FLAVOUR PHYSICS AT THE FCC-ee*

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The perspectives of flavour physics studies at the future FCC-ee collider are briefly discussed. The latter comprises a project of giant circular electron–positron collider which is under consideration at CERN. The following three specific issues will be addressed: studies of the decay $B \to K^{*0}(892)\tau^+\tau^-$, searches for charged lepton flavour violation in Z^0 boson and τ lepton decays, together with the detection prospects of heavy, long-living sterile neutrinos.

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1. Introduction

The main task of particle physics for the next few decades is to elucidate the nature of so-called new physics (NP) [1]. This buzzword encompasses a vast set of models which generally extend and cure shortcomings of the current theory, *i.e.* Standard Model (SM) [2]. In pursuit of this goal, the construction of new electron–positron collider operating at the energy frontier is being seriously considered. Four such projects are currently under development. Two of them are proposed as linear accelerators: ILC [3] in Japan and CLIC [4] at CERN. The remaining two, CEPC [5] in China and FCC-ee [6] at CERN, are considered as circular colliders. In the scenario in which no new particle and/or interaction will be directly observed in the near future, the searches for NP can rely heavily on virtual effects from new particles present in the loops. Such phenomena are expected predominantly in the interactions involving so-called heavy flavours *i.e.* the quarks b and c and the τ lepton. The importance of this approach, commonly labelled flavour physics, was broadly discussed at this conference, devoted to discrepancies w.r.t. the SM expectations, which were recently observed in the $b \to s$ quark transitions [7].

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The paper is organized as follows. First, the FCC-ee project is briefly discussed (Section 2). The next three sections (Sections 3–5) are devoted to the flavour physics studies, aimed at estimation of FCC-ee sensitivity to the selected NP phenomena. The issues related to the $\bar{B}^0 \to \bar{K}^{*0}(892)\tau^+\tau^-$ decay[1], charged Lepton Flavour Violation and searches for Heavy Neutral Leptons will be presented.

2. The FCC project

The Future Circular Collider (FCC) project [6] assumes the construction of a 100 km circumference accelerator tunnel in the Geneva area, thus taking advantage of the present CERN infrastructure. The possible first phase of the project, labelled FCC-ee, would comprise the instrumentation of the tunnel with a high-luminosity e^+e^- collider. The latter would operate in the centre-of-mass energy spanning the range from the Z^0 mass up to beyond the $t\bar{t}$ threshold. The flagship part of the overall project is a 100 TeV proton–proton collider FCC-pp, which is to be commissioned after the e^+e^- phase.

The FCC Collaboration aims at providing the Conceptual Design Report, together with a cost estimate, by the end of 2018. Thus, the FCC project will be taken into account in the discussions about the update of European Strategy for particle physics in 2020.

TABLE I

Selected parameters of the FCC-ee accelerator. The characteristics of LEP collider have been supplemented for comparison. The following parameters are presented: beam energy ($E_{\rm b}$), number of Interaction Points (IPs), beam current (I), number of bunches, horizontal (vertical) beta function at the IP ($\beta_x^*(\beta_y^*)$), horizontal (vertical) emittance ($\epsilon_x(\epsilon_y)$), synchrotron radiation power ($P_{\rm SR}$) and luminosity (L).

Parameter	LEP2	FCC-ee			
$E_{\rm b}$ [GeV]	104	45.6	80	120	182.5
# of IPs	4	2	2	2	2
I [mA]	4	1390	147	29	6.4
# of bunches	4	16640	2000	393	39
β_x^* [mm]	1500	150	200	300	1000
β_y^* [mm]	80	0.8	1	1	2
ϵ_x [nm]	30–50	0.27	0.28	0.63	1.45
ϵ_y [pm]	250	1	1	1.3	2.7
$P_{\rm SR}$ [MW]	22	100	100	100	100
L [10^{34} cm $^{-2}$s^{-1}/IP]	0.012	230	32	8	1.5

[1] The inclusion of charge conjugate modes is implied throughout this paper.

The FCC-ee physics programs envisions high-luminosity operation at four working points, corresponding to the centre-of-mass energy of Z^0 pole and masses of W^+W^-, Z^0H and $t\bar{t}$ pairs [8]. Their most relevant parameters are presented in Table I and compared with LEP collider [9].

3. Studies of the $\bar{B}^0 \to \bar{K}^{*0}(892)\tau^+\tau^-$ decay

The processes $b \to sl^+l^-$ proceeds via quark flavour-changing neutral current transition. The experimental sensitivity for studies of these decays was estimated by the FCC-ee Collaboration for the particular case of the decay $\bar{B}^0 \to \bar{K}^{*0}(892)\tau^+\tau^-$ [10, 11]. The clear advantage of this process lies in the opportunity of reconstruction of the $\bar{K}^{*0}(892)$ ($\to K^-\pi^+$) secondary vertex. In addition, the study was restricted to the decays of τ leptons involving three charged prongs in the final state. This approach ensures the reliable reconstruction of tertiary vertices of τ decays. The above-described decay topology provides sufficient number of kinematical constraints in order to solve the system, in spite of the lack of information about the four momenta of two neutrinos present in the final state.

The sample of 10^{13} events was generated with a fast simulation featuring a generic detector. Such statistics would correspond to the full data sample expected from the FCC-ee operation at the Z^0 pole. The resulting spectrum of the $K^*(892)\tau^+\tau^-$ invariant mass is shown in Fig. 1. More than thousand

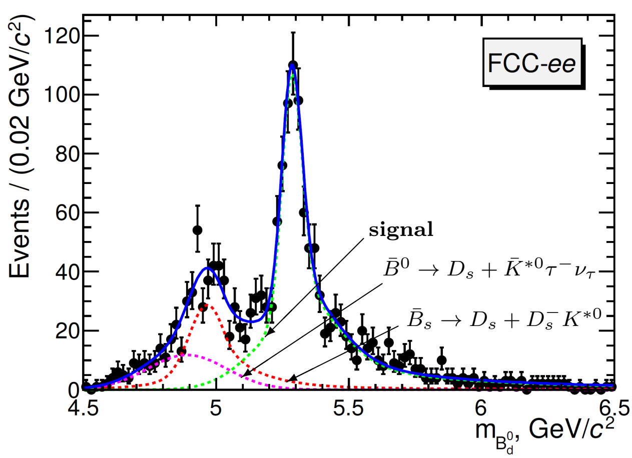

Fig. 1. (Colour on-line) The distribution of $K^*(892)\tau^+\tau^-$ invariant mass. The overall fit to candidates obtained from a fast simulation is shown as solid/blue line, while the signal is represented by the green Gaussian distribution. Also shown are the two dominant background spectra from $\bar{B}_s \to D_s + D_s^- K^{*0}(892)$ and $\bar{B}^0 \to D_s + \bar{K}^{*0}(892)\tau^-\nu_\tau$ decays (red and pink lines, respectively).

of reconstructed signal events are expected to be reconstructed. With such a sample of $\bar{B}^0 \to \bar{K}^{*0}(892)\tau^+\tau^-$ events, it would be possible, for the first time, to perform the angular analysis of the decay in question.

4. Searches for charged Lepton Flavour Violation

So far, no signs of violation of lepton number conservation were observed in the sector of charged leptons. This phenomenon is commonly denoted as cLFV (charged Lepton Flavour Violation). The cLFV decays are excruciatingly forbidden in the Standard Model as they can occur only via box and penguin processes. However, in a broad category of NP models, the expectations of branching ratios for such transitions reach the level of 10^{-9}, thus matching the sensitivity of cLFV studies of the FCC-ee Collaboration. The latter were performed for two categories of decays. The first one encompasses the decays of Z boson to the pair of charged leptons, carrying different flavours *e.g.* $Z \to \mu^+e^-$ [10, 12]. The FCC-ee sensitivity for these decays was found to reach 10^{-9}–10^{-10} with the maximum impact from the final state $\mu\tau$. This value can be compared with the current experimental limits, spanning the range of 10^{-5}–10^{-7} [13]. The second class of cLFV processes includes rare decays of the τ lepton, in particular those leading to the final states $\mu\gamma$ and $\mu\mu\mu$. For the latter, the current experimental limits are of the order of 10^{-8} [13]. Here, the FCC-ee is expected to reach the sensitivity of 10^{-10}–10^{-11} [14].

5. Searches for Heavy Neutral Leptons

The masses of light neutrinos can be effectively generated via the see-saw mechanism upon the inclusion of right-handed sterile neutrinos. These particles are generally very heavy and in many models they exhibit substantial lifetimes, leading to macroscopic decay lengths, reaching even the distances of the order of 1 m. Such neutrinos are usually named Heavy Neutral Leptons (HNL) [15, 16]. In their presence, the physical neutrino states (ν_L) are mixtures of light Dirac neutrino (ν) and an HNL state (N)

$$\nu_L = \nu \cos\theta + N \sin\theta \tag{1}$$

with the mixing angle given by the ratio of the respective masses: $\theta \approx m_\nu/m_N$. Thus, the HNL can be produced in electron–positron annihilation in the process $e^+e^- \to \nu N$ via Z formation or W exchange. The decay signatures of heavy sterile neutrinos can be truly unique as they would form secondary vertices with macroscopic decay length and a high invariant mass. In particular, the following two topologies: a lepton and two hadronic jets or a pair of charged leptons with different flavours and a missing mass, are attractive for experimental searches.

The sensitivity of experimental searches for HNL is usually parametrized in terms of the ν–N coupling ($|U|^2 \propto \theta^2$) and the HNL mass. As shown in Fig. 2 (from [16]), the expected sensitivity of the FCC-ee Collaboration, evaluated in terms of the coupling $|U|^2$, spans the range of 10^{-6}–10^{-12}.

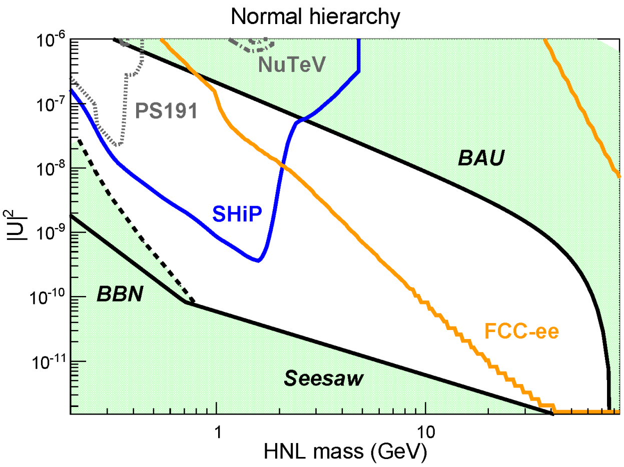

Fig. 2. (Colour on-line) Regions of sensitivity for HNLs as a function of mass and mixing to light neutrinos ($|U|^2$). The solid grey/orange curve corresponds to the FCC-ee sample of 10^{13} Z bosons. The shaded/light-green regions are excluded due to the constraints from the Baryon Asymmetry in the Universe (BAU), the Big Bang Nuclesynthesis (BBN) and the see-saw mechanism (no possibility to reproduce the masses of light neutrinos in the respective part of the plot). The normal mass hierarchy of light neutrinos is assumed.

6. Summary

The FCC-ee project offers a vast physics programme, in particular in the flavour physics sector. A few selected topics from this field have been briefly discussed.

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