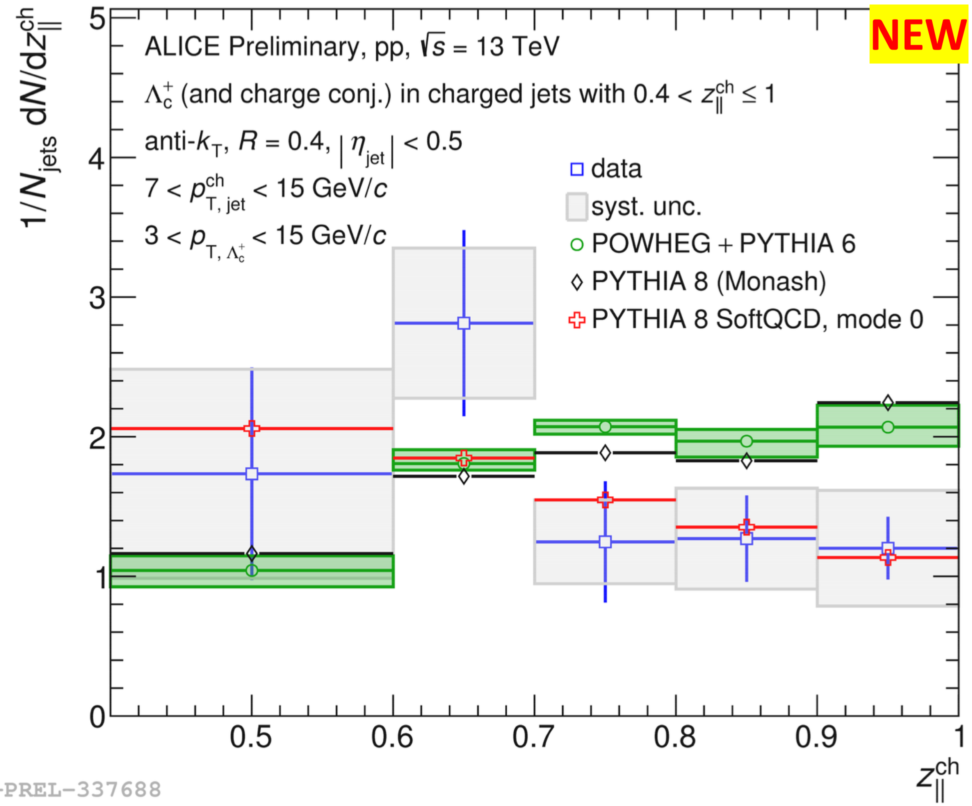
Λ_c^+ -tagged jets: $z_{\parallel}^{ch}$ probability density

$$z_{\parallel}^{ch} = \frac{\vec{p}_{\Lambda_c^+} \cdot \vec{p}_{\mathrm{ch\,jet}}}{\vec{p}_{\mathrm{ch\,jet}} \cdot \vec{p}_{\mathrm{ch\,jet}}}$$

- Λ_c^+ -tagged jets $z_{\parallel}^{ch}$ probability density at **13 TeV**
  - R=0.4
  - **First measurement of Λ_c^+ in jets at LHC**
  - Measurement with large uncertainties.
  - **Exciting prospects for high luminosity LHC run!**
- **Comparison to model**
  - **POWHEG hvq CT10NLO + PYTHIA6**
    - Softer fragmentation in data
  - Seems to favor PYTHIA with softer settings
    - Allow to put constrains on models

$p_{\mathrm{T,jet}} \in (7 - 15)$ GeV/c

$p_{\Lambda_c^+} \in (3 - 15)$ GeV/c

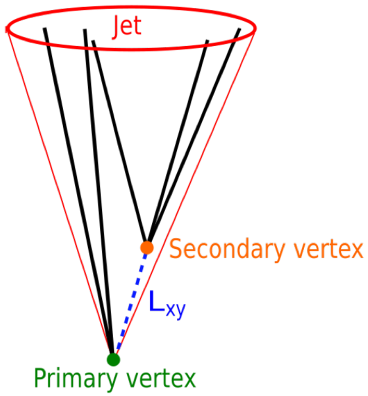


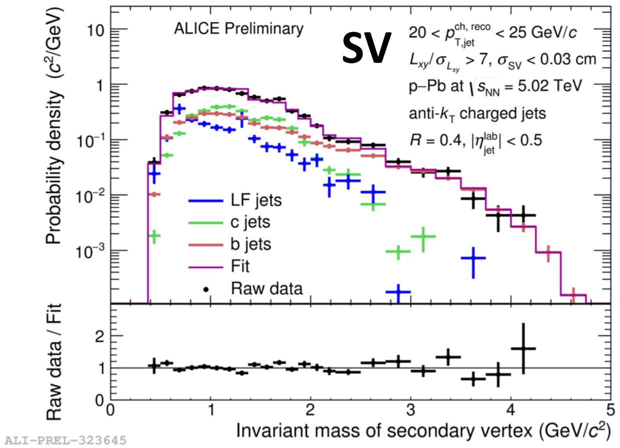
ALI-PREL-337688

b-tagged jets: Methods overview

- **Selection strategy:**
  - **Most displaced Secondary Vertex (SV)**
    - 3 prongs, **p-Pb 2016 data at 5.02 TeV**

1. Displacement significance: $SL_{\mathrm{xy}} = \frac{L_{\mathrm{xy}}}{\sigma_{L_{\mathrm{xy}}}}$
2. Dispersion of SV: $\sigma_{SV} = \sqrt{\sum_i (d_{0,i})^2}$





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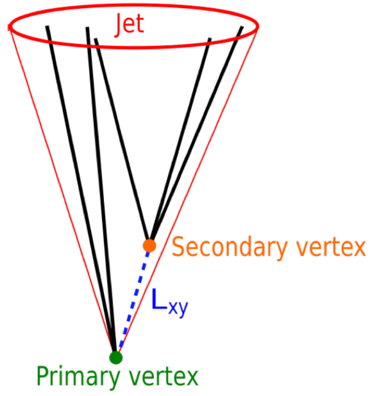
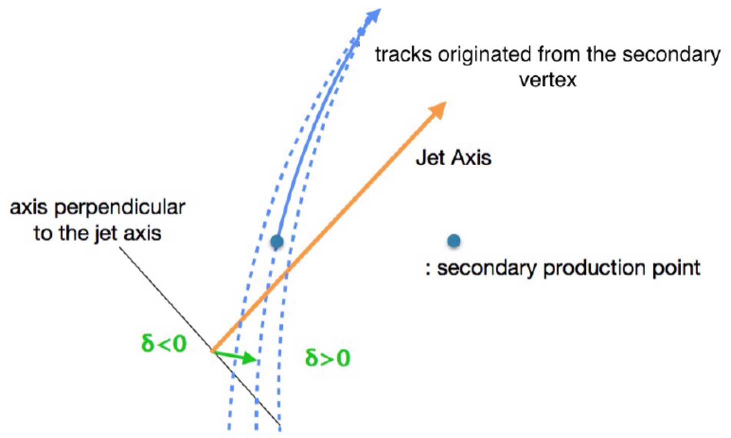
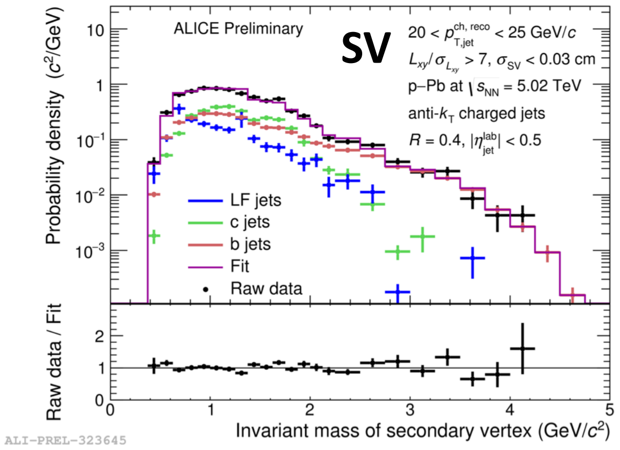
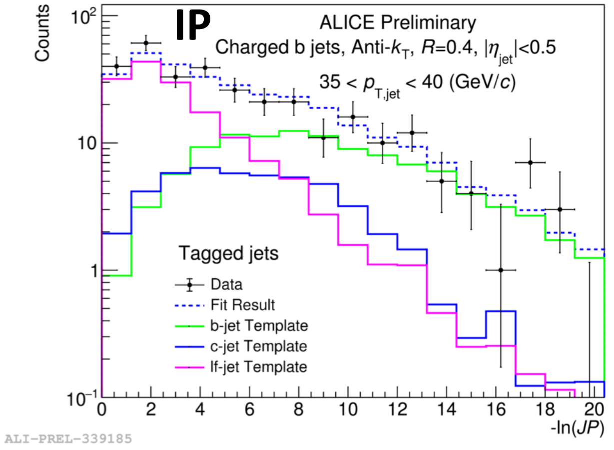
  - **Track counting algorithm (IP)**
    - It uses the large Impact Parameter (IP) of the b-hadrons, **pp 2016 data at 5.02 TeV**
    1. Evaluate a discriminator $sd_{xy} = sign(\overrightarrow{d_{xy}} \cdot \overrightarrow{p_{jet}}) d_{xy}$
    2. Sort the sd_{xy} of the tracks inside the jet in descending order.
    3. A jet is tagged as a b-jet if the Nth most displaced track with IP larger than a threshold parameter $d_{xy}^{threshold}$









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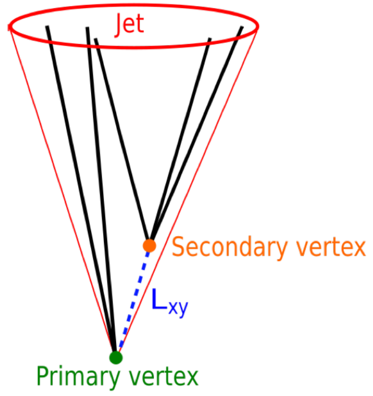
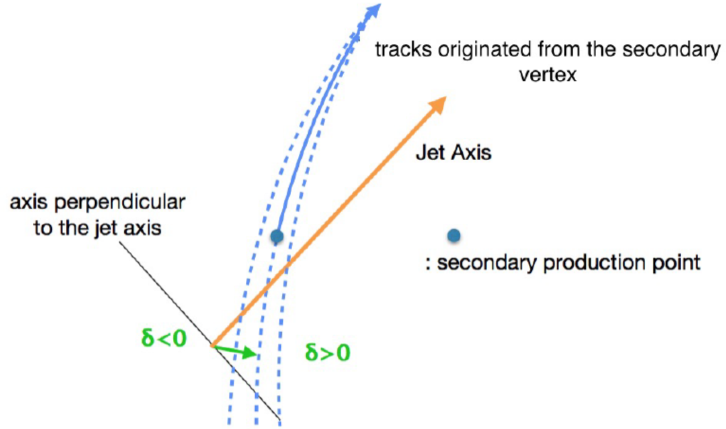
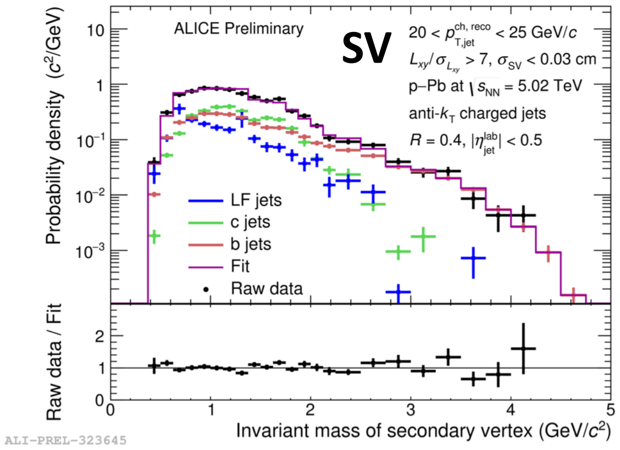
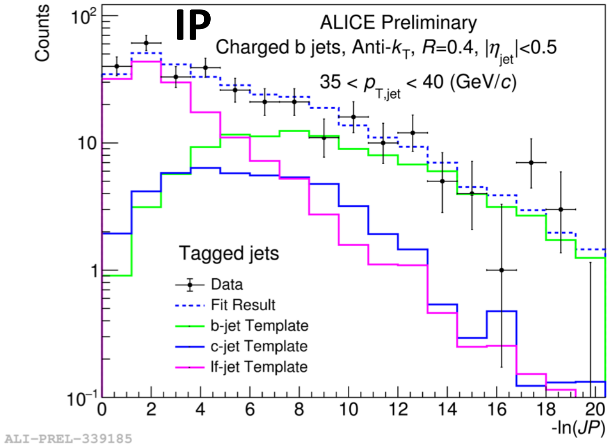
    3. A jet is tagged as a b-jet if the Nth most displaced track with IP larger than a threshold parameter $d_{\mathrm{xy}}^{\mathrm{threshold}}$
- Correction strategy
  - Secondary Vertex
    - Tagging efficiency is determined from PYTHIA+EPOS
    - Tagging purity based on a data-driven method and POWHEG
  - Impact Parameter
    - data-driven methods for both efficiency and purity





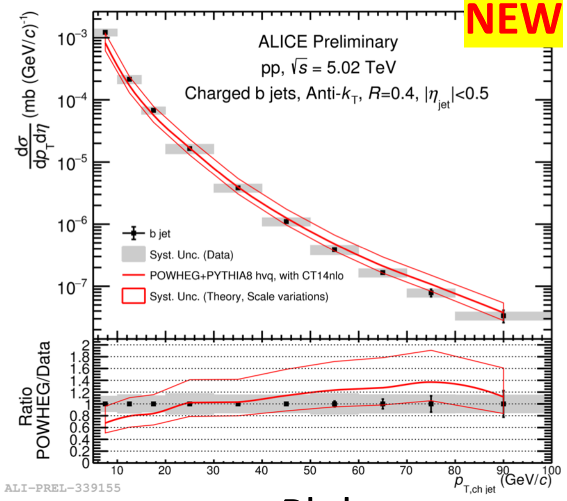




b-tagged jets: cross-section and R_{pPb}

- Consistent with theory prediction
  - **POWHEG HVQ EPS09NLO + PYTHIA6 (SV)**
  - **POWHEG HVQ CT14NLO + PYTHIA8 (IP)**

pp hvq



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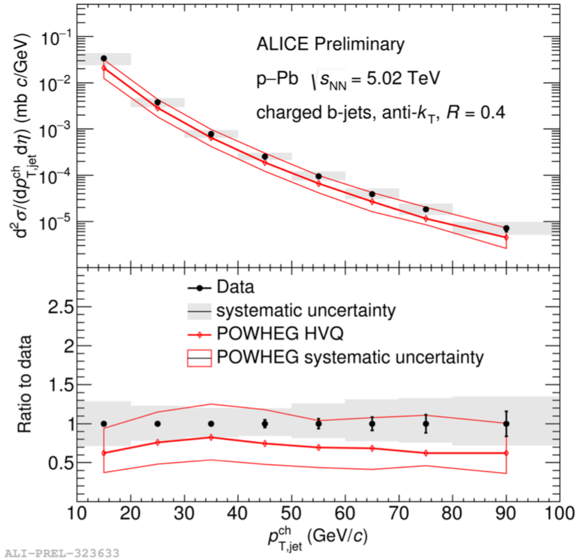

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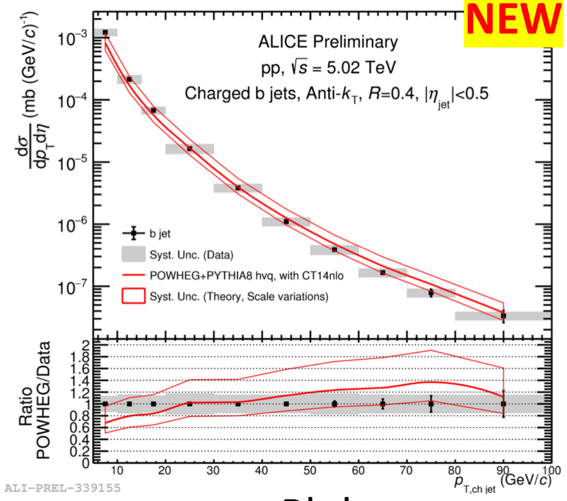
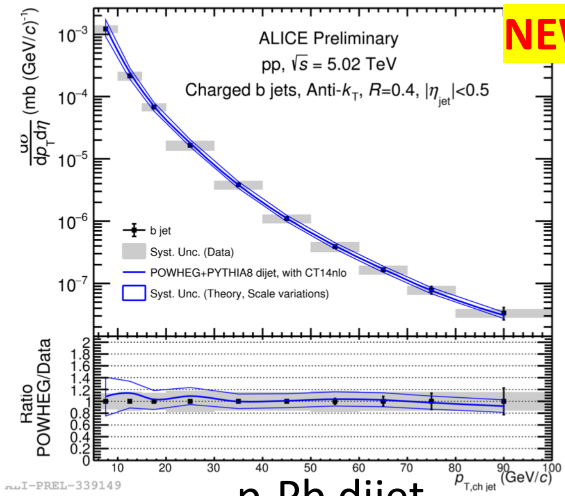
  - **POWHEG HVQ CT14NLO + PYTHIA8 (IP)**
  - **POWHEG Dijet EPPS16 + PYTHIA8 (CT14NLO for IP)**

pp hvq



pp dijet



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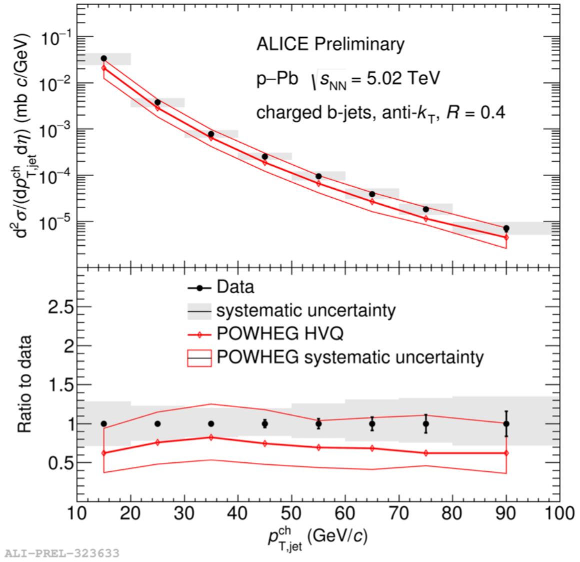

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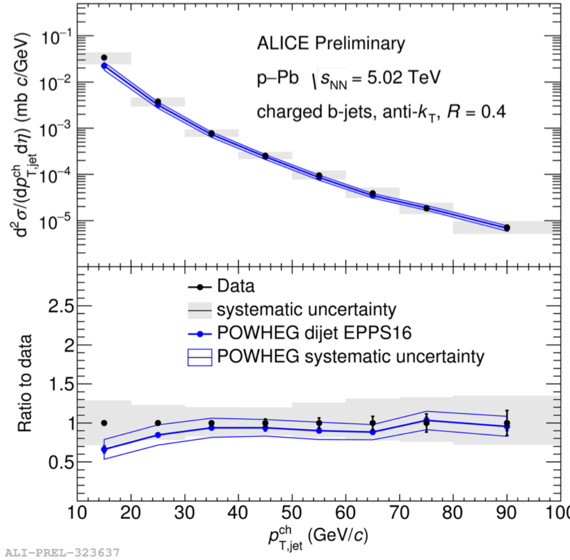

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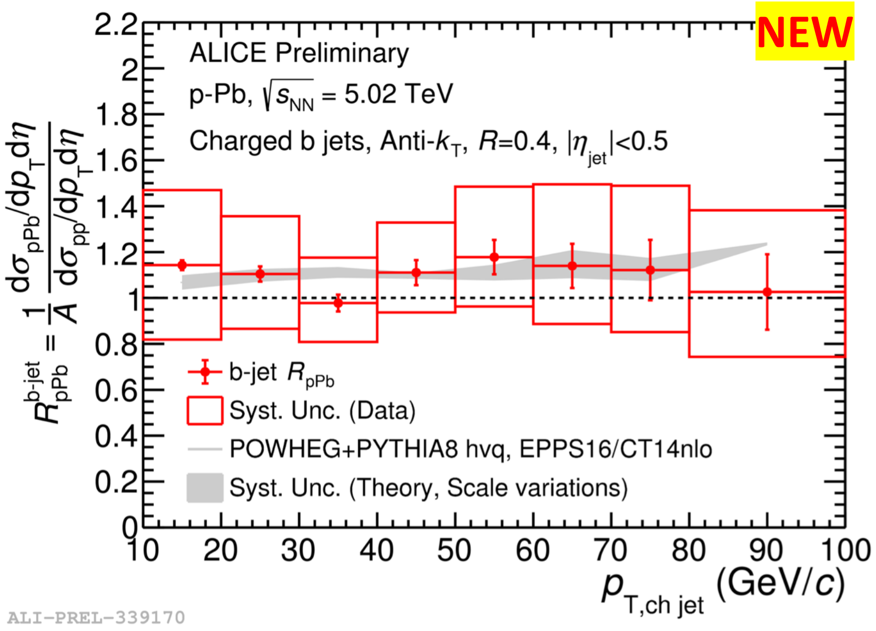
  - **POWHEG HVQ CT14NLO + PYTHIA8 (IP)**
  - **POWHEG Dijet EPPS16 + PYTHIA8 (CT14NLO for IP)**
- **b-jet production is not affected by cold-nuclear-matter effect within the current uncertainties**



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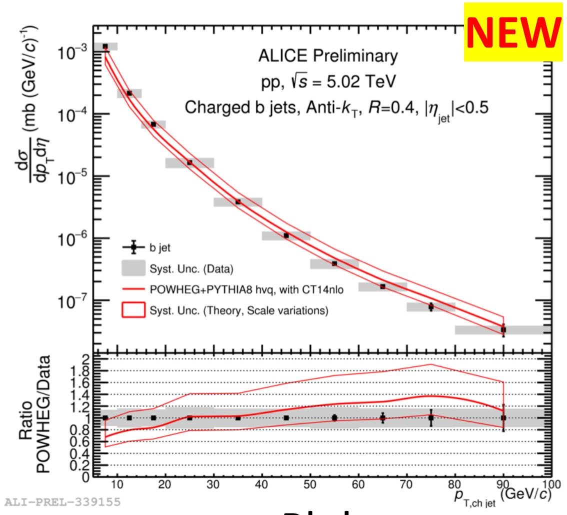

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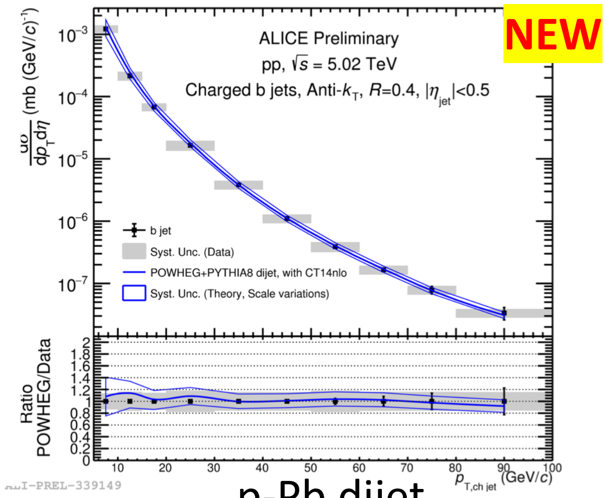

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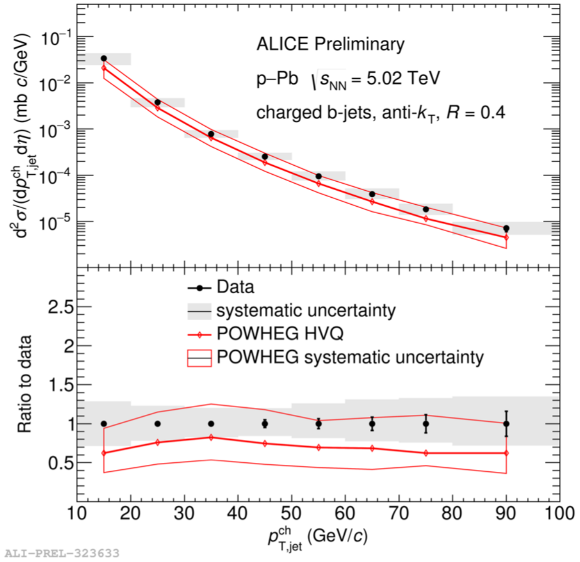

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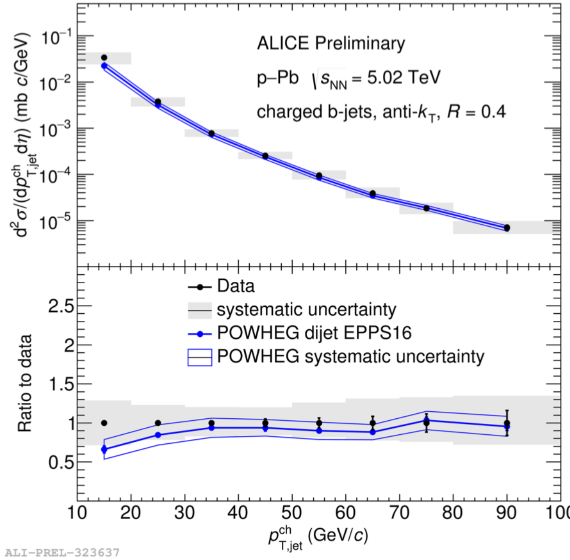
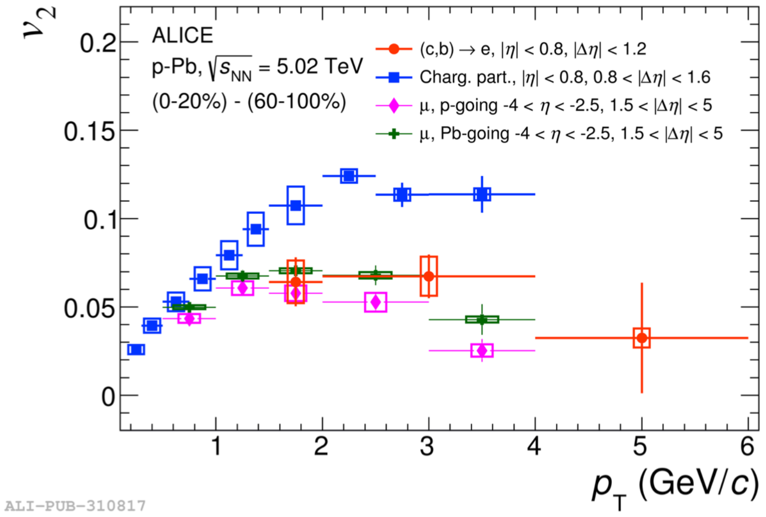


HFe-jets: Final state effects?

- Observed positive v_2 of heavy flavours (leptonic channel) in p-Pb collisions at 5.02 TeV
  - **Indicate final-state effects in small system?**
  - in case of final-state effects we could also see a suppression of jet spectra
  - Jets with different R (jet cone size) is sensitive to modification of jet shape – broadening
- Measured jets containing electrons from heavy-flavour hadron decays (HFe-jets) with various jet resolution parameters



Published: Phys. Rev. Lett. 122, 072301 (2019)

Poster: S. Sakai

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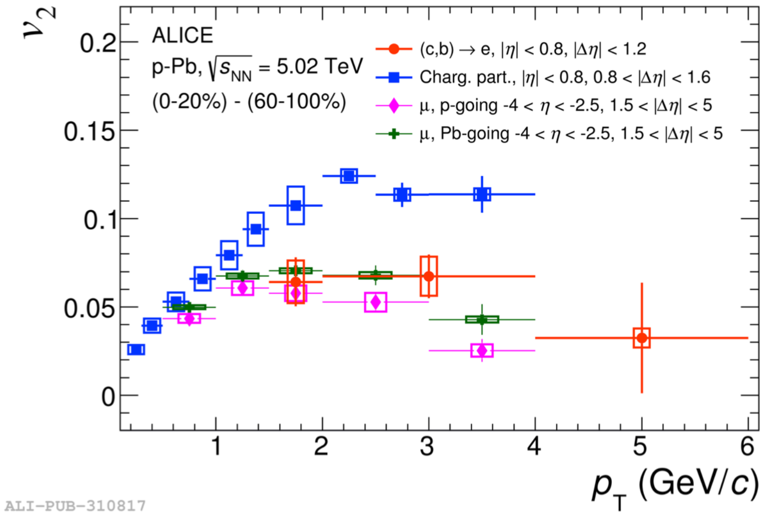
1. R dependence of R_{pPb}
   - No modification of $p_{T,jet}$ spectrum of HFe-jet in p-Pb



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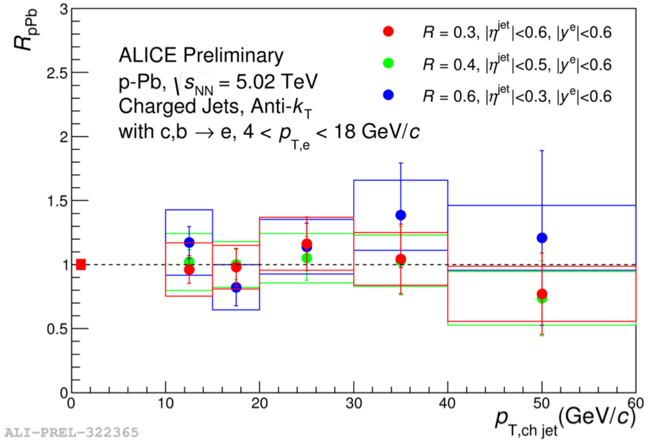

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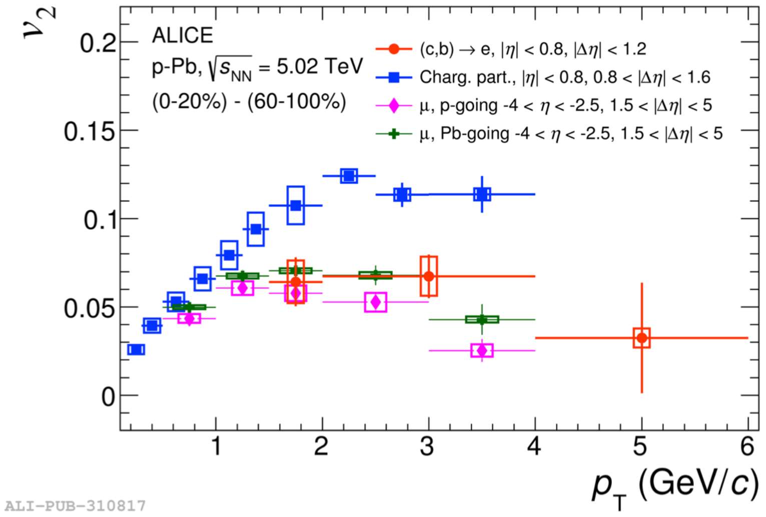
1. R dependence of R_{pPb}
   - No modification of $p_{T,jet}$ spectrum of HFe-jet in p-Pb
2. $\sigma(R = 0.3)/\sigma(R = 0.6)$ in pp and p-Pb
   - No modification of jet shape of heavy-flavour jets

- **we observe that there is no modification of the jet spectra in small system**
  - System not large enough where parton lose energy in p-Pb collisions?



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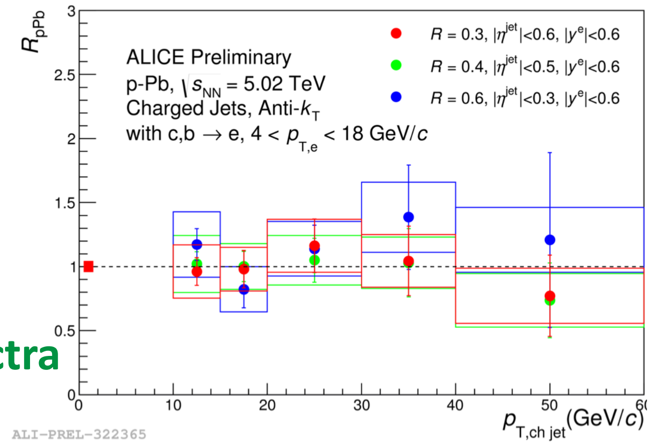
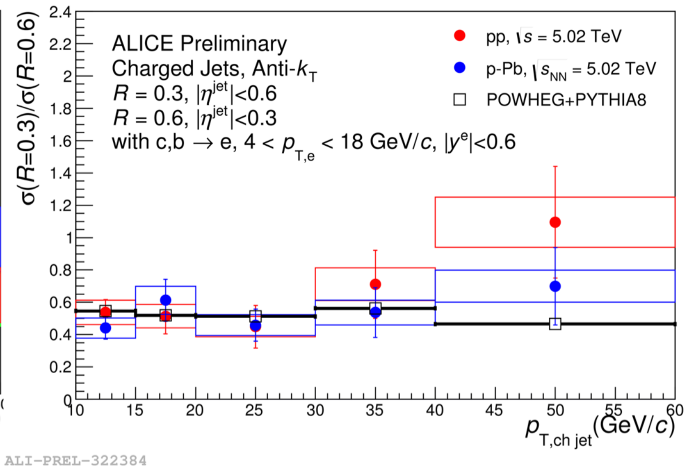
Phys. Rev. Lett. 122, 072301 (2019)

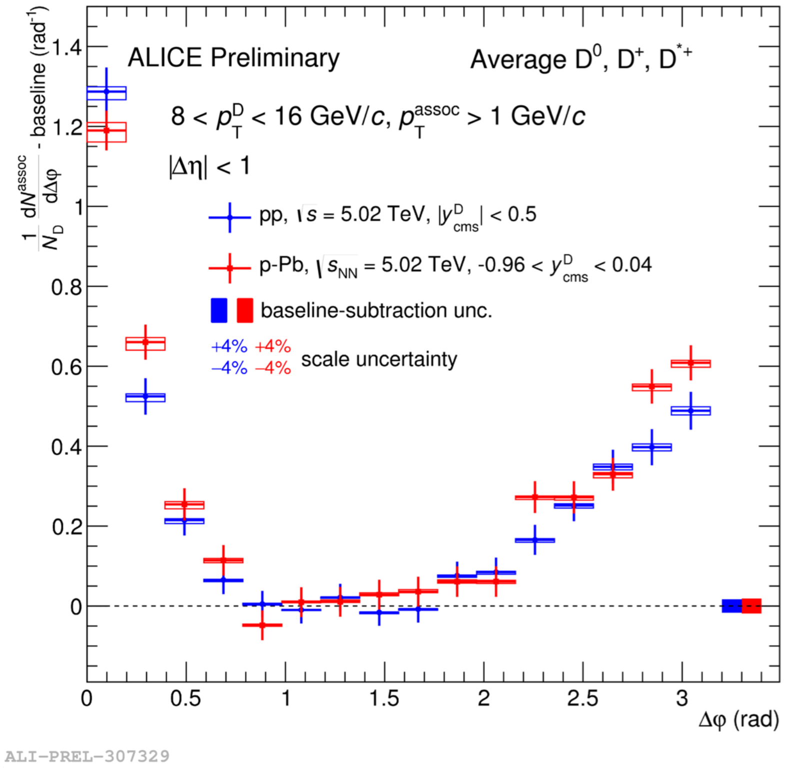




Poster: S. Sakai

Physics motivation: D-h correlation

- Correlation of “trigger” D mesons with “associated” charged particles
  - alternate and complementary approach to study D-tagged jets



Physics motivation: D-h correlation

- Correlation of "trigger" D mesons with "associated" charged particles
  - alternate and complementary approach to study D-tagged jets
- highly sensitive to the charm production mechanism
  - At leading order (LO)
    - The quark pair is produced back-to-back in azimuthal angle
    - The near-side peak $(\Delta\phi, \Delta\eta) = (0,0)$ is containing the D-meson trigger and the other particles produced from the fragmentation of its parent c or $\bar{c}$ quark
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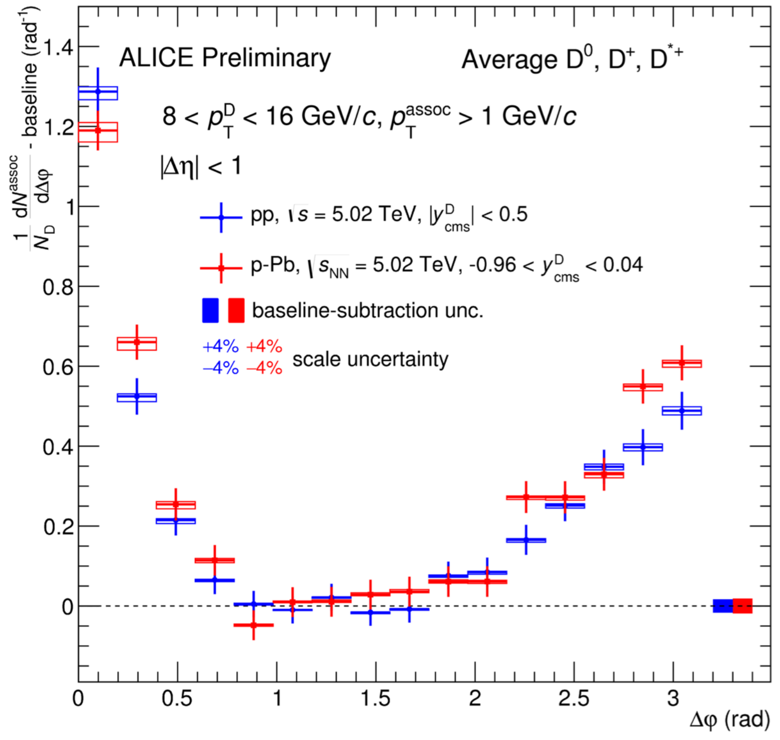

ALI-PREL-307329

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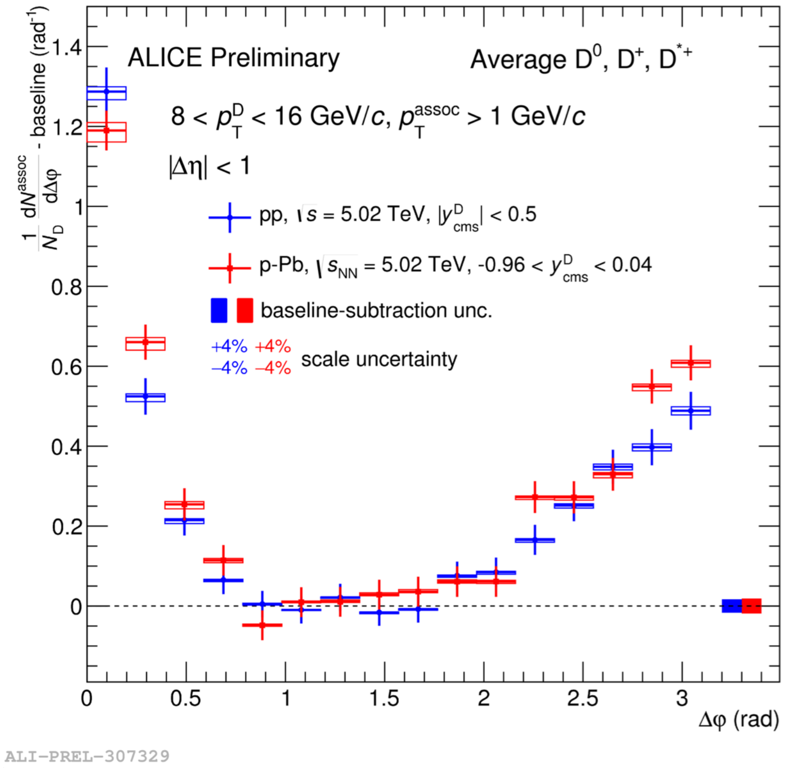
  - At next-to-leading order (NLO) the correlation pattern can be modified by:
    - The "gluon splitting" (broader and higher near-side peak)
    - The radiation of a hard gluon (broadening of near- and away-side)
    - Flavour excitation (flatter contribution than LO in $\Delta\phi$)
    - Gluon recoil (small bump in away-side)



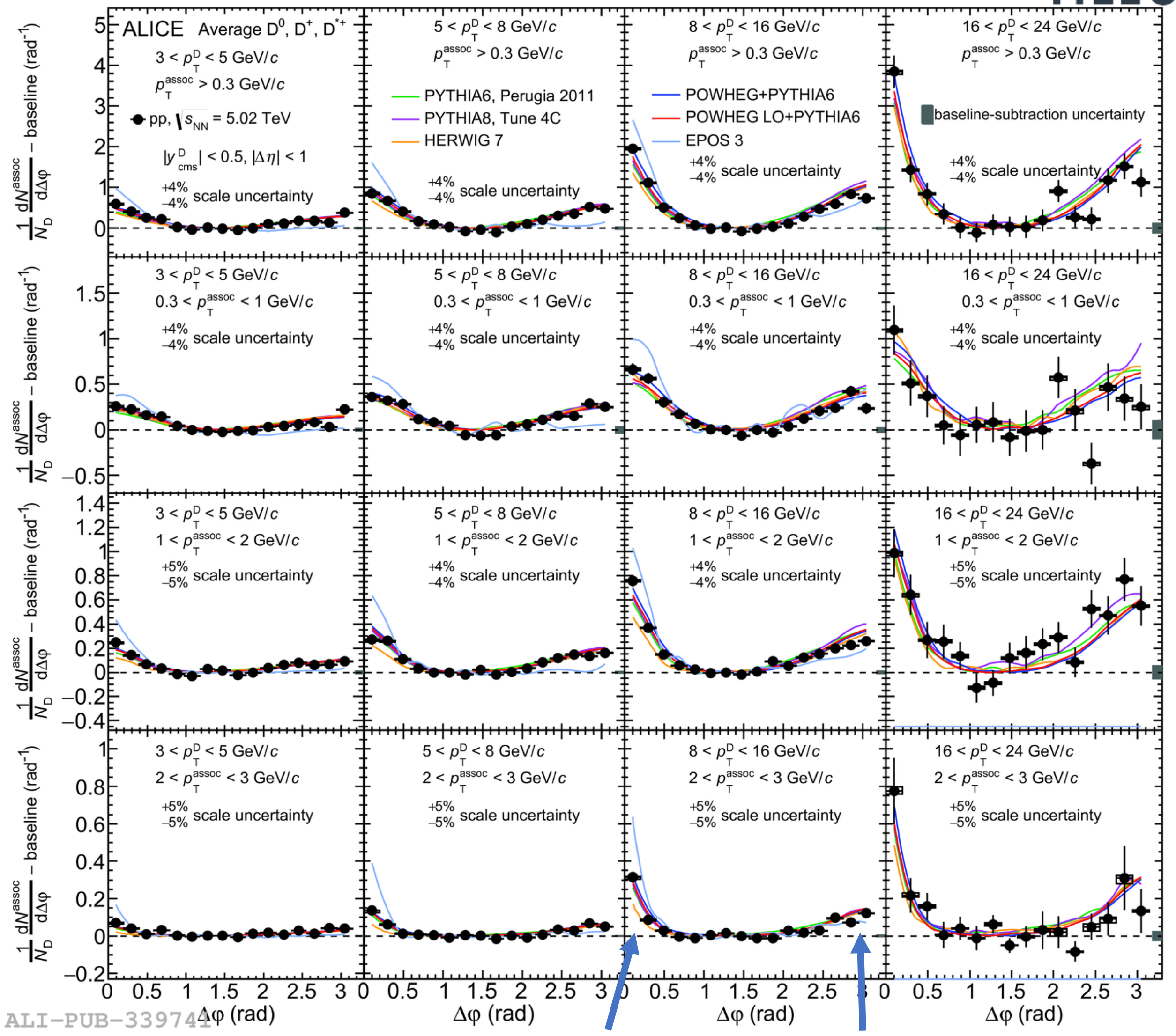
D-h correlation: Analysis overview

- D-h correlation in pp at **5.02 TeV**

1. reconstruction and selection of D mesons and primary charged particles
    - $D^0 \rightarrow K^-\pi^+$ + conj.
    - $D^+ \rightarrow K^-\pi^+\pi^+$ + conj.
    - $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$ + conj.
  - Associated particles are all charged primary particles
    - Excluding D decay products

NEW paper! ArXiv:1910.14403

$p_{T,D} \in (3-5)$ (5 – 8) (8 – 16) (16 – 24)



Near side Away side

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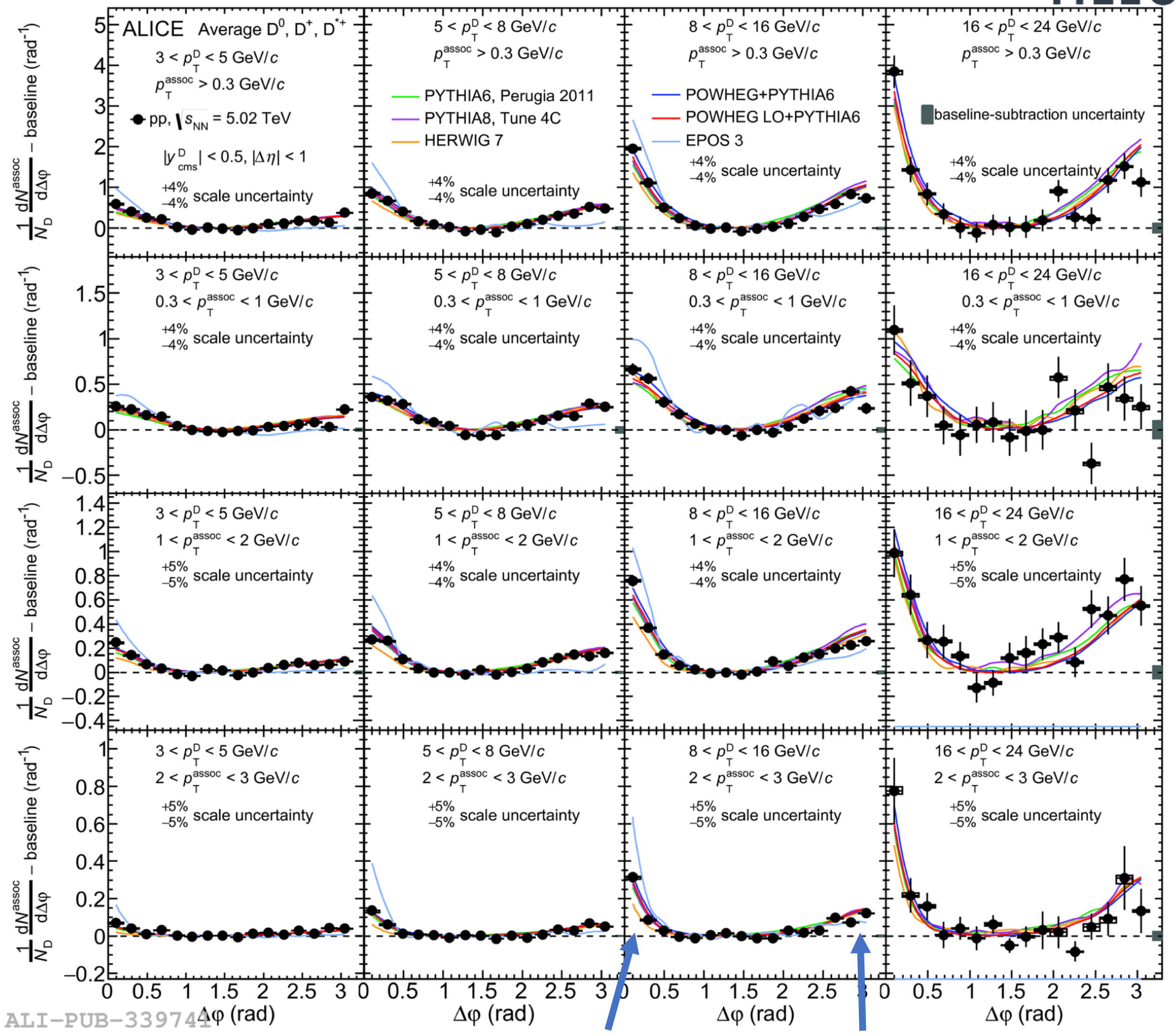

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2. evaluation of azimuthal-correlation distribution
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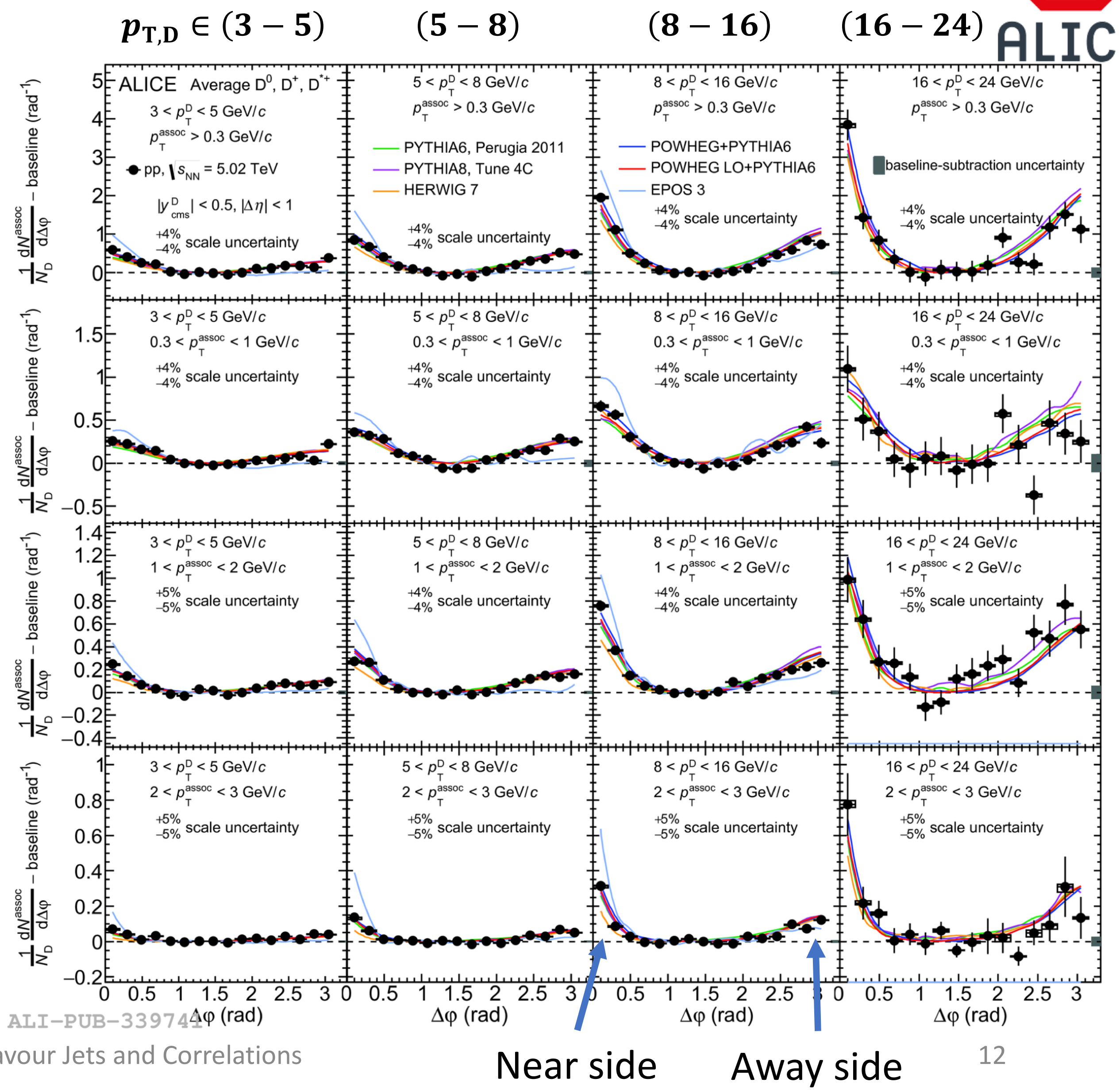
3. extraction of correlation properties via fits to the average D-meson azimuthal-correlation distributions
    - Generalizes Gaussian (near side) + Gaussian (away side) + constant fit

NEW paper! ArXiv:1910.14403

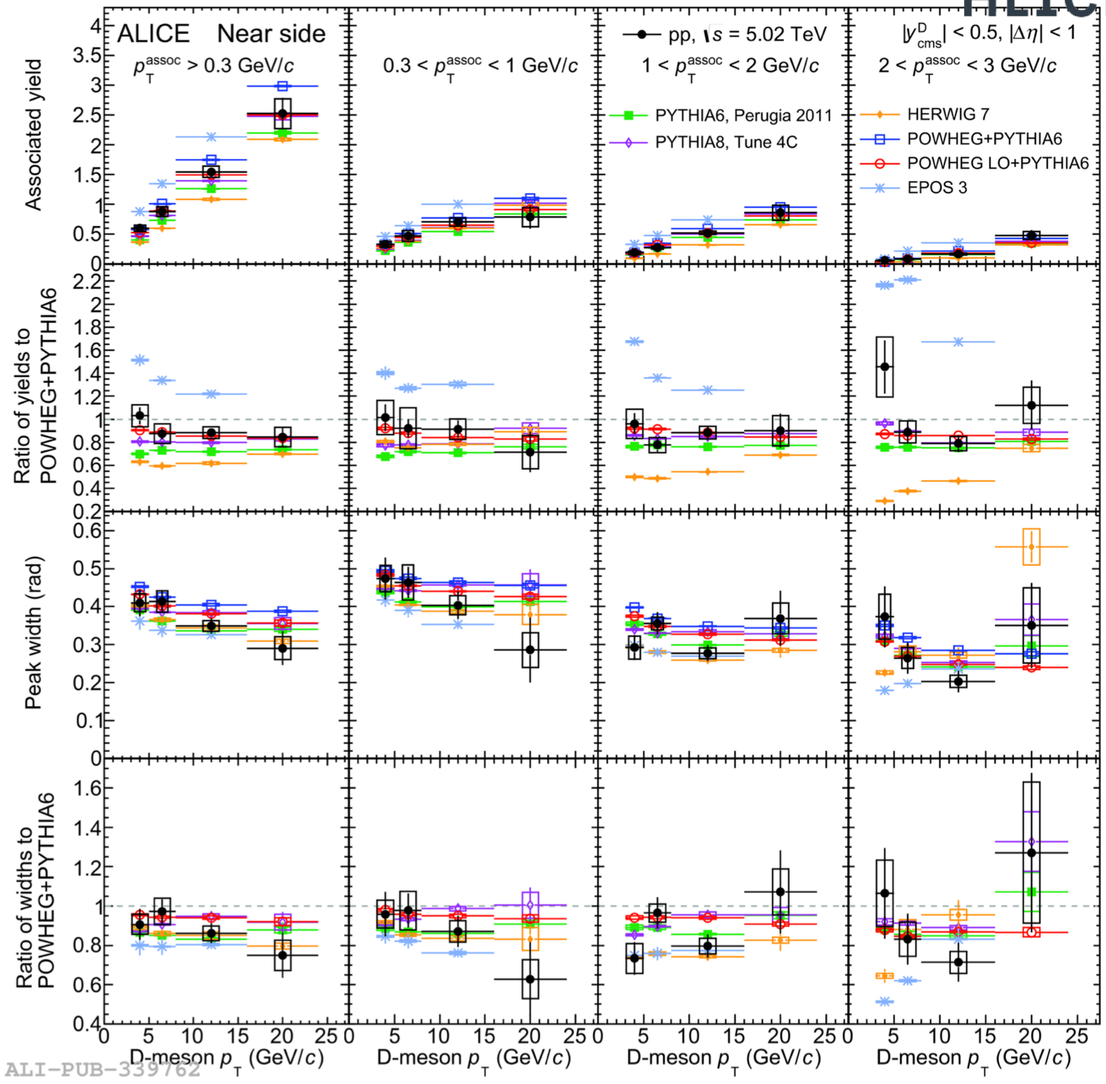


D-h correlation: Comparison to models

- PYTHIA: LO, LL p_T ordering of parton showers, Lund string model for hadronization
- HERWIG: NLO, angular ordering of parton showers, cluster hadronization model
- POWHEG: NLO, coupled to PYTHIA for parton showers and hadronization
- EPOS: string fragmentation, normally hadronized “corona” and collectively hadronized “core”
- Most of the models provide a fair description of the two correlation peaks
  - POWHEG+PYTHIA6 and PYTHIA8 provide the best description
    - the best candidates for building model references for PbPb studies
  - HERWIG misses completely the near-side peak yield at low $p_{\mathrm{T,D}}$ and high $p_{\mathrm{T,assoc}}$
  - EPOS predicts too large near-side yields and qualitatively too small away-side yields

NEW paper! ArXiv:1910.14403

pp, near side



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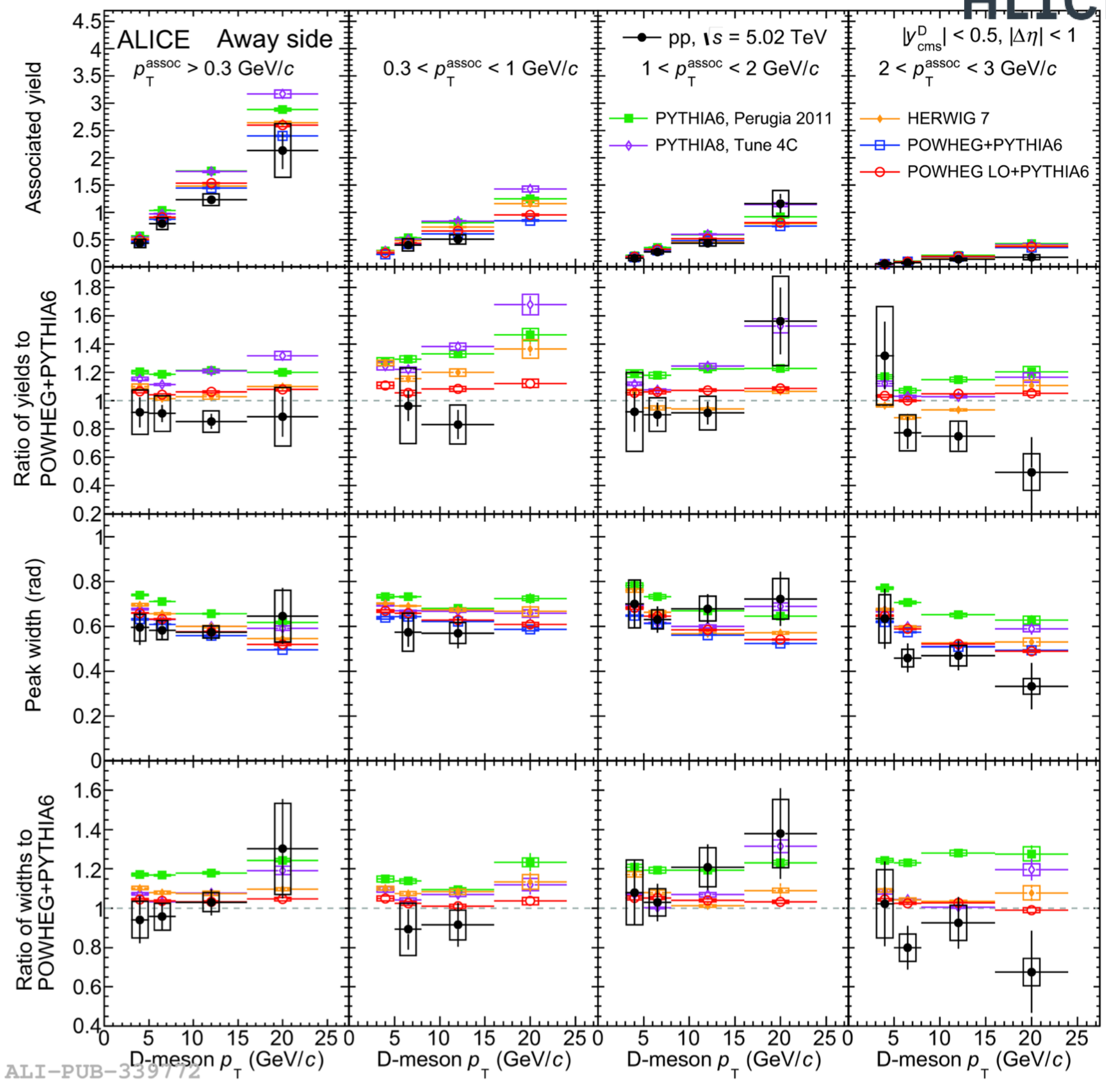
pp, away side



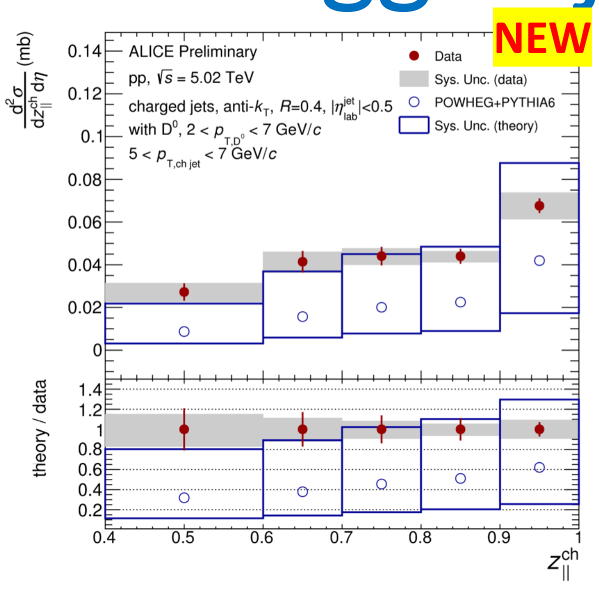
Conclusion

- **D-tagged jets**
  - p_{T} differential cross-section consistent with theory
  - D-meson jet momentum fraction in pp shows softer fragmentation in data for low $p_{\mathrm{T,jet}}$
  - Pb-Pb: analysis of the 2018 data starting now
- **Λ_c^+-tagged jets**
  - First measurement of Λ_c^+ in jets at LHC
  - Allow to put constrains on models
- **b-jets**
  - First measurement in ALICE
  - Good agreement with POWHEG+PYTHIA
  - R_{pPb} indicating no cold nuclear matter effects
- **HFe-jets**
  - Measurement indicated no final state effects in small systems
- **D-h correlation**
  - Best description given by POWHEG+PYTHIA6 and PYTHIA8
  - Paper released! ArXiv:1910.14403
- **Looking forward to theoretical predictions for these observables !**

Thank you for your attention

backup

D^0-tagged jets: 5.02 TeV – additional plots



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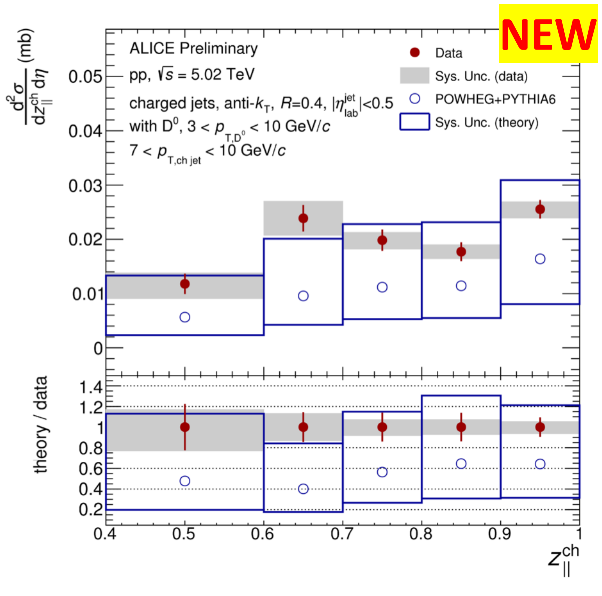

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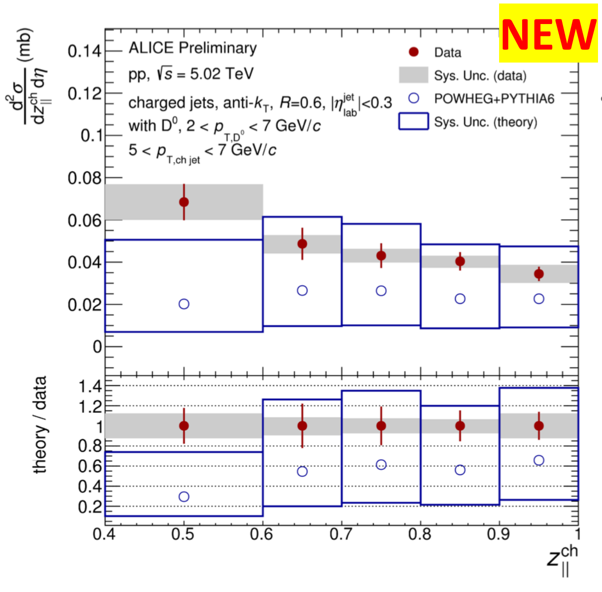

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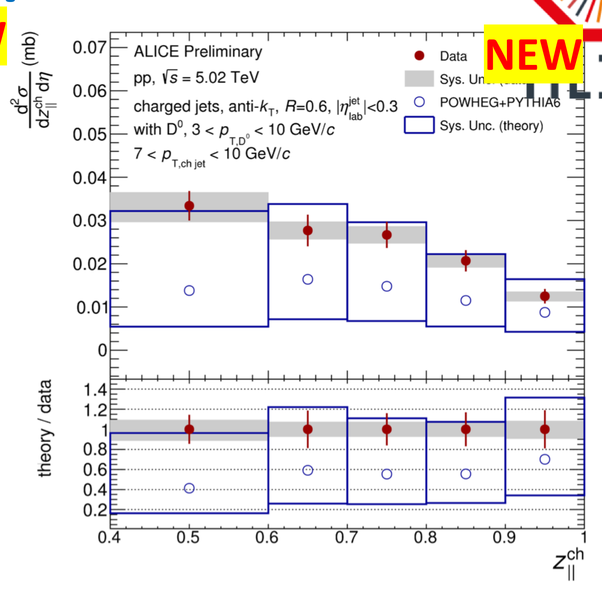

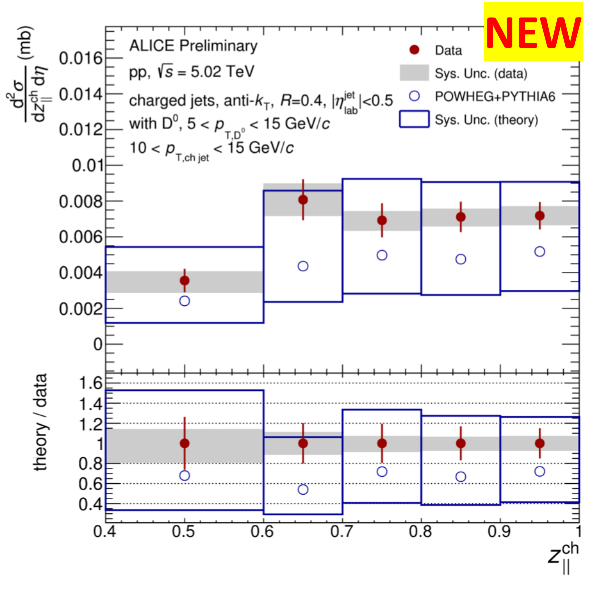

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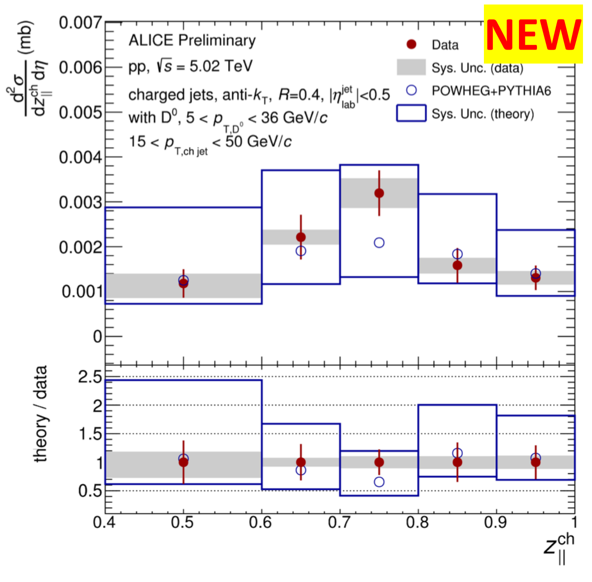

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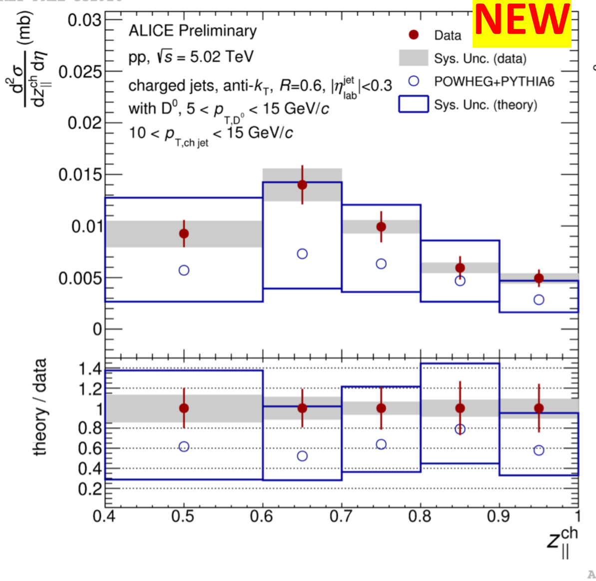

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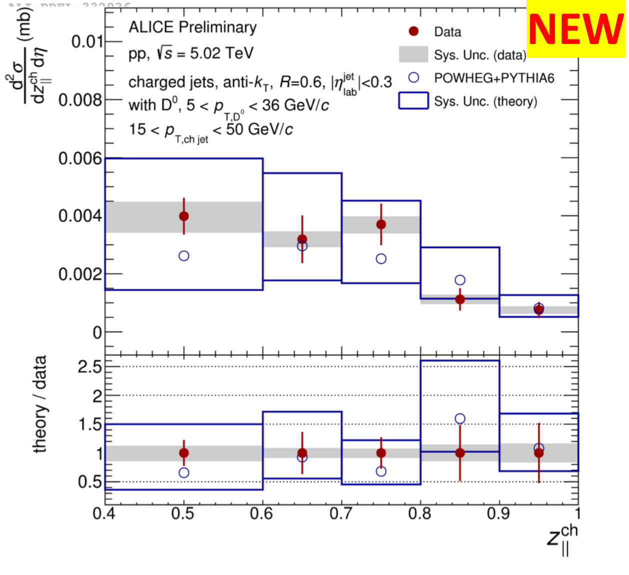

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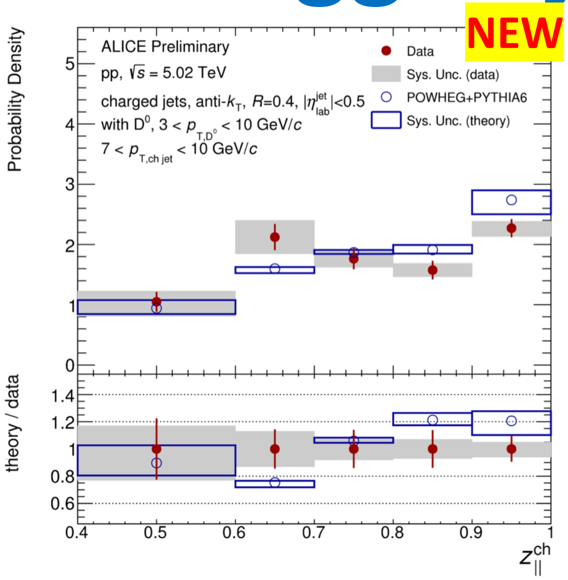
D⁰-tagged jets: 5.02 TeV – additional plots



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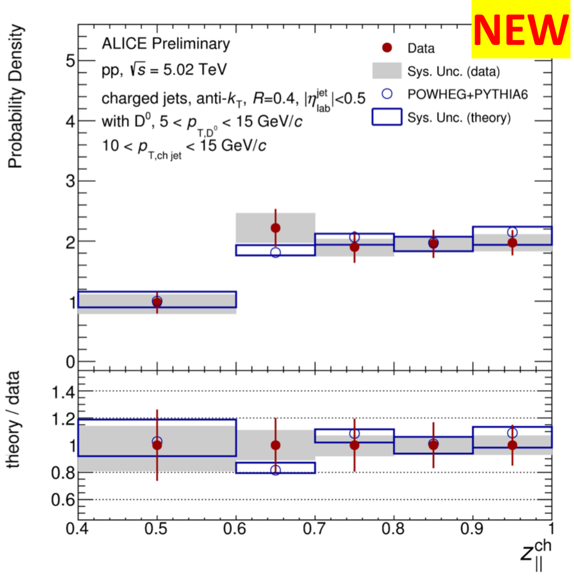

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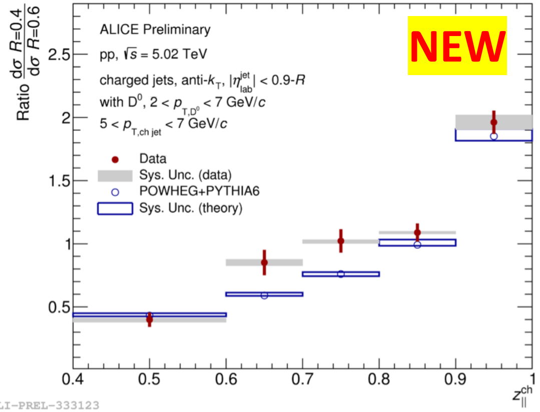

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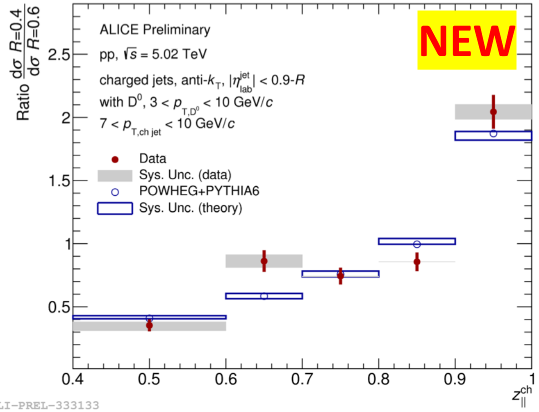

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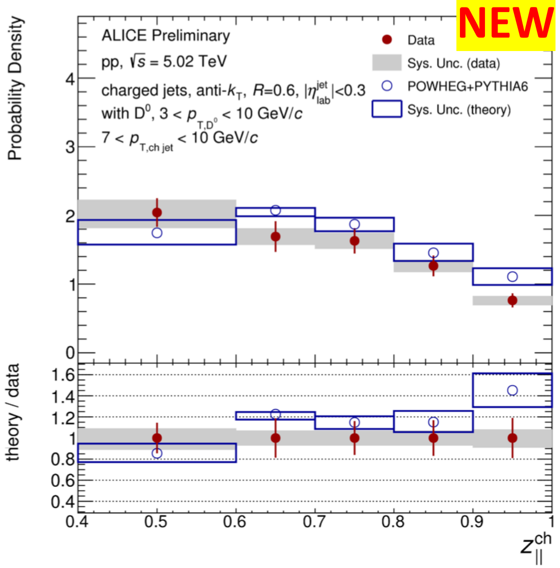

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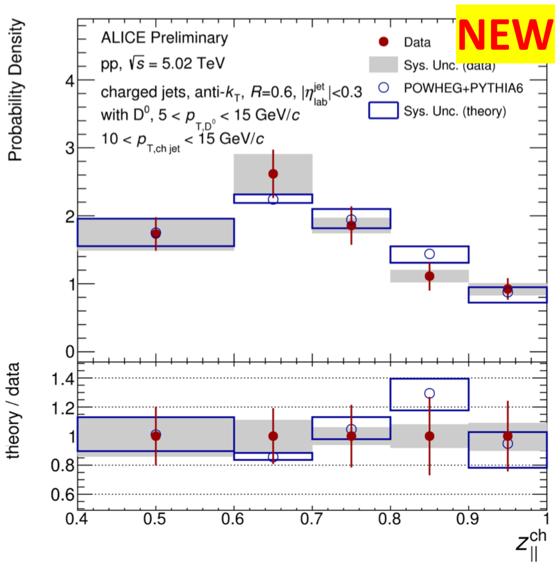

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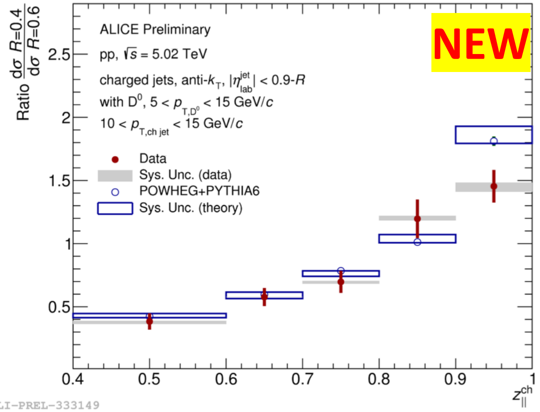

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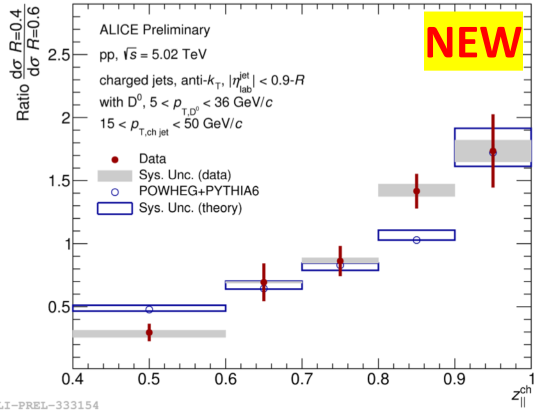

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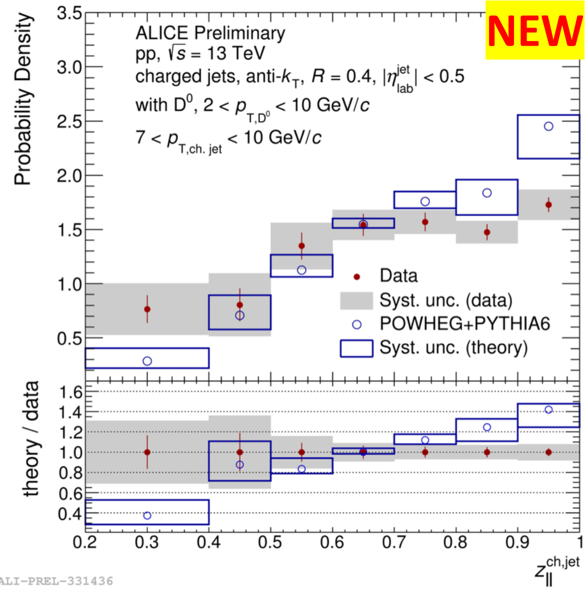
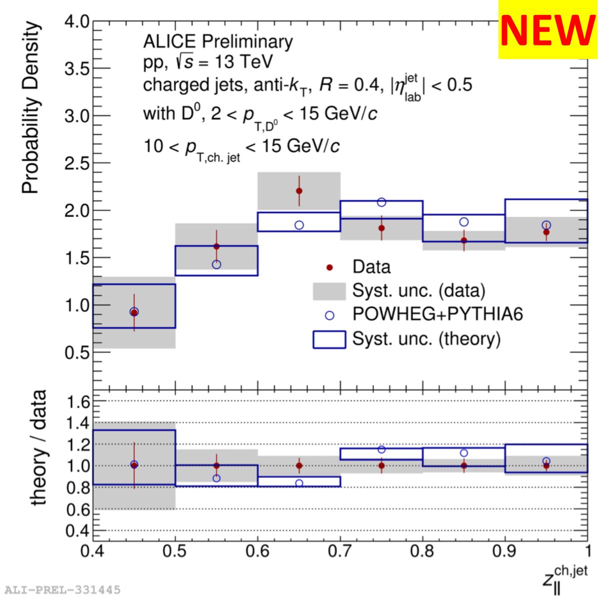
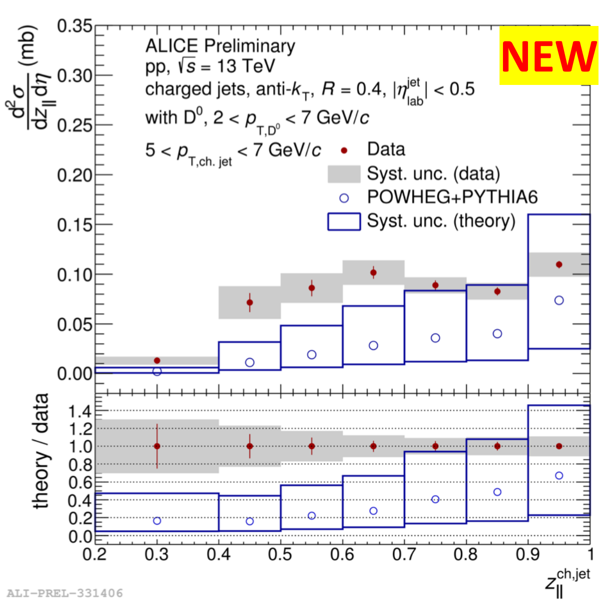
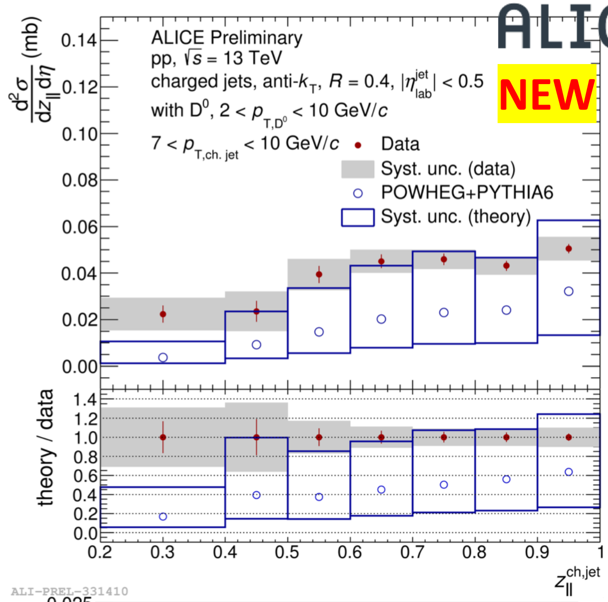
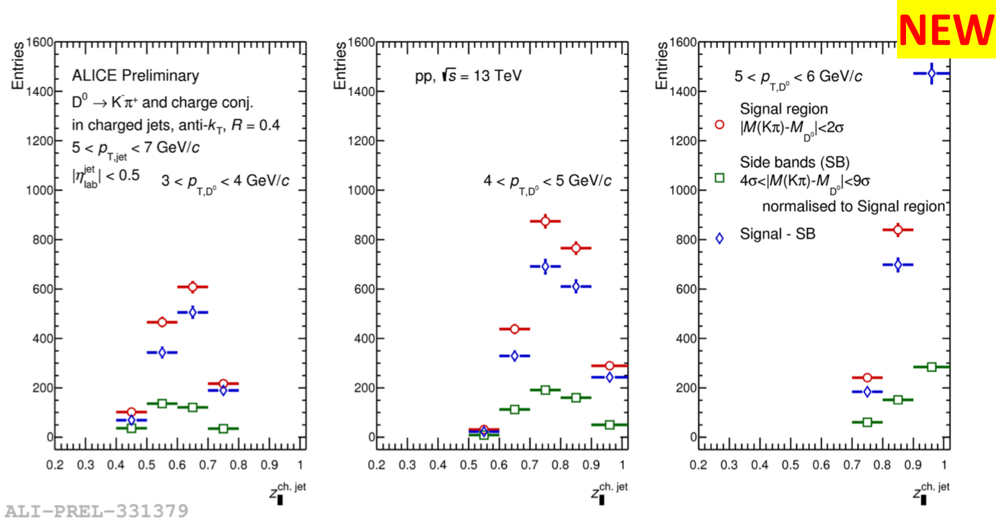
D^0-tagged jets: 13 TeV – additional plots

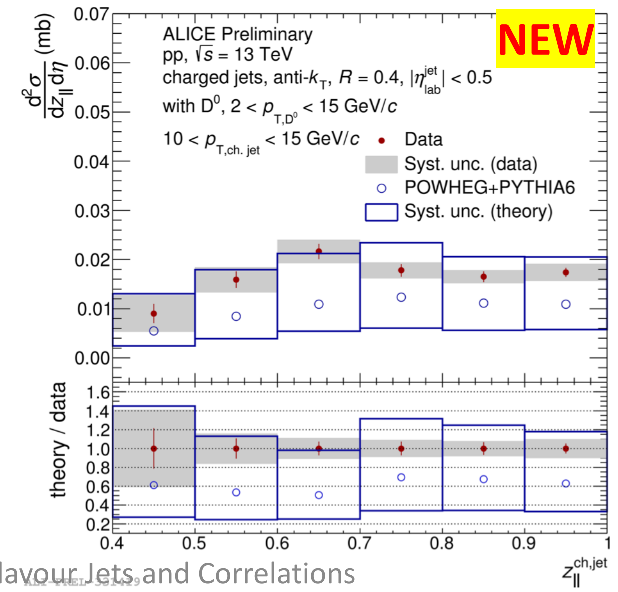


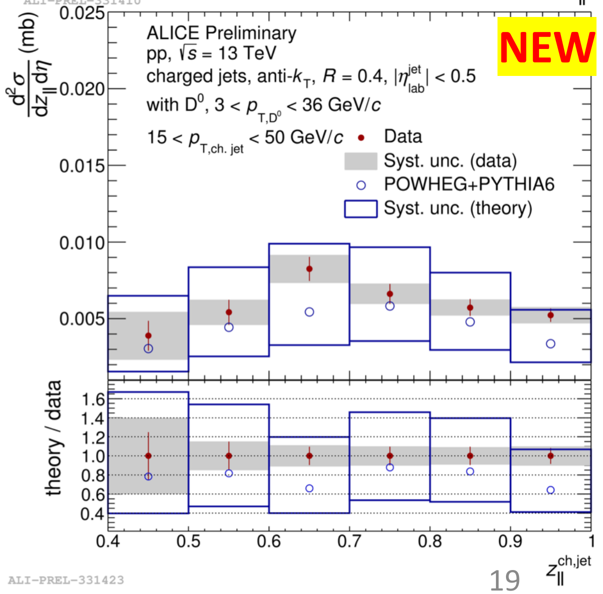




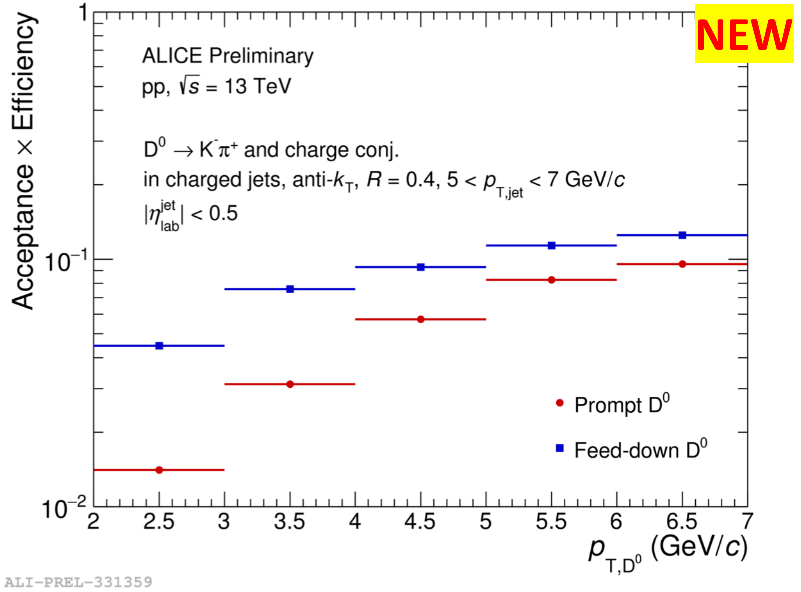


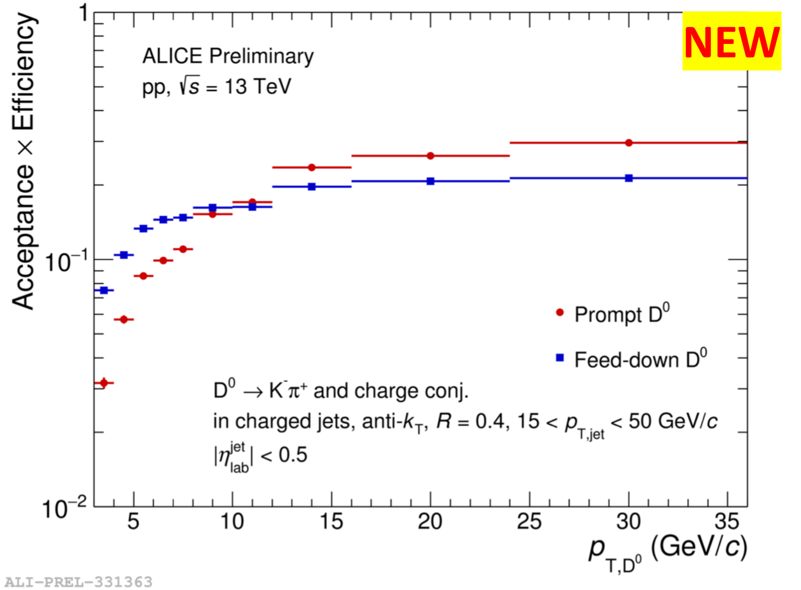


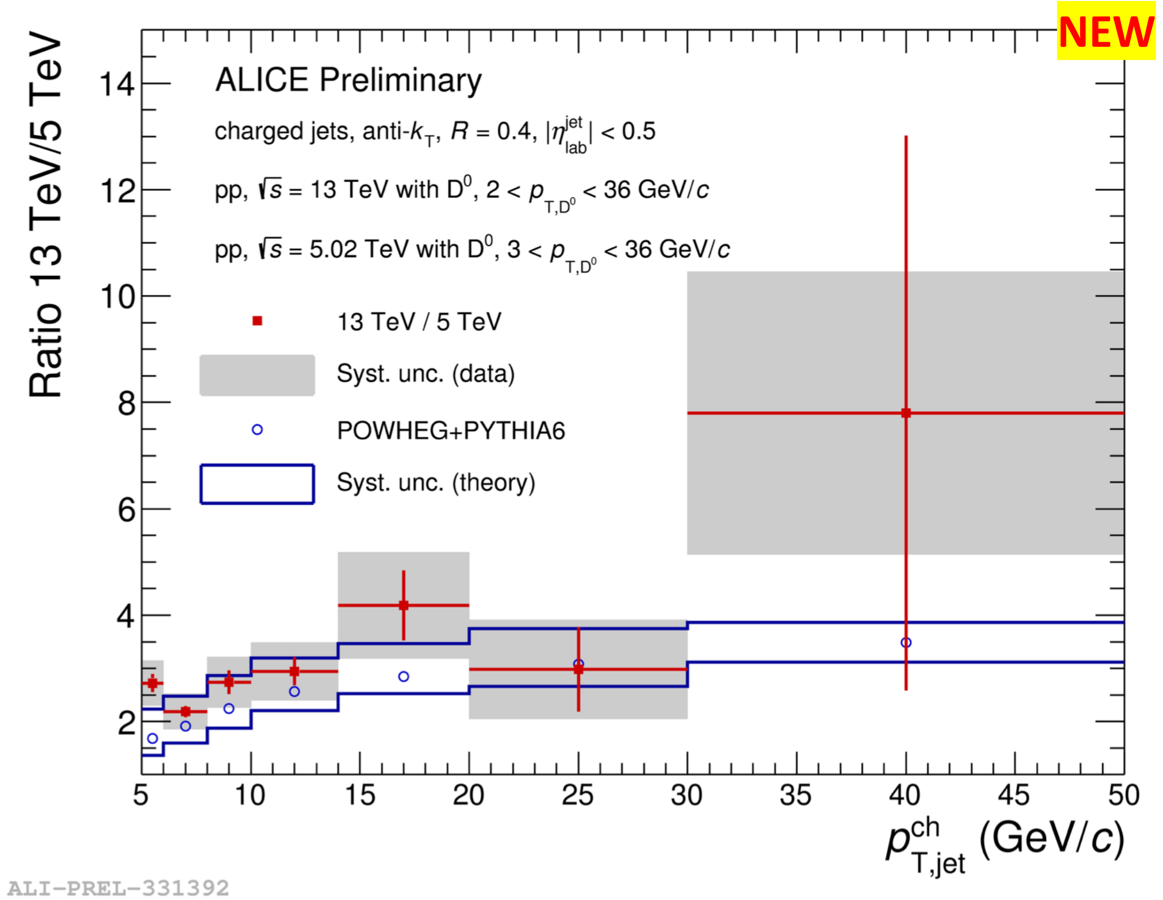




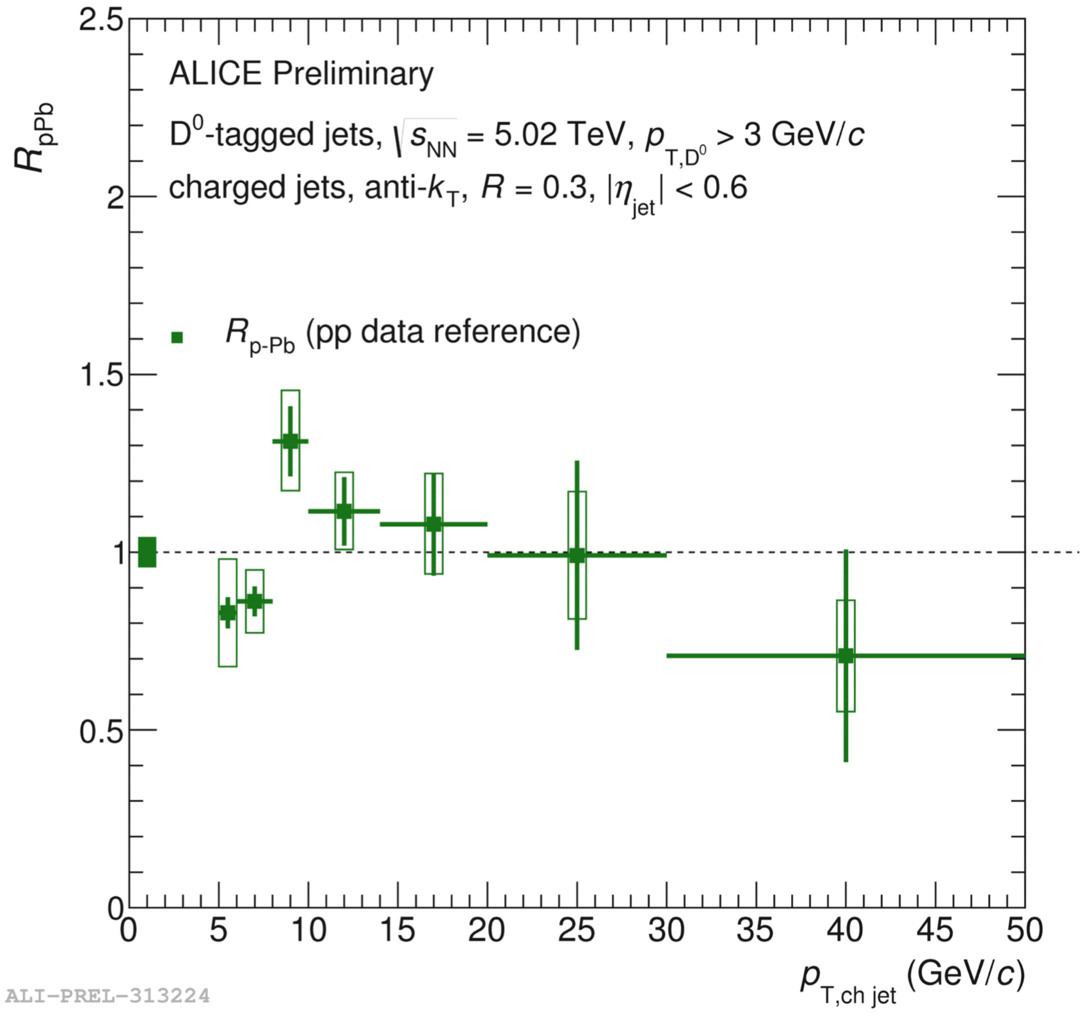
D^0-tagged jets: 13 TeV – additional plots



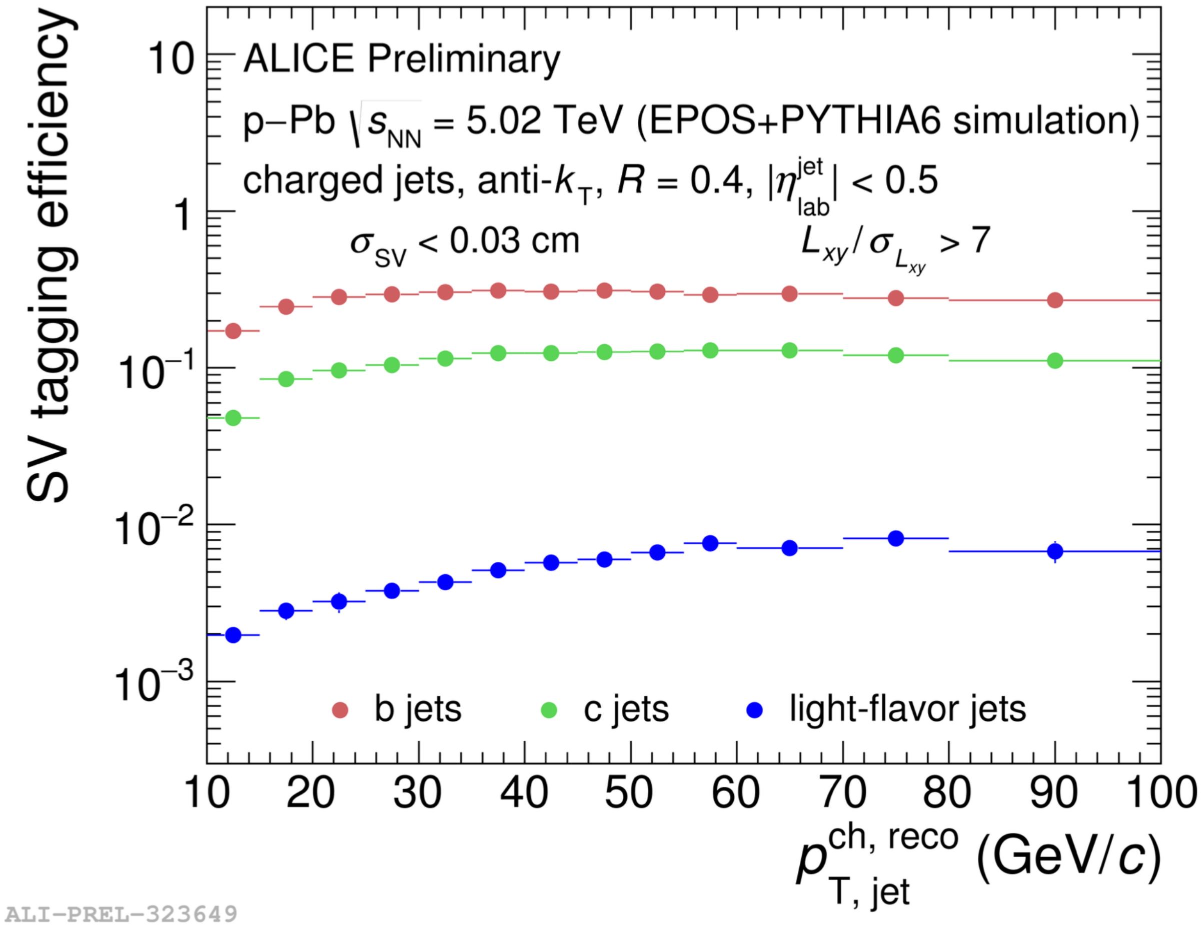


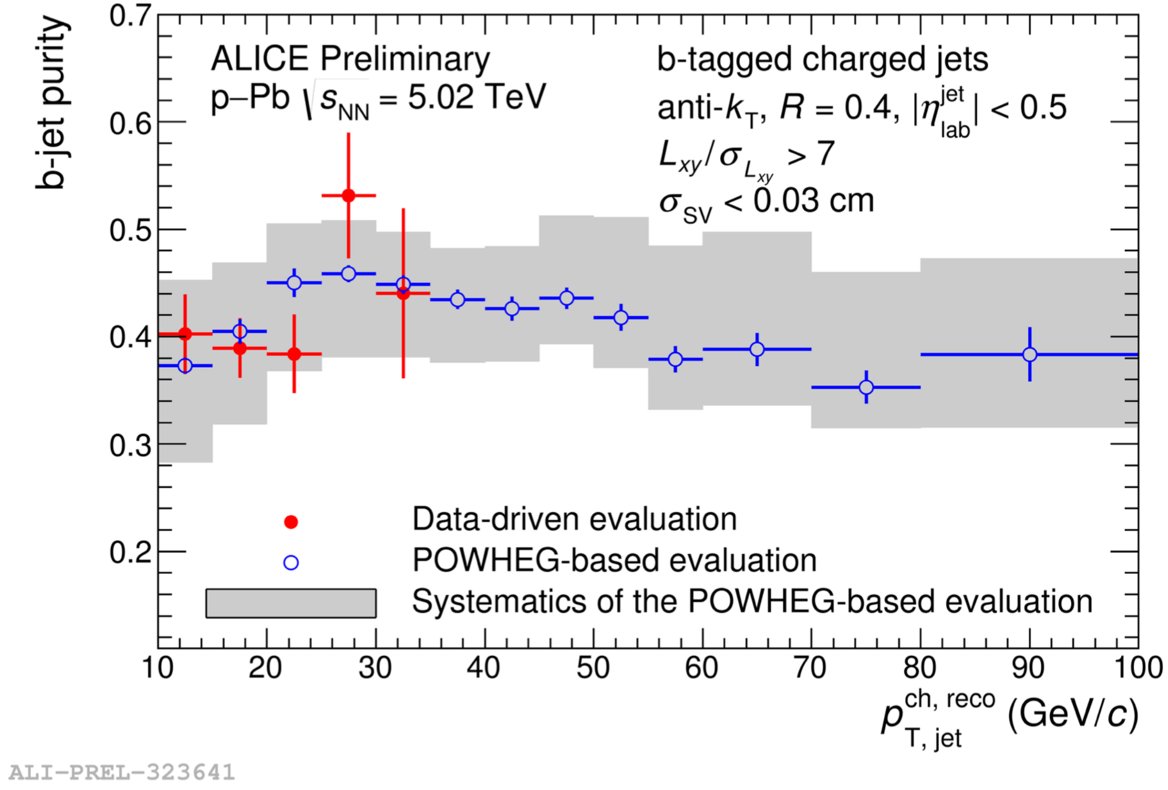


D^0-tagged jets: 5.02 TeV – R_{pPb}

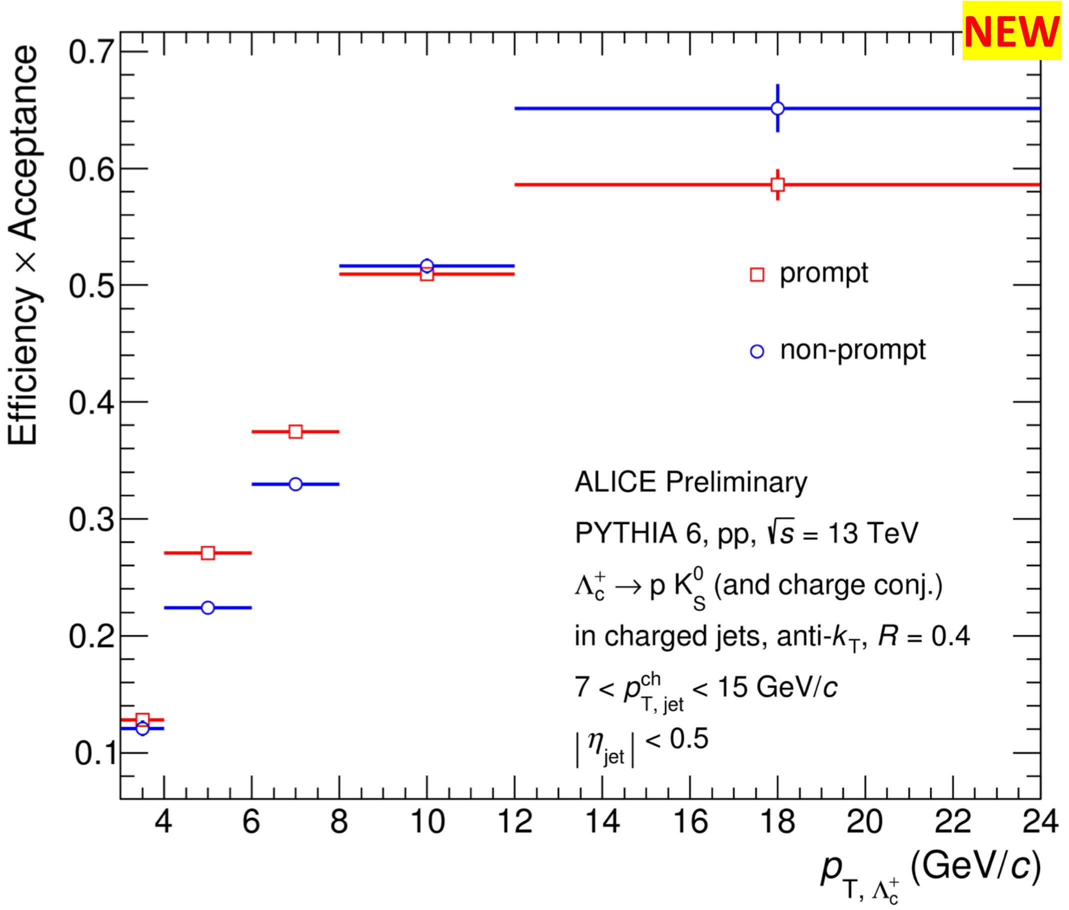


b-tagged jets: Secondary Vertex





Λ_c^+ -tagged jets



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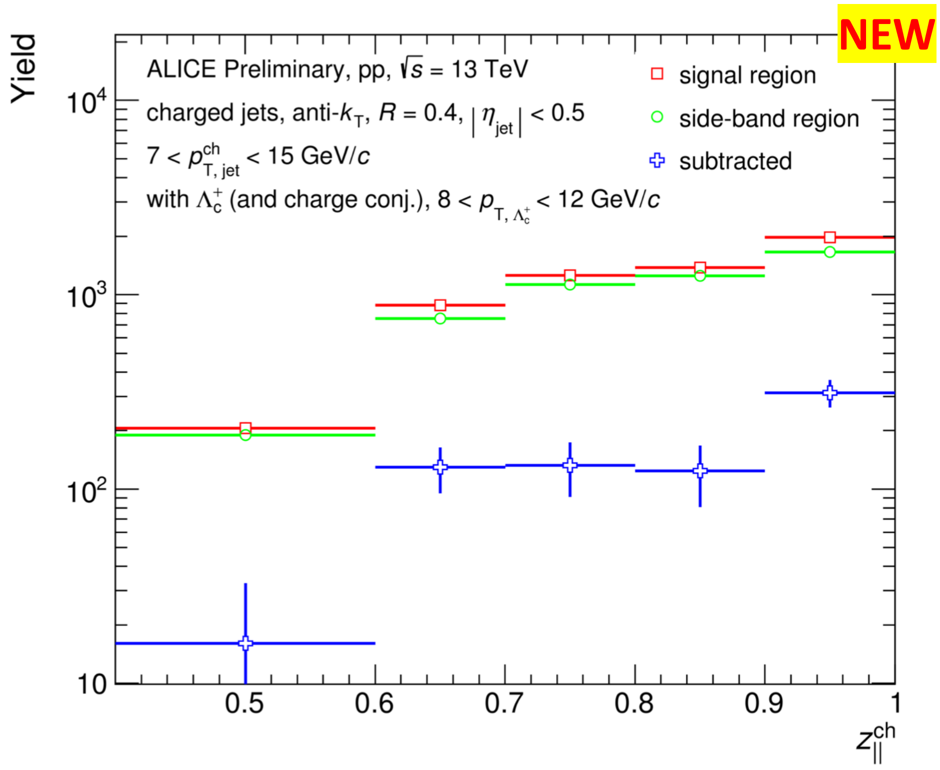

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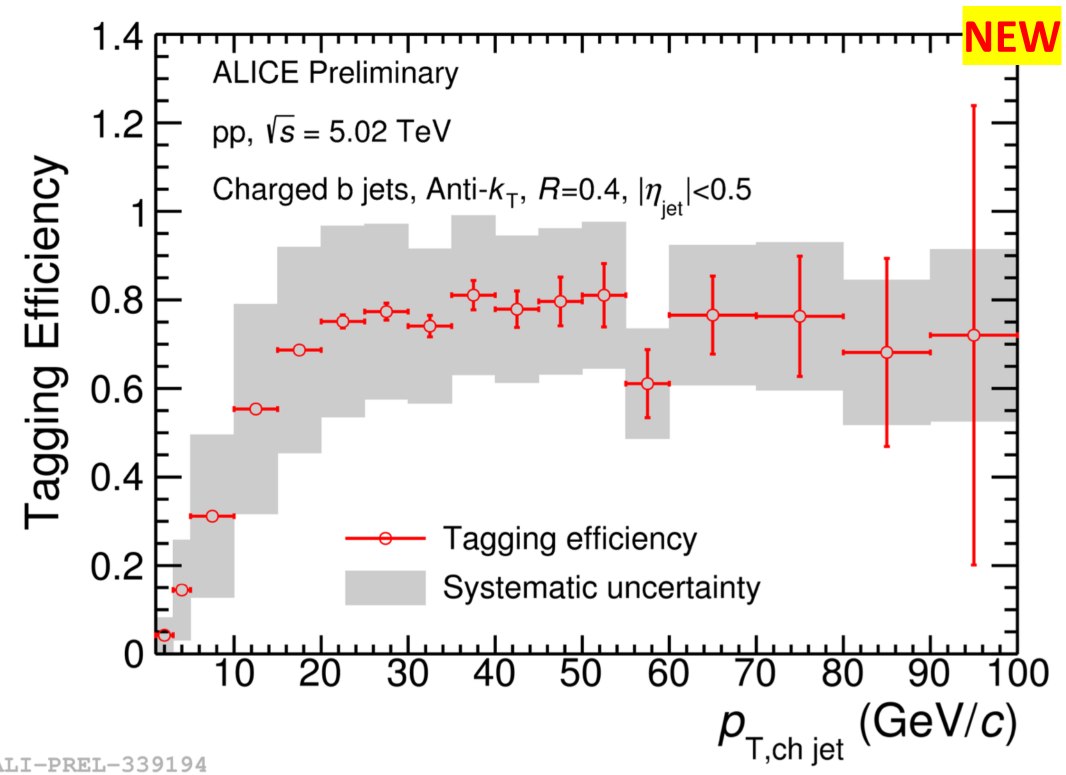
b-tagged jets: Impact Parameter



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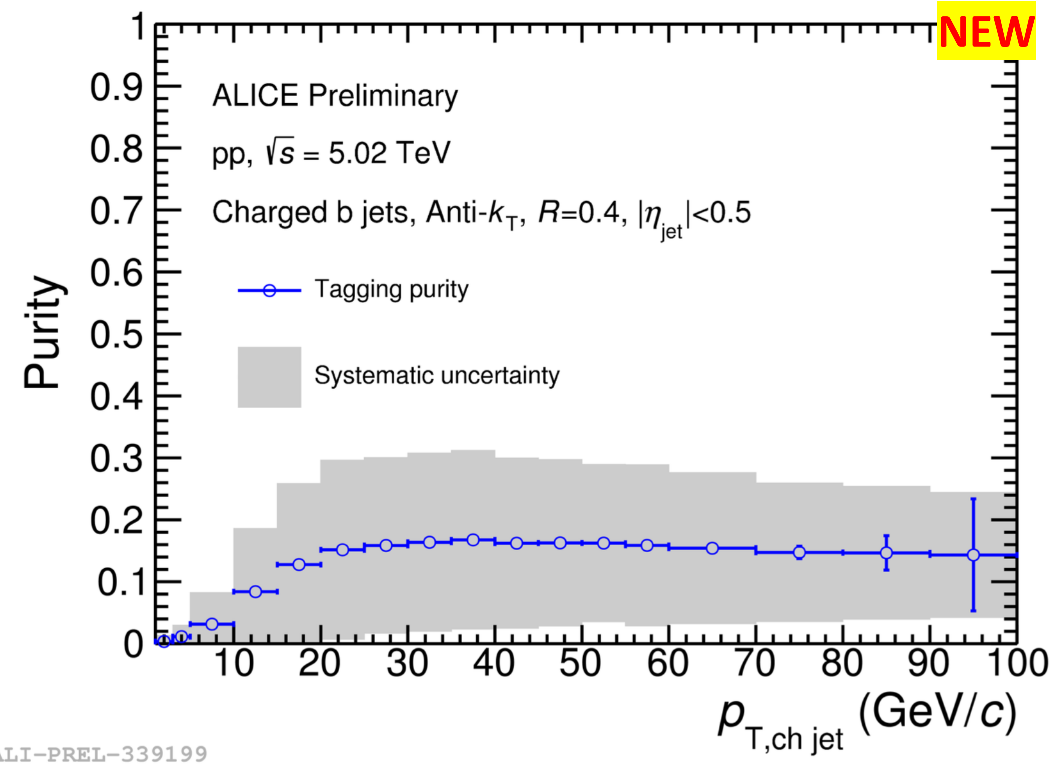

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