C Limit

When you are studying the expected limits for the electron or muon channel only, you have to be careful. Note, we should always set limits either on

$$\sigma(Z') * \mathcal{B}(Z' \to Zh) * \mathcal{B}(h \to b\bar{b}) * \mathcal{B}(Z \to ee, \mu\mu, \tau\tau)$$

or

$$\sigma(Z') * \mathcal{B}(Z' \to Zh)$$

There is no way that we could set limit for one specific flavor only in a clean way because there is always some small contribution from the leptonic decays of tau that give you either electron or muon final states.

Assuming we are setting limits on $\sigma_{\text{effective}}$ where

$$\sigma_{\text{effective}} = \sigma(Z') * \mathcal{B}(Z' \to Zh) * \mathcal{B}(h \to b\bar{b}) * \mathcal{B}(Z \to ee, \mu\mu, \tau\tau).$$

Below is what you need to pay attention to:

- theory cross section in the figure (the red line in your typical limit figures): Here, you have to put in the theory predictions of $\sigma_{\text{effective}}$.
- expected limits: what is expected limit?

A simple way to obtain expected limit is as follows:

1. estimate the number of background events and its corresponding uncertainty: $N_b \pm \sigma_b$
2. The 95% upper limit on the number of signal events is derived by assuming that there is 1.645 sigma of downward fluctuation of background. Then, the upper limit on the number of signal events is

$$N_{\text{sig}}^{\text{upper}} = N_b - (N_b - 1.645\sigma_b) = 1.645\sigma_b.$$

   How to derive this upper limit on the number of signal events can vary from one method to the other. But here we assume it's like this.
3. To derive the upper limit on the $\sigma_{\text{effective}}$, you have to divide $N_{\text{sig}}^{\text{upper}}$ with signal efficiency ϵ_{sig}, and integrated luminosity $\mathcal{L}$.

In the higgs combination tool, the output is the signal strength, namely

$$r = \frac{N_{\text{sig}}^{\text{upper}}}{N_{\text{sig}}^{\text{predicted}}}$$

Then, you have to multiply this r with theory prediction of $\sigma_{\text{effective}}$ to get the upper limit because

$$r = \frac{N_{\text{sig}}^{\text{upper}}}{N_{\text{sig}}^{\text{predicted}}} = \frac{N_{\text{sig}}^{\text{upper}}}{\sigma_{\text{effective}}^{\text{theory}} \cdot \mathcal{L} \cdot \epsilon_{\text{sig}}}.$$

Therefore,

$$r \cdot \sigma_{\text{effective}}^{\text{theory}} = \frac{N_{\text{sig}}^{\text{upper}}}{\mathcal{L} \cdot \epsilon_{\text{sig}}} = \sigma_{\text{effective}}^{\text{upper}}.$$

When you derive expected limits for the electron and muon channels separately, $\sigma^{\text{theory}}_{\text{effective}}$ should ALWAYS be the same as what you used for plotting theory cross section curve (the red line).

Note, your signal MC samples contain all 3 lepton flavors.

In order to obtain $N^{\text{predicted}}_{\text{sig}}$ (the numbers to put in the data card), you count how many events in your MC pass your selection, N_{pass}, the total number of generated events is N_{total}, then you get

$$N^{\text{predicted}}_{\text{sig}} = \frac{N_{\text{pass}}}{N_{\text{total}}} \times \sigma^{\text{theory}}_{\text{effective}} \times \mathcal{L},$$