$H \to \tau\tau \to lep\ had$ **(exclusion)**
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We treat two kinds of systematic errors. The common ones, which we assume (for simplicity) are fully correlated and the channel specific ones. The common correlated systematics include the Luminosity, the Jet Energy Scale (JES) and Acceptance. We perform a Profile Likelihood statistical analysis using both, a simple counting and a shape analysis. Systematic uncertainties can influence both, the expected event yield (normalization) and the shape of the discriminant distribution, the mass. For simplicity, we ignore the shape uncertainties except for the QCD data driven background. In this case, the SS events, are treated as a side band measurement of the expected underlying QCD background with a Poisson distribution. Normalization uncertainties are estimated by calculating the variation in the expected event yield due to a systematic effect for all channels. For the data driven $Z \to \tau\tau$ background we assigned the error based on the $Z \to \mu\mu, ee$ measurements.

The likelihood (for one bin, or for the global counting analysis) is given by

$$\mathcal{L}(\mu, \beta_7^0; \delta_{\epsilon_{lk}^s}, \delta_{\epsilon_{jk}^b}, \delta_{\beta_j}, \delta_i) = \text{Pois}(n|\mu_T)\ \text{Pois}(n_{SS}|\beta_7^0) \prod_{k=1}^{2} N(\delta_{\epsilon_k^s}) \prod_{j=1}^{7} N(\delta_{\beta_j}) \prod_{i=1}^{5} N(\delta_i) \tag{1}$$

where k is an index over production mode, j is an index over background processes, i is an index over systematic effects, μ_T is the total number of expected events given by

$$\begin{aligned} \mu_T \quad &= \textstyle\sum_{l=1}^{4} \mu L\ \sigma_l(tg\beta, m_A) \prod_{k=gg,bb}(1+\epsilon_{lk}^s \delta_{\epsilon_k^s}) \prod_i (1+\epsilon_{li}^s \delta_i) \\ &\quad + \textstyle\sum_{j=1}^{7} L\beta_j^0 (1+\epsilon_j^b \delta_{\beta_j}) \prod_i (1+\epsilon_{ji}^b \delta_i), \end{aligned} \tag{2}$$

- n is the number of events in the signal region,
- n^{SS} is the number of events measured in the QCD control sample (141) which is scaled by an extrapolation coefficient τ to estimate the number of OS events in the signal region. Since τ itself has uncertainty, we standardize it by writing $\tau = 1 + \epsilon_{\beta_7}\delta_{\beta_7}$,
- L is the nominal integrated luminosity,
- μ is the one parameter of interest, the signal strength,
- $\sigma_l(tg\beta, m_A)$ is the effective cross section (in pb) for signal events in channel l,
- ϵ_{lk}^s is relative uncertainty on the efficiency of the channel l with production mode k being either gg or $bbA/H/h$ channel,
- β_j^0 is the nominal effective cross section (in pb) for background j,
- ϵ_j^b is the relative uncertainty on the effective cross section for background j,
- ϵ_{li}^s is the relative change in the effective cross-section due to the i^{th} systematic effect on signal channel l, and
- ϵ_{ji}^b is the relative change in the effective cross-section due to the i^{th} systematic effect on channel j.

The nuisance parameters are $\theta = (\beta_7^0; \delta_{\epsilon_k^s}, \delta_{\epsilon_{jk}^b}, \delta_{\beta_j}, \delta_i)$ and the δ are constrained by the normal distribution $N(\delta) = G(\delta|0,1)$. A full list of the signal channels, the background channels and the corresponding systematics is given in table . Due to low statistics all background channels but the $Z \to \tau\tau$ are summed up together in the actual calculation.

	$\epsilon_{lk}^s, \epsilon_j^b$	$\epsilon_{l1,j1}^{s,b}$	$\epsilon_{l2,j2}^{s,b}$	$\epsilon_{l3,j3}^{s,b}$	$\epsilon_{l4,j4}^{s,b}$	$\epsilon_{l5,j5}^{s,b}$	σ_l , β_j^0
		LUMI	JES	Acceptance	ALPGEN	QFAC	
bbA/H (l=1,k=bb)	0.15	0.11	0.05	0.122	0	0	0.62
bbh (l=2,k=bb)	0.15	0.11	0.05	0.122	0	0	29.2
$gg \to A/H$ (l=3,k=gg)	0.15	0.11	0.05	0.122	0	0	0.86
$gg \to h$ (l=4,k=gg)	0.15	0.11	0.05	0.122	0	0	8.5
Diboson (j=1)	0.15	0.11	0.05	0.122	(0.13)	(0.03)	0.22
Single top (j=2)	0.15	0.11	0.05	0.122	(0.13)	(0.03)	0.56
$Z \to ee, \mu\mu$ (j=3)	0.15	0.11	0.05	0.122	(0.13)	(0.03)	1.44
$t\bar{t}$ (j=4)	0.15	0.11	0.05	0.122	(0.13)	0.03	3.46
$Z \to \tau\tau$ (j=5)	0.15	0.11	0.05	0.122	0.131	0	44.6
Addon (j=6)	0.173	0	0	0	0	0	31.0
QCD SS/OS (j=7)		0	0	0	0	0	0.068

Table 1: Systematic errors and expected number of events (in the electron-hadron final state) for a luminosity of 35.2 pb^{-1} and $(tg\beta = 40, m_A = 120)$.

For the shape-based analysis, the one-bin likelihood is replicated for each bin in the discriminating variable distribution identifying the common parameters $(\mu, \beta_7^0, \delta_{\epsilon_{lk}^s}, \delta_{\epsilon_{jk}^b}, \delta_{\beta_j}, \delta_i)$ and adding an additional bin index m to the nominal cross-sections; thus $\sigma_l \to \sigma_{lm}$ and $\beta_j^0 \to \beta_{jm}^0$. Similarly, systematics on the shape of a background can be incorporated by adding a bin index m to the relative uncertainties, so that $\epsilon_{lk}^s \to \epsilon_{lkm}^s$ and $\epsilon_{lk}^s \to \epsilon_{jkm}^b$, and instead of specifying the ϵ in a table, they are taken as the relative difference of a variational histogram and the nominal histogram. In this analysis, only the JES is treated as having a shape uncertainty. With these bin-by-bin specifications we can write the likelihood function for bin m via $\mathcal{L}(\mu, \beta_7^0, \delta_{\epsilon_{lk}^s}, \delta_{\epsilon_{jk}^b}, \delta_{\beta_j}, \delta_i) \to \mathcal{L}_m(\mu, \beta_7^0, \delta_{\epsilon_{lkm}^s}, \delta_{\epsilon_{jkm}^b}, \delta_{\beta_j}, \delta_i)$. Finally, the full likelihood function is given by

$$\mathcal{L}(\mu, \beta_7^0, \delta_{\epsilon_{lk}^s}, \delta_{\epsilon_{jk}^b}, \delta_{\beta_j}, \delta_i) = \prod_{m=1}^{M} \mathcal{L}_m(\mu, \beta_7^0, \delta_{\epsilon_{lkm}^s}, \delta_{\epsilon_{jkm}^b}, \delta_{\beta_j}, \delta_i) \qquad (3)$$

1 Implementation with HistFactory

Note, when using the `HistFactory` the production modes l and backgrounds j correspond to a single XML `Sample` element. The `HistoName` attribute inside each sample element specifies the histogram with the σ_{lm} and β_{jm}^0. Between the open `<Sample>` and close `</Sample>` one can add

- An `OverallSys` element where the `Name='X'` attribute identifies which δ_X is the source of the systematic and implies that the Gaussian constraint $N(\delta_X)$ is present. The `High` attribute corresponds to $1 + \epsilon_X$, eg when the source of the systematic is at $+1\sigma$ and $\delta_X = 1$. Similarly, the `Low` attribute corresponds to $1 - \epsilon_X$, eg when the source of the systematic is at -1σ and $\delta_X = -1$. The distinction between the sign of the source δ and the effect ϵ allows one to have anti-correlated systematics. The `HistFactory` is able to deal with asymmetric uncertainties as well, by using a piece-wise linear interpolation for the $\delta > 0$ and $\delta < 0$ regions.

- A `NormFactor` element is used to introduce an overall constant factor into the expected number of events. For example, the term μ corresponds to `<NormFactor Name='SigXsecOverSM'>`. In this case, the histograms were normalized to unity, so `NormFactor` elements were used to give the overall cross-sections σ_l and β_j.

- A `HistoSys` element is used to introduce shape systematics and the `HistoNameHigh` and `HistoNameLow` attributes have the variational histograms corresponding to $\delta = +1$ and $\delta = -1$, respectively.

Below is an example XML file for the electron channel.

```
<!DOCTYPE Channel  SYSTEM 'HistFactorySchema.dtd'>
  <Channel Name="channelEle" InputFile="./data/central_Ele_5jet_inc_35invpb.root" HistoName="" >
    <!--<Data HistoName="data" HistoPath="" />-->
    <Sample Name="bbAtautau120" HistoPath="" NormalizeByTheory="True" HistoName="bbAtautau120All">
      <OverallSys Name="JES" High="1.05" Low="0.95"/>
      <OverallSys Name="EVTEFF" High="1.122" Low="0.878"/>
      <OverallSys Name="bbAtautau" High="1.15" Low="0.85"/>
      <NormFactor Name="NEle_bbAtautau120" Val=".83202" Low=".83202" High=".83202" Const="True" />
      <NormFactor Name="SigXsecOverSM" Val="0" Low="-10." High="30." Const="True" />
    </Sample>
    <Sample Name="Atautau120" HistoPath="" NormalizeByTheory="True" HistoName="Atautau120All">
      <OverallSys Name="JES" High="1.05" Low="0.95"/>
      <OverallSys Name="EVTEFF" High="1.122" Low="0.878"/>
      <OverallSys Name="Atautau" High="1.15" Low="0.85"/>
      <NormFactor Name="NEle_Atautau120" Val=".24224" Low=".24224" High=".24224" Const="True" />
      <NormFactor Name="SigXsecOverSM" Val="0" Low="-10." High="30." Const="True" />
    </Sample>
    <Sample Name="bbAtautau130" HistoPath="" NormalizeByTheory="True" HistoName="bbAtautau130All">
      <OverallSys Name="JES" High="1.05" Low="0.95"/>
      <OverallSys Name="EVTEFF" High="1.122" Low="0.878"/>
      <OverallSys Name="bbAtautau" High="1.15" Low="0.85"/>
      <NormFactor Name="NEle_bbAtautau130" Val=".01767" Low=".01767" High=".01767" Const="True" />
      <NormFactor Name="SigXsecOverSM" Val="0" Low="-10." High="30." Const="True" />
    </Sample>
    <Sample Name="Atautau130" HistoPath="" NormalizeByTheory="True" HistoName="Atautau130All">
      <OverallSys Name="JES" High="1.05" Low="0.95"/>
      <OverallSys Name="EVTEFF" High="1.122" Low="0.878"/>
      <OverallSys Name="Atautau" High="1.15" Low="0.85"/>
      <NormFactor Name="NEle_Atautau130" Val=".02441" Low=".02441" High=".02441" Const="True" />
      <NormFactor Name="SigXsecOverSM" Val="0" Low="-10." High="30." Const="True" />
    </Sample>
    <Sample Name="Ztautau" HistoPath="" NormalizeByTheory="True" HistoName="ZtautauAll">
      <OverallSys Name="JES" High="1.05" Low="0.95"/>
      <OverallSys Name="EVTEFF" High="1.122" Low="0.878"/>
      <OverallSys Name="Alpgen" High="1.131" Low="0.869"/>
      <OverallSys Name="Ztautau" High="1.15" Low="0.85"/>
      <NormFactor Name="NEle_Ztautau" Val="1.26818" Low="1.26818" High="1.26818" Const="True" />
    </Sample>
   <Sample Name="AddOn" HistoPath="" NormalizeByTheory="False" HistoName="AddOnAll">
      <OverallSys Name="AddOn" High="1.173" Low=".827"/>
      <NormFactor Name="NEle_AddOn" Val=".88267" Low=".88267" High=".88267" Const="True" />
    </Sample>
    <Sample Name="SameSign" HistoPath="" NormalizeByTheory="False" HistoName="SameSignAll">
      <OverallSys Name="SameSign" High="1.06828" Low=".93172"/>
      <NormFactor Name="NEle_SameSign" Val="4.00568" Low="4.00568" High="4.00568" Const="True" />
    </Sample>
    <Sample Name="Others" HistoPath="" NormalizeByTheory="True" HistoName="OthersAll">
      <OverallSys Name="JES" High="1.05" Low="0.95"/>
      <OverallSys Name="EVTEFF" High="1.122" Low="0.878"/>
      <OverallSys Name="QFAC" High="1.03" Low="0.97"/>
      <OverallSys Name="Alpgen" High="1.131" Low="0.869"/>
      <OverallSys Name="Others" High="1.15" Low="0.85"/>
      <NormFactor Name="NEle_Others" Val=".17949" Low=".17949" High=".17949" Const="True" />
    </Sample>
  </Channel>
```

Finally, the `SameSign` sample should probably have an additional line:

```
<OverallSys Name="SameSignBeta7" High="1.08421519209" Low="0.9157848079"/>
```

corresponding to the $1 \pm 1/\sqrt{n_{SS}}$ and in the top-level XML file, one would convert this Gaussian systematic into a Poisson/Gamma systematic by adding

```
<ConstraintTerm Type="Gamma" RelativeUncertainty="0.084215">SameSignBeta7</ConstraintTerm>
```

to the `Measurement` element. For example:

```
<Measurement Name="AllSYS" Lumi="35.2" LumiRelErr="0.11" BinLow="0" BinHigh="20" Mode="comb"  ExportOnly="True">
  <POI>SigXsecOverSM</POI>
  <ParamSetting Const="False">Lumi alpha_AddOn alpha_Alpgen alpha_Atautau
    alpha_EVTEFF alpha_JES alpha_Others alpha_QFAC alpha_SameSign
    alpha_Ztautau alpha_bbAtautau
  </ParamSetting>
  <ParamSetting Const="True">NEle_AddOn,NEle_Atautau120,NEle_Atautau130,NEle_Others,
    NEle_SameSign,NEle_Ztautau,NEle_bbAtautau120,NEle_bbAtautau130,NMuo_AddOn,
    NMuo_Atautau120,NMuo_Atautau130,NMuo_Others,NMuo_SameSign,NMuo_Ztautau,NMuo_bbAtautau120,
    NMuo_bbAtautau130
  </ParamSetting>
  <ConstraintTerm Type="Gamma" RelativeUncertainty="0.084215">SameSignBeta7</ConstraintTerm>
</Measurement>
```