PROCEEDINGS OF SCIENCE

Tau Physics at the SuperB factory

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SuperB factory will be a high luminosity asymmetric e^+e^- factory with a projected peak luminosity of $10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and running at the $\Upsilon(4S)$ resonance energy. Thanks to the high cross section for τ-pair production SuperB will be able to record one of the largest τ decay samples making it possible to study rare decays, to search for Lepton Flavor Violation, and to test the Electro Weak sector at unprecedented sensitivities. The 80% electron beam polarization option provide further capabilities in the search for Lepton Flavor Violaton and precision EW measurements.

The Xth Nicola Cabibbo International Conference on Heavy Quarks and Leptons,
October 11-15, 2010
Frascati (Rome) Italy

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PoS(HQL 2010)038

1. Introduction

SuperB is a proposed asymmetric e^+e^- factory designed to reach a peak luminosity of 10^{36}cm^{-2} s^{-1}, with a projected integrated luminosity of 75 ab^{-1} in a five-year period of data taking, it is expected to record a sample of more than 80×10^9 τ pairs. The recorded sample will be the largest data sample available in the world, ensuring unprecedented sensitivities to rare processes involving τ decays. SuperB machine will have the possibility to have an 80% longitudinally polarized e^- beam, which is not expected at other super flavor factories such as BelleII at SuperKeK. The polarization option would give a clear edge for both Lepton Flavor Violating decays signal selection and the possibility to test with high precision the Electro-Weak sector of the Standard Model (SM) [1]. In Fig. 1 luminosities for present and past machines are reported, along with the projected peak luminosity for Super Flavor Factories.

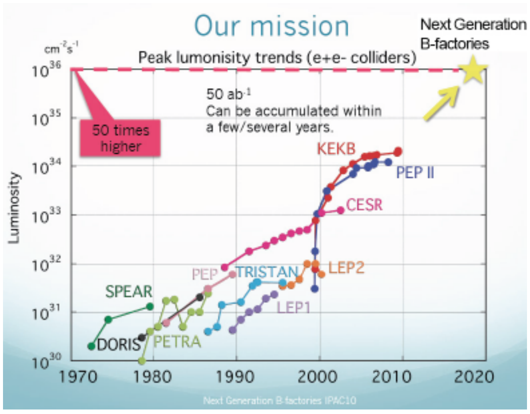

Figure 1: Luminosity trends for e^+e^- colliders as a function of the time.

2. Lepton Flavor Violation

Lepton Flavor Violation (LFV) involving charged leptons has never been observed, and stringent experimental limits exist for both μ and τ decays [2], on the other hand results from ν oscillations [3] show that LFV does indeed occur, although branching ratios (BR) for charged leptons in SM have an expected rate of $\mathscr{O}(10^{-40})$. Many NP models predict BR larger than $\mathscr{O}(10^{-10})$, which are within the expected SuperB experimental sensitivities. An observation of LFV in τ decays would be a clear signature of NP, while improved limits provide further constraints on theoretical models [4]. Looking for LFV processes not only provide a direct test for NP: if more than one LFV channel BF is going to be measured, SuperB would be also able to get informations on the NP flavor structure by looking at the BF ratios between different channels [5].

2.1 Search for $\tau \to \mu\gamma$

Most NP models identify $\tau \to \mu\gamma$ decay to be the LFV process involving τ decays with the largest BR, so the search for this particular decay is of great importance for NP searches in the τ sector. Results from the previous B-factories presented some irreducible backgrounds which came from radiative τ decays such as $\tau \to \mu\nu\nu\gamma$, where the νs are produced almost at rest. This background can not be reduced due to the similarity to the process of interest, since background events have the same reconstructed energy and momenta expected for signal candidate τs. BaBar performed a blind analysis for $\tau \to \mu\gamma$ search, expecting 5.1 backround events in the 2σ blinded region, 1.7 coming from lepton tags and 2.0 coming from single hadron tags (π and ρ), 96% of the backgrounds come from real τ decays (86% from radiative $\tau \to \mu\nu\nu\gamma$). If no further backgrounds are introduced, it is possible to extrapolate the present background expectation to the Super Flavor Factories by making a simple luminosity scaling. Considering an integrated luminosity of 75 ab^{-1} the expected backgrounds for a Super Flavor Factory are of $\mathscr{O}(300)$ events in the signal region, leading to an UL$\sim 6.4 \times 10^{-9}$, obtained by the scaling of the previous BaBar result with $\sqrt{\mathscr{L}}$. Considering BaBar results if no further background reduction is achieved there will not be a great improvement in the UL, however the polarization option would make it possible to use the information on the dynamics of the decay, which are not accessible with unpolarized beams, leading to the possibility of strong background reductions along with high selection efficiencies.

Polarization allows to study the dynamical properties of the decay: in the case of single hadron tag modes ($\tau \to \rho\nu$ and $\tau \to \pi\nu$), the event candidate has only one ν (in the signal hypothesis), this has two main effects, the event kinematics is fully reconstructed with missing momenta being the ν momenta, and more importantly the helicity of the event is fixed, since the ν is considered massless and hence chiral. Due to the event fixed helicity it is possible to exploit the angular correlation between the signal and tag tracks helicity angle: the helicity angle is defined as the angle between the track momentum in the parent τ rest frame and the momentum direction of the other τ in the laboratory frame. The correlation for both signal and backgrounds is shown in Fig. 2.

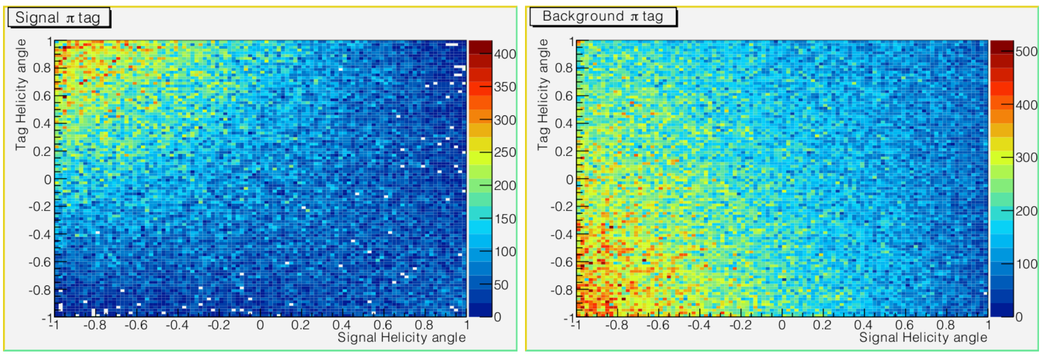

Figure 2: Correlation between signal track and tag track helicity angles for signal events (left) and background events (right) for $\tau \to \pi\nu$ tag. On the horizontal axis the signal helicity angle is plotted while on vertical axis tag helicity angle is shown.

Applying simple selection on the helicity correlation it is possible to reduce the backgrounds of a factor of 10 retaining 50% of the signal. The use of only single hadron tags and helicity selection would reduce the expected background to $\mathscr{O}(15)$ events, with an UL scaling almost proportional to the $\mathscr{L}$. The improvement using polarized beams would lead to a sensitivity of 3.9×10^{-9} corresponding to an increase of the $\mathscr{L}$ of a factor 2.6, albeit using only 25 % of the τs produced. Further improvements are expected using the same method on lepton tags, even if the effect is going to be diluted due to the presence of two νs in the event.

2.2 Search for $\tau \to \ell\ell\ell$

The search for $\tau \to \ell\ell\ell$ decays allows the simultaneous study of six different channels, and even if the theoretical predictions generally expect smaller BF with respect to $\tau \to \mu\gamma$, the study of these channels would make it possible to discover the NP flavor structure if more than one channel is observed. Background expectation for $\tau \to \ell\ell\ell$ were small in both BaBar and Belle analyses, so even considering a scaling of the backgrounds proportional to the increase in integrated luminosity, the ULs are expected to scale almost linearly with $\mathscr{L}$ as shown in Fig. 3. SuperB will be able to reach ULs of the order of 10^{-10} for all the $\tau \to \ell\ell\ell$ channels with an improvement of almost 2 orders of magnitude with respect to the previous generation flavor factories.

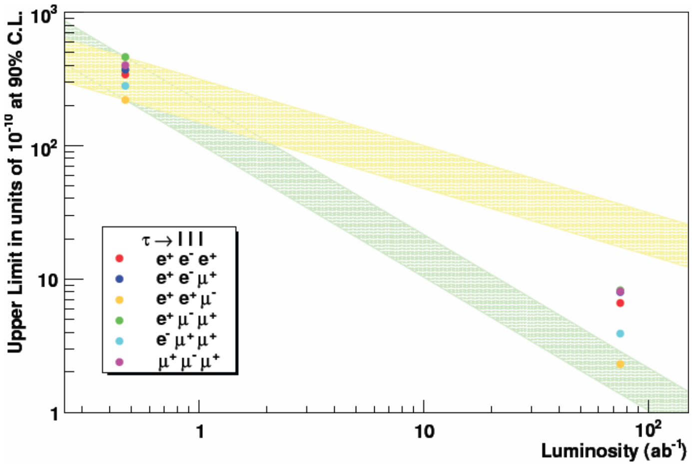

Figure 3: UL measured at the B-factories and extrapolation at 75 ab^{-1}. The yellow shading presents the background dominated expectation ($\propto \sqrt{\mathscr{L}}$) and the green shading the background free expectation ($\propto \mathscr{L}$) for the ULs

If the BR are large enough to observe many events in one of the channels, it would be possible to look at the Dalitz plot for the three leptons in order to look for the chiral simmetry of the NP interactions, which would be impossible to study with $\tau \to \mu\gamma$ decays.

3. g-2 measurement in τ decays

Recent observations shown a discrepancy between the QED expectation on Δa_μ and the experimental results. Since most of the theoretical models predict a positive power dependence on the mass of the lepton involved the effects on Δa_τ should be almost three order of magnitude larger than in muons, with $\Delta a_\tau \sim 0.4 - 1.4 \times 10^{-6}$[6]. By measuring the differential cross section in the τ pair production it is possible to measure the real part of the magnetic form factor of the τ. Present results are limited mainly by tracking systematics, however experience with the BaBar analysis shown that such systematic uncertainties could be reduced using control samples, and so they would become much smaller at super flavor factories thanks to larger statistics, achieving resolutions on the real part of F_2 of $(0.75 - 1.7) \times 10^{-6}$. Comparisons between present flavor factories and future flavor factories results are shown in Tab. 1.

Table 1: Resolution on real and imaginary parts of the τ electromagnetic form factor for present and future flavor factories.

EXPERIMENT	Cross Section	Normal Asymmetry
$\Downarrow$	$Re\{F_2\}$	$Im\{F_2\}$
Babar+Belle $2ab^{-1}$	4.6×10^{-6}	2.1×10^{-5}
Super B/Flavor Factory (1 yr. running) $15ab^{-1}$	1.7×10^{-6}	7.8×10^{-6}
Super B/Flavor Factory (5 yrs. running) $15ab^{-1}$	7.5×10^{-7}	3.5×10^{-6}

4. CP violation in τ decays

In the last ten years flavor factories provided many results concerning CP violation, ranging from b-quark sector to charm oscillation in D mesons, however no CP violation in the lepton sector was observed. SM accounts for CPV in τ sector, but theoretical expectations are well below the present sensitivity to such processes, with expected CPV effects of $\mathscr{O}(10^{-12})$. Any evidence of CPV in the τ sector would be a clear signature for NP, even with SuperB statistics. The most interesting channels for CPV studies in τ sector are $\tau \to K_S \pi \nu$ and $\tau \to K_S \pi \nu$, in both cases K_S mixing may provide fake CPV effects, however the mixing in the K sector is well know and could be easily subtracted. The analysis is limited by tracking systematics and K_S reconstruction efficiency, however the large statistics provided by SuperB would lead to unprecedented sensitivities to CPV, extending the present UL on CPV processes and offering a great prospect for the discovery of NP in the leptonic sector.

5. Conclusion

SuperB has a large and wide physics case, ranging from CPV in both up and down sectors, to precision measurement in the leptonic sector. Among the topics that will be investigated by SuperB the τ physics constitutes one of the most interesting ones. Thanks to the 80% polarization of the e^- beam it would be possible to have new handles to improve background rejection for $\tau \to \mu\gamma$ searches, and together with the increase in statistics SuperB is expected to reach sensitivities up to 3.9×10^{-9} for such processes. LFV will also be investigated by searching for $\tau \to \ell\ell\ell$ decays, reaching sensitivities of $O(10^{-10})$. SuperB will also be able to make precision studies in the leptonic sector, both concerning the electromagnetic structure of the τ by looking at g-2 and EDM, and the leptonic sector flavor structure, by searching for CPV in τ decays. In conclusion for SuperB τ physics will be one of the main tools for the search of NP and the understanding of NP flavor structure in the near future.

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