Spin measurements in $H \rightarrow WW \rightarrow 2\ell 2\nu$ with CMS

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On behalf of CMS

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Introduction

- A narrow resonance was found in multiple channels at a mass of 125 GeV in both ATLAS and CMS

- Next step: the determination of Quantum Numbers such as Spin and Parity is

- This talk covers the spin-parity measurement in $H \rightarrow WW \rightarrow 2\ell 2\nu$ with CMS data
As shown in arXiv:1208.4018 (Y. Gao et al.), the WW channel is sensitive to test the tensor structure of the couplings of the new boson to WW:

We considered 2 different possibilities:

- Spin-0 scalar: \( J^P = 0^+ \)
  SM predicted value
- Spin-2 tensor: \( J^P = 2^+ \)
  The minimal couplings spin-2 model

### Table

<table>
<thead>
<tr>
<th>scenario</th>
<th>( X \rightarrow ZZ )</th>
<th>( X \rightarrow WW )</th>
<th>( X \rightarrow \gamma \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0^+_m ) vs background</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>( 0^+_m ) vs ( 0^+_h )</td>
<td>1.8</td>
<td>1.1</td>
<td>0.0</td>
</tr>
<tr>
<td>( 0^+_m ) vs ( 0^- )</td>
<td>2.9</td>
<td>1.2</td>
<td>0.0</td>
</tr>
<tr>
<td>( 0^+_m ) vs ( 1^+ )</td>
<td>2.1</td>
<td>2.0</td>
<td>–</td>
</tr>
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<td>2.8</td>
<td>3.2</td>
<td>–</td>
</tr>
<tr>
<td>( 0^+_m ) vs ( 2^+_m )</td>
<td>1.1</td>
<td>2.8</td>
<td>2.4</td>
</tr>
<tr>
<td>( 0^+_m ) vs ( 2^+_h )</td>
<td>~5</td>
<td>1.1</td>
<td>3.1</td>
</tr>
<tr>
<td>( 0^+_m ) vs ( 2^-_h )</td>
<td>~5</td>
<td>2.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Briefly: $H \rightarrow WW \rightarrow 2\ell 2n$

**Signature:**
- 2 isolated high $p_T$ leptons ($e$, $\mu$)
- Large missing $E_T$
- Small $\Delta\phi_{\ell\ell}$ and low $M_{\ell\ell}$ for low $M_H$
- No resonance peak

**Backgrounds:**
- $WW$ : continuum
- $tt$ / $tW$ : $b$-jets
- $W$+jets : « fake » lepton
- $Z / \gamma^*$ : mis-measured MET
- $W / Z + \gamma^* : \gamma^* \rightarrow \ell \ell$
- $WZ / ZZ : V+jj/\nu\nu$ or missing lepton
Spin Analysis

➢ Try to separate the SM hypothesis (0⁺) and the spin-2 minimal coupling graviton (2⁺)

➢ Set ZH, WH and qqH components to 0 in all hypotheses
  → tested ggH processes against each other:
    - 0⁺ from POWHEG (NLO)
    - 2⁺ from JHU (LO generator)

➢ Fix the 2⁺ normalization to the same values as the 0⁺

➢ Let the signal event rate float and threat it as a nuisance parameter
Briefly : Analysis overview

- Analysis optimized in different categories to reach better sensitivity
  - Lepton flavour pairs : DF (eμ) (and SF (ee/μμ) in main analysis)
  - Exclusive jet multiplicity (0, 1 -jet)
  - Use the full 7 + 8 TeV datasets (4.9 and 19.5 invfb)

- The spin analysis is based on the same selection as the 2D shape analysis but only uses DF!
2D Shape analysis $M_T : M_{\ell\ell}$

- **Binning in mass-like variables:**
  - $m_T$: higgs transverse mass
  - $m_{\ell\ell}$: di-lepton invariant mass
  - These 2 variables are both correlated to the angles of the leptons
  - binning chosen to ensure sufficient statistics
    - is a bit finer in signal region

$$m_T = \sqrt{2p_T^{\ell\ell} E_T^{miss} (1 - \cos \Delta \phi E_T^{miss})}$$

<table>
<thead>
<tr>
<th>$M_T$ (GeV)</th>
<th>$M_{\ell\ell}$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[60 - 280]</td>
<td>[0 - 200]</td>
</tr>
</tbody>
</table>

- **Different backgrounds peak at different locations**

0-jet

**Background**
CMS preliminary $L = 19.5$ fb$^{-1}$ (8 TeV)

**$0^+ M_H = 125$ GeV**
CMS preliminary $L = 19.5$ fb$^{-1}$ (8 TeV)
Spin : 0j DF (8 TeV)

SM Hypothesis

\[ M_H = 125 \text{ GeV} \]
CMS preliminary \( L = 19.5 \text{ fb}^{-1} \) (8 TeV)

Spin-2 Hypothesis

\[ 2^+_{\text{min}} (125 \text{ GeV}) \]
CMS preliminary \( L = 19.5 \text{ fb}^{-1} \) (8 TeV)

➢ Only difference between spin and main analysis is 2 different signal shapes
The kinematic of the final leptons is sensitive to spin structure of the resonance
Spin hypothesis separation

- Perform a maximum likelihood fit to extract the best fit signal strength for each model.
- Compare the best fit likelihoods to determine the consistency of each hypothesis with the data.
- Test \( q = -2 \ln \left( \frac{L_{2^+}}{L_{0^+}} \right) \).
- Expect hypothesis separation at the 2-sigma level.

<table>
<thead>
<tr>
<th>case</th>
<th>expected</th>
<th>observed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>assuming ( \sigma / \sigma_{SM} \equiv 1 )</td>
<td></td>
</tr>
<tr>
<td>0^+</td>
<td>1.9</td>
<td>0.9</td>
</tr>
<tr>
<td>( 2^+_{\text{min}} )</td>
<td>2.4</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>assuming ( \sigma / \sigma_{SM} \approx 0.8 )</td>
<td></td>
</tr>
<tr>
<td>0^+</td>
<td>1.5</td>
<td>0.5</td>
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Spin separation combined with $H \to ZZ$

Combining $H \to WW$ with $H \to ZZ$ disfavours the $2^+ \pm$ signal hypothesis with a CLs value of 0.6%.

See Talk: S. Bolognesi, Properties of the Higgs-Like resonance
Spin Parity result for the $H \to WW \to 2\ell 2\nu$ analysis with full 7 and 8 TeV datasets (4.9 and 19.5 invfb) is performed in the DF 0/1 jet channel.

- The $2^+$ hypothesis is disfavored with a CLs value of 0.6 % in the combined $H \to WW$ and $H \to ZZ$ observed data.

Future

- add the $qqH$ instead of only $ggH$
BACKUP
Spin : 1j DF (8 TeV)

- Only difference between spin and main analysis is 2 different signal shapes
- The kinematic of the final leptons is sensitive to spin structure of the resonance

**SM Hypothesis**

\[ M_H = 125 \text{ GeV} \]

CMS preliminary \( L = 19.5 \text{ fb}^{-1} \) (8TeV)

**Spin-2 Hypothesis**

\[ 2^+_{\text{min}} (125 \text{ GeV}) \]

CMS preliminary \( L = 19.5 \text{ fb}^{-1} \) (8TeV)