17TH ADVANCED BEAM DYNAMICS WORKSHOP ON

FUTURE LIGHT SOURCES

WG4 Summary Viewgraphs

J. Bahrdt, BESSY

APRIL 6-9, 1999
ARGONNE NATIONAL LABORATORY, ARGONNE, IL U.S.A.

Insertion Device Development for 4th generation light sources

- coherent light at 10 keV
  high brightness at even higher energies
- circularly polarized light (variable)
- small amount of "useless" on axis
  power density
  minor contamination with higher harmonics
- short pulses
- tunability by users

these demands trigger the following technical **developments** in insertion device design:

high energies

→ SASE FEL
- high magnetic field quality
- alignment of modules
- beam based alignment
- integrated diagnostics
  and steering coils
- integrated focussing

→ Storage rings
- → wigglers
- → undulators

storage ring

wiggler: higher fields
- permanent magnet wiggler 3,6 T @ gap 6mm (ESRF)
- electromagnetic devices > 3 Tesla (LBNL, in study)
- superconducting multipole wiggler (MAXLAB) | 47 poles, 3,5 Tesla, $\lambda = 60$ mm
- 3,4 Tesla hybrid (SRRC)
- superbends (ALS)
- superconducting WCS (10 Tesla already demonstrated)

undulator
smaller periods
lower gaps
- in vacuum IDs
- mini-micropole IDs

higher harmonics
- phase shimming

circularly polarized light
control of higher harmonics

SASE-FEL
- "crossed undulator" (Kim) (no monochromator needed)
- superconducting helical devices
- planar helical (permanent magnet)

storage ring
- many designs with permanent magnets
- electromagnets

tunability

SASE
- e^- energy variation (how fast?)
- helicity switching (dispersive section optics)

Storage ring
- gap variation at long IDs
- polarization switching
- ID-monochromator coupling

long undulators for storage rings

- optimum segmentation length: ~2,5 m

- phasing between segments
  - i) magnetically one piece but mechanically decoupled (SPRING8, BESSY...)
  - ii) gap of several mm
    - pure permanent magnet: special termination developed at ESRF
    - hybrid: no solution yet

- strong focussing for small gap IDS (Tatchyn)
- synchronization of axis within a few μm if high harmonics shall be used
  - → closed loop, direct gap reading
  - → compensation of Abbe comparator error (which is due to beam roll)

- coupling with monochromator
  - stop and go mode realized at several facilities
  - continuous mode not yet realized

Challenges for SASE undulators

specs: trajectory errors have to be minimized to guarantee overlap of electron beam and photon beam. phase error do not play dominant role.

this implies:

- tight field tolerances: can be achieved with conventional tools, however i) averaging is necessary for noise reduction ii) calibration of Hallprobes
- additional focussing: field gradient ⇒ precise alignment of quadrupoles essential
- ID cannot be measured completely in one scan ⇒ segmentation (TESLA and VISA: 2 modules can be measured in combination)
- alignment of modules:
  i) align quadrupoles within individual modules
  ii) transfer quadrupole centers to fiducials
  iii) align fiducials of different modules with lasertracker
  iv) beam based alignment (varying e⁻ energy instead of quad-settings)

Challenges of SASE undulators: 3 examples

	APS		TESLA		VISA	
energy (MeV)	220	700	230-390	1000	72	220
λ (nm)	532	52	120-40	6,4	814	87
undulator design	hybrid (Undulator A with fixed gap girder)		hybrid		pure permanent magnet, in vacuum	
gap (mm)	9,3		12,0		6,0	
total length (m)	30		15/30		4/6	
B (T)	1,01		0,497		0,75	
magnet sorting	yes		yes		yes	
	~~after sorting~~ much better quality than for randomly distributed blocks					
shimming	conventional (iron shims)		pole height adjustment		movement of quad magnets + trim magnets	
measurement	Hallprobe / coil		Hallprobe / coil		pulsed wire	
achieved accuracy			5 Tmm²			
integrated focusing	no: natural focusing + hor. f. quads between sections		yes		yes	
focusing strength			12 T/m		33 T/m	

	APS	TESCA	VISA
measurement of quadrupole + transformation to fiducials		coil transversely moved	pulsed wire, sag test: 0° + 90° measurement
accuracy of adjustment of quad center ~~+ transformation to fiducials~~		± 50 µm	± 25 µm
module length (m)	2,4	4,5	1,0
BPM + steerer inside undulator	no	every 0,5 m	every 0,5 m
diagnostics where between modules	yes	wire scanner absolute accuracy ± 10 µm	magnetically one ID, mechanically separately adjustable

further development of SASE undulators

(as soon as principle has been proven by experiment)

⇓

circularly polarized light is highly demanded by users

- vertical ID at end of long horizontal ~~planar~~ ID (Kim)
- circular ID at end of long horizontal ID
- (full length circular ID)

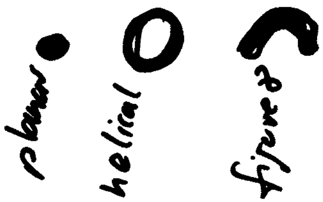
improve performance of SASE undulator with full length helical device

- permanent magnet planar helical device (?)
- superconducting

- automatic (robotic) shimming (Ramien SB) new magnet designs for:

- less on axis power density
- less higher harmonics contamination
- variable polarization

power density:

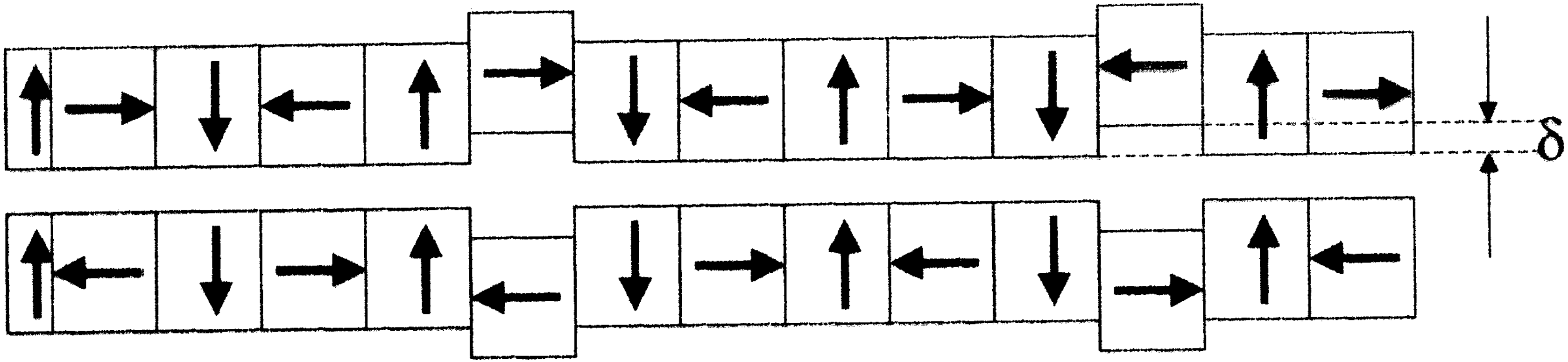


design	polarization	less on axis power density	less higher harmonics contamination	complexity			Status
				blocks/period	# movable rows	# rows	
new QPU	hor. linear	no	yes	8	–	2	built ESRF
APPLE QPU	variable	yes (circular)	yes	16	2	4	planned ELETTRA
figure 8	hor / vertical linear	yes	yes	16	–	6	built SPRING8
vertical undulator	vert. linear	no	no	16	–	4	built SPRING8
SPRING8 type EPU	variable	yes (circular)	yes	24		6	built SPRING8
APPLE8	variable	yes	yes	24	2	4	proposed
PERA	vert. linear	yes	yes	14	–	6	proposed
crossed EPU	variable	yes (linear)	yes	16	2	4	under constr. BESSY
helical ID + higher harmonics	helical	no	no	48	–	6	proposed

New quasiperiodic scheme (Sasaki)

built or under construction at several places

- permanent magnet designs (ESRF, ELETTRA)
- electromagnetic designs (SLS)

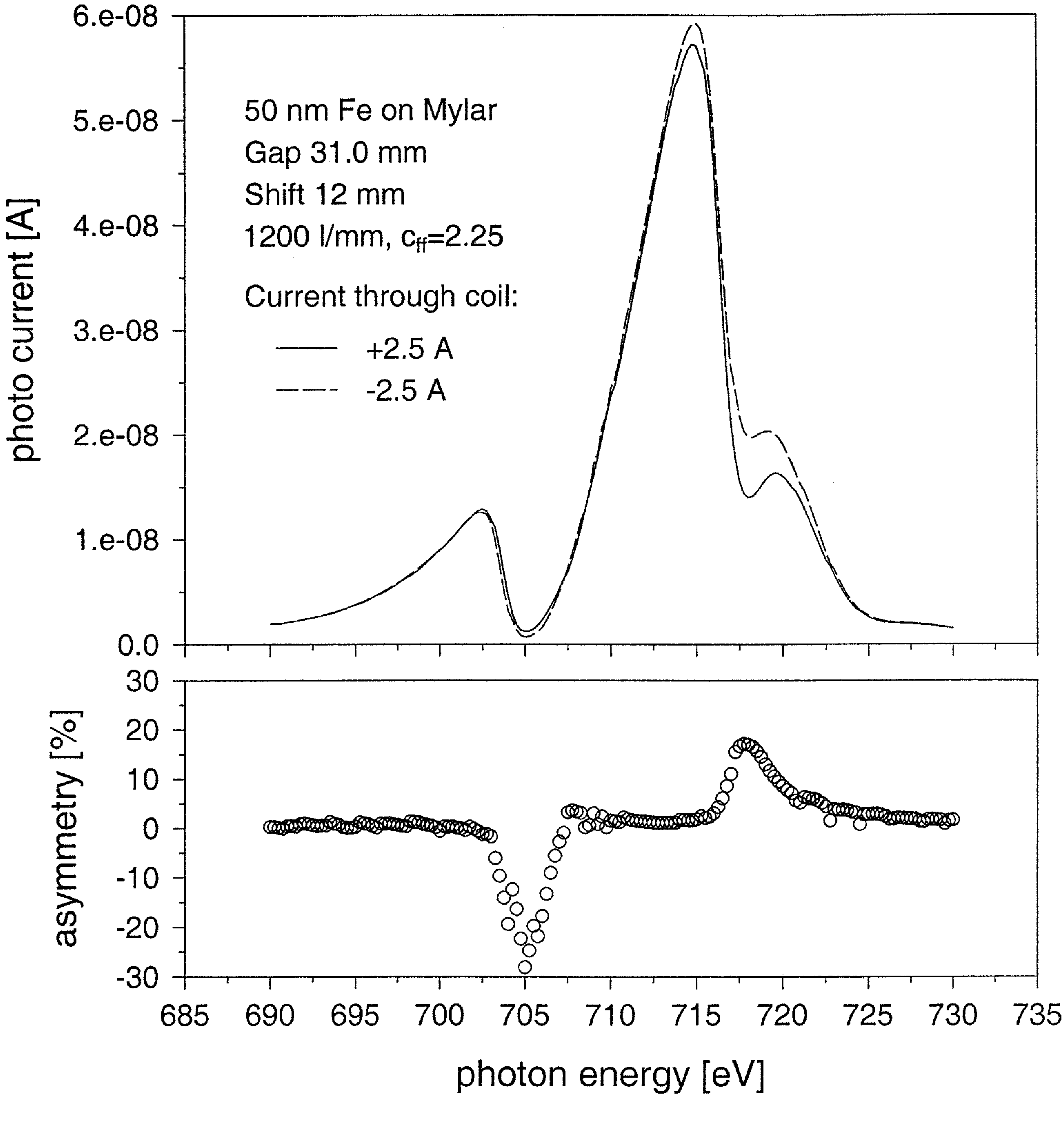


Circularly Polarizing Undulators (Sasaki Type) in Operation or under Construction (17.2.1999)

Facility	period length (mm)	total length (m)	Status (Feb. 1999)
SSRL	65	1.8	in operation for 5 years (second generation storage ring)
ALS	50	2	commisioning phase
SPRING 8	120	2	commisioning phase
SRRC	56	4	installation: April 1999
PLS	60	2.5	under construction
ELETTRA	60	2	under construction
	125	2	under construction
	46	2	under construction
	76	2	under construction
BESSY II	56	2 x 1.8	under construction
	56	2 x 1.8	under construction
	45	**3.4**	[redacted]

ESRF

First circularly polarized light at BESSY II
UE56/1, 31.3.1999



"Surprises" with new circularly polarizing permanent magnet devices

- field integrals dependent on gap + phase due to non unity of permeability of magnets
  solution: new end pole termination (ESRF)

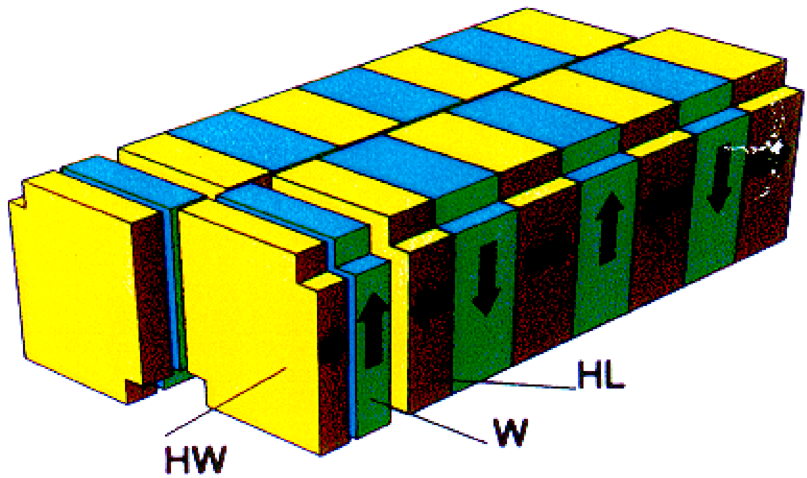
- old shimming techniques not applicable (shims move or change sensitivity during phase operation)
  elaboration of new shimming schemes:
  i) magnet block movement (hor. + vert.)
  ii) iron shims in special configuration
  iii) permanent magnet shims

- forces change direction!
  careful FEM based construction of mechanics

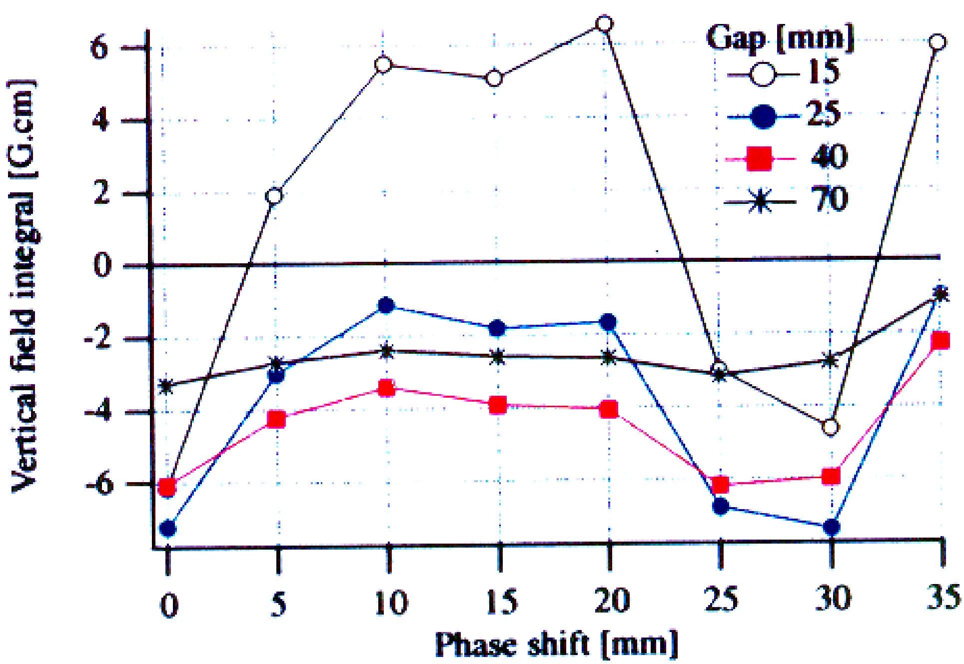
⟹ with this in mind IDs can achieve probably same quality as planar devices!

New Termination for an Apple II Undulator

- J. Chavanne et al., Presented at PAC 99
- Computed with Radia



NdFeB Magnets
Period = 70 mm
Symmetric Vertical Field



Magnet Blok Quality

- it is still necessary to do both:
  - i) sorting
  - ii) shimming

  (at least for permanent magnet devices)

- some vendors accept tight tolerances on inhomogenities (North South Pole ≤ 0,5%) but not all!

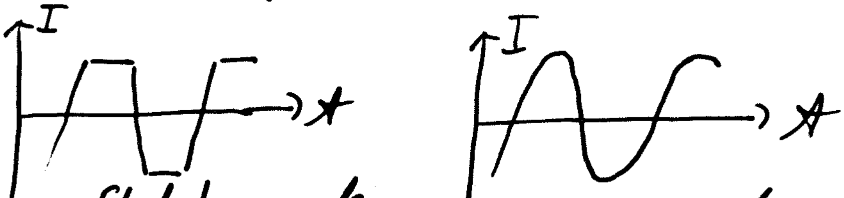
- 1 number might not be sufficient to characterize inhomogenities
  → supply vendor with equipment to characterize bloks more carefully in house

Electromagnetic elliptical/helical undulators

(only new devices)

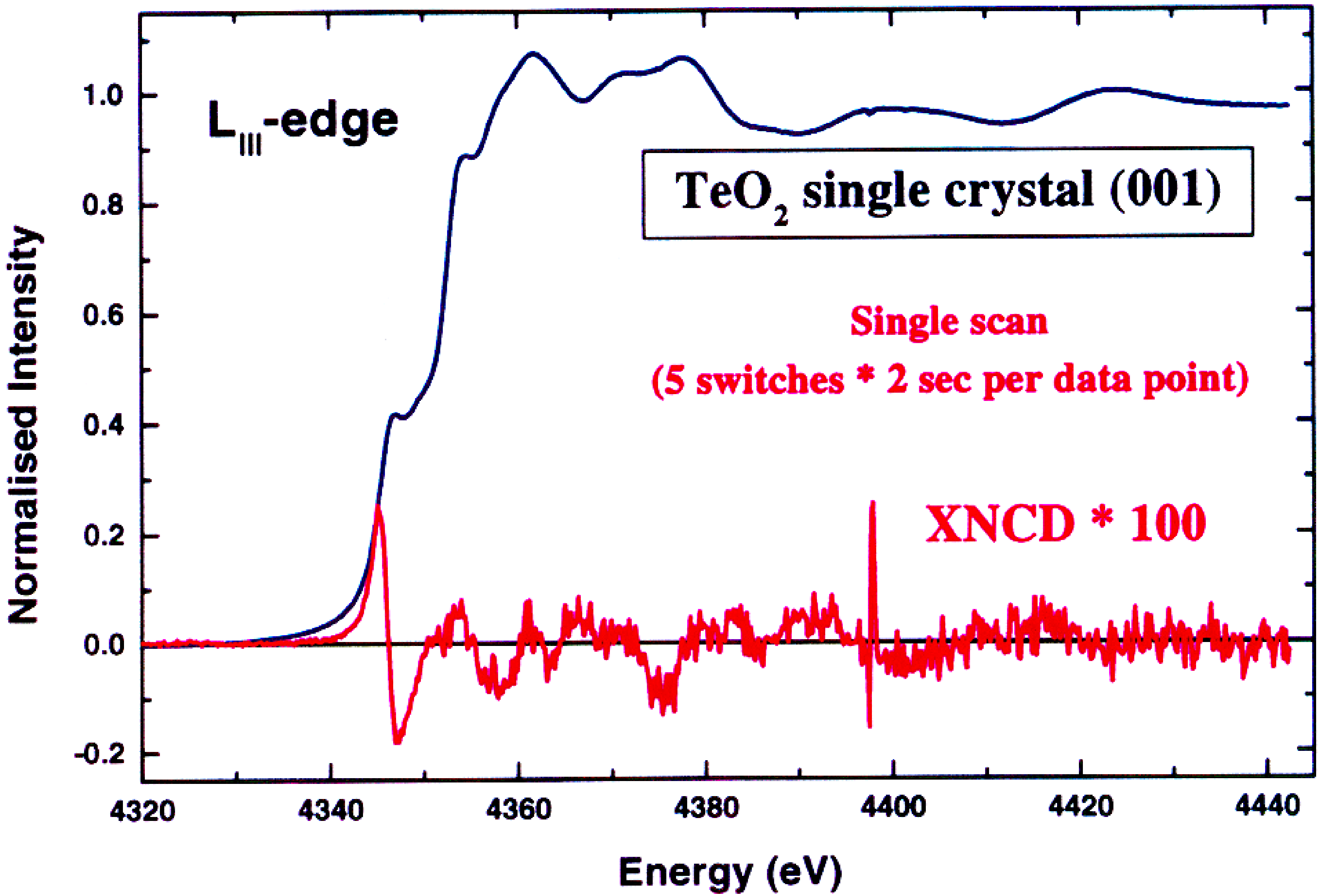
design	polarization	switching rate: typical	switching rate: max.	states
coils + permanent magnets	elliptical	2/100	100 Hz	NSLS in operation
coils + permanent magnets	elliptical	1	10	APS in operation
electromagnet	helical or elliptical		10 Hz	ELETTRA in operation
~~coils +~~ permanent magnets	helical	1 Hz	10[illegible] Hz	ESRF in operation

- dynamical changes of field integrals are compensated (DSP ...) → transparent IDs
  NSLS: $f \leq 10\,Hz$: combination of feed forward and feed back
- hysteresis effects can be handled
- undulators require flat top mode → $f \leq 10\,Hz$
- elliptical wigglers work also in transient mode



flat top mode — transient mode

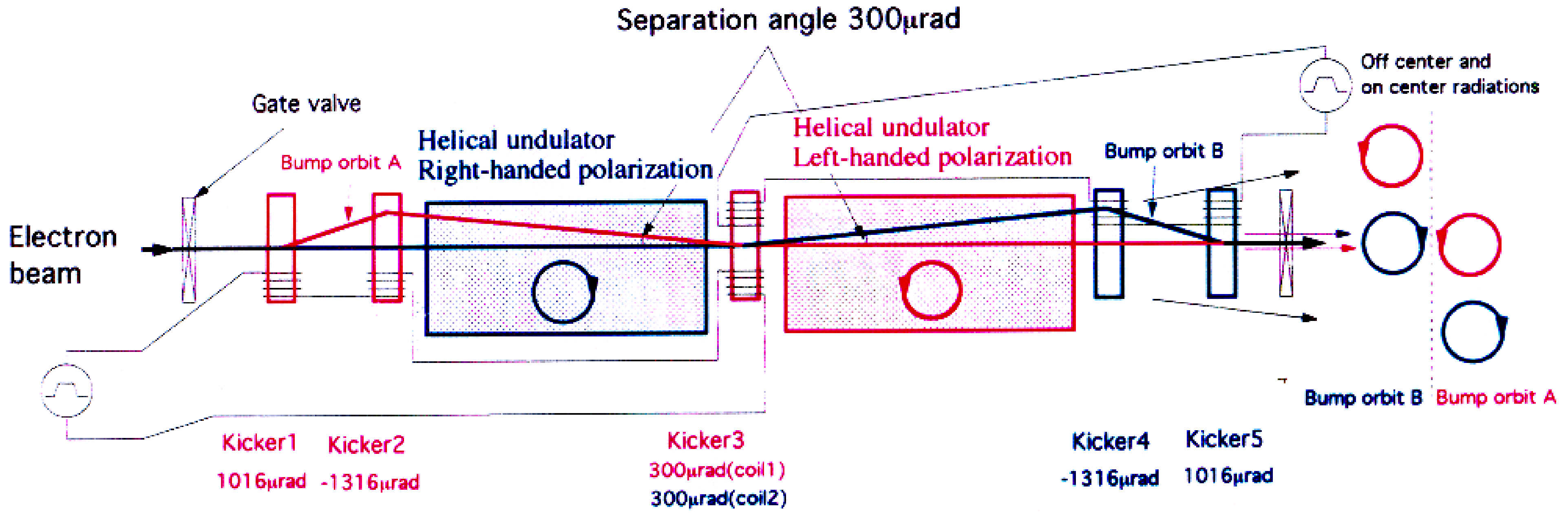
FIRST TEST OF EMPHU



Elliptically / Circularly polarizing Double Undulators

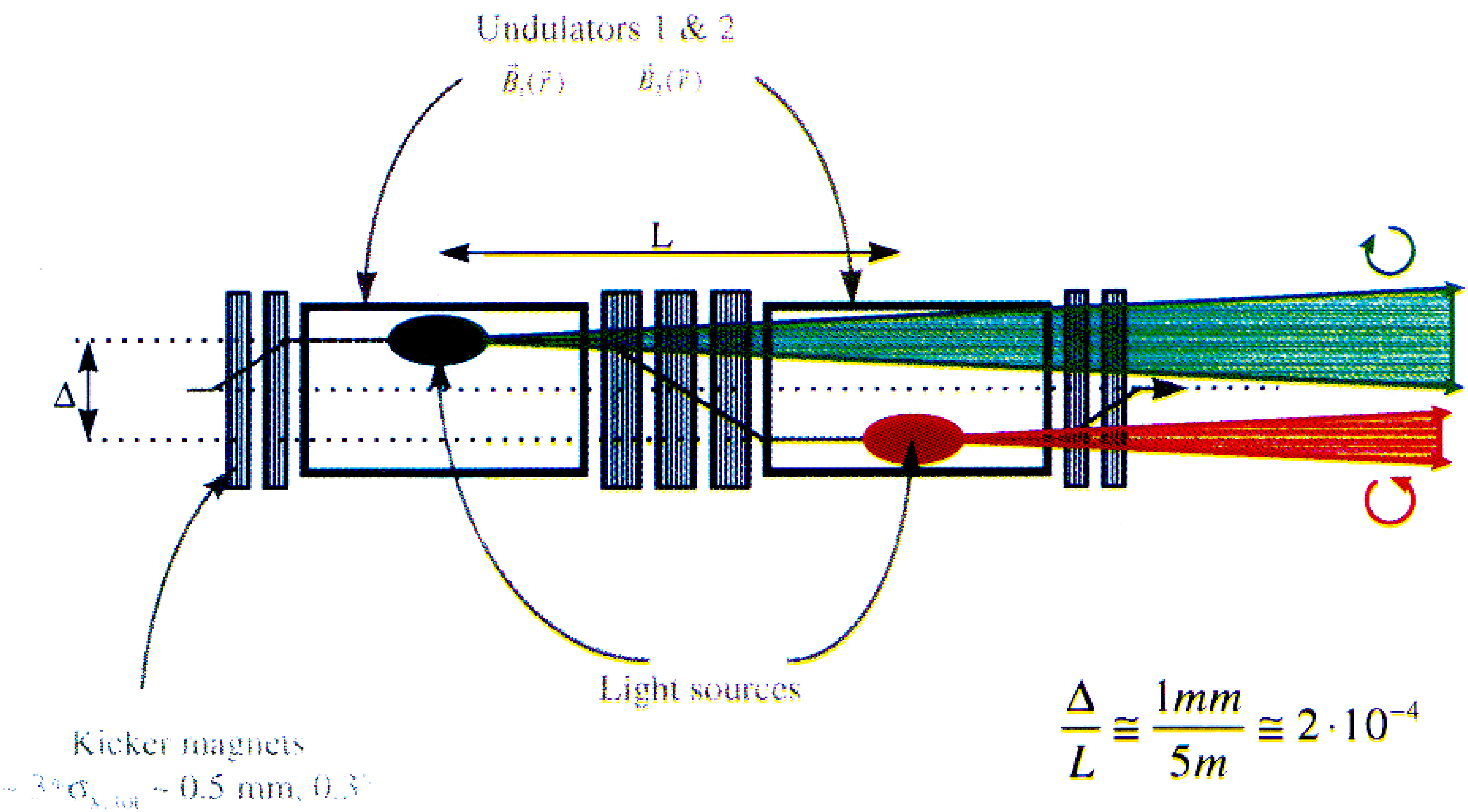
fast helicity switching!

design of undulator	Kicker magnets		Status
	design	operation	
permanent magnet	electro-magnets	dynamically	under construction SPRING8
permanent magnet	permanent magnet	statically (chopper in beamline)	under construction BESSY
electromagnet quasiperiodic	electromagnets	statically (chopper)	design phase SLS
permanent magnet	electromagnets	statically (chopper)	design phase SLS



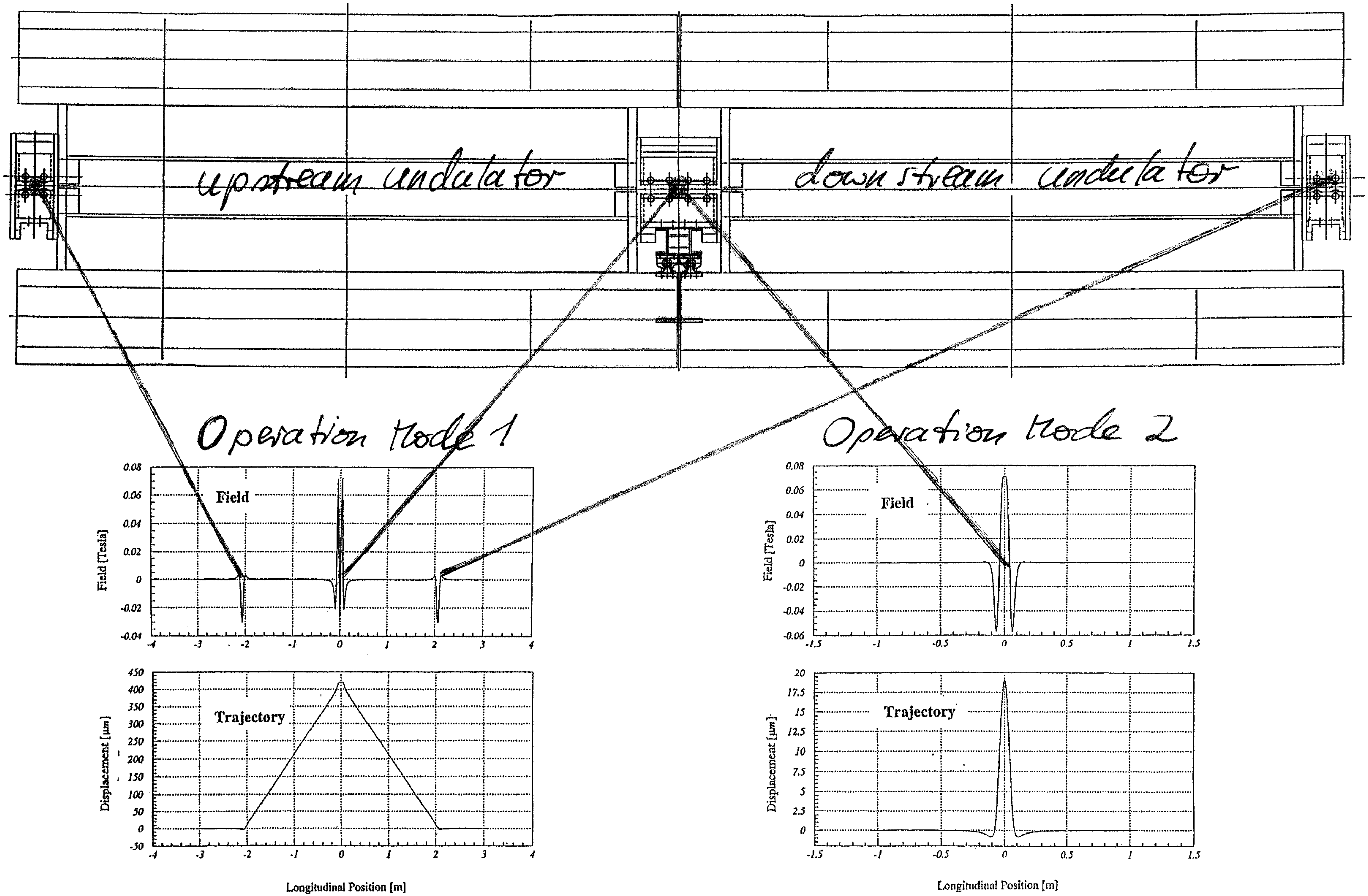
Twin helical undulator polarization switching

Parallel Displaced Beam



$$\frac{\Delta}{L} \cong \frac{1mm}{5m} \cong 2\cdot 10^{-4}$$

UE-56 Side View of Magnetic Structure



In Vacuum Undulators / Wigglers

mashine studies at ESRF:

0,8 mm gap → 2h lifetime
ok from mashine point of view
if topping up mode is active

but open questions concerning
- degradation of magnets (ID is scraping the beam)
- radiation shielding (Bremsstrahlung, Neutron
→ optimitation of injection efficiency
not only injection rate in topping up mode

no lifetime reduction for

gap	lifetime	facility
> 5	39 h	ESRF
> 4	14 h	NSLS ($\beta_x = 1{,}7\,m$, $\beta_y = 0{,}3$

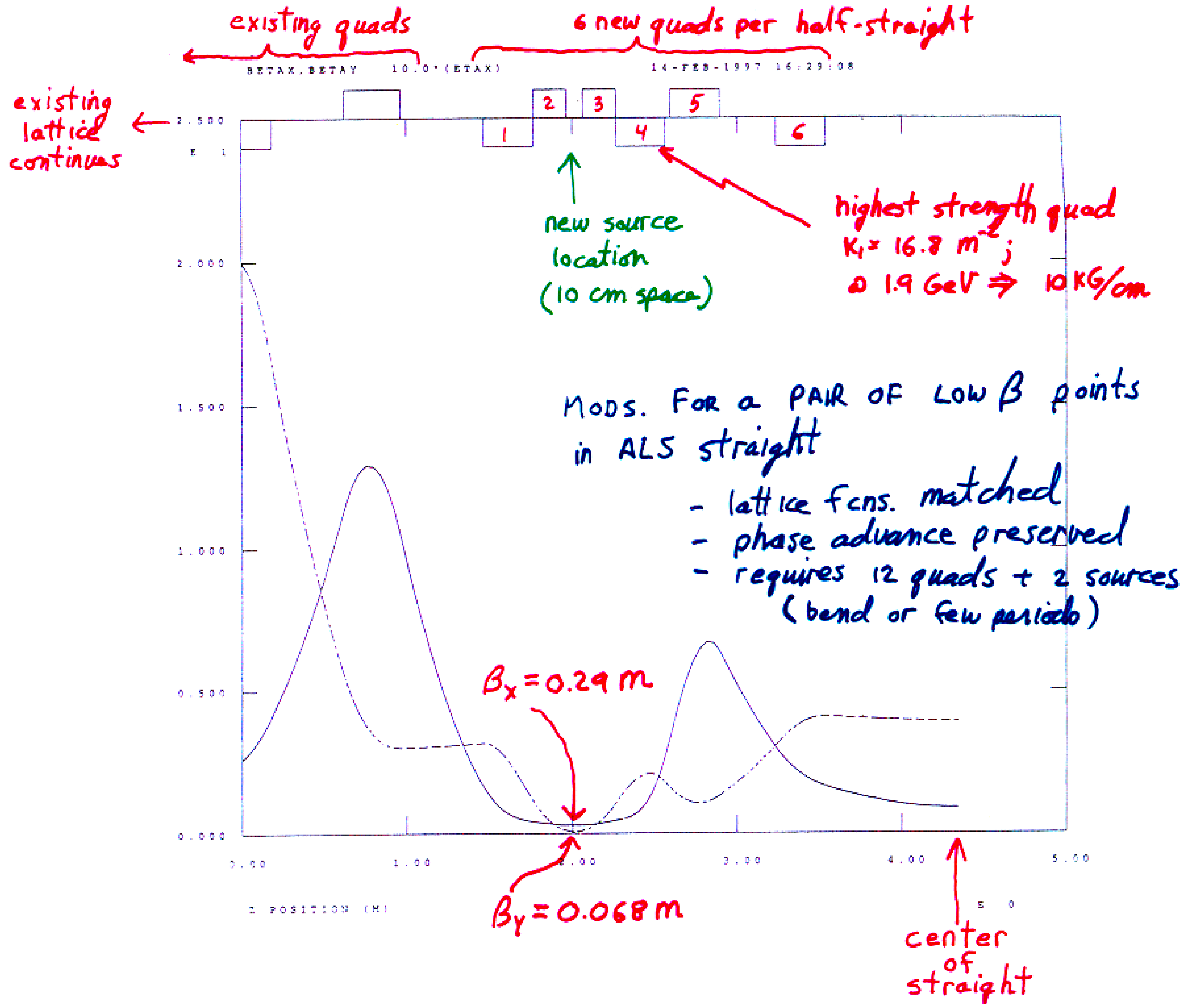
scraper somewhere in the ring does not neceseraly protect the insertion device

strong focussing inside undulator (Tatchyn)
would help → strong influence on lattice
additional quads etc...
Bypass would be fine for test!

mini β-sections

ACS-study

$\beta_y = 0{,}06\,m$ additional 6 quads/half straig
$\beta_x = 3\,m$ 10 cm available for ID



existing quads
6 new quads per half-straight
BETAX.BETAY 10.0*(ETAX)
14-FEB-1997 16:29:08
existing lattice continues
2.500
2.000
1.500
1.000
0.500
0.000
1
2
3
4
5
6
new source location (10 cm space)
highest strength quad
K_1 = 16.8 m^{-2};
@ 1.9 GeV ⇒ 10 kG/cm
MODS. FOR a PAIR OF LOW β points in ALS straight
- lattice fcns. matched
- phase advance preserved
- requires 12 quads + 2 sources (bend or few periods)
β_x = 0.29 m
β_y = 0.068 m
0.00
1.00
2.00
3.00
4.00
5.00
Z POSITION (M)
center of straight

In Vacuum Undulator Technology (SPRING 8 driving force.

magnet coating → Ti + TiN
after heating : $6 \cdot 10^{-11}$ Torr
image current heating: 50μ Ni + 10μ Cu foil
RF fingers water cooled
shimming technique: — magnet chips at backside (SPRING8)
\ conventional shimming (ESRF)
magnet material high coercive force required
NdFeB (SPRING8)
Sm_2Co_{17} (ESRF)
thermal expansion during baking: careful design

problems seem to be solved
⇒ even more ambitious plans
- in vacuum revolver
- 25 m long in vacuum undulator
flexible chamber as expensive as in vacuum undulator → no need for it

nevertheless: continuous monitoring of ID quality
- routinely checking field integrals of IDs (done every month at ESRF)
- reference spectra are even more sensitive but might interfere with user activities
i) shape of higher harmonics
ii) polarization

superconducting planar undulators (Backe)

development at Forschungszentrum Karlsruhe

$\lambda = 3{,}8$ mm $B = 0{,}56$ Tesla
$N = 100$ $I_{max} = 1400$ A
gap = 2 mm

already tested at MAMI Microtron (Mainz, Germany)
one has to go far into saturation to gain field compared to permanent magnet design.
In this case, however, field errors due to winding errors dominate machining errors.

superconducting variable period undulator (Tatchyn)

variable polarization can be provided

Codes

- Spectrum calculation including diffraction wave front propagation through beamlines
- magnetic field calculations → RADIA (ESRF)