Search for the standard model Higgs boson produced through vector boson fusion and decaying to bottom quarks with CMS

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Outline

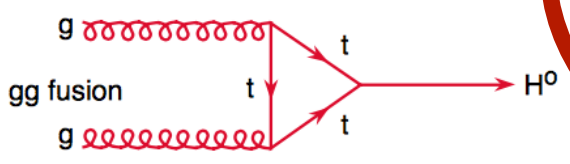
- Motivation
- Higgs boson production and decay modes at LHC
- Vector Boson Fusion process
- Analysis of VBF H$\longrightarrow b\bar{b}$
- Future work

Motivation

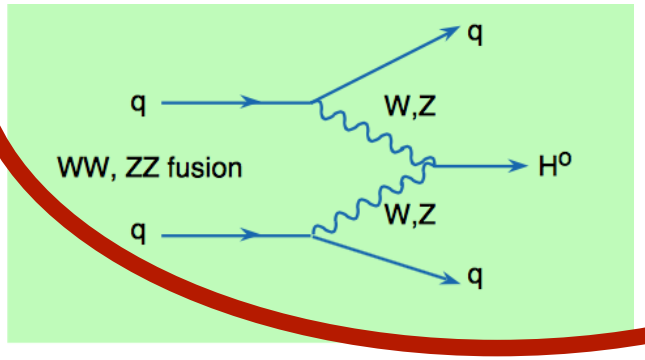
- Higgs $\rightarrow b\bar{b}$: measure coupling to fermions and **down-type quarks** [not yet established!]
- Inclusive search is impossible.
- VBF is crucial to check the unitarity of SM.
- CMS Run I - the **only fully hadronic SM search** for Higgs $\Longrightarrow$ need to increase the sensitivity in Run II.

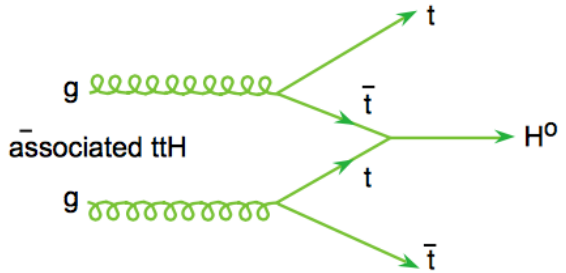
Higgs production at LHC

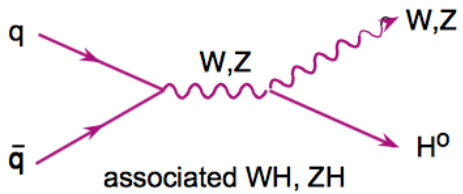
Gluon-Gluon fusion
tag specific Higgs decay products



Vector Boson Fusion
tag 4 jets, 2 forward q-jets





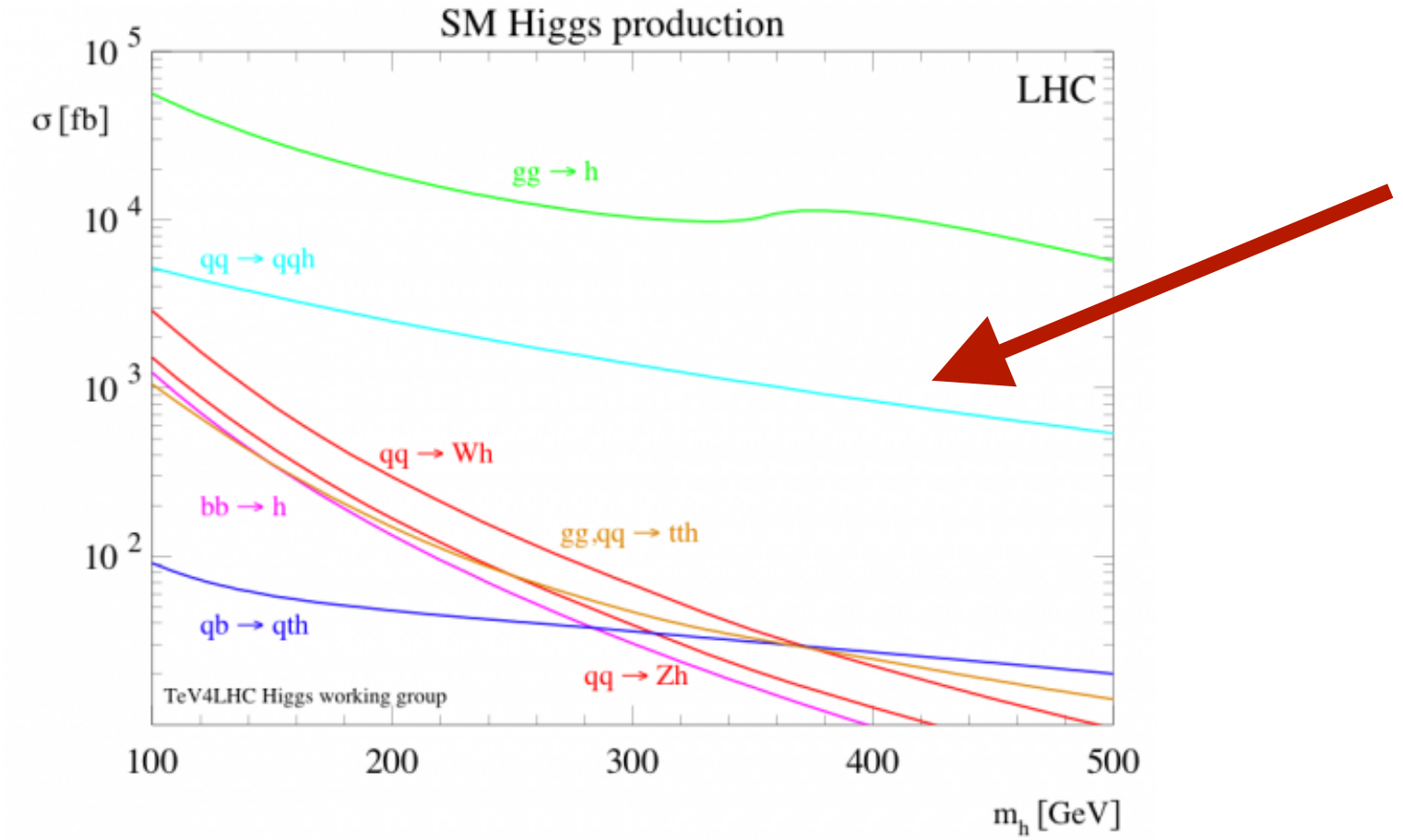


Heavy-quark associated
tag top-quark decays

Vector Boson associated
tag vector boson decay products

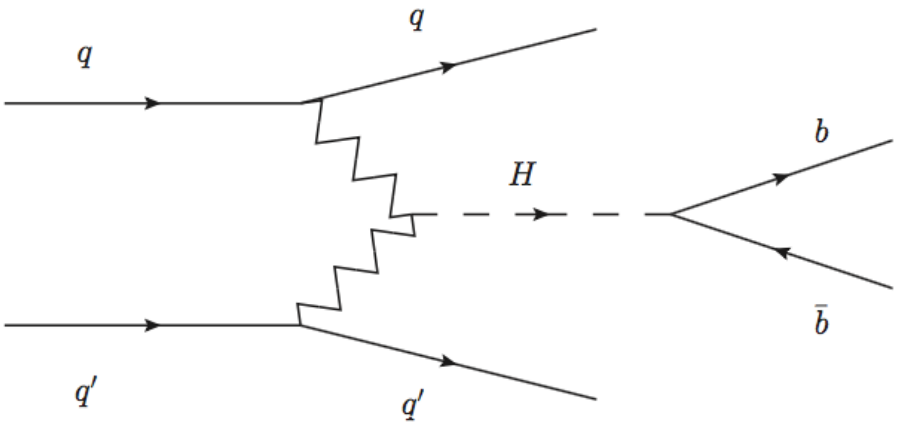
Higgs boson production cross-section

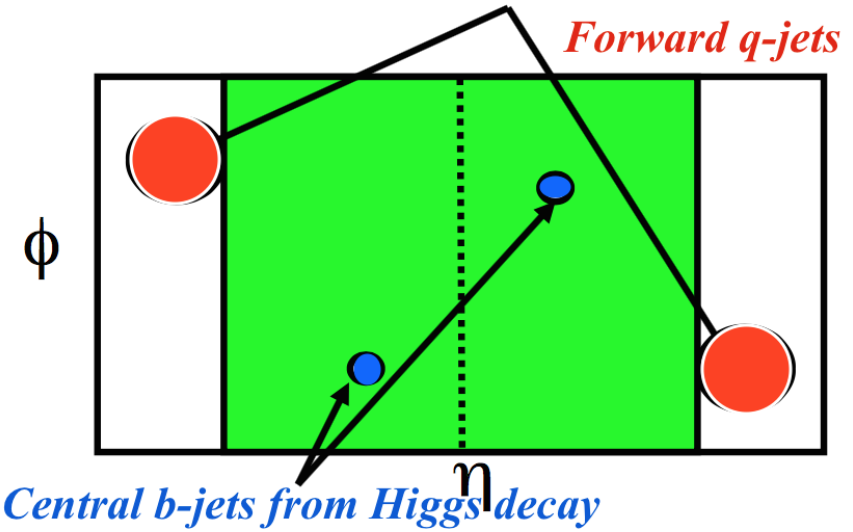
VBF has the second largest production cross-section following GF.



VBF H $\longrightarrow b\bar{b}$

- 4 jets high p_T jets
  - 2 froward q-jets from colliding protons with large $\Delta\eta$
  - 2 central b-jets from Higgs boson decay
- Rapidity gap in the central region due to NO exchange of color singlet at LO
- Main background:
  - **QCD**
  - hadronic decays of Z,W
  - hadronic decays of top-quark





MC samples for Run II, trigger, offline preselection

MC samples : 13 TeV, 20 PU, 25 ns Bunch crossing
VBF signal is AMC at NLO + Pythia8, $m_H = 125$ GeV, x-sec 2.16 pb^{-1}, BR = 0.58

Huge BG $\rightarrow$ **dedicated trigger is required!**
4 jets, 2 of which are b-tagged and a cut on M_{qq}.

My offline preselection :

- Jets : $p_T(1^{st}) > 92$ GeV; $p_T(2^{nd}) > 76$ GeV; $p_T(3^{rd}) > 64$ GeV; $p_T(4^{th}) > 30$ GeV
- 2 Bjets : btag > 0.4
- $M_{qq} > 200$ GeV, qq-jets are the p_T-leading pair, excluding the bb-jets
- $\Delta\eta_{qq} > 1.2$ (qq-jets separated in pseudorapidity)
- $\Delta\phi_{bb} < 2.4$ (remove back-to-back b-jets)

Preselection + trigger efficiency

Sample	yield(per fb^{-1})	efficiency
VBF, M_H = 125 GeV	95.3	0.03
QCD, H_T=100-200 GeV	628.9	2.3e-08
QCD, H_T=200-300 GeV	2411.8	3.6e-04
QCD, H_T=300-500 GeV	51915.6	1.4e-04
QCD, H_T=500-700 GeV	17049.3	5.7e-04
QCD, H_T=700-1000 GeV	9752.0	0.38
QCD, H_T=1500-2000 GeV	240.6	1.3e-07
QCD, H_T=2000-Inf GeV	6.28	5.1e-05
Total BG	82100.1	

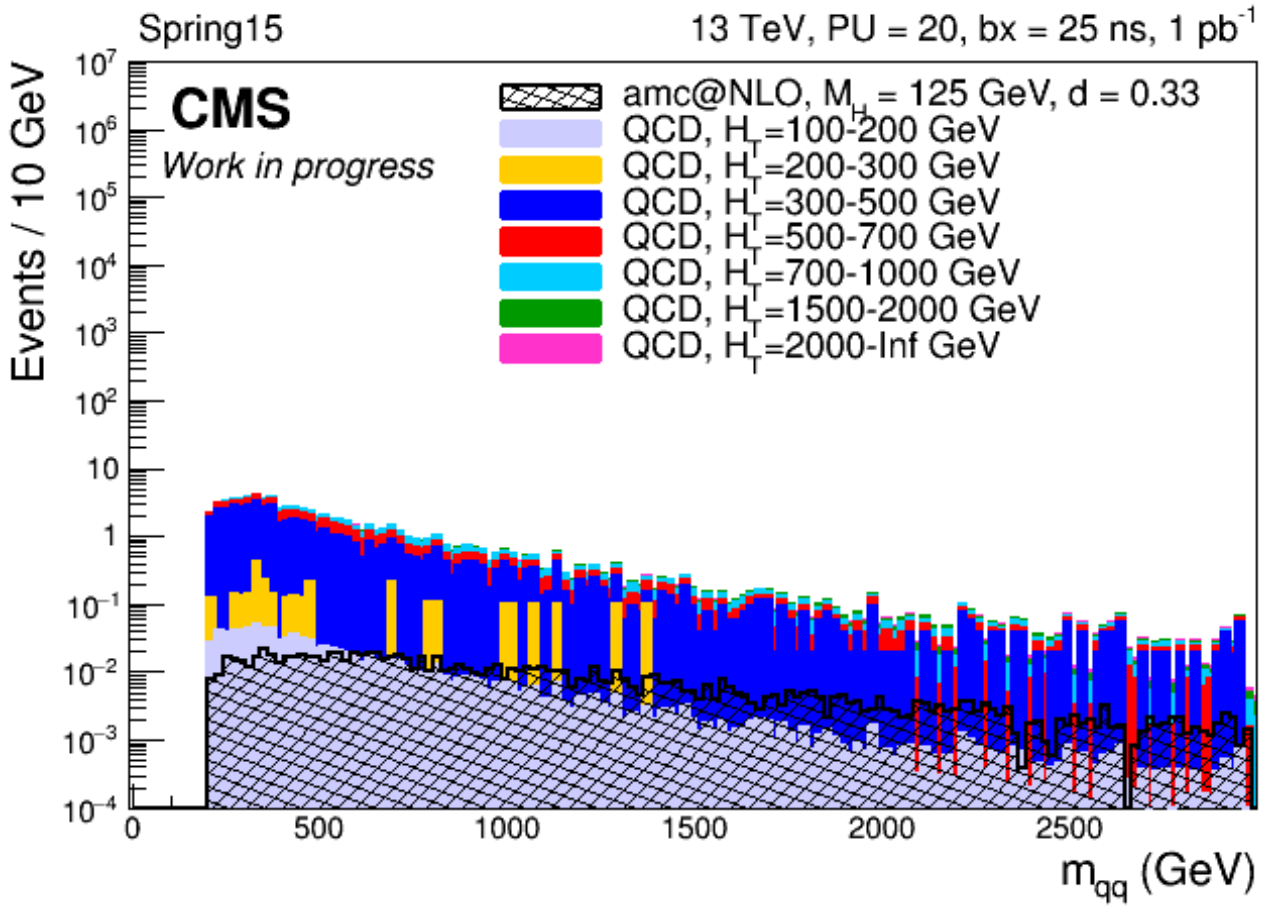
For $1fb^{-1}$we have already 100 signal events after the preselection and trigger!

Mass of two quark jets

Harder for the signal!

$$\text{Separation power : } d = \frac{1}{2}\Sigma|s - b|$$

d $\rightarrow$ 1 - good separation; 0 - bad separation.

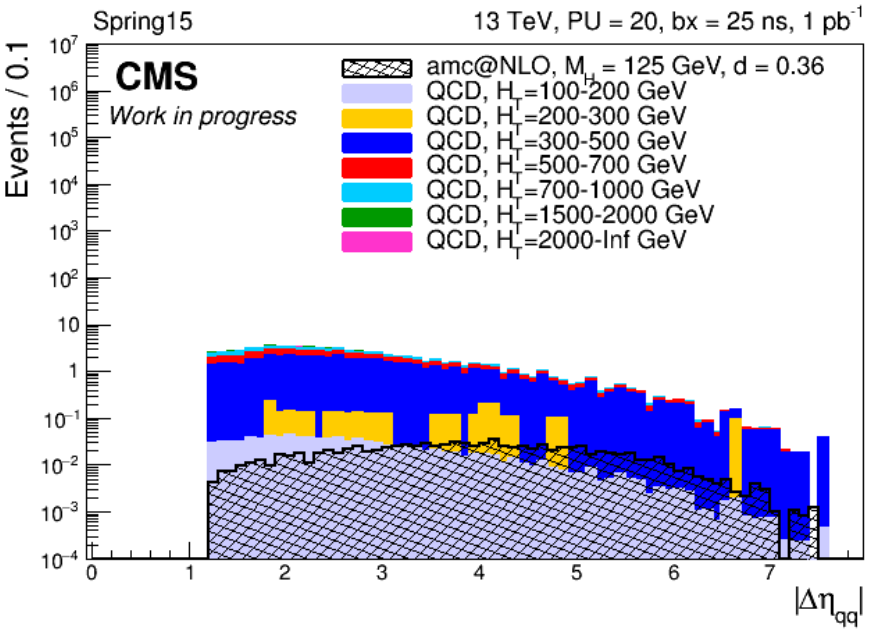


Two jets : η, ϕ

$$d = \frac{1}{2}\Sigma|s - b|$$

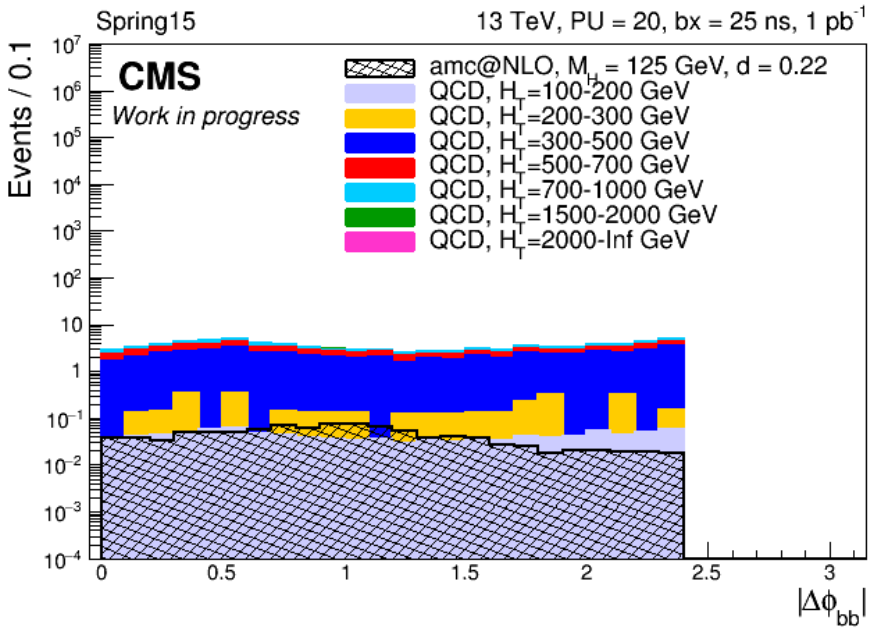
$\Delta\eta_{qq} > 1.2$

qq-jets separated in pseudorapidity



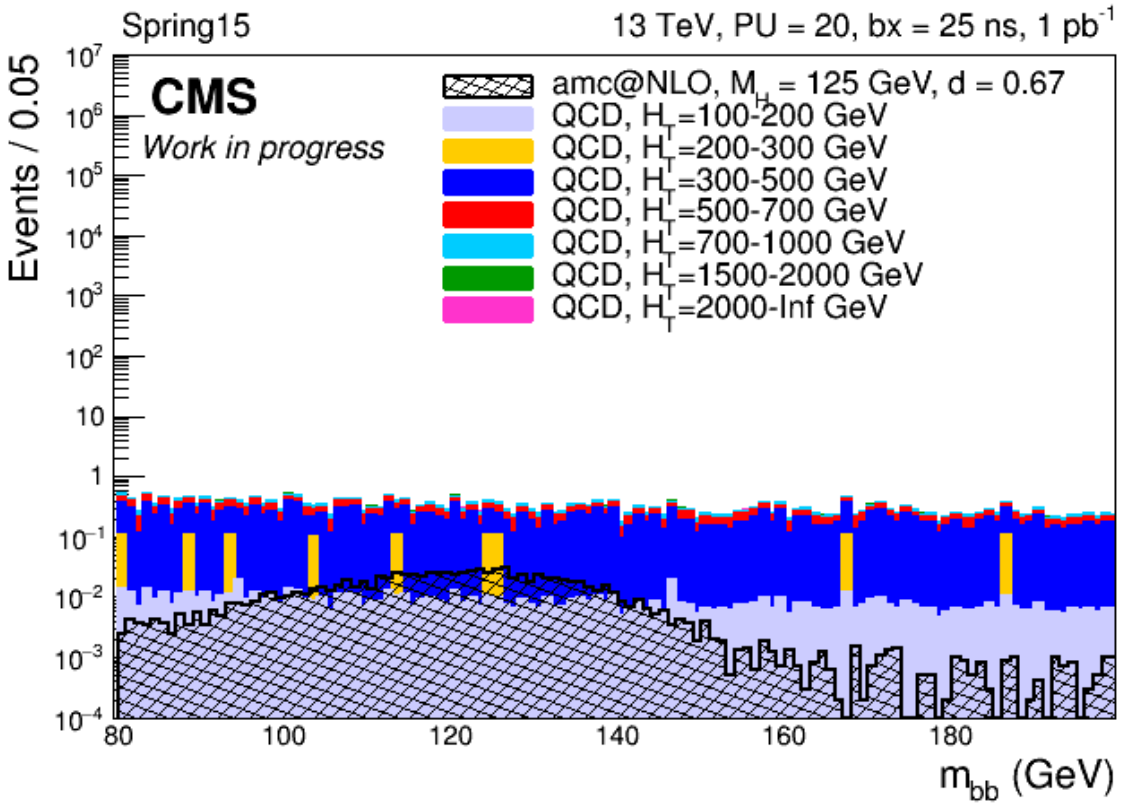
$\Delta\phi_{bb} < 2.4$

remove back-to-back b-jets



Mass of two b-jets

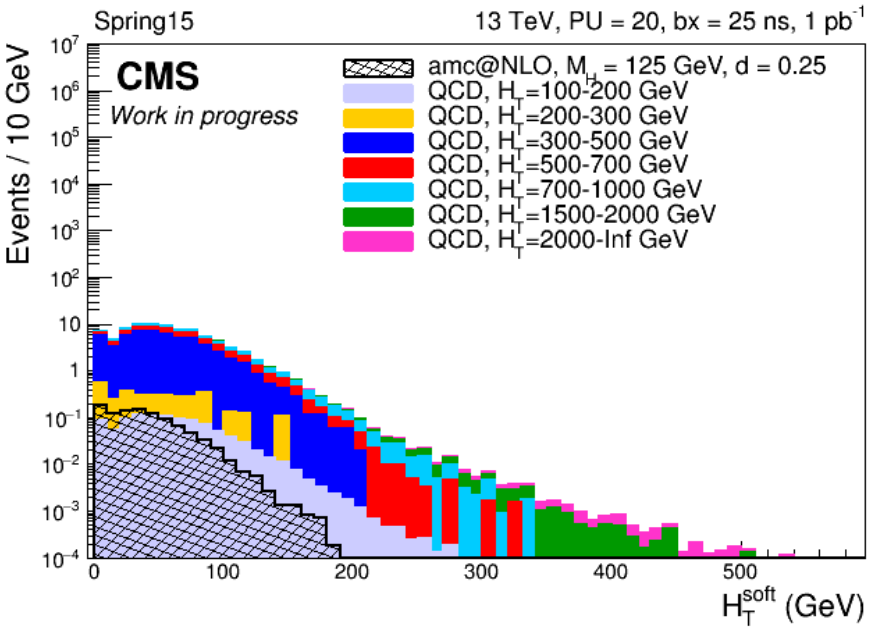
$$d = \frac{1}{2}\Sigma|s - b|$$



Soft Jets : H_T

$$d = \frac{1}{2}\Sigma|s - b|$$

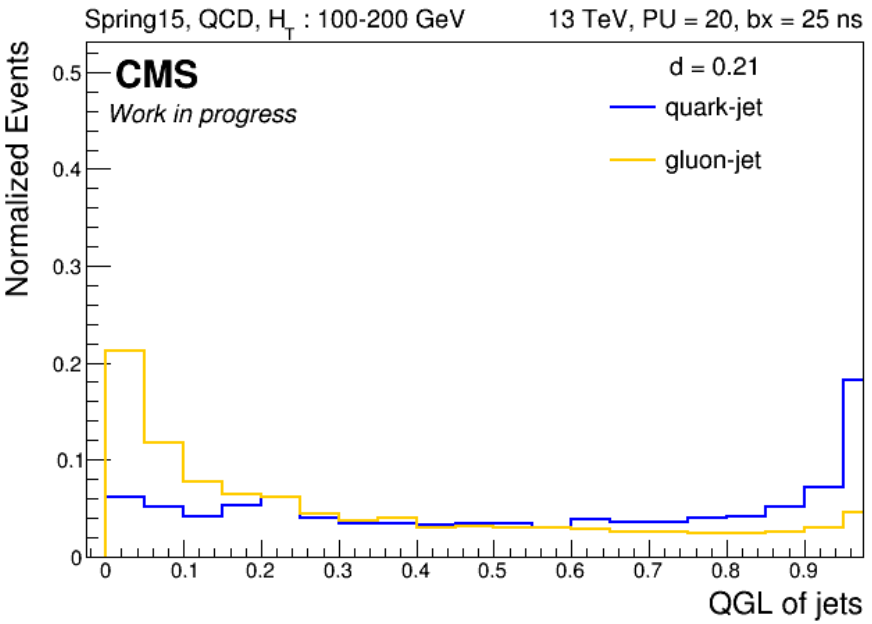
Additional hadronic soft QCD activity outside the jets. $H_T = \Sigma|p_T|$

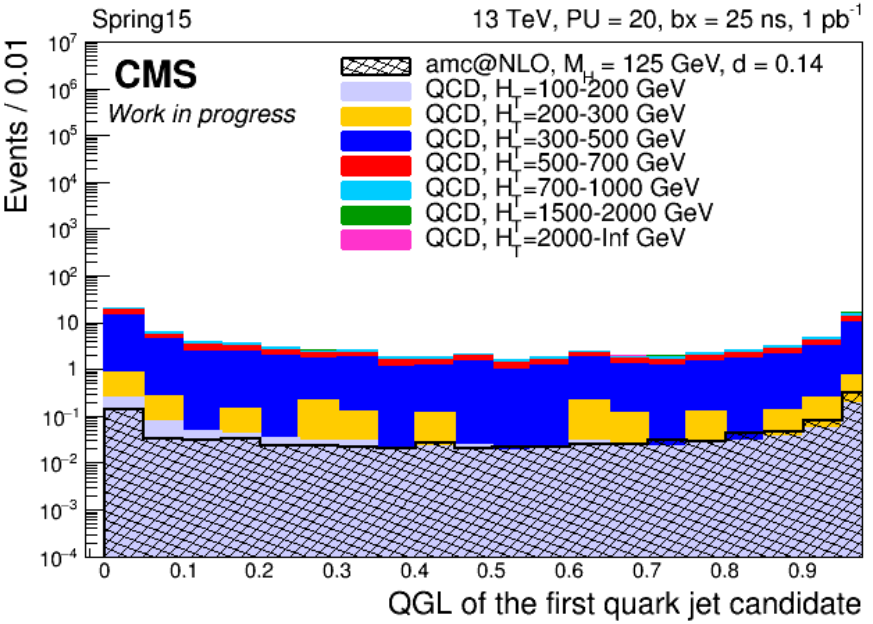


QGL of two quark jets

$$d = \frac{1}{2}\Sigma|s - b|$$

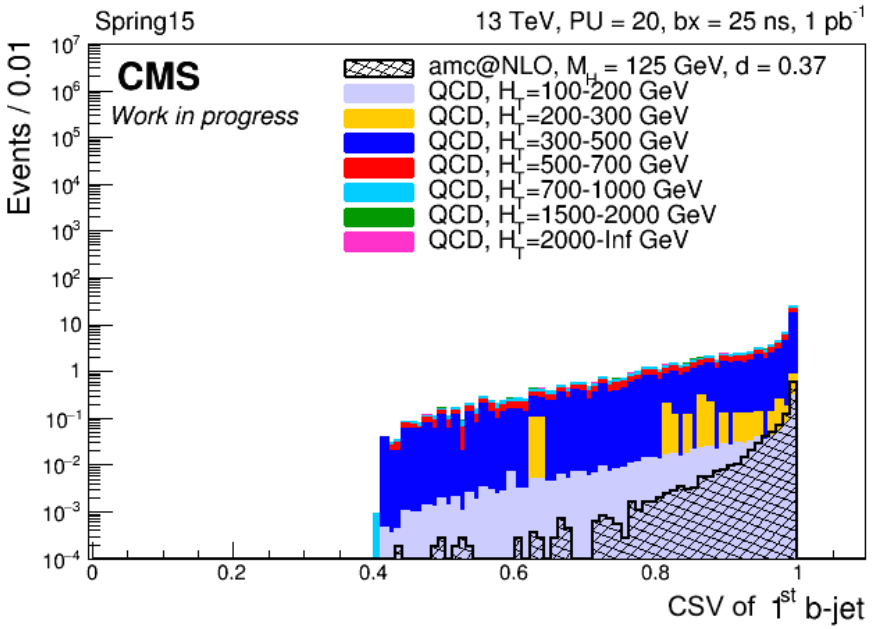
Quark Gluon likelihood - discriminator between quarks and gluons. Signal events (dominated by q-jets) $\Longrightarrow$ peak at 1, BG $\Longrightarrow$ peaks at 0.

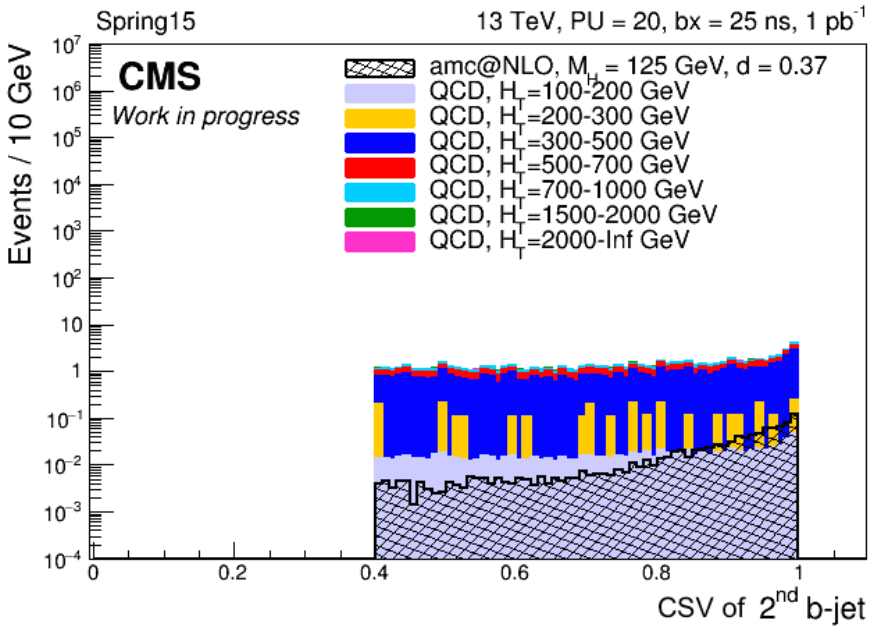




Btag of two b jets

$$d = \frac{1}{2}\Sigma|s - b|$$



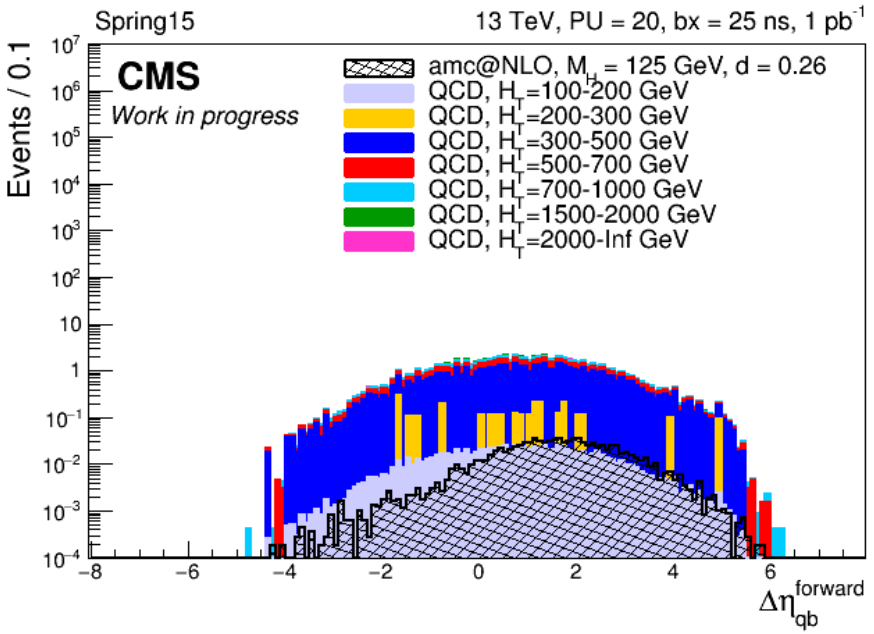


New proposal! $\Delta\eta_{qb}$

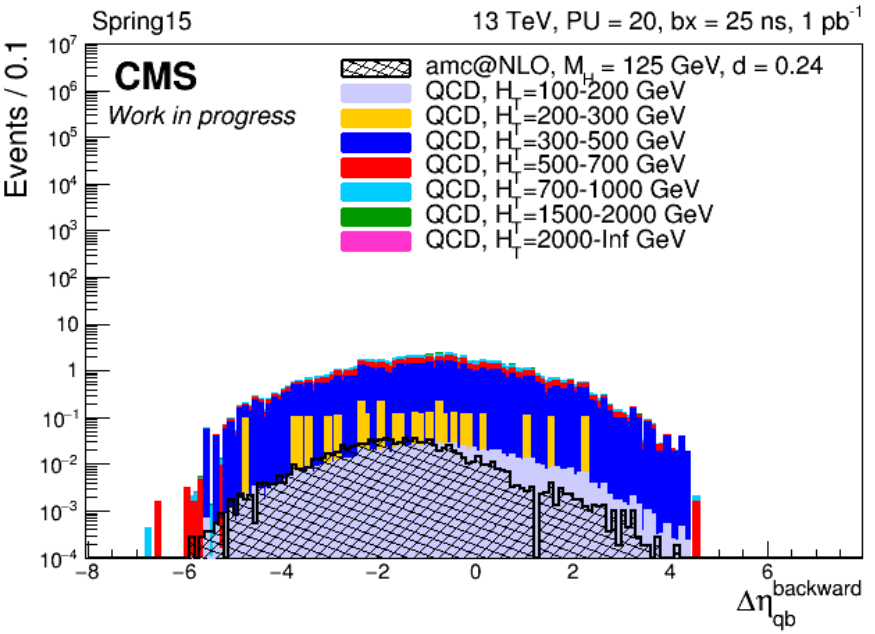
$$d = \frac{1}{2}\Sigma|s - b|$$

Signature : 2 q-jets, 2 b-jets. Look at the $\Delta\eta_{qb}$ for most forward and most backward q- and b-jets :

forward



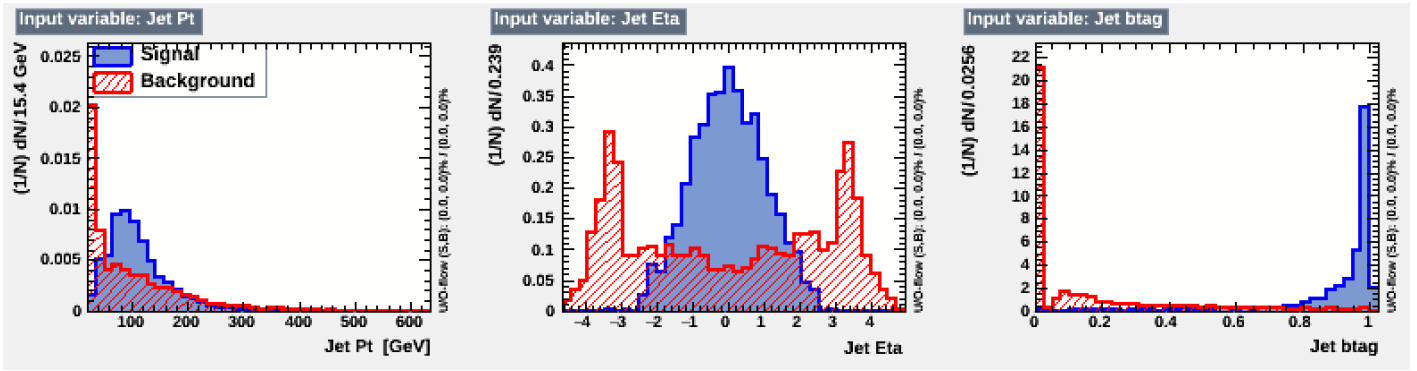
backward

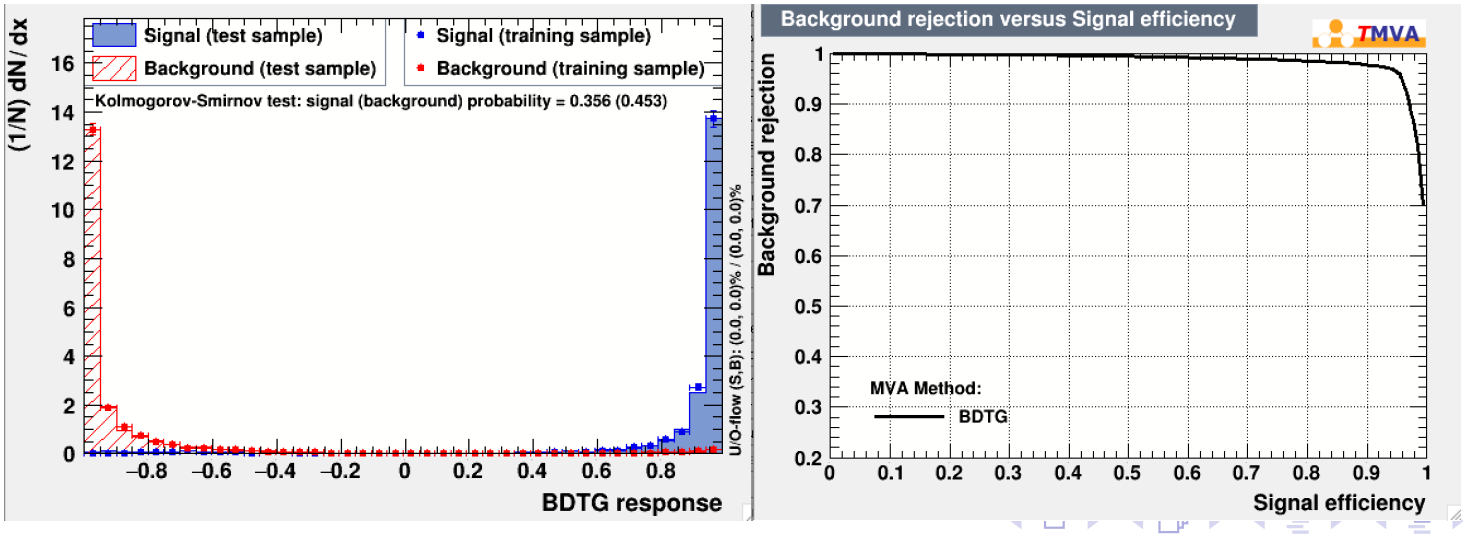


Good separation power!

b-likelihood, q-likelihood

Right tagging of 2 b-jets and 2 q-jets are crucial for the analysis! To improve it $\Longrightarrow$ use TMVA. Train the BDT to find b-tagged and q-tagged jets on MC and then use it on data.





Shape comparison. Final TMVA.

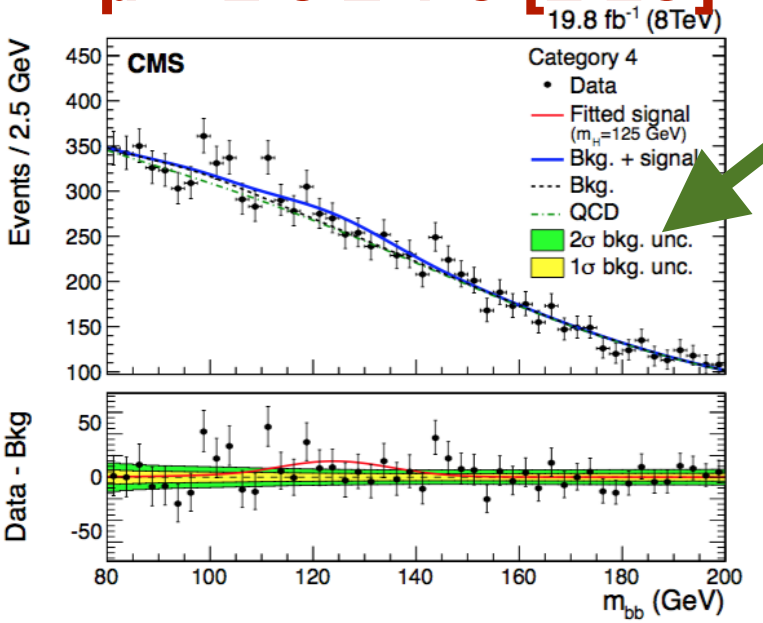
$$d = \frac{1}{2}\Sigma|s - b|$$

We can use the following variables to train the TMVA to distinguish between signal and BG.

Variable	d
M_{bb}	0.67
$btag2$	0.37
$btag$	0.37
η_{qq}	0.36
M_{qq}	0.33
$\eta_{qb}^{forward}$	0.26
H_T^{soft}	0.25
$Soft\ Multiplicity$	0.25
$\eta_{qb}^{backward}$	0.24
ϕ_{bb}	0.22

μ = 2.8 ± 1.5 [2.2σ]

Run I



And then evaluate all the possible uncertainties..☹

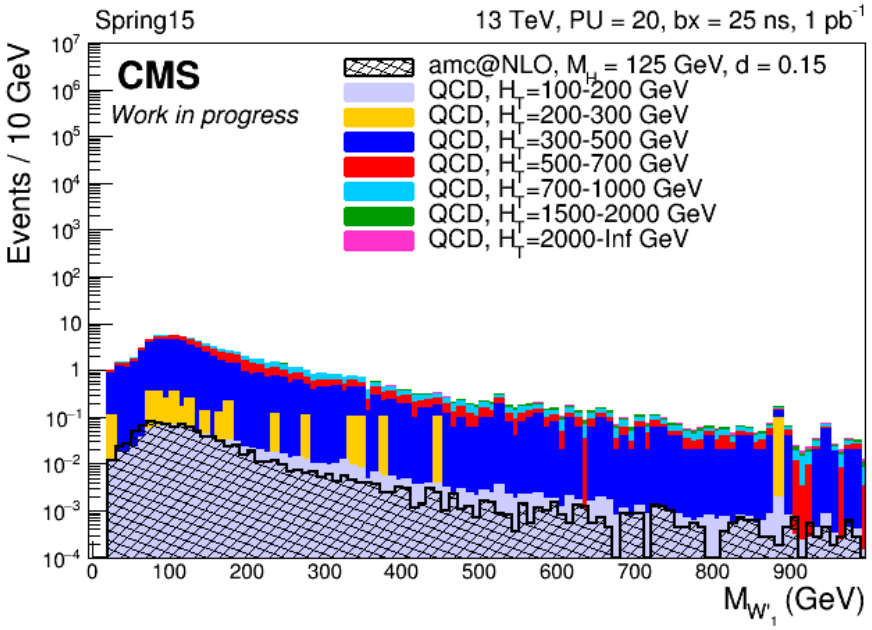
Conclusion

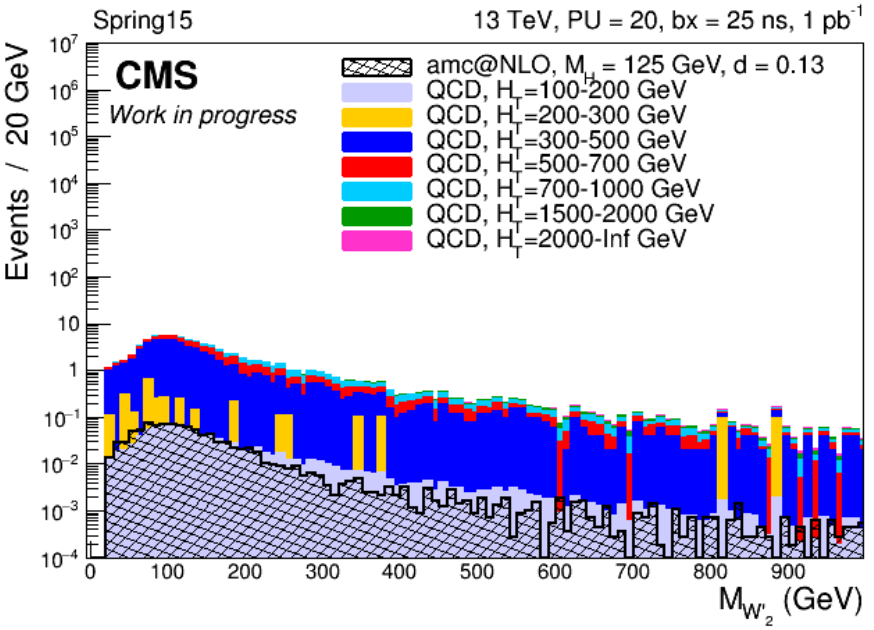
- The Run II VBF Hbb analysis has started
- With $1fb^{-1}$ we expect to have $\sim$ 80-100 signal events
- New discriminating variable $\Delta\eta_{qb}$ with good separation power was proposed
- The work is still in progress
- And we patiently wait for the new data from LHC!

Thank you for your attention!

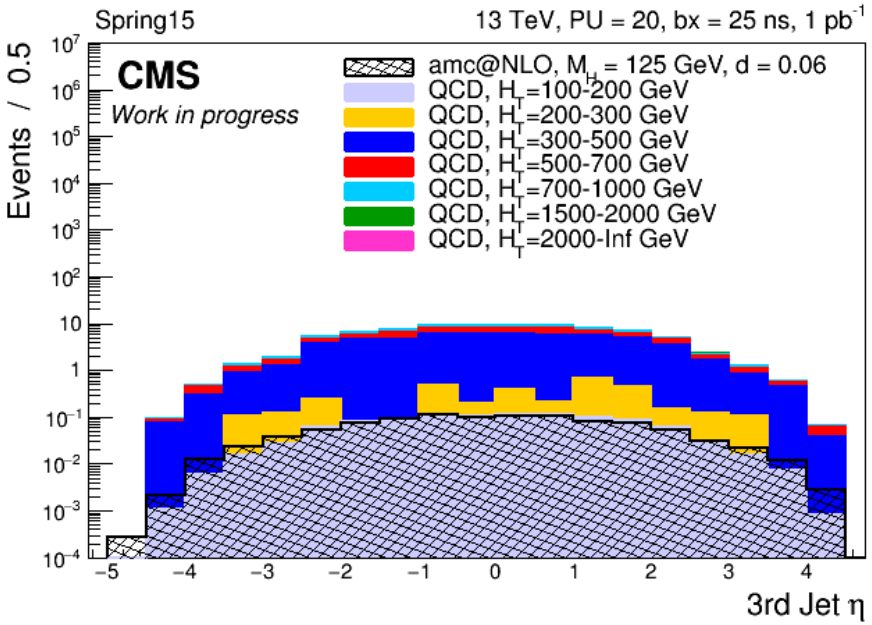
BACK UP

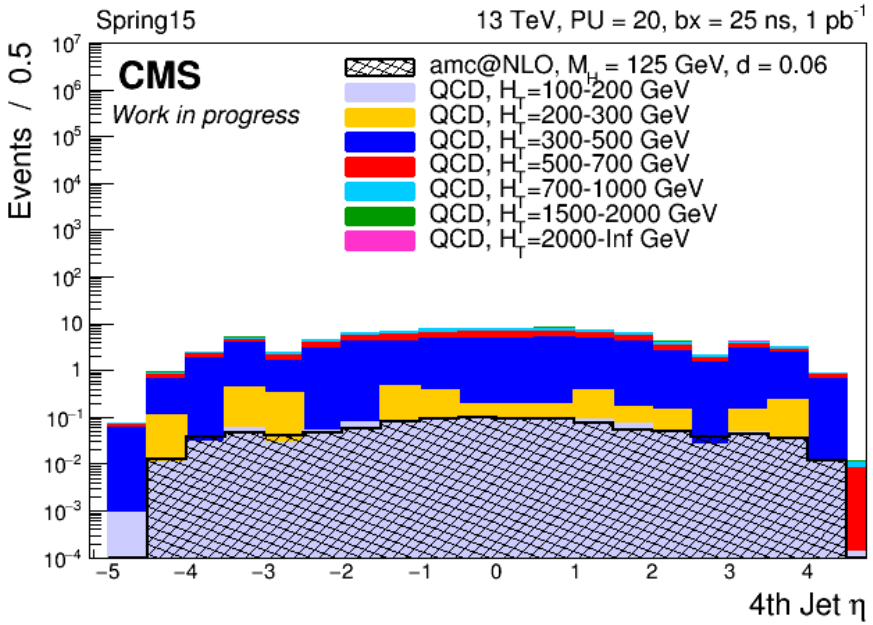
Mass of the virtual bosons W_1 and W_2



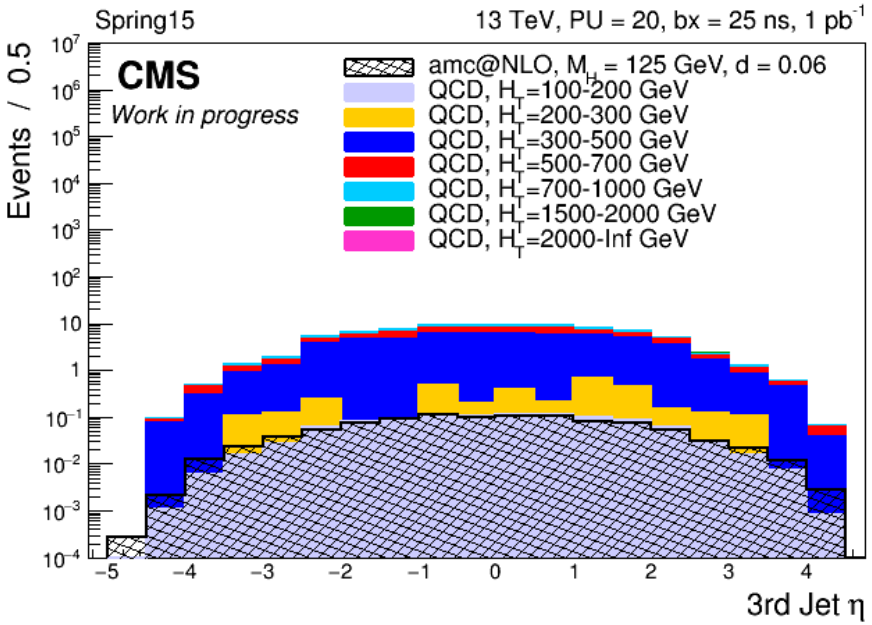


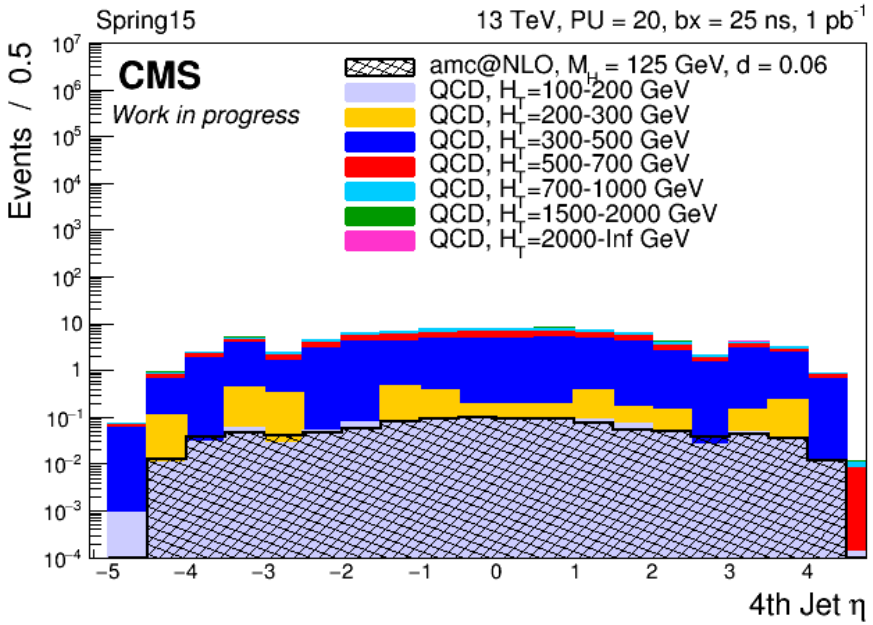
η distribution of jets. Third and Forth.



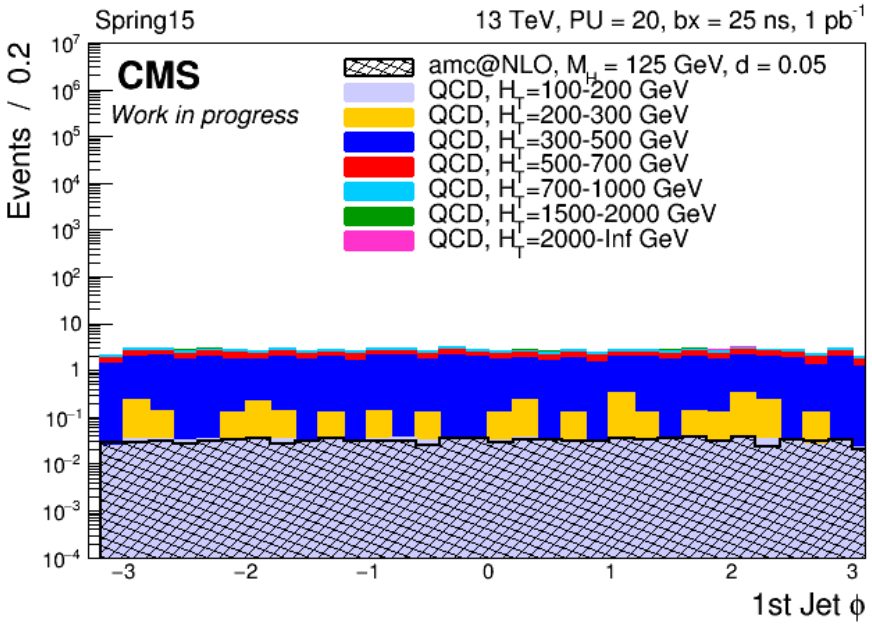


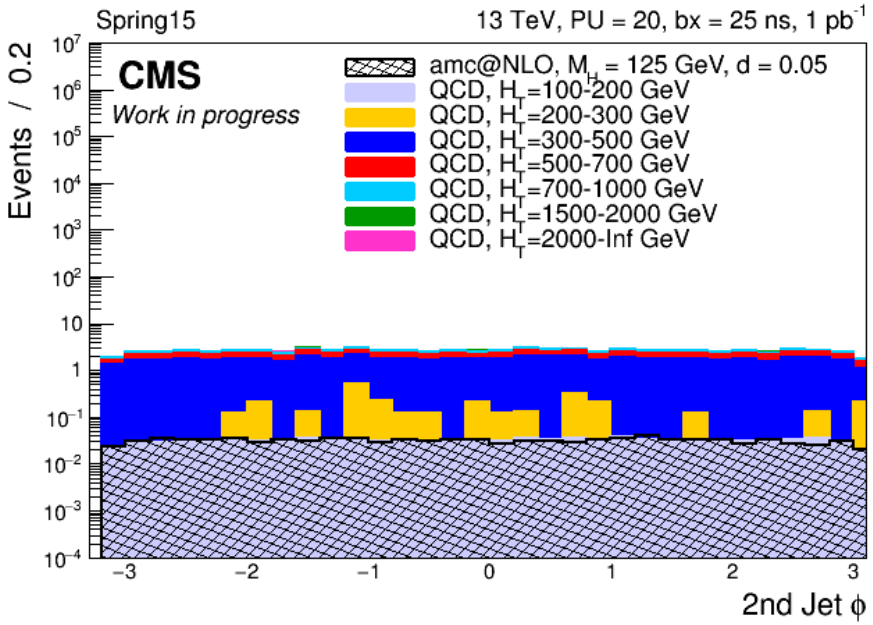
η distribution of jets. Third and Forth.



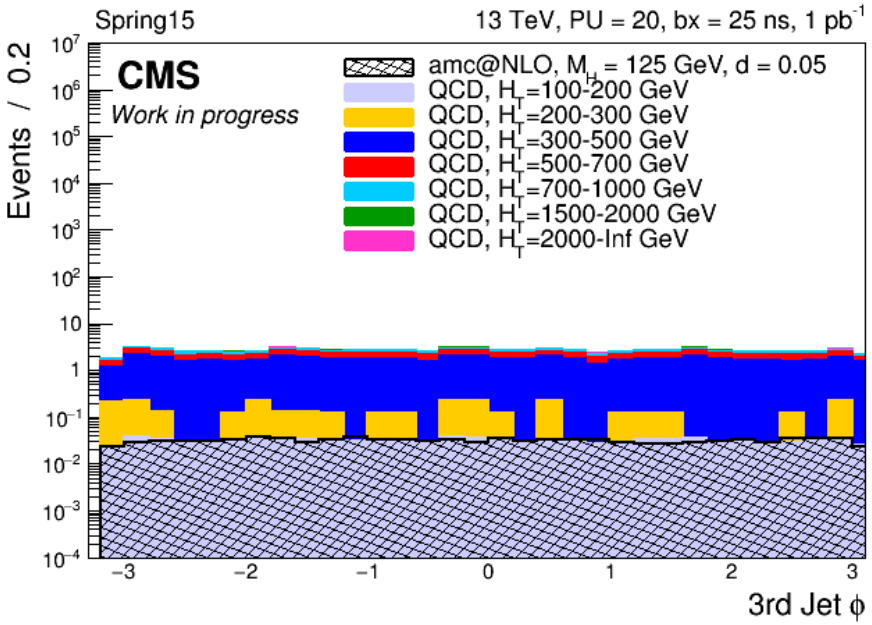


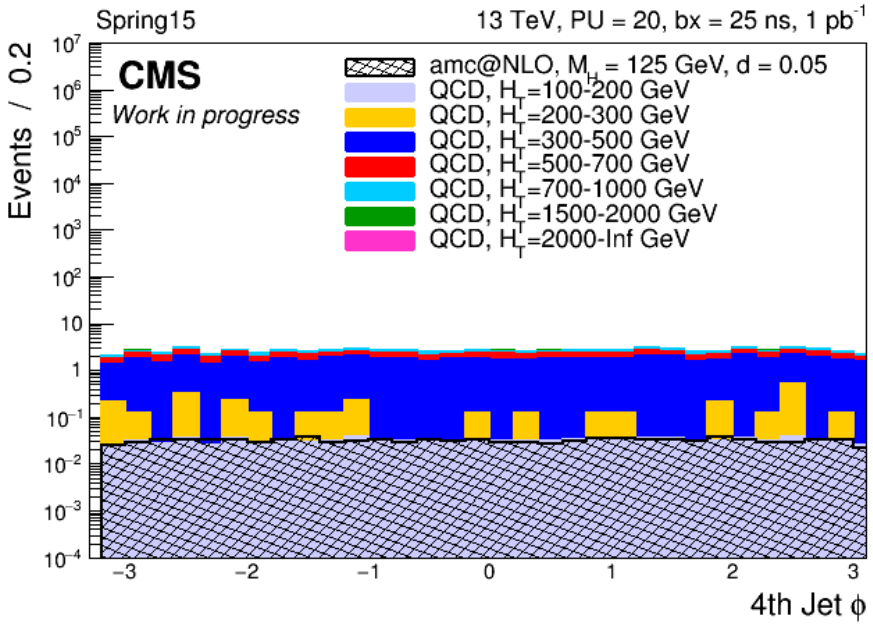
ϕ distribution of jets. First and Second.



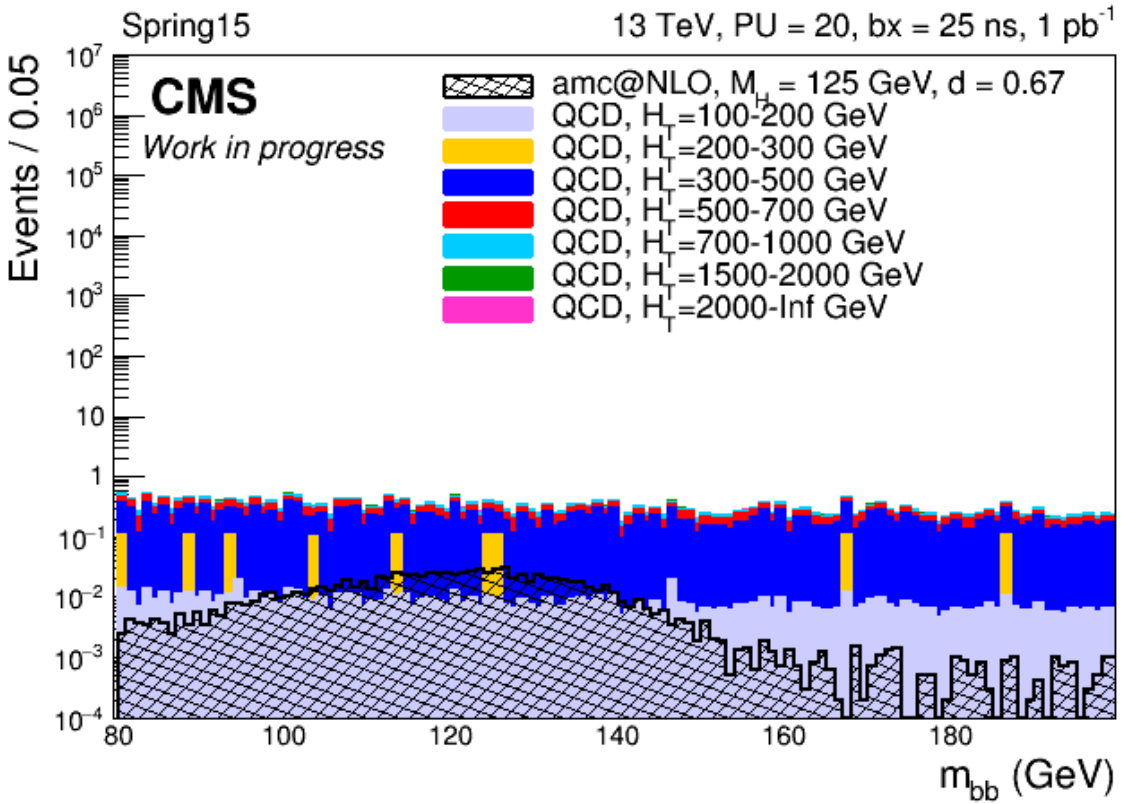


ϕ distribution of jets. Third and Forth.

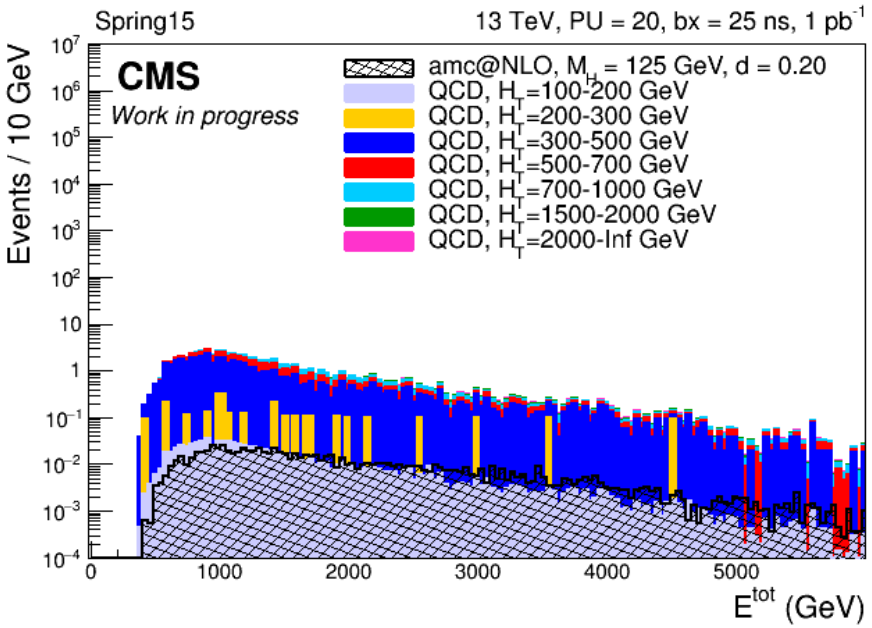


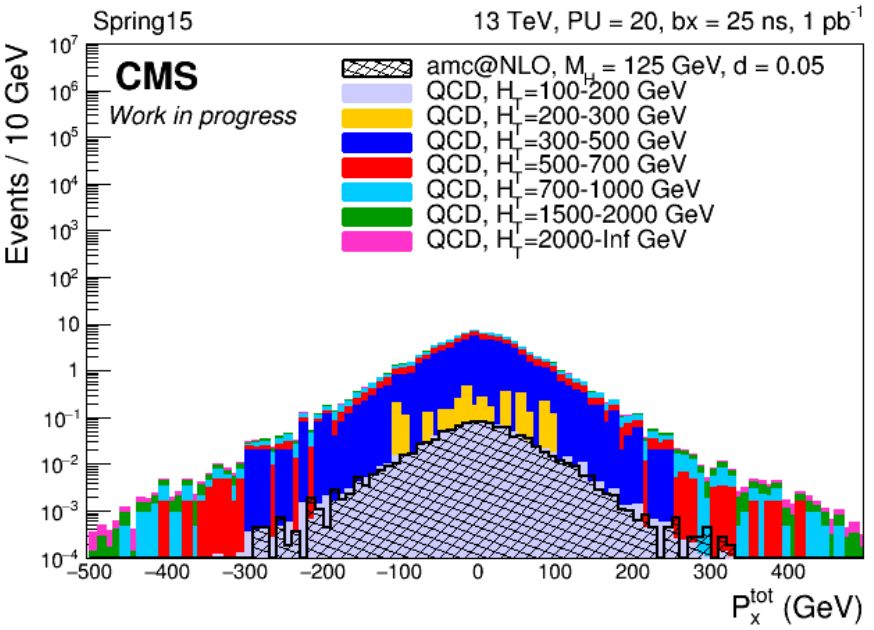


Mass of two b-jets

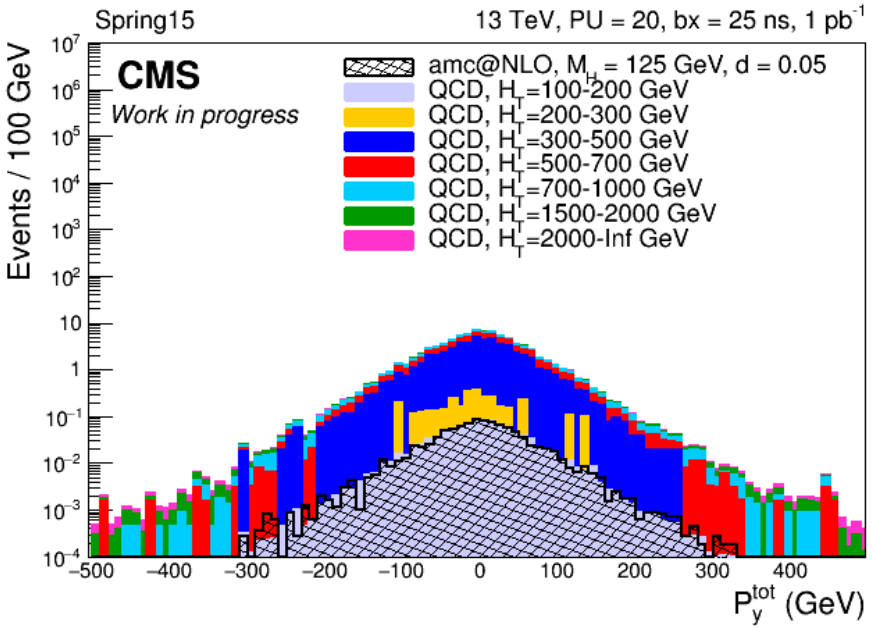


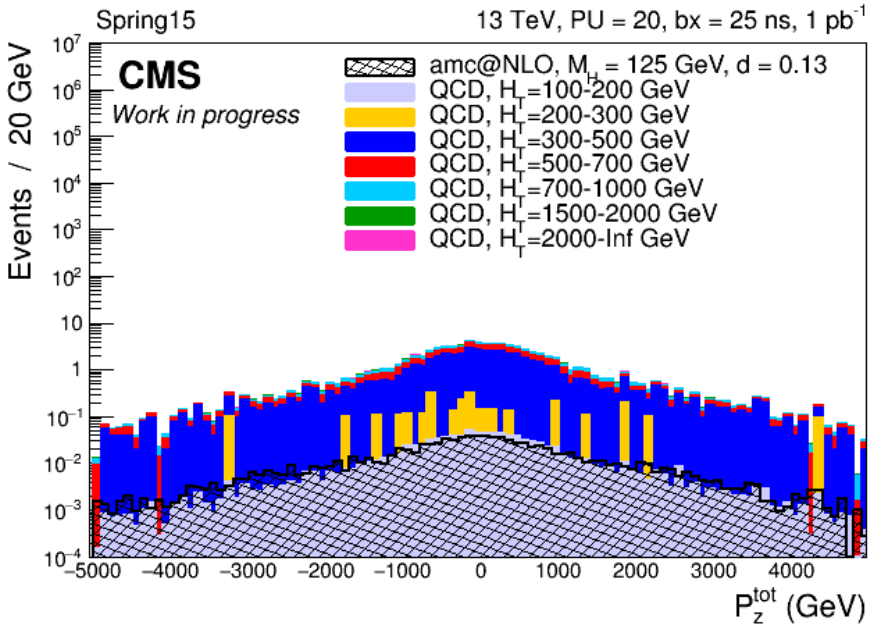
E^{tot}, p_x^{tot}, p_y^{tot}, p_z^{tot}





E^{tot}, p_x^{tot}, p_y^{tot}, p_z^{tot}



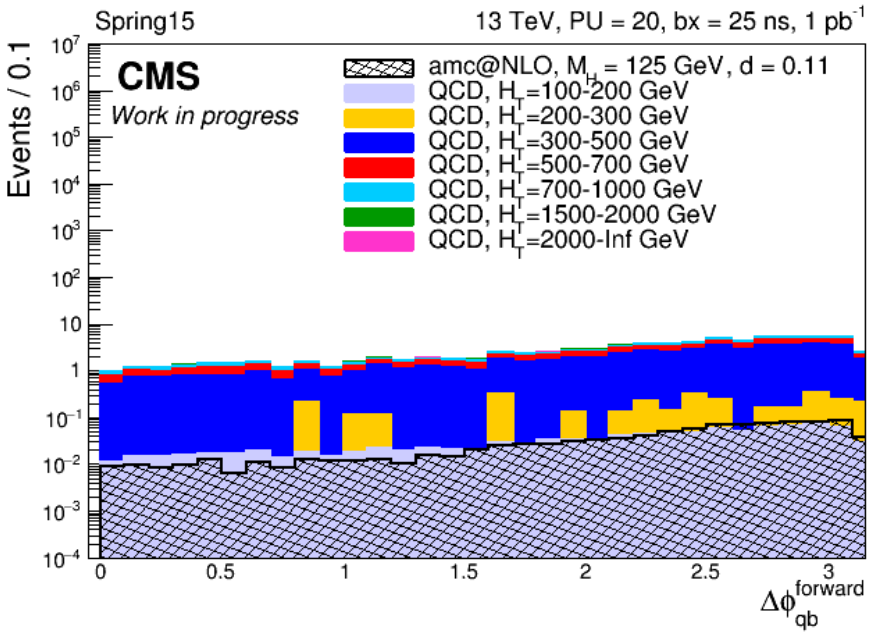


Everything is consistent with expectations.

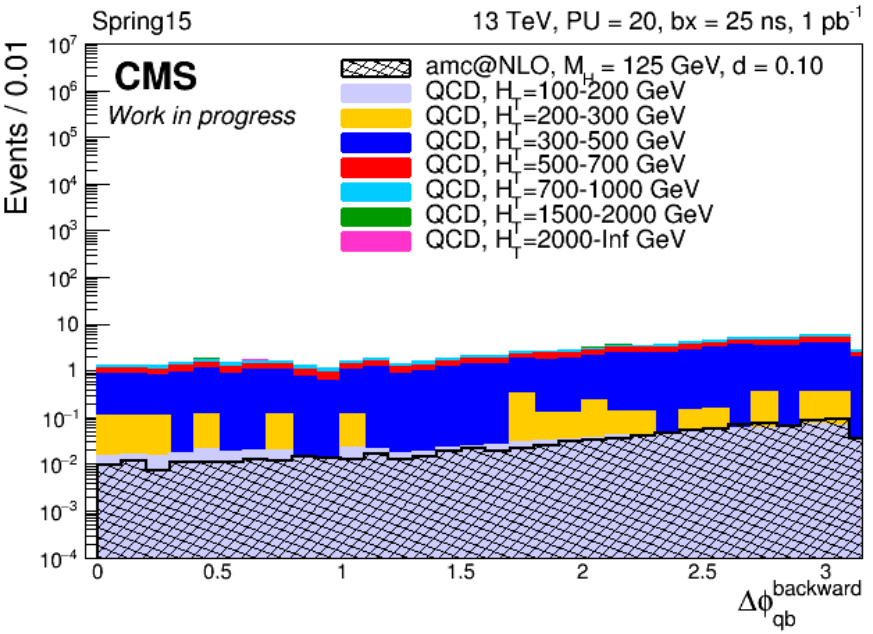
New proposal! $\Delta\eta_{qb}$

Signature : 2 q-jets, 2 b-jets. Look at the $\Delta\phi_{qb}$ for most forward and most backward q- and b-jets :

forward



backward



Discriminating variables. Shape comparison

$$d = 1/2\Sigma|s - b|$$

Variable	d
hMbb	0.67
hbtag2	0.37
hbtag	0.37
hEtaQQ	0.36
hMqq	0.33
hEtaQB1	0.26
hHTsoft	0.25
hSoft_n5	0.25
hEtaQB2	0.24
hSoft_n2	0.23
hPhiBB	0.22
hSoft_n10	0.21
hPtSoftJets2	0.21
hPtSoftJets	0.2
hEtot	0.2
hVB1_mass	0.15

Variable	d
hEtaqqbb	0.14
hqgl	0.14
hqgl2	0.13
hVB2_mass	0.13
hPztot	0.13
hx2	0.12
hcosOqqbb	0.12
hJet5_pt	0.12
hJet1_eta	0.11
hPtSoftJets3	0.11
hPhiQB1	0.11
hJet2_pt	0.1