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Towards ultra-low β* in ATF2

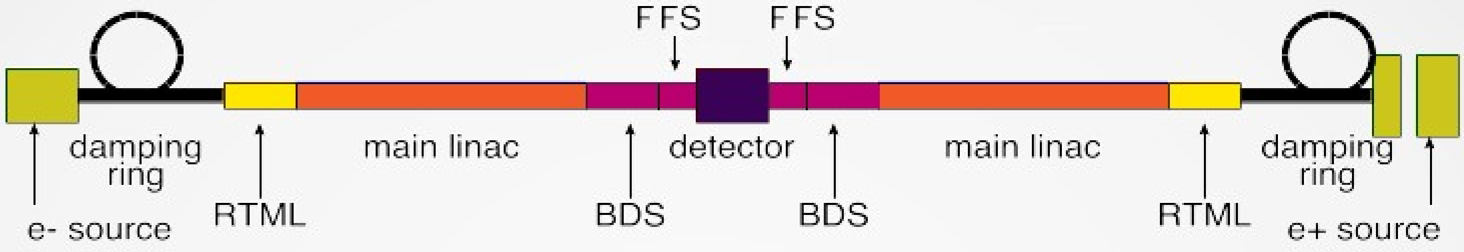
Marcin Patecki[1,2],
A. Aloev[1], K. Kubo[4,5], S. Kuroda[4,5], E. Marin[3], M. Modena[1], T. Okugi[4,5], T. Tauchi[4,5], N. Terunuma[4,5], R. Tomás[1], G. White[3]

[1] CERN, The European Organization for Nuclear Research , Geneva, Switzerland.
[2] Warsaw University of Technology, Faculty of Physics, Poland.
[3] SLAC, National Accelerator Laboratory, California, USA.
[4] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan.
[5] SOKENDAI, School of High Energy Accelerator Science, Hayama, Japan.

Outline

- Introduction
  - Final focus system for future linear colliders
  - Accelerator Test Facility (ATF2)
- Motivation for ultra-low β* ($1\beta_x 0.25\beta_y$) in ATF2
- Investigation of ultra-low β* feasibility:
  - IP vertical beam size predictions and mitigation methods
  - Correction of the magnetic multipole fields and quadrupole fringe fields
  - Octupole magnets installation
- Half β_y* study ($10\beta_x 0.5\beta_y$) in ATF2 December'14 run
  - Optics design
  - Estimation of β* values
  - Beam size tuning and measurements
- Future plans
- Conclusions

Final focus system for future linear colliders



- High luminosity is one of the most important requirements for particle colliders:

$$L = \frac{N_p^2 n_b f_{rep}}{4\pi \sigma_x^{IP} \sigma_y^{IP}} H_D$$

N_p – number of particles per bunch
n_b – number of bunches per train
f_{rep} – trains repetition rate
σ^{IP} – transverse beam size at the IP
H_D – luminosity enhancement factor

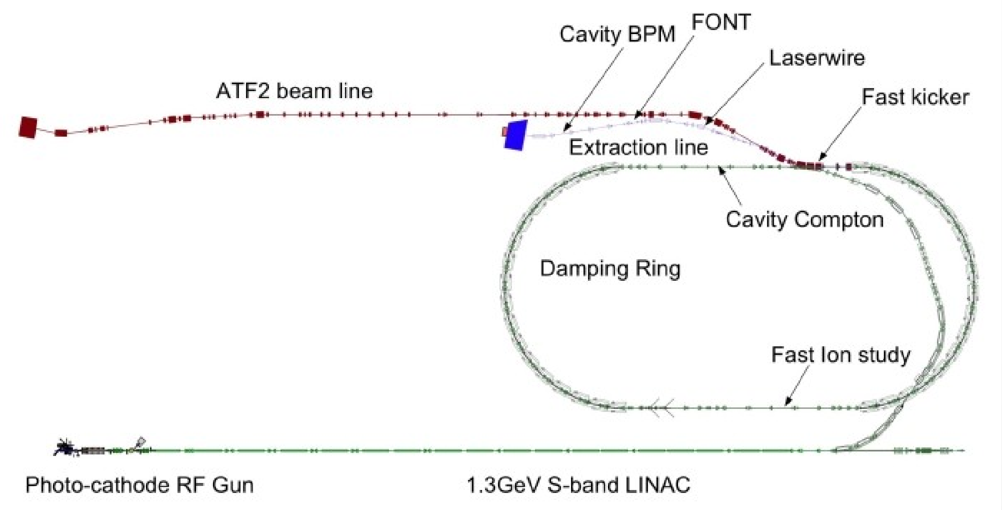
- Beam delivery system (BDS) acts on the beam coming from the main linac and prepares the beam (collimation, diagnostics, matching) for focusing.
- Final focus system (FFS) is the last part of BDS where two strong quadrupole magnets focus the beam to be collided with a smallest possible beam size.

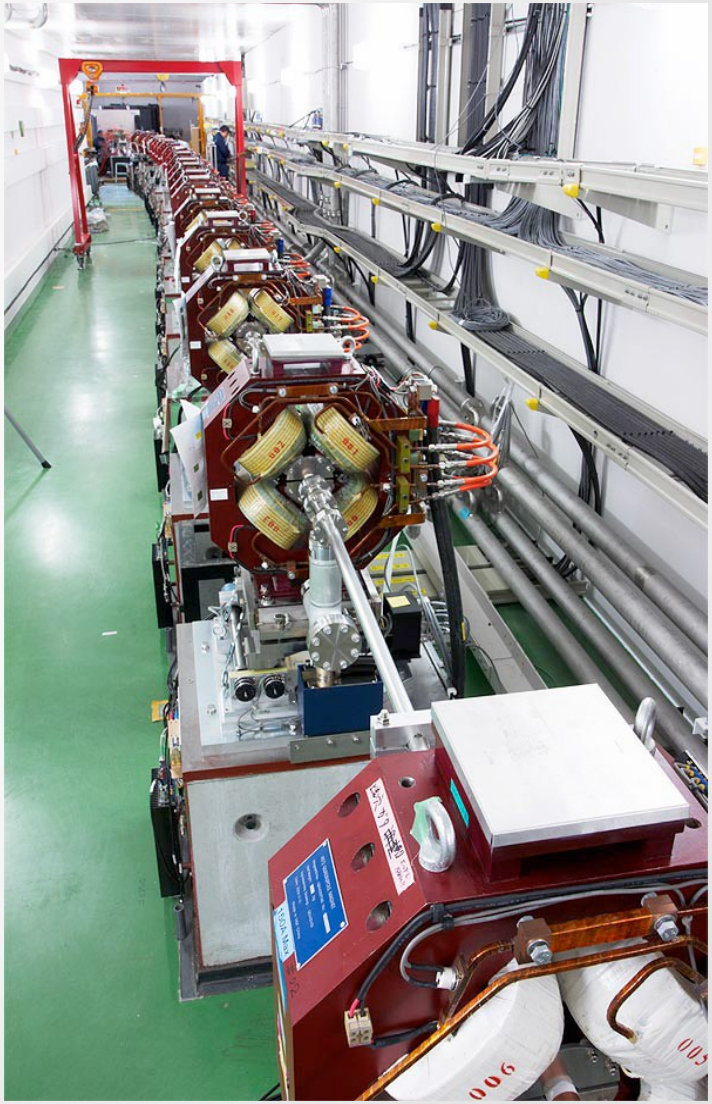
$$\sigma_{x,y}^{IP} = \sqrt{\frac{\beta_{x,y} \varepsilon_{x,y}}{\gamma}}$$

β – optical function, characterizes the focusing strength
ε – beam emittance
γ – relativistic factor

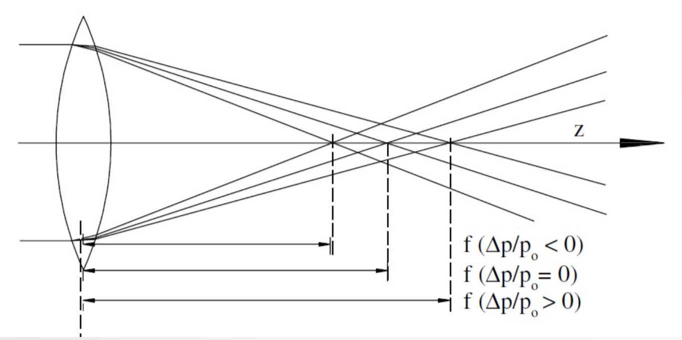
Accelerator Test Facility ATF2

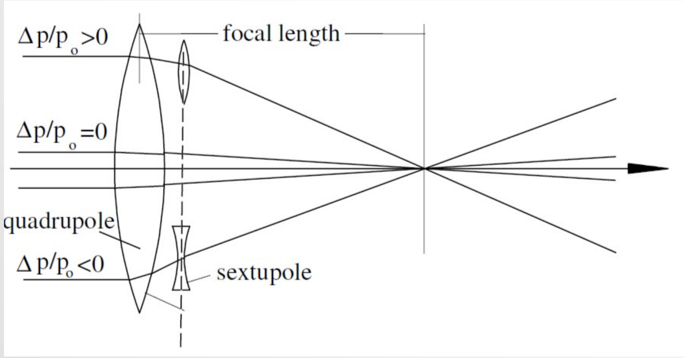
- Test facility for future linear colliders located in KEK in Japan. [1]
- First Final Focus beam line using a local chromaticity correction scheme. [2]
- **World record of smallest vertical beam size: < 45 nm (design is 37 nm). [3,4]**
- Soon, first Final Focus beam line using octupole magnets.





Chromaticity correction





- Chromatic aberration causes the off-momentum particles to be not exactly focused at the IP and therefore significant spot size growth.
- The vertical displacement at the IP is proportional to the length of the last drift, beam momentum spread and inversely proportional to β^* value:

$$\frac{\Delta y^*_{rms}}{\sigma^*_y} \approx \frac{L^*}{\beta^*_y}\sigma_\delta \approx \zeta_y \sigma_\delta$$

- The beam size growth due to chromaticity and momentum spread:

$$\sigma^*_y = \sigma^*_{y,0}\sqrt{1+\zeta^2_y\sigma^2_\delta}$$

- Chromaticity can be corrected with sextupole magnets.
- IP vertical beam size in Accelerator Test Facility (ATF2):
  - With chromaticity correction: 37 nm (design)
  - Without chromaticity correction 450 nm

Motivation for ultra-low β* in ATF2

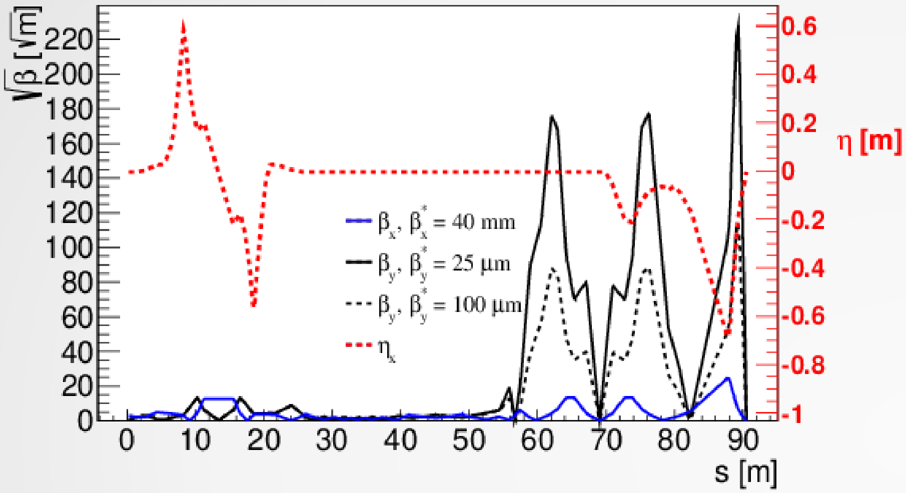
- **ATF2 ultra-low β* optics is a project [5] to test the tunability of the FFS at the chromaticity level comparable with CLIC.**
  - Larger chromaticity ξ makes the FFS more difficult to operate.
  - Level of chromaticity ξ_y in ATF2 is comparable to ILC.
- **Ultra-low β* lattice also gives the opportunity to lower the beam size down to about 20 nm and collect the experience with strong beam focusing and small beam at the IP.**
  - Utilization of octupole magnets for stronger beam focusing will be tested.

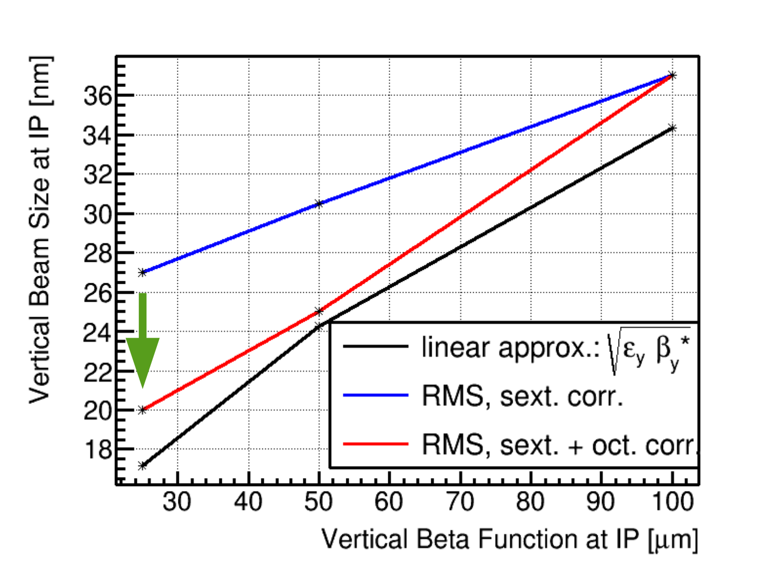
	β_y^* [mm]	$\sigma_{y,\,design}$ [nm]	L* [m]	$\xi_y \sim (L^*/\beta_y^*)$
ILC	480	5.9	3.5/4.5	7300/9400
CLIC	70	1	3.5	50000
ATF2 nominal	100	37 (44[a])	1	10000
ATF2 half β_y^*	50	25[b]	1	20000
ATF2 ultra-low β*	25	20[b]	1	40000

[a] measured, June 2014

[b] using octupoles

IP vertical beam size for ultra-low β*





Decreased β_y* causes the increase of β_y in the Final Focus region. In consequence the beam size is larger in the FF and more sensitive to beam line imperfections. It was checked that:

- **magnetic multipole fields [6]** and
- **fringe fields [7]**

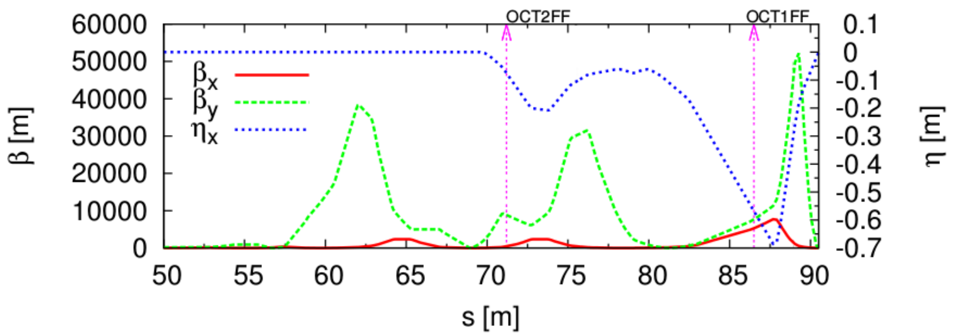
are limiting factors for IP beam size.

Proposed mitigation method:

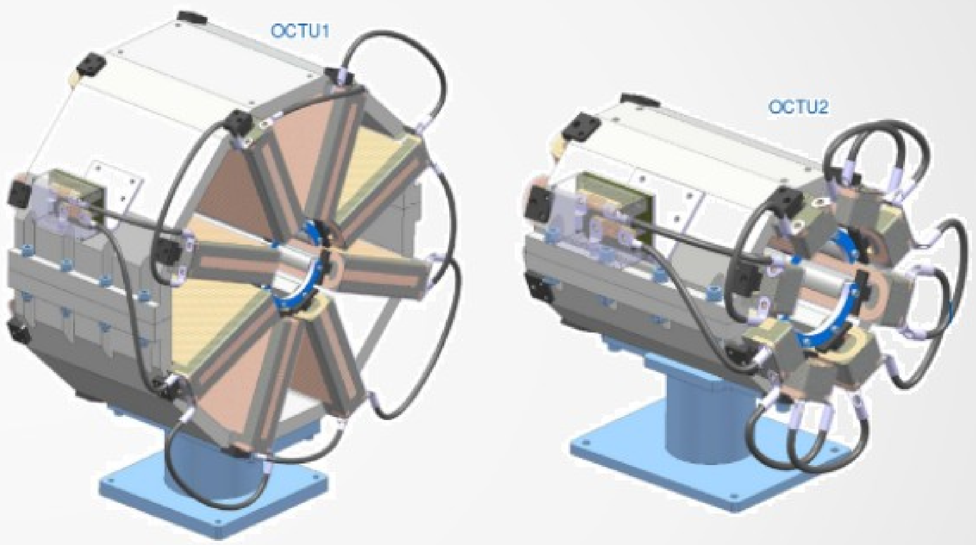
- Installation of two octupole magnets
  - Corrects both multipole fields and fringe fields.
  - Makes sextupoles strength adjustment easier and therefore allows for more effective chromaticity correction.
  - **Bring the IP beam size from 27nm to 20 nm for ultra-low β* lattice.**

Octupole magnets for ATF2

- Octupoles will be installed in the dispersive and non-dispersive regions with 180° difference of phase advance [8]:
  - OCT1 at 86.41 m between QD2AFF and SK1FF (3.8 m)
  - OCT2 at 71.85 m between QD6FF and SK3FF (1.0 m)



- Magnets design was done at CERN [9]:



- OCT1 is planned to be install on a mover, with initial tilt of 0.5 deg.
- Octupoles are air cooled and their yokes are composed of two halves for mounting simplicity.

	G [T/m^3]	tunability	magnetic length [mm]	aperture radius [mm]	ampere-turns per coil [A]	# of turns per coil	I [A]	power max. [W]
OCT1	6820	-90%/+20%	300	52	1800	60	30	152
OCT2	708	-90%/+20%	300	52	180	6	30	15.2

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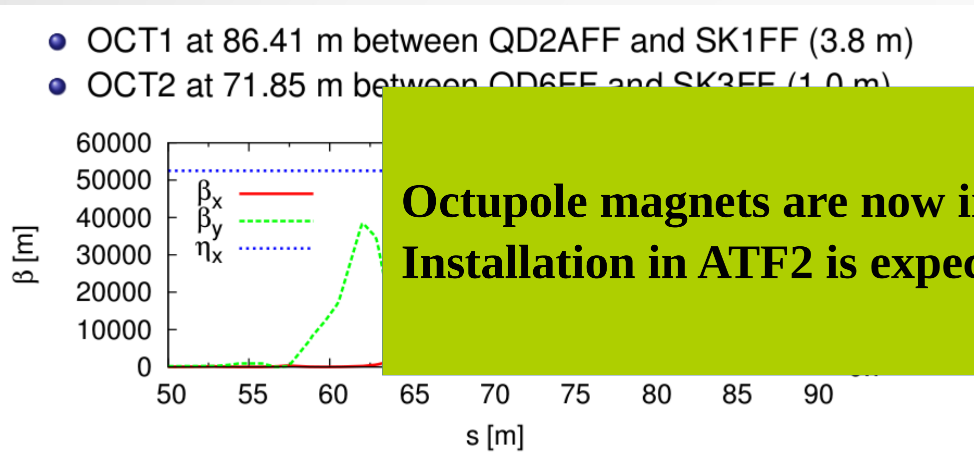

Octupole magnets are now in procurement phase.
Installation in ATF2 is expected for the beginning of 2016.

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Misalignments of octupole magnets

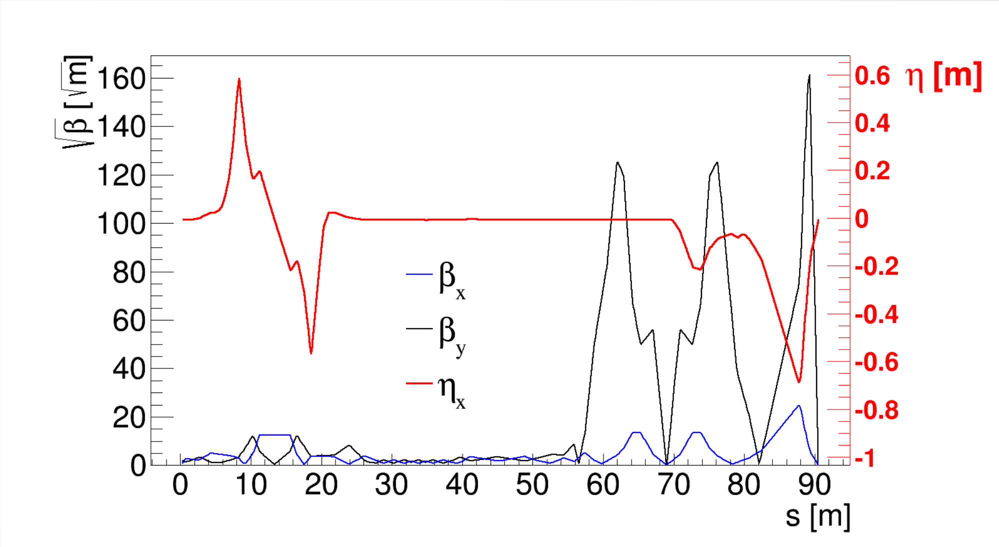
	ΔX	ΔY	$\Delta\sigma_y$*	ΔK_2	Dist. to sext.
OCT1	500 μm	0	2%	1% (SF1FF)	86.5 cm
OCT1	0	500 μm	3%	300% (SK1FF)[a]	57 cm
OCT2	500 μm	0	0.25%	1.5% (SF5FF)	1.5 m
OCT2	0	500 μm	0.4%	22% (SK3FF)[a]	54 cm

[a]Strength of skew sextupoles is well within their limits

- Octupoles installation on movers is considered.
- However, the misalignments of up to 500 μm can be corrected by adjusting the strengths of the nearby sextupole magnets.
- Alignment with accuracy much better than 500 μm is expected for the installation of octupoles in ATF2.

Half β_y* study in ATF2 December'14 run

- For the December 2014 run the $10\beta_x 0.5\beta_y$ optics (40mm, 50µm) was applied;
- **Expected IP vertical beam size: 26 nm**, after very fine tuning of sextupole magnets and assuming vertical emittance ε_y = 12 pm.



ATF2 December'14 run: β_y* estimation

- The values of IP β were estimated from the beam divergence using the QF1FF and QD0FF scans:

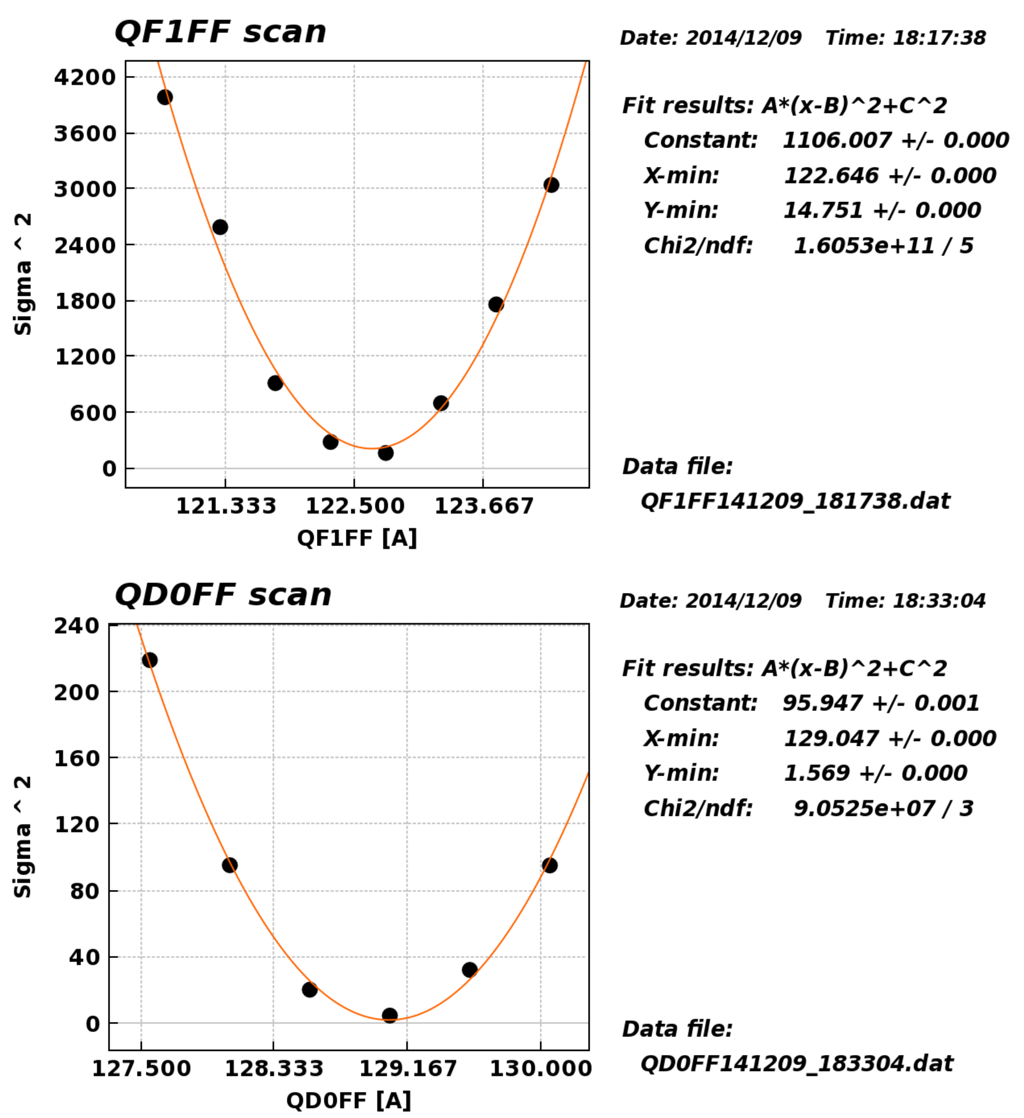
$$\beta \approx \frac{\varepsilon}{\sigma^2}(\Delta f)^2$$

Δf – distance from nominal IP

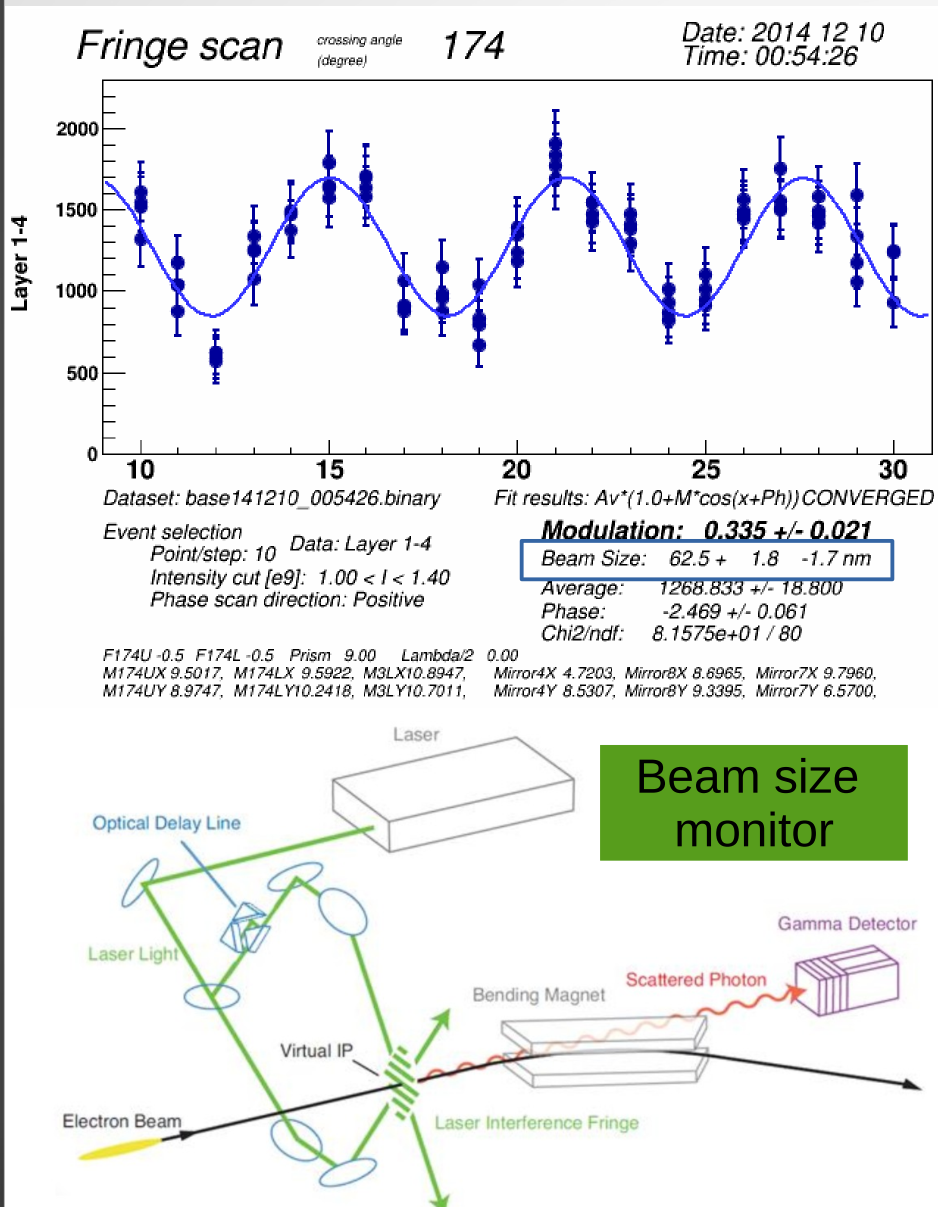
- For **measured (OTR) vertical emittance of 29 +/- 5 pm**, the β_y* estimated from scans

β_y^*= 52 +/- 8 µm

- We suspect that the measured emittance is overestimated which affects the value of β_y*. Good knowledge of emittance is needed.



ATF2 December run: IP beam size tuning



- Tuning with the use of linear knobs.
- After 8h of tuning the vertical beam size measured in 174 degree mode was **62.5 ± 1.8 nm**.
  Far from expected value of about 41 nm (assuming measured emittance).
- Modulation was lost during the pitch scan because of a problem with the lasers position adjustment;
- We tried to repeat the tuning but it was not successful because of the problem with lasers;
- However, this measured beam size is consistent with 52 nm (design is 37 nm) measured in November'14 for $10\beta_x 1\beta_y$ optics (which in principle should be easier to operate).

Remarks on lower β_y* study

- The optics applied to the machine is close to the design.
- Further optimisation of the optics is planned for the next ATF2 runs.
- We were very unfortunate with the lower β_y* experiment so far:
  - In the 2nd week of December'14, the experiment was stopped due to the IP Beam Size Monitor failure;
  - In the 3rd week of December'14, the experiment was stopped due to the extraction kicker failure;
  - During the April'15 run, the experiment was delayed because of the QD0FF mover failure and later interrupted after serious power drop caused by a thunderstorm.

Experience from the half β_y* experiment

- Larger chromaticity requires very fine 2nd order beam size tuning with the use of normal and skew sextupoles.
- The IP Beam Size Monitor (IPBSM) performance plays a key role in the realisation of this study because it is used for the beam size minimisation.
- Stronger focusing increases the beam divergence and angular jitter at the IP causing larger signal jitters of IPBSM and therefore spoiling its performance.
- Precise measurements and control of beam emittance is critical.

Future plans

- Final verification of the half β_y* optics.
- Beam size minimisation.
- More detailed study with the half β_y* optics (dispersion measurements, orbit response measurements, ...).
- Experiment with 1β_x* optics (10β_x* = 40 mm is currently used).
- Installation of octupoles (beginning of 2016).
- Study of the ultra-low β* optics (β_x* = 4 mm, β_y* = 25 μm).

Conclusions

- The simulations of the ultra-low β^* lattice show that the multipole field errors and final doublet fringe fields spoil the IP beam size.
- The use of octupole magnets is a common solution for lowering the beam size. The octupoles design was done at CERN and they are already in the procurement phase.
- The first experience with half β_y^* optics was collected during the December 2014 and April 2015 runs in ATF2.
- High performance of the IP Beam Size Monitor is necessary.
- Control over the beam emittance is essential.
- The applied $10\beta_x 0.5\beta_y$ (β values at the IP: 40mm, 50 μm) optics was validated by evaluating the $\beta_y^* = 52 \pm 8$ μm.

Thank you for listening!

Many thanks to the ATF2 Collaboration!

References

[1] B. I. Grishanov et al. (ATF2 Collaboration), “ATF2 Proposal”,2005.

[2] P. Raimondi and A. Seryi, “Novel Final Focus Design for Future Linear Colliders”, Phys. Rev. Lett.86, 3779 (2001).

[3] S. Kuroda, “ATF2 for final focus test beam for future linear colliders”, ICHEP 2014.

[4] K. Kubo et al. (ATF2 Collaboration), “Towards an International Linear Collider: Experiments at ATF2”, IPAC 2014.

[5] D. Angal-Kalinin, S. Bai, P. Bambade, H. Braun, J.P. Delahaye, et al., “Exploring ultra-low beta* values in ATF2 – R&D Programme proposal.” 2008, pp.1-6. <in2p3-00308662>.

[6] E. Marin et al., “Design and high order optimization of the Accelerator Test Facility lattices”, Phys. Rev. St. Accel. Beams 17, 021002, 2014.

[7] M. Patecki, R. Tomás, “Effects of quadrupole fringe fields in final focus systems for linear colliders”, Phys. Rev. St. Accel. Beams 17, 101002 (2014).

[8] E. Marin et al., “Specifications of the octupole magnets required for the ATF2 ultra-low β lattice”, SLAC Technical Note: SLAC-TN-14-019.

[9] M. Modena, “Update on 2 Octupoles Procurement for ATF2 Final Focus Systems”, 18th ATF2 Project meeting 2015.