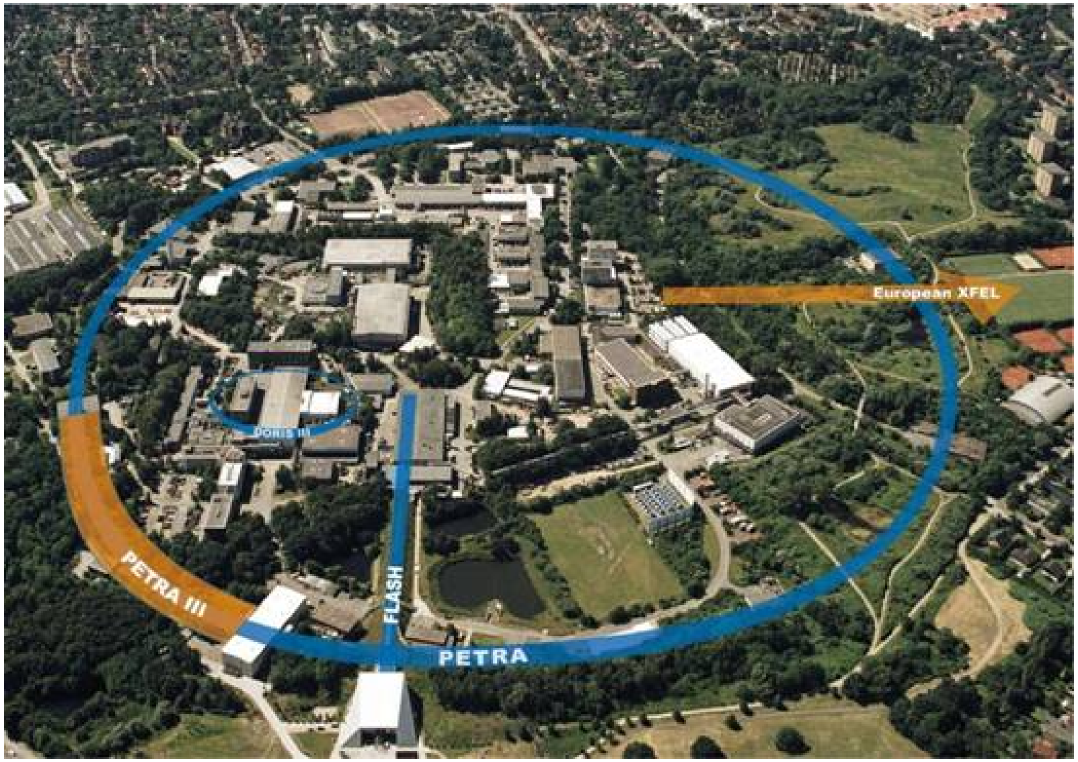
Undulators at PETRA: Experience and Perspectives



Markus Tischer

for the Insertion Devices Group at DESY

HELMHOLTZ ASSOCIATION

3-Way Meeting, Argonne, Aug 1st - 2nd 2013

DESY

Outline

- PETRA III IDs
- Commissioning experience
- Radiation Damage Issues
- PETRA III Extension IDs

Coworkers:

A. Schöps, G.Naulin

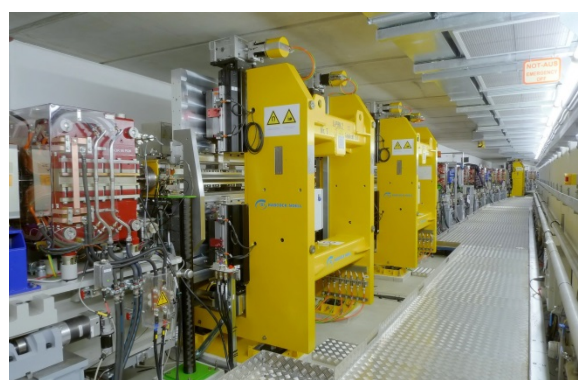
P. Vagin, S. Tripathi, O. Zeneli

P. Neumann, T. Vielitz, T. Cheung

Parameters and Spectral Performance of PETRA III Undulators

	U29_5m	U29	U32	U23	UE65 *	U19	U32_10m
Minimum magnetic gap [mm]	9.5	9.5	9.5	9.5	11.0	7.0	12.5
Period length λ_U [mm]	29	29	31.4	23	65.6	19	31.4
Length L [m]	5	2	2	2	5	4	10
Periods	168	67	61	84	72	204	154
Peak field B_0 [T]	0.81	0.81	0.91	0.61	1.03	0.7	0.68
Deflection parameter K_{max}	2.2	2.2	2.7	1.3	6.3	1.24	2.0
1st Harmonic E_1 [keV]	3.5	3.5	2.4	8.0	0.3	10.1	3.6
Total power P_{tot} [kW]	7.5	3.0	3.8	1.7	11.8	4.5	10.7
On-axis power dens. [kW/mrad^2]	190	76	80	71	0.17	200	300
Power in 1x1mm^2 at 40m [W]	119	47	49	44	0.1	122	185
High-β source (10keV)	size : 140 x 5.6 µm^2 divergence : 7.9 x 4.1 µrad^2						
Low-β source (10keV)	size : 36 x 6.1 µm^2 divergence : 28 x 4.0 µrad^2						

* in helical mode



Operation Experience at PETRA III

> Only small closed orbit distortions

- Corrected by air coils (CODs → ±20 / ±5µm (horiz./vertical)
- No problems with injection at closed gap

> Gap dependent pointing direction

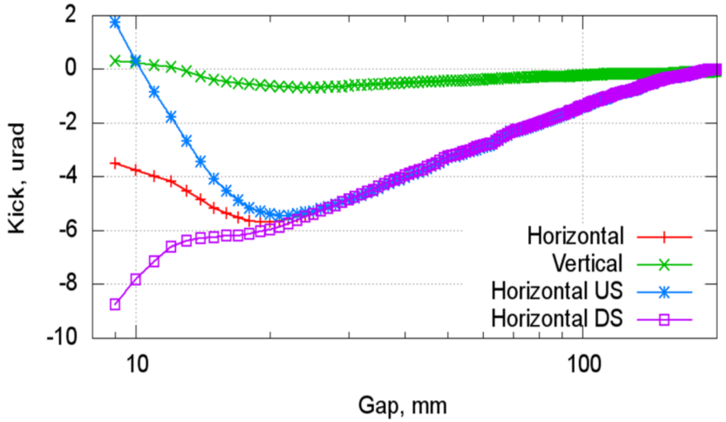
- Some very sensitive experiments required sub-µrad corrections to assure pointing accuracy

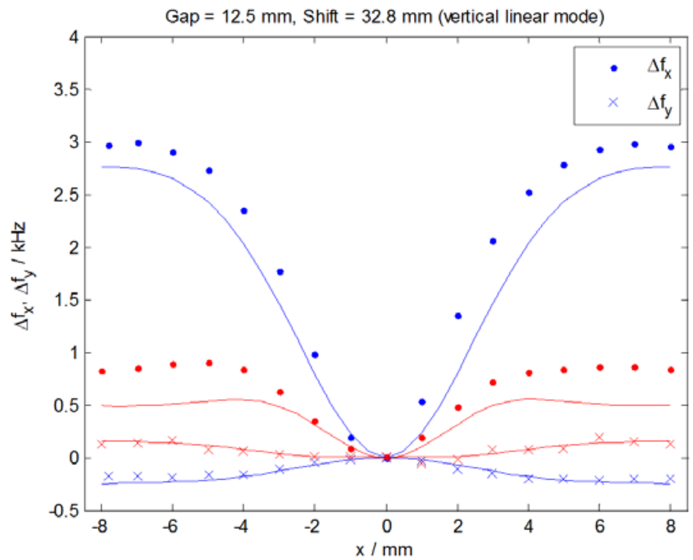
> Tune shift of UE65 (APPLE2)

- 3kHz, 0.5kHz (horiz., vertical), shift dependent
- → 3x reduced by dynamic multipole shims
- Further reduction possible by feed-forward (not needed at present)

> Radiation Damage at several undulators

- Known since quite a while
- …

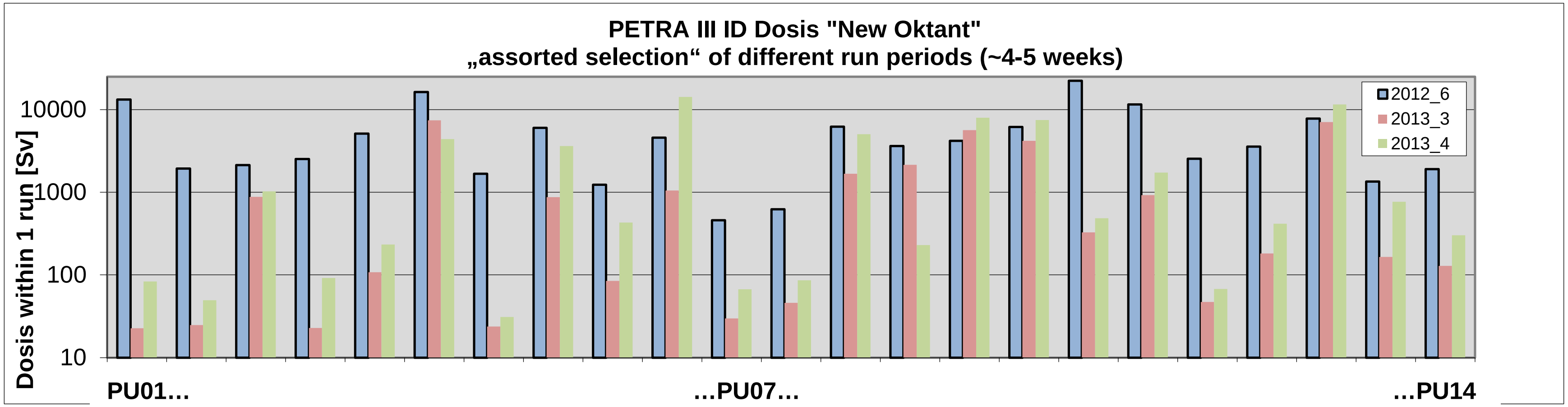


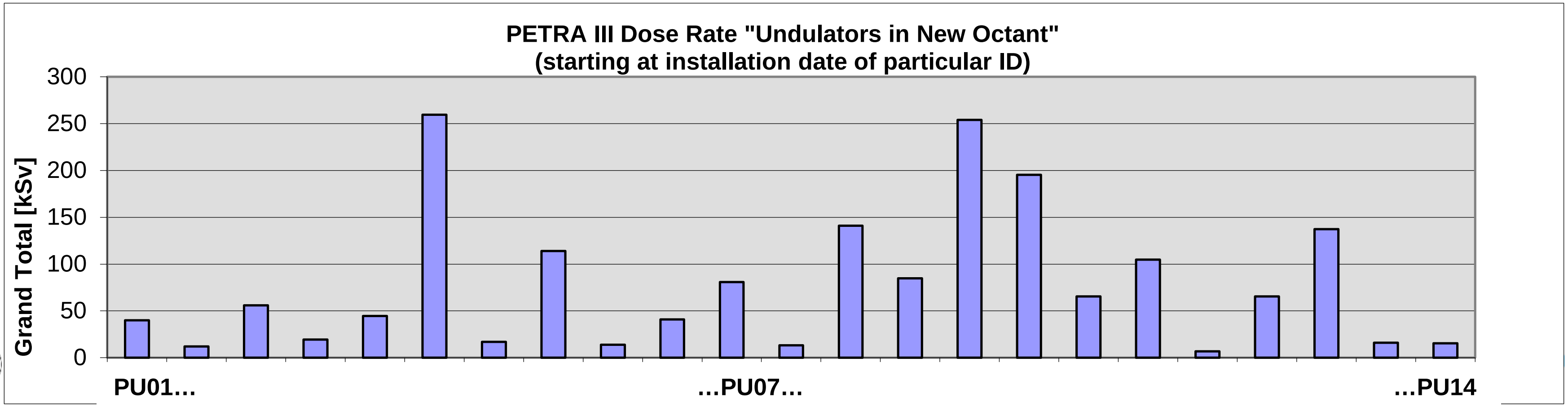


Radiation Damage Issues

> Summary of previous observations

- High dose rate in the tunnel
(~kGy per 5 weeks on TLDs)
- …
- Damaged components
(several motor and linear encoders at IDs, various other electronics)

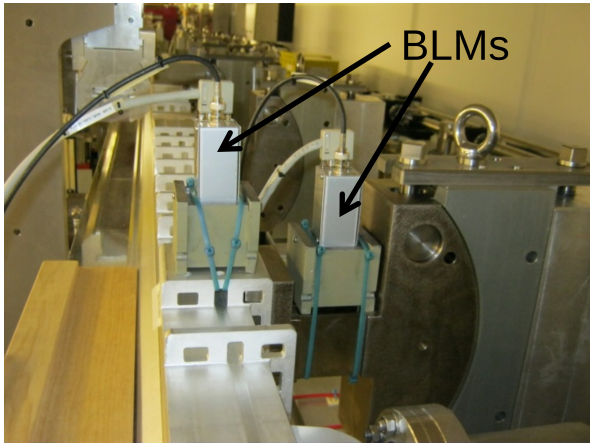


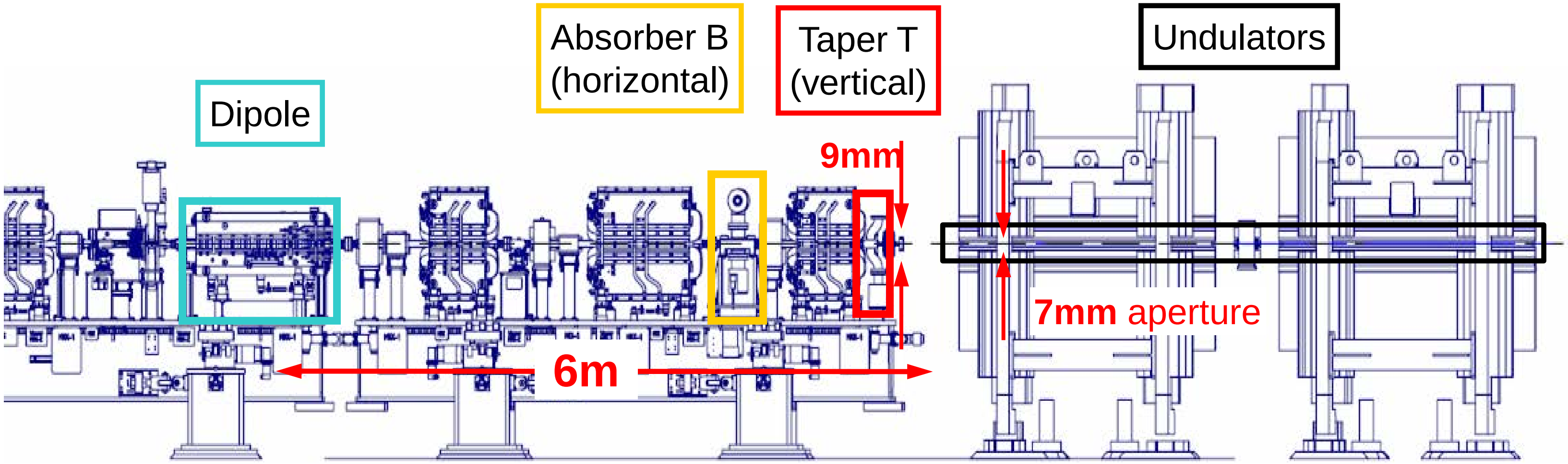


Radiation Damage Issues

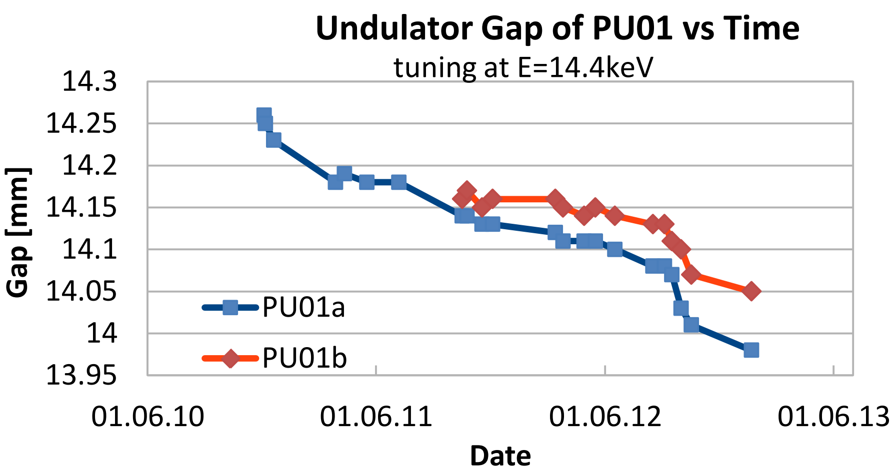
> Summary of previous observations

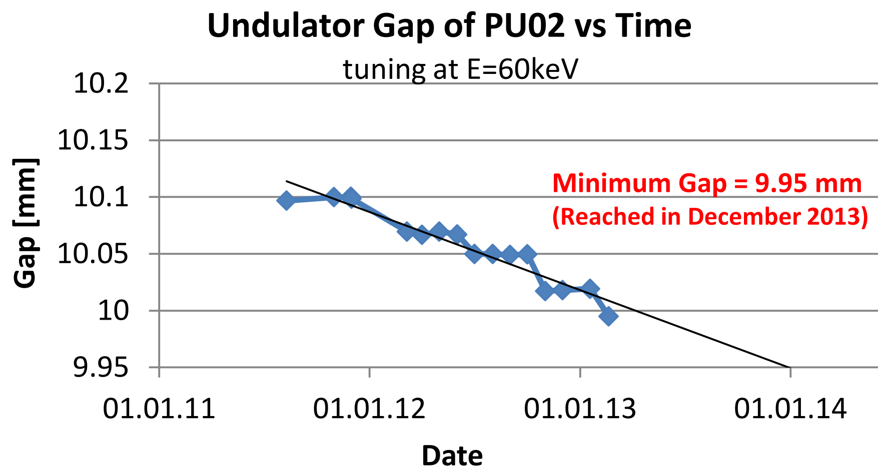
- …
- Strong dependence of dose rate as function of vertical angle through the upstream dipole (SR)
- Corrosion of magnet structure due to radiochemistry (humidity problem solved)
- BeamLossMonitors (pin diodes) were installed at all IDs as online-diagnostics (but not usable by normal shift operators)

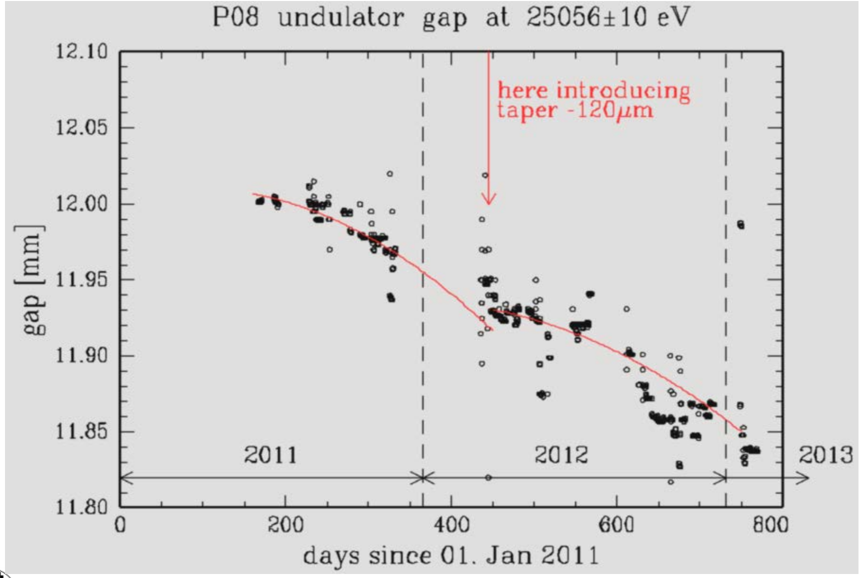




Radiation Damage Issues







> Gap decrease for a desired energy

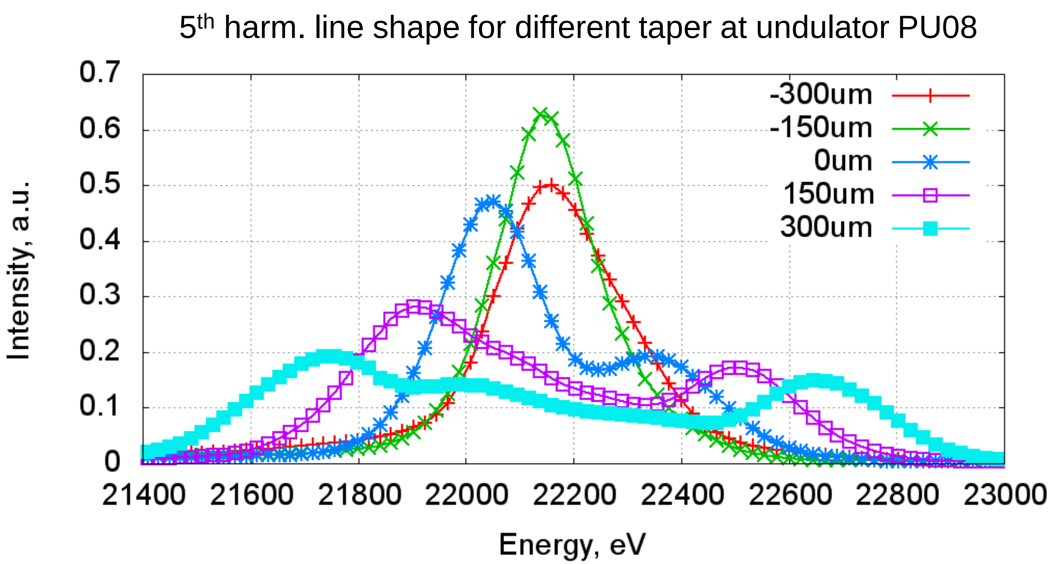
- Systematic decrease of gap for a particular energy over time
- Gap optimized for max. throughput for otherwise same beamline settings
- Observed at some beamlines which do not change the setup frequently

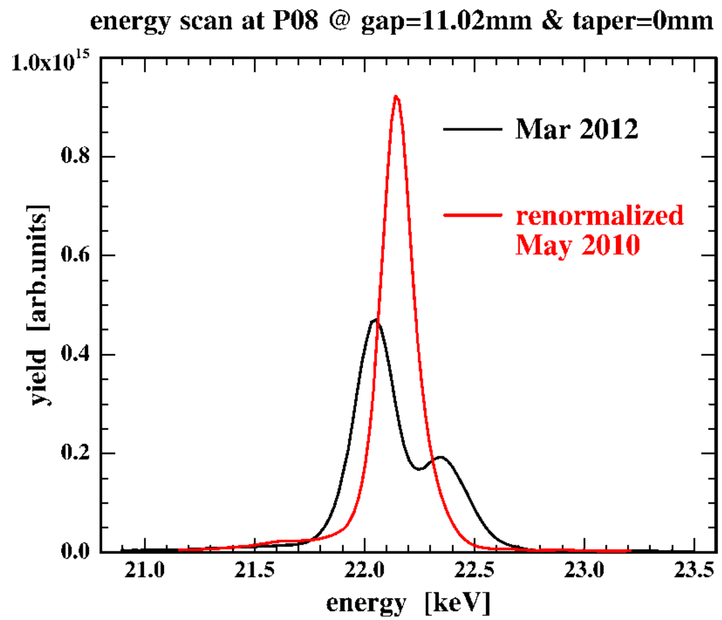
Radiation Damage Issues

> Spectral Degradation

- Broadened undulator harmonics, even with satellites
- Intensity loss
- Spoiled line shape can only be partly cured by applying a taper
- At PU08: Upstream end suffered magnetization loss (corresponding to a negative taper for correction)

- Total intensity drop by at least a factor of 2 since installation

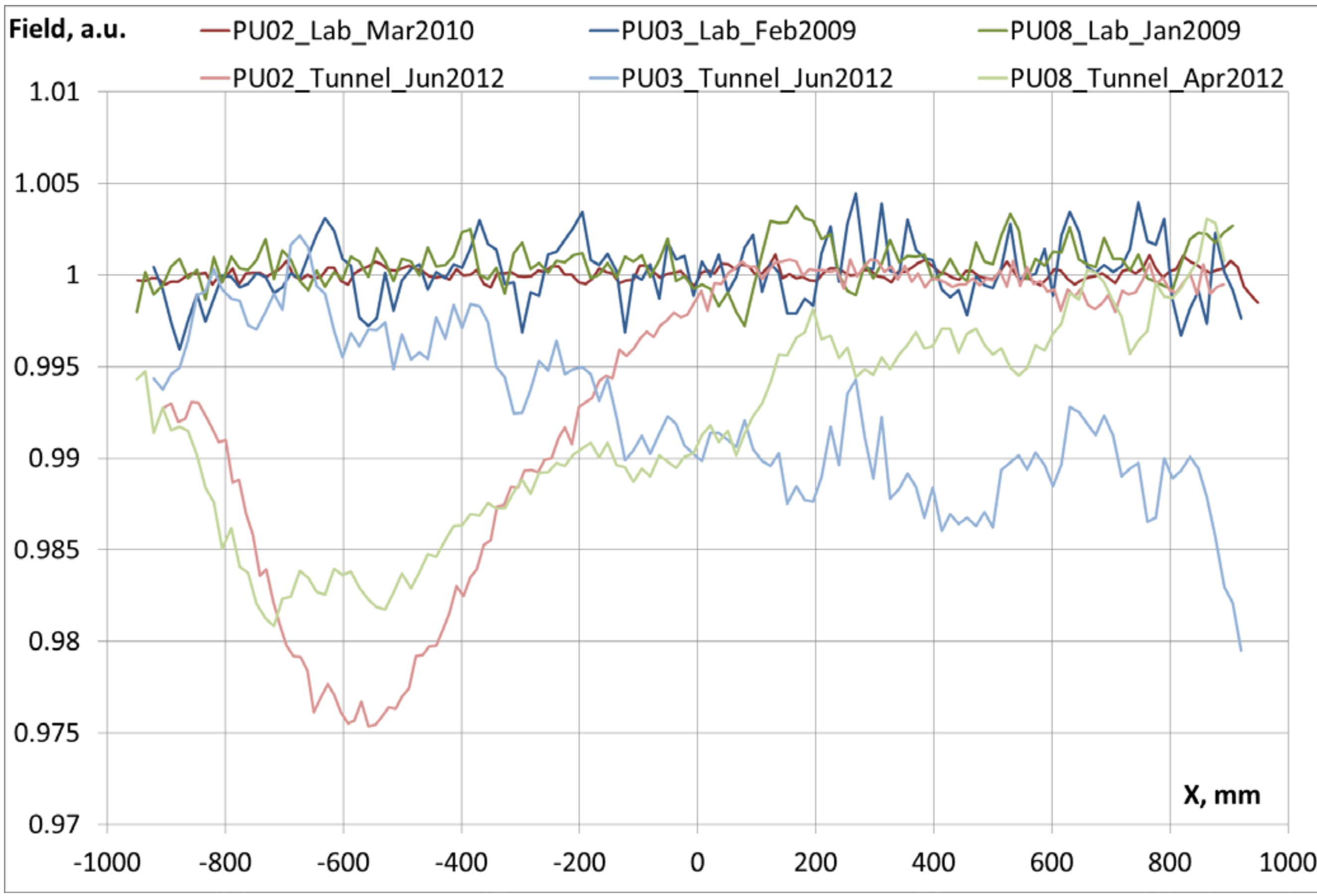




Radiation Damage Issues

> Magnetic Measurements

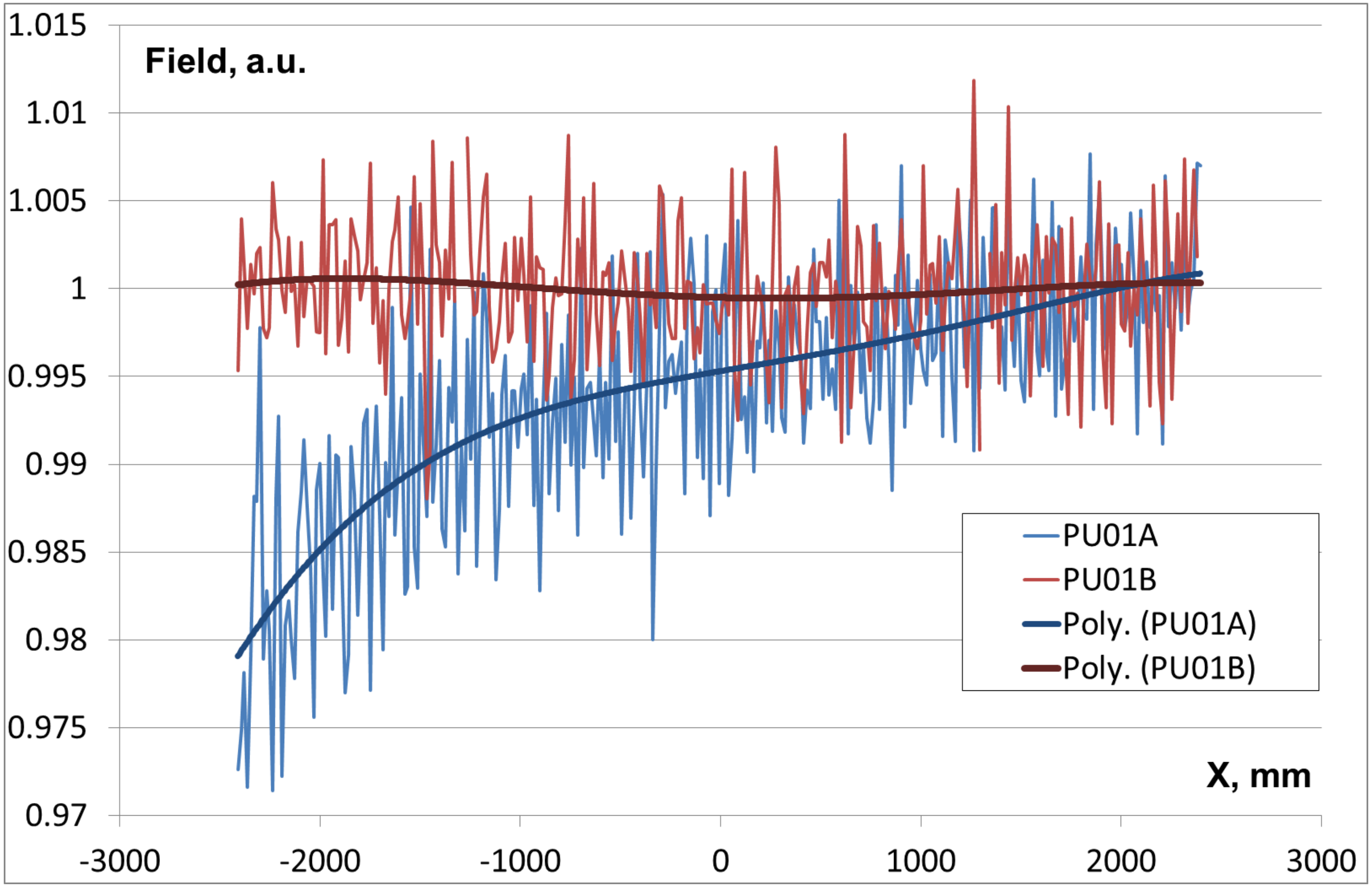
- Performed in the tunnel at the installed ID
- Hall probe moved manually over the magnet structure in a carriage
- Comparison of peak field values
- Coarse measurement, but error bar below <0.2%



Radiation Damage Issues

> Magnetic Measurements (cont'd)

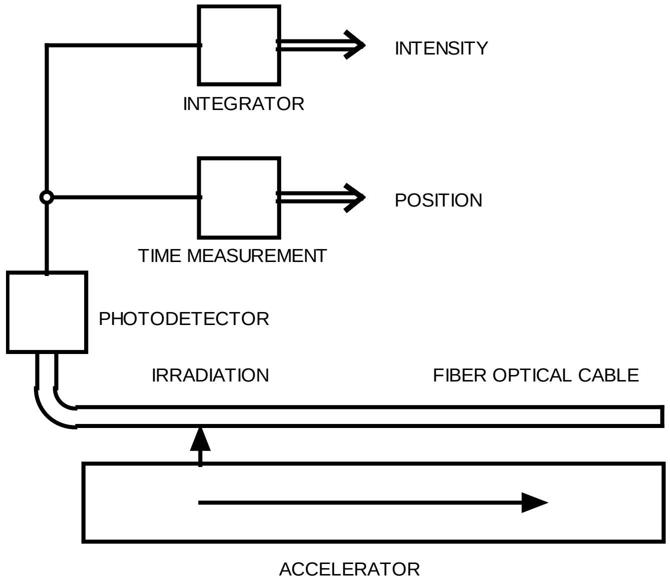
- Both 5m IDs at the beginning of the new octant (2012):



Radiation Damage Issues

> BLMs using Cherenkov Radiation in optical fibers

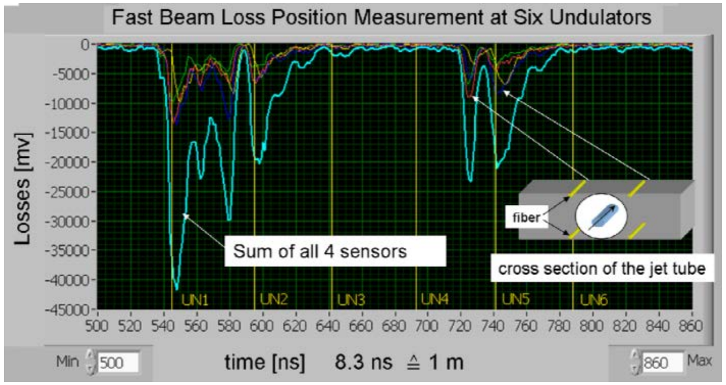
- Present test-setup at 2 straight sections in PETRA (under construction)
- Well established system at FLASH IDs and other locations (e.g. DIPAC (2009) 411; EPAC (2008) 1032)
- Principle: Radiation shower is converted into Cerenkov light
- Detection by photomultiplier + counter and/or fast ADC (→ dose rate)
- Position-sensitive
- Extremely high temporal resolution (depending on fiber length)
- Will allow to distinguish different operation states



M. Körfer, 2001

> No consistent picture up to now

- Only particular IDs are affected
- No correlation to visible corrosion patterns
- TLD results do not match well to the damage locations
- BLM and TLD measurements agree only qualitatively
- → mechanism not yet understood, but both electrons and SR are involved at different locations

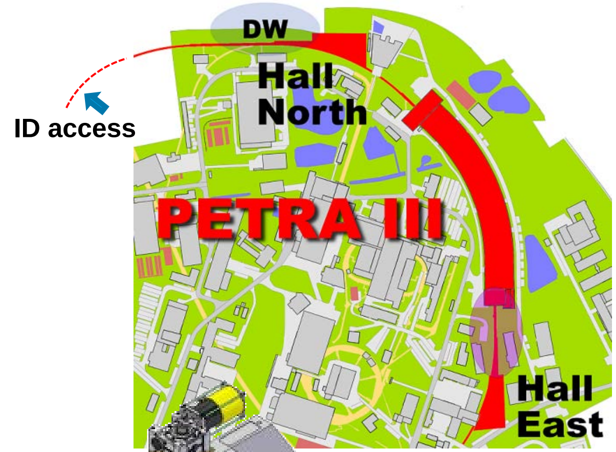


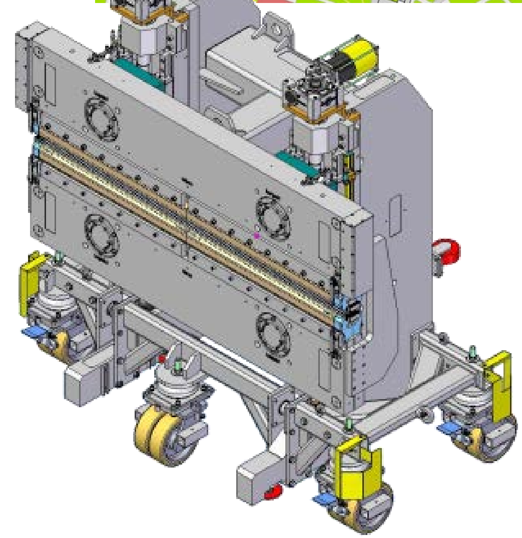
F.Wulf, M.Körfer, DIPAC (2009) 411

Undulators for PETRA III Extension

BL	length	period	energy	technique
P61	10 x 4 m	200 mm	50-150 keV	mater. sci., PDF
P62	N = 12	Tbd	6-35 keV	SAXS
P63	N = 12	32 mm	3-44 keV	micro XRF
P64	2 m	32 mm	3-44 keV	(Q)EXAFS
P65	N = 12	32 mm	4-44 keV	XAFS

BL	length	period	energy	technique
P21a	4 m	IVU	50-200 keV	mater. sci.
P21b	2 m	wiggler	50-200 keV	imaging
P21c	2 m	29mm	~100 keV	mater. sci.
P22	2 m	tbd	3-50 keV	nano XRF
P23	2 m	tbd	5-50 keV	nano XRD
P24	N = 12	tbd	8-40 keV	(Q)EXAFS
P25	N = 12	tbd	tbd	education



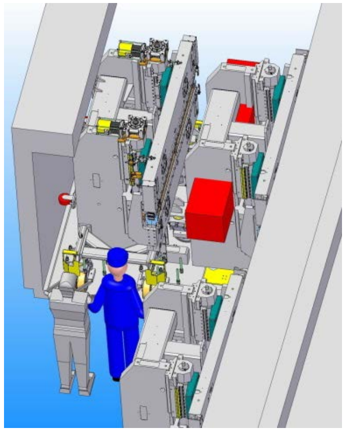


Vehicle for undulator transport in the tunnel (several 100 meters) due to lack of crane access.

Undulators for PETRA III Extension

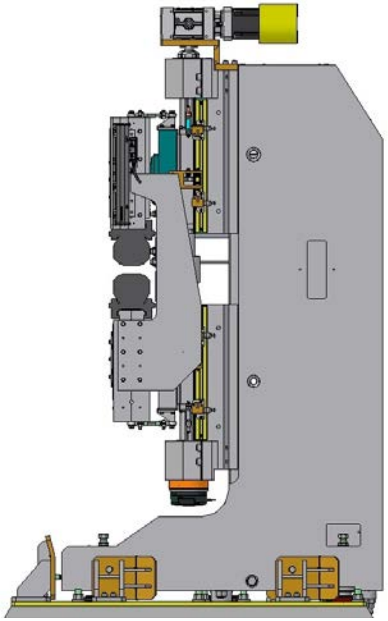
> Boundaries for ID design, transport, operation

- Various obstacles for transport in the present tunnel (existing installations, cable trays, doors, steps)
- Different beam height in the new arcs (1400mm) and in the old tunnel (~1.2m) → need for 2 different support structures
- Temperature control: ~slim concept with potential for upgrade

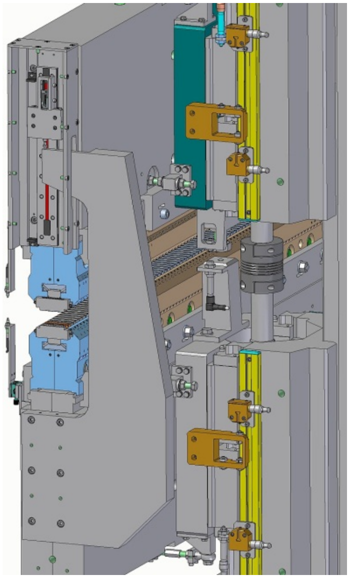


> Undulator design

- Same concept for FLASH II and PETRA Extension IDs
- Various mechanical improvements (stiffness, adjustment, floor mount)
- Revised drive system: 2 motors and 2 pairs of left/right-handed spindles
- Additional chamber touch sensors
- New linear encoder gap measurement system

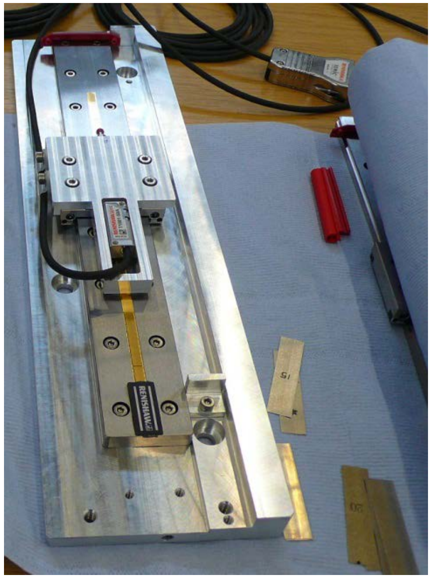


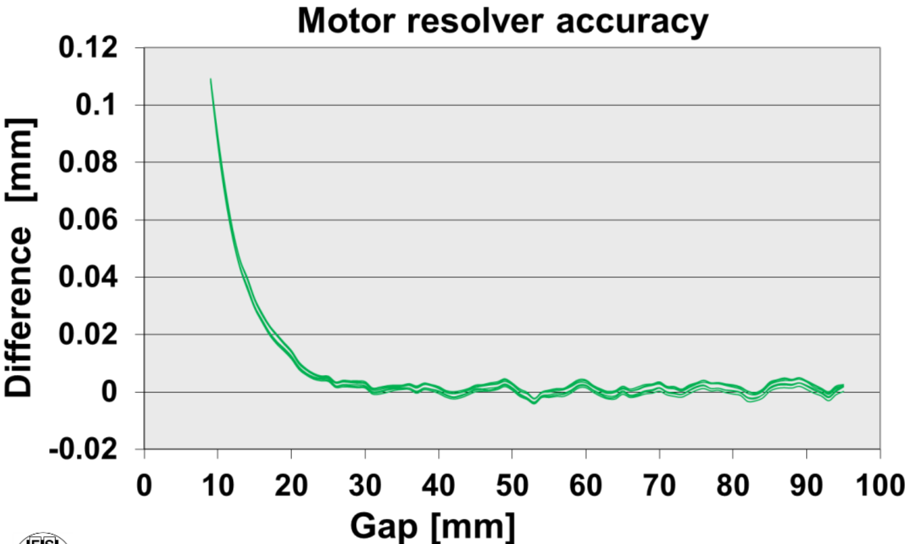
Linear Encoder Systems (FLASH II)

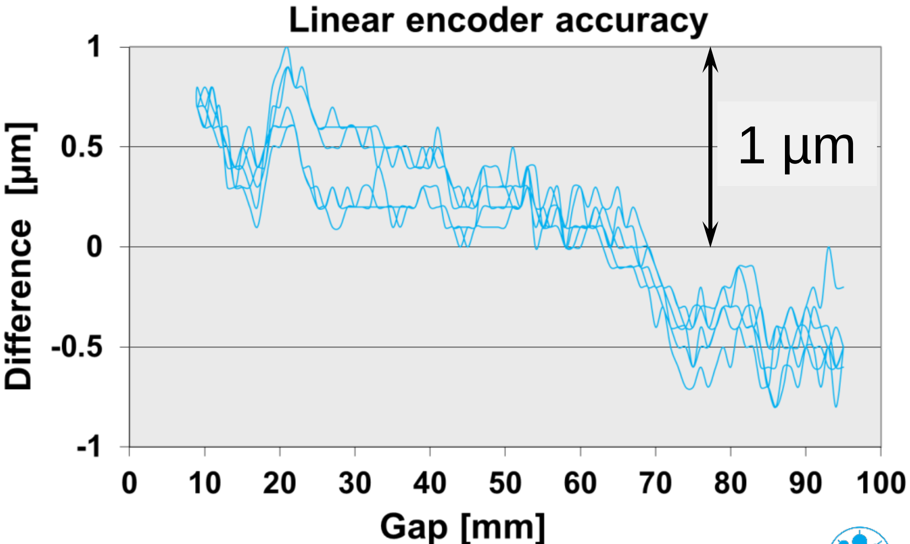


- **Rotary motor encoders**
  - systematic deviation reflects magnetic forces, compensated by feed-forward correction
  - resulting accuracy below 10µm, i.e. very precise drive mechanics

- **Linear encoders**
  - different versions built & tested
  - open Renishaw system
  - hysteresis reduced to less than 1µm
  - reproducibility is much better (sub-µm)



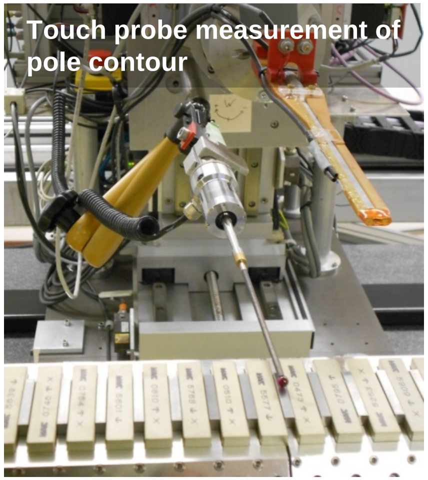


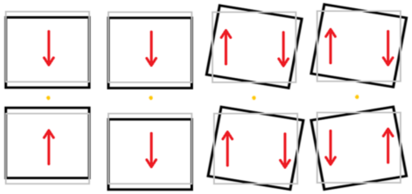


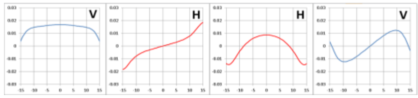
Undulators for PETRA III Extension

> Developments for magnetic measurements and tuning

- 3D metrology with the measurement bench for mechan. characterization and transfer measurements
- Investigation of Hall probe calibration errors, wire probe etc.
- Use additional pole movements for correction of higher order magnetic errors



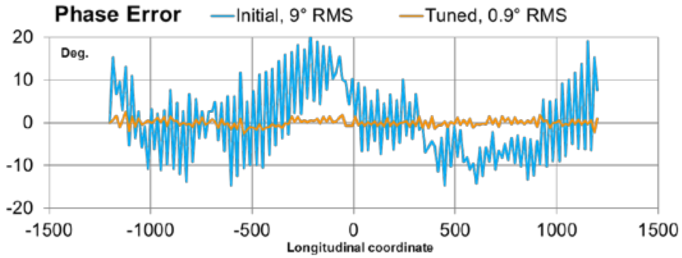


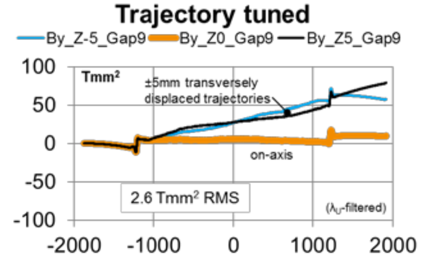


> Improved tuning results for FLASH II IDs

- Reduced phase error
- Enhanced trajectory straightness
- Smaller gap dependence of field integrals
- Local correction of quadrupole errors

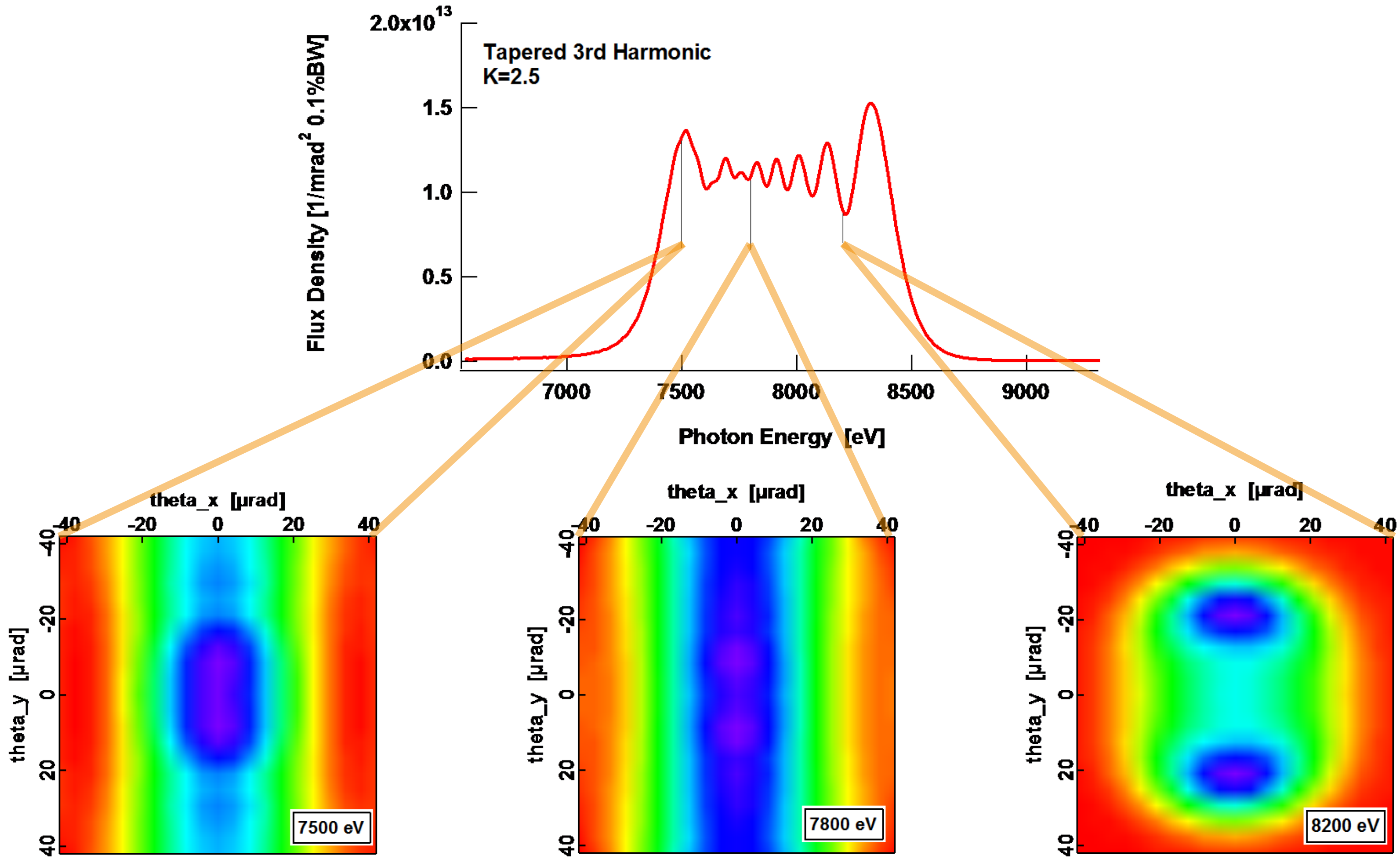
→ Beneficial improvements in particular for P3 extension IDs





Undulator Source for EXAFS

- EXAFS requires frequent scanning of the energy, i.e. gap! → Tapered Undulator?
- Tapered Undulator: Spatial distribution changes with energy !



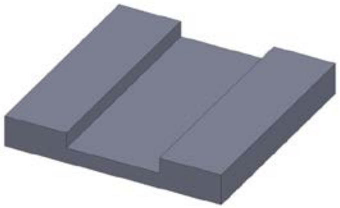
Undulator Source for EXAFS

Courtesy of O.Müller, Univ. Wuppertal

> Simulated EXAFS with Tapered Undulator

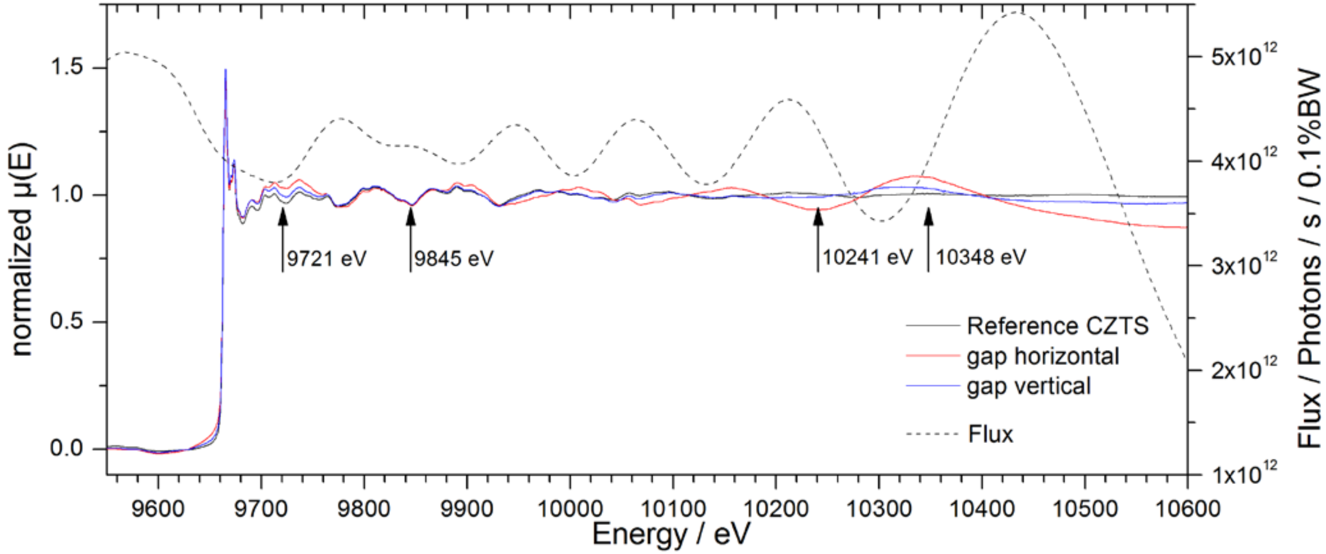
Inhomogeneous test sample:

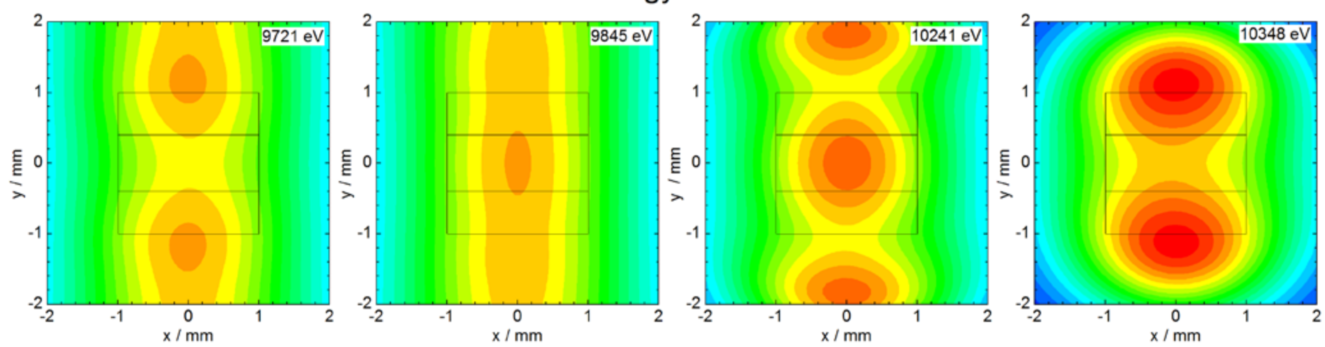
- Zn-K edge = 9669 eV
- Area: 700 µm x 700 µm
- Gap: 350 µm



Non-uniform illumination of an inhomogeneous sample → large artefacts in the spectrum (show stopper)

$$\overline{\mu d} = \ln\left(\frac{\overline{I_0}}{\overline{I}}\right) = \ln\left(\frac{\int I_0(E,x,y)dA}{\int I_0(E,x,y)e^{-\mu(E,x,y)d(x,y)}dA}\right)$$

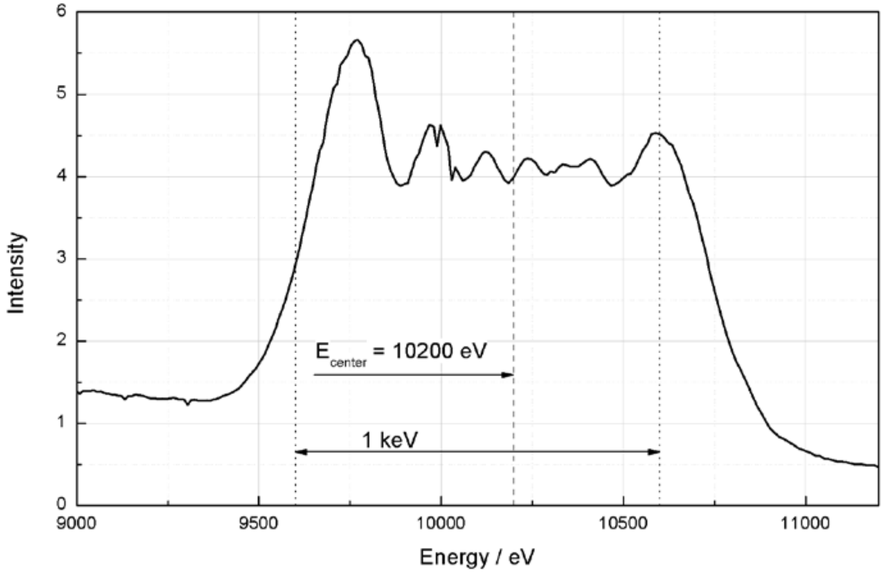




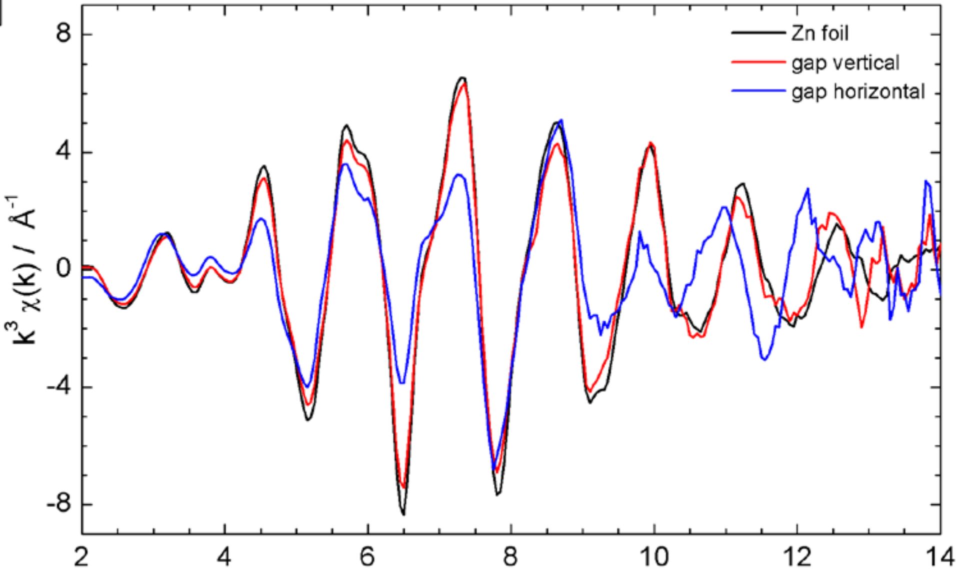
Undulator Source for EXAFS

Courtesy of O.Müller, Univ. Wuppertal

> Real EXAFS Measurement with Tapered Undulator



Undulator P06:
- $E_{Undulator}$ = 10200 eV
- Taper = 1 mm
- λ_U = 31.4 mm; L=2m
- Source Distance = 90 m



> Tapered spectrum shows sub-structure

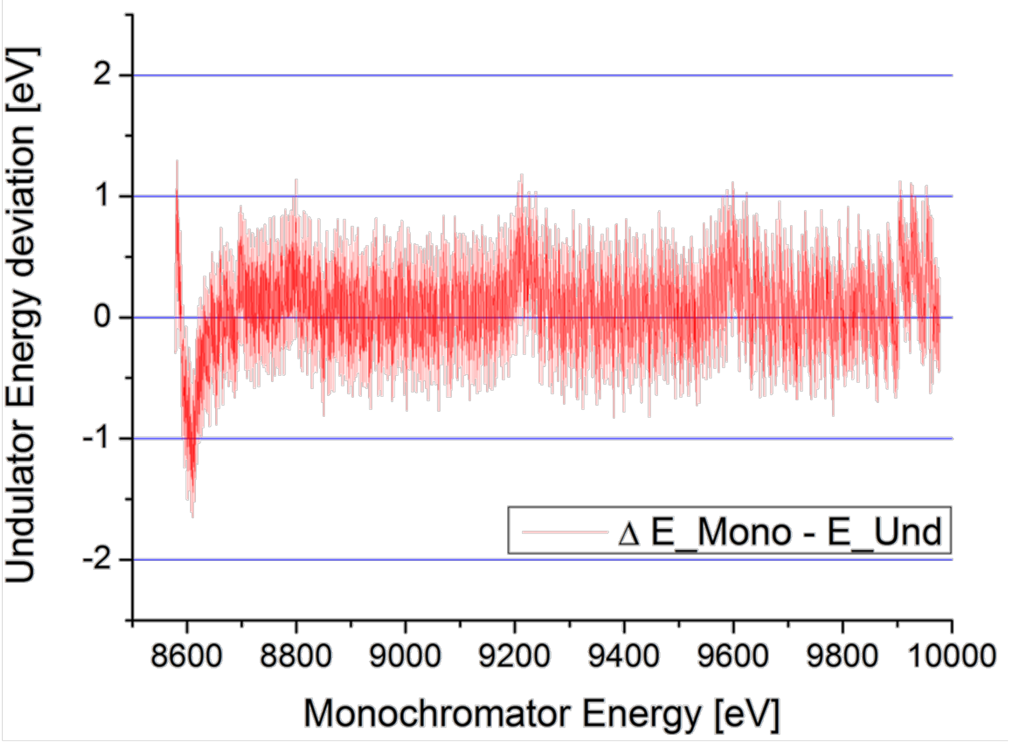
> XAFS spectra strongly depend on the orientation of the test sample

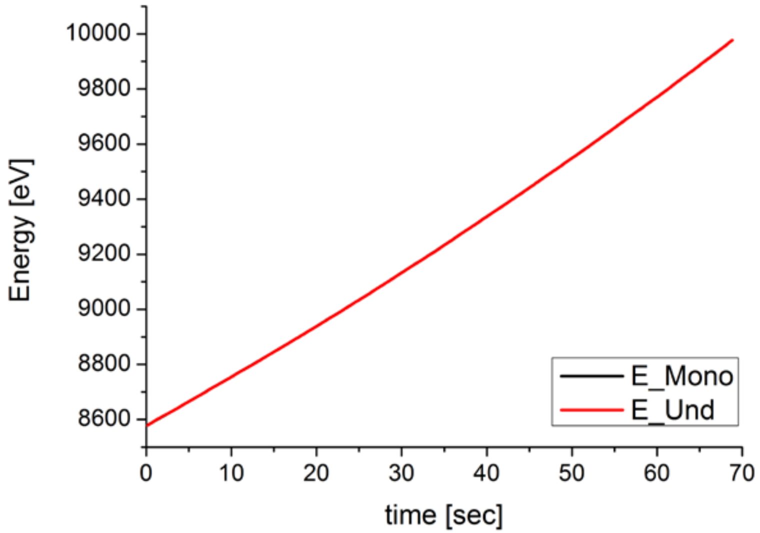
> Tapered undulator is an inadequate source for (most) XAFS applications
→ On-the-fly measurements with synchronized monochromator and undulator

> Wiggler not possible due to power restrictions, short wiggler as “bad” as tapered undulator

Energy Scan Monochromator vs. Undulator

> Energy Scan 20 eV / sec (und. velocity control OK)



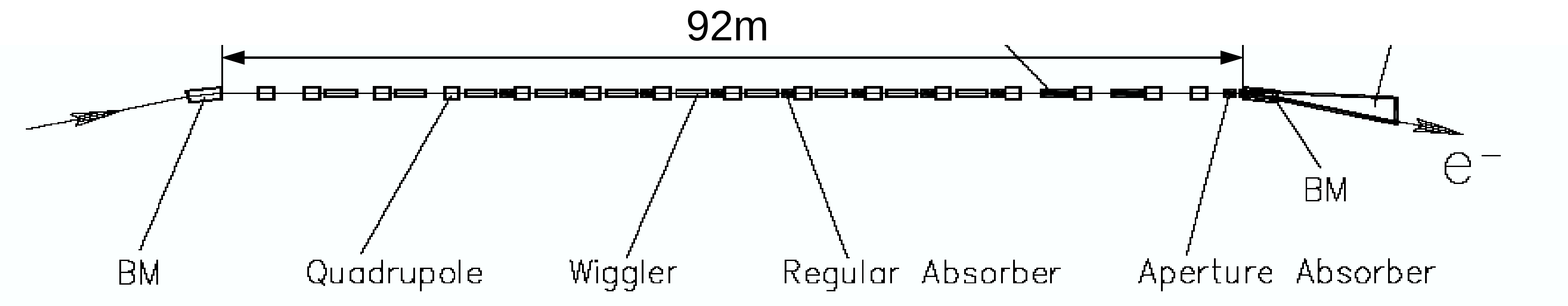


> Preliminary tests very promising, next: (still the previous status)

- Include the undulator velocity control in a TANGO device
- **Treat undulator gap as slave of the Bragg axis**
- Feeding the Bragg-encoder signals directly into the undulator NC

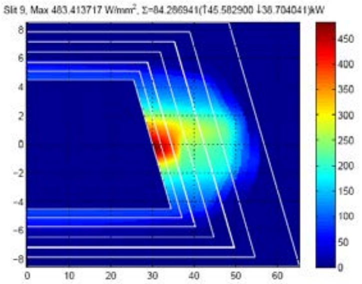
A. Schöps
G. Wellenreuther

Damping Wigglers for PETRA III Extension PU61



Damping section North

6 m long final absorber



Damping Wigglers: Parameters

Magnet structure	
Peak field B_0	1.52 T
Magnetic gap	24 mm
Period length	0.2 m
Number of poles	38 + 2·½
Magnet volume / period	2200 cm^3
Field quality at x_0 = 10 mm	< 10^{-3}
Damping integral / segment	3.9 T^2m
Overall length / segment	3.97 m
Number of wiggler segments (West + North)	10 + 10

SR characteristics	
SR critical energy	35.8 keV
K -Parameter	28.4
Wiggler SR power*	21 kW
Vertical SR spread	170 µrad
Horizontal SR spread	4.84 mrad

* I=100mA

NdFeB magnets

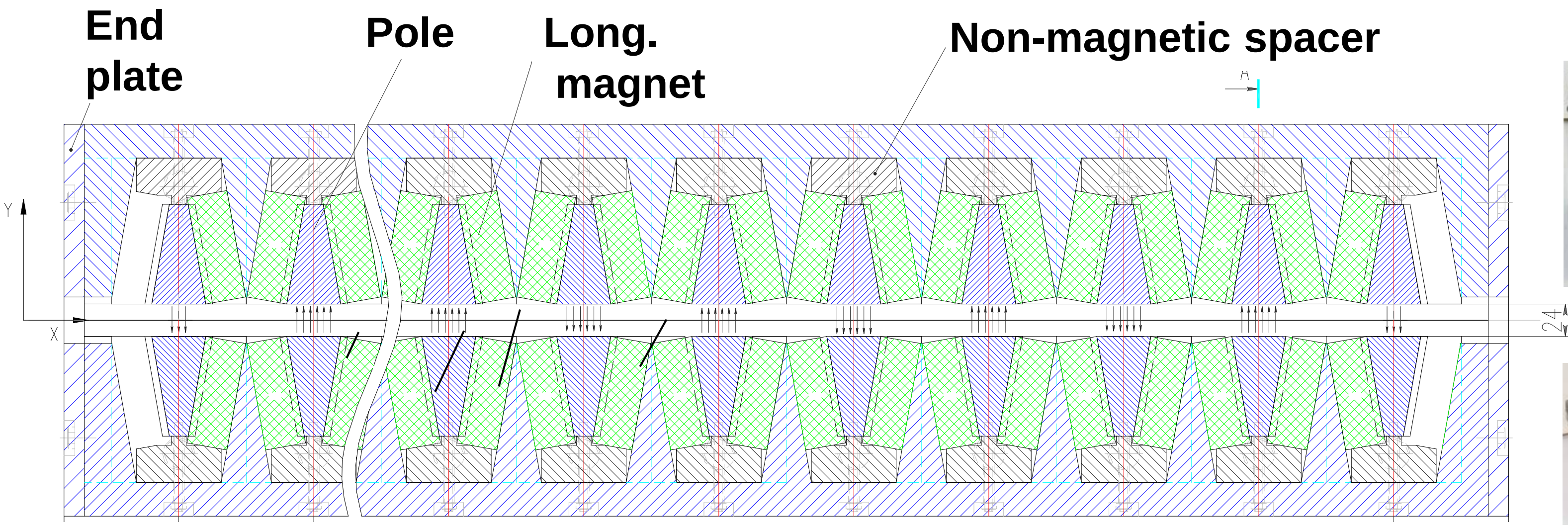
B_r = 1.3T

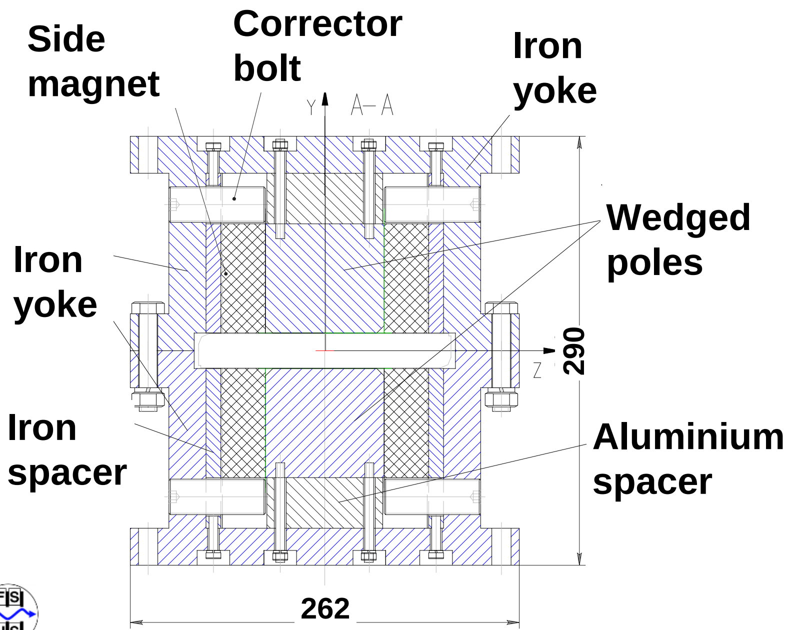
H_{cj} = 1430kA/m (17.9kOe)

built in collaboration with BINP

→Proceedings EPAC08, Genoa (2008) 2317

Damping Wigglers: Magnetic Design





- **Modified hybrid structure**
  Wedge-shaped iron poles
  also powered by side magnets
- **Iron enclosure**
  Magnetic yoke
  Mechanical support
- **Zero potential surface**
  Axial magnets split into 2 halves
  by soft iron V-notches sitting on the yoke
  almost no cross talk between poles

Conclusion

> PETRA III

- Reliable operation of all IDs
- Several magnet structures suffer from radiation damage; investigation will continue
- IVU for PU07 in 2014

> PETRA Extension IDs

- ID parameters ~specified, construction partly started,
  even more safety margin needs to be included in the magnet design
- IVU for PU21
- EXAFS-IDs shall be undulators

> Measurement Lab

- Assembly and tuning of 12 SASE IDs for FLASH II presently ongoing
- In this context, improvements and extensions of calibration and measurement techniques and also tuning procedures