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Energy Calibration and Stability of the ANKA Storage Ring

A.-S. Müller, I. Birkel, E. Huttel, F. Pérez*, M. Pont*, R. Rossmanith

Institut für Synchrotronstrahlung – ISS
Forschungszentrum Karlsruhe

* now at ALBA Synchrotron Light Source, Spain

Overview

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- Brief introduction to ANKA
- Why energy stability is an issue at ANKA
- How to calibrate the beam energy in a very precise (but simple) way
  - ➜ resonant depolarisation
  - ➜ makeshift polarimeter
- Summary

Research Centre Karlsruhe

Research & development in various fields:

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

ÅNgströmquelle KArlsruhe

- Tradition in the production of electromagnetic radiation in KA

1887

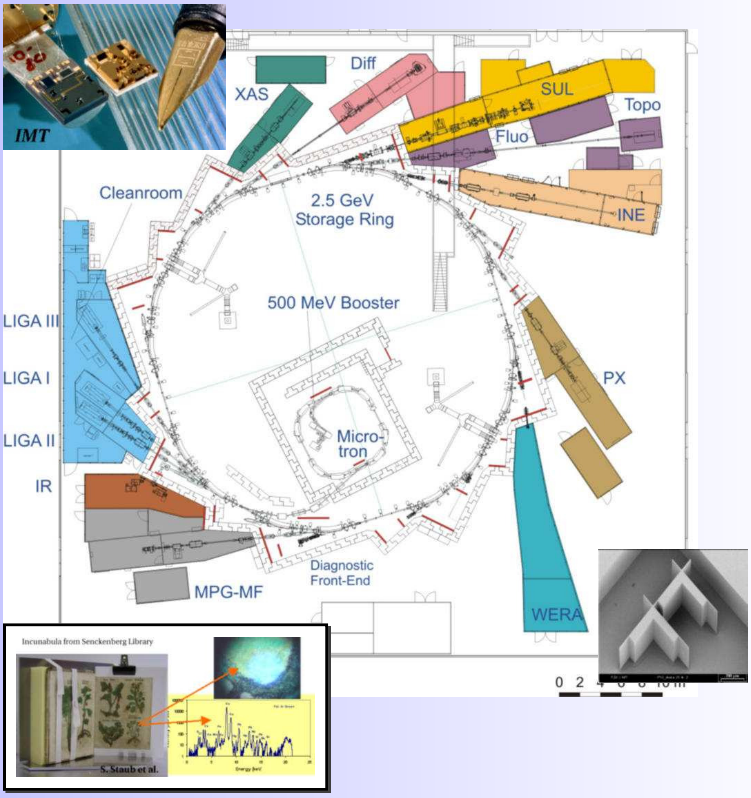
First observation of electromagnetic waves in Karlsruhe by Heinrich Hertz ("Hertz Dipole")

1996

Ground-breaking ceremony for ANKA
First beam in 2000
Regular user operation since 2001/2002

The ANKA Facility

- Electron storage ring with a beam energy of 2.5 GeV
- hosts 12 beamlines
  - ➜ running: 6 + 3
  - ➜ commissioning: 3
  - ➜ planned: 1
- Mostly bending magnet beam lines
  - ➜ free space for 5 IDs
  - ➜ two installed
- Development of SC IDs
  - ➜ planar SCU to come in the near future
  - ➜ first prototype of helical SCU

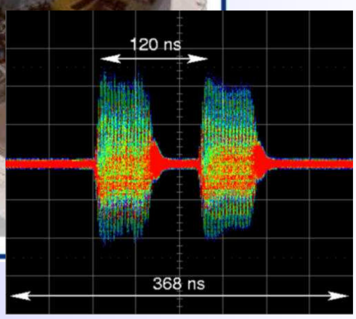


The ANKA Storage Ring

- ✔ C = 110.4 m
- ✔ 0.5 ≤ E_0 ≤ 2.5 GeV
- ✔ ε_x = ~~80~~ 40 nm·rad
- ✔ coupling ≈ 1%

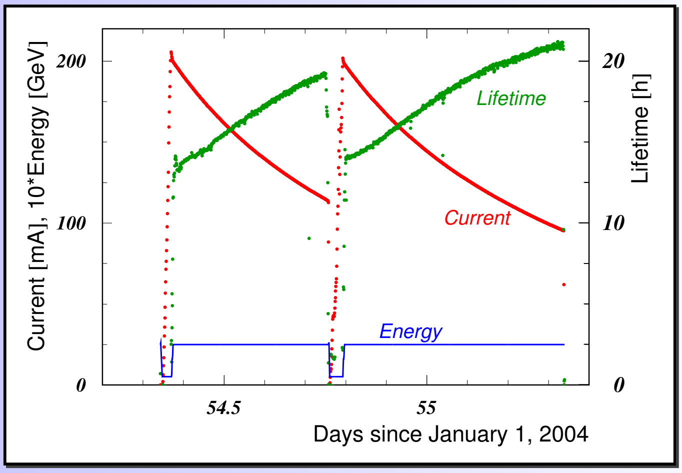
Beam position reproducibility:

- ✘ 6 weeks RMS: 15 μm
- ✘ 6 weeks RMS without ramp drift: 8 μm
- ✘ 1 h RMS: < 2 μm



A Typical Day in ANKA´s Life

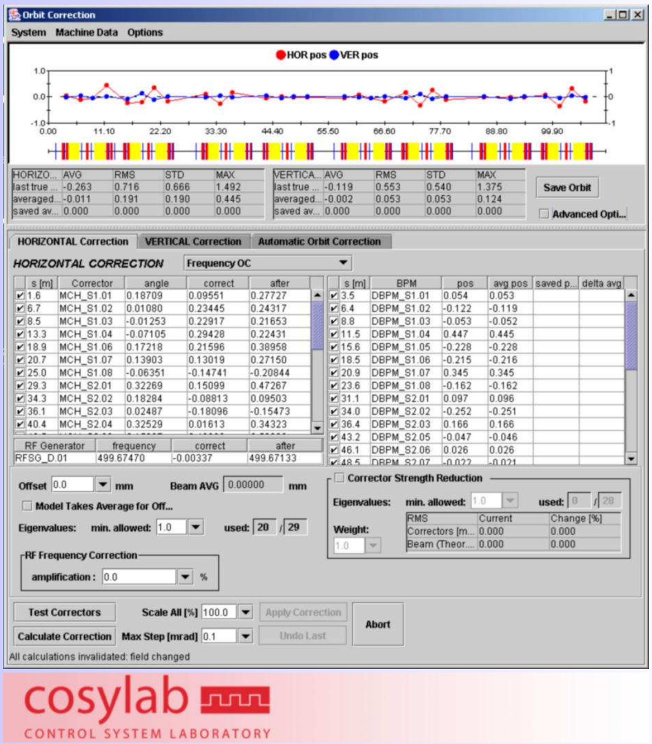
- A typical day at ANKA sees two injections of ≈ 200 mA: re-fills in the morning and late afternoon
- Regular user operation at 2.5 GeV
- Special operation mode: beam at 1.3 GeV (e.g. for lithography)
- This means:
  - ➜ large current changes
  - ➜ cycling of bends and quadrupoles
  - ➜ ramp (B_{dipole} range from 0.3 to 1.5 T)
- Compensate thermally induced drifts in the bending field (E_0)



Field Drift Correction

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

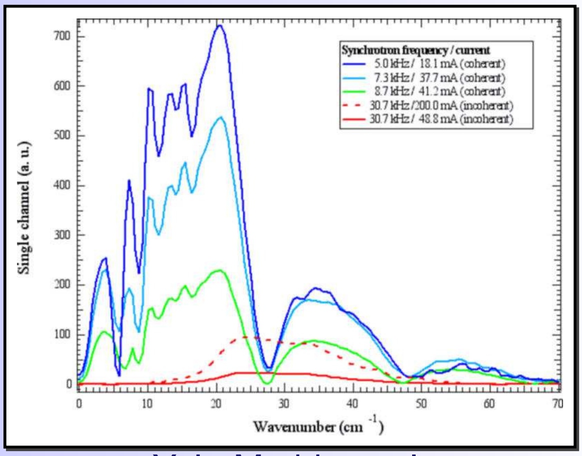
$$\frac{\Delta p}{p} = -\frac{1}{\alpha_c}\frac{(f_{RF} - f_{RF}^c)}{f_{RF}}$$



Low α_c Optics

- Since spring 2004 new operation mode with reduced α_c for short bunches
  - ➜ production of CSER in the FIR range
  - ➜ intensity enhancement of up to 5 orders of magnitude

- small changes in corrector strengths lead to visible energy changes
  - ➜ orbit correction with RF frequency as free parameter necessary for reproducible conditions

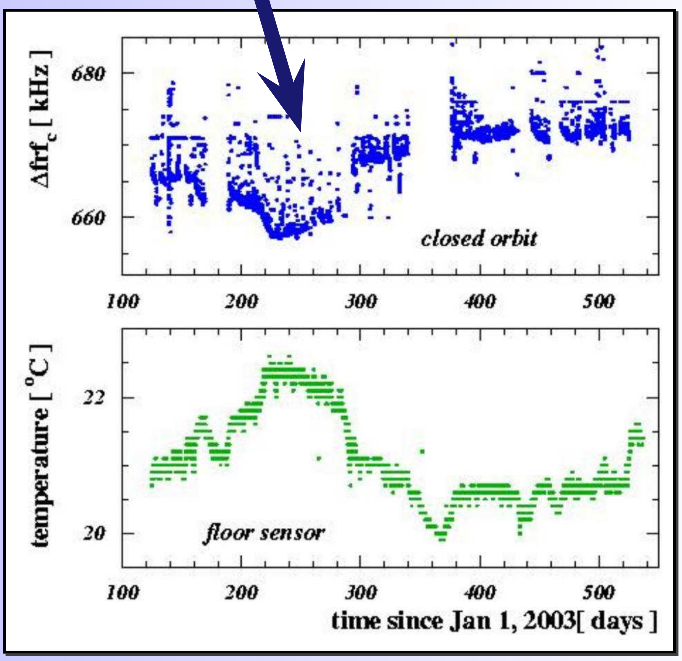


Y.-L. Mathis et al.

External Influence

- RF frequency adjustment keeps path length constant

$$\frac{\Delta f_{RF}}{f_{RF}} \propto \frac{\Delta C}{C} \propto -\frac{\Delta E}{E}$$



- daily drifts caused by injection and ramping scheme
- significant seasonal dependence
- how well does this truly reproduce the nominal beam energy?

Energy Calibration

- Why do we need to know the beam energy?
  - ➜ as a cross-check for the energy correction by frequency adjustment
  - ➜ for ID characterisation:

    $\epsilon_\gamma \propto E^2 \quad \Rrightarrow \quad 1\%\ \Delta E/E$ ➜ $2\%\ \Delta\epsilon_\gamma/\epsilon_\gamma$
  - ➜ for further development of optics, an excellent knowledge and understanding of the present optics is needed: energy errors are gradient errors!
- Measure E_0 with highest possible precision: Resonant Depolarisation

Transverse Polarisation

- Polarisation build-up by emission of synchrotron radiation:
  - ➜ asymmetry in spin flip probability leads to transverse polarisation
  - ➜ max. polarisation is given by size of asymmetry term:

$$8/5\sqrt{3} \approx 92.4\%$$

- Polarisation level increases exponentially with build up time

$$\tau_p = \frac{8}{5\sqrt{3}} \frac{m_0^6\, c^{10}\, \rho^3}{\hbar\, r_c\, E_0^5}$$

  - ➜ for ANKA at 2.5 GeV: $\tau_p \approx$ 10 minutes

Spin Motion

- The motion of the spin vector $\vec{s}$ of a relativistic electron in the presence of electric and magnetic fields $\vec{E}$ and $\vec{B}$ is described by the Thomas-BMT (Bargmann, Michel, Telegdi) equation:

$$\frac{d\vec{s}}{dt} = \vec{\Omega}_{BMT} \times \vec{s}$$

- The spin precession frequency $\vec{\Omega}_{BMT}$ can be written as

$$\vec{\Omega}_{BMT} = -\frac{e}{\gamma m_0}\left[(1+a\gamma)\,\vec{B}_{\perp} + (1+a)\,\vec{B}_{\parallel} - \left(a\gamma + \frac{\gamma}{1+\gamma}\right)\vec{\beta}\times\frac{\vec{E}}{c}\right]$$

- $a = (g_e - 2)/2 = 0.001159652193(10)$
- The average over all particles of the number of spin oscillations per revolution is defined as the spin tune

$$\nu = f_{spin}/f_{rev} = \frac{(g_e-2)/2}{m_0c^2}\,E_0$$

Resonant Depolarisation

- Horizontal magn. field B_x modulated with f_B is applied to the beam
- For a certain phase relation between the kicks of the depolariser and the spin tune the small spin rotations add up coherently from turn to turn and the polarisation is destroyed

  ➜ resonance condition for spin rotations

$$f_{dep} = (k \pm [\nu]) \cdot f_{rev}$$

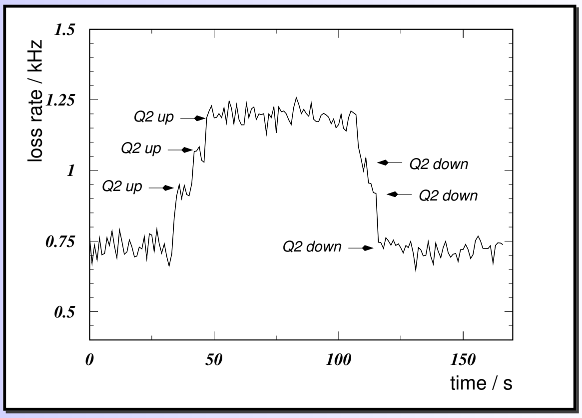
- To determine the spin tune, the frequency of the depolariser field is slowly varied with time over a given frequency range

  ➜ precision: $\Delta E/E \approx 10^{-5}$

Polarisation and Loss Rate

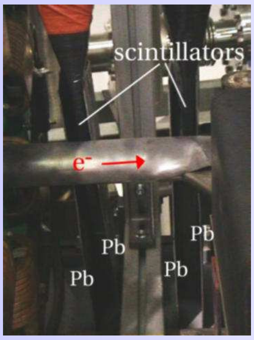
- Touschek cross-section depends on electron beam polarisation
  - ➜ use particle loss rate as a measure for polarisation level
- Pioneering work by
  - ➜ P. Kuske et al., *"High Precision Determination of the Energy at BESSY II"*, EPAC 2000
  - ➜ C. Steier et al., *"Energy Calibration of the Electron Beam of the ALS Using Resonant Depolarisation"*, EPAC 2000
  - ➜ S.C. Leeman et al., *"Precise Beam Energy Calibration at the SLS Storage Ring"*, EPAC 2002
- Set up a beam loss monitor in a Touschek sensitive region...

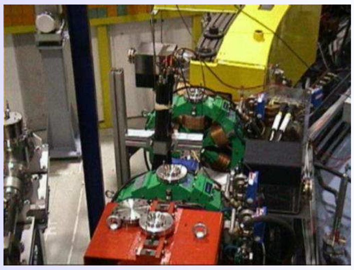
(test of detector sensitivity) ➜

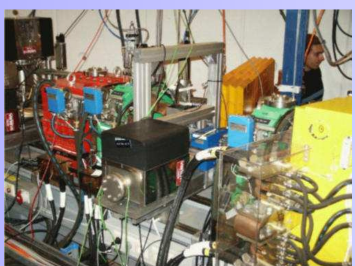


Polarisation Detection

- First attempts with scintillators wrapped in lead sheets to suppress the contribution of synchrotron radiation to the count rate

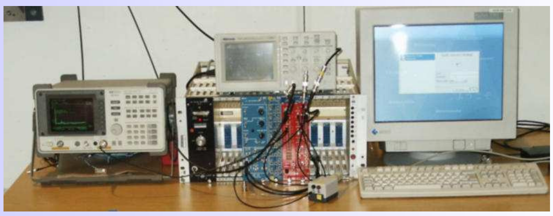






- Final setup: Pb-Glass block with photo multiplier

- Photo multiplier pulses are converted to NIM signals and counted using a custom made interface to a Linux PC



Some RDP Results

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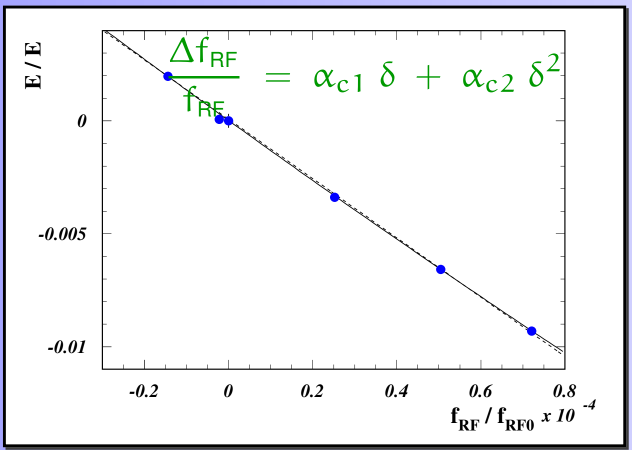
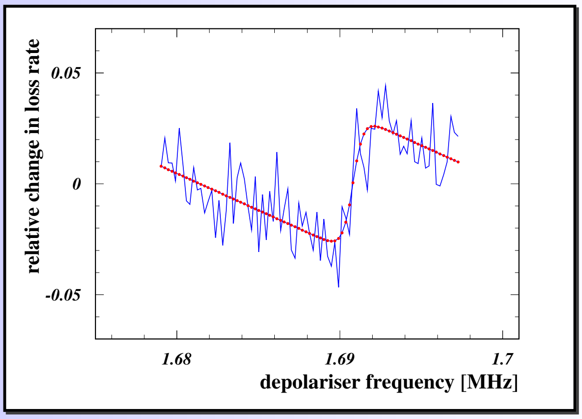
- Fit to loss rate scans using

$$r = a - \frac{\partial r_I}{\partial t} t + \frac{\Delta r}{1 + \exp\left\{-\frac{t - t_d}{\sigma_d}\right\}}$$

- Measure α_c using RDP scans for different f_{RF}:





- Expectation for linear term: $7.2 \cdot 10^{-3}$
- $\alpha_{c1} = (7.39 \pm 0.01) \cdot 10^{-3}$
- Quadratic term: $\alpha_{c2} = (4.1 \pm 0.2) \cdot 10^{-2}$
  ➜ highly significant but small

Bunch Lengthening & RDP

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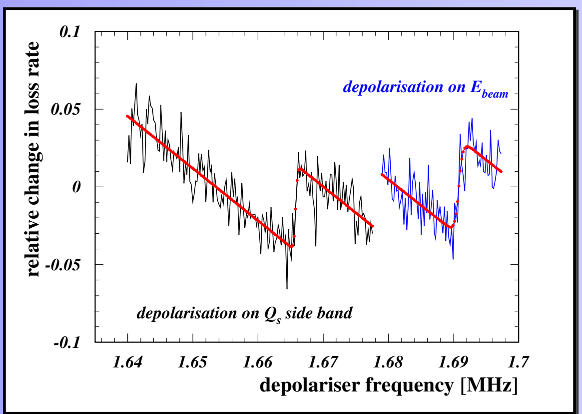
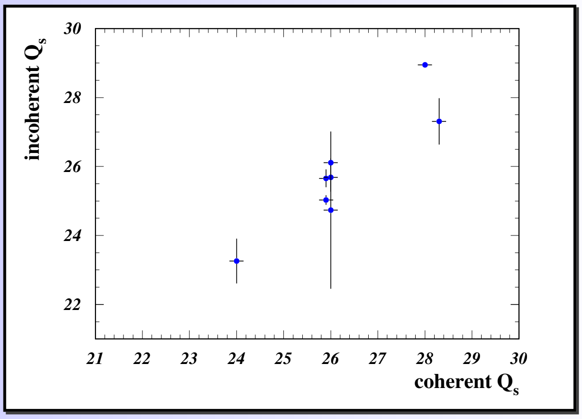


- Depolarisation can also occur on synchrotron side bands
- Due to the single particle nature of the depolarisation process, this happens at $f_{dep}/f_{rev} = [\nu] \pm Q_s^{inc}$
- RMS bunch length: $\sigma_s \propto 1/Q_s^{inc}$

- The coh./inc ratio is a measure for bunch lengthening with current

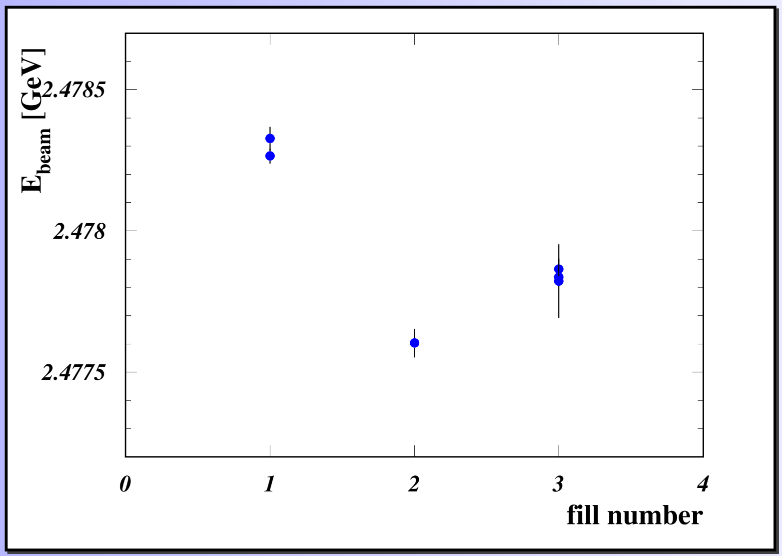
$$\frac{Q_s^{coh}}{Q_s^{inc}} = 1 - \lambda I_{bunch}$$

- Average coherent/incoherent ratio: (1.02 ± 0.03)
  ➜ no significant lengthening



Energy Reproducibility

- Fill-to-fill variations of the order of 10^{-4}
- Reproducibility within single fill $\approx 10^{-5}$



- Energy drift compensation by RF frequency adjustment seems to work reasonably well

Summary

- The beam energy is an important parameter for accelerator and insertion devices ✔
- Very precise measurement possible with resonant depolarisation ✔
- Detection of polarisation change with Touschek-loss-polarimeter ✔
- Energy stability acceptable: $\mathcal{O}(10^{-4})$ ✔