Desired optics developments for colliders, storage rings, final-focus systems & plasmas

February, 2017. Valencia

R. Tomás

E.D. Courant and H.S. Snyder 1957

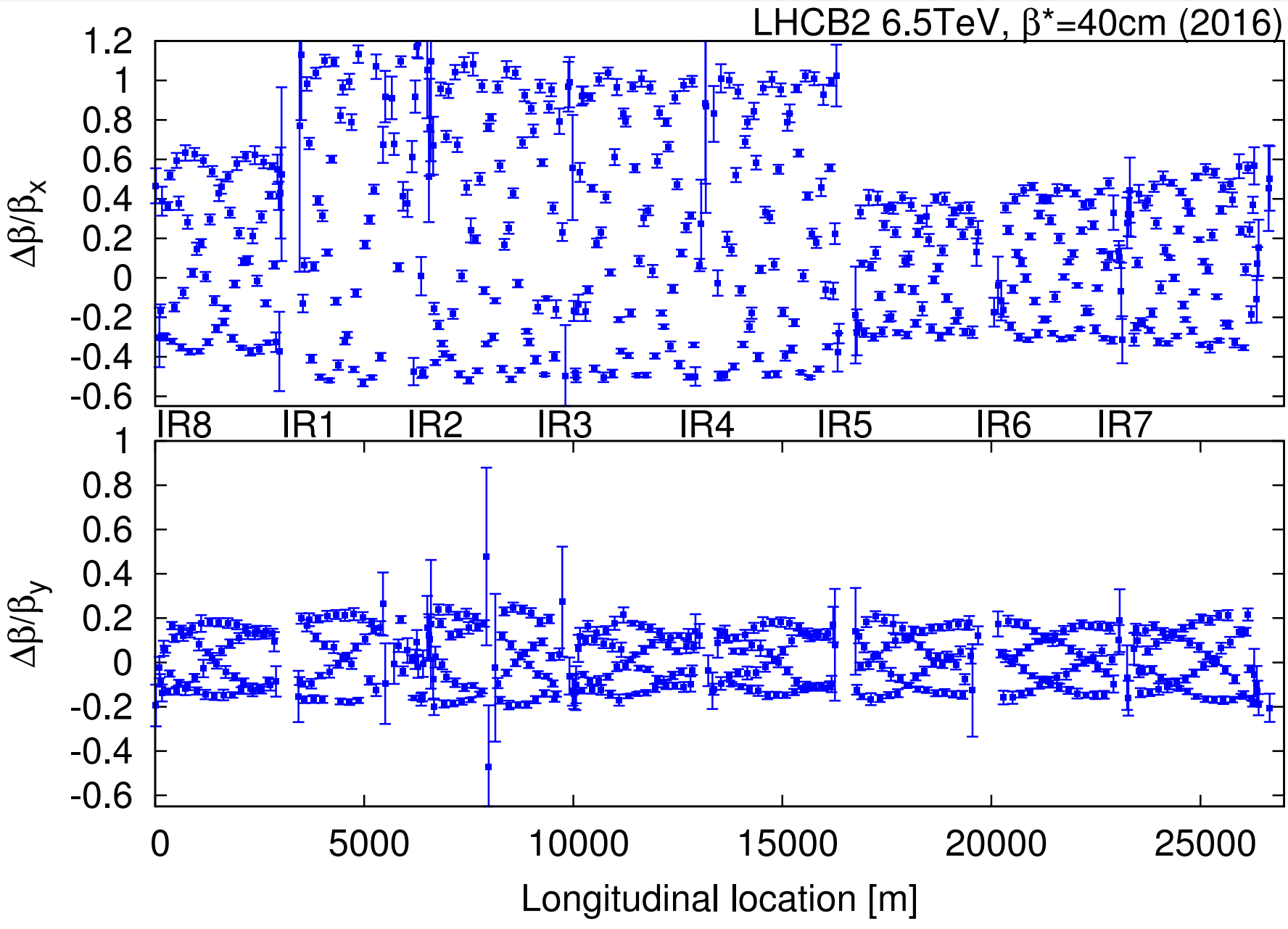
Theory of the Alternating-Gradient Synchrotron:

$$\left(\frac{\Delta\beta}{\beta}\right)_{\max} = 4.0\left(\frac{\Delta k}{k}\right)_{\rm rms}$$

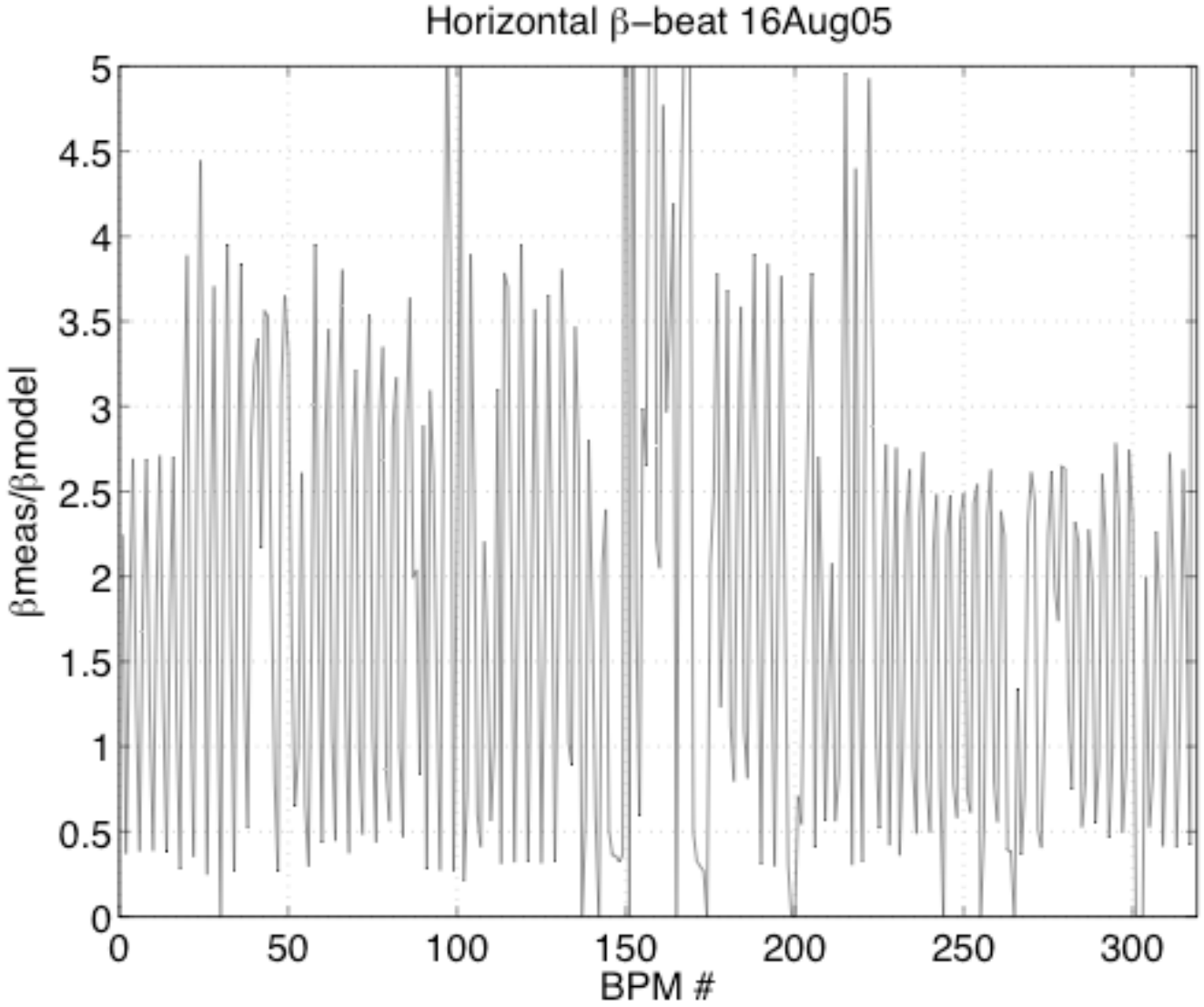
"Thus if the variation in k from magnet to magnet were 1% (...) we would have a β-**beating of 4%**. Any particular machine (...) would be unlikely to be worse by more than factor of 2."

$\rightarrow$ Expected β-beating below 8% for *any machine*

120% in LHC, commissioning 2016



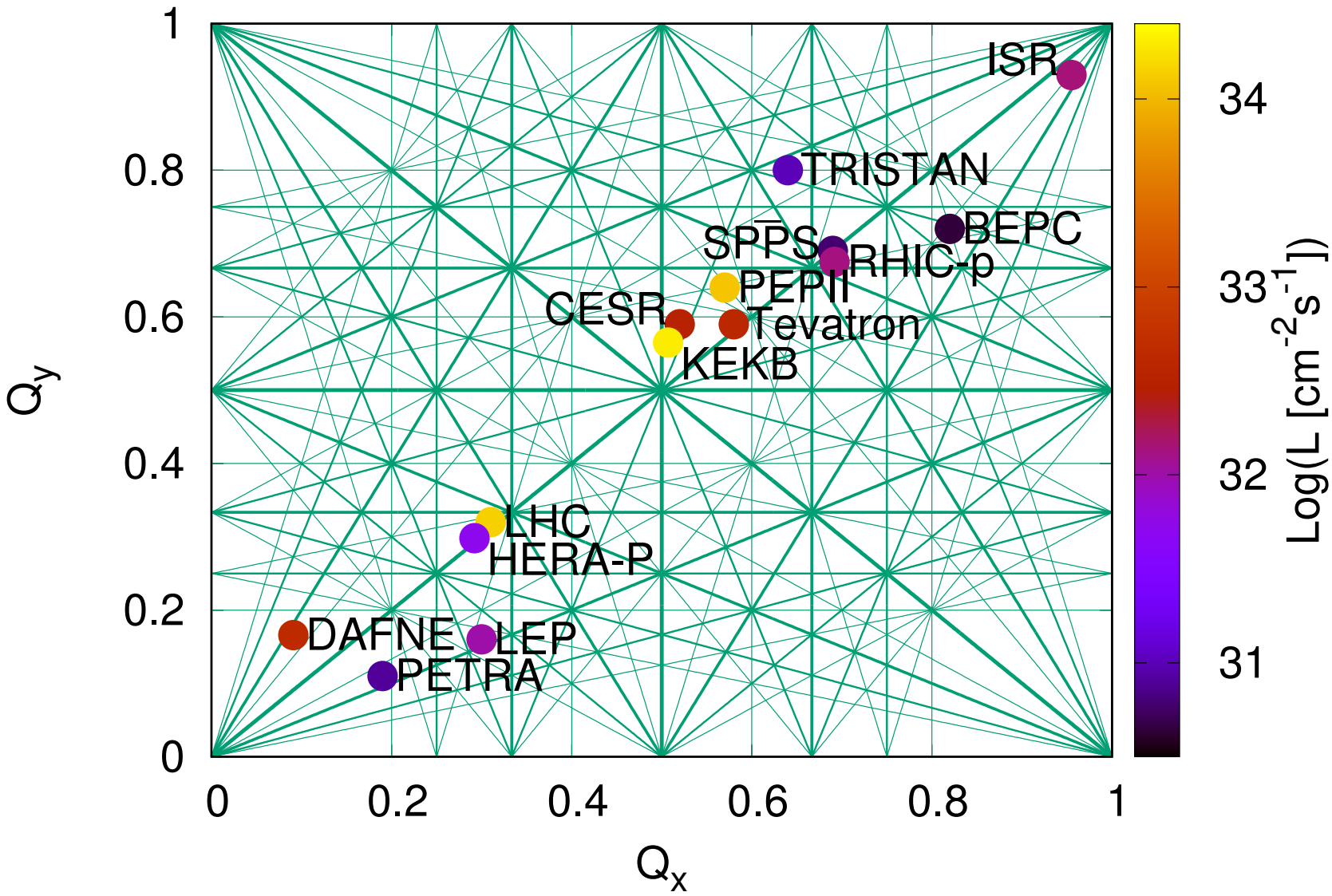
≈400% in PEP-II, commissioning 2005



G. Yocky,
SLAC-PUB-12523

Even $\Delta\beta/\beta \approx 700\%$ was reached when LER tune was pushed closer to the half integer

Colliders in the tune space

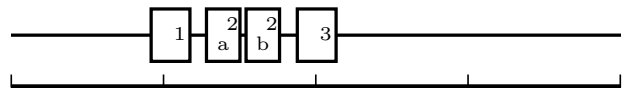
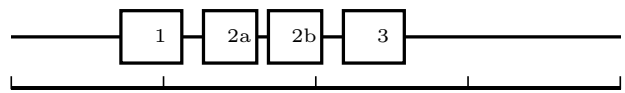
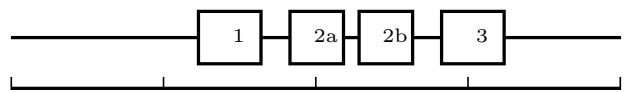
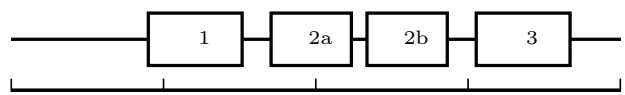


β^* in hadron colliders

	$\beta^*_{\parallel}$ [m]	$\beta^*_{\times}$ [m]
ISR	0.3	3
S$p\bar{p}$S	**0.15**	**0.6**
Hera-p	0.18	2.4
RHIC	0.50	
Tevatron	**0.28**	
LHC	0.4	
HL-LHC	0.15	

β^* in FCC-hh? 5 cm?

TABLE VI. Summary of the presented triplet options. The shielding thickness defines the minimum β^*. The β^* used for FLUKA studies was set to the "ultimate" goal where possible and mainly impacts the dose via the crossing angle.

	L^* [m]	Shielding thickness [mm]	Minimum β^* [a] [m]	β^* for FLUKA study [m]	Crossing angle [μrad]	Dose for 17 500 fb^{-1} [MGy]
	46	0	0.8	0.8	86 (horizontal)	14000
	36	15	0.2	0.3	140 (vertical)	250 175[b] 120[c]
	61	15	0.2	0.3	170 (vertical)	215
	45	15 55	0.05[d] 0.15	0.3	178 (vertical)	145 15

0 0 100 1 0 200

0 0 100 1 0 200

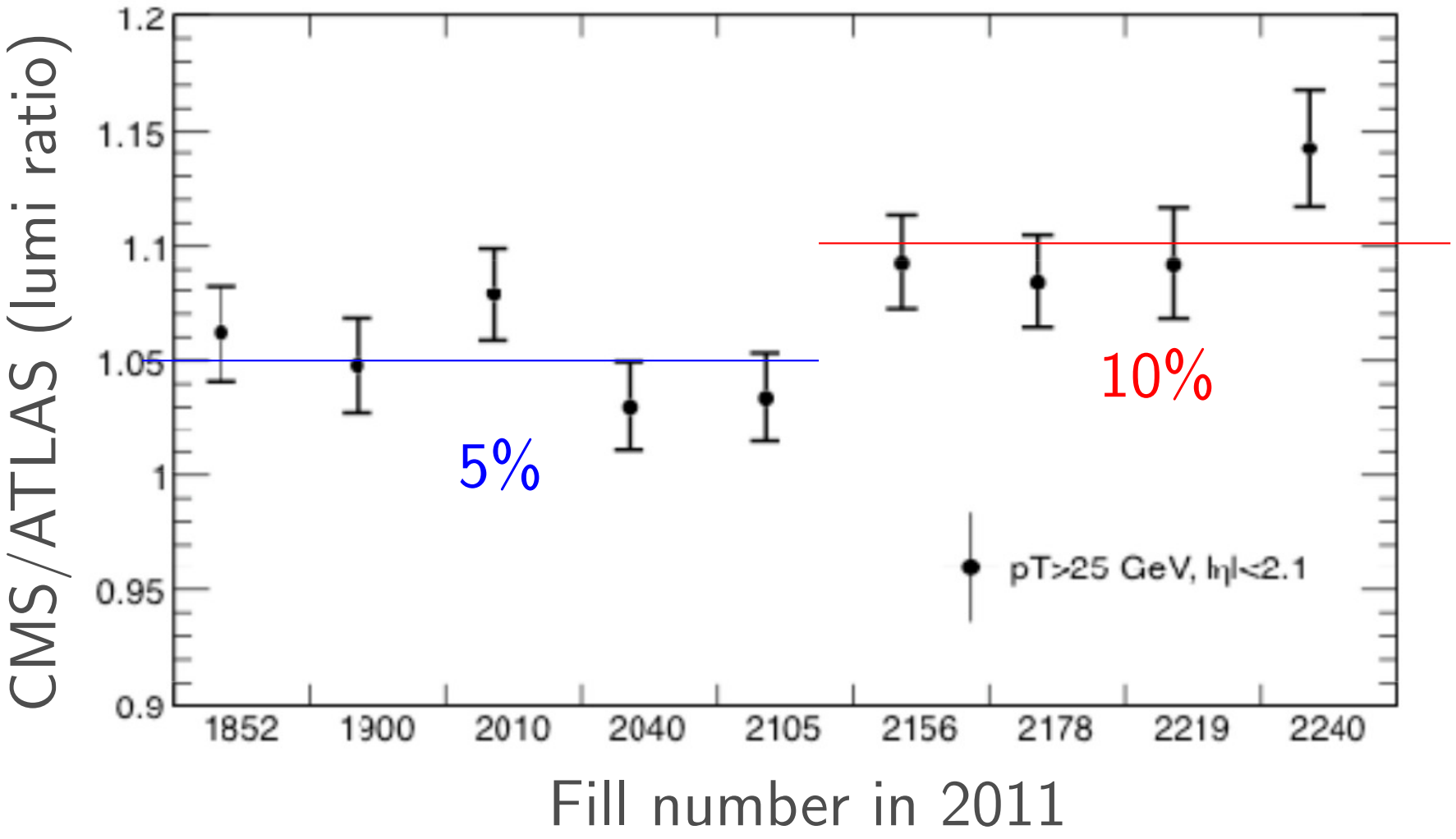
0 0 100 1 0 200

0 0 100 1 0 200

Distance from P [m]

R. Martin et al, submitted to Phys. Rev. Accel. & Beams

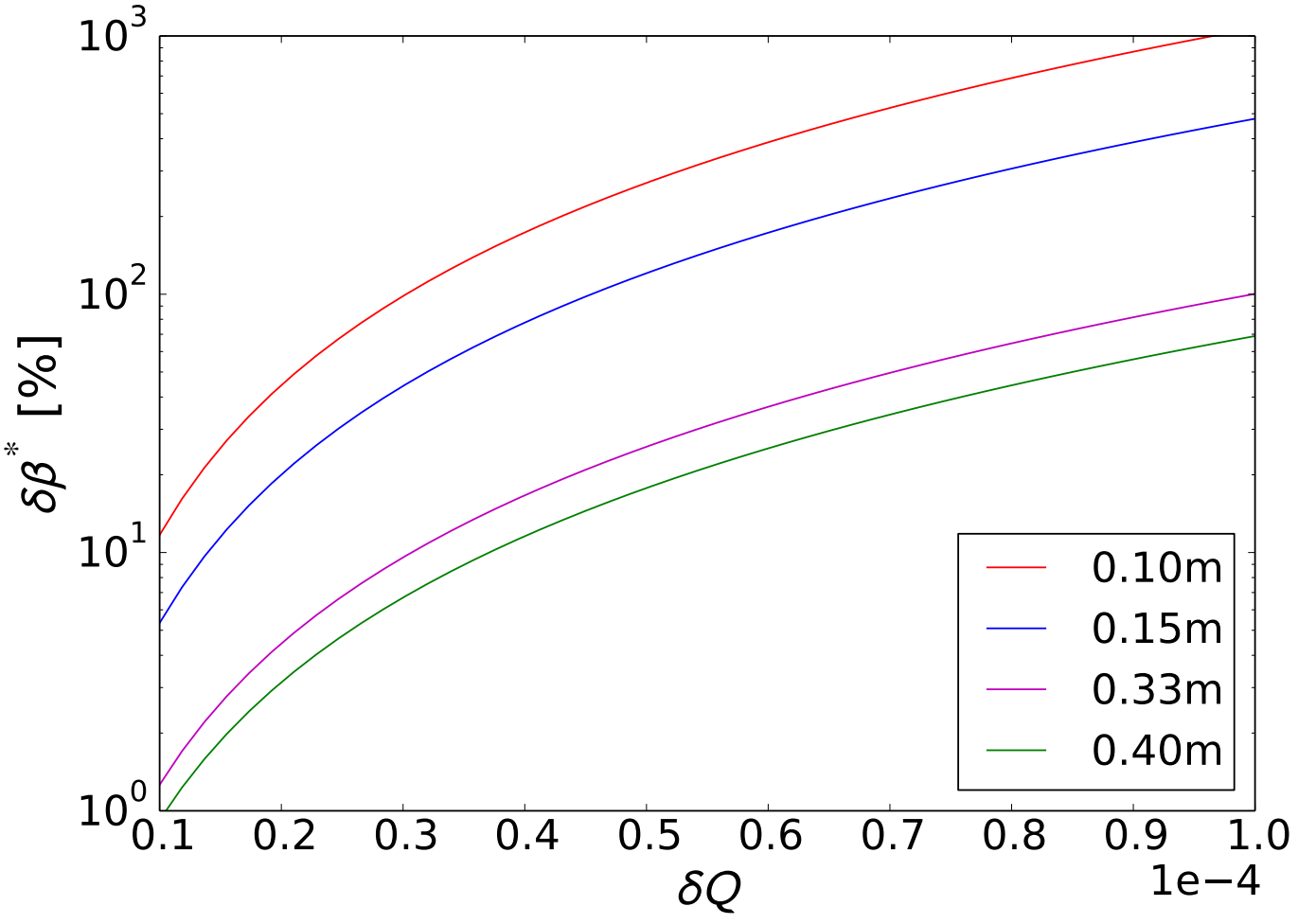
Luminosity imbalance CMS/ATLAS



ATLAS was not happy to get lower luminosity (due to β-beating). Now 5% imbalance is too large.

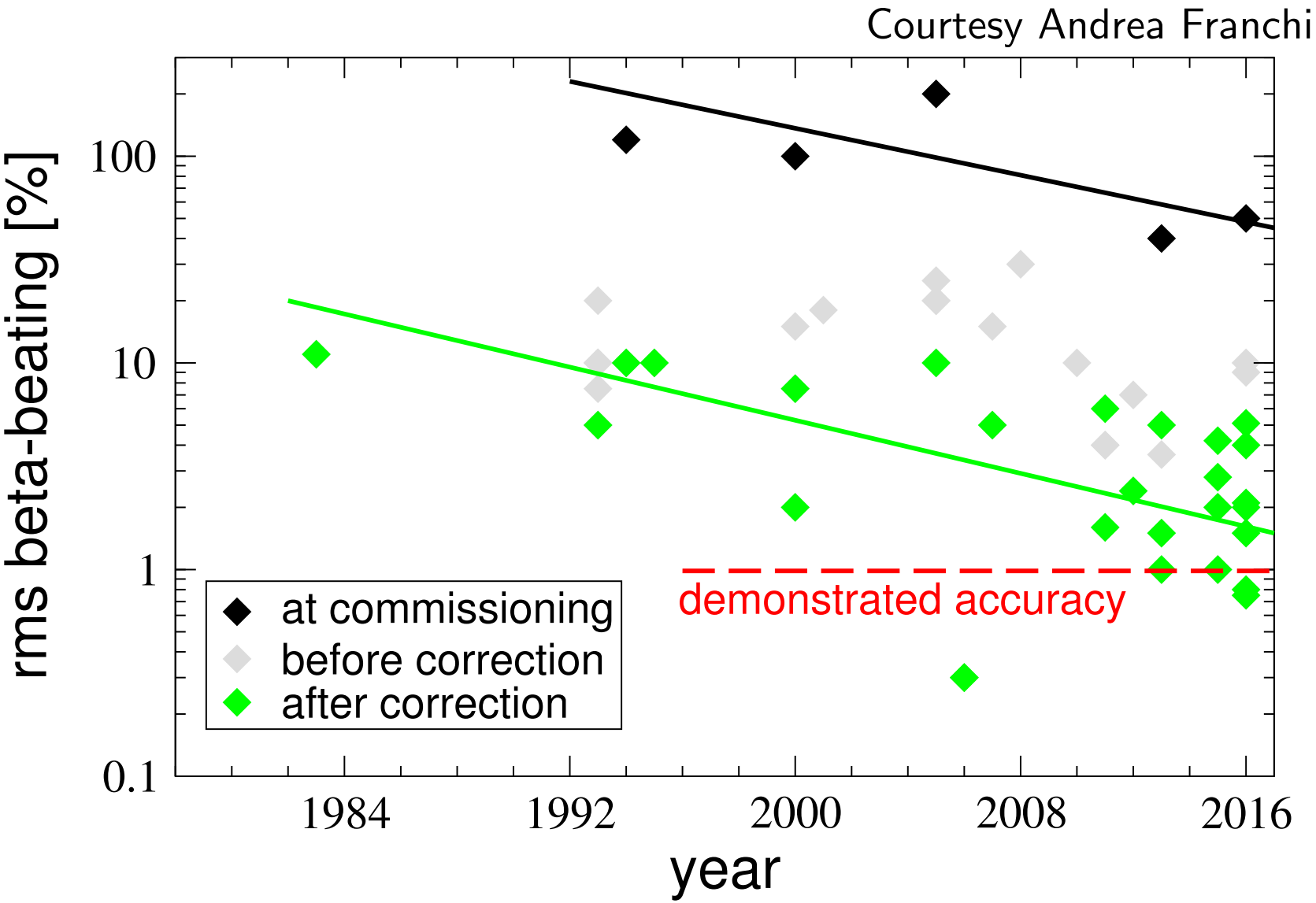
HL-LHC: β^* accuracy Vs tune resolution

F. Carlier et al, Phys. Rev. Accel. Beams, **20**, 011005 (2017)



1% accuracy challenging for β^* below 0.2 m.

β-beating versus time



Comparing β measurement techniques I

ALBA

Method vs. Nominal model	Horizontal	Vertical
N-BPM (phase)	1.4	2.0
From amplitude	2.0	2.7
LOCO	1.1	1.6
Method 1 vs. Method 2		
N-BPM (phase) vs. LOCO	1.0	1.3
N-BPM (phase) vs. amplitude	1.7	1.9
From amplitude vs. LOCO	1.4	1.7
***N**-BPM using LOCO model*		
N-BPM (phase) vs. LOCO	0.8	1.1

A. Langner et al,
Phys. Rev. Accel. Beams **19**, 092803

ESRF

Relative difference of βs	rms_x [‰]	rms_y [‰]
N-BPM vs Amplitude	17	12
Amplitude vs ORM model	20	13
N-BPM vs ORM model	11	9

L. Malina et al,
to be published

Comparing β measurement techniques II

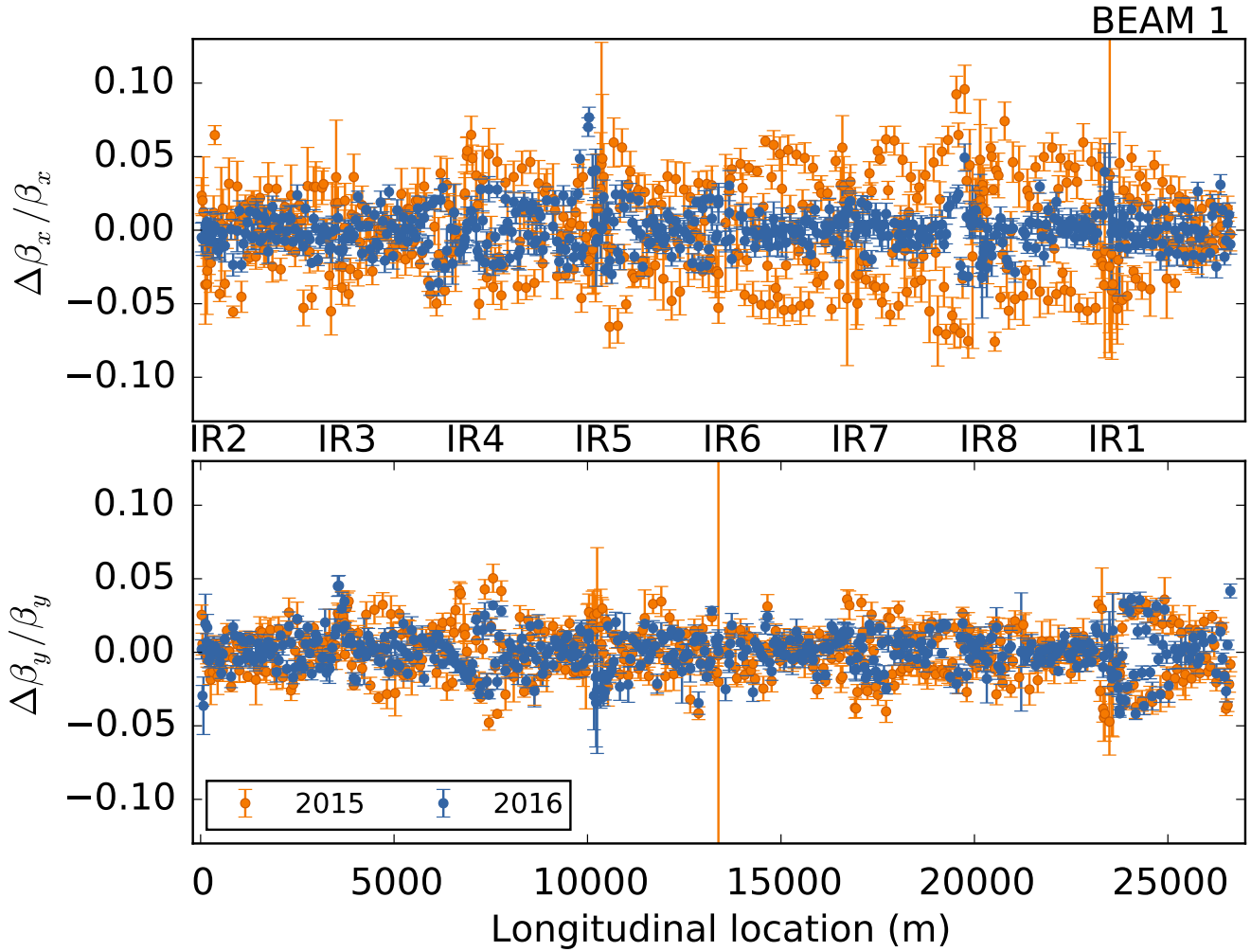
NSLS-II

Algorithm	$\Delta\beta_x/\beta_x$ %	$\Delta\beta_y/\beta_y$ %
no corr.	8	10
LOCO	2.1	1.4
phase only[1]	2.3	1.8
phase&amp.[1]	2.8	1.7
ICA	2.6	1.6
MIA	2.8	1.7
DTBLOC	3.0	1.9

V. Smaluk et al, IPAC 2016

Techniques agree to the $\approx$1% level

LHC optics correction

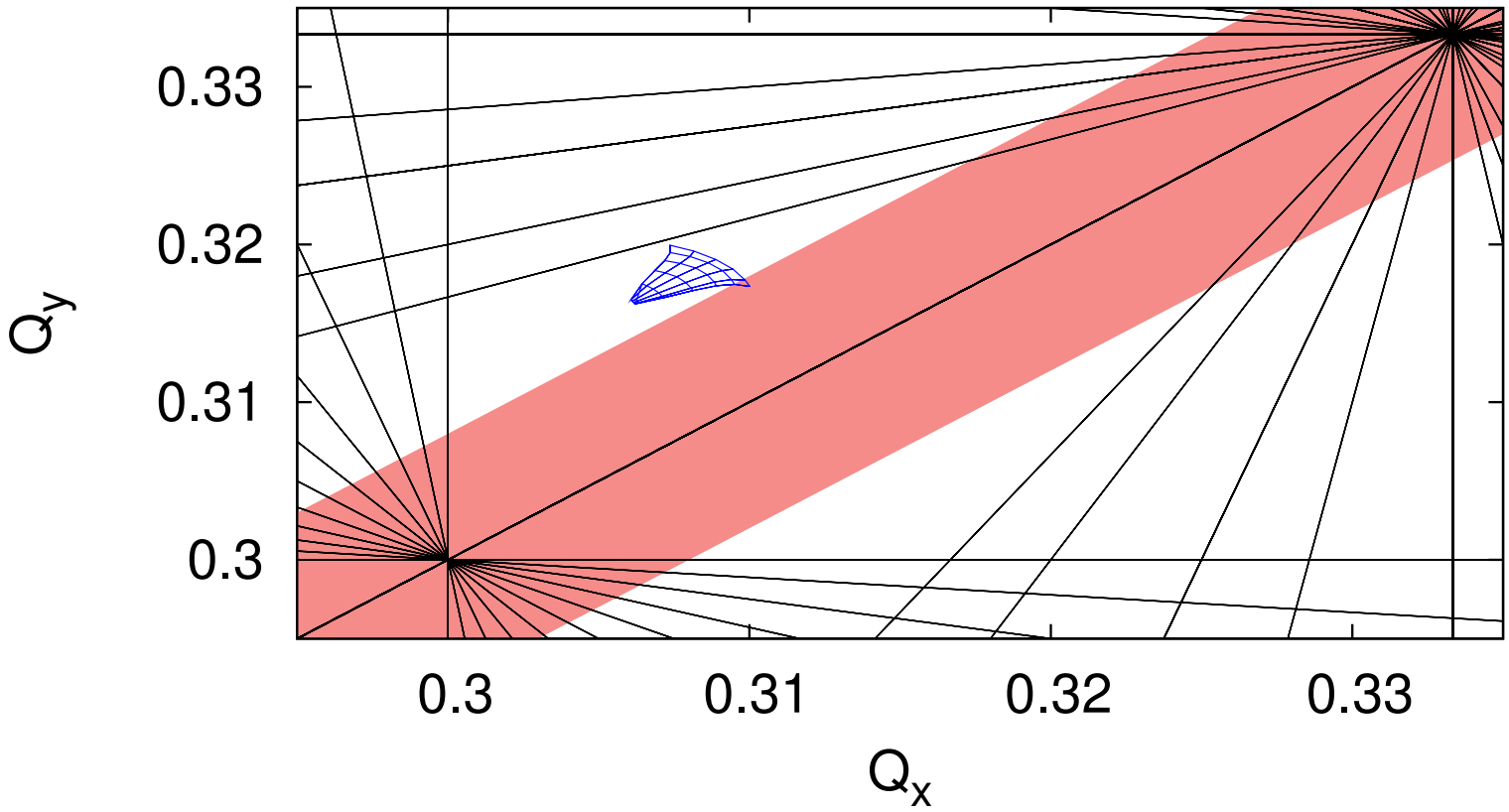


T. Persson et al, submitted to Phys. Rev. Accel. Beams

LHC has reached below 2% rms β-beating

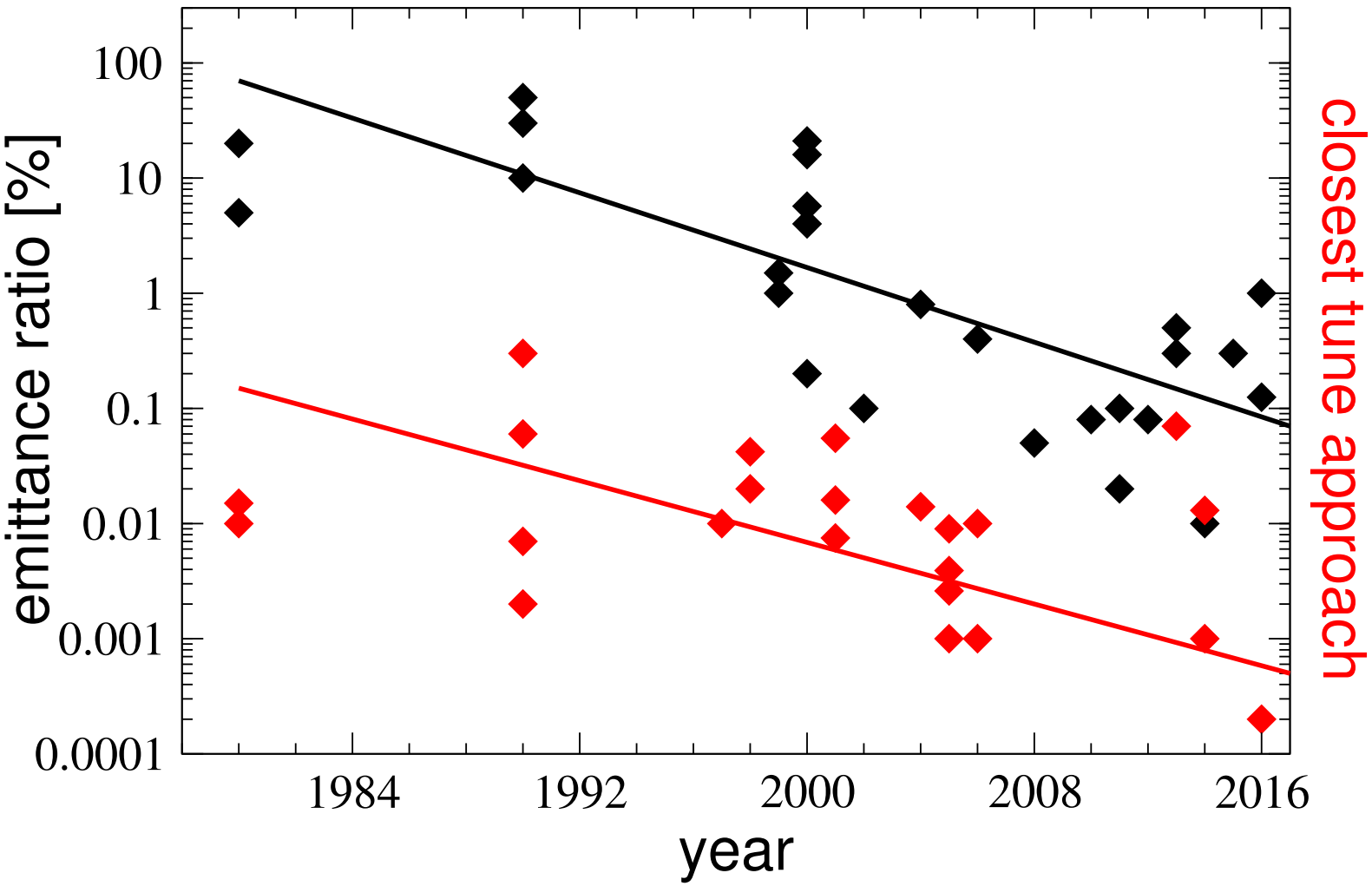
ΔQ_{min} limits the resonance-free space

LHC beam-beam tune footprint and a hypothetical large coupling:



Coupling control versus time

Courtesy Andrea Franchi

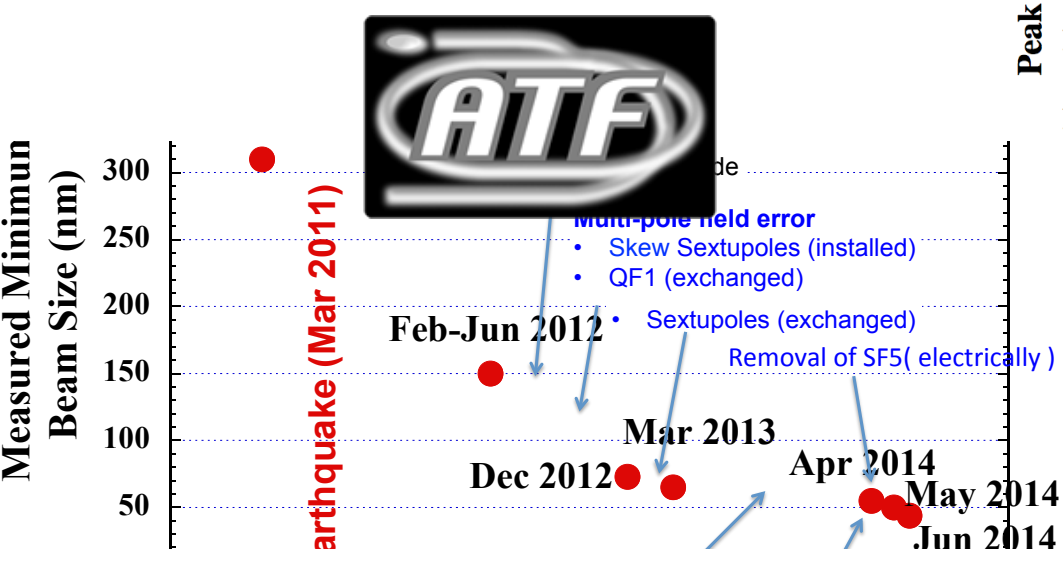


Accuracy limits in coupling still to be probed.

Three world records via passive corrs.

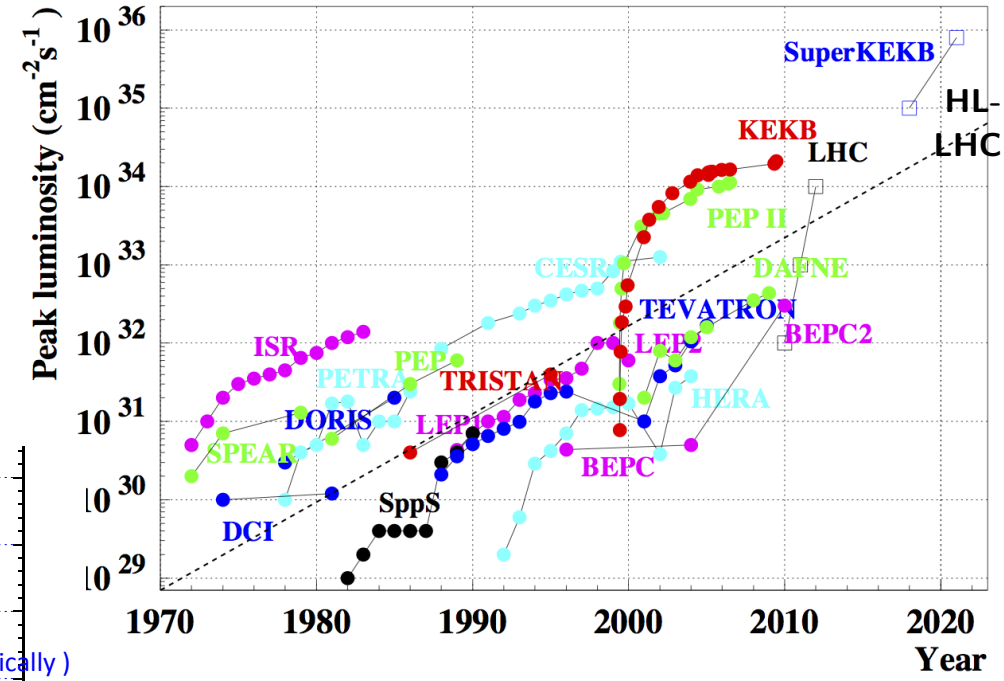
$\epsilon_y = 0.9 \pm 0.4$ pm

via random walk optimization



$\sigma_y = 44 \pm 3$ nm

via scanning orthogonal knobs



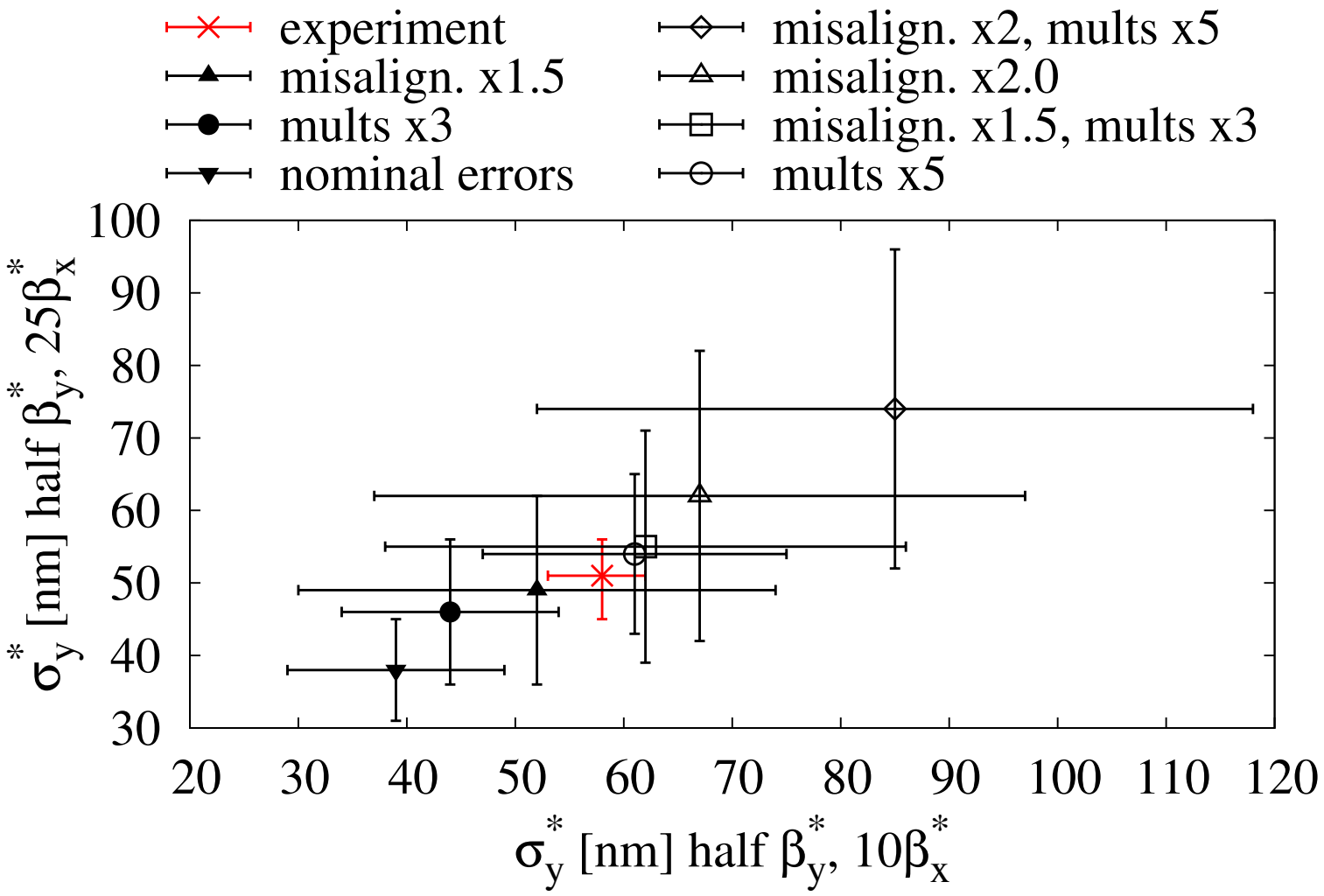
$L = 2.1 \times 10^{34}$ cm^{-2}s^{-1}

Luminosity optimized via downhill Simplex

FFS of future lepton colliders

	L^*[m]	$\beta_y^*[\mu m]$	$\xi_y \sim (L^*/\beta_y^*)$
CLIC	3.5	70	50000
ILC	4.5	480	9000
ATF2	1.0	100	10000
ATF2 Ultra-low	1.0	**25**	40000
SuperKEKB LER	0.9	270	3460
FCC-ee	2	1000	2000

ATF2 finding: Something is missing



M. Patecki et al, Phys. Rev. Accel. Beams **19**, 101001

→Predictions are too optimistic

→Was it the same in SLC and FFTB?

Conclusion for Linear Colliders

$$\mathcal{L} \propto H_D \frac{n_\gamma^{\frac{3}{2}}}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\epsilon_y \beta_y}} \frac{R+1}{R} \frac{\eta P_{wall}}{mc^2}$$

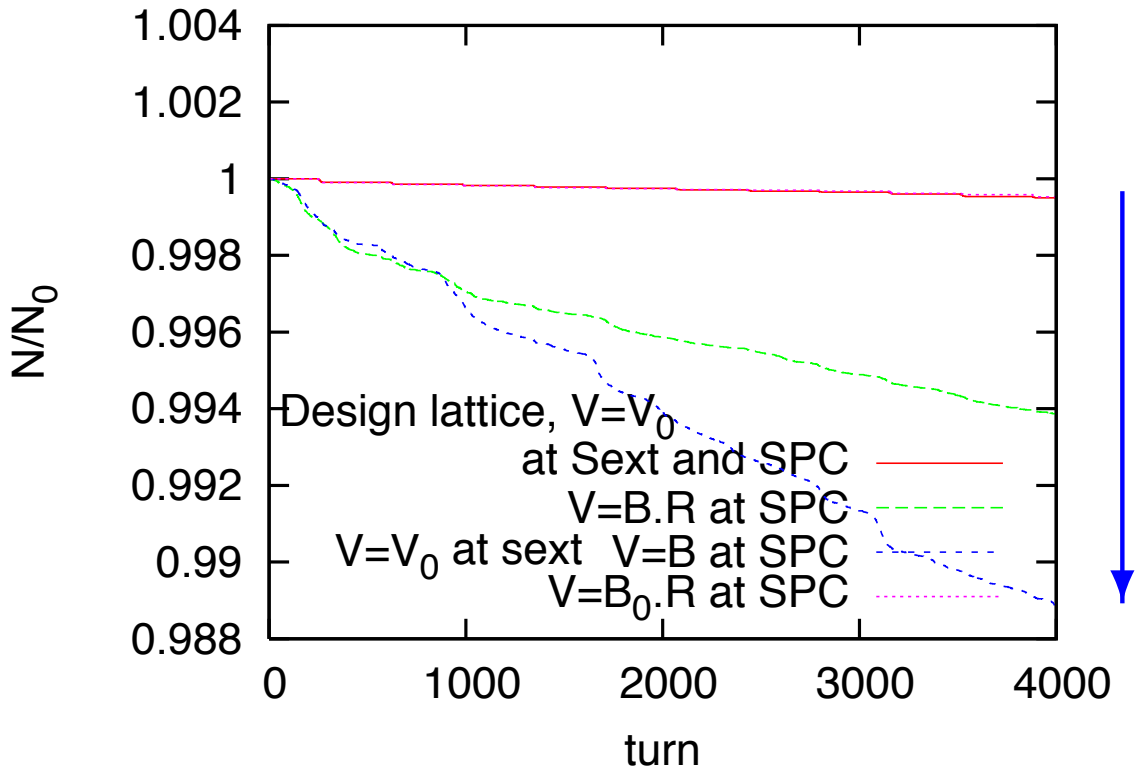
Reduce the vertical betafunction and emittance as much as possible

Plasma-based linacs might lead to larger energy spreads
⇒ R&D required to get to same beamsizes as with conventional technology
⇒ Or reduce energy spread and take a hit in efficiency

- Smaller emittance need better sources
  - e.g. undulator-based damping?
  - But makes emittance preservation in linac even more challenging

- Smaller betafunction could be achieved using novel beam delivery system design
  - Plasma lenses?
  - Crystals?
  - Electron/proton lenses?
  - RF quadrupoles to correct correlated energy spread?

Space charge simulations with measured optics in J-PARC, K. Ohmi et al., IPAC 2013

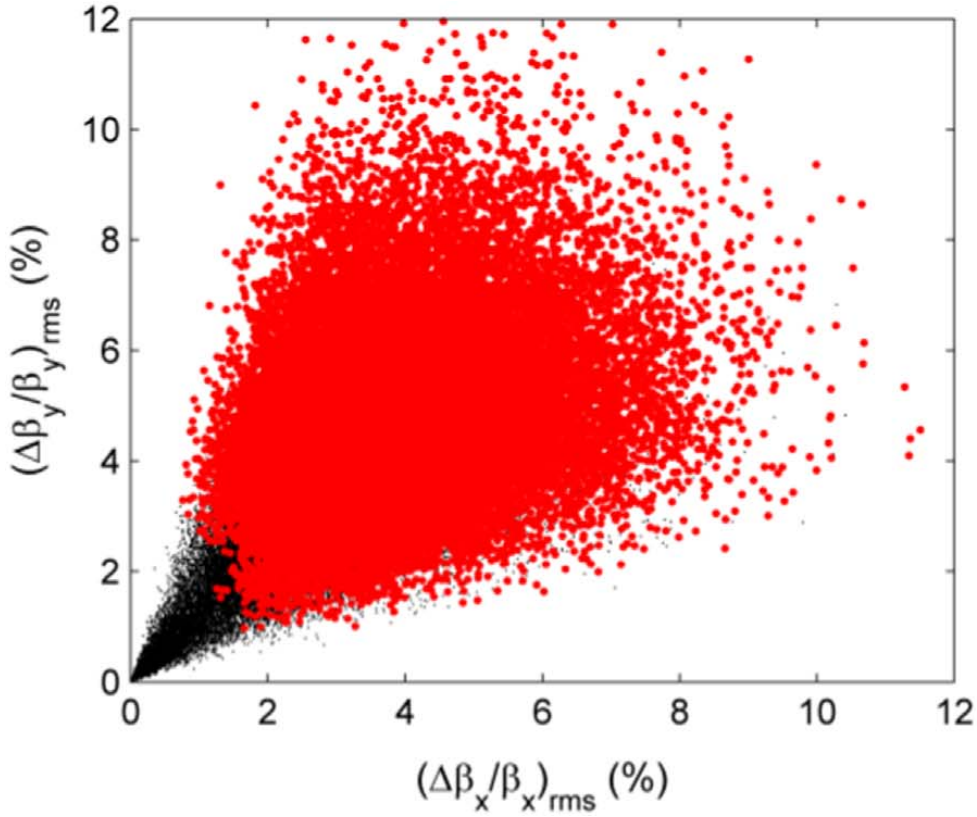


Beam loss due to introducing measured $\frac{\Delta\beta}{\beta}$=5% in simulations

K. Ohmi et al.: "Estimation of errors of accelerator elements is inevitable to study beam loss."

Momentum acceptance Vs β-beating in diffraction limited light sources

High Energy Photon Source Y. Jiao, Z. Duan, NIM-A **841** 2017



MA $>$ 3.5%

MA $<$ 3.5%

In HEPS rms β-beating should be below 1.5%

Summary & outlook

- ★ Will hadron colliders' β^* reach the cm level?
- ★ Linear colliders' FFS not fully understood
  - Plasma will require even harder FFS
  - Novel FFS designs?
  - Need more R&D
- ★ β-beating after correction has reached the measurement resolution of $\approx$1%.
  - Luminosity imbalance, Diffraction limited SRs and Space charge limited rings would benefit from sub-% optics control
  - New faster and more accurate techniques are needed: AC ORM? AC dipole in light sources?
- ★ Transverse coupling accuracy limits still to be probed