Heavy-flavour jet properties and correlations from small to large systems with ALICE

Marianna MAZZILLI for the ALICE Collaboration

06/04/2022 - Krakow

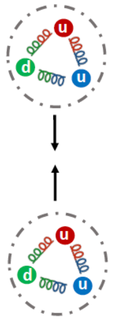
Physics Motivations

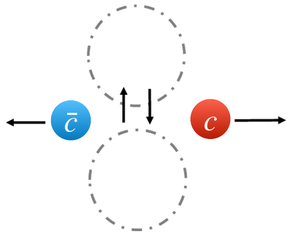
p-p

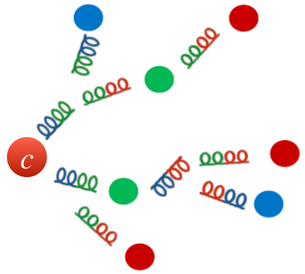
Hard scattering

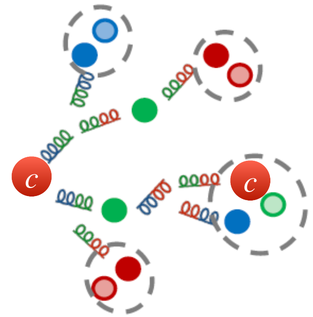
Parton shower

Hadronisation









time

Heavy flavour (HF) quarks **originate in hard scattering** processes at the early stage of the collision

HF **production measurements** as test of pQCD

Heavy quark flavour is conserved trough the shower process → **trace back the emission history of the charm quark**

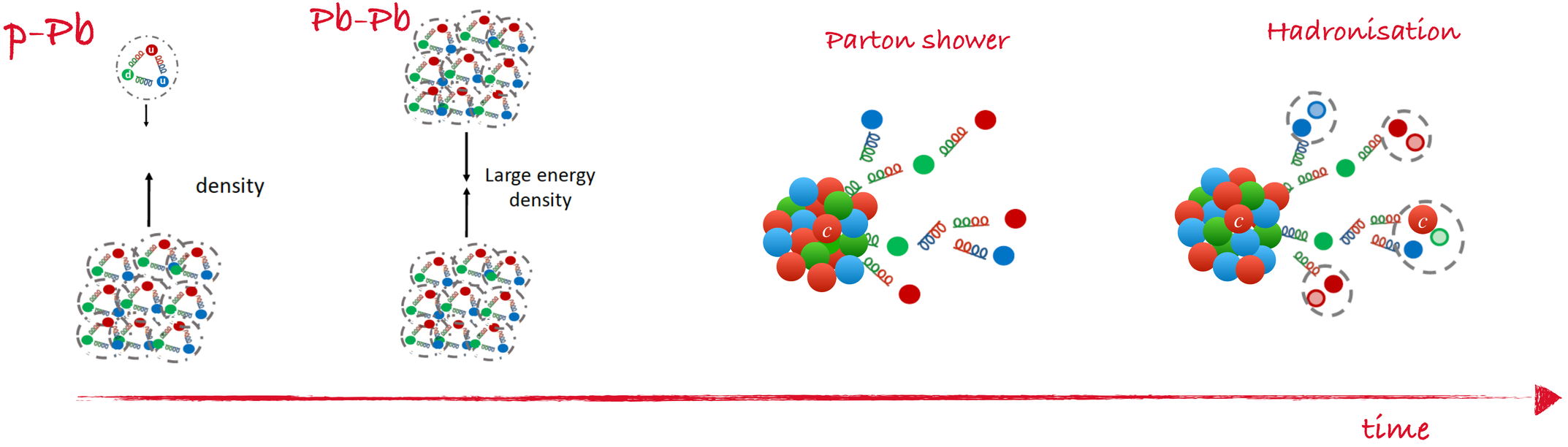
The pattern of the shower depends on the mass of the initial parton through the **dead-cone effect**

Multi particle final state: **transition of quarks to hadrons**

Which fraction of the original heavy quark (HQ) momentum is carried by HF hadron?

Is the hadronisation different for baryons and mesons?

Physics Motivations



Cold nuclear matter effects?

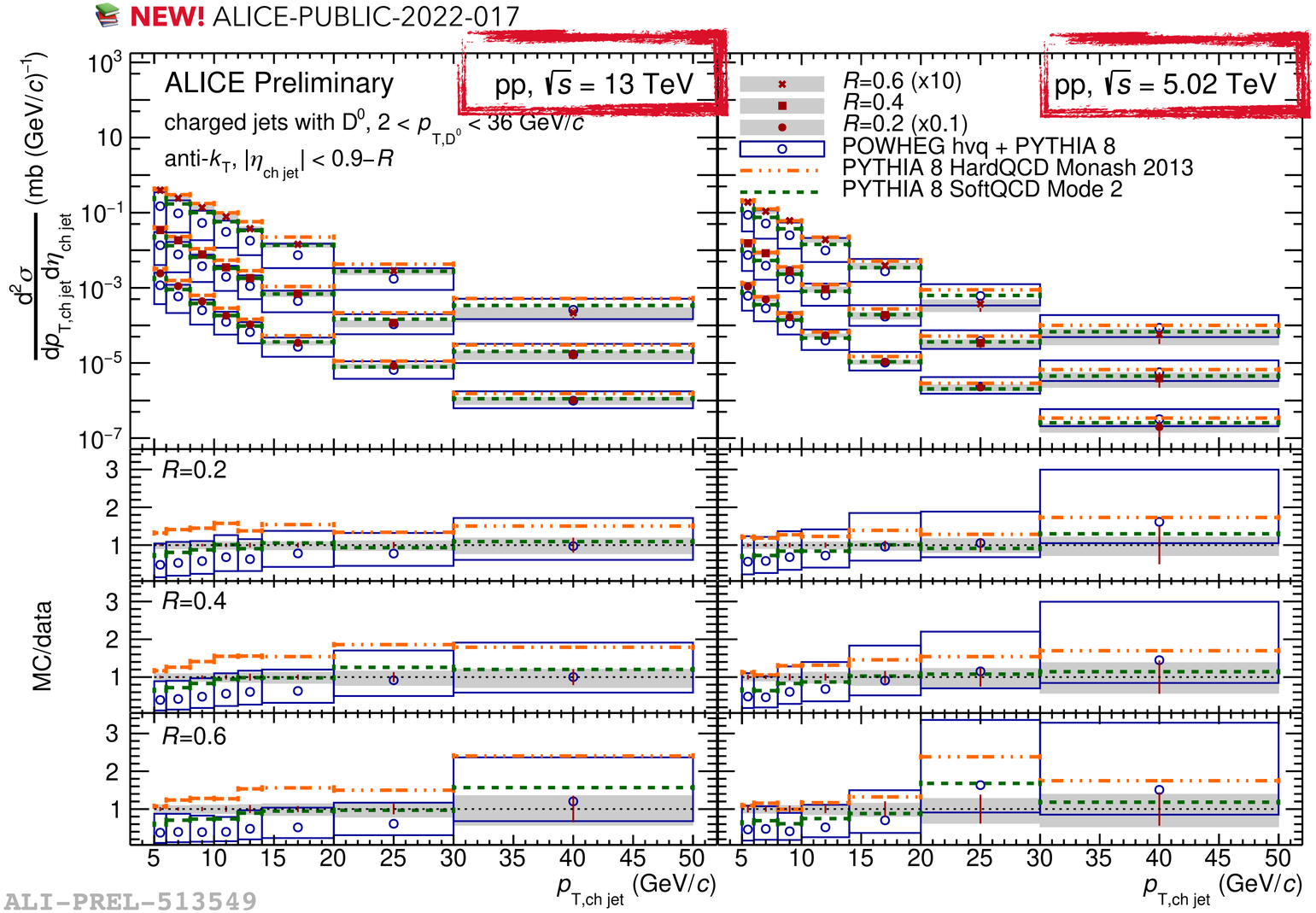
Do charm and beauty experience **collective effects**?

HF quarks: **ideal probe of QGP effects**

How are the parton **fragmentation** and **hadronisation** modified in the medium?

Energy loss of heavy quarks in QGP medium

HQ production: D^0 jet cross section

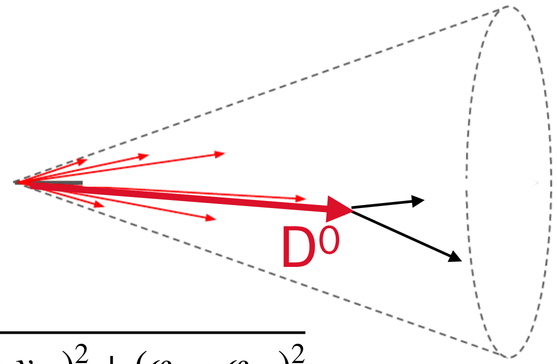


The 4-momentum of the jet is a **proxy** for the 4-momentum of the charm quark initiating the parton shower

Hardening of the $p_{T,\,jet}$ spectra with increasing centre-of-mass energy

Jet resolution parameter (*R*) dependence: allows to access the interplay between perturbative and non-perturbative effects

D-meson tagged jets measurements agree with pQCD predictions in pp collisions ⇒ **well understood baseline for Pb-Pb collisions**



$$R = \sqrt{(y_i - y_{jet})^2 + (\varphi_i - \varphi_{jet})^2}$$

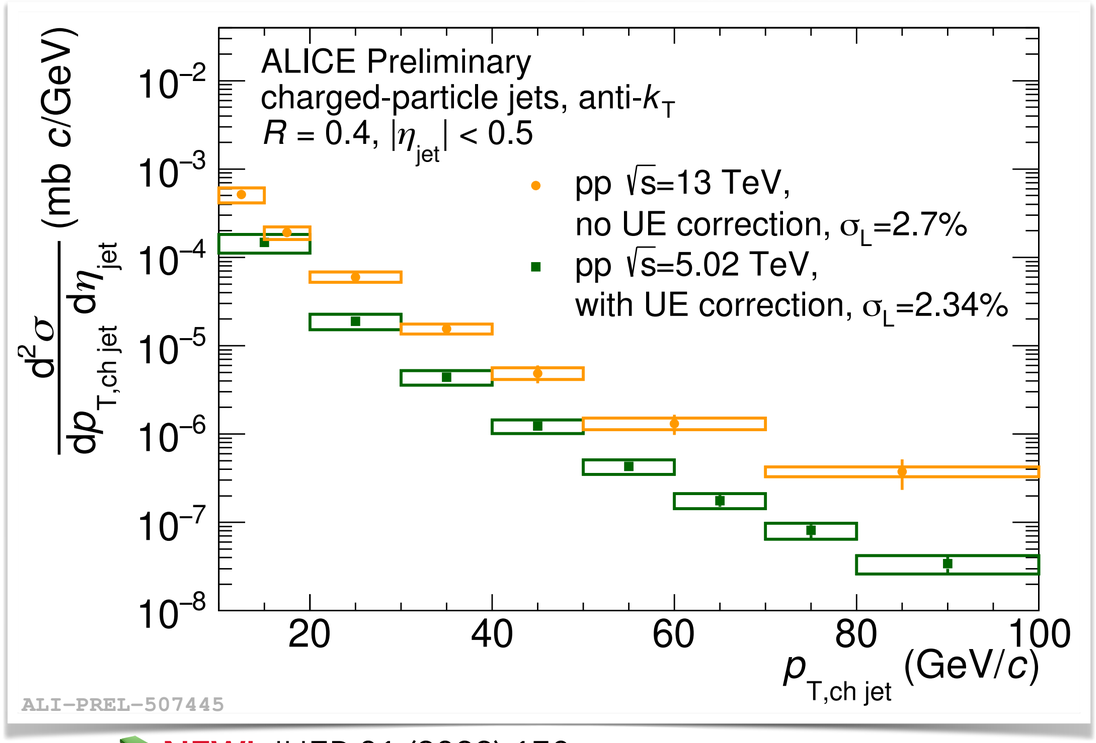
PYTHIA8: JHEP 1508 (2015) 003

POWHEG: JHEP 06 (2010) 043

HQ production: b-jets

New

New b-jets cross section measurement in pp at 13 TeV

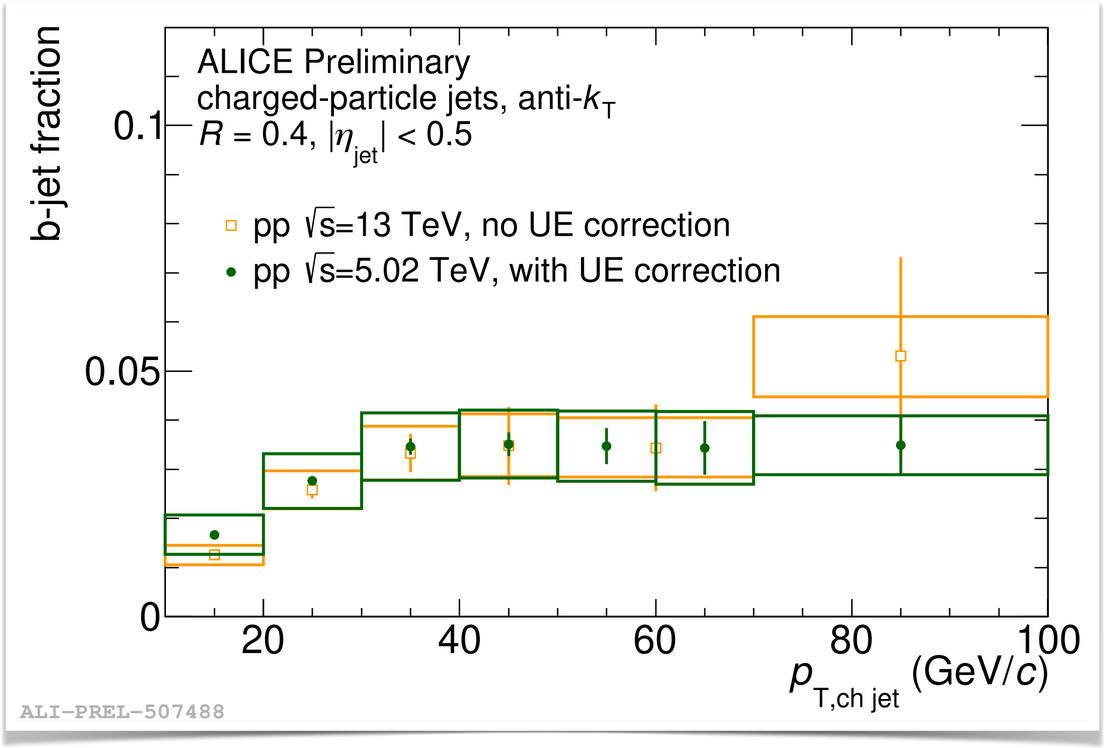


NEW! JHEP 01 (2022) 178

Identification of b-jets exploits the long lifetime of b-hadrons, using the impact parameter distribution

- Hardening of cross section with increasing center-of-mass energy

Fraction of the charged-particle b-jets among inclusive charged-particle jets



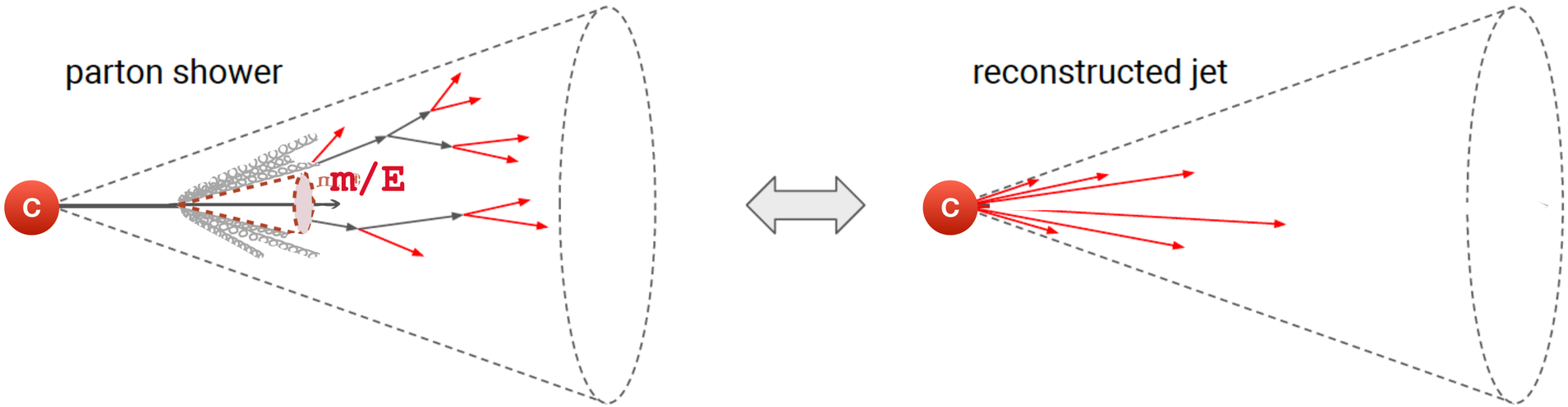
b-jet fraction: ~1-2% in the lowest $p_{T,jet}$ interval, saturating at about ~3% for $p_{T,jet}$ > 30 GeV/c

POSTERS
K. Demmich
A. Isakov

POWHEG: JHEP 06 (2010) 043

Looking into the parton shower

Radiating heavy flavour survives the shower process

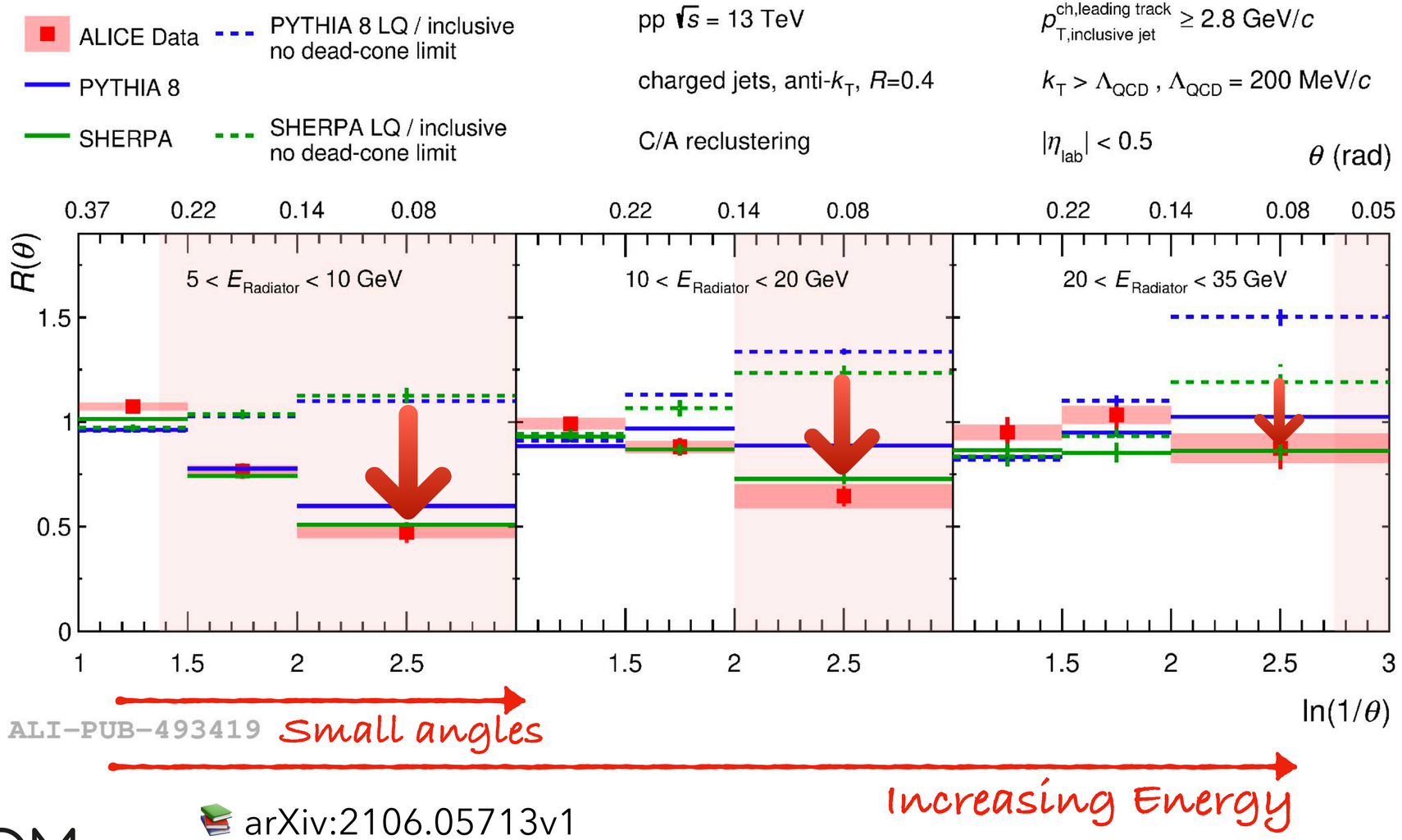


Jet algorithms can be used to cluster the final state hadrons originating from a scattered parton

Fundamental QCD predictions for flavour dependence of strong interactions:

- **Casimir colour factors**: different fragmentation of quarks vs gluons
- **Dead-cone effect**: suppression of emission phase space $\theta < \theta_{DC} = m_q/E_q$, sizeable mass effect (heavy quarks vs light quarks and gluons)

Direct experimental access to the dead-cone

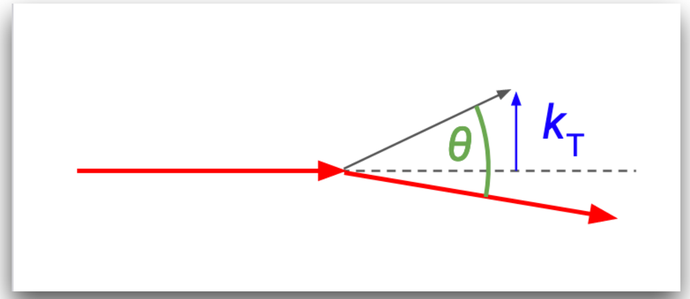


arXiv:2106.05713v1

Ratio of emission angle distributions for charm quarks and inclusive partons reveals the **dead-cone effect.**

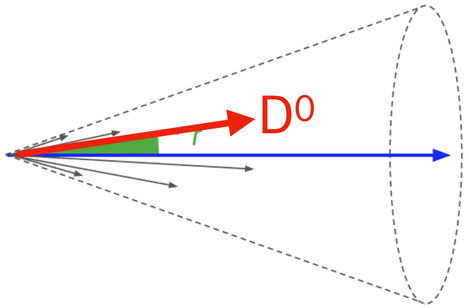
Significant suppression of small-θ emissions

Dead cone narrows with increasing charm-quark energy

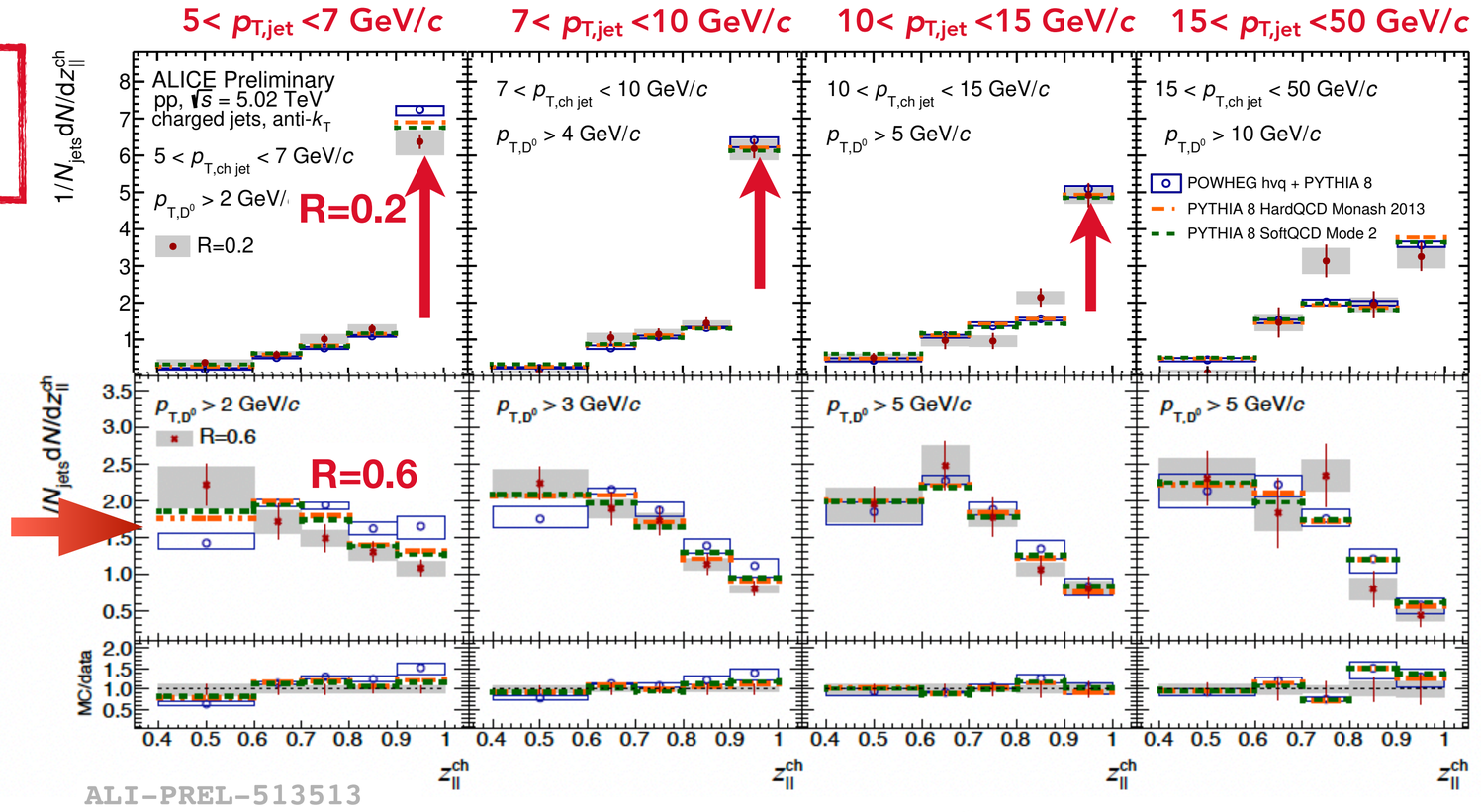


HF jets to look into fragmentation

HF-tagged jets provide a handle on the evolution of quarks to hadrons



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



Hint of a softer fragmentation in data wrt model predictions (especially NLO) for low $p_{T,ch\ jet}$ and larger R

The core of the jet (R=0.2) is dominated by the HF hadron, as expected from the suppression of small angle emissions

At large angles (R>0.2) the charm quark emissions are recovered

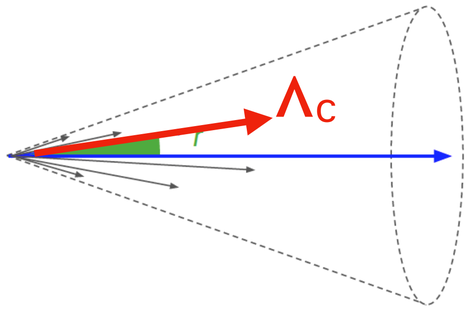
NEW! ALICE-PUBLIC-2022-017

PYTHIA8: JHEP 1508 (2015) 003

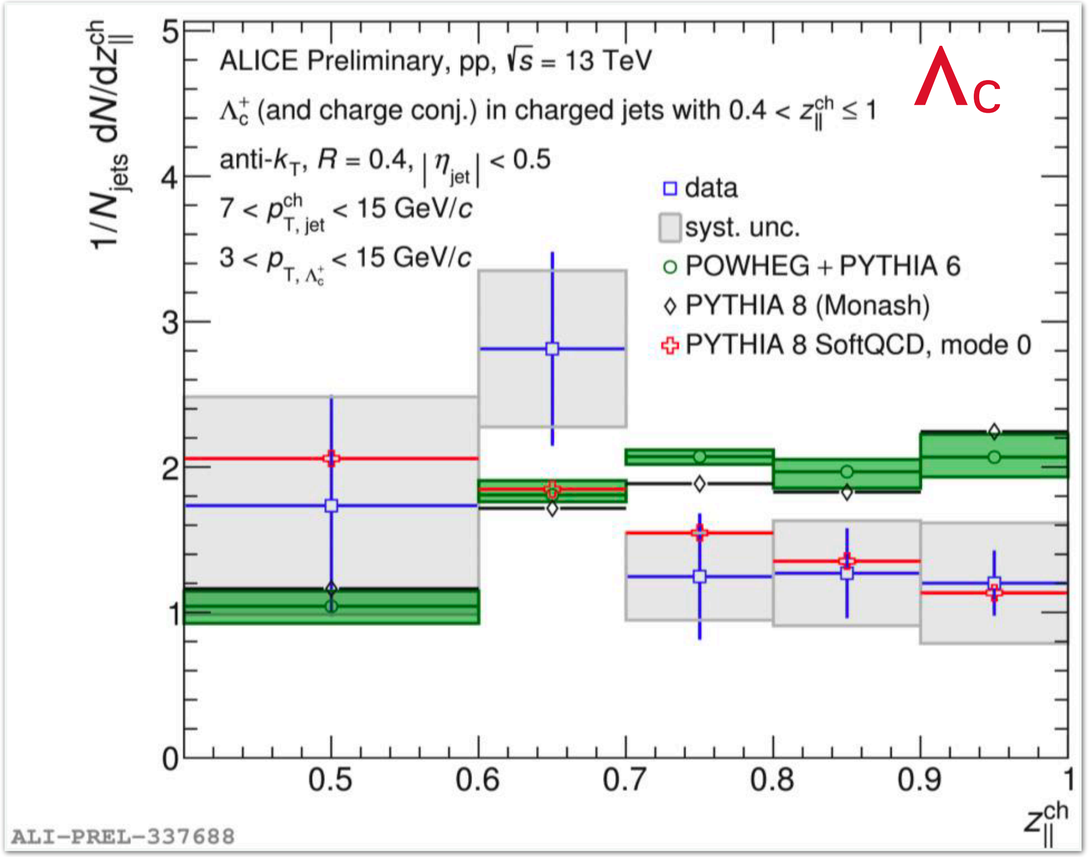
POWHEG: JHEP 06 (2010) 043

HF jets to look into fragmentation

HF-tagged jets provide a handle on the evolution of quarks to hadrons



$$z_{//}^{\mathrm{ch}} = \frac{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{HF}}}{\vec{p}_{\mathrm{ch\ jet}} \cdot \vec{p}_{\mathrm{ch\ jet}}}$$

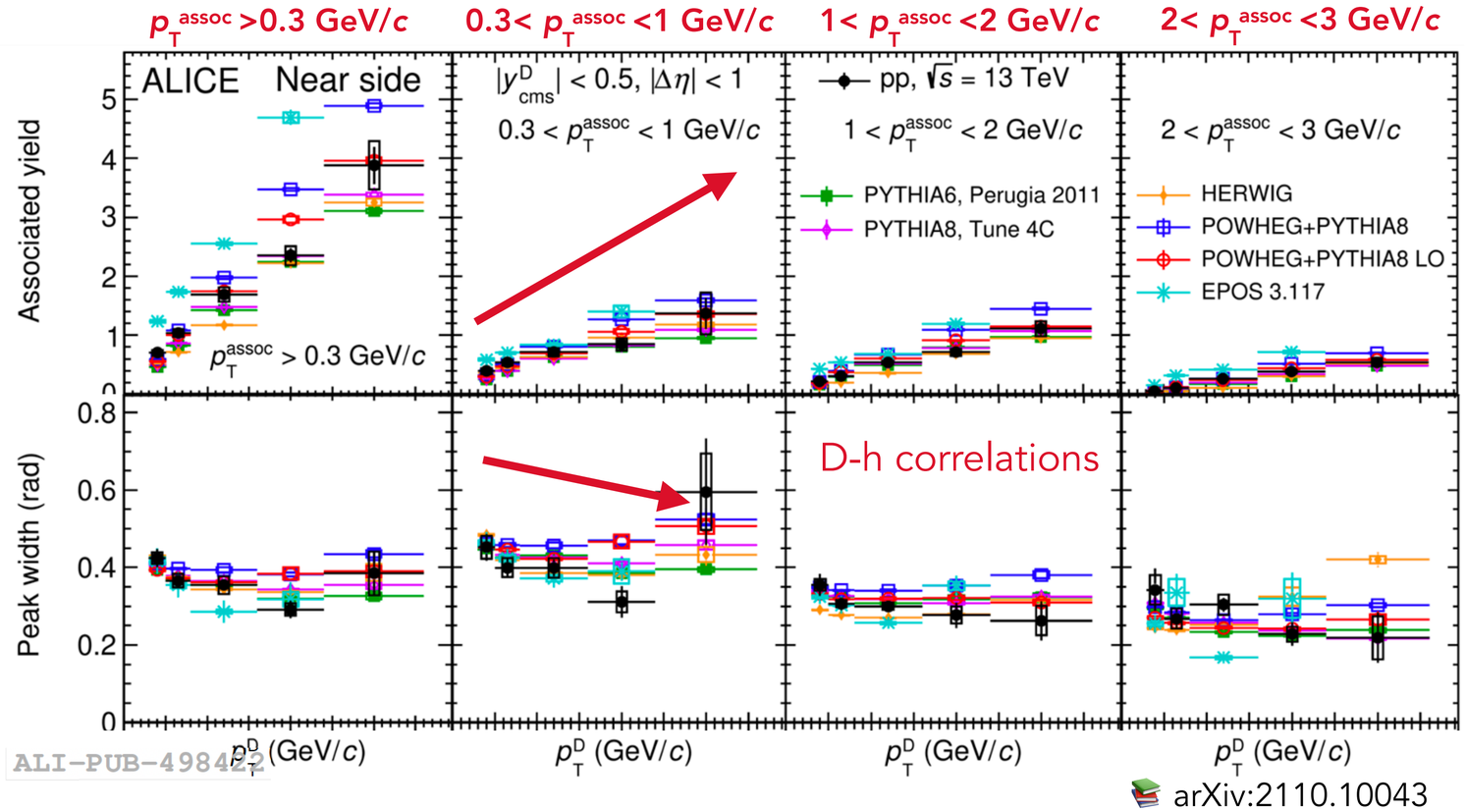


Data point toward a **softer fragmentation** w.r.t. classic in vacuum fragmentation models in the low $p_{\mathrm{T,ch\text{-}jet}}$ range (beyond Leading Color fragmentation needed)

TALK
M. Faggin
07/04 11:10

PYTHIA8: JHEP 1508 (2015) 003
POWHEG: JHEP 06 (2010) 043

HQ fragmentation via correlation measurements

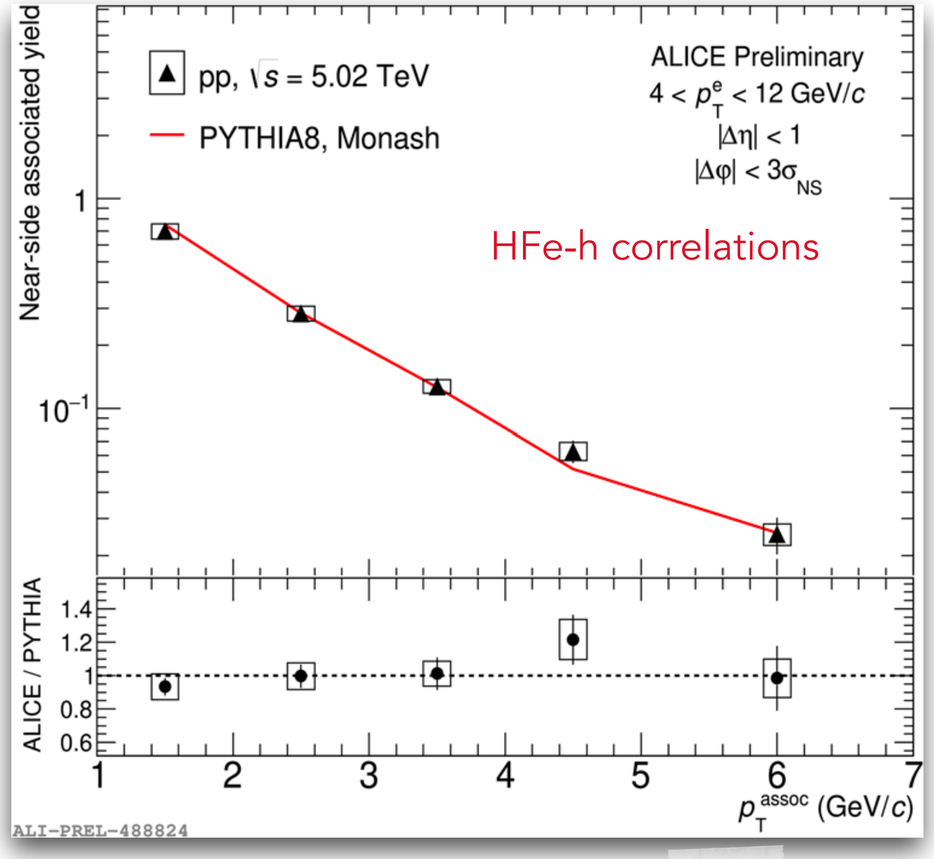


arXiv:2110.10043

NS yields and widths characterise the jets in terms of particle multiplicity (NS yields) and angular profile (NS widths)

All the models describe the peak yields and widths within uncertainties, with PYTHIA and POWHEG+PYTHIA providing the best description

Additional insight on HQ fragmentation from HF semileptonic decay-electron correlation measurements → gives **access also to beauty**



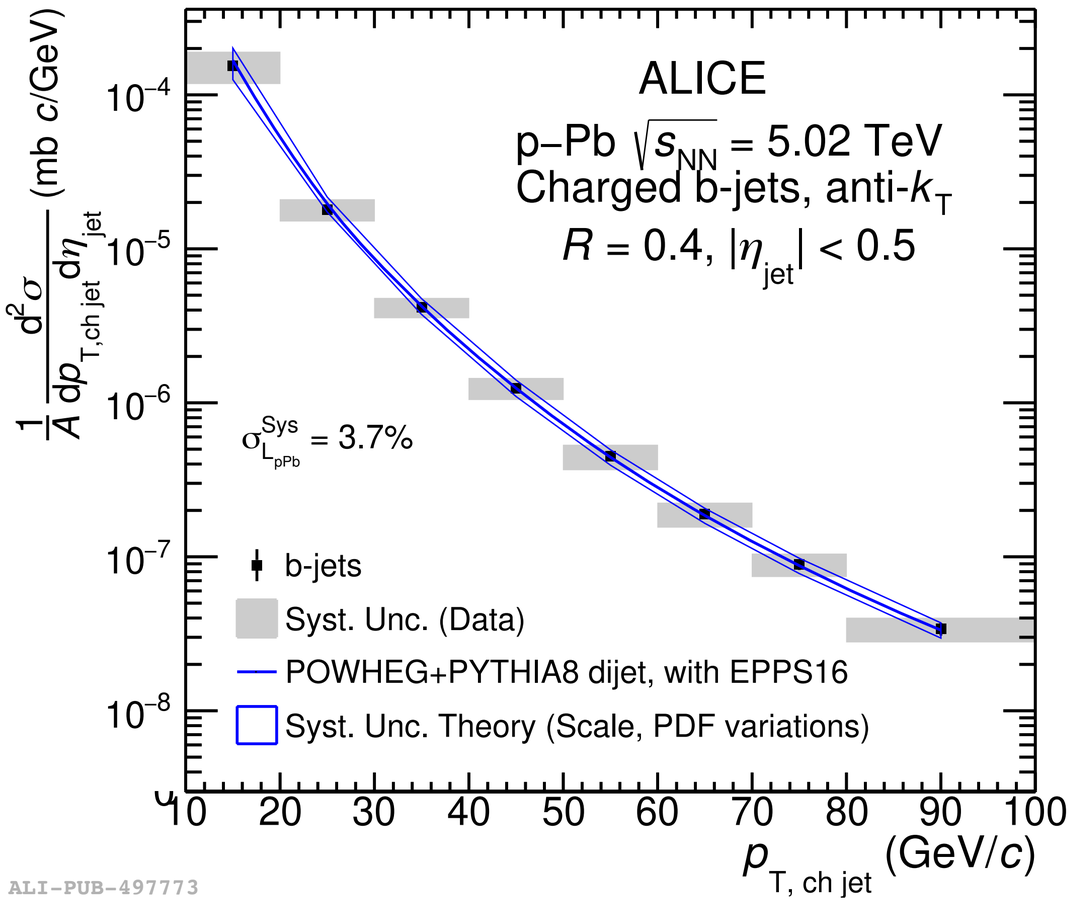
PYTHIA: JHEP 1508 (2015) 003 EPOS 3: Phys.Rev.C 82(2010)044904
POWHEG: JHEP 06 (2010) 043 HERWIG: Eur.Phys.J C76 (2016) 196

QUARK MATTER KRAKÓW 2022

Marianna Mazzilli

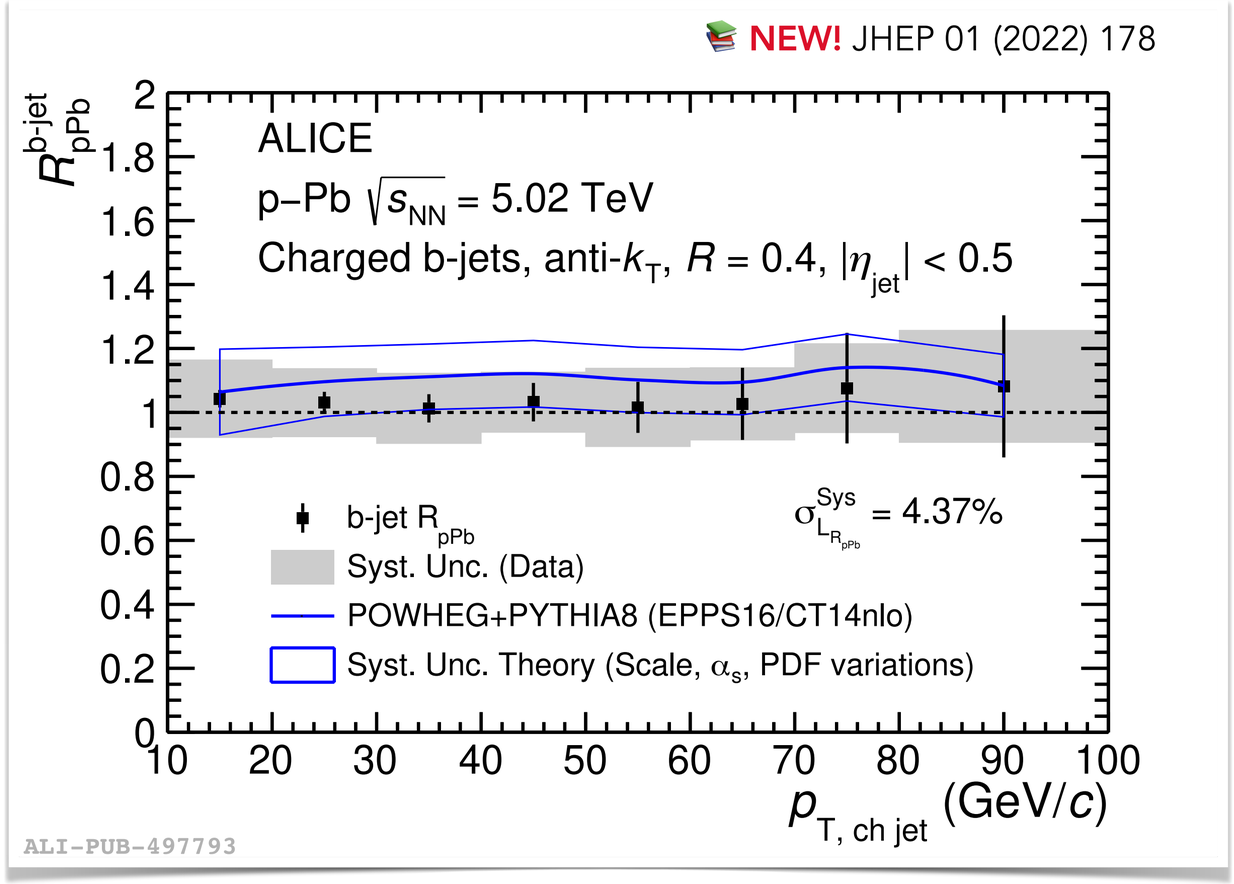
POSTER R. Singh

Larger systems: b-jets in p-Pb



ALI-PUB-497773

b-jet measurements are described by NLO pQCD POWHEG calculations with PYTHIA 8 fragmentation within uncertainties



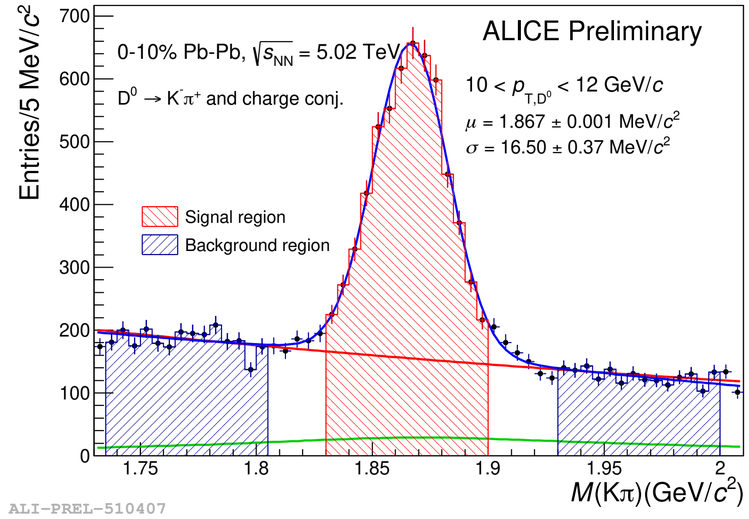
ALI-PUB-497793

In p-Pb, possible modification of the jet shape or spectrum could indicate **cold nuclear matter effects** → R_{pPb} consistent with unity within the current precision

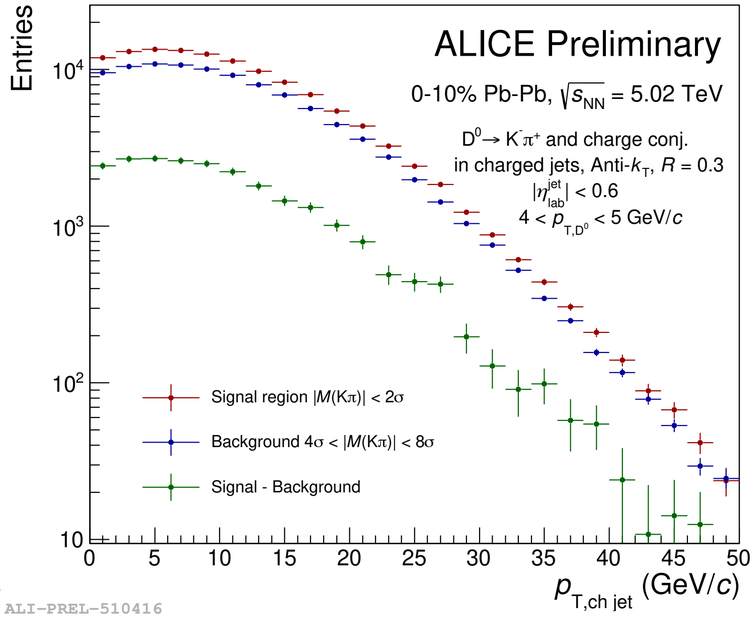
POSTERS
A. Isakov, H. Alfanda

New

Medium effects: D^0 jets in 0-10% Pb-Pb



ALI-PREL-510407



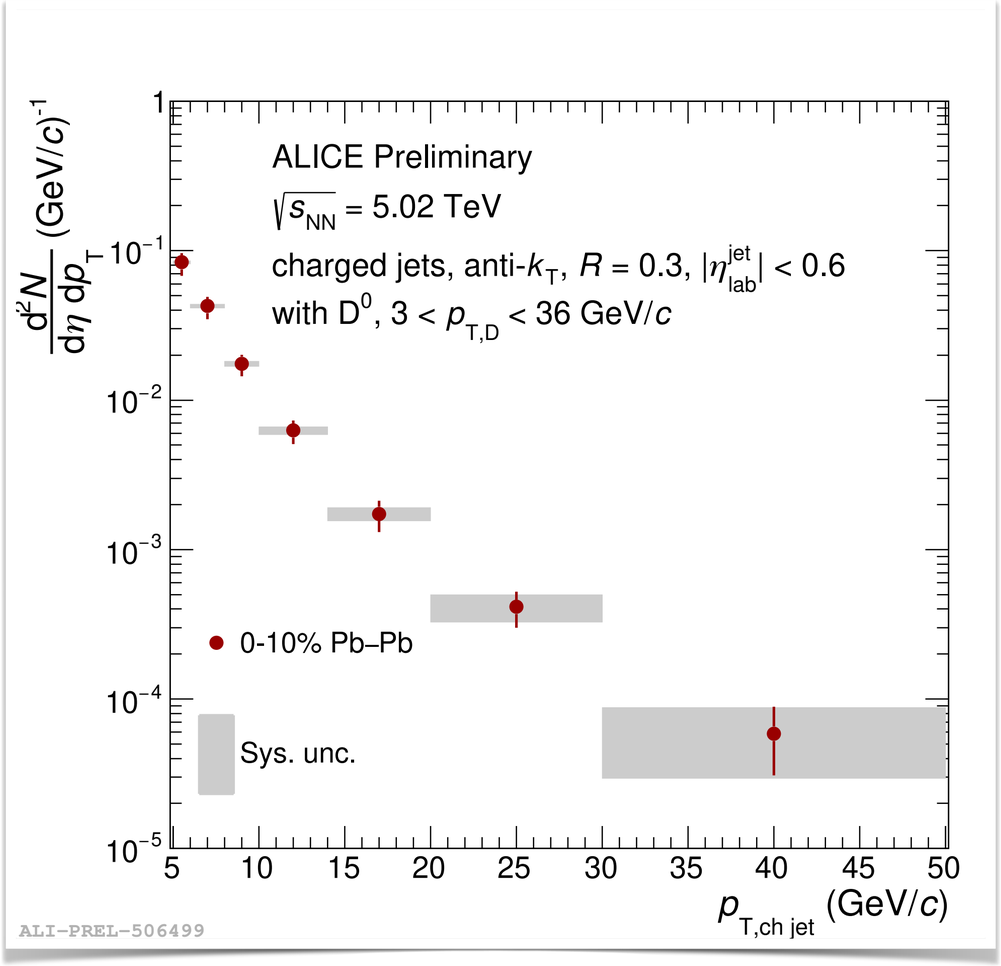
ALI-PREL-510416

Raw jet spectrum corrected for D^0-jet efficiency

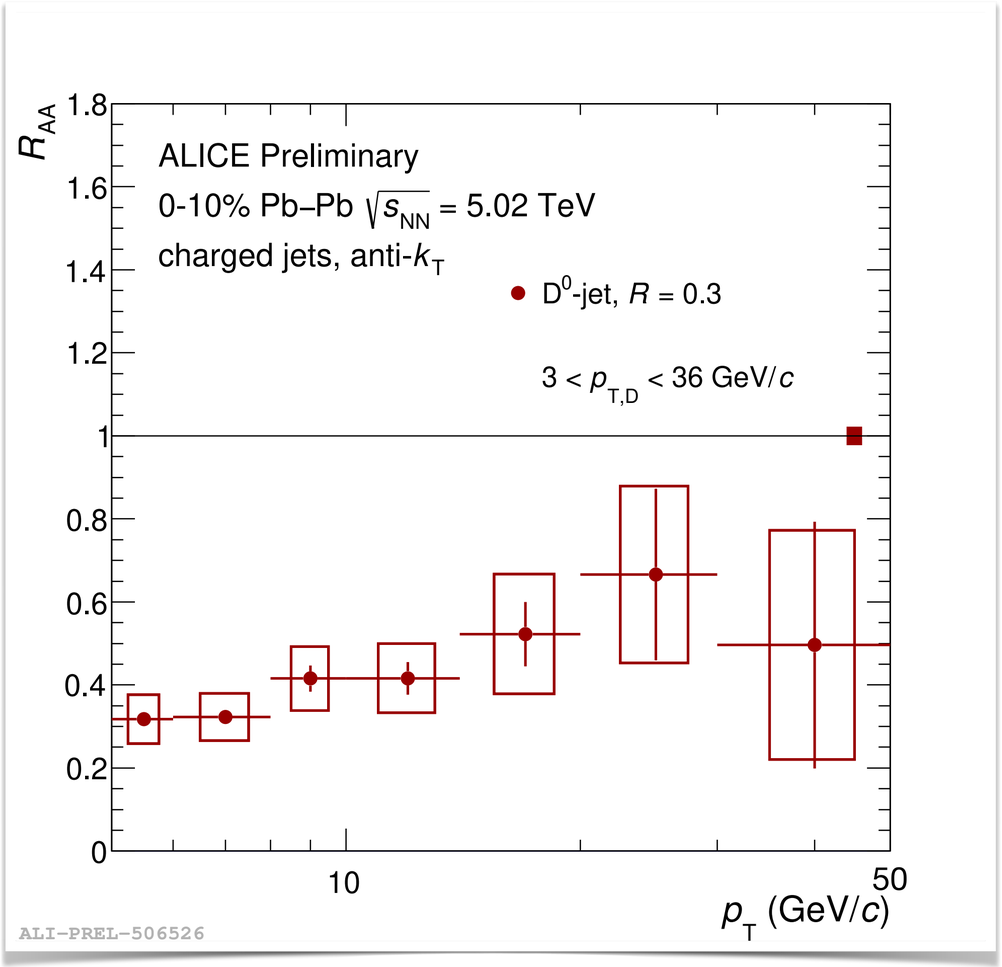
- Invariant mass used to extract D^0-jet raw signal spectrum with side-band subtraction
- Correction for the D^0-jet efficiency
- Subtraction of feed-down D^0-jet component
  - POWHEG predictions convoluted with measured non prompt D^0 R_{AA}
- Jet-p_T spectra corrected for detector effects and background fluctuations
  - Unfolding using an iterative Bayesian method

- D^0-meson $3 < p_T < 36$ GeV/c
- Charged jets, anti-k_T algorithm with $R = 0.3$
- Jet $5 < p_T < 50$ GeV/c

Medium effects: D⁰ jets in 0-10% Pb-Pb



p_T-differential cross section in Pb-Pb central collisions

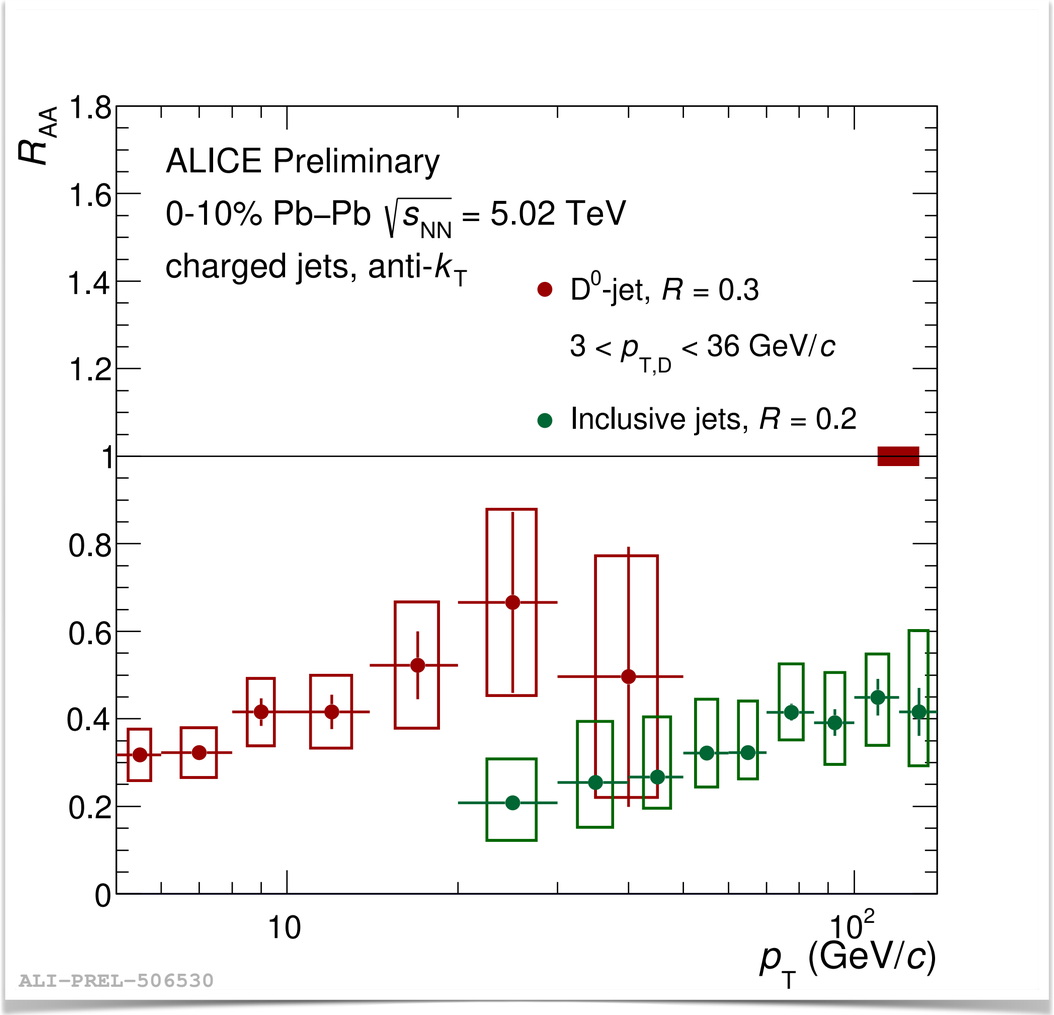


Baseline: D⁰-jet p_T differential cross section in pp at 5.02 TeV with same jet reconstruction

New

Medium effects: D^0 jets in 0-10% Pb-Pb

- Higher R_{AA} of D^0-jet compared to inclusive jets in PbPb?
  - Comparison is sensitive to difference between quarks and gluon energy loss (**Casimir colour effect**)
  - Comparison could also be sensitive to mass effects (**dead-cone effect**)



TALKS
H. Bossi 07/04 18:10
L. Vermunt 07/04 09:00

Medium effects: D^0 jets in Pb-Pb

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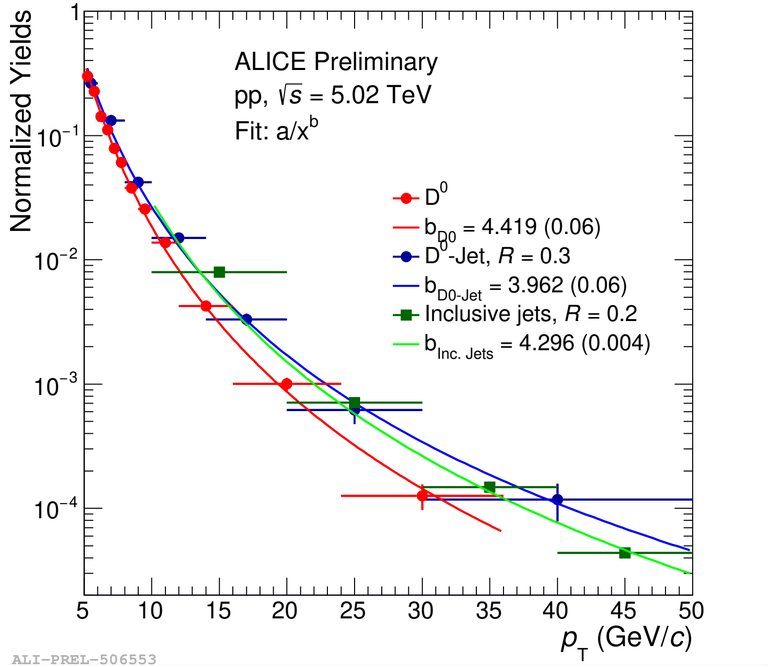
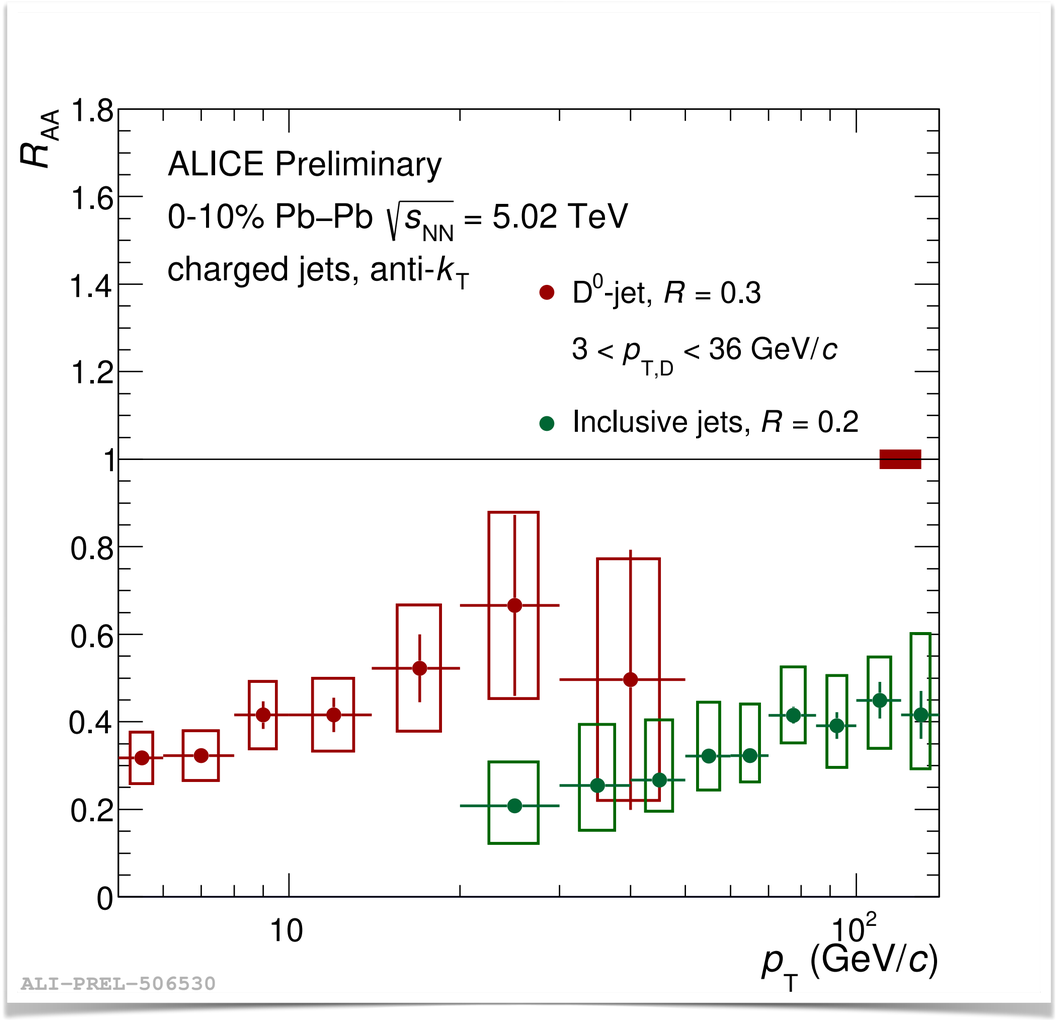




Summary and outlook

- HF-tagged jets and correlations provide a handle on the evolution of quarks to hadrons:
  - Data constrain model predictions in describing the HF production
  - Charm mass influences the parton shower evolution of a jet
  - Measurement of fragmentation functions → more insight into the hadronization mechanisms
  - Hint of flavour ordering in jet R_{AA}

Run 3/4 plans:

- Higher statistics (x100) and improved DCA resolution in Run 3/4
- Expand the successful pp program to study pQCD and hadronisation mechanisms in central AA collisions
- Access to beauty HF-jet chemistry and HF-jet substructure

Thanks for your attention!

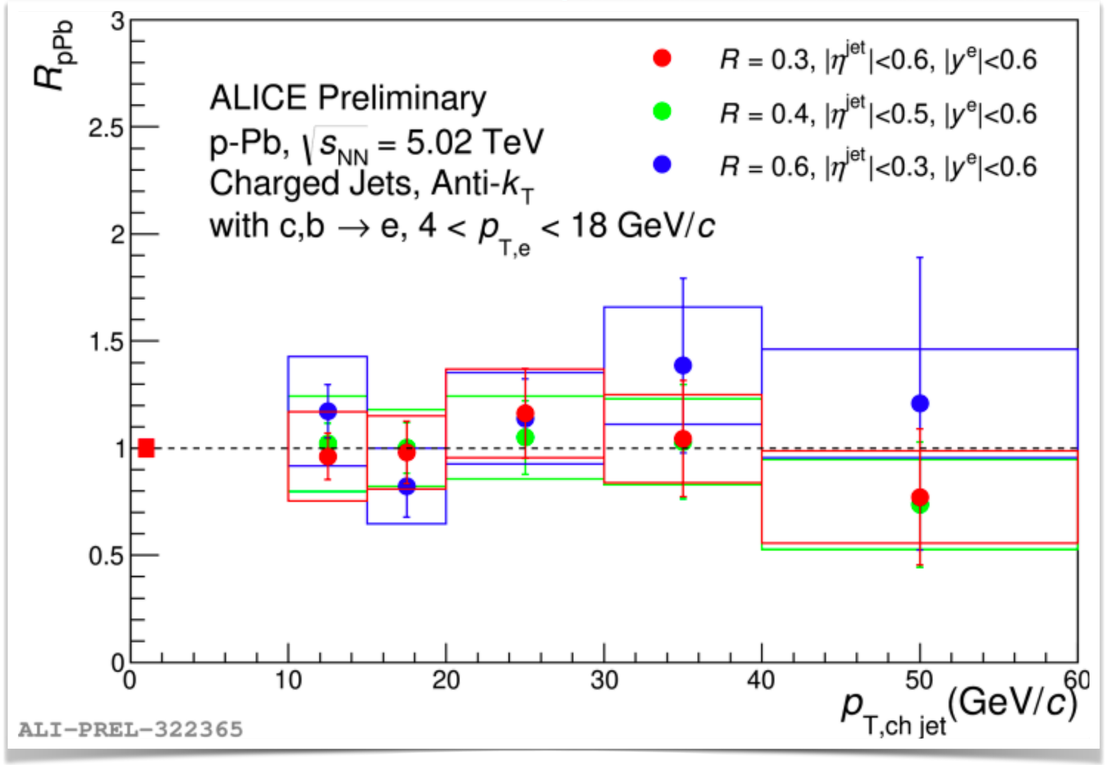
Additional slides

ALICE jet results at QM

	Longitudinal: energy loss, path length dependence	Transverse: wide vs. narrow, quark/ gluon, intrajet broadening	Jet Deflection	Mass/Flavor Dependence	Jet Grooming	Non-Perturbative Effects	Small Systems
Isolated photon-jet correlations: Alwina Liu Tues. 16:30	ALICE		ALICE				
Path length dependence in Pb--Pb and p—Pb collisions: Caitie Beattie Wed. 8:40	ALICE						ALICE
Jet angularity and fragmentation in Pb-Pb: James Mulligan Wed. 10:00	ALICE	ALICE			ALICE	ALICE	
Search for jet quenching in high-multiplicity pp collisions: Filip Krizek Wed. 12:50			ALICE				ALICE
Heavy-flavor jets from small to large systems: Marianna Mazzilli Wed. 14:40	ALICE	ALICE		ALICE		ALICE	ALICE
R-dependence of jet suppression and groomed jet splittings in Pb--Pb: Hannah Bossi Thurs. 18:10	ALICE	ALICE	ALICE		ALICE		
Jet acoplanarity and energy flow within jets in Pb—Pb and pp: Rey Cruz-Torres Thurs. 18:30	ALICE	ALICE	ALICE		ALICE	ALICE	

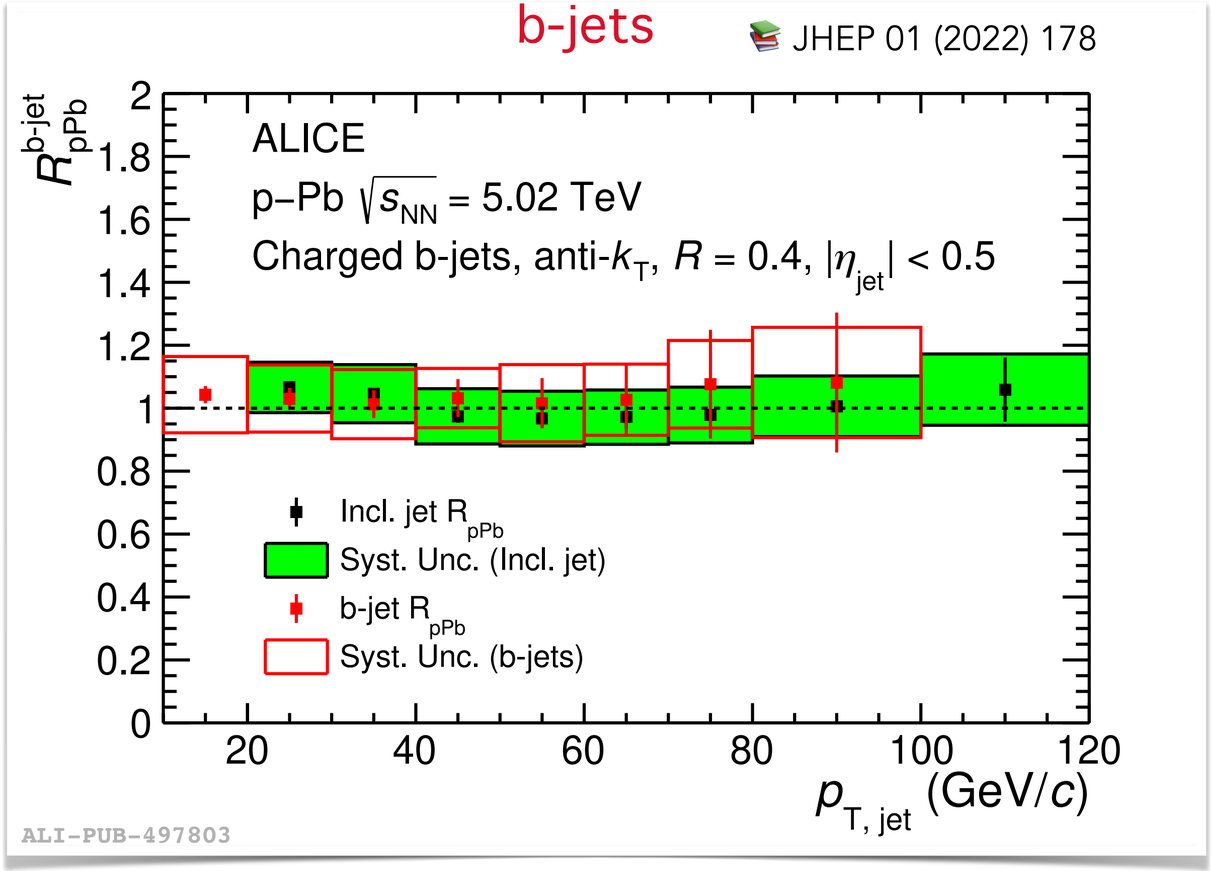
Larger systems: HF-jets in p-Pb

HFe-jets



b-jets

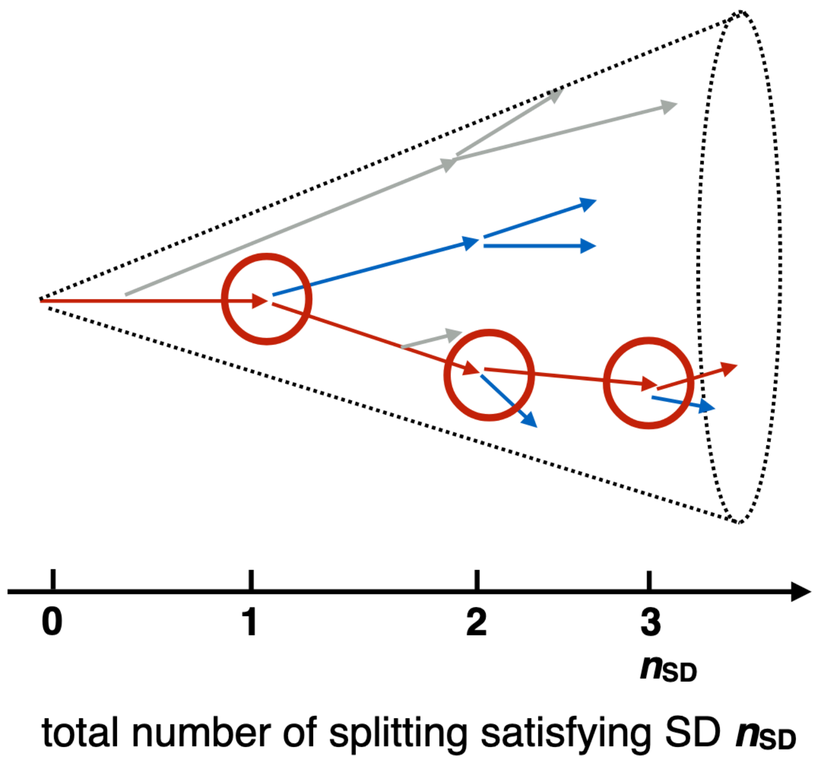
JHEP 01 (2022) 178



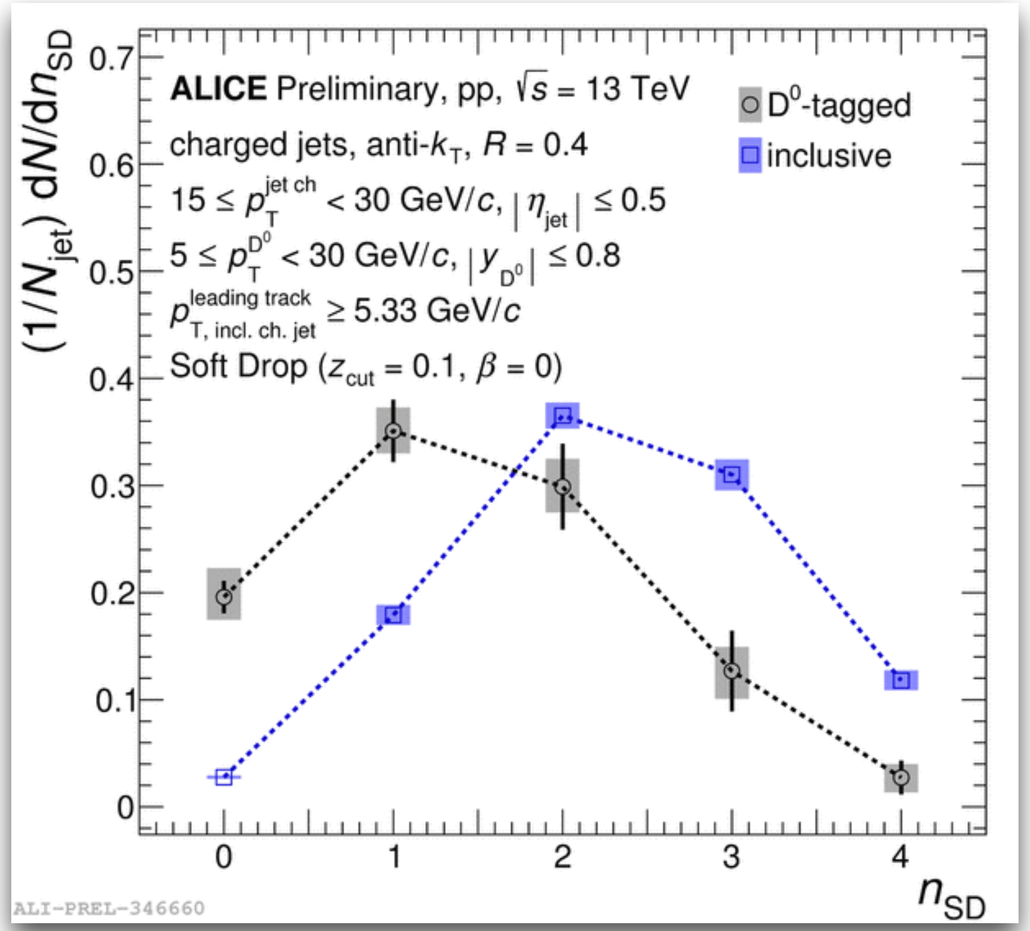
In p-Pb, possible modification of the jet shape or spectrum could indicate **cold nuclear matter effects**

- No jet suppression/broadening as a function of the resolution parameters

Looking into the parton shower



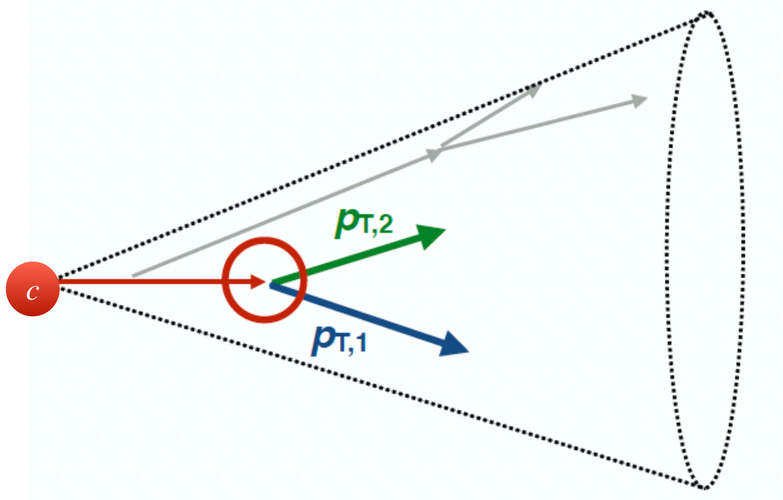
total number of splitting satisfying SD n_{SD}



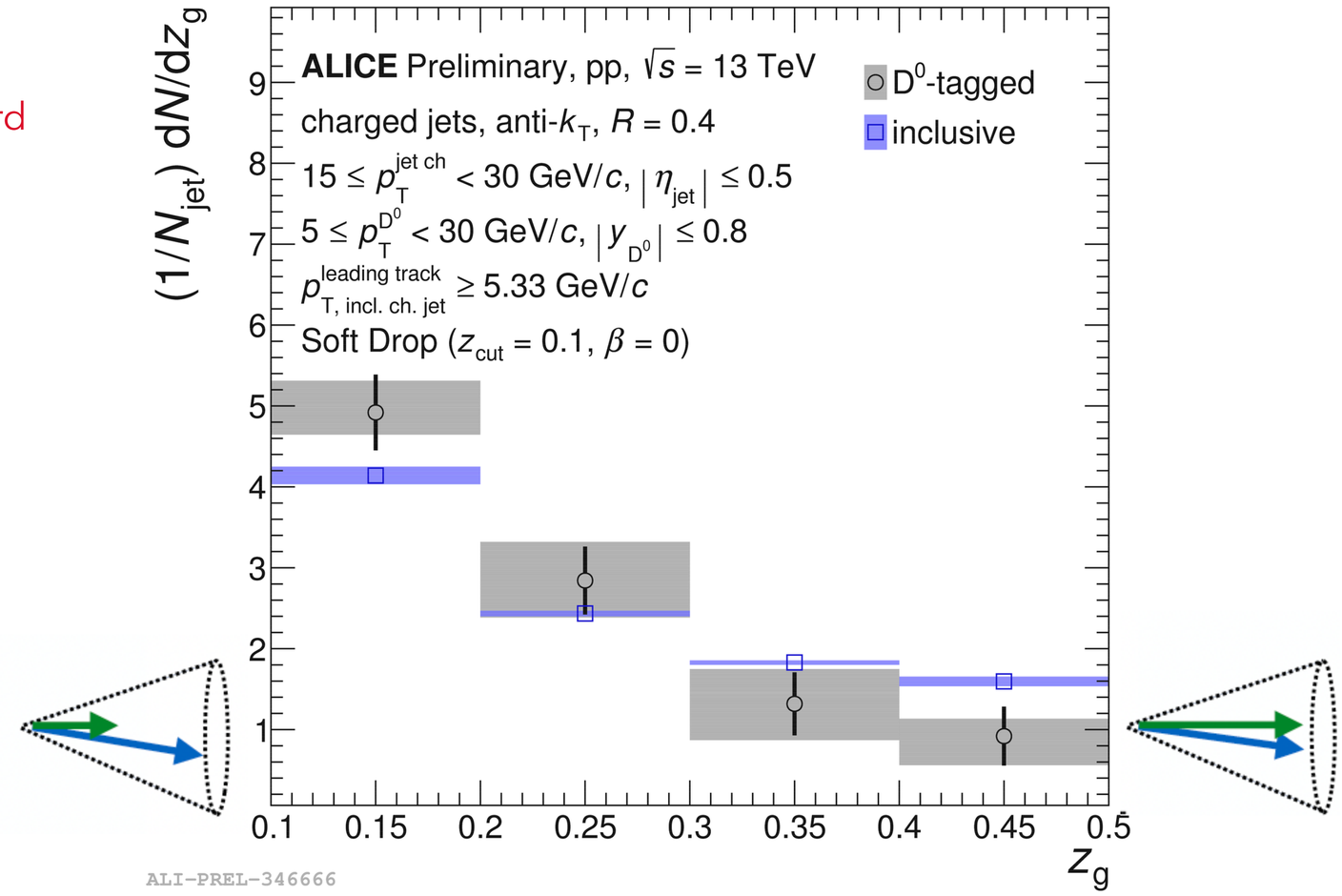
- charm jets have fewer "hard" splittings than inclusive jets
  - Low p_T region: strongest mass effect
- **described by PYTHIA**

Looking into the parton shower

- Access evolution of the parton shower: **jet splittings** (declustering)
- Groom away soft radiation at large angles: isolate hard structures inside the jet (**grooming**)
- Probing the $c \to cg$ splitting function

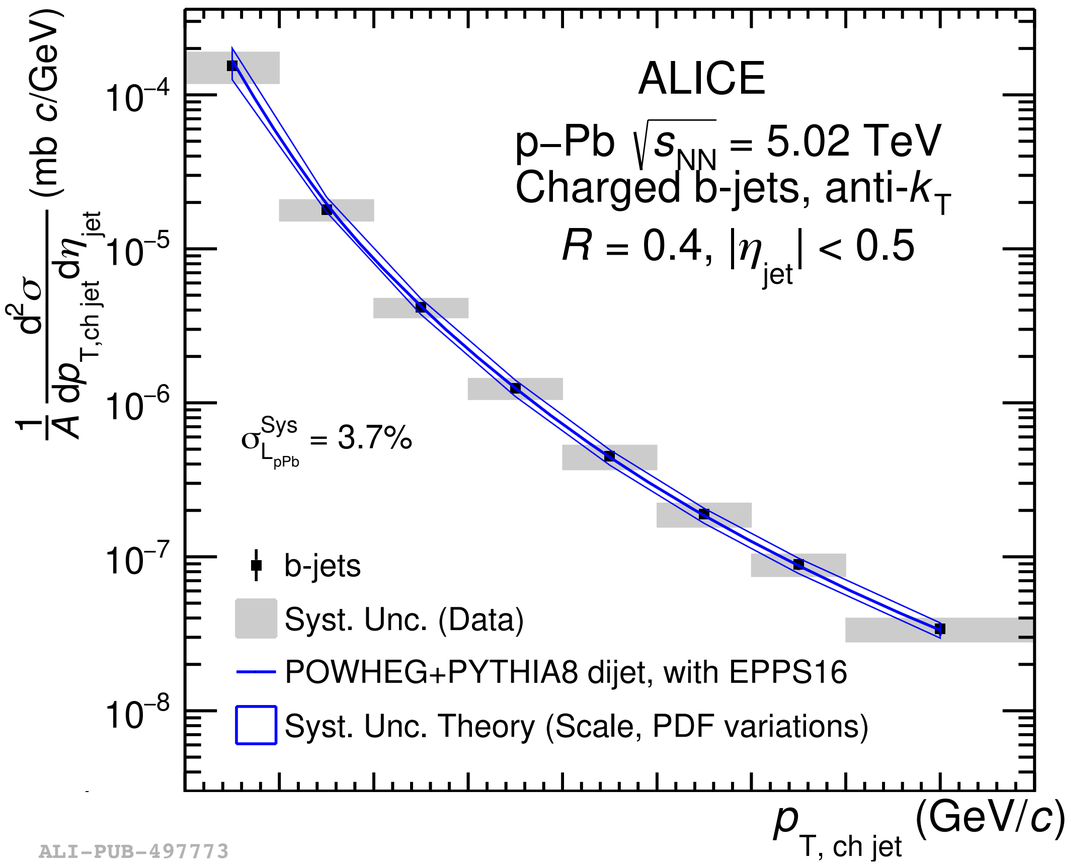


p_T balance between prongs $z_g = \dfrac{p_{T,2}}{p_{T,2} + p_{T,1}}$

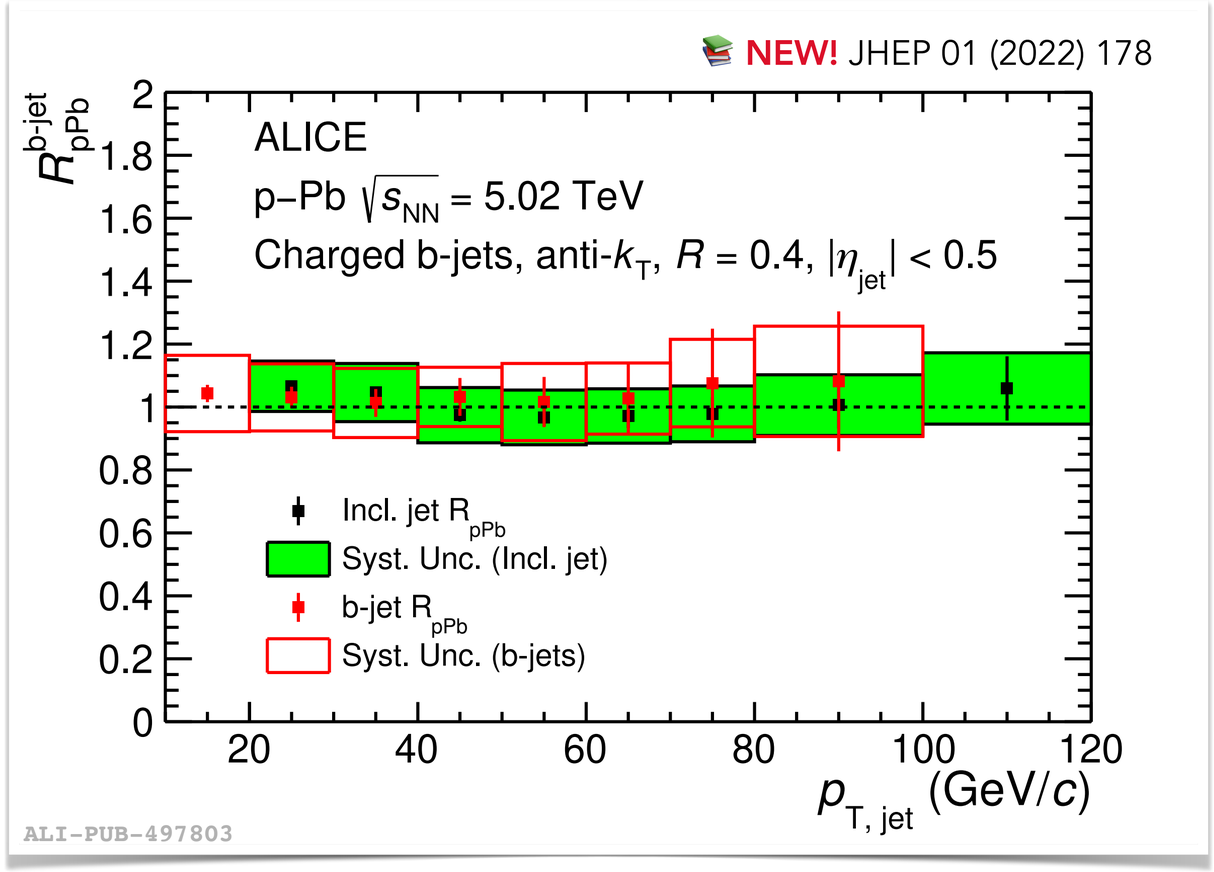


Larger p_T asymmetry for charm jets?

Larger systems: b-jets in p-Pb

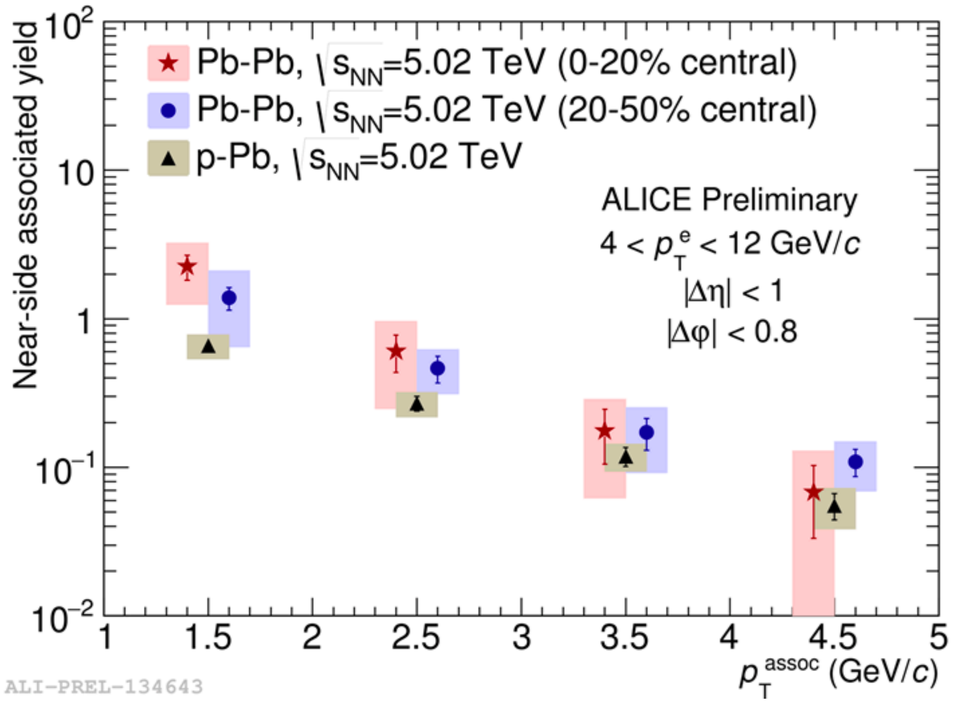


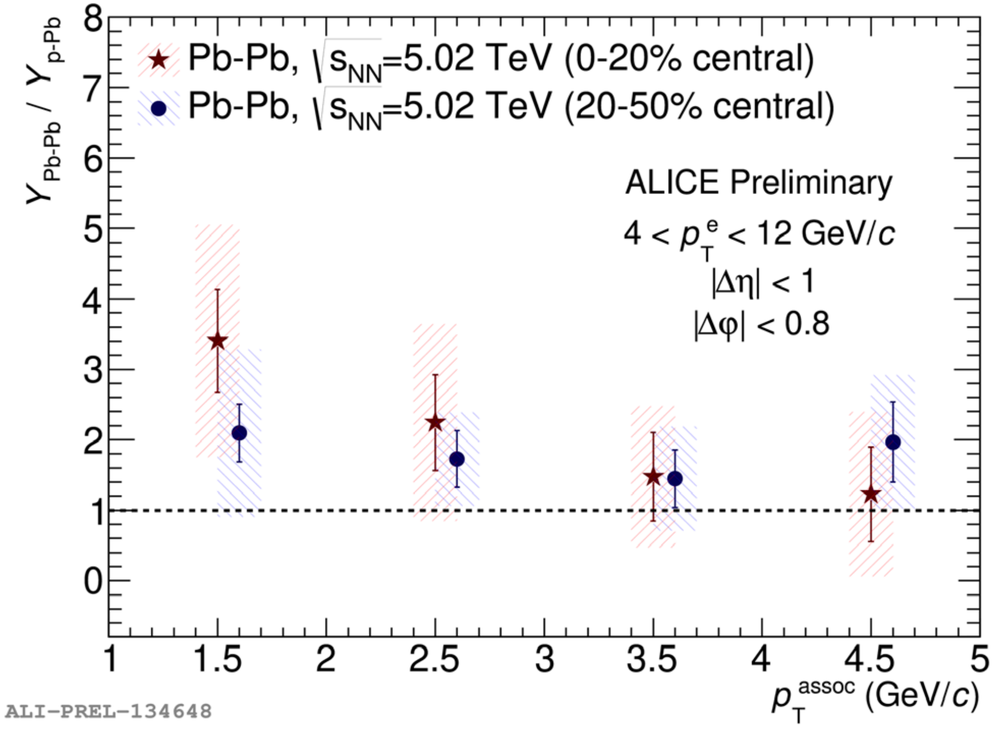
b-jet measurements are described by NLO pQCD POWHEG calculations with PYTHIA 8 fragmentation within uncertainties



In p-Pb, possible modification of the jet shape or spectrum could indicate **cold nuclear matter effects —> R_{pPb} consistent with unity within the current precision**

HFe-h correlations in Pb-Pb





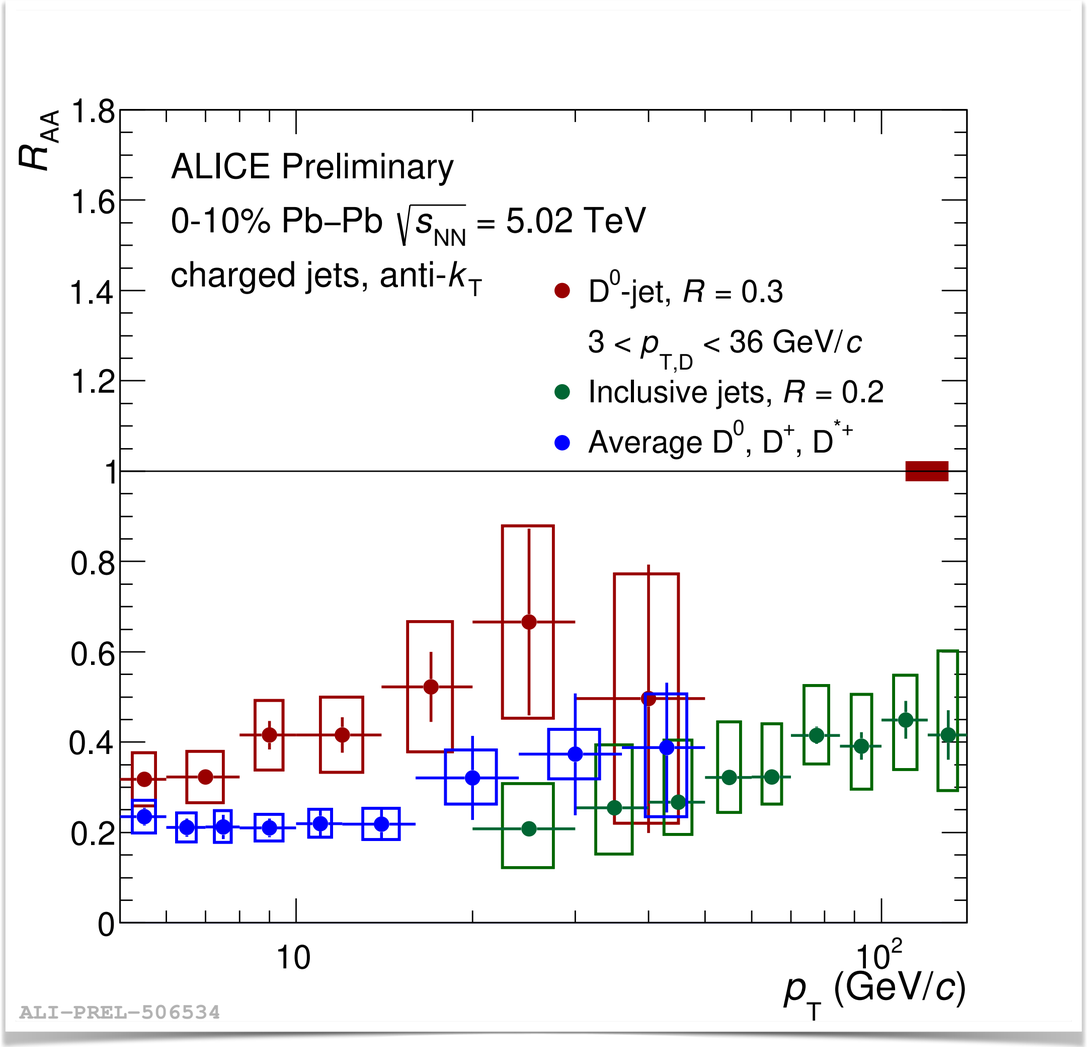
- Hints of NS hierarchy among collision systems at low p_T^{assoc}, though with large uncertainties

- Similar features for HF and LF quarks but different fragmentation, energy loss in medium, kinematic bias!
  I_{AA} is not directly comparable
  - Model predictions would be helpful as a link to parton kinematics

New

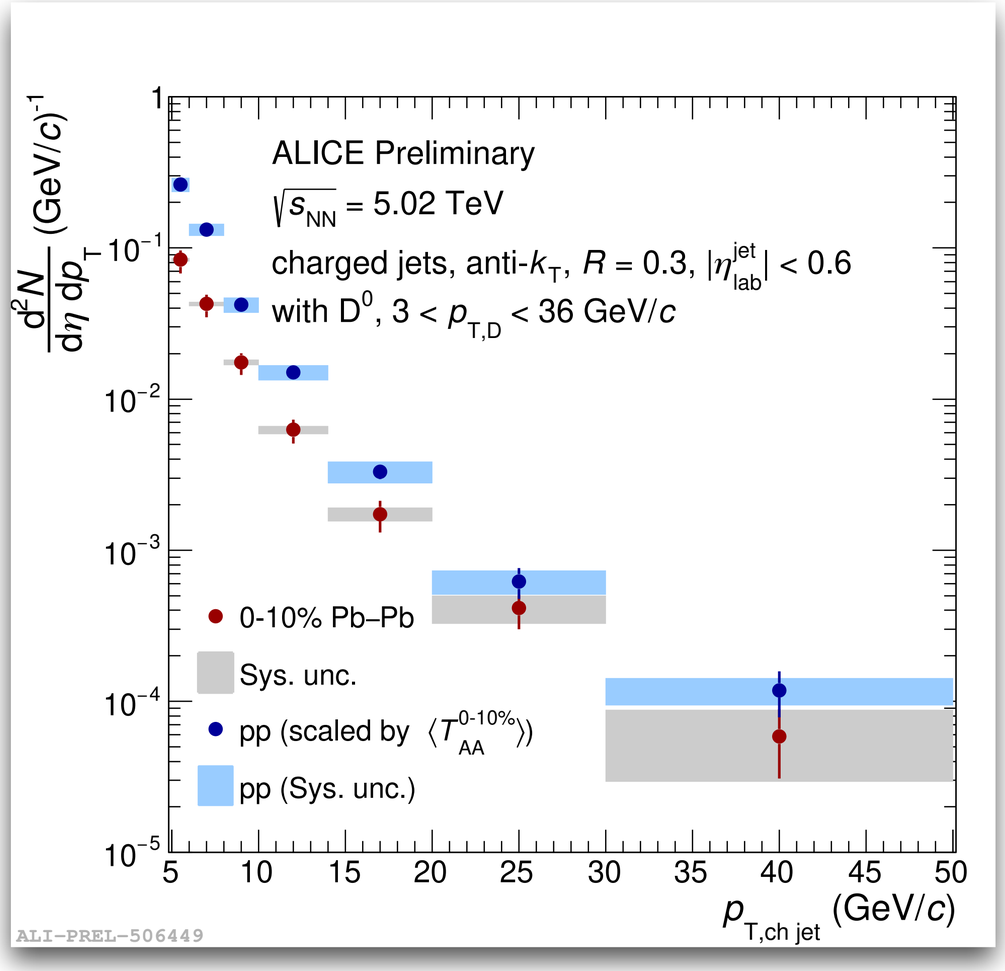
Medium effects: D^0 jets in 0-10% Pb-Pb

- Higher R_{AA} of D^0-jet compared to inclusive jets in PbPb?
  - Comparison is sensitive to difference between quarks and gluon energy loss (**Casimir colour effect**)
  - Comparison could also be sensitive to mass effects (**dead-cone effect**)
  - When comparing to single hadrons (charged hadron or D0 meson) need to take into account that the high pT hadrons will come from non-average jets which are fragmenting very hard

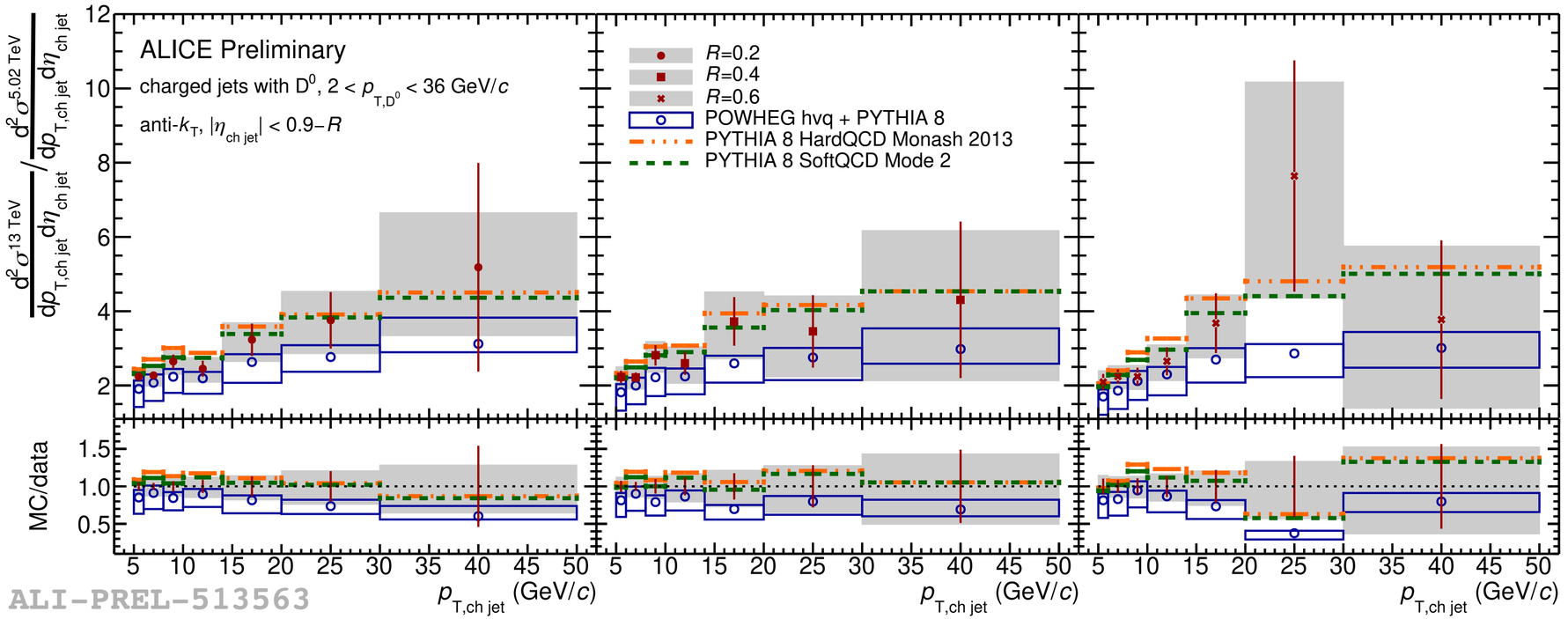


TALKS
C. Beattie 06/04 8:40
L. Vermunt 07/04 09:00

QUARK MATTER KRAKÓW 2022


ALICE Preliminary
$\sqrt{s_{NN}}$ = 5.02 TeV
charged jets, anti-k_T, R = 0.3, $|\eta^{jet}_{lab}| < 0.6$
with D^0, $3 < p_{T,D} < 36$ GeV/c
0-10% Pb–Pb
Sys. unc.
pp (scaled by $\langle T_{AA}^{0\text{-}10\%} \rangle$)
pp (Sys. unc.)
$\frac{d^2N}{d\eta\, dp_T}$ (GeV/c)$^{-1}$
$p_{T,ch\ jet}$ (GeV/c)
ALI-PREL-506449

HQ production: D^0 jet cross section



Hardening of the $p_{T,\,jet}$ spectra with increasing centre-of-mass energy

Larger systems: collectivity?

Positive v_2 for HFe in p-Pb collisions

- Consistent with HF muon measurement (at forward rapidity)
- Compatible with $v_2(D^0)$ by CMS

Final state effects (QGP droplets) or collective motion in HM collisions?

Or related to initial state effects (e.g. gluon saturation in CGC framework)?