

# FOCUS documentation

## (version 1.0)

### Introduction

*“Fast Monte Carlo approach to Coherence of Undulator Sources” (FOCUS)* is a GPU-based computer code for calculation of the transverse coherence properties of undulator X-ray radiation generated by ultra-relativistic electrons in an undulator device.

The code relies on scaled dimensionless quantities and analytic expressions for the emitted electric fields obtained with a Fourier optics approach to classical relativistic electrodynamics. In particular, the slowly varying amplitude of the electric field in the space-frequency domain is obtained by solving paraxial Maxwell equations in free space with the help of a parabolic Green’s function, in addition with the resonance approximation. Disregarding optical surface imperfections, the method can be adapted to imaging geometries as well, simply by looking at conjugate planes with the proper magnification factor.

*FOCUS* is written in C++, accelerated with CUDA to harness the compute capabilities of modern GPUs. The main aim of the code is to enable fast and accurate evaluation of the transverse coherence properties of undulator X-ray radiation as a function of the electron beam parameters.

*FOCUS* is freely available from the official homepage at the website of the Instrumental Optics Group of the Physics Department at Università degli Studi di Milano<sup>1</sup>. The source code is also freely available from the GitHub page of the corresponding author<sup>2</sup>.

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<sup>1</sup> <https://instrumentaloptics.fisica.unimi.it/focus/>

<sup>2</sup> <https://github.com/MirkoSiano/FOCUS>

## Prerequisites (required dependencies)

*FOCUS* natively runs on GPUs via CUDA, therefore a platform with a CUDA-capable NVIDIA graphic card is required. The CUDA Toolkit from NVIDIA must also be installed. Detailed installation instructions for the CUDA Toolkit on Windows platforms can be found on the official NVIDIA website<sup>3</sup>. For Linux users, it is preferred to refer to the official documentation from the package manager of the installed distribution.

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<sup>3</sup> <https://docs.nvidia.com/cuda/cuda-installation-guide-microsoft-windows/index.html>

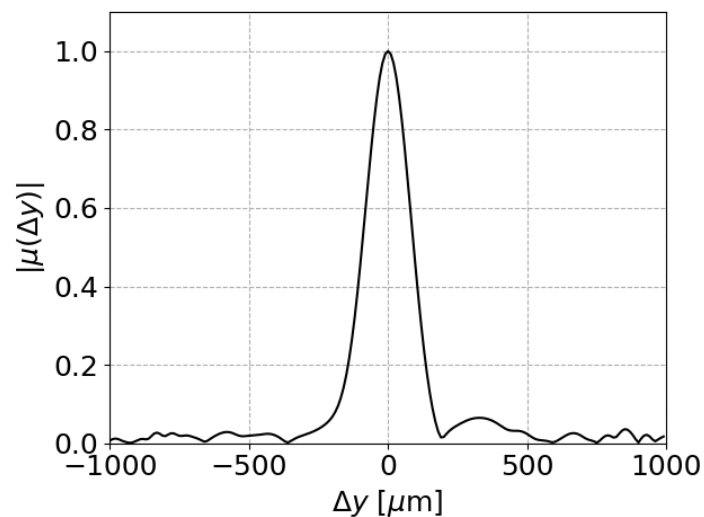
## Running pre-compiled executables (Windows only)

Pre-compiled executables are provided on the FOCUS homepage as a zipped archive. The content of the archive, with a brief description of each item, is listed in the following table.

<i>FOCUS_Example01.exe</i>	It computes the 1D profiles (either horizontal or vertical) of the Spectral Degree of Coherence, sampling the electron beam phase space by an internal method relying on random number generators.  It can be run directly from a command prompt by typing: <i>"FOCUS_Example01.exe"</i>
<i>FOCUS_Example02.exe</i>	It computes the 1D profiles (either horizontal or vertical) of the Spectral Degree of Coherence, reading the electron beam phase space from a user-supplied file.  It can be run directly from a command prompt by typing: <i>"FOCUS_Example02.exe name_of_phase_space_file.txt"</i>
<i>__configElectronBeam.txt</i>	Configuration file for the electron beam (see dedicated section for details).
<i>__configUndulator.txt</i>	Configuration file for the undulator device (see dedicated section for details).
<i>__configObserver.txt</i>	Configuration file for the observer (see dedicated section for details).
<i>phaseSpace_example_1e4_part.txt</i>	Example of user-supplied phase space file, with $10^4$ electrons.

**Note on the external phase space file formatting.** *FOCUS* assumes that the external phase space file supplied by the user to *FOCUS\_Example02.exe* is formatted as different rows with 5 entries. Each row corresponds to a different electron, and the 5 entries describe the horizontal position, horizontal deflection angle, vertical position, vertical deflection angle, and relative energy deviation of the electron, respectively. Positions and angles are expressed in m and rad, respectively. Notice that an internal conversion to  $\mu\text{m}$  and  $\mu\text{rad}$  is automatically performed during the simulation.

As an example, running *FOCUS\_Example02.exe* with the supplied *phaseSpace\_example\_1e4\_part.txt* and default values for the configuration files (see dedicated section) should produce the following result:



## Compile the source code (Windows and Linux)

The full source code of *FOCUS* can be found on GitHub. To compile it, follow the instructions reported below.

First, make sure to satisfy all prerequisites. Then, clone or download the *FOCUS* Git repository onto a local machine.

**On Windows.** Download and install the *make* utility from the *GnuWin* project homepage<sup>4</sup>. Then open a command prompt inside the *FOCUS* folder and type “*make all*”. This will compile the *FOCUS* class, the *FOCUS* kernels, and the source code of all examples, linking them into executable files. To run the examples, simply write the name of the corresponding executable in the command prompt.

**On Linux.** Install the *make* utility from the package manager of the installed distribution. Open the *makefile* provided within the *FOCUS* folder with a text editor. Change the suffix “.obj” in all object files into “.o”, and the suffix “.exe” in all executable files into “.x”, and save. Then open a terminal inside the *FOCUS* folder and type “*make all*”. This will compile the *FOCUS* class, the *FOCUS* kernels, and the source code of all examples, linking them into executable files. To run the examples, simply write the name of the corresponding executable in the terminal.

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<sup>4</sup> <http://gnuwin32.sourceforge.net/packages/make.htm>

## How to use the configuration files

All parameters required to run a *FOCUS* simulation are contained in three configuration files:

- `__configElectronBeam.txt`, with all parameters strictly related to the electron beam
- `__configUndulator.txt`, with all parameters strictly related to the undulator device
- `__configObserver.txt`, with all parameters strictly related to the observer

**Do not modify the name of these files, as they are automatically searched for by the *FOCUS* class.**

Each file has two columns. The first column reports text labels for the input quantities, with an indication of units where needed. The second column is where the user can change and set the values of the corresponding input parameters.

**Do not change any of the label in the first column nor the order of the parameters, as this would result in unwanted and unpredictable behaviors.**

A detailed list of the parameters in each configuration file is provided hereafter, alongside with default values describing to the NCD-SWEET beamline at ALBA<sup>56</sup>.

### `__configElectronBeam.txt`

- `SIGMAX_[um]`: horizontal beam size (rms) at the undulator center, in  $\mu\text{m}$ . Default values is 130  $\mu\text{m}$ .
- `SIGMAXP_[urad]`: horizontal beam divergence (rms) at the undulator center, in  $\mu\text{rad}$ . Default value is 48  $\mu\text{rad}$ .
- `SIGMAY_[um]`: vertical beam size (rms) at the undulator center, in  $\mu\text{m}$ . Default values is 6  $\mu\text{m}$ .
- `SIGMAYP_[urad]`: vertical beam divergence (rms) at the undulator center, in  $\mu\text{rad}$ . Default value is 5  $\mu\text{rad}$ .
- `ENERGY_SPREAD`: energy spread of the electron beam. Default value is  $1.05 \cdot 10^{-3}$ .
- `NMC`: number of electrons in the beam. Default value is  $10^6$ .

### `__configUndulator.txt`

- `GAMMA`: Lorentz relativistic factor (nominal or average value) of the electron beam. Default value is roughly 6000.
- `K`: undulator strength parameters. Default value is roughly 1.56.
- `PERIOD_NUM`: undulator number of periods. Default values is 92.
- `PERIOD_LENGTH_[mm]`: undulator period length, in mm. Default value is 21.6.
- `HARMONIC`: harmonic number of the undulator radiation. Default value is 7.

### `__configObserver.txt`

- `MESH_SIZE`: mesh size, in pixels. Default value is 200.
- `PIXEL_SIZE_[um]`: pixel size (i.e. mesh resolution), in  $\mu\text{m}$ . Default value is 10.0.
- `Z_[m]`: distance of the observation plane from the undulator center, in m. Default value is 33 m.
- `LAMBDA_OBS_[nm]`: observed radiation wavelength, in nm. Notice that it can be different from the wavelength of the undulator harmonic (detuned conditions). To ensure perfect resonance with the undulator harmonic, insert a negative value. Default value is -0.1 nm.
- `PLANE`: choose between horizontal or vertical coherence. Only HOR and VER values are allowed. HOR will compute the transverse coherence properties along the horizontal direction, while VER will compute the transverse coherence properties along the vertical direction. Default value is VER.

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<sup>5</sup> <https://www.cells.es/en/beamlines/bl11-ncd>

<sup>6</sup> <https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.25.052801>

- REFERENCE\_POINT: choose the reference point that is fixed. Only OBS\_POINT and MID\_POINT values are allowed. OBS\_POINT keeps  $\vec{x}_1$  fixed, and only  $\vec{x}_2$  is moved. This corresponds to a Young double-pinhole experiment where the first aperture is fixed, and the second one changes position. MID\_POINT keeps the midpoint  $(\vec{x}_1 + \vec{x}_2)/2$  fixed, and  $\vec{x}_1$  and  $\vec{x}_2$  are moved symmetrically with respect to it. This corresponds to a Young double-pinhole experiment where the two apertures are moved symmetrically with respect to a reference point. Default value is OBS\_POINT.
- XO\_[um]: horizontal coordinate of the reference point, in  $\mu\text{m}$ . Default value is 0  $\mu\text{m}$ .
- YO\_[um]: vertical coordinate of the reference point, in  $\mu\text{m}$ . Default value is 0  $\mu\text{m}$ .