Higgs Physics at LHCb

Davide Zuliani*

University and INFN of Padova

On behalf of the LHCb Collaboration

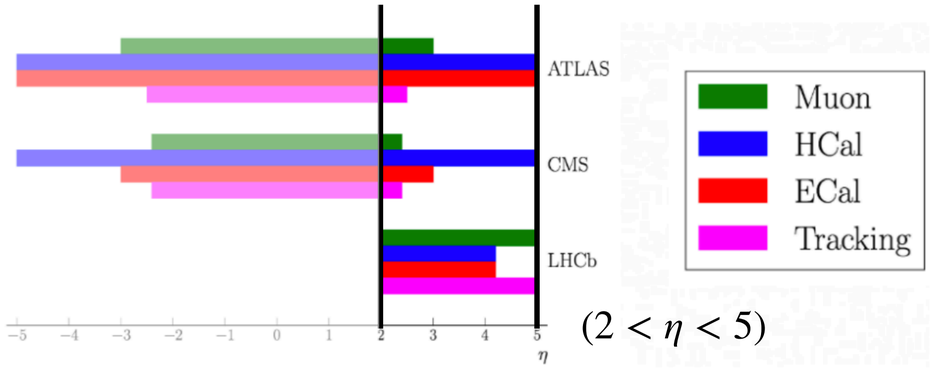
* for questions/comments:
davide.zuliani@cern.ch

LHCb experiment

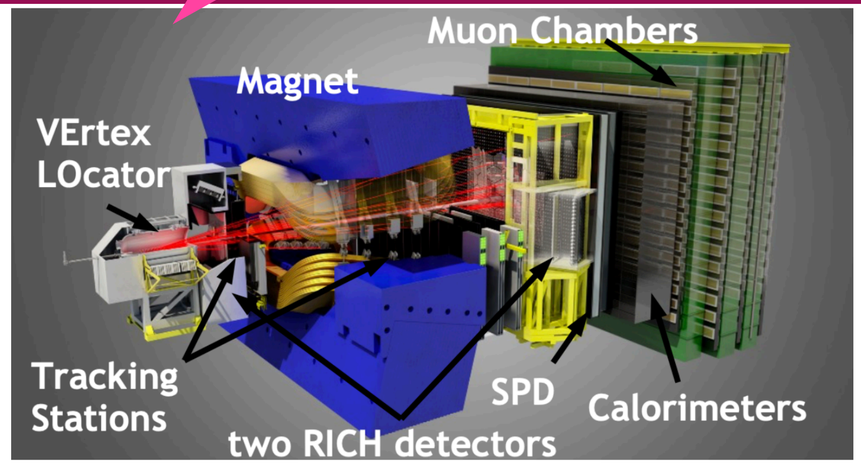
A General Purpose *Forward* Detector

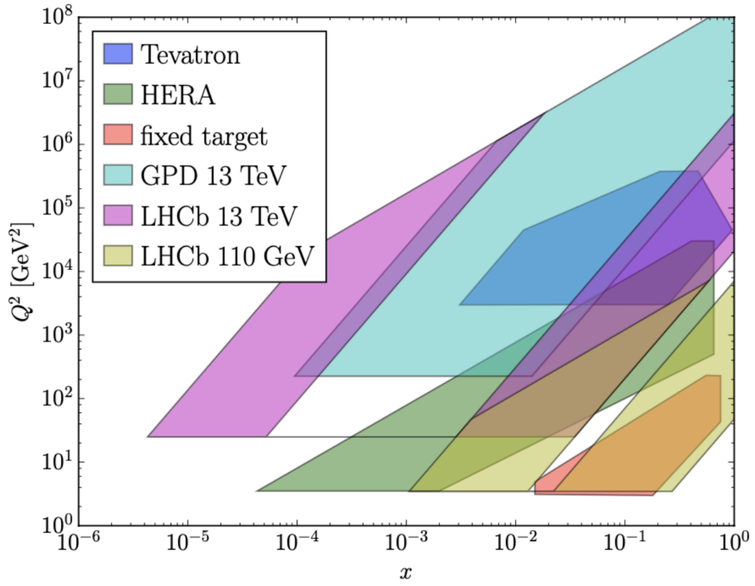
JINST 3 (2008) S08005
Int. J. Mod: Phys. A 30, 1530022 (2015)
CERN-LPCC-2018-04

- LHCb, originally designed for b- and c-hadron physics, is now considered a **general purpose forward detector**
- **Excellent track momentum resolution**: 0.4% at 5 GeV and 0.6% at 100 GeV
- Very good muon and electron ID efficiency
- **Excellent vertex reconstruction helps in jets identification**: tagging of b- and c-jets with reconstruction of secondary vertices
- LHCb allows to test perturbative QCD (pQCD) predictions in a phase space $(2 < \eta < 5)$ **complementary to General Purpose Detectors** (ATLAS & CMS)
- Parton distribution functions (PDFs) and proton structure can be studied in **regions not accessible by other LHC experiments**



$(2 < \eta < 5)$



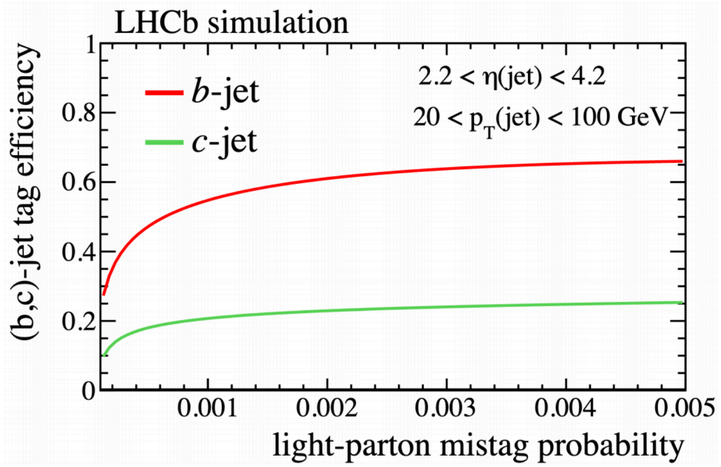


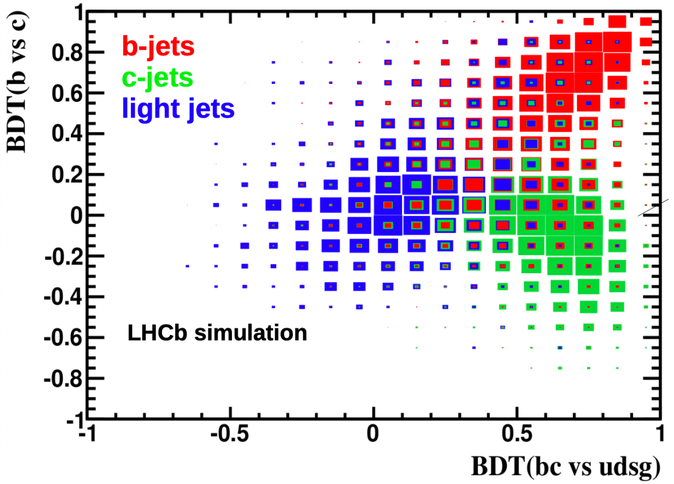
Search for $H \to b\bar{b}$ and $H \to c\bar{c}$ in association W/Z

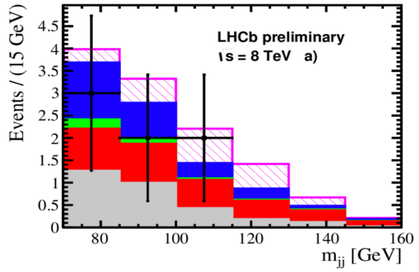
First tentative @ LHCb

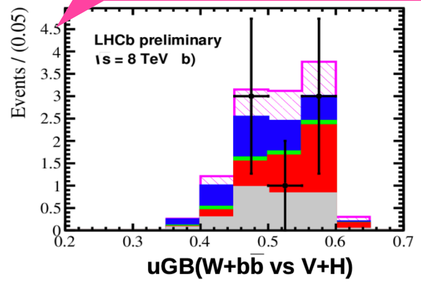
JINST 10 P06013
LHCb-CONF-2016-006

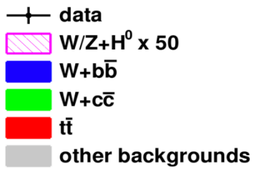
- The Higgs boson can be produced associated with a vector boson
- Search for a $b\bar{b}$ ($c\bar{c}$) + lepton signature, sensitive to WH and ZH signals, using Run I data ($\mathscr{L} \sim 2$ fb^{-1})
- Need to **efficiently tag jets** coming from b, c and light quarks (u, d, s, gluon)
- Jet tagging by means of **Boosted Decision Trees (BDT)**
- Good tagging efficiency with respect to mistag

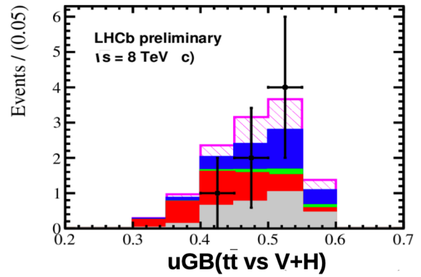


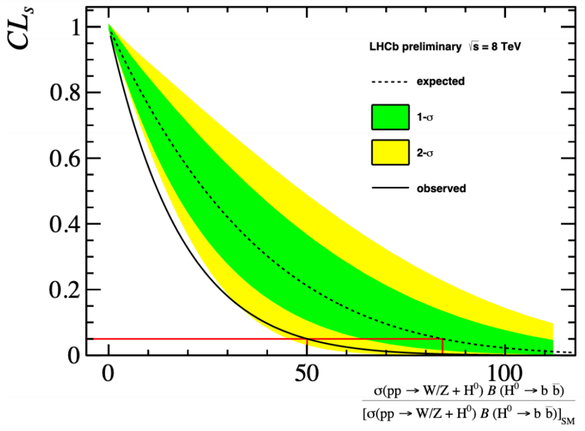












- No signals are observed, upper limits on Yukawa couplings: $y^b < 7y^b_{SM}$, $y^c < 80y^c_{SM}$

Measurement of $b\bar{b}$ and $c\bar{c}$ differential cross section

Disentangling b and c jets

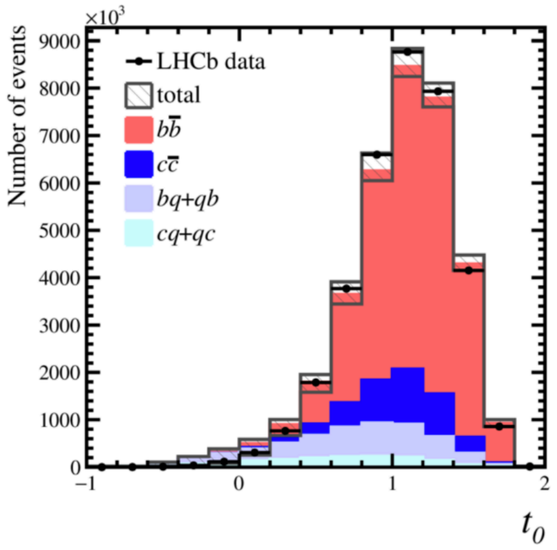
- The main idea is to study the inclusive decay of high mass resonances decaying to $b\bar{b}$ and $c\bar{c}$ di-jets
- It is possible to study lower invariant masses with respect to ATLAS/CMS
- **A first study has been performed to measure $b\bar{b}$ and $c\bar{c}$ differential cross sections with 2016 data**
- Fit to combination of two MVA discriminators t_0 and t_1 to get flavour composition:

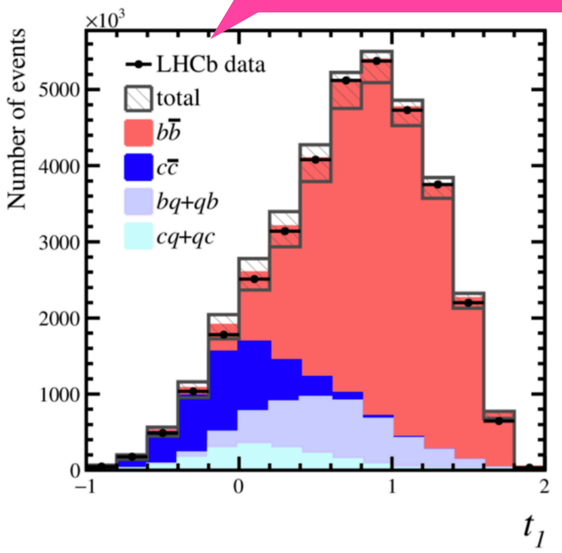
$$t_0 = \mathrm{BDT}_{bc|q}(j_0) + \mathrm{BDT}_{bc|q}(j_1)$$

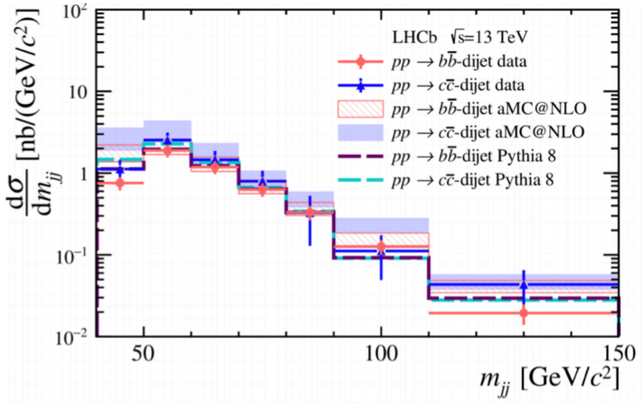
$$t_1 = \mathrm{BDT}_{b|c}(j_0) + \mathrm{BDT}_{b|c}(j_1)$$

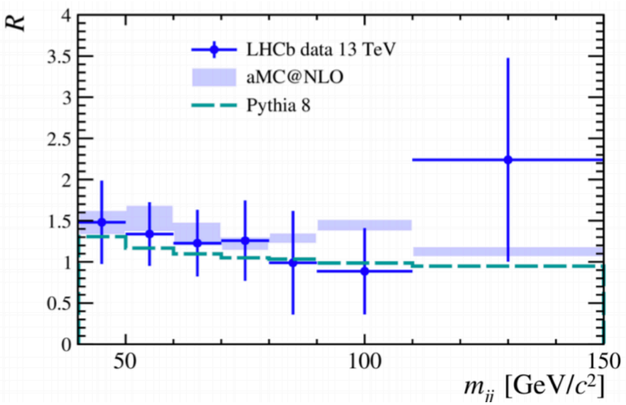
- The cross section ratios $R = \sigma_{b\bar{b}}/\sigma_{c\bar{c}}$ are also computed as functions of kinematic variables
- Results are compatible with expectations
- **First measurement of $c\bar{c}$ di-jet differential cross section at a hadron collider**

JHEP 02 (2021) 023









Towards an inclusive search for $H \to b\bar{b}$ and $H \to c\bar{c}$

What can we do @ LHCb?

- We are aiming towards a search for $H \to b\bar{b}$ and $H \to c\bar{c}$ in a **two jets final state**
  - Full Run 2 search, using $\mathscr{L} \sim 6$ fb^{-1}
  - No requirements applied to additional objects
  - **Model-independent approach** → no dependence on the Higgs production mechanism

- With respect to the past, **two main improvements**:
  - **Regression technique** for **jet energy correction**
  - **Deep Neural Network** for **jet identification**

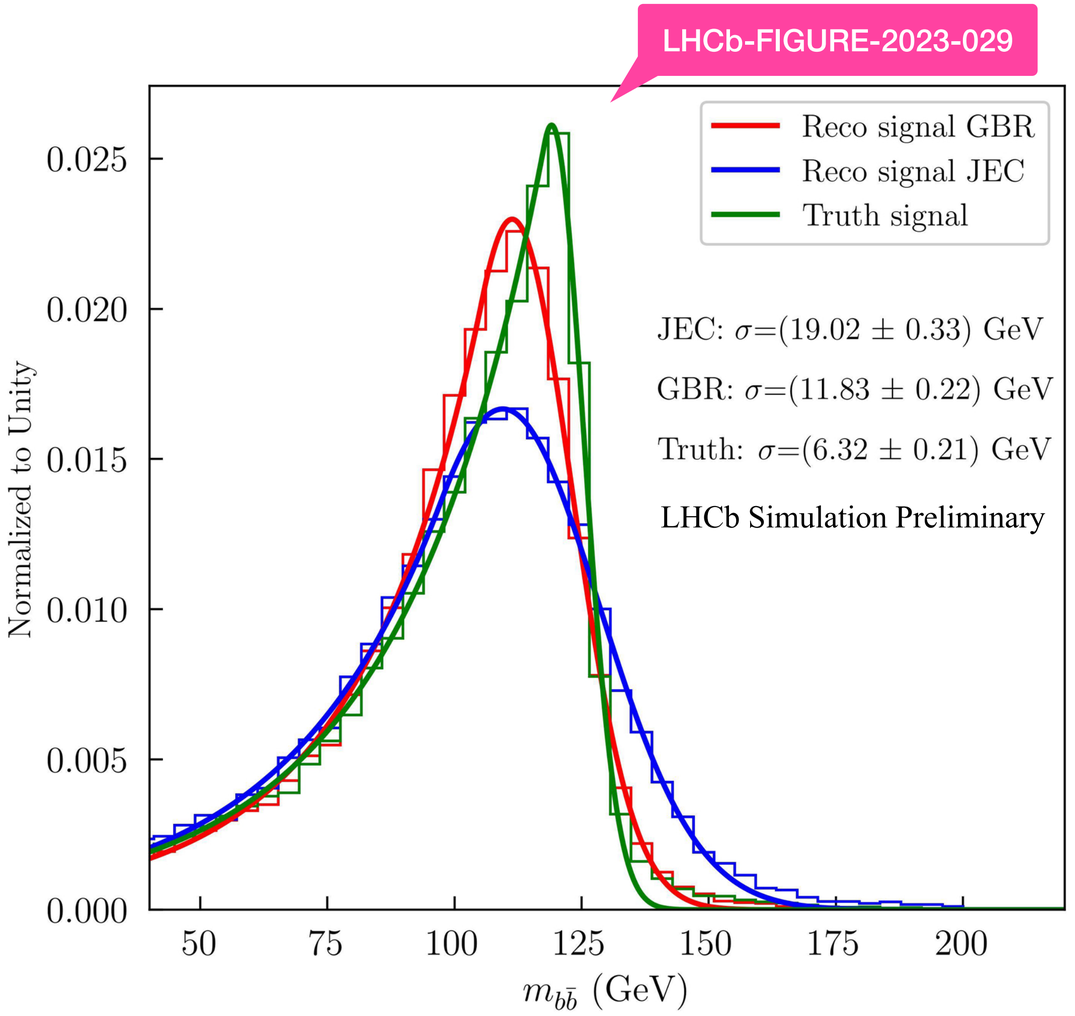
- Today showing only a few performance plots on these new improvements
  - Analysis almost ready and in review

Towards an inclusive search for $H \to b\bar{b}$ and $H \to c\bar{c}$

Regression technique for di-jets invariant mass

- The search for $H \to b\bar{b}$ and $H \to c\bar{c}$ is based on a fit to the invariant mass
- A new reconstruction tool is used, based on a **regression technique**
- A **Gradient Boosted Regressor** (GBR) is used to reconstruct the reconstructed invariant mass
- 51 observables from the **jet kinematics** and **substructure** are used

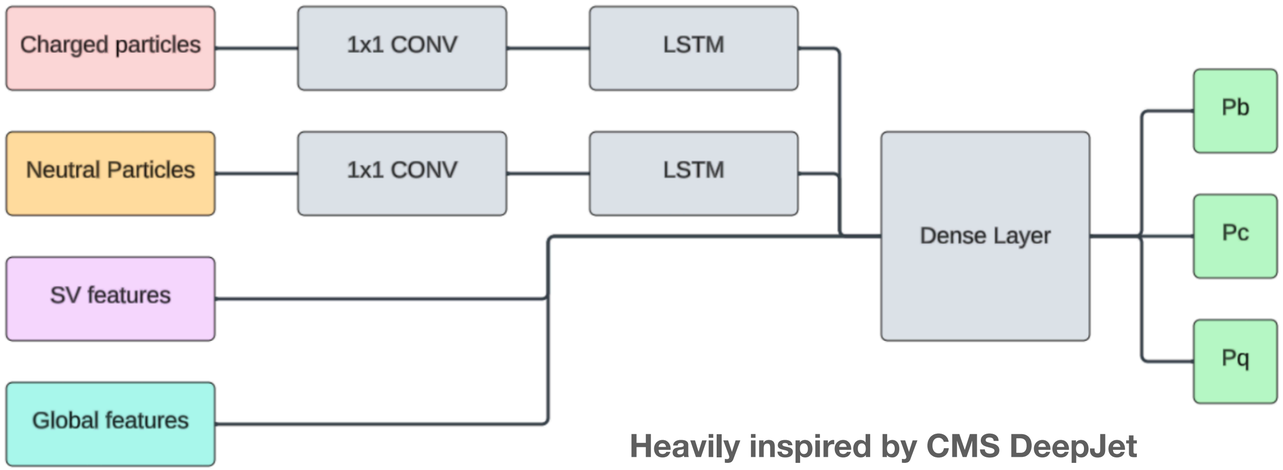
- This technique specifically targets the **Higgs reconstruction**
- Compared to standard Jet Energy Correction (JEC) tools, a 50% **improvement** on the Higgs invariant mass is found



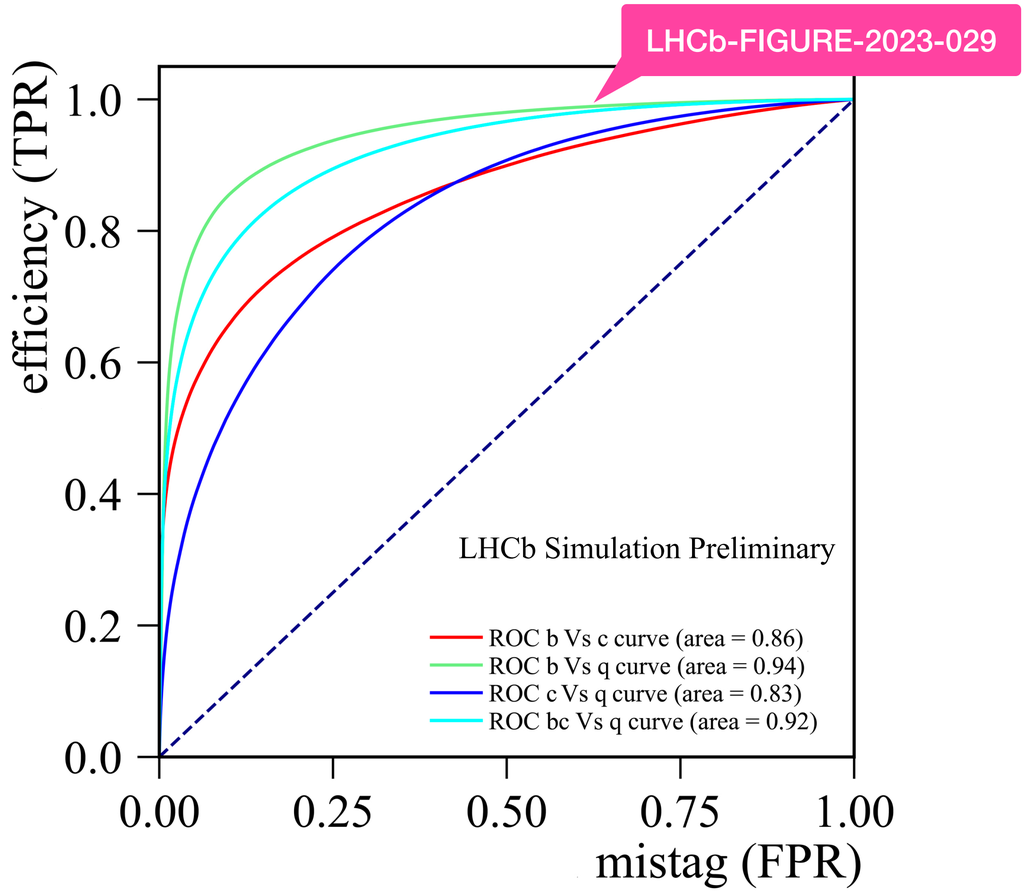
Towards an inclusive search for $H \to b\bar{b}$ and $H \to c\bar{c}$

DNN for jet tagging

- Currently, jet tagging relies on **Secondary Vertex** (SV) identification and BDTs to distinguish between bc vs. q and b vs. c
  - This is **limited** by the **SV reconstruction efficiency**
- "New" approach: Deep Neural Network (DNN)
  - 400 jet observables are used as inputs (**not necessarily requiring SV**)
  - Features related to **jet constituents** and **sub-structure**
  - 3 output probabilities: P_b, P_c and P_q



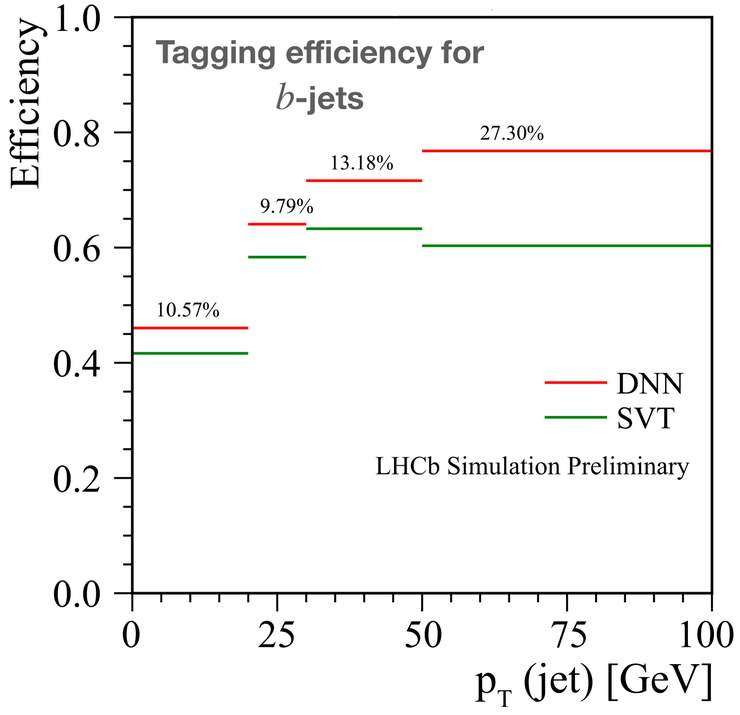
Heavily inspired by CMS DeepJet

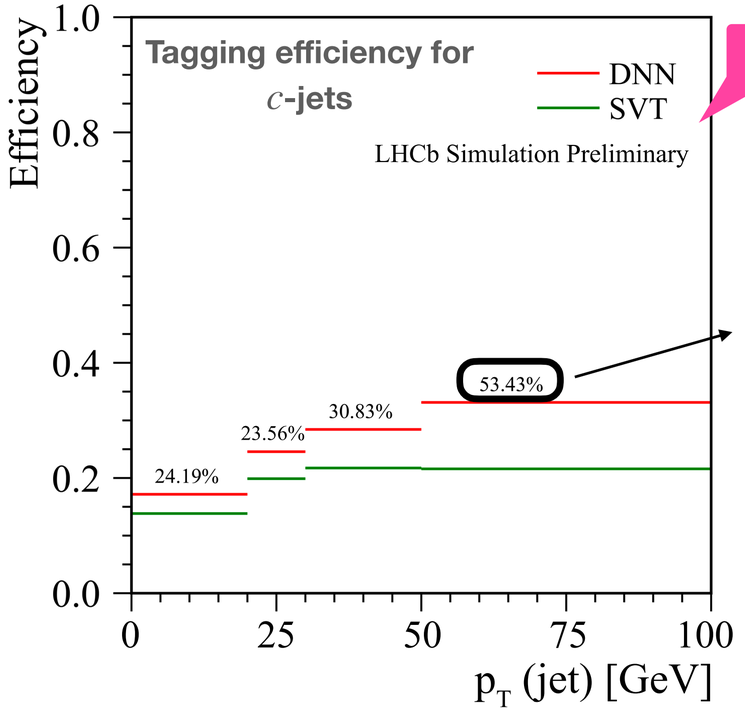


Towards an inclusive search for $H \to b\bar{b}$ and $H \to c\bar{c}$

DNN for jet tagging

- The DNN is trained using $b\bar{b}$, $c\bar{c}$ and $q\bar{q}$ di-jets simulation
  - **SV is not strictly required** (very important for future runs of LHCb)
- Performance with respect to standard SV tagging (SVT) algorithm show **good improvement** ($> 20\,\%$ for c-jet tagging)
  - These plots are obtained requiring the DNN to have the **same light jet mis-identification** as SVT ($\sim 1\,\%$)





LHCb-FIGURE-2023-029

Relative improvement wrt SVT

Higgs @ LHCb in future upgrades

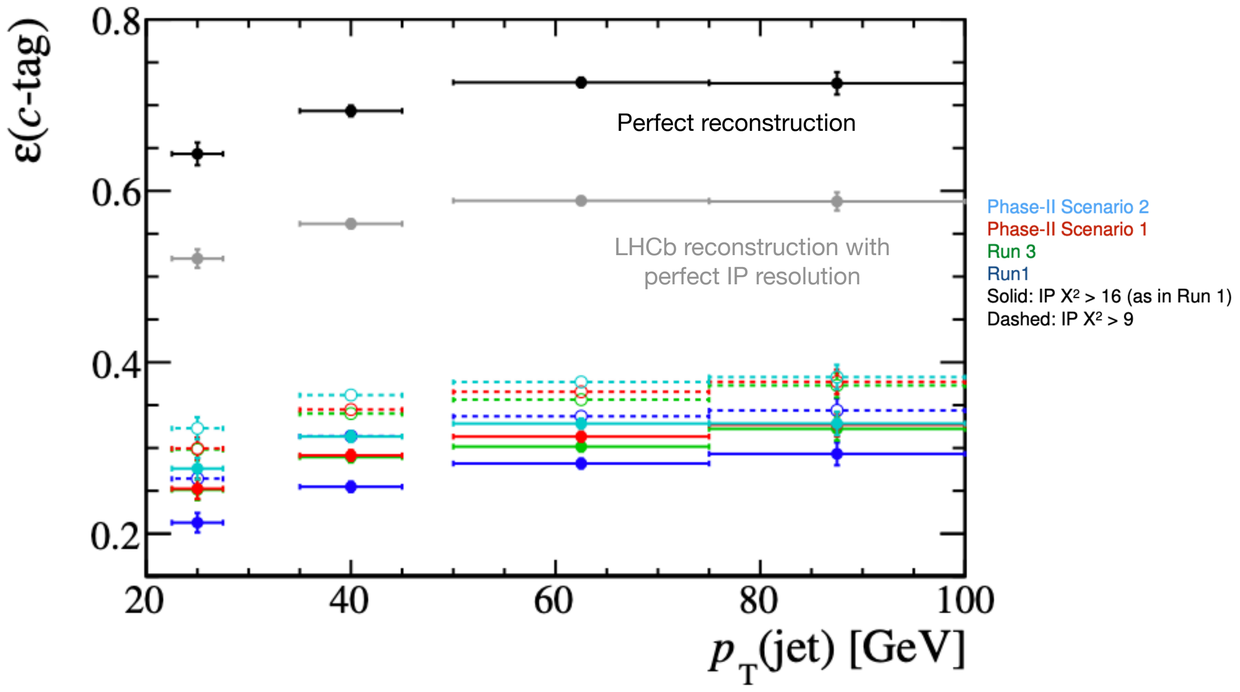
What is the future of Higgs boson studies at LHCb upgrades?

- LHCb could definitely improve its results for $H \to c\bar{c}$:
  - Simply rescaling results by **increasing integrated luminosity** to 300 fb^{-1} (end of Run 5)
  - **Loosing c-tagging criteria** would allow us to get jet tagging efficiency $> 30\,\%$
  - VELO-induced c-tagging efficiency (from $25\,\%$ to $30\,\%$)
  - **Better** discrimination between b- and c-quarks (e.g. **Machine Learning** algorithms, similar to CMS and ATLAS)

- **We are expecting a sensitivity on Yukawa coupling for c quark** $\sim 2y^c_{SM}$

- Extrapolations to HL-LHC results will be updated once Run 2 analysis is complete

LHCB-PUB-2018-009
CERN-LPCC-2018-04



Conclusions

Wrap up

- LHCb is by all means a **general purpose forward detector**
  - At LHCb it is possible to study QCD and EW physics
- **We are towards the first inclusive search for $H \to b\bar{b}$ and $H \to c\bar{c}$ in the forward region**
  - New tagging approach
  - New GBDT mass regressor to reconstruct di-jet invariant mass

Stay tuned for some interesting results!

Thank you for your attention!