# FCC-ee accelerator design, monochromatization and other progress

Frank Zimmermann

FCC-ee Physics Meeting

27 June 2016

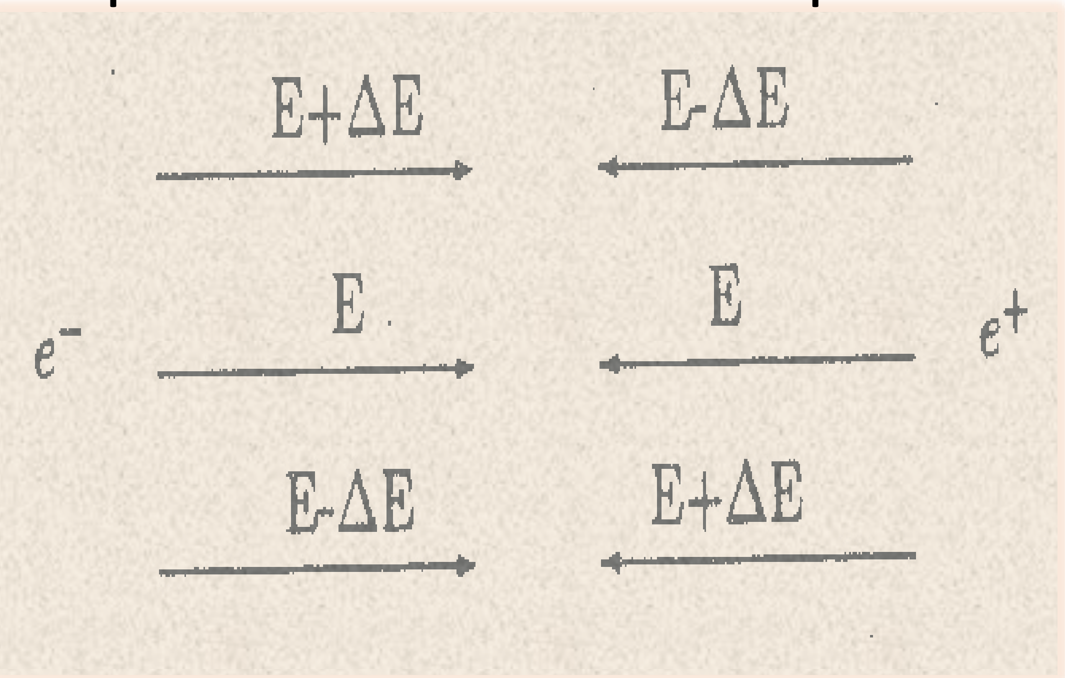
# monochromatization - history

- A. Renieri, “Possibility of Achieving Very High Energy Resolution in $e^+e^-$ Storage Rings”, Frascati, Preprint INF/75/6(R) (**1975**).
- A.A. Avdienko et al., “The Project of Modernization of the **VEPP-4 Storage Ring** for Monochromatic Experiments in the Energy Range of Ψ and Υ Mesons”, Proc. 12th Intern. Conf. High Energy Accelerators, Fermilab, **1983**, p. 186.
- K. Wille and A.W. Chao, “Investigation of a Monochromator Scheme for **SPEAR**”, SLAC/AP-32 (**1984**).
- M. Jowett, “Feasibility of a Monochromator Scheme in **LEP**”, CERN LEP Note 544, September (**1985**).
- Yu.I. Alexahin, A. Dubrovin, A.A. Zholents, “Proposal on a **Tau-Charm Factory** with Monochromatization”, Proc. 2nd European Particle Accelerator Conference, Nice, France, 12–16 June **1990**, pp. 398
- A. Zholents, “Polarized J/Ψ Mesons at a **Tau-Charm Factory** with a Monochromator Scheme”, CERN SL/97-27, June (**1992**).
- A. Faus-Golfe and J. Le Duff, “Versatile DBA and TBA Lattices for a **Tau-Charm Factory** with and without Beam Monochromatization”, Nucl. Instr. Methods A 372 (**1996**) 6–18.

several studies, but
never used in any real machine;
new feature for FCC: beamstrahlung

# mono-chromatization for direct Higgs production $e^+e^- \rightarrow H$ at FCC-ee

concept: introduce antisymmetric dispersion at the collision point




rel. collision energy spread for standard conditions

$$\left(\frac{\sigma_W}{W}\right)_{\text{standard}} = \frac{\sigma_\delta}{\sqrt{2}}$$

rel. collision energy spread w. monochromatization

$$\left(\frac{\sigma_W}{W}\right)_{\text{m.c.}} = \frac{\sigma_\delta}{\sqrt{2}}\frac{1}{\lambda}$$

monochromatization factor

$$\lambda = \sqrt{\frac{D_x^{*2}\sigma_\delta^2}{\epsilon_x\beta_x^*} + 1}$$

in LEP(-1) bunch train operation created unwanted antisymmetric vertical dispersion (G. Wilkinson, Rome), $\varepsilon_y$~400 pm, $\beta_y$*=50 mm, $\sigma_\delta$=0.07%, $D_y$*~2 mm:→ λ~1.05

# effect of beamstrahlung (BS) on transverse emittance

BS : synchrotron radiation emitted during collision

- blow up of energy spread and bunch length
- in particular: $D_x^* \neq 0 \rightarrow \Delta\varepsilon > 0$

two coupled nonlinear equations determine equilibrium emittance and energy spread:

$$\epsilon_{x,\mathrm{tot}} = \epsilon_{x,\mathrm{SR}} + \frac{\tau_x n_{\mathrm{IP}}}{4T_{\mathrm{rev}}} \{ n_\gamma < u^2 > \} \mathcal{H}_x^*$$

**nonlinear function of $\sigma_{\delta,\mathrm{tot}}$ and $\varepsilon_{x,\mathrm{tot}}$**

$$\sigma_{\delta,\mathrm{tot}}^2 = \sigma_{\delta,\mathrm{SR}}^2 + \frac{n_{\mathrm{IP}} \tau_{E,\mathrm{SR}}}{4T_{\mathrm{rev}}} \{ n_\gamma < u^2 > \}$$

$$\sigma_{z,\mathrm{tot}} = \frac{\alpha_C C}{2\pi Q_s} \sigma_{\delta,\mathrm{tot}}$$

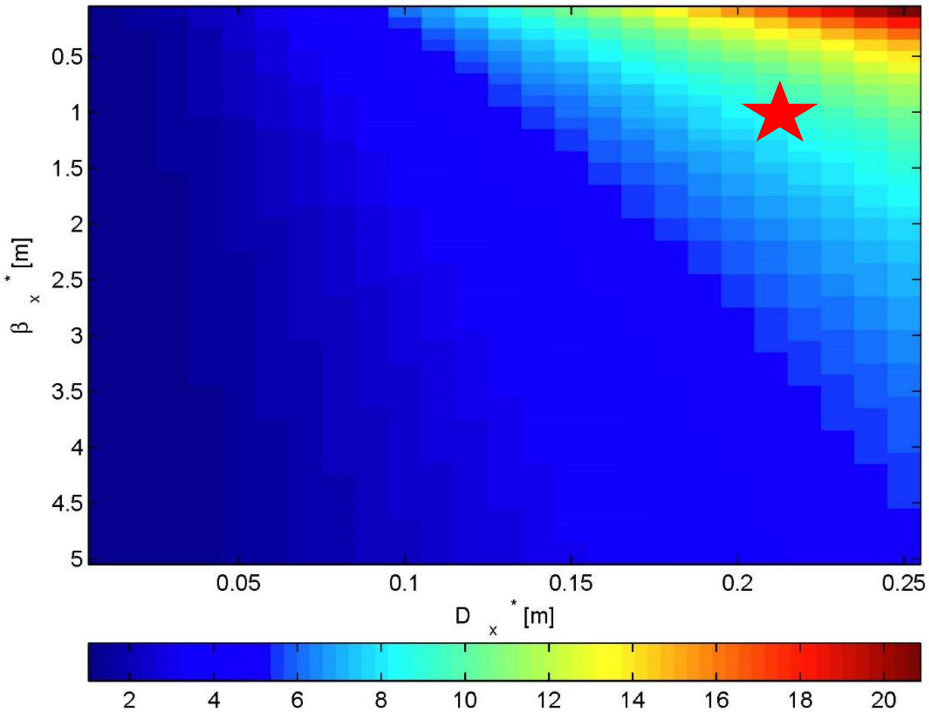
$$n_\gamma \langle u^2 \rangle \propto \frac{N_b^3 \gamma^2}{\sigma_z^2 \sigma_x^3}$$

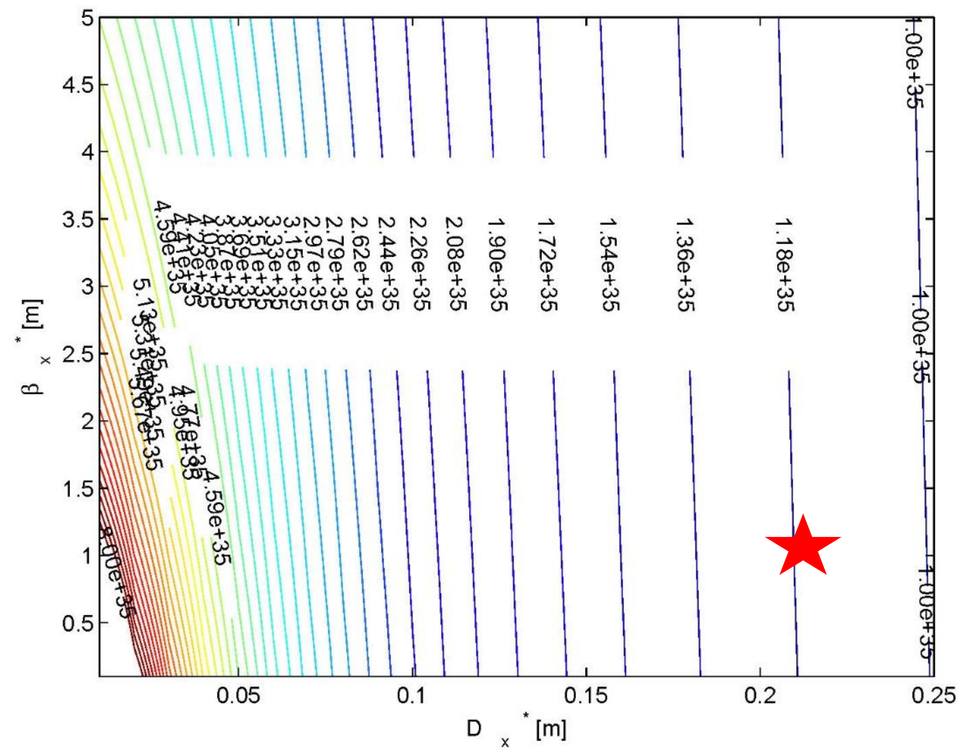
M.A. Valdivia Garcia
F. Zimmermann

# baseline monochromatization

width of SM Higgs 4-5 MeV → requires monochromatization factor λ ≥ 10; optimizing IP & beam parameters; 2D scans in $D_x^*$ - $\beta_x^*$ space: baseline $N_b$=3.3x$10^{10}$, $n_b$=25760, $\beta_y^*$=2 mm

M.A. Valdivia Garcia




★ : **λ=9.2, *L*=$10^{35}$ cm$^{-2}$s$^{-1}$**

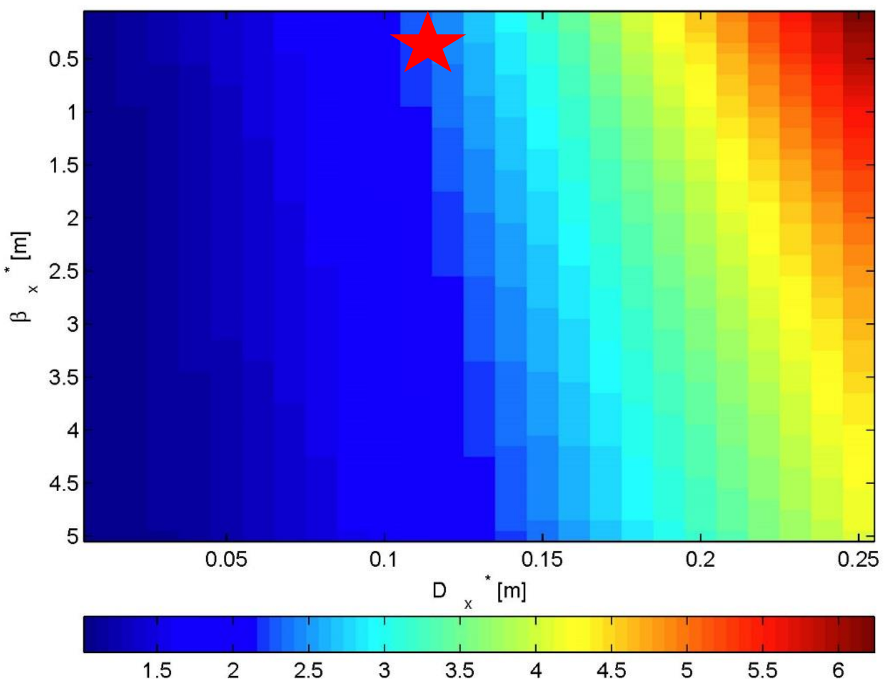
monochromtization factor lambda

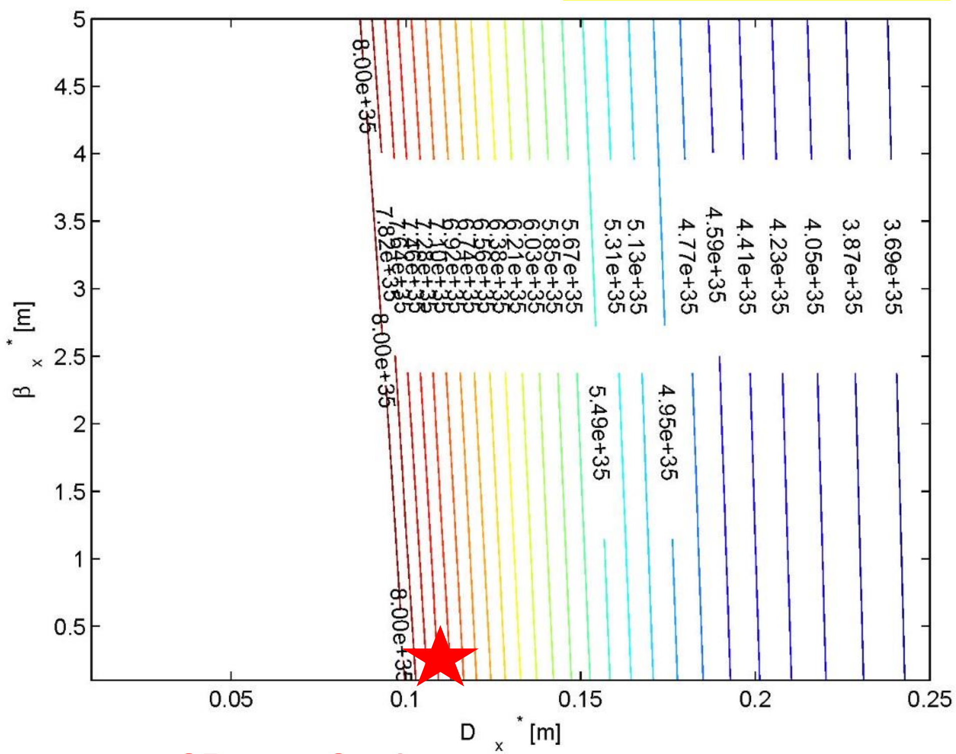
luminosity contours

# failed "pushed" monochromatization

pushed monochromatization: $N_b$=8.5x10$^{10}$, $n_b$=10000, $\beta_y^*$=1 mm

M.A. Valdivia Garcia




★ : $\lambda$=2.3, $L$=7.5x10$^{35}$ cm$^{-2}$s$^{-1}$

monochromtization factor lambda

luminosity contours

# parameter table – part 1

| $E_e$ [GeV] | 45.6 | 62.5 | 62.5 | 62.5 | 80 |
|---|---|---|---|---|---|
| scheme | CW | h.-o. | m.c. basel. | m.c. push'd | CW |
| $I_b$ [mA] | 1450 | 410 | 410 | 410 | 152 |
| $N_b$ [$10^{10}$] | 0.7 | 3.3 | 3.3 | 8.5 | 6.0 |
| $n_b$ | 91500 | 80960 | 25760 | 10000 | 5260 |
| $\beta_x^*$ [m] | 1 | 1.0 | 1.0 | 0.25 | 1 |
| $\beta_y^*$ [mm] | 2 | 2 | 2 | 1 | 2 |
| $D_x^*$ [m] | 0 | 0 | 0.22 | 0.11 | 0 |
| $\epsilon_{x,\mathrm{SR}}$ [nm] | 0.09 | 0.17 | 0.17 | 0.17 | 0.26 |
| $\epsilon_{x,\mathrm{tot}}$ [nm] | 0.09 | 0.17 | 0.21 | 4.16 | 0.26 |
| $\epsilon_{y,\mathrm{SR}}$ [pm] | 1 | 1 | 1 | 1 | 1 |
| $\sigma_{x,\mathrm{SR}}$ [$\mu$m] | 9.5 | 9.2 | 132 | 66 | 16 |
| $\sigma_{x,\mathrm{tot}}$ [$\mu$m] | 9.5 | 9.2 | 144 | 323 | 16 |
| $\sigma_y$ [nm] | 45 | 45 | 45 | 32 | 45 |

M.A. Valdivia Garcia,
A. Faus-Golfe,
F. Zimmermann,
IPAC'16

# parameter table – part 2

| $E_e$ [GeV] | 45.6 | 62.5 | 62.5 | 62.5 | 80 |
|---|---|---|---|---|---|
| scheme | CW | h.-o. | m.c. basel. | m.c. push'd | CW |
| $\sigma_{z,\mathrm{SR}}$ [mm] | 1.6 | 1.8 | 1.8 | 1.8 | 2.0 |
| $\sigma_{z,\mathrm{tot}}$ [mm] | 3.8 | 1.8 | 1.8 | 1.8 | 3.1 |
| $\sigma_{\delta,\mathrm{SR}}$ [%] | 0.04 | 0.06 | 0.06 | 0.06 | 0.07 |
| $\sigma_{\delta,\mathrm{tot}}$ [%] | 0.09 | 0.06 | 0.06 | 0.06 | 0.10 |
| $L$ [$10^{35}$ cm$^{-2}$s$^{-1}$] | 9.0 | 2.2 | 1.0 | 7.5 | 1.9 |
| $\theta_c$ [mrad] | 30 | 0 | 0 | 0 | 30 |
| $\xi_x$ | 0.05 | 0.12 | 0.01 | 0.00 | 0.07 |
| $\xi_y$ | 0.13 | 0.15 | 0.04 | 0.03 | 0.16 |
| c.m. spread $\sigma_w$ [MeV] | 58 | 53 | 5.8 | 23.1 | 113 |
| $\lambda$ | 58 | 88 | 9.2 | 2.3 | 113 |

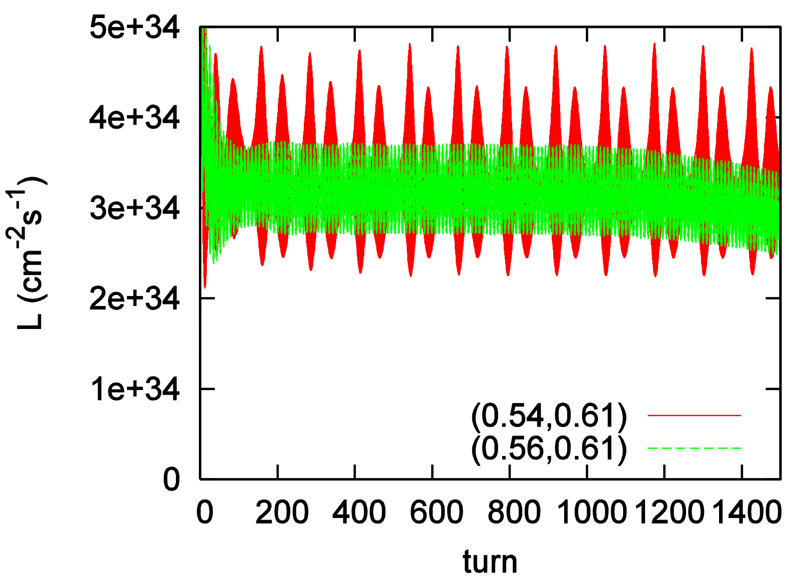
# plan

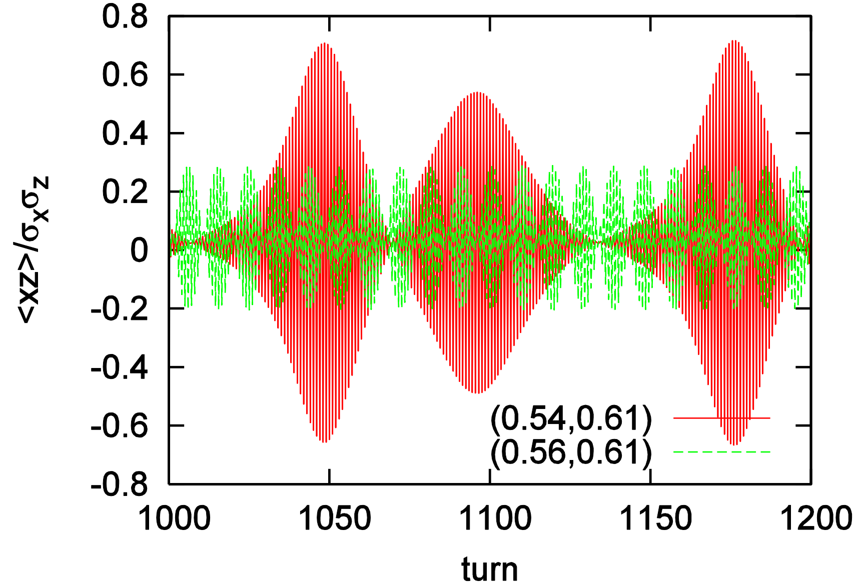
- we will scan not only $\beta_x^*$ and $D_x^*$ but also $\beta_y^*$ and $N_b$ (and $V_{RF}$?)
- which constraints should be put on $L$ and $\lambda$? (i.e. which trade off between the two?)

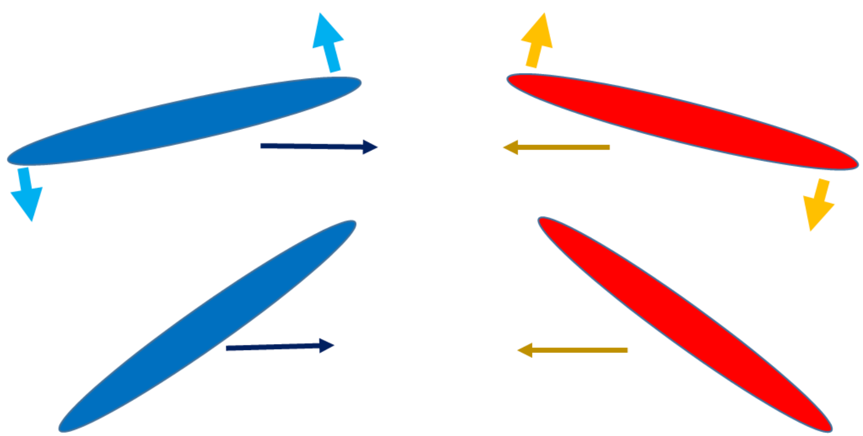
# recent news, highlights, and outstanding issues

# strong-strong beam-beam simulations

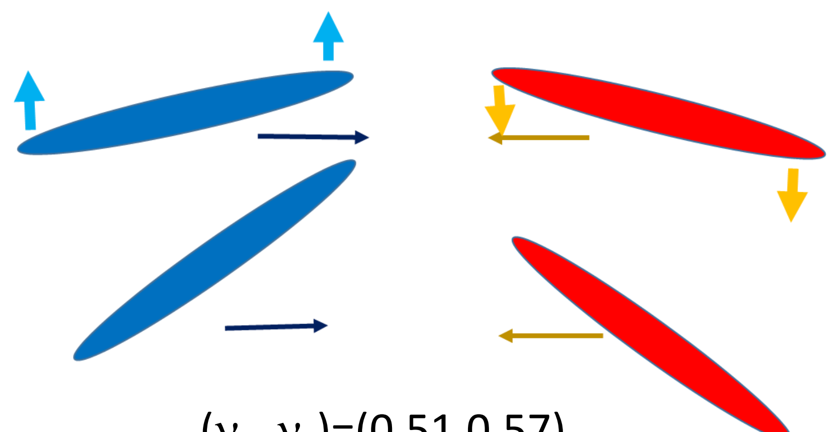
fluctuations in **luminosity** and beam size due to fluctuation of **<xz> correlation**



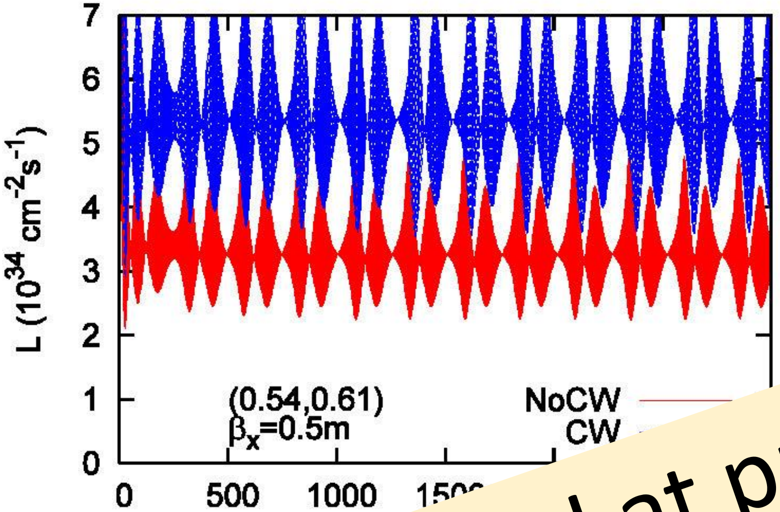
$(\nu_x, \nu_y)=(0.54,0.61)$

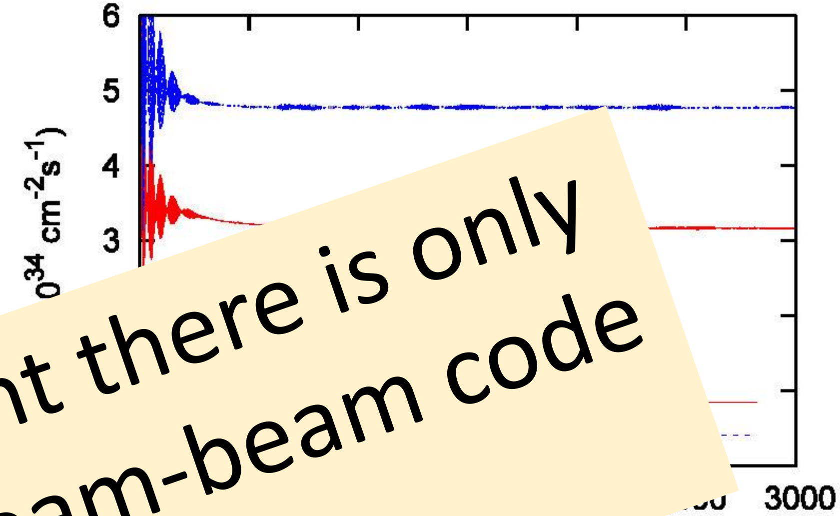


$(\nu_x, \nu_y)=(0.51,0.57)$

K. Ohmi

# strong-strong beam-beam simulations




in the world at present there is only one strong-strong beam-beam code for our problem

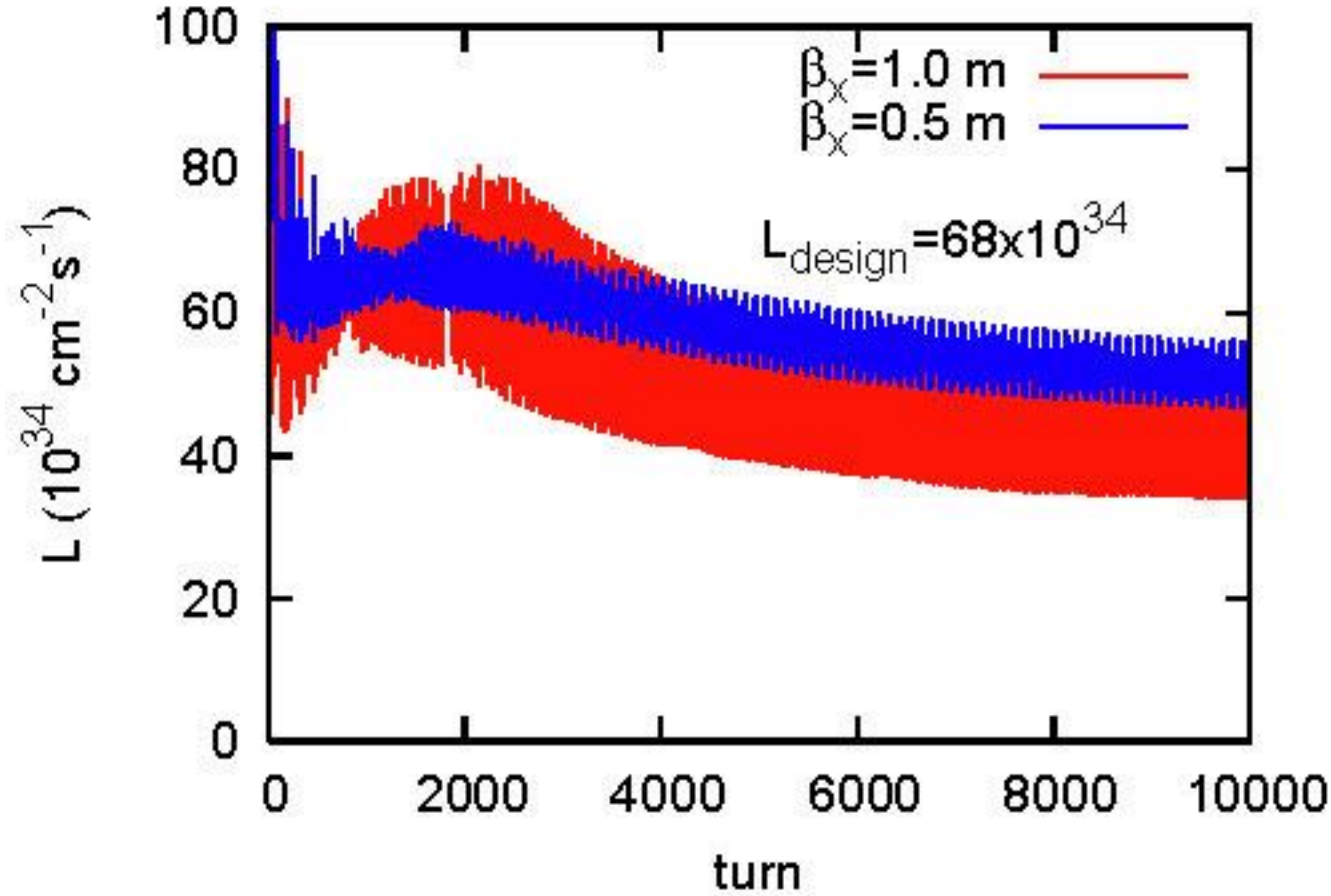
...eline $\beta_x^*$=1 m

fo... also at $\beta_x^*$=1 m

K. Ohmi will visit CERN from 23 August 1 to September

K. Ohmi

# strong-strong beam-beam simulations

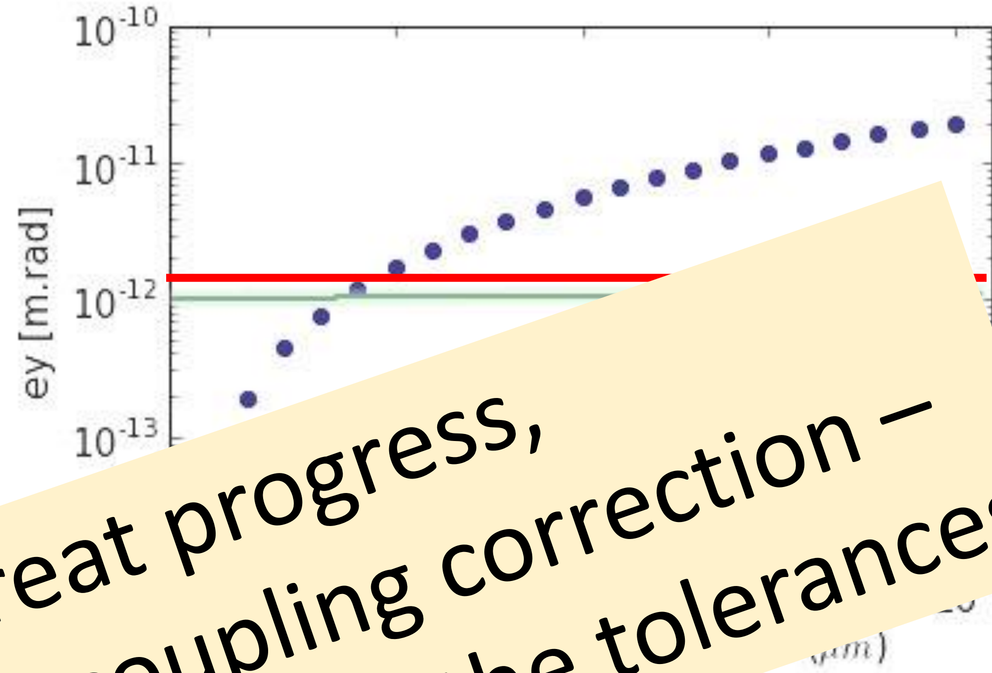



K. Ohmi

# errors and vertical emittance tuning

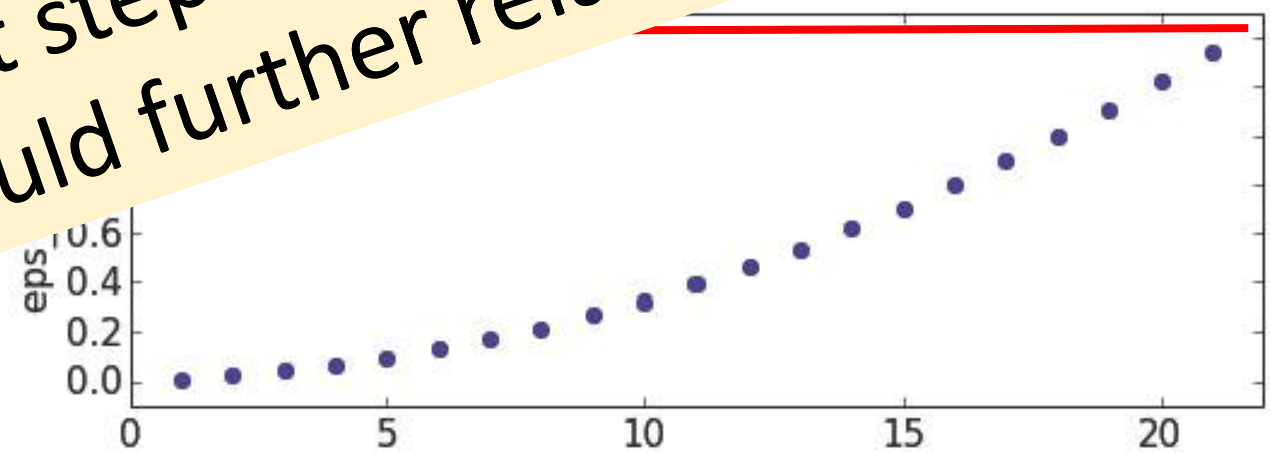
FCC week in Rome
(no sextupole fields;
only global DFS)_

alignment
tolerance
5→20




great progress,
next step – coupling correction –
should further relax the tolerances

DFS wi
sextupo
local disp
correctio

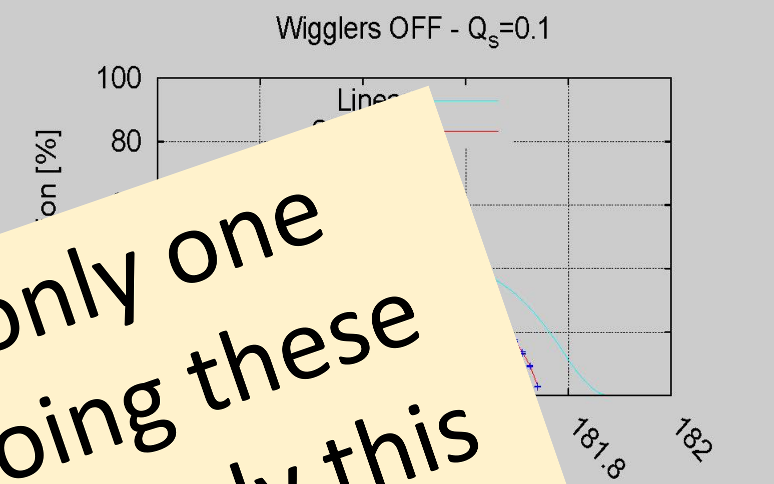



S. Aumon

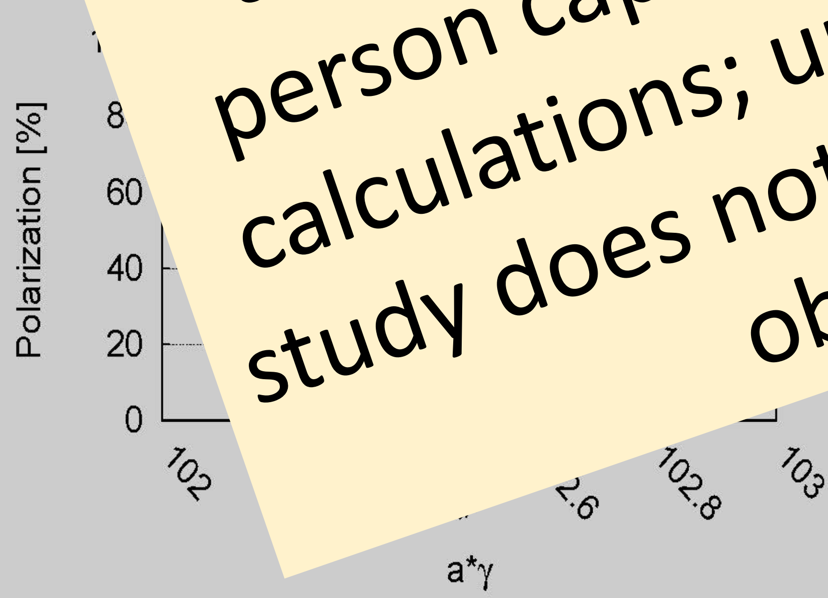
# FCC-ee self polarization allows precise *E* calibration

- 45 GeV   - goal *E*_CM calibration: 100 keV
  - limit $\Delta E$=50 MeV (extrapolating from LEP)
  - 4 wigglers with $B^+$= 0.7 T
  - 10% polarization in 2.9 h for energy calibration
- 80 GeV
  - no wigglers
  - 10% polarization in 1.6 h
- BPMs errors

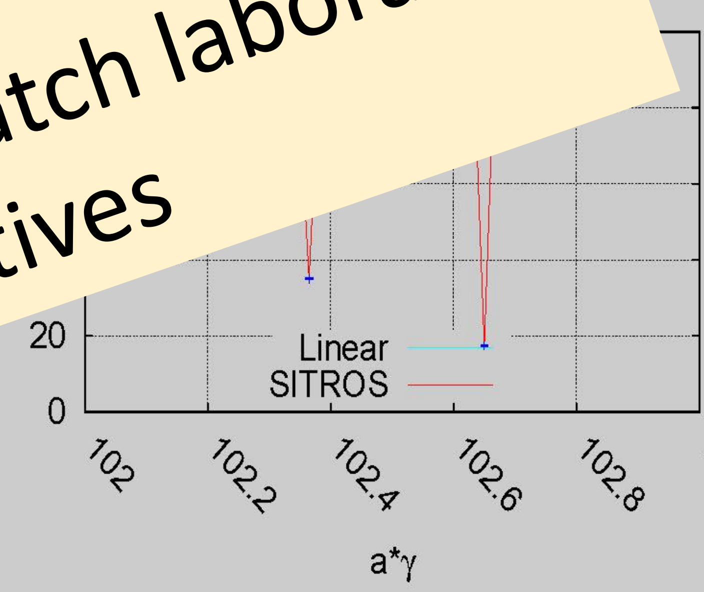
**80 GeV**




at present there is only one person capable of doing these calculations; unfortunately this study does not match laboratory objectives




SVD




SVD + harmonic bumps

E. Gianfelice-Wendt

# polarimetry: from ELSA to FCC-ee

## Precise Compton Polarimetry:

- Compton backscattering of ~515 nm photons
- circularly polarized photons ↔ transverse polarized e-beam
- measurement of shift of photon intensity distribution
- counting silicon microstrip detector with $p = 50\ \mu m$

## Achievable precision: (bunch by bunch, turn by turn)

- ELSA (3.5 GeV, distance 15 m): $\Delta P \approx 1\%$
- FCC-ee (< 90 GeV, distance 500 m): $\Delta P < 0.1\%$
- FCC-ee (175 GeV, distance 500 m): $\Delta P \approx 0.2\%$

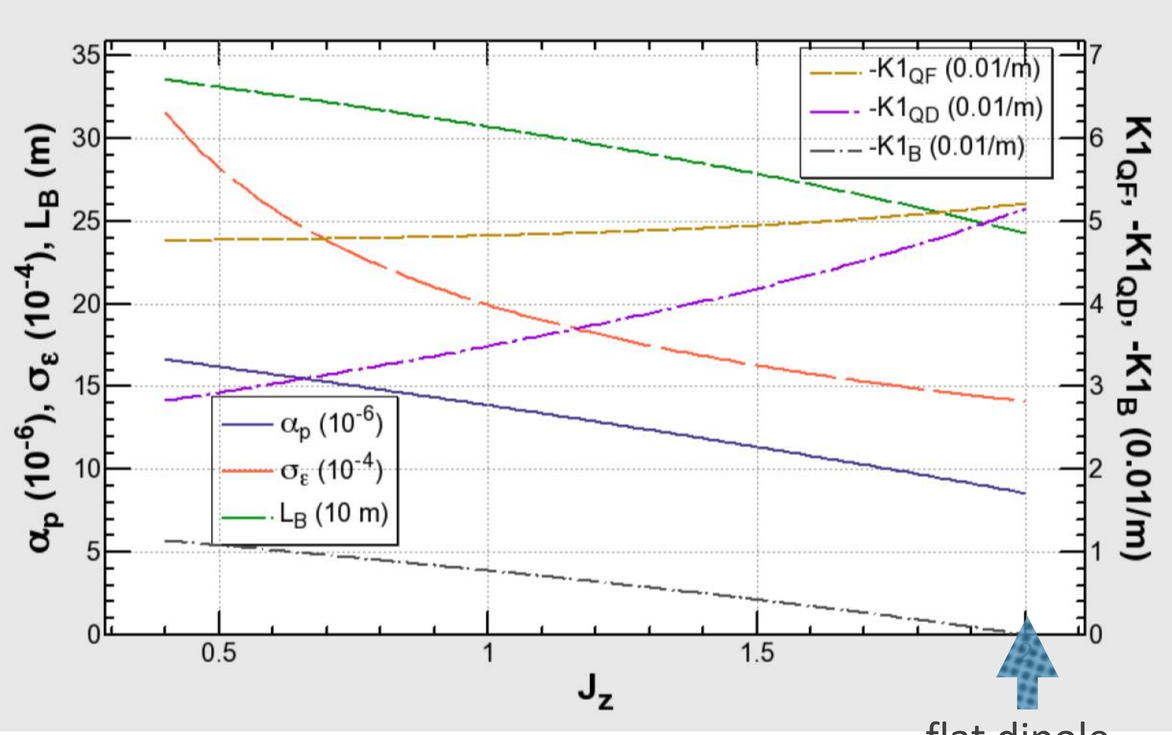
using conventional high power laser

W. Hillert

# combined function dipole in the arcs?

**K. Oide**

$$\varepsilon_x = 1.25 \text{ nm @ } 175 \text{ GeV}$$




A negative field gradient in the main dipole of the unit cell provides:

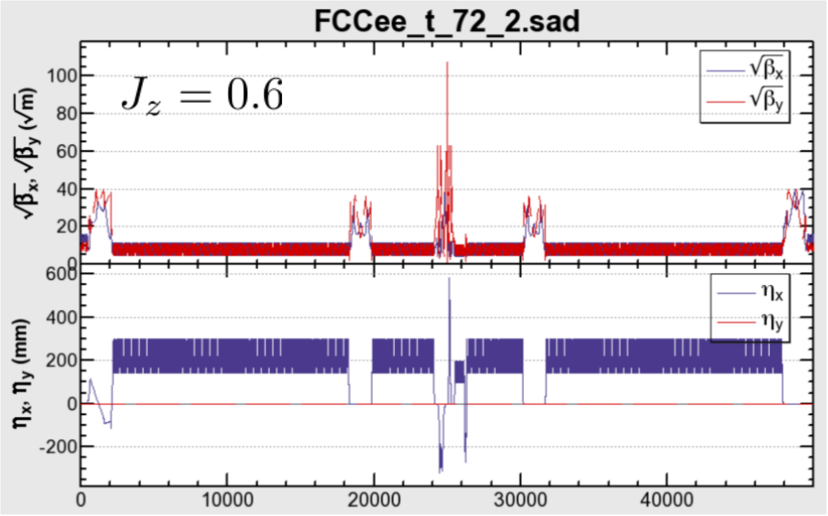
- longer cell length for a given emittance / better packing factor
- larger momentum compaction (longer bunches @ same RF voltage)
- larger energy spread
- larger dispersion
- weaker sextupoles

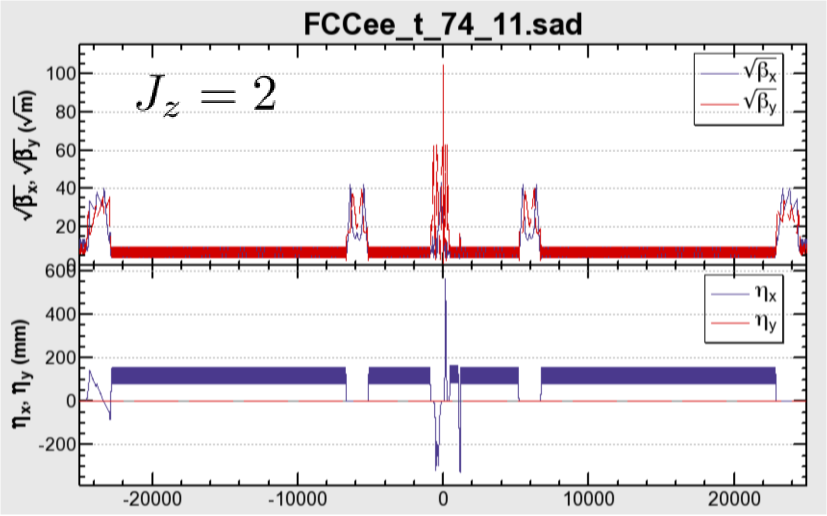
Suggested by E. Levichev

# ex. combined function, $J_z$=0.6 @175 GeV

**K. Oide**

| $J_z$ | 0.6 | 2 |
|---|---|---|
| # of FODO cells | **1062** | 1442 |
| Length of dipole (m) | 33.9 | 23.1 |
| H dispersion at SF (cm) | **29.6** | 16.3 |
| 1 turn energy loss (GV) | **7.09** | 7.74 |
| momentum spread (%) | 0.24 | 0.14 |
| momentum compaction ($10^{-6}$) | **12.8** | 7.2 |
| bunch length (mm) | 5.0 | 2.4 |
| RF voltage (GV) | 9.6 | 9.4 |
| synchrotron tune | -0.10 | -0.068 |



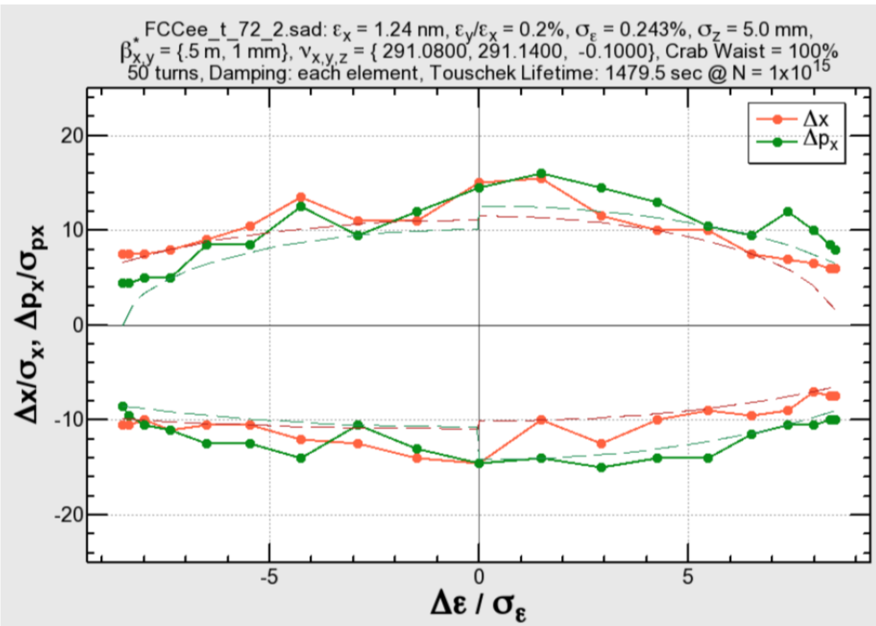



# dyn. aperture of combined function lattice

**K. Oide**

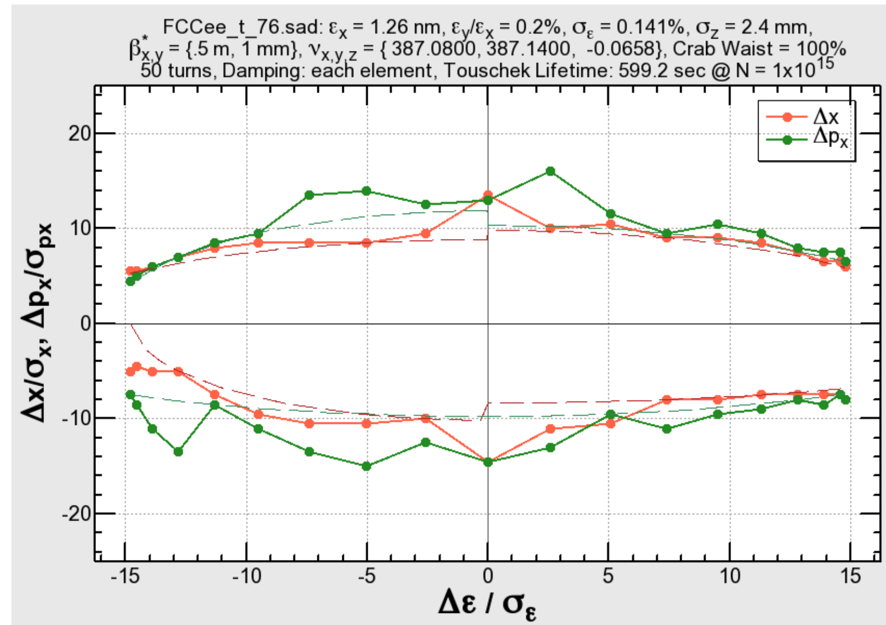
## 175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)

Combined function dipole




±2%

Flat dipole




±2%

- the dynamic aperture is comparable to the one of the flat-dipole lattice
- looking for beam-beam simulation and hardware solution of the dipole…

# official KET WS conclusions

Conclusions of the

# KET Workshop on Future $e^+e^-$ Colliders[a]

## Max-Planck-Institut für Physik Munich, May 2-3, 2016

1. The physics case for a future $e^+e^-$ collider, covering energies from $M_Z$ up to the TeV regime, is regarded to be very strong, justifying (and in fact requiring) the timely construction and operation of such a machine.[i]

2. The ILC meets all the requirements discussed at this workshop.[ii] It is currently the only project in a mature technical state. Therefore this project, as proposed by the international community and discussed to be hosted in Japan, should be realised with urgency. As the result of this workshop, this project receives our strongest support.[iii]

3. FCC-ee, as a possible first stage of FCC-hh, and CEPC could well cover the low-energy part of the $e^+e^-$ physics case, and would thus be complementary to the ILC.[iv]

4. CLIC has the potential to reach significantly higher energies than the ILC. CLIC R&D should be continued until a decision on future CERN projects, based on further LHC results and in the context of the 2019/2020 European Strategy, will be made.

[ii] The basic requirements and features of $e^+e^-$ circular and linear collider projects have been extensively discussed at this workshop, and are summarized, in a simplistic scheme, in the following table:

| Topic | CEPC | FCC-ee | ILC | CLIC |
|---|---|---|---|---|
| Higgs Mass, couplings | + | + | + | + |
| Higgs self-coupling | - | - | + | + |
| Top physics | - | + | + | + |
| ew- precision parameters | + | + | + | - |
| BSM (direct searches) | - | - | + | + |
| Flexibility to new high mass signal | - | - | - | + |
| Maturity of project | - | - | + | - |
| Start by/before 2035 | + | - | + | - |

[iii] Technological maturity is reached in general, proven by successful industrial mass production and implementation in the European XFEL, which can be considered as a large scale technological prototype of the ILC. The design provides the possibility of beam polarisation, which is an essential ingredient for precision physics results. The project is under political consideration in Japan. There exist superior detector designs and respective R&D.

[iv] Circular colliders are especially advantageous for efficient measurements with highest statistics at the “low-energy” ($M_Z$ and below) side of the targeted energy spectrum. This “Tera-Z” operation allows to reduce the uncertainties of electroweak parameters substantially, which are an important ingredient for theoretical predictions at high energies. The efficiency of the linear collider projects at $M_Z$ and below is limited and requires substantial effort. This opens the possibility of efficient task- and cost-sharing between circular and linear colliders, if regional considerations and possibilities lead to the realization of more than one project.