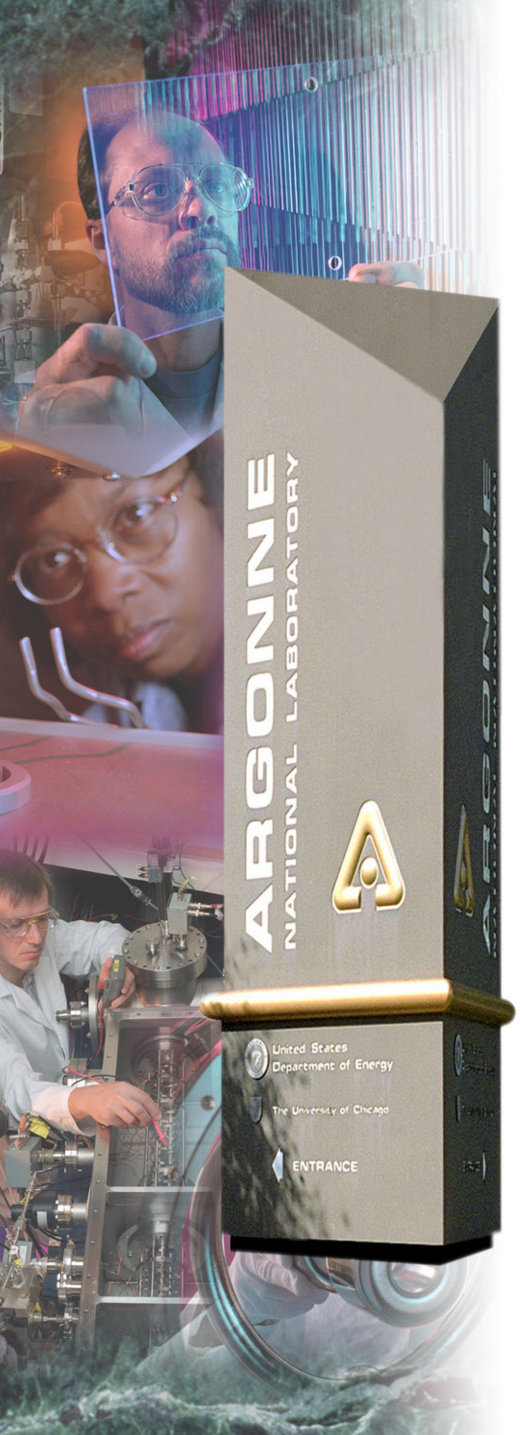

Calculation of X-ray parameters

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Radiation from a moving charge

- Expression for electric field is derived in textbooks. The energy radiated per unit solid angle per unit frequency by a single electron is given by the Fourier Transform:

$$\frac{d^2 I}{d\omega\, d\Omega} = \frac{c}{4\pi^2} \left| \int_{-\infty}^{\infty} R\, E(t)\, e^{i\omega t} dt \right|^2$$

- Substituting electric field and assuming far field approximation:

$$\frac{d^2 I}{d\omega\, d\Omega} = \frac{e^2 \omega^2}{4\pi^2 c} \left| \int_0^T n \times (n \times \beta)\, e^{i\omega(t - n \cdot r / c)} dt \right|^2$$

Radiation from an undulator

- The radiation intensity in the case of an ideal sinusoidal trajectory and on-axis is given by the following:

$$\frac{d^2 I}{d\omega \, d\Omega} = \frac{e^2 \gamma^2 N^2}{c} L(N\Delta\omega / \omega(\theta)) \, F_n(K)$$

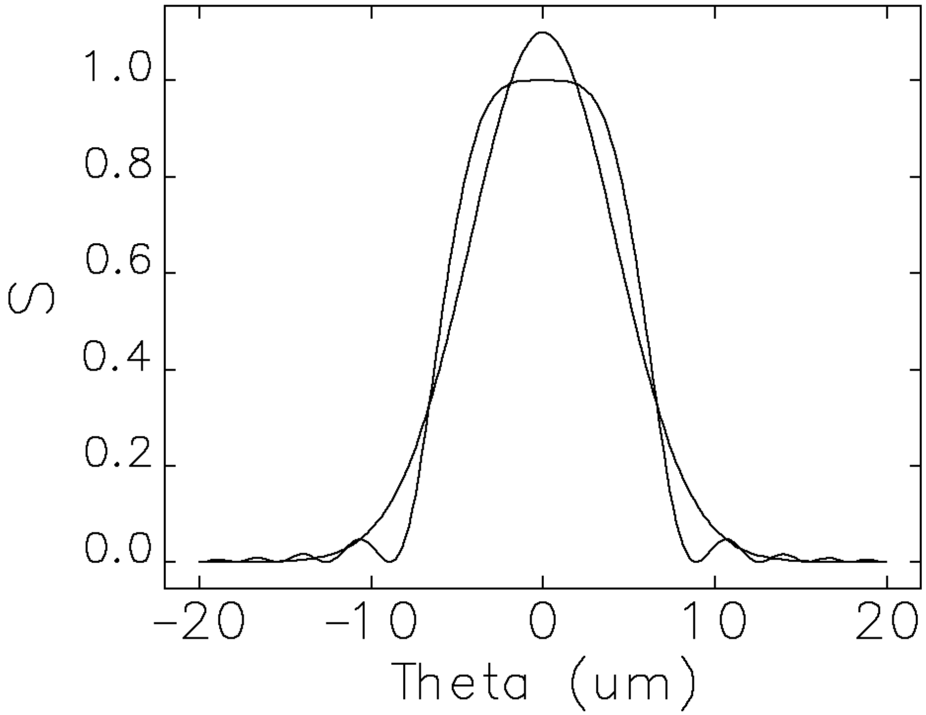
where L is periodic lineshape function (sometimes called grating function) and F is on-axis angular flux density function

Brightness including electron beam emittance

- It may be shown that for electron passing through an undulator at an angle, the radiation pattern is shifted by the same angle
- The irradiance distribution at a screen located at distance from the source is then given by the convolution of the radiation brightness and electron beam distribution function
- To get analytic expression for brightness, one assumes the angular distribution function to be gaussian, then the effective divergence of the source is easy to calculate:

$$\sigma'_x = \sqrt{\sigma'^2_x + \sigma'^2_R} \qquad \sigma'_y = \sqrt{\sigma'^2_y + \sigma'^2_R}$$

Angular distribution function compared to a gaussian fit



Practical computation of radiation spectra

- Various computer programs exist that calculate the spectral and angular distribution of undulator radiation using different approaches
  - Direct integration of field expression
  - Use of analytic approximation for a pure sinusoidal field involving series of Bessel functions
- Analytical codes are useful for rapid calculation of the main effects in far field approximation

Software we use to calculate radiation

- sddsurgent – sdds compliant version of program URGENT by R. Walker
  - calculates flux, spectrum in various approximations
- sddsbrightness – program for calculating brightness curves
  - on-axis brightness for different K values of an undulator

- Both programs use analytic approach

- sddsurgent and sddsbrightness are part of extensive sdds toolkit

sddsurgent

- Takes the following input parameters:
  - Undulator parameters
  - Beam parameters in the middle of the undulator
  - Observation point parameters – distance, coordinates, acceptance
- Can calculate zero or non-zero emittance approximation
- Provides the following output:
  - Angular and spatial flux distribution
  - Spectrum of flux density at position of observation
  - On-axis brightness
  - etc

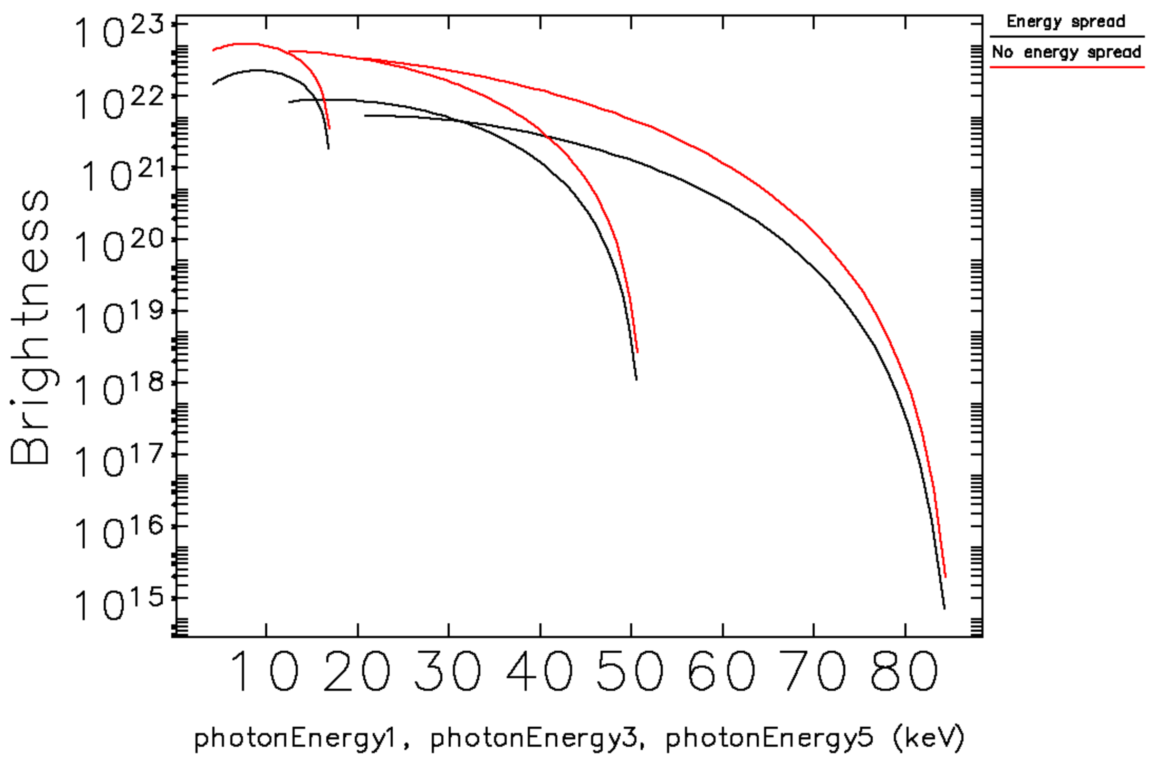
sddsbrightness

- Takes the following input parameters
  - Undulator parameters
  - Beam parameters from elegant twiss file

- Provides the following output
  - On-axis brightness curves for different harmonics

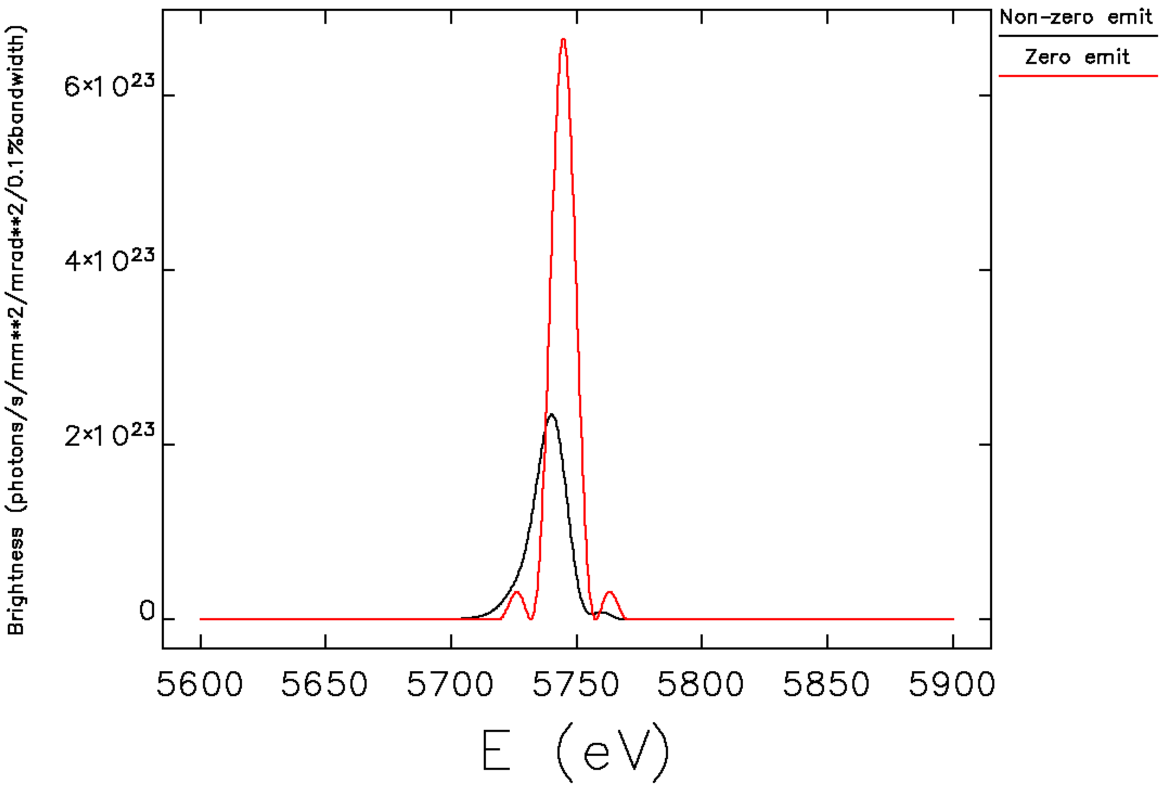
Energy spread effect on on-axis brightness

- sddsbrightness simulations for XPS7:



Emittance effect on radiation spectrum

- sddsurgent simulation for XPS7:



Simple analytical expression for brightness in not enough

- For extremely small beams and long undulators that will be provided in ERLs and next generation storage rings, precise calculation of radiation parameters is important
- Simple analytical expressions could lead to significant errors in brightness calculations
- Programs calculating brightness should be integrated into the optimization process
- It can be done using SDDS toolkit

SDDS

- SDDS = Self-Describing Data Sets
  - A file protocol for data storage
  - A toolkit of programs that transform such files
  - A set of libraries for working with such files
- Unix-inspired toolkit approach
  - In UNIX "Everything is a file"
  - Programs are "filters" that transform files
  - Using pipes allows composing new filters from a sequence of existing filters
- We do the same thing using SDDS data files
  - sdds programs are operators that transform data
  - Using pipes allows concatenating operators to make a complex transformation

Why use SDDS files

- Programs that use SDDS are robust and flexible
  - Check existence, data-type, units of data instead of crashing or doing an incorrect calculation
  - Respond appropriately to the data provided
    - *Exit and warn user if required data is missing, has unknown units, etc.*
    - *Supply defaults for missing data (e.g., old data set)*
- Existing data doesn't become obsolete when the program is upgraded
- Self describing files make generic toolkits possible, which saves effort on writing pre- and post-processor
- Using of SDDS files increase productivity by letting programs interface smoothly

elegant

- **Elegant is a very complex SDDS “ operator.” E.g., it**
  - Transforms phase space from beginning to end of a system
  - Transforms magnet parameters into, e.g., Twiss parameters, tunes
- **All input to and output from elegant is in SDDS files except**
  - Lattice structure: lattice file is MAD-like
  - Command stream: command file is namelist-like

elegant: quality control

- Elegant is important to APS operations, so we are careful about this
- Source code is in CVS for version control and tracking
- Use extensive regression testing to “ guarantee” that program updates don't break anything
  - When a feature is added, it is thoroughly tested
  - The test results are saved and used for checking of later versions
  - SDDS largely automates this process

Some applications of elegant

- First application: beam transport lines for the SSRL preinjector
- Design of the APS Positron Accumulator Ring and transport lines
- APS top-up safety tracking
- LCLS start-to-end and S2E jitter simulations
- Low-emittance optics development for the APS and APS booster
- Design of bunch compressor and linac optics for LEUTL
- APS optics correction using response matrix fit
- 2xAPS and XPS7 design
- Pulse compression using RF kick
- All APS accelerators now use elegant-designed optics

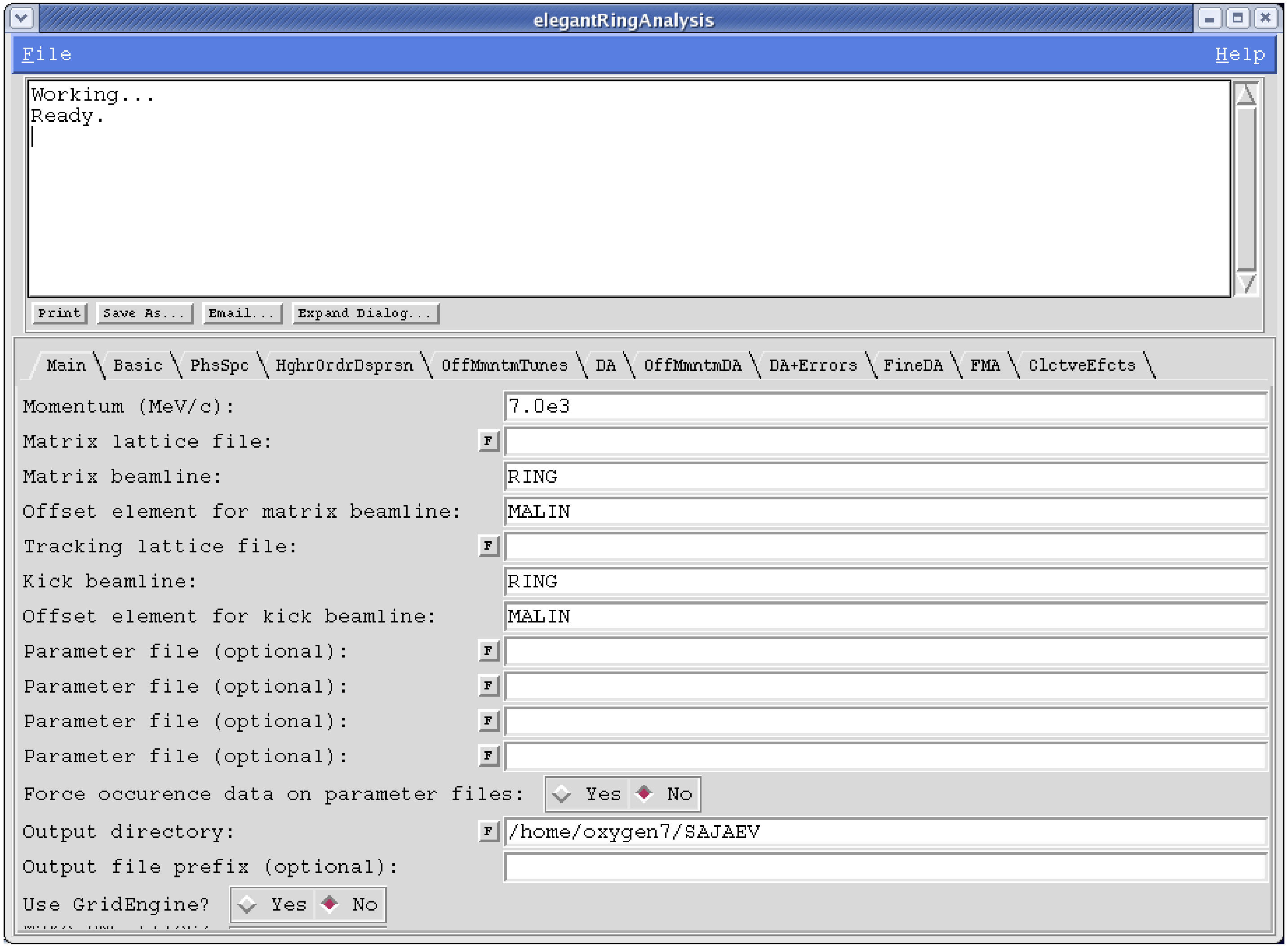
Related programs

- sddsbrightness and sddsurgent
- haissinski – lifetime calculations
- ibsEmittance – computes growth rates and equilibrium emittances for electron rings due to intrabeam scattering
- sddsanalyzebeam – analyzes a beam of macro-particles and produces an SDDS file containing beam moments, emittances, equivalent beta functions, etc
- sddsrandmult – simulates random construction errors for multipoles and provides data for elegant tracking

elegantRingAnalysis

- Graphical User Interface for elegant which allows user to perform multiple standard tasks of ring analysis like
  - Twiss parameter calculations
  - Phase space tracking
  - Frequency map analysis
  - Dynamic aperture calculations
  - Etc.
- Allows parallel computations using cluster
- Written in tcl/tk

elegantRingAnalysis



Possible applications for ERL

- Integration of multiple codes for entire system simulation
  - **Start-to-end simulation from electron production in gun to brightness calculations in undulator**
  - **Error simulations**
  - **Parameter scans**
  - **Optimization of parameters**