Heavy-flavour jet production and charm fragmentation with ALICE at LHC

Auro Mohanty

for the ALICE Collaboration.

*The 18th International Conference on **Strangeness in Quark Matter**.*

Bari. 10-15 June 2019.

Universiteit Utrecht

Netherlands Organisation for Scientific Research

Physics Motivation

Pb-Pb collisions:

- Mass/flavour dependence of energy loss in medium.
- Modification of jet sub-structure.

p-Pb collisions:

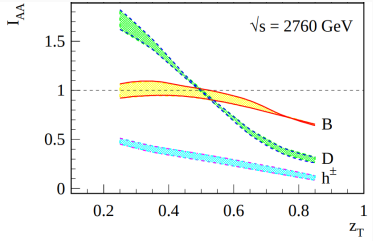
- Cold nuclear matter effects?

pp collisions:

- Reference measurement for p-Pb and Pb-Pb collisions.
- Heavy-flavour observables calculable in pQCD down to $p_{\mathrm{T}} \approx 0$.

Zhong-Bo Kang, Ivan Vitev. [Phys.Rev.D84:014034,2011]

$$10 < p_{\mathrm{T}}^{\gamma} < 20 \text{ GeV}c.$$



γ-tagged jets, $z_{\mathrm{T}} = \dfrac{p_{\mathrm{T,h}}}{p_{\mathrm{T},\gamma}}$

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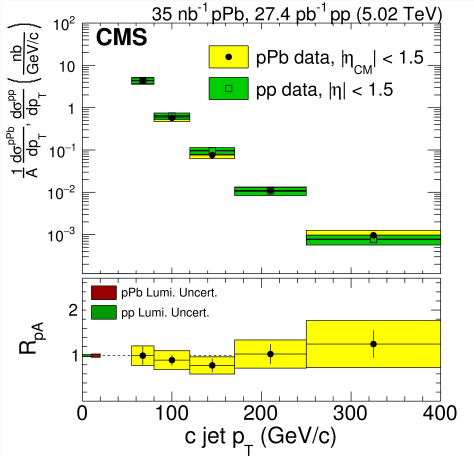
CMS: *c*-jets, pp, p-Pb, 5.02 TeV. [Phys. Lett. B 772 (2017) 306]



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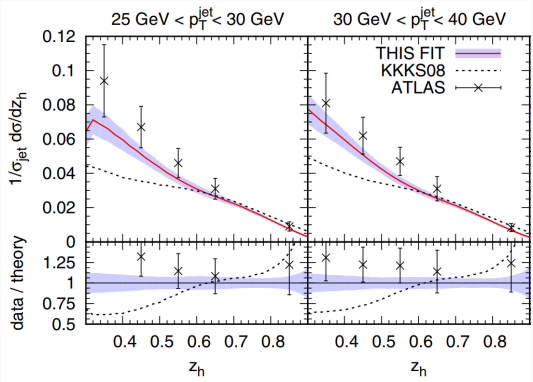
D.P. Anderle et al., $D^{*\pm}$-jets, pp, 7 TeV. [PRD 96 (2017) 034028]



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ALICE $\rightarrow$ significant role in low p_T sector.

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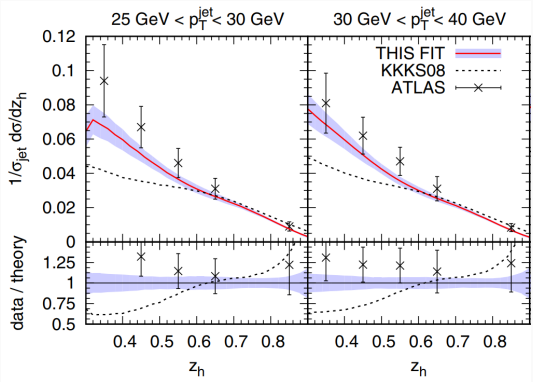
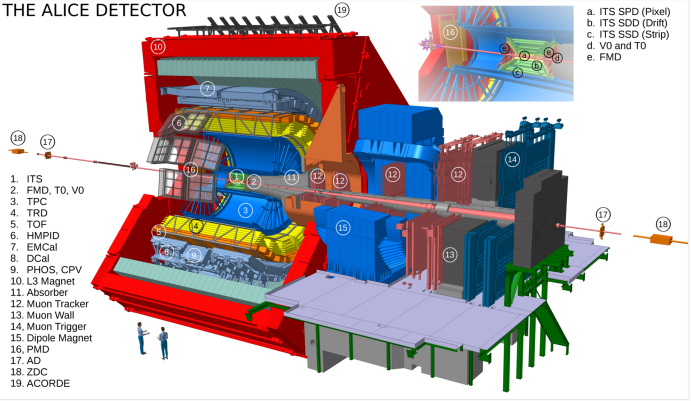


Tracking and PID with ALICE



- Low p_{T} tracking.
- Secondary vertex with ITS (1).
- Particle IDentification with
  - dE/dx from TPC (3).
  - Time of flight from TOF (5).
  - E/p from EMCal (7).

Heavy-Flavour Jets

Auro Mohanty, UU

Heavy-Flavour Electron Jet Reconstruction

HF electrons:

- Semi-leptonic decays:
  $c, b \rightarrow D, B \rightarrow e^{\pm} + X$ (BR 10%).
- PID: TPC dE/dx, EMCal E/p.
- $p_{\mathrm{T,\,e}} > 4$ GeV/c.

Jets

- With identified electrons.
- Track-based, charged jets, anti-k_{T}, R=0.3, 0.4, 0.6.
- $p_{\mathrm{T,\,ch\,jet}} > 10$ GeV/c.

Jets containing non-HF (photonic) $e^{\pm}$ subtracted (inv. mass).

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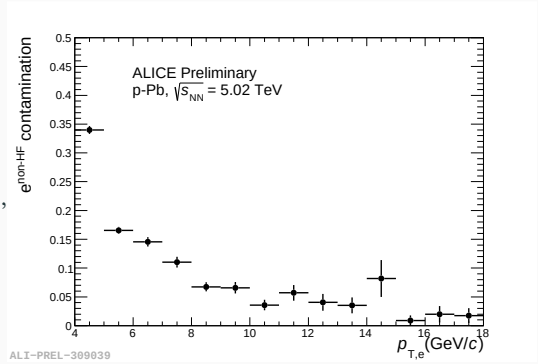
Corrections

- Residual contamination from photonic $e^{\pm}$.



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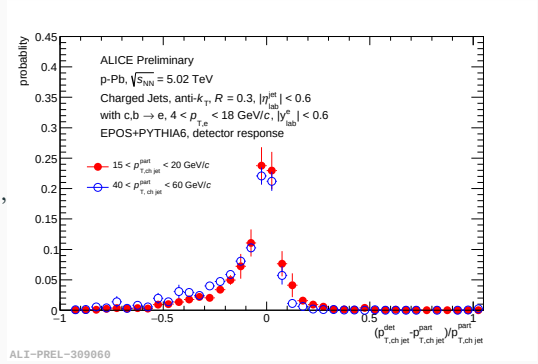
- Unfolding for detector $p_{\mathrm{T,\,ch\ jet}}$ resolution.



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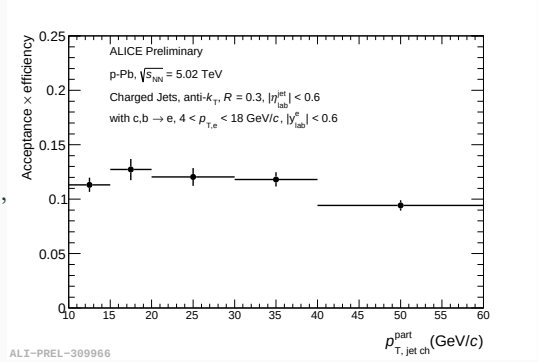
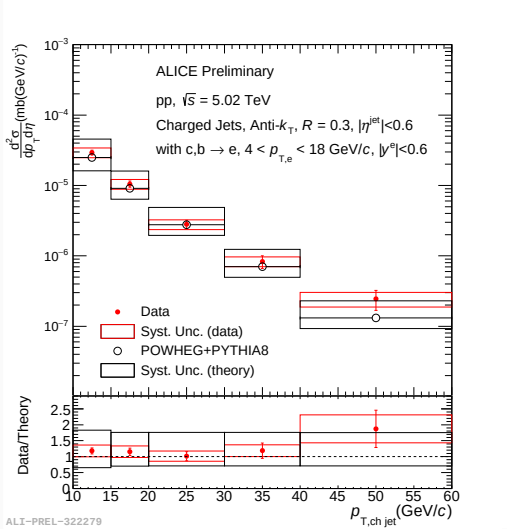
Corrections

- Residual contamination from photonic $e^{\pm}$.
- Unfolding for detector $p_{\mathrm{T,\,ch\ jet}}$ resolution.
- Reconstruction efficiency.



Heavy-Flavour Electron Jets, R=0.3

p_T differential cross-section in pp: NEW

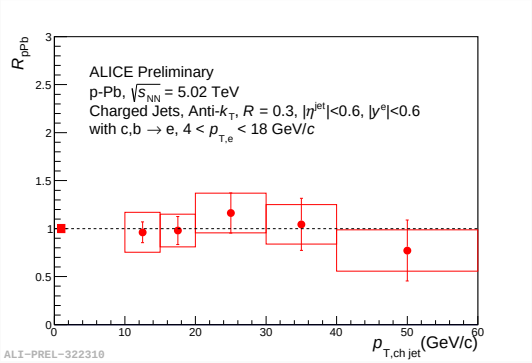


HFe jets, $\sqrt{s}$= 5.02 TeV, R=0.3.

- Good agreement with NLO pQCD POWHEG+PYTHIA8 predictions.

Heavy-Flavour Electron Jets, R=0.3

$$\text{NEW}: R_{\mathrm{pPb}} = \frac{1}{A_{\mathrm{Pb}}} \frac{d\sigma_{\mathrm{pPb}}/dp_{\mathrm{T}}}{d\sigma_{\mathrm{pp}}/dp_{\mathrm{T}}}$$

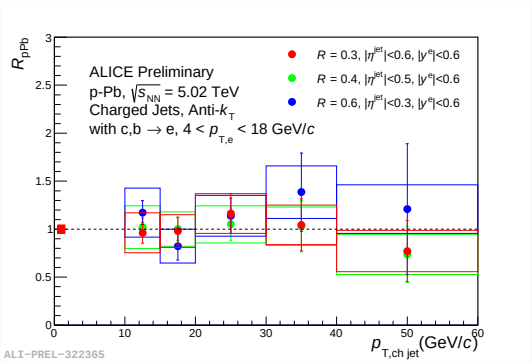


HFe jets, $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV, R=0.3.

- No evidence of CNM effects down to 10 GeV/c.

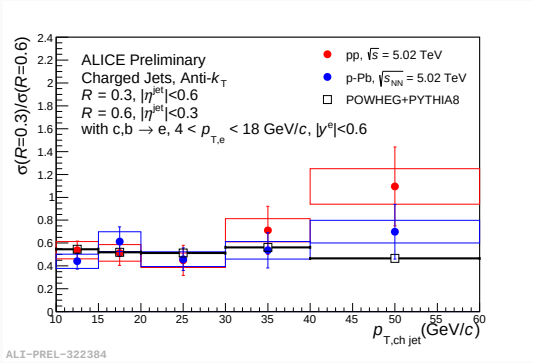
Radius Dependence of Heavy-Flavour Electron Jets

R_{pPb}, R=0.3, 0.4, 0.6: NEW



No evidence of CNM effects in any jet-R

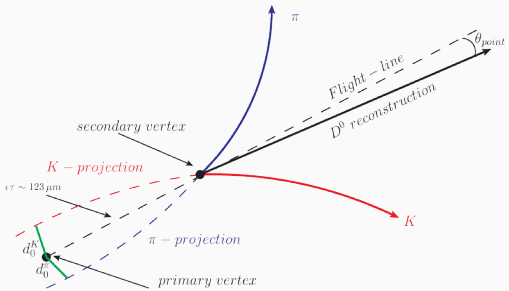
pp, p-Pb: R=0.3/R=0.6: NEW



Looking at internal jet structure

D^0-Meson Jet Reconstruction

- **D^0 reconstruction**: Hadronic decay channel ($D^0 \rightarrow K^- \pi^+$, BR = 3.89%).
  - Topological (secondary vertex) selection.
- **D^0 decay products replaced** by the D^0 candidate in jet finding algorithm.
- **Jet reconstruction**
  - Anti-k_T algorithm with R = 0.3, 0.4.
  - Track-based jet reconstruction.



D^0 reconstruction

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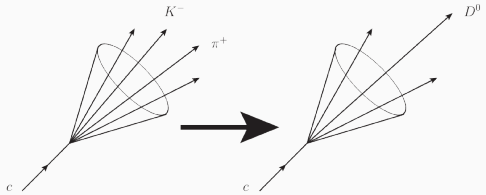

Daughters K^- and π^+ replaced by mother D^0

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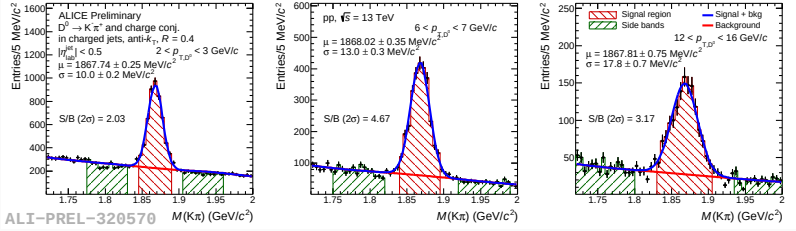
  - Topological (secondary vertex) selection.
- **D^0 decay products replaced** by the D^0 candidate in jet finding algorithm.
- **Jet reconstruction**
  - Anti-k_T algorithm with R = 0.3, 0.4.
  - Track-based jet reconstruction.

- **D^0-tagged jets**: D^0 candidate required to be among the jet constituents.
- $p_{T,\,D} > 3$ GeV/c, $p_{T,\,\text{ch jet}} > 5$ GeV/c.

D^0-Meson Jet Reconstruction

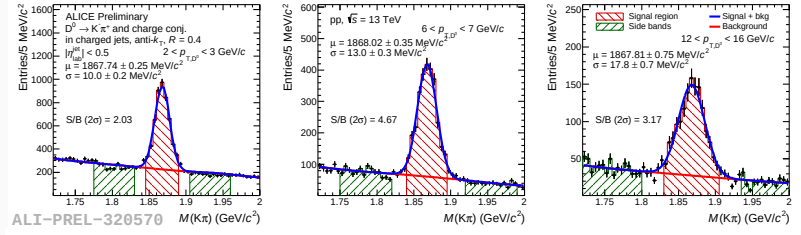
$2 < p_{\mathrm{T,D}} < 3$ GeV/c, $6 < p_{\mathrm{T,D}} < 7$ GeV/c, $12 < p_{\mathrm{T,D}} < 16$ GeV/c



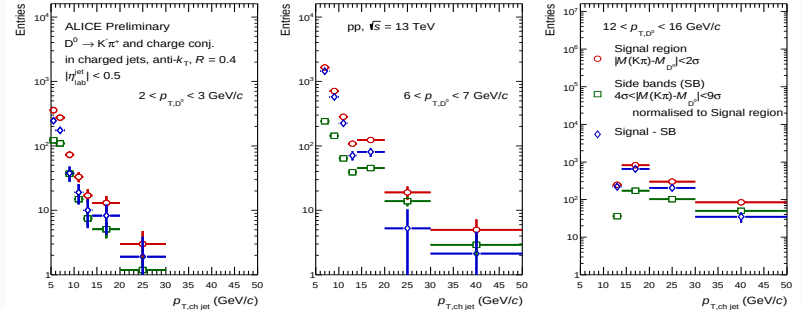
- Invariant mass fit of D^0-mesons in jets in $p_{\mathrm{T,D}}$ bins.
- 2σ **signal** window.
- 4-9σ **side bands**.

D^0-Meson Jet Reconstruction

$2 < p_{T,D} < 3$ GeV/c, $6 < p_{T,D} < 7$ GeV/c, $12 < p_{T,D} < 16$ GeV/c



ALI-PREL-320570



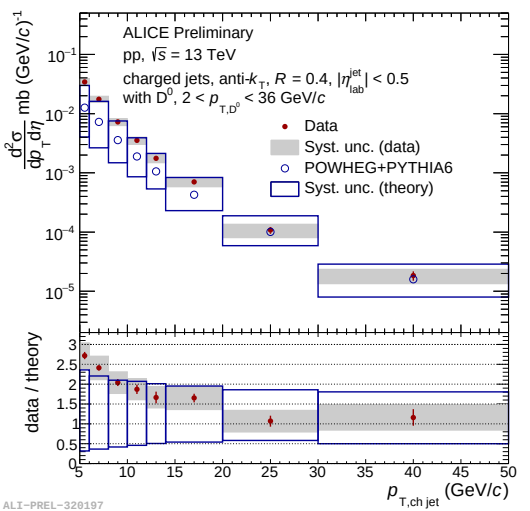
ALI-PREL-320582

- Invariant mass fit of D^0-mesons in jets in $p_{T,D}$ bins.
- 2σ **signal** window.
- 4-9σ **side bands**.

- Jet p_T spectra of **signal**(2σ) and **side bands bkg** (4-9 σ).
- Side-band bkg scaled to 2σ region and **subtracted**: *side band subtraction.*

D^0-Meson Jets in pp

p_T differential cross-section in pp. NEW



D^0-tagged jets, $\sqrt{s}$= 13 TeV, R=0.4.

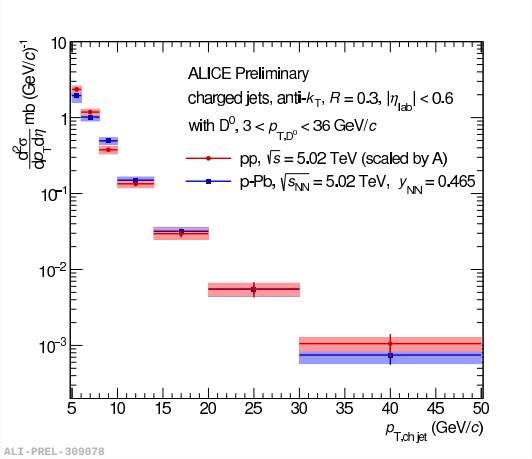
Corrections:

- D^0-jet reconstruction efficiency
- B feed-down subtraction (POWHEG-based).
- Unfolding for detector resolution

Good agreement with NLO-pQCD POWHEG+PYTHIA6 predictions.

D^0-Meson Jets in pp, p-Pb

p_T differential cross-section in p-Pb and pp (scaled by $A_{Pb} = 208$)



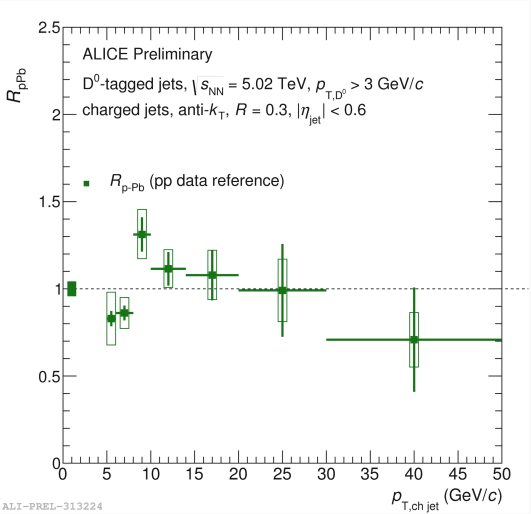
D^0-tagged jets, $\sqrt{s_{NN}}$= 5.02 TeV, R=0.3.

Corrections for p-Pb (and also Pb-Pb):

- D^0-meson reconstruction efficiency
- B feed-down (POWHEG-based)
- **Average jet-p_T background** density subtracted
- Unfolding for detector resolution and **background fluctuations**

D^0-Meson Jets: Nuclear Modification in p-Pb

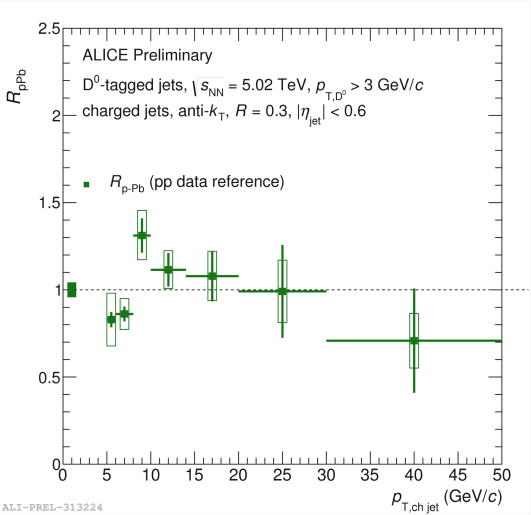
D^0-tagged jets, $\sqrt{s_{NN}} = 5.02$ TeV, R=0.3



- $R_{\mathrm{pPb}} = \dfrac{1}{A_{\mathrm{Pb}}} \dfrac{d\sigma_{\mathrm{pPb}}/dp_T}{d\sigma_{\mathrm{pp}}/dp_T}$

D^0-Meson Jets: Nuclear Modification in p-Pb

D^0-tagged jets, $\sqrt{s_{NN}} = 5.02$ TeV, R=0.3



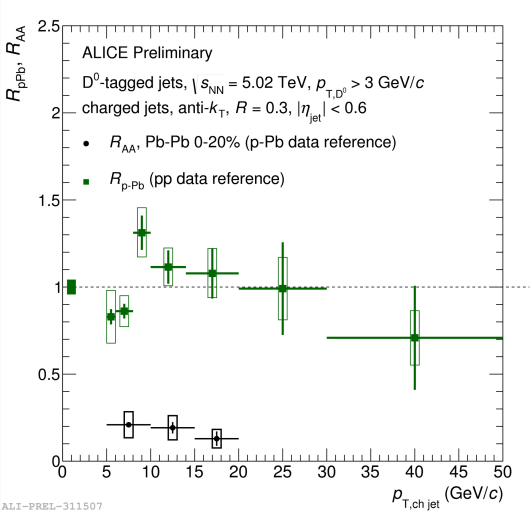
- $R_{\mathrm{pPb}} = \dfrac{1}{A_{\mathrm{Pb}}} \dfrac{d\sigma_{\mathrm{pPb}}/dp_T}{d\sigma_{\mathrm{pp}}/dp_T}$
- $R_{\mathrm{pPb}} \approx 1$ within uncertainties

  for $5 < p_{T,ch\ jet} < 50$ GeV/c.

  $3 < p_{T,D} < 36$ GeV

D^0-Meson Jets: Nuclear Modification in p-Pb, Pb-Pb

D^0-tagged jets, $\sqrt{s_{NN}} = 5.02$ TeV, R=0.3



- $R_{AA} = \dfrac{1}{\langle T_{AA} \rangle} \dfrac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$

  $= \dfrac{1}{\langle T_{AA} \rangle} \dfrac{dN_{AA}/dp_T}{d\sigma_{pPb}/dp_T} \times A_{Pb}$

- Pb-Pb 0-20%:

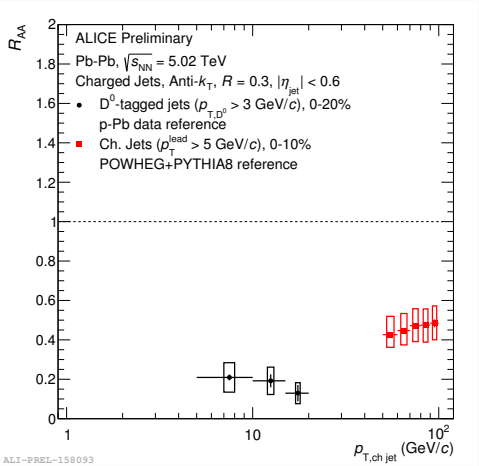
  $R_{AA} \approx 0.2$, Strong suppression.

  for $5 < p_{T,\,ch\ jet} < 20$ GeV/c,

  $3 < p_{T,\,D} < 20$ GeV/c.

D^0-Meson Jets: Nuclear Modification in Pb-Pb

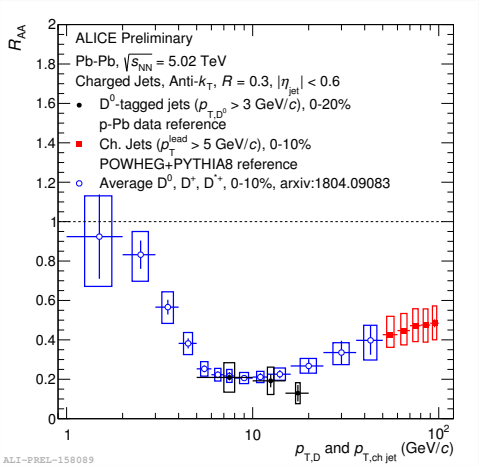
Jets, D-jets, 5.02 TeV, R=0.3



- Hint of **smaller R_{AA}** for **low p_T D-jets** than high p_T charged jets.

D^0-Meson Jets: Nuclear Modification in Pb-Pb

D mesons, Jets, D-jets, 5.02 TeV, R=0.3



- Hint of **smaller R_{AA}** for **low p_T D-jets** than high p_T charged jets.
- D-jets trend similar to D mesons.

D^0-tagged jets, pp, $\sqrt{s} = 7$ TeV, R=0.4

- Momentum fraction carried by the D^0 meson in the direction of the jet axis

$$z_{||}^{\text{ch}} = \frac{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{D}}}{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{ch jet}}}$$

D^0-Meson Jets: Parallel Momentum Fraction

ALICE [arXiv:1905.02510]

D^0-tagged jets, pp, $\sqrt{s} = 7$ TeV, R=0.4

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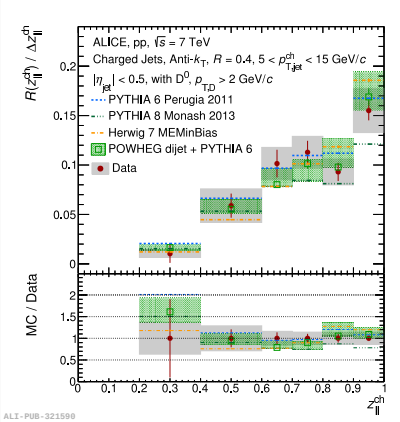
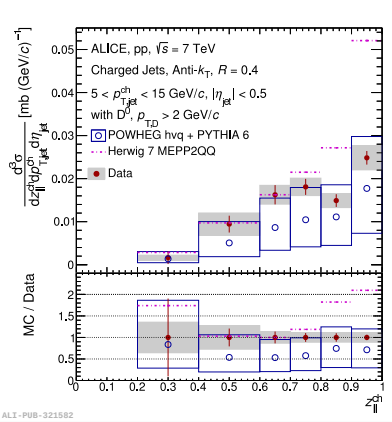
$$z_{||}^{\text{ch}} = \frac{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{D}}}{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{ch jet}}}$$

- $R(p_{\text{T,jet}}^{\text{ch}}, z_{||}^{\text{ch}}) = \dfrac{N_{\text{D}^0\text{jet}}(p_{\text{T,jet}}^{\text{ch}}, z_{||}^{\text{ch}})}{N_{\text{jet}}(p_{\text{T,jet}}^{\text{ch}})}$
- **$5 < p_{\text{T, ch jet}} < 15$ GeV/c**
- Hard fragmentation.





Good agreement with Herwig 7, and PYTHIA6/8 generators

Also with NLO pQCD POWHEG+PYTHIA6 simulations

D^0-Meson Jets: Parallel Momentum Fraction

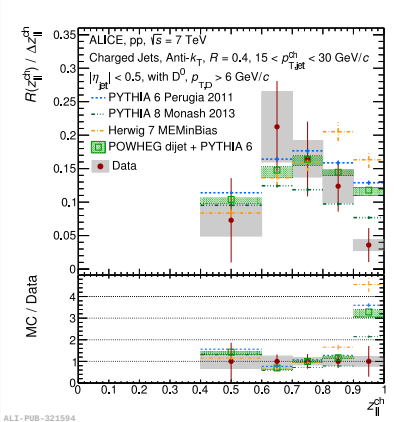
ALICE [arXiv:1905.02510]

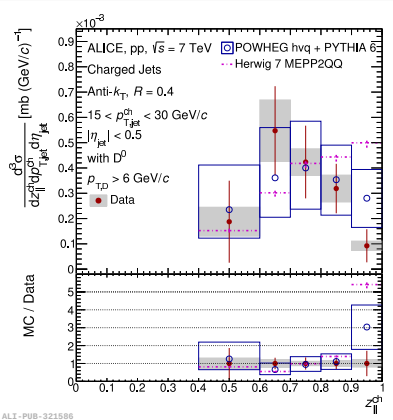
D^0-tagged jets, pp, $\sqrt{s} = 7$ TeV, R=0.4

- Momentum fraction carried by the D^0 meson in the direction of the jet axis

$$z_{||}^{\text{ch}} = \frac{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{D}}}{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{ch jet}}}$$

- $R(p_{\text{T,jet}}^{\text{ch}}, z_{||}^{\text{ch}}) = \dfrac{N_{\text{D}^0\text{jet}}(p_{\text{T,jet}}^{\text{ch}}, z_{||}^{\text{ch}})}{N_{\text{jet}}(p_{\text{T,jet}}^{\text{ch}})}$
- **$15 < p_{\text{T, ch jet}} < 30$ GeV/c**
- Hint of **softer** fragmentation in data.





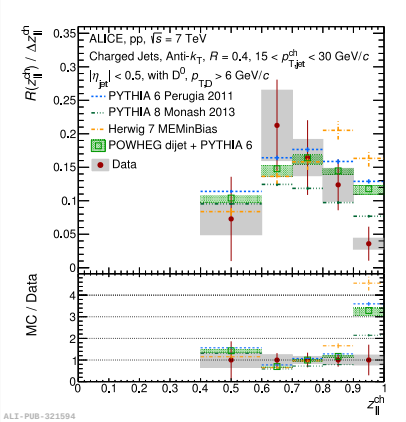
Good agreement with Herwig 7, and PYTHIA6/8 generators

Also with NLO pQCD POWHEG+PYTHIA6 simulations for $z_{||}^{\text{ch}} < 0.9$

D^0-Meson Jets: Parallel Momentum Fraction

ALICE [arXiv:1905.02510]

"D-tagged jet production and fragmentation measurements in pp collisions with ALICE"
poster by Barbara Trzeciak



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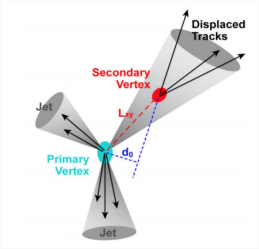
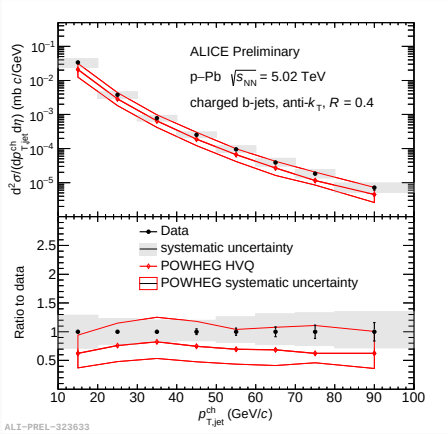
"Beauty Production with ALICE at LHC" talk by Erin Gauger, 11 June, 15:20

- Jets with 3-pronged secondary vertex



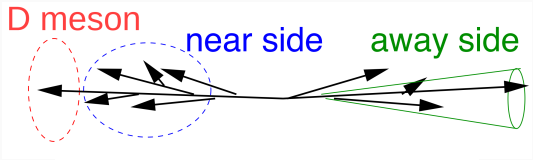
p_T differential cross-section in p-Pb, $\sqrt{s}$ =5.02 TeV: NEW

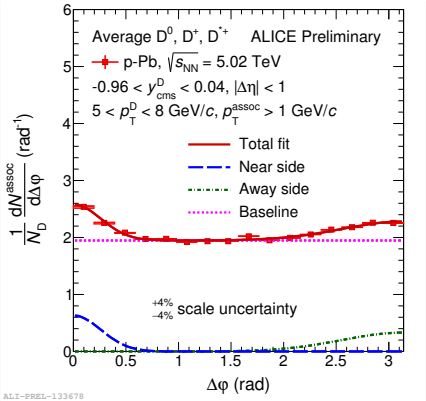


D-Meson – Hadron Correlations

Auro Mohanty, UU

D Meson – Hadron Correlations



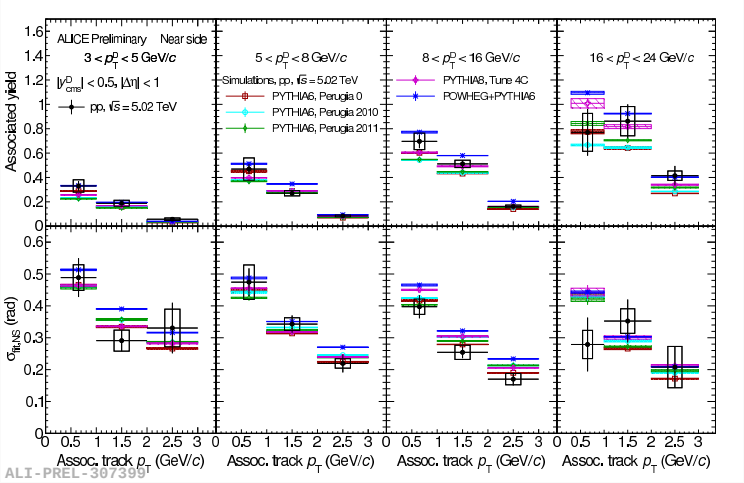


- Reference “trigger” particle: D meson.
- Associated particles: **charged tracks**.
- Direct investigation of **charm jet fragmentation**.

- Finite acceptance correction with event mixing
- B feed-down subtraction (FONLL based).
- Fit performed with a double Gaussian and a constant for the baseline.

D-h correlations: pp at $\sqrt{s} = 5.02$ TeV vs. models

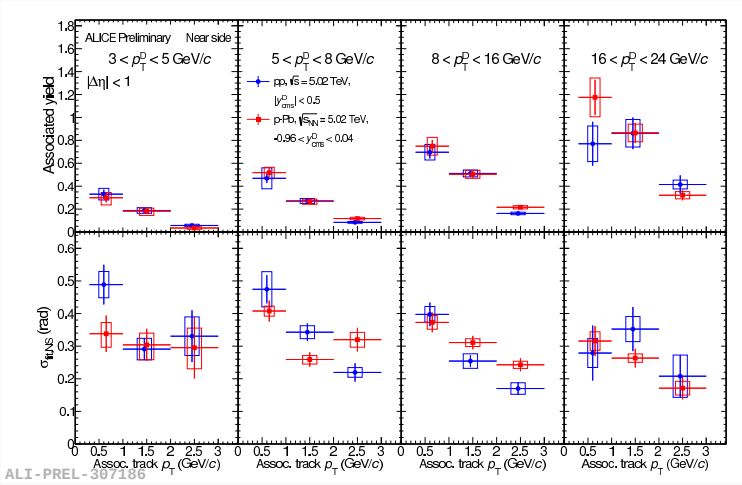
- Yield and width vs. assoc. track p_T.
- Agreement with PYTHIA6/8 and POWHEG+PYTHIA6.



D Meson – Hadron Correlations: *Near Side*

D-h correlations: pp vs. p-Pb at $\sqrt{s} = 5.02$ TeV

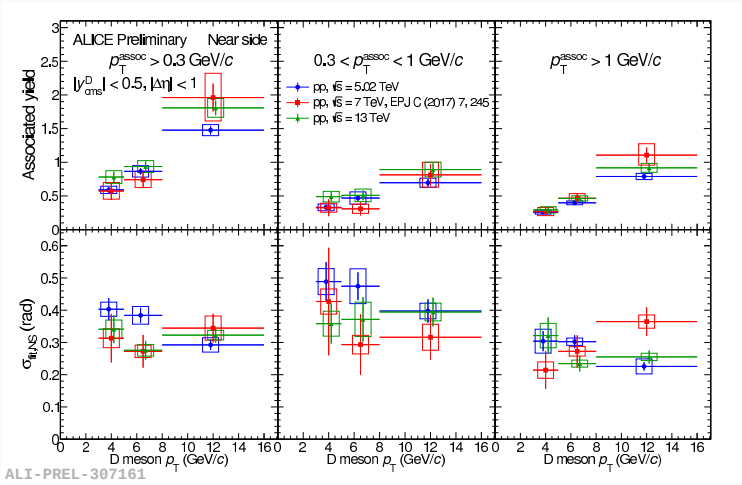
- No evidence of cold nuclear matter effects within uncertainties.



D Meson – Hadron Correlations: *Near Side*

D-h correlations: pp at $\sqrt{s} = 5.02, 7, 13$ TeV

- Associated yield increases with D p_T.
- No $\sqrt{s}$ dependence within uncertainties.



Conclusions

- New measurements of HFe jets in pp, p-Pb with ALICE.
- First measurement of D-tagged jets in Pb-Pb: $R_{AA} \approx 0.2$.
- Hard fragmentation for D^0-jets in $5 < p_T < 15$ GeV/c and hint of softer fragmentation in $15 < p_T < 30$ GeV/c in pp.
- No $\sqrt{s}$ dependence of D-h correlations in pp.
- No evidence of cold nuclear matter effects in p-Pb.

Conclusions

Outlook

- Momentum fraction studies will be extended with large statistics pp data sets at $\sqrt{s}$ = 5.02 and 13 TeV.
- 2018 Pb-Pb run essential for more precise measurements with greater jet p_{T} range.
- Looking forward to theoretical predictions for nuclear modification!

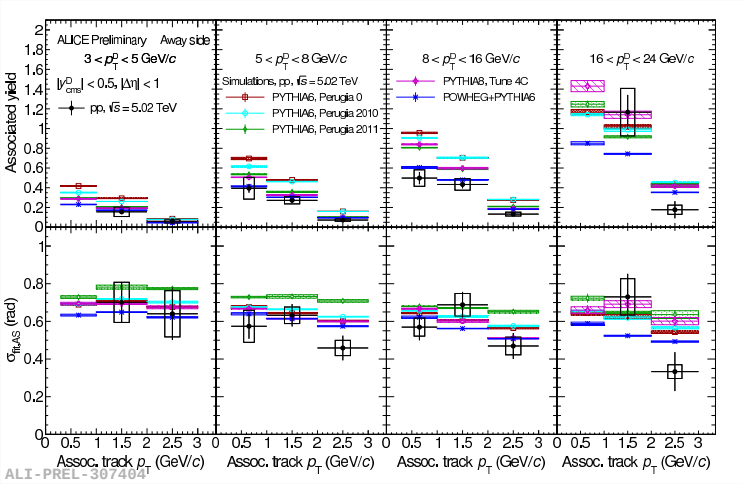
HF-jets: unique opportunity to study jet production and structure with identified (massive) quarks

Thank you!

D Meson – Hadron Correlations: *Away Side*

D-h correlations: pp at $\sqrt{s} = 5.02$ TeV vs. models

- Yield and width vs. assoc. track p_T.
- Agreement with PYTHIA6/8 and POWHEG+PYTHIA6.



D Meson – Hadron Correlations: *Away Side*

D-h correlations: pp vs. p-Pb at $\sqrt{s} = 5.02$ TeV

- No evidence of cold nuclear matter effects within uncertainties.