Coherent Synchrotron Radiation and Short Bunches in Electron Storage Rings

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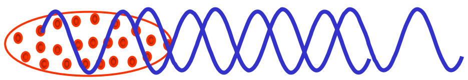
two example electron rings:

BESSY II	MLS
E = 1.7 GeV	E = 0.1 GeV to 0.63 GeV
$2\pi R$ = 240 m	$2\pi R$ = 48 m
16 cell DBA	4 cell DBA
	⇒ just started operation

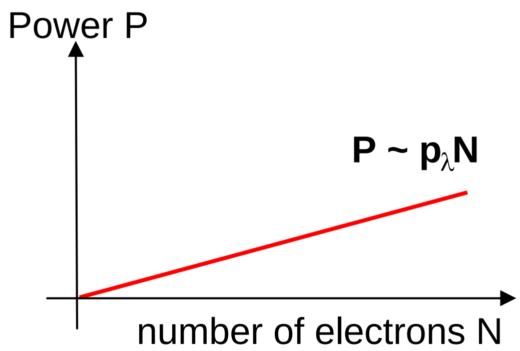
MLS= Metrology Light Source,
owned by German PTB

superposition of radiation

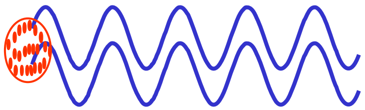
incoherent emission



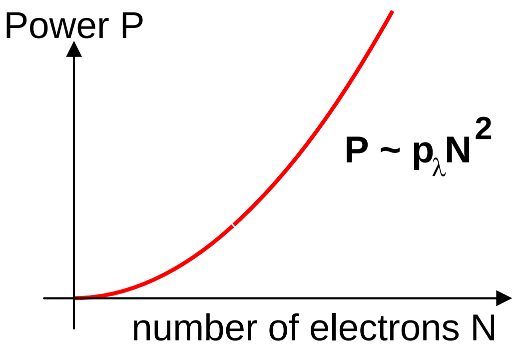
long bunch* $\sigma > \lambda$



coherent emission

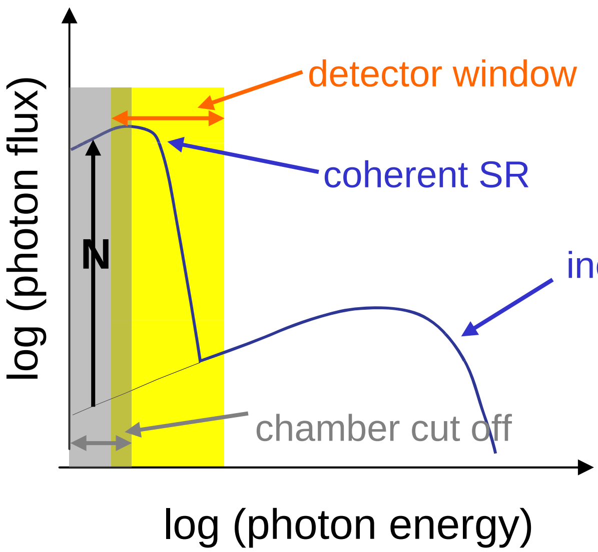


short bunch $\sigma < \lambda$



*σ always rms!

superposition of radiation



"cut off" wave length

$\lambda_{co} = 2h \sqrt{h/\rho}$

bunch form factor

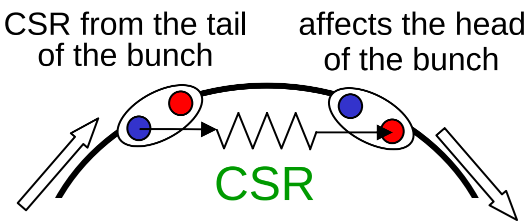
$g_\lambda = |\int n(z) e^{2\pi i z/\lambda}\, dz|^2$

g_λ depends sensitive on the bunch density distribution n(z)

$\mathrm{Power}(\lambda) = p_\lambda (N + N^2 g_\lambda)$

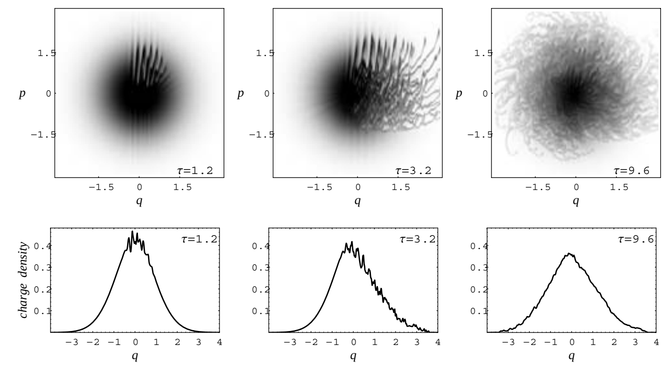
total / incoherent power $= \mathrm{Power}(\lambda) / (p_\lambda N) = 1 + N\, g_\lambda$, $N \sim 10^8$

Scheme of CSR-bunch interaction



simple interaction model
bunch-CSR on curved orbit

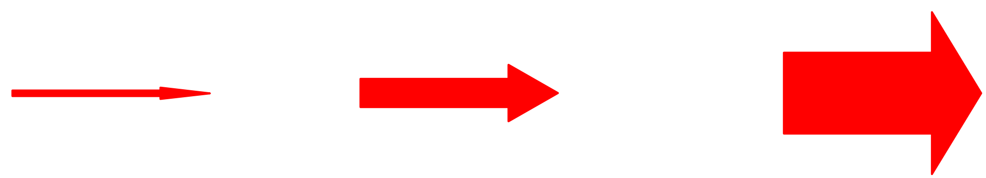
phase space distribution



M. Venturini & R. Warnock et al.

bunch density distribution

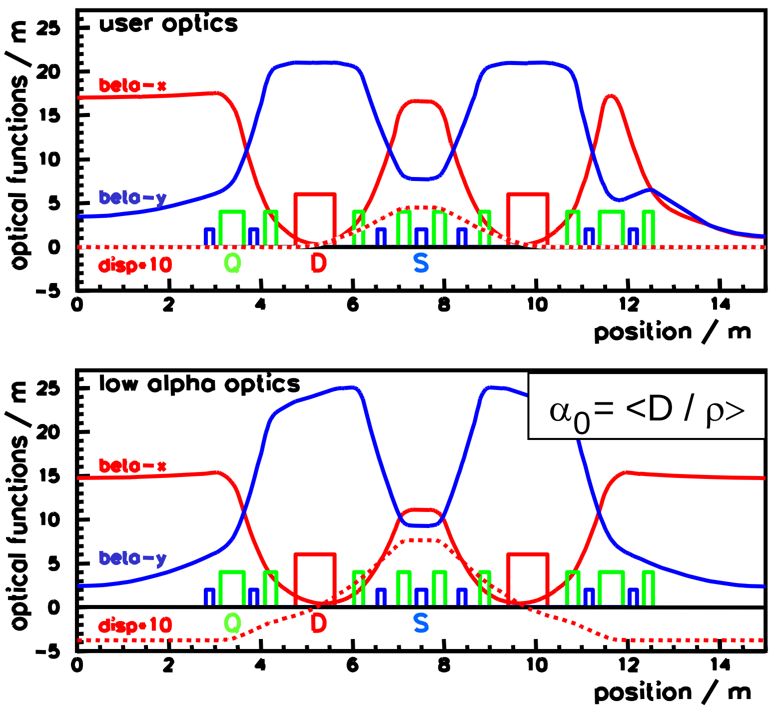
CSR power



bunch shape Gaussian → stable deformed → unstable, bursting

BESSY II low alpha optics

the machine optics



➡ relation: $(f_s\ ,\ \Delta rf) \leftarrow\rightarrow (\alpha\ ,\ \Delta p/p)$

➡ $\alpha_0 \sim f_s^2$ and $\sigma \sim f_s$

BESSY II main parameters

optics parameter	reg.user optics	low alpha optics
nat. emitt / nmrad	6	30
synchr. freq. / kHz	7.5	7.5 … **1.75** … 0.35
mom. com. factor α	7.2E-4	7.2E-4 …**4E-5**…1.6E-6
nat. bunch length rms /ps	12	12 … **3** … 0.7

low alpha at fs=1.75kHz : very stable machine operation, good life time 20 mA and 20 hours

Tuning of non. lin. synchrotron frequency & α

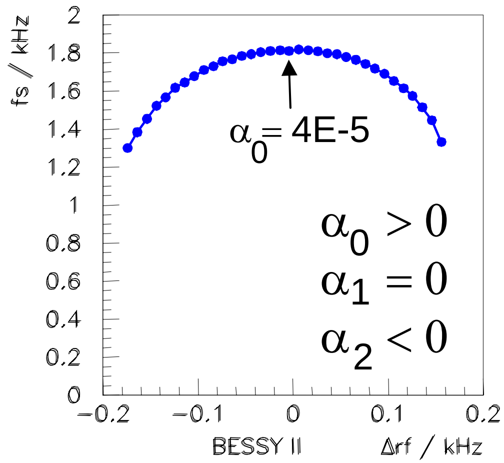
expansion of α:

$\alpha = \alpha_0 + \alpha_1 \Delta p/p + \alpha_2 \Delta p/p^2 \ldots$

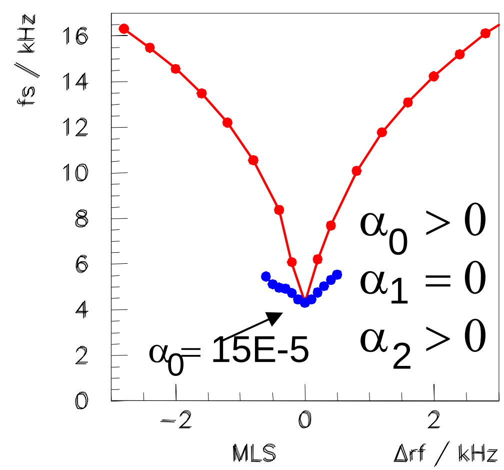
tuning of α

quad → α_0
sext → α_1
octu → α_2

BESSY II, 1.7GeV
4 chrom. sextupole families, limited flexibility



MLS, 630 MeV
3 chrom. sextupole families, & octupole family



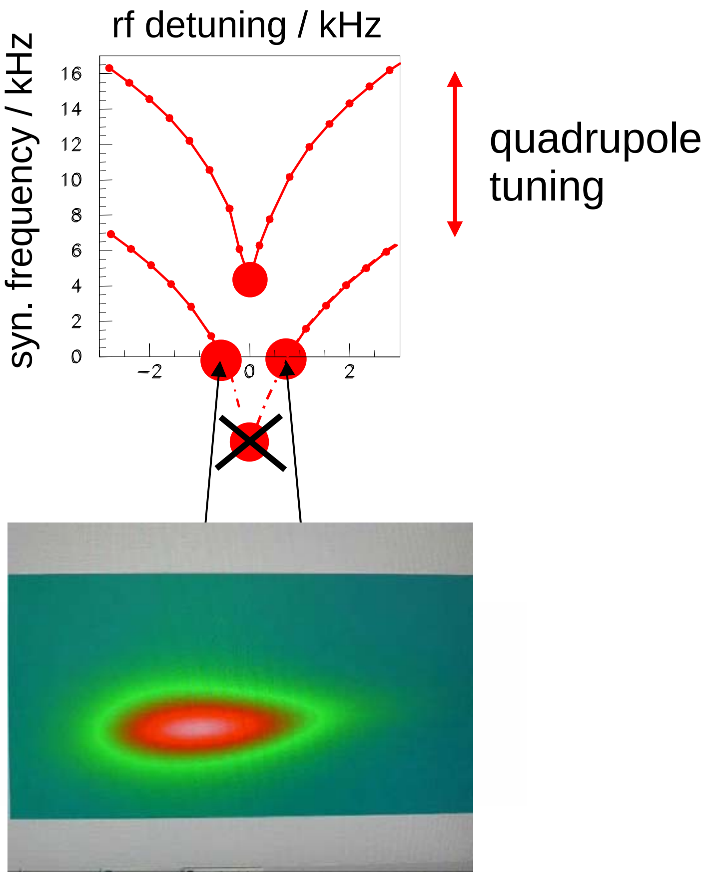
synchrotron frequency fs as a function of Δrf frequency

Observation of Simultaneous Alpha Buckets

- fixed points:

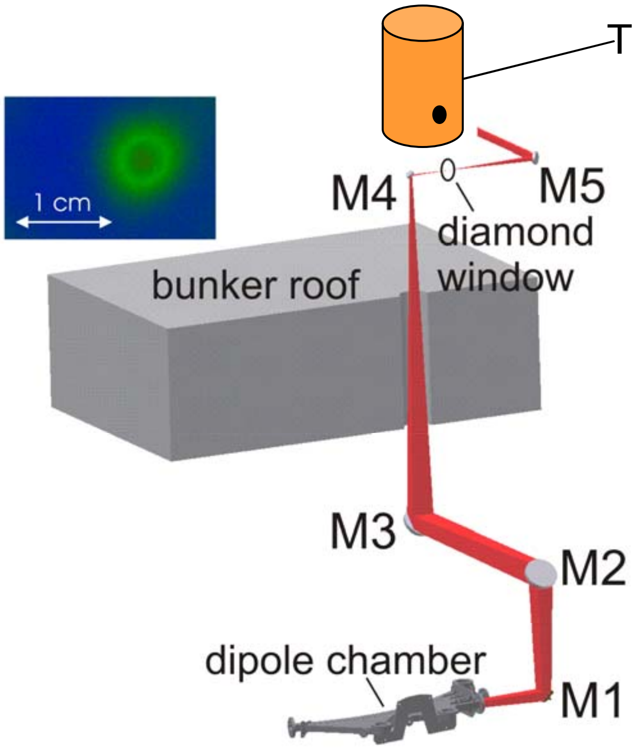
  $\sin\varphi = 0, \ \alpha \, \Delta p/p = 0 \quad \hat{=} \ f_s = 0$

MLS measurement:



IR beam line at MLS

acceptance 64x43 mrad^2

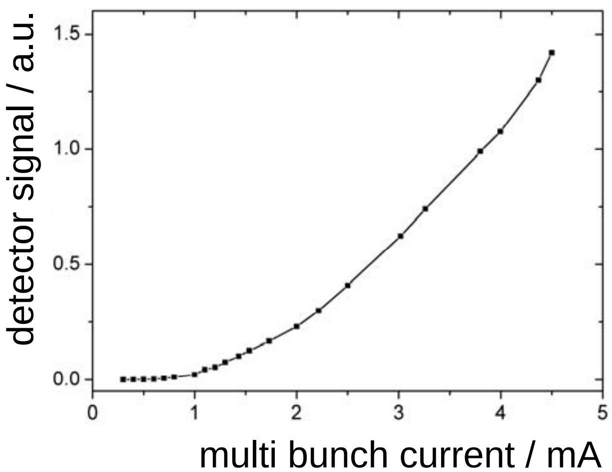


Si-bolometer
rise time ~1 ms
frequency 0.1 – 15 THz
NEP ~10^{-13} W/√Hz

InSb-detector
rise time ~1 μs
frequency 0.1 – 1.5 THz
NEP ~10^{-12} W/√Hz

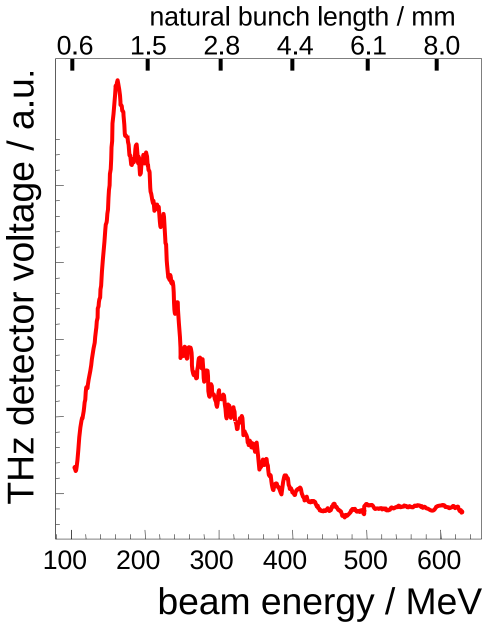
Coherent radiation

THz detector signal versus ring current



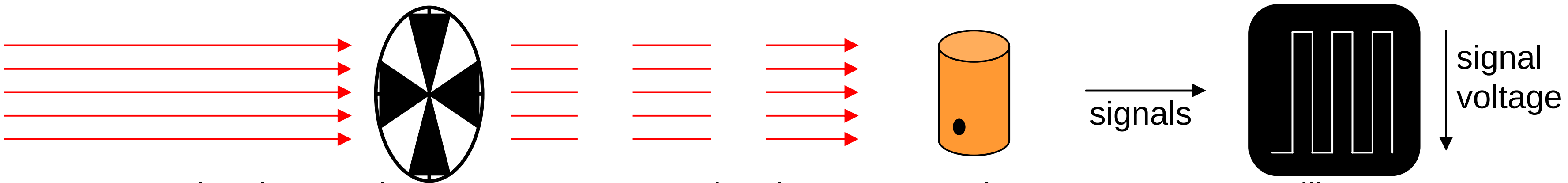
Low alpha, 630 MeV: the THz signal growth stronger than the ring current, a clear indication of coherent radiation

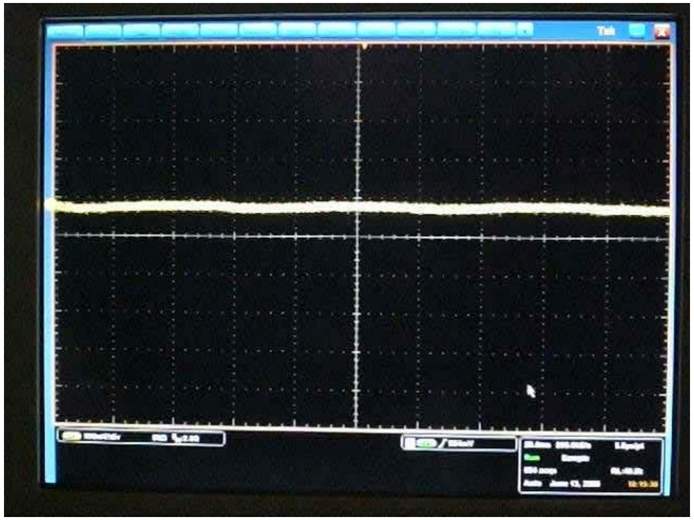
THz signal versus beam energy 100 – 600 MeV, 55mA at 250 kV



less THz power than expected
- intra beam scattering
- ion trapping
- CSR beam excitation, slow damping

chopped THz signals at MLS





MLS measurement:

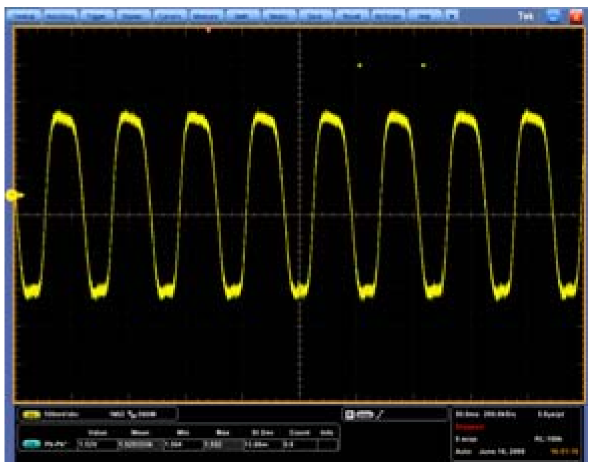
THz power, 30 mA

by low alpha tuning

Stable THz Signals at MLS

E=630MeV, I=19mA, HV=200 kV, fs=10kHz, InSb-detector

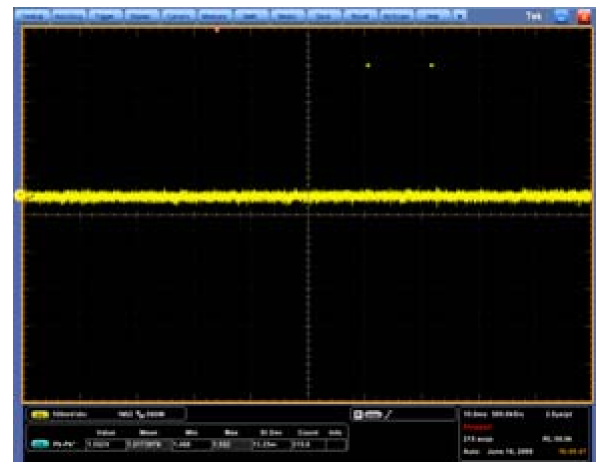
100mV/div



50ms/div

THz signal, chopper=on

100mV/div



10ms/div

THz signal, chopper=off

signal amplitude is constant & stable

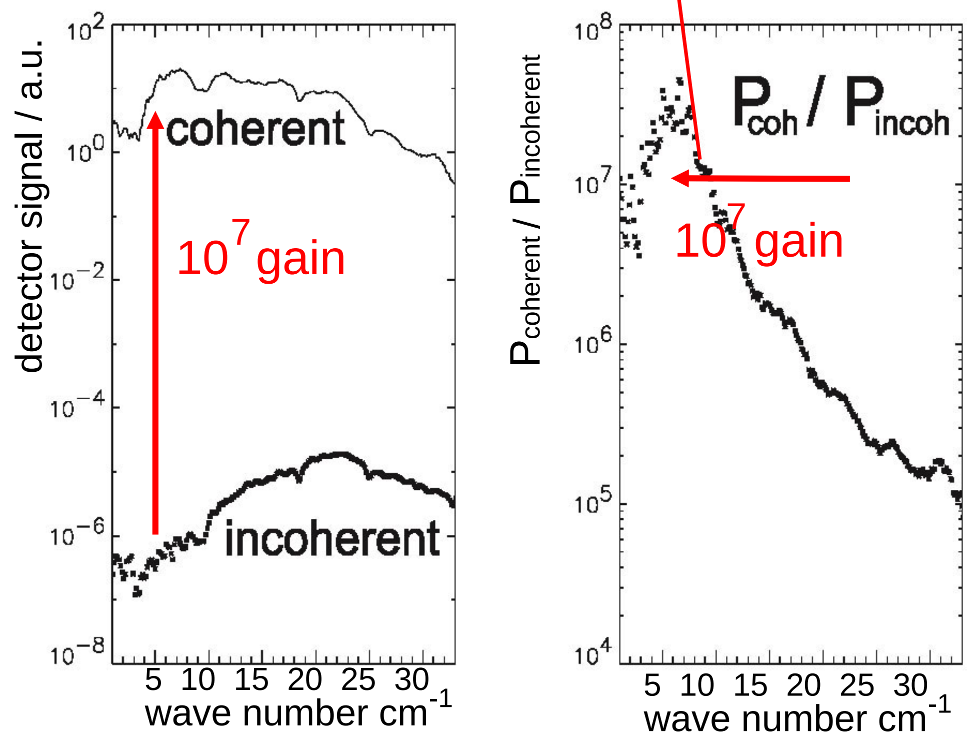
N_e

power spectrum analysis

power spectra by Fourier transform spectroscopy

power spectra

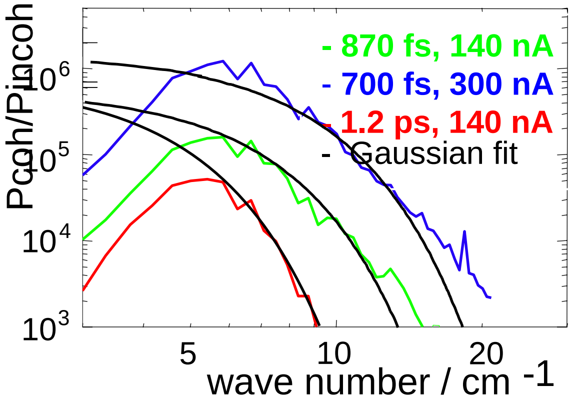
$N_e \times$ form factor



BESSY II user optics, single bunch 15 mA

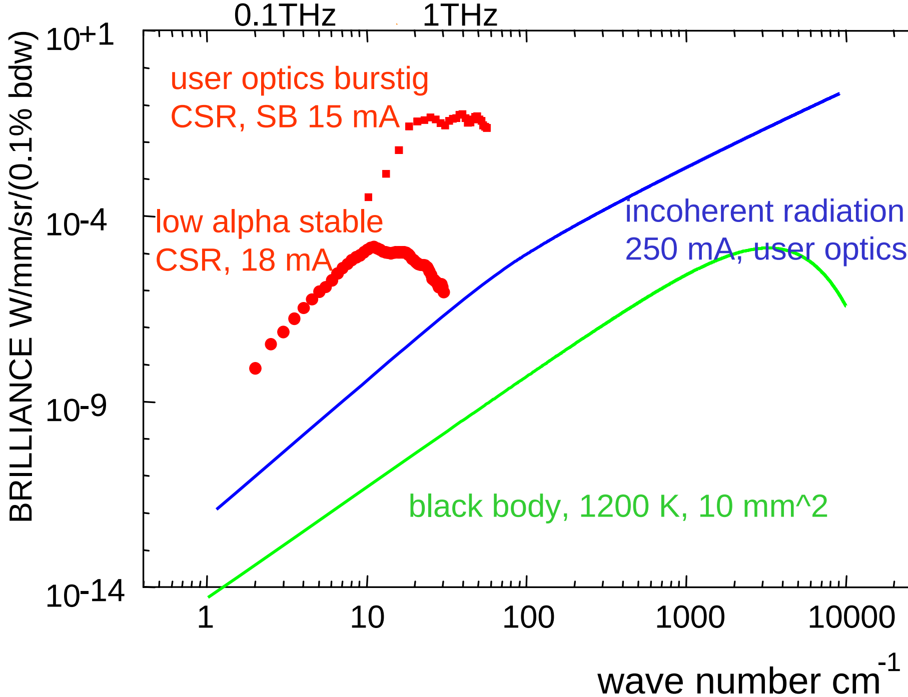
power spectrum analysis

$N_e \times$form factor, sub-ps bunches



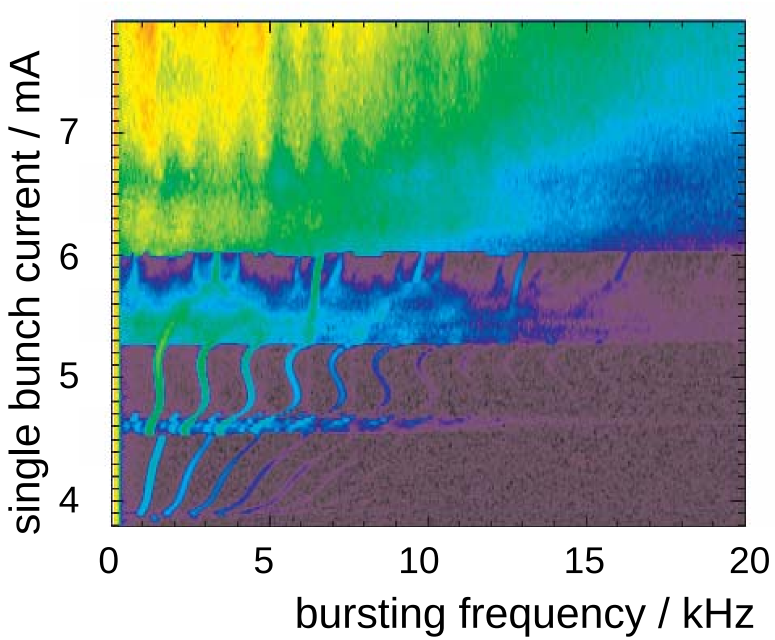
sub-ps beam diagnostics
at low currents

brilliance of the BESSY II THz spectrum

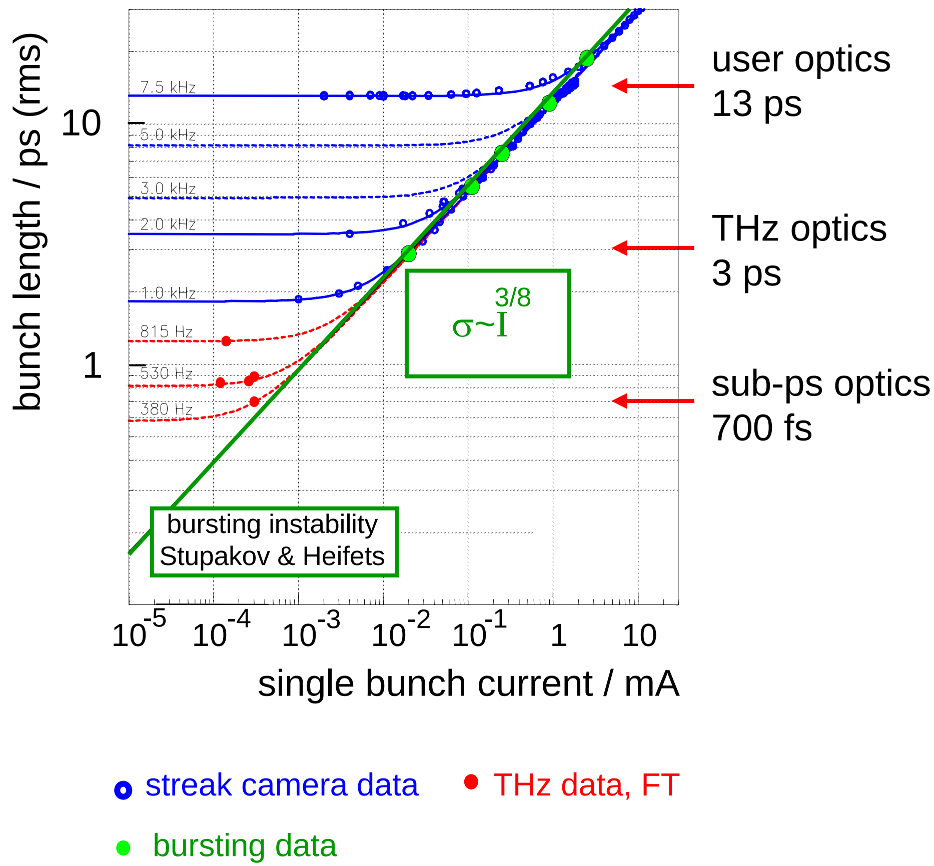


bursting threshold

current dependent bursting
in time domain / user optics

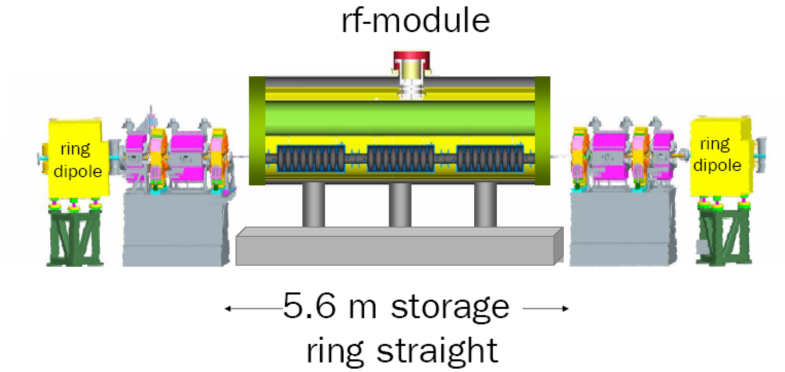


bunch length - current scaling

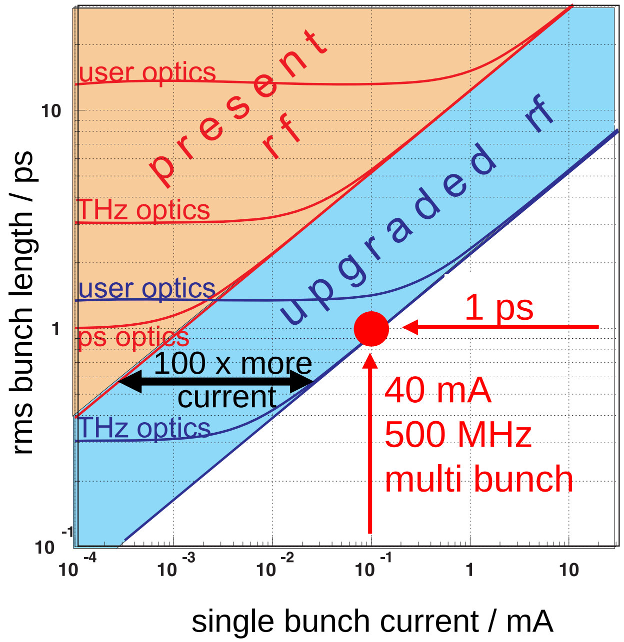


option for short bunches & more currents

upgraded rf-gradient 1.5 GHz, 50MV,
superconducting rf-structure

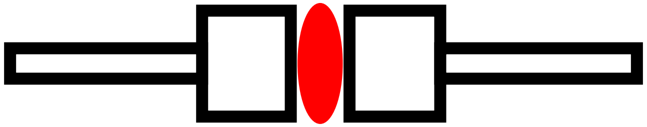


rf-module in one of the ID-straights



bunch length-current diagram

Limits of ultra short bunches:



small / low energy rings

- ion trapping
- slow damping of
  CSR / impedance heating
  intra beam scattering

- power supply noise
- coupling of long. - trans. planes
- quantum emission

Conclusion:

the low alpha optics extends the usage of storage rings to intense THz and short, Pico second X-ray pulses

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

presently achieved results without any larger hardware investment

Acknowledgment

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