Higgs Searches at the LHC

eilam gross, Weizmann Institute of Science

Acknowledgements: ATLAS, CMS and LHC-HCG
and Ohad Silbert, Raz Alon for their assorted help
The Higgs Car

Layman: What drives the SM car?
Theorist: The Higgs engine

Layman: How fast does it go?
Theorist: Don’t know, if it’s a standard model, it must be no more than ~160 GeV

Experimentalist: Let’s get it and check the engine....
2011 - Oh What a Year

- The new thumb rule: $\sim 500 \text{ pb}^{-1}/\text{week}$ and more to come

- 50 ns bunch trains with 6-8 interactions/crossing

- The analyses presented here are based on 1-2.3 fb$^{-1}$/experiment
Pile Up - A Manageable Nuisance

V. Sharma
Higgs Production

is $x10$
then

is even smaller, yet distinct

is the smallest and also difficult

eilam gross, WIS, LHC2TSP, August 2011

Saturday, September 3, 2011
Branching Ratios

[Graph showing branching ratios as a function of $M_H$ (GeV)]
All Ingredients

Branching Ratios

Mass [GeV]

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

114 120 140 160 180 200 250 300 400 500 600

H→bb
H→ZZ→4q

cc
gg
4q
tt
vvqq
bb
l=τ
llqq
llvv
4l
lv lv
TT
YY
The Killing Trigger

For a channel to be usable, we must be able to trigger it.

Most efficient and clean triggers are lepton based.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma\gamma$</td>
<td>Diphoton</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>Single lepton (+isolated jet), Dilepton</td>
</tr>
<tr>
<td>WH</td>
<td>Single lepton</td>
</tr>
<tr>
<td>ZH</td>
<td>Single lepton (ATLAS, CMS); Dielectron (CMS)</td>
</tr>
<tr>
<td>WW (l\nu\nu)</td>
<td>0-jet Single lepton (ATLAS, CMS); Dilepton (CMS)</td>
</tr>
<tr>
<td>WW** (l\nuqq)</td>
<td>0-jet Single lepton (CMS)</td>
</tr>
<tr>
<td>WW** (l\nuqq)</td>
<td>1-jet Single lepton (CMS)</td>
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<tr>
<td>ZVBF*</td>
<td>Single lepton, dilepton</td>
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<tr>
<td>ZZ (llll)</td>
<td>Single lepton (ATLAS); Single lepton (early data), dilepton (CMS)</td>
</tr>
<tr>
<td>ZZ (ll\nu\nu)</td>
<td>Single lepton (ATLAS); Dilepton (CMS)</td>
</tr>
<tr>
<td>ZZ (llqq)</td>
<td>Single lepton</td>
</tr>
<tr>
<td>ZZ (ll\tau\tau) *</td>
<td>Dilepton</td>
</tr>
</tbody>
</table>

* CMS only / ** ATLAS only
All Ingredients

Branching Ratios

- $H \to bb$
- $H \to ZZ \to 4q$

Mass [GeV]

0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1

114 120 140 160 180 200 250 300 400 500 600

Legend:
- $cc$
- $gg$
- $4q$
- $tt$
- $\nu\nuqq$
- $bb$
- $l=\tau$
- $llqq$
- $lvqq$
- $llvv$
- $4l$
- $lv lv$
- $\tau\tau$
- $YY$
Usable Ingredients

Branching Ratios

Trigger ripped off the jet channels

Mass [GeV]

<table>
<thead>
<tr>
<th>Mass [GeV]</th>
<th>114</th>
<th>120</th>
<th>140</th>
<th>160</th>
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Saturday, September 3, 2011
Usable Apparent Channels Weight

- Here we normalize the usable channels BRs
- Looks like tau tau is the best channel to probe LEP. Is it really so?
- Tau→ (low pT) lepton or hadrons, not so easy to trigger
The BG: Powers of Ten

\( \sqrt{s} = 7 \text{ TeV} \)

<table>
<thead>
<tr>
<th>( \sigma(\text{pb}) )</th>
<th>( W + \text{jets} )</th>
<th>( Z + \text{jets} )</th>
<th>( t + X ) (t-chan)</th>
<th>( tW )</th>
<th>( W^+W^- )</th>
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<tr>
<td></td>
<td>( W \rightarrow \ell \bar{\ell} )</td>
<td>( Z \rightarrow \ell^+\ell^- )</td>
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<td>30000</td>
<td>28000 pb NLO</td>
<td>28000 pb NLO</td>
<td>63 pb NLO</td>
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<td>43 pb</td>
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<td>25000</td>
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<td>0</td>
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</tbody>
</table>

Vivek Sharma

eilam gross, WIS, LHC2TSP, August 2011
A nano statistical interlude

Understanding The Yellow and Green Bands
Understanding The Yellow and Green Bands

\[ \mu = \frac{\sigma}{\sigma_{SM}} \]

- Red: "Observed" (example data)
- Blue dashed: Higgs excluded at 95% CL below this line
- Black dashed: Expected without Higgs
- Green: Expected region at 68% Confidence Level
- Yellow: Expected region at 95% Confidence Level

95% CL Limit on \( \sigma/\sigma_{SM} \) vs. mass of Higgs [GeV]

Excluded regions are marked with grey bars.
Understanding The Yellow and Green Bands

\[ \mu = \frac{\sigma}{\sigma_{SM}} \]
channels weight

\[ \mu = \frac{\sigma}{\sigma_{SM}} \]

\[ \mu_{\text{up,obs}} = \hat{\mu} + \sigma_{\mu_{\text{up}}} \cdot 1.64, \]

\[ \mu_{\text{up,exp}} = \hat{\mu}_A + \sigma_{\mu_{\text{up}}} \cdot 1.64 = \sigma_{\mu_{\text{up}}} \cdot 1.64 \rightarrow \frac{1.64}{s / \sqrt{s + b}} \]

\[ w_i = \left( \frac{\mu_{\text{up,exp,C}}}{\mu_{\text{up,exp,i}}} \right)^2 = \frac{1}{\mu_{\text{up,exp,i}}} \left( \frac{1}{\mu_{\text{up,exp,i}}} \right)^2 \rightarrow \frac{(s_i / \sqrt{s_i + b_i})^2}{\sum_i (s_i / \sqrt{s_i + b_i})^2} \]

If we normalize individual channels to the same luminosity, the weight, \( w_i \), is independent of the luminosity.

\[ \mu_{\text{up,exp,i}} (\mathcal{L}_i) \rightarrow \mu_{\text{up,exp,i}} (\mathcal{L}_0) = \mu_{\text{up,exp,i}} (\mathcal{L}_i) \sqrt{\frac{\mathcal{L}_1}{\mathcal{L}_0}} \]
CMS vs ATLAS channel weights

Spot the differences

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Distinct mass regions $\gamma\gamma$, $l\nu l\nu$, $4l$, $ll\nu\nu+llqq$
Probing the LEP Edge

The LEP edge 114–140 GeV

Probing channels: \( H \rightarrow \gamma\gamma, V_{bb}, \tau\tau \)
$H \rightarrow \gamma \gamma$  Probing LEP 114 GeV

- Though it's the most important channel for very low mass Higgs, $\sigma \times BR = 0.04 \text{pb}$

- Large irreducible BG from $pp \rightarrow \gamma \gamma + X$ (continuum)

- Large BG from fakes $pp \rightarrow \gamma j, jj + X$
H→γγ Probing LEP 114 GeV

- Clean signature: 2 energetic isolated photons → narrow mass peak
- A narrow peak is searched for over a large, smooth background.
- Data are split into categories based on direction of photons (detector region) and conversion mode (which affect γγ mass resolution, which is excellent)
- A fit is performed to the background side band under the BG only hypothesis (only data is considered)
**H → γγ** Probing LEP 114 GeV

- 114 GeV expected sensitivities
  - ATLAS 3.6xSM, CMS 2.9xSM
- Projected illustrative current combined @
  - 114 expected ~2xSM
- Need a few more fb⁻¹/experiment to close the 114 GeV gap

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**Figure 1:**
- Observed CL <sub>μ</sub> limit
- Expected CL <sub>μ</sub> limit

**Figure 2:**
- Observed
- Expected ± 1σ
- Expected ± 2σ
Probing Deeper: $W/ZH \to W/Zbb$

- $H \to bb$ is the dominant decay of a low mass Higgs. It also extremely important to measure Higgs couplings.
- Multi-jet background kills its inclusive production.
- $W/ZH$ is feasible for low Higgs mass channels: $\ell\nu bb, lllbb$ and $\nu\nu bb$ (CMS only).

**Signature**
Lepton, MET and b-tag

- $Z/W+jets$ and $tt$ BG can be reduced by requiring boosted Higgses with combined b-tag (CMS).
- Jet substructure is an analysis option (ATLAS have not yet implemented any boosted feature).

- CMS introduce two analyses, cut & count and BDT; ATLAS are using a shape analysis based on $m_{bb}$.
- Sensitivity is 6-10xSM (CMS) @ 110-130 GeV.
$H \rightarrow \tau\tau$

- **VBF (CMS)**
  - Clean and sensitive
- 2 tagged back to back forward jets and two tagged taus

**Diagram:**
- $Jet_1 E_T = 177$ GeV
- $Jet_2 E_T = 46$ GeV
- $\mu P_T = 20$ GeV
- Missing $E_T = 97$ GeV
- Visible Mass($\tau\tau$) = 75 GeV
- Mass ($jj$) = 580 GeV
- $\Delta \eta (jj) = 3.5$

**Graph:**
- CMS Preliminary
  - 1.1 fb$^{-1} \sqrt{s}=7$ TeV
  - $\tau_{\mu} \tau_h$
  - (10x) $H \rightarrow \tau\tau$ $m_h=120$
  - Observed
  - $Z \rightarrow \tau\tau$
  - $t\bar{t}$
  - Electroweak
  - QCD

**Legend:**
- Events
- $m_{vis}$ [GeV]

*eilam gross, WIS, LHC2TSP, August 2011*


**H→TT**

- **Non VBF** - $ll+jets$(ATLAS), $e\mu$(CMS), $lh$

- **Dominant BG**: Data driven $tt$ and $Z\rightarrow\tau\tau$ (using Embedding (ATLAS), using $Z\rightarrow ll$ (CMS))

- **QCD, W+jets from data**

**Sensitivity $>\times10$ SM**

CMS has a downward fluctuation which improves the observed limit.
“TEVATRON++” mass region

140-200 GeV

Probing channel:
$H \rightarrow WW \rightarrow \ell \nu \ell \nu$

Combination - Channel Weight (L Norm)
The channel is challenging (2 neutrinos-no mass reconstruction)

Signature: 2 high pT opposite sign isolated leptons with large MET

3 bins: +0,1 and 2 jets (VBF)
WW can be reduced by exploiting the Higgs spin, require small $\Delta \Phi_{\mu\mu}$.
Event display of a top pair e-mu dilepton candidate with two b-tagged jets. The electron is shown by the green track pointing to a calorimeter cluster, the muon by the long red track intersecting the muon chambers, and the missing ET direction by the dotted line on the XY view. The secondary vertices of the two b-tagged jets are indicated by the orange ellipses on the zoomed vertex region view.

**Reject by b-tag veto**
BG: WW, W+jets, DY, top

Irreducible WW BG can be slightly reduced requiring small \(\Delta\phi_{\ell\ell}\)

Large MET and Z Veto against DY

b-tag veto to remove top contamination

Finally mass dependent cuts are applied (e.g. ATLAS \(0.75m_H < m_T < m_H\))
**H -> WW -> L ν L ν**

- Background is estimated from control samples in various sophisticated ways.

- A control region is defined rich in the measured BG (e.g. WW or top), contaminations are being subtracted and then the BG is extrapolated to the signal region (mostly using MC).

- Example: $b$-tag is inverted to estimate Top BG.

- (CMS) DY estimated by inverting Z-veto.

- $W$+jets and QCD multi-jet BG are data driven (estimating fakes).
H→WW→lνlν Limits

Results are counting based

Obs: 154<mH<186
Exp: 135<mH<196
Both cut based

Obs: 147<mH<194
Exp: 136<mH<200
ATLAS: only +0,1 jets
The Golden Channel - $H \rightarrow ZZ \rightarrow 4l$

- Around 140 and above 200 GeV
- Probing channel: $H \rightarrow ZZ \rightarrow 4l$
The Golden Channel: $H \rightarrow ZZ \rightarrow 4l$

- CLEAN but very low rate, yet probably most trustable
- All information is available, one can fully reconstruct the kinematics and the masses ($m_{2l}$, $m_{4l}$)
- Signature: Two pairs of same flavor high $p_T$ opposite charged isolated leptons, one or both compatible with $Z$
The Golden Channel: $H \rightarrow ZZ \rightarrow 4l$

- A distinct signature due to the excellent mass resolution
- Highly sensitive to lepton ID performance
- Irreducible BG from ZZ
- $Z+jets \ (Z+bb)$ BG estimated from data
- Reducible BG: $tt, Zbb$ removed by isolation and small impact parameter (for $m_{4l}<2m_{Z}$) requirements

![Graph](image-url)
Both experiments are getting closer to exclude

There is no real excess anywhere

A projected illustrative combination shows that the combined sensitivity range is $190 < m_{H} < 300$ and the region $190 < m_{H} < 340$ is rather unlikely already
Heavy Higgses

- $m_H > 300$
- Probing channels:
  - $H \rightarrow ZZ \rightarrow llvv$
  - $H \rightarrow ZZ \rightarrow llqq$
  - and 4l
Heavier Higgs: $H\rightarrow ll\nu\nu$

Signature: two high $p_T$ opposite charged isolated leptons with high MET

Candidate Event with a $Z\rightarrow \mu\mu$ and missing $E_T$

$\rho_{T\mu} = 50.126$ GeV
$m_{\mu\mu} = 94$ GeV
$E_{Tmiss} = 161$ GeV

Run 167776, Event 129360643
Time 2010-10-28 10:41:18 CET
Heavier Higgs: $H \rightarrow ll\nu\nu$

- Main BG: irreducible di-Boson ZZ, WZ & WW

- Reducible, measured or verified with data control samples: QCD, W/Z+jets (suppressed by MET) and top (rejected by anti b-tag)

- Discriminating variables: $\Delta \Phi_{ll}, MET$ and Transverse mass (two mass bins (ATLAS) and mass dependent cuts (CMS)).

$$m_T^2 \equiv \left( \sqrt{\vec{p}_{TZ}^2} + m_Z^2 + \sqrt{\vec{p}_{T\nu}^{\text{miss}} \, l^2} + m_Z^2 \right)^2 - (\vec{p}_{TZ} + \vec{p}_{T\nu}^{\text{miss}})^2$$
Heavier Higgs: \( H \rightarrow ll\nu\nu \)

\[ m_T^2 \equiv \left( \sqrt{\vec{p}_{TZ}^2 + m_Z^2} + \sqrt{\vec{p}_T^{\text{miss}}^2 + m_Z^2} \right)^2 - (\vec{p}_{TZ} + \vec{p}_T^{\text{miss}})^2 \]

Final analysis by counting (CMS) or \( m_T \) shape (ATLAS)

ATLAS Preliminary

Obs: excl \( 350 < m_H < 450 \)

Obs: excl \( 340 < m_H < 375 \)
Heavier Higgs: \( H \rightarrow llq\bar{q} \)

- Clear signature: Exactly one pair of oppositely charged same flavor leptons and a pair of jets. Both pairs compatible with a Z boson. Low MET

\[ M_{2l2j} = 580 \text{ GeV} \]

\[ e: 177 \text{ GeV} \]
\[ e: 114 \text{ GeV} \]

\[ \text{Jet: 207 GeV} \]
\[ \text{Jet: 114 GeV} \]
Heavier Higgs: $H\rightarrow llqq$

- Even though this channel has the highest rate of all $H\rightarrow ZZ$ final states, it has less weight due to High $Z$+jets BG.

- Strategy:
  - “Bump search” in $m_{llqq}$ distribution
  - Use b-tagged bins (ATLAS 0+1,2; CMS 0,1,2 b-tagged jets)
  - CMS are using spin related angular variables
  - Use side bands in $m_{ll}$ and $m_{jj}$ to measure the $Z$+jets BG.
Heavier Higgs: $H \rightarrow llqq$

- This channel is approaching a sensitivity for exclusion.
- Both experiments almost touch the SM exclusion line due to a downwards fluctuation of the data.
CMS “exclusive”: ZZ→llττ

![Graph showing combination - channel weight (L Norm) vs Higgs Mass [GeV]]
CMS “exclusive”: ZZ→llττ

- Search performed by CMS
- Signature: ee or μμ from Z and a pair of taus.
- Major BG ZZ, WZ and Z+jets estimated with data driven ways.
- For tau leptonic decays only ee final states are considered (to avoid overlap with 4l)
- ONE event survived in the eeeτh final state
- Sensitivity ~x10 SM 200-400 GeV
ATLAS “exclusive”: $WW\rightarrow l\nu qq$
**ATLAS “exclusive”: WW→lνqq**

- **Signature**: One and only one high pT isolated lepton accompanied with high E_T^{miss} and a pair of high pT jets compatible with a W boson.
- One can solve for the p_T^ν using m_lν=m_Z and find m_lνqq
- **Shape based analysis (m_lνqq)**, two bins (+0,+1 jet);
  
  Main BG W+jets derived from data
  
  - Anti b-tag against top
  - Sensitivity is ~ x4 SM @350-450 GeV
All for one - Combine forces

YY
WW
ZZ
vbb

SM car; powered by the Higgs?
Disclaimer

- Correlated uncertainties (Jet energy scales, Luminosity etc... taken into account)

- When data driven methods are used, systematics are not correlated

- Theory uncertainties are carefully taken into account across channels using the recommendation of the LHC cross section group (see talk by R. Tanaka)
ATLAS ingredients

Limit in low mass completely driven by $H \rightarrow \gamma\gamma$, then $\ell\ell\nu\nu$, 4$\ell$ and $\ell\ell\nu\nu$
CMS Ingredients

Limit in low mass completely driven by $H \rightarrow \gamma \gamma$, then $l\nu l\nu$, $4l$ and $l\nu l\nu$
And, ATLAS: first, Low Mass

exp. exclusion: >130, obs. exclusion: 146-232
And, **ATLAS: full range**

- **exp. exclusion:** ~130-444
- **obs. exclusion:** 146-232, 256-282, 296-466
CMS, Full Range

exp. exclusion: \(~130-440\)

obs. exclusion: 145-216, 226-288, 310-400
Local p-values

The local p-value is the probability that the background only will fluctuate up to the observed local significance ($Z_{\text{max}}$) or more.

An approximate way to calculate the LEE, i.e. the probability to see an excess anywhere in the search mass range above some $Z_{\text{max}}$ is calculated via the most famous formula in the world 😊

$$p_{\text{global}} = p_{\text{min}} + N_0 e^{-Z_{\text{max}}^2/2}$$

$N_0$ is the average number of upcrossings at $Z=0$ which is estimated from data, and $Z_{\text{max}}$ is the local significance. Formula is asymptotically accurate for increasing $Z_{\text{max}}$. 
No incompatibility with the SM is seen in ATLAS.
A local moderate (yet genuine) $2.3\sigma$ excess is seen in CMS around 120. The probability to observe such an excess or more anywhere in the mass range is $\sim 40\%$. LEE washes out the excess....

The excess @ 120 and 160 is incompatible with SM Higgs. (@120 compatible with $0.6\times$SM)

There is $2.8\sigma$ with $H \rightarrow \gamma\gamma$ which is reduced to $1.7\sigma$ with the LEE.
Including the 4l current results, it is unlikely that the SM Higgs is in the range 145<m_H<460 GeV.
A Prelude to the Nobel Prize

The 2004 Wolf prize, awarded by the Wolf Foundation, is often thought to be the most prestigious prize in physics after the Nobel prize (in the pic, Brout & Englert).
Nightmare Scenario I: SM Higgs, period.

- Not much living space is left for the Higgs boson.
- Yet, if all bounds are well established, the SM Higgs could be EXACTLY where it is supposed and expected to be 130-145 GeV.
Nightmare Scenario II: No Higgs

- Not much living space is left for the Higgs boson.
- If there is no engine, how does the SM car drives so smooth and fast?
2011-2012 Miraculous Years

- 2011-2012 are the Higgs Miraculous Years
  OR 2011-2012 are the LHC Miraculous Years

- The SM Higgs is probably light $m_H < 145$ GeV
  OR we are on our way to discover an MSSM Higgs

- The LHC is approaching a sensitivity to discover a light Higgs, be it SM or (maybe even a bit more likely) MSSM or...

- The “other” less weighted channels ($Vbb, l\nu qq, ...$) get more weight as we fail to discover the SM Higgs boson, keep searching, leave no stone unturned!

- I think from any point of view (SM, EXotic, SUSY, Higgs .......) this is the prime time for any High Energy Physicist

- Don’t worry be happy ☺️
A careful study of systematics was performed in both experiments. Systematics were taken into account within the limit machinery base on the PL, including correlations across channels with nuisance parameters such as Luminosity and JES etc.....

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<tr>
<th>Channel</th>
<th>Systematics</th>
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<td>$\gamma\gamma$</td>
<td>id eff $\sim 11%$</td>
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<tr>
<td>$\tau\tau$</td>
<td>JES $\sim 10%$, $\tau$ES $\sim 15%$ (ATLAS); Lumi, $\tau$id $\sim 6%$ (CMS)</td>
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<tr>
<td>WH</td>
<td>btag eff $\sim 10$-16% (ATLAS); JER $\sim 10%$ (CMS)</td>
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<tr>
<td>ZH</td>
<td>btag eff $\sim 10$-16% (ATLAS); JER $\sim 10%$ (CMS)</td>
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**WW** (l\nu l\nu)

<table>
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<th>0-jet</th>
<th>JES $\sim 6$ (ATLAS)</th>
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<td>WW, W+jets norm $\sim 10$-30% (CMS)</td>
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<td>1-jet</td>
<td>JES $\sim 6$ (ATLAS)</td>
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<td>VBF*</td>
<td>WW, W+jets norm $\sim 10$-30% (CMS)</td>
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**WW** (l\nu qq)

<table>
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<th>JES $\sim 18%$</th>
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<tbody>
<tr>
<td>1-jet</td>
<td>JES $\sim 18%$</td>
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</table>

**ZZ** (l\nu l\nu)

| L $\sim 3.7$-4.5\%, eid $\sim 2$-3\% |

**ZZ** (l\nu qq)

| MET $\sim 6.6\%$, JES $\sim 6\%$ (ATLAS) |
| Z+jets norm $\sim 19$-57\% (CMS) |

**ZZ** (l\nu tt)

| JES $\sim 10\%$ (ATLAS) |
| btag $\sim 13$-18\% e reco $\sim 4.5\%$ |

**ZZ** (l\nu tt) *

| Z+jets estimation $\sim 30\%$ |

* CMS only / ** ATLAS only
## Channels Nano Review

<table>
<thead>
<tr>
<th>Channel</th>
<th>btag (veto)</th>
<th>Jets</th>
<th>MET (GeV)</th>
<th>Shape</th>
<th>Mass Range (GeV/c^2)</th>
<th>Main backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>gg</td>
<td></td>
<td></td>
<td></td>
<td>(M_{gg})</td>
<td>110-150</td>
<td>(gg) (from sidebands)</td>
</tr>
<tr>
<td>tt</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>(M_{tt})</td>
<td>110-140</td>
<td>(Z) from data driven methods</td>
</tr>
<tr>
<td>WH</td>
<td>✔</td>
<td>2</td>
<td></td>
<td>(M_{bb})</td>
<td>110-130</td>
<td>Top (3j - high (M_{bb})) and (W)+jets (low (M_{bb}))</td>
</tr>
<tr>
<td>ZH</td>
<td>✔</td>
<td>2</td>
<td></td>
<td>(M_{bb})</td>
<td>110-130</td>
<td>(Z)+jets (low (M_{bb}))</td>
</tr>
<tr>
<td>WW ((\ln \ln))</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0-jet</td>
<td>veto</td>
<td>0</td>
<td>&gt;30</td>
<td>(M_{WW})</td>
<td>110-600</td>
<td>(WW) (control region (M_{ll}))</td>
</tr>
<tr>
<td>1-jet</td>
<td>veto</td>
<td>1</td>
<td>&gt;30</td>
<td>(M_{WW})</td>
<td>110-600</td>
<td>Top (from reverse btag) and (WW) ((M_{ll}) CR)</td>
</tr>
<tr>
<td>VBF*</td>
<td>veto</td>
<td>2</td>
<td>&gt;30</td>
<td>(M_{WW})</td>
<td>110-600</td>
<td>Top from CS</td>
</tr>
<tr>
<td>WW** ((\ln \qq))</td>
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<td></td>
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</tr>
<tr>
<td>0-jet</td>
<td>veto</td>
<td>0</td>
<td>&gt;30</td>
<td>(M_{WW})</td>
<td>200-600</td>
<td>(W)+jets (sidebands)</td>
</tr>
<tr>
<td>1-jet</td>
<td>veto</td>
<td>1</td>
<td>&gt;30</td>
<td>(M_{WW})</td>
<td>200-600</td>
<td>(W)+jets (sidebands)</td>
</tr>
<tr>
<td>ZZ ((\ll \ll))</td>
<td>IP</td>
<td></td>
<td></td>
<td>(M_{4l})</td>
<td>110-600</td>
<td>(ZZ) (from MC), (Z)+jets and top (CR)</td>
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<tr>
<td>ZZ ((\ll \nn))</td>
<td>✔</td>
<td></td>
<td>&gt;30</td>
<td>(M_T)</td>
<td>200-600</td>
<td>(VV) (from MC) and top (MC and checks)</td>
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<tr>
<td>ZZ ((\ll \qq))</td>
<td>✔</td>
<td>2</td>
<td>&lt;50</td>
<td>(M_{llqq})</td>
<td>200-600</td>
<td>(Z)+jets (from MC) and top (from MC)</td>
</tr>
<tr>
<td>ZZ ((\llt \llt)) *</td>
<td>✔</td>
<td></td>
<td></td>
<td>(M_{lltt})</td>
<td>200-400</td>
<td>(Z)+jets (CR) (ZZ) normalization (from data)</td>
</tr>
</tbody>
</table>

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