FUTURE CIRCULAR COLLIDER

CERN

SuperKEKB Studies and Plans

Jacqueline Keintzel*, Yukiyoshi Ohnishi, Rogelio Tomas

FCC-ee IS WP2 Workshop

Rome, Italy

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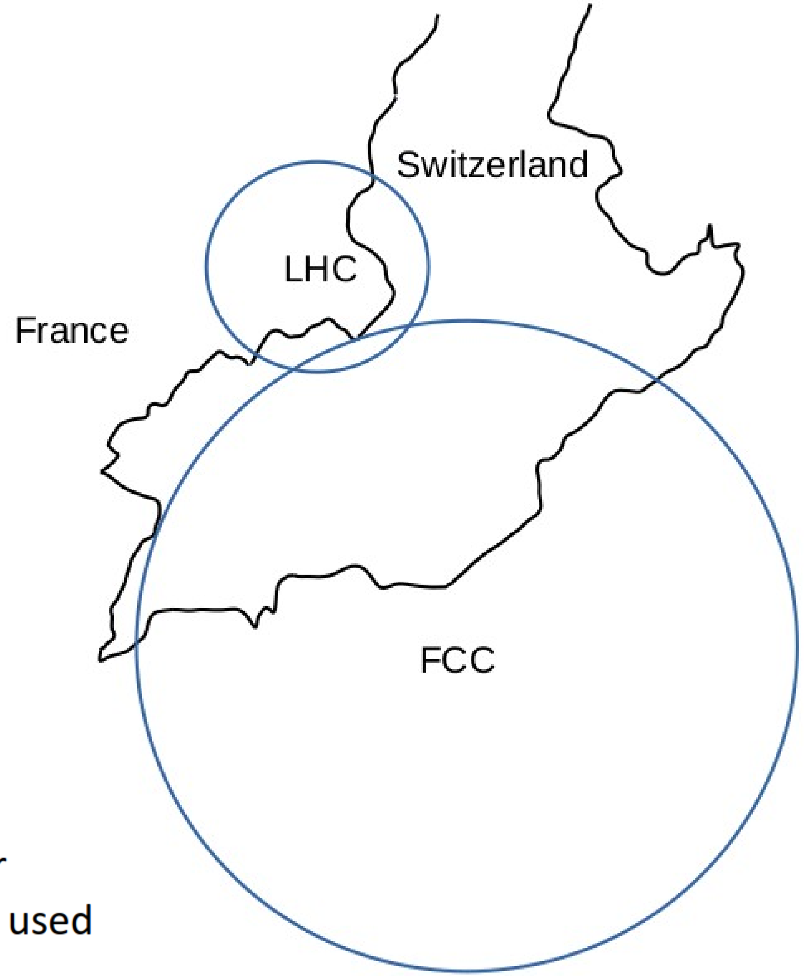
FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

*jacqueline.keintzel@cern.ch

Introduction

- Integrated FCC project spans over this century
- FCC-ee first stage with commissioning in 2040s
- FCC-ee requires
  - Robust optics design and tuning techniques
  - Controlling alignment tolerances
  - Accurate and fast optics measurement techniques
- M. Benedikt:

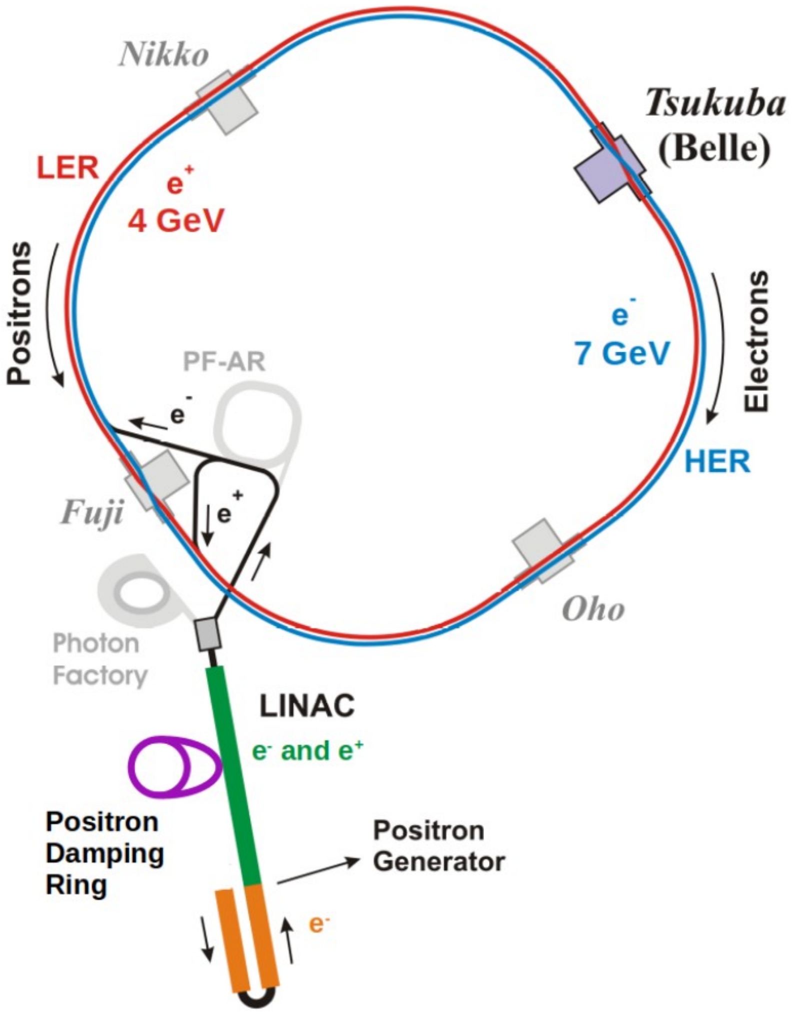
- **Low-risk technical solution** based on 60 years of e^+e^- circular colliders and particle detectors ; R&D on components for improved performance, but no need for “demonstration” facilities; LEP2, VEPP-4M, PEP-II, KEKB, DAΦNE, or SuperKEKB already used many of the key ingredients in routine operation



Requires beam tests at existing machines to test FCC-ee challenges
Understanding SuperKEKB is crucial for FCC-ee

SuperKEKB

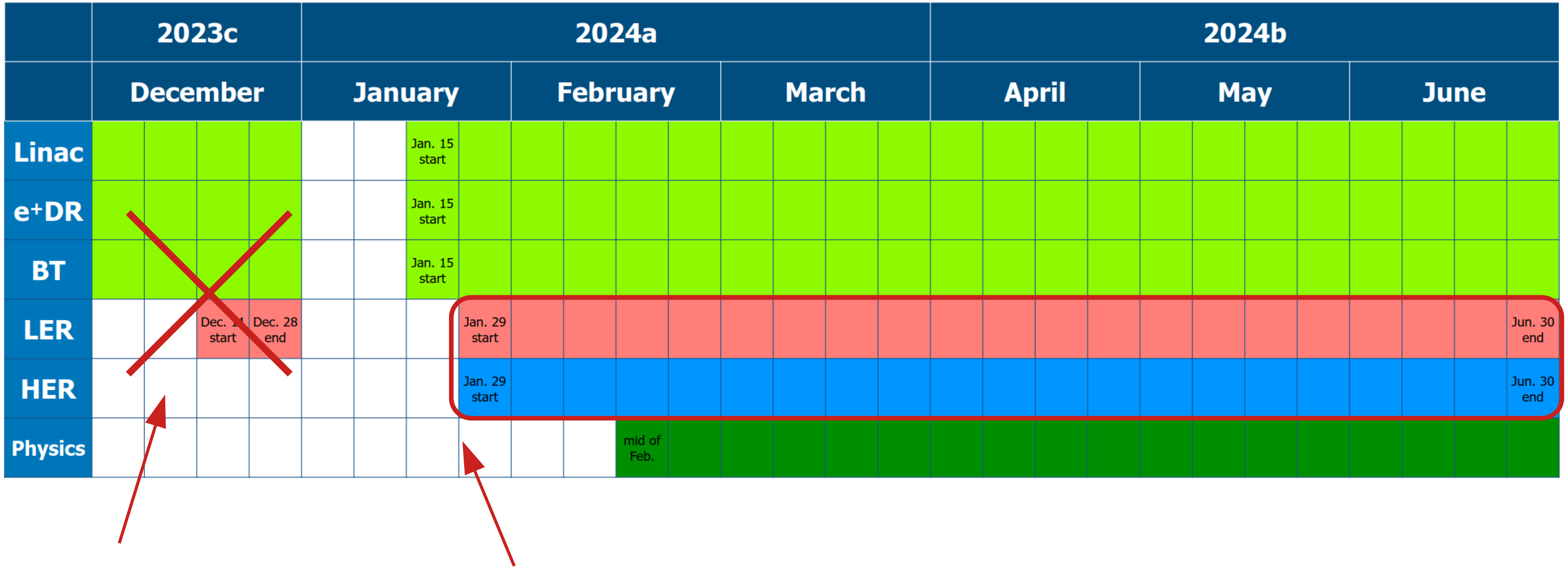
- Collider with 3 km circumference
- Record luminosity of 4.65 x 10^{34} $cm^{-2}s^{-1}$
- Very similar to FCC-ee
  - Non-interleaved sextupoles with -I transformation
  - Crab-waist collisions
  - Top-up injection
  - ...



SuperKEKB is small FCC-ee

Schedule and Status for 2024

Y. Ohnishi, 19 September 2023: https://kds.kek.jp/event/48117



December run cancelled

Start of Main Rings Operation: Foreseen for End of January

Machine Parameters

	June 8, 2022		Target at post-LS1 (1)		Target at post-LS1 (2)		Unit
Ring	LER	HER	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	4.0	4.6	nm
Beam Current	1321	1099	2080	1480	2750	2200	mA
Number of bunches	2249		2346		2346		
Bunch current	0.587	0.489	0.89	0.63	1.17	0.94	mA
Horizontal size σ_x*	17.9	16.6	17.9	16.6	17.9	16.6	μm
Vertical cap sigma Σ_y*	0.303		0.217		0.178		μm
Vertical size σ_y*	0.215		0.154		0.126		μm
Betatron tunes ν_x / ν_y	44.525 / 46.589	45.532 / 43.573	44.525 / 46.589	45.532 / 43.573	44.525 / 46.589	45.532 / 43.573	
β_x* / β_y*	80 / 1.0	60 / 1.0	80 / 0.8	60 / 0.8	80 / 0.6	60 / 0.6	mm
σ_z	4.6	5.1	6.5	6.4	6.5	6.4	mm
Piwinski angle	10.7	12.7	10.7	12.7	10.7	12.7	
Crab waist ratio	80	40	80	80	80	80	%
Beam-Beam ξ_y	0.0407	0.0279	0.0444	0.0356	0.0604	0.0431	
Specific luminosity	7.21×10^{31}		7.62×10^{31}		9.31×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	4.65×10^{34}		1×10^{35}		2.4×10^{35}		$cm^{-2}s^{-1}$

10^{35} and 2.4×10^{35} are tentative and considered by Y. Funakoshi.

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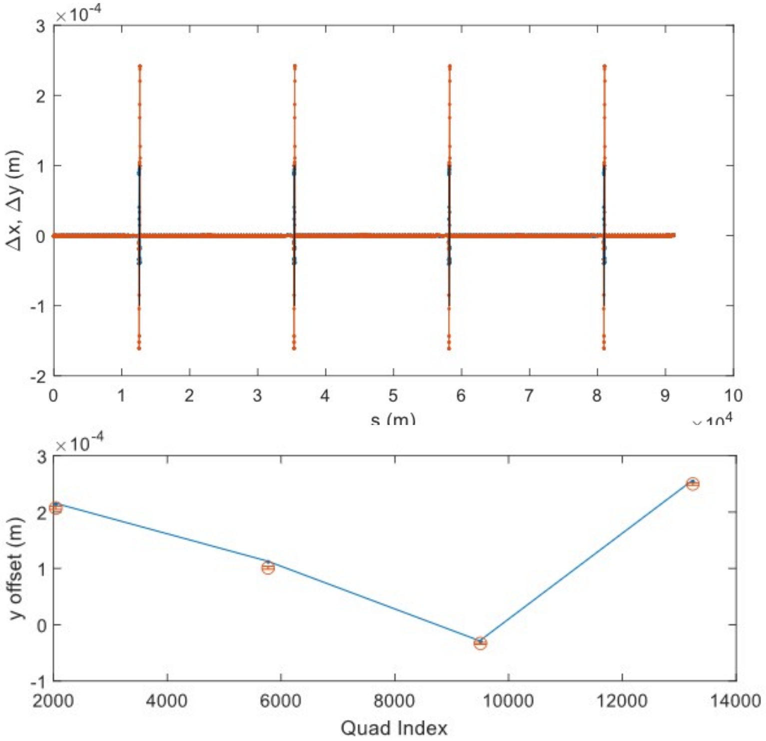
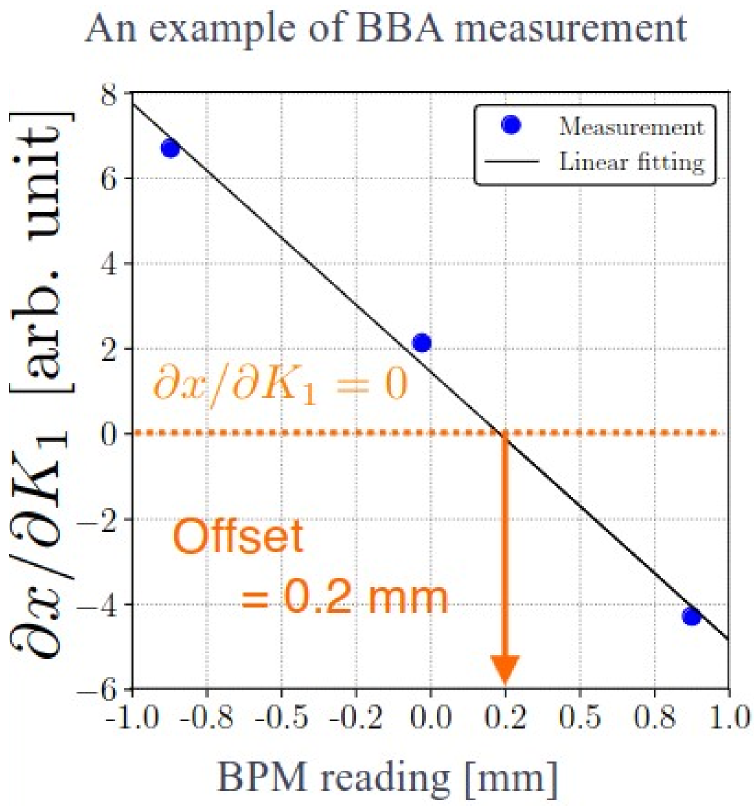
BBA Studies and Commissioning

- For arc quadrupoles and possibly also arc sextupoles (takes about 10 mins per element)
- Alignment of crab-waist sextupoles
- Possibly also try parallel beam-based alignment by X. Huang



Parallel BBA of 4 arc quadrupoles, with residual errors of about 20 µm

X. Huang, 14 September 2023: https://indico.cern.ch/event/1325263/



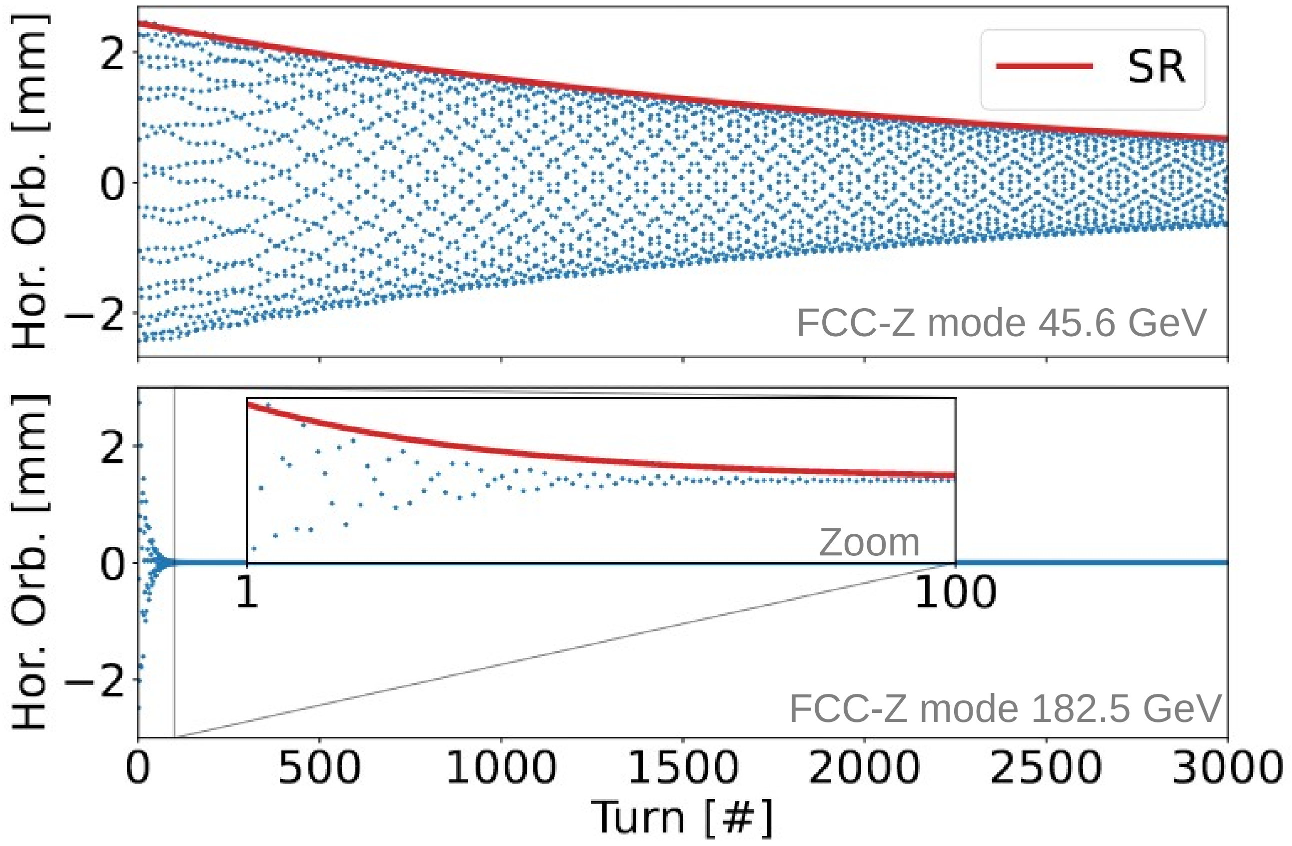
H. Sugimoto, 19 September 2023: https://kds.kek.jp/event/48117

Turn-by-Turn Measurements

- Orbit recorded ideally horizontally and vertically Turn-by-Turn (TbT)
- Requires beam excitation
  - Single kick

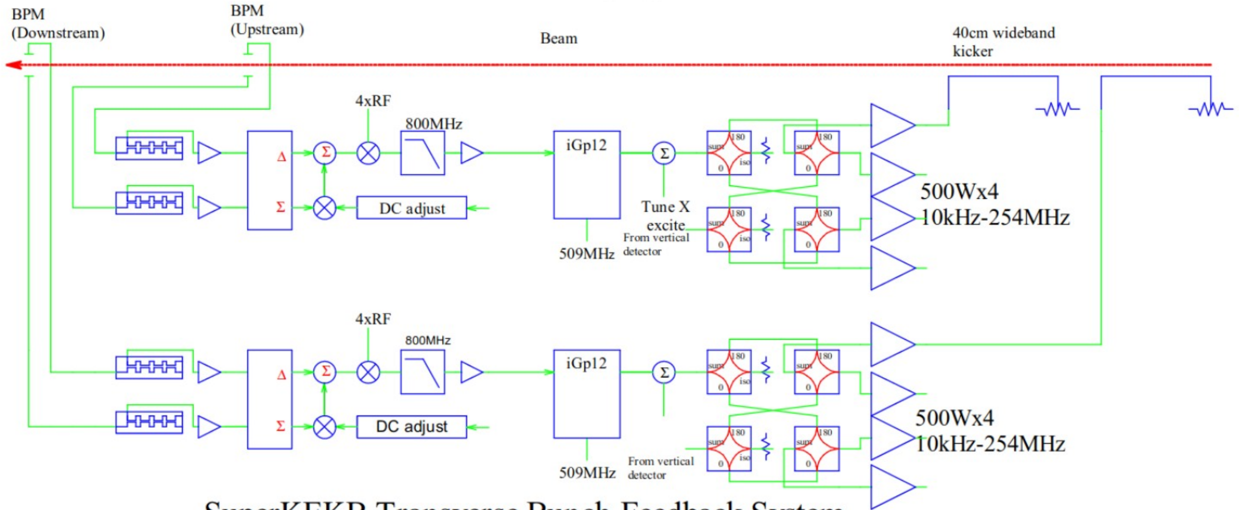
Top: FCC-Z mode 45.6 GeV beam energy
Damping of single particle tracking orbit after $10\sigma_x$, $10\sigma_y$ kick
2300 turns damping time
→ **Slow enough to be used for TbT measurements**

Bottom: FCC-ttbar mode 182.5 GeV beam energy
Damping of single particle tracking orbit after $10\sigma_x$, $10\sigma_y$ kick
40 turns damping time
→ **Too fast to be used for TbT measurements**



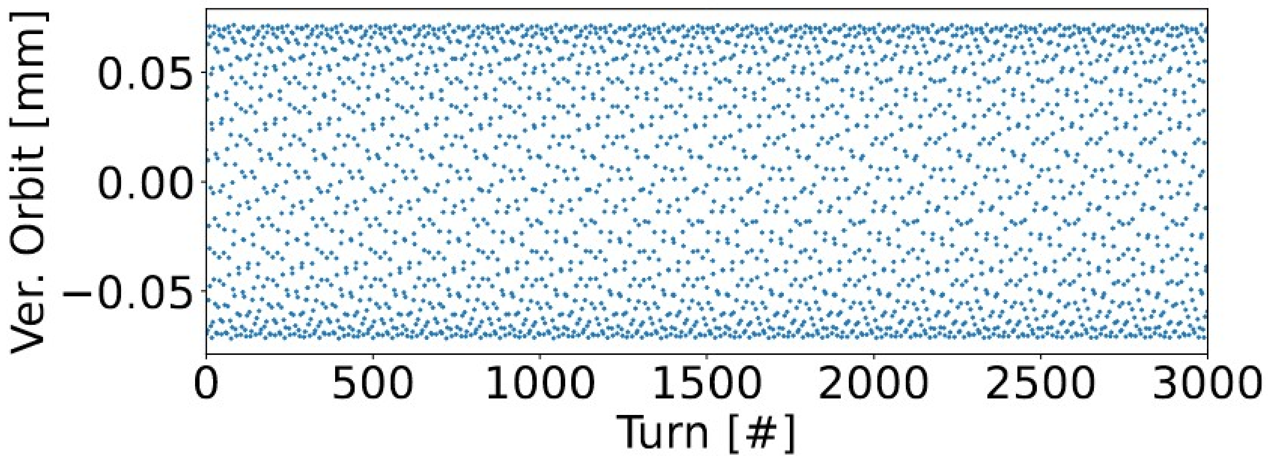
Turn-by-Turn Measurements

- Orbit recorded ideally horizontally and vertically Turn-by-Turn (TbT)
- Requires beam excitation
  - Single kick
  - Driven motion



SuperKEKB Transverse Bunch Feedback System

FCC-Z mode with 45.6 GeV beam energy
Single particle tracking without radiation damping



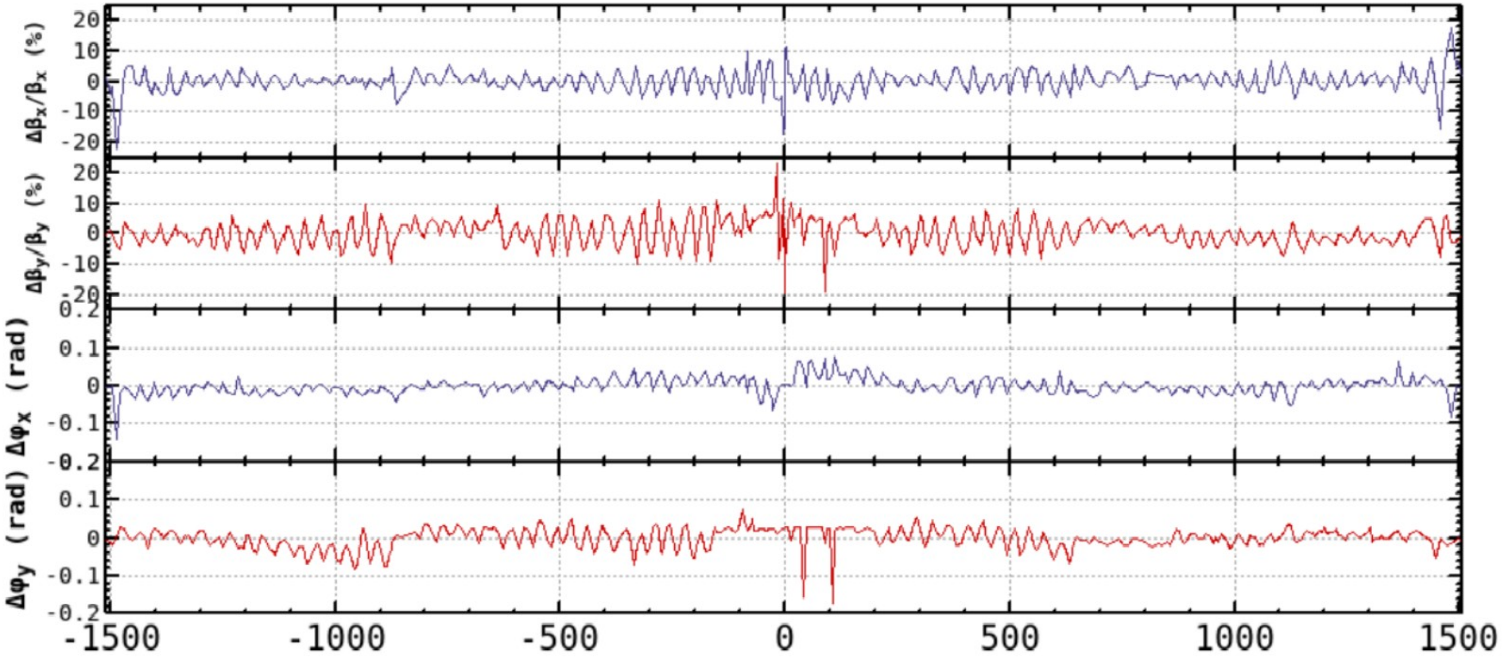
Continous excitation achieved in SuperKEKB using transverse feedback system and amplification
+ Drives the beam at the natural tune (no compensation)
- Typically limited in amplification (low excitation)

H. Sugimoto

Orbit Response Matrix SKEKB

- Explore Orbit Response Matrix (ORM) approach for FCC-ee
- Including Closed Orbit Distortion (COD) method with fewer correctors as in SKEKB

In SuperKEKB:
Closed Orbit Distortion (COD) performed
3 pairs of orbit correctors generate 6 closed orbit distortions
+ Routinely performed and used to calculate corrections
+ Very good resolution of about 5 µm
- Rather time consuming procedure
- Orbit limited to 10-20 µm to avoid distortions from interaction region quadrupoles and sextupoles



Measurement Techniques

- **Various excitation techniques for TbT measurements and comparison to closed-orbit measurements**
  - Use horizontal kicker and new vertical kicker for the first time (possibly to be commissioned 2024)
  - Continue exploring using feedback kicker (PLL) further for simultaneous H and V measurements
  - Compare various measurement techniques and benchmark results

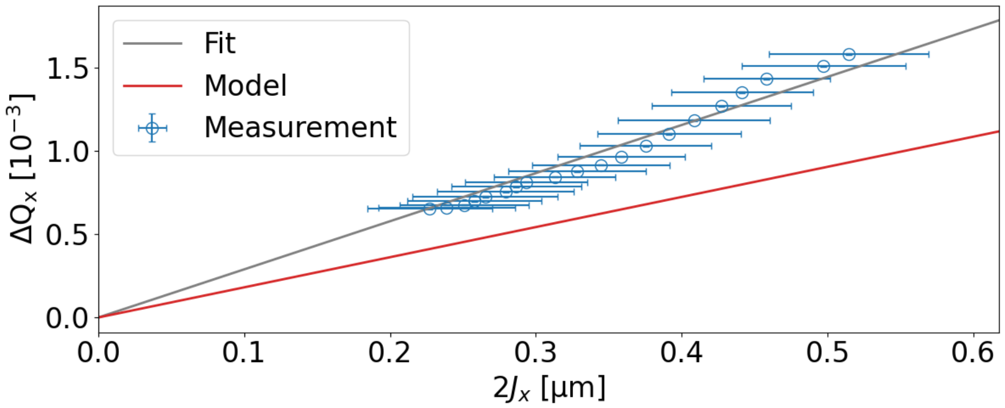
Parameter	Closed Orbit Distortion	Turn-by-Turn	
		Injection Kicker	Phase Lock Loop
BPMs in HER	466	68	68
BPMs in LER	444	70	70
Hor. optics measurement	yes	yes	yes
Ver. optics measurement	yes	no	yes
RDTs measurement	no	some	yes
Calibration independent	no	yes	yes
Status for measurements	stable	stable	being explored
Trigger to record data	yes	yes	no
Time for measurement	≈20 mins	≈2 mins	≈2 mins

More TbT BPMs possible?

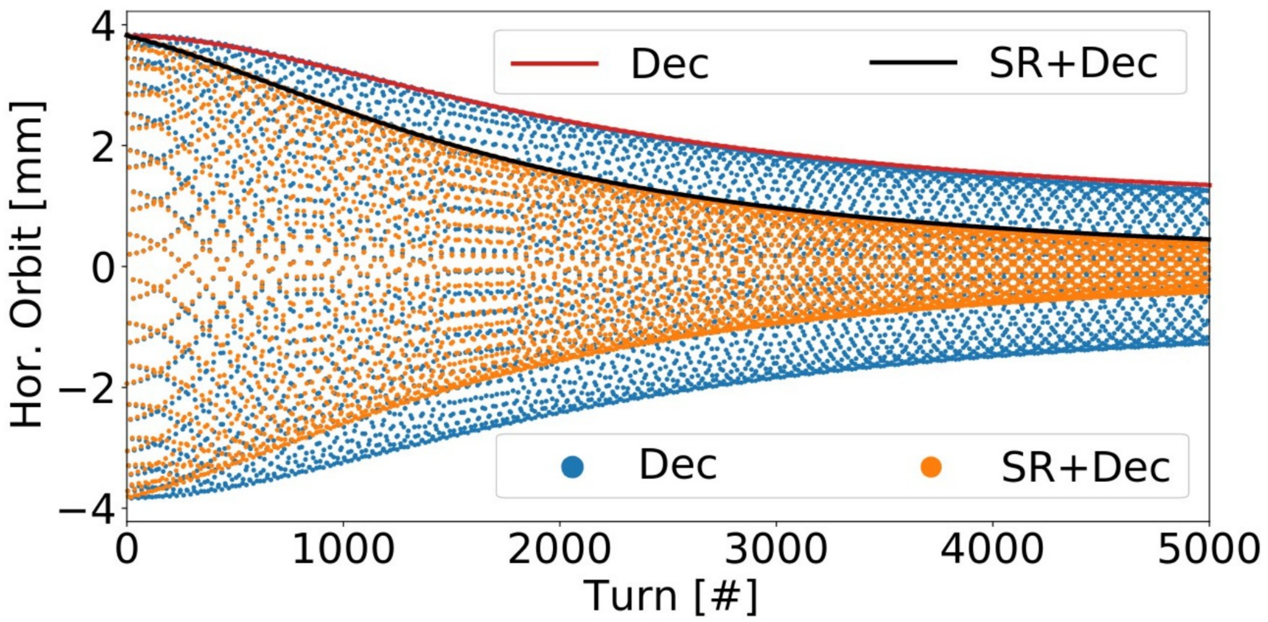
TbT typically faster

Lepton Decoherence

- **Decoherence studies for kicked lepton beams**
  - Single kicks to observe decoherence, ideally horizontally and vertically
  - Aim to reduce decoherence value using various octupole settings
  - Damping over various kick strengths
  - Benchmark (new) theory

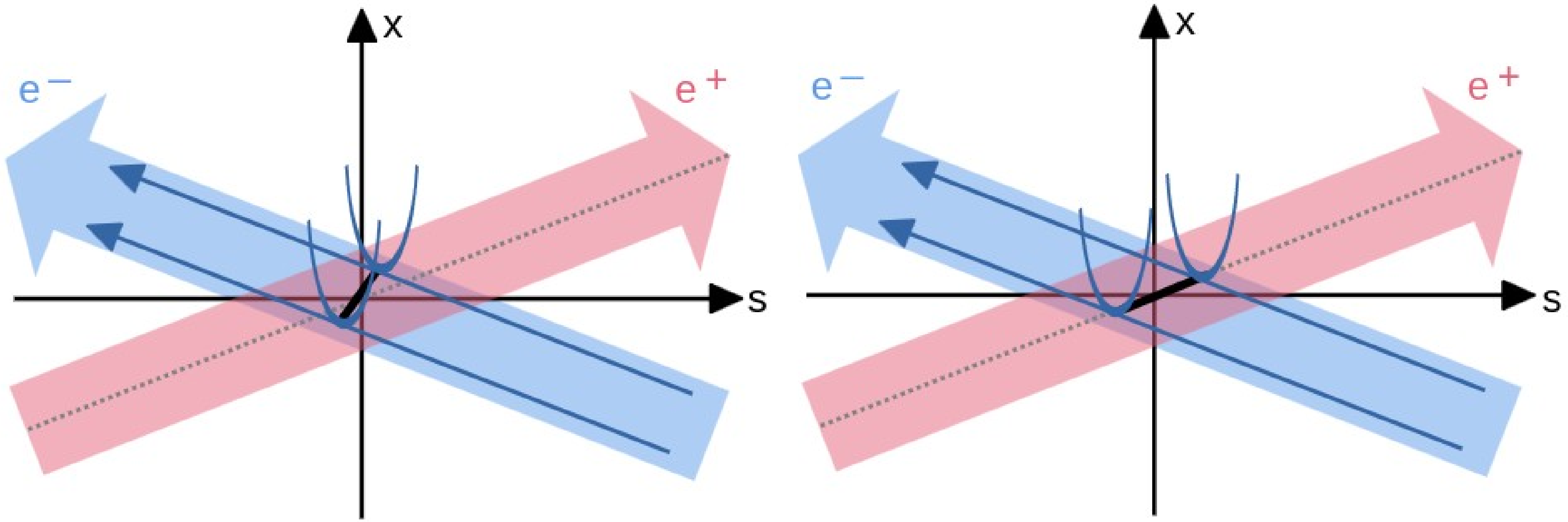


Improved technique for amplitude detuning measurement in lepton storage rings



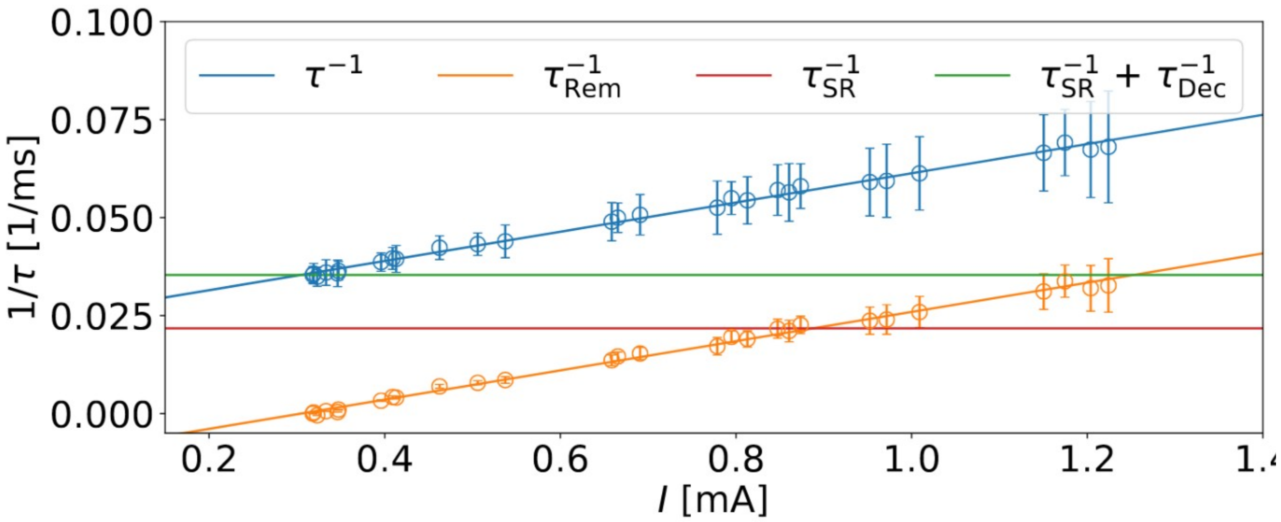
Crab-Waist and Sextupole Schemes

- **Exploration of crab-waist sextupole and other sextupole settings**
  - Optics measurements at various (crab-waist sextupole) settings for both beams
  - Measurement of lifetime and luminosity over crab-waist transformation
  - Dynamic aperture optimization studies



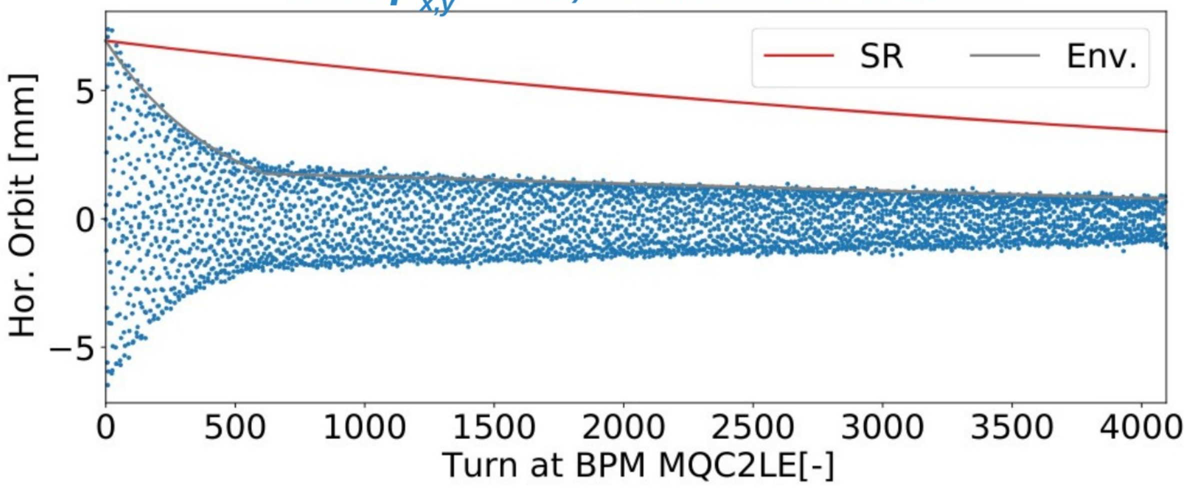
Intensity Dependent Effects

- **Different bunch configurations to understand single and multi-bunch effects**
  - Various bunch intensities for both beams
  - Various number of bunches circulating for measurements for both beams



Measurement with different single bunch current, helps distinguishing decoherence from head-tail damping

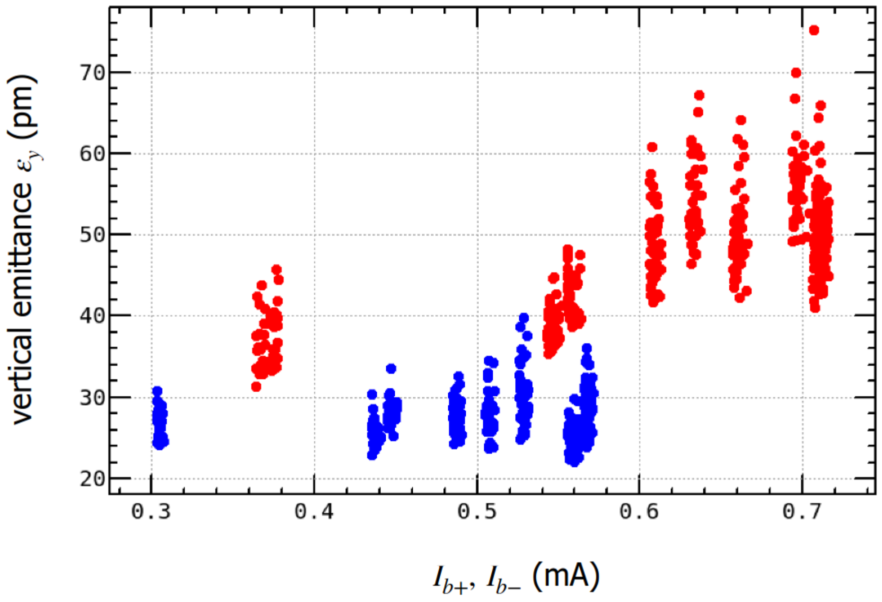
HER $\beta_{x,y}$ = 80,1.2 mm in IK-H mode*



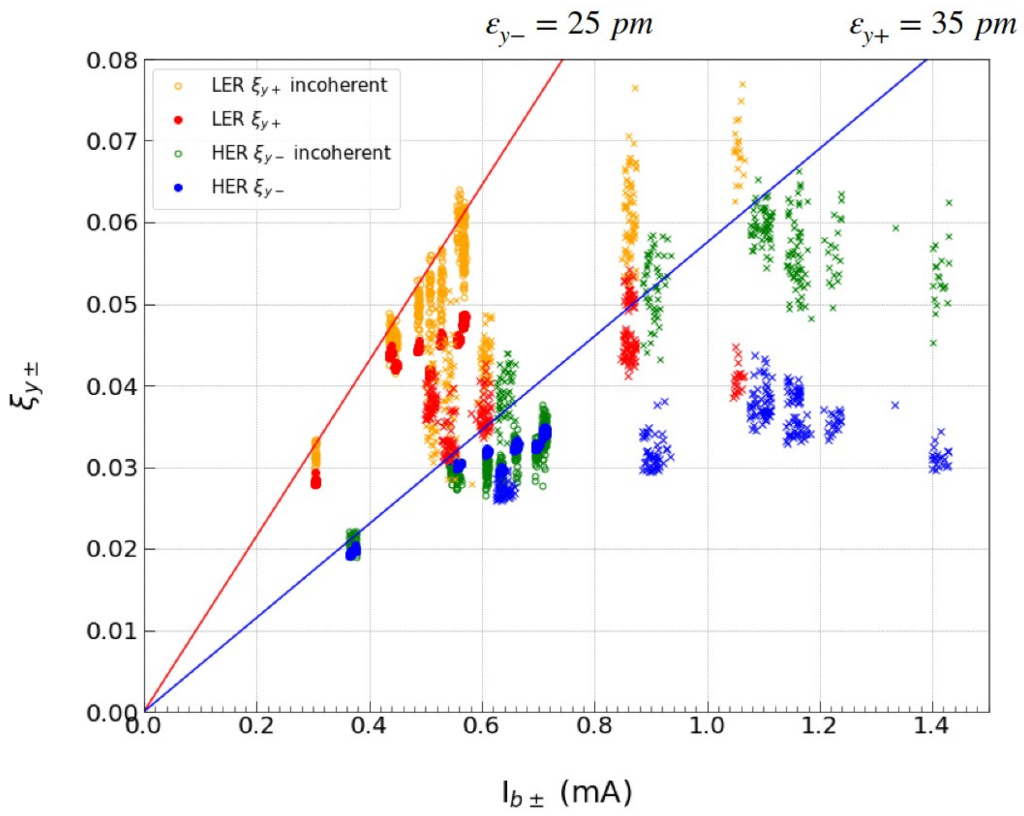
Measurement with multiple bunches present in the machine lead to observation of fast damping, but high BPM resolution

Beam-Beam and Emittance

- **Beam-beam parameter and beam-size blow-up and emittance increase:**
  - Measure tune shift over bunch intensity
  - Measure beam-size with x-ray monitor
  - Use data during physics run



LER: large beam size blow-up



LER: beam-beam parameter large at 0.8 mA

Y. Ohnishi, 19 September 2023: https://kds.kek.jp/event/48117

Summary

- SuperKEKB is similar to FCC-ee in various aspects
- Understanding and solving SuperKEKB challenges helps improving FCC-ee and shape its design
- Start of next SuperKEKB run foreseen end of January 2024, until end of June 2024
- Many opportunities to engage in experimental beam tests on various topics

  (Optics measurements, BBA, intensity dependent effects, machine learning, etc.)

Thank you!

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LER operation only in 2023c

- Vacuum scrubbing
  - 80 ~ 100 Ah (Owl shift on weekday, 3 shifts for holiday)
- Adjustment and check of hardware devices (need time because it is after 1 year and half shutdown)
  - beam monitors, magnet polarity, magnet power supplies, timing system, injection system, cooling system, etc.
  - Mis-wiring of magnet cable and BPM cable should be considered.
- Commissioning of the nonlinear collimator (including OHO wiggler optics tuning)
- Correction of beam obit and optics (including BPM gain mapping, beam based alignment)
- Measurements of optics parameters, orbit fluctuations, tune scan, tune shift, TBT BPM analysis, etc.
  - chromatic X-Y coupling($r_1^{*\prime}$ and $r_2^{*\prime}$) adjustment by using rotatable sextupoles
- Measurement and optimization of dynamic aperture
  - change sextupole setting, change crab-waist ratio, use QCS octupoles, etc.
- High bunch current operation with low total current and low impedance (test of SBL?)

LER and HER operation in 2024a

- BPM gain mapping, Quad BPMs (as early as possible) in the HER
- Adjustment and check of hardware devices of HER as well as the LER
- Isolation of BPM from quadrupole magnet in the local chromaticity correction region in the HER
- Measurements of optics parameters, orbit fluctuations, tune scan, tune shift, TBT BPM analysis, etc. (cont'd)
- Measurement of dynamic aperture by using kicker and TBT BPMs
- Sextupole optimization to make Touschek lifetime longer in the HER
- Octupole optimization to suppress detuning and to check beam lifetime in the HER
- Tune scan (beam size, lifetime, injection efficiency) in the HER
- Scan of vertical angle at IP orbit to maximize luminosity: check SR from IR in the HER
- Change crab-waist ratio (0% to 80 % to check lifetime and luminosity)
- Beta squeezing down to 0.8 mm (in 2024b ?)