

Computation of FCC-ee sensitivity to heavy new physics with interactions of any flavor structure

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We present a tool to compute the sensitivity of the Future Circular Electron-Positron Collider (FCC-ee) to the interactions of new, heavy particles via publicly available extensions to the SMELLI and FLAVIO computer programs. We parametrize new particles' effects without any flavor assumptions and take into account the projected experimental and correlated theoretical uncertainties of various electroweak and Higgs observables at the proposed collider. We illustrate a use of the tool by estimating the sensitivity of the FCC-ee to a Z' model with flavor-specific couplings, which explains anomalies inferred from present-day measurements and Standard Model predictions of observables that involve the $b \rightarrow s\ell^+\ell^-$ transition.

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The Future Circular Electron-Positron Collider (FCC-ee) is a proposed e^+e^- collider envisaged to be based at CERN [1] and start collisions in the 2040s. It is designed to provide detailed studies of the four most massive particles of the Standard Model (SM): $W^\pm$ bosons, Higgs bosons, Z bosons, and top quarks. The FCC-ee affords a significant increase in the precision of measurements of the properties of these heavy particles and sensitivity to rarer decay modes. This enhanced precision enables the exploration of the effects of new particles that may have hitherto evaded detection due to their high mass scales or small interaction strengths. Currently there is much activity to investigate the scientific benefits of the FCC-ee in order to further motivate funding and building it.

We provide here a computational tool utilizing existing estimates of the collider's experimental precision to aid this activity. The tool estimates the sensitivity of the FCC-ee to extensions of the SM, making no assumptions about the flavor structure of new physics. As such, it can be used to study highly flavorful new physics scenarios, and it can later be augmented with observables deriving from the FCC-ee flavor physics program, on which there is ongoing research.

We will illustrate the use of our tool by quantifying the substantial testing power the FCC-ee would provide on a flavorful new physics model that has been proposed to

explain aspects of the fermion mass problem and certain discrepancies between measurements of B meson decays and their SM predictions. We shall find that the set of FCC-ee observables we include has the sensitivity to easily rule out such an explanation. This provides a concrete illustration of the potential power of the FCC-ee in a flavored new physics context and adds to the FCC-ee physics case.

Our assumptions are that only one linearly realized Higgs field contributes significantly to electroweak symmetry breaking, that the masses of beyond-the-SM fields are significantly greater than 365 GeV, and that in the infinite mass limit all of those fields decouple. Under such circumstances, the effects of new physics can be characterized by the SM Effective Field Theory (SMEFT). Using the language of the SMEFT allows us to leverage the SMELLI [2] and FLAVIO [3] computer packages, which already contain the predictions and experimental measurements of hundreds of B meson, electroweak, and other observables using the SMEFT framework [4]. We shall extend these programs to include the estimated FCC-ee uncertainties of various Higgs and electroweak observables for which well-studied and official sensitivity estimates are available.

I. STANDARD MODEL EFFECTIVE FIELD THEORY

The SMEFT encodes the effects of new physics in Wilson coefficients (WCs)—dimensionless numbers multiplying local, irrelevant operators composed of the SM degrees of freedom and invariant under the SM gauge group. The SMEFT Lagrangian density is

$$\mathcal{L} = \mathcal{L}_4 + \sum_{d=5}^{\infty} \sum_i \frac{C_i}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}, \quad (1)$$

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where $\mathcal{L}_4$ is the usual renormalizable SM Lagrangian. The parameter Λ stands for the SMEFT cutoff scale, usually taken to be the mass scale of heavy states that have been integrated out of an underlying renormalizable field theory. The C_i are the dimensionless WCs. The index i labels independent operators whereas d is the canonical mass dimension of the operator $\mathcal{O}_i^{(d)}$.

The only $d = 5$ operator in the SMEFT expansion, the Weinberg operator [6], describes neutrino masses and mixing. At the $d = 6$ level, the number of independent gauge invariant operators is large: 2499; these terms describe the physical effects that we are most interested in. A judicious choice of a nonredundant operator basis is important to make sense of the expansion, and we shall henceforth adopt the operators and conventions of the Warsaw basis [7]. Effects of yet higher dimension are suppressed by growing powers of $(E/\Lambda) \ll 1$, where E is the energy scale of the physical process of interest. Since such higher d operators are generically expected to make smaller impacts on observables, they are not accounted for in our approximation.

In a specific SM extension with heavy new fields, many effective operators are typically induced. The WCs of these operators are highly correlated with each other, being controlled by a small number of fundamental parameters.

II. FCC-EE OBSERVABLES

This section aims to present and discuss the FCC-ee observables incorporated in our newly developed extensions of FLAVIO v2.6.1 and SMELLI v2.4.2. Where possible, we have followed the principles established in [8]. We adhere to the sensitivity estimates reported in the 2021 Snowmass proceedings [9–11]. The assumed running program corresponds to unpolarized electron and positron beams at center-of-mass energies $\sqrt{s} = 91, 161, 240, 350$, and 365 GeV with luminosities 150, 10, 5, 0.2, and 1.5 ab^{-1} , respectively. All projected measurements are assumed to be centered on the SM predictions. The FCC-ee observables are divided into two classes, which we shall discuss in the following sections: electroweak precision observables (EWPOs) and Higgs observables.

A. Electroweak precision observables

The FCC-ee would probe the electroweak sector at an unprecedented level of precision, improving upon the current measurements of many observables by two orders of magnitude. Its planned runs at a variety of $\sqrt{s}$ values ensure experimental sensitivity to a host of SMEFT operators, ranging from four-fermion contact interactions to bosonic field strength operators. Using the estimates of [10] for the FCC-ee measurement uncertainties, we have included FCC-ee uncertainties for the key Z -pole precision observables: the Z boson width, the total hadronic cross-section σ_{had}^0 , the hadronic cross-section ratios R_f and left-right asymmetries A_f . Furthermore, the WW , Zh , and $t\bar{t}$

runs allow for precise determinations of many W boson observables, and we include FCC-ee uncertainties for the W boson mass M_W , the W boson width Γ_W , as well as the inclusive WW production cross-sections and leptonic branching ratios $\text{BR}(W \rightarrow \ell\nu)$ measured in the 161, 240 and 365 GeV runs of the collider. The uncertainty estimates for the latter two sets of observables are taken from [11].

The inclusive WW production cross sections are simulated using the MadGraph5_aMC [12] event generator together with the SMEFTsim [13,14] model files. We use the built-in electroweak parton distribution functions [15] on MadGraph that account for initial state radiation (and beamstrahlung effects for $\sqrt{s} = 240$ and 365 GeV), turn on WCs one at a time, and seek corrections to the SM cross-sections at linear order in the WCs. This amounts to considering the interference terms between the SM amplitude and the SMEFT corrections

$$\sigma = \sigma_{\text{SM}} + \sum_i a_i \frac{C_i}{\Lambda^2}, \quad (2)$$

where a_i gives the interference contribution to the cross section. We include in the cross sections those SMEFT operators for which

$$\frac{|a_i|}{\sigma_{\text{SM}}} > 10^3 \text{ GeV}^2. \quad (3)$$

Finally, we also include fermion scattering cross sections and forward-backward asymmetries at $\sqrt{s} = 240$ and 365 GeV for the $e^+e^- \mu^+\mu^-$, $\tau^+\tau^-$, $\bar{c}c$, and $\bar{b}b$ final states, as reported in [10]. These observables excel at probing four-fermion operators because their interference with the SM grows with $\sqrt{s}$ [16,17], and their ability to test flavor nonuniversal models has recently been analyzed in [18]. When applicable, we have cross-checked our analytic results with similar calculations in [19,20]. The scattering amplitudes are calculated at tree level including $\mathcal{O}(\Lambda^{-2})$ corrections. We mod-square each amplitude to calculate the cross section, thus including the effects of four-fermion operators that do not interfere with the SM amplitudes. The full set of electroweak observables is collected in Table II.

B. Higgs measurements

The two leading Higgs production modes at the FCC-ee are $e^+e^- \rightarrow Zh$ (Higgstrahlung) and $e^+e^- \rightarrow h\nu\nu$ (W boson fusion), where h stands for the physical Higgs field. The thirdmost prevalent mode, Z boson fusion, is tenfold suppressed [9] relative to the first two at the FCC-ee energies 240 GeV and 365 GeV and is neglected. The Higgs measurements are often reported in the form of signal strengths, μ , defined as

$$\mu \equiv \frac{[\sigma_i \cdot \text{BR}(h \rightarrow f)]_{\text{observed}}}{[\sigma_i \cdot \text{BR}(h \rightarrow f)]_{\text{SM}}}, \quad (4)$$

for a given h production mode cross-section σ_i and branching ratio $\text{BR}(h \rightarrow f)$ into final state f .

MadGraph and SMEFTsim are employed to simulate the dominant Higgs production modes at the FCC-ee, following precisely the same procedure as outlined above for WW production. These are then normalized to their SM predictions to derive signal strengths. The full set of Higgs observables can be found in Table III.

C. Treatment of theory uncertainties

In order to translate the vast improvements in experimental precision at the FCC-ee into tests of the SM, it is imperative that the theory errors of the relevant observables are improved to match, or surpass, the experimental precision. Both parametric theory errors, arising from the finite measurement precision of the SM input parameters, and intrinsic theory errors, emerging from missing higher order contributions in the SM predictions for various observables, must be controlled. The feasibility of sufficiently large improvements before FCC-ee switch-on was the subject of [21,22], where it was deemed that with a concerted effort the theory errors may be brought down to match the experimental precision for the observables considered in this letter. Furthermore, explicit estimates for the parametric and theory uncertainties were listed. We have incorporated these estimates into the FCC-ee observables introduced here. Where projected theoretical uncertainties for a given observable are unavailable, we assume the total theoretical uncertainty matches the projected experimental error, unless the current theoretical error is smaller, in which case we adopt the present-day value.

We add the parametric and intrinsic theory uncertainties to the projected experimental uncertainties in quadrature, both for the EWPOs and for the Higgs observables. This implicitly assumes that the three sources of uncertainty are uncorrelated, which should hold to a reasonable degree. Our procedure also implicitly treats the theory uncertainty as a Gaussian random variable. This makes our procedure operationally simple, as other treatments would likely require dedicated changes to the core FLAVIO program.

All projected experimental uncertainties are treated as uncorrelated. As for the theory errors, whenever the predicted values of two observables are obviously correlated, we treat them as such. Thus, for instance, we take into account that the cross sections $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ and $\sigma(e^+e^- \rightarrow \tau^+\tau^-)$ rely on the same theory prediction to a good approximation, as do the Higgs signal strength predictions for a given production mode but different decay channels. Where the correlation between two theory predictions is approximately unity, we treat the theory errors as fully correlated. For another example, we therefore treat the theory errors in $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ at $\sqrt{s} = 240$ GeV and at $\sqrt{s} = 365$ GeV as fully correlated.

The estimation and implementation of both projected experimental and theory errors is not an exact science.

We caution that our estimates are subject to refinement over the coming decades prior to FCC-ee operation.

III. AN ILLUSTRATION: SENSITIVITY TO THE THIRD FAMILY HYPERCHARGE MODEL

We now demonstrate the new code with a use case: that of estimating the sensitivity of the FCC-ee to a particular new physics model that explains discrepancies between certain measurements and SM predictions of B meson decay observables. The third family hypercharge model (TFHM) [23] extends the SM gauge group by a $U(1)_{Y_3}$ factor under which the third family fermions and the Higgs boson have charges proportional to their hypercharge, but under which the other SM fields are uncharged. $U(1)_{Y_3}$ is spontaneously broken around the TeV scale by a SM singlet complex scalar field, the flavon, θ , which takes on a vacuum expectation value (VEV) v_θ . As a result, the Z' gauge boson that mediates the new interaction acquires a mass, $M_{Z'}$. Despite being coupled to only the *third* generation of SM fermions in the gauge eigenbasis, the Z' acquires interactions with the lighter fermion species when the fermions are rotated into the mass eigenbasis; an angle θ_{sb} , for example, parametrizes the mixing between the left-handed strange and bottom quark fields. This allows the Z' field to mediate $b \rightarrow s\ell^+\ell^-$ transitions via Feynman diagrams that, after matching to the SMEFT, yield four-fermion operators suppressed by the ratio $C_i/\Lambda^2 \sim g_{Z'}^2/M_{Z'}^2$ with $g_{Z'}$ being the $U(1)_{Y_3}$ gauge coupling. Furthermore, as the Higgs field H is charged under both $U(1)_Y$ and $U(1)_{Y_3}$, the Z boson and the Z' mix with mixing angle α_z ,

$$\sin \alpha_z = \frac{g_{Z'}}{\sqrt{g_L^2 + g_Y^2}} \left(\frac{M_Z}{M_{Z'}} \right)^2 + \mathcal{O}\left(\frac{M_Z^4}{M_{Z'}^4} \right), \quad (5)$$

at tree level.

To leading order, two parameters of the TFHM determine its ability to fit B meson decay data: the ratio $g_{Z'}/M_{Z'}$ and θ_{sb} . Whilst the $b \rightarrow s\ell^+\ell^-$ anomaly landscape has evolved over the recent years (see [24]), the ability of the TFHM to improve the fit to the anomalous B meson decay measurements endures. We use three sets of observables defined in SMELLI to calculate a global likelihood consisting of hundreds of current measurements. The “Quarks” dataset contains various rare B meson decay observables, some of which are in tension with the SM, as well as neutral meson mixing and other commonly studied flavor observables. The dataset “lepton-flavor universal flavor changing neutral currents (LFU FCNCs)” consists of measurements testing lepton flavor universality, including the formerly anomalous R_K and R_{K^*} , and “EWPOs” are made up of Z - and W -pole electroweak observables. The best-fit point of the resulting fit improves upon the SM by 29.1 units of χ^2 [25].

Another point of interest is the scalar sector of the model. Aside from the mass terms and quartic self-interaction terms that generically exist for both the Higgs field H and the flavon field θ in the Lagrangian, the symmetries of the model allow for a marginal interaction term $\lambda_{H\theta}(H^\dagger H)(\theta^* \theta)$. As a result, integrating out the heavy flavon from the theory yields a contribution to the $d=6$ bosonic operator $(H^\dagger H)\square(H^\dagger H)$, which in the broken electroweak phase and under canonical normalization of the physical, real Higgs field results in the rescaling of all Higgs couplings in the SM (see for instance [27]). This operator can also be viewed as capturing the mixing between the Higgs and flavon fields, necessitating a rotation into a new scalar mass basis. At tree level, the mixing angle ϕ required to diagonalize the mass matrix obeys

$$\sin 2\phi = \frac{2\lambda_{H\theta}v_H v_\theta}{m_\theta^2 - m_h^2}, \quad (6)$$

where v_θ and v_H are the VEVs of the flavon and Higgs fields, respectively, with m_θ and m_h being their respective physical masses.

The Z' leaves an imprint on the EWPOs (a detailed discussion of the fit to present-day EWPO data can be found in [26]), not least because the custodial symmetry of the SM is now violated. Furthermore, ϕ influences the electroweak sector through one-loop effects, in addition to its tree-level impact on Higgs production processes. These features make the model susceptible to constraints from both electroweak and Higgs production observables, measurable at current colliders as well as at the FCC-ee.

Figure 1 shows the expected improvement in precision of constraints on the model from Higgs observables and EWPOs at the FCC-ee in a plane of TFHM parameter space. The SM point lies at the origin: we see initially that the “Quarks + LFU” region, preferred by B meson decay data, is far from this point, but that current Higgs and EWPO measurements are compatible with it. The figure also illustrates the improvement in precision and sensitivity once FCC-ee measurements are taken into account. Supposing the SM to be the theory chosen by nature,

TABLE I. Goodness of fit of the TFHM at its best-fit point, $\{g_{Z'} = 0.412, \theta_{sb} = -0.182\}$, when $M_{Z'}$ is set to 3 TeV. From left to right, the columns show the names of the observable set used, the χ^2 values, the number of observables in each set, the p -values, and finally the improvements in χ^2 relative to the SM fit, with positive values signaling an improved fit.

Dataset	χ^2	n	p value	$\Delta\chi^2$
Quarks	393.8	306	5.14×10^{-4}	29.45
LFU FCNCs	19.0	24	0.75	-0.43
EWPOs	36.9	31	0.22	0.08
Global	449.4	361	1.0×10^{-3}	29.10

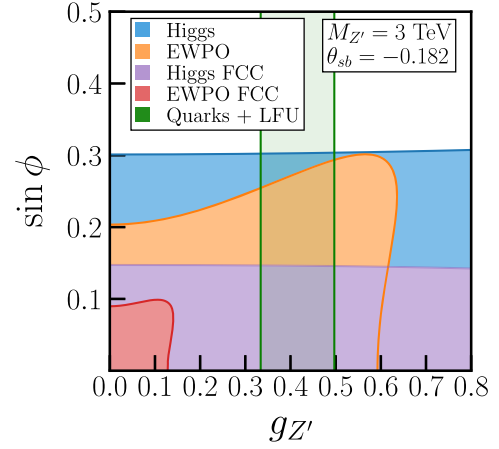


FIG. 1. 95% confidence level contours of the TFHM in the $\sin \phi - g_{Z'}$ plane for $M_{Z'} = 3$ TeV and $\theta_{sb} = -0.182$. The plot shows current constraints and SM-centered FCC-ee projections. The colored region corresponding to the legend is “allowed” for each class of observables: that of “Quarks + LFU” shows the current 95% region preferred by the fit to B meson data; “Higgs” and “EWPO” refer to current constraints. Legend items including the word “FCC” show FCC-ee sensitivity estimates.

the TFHM region of parameter space currently preferred by the “Quarks + LFU” data (which includes the anomalous B decays) would be strongly disfavored by the FCC-ee.

Both current and projected electroweak measurements show a mild degeneracy, where increasing $g_{Z'}$ and ϕ simultaneously allows for a mixing angle larger than when the gauge coupling is zero. This is because an increased Higgs-flavon mixing angle acts to lower M_W , whilst an increased $g_{Z'}$ makes the W boson heavier. It is these opposite sign contributions to M_W , whose experimental world average (prior to the 2022 CDF measurement) is in 2σ tension with the SM [28], that give rise to this behavior.

IV. CLOSING REMARKS

We have extended the SMELLI and FLAVIO computer packages to provide an estimate of the FCC-ee sensitivity to heavy new physics with family-dependent couplings. We have accounted for the leading correlations among theoretical uncertainties, which, to the best of our knowledge, is not implemented in other tools. To illustrate the use of the new features, we have shown how the current TFHM fit can be strongly disfavored by electroweak and Higgs measurements at the FCC-ee. The FCC-ee is expected to deliver 10^{12} B mesons [29], allowing for a further increase in precision on the measurement of processes involving the $b \rightarrow s\mu^+\mu^-$ transition. This may lead to the abandonment or further tweaking of the TFHM, since such processes were a large part of the initial motivation for it; in either case, indirect measurements at the FCC-ee will lead our direction beyond (or indeed back to) the SM.

We hope to improve our computations in many ways in the future. Several more observables could be added, for

instance *differential* Higgs and W production observables, observables derived from $t\bar{t}$ production and projected FCC-ee B meson measurements, which are important in flavorful SM extensions. It will also be of interest to study the correlations between various intrinsic theory errors in greater detail and to include estimates of correlations among the experimental uncertainties, for example from the luminosity measurement, which has a goal fractional precision of 10^{-4} [30]. This uncertainty would have almost complete correlation across all cross-section measurements and will be taken into account in future versions of the program. We note that a potential source of systematic uncertainty is from new physics affecting the luminosity measurement, which then will filter into other observables. At the FCC-ee, the luminosity will be inferred from small-angle Bhabha scattering, $e^+e^- \rightarrow e^+e^-$ [30], which would be affected by new physics that gives nonzero contributions to it [31]. This will be mitigated in future versions of the program by including the new physics contribution to low-angle Bhabha scattering.

The features introduced here could be straightforwardly extended to other proposed e^+e^- colliders. In addition to e^+e^- colliders comparable to the FCC-ee, a similar analysis could be conducted for the proposed TeV-scale muon colliders, although the domain of validity of the SMEFT approach would be smaller because a muon collider would operate at a larger center-of-mass energy, which the mass of new degrees of freedom must be larger than. We believe that high-energy physics stands to benefit greatly from the development of accessible and automated tools for

comparing the sensitivities of various proposed colliders to a range of concrete extensions of the SM. In this letter, we hope to have taken a meaningful step toward that goal. The computer programs and instructions for their use can be found at [32] and [33].

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DATA AVAILABILITY

The data that support the findings of this article are openly available [34].

APPENDIX: LIST OF FCC-EE OBSERVABLES

Tables I and II of this appendix display the full sets of Higgs and electroweak observables included in our tool. Whenever an observable is defined at many different center-of-mass energies, $\sqrt{s}$ is treated as an extra parameter for the EWPOs, whereas $\sqrt{s}$ appears in the name of the Higgs signal strength observables. This feature, which results from striving to modify the existing FLAVIO program as minimally as possible, explains the differences in the naming conventions between the two tables.

TABLE II. Electroweak precision observables in FLAVIO and SMELLI whose projected measurements have been added to the programs. The first column shows the name of the observable, the second its name in the code, and the third a brief description.

	Observable	Name in program	Description
Z-pole observables	Γ_Z	GammaZ	Total Z boson decay width
	σ_{had}^0	sigma_had	Cross-section $\sigma(e^+e^- \rightarrow \text{hadrons})$ at the Z-pole
	A_e	A(Z->ee)	Left-right asymmetry in $Z \rightarrow e^+e^-$ decays
	A_μ	A(Z->mumu)	Left-right asymmetry in $Z \rightarrow \mu^+\mu^-$ decays
	A_τ	A(Z->tautau)	Left-right asymmetry in $Z \rightarrow \tau^+\tau^-$ decays
	A_b	A(Z->bb)	Left-right asymmetry in $Z \rightarrow b\bar{b}$ decays
	A_c	A(Z->cc)	Left-right asymmetry in $Z \rightarrow c\bar{c}$ decays
	R_e	R_e	Partial decay width $\Gamma_{Z \rightarrow ee}$ relative to hadronic width
	R_μ	R_mu	Partial decay width $\Gamma_{Z \rightarrow \mu\mu}$ relative to hadronic width
	R_τ	R_tau	Partial decay width $\Gamma_{Z \rightarrow \tau\tau}$ relative to hadronic width
	R_b	R_b	Partial decay width $\Gamma_{Z \rightarrow bb}$ relative to hadronic width
	R_c	R_c	Partial decay width $\Gamma_{Z \rightarrow cc}$ relative to hadronic width

(Table continued)

TABLE II. (Continued)

	Observable	Name in program	Description
Z-pole fermion scattering	$\sigma(e^+e^- \rightarrow e^+e^-)$	sigma(ee->ee) (high_E)	Cross section of $e^+e^- \rightarrow e^+e^-$; $\sqrt{s} = 240, 365$ GeV
	$A_{\text{FB}}(e^+e^- \rightarrow e^+e^-)$	AFB(ee->ee) (high_E)	Forward-backward asymmetry in $e^+e^- \rightarrow e^+e^-$; $\sqrt{s} = 240, 365$ GeV
	$\sigma(e^+e^- \rightarrow \mu^+\mu^-)$	sigma(ee->mumu) (high_E)	Cross section of $e^+e^- \rightarrow \mu^+\mu^-$; $\sqrt{s} = 240, 365$ GeV
	$A_{\text{FB}}(e^+e^- \rightarrow \mu^+\mu^-)$	AFB(ee->mumu) (high_E)	Forward-backward asymmetry in $e^+e^- \rightarrow \mu^+\mu^-$; $\sqrt{s} = 240, 365$ GeV
	$\sigma(e^+e^- \rightarrow \tau^+\tau^-)$	sigma(ee->tautau) (high_E)	Cross section of $e^+e^- \rightarrow \tau^+\tau^-$; $\sqrt{s} = 240, 365$ GeV
	$A_{\text{FB}}(e^+e^- \rightarrow \tau^+\tau^-)$	AFB(ee->tautau) (high_E)	Forward-backward asymmetry in $e^+e^- \rightarrow \tau^+\tau^-$; $\sqrt{s} = 240, 365$ GeV
	$\sigma(e^+e^- \rightarrow \bar{b}b)$	sigma(ee->bb) (high_E)	Cross section of $e^+e^- \rightarrow \bar{b}b$; $\sqrt{s} = 240, 365$ GeV
	$A_{\text{FB}}(e^+e^- \rightarrow \bar{b}b)$	AFB(ee->bb) (high_E)	Forward-backward asymmetry in $e^+e^- \rightarrow \bar{b}b$; $\sqrt{s} = 240, 365$ GeV
	$\sigma(e^+e^- \rightarrow \bar{c}c)$	sigma(ee->cc) (high_E)	Cross-section of $e^+e^- \rightarrow \bar{c}c$; $\sqrt{s} = 240, 365$ GeV
	$A_{\text{FB}}(e^+e^- \rightarrow \bar{c}c)$	AFB(ee->cc) (high_E)	Forward-backward asymmetry in $e^+e^- \rightarrow \bar{c}c$; $\sqrt{s} = 240, 365$ GeV
W boson observables	M_W	m_W	Pole mass of the W boson
	Γ_W	GammaW	Width of the W boson
	$R(e^+e^- \rightarrow W^+W^-)$	R(ee->WW)	Inclusive WW production cross-section normalized to SM prediction; $\sqrt{s} = 161, 240, 365$ GeV
	$\text{BR}(W \rightarrow e\nu)$	BR(W->enu)	W boson branching ratio into $e\nu$
	$\text{BR}(W \rightarrow \mu\nu)$	BR(W->munu)	W boson branching ratio into $\mu\nu$
	$\text{BR}(W \rightarrow \tau\nu)$	BR(W->taunu)	W boson branching ratio into $\tau\nu$

TABLE III. Higgs signal strength observables whose projected measurements were added into the programs. The first column shows the name of the observable, whereas the second column gives its name in the code. The notation $\{240|365\}$ means that the observable is defined for two values of $\sqrt{s}$, one of which should be specified by the user.

Observable	Name in program
$\mu(e^+e^- \rightarrow Zh)$	mu_Zh_{240 365} (h->inc)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow \bar{b}b)$	mu_Zh_{240 365} (h->bb)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow \bar{c}c)$	mu_Zh_{240 365} (h->cc)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow gg)$	mu_Zh_{240 365} (h->gg)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow ZZ)$	mu_Zh_{240 365} (h->ZZ)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow WW)$	mu_Zh_{240 365} (h->WW)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow \tau\tau)$	mu_Zh_{240 365} (h->tautau)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow \gamma\gamma)$	mu_Zh_{240 365} (h->gammagamma)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow Z\gamma)$	mu_Zh_240 (h->Zgamma)
$\mu(e^+e^- \rightarrow Zh; h \rightarrow \mu\mu)$	mu_Zh_{240 365} (h->mumu)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow \bar{b}b)$	mu_hnunu_{240 365} (h->bb)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow \bar{c}c)$	mu_hnunu_365 (h->cc)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow gg)$	mu_hnunu_365 (h->gg)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow ZZ)$	mu_hnunu_365 (h->ZZ)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow WW)$	mu_hnunu_365 (h->WW)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow \tau\tau)$	mu_hnunu_365 (h->tautau)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow \gamma\gamma)$	mu_hnunu_365 (h->gammagamma)
$\mu(e^+e^- \rightarrow h\nu\nu; h \rightarrow \mu\mu)$	mu_hnunu_365 (h->mumu)

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