

CP properties from VH production at LHC

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Based on A. Djouadi, R.Godbole, B. Mellado and K.M., 1301.4965
&
work in preparation with R. Godbole , C. White , D. Miller

GDR Terascale May 2013



Higgs CP properties

- Determination of the nature of HVV couplings requires knowledge of:
 - Strength of couplings
 - Lorentz structure of the HVV vertex.(Information on spin and CP.)

$$\Gamma_{HVV}^{\mu\nu} = ag^{\mu\nu} + bp^\mu k^\nu + c\epsilon^{\mu\nu\alpha\beta} p_\alpha k_\beta$$

- Important to determine the nature of the interactions for each of the gauge bosons.
- Can be done from decay and production of H
- $H \rightarrow ZZ$ - CP and spin both
- $H \rightarrow WW$ - spin only
- VBF - spin and CP (talk by Dorival)
- VH - spin and CP

VH versus VBF

- VBF :
 - Sensitive to spin and CP properties
 - Not possible to differentiate contribution from Z and W separately.
 - Acceptance to the SM VBF like cuts is weak. The BSM vertex tends to populate regions of phase space that have stronger backgrounds.
- VH :
 - Low cross-section and swamped in background
 - possible to distinguish between W and Z
- Jet-Substructure can alleviate the problem of backgrounds in VH.

Jet Substructure

- ➊ Select events with exactly 1 hard isolated lepton ($p_T > 30\text{ GeV}$ and $|\eta| < 2.5$). Veto on events with more or less of such a lepton.
- ➋ Presence of a fat jet with radius $R = 1.2$ and $p_T > 200\text{ GeV}$. After applying the filtering procedure ¹, require no more than three subjets with $p_T > 20\text{ GeV}$, $|\eta| < 2.5$, and radius $R_{sub} = \min(0.3, R_{bb})$, where R_{bb} is the separation of the two hardest subjets, both of which must be *b*-tagged.
- ➌ Demand that the reconstructed W has a $p_T > 150\text{ GeV}$
- ➍ $\Delta\phi(h, W) > 1.2$
- ➎ Veto for additional jet activity with $p_T^{jet} > 30\text{ GeV}$, $|\eta| < 3$ (to suppress $t\bar{t}$ and Single Top backgrounds).

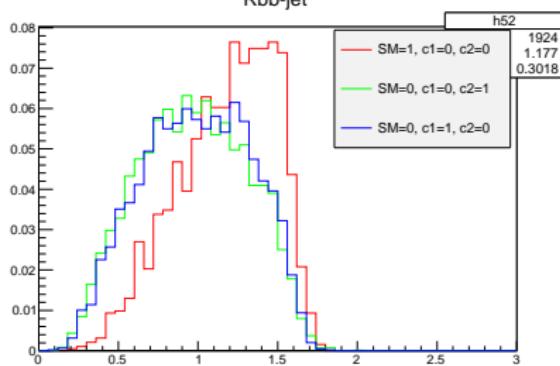
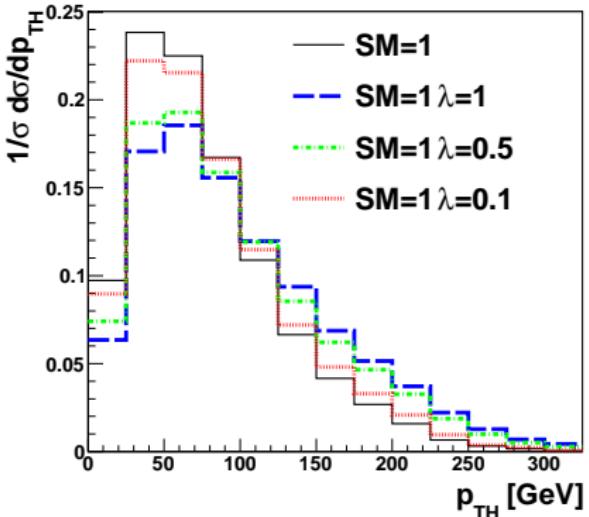
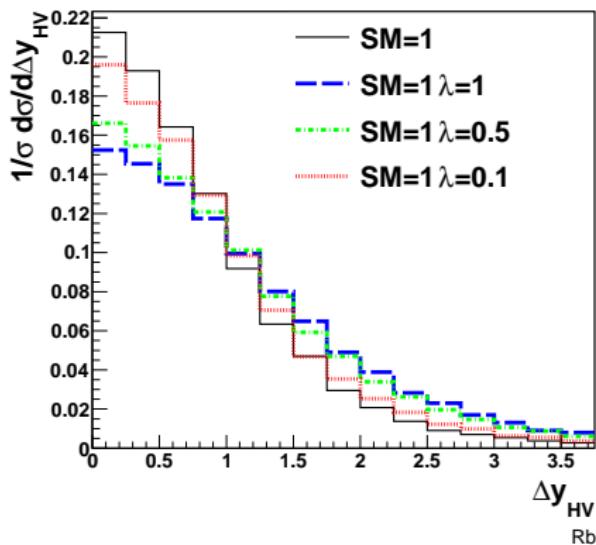
¹Butterworth, Davison, Rubin, Salam, 2008

VH acceptance

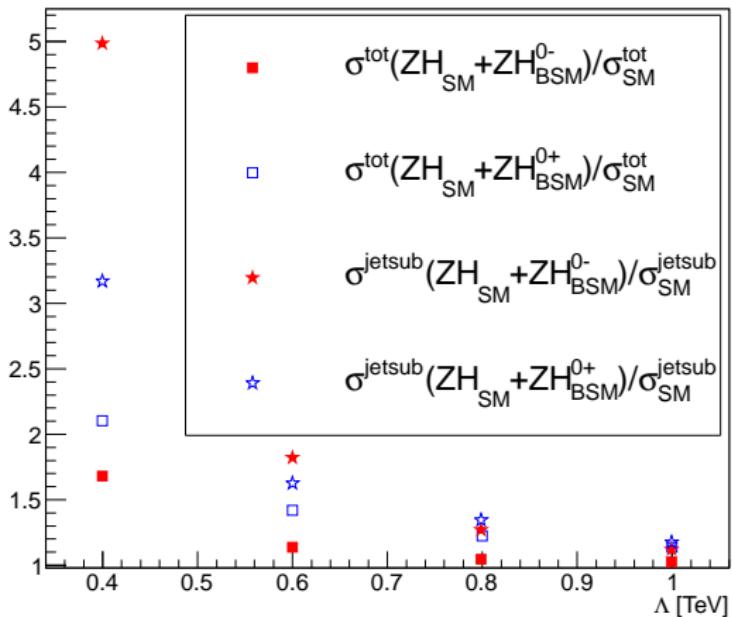
Channel	VH_{SM}	V+jets	$t\bar{t}$	Single top	VH_{BSM}^{0+}	VH_{BSM}^{0-}
ZH	0.153	0.416	0	0	0.61	0.93
WH	0.455	0.33	0.16	0.06	1.86	2.74

Table: cross-sections (femtobarn) evaluated at leading order for 14 TeV LHC after applying all cuts.

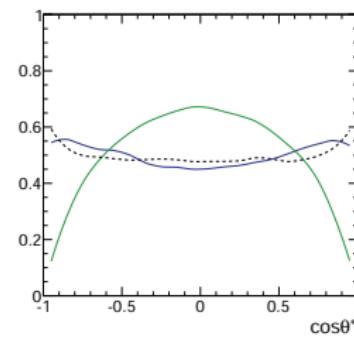
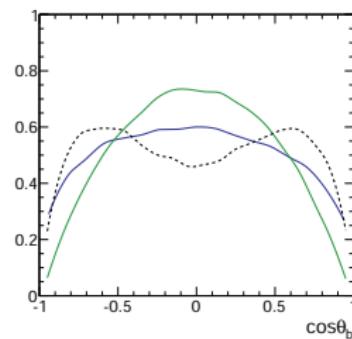
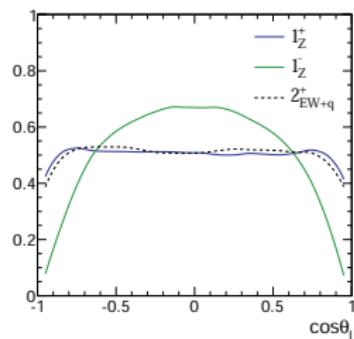
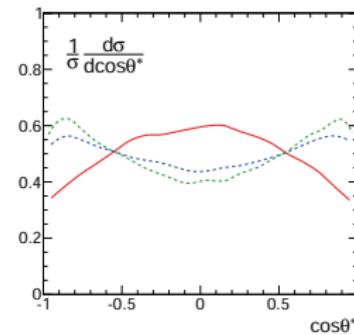
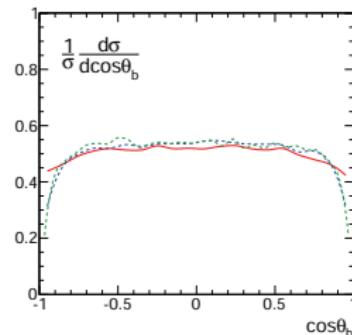
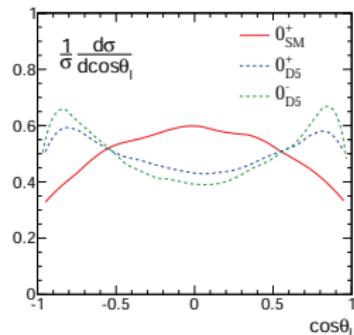
Acceptance of non SM vertex about $4 \sim 6$ times larger than SM.



$$\mathcal{L}_{VWH} = \mathcal{L}_{SM} + g_W^2 \frac{c_1}{2\Lambda_1^2} \Phi^\dagger \Phi W_{\mu\nu} W^{\mu\nu} + g_W^2 \frac{c_2}{2\Lambda_2^2} \Phi^\dagger \Phi \tilde{W}_{\mu\nu} W^{\mu\nu},$$



Angular discriminants



Angles suggested². Cannot distinguish BSM CP even and CP odd

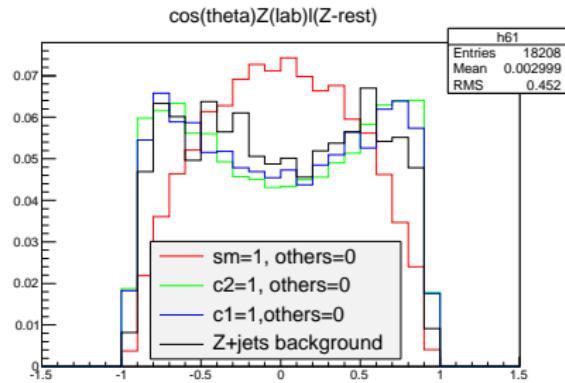
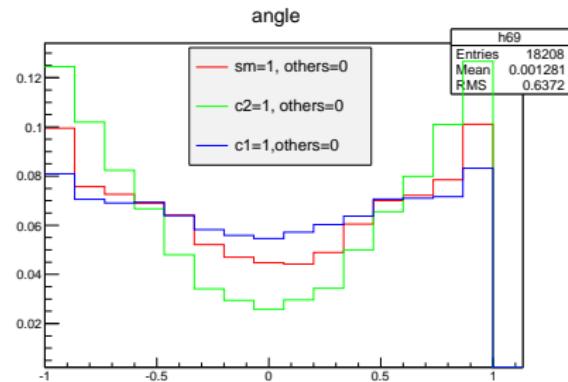
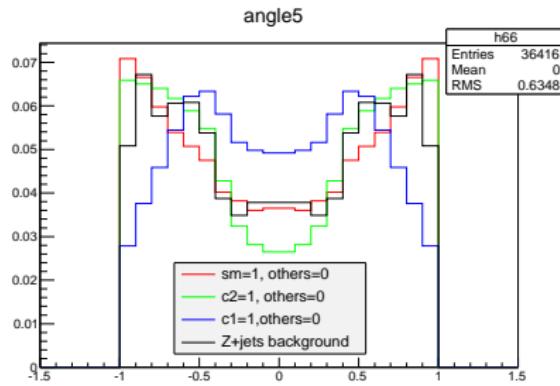
² Englert, Goncalves-Netto, Mawatari, Plehn, 2012

Angular discriminants for CP

- $\cos \theta^* = \frac{\vec{p}_{l_1}^{(V)} \cdot \vec{p}_V}{|\vec{p}_{l_1}^{(V)}| |\vec{p}_V|}$
- $\cos \delta^+ = \frac{\vec{p}_{l_1}^{(V)} \cdot (\vec{p}_V \times \vec{p}_H)}{|\vec{p}_{l_1}^{(V)}| |\vec{p}_V \times \vec{p}_H|}$
- $\cos \delta^- = \frac{(\vec{p}_{l_1}^{(H-)} \times \vec{p}_{l_2}^{(H-)}) \cdot \vec{p}_V}{|(\vec{p}_{l_1}^{(H-)} \times \vec{p}_{l_2}^{(H-)})| |\vec{p}_V|}$

One can use these angles to differentiate between BSM CP odd and CP even

Angular discriminants for CP

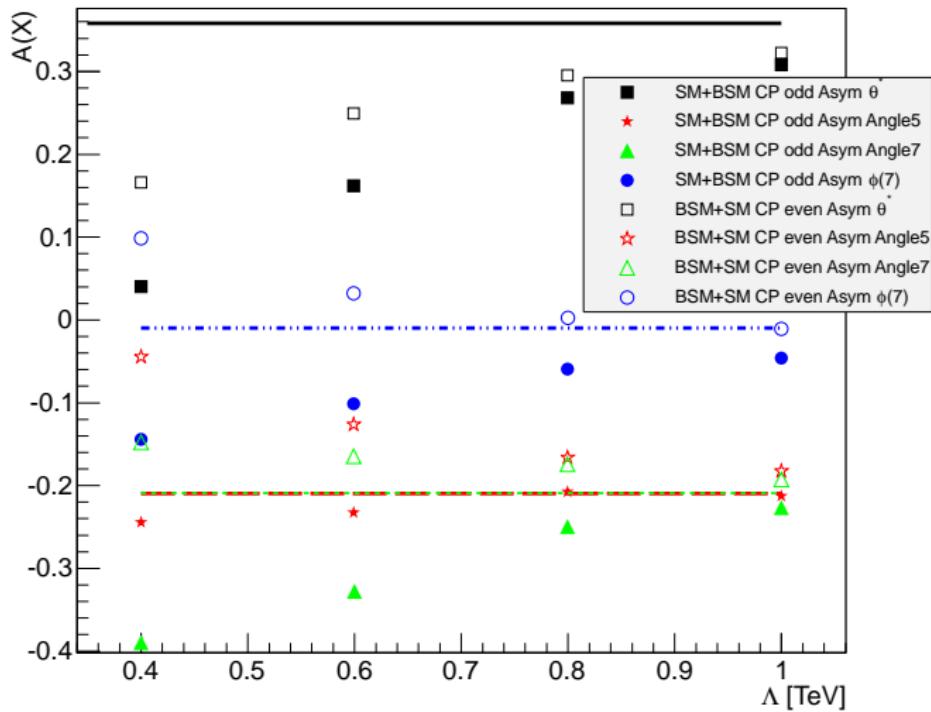


Asymmetries

Asymmetries	ZH_{SM}	ZH_{BSM}^{0-}	ZH_{BSM}^{0+}	Z+jets
$A(\cos \theta^*)$	0.35	-0.05	-0.02	0.07
$A(\cos \delta^+)$	-0.207	-0.262	0.088	-0.188
$A(\cos \delta^-)$	-0.209	-0.435	-0.103	-0.321

Table: Asymmetries constructed from the angles for ZH production

Asymmetries



Asymmetries WH

Asymmetries	WH_{SM}	WH_{BSM}^{0-}	WH_{BSM}^{0+}	W+jets
$A(\cos \theta^*)$	$0.396^{0.413}_{0.411}$	$0.073^{0.082}_{0.060}$	$0.100^{0.096}_{0.095}$	$0.142^{0.152}_{0.132}$
$A(\cos \delta^+)$	$-0.150^{0.204}_{0.161}$	$-0.284^{0.342}_{0.289}$	$0.142^{0.093}_{0.141}$	$-0.138^{0.189}_{0.138}$
$A(\cos \delta^-)$	$-0.058^{0.104}_{0.059}$	$-0.353^{0.403}_{0.367}$	$0.042^{0.003}_{0.030}$	$-0.118^{0.173}_{0.135}$

Table: Asymmetries for WH production the numbers are written as follows BT_{BS}^{MCT} , where BS, MCT and BT are the three ways the neutrino momentum is reconstructed.

Summary

- Determination of HVV vertex lorentz structure is important for both W and Z bosons separately.
- This is difficult to do from $H \rightarrow WW$ decays.
- VBF does not differentiate between W and Z and the BSM contributions populate areas of phase space that have stronger contributions from background
- VH can do this, but needs jet substructure.
- The larger boost in the VH system from BSM terms means increased acceptance to the BSM contributions.
- Possible to construct angular correlations that determine the lorentz structure of the interactions entirely.