Polarization in VV production in CMS

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The study of vector boson (V = W, Z) polarization in diboson production serves as an important test of the electroweak symmetry breaking mechanism and can be used as a tool to search for new physics effects. This is also a first step to studying longitudinal polarization in the rare process of vector boson scattering. In this proceeding, we present recent measurements of polarization observables in VV production using data collected by the CMS detector using Run2 of the LHC. The analyses explore angular distributions and polarization fractions of the W and Z bosons in final states with leptons and missing transverse energy. We discuss the techniques used to extract polarization information and compare the results with theoretical predictions from the Standard Model.

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1. Introduction

In the Standard Model, the Higgs mechanism provides mass to elementary particles. The gauge bosons (W, Z) gain mass and an additional longitudinal polarization from their coupling to the Higgs field through the electroweak symmetry breaking (EWSB) mechanism. Polarization of W and Z bosons therefore becomes an important test of EWSB. Deviations in polarization fractions from Standard Model predictions can hint towards physics Beyond Standard Model (BSM). Therefore, gauge boson polarization can also be used as a tool to search for new physics effects.

Diboson production channels allows us to study two vector bosons produced simultaneously with longitudinally polarization. Diboson production channels have high yield and high purity in LHC and are, therefore, excellent probes to study polarization effects. Polarization of gauge bosons is inferred from angular distribution of their decay products and is intrinsically a frame-dependent measurement.

This report focuses on two polarization measurements in CMS[1]. Section 2.1 describes the measurement of single boson polarization of W and Z in the WZ channel [2] and Section 2.2 discusses the WW polarization measurement which reports the first measurements of the production cross-section of polarized same-sign WW bosons [3]. Both the analyses have reported their measurements on data collected with CMS detector at the LHC taken during Run2.

2. Polarization measurements in CMS

2.1 WZ Polarization

This analysis targets the associated production of a W and a Z boson in the trilepton final state. It reports the measurements of fiducial and differential cross-sections for several observables in all the lepton-flavour and charge composition final states. This proceeding focuses on the single boson polarization measurement of the W and Z reported in the helicity frame where the W (Z) polarization angle is defined as the angle between the momentum of decay of the (negatively) charged lepton in rest frame of the respective boson and momentum of parent the W/Z in lab frame. When no kinematic selections are applied, the differential cross-sections with respect to the cosine of the polarization angle are directly related to the polarization fractions for the longitudinal/transverse bosons in the following way [4][5]:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos(\theta_{W^\pm})} = \frac{3}{8}[(1 \mp \cos(\theta_{W^\pm}))^2 {f_L}^W + (1 \pm \cos(\theta_{W^\pm}))^2 {f_R}^W + 2\sin^2(\theta_{W^\pm}) {f_0}^W)] \tag{1}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos(\theta_Z)} = \frac{3}{8}[(1+\cos(\theta_Z)-2c\cos(\theta_Z)){f_L}^Z+(1+\cos(\theta_Z)+2c\cos(\theta_Z)){f_R}^Z+2\sin^2(\theta_Z){f_0}^Z)] \tag{2}$$

The constant c defines how Z couples to fermions of different chiralities, $c = \frac{{c_L}^2-{c_R}^2}{{c_L}^2+{c_R}^2}$ where $c_L = -(1/2)\sin\theta^2_{eff}$ and $c_R = \sin\theta^2_{eff}$, θ_{eff} is the effective weak mixing angle. The variables f_L, f_R and f_0 are the polarization fractions. With data we are limited by our detector acceptance, hence we cannot directly extract these polarization fractions. Hence, a reweighting procedure is applied where the generator-level nominal WZ sample is separated into three exclusive polarization components (left, right and longitudinal). Events in each component sample are weighted by generator-level $\cos(\theta_W)\cos(\theta_Z)$ distributions that follow the expected quadratic dependence associated with the corresponding polarization state and the polarization fractions are extracted from an analytical fit of the $\cos(\theta)$. These weighted events are used to model polarization states for W and Z at the reconstructed level.

The polarization measurements are then carried out for the W and Z boson separately for the inclusive charged state and the two different charged states for the W boson. A joint extended binned likelihood is built for each of the distributions as shown in Figure 1. Due to the constraint on the polarization fractions, $f_0 + f_L + f_R = 1$, an independent basis with f_0 and $f_{LR} = f_L - f_R$ is used to parametrize normalization effects. The two-dimensional confidence regions for these polarization parameters are shown in Figure 2 where we see near complete de-correlation between longitudinal and transverse polarizations for the W and Z boson. This measurements reports the first observation of longitudinally polarized W boson in WZ production with an observed (expected) significance of 5.6 (4.3) standard deviations.

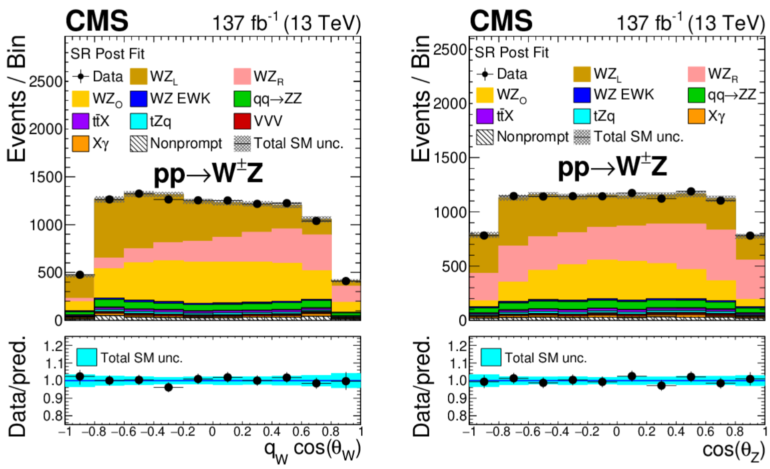

Figure 1: Distribution of the cosine of polarization angle in the charge-inclusive case for W (left) and Z (right) boson

2.2 WW Polarization Measurement in CMS

This analysis measures the production cross-sections of a polarized WW pair in pp collisions in CMS. The polarized samples $W_L W_L$,$W_T W_T$ and $W_L W_T$ are generated using MadGraph 2.7.2 at leading order [6]. Polarization fraction results are reported in two reference frames: WW centre-of-mass reference frame and initial parton-parton reference frame. Events are selected such that they have exactly two same-sign leptons with p_T >25/20 GeV and two jets with p_T >50 GeV. The vector boson scattering (VBS) topology is targeted by requiring that the events have two jets with dijet mass greater than 500 GeV and rapidity separation greater than 2.5. Four control regions

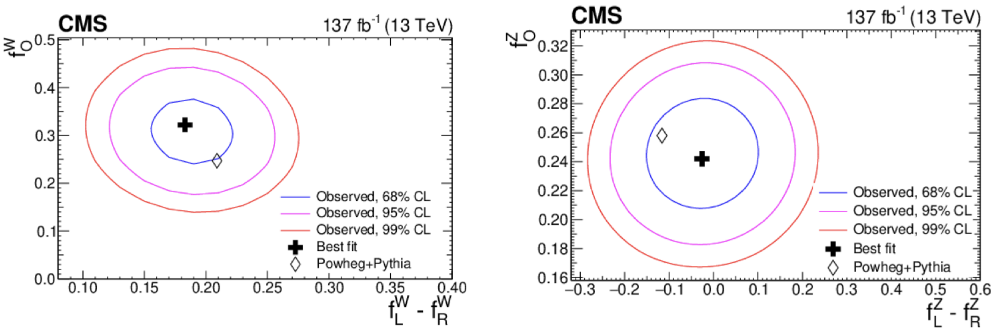

Figure 2: Confidence regions in the parameter plane $f_{LR} - f_0$ for the W (left) and Z (right) boson

enriched in different backgrounds (WZ, non-prompt lepton, tZq and ZZ) are used for background estimation.

A multivariate approach is used to distinguish the signal (WW) production from the background and for estimating polarization fractions. A total of three different boosted decision trees (BDTs) are trained. One is used to separate signal over background (inclusive BDT) (Figure 3). The dijet mass and difference in pseudo-rapidity between leading and sub-leading jets are a few of the input variables for the inclusive BDT. Two different signal BDTs are trained to separate polarization components: one to separate W_LW_L and W_XW_T (Figure 3) and another to separate W_TW_T and W_LW_X (Figure 3). Variables such as the difference in azimuthal angle between leading and sub-leading jet $\Delta\Phi_{jj}$ and leptons $\Delta\Phi_{ll}$, p_T of the leading and sub-leading jet are used as input variables to these signal BDTs.

A two-dimensional binned likelihood fit is performed by combining the inclusive BDT and signal BDTs to extract the cross-section for the polarization components. The cross-section for W_LW_L and W_XW_T , W_TW_T and W_LW_X are measured simultaneously from two separate fits. Results for the cross-section are reported in the WW centre-of-mass reference frame and the parton-parton reference frame. The significance of observing at least one longitudinally polarized 2.3 (3.1 σ expected) in the WW CM frame. An observed (expected) 95% confidence level upper limit on the production cross-section for longitudinally polarized W boson pairs is found to be 1.17 (0.88) fb in the WW centre of mass reference frame (Figure 4).

3. Conclusion

With the full Run2 dataset, two measurements performed by CMS on diboson polarization are reported here with results consistent with standard model expectations. The WZ analysis reports an observation of longitudinally polarized W and Z in WZ production. The observation of longitudinally polarized W bosons is reported in the WW VBS production channel along with the production cross-section for polarized same-sign W boson pairs. These diboson polarization measurements serve as powerful tests of the electroweak sector in Standard Model. The full Run3 dataset from CMS will provide more statistics [7], and, with improvements in modeling of polarized samples, we can look forward to more precise measurements.

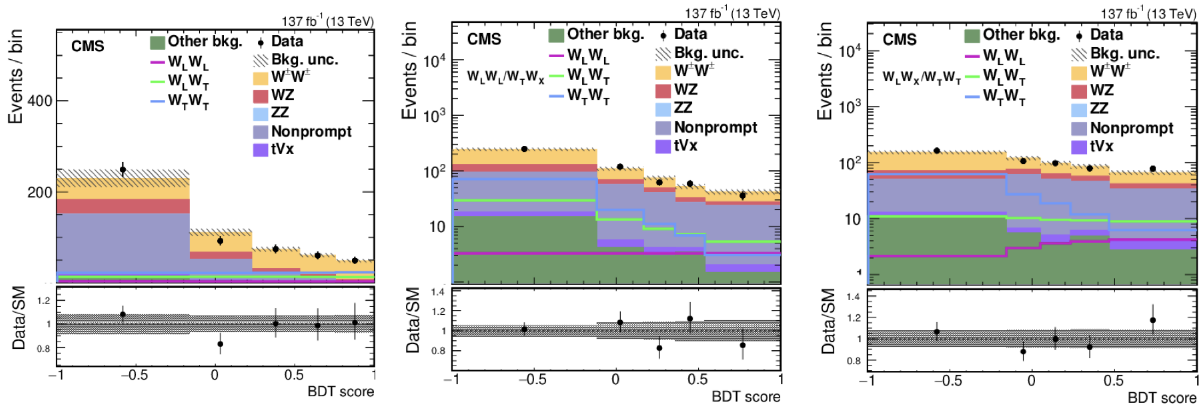

Figure 3: Left: Distribution of the output score of the inclusive BDT, Centre: Distribution of the output score of the signal BDT used for measuring $W_L W_L$ and $W_X W_T$ cross-section , Right: Distribution of the output score of the signal BDT used for measuring $W_T W_T$ and $W_L W_X$ cross-section

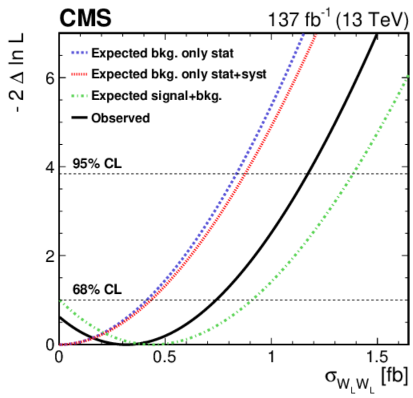

Figure 4: Profile likelihood scan as a function of $W_L W_L$ cross-sections

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