Heavy flavor jets as probes of the QGP

Lida Kalipoliti (she/her)
LLR, École Polytechnique

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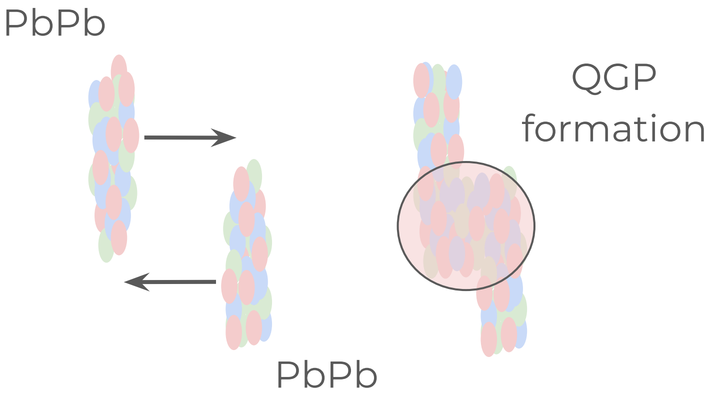
Heavy flavor jets

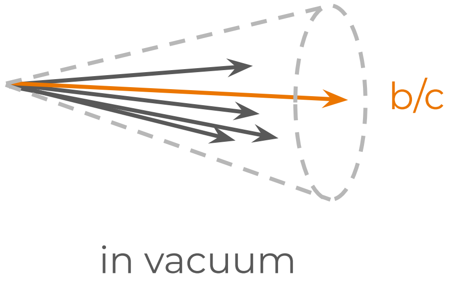
vs isolated HF hadrons

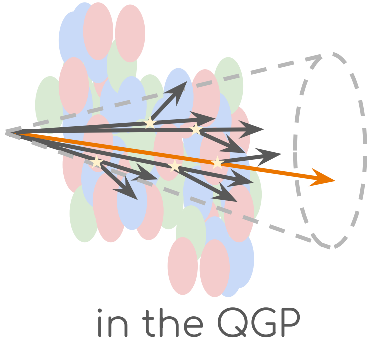
- Parton shower
- Hadronization
- q/g discrimination

In medium

- Penetrating probes
- t(b,c) < t_0(QGP) ⇒ produced early
- m(b,c) ≫ T(QGP) ⇒ negligible QGP production





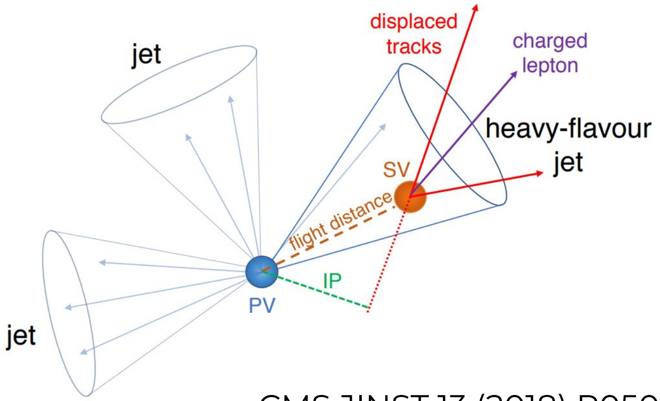


What do we know from b jets?

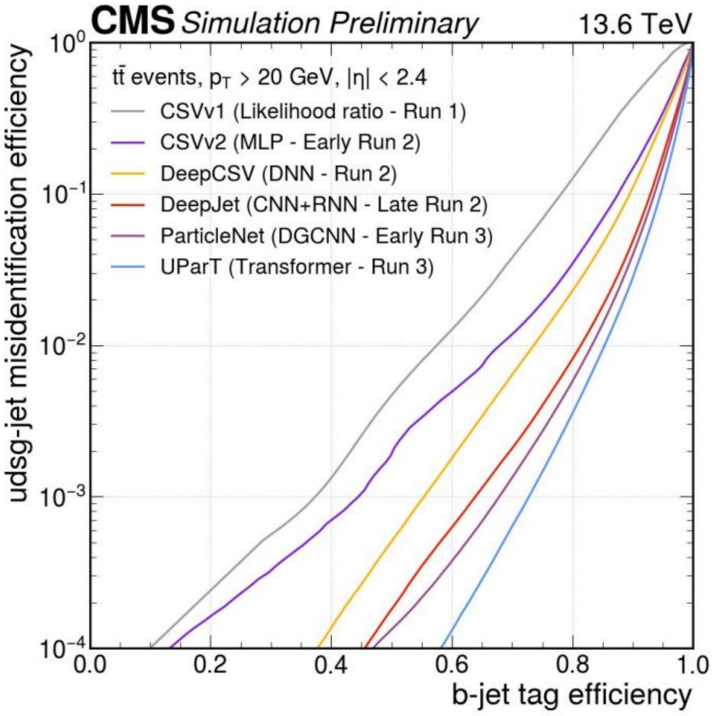
b tagging

Depends on

- Displaced tracks
- Secondary vertices (SV)
- Charged leptons



CMS JINST 13 (2018) P05011

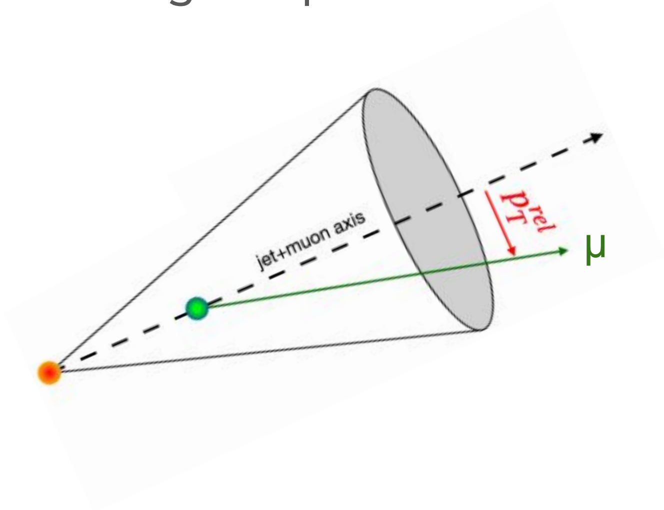


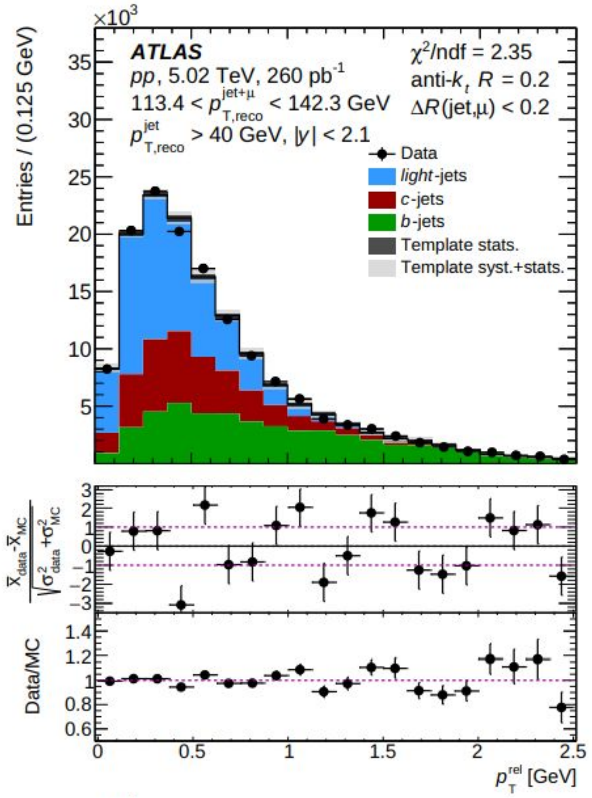
CERN-CMS-DP-2024-066

Muon tagging

Depends on

- Displaced tracks
- Secondary vertices (SV)
- Charged leptons





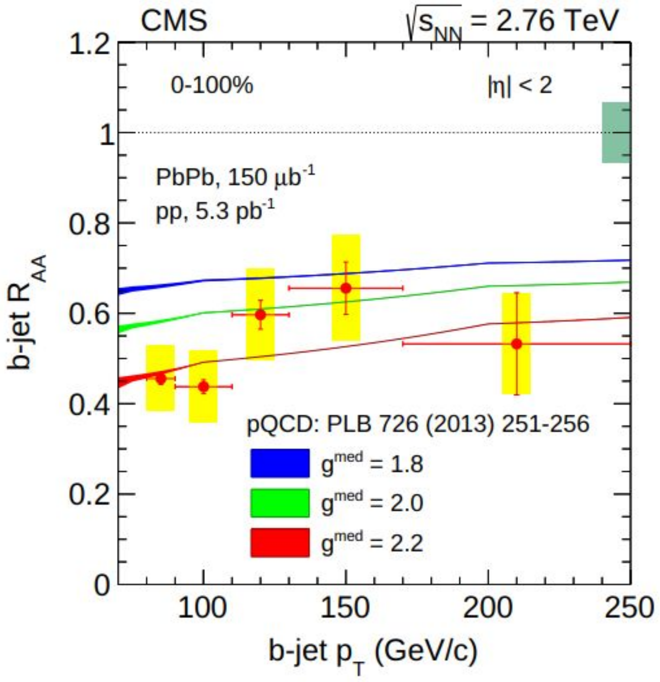
ATLAS EPJC 83 (2023) 438

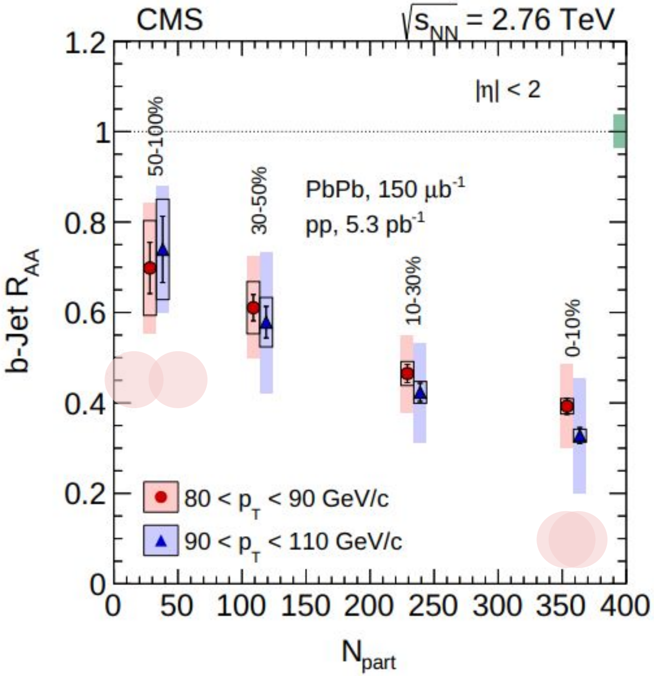
b jet production at 2.76 TeV

$$R_{AA}^{b\text{-jet}} \equiv \left. \frac{1}{N_{evt}} \frac{d^2 N_{AA}^{b\text{-jet}}}{dp_T dy} \right|_{cent} \Bigg/ \langle T_{AA} \rangle \frac{d^2 \sigma_{pp}^{b\text{-jet}}}{dp_T dy}$$

CMS PRL 113 (2014) 132301
R=0.3

b jet energy loss in medium (jet quenching)





b jet production at 5.02 TeV

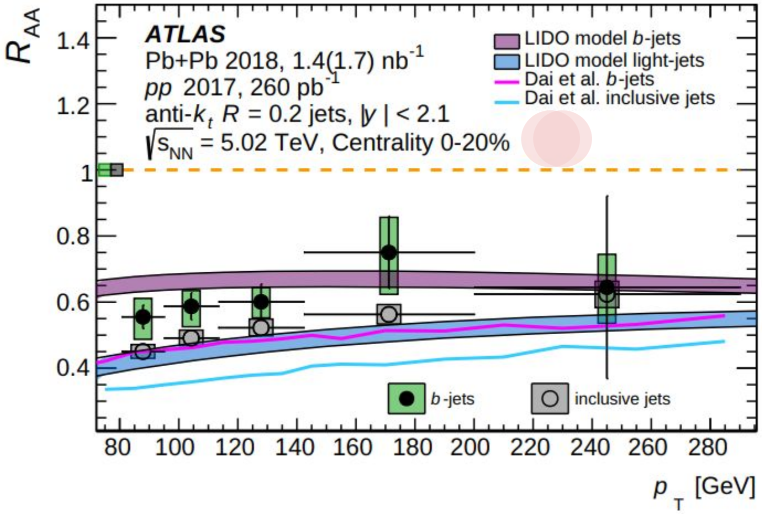
$$R_{AA}^{b\text{-jet}} \equiv \frac{1}{N_{evt}} \frac{d^2N_{AA}^{b\text{-jet}}}{dp_T dy}\bigg|_{cent} \bigg/ \langle T_{AA} \rangle \frac{d^2\sigma_{pp}^{b\text{-jet}}}{dp_T dy}$$

ATLAS EPJC 83 (2023) 438

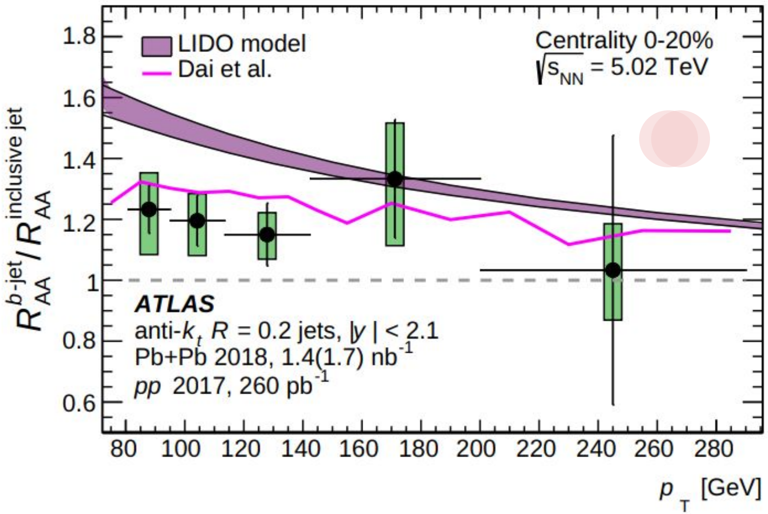
R=0.2

Larger R_{AA} = smaller energy loss

b jets are less quenched than inclusive

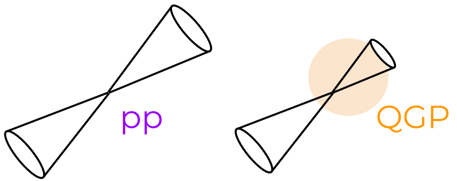


b / inclusive



b dijet asymmetry

CMS JHEP 03 (2018) 181
R=0.4

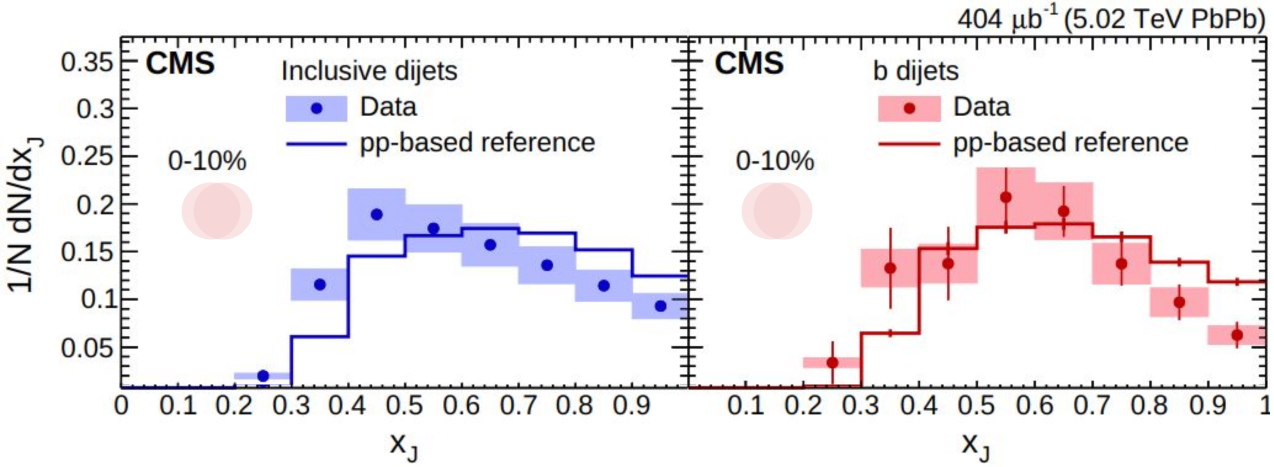


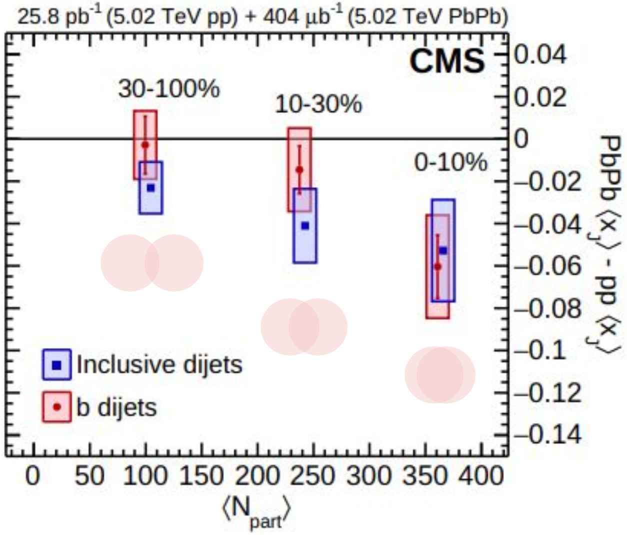
$x_J = p_T^{sub} / p_T^{lead}$

Increased imbalance in central PbPb
⇒ another signature of **jet quenching**

b dijets comparable to inclusive

PbPb - pp



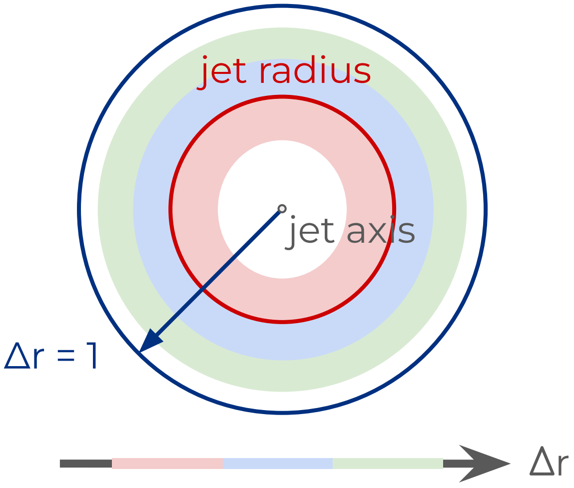


b jet shape

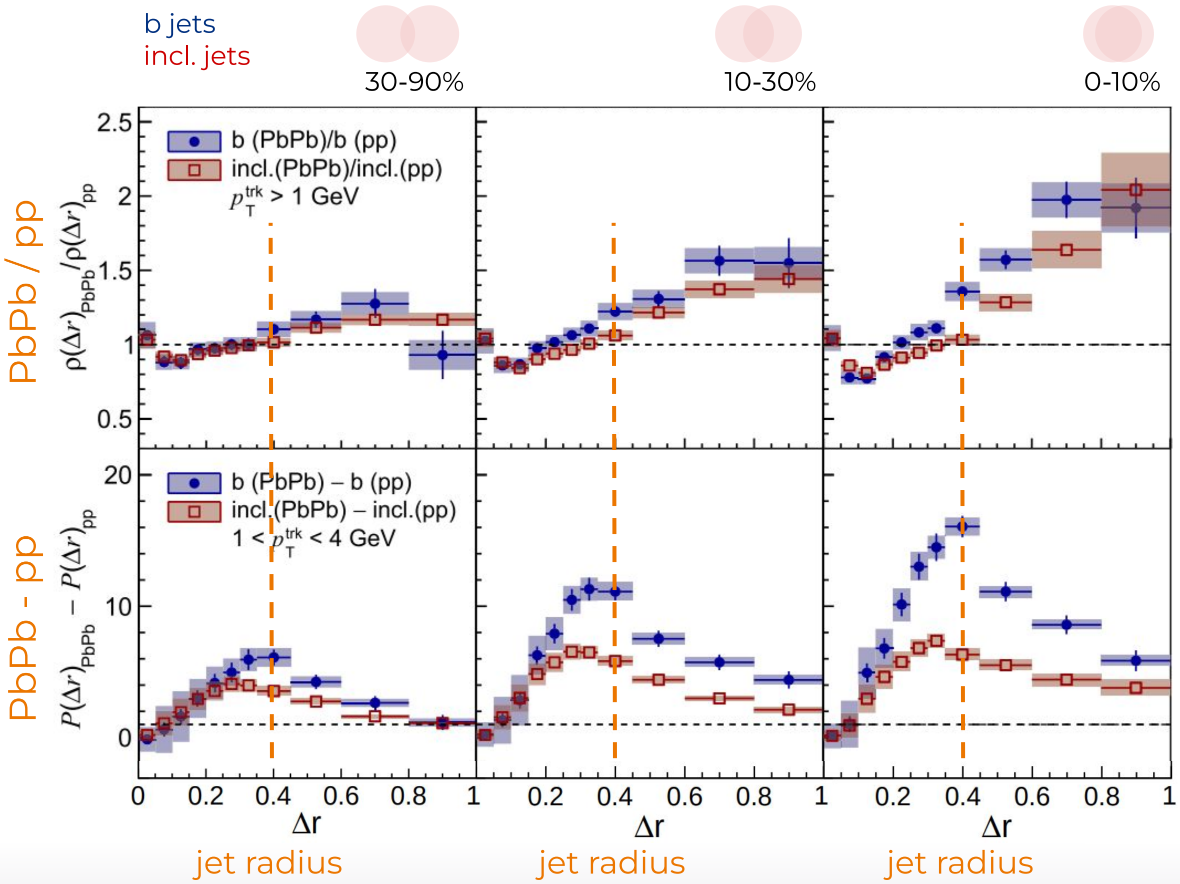
PLB 844 (2023) 137849

R=0.4

Redistribution of energy to larger angles



More so for b than for inclusive jets

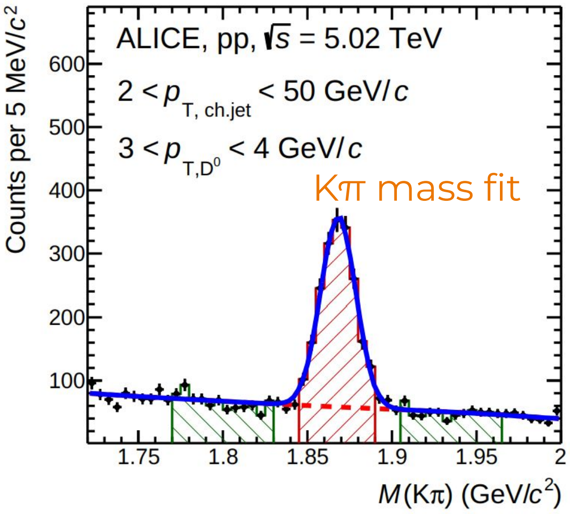


What do we know from c jets?

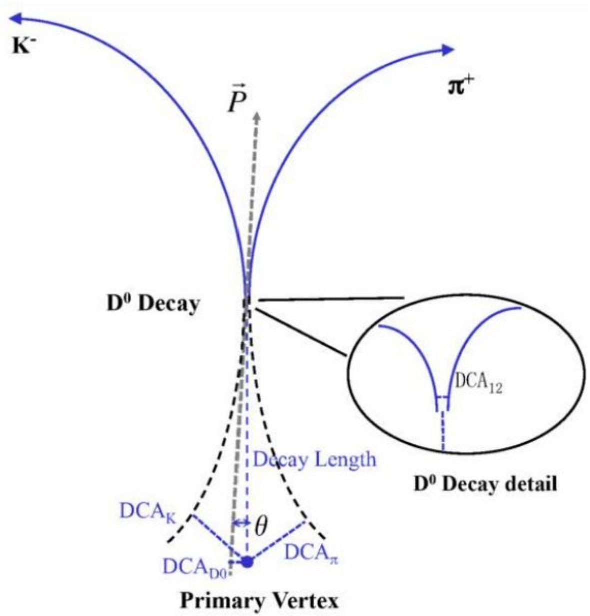
D^0 tagging

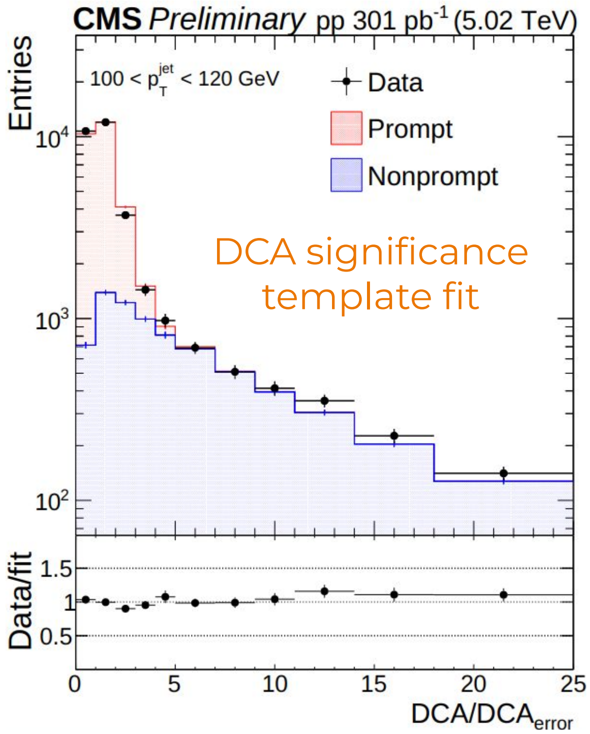
Depends on

- D^0 from displaced K, π
- Prompt vs non-prompt



ALICE JHEP 06 (2023) 133





CMS-PAS-HIN-24-007

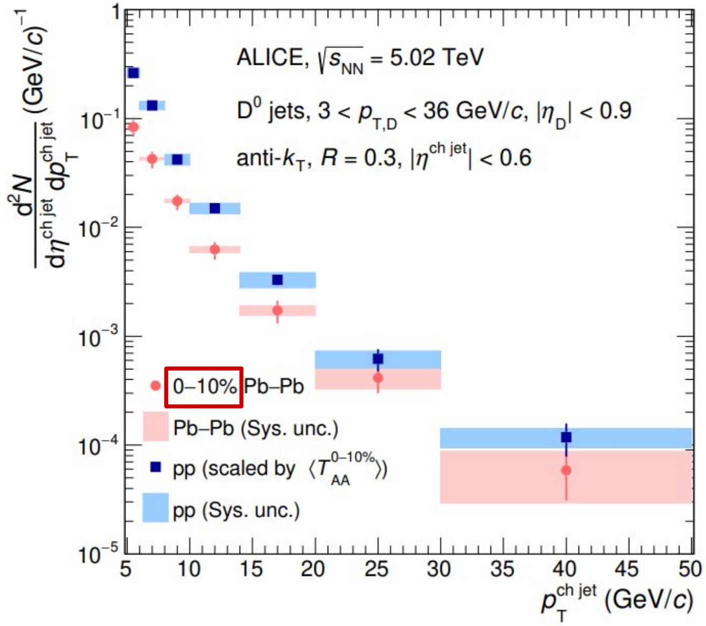
D^0 jet production at 5.02 TeV

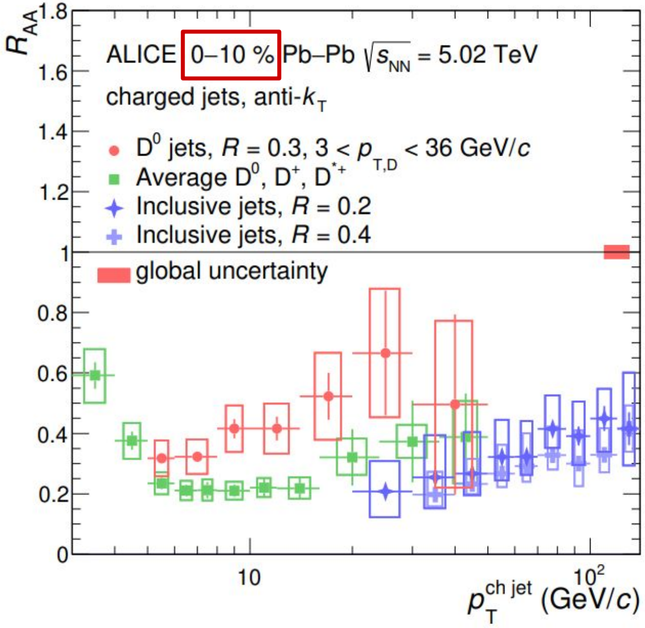
$$R_{AA}^{b\text{-jet}} \equiv \frac{1}{N_{evt}} \frac{d^2 N_{AA}^{b\text{-jet}}}{dp_T dy}\bigg|_{cent} \Big/ \langle T_{AA} \rangle \frac{d^2 \sigma_{pp}^{b\text{-jet}}}{dp_T dy}$$

ALICE CERN-EP-2024-240

charged-particle jets
R=0.3

D^0 jet energy loss in medium (jet quenching)
smaller than inclusive jets





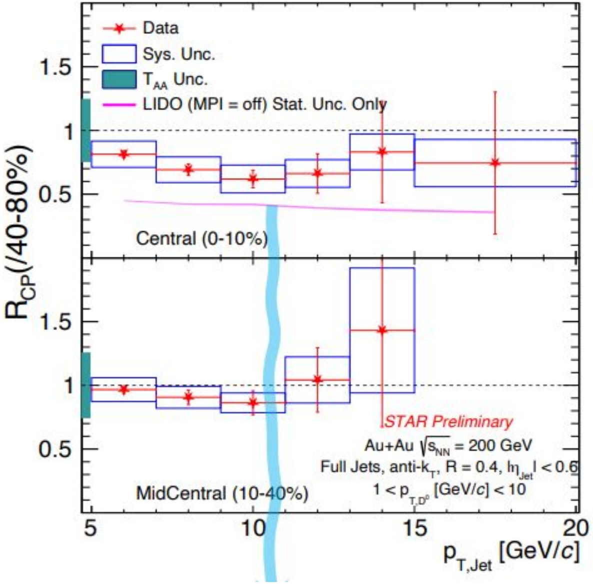
D^0 jet production in Au+Au at 200 GeV

Diptanil Roy's talk at HP2024
R=0.4

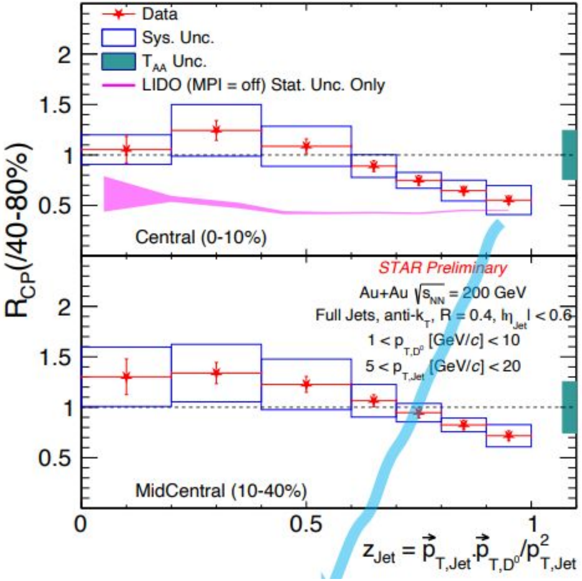
R_{CP} = central / peripheral

z-dependent energy loss in central Au+Au

R_{CP} vs jet p_T



R_{CP} vs D^0 z



What’s next?

Jet substructure!

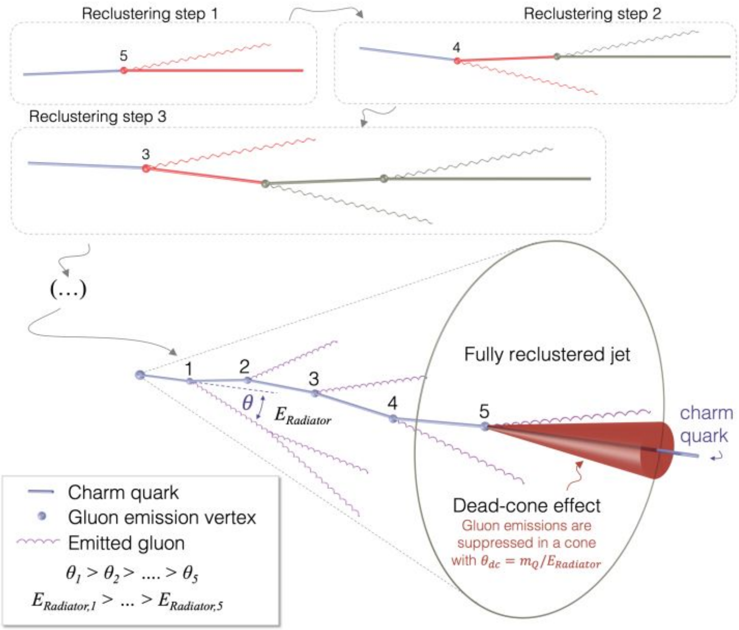
Exploiting the dead cone

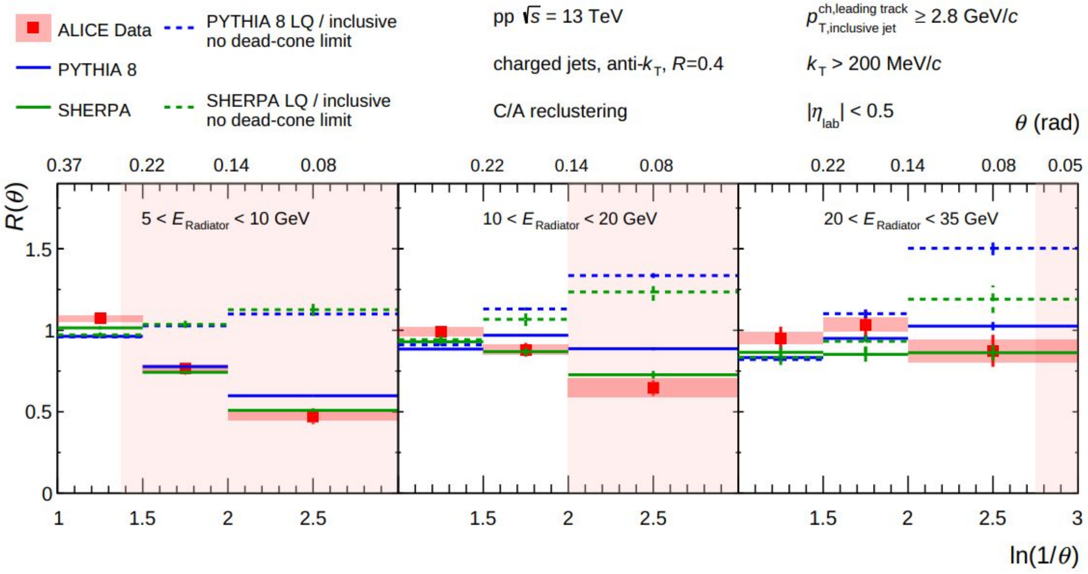
ALICE Nature 605 (2022) 440-446

charged-particle jets
R=0.4

Employ jet declustering techniques to access directly the dead cone

dead cone angle $\theta_0 \equiv \frac{m_Q}{E}$



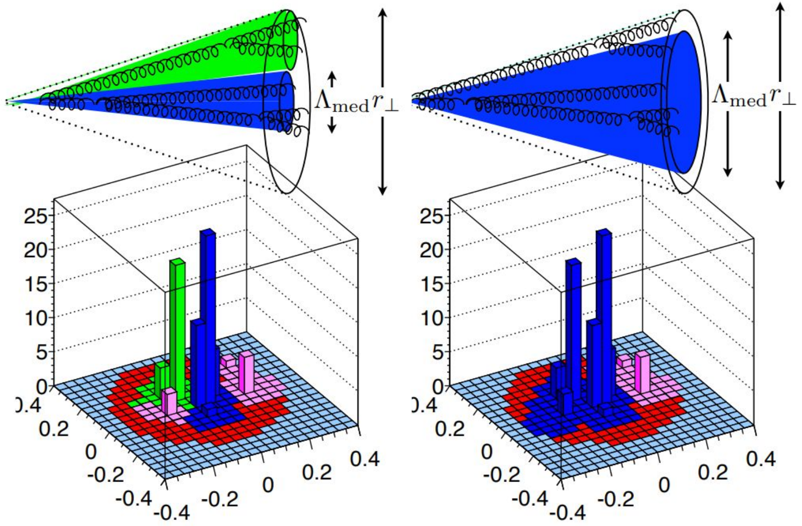


First observation of c quark dead cone in pp

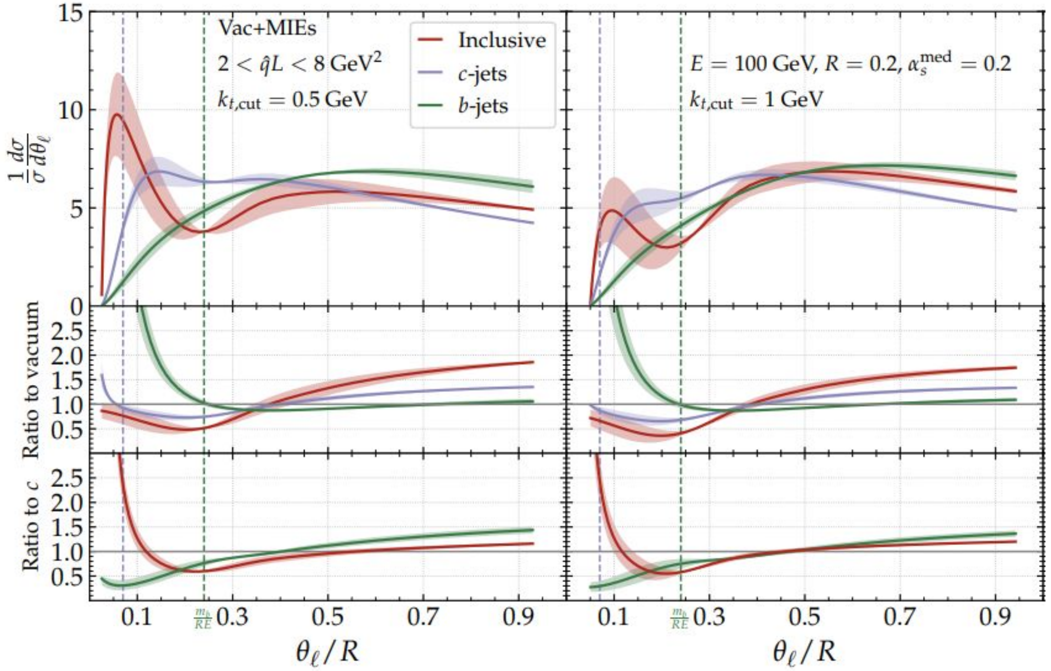
Exploiting the dead cone

dead cone angle θ_0 vs color decoherence angle θ_c

$\theta_{0,b} > \theta_c > \theta_{0,c}$?
dead cone filled?



Casalderrey-Solana et al. PLB 725 (2013) 357



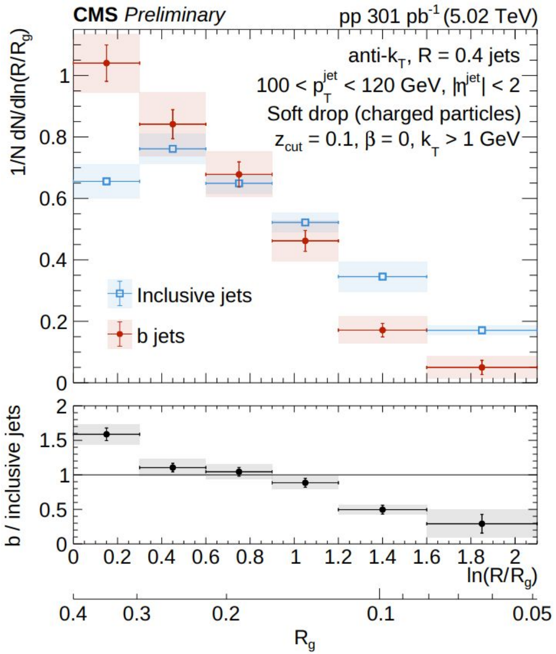
Cunqueiro, Napoletano, Soto-Ontoso PRD 107 (2023) 094008

Exploiting the dead cone

Soft drop selects least collinear hard splitting

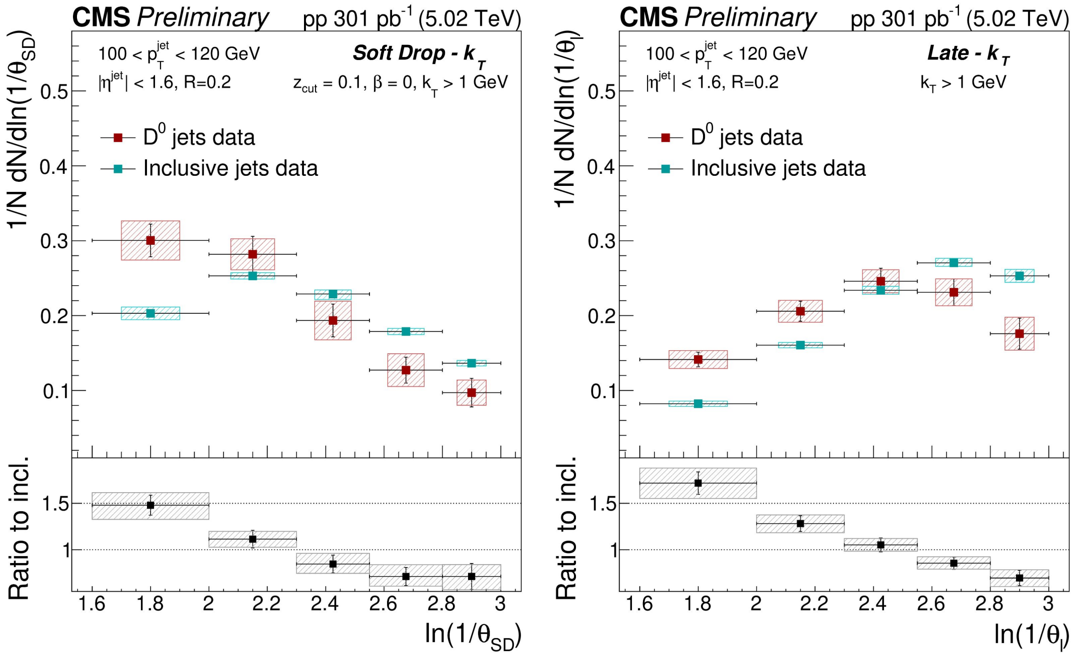
Late-k_T selects most collinear hard splitting

CMS-PAS-HIN-24-005



b quark dead cone manifestation

CMS-PAS-HIN-24-007

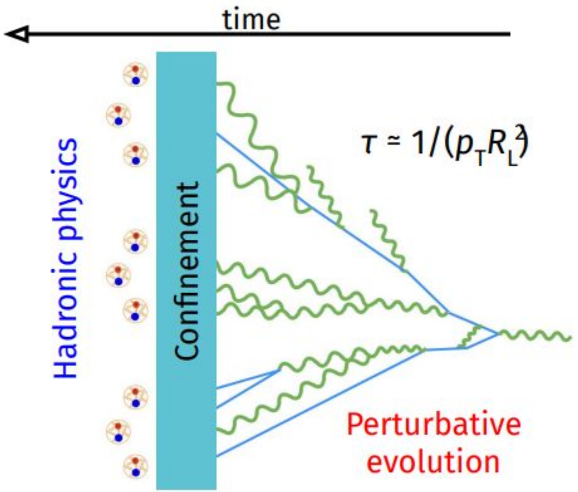


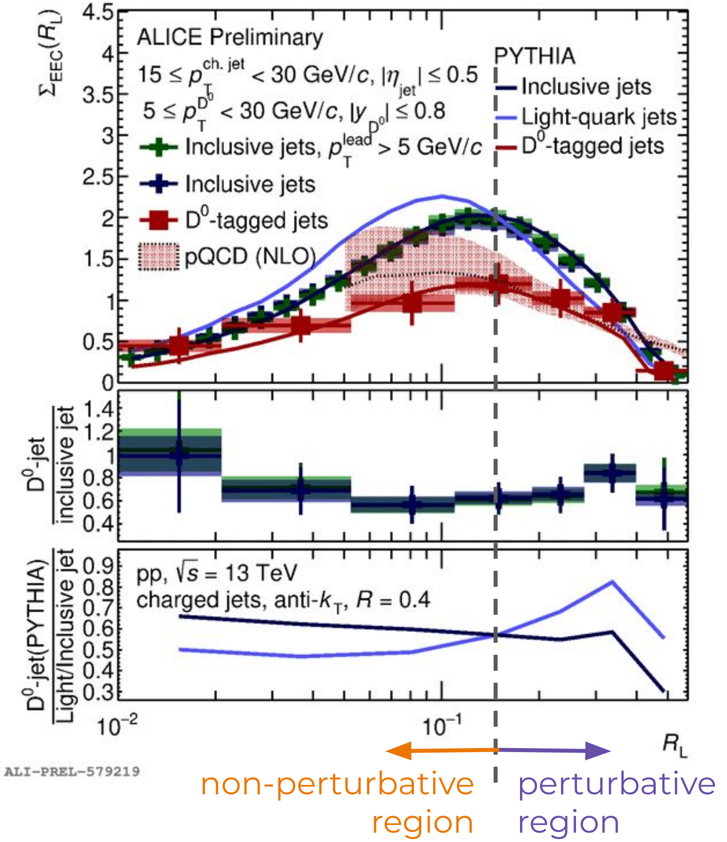
Late-k_T is more sensitive to the c quark dead cone

Energy-energy correlators

Energy weighted particle correlation

$$\frac{d\sigma_{EEC}}{dR_L} = \sum_{i,j} \int d\sigma(R'_L) \boxed{\frac{p_{T,i}\,p_{T,j}}{p^2_{T,jet}}} \delta(R'_L - R_{L,ij})$$



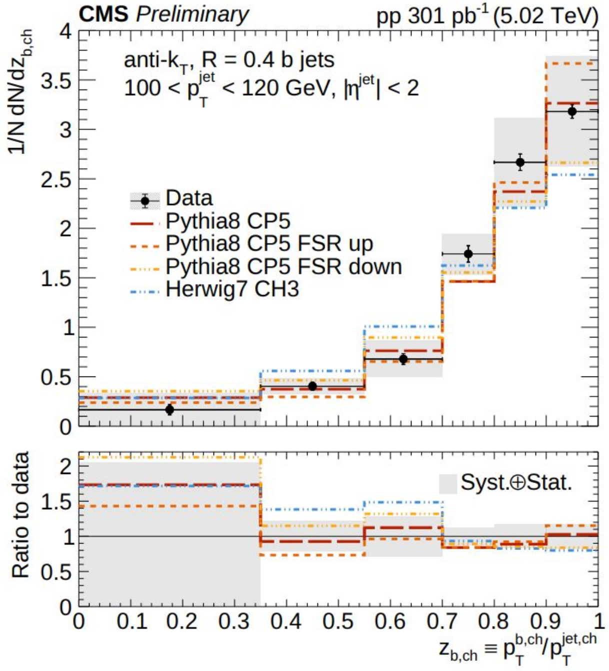


Transition from perturbative to non-perturbative

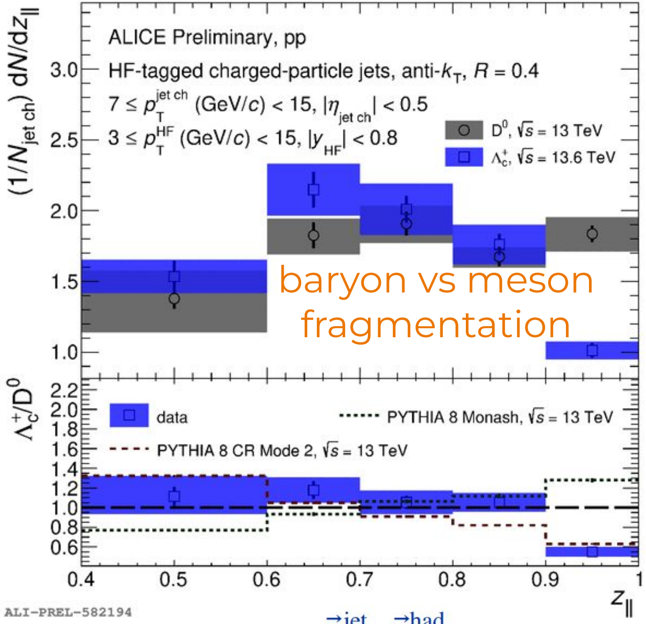
Jet fragmentation function

Fraction of jet momentum carried by the hadron

CMS-PAS-HIN-24-005



Jochen Klein's talk at HP2024



$$z_{||} = \frac{\vec{p}^{\,jet} \cdot \vec{p}^{\,had}}{\vec{p}^{\,jet} \cdot \vec{p}^{\,jet}}$$

Summary

HF jet identification

- HF hadron reconstruction
- Charged lepton
- Tagging
  - Previously limited performance
  - New possibilities with ML

HF jet energy loss

- Smaller than that of inclusive jets
- Imbalanced energy loss for dijets
- Redistribution of p_T out of the jet cone
- Larger loss for harder fragmentation

Missing pieces

- Modification of fragmentation (b hadron, baryon vs meson)
- Mechanism of energy loss at the **constituent level**
  - Jet declustering (dead cone vs decoherence angle)
  - EECs (shape, peak position)

Thank you!