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### Trigger

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<th>Fig.</th>
<th>Abbreviated Caption</th>
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<tbody>
<tr>
<td><img src="image1" alt="Trigger Efficiency" /></td>
<td>Trigger efficiency for the L1 electromagnetic objects (red $E_T &gt; 10$ CMS.GeV, black $E_T &gt; 22$ CMS.GeV) used to seed the High Level Trigger of the $H \rightarrow \gamma\gamma$ analysis. The efficiency is computed as a function of the photon $p_T$ using the tag-and-probe method on electrons from the decay of $Z$ bosons, and obtained with respect to analysis pre-selections ($p_T &gt; 30$ (20) CMS.GeV on the leading (sub-leading) $p_T$ photon and loose requirements on the candidate shower shapes and isolation).</td>
</tr>
<tr>
<td><img src="image2" alt="High Level Trigger Efficiency" /></td>
<td>High Level Trigger efficiency for the filters used in the $H \rightarrow \gamma\gamma$ analysis for events passing the L1-trigger requirements of at least one L1 single EG with $E_T &gt; 10$ CMS.GeV and at least one L1 single EG with $E_T &gt; 20$ CMS.GeV. The leading $p_T$ (black) photon trigger selection has a $p_T$ threshold at 30 CMS.GeV, while the sub-leading (red) has a threshold at 18 CMS.GeV. The $H \rightarrow \gamma\gamma$ analysis employs mass-dependent scaling $p_T$ thresholds equal to $m_{\gamma\gamma}/3$ and $m_{\gamma\gamma}/4$ for the leading and sub-leading $p_T$ photon respectively. The efficiency is computed as a function of the number of reconstructed vertices using the tag-and-probe method on electrons from the decay of $Z$ bosons and is obtained with respect to analysis pre-selections ($p_T &gt; 30$ (20) CMS.GeV on the leading (sub-leading) $p_T$ photon and loose requirements on the candidate shower shapes and isolation).</td>
</tr>
<tr>
<td><img src="image3" alt="High Level Trigger Efficiency" /></td>
<td>High Level Trigger efficiency for the filters used in the $H \rightarrow \gamma\gamma$ analysis for events passing the L1-trigger requirements of at least one L1 single EG with $E_T &gt; 10$ CMS.GeV and at least one L1 single EG with $E_T &gt; 20$ CMS.GeV. The leading $p_T$ photon (black) trigger selection has a $p_T$ threshold at 30 CMS.GeV, while the sub-leading (red) has one at 18 CMS.GeV. The $H \rightarrow \gamma\gamma$ analysis employs mass-dependent scaling $p_T$ thresholds equal to $m_{\gamma\gamma}/3$ and $m_{\gamma\gamma}/4$ for the leading and sub-leading $p_T$ photon respectively. The efficiency is computed as a function of the number of reconstructed vertices using the tag-and-probe method on electrons from the decay of $Z$ bosons and is obtained with respect to analysis pre-selections ($p_T &gt; 30$ (20) CMS.GeV on the leading (sub-leading) $p_T$ photon and loose requirements on the candidate shower shapes and isolation).</td>
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**Vertex identification**

Fraction of $Z \rightarrow \mu\mu$ events for which the vertex has been correctly assigned by the H→γγ identification algorithm, as a function of the transverse momentum of the dimuon system for data (red) and MC simulated events (black) at 13 CMS.TeV and their ratio. The muon tracks have been ignored during the vertex reconstruction process to mimic a diphoton system. The vertex is considered as correctly identified if its $z$ coordinate lies within 10 mm of the $z$ coordinate of the vertex tagged by the muon tracks. The simulated events are weighted such that the distribution of the per event vertex multiplicity matches the one in data.

Fraction of $\gamma$+jet events with a converted photon for which the vertex has been correctly assigned by the H→γγ identification algorithm, as a function of the transverse momentum of the photon-plus-jet system. The tracks associated with the jet have been ignored during the vertex identification process to mimic a diphoton system. The simulated events are weighted such that the distribution of the per event vertex multiplicity matches the one in data. The vertex is considered as correctly identified if its $z$ coordinate lies within 10 mm of the $z$ coordinate of the vertex tagged by the jet. (top plot) data (in red) and simulated events (in black) at 13 CMS.TeV and (bottom plot) their ratio are shown.

The vertex finding efficiency in H→γγ simulated events at 13 CMS.TeV as a function of the transverse momentum of the diphoton system. The efficiency is computed as the fraction of events where the $z$ coordinate of the vertex selected by the vertex identification algorithm lies within 10 mm of the $z$ coordinate of the vertex that is closest to the simulated true vertex. The vertex finding efficiency for a Higgs boson of mass 125 CMS.GeV, integrated over its pT spectrum, is computed to be about 81%. The distribution is reweighted to the 2015 average pileup measured in data, but not rescaled for the data to MC ratio shown in the $Z \rightarrow \mu\mu\mu$ validation plot.

**Photon identification**

CMS.GeV on the leading(subleading) $p_T$ photon and loose requirements on the candidate shower shapes and isolation).
Photon identification BDT score of the lower-scoring photon of diphoton pairs with an invariant mass in the range $100 < m_{\gamma\gamma} < 180$ CMS.GeV, for events passing the preselection in the 13 CMS.TeV dataset (points), and for simulated background events (cyan histogram). Histograms are also shown for different components of the simulated background, in which there are either two, one, or zero prompt candidate photons. The distribution of the sum of all the simulated background events is scaled to data preserving the relative ratio of the single components, generated at leading order. The red histogram corresponds to simulated Higgs boson signal events.

### Diphotoon MVA

Comparison of diphoton BDT classifier score distributions for data (points) and MC (stacked histograms), for events passing the preselection and in the mass range $100 < m_{\gamma\gamma} < 180$ CMS.GeV. The MC backgrounds are split into photon-photon (green), photon-jet (red) and jet-jet (blue) components. The analysis employs a BDT classifier to discriminate between signal-like and background-like diphoton pairs. The distribution of the sum of all the simulated background events is scaled to data preserving the relative ratio of the single components, generated at leading order.

Comparison of diphoton BDT classifier score distributions for $Z \rightarrow ee$ events with electrons reconstructed as photons in data (points) and MC (histograms). Events in the mass range $70-120$ CMS.GeV with leading $p_T > m_{\gamma\gamma}/3$ and sub-leading $p_T > m_{\gamma\gamma}/4$ are required to pass the full analysis preselection, inverting the veto condition on the electrons. The BDT classifier trained on diphoton MC samples is applied to an independent di-electron sample for validation.

$H \rightarrow WW$

$ggH$ plots

Control region definition for $ggH$

Top control region:

Photon identification
• one electron and one muon with opposite charge
• lepton transverse momentum $p_T > 20/15$ CMS.GeV
• extra lepton veto ($p_T > 10$)
• $m_{ll} > 50$ CMS.GeV
• $p_{Tll} > 45$ CMS.GeV
• $m_{T} > 20$ CMS.GeV
• $n_{jet}=0$ (jet $p_T > 30$ CMS.GeV)
• at least one jet b-tagged (loose working point) with $p_T$ between 10 and 30 CMS.GeV

**WW control region:**

• one electron and one muon with opposite charge
• lepton transverse momentum $p_T > 20/20$ CMS.GeV *- extra lepton veto ($p_T > 10$)
• $m_{ll} > 50$ CMS.GeV (to suppress Higgs contribution)
• $p_{Tll} > 45$ CMS.GeV
• $m_{T} > 20$ CMS.GeV
• $n_{jet}=0$ (jet $p_T > 30$ CMS.GeV)
• b-veto for jets between 10 and 30 CMS.GeV (loose working point)

### ggH Figures

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<th>Fig.</th>
<th>Abbreviated Caption</th>
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<tr>
<td><img src="image1.png" alt="Mass Spectrum" /></td>
<td>Top control region. Invariant mass spectrum reconstructed using di-leptons (e$\mu$ final state).</td>
</tr>
<tr>
<td><img src="image2.png" alt="Transverse Mass" /></td>
<td>Top control region. Transverse mass obtained combining lepton and met information.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Mass Spectrum" /></td>
<td>WW control region. Invariant mass spectrum reconstructed using di-leptons (e$\mu$ final state)</td>
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</table>

Control region definition for ggH
ttH plots

The ttH multilepton analysis uses a MVA lepton identification algorithm to better reject non-prompt leptons mostly from b-jets in t\bar{t}. The same overall strategy as in the Run-1 analysis is used with a revised choice of input variables, benefiting from the developments done in leptonic SUSY searches. Data/MC comparisons of the output discriminator of the lepton MVA in two control regions.

Control region definition for ttH

Pure control region:

- Dilepton events (same sign and opposite sign)
- Third lepton veto
- For opposite-sign events (targeting prompt leptons from dileptonic t\bar{t} decays):
  - at least two jets
  - at least one b-jet satisfying the medium WP, or at least two satisfying the loose WP
- For same-sign events (targeting semileptonic t\bar{t} decays with one non-prompt lepton):
  - exactly 3 or 4 jets
  - exactly one b-jet satisfying the medium WP

Mixed control region:

- Trilepton events
- one Z candidate (same-flavour opposite-sign pair, 60 < m(ll) < 120 CMS.GeV)
- E_{T}^{miss} > 20 CMS.GeV
- relaxed requirements on the 3rd lepton (pT > 10, loose id/iso/sip, no lepton mva cut)

ttH Figures

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<th>Fig.</th>
<th>Abbreviated Caption</th>
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<tbody>
<tr>
<td><img src="Image" alt="ttH Figures" /></td>
<td>Pure control region enriched in prompt leptons, opposite sign leptons. Lepton MVA score of the trailing lepton, after tight selection requirements applied on leading lepton. Simulation normalized to data yield. Statistical uncertainty due to the size of the simulated samples represented as a hatched area.</td>
</tr>
</tbody>
</table>
Pure control region enriched in non-prompt leptons, same sign leptons. Lepton MVA on the trailing lepton, after tight selection requirements applied on leading lepton. Simulation normalized to data yield. Statistical uncertainty due to the size of the simulated samples represented as a hatched area.

Mixed control region. Lepton MVA for the third lepton, tight selection requirements applied on leading lepton. Simulation normalized to data for the three components from fits to the dilepton mass for the Z candidate (for Z- vs non-Z backgrounds) and the transverse mass of the third lepton plus missing energy (for Z+X vs VZ+X). Statistical uncertainty due to the size of the simulated samples and statistic uncertainty on fitted normalizations for the three MC components represented as a hatched area.

Supporting material

Control regions where normalization factors for the mixed sample plot are fitted:

Mixed sample, split in electrons and muons:
Data/MC comparisons for the main input variables in the pure samples:

- significance of the 3D impact parameter
- lepton mini Isolation (pT dependent isolation cone)
- variables built from the jet containing the lepton
  - pT rel. with respect to jet, documented here
  - Ratio between pT lepton and pT jet, also documented here
  - b-tagging discriminator of the jet

<table>
<thead>
<tr>
<th>Prompt enriched</th>
<th>Non-prompt enriched</th>
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<tbody>
<tr>
<td>CMS Preliminary</td>
<td>CMS Preliminary</td>
</tr>
<tr>
<td>2.2 fb$^{-1}$ (13 TeV)</td>
<td>2.2 fb$^{-1}$ (13 TeV)</td>
</tr>
<tr>
<td>Events</td>
<td>Events</td>
</tr>
<tr>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
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<tr>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
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$H \rightarrow \tau\tau$

Mass distribution in $\mu\tau_{h}$ channel

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<th>Figure</th>
<th>Format</th>
<th>Caption</th>
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<tbody>
<tr>
<td>png pdf</td>
<td>Observed and predicted visible di-$\tau$ mass distribution in events requiring the presence of an opposite-charge $\mu\tau_{h}$ pair and in which both leptons are required to pass identification and isolation criteria. The electroweak background contribution includes events from $W +$ jets, diboson, and single-top-quark production. The data sample is collected with a single muon trigger and corresponds to $2.2 , \text{fb}^{-1}$ of $\sqrt{s} = 13 , \text{CMS}, \text{TeV} , \text{pp}$ collision data.</td>
<td></td>
</tr>
</tbody>
</table>
Mass distribution in $\mu\tau_{h}$ channel

Observed and predicted visible di-$\tau$ mass distribution in events requiring the presence of an opposite-charge $\mu\tau_{h}$ pair and in which both leptons are required to pass identification and isolation criteria. The electroweak background contribution includes events from $W + \text{jets}$, diboson, and single-top-quark production. The data sample is collected with a single electron trigger and corresponds to 2.2 fb$^{-1}$ of $\sqrt{s} = 13$ CMS TeV pp collision data.

$H \rightarrow b\bar{b}$

b-tagged jet multiplicity in $ttH$ events

Number of b-tagged jets after applying the b-tag and mis-tag scale factors derived from the shape-based b-tag discriminator reweighting method for events with exactly one tight lepton, at least four jets, and at least one jet passing the CSVv2 medium working point in the $ttH$ analysis. The shape-based calibration of the b-tag discriminator uses a tag-and-probe technique to correct the per-jet b-tag discriminator distribution for both heavy- and light-flavour jets.
Performance of b-jet regression on event $p_T$ balance

Distribution of the ratio between the pT(jj) and the pT of the dilepton system on data versus MC using anti-kT 0.4 jets. Data and simulated events selected requiring two opposite sign same flavor leptons with pT > 20 CMS.GeV and two central jets with pT > 20 CMS.GeV and CSVv2 Loose WP. Only JEC and PU correction applied to MC. The average of the data distribution is 0.96.

Distribution of the ratio between the pT(jj) and the pT of the dilepton system on data versus MC after applying the jet energy regression to the anti-kT 0.4 jets. Data and simulated events selected requiring two opposite sign same flavor leptons with pT > 20 CMS.GeV and two central jets with pT > 20 CMS.GeV and CSVv2 Loose WP. Only JEC and PU correction applied to MC. The average of the data distribution is 0.99.

Performance of b-jet regression on simulated $ZH$ signal

Simulated ZH to llbb events with mH=125 CMS.GeV, selected requiring two opposite sign same flavor leptons with pT > 20 CMS.GeV and two central jets with pT > 20 CMS.GeV and CSVv2 Loose WP and Z(ll) pT > 100 CMS.GeV. Invariant mass distribution of the reconstructed Higgs to bb candidate, with (red) and without (black) b-jets specific corrections are applied. A fit to both distributions has been performed using the Bukin function.

$H \rightarrow ZZ$

$H \rightarrow ZZ \rightarrow 4\ell$

The plots below are obtained using the following Monte-Carlo samples:

- SM Higgs bosons: all SM production modes included, m(H) = 125 CMS.GeV
- Irreducible backgrounds: qqZZ (Powheg), ggZZ (background only, MCFM)

The following cross sections for the irreducible backgrounds have been used:

Performance of b-jet regression on event $p_T$ balance
- $qqZZ$: the NLO cross section from Powheg multiplied by a (NNLO/NLO) k-factor of 1.1
- $ggZZ$: the LO cross section from MCFM multiplied by an approximate (NLO/LO) k-factor of 1.7

These are additionally scaled for the ZZ measured signal strength (0.99). The reducible background contribution is estimated from data.

### Figures for $70 < m_{4\ell} < 110$ CMS.GeV

<table>
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<tr>
<th>Figure</th>
<th>Description</th>
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<tbody>
<tr>
<td><img src="image" alt="Distribution of the four-lepton reconstructed mass $m_{4\ell}$ in the [70, 110] CMS.GeV range." /></td>
<td>Distribution of the four-lepton reconstructed mass $m_{4\ell}$ in the [70, 110] CMS.GeV range. Points with error bars represent the data and stacked histograms represent expected distributions. The ZZ backgrounds are normalized to the SM expectation, the Z+X background to the estimation from data.</td>
</tr>
<tr>
<td><img src="image" alt="Distribution of the kinematic discriminant $D^{\text{kin}}{\text{bkg}}$ for events in the 70 &lt; $m{4\ell}$ &lt; 110 CMS.GeV region." /></td>
<td>Distribution of the kinematic discriminant $D^{\text{kin}}<em>{\text{bkg}}$ for events in the 70 &lt; $m</em>{4\ell}$ &lt; 110 CMS.GeV region. Points with error bars represent the data and stacked histograms represent expected distributions. The ZZ backgrounds are normalized to the SM expectation, the Z+X background to the estimation from data.</td>
</tr>
<tr>
<td><img src="image" alt="Distribution of the kinematic discriminant $D^{\text{kin}}{\text{bkg}}$ versus the four-lepton reconstructed mass $m{4\ell}$ in the 70 &lt; $m_{4\ell}$ &lt; 110 CMS.GeV region." /></td>
<td>Distribution of the kinematic discriminant $D^{\text{kin}}<em>{\text{bkg}}$ versus the four-lepton reconstructed mass $m</em>{4\ell}$ in the 70 &lt; $m_{4\ell}$ &lt; 110 CMS.GeV region. The color scale represents the expected event yield (not including the Z+X background contribution), and the points represent the data.</td>
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### Figures for $m_{4\ell} > 150$ CMS.GeV

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$H \rightarrow ZZ \rightarrow 4\ell$
Distribution of the kinematic discriminant $\text{D}^{\text{kin}}_{\text{bkg}}$, for events in the $m_{4l} > 150$ CMS.GeV region. Points with error bars represent the data and stacked histograms represent expected distributions. The ZZ backgrounds are normalized to the SM expectation, the Z+X background to the estimation from data.

Distribution of the kinematic discriminant $\text{D}^{\text{kin}}_{\text{bkg}}$ versus the four-lepton reconstructed mass $m_{4l}$ in the $m_{4l} > 150$ CMS.GeV region. The color scale represents the expected event yield (not including the Z+X background contribution), and the points represent the data.

Figure for $m_{4l} > 70$ CMS.GeV, excluding the [110, 150] CMS.GeV region

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<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td>Distribution of the four-lepton reconstructed mass $m_{4l}$ in the full mass range. The [110, 150] CMS.GeV region is blinded. Points with error bars represent the data and stacked histograms represent expected distributions. The $H(125)$ signal and the ZZ backgrounds are normalized to the SM expectation, the Z+X background to the estimation from data. No events are observed with $m_{4l} &gt; 800$ CMS.GeV.</td>
</tr>
</tbody>
</table>

$H \rightarrow ZZ \rightarrow 2\ell2\nu$

All backgrounds are estimated using only Monte Carlo predictions, also the DY contribution where a data-driven method is preferred.

An electroweak singlet signal with standard model couplings ($m_{H}=400$ and 1000 CMS.GeV) produced by gluon fusion (full line) and by vector boson fusion (dashed line) is superimposed.
The invariant mass spectrum reconstructed using di-leptons (ee/µµ) with a transverse momentum greater than 20 CMS.GeV, and leptons that satisfy the tight ID and isolation requirements.

Transverse momentum of di-leptons pairs (ee/µµ) reconstructed using all the events where leptons pass tight ID and isolation requirements, and the reconstructed di-lepton invariant mass satisfies \([m_{ll} - 91] < 15\) CMS.GeV.

In the plots below the following event selection is applied:

- exactly two leptons coming from the Z boson
- the \(Zp_T > 55\) CMS.GeV
- a veto on the third lepton
- no b-jets must be present in the event.

Missing transverse energy obtained using Particle Flow Met (Type 1).

The region above 100 CMS.GeV is kept blind, as shown in the plot.

Distribution of the transverse mass obtained using kinematic information on leptons & neutrinos.

The region above 325 CMS.GeV is kept blind, as shown in the plot.

### Higgs exotics

$H \rightarrow $invisible

Trigger efficiencies:

- VBF trigger requires (at HLT) 2 PF jets with \(p_T > 40\) CMS.GeV, \(\Delta\eta_{jj} > 3.5\) and \(M_{jj} > 600\) CMS.GeV in addition to PFMET ignoring muons (METnoMU) \(> 140\) CMS.GeV and at L1 MET$>60$ CMS.GeV.
- MET-only trigger requires (at HLT) PFMET$>170$ CMS.GeV and at L1 MET$>60$ CMS.GeV.

$H \rightarrow ZZ \rightarrow 2\ell2\nu$
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<tr>
<td><img src="image1.png" alt="Efficiency of VBF Higgs to invisible trigger and MET only trigger in single muon data as a function of MET ignoring muons (METnoMU). The denominator of the efficiency is the number of events passing a single muon trigger which have two jets with $p_T &gt; 80$ CMS.GeV, $M_{jj} &gt; 600$ CMS.GeV and $\Delta\eta_{jj} &gt; 3.6$ CMS.GeV." /></td>
<td>Efficiency of VBF Higgs to invisible trigger and MET only trigger in single muon data as a function of MET ignoring muons (METnoMU). The denominator of the efficiency is the number of events passing a single muon trigger which have two jets with $p_T &gt; 80$ CMS.GeV, $M_{jj} &gt; 600$ CMS.GeV and $\Delta\eta_{jj} &gt; 3.6$ CMS.GeV.</td>
</tr>
<tr>
<td><img src="image2.png" alt="Efficiency of VBF Higgs to invisible trigger in single muon data as a function of sub-leading jet $p_T$. The denominator of the efficiency is the number of events passing a single muon trigger which have a leading jet with $p_T &gt; 80$ CMS.GeV, METnoMU $&gt; 300$ CMS.GeV, $M_{jj} &gt; 600$ CMS.GeV and $\Delta\eta_{jj} &gt; 3.6$" /></td>
<td>Efficiency of VBF Higgs to invisible trigger in single muon data as a function of sub-leading jet $p_T$. The denominator of the efficiency is the number of events passing a single muon trigger which have a leading jet with $p_T &gt; 80$ CMS.GeV, METnoMU $&gt; 300$ CMS.GeV, $M_{jj} &gt; 600$ CMS.GeV and $\Delta\eta_{jj} &gt; 3.6$.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Efficiency of VBF Higgs to invisible trigger in single muon data as a function of dijet $\Delta\eta$. The denominator of the efficiency is the number of events passing a single muon trigger which have two jets with $p_T &gt; 80$ CMS.GeV, METnoMU $&gt; 300$ CMS.GeV and $M_{jj} &gt; 600$ CMS.GeV" /></td>
<td>Efficiency of VBF Higgs to invisible trigger in single muon data as a function of dijet $\Delta\eta$. The denominator of the efficiency is the number of events passing a single muon trigger which have two jets with $p_T &gt; 80$ CMS.GeV, METnoMU $&gt; 300$ CMS.GeV and $M_{jj} &gt; 600$ CMS.GeV.</td>
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<tr>
<td><img src="image4.png" alt="Efficiency of VBF Higgs to invisible trigger in single muon data as a function of dijet mass ($M_{jj}$). The denominator of the efficiency is the number of events passing a single muon trigger which have two jets with $p_T &gt; 80$ CMS.GeV, METnoMU $&gt; 300$ CMS.GeV and $\Delta\eta_{jj} &gt; 3.6$" /></td>
<td>Efficiency of VBF Higgs to invisible trigger in single muon data as a function of dijet mass ($M_{jj}$). The denominator of the efficiency is the number of events passing a single muon trigger which have two jets with $p_T &gt; 80$ CMS.GeV, METnoMU $&gt; 300$ CMS.GeV and $\Delta\eta_{jj} &gt; 3.6$.</td>
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