

# Study of resonant double-Higgs production in the vector boson fusion process at a 100 TeV pp collider

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# Motivation

- Assumption is that there is a strong dynamics at the energy scale “ $f$ ” which causes a condensate to form and break the  $SO(5)$  symmetry
- Resonances will be associated with this strong dynamics
- Lightest resonance will decay to the “pseudo-Goldstones” which are much lighter, ie longitudinal gauge bosons and Higgs bosons
  - Similar to QCD  $\rho \rightarrow \pi\pi$
- Simplified model: arXiv:1109.1570 (Contino *et al.*) “On the effect of resonances in composite Higgs phenomenology”
  - Scalar resonance:  $\eta \rightarrow hh, V_L V_L$

# Motivation

- Lagrangian from Contino *et al.* paper for a scalar resonance  $\eta$  coupling to the Goldstones

$$\mathcal{L}^{(\eta)} = \frac{1}{2} (\partial_\mu \eta)^2 - \frac{1}{2} m_\eta^2 \eta^2 + \frac{f^2}{4} \left( 2a_\eta \frac{\eta}{f} + b_\eta \frac{\eta^2}{f^2} \right) \text{Tr} [d_\mu d^\mu]$$


$$(D_\mu \Phi)^T (D^\mu \Phi)$$

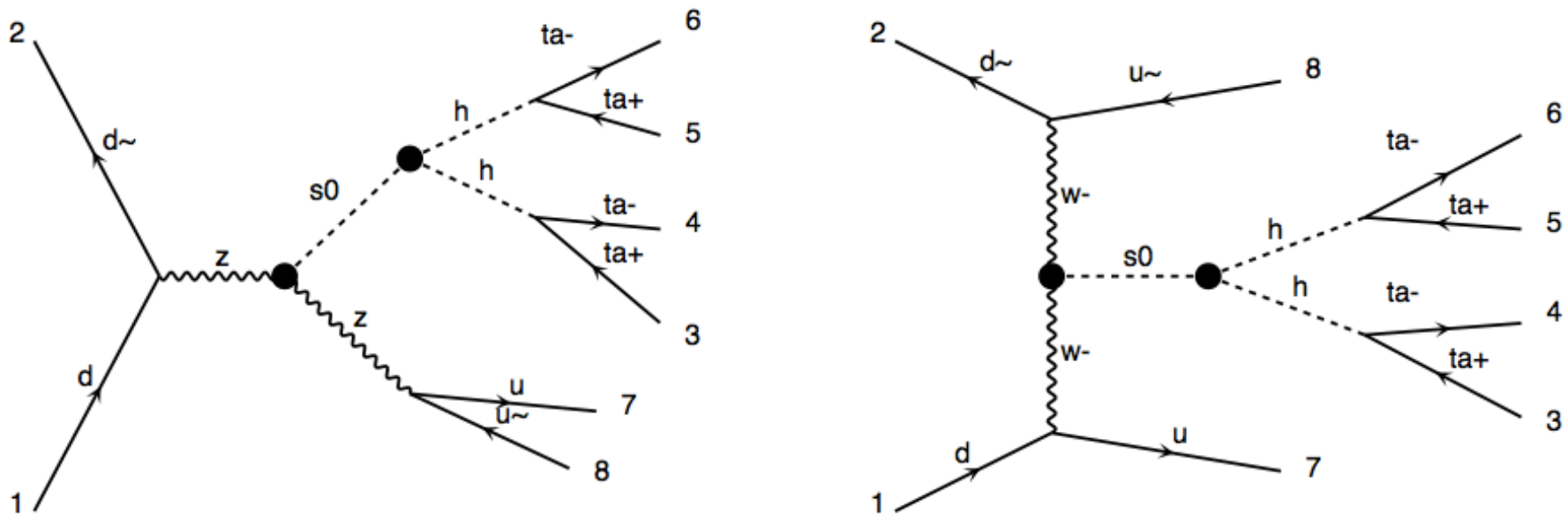
- Width of the resonance:

$$\Gamma_\eta = \frac{a_\eta^2 m_\eta^3}{8\pi f^2}$$

Free parameters: mass and width of the resonance

# Madgraph Model

- Madgraph model coded by Matthew Low (U. Chicago) which he is also using for the  $WW$  resonance study



Resonance decaying to two Higgs bosons is a distinctive signature

Branching ratio to  $hh$ ,  $W_L W_L$  and  $Z_L Z_L$  in the 1:2:1 ratio is a definitive prediction

# Final States for Higgs Detection

Channels with three largest branching ratios swamped by QCD and top-antitop production

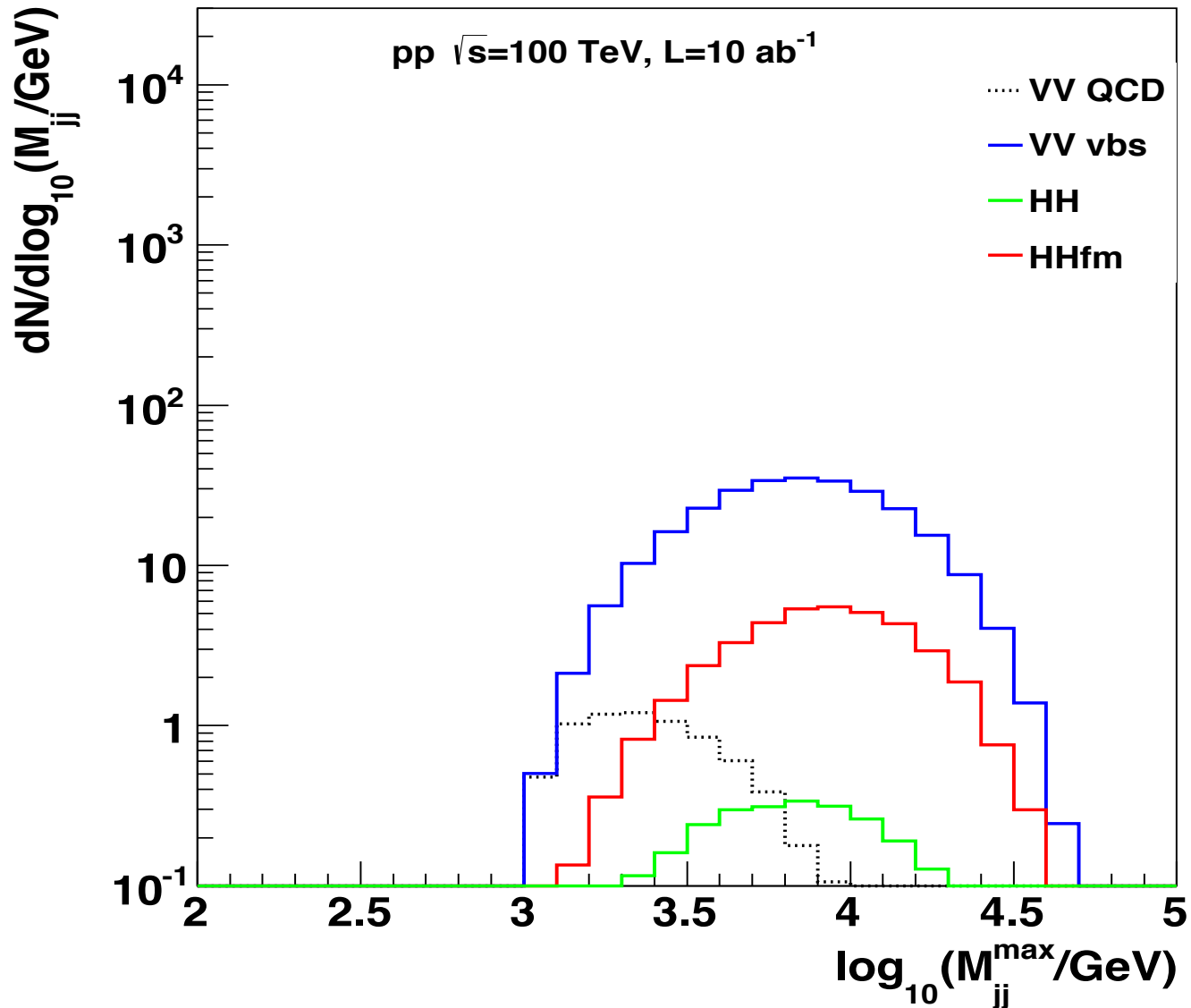
Started investigation of 4-tau final state

diphoton + bb may also give enough rate

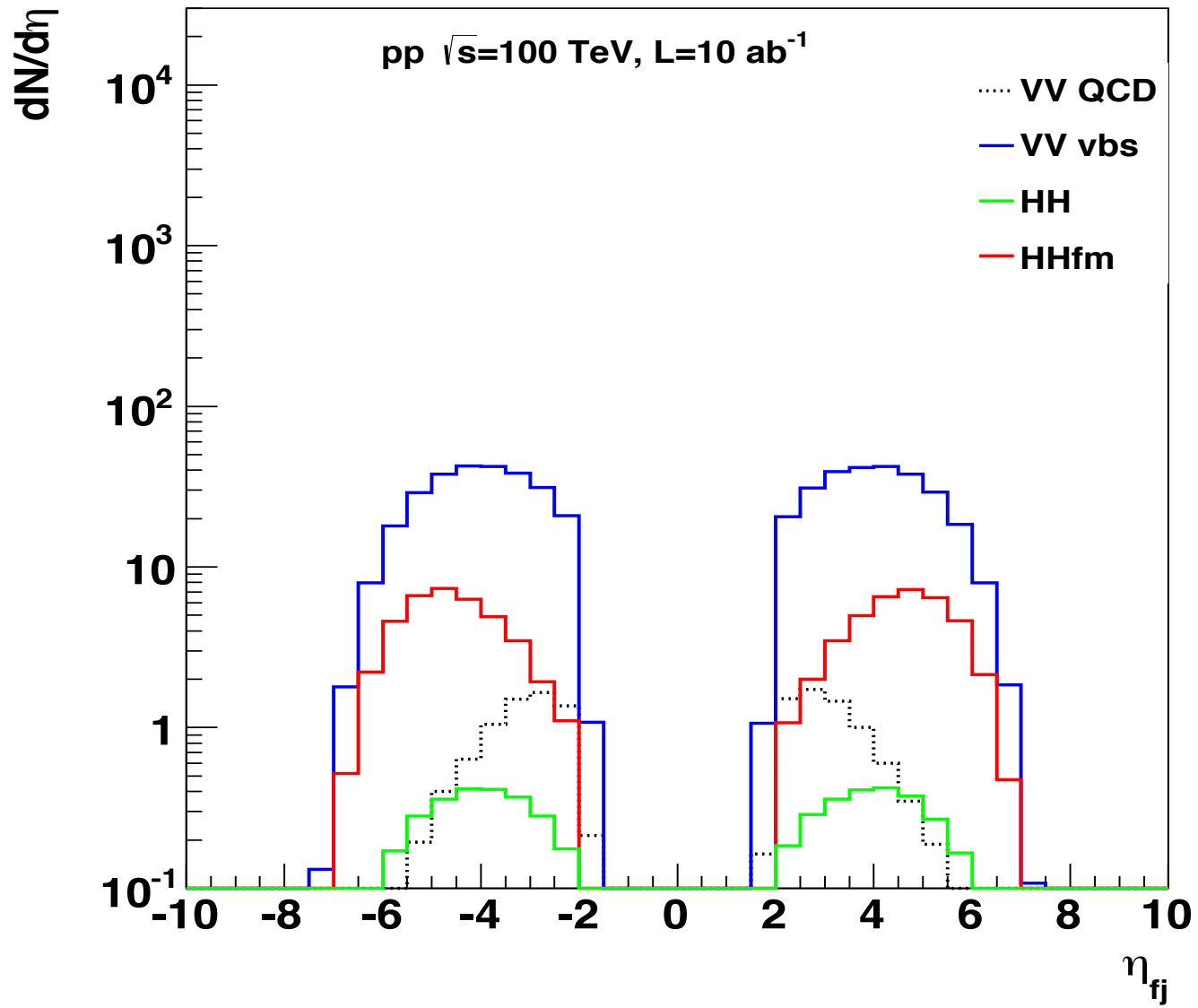
Decay channel	Branching ratio	Uncr. ( $\pm$ )
$b\bar{b}b\bar{b}$	$3.33 \cdot 10^{-01}$	$1.55 \cdot 10^{-02}$
$\tau\tau b\bar{b}$	$3.65 \cdot 10^{-02}$	$2.40 \cdot 10^{-03}$
$W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)b\bar{b}$	$5.47 \cdot 10^{-03}$	$2.97 \cdot 10^{-04}$
$\tau\tau\tau\tau$	$3.99 \cdot 10^{-03}$	$3.22 \cdot 10^{-04}$
$\gamma\gamma b\bar{b}$	$1.32 \cdot 10^{-03}$	$7.88 \cdot 10^{-05}$
$W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)\tau\tau$	$5.99 \cdot 10^{-04}$	$4.28 \cdot 10^{-05}$
$\gamma\gamma\tau\tau$	$1.44 \cdot 10^{-04}$	$1.09 \cdot 10^{-05}$
$b\bar{b}\mu^+\mu^-$	$1.26 \cdot 10^{-04}$	$8.65 \cdot 10^{-06}$
$W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)$	$8.99 \cdot 10^{-05}$	$5.47 \cdot 10^{-06}$
$Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)b\bar{b}$	$7.04 \cdot 10^{-05}$	$3.82 \cdot 10^{-06}$
$b\bar{b}Z(\rightarrow l^+l^-)\gamma$	$6.04 \cdot 10^{-05}$	$5.79 \cdot 10^{-06}$
$\gamma\gamma W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)$	$2.16 \cdot 10^{-05}$	$1.43 \cdot 10^{-06}$
$\tau\tau\mu^+\mu^-$	$1.38 \cdot 10^{-05}$	$1.15 \cdot 10^{-06}$
$Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)\tau\tau$	$7.72 \cdot 10^{-06}$	$5.51 \cdot 10^{-07}$
$\tau\tau Z(\rightarrow l^+l^-)\gamma$	$6.62 \cdot 10^{-06}$	$7.05 \cdot 10^{-07}$
$\gamma\gamma\gamma\gamma$	$5.20 \cdot 10^{-06}$	$3.68 \cdot 10^{-07}$
$W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)\mu^+\mu^-$	$2.08 \cdot 10^{-06}$	$1.53 \cdot 10^{-07}$
$Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)$	$1.16 \cdot 10^{-06}$	$7.04 \cdot 10^{-08}$
$W^+(\rightarrow l\nu)W^-(\rightarrow l\nu)Z(\rightarrow l^+l^-)\gamma$	$9.93 \cdot 10^{-07}$	$9.90 \cdot 10^{-08}$
$\gamma\gamma\mu^+\mu^-$	$4.99 \cdot 10^{-07}$	$3.90 \cdot 10^{-08}$
$\gamma\gamma Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)$	$2.78 \cdot 10^{-07}$	$1.84 \cdot 10^{-08}$
$\gamma\gamma Z(\rightarrow l^+l^-)\gamma$	$2.39 \cdot 10^{-07}$	$2.46 \cdot 10^{-08}$
$Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)\mu^+\mu^-$	$2.67 \cdot 10^{-08}$	$1.97 \cdot 10^{-09}$
$Z(\rightarrow l^+l^-)\gamma\mu^+\mu^-$	$2.29 \cdot 10^{-08}$	$2.48 \cdot 10^{-09}$
$Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)$	$1.49 \cdot 10^{-08}$	$9.06 \cdot 10^{-10}$
$Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)Z(\rightarrow l^+l^-)\gamma$	$1.28 \cdot 10^{-08}$	$1.28 \cdot 10^{-09}$
$Z(\rightarrow l^+l^-)\gamma Z(\rightarrow l^+l^-)\gamma$	$1.10 \cdot 10^{-08}$	$1.40 \cdot 10^{-09}$

Table from Sergei Chekanov

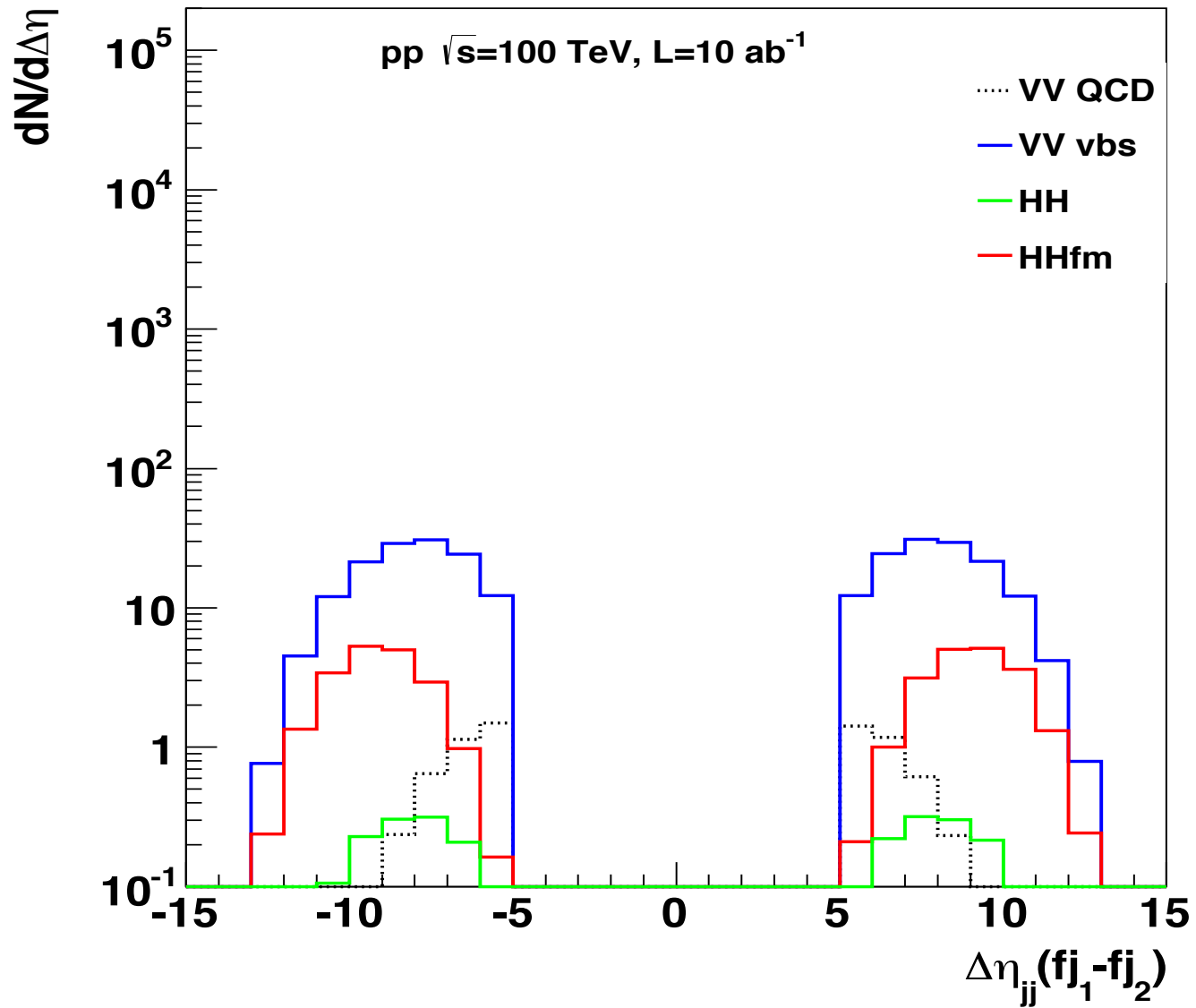
# Invariant Mass of forward Jets



# $\eta$ of forward Jets

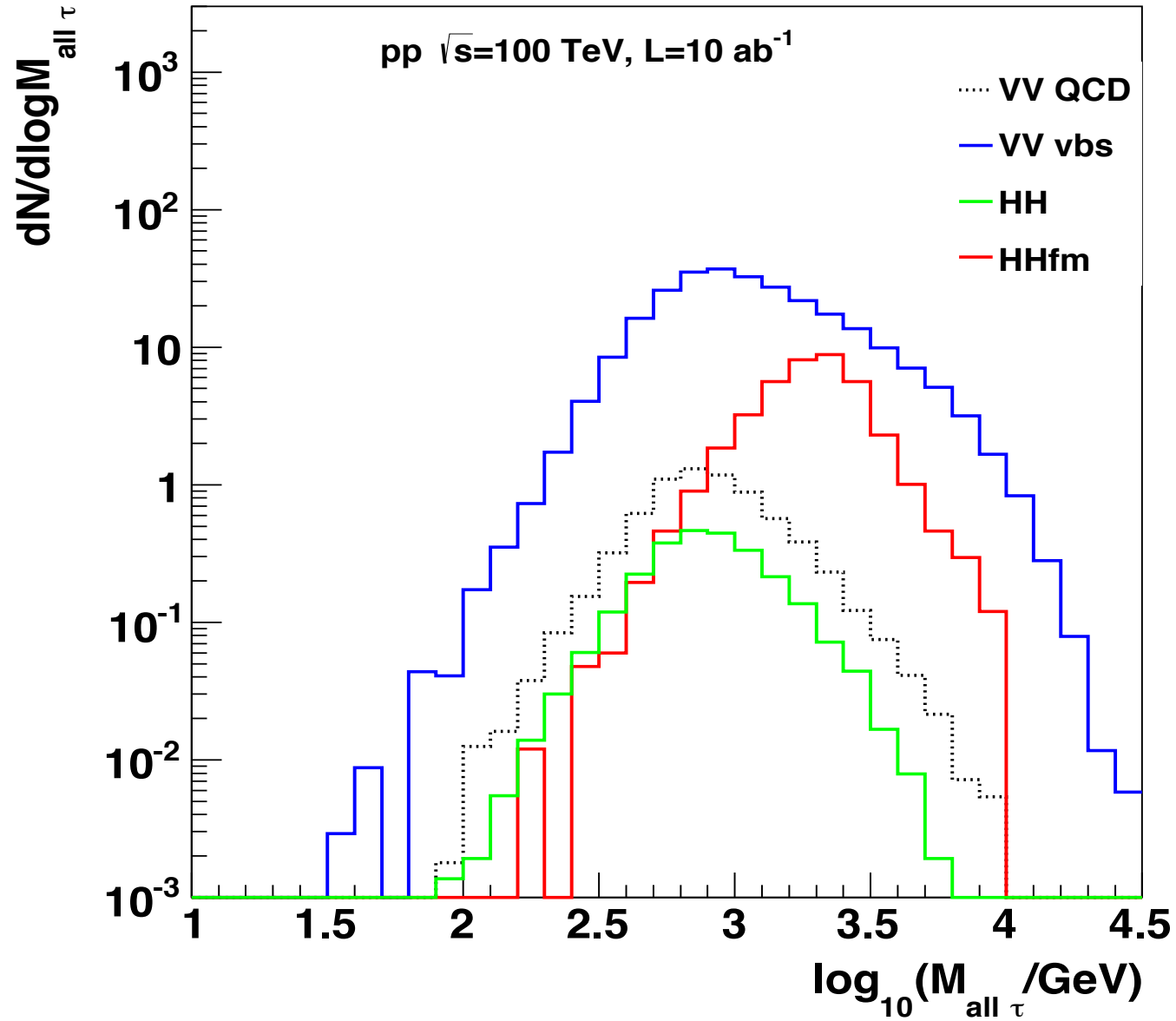


# $\Delta\eta$ of forward Jets

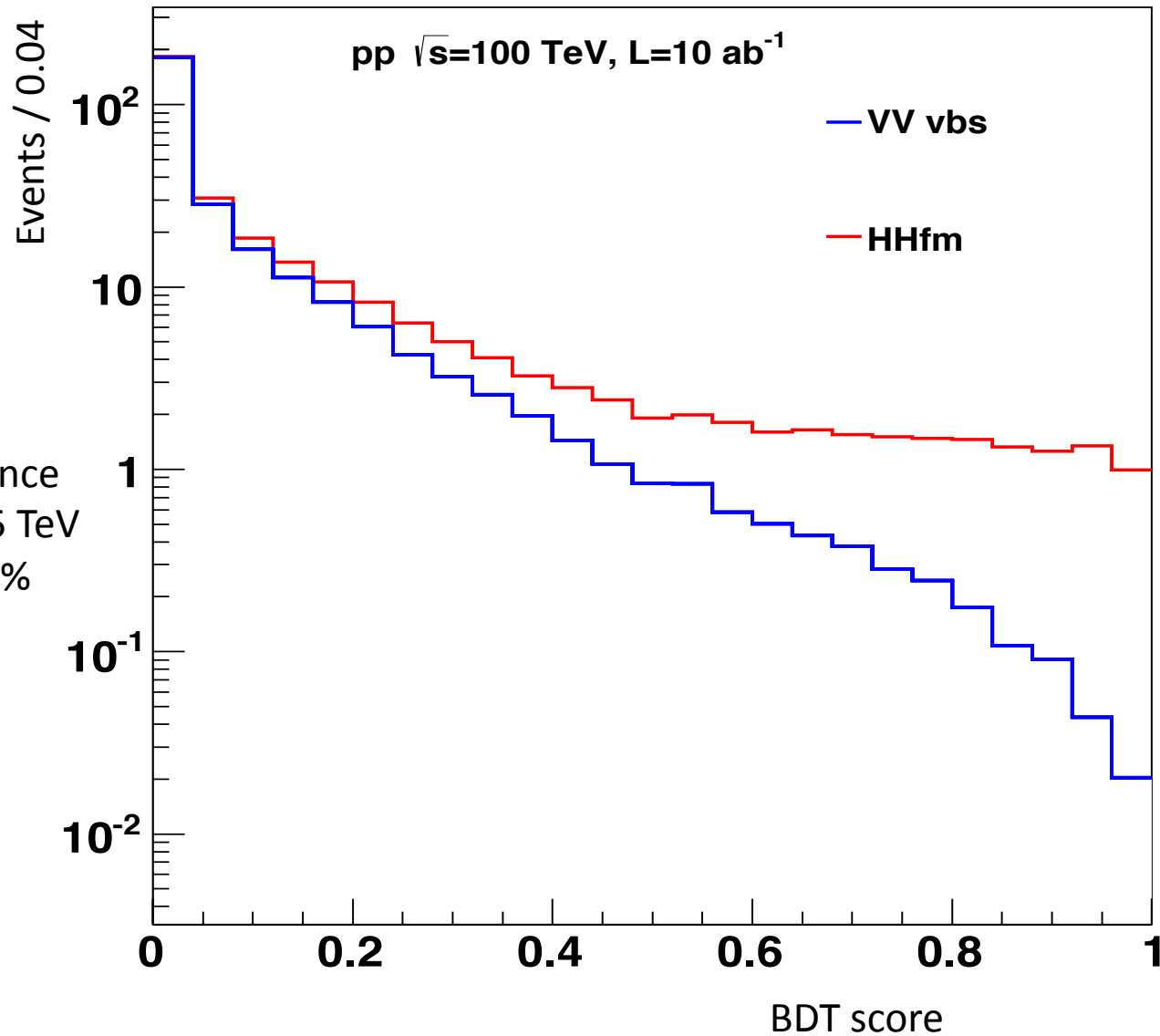




# Invariant Mass of all visible tau momenta



# BDT Multivariate Discriminant



Signal is  
 $\eta \rightarrow$  HH resonance  
with mass = 3.5 TeV  
And width = 20%

Frequentist  
Significance  
=  $5\sigma$

# Summary

- Detection of double-Higgs resonance in VBS topology requires tagging forward jets up to rapidity of 6-7
- Requirement of detecting four (boosted) taus put stringent demand on tau identification efficiency (results shown today assume 100% efficiency for rapidity  $< 3$ )
- Diphoton +  $b\bar{b}$  channel may be competitive (factor of 3 smaller branching ratio but higher efficiency and narrower resonance peak)