Searches for $H \rightarrow b\bar{b}$ and $H \rightarrow c\bar{c}$ at LHCb

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The LHCb detector

The LHCb detector is a forward spectrometer designed to perform precision measurements of the $b$ and $c$ hadrons properties.

Unique detector at LHC:

- Lower luminosity, $\sim 3\text{fb}^{-1}$ in Run 1
- Complementary $\eta$ coverage ($2 < \eta < 5$)
- Excellent vertexing (IP resolution of 13-20 $\mu\text{m}$), momentum resolution (0.4%-0.6%), particle ID

(JINST 3 (2008) S08005)
LHCb as general purpose forward detector

Beside flavor physics measurements, LHCb has demonstrated his capability also as a general purpose forward detector

**EW measurements**

**QCD measurements**

**Exotic searches**

Higgs boson at LHCb

Lower acceptance wrt CMS and ATLAS, but:

- Low $p_T$ triggers
- Low pile up thanks to the leveled luminosity
- Tracking in the forward region, $b/c$ jet tagging
Jets at LHCb

- Particle Flow approach, with neutral recovery
- Reconstructed using anti-kT (R = 0.5)
- Calibration in data, using $Z \rightarrow \mu\mu$+jets
- Since Run 2, reconstructed both offline and online

\[ \text{BDT}(b|c) \text{ trained to discriminate } b \text{ jets from } c \text{ jets} \]
\[ \epsilon_b \sim 65\%, \epsilon_c \sim 25\% \text{ light jet mistag probability } \sim 0.3\% \]

\[ \text{BDT}(bc|udsg) \text{ trained to separate } (b,c) \text{ jets from light-parton jets} \]
$H \rightarrow b\bar{b}(c\bar{c})$ in association with a $Z$ or $W$

**Signal signature:** one high-$p_T$ lepton and two $b(c)$-jets

**Main background processes at LHCb**

- $W + b\bar{b}$
- $W + c\bar{c}$
- $t\bar{t}$

studied with an ad-hoc analysis:

- **Analysis sample:** 2 fb$^{-1}$ at 8 TeV
  - one high-$p_T$ isolated lepton (electron or muon) and two heavy-flavour jets
  - Jets: $p_T > 12.5$ GeV/c and $2.2 < \eta < 4.2$
  - Lepton: $p_T > 20$ GeV/c and $2 < \eta < 4.5$
  - 4 categories: $l_{flavour} \times l_{charge}$
Backgrounds for the $H \rightarrow b\bar{b}(c\bar{c})$ in association with a $Z$ or a $W$.

**Fit strategy**

Simultaneous 4D fit to the four data categories ($\mu^+, \mu^-, e^+, e^-$)

**Fit variables:**

- MVA (uGB) to separate $W + b\bar{b}$ from $t\bar{t}$
- BDT($b|c$) for both jets
- Di-jet mass

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**Data($\mu^+$)**

- $W + b\bar{b}$
- $t\bar{t}$
- $W +c\bar{c}$
- Background
Backgrounds for the $H \rightarrow b\bar{b}(c\bar{c})$ in association with a $Z$ or a $W$ @ 8 TeV

Result:

LHCb, $\sqrt{s} = 8$ TeV

Nice agreement between measurement and prediction
Measurements dominated by statistic uncertainty
Search for the $H \rightarrow b\bar{b}$ in association with a $Z$ or a $W$

Backgrounds are well understood: moving toward the $H \rightarrow b\bar{b}$ search:

- Same selection, except for tighter $p_T$ cut on the jets (20 GeV/c)
- Background yields fixed to theory predictions

Signal searched using three variables:

- Dijet invariant mass ($m_{jj}$)
- MVA (uGB) to separate signal from $W + b\bar{b}$
- MVA (uGB) to separate signal from $t\bar{t}$
Search for the $H \rightarrow c\bar{c}$ in association with a $Z$ or a $W$

The good jet tagging performance gives the possibility to discriminate $b$- and $c$-jets

$\implies$ unique possibility to search for the $H \rightarrow c\bar{c}$ at LHC

An enhancement of the SM predictions due to new physics have been suggested

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Same event selection used for the $W/Z + H(b\bar{b})$ process, but:

Additional requirement on the BDT $b|c$ tagging variable:

- Separation of $b$ jets from $c$ jets is applied
- It removes about 90% of $W/Z + H(b\bar{b})$ events while retaining 62% of the $W/Z + H(\bar{c}c)$
$W/Z + H(b\bar{b}/c\bar{c})$ results @ 8 TeV

No excess has been found either in the $W/Z + H(b\bar{b})$ or the $W/Z + H(c\bar{c})$ channel.

95% C.L. upper limit set using the $CL_s$ method.

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$H \rightarrow b\bar{b}$

Limit: $< 1.6$ pb (50 times SM)

$H \rightarrow c\bar{c}$

Limit: $< 9.4$ pb (6400 times SM)
Toward the inclusive $H \rightarrow b\bar{b}$: $Z \rightarrow b\bar{b}$ cross section measurement @ 8 TeV

Recent measurement of the $Z \rightarrow b\bar{b}$ cross section

Benchmark for the inclusive $H \rightarrow b\bar{b}$ search

Key point: balancing jet (jet$_3$) that makes $p_T(Z+\text{jet}_3)$ minimum to separate $Z \rightarrow b\bar{b}$ from QCD

Discrimination achieved using an uGB

$\sigma \times B = 332 \pm 46(\text{stat}) \pm 59(\text{sys})$

In nice agreement with the aMC@NLO prediction

This measurement shows the LHCb capability to describe the QCD multijet background and validates the inclusive search for the $H \rightarrow b\bar{b}$ with the new data
Conclusion and outlook

LHCb has proved its capability also in the Higgs sector:

- Limit on the $W/Z + H(b\bar{b})$ process
- First limit on the $W/Z + H(c\bar{c})$ process
- Measurement of the $Z \rightarrow b\bar{b}$ cross section

It can take advantage of its unique features to search in a phase space and in decay channels complementary to ATLAS and CMS

Outlook for Run II

- More statistics, about 5 fb$^{-1}$
- Higgs cross section more than a factor 2 greater
- Factor 2 in acceptance due to more boosted Higgs
- New dedicated trigger lines for jets
- Work is ongoing to improve the jet tagging performance

After Run II, much better tagging (upgraded vertex detector, only 5mm from the beams)
Backup
uGB response in different intervals of $m_{jj}$ for $W + b\bar{b}$ and $tt$