Karlsruhe Institute of Technology

# CSR in Light Sources

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Institute for Synchrotron Radiation

ANKA THZ GROUP

HELMHOLTZ GEMEINSCHAFT

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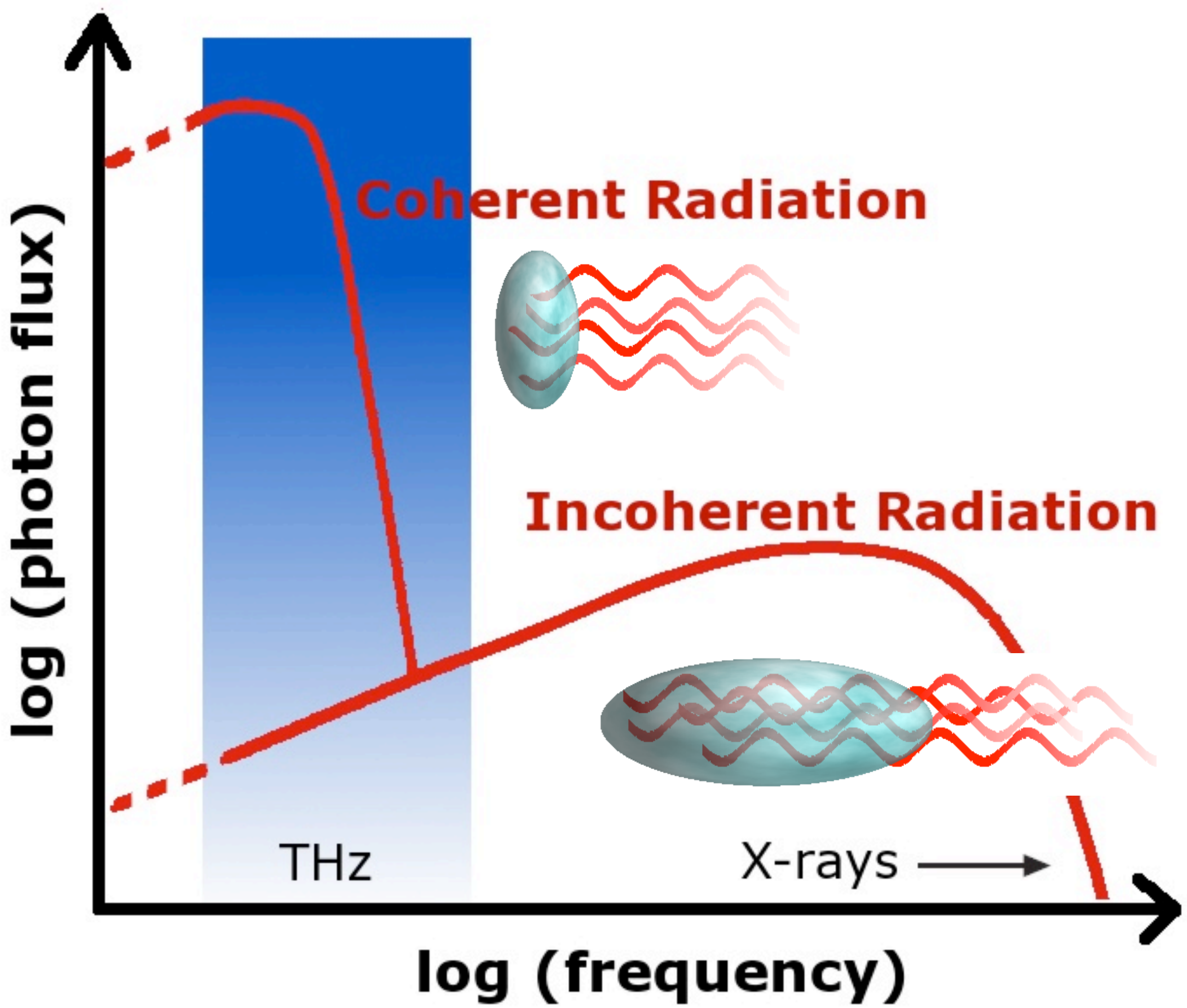
# Outline

- Why CSR?
- Optics considerations for CSR generation in storage rings
- CSR observed in time & space
- CSR and bunch charge distribution
  - ➜ bursting/stable emission, bunch deformation
  - ➜ influence of other impedances
- Summary

# Why Coherent Synchrotron Radiation?

- Enormous increase in power in comparison to incoherent emission
- Extension of successful experimental methods to the low frequency (Terahertz) range
- Coherent synchrotron radiation is emitted from electrons in a deflecting magnetic field for wavelengths equal to or longer than the bunch length

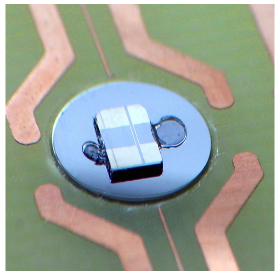
➜ short bunches are needed

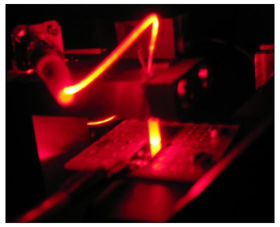


# 456. Wilhelm und Else Heraeus Seminar

# THz Radiation: Generation, Detection and Applications

18. – 21. April 2010 Physikzentrum Bad Honnef





- Lectures on all fields related to THz radiation
  - ➜ accelerator & laboratory sources
  - ➜ standard & advanced detection techniques
  - ➜ applications in life sciences, non destructive testing, metrology, security, astronomy
- Web page:

http://ankaweb.fzk.de/science_at_anka/ANKA_THz_Group/ANKA_THz_Group/WEH-Seminar/Home.html

- Venue:

Photographs of the Physikzentrum Bad Honnef (Courtesy PBH)

# Example: The ANKA Storage Ring

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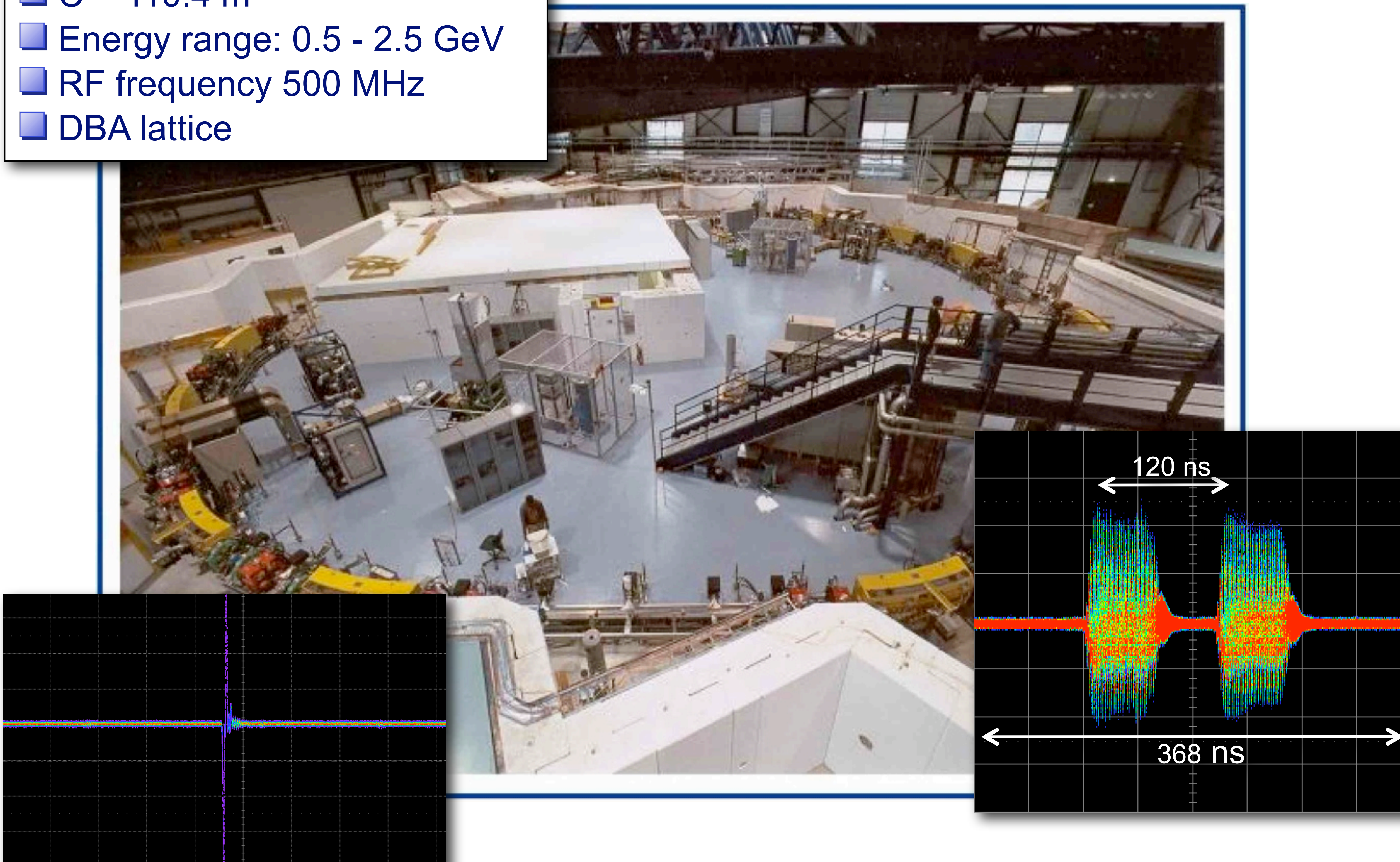
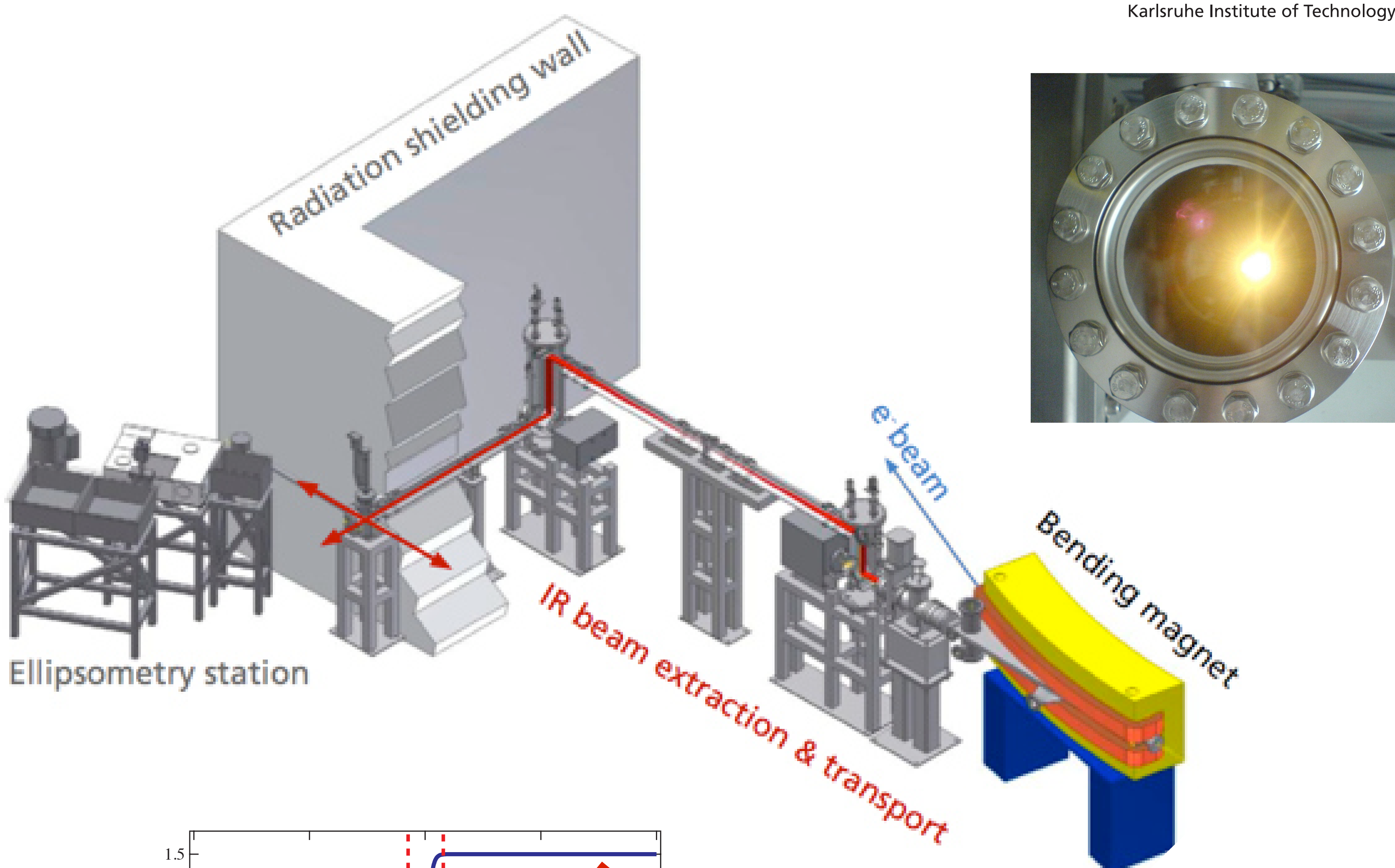
- C = 110.4 m
- Energy range: 0.5 - 2.5 GeV
- RF frequency 500 MHz
- DBA lattice

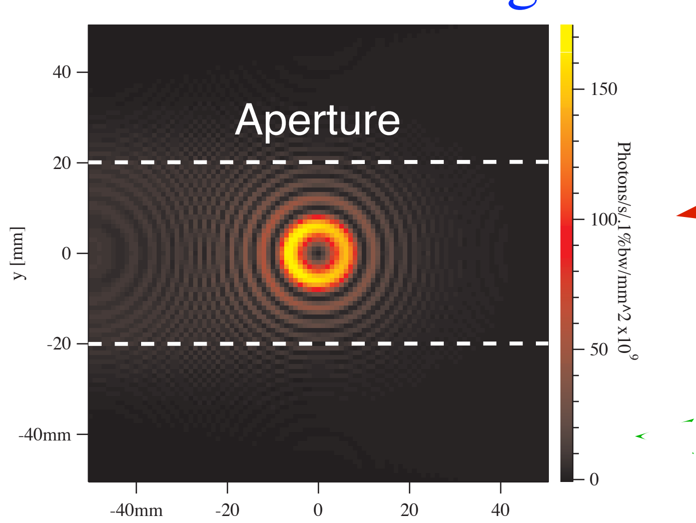


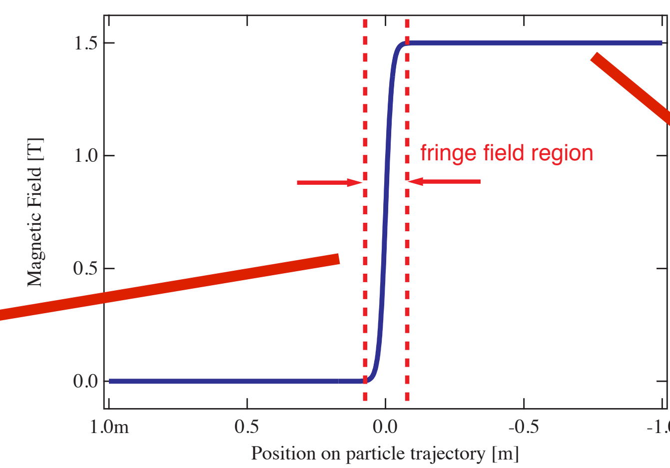
# Synchrotron (Edge) Radiation

- CSR is observed as ‘regular’ synchrotron radiation but also as ‘edge’ radiation
- Can be an advantage for a beamline
  - ➜ lower frequencies observable for the same aperture

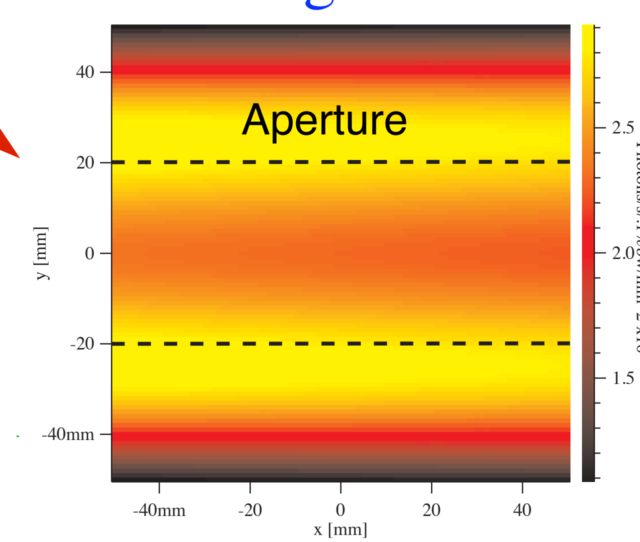



Source at ANKA–IR: fringe field




Main bending field as source



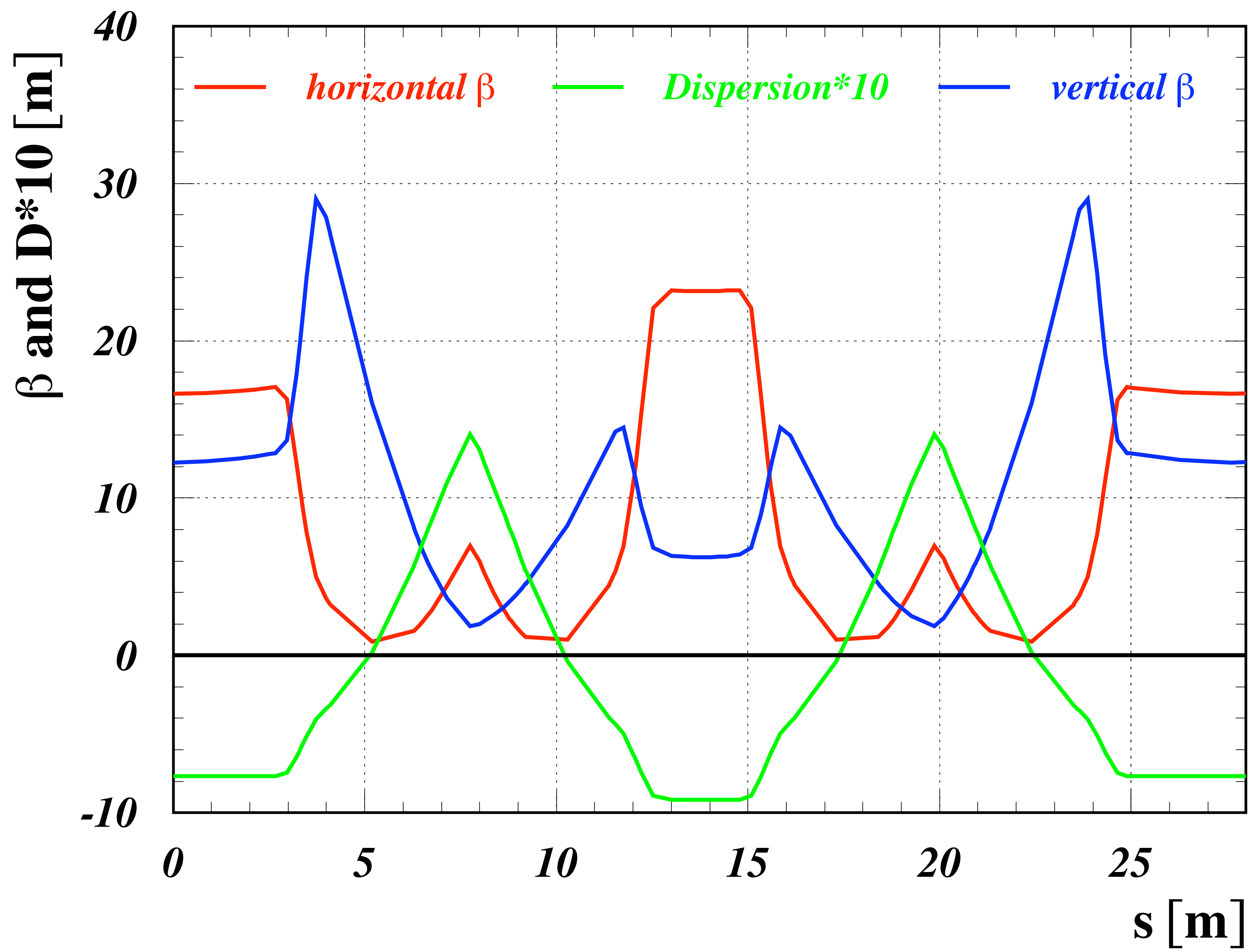

*Courtesy Y.-L.Mathis*

# Low-$\alpha_c$ Optics at ANKA

- Condition for CSR emission: $$\frac{2\pi\sigma_s}{\sqrt{\ln N}} \lesssim \lambda \lesssim 2h\sqrt{\frac{h}{\rho}}$$
  - ➜ for 100 µA/bunch: $1.4\,\sigma_s \lesssim \lambda \lesssim 4.9\,\text{mm}$
  - ➜ further bunch length reduction necessary

$$\alpha_c = \frac{1}{L}\oint ds\,\frac{D(s)}{\rho(s)}$$

- Dedicated low-$\alpha_c$ optics with negative dispersion in the long and short straight sections for flexible bunch length tuning following the pioneering work of e.g. BESSY II




- At ANKA: Observed momentum compaction factor range as extrapolated from $Q_s$ measurements:
  - ➜ from $7.2\ 10^{-3}$ to $1.4\ 10^{-4}$

# Momentum Compaction Factor

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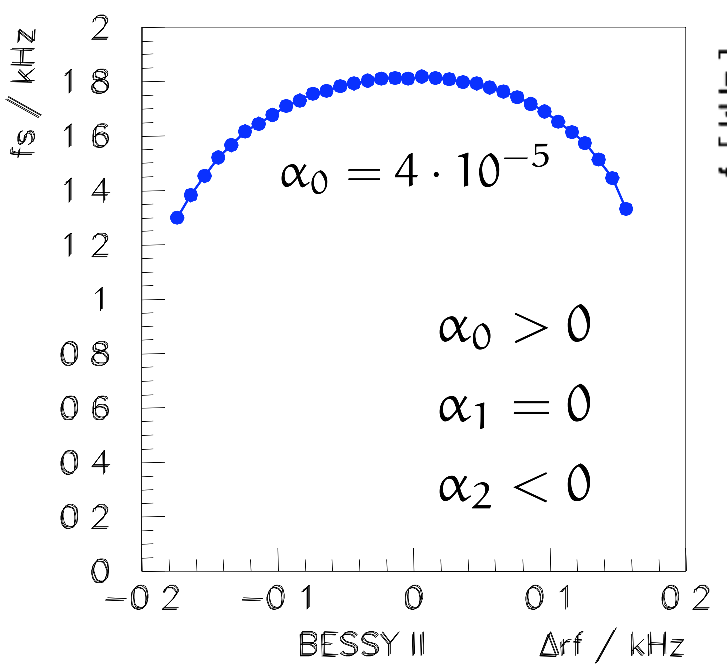
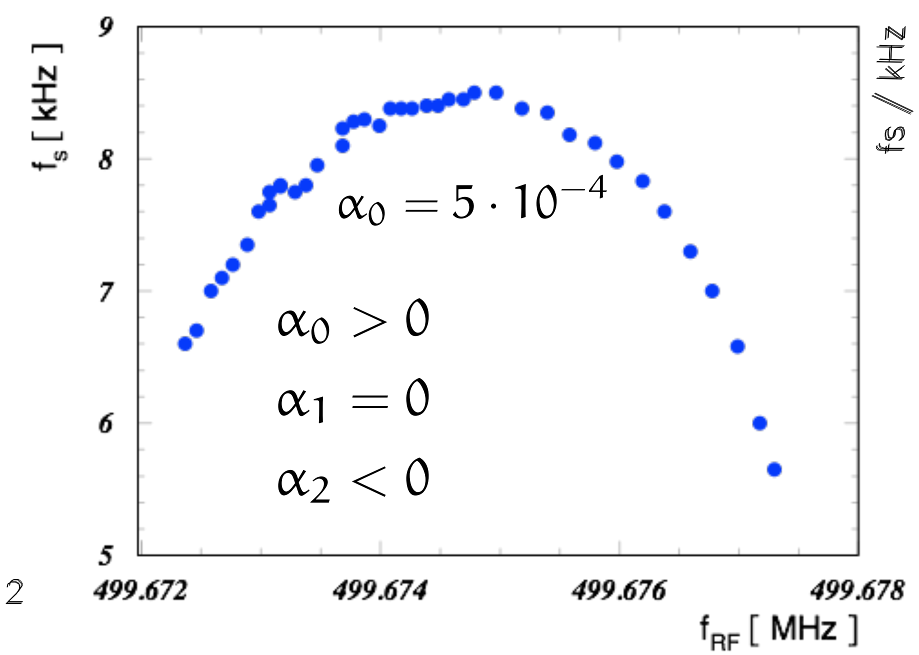
- Synchrotron frequency $f_s$ as a function of $\Delta f_{rf}$ detuning

**BESSY II**, 1.7 GeV
4 chrom. sext. families,
limited flexibility

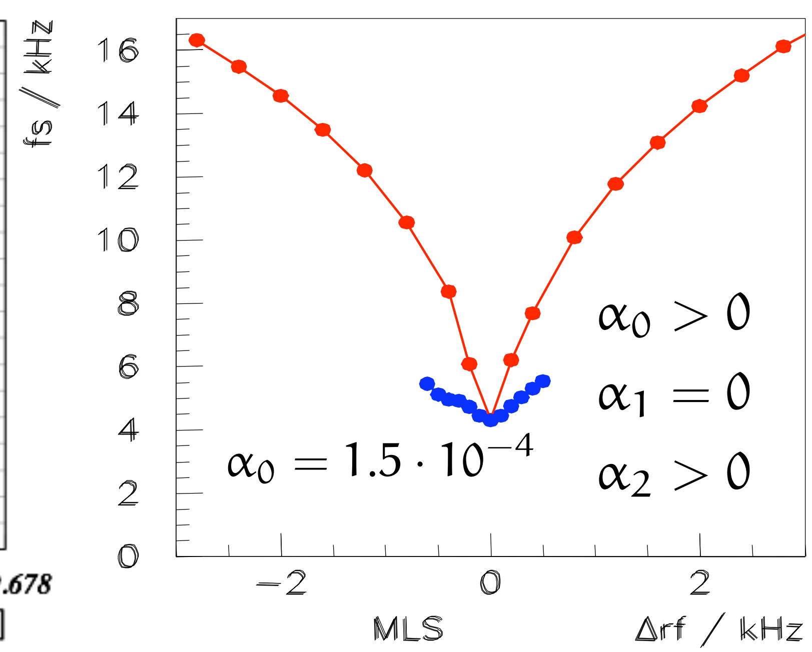



**ANKA**, 1.3 GeV
Low alpha optics,
2 chrom. sext. families




$\Delta f_{rf} \approx 4$ kHz

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




★ **MLS: <u>first ring</u> with low alpha correction scheme**

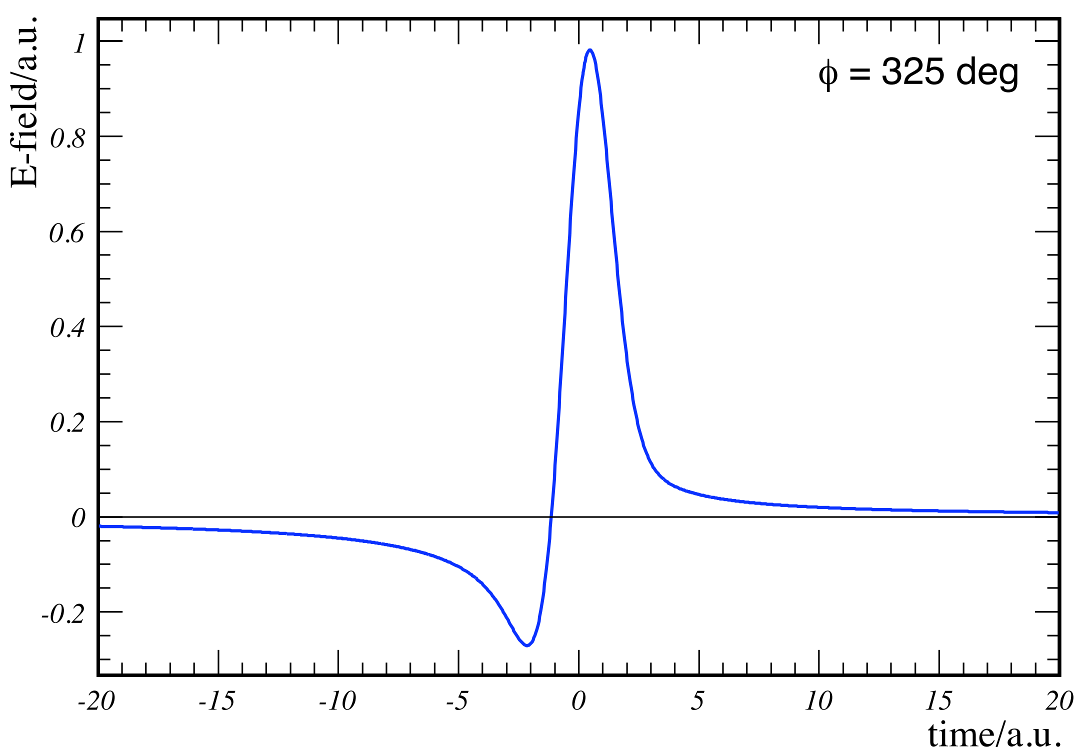
*G. Wüstefeld, HZB*

# THz Pulse in the Time Domain

- Superposition of plane waves emitted over the bunch:

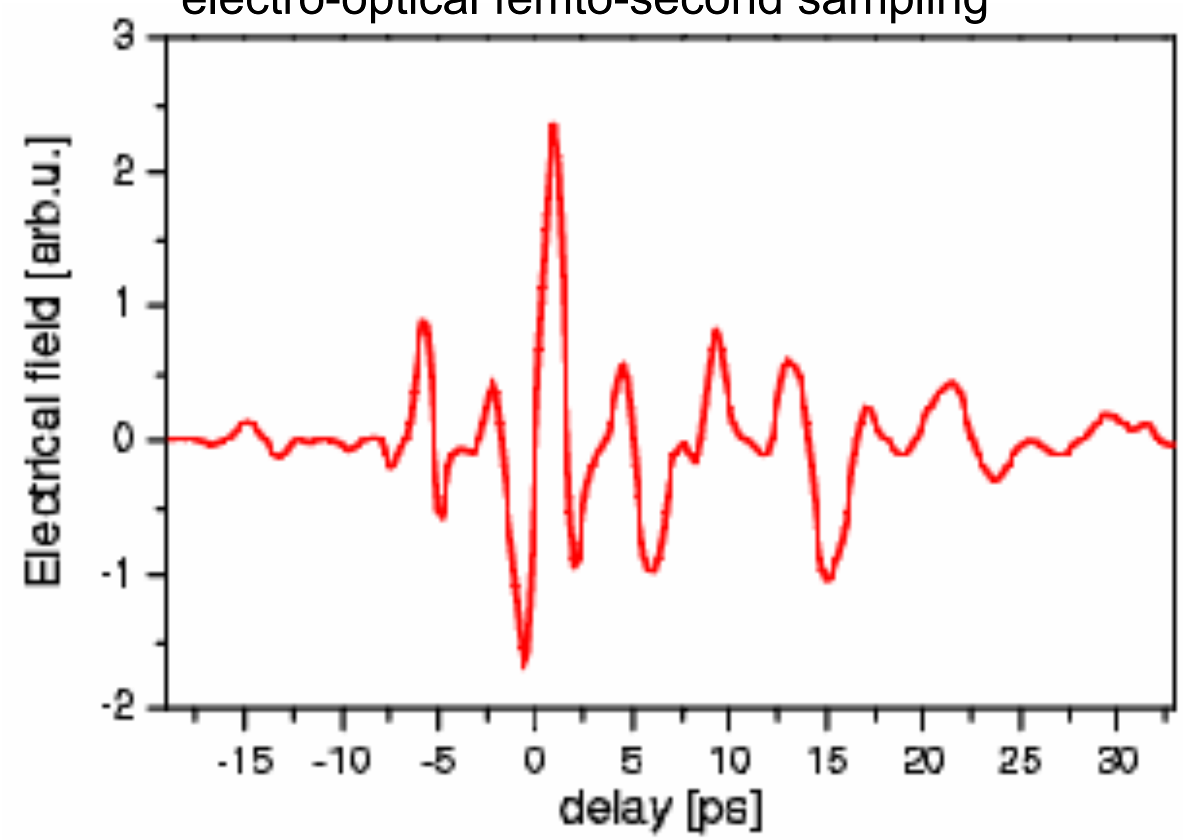
$$A(t) = \int_0^{\infty} d\omega \int_{-\infty}^{\infty} dx\, s(\omega)\, \rho(x)\, e^{-i\omega(t-x/c)}$$

- Resulting electrical field: $E(t) \sim \cos\phi \cdot \mathrm{Re}A(t) + \sin\phi \cdot \mathrm{Im}A(t)$
(The phase determines the relative weight of the two independent solutions. It is not fixed a priori and given by the ring structure.)




*ASM et al.: Modeling the Shape of Coh.THz Pulses Emitted by Short Bunches in an El. SR, EPAC 2008*

Phase sensitive detection of THz radiation with electro-optical femto-second sampling

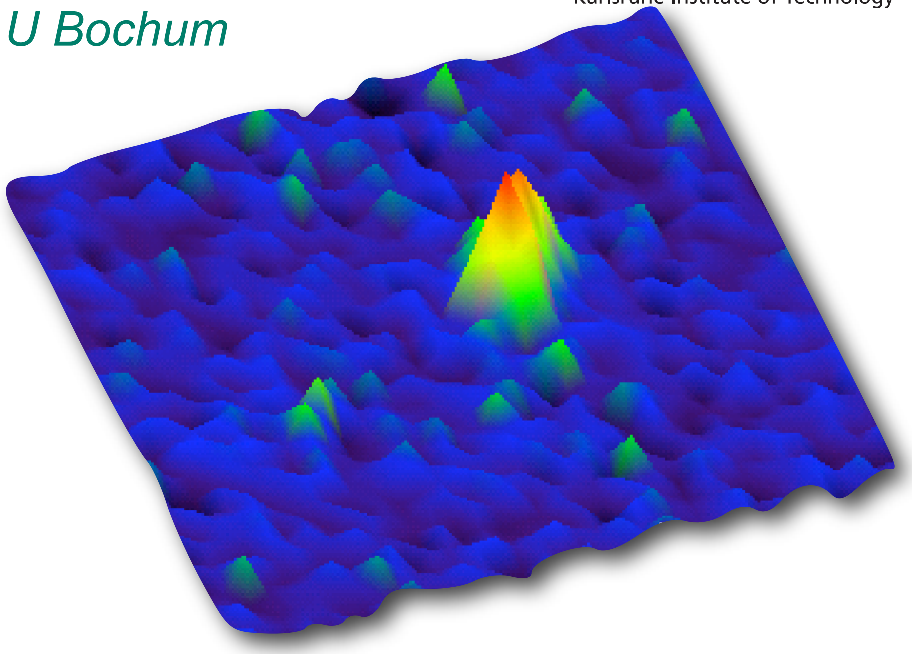



*A. Plech et al.: Electro-Optical sampling of Terahertz radiation emitted by short bunches in the ANKA synchrotron, PAC 2009*

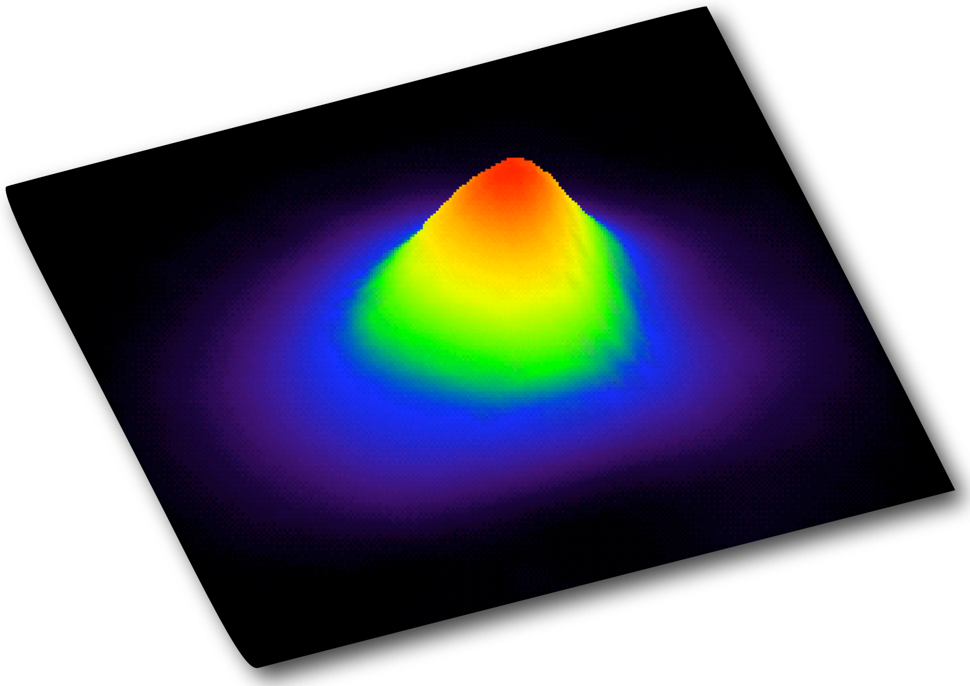
# The THz Beam Profile

- Setup of beam line and detector :
  - ➜ Measurement behind a Si or $CaF_2$ vacuum window
  - ➜ room temperature pneumatic (Golay) detector
  - ➜ aperture of 6 mm diameter (defined by white high density polyethylene window) plus add. 1.9 mm diameter aperture in front of the detector for better spatial resolution
  - ➜ two 0.1 mm thick foils of black low density PE to further reduce IR and visible radiation
  - ➜ setup with 10 Hz chopper and Lock-In amplifier
  - ➜ detector and aperture are mounted on a x-y imaging stage and scanned vs distance and lateral position relative to the vacuum window

*Courtesy E. Bründermann, U Bochum*



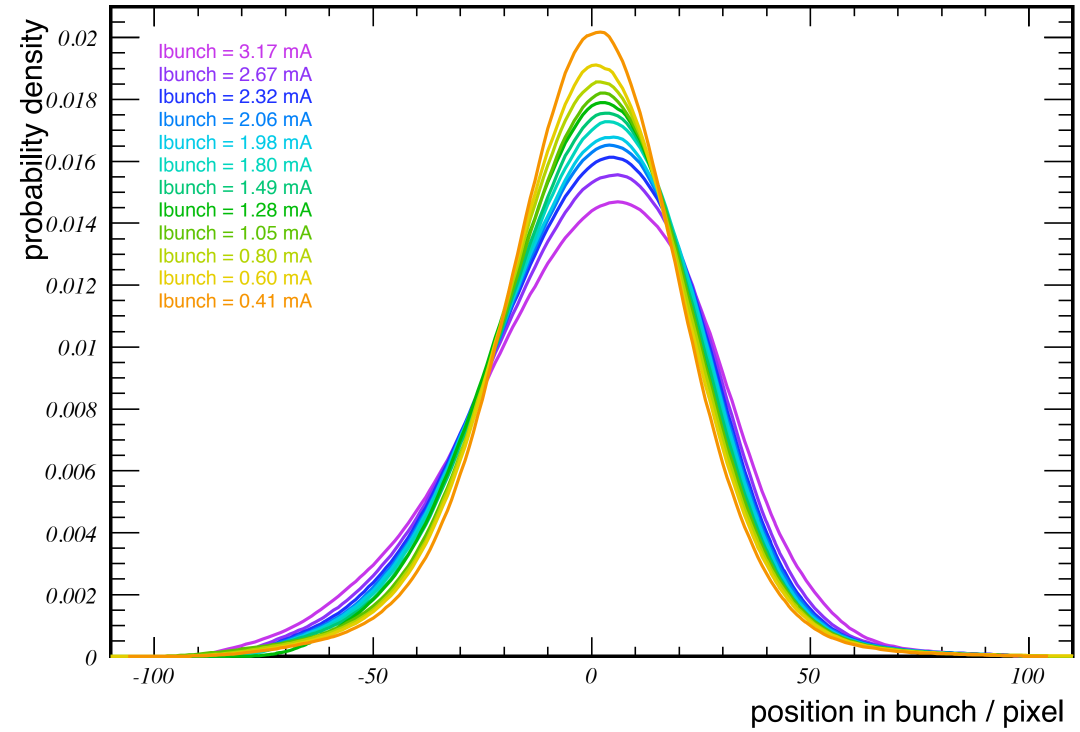
incoherent, $A_{max} \approx 0.1$ mV



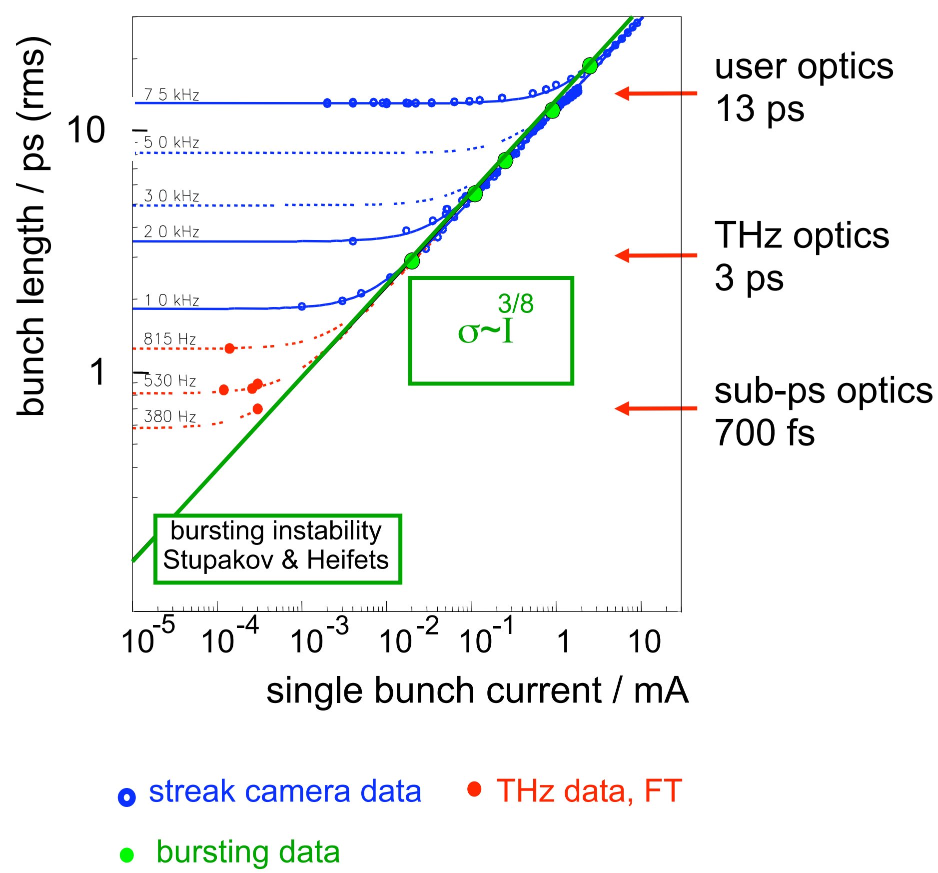
coherent, $A_{max} \approx 2.9$ mV

# Bursting Threshold

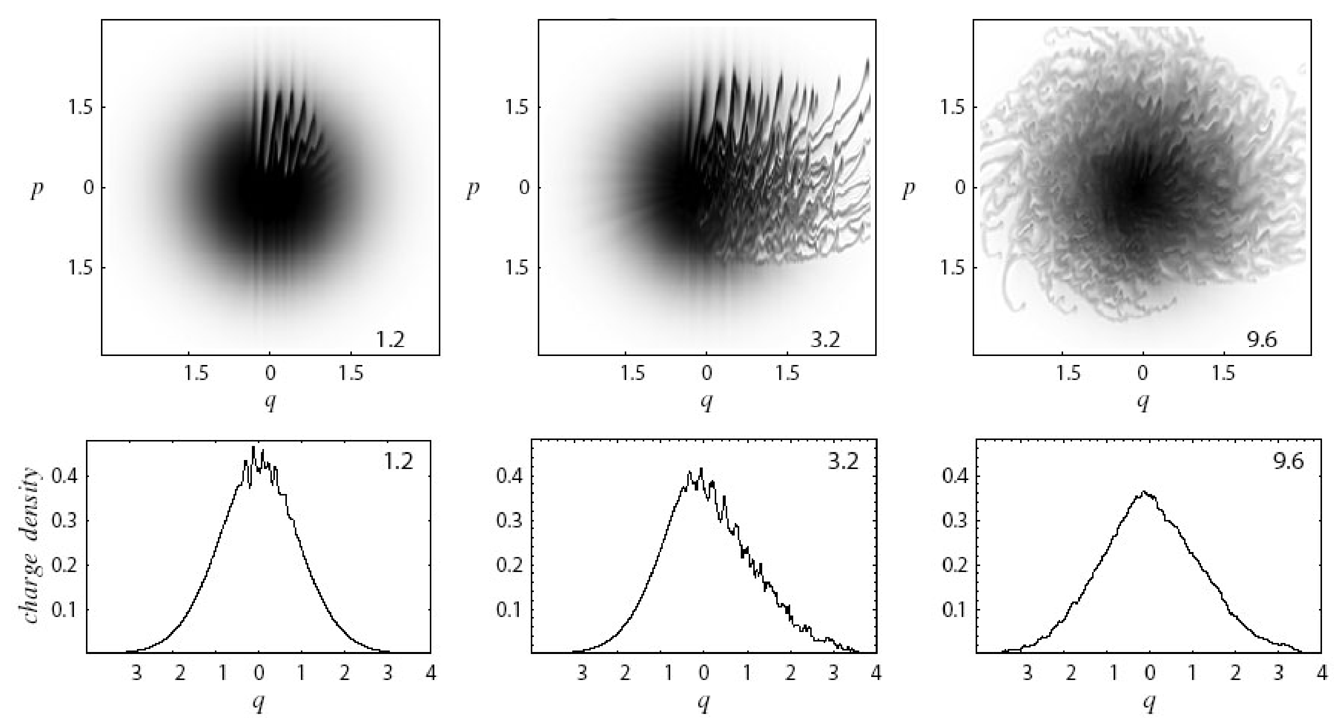
- CSR-Bunch interaction:
  - ➜ deformation with increasing current
  - ➜ above threshold a microbunching instability results in (periodic) burst of high intensity




BESSY II bunch length - current scaling




*G. Wüstefeld, HZB*




*M. Venturini and R. Warnock, PRL 89, 224802 (2002)*

# Time Evolution of CSR Emission

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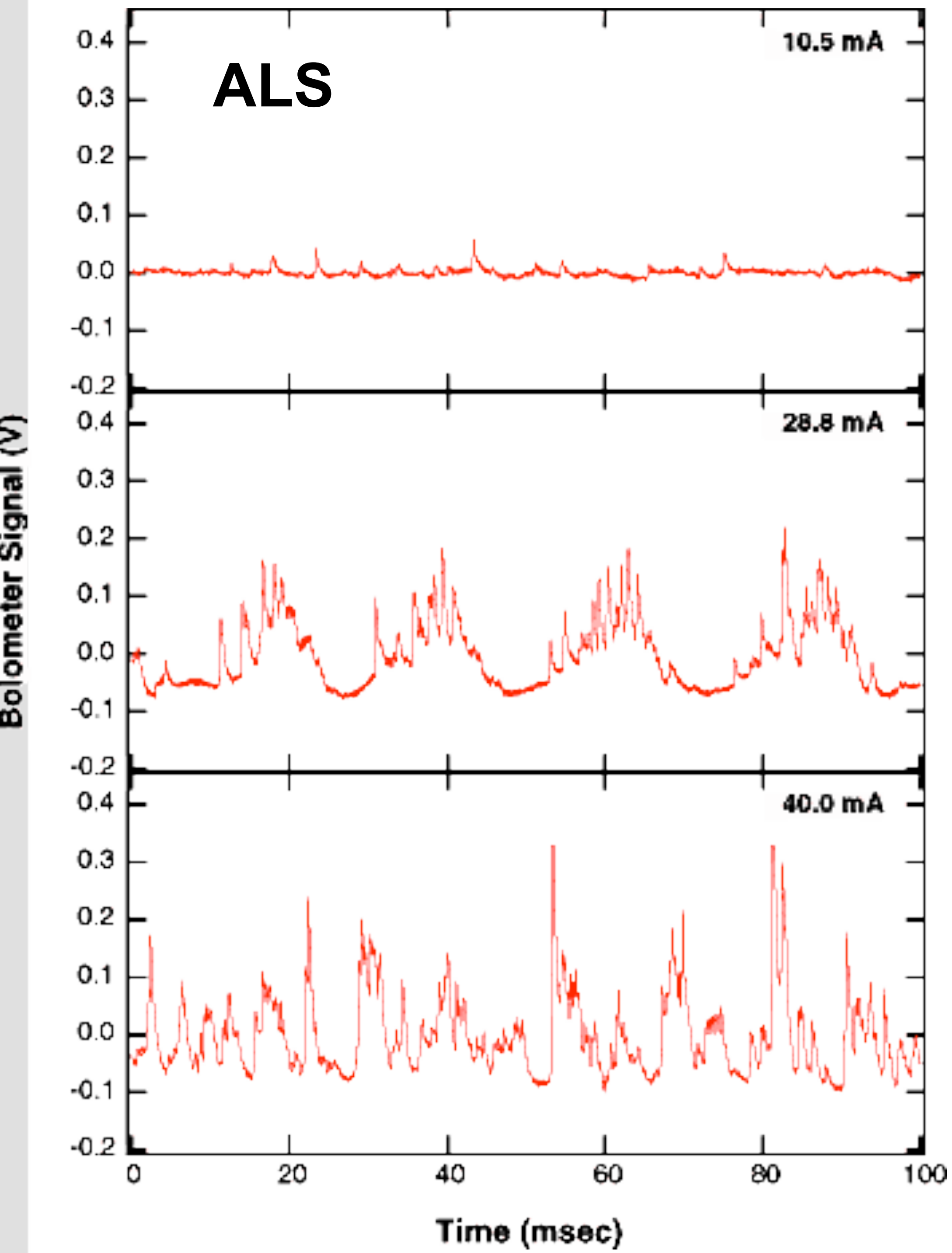
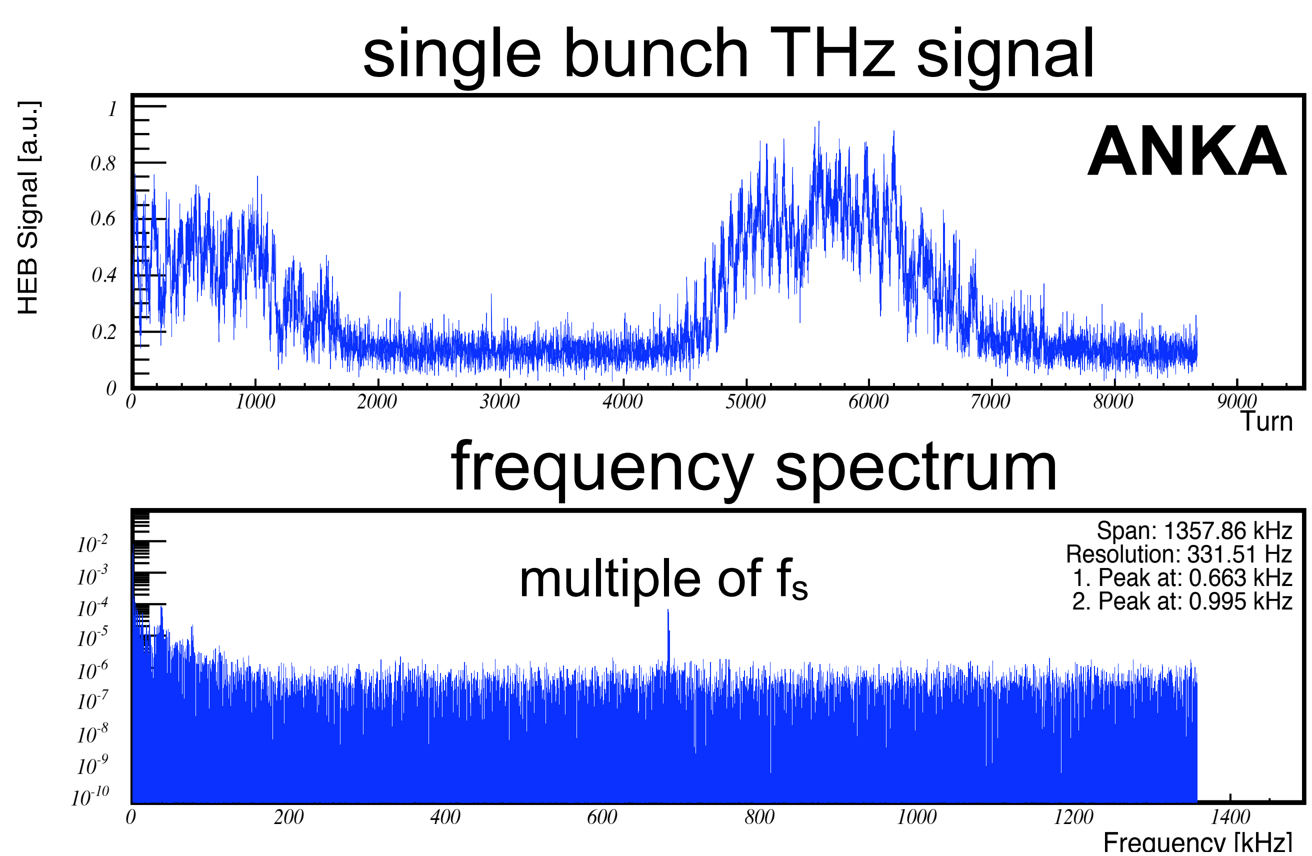



*J. Byrd et al., PRL 89, 224801 (2002)*

- Saturation of the generating instability and subsequent radiation damping leads to a sawtooth-like pattern as a function of time



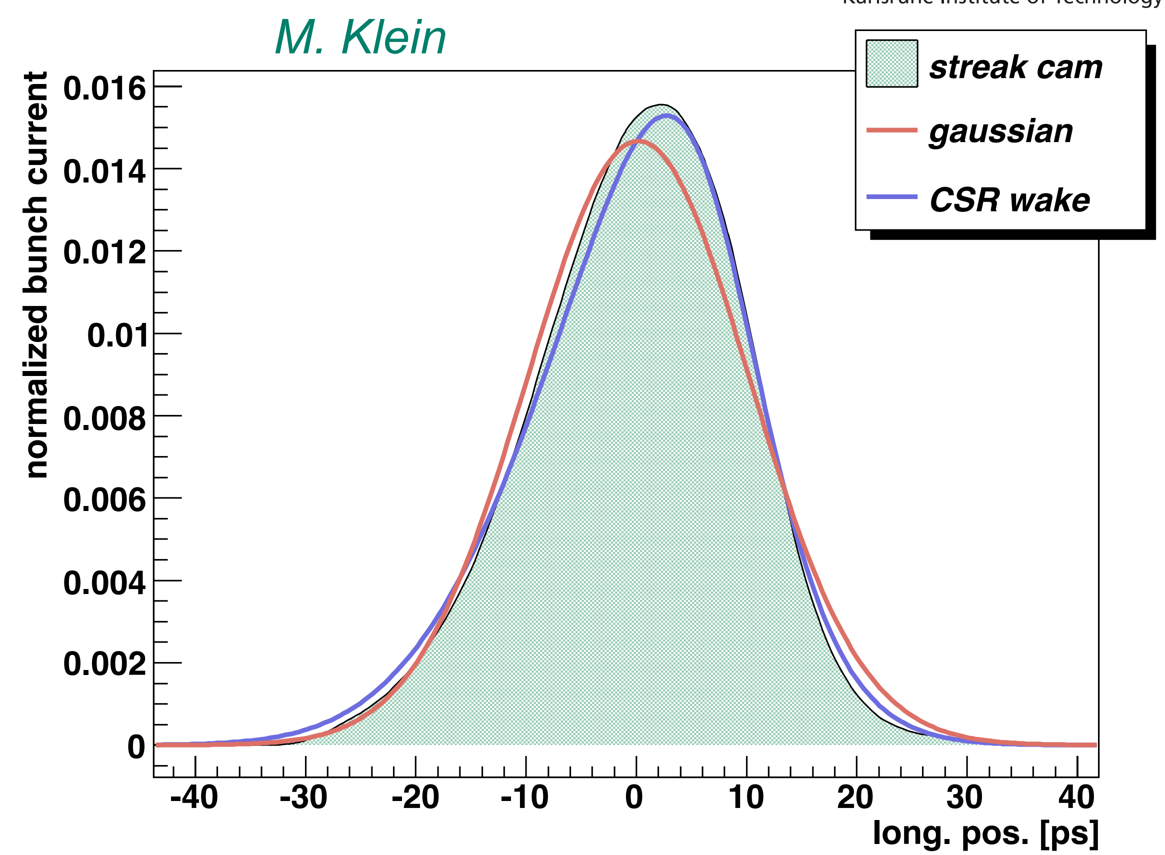

*V. Judin*

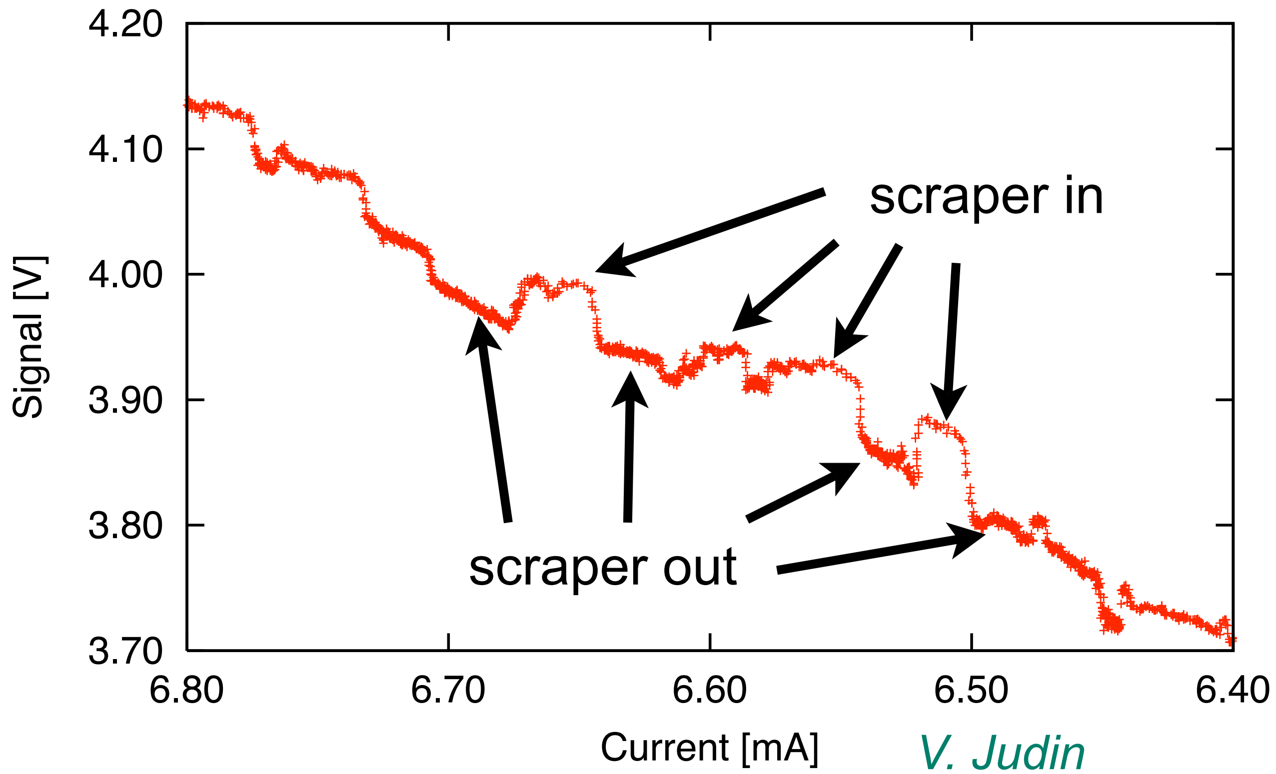
# Impedance & CSR Power

- The total power radiated by a bunch of N particles is described by

$$P_{total} = N P_{incoh}(1 + N f_\lambda)$$

  ➜ change in form factor $f_\lambda$ is seen on the emitted THz power



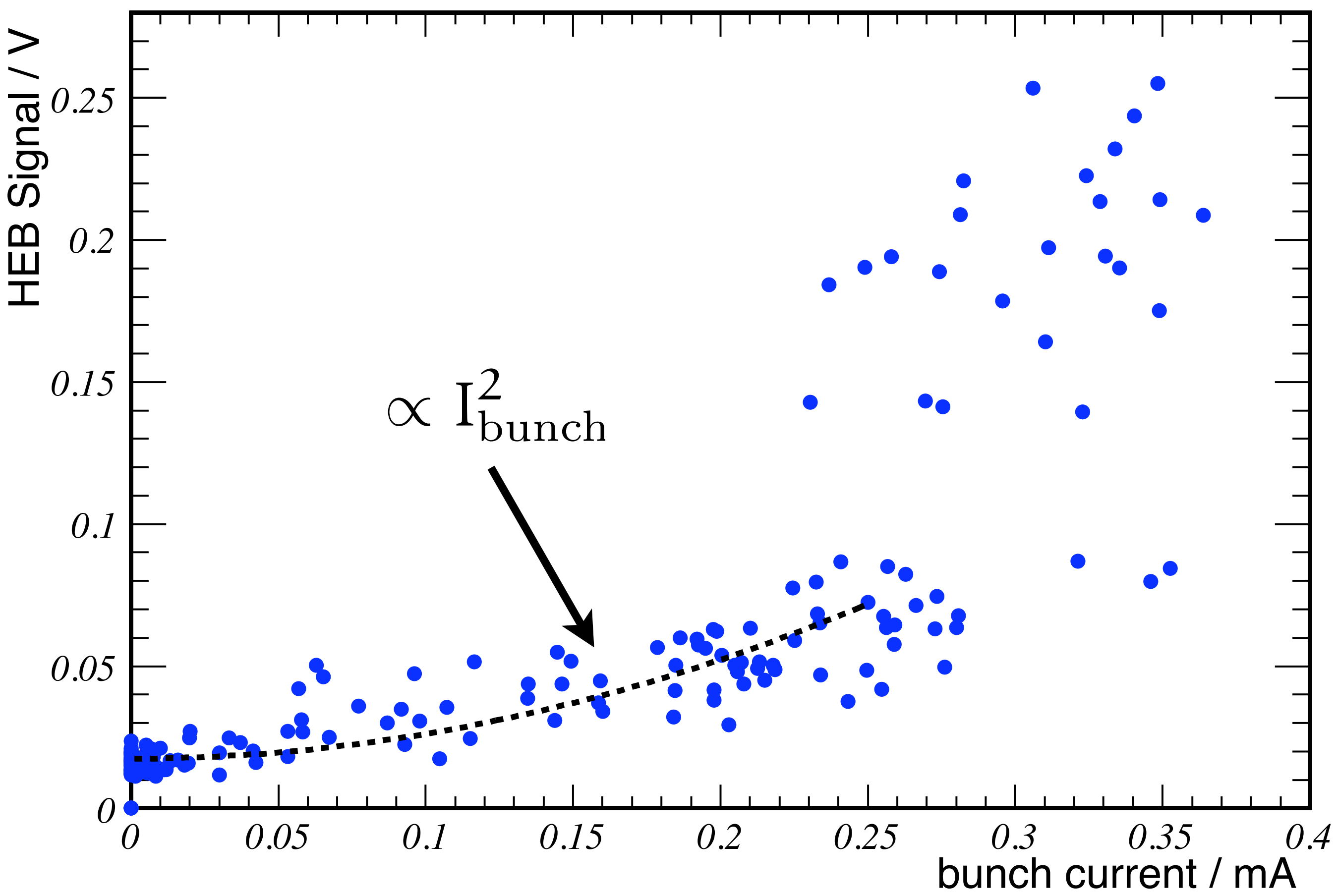



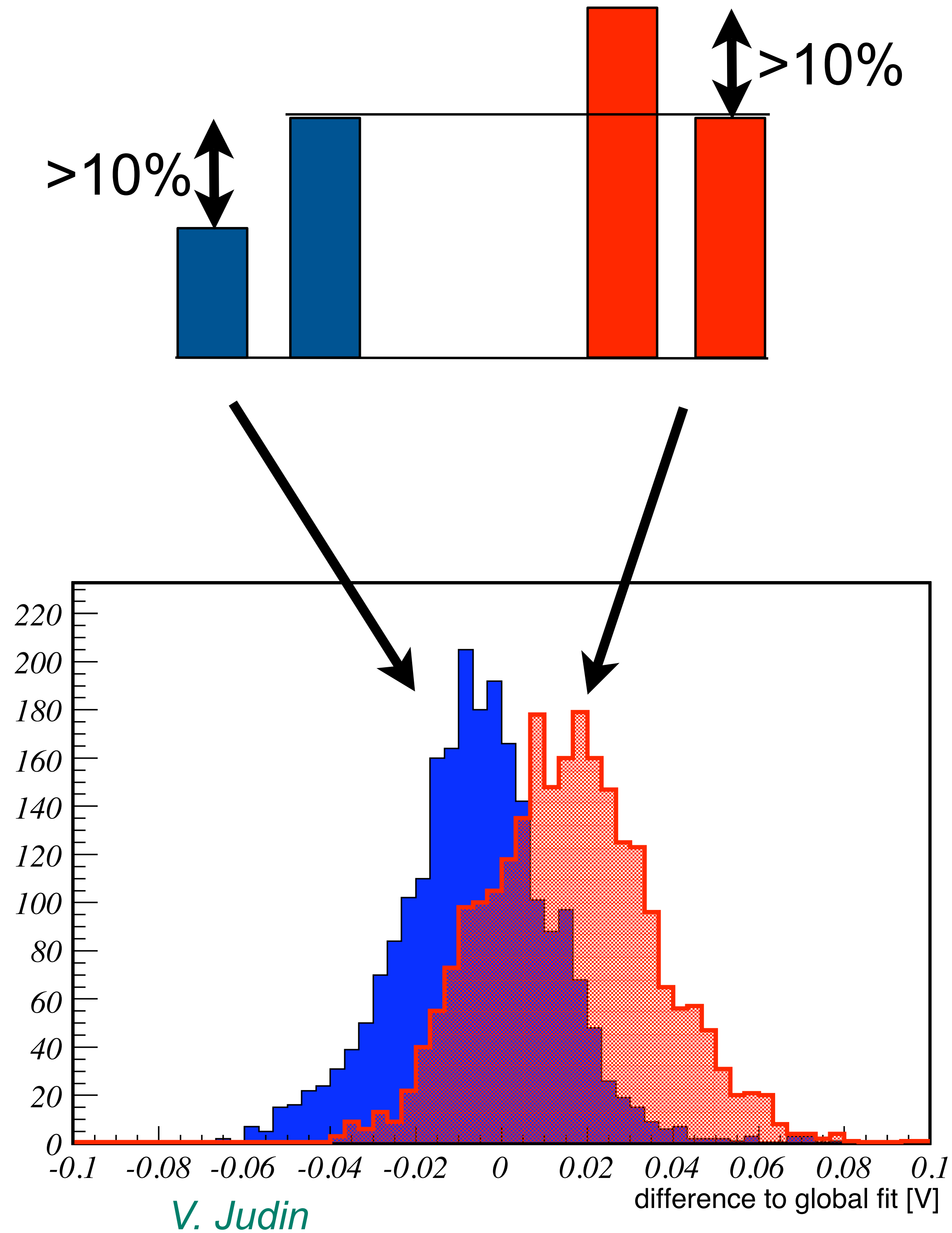

- Controlled change of the impendance by an asymmetric vertical scraper

  ➜ clear influence on emitted CSR

# Single & Multi-Bunch Effects

- Fast THz detector (HEB) allows to study signals from individual bunches in a multi-bunch environment




➜ THz emission depends on filling pattern

# Summary

- Unshielded CSR is an important effect for electron rings with short bunches
  - ➜ radiation from main and fringe fields
  - ➜ mainly in the THz range

- Dedicated low-$\alpha_c$ optics

- CSR emission changes
  - ➜ with bunch current (stable ➜ bursting)
  - ➜ with shape of charge distribution (CSR & other impedances)

# Summary

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**Help wanted!**
Open position in beam dynamics of short bunches