Study of weak vacuum polarization in $Z \to 2l\gamma$

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1 Introduction

The goal of the work was to perform a search of weak vacuum polarization in the channel $Z \to 2l\gamma$ using 20 fb^{-1} of pp collision data collected by the ATLAS experiment in 2012 at 8 TeV [1]. The ratio:

$$F(M) = \frac{N_{MC}}{N_{exp}} \frac{\frac{\partial N_{exp}}{\partial M}}{\frac{\partial N_{MC}}{\partial M}}, \tag{1}$$

where M is an invariant mass of $l\gamma$ (for weak polarization search) or $2l\gamma$ (for Higgs search), obtained from the experimental data was used for the search of the effect.

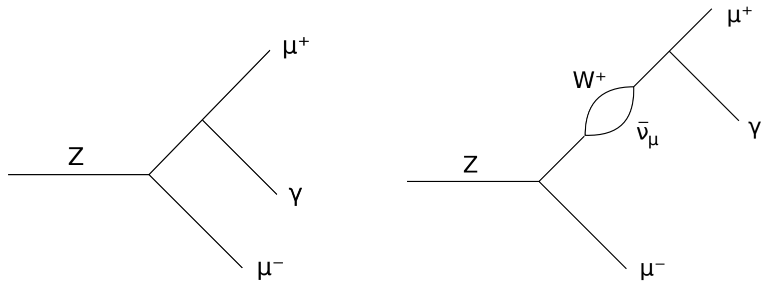

Figure 1: Main part of process $Z \to 2l\gamma$ is FSR (left), and weak vacuum polarization (right, in the form of $W - \nu$ loop) gives an additional contribution to the process.

The aim of the work was to test the significance of the vacuum polarization contribution to the ratio F(M) obtained at [1]. The weak vacuum polarization is described by the loop at Fig. 1 and should have pole at W mass with the width consistent with W width. Using pole approximation, one could write the following formula

$$F_{vac}(M) = \left| 1 + \frac{A\Gamma_W M_W e^{i\phi}}{M_W^2 - M^2 - i\Gamma_W M_W} \right|^2 \otimes f_{resol}(\Delta M), \tag{2}$$

for the contribution of the effect into the ratio (1), more presice formula could be obtained from [2]. The goals of the work were:

1. Get the resolution function $f_{resol}(\Delta M)$ from MC;
2. Convolute the resolution with the interference formula (2);
3. Fit the experimental $F(M)$ (1) from [2] with the convoluted formula (2);
4. Find the significance as the $\sqrt{\chi^2 - \chi_0^2}$;
5. Test the convoluted formula for the H (125) fig. 125 from [1].

2 Determination of Resolution

The detection resolution was determined by comparsion of true (inititial) and reconstructed values of a given variable in MC modelling. In order to determine the resolution of $l\gamma$ invariant mass near the mass of W-boson, the distribution of $\Delta M = (M_{l\gamma})_{rec} - (M_{l\gamma})_{true}$ in the range form 70 to 90 GeV was fitted by the sum of gaussian functions. Different resolution function were obtained for electron and mouon channels. The shapes were convolved with the signal for further fitting.

To obtain the distribution of a reconstructed variable from the known true disctribution, one should preform a convolution of the true distribution with the detection resolution function:

$$f_{rec}(x) = f_{true}(x) \otimes f_{resol}(\Delta x) = \int f_{true}(x + \Delta x) f_{resol}(\Delta x) d(\Delta x).$$

When performing a fitting procedure, this operation is executed many times with a different $f_{true}(x)$ but the same $f_{resol}(\Delta x)$, thus some information can be cached. The numerical integration with possible optimizations could be expressed with the formula:

$$f_{rec}(x_i) = \sum_j f_{true}(x_{i+j}) f_{resol}(\Delta x_j) + f_{true}(x_i) \left(1 + \sum_j f_{resol}(\Delta x_j)\right).$$

3 Binned fitting

The distribution of $l\gamma$ invariant mass was obtained in four different channels $e^+\gamma$, $e^-\gamma$, $\mu^+\gamma$ and $\mu^-\gamma$ for the experiment as well for MC modelling. Then each experimental distribution was devided by the corresponding MC distribution. But the convolution in this context is approximate because in the precise formula the convolution is applied to individual distribution before their division. Thus the resulting formula for numerical integration is

$$F_{vac}(M_i) = 1 + \sum_j \left(\frac{f_{MC}^{true}(M_{i+j})}{f_{MC}(M_i)} (F_0(M_{i+j}) - 1) \right) f_{resol}(\Delta M_j),$$

where $f_{MC}(M) = \partial N_{MC}/\partial M$, f_{MC}^{true} is MC with true variables and

$$F_0(M) = \left| 1 + \frac{A\Gamma_W M_W e^{i\phi}}{M_W^2 - M^2 - i\Gamma_W M_W} \right|^2.$$

4 Search for weak vacuum polarization

From calculated number of events, one could determine the vacuum polarization (VP) branching fraction by using the ratio of the number of vacuum polarization model events to the number of the SM events:

$$Br_{VP}(Z \to 2l\gamma) = \frac{\sigma_V P(Z \to 2l\gamma)}{\sigma(Z \to all)} = \frac{N_{VP}(Z \to 2l\gamma)\epsilon_{SM}}{N_{SM}(Z \to 2l\gamma)\epsilon_{VP}} \times \frac{\sigma_{SM}(Z \to 2l)}{\sigma(Z \to all)} \times Br(Z \to 2l),$$

where the number of VP events is calculated according to the square of matrix element without interference.

Total significance of weak vacuum polarization signal in invariant mass distribution of $l\gamma$ in only one of four channels has some significance. First studies indicate that an evidence of about 3.5σ can be reached. The parameters, amplitude and phase, determined from the fit are different in each channel and thus inconclusive. Estimates of branching via this mechanisms are $(3 \pm 1) \times 10^{-7}$ for μ-channel and less than 4×10^{-7} for e-channel.

4.1 Search for Higgs (125)

We attempted to apply developed method to find signal of H (125) in invariant mass distribution of $e^+e^-\gamma$ (from [2]). No significant signal was found, the signal of H (125) in invariant mass distribution is not found by the fit and can be attributed to statistical fluctuations.

5 Conclusion

During my studies I have learned:

1. How to analyze the process $Z \to 2l\gamma$ including event selection and background subtraction;
2. What is a Final state radiation (FSR) and what is a three body decay;
3. What is a Vacuum Polarization and how it influence the data via the interference;
4. How to fit the interference picture with respect to the detector resolution function;
5. How to calculate significance, set upper limit and calculate the branching for the decay.

References

[1] A.G. Kharlamov, et al. Z vertex form factor with $Z \to 2l\gamma$ process, June 29, 2017, ATLAS NOTE `ATL-COM-PHYS-2016-839`.

[2] D.Bardin, G.Passarino. The Standard Model in the Making, Oxford, UK; Clarendon 1999