Hadron-in-jet Fragmentation Functions: Experimental review

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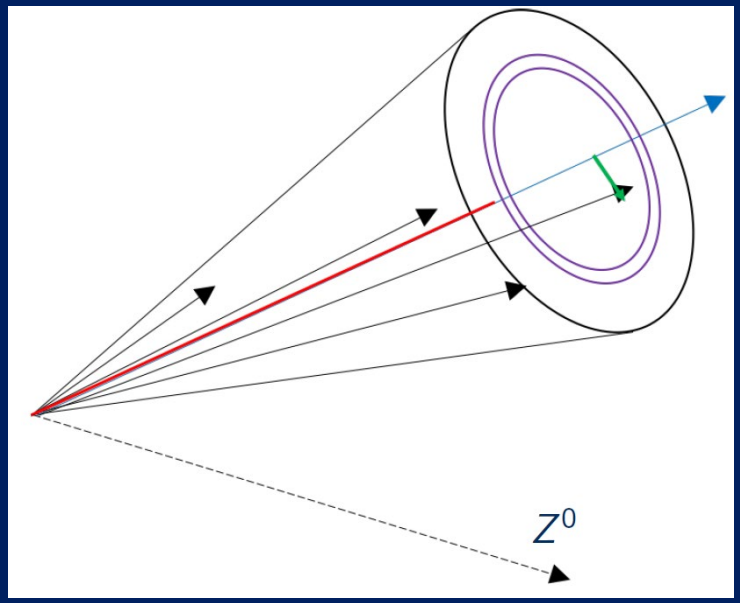
INT Workshop on Fragmentation Functions
November 1-5, 2021



Hadronization in jets

- Hadronization connected to jets
  - Anti-k_T jet reconstruction algorithm has opened up many new possibilities to make robust comparisons of jets between theory and experiment – Cacciari, Salam, Soyez, JHEP 04, 063 (2008)

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  - Single hadron-in-jet FFs – introduced in Procura and Stewart, PRD81, 074009 (2010)
  - Fragmenting jet functions – introduced in Procura and Stewart, PRD81, 074009 (2010)

Hadrons in jets: Interest across communities

- Driven by multiple physics communities
  - Beyond the Standard Model
  - Heavy ions/hot QCD
  - Cold QCD/nucleon structure
- A number of measurements relevant to collinear and TMD fragmentation in jets have been coming out in recent years

Hadrons in jets: Interest across communities

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  - Beyond the Standard Model
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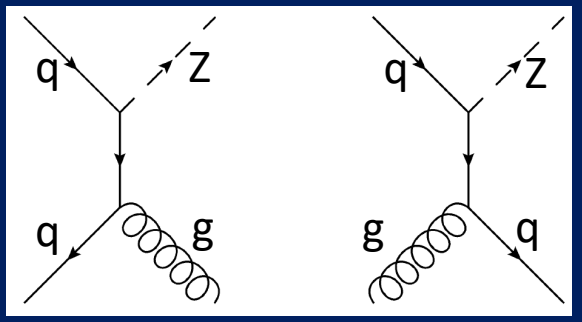
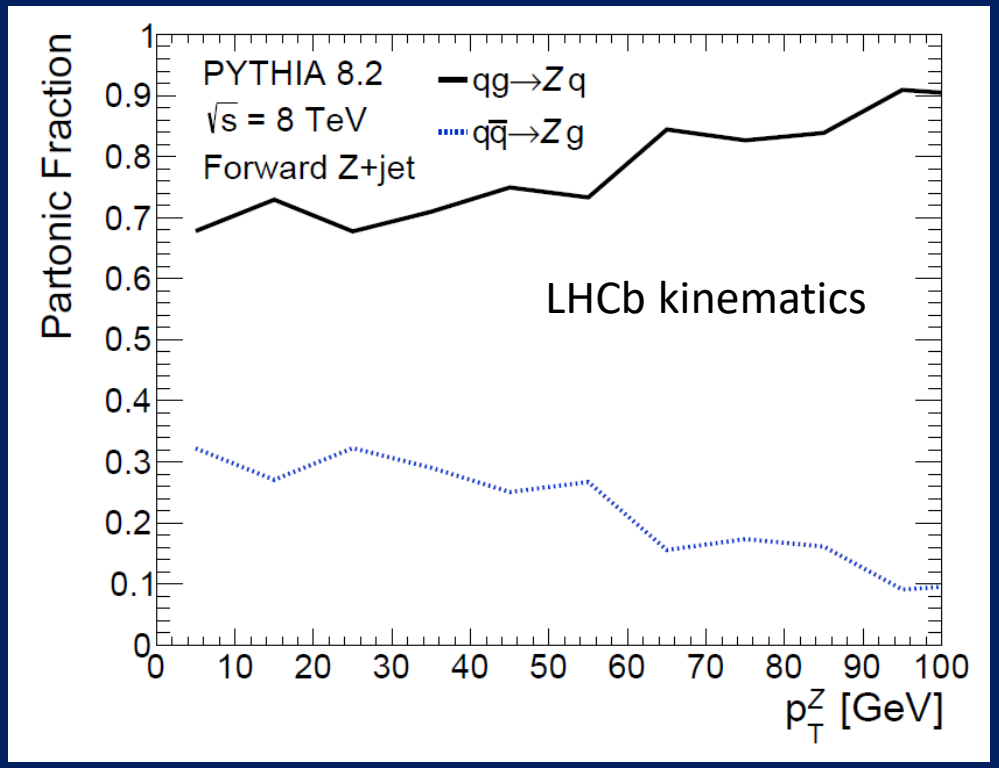
- A number of measurements relevant to collinear and TMD fragmentation in jets have been coming out in recent years
- Also broad interest in jet substructure more generally
  - See talk later today by Zhongbo Kang

Enriched quark-jet samples

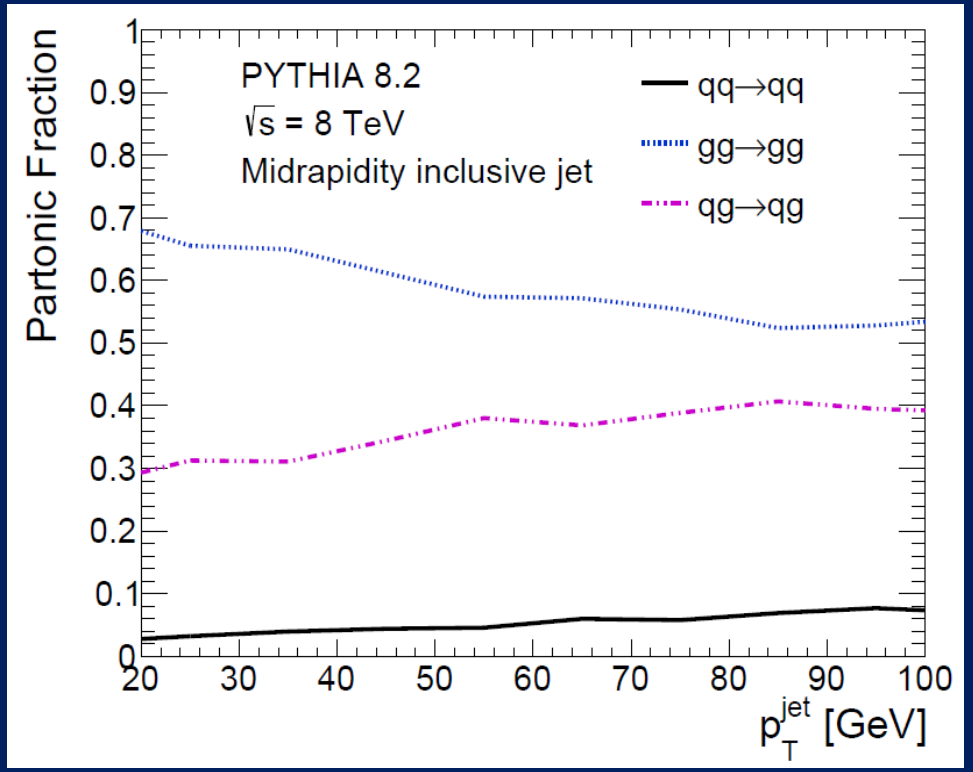
- Z+jet or γ+jet is predominantly sensitive to quark jets
- At LHCb, forward kinematics increases fraction of light quark jets





Enriched gluon-jet samples

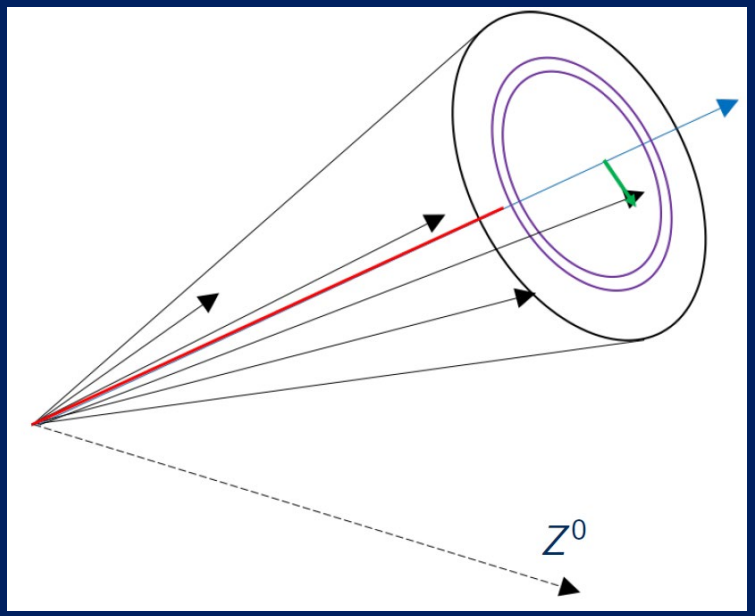
- Midrapidity inclusive jets at the LHC are instead dominated by gluons
- Opportunity to study light quark vs. gluon jets
  - Hadronization dynamics
  - Jet properties



Note modest jet p_T range

Charged hadrons in forward Z+jet at LHCb: Observables

- Longitudinal momentum fraction z
- Transverse momentum with respect to jet axis j_T
- Radial profile r



$$z = \frac{p_{jet} \cdot p_h}{|p_{jet}|^2}$$

$$j_T = \frac{|p_h \times p_{jet}|}{|p_{jet}|}$$

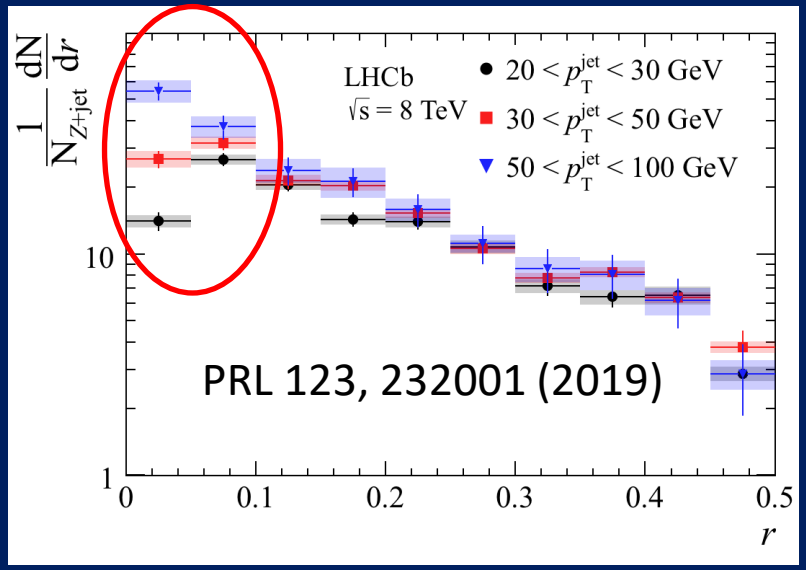
$$r = \sqrt{(\phi_h - \phi_{jet})^2 + (y_h - y_{jet})^2}$$

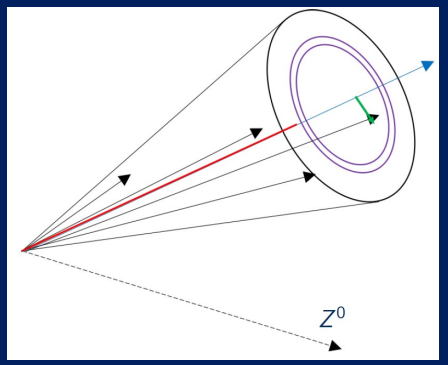
PRL 123, 232001 (2019)

Radial profiles

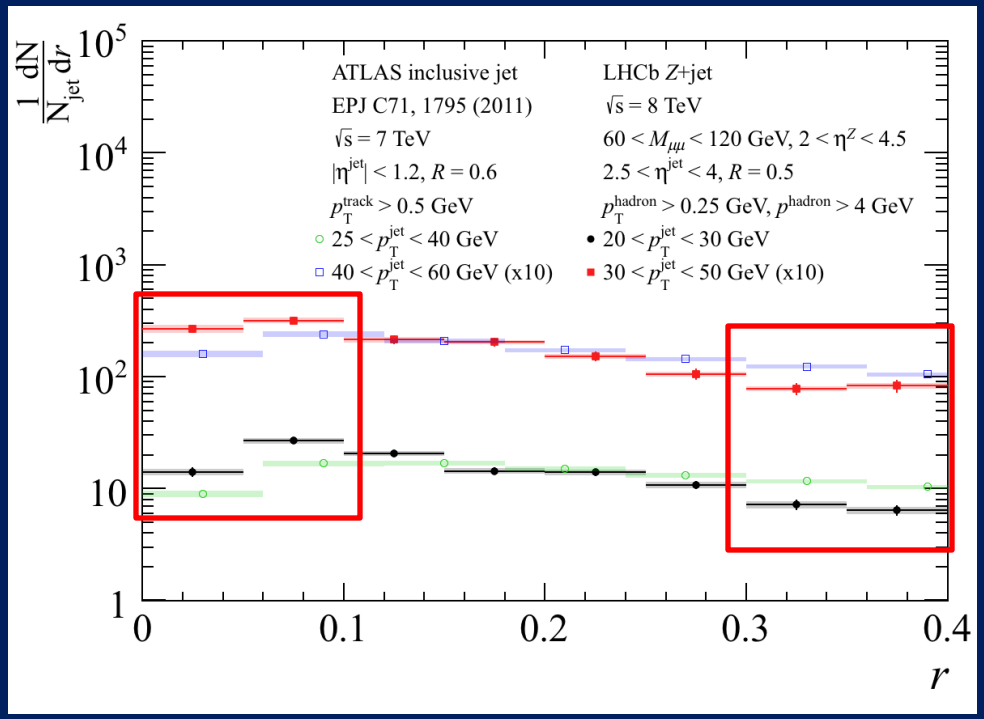
- Observe that the greater energy available in higher transverse momentum jets leads to more hadrons produced (logical)

- ~All of the additional particles are produced close to the jet axis, and go from a depletion close to the axis to an excess





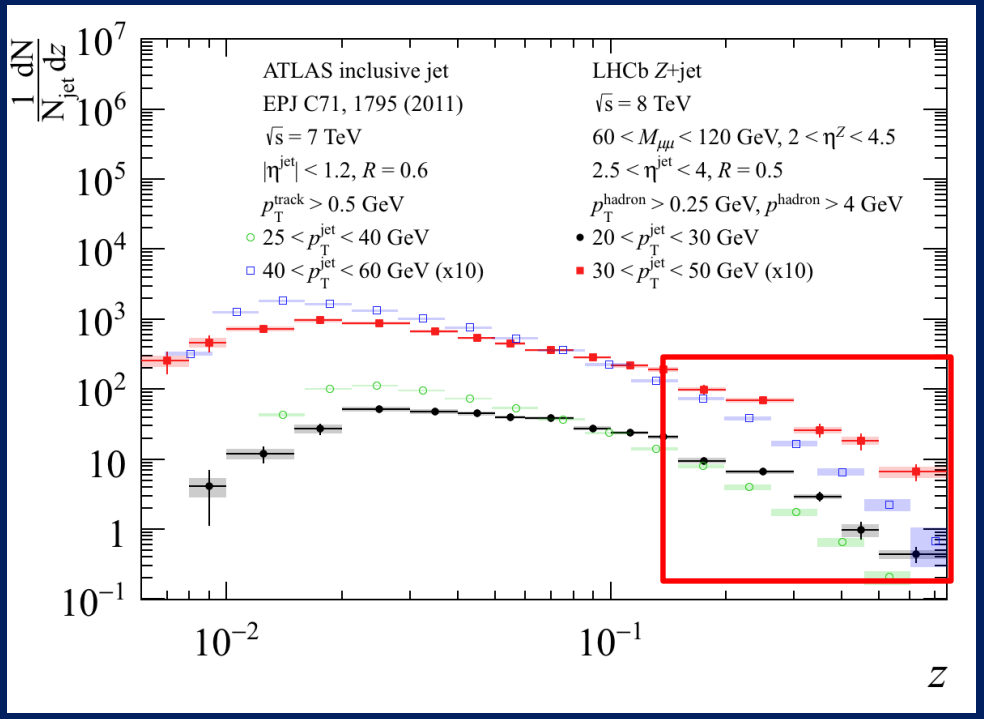
Differences between quark- and gluon-dominated jet samples: Radial profile



- Quark-dominated jets more collimated than gluon-dominated jets measured by ATLAS
  - I.e. more charged hadrons at small radii, fewer at large radii
  - Qualitatively agrees with conventional expectations, but this shows clear and quantitative evidence from data

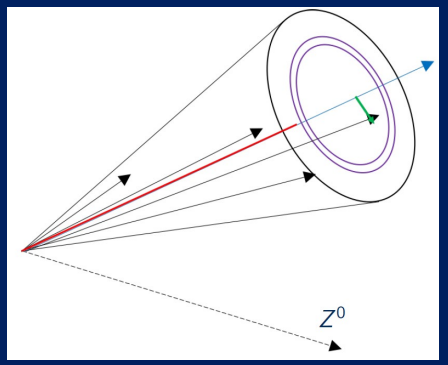
PRL 123, 232001 (2019)
LHCb-PAPER-2019-012

Differences between quark- and gluon-dominated jet samples: Longitudinal profile



- Quark-dominated jets have relatively more hadrons produced at higher longitudinal momentum fractions than gluon-dominated jets

PRL 123, 232001 (2019)
LHCb-PAPER-2019-012



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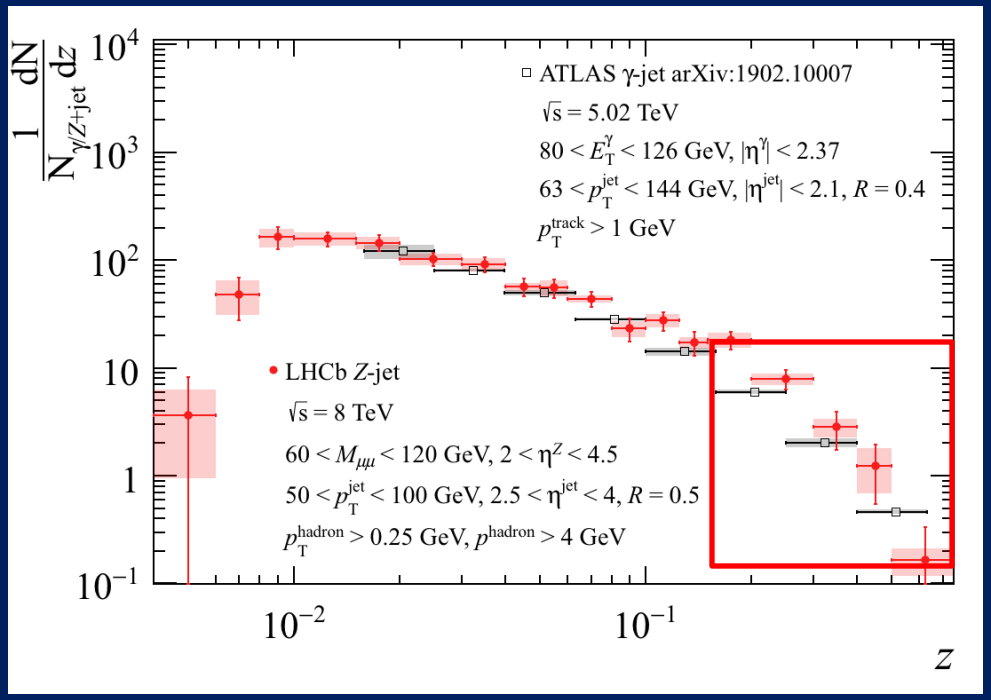
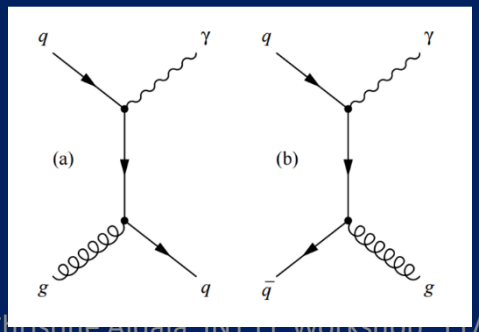


- ATLAS midrapidity γ+jet and LHCb Z+jet longitudinal momentum distributions are more similar
  - γ+jet, like Z+jet, enhances quark jet fraction
  - Further evidence that differences observed between LHCb results and ATLAS gluon-dominated results are due to differences in quark and gluon hadronization

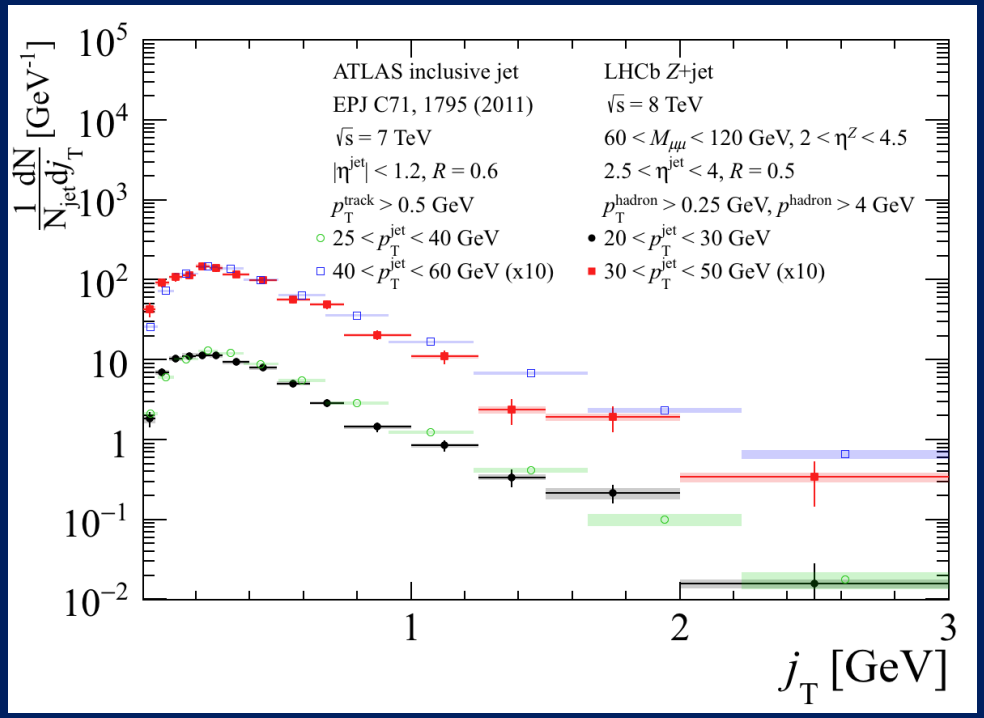
LHCb: PRL 123, 232001 (2019)
LHCb-PAPER-2019-012

ATLAS: PRL 123, 042001 (2019)



Differences between quark- and gluon-dominated jet samples: Transverse momentum distributions

- Transverse momentum distributions similar



LHCb: PRL 123, 232001 (2019)

Midrapidity inclusive jet transverse momentum fraction, 13 TeV

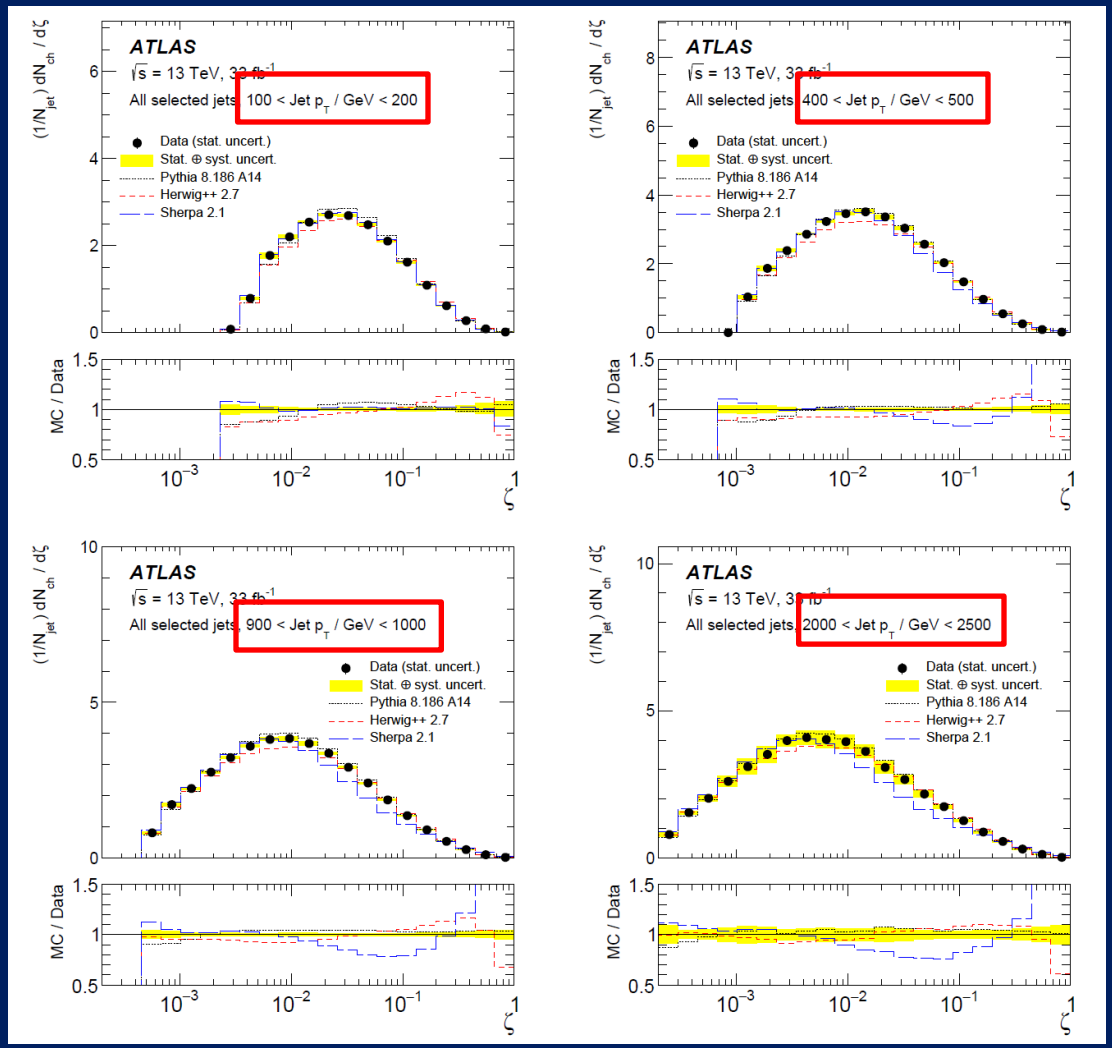
The two leading jets in each event are studied.

$|\eta| < 2.1$

Four bins of jet p_T

$$\zeta = \frac{p_T^{particle}}{p_T^{jet}}$$

PRD 100, 052011 (2019)
arXiv:1906.09254



Midrapidity inclusive jet transverse momentum profile, 13 TeV

The two leading jets in each event are studied.

$|\eta| < 2.1$

Four bins of jet p_T

$$p_T^{rel} = p_T^{particle} \sin \Delta\phi$$

PRD 100, 052011 (2019)
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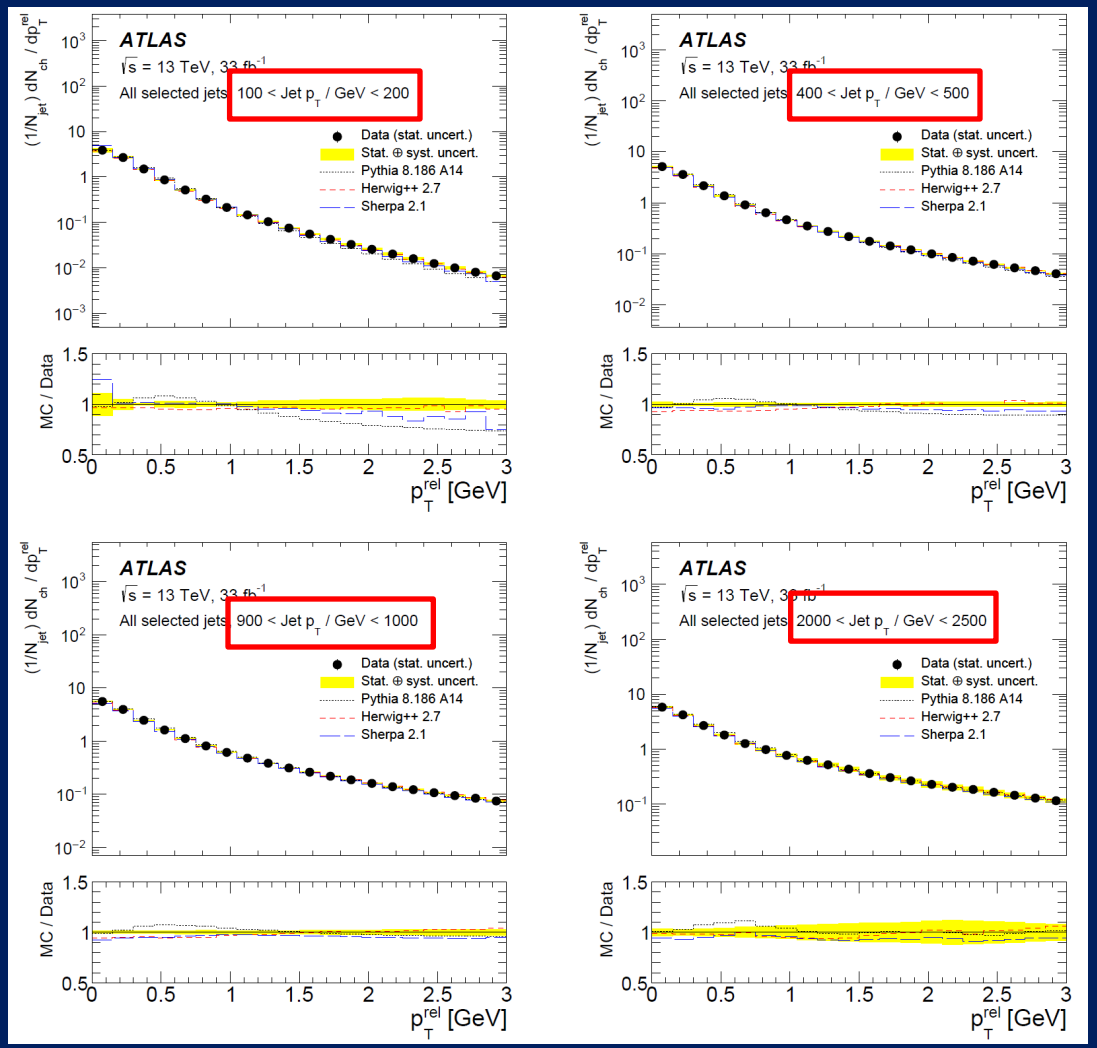
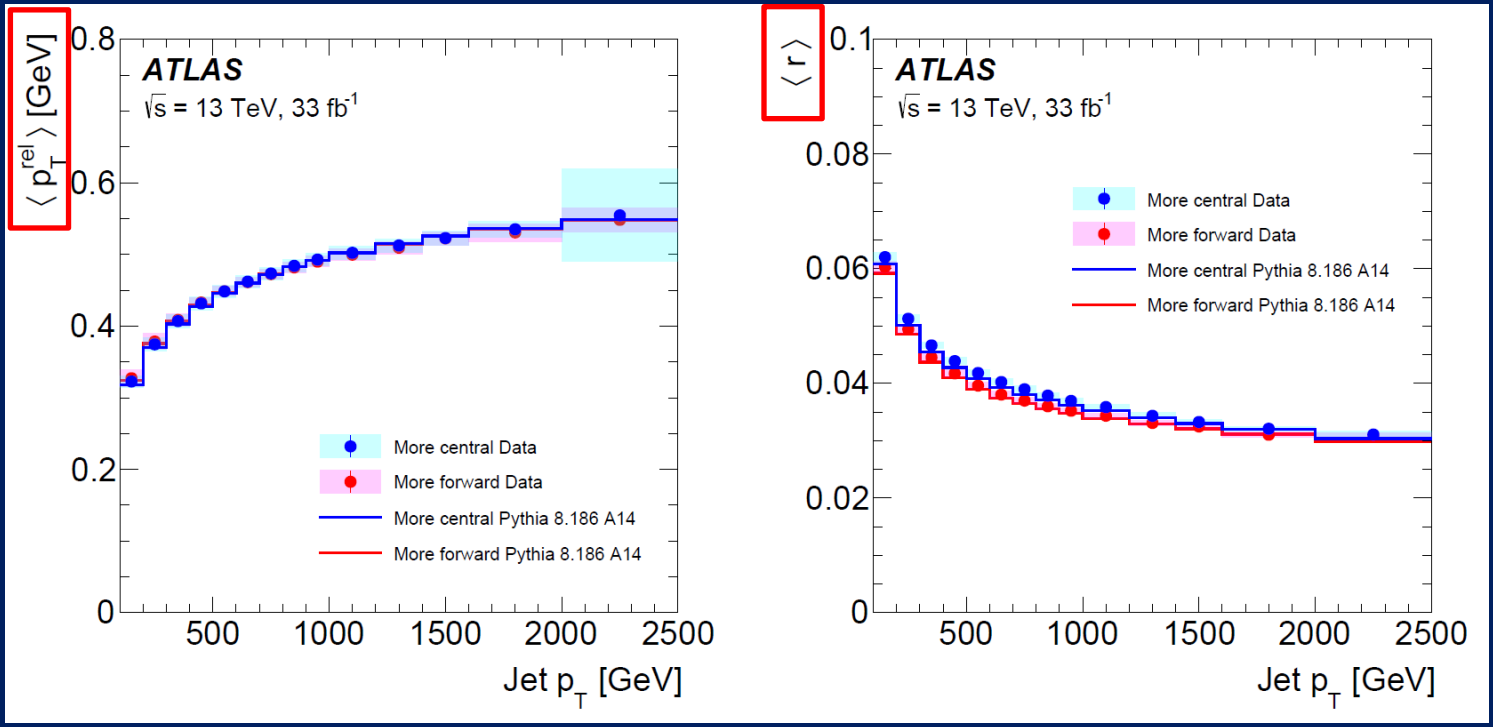


Midrapidity inclusive jet fragmentation, 13 TeV

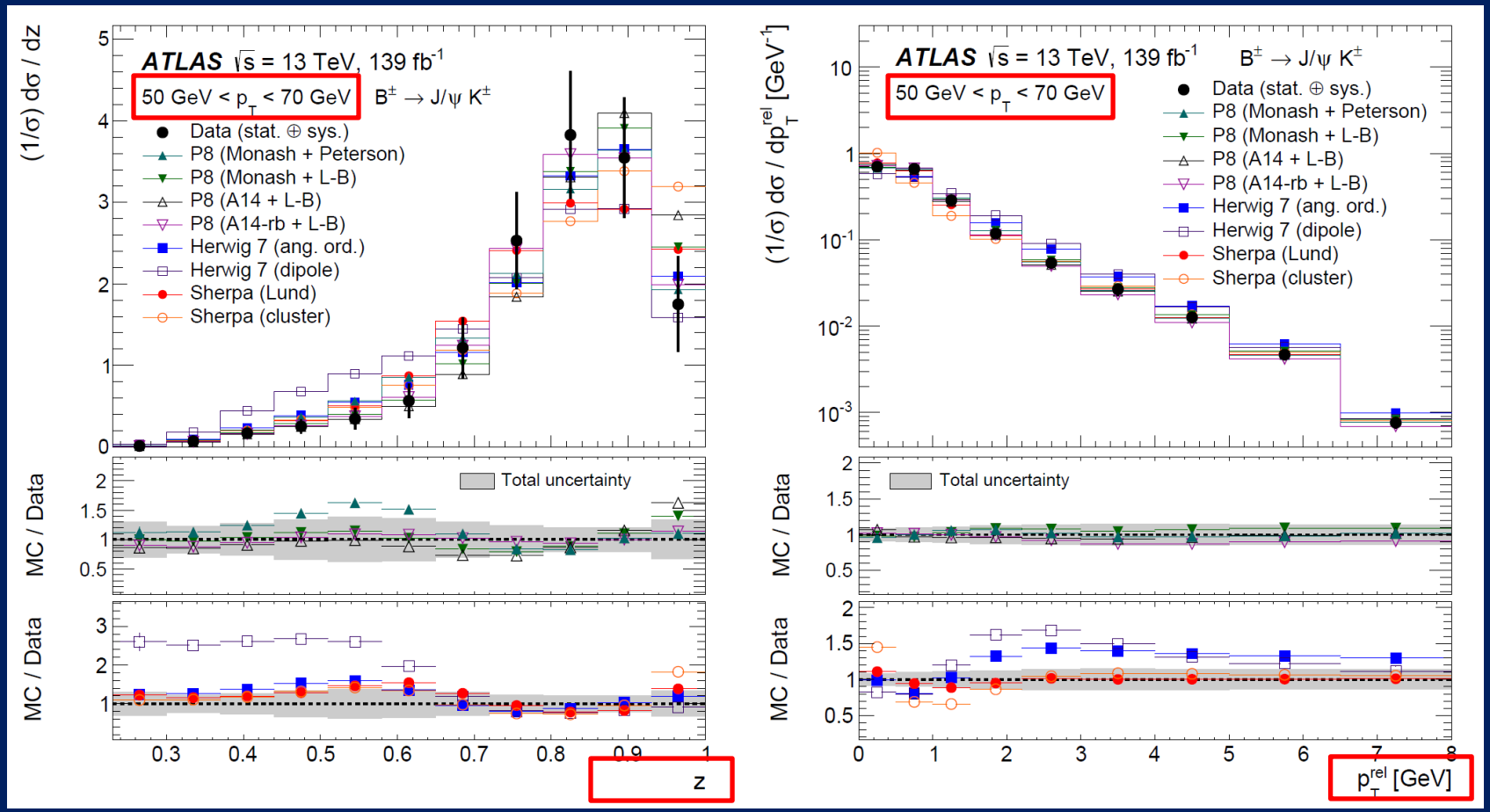


PRD 100, 052011 (2019)
arXiv:1906.09254

Mean p_T^{rel} and r vs. jet p_T.

Separated for the more central or forward of the two leading jets

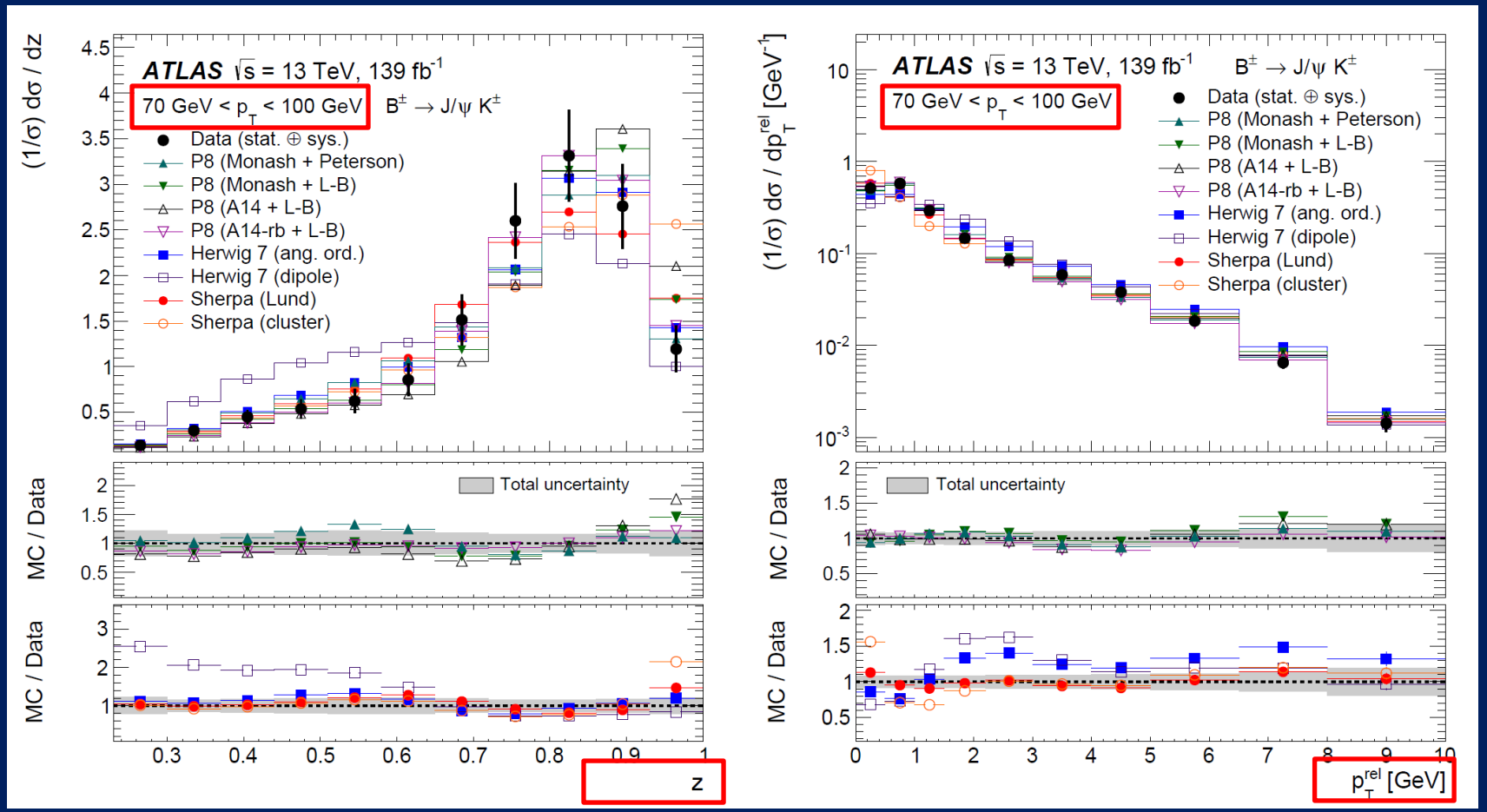
b quark fragmentation in jets via $B^{\pm} \rightarrow J/\psi K^{\pm}$



Heavy flavor hadronization peaked at high z.

arXiv:2108.11650

b quark fragmentation in jets via $B^{\pm} \rightarrow J/\psi K^{\pm}$



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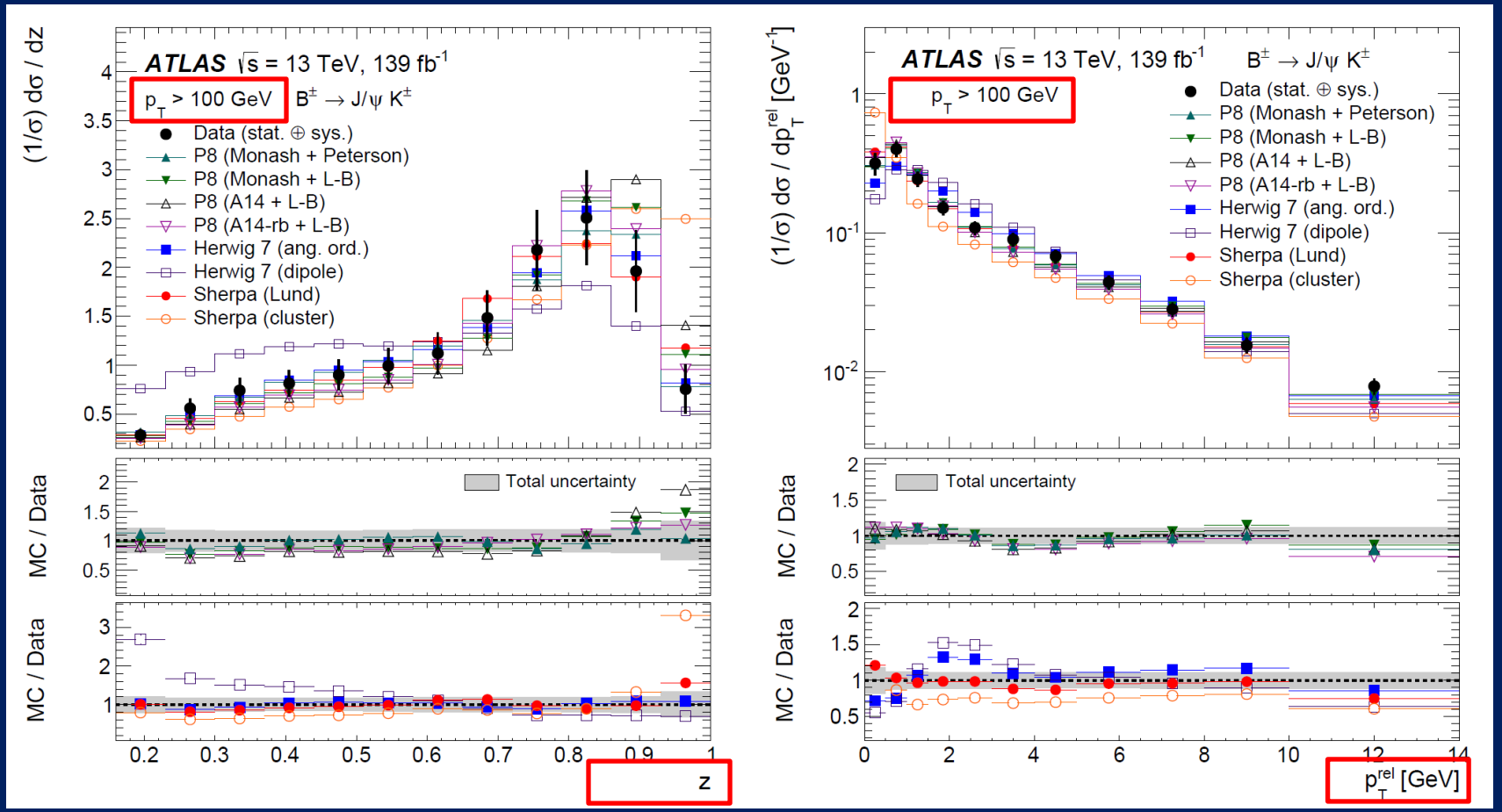

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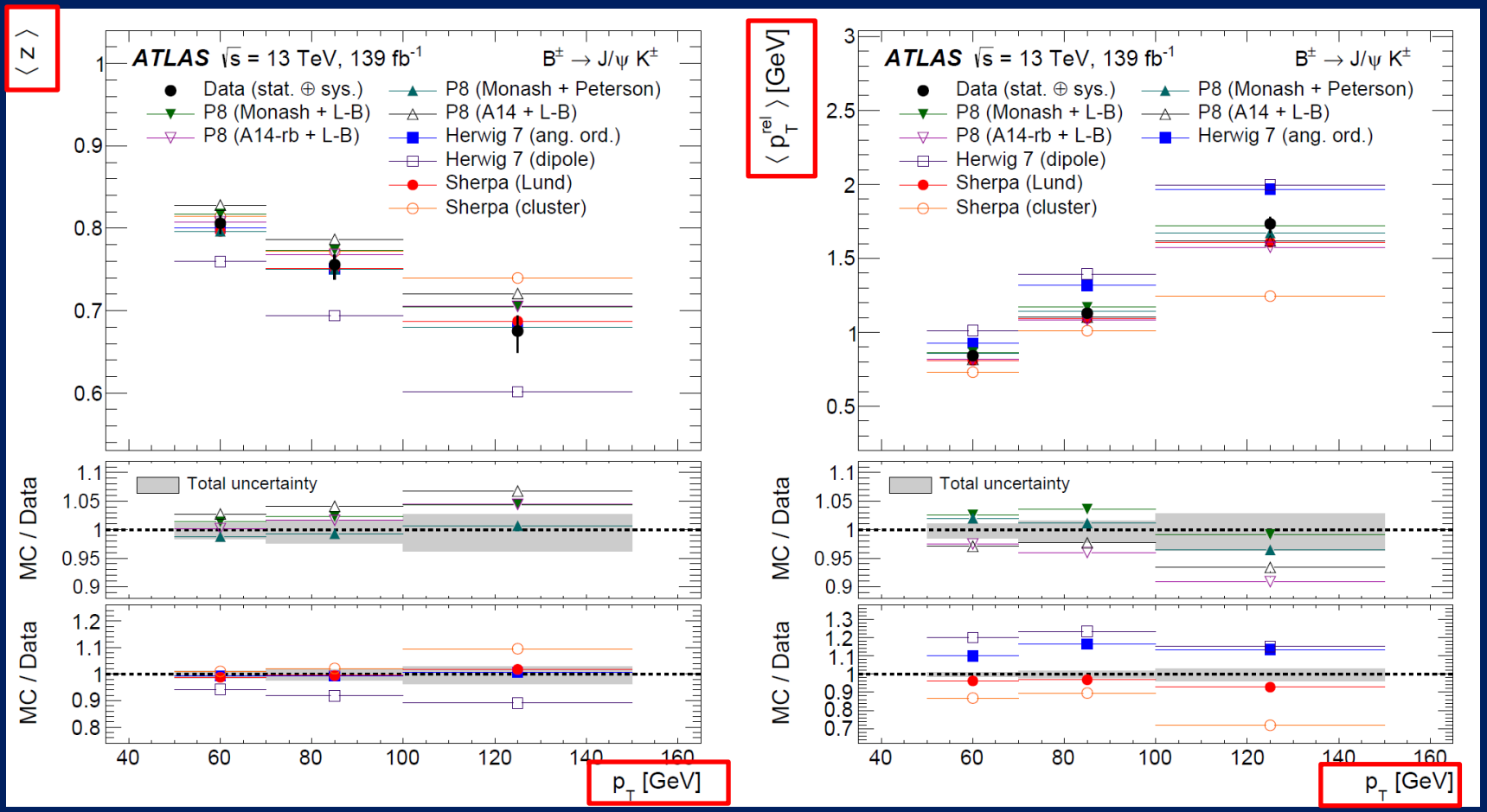
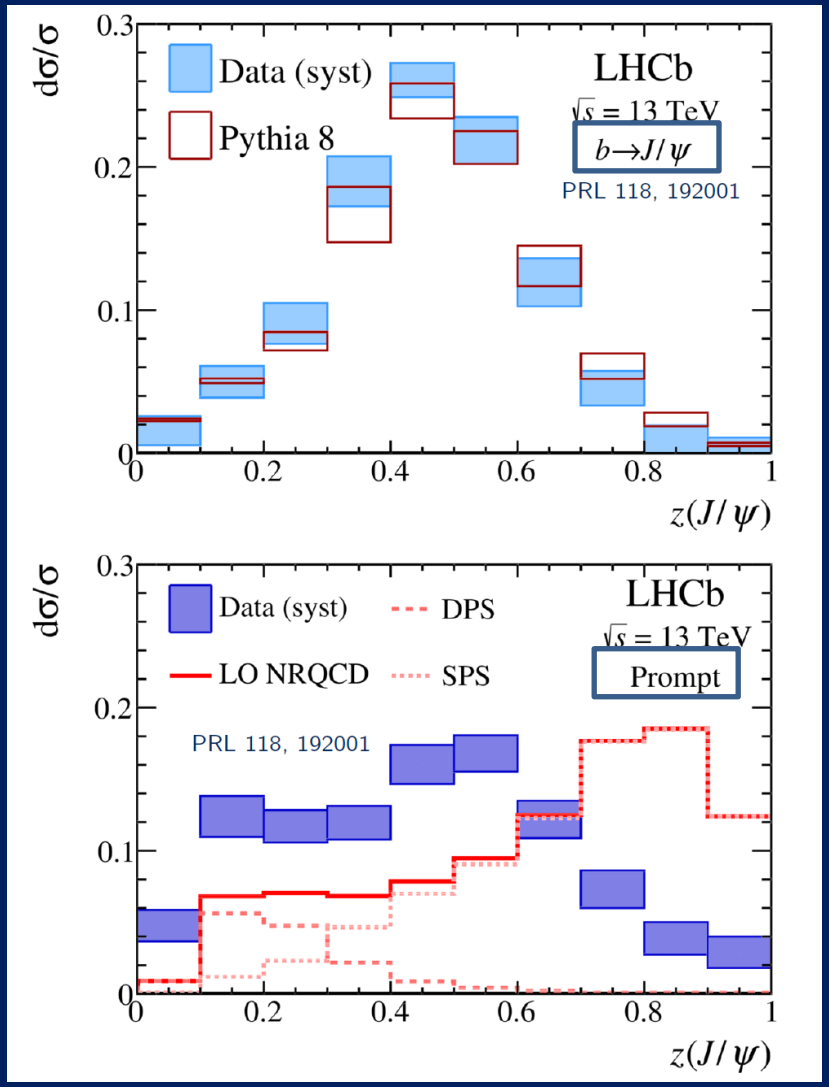


Mean z and p_T^{rel} vs. jet p_T

arXiv:2108.11650

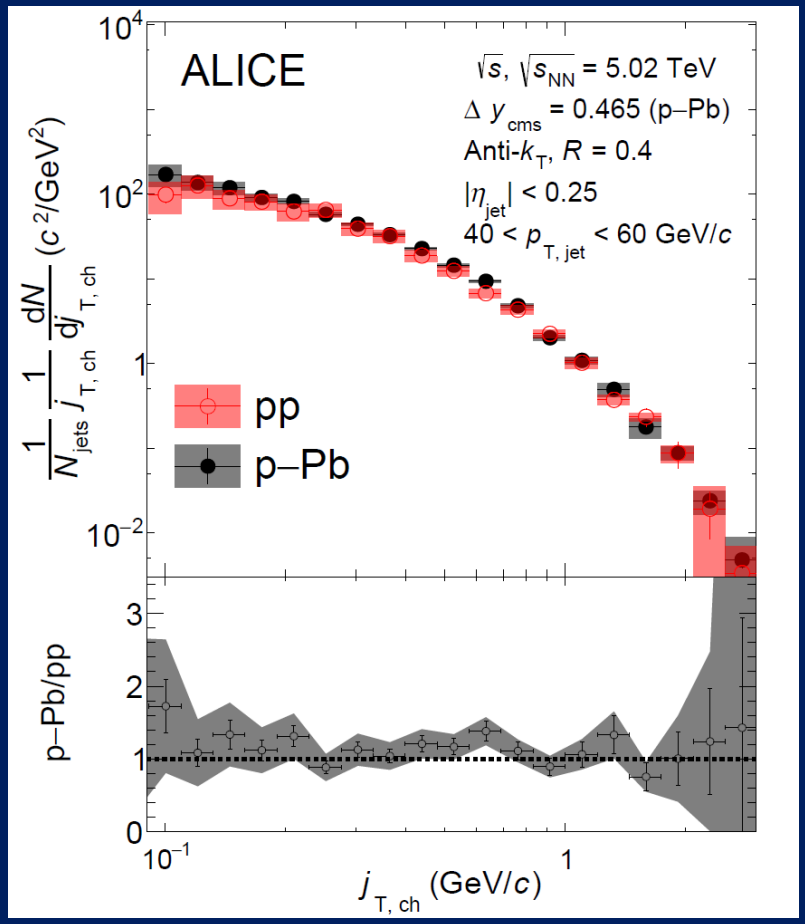
J/Ψ production in jets

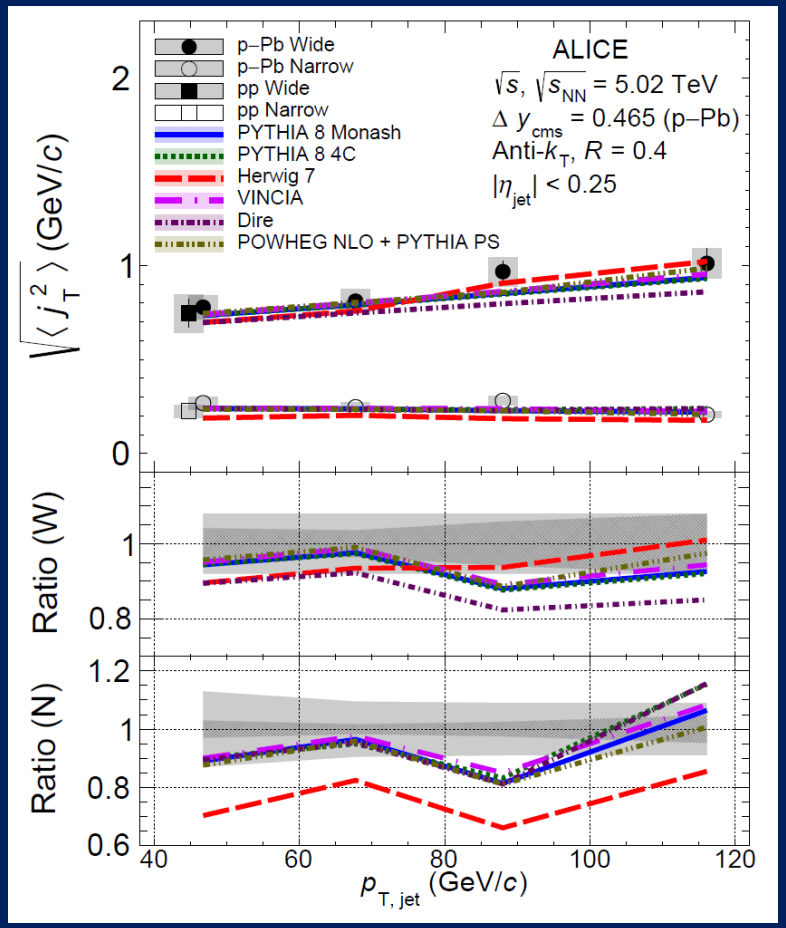
- J/ψ from b decay well described by PYTHIA
- Prompt J/ψ-in-jet not! Can shed light on prompt J/ψ production mechanism(s). How is a prompt J/ψ produced within a jet?



Midrapidity inclusive jet fragmentation in p+p and p+Pb

arXiv:2011.05904

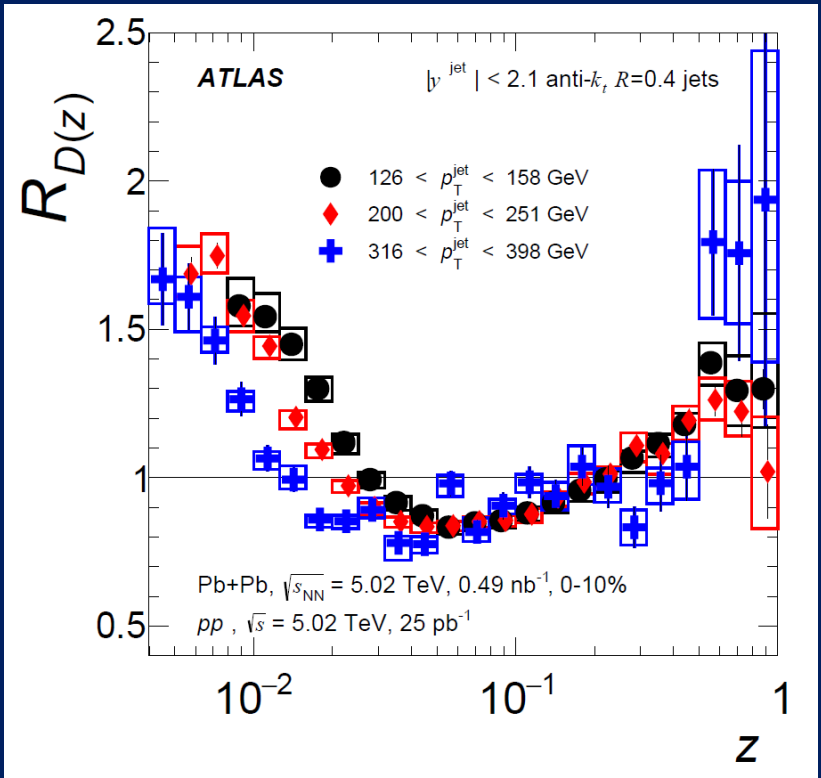




j_T distributions consistent between p+p, p+Pb

"Narrow" (open symbols): Gaussian part of distribution at low j_T

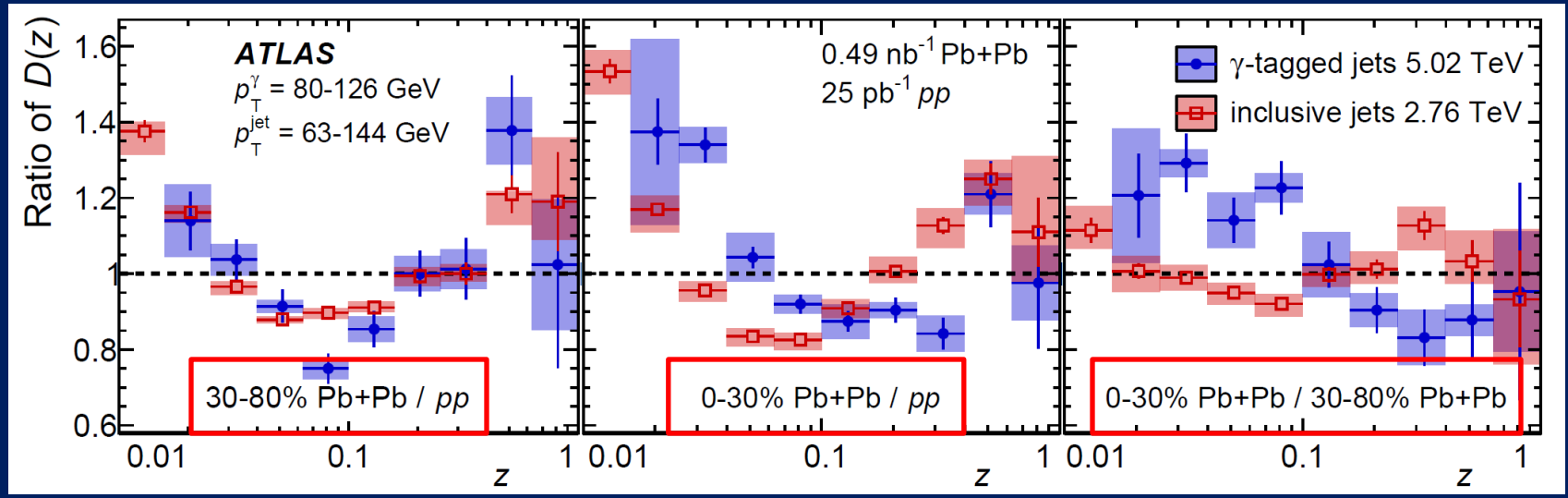
Ratio of hadrons in inclusive jets, Pb+Pb/p+p



- Depletion of charged hadrons seen in Pb+Pb around $z \approx 0.1$, excess at both lower and higher z
- Scaling behavior at high z
- Differences for different jet p_T bins for $z < \sim 0.05$
- Also shown in paper
  - Separate $D(z)$ distributions for p+p and Pb+Pb
  - Ratios in different rapidity ranges
  - Ratios for different jet p_T ranges

PRC 98, 024908 (2018)
arXiv:1805.05424

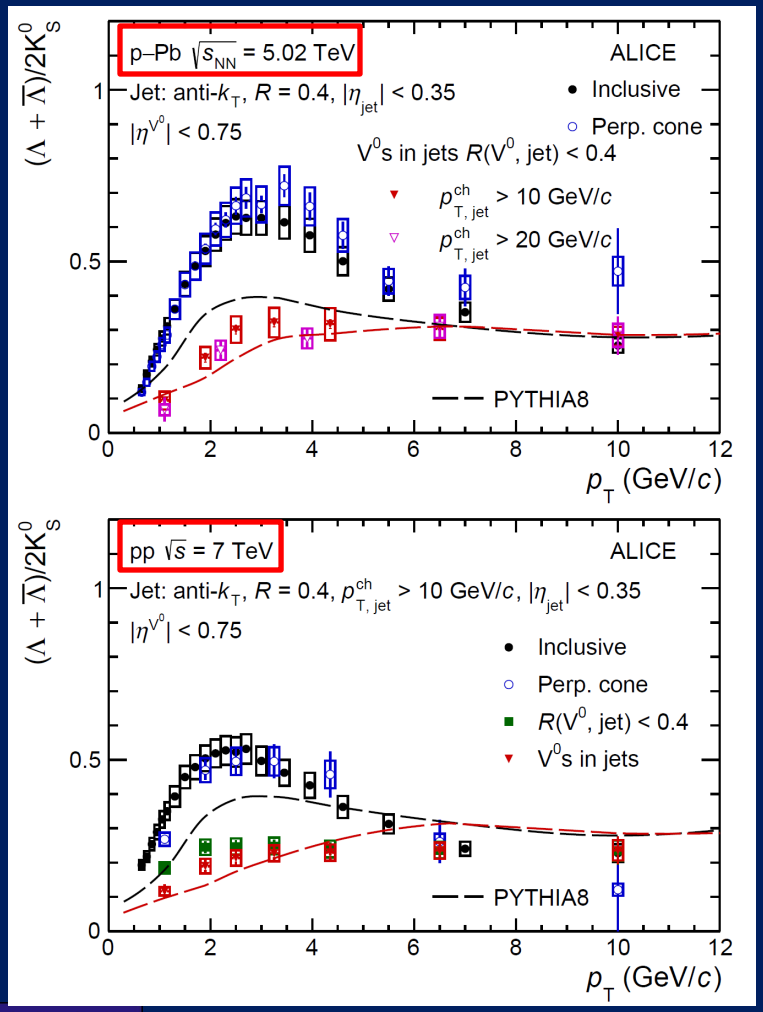
Hadrons in γ-tagged and inclusive jets, p+p and Pb+Pb



- Ratio of Pb+Pb to p+p. Depletion of charged hadrons seen in Pb+Pb around $z \approx 0.1$, excess at both lower and higher z
- Indication of differences for gluon-dominated inclusive jets and quark-enhanced γ-tagged jets

PRL 123, 042001 (2019)
arXiv:1902.10007

Baryon enhancement for strange hadrons within and outside of jets in p+Pb and p+p



- Strange baryon-to-meson enhancement seen for both p+Pb and p+p perpendicular to the jet, but not within the jet

arXiv:2105.04890

Some forthcoming measurements from LHCb

- Nonidentified charged hadrons in Z+jet at 13 TeV, double-differential in (z, j_T)
- Identified $\pi^{\pm}, K^{\pm}, p^{\pm}$ in Z+jet
- Nonidentified charged hadrons in b-tagged jets
- Reconstructed $B^{\pm}$ in jets
- Υ in jets
- Polarization of J/ψ, Υ in jets

Conclusions

- A number of hadron-in-jet results already available from the LHC, with plenty of data for further analysis and even more data about to arrive with the start of Run 3 in 2022
- (Unpolarized) Hadron-in-jet results also to come from RHIC – STAR and sPHENIX
  - See following talk by Maria Zurek on current spin-dependent hadron-in-jet results from STAR
- See also jet substructure talk later today by Zhongbo Kang

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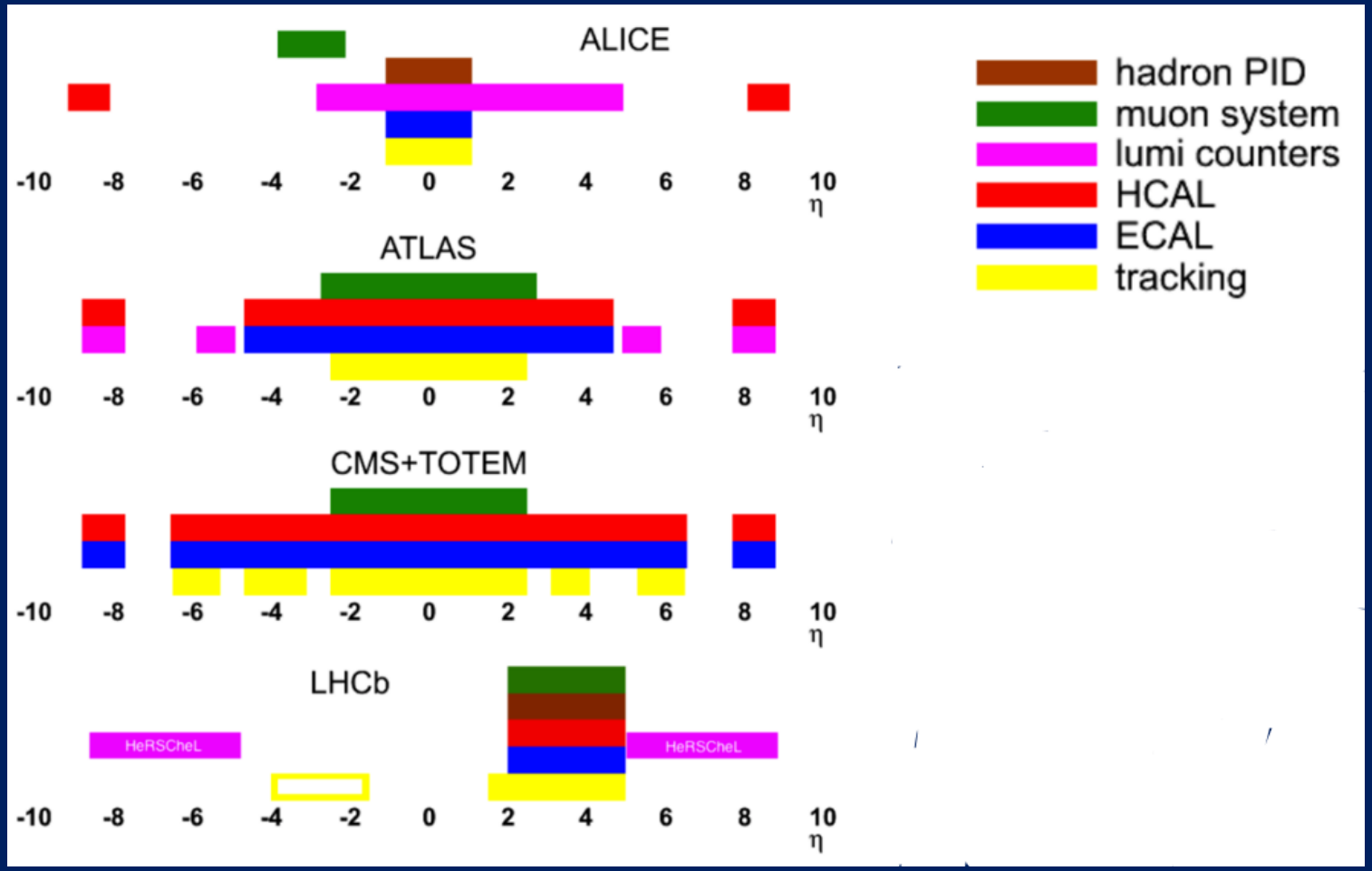
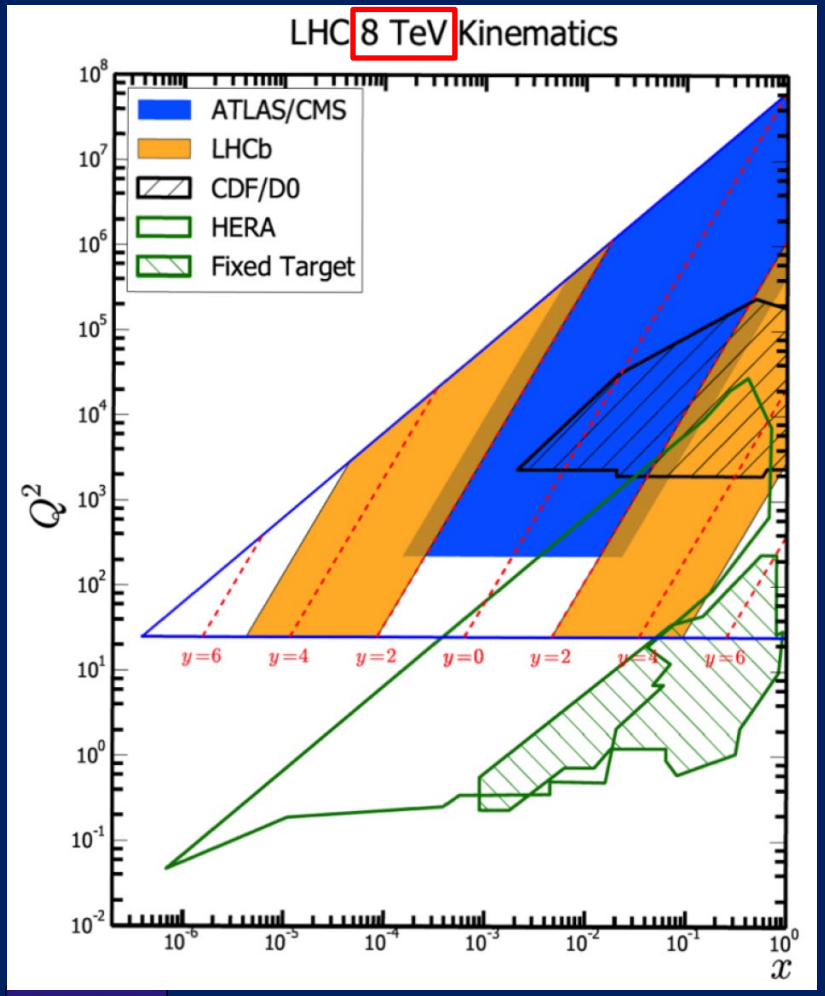
Modern approaches to jets allow more robust comparison between theory and experiment and have opened up a wealth of new observables to study hadronization

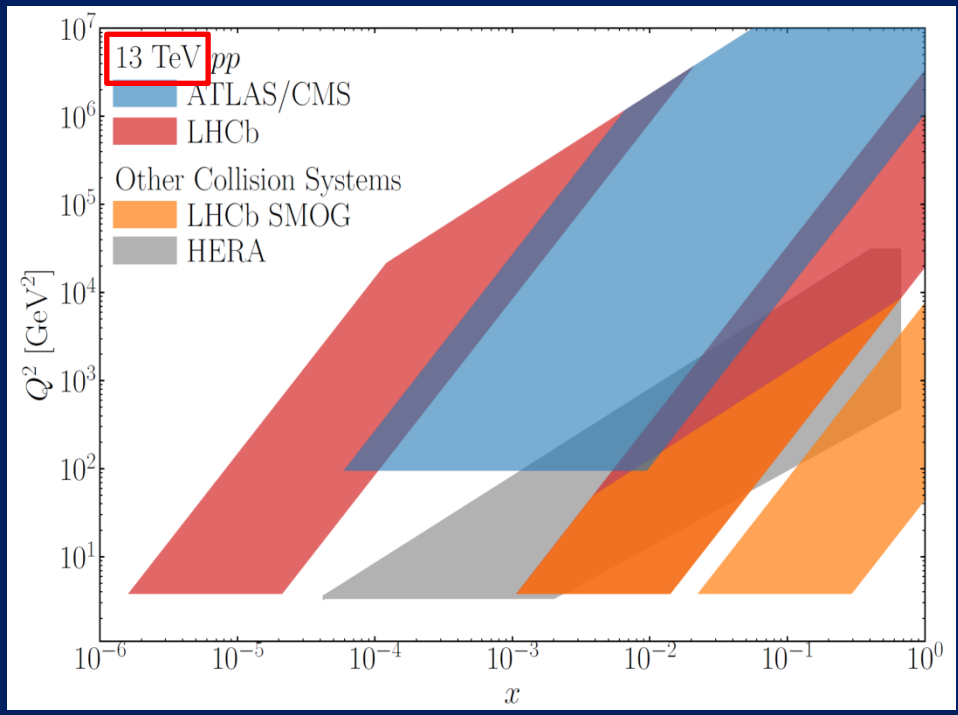
Backup

Pseudorapidity coverage at LHC



x-Q^2 coverage



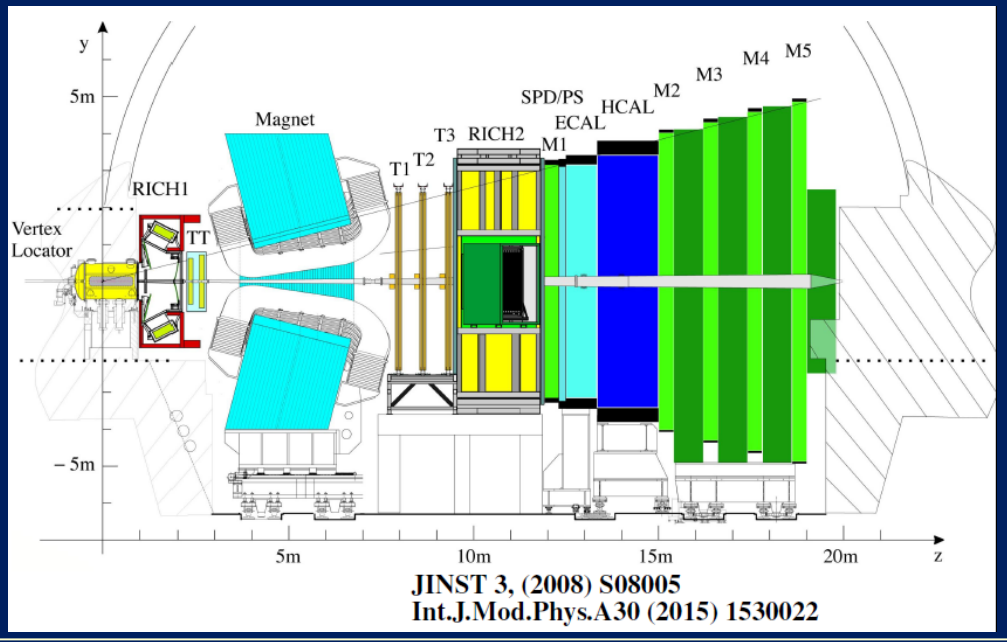


LHCb: Opportunities for hadronization measurements in p+p

LHCb is the experiment devoted to heavy flavor at the LHC

Detector design:

- Forward geometry to optimize acceptance for $b\bar{b}$ pairs: $2 < \eta < 5$
- Tracking: Momentum resolution <1% for $p < 200$ GeV/c
- Particle ID: Excellent capabilities to select exclusive decays

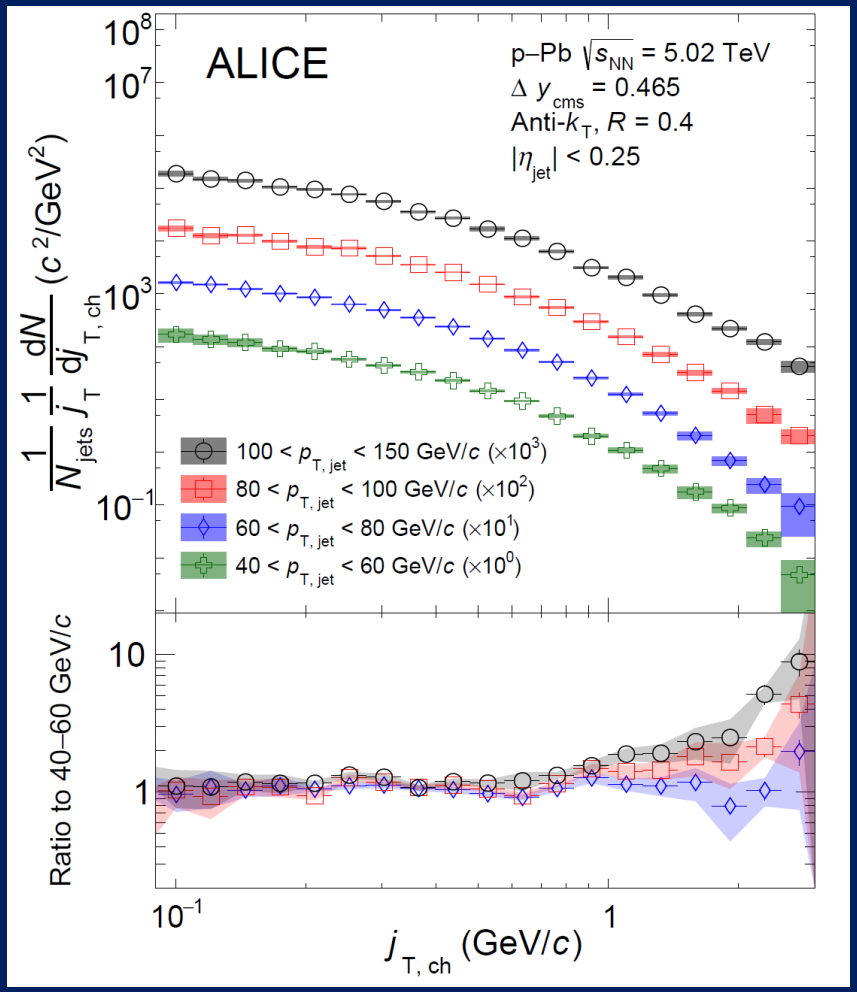


Some features specifically attractive for hadronization:

- Full jet reconstruction with tracking, ECAL, HCAL
  - Heavy flavor tagging of jets
- Charged hadron PID from $2 < p < 100$ GeV

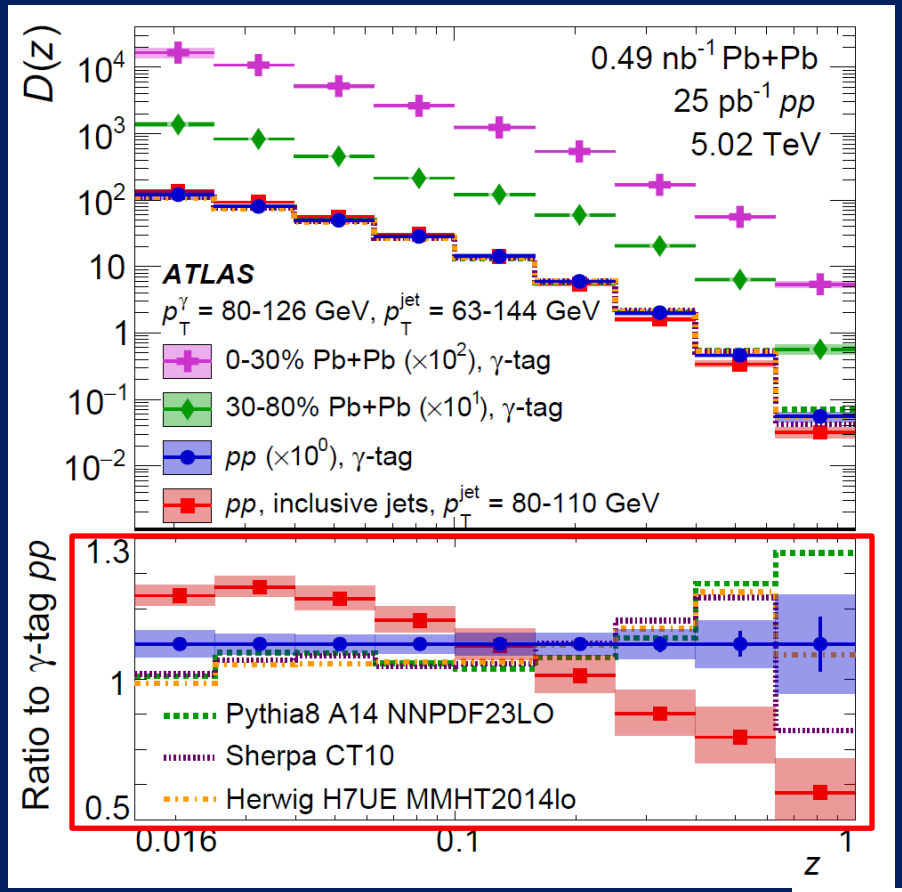
Can study identified particle distributions within jets!

Jet fragmentation in p+Pb



arXiv:2011.05904

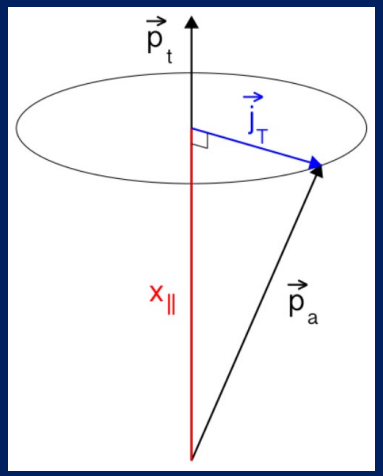
Hadrons in γ-tagged and inclusive jets, pp and PbPb



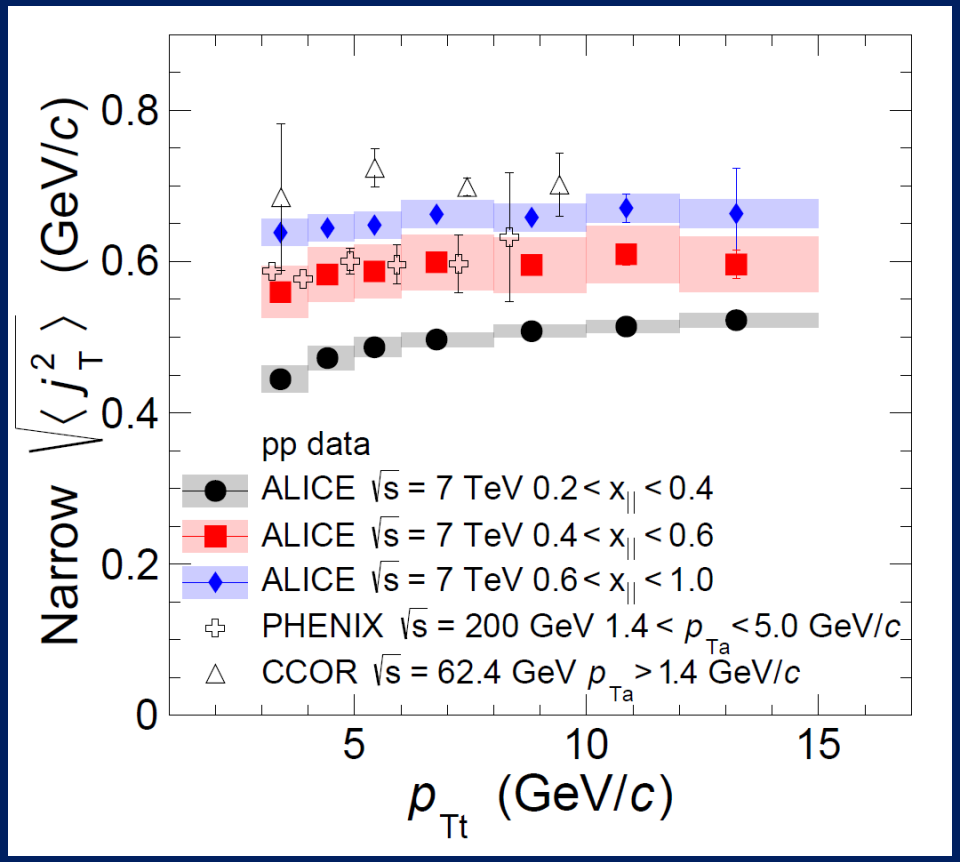
- Gluon-dominated inclusive (midrapidity) jets in pp show significantly different longitudinal momentum fraction profile than quark-enhanced γ-tagged jets

PRL 123, 042001 (2019)
arXiv:1902.10007

Jet fragmentation transverse momentum measurements from dihadron correlations



- No explicit jet reconstruction.
- p_t = momentum of the "trigger" reference hadron
- p_a = momentum of the "associated" hadron



JHEP 03, 169 (2019)
arXiv:1811.09742