Possible Beam Studies at SuperKEKB

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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, Kazuhito Ohmi, Katsunobu Oide, Salim Ogur, Makoto Tobiyama, Hiroshi Sugimoto, Rogelio Tomás, Renjun Yang, Frank Zimmermann

FCC November Week

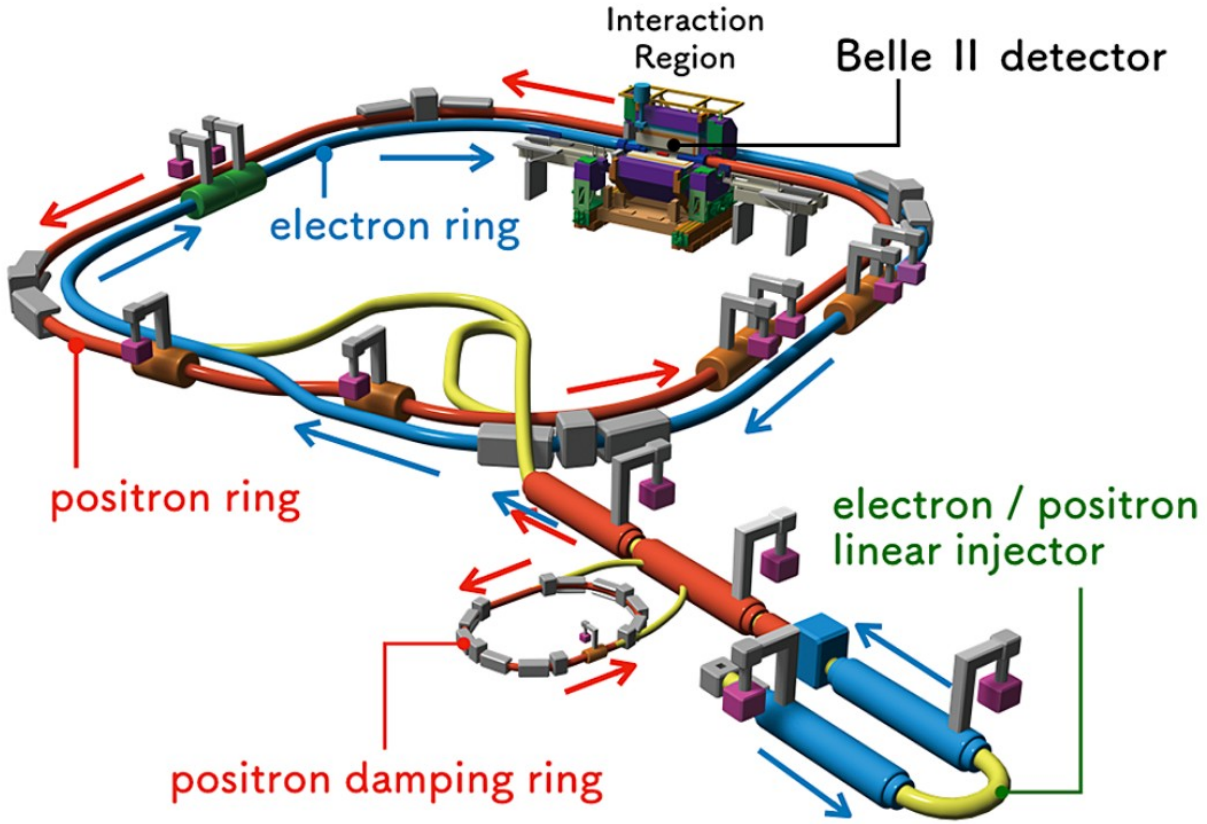
10th November 2020

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

Ref: [1,2,3]

- 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 2.4×10^{34} $cm^{-2}s^{-1}$



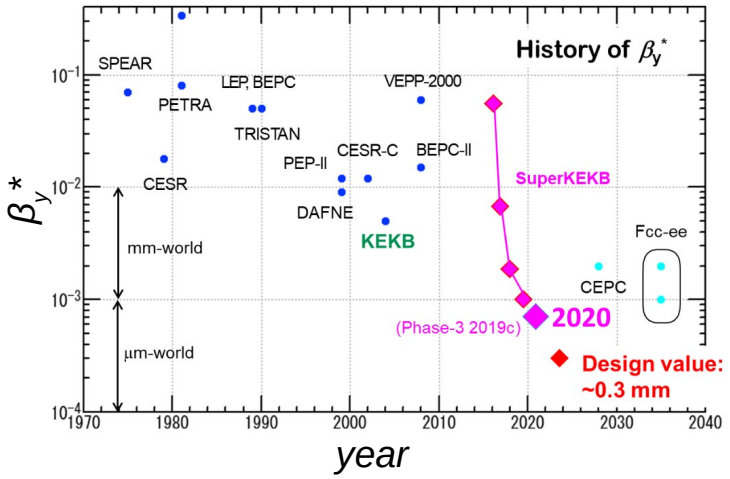
SuperKEKB and FCC-ee

Ref: [1,2,4-8]

Parameter	FCC-ee				SuperKEKB	
	Z	WW	ZH	tt	LER	HER
Circumference [km]	97.756				3.016	
Beam Energy [GeV]	45.6	80	120	182.5	4	7
Hor. Emittance [nm]	0.27	0.84	0.63	1.46	1.9	4.4
Ver. Emittance [pm]	1.0	1.7	1.3	2.9	2.8	1.5
βx* [cm]	15	20	30	100	3.2	2.5
βy* [mm]	0.8*	1.0	1.0	1.6	0.27	0.30
Bunch Length with SR/BS [mm]	3.5/12.1	3.0/6.0	3.3/5.3	2.0/2.5	4.7	4.9

** Achieved during spring run 2020 in SuperKEKB*

- Electron-positron circular collider
- Comparable beam parameters



Design βy = 0.3 mm in SuperKEKB*
Smallest βy for FCC already reached in 2020*

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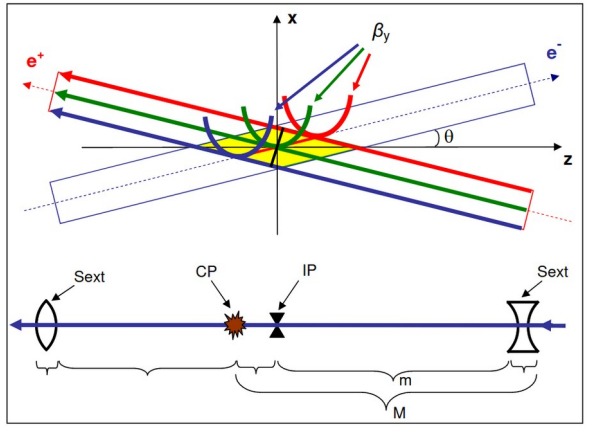
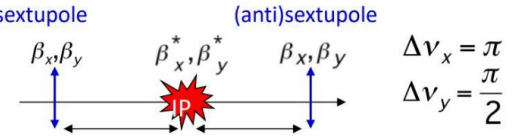


3 Steps:
1) Large Piwinski angle
2) βy comparable to overlap area size
3) Crab-waist transformation

Same sextupoles for local chromaticity correction and crab-waist



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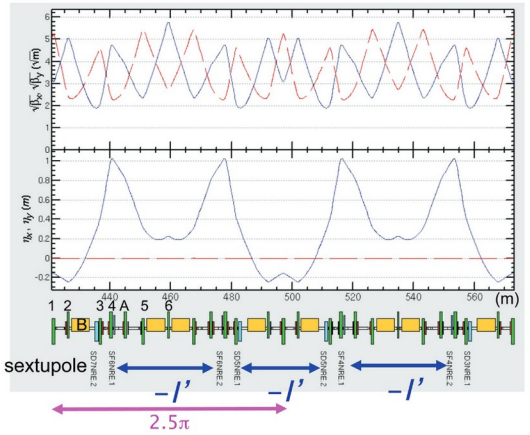
- -I transformation between sextupoles



2.5π phase advance between non-interleaved sextupole pairs in SuperKEKB

Transverse non-linearities are cancelled within a pair of sextupoles

Pseudo -I transformer

$$\begin{pmatrix} -1 & 0 & 0 & 0 \\ m_{21} & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & m_{43} & -1 \end{pmatrix}$$

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- Similar beam instrumention
- Top-up injection

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- Similar beam instrumention
- 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
- Experience with crab-waist
- Impedance and wake fields
- ...

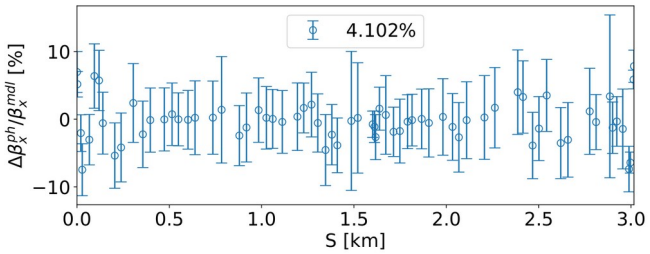
- Optics measurement and correction
- Benchmark and improve codes used for FCC-ee design
- Background studies at the experiment
- Studies at injectors
- Luminosity dither system could be similar to FCC-ee

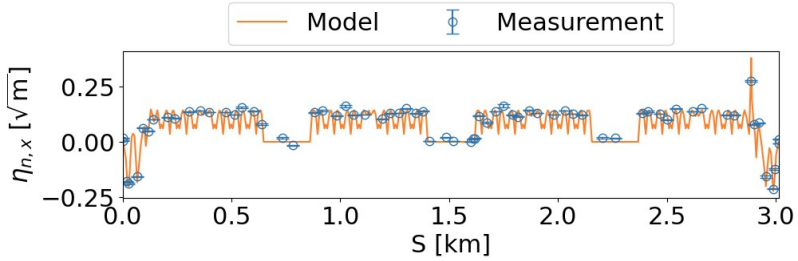
Already successfully performed or presently ongoing

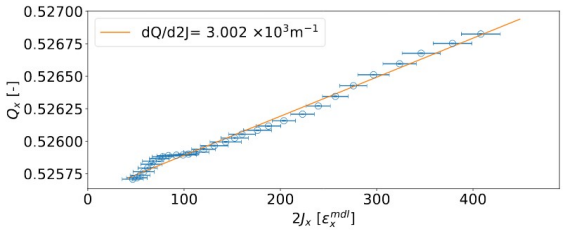
Optics

Ref: [9-12]

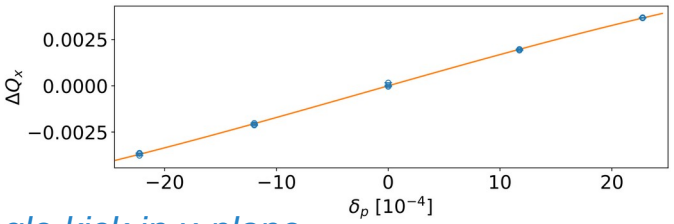
- Using turn-by-turn data
  - Similar BPMs design
  - Single kick or driven motion

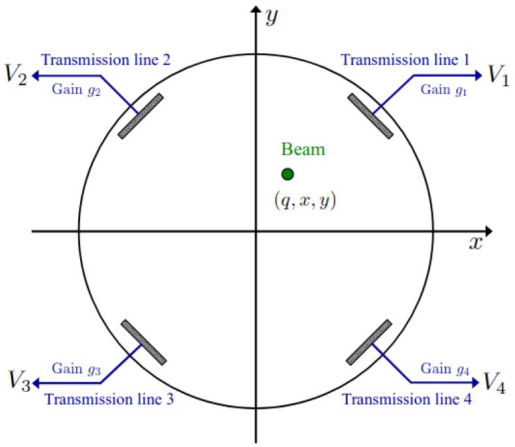






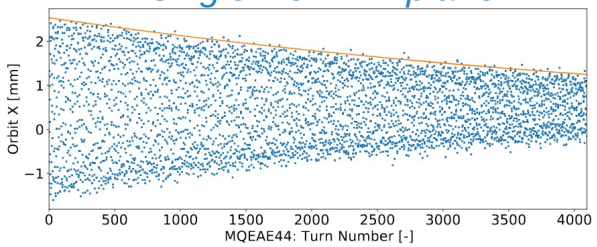
LER amplitude detuning and chromaticity



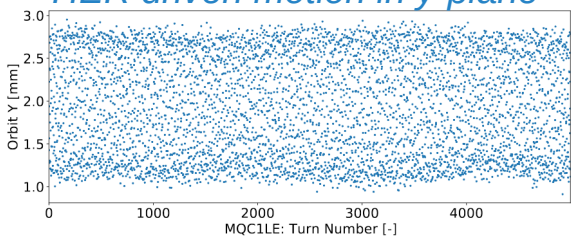


Button BPMs with 45° rotation angle in SuperKEKB

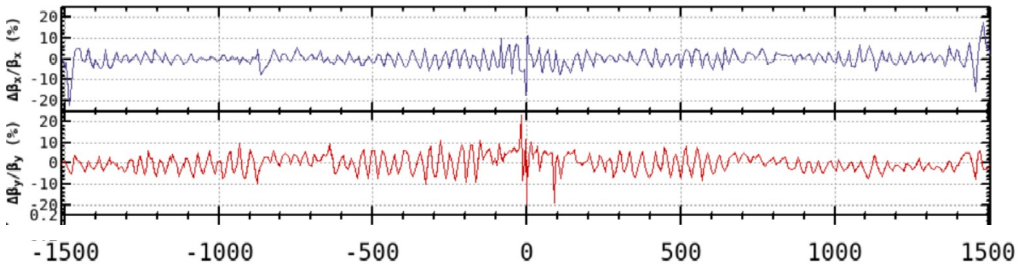
HER single kick in x-plane



HER driven motion in y-plane



- Closed orbit distortion (COD)



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

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*

Acknowledgements: Helmut Burkhardt, Marian Lückhof, Hiroyuki Nakayama

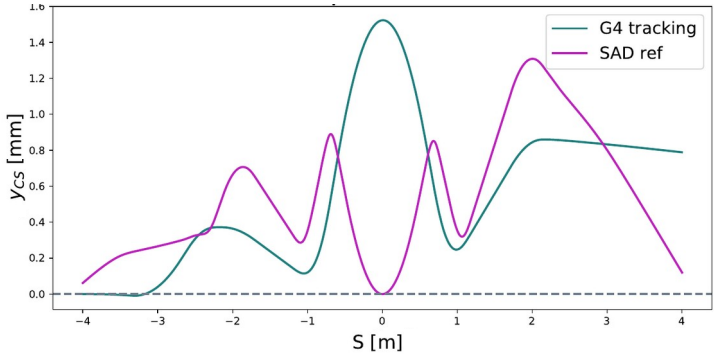
Background Studies

Ref: [13-17]

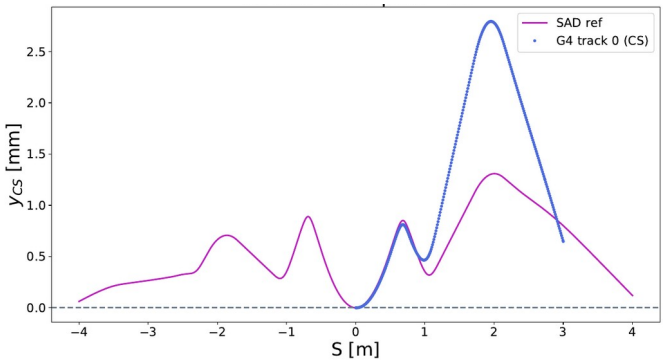
Aim to measure orbit using e.g. beam-gas vertex in SuperKEKB

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

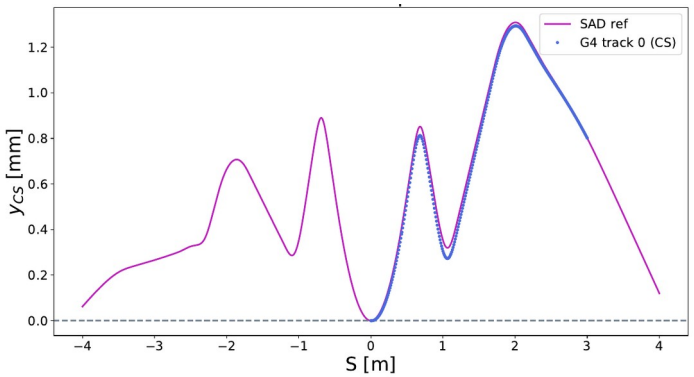
Start



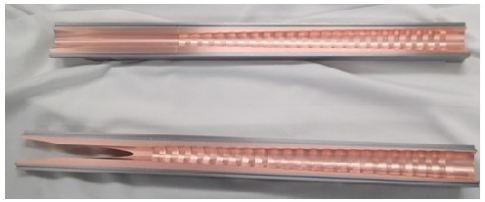
Intermediate



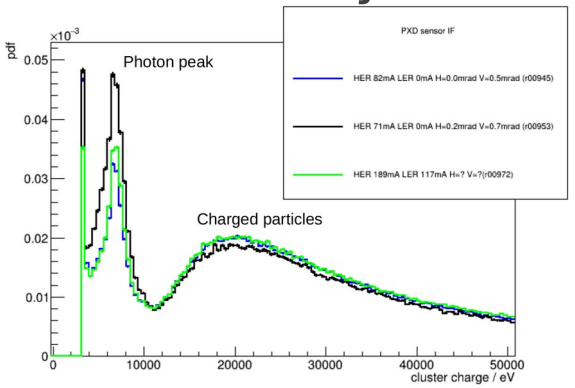
Final



- Strong 10 keV photon line in synchrotron radiation background



Beam pipe next to interaction point



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*

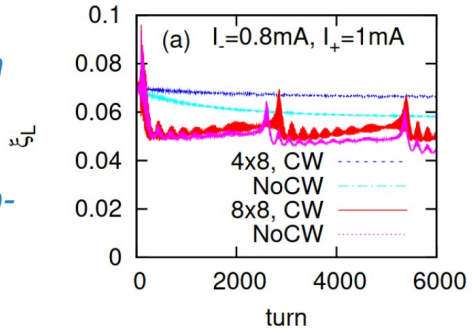
Acknowledgements: Dima El Khechen

Beam-Beam and Luminosity Dither

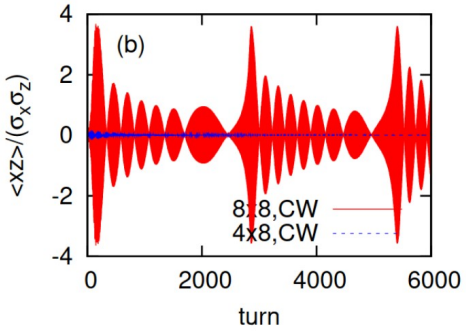
Ref: [18-23]

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

Beam-beam parameter with and without crab-waist in SuperKEKB



*Head-tail motion during SuperKEKB commissioning (8x8 β*x,y = 8xdesign)*



- Luminosity dither system
  - Increase luminosity

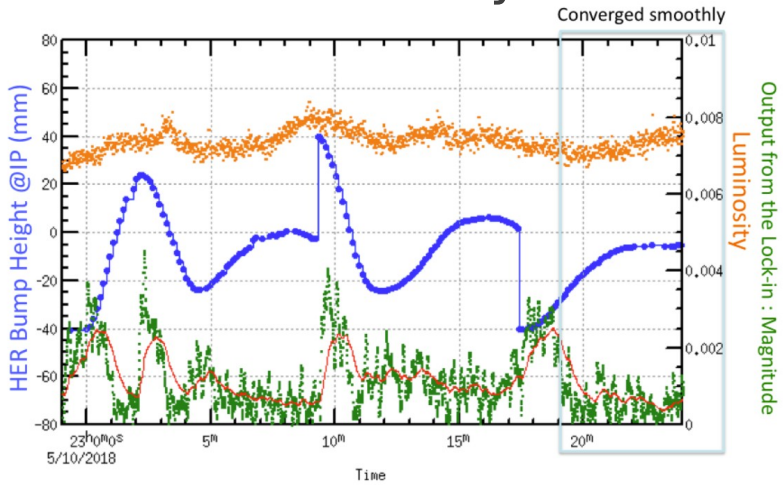
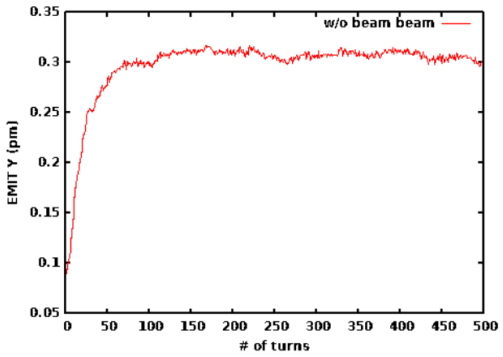
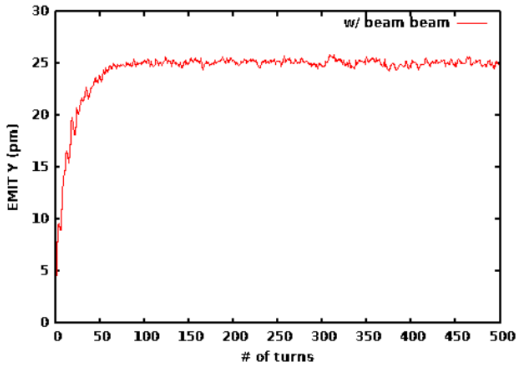


Figure 8: V_x (green) and bump height at the IP (blue) are plotted with luminosity (orange) during the dither feedback test.

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

Vertical emittance blow-up due to beam-beam in FCC-ee





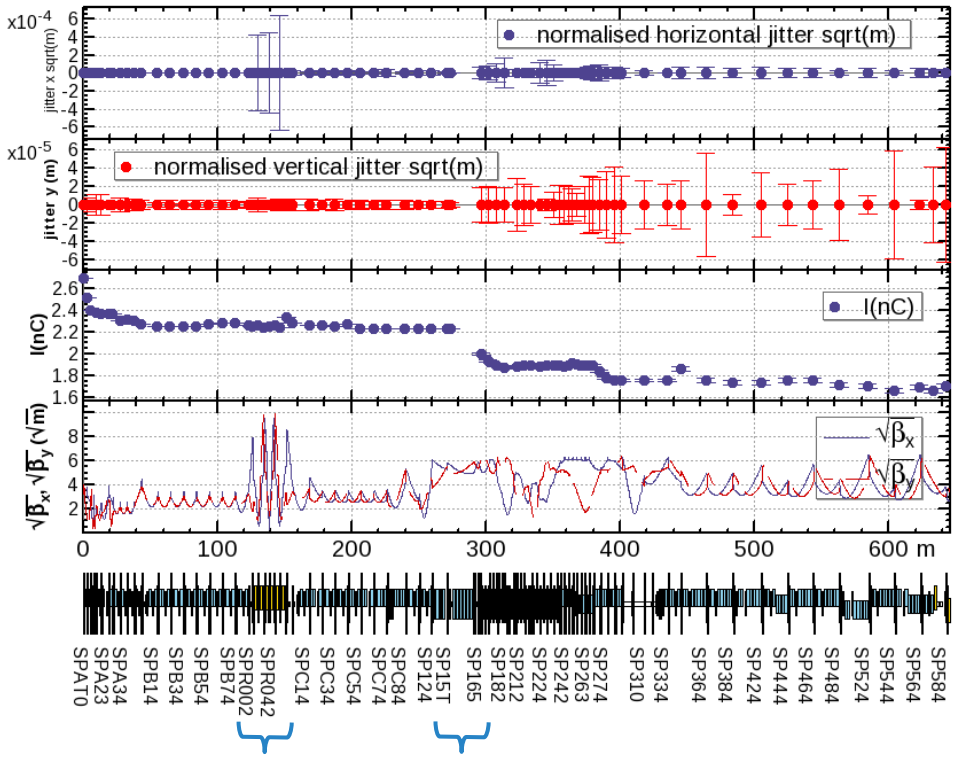
FCC-ee:
- ✔ *Gain experience with possible similar luminosity dither system*
- ✔ *Benchmark beam-beam simulation codes*
- ✔ *Rebuild possible emittance blow-up challenges*

Acknowledgements: Salim Ogur

Studies at Injectors

Ref: [24,25]

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



Fluctuation starts in linac arc

Target for positron prodction

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

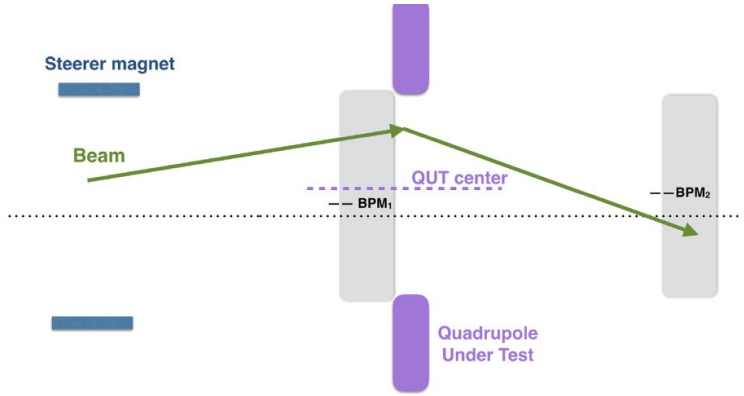


Fig. 5. A sketch of the orbit change caused by the dipolar kick from a displaced quadrupole.

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*

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

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