Michael Scheer ICAP 2012 Rostock

WAVE A Computer Code for the Tracking of Electrons through Magnetic Fields and the Calculation of Spontaneous Synchrotron Radiation

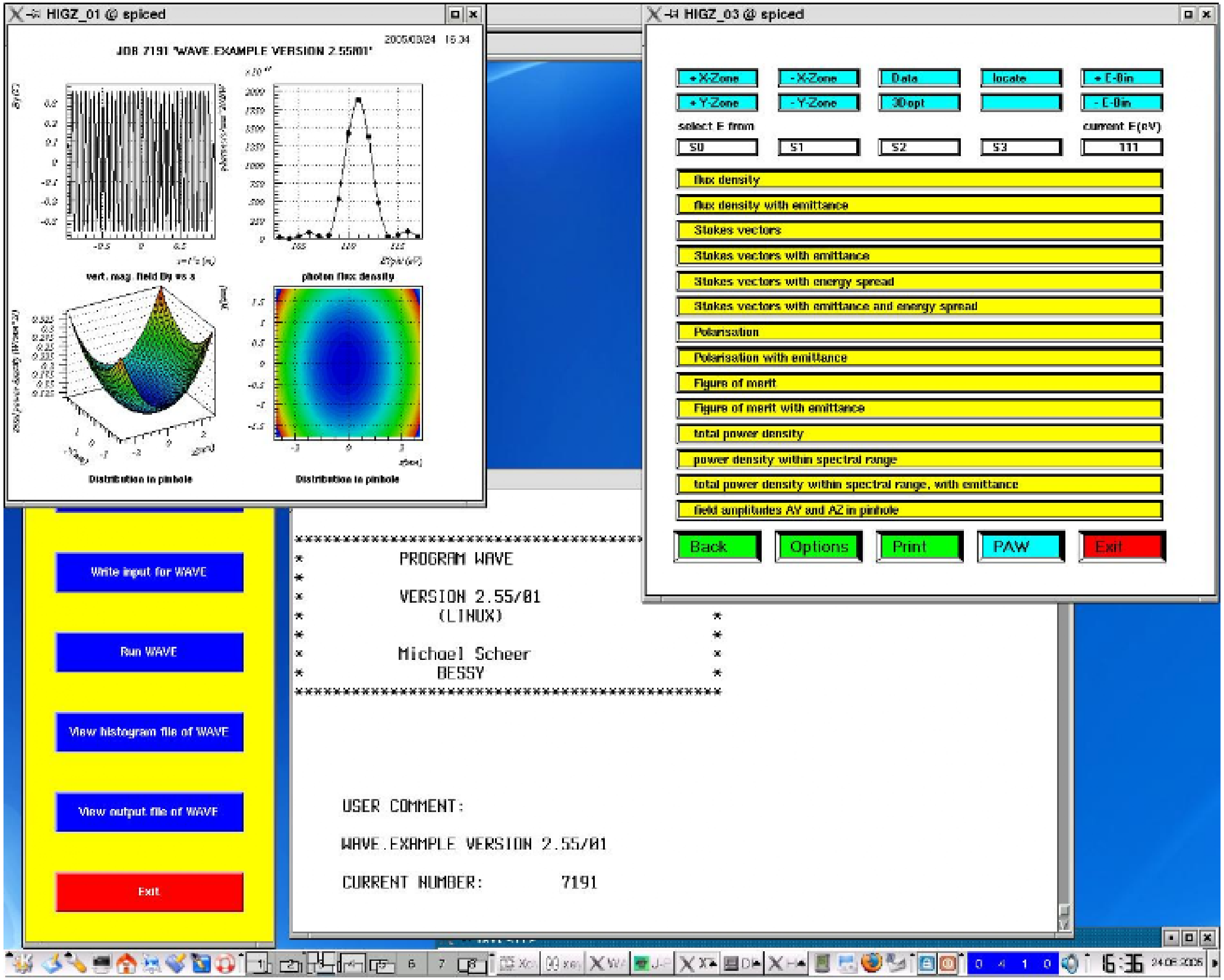
Developed since 1990 for an expert's report about WLS for metrology in the x-ray regime requiring:

- High accuracy ($\Delta < 10^{-4}$) for the calculation of SR
- Investigation of the impact of the WLS on the machine, with respect to beta-functions, emittance, beam polarization, and dynamic aperture

Since 1993 the emphasis is placed on undulators, both magnetic fields and SR spectra.

Since 2009: Coherent radiation (NOT FEL) of electrons in a phase-space, CPU cluster

Graphical User Interface



WAVE is controlled by input files, to be run in batch mode

GUI:

To handle files and visualize results

Based on Perl-Tk and PAW

The Main Input File for WAVE

```
$Contrl
  !---------------------------------- User Comment ----------------------------------
            CODE='WAVE.EXAMPLE'
  !---------------------------------- Main Modes --------------------------------

              ! The undulator and wiggler modes should work for standard
              ! insertion devices. Reasonable settings for some parameters
              ! are taken (mainly in namelist COLLIN).
              ! Experienced users might prefere there own settings.

              IUNDULATOR=1       ! UNDULATOR MODE:
                                 ! whole trajectory is taken as source of
                                 ! synchroton light (ignoring input of
                                 ! parameters WGWINFC, collimators ...)
                                 ! ISPECMODE = 1
                                 ! IMAGSPLN = -9999
                                 ! NLPOI = -9999
                                 ! WGWINFC = 45.
                                 ! ISPECDIP = 0
                                 ! IFOLD = 1, if IFOLD.NE.0
                                 ! IEFOLD = 1, if IEFOLD.NE.0
                                 ! IF (IPIN.GT.0) IPIN = 1
                                 ! BMOVECUT = 1.E-7
```

The Main Input File for WAVE

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```
!----------------------------  Magnetic Fields -----------------------------------------------------

         KHALBA=0             ! insertion device described by HALBACHs formulas
                              ! parameter namelist HALBACH
                              ! magnetic field routine BHALBA
                              ! KHALBA.lt.0 means zero field outside device

!-------------------- Parameter Namelists ------------------------------------------------------------

$HALBACH                      ! magnetic field defined by HALBACH formula
                              ! coordinate system here different from the
                              ! standard of WAVE, HALBACH's conventionused
                              ! i.e. z is longitudinal device axis
                              ! the system is internally converted to WAVE standard
      B0HALBA=0.5             ! peak field [T]
      XLHALBA=0.0             ! 2*pi/kx (horizontal gradient) [m]
                              ! XLHALBA=0 means YLHALBA=ZLHALBA (no gradient)
      ZLHALBA=0.04            ! 2*pi/kz [m]
      PERHAL=50               ! number of periods

$END
```

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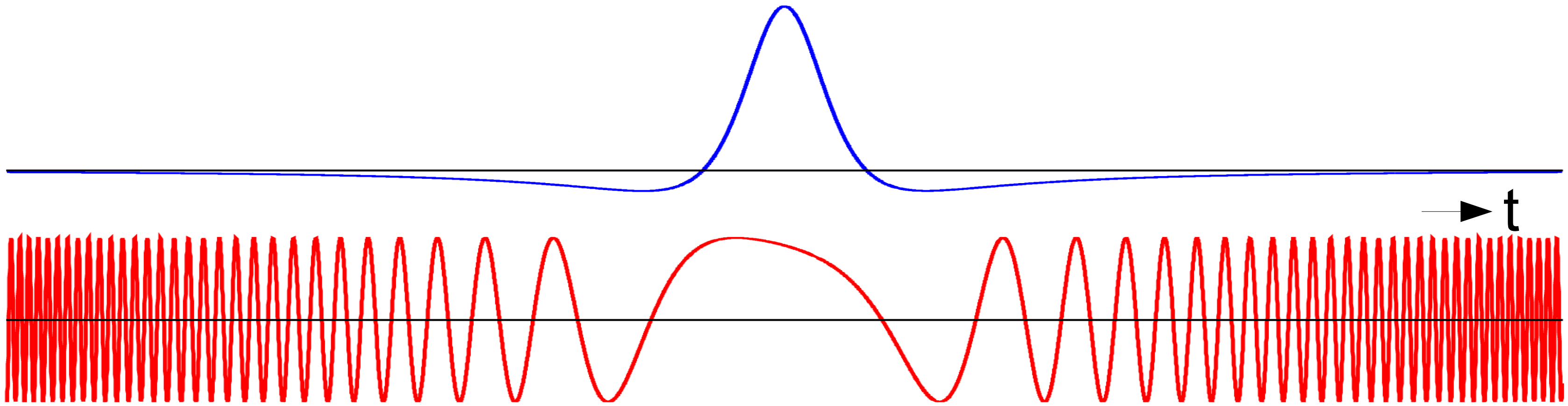
Numerical integration over the steps of the trajectory

$$\int_0^{\Delta T} \frac{1}{R(t)} \frac{\vec{n}(t) \times [(\vec{n}(t) - \vec{\beta}(t)) \times \dot{\vec{\beta}}(t)]}{(1 - \vec{\beta}(t)\vec{n}(t))^2} e^{i\omega(t+R(t)/c)} \, dt$$



$\Delta s = c \cdot \Delta T = 6$ mm

Evaluate integral numerically for steps of trajectory

$$\int_0^{\Delta T} \frac{1}{R(t)} \frac{\vec{n}(t) \times [(\vec{n}(t) - \vec{\beta}(t)) \times \dot{\vec{\beta}}(t)]}{(1 - \vec{\beta}(t)\vec{n}(t))^2} e^{i\omega(t+R(t)/c)} \, dt$$

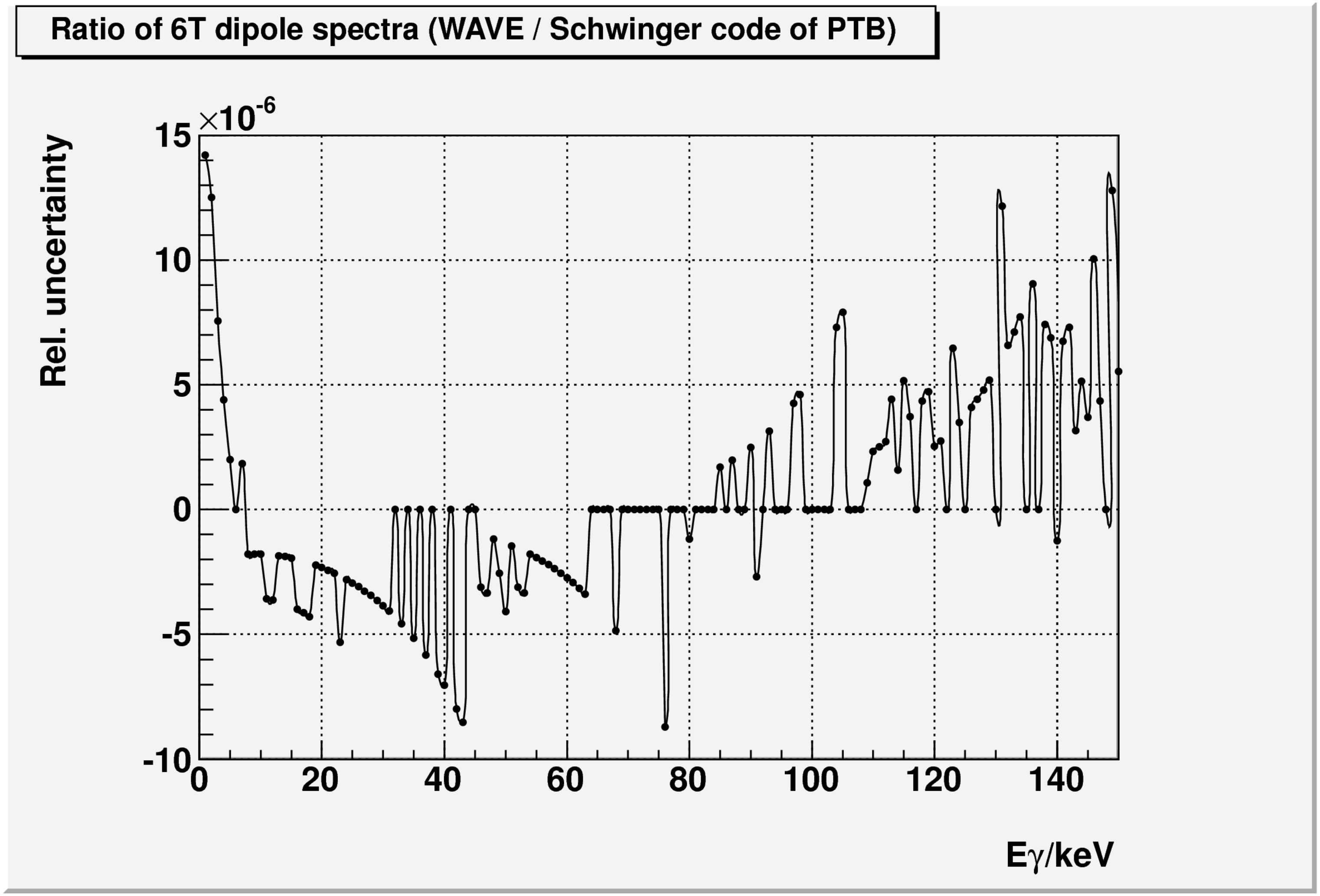
Treat ω-independent part as constant for each integration step and expand phase to first order

$$\sum_{j=1}^{N} \frac{1}{R(t_j)} \frac{\vec{n}(t_j) \times [(\vec{n}(t_j) - \vec{\beta}(t_j)) \times \dot{\vec{\beta}}(t_j)]}{(1 - \vec{\beta}(t_j)\vec{n}(t_j))^2} e^{i\omega(t_j+R(t_j)/c)}$$

$$\times \frac{1 - e^{i\omega(1-\vec{\beta}(t_j)\vec{n}(t_j))\Delta t_j}}{(1 - \vec{\beta}(t_j)\vec{n}(t_j))\omega}$$

$$e^{i\omega(t_{j+1}+R(t_{j+1})/c)} \approx e^{i\omega(t_j+R(t_j)/c)} \times e^{i\omega(1-\vec{\beta}(t_j)\vec{n}(t_j))\Delta t_j}$$

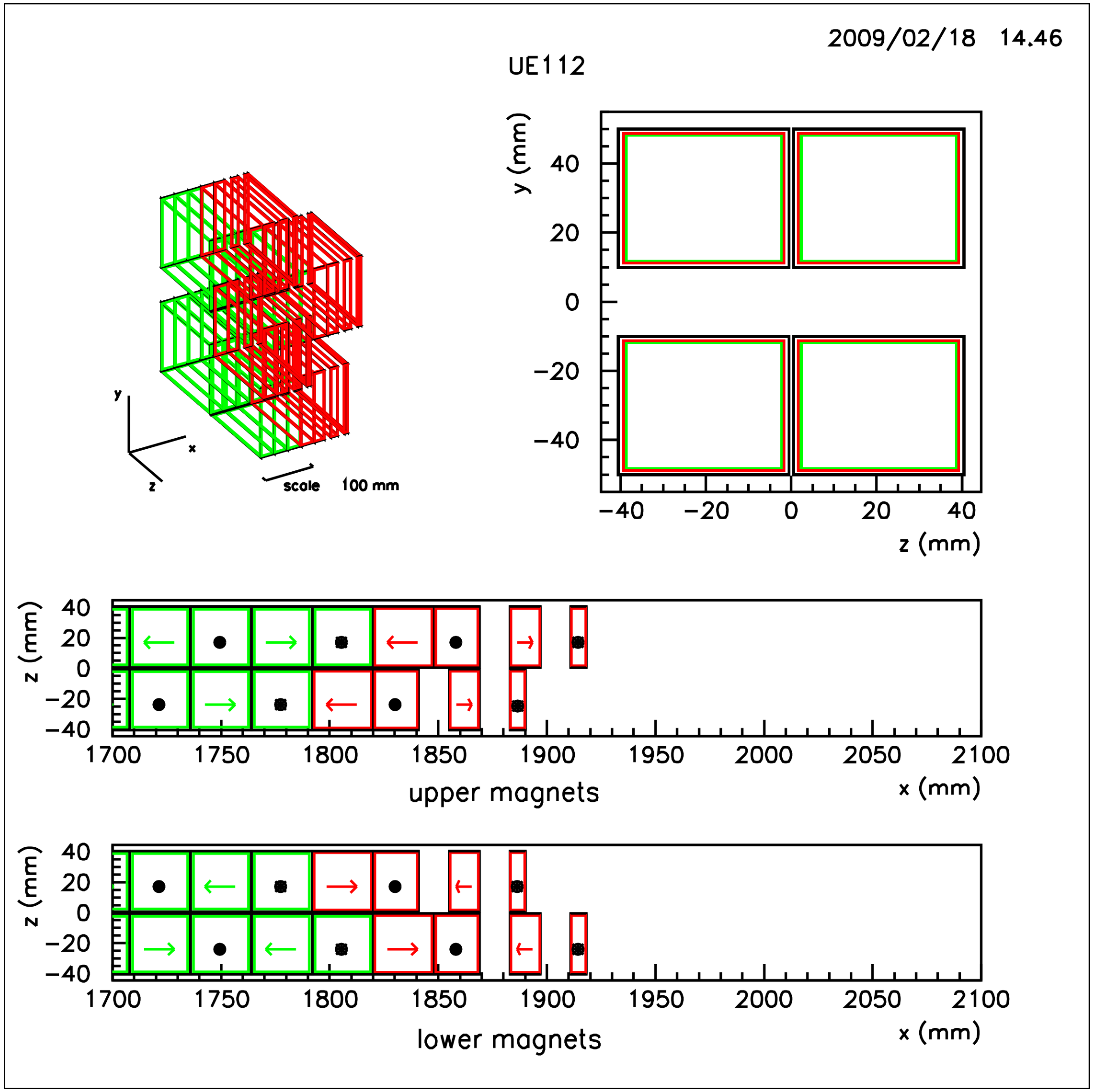
Algorithms



Ratio of 6T dipole spectra (WAVE / Schwinger code of PTB)
Rel. uncertainty
×10-6
15
10
5
0
-5
-10
0
20
40
60
80
100
120
140
Eγ/keV

Magnetic fields

- Planar and helical wigglers and undulators as analytical models of permanent magnet structures
- Tapers and field errors of insertion devices
- Dipoles, quadrupoles, sextupoles with fringe fields
- In- and output of magnetic fields maps or tables
- Maxwell-conform parametrization and interpolation of magnetic fields



REC model of UE112

Current sheet method

Endpole configuration

Maxwell-conform 2D fields as a superposition of functions

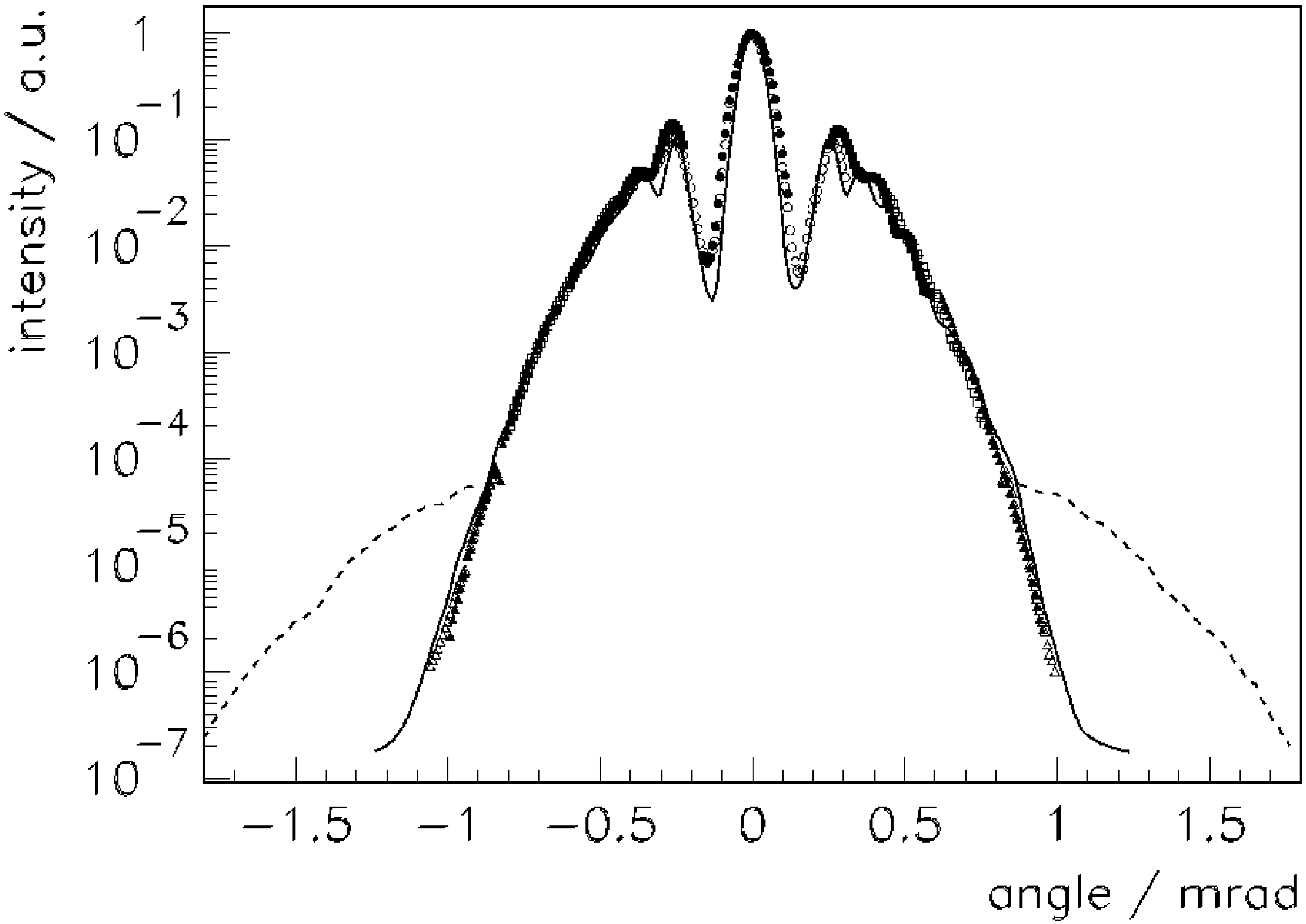
$$B_y(y,z) = B_0 \sum_{0<m,n} C_{mn} \cosh(mk_y y) \cos(nk_z z)$$

$$B_z(y,z) = -B_0 \sum_{0<m,n} \frac{nk_z}{mk_y} C_{mn} \sinh(mk_y y) \sin(nk_z z)$$

$$nk_z = mk_y$$

3D expansion for undulators are given in, J. Bahrdt, G. Wüstefeld, Phys. Rev. ST Accel. Beams 14, 040703 (2011)

Horizontal distribution of synchrotron radiation of the UE56



Comparison of measurements and WAVE calculations

Marker: Measurement

Solid line: WAVE

Dashed line: Slicing signal

http://cern.ch/AccelConf/p03/papers/mppb005.pdf

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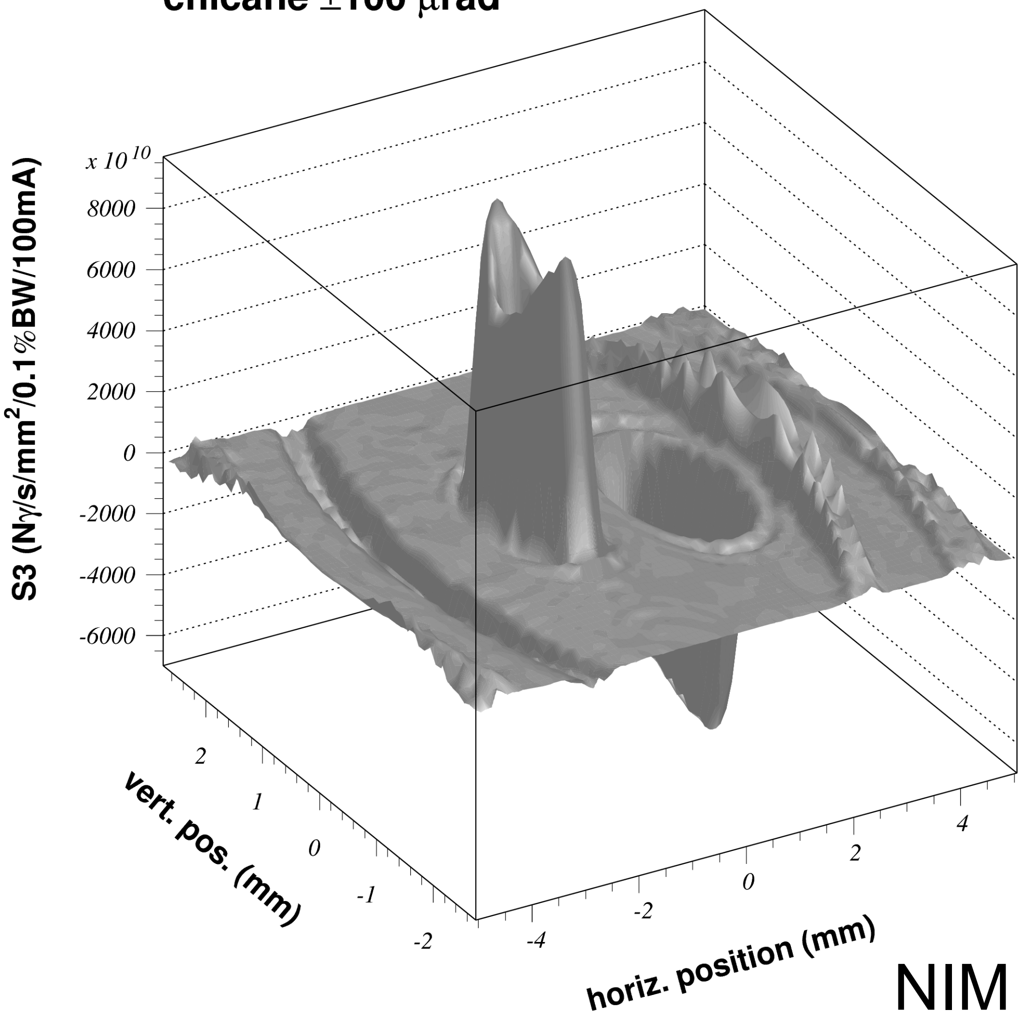
UE56, 3. Harm., K=2.5, Eγ=354eV, 13m distance
chicane ±100 μrad



The radiation cones of the two undulators are separated by a 100μrad-chicane

The figure shows the spatial distribution of the circularly polarized radiation

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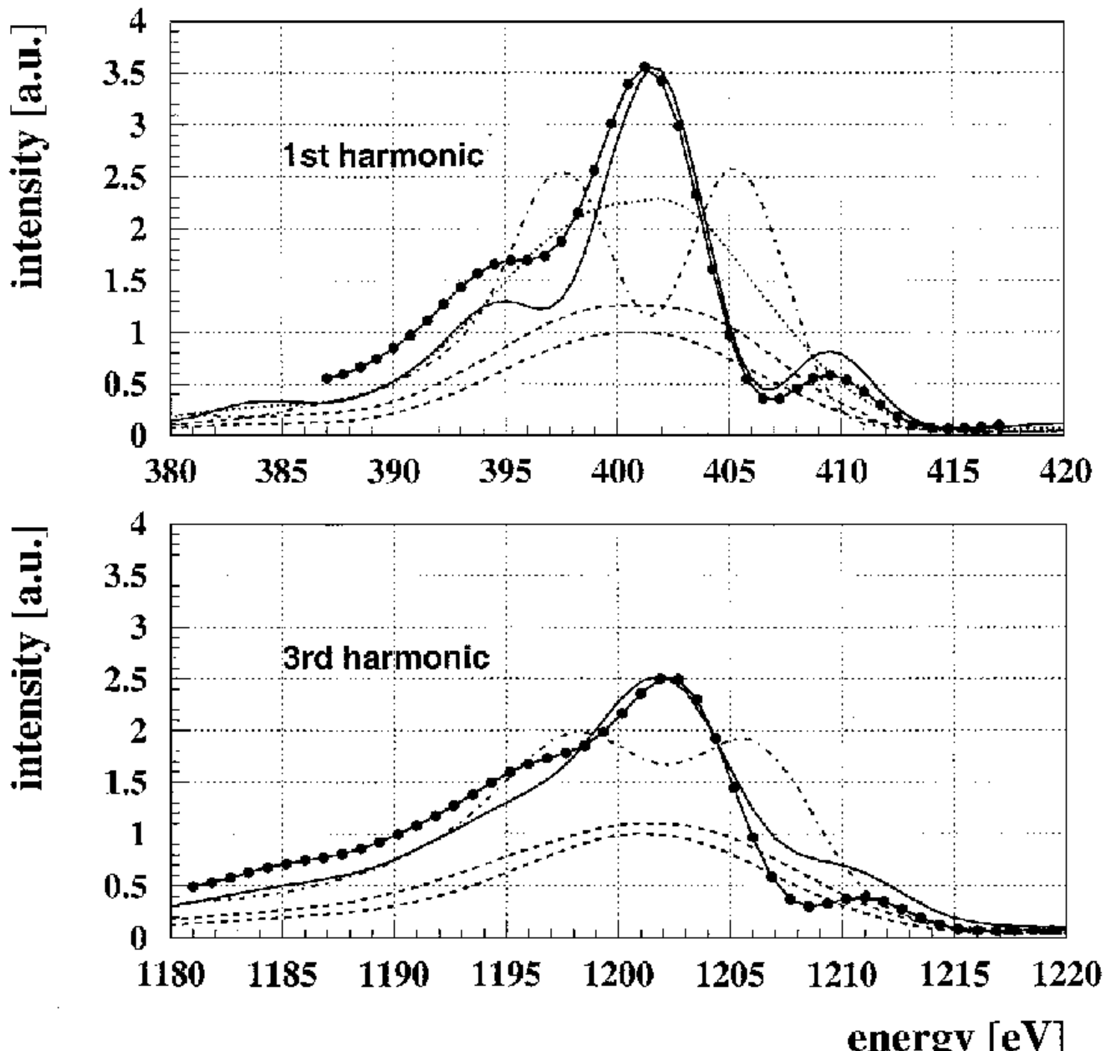
Coupled Undulators UE56



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Interference of two coupled UE56

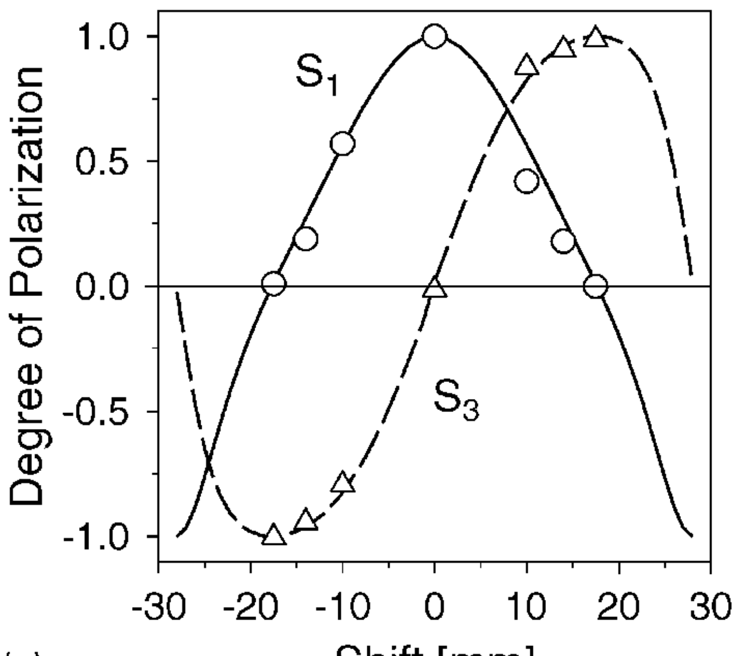
Solid line:
Constructive interference

Solid line with markers:
WAVE calculations
Magnets are modeled by current sheets

Dashed and dotted line:
Destructive interference, contribution of each UE56 and incoherent sum

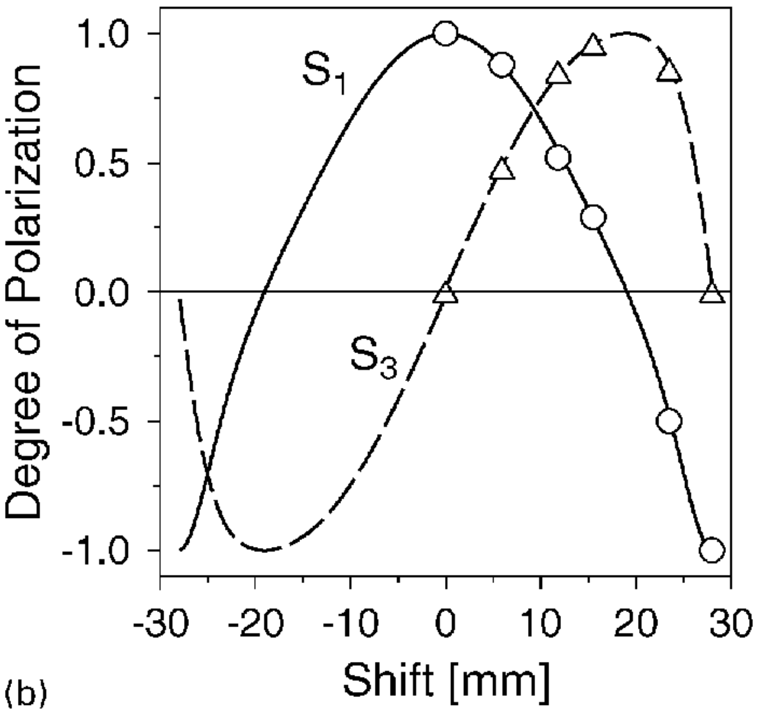
Polarization of Double Undulator UE56

DSU: 1. Harmonic (98 eV), PGM1



(a)

USU: 3. Harmonic (712 eV), PGM2



(b)

Markers: Measurements Lines: WAVE calculations

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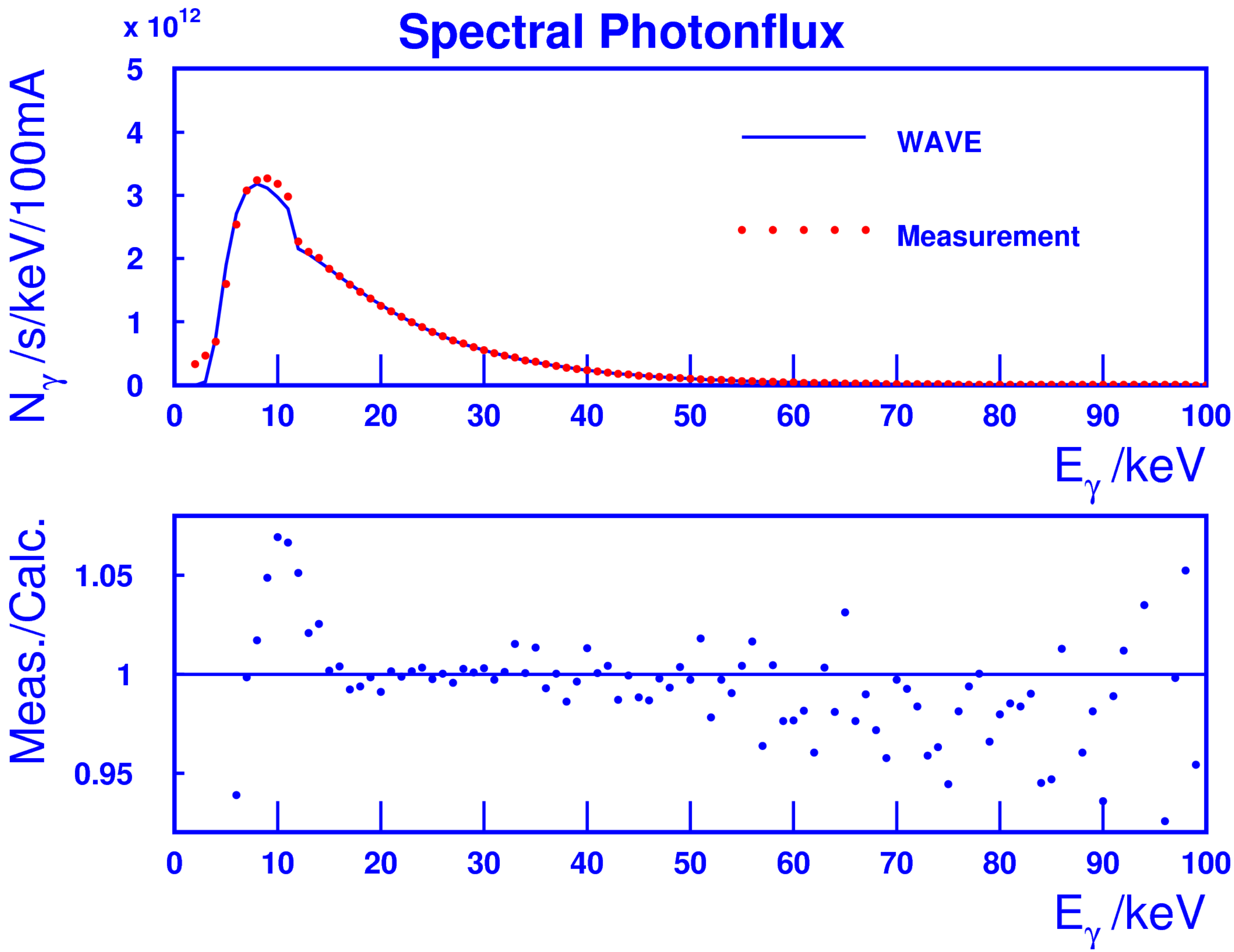


Calculation and Measurement of absolute photon flux of a 6T-WLS

Ratio of measurement and calculation

New features and developments

- Energy loss, continuous and with quantum fluctuations

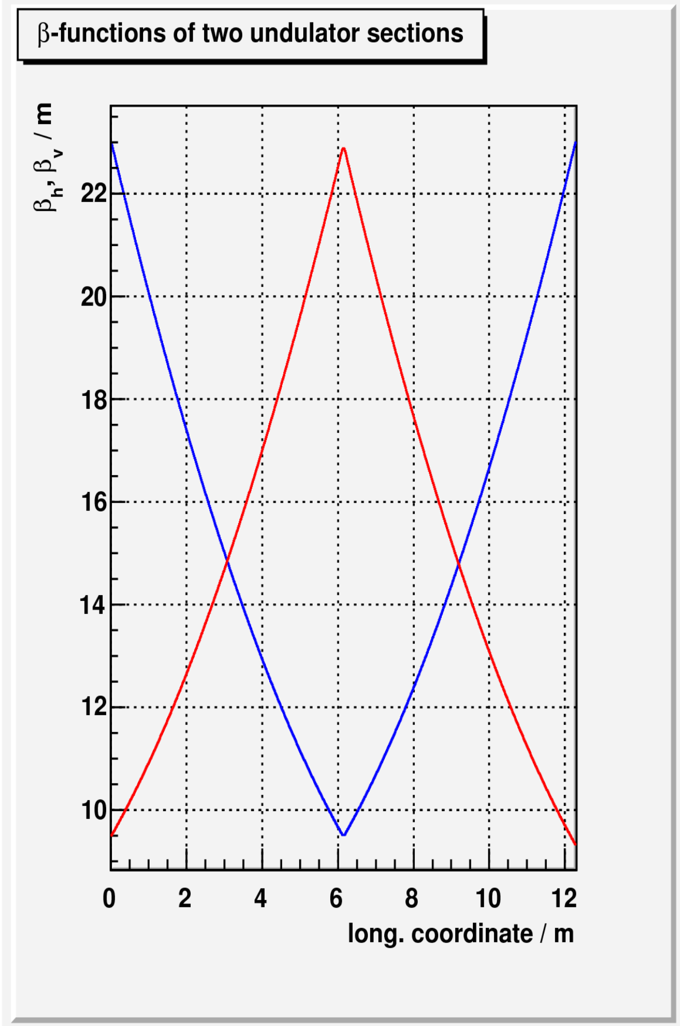
- Concept of bunches:

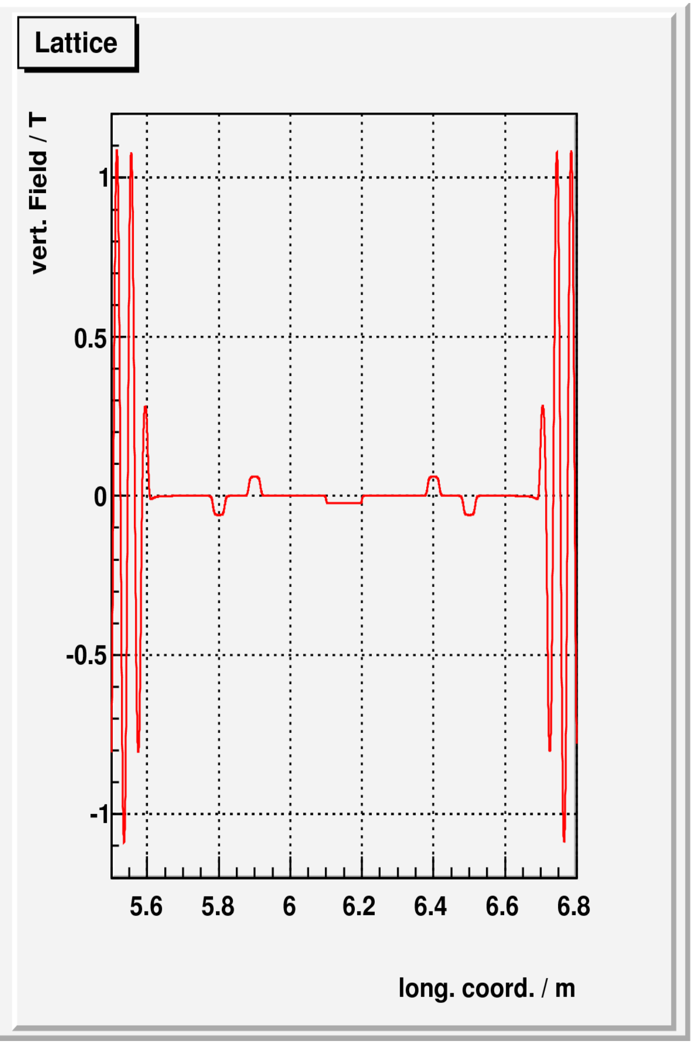
  - Particles within a bunch are treated coherently

  - Bunches are treated incoherently

- Parallel runs of WAVE on a cluster:
  Results of radiation calculations of all runs are summed up

All these new features need intensive test and cross-checking



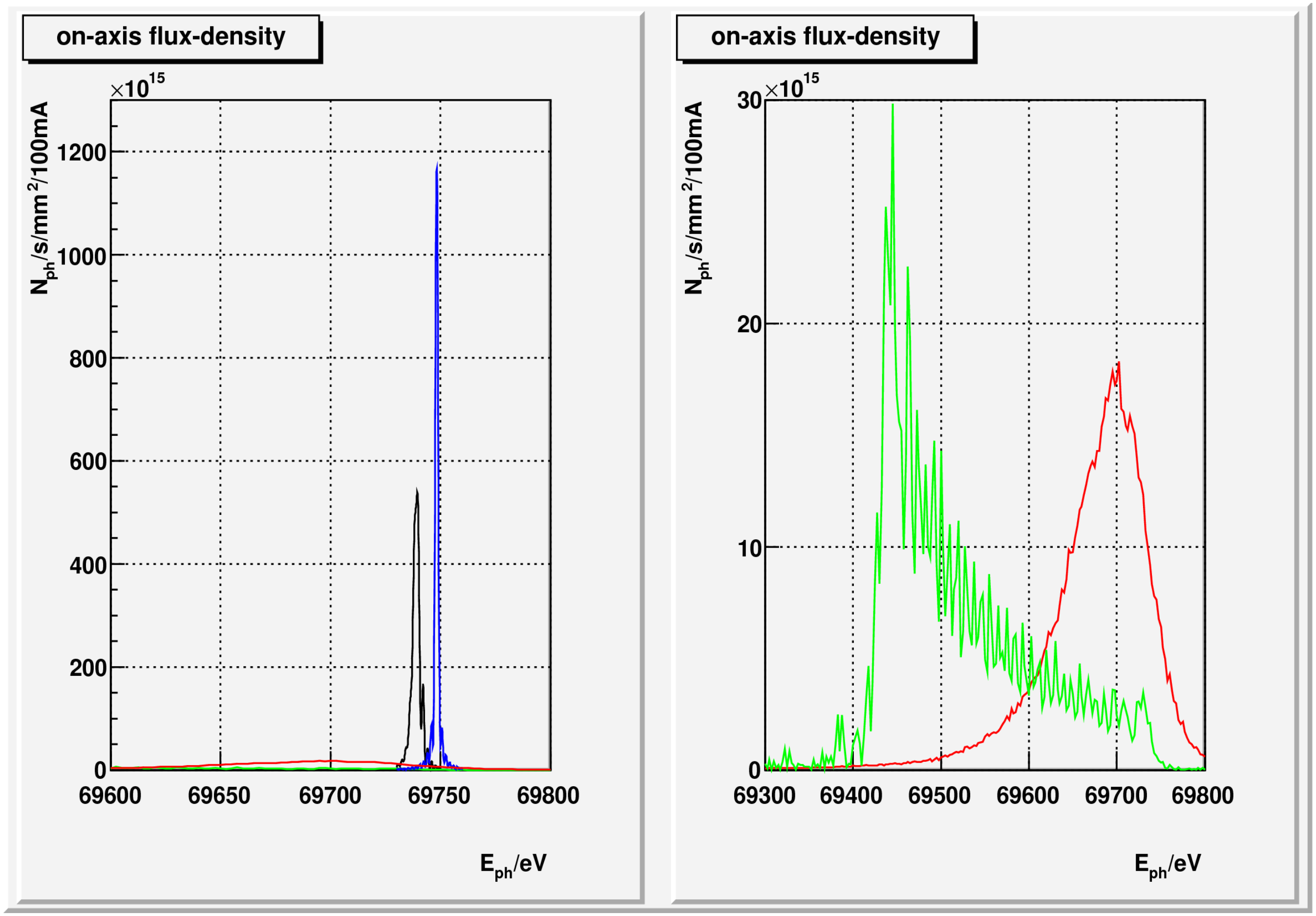


Lattice with undulators, quadrupoles, and dipoles as phase-shifters

Field for a e^- starting at z=y=0.5mm

9th harmonic, on-axis, 35 sections

17.5 GeV



pencil beam, no enery loss

pencil beam, cont. ener. loss

pencil beam, cont. ener. loss, taper

"real" beam, taper

Cross-checks pending!