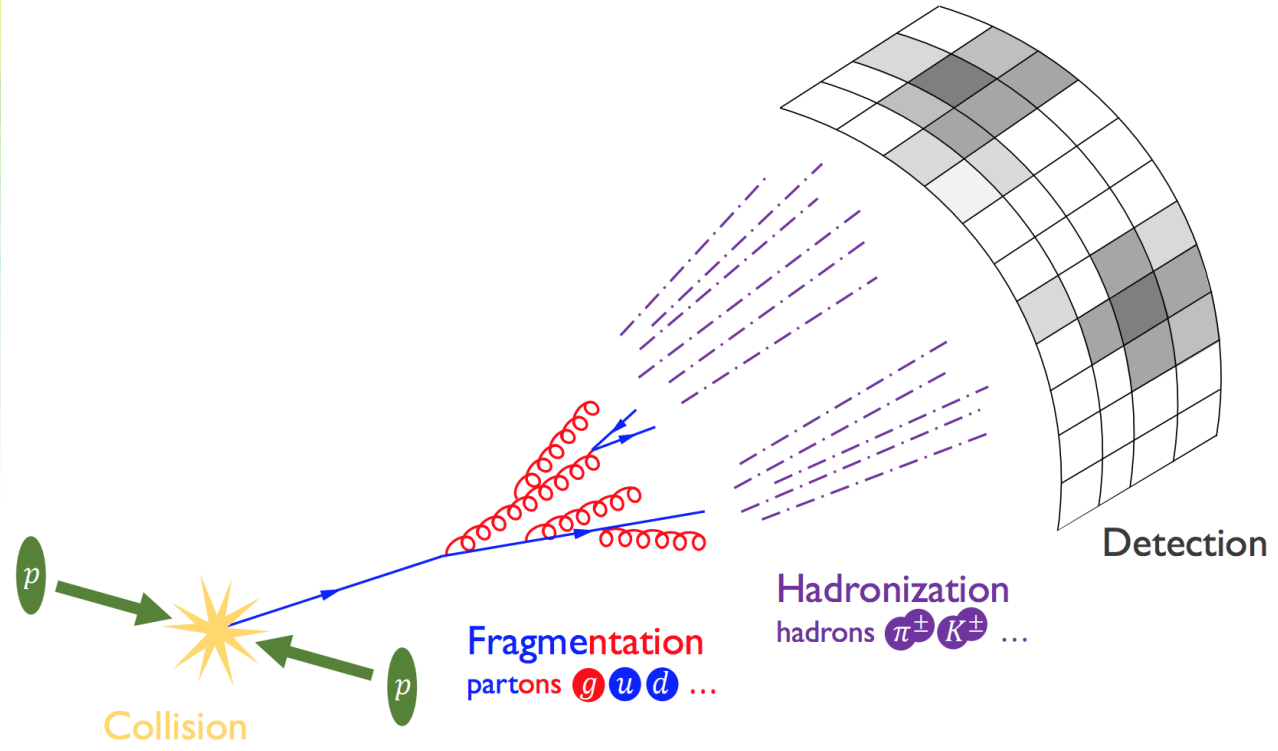
Physics with jets

Alessio Gianelle, Donatella Lucchesi, Lorenzo Sestini, Davide Zuliani

LHCb Padova Meeting, 1-12-2020

Jets

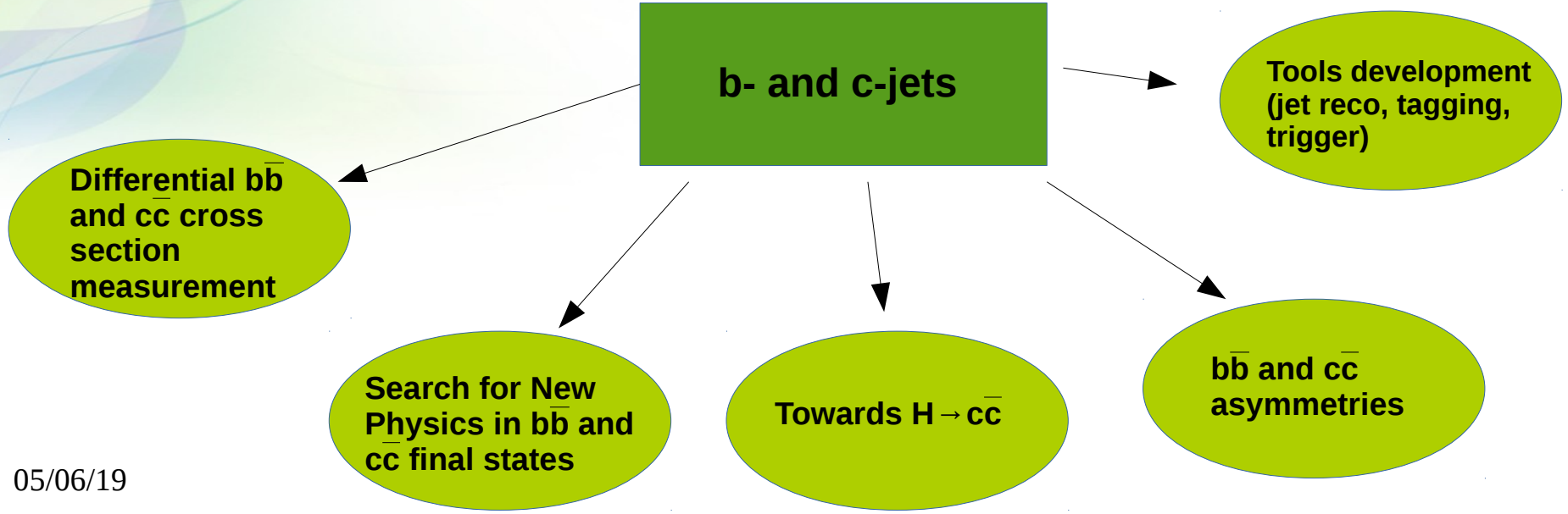
- **Collimated stream of particles produced by quark and gluon fragmentation**



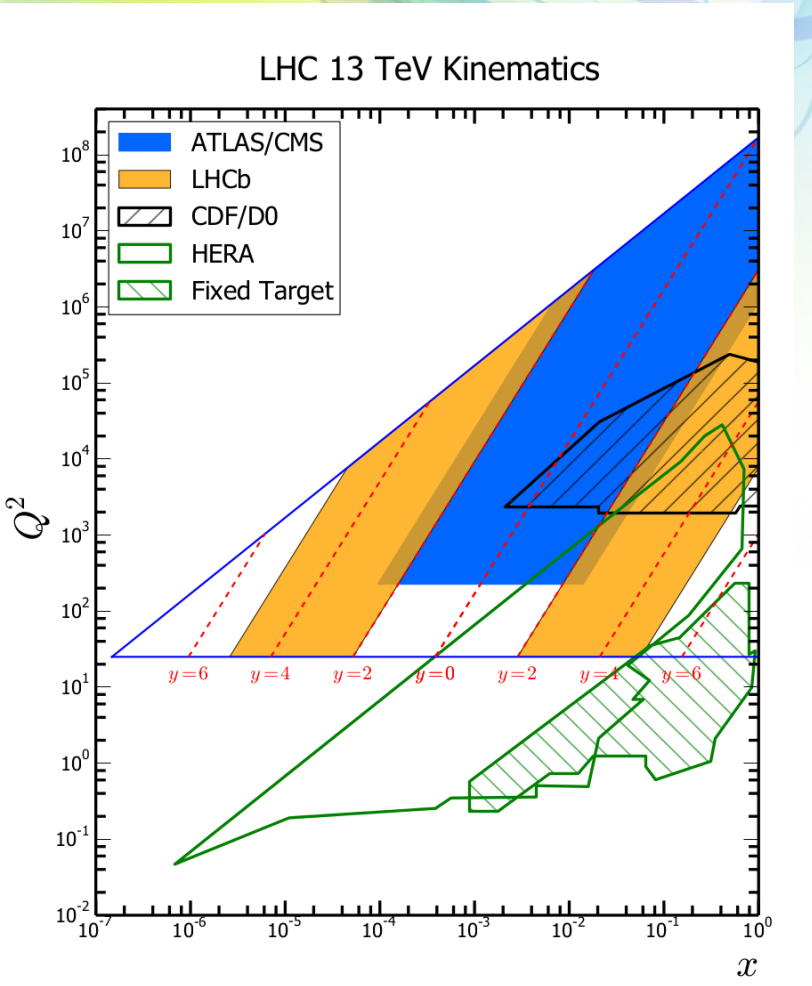
Why b- and c-jets Physics at LHCb?

Why b- and c-jets Physics at LHCb?

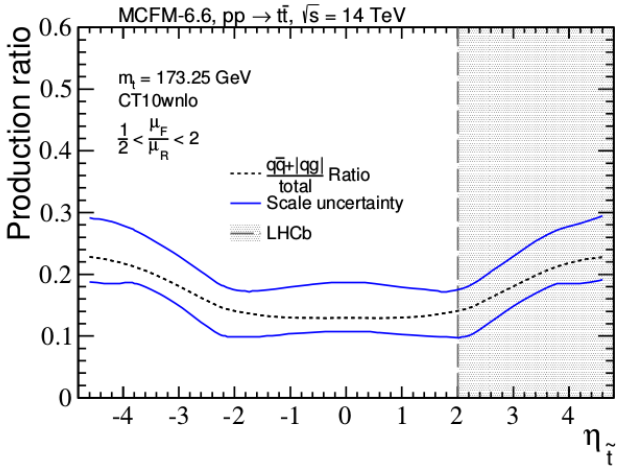
- Excellent vertex reconstruction: high performance b- and c- tagging
- Unique phase space region: Parton Distribution Functions and searches
- Boosted $q\bar{q} \rightarrow Z/\gamma^*$: asymmetries
- At ATLAS and CMS many b- and c-jets measurements are dominated by systematics: **luminosity is not the only thing that matters!**



EW, Top and jets physics @LHCb: motivations



- Cross-sections measurements of **W, Z, jets and Top production in the forward acceptance** are important tests of the Standard Model → **to be compared with (N)NLO EW and pQCD predictions**



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- These measurements provide access to **Parton Distribution Functions** in two different regions:
  - ➔ at high Bjorken-x values;
  - ➔ at low x values, **unexplored by other experiments.**
- Precise measurements of SM parameters: **the electroweak mixing angle, the W mass** etc.

Jet reconstruction algorithm

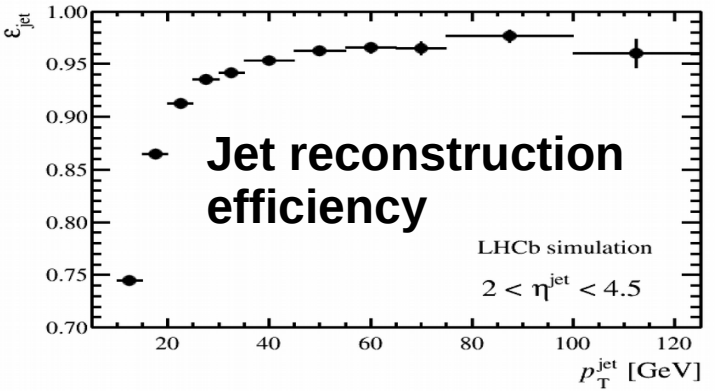
JHEP 01 (2014) 033

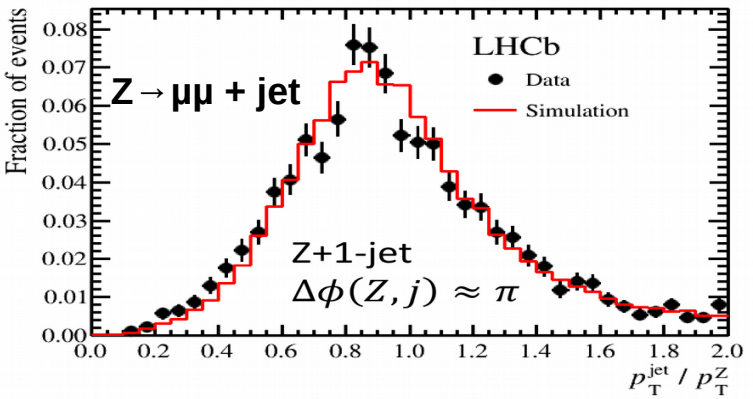
Particle Flow → **Tracks and calorimeter clusters are selected as inputs**

Anti-kt clustering → **Inputs are used to form jets of a given cone radius R=0.5**

Jet four-momentum → $E_{jet} = \sum_i E_i \quad \vec{p}_{jet} = \sum_i \vec{p}_i$

Jet energy correction → **The jet energy is corrected for detector inefficiencies (calibrated on simulation)**



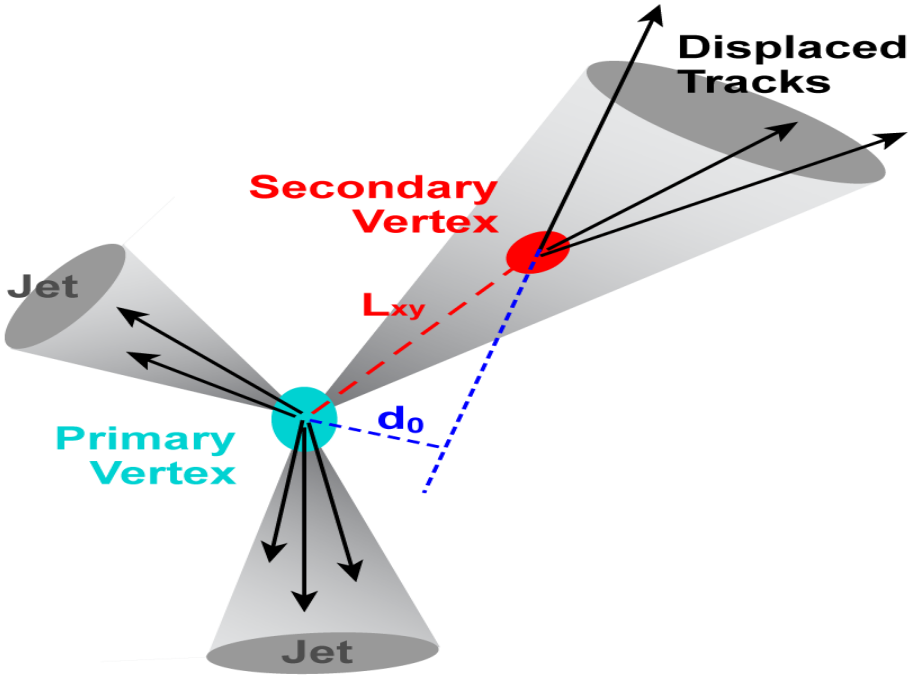


Energy resolution of final jets δE/E ≈ 10-16% in 20-100 GeV p_T range.

Jet tagging at LHCb

JINST 10 (2015) P06013

- **The jet tagging system takes advantage of LHCb features → precise vertex reconstruction!**
- As first step **Secondary Vertices** are reconstructed using tracks.
- A jet is identified to be generated from a **b** or **c** quark (**b-jet** or **c-jet**) if a **Secondary Vertex** is reconstructed within the jet cone (**ΔR <0.5**).



LHCb results with jets

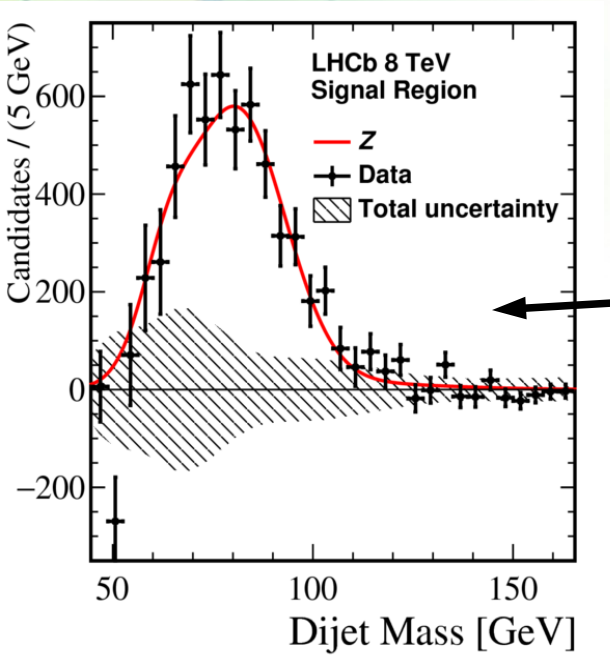
LHCb jets measurements where Padova contributed with main authors:

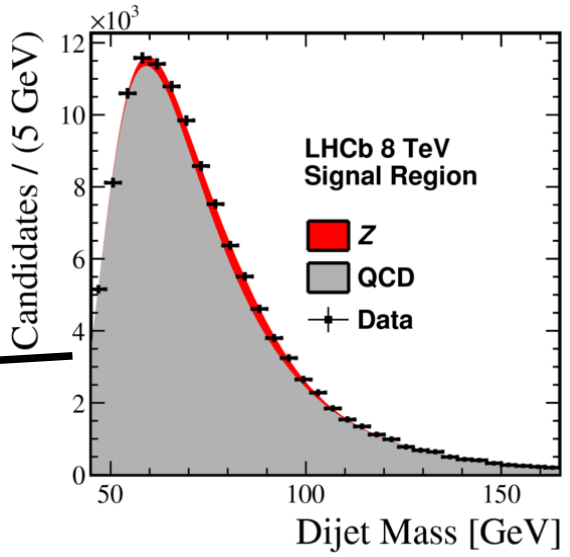
- $W+b\bar{b}$, $W+c\bar{c}$ and $t\bar{t}$ @ 8 TeV
- $VH(\rightarrow b\bar{b})$ and $VH(\rightarrow c\bar{c})$ search @ 8 TeV
- $Z \rightarrow b\bar{b}$ @ 8 TeV
- $b\bar{b}$ and $c\bar{c}$-dijet cross sections @ 13 TeV

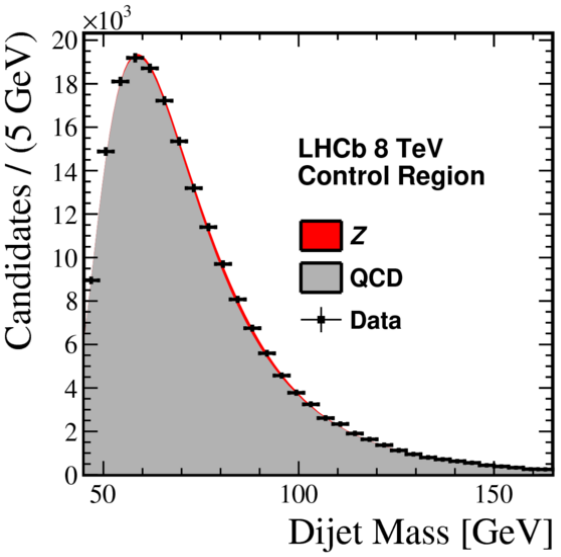
$Z \to b\bar{b}$

Phys. Lett. B776 (2017) 430-439

- Two heavy flavour tagged **anti-kt jets** with R=0.5 are selected (i.e. jet contains a secondary vertex)
- Fiducial region: $p_T(jet_{1,2}) > 20$ GeV, $2.2 < \eta(jet_{1,2}) < 4.2$, $45 < m_{jj} < 165$ GeV
- Signal and QCD-enriched control regions defined exploiting the **Z+recoil jet** kinematic







Measured: $\sigma(pp \to Z)\mathcal{B}(Z \to b\bar{b}) = 332 \pm 46(\text{stat.}) \pm 59(\text{syst.})$ pb

NLO Prediction: $\sigma(pp \to Z)\mathcal{B}(Z \to b\bar{b}) = 272^{+9}_{-12}(\text{scale}) \pm 5(\text{PDFs})$ pb

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

NEW LHCb-PAPER-2020-018

- Two heavy flavour tagged jets are selected, with $p_T(jet_{1,2}) > 20$ GeV, $2.2 < \eta(jet_{1,2}) < 4.2$, $\Delta\Phi > 1.5$

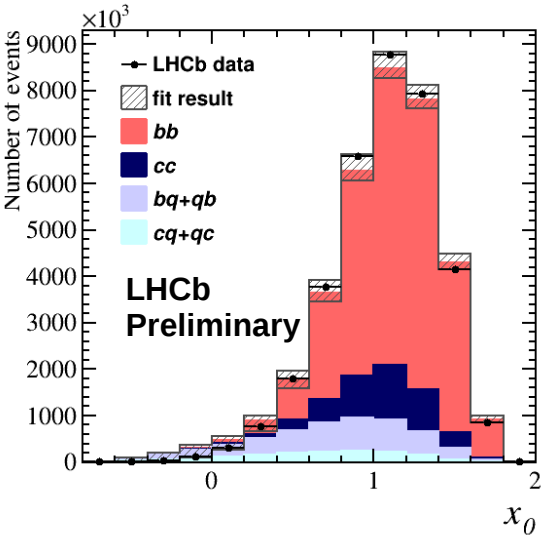
- Differential cross section measurement as a function of
  - leading jet pseudorapidity
  - leading jet transverse momentum
  - dijet invariant mass
  - $\Delta y^* = \frac{1}{2} |y_0 - y_1|$

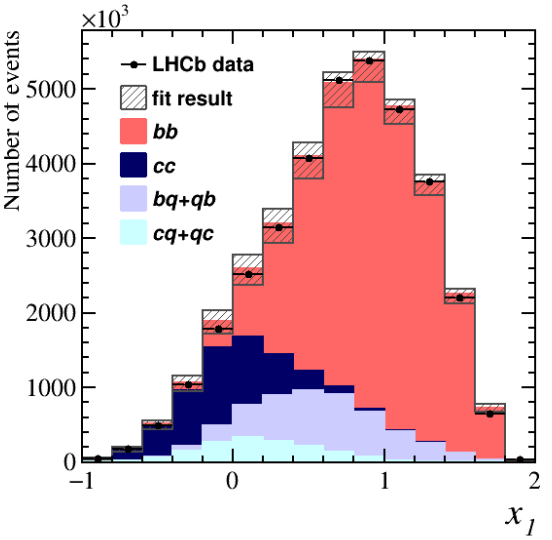
- 1.6 fb^{-1} of integrated luminosity have been used (2016 data taking)

- **2D fit to extract the flavour composition**

$$x_0 = BDT_{bc|udsg}(j_0) + BDT_{bc|udsg}(j_1)$$
$$x_1 = BDT_{b|c}(j_0) + BDT_{b|c}(j_1)$$

- Fit result dominated by systematic uncertainties on procedure and template modeling.

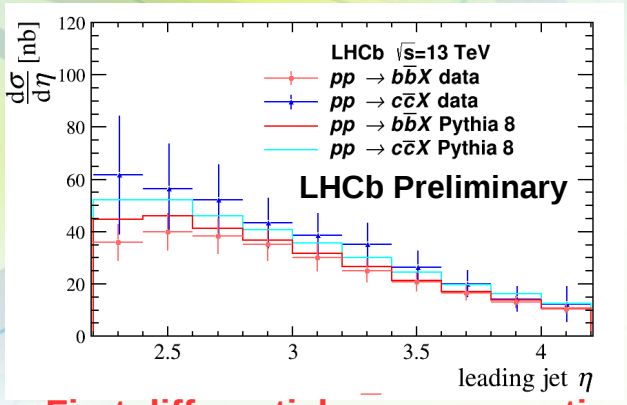


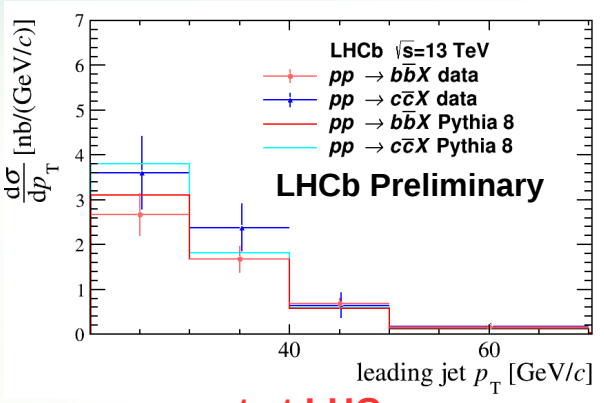


$b\bar{b}$- and $c\bar{c}$-dijet production

NEW LHCb-PAPER-2020-018

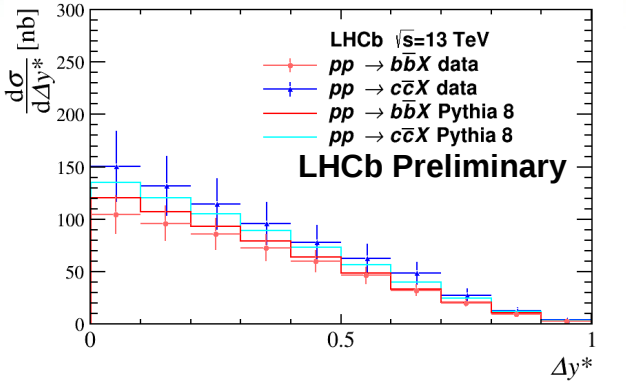
- Measured yields are unfolded for detector effects and corrected for selection efficiencies.
- Overall uncertainty (~20%) dominated by heavy flavour tagging efficiency.

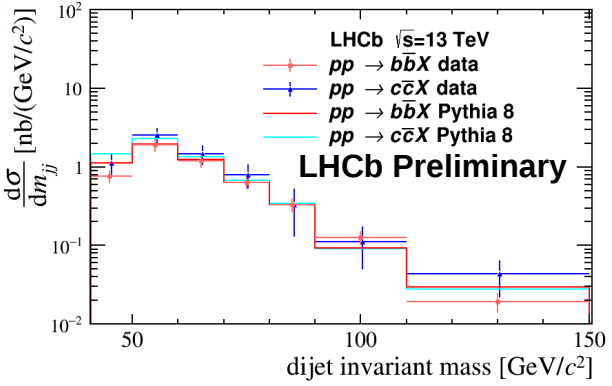


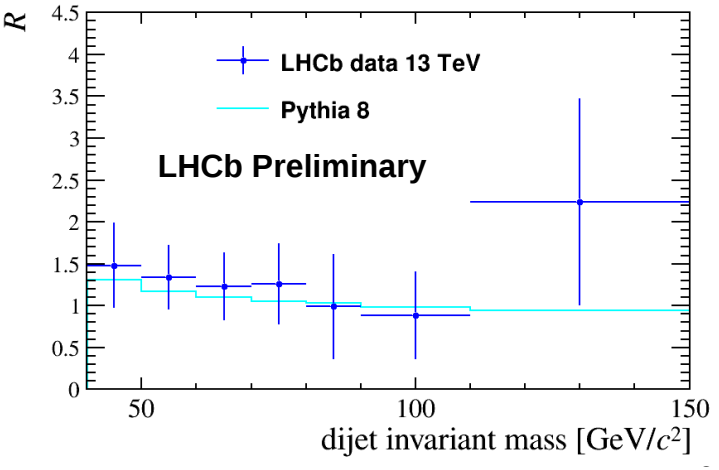


First differential $c\bar{c}$ cross section measurement at LHC

The cross section ratio (cc/bb) is also determined

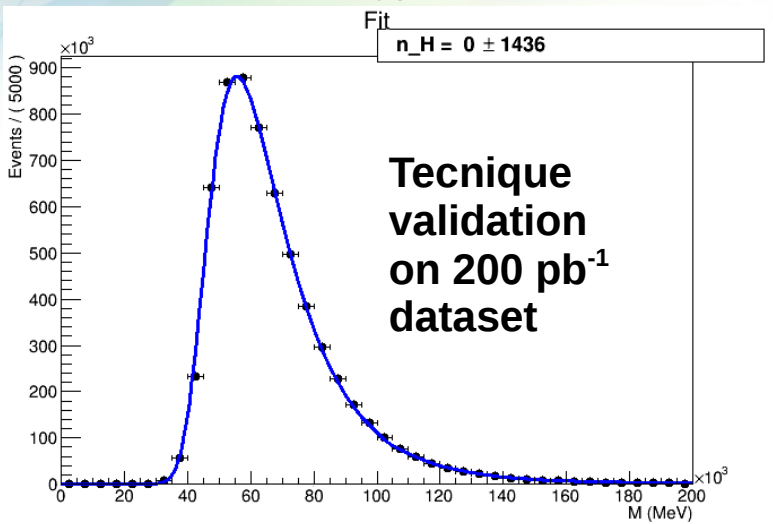


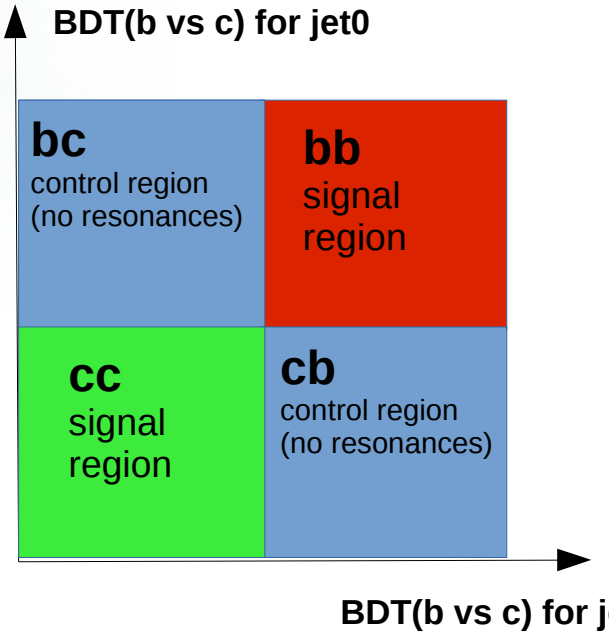




Search for New Physics in $b\bar{b}$ and $c\bar{c}$ final states

- $b\bar{b}$ and $c\bar{c}$ are preferred decay channels in several New Physics models.
- **Inclusive search for $b\bar{b}$ and $c\bar{c}$ resonances at LHCb.**
- **Analysis leaded by LHCb-Padova.**
- Set a model independent limit on Higgs-like particles at different masses.
- First $c\bar{c}$ search of this type.

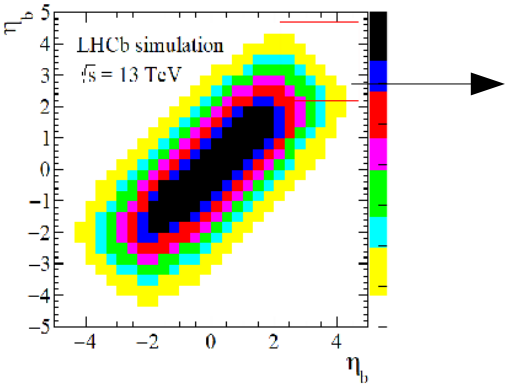




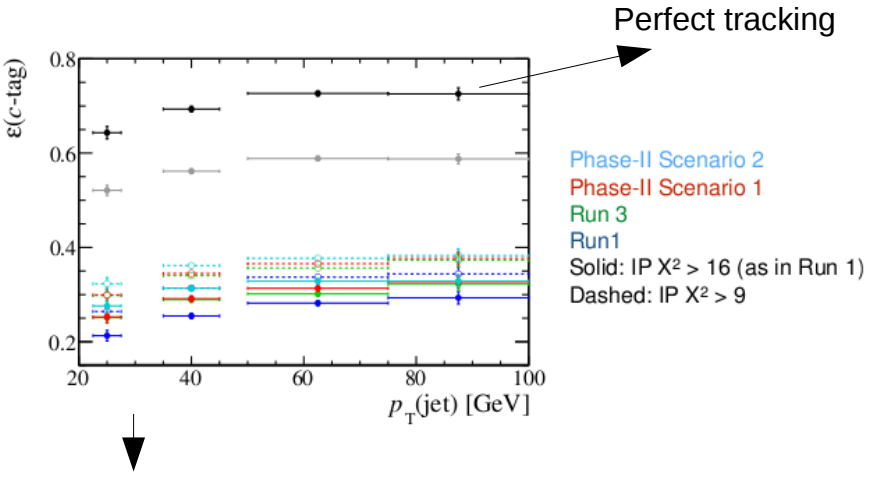
- The modelling of the QCD background is the challenge.
- Control region + transfer function technique.

Towards H → $c\bar{c}$ at HL-LHCb

- **Prospects on W/Z+H→$c\bar{c}$ in HL-LHC yellow paper** (Section written by L. Sestini and O. Augusto)
- Without improvements (Run II detector and algorithms) with 300 fb^{-1} we can set a limit on the signal strenght of **$\mu^{cc} < 50$**
- Assuming Phase 2 upgrade (in particular new SV reconstruction and ECAL) → **$\mu^{cc} < 5\text{-}10$**
- Limits on the Yukawa coupling of **$g^{cc}/g^{cc}_{SM} < 2\text{-}3$**
- Sensitivity of the same order of ATLAS and CMS: **the LHC experiments combination would not be far from the observation!**



5% Higgs acceptance at LHCb



c-tagging performance with standard LHCb algorithm

$b\bar{b}$ and $c\bar{c}$ asymmetry measurements

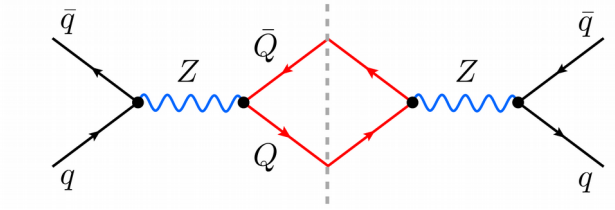
- Differential charge asymmetry:

$$\frac{\mathrm{d}A}{\mathrm{d}m_{Q\bar{Q}}} = \left(\frac{\mathrm{d}\sigma_S}{\mathrm{d}m_{Q\bar{Q}}}\right)^{-1} \left(\left.\frac{\mathrm{d}\sigma_A}{\mathrm{d}m_{Q\bar{Q}}}\right|_{\Delta y>0} - \left.\frac{\mathrm{d}\sigma_A}{\mathrm{d}m_{Q\bar{Q}}}\right|_{\Delta y<0}\right)$$

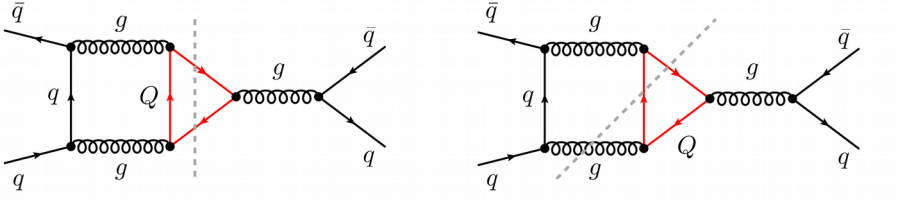
- Strictly related to fundamental SM parameters (electroweak mixing) → sensitivity to New Physics, in particular near the Z peak.

- **Test of fermionic universality of Z couplings**: a 3σ discrepancy still exists between A_{FB}^{bb} at LEP and A_{FB} with polarised electrons at SLC.

Interesting region 1: $m_{Q\bar{Q}}$ ~ 90 GeV



Interesting region 2: $m_{Q\bar{Q}}$ ~ [100,350] GeV

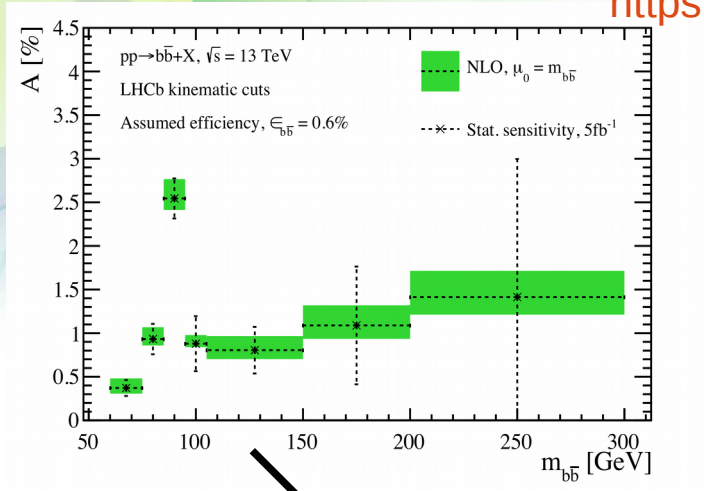


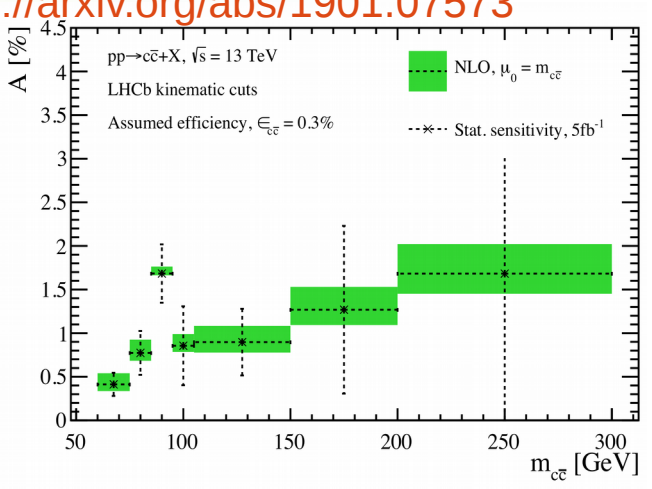
→ Sensitivity to both regions enhanced at LHCb: less gluon fusion, PDF asymmetry larger

$b\bar{b}$ and $c\bar{c}$ asymmetry measurements

- LHCb phase space region: asymmetries are less diluted with respect to ATLAS and CMS!
- First measurement of $c\bar{c}$ asymmetry, update of $b\bar{b}$ asymmetry (previous LHCb measurement).

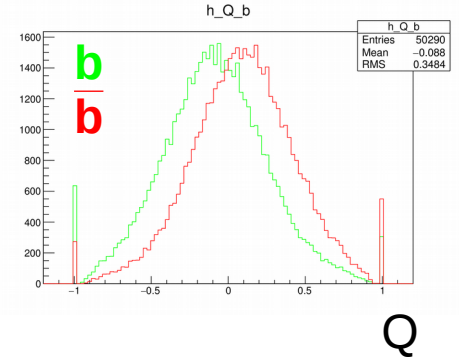
https://arxiv.org/abs/1901.07573





Sensitivity obtained assuming just muon tagging

Charge tagging

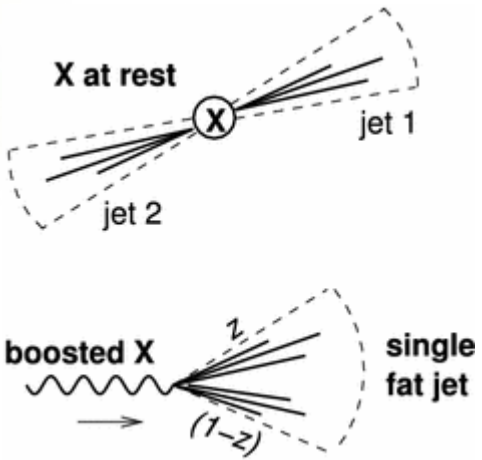


Inclusive tagging (jet sub-structure)

New jet flavour tagging algorithms are under study

Other topics we are studying

- W → jets decay
- inclusive dijets → measurement of α_s
- measurements with boosted topologies: fat jets



Backup

Heavy flavour jet tagging

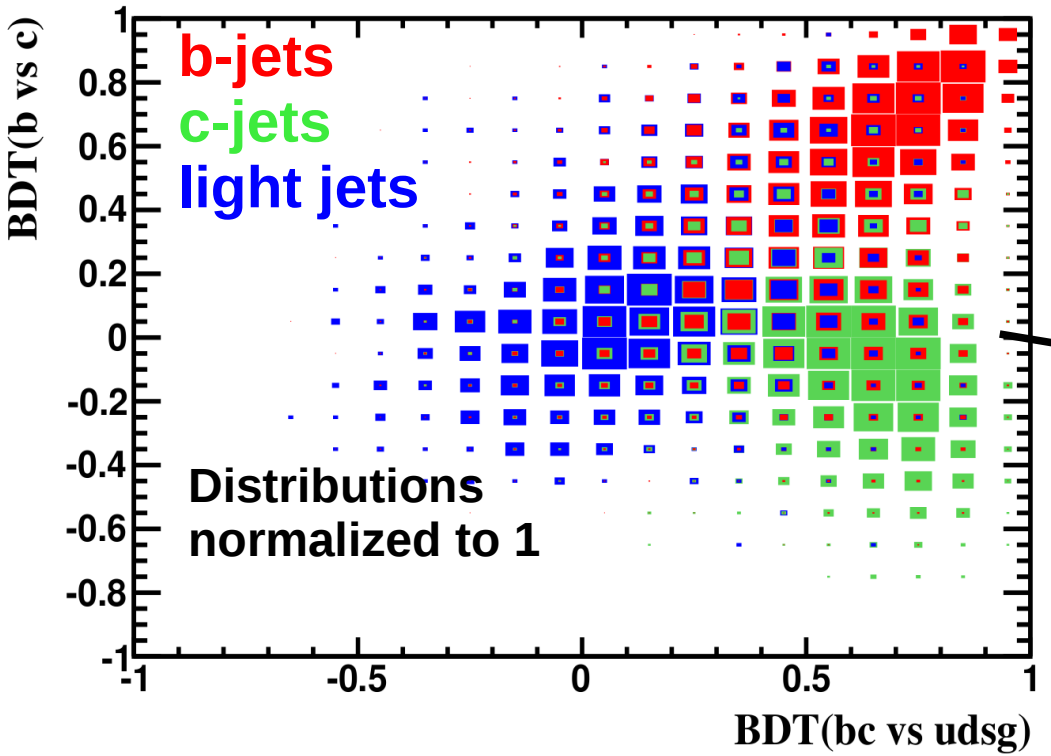
JINST 10 (2015) P06013

• Jets are heavy flavour tagged if one Secondary Vertex compatible with a b or c hadron decay is found with $\Delta R < 0.5$ from the jet axis.

• Two **Boosted Decision Trees** are used to identify b and c jets.

BDT(bc|udsg)
To separate **heavy flavour** jets from **light** jets

BDT(b|c)
To separate **b-jets** from **c-jets**



A good discrimination power is achieved!

Dedicated talk in QCD session last tuesday