# QCD physics measurements at the LHCb experiment

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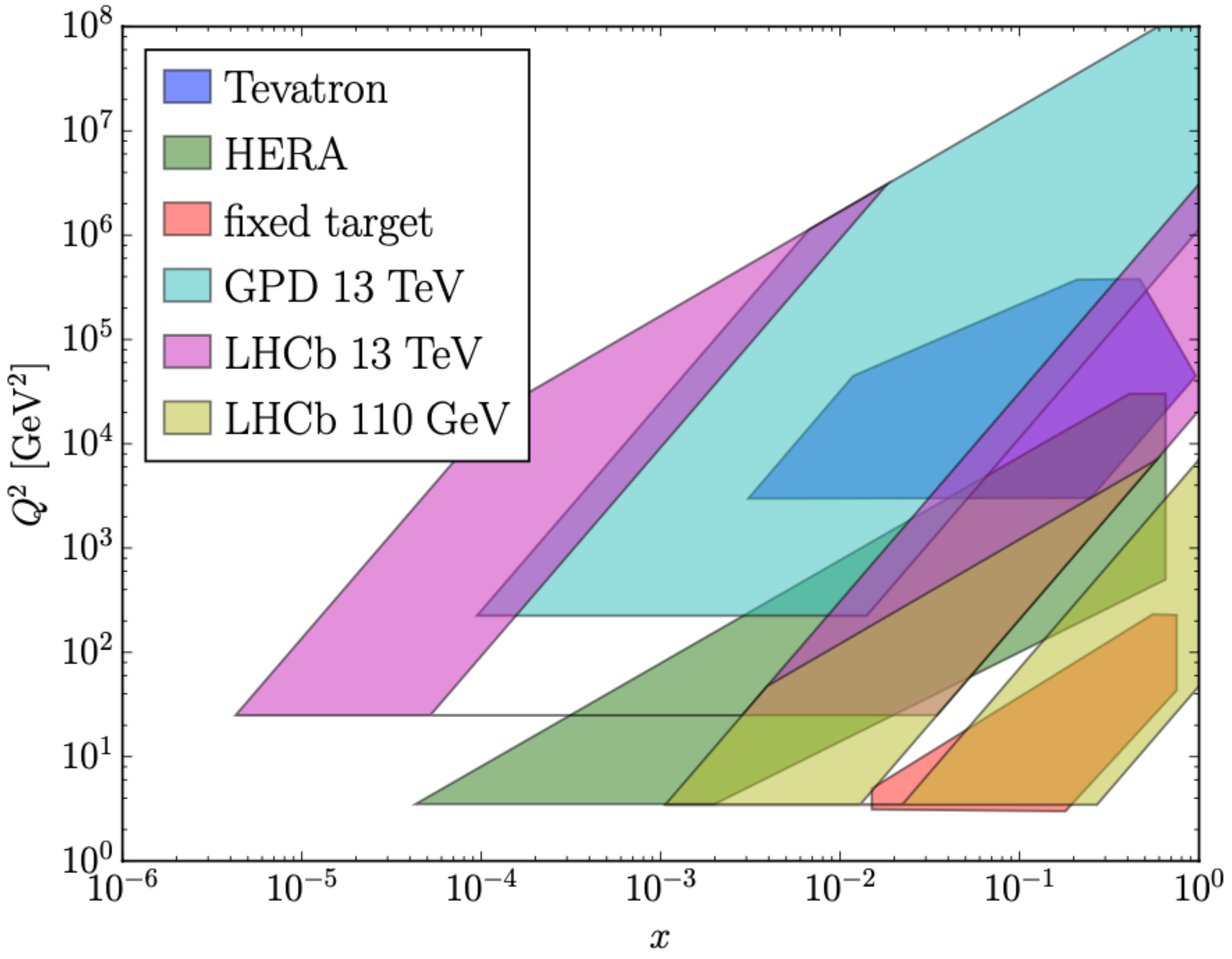
VIRTUAL EDITION

# Why QCD physics at LHCb?

- **LHCb** allows to **test perturbative QCD (pQCD) predictions in a phase space (2< η< 5) complementary to General Purpose Detectors**.
- **Parton distribution functions (PDF) and proton structure** can be studied in regions not accessible by other LHC experiments.
- **Fragmentation functions of forward jets can be studied**.
- For QCD results on heavy ions and fixed target collisions check the talks from **Giulia** (Heavy ion session) and **Saverio** (tomorrow this session).
- Charged particles production in forward region presented by **Óscar** tomorrow in this session.



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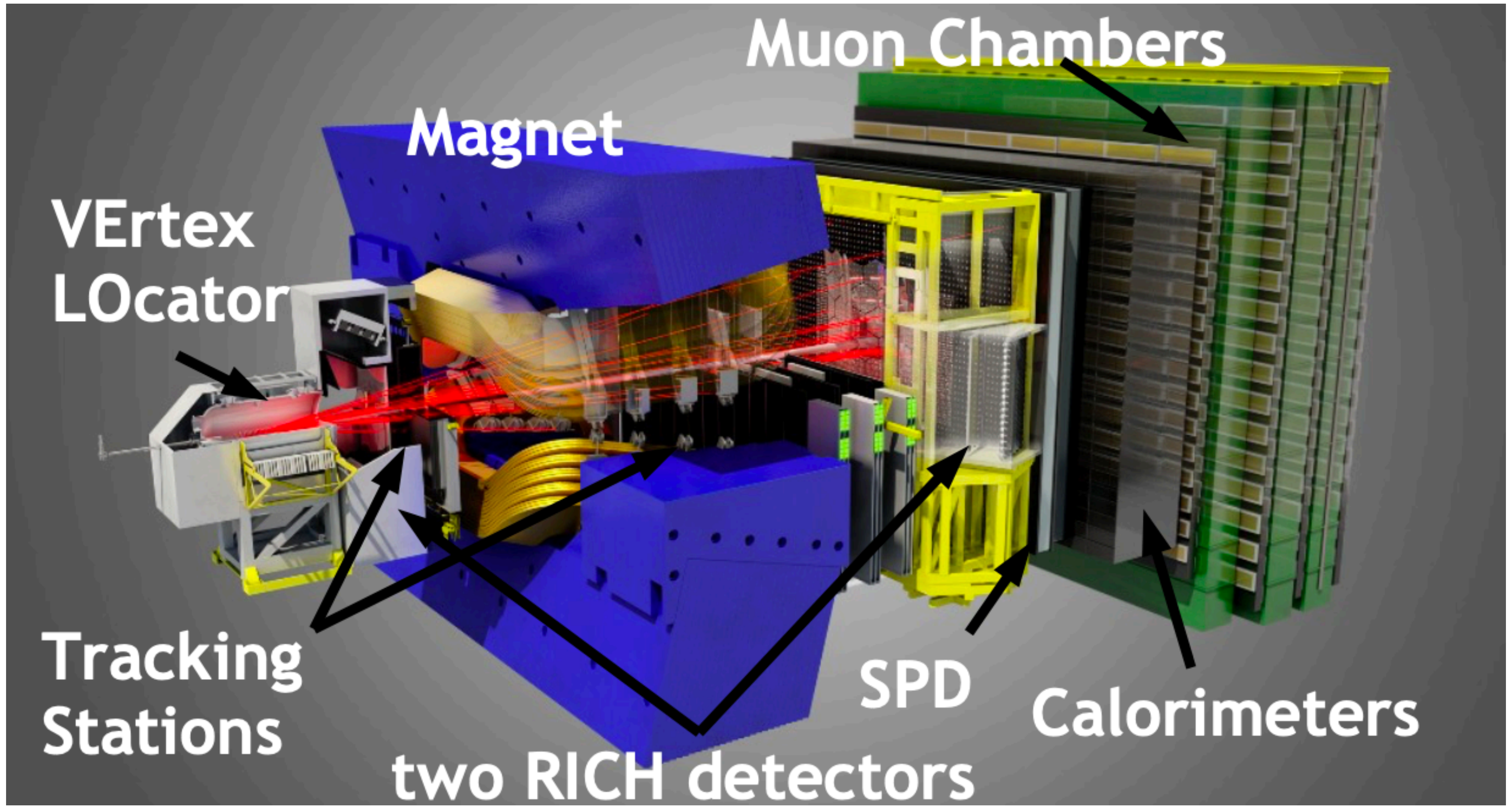
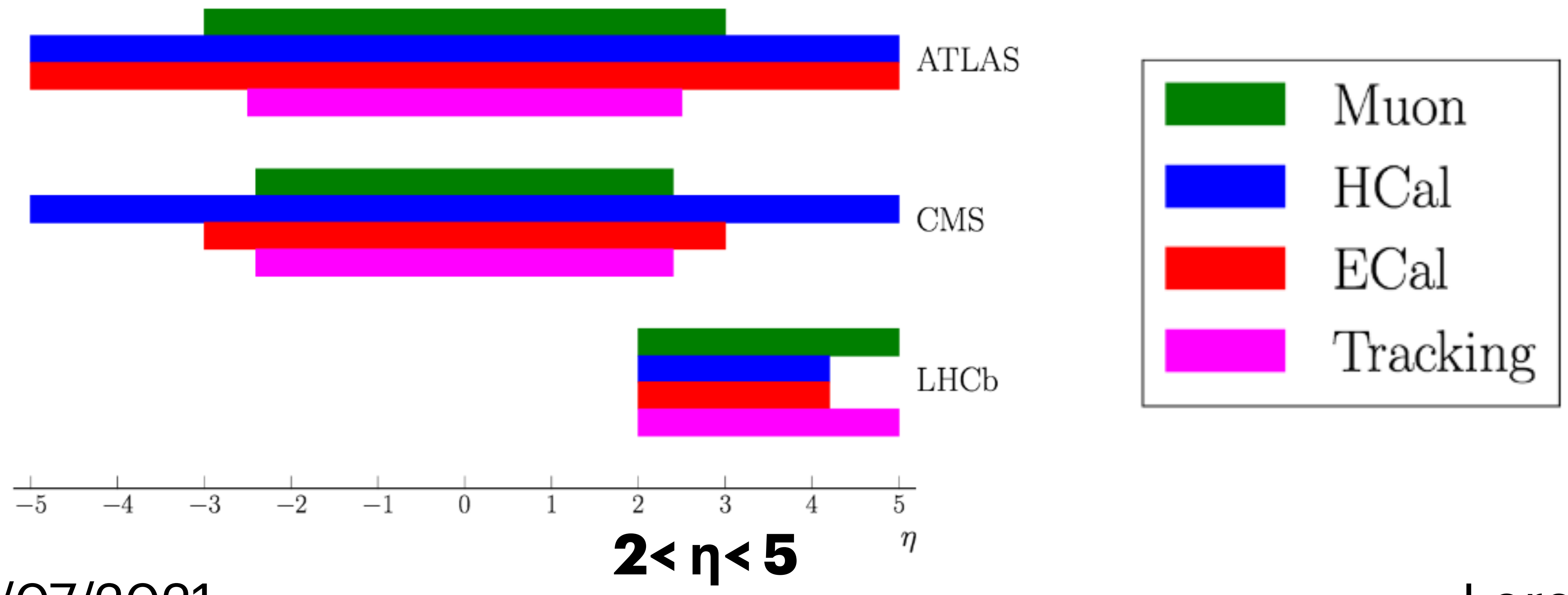
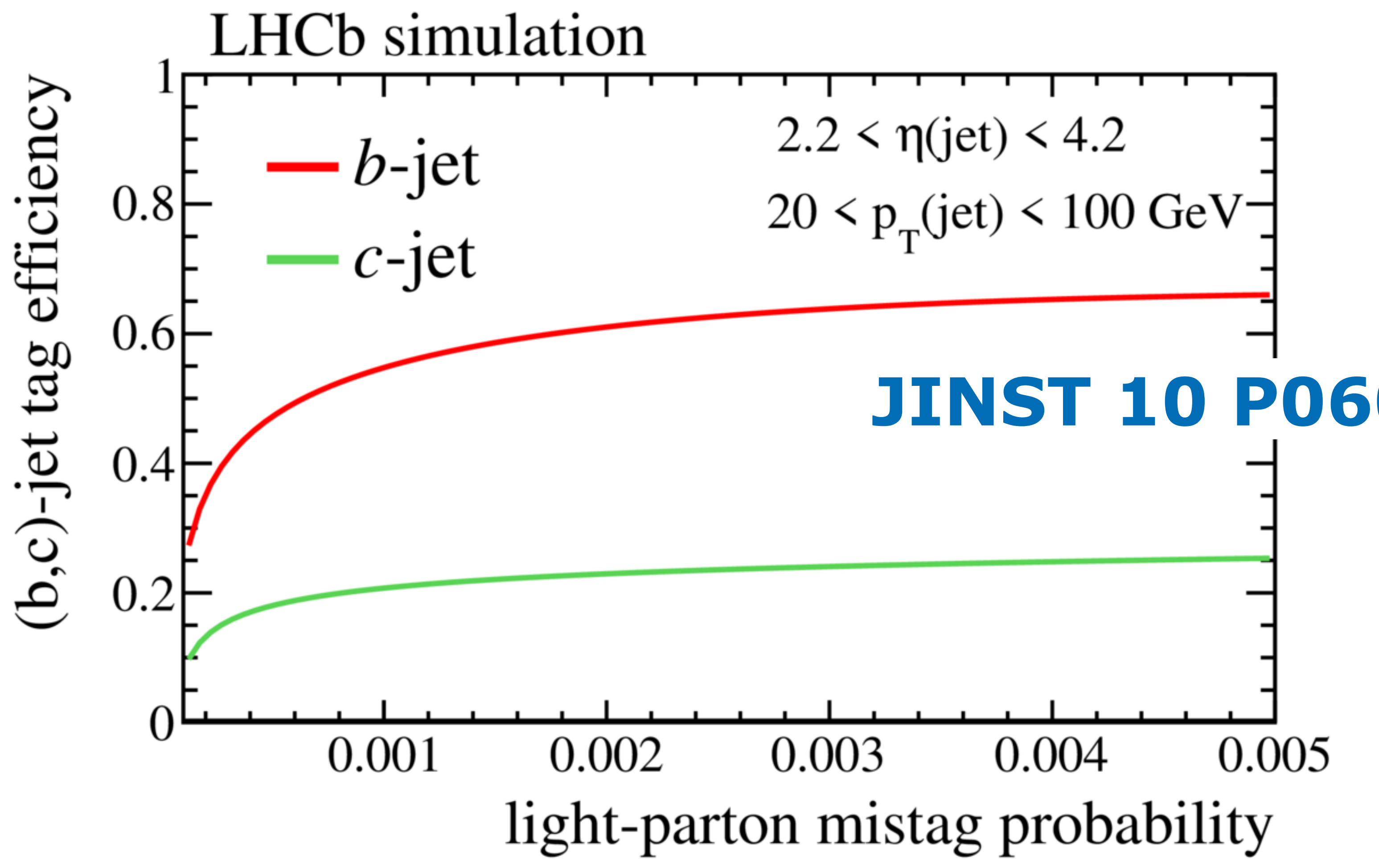
  **JHEP 02 (2021) 023**
- **Measurement of charged hadrons in Z+jet events:**
  **Phys. Rev. Lett. 123 (2019) 232001**
- **Z+c-jet production -> NEW**

# LHCb detector JINST 3 (2008) S08005




- LHCb, originally designed for b- and c-hadron physics, is now considered a **general purpose forward detector**.
- Track momentum resolution: 0.4% at 5 GeV and 0.6% at 100 GeV.
- Muon ID efficiency: 97% with 1-3% $\mu \rightarrow \pi$ mis-identification.
- Excellent vertex reconstruction system: tagging of b- and c-jets with reconstruction of secondary vertices formed by tracks inside the jet cone.

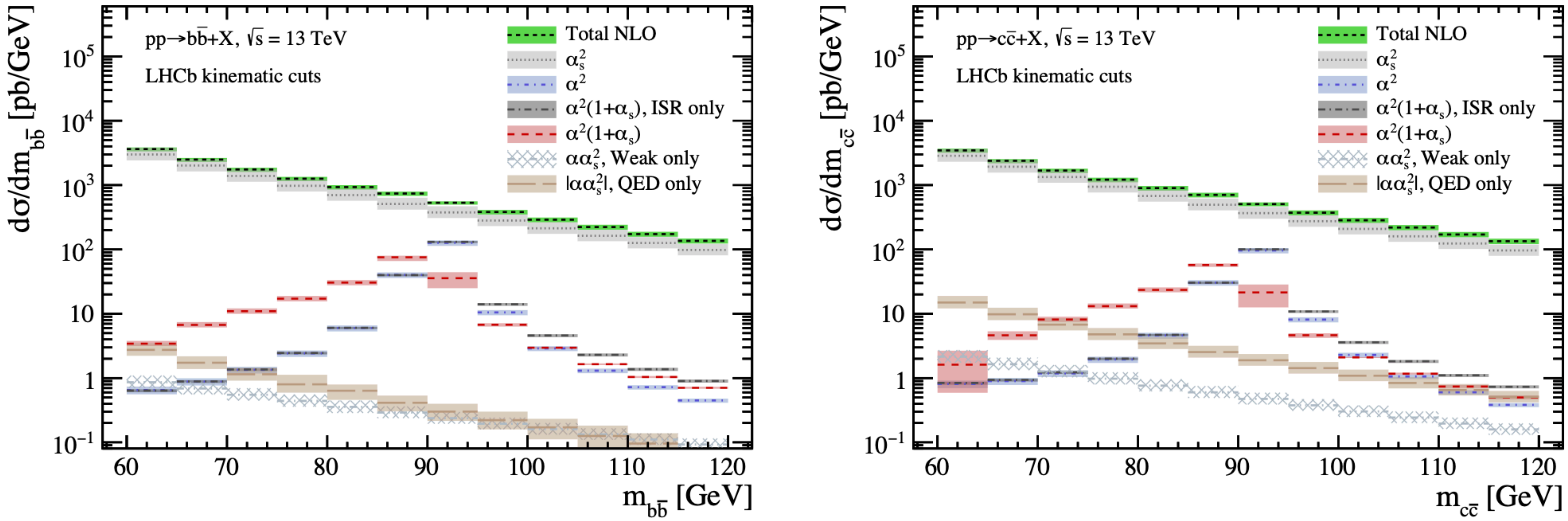



JINST 10 P06013

# $b\bar{b}$ and $c\bar{c}$-dijet production

- **Heavy flavor dijet production in the forward region is an excellent test of pQCD.**
- **Differential measurements are performed with the 2016 dataset (1.6 fb$^{-1}$)**
- Preliminary measurement for $b\bar{b}$ and $c\bar{c}$ charge asymmetry and for new physics searches in $b\bar{b}$ and $c\bar{c}$ final states.

**Predictions in the forward region: JHEP03(2019)166**



# $b\bar{b}$ and $c\bar{c}$-dijet differential cross sections

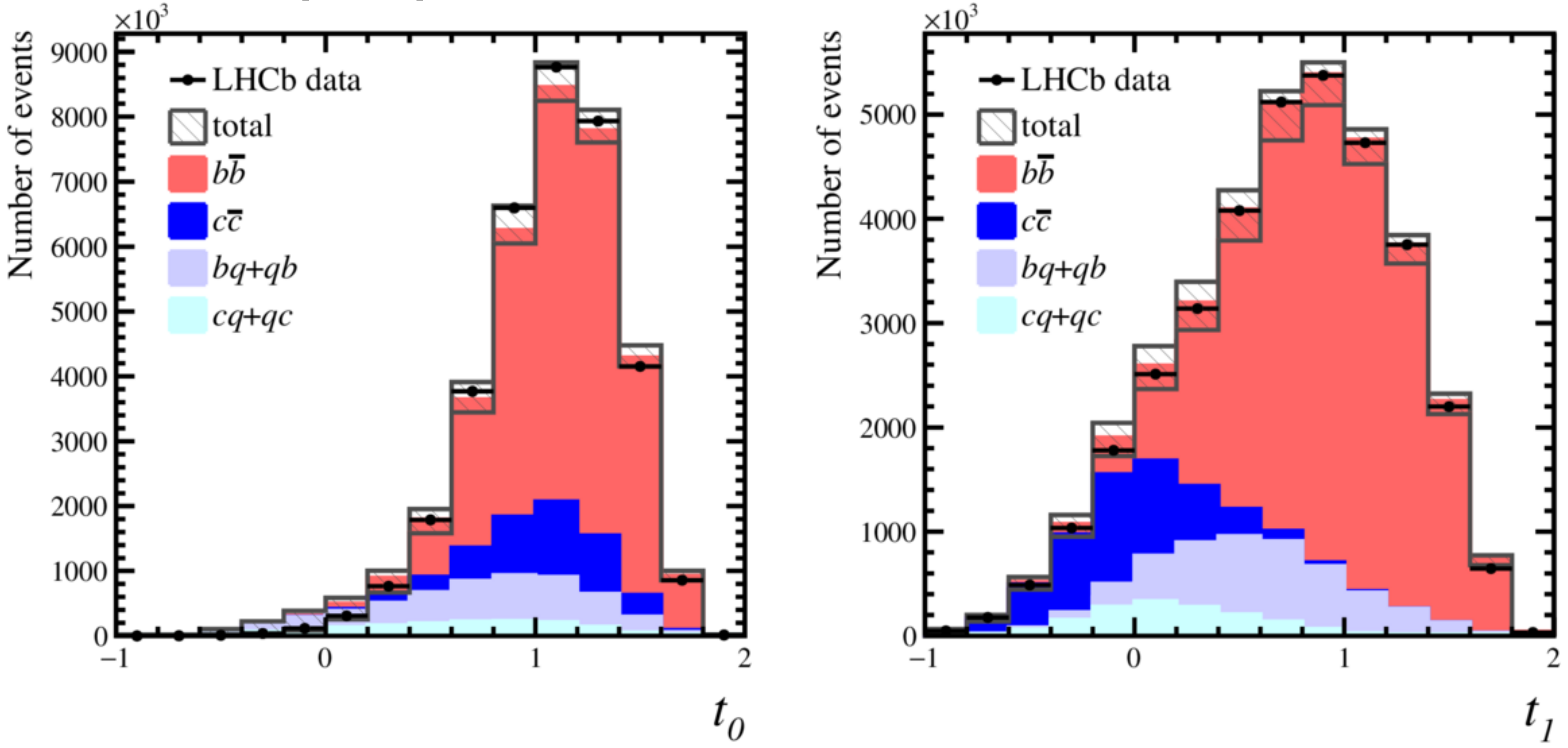
- Two Secondary-Vertex (SV) tagged jets are selected, with $p_T(jet_{1,2})$ > 20 GeV, 2.2 < $\eta(jet_{1,2})$ < 4.2, $\Delta\Phi$>1.5
- Cross section measured as a function of 4 observables (1D differential measurement): **leading jet $p_T$, leading jet $\eta$, dijet invariant mass, $\Delta y^* = \frac{1}{2}|y_0-y_1|$**

- Flavour composition obtained by fitting the **combination of two multivariate discriminators**:

$$t_0 = \mathrm{BDT}_{bc|q}(j_0) + \mathrm{BDT}_{bc|q}(j_1),$$
$$t_1 = \mathrm{BDT}_{b|c}(j_0) + \mathrm{BDT}_{b|c}(j_1).$$

- BDTs are trained to separate heavy (bc) versus light (udsg) flavors and b vs c.
- Fit result dominated by systematic uncertainties on procedure and template modeling.

**JHEP 02 (2021) 023**



# $b\bar{b}$ and $c\bar{c}$-dijet differential cross sections

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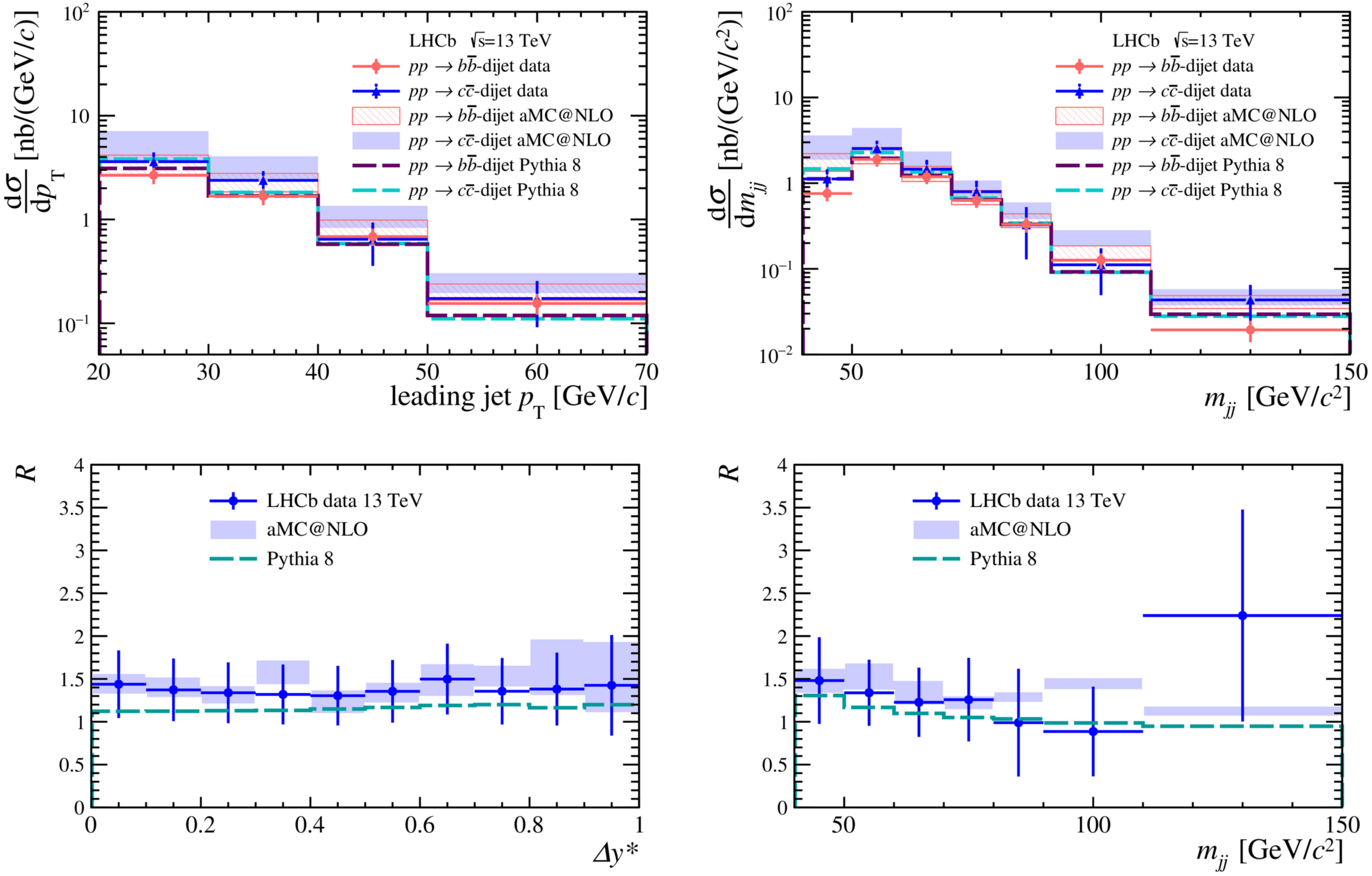
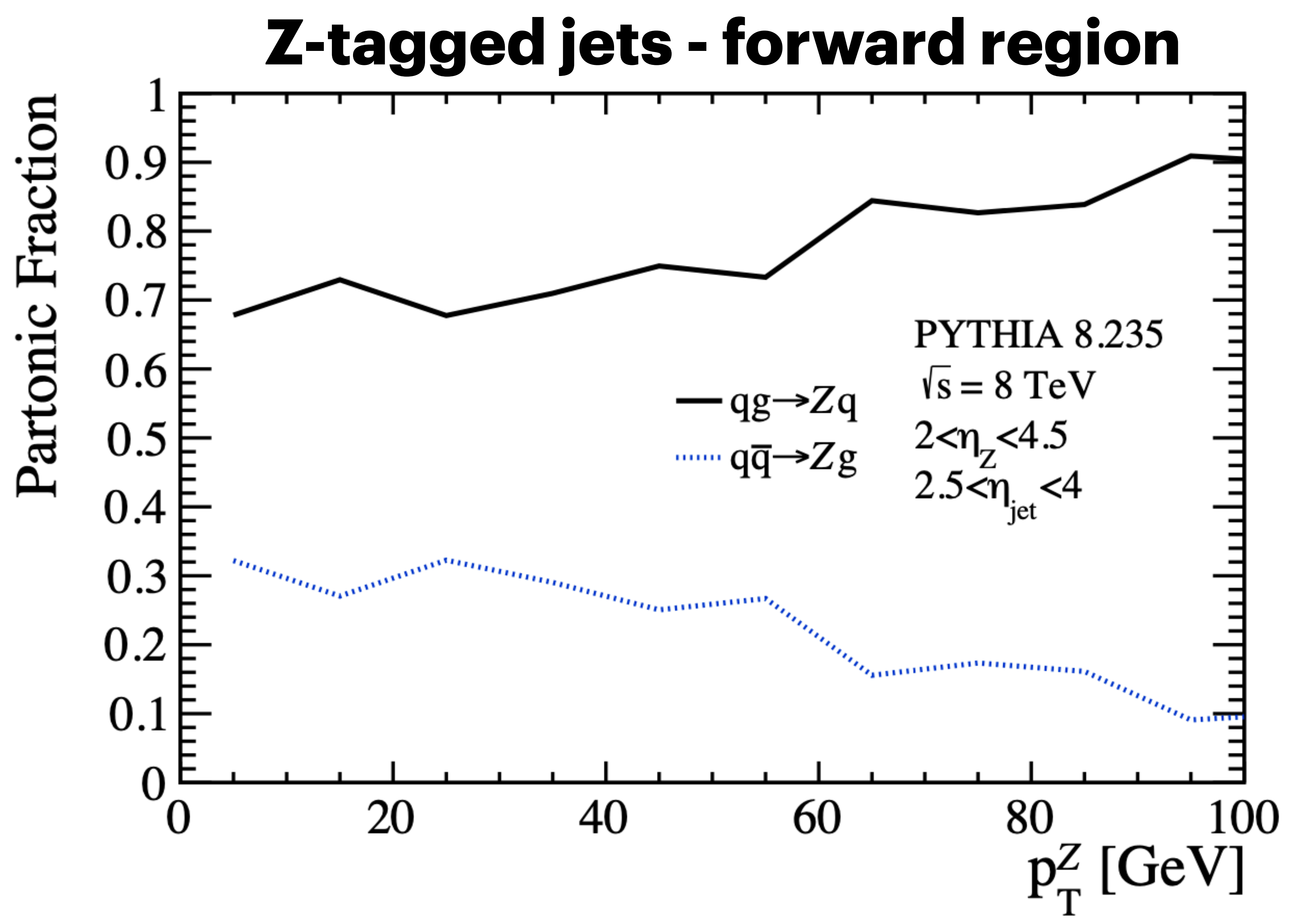


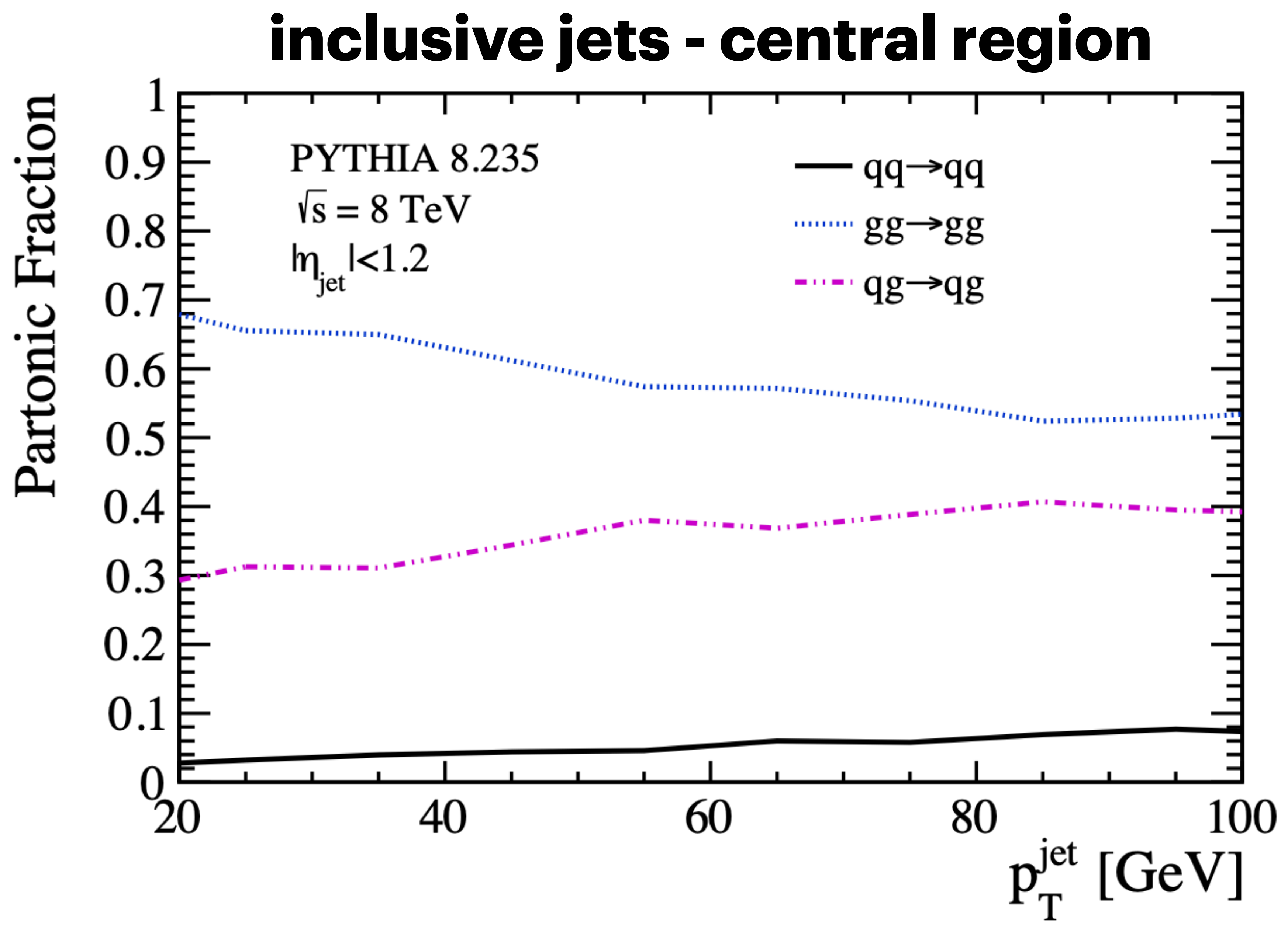

- Measured yields are unfolded for detector effects and corrected for selection efficiencies.
- Overall uncertainty (~20%) dominated by heavy flavour tagging efficiency.
- **The cross section ratio R**($c\bar{c}/b\bar{b}$) is also determined -> systematic cancellation in both theory and uncertainty.
- **This is the first measurement of $c\bar{c}$-dijet differential cross-section at a hadron collider.**

# Charged hadrons production in Z+jet

Phys. Rev. Lett. 123 (2019) 232001

- **Z(->μμ)+jet is the ideal system to study transverse momentum dependent jet sub-structure**.
- Z+jet production in the forward region is dominated by quark-jets.
- Moreover LHCb can access a lower jet $p_T$ (from 20 GeV) with respect to ATLAS/CMS.



# Charged hadrons production in Z+jet

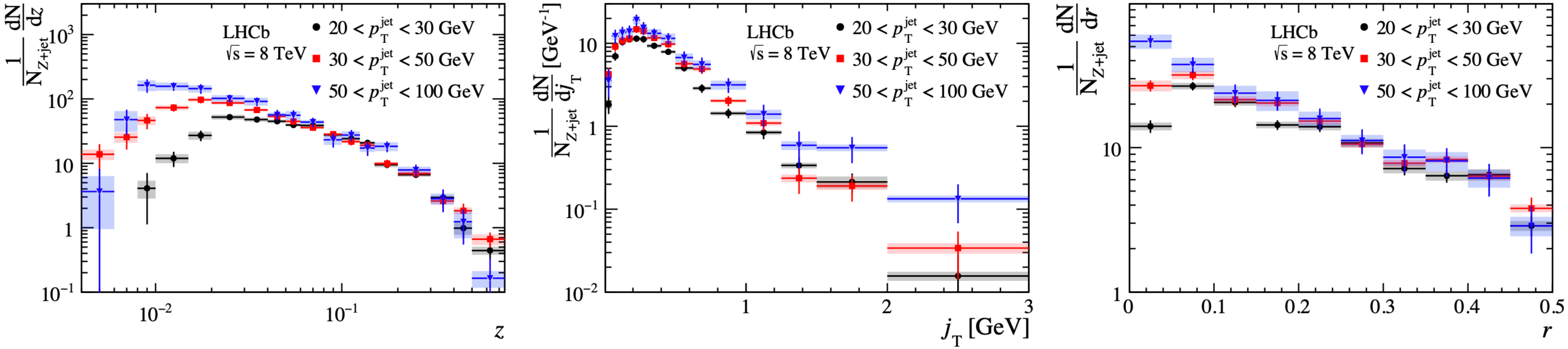
**Phys. Rev. Lett. 123 (2019) 232001**

- **Three differential distributions** for charged hadrons in Z-tagged jets are measured:

$$z \equiv \frac{\mathbf{p}_{\mathrm{jet}} \cdot \mathbf{p}_{\mathrm{hadron}}}{|\mathbf{p}_{\mathrm{jet}}|^2} \qquad j_{\mathrm{T}} \equiv \frac{|\mathbf{p}_{\mathrm{jet}} \times \mathbf{p}_{\mathrm{hadron}}|}{|\mathbf{p}_{\mathrm{jet}}|} \qquad r \equiv \sqrt{(\phi_{\mathrm{jet}} - \phi_{\mathrm{hadron}})^2 + (y_{\mathrm{jet}} - y_{\mathrm{hadron}})^2}$$

- Distributions are corrected for track and jet reconstruction efficiencies.
- A 2-D unfolding [$z, p_T^{jet}$], [$j_T, p_T^{jet}$] and [$r, p_T^{jet}$] is applied.

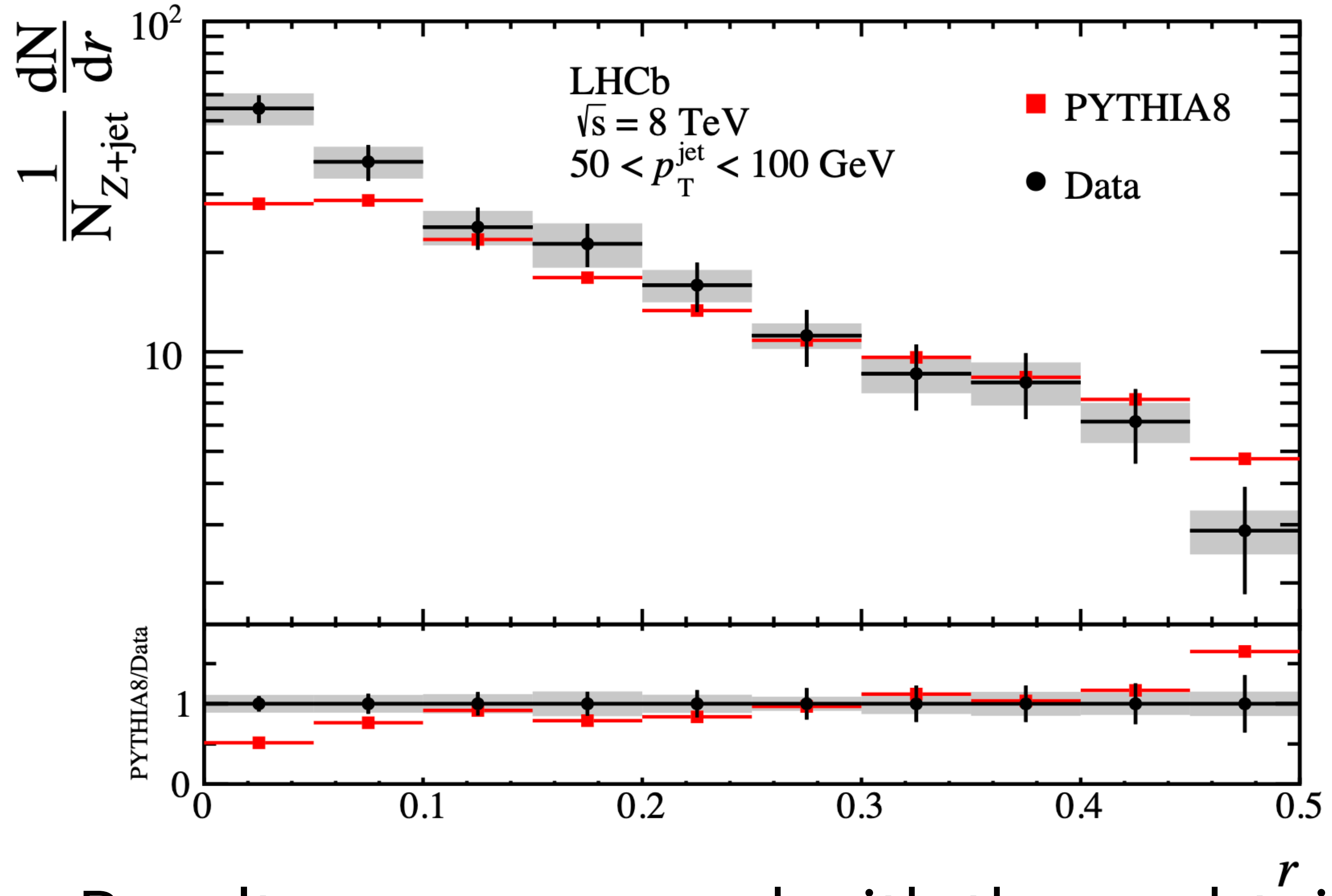
**Results: first measurements of jet hadronization at forward rapidities**



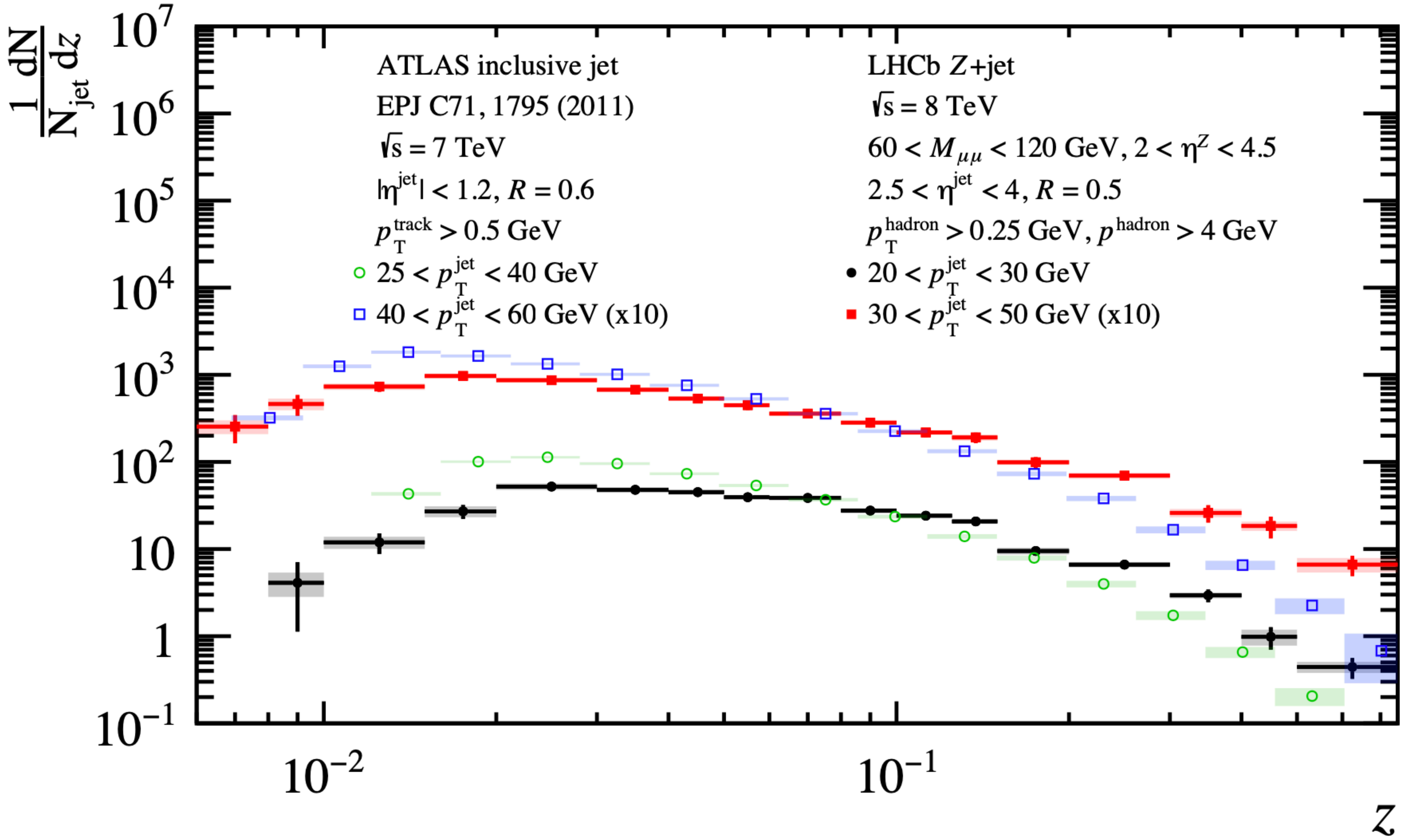
# Charged hadrons production in Z+jet

**Phys. Rev. Lett. 123 (2019) 232001**

- These measurements **are important inputs for fragmentation functions**.
- **Pythia prediction does not match exactly the measurements.**

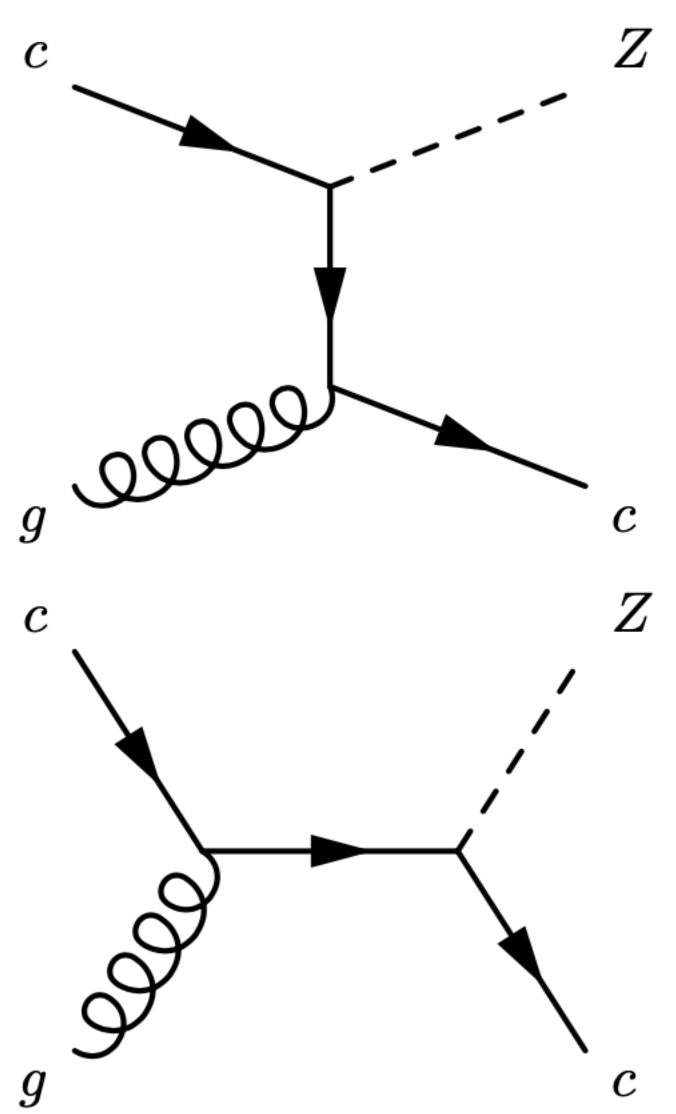


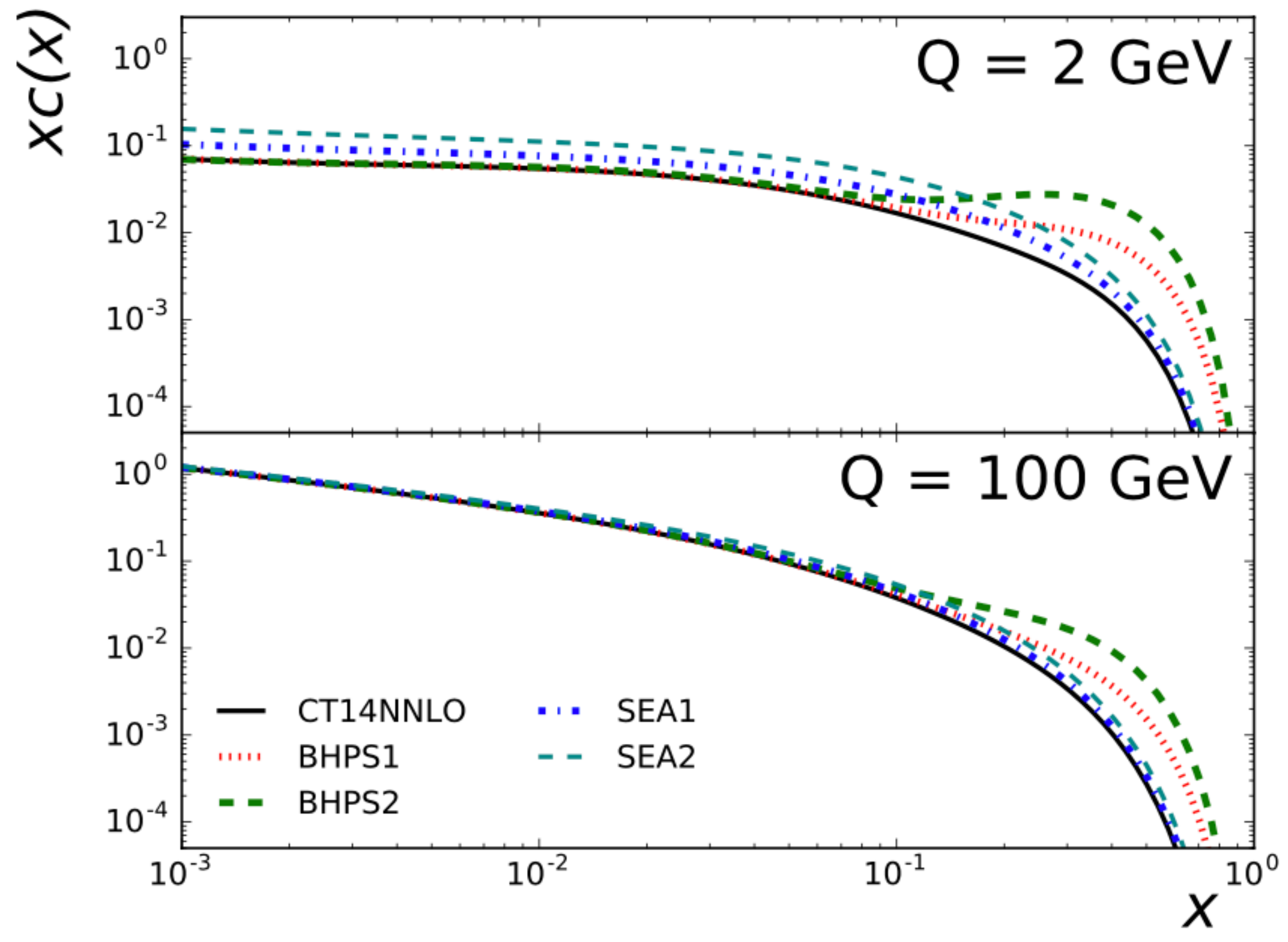

- Results are compared with those obtained by ATLAS with inclusive jets.
- Main differences are due to the different fragmentation of quark and gluons, as expected.



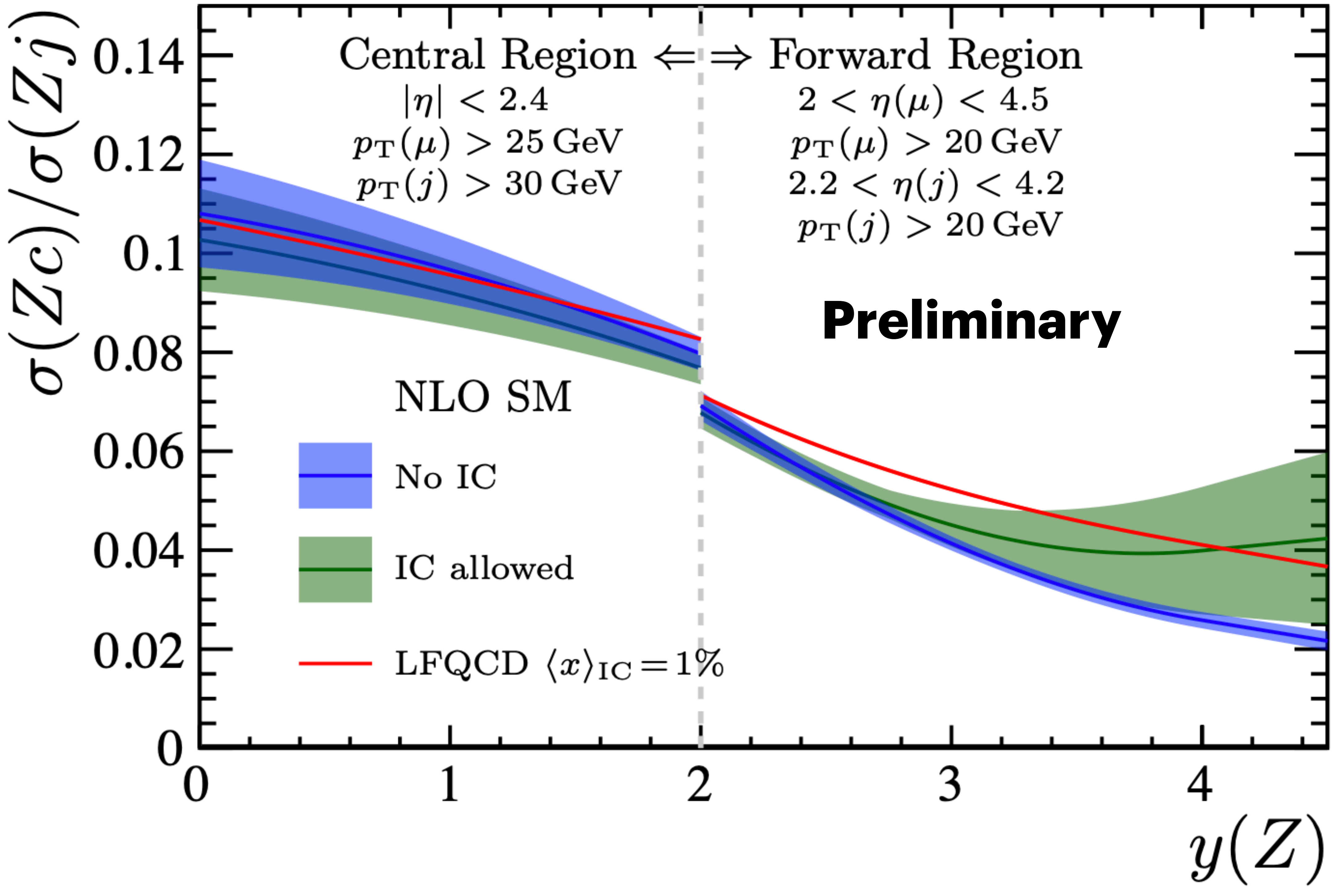
# Z+c-jet production: Intrinsic charm

- **In proton content charm** can be **extrinsic** (produced by gluon splitting) or **intrinsic** (bound to valence quarks).
- Intrinsic charm PDF can be valence-like or sea-quark-like. **Valence-like intrinsic charm is predicted by Light Front QCD** (LFQCD, not-perturbative).




Phys. Rev. D **93**, 074008



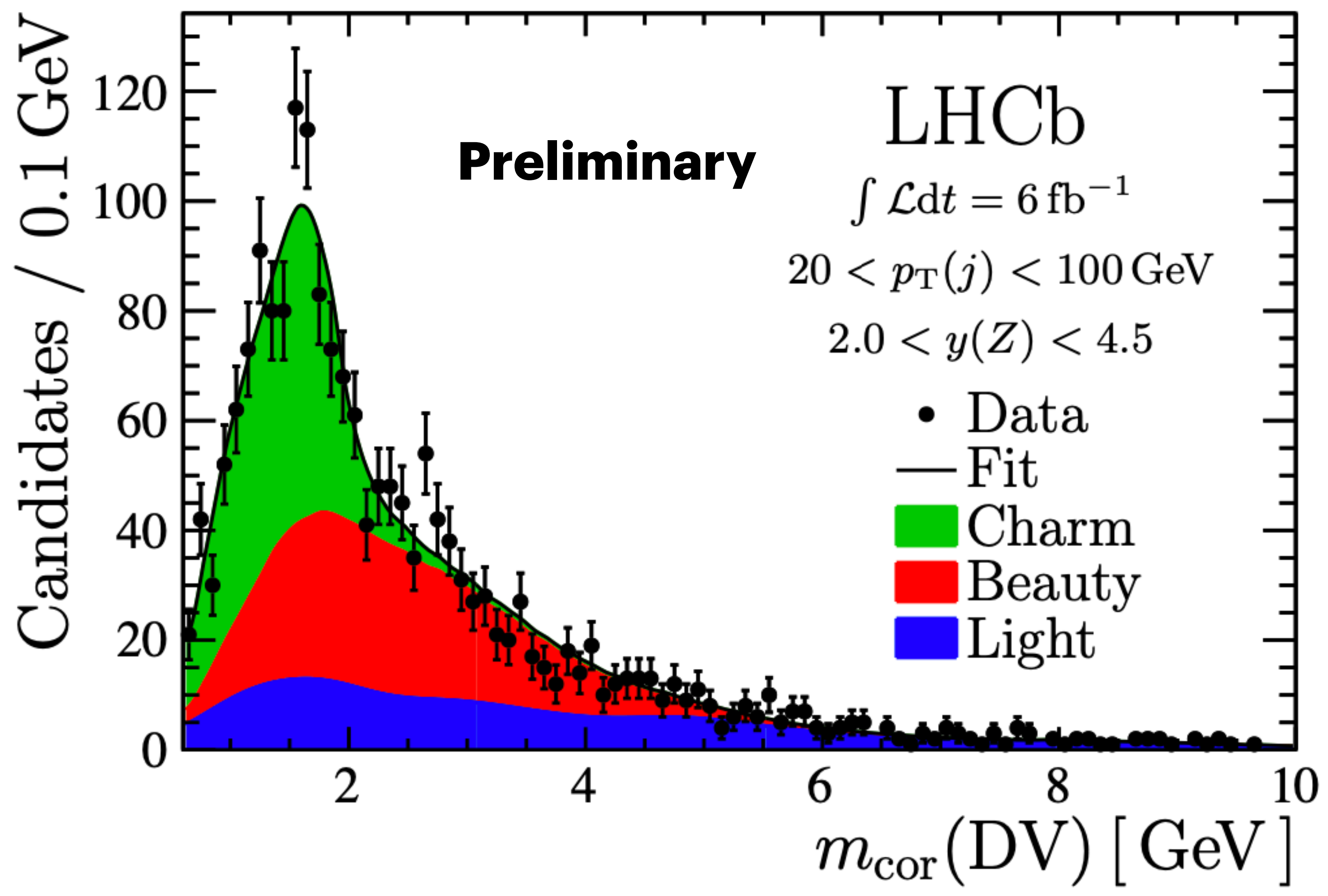

- Current limits **do not rule out the intrinsic charm content at % level**.
- The **Z+c-jet production** in the forward region is sensitive to the high-x intrinsic charm component.

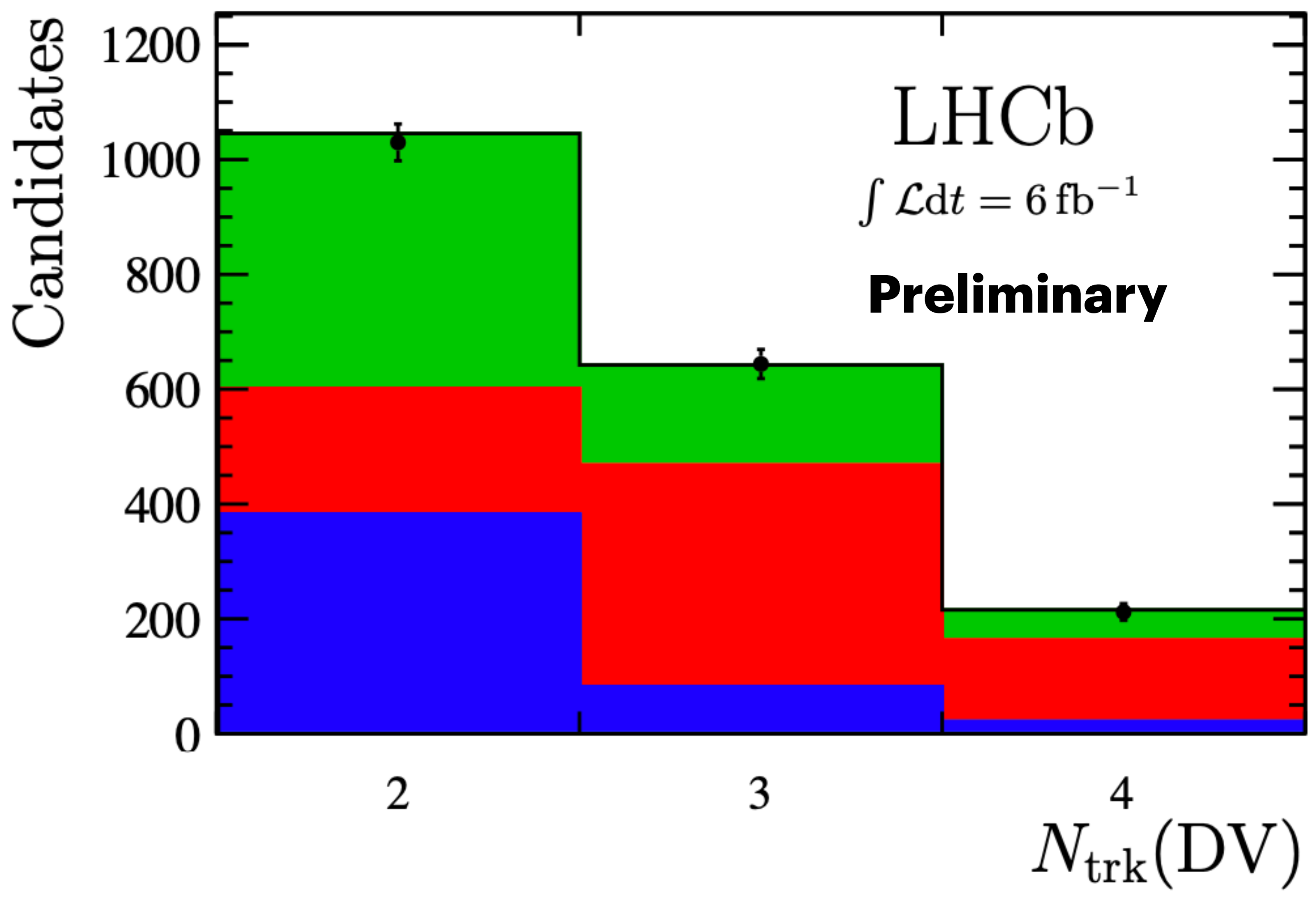
# Z+c-jet production in the forward region

NEW

**LHCb-PAPER-2021-029 in preparation**

- The 13 TeV dataset is used, for a total integrated luminosity of 6 $fb^{-1}$.
- Z boson is reconstructed in the dimuon final state -> high purity.
- Heavy flavour jets are tagged with a Displaced Vertex (DV) technique.
- **The corrected DV-mass and the number of tracks in the DV are fitted to obtain the flavour components**. Templates are obtained from calibration samples (heavy flavour enriched dijets).



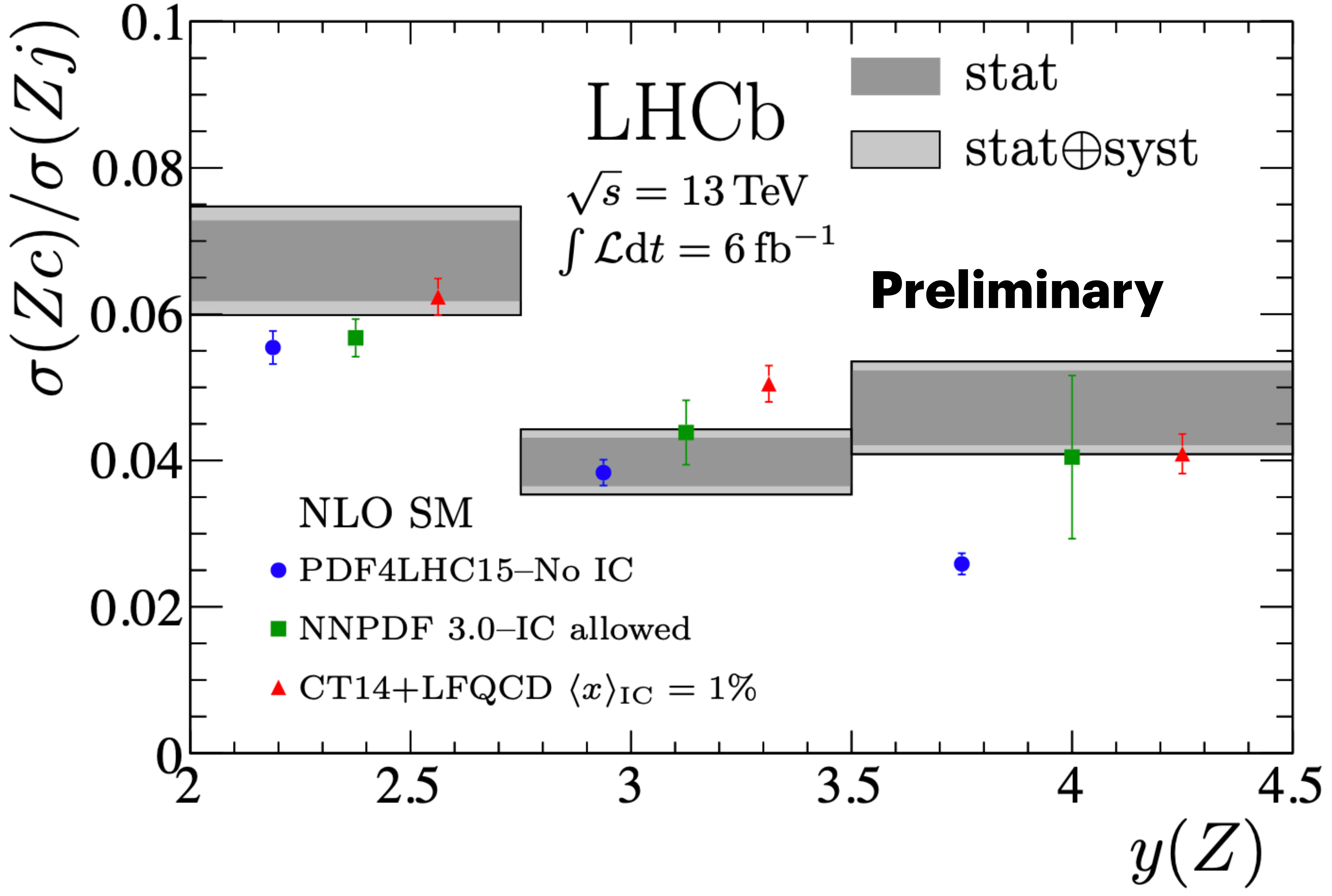
# Z+c-jet production in the forward region

NEW

**LHCb-PAPER-2021-029 in preparation**

- Systematic uncertainty dominated by the c-tagging efficiency systematic, obtained from calibration samples.

| Source | Relative Uncertainty |
|---|---|
| $c$ tagging | 6–7% |
| DV-fit templates | 3–4% |
| Jet reconstruction | 1% |
| Jet $p_{\mathrm{T}}$ scale & resolution | 1% |
| Total | 8% |




- **Hint of the intrinsic charm component in the high rapidity interval.**
- More data is needed!

# Conclusions

- **Not only flavour physics**: **LHCb is qualified as a general purpose forward experiment**!
- LHCb can perform **QCD physics measurements** in a **complementary phase space** with respect to General Purpose Detectors.
- Both perturbative and not-perturbative QCD models have been tested.
- **More exciting results are coming with Run 3**!

# Thanks for your attention!

# Backup