Physics Letters B 730 (2014) 149–154

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

New Physics signals from measurable polarization asymmetries at LHC

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ARTICLE INFO

Article history:
Received 9 September 2013
Received in revised form 8 January 2014
Accepted 8 January 2014
Available online 10 January 2014
Editor: G.F. Giudice

ABSTRACT

We propose a new type of Z polarization asymmetry in bottom-Z production at LHC that should be realistically measurable and would provide the determination of the so-called A_b parameter, whose available measured value still appears to be in disagreement with the Standard Model prediction; we discuss the overall expected precision of this measurement and its implications. If Supersymmetry is found, a second polarization, i.e. the top longitudinal polarization in top-charged Higgs production, would neatly identify the $\tan\beta$ parameter. In this case, the value of A_b should be in agreement with the Standard Model. If Supersymmetry does not exist, a residual disagreement of A_b from the Standard Model prediction would be a clean signal of New Physics of "non-Supersymmetric" origin.

1. Introduction

The polarized bottom-Z forward–backward asymmetry has been defined several years ago [1], and considered to be the best way of measuring, in a theoretical SM approach, a combination of the polarized bottom-Z couplings. The definition of this quantity was chosen as

$$A_{\mathrm{FB}}^{b,pol} = \frac{(\sigma_{e_L^- b_F} - \sigma_{e_R^- b_F}) - (\sigma_{e_L^- b_B} - \sigma_{e_R^- b_B})}{\sigma_{e_L^- b_F} + \sigma_{e_R^- b_F} + \sigma_{e_L^- b_B} + \sigma_{e_R^- b_B}}, \tag{1}$$

where $b_{F,B}$ indicates forward and backward outgoing bottom quarks respectively (a polarization degree of the incoming beam $= 1$ is for simplicity assumed). At the Z peak one may easily verify that

$$A_{\mathrm{FB}}^{b,pol} = \frac{3}{4}\frac{g_{Lb}^2 - g_{Rb}^2}{g_{Lb}^2 + g_{Rb}^2}, \tag{2}$$

where $g_{L,Rb}$ are the couplings of a left and right handed bottom to the Z. Calling

$$A_b = \frac{g_{Lb}^2 - g_{Rb}^2}{g_{Lb}^2 + g_{Rb}^2}, \tag{3}$$

one finds that

$$A_{\mathrm{FB}}^{b,pol} = \frac{3}{4}A_b. \tag{4}$$

The quantity A_b appears also in an unpolarized transition from an electron–positron to a b–$\bar{b}$ pair. One finds in that case that the unpolarized forward–backward b asymmetry at the Z peak can be written as

$$A_{\mathrm{FB}}^{b} = \frac{3}{4}A_e A_b, \tag{5}$$

where A_e is the longitudinal electron polarization asymmetry [2]

$$A_e = \frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2} \tag{6}$$

and Eqs. (5) and (6) can be extended to a different final quark–antiquark couple $f\bar{f}$, giving

$$A_{\mathrm{FB}}^{f} = \frac{3}{4}A_e A_f, \tag{7}$$

where A_f is the analogue of A_b Eq. (3) with f replacing b. The direct measurement of A_b, that requires the use of initially longitudinally polarized electrons, was performed at SLAC [3,4], and the result was found to be in good agreement with the Standard Model prediction, that is [5]

$$A_b^{\mathrm{SM},th} = 0.93464^{+0.00004}_{-0.00007}.$$

Later, LEP1 performed a number of unpolarized measurements at the Z peak from which the value of A_b was derived. This was obtained from Eq. (7) and found to be in severe disagreement, at the

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http://dx.doi.org/10.1016/j.physletb.2014.01.010
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3σ level, with the SM prediction [6]. This result was in a certain sense unexpected, because the relative decay rate of the Z into bottom pairs $R(b) = \Gamma(Z \to b\bar{b})/\Gamma(Z \to hadrons)$ provided a value

$$R_b \simeq g_{Lb}^2 + g_{Rb}^2 \tag{8}$$

in perfect agreement with the SM prediction [6]. Accepting the LEP1 result for A_b, a search started of possible New Physics models that might have cured the disagreement. In particular, it was concluded that a conventional MSSM was unable to save the situation [7]. This conclusion remained problematic, since no extra measurements of A_b were eventually performed, and the emerging picture seems definitely unclear. In addition to the previous statements, a new feature has now appeared. In a very recent important paper [8], a SM calculation of $\sin^2\theta_W^{eff,b}$ and R_b has been redone including higher order previously neglected effects. The result is that the SM theoretical prediction for A_b and R_b are now different [5], in the sense that the disagreement of A_b has been slightly ($\sim 2.5\sigma$) reduced, while a new disagreement ($\sim 2.4\sigma$) for R_b has appeared. Certainly, a new measurement of A_b and R_b would therefore represent an undoubtedly relevant improvement of our understanding. In this Letter, we discuss the possibility of a measurement of A_b.

In a recent paper [10], we have defined a certain polarization asymmetry $A_Z^{pol,b}$ to be measured in bottom-Z production at LHC, and shown that this would represent a possibility of measuring the A_b quantity. From a theoretical point of view, this asymmetry exhibits the remarkable properties of being QCD scale and PDF set choice independent, which would represent a quite remarkable feature. From the realistic experimental point of view, this asymmetry should be derived from the experimental determination of the so-called *polarization fractions* (see for example [9] and references therein) of the Z boson in bZ associated production, known to be affected by intrinsically large *systematic* uncertainties. The aim of this Letter is that of proposing an alternative quantity, proportional to A_b, measurable in the same process of bottom-Z production at LHC, that would be experimentally clean being eventually limited in precision only by statistical uncertainties. Beyond tree level, the relation between A_b and A_Z^{pol} can be modified by EW radiative corrections beyond the important QCD corrections. In principle, these do not trivially factorize into vertex correction factors in contrast to Z-pole observables, where off-shell effects enter at two loop [11] or at order $O(\Gamma_Z/M_Z\alpha)$. Nevertheless, as discussed in details and checked numerically in [10], the ratio defining A_Z^{pol} is dominated by helicity amplitudes that have EW corrections mutually canceling. Thus, a small non-zero effect only comes from the smaller amplitudes (suppressed by a factor $\sim 1/25$) and from the small differences due to the subleading (mass suppressed) terms, leaving an overall EW effect from non-factorizable one-loop corrections on the asymmetry of less than the 1%. These remarks allows to consider A_Z^{pol} as an alternative way to measure A_b, at least in the SM. Of course, if New Physics effects are responsible for the discrepancy in A_b, their detailed factorizability properties have to be reconsidered in a model dependent way. The definition of our proposed asymmetry will be done in the following Section 2 of the Letter. In Section 3, the possible relevance of the measurement of another polarization asymmetry, the top longitudinal polarization in top-charged Higgs production, will be discussed in the case of a SUSY discovery. The importance of a measurement of the Z polarization in bottom-Z production with or without Supersymmetry will be finally discussed in Section 4.

2. Helicity amplitudes and A_{FB}^b

The process of associated production of a single b-quark and a Z boson with its subsequent decay into a lepton–antilepton pair,

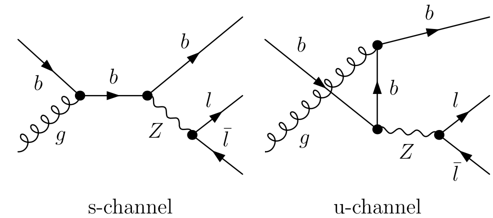

Fig. 1. Leading order Feynmann diagrams for the process $bg \leftrightarrow bl\bar{l}$.

represented in Fig. 1, is defined at parton level by subprocesses $bg \to bl\bar{l}$ involving two Born diagrams with bottom quark exchange in the s-channel and in the u-channel. The interaction vertexes involved in the diagrams of Fig. 1 are defined as follows:

$$\begin{aligned} gqq: &\quad ig_s \not\epsilon \left(\frac{\lambda_c^k}{2}\right), \\ Zff: &\quad -ie\gamma^\mu\left[g_{Zf}^L P_L + g_{Zf}^R P_R\right] \equiv -ie\gamma^\mu\left[g_{Z_f}^j P_j\right]. \end{aligned} \tag{9}$$

Therefore, the Born invariant amplitude is given by

$$\begin{aligned} &A^{Born}(bg \to bZ \to bl\bar{l}) \\ &\quad = 4\pi\alpha g_s\left(\frac{\lambda_c^k}{2}\right)\bar{u}(b') \\ &\qquad \times\left[\gamma^\mu\{g_{Zb}^j P_j\}\frac{(\not q + m_b)}{s - m_b^2}\not\epsilon + \frac{\not\epsilon(\not q' + m_b)\gamma^\mu}{u - m_b^2}\{g_{Zb}^j P_j\}\right] \\ &\qquad \times u(b) D_Z(p_Z^2)\bar{u}(l)\gamma_\mu\{g_{Zl}^j P_j\}v(\bar{l}), \end{aligned} \tag{10}$$

where ϵ, λ_c^k are the gluon polarization vector and color matrix, $p_l + p_{\bar{l}} \equiv p_Z$, $D_Z(p_Z^2)$ is the usual Z effective propagator, $q = p_b + p_g = p_Z + p'_b$, $s = q^2$, $q' = p'_b - p_g = p_b - p_Z$, $u = q'^2$ and with the kinematic decompositions in the center of mass frame (all fermion massless)[1]

$$p_b = (p; 0, 0, p), \qquad p'_b = (p_1; 0, p_1\sin\theta_1, p_1\cos\theta_1), \tag{11}$$

$$p_g = (p; 0, 0, -p), \tag{12}$$

$$p_l = (p_2; p_2\sin\theta_2\sin\phi_2, p_2\sin\theta_2\cos\phi_2, p_2\cos\theta_2), \tag{13}$$

$$p_{\bar{l}} = (p_3; p_3\sin\theta_3\sin\phi_3, p_3\sin\theta_3\cos\phi_3, p_3\cos\theta_3), \tag{14}$$

$$\epsilon(g) = \left(0; \frac{\lambda_g}{\sqrt{2}}, -\frac{i}{\sqrt{2}}, 0\right), \tag{15}$$

where the variables p_i, θ_i, ϕ_i do not yet satisfy momentum conservation, for clarity of notation; a more appropriate set of variables that fulfill $p_b + p_g = p'_b + p_l + p_{\bar{l}}$ is found rotating the three momenta of the leptons in a new 'helicity' frame, in which the polar axis is the direction of b' and the azimuthal angle is measured from the normal to the production plane (i.e. the one spanned by the colliding and decaying bottom quarks momenta[2]). The rotation matrix between the two coordinate systems is

$$R_{\theta_1} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_1 & -\sin\theta_1 \\ 0 & \sin\theta_1 & \cos\theta_1 \end{pmatrix}, \tag{16}$$

from which one can define the polar angles $\theta_l, \theta_{\bar{l}}$ and the azimuthal angle ϕ'

[1] An additional azimuthal angle for b' would manifest itself only through overall phase factors in the amplitudes.

[2] The ambiguity coming from the orientation of the normal to the production plane will be canceled after integration over the azimuthal angle in the definition of observable quantities.

$$p_l^{hf} = \left(p_2; p_2 \sin\theta_l \sin\phi', p_2 \sin\theta_l \cos\phi', p_2 \cos\theta_l\right),$$
$$p_{\bar{l}}^{hf} = \left(p_3; -p_3 \sin\theta_{\bar{l}} \sin\phi', -p_3 \sin\theta_{\bar{l}} \cos\phi', p_3 \cos\theta_{\bar{l}}\right).$$

In this frame the coplanarity of the final particles is manifest through the dependence on the same variable ϕ' for both leptons. Energy conservation leads, in this frame and for massless particles, to simple formulas for the energies of the final particles ($\{\theta_l, \theta_{\bar{l}}\}^h \equiv \{\theta_l, \theta_{\bar{l}}\}/2$):

$$p_1 = p\left(1 - \cot\left(\theta_{\bar{l}}^h\right)\cot\left(\theta_l^h\right)\right), \tag{17}$$
$$p_2 = p\cos\left(\theta_{\bar{l}}^h\right)\csc\left(\theta_l^h\right)\csc\left(\theta_{\bar{l}}^h + \theta_l^h\right), \tag{18}$$
$$p_3 = p\csc\left(\theta_{\bar{l}}^h\right)\cos\left(\theta_l^h\right)\csc\left(\theta_{\bar{l}}^h + \theta_l^h\right), \tag{19}$$

which make manifest the (maximal) domain of integration

$$\theta_l \in [0, \pi], \quad \theta_{\bar{l}} \in [\pi - \theta_l, \pi].$$

The introduction of this reference frame is motivated by the cleaner form the matrix elements assume there. In the massless case, the helicity amplitudes can be expressed as

$$\mathcal{M}_{\lambda_b\lambda_g;\lambda_{b'}\lambda_l\lambda_{\bar{l}}} \equiv \delta_{\lambda_b\lambda_{b'}}\delta_{\lambda_l\bar{\lambda}_{\bar{l}}}\mathcal{M}_{\lambda_g;\lambda_{b'}\lambda_l},$$

where $\lambda_f = \pm\frac{1}{2} \equiv \pm$, $\lambda_g = \pm 1 \equiv \pm$ and $\lambda_i \equiv -\bar{\lambda}_i$. Modulo a common factor

$$\mathcal{M}_{\lambda_g;\lambda_{b'}\lambda_l} \equiv \left(D_Z\left(p_Z^2\right)16\sqrt{2}\pi\alpha g_s\lambda_c^k\right)F_{\lambda_g;\lambda_{b'}\lambda_l},$$

the non-vanishing helicity amplitudes factors read:

$$F_{+++} = -i\left(g_{Zb}^R g_{Zl}^R\right)e^{i\phi'}\sqrt{\frac{p_1p_2p_3}{p}}\frac{\cos\theta_{\bar{l}}^h \sin\theta_l^h}{\cos\theta_1^h}, \tag{20}$$

$$F_{++-} = i\left(g_{Zb}^R g_{Zl}^L\right)e^{i\phi'}\sqrt{\frac{p_1p_2p_3}{p}}\frac{\cos\theta_l^h \sin\theta_{\bar{l}}^h}{\cos\theta_1^h}, \tag{21}$$

$$F_{-++} = i\left(g_{Zb}^R g_{Zl}^R\right)e^{-i\phi'}\sqrt{\frac{p_1p_2p_3}{p}}\frac{\sin\theta_l^h}{\cos(\theta_{\bar{l}}^h + \theta_l^h)}\frac{\cos\theta_l^h}{\cos\theta_1^h} \times \left(\cos\theta_1^h \sin\theta_{\bar{l}}^h - e^{i\phi'}\sin\theta_1^h\cos\theta_{\bar{l}}^h\right)^2, \tag{22}$$

$$F_{-+-} = -i\left(g_{Zb}^R g_{Zl}^L\right)e^{-i\phi'}\sqrt{\frac{p_1p_2p_3}{p}}\frac{\sin\theta_{\bar{l}}^h}{\cos(\theta_{\bar{l}}^h + \theta_l^h)}\frac{\cos\theta_{\bar{l}}^h}{\cos\theta_1^h} \times \left(\cos\theta_1^h \sin\theta_l^h + e^{i\phi'}\sin\theta_1^h\cos\theta_l^h\right)^2, \tag{23}$$

while the other four can be derived by these by parity conjugation, that in our conventions is represented by complex conjugation together with the switch $g_{Zf}^L \leftrightarrow g_{Zf}^R$. As an example

$$F_{---} = i\left(g_{Zb}^L g_{Zl}^L\right)e^{-i\phi'}\sqrt{\frac{p_1p_2p_3}{p}}\frac{\cos\theta_{\bar{l}}^h \sin\theta_l^h}{\cos\theta_1^h}.$$

Note that formulas related by switch of the lepton helicities are related one to each other by the replacements

$$\left(\theta_l \leftrightarrow \theta_{\bar{l}}, \phi' \to \phi' + \pi\right) \equiv l \leftrightarrow \bar{l}, \tag{24}$$
$$g_{Zl}^L \leftrightarrow g_{Zl}^R. \tag{25}$$

From these formulas one can build the total cross section by introducing the usual flux factor and the convolution with the relevant partons density functions for the proton. For our purposes it suffices to define the squared amplitude summed over the initial state helicities as

$$\rho_{\lambda_{b'}\lambda_l} \equiv \sum_{\lambda_g}|\mathcal{M}_{\lambda_g;\lambda_{b'}\lambda_l}|^2$$

and to identify

$$\rho_{++} + \rho_{--} \equiv \left(g_{Lb}^2 g_{Ll}^2 + g_{Rb}^2 g_{Rl}^2\right)f\left(\theta_l^h, \theta_{\bar{l}}^h, \theta_1, \phi'\right)$$

(one can check that actually in the sum in the RHS the couplings factorize out). The complete unpolarized squared amplitude can now be simply written as

$$|\mathcal{M}|^2 = \left(g_{Lb}^2 g_{Ll}^2 + g_{Rb}^2 g_{Rl}^2\right)f\left(\theta_l^h, \theta_{\bar{l}}^h, \theta_1, \phi'\right) + \left(g_{Lb}^2 g_{Rl}^2 + g_{Rb}^2 g_{Ll}^2\right)\bar{f}\left(\theta_l^h, \theta_{\bar{l}}^h, \theta_1, \phi'\right) \tag{26}$$
$$\equiv c_+\frac{f+\bar{f}}{2} + c_-\frac{f-\bar{f}}{2}, \tag{27}$$

where $\bar{f} \equiv f|_{l\leftrightarrow\bar{l}}$. In the last line (27), the two terms have definite symmetry properties under $l \leftrightarrow \bar{l}$, with coefficients

$$c_+ = \left(g_{Lb}^2 + g_{Rb}^2\right)\left(g_{Ll}^2 + g_{Rl}^2\right),$$
$$c_- = \left(g_{Lb}^2 - g_{Rb}^2\right)\left(g_{Ll}^2 - g_{Rl}^2\right),$$
$$\frac{c_-}{c_+} = A_b A_l.$$

This allows us to extract (c_-) c_+ simply measuring (anti) symmetrized combination of cross sections in kinematic domains related one to each other under exchange of the two leptons angles. The simplest choice in the CM frame is

$$\mathcal{D}_\pm \equiv \theta_l \gtrless \theta_{\bar{l}}. \tag{28}$$

To be more explicit, note that the condition $\theta_l \gtrless \theta_{\bar{l}}$ translates in the Z rest frame to the experimentally simpler condition of forward/backward lepton momentum respect to the bottom momentum versor. This finally leads to the definition of $A_{\mathrm{FB}}^{b,\mathrm{LHC}}$

$$A_{\mathrm{FB}}^{b,\mathrm{LHC}} \equiv \frac{\sigma(\mathcal{D}_F) - \sigma(\mathcal{D}_B)}{\sigma(\mathcal{D}_F) + \sigma(\mathcal{D}_B)}, \tag{29}$$

where the reference axis is the b momentum in the Z rest frame. From (27) this quantity will be proportional, modulo a kinematic factor k, to the LEP A_{FB}^b

$$A_{\mathrm{FB}}^{b,\mathrm{LHC}} = kA_{\mathrm{FB}}^b, \tag{30}$$

where FB, as already emphasized, has different meaning in the two expressions.

A theoretical prediction of $A_{\mathrm{FB}}^{b,\mathrm{LHC}}$ (and, in particular, of the numerical value of the kinematical constant k) has to take into account several experimental issues, thus needing a realistic simulation of the detector features, and in particular of its geometrical properties and of intrinsic cuts applied to the event reconstruction. In such a contest, kinematic cuts on transverse momentum and pseudorapidity of the decaying particles introduce some subtleties in the derivation of a direct connection of $A_{\mathrm{FB}}^{b,\mathrm{LHC}}$ to the LEP asymmetry A_{FB}^b. To prove the validity of (30) also in the presence of a realistic event selection, one can vary fictitiously $g_{Zb}^{L,R}$ in a wide range of values, determining the corresponding values of $A_{\mathrm{FB}}^{b,\mathrm{LHC}}$ with usual kinematic cuts. Fig. 2 shows the results of a simulation with 10 different choices of $g_{Zb}^{L,R}$, including the SM one (for the events simulation we have used CalcHEP [12] and checked good agreement with different event generators). The particular choice of selection criteria closely follows the one used by ATLAS for the Z–b-jets cross section analysis [13]. With these assumptions, the kinematical constant k is found to be −0.37 at LO. Its QCD scale dependence has been inspected varying simultaneously the renormalization and factorization scales and computing

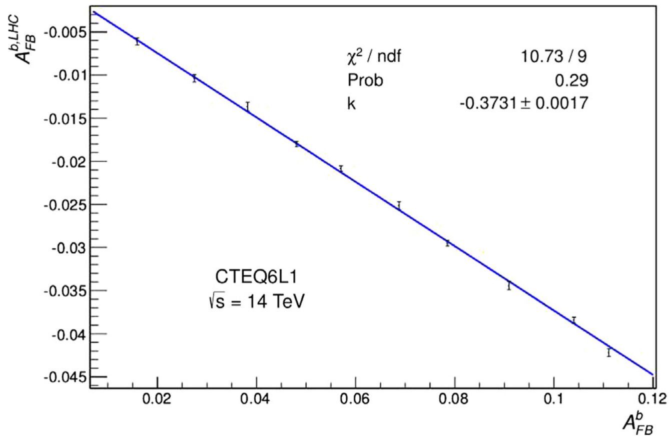

Fig. 2. Event level (i.e. without parton showering) dependence of the asymmetry defined in the text on A^b_{FB}, in a fictitiously wide range of A^b_{FB} values, aiming to prove the direct proportionality also in the presence of typical kinematic cuts [13] on decay products pseudorapidities and transverse momenta. The uncertainty on k is only numerical, i.e. related to MC statistics (see the text for other uncertainties).

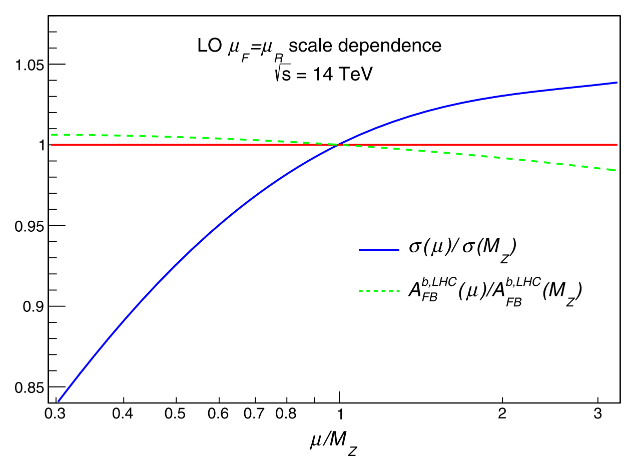

Fig. 3. Comparison between the LO $\mu_F = \mu_R = kM_Z$ scale variation dependencies of the total cross section and our asymmetry.

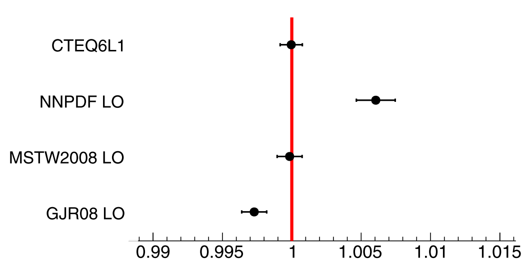

Fig. 4. Comparison of different pdf set LO asymmetry predictions taking CTEQ6L1 as reference.

the corresponding $A^{b,\mathrm{LHC}}_{\mathrm{FB}}$ values, Fig. 3. Similarly the PDF set choice dependence is depicted in Fig. 4. The total theoretical uncertainty in both cases is at the 1 percent level.

For a detector level simulation one has to choose an appropriate procedure to measure the b-jet charge, that can be achieved adapting the LEP procedure to the LHC case [14,15]. Here a weighting technique [16,17] is applied in which the b-jet charge is defined as a weighted sum of the b-jet track charges,

$$Q_{b\text{-jet}} \equiv \frac{\sum_i Q_i |\vec{j}\cdot\vec{p}_i|^k}{\sum_i |\vec{j}\cdot\vec{p}_i|^k} \qquad (31)$$

where Q_i and $\vec{p}_i$ are the charge and momentum of the i-th track, $\vec{j}$ defines the b-jet axis direction, and k is a parameter which was set to 0.5 following literature (this value optimizes the separation between b- and $\bar{b}$-jets mean charges). In addition, in events with muons with transverse momentum relative to the jet axis $p_T^{\mathrm{rel}} > 0.8$ GeV (this value is known to maximize the b-purity times efficiency, see [21]), we have defined an effective jet charge as

$$Q^{\mu}_{b\text{-jet}} \equiv \left(\frac{p_T^{\mathrm{rel}}}{m_b}\right)^k q_\mu \qquad (32)$$

where q_μ is the reconstructed muon charge and k was set to 0.5 from optimization. This method is a simplified version of similar ones present in literature [21] mixed with the tracks weighted one, from which it inherits the advantage of taking already into account the problem of the B^0–$\bar{B}^0$ mixing. For both methods, one can then define

$$\langle Q_{\mathrm{FB}}\rangle \equiv \left\langle (-1)^{\mathrm{FB}} Q_{\mathrm{jet}}\right\rangle,$$

where $(-1)^{\mathrm{FB}}$ is computed event by event as the sign of $\vec{j}^* \cdot \vec{p}^*_{e-}$, both taken in the Z rest frame. The mean b-jet charge $\delta^b \equiv \langle Q_b\rangle$ is obtained from the average value of Q_{jet} for events with a b-quark initiated jet (i.e. not a $\bar{b}$), and was here taken from simulations (but will be experimentally constrained in a real measurement). With these definitions, in a pure $b/\bar{b}$ sample, the b asymmetry $A^{b,\mathrm{LHC}}_{\mathrm{FB}}$ is proportional to $\langle Q_{\mathrm{FB}}\rangle$:

$$\langle Q_{\mathrm{FB}}\rangle = \delta^b A^{b,\mathrm{LHC}}_{\mathrm{FB}}. \qquad (33)$$

With a non-pure sample of jets originated from different quark flavors, (33) gets modified into:

$$\langle Q_{\mathrm{FB}}\rangle = \sum_f \delta^f A^{f,\mathrm{LHC}}_{\mathrm{FB}} r_f, \qquad (34)$$

where the sum runs over the quark flavors present in the sample, while r_f are the fractions of events with flavor f. For the purposes of this article, given the usual efficiencies and mistag rates of b-tagging algorithms on the market, it suffices to consider only the c-jet background (represented at LO from the process $p\ p \to c\ l\ \bar{l}$). The simulated samples were generated using MadGraph 5 [18] interfaced with PYTHIA 6.4 [19] for the showering and with Delphes 3 [20] for the detector simulation (the Delphes card was modified for ATLAS updated parameters). The event selection criteria was taken from [13]. The number of events generated corresponds to a conservative estimate of a ten years luminosity of 400 fb^{-1} at 14 TeV, though results can also be extrapolated to a possible final total integrated luminosity of 3 ab^{-1}, predicted for the (not yet approved) High Luminosity LHC. Due to partial cancellation from opposite values of mean jet charges in (34), the value of b-tagging efficiency that optimizes the relative uncertainty on $\langle Q_{\mathrm{FB}}\rangle$ was found to be around 55% (see [22]): for this reason we present results at two different b-tagging efficiency working points ($\{\epsilon_b, \epsilon_c\} = \{50, 3\}\%$, $\{60, 8\}\%$), which, from inversion of (34), allows in principle also an independent determination of A^c_{FB}, taking as input the predicted flavor fractions and mean charges. Table 1 collects the number of generated events and computed input parameters, while results are presented in Table 2, and refers to a single experiment (ATLAS in this case). Systematic uncertainties from ISR/FSR has been inspected switching them separately off and taking, as the associated uncertainty, 20% of the total effect. While FSR has no impact at all, ISR gives a relative systematic uncertainty lower than 2%, and needs a deeper understanding of the source of this variation. The impact of pile-up effects has been inspected using the related Delphes Pile-Up

Table 1
Generated events and input parameters. Systematic errors on flavor fractions and δ_f are irrelevant given the estimated statistical uncertainty on the final results, while they should be taken into account (comprising possible effects giving $\delta^f \neq -\delta^{\bar{f}}$) in a possible HL-LHC upgrade.

		$b/\bar{b}$ sample		$c/\bar{c}$ sample	
		Jet charge	Soft muon	Jet charge	Soft muon
Total number of events		$8.96 \cdot 10^6$		$10.08 \cdot 10^6$	
Flavor fractions	ϵ_b 50%	0.94	0.99	0.06	0.01
	ϵ_b 60%	0.88	0.97	0.12	0.03
δ^f		−0.0736	−0.3027	0.0721	0.535

Table 2
Results (times a factor 10^4) for an integrated luminosity of 400 fb^{-1} for both electron and muon channels, assuming lepton universality.

	ϵ_b 50%	ϵ_b 60%	$A_{FB}^{b,\mathrm{LHC}}$	Combined value
$\langle Q_{FB}\rangle$	23.4 ± 2.3	21.3 ± 2.0	-343 ± 54	-347 ± 47
$\langle Q_{FB}^{\mu}\rangle$	104 ± 17	96 ± 15	-361 ± 95	

module, setting the average amount of pile-up events per bunch-crossing to 50, and found to be negligible.

This simplified study shows that a relative overall uncertainty on the measured asymmetry value of less than 10% can be easily reached at 400 fb^{-1} (taking into account also ATLAS and CMS combination). This value, extrapolated at an integrated luminosity of 3 ab^{-1}, can be lower than 4%, imposing at that level also a deeper study of systematic uncertainties, out of the scopes of this Letter. One should also take into account that these values have to be intended as very conservative, and will most likely be lowered in a real experimental measurement, owing to the use of more involved methods (ready from LEP studies) and improvements on b-purities and mean charges (e.g. from tagging and rejection of double b-hadron jets from ISR [23]). Furthermore, one should compare this kind of uncertainties with the present one of 1.6% on the world average value of $A_{FB}^{0,b}$, that results in a discrepancy around 2.5 standard deviations from its theoretical prediction. A new determination of $A_{FB}^{0,b}$ through $A_{FB}^{b,\mathrm{LHC}}$ with a relative uncertainty lower than 5% would definitely influence this discrepancy. In conclusion, we can firmly assess that a measurement of this quantity at LHC (and, possibly, at HL-LHC) will be of crucial importance.

3. The top longitudinal polarization in top-charged Higgs production

The previous discussion about A_b is not dependent on the assumption of a Supersymmetric model of New Physics. In particular, there is no impact of SUSY on A_b if one assumes a heavy enough charged Higgs and sbottoms/stops squarks which seems to be the case. If Supersymmetry is found, a different asymmetry measurement becomes relevant at LHC, the top longitudinal polarization asymmetry in top-charged Higgs production. This quantity has been exhaustively discussed in a previous paper [24], where it was shown that its value would essentially mostly depend on that of the MSSM $\tan\beta$ parameter, and would be almost rigorously QCD scale and PDF choice independent. In particular, it was shown in Ref. [24] that varying $\tan\beta$ from approximately one to approximately ten, the value of the asymmetry changes sign, making an experimental determination effective even in the presence of a realistic experimental and theoretical error. For larger $\tan\beta$ values, on the contrary, the asymmetry remains essentially constant and provides a minor but still relevant information, and we defer to Ref. [24] for more details. The relevance of the considered asymmetry appears to us to have been enormously increased by the latest results on the Higgs boson mass derived at LHC [25,26]. If one wants to retain a MSSM scheme, the residual range of the Supersymmetric parameters has been greatly reduced. In

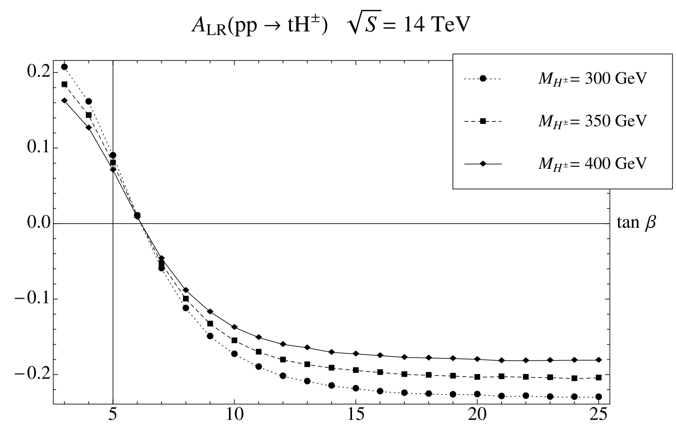

Fig. 5. Top polarization asymmetry in $tH^{\pm}$ associated production as a function of $\tan\beta$ with tree different assumptions on the charged Higgs mass.

particular the allowed values of $\tan\beta$ lie exactly in our "optimal" range, roughly from one to ten, with a mass of the charged Higgs in the 300–600 GeV range. Indeed, according to a recent analysis [27], while the best fit MSSM point derived from the latest LHC Higgs data gives $M_{H+} \approx 600$ GeV and $\tan\beta \approx 1$, data are still in a good agreement with low $\tan\beta$ values and M_{H+} values down to 300 GeV (the reason being that the χ^2 is relatively flat). The variation of the top polarization asymmetry with $\tan\beta$ in scenarios of this kind is shown in Fig. 5. In our calculation, we have used the previous results of Ref. [28] and have remained essentially limited to an effective Born approximation. The Figure shows the top polarization asymmetry for three different choices of the Higgs mass: the center of mass energy is $\sqrt{s} = 7$ TeV and, following [28,29], the factorization scale μ_F is set to $1/6(M_{H^\pm} + m_t)$ to minimize the QCD corrections. The value of the bottom mass in the Yukawa coupling $tbH^{\pm}$ is evaluated in the $\overline{MS}$-scheme at the factorization scale.

The main conclusion of our analysis is that a determination of $\tan\beta$ in the residual range would not request an "extremely" precise experimental measurement. This is a consequence of the fact that a jump from a positive value of approximately twenty percent to the same value of opposite sign would not escape a "reasonable" determination.

4. A_b indications if Supersymmetry is not found at LHC

Coming back to the bottom Z process, assuming that Supersymmetry is found, the proposed determination of A_b from Z polarization becomes now extremely relevant, given the fact that Supersymmetry would be unable to explain a discrepancy with the available Standard Model result. But this asymmetry could also play a fundamental role in the case of a negative Supersymmetric search at LHC. In particular we shall consider two opposite cases:

(A) The A_b value is in disagreement with the Standard Model prediction. This result would completely eliminate Supersymmetry, even at a more powerful proton–proton CERN collider, but would necessarily indicate the presence of New Physics of non-Supersymmetric nature, like that discussed in some recent papers (see e.g. [30–32] and references therein).

(B) The A_b value is in agreement with the Standard Model prediction. This would leave an "open door" for very heavy Supersymmetry, to be searched at a future more powerful CERN collider, or also exclude effects at LHC due to a large class of considered New Physics models [32].

The conclusion that we personally think can be derived from our Letter is that, in full generality, a measurement of the Z polarization and top longitudinal asymmetries, which could be performed at LHC under reasonably expected experimental conditions, is, to use a mild definition, "worth". We are ready and willing to collaborate with possibly interested experimental teams to make this project fulfilled.

Acknowledgements

We are very grateful to Abdelhak Djouadi, Michele Pinamonti and Marina Cobal for useful discussions and comments on the manuscript.

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