Possible Beam Studies at SuperKEKB

Acknowledgements:
Michael Benedikt, Helmut Burkhardt, Yoshihiro Funakoshi, Kazuro Furukawa, Naoko Iida, Dima El Khechen, Haruyo Koiso, Marian Lückhof, Toshi Mitsuhashi, Gaku Mitsuka, Akio Morita, Hiroyuki Nakayama, Yukiyoshi Ohnishi, Kazuhiro Ohmi, Katsunobu Oide, Salim Ogur, Makoto Tobiyama, Hiroshi Sugimoto, Rogelio Tomás, Renjun Yang, Frank Zimmermann

The Future Circular Collider Innovation Study (FCCIS) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 951754.
Introduction SuperKEKB

- Injection linac (electrons and positrons)
- Positron damping ring
- High energy ring: electrons, 7 GeV
- Low energy ring: positrons, 4 GeV
- 2 beam crossings
- 1 interaction point (Belle II)
- Nano beam collision scheme
- Crab waist collision scheme
- Record luminosity of $2.4 \times 10^{34}$ cm$^{-2}$s$^{-1}$

Ref: [1,2,3]
## SuperKEKB and FCC-ee

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FCC-ee</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z</td>
<td>WW</td>
</tr>
<tr>
<td>Circumference [km]</td>
<td>97.756</td>
<td>3.016</td>
</tr>
<tr>
<td>Beam Energy [GeV]</td>
<td>45.6</td>
<td>80</td>
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<td>Hor. Emittance [nm]</td>
<td>0.27</td>
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<tr>
<td>Ver. Emittance [pm]</td>
<td>1.0</td>
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<tr>
<td>$\beta_x$ [cm]</td>
<td>15</td>
<td>20</td>
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<td>$\beta_y$ [mm]</td>
<td>0.8*</td>
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<td>Bunch Length with SR/BS [mm]</td>
<td>3.5/12.1</td>
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* Achieved during spring run 2020 in SuperKEKB

- Electron-positron circular collider
- Comparable beam parameters

Design $\beta_y^*$ = 0.3 mm in SuperKEKB
Smallest $\beta_y^*$ for FCC already reached in 2020

Ref: [1,2,4-8]

Design value: $\sim 0.3$ mm

**History of $\beta_y^*$**

<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>2020</td>
<td>0.3 mm</td>
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SuperKEKB and FCC-ee

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<td>4 7</td>
</tr>
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<td>Hor. Emittance [nm]</td>
<td>0.27 0.84 0.63 1.46</td>
<td>1.9 4.4</td>
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<td>1.0 1.7 1.3 2.9</td>
<td>2.8 1.5</td>
</tr>
<tr>
<td>βx* [cm]</td>
<td>15 20 30 100 3.2 2.5</td>
<td>3.2 2.5</td>
</tr>
<tr>
<td>βy* [mm]</td>
<td>0.8* 1.0 1.0 1.6</td>
<td>0.27 0.30</td>
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* Achieved during spring run 2020 in SuperKEKB

- Electron-positron circular collider
- Comparable beam parameters
- New crab-waist collision scheme

3 Steps:
1) Large Piwinski angle
2) βy comparable to overlap area size
3) Crab-waist transformation

Same sextupoles for local chromaticity correction and crab-waist
SuperKEKB and FCC-ee

Ref: [1,2,4-8]

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* Achieved during spring run 2020 in SuperKEKB

- Electron-positron circular collider
- Comparable beam parameters
- New crab-waist collision scheme
- -I transformation between sextupoles

2.5π phase advance between non-interleaved sextupole pairs in SuperKEKB
Transverse non-linearities are cancelled within a pair of sextupoles
Pseudo -I transformer

\[
\begin{pmatrix}
-1 & 0 & 0 & 0 \\
0 & -1 & 0 & 0 \\
0 & 0 & -1 & 0 \\
0 & 0 & m_{43} & -1
\end{pmatrix}
\]
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* Achieved during spring run 2020 in SuperKEKB

- Electron-positron circular collider
- Comparable beam parameters
- New crab-waist collision scheme
- -I transformation between sextupoles
- Similar beam instrumentation
- Top-up injection

Ref: [1,2,4-8]
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- Electron-positron circular collider
- Comparable beam parameters
- New crab-waist collision scheme
- $-I$ transformation between sextupoles
- Similar beam instrumentation
- Top-up injection

**SuperKEKB is a small FCC-ee!**
Possible Studies at SuperKEKB

- Beam-beam effects
- Beam loss and collimation
- Top-up injection
- Electron cloud
- Experience with beam diagnostics
- Optics measurement and correction
- Benchmark and improve codes used for FCC-ee design
- Background studies at the experiment
- Studies at injectors
- Luminosity dither system could be similar to FCC-ee

- Experience with crab-waist
- Impedance and wake fields
- ...

Already successfully performed or presently ongoing
Optics

- Using turn-by-turn data
- Similar BPMs design
- Single kick or driven motion

Ref: [9-12]

- Closed orbit distortion (COD)

FCC-ee:
- Gain hands-on operation experience
- Measure and control optics similar as it will be in FCC-ee
- Test novel correction strategies
- Use observations to build more realistic models
- Compare different measurement techniques

Measured β-beating using COD at βx,y = 80 mm, 3 mm
**Background Studies**

**Aim to measure orbit using e.g. beam-gas vertex in SuperKEKB**

- MDISIM developments: rebuilt SuperKEKB interaction region based on SAD
- Simulate SAD-model vertical closed orbit in the presence of solenoid and quadrupoles

![Graph showing orbit measurements](image)

- Strong 10 keV photon line in synchrotron radiation background

**FCC-ee:**
- ✔ Code development driven by SuperKEKB experience
- ✔ Accurate model of the interaction region with solenoids
- ✔ Help to determine number of collimators in interaction region

**Acknowledgements:** Helmut Burkhardt, Marian Lückhof, Hiroyuki Nakayama

Beam pipe next to interaction point
Beam-Beam and Luminosity Dither

- Beam-beam simulations
  - Emittance blow up
  - Benchmark codes

Head-tail motion during SuperKEKB commissioning
\( (8 \times 8 \beta^* x, y = 8x \text{design}) \)

- Luminosity dither system
  - Increase luminosity

FCC-ee:
- Gain experience with possible similar luminosity dither system
- Benchmark beam-beam simulation codes
- Rebuild possible emittance blow-up challenges

Figure 8: \( V_y \) (green) and bump height at the IP (blue) are plotted with luminosity (orange) during the dither feedback test.

With feedback improve beam-beam position at the IP using bumps to increase luminosity

## Acknowledgements
Dima El Khechen
Studies at Injectors

- Beam jitter studies in electron mode
  - Result of mismatch in linac arc

- Beam based misalignment determination in quadrupoles
  - Avoid emittance blow-up
  - RMS alignment precision of 37 µm

Acknowledgements: Salim Ogur

Ref: [24,25]

Precise alignment also possible with virtual BPMs

Applicable to other machines to improve misalignments

FCC-ee:
- Improve positron production
- Improve magnet alignments and determine number of required BPMs

Fluctuation starts in linac arc
Target for positron production
Summary

• SuperKEKB is demonstrating FCC-ee key concepts
  • Crab waist collision scheme
  • Similar lattice, optics, injection and beam instrumentation system
• Existing studies and results useful for FCC-ee design and future operation
  • Optics and experience with beam instrumentation
  • Code benchmarking and improvement
• More future studies possible to perform in the future
  • Optics and corrections
  • Electron cloud
  • Wake fields and impedance studies
  • Collective effects
  • Extensive crab-waist studies
  • Code benchmarking
  • ...
Possible Beam Studies at SuperKEKB

Thank you!

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FCC November Week
10th November 2020

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References II


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References III

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