ILC new luminosity design and small beam experiments at ATF

ALCWS2018 2018.5.31

K. Kubo (KEK)

Luminosity at E_{CM}=250GeV

ILC TDR is optimized for 500GeV.

Luminosity at 250GeV was low

New design: Higher luminosity at 250 GeV

By reduction of horizontal beam size

(Increase beamstrahlung (energy loss in collision))

TDR 500GeV	TDR 250 GeV	New 250GeV
1.79 $\times 10^{34}$ /cm^2/s	0.82	1.35

(Reported by K.Yokoya in AWLC2017)

Reduce σ_x

- By reducing horizontal emittance. 10 → 5 um.

  (Reduction of beta_x* will cause problems.

  Can be tried later.)

- Need lower emittance in Damping Rings
  - Possible with minor design change
- Disruption (strength of beam-beam force) will become large → tighter positioning tolerance
  - Cured by fast feedback

Part of parameter table

		TDR		New
Ecm	GeV	250	500	250
ε_{nx}	μm	10.00	10.00	5.00
σ_x	nm	729.0	474.2	515.5
Dx		0.26	0.30	0.51
Dy		24.5	24.6	34.5
Upsilon (average)		0.020	0.062	0.028
Ngamma		1.21	1.82	1.91
δ_{BS}	%	0.97	4.50	2.62
L geo	1.0E+34	0.374	0.751	0.529
L (simulation, waist shift)	1.0E+34	0.82	1.79	1.35

New Parameter Set

- Half Horizontal Emittance
- Same beta*

Luminosity

0.82 → 1.35 E34 /cm²/s

- δ_{BS} 0.97 → 2.62%
- D_y 24.5 → 34.5
- ε_x 10 → 5 μm

		TDR		New
Ecm	GeV	250	500	250
N	e10	2.0	2.0	2.0
Collision frequency	Hz	5.0	5.0	5.0
Electron linac rep rate	Hz	10.0	5.0	5.0
Nb		1312	1312	1312
Bunch separation	ns	554	554	554
Beam current	mA	5.78	5.78	5.78
P_B	MW	5.3	10.5	5.3
σ_z	mm	0.3	0.3	0.3
σ_E/E(e-)	%	0.188	0.124	0.188
σ_E/E(e+)	%	0.15	0.07	0.15
ε_{nx}	μm	10.00	10.00	5.00
ε_{ny}	nm	35.0	35.0	35.0
electron polarization	%	80	80	80
positron polarization	%	31	22	31
β_x	mm	13.0	11.0	13.0
β_y	mm	0.41	0.48	0.41
σ_x	nm	729.0	474.2	515.5
σ_y	nm	7.66	5.86	7.66
θ_x	μr	56.1	43.1	39.7
θ_y	μr	18.7	12.2	18.7
Dx		0.26	0.30	0.51
Dy		24.5	24.6	34.5
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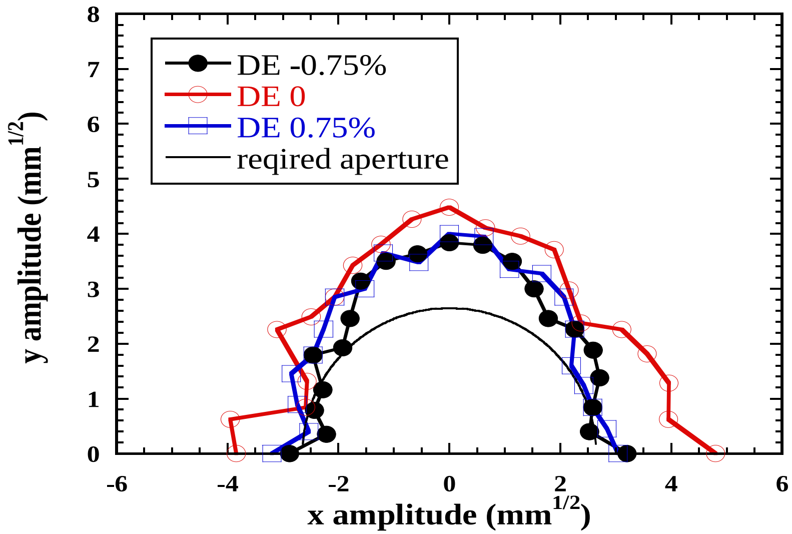
Damping Ring Design for lower ε_x

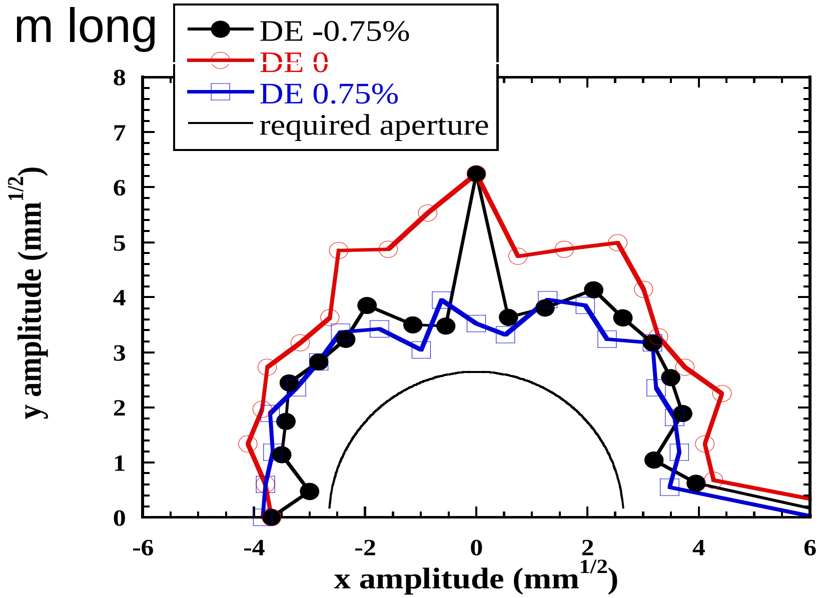
- Stronger focusing optics can make smaller horizontal emittance
- Possible problem is reduction of dynamic aperture
- There is a space to lengthen the dipoles in the arcs 3m → ~5m
  - This (weaker bending field) will make dynamic aperture larger
- Still conservative, compare with recent light sources

Dynamic aperture of small emittance (4 um) design

3 m long Bend



5 m long

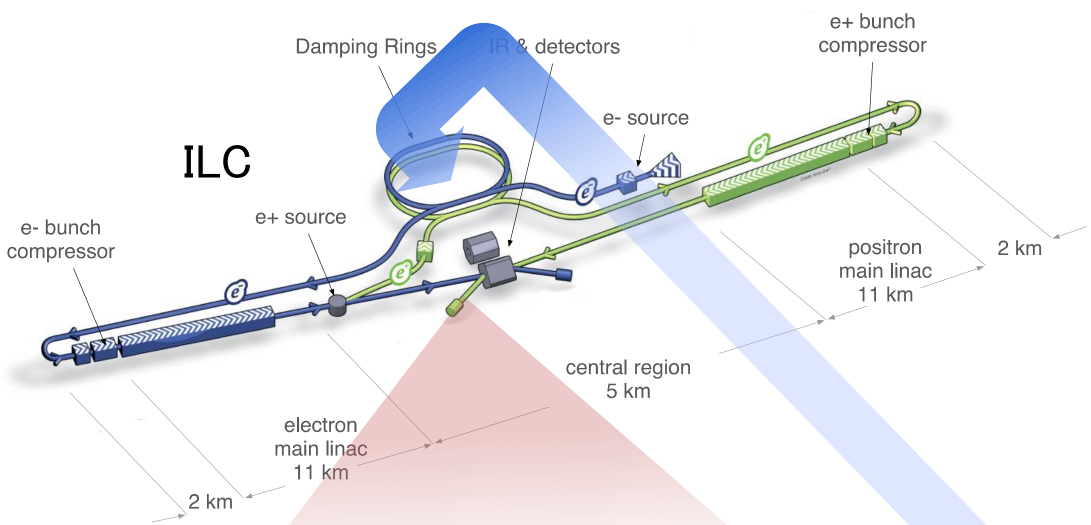


Luminosity Preservation

At IP

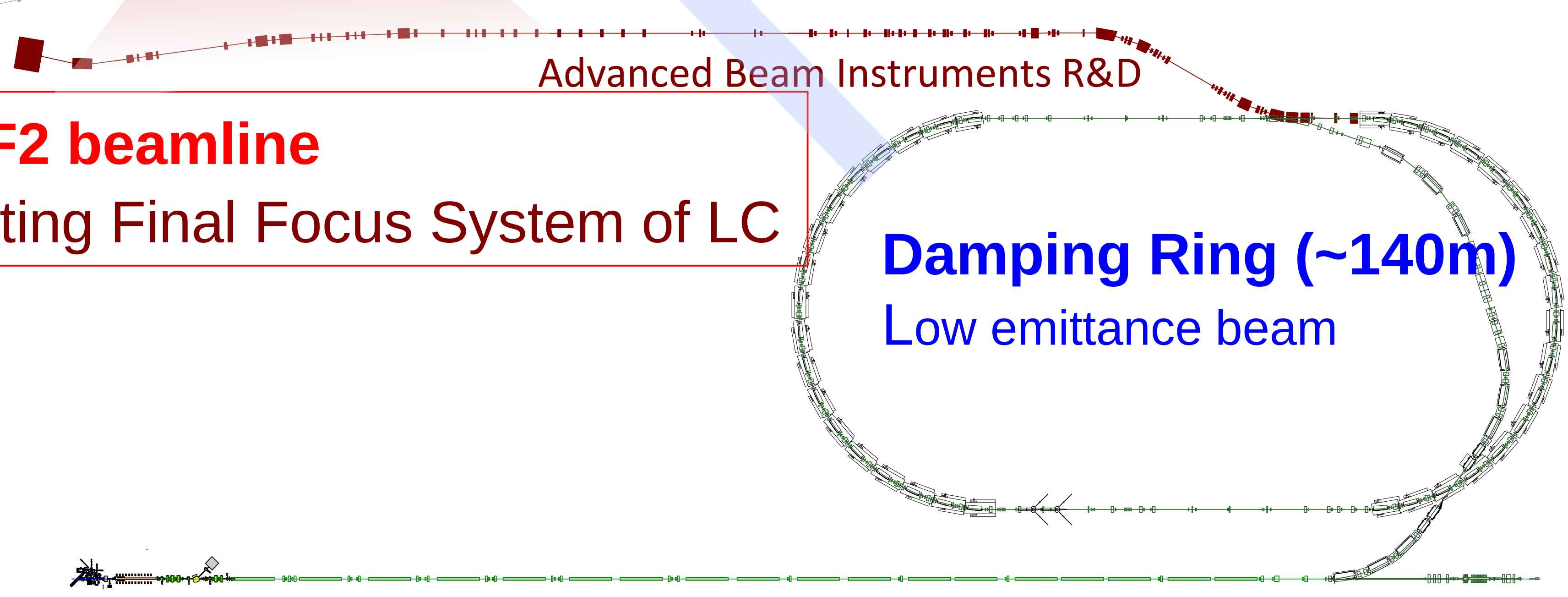
- Small beam
- Position stability

Tested at ATF2



Accelerator Test Facility

Energy: 1.3 GeV, Repetition: 3.12 Hz
Intensity: 1×10^{10} e-/bunch (max. 2×10^{10}),
1~20 bunches/pulse
Emittance: Design, 1 nm(H)/ 10 pm(V),
Achieved 4 pm(V)



Advanced Beam Instruments R&D

ATF2 beamline

Testing Final Focus System of LC

Damping Ring (~140m)

Low emittance beam

Cs_2Te Photocathode RF Gun

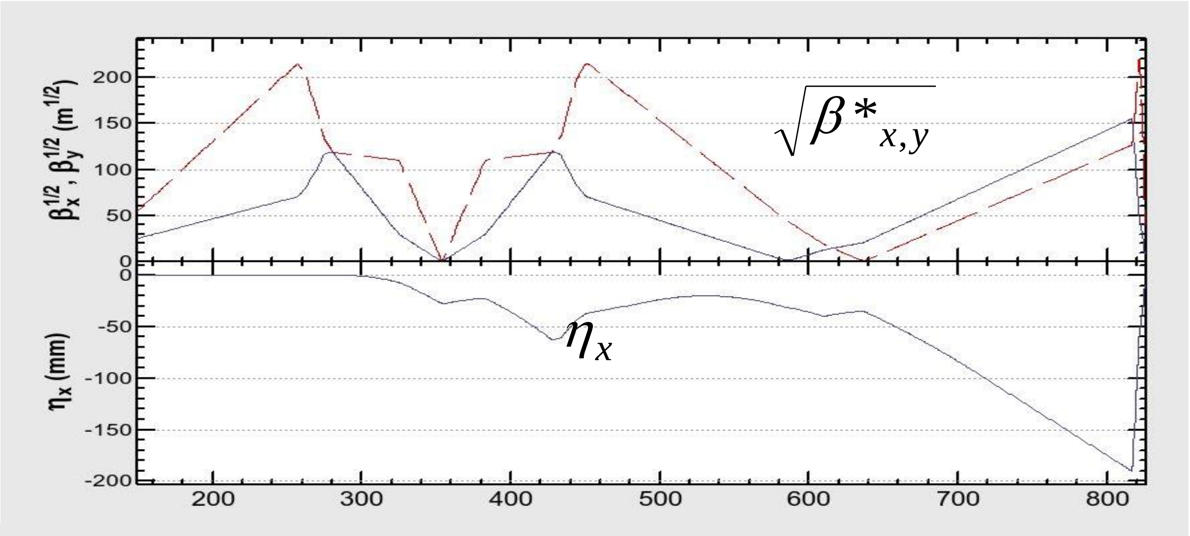
1.3 GeV S-band Electron LINAC (~70m)

Final Focus Optics, ILC and ATF2

Almost identical optics
Same magnet configuration (Same magnet names)

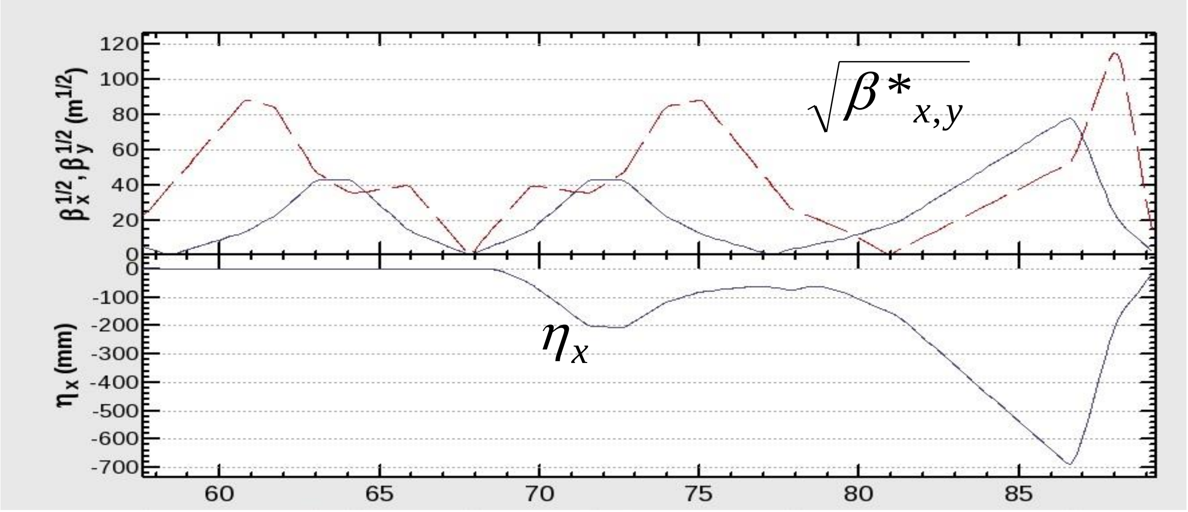
ILC

125 GeV
~700 m



ATF2

1.3 GeV
~30 m



How can we compare difficulties in ILC and ATF2

	TDR 500	TDR 250	New 250	ATF2
Beam energy (GeV)	250	125	125	1.3
Vertical size (nm)	5.9	7.7	7.7	37/41 (Design/measured)
beta_y* (mm)	0.48	0.41	0.41	0.1
Physical emittance (pm)	0.08	0.16	0.16	12
L*/beta_y* (~Natural chromaticity)	4100/0.48	4100/0.41	4100/0.41	1000/0.1
Energy spread (e-/e+) (%)	0.12/0.07	0.19/0.15	0.19/0.15	0.06~0.08

Difficulty in final focus.
Roughly, relative difficulty can be represented by
L*/beta_y*
(for geometrical aberrations and chromatic aberrations)

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L*: Distance between final quad magnet to IP

Difficulty in final focus.
Roughly, relative difficulty can be represented by
L*/beta_y*
(for geometrical aberrations and chromatic aberrations)

How can we compare difficulty in ILC and ATF2

L*/beta*

~ Natural chromaticity

~ (beam size in final magnet) / (beam size at IP)

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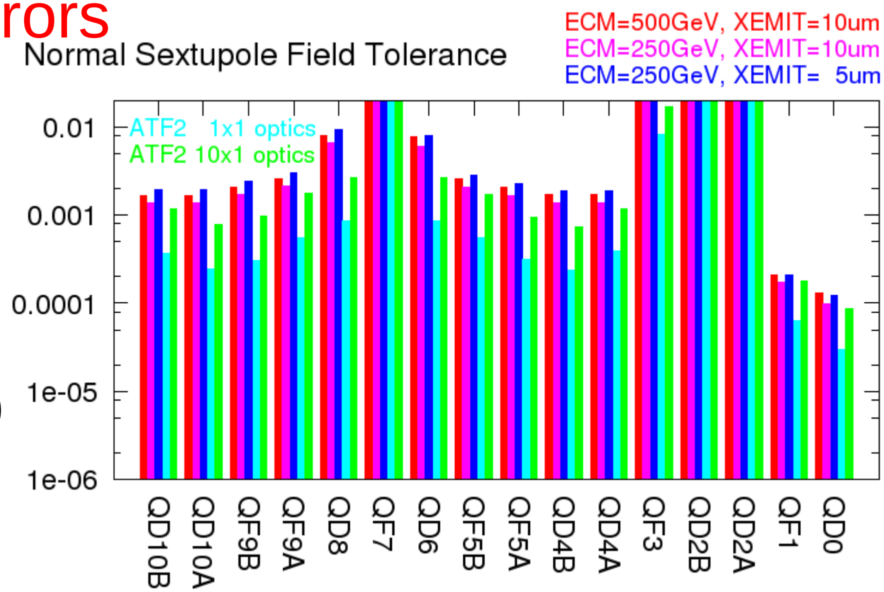
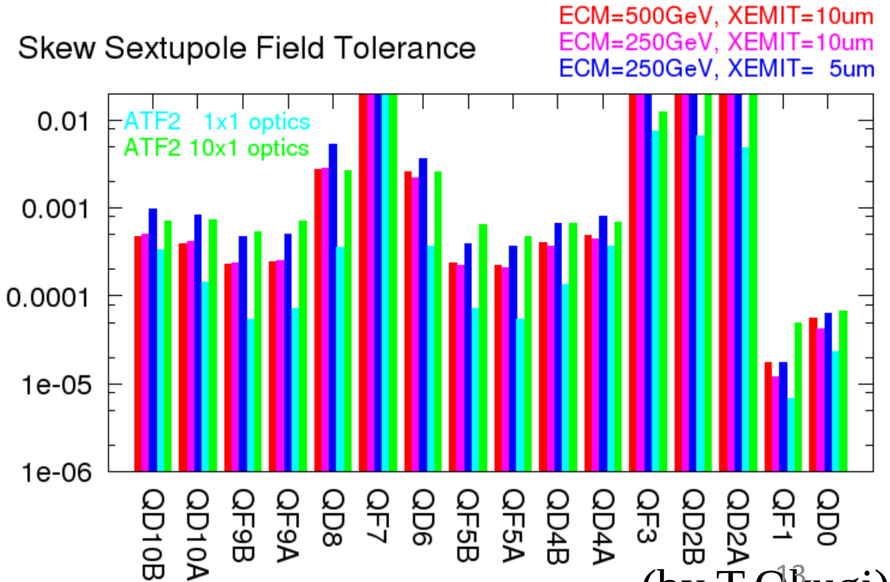
(for chromatic aberrations and geometrical aberrations)

Tolerances of magnet field errors

ILC TDR 500 GeV
ILC TDR 250 GeV
ILC new 250 GeV
ATF2 1x1 optics (original design)
ATF2 10x1 optics (usual operation)

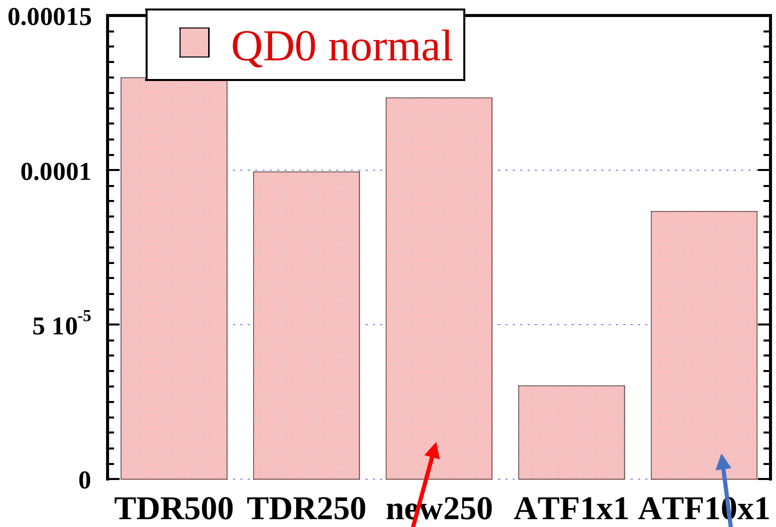


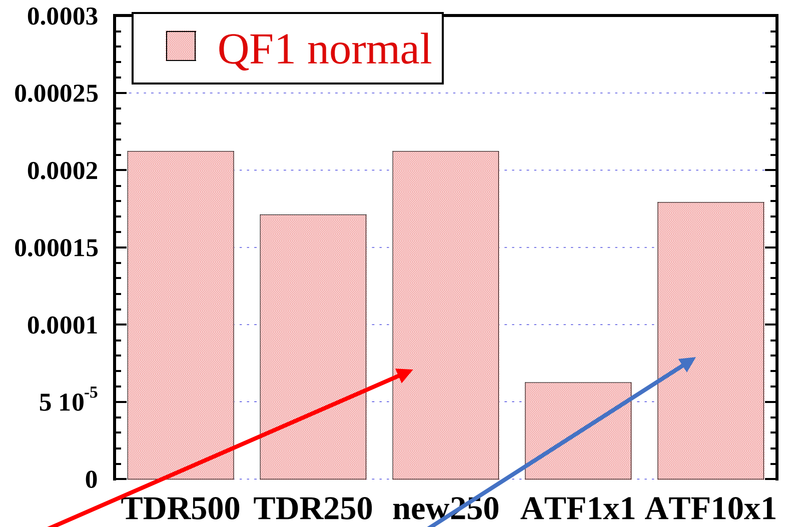
Normal sextupole and
Skew sextupole strength
causing 1% beam size growth



(by T.Okugi)

Tolerance of normal sextupole field of QF1, QD0 (Final Doublet)





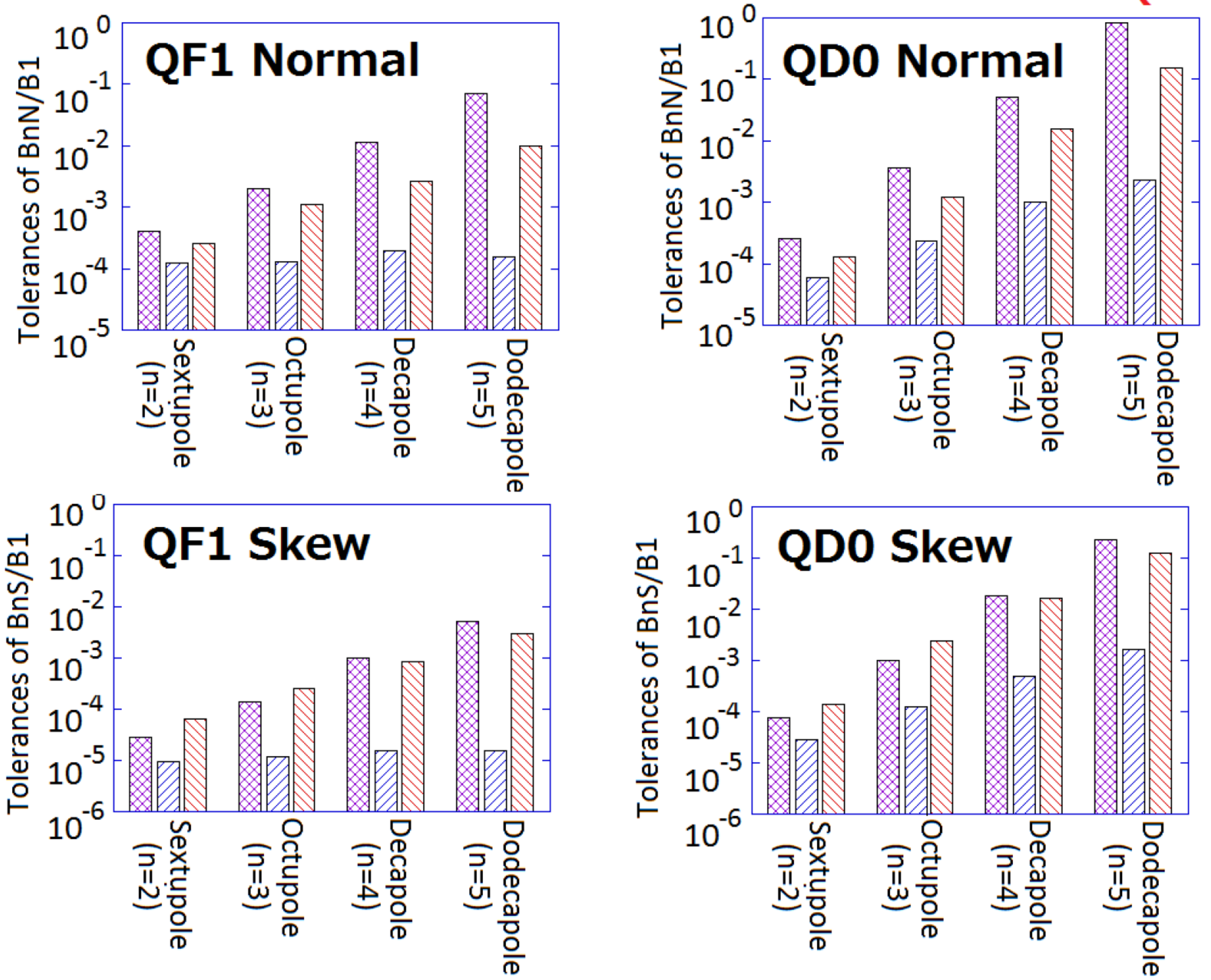
ILC new250

ATF2 10x1 (usual operation)

(by T.Okugi)

Tolerances of FD multipole field error to IP vertical beam size

ILC
ATF (1 x 1)
ATF (10 x 1)



(by T.Okugi)

e tolerances of FD multipole errors for ATF2 10x1 optics is comparable to ILC.

Roughly,
Tolerance of magnetic field error
in New250
~ TDR500
~ TDR250
~ ATF2 10x1 (usual optics)
> ATF2 1x1 (original design)

ATF2 10x1 (usual optics) is good for testing ILC Final Focus

Tuning knobs for vertical beam size

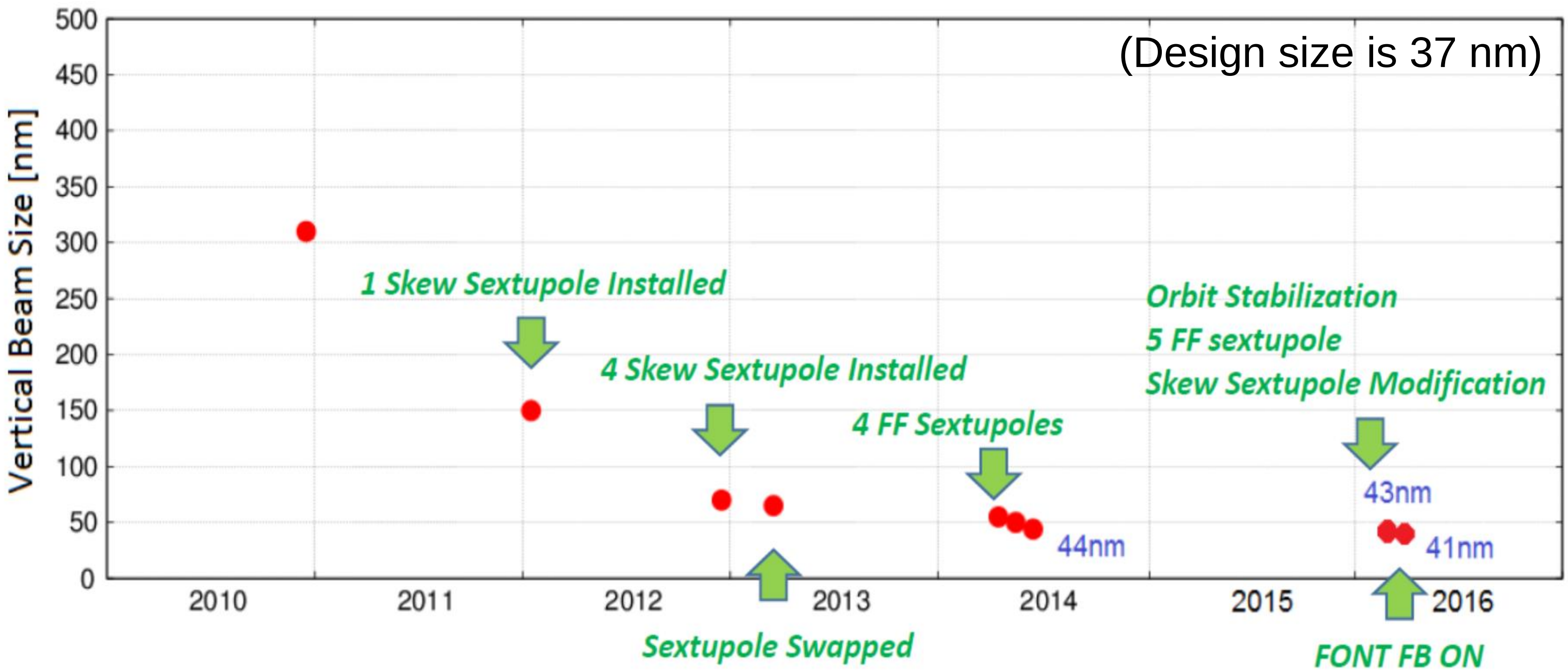
5 sextupole magnets (on movers) and
4 skew-sextupole magnets

Same design for ILC and ATF2

		Corrected coupling
Linear knob	Horizontal move of sextupole magnets	yy'
	vertical move of sextupole magnets	Ey
		$x'y$
Non-linear knob	Strength change of sextupole magnets	$x'yy'$
		Eyy'
	Strength change of skew sextupole magnets	xxy
		Exy
		EEy
		$yy'y'$

T. Okugi et al., Phys. Rev. ST-AB **17**(2014) 023501.

History of measured minimum beam size of ATF2



Achieved small beam, very close to design

Figure by T.Okugi

Study continued

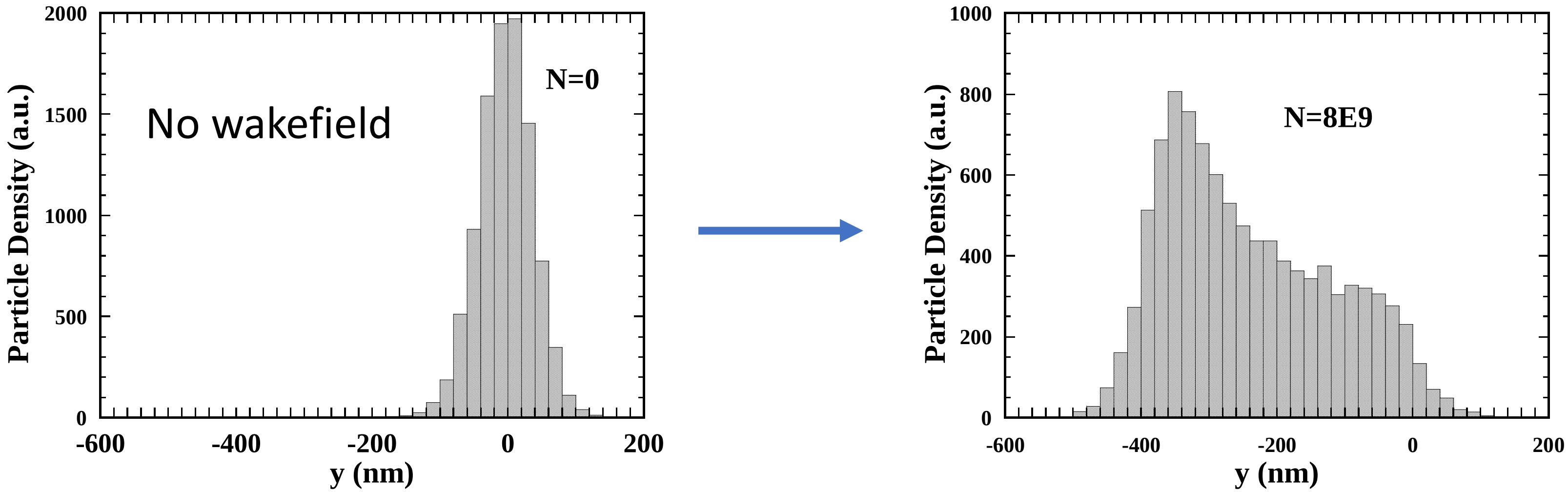
- Understand Non-linear Aberrations in details
- Possibility of smaller beta_y*
- **Intensity dependence (next slides)**

Intensity dependence at ATF2

- Beam size depend on bunch intensity
- Small beam (~40) nm observed only at low intensity

  (N~1x10^9) (ATF2 design 1x10^{10}, ILC 2x10^{10})
- Effect of wakefield

Beam profile at IP (simulation)

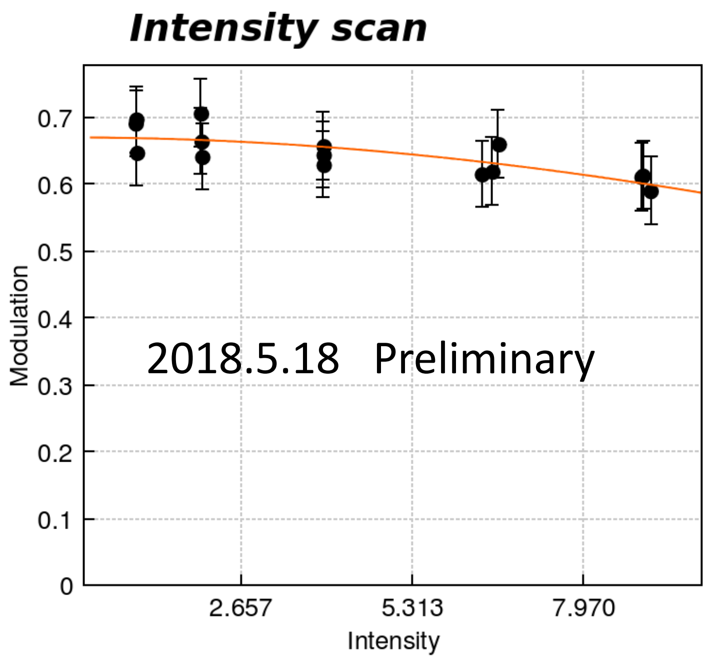


Reported in this workshop, ATF2 session

Beam size vs. bunch Intensity at ATF2

Assuming $\sigma_y^2(q) = \sigma_y^2(0) + w^2 q^2$

Use w as intensity dependence paramter (nm/nC or nm/1e9)



In recent operation,

w: ~ 10 nm/1e9

(beam size growth 3.6% at $N=1\times10^9$)

Depending on conditions

Comparison of Wakefield effect at ILC and ATF2

Assumptions

- Wakefield sources
  - At every quadrupole magnet
  - Similar structure in ILC and ATF

- Same random misalignment.

or

- Same orbit jitter relative to beam size

Estimate beam size growth relative to beam size at IP

Effect of wakefield with Random misalignment

$$\frac{\sqrt{\sigma^2-\sigma_0^2}}{\sigma_0} \propto \frac{qW}{E\sqrt{\varepsilon}}\sqrt{\sum \beta}$$

q : bunch charge
W : strength of wakefield
E : beam energy
ε : emittance
β : beta-function at wake source

	ILC	ATF2	Ratio of effect
E (GeV)	125	1.3	0.01
W (bunch length effect)	0.4	1	0.5~0.7
Emittance (pm)	1.6	12	2.7
$\sum \beta$ (m)	3.9E5	6.1E4	2.5
Total			0.033~0.047

(Same bunch intensity)

Effect of wakefield with Orbit distortion (orbit jitter)

$$\frac{\sqrt{\sigma^2 - \sigma_0^2}}{\sigma_0} \propto \frac{qW}{E} \sum \beta$$

	ILC	ATF2	Ratio of effect
E (GeV)	125	1.3	0.01
W (bunch length effect)	0.4	1	0.4~0.7
$\sum \beta$ (m)	3.9E5	6.1E4	6.4
Total			0.026~0.045

(Same bunch intensity)

Wakefield effects at ILC and ATF2

Effect at ILC Final Focus line is factor

0.026~0.047

of effect at ATF2 for the same charge/bunch

ATF2 minimum beam size observed with

~0.1×10^{10} e/bunch

→Corresponds to $2.1 \sim 3.8 \times 10^{10}$ e/bunch > 2.0×10^{10} (ILC design)

Effect at ILC: smaller than ATF2 low intensity operation

Expect further reduction at ILC.

We did not realize the significance of wakefield effects and ATF2 beam line was not carefully designed.

Luminosity Preservation

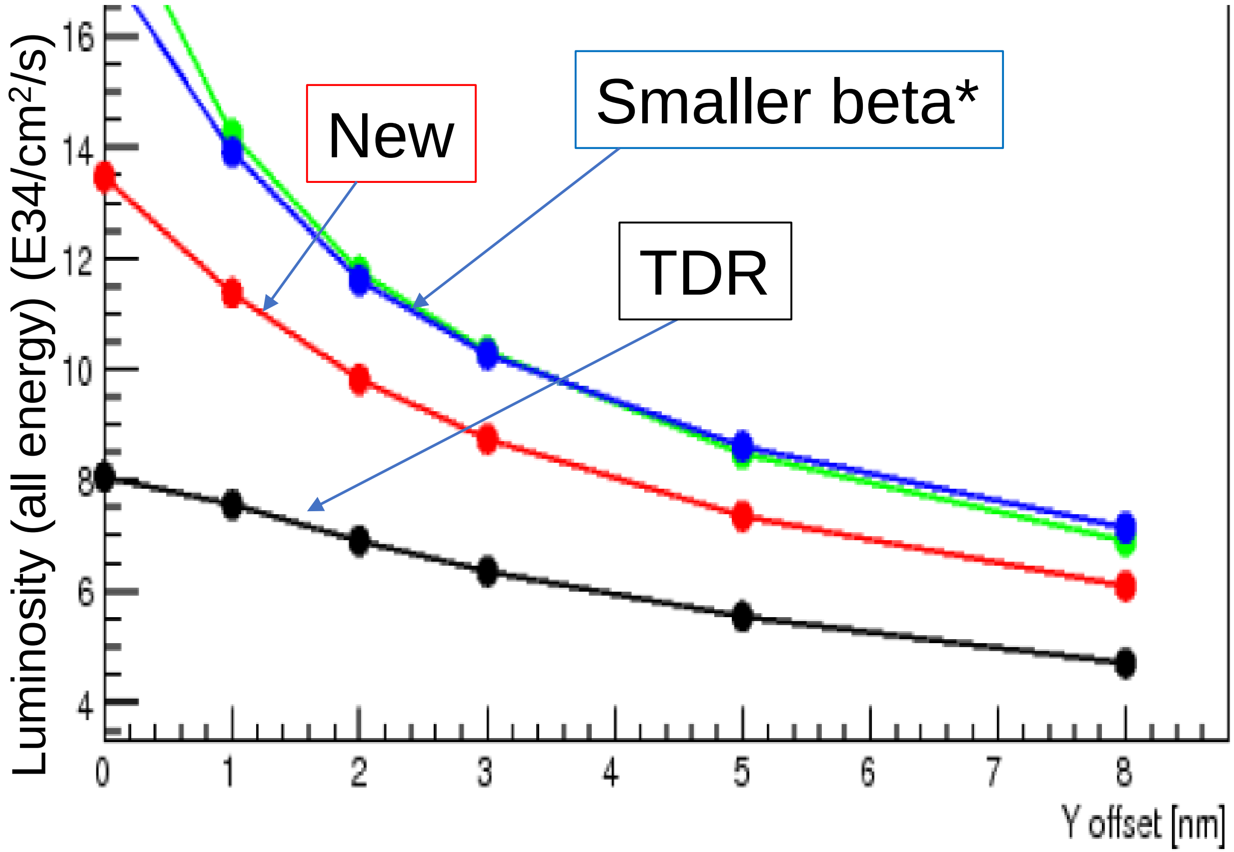
At IP

- Small beam
- Position stability

Tested at ATF2

Luminosity Sensitivity against vertical offset

Relative Luminosity reduction is larger in new design than TDR for the same offset.



D. Jean, MDI KEK Meeting 2017

ILC intra-pulse Feedback

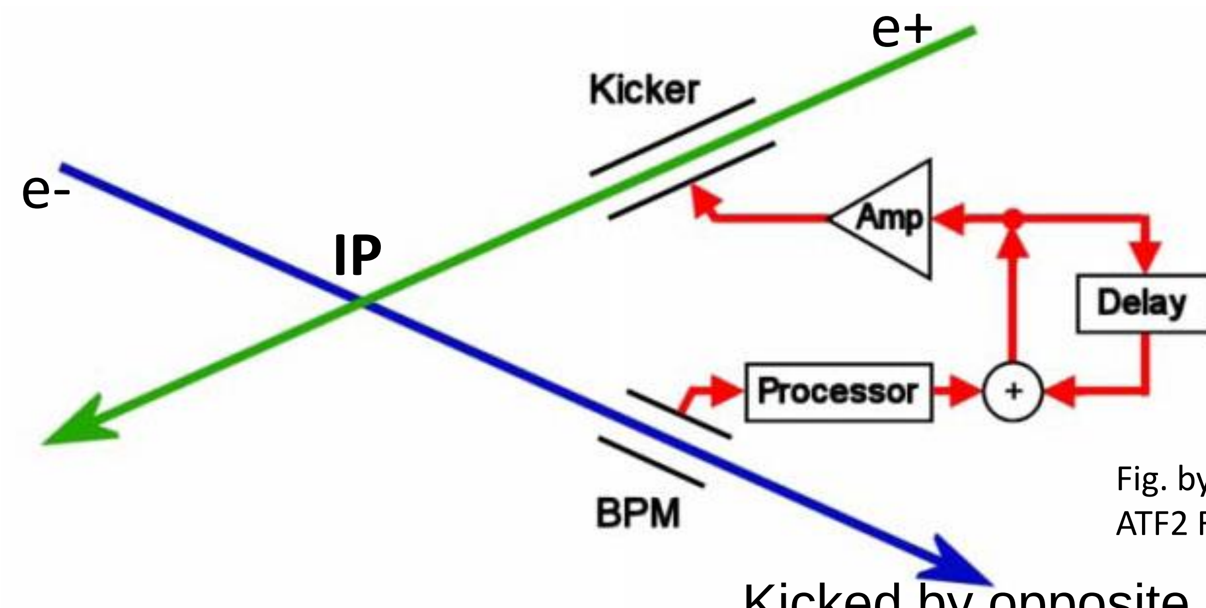


Fig. by P.Burrows
ATF2 Review 2013

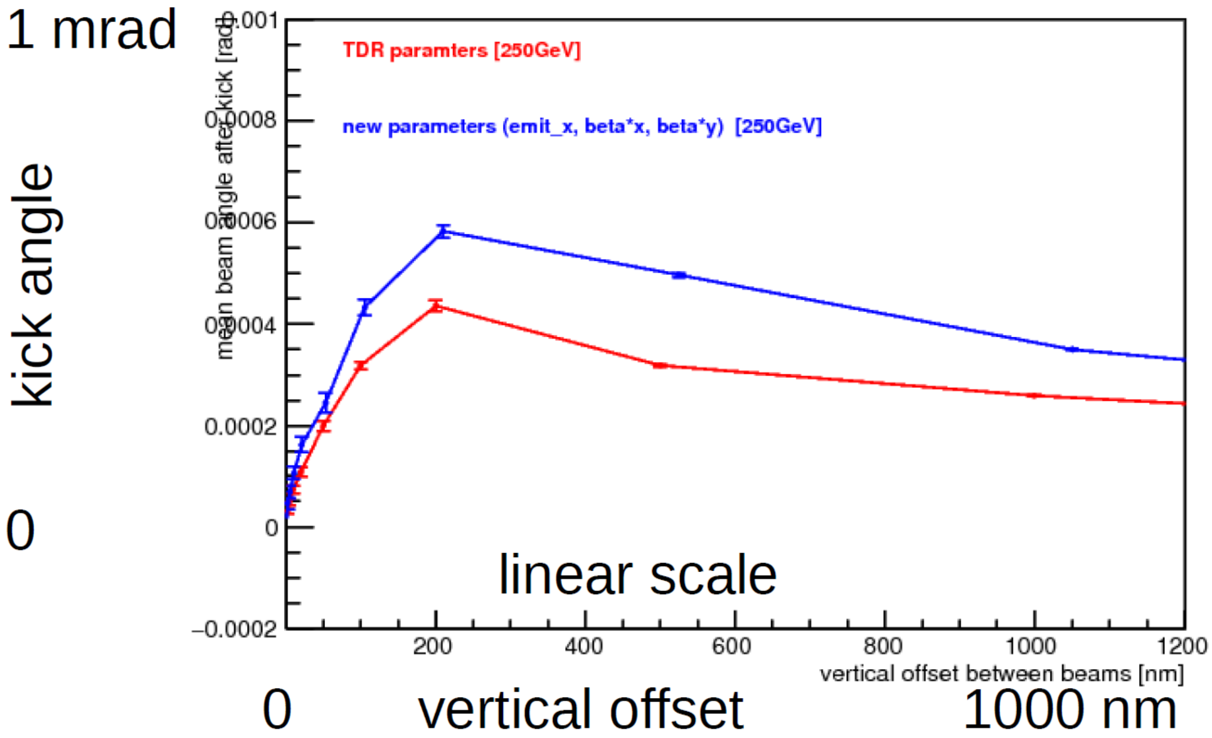
Kicked by opposite beam
Depending on offset

Required BPM resolution
~ (Kick angle at tolerated offset) x Distance
> 10 um for offset < 0.5 nm

BPM resolution is not an issue

Kick angle vs. offset

- Does not change much from TDR



Monotonical up to 200 nm offset
1 nm offset → >20 micro-radian kick

From slide D. Jean, MDI-KEK Meeting 2017, modified

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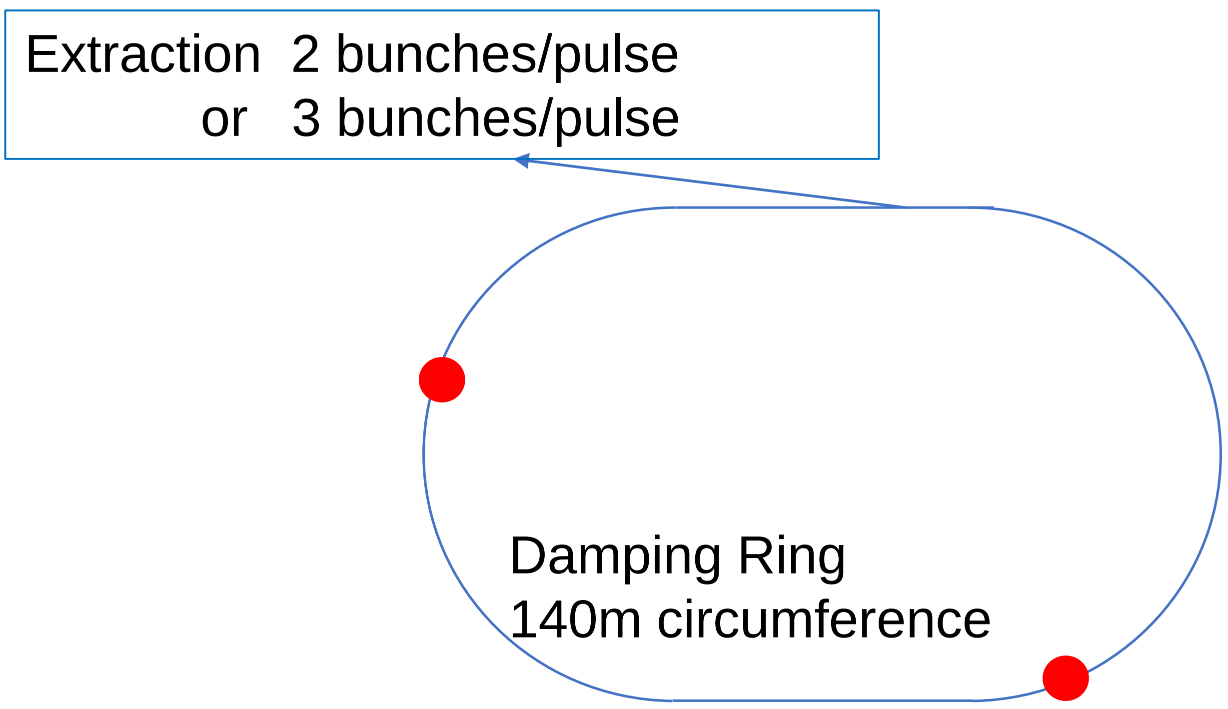
Intra Pulse Feedback test at ATF2 (FONT)

ILC like beam in ATF2:

2 bunches/pulse or 3 bunches/pulse

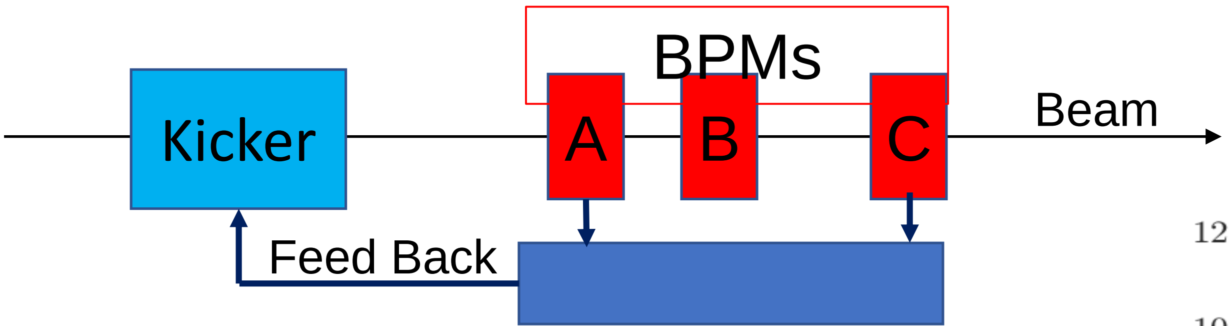
Spacing 150 ns ~ 300 ns



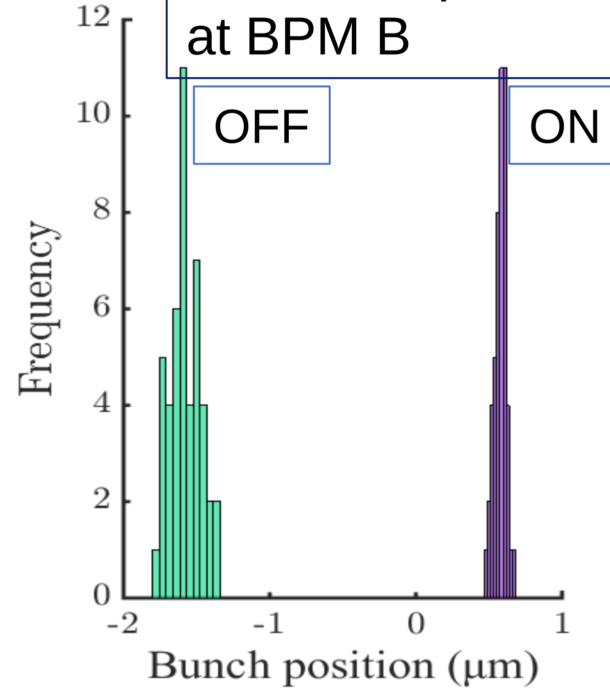
FONT at ATF2

Fast Feedback demonstrated

Example: BPM A and C used to stabilize beam at BPM B



Distribution of Measured position at BPM B



Measure Bunch 1 position and Feedback to Bunch 2:

Feedback OFF: jitter ~ 96nm
Feedback ON: jitter ~ 41nm

Bunch Spacing 280 ns
Latency 235ns

R. Ramjiawan, et.al., IPAC2017
Also reported in this workshop

BPM resolution is dominant source of residual jitter

Summary

- New ECM 250 GeV designed for higher luminosity. (0.82 -> 1.35 ($\times 10^{34}/cm^2/s$))
  - Reduce horizontal emittance (half)

- Making small beam
  - Not more difficult than TDR250 design
  - Tested at ATF2 (almost identical design)
- Position stability
  - Tighter tolerance than TDR
  - Intra pulse feedback tested at ATF2