Hadronization Studies in Z-tagged Jets at LHCb

Kara Mattioli
University of Michigan

On behalf of the LHCb Collaboration

9th Workshop of the APS Topical Group on Hadronic Physics
April 14, 2021

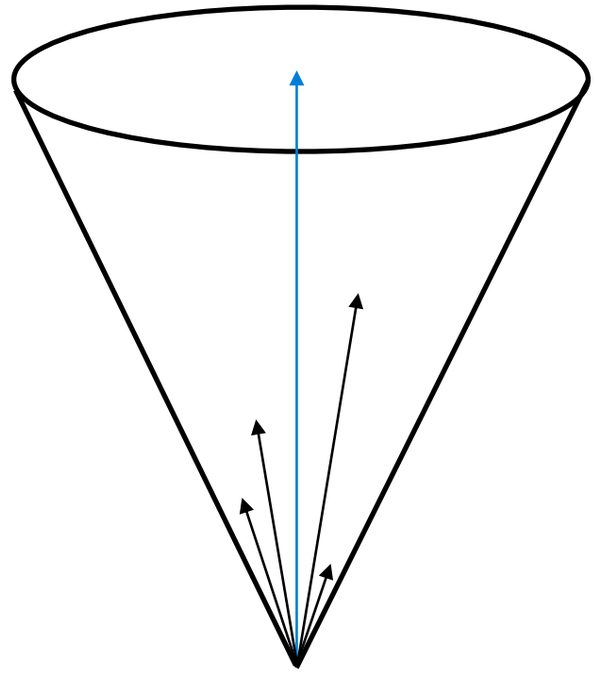
Jets as systems for studying hadronization

- Hadronization remains poorly understood despite being a fundamental component of QCD
- Jets contain the final state particles produced during the high-energy hadronization process - **measuring hadron distributions in jets can help us learn about hadronization!**

Jets can probe:

- Hadronization dynamics
- Flavor dependence of hadronization
  - u/d/s
  - b/c
- Color neutralization mechanisms

Final states: produced hadrons



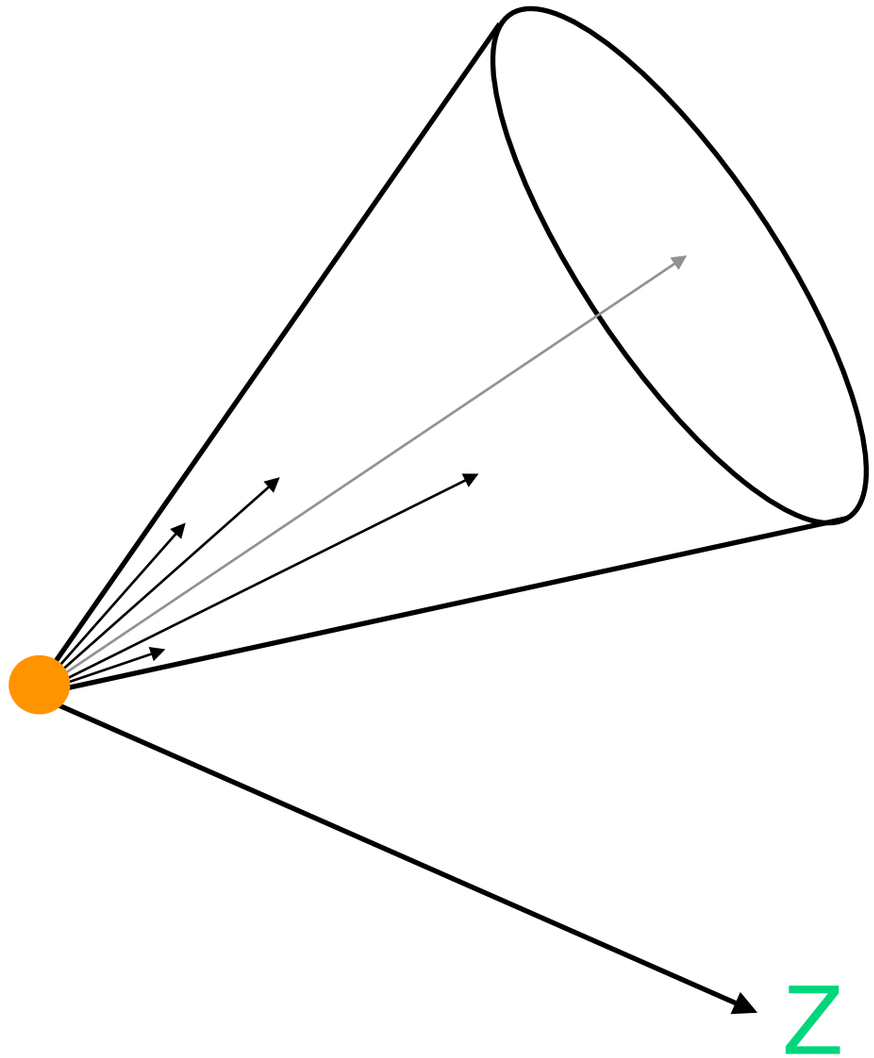
Initial state: fragmenting parton

This talk: **Forward Z-tagged jets** as systems for studying **light-quark** hadronization

I) Light quark jet tagging at LHCb with Z-tagged jets

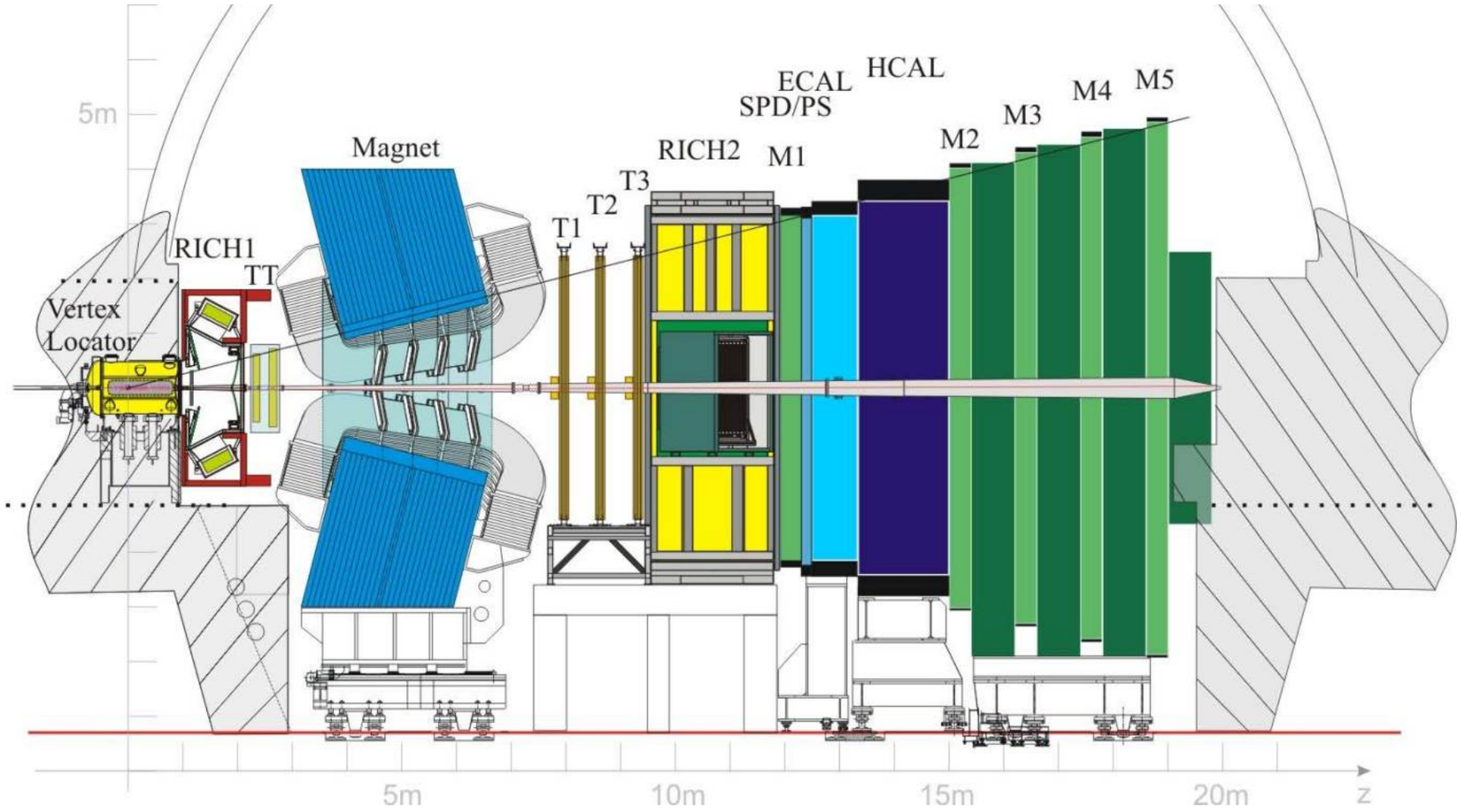
II) LHCb results of charged hadron distributions in Z-tagged jets

III) Comparison to ATLAS inclusive jet results, which are gluon-jet dominated



The Large Hadron Collider beauty (LHCb) Detector

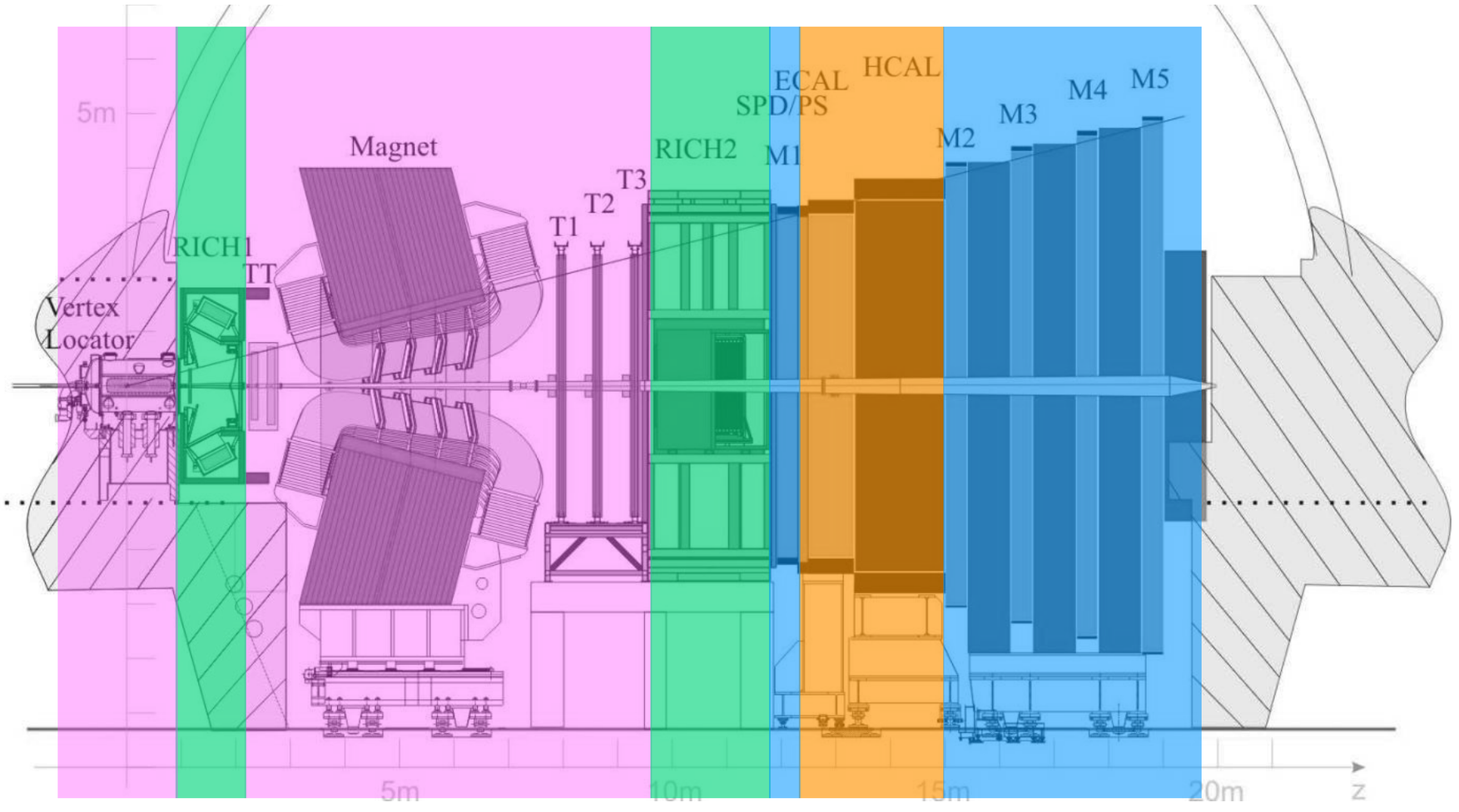
Forward spectrometer designed to study the production and decay of heavy flavor hadrons



Int. J. Mod. Phys. A **30**, 1530022 (2015)

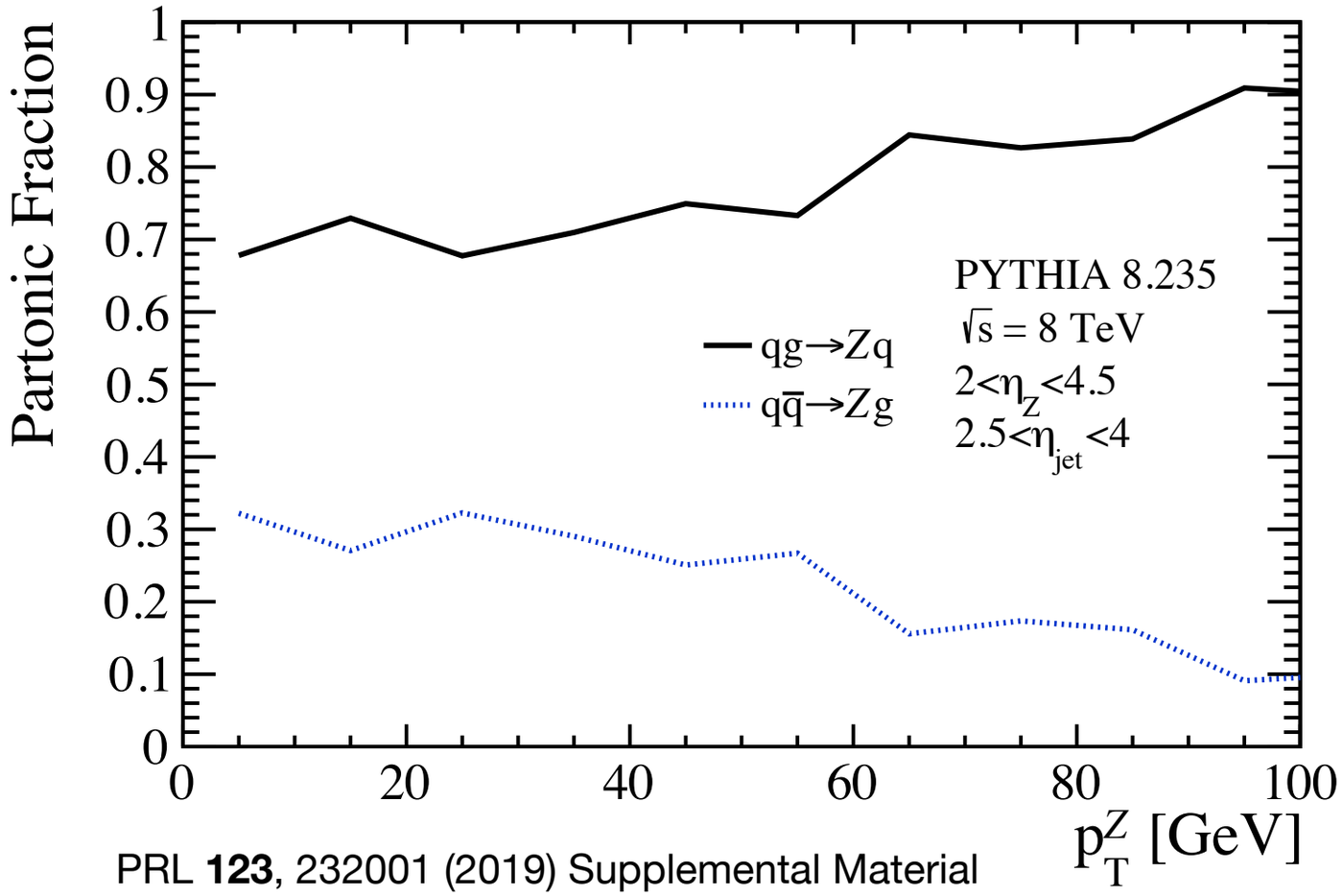
The Large Hadron Collider beauty (LHCb) Detector

Full **hadronic and electromagnetic calorimetry**, **tracking**, **particle identification**, and **muon ID** in $2 < \eta < 5$



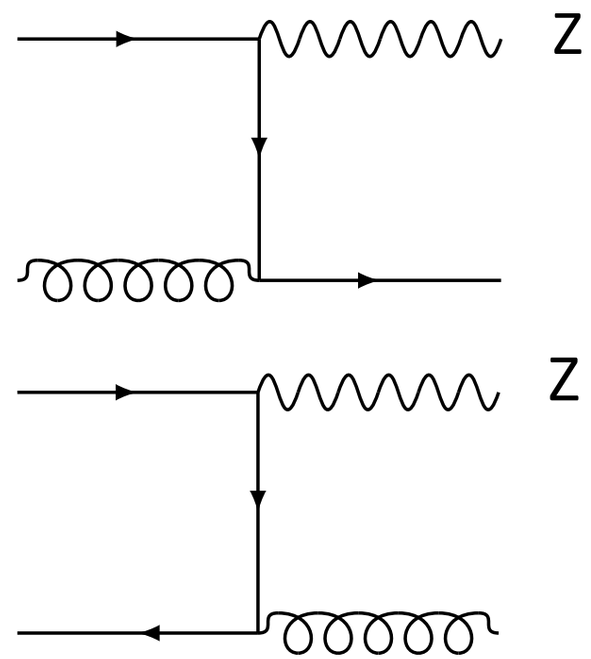
Int. J. Mod. Phys. A **30**, 1530022 (2015)

Light-quark-jet tagging with Z bosons



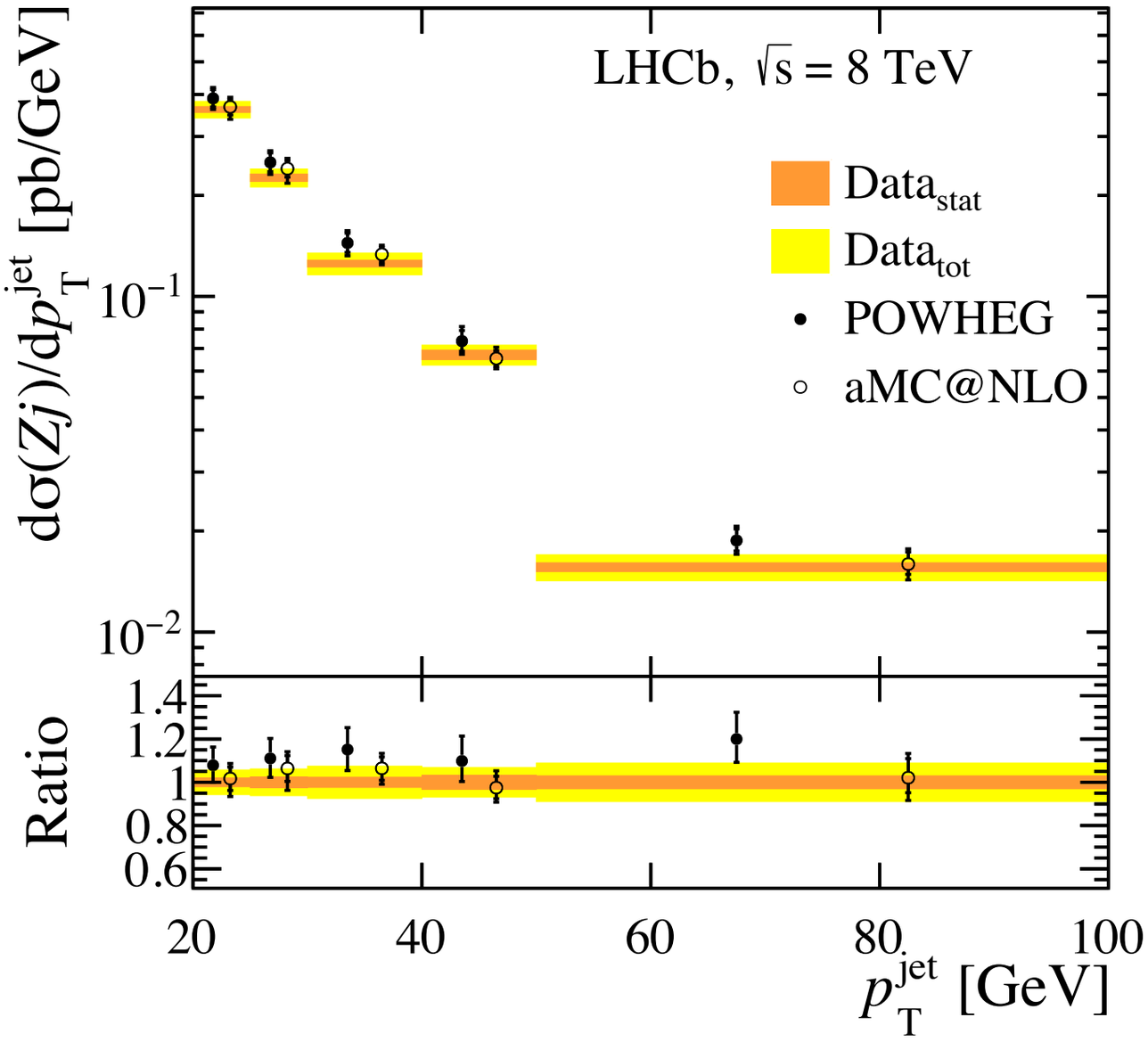
PRL **123**, 232001 (2019) Supplemental Material

LO Z+jet processes:



- Quark-gluon LO process dominates at LHC energies, selecting quark-initiated Z-tagged jets
- Most forward Z-tagged jets are quark-initiated, with the majority being light-quark-initiated due to the large-x quark needed for forward production

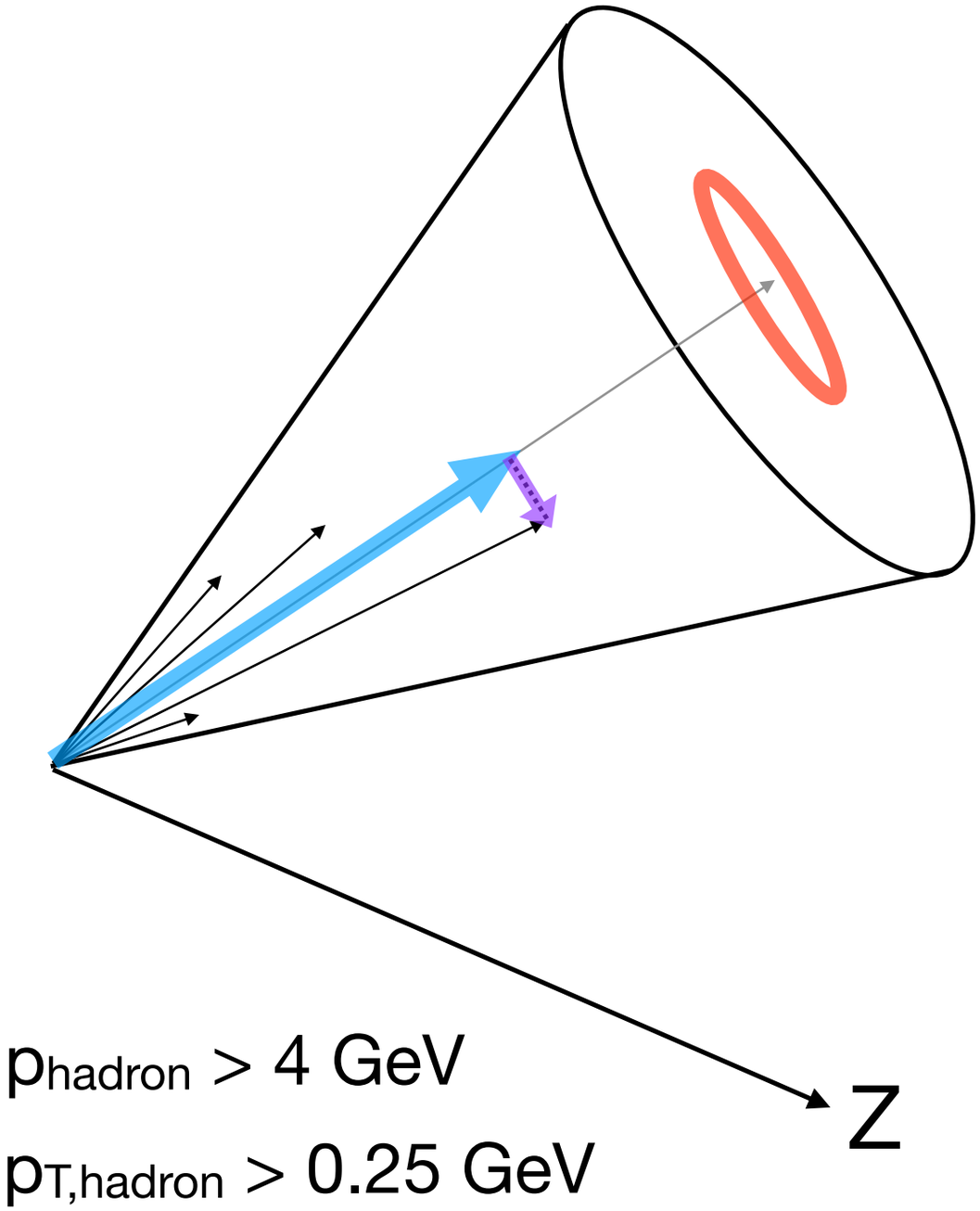
Z-tagged Jets at LHCb



JHEP **05**, 131 (2016)

- LHCb has measured the Z+jet cross section at $\sqrt{s}$ = 7 and 8 TeV
- Jet reconstruction is performed with a particle flow algorithm and anti-k_T clustering with a distance parameter R = 0.5
- Z bosons are reconstructed in the Z->μμ decay channel
- For charged hadron measurements, an additional cut requiring $\Delta\phi(Z, jet) > 7\pi/8$ is applied to enhance 2->2 partonic scattering events

Charged Hadron Observables



$p_{hadron} > 4$ GeV

$p_{T,hadron} > 0.25$ GeV

Longitudinal momentum fraction z

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

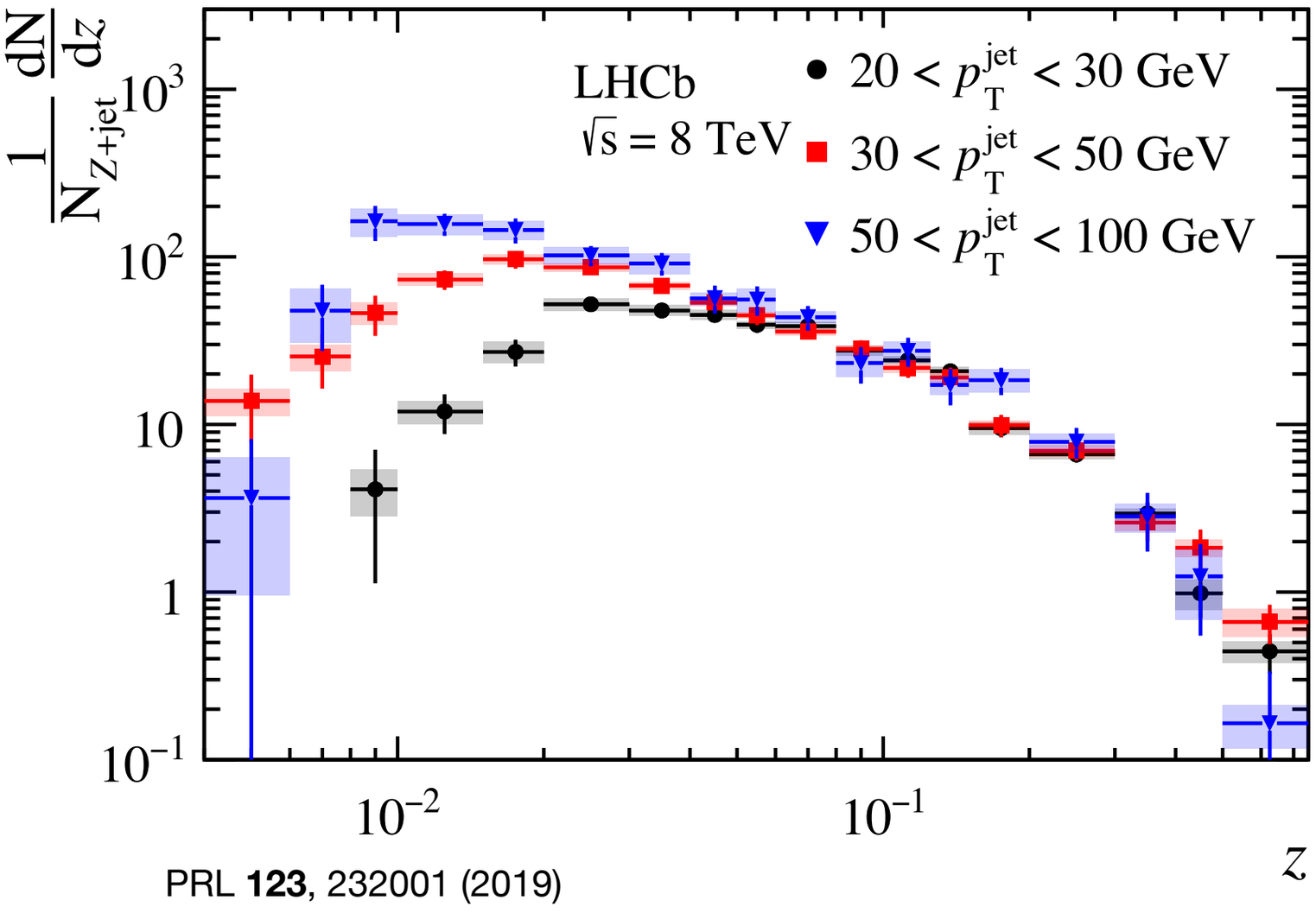
Transverse momentum with respect to the jet axis j_T

$$j_T = \frac{|\mathbf{p_{jet}} \times \mathbf{p_{hadron}}|}{|\mathbf{p_{jet}}|}$$

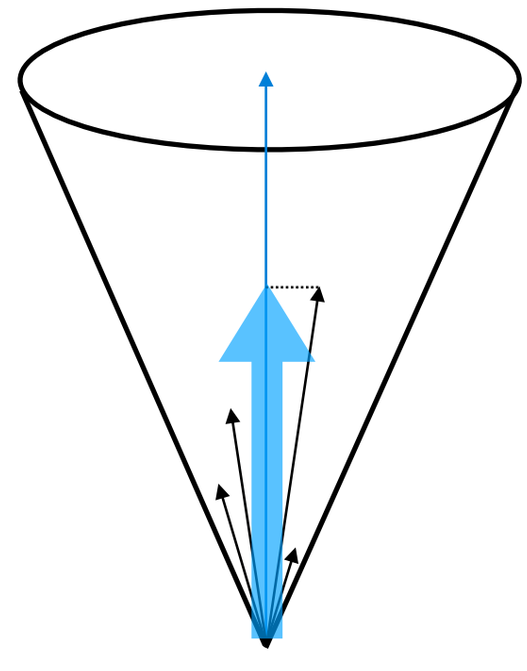
Radial distribution r

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

Results: Longitudinal Momentum Fraction z



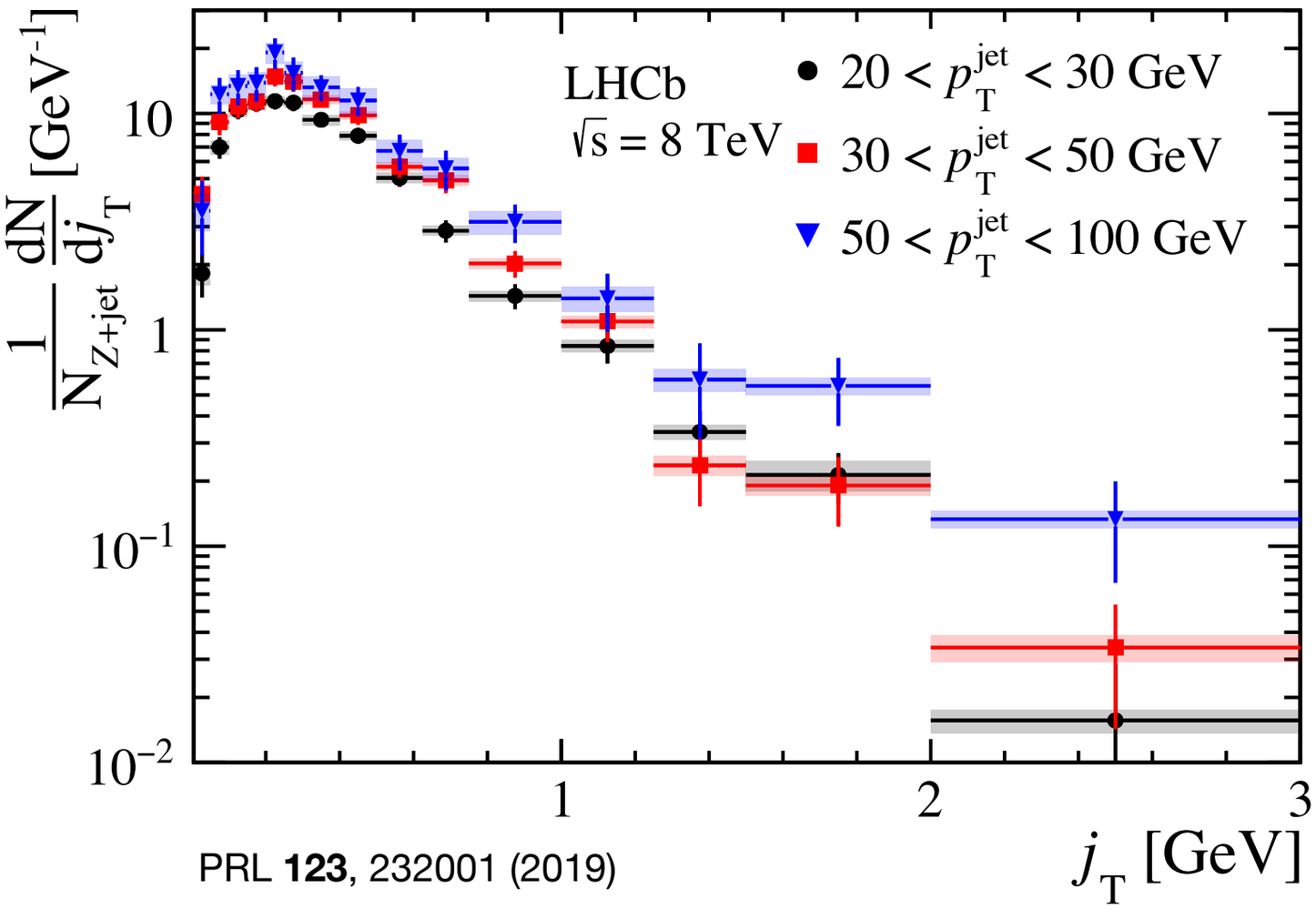
PRL **123**, 232001 (2019)



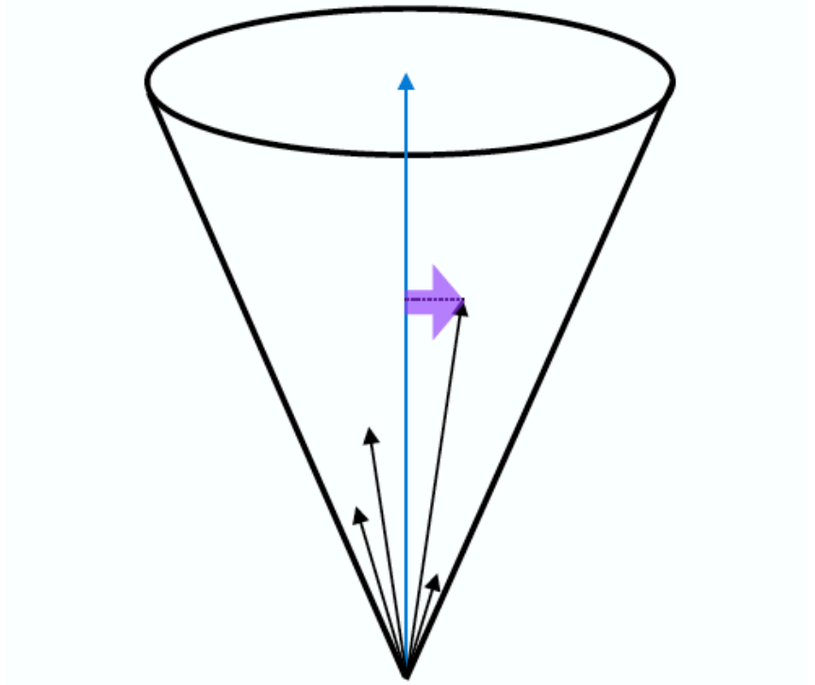
$$z = \frac{\mathbf{p_{jet}} \cdot \mathbf{p_{hadron}}}{|\mathbf{p_{jet}}|^2}$$

- Distributions are approximately constant as a function of jet p_T at high z
- Higher p_T jets probe lower z values

Results: Transverse Momentum j_T



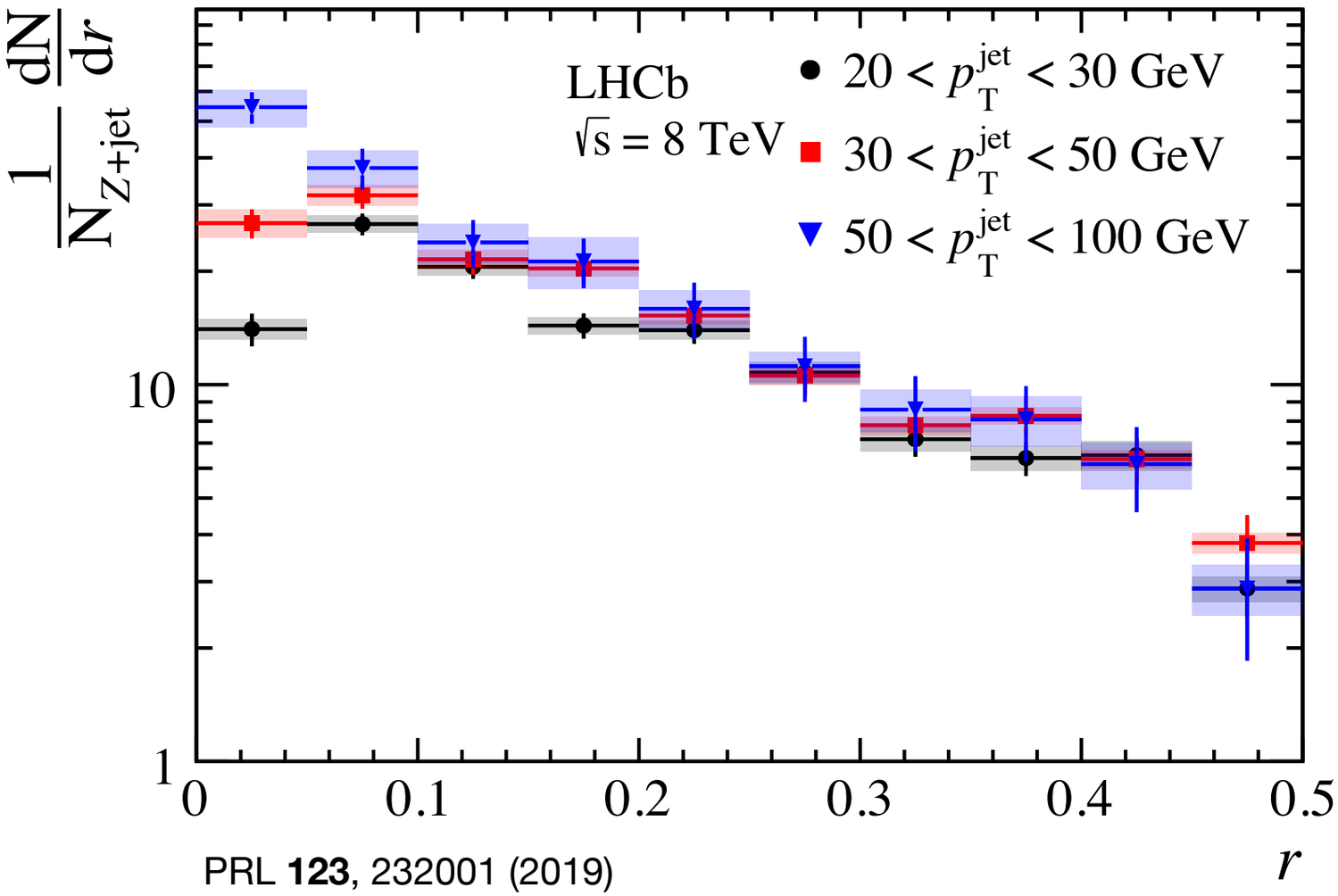
PRL **123**, 232001 (2019)



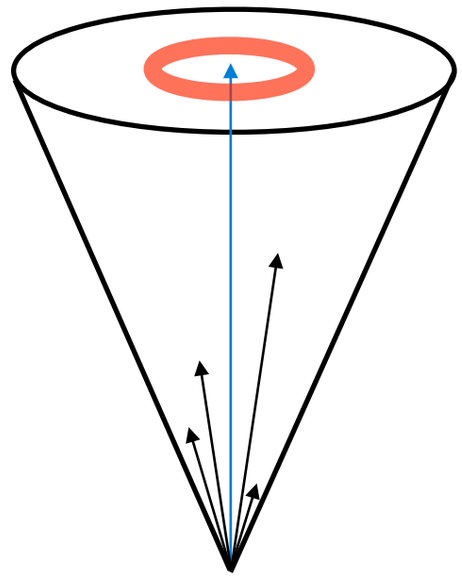
$$j_T = \frac{|\mathbf{p_{jet}} \times \mathbf{p_{hadron}}|}{|\mathbf{p_{jet}}|}$$

- Transition from a nonperturbative shape at small j_T to a perturbative tail at large j_T indicates sensitivity to both small and large transverse momentum scales
- Needed to constrain transverse momentum dependent (TMD) jet fragmentation functions

Results: Radial distribution r



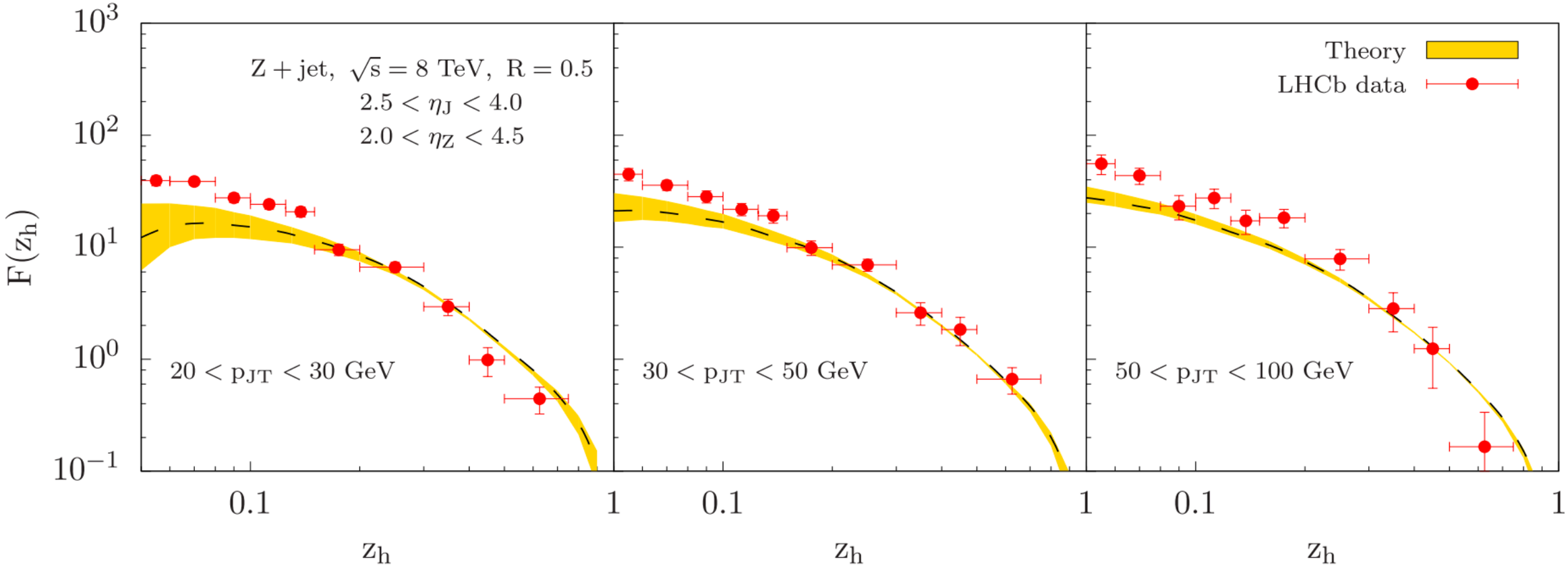
PRL **123**, 232001 (2019)



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

- Strong dependence on jet p_T at very small r, with more hadrons produced close to the jet axis in high-p_T jets
- Reduced jet p_T dependence at larger values of r could indicate that nonperturbative contributions away from the jet axis do not depend strongly on jet p_T

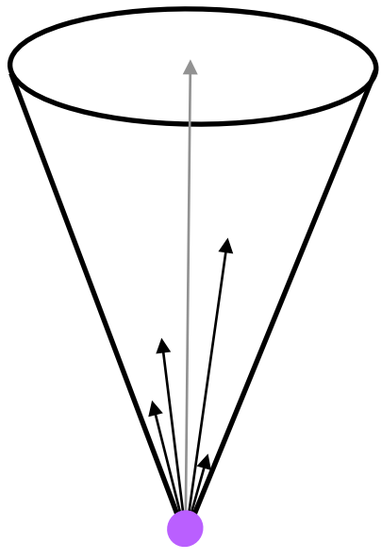
Theoretical comparisons



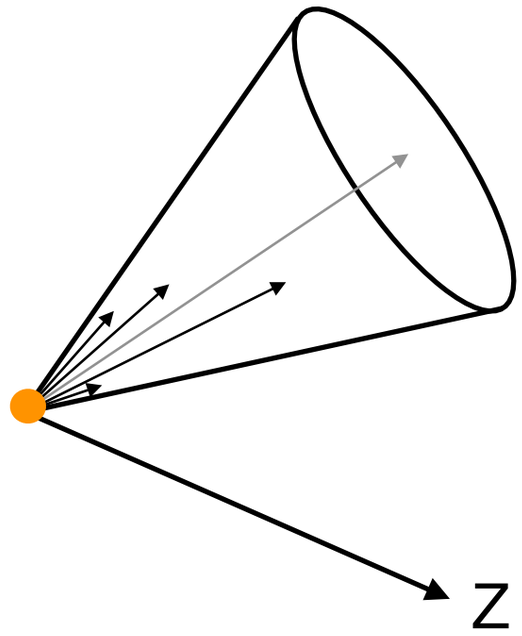
Kang, Lee, Terry, Xing PLB **798**, 134978 (2019)

- Perturbative QCD calculations agree well with measured z distributions for intermediate z values
- 2D j_T vs. z distribution measurements in progress - will allow for jet TMD FF extraction

Comparing **gluon-dominated** and **light-quark-dominated** jets



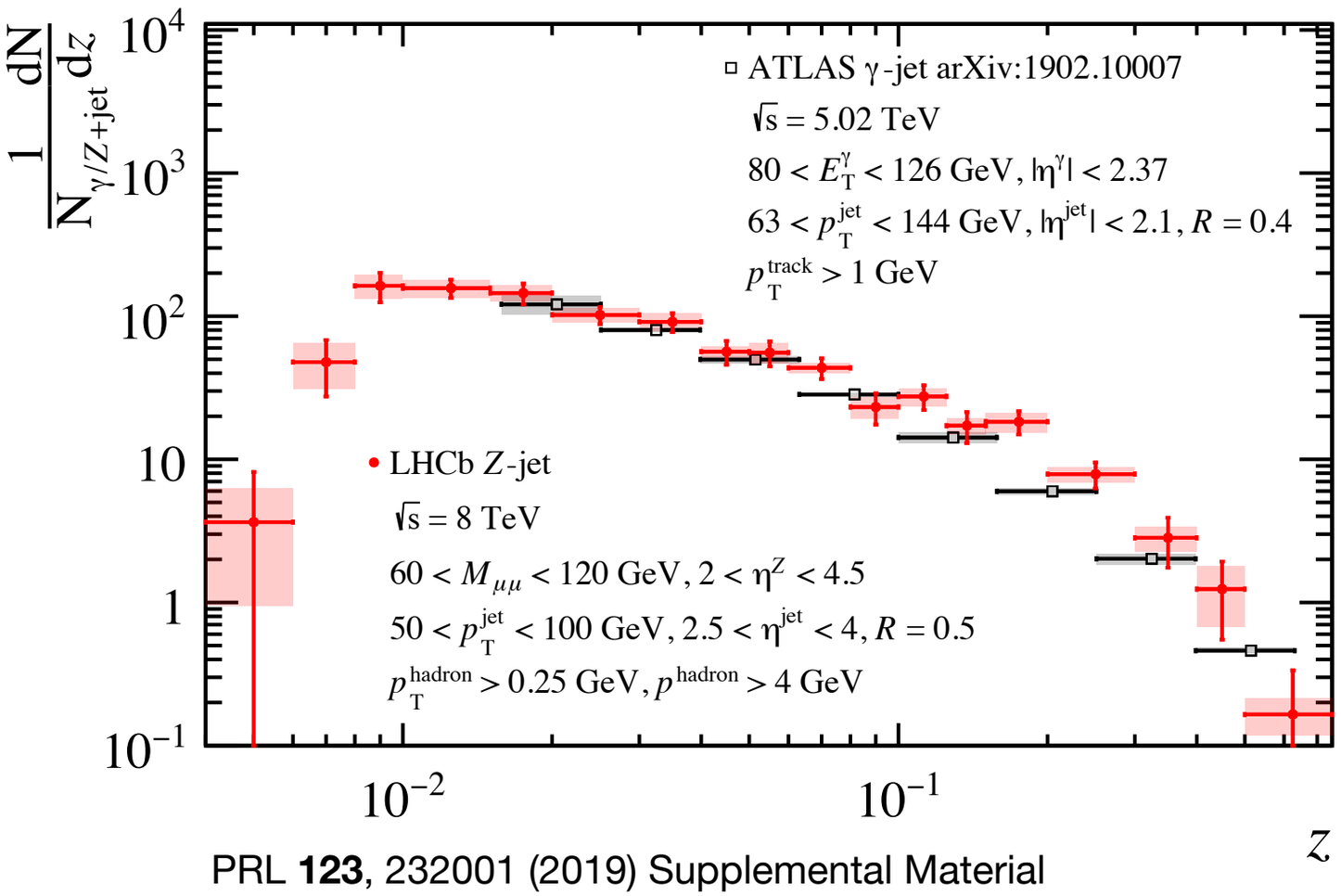
Midrapidity inclusive jets: gluon-dominated



Forward Z-tagged jets: light-quark-dominated

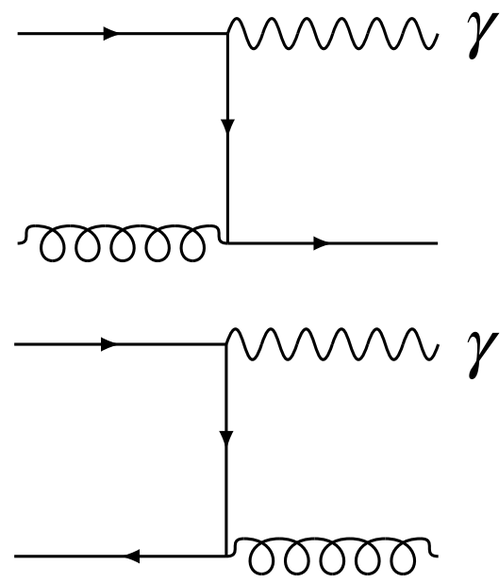
Comparisons between midrapidity inclusive jets and forward Z-tagged jets can probe differences between light-quark and gluon hadronization

Controlling for η dependence: z



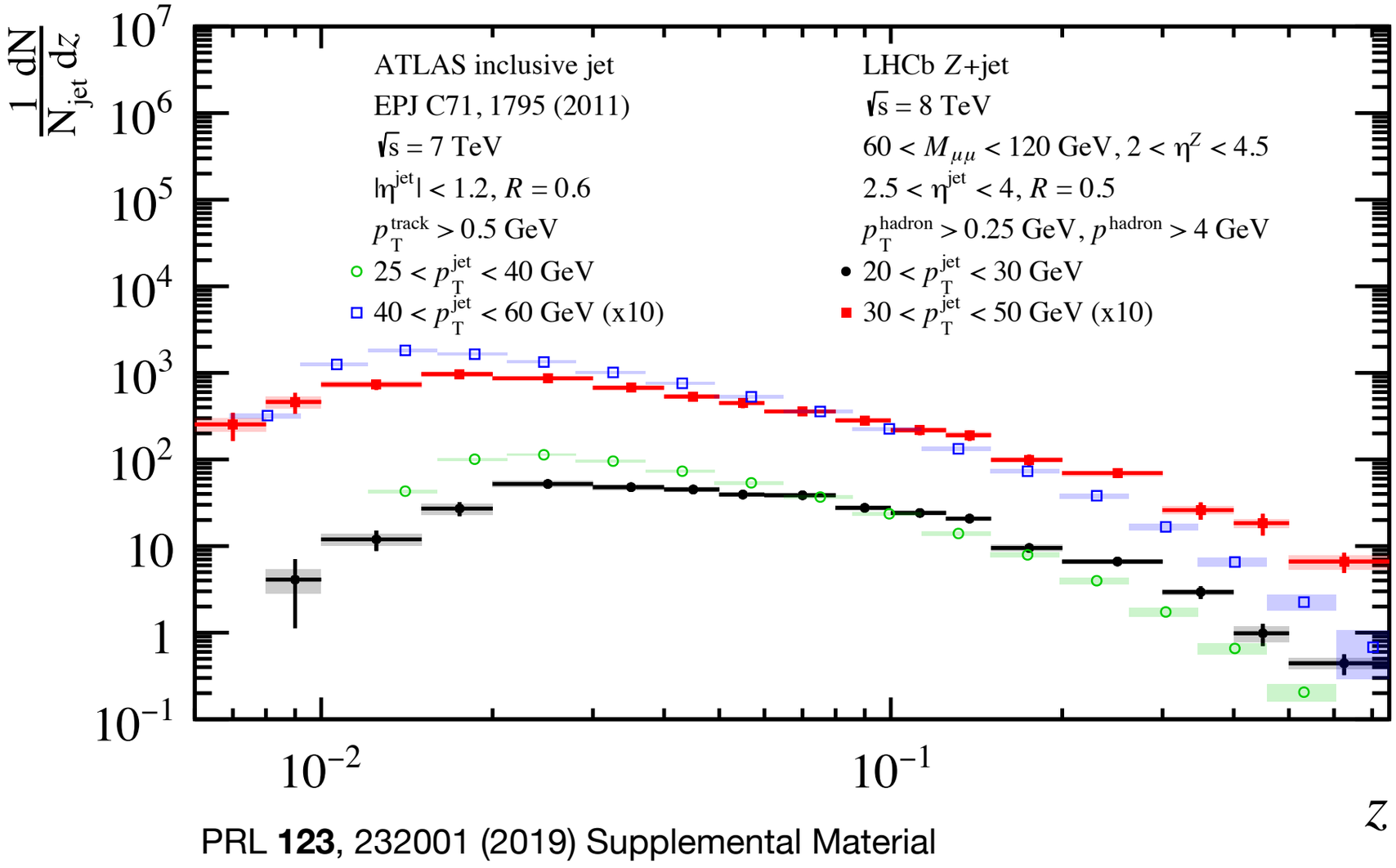
PRL **123**, 232001 (2019) Supplemental Material

γ-tagged jets have same LO diagrams as Z-tagged jets:

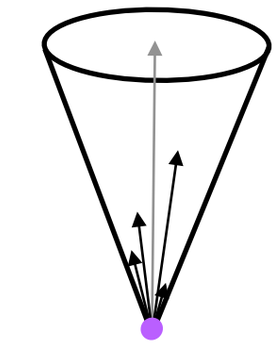


- Similar z distributions between forward Z-tagged jets and midrapidity **γ**-tagged jets
- Differences between inclusive midrapidity jets and forward Z-tagged jets should be due to quark vs. gluon hadronization

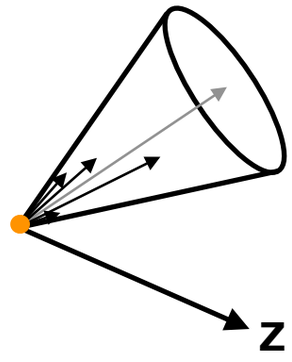
Comparison to gluon-dominated jets: z



PRL **123**, 232001 (2019) Supplemental Material



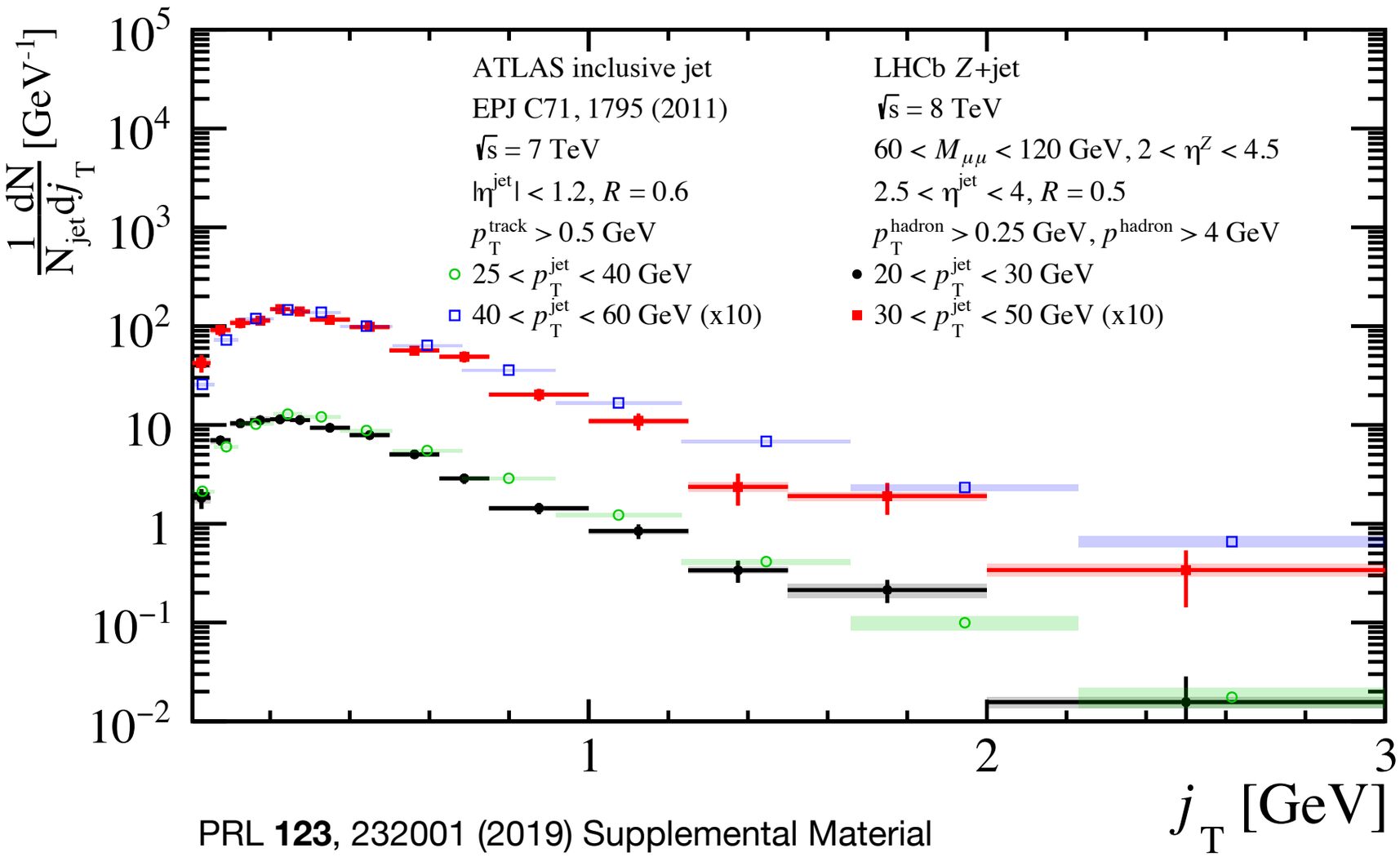
ATLAS inclusive jets: gluon-dominated



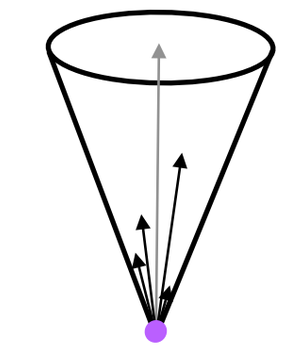
LHCb Z-tagged jets: light-quark dominated

- Gluon-initiated jets have a more steeply falling z distribution than light-quark-initiated jets
- Light-quark-initiated jets have slightly more hadrons produced at higher z values

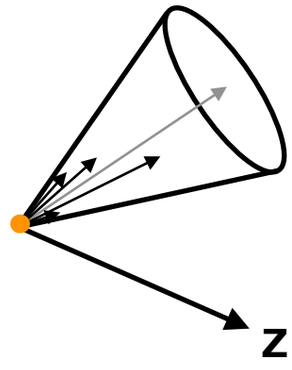
Comparison to gluon-dominated jets: j_T



PRL **123**, 232001 (2019) Supplemental Material



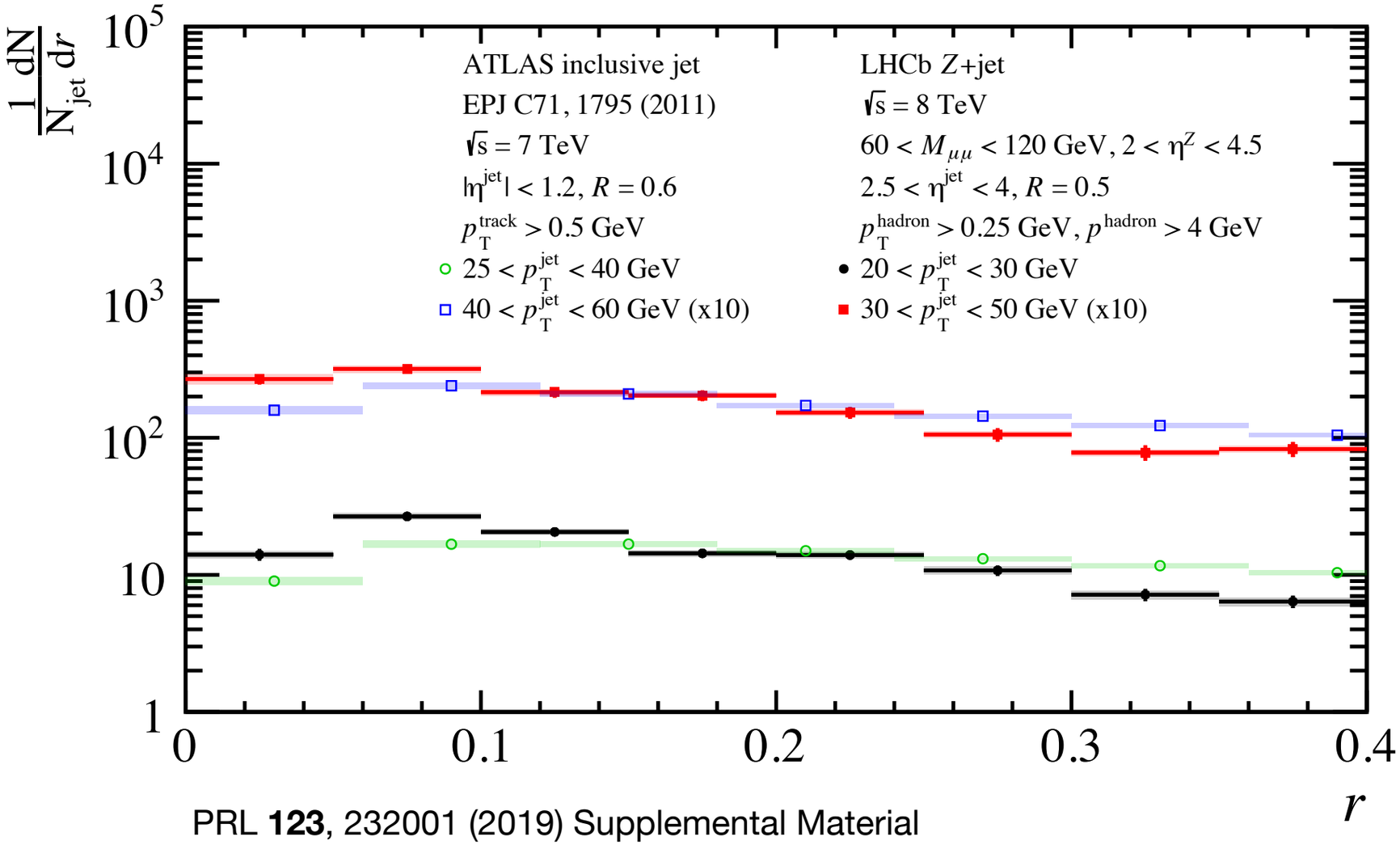
ATLAS inclusive jets: gluon-dominated



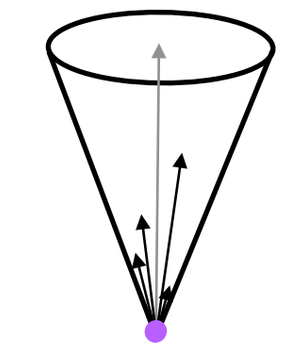
LHCb Z-tagged jets: light-quark dominated

- Light-quark-initiated jets and gluon-initiated jets have similar j_T distributions

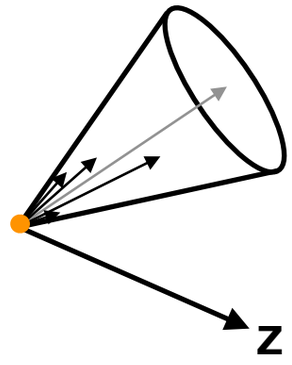
Comparison to gluon-dominated jets: r



PRL **123**, 232001 (2019) Supplemental Material



ATLAS inclusive jets: gluon-dominated

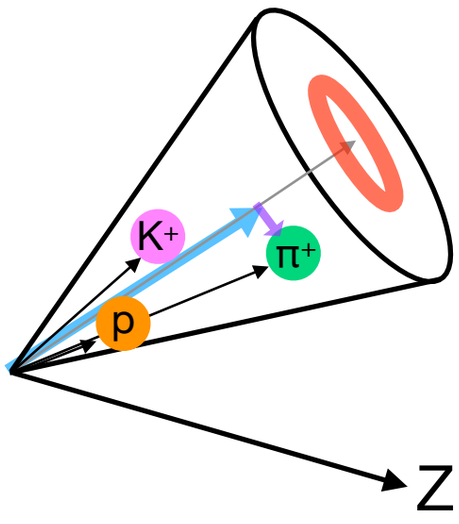


LHCb Z-tagged jets: light-quark dominated

- Light-quark-initiated jets are more collimated than gluon-initiated jets

More to come from LHCb's hadronization program!

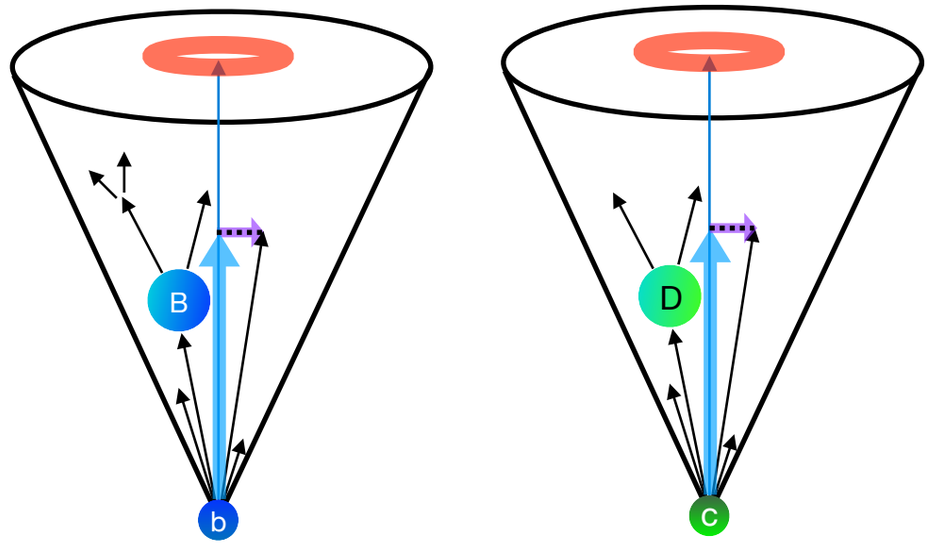
- **Identified** charged hadron distributions in Z-tagged jets, utilizing LHCb's excellent particle ID capabilities



coming soon!

- Charged hadron distributions in **beauty and charm-tagged** jets utilizing LHCb's heavy flavor jet tagging

coming soon!



- **Quarkonia in jets** - J/ψ polarization, Υ, ϕ
- **Strange hadron correlations in jets,** to test ideas about string breaking models of hadronization

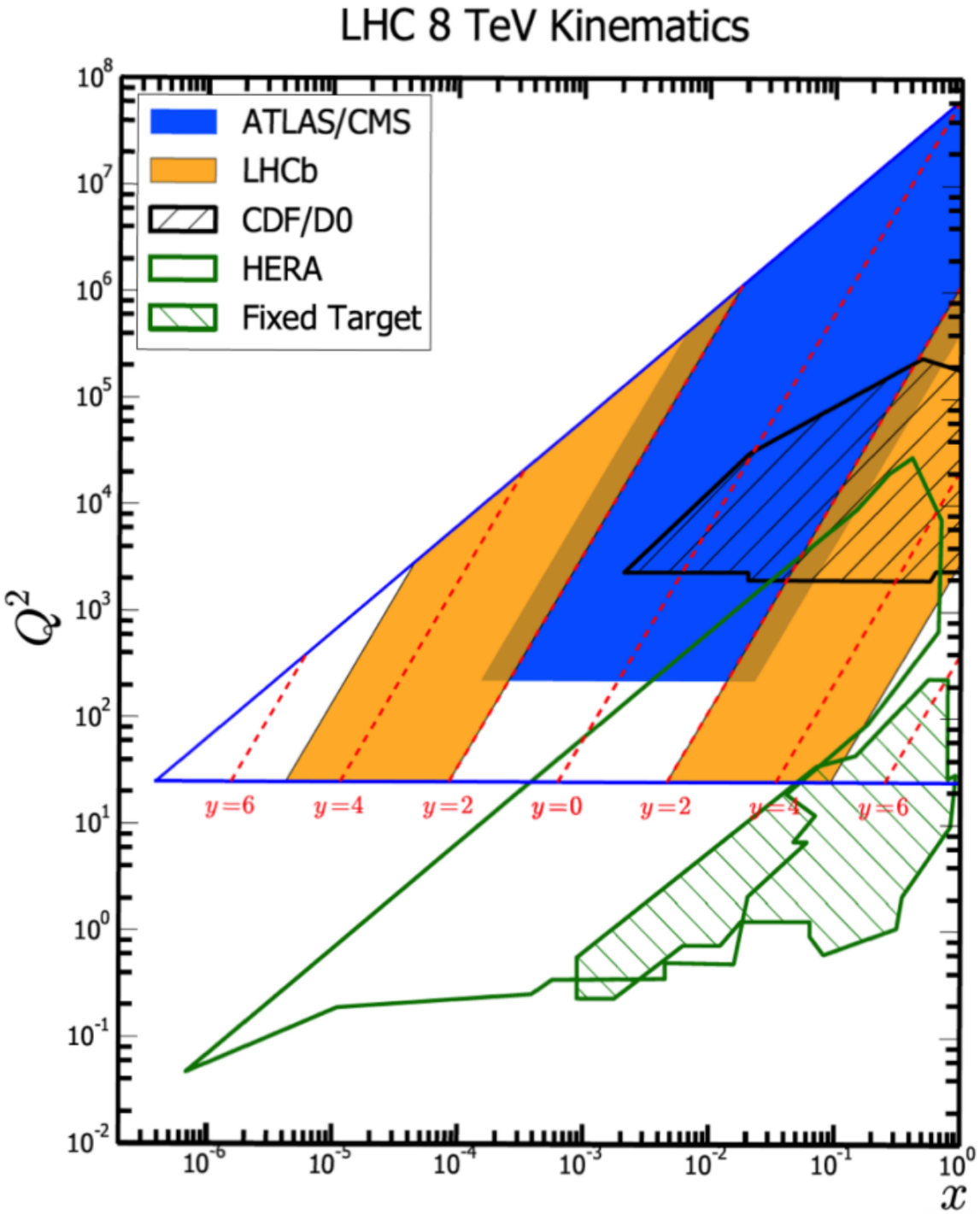
Summary

- Jets are ideal systems in which to study high-energy hadronization
- LHCb has measured the longitudinal momentum fraction z, transverse momentum with respect to the jet axis j_T, and radial distribution r of charged hadrons in Z-tagged jets
- Comparisons between light-quark-dominated forward Z-tagged jets and gluon-dominated midrapidity inclusive jets show that light-quark-initiated jets are more collimated and have more charged hadrons at high z values than gluon-initiated jets
- Many more hadronization measurements are still to come from LHCb, including identified charged hadron distributions in Z-tagged jets and charged hadron distributions in b- and c-tagged jets

Thanks for your attention!

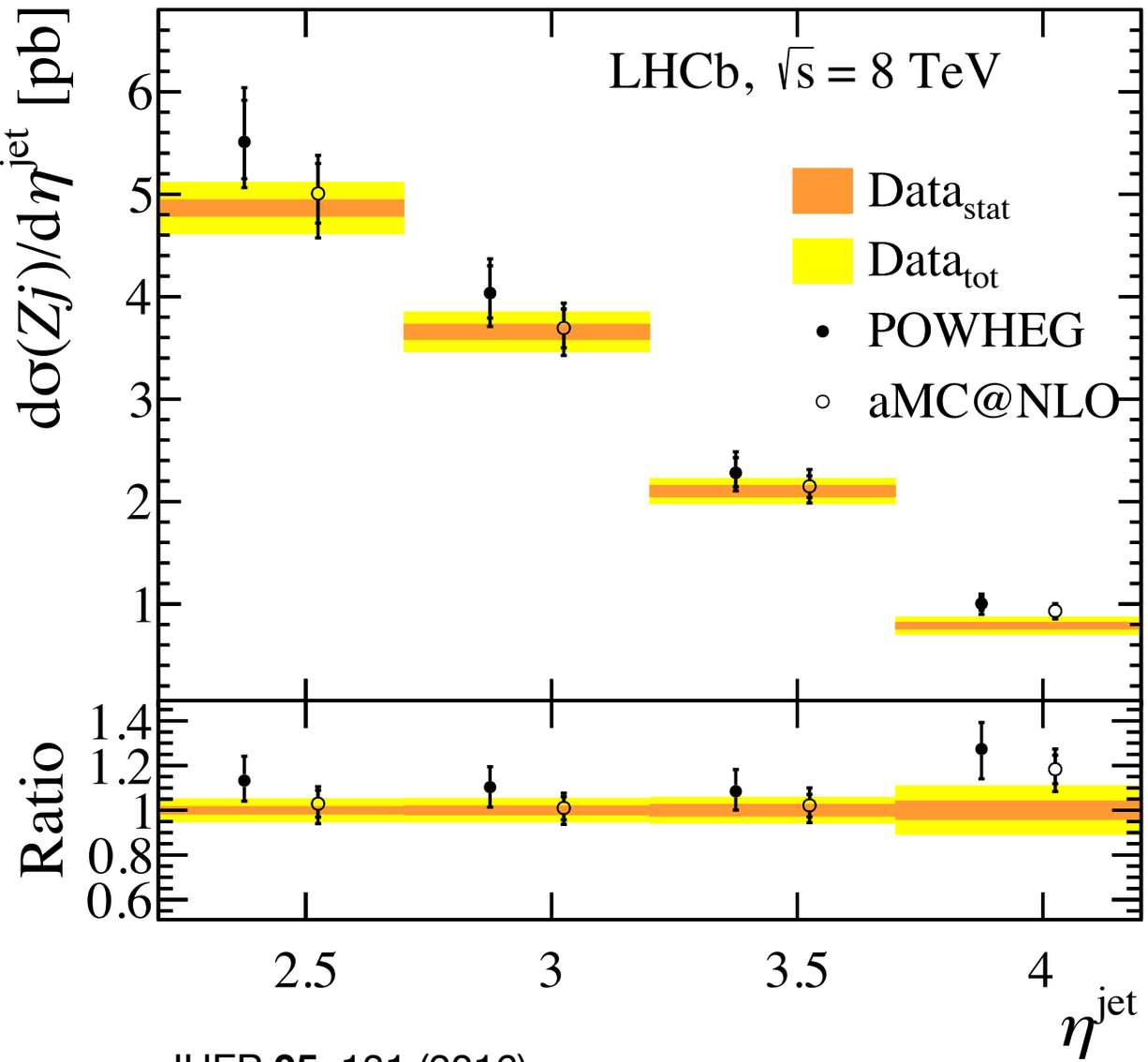
backup

LHCb phase space at $\sqrt{s}$ =8 TeV



- Forward kinematics of LHCb provide access to low- and high-x PDFs
- Complementary to phase space of midrapidity LHC experiments

η dependence of Z-tagged jet cross section



JHEP **05**, 131 (2016)