SUMMARY OF INJECTOR AND BEAM INJECTION*

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Abstract

This summary covers the Injection and Sources Session of the e+e- Factories Workshop held at Daresbury Laboratory, UK, October 24-27, 2016, which had six presentations. Here we discuss the goals for top-up injection for a collider and their sources and then covers the highlights, discussion topics, and future plans for each presentation. The talks [1-6] will be covered in alphabetical order by author's name.

INJECTION AND SOURCES GOALS

Extracted from the six talks in this session, the required qualifications for injection and sources for present and future e+e- colliders can be broken down into three general areas: parameters, construction, and operation. The desired parameters are full energy injection (up to 175 GeV), varied injected bunch charges (quanta), short fill times from scratch, low detector backgrounds while injecting while taking data, polarization of about 80% for electrons and, if possible, for positrons (under development), well integrated into the collider design, and well instrumented. For construction, the desire is to be inexpensive as possible using existing technology if possible. For operations, the need is for low power costs, reliable running, low maintenance costs with many common-standard units, and bunch number flexibility.

The goals for the injector for an e+e- collider are shown in Table 1 where 50 to 90000 overall bunches are needed and 6 to 1450 mA per beam of stored currents are needed. The injection rates depend on how many bunches are to be injected per booster cycle, the expected beam lifetimes (~10 to 60 min) and the charge per bunch needed to maintain the luminosity near the maximum.

Table 1:Injection Parameters for a Future e+e- Collider

parameter	FCC-ee			CEPC	LEP2
energy/beam [GeV]	**45**	**120**	**175**	**120**	105
bunches/beam	90000	770	78	50	4
beam current [mA]	1450	30	6.6	16.6	3
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**70**	**5**	**1.3**	**2.0**	0.0012
energy loss/turn [GeV]	0.03	1.67	7.55	3.1	3.34
synchrotron power [MW]	100			103	22
RF voltage [GV]	0.08	3.0	10	6.9	3.5

FCC-ee: 2 separate rings & 2 IPs

CEPC: single beam pipe version

TIANJIAN BIAN (IHEP): DESIGN STUDY OF CEPC BOOSTER

The injector of the proposed CEPC e+e- collider in China has been studied for several years with a converging design. It consists of a linac, positron source, damping ring and, finally, a full energy booster ring in the same tunnel as the collider with a circumference of 63.8 km. The injected bunches go through a septum and then a kicker to be stacked onto (top-up) an existing bunch in the collider. The highest energy of the booster would be 120 GeV for the Higgs energy with an injected emittance of 3.5 nm-rad. A booster optical lattice has been generated which looks acceptable in term of tunability, chromatic corrections, earth's field correction, element error tolerances, and magnet technical features.

The very low magnetic field in the booster at injection energy is a concern with several cures being studied including shielding of the earth's field, reverse bends, special steel, and low energy orbit corrections. A reverse (wiggling) bend scheme is the primary choice at the present (See Figure 1) to boost the magnet field about a factor of 6 (25 gauss to (-129 and +180) gauss).

A computer code has been developed (MOOLA) to optimize the design of a ring lattice. It uses Hamilton canonical coordinates and has fourth order symplectic integration. This code has been used to maximize the properties of the CEPC injector booster lattice and the HEPS light sources lattice.

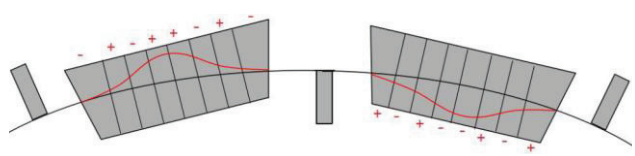

Figure 1: Proposed booster dipole magnet layout to increase the low energy fields in China CEPC.

Further work and discussion:

1) Construct a real model of the 25 gauss dipole magnet and test the reproducibility of the low filed state.
2) Construct a working model of the reverse bend dipole magnet and measure the remnant fields through field reversal.
3) Further work on lattice dynamic aperture optimization with MOOLA is ongoing.
4) Study if the partial double ring collider design changes the requirements for the CEPC injector.

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ZHE DUAN (IHEP): TOP-UP INJECTION SCHEMES FOR HEPS

The High Energy Photon Source (HEPS) is a proposed 6 GeV low emittance light source in Beijing, China, about 90 km from IHEP. The injection energy needs to be 6 GeV and total stored charge of 200 mA in 648 bunches (See Figure 2 and Table 2). The proposed injector scheme contains a linac and a booster with longitudinal on-axis injection into the storage ring. The injected bunches are merged with the stored bunches with longitudinal phase space gymnastics by RF phase manipulations using 166 and 499 MHz RF systems. The time scale is about the synchrotron damping time. A fast RF control feedback loop is needed for these manipulations. Also, a fast injection kicker is needed with about a 1 nsec rise time, 2.5 nsec fall time, and total duration of about 3.5 nsec with a 300 Hz burst-mode repetition rate. A single injection period takes about 200 msec. The longest refill cycle time is 3.5 minutes.

Further work and discussion:

1) The effect of IBS on the stored bunches of about 2.8 mm bunch length affecting injection is understudy.
2) Work on the injection kicker is ongoing.
3) The stability of the two frequency RF system under bunch phase merging is under review.
4) The effect on injection from different bunch pattern requirement needs to be investigated.

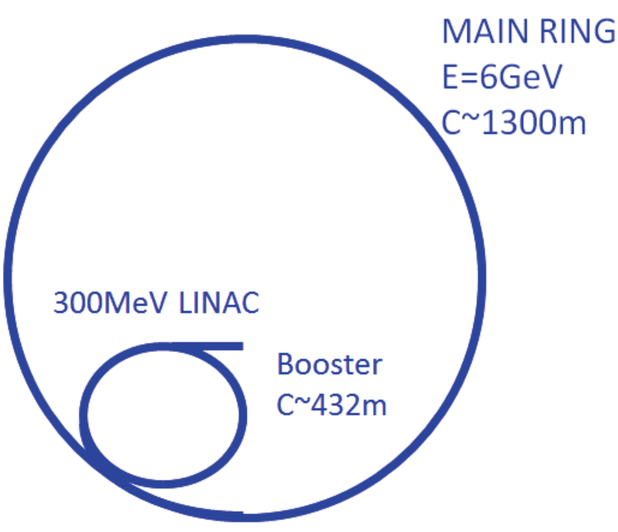

Figure 2: Injector for the future Beijing HEPS light source.

Table 2: Injection Parameters for Beijing HEPS

parameters	648 bunches	60 bunches
charge	1.33 nC	14.4 nC
lifetime (during operation)	30 hours	3 hours
refill time	3.5 min	20 second
number of injection in each refill	4	2
bunch filled in each refill	30 * 4 = 120	30 * 2 = 60
injection time	200 ms *4	200 ms *2
total duration of each refill	9 s * 3 =27 s	9s * 1 = 9 s

TAKUYA NATSUI (KEK): INJECTOR LINAC UPGRADE AND NEW RF GUN FOR SUPERKEKB

The gun and linac for the SuperKEKB collider (7x4 GeV)is being upgraded to provide rapid top-up injection. Several upgrades are needed as the luminosity lifetimes of the SuperKEKB beams are expected to be about 10 to 20 minutes and the stored beam charge is about twice that of KEKB. Also, the emittance of the injected beam needs to be smaller to fit into the reduced SuperKEKB dynamic aperture. The injector must also inject beams into the Photon Factory (2.5 GeV) and Accumulator Ring (6.5 GeV) light sources at KEK. The layout of the injector chain at KEK is shown in Figure 3.

The thermionic gun was used for commissioning of Phase 1. The charge of the electron beam was 1 nC. The charge of positron beam was 1 nC with the new flux concentrator.

The new injector achieved a charge of 1 nC beam generation by using the new photo-cathode RF gun. The laser power stability is acceptable giving a charge stability of about 5%. The beam position stability, however, needs improvement for the RF gun. The emittance was approximately 20 mm-mrad. So overall, the SuperKEKB HER Ring injection tests were successful using the RF gun achieving 10 days of stable injection.

Further work and discussion:

1) Work to bring the photo-gun to full specifications is ongoing including laser work.
2) More work on the linac emittance preservation is needed.
3) Preparation for damping ring commissioning is ongoing.

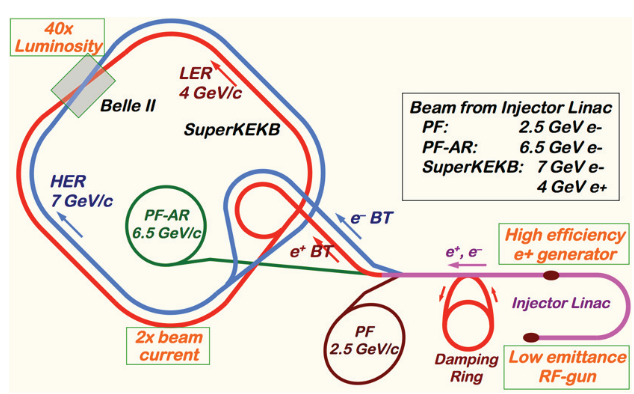

Figure 3: Layout of the injector for SuperKEKB and the KEK light source rings.

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SALIM OGUR (CERN): TOWARDS A PRELIMINARY FCC-EE INJECTOR DESIGN

The FCC-ee injector must accommodate from 81 to 91500 bunches to cover four different operational modes (Z, W, H, and tt). The highest energy (175 GeV) but lowest beam current is for tt. The highest number of bunches and highest current is for the Z. The present concept has a 100 Hz 6 GeV linac, a 257 m damping ring at 1.54 GeV for e+, and a 100 km booster reaching 175 GeV top energy housed in the same tunnel as the collider. This concept is shown in Figure 4. The linac accelerates two bunches at a time to an energy of 6 GeV and $4x10^{10}$ particles per bunch. The booster fill time is 4 seconds with 800 bunches with a following ramp to full energy of 6 seconds.

Studies have been started to study the evolution of the electron and positron bunch qualities throughout the injector chain. The beam optics of the linac and of the damping ring have initial lattices which are being studied for dynamic aperture and emittance growth with various component errors. Linac alignment tolerances must be on the order of 100 microns and 0.1 milliradians to keep the injected beam from causing large backgrounds and have good injection efficiencies.

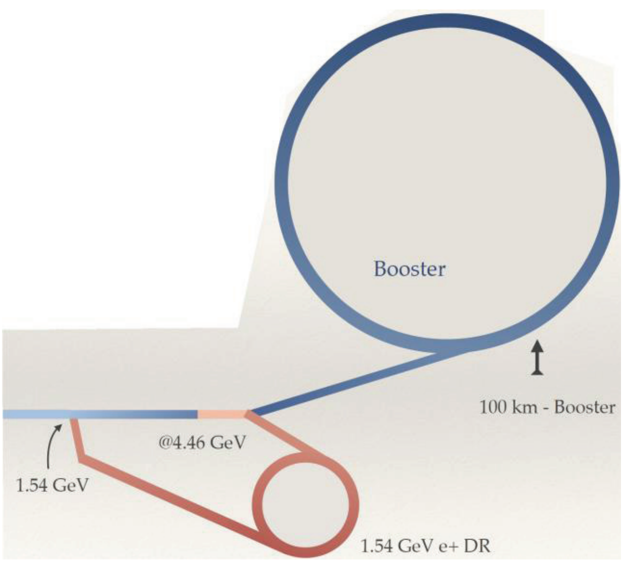

Figure 4: Injector concept for the CERN FCC-ee.

Further work and discussion:

1) The whole injection process can be shortened if the linac can accelerator more than 2 electron bunches per pulse (4 bunches is under study).
2) The very low magnetic field of the booster at low energy is a concern and further work is planned to investigate the consequences and mitigations.
3) Simulated transmission losses have brought up the questions of collimation and the required bunch charges before losses.
4) Most of the cost for the injector is in the highest energy booster needed. Are there ways to reduce this?
5) The filling time from scratch is about 46 minutes at the Z. A configuration to reduce this time is desired.

JOHN SEEMAN (SLAC): TOP-UP INJECTION SCHEMES

Top-up injection schemes for PEP-II, KEKB and future e+e- colliders were discussed. Beams were injected at several Hz in both PEP-II HER and LER to keep the currents constant. In KEKB bunches were injected alternatively every few minutes between electron and positrons. Backgrounds and detector masking are important issues. In Figure 5 is shown the elapsed time after a bunch is injected into PEP-II showing the backgrounds decaying on the order of a synchrotron damping time. In Figure 6 is shown the injection masking of the BaBar detector for about 2000 turns but only centered near part of the turn where the injected bunch is located.

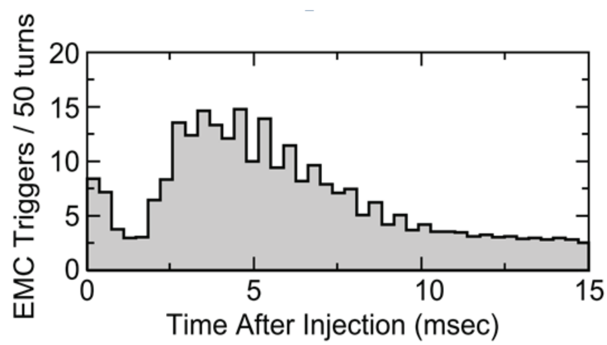

Figure 5: Background in BaBar from a single injected LER bunch during top up injection but it only affects a small part of the ring keeping the data taking efficient.

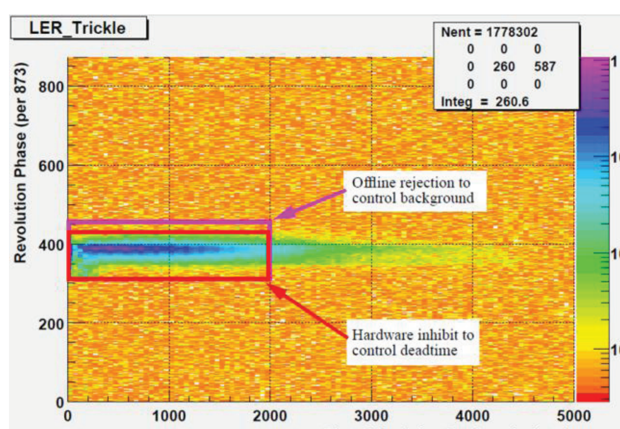

Figure 6: Injection masking for BaBar data taking covering only the injection bunch's segment of the circumference for about 10 milliseconds.

Conclusions from PEP-II and KEKB top-up injection results: Top-up injection will work for a circular e+e- factory. Top-up or full charge exchange will work for a

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future collider. A full energy injector is needed because of the observed short beam lifetime from beam-beam, Toushek and beam gas effects. The detectors will need to mask out the nearby buckets during damping of the injected bunches during data-taking but not the whole circumference. A singe bunch injection controller needs to be worked out in detail for both the accelerator (quanta, feedbacks, jitter) and the detector. Commissioning can be complicated as many issues both on the accelerator and detector arise and both have to work out the problems together: mainly detector backgrounds, beam lifetimes, injection efficiencies, masking, and luminosity versus beam lifetimes.

Further work and discussion:

1) Diagnostics are needed to resolve the efficiency of the injected bunches for capture.
2) Higher energies could make the power lost in the IR higher per injected particle. Does IR collimation need to be more thorough?
3) The detector DAQ needs to be able to make complex masking configurations. How flexible does it need to be?

RONG XIANG (HZDR): ELECTRON AND POSITRON SOURCES

The demands on electron sources for the upcoming new colliders are higher than before in terms of high charge, low emittance and maximum polarization. There are requirements for high current, high brilliance, low emittances, polarization, total charge, as well as stability and reliability. There are several available and future type of sources: thermionic cathode guns (DC, NC-RF), photocathode guns (DC, NC-RF, SC-RF), and photo-induced field emission cathodes (NC-RF, SC-RF). Several new ideas include plasma wakefield accelerators (PWFA) and laser wakefield accelerators (LWFA). In Figure 7 are shown the performance levels of various working guns in terms of brightness and average current.

DC and NC-RF guns are well established. SC RF guns are getting serious attention now with several laboratories leading the effort (e.g. ELBA). SLAC, LBNL, DESY, and others are looking at PWFA and LWFA sources.

For polarization, there are new studies for polarized electron sources beyond strained InGaP or GaAsP cathodes. Multilayer structures are nearing the testing stage.

Further work and discussion:

1) Extending cathode lifetimes of total coulombs emitted is an issue, especially for an Electron Ion Collider.
2) Investigate the near term results of multilayer photo-polarization sources.
3) Work on higher gun fields and cathode voltages.
4) Make better models for particle tracking from guns including all 3D effects.
5) Work on polarized positron sources has started but more work is needed to make their case viable.

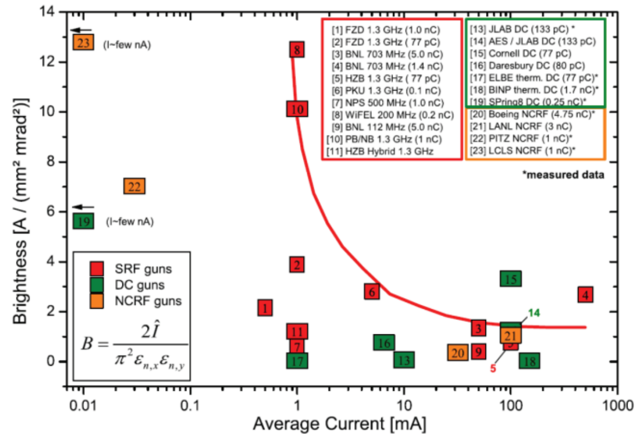

Figure 7: Plot of the trade-off of high brightness and high average currents in existing electron gun sources.

CONCLUSION

The injection session of the e+e- Factory Workshop was well attended, many questions were asked, and discussions were of a very technical nature.

ACKNOWLEDGMENT

The author would like to thanks the speakers of the eeFACT2016 Injectors and Sources Session for their clear and interesting presentations.

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