WOFRY: a package for partially coherent beamline simulations in fourth-generation storage rings

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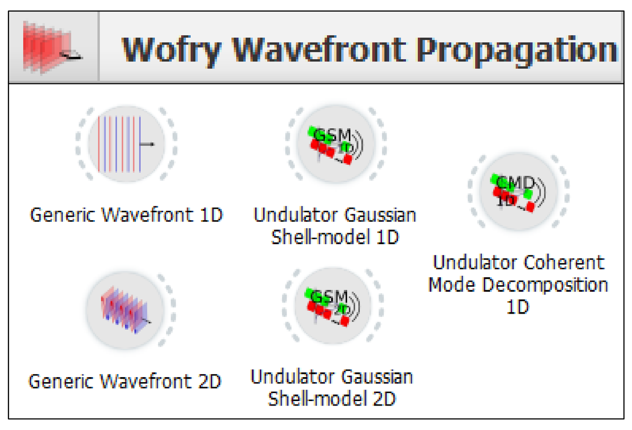
A new fast and lightweight wavefront simulation package is presented. It creates a wavefront (1D or 2D), propagates it in free space, and modifies it by optical elements (slits, lenses, mirrors, etc.). It simulates partial coherence of undulator radiation using a novel quick and fast coherent mode decomposition for 1D wavefronts. Real lenses and CRL are simulated including surface errors and misalignments. Mirrors are implemented in 1D also allowing customized aspherical profiles and surface errors.

Main features

- Prototype a synchrotron beamline using wave-optics methods
- Quick and fast to be run in a laptop
- Powerful interface (OASYS addon)
- Allow fast calculation of partial coherence (including coherent fraction along the beamline)
- Model accurately the effects of the surface errors (in lenses and mirrors)
- Automatic generation of python scripts (*wofryimpl* package)

Sources



- Generic sources (in 1D and 2D):

  - Plane
  - Spherical (diverging or collapsing)
  - Gaussian with an electric field distribution in space that follows a Gaussian function
  - Gaussian Shell-model (GSM) It extends the concept of Gaussian beams to partially coherent light with a well defined "double Gaussian" Cross Spectral Density. These models are available in both 1D and 2D.

  -1D Coherent mode decomposition for undulator emission [1]
  The GSM fails to reproduce correctly the emission angles and sizes and the coherent fraction. A numeric coherent mode requires supercomputers. We provide a light 1D model that runs in a laptop and is able to compute accurately the coherent fraction at the source and along the beamline.

Free-space propagators

- Fresnel propagator using FFT (zoom propagator)

$$E(x;y_1) = P^G\mathcal{F}^{-1}\{\mathcal{F}\{E\,P\}K\},$$

where

$$P^G = \frac{\exp(ik(y_1-y_0))}{\sqrt{m_x}}\exp\left(i\frac{k}{2(y_1-y_0)}\frac{m_x-1}{m_x}x_2^2\right),$$

$$P = \exp\left(i\frac{k}{2(y_1-y_0)}(1-m_x)x_1^2\right),$$

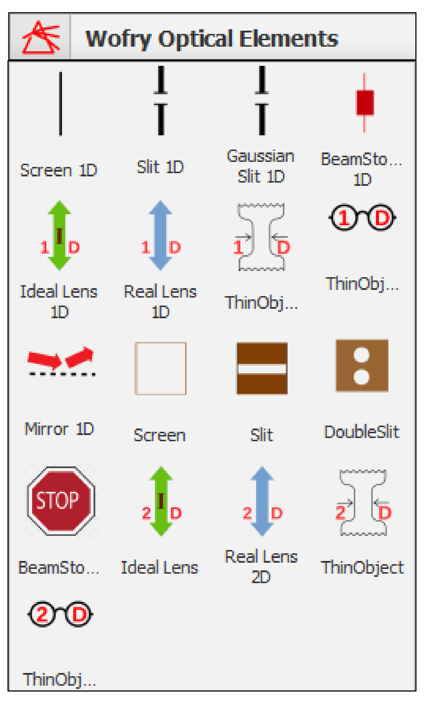
$$K = \exp(-i\pi\lambda(y_1-y_0))\frac{u^2}{m_x}.$$

- Direct implementation of integral Rayleigh-Sommerfeld propagator

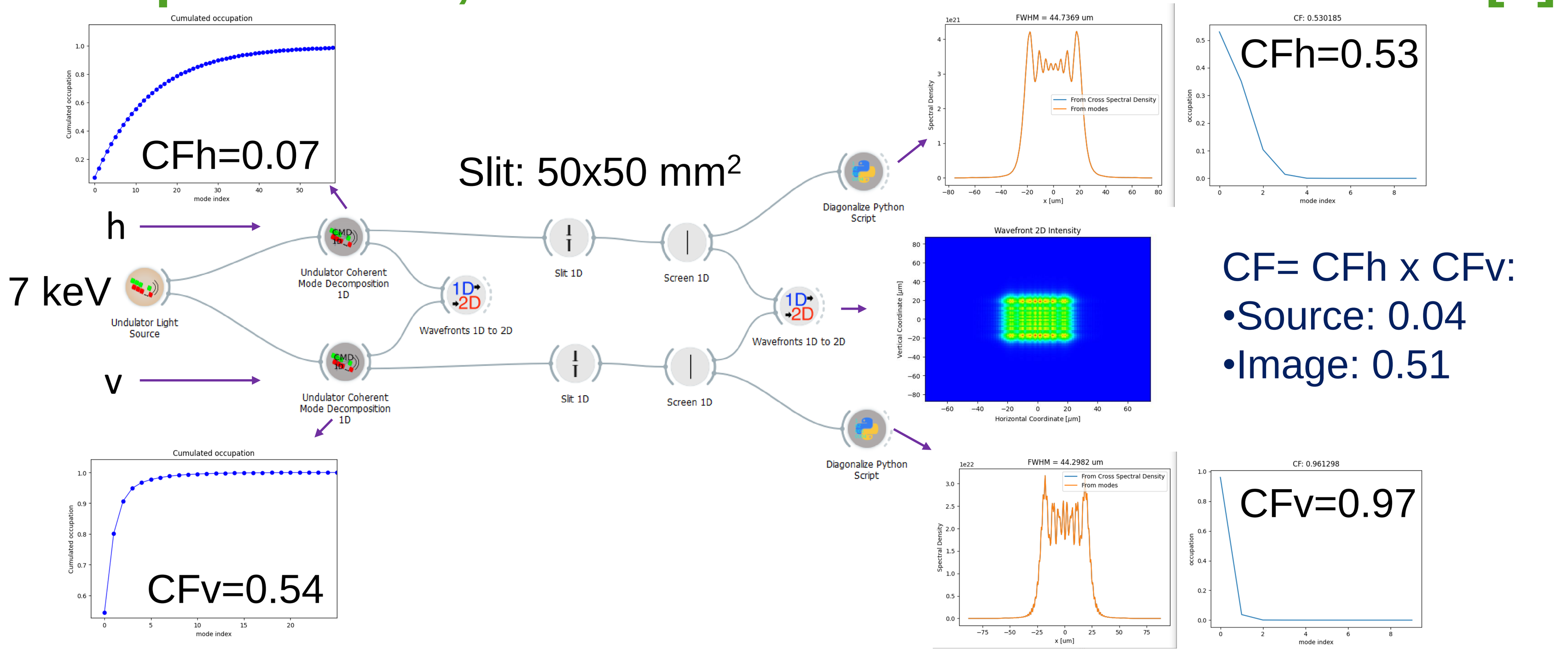
$$E(x_1,y_1) \approx \frac{k}{2\pi i \Delta y}\sum_{i=0}^{N-1} E(x_0,i,y_0,i)\, e^{ik\sqrt{(x_1-x_{0,i})^2+(y_1-y_{0,i})^2}}\Delta x_0$$

Optical elements

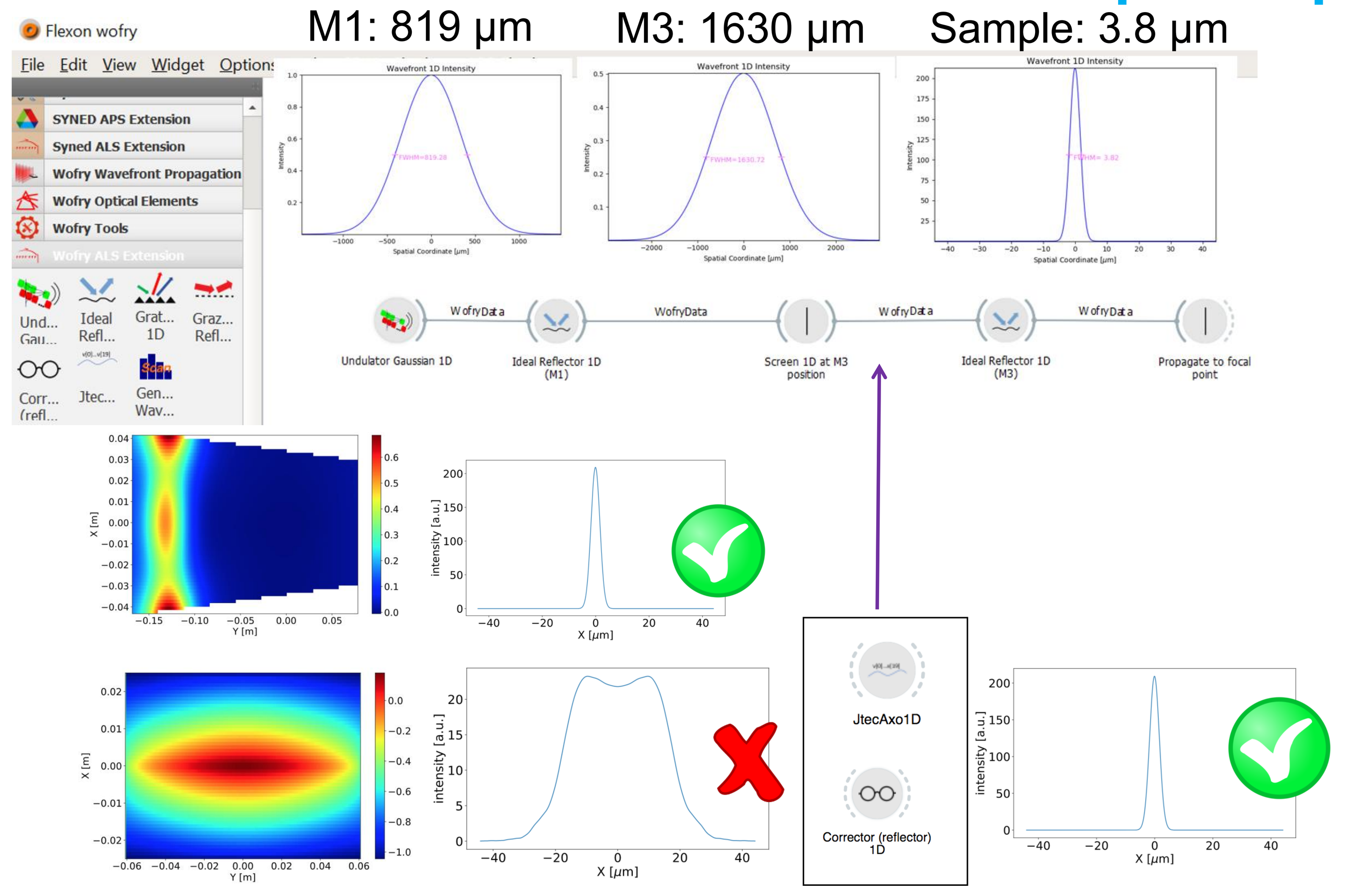
- Screens
- Slits and Stops
- Ideal lenses
- Real lenses (and CRLs) with misalignments and errors
- Mirrors 1D (any profile, grazing incidence)



Example 1: CMD, Coherent fraction & coherence slits [1]



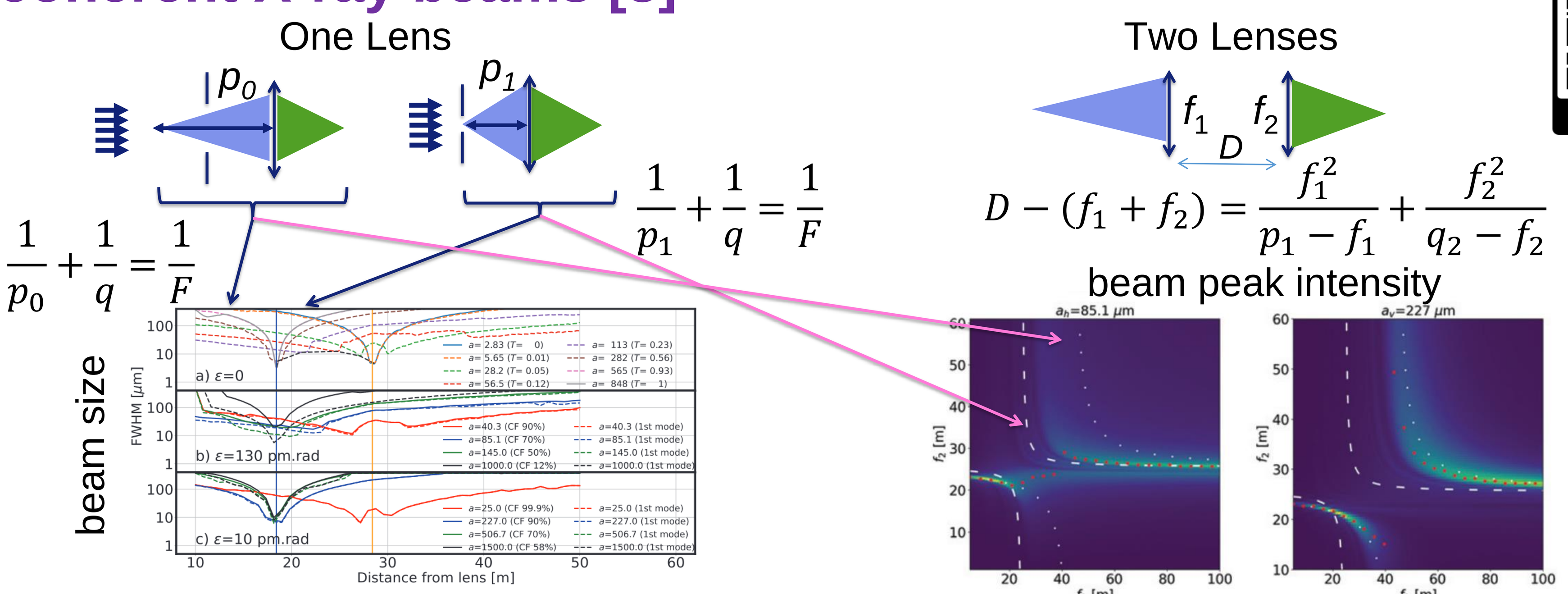
Example 2: Correction of thermal errors with adaptive optics at ALS [2]



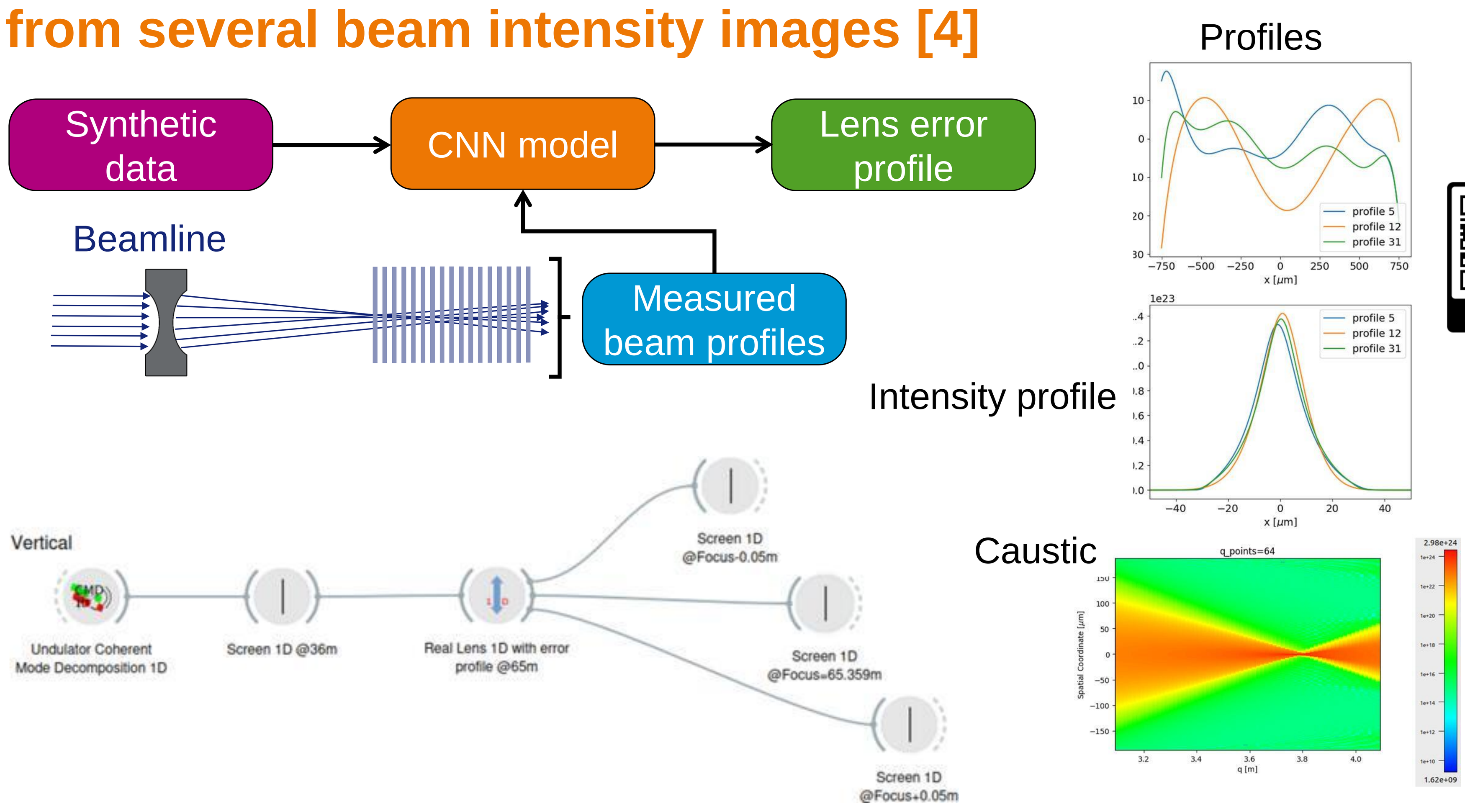
LN_2 cooling
Cutler et al.
https://doi.org/10.1117/12.2568101

Water cooling

Example 3: Beam focus modifications by cropping partially coherent X-ray beams [3]



Example 4: X-ray lens figure errors retrieved by deep learning from several beam intensity images [4]



[1] Sanchez del Rio, M., Celestre, R., Reyes-Herrera, J., Brumund, P. & Cammarata, M. (2022). A fast and lightweight tool for partially coherent beamline simulations in fourth-generation storage rings based on coherent mode decomposition. J. Synchrotron Rad. 29, 1354â€367. https://doi.org/10.1107/S1600577522008736
[2] Sanchez del Rio, M., Wojdyla, A., Goldberg, K. A., Cutler, G. D., Cocco, D. & Padmore, H. A. (2020). Compensation of heat load deformations using adaptive optics for the ALS upgrade: a wave optics study. J. Synchrotron Rad. 27, 1141-1152. https://doi.org/10.1107/S1600577520009522
[3] Sanchez del Rio, M., Celestre, R., Reyes-Herrera, J., Brumund, P. & Cammarata, M. (2022). Beam focus modifications by cropping partially coherent X-ray beams, EPL 140 5 https://doi.org/10.1209/0295-5075/aca4ef
[4] Sanchez del Rio, M., Celestre, R. & Reyes-Herrera, J. (2024). X-ray lens figure errors retrieved by deep learning from several beam intensity images. J. Synchrotron Rad. 31 https://doi.org/10.1107/S1600577524004958