Karlsruhe Institute of Technology

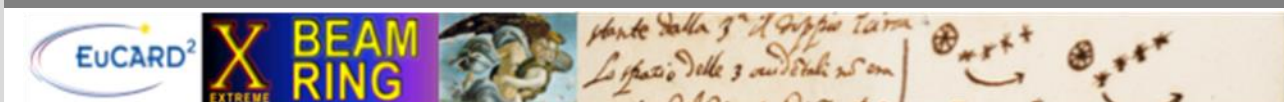
ANKA Synchrotron Radiation Facility

Diagnostics with undulator radiation

Sara Casalbuoni

ANKA, Karlsruhe Institute of Technology, Karlsruhe, Germany

ANKA



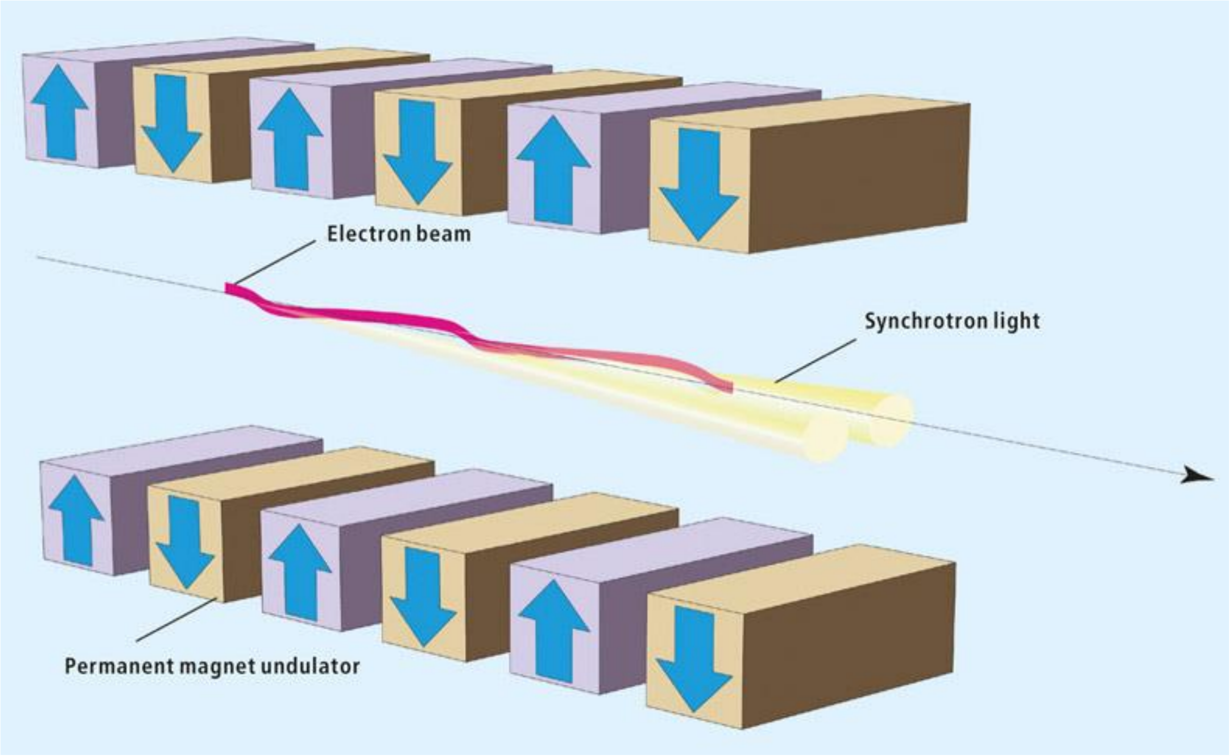
Beam Dynamics meets Diagnostics

Outline

- Undulator
- Undulator radiation
- Diagnostics examples
  - Emittance
  - Energy spread
  - Momentum compaction
- Conclusions

Undulator

- Undulators are periodic structures made by sequences of dipole magnets and are used in synchrotron light sources to increase the flux produced in a narrow cone



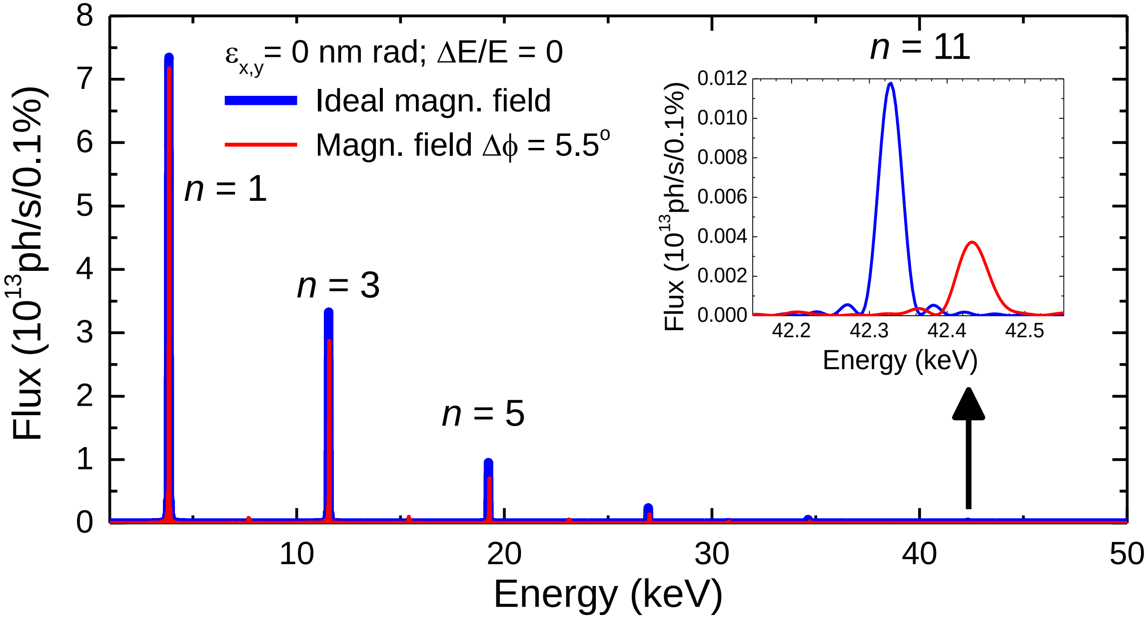
http://www.esrf.eu/Accelerators/news/art-undulator

Undulator radiation

- The constructive interference of the radiation emitted at each pole gives rise to flux peaks at certain photon energies in the undulator spectrum: this can be used to qualify the undulator field quality as well as electron beam characteristics as emittance and energy spread.

$$\lambda = \frac{\lambda_U}{2\,n\,\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right) \qquad K = \frac{e}{2\pi mc} B_0\, \lambda_U = 0.9336\, B_0[T]\, \lambda_U[cm]$$

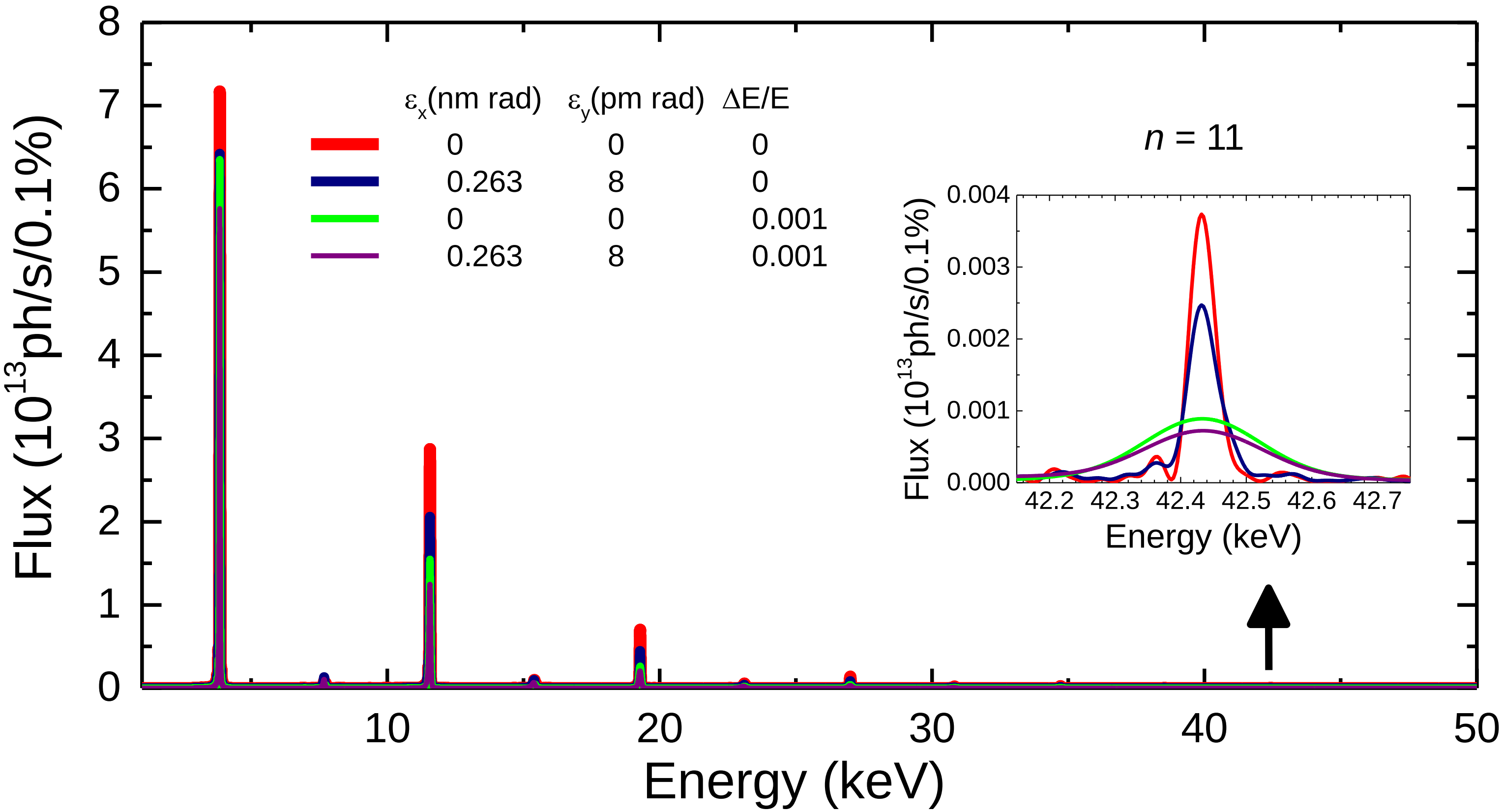
Flux through a slit 50 µm x 50 µm at 10 m



MAXIV parameters

E (Gev)	**3**
I (A)	**0.5**
ΔE/E	**0.001**
ϵ_x (nm rad)	**0.26**
ϵ_y (nm rad)	**0.008**
β_x (m)	**9**
β_y (m)	**4.8**
η_x (m)	**0**
λ_U (mm)	**15**
B_{max} (T)	**0.7**
# full periods	**102**

Spectrum dependence on ε and ΔE/E

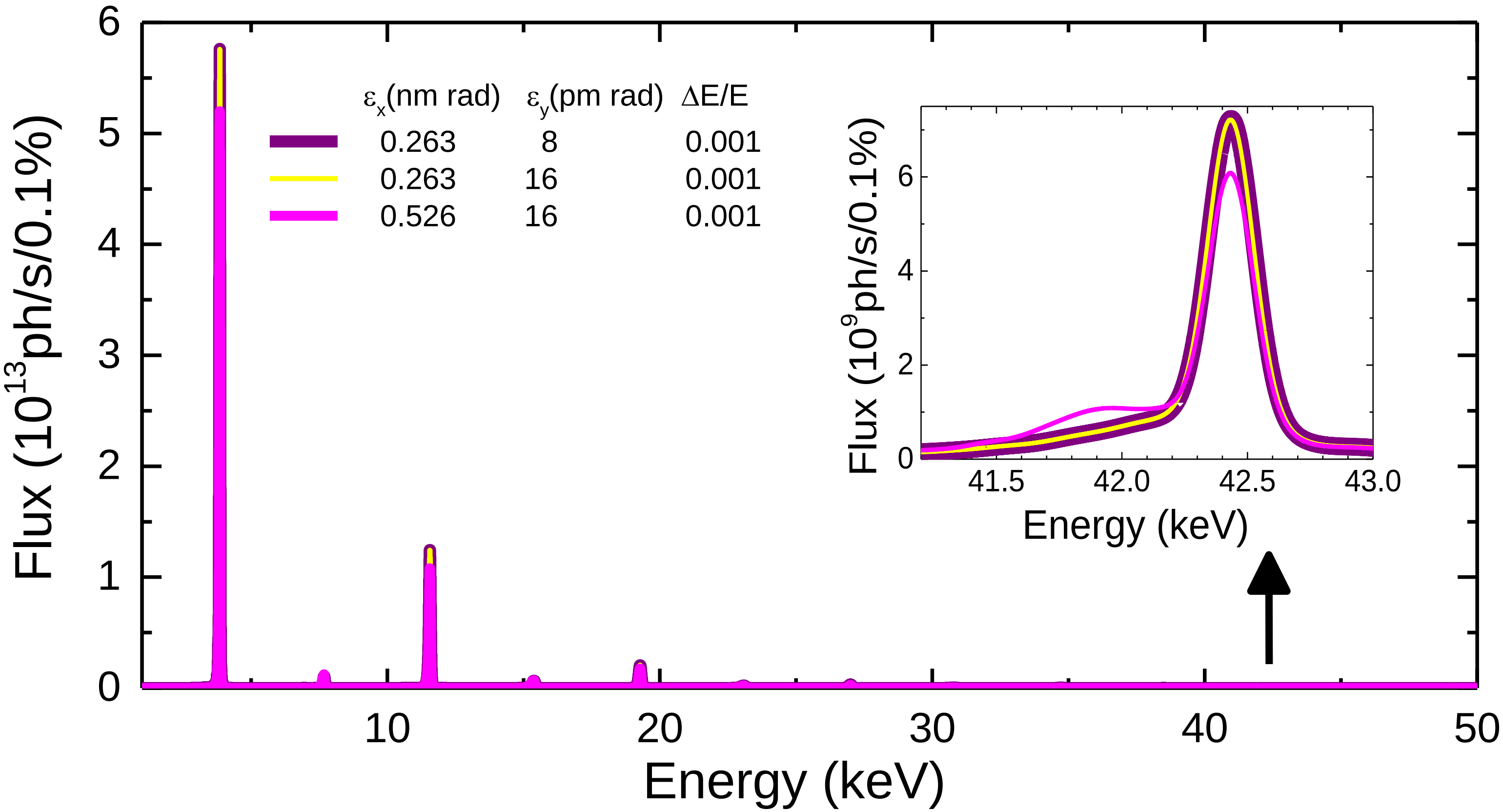


Largest suppression of higher harmonics from finite ΔE/E
Minimum value reached in storage rings ΔE/E ~ 0.001

Simulations performed with SPECTRA§

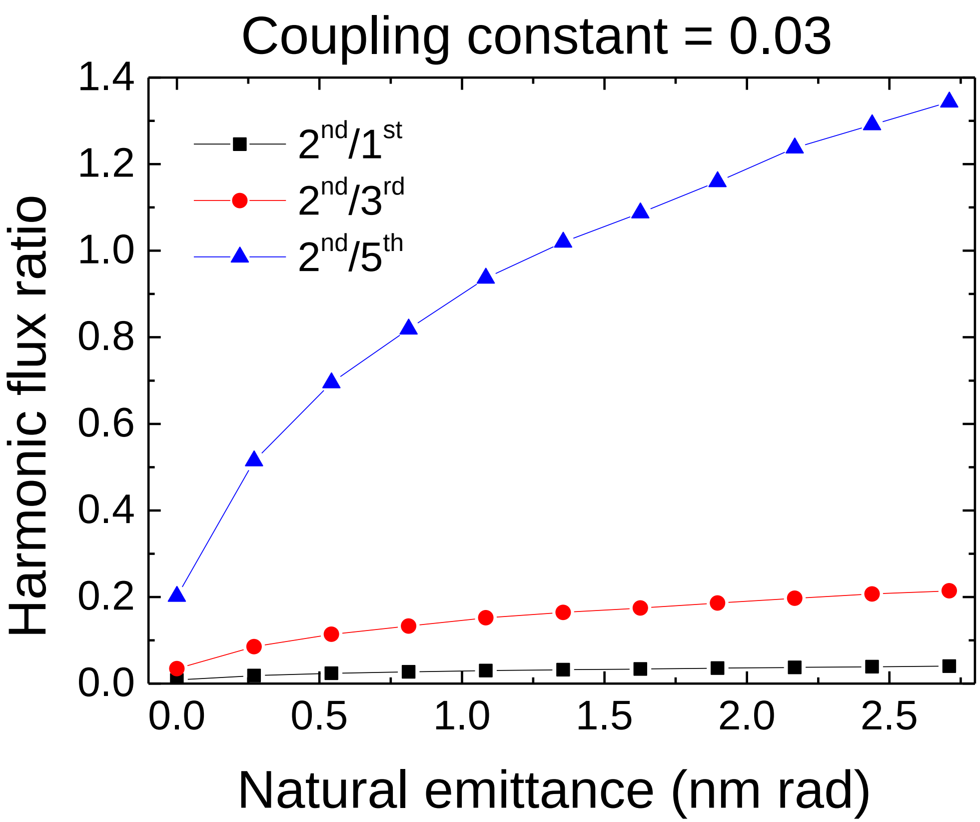
§T. Tanaka and H. Kitamura, J. Synchrotron Rad. 8, 1221 (2001)

Spectrum sensitivity to ε

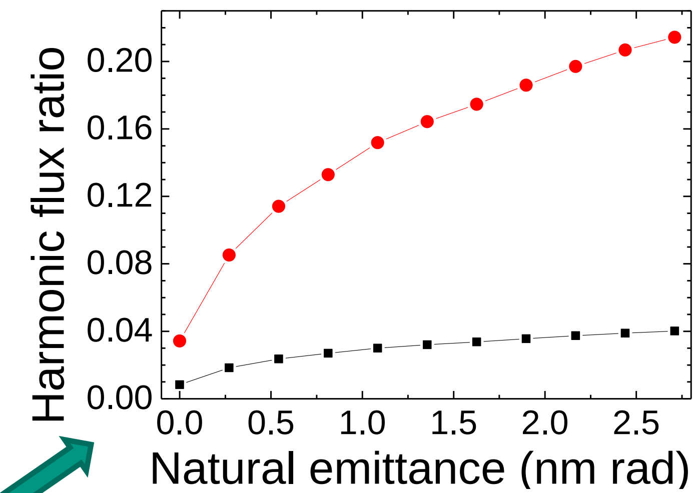


Increasing ε_y by a factor of 2 there is no change in the spectrum.
Increasing ε_x by a factor of 2 the peaks decrease by about 20%.

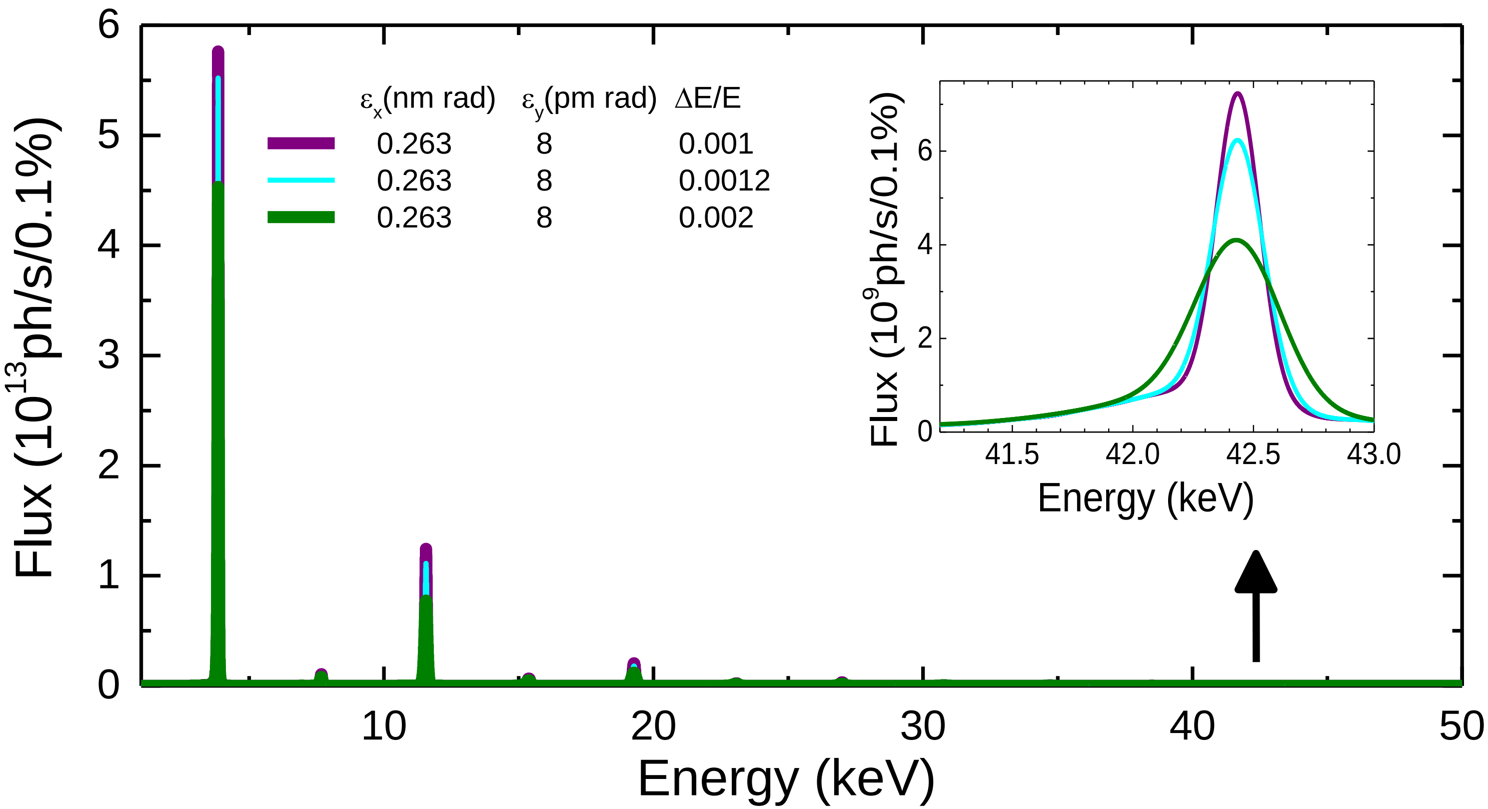
Spectrum sensitivity to ε: harmonic flux ratio



$$\frac{\Delta E}{E} = 0.1\%$$

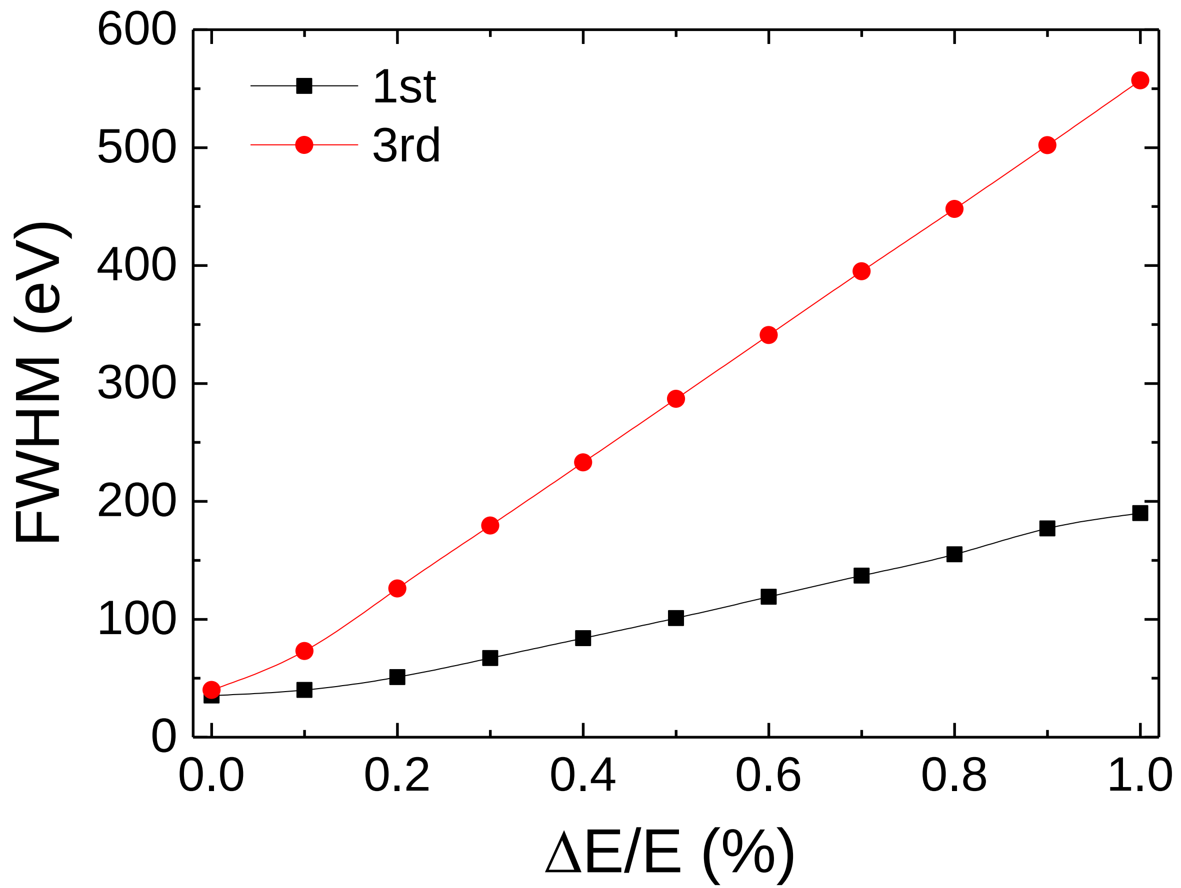


Spectrum sensitivity to ΔE/E



Increasing ΔE/E by a factor of 2 there is 20% change in the height of the 1st harm. and about 50% in the height of the 11th.
The higher harmonics are very sensitive to ΔE/E changes: 20% change in ΔE/E corresponds at the 11% harm. in a similar change in the peak height.

Spectrum sensitivity to ΔE/E: line width



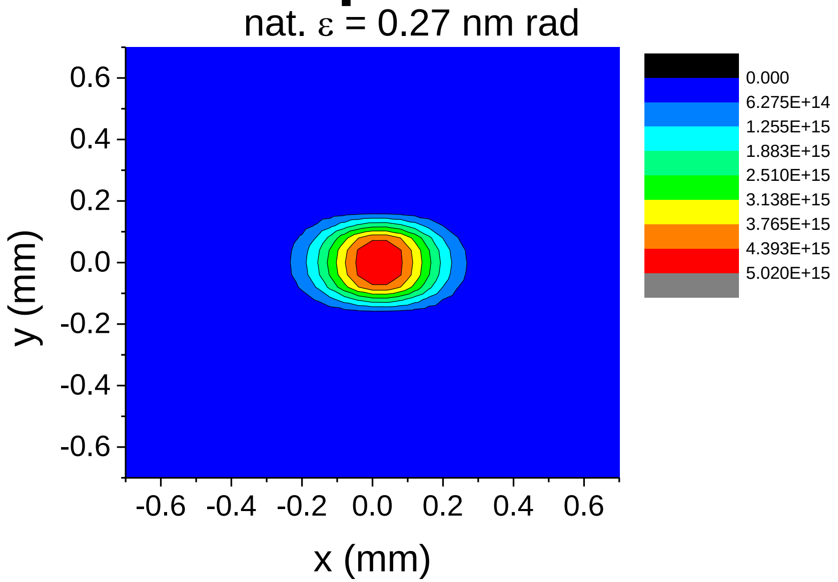
ϵ_x = 0.26 nm rad

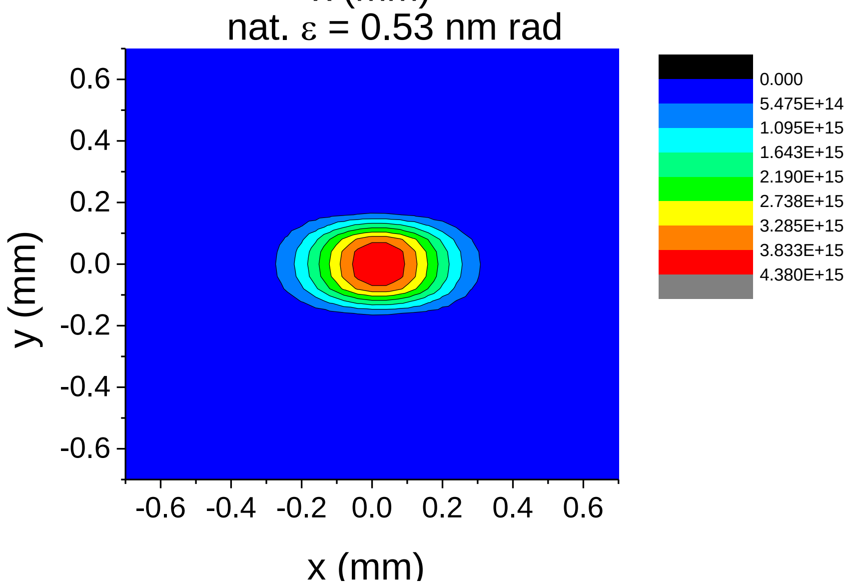
ϵ_y = 8 pm rad

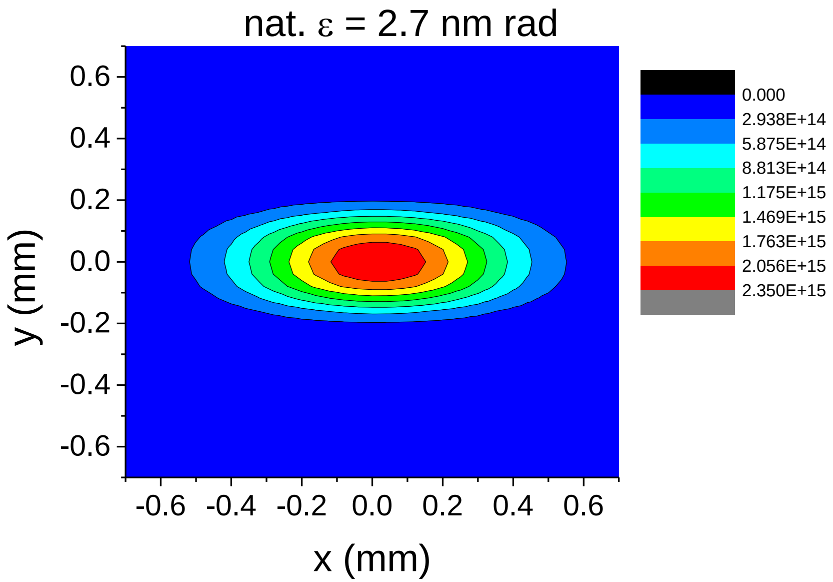
Harmonic spatial distribution

Coupling constant =0.03

$$\frac{\Delta E}{E} = 0.1\%$$

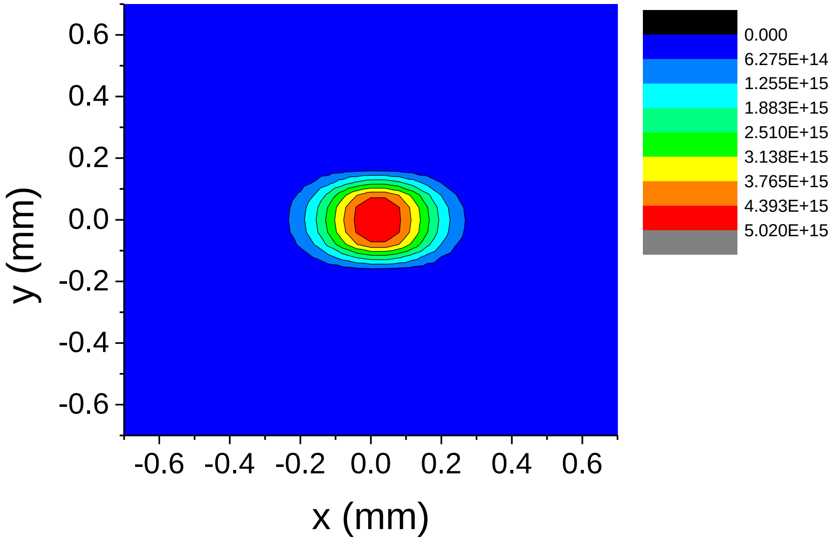






Harmonic spatial distribution

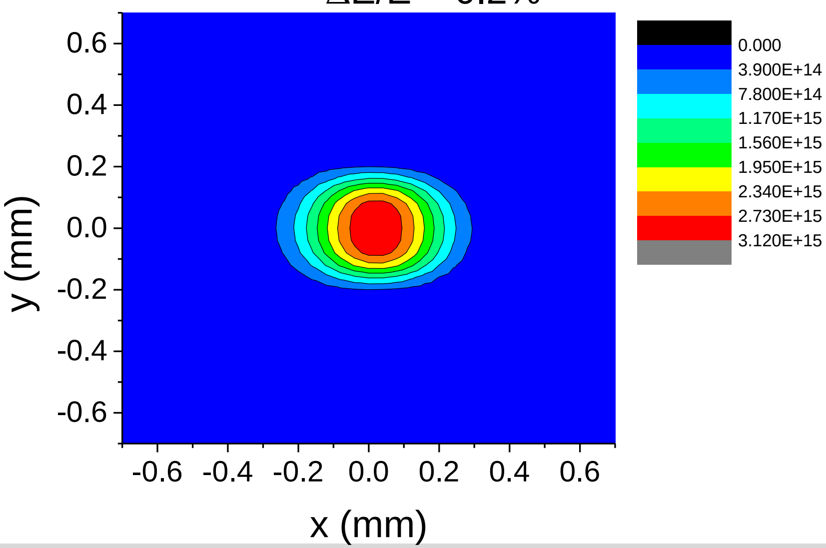
ΔE/E = 0.1%



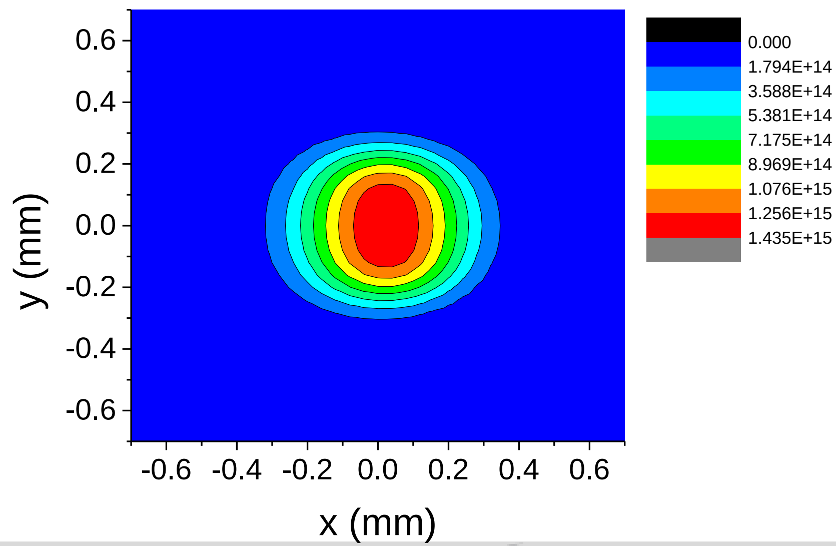
ϵ_x = 0.26 nm rad

ϵ_y = 8 pm rad

ΔE/E = 0.2%



ΔE/E = 0.5%



Examples

- Storage rings (SR): ESRF, APS
- Laser wakefield accelerator

SR: Emittance measurements

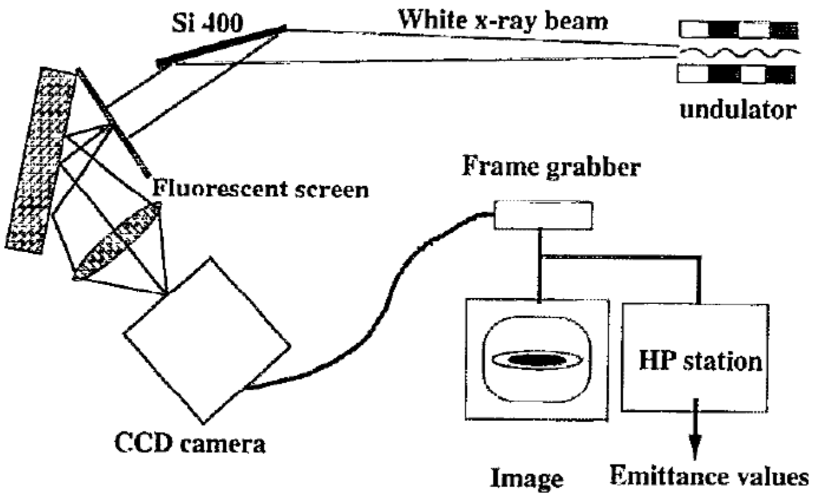


FIG. 1. Emittance monitor setup.

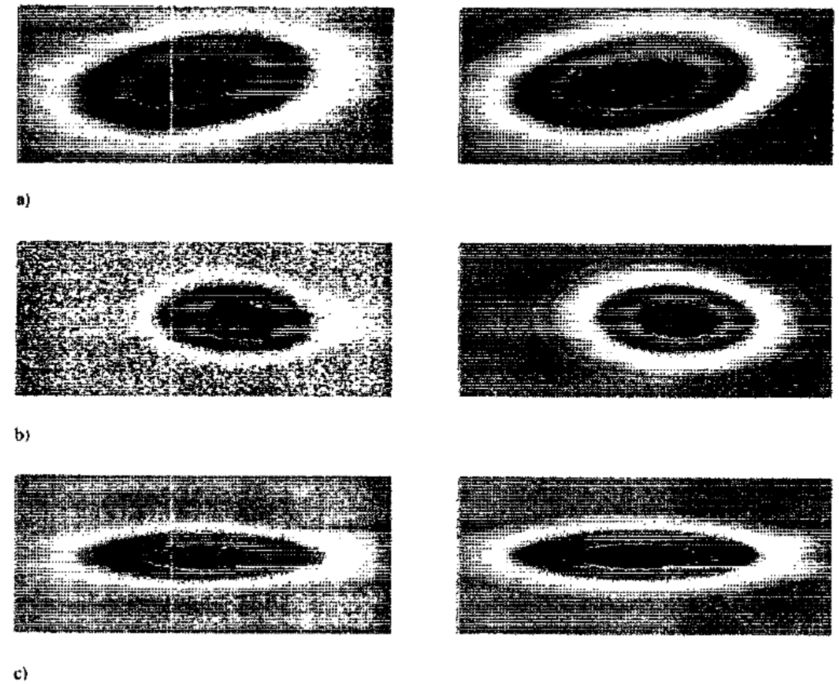


FIG. 2. Three different images of ID6 beam corresponding to different values of the emittance (on the left-hand side) and the fitted images (on the right-hand side). (a) $\epsilon_x = 10.6$ nm, $\epsilon_z = 1.3$ nm; (b) $\epsilon_x = 4.3$ nm, $\epsilon_z = 0.55$ nm; (c) $\epsilon_x = 10.3$ nm, $\epsilon_z = 0.2$ nm.

$$\epsilon = \frac{\Sigma_l^2 - \sigma_{scr}^2 - \sigma'^2_{und} l^2}{\beta + l^2/\beta} \qquad \sigma'_{und} = \sqrt{\frac{\lambda}{2L}}$$

Estimated error on ε ~ 20%

uncertainties in β functions and image quality (screen finite resolution ~30 µm)

ESRF

E. Tarazona and P. Elleaume, Rev. Sci. Instr. 1974-1977 **66** (1995)

SR: Energy and energy spread measurements

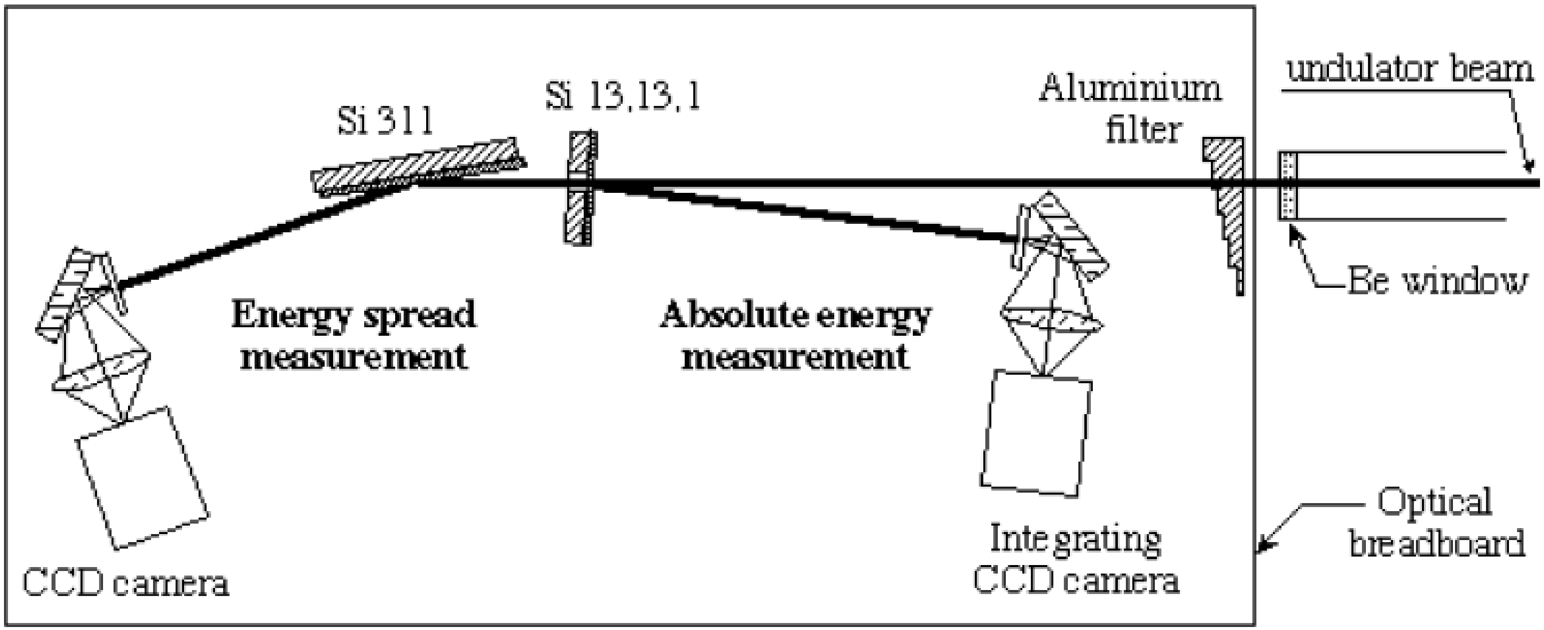


FIG. 1. Schematic of the electron average energy and energy spread measurement setups.

E. Tarazona and P. Elleaume, Rev. Sci. Instr. **67,** 3368 (1995)

ESRF

SR: Energy and energy spread measurements

Adjusting the magnetic gap, one makes the 3rd harmonic of the undulator coincide with the energy selected by the crystal

$$\lambda_n = \frac{1 + K^2/2}{2n\left(E/E_0\right)^2}\lambda_u \qquad\qquad \frac{dE}{E} = \frac{dK}{K}\frac{K^2}{2+K^2} < 0.1\%$$

Error on λ_n ~ 0.0001, minimized when θ ~90º (Bragg law)
Error on K ~ 0.01

E. Tarazona and P. Elleaume, Rev. Sci. Instr. **67,** 3368 (1995)

SR: Energy and energy spread measurements

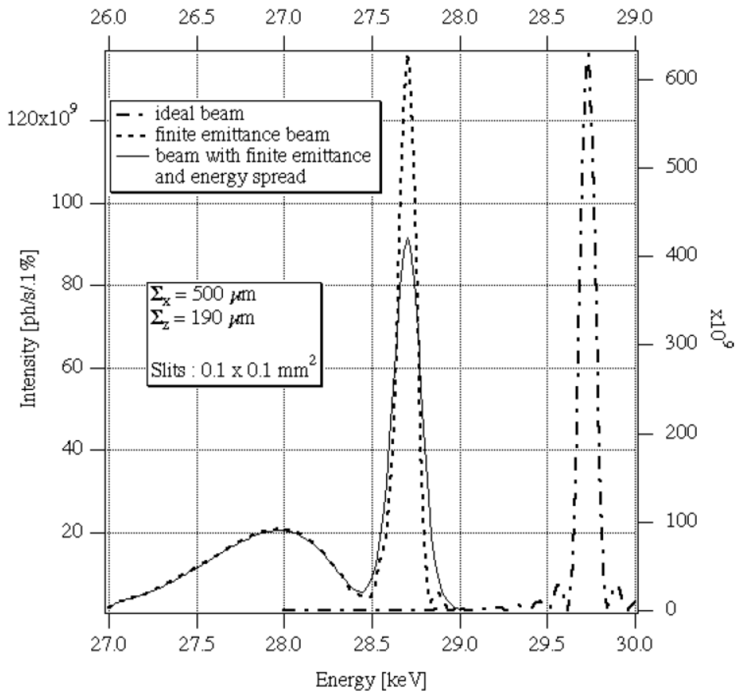


FIG. 2. Influence of the electron beam characteristics on the shape of the seventh harmonic. The case of a filament beam without energy spread is shown on the right curve (right and upper axes). The electron beam size and divergence are taken into account through the parameters Σ_X and Σ_Z which are the horizontal and vertical sizes of the electron beam projected onto the slits. The effects of non-zero Σ_X, Σ_Z (ie of a finite emittance beam) and energy spread are shown on the left curves.

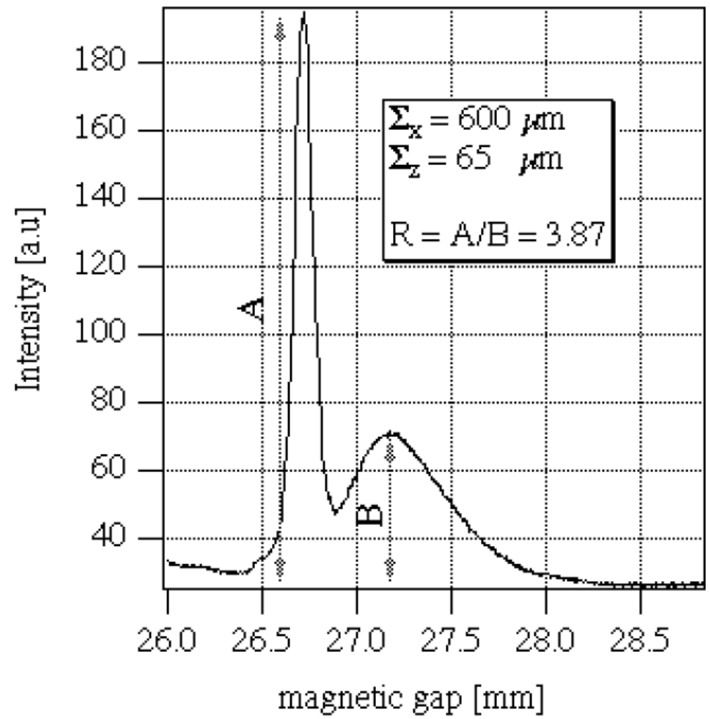


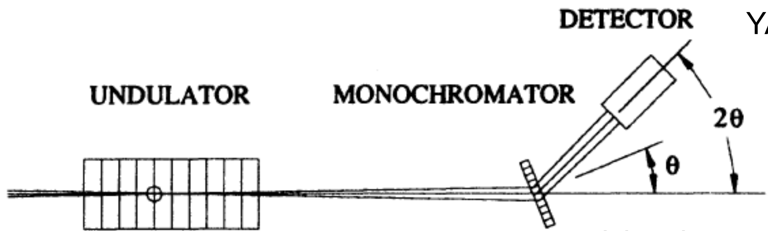
FIG. 4. Seventh harmonic profile recorded at a constant energy by varying the undulator gap. The energy spread deduced from Σ_X, Σ_Z and R is 1.1×10^{-3}.

$$\frac{\Delta E}{E} = 0.0011 \pm 0.0002$$

E. Tarazona and P. Elleaume, Rev. Sci. Instr. **67,** 3368 (1995)

SR: Momentum compaction factor

Karlsruhe Institute of Technology



YAG scintillation detector

Si (220)

APS

$$\left(\frac{\Delta\alpha_C}{\alpha_C}\right)_{TOTAL} \sim 1\%$$

FIGURE 3. Schematic of the spectrum measurement of angle-integrated flux. The monochromator crystal uses Laue reflection with a Bragg angle θ, and the detector is located on a second rotary stage following 2θ.

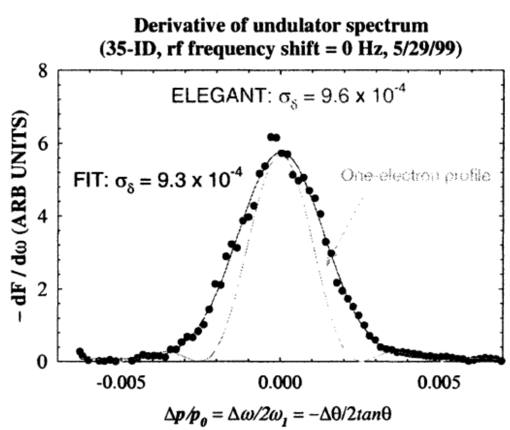


FIGURE 4. Scaled derivative spectrum of the total flux: (Dashed line) One electron radiation profile; (Circles) experimental measurements; and (Solid line) calculated value with electron energy spread assumed to be 0.93 x 10^{-3}.

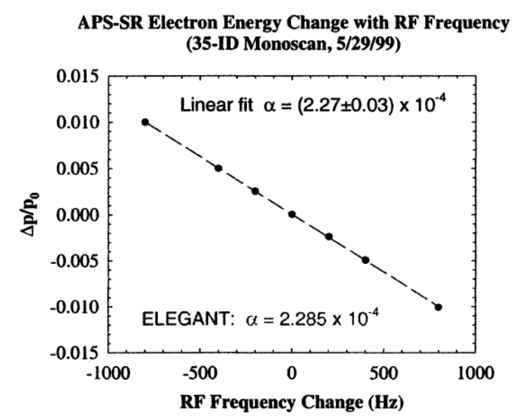


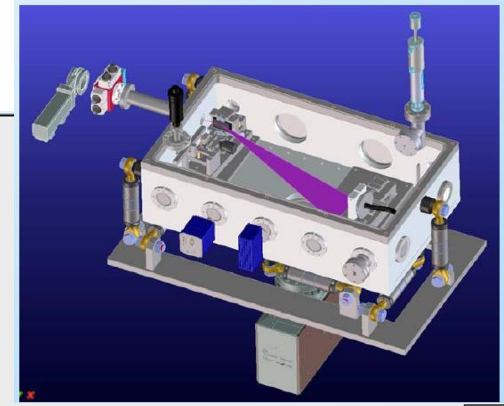
FIGURE 5. Energy centroid change as a function of rf frequency change. The slope of this curve gives the momentum compaction of the APS storage ring, 2.27 × 10^{-4}, compared with the simulation result of 2.285 × 10^{-4}.

B. Yang, M. Borland and L. Emery, Beam Instrumentation Workshop 2000

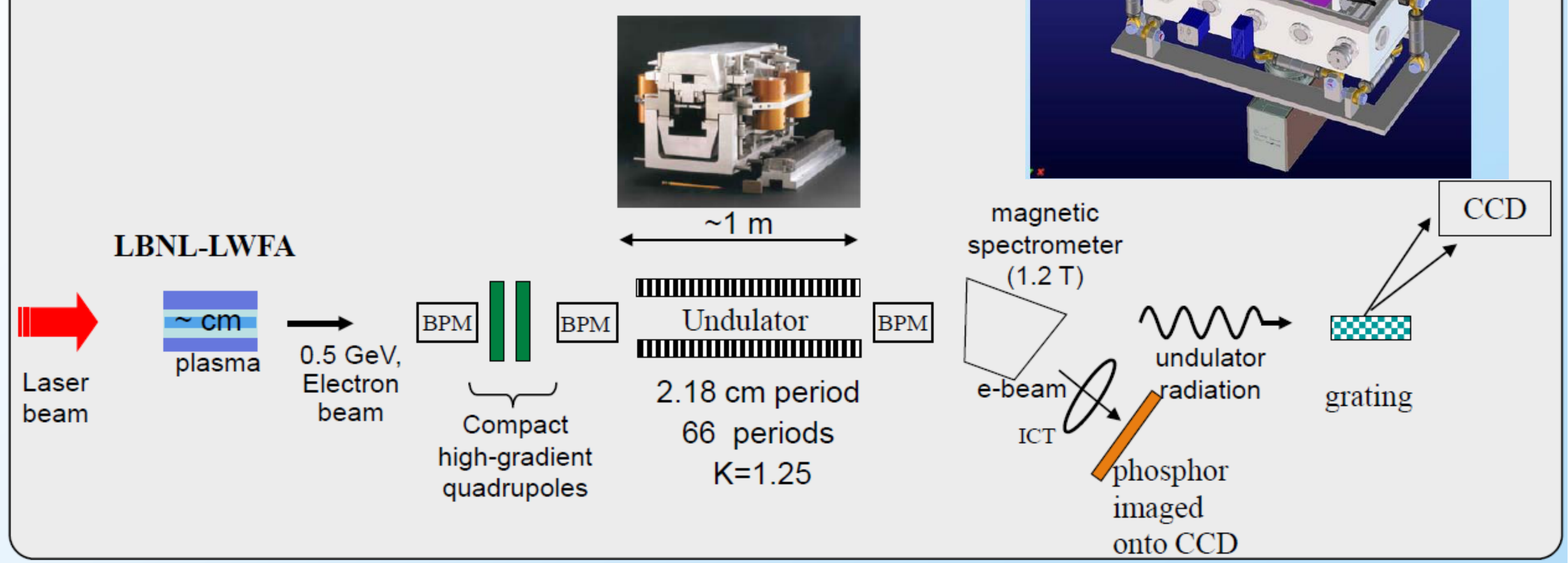
LWFA: Emittance and energy spread

XUV Spectrometer properties

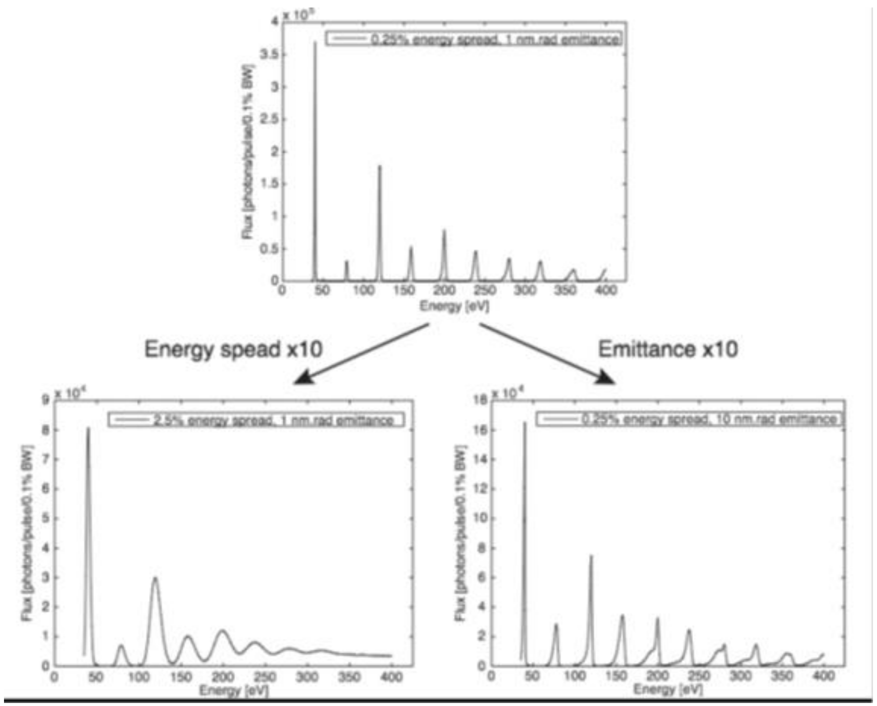
- 8-62nm spectral range
- Four jaw Aperture System
- MCP detector with CsI photocathode
- Aberration corrected concave grating

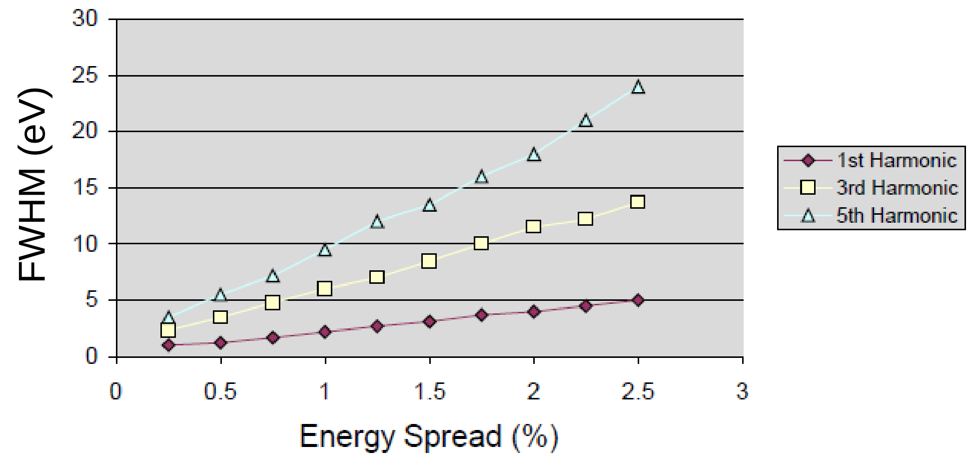


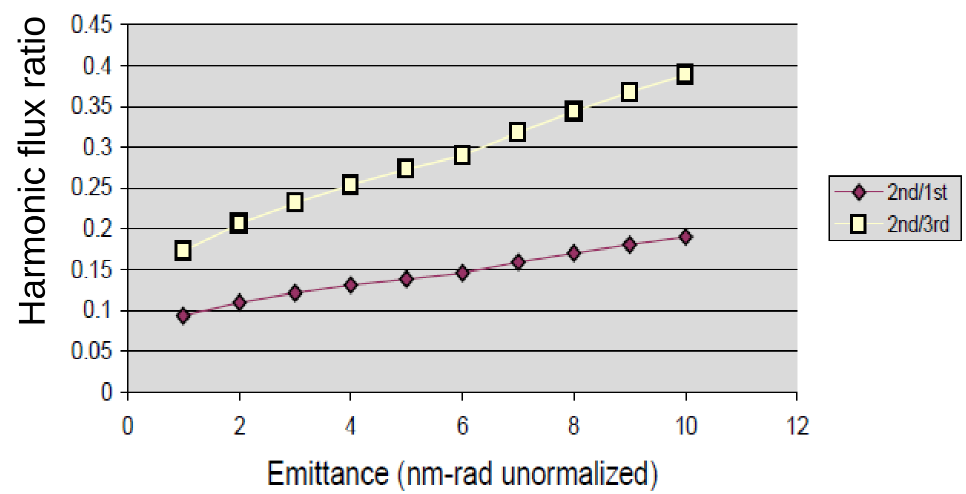
M.S. Bakeman et al, FLS 2010



LWFA: Emittance and energy spread







M.S. Bakeman et al, FLS 2010

Conclusions

- Low emittance storage rings, free electron lasers and energy recovery linacs are designed to optimize the performance of the photons emitted by undulators

- Undulator radiation is a powerful diagnostic tool to measure emittance, energy spread and momentum compaction factor

Thanks to EUCARD² for providing the opportunity to attend this workshop