Imperial College London

Status of the VBF Higgs to Invisible Analysis

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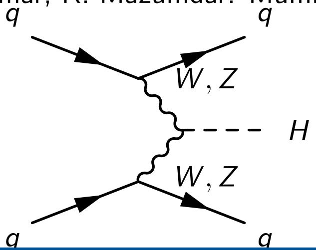
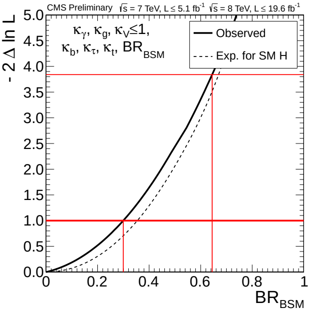


Introduction

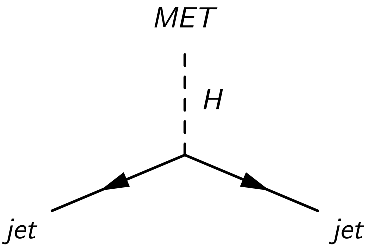
- Searching for VBF produced Higgs decaying to invisible final state
- Visible decays constrain invisible BF to less than 64% at 95% C.L. (assumes standard model width)
- Many theoretical possibilities for BSM invisible final states:
  - $H \rightarrow 2LSPs$ (SUSY)
  - $H \rightarrow$ dark matter (Extra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



Measurement Strategy

Select VBF Topology

- 2 jets with a large η 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

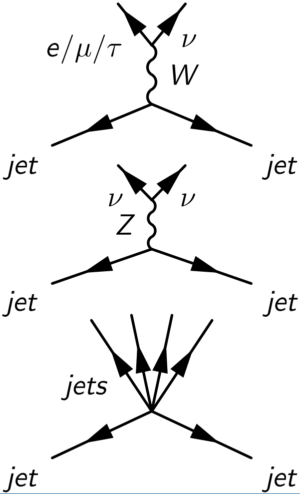
Backgrounds Overview

Main backgrounds:

- W + jets where lepton is missed
- $Z \to \nu\nu$ + jets
- QCD

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/$Z \to \nu\nu$
- Check data/MC agreement in control regions
- Assume MC signal/control ratio is the same as that in data



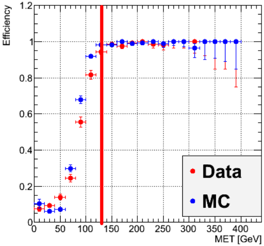
Datasets and Trigger

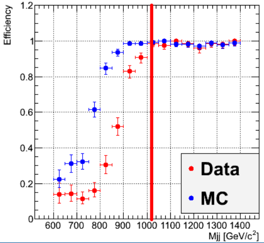
Datasets:

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

Trigger:

- HLT_DiPFJet40_PFMET noMu65_MJJ800VBF_AllJets
  - VBF means $|\Delta\eta_{j_1 j_2}| > 3.5$





Objects

VBF Selections

- Applied to all regions
- 2 jets:
  - Both jets must pass loose PUJetID
  - $p_T > 50 GeV$, $|\eta| < 4.7$
  - $|\Delta\eta| > 4.2$, $\eta_{j_1} * \eta_{j_2} < 0$
  - $m_{jj} > 1200 GeV$

MET

- Using Type $0 + 1$ Corrections

Electrons

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

Muons

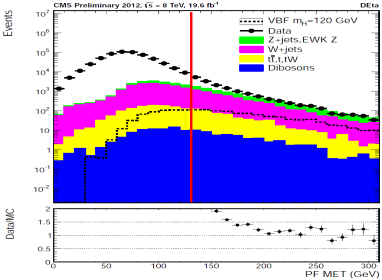
- Veto:
  - $p_T > 10 GeV$, $|\eta < 2.1|$
  - rel PF Iso < 0.2
- Tight:
  - $p_T > 20 GeV$, $|\eta < 2.1|$

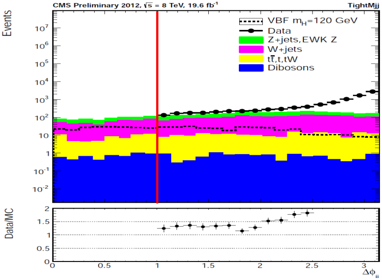
Signal Event Selection

Signal Region Selection:

- PFMET $> 130GeV$ & $\Delta\phi_{jj} < 1.0$ to reduce QCD
- e/μ 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

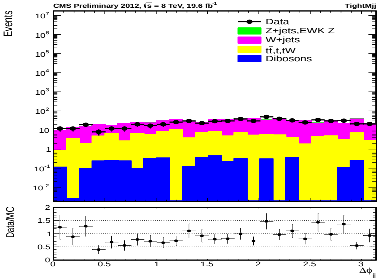
Background estimation formula:

$$N^S_{data}(W \rightarrow e/\mu) = (N^C_{data} - N^C_{bkg})\frac{N^S_{MC}}{N^C_{MC}}$$

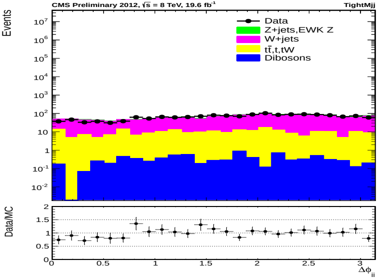
$W \rightarrow \mu/e$ Control Region Selection:

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

$W \rightarrow e\nu$



$W \rightarrow \mu\nu$



$N^S_{MC} = 142 \pm 11(stat.)$ events
$N^S_{data} = 87 \pm 17(stat.)$ events

$N^S_{MC} = 130 \pm 10$ events
$N^S_{data} = 105 \pm 13(stat.)$ events

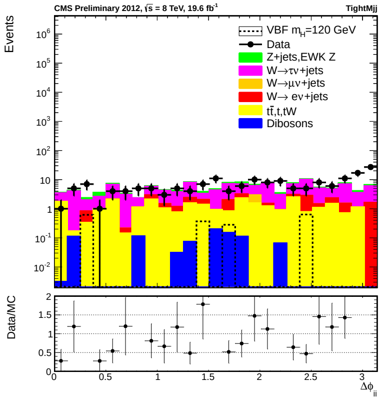
$W \to \tau$ Background Estimation

$W \to \tau$ Method:

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

Result

- MC expectation: 130 ± 10
- $N^{data}_{W \to \tau\nu} = 135 \pm 52(stat) \pm 11(syst)$



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

Systematics

work in progress

Uncertainties considered

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

Preliminary W + Jets Background Uncertainties

$N^{data}_{W\rightarrow e\nu}$	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

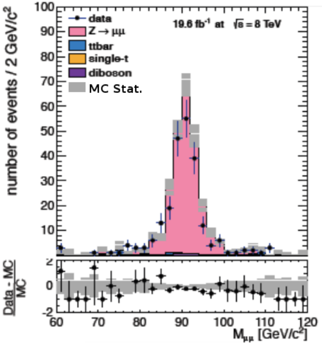
Z+jets background estimation formula:

$$N^S_{data}(Z \to \nu\nu) = (N^C_{data} - N^C_{bkg}) \frac{\sigma(Z \to \nu\nu)}{\sigma(Z/\gamma^* \to \mu\mu)} \frac{\epsilon^S_{VBF}/\epsilon^C_{VBF}}{\epsilon_{\mu\mu}}$$

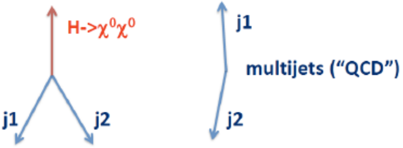
$Z \to \nu\nu$ Control Region Selection:

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

$$N^S_{data} = 162 \pm 48$$



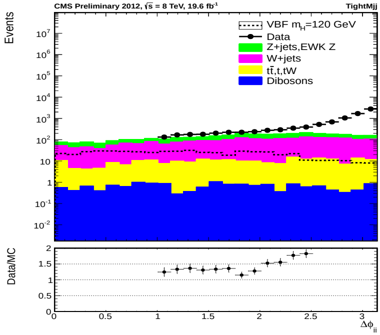
QCD



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

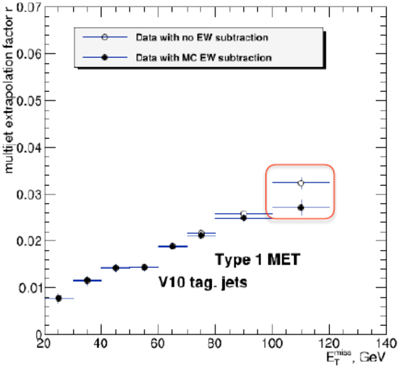
Formula:

$$N^S_{multijet} = (N^C - N_{non-multijet})xr$$

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

Method:

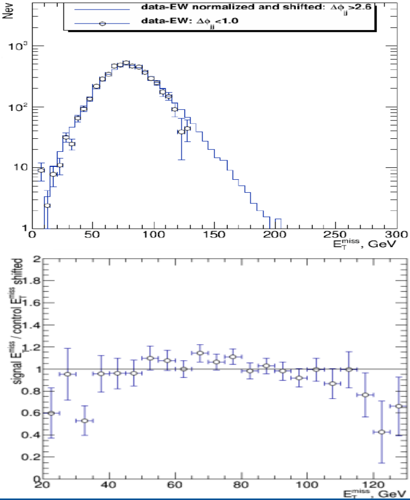
- Extrapolate from $\Delta\phi_{jj} > 2.6$ to $\Delta\phi_{jj} < 1.0$
- Preliminary study showed r appeared flat
- After more analysis method is not usable



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

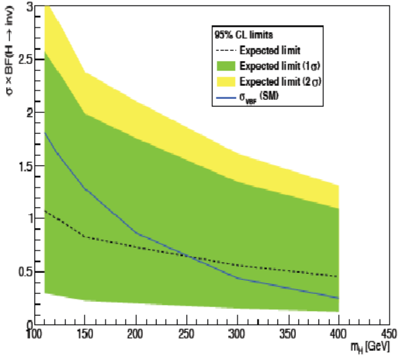


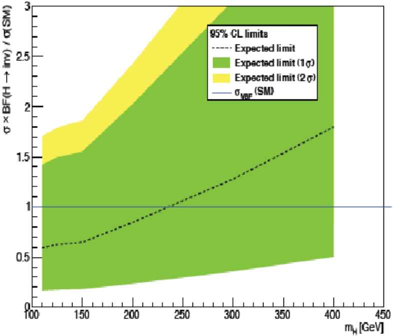
Reducing QCD Contribution

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. α_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

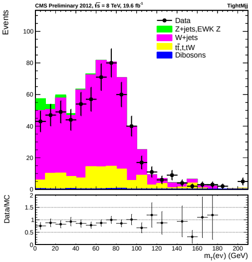
BACKUP

Parked Data

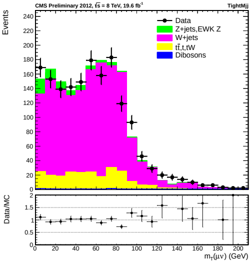
- Jet $E_T > 35(30) GeV$, $\Delta\eta_{jj} > 3.5$, $m_{jj} > 700 GeV$
  - Trigger with $E_T > 30 GeV$ added for runs C+D
- Good efficiency for visible and invisible VBF Higgs channels
- Plan to update result with parked data included after PAS

W+jets background m_T plots

$e\nu$



$\mu\nu$



$\tau\nu$