Status of VBF Higgs search in ATLAS & CMS

Andrea Massironi, INFN and University Milano-Bicocca for the CMS collaboration

- VBF searches
- Results from CMS and ATLAS
  - $H \rightarrow \tau \tau$
  - $H \rightarrow \gamma \gamma$
  - $H \rightarrow WW \rightarrow l\nu l\nu$
- Future developments

Implications of LHC results for TeV-scale physics
29 Aug-2 Sep 2011
CERN, Geneva (Switzerland)
Why VBF Higgs searches

**Vector Boson Fusion** production mechanism of Higgs

- Spontaneous Symmetry Breaking mechanism to give mass to weak bosons
- VVH coupling directly accessible
- WW scattering and unitarity (see P. Govoni talk)
- BSM models
  - fermiophobic Higgs, no coupling to fermions → no gluon fusion
- If Higgs is found → spin and CP properties
... but cross section

**Gluon Fusion**

\[ g + t \rightarrow H \]

**VBF ~ 10% gluon fusion**

\[ q_2 \rightarrow q_2' \]
\[ Z/W \]
\[ H \]
\[ q_1 \rightarrow q_1' \]

\[ \sigma(pp \rightarrow H + X) \ [pb] \]

\[ \sqrt{s} = 7 \text{ TeV} \]

\[ M_H [\text{GeV}] \]

Implications of LHC - A. Massironi
... however: VBF signature

- Energetic jets in forward – backward direction
- Big rapidity separation \((\Delta \eta > 3.5 \text{ } & \text{ } M_{jj} > 350 \text{ GeV}/c^2)\)
- Low jet activity in central region

Exploitation of VBF signature

- Background reduction with kinematic selections based these features (see H\(\tau\)\(\tau\))
- Separately optimize the analysis as a function of jet multiplicity (see HWW)
Where: CMS and ATLAS @ LHC

LHC
Large Hadron Collider

Proton-proton collider $\sqrt{s} = 7$ TeV
High luminosity, up to $L \sim 2 \cdot 10^{33}$ cm$^{-2}$s$^{-1}$ in 2011 (till now!)

CMS
Compact Muon Solenoid

ATLAS
A Toroidal LHC ApparatuS

Forward calorimeters up to $\eta = 5$ (HF)

Forward calorimeters up to $\eta = 5.9$

Whole experiment potential exploited:
Forward detectors for jets - Central detectors for H decay products
SM Higgs decay channels

Current VBF searches

  - $H \rightarrow \tau\tau$
  - $H \rightarrow \gamma\gamma$

  - $H \rightarrow WW \rightarrow l\nu l\nu$

- High mass region $[200 \text{ GeV/c}^2 – 1 \text{ TeV/c}^2]$
  - $H \rightarrow WW \rightarrow l\nu l\nu$

LHC Higgs Cross Section Working Group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

30 Aug 2011

Implications of LHC - A. Massironi
Different final states for $\tau\tau$ decay

- $\mu + \text{had}$
- $e + \text{had}$
- $e + \mu$
- $\mu + \mu$
- $e + e$

Jet $p_T > 30$ GeV

$\Delta\eta > 3.5$

$M_{jj} > 350$ GeV/$c^2$

$\eta_{jet-1} \times \eta_{jet-2} < 0$

CMS (CMS-PAS-HIG-11-020)

ATLAS (ATLAS-CONF-2011-133)
**H → ττ event display**

**μτ channel**

\[ \mu - p_T = 19.8 \text{ GeV} \]

\[ \tau\text{-had} - p_T = 69.3 \text{ GeV} \]

\[ \text{MET} = 97 \text{ GeV} \]

Jet\(_1\) – \(p_T\) = 177 GeV

Jet\(_2\) – \(p_T\) = 46 GeV

\[ M_{jj} = 580 \text{ GeV} \]
H → ττ exclusion plot

- Exclusion plot: combination of all channels
- $6 \times \sigma_{SM}$ excluded Higgs

- Signal
  - $\sigma_{VBF-SM} \times BR(H [120 \text{ GeV}/c^2] \rightarrow \tau\tau) = 90 \text{ fb}$

- Background
  - $\bar{t}\bar{t}$
  - $Z \rightarrow \tau\tau$
  - Electroweak

See S. Gennai talk for di-τ mass reconstruction
Low branching ratio → but very clear signature
2 energetic photons

Search for peak in invariant mass spectrum

Excellent calorimeter resolution (goal precision ~0.5%) and good vertex reconstruction (<10mm) to get a narrow peak from $H \rightarrow \gamma\gamma$ decay
**H → γγ  Fermiophobic Higgs**

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/Fermiophobic

Fermiophobic model → no gluon fusion Higgs

Only VBF and VH production mechanisms survive

- **Signal**
  - $\sigma_{FP} \times \text{BR}(H [120 \text{ GeV}/c^2] \rightarrow \gamma\gamma) = 29 \text{ fb}$
  - $\sigma_{VBF-SM} \times \text{BR}(H [120 \text{ GeV}/c^2] \rightarrow \gamma\gamma) = 2 \text{ fb}$

- **Background**
  - QCD: $2\gamma$, $\gamma$+jet, 2 jet

**Exclusion limit**

$m_{H-FP} < 112 \text{ GeV} @ 95\% \text{CL}$
H → WW → ℓνℓν analysis divided in jet-bins:

- 0-jet: ggH
- 1-jet: mainly ggH
- 2-jet: 85% VBF

Jet $p_T > 30$ GeV

$\Delta\eta > 3.5$

$M_{jj} > 450$ GeV/$c^2$

Central Jet Veto

No additional jets between 2 tag jets

```
Jet $p_T > 30$ GeV

$\Delta\eta > 3.5$

$M_{jj} > 450$ GeV/$c^2$

Central Jet Veto
```

Tag jet

Tag jet
**H → WW → lνlν** Exclusion plot

- **Signal**
  - $\sigma_{VBF-SM} \times \text{BR}(H [160 \text{ GeV/c}^2] \rightarrow WW \rightarrow l\nu l\nu) = 37 \text{ fb}$

- **Background**
  - $Z/\gamma \rightarrow ll$
  - $t\bar{t}$
  - $WW$

- Observed limit in good agreement with SM expectations

- VBF channel alone is sensitive to $<2 \times \sigma_{SM}$ in mass range $[150-200]$ GeV
Future developments

- VBF potentiality to Higgs exclusion projections (rough calculation)
  - VBF $H \rightarrow WW \rightarrow lvlv \sim 160 \text{ GeV}/c^2 \sim 4 \text{ fb}^{-1} \rightarrow 2 \text{ fb}^{-1}$ (ATLAS+CMS)

- New channels addressed
  (more luminosity needed!)
  - VBF $H \rightarrow WW \rightarrow lvqq'$
  - VBF $H \rightarrow ZZ \rightarrow llqq$
  - VBF $H \rightarrow bb$

- Study of Higgs properties (spin and CP) [¹]
- If no Higgs $\rightarrow VV$ scattering (see P.Govoni talk)

Ruwiedel, Schumacher, Wermes “Prospects for the Measurement of the Structure of the Coupling of a Higgs Boson to Weak Gauge Bosons in Weak Boson Fusion with the ATLAS Detector”
Conclusions

Analyses presented are based on $1.1 - 2.3 \ \text{fb}^{-1}$ in pp at $\sqrt{s} = 7 \text{ TeV}$ collected by ATLAS & CMS

Results:

- VBF SM H can be isolated from gluon fusion production and offers additional handles to control backgrounds
- Included in exclusion limits combination (... and discovery as well!)
- Needed in some BSM models (e.g. Fermio-Phobic Higgs)

Future developments:

- If Higgs is found → Higgs properties (spin / CP)
- If Higgs not found → VBF topology for WW scattering → new physics?

LHC is running fast: stay tuned!
Total weight of 12500 t, overall diameter 15m, overall length 21.6 m, magnetic field 4T
References

- $H \rightarrow \tau \tau$
  - CMS-PAS-HIG-11-020, Search for Neutral Higgs Bosons Decaying to Tau Pairs in pp Collisions at $\sqrt{s}=7$ TeV
  - ATLAS-CONF-2011-132, Search for neutral MSSM Higgs bosons decaying to tau+tau- pairs in proton-proton collisions at $\sqrt{s}=7$ TeV with the ATLAS detector
  - ATLAS-CONF-2011-133

- $H \rightarrow \gamma \gamma$
  - CMS-PAS-HIG-11-021, Search for a Higgs boson decaying into two photons in the CMS detector
  - ATLAS-CONF-2011-085, Search for the Higgs Boson in the Diphoton Channel with the ATLAS Detector using 209 pb$^{-1}$ of 7 TeV Data taken in 2011

- $H \rightarrow WW \rightarrow l\nu l\nu$
  - CMS-PAS-HIG-11-003 and CMS-PAS-HIG-11-014, Search for the Higgs Boson in the Fully Leptonic $W^+W^-$ Final State
  - CMS-PAS-HIG-11-022, Combination of Higgs Searches
Future developments: new channels

- **Low mass region [110 - 130]**
  - $H \rightarrow \tau\tau$
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow bb$

- **Intermediate mass region [120 – 200]**
  - $H \rightarrow WW \rightarrow l\nu l\nu$

- **High mass region [200 -]**
  - $H \rightarrow WW \rightarrow l\nu l\nu$
  - $H \rightarrow ZZ \rightarrow llqq'$
  - $H \rightarrow ZZ \rightarrow ll\bar{q}\bar{q}$

Possible new channels in VBF Higgs searches
SM Higgs $\sigma \times BR$

![Graph showing SM Higgs cross section versus $M_H$](image)

- $\sqrt{s} = 7\text{TeV}$
- $\sigma \times BR$ [pb]
- $\sigma \times BR$ for different processes:
  - $WW \rightarrow l^+l^-v\bar{v}$
  - $ZZ \rightarrow l^+l^-l^+l^-$
  - $WW \rightarrow l^+v\nu\bar{q}$
  - $ZZ \rightarrow l^+l^-q\bar{q}$
  - $ZH \rightarrow l^+l^-b\bar{b}$
  - $VBF H \rightarrow \tau^+\tau^-$
  - $\gamma\gamma$

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Main systematics in the analyses

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<thead>
<tr>
<th>H → γγ</th>
<th>luminosity</th>
<th>5%</th>
<th>0.5%</th>
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<tbody>
<tr>
<td>H → ττ</td>
<td>6%</td>
<td></td>
<td>4%</td>
</tr>
<tr>
<td>H → WW → lνlν</td>
<td>5%</td>
<td>5%</td>
<td>Background estimation 20-60%</td>
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</tbody>
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