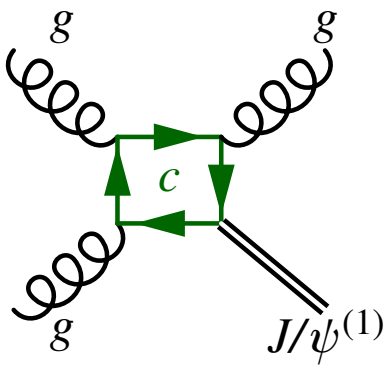
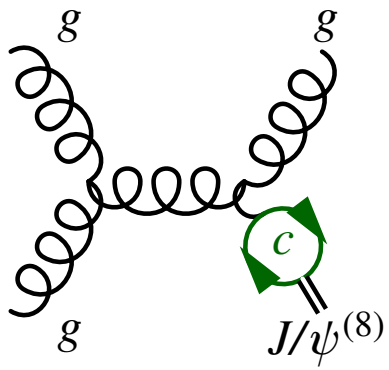
Jet fragmentation and QCD measurements at LHCb

colour singlet
low p_{T}
longitudinal pol.





colour octet
high p_{T}
transverse pol.

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University of Birmingham
ICHEP 2022

July 7, 2022

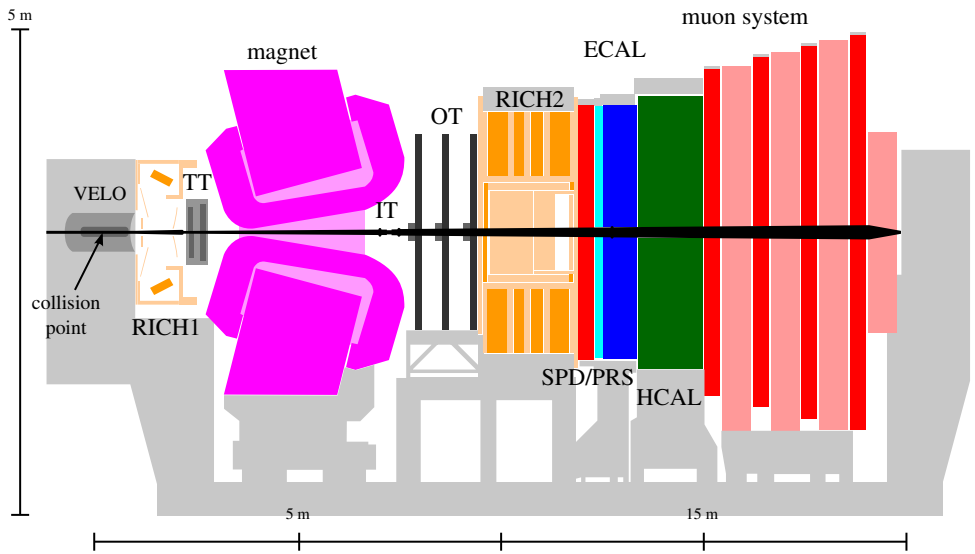
Introduction

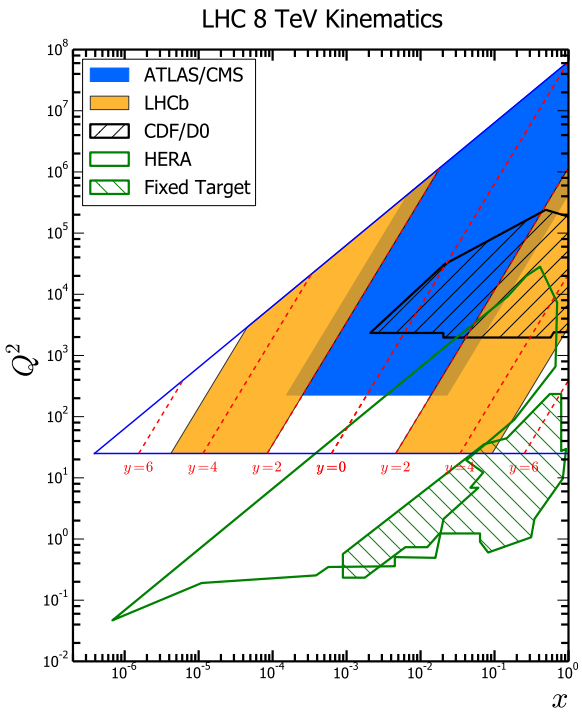
Today, discuss three analyses:

- Charged hadron production in Z-tagged jets
- Identified charged hadron production in Z-tagged jets (π,K,p)
- Study of J/ψ production in jets

Why LHCb?:

- Very good PID: Hadrons (RICH), di-muon masses (MUON)
- Probe unique phase space due to forward region
- Trigger: probe low momentum particles

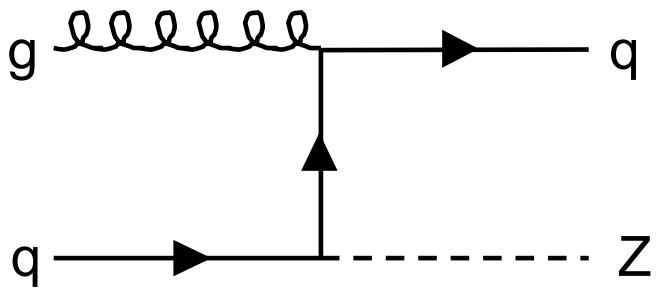


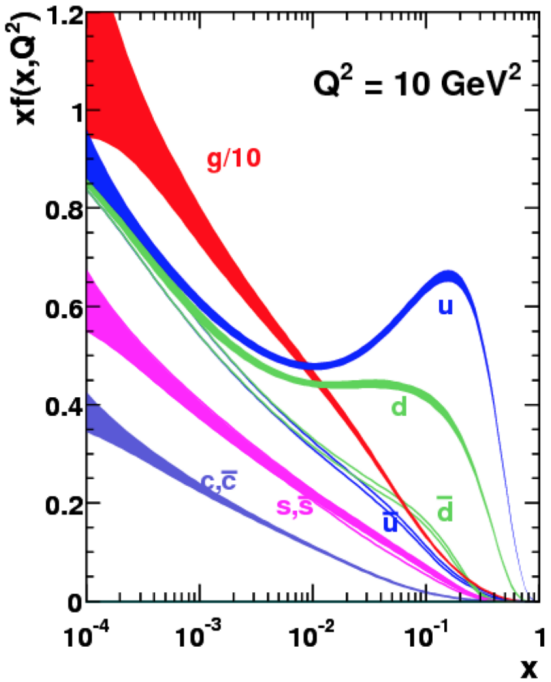


Charged hadron production in Z-tagged jets

Charged hadron production in Z-tagged jets (i)

- Fragmentation: probability for a parton $\rightarrow$ hadron.
- Jet fragmentation: jets correlated to scattered parton.
- First measurement of charged hadrons produced in jets recoiling against Z-boson (Z-tagged jets) in forward region.
- Most LHC inclusive jet measurements dominated by gluon jets.
- Here, predominantly light-quark jets.
- Constrain transverse-momentum-dependent fragmentation functions + hadronisation models.



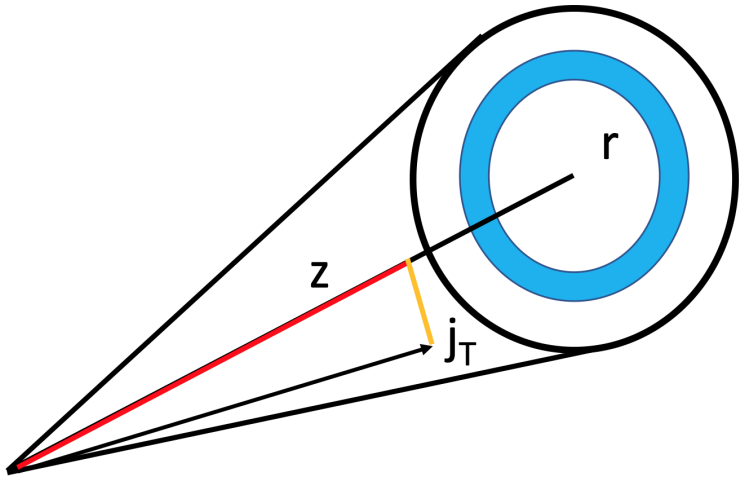


Charged hadron production in Z-tagged jets (ii)

z - longitudinal momentum fraction, j_T - momentum transverse to jet axis, and r - radial distance, all measured wrt jet axis in lab frame.

$$z \equiv \frac{\vec{p}_{jet} \cdot \vec{p}_{hadron}}{|\vec{p}_{jet}|^2}$$

$$j_T \equiv \frac{|\vec{p}_{jet} \times \vec{p}_{hadron}|}{|\vec{p}_{jet}|}$$



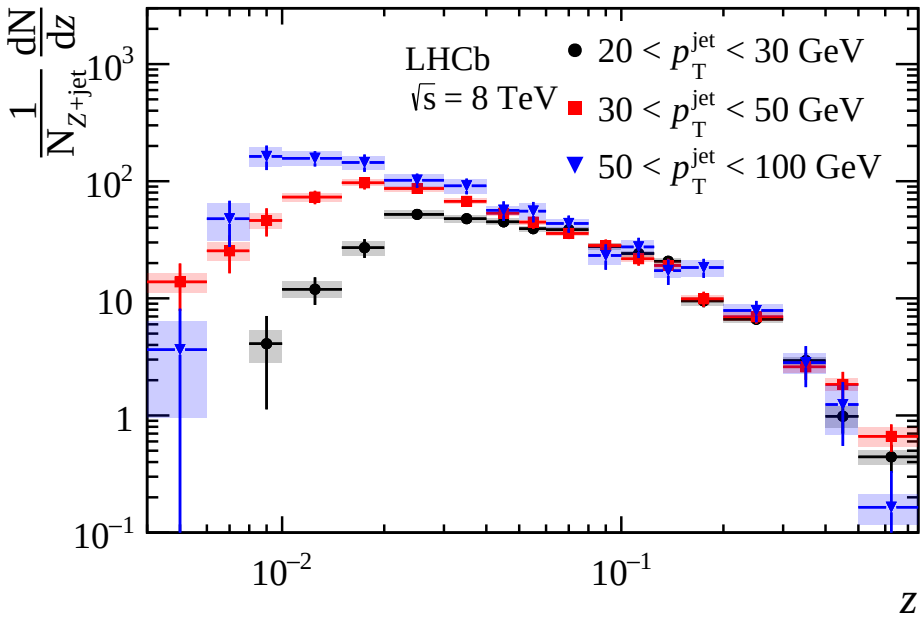
$$r \equiv \sqrt{(\varphi_{jet} - \varphi_{hadron})^2 + (y_{jet} - y_{hadron})^2}$$

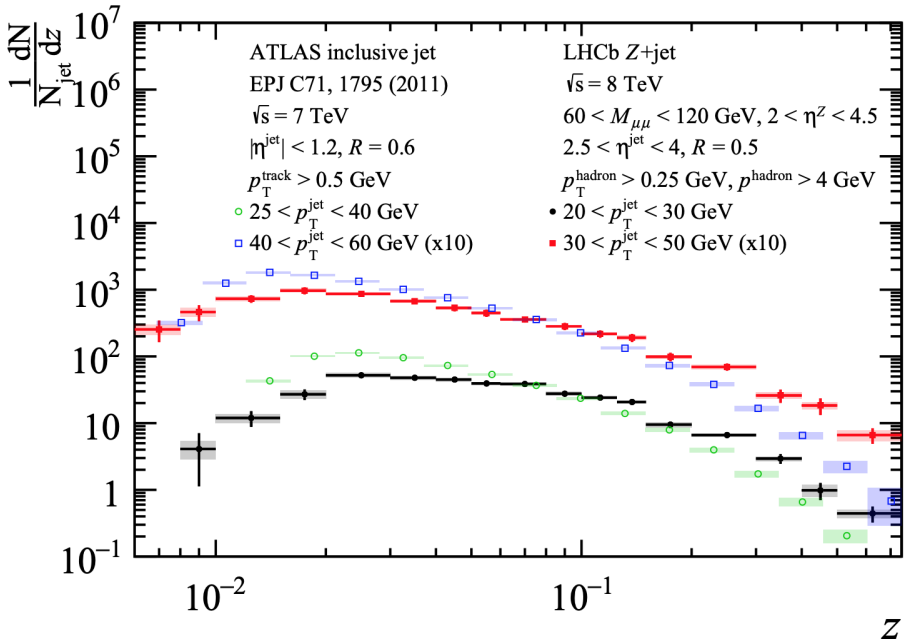
Procedure:

- 2 fb^{-1} of LHCb 2012 data used at $\sqrt{s} = 8$ TeV.
- Decay channel: $Z \to \mu\mu$.
- Main cuts: $p_T(\text{jet}) > 20$ GeV, $2.5 < \eta(\text{jet}) < 4$, $\Delta\varphi_{Z-\text{jet}} \equiv |\varphi_Z - \varphi_{jet}| > 7\pi/8$
- Efficiency corrected + Bayesian unfolded for jet energy resolution.

Charged hadron production in Z-tagged jets (iii)

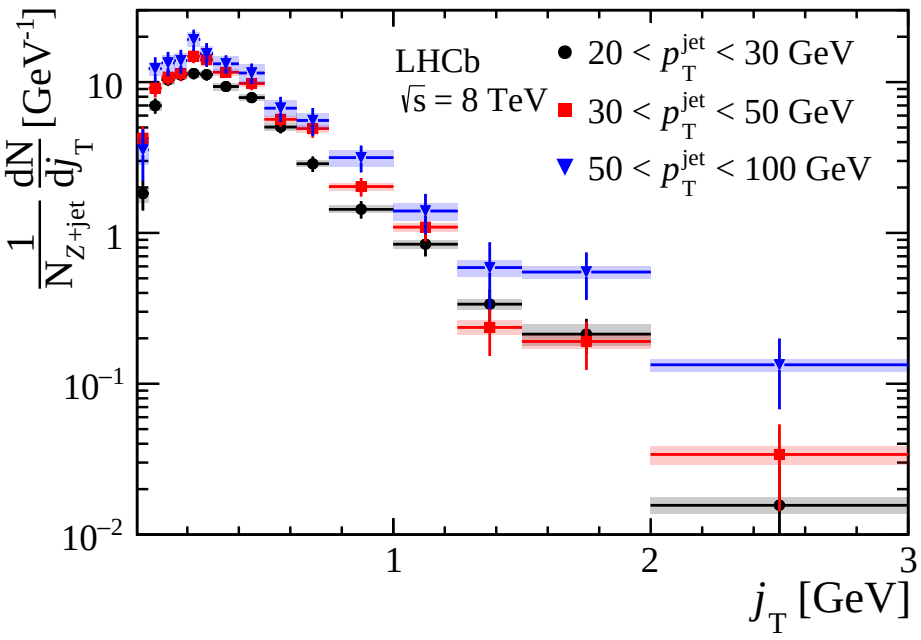
- z $\sim$ constant as function of p_T(jet) at high z.
- Low z differs due to p(hadron) > 4 GeV. Higher p_T(jet) probes smaller z, due to higher energy hadrons. Color coherence effects.
- Comparison with ATLAS plots, does not fall as steeply at high z. Maybe due to light-quark and gluon jets [Phys. Rev. Lett. 123, 232001 (2019)].

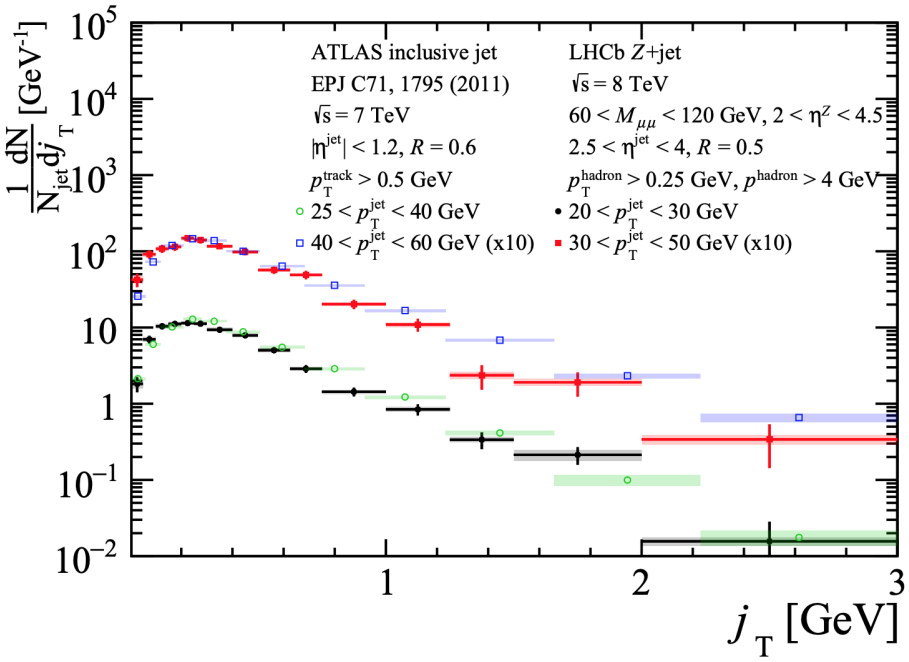




Charged hadron production in Z-tagged jets (iv)

- j_T peaks at small values, then has a perturbative tail.
- Looks similar to ATLAS central pseudorapidity results [Phys. Rev. Lett. 123, 232001 (2019)].

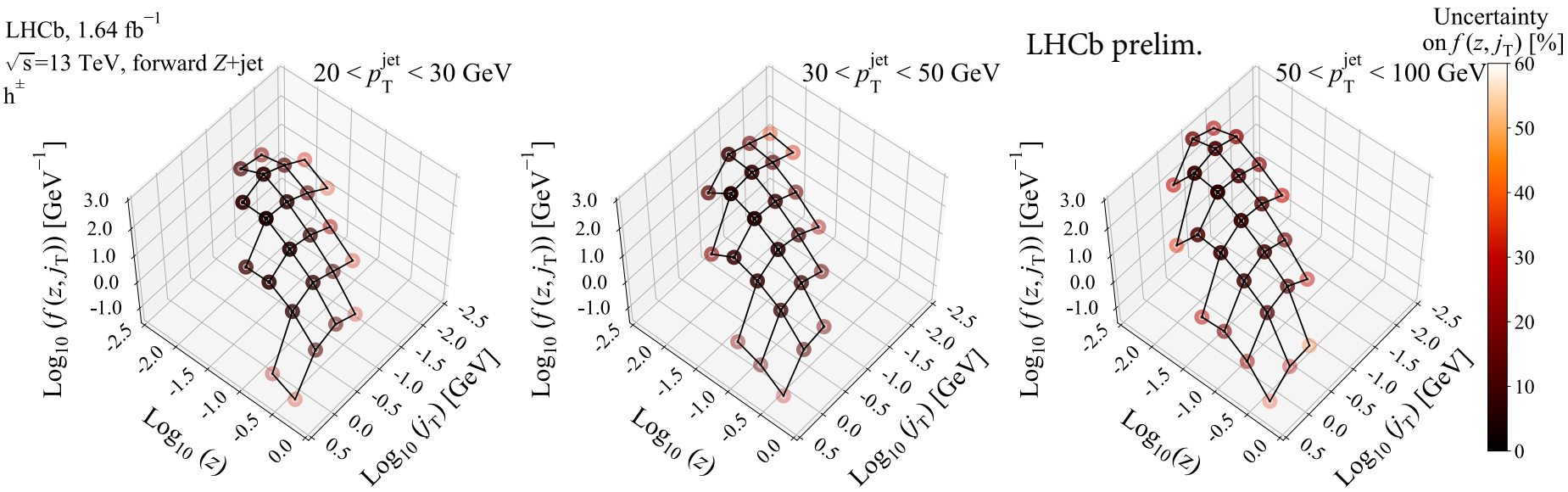




Identified charged hadron production in Z-tagged jets (π,K,p)

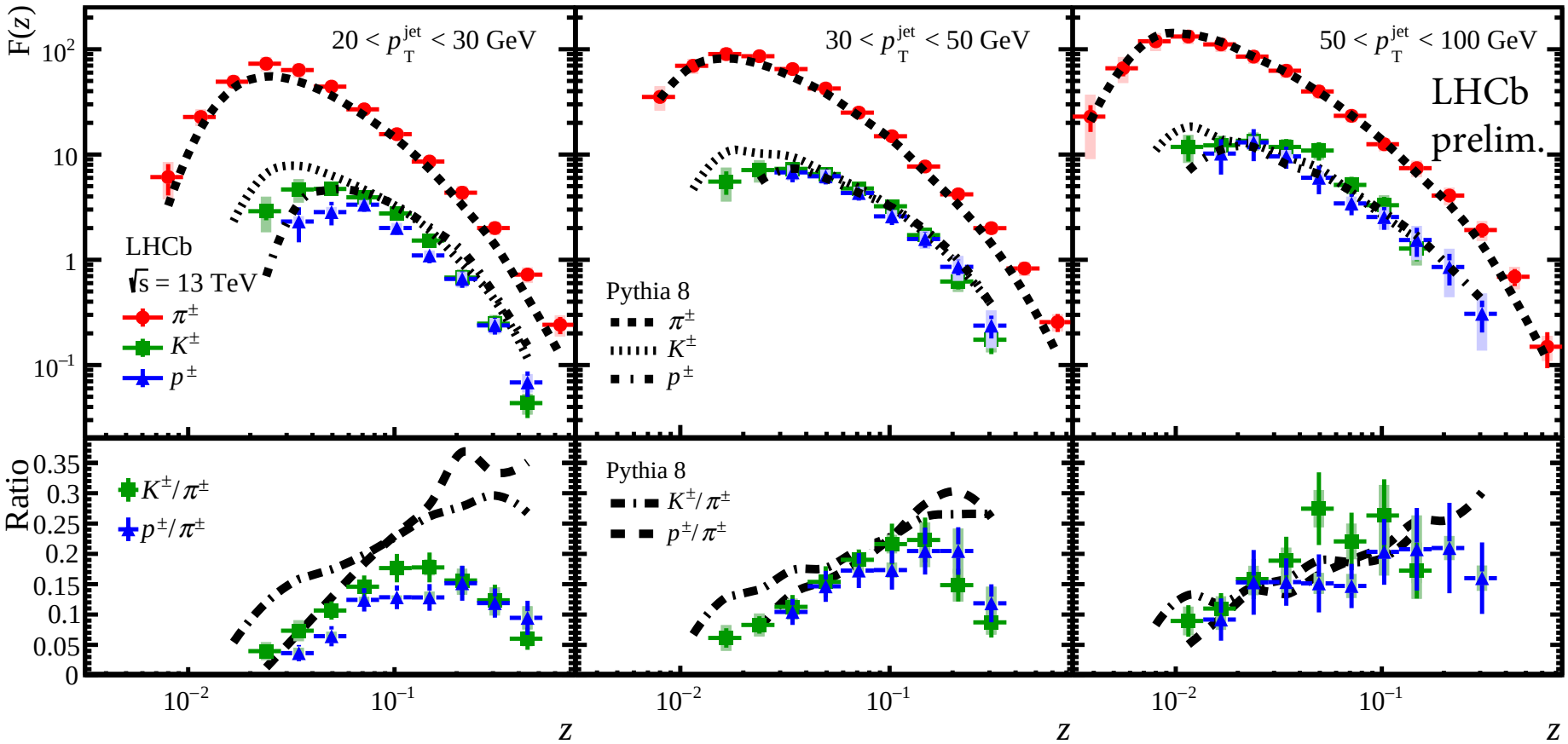
Identified charged hadrons in Z-tagged jets (i)

- Triple differential dists in j_T, z & p_T(jet) for unidentified hadrons.
- Larger z $\rightarrow$ larger j_T.
- Larger p_T(jet) $\rightarrow$ smaller z (soft particles) $\rightarrow$ larger j_T: fatter jets [LHCb-PAPER-2022-013].



Identified charged hadrons in Z-tagged jets (ii)

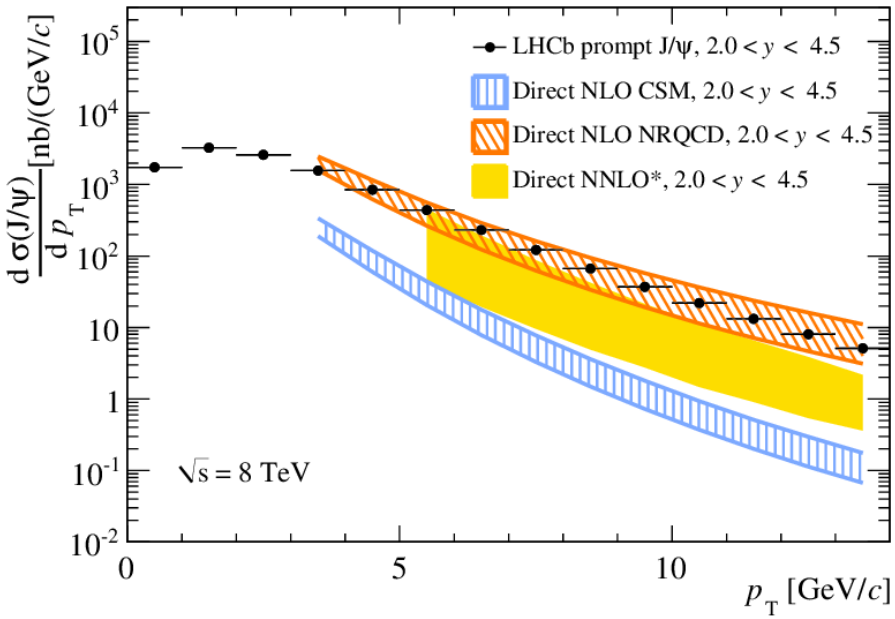
- z ratios for heavier identified hadrons wrt pions.
- Heavier mass hadrons require larger z threshold for formation.
- Suppression: $K^{\pm} \rightarrow$ content of proton, $p^{\pm} \rightarrow$ baryon formation [LHCb-PAPER-2022-013].

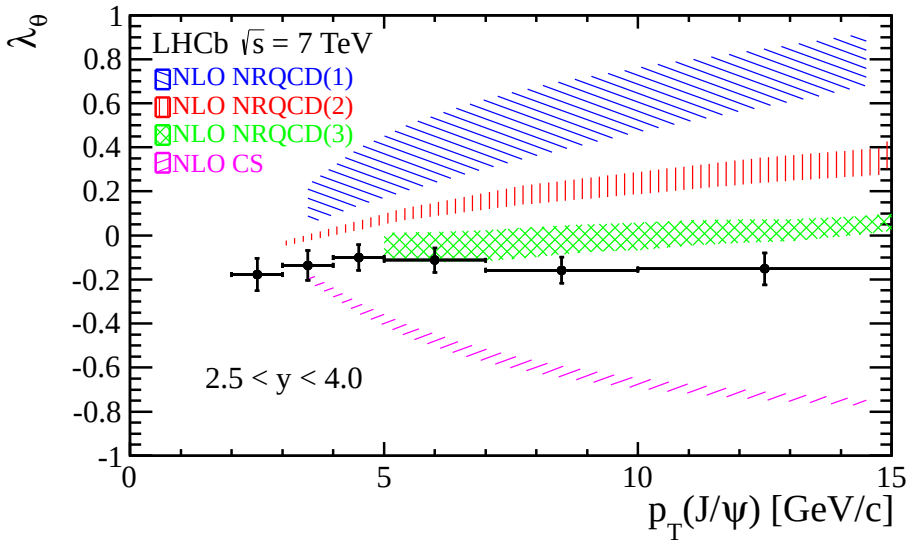


Study of J/ψ production in jets

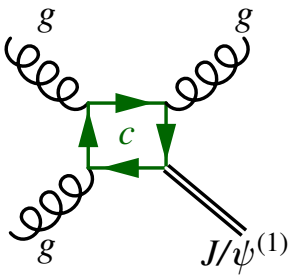
Study of J/ψ production in jets (i)

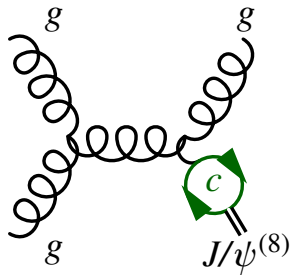
- Hard production Non-Relativistic QCD (NRQCD) predicts:
  - Differential production cross section consistent with measurement.
  - J/ψ produced largely isolated [JHEP 10 (2015) 172].
  - Large transverse polarisation [Eur. Phys. J. C 73, 2631 (2013)].





colour singlet
low p_T
longitudinal pol.

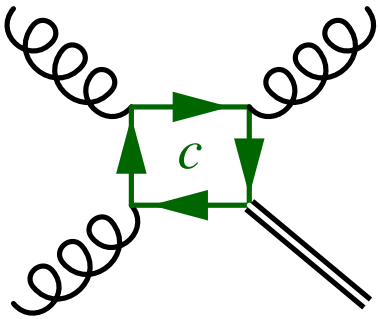


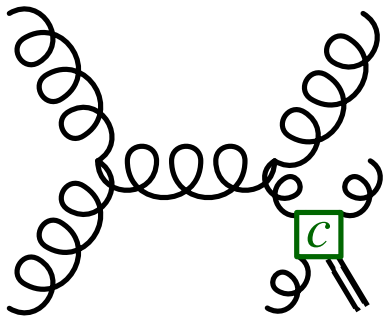


colour octet
high p_T
transverse pol.

Study of J/ψ production in jets (ii)

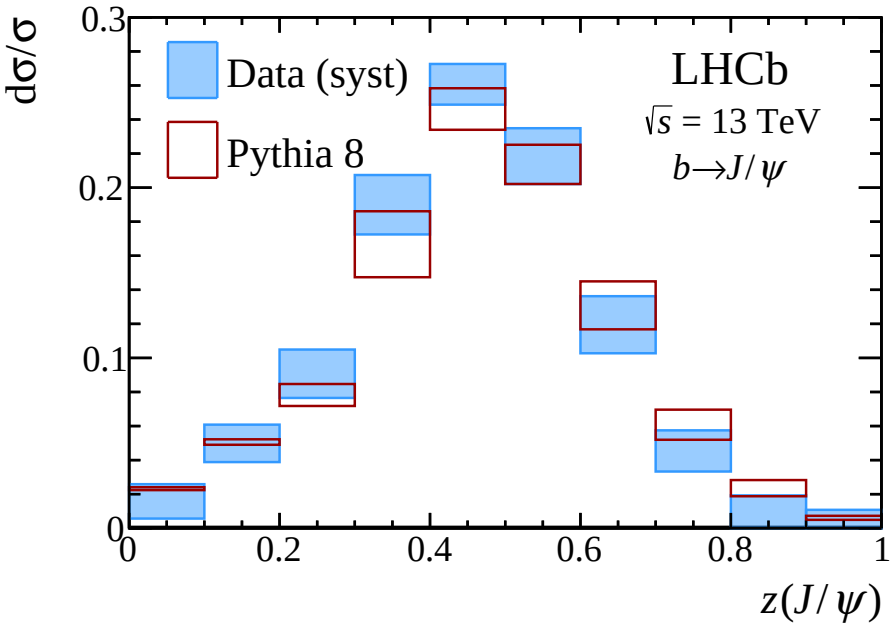
- Shower production analytic resummation NRQCD predicts:
  - Lack of polarisation.
  - J/ψ rarely produced in isolation.
- Two quarkonia production mechanisms distinguishable by studying radiation associated with them → jets.
- Instead of measuring cross section wrt $p_T(J/\psi)$, take into account surrounding radiation with $z(J/\psi) \equiv p_T(J/\psi)/p_T(\text{jet})$.

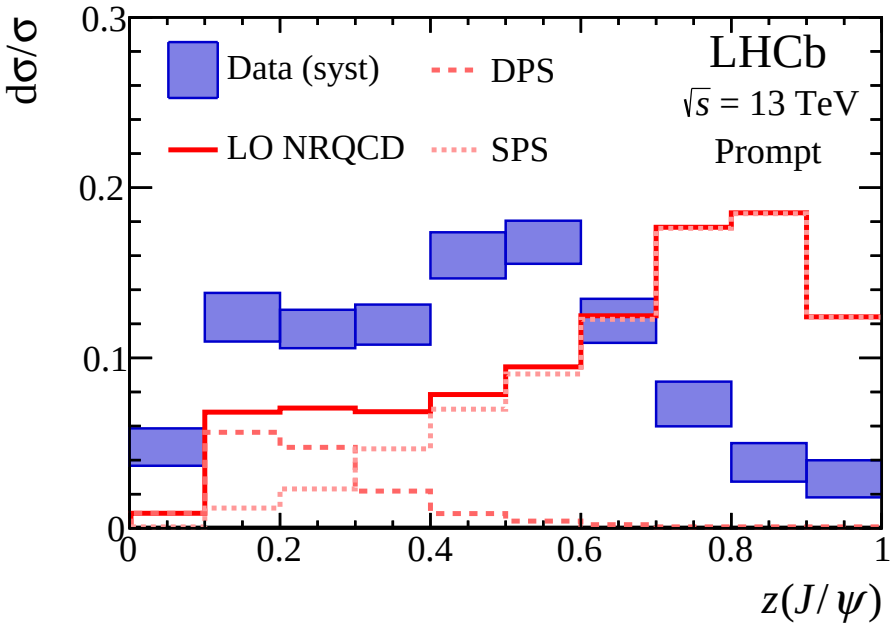


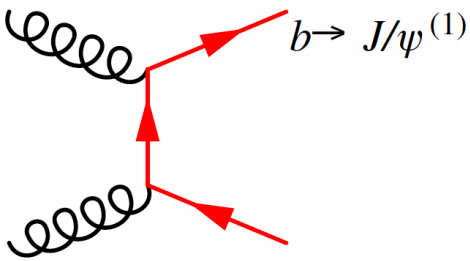


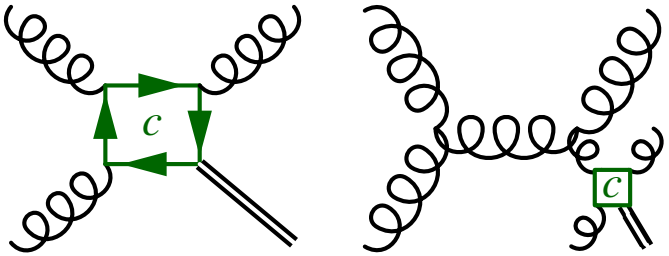
Study of J/ψ production in jets (iii)

Measure $d\sigma/\sigma$ verses $z(J/\psi) \equiv p_T(J/\psi)/p_T(\text{jet})$, to probe DPS. Prompt (direct from PV) and displaced (i.e. b decay) distributions measured [Phys. Rev. Lett. 118, 192001 (2017)].





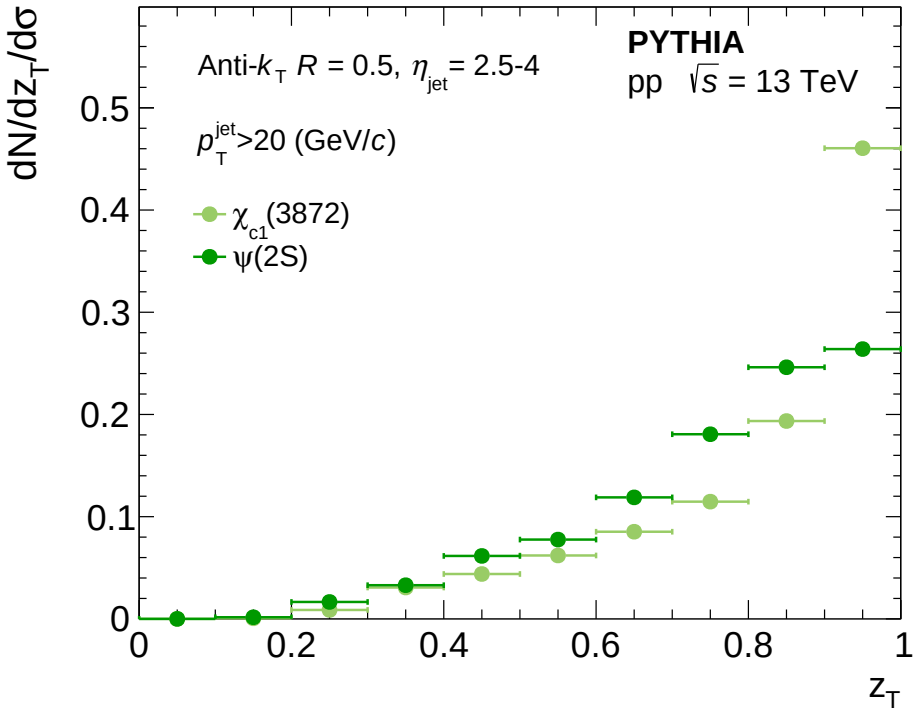


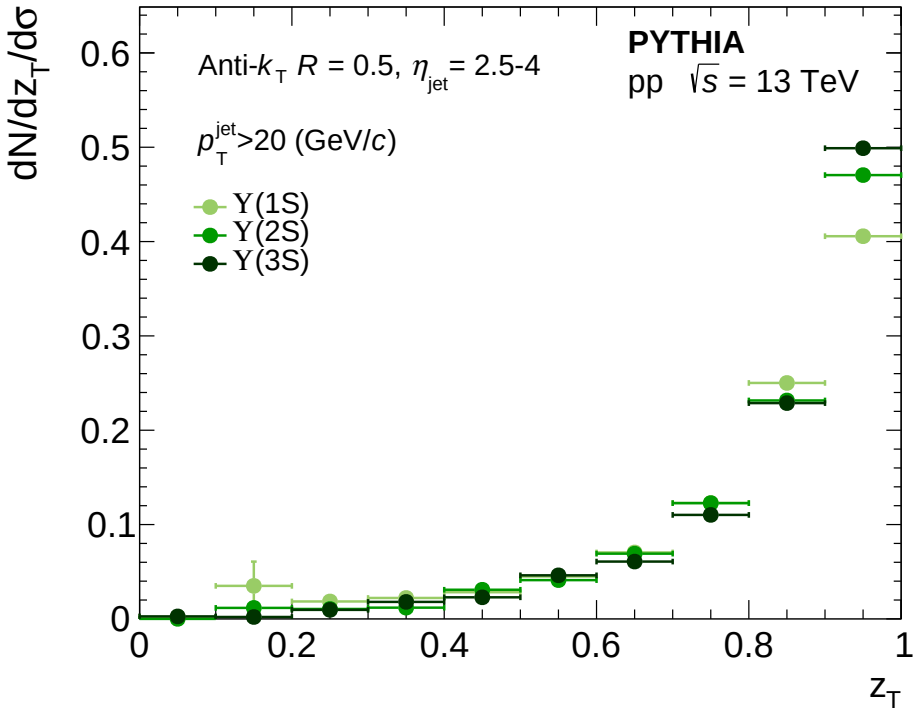


Future prospects

Quarkonia in jets measurements:

- Analyses for $\psi(2S)$, $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ and X(3872) are in progress.
- Predictions for the z distributions are shown below, where Υ's are predicted to be more isolated than $\psi(2S)$ and X(3872).





Conclusions

Charged hadron production in Z+jet [Phys. Rev. Lett. 123, 232001 (2019)]:

- Measurements seem to be more transversely and longitudinally collimated than gluon dominated jet measurements (inclusive jets).
- Constrains transverse-momentum dependent fragmentation functions.

Identified charged hadron production in Z+jet [LHCb-PAPER-2022-013]:

- Full picture of collinear + transverse kinematics wrt jet axis.
- Probes hadron-mass hierachy in hadronisation processes.
- z ratios: insight to role of valence vs sea quarks in fragmentation.

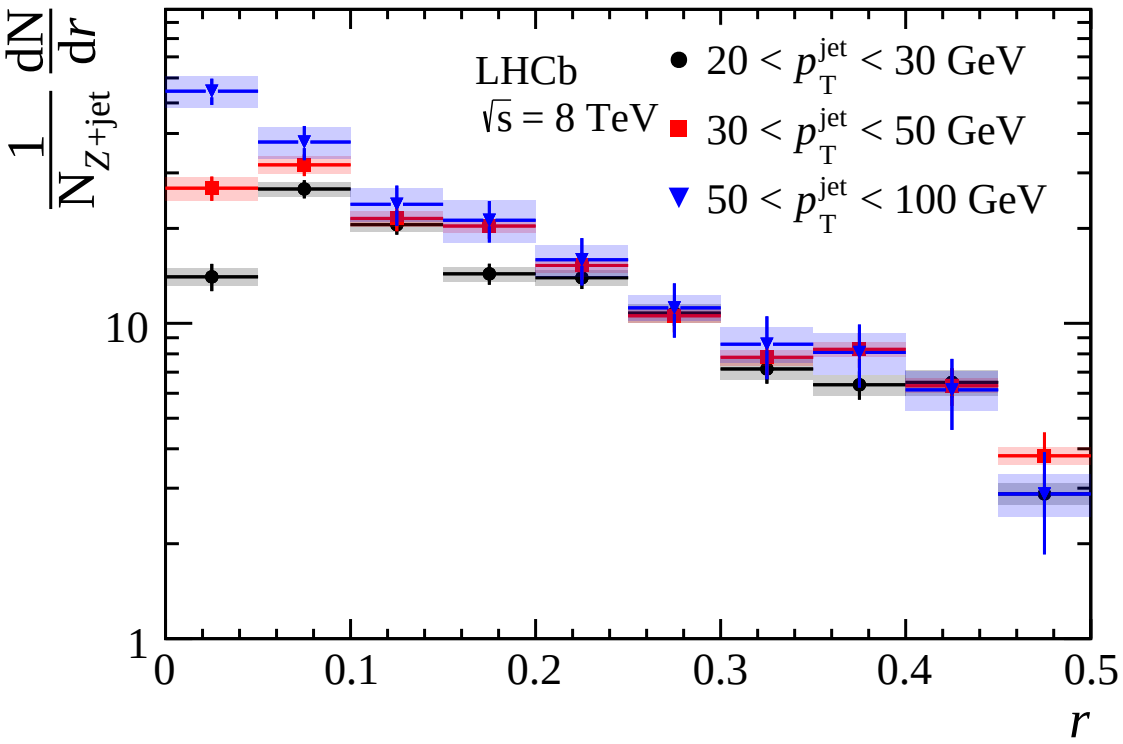
Study of J/ψ production in jets [Phys. Rev. Lett. 118, 192001 (2017)]:

- Displaced z(J/ψ) distribution described by PYTHIA8 predictions.
- Prompt z(J/ψ) distribution is less isolated than PYTHIA8 prediction.
- Analyses for ψ(2S), Υ(1S), Υ(2S), Υ(3S) and X(3872) to be published soon.

Appendix

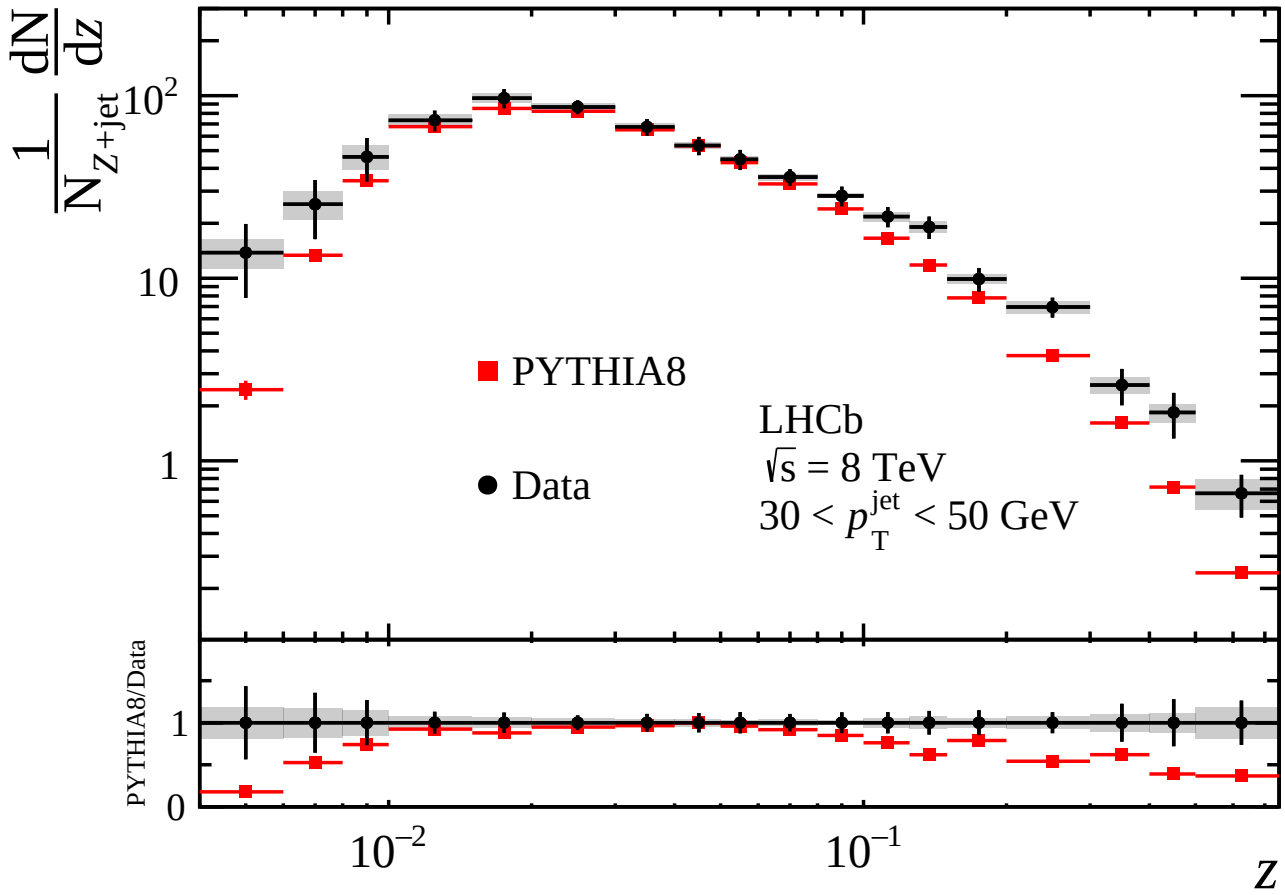
Charged hadron production in Z-tagged jets

- Number of charged hadrons depends on p_T(jet) at small r , $\sim$ constant at high r.
- Qualitatively, seem to be more collimated in r than inclusive jet measurements. r correlated to z. Dependent either on fiducial cuts or differences in light-quark vs gluon jets [Phys. Rev. Lett. 123, 232001 (2019)].

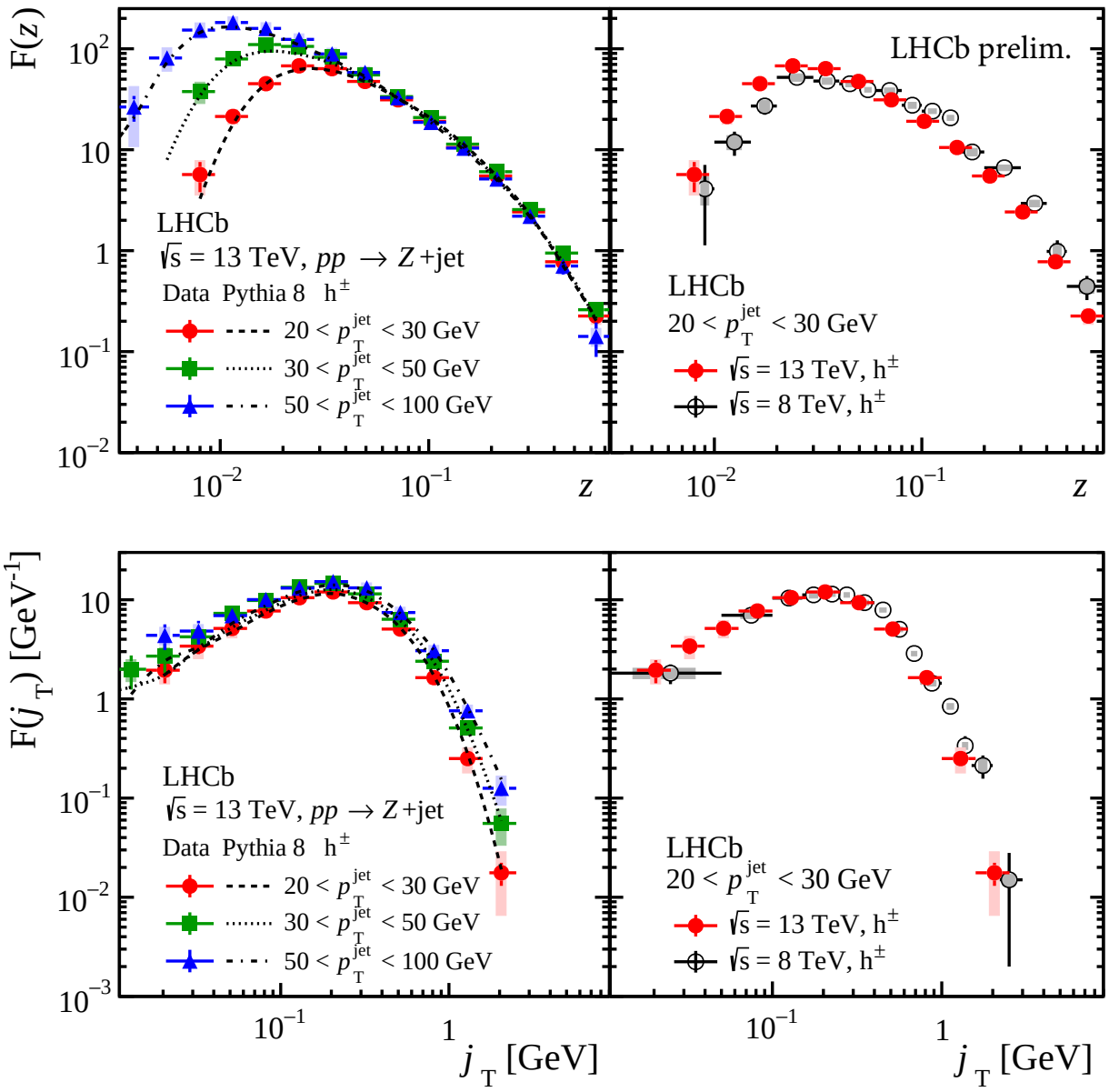


Charged hadron production in Z-tagged jets

- Data described qualitatively by PYTHIA8.
- Underestimates number of charged particles at low & high z. j_T shape consistent, but lower total number of events by 20% in each bin [Phys. Rev. Lett. 123, 232001 (2019)].

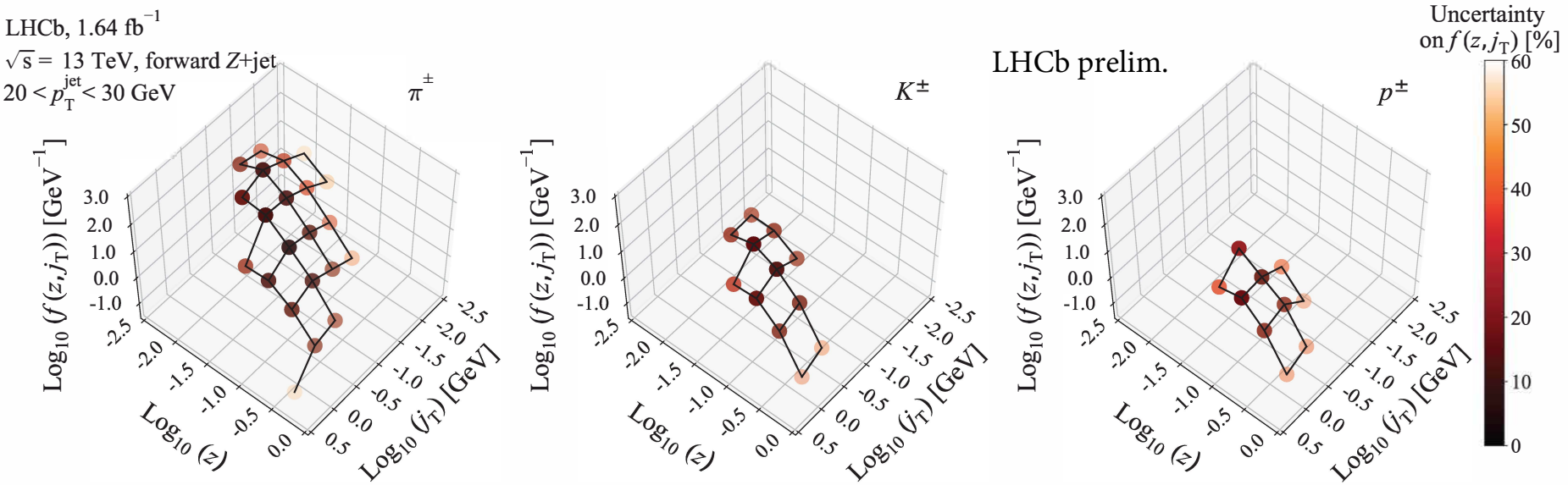


Identified charged hadrons in Z-tagged jets



Identified charged hadrons in Z-tagged jets

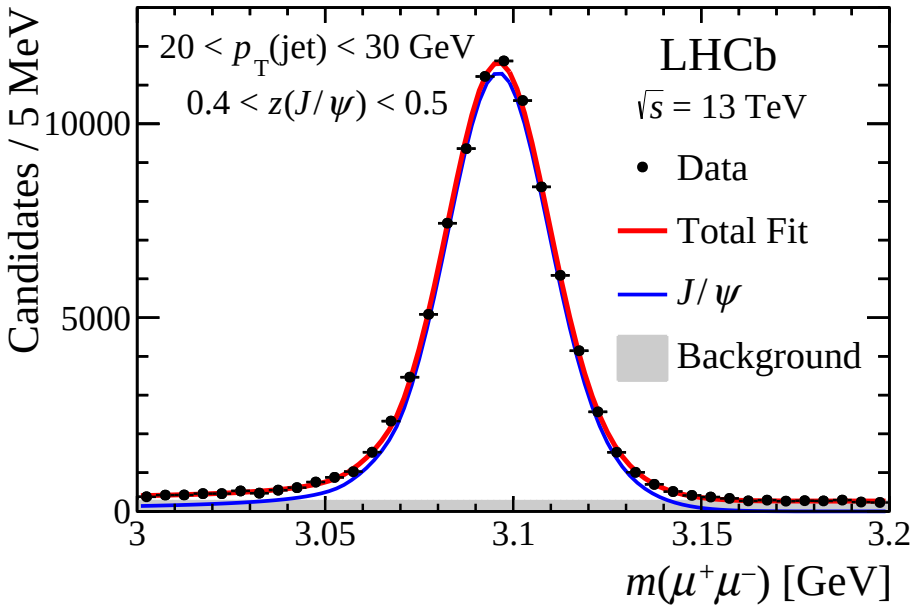
- Triple differential distributions in j_T, z and p_T(jet) for three hadron species.
- Centre of distribution: higher mass $\rightarrow$ larger z and j_T.
- Heavier hadrons produced from heavier partons.
- Comparison to PYTHIA8: number of charged pions (kaons & protons) largely underestimated (overestimated). [LHCb-PAPER-2022-013].

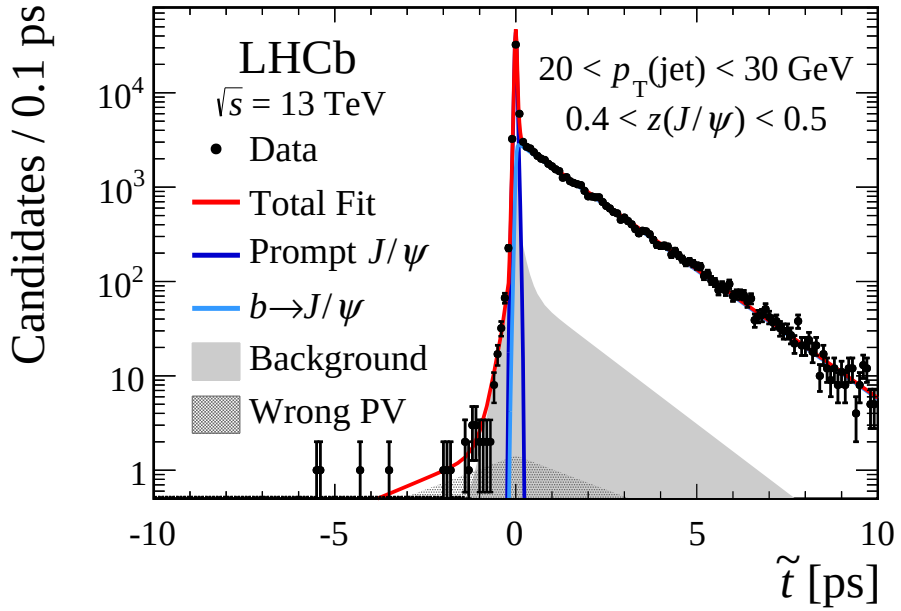


Study of J/ψ production in jets

Procedure [Phys. Rev. Lett. 118, 192001 (2017)]:

- Build $J/\psi \to \mu^+\mu^-$ candidates in jets.
- Determine J/ψ signal yield with mass fits.
- Separate prompt (direct) from displaced (i.e. b decay) yields with pseudo-lifetime fits, $t \equiv x_z - x_z(PV)m_{J/\psi}/p_z$.
- Efficiency corrected + Bayesian unfolded for jet energy resolution.





Study of J/ψ production in jets

- Distributions are efficiency corrected.
- Unfolding p_T(jet) from reconstruction to truth level is done to correct for jet energy resolution effects [Phys. Rev. Lett. 118, 192001 (2017)].