Calculating the Higgs Mass Resolution at ATLAS

Kareem Hegazy

Motivation

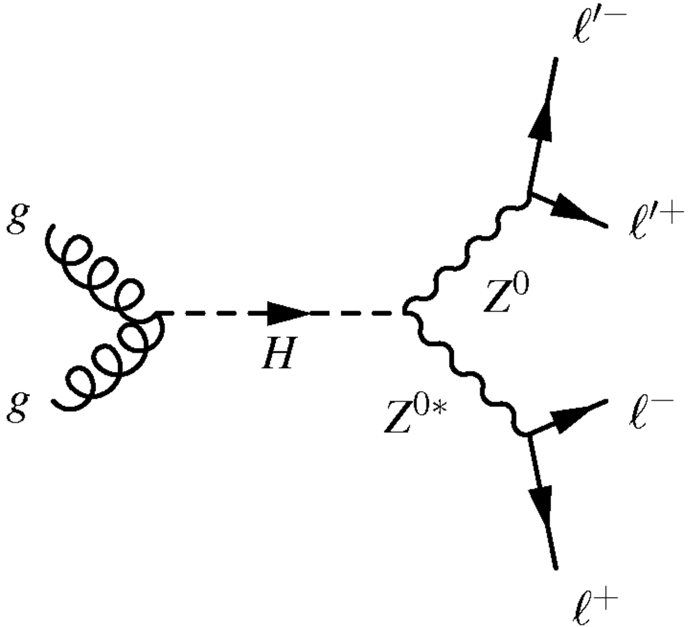
A precise mass measurement of this Higgs-like particle is essential for two reasons:

Confirm Particle Identity

To prove the identity of a particle the mass and other quantum numbers must be well measured and agree with predictions.

Theoretical Ramifications

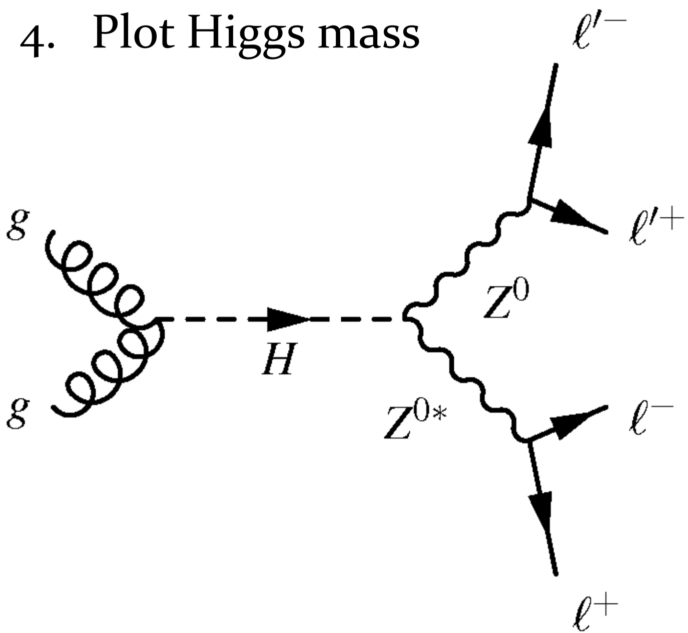
For the Higgs, it's mass may be indicative of new physics and important for modeling other decay channels.



Mass Measurement

Higgs Reconstruction Method

1. Select 4 "good" leptons.
2. Reconstruct the Z and Z*.
   - Create two pairs of same flavor opposite sign leptons.
3. Reconstruct the Higgs from "good" Zs
4. Plot Higgs mass



Mass Measurement

The mass of a particle is determined by a likelihood fit from plotting many Higgs events, where mass resolution of each event is an important fitting input parameter.

Higgs Modeling (MC Study)

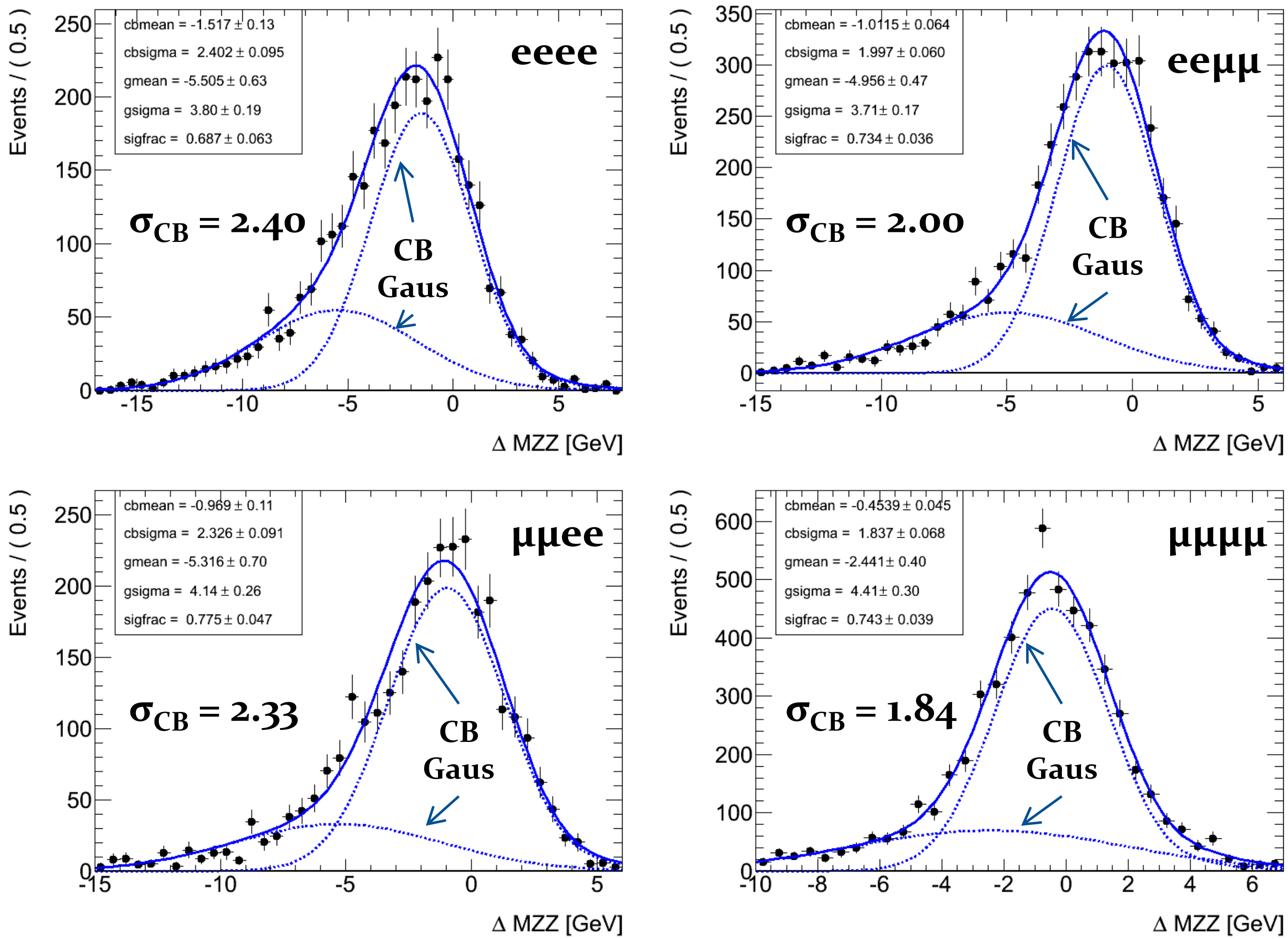
The Higgs mass peak is fit with a Gaussian and Crystal Ball fit to obtain the resolution of the peak. Since the natural width of the Higgs mass is about 20 MeV, the width in these plots are induced by the detector resolution and Bremsstrahlung radiation.

Things to Notice:

- Large tail when electrons are present.
- Peak is below 0.

Higgs Mass Plots

$$\Delta M_{ZZ} \equiv M_{Higgs}^{Rec} - M_{Higgs}^{Truth}$$



Lepton Error Propagation

Measurement errors induced by the detector can be calculated as a function of the particle's energy, and the region of the detector the particle was measured. Using standard error propagation methods, the mass resolution of the Higgs induced by the detector can be calculated.

The mass of the Higgs is calculated from the four leptons:

$$M^2 = (E_1 + E_2 + E_3 + E_4)^2 - \left(\vec{P}_1 + \vec{P}_2 + \vec{P}_3 + \vec{P}_4\right)^2$$

$$M^2 = \left(\sum_{i=1}^{4} E_i^2 + \sum_{i=1}^{3}\sum_{j>i}^{4} 2E_iE_j\right) - \left(\sum_{i=1}^{4} \vec{P}_i^2 + \sum_{i=1}^{3}\sum_{j>i}^{4} 2\vec{P}_i\vec{P}_j\right).$$

Since the mass of the lepton is much less than it's momentum, we can ignore the mass and assume E=P. This simplification leads to the following approximation:

$$M^2 = \sum_{i=1}^{3}\sum_{j>i}^{4} 2P_iP_j\left(1 - cos\left(\theta_{ij}\right)\right).$$

Lepton Error Propagation

Measurement errors induced by the detector can be calculated as a function of the particle's energy, and the region of the detector the particle was measured. Using standard error propagation methods, the mass resolution of the Higgs induced by the detector can be calculated.

Using the standard error propagation techniques:

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 dx^2 + \left(\frac{\partial f}{\partial y}\right)^2 dy^2}.$$

The mass resolution of the Higgs induced by the detector can be calculated by

$$\Delta M = \frac{1}{M}\left[\sum_{i=1}^{4}\left[\sum_{j=1, j\neq i}^{4} P_j\left(1 - cos\left(\theta_{ij}\right)\right)\right]^2 \Delta P_i^2\right]^{\frac{1}{2}}$$

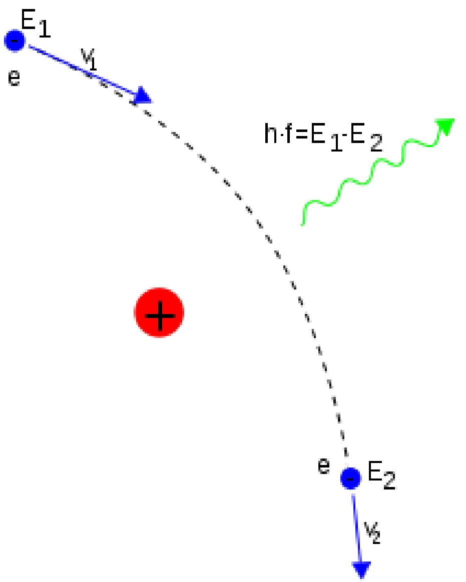
Final State Radiation

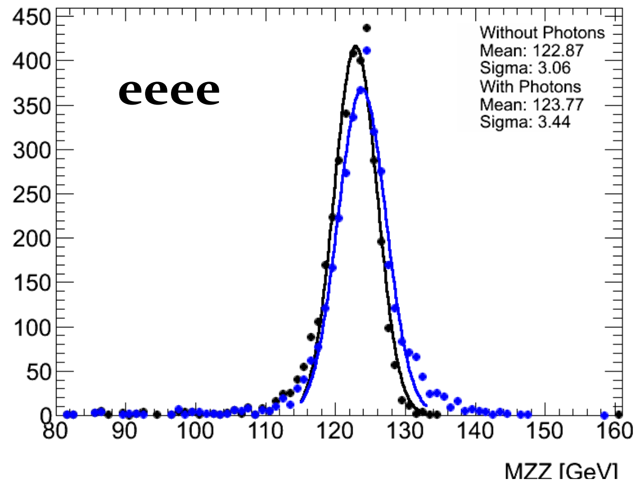
	eeee	eeμμ	μμee	μμμμ
Orig. Offset	-2.04	-1.29	-1.21	-0.56
γ Addition	-1.16	-0.86	-0.63	-0.22

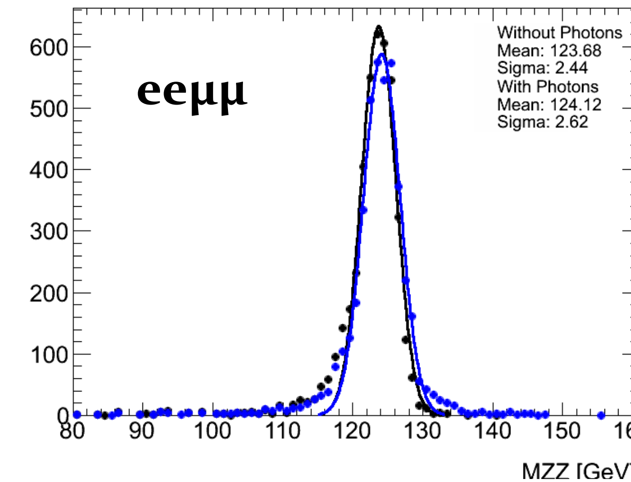
M_{llll}

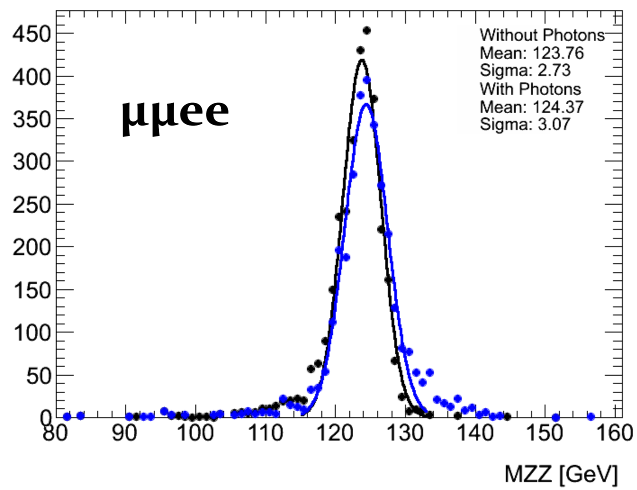
$M_{llll\gamma}$

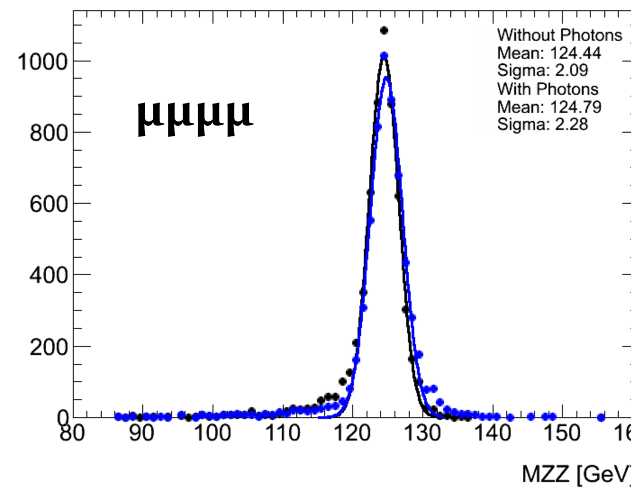
Photon radiation caused by the deceleration of electrons and muons will affect the mass calculation.







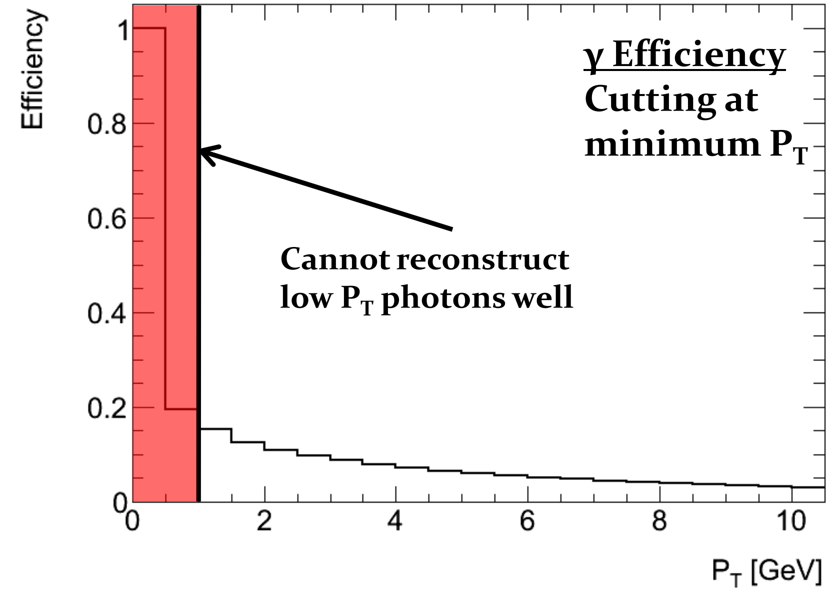


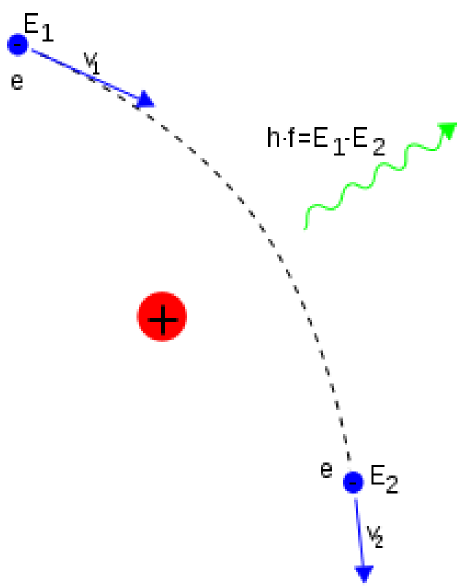


Final State Radiation

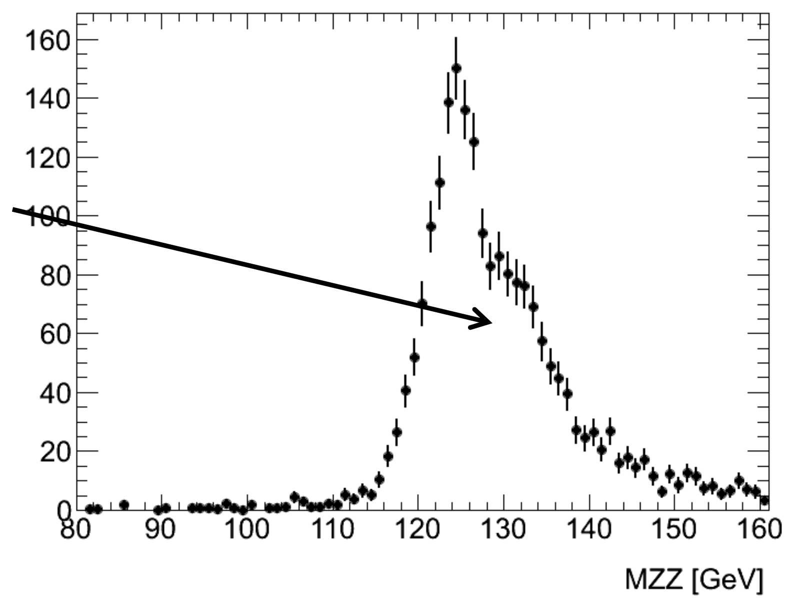
It is difficult to add the final state radiation (FSR) photons back into the leptons:

- Large amount of background
- 82% cannot be reconstructed
- Vast majority overlap with background





Most often too many photons are added due to the large overlap of signal and background.



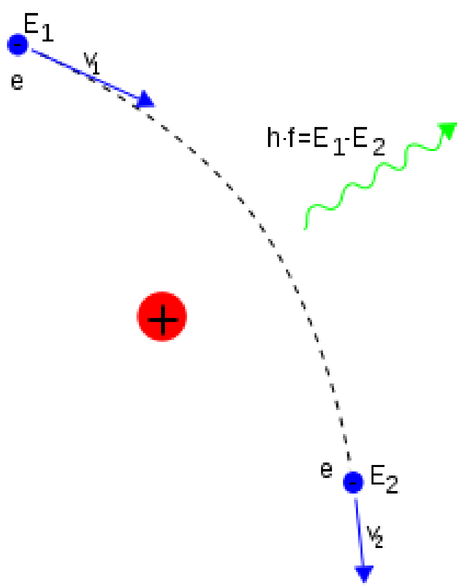
Measuring Final State Radiation

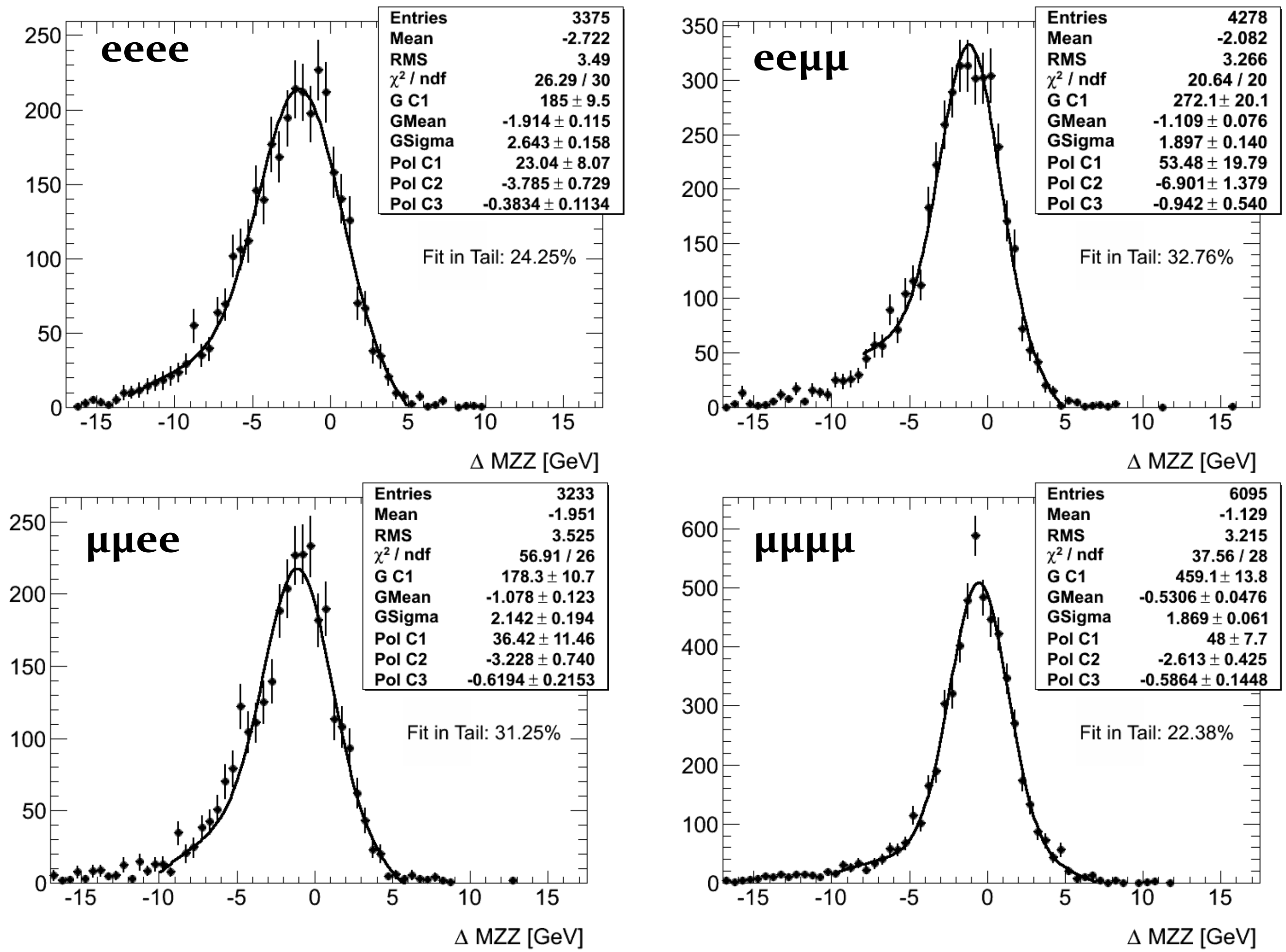
	eeee	eeμμ	μμee	μμμμ
Mean	-2.722	-1.109	-1.078	-0.531

Higgs Mass Plots

$$\Delta M_{ZZ} \equiv M^{Rec}_{Higgs} - M^{Truth}_{Higgs}$$

These plots are fit with a Gaussian + a second degree polynomial. The mean of the Gaussian gives us the average shift from FSR radiation.





Calculating Total Resolution

The total mass resolution is a function of two mechanisms:

Measurement Error Induced by the Detector: ΔM_{Trk}

This is calculated using the lepton measurement error and error propagation.

Final State Radiation: $\Delta M_{\gamma\ Shift}$

This is measured by fitting the ΔM_{ZZ} plot and finding the mean.

The total mass resolution is found by a quadratic sum of ΔM_{Trk} and $\Delta M_{\gamma\ Shift}$.

$$\Delta M = \sqrt{\Delta M_{Trk}^{2} + \Delta M_{\gamma\ Shift}^{2}}$$

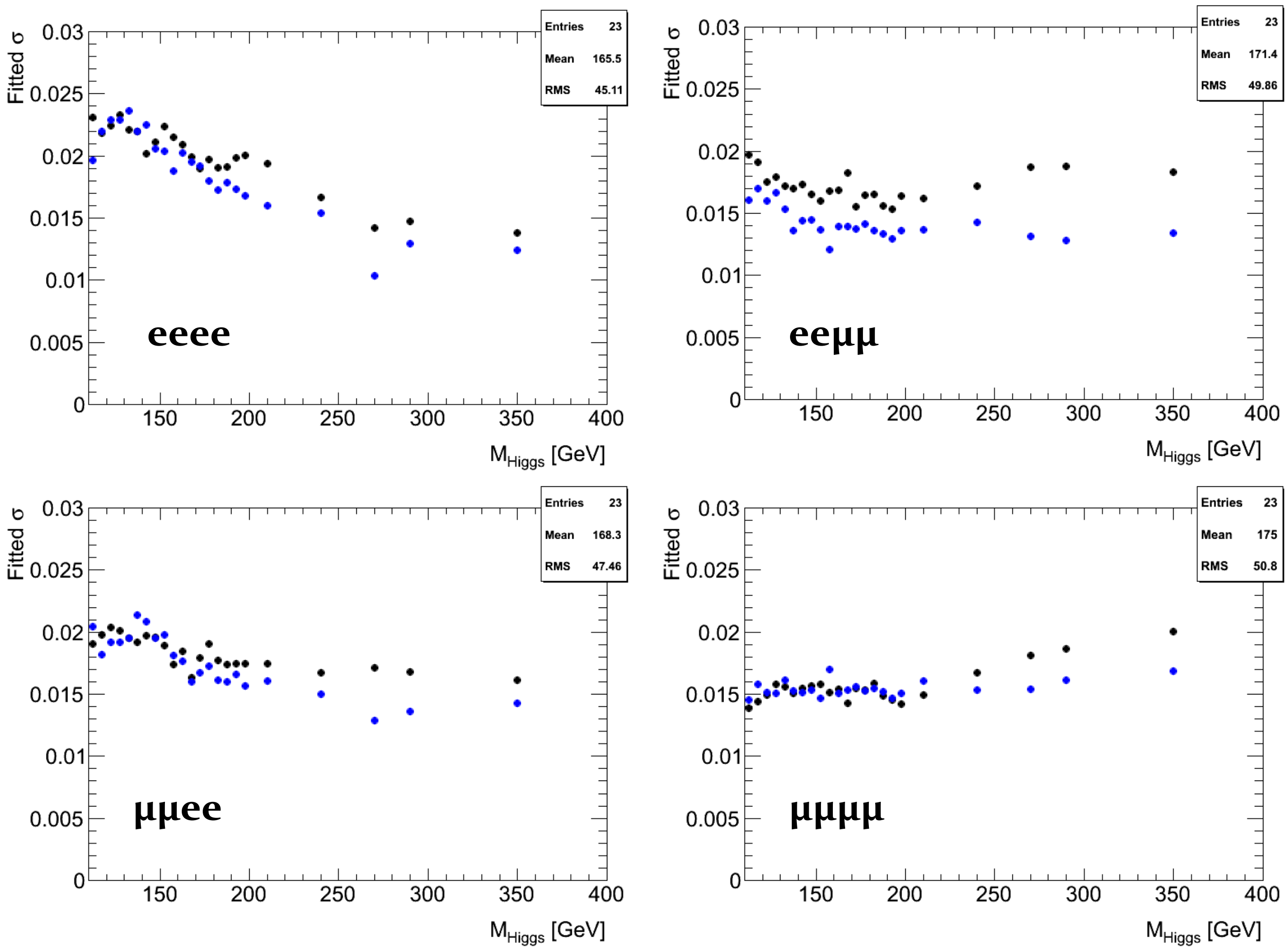
Closure Test

$$\sigma_{ZZ}^{C} \equiv GRand * \sqrt{\left(\frac{\Delta M_{ZZ}^{FM}}{M_{ZZ}^{T}} * M_{Higgs}\right)^2 + \left(MRes_{Trk}^{C}\right)^2}$$

$\Delta M_{ZZ}/M_{ZZ}$

σ^{C}/M_{ZZ}

Comparing the resolution of the absolute mass error with the resolution of our calculated mass error we can see our method has good agreement with what we observe in MC.



Conclusion

To find the Higgs mass resolution for each event we must need two parameters:

Measurement Error from the Detector: ΔM_{Trk}

This is calculated using the lepton measurement error and error propagation.

$$\Delta M = \frac{1}{M}\left[\sum_{i=1}^{4}\left[\sum_{j=1,j\neq i}^{4} P_j\left(1-cos\left(\theta_{ij}\right)\right)\right]^2 \Delta P_i^2\right]^{\frac{1}{2}}$$

Final State Radiation: $\Delta M_{\gamma\ Shift}$

This is measured by fitting the ΔM_{ZZ} plot and finding the mean.

It's been shown that by quadratically summing the error propagation to calculate the error induced by the detector and the fitted mean to estimate the FSR shift, we can claim an accurate calculation of the Higgs mass resolution event by event.

Data: Higgs Candidates