$\rm HH{\rightarrow}~4\tau$ final state

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Saswati Nandan Double Higgs Production at Colliders

Introduction

 cross section of HH production in SM is small

0.033pb at $\sqrt{s} = 13$ TeV

 HH production can be enhanced in BSM physics



Non Resonant Production : Anomalous coupling

 $k_t = \frac{y_t}{y_t^{SM}}$ $k_\lambda = \frac{y_\lambda}{y_\lambda^{SM}}$

Effective field theory

contact interaction of Higgs boson with

gluons or two Higgs bosons with two gluons or

top-antitop pair

Resonant Production :

Many models are present in BSM MSSM/2HDM Singlet Model Warped Extra Dimensions spin zero Radion spin two Graviton

Will focus on resonant (spin zero Radion) HH production in mass range 260-900 GeV.

HH production at CMS



- HH → bbbb; bbWW : provides large branching ratio for signal, but needs to deal with large backgrounds also (mainly from tt production)
- $HH \rightarrow \tau \tau \tau \tau \tau$: small branching ratio, but also small background contamination

- $HH \rightarrow \tau \tau \tau \tau \tau$ not yet studied. Showing some work in progress today
- this channel may be competitive in low mass region

Double Higgs Production at Colliders

Final state and background

• Studied 6 channels: $\mu\tau\mu\tau$, $e\tau e\tau$, $\mu(e)\tau e(\mu)\tau$, where events with OS and SS lepton pairs are analyzed separately, to take advantage of significantly lower backgrounds in SS channels



Reducible background

- DY+jets \Rightarrow important for $\mu \tau_h \mu \tau_h, e \tau_h e \tau_h$ channels
- Multijet
- WZ+jets
- WW+jets
- W+jets
- Contribution of events containing bjets is small

All backgrounds except Multijet background, are estimated from MC

Trigger

- lace Dimuon trigger with threshold of 17 GeV (8 GeV) for higher (lower) $p_{m{ au}}$ μ
- Single muon trigger with p_T threshold 24 GeV



Event selection

- b jet veto
- all particles are separated from each other by $\Delta R > 0.3$
- μ, electron veto
- ullet In the OS channel, veto events that are within Z-mass window \Rightarrow 70 GeV $> M_{\mu\mu} >$ 100 GeV

Event Selection in $e\tau e\tau$ channel

Trigger

- Double electron trigger with 23 GeV (12 GeV) threshold for higher (low) p_T electron
- Single electron trigger with p_T threshold 25 GeV



Event selection

- b jet veto
- all particles are separated by $\Delta R > 0.3$
- μ, electron veto
- ullet In the OS channel, veto events that are within the Z-mass window \Rightarrow 70 GeV $>M_{ee}>$ 100 GeV

Event Selection in $\mu \tau \mathbf{e} \tau$ channel

Trigger

- Single electron trigger with p_T threshold 25 GeV for electron
- Single muon trigger with p_T threshold 24 GeV for μ
- Electron-muon cross trigger with threshold 23 GeV (8 GeV) for higher (lower) p_T lepton



Event selection

- b jet veto
- all particles are separated from each other by $\Delta \mathsf{R} > 0.3$
- μ, electron veto

Estimation of Multijet background

Contribution of Multijet background is estimated from data using jet to $\boldsymbol{\tau}$ fake rate

- Select two good leptons(μ /electron) which satisfy all analysis cuts
- Select two hadronic taus which satisfy all analysis cuts except isolation
- Split the sample into 3 following mutually exclusive regions
 - FP \rightarrow leading au fails the isolation cut
 - $\mathsf{PF} \to \mathsf{subleading} \ au$ fail the isolation cut
 - FF \rightarrow both τ 's fail the isolation cut
- Calculate the non Multijet background from MC in all three regions
- Apply fake weight to the failed au legs
- Excess in data, after subtracting non Multijet background is coming from Multijet background

Multijet background, in signal region = FP + PF - FF

Measurement of τ fake rates from data

$\mathbf{Jet} \to \tau \,\, \mathbf{fake}$

Events are selected in a region with no real au

 $W \rightarrow \mu \nu_{\mu}$ +jets, $W \rightarrow e \nu_{e}$ +jets

Trigger

- Single electron trigger with p_T threshold 25 GeV (e channel)
- Single muon trigger with p_T threshold 24 GeV (μ channel)

Electron (μ) selection

- p_T > 26 GeV
- $|\eta| < 2.5$ (2.4)
- Isolated lepton

Event selection

- b jet veto
- pfMET > 40 GeV
- $m_T > 50 \text{ GeV}$
- electron, μ veto

τ selection

- Leading $p_T > 20 \text{ GeV}$
- $|\eta| < 2.3$
- MVA based discriminator to reject
 τ's faked by electron or μ
- Reconstructed τ's should be either one prong or three prong
- all au's are with same charge

Fake Rate = # of au passing isolation cut / All au irrespective of isolation cut

$$f(p_{T}) = [0] \times \exp([1] \times p_{T}) + [2]$$



Estimation of Multijet background from data

 To measure Multijet background using jet→ τ fake, fake rate is applied to the region which is orthogonal to the fake rate measurement. Events are selected with

 $m_T <$ 40 GeV

all τ 's are of opposite sign

- Selected events are divided into three mutually exclusive region: FP, PF, FF
- non Multijet background is estimated in the three regions from MC
- Fake weight is applied to the au which fails isolation cut, in three regions :

Fake weight in FP = $f(p_T \tau_1)/(1 - f(p_T \tau_1))$

Fake weight in $PF = f(p_{T\tau_2})/(1-f(p_{T\tau_2}))$

Fake weight in FF = f($p_T \tau_1$) × f($p_T \tau_2$)/(1-f($p_T \tau_1$)) × (1-f($p_T \tau_2$))

- Contribution of all backgrounds, estimated from MC is subtracted from data in three regions
- Excess in data is due to Multijet background

Multijet background, in isolated region = FP + PF(-FF)

to avoid double counting of events in FP,PF and FF

Invariant mass of $\mu\tau$ pair



- Excess in data in FP, PF, FF is due to Multijet background which is not well simulated in MC and is estimated from data
- Multijet background measured in the PF, FP, FF regions as excess of data above the sum of MC predictions from other processes

Invariant mass of $e\tau$ pair



- Excess in data in FP, PF, FF is due to Multijet background which is not well simulated in MC and is estimated from data
- Multijet background measured in the PF, FP, FF regions as excess of data above the sum of MC predictions from other processes

Jet $\rightarrow \tau$ fake in signal region

To estimate Multijet background contribution in signal region using jet $\rightarrow \tau$ fake method, fake rate is calculated by selecting events with two OS leptons with :

- 70 GeV $< M_{II} <$ 110 GeV
- E_T^{miss} < 20 GeV

au selections are same as previous case



 $f(p_T) = [0] \times \exp([1] \times p_T) + [2]$

Control plots

Validation of Multijet background contribution from data driven method and other background contribution from MC is done in a region where event selection is same as signal region with two OS sign leptons but with two SS τ 's i.e total charge of selected particles is ± 2

Invariant mass of 4 particles



Good agreement between data and expected background contributions

Signal extraction

Expected signal and background yield

channel	epton sign			
$\mu \tau \mu \tau$	SS			
Background				
$zz \rightarrow 4$	0.139			
ZH	0.047			
ZZ	0.190			
Multijet	0.545			
Total bkg	0.921			
signal	$\sigma \times BR = 1pb$			
300 G eV	24.063			
800 G eV	61.374			

channe	epton sign		
eτeτ	SS		
Background			
$zz \rightarrow 4$	0.103		
ZH	0.008		
DY	0.561		
WZ	0.185		
tī	0.248		
Multijet	0.326		
Total bkg	1.431		
signal	$\sigma \times BR = 1pb$		
300 GeV	10.328		
800 GeV	28.810		

channel	epton sign			
$\mu(e)\tau e(\mu)\tau$	SS			
Background				
zz→4	0.852			
ZH	0.244			
tī	4.199			
Single top	0.600			
Multijet	0.187			
Total bkg	6.082			
signal	$\sigma \times BR = 1pb$			
300 G eV	99.255			
800 G eV	V 242.232			

channel	epton sign			
$\mu \tau \mu \tau$	05			
Background				
$zz \rightarrow 4$	0.822			
ZH	0.086			
DY	10.904			
ZZ	0.222			
tī	2.397			
Multijet	4.224			
Total bkg	18.655			
signal	$\sigma \times BR = 1pb$			
300 G eV	37.783			
800 G eV	100.072			

channel	epton sign		
$e\tau e\tau$	OS		
Background			
zz→4	0.591		
ZH	0.040		
DY	4.445		
ZZ	0.635		
tī	0.655		
Multijet	4.224		
Total bkg	10.59		
signal	$\sigma \times BR = 1pb$		
300 GeV	10.225		
800 GeV	60.562		
Multijet Total bkg signal 300 GeV 800 GeV	$ \begin{array}{r} 0.655 \\ 4.224 \\ \hline 10.59 \\ \sigma \times BR = 1pb \\ 10.225 \\ 60.562 \\ \end{array} $		

channe	epton sign			
$\mu(e) au e(\mu) au$	OS			
Background				
$zz \rightarrow 4$	1.331			
ZH	0.248			
DY	3.075			
WZ	0.470			
ZZ	0.340			
tī	10.794			
Singletop	0.536			
Multijet	3.060			
Total bkg	bkg 19.854			
signal	$\sigma \times BR = 1pb$			
300 GeV	210.117			
800 GeV 625.991				

For SS leptons, statistics is low compared to OS leptons

Signal extraction

- Signal is extracted from visible mass of leptons plus au's
- For OS leptons, shape analysis is done
- For SS leptons, the event yield is too low to perform shape analysis

 \Rightarrow Events are counted within a sliding mass window

 \Rightarrow Mass window is fixed by maximizing the asymptotic formula

$$\sqrt{2} \times ((s+b)\ln(1+s/b)-s)$$

s = expected signal yield

b = expected background yield

Optimization of mass window for Radion mass, 300 GeV and 800 GeV

$\mu au \mu au$ (SS)		e $ au$ e $ au$ (SS)		$\mu(\mathbf{e})\tau\mathbf{e}(\mu)\tau$ (SS)	
Radion mass in GeV	Mass window in GeV	Radion mass in GeV	Mass window in GeV	Radion mass in GeV	Mass window in GeV
300	100-300	300	100-300	300	100-300
800	300-700	800	300-600	800	200-700

Invariant mass of 4 particles (prefit plot)

OS leptons



SS leptons



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Expected limit



• $\mu e \tau \tau$ channels (OS as well as SS) give the best limits

Comparison with other channels



- Four main channels (bbbb, bbττ, bbγγ, bbVV), have been studied so far
- ${\it HH} \rightarrow \tau \tau \tau \tau$ final state is being explored for the first time in CMS
- Background contribution is small compared to other final states
- This channel is competitive in low mass region
- Many improvements will be coming soon reconstruct the HH mass using SVFit algorithm add more decay modes of τ's

Back up

Expected limit





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