SUMMARY OF DESIGN CONCEPTS*

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Abstract

This paper summarizes the session on design concepts at the ICFA workshop on future circular electron-positron factories “eeFACT2016” [1] held at the Cockcroft Institute, Daresbury, from 24 to 27 October 2016.

OVERVIEW

The eeFACT2016 [1] session on design concepts featured the following four presentations:

1. Crab Waist Concept [2], by Pantaleo Raimondi, ESRF;
2. Higgs Factory Concept [3], by Frank Zimmermann, CERN;
3. Implementation of Round Colliding Beams Concept at VEPP-2000 [4], by Dmitry Shwartz, BINP; and
4. New Concept of a very Compact e^+e^- Collider with Monochromatization and Maximum Beam Energy of around 200 MeV [5], by Anton Bogomyagkov, BINP.

Another important design concept is maximizing the synergies between kepton and hadron colliders, which was highlighted by Alain Blondel, U. Geneva, during the summary session.

CRAB WAIST CONCEPT

The crab-waist scheme overcomes, or exploits, the classical limitations from hourglass and beam-beam effect, allowing for much lower values of β^* and gaining luminosity with a large Piwinski angle [2]. Its key feature is the crab-waist compensation, a new idea from 2006. Positive and useful experience comes from an actual implementation at the DAFNE collider, where the crab-waist scheme significantly increased the luminosity, as is illustrated in Figs. 1 and 2. The price to pay is a more challenging final-focus system design/construction, in particular the realization of particular phase advances and the possible impact of crab waist sextupoles on the dynamic aperture. Regardless, DAFNE experience and several designs for future have proven the feasibility of this novel approach. Now crab waist is a key concept for the next generation of high luminosity colliders, such as FCC-ee or the Super charm-tau factory at BINP.

At eeFACT2016, the possible conversion of DAFNE into a test facility for studies on the large Piwinski angle and the crab waist scheme was discussed. While this would be useful, it was not entirely clear if there was an added value

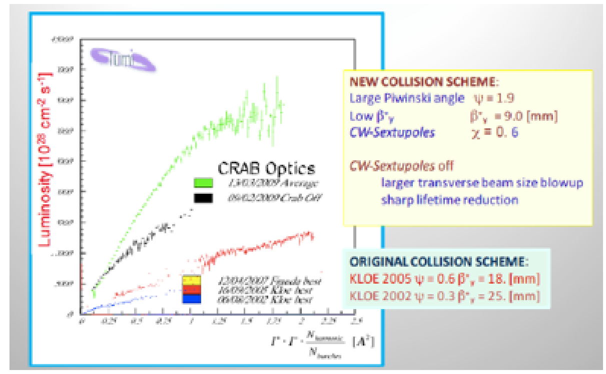

Figure 1: DAFNE luminosity versus product of beam currents for the classical and crab-waist collision scheme [2].

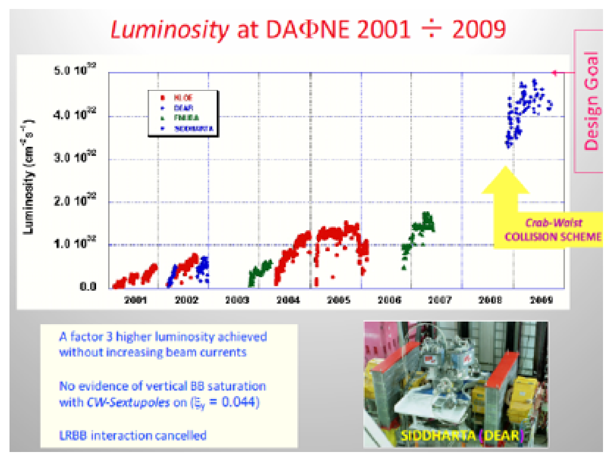

Figure 2: DAFNE luminosity versus time, showing a step-like increase at the moment the crab-waist was introduced, together with a photograph of the DAFNE installation [2].

beyond the SuperKEKB experience and whether this would not interfere with the DAFNE physics programme. The resource needs and the benefits would need to be analysed.

Discussion: The limit on β^* in the crab waist scheme was addressed including the question whether such limit would be consistent with the FCC-ee design. The subsequent discussion revealed that other limits in the final focus design (e.g. dynamic aperture) must also be considered.

HIGGS FACTORY CONCEPTS

The designs of FCC-ee & CEPC exploit lessons or recipes from past and present e^+e^- and pp colliders: combining successful ingredients of recent colliders leads to extremely high luminosity at high energies (Fig. 3), up to and beyond 10^{36} cm^{-2}s^{-1} [3]. Crab waist is successfully implemented in the design of the proposed new machines. Obtaining a low

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emittance is "easy" for large rings. Limitations are being carefully studied: particle loss from beamstrahlung [6, 7], energy sawtooth, luminosity lifetime, synchrotron-radiation fans in the interaction region, the "Talman barrier" for β_y^*, electrical power consumption, emittance growth from beamstrahlung [8], etc. Mitigations and innovative schemes are being implemented, including double ring, partial double ring, magnet tapering, top-up injection, weak bends, asymmetric interaction-region optics, monochromatization [9], improved klystron efficiency, and 2-in-1 arc magnets.

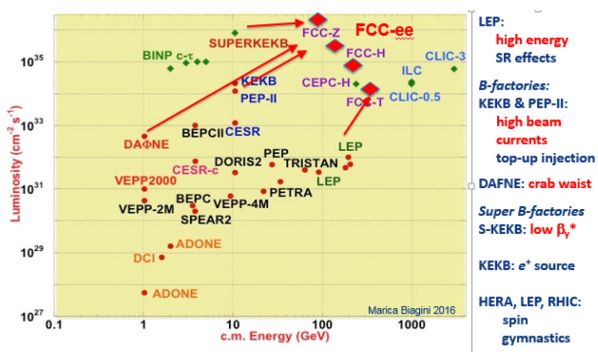

Figure 3: Luminosity vs. c.m. energy for past, present and future e^+e^+ colliders, sketching the paths to FCC-ee/CEPC and the origins of some of the key ingredients [3].

Discussion: The question was raised when FCC-ee could start operation. The answer was not before 2035–2037 given the present schedule of the HL-LHC. Also, the technical readiness for a large e^+e^- collider like FCC-ee or CEPC was discussed. It was concluded that the required technologies exist today, feasibility is guaranteed and performance estimates are realistic. Ongoing R&D will improve the power efficiency.

IMPLEMENTATION OF ROUND COLLIDING BEAMS CONCEPT AT VEPP-2000

Round beams offer advantages in the geometric luminosity factor, an enhanced beam-beam limit thanks to a reduction in the degrees of freedom [10], and suffer less from intrabeam scattering and Touschek effect [4]. Lattice requirements for round beams are summarized in Fig. 4. Round beams were implemented in VEPP-2000. Diffreent modes are possible. Round beams on the coupling resonance are operational at VEPP-2000. The round beam configuration with a Möbius ring has insufficient dynamic aperture. Machine tuning is essential: orbit correction, beta functions, betatron coupling, and betatron tunes. VEPP-2000 achieved a measured coherent beam-beam tune shift of 0.175, corresponding to a beam-beam parameter of 0.125 per IP, as is indicated in Fig. 5. This value of beam-beam parameter was confirmed independently from luminosity-monitor data. Issues studied at VEPP-2000 include the microwave instability and coherent oscillations. The injection chain of VEPP-2000 has recently been upgraded to remove a limitation on the e^+ intensity. This should allow obtaining the round-beam target luminosity also at higher VEPP-2000 energies [4].

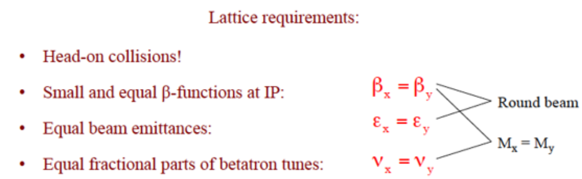

Figure 4: Lattice requirements for round beams [4].

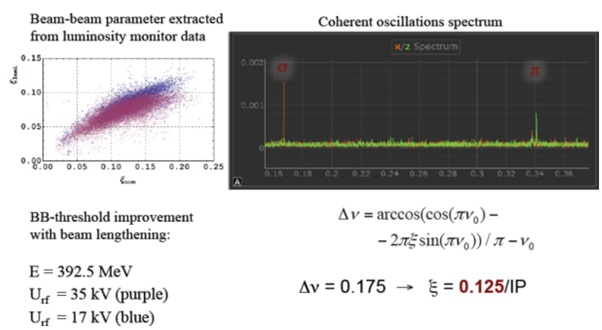

Figure 5: Beam-beam parameter extracted from luminosity-monitor data (left) and from the coherent beam-beam oscillation sprectrum (right) [4].

Discussion: It was discussed whether the dynamic aperture can be improved in VEPP-2000, such that the Möbius scheme can also be investigated. This is not possible, however, due to missing space for sextupoles. The reason for missing a factor 10 from the design luminosity (at high energy) while reaching a beam-beam tune shift of about 0.1 was discussed.

VERY COMPACT e^+e^- COLLIDER WITH MONOCHROMATIZATION

A new concept of an e^+e^- double-ring collider with monochromatization and maximum beam energy of 200–300 MeV for true muonium production has been developed. Exciting physics can be explored at such a machine, as is sketched in Figs. 6 and 7.

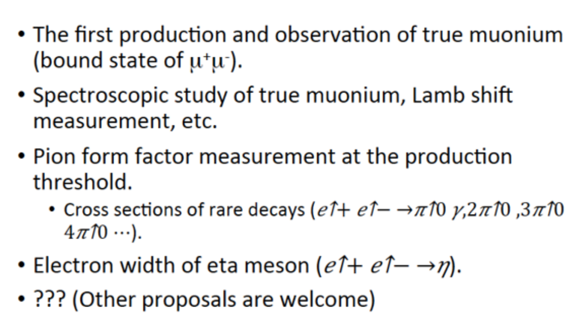

Figure 6: Possible physics programme for a compact monochromatized collider operating at 200–300 MeV [5].

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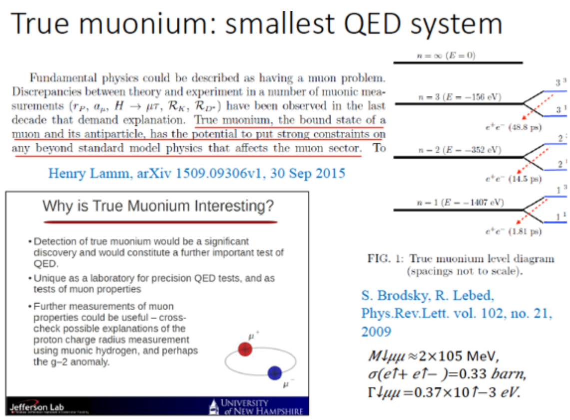

Figure 7: Production of true muonium as key study element for a compact monochromatized collider at 200–300 MeV [5]. The left-bottom picture is from S. Philips, U. New Hampshire, 2012.

All dipoles, quadrupoles could be made without cooling, rendering them simple and cheap. The synchrotron radiation energy loss is small. Therefore, the vacuum chambers need not have radiation absorbers and cooling. The RF system is straightforward and inexpensive too. For the proposed double-ring mirror-symmetric double-ring layout (Fig. 8), electrostatic separator plates are required: 1 m long with 100 kV voltage. The only more complicated element is the wiggler (B=5 T, λ=10 cm, L=1.8 m), but BINP has already developed and produced several of such wigglers.

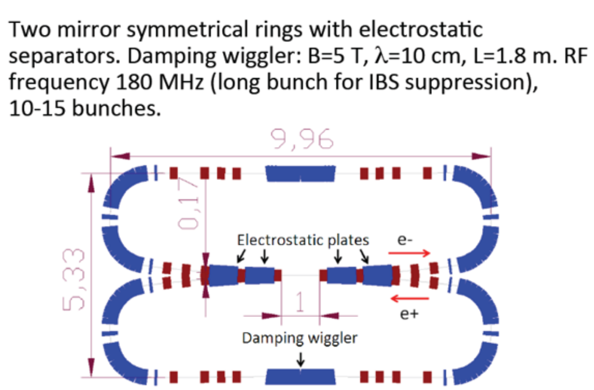

Figure 8: Proposed layout of compact monochromatized collider [5].

Discussion: It was pointed out that the collider would be quite compact, but the required e^+ generation chain providing 11 mA of e^+ current might not be compact at all. Fortunately, at BINP a powerful e^+ injector exists, which could be used to inject into the compact collider.

LEPTON-PROTON SYNERGIES

A future large e^+e^- collider like FCC-ee and CEPC will prepare the tunnel, infrastructure, time and physics case for a subsequent highest-energy hadron collider, just as LEP did for the LHC [11] (Fig. 9), or as had been proposed, in the U.S., for both a 50 TeV 513 km hadron collider [12] (Fig. 10) and, later, for the 200 km VLHC [13]. Conversely, had its first stage been an e^+e^- factory, the SSC project in Texas might not have been cancelled and would have discovered the Higgs boson long before the LHC.

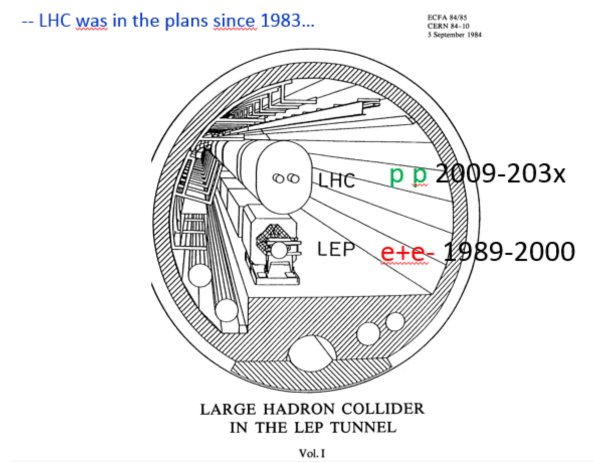

Figure 9: ECFA/CERN LEP-LHC project proposal from 1984, highlighting the historical synergy [14].

Figure 10: Promising but failed attempt to invoke lepton-hadron synergies for a 500 km machine, after the top-quark discovery at the Tevatron [14].

CONCLUSIONS

Circular colliders have been a frontier technology for over 50 years, with more than a factor 10 luminosity increase every 10 years. SuperKEKB will be the next step. Super-charm-tau, CEPC and FCC-ee are being designed.

The session on "design concepts" showed that there continues to be a high level of innovation in collider concepts despite the maturity of the collider field. Several game-changing schemes were proposed during the last 10 years (e.g. crab waist, large Piwinski angle, low emittance). The novel schemes give access to uncharted regimes in luminosity and performance. Upcoming colliders like SuperKEKB will probe the potentials and limits of these new concepts, and will demonstrate their positive impact.

The upgraded VEPP-2000 collider will push the concept of round beams. The large future collider concepts FCC-ee and CEPC build on the recent innovations, and plan to exploit their full potential at the precision frontier, exploring the Higgs and other high-energy particles.

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New ideas for low energy colliders are emerging as well. They might offer attractive alternative paths for research and science. Continuing investigation of their potential is very interesting and exciting.

REFERENCES

[1] Joint ICFA/EuCARD-2 Workshop on future circular electron-positron factories “eeFACT2016”, Cockcroft Institute, Daresbury, 24–27 October 2016; `https://eventbooking.stfc.ac.uk/news-events/eefact2016-349` .

[2] P. Raimondi, “Crab Waist Concept,” presented at eeFACT216, Cockcroft Institute, Daresbury, 23-27 October 2016 [1].

[3] F. Zimmermann, “Higgs Factory Concepts,” in *Proc. eeFACT2016*, Cockcroft Institute, Daresbury, 23-27 October 2016 [1].

[4] D. Shwartz, “Implementation of Round Colliding Beams Concept at VEPP-2000,” in *Proc. eeFACT216*, Cockcroft Institute, Daresbury, 23-27 October 2016 [1].

[5] A. Bogomyagkov, “e+e- Collider with Monochromatization and Maximum Beam Energy of $\tilde{2}$00-300 MeV for True Muonium Production and Other Experiments,” in *Proc. eeFACT216*, Cockcroft Institute, Daresbury, 23-27 October 2016 [1].

[6] V.I. Telnov, “Restriction on the Energy and Luminosity of e+e- Storage Rings due to Beamstrahlung,” *Phys. Rev. Lett.*, 110 (2013) 114801.

[7] A. Bogomyagkov, E. Levichev, and D. Shatilov, “Beam-Beam Effects Investigation and Parameter Optimization for Circular e^+e^- Collider TLEP to study the Higgs Boson”, *Phys. Rev. ST Accel. Beams*, 17, 041004 (2014).

[8] M.A. Valdivia Garcia, F. Zimmermann, “Effect of Beamstrahlung on Bunch Length and Emittance in Future Circular e^+e^- Colliders,” in *Proc. IPAC’16*, Busan (2016), pp. 2438-2441.

[9] M.A. Valdivia Garcia, A. Faus-Golfe, F. Zimmermann, “Towards a Monochromatization Scheme for Direct Higgs Production at FCC-ee,” in *Proc. IPAC’16*, Busan (2016), pp. 2434–2437.

[10] V.V. Danilov et al., “The Concept of Round Colliding Beams,” in *Proc. EPAC’96*, Barcelona, (1996) p. 1149.

[11] A. De Rujula, R. Ruckl, “Large Hadron Collider in the LEP Tunnel,” ECFA 84/85, Rep. CERN 84-10 (1984).

[12] J. Norem et al., “An e^+e^- Top Factory in a 50+50 TeV Hadron Collider Tunnel,” presented at Snowmass 1996 and Proc. PAC’97 Vancouver (1996). in *Conf. Proc. C970512*, (1997) pp. 363–368.

[13] T. Sen, J. Norem, “A Very Large Lepton Collider in the VLHC Tunnel,” *Phys. Rev. ST Accel. Beams*, 5 (2002) 031001.

[14] P. Raimondi, “Important Synergy of Lepton and Hadron Colliders,” comment at eeFACT216, Cockcroft Institute, Daresbury, 23-27 October 2016 [1].

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