Operation of the ANKA Storage Ring with Short Bunches

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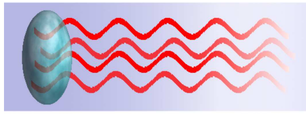


Overview

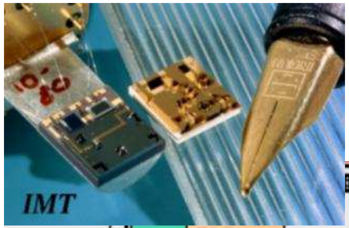
- Brief introduction to ANKA
- A low-α_c optics for ANKA
- Establishing the operation mode
- The ANKA-IR beamline
- Beam size and current
- The FIR spectrum
- Summary & Outlook

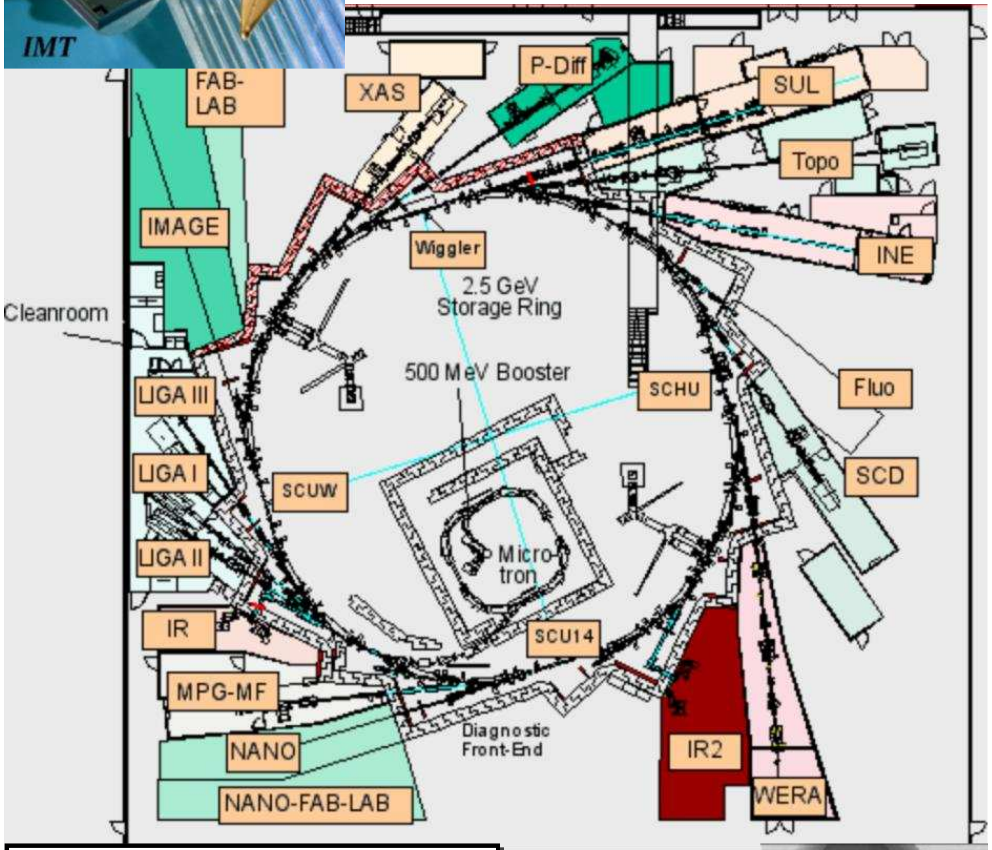
Research & development in various fields:

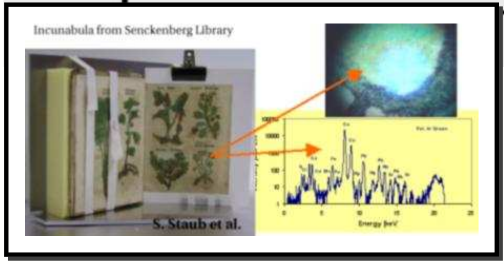
- environmental analysis
- medicine/bio technology
- material science
- microsystem technology
- (astro) particle physics
- IT science
- nano technology
- ...

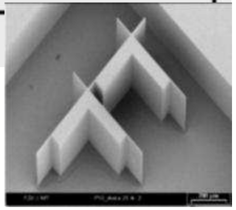
The ÅNgström Source KArlsruhe

- Electron storage ring
  - ➜ injection energy 0.5 GeV
  - ➜ special operation 1.3 GeV
  - ➜ nominal energy 2.5 GeV
- Insertion Devices
  - ➜ NC wiggler
  - ➜ NC undulator
  - ➜ SCU14 (demonstrator)
- Beamlines
  - ➜ IR (1)
  - ➜ Spectroscopy (4)
  - ➜ Scattering/Imaging (4)
  - ➜ LIGA (3)



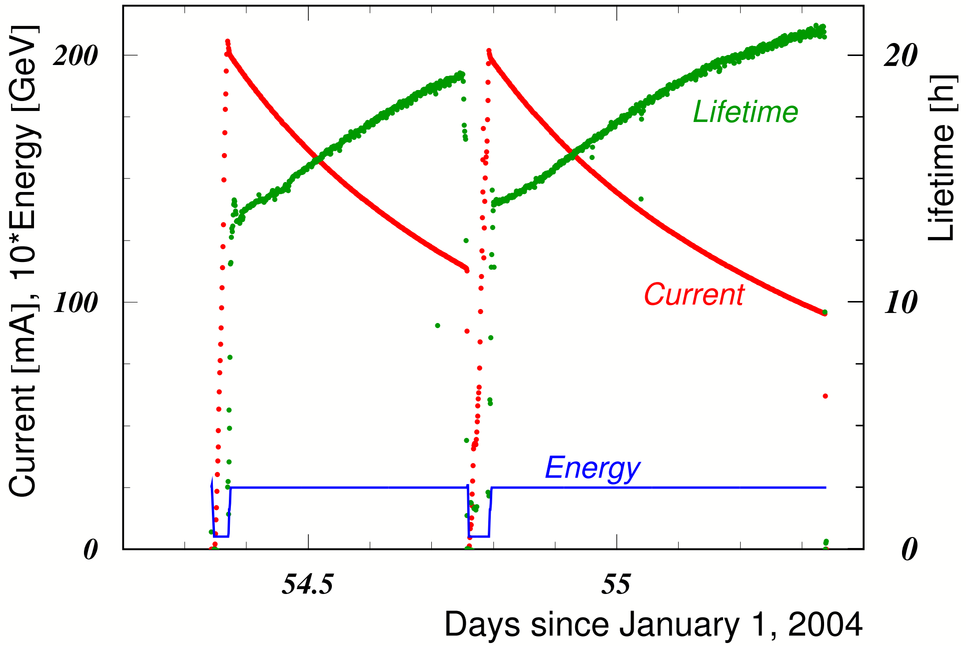


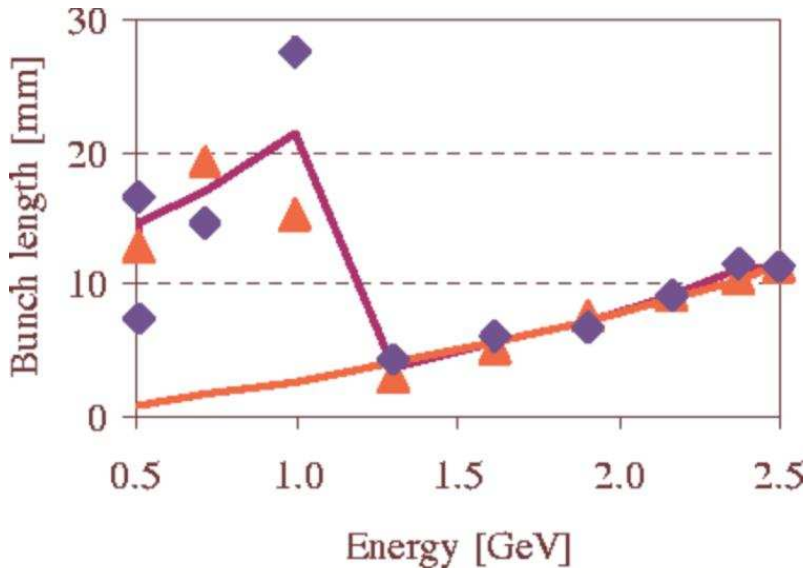




Bunch Length and Beam Energy

- Standard operation:
  two injections per day at
  0.5 GeV, ramped to 2.5 GeV
- Special operation at 1.3 GeV
  e.g. for LIGA
- Measure bunch length as a
  function of the beam energy

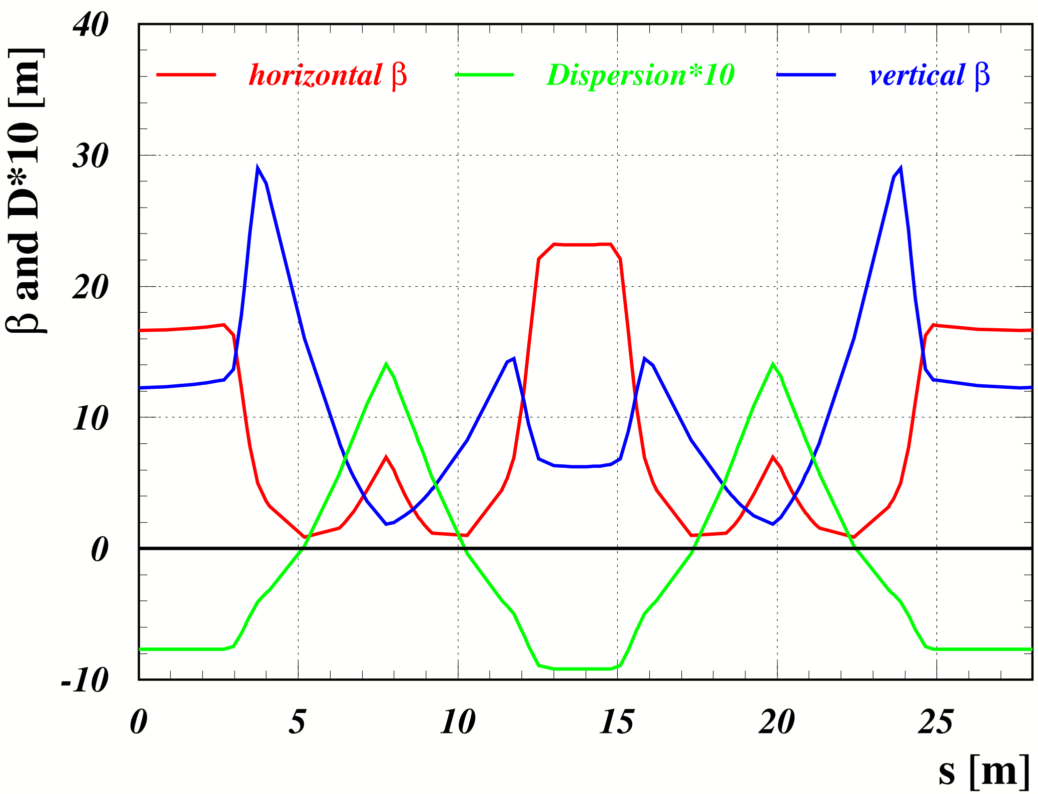




- Measure by recording RF harmonics of bunch spectrum: FT is related to σ_s
- Longitudinal instability due to one higher order cavity mode for $E_0 < 1$ GeV
  - ➜ Energy of choice for short bunch operation: 1.3 GeV

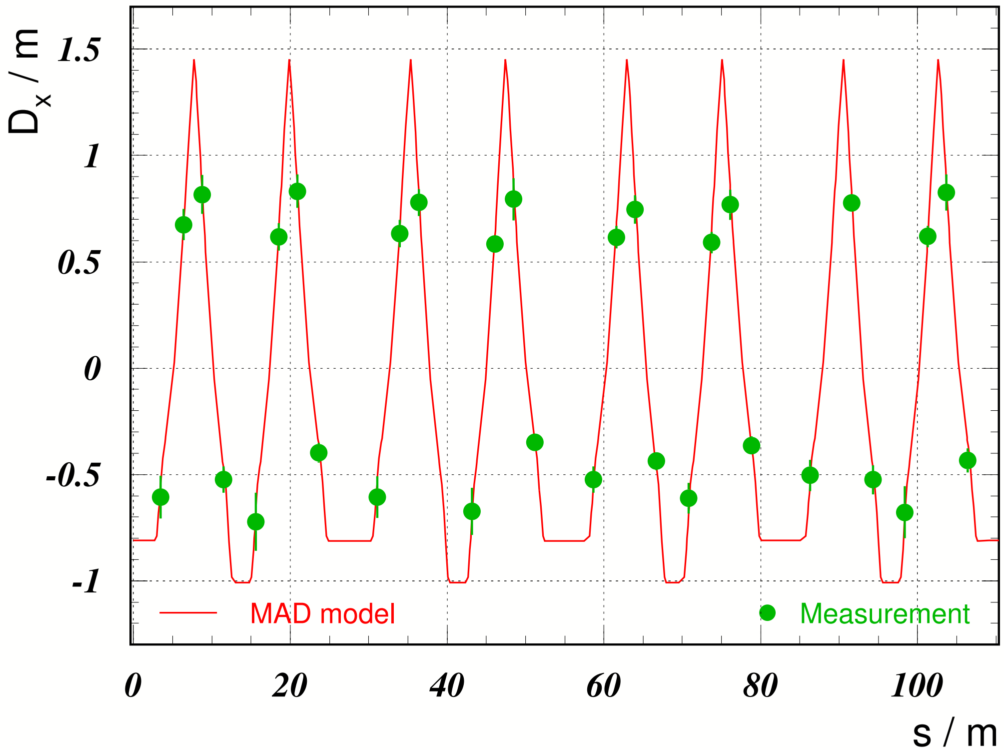
The Low-α_c Optics

- Condition for CSR emission: $\frac{2\pi\sigma_s}{\sqrt{\ln N}} \lesssim \lambda \lesssim 2h\sqrt{\frac{h}{\rho}}$
  - ➜ for 100 μA/bunch: $1.4\,\sigma_s \lesssim \lambda \lesssim 4.9$ mm
  - ➜ further bunch length reduction necessary
- A dedicated low-α_c optics with negative dispersion in the long and short straight sections has been put in operation following the pioneering work of e.g. BESSY II

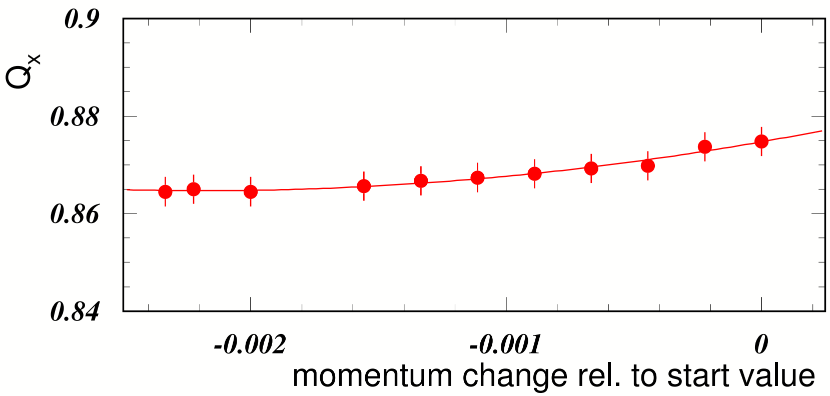


- Observed momentum compaction factor range as extrapolated from Q_s measurements:
  - ➜ from $7.2 \cdot 10^{-3}$
  - ➜ to $1.4 \cdot 10^{-4}$

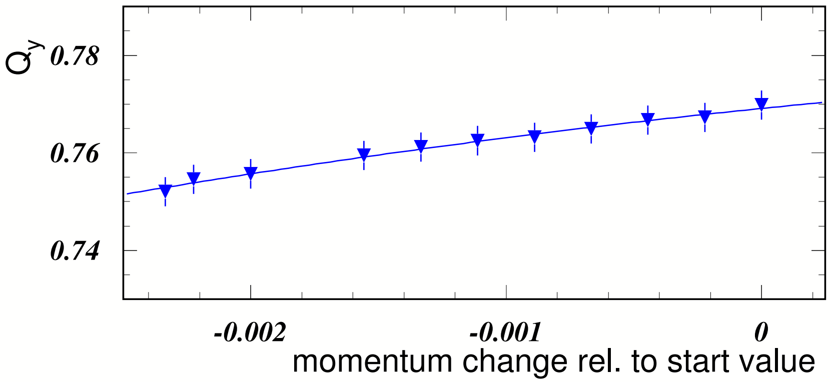
Optics Measurements



- Calculated (MAD model) and measured horizontal dispersion for $\alpha_c = 0.5 \cdot 10^{-3}$



- Measured chromaticities for $\alpha_c = 0.5 \cdot 10^{-3}$
  - ➜ $Q'_x = 9.2 \pm 1.7$
  - ➜ $Q'_y = 5.3 \pm 1.9$



Measurements of α_c I

- Measurement at 2.5 GeV with resonant depolarisation: true energy shift as a function of change in RF frequency

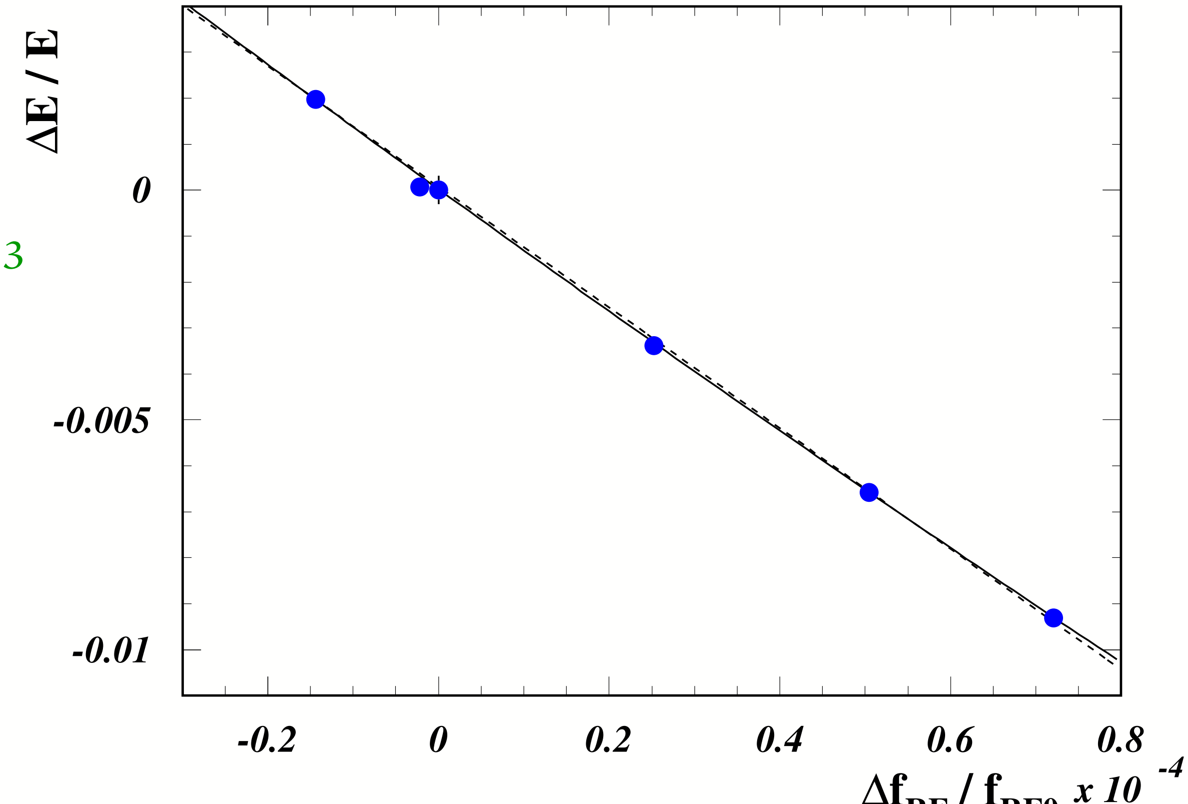
$$\frac{\Delta f_{RF}}{f_{RF}} = \alpha_{c1}\,\delta + \alpha_{c2}\,\delta^2$$

➜ Expectation for linear term: $7.2 \cdot 10^{-3}$

➜ $\alpha_{c1} = (7.39 \pm 0.01) \cdot 10^{-3}$

➜ $\alpha_{c2} = (4.1 \pm 0.2) \cdot 10^{-2}$

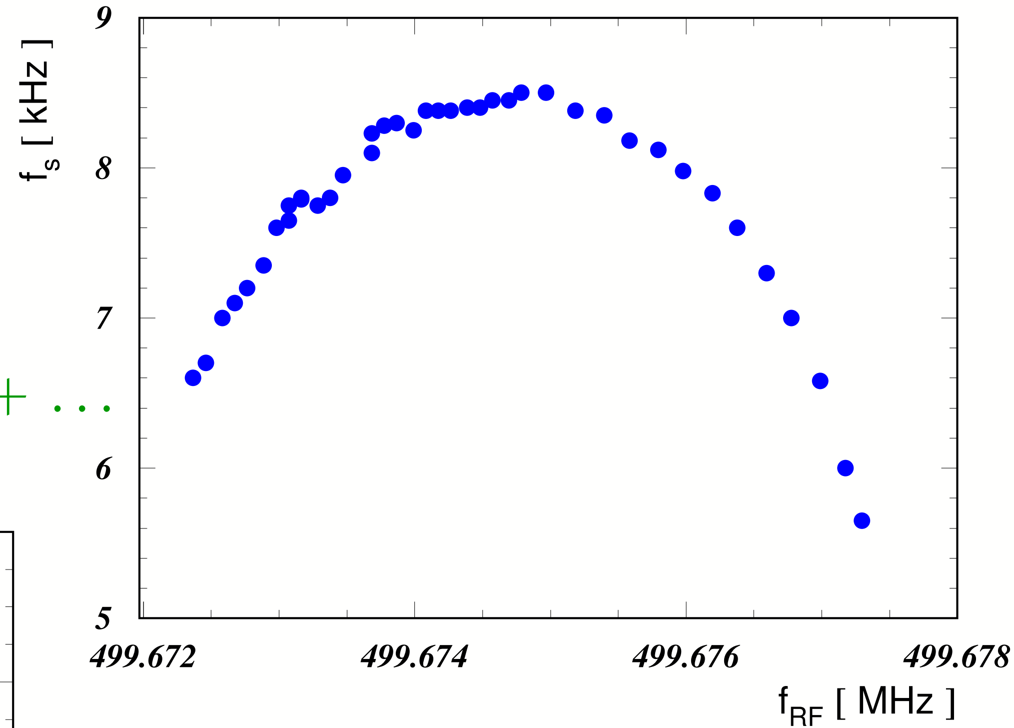
(highly significant but quite small)

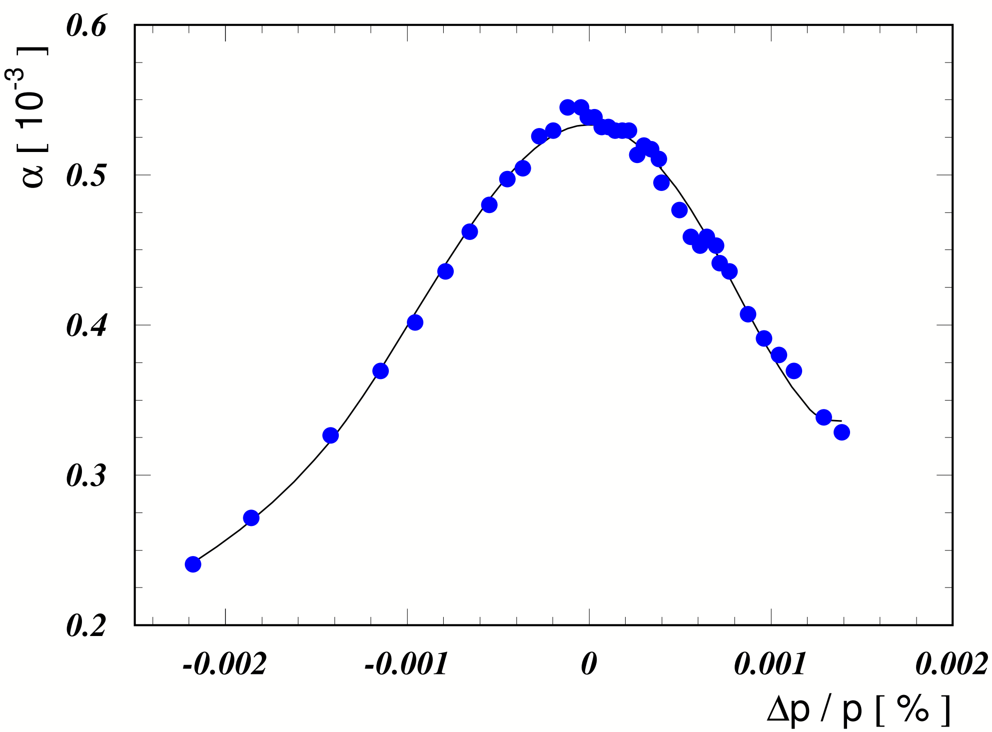


Measurements of α_c II

- Derive momentum compaction factor in the low-α_c mode using scans of f_s measured with a strip line

$$\alpha_c = \alpha_{c0} + \alpha_{c1}\frac{\Delta p}{p_0} + \alpha_{c2}\left(\frac{\Delta p}{p_0}\right)^2 + \ldots$$

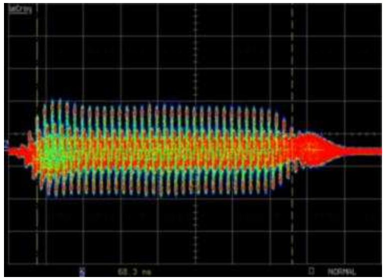


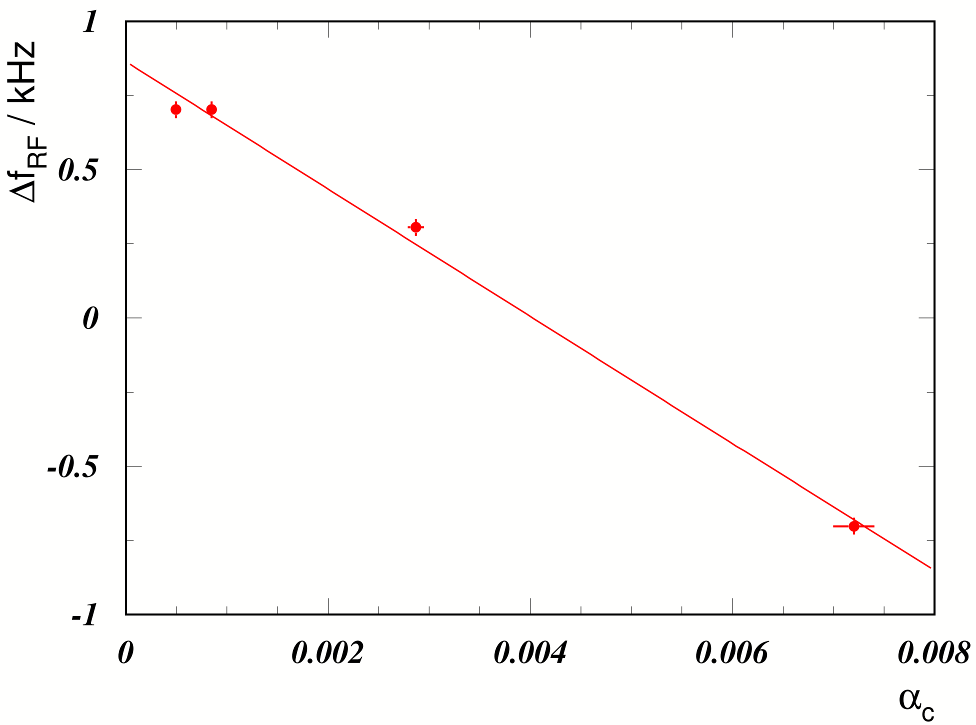


- Fit results:
  - ➔ $\alpha_{c0} = +(0.533 \pm 0.002)\cdot 10^{-3}$
  - ➔ $\alpha_{c1} = +(0.7 \pm 3.7)\cdot 10^{-3}$
  - ➔ $\alpha_{c2} = -(185 \pm 5)$

Operation in the Low-α_c Mode

- Energy ramp (regular optics)
  - ➜ fill 1 train (34 bunches) at 0.5 GeV, ramp to 1.3 GeV
- Low-α_c "squeeze"
  - ➜ change quadrupoles & sextupoles in small steps
  - ➜ orbit correction between steps



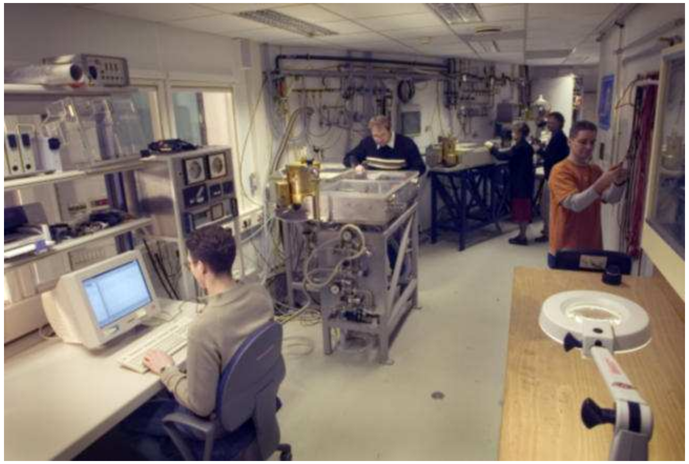


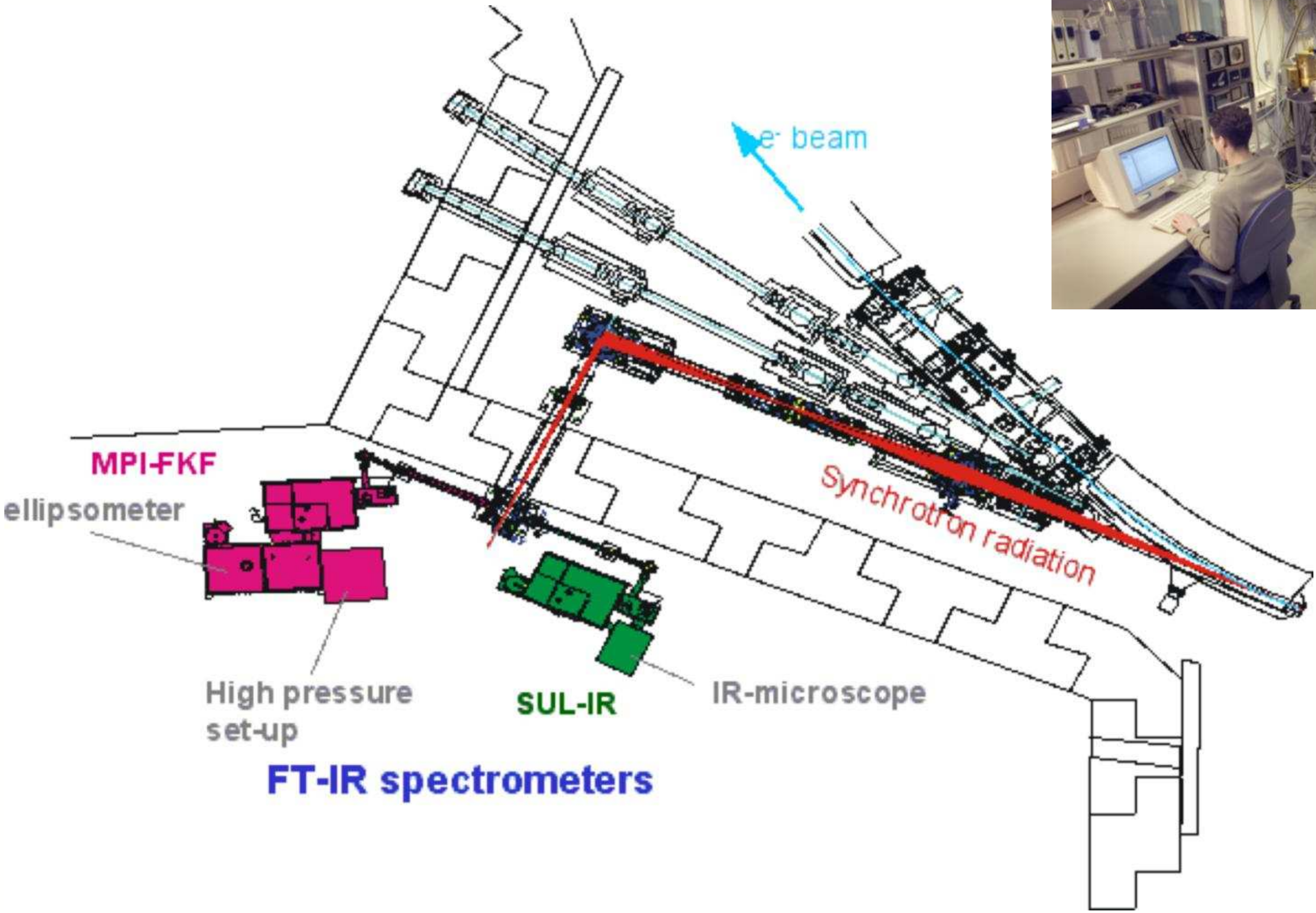
- RF frequency adjustment
  - ➜ Beam energy: $E \propto \oint B dL$
  - ➜ contribution from correctors
  - ➜ depends on α_c
  - ➜ solution: correct simultaneously orbit and f_{RF}

$$\frac{\Delta p}{p} = -\frac{1}{\alpha_c}\frac{(f_{RF} - f_{RF}^c)}{f_{RF}}$$

The ANKA-IR Beamline

- Edge radiation beamline





FT-IR spectrometer

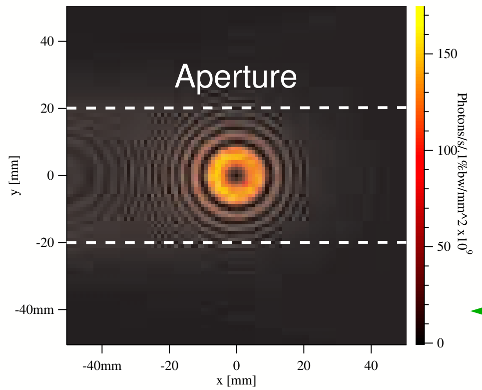
Ellipsometer

IR-Microscope

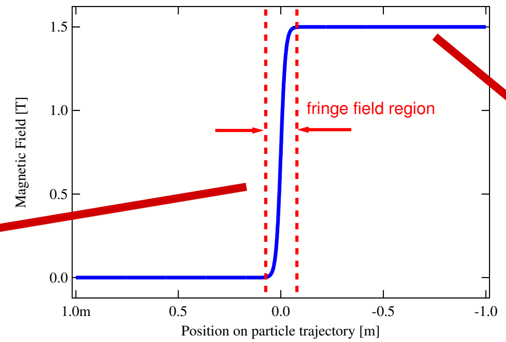
Edge Radiation?

- Advantage: more collimated than constant field radiation
  - ➜ allows the observation of frequencies up to 30 GHz through a modest vertical aperture, which would not be possible with classical constant field emission due to the increasing beam divergence with decreasing frequency

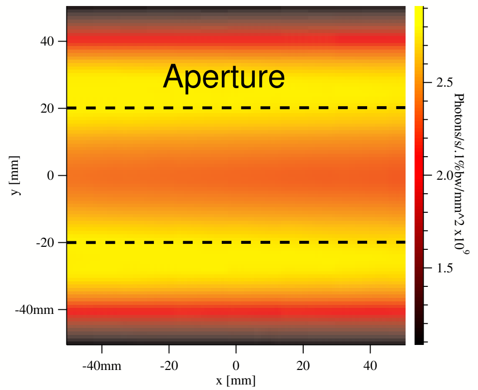
Source at ANKA–IR: fringe field



(spatial distribution of the radiation 3m from the source)



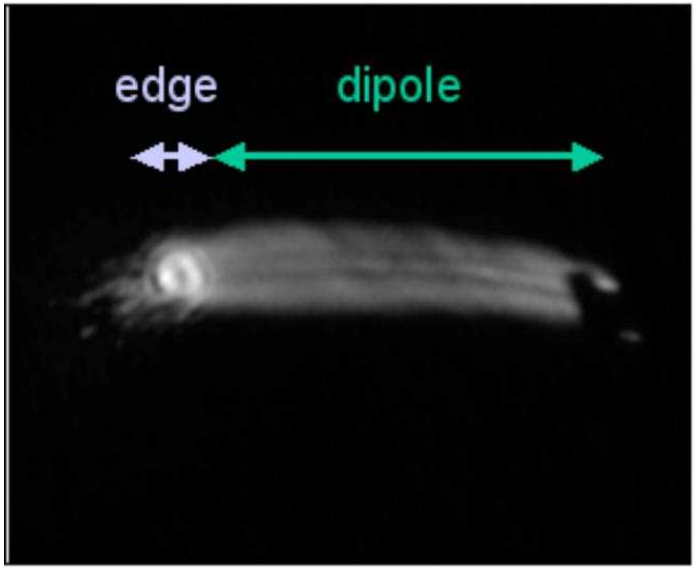
Main bending field as source



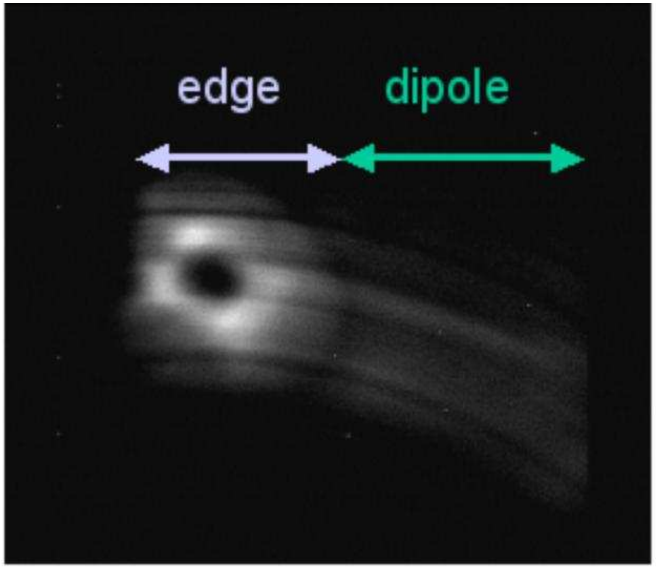
(spatial distribution of the radiation 3m from the source)

Calculated for a frequency of 3 THz

Edge Radiation!



in the visible

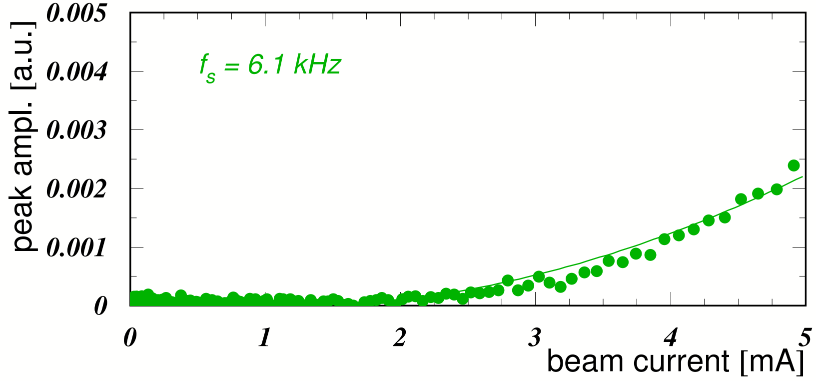


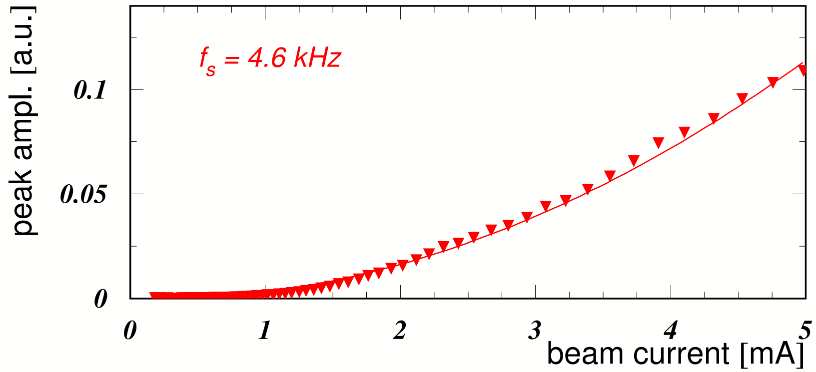
in the mid-IR (700-1400 cm^{-1})

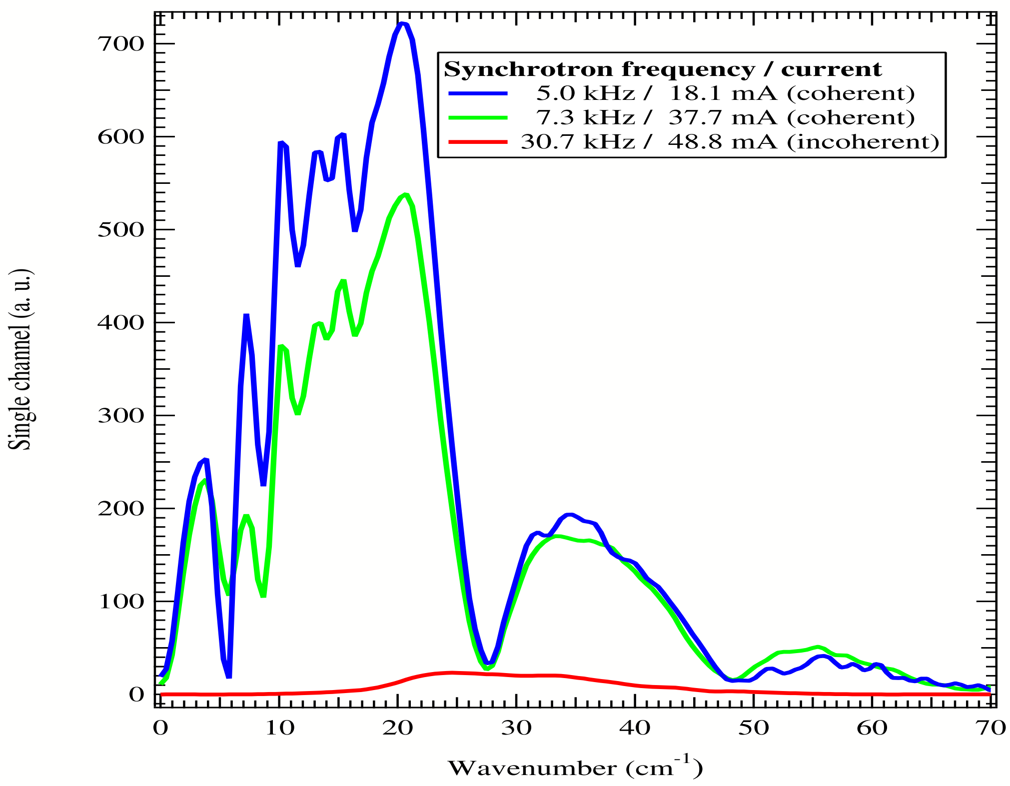
- Detector used for CSER studies: liquid He cooled Si bolometer
- The Spectral dependence is recorded using a Bruker IFS66v/S spectrometer equipped with Mylar beam splitters with thicknesses between 6 and 125 μm depending on the application.

FIR Spectrum

- The inferferogram peak height as a function of beam current clearly shows a quadratic behaviour ➜ CSR

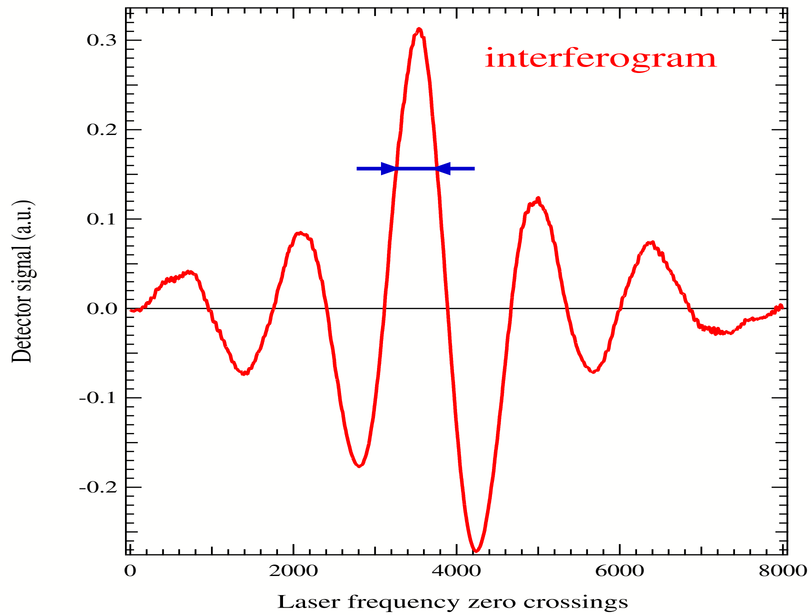




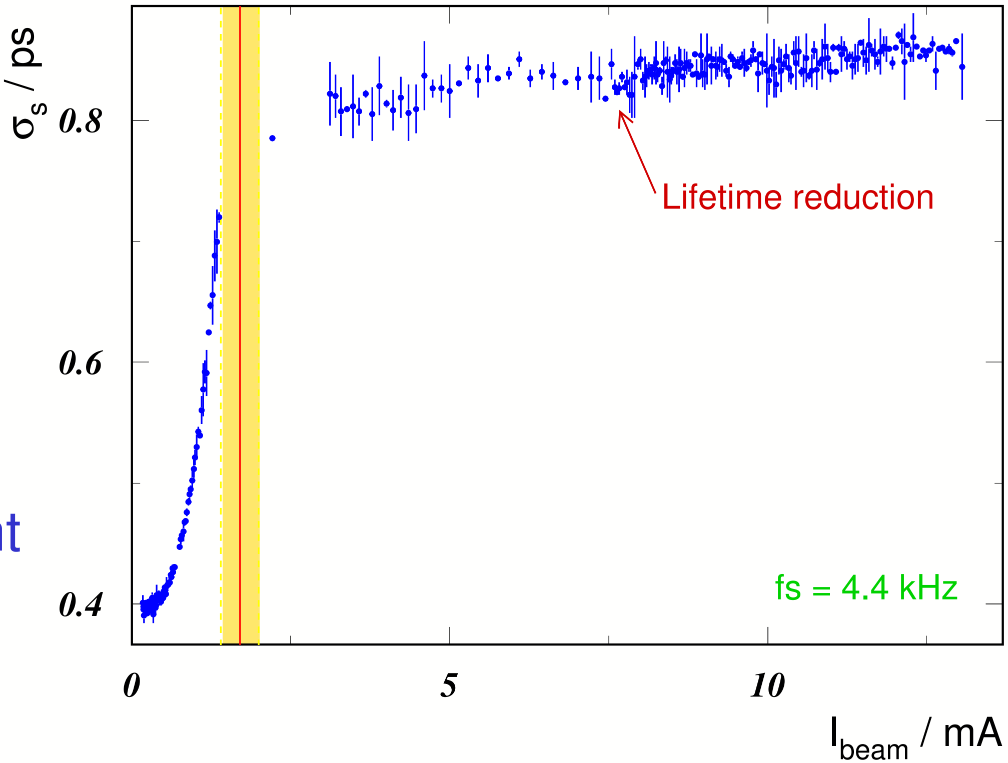


- Individual spectral regions show different current dependence
  ➜ change of effective bunch length/instability regime?

Beam Size from IR Interferogram

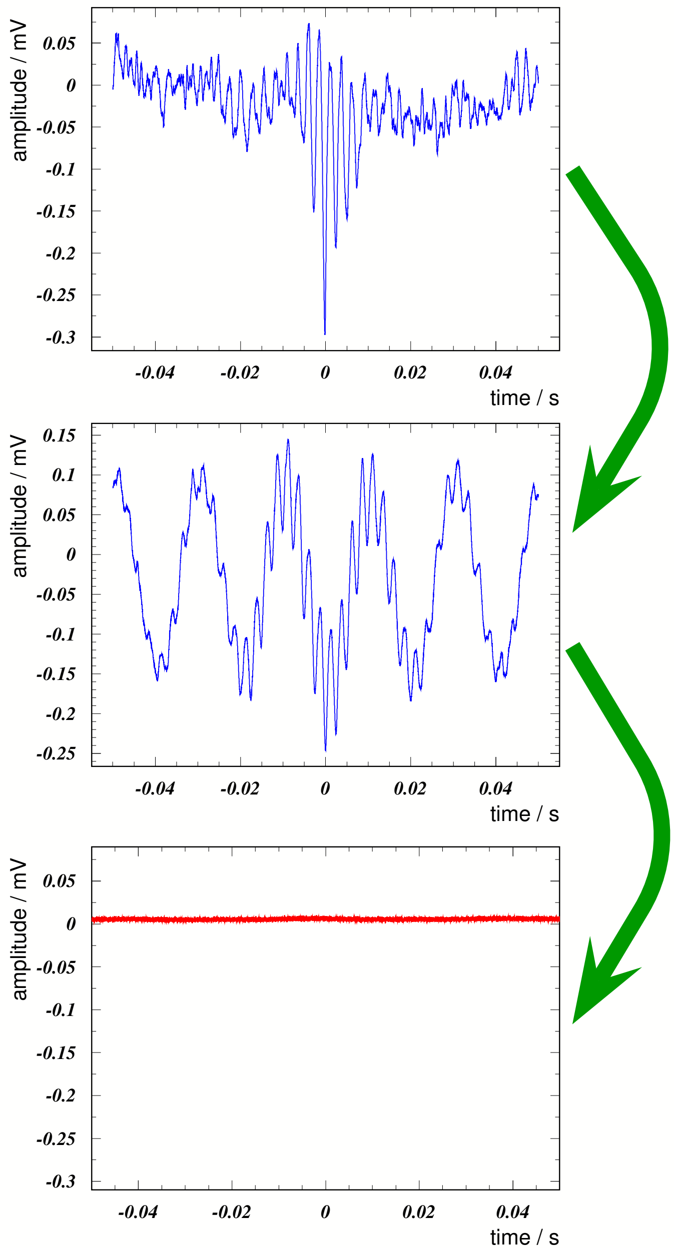


- Bunch length can be derived from FWHM of IR-interferogram
- Systematic effects arise e.g. from beam splitter thickness

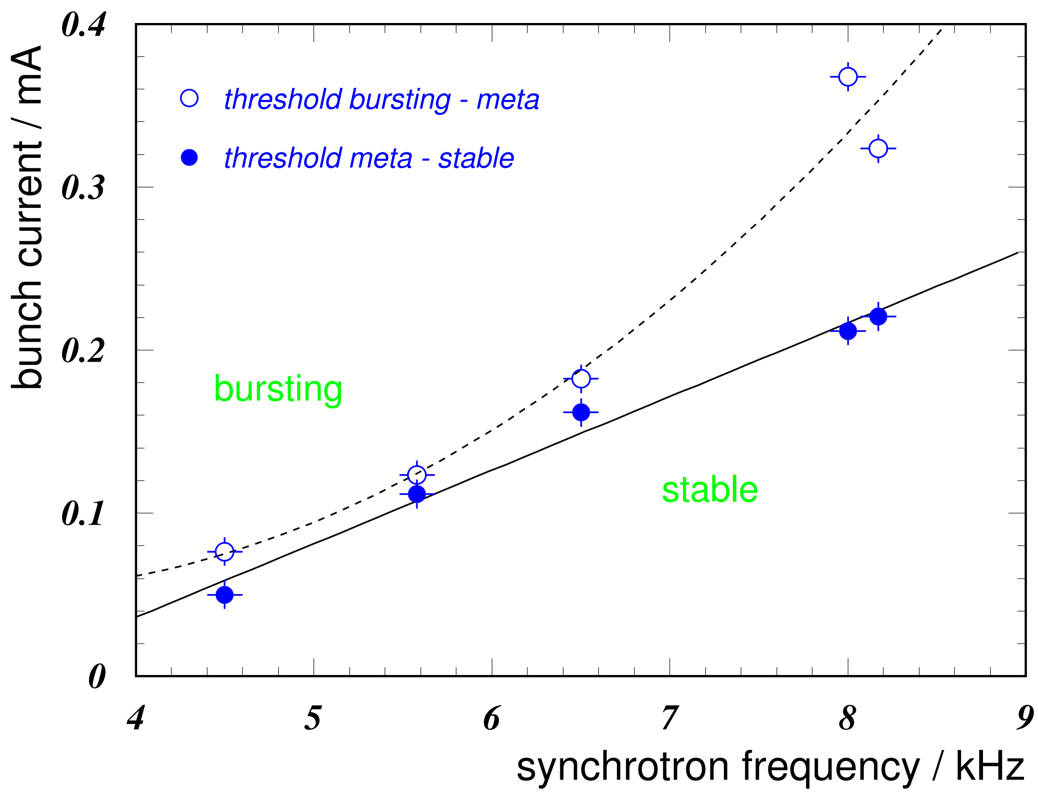


- Measure bunch length as a function of beam current
  - ➜ fast reduction of bunch length at a threshold current of about 50 μA/bunch

Bursting and Steady State Emission



- Time domain signals of the bolometer show transition from bursting emission via an intermediate regime to steady state emission



Summary & Outlook

- Bunch lengths $<$ 1 ps can be stored in the ANKA storage ring ✔
- Reproducible procedure for low-α_c operation ✔
- Steady state CSR has been observed ✔
- Thorough investigation of longitudinal instabilities and FIR spectra in progress ✘
- First user experiments have already done with this mode – more are scheduled ✘

Acknowledgements

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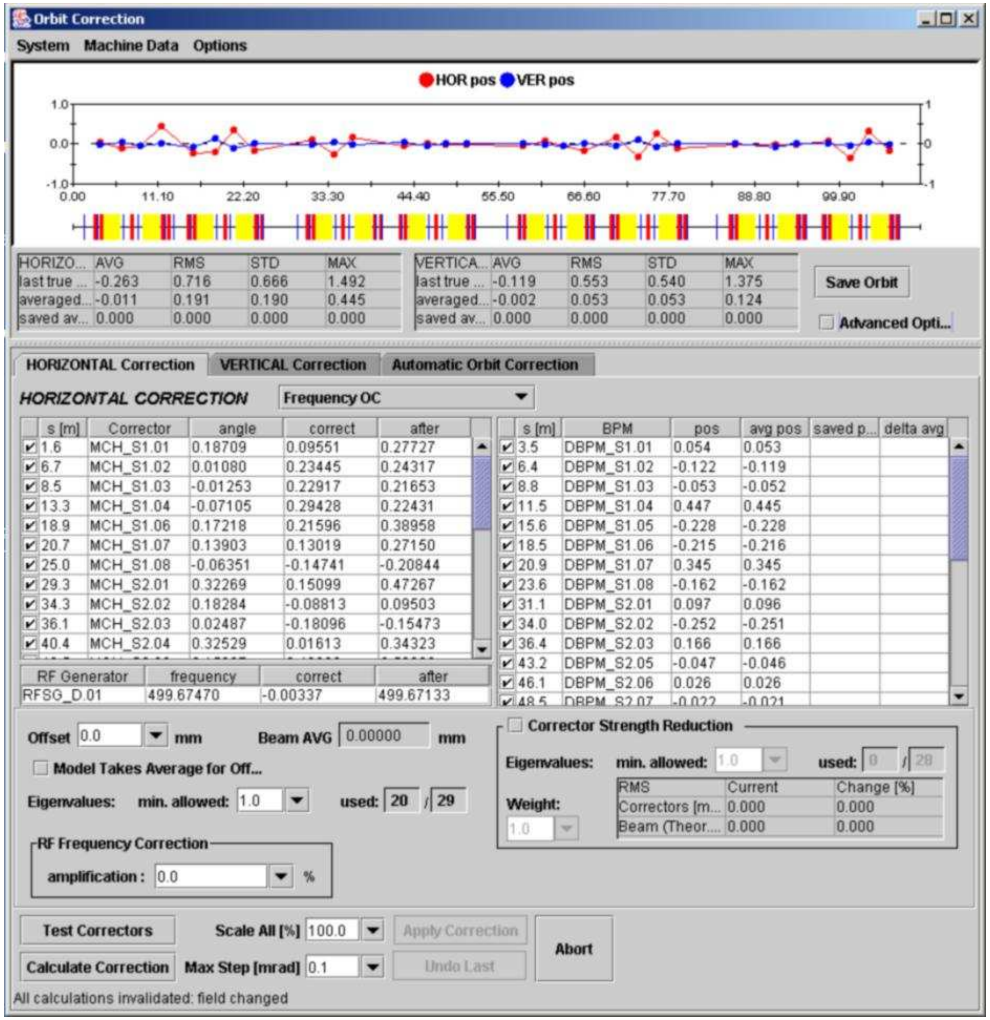
Orbit Correction

- 36 beam position monitors
- 28 horizontal correctors
- 16 vertical correctors
- SVD based orbit correction
- choice between measured or model response matrix
- RF frequency as a free parameter in the correction

$$\frac{\Delta p}{p} = -\frac{1}{\alpha_c}\frac{(f_{RF} - f_{RF}^{c})}{f_{RF}}$$



cosylab

CONTROL SYSTEM LABORATORY