Towards Demonstrating CLIC FFS in SuperKEKB

P. Thrane[1,2] K. Ohmi[3] Y. Onishi[3]
R. Tomás[2] A. Wegscheider[2,4]

[1]Norwegian University of Science and Technology(NTNU), Trondheim, Norway

[2]European Organization for Nuclear Research(CERN), Geneva, Switzerland

[3]High Energy Accelerator Research Organization(KEK), Tsukuba, Japan

[4]Hamburg University, Germany

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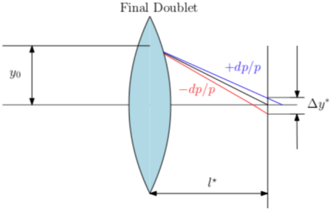
Outline

- Motivation for testing future LC FFS in SuperKEKB.
- Measuring β^* in SuperKEKB.

FFS in Future Linear Colliders

- To achieve the required high luminosities, future linear colliders must focus the beams to extremely small sizes at the IP.
- This requires strong focusing quadrupoles with large chromatic aberrations that must be corrected.
- Large β in the IR increases effects from misalignments, nonlinearities etc.



$$\sigma_y^* \approx \sigma_{0y}^* \sqrt{1 + \xi_y^2 \sigma_\delta^2}$$

$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$

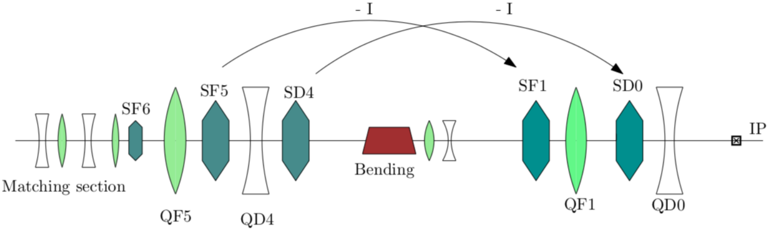
H. Garcia, R. Tomás and Y. Kubyshin. "Comparative study of Final Focus Systems for CLIC and other luminosity ehancement studies for future linear colliders", CERN-THESIS-2014-230.

FFS chromaticity comparison

	L^*[m]	$\beta_y^*[\mu m]$	$\xi_y \sim (L^*/\beta_y^*)$
CLIC	3.5	70	50 000
ILC	3.5 /4.1	410	8540 /10 000
ATF2	1	100	10 000
FFTB	0.4	100	4 000
SuperKEKB LER	0.74	270	2740
SuperKEKB HER	1.22	300	4070

- Nominal SuperKEKB will demonstrate chromaticity correction on same scale as FFTB.
- A factor 3 reduction of β_y^* in SuperKEKB would be on scale with ATF2 and ILC.

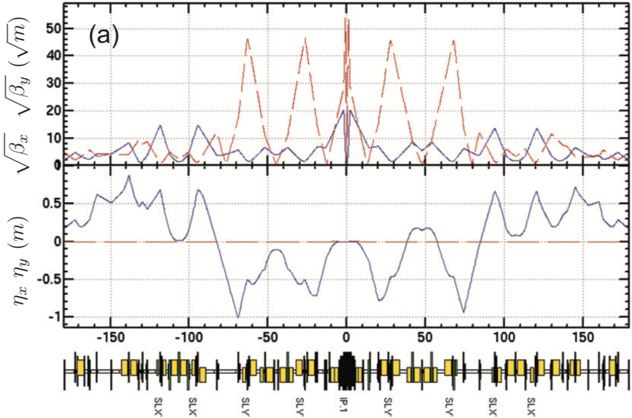
ATF2



- Uses two pairs of sextupoles interleaved with the final doublet to correct chromaticity.
- Similar to baseline CLIC design.

H. Garcia, R. Tomás and Y. Kubyshin. "Comparative study of Final Focus Systems for CLIC and other luminosity ehancement studies for future linear colliders", CERN-THESIS-2014-230.

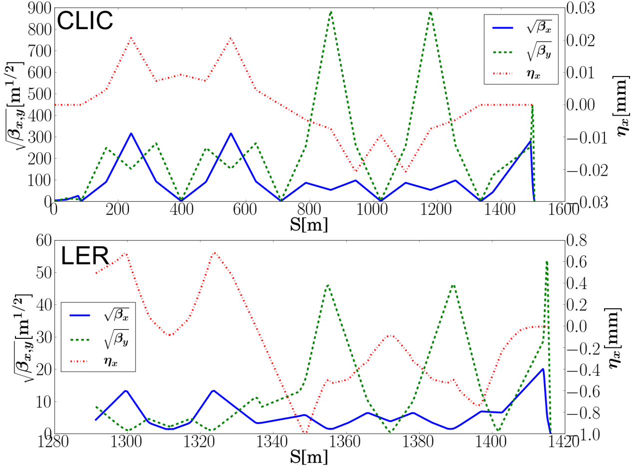
FFS of SuperKEKB



- Two sections with sextupoles for correcting the vertical and horizontal chromaticity separately. Likewise downstream.

Y. Onishi et. al. "Accelerator design at SuperKEKB", Prog. Theor. Exp. Phys. 2013.

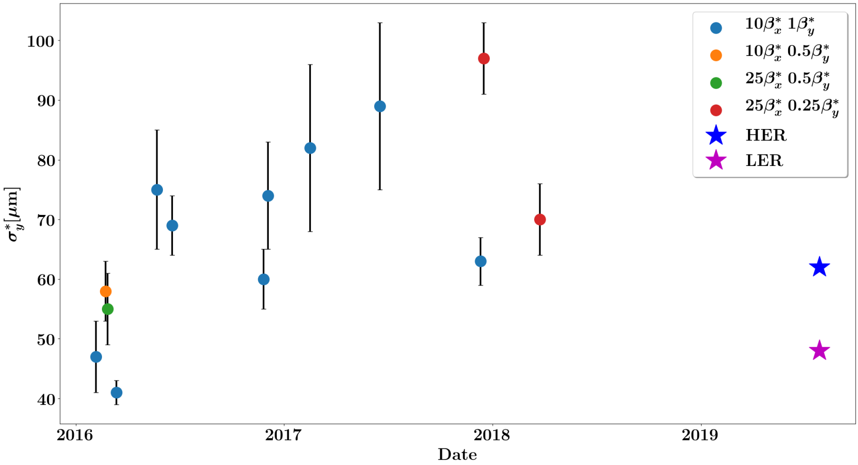
FFS of SuperKEKB Compared to CLIC



- CLIC has second proposed FFS similar to SuperKEKB.

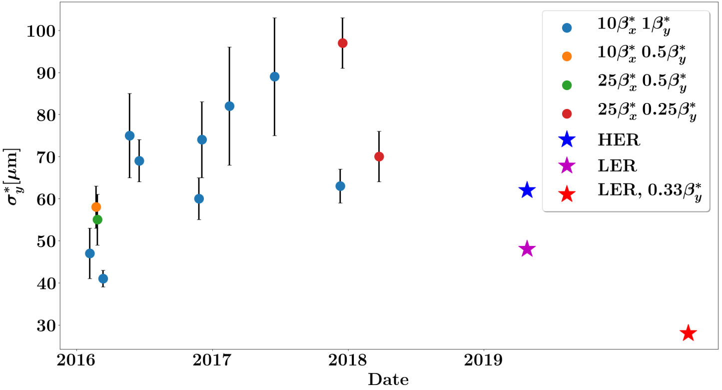
P. Thrane et. al. "Probing LINEAR Collider Final Focus Systems in SuperKEKB", CERN-ACC-2017-0052. CLIC-Note-1077, 2017.

Beam Size Measurements in ATF2



Fabien Plassard. Optics optimization of Longer L* Beam Delivery System Designs for CLIC and Tuning of the ATF2 Final Focus System at Ultra-low β^* Using Octupoles. HEP-EX. Université Paris-Saclay, 2018.

Reducing β^* in SuperKEKB



- Introductory studies have been made into the possibility of pushing down β_y^* further at SuperKEKB LER.
- A reduction up to a factor 3 might be possible, giving a β_y^* of 90 μm.[a]

[a] P. Thrane et. al. "Probing LINEAR Collider Final Focus Systems in SuperKEKB", CERN-ACC-2017-0052. CLIC-Note-1077, 2017.

Measuring β in SuperKEKB

- A precise measurement of β_y^* is important for both nominal SuperKEKB operation and potential dedicated FFS studies.
- Current β function measurements done globally using an orbit response matrix method.

Measurements from SuperKEKB

- Turn-by-turn measurements taken in HER during phase 2 of commissioning. Currently looking at potential of measuring the β function through:
  - Phase information between different BPMs.
  - Amplitude information for individual BPMs.
- Quadrupole gradients in the IR were modulated to study accuracy of β^* measurements from k-modulation.

K-Modulation

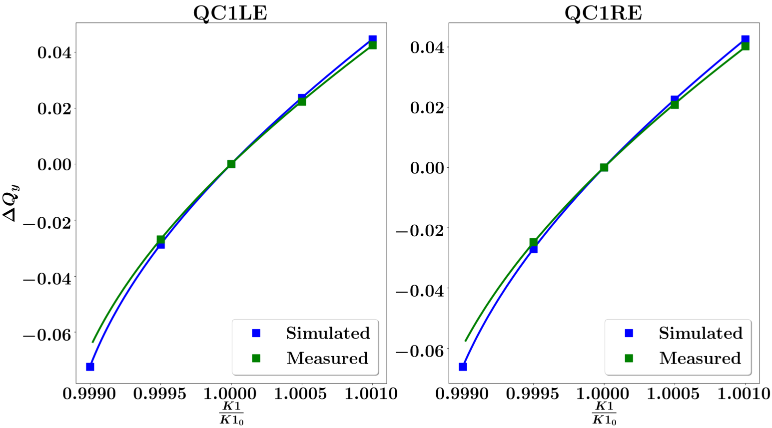
- By modulating the strength of a quadrupole and measuring the resulting tune shift, the average of the β function in the modulated quadrupole is found.

$$\beta_{average,x,y} = \pm\frac{2}{\Delta KL}\left(\frac{1-\cos(2\pi\Delta Q_{x,y})}{\tan(2\pi Q_{x,y})} + \sin(2\pi\Delta Q_{x,y})\right)$$
$$\approx \pm 4\pi\frac{\Delta Q_{x,y}}{\Delta KL}$$

- The average value of quadrupoles near the IP can then be used to find β^* as well as any longitudinal shift in the waist away from the IP.[a]

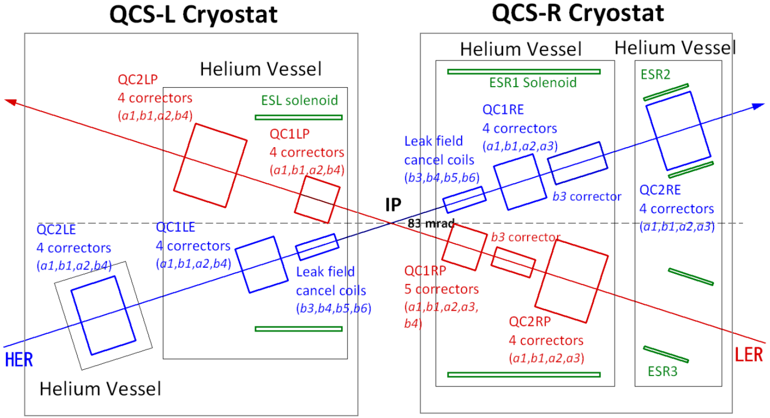
[a] F. Carlier and R. Tomás. "Accuracy and feasibility of the β^* measurement for LHC and High Luminosity LHC using k modulation", Physical Review Accelerators and Beams, 2017.

Preliminary Results, Tune Shift



- Shift in vertical tune from changing strength of the two quadrupoles in SuperKEKB HER closest to the IP. Measured and simulated values. Lines are made by fitting $\beta_{average}$.

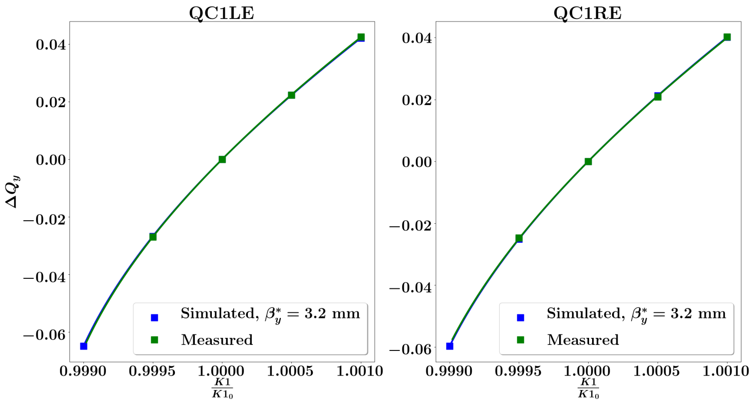
Preliminary Results, Propagating β to IP



- K1 field from inner quadrupoles in LER leaks into HER orbit.

Y. Funakoshi, Overview of SuperKEKB, issues and Commissioning Plan. Presentation at KEK 11. November 2013.

Preliminary Results, β_y^*



- Design $\beta_y^* = 3.0$ mm
- Measured $\beta_y^* = 3.2$ mm

Conclusions and Further Work

- The tuning of SuperKEKB to achieve nominal machine parameters faces many of the same challenges as a future LC FFS.
- A dedicated FFS study could be possible, if planned thoroughly.
- Accurate β^* measurements are needed. Current studies are looking into the possibility of using turn-by-turn measurements and k-modulation.
  - First analysis indicates $\beta_y^* = 3.2$ mm was achieved with goal 3 mm during the measurements, indicating 7% β beating.

Backup Slides.

SuperKEKB Nominal Machine Parameters

	LER (e^+)	HER (e^-)	Unit
E	4.000	7.007	[GeV]
I	3.6	2.6	[A]
Number of bunches	2 500		
Bunch current	1.44	1.04	[mA]
Circumference	3 016.315		[m]
ϵ_x/ϵ_y	3.2/8.64	4.6/12.9	[nm/pm]
Coupling	0.27	0.28	[%]
β_x^*/β_y^*	32/0.27	25/0.30	[mm]
Crossing angle	83		[mrad]
α_p	3.18×10^{-4}	4.53×10^{-4}	
σ_δ	8.10×10^{-4}	6.37×10^{-4}	
V_c	9.4	15.0	[MV]
σ_z	6.0	5.0	[mm]
ν_s	-0.0244	-0.0280	
ν_x/ν_y	44.53/46.57	45.53/43.57	
U_0	1.86	2.43	[MeV]
$\tau_{x,y}/\tau_z$	43.2/21.6	58.0/29.0	[msec]
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.807	
Luminosity	8×10^{35}		[cm^{-2}s^{-1}]

http://www-superkekb.kek.jp

ATF2 Beam Size Measurements

Optics	run date	Minimum σ_y^* [nm]	Comments
10 β_x^* × 1 β_y^*	16/02/05	47±6	-
10 β_x^* × 0.5 β_y^*	16/02/22	58±5	-
25 β_x^* × 0.5 β_y^*	16/02/25	55±6	-
10 β_x^* × 1 β_y^*	16/03/10	41±2	2 bunch mode
10 β_x^* × 1 β_y^*	16/05/20	75±10	-
10 β_x^* × 1 β_y^*	16/06/16	69±5	-
10 β_x^* × 1 β_y^*	16/11/24	60±5	-
10 β_x^* × 1 β_y^*	16/12/01	74±9	-
10 β_x^* × 1 β_y^*	17/02/15	82±14	-
10 β_x^* × 1 β_y^*	17/06/15	89±14	mOTR non-operational
10 β_x^* × 1 β_y^*	17/12/08	63±4	mOTR non-operational + correction of the matching optics
25 β_x^* × 0.25 β_y^*	17/12/14	97±6	mOTR non-operational + bad optics matching
25 β_x^* × 0.25 β_y^*	18/02/22	70±6	mOTR non-operational + correction of the matching optics w/o 2nd order knobs and octupoles

Fabien Plassard. Optics optimization of Longer L* Beam Delivery System Designs for CLIC and Tuning of the ATF2 Final Focus System at Ultra-low β^* Using Octupoles. HEP-EX. Université Paris-Saclay, 2018.