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Search for Higgs decay to charm quark pair at LHCb

Davide Zuliani*

University and INFN of Padova

On behalf of the LHCb Collaboration



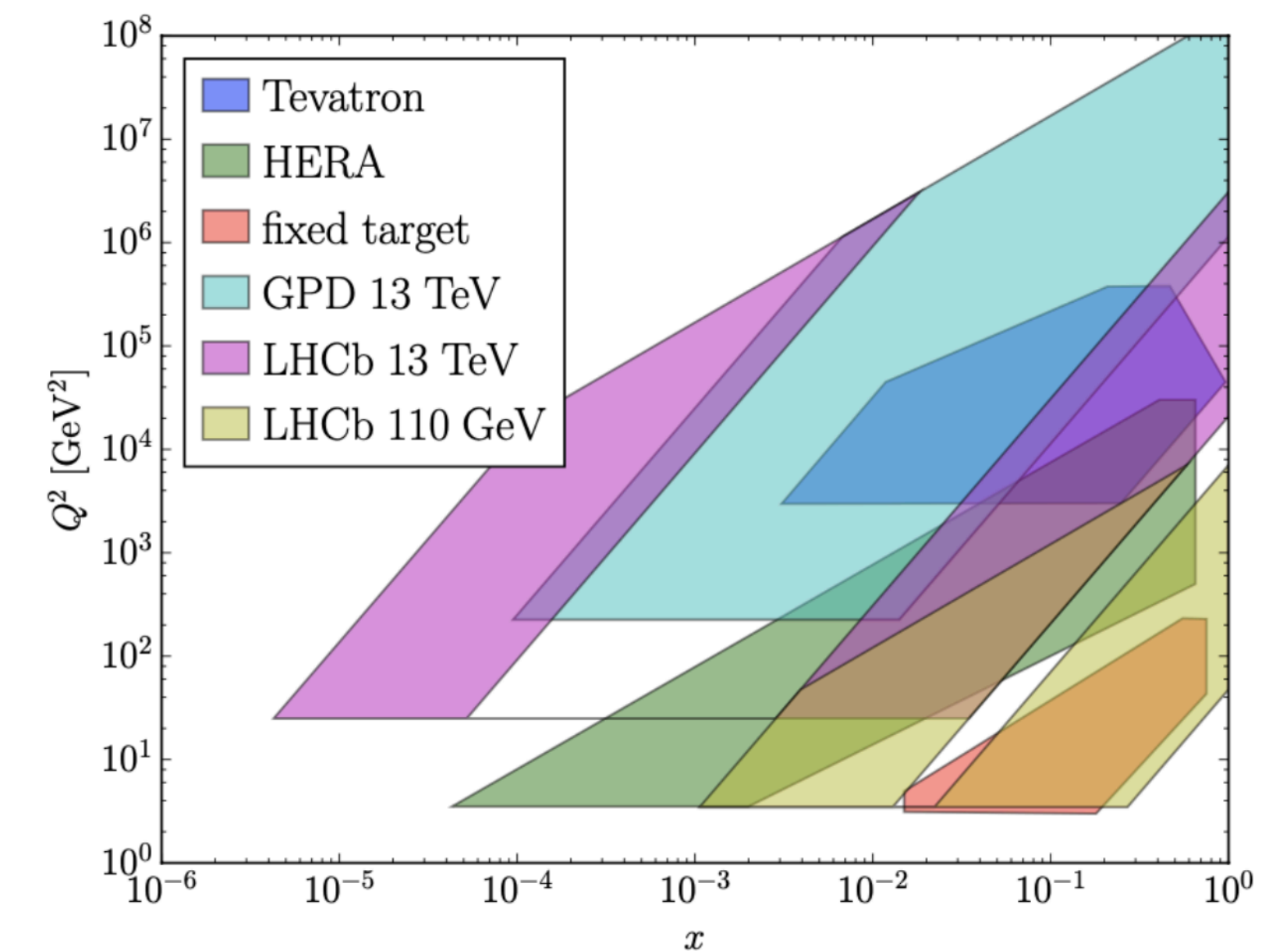
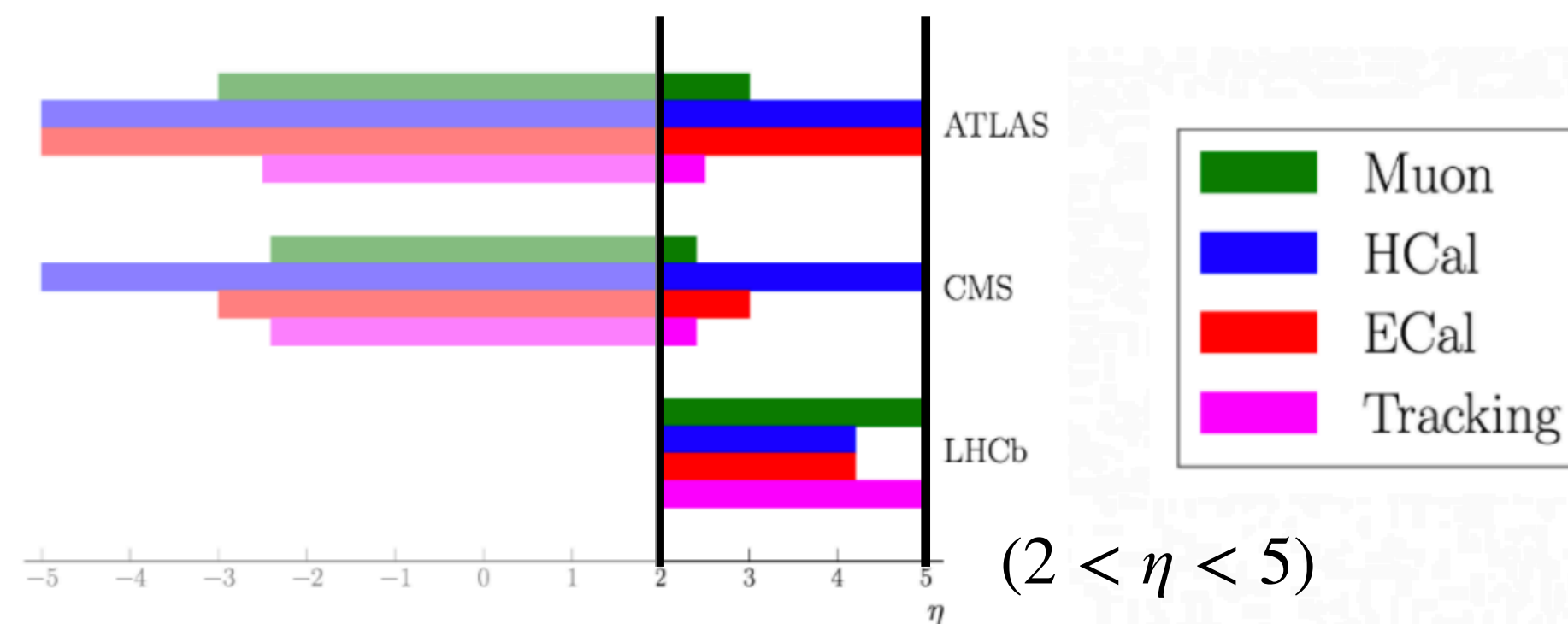
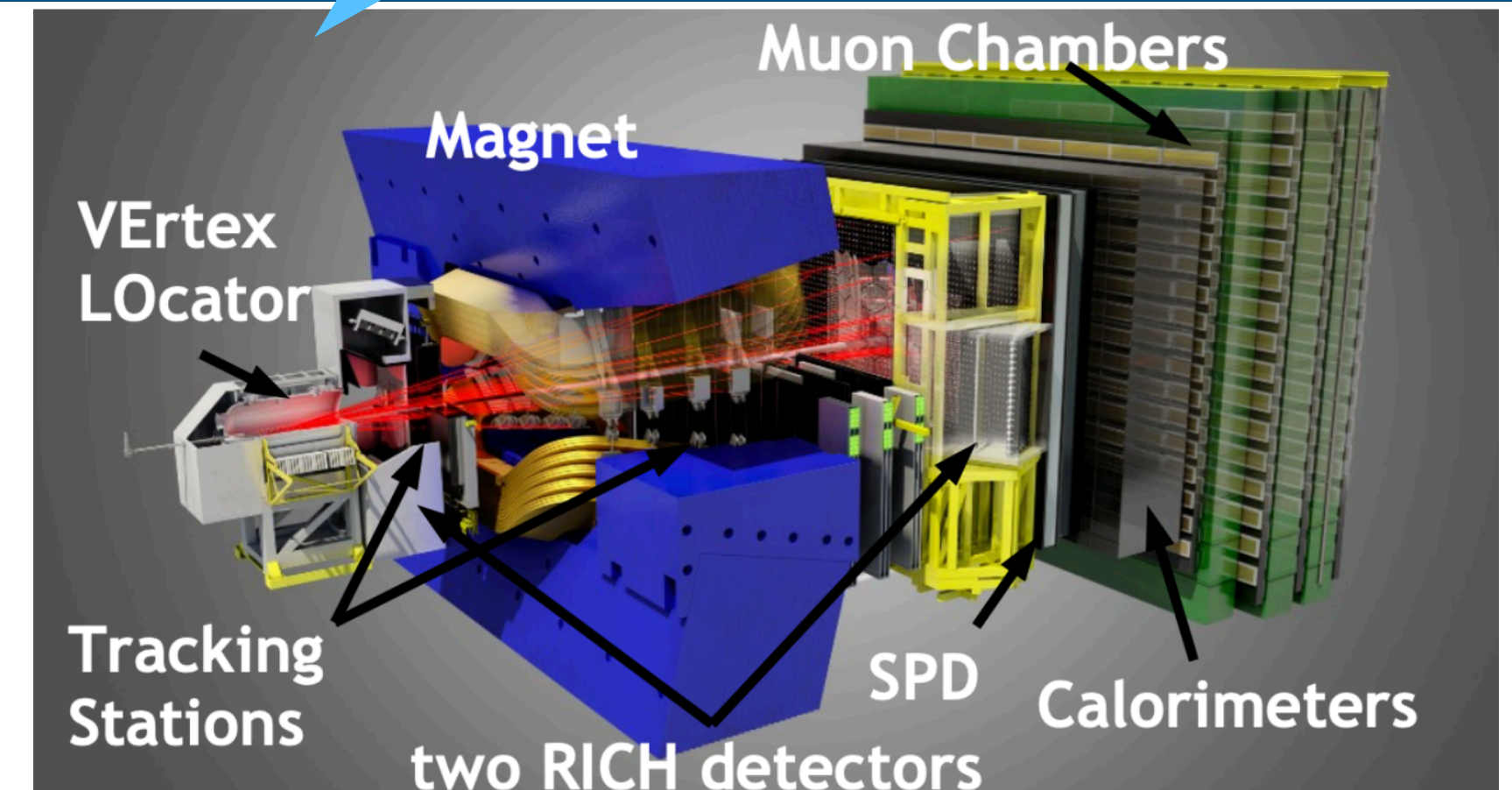
* for questions/comments: davide.zuliani@cern.ch

LHCb experiment

A General Purpose *Forward* Detector

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

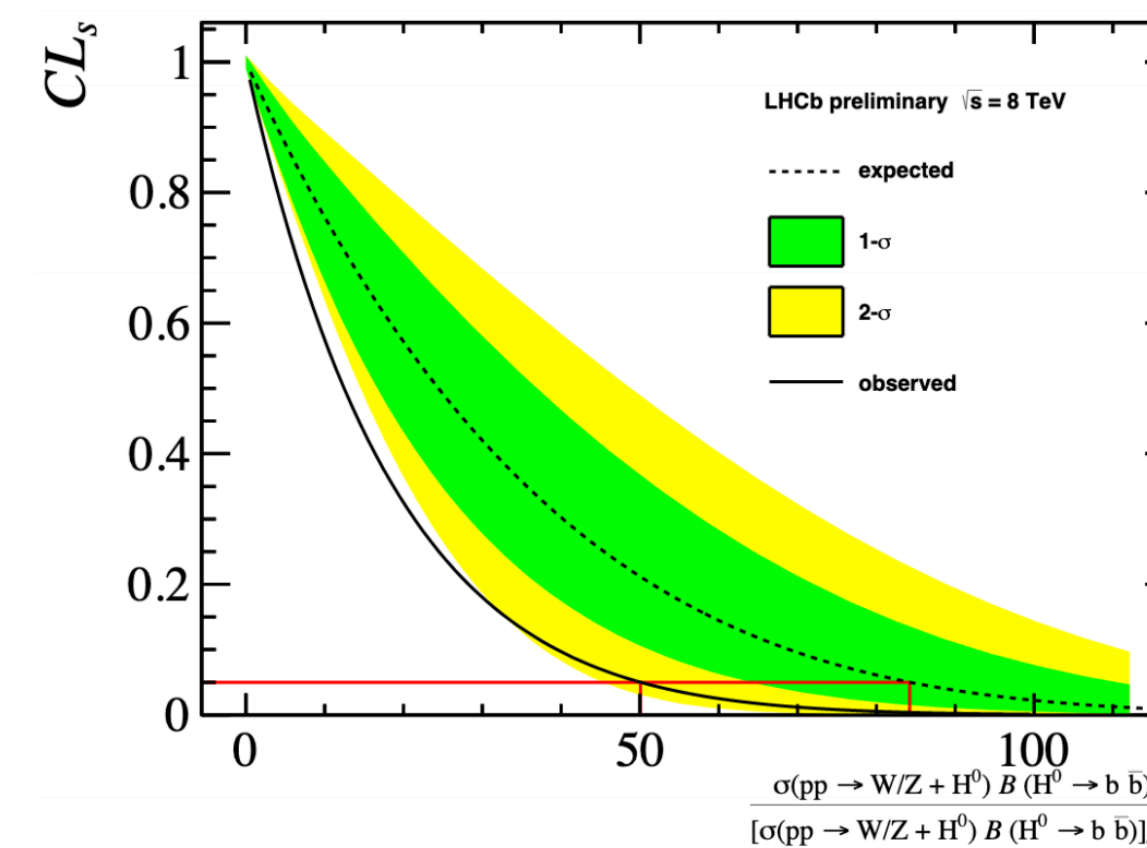
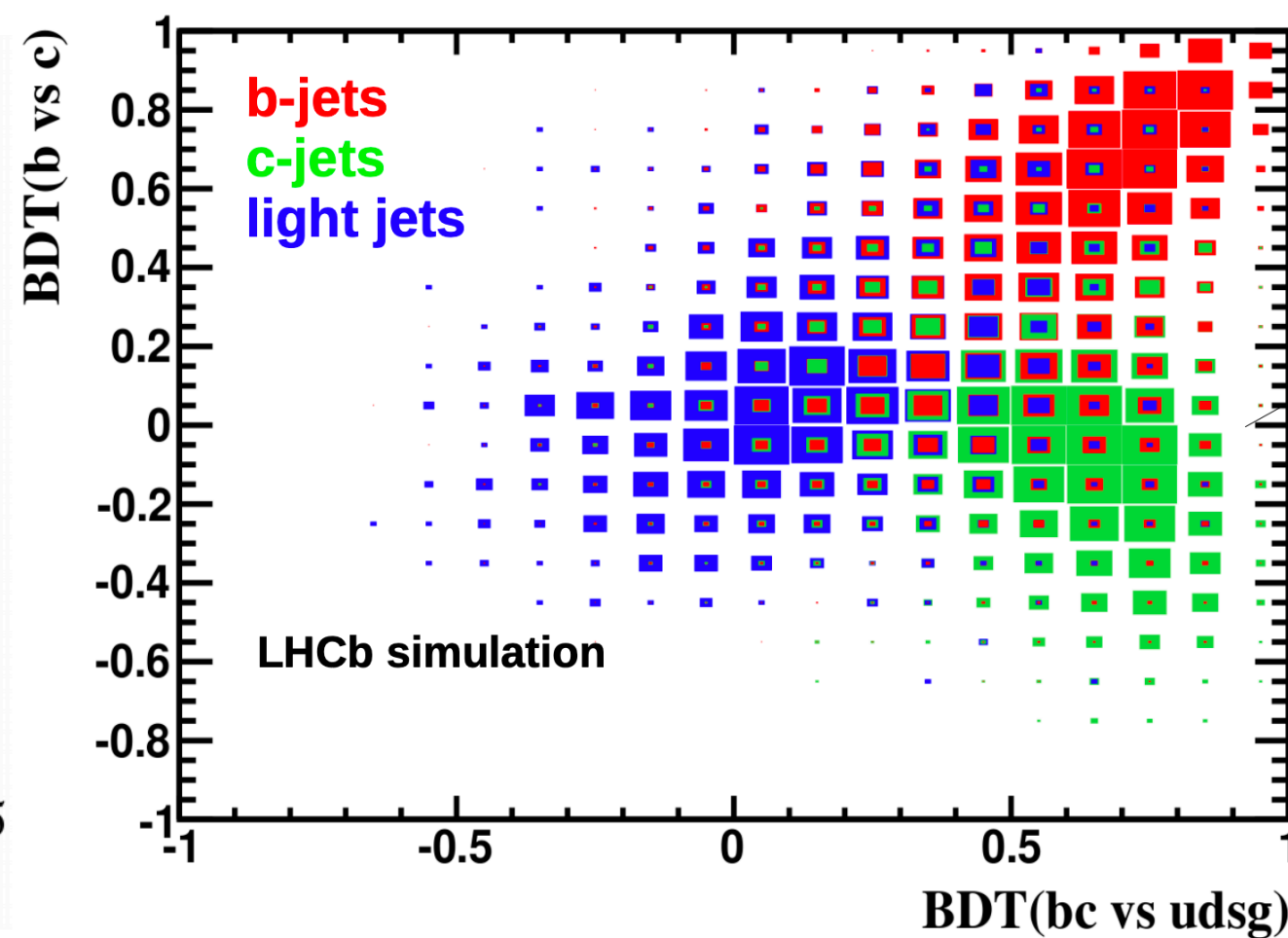
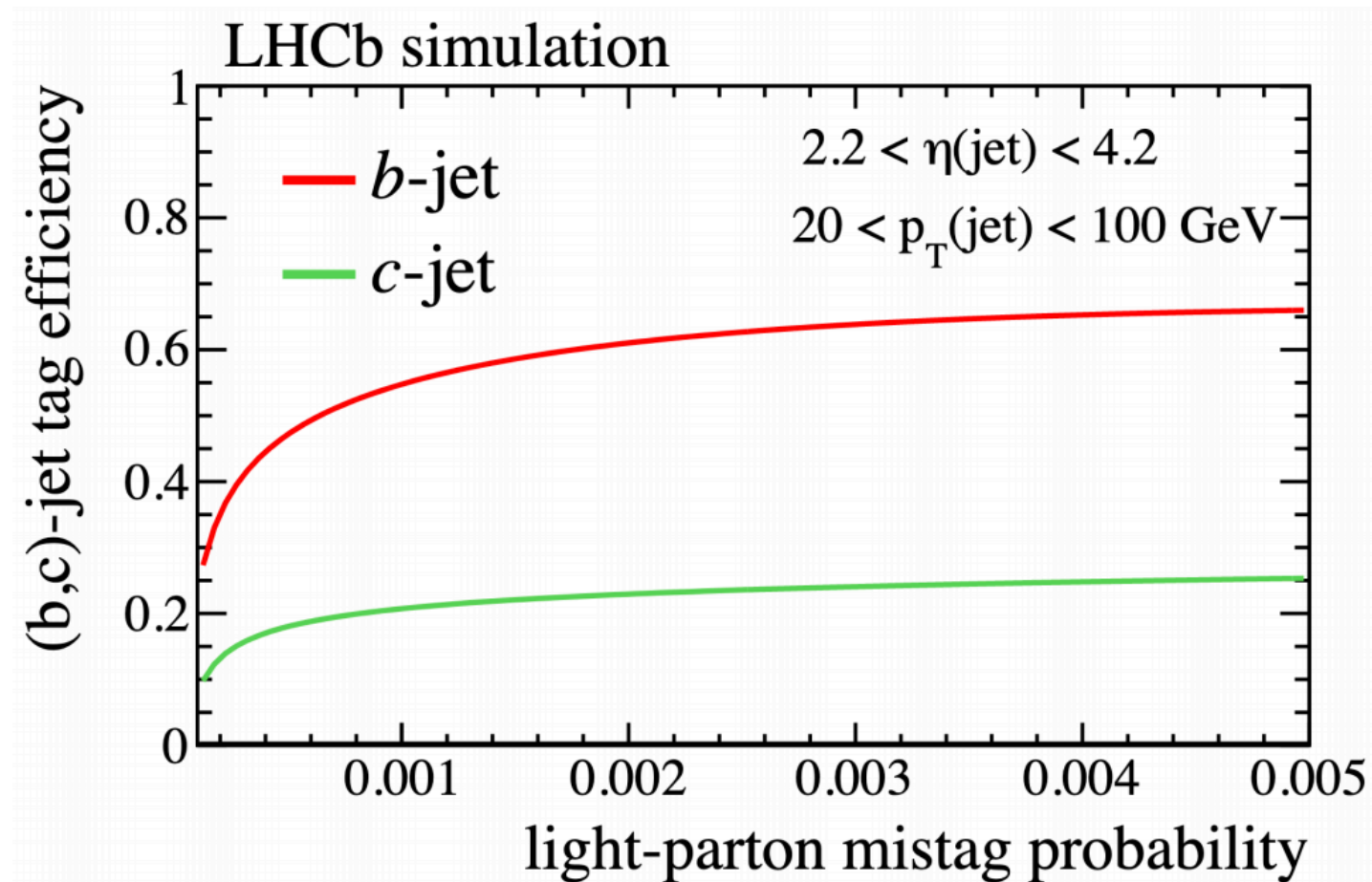
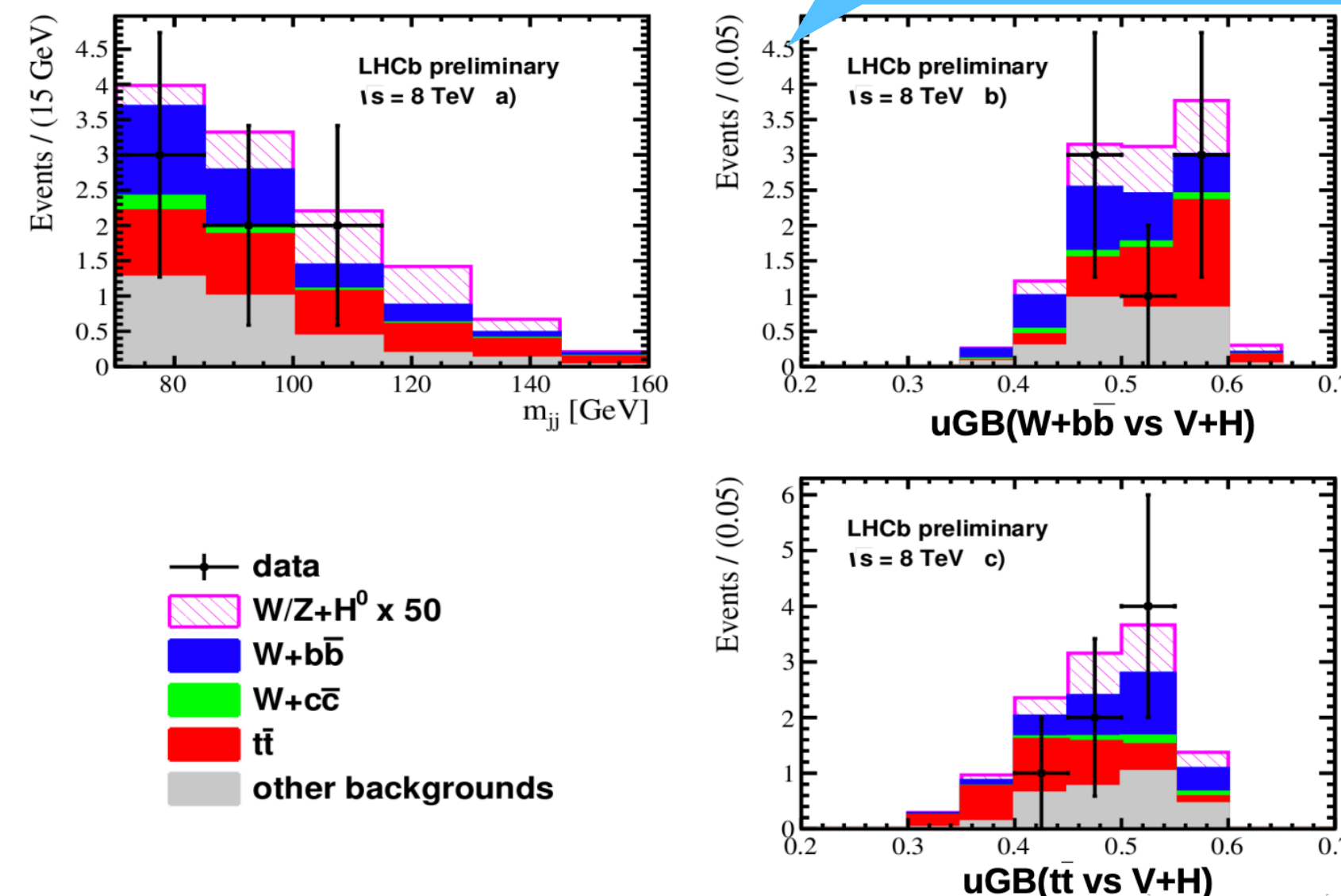
- LHCb, originally designed for *b*- and *c*-hadron physics, is now considered a **general purpose forward detector**
- **Excellent track momentum resolution:** 0.4% at 5 GeV and 0.6% at 100 GeV
- Very good muon and electron ID efficiency
- **Excellent vertex reconstruction helps in jets identification:** 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**



Search for $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$ 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 ($\mathcal{L} \sim 2 \text{ fb}^{-1}$)
- 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: $y^b < 7y_{SM}^b$, $y^c < 80y_{SM}^c$

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

Disentangling b and c jets

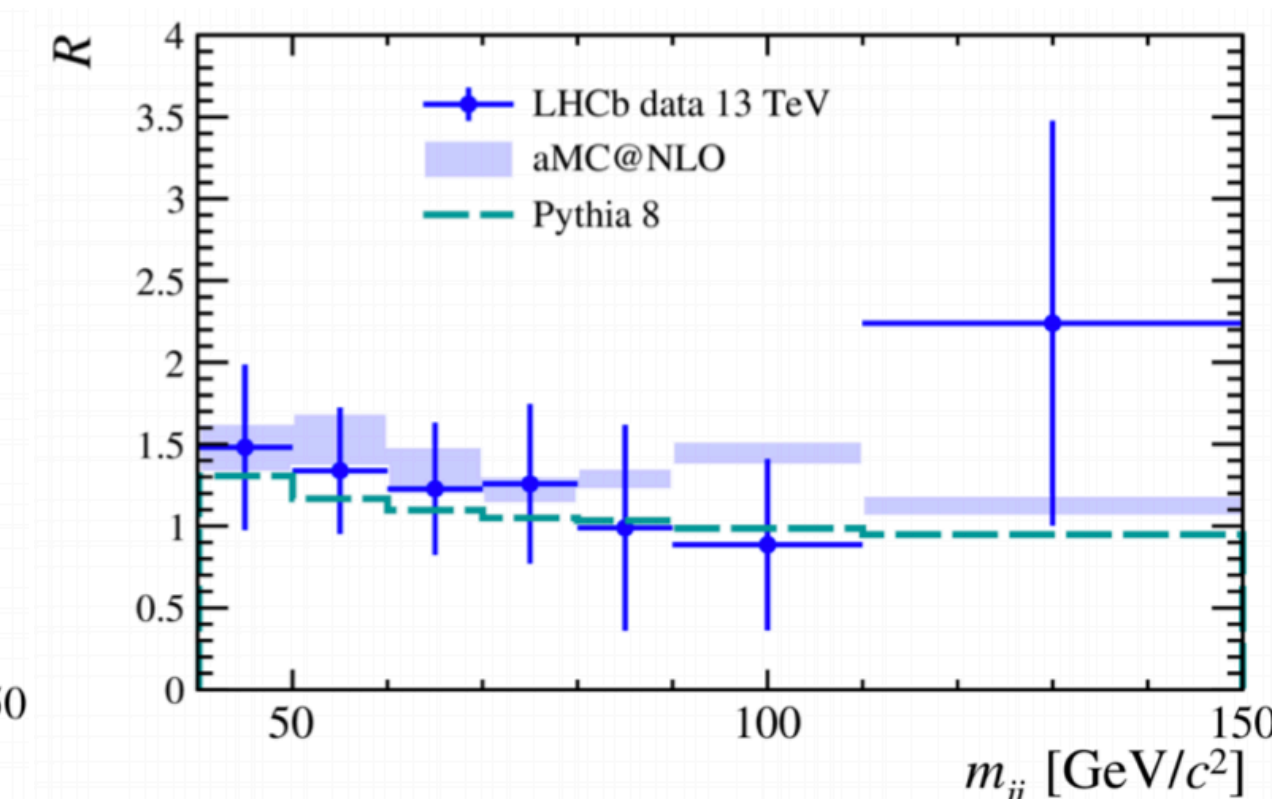
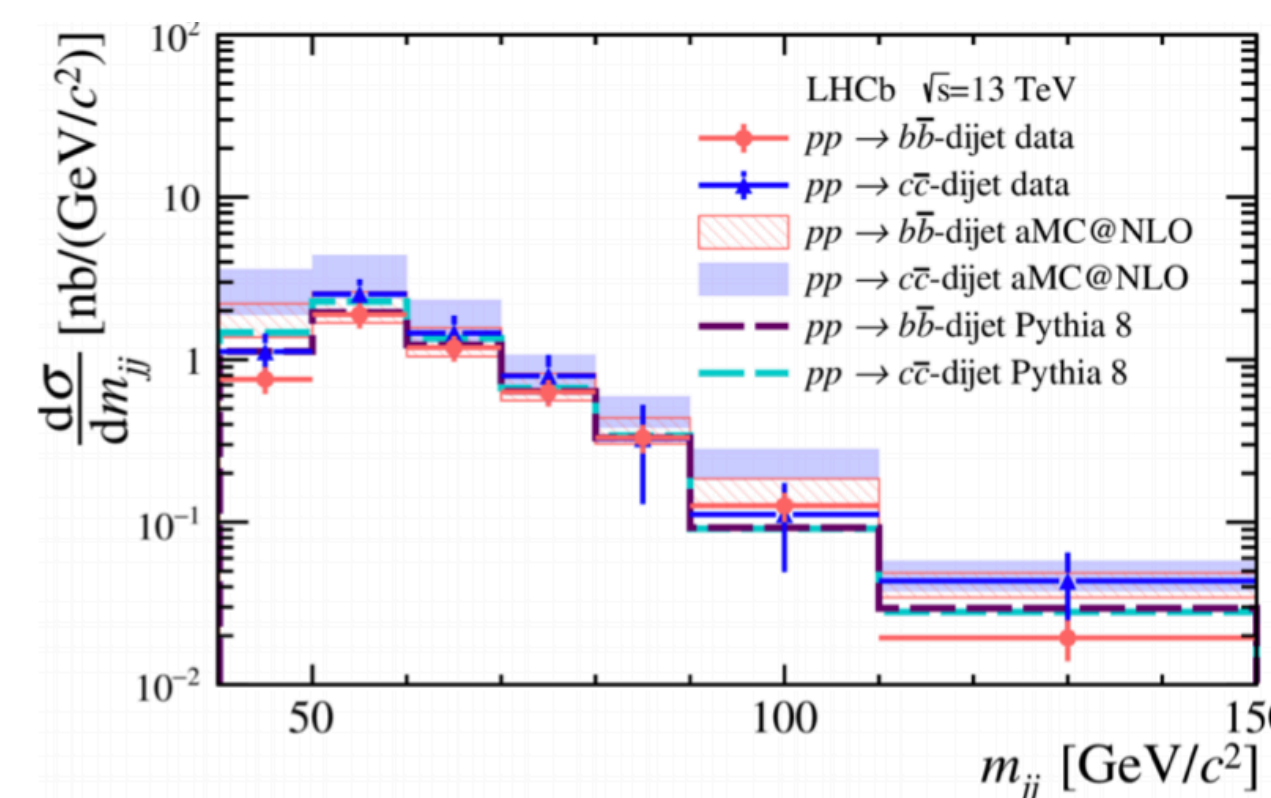
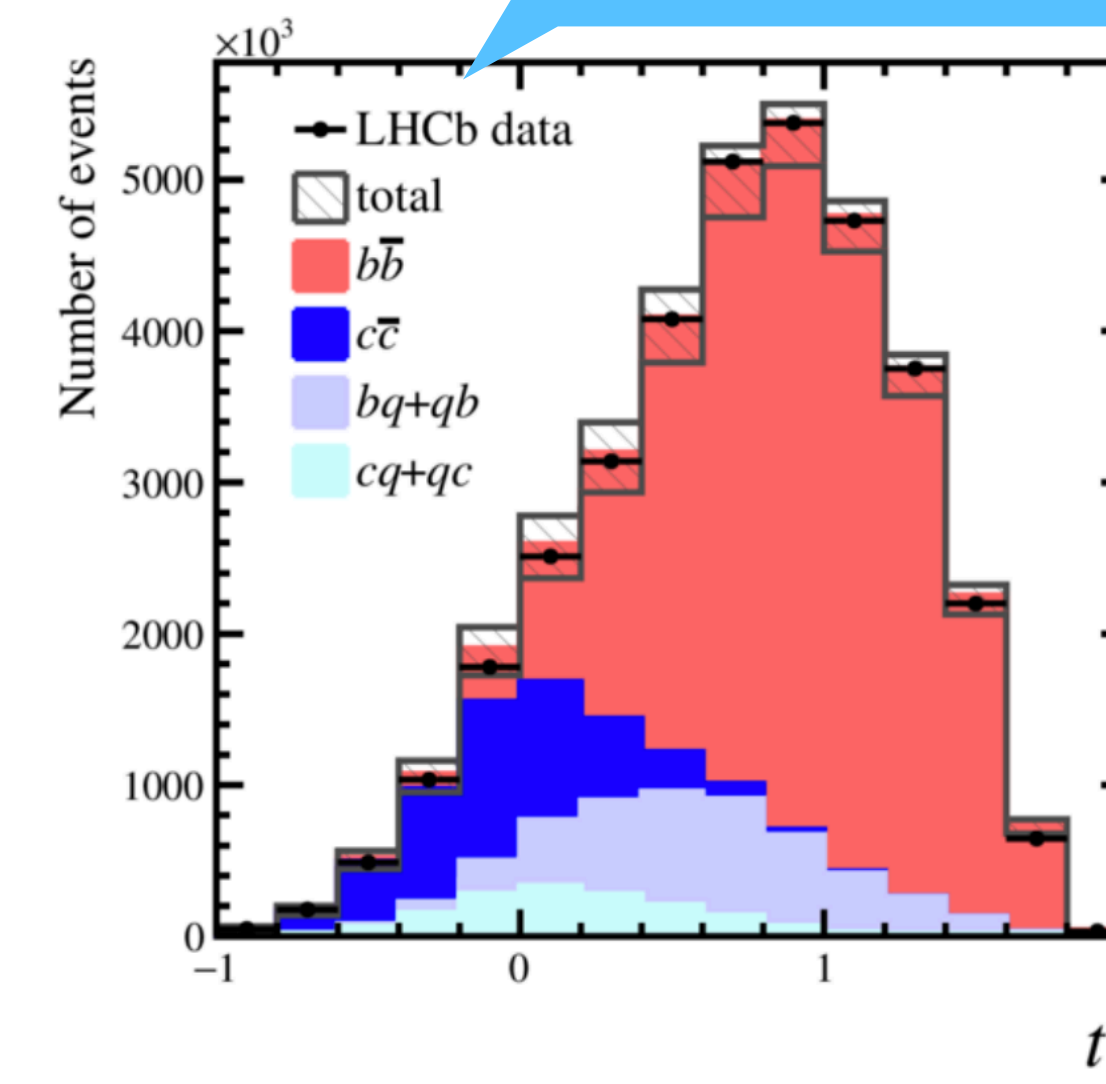
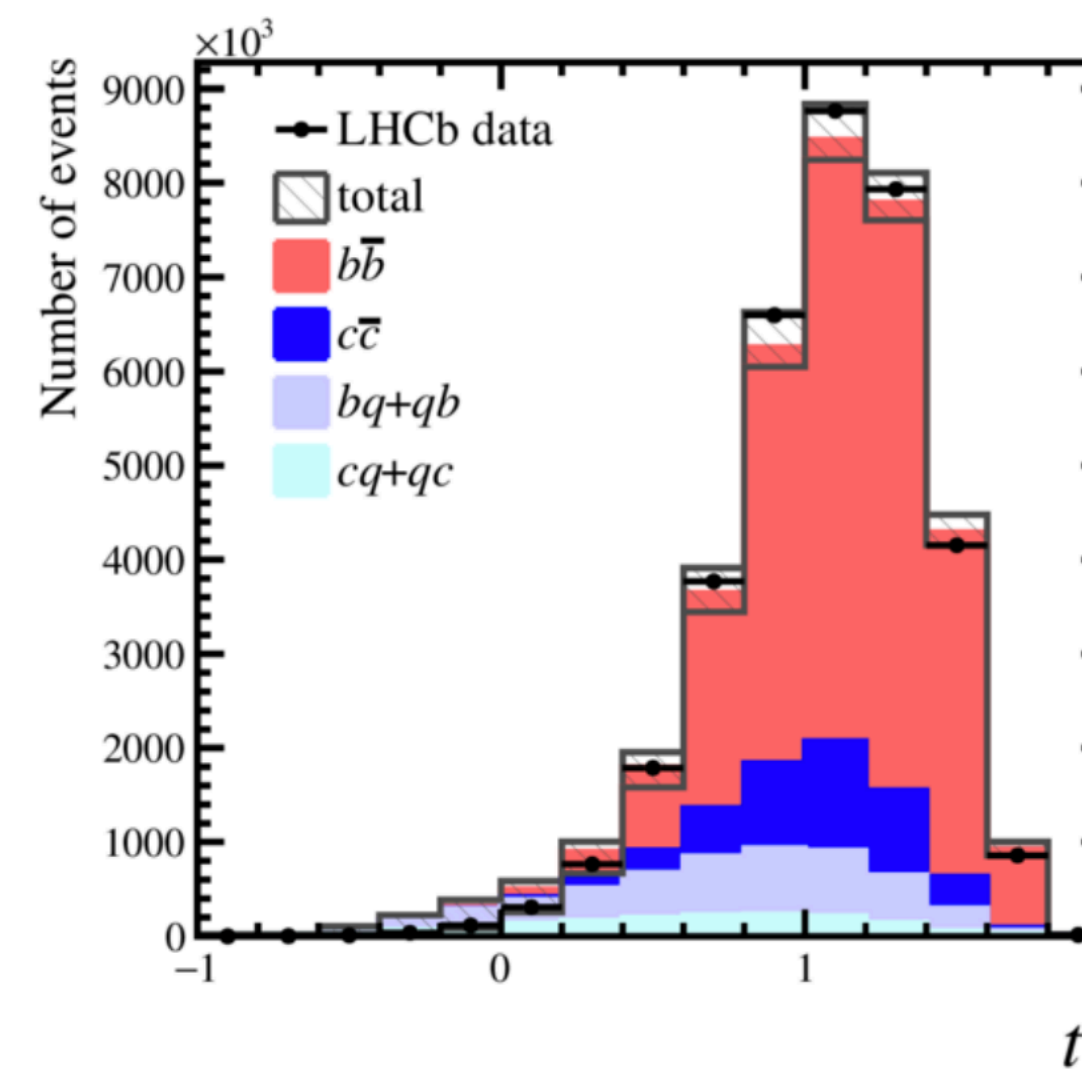
JHEP 02 (2021) 023

- 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:

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

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

- 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**



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

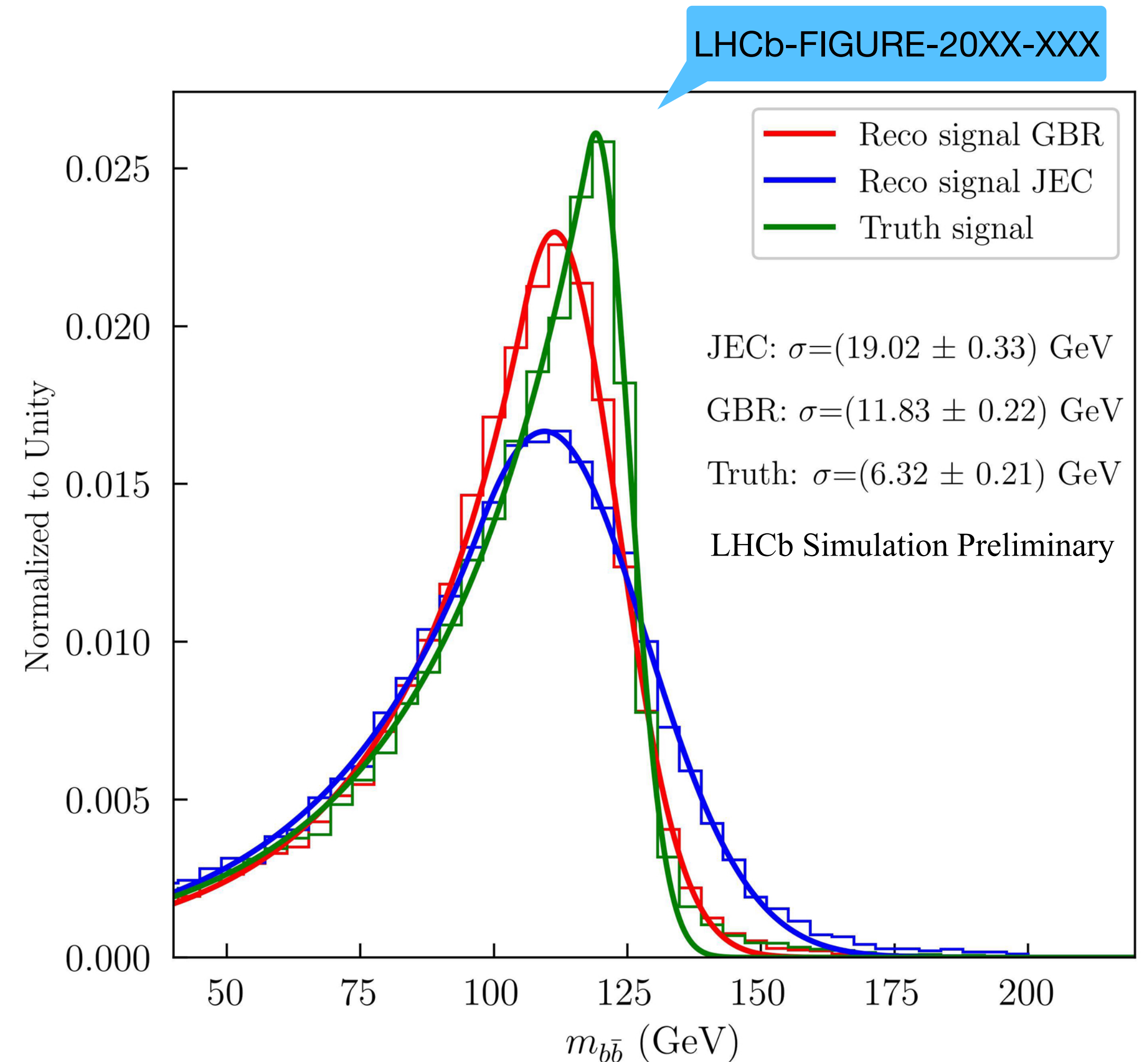
What can we do @ LHCb?

- We are aiming towards a search for $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$ in a **inclusive** final state
 - Just **two jets are required**, no requirements applied to additional objects
 - Full Run 2 search, using $\mathcal{L} \sim 6 \text{ fb}^{-1}$
 - **Model-independent approach** \rightarrow 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 $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$

Regression technique for di-jets invariant mass

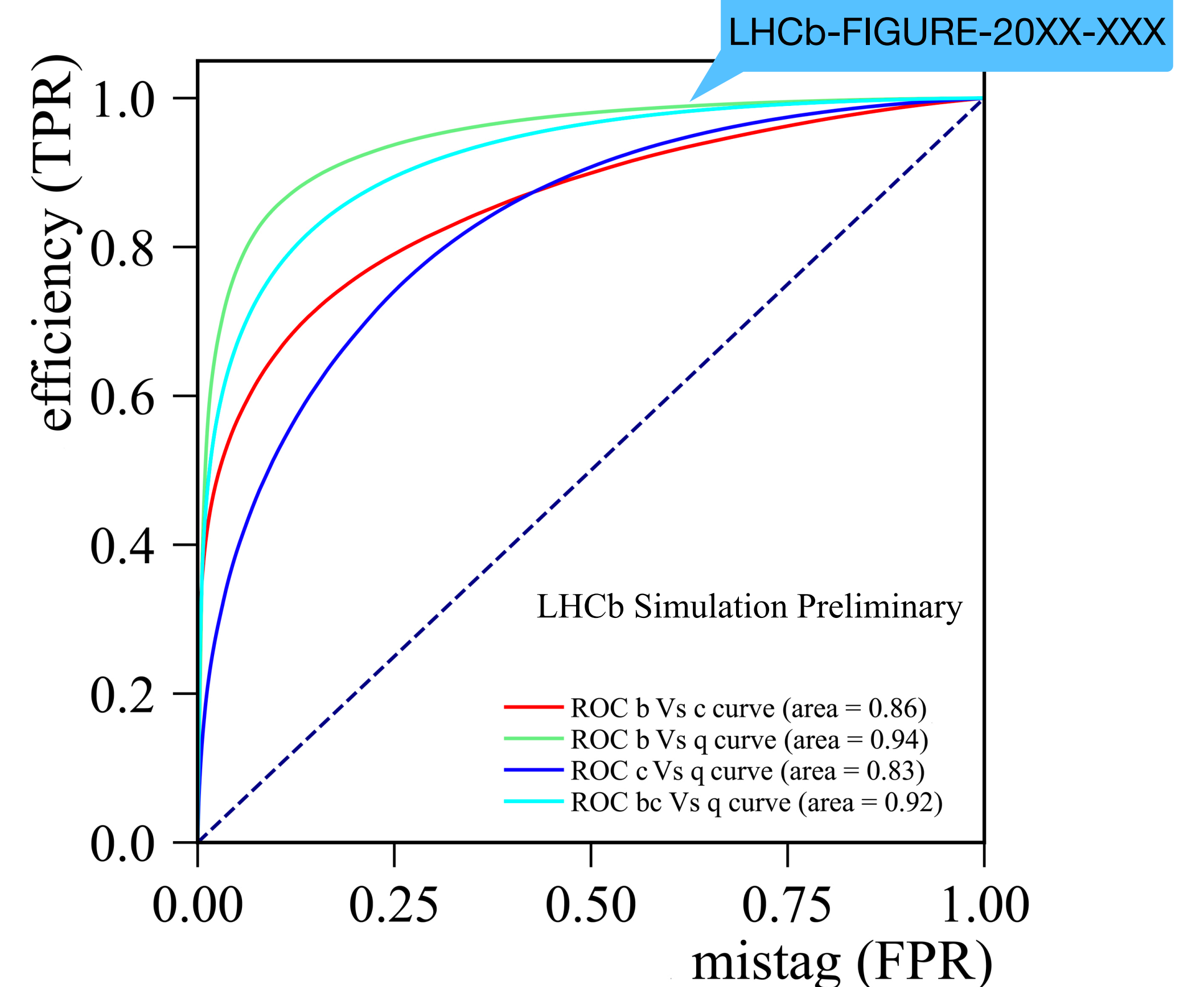
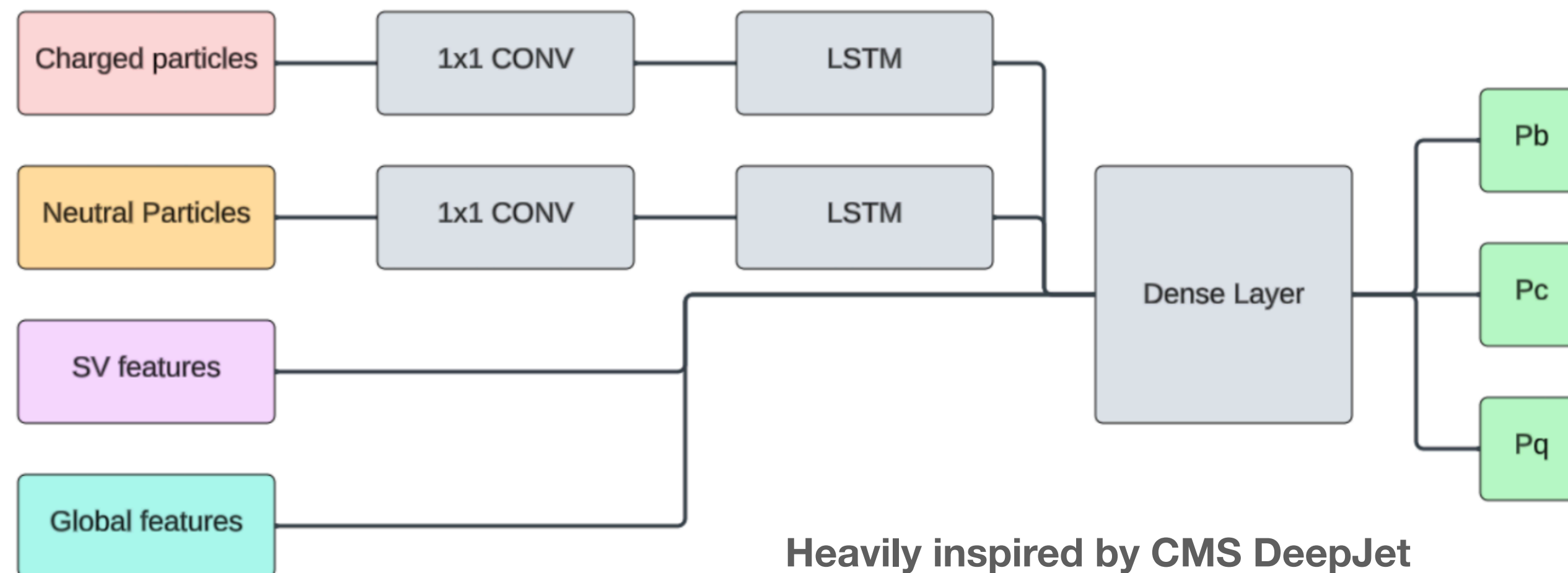
- The search for $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$ is based on a fit to the invariant mass
- A new reconstruction tool is used, based on a **regression technique**
- A **Gradient Boosted Regressor** (GBR) is used to reconstruct the reconstructed invariant mass
- 51 observables from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

DNN for jet tagging

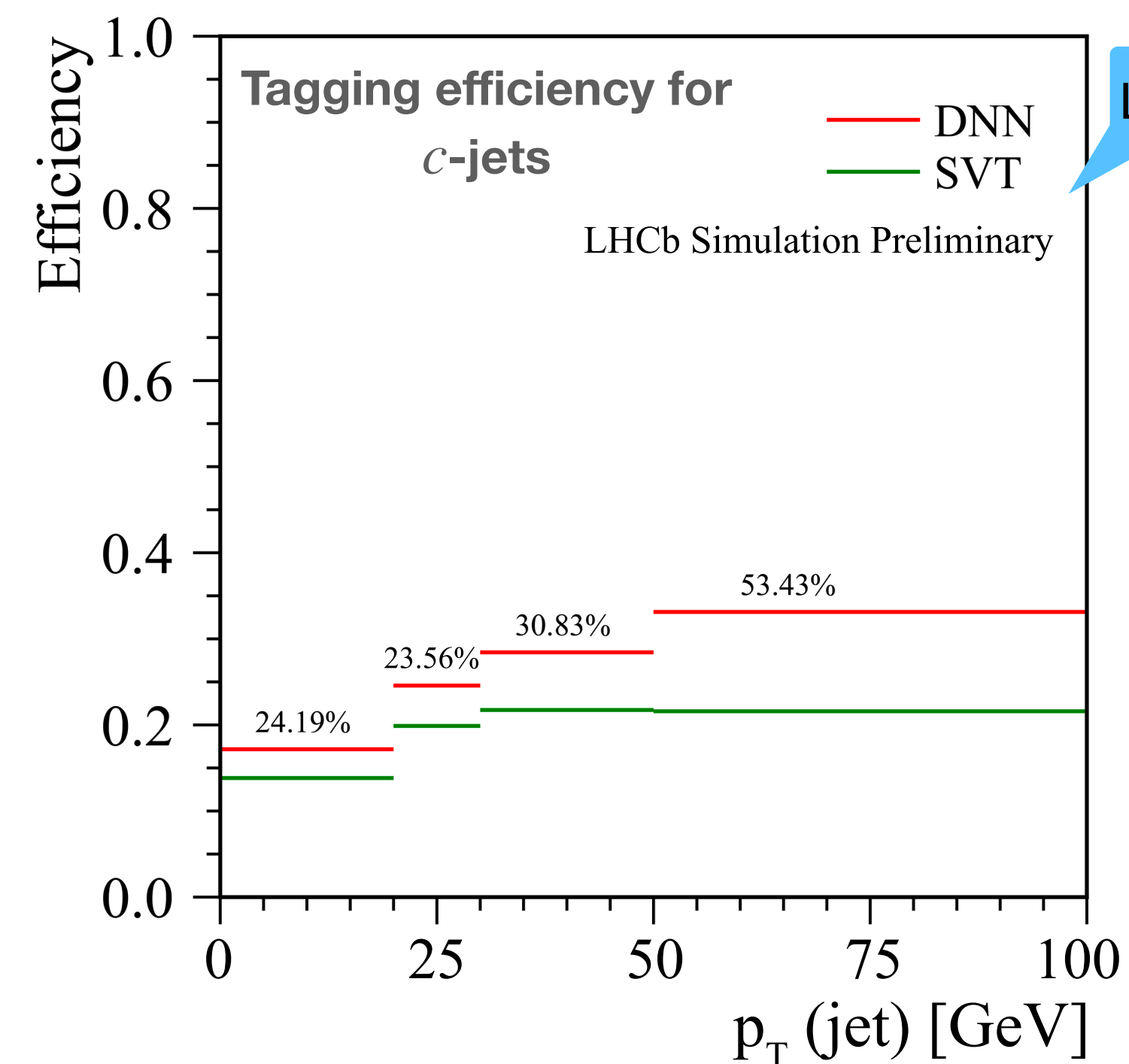
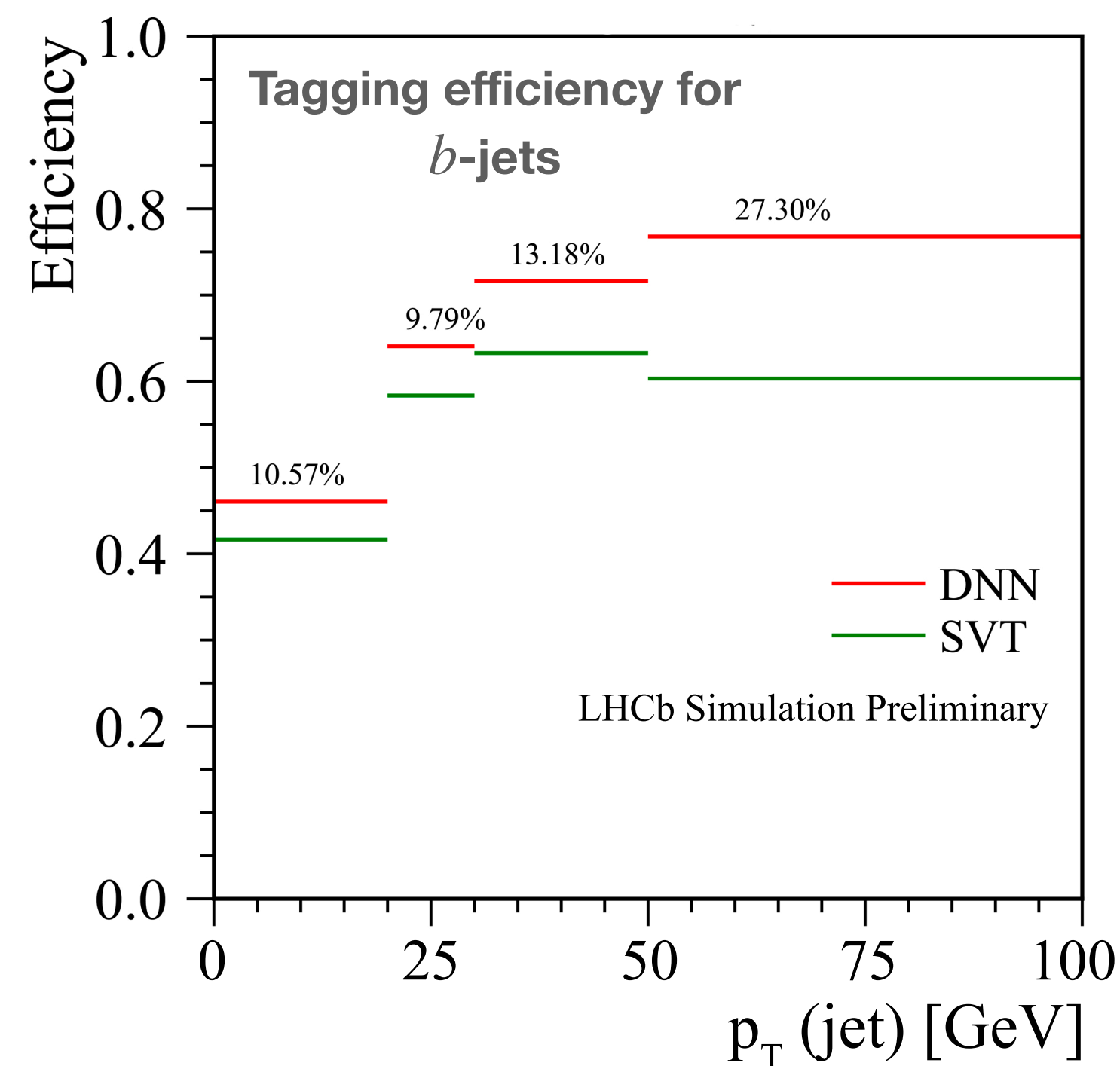
- Currently, jet tagging relies on **Secondary Vertex (SV)** identification and BDTs to distinguish between bc vs. q and b vs. c
 - This is **limited** by the **SV reconstruction efficiency**
- “New” approach: Deep Neural Network (DNN)
 - 400 jet observables are used as inputs
 - Features related to **jet constituents** and **sub-structure**
 - 3 output probabilities: P_b , P_c and P_q



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

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 ($\sim 1\%$)



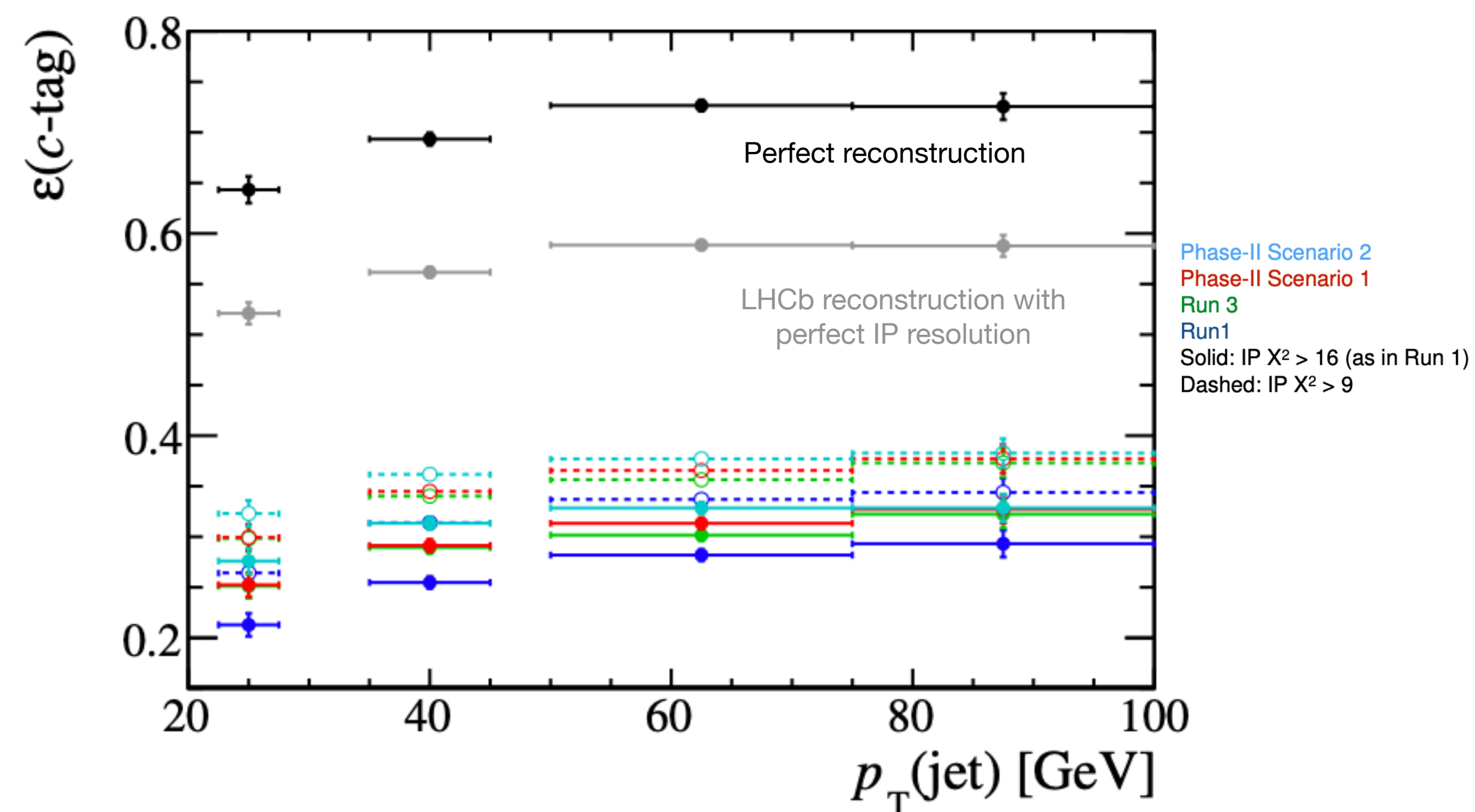
LHCb-FIGURE-20XX-XXX

Higgs @ LHCb in future upgrades

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

- LHCb could definitely improve its results for the process $H^0 \rightarrow c\bar{c}$:
 - Rescaling results by **increasing integrated luminosity** to 300 fb^{-1} (end of Run 5)
 - **Loosing c -tagging criteria** would allow us to get a di-jet tagging efficiency $\sim 30\%$
 - VELO-induced c -tagging efficiency (from 25% to 30%)
 - **Better discrimination between b - and c -quarks** (e.g. **Machine Learning** algorithms, similar to CMS)
- We are expecting the best LHC sensitivity on Yukawa coupling for c quark $\sim 2y_{SM}^c$

LHCB-PUB-2018-009
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Conclusions

Wrap up

- LHCb is by all means a **general purpose forward detector**
 - At LHCb it is possible to study high p_T physics
- **We are towards the first inclusive search for $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$ in the forward region**
- In the meantime:
 - Study Higgs BSM scenarios (see talk by Hengne)
 - We are getting ready for the next runs and upgrades



Stay tuned for some interesting results!



**Thank you for
your attention!**

