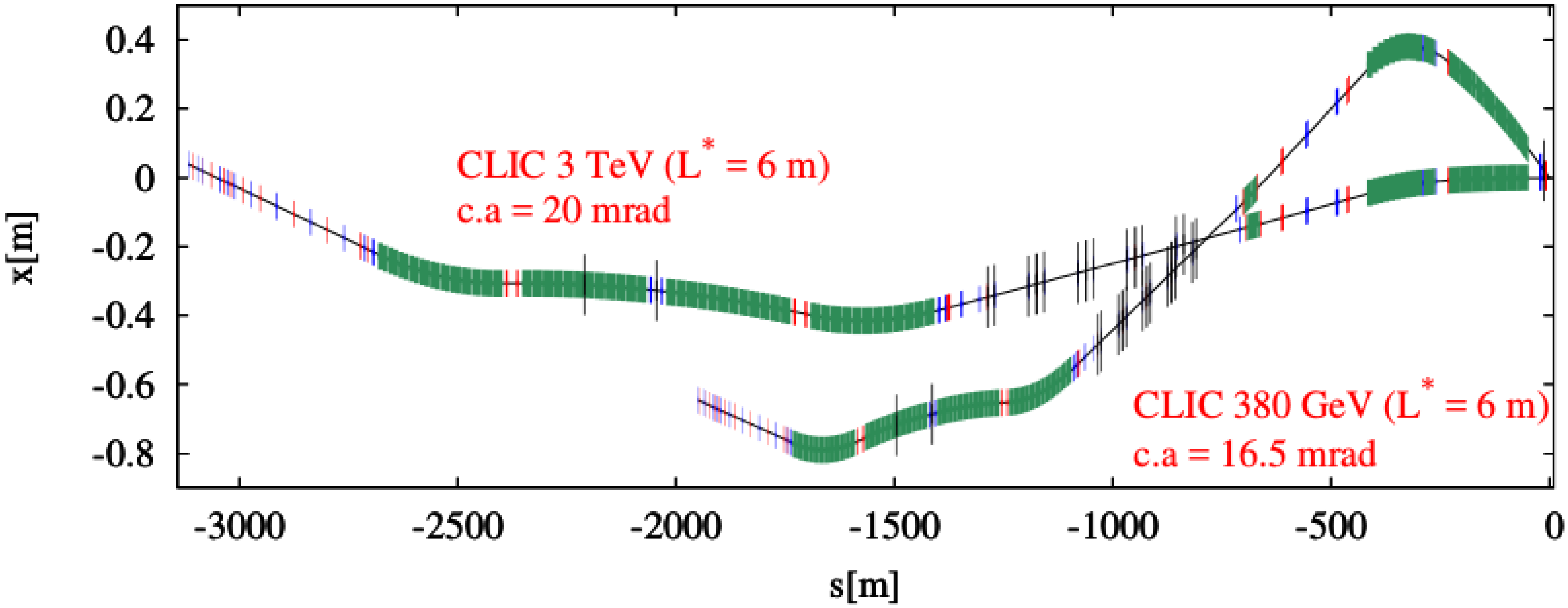
Final Focus System limitations

R. Tomas

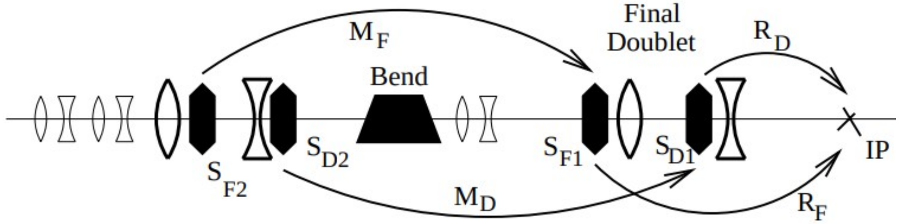
CLIC Beam Delivery system Layout

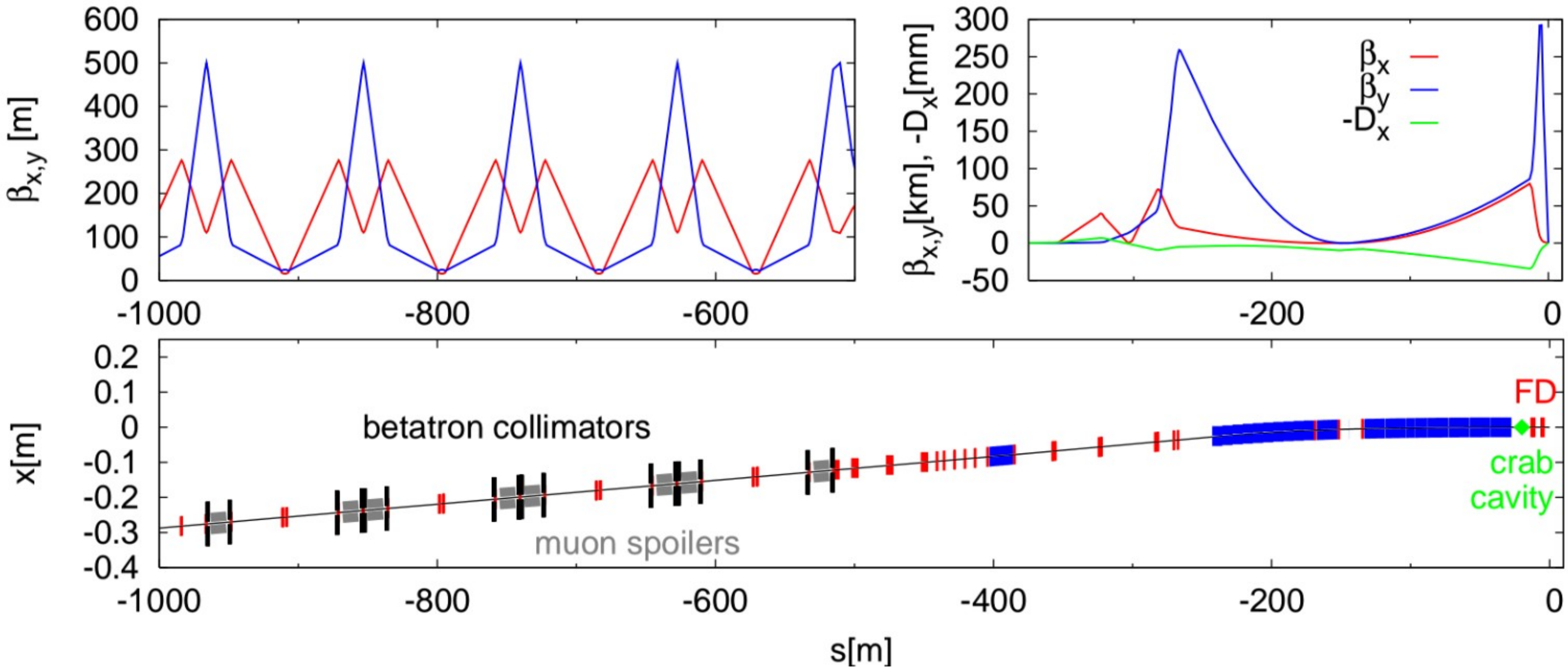


http://clicr.web.cern.ch/CLICr/MainBeam/BDS_380GeV/

Optics @ 3 TeV: collimation and FFS

Local chromaticity correction:





Scaling with energy

According to [1] the length of the system should scale as:

$$L \propto \gamma^{2/5}.$$

E.g.: A 30 TeV collider would need a beam delivery system of about 7 km (per side), assuming favorable scaling of emittance with energy.

[1] P. Raimondi & A. Seryi, A novel FFS for future linear colliders, 2000

Design aspects of IP parameters

- Vertical β^* >= bunch length, σ_z for hourglass effect
- Vertical beam size $\sigma_y > \sigma_{oide}$, for synchrotron radiation in the last quadrupole
- Horizontal beam size is decided upon spectrum quality (beamstrahlung)

Current FFS optics designs comply with these physical limits, so optics does not limit.

Example Linear Collider Parameters

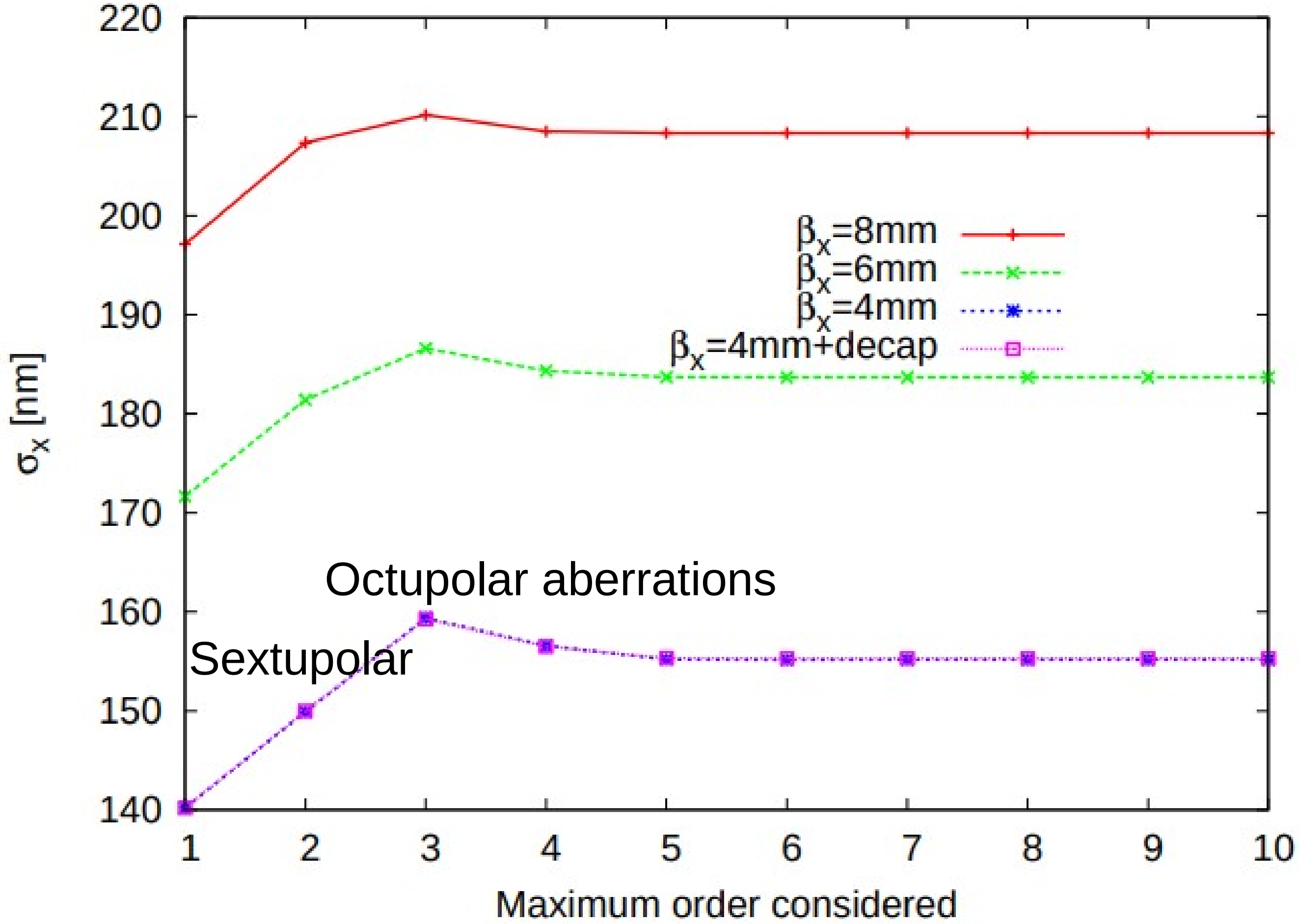
Old table from RAST paper

Parameter	Symbol [unit]	ILC	CLIC	LPA	PWFA	DLA
CMS energy	E_{cm} [GeV]	500	2000	2000	2000	2000
Luminosity	$L [10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.8	6	10	6.3	10.7 (4.4)
Luminosity in peak	$L_{0.01}$ $[10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}]$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total beam power	[MW]	10.5	28	48	48	68.8
Loaded gradient	G [MV/m]	31.5	100	5000	7600	1000
Particles per bunch	N $[10^9]$	20	3.72	1.19	10	$3 \cdot 10^{-5}$
Bunch length	σ_z [μm]	300	44	8	20	0.0028
Interaction point beam size	σ_x/σ_y [nm/nm]	474/6	40/1	18/0.5	194/1.1	0.75/0.75
Normalized emittances	ϵ_x/ϵ_y [nm]	$10^4/35$	660/20	50/5	$10^4/35$	0.1/0.1
Beta functions	β_x/β_y [mm]	10/0.4	7/0.07	-/-	11/0.1	16.5/16.5
Initial beam energy spread	σ_E [%]	O(0.1)	0.35	—	—	—
Bunches per train	n_b	1312	312	1	1	159
Bunch distance	Δz [ns]	554	0.5	$11.9 \cdot 10^3$	10^5	$6.7 \cdot 10^{-6}$
Repetition rate	f_r [Hz]	5	50	$84 \cdot 10^3$	10^4	$3 \cdot 10^7$

Actually, PWFA and DLA IP parameters do not seem crazy, without knowing energy spread.

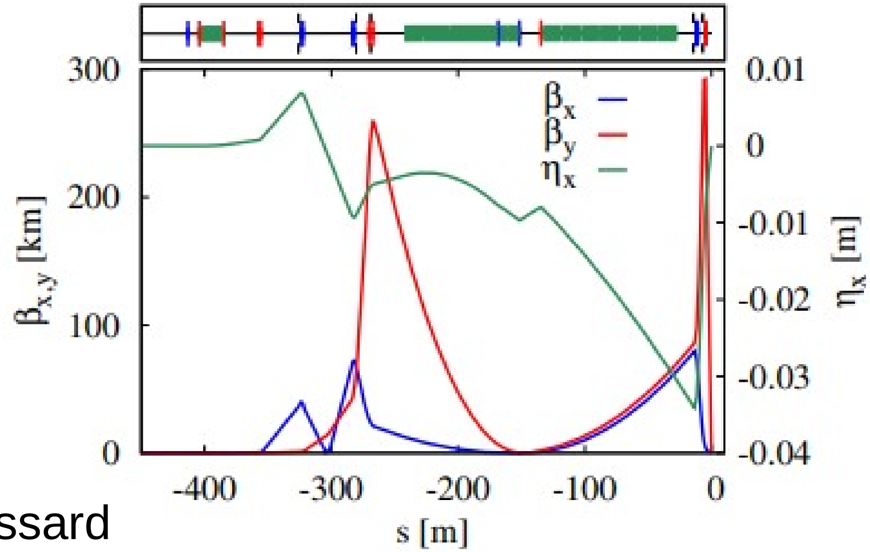
Lower horizontal beam size for CLIC 500 GeV with lower charge

Hector Garcia

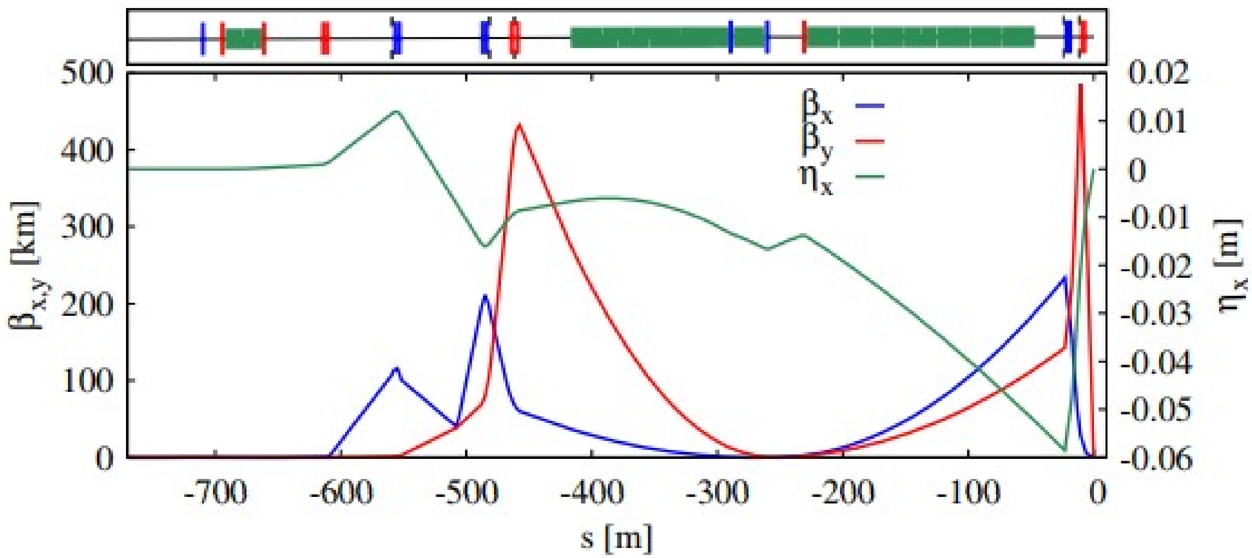


CLIC: moving to a longer L*

- Successful increase of L* from 4.3m to 6m

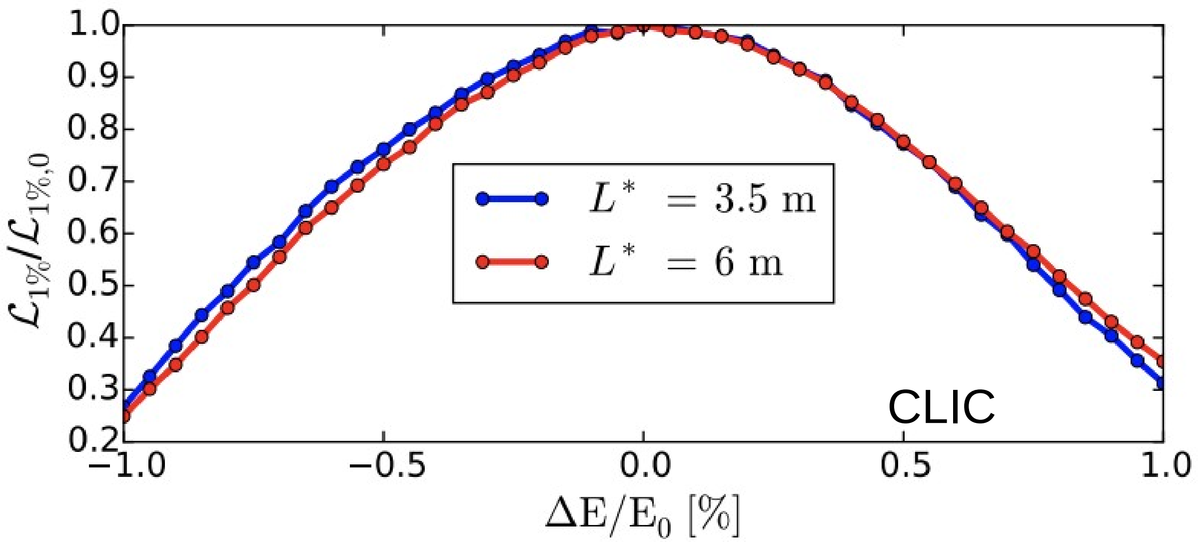


Fabian Plassard

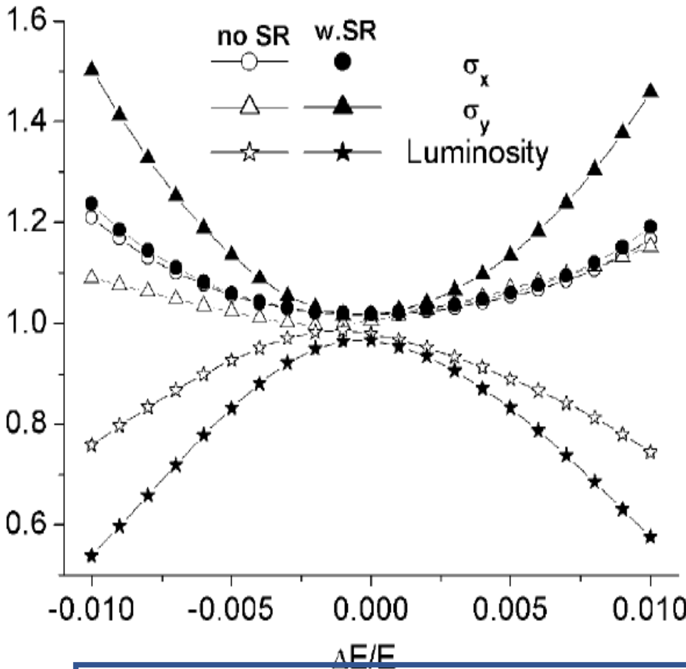


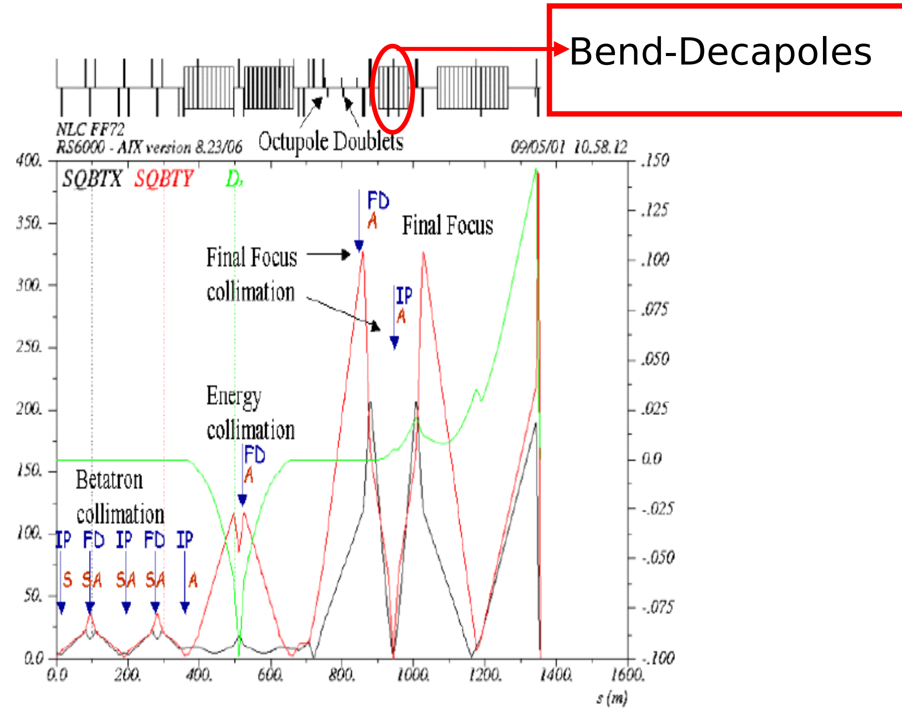
Design aspects to improve

- **Aberrations**: some residual aberrations are present in almost all FFS designs. Room to improve in the 10% level.
- **Energy bandwidth**:



Energy bandwidth in NLC



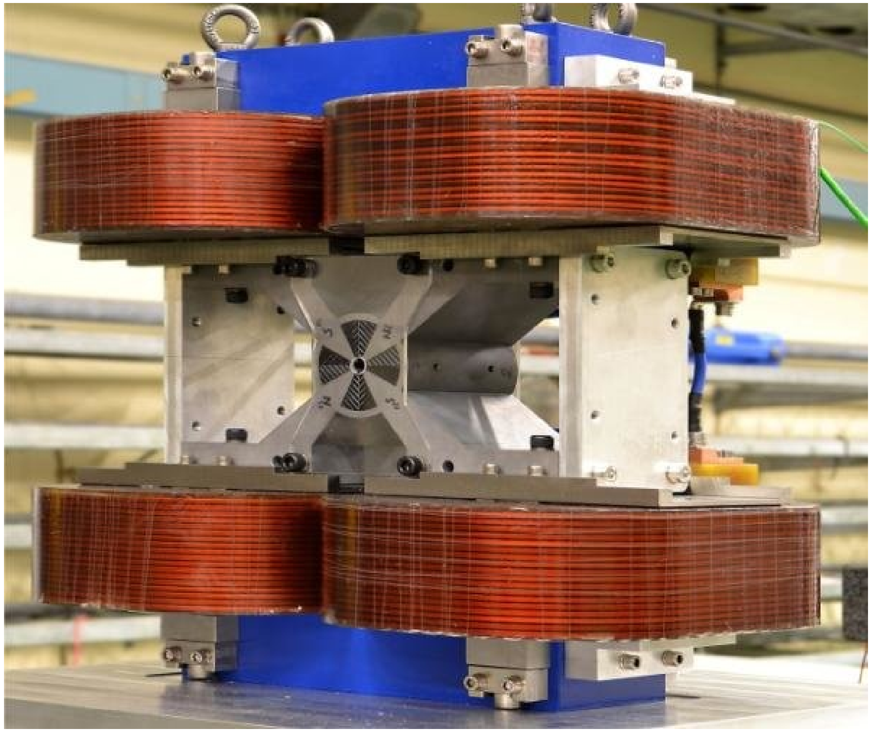


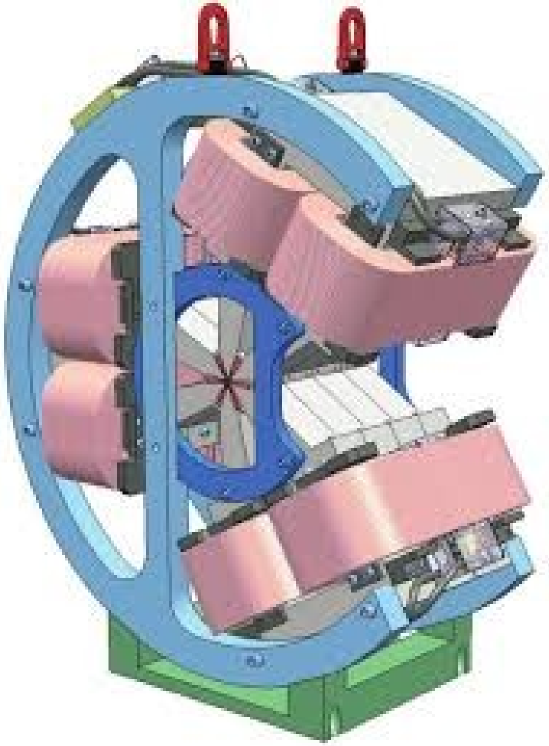
The energy bandwidth was improved in NLC thanks to:

- A bend between the X and Y geometric sextupoles to provide a more local chromatic correction and a better cancellation of the second order dispersion.
- Two decapoles, separated by an "Identity Transformation" in between the X and Y geometric sextupoles to cancel 4th order chromo-geometric aberrations.

From Pantaleo Raimondi, Andrei Seryi and Peter Tenenbaum. "Tunability of the NLC final focus system." *Particle Accelerator Conference, 2001. PAC 2001. Proceedings of the 2001*. Vol. 5. IEEE, 2001.

CLIC FFS magnets





In real life magnets have imperfections

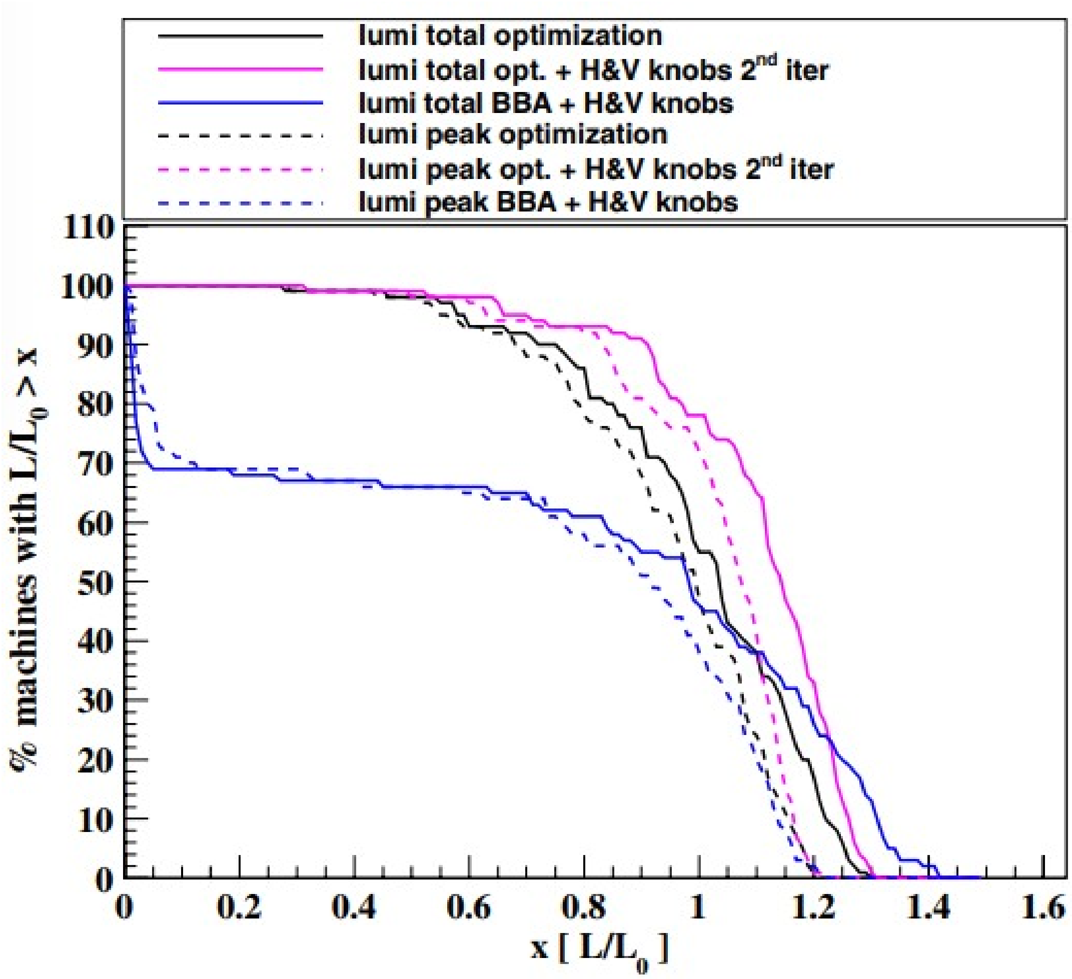
TABLE VI. Vertical offset tolerances (in nanometers) for the last quadrupole magnets in the CLIC FFS for a relative peak luminosity loss of 2%.

Magnet	$L^* = 3.5$ m	$L^* = 6$ m
QD0	0.2	0.25
QF1	0.8	1
QD2	8	9
QF3	16	19

- Tolerances of 0.2 nm while good alignment systems can do ~10 µm!!!!
- Need to rely on beam tuning techniques

CLIC CDR single beam tuning

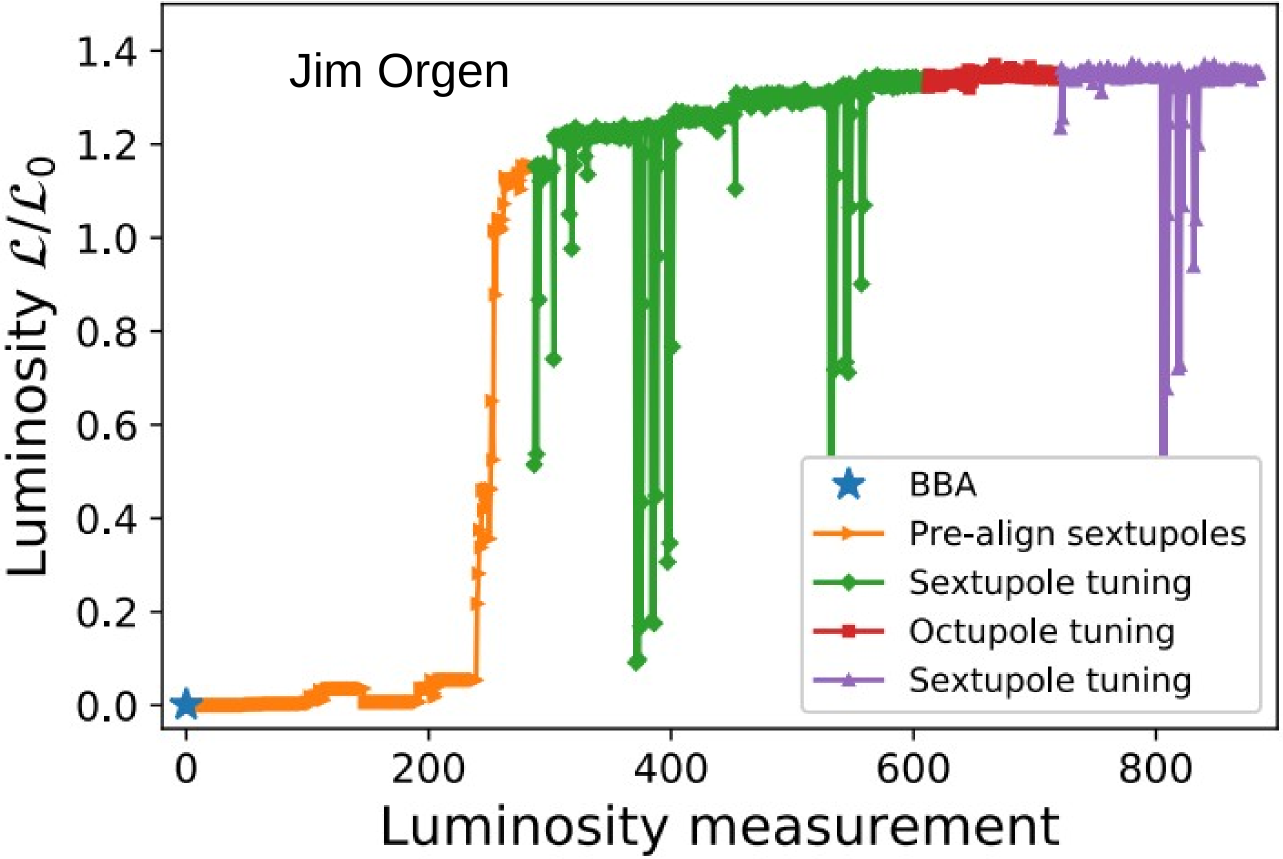
- Only 80% of the machines would reach design luminosity
- 18000 luminosity measurements were needed...



https://journals.aps.org/prab/pdf/10.1103/PhysRevSTAB.15.051006

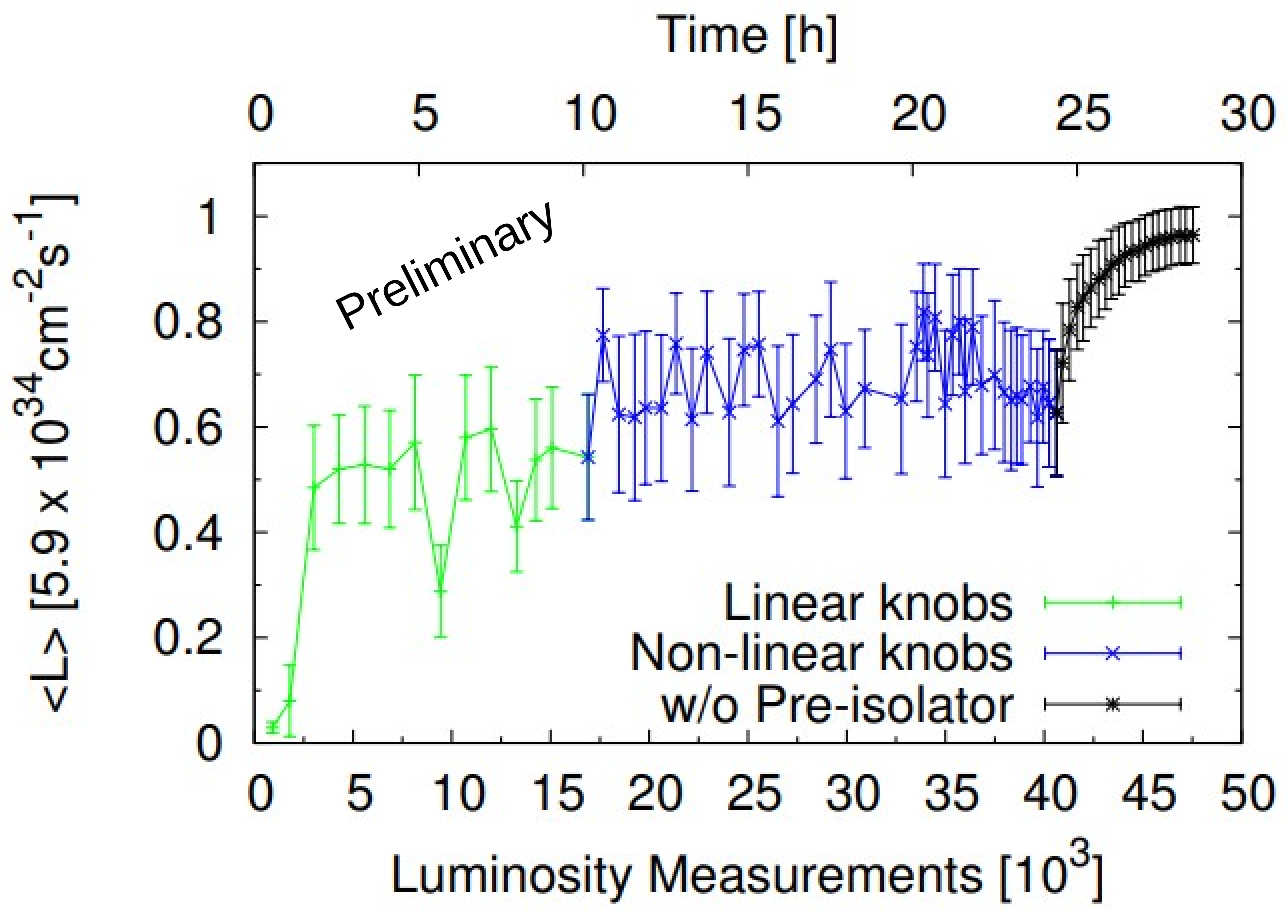
Progress on single beam tuning

For CLIC at 380 GeV about 900 measurements would be needed to reach design performance.



2-beam tuning and dynamic effects!

Tens of thousands of luminosity measurements needed!!!



FFTB ATF2 SuperKEKB

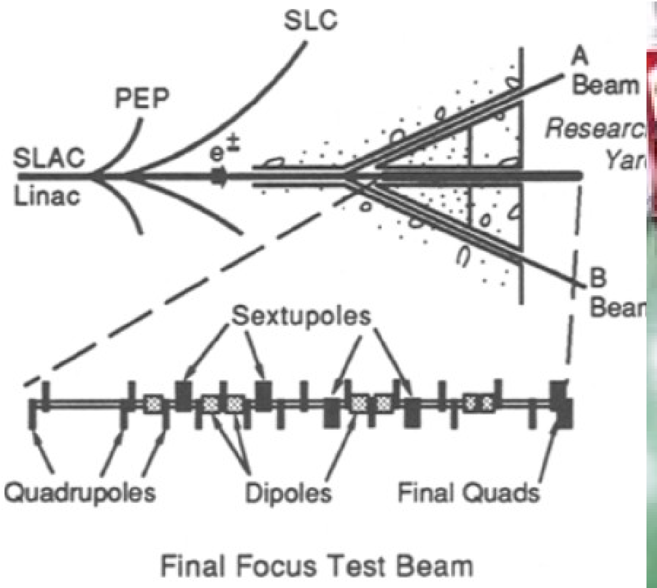
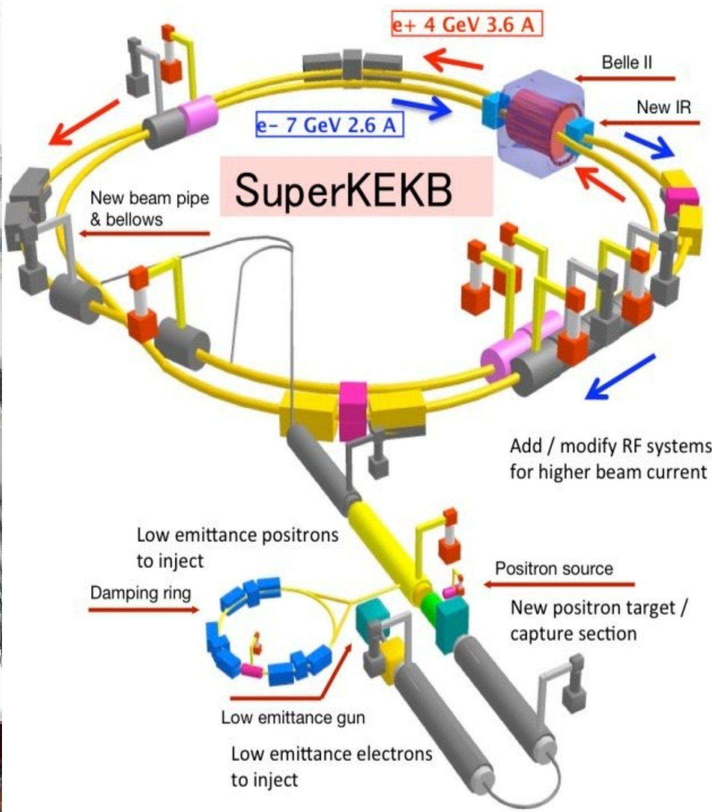


Fig. 1. Location of the FFTB at the end of the SLAC 50 GeV linac.

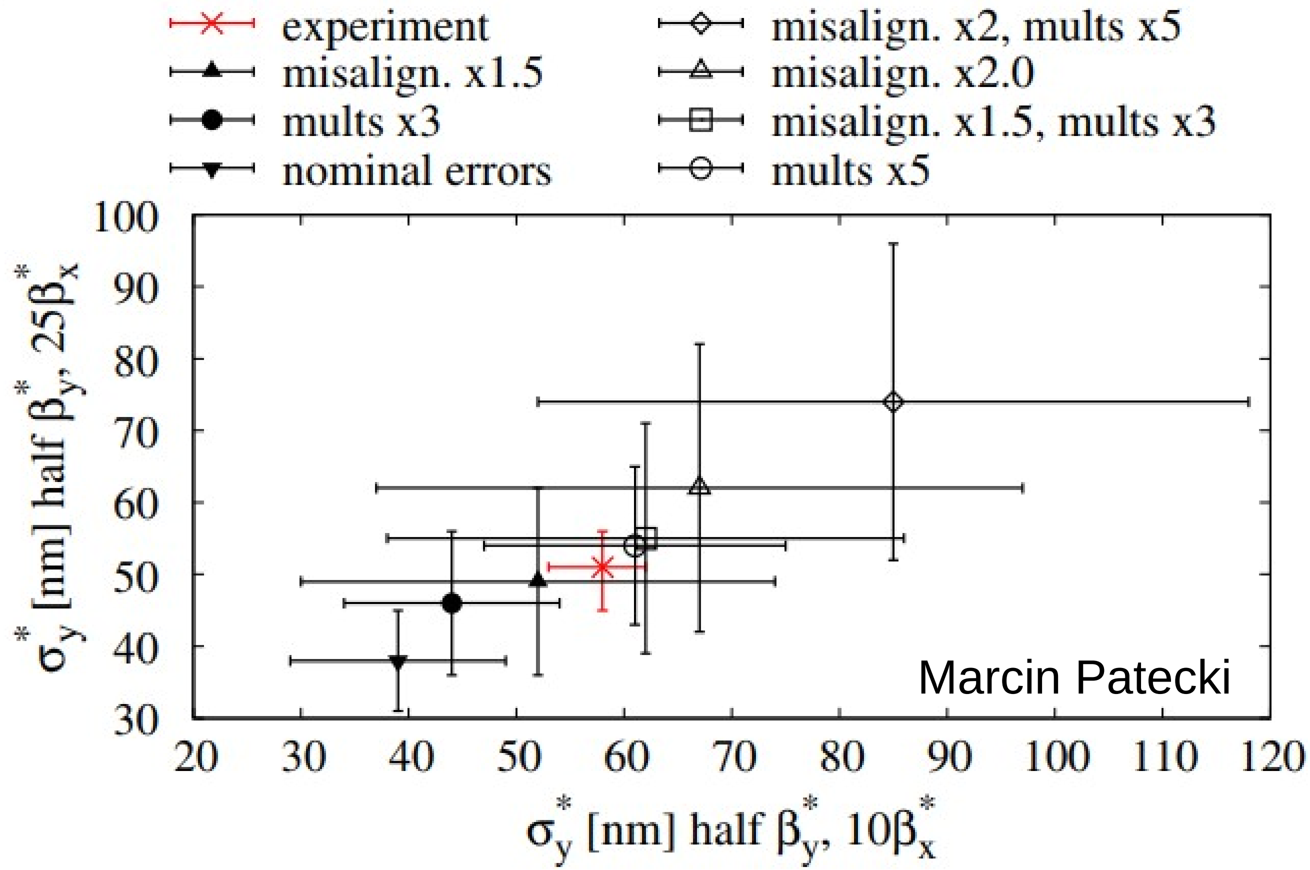


The 2 FFS experimental facilities: FFTB & ATF2

	ILC (TDR 500 GeV)	ATF2	FFTB	ATF2 (pushed)	CLIC (CDR 3 TeV)
L^* (m)	3.5/4.5[a]	1	0.4	1	3.5
ϵ_y (pm rad)	0.07	12	22	12	0.003
$\xi_y \sim (L^*/\beta_y^*)$	7,300/9,400[a]	10,000	4,000	40,000	50,000
$\sigma_E(\%)$	0.07/0.12[b]	0.08	0.1	0.08	0.3
$\Delta\sigma_y/\sigma_y \sim (\sigma_E.L^*/\beta_y^*)$	5/9, 7/11[b,a]	8	4	32	150
σ_y (nm) *design*	5.9	37	52	23	1
σ_y (nm) *measured*	-	65 ± 5[c]	70 ± 6	-	-
$\beta_x^*(mm)$	11	4 (40[c])	10	4	4
$\beta_y^*(mm)$	0.48	0.1	0.1	0.025	0.07

[a]SiD/ILD ILC detector configurations.
[b]Positron/electron side of ILC.
[c]March 2013 results and configuration of ATF2 with bunch charge 80–130 pC.

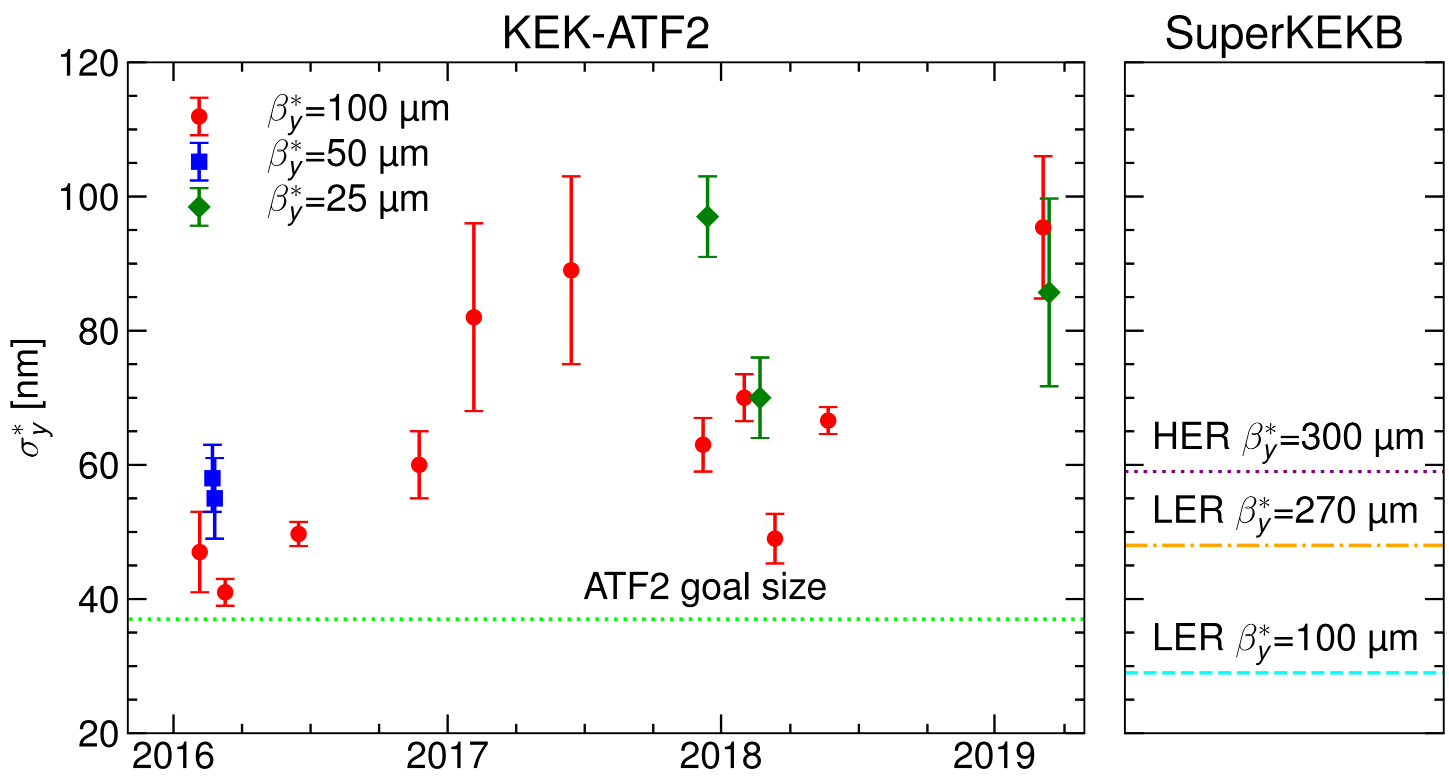
ATF2 experiments vs simulations

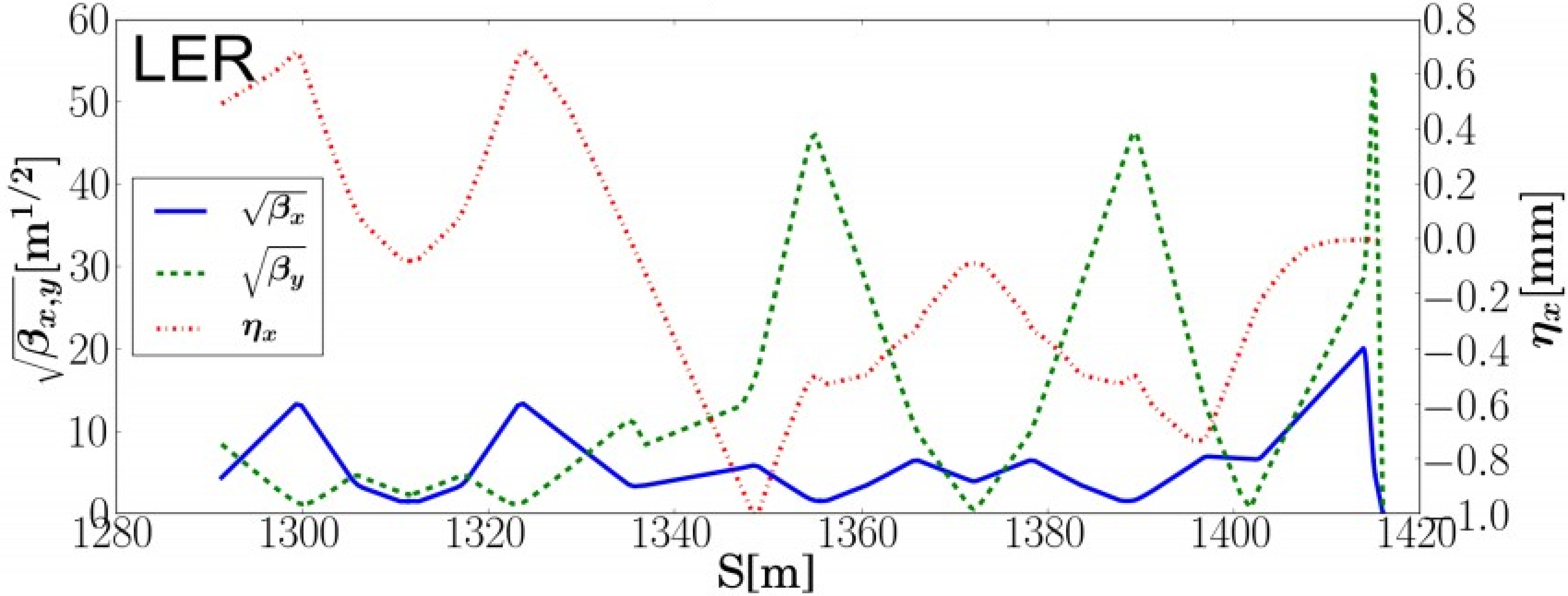


Limitations in ATF2 beam size could come from twice larger misalignment and multipolar errors than expected

ATF2 recent performance and SuperKEKB opportunity

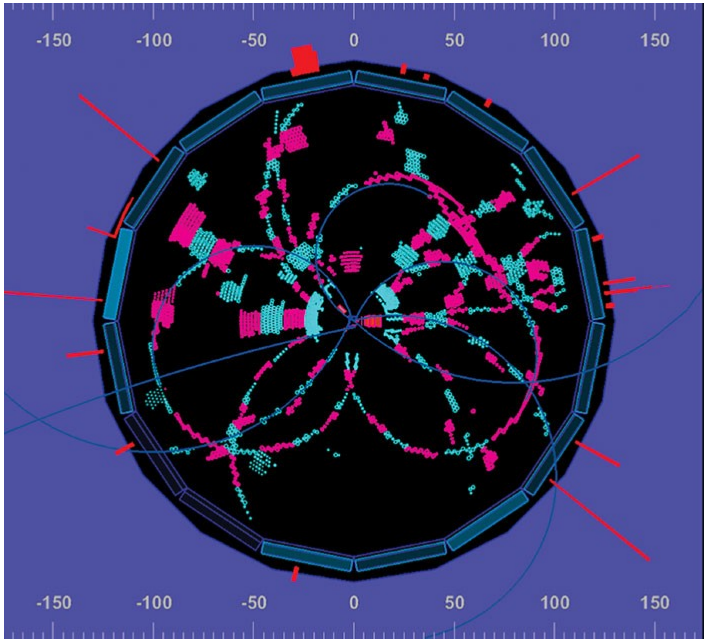
ATF2 design optics has not been demonstrated, exps on-going.

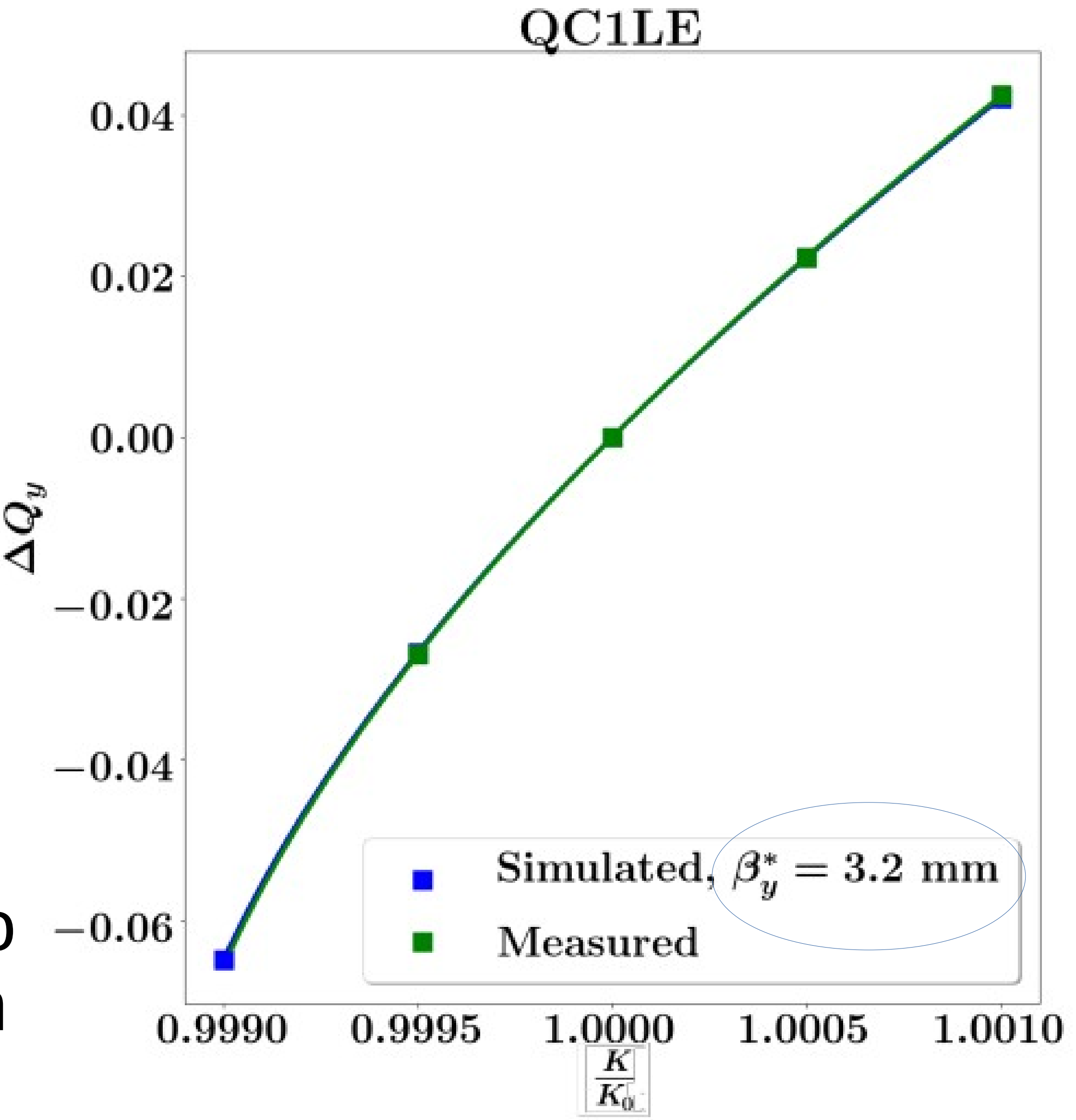




	L*[m]	$\beta_y^*[\mu m]$	$\xi_y \sim (L^*/\beta_y^*)$
CLIC	3.5	70	50 000
ILC	3.5 /4.1	410	8500 /10 000
ATF2	1	100	10 000
FFTB	0.4	100	4 000
SuperKEKB LER	0.94	270	3 500
SuperKEKB HER	1.41	300	4 700

On-going experiments in SuperKEKB





Still a long way to reach β*=0.1 mm

Summary & outlook

- ALIC FFS design parameters should be doable, yet studies should confirm length, energy spread effects, etc.
- The actual concern is system performance in real life:
  - Lots of progress in simulation but 2-beam tuning not fully demonstrated yet
  - Experimental demonstrations of FFS concepts have been only partially successful
  - **Need to exploit ATF2 and SuperKEKB to bring full confidence in FFS optics designs!**