Z Background Formulae

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Definitions

Regions

- Control Region: Reco dimuon, with $60 < m^{reco}_{\mu\mu} < 120 GeV$ passing VBF selections
  - N^{MC}_{C} is measured in $Z \rightarrow \mu\mu + Jets$ MC with a generator level cut of $m^{Gen}_{Z} > 50 GeV$
- Signal Region: VBF selections and no veto leptons
  - We use the same $Z \rightarrow \mu\mu$ sample as for N^{MC}_{C} and ignore the leptons to approximate a $Z \rightarrow \nu\nu$ sample, this will be denoted N^{MC}_{S}
  - For the efficiencies to be the same for the $Z \rightarrow \mu\mu$ and $Z \rightarrow \nu\nu$ samples a generator level mass window of $60 < m^{Gen}_{Z} < 120$ must be applied, this will be denoted $N^{MC}_{S}[60, 120]$.

Derivation of formula

- Basic formula for data driven estimate

$$N_S^{\nu\nu\ Data} = \frac{N_C^{Data} - N_C^{BKG}}{N_C^{MC}} \cdot N_S^{\nu\nu\ MC}$$

- To use $Z \to \mu\mu$ MC we use the formula:

$$N_S^{\nu\nu\ MC} = N_S^{MC}[60,120] \cdot \underbrace{\frac{\sigma(Z \to \nu\nu)}{\sigma(Z/\gamma^* \to \mu\mu,\ 60 < m_Z^{Gen} < 120GeV)}}_{R[60,120]}$$

- The cross-section ratio that we have calculated is:

$$R[50,\infty] = \frac{\sigma(Z \to \nu\nu)}{\sigma(Z/\gamma^* \to \mu\mu,\ m_Z^{Gen} > 50)}$$

- We therefore use:

$$R[60,120] = \frac{\sigma(Z/\gamma^* \to \mu\mu,\ m_Z^{Gen} > 50GeV)}{\sigma(Z/\gamma^* \to \mu\mu,\ 60 < m_Z^{Gen} < 120GeV)} \cdot R[50,\infty]$$
$$= \frac{N(Z/\gamma^* \to \mu\mu,\ m_Z^{Gen} > 50GeV)}{N(Z/\gamma^* \to \mu\mu, 60 < m_Z^{Gen} < 120GeV)} \cdot R[50,\infty]$$

Derivation of formula (2)

- Substituting our expression for $N_S^{\nu\nu\ MC}$ into the original formula gives:

$$
\begin{aligned}
N_S^{\nu\nu\ Data} &= \frac{N_C^{Data} - N_C^{BKG}}{N_C^{MC}} \cdot N_S^{MC}[60,120] \cdot R[60,120] \\
&= \frac{N_C^{Data} - N_C^{BKG}}{N_C^{MC}} \cdot N_S^{MC}[60,120] \cdot \frac{N(Z/\gamma^* \to \mu\mu, m_Z^{Gen} > 50\,GeV)}{N(Z/\gamma^* \to \mu\mu, 60 < m_Z^{Gen} < 120\,GeV)} \cdot R[50,\infty]
\end{aligned}
$$

Formulae from paper

$$N_S^{Data} = (N_C^{Data} - N_C^{BKG}) \cdot R[50,\infty] \cdot \frac{\epsilon_S^{VBF}}{\epsilon_C^{VBF}\epsilon_{\mu\mu}}$$

- $\epsilon_{\mu\mu} = \frac{N(\mathrm{Z}/\gamma^* \to \mu\mu, \mathrm{reco\,dimuon}, 60 < \mathrm{m}_{\mu\mu}^{\mathrm{reco}} < 120\mathrm{GeV})}{N(Z/\gamma^* \to \mu\mu, m_Z^{Gen} > 50 GeV)}$
- $\epsilon_C^{VBF} = \frac{N_C^{MC}}{N(Z/\gamma^* \to \mu\mu, \mathrm{reco\,dimuon}, 60 < \mathrm{m}_{\mu\mu}^{\mathrm{reco}} < 120\mathrm{GeV})}$
- $\epsilon_S^{VBF} = \frac{N_S^{MC}[60,120]}{N(Z/\gamma^* \to \mu\mu, 60 < m_Z^{Gen} < 120 GeV)}$
- n.b. efficiencies are not defined in the paper, so the differences in the denominator between $\epsilon_{\mu\mu}$ and ϵ_S^{VBF} are not apparent

Simplifications

- Numerator of $\epsilon_{\mu\mu}$ and denominator of ϵ_C^{VBF} cancel so they should not be included in the error calculation
  - Currently stat, lepton ID, JES, JER and UES uncertainties are considered on all terms
- $\epsilon_C^{VBF} \cdot \epsilon_{\mu\mu} = \frac{N_C^{MC}}{N(Z/\gamma^* \rightarrow \mu\mu, m_Z^{Gen} > 50 GeV)}$
- $\frac{\epsilon_S^{VBF}}{\epsilon_C^{VBF} \cdot \epsilon_{\mu\mu}} = \frac{N_S^{MC}[60,120]}{N_C^{MC}} \cdot \frac{N(Z/\gamma^* \rightarrow \mu\mu, m_Z^{Gen} > 50 GeV)}{N(Z/\gamma^* \rightarrow \mu\mu, 60 < m_Z^{Gen} < 120 GeV)}$

Final formula

$$N_S^{\nu\nu\ Data} = \frac{N_C^{Data} - N_C^{BKG}}{N_C^{MC}(Z^{Gen} \rightarrow \mu\mu)} \cdot N_S^{MC}[60, 120](Z^{Gen} \rightarrow \mu\mu)$$

$$x \frac{N(Z/\gamma^* \rightarrow \mu\mu, m_Z^{Gen} > 50 GeV)}{N(Z/\gamma^* \rightarrow \mu\mu, 60 < m_Z^{Gen} < 120 GeV)} \cdot R[50, \infty]$$

- This is the same as the formula derived above

Conclusions

- Method does seem consistent
- Is there a reason not to calculate the cross-section ratio with the mass window?
  - It would remove the need for the additional event ratio.
- There is some overcounting of uncertainties at the moment due to cancellations between the efficiencies.
- The description of the cross-section ratio in the current draft of the paper is incorrect, as it states that it is calculated in the $60 < m_Z < 120 GeV$ mass window. aware this is being fixed in next draft

Backup