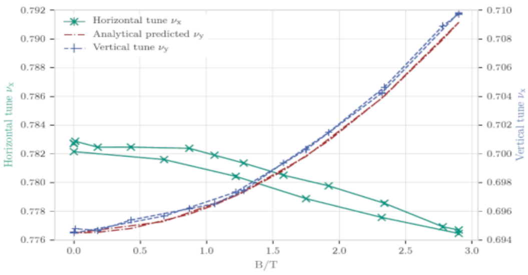
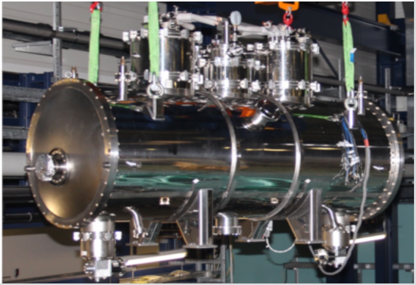
Insertion Device for CERN at the KArlsruhe Research Accelerator

Julian Gethmann | 27.2.2019

Instute for Beam Physics and Technology, IBPT





Content

- Introduction – IBPT
- Basics of accelerator physics
- Damping wiggler
- Experiments for CERN and KIT

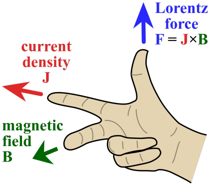
Introduction – IBPT

- Institute for Beam Physics and Technology (founded 2016)
- Operating accelerator facilities at Campus North
- Operating magnet lab and doing simulations at Campus South

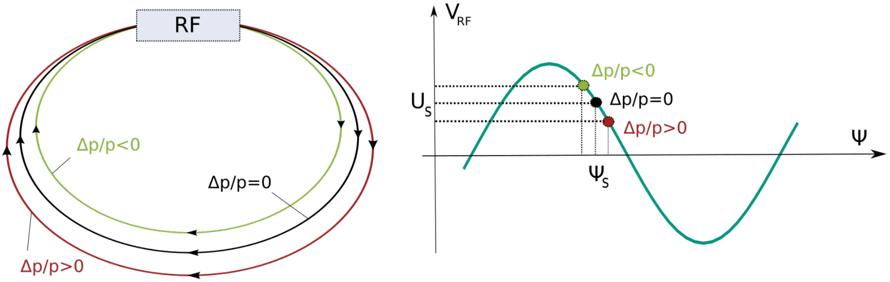
- **KA**rlsruhe **R**esearch **A**ccelerator (KARA)
  - 0.5 to 2.5 GeV electron storage ring
  - Accelerator test facility and synchrotron radiation source
- **F**erninfrarot **L**inac- **u**nd **T**est-**E**xperiment (FLUTE)
  - 40 to 50 MeV ultra short pulse facility
  - Pico- and femtosecond electron and photon beam studies

Basics – Acceleration of Particles

- Lorentz force: $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
  - $\vec{F}$: force
  - q: charge
  - $\vec{E}$: electric field
  - $\vec{B}$: magnetic field
  - $\vec{v}$: velocity
- Transverse deflection
  - Using magnetic fields
- Longitudinal acceleration
  - Using electric fields
  - Microwaves
  - Radio frequency in cavities: 100 MHz to 3000 MHz
    - House hold microwave oven: 2450 MHz



Basics – Longitudinal Motion

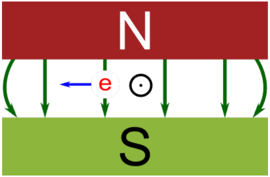


- Low energy particles: more acceleration
- High energy particles: less acceleration
- RF wave leads to bunching
- Self-focusing effect (“phase focusing”)
  ⇒ longitudinal/synchrotron oscillation

Basics – Deflection of Particles

Transverse deflection by magnets

- Dipole for bending the beam



- Quadrupole for focusing
- Higher order poles for correction of higher order effects

Basics – Deflection of Particles

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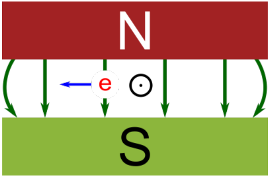
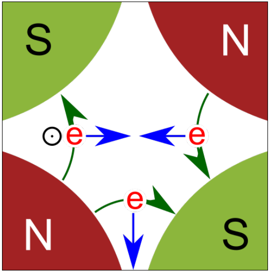


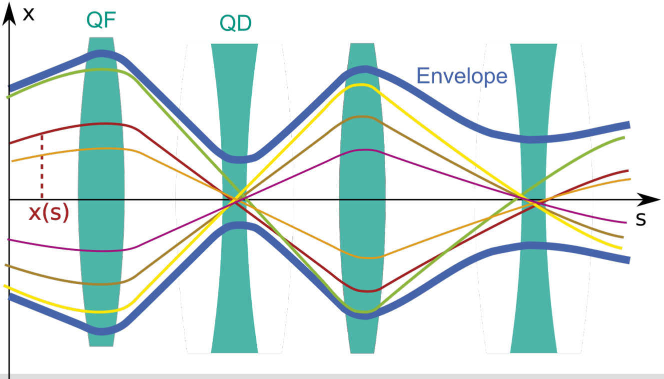
- Quadrupole for focusing



- Higher order poles for correction of higher order effects

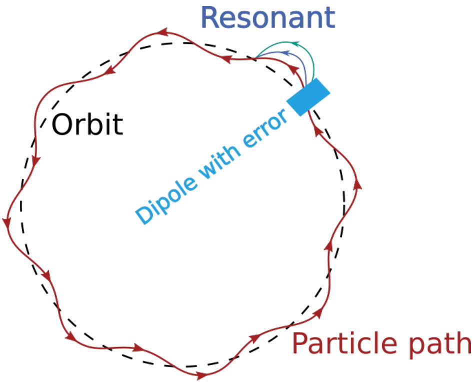
Basics – Transverse Motion

- Quadrupoles focus in one plane, defocus in the other plane
- Alternating gradient quadrupoles lead to overall focusing
  - So-called “strong focusing”, similar to optical lenses
- Transverse single particle motion: Oscillation with envelope β-function and emittance ε: $\sigma = \sqrt{\beta(s)\varepsilon}$



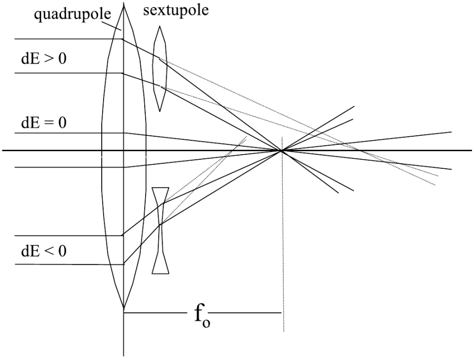
Basics – Tunes

- Number of oscillations per revolution: Tune Q
- Characteristic parameter of beam motion
- Stay away from resonances (see picture, here $Q = 8$))



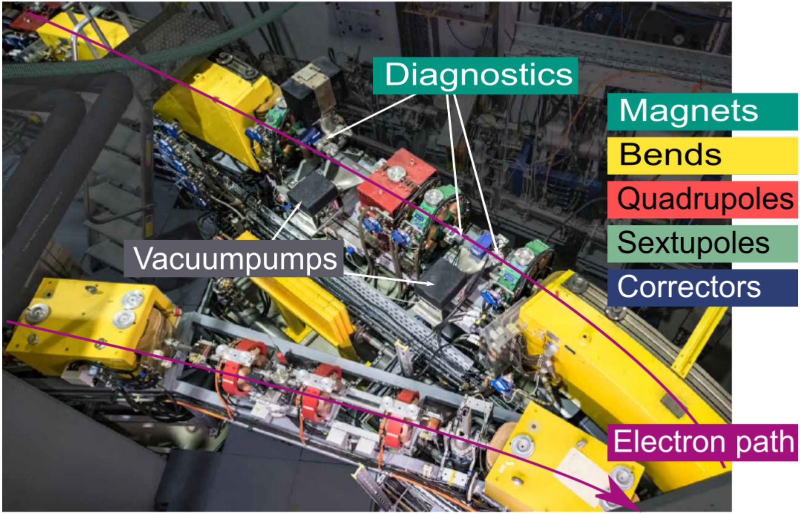
Basics – Chromaticity

- Chromaticity $Q' = \frac{dQ}{dp}$
- Momentum dependent tune
- Negative for quadrupoles only optics
- Similar to chromatic aberation (optics/photography)
- Sextupoles for compensation
- Keep slightly above zero

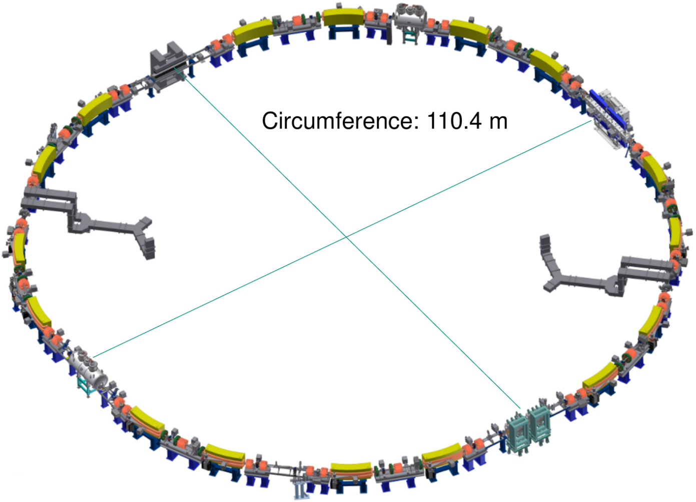


[Helmut Wiedemann, Particle Accelerator Physics, Springer, 2007] Chromaticity creation and mittigation

Basics – Accelerator Components



KArlsruhe Research Accelerator



KARA compared to LHC

Parameter	KARA	LHC
Use case	Synchrotron Radiation	Collider
Circumference	110.40 m	26.66 km
Beam(s)	1 electron beam	2 proton/ion beams
Energy	0.5 GeV to 2.5 GeV	450 GeV to 7000 GeV
Tunes (H/V)	6.77 / 2.81	64.31 / 59.32
Radiation Power $P \propto E^4/\rho^2$	~ 93 kW	$\sim 2 \cdot 6$ kW

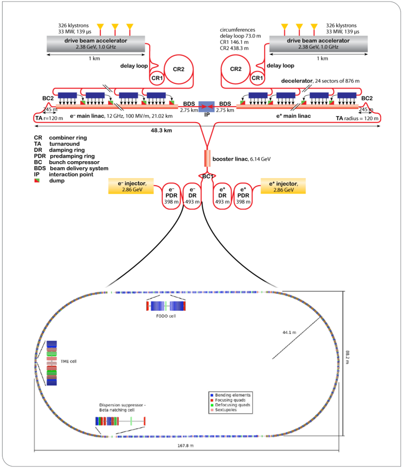
[https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.lhc_parameters]

- Experiments at KARA for EuroCirCol (FCC)
- Experiments at KARA for CLIC

Compact LInear Collider damping rings

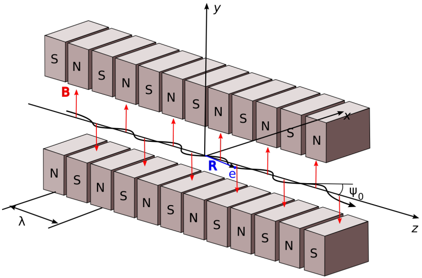
Karlsruhe Institute of Technology

- Many (e. g. 52) wiggler per damping ring
- Emittance shrinks $(\varepsilon_{\mathrm{x,y}} = \sigma^2_{\mathrm{x,y}} / \beta_{\mathrm{x,y}})$ $\rightarrow$ Luminosity increases $\left(\mathcal{L} = \frac{N_1 N_2}{4\pi\sigma_{\mathrm{x}}\sigma_{\mathrm{y}} B} f_{\mathrm{rev}}\right)$
  - Crucial for linear accelerators like the ILC or CLIC
- Strong wigglers
- Light source for hard x-ray light



[M. Aicheler et al. (eds.): A Multi-TeV linear collider based on CLIC technology: CLIC Conceptual Design Report. Technical report, CERN (2012)] CLIC facility with damping ring

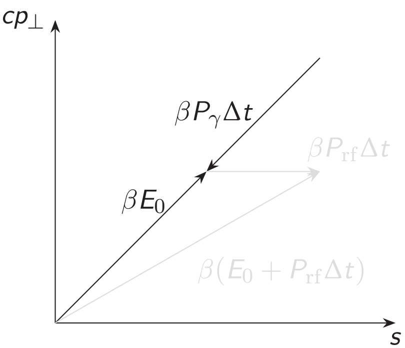
Wiggler

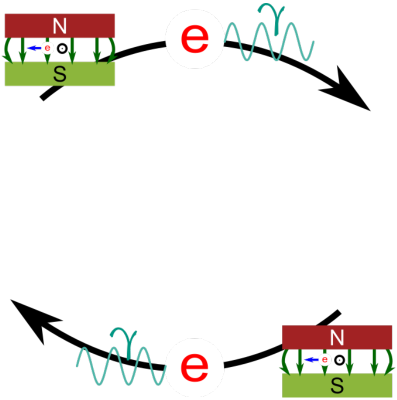


[Axel Bernhard, Beschleunigerphysik II, WS 12/13]

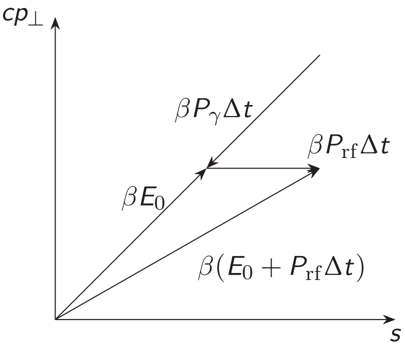
- Many strong additional dipoles
- Local deflection only
- Electrons wiggle in the alternating field
- Radiate strongly in short space
- Radiate in forward direction with opening angle $\approx 1/\gamma$

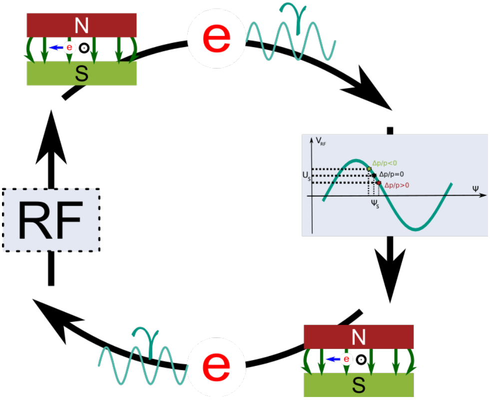
Radiation damping





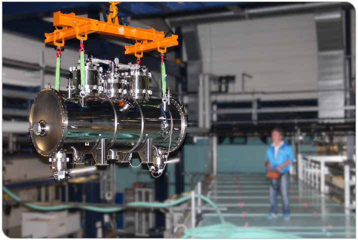
Radiation damping





Transeverse momentum loss called damping

CLIC damping wiggler – technical details



[Courtesy: Richard Kubat] CLIC damping wiggler installation into KARA

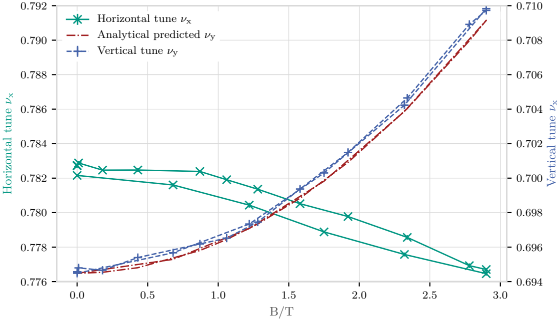
- Strong damping and high x-ray flux

Parameter	Unit	Value
Magnetic length L_w	mm	1836
Period length λ_w	mm	51.4
Superconductor	NbTi	
Magnetic field B_{max}	T	2.9

KARA	Radiation power
without wiggler	75 kW
with CLICdw	89 kW
with all "wigglers"	93 kW

Experiments for CERN – Beam dynamics

- Heat load of the synchrotron radiation is not an issue
- Vertical tune does behave as expected
- Horizontal tune shows non-linear features



Testing a new chromaticity measurement technique

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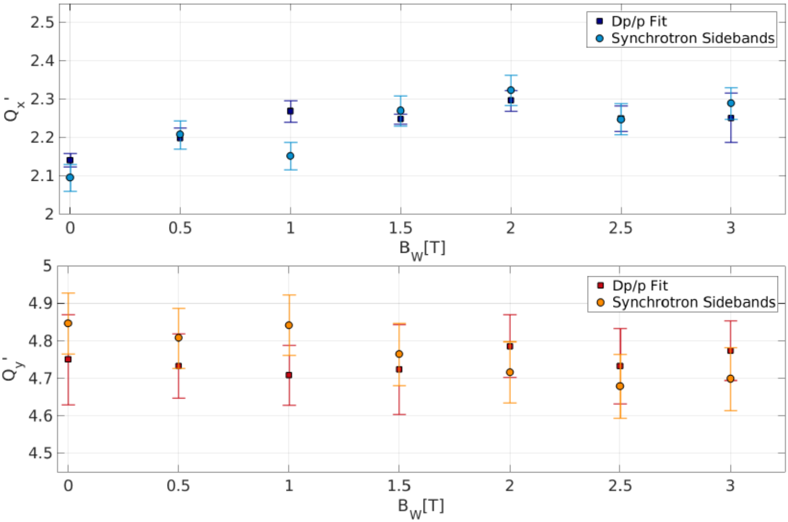
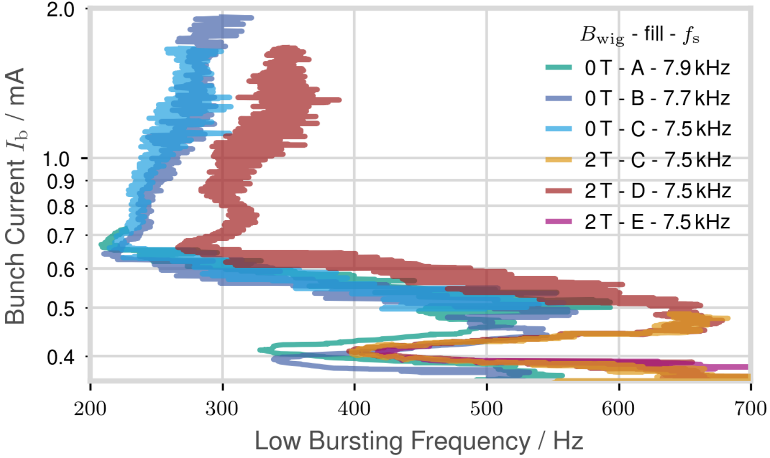


[Panagiotis Zisopoulos, 1st ARIES Annual Meeting 2018] Wiggler field dependent chromaticity

Experiments for KARA – THz



Summary

Accelerator Physics

- Electron beams oscillate in all planes
- Insertion devices radiate bright synchrotron light
- Strong wiggler can increase the luminosity

CLIC damping wiggler at KARA

- Works as a light source for KIT
- Scaled to linear collider's needs
- Test beam dynamics detection schemes for CERN
- Influence parameters for CSR THz bursting effects