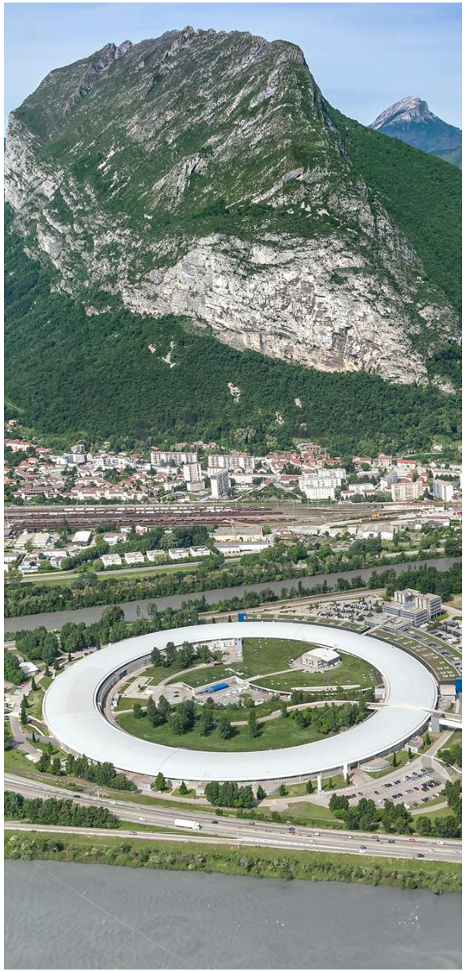
ESRF | The European Synchrotron



Undulator models for ray-tracing simulations

Manuel Sánchez del Río & Juan Reyes-Herrera*

*juan.reyes-herrera@esrf.fr

Advanced Analysis & Precision Unit, MEG/ISDD, ESRF

Tuesday 27 August, 2024

Outline

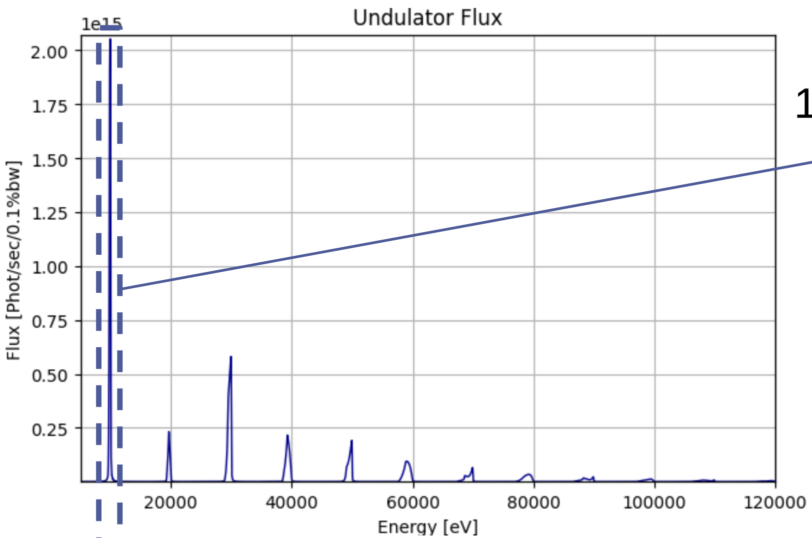
SHADOW4 undulators:

- Gaussian undulator
- Undulator light source
- Short summary

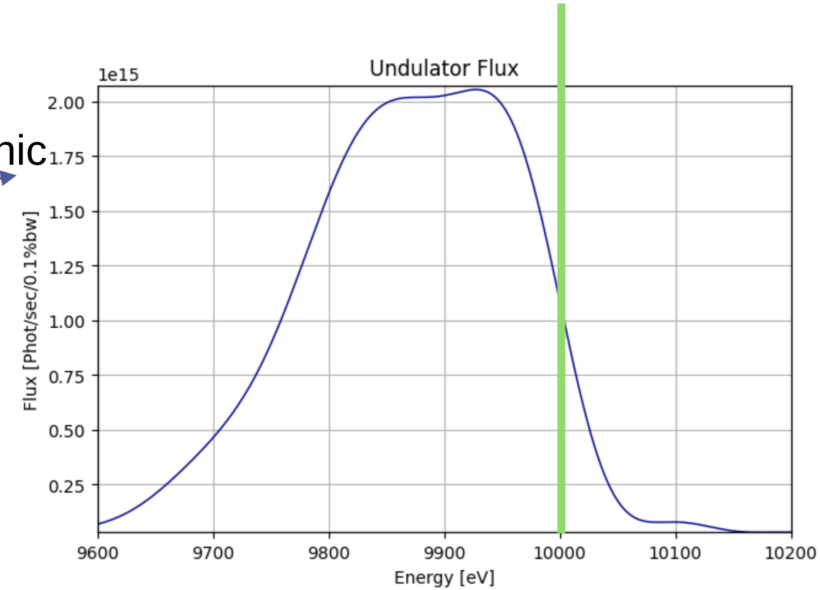
Gaussian undulator

Undulator radiation emission

Gaussian emission approximation



1st harmonic



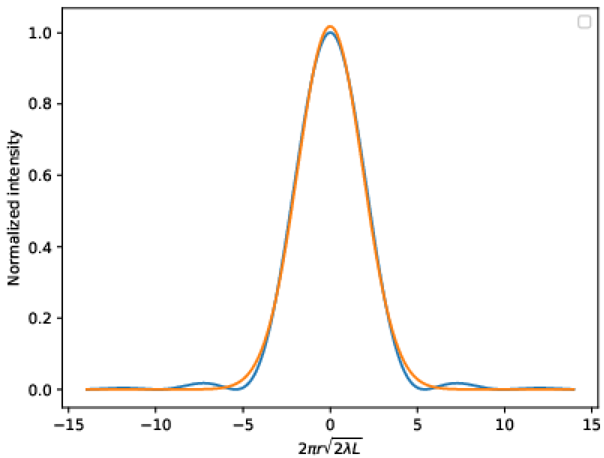
Spectrum through a slit: 30m (1mm x1mm)

Resonance energy @10 keV

Gaussian approximation

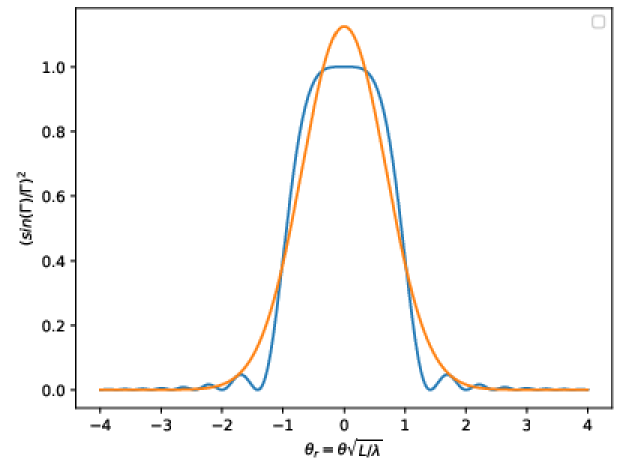
SHADOW4: Elleaume's approach [1]

Source size



$$\sigma_r = \frac{2.740}{4\pi}\sqrt{\lambda L}$$

Source divergence



$$\sigma_{r'} = 0.69\sqrt{\frac{\lambda}{L}}$$

Electron beam: $$\Sigma_{x,y} = \sqrt{\sigma_r^2 + \sigma_{x,y}^2}$$

$$\Sigma_{\theta_x,\theta_y} = \sqrt{\sigma_{r'}^2 + \sigma_{\theta_x,\theta_y}^2}$$

λ: photon wavelength, L: undulator length

[1] *Undulators, Wigglers and Their Applications*, chap. 3: Undulator Radiation. In (Onuki & Elleaume, 2003)

Electron beam energy spread

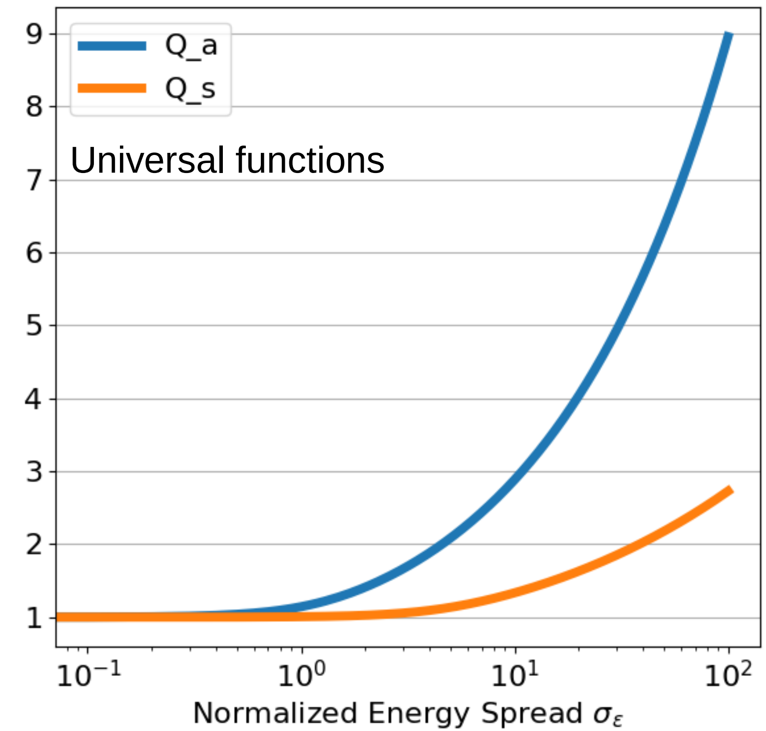
Electron beams do not have exactly the same energy ($\delta_\varepsilon \neq 0$).

SHADOW4: Tanaka and Kitamura approach [2]

$$\Sigma_{x,y} = \sqrt{(Q_s(\sigma_\epsilon)\sigma_r)^2 + \sigma_{x,y}^2}$$

$$\Sigma_{\theta_x,\theta_y} = \sqrt{(Q_a(\sigma_\epsilon))\sigma_{r'})^2 + \sigma_{\theta_x,\theta_y}^2}$$

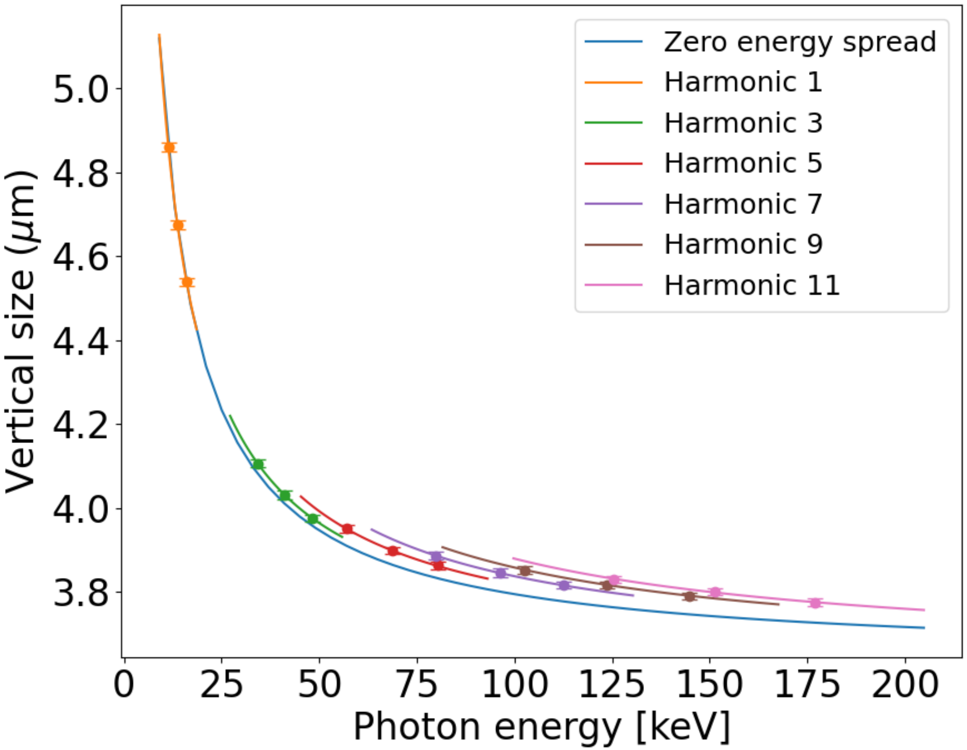
$$\sigma_\epsilon = 2\pi n N \delta_\varepsilon$$

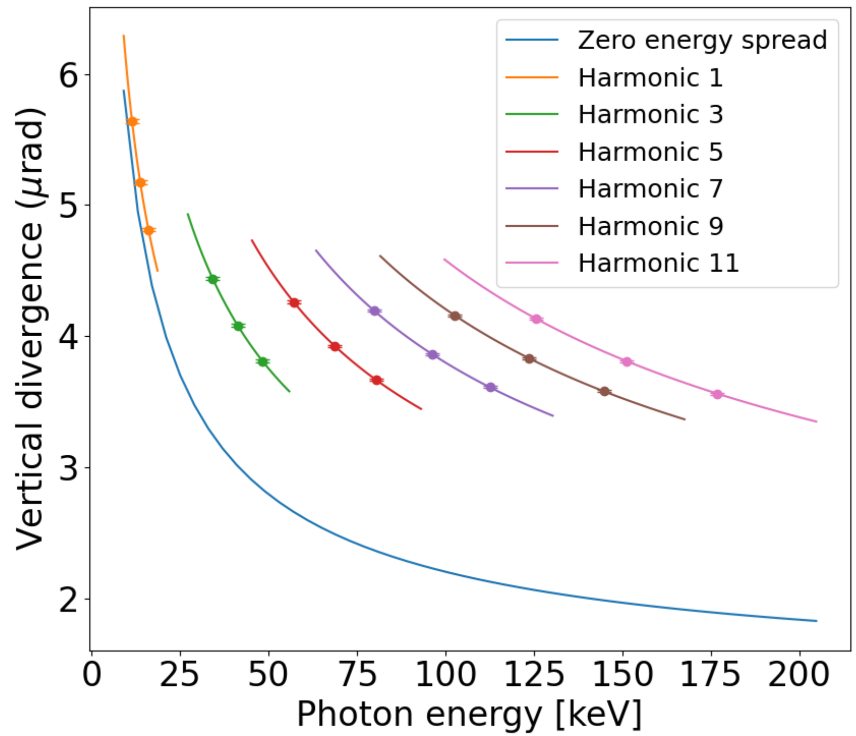


[2] *Universal function for the brilliance of undulator radiation considering the energy spread effect*, Tanaka & Kitamura, J. Synchrotron Rad. (2009) **16**, 380-386.

Example1: Source size and divergence

$\delta_{\varepsilon} = 0.001$





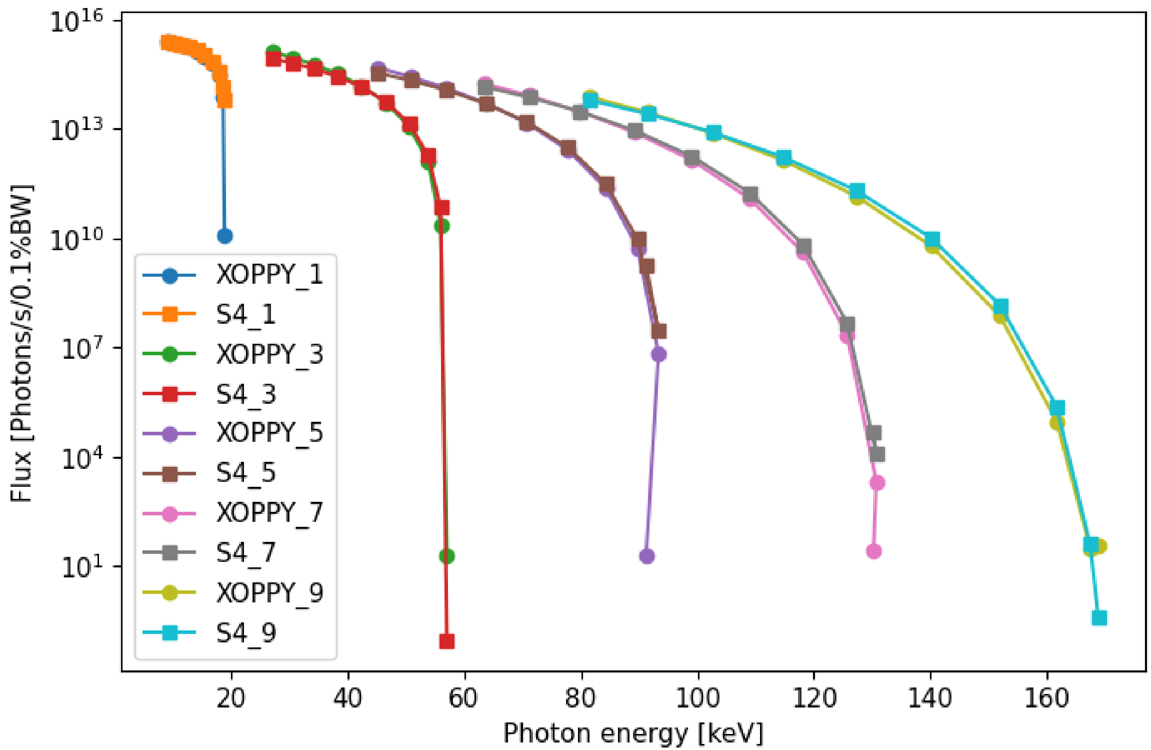
Tanaka & Kitamura

- SHADOW4 Gaussian undulator

U18 – 2 m

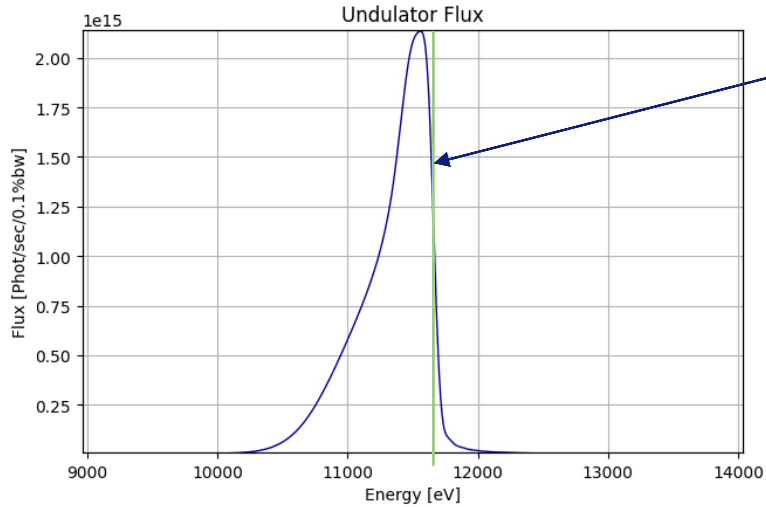
Example2: Photon flux (Tuning curves)

SHADOW4: Gaussian undulator



XOPPY: SRW

Undulator: far field emission

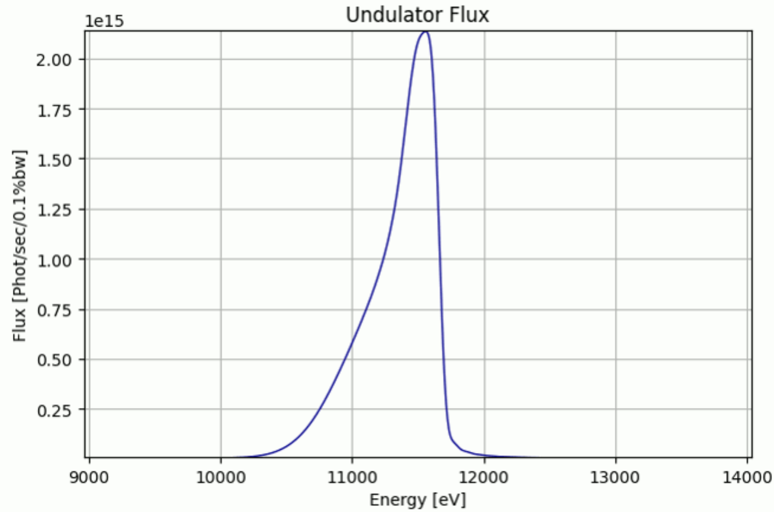


Gaussian emission approximation: **On-resonance**

-What if we need to simulate other off-resonance undulator emission?

Undulator: far field emission

1st harmonic
SRW

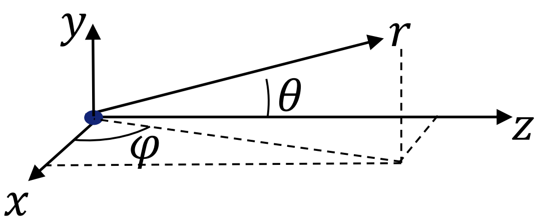


Undulator emission
-U16.4
-Slit @ 31.5 m (2 mm x 1 mm)

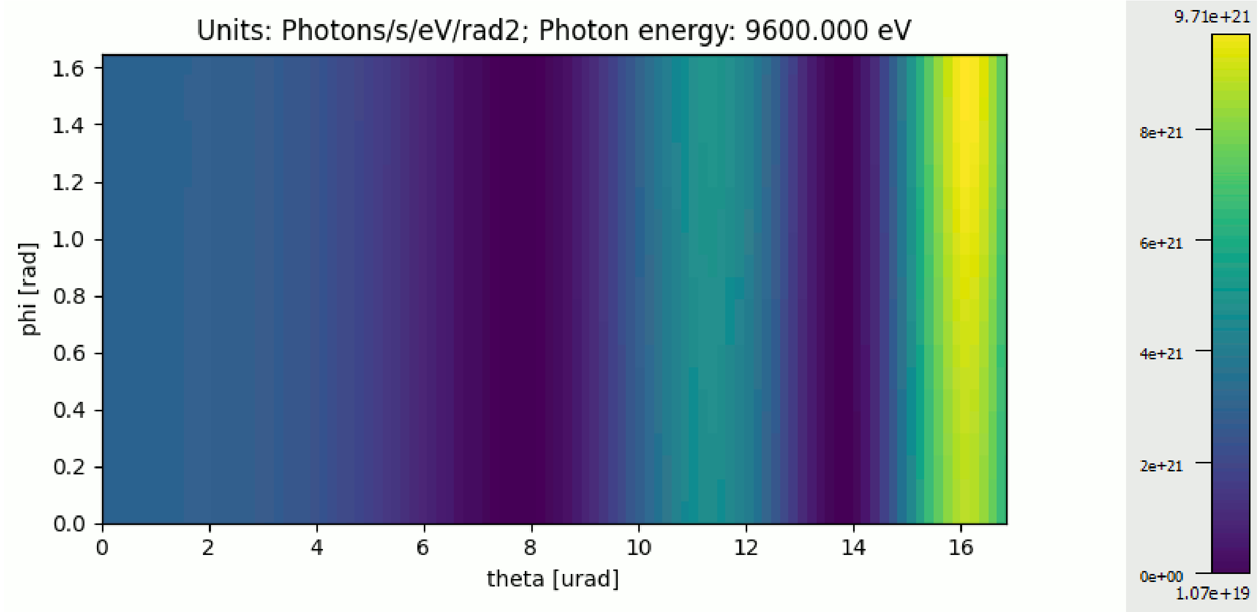
Shadow4 undulator: model algorithm

3D Stack of: N_{Energy}, N_{θ} and N_{φ}

Far field



Polar coordinates



Intensity and Polarization

&

Points into Cartesian coordinates (x, y)

2D integral back-propagator

Source size

&

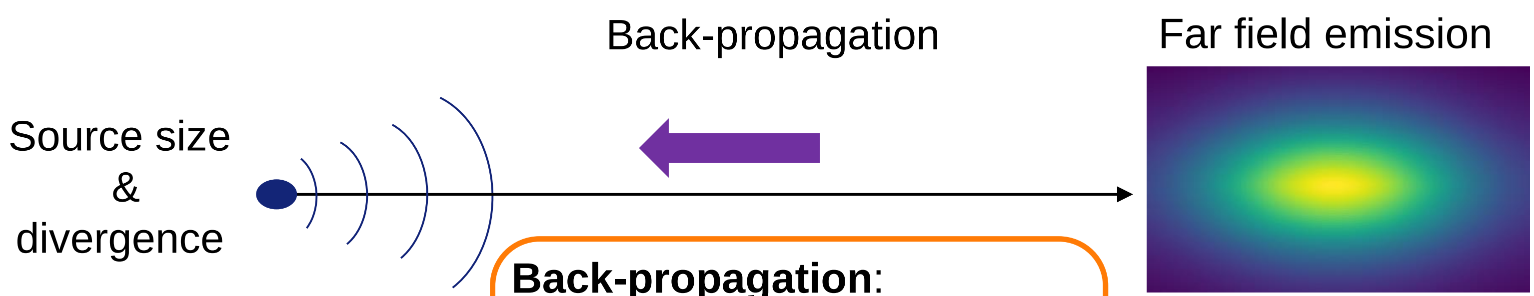
divergence

Shadow4 undulator: model algorithm

Optionally, external packages:

- ***SRW* [4]:** Far field emission and Back-propagation
- ***PySRU* [5]:** Far field emission + ***WOFRY2D*:*** Back-propagation

* POSTER SESSION 1: **Manuel Sánchez del Río** – WOFRY (**141**)

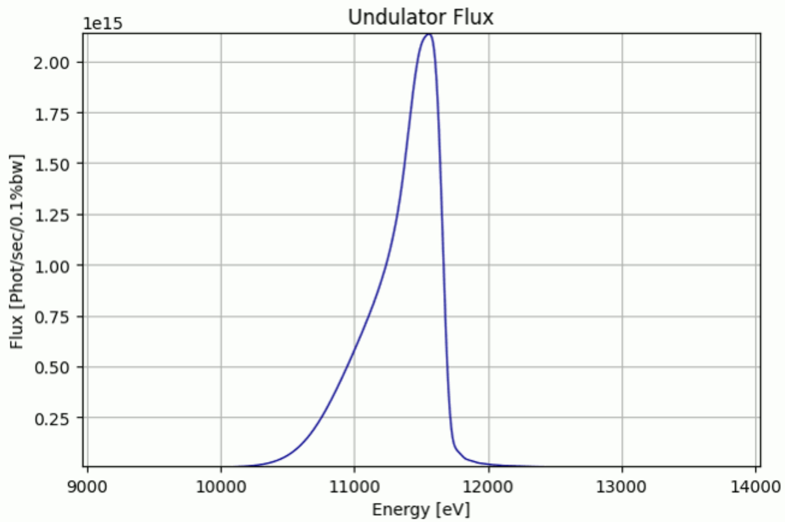


Back-propagation:
It is not always straightforward, it is necessary the fine adjustment of a few parameters.

[4] O. Chubar & P. Elleaume, Proceedings of the 6th European Particle Accelerator Conference - EPAC-98, pp. 1177–1179
[5] S. Thery et al. *https://www.github.com/oasys-kit/pySRU*.

Shadow4 undulator: far field emission

1^{st} harmonic



Undulator emission

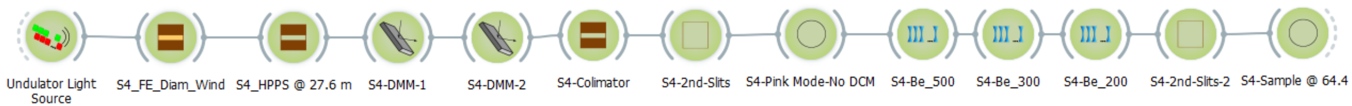
-U16.4

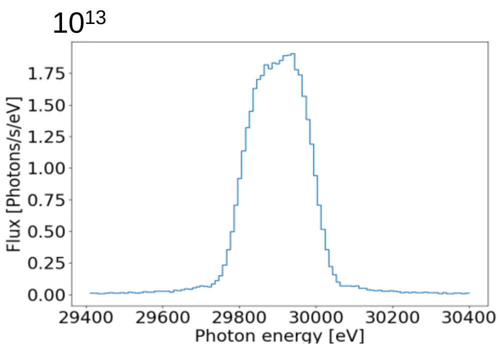
-Slit @ 31.5 m

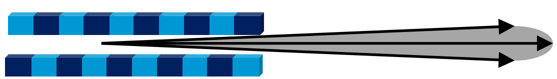
(2 mm x 1 mm)

*Internal

Shadow4 undulator: polychromatic







N runs

- Monochromatic source + energy loop

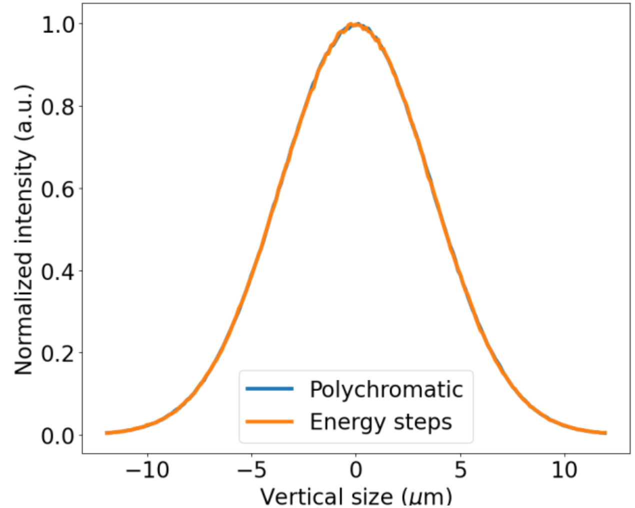
- Polychromatic source + single run

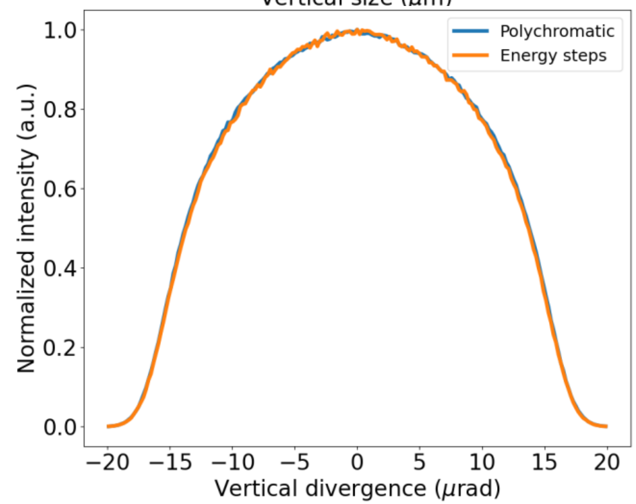
Test1 - Shadow4 undulator: polychromatic

Energy range: 9.6 keV – 10.2 keV

Energy steps:
monochromatic
101 runs
10^5 rays

Polychromatic:
full energy range
Single run:
11×10^6 rays





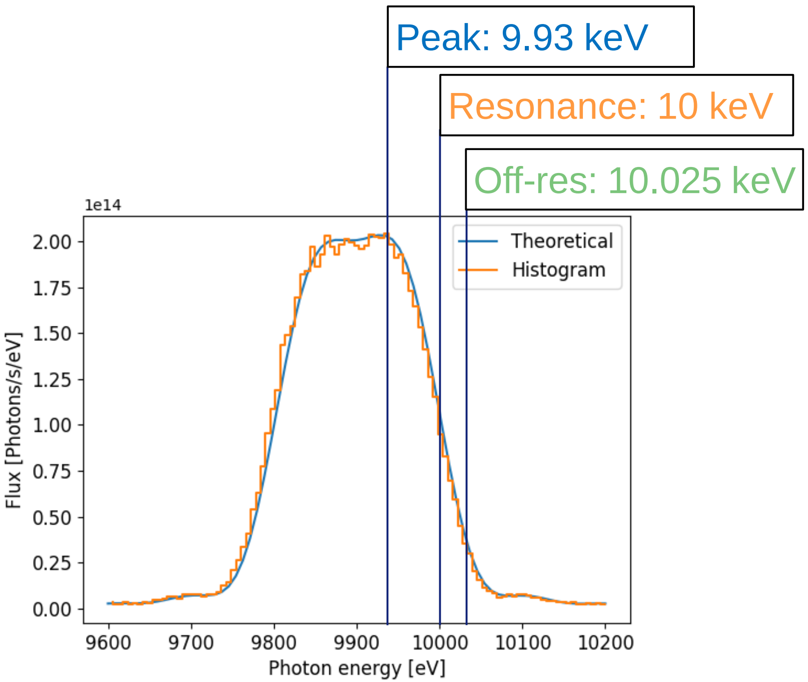
U18 – 2 m

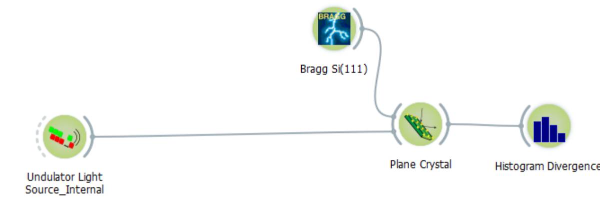
Test2 - Shadow4 undulator: polychromatic

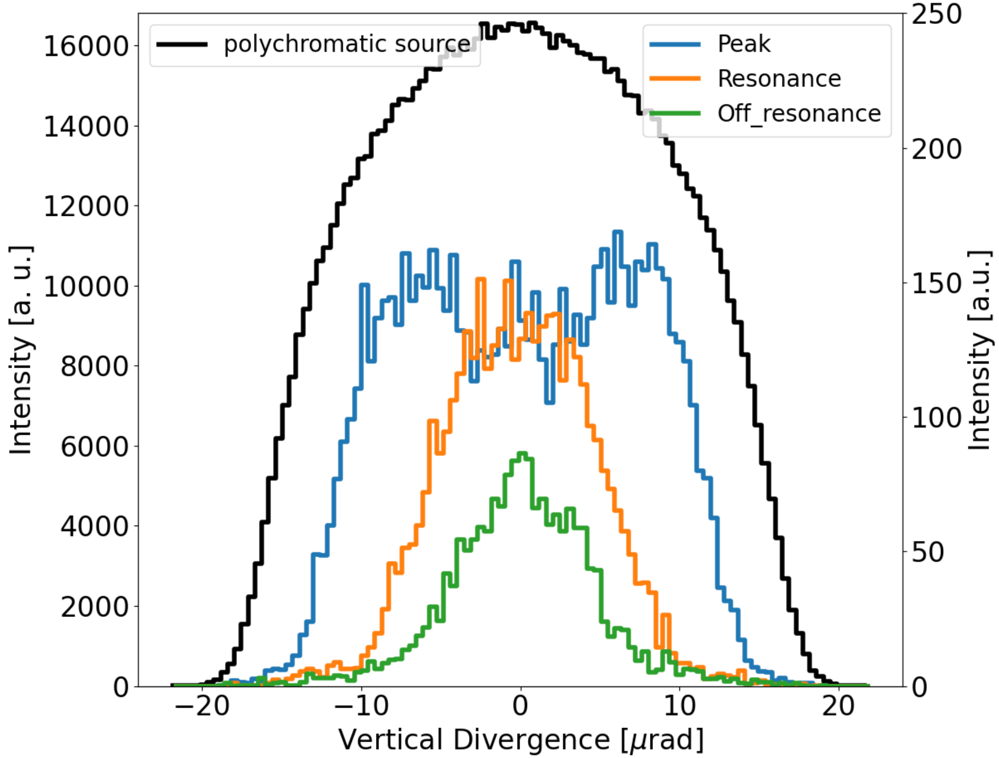
U18 – 2m

Energy range: 9.6 keV – 10.2 keV

Energies:







Short summary

SHADOW4:
Undulators sources

Gaussian undulator source

- On-resonance approximation
- Considers energy spread
- Photon flux estimation

Undulators source

- Full emission
- Off-resonance
- Monochromatic (energy spread)
- Polychromatic

Thank you

Thank you for your attention!

Download these slides:

Extra slides

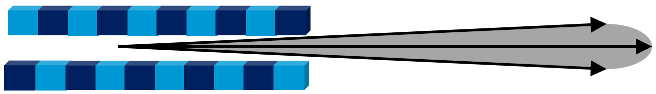
Extra slides

Photon flux

SHADOW4: Photon flux manual or flux in the central cone [3]

$$\theta_{\text{cen}} = \frac{1}{\gamma^* \sqrt{N}}$$

*effective Lorentz factor



$$F = \pi \alpha N \frac{\Delta\omega}{\omega} \frac{I}{e} Q_n(K), K \text{ odd}$$

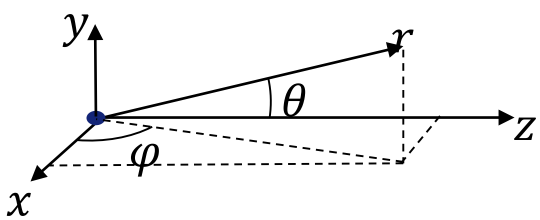
$$Q_n(K) = (1 + K^2/2) F_n / n$$

α: fine−struct const., I: electron current, K: mag. deflection param., F_n: univ. func.

[3] *X-ray Data Booklet.* Thompson, Lawrence Berkeley National Laboratory, Univ. of California.

Full model undulator algorithm

Far field



D. Jackson: $$E_\omega(\boldsymbol{r}) = \frac{ie\omega}{4\pi c\epsilon_0}\int_{-\infty}^{\infty}\left[\frac{\mathbf{n}\times[(\mathbf{n}-\boldsymbol{\beta})\times\dot{\boldsymbol{\beta}}}{(1-\boldsymbol{\beta}\cdot\mathbf{n})^3}\right.$$

3D Stack of:
- N-Energy
- N_θ
- N_φ

→

Intensity
&
Polarization

Internal: Points into Cartesian coordinates (x, y) + 2D integral back-propagator.

←

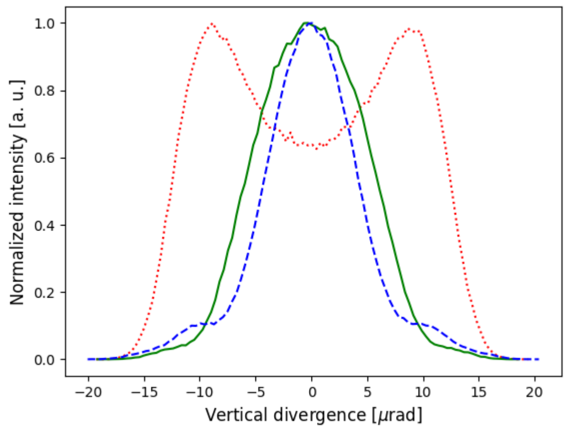
Back-propagation

Source size
&
divergence

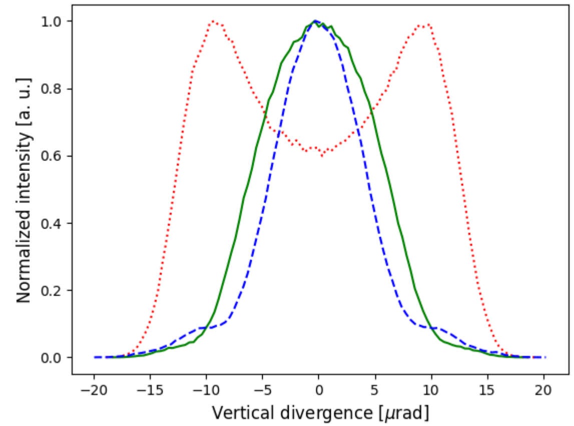
Full model undulator - monochromatic

U18
Off-resonance

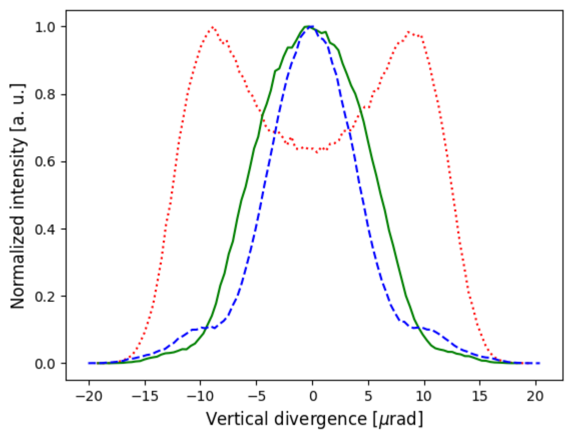
Internal

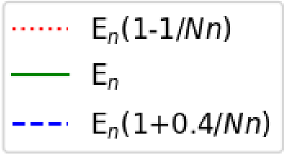


SRW



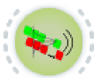
PySRU + WOFRY2D





SHADOW4 GUI

SHADOW4:
Gaussian undulator



Undulator Gaussian