Letter of Interest for Snowmass 2021

Physics in the τ-charm Region at BESIII

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The BESIII collaboration, which operates the BESIII spectrometer at the Beijing Electron Positron Collider (BEPCII), uses e^+e^- collisions with center-of-mass (c.m.) energies ranging from 2.0 to 4.7 GeV to study the broad spectrum of physics accessible in the tau-charm energy region. Since the start of operations in 2009, BESIII has collected a total of approximately 30 fb^{-1} of data, comprising several world-leading data samples, including:

- 10 billion J/ψ decays, giving unprecedented access to the light hadron spectrum;
- 450 million $\psi(2S)$ decays, allowing precision studies of charmonium and its transitions;
- targeted data samples above 4 GeV, providing unique access to exotic XYZ hadrons;
- 3 fb^{-1} of data at the $\psi(3770)$ mass, providing a large sample of D decays and quantum-correlated $D^0\bar{D}^0$ pairs, crucial for global flavor physics efforts;
- 3 fb^{-1} at 4.18 GeV, near the peak of the $D_s^{\pm}D_s^{*\mp}$ cross section, for D_s studies;
- more than 3 fb^{-1} above $\Lambda_c\bar{\Lambda}_c$ threshold for precision Λ_c studies; and
- fine-scan samples for measurements of R, the mass of the τ, and electromagnetic form factors.

The program will continue for at least the next 5-10 years, building on the data sets already collected, and ensuring the BESIII collaboration will remain a key player in future global efforts in hadron spectroscopy, flavor physics, and searches for new physics. The maximum energy of BEPCII will soon be upgraded to 4.9 GeV, and there are preliminary plans to double the BEPCII luminosity by increasing the maximum achievable beam currents. Below we briefly outline a few highlights from BESIII, how these achievements have contributed to global physics efforts, and how the next era at BESIII will build on this momentum. More details and references can be found in a recent white paper describing the future physics program at BESIII [1].

Light Hadron Physics. The centerpiece of the BESIII light hadron physics program is the recently-collected sample of 10 billion J/ψ decays. Radiative decays of the J/ψ provide a gluon-rich environment ideal for the production of scalar, pseudoscalar, and tensor glueballs. The combination of advancements in theory, especially lattice QCD, and continuing innovation in amplitude analysis techniques, such as coupled-channel analyses, have brought the study of glueballs into finer focus. The J/ψ data set also provides hundreds of other exclusive decay channels with well-defined initial and final states in which both the light quark meson and baryon spectra can be investigated in fine detail. Through the decays $J/\psi \to \phi\eta^{(\prime)}$ and $J/\psi \to \gamma\eta^{(\prime)}$, BESIII has also gathered competitive samples of η and η' decays, crucial for precision tests of chiral perturbation theory.

Charmonium and XYZ Physics. The well-established spectrum of charmonium states below open-charm threshold, including the $\eta_c(1S, 2S)$, the $h_c(1P)$, and the $\chi_{cJ}(1P)$ states, can be cleanly accessed through $\psi(2S)$ hadronic and radiative transitions. Large samples of $\psi(2S)$ decays and transitions, with plans to eventually reach a sample of 3-5 billion $\psi(2S)$, allow detailed studies of the behavior of QCD between the perturbative and non-perturbative regimes and are an ideal testing ground for effective field theories like NRQCD. Above open-charm threshold, the charmonium spectrum has revealed exciting evidence for states beyond the simple $c\bar{c}$ model. These XYZ states are produced at BESIII in ways complementary to the B-factories and the LHC. The $Y(4260)$, for example, was discovered by BaBar using initial state radiation; but BESIII, by producing the $Y(4260)$ directly, has revealed intriguing fine structure that is rewriting the story of the Y states. BESIII has also used hadronic decays of the Y to discover manifestly exotic isovector Z_c states and has used radiative transitions to study properties of the $X(3872)$. Future luminosity and energy upgrades will push these studies into new territories.

Charm Physics. BESIII will ultimately collect data samples with integrated luminosities of 20 fb^{-1} at $\sqrt{s}$ = 3.773 GeV, 6 fb^{-1} at $\sqrt{s}$ =4.178 GeV, and 5 fb^{-1} at energies between 4.6 and

4.7 GeV; these c.m. energies are optimal values for the accumulation of $D\bar{D}$, $D_s^{*+}D_s^-$, and $\Lambda_c^+\bar{\Lambda}_c^-$ events near threshold, respectively. The kinematics at threshold allow a double-tag technique to be employed where the full event can be reconstructed, even if it contains one undetected particle. This provides a unique, low-background environment to measure the absolute branching fractions for charmed hadrons decaying to leptonic, semi-leptonic, and hadronic final states. Such measurements provide rigorous tests of QCD, CKM unitarity, and lepton flavor universality that complement similar studies of beauty hadrons. Furthermore, the 20 fb^{-1} data sample of coherent $\psi(3770) \to D^0\bar{D}^0$ events allow measurements of the strong-phase differences between the D^0 and $\bar{D}^0$ that are essential inputs to determine the Unitarity Triangle angle γ in an amplitude model-independent fashion from B decays. These strong-phase measurements are also important ingredients of model-independent measurements of $D^0\bar{D}^0$ mixing and searches for indirect CP violation in D^0 decay. For charmed baryons, in addition to precision branching fractions of the Λ_c, electromagnetic form factors can be studied. If the BEPCII c.m. energy were upgraded to reach above 4.95 GeV, slightly beyond the current plan of 4.9 GeV, pairs of Σ_c and Ξ_c baryons could also be produced and studied.

R Values, QCD, and tau Physics. BESIII is able to measure the e^+e^- annihilation cross section from threshold to the maximum BEPCII energy using a combination of initial state radiation and fine energy scans. The data allow fundamental physics measurements of the hadronic vacuum polarization (HVP), crucial input to hadronic corrections to the muon $g-2$ and to the fine structure constant $\alpha_{\rm EM}(s)$. Beyond HVP, the next important contribution to the uncertainty of $(g-2)_\mu$ is given by the HLbL contribution. The leading contribution to the HLbL diagram is given by the coupling of photons to the pseudoscalar mesons π^0, η, η' as well as channels like $\pi\pi$ and $\pi\eta$ in the region of small momentum transfers, exactly where BESIII can provide precision results. The same data provides access to time-like baryon form factors, where a number of surprising features have been discovered. Among them, the sharp rise of baryon-antibaryon cross sections close to threshold appears very intriguing. BESIII has initiated a program to systematically study this effect for all accessible baryons. In addition, the τ mass can be measured at BESIII with a precision reaching 0.1 MeV, providing a stringent test of lepton universality in the SM. This measurement uses the beam energy measurement system (BEMS) based on the back-scattered Compton photon energy spectrum, allowing beam energy measurements reaching a precision of a few 10 keV.

Exotic Decays and New Physics. With the world's largest samples of J/ψ, $\psi(3686)$, D, D_s, and Λ_c decays at rest, plus large samples of η, ω, η', ϕ, Λ, and χ_{cJ} decays, among others, BESIII has unique sensitivity to New Physics. The scientific goals can be grouped into three categories. The first involves searching for unexpected deviations from the Standard Model (SM) in precision measurements. This includes tests of lepton flavor universality, searches for weak decays of charmonia states, rare radiative decays of D/D_s mesons, flavor changing neutral current processes, and measurements of CP symmetry in decays of polarized quantum entangled hyperon pairs or in the triple-product of certain decays. Second, BESIII can search for SM-forbidden decays, such as baryon number violation in second generation quark decays, and baryon oscillations. In addition, lepton number violation can be probed in the decays of charmonia, light hadrons, and in charm meson decays with the same-charged leptons in the final states. Charged lepton flavor violation processes can also be investigated at BESIII in the decays of charm mesons, charmonia states, and the tau lepton, although the potential of the latter is less competitive compared to Belle II or future super tau-charm facilities. Third, BESIII data can be used to search for exotic and dark sector particles. Examples of the former include milli-charged particles, X17, and axion-like particles. Examples of the latter include low mass dark matter candidates in the invisible decays of charmonia and the charm mesons, dark photons, or the dark/light Higgs.

References

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