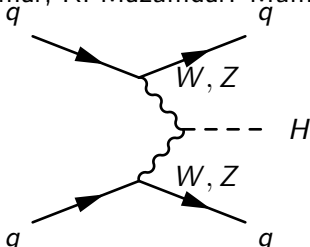


## Status of the VBF Higgs to Invisible Analysis

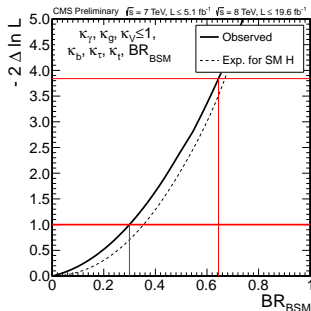
AN-12-403,PAS-HIG-13-013

D.Colling, P. Dunne, A. Magnan, A. Nikitenko, J. Pela with  
R. Aggleton, J. Brooke: Bristol  
C.Asawangtrakuldee, Q.Li: Peking  
P. Srimanobhas: Chulalongkorn  
S. Kumar, K. Mazumdar: Mumbai



## Introduction

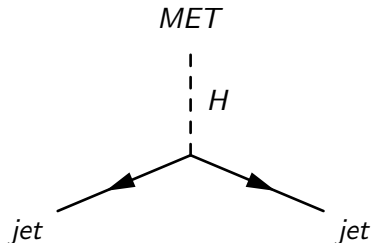
- ▶ Searching for VBF produced Higgs decaying to invisible final state
- ▶ Visible decays constrain invisible BF to less than 64% at 95% C.L. (assumes standard model width)
- ▶ Many theoretical possibilities for BSM invisible final states:
  - $H \rightarrow 2LSPs$  (SUSY)
  - $H \rightarrow$  dark matter (Extra Dimensions)
  - etc.



## Measurement Strategy

### Select VBF Topology

- ▶ 2 jets with a large  $\eta$  separation
- ▶ Nothing in the gap between the jets
- ▶ Need dedicated VBF trigger



- ▶ Clean data from pileup and mismeasured MET
- ▶ Use hard cuts to restrict backgrounds
- ▶ Remaining background estimation must be data driven as hard cuts make MC unreliable
- ▶ This iteration just a counting experiment, shape based analysis planned for final paper with parked data

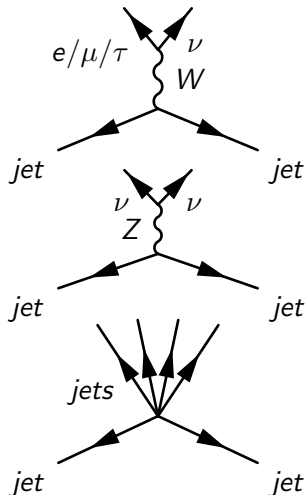
## Backgrounds Overview

### Main backgrounds:

- ▶  $W$  + jets where lepton is missed
  - AM+Patrick cross check  $W \rightarrow e/\mu$  & measure  $W \rightarrow \tau_h$  background from data
- ▶  $Z \rightarrow \nu\nu$  + jets
- ▶ QCD: **Sasha**

### Data driven $W/Z$ + jets estimation:

- ▶ Pick  $W/Z$  dominated control region in same trigger sample with same VBF selection
- ▶ Recalculate MET after removing leptons from  $W$  &  $Z$ 
  - Mimics  $W$  with missed leptons/ $Z \rightarrow \nu\nu$
- ▶ Check data/MC agreement in control regions
- ▶ Assume MC signal/control ratio is the same as that in data



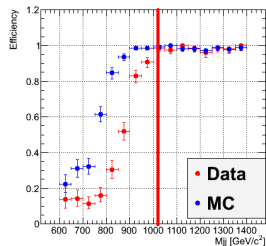
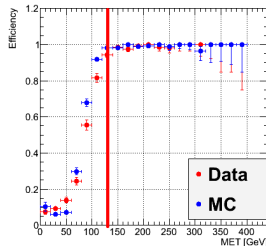
## Datasets and Trigger

### Datasets:

- ▶ 8 TeV MET datasets
  - Total of  $19.6 \text{ fb}^{-1}$
- ▶ MET filters are used to cut out events with mismeasured MET

### Trigger:

- ▶ HLT\_DiPFJet40\_PFMET  
noMu65\_MJJ800VBF\_AllJets
- VBF means  $|\Delta\eta_{j_1 j_2}| > 3.5$
- ▶ IC heavily involved in design of the trigger



## Objects

### VBF Selections

- ▶ Applied to all regions
- ▶ 2 jets:
  - Both jets must pass loose PUJetID
  - $p_T > 50\text{GeV}$ ,  $|\eta| < 4.7$
  - $|\Delta\eta| > 4.2$ ,  $\eta_{j1} * \eta_{j2} < 0$
  - $m_{jj} > 1200\text{GeV}$

### MET

- ▶ Using Type 0 + 1 Corrections

### Electrons

- ▶ Veto:
  - $p_T > 10\text{GeV}$ ,  $|\eta| < 2.5$
  - rel PF Iso  $< 0.2$
- ▶ Tight:
  - $p_T > 20\text{GeV}$ ,  $|\eta| < 2.5$

### Muons

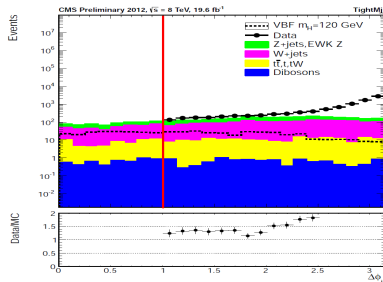
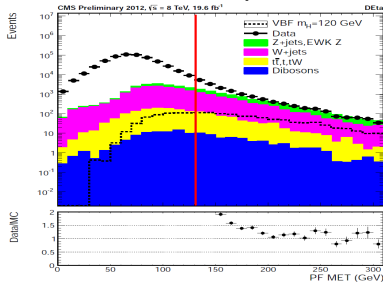
- ▶ Veto:
  - $p_T > 10\text{GeV}$ ,  $|\eta| < 2.1$
  - rel PF Iso  $< 0.2$
- ▶ Tight:
  - $p_T > 20\text{GeV}$ ,  $|\eta| < 2.1$

## Signal Event Selection

### Signal Region Selection:

- ▶  $\text{PFMET} > 130 \text{ GeV}$  &  $\Delta\phi_{jj} < 1.0$  to reduce QCD
- ▶  $e/\mu$  veto to reduce  $W/Z$ +jets

### Data MC difference is QCD



Top	W+jets	Z+jets	VV	SumMC	Data	Signal 120
55 ± 6	382 ± 18	258 ± 10	5.2 ± 0.6	700.2 ± 21.5	XXX	209 ± 9

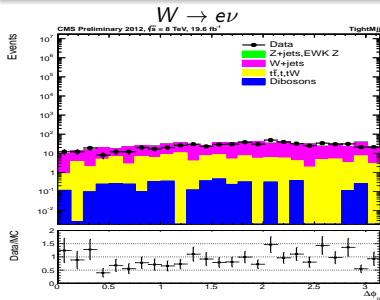
## $W$ +jets Background Estimation

Background estimation formula:

$$N_{data}^S(W \rightarrow e/\mu) = (N_{data}^C - N_{bkg}^C) \frac{N_{MC}^S}{N_{MC}^C}$$

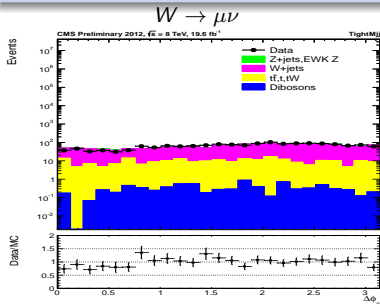
$W \rightarrow \mu/e$  Control Region Selection:

- ▶ 1 tight muon/electron:
- ▶ MET without  $(\mu/e) > 130 \text{ GeV}$



$$N_{MC}^S = 142 \pm 11(\text{stat.}) \text{ events}$$

$$N_{data}^S = 87 \pm 17(\text{stat.}) \text{ events}$$



$$N_{MC}^S = 130 \pm 10 \text{ events}$$

$$N_{data}^S = 105 \pm 13(\text{stat.}) \text{ events}$$



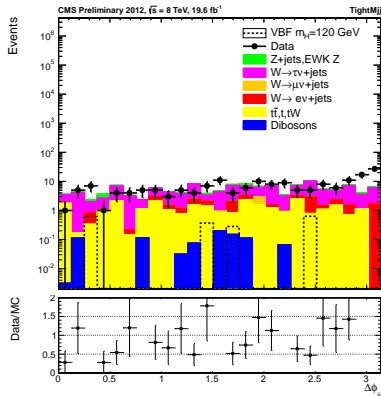
## $W \rightarrow \tau$ Background Estimation

### $W \rightarrow \tau$ Method:

- ▶ Select subsample of signal region
- ▶ Require 1  $\tau_{hadronic}$  candidate
  - $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.3$
  - Discriminant “byTightCombinedIsolationDeltaBetaCorr3Hits”
- ▶ Correct with the efficiency: 0.55
- ▶ Fake rate: 0.02/0.03 in barrel/endcap

### Result

- ▶ MC expectation:  $130 \pm 10$
- ▶  $N_{W \rightarrow \tau \nu}^{data} = 135 \pm 52(stat) \pm 11(syst)$



Thanks to A. Gilbert and M. Acosta for explanations of tau id

## Systematics

IC doing  $W + \text{jets}$  uncertainties: work in progress

### Uncertainties considered

- ▶ Statistics
- ▶ Jet Energy Scale(JES)
- ▶ Jet Energy Resolution(JER)
- ▶ Unclustered Energy Scale
- ▶ Pileup ID
- ▶ Luminosity

### Preliminary $W + \text{Jets}$ Background Uncertainties

$N_{W \rightarrow e\nu}^{\text{data}}$	Electron	Muon
Central num. of events	87	105
Statistical	$\pm 19.8\%$	$\pm 12.2\%$
JESUP	$-3.75\%$	$+4.6\%$
JESDOWN	$+3.57\%$	$+1.91\%$
JERBETTER	$+2.91\%$	$-0.616\%$
JERWORSE	$+7.01\%$	$+6.84\%$

## Z+jets Background Estimation

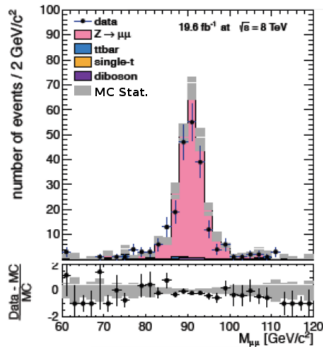
Z+jets background estimation formula:

$$N_{data}^S(Z \rightarrow \nu\nu) = (N_{data}^C - N_{bkg}^C) \frac{\sigma(Z \rightarrow \nu\nu)}{\sigma(Z/\gamma^* \rightarrow \mu\mu)} \frac{\epsilon_{VBF}^S / \epsilon_{VBF}^C}{\epsilon_{\mu\mu}}$$

### $Z \rightarrow \nu\nu$ Control Region Selection:

- ▶ Select  $Z \rightarrow \mu\mu$  and extrapolate to  $Z \rightarrow \nu\nu$
- ▶ 2 tight muons
- ▶ MET after Z candidate removed  $> 130\text{GeV}$
- ▶ No additional veto muons/electrons

$$N_{data}^S = 162 \pm 48$$



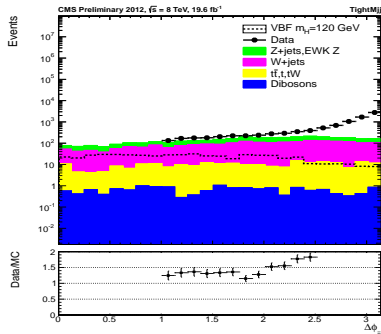
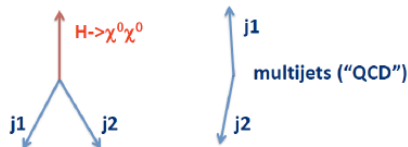
## QCD

### QCD Background Strategy

- ▶ Critical part of analysis
- ▶ V. low MC statistics
- ▶ Therefore two options:
  - 1) Estimate from data
  - 2) Reduce background further

### QCD Control Region Selection

- ▶  $\Delta\phi_{jj} > 2.6$



## QCD Background Estimation - Method 1

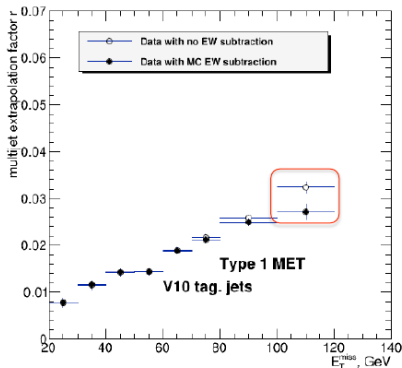
Formula:

$$N_{multijet}^S = (N^C - N_{non-multijet}) \times r$$

$$r = \frac{N_{data}(\Delta\phi_{jj} < 1.0) - N_{non-multijet}(\Delta\phi_{jj} < 1.0)}{N_{data}(\Delta\phi_{jj} > 2.6) - N_{non-multijet}(\Delta\phi_{jj} > 2.6)}$$

Method:

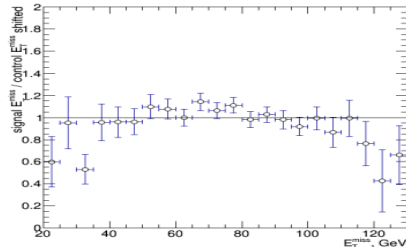
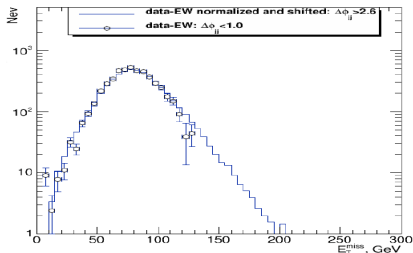
- ▶ Extrapolate from  $\Delta\phi_{jj} > 2.6$  to  $\Delta\phi_{jj} < 1.0$
- ▶ Preliminary study showed  $r$  appeared flat
- ▶ After more analysis method is not usable



## QCD Background Estimation - Method 2

### Method:

- Find a distribution that is the same shape in  $\Delta\phi_{jj} < 1.0$  and  $\Delta\phi_{jj} > 2.6$  regions
- We use MET
- Normalise below MET cut and extrapolate
- If you shift control region distribution by 10 GeV they look similar but still not entirely satisfactory

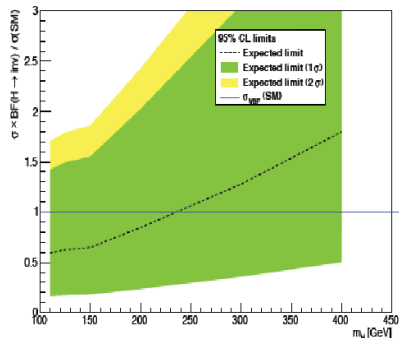
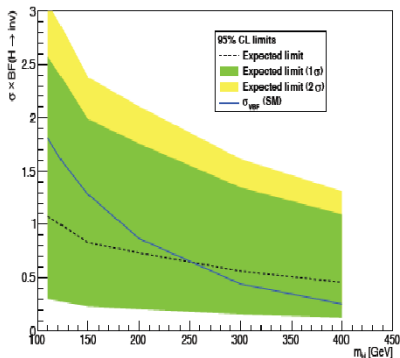


## Reducing QCD Contribution

### Other Solutions

- ▶ Given estimation has issues try cutting most of QCD so large estimation errors are less important
- ▶ Work in progress!
- ▶ Several options:
  - ▶ Central Jet Veto (CJV)
    - Veto events with additional jets above a  $p_T$  threshold between VBF Jets
  - ▶ Additional Jet Veto
    - Veto additional jets above a  $p_T$  threshold in the tracker region
- ▶ Variables used for SUSY hadronic searches, e.g.  $\alpha_T$

## Preliminary Expected Limits - QCD Method 1



- ▶ Very preliminary to make sure we can go to the end of the analysis
- ▶ Produced with combine package using  $CL_s$  statistics, cross-checked with RooStats
- ▶ 95% CL expected limit on the invisible BR for 125 GeV: 62%



## Summary

- ▶ Most of the analysis is complete
- ▶ QCD still needs to be understood
- ▶ Some systematics still need to be included
- ▶ Expected limit on BR 62% is promising and competitive with:
  - CMS ZH expected 79% (AN-13-116,AN-12-123)
  - ATLAS ZH 65% observed 84% expected (ATLAS-CONF-2013-011)
  - CMS indirect observed 64%
- ▶ Plan to have PAS for 8 TeV data then paper with additional parked data

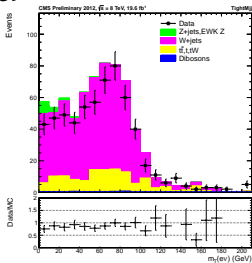
## BACKUP

## Parked Data

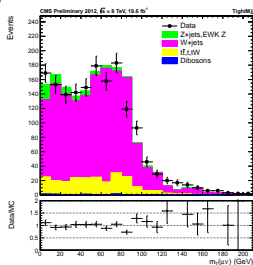
- ▶ IC pushed strongly for data parking
- ▶ Jet  $E_T > 35(30)\text{GeV}$ ,  $\Delta\eta_{jj} > 3.5$ ,  $m_{jj} > 700\text{GeV}$ 
  - Trigger with  $E_T > 30\text{GeV}$  added for runs C+D
- ▶ Good efficiency for visible and invisible VBF Higgs channels
- ▶ Plan to update result with parked data included after PAS

## $W$ +jets background $m_T$ plots

$e\nu$



$\mu\nu$



$\tau\nu$

