QCD physics measurements at LHCb

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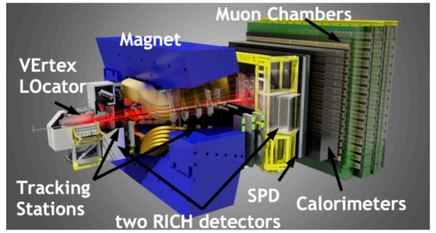
LHCb detector[1]

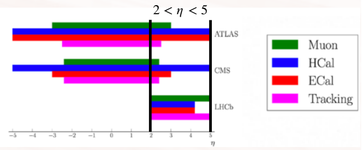
- LHCb, originally designed for b- and c-hadron physics, is now considered a **general purpose forward detector**
- Track momentum resolution: 0.4% at 5 GeV and 0.6% at 100 GeV
- Muon ID efficiency: 97% with 1-3% $\mu \to \pi$ misidentification
- Electron ID efficiency: 90% with 5% $h \to e$ misidentification
- Electron reconstruction: bremsstrahlung recovery and well-measured direction
- Excellent vertex reconstruction system → tagging of b- and c-jets with reconstruction of secondary vertices formed by tracks inside the jet cone

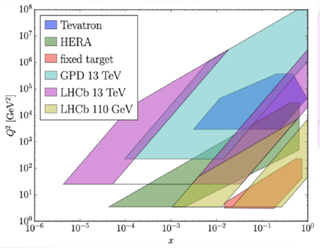


QCD physics at LHCb

- At LHCb perturbative QCD (pQCD) predictions are tested in a phase space region complementary to ATLAS and CMS
- Parton distribution functions (PDFs) and proton structure can be studied in regions not accessible by other LHC experiments:
  - **At high x values**
  - **At low x values and high Q^2, unexplored by other experiments**
- It is possible to study jet fragmentation functions in the forward region
- Results are then compared with the ones obtained by other experiments

Here results are shown for pp collisions, but also pPb, PbPb and fixed target studies are performed at LHCb



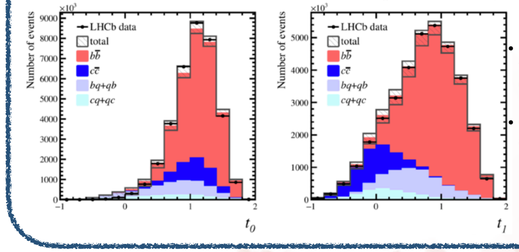


$b\bar{b}$ and $c\bar{c}$ di-jet production[2]

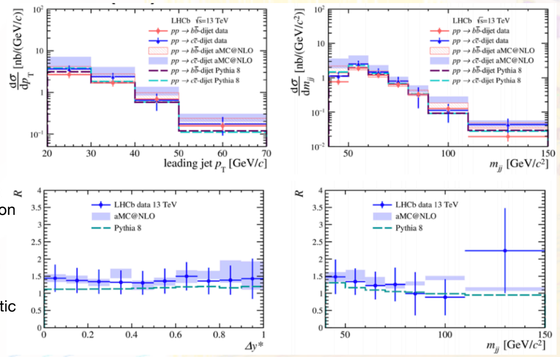
- Heavy flavour di-jet production is an excellent test of pQCD in the forward region
- 2016 dataset (1.6 fb^{-1}) is used to perform differential measurements
- Cross section measured as a function of 4 observables:

leading jet p_T | leading jet η | di-jet invariant mass m_{jj} | $\Delta y^* = 1/2\,|y_0 - y_1|$

- Fit to combination of two MVA discriminators to get flavour composition



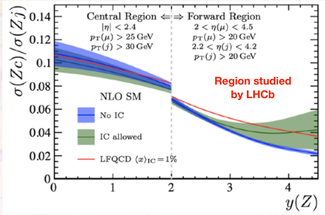
- Unfolding procedure to correct for detector effects and selection efficiencies
- Cross section ratios $R(c\bar{c}/b\bar{b})$ are also determined w.r.t. kinematic variables→ systematic uncertainty cancellation

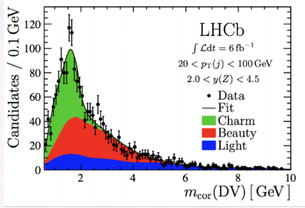


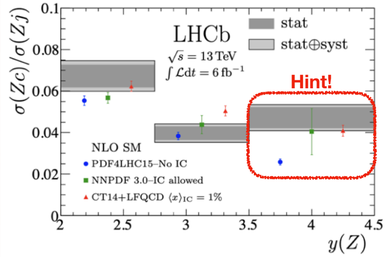
- **First measurement of $c\bar{c}$ di-jet differential cross section at a hadron collider**

$Z + c$-jet production: intrinsic charm[3]

- In proton content charm can be extrinsic or intrinsic
- Intrinsic charm PDF can be valence-like or sea-quark-like, clear signature at $x > 0.1$
- The $Z + c$-jet production in the forward region is sensitive to the high x and high Q^2 intrinsic charm component
- 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
- **Hint of the intrinsic charm component in the high rapidity interval** $(3.5 < y(Z) < 4.5)$





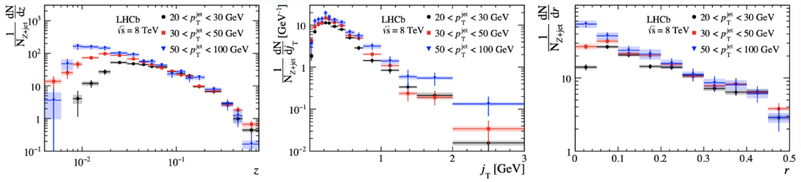


Charged hadron production in Z+jet[4]

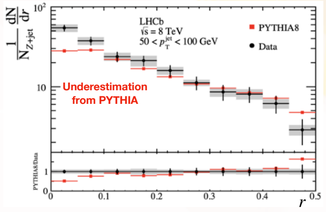
- In the forward region, $Z(\to \mu\mu)$+jet production is dominated by jets produced by light-quarks
- At LHCb it is possible to access jets with lower p_T (from 20 GeV) with respect to ATLAS and CMS
- Cross section is measured w.r.t. kinematic distributions for charged hadrons:

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

Longitudinal distribution | Transverse momentum w.r.t. jet | Radial distribution



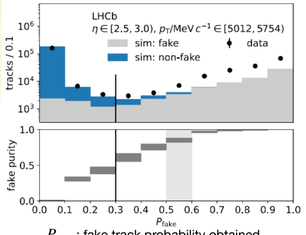
- Results are then compared with ATLAS measurements on inclusive jets
- **Main differences are due to different fragmentation of quarks and gluons**



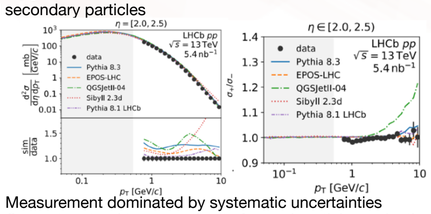
- **PYTHIA prediction does not exactly match the measurements**
- These measurements are important inputs for fragmentation functions in the forward region

Prompt charged particle production in pp collisions at 13 TeV[5]

- **Prompt charged particles**: long-lived particles produced in primary interaction or without long-lived ancestors
- Tracks considered: $2 < \eta < 4.8$ and $0.08 < p_T < 10$ GeV → loose selection with high efficiency
- Background contributions: fake tracks and secondary particles



P_{fake}: fake track probability obtained from NN classifier



- Measurement dominated by systematic uncertainties
- Generators tend to overestimate forward particle production
- Best agreement with:
  - EPOS-LHC and Pythia 8.1 (LHCb tuned) for particle density
  - Pythia 8.3 for charged ratio

Conclusions

- LHCb is now considered a **general purpose forward detector**
- QCD physics measurements are performed at LHCb studying a phase space region **complementary** to ATLAS and CMS
- Interesting results have been obtained and models for **QCD** and **pQCD** have been tested
- **New data** and **more interesting results** are coming with next Runs!

References

[1] JINST 3 (2008) S08005
[2] JHEP 02 (2021) 023
[3] LHCb-PAPER-2021-029
[4] Phys. Rev. Lett. 123 (2019) 232001
[5] LHCb-PAPER-2021-010