Higher order harmonics coupling in different free electron laser codes

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- The possibility of simulating the dynamics of a FEL including the fields of the higher order harmonics in linear undulators, is available is several existing codes as Medusa [1] and Perseo [2], and has been recently implemented in Genesis 1.3 [3-4].

- Medusa and Genesis also include the dynamics of even harmonics induced by the coupling through the betatron motion. In addition Medusa, which is based on a non – wiggler averaged model, is capable of simulating the generation of even harmonics in the transversally cold beam regime, i.e. when the even harmonics coupling arises from the non-linear effects associated to longitudinal particles dynamics and not to a finite beam emittance.

[1] H.P. Freund, S.G. Biedron, and S.V. Milton, IEEE J. Quantum Electron. ***27****, 243 (2000).*

[2] L. Giannessi in Proc of FEL 2006 conference, BESSY, Berlin, Germany http://www.jacow.org, p.91 (2006)

[3] L. Giannessi, P. Musumeci, New Journal of Physics 8 (2006) 294

[4] S. Reiche, P. Musumeci, K. Goldammer, Proceedings of PAC07, Albuquerque, New Mexico, USA TUPMS038

Codes tested

- **Perseo**
  - 1D (pendulum equation+pulse prop.)
  - 1D + filling factor & inhomogeneous broadenings for emittances (1DPlus)
  - 3D Kirchhoff integral
- **Medusa**
  - 1D version (non wiggler averaged, pulse prop)
  - 3D version
- **Genesis 1.3**
  - New version including higher order harmonics

Medusa

Caravaggio

- **Fully 3-D & 1-D versions**

- **E&M fields treated using the polychromatic SVEA approximation**
  - Time-dependent and/or polychromatic physics
  - Modal decomposition of the fields
  - Amplifier/Oscillator

- **Particle dynamics are treated from first principles (not KMR)**
  - Harmonics & sidebands implicitly included in orbit dynamics

- **Can easily add of new features for Engineering Design Evaluation**
  - New wiggler models
    - For example, an APPLE wiggler that can be configured for planar or helical symmetry
    - Input from a field map
  - New beam models
    - non-Gaussian distributions
- Single CPU & parallel cpu versions available

Perseo

Perseo is a library of functions devoted to the simulation of FEL dynamics in the *Mathcad* environment.

Functions for the generation of phase space variables, for the solution of the pendulum-like equation and for manipulating the phase space in a number of devices are available.

These function can be combined in order to model more complicated situations as time dependent simulations, 3D simulations, oscillator FEL configurations, optical klystron, cascaded FELs …

Mathcad Worksheet for 1D – 1D plus correction for 3D filling factor & emittance induced inhomogeneous broadenings and 3D versions have been tested

Genesis 1.3

Features

- Solves eikonal field equation (slow varying amplitude).
- Field discretized on fully Cartesian grid
- Fully 6 dimensional tracking of electron beam
- Equations of motion averaged over undulator period.
- Runs in steady-state, time-dependent and scan mode.
- External input of magnetic lattice, electron distribution and seeding radiation pulse
- Parallel & serial versions available

Test Cases

E_b = 200 MeV
I_{pk} = 110 A
R_b =95.3 microns
$\Delta\gamma/\gamma$=0.0001
B_w=7.4588 kG
K = 1.95
λ_{und} = 2.8 cm
λ_{rad} = 265.151 nm

Only in 3D simulations

ε_x = 1 μm
ε_y = 1 μm

- **1D Simulations**
  1. Perseo – Medusa – Steady state 10 kW seed on fundamental
  2. Perseo – Medusa – Time dependent seed on fundamental
  3. Perseo – Medusa – Time dependent seed on 3h

- **3D Simulations**
  4. Perseo (1DPlus,3D) / Medusa 3D / Genesis 1.3 – Steady state, Seed on fundamental
  5. Perseo (1DPlus,3D) / Medusa 3D / Genesis 1.3 – Steady state Seed on third harmonic 1-2-3 harmonic (Perseo only odd)
  6. Perseo (1DPlus) / Genesis 1.3 – Time dependent, seed on fundamental

Other details

- **Seed**:
  - Matched at the spontaneous emission central frequency (first, second , third harmonic ..)
  - Peak 10 kW
  - Duration 50 fs rms (in time dep simulations)

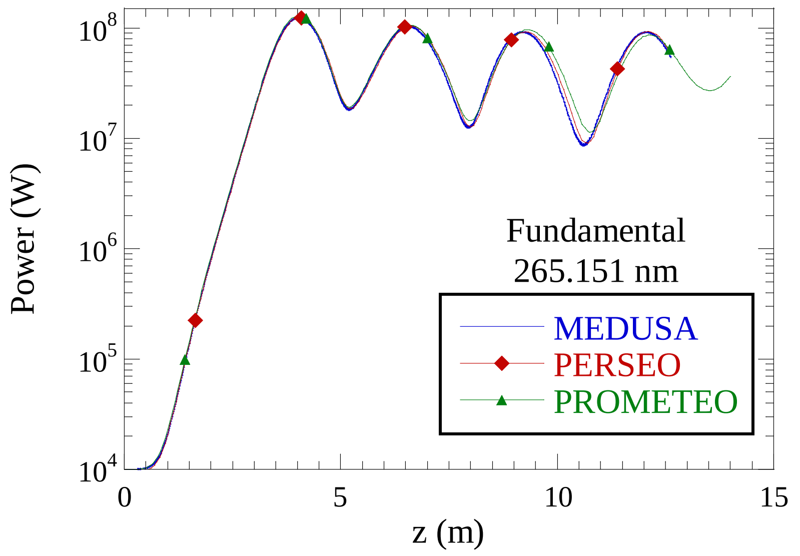
- **Time dependent simulations:**
  - 1 ps flat top current pulse
  - About 700 slices in z
  - 2 ps long z window
  - Shot noise off

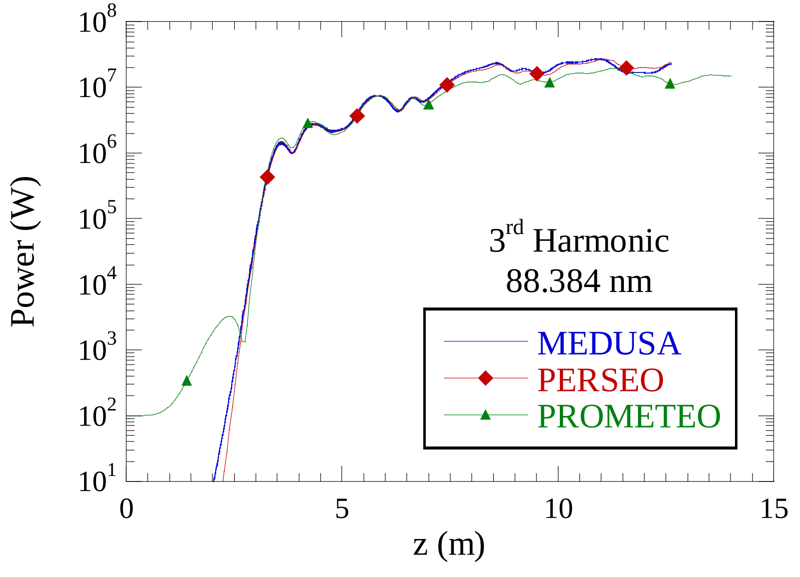
- **1D Simulations**
  - without any inhomogeneous broadening due to emittances,
  - without any correction for diffraction (Filling factor, Xie scaling …)

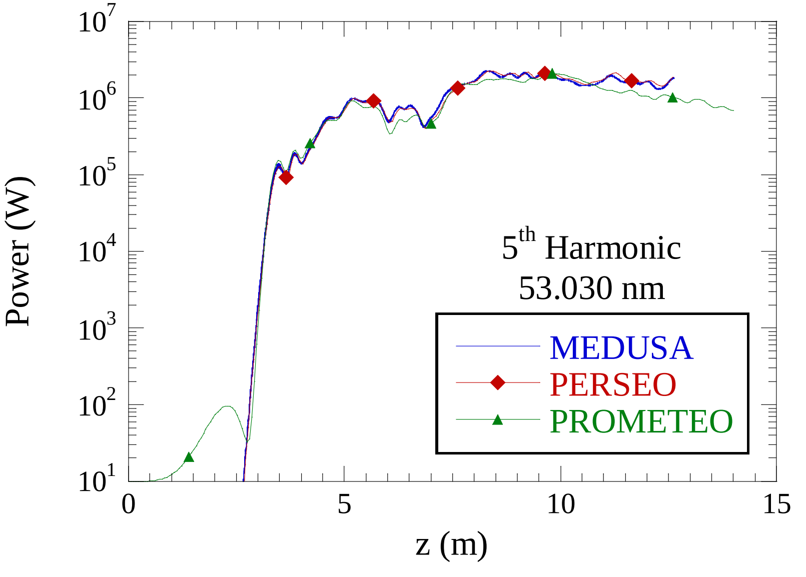
- **3D Simulations**
  - Seed Rayleigh range 40 cm
  - Waist position 70 cm
- **Output**
  - Energy vs Z
  - And @ z = 3.25m/4.06m/4.6 m
    - In time dep. simulations: Pulse & Spectrum

RUN 1 – 1D Steady state

Perseo 1D – Medusa 1D

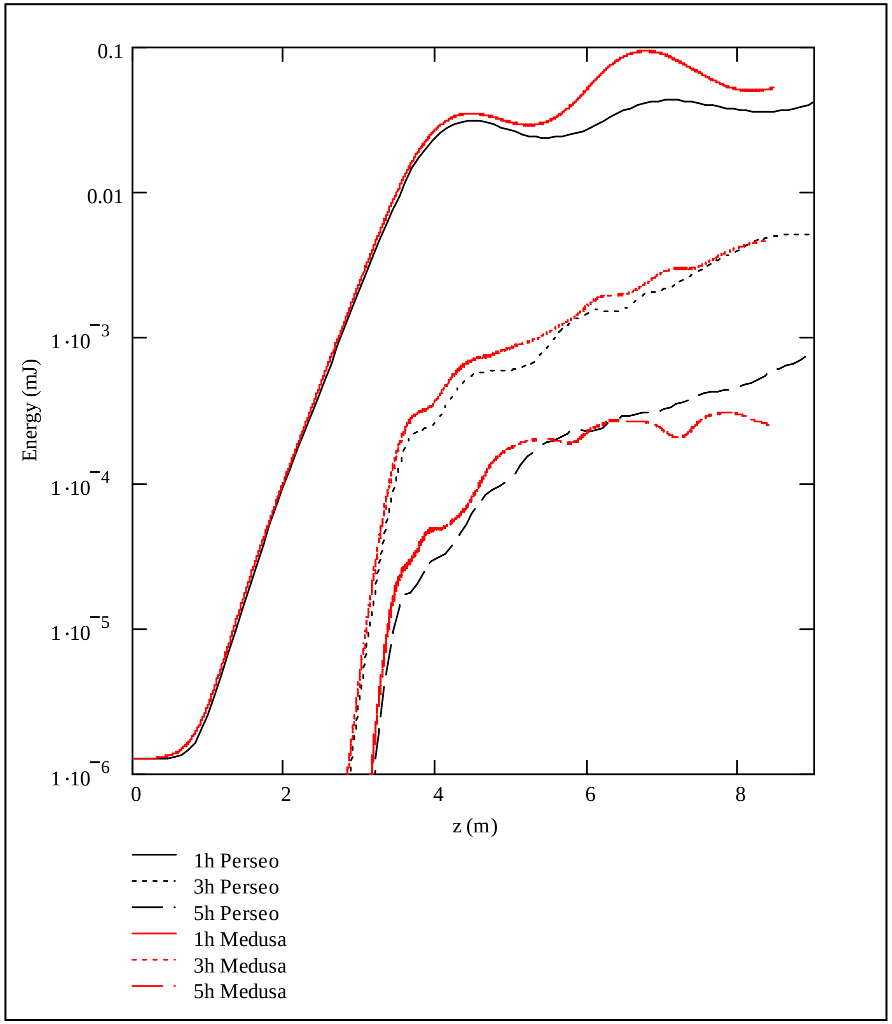






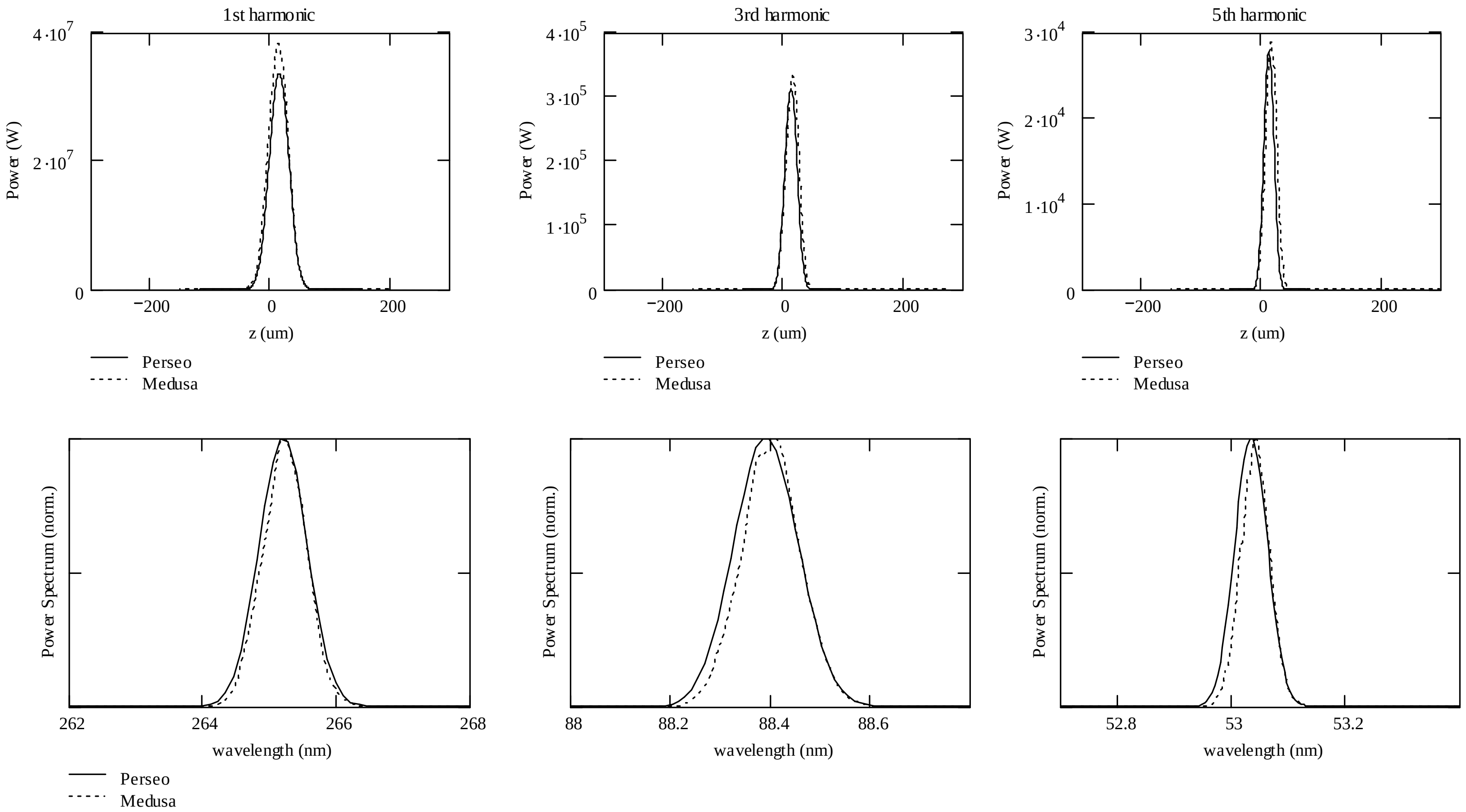
RUN2 – 1D time dep.

Energy vs. z



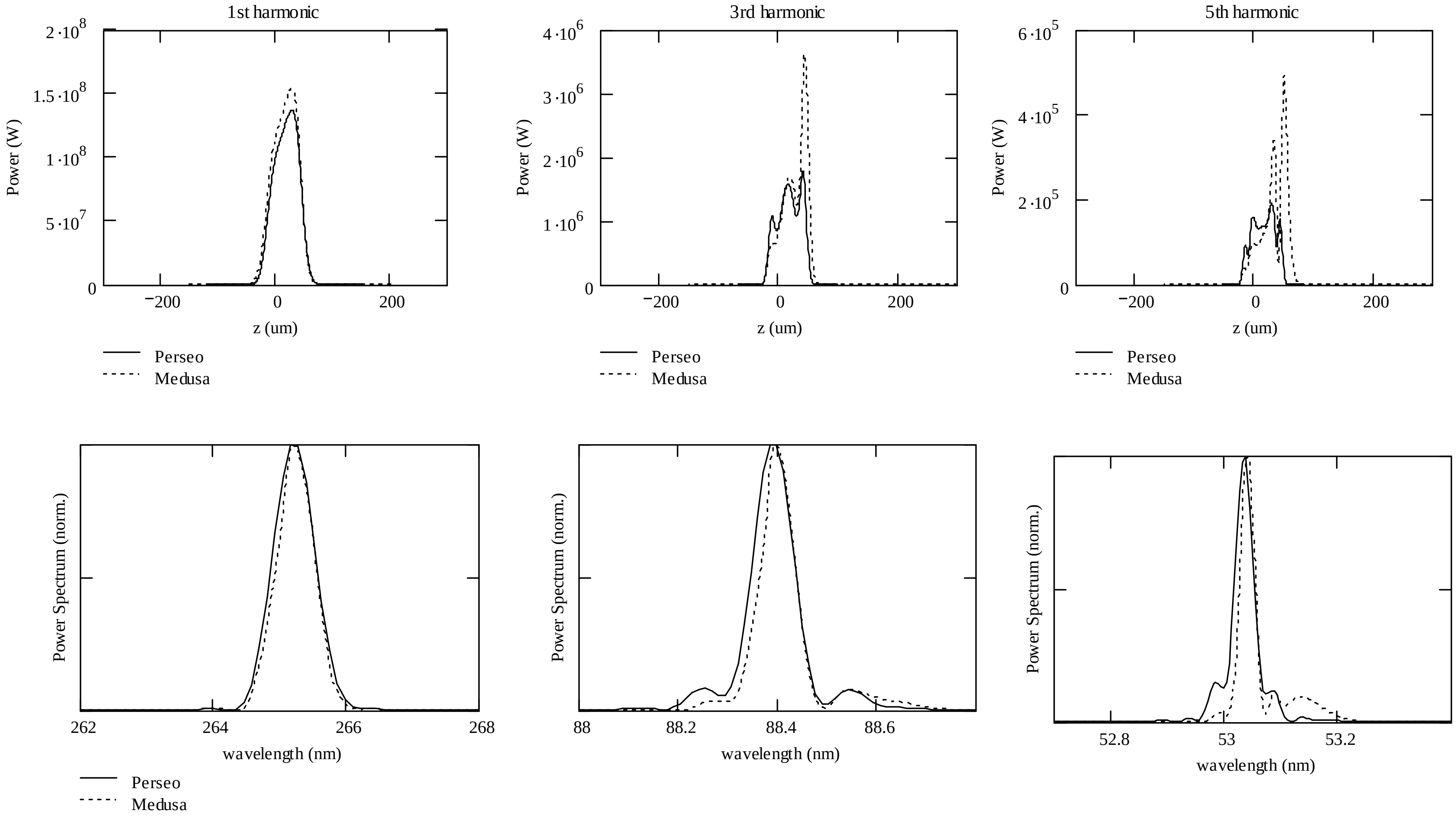
RUN2 – 1D time dep.

Medusa 1D – Perseo 1D, z = 3.25 m



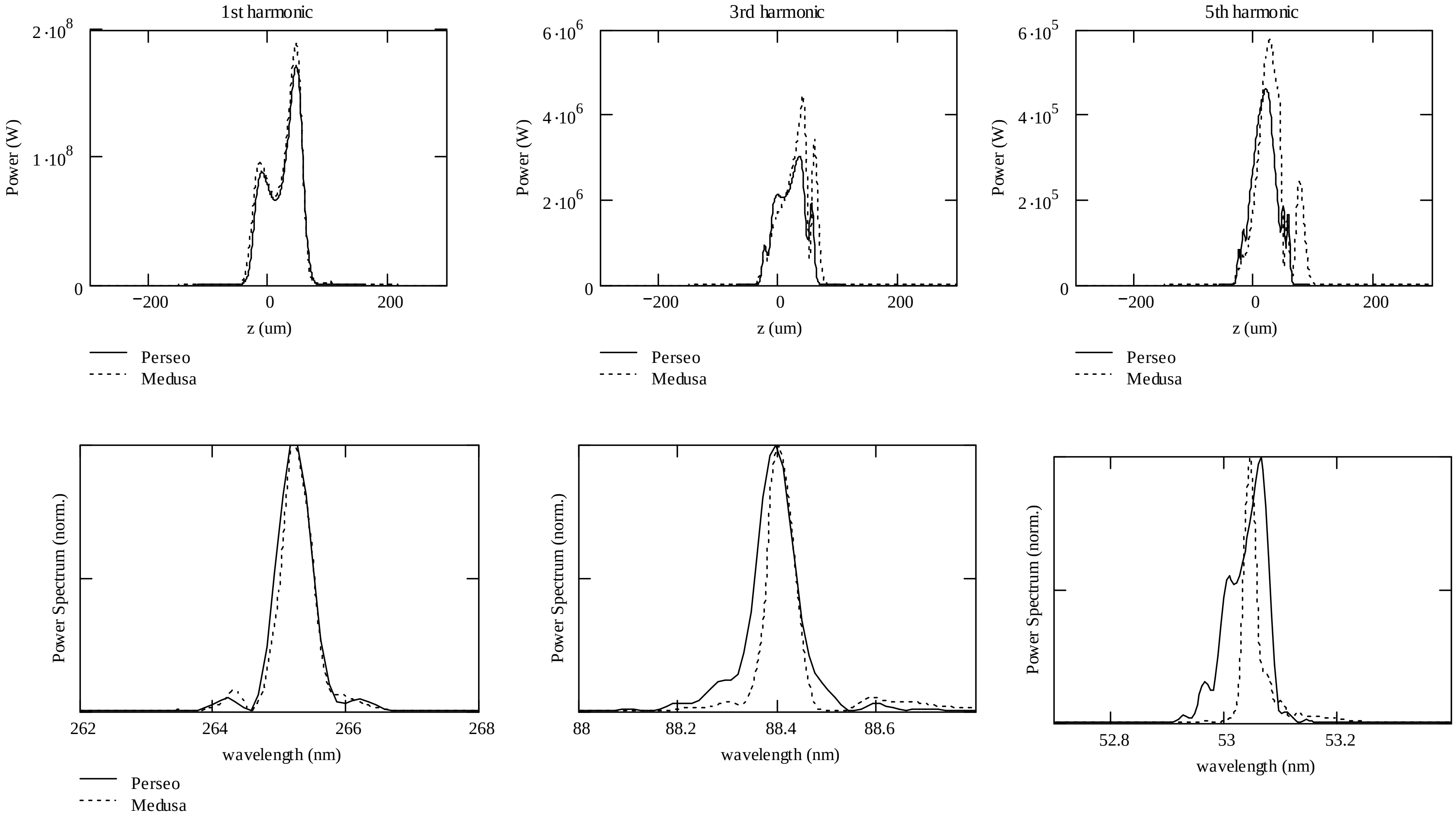
RUN2 – 1D time dep.

Medusa 1D – Perseo 1D, z = 4.06 m



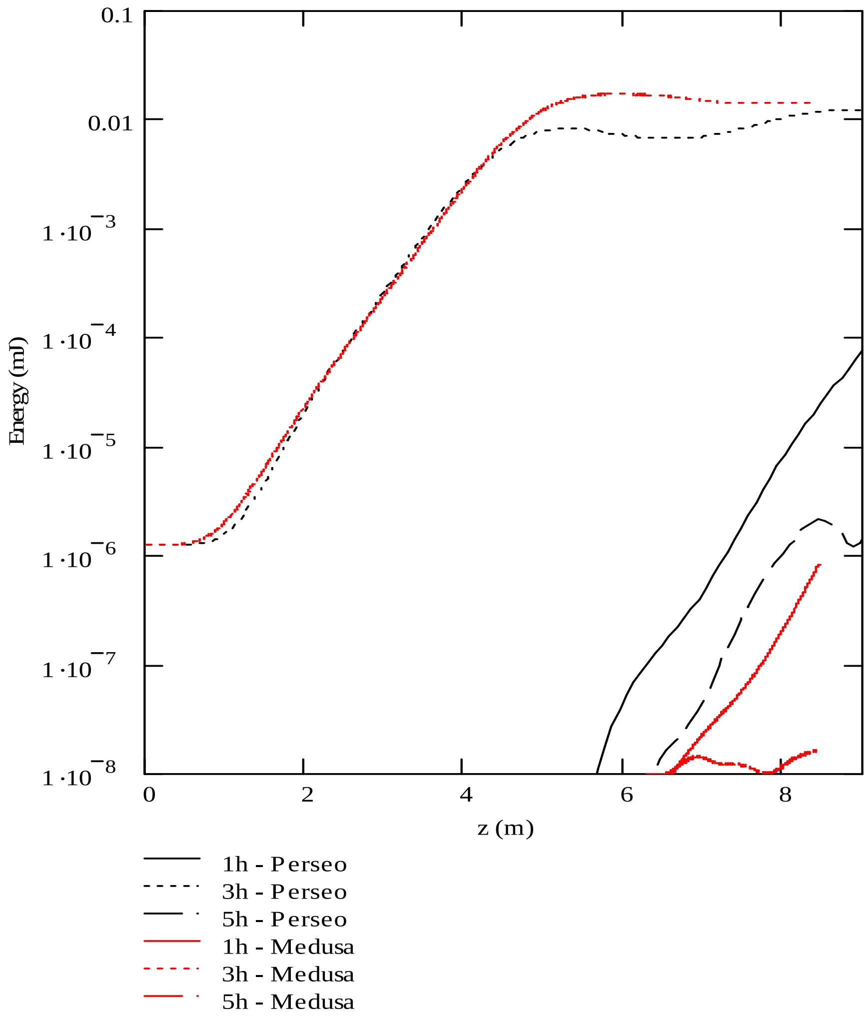
RUN2 – 1D time dep.

Medusa 1D – Perseo 1D, z = 4.60 m



RUN3 – 1D time dep. Seed 3h

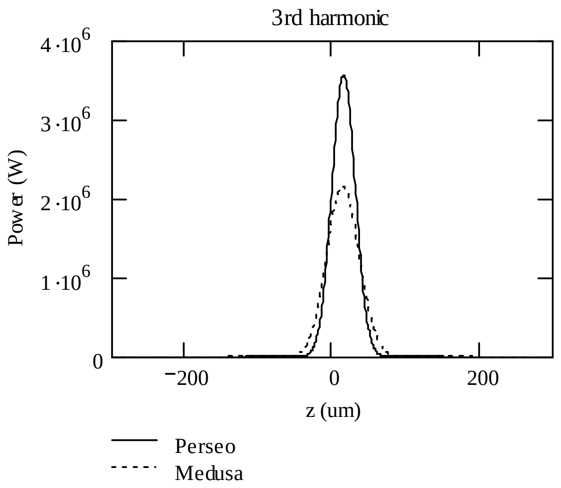
Medusa 1D – Perseo 1D, Energy vs. z

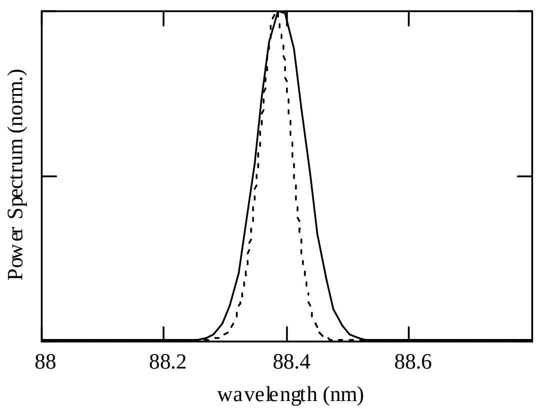


RUN3 1D time dep. Seed 3h

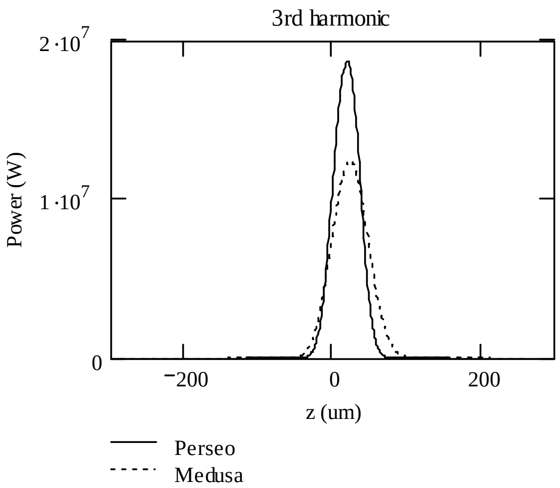
Medusa 1D – Perseo 1D

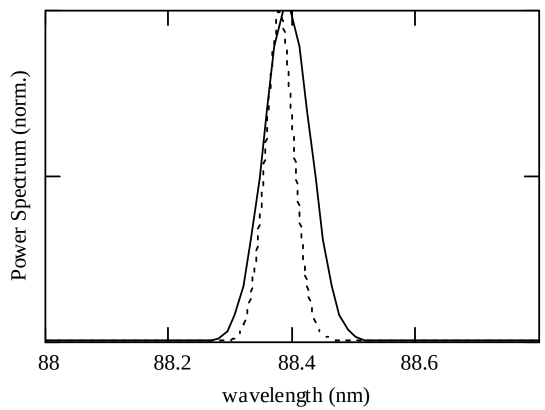
Z=3.25 m



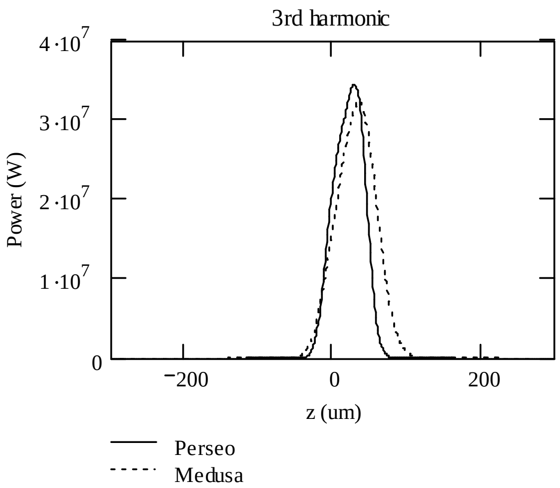


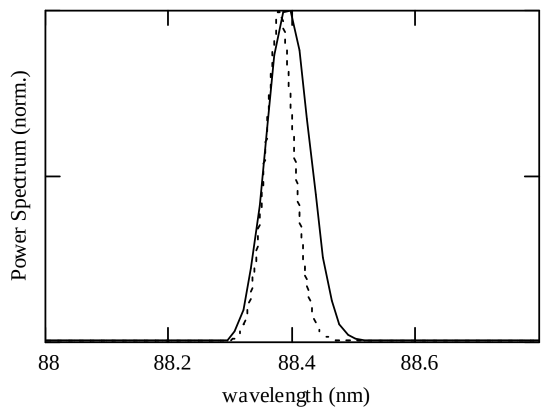
Z=4.06 m





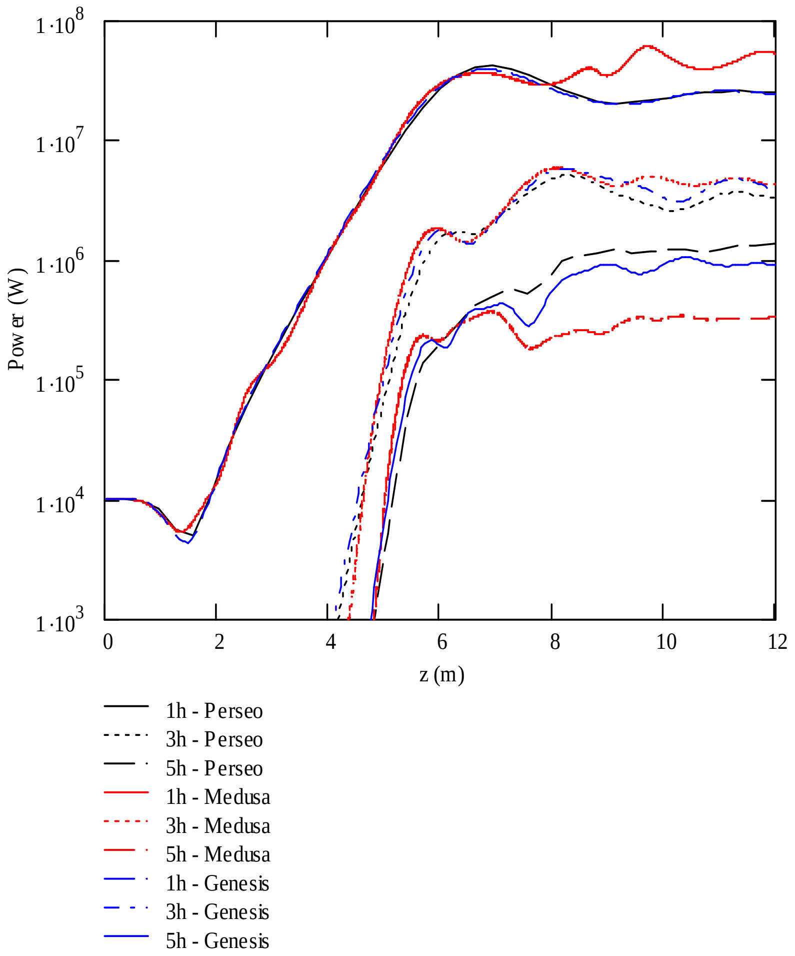
Z=4.6 m

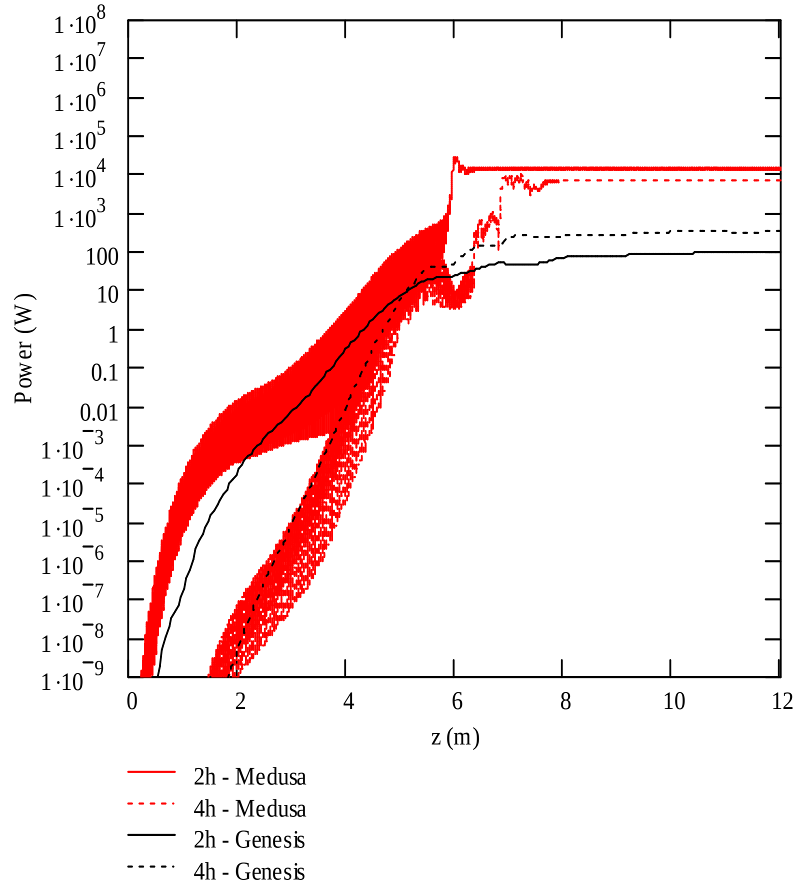




RUN4 - 3D steady state

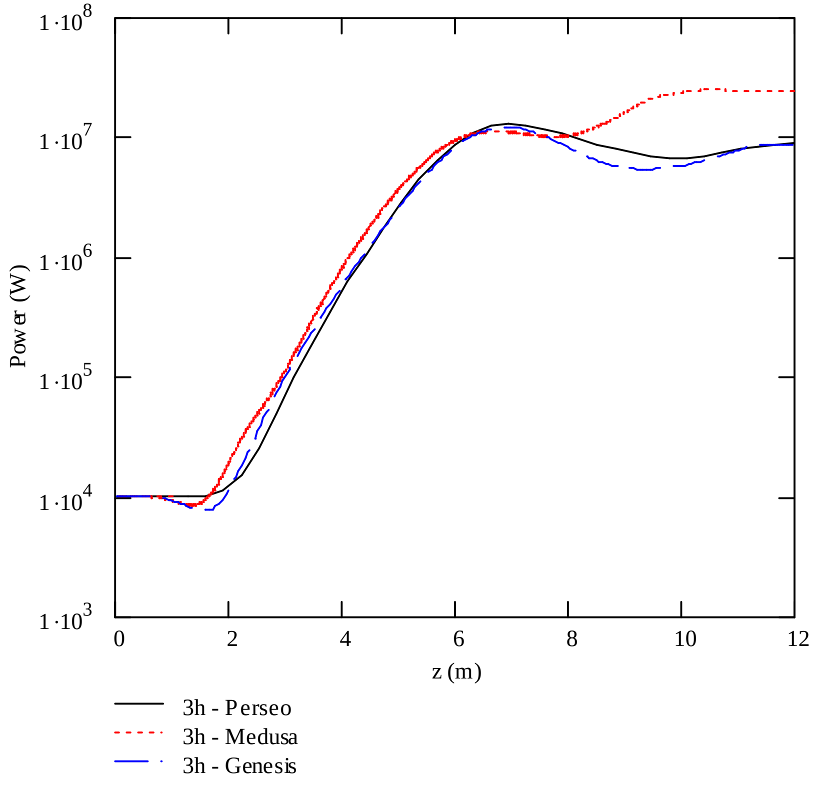
3D Medusa – 3D Perseo – Genesis 1.3

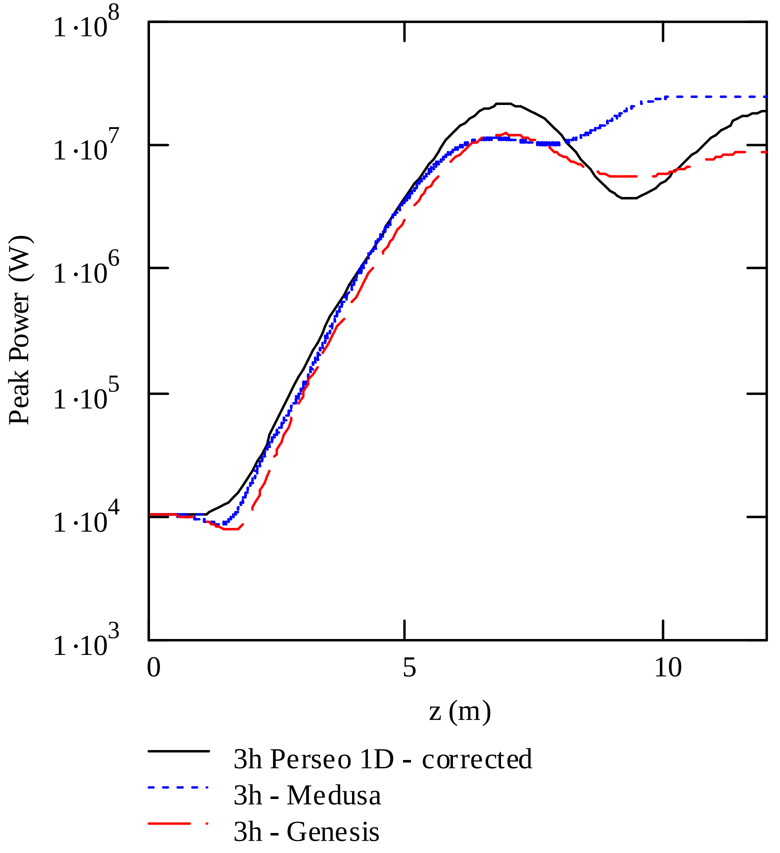




RUN5 - 3D steady state, seed 3h

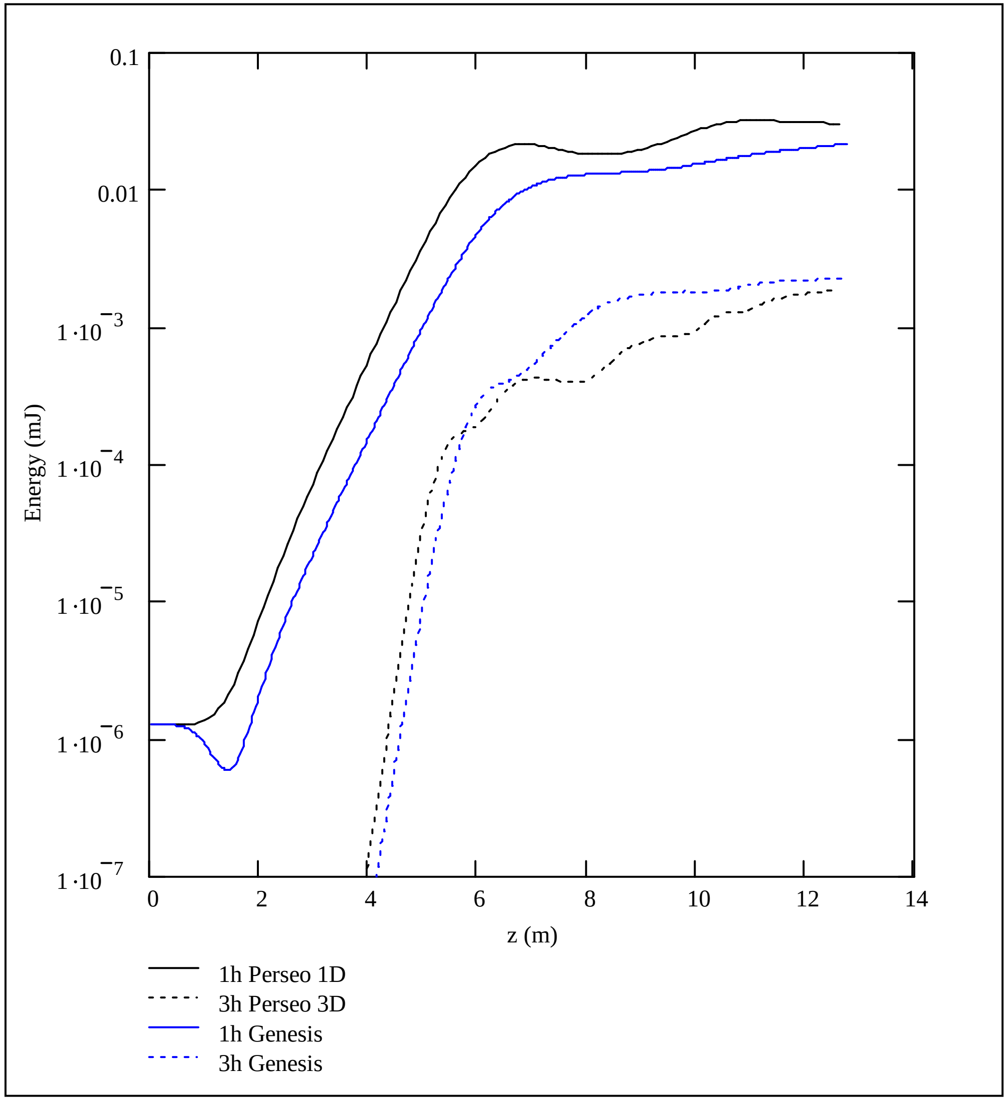
Perseo 3D/1D - Medusa 3D - Genesis





RUN6 – 3D time dep.

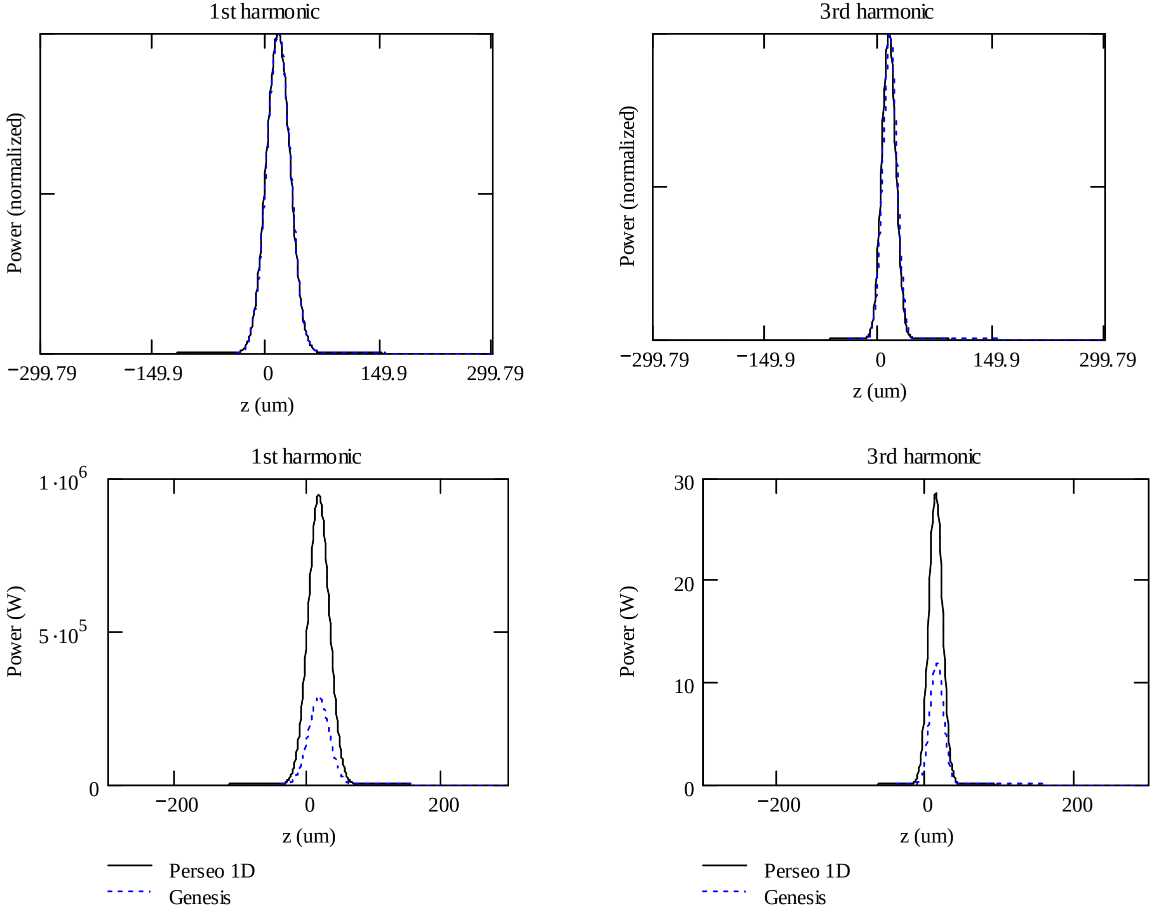
Perseo 1DPlus - Genesis



RUN6 – 3D time dep.

Perseo 1DPlus - Genesis

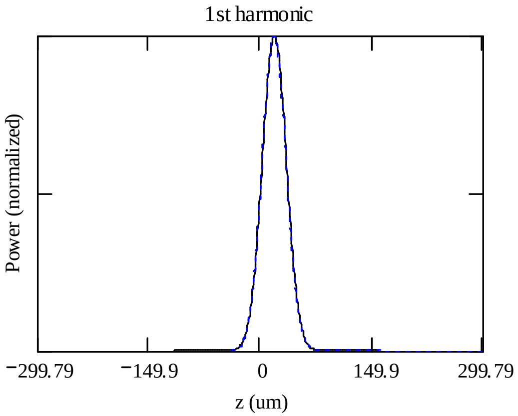
Pulse @ z=3.25m

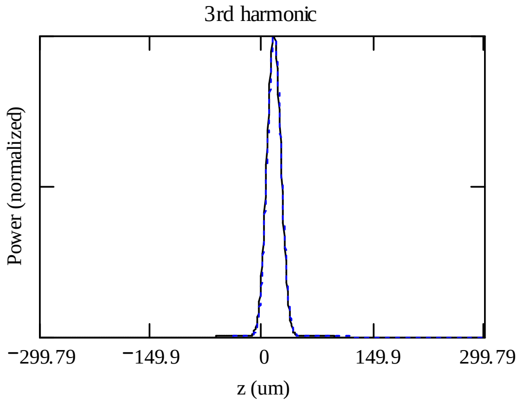


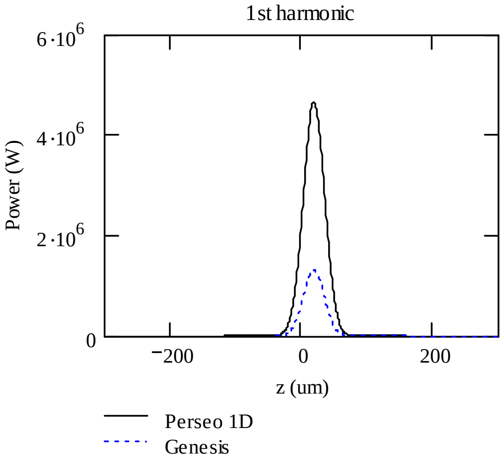
RUN6 – 3D time dep.

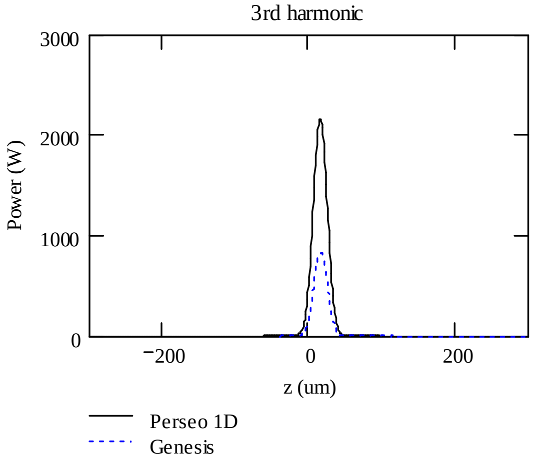
Perseo 1DPlus - Genesis

Pulse @ z=4.06m



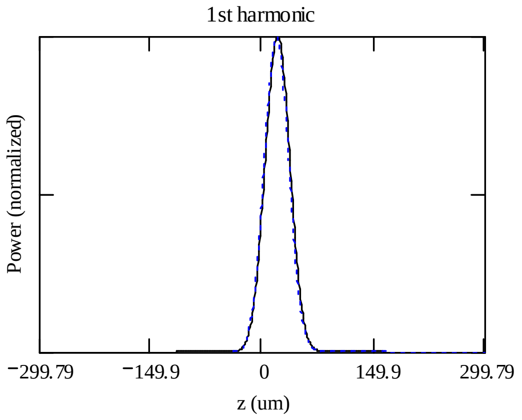


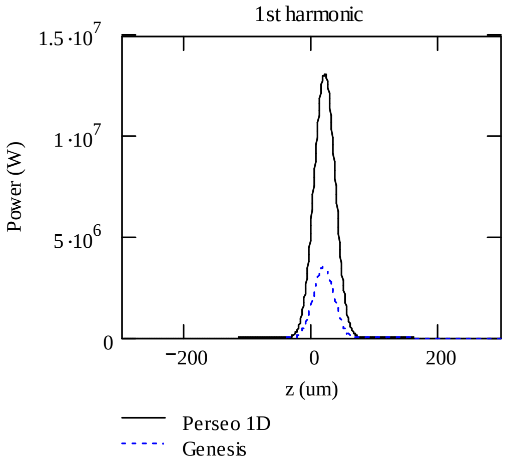




RUN6 – 3D time dep.

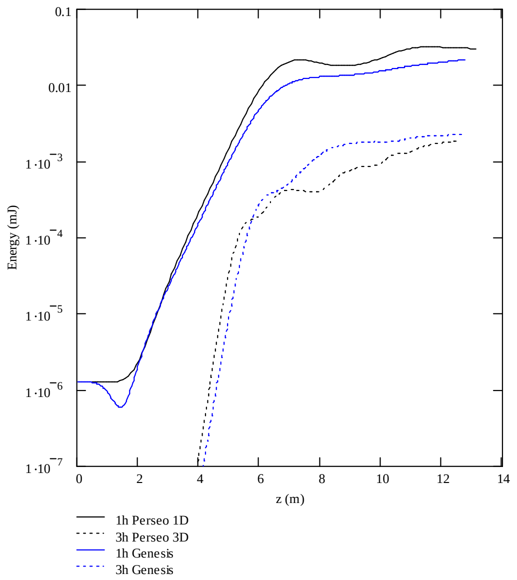
Perseo 1DPlus - Genesis
Pulse @ z=4.60m



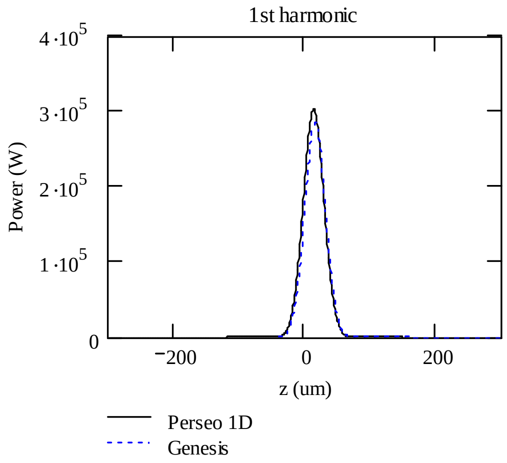


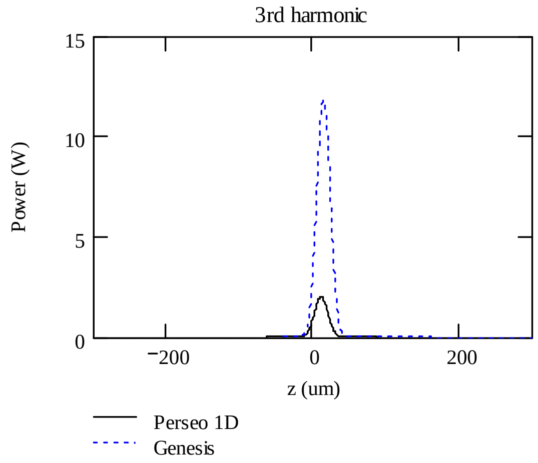
RUN6

Shift of 0.5 m in z

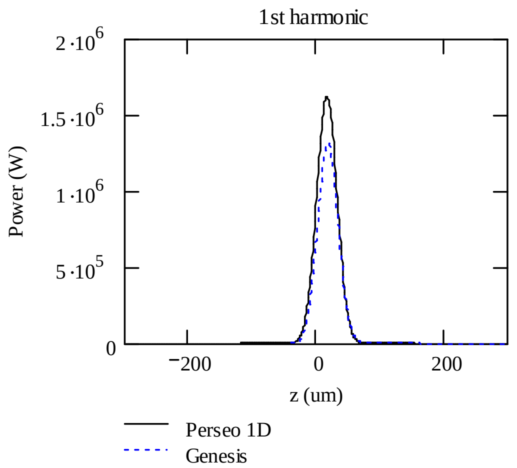


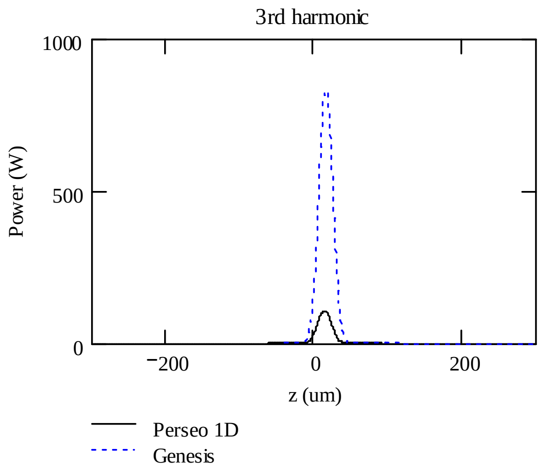
Z=2.7 m - Perseo
Z=3.25 m - Genesis





Z=3.51 m - Perseo
Z=4.06 m - Genesis





Conclusions

- Despite the differences in the models on which the codes are based, a reasonably (sometime very) good agreement has been observed in almost all the tested cases
- The even harmonics comparison between MEDUSA and GENESIS 1.3 has pointed out some of the physical differences associated to non averaged codes, as Medusa 1D & 3D
- The comparison of higher order harmonics is leading to similar results and the relative implementation of the underlying model may be considered reliable