



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

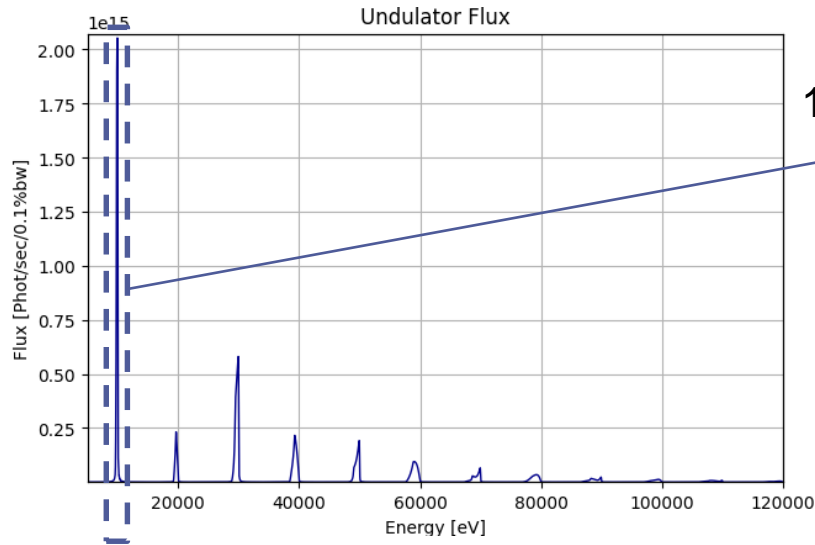
Tuesday 27 August, 2024

SHADOW4 undulators:

- Gaussian undulator
- Undulator light source
- Short summary

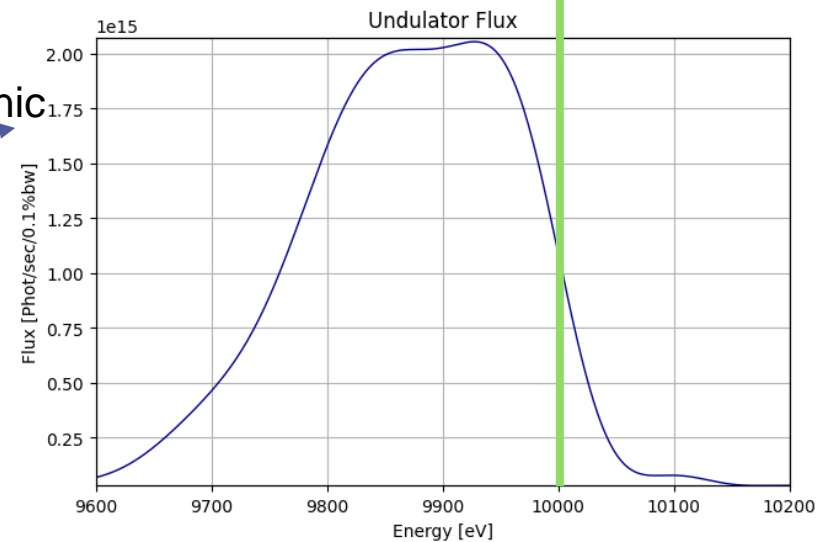
Gaussian undulator

Undulator radiation emission



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

Gaussian emission approximation

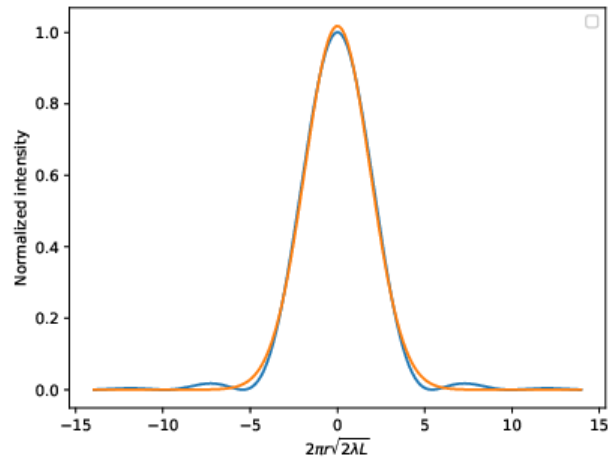


Resonance energy @10 keV

Gaussian approximation

SHADOW4: Elleaume's approach [1]

Source size

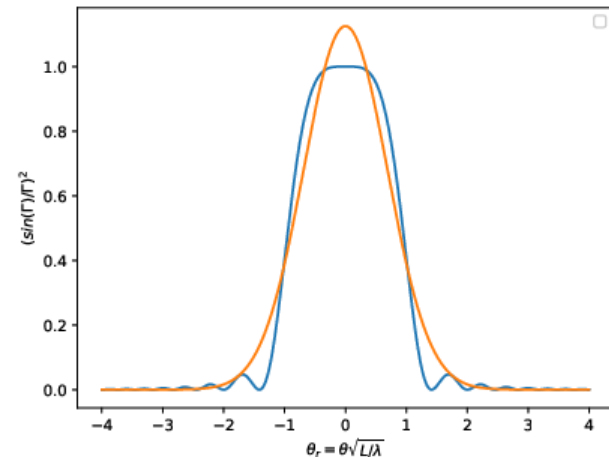


$$\sigma_r = \frac{2.740}{4\pi} \sqrt{\lambda L}$$

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

λ : photon wavelength, L : undulator length

Source divergence



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

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

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

Electron beam energy spread

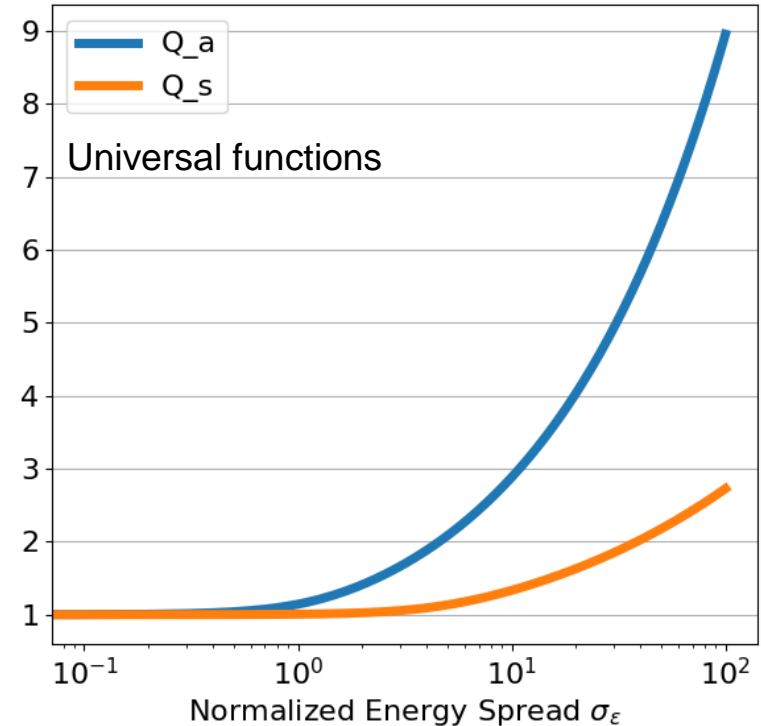
Electron beams do not have exactly the same energy ($\delta_\epsilon \neq 0$).

SHADOW4: Tanaka and Kitamura approach [2]

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

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

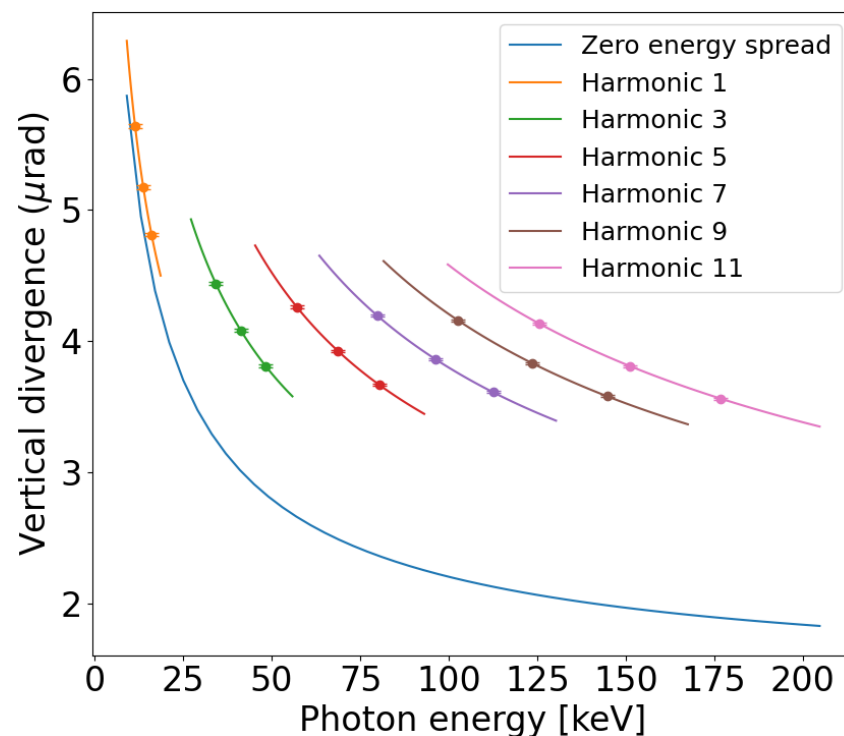
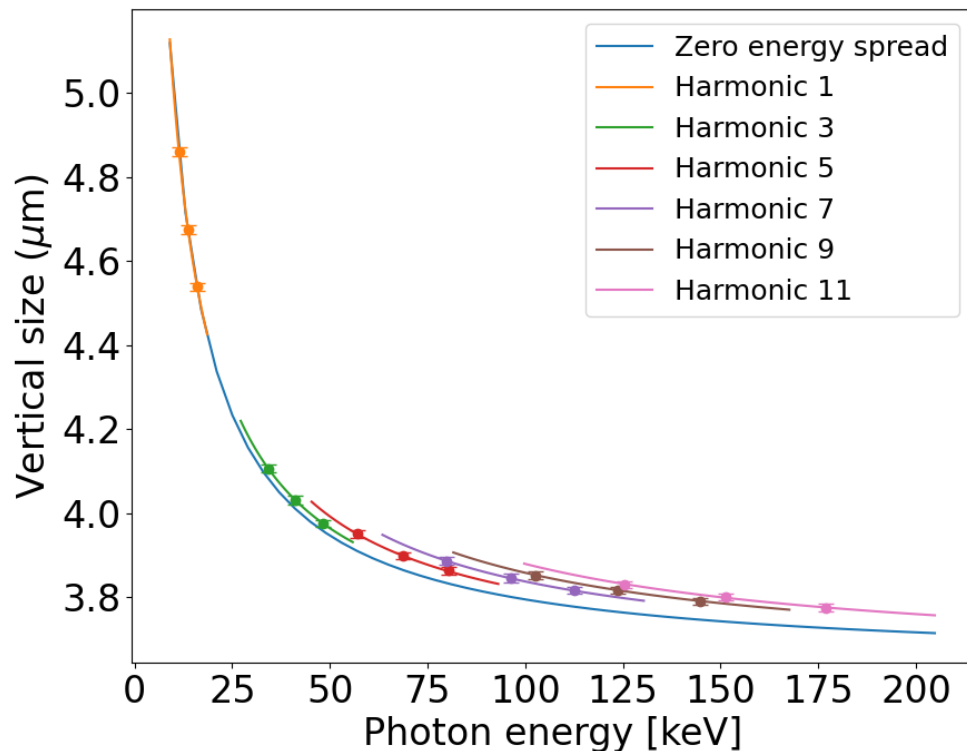
$$\sigma_\epsilon = 2\pi n N \delta_\epsilon$$



[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

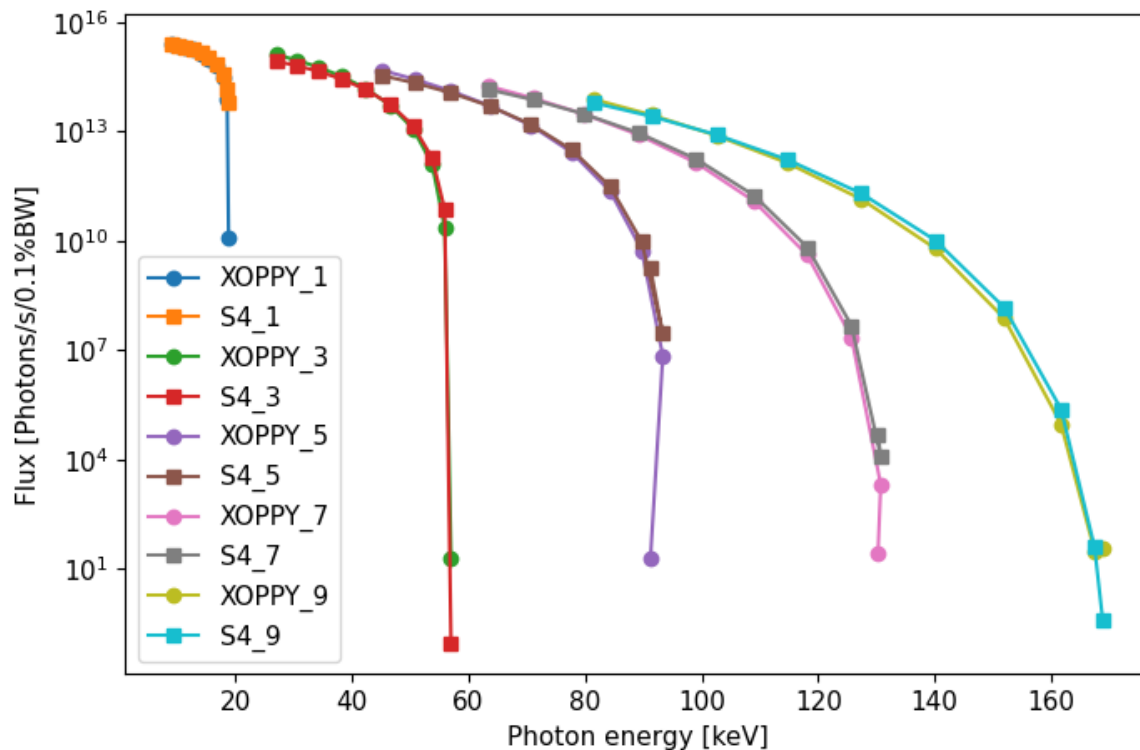
U18 – 2 m

- SHADOW4 Gaussian undulator

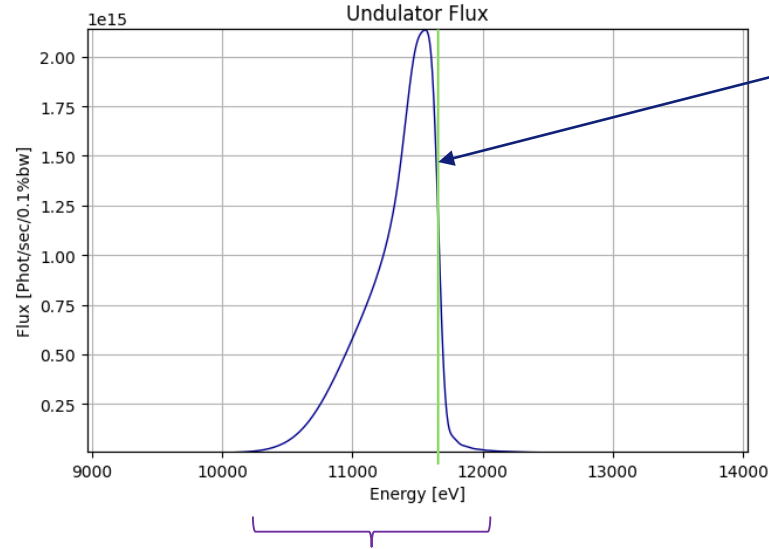
Example2: Photon flux (Tuning curves)

SHADOW4:
Gaussian
undulator

XOPPY: SRW



Undulator: far field emission

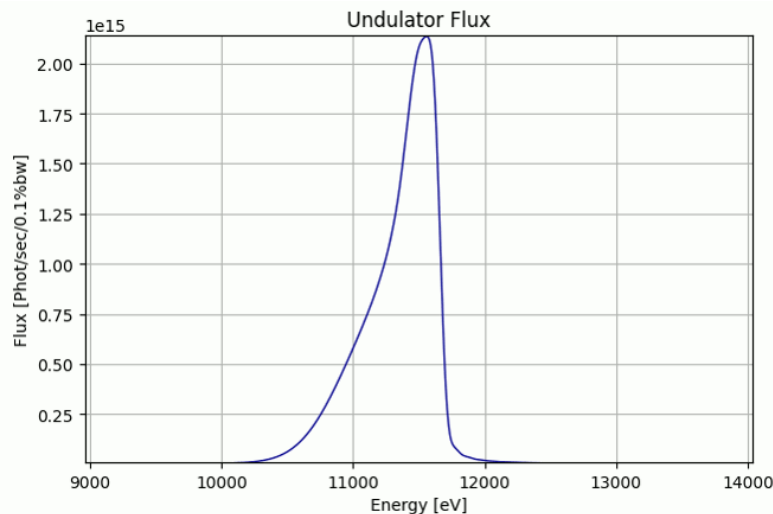


Gaussian emission approximation:
On-resonance

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

Undulator: far field emission

1st harmonic
SRW

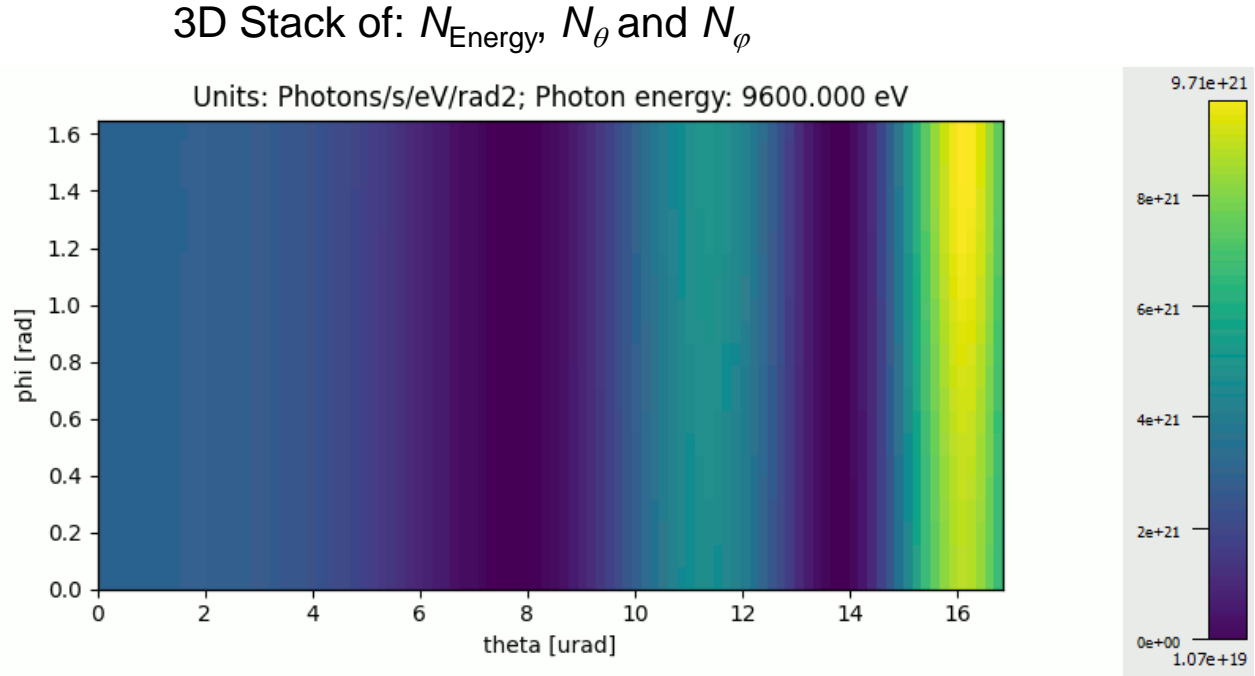
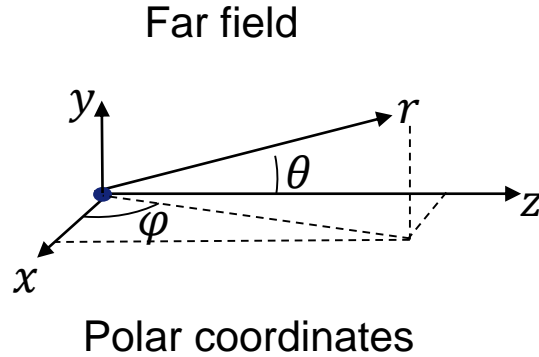


Undulator emission

-U16.4

-Slit @ 31.5 m (2 mm x 1 mm)

Shadow4 undulator: model algorithm



Source size
&
divergence



2D integral
back-propagator



Points into Cartesian coordinates (x, y)

Intensity and Polarization
&

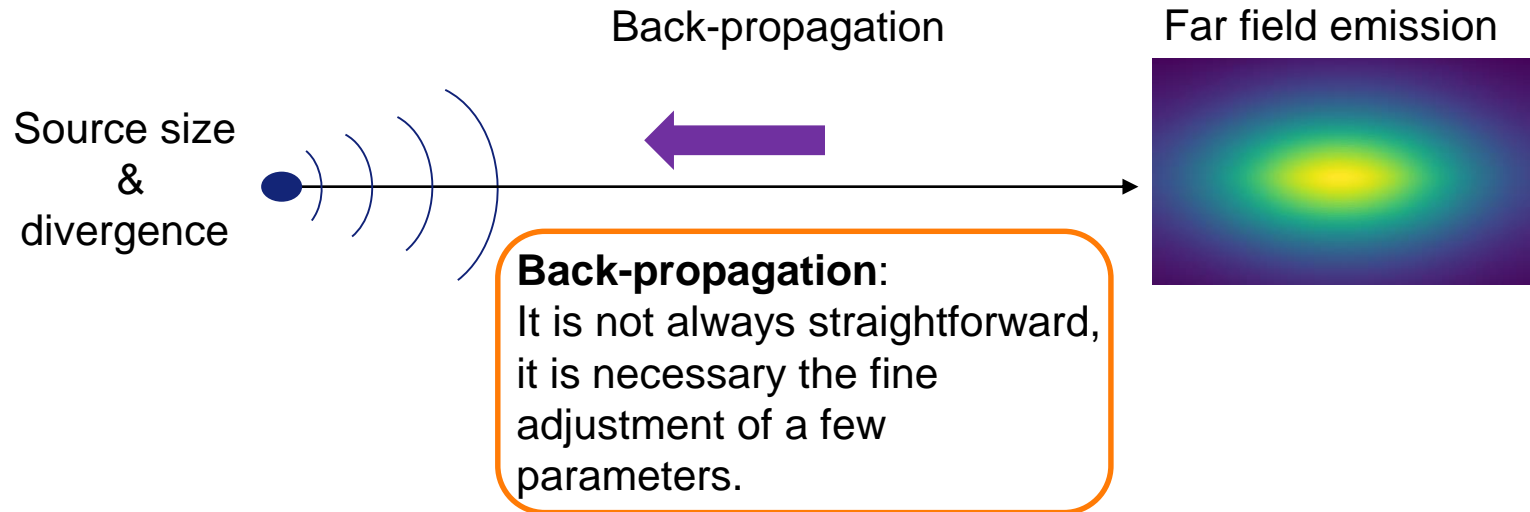


Shadow4 undulator: model algorithm

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)**

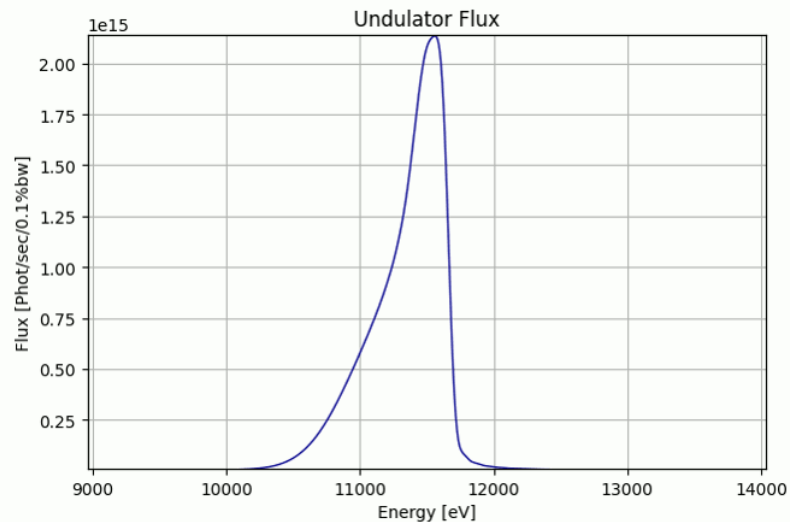


[4] O. Chubar & P. Elleaume, Proceedings of the 6th European Particle Accelerator Conference - EPAC-98, pp. 1177–1179

[5] S. Thery et al. <https://www.github.com/oasys-kit/pySRU>.

Shadow4 undulator: far field emission

1st harmonic

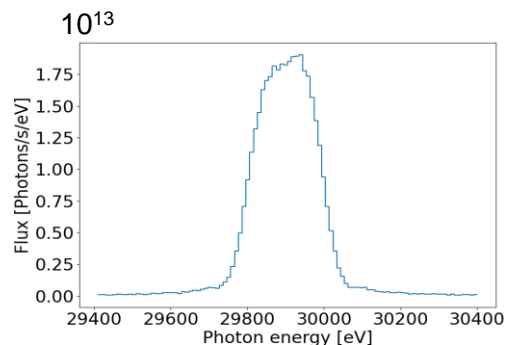
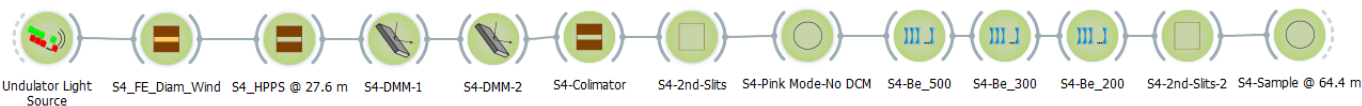


Undulator emission

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

*Internal

Shadow4 undulator: polychromatic



- Monochromatic source + energy loop

N runs



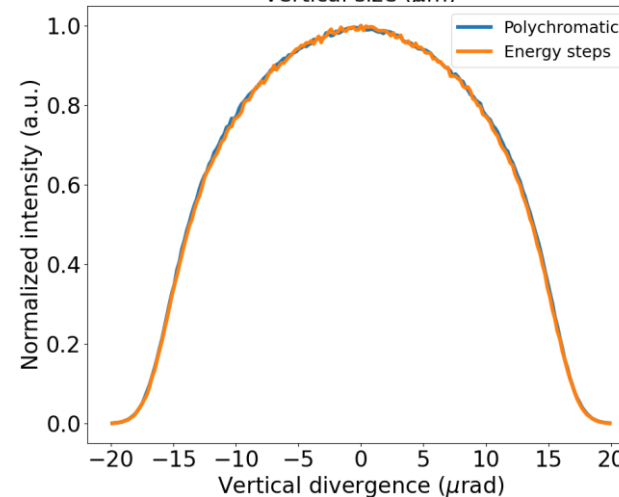
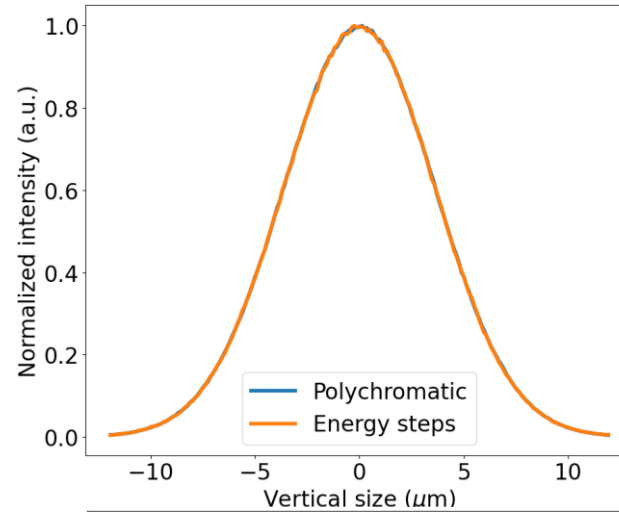
- Polychromatic source + single run

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



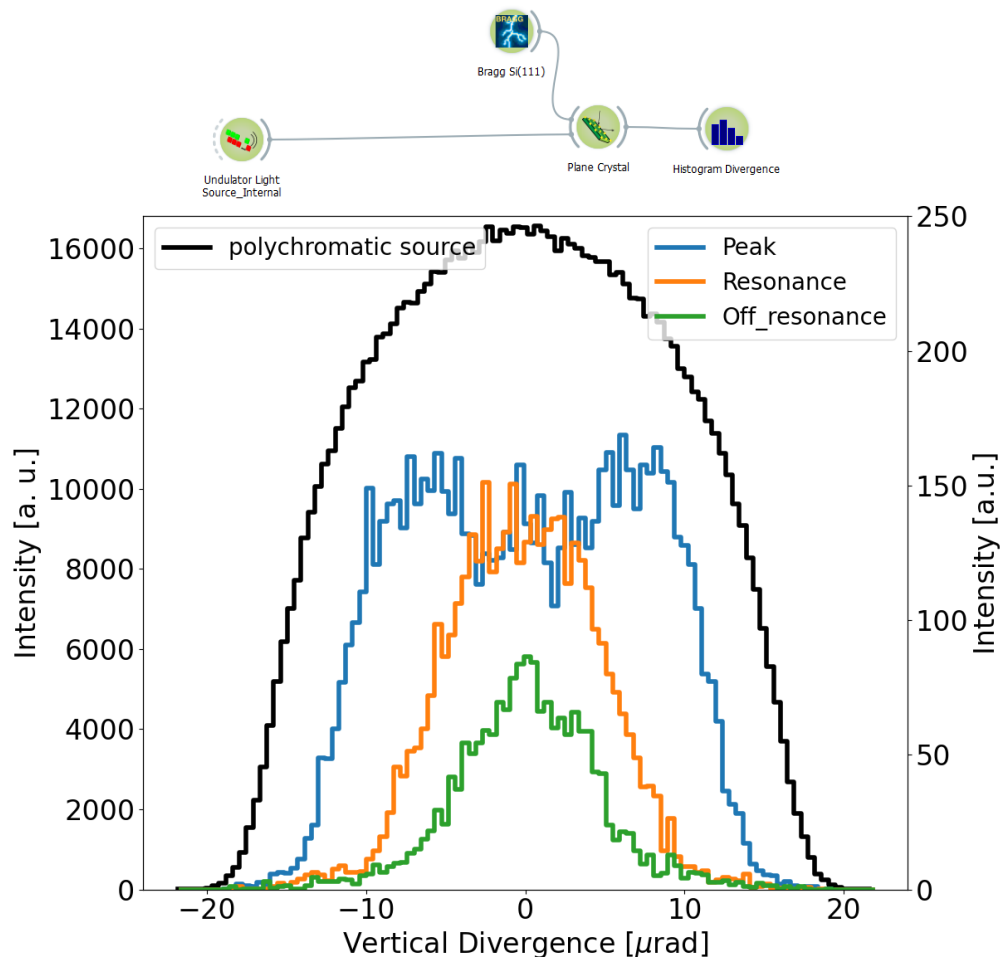
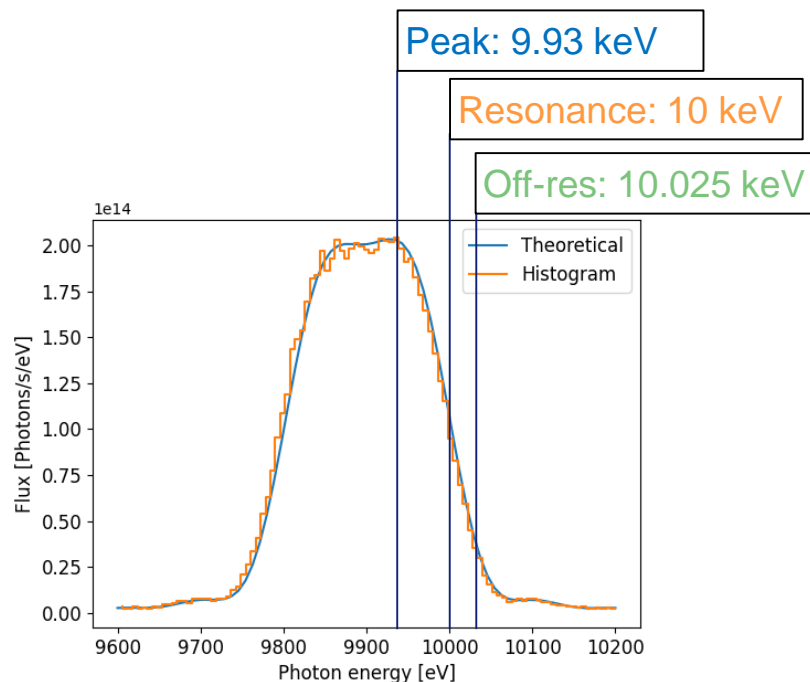
U18 – 2 m

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

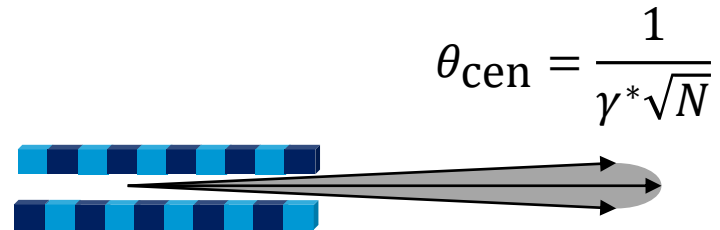
Thank you for your attention!

Download these slides:

Extra slides

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.

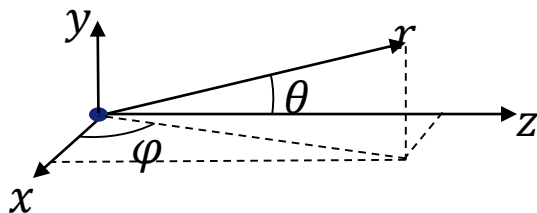
[3] *X-ray Data Booklet*. Thompson, Lawrence Berkeley National Laboratory, Univ. of California.

Full model undulator algorithm

Far field

D. Jackson:

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



3D Stack of:

- N -Energy
- N_{θ}
- N_{φ}



Intensity
&
Polarization

Source size
&
divergence

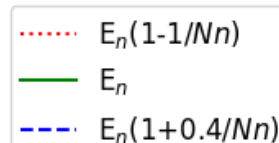
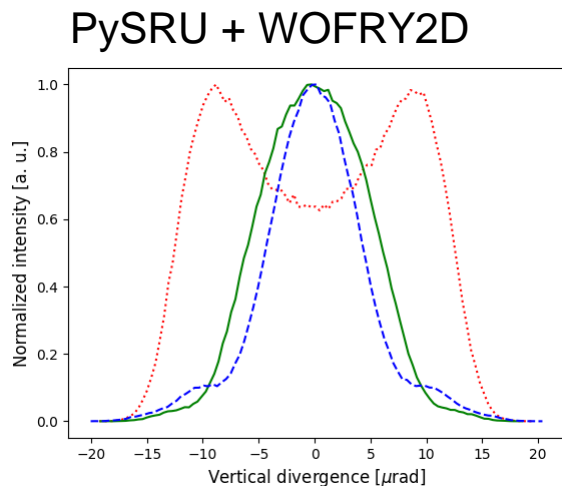
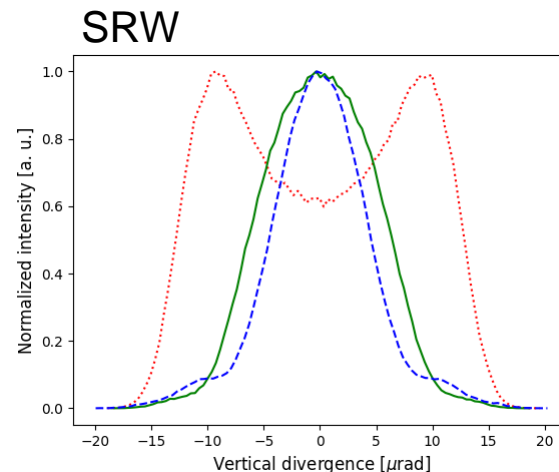
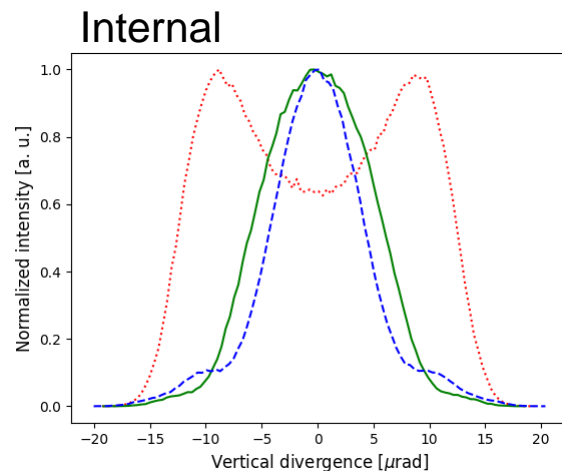
Back-propagation



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

Full model undulator - monochromatic

U18
Off-resonance



SHADOW4: Gaussian undulator



Undulator Gaussian

Run shadow4/source

Reset Fields

Electron Beam Setting

Undulator Setting

Advanced Setting

Flux normalization

Auto calculate central cone flux

Yes

Specific parameters for undulator plots

Number of energy points

50

Minimum K

0.2

Maximum K

1.341095

Maximum harmonic number

1

Plots

Undulator Plots

Output

Script

Python script

```
# electron beam
from shadow4.sources.s4_electron_beam import S4ElectronBeam
electron_beam = S4ElectronBeam(energy_in_GeV=6,energy_spread=0.001,current=0.2)
electron_beam.set_sigmas_all(sigma_x=3.01836e-05, sigma_y=3.63641e-06, sigma_xp=4.36821e-06,
sigma_yp=1.37498e-06)

# magnetic structure
from shadow4.sources.undulator.s4_undulator_gaussian import S4UndulatorGaussian
source = S4UndulatorGaussian(
    period_length = 0.018, # syned Undulator parameter (length in m)
    number_of_periods = 111.111, # syned Undulator parameter
    photon_energy = 10000.0, # Photon energy (in eV)
    delta_e = 0.0, # Photon energy width (in eV)
    ng_e = 50, # Photon energy scan number of points
    flag_emittance = 1, # when sampling rays: Use emittance (0=No, 1=Yes)
    flag_energy_spread = 0, # when sampling rays: Use e- energy spread (0=No, 1=Yes)
    harmonic_number = 1, # harmonic number
    flag_autoset_flux_central_cone = 1, # value to set the flux peak
    flux_central_cone = 2271218432011813.5, # value to set the flux peak
)

# light source
from shadow4.sources.undulator.s4_undulator_gaussian_light_source import
```

Python 3.8.5 (default, Sep 3 2020, 21:29:09) [MSC v.1916 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
(PythonConsole)
>>>

Run Script

Save Script to File