Precision experiments at Super Charm-Tau Factory
Letter of Interest for Snowmass 2021

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The role of the precision particle physics experiments at low energy is going to grow in the next 10 - 20 years as complimentary to direct search of the new physics at energy frontier. Super flavour factories are electron-positron colliders with high luminosity which provide an opportunity for such experiments. Super charm-tau factory (SCTF) is going to operate in the center-of-mass energy range $\sqrt{s}$ between 2 GeV and 6 GeV with the peak luminosity of 10^{35} cm^{-2}s^{-1}. SCTF has one interaction point with a general-purpose particle detector with outstanding detection efficiency of soft tracks and particle identification quality. The goal of SCTF is to study a wide range of phenomena with charmed hadrons and tau lepton with high accuracy at threshold production, which gives an opportunity for discovery of rare or forbidden by standard model (SM) effects and makes it complementary to already operating Belle II and LHCb.

SCTF EXPERIMENT SUMMARY

Budker Institute of Nuclear Physics proposed and develops the SCTF project [1]. Conceptual design report of SCTF accelerator facility and detector is published [2]. The accelerator complex consists of positrons and polarized electrons sources, linear accelerators and a double-ring collider. Crab-waist collision scheme [3, 4] ensures high luminosity.

The SCTF detector includes: 1) inner tracker, with alternative designs based on the TPC and Micro-Pattern Gas detector; 2) drift chamber as a central tracker; 3) system of charged particle identification via Cherenkov light detection; 4) crystal calorimeter; 5) solenoid with uniform 1.5 T magnetic field; 6) dedicated system for detection of muons and K_L^0 meson decays.

The SCTF collider will deliver 1 ab^{-1} of integrated luminosity per year with yield of 10^{12} J/ψ mesons, 10^9 charmed mesons, 10^9 tau leptons, and 10^8 charmed baryons.

The maximal trigger rate is 300 kHz at the J/ψ resonance and corresponds to the front-end electronics data flow at 1 GB/s. The experiment requires a medium-size data processing and storage system with 200 PB storage space.

The total cost of the SCTF project is 600 MUSD, 80% of which goes to the accelerator complex and the remaining 20% — to the detector and the computing facility. Construction time is six years after funding.

HIGHLIGHTS OF SCTF PHYSICS PROGRAM

Diverse physics program of the SCTF experiment covers 1) charm physics, 2) tau lepton physics, and 3) studies of light quarks strong interactions. Advantages of SCTF in comparison with Belle II and LHCb are 1) the threshold kinematics, 2) low multiplicity of final-state particles, 3) well-identified initial state, 4) full event reconstruction technique providing the best possible signal-to-background ratio for the processes with final-state neutrals.

SCTF is unique because of the following features.

Only SCTF allows precision studies of the vast majority of the charmonium family, for example, the not yet observed rare charmonium transitions like $\eta_c(2S) \to h_c\gamma$, weak J/ψ decays such as $J/\psi \to D_s^+\rho^-$, and C-parity violating decays like $J/\psi \to \phi\phi$. The importance of rare processes is in testing the SM since non-standard mechanisms can change their rates significantly.

Near-threshold production of charmed hadrons is the only way to measure precisely *the absolute* branching fractions of the charmed hadrons, among them of particular interest are $D^0 \to K^-\pi^+$, $D^+ \to K^-2\pi^+$, $\Lambda_c^+ \to pK^-\pi^+$. The uncertainties on the branching fractions of these decays affect many measurements at LHCb and Belle II.

At threshold, the pairs of neutral charm mesons $D^0\overline{D}^0$ are produced in the coherent state. Coherence makes their decay rates sensitive to the decay amplitudes' phases and provides a unique opportunity to measure these phases [5]. Approaches to measurements of the charm mixing and CP symmetry breaking with coherent $D^0\overline{D}^0$ pairs are different from other experimental setups, but possess comparable accuracy. Both charm mixing and CP violation in charm are small in nature and provide a good null test for the SM.

The D^0 decay amplitude phases are essential external input for measuring the CKM phase γ at LHCb and Belle II in $B^\pm \to DK^\pm$ decays [8]. Currently, this information comes from CLEO-c and BES-III measurements [9, 10] only. In the future, the data from high luminosity LHC will require higher precision, which will be achieved at the SCTF.

The SCTF project designed to have longitudinal polarized electrons in the interaction point. If realized, SCTF will be the only flavor factory with a polarized beam [1]. Left-right cross-section

[1] but possible upgrade of SuperKEKB [arXiv:1907.03503 [hep-ex]]

asymmetry at the J/ψ resonance, generated by the polarization, is used to measure the weak mixing angle (the Weinberg angle) at sub-percent precision level [6]. Polarized beam boosts the measurements of the baryonic form factors and CP violation in baryons (see ref. [6] for the detailed study of the $J/\psi \to \Lambda\overline{\Lambda}$ case).

Belle II will yield a larger tau-lepton data set, than SCTF. However, the accuracy limitation of many tau lepton experiments comes from systematic uncertainties rather than statistical ones, so careful analysis is required to compare different experimental setups. It was done for a lepton-flavor-violating $\tau \to \mu\gamma$ search in ref. [7], where the authors showed a clear advantage of SCTF over a Super B factory. Another well-studied case is measurement of Michel parameters with a polarized beam. The SCTF setup with a polarized beam allows to perform a 3D analysis instead of 6D as in the B-factory case resulting in a better final precision.

The SCTF is also a factory of light mesons produced via the decays of 10^{12} J/ψ per year, which opens an opportunity for comprehensive studies of strong interactions at low energies and for a search for exotic resonances.

CURRENT ACTIVITY AND COLLABORATION AROUND SCTF

The SCTF project is in the list of megascience projects, selected by the Russian government to be implemented in the future. Several research organizations expressed their interest to participate in the SCTF experiment including CERN, INFN, KEK (Tsukuba), IHEP (Beijing), in the form of bilateral MoSs and MoUs with BINP.

ECFA evaluated and supported the SCTF accelerator project. The SCTF project was discussed at the Granada symposium (2019) in the framework of the Eurostrategy in particle physics update and is mentioned in the updated version of the Strategy (May 2020).

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BINP is forming an international collaboration around the SCTF experiment. The International advisory committee (IAC) was formed in 2018 for the regular assessment of the project development. Regular international workshops devoted to future Super charm-tau factories are held annually [12–14].

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