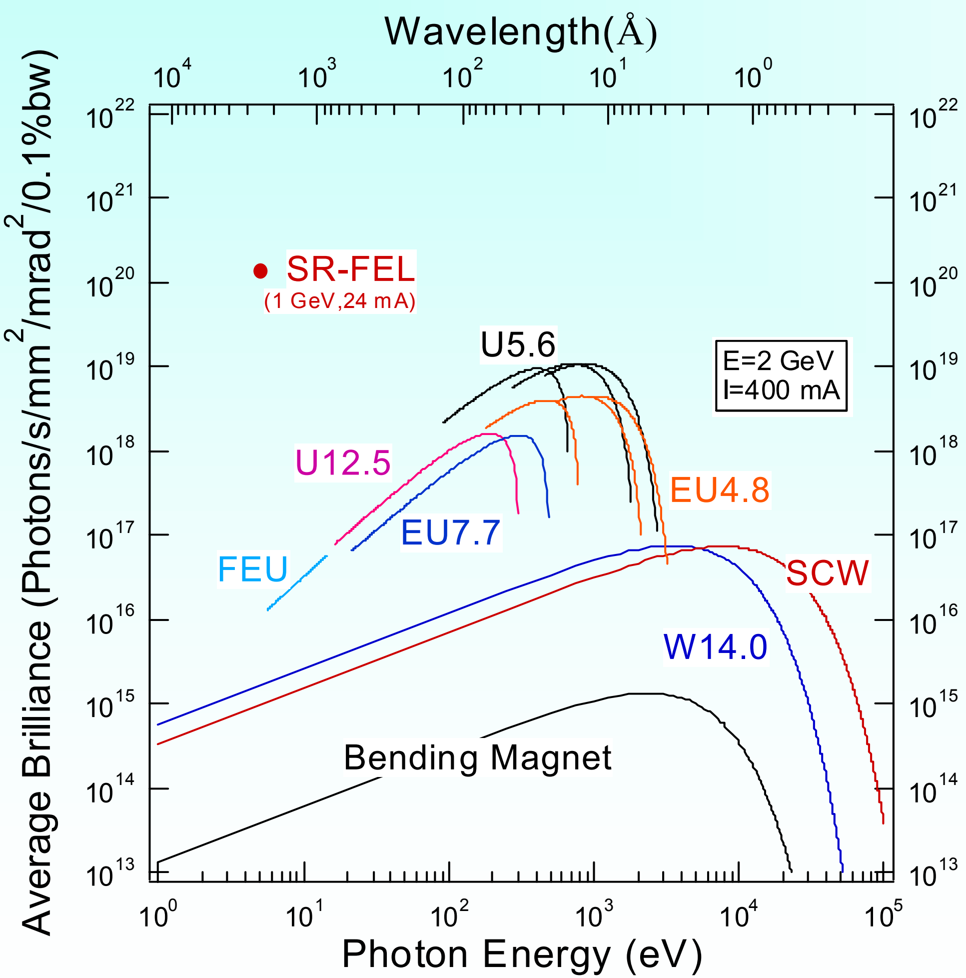
Status of Photon Sources at ELETTRA

B. Diviacco, Sincrotrone Trieste



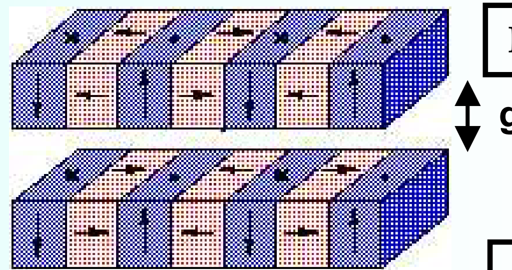
- ***General ID Status***
- ***Elliptical Undulators***
  - *- Layout*
  - *- Effects on beam dynamics*
  - *- Power load issues*
  - *- Selected commissioning results*
  - *- Quasi-periodic undulator*
- ***The Figure-8 Undulator***
  - *- design & characteristics*
  - *- magnetic measurements data*
  - *- commissioning results*
- ***Shord IDs***
  - *- concept & prototype results*

ELETTRA Insertion Devices Status (Dec. 2002)

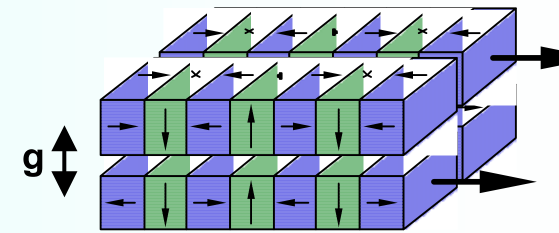
Argonne Workshop
December 5th, 2002
Bruno Diviacco

ID	type	sectioı	Period (mm)	Nper	gap (mm	status
.U10.0	PM/Elliptical	1	100	20+20	19.0	operating
U5.6	PM/Linear	2	56	3 x 27	19.5	operating
U12.5	PM/Linear	3	125	3 x 12	32.0	operating
EEW	EM/Elliptical	4	212	16	18.0	operating
W14.0	HYB/Linear	5	140	3 x 9.5	22.0	operating
U12.5	PM/Linear	6	125	3 x 12	29.0	operating
U8.0	PM/Linear	7	80	19	26.0	operating
EU4.8	PM/Elliptical	8	48	44	19.0	operating
EU7.7	PM/Elliptical	8	77	28	19.0	operating
EU6.0	PM/Elliptical	9	60	36	19.0	operating
.U12.5	PM/Elliptical	9	125	17	18.6	operating
FEU	PM/Figure-8	10	140	16+16	19.0	commissioning
CW	SC/Linear	11	64	24.5	10.7	testing
hortID	PM/Linear	-	56	17	25	operating

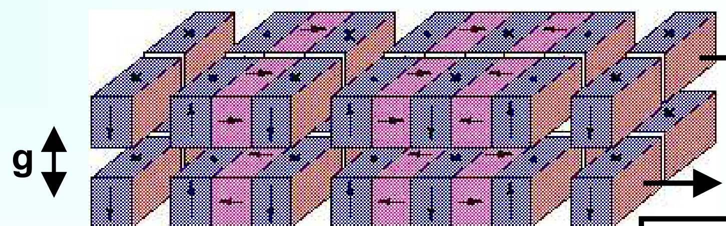
24 ID segments installed



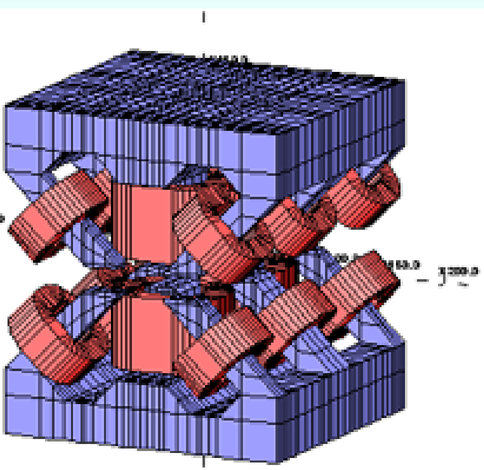
PM-LINEAR



PM-ELLIPTI

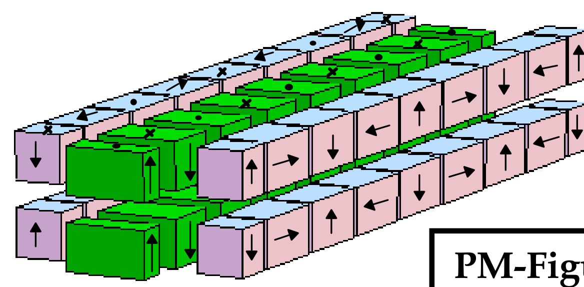


PM-



-ELLIPTICAL

EM-SCW

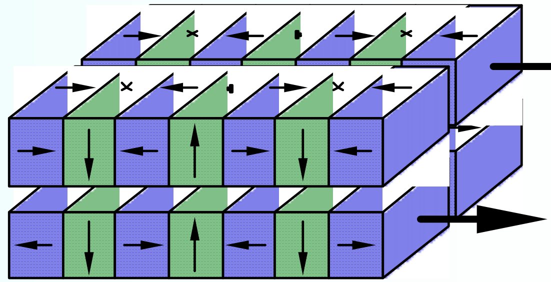


PM-Figur

Elliptical Polarization Undulators (EPUs)

6 APPLE-II type undulators have been installed, serving three beamlines

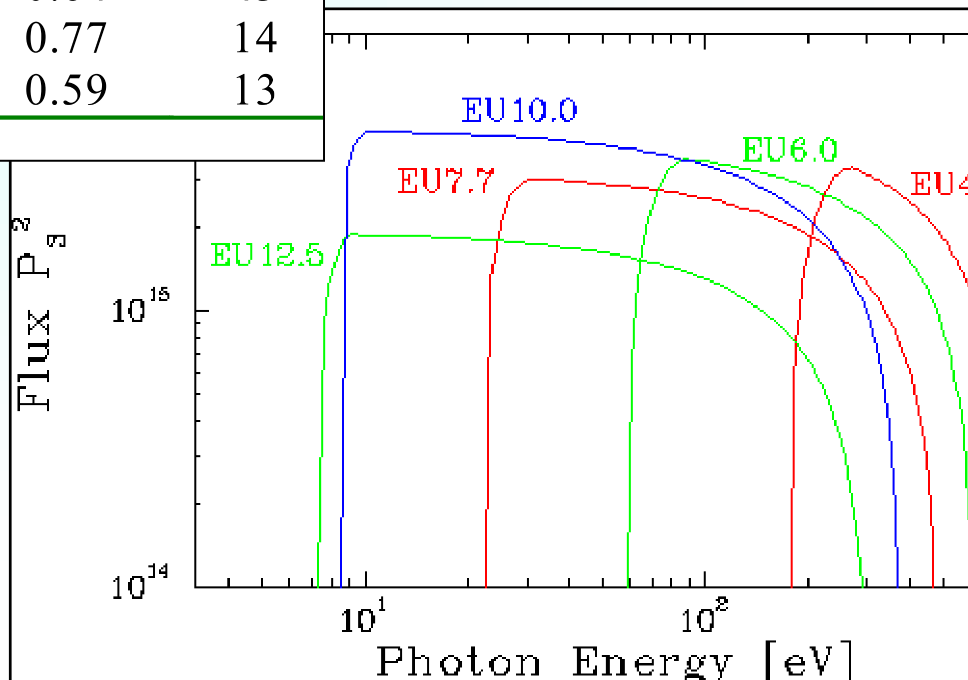
(APE, BACH and FEL/Nanospectroscopy)



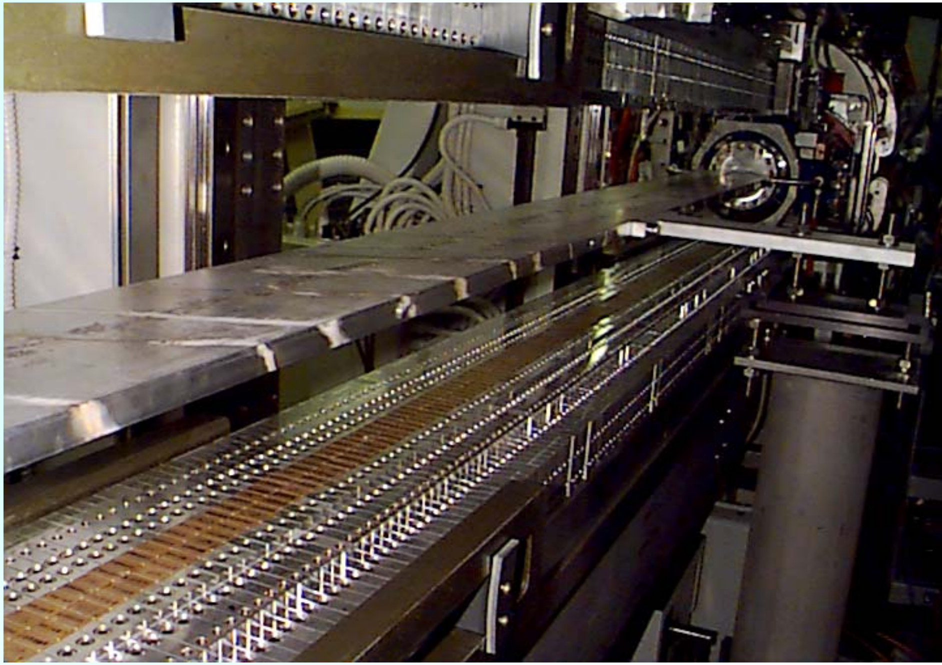
eriod (cm)	Np	Horizontal Polarization		Circular Polarization		Vertical Polarization	
		B0 (T)	ε1(ev)	B0 (T)	ε1(ev)	B0 (T)	ε1(ev)
4.8	44	0.58	178	0.29	287	0.34	366
6.0	36	0.78	59	0.42	94	0.51	123
7.7	28	0.92	21	0.53	32	0.64	43
10.0	20	1.02	8	0.63	11	0.77	14
2.5*	17	0.77	8	0.48	10	0.59	13

quasi-periodic

Main parameters of the APPLE-II undulators at the minimum gap of 19 mm



EPUs arrangements at ELETTRA (I)

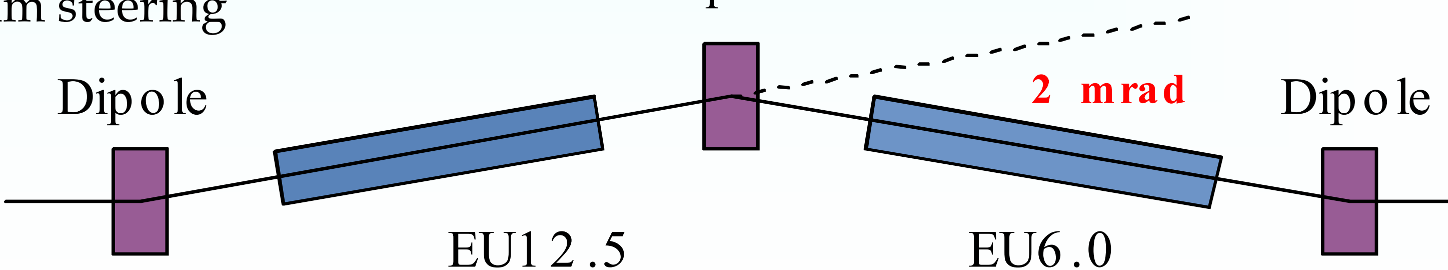


BACH beamline (EU4.8+EU7.7)

two different undulators are placed collinearly on one straight section

APE beamline (EU6.0+EU12.5)

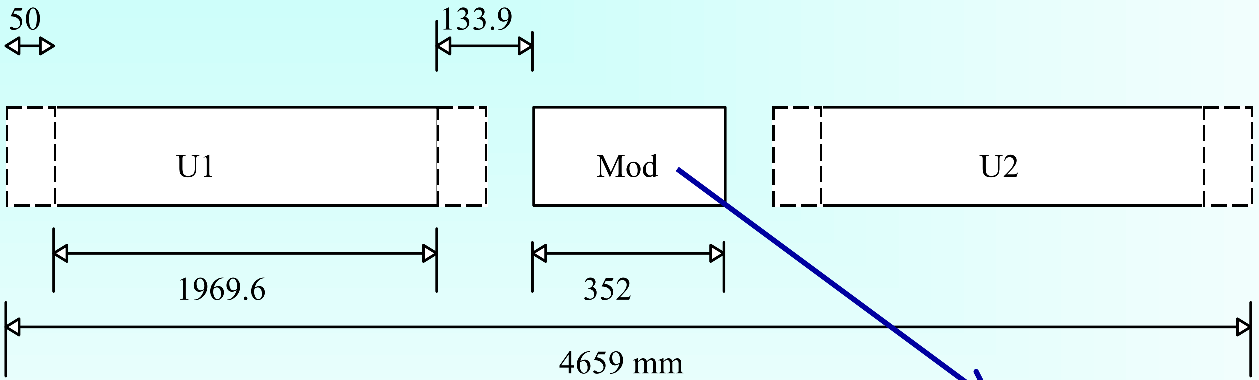
two different undulators are placed on the same straight section; simultaneous use of the two sources is made possible by a chicane-like e-beam steering



EPUs arrangements at ELETTRA (II)

FEL/NANOSPECTROSCOPY beamline (EU10.0)

Two identical undulators, together with a phase-modulator magnet, form an <u>Optical Klystron</u>

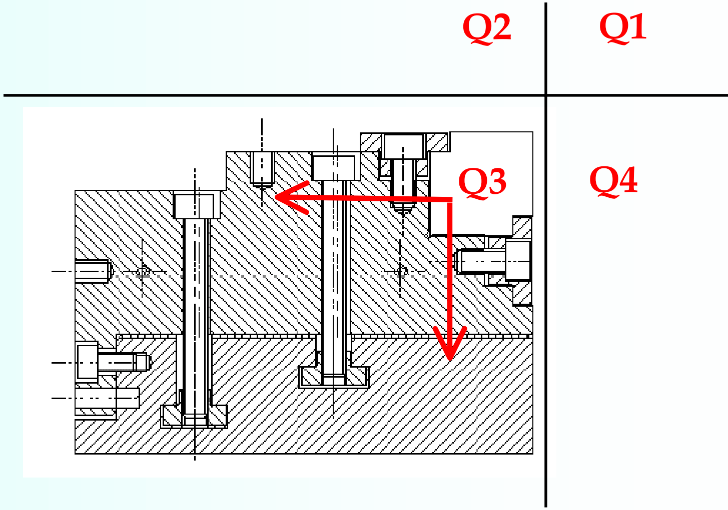


Two uses of the modulator magnet:

- OK mode (high field): increased FEL gain
- SR mode (low field): phasing of the two undulators

APPLE undulator: general design considerations

4-quadrant geometry gives enhanced flexibility for:



• Correcting multipole/trajectory/phase errors

(virtual shimming)

• Optimizing for specific applications by adjustment of block width/heigth/separation

- minimum variation of photon energy with phase at fixed gap (ESRF HU88)
- approx. constant degree of circular polarization vs gap at fixed phase

On the other hand:

• (μ-1) effects are typically bigger and more complicated than for plane-field devices (ΔB, ΔI changing with phase)

• the poor Bx transverse homogeneity (strong focusing effects) appears to be intrinsic to the magnetic structure, and impossible to overcome except by complicated shaping of the magnetic blocks

mpact on beam dynamics

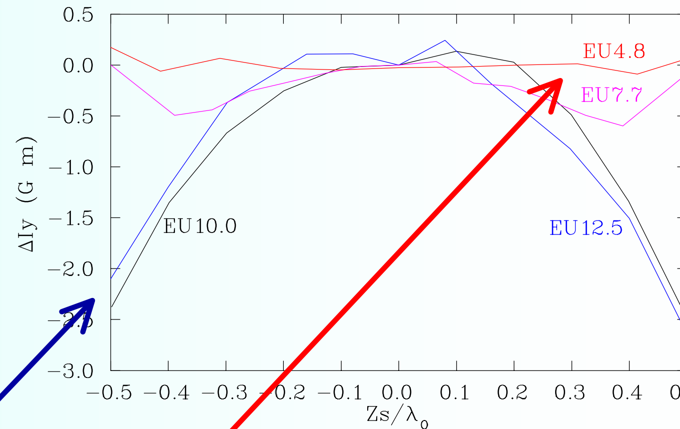
Main effects of insertion devices on the e-beam:

- closed orbit distortion (non-zero on-axis field integrals)
- effects due to higher order multipole errors (first-order (~1/E) tune shift, excitation of resonances, etc.)
- intrinsic focusing effects (second-order (~$1/E^2$) tune shift and beta-beat)
- dynamic aperture reduction

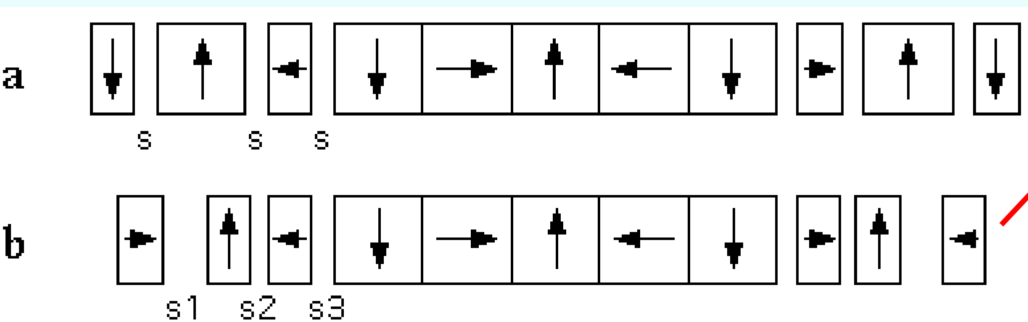
In the case of APPLE type undulators, these effects are a function of both the vertical gap and the longitudinal phasing of the magnetic arrays.

Closed orbit (I)

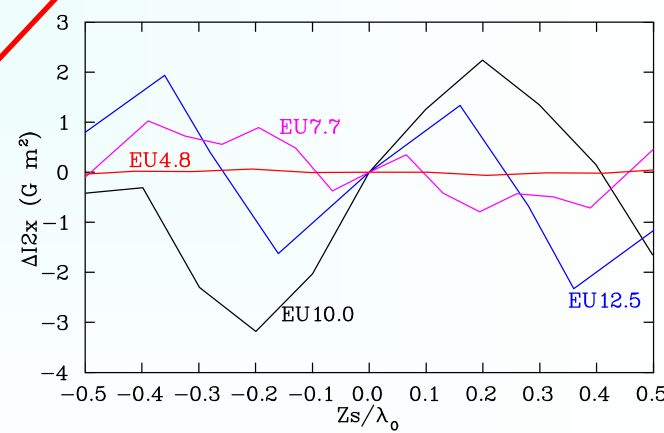
- he measured effect is correlated with the first and econd field integrals
- he amplitude of this variations is determined by the pecific <u>undulator parameters</u>, the design chosen for the <u>erminations</u> of the magnetic structure and the properties f the permanent magnet material used (<u>permeability</u>).
- n our case, due to symmetric field, in first approximation nly the vertical first integral and the horizontal second ntegral components are non zero.



First vertical field integral vs Zs for t different undulators.



Low fringe-field termination (EU6.0, EU10.0, EU12.5) and low field integral termination (EU4.8, EU7.7)



Second horizontal field integral.

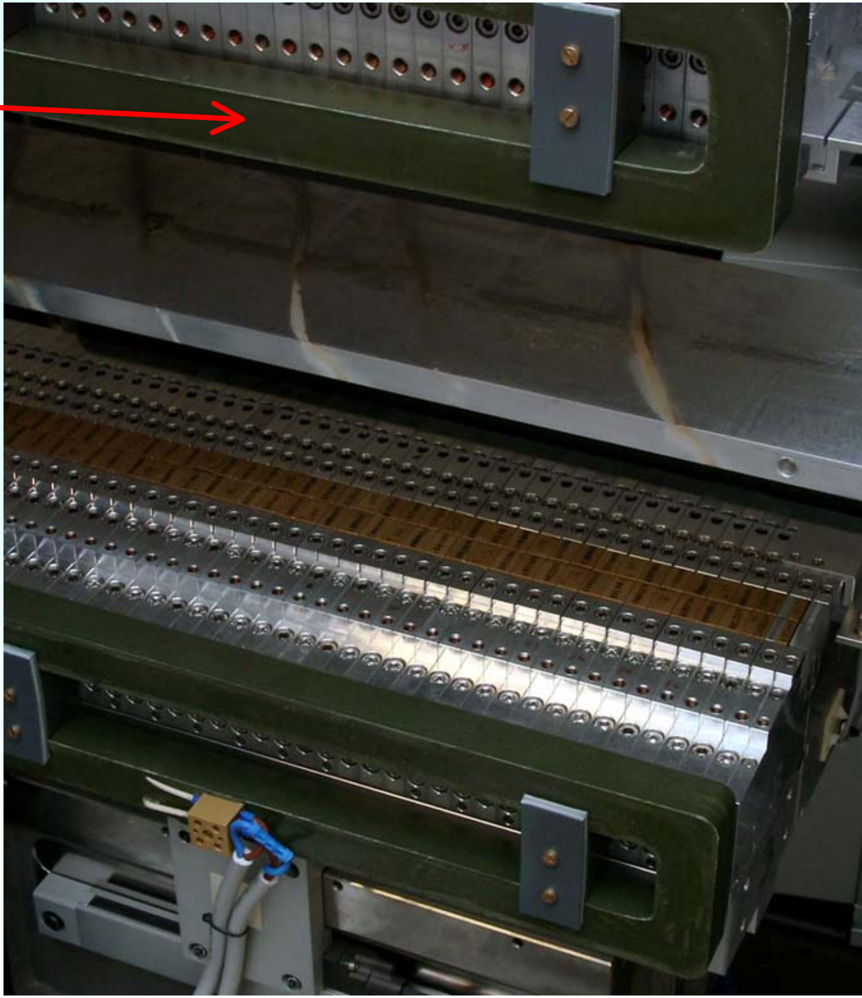
Closed orbit (II)

• Compensation of the effect is achieved with **correction coils**, located at the ends of each undulator.

• The currents required to minimise the orbit distortion are generated using the storage ring beam position monitors by minimizing rms orbit deviation.

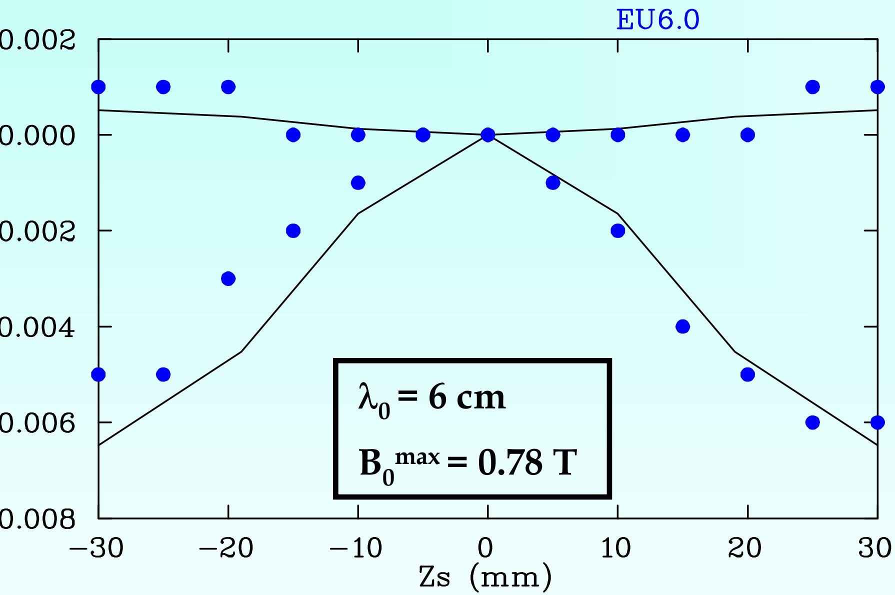
• Optimised currents are then stored in look-up tables as a function of gap and phase for each device.

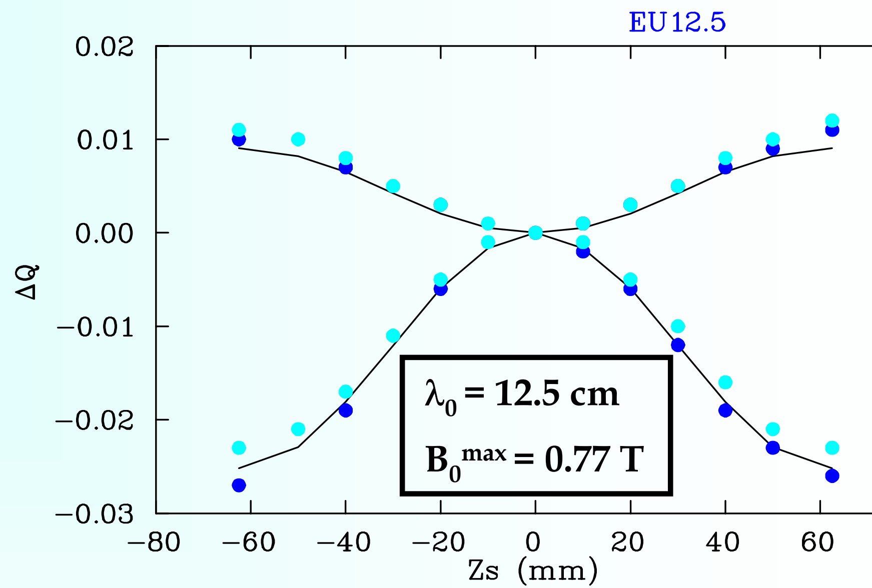
• The ultimate accuracy obtainable with this methos is limited by the BPMs resolution and the beam stability during calibration (~ few μm rms)



Focusing effects (I)

Significant focusing effects have been measured in the form of a Z_S-dependent tune shift, in good agreement with model calculations:





Focusing effects are inherent to the ideal magnetic configuration (field amplitude and roll-off coefficients) and not due to magnetic field errors and/or magnetic material properties

Focusing effects (II)

Tune-shift is related to transverse field roll-off:

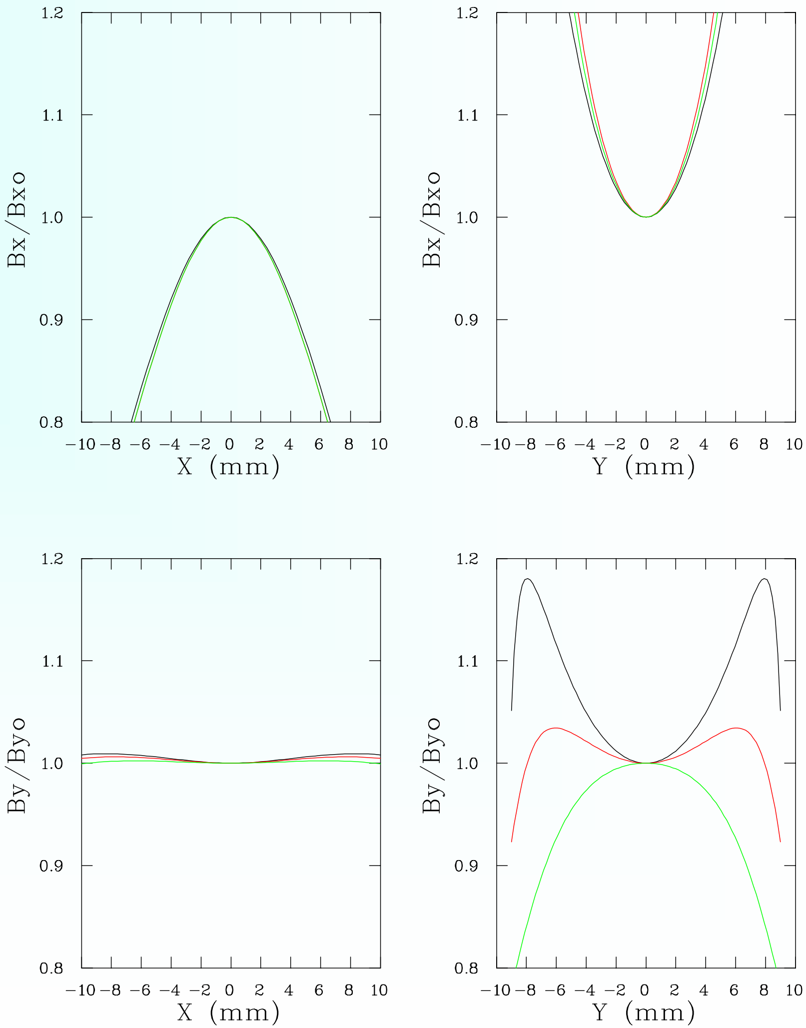
$$\Delta Q_x \sim \beta_x \left(\frac{k_x^2}{2\rho^2 k^2} + \frac{k'^2_x}{2\rho'^2 k^2} \right)$$

$$\Delta Q_y \sim \beta_y \left(\frac{k_y^2}{2\rho^2 k^2} + \frac{k'^2_y}{2\rho'^2 k^2} \right)$$

k=2π/λo
ρ=γmc/eByo
ρ'=γmc/eBxo
kx, ky:roll-off of By with x, y
k'x, k'y :roll-off of Bx with x, y

$\Delta Q \approx (\lambda o/E)^2$ => effect larger for long-period devices and low electron energies.

Transverse field distribution (EU10.0) for Z_S=20, 30, 40 mm:



Dynamic aperture

dynamic aperture calculations (2 GeV), with compensated tunes:

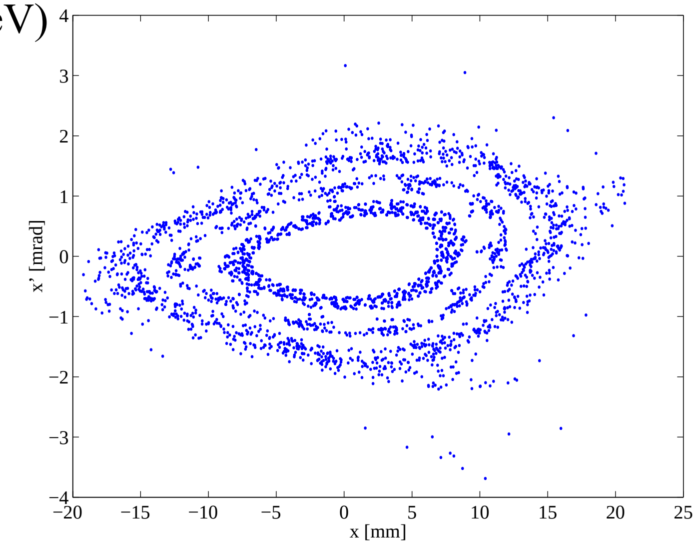
16 mm (H) & 5 mm (V) (no helical undulators)

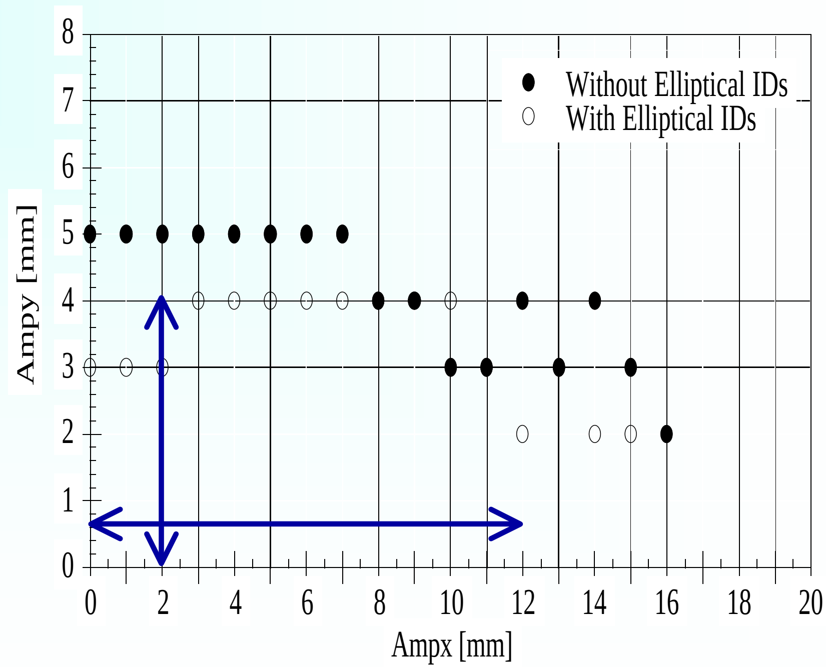
12 mm (H) & 4 mm (V) (all undulators at min gap and circular polarisation)

Experimental results (from scraper/lifetime measurements) confirmed this results:

12 mm ± 1 mm (H), 4 mm ± 1 mm (V)

Horizontal phase space over 50 turns with all devices closed at minimum gap and in circular polarisation mode (E=2 GeV)





Tune shift compensation (I)

Compensation of tune shift: external quadrupoles

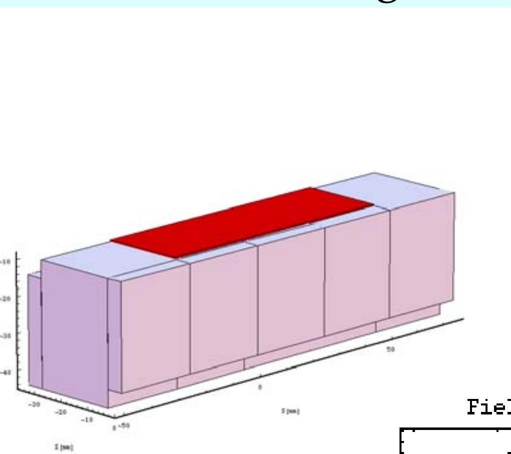
- **The overall vertical tune shift can be as large as $\Delta Qx = -0.09$, $\Delta qy = 0.04$ when all undulators are closed to the minimum gap in vertical polarisation.**
- **A software has been written to dynamically compensate the tunes by acting on the quadrupoles in the dispersion free straights. It is based on the computed focusing strengths of the various devices stored in look-up tables as a function of gap and phase. Different schemes can be used (local, global, alpha matching)**
- **This program works well, and is regularly used at 1 GeV (FEL operation).**
- **However, due to quadrupole misalignments, changing their current leads to a C.O. distortion exceeding the source points stability requirements for user's operation (to be checked again after the foreseen machine realignment).**

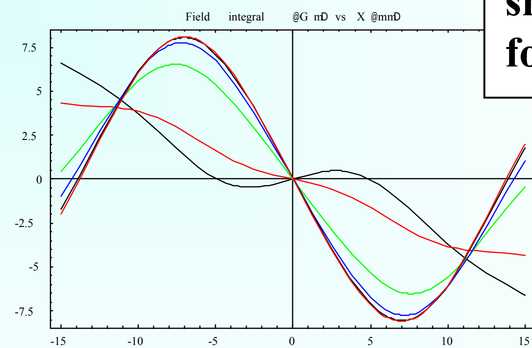
Tune shift compensation (II)

Compensation of tune shift: shimming

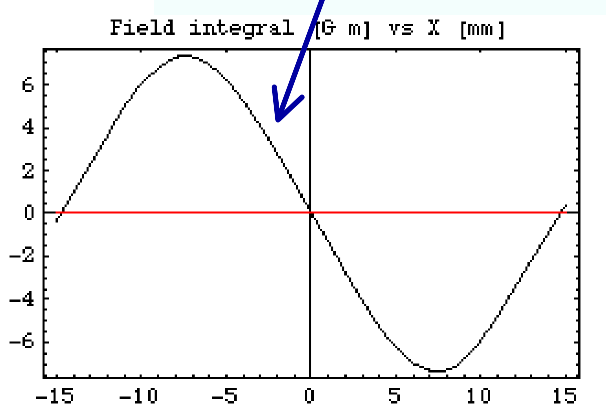
• Motivated by the problems introduced by the adjustment of external quadrupoles special magnetic shimming technique was tested on EU10.0

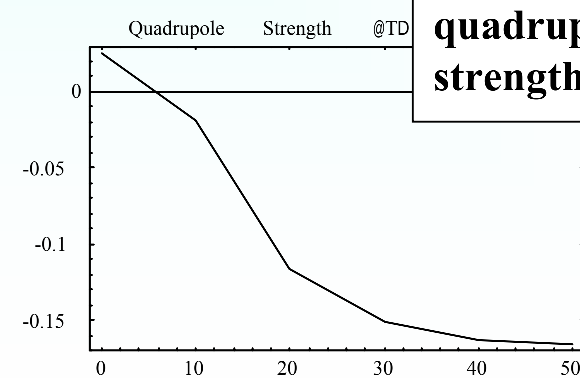
• The method was originally proposed at ESRF and consists in creating inside t undulator a <u>phase dependent quadrupole</u> in order to (partially) cancel the intrin undulator focusing.





shim signatures for different Zs





quadrupole strength vs. Zs

Tune shift compensation (III)

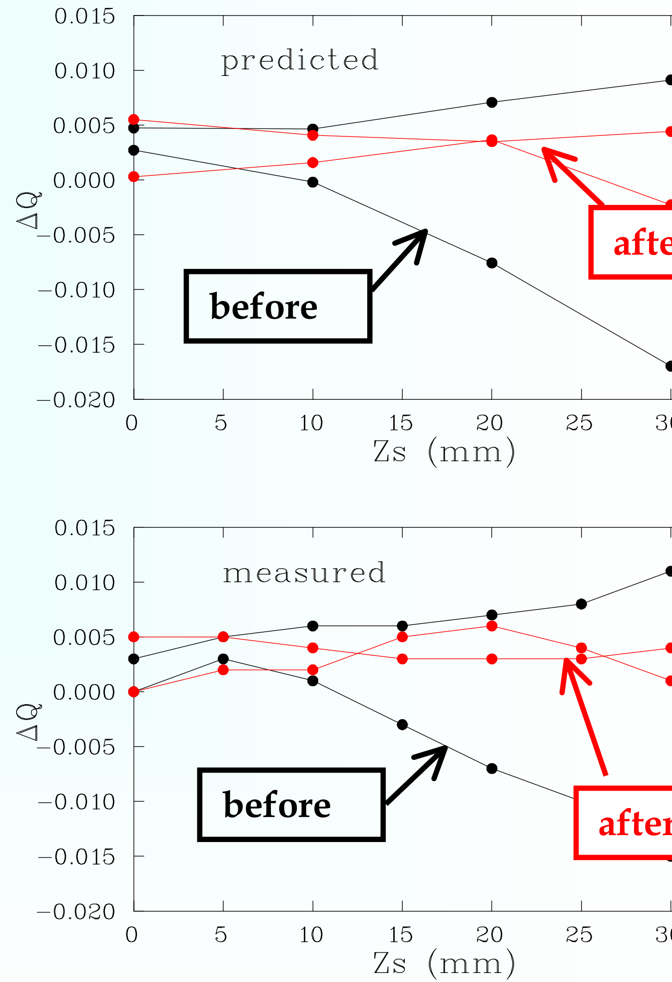
Experimental results confirmed the expected reduction of the maximum tune-shift by nearly a factor of 4 over the whole operational range.

Despite these positive results, other facts need to be considered:

- Increased sensitivity to beam centering errors due to the additional quadrupole focusing.

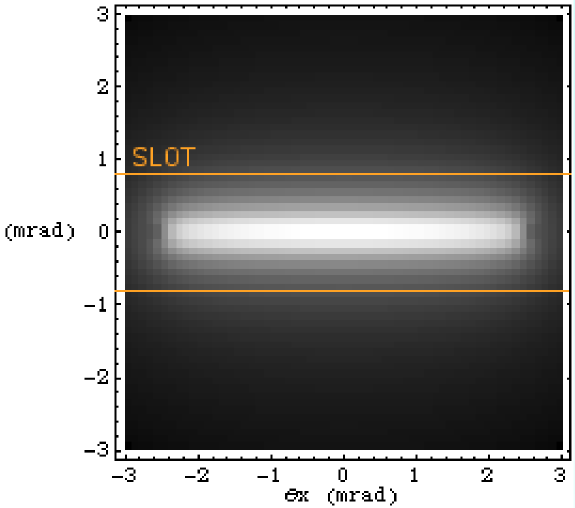
- Since compensation is achieved by correcting a second order effect ($\sim 1/E^2$) with a "real" quadrupole ($\sim 1/E$), this technique only work for a particular electron energy.

ELETTRA is operated at energies ranging from 0.9 GeV (FEL experiments) to 2 and 2.4 GeV (users' dedicated operation) and therefore this method cannot be applied. It could however find application in other fixed energy machines.

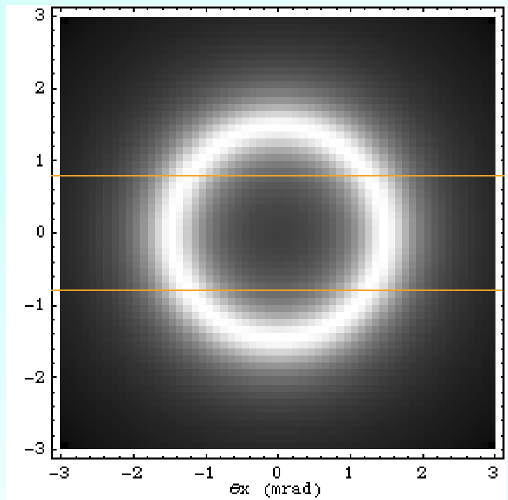


Power distribution from elliptical undulators

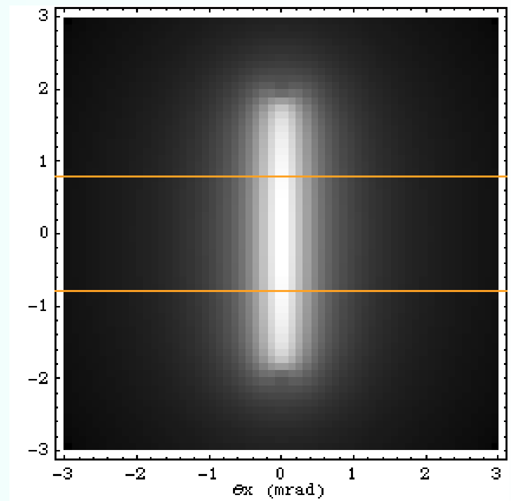
Angular power distribution from elliptical field undulators is widened vertically due to the helical motion of the electron beam:



Horizontal polarisation



Circular polarisation

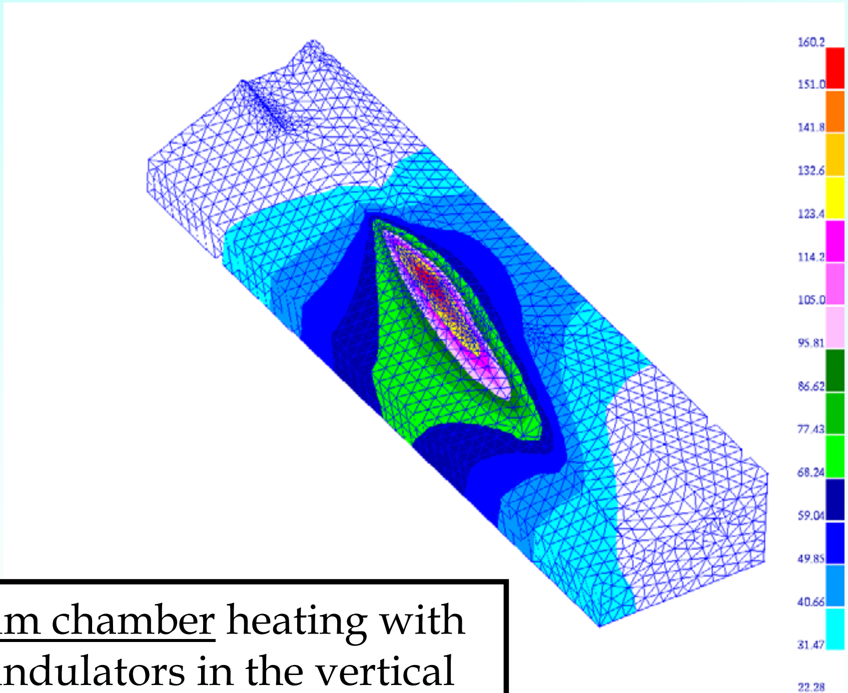


Vertical polarisation

- **Increased heat load on ID and BM vacuum chamber when given Kx exceeded**
- **Vertically larger incident power footprint on shutters, stoppers, masks, etc**

Heat load (I)

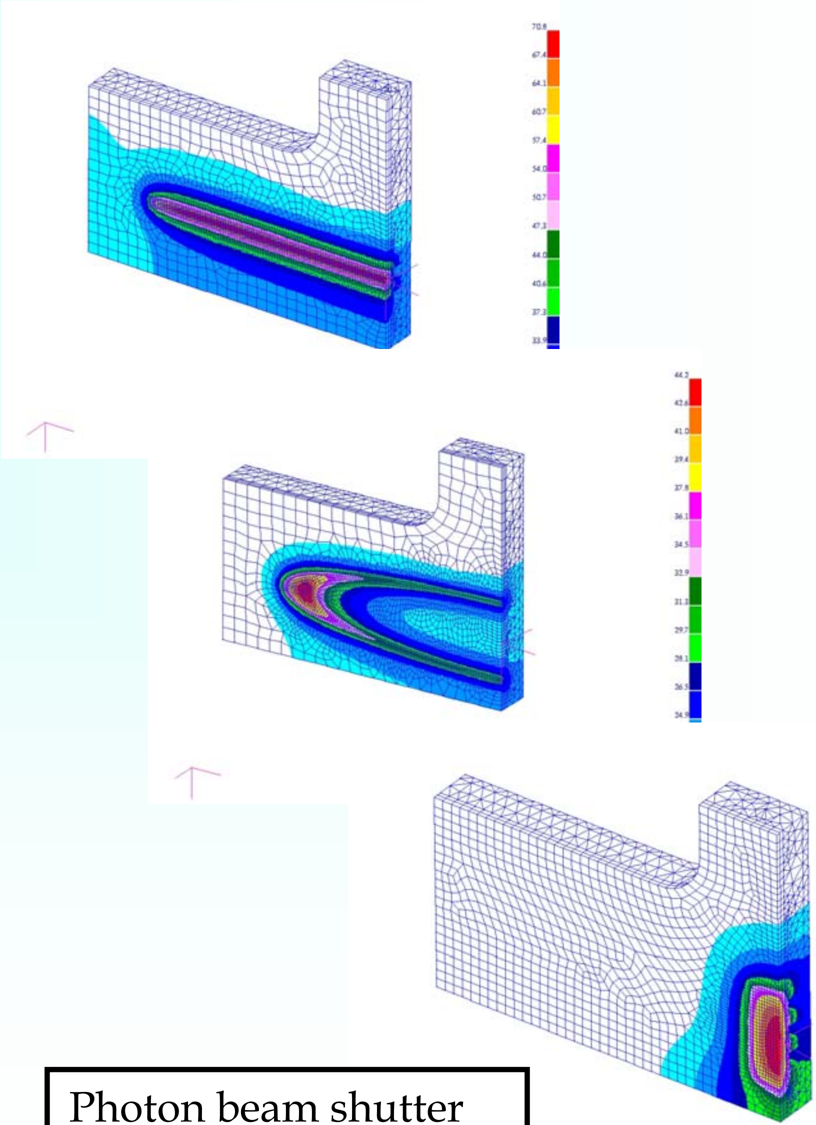
New water cooled Al vacuum chambers in ID straight and downstream BM were designed to sustain the additional power in any polarisation mode:



<u>cuum chamber</u> heating with th undulators in the vertical larisation (worst case)

nax = 160 °C

H_2O = 77 °C



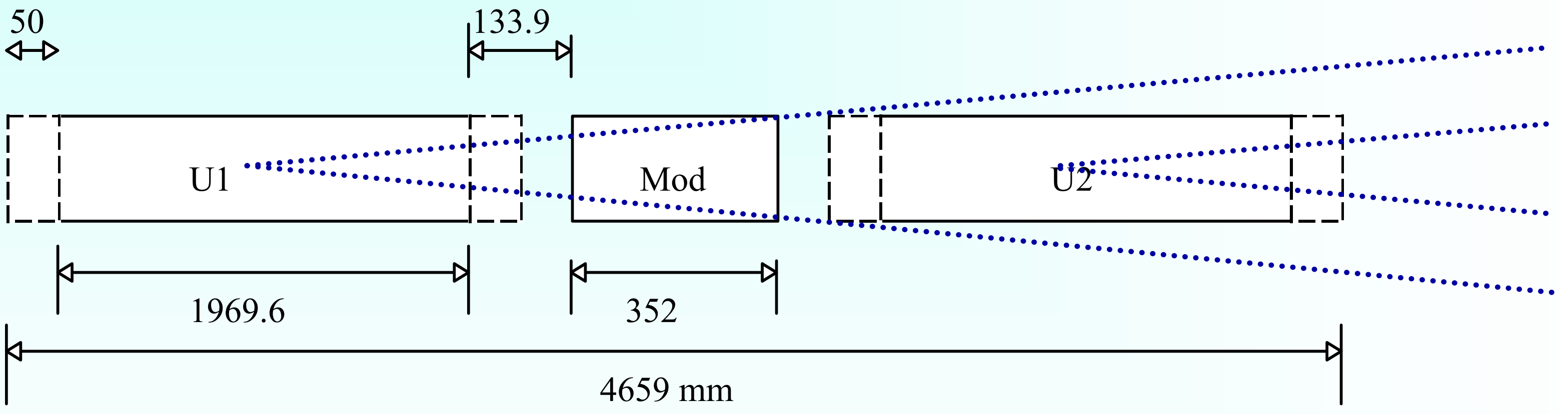
Photon beam <u>shutter</u>

Heat load (II)

Despite the effort put into design of components, for the most powerful EPU
EU10.0, Ptot = 4.2 kW) some problems were encountered.

At small gap in vertical polarization mode <u>increased temperature and pressure at</u>
<u>ocations immediately downstream the ID were observed</u> (bellows with no water
ooling)

The effect was found to be entirely due to the upstream undulator segment.

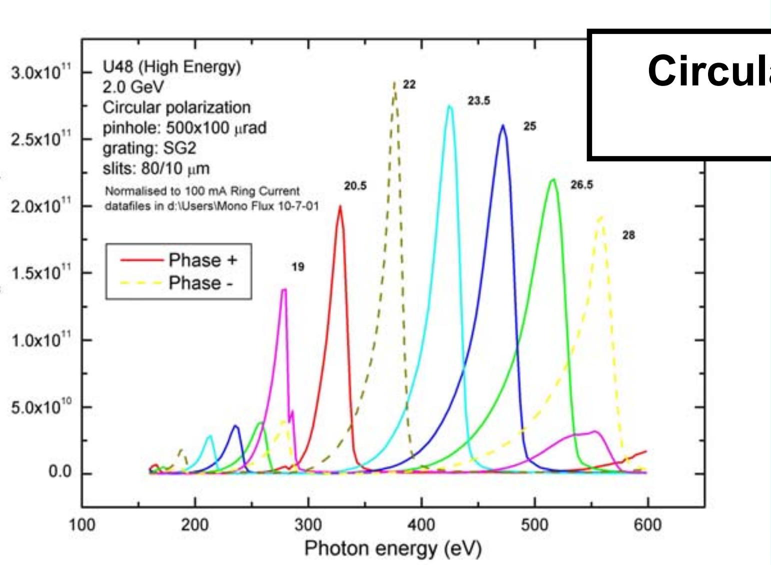


- Implemented different operational limits for the two undulator segments:

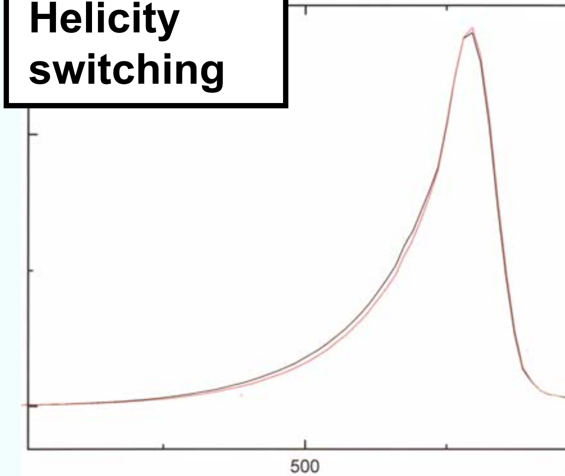
  U1: horizontal to circular (Zs_max = 35 mm)

  U2: horizontal to vertical (Zs_max = $\lambda_0/2$ = 50 mm)

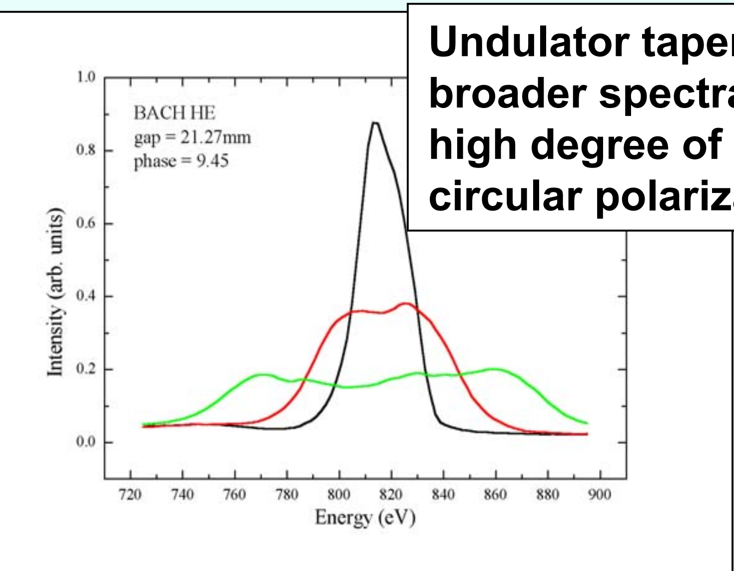
Commissioning results: BACH beamline



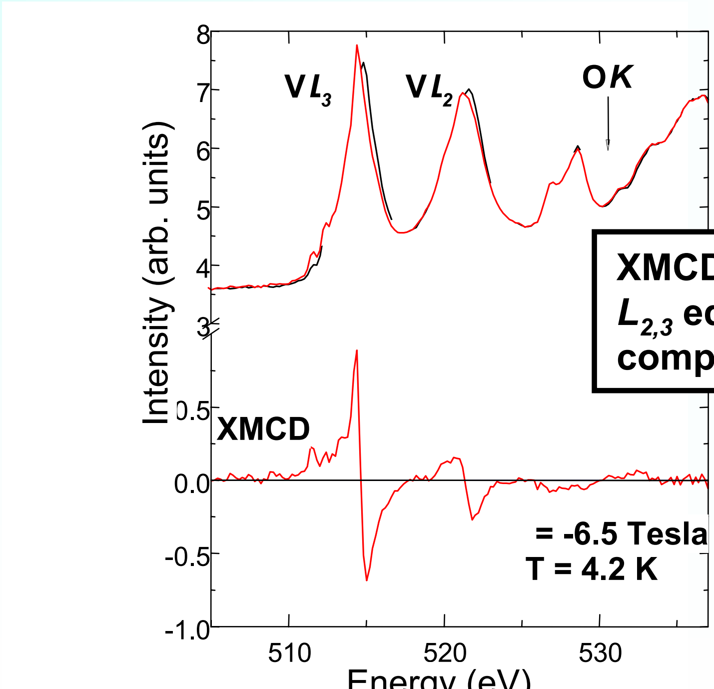
Circular polarization spectra



Helicity switching



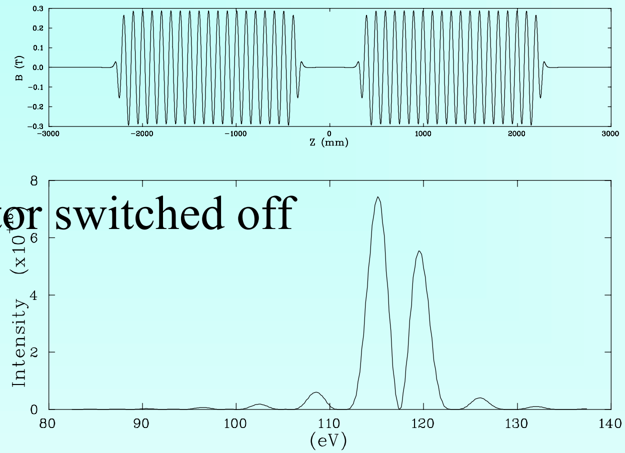
Undulator tapering: broader spectra with high degree of circular polarization



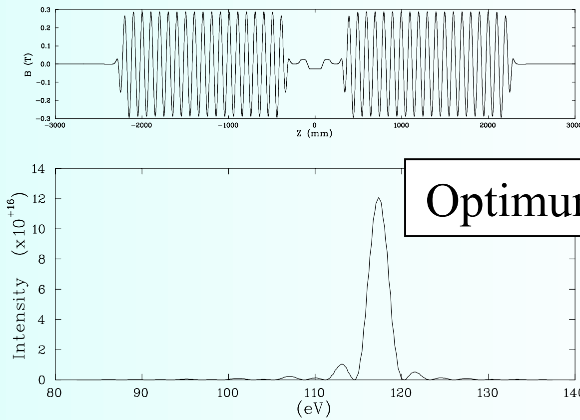
XMCD at the V-$L_{2,3}$ edges on V^{2+} complex

Phasing the two-segment EU10 undulator (I)

dulator switched off

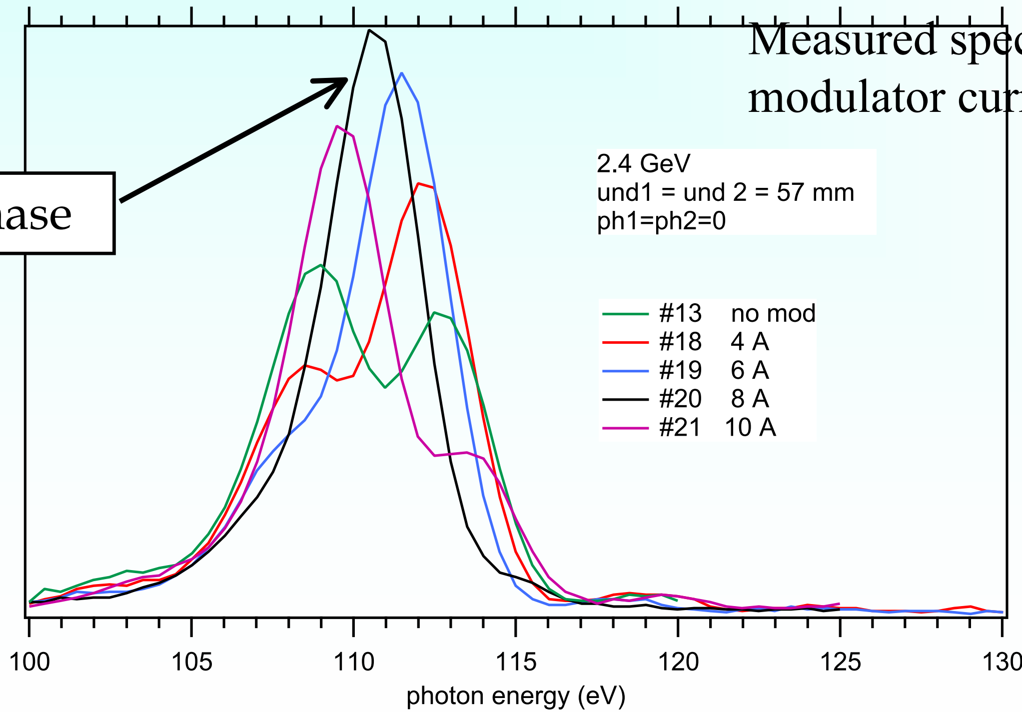


Optimum modulator setti



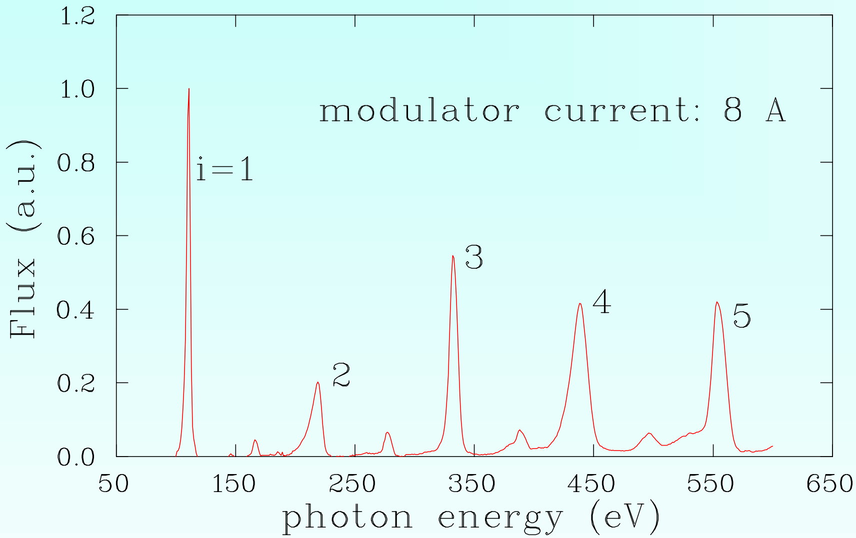
Measured spectra for different modulator currents

Optimum phase

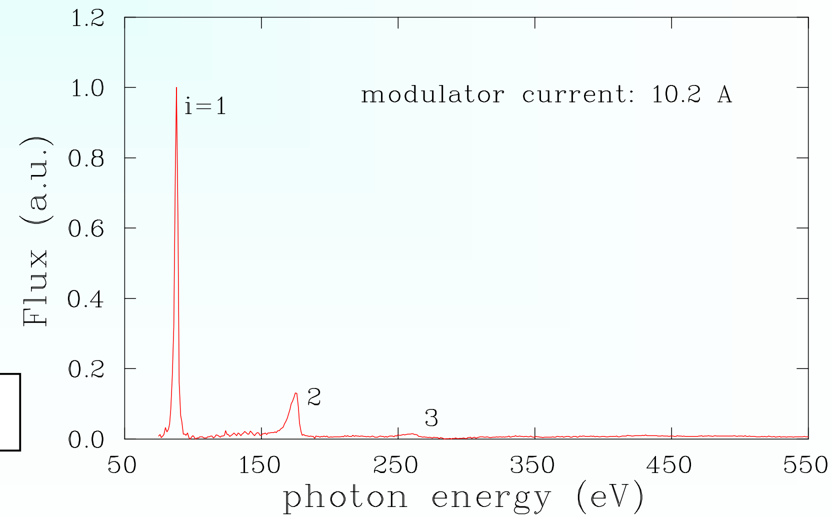


Phasing the two-segment EU10 undulator (II)

Extended range spectra at optimized phasing show almost the same performance as fo
ingle 2·Np undulator:



Horizontal polarisation



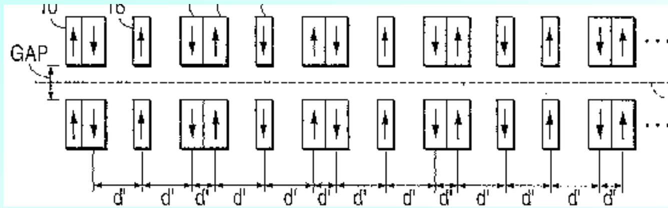
Circular polarisation

Quasi-periodic EPU (I)

U12.5 quasi-periodic undulator: first realisation of a novel scheme combining:

- quasi periodicity (reduction of harmonic contamination)
- variable polarisation

iginal quasi-periodic
ucture
Sasaki)



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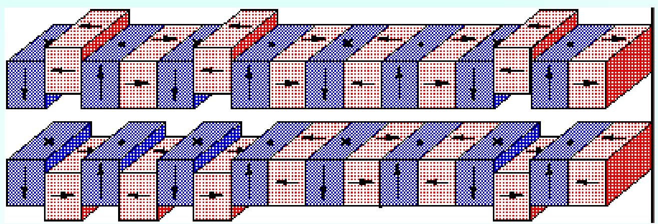
riation based on
splacement/removal
H-blocks



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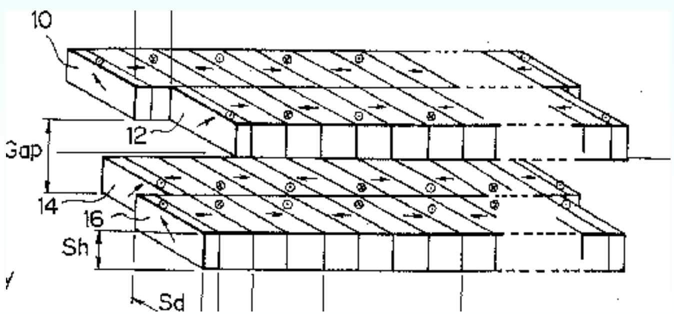
PPLE-II concept
.Sasaki)



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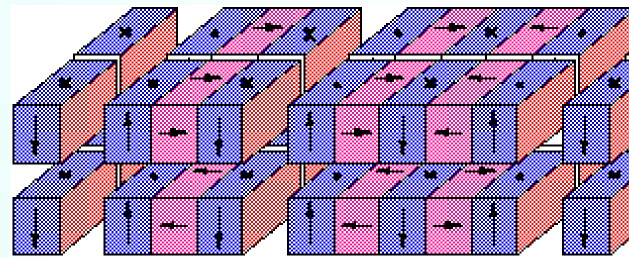
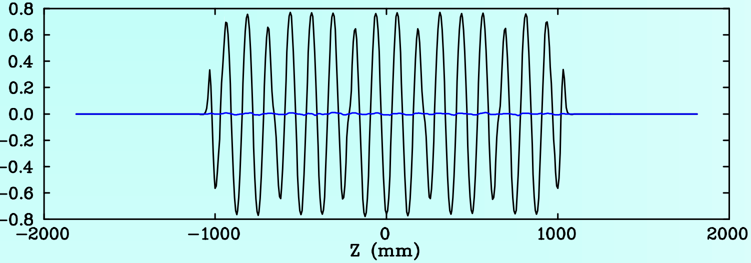
Quasi-periodic APPLE-II:

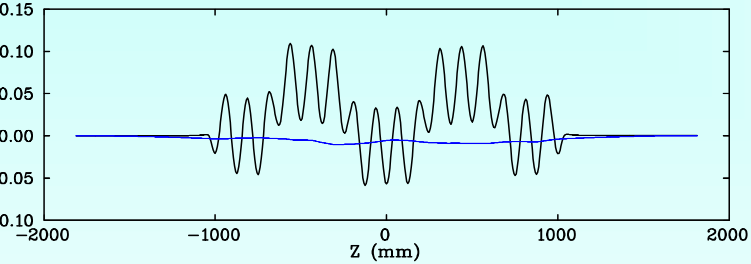
a tribute to Shigemi inventivenes

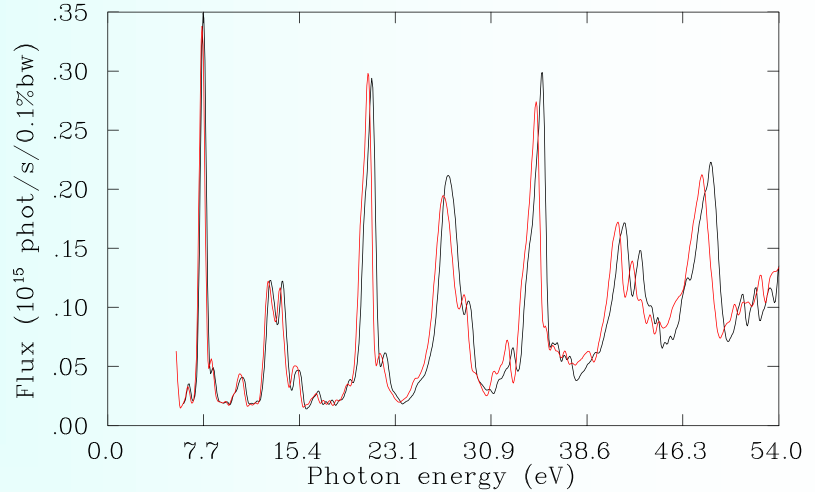


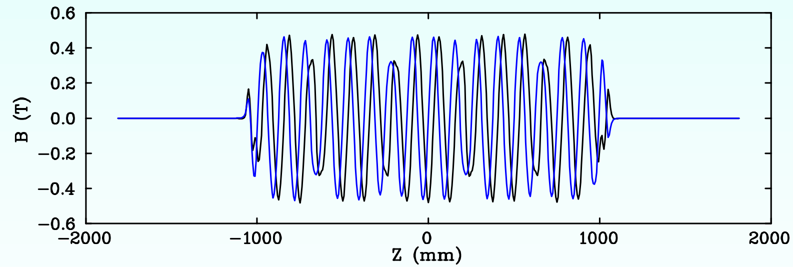
Quasi-periodic EPU (II)

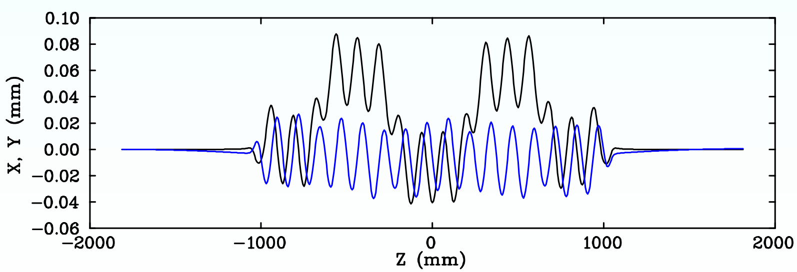
measured field distributions and corresponding trajecto and spectra in linear and circular polarisation modes

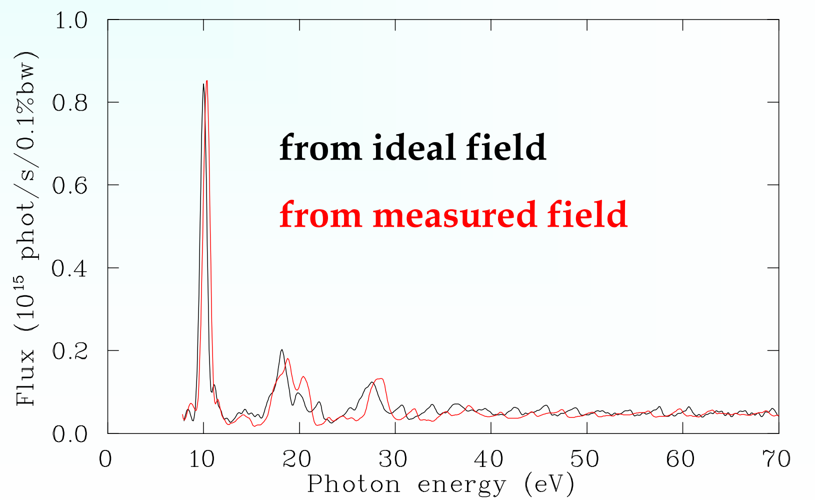




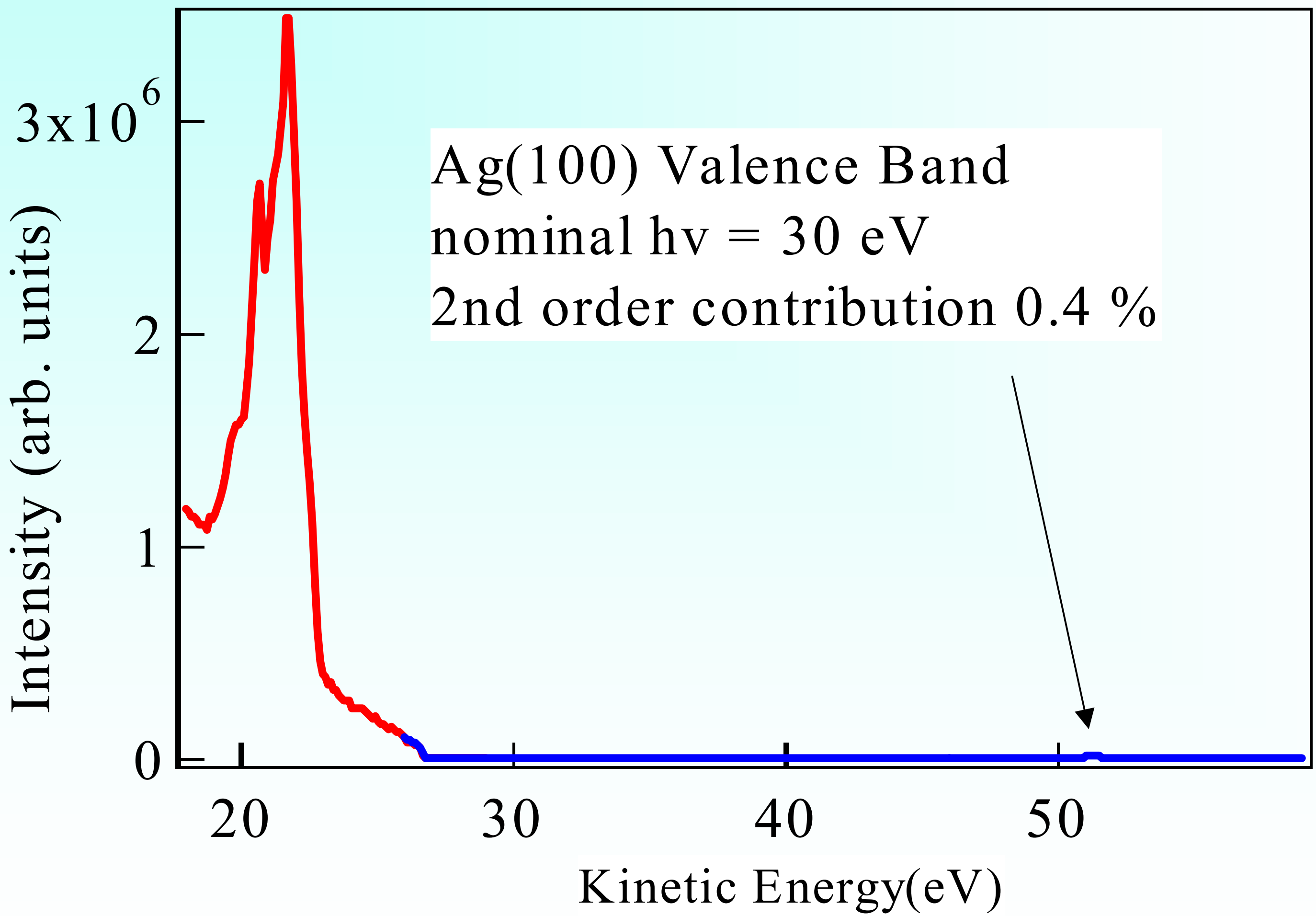








APE – LE Higher Order(s) Contamination



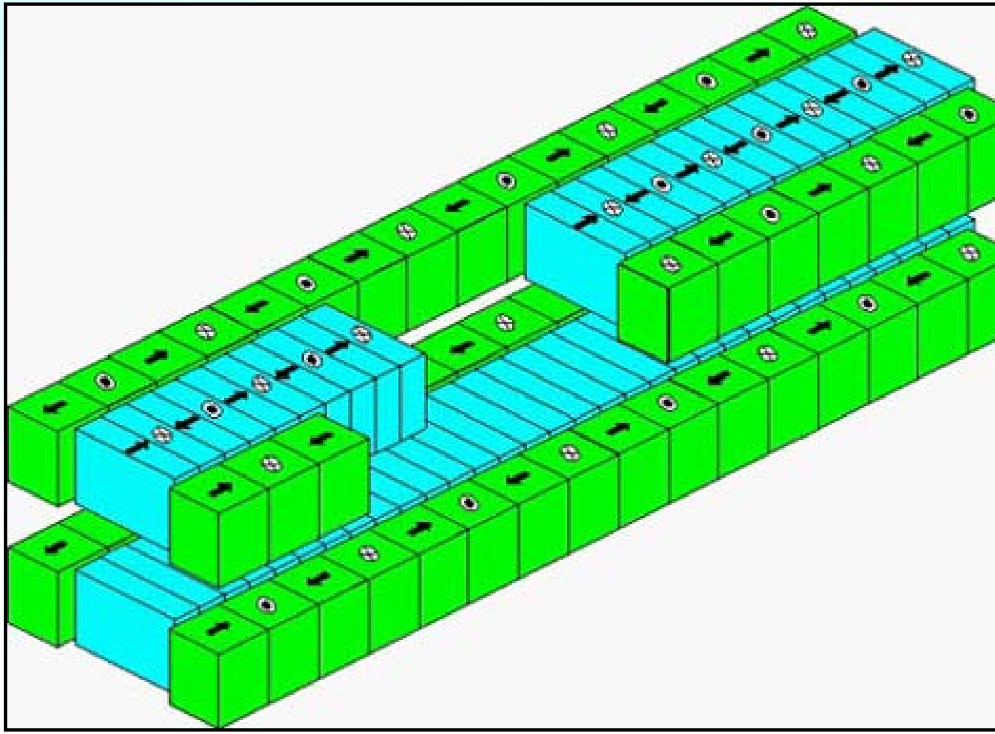
The Figure-8 Undulator

- Designed as a high-flux linearly polarized radiation source in the 5-10 eV range for the IUVS beamline

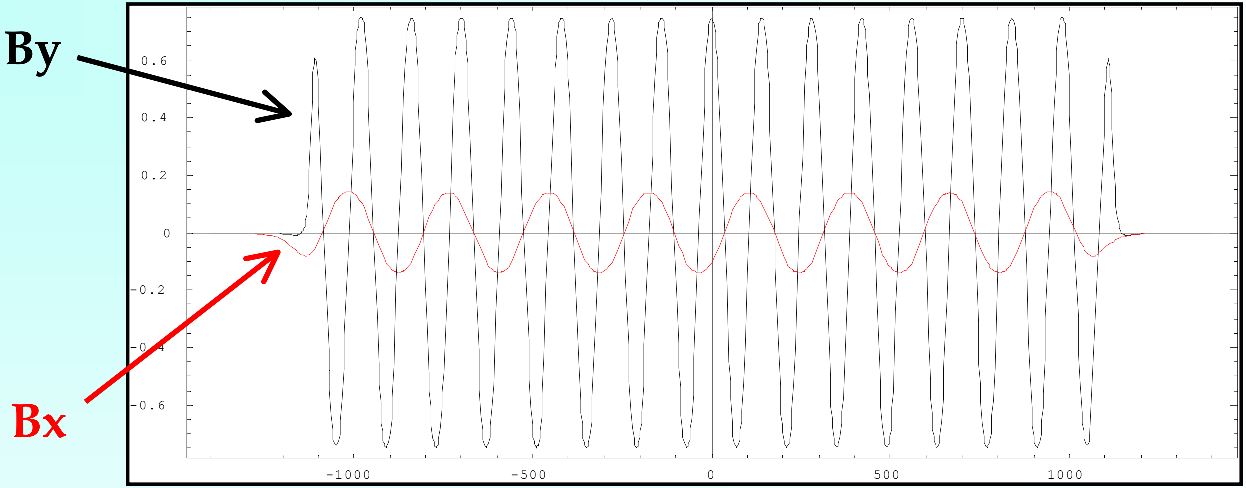
- First realization of this type of device outside Japan (original design by Tanaka & Kitamura, SPRING-8)

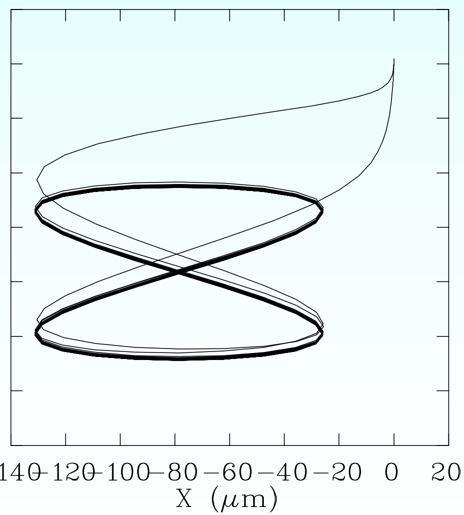
Design parameters

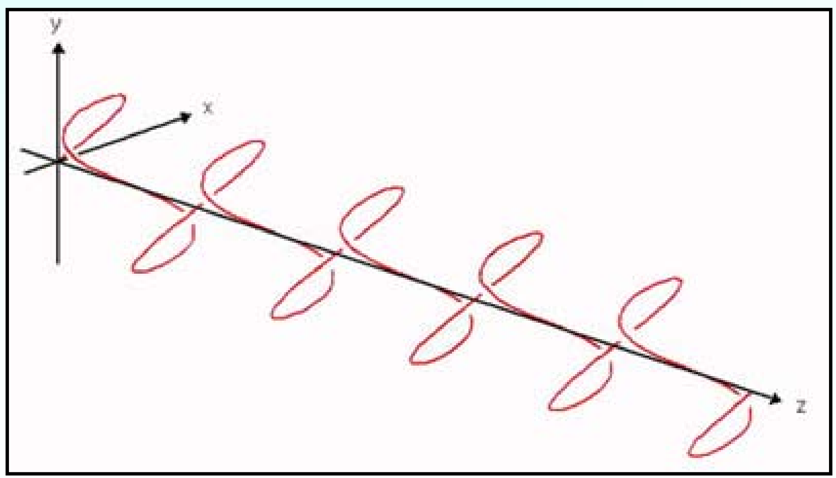
Photon energy range	5-10 eV
Polarization	linear
Period	140 mm
Number of periods	2 x 16
Minimum gap	19 mm
Bx, By max.	0.13 T, 0.72 T
Kx, Ky max.	3.4, 9.4
Total Power (400 mA)	2.5 kW
Flux (photons/s/0.1%bw)	1.2 10^{15}

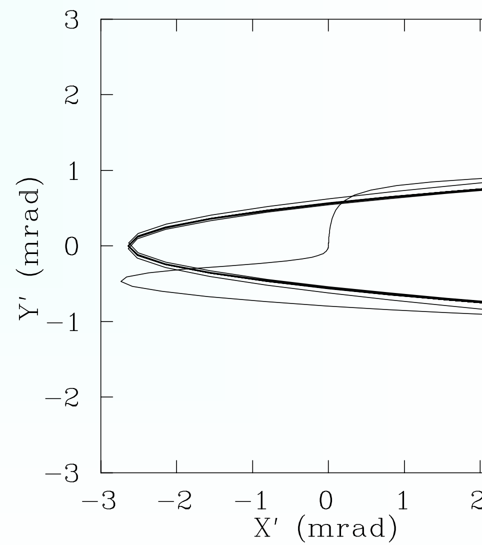


Field & Trajectory



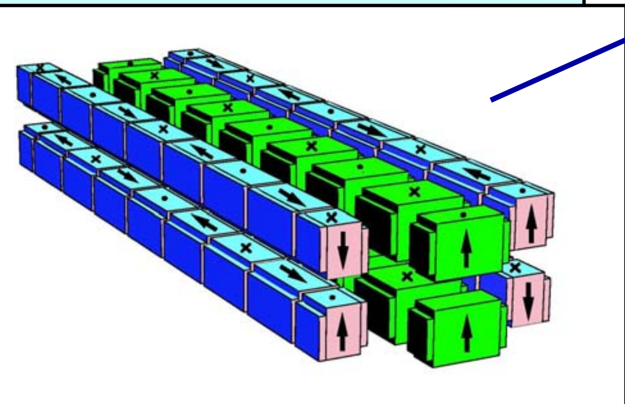


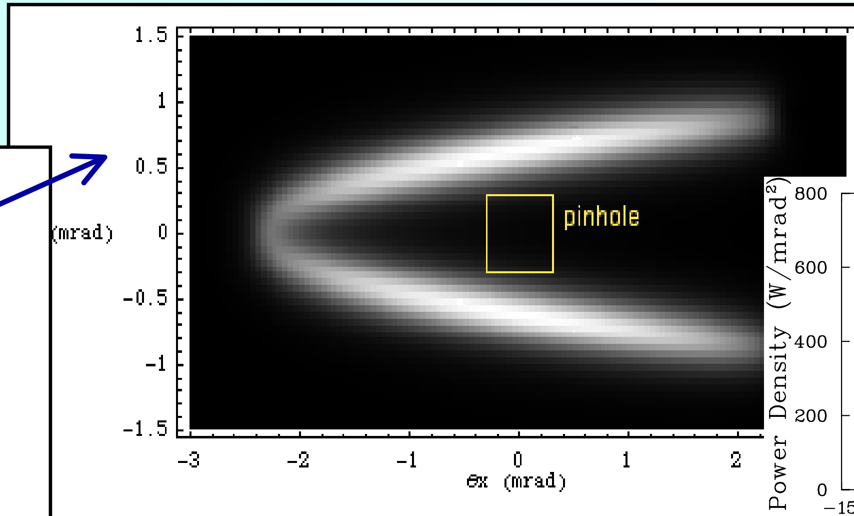


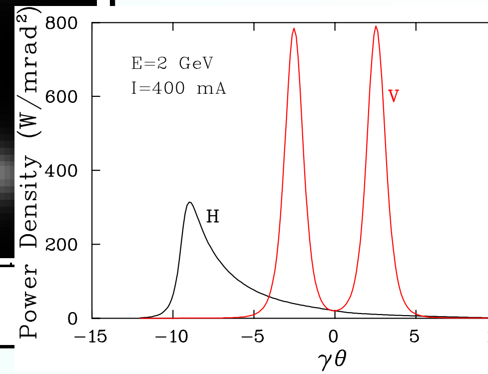


Angular Power Distribution

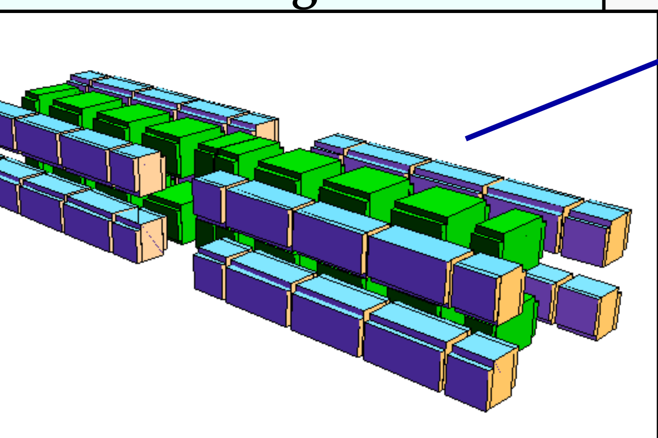
Single segment

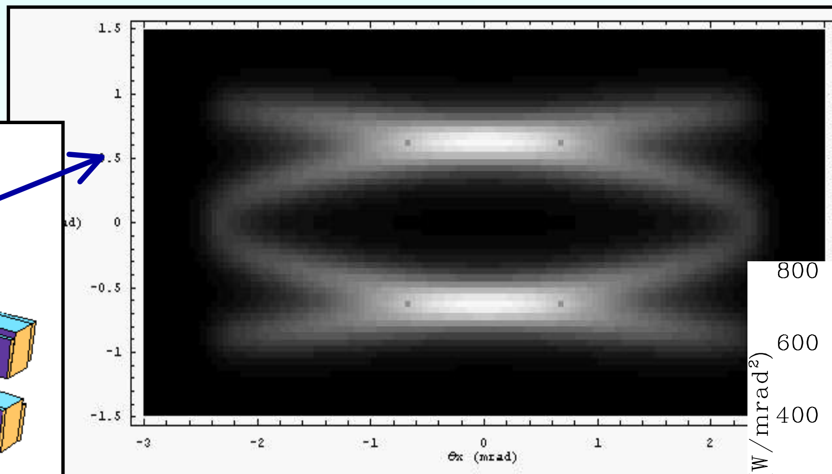


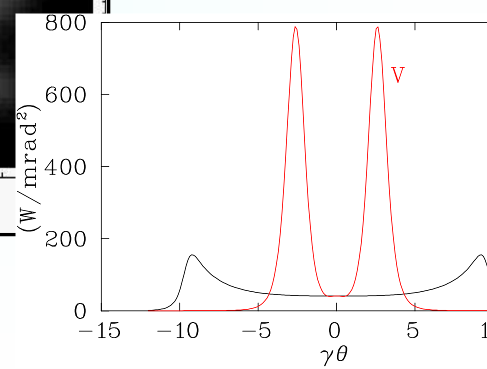




Two segments

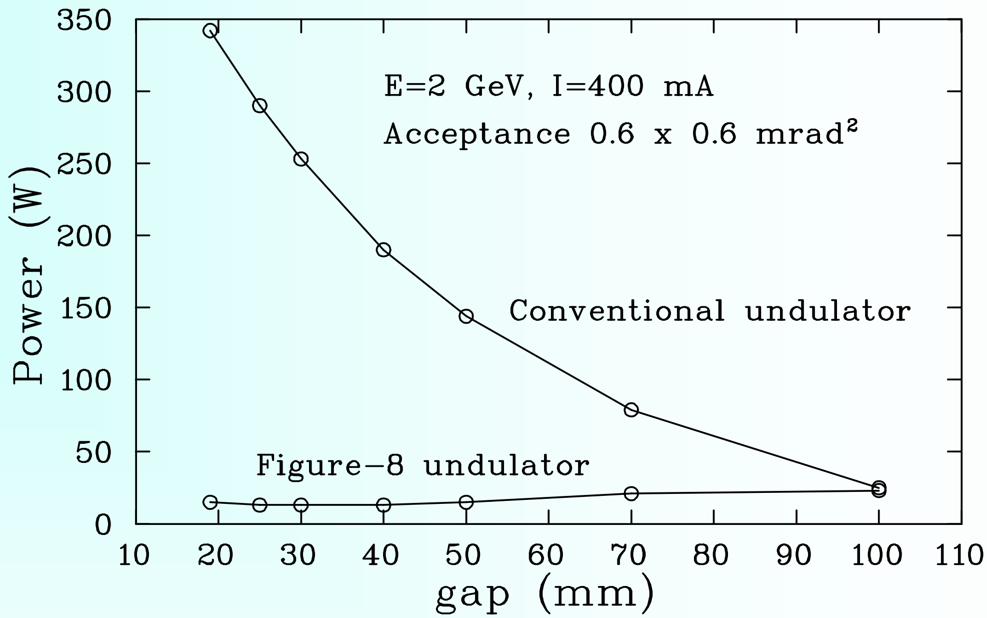




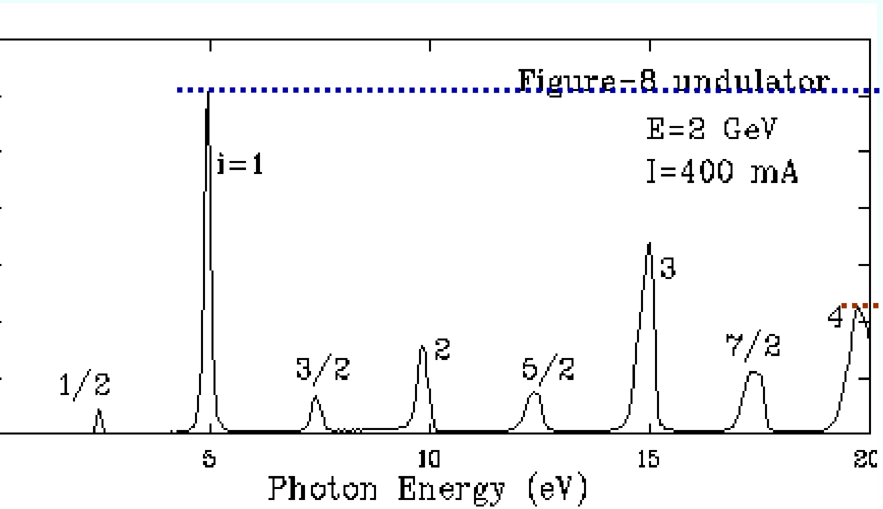


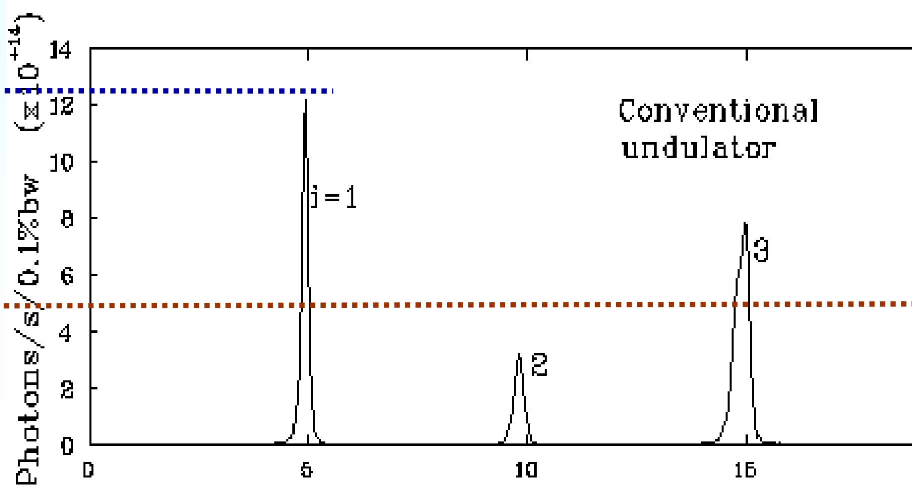
Angular Power Distribution

Low on-axis power density enables efficient pinhole power filtering …



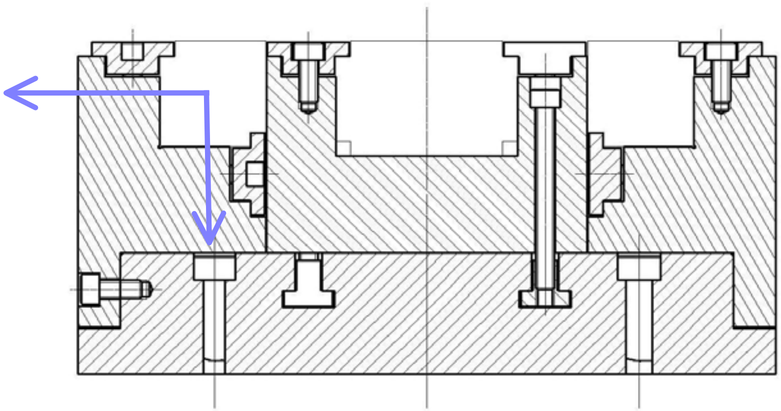
… without flux loss in the fundamental harmonic





Construction

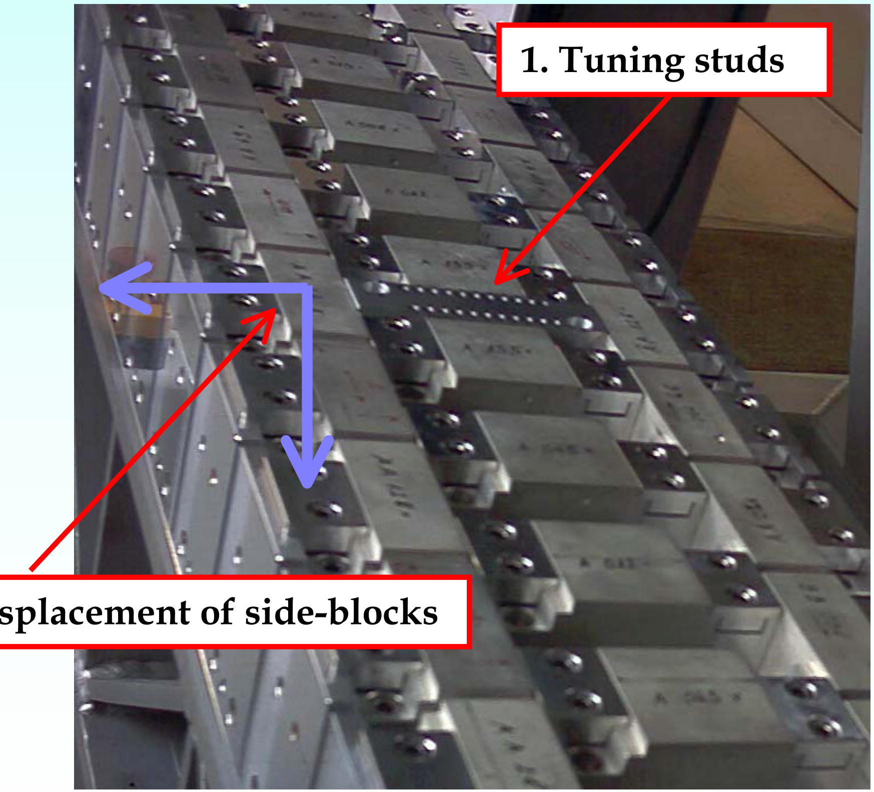
Adjustable position block holders (side blocks only)

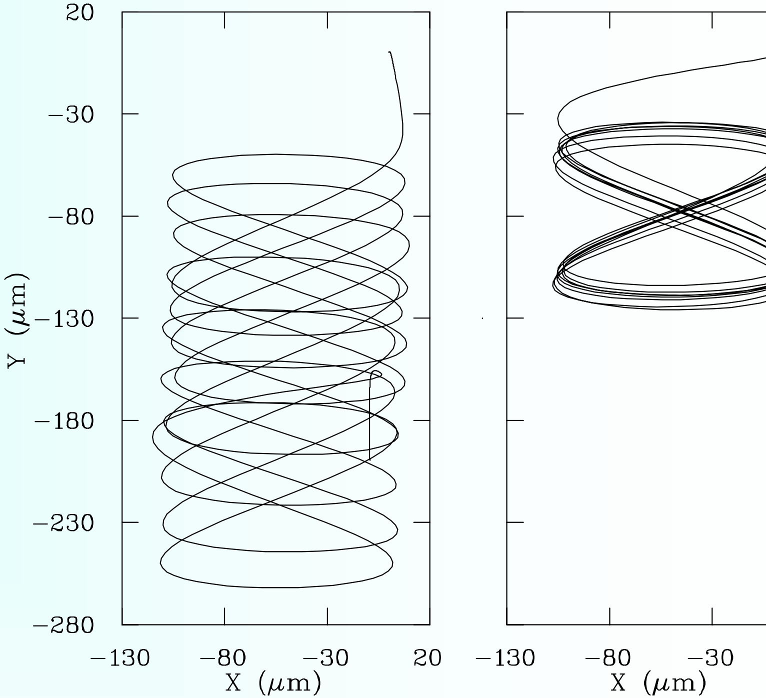


Standard variable-gap support structure

Performance Optimization

After assembly, a <u>two-stage shimming</u> was applied in order to compensate the main field imperfections, bringing trajectory wander, phase error and multipoles very close to zero.



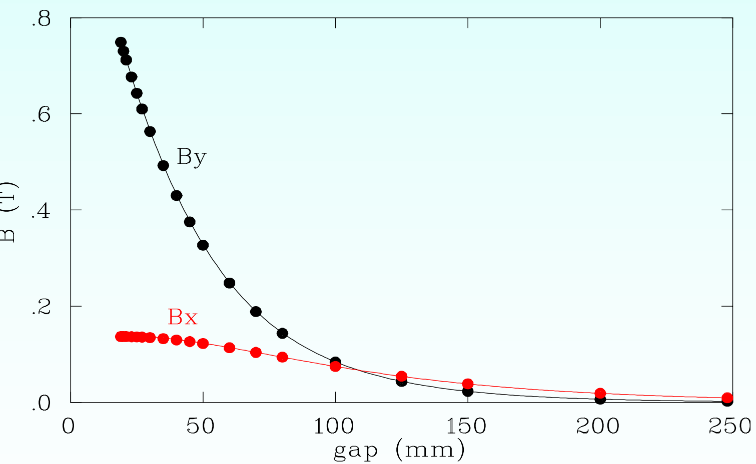


Trajectory Before and After Shimming

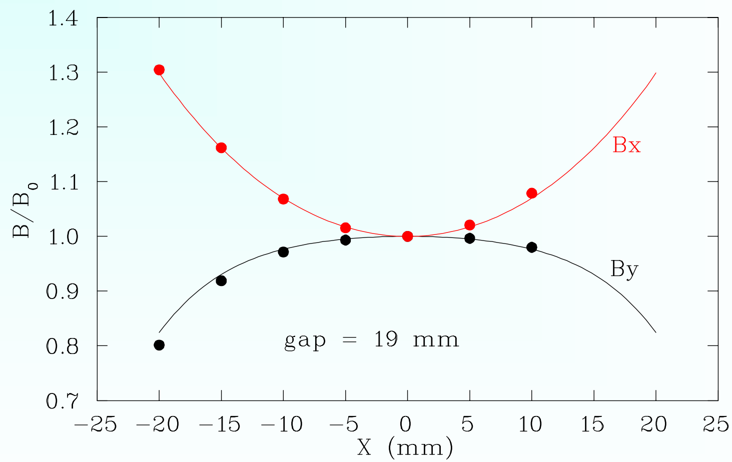
Magnetic measurement results (I)

Measured magnetic field parameters: first undulator segment (FINAL)

gap (mm)	Hor / Vert peak magnetic field (T)	Hor / Vert rms trajectory straightness (µm)	rms optical phase error (degrees)	Hor / Vert integrated quadrupole (G)	Hor / Vert integrated sextupole (G/cm)
19	0.14 / 0.75	6 / 8	1.0	-6 / -28	84 / -67
30	0.13 / 0.56	5 / 4	0.9	6 / -3	50 / 0
50	0.12 / 0.33	3 / 4	1.2	3 / -28	4 / -37



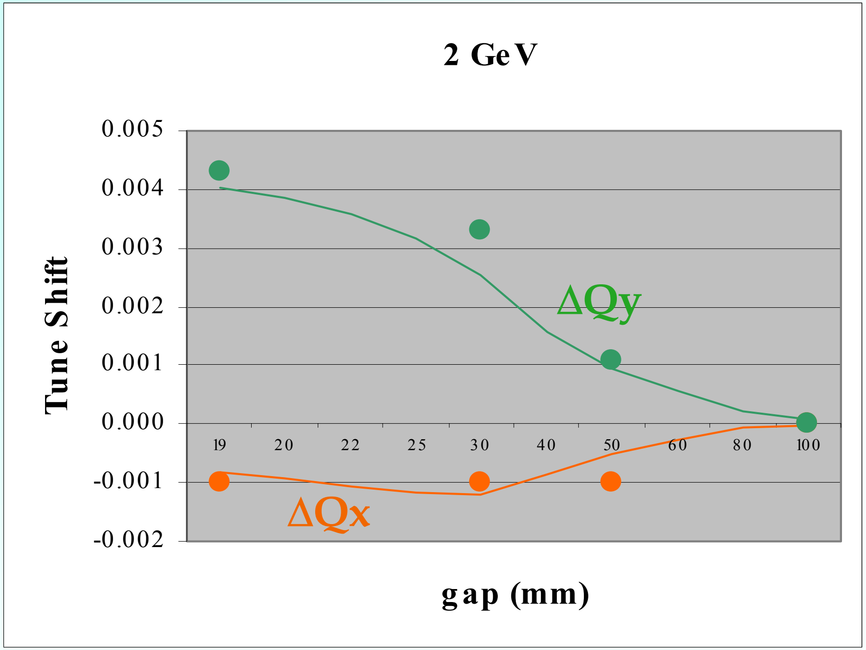
Measured (dots) and computed (solid line) peak field as a function of the magnetic gap



Measured (dots) and computed (solid line) transverse field distributions at miinimum gap

Recent commissioning results

• Measured tune-shift in excellent agreement with calculations from ideal field ($\Delta Q<5\cdot10^{-3}$ @ 2 GeV)



• Measured closed-orbit deviation (uncorrected): < 50 µm rms @ 2 GeV; correction coils succesfully calibrated

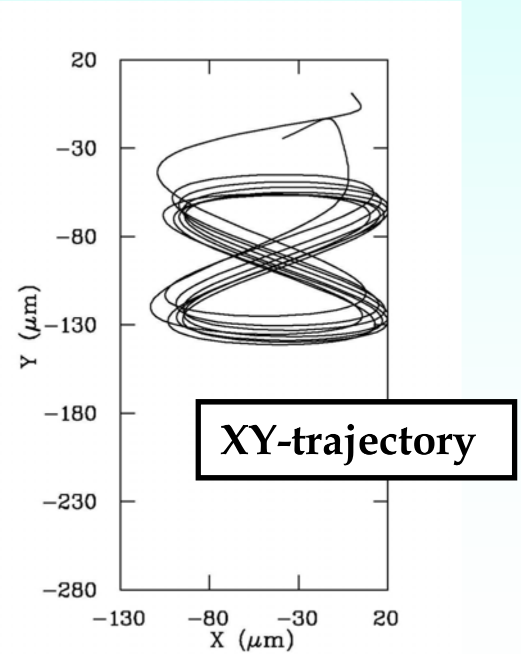
• Second undulator segment assembled, measurements in progress

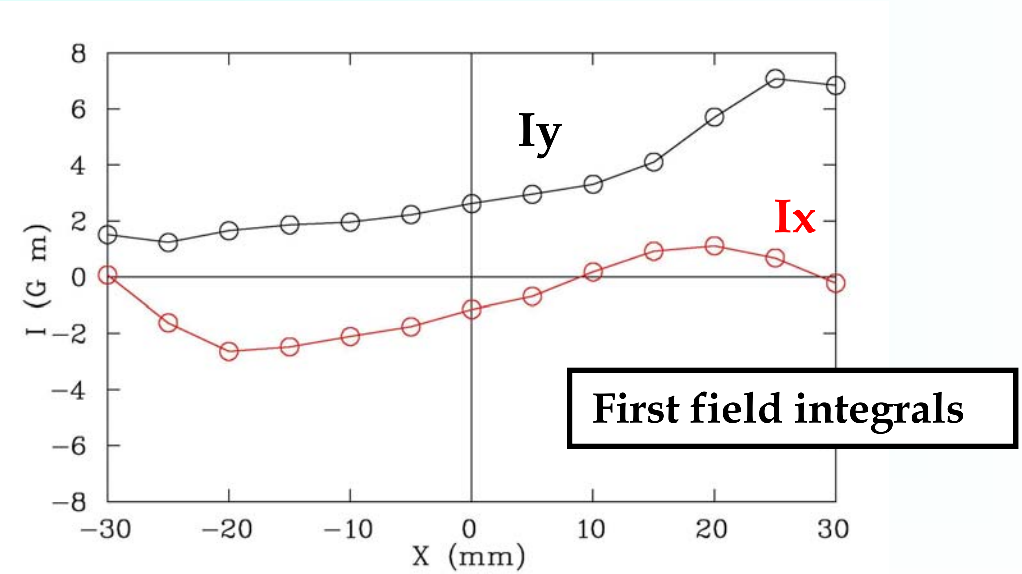
Magnetic measurement results (II)

Measured magnetic field parameters: second undulator segment

(BEFORE SHIMMING, 2/12/2002)

gap (mm)	Hor / Vert peak magnetic field (T)	Hor / Vert rms trajectory straightness (µm)	rms optical phase error (degrees)	Hor / Vert integrated quadrupole (G)	Hor / Vert integrated sextupole (G/cm)
19	0.14 / 0.75	11 / 10	1.8	72 / 107	-12 / -31



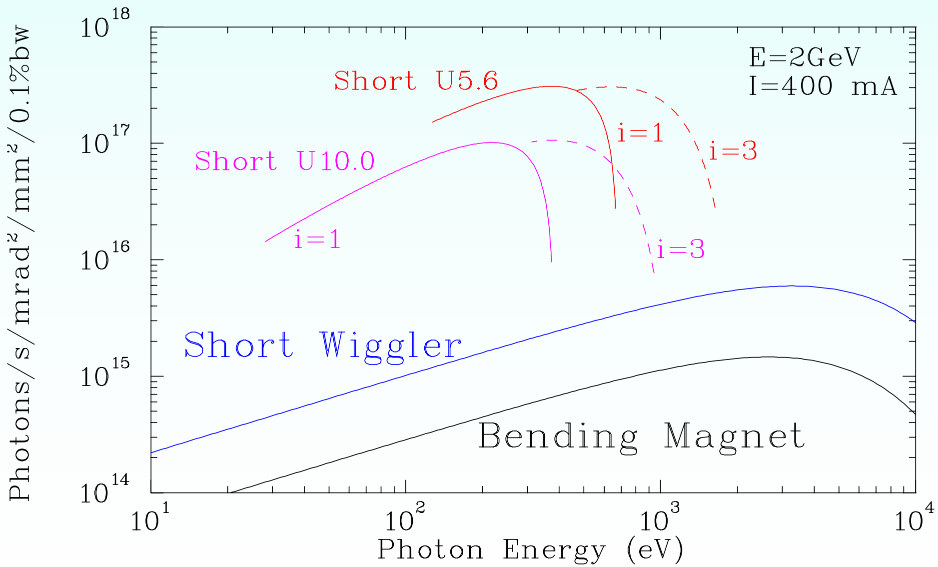


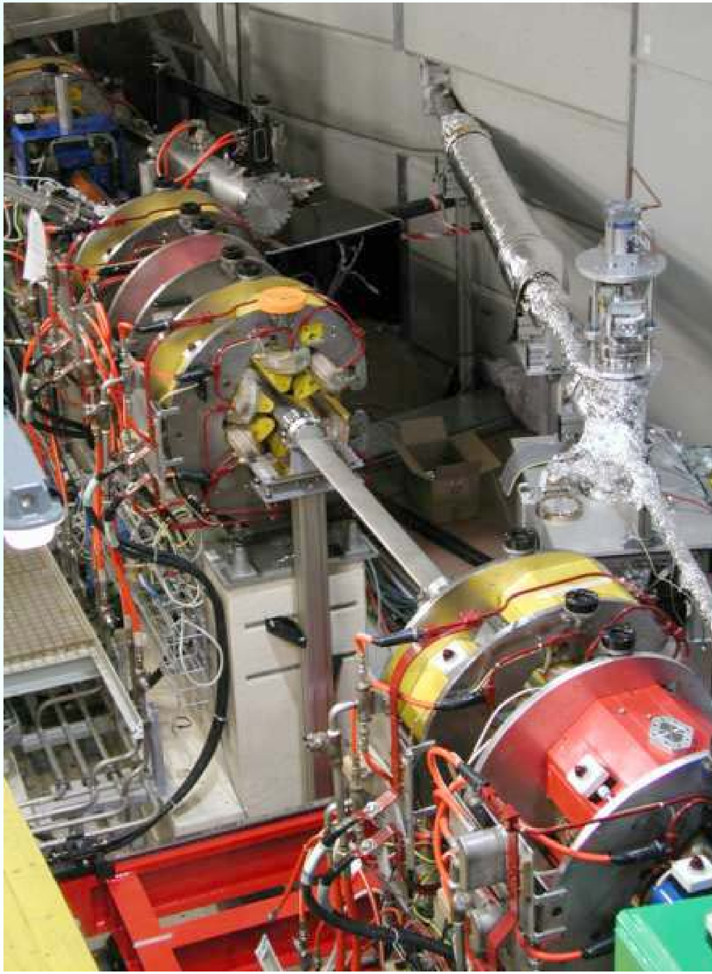
Short IDs

Motivation:

ncrease the number of insertion devices beyond hat allowed by the 11 long straight sections (10 ther positions available in the ring, with length .8 or 1 m)

Despite some limitations on the minimum gap / naximum field, useful sources can be produced hat far exceed bending magnet sources in terms f flux and brilliance.



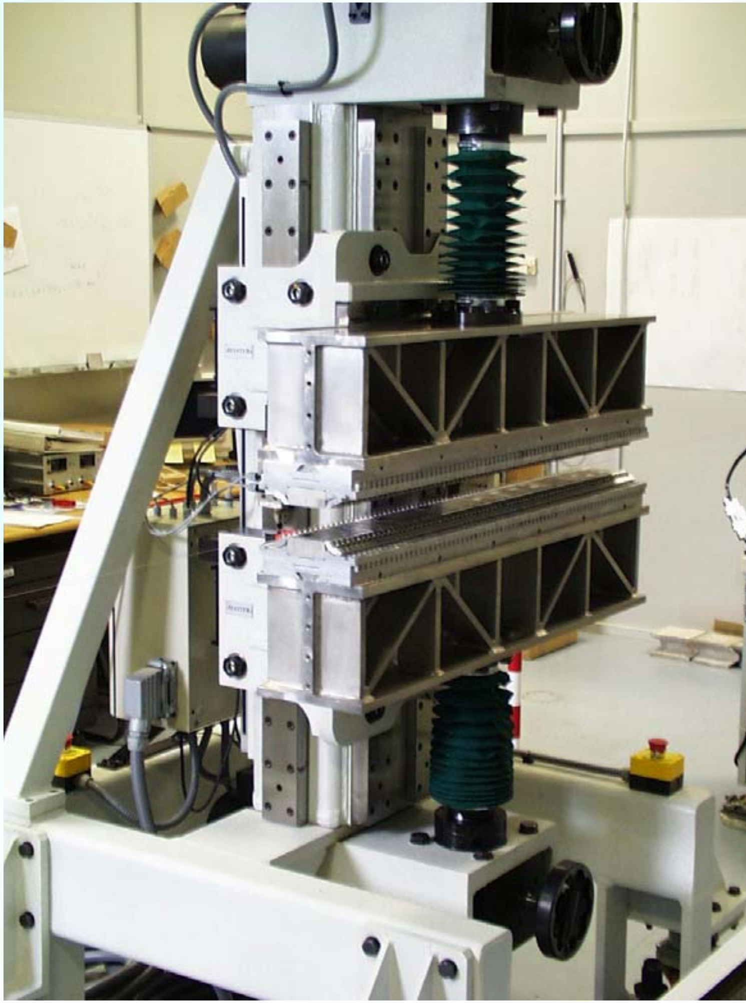


Short ID prototype (I)

otential problems of installing IDs in dispersive ections: increase of emittance, reduction of ynamic aperture, spectral degradation due to nergy spread, orbit correction issues.

o test this possibility, a short undulator rototype was constructed using existing agnetic arrays and installed together with a ew stainless steel low gap vacuum chamber.

Period = 56 mm
No. of periods = 18
Length = 1014 mm
Min. gap = 25 mm
K = 2.6



 novel two-motor support structure has been eveloped and built that reduces the complexity f the drive system, avoiding the risk of gap pering in case of control system faults.

Short ID prototype (II)

)perational experience:

Closing the undulator gap, no measurable ffect has been observed on the vacuum, etatron tunes and dynamic aperture / lifetime

Closed orbit distortion could be easily ompensated using the standard correction oils method

Using a new 7-corrector bump scheme, orbit an now be corrected on the long and short raight sections simultanoeously

These positive results open the way to dditional beamlines at ELETTRA (this rototype has been proposed as the source for new soft X-ray microscopy beamline)