Berliner Elektronenspeicherring-Gesellschaft
für Synchrotronstrahlung m.b.H.

The BESSY (and MLS) Low Alpha Optics and the Generation of Coherent Synchrotron Radiation

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see contribution in ICFA Beam Dynamics Newsletter No. 35, December 2004

Leibniz Gemeinschaft

Abstract
The BESSY II optics is tuned to a low alpha mode for bunch length shortening. About 1mm short bunches emit coherent synchrotron radiation in the THz range. Details of the machine optics and measured THz signals are discussed.
Plans for the presently commissioned MLS ring * for short bunch generation are presented.

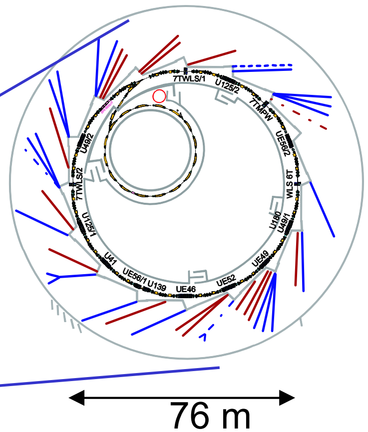
Content

* thanks to the PTB and BESSY commissioning team

Berlin-Adlershof (south east of Berlin)

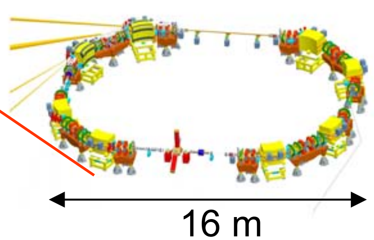
Europe's most modern Technology Park

BESSY II foot print



The BESSY II ring:
energy 1.7 GeV
circumference 240 m
number of cells 16 / DBA
rf frequency 500 MHz

new : Metrology light source MLS

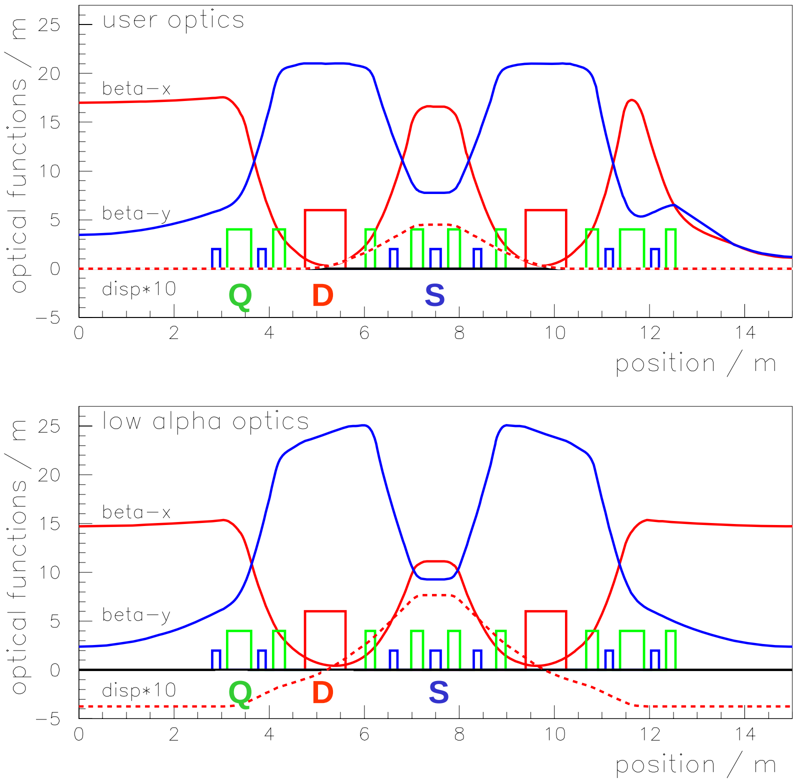


the MLS ring:
energy 0.2 – 0.6 GeV
circumference 48 m
number of cells 4/ DBA
rf frequency 500 MHz

Scientific employes: 6500 (+ 6500 students)
New media: 1500 employes
others: 4300 empoyes

Low alpha optics for bunch length manipulation

the machine optics



tune parameters

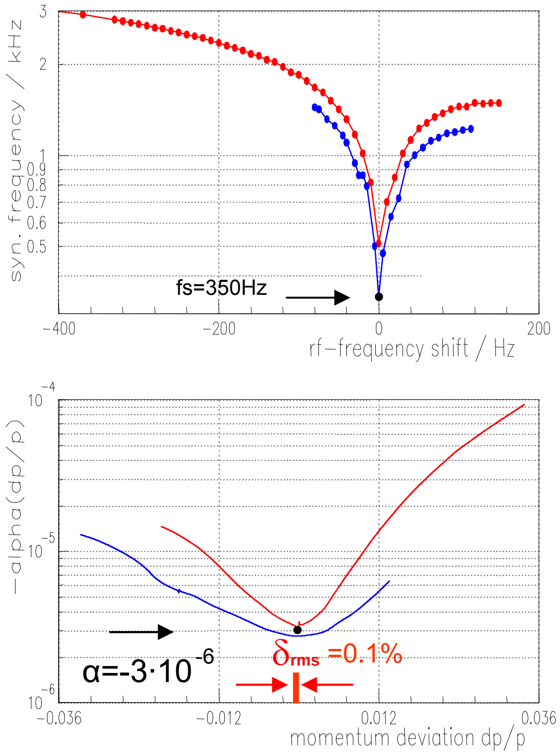
optics parameter	reg.user optics	low alpha optics
tunes Qx / Qy	17.8 / 6.7	14.7 / 6.2
nat. chrom ξx / ξy	-53 / -27	-35 / -27

- 4 sextuple families for beam dynamics corrections
- single & multi bunch 1.25 MHz to 500 MHz rep. rate current per bunch 10 µA < I< 0.1 mA
- very stable machine operation, good life time 20 mA and 20 hours

longitudinal chromaticity

condition for stable beam operation: $\alpha \neq 0$

synchrotron frequency and alpha



synchrotron frequency fs as a function of rf frequency

- fs increases strongly with deviating rf frequency
- optics tuned by sextupoles (long. chromaticity)

extracted momentum compaction factor α

- fit to measured data $\alpha = \alpha_0 + \alpha_1 \delta + \alpha_2 \delta^2$

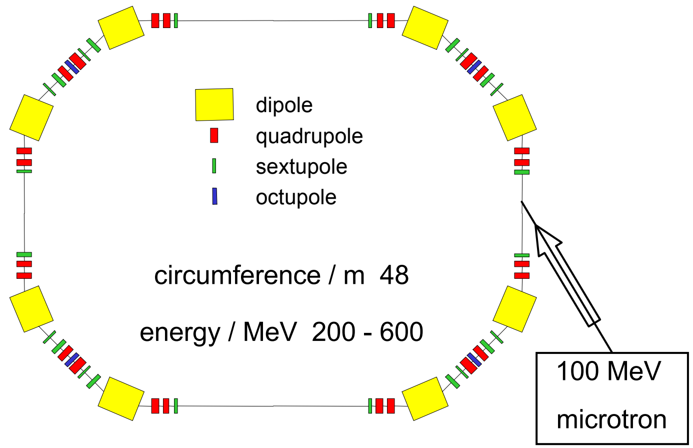
$$\alpha_0 = -3 \cdot 10^{-6}, \alpha_1 = 0, \alpha_2 = -0.03$$

See also: Control of the bunch length on an electron storage ring
H. Hama, S. Takano and G. Isoyama, NIM **A329** (1993)

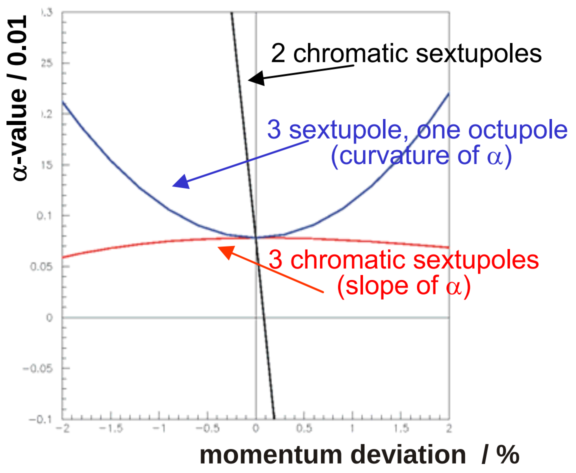
low alpha tuning (simulation) for the presently commissioned MLS ring

Metrology **L**ight **S**ource (**MLS**) of the Physikalisch-Technische Bundesanstalt (PTB), next to the BESSY II site, expected values:

User optics α=0.02 , bunch length σ= 4.5 mm at 600 MeV
THz optics α=0.001, bunch length σ= 1.0 mm at 600 MeV
applied rf: 500 kV, 500 MHz



scheme of MLS ring

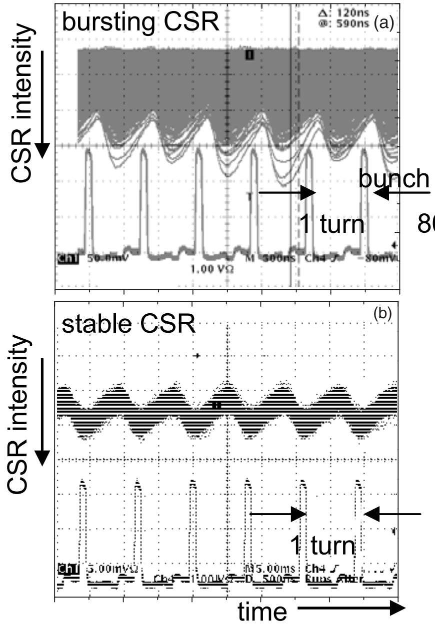


non. lin. low alpha tuning

see also R. Müller et al., Infrared Phys. Technol. 49 (2006) 161

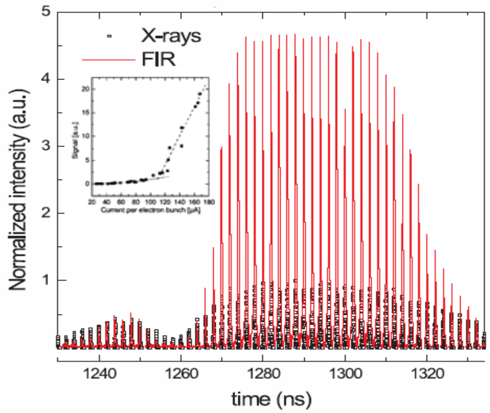
CSR signals & fast THz detectors

InSb-bolometer



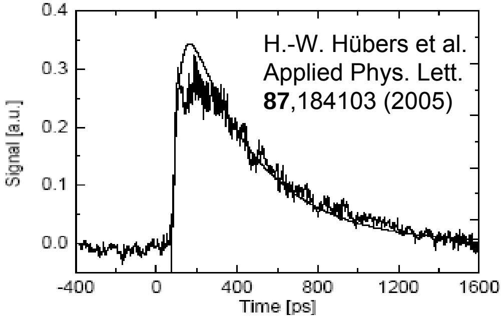
resolution of single turns,
detector τ=1μs

hot-electron bolometer HEB



resolution of single bunches,
detector τ=30**ps**

H.-W. Hübers et al.,
ICFA Newsletter No. 35



temporal resolved THz pulse of
pulse length of few 100 ps:
multiple reflections in THz beam line

Detector parameters

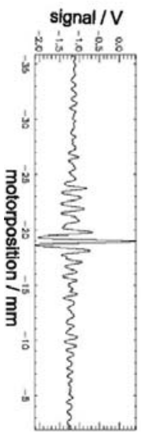
Typical values	Si-Bol.	InSb	HEB
NEP ($W/Hz^{1/2}$)	~10^{-13}	~10^{-12}	~10^{-10}
Rise time τ (ns)	~10^6	~1000	~0.03
Frequency (THz)	0.1 - 15	0.1 -1.5	0.3 - 6

first strong CSR signals

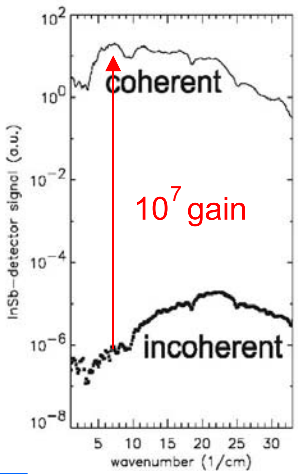
T. Nakazato et al.,Phys. Rev. Lett. 63, 1245 (1989)

from Fourier spectra to power spectra

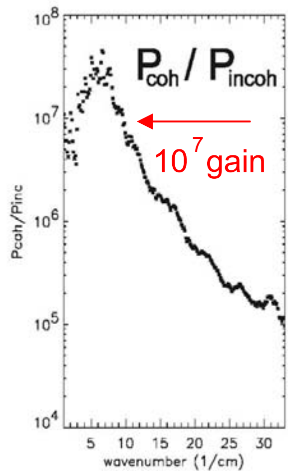
interferogram

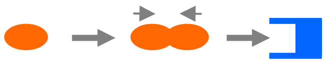


raw data



power spectrum

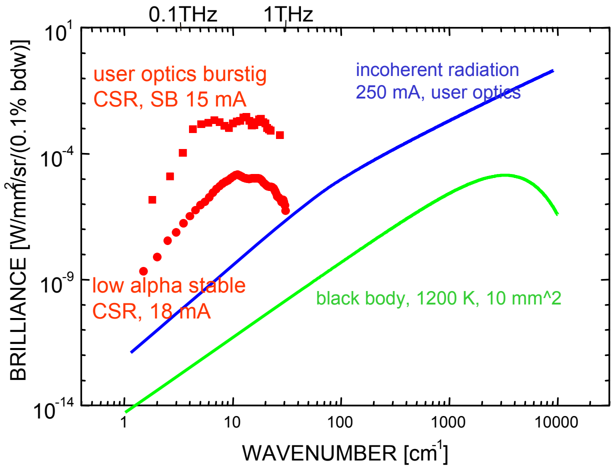




user optics, single bunch 15 mA

power spectrum analysis by Fourier transform spectrometer

source comparison



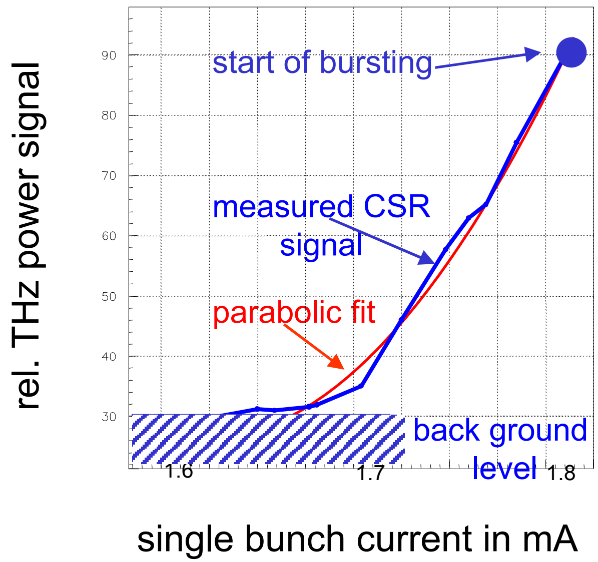
brilliance of the BESSY THz spectrum
in cooperation with Dr. U. Schade, BESSY

BESSY offers 4 low alpha shifts of 3 days / year

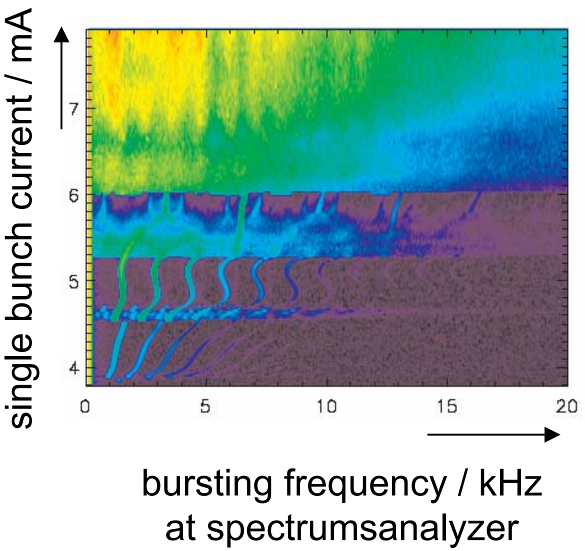
application: coherent THz radiation, ICFA No. 35, article by U. Schade et al.
short x-ray pulses at BESSY, PRL **95**, A. Krasyuk et al., 2005

transition from stable to bursting CSR, user optics

CSR from deformed, but stable bunch, fs=7.2 kHz



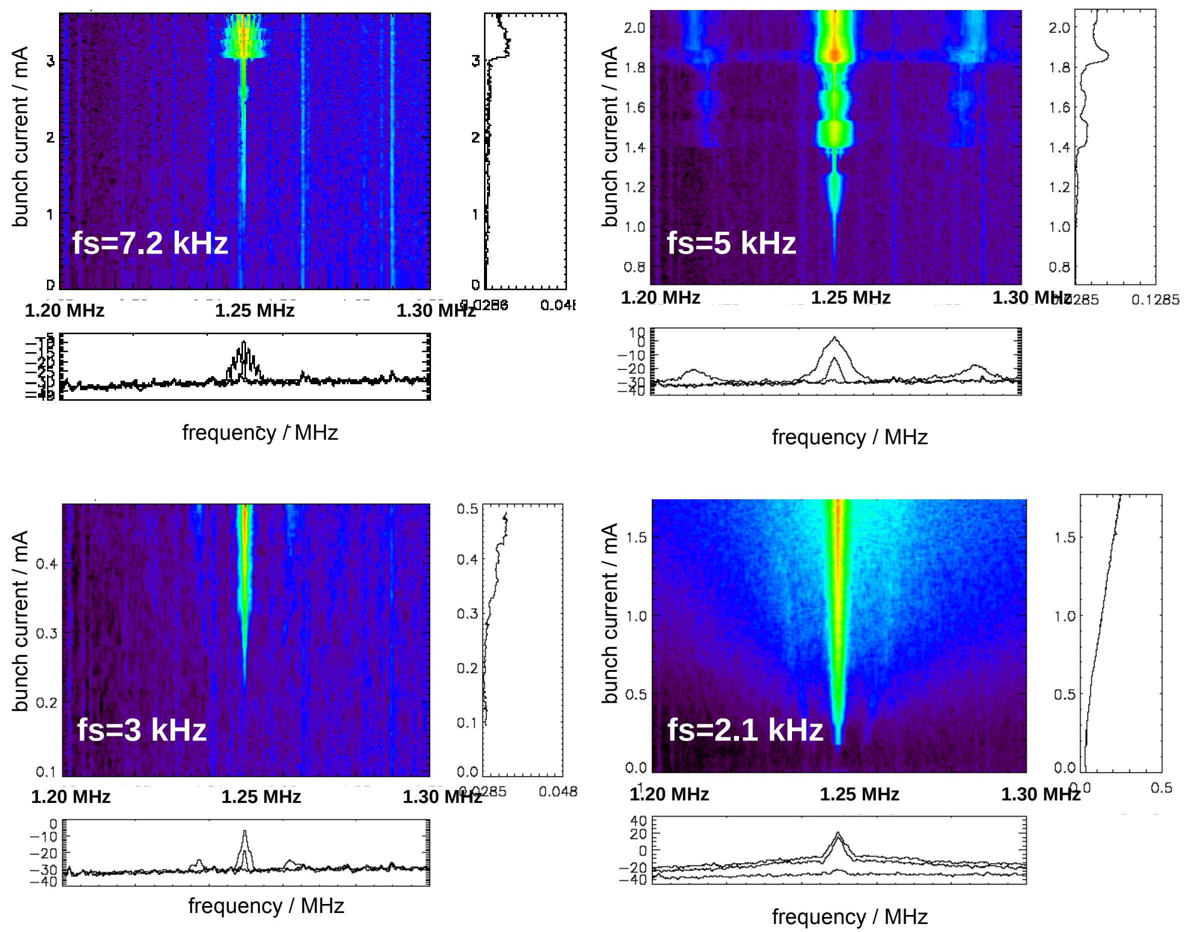
temporal emission spectrum of CSR bursts (user optics)



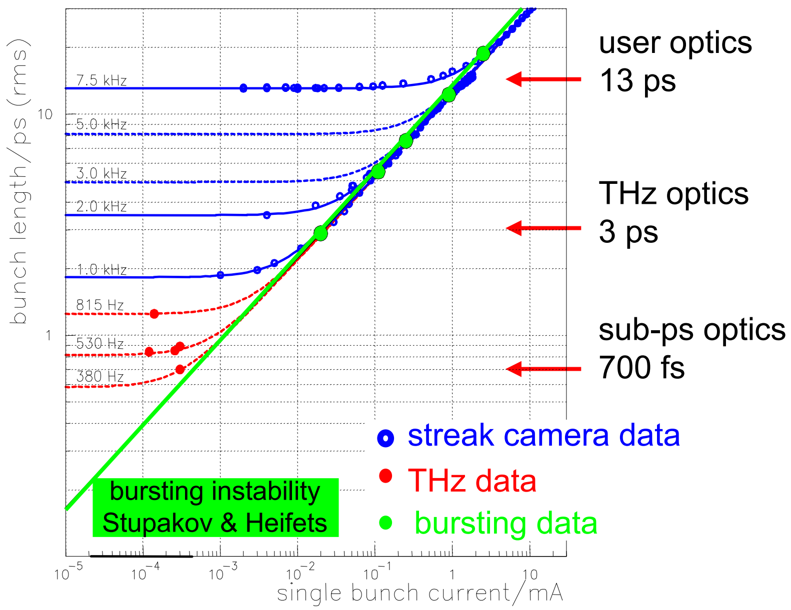
single bunch CSR-intensity II

spectrums analyzer records, centered around 1.25 MHz rev. frequency

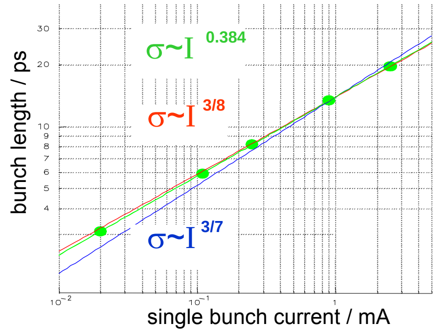
Current and temporal emission dependencies of CSR radiation at different settings of the low alpha parameter fs



bunch length - current relation



bursting data



empirical scaling relation between bunch length σ, synchrotron frequency f and current I:

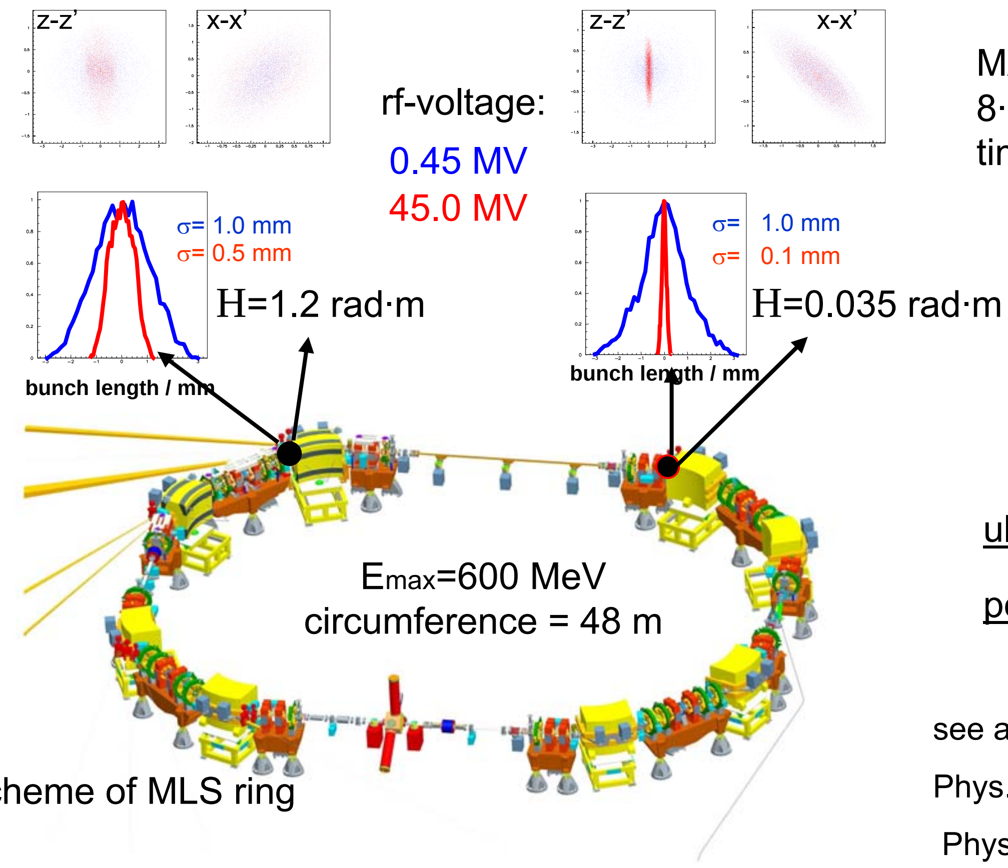
$$(\sigma / \sigma_0)^4 = (f / f_0)^4 + (I / I_0)^{3/2}$$

results at bursting threshold:

- eff. / naturale bunch length $\sigma/\sigma_0 = 1.5$
- eff. bunch length · unstable mode $\sigma k_i = 2\pi\sigma/\lambda_i = 5$
- bunch length ~ current relation $\sigma \sim I^{a}$
  a=3/8 from experiments, a=3/7 from theory

longitudinal-horizontal couplings effect in the MLS ring

longitudinale bunch length is chromatic $\mathcal{H}$ dependent.



scheme of MLS ring

MAD tracking simulation, $8 \cdot 10^5$ turns = 10 damping times & quantum excitation

<u>ultra short bunches are only possible at small $\mathcal{H}$ locations</u>

see also : Y. Shoji in

Phys. Rev. ST Accel. Beams **8** 094001 (2005)

Phys. Rev. ST Accel. Beams **7** 090703 (2004)

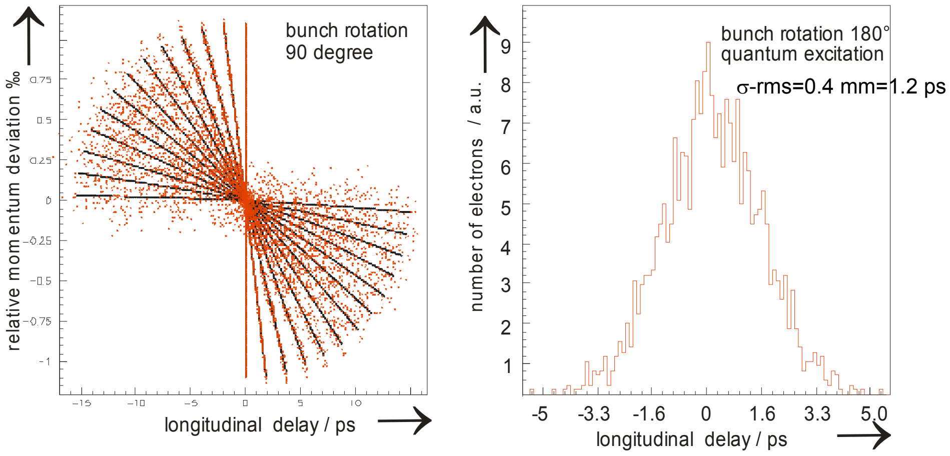
BESSY II, user optics: MAD-simulation of electron diffusion due to radiation damping

initial value: no spread in phase space, only natural spread in momentum distribution

180° in phase long. space → 80 turns around machine

long. bunch length spread of σ=0.4 mm

conclusion:
radiation damping limits the multiple usage of
- 'laser sliced' electrons for short x-rays
- 'laser sliced' dip as a THz-source



idea of enhanced THz radiation and short X-ray pulses at BESSY II

applying the scaling law for bursting threshold:

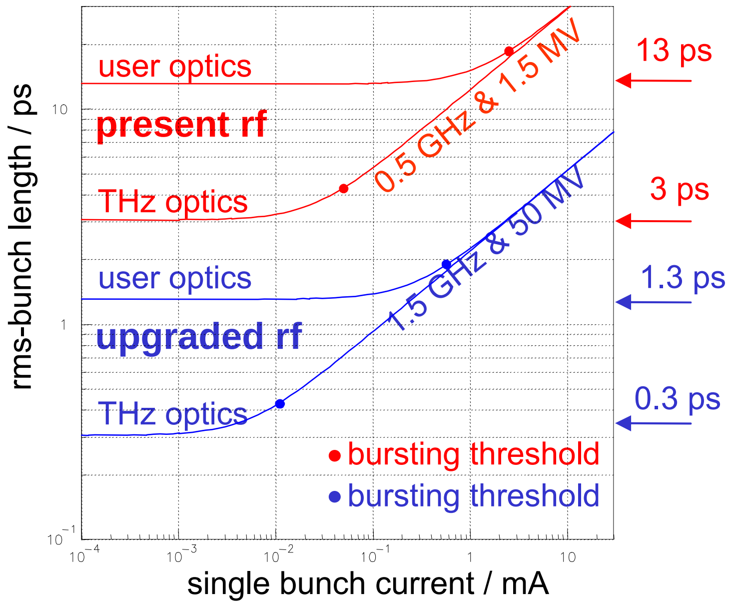
$$I \propto \sigma_z^{8/3} dV_{rf} / dz$$

for upgrading the rf-gradient by a

1.5 GHz, cw superconducting rf-structure

placed into one straight ID-section

rf-upgrading: 1.5 GHz & 50 MV
sub-ps bunches!



Conclusion:

the low alpha optics is a scheme to extends the photon spectrum of storage rings to intense THz and short X-ray pulses

coherent THz radiation as a diagnostics tool delivers sensitive and new information on beam dynamics