Experience with half β_y^* in ATF2

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Outline

- Motivation for ultra-low β^* in ATF2
- Optics design and optimisation
- IP beam size tuning
- Tuning simulations
- Conclusions

Motivation for ultra-low β* in ATF2

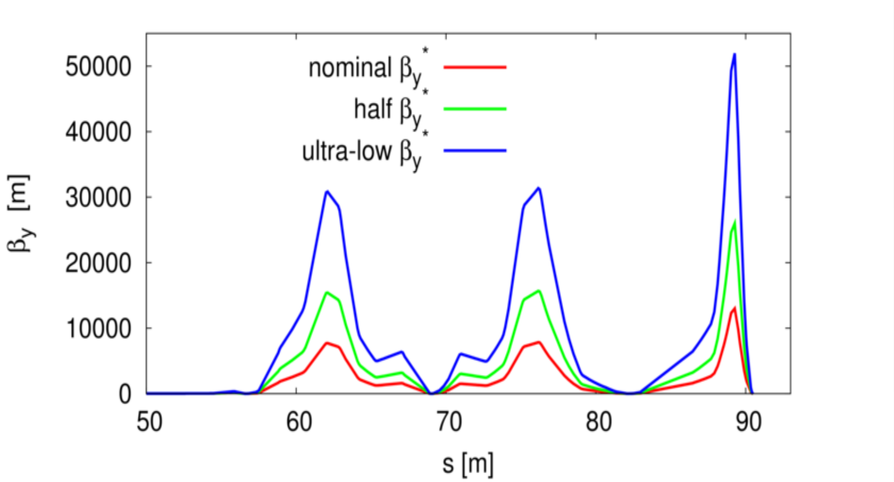
- **ATF2 ultra-low β* project aims to test a Final Focus System at the chromaticity level similar to CLIC.**
  - Larger chromaticity ξ makes the Final Focus System more difficult to operate.
  - Level of chromaticity ξ_y in ATF2 is comparable to ILC.
- **Ultra-low β* optics also reduces the IP vertical beam size to 20 nm. Close to linear collider beam sizes.**
- **Octupole magnets for stronger beam focusing are required.**

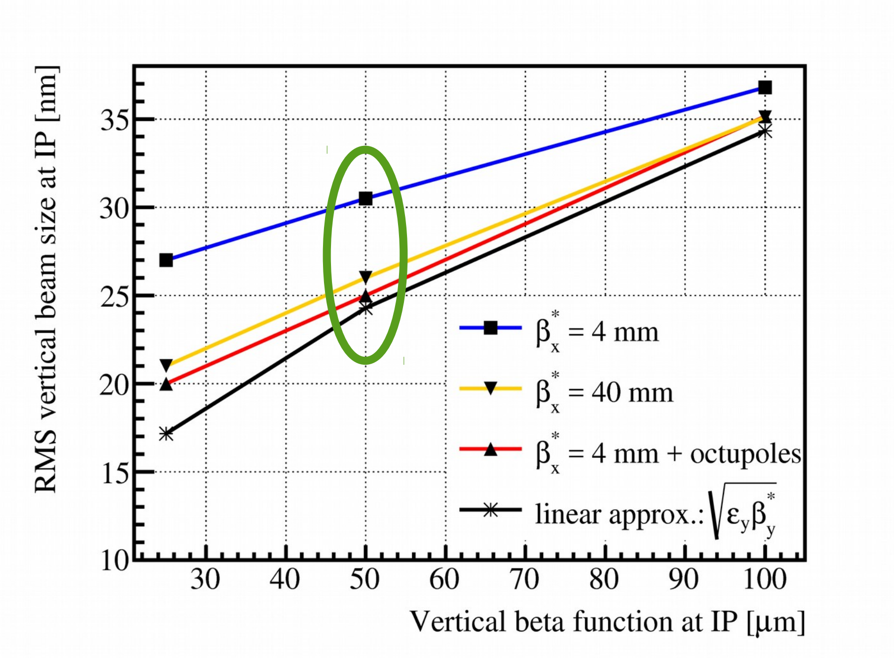
	β_y* [μm]	$\sigma^*_{y, design}$[nm]	L* [m]	$\xi_y \sim (L^*/\beta_y^*)$
ILC	480	5.9	3.5/4.5	7300/9400
CLIC	70	1	3.5	50000
ATF2 nominal	100	37 (44[a])	1	10000
ATF2 half β_y*	50	25[b]	1	20000
ATF2 ultra-low β_y*	25	20[b]	1	40000

[a]measured, June 2014

[b]using octupoles

Optics design and optimisation





Decreased β_y* makes the FFS more sensitive to beam line imperfections. It was checked that:

- **magnetic multipole fields** and
- **fringe fields**

are limiting factors for the IP beam size.

Proposed mitigation method:

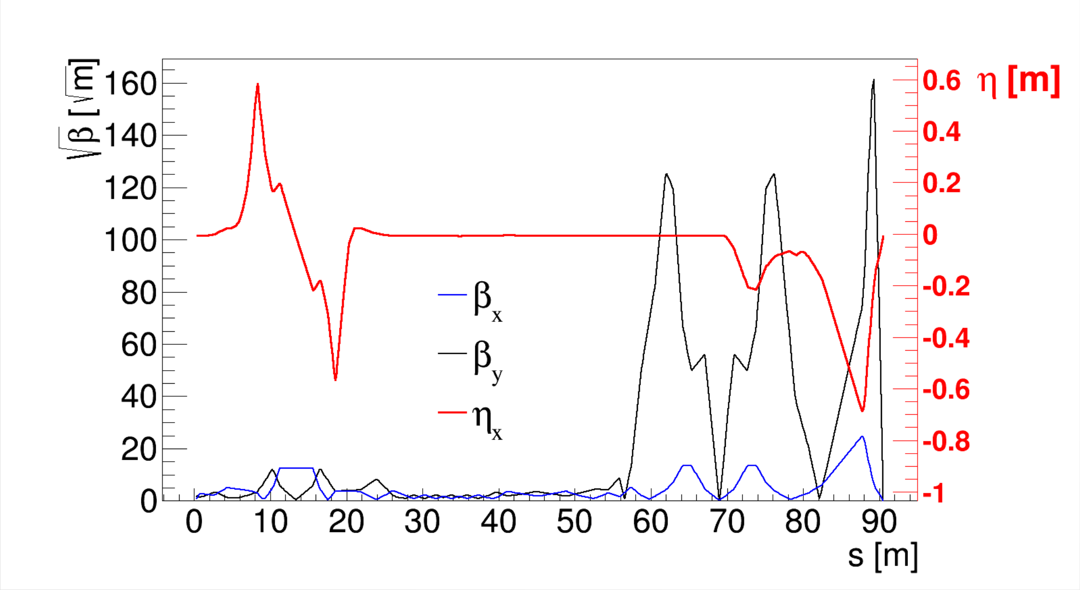
- Installation of two octupole magnets
  - Corrects both multipole fields and fringe fields.
  - Makes sextupolar correction easier.
  - **Brings the IP beam size from 27 nm to 20 nm for ultra-low β* optics.**

Half β_y^* experiment (10x0.5 optics)

Collecting the experience and having a training before the ultra-low β^* optics:

- Preparing tools for optics modification, measurement and control;
- Checking the beam size tuning performance in more demanding conditions;
- Finding the issues and addressing them;
- Finding the minimum beam size without octupoles.

notation	β_x^* [mm]	β_y^* [μm]
1x1	4	100
10x1	40	100
10x0.5	40	50
25x0.5	100	50

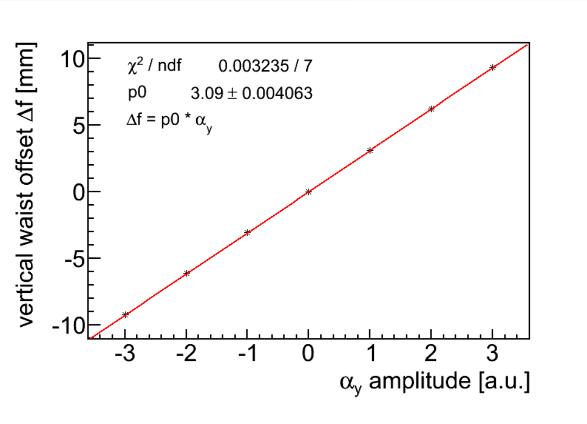


10x0.5 optics (on the plot) has been tested in ATF2 since December 2014.

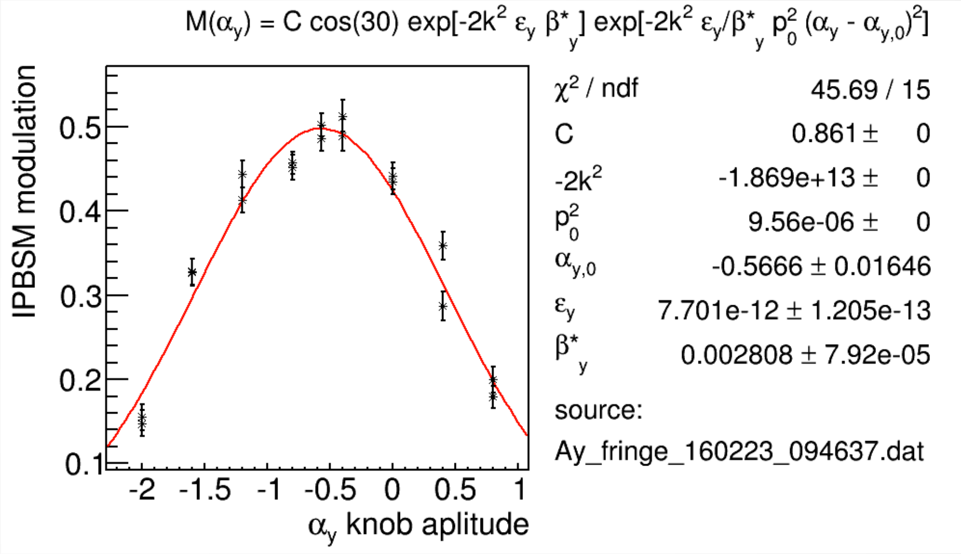
The expected IP vertical beam size is 26 nm, assuming vertical emittance ε_y = 12pm.

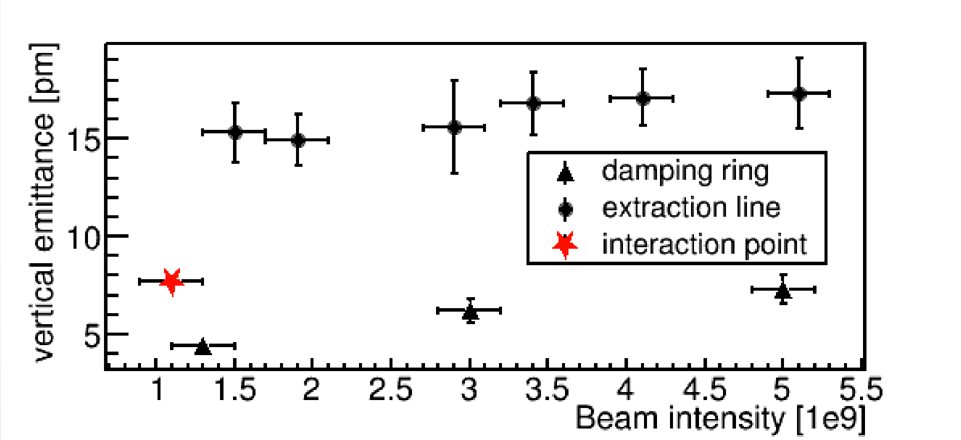
New method for precise emittance evaluation (Feb'16)

- We suspected that vertical emittance is overestimated;
- IP beam size can be precisely measured using shintake monitor in 30deg mode;
- Special optics was applied to use the whole dynamic range of IPBSM 30deg (100 – 360 nm);
- Beam waist was precisely shifted using α_y knob;



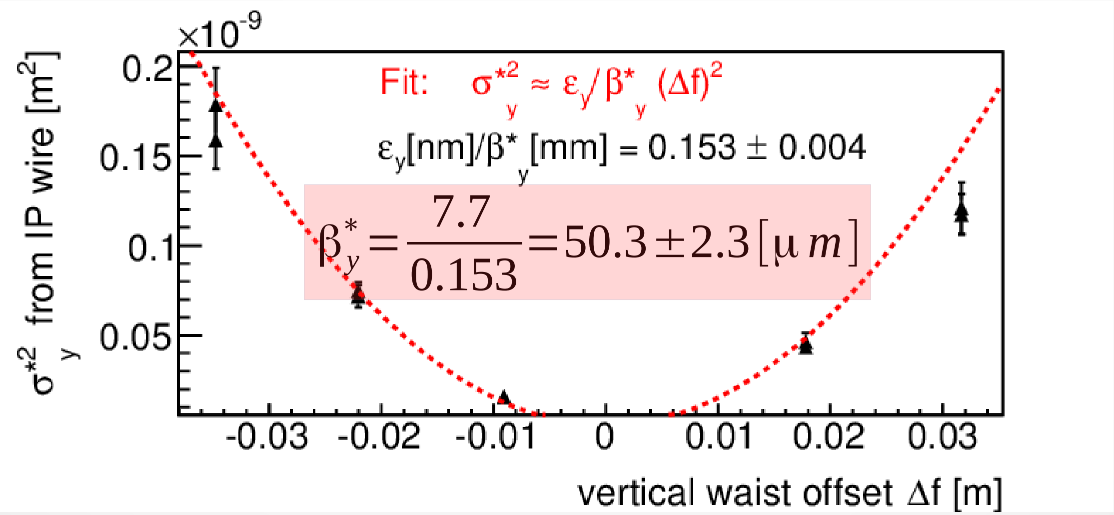
- Shintake monitor systematic error is evaluated.



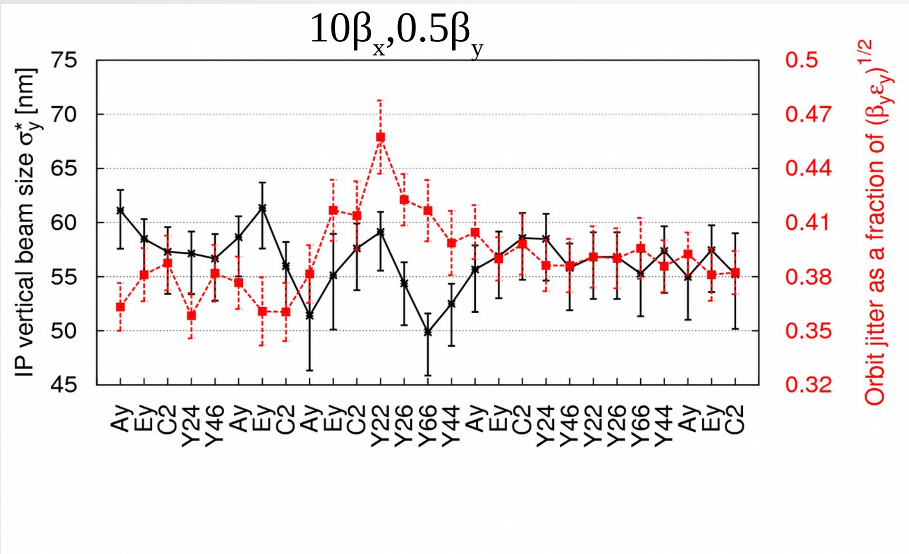


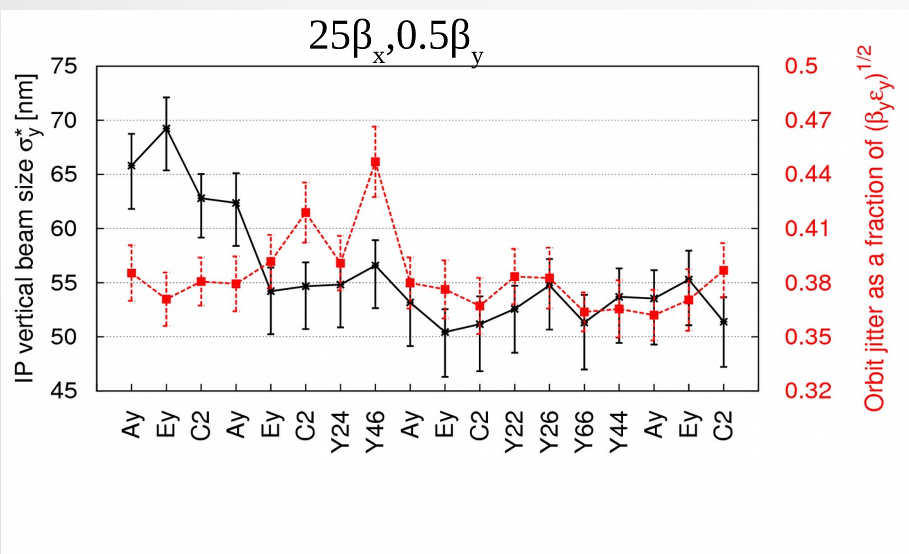
Setting half β_y* (β_y* = 50 μm)

- The optics was applied and verified using QD0FF scan:



IP beam size tuning





- Low tuning efficiency (in black) – knobs setting close to optimum or knobs effect hidden behind other beam size contributions.
- Significant error bars of measured beam size.
- Large orbit position jitter in the FF line (in red).
- Measured beam size after tuning:

TABLE III. Measured IP vertical beam size after the tuning for half β_y^*, $10\beta_x^*$ optics and half β_y^*, $25\beta_x^*$ optics compared with the design values assuming the measured vertical emittance.

Optics	$\sigma^*_{y,\mathrm{meas.}}$ [nm]	$\sigma^*_{y,\mathrm{design}}$ [nm] (for $\epsilon_y = 7.7$ pm)
Half β_y^*, $10\beta_x^*$	58^{+4}_{-5}	21
Half β_y^*, $25\beta_x^*$	51^{+5}_{-6}	20

Intensity dependence

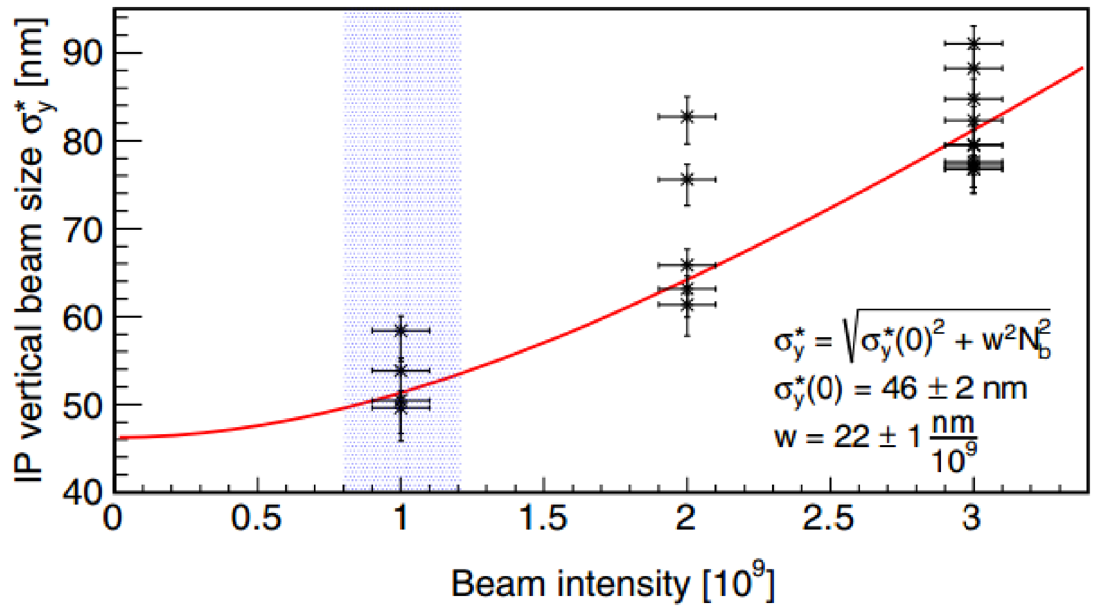


FIG. 9. Intensity dependence of IP vertical beam size for half β_y^*, $10\beta_x^*$ optics. Black points stand for the measured beam size, red curve for the fit according to Eq. (11) and blue band for the bunch intensity restriction of the tuning and final beam size measurement.

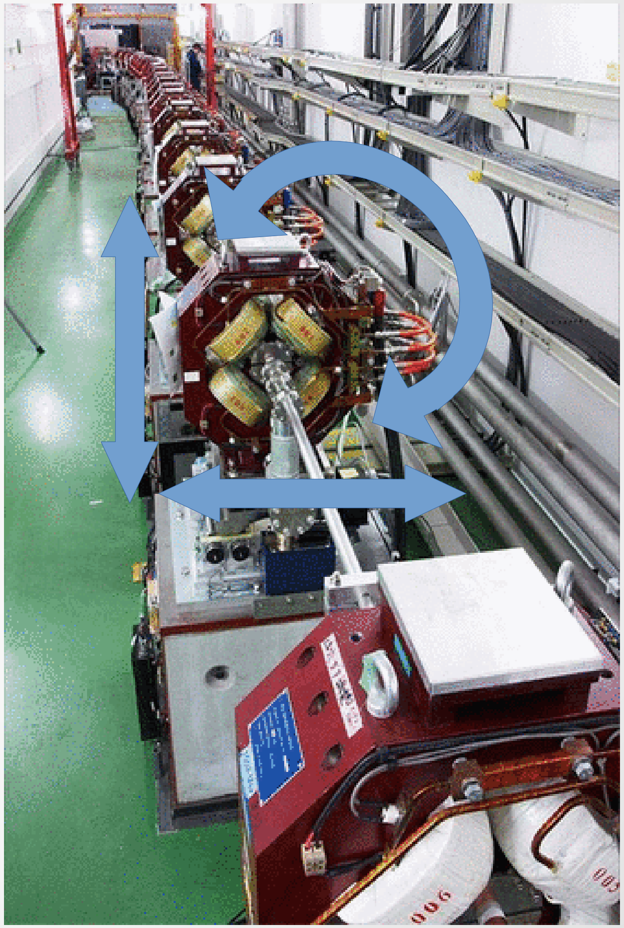
$$\sigma_y^* = \sqrt{\sigma_y^*(0)^2 + w^2 N_b^2}, \qquad (11)$$

Tuning simulations

- The **realistic machine performance** is studied by simulating the **realistic machine errors**

case	misalignments			multipolar	strength
	Δx [μm]	Δy [μm]	$\Delta\theta$ [μrad]	errors	error [%]
nominal errors	**100**	**100**	**200**	**x1**	**0.1**
misalign. x1.5	150	150	300	x1	0.1
misalign. x2.0	200	200	400	x1	0.1
mults x3	100	100	200	x3	0.1
mults x5	100	100	200	x5	0.1
misalign. x1.5, mults x3	150	150	300	x3	0.1
misalign. x2.0, mults x5	200	200	400	x5	0.1

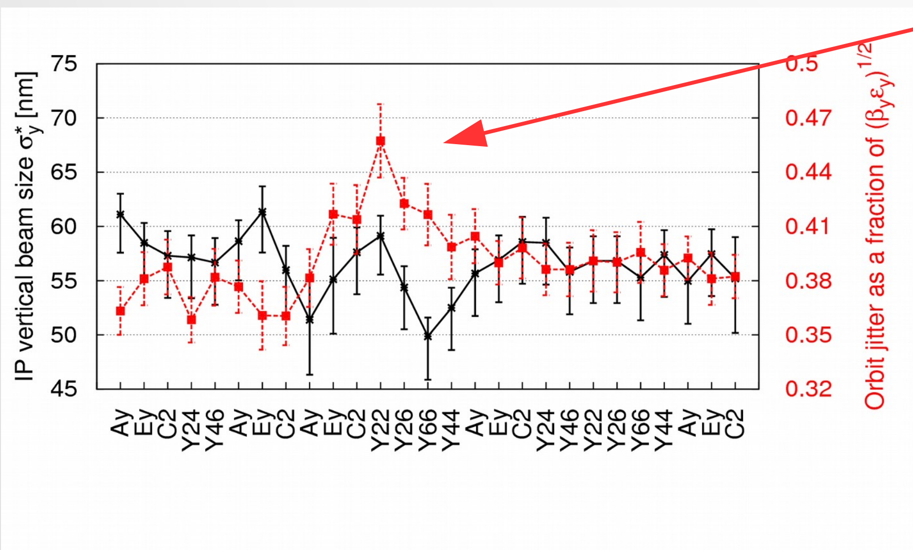
- 100 random machines generated.
- **Tuning** means **adjusting the machine parameters** to reach as close as possible to the **design performance**
- Two cases: with and without the orbit correction (MADX CORRECT command)
- Two sets of optics studied:
  - $\beta_x^* = 40$mm, $\beta_y^* = 50\mu$m (half β_y^*, $10\beta_x^*$)
  - $\beta_x^* = 100$mm, $\beta_y^* = 50\mu$m (half β_y^*, $25\beta_x^*$)

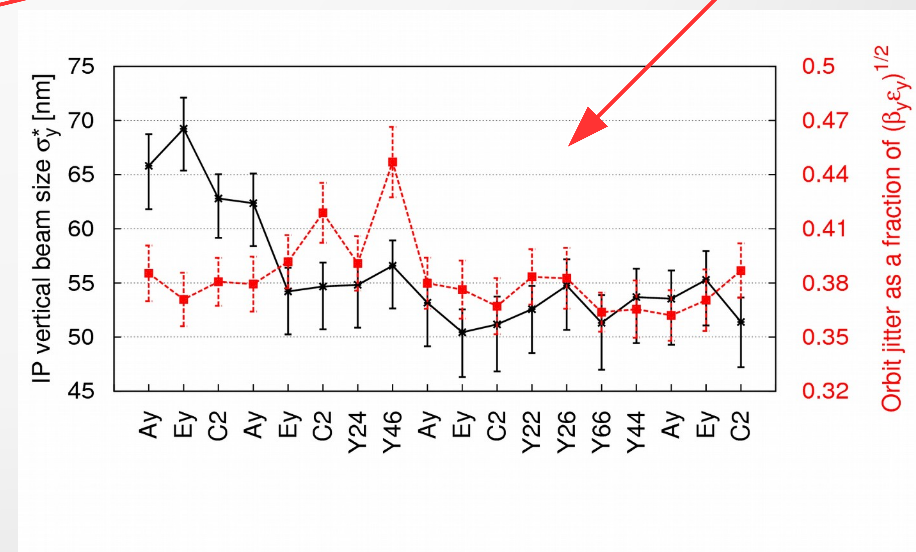


Tuning simulations results vs. experimental results

case	misalignments			multipolar	$\sigma^*_{y,sim}$ [nm] w/o orbit corr.		$\sigma^*_{y,sim}$ [nm] w/ orbit corr.	
	Δx [μm]	Δy [μm]	$\Delta\theta$ [μrad]	errors	half β^*_y, $10\beta^*_x$	half β^*_y, $25\beta^*_x$	half β^*_y, $10\beta^*_x$	half β^*_y, $25\beta^*_x$
nominal errors	100	100	200	x1	39 ± 10	38 ± 7	32 ± 3	32 ± 3
misalign. x1.5	150	150	300	x1	52 ± 22	49 ± 13	36 ± 8	35 ± 5
misalign. x2.0	200	200	400	x1	67 ± 30	62 ± 20	39 ± 10	40 ± 8
mults x3	100	100	200	x3	44 ± 10	46 ± 10	38 ± 6	37 ± 5
mults x5	100	100	200	x5	61 ± 14	54 ± 11	45 ± 8	44 ± 7
misalign. x1.5, mults x3	100	100	200	x5	62 ± 24	55 ± 16	42 ± 7	42 ± 8
misalign. x2.0, mults x5	100	100	200	x5	85 ± 33	74 ± 22	54 ± 12	55 ± 11
experiment	-	-	-	-	-	-	(58^{+4}_{-5})[a]	(51^{+5}_{-6})[a]

[a] Orbit correction in the experiment is different than in the simulation.





Tuning simulations results

case	misalignments			multipolar	$\sigma^*_{y,sim}$ [nm] w/o orbit corr.		$\sigma^*_{y,sim}$ [nm] w/ orbit corr.	
	Δx [μm]	Δy [μm]	Δθ [μrad]	errors	half β^*_y, $10\beta^*_x$	half β^*_y, $25\beta^*_x$	half β^*_y, $10\beta^*_x$	half β^*_y, $25\beta^*_x$
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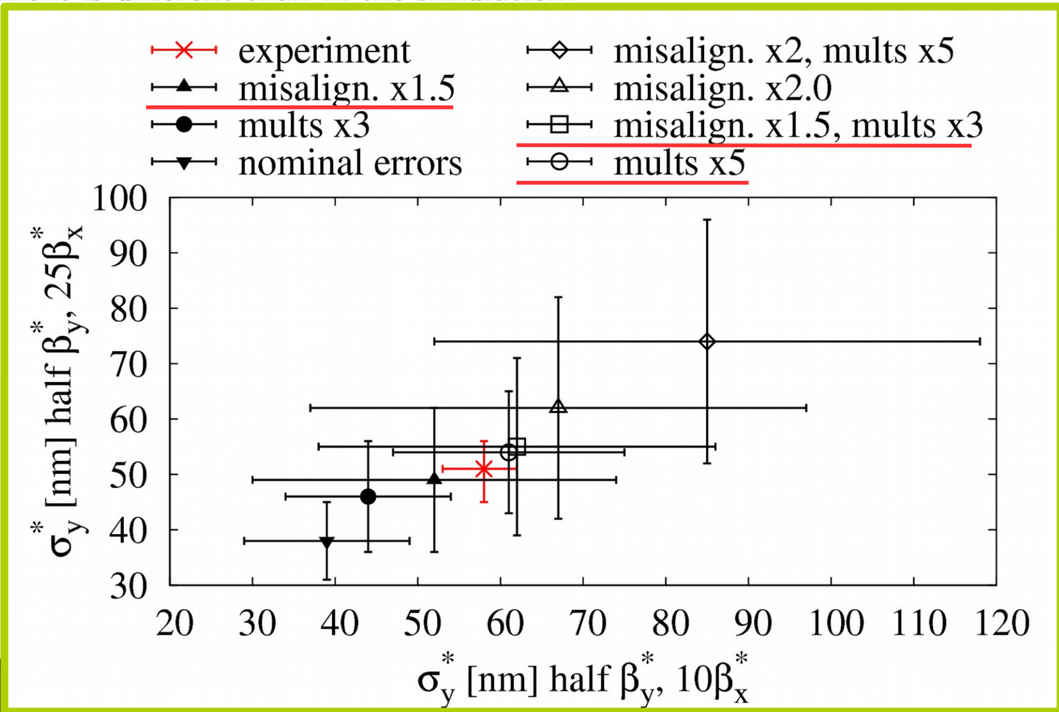

Conclusions

- Half β_y^* optics were precisely set using a new method of emittance measurement at the IP.
- Beam sizes larger than expected were measured for half β_y^* optics.
- The realistic (nominal) errors applied in the simulations do not reproduce the measured beam sizes,
- The simulation results get closer to the measured beam sizes for the following set of errors (w/o orbit correction): misalign. x1.5, mults x5, misalign. x1.5, mults x3.
- The orbit correction included in the simulations highly improves the simulation results.
- Possible reasons for observing larger beam sizes than expected:
  - Insufficient orbit control and sensitivity to machine drifts;
  - Contribution of wakefields combined with the beam orbit jitter;
  - Larger and/or additional multipolar fields (QF1FF, crosstalk, …);
  - Larger alignment errors;
  - Instrumentation errors.
- Results are published in Phys. Rev. Accel. Beams 19, 101001 (2016).

Many thanks to ATF2 collaboration!