Role of the Z polarization in the $H \rightarrow b\bar{b}$ measurement

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It is widely known that the ZH production channel provides a promising probe to the $H \rightarrow b\bar{b}$ decay at the LHC, when the Higgs and the Z bosons are highly boosted along the transverse direction. We show how information on the Z boson polarization—that is disregarded in the current LHC analyses—can relevantly improve the signal from background discrimination, helping us to observe and achieve a larger precision for the $H \rightarrow b\bar{b}$ measurement in the $Z(\ell\ell)H$ channel.

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I. INTRODUCTION

The decay of the standard model Higgs boson to a bottom quark pair ($b\bar{b}$) has the largest branching ratio among all Higgs decay modes, approximately 58% [1]. Measuring this decay is therefore crucial, not only for determining the coupling to bottom quarks, but also for constraining the total Higgs boson decay width under reasonably general assumptions [2,3].

The largest sensitivity to $H \rightarrow b\bar{b}$ can be gained from the boosted VH production, where V denotes a W or Z boson that is boosted along the transverse direction; their leptonic decays result in clean signatures which can be efficiently triggered on, while vetoing most of the multijet backgrounds [4,5]. Very recently ATLAS and CMS have reported observed significances of 4.9σ and 4.8σ for the $VH(b\bar{b})$ channel, and 5.4σ and 5.6σ for the $H \rightarrow b\bar{b}$ decay, respectively, in combinations with other Higgs production modes with their Run 1 and Run 2 data [6,7]. Although the $VH(b\bar{b})$ is already very close to a 5σ significance, each channel of the $VH(b\bar{b})$ process, categorized by the number of observed charged leptons, has a considerably smaller significance. For instance, the observed significance for the two-lepton channel is $3.4\sigma(1.9\sigma)$ for ATLAS (CMS) with the 13 TeV and 79.8 fb^{-1} (41.3 fb^{-1}) of data [6,7]. The significances of all three channels are comparable

[6–9]. Therefore, an improvement in each channel would be important for a larger precision gain in the $H \rightarrow b\bar{b}$ measurement.

When a search for the two-lepton $Z(\ell^+\ell^-)H(b\bar{b})$ channel is performed at the Large Hadron Collider (LHC), the dominant background after signal extraction procedures is $Zb\bar{b}$ [6–9]. Although many theoretical efforts to identify the $H \rightarrow b\bar{b}$ decay have thrived since the pioneering work of Ref. [4], the Z polarization has not been exploited to further discriminate the signal from the $Zb\bar{b}$ background.¹ In general, the Z polarization can intrinsically differ from one process to another and manifests itself in the $Z \rightarrow \ell^+\ell^-$ decay angular distributions.

In this paper, we show that the Z boson polarization has relevant information to distinguish the signal from the dominant background that is currently neglected [6–9]. We present a procedure to maximally exploit this information and estimate the possible sensitivity gains to the LHC analyses.

II. APPROACH

The differential cross section including the $Z \rightarrow \ell^+\ell^-$ decay for both ZH and $Zb\bar{b}$ processes can be expanded in general as (we employ the notation of Ref. [10])

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¹ATLAS and CMS [6–9] use multivariate analyses to maximize the signal sensitivity. In the two-lepton channel, the variables used for the multivariate analyses include only the two-lepton invariant mass $m_{\ell\ell}$ as the information of the charged leptons. Hence, the information on Z boson polarization is not used.

$$\begin{aligned}
& \frac{d\sigma}{dq_T^2 dY d\cos\Theta d\cos\theta d\phi} \\
&= F_1(1 + \cos^2\theta) + F_2(1 - 3\cos^2\theta) + F_3 \sin 2\theta \cos \phi \\
&\quad + F_4 \sin^2\theta \cos 2\phi + F_5 \cos \theta + F_6 \sin \theta \cos \phi \\
&\quad + F_7 \sin \theta \sin \phi + F_8 \sin 2\theta \sin \phi + F_9 \sin^2\theta \sin 2\phi,
\end{aligned} \tag{1}$$

where q_T is the transverse momentum of the Z boson in the laboratory frame, Y is the rapidity of the $Z + H$ (or $b\bar{b}$) system in the laboratory frame, Θ is the polar angle of the Z boson from the collision axis in the $Z + H$ (or $b\bar{b}$) center-of-mass frame, and θ ($0 \leq \theta \leq \pi$) and ϕ ($0 \leq \phi \leq 2\pi$) are the polar and azimuthal angles of the lepton (ℓ^-) in the Z rest frame. We choose the coordinate system of the Z rest frame following Collins and Soper (Collins-Soper frame) [11]. This frame is well recognized and the angular coefficients for the Drell-Yan Z production have been measured by ATLAS [12,13] and CMS [14]. F_i are functions of only q_T , Y and Θ ; integrations over other phase space variables are already performed. After integrations over the lepton angles, only F_1 remains; F_1 is directly related to the total cross section and determines the overall normalization of the $Z \rightarrow \ell^+ \ell^-$ decay angular distributions. The eight functions F_i ($i = 2$ to 9) are described by polarization density matrices of the Z boson.

Equation (1) opportunely simplifies for the signal and background processes under consideration. First, we notice that the signal displays two relevant subprocesses: the quark-initiated Drell-Yan like $q\bar{q} \rightarrow ZH$ and the loop-induced gluon-fusion $gg \rightarrow ZH$. They are denoted by ZH_{DY} and ZH_{GF} , respectively. Despite ZH_{GF} being $\mathcal{O}(\alpha_s^2)$ suppressed, it results in important contributions at the boosted regime [15–18]. When CP nonconservation is neglected, the three coefficients $F_{7,8,9}$ are always 0 in tree-level calculations of any process [10], because these are proportional to relative complex phases of scattering amplitudes. ZH_{DY} can be analytically evaluated without difficulty at the leading order (LO); we find that the scattering amplitudes for the $J_z = 0$ state of the Z boson are 0; therefore $F_{2,3,6}$ are all 0. F_5 is totally antisymmetric around $Y = 0$; therefore, it does not contribute after the integration over Y . Consequently, only F_1 and F_4 contribute after the Y integration in ZH_{DY} . ZH_{GF} receives constraints from CP conservation and Bose symmetry; as a result, $F_{5,6,8,9}$ are 0 at the LO. Although the coefficients $F_{3,7}$ are nonzero in ZH_{GF} , these are totally antisymmetric around $\cos\Theta = 0$, and thus do not contribute after the integration over $\cos\Theta$. Consequently, only F_1 , F_2 and F_4 contribute after the $\cos\Theta$ integration in ZH_{GF} . Estimation of the coefficients apart from $F_{7,8,9}$ in the $Zb\bar{b}$ background process is not easy due to the large number of the scattering amplitudes. This process is part of the $\mathcal{O}(\alpha_s^2)$ correction to the Drell-Yan Z production. Although the angular

coefficients in this production have been calculated at $\mathcal{O}(\alpha_s^3)$ accuracy [19], an exclusive calculation of those in the $Zb\bar{b}$ events does not exist in the literature to our knowledge. We have numerically found that only F_1 , F_2 and F_4 contribute after the integration over Y and $\cos\Theta$, when the signal selections are imposed. The signal selections for the LO analysis are given later in Eq. (5) and for the full hadron level study in Sec. III. To conclude, both for the signal and for the $Zb\bar{b}$ background, Eq. (1) simplifies to

$$\begin{aligned}
& \frac{d\sigma}{dq_T^2 d\cos\theta d\phi} \\
&= \hat{F}_1[1 + \cos^2\theta + A_2(1 - 3\cos^2\theta) + A_4 \sin^2\theta \cos 2\phi],
\end{aligned} \tag{2}$$

where $A_2 = \hat{F}_2/\hat{F}_1$ and $A_4 = \hat{F}_4/\hat{F}_1$. The hat above the coefficients implies that the integrations over $\cos\Theta$ and Y are performed. For ZH_{DY} , we derive that

$$A_4 = -\frac{q_T^2}{2m_Z^2 + q_T^2}, \tag{3}$$

which has a large negative value in the high q_T region. Equation (2) suggests that the angles θ and ϕ can be defined in the restricted ranges $0 \leq \theta \leq \pi/2$ and $0 \leq \phi \leq \pi/2$ without losing any information. They can be obtained from

$$|\cos\theta| = \frac{2|q^0 p_\ell^3 - q^3 p_\ell^0|}{Q\sqrt{Q^2 + |\vec{q}_T|^2}}, \tag{4a}$$

$$|\cos\phi| = \frac{2}{\sin\theta} \frac{|Q^2 \vec{p}_T \cdot \vec{q}_T - |\vec{q}_T|^2 p_\ell \cdot q|}{Q^2 |\vec{q}_T| \sqrt{Q^2 + |\vec{q}_T|^2}}, \tag{4b}$$

where $q^\mu = (q^0, \vec{q}_T, q^3)$ and $p_\ell^\mu = (p_\ell^0, \vec{p}_T, p_\ell^3)$ are four-momenta of the reconstructed Z boson and one of the leptons, respectively, in the laboratory frame and Q is the reconstructed Z invariant mass ($Q = m_{\ell\ell}$). We stress that p_ℓ^μ can be the momentum of either ℓ^- or ℓ^+ (i.e., either gives the same θ and ϕ values). This is simply because interchanging ℓ^- and ℓ^+ corresponds to $\theta \rightarrow \pi - \theta$ and $\phi \rightarrow \phi + \pi$ (i.e., $\cos\theta \rightarrow -\cos\theta$ and $\cos\phi \rightarrow -\cos\phi$). Practically speaking, we do not need to distinguish ℓ^- and ℓ^+ . This feature is particularly important for $Z \rightarrow e^- e^+$ in which case the charge misidentification rate is not negligible [8].

To evaluate the two coefficients A_2 and A_4 , we simulate the signal and the background at the LO with MADGRAPH5_AMC@NLO [20,21], using the NNPDF2.3 [22] parton distribution functions. The $Z(\ell\ell)b\bar{b}$ background sample accounts for the interference with $\gamma^*(\ell\ell)b\bar{b}$. The events are required to pass the following selections:

TABLE I. Normalized angular coefficients A_2 and A_4 in two regions of q_T at the LO, after the selection in Eq. (5). The statistical uncertainty for the last digit is shown in the parentheses.

	ZH_{DY}	ZH_{GF}	$Zb\bar{b}$
$A_2(q_T > 200 \text{ GeV})$	0.001(1)	0.026(1)	0.470(1)
$A_2(q_T > 400 \text{ GeV})$	-0.002(3)	0.052(8)	0.498(4)
$A_4(q_T > 200 \text{ GeV})$	-0.825(2)	-0.972(2)	0.447(2)
$A_4(q_T > 400 \text{ GeV})$	-0.947(5)	-0.92(1)	0.462(8)

$$75 \text{ GeV} < m_{\ell\ell} < 105 \text{ GeV}, \quad 115 \text{ GeV} < m_{bb} < 135 \text{ GeV},$$

$$p_{\text{Tb}} > 25 \text{ GeV}, \quad |y_b| < 2.5, \quad 0.3 < \Delta R_{bb} < 1.2,$$

(5)

where ΔR_{bb} is a cone radius between the two b-quarks. In Table I, we display the results in two q_T regions. The statistical uncertainty for the last digit is shown in parentheses. We find that both ZH_{DY} and ZH_{GF} present very distinct values $A_{2,4}$ from the $Zb\bar{b}$ background process. It is also observed that the A_4 values in ZH_{DY} are consistent with the analytic formula in Eq. (3). These differences clearly appear in the $(\cos\theta, \phi)$ distribution.

In Fig. 1, we show the ratio of the normalized $(\cos\theta, \phi)$ profile for the ZH_{DY} process to that for the $Zb\bar{b}$ process, imposing $q_T > 200 \text{ GeV}$. The information on the differences in A_2 and A_4 between the signal and the background completely appears in this restricted (i.e., $0 \leq \theta \leq \pi/2$ and $0 \leq \phi \leq \pi/2$) two-dimensional $(\cos\theta, \phi)$ distribution. For example, it is observed that signal events are more distributed at $\phi \sim \pi/2$ and $Zb\bar{b}$ more at $\phi \sim 0$, as the consequence of the large difference in A_4 between the

FIG. 1. Ratio of the normalized $(\cos\theta, \phi)$ distribution at the LO for the ZH_{DY} process to that for the $Zb\bar{b}$ background process, imposing the cuts in Eq. (5) and $q_T > 200 \text{ GeV}$.

ZH_{DY} and $Zb\bar{b}$ processes. Therefore, the $Z \rightarrow \ell^+\ell^-$ decay angular distributions can be useful in distinguishing the signal from the background.

So far, minimum selections in the lepton transverse momentum $p_{\text{T}\ell}$ are not considered. Defining the lepton angles in the Collins-Soper frame has a great advantage: $p_{\text{T}\ell}$ has a simple expression in terms of these angles. In the laboratory frame, in which the x -axis is chosen along $\vec{q}_T$, the vectorial transverse momenta of the harder (ℓ_1) and softer (ℓ_2) leptons are given by

$$\vec{p}_{\text{T}\ell_1(\ell_2)} = \frac{1}{2} \left(q_T \pm \sqrt{Q^2 + q_T^2} \sin\theta \cos\phi, \pm Q \sin\theta \sin\phi \right). \quad (6a)$$

Therefore, their absolute values are given by

$$p_{\text{T}\ell_1(\ell_2)} \equiv |\vec{p}_{\text{T}\ell_1(\ell_2)}| = \frac{1}{2} \sqrt{q_T^2 + Q^2 \sin^2\theta + q_T^2 \sin^2\theta \cos^2\phi \pm 2q_T \sqrt{Q^2 + q_T^2} \sin\theta \cos\phi}, \quad (6b)$$

which are now independent of a choice of the x -axis in the laboratory frame. In the boosted kinematic region $Q^2/q_T^2 \ll 1$, we derive

$$p_{\text{T}\ell_1(\ell_2)} = \frac{1}{2} q_T (1 \pm \sin\theta \cos\phi + \mathcal{O}(Q^2/q_T^2)). \quad (7)$$

This in fact shows that Z polarization can largely affect the lepton p_T distributions even if the Z is highly boosted. Representative differences in $p_{\text{T}\ell}$ between the signal and the background can be revealed as follows. In the phase space where the signal is more concentrated $\phi \sim \pi/2$, we find

$$p_{\text{T}\ell_1} = p_{\text{T}\ell_2} = \frac{1}{2} \sqrt{q_T^2 + Q^2 \sin^2\theta}. \quad (8)$$

While in the region where the background displays more events $\phi \sim 0$, we have

$$p_{\text{T}\ell_1(2)} = \frac{1}{2} \left| q_T \pm \sqrt{Q^2 + q_T^2} \sin\theta \right|, \quad (9)$$

$$p_{\text{T}\ell_1} - p_{\text{T}\ell_2} = \min \left\{ q_T, \sqrt{Q^2 + q_T^2} \sin\theta \right\}.$$

Equations (8) and (9) tell us that the higher (lower) p_T lepton in the background is predicted to be harder (softer) than that in the signal. To illustrate this feature, we show in Fig. 2 the normalized distributions of $p_{\text{T}\ell_1(2)}$ for the ZH_{DY} (solid curve), ZH_{GF} ($\times$) and $Zb\bar{b}$ (dashed curve) processes at the LO. The cuts in Eq. (5), $200 \text{ GeV} < q_T < 300 \text{ GeV}$ and a lepton rapidity cut $|y_\ell| < 2.5$ are imposed. The distributions

FIG. 2. Normalized p_T distributions of the harder lepton (left) and softer lepton (right) for the ZH_{DY} (solid curve), ZH_{GF} ($\times$) and $Zb\bar{b}$ (dashed curve) processes.

roughly follow Eqs. (8) and (9) which were derived under the extreme conditions (i.e., $\phi = \pi/2$ and $\phi = 0$). This observation confirms that the differences in $p_{T\ell 1(2)}$ distributions are consequences of the difference in the Z polarization. It is, therefore, expected that a lepton p_T selection can partially capture the difference in the Z polarization (A_4 in particular) and improve the sensitivity to the signal.

We note in passing that the results in Eqs. (8) and (9) and Fig. 2 illustrate the fundamental importance of taking account of the Z polarization in its decays in the Monte Carlo simulations, even without performing a tailored polarization analysis.

III. RESULTS

We now estimate the potential sensitive gains from the polarization information to a detailed hadron level $pp \rightarrow Z(\ell\ell)H(b\bar{b})$ LHC study. Our signal is characterized by two charged leptons, $\ell = e$ or μ , which reconstruct a boosted Z boson recoiling against two b -jets. The major backgrounds are $Zb\bar{b}$, $t\bar{t}$ + jets, and ZZ .

We simulate our samples with Sherpa + OpenLoops [23–25]. The ZH_{DY} and ZH_{GF} signal and $Zb\bar{b}$ and ZZ

TABLE II. Signal ZH_{DY} and ZH_{GF} and background $Zb\bar{b}$, $t\bar{t}$, and ZZ rate after the BDRS analysis. Hadronization and underlying event effects are taken into account. The rates are given in units of fb and take account of 70% b -tagging efficiency and 1% miss-tag rate.

	ZH_{DY}	ZH_{GF}	$Zb\bar{b}$	$t\bar{t}$	ZZ
BDRS reconstruction	0.16	0.03	0.35	0.02	0.02
$ m_H^{\text{BDRS}} - m_H < 10 \text{ GeV}$					

background samples are merged at LO up to one extra jet emission via the CKKW algorithm [26,27]. The ZH_{DY} , $Zb\bar{b}$ and ZZ cross sections are normalized to the next-to-leading order (NLO) rates obtained from Ref. [17]. Finally, the $t\bar{t}$ is generated at NLO with the MC@NLO algorithm [28,29]. Hadronization and underlying event effects are taken into account in our simulation [30].

Pileup is not simulated. The expected effects of pileup relevant to our analysis are a degradation of the lepton isolation and b -tagging performance; see e.g., Sec. 6.4 of [31]. Pileup affects both the signal and the dominant background $Zb\bar{b}$ equally, and leads to a lower sensitivity overall. Therefore, it would not alter the main conclusions of our study on the improvement in the signal significance gained from Z polarization.

We follow the BDRS [4] analysis for tagging the $H \rightarrow b\bar{b}$ as a well-understood benchmark. However, we stress that our proposal uses only the lepton information, completely independent of how the $H \rightarrow b\bar{b}$ tagging is performed. We require two leptons, which have the same flavor and opposite-sign charges, with $|\eta_\ell| < 2.5$ in the invariant mass range $75 \text{ GeV} < m_{\ell\ell} < 105 \text{ GeV}$. The Z boson is required to have a large boost $q_T \equiv p_{T\ell\ell} > 200 \text{ GeV}$. The hadronic activity is reclustered with the Cambridge-Aachen jet algorithm [32–34] with $R = 1.2$, requiring at least one boosted ($p_{TJ} > 200 \text{ GeV}$) and central ($|\eta_J| < 2.5$) fat jet. This must be Higgs tagged via the BDRS algorithm, demanding three subjets with the hardest two being b tagged. Our study assumes a flat 70% b -tagging efficiency and 1% miss-tag rate. To further enhance the signal to background ratio, we demand that the filtered Higgs mass be in the range $|m_H^{\text{BDRS}} - m_H| < 10 \text{ GeV}$ with $m_H = 125 \text{ GeV}$. The resulting event rate is presented in Table II, for which $p_{T\ell} > 30 \text{ GeV}$ is imposed.

To quantify the importance of the Z polarization, we perform a two-dimensional binned log-likelihood analysis based on the $(\cos\theta, \phi)$ distribution with a uniformly 5×5 binned grid, invoking the CL_s method [35]. In Fig. 3, we display the luminosities required for a 5σ observation as functions of the lower $p_{T\ell}$ threshold. The solid curve represents the result of the polarization analysis, while the dashed curve is the result without the polarization study and thus purely rate based. The latter continuously improves from 385 to 355 fb^{-1} by changing the $p_{T\ell}$ threshold from

FIG. 3. Luminosities required for a 5σ observation of the two-lepton $pp \rightarrow Z(\ell\ell)H(bb)$ channel as functions of the lepton p_T lower threshold. The solid curve takes the Z polarization into account by performing a two-dimensional binned log-likelihood analysis on the $(\cos\theta, \phi)$ distribution, while the dashed curve accounts only for the rate.

5 to 35 GeV. This is precisely what we have expected as a consequence of the difference in the polarization; see the discussion below Eq. (9). It does not improve anymore above 35 GeV, because the statistics of the signal is also much depleted. On the other hand, the solid curve shows that the required luminosity monotonically increases with the $p_{T\ell}$ threshold. This is because the polarization information [more practically the $(\cos\theta, \phi)$ distribution] is disturbed by the $p_{T\ell}$ lower cut. This selection can capture the difference in polarization only partially; therefore it is never better than the explicit use of the polarization

FIG. 4. 95% confidence level bounds for separating an anomalous $Z(\ell\ell)H(bb)$ signal strength from the standard model prediction as a function of the LHC luminosity. The solid curve accounts for the Z polarization via a two-dimensional binned log-likelihood analysis on $(\cos\theta, \phi)$, while the dashed curve accounts only for the rate. We assume a lepton p_T threshold of $p_T > 5$ GeV.

information. It is, therefore, suggested to define $p_{T\ell}$ threshold as small as possible and to exploit the difference in the $(\cos\theta, \phi)$ distribution between the signal and the background. We stress that, because our proposal relies only on lepton reconstruction, it can be readily included in the current ATLAS and CMS studies. The current ATLAS (CMS) study [6,7] uses the $p_{T\ell}$ threshold 7 GeV (20 GeV), in which case the benefit of exploiting the Z polarization is estimated to be $\sim 15\%$ ($\sim 10\%$) in the required luminosity for 5σ observation.

In Fig. 4, we show the 95% confidence level bounds for separating an anomalous $Z(\ell\ell)H(bb)$ signal strength from the standard model prediction as a function of the 13 TeV LHC luminosity. We assume 5% systematic uncertainties on the backgrounds, which are modeled as nuisance parameters. The result with the polarization considerably enhances the precision on the signal strength determination and makes the bounds less systematic limited at high luminosities. This is a result of the larger $\mathcal{S}/\mathcal{B}$ for several bins in the two-dimensional phase space $(\cos\theta, \phi)$; see Fig. 1. While only 1.5 ab^{-1} is required for the polarization analysis to achieve a precision of 29% on the signal strength, if we disregard the polarization, one would demand the double of the data, 3 ab^{-1} , to achieve the same precision.

IV. SUMMARY AND DISCUSSION

We have studied the potential of the Z polarization to improve the sensitivity to the signal $pp \rightarrow Z(\ell\ell)H(bb)$. At first, we have shown that the signal and the $Zb\bar{b}$ dominant background exhibit different states of Z polarization, whose information completely appears as a large difference in the restricted two-dimensional $(\cos\theta, \phi)$ distribution, where $\cos\theta$ and ϕ parametrize the lepton momentum in the Z rest frame. This difference can be partially captured by a suitable value for the $p_{T\ell}$ lower threshold, and fully taken into account by explicitly analyzing the $(\cos\theta, \phi)$ distribution. We have estimated the impact of these two approaches on the 5σ observation and that of the latter approach on 95% CL upper bound on the uncertainty in the signal strength determination in the two-lepton $Z(\ell\ell)H(bb)$ channel, and found relevant improvements. Since this proposal relies only on lepton reconstruction, displaying small experimental uncertainties, it can be promptly included in the current ATLAS and CMS studies.

In our study, we consider inclusive events in a high q_T region ($q_T > 200$ GeV); namely we do not make use of F_i dependences on q_T , Y and $\cos\Theta$. The q_T dependence is shown in Table I; the difference between ZH_{DY} and $Zb\bar{b}$ is a little enhanced as q_T becomes high. Some of the Y and $\cos\Theta$ dependences are already described above Eq. (2). In the $Z(\ell^+\ell^-)H(bb)$ channel, Y and $\cos\Theta$ can be reconstructed for each event. It may be, therefore, possible, by

using these additional information, to achieve a better signal sensitivity.

With our encouraging results, our approach could be applicable to other important channels, e.g., (i) $Z(\ell\ell) \times H(\text{invisible})$ and (ii) $W(\ell\nu)H(b\bar{b})$. We conclude with several comments on these two channels. (i) Needless to say, the Z polarization is independent of how the Higgs boson decays; the Z polarization in the $ZH(\text{invisible})$ is the same as that in the $ZH(b\bar{b})$. The dominant background in this channel is $Z(\ell\ell)Z(\nu\nu)$. The ZZ process shows almost the same $A_{2,4}$ values as the $Zb\bar{b}$ process. See Ref. [36] for more details. (ii) Despite the neutrino in the final state, by assuming that the charged lepton and the neutrino construct a W boson nominal mass, $|\cos\theta|$ and $|\cos\phi|$ in Eq. (4) are

still uniquely determined [10]. Since the W^- and W^+ are always in the same state of polarization [37], we can simply add W^-H events and W^+H events. The WH and the irreducible background $Wb\bar{b}$ show the similar $A_{2,4}$ values as the ZH_{DY} and the $Zb\bar{b}$, respectively. Details will be published elsewhere [38].

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