Elements for future collider electron rings

M. Benedikt (CERN), M. Blaskiewicz (BNL), A. Blondel (U. Geneva & CNRS), M. Boscolo (INFN-LNF), H. Burkhardt (CERN), M. Chamizo Llatas (BNL), W. Fischer (BNL), J. Fox (Stanford U.), C. Garion (CERN), D. Gassner (BNL), F. Gerigk (CERN), E. Gianfelice (FNAL), C. Hetzel (BNL), W. Höfle (CERN), E. Jensen (CERN), R. Kersevan (CERN), M. Koratzinos (MIT), T. Lefevre (CERN), E. Levichev (BINP), F. Lin (JLab), T. Mastoridis (Cal Poly), G. McIntyre (BNL), M. Migliorati (Sapienza), A.-S. Müller (KIT), A. Novokhatski (SLAC), K. Oide (CERN and KEK), D. Padrazo (BNL), B. Parker (BNL), V. Ptitsyn (BN), R. Rimmer (JLab), T. Satogata (JLab), A. Seryi (JLab), E. Shaposhnikova (CERN), K. Smith (BNL), M. Sullivan (SLAC), J. Wenninger (CERN), F. Willeke (BNL), M. Wiseman (JLab), H. Witte (BNL), W. Wittmer (JLab), F. Zimmermann (CERN)

Abstract

The electron (and positron) rings of the proposed future circular electron-positron collider FCC-ee, studied by an international collaboration hosted by CERN, and of the recently approved Electron-Ion Collider (EIC), under development by JLab and BNL, feature strikingly similar beam parameters, for example identical high bunch charge, and comparable bunch spacing. Accordingly, they face rather similar beam dynamics challenges and could greatly profit from common developments and hardware solutions. CERN contributions and expertise might prove helpful for advancing the EIC project, while beam tests and practical validation of jointly developed systems at the EIC, around the year 2030, i.e., roughly ten years before the envisaged commissioning date of the FCC-ee, would be of great interest for the FCC program. Aside from the superconducting radiofrequency systems, which are covered by an even wider collaboration, the common elements and challenges of the EIC and FCC electron rings include beam diagnostics, impedance models, beam instabilities and their mitigation via feedback systems, the interaction region with shielding and final quadrupole magnets, various elements of the collider arcs, the vacuum systems, and measures for the handling of synchrotron radiation. In this LoI, BNL, JLab, and CERN express their intention in pursuing joint R&D efforts on common elements of large electron collider rings. This collaboration is inviting other potential partners, including at US universities, to join the endeavour.

This letter highlights the great potential and opportunities opened up by a planned collaboration between the EIC [1,2] project teams at BNL and JLab, and the FCC study hosted by CERN [3,4,5]. Table 1 compares key parameters of the two projects. For FCC-ee the most challenging parameters for the initial Z pole running are presented. The parameters of the NSLS-II light source at BNL are added for comparison. The EIC and FCC-ee designs foresee an identical bunch population, at least an order of magnitude higher than in typical light sources or linear colliders, comparable bunch spacing in the 10-20 ns range, similar short bunch lengths in the few mm range, average beam currents in the Ampere or few-Ampere range, beam energies in the 10s of GeV range, synchrotron radiation power per unit length in the kW/m range, and critical photon energies of 10s of keV.

Table 1: Key parameters of NSLS-II, EIC and FCC-ee (Z pole).

	NSLS-II	**EIC**	**FCC-ee Z pole (W)**
Beam energy [GeV]	3	**10 (18)**	**45.6 (80)**
Bunch population [10^{11}]	0.08	**1.7**	**1.7**
Bunch spacing [ns]	2	**10**	**15, 17.5 or 20**
Rms bunch length [mm]	4.5-9	**10**	**3.5 from synchrotron radiation** **12 including beamstrahlung**
Beam current [A]	0.5	**2.5 (0.27)**	**1.39**
RF frequency [MHz]	500	**591 or 394**	**400**
SR power / beam / meter [W/m]	900	**7000**	**600**
Critical photon energy [keV]	2.4	**9 (54)**	**19 (100)**

Aside from superconducting RF systems, the potential topics of collaboration include:

- beam instrumentation, especially beam-position monitors and beamstrahlung monitors,
- impedance models, assessment of instability-driven beam instabilities and their mitigation, higher-order mode heating, and beam ion instability,
- beam feedback systems,
- interaction region (IR) design including masking and shielding of synchroton radiation from dipoles and quadrupoles,
- development and perhaps prototyping of the SC final-focus quadrupole system, and possibly other magnetic elements related to the interaction region,
- synchrotron-radiation monitors and handling equipment associated with the IR,
- self-polarization (or depolarization), strategies for spin-orbit matching, and simulation tool adaptations or developments of new tools,
- polarimeter design, and
- the arc vacuum system, possibly with NEG coating, photon absorbers, water cooling and radiation shielding.

In summary, BNL, CERN and JLab are looking forward to a fruitful and expanding collaboration for mutual benefit. Motivated by great similarities between the FCC-ee and EIC beam parameters and evident synergies, they expect to jointly address many common challenges. In the frame of Snowmass 2021, this collaboration is inviting additional partners to join the effort, e.g., other domestic and international laboratories and, in particular, US universities.

References

1. F. Willeke, *Designs of Electron Ion Colliders*, IPAC'20 (2020).
2. *Electron-Ion Collider eRHIC Pre-Conceptual Design Report*, BNL Report BNL-211943-FORE, July 2019 – not publicly available.
3. M. Mangano et al., *FCC Physics Opportunities - Future Circular Collider Conceptual Design Report Volume 1*, EPJ C 79, 6 (2019) 474 [Open Access]
4. M. Benedikt et al., *FCC-ee: The Lepton Collider – Future Circular Collider Conceptual Design Report Volume 2*, EPJ ST 228, 2 (2019) 261-623 [Open Access]
5. M. Benedikt et al., "*Future Circular Colliders succeeding the LHC*," Nature Physics, vol. 16, pp 402–407 (2020) [Open Access]