Status of the SM Scalar boson searches at CMS;
New physics searches at the LHC

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Plan of the talk

- CMS and ATLAS detectors
- LHC performance in 2011
- Physics objects

PART I. Search for the SM scalar boson at CMS

- Low mass channels : $H \rightarrow \gamma \gamma$, $H \rightarrow \tau \tau$
- Full mass range channels : $H \rightarrow WW \rightarrow l\nu l\nu$, $H \rightarrow ZZ \rightarrow 4l$
- Combination

PART II. New physics searches at the LHC

- Non-SM scalar boson searches
- some SUSY searches
- Some exotics searches

Public physics results :
- CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic
- ATLAS : https://twiki.cern.ch/twiki/bin/view/AtlasPublic
CMS : Compact Muon Solenoid
- $r = 7.5 \text{ m}$, $L = 29 \text{ m}$
- $B = 4 \text{ T}$ central solenoid
  Calorimeter inside

ATLAS : A Toroidal LHC ApparatuS
- $r = 11 \text{ m}$, $L = 45 \text{ m}$
- $B = 2 \text{ T}$ central solenoid
  and 3 outer toroids
Excellent performance of LHC and CMS in 2011!

ATLAS and CMS results presented here:
- based on the 7 TeV collisions recorded in 2011
- More than 5 fb\(^{-1}\) for each experiment
- Luminosity increased during the year:
  Maximum was 3.5\(\times\)10\(^{33}\) cm\(^{-2}\) s\(^{-1}\)
- Multiple interactions per beam crossing:
  Average more than 10

Number of vertices in the second part of 2011 data
Physics objects

Basic physics objects:
- Jet: Cluster in EM and hadronic calorimeters (and inner tracker)
- Photon: EM cluster without matching track
- Electron: EM cluster with matching track
- $\mu$: Matching tracks in inner and $\mu$ trackers
- $\tau$ lepton: Narrow jet with matching track(s)
- MET: pT required to balance all of the above

Higher level objects:
- B-jet: Jet with displaced secondary vertex (or lepton tag)
- W-boson: $l^+l^-+$MET or dijet with $m=80$ GeV
- Z-boson: OS dilepton or dijet with $m=90$ GeV
- Top quark: $W+b$, $m=173$ GeV

Particle flow algorithm (PF): global event description in form of a list of particles and avoids double-counting - Large improvement in tau, jet, and MET
PART I:

Status of the SM Scalar boson searches at CMS;

How can we break the EW symmetry?

→ The Brout-Englert-Higgs mechanism

- P. Higgs, Phys. Rev. Lett. 13, 508 (1964)
- Direct searches: LEP: $M_H > 114.4$ GeV excluded at 95% CL

- Indirect constraints from precision EW measurements:

LEPEWWG/ZFitter
With $M_W = 80399\pm23$ MeV
$M_H < 161$ GeV at 95% CL

Including the new $M_w$ tevatron measurement (Moriond 2012):
With $M_W = 80385\pm15$ MeV
$M_H < 152$ GeV at 95% CL

SM scalar boson favoured at low mass above the LEP limit
SM scalar boson production at LHC

gg→H

VBF

VH
SM scalar boson channels at CMS

<table>
<thead>
<tr>
<th>Channel</th>
<th>$m_H$ range (GeV)</th>
<th>Luminosity (fb$^{-1}$)</th>
<th>Sub-channels</th>
<th>$m_H$ resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>new H $\to \gamma\gamma$</td>
<td>110–150</td>
<td>4.8</td>
<td>2</td>
<td>1–2%</td>
</tr>
<tr>
<td>H $\to \tau\tau \to e\tau_h/\mu\tau_h/e\mu + X$</td>
<td>110–145</td>
<td>4.6</td>
<td>9</td>
<td>20%</td>
</tr>
<tr>
<td>new H $\to \tau\tau \to \mu\mu + X$</td>
<td>110–140</td>
<td>4.5</td>
<td>3</td>
<td>20%</td>
</tr>
<tr>
<td>new WH $\to e\mu\tau_h/\mu\mu\tau_h + \nu$s</td>
<td>100–140</td>
<td>4.7</td>
<td>2</td>
<td>20%</td>
</tr>
<tr>
<td>(W/Z)H $\to (e\nu/\mu\nu/ee/\mu\mu/\nu\nu)(bb)$</td>
<td>110–135</td>
<td>4.7</td>
<td>5</td>
<td>10%</td>
</tr>
<tr>
<td>H $\to WW^{*} \to 2\ell 2\nu$</td>
<td>110–600</td>
<td>4.6</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>new WH $\to W(WW^{*}) \to 3\ell 3\nu$</td>
<td>110–200</td>
<td>4.6</td>
<td>1</td>
<td>20%</td>
</tr>
<tr>
<td>H $\to ZZ^{(*)} \to 4\ell$</td>
<td>110–600</td>
<td>4.7</td>
<td>3</td>
<td>1–2%</td>
</tr>
<tr>
<td>H $\to ZZ^{(*)} \to 2\ell 2q$</td>
<td>130–164</td>
<td>4.6</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>200–600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H $\to ZZ \to 2\ell 2\tau$</td>
<td>190–600</td>
<td>4.7</td>
<td>8</td>
<td>10–15%</td>
</tr>
<tr>
<td>H $\to ZZ \to 2\ell 2\nu$</td>
<td>250–600</td>
<td>4.6</td>
<td>2</td>
<td>7%</td>
</tr>
</tbody>
</table>

11 independent channel searches for mass range 110-600 GeV

Expected combined 95% exclusion : 114.5-543 GeV
Low mass $H \rightarrow \gamma\gamma$ channel

- ET = 86 GeV
- ET = 56 GeV

Signature: small mass peak over large smoothly decreasing background

Irreducible: $2\gamma$ QCD production
Reducible: $\gamma$+jet with one fake $\gamma$
DY with electrons faking photons

Studied mass range: 110-150 GeV

- Small BR: $\sim 2 \times 10^{-3}$
- Two isolated high Et photons
- VBF channel has two additional jets from outgoing quarks
- Narrow mass peak: very good mass resolution 1-2%

bg MC only used for optimization

$M_H = 120$ GeV
signal x 5

$\sqrt{s} = 7$ TeV $L = 4.8$ fb$^{-1}$
- **Multivariate (MVA) analysis**
  Event-by-event mass resolution, photon id discriminant, di-photon kinematic variables and vertex probability combined using with boosted decision tree (BDT)

- **4 non-VBF event classes**
  split based on the diphoton BDT classifier output

- **BG estimation**
  by fitting to a polynomial in the full mass range (3rd to 5th order)

<table>
<thead>
<tr>
<th>$m_H=120\text{ GeV}$</th>
<th>class 0</th>
<th>class 1</th>
<th>class 2</th>
<th>class 3</th>
<th>Dijet class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total signal expected events</td>
<td>3.4</td>
<td>19.3</td>
<td>18.7</td>
<td>33.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Data (events/GeV)</td>
<td>4.5</td>
<td>55.1</td>
<td>81.3</td>
<td>229.1</td>
<td>2.1</td>
</tr>
<tr>
<td>resolution FWHM/2.35 (%)</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
<td>1.7</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Dijet tag selection: exploits two additional VBF high pT jets at large rapidity

**Exclusive dijet tag improves sensitivity by ~10%**

Photon identification is the same

Tighter lead photon Et cut (Et lead/Mγγ > 55/120)

\[ M_{γγ} = 121.9 \text{ GeV} \]
\[ M_{jj} = 1460 \text{ GeV} \]
H → γγ results: limits

**Expected from MVA analysis**

Improvement ~20%

**Expected 95% CL exclusion: 1.2-2 x SM**

Excluded at 95% CL:

- 110.0-111.0, 117.5-120.5, 128.5-132.0, 139.0-140.0, 146.0-147.0 GeV

Cut based analysis gives consistent results

P-value: probability that a bg only fluctuation is at least as large as the observation

**Largest excess around 125 GeV**

- Local significance 2.9 σ
- Global significance 1.6 σ
Low mass $H \rightarrow \tau \tau$ channel

No narrow mass peak : $\sigma(M) \sim 20$
Also important for MSSM
Search in 3 categories for SM:
- 0/1 jet case : no more than 1 jet $p_t > 15$ GeV
- Boosted case: one jet with $p_t > 150$ GeV
- VBF case : two additional forward jets

Two new channels added:

1. $H \rightarrow \tau \tau \rightarrow \mu \mu$ (VBF, or boosted H)
   
   Large bg from DY $Z \rightarrow \mu \mu, \tau \tau$

2. $WH \rightarrow l \tau \rightarrow e \tau, \mu \tau$
   
   Same sign $e$ and $\mu$
Channel sensitive in a large mass range!
Most sensitive channel around $2xM_W$

**No narrow mass peak (mass resolution $\sim 20\%$)**
Two high $p_t$ isolated leptons + MET

Main backgrounds
- WW (irreducible)
- Z+jets, WZ, ZZ, tt, W + jets
Main bg estimated from data

Scalar boson + V-A structure of W decay favours small opening angle between the 2 charged leptons
To improve signal sensitivity:

Analysis is performed in: jet multiplicities (0, 1, 2-jet bins) and flavour (ee, μμ, eμ)

- WW bg contributes more to the 0-jet bin
- tt bg contributes more to the 1 and 2-jet bins
- Z+jet and ZZ contribute more to same flavour (ee and μμ)
- 2 jet bin corresponds to VBF dijet tag

Two different analyses performed:

- Cut and count in 0, 1, 2-jet bins
- Multivariate in 0 and 1-jet bin

MET affected by pile-up
Special treatment
Z mass veto for ee, μμ channels

0-jet bin, $M_H = 130$ GeV
Data-bg comparison after various cuts

CMS, $\sqrt{s} = 7$ TeV, $L_{int} = 4.6$ fb$^{-1}$

- data
- $H(130) \to WW$
- W+jets
- di-boson
- top
- Z+jet
- WW
- Cut based analysis:
  \( pt(max), pt(min), m(ll), \Delta \varphi(ll), m_{t(t)} \)

- MVA uses in addition:
  \( P_{t(ee)}, M_{ll}, \Delta \varphi(ll), \Delta R(ll), m_{t(t)} \) (for each lepton), lepton flavour

BDT trained at \( \neq \) masses:
Using \( H \rightarrow WW \) as signal and Non-resonant WW as bg

- Use BDT output classifier distribution for CL estimation

Most sensitive channel is \( e\mu \) in 0-jet bin
higher s/b and smaller systematic errors

CMS arXiv:1202.1489
Full mass range: $H \rightarrow WW \rightarrow l\nu l\nu$

**Cut based**

**MVA based**

No significant excess in the full mass range
Multivariate analysis more sensitive, especially at low mass

95% C.L. expected exclusion for MH in [127-270] GeV
95% C.L. observed exclusion for MH in [129-270] GeV
Slight excess at low mass in BDT analysis
Full mass range: $H \rightarrow ZZ \rightarrow 4\ell$

Clean channel: 2 high mass pairs of isolated electrons or muons
Narrow mass peak
Very good mass resolution 1-2 %
Small BR $\sim 1E^{-3}$ at high mass

Need: Very good lepton id
Select down to very low Pt
Background
irreducible: ZZ,
Reducible: $Z+$jets, $Zbb$, $tt$, WZ

H→ZZ→4l : mass spectrum

**Full mass range**

- CMS
- √s = 7 TeV L = 4.7 fb⁻¹

<table>
<thead>
<tr>
<th>Channel</th>
<th>4e</th>
<th>4μ</th>
<th>2e2μ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZZ continuum</td>
<td>12.27 ± 1.16</td>
<td>19.11 ± 1.75</td>
<td>30.25 ± 2.78</td>
</tr>
<tr>
<td>Z+X</td>
<td>1.67 ± 0.55</td>
<td>1.13 ± 0.55</td>
<td>2.71 ± 0.96</td>
</tr>
<tr>
<td>All background</td>
<td>13.94 ± 1.28</td>
<td>20.24 ± 1.83</td>
<td>32.96 ± 2.94</td>
</tr>
<tr>
<td>m_H = 120 GeV/c²</td>
<td>0.25</td>
<td>0.62</td>
<td>0.68</td>
</tr>
<tr>
<td>m_H = 140 GeV/c²</td>
<td>1.32</td>
<td>2.48</td>
<td>3.37</td>
</tr>
<tr>
<td>m_H = 350 GeV/c²</td>
<td>1.95</td>
<td>2.61</td>
<td>4.64</td>
</tr>
<tr>
<td>Observed</td>
<td>12</td>
<td>23</td>
<td>37</td>
</tr>
</tbody>
</table>

bg exp.: 67±6
Data: 72

**Low mass range**

- CMS
- √s = 7 TeV L = 4.7 fb⁻¹

bg exp.: 9.5±1.3
Data: 13

In 100-160 GeV

SM scalar boson excluded at 95% CL for \( M_H \) in [134-158], [180-305] and [340-465] GeV

Largest excess observed at 119.5 GeV
- local significance 2.5 \( \sigma \)
- global significance 1.0 \( \sigma \) in the full mass range, 1.6 in the mass range 100-160 GeV
Method for CL calculation is LHC-type CIs: Frequentist CLs with profiled likelihood test statistics and log-normal treatment of nuisance parameters.

SM cross sections and BR are assumed with their theoretical uncertainties.

Combination of 11 channels
Expected: 95% exclusion MH in [114.5-543] GeV
Observed: 95% exclusion MH in [127.5-600] GeV
99% exclusion MH in [129-525] GeV

95% allowed Mass range: 114.4-127.5 GeV
Observed lower limit higher than expected: because of excess in data at low mass
Combination : p-value

**Low mass region :**

Minimum p-value observed at 125 GeV
local significance: 2.8 $\sigma$
global significance in [110-145] : 2.1 $\sigma$

$\rightarrow$ More data are needed to investigate the excess.

all channels are compatible with a 125 GeV scalar boson
SM scalar boson: summary

Tevatron results combined:
- excess in range 110-135 GeV:
  - global pvalue of 2.2 s.d.
  - (2.7 local)
PART II:

New physics searches at the LHC
In the SM, the EWSB mechanism requires at minimum one doublet of a complex scalar field. Is this minimal version realised in nature?

There are many extensions of the SM that change the predictions of this minimal version some particular examples:

- **Fourth (heavy) generation of fermions modify scalar couplings**:
  Enhanced SM4 scalar cross section compared to SM

- **Fermiophobic boson**:
  different mechanism to provide mass to gauge bosons and to fermions
  Changes low mass scalar production & decays dramatically

- **Two or more scalar doublet fields**:
  - 2HDM : Multiple scalar bosons: 3 neutral and 2 charged
  - Example : Minimal Supersymmetric Model
  - NMSSM, triplets … more complex:
    very light pseudoscalar boson, doubly charged scalars …
Fourth generation

Additional heavy quarks enhance significantly the $gg\rightarrow H$ production
BR is also affected (virtual heavy quarks)

Benchmark fourth generation quark masses of $\sim 600$ GeV

$\sigma$(SM4) = $10^{-4} \times \sigma$(SM) for
$M_H$ 110–600 GeV

$M_H > 120$ GeV excluded
Should have excluded $M_H > 110$ GeV
Exclusion of most of the parameter space for models with a fourth generation fermion
Fermiophobic scalar appears in a variety of extensions to the SM

Scalar does not couple to fermions:
- $gg \rightarrow H$ and $ttH$ production disappear while VBF, VH are unchanged
- direct decay $H \rightarrow \tau\tau$, $bb$ impossible
  $H \rightarrow \gamma\gamma$, $WW$, $ZZ$ enhanced

CMS PAS HIG-12-008

ATLAS CONF 2012-13

ATLAS Preliminary

$\sqrt{s} = 7$ TeV
$L = 4.6 - 4.8$ fb$^{-1}$

CMS : $H \rightarrow \gamma\gamma$, $WW$, $ZZ$ combined : $M(FB) > 192$ GeV at 95% CL
ATLAS : $H \rightarrow \gamma\gamma$
$M(FB) > 121$ GeV at 95% CL
Five BEH bosons
- Three neutral: h, H, A, two charged: H±
- \( m_A \): mass of pseudoscalar, \( \tan(\beta) \): ratio of the vacuum expectation values of the two Higgs doublets
- Look for \( \phi = (h, A, H) \) in decay to \( \tau \)-leptons
- Look for \( H^+ \) in top decay

ATLAS CONF 2012-011
arXiv:1202.4083, CMS PAS HIG-11-019

Event with (\( \tau + \text{MET} \)) from \( H^\pm \), 2 b-jets
2 jets or (e/\( \mu + \text{MET} \)) from W
Searches at LHC : latest results

Searches in lepton production
- Z' ->ee,mm (CMS, Atlas)
- W' ->ev, W'->mu v, W'->WZ (CMS)
- Multileptons in RPV (CMS)
- Excited leptons (Atlas)

Searches for TeV scale gravity
- black holes (CMS)
- Large ED in mm+ee (CMS)
- DM + LED in g+MET (CMS)
- DM + LED in monojet events (CMS)
- RS graviton in jets+MET (CMS)

Searches in lepton + jet production
- 2nd generation LeptoQuarks (Atlas)
- Heavy bottom like quark (CMS)
- Search for t' ->bW(CMS)
- searches for Z'-> ttbar (CMS)
- Search for heavy V- like quark (CMS, Atlas)
- Fourth gen up-type quark (CMS)
- new particle decaying in ZZ (Atlas)
- Fourth gen Down type quark (Atlas)
- Same sign top pair (Atlas)
- Heavy quark in Wq, Wb (Atlas)

Searches in jet production
- Search quark compositeness in dijet angular distribution (CMS)
- resonance in dijet, delta-eta ratio (CMS, Atlas)

Searches for long lived charged particles
- Heavy Stable Charged Particle (CMS)
- Light Higgs -> long lived pp(Atlas)

Searches for SUSY :
- lepton + MET (CMS)
- opposite sign leptons + jet + MET (CMS)
- Razor variable (CMS)
- photon + MET (CMS)
- SS dileptons with b-jets + MET (CMS)
- SS dileptons + MET (CMS)
- multileptons (CMS)
- Z+jet + MET (CMS)
- 0 lepton + (6-8) jets + MET (Atlas)
- 0 lepton + (2-4) jets + MET (Atlas)
- 1 lepton + jets + MET (Atlas)
- 2, 3, >4 leptons + MET (Atlas)
- search for disappearing tracks (Atlas)
- Long lived particles (Atlas)

Searches for rare decay process
- Bs->mu+mu (LHCb, CMS)

See “Electroweak and Searches” parallel session
Squark-gluino mediated SUSY production was the first line of attack
Large production cross section - rich phenomenology of final states to explore

**Multi jet + MET searches**

**Same sign lepton + jet + MET searches**
With the large luminosity we now also become sensitive to more exclusive production modes

(1) Direct sbottom and stop production:
i. in general the third generation is special
   - desired light for SUSY naturalness
   - mixing can push the stop, sbottom and stau masses below other generations

Search for direct sbottom pair production
with $sb \rightarrow b + \chi^0$: Exactly 2 b-jets + MET

MSSM Reference point ★ : $m(sb) = 300 \text{ GeV}, m(\chi^0) = 100 \text{ GeV}$

$\rightarrow$ For $m(\chi^0) < 60 \text{ GeV}$, $m(sb) > 390 \text{ GeV}$

MSSM BR( $sb \rightarrow b + \chi^0$) = 100 %
With the large luminosity we now also become sensitive to more exclusive production modes

(2) Electroweak chargino/neutralino production
3 isolated leptons (e and μ)
MET > 50 GeV
→ 2 regions in/out Z-mass window

MSSM, simplified model scenario
Reference point ★ : $m_{\chi^+}$, $m_{\chi^02}$, mslL, $m_{\chi^01}$ = 150, 150, 100, 50 GeV

→ Degenerate $\chi^+$ and $\chi^02$ excluded up to 300 GeV
BSM: heavy resonance searches

Search for narrow high mass resonances decaying into ee or $\mu\mu$ pairs
Predicted by many BSM models: spin 1 (GUT, LED, techni-mesons, ...) and spin 2 (RS gravitons, ...)

Very clean signature:
Two isolated high pt electrons or muons

CMS (ATLAS):
electrons: $\text{Et}>35$ barrel/40 endcap (25)
$|\eta|< 2.5(2.47)$

-muons: $p_\text{t}>35((25)$ GeV

Z' SSM: benchmark model
Same couplings as SM Z boson
BSM : heavy resonance searches

95% CL lower limits on heavy resonance mass:

<table>
<thead>
<tr>
<th></th>
<th>mass Z' SSM</th>
<th>mass RS Graviton</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS</td>
<td>2.32 TeV</td>
<td>1.81 TeV</td>
</tr>
<tr>
<td>ATLAS</td>
<td>2.21 TeV</td>
<td>1.71 TeV</td>
</tr>
<tr>
<td></td>
<td>c=0.05</td>
<td>c=0.1</td>
</tr>
<tr>
<td>CMS</td>
<td>2.14 TeV</td>
<td></td>
</tr>
<tr>
<td>ATLAS</td>
<td>2.16 TeV</td>
<td></td>
</tr>
</tbody>
</table>
DM searches: monojet and monophoton

Search for high pt $\gamma$+MET and high pt jet+MET - Look for evidence of:
(i) Extra-dimension ADD model
(ii) Dark Matter production

Monojet: ADD limits set $M_D > 3.7$ TeV for $n=2$
Monophoton: $M_D > 1.65(1.71)$ TeV for $n = 3$ (6)

Effective operator: [Bai, Fox and Harnik, JHEP 1012:048(2010)]
massive mediator vector or axial vector

Best limits for low Mass DM, below 3.5 GeV,
A region yet unexplored by direct detection experiments

CMS EXO-11-096, CMS EXO-11-059
BSM searches: $B_s \rightarrow \mu \mu$

Search for NP in rare decay: $B_s \rightarrow \mu \mu$

SM prediction (FCNC, helicity suppressed):
$\text{SM } B(B_s \rightarrow \mu \mu) = (3.2 \pm 0.2) \times 10^{-9}$

CMS limit (5 fb$^{-1}$)
$B(B_s \rightarrow \mu \mu) < 7.7 \times 10^{-9}$ 95 % C.L (CMS)

LHCb: Results with 1 fb$^{-1}$
$B(B_s \rightarrow \mu \mu) < 4.5 \times 10^{-9}$ at 95% CL

CMS arXiv:1203.3976

LHCb-PAPER-2012-007
Conclusions

- CMS SM scalar boson search in 11 independent channels
  Expected 95% CL exclusion : $M_H$ in (114.5-543) GeV
  Observed 95% CL exclusion : $M_H$ in (127.5-600) GeV
  Thanks to : (i) great LHC performance in 2011, (ii) precise measurement from CMS detector, (iii) very hard working people

- Observe an small excess around 125 GeV in the unexcluded region
  Local significance 2.8 $\sigma$, and 2.1 $\sigma$ (in 110-145 GeV), global significance 0.8 $\sigma$
  Compatible with both minimal SM scalar signal and bg fluctuation
  Some small excess for at 125 GeV also observed in Atlas
  Some small broad excess also observed in D0 and CDF

- Search for new physics in many different possible topologies
  More exotic final states – more exclusive final states
  No evidence of new physics so far

- Need more data :
  - 2012 run at 8 TeV :
    will give a final answer for the minimal SM scalar boson
    Continue searching for new physics - more phase space
  - LHC Data > 2014 at 14 TeV : identify/study the properties of any signal hopefully
Back up
CMS exotics searches

GRAND SUMMARY MORIOND 2012

Z' SSM II
Z' Y II
Z', ttbar, hadronic, width=396
Z', ttbar, lep+jet, width=396
GKK jet+MET k/M = 0.2
GKK jet+MET k/M = 0.3
GKK II k/M = 0.1
GKK YY k/M = 0.1
GKK II k/M = 0.05
GKK YY k/M = 0.05
W' IV, constructive inter.
W' IV, destructive inter.
WKK µ = 0.06 TeV
W' dijet
WR, MNR < 1.0 TeV
W' → WZ
pTC, nTC > 700 GeV

Ms, YY, HLZ, nED = 2
Ms, II, HLZ, nED = 2
Ms, YY, HLZ, nED = 6
Ms, II, HLZ, nED = 6
MD, monojet, nED = 3
MD, monojet, nED = 6
MD, mono-Y, nED = 3
MD, mono-Y, nED = 6
LQ1, β=0.6 (2010)
LQ1, β=1.0 (2010)
LQ2, β=0.5
LQ2, β=1.0
LQ3, β=1.0

MBH, rotating, MD=3TeV, nED = 2, BlackMax
MBH, non-rot, MD=3TeV, nED = 2, BlackMax
MBH, Quantum BH, MD=3TeV, nED = 2,
String Ball M, MD=2.1, Ms=1.7, gs=0.4
String Resonances
E6 diquarks
Axigluon/Coloron
q*, dijet
q*, dijet pair
q*, boosted Z
µ*, L = 2 TeV (2010)
µ*, L = 2 TeV (2010)
C.I. A, X analysis, A+ LL/RR
C.I. A, X analysis, A- LL/RR
Mb*, b' → tW, l+jets
Mt*, t' → tZ (100%) Mt', t' → bW (100%), l+jets
Mt', t' → bW (100%), l+I

gluino, HSCP, gluonball=0.5
gluino, Stopped Gluino stop, HSCP
stop, Stopped Gluino stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
# ATLAS exotics searches

<table>
<thead>
<tr>
<th>ATLAS Exotics Searches - 95% CL Lower Limits (Status: Moriond QCD 2012)</th>
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<tbody>
<tr>
<td>$L = 1.0 \text{ fb}^{-1}$ [ATLAS-CONF-2011-096]</td>
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<td>$L = 1.0 \text{ fb}^{-1}$ [ATLAS-CONF-2012-026]</td>
</tr>
</tbody>
</table>

*Only a selection of the available mass limits on new states or phenomena shown*
bg too large, needs additional tag
Exploit VH associated production
with W and Z decaying leptonically
  W→e,μ
  Z→ee,μμ, νν
Require boosted bb system
Mass resolution ~10%

Excluded at
95% CL
3-9×SM

arXiv:1202.4083
Submitted to JHEP
Most sensitive channel for high mass search
   BR 6 times larger than ZZ → 4l
Missing neutrinos implies mass resolution 7%
Only accessible for high mass (MH >~ 250 GeV):
   the two Z bosons are boosted
   large MET due to invisible decay
Main backgrounds
   ZZ (irreducible)
   Z+jets, tt, WZ
High mass: others

\[ H \rightarrow ZZ \rightarrow llqq \text{ (high mass)} \]

Sensitivity similar to other ZZ decays

arXiv:1202.1416
Submitted to JHEP

\[ H \rightarrow ZZ \rightarrow ll\tau\tau \text{ (high mass)} \]

All \( \tau \) decay channels searched for
Lower sensitivity (~4xSM)

arXiv:1202.3617
Accepted by JHEP
High mass: $H \rightarrow ZZ \rightarrow ll\nu\nu$

Two analyses: cut and count and mass shape

Discriminating variable for shape analysis

Transverse mass:

$$M_T^2 = \left( \sqrt{p_T(\ell\ell)^2 + M(\ell\ell)^2} + \sqrt{E_T^{\text{miss}} + M(\ell\ell)^2} \right)^2 - (p_T(\ell\ell) + E_T^{\text{miss}})^2$$

MET after preselection

BG estimation:
- $Z$+jets estimated using $\gamma$+jet to model the MET distribution
- Non-resonant BG normalization from $e\mu$ events
- $ZZ$ and $WZ$ from MC

No excess observed in data
Expected 95% exclusion for MH in [290-480] GeV
Observed 95% CL exclusion for MH [270-440] GeV
**Similar to WW analysis**

Cut and count analysis with mass independent selection

Main backgrounds estimated from data

<table>
<thead>
<tr>
<th>stage</th>
<th>WH (120) $H \rightarrow \tau\tau$</th>
<th>WH (120) $H \rightarrow WW$</th>
<th>data</th>
<th>all bkg. $\rightarrow 3l\nu$</th>
<th>WZ $\rightarrow 4l$</th>
<th>ZZ $\rightarrow 4l$</th>
<th>tof + $Z/\gamma^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-lepton preselection</td>
<td>$2.1 \pm 0.0$</td>
<td>$3.5 \pm 0.1$</td>
<td>950</td>
<td>$968.3 \pm 11.9$</td>
<td>$482.9 \pm 1.8$</td>
<td>$78.4 \pm 0.9$</td>
<td>$348.0 \pm 9.7$</td>
</tr>
<tr>
<td>min-MET &gt; 40 GeV</td>
<td>$1.0 \pm 0.0$</td>
<td>$1.8 \pm 0.1$</td>
<td>244</td>
<td>$270.5 \pm 4.4$</td>
<td>$208.2 \pm 1.1$</td>
<td>$7.9 \pm 0.3$</td>
<td>$54.5 \pm 4.3$</td>
</tr>
<tr>
<td>Z removal</td>
<td>$0.4 \pm 0.0$</td>
<td>$1.0 \pm 0.1$</td>
<td>40</td>
<td>$47.9 \pm 3.1$</td>
<td>$15.9 \pm 0.4$</td>
<td>$0.7 \pm 0.1$</td>
<td>$31.3 \pm 3.1$</td>
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<tr>
<td>top veto</td>
<td>$0.1 \pm 0.0$</td>
<td>$0.6 \pm 0.1$</td>
<td>12</td>
<td>$14.2 \pm 1.3$</td>
<td>$8.8 \pm 0.4$</td>
<td>$0.4 \pm 0.1$</td>
<td>$4.9 \pm 1.3$</td>
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<tr>
<td>$\Delta R_{\ell+\ell^-}$</td>
<td>$0.1 \pm 0.0$</td>
<td>$0.5 \pm 0.1$</td>
<td>7</td>
<td>$8.4 \pm 0.9$</td>
<td>$5.7 \pm 0.2$</td>
<td>$0.3 \pm 0.1$</td>
<td>$2.6 \pm 0.9$</td>
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<tr>
<td>$m_{\ell\ell}$</td>
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</tbody>
</table>

CMS preliminary

WH $\rightarrow 3l3\nu$

$L = 4.6 \text{ fb}^{-1}$

95% CL limit on $\sigma/\sigma_{SM}$

**NEW**

CMS document

HIG-11-034
CMS Detector

SUPERCONDUCTING COIL

Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 Tesla

CALORIMETERS

ECAL Scintillating PbWO₄ Crystals
HCAL Plastic scintillator brass sandwich

IRON YOKE

TRACKERs

Silicon Microstrips
Pixels

MUON BARREL

Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)