PRELIMINARY CONCEPTUAL STUDY OF NEXT GENERATION TAU CHARM FACTORY ACCELERATOR AT CHINA *

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Abstract

As BEPC II would accomplish its mission in the next decade, research on high energy science demands a successor. The luminosity of this successor should be one or two orders higher than BEPC II, while the electron beam should be longitudinal polarized at the IP. This paper discusses the feasibility and key technologies of the next tau-charm collider: a greenfield new facility or an upgrade of BEPC II.

INTRODUCTIONS

The best tau-charm factory of the world in operation is BEPC II, which finished its upgrade project in the year 2009, and reached its designed peak luminosity in the year 2016. It is believed that BEPC II would accomplish its mission in the next decade, maybe the year 2022 or later. During the year 2014 to 2015, high energy physicists in the Collaborative Innovation Center for Particles and Interactions (CICPI, China) proposed a new facility [1] as BEPC II's successor, with a name "High Intensity Electron Positron Accelerator (HIEPA)" due to its very high luminosity and current. It is a next generation electron-positron collider operating in the range of center-of-mass energies from 2 to 7 GeV with a high luminosity of about 5×10^{34} $cm^{-2}s^{-1}$ and utilize polarized electron beam in collision.

Meanwhile, scientists shown a strong interest in Higgs factory proposal in China, known as CEPC-SPPC. It is clear that CEPC would cost a price of several orders higher than a tau charm factory, and requires global cooperation. To make it possible, it is important that accelerator scientists do their best in preliminary study and develop the key technologies that will be needed.

Therefore, preliminary conceptual study for a tau charm factory is still meaningful even if we decided to build a Higgs factory. First, it is important to maintain China's leading advantage at tau-charm area, no matter it is greenfield or brownfield. Second, there are a lot of common technologies which are useful for both CEPC-SPPC and tau charm factory. At last, a tau-charm factory would be a good backup plan if the CEPC-SPPC construction cannot begin on time as planned.

This paper discussed the feasibility of the next tau-charm factory in China and related key technologies needed to be developed in the future 5~10 years. The next tau-charm factory can be a brand new one, or an upgrade of BEPC II.

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Most of the collaboration colleague work for the next tau charm factory at China come from NSRL and CICPI. NSRL, for National Synchrotron Radiation Laboratory at Hefei, has run the Hefei Light Source for decades and possesses abundant technologies and experiences for construction and running huge accelerator facilities.

SIGNIFICANCES OF THE PROPOSAL OF HIEPA FACILITY

The collision luminosity of the HIEPA facility is set to be 5×10^{34} $cm^{-2}s^{-1}$, which is fifty times as BEPC II, means physicists will collect 50 times of data during the same work time. Besides, HIEPA has broader energy region and polarized electron beam.

The feature of 2-7GeV energy region

- Rich of resonances: charmonium states, such as J/ψ, ψ(2S), ψ(3770) and particles are copiously produced at/around production threshold, providing a clear and unique laboratory to study the physics with charm quarks, and for the search of the existence of the new form of matter/hadron, including exotic hadrons, multi-quark states hybrids and glue balls.
- Threshold characteristics: Pairs of τ lepton, charmed mesons and charmed baryons can be directly produced at their production thresholds, which leads to a better handling of backgrounds for the study of CP violation from the decays of tau and charmed mesons, as well as for the search for lepton number violating process from the tau decays.
- Transition between smooth and resonances, perturbative and non-perturbative QCD. It is also the energy region where exotic hadron, hybrid, glueballs are located.

The significances of the physics for HIEPA

Therefore, the significances of the physics for HIEPA are:

- Search for new forms of matter/hadron and study their properties.
- Measurement of the nucleon electromagnetic form factor.
- Search for new physics.

Longitudinal Polarized collision

If there's longitudinal polarization of beam at the interaction point, we can say that the effective luminosity enhancement is:

$$\frac{L}{L_0}=1+\omega_{e-}\omega_{e+},$$

where ω_{e-} and ω_{e+} are the linear polarization of the electron and positron beams.

Besides the luminosity enhancement, longitudinal polarization at IP can also be beneficial to a lot of high energy physics study, for example:

- Study the polarized quark fragmentation and study the Collins effect directly.
- Understand the longitudinal polarization of Λ and the Collins effect of hyperon spin structure.
- Try to observe C-P violation directly by study polarized tau sample.

GENERAL DISCRIPTION OF THE ACCELERATOR

If we decide to build a brand new collider, the plan of HIEPA will be helpful. The peak luminosity of the HIEPA will be 5×10^{34} cm^{-2}s^{-1}, with a long-term plan to upgrade to a peak luminosity of 10^{35} cm^{-2}s^{-1} and to utilize polarization positron beam in collision. If we decide to upgrade BEPC II to BEPC III, the luminosity could be 5×10^{33} cm^{-2}s^{-1} to 10^{34} cm^{-2}s^{-1}.

Collision scheme

The new facility will be a dual-ring collider with symmetric and flat beams and one interaction region.

For such a collider, the luminosity can be

$$L=\frac{\gamma n_b I_b}{2er_e\beta_y^*}\xi_y H,$$

where γ is relative energy of the beam, n_b is number of the bunches, I_b is current of a single bunch, ξ_y is vertical beam-beam effect parameter, H is hourglass factor, β_y^* is vertical envelope function at IP. Its luminosity is proportional to its current, vertical beam-beam effect parameter and Hourglass factor, and inversely proportional to the vertical envelope function. The future facility should have two long straight sections, one for IP, another set up for injection and beam control.

The parameters of the collision and the beam are all connected. In a head-on collision system, to achieve the luminosity, assume ξ_y can reach 0.04, β_y^* should be compressed to 0.3-0.4mm. To avoid the luminosity loss due to hourglass effect, the bunch length should be even shorter than β_y^*. Take the collective effects into consideration, the sensible way is use large Piwinski angle collision and crabbed waist scheme. Therefore, the ξ_y can approach 0.1, while the hourglass effect can also be suppressed and the limit to bunch length can be avoided [2].

Main parameters for a new collider

Table 1 and 2 show two phases of the HIEPA facility. We build a collider with advanced technologies, but first operate it with conservative parameters and loose conditions. Then we utilize a modified lattice with higher current and enhance the focus.

After service life of high energy physics experiment, the facility will be modified to a 4th generation light source with a horizontal emittance of 30~50 pm·rad (with IBS).

Table 1: Main Parameters for Accelerators, Phase 1

Design Goals	Value
Peak Luminosity	5×10^{34} cm^{-2}s^{-1}
Beam Energy	2GeV，1-3.5GeV tunable
Current	1.5 A
Beam Emittance $\varepsilon_x/\varepsilon_y$	5/0.05 nm·rad
β_x^*/β_y^*	100/0.9 mm
Crossing Angle	60 mrad
Hourglass factor H	0.8
ξ_y	0.06
Circumstance	~600m

Table 2: Main Parameters for Accelerators, Phase 2

Design Goals	Value
Peak Luminosity	1×10^{35} cm^{-2}s^{-1}
Beam Energy	2GeV，1-3.5GeV tunable
Current	2 A
Beam Emittance $\varepsilon_x/\varepsilon_y$	5/0.05 nm·rad
β_x^*/β_y^*	67/0.6 mm
Crossing Angle	60 mrad
Hourglass factor H	0.8
ξ_y	0.08
Circumstance	~600m

Injection scheme

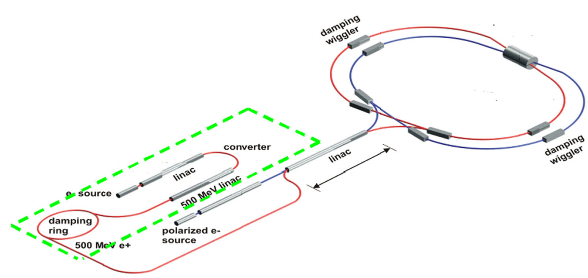

Figure 1: Schematic drawing of the rings with full energy injection, refers to the tau-charm factory plan of BINP [3].

Figure 1 shows a global layout with full energy linac injection method. If we try to build the linac for multiple usage, i.e., an FEL facility, it will be a better choice. A booster is cheaper in a way and may be also used as a polarized source, which will be discussed later.

Upgrade of BEPC III

As Beijing Advance Photon Source is approved and will be available for operation in the 2020s [4], the old synchrotron radiation light source of BSRF, as part of BEPC II facility, will retire. It will then be possible for scientists to remove all equipment of the light source at BEPC II and clear up enough space for magnets and solenoids with stronger focus and for polarization rotators.

As the circumference of the facility and the shape of tunnel is fixed, the luminosity of BEPC III would be limited. By using large Piwinski angle and crab waist

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scheme, the luminosity could be improved to 5×10^{33} $cm^{-2}s^{-1}$ to 10^{34} $cm^{-2}s^{-1}$.

POLARIZED BEAM

For full energy linac injection method, the negative electron affinity photocathode guns will be used as polarized electron sources. It will be more likely the final decision.

Meanwhile, because of the Sokolov-Ternov effect due to synchrotron radiation, it might be possible to build a highly polarized beam in a smaller storage ring, as a booster.

A long-term plan is to utilize polarized positron in the new collider. The polarized positrons come from circular polarized gamma-rays bombarding amorphous targets. Scientists around the world now pay more attention to inverse Compton scattering gamma ray source. By using the method that developing very quickly, it is possible to get a positron beam of quality and yield that meets the demands in the next decade. As it is shown in Fig. 2, an ERL loop can also be induced in the facility.

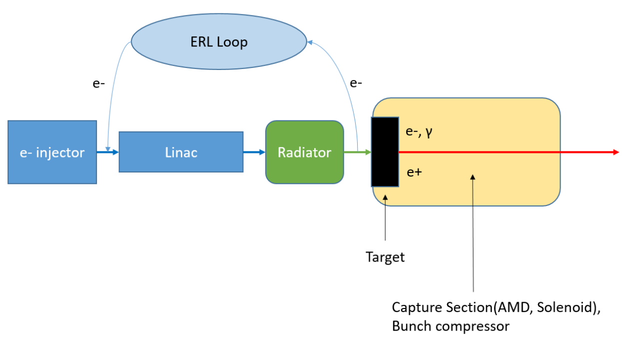

Figure 2: Gnenerate Polarized Positron by Circular Polarized Gamma Ray from Inverse-Compton Scattering with ERL Loop.

FUTURE STUDY AND KEY TECHNOLOGIES REQUIRED

To build this new facility, new study has to be done and key technologies will be developed in next few years. They are:

Collective effects and feedback systems

A next generation tau-charm factory has much lower energy compared to Higgs factories and super B factories, while its current is very high. This means the facility will face serious collective effect, result in emittance growth, lifetime loss and beam instabilities. Beam loss and beam quality depravation restrict the peak luminosity, so this is the most important accelerator physics problem. Powerful feedback systems, such as transverse and longitudinal bunch-by-bunch feedback and slow orbit feedback is required.

Meanwhile, the lattice and interaction region design is another key point. The high current and strong focus induce strong nonlinearity, result in very small dynamic aperture. Nonlinearity optimization requires further work and also new technologies for injection.

Superconducting magnets and solenoids

High luminosity and rotation of polarization all require superconducting magnets and solenoids. The magnets to be designed are listed in table 3.

Table 3: Superconducting Magnets

Type	Maximum Magnetic Field
Anti-solenoid	4.5 Tesla
Quadrupole	107Tesla/m
Damping wigglers	4.5 Tesla
Siberian snake solenoids	6 Tesla

CONCLUSION AND FUTURE WORK

The idea to build a successor of the BEPC II tau-charm factory after 5-10 years is attractive, but there's still lots of work to do. We should not only discuss the possible ways to build the new collider, but also pay attention to new method of accelerator physics and key technologies. The preliminary conceptual work for the new tau charm factory will be proved to be beneficial.

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