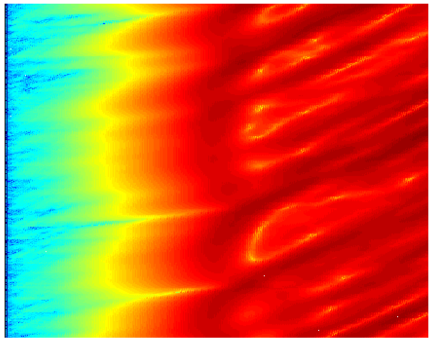


ALICE is a **L**asing **I**nvestigation **C**o-d**E**

Igor Zagorodnov
BDGM, DESY

16.10.06

Mathematical model

1D and 3D mathematical models are described in [SSY, 1999]
and coincide with those used in the code FAST of the same authors

Equations of motion correspond to effective Hamiltonian

$$H(P,\psi,z) = CP + \frac{\omega}{2c\gamma_z{}^2\varepsilon_0}P^2 - (Ue^{i\psi} + C.C.) + \int eE_z d\psi$$

Field Equations are used in parabolic approximation

$$c^2\left[\Delta_\perp + 2i\frac{\omega}{c}\frac{\partial}{\partial z}\right]\tilde{E} = -4\pi\theta_s\omega\tilde{j}_1 \qquad \tilde{E} = \left(E_x + iE_y\right)e^{-i\omega(z/c-t)}$$

with simplified space charge model

$$\frac{\partial}{\partial t}E_z = 4\pi(j_z - j_0)$$

[SSY, 1999] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, Springer, 1999

Motivation

Why write a code with the same mathematical model

- **There are a lot of codes for Maxwell's equations (wakefields), why do not write one more for the FEL equations?**
- **To study the theory through numerical modeling**
- **To implement simpler and faster numerical methods without loss of accuracy**
- **To have consistent and matched 1D, 2D and 3D models in the same code**
- **To have a thoroughly tested code with full control and possibility of future development**

Numerical methods

FAST	ALICE
Equations of motion	
Runge-Kutta method	Leap-Frog method
Field Equation	
Non-local integral representation (two fold singular integral with special functions)	Finite-Difference Solver with Perfectly Matched Layer

Why other methods?

- Leap-Frog is **faster** than Runge-Kutta and „symplectic“(?)
- Finite-Difference solver is **local**: uses only information from one previous „slice“; it should be faster than non-local retarded integral representation which uses all slices in the slippage length
- Like to the integral representation the Perfectly Matched Layer approximates the **„open boundary“ condition accurately**

Computer realization and testing

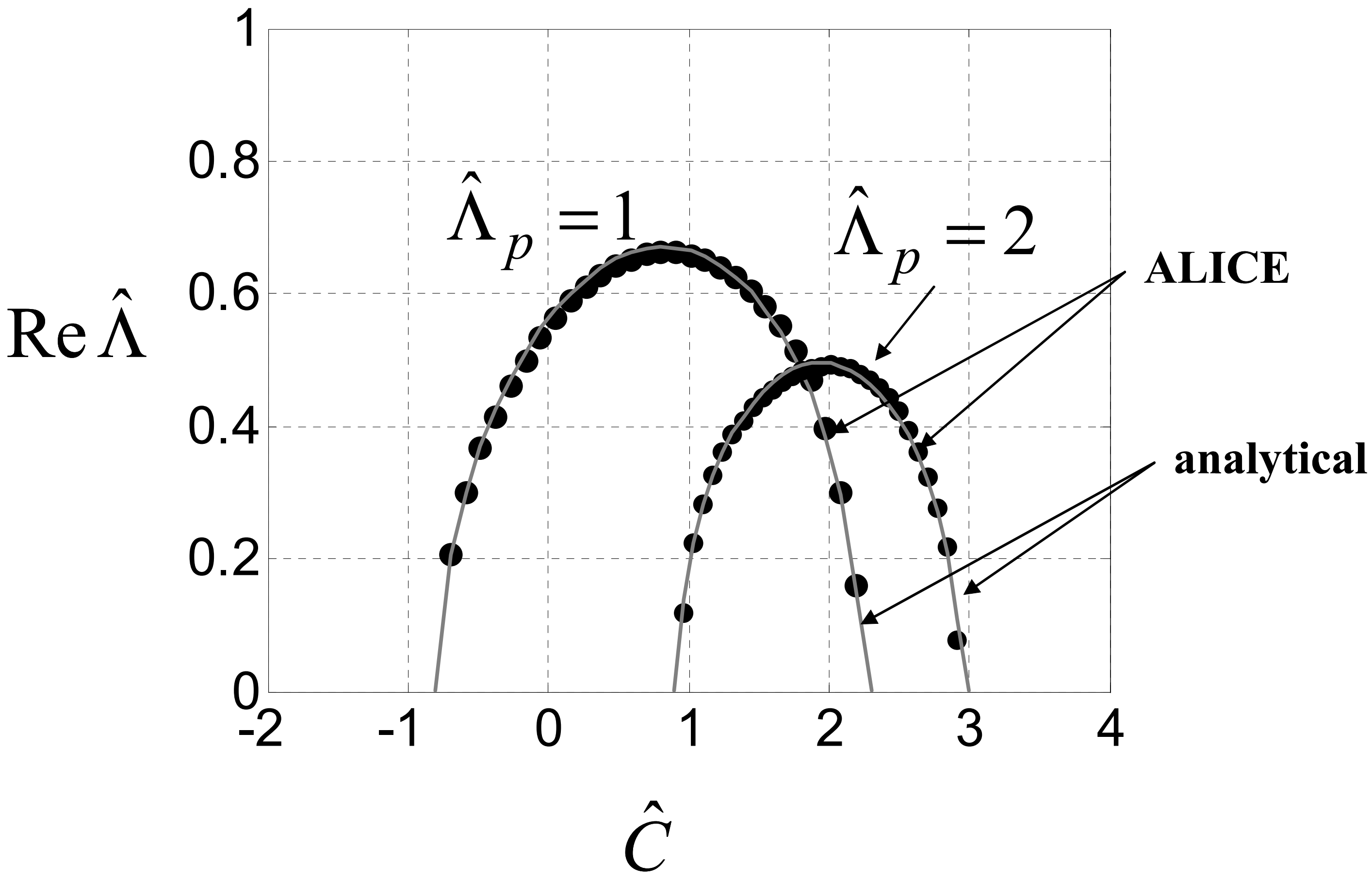
- **The code was initially developed in Matlab and then rewritten in C/C++**

- **the numerical results are compared with the analytical ones when possible (propogation of different Laguerre-Gaussian azimuthal modes, analytical results for linear regime in 1D and 3D theories)**

- **The figures from chapters 2, 3, 6 of [SSY, 1999] are reproduced with the new code**

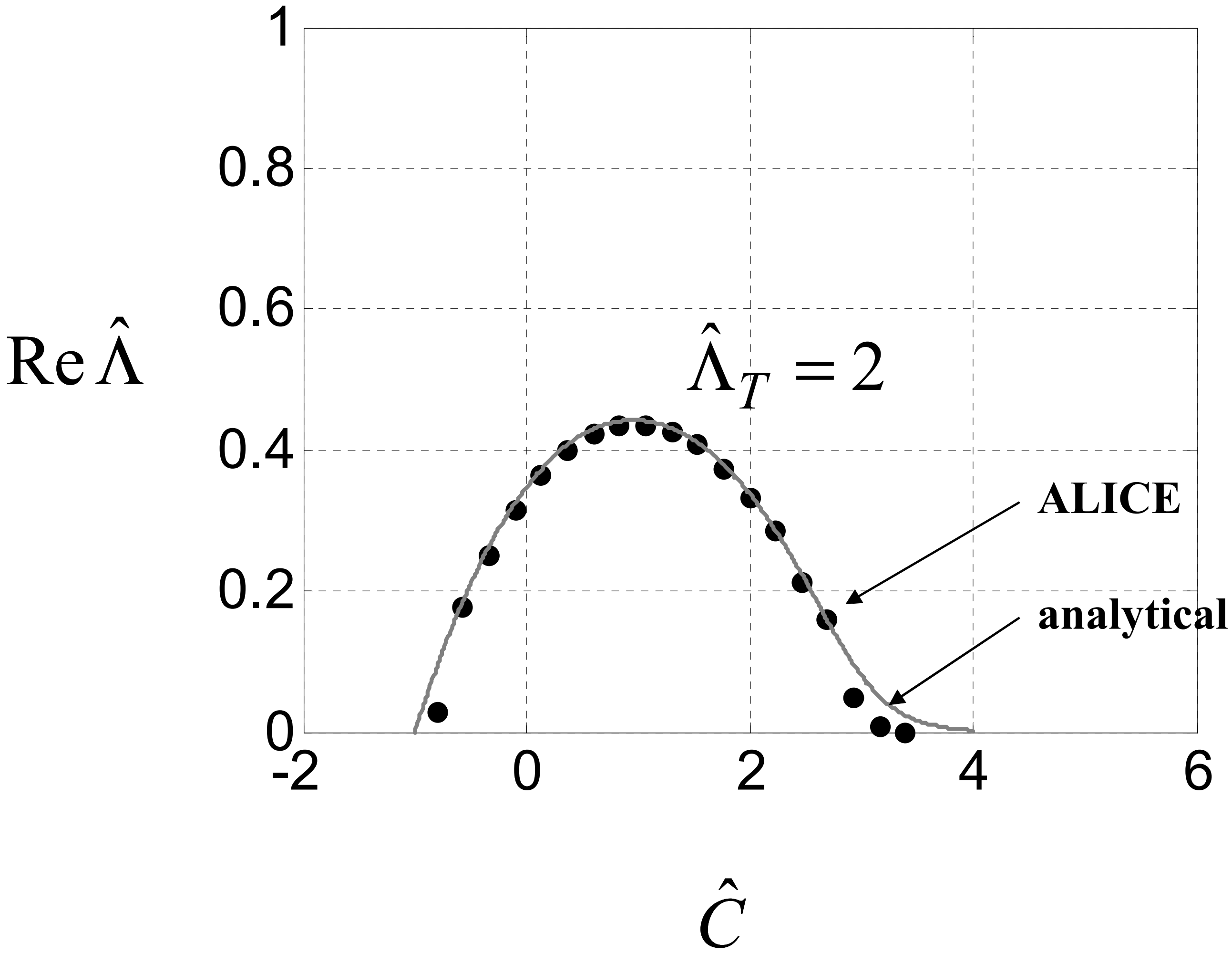
[SSY, 1999] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, Springer, 1999

Tests. Space charge algorithm (1D)



Field growth rate.

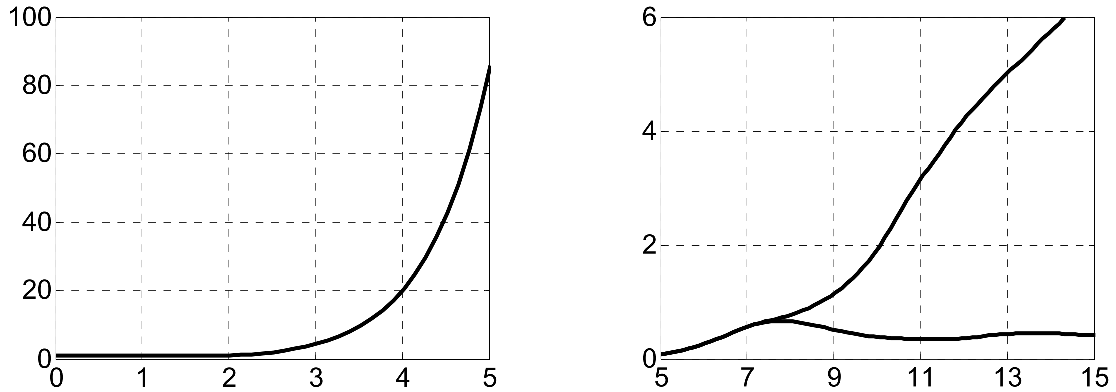
Tests. Energy spread algorithm (1D)



Field growth rate.

Tests. Tapering (3D)

ALICE



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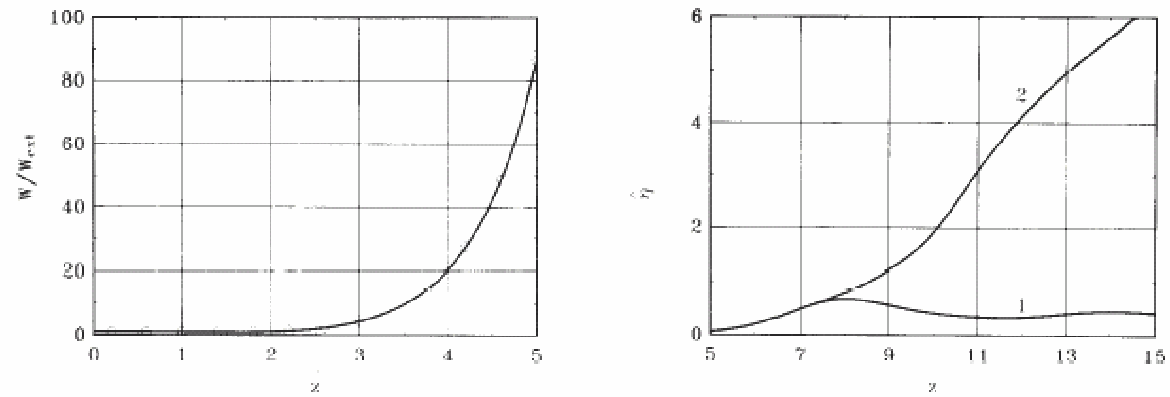


Fig. 11.1. The power gain at the linear stage of amplification. The curve is calculated with the initial problem solution code and the circles are calculated with the nonlinear simulation code. Here $B = 1$, $\hat{C} = 0$, $\hat{\Lambda}_p^2 = 0$, $\hat{\Lambda}_T^2 = 0$, $N = 5$, $M = 100$, $\hat{w} = 1.2$.

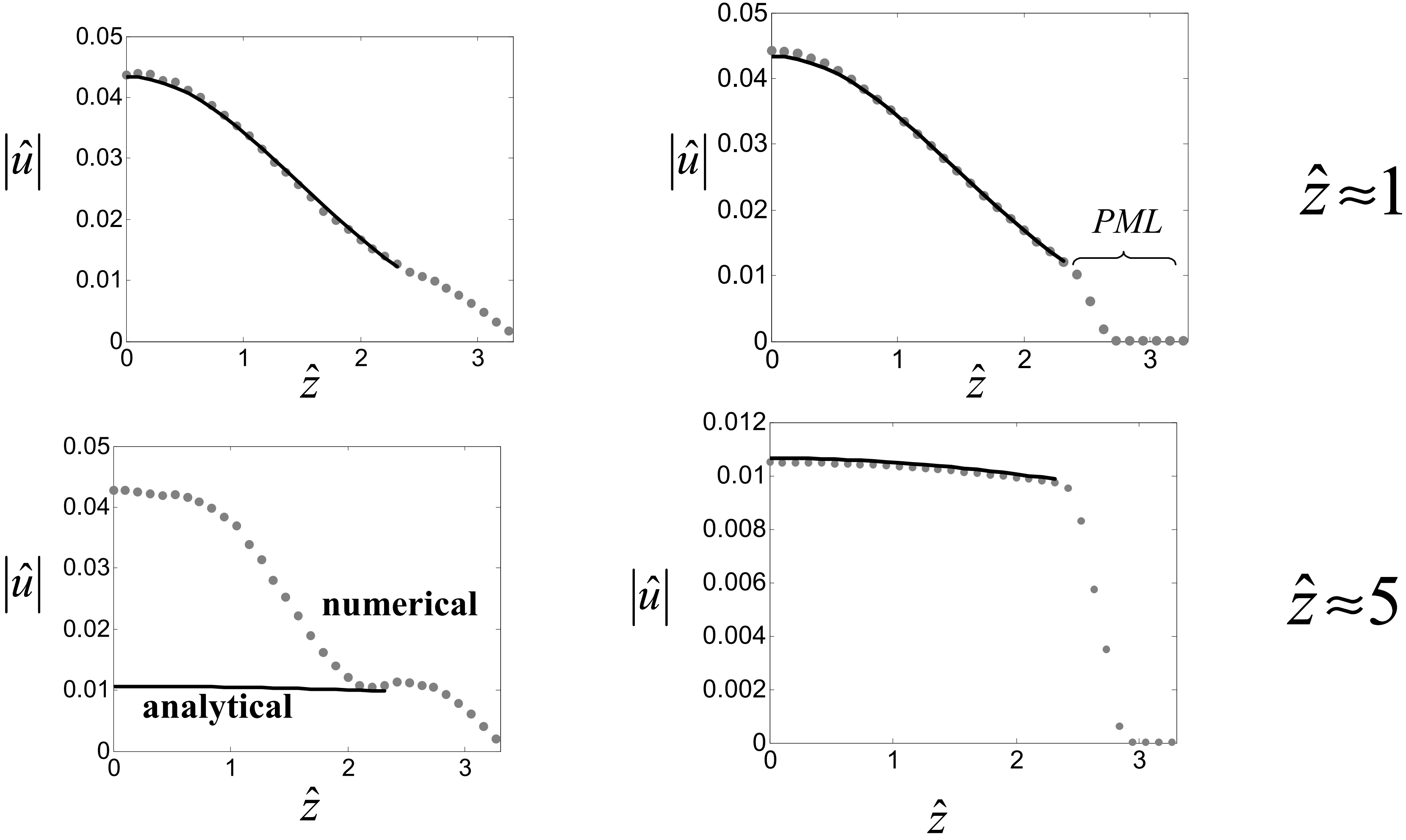
Fig. 11.2. The reduced efficiency $\hat{\eta}$ versus the interaction length. Here $B = 1$, $\hat{C} = 0$, $\hat{\Lambda}_p^2 = 0$, $\hat{\Lambda}_T^2 = 0$, $N = 5$, $M = 100$, $\hat{w} = 1.2$ and $\hat{W}_{ext} = 10^{-3}$. Curve (1): without tapering and curve (2): the tapering according to formula (11.6).

*[SSY, 1995] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, An Introduction, Physics Reports 260 (1995) 187-327

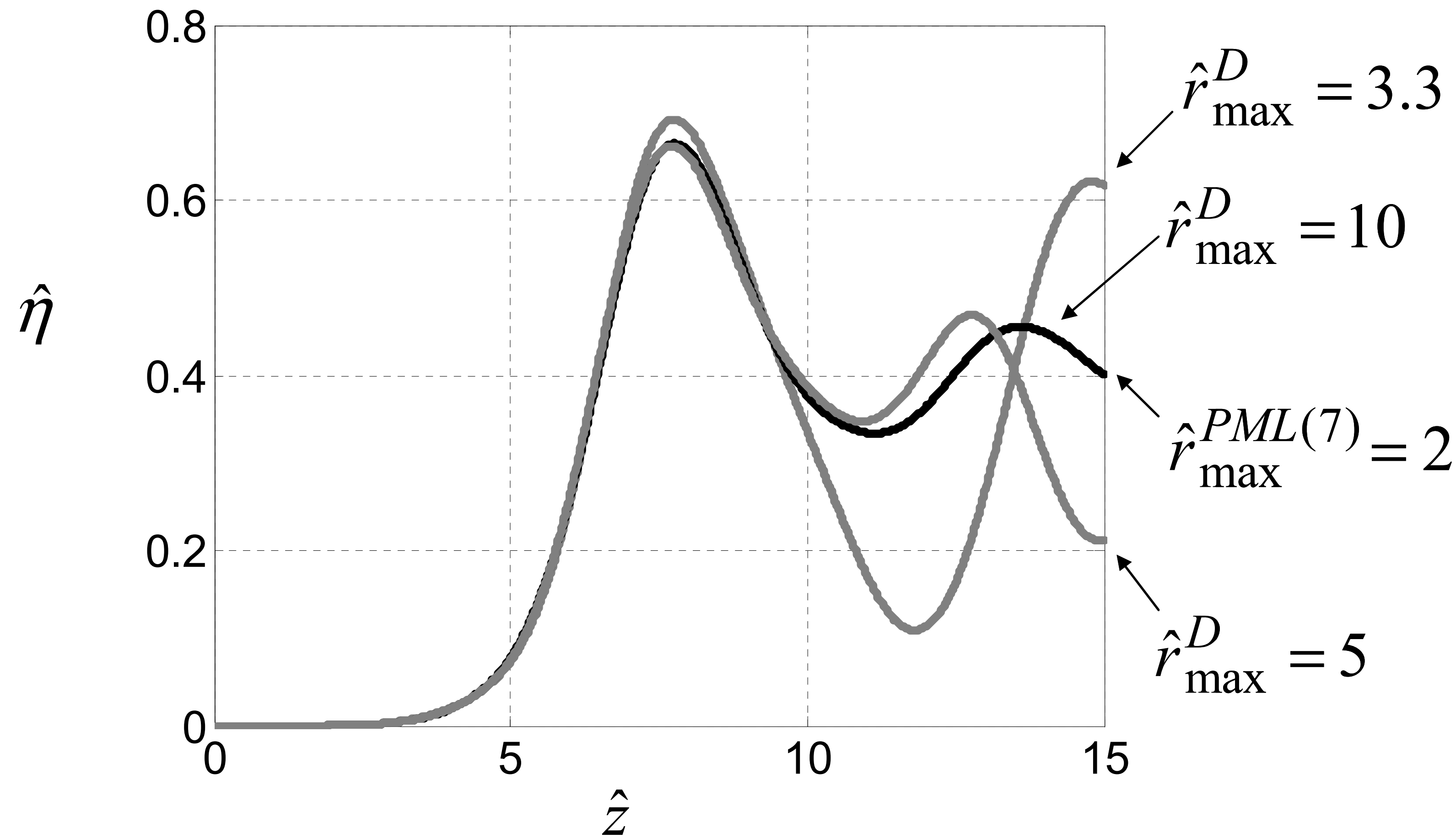
Tests. Field Solver, Perfectly Matched Layer (3D)

Dirichlet BC

PML



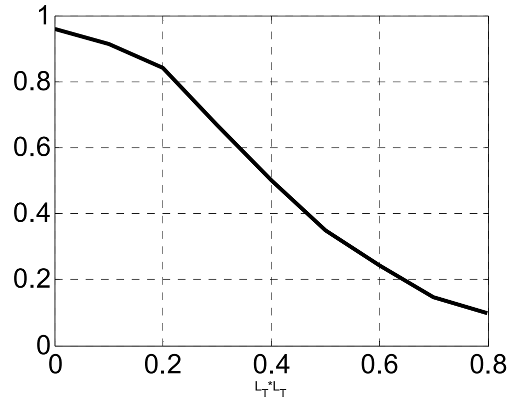
Tests. Field Solver, Perfectly Matched Layer (3D)

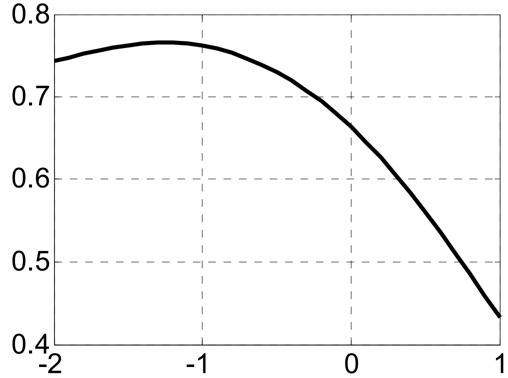


Dirichlet BC vs. PML

Tests. Energy spread and diffraction (3D)

ALICE





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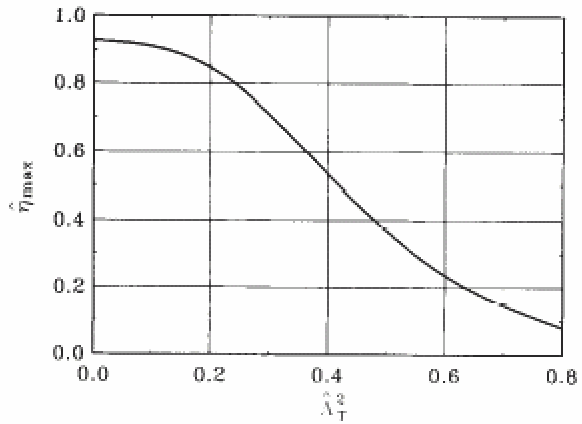


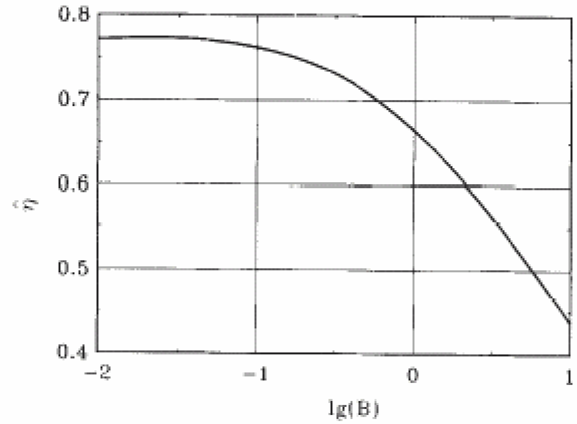


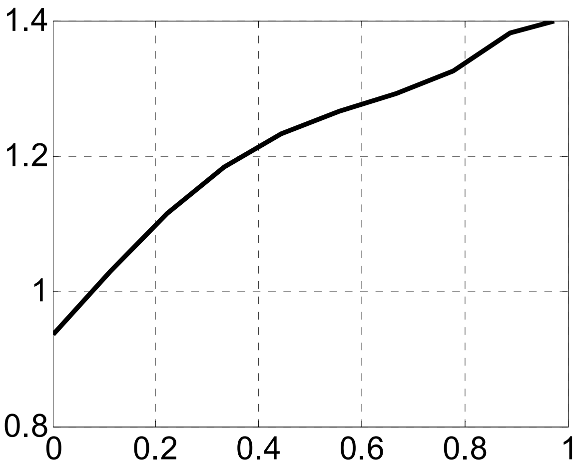
Fig. 11.5. The reduced efficiency $\hat{\eta}$ at the saturation versus the energy spread parameter $\hat{\Lambda}_T^2$. Here $B = 1$ and $\hat{\Lambda}_p^2 = 0$. (The detuning parameter corresponds to the maximum gain at the linear high-gain limit).

Fig. 11.6. The reduced efficiency $\hat{\eta}$ at the saturation versus the diffraction parameter B. Here $\hat{C} = 0$, $\hat{\Lambda}_p^2 = 0$ and $\hat{\Lambda}_T^2 = 0$.

*[SSY, 1995] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, An Introduction, Physics Reports 260 (1995) 187-327

Tests. Space charge (3D)

ALICE



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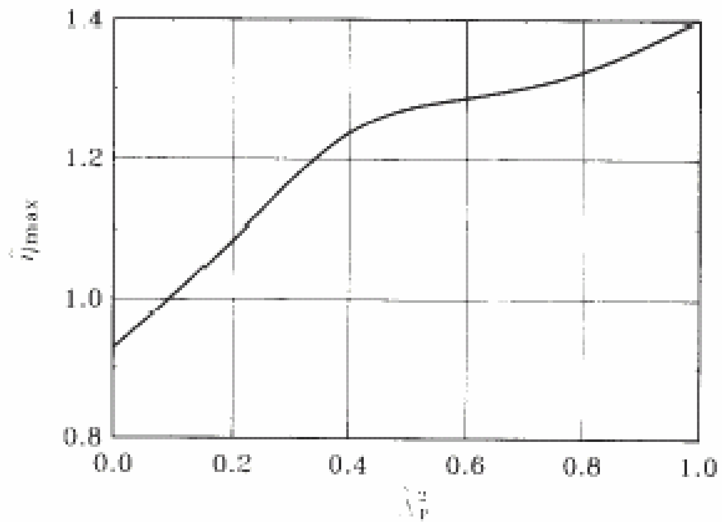
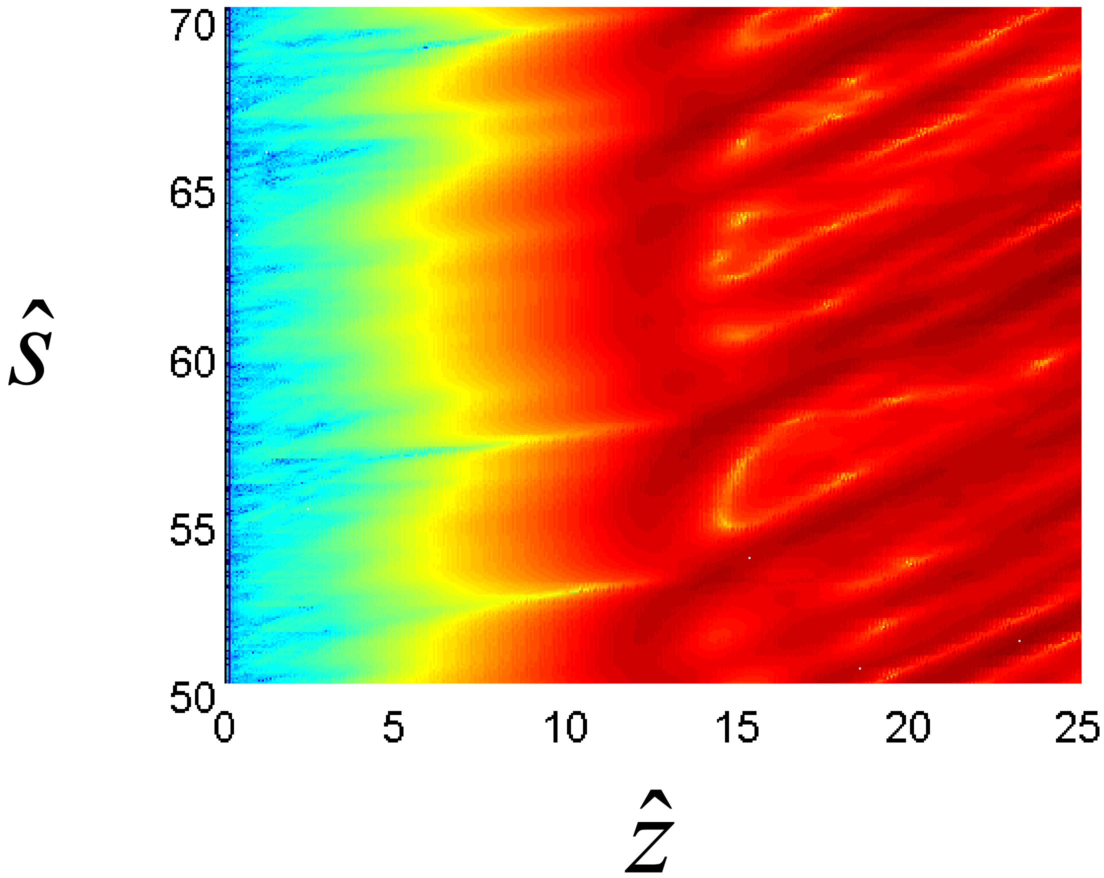


Fig. 11.4. The reduced efficiency $\hat{\eta}$ at the saturation versus the space charge parameter $\hat{\Lambda}_p^2$. Here $B = 1$ and $\hat{\Lambda}_T^2 = 0$. (The detuning parameter corresponds to the maximal increment at the linear high-gain limit).

*[SSY, 1995] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, An Introduction, Physics Reports 260 (1995) 187-327

Tests. SASE (1D)

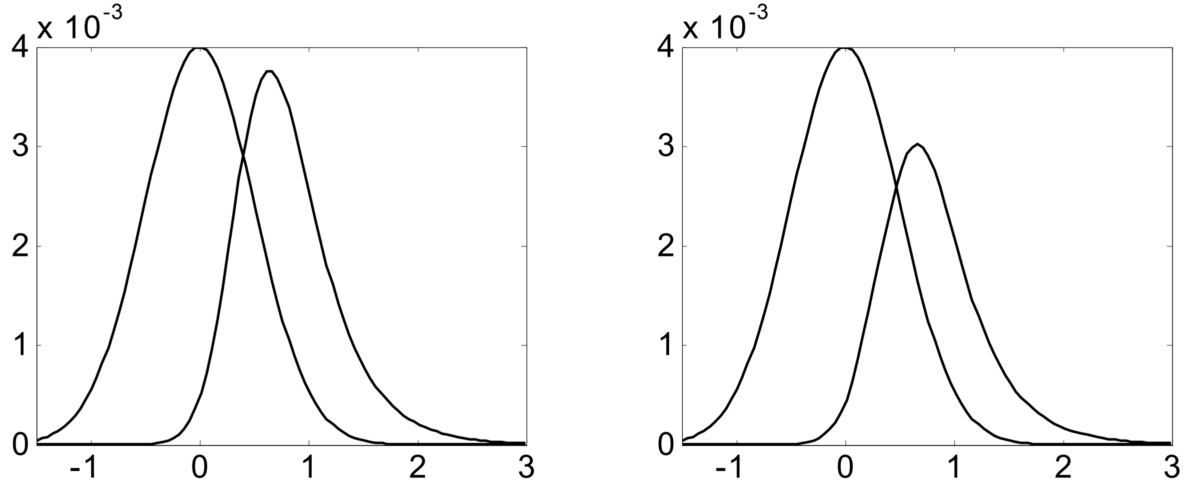


ALICE

Normalized power in the radiation pulse

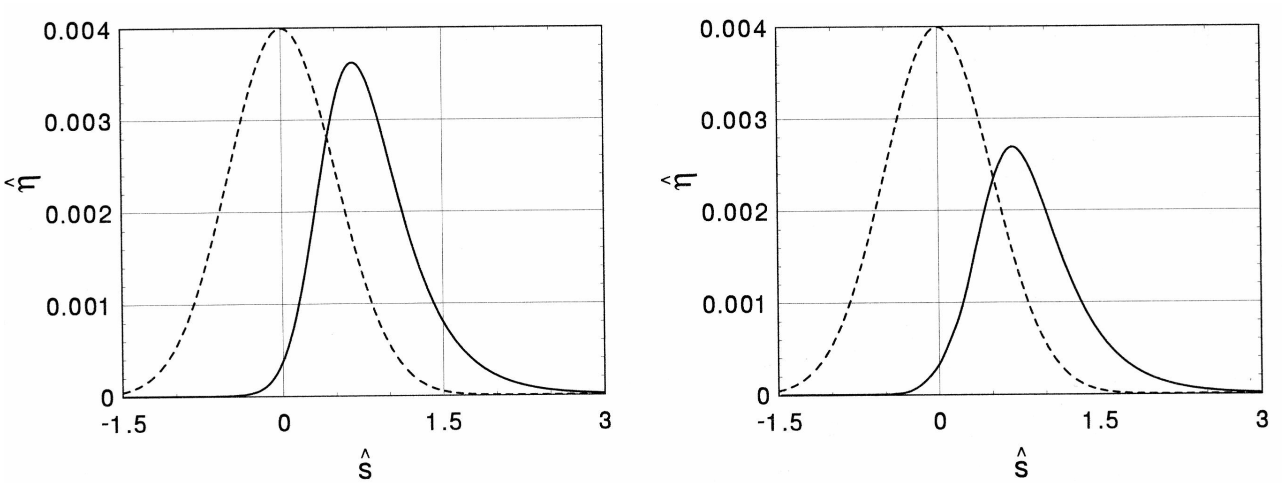
Tests. SASE, Gaussian axial bunch profile (1D)

ALICE



$\hat{\sigma}_b = 0.5$

FAST*

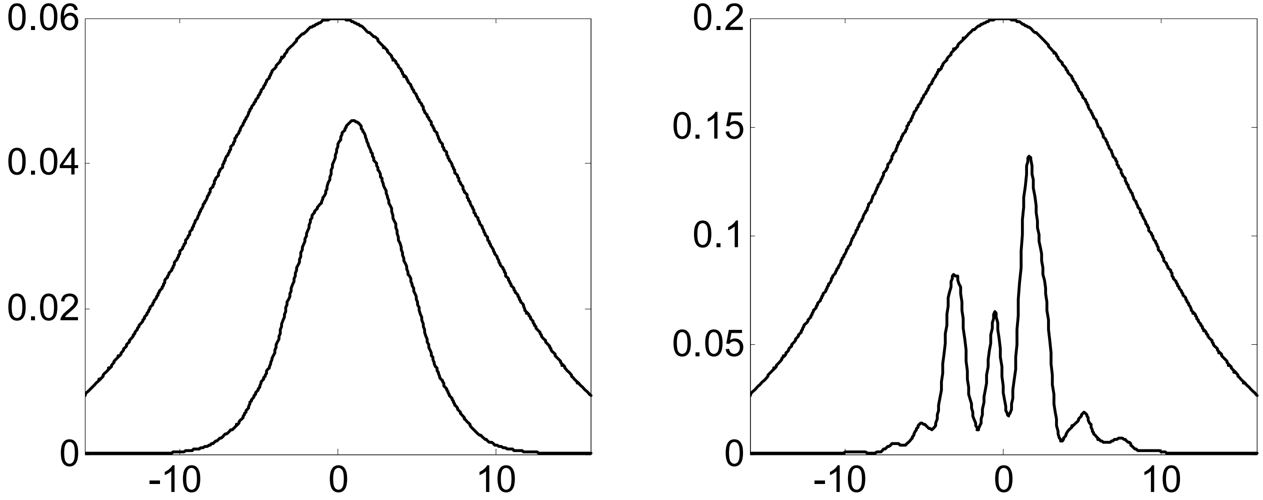


*[SSY, 1999] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, Springer, 1999

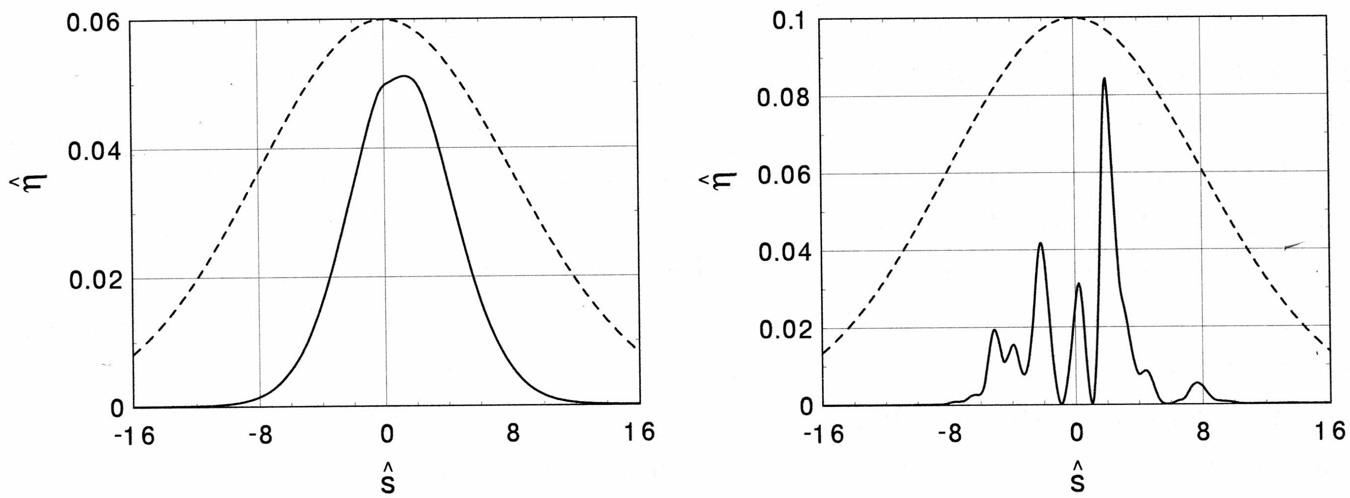
Tests. SASE, Gaussian axial bunch profile (1D)

ALICE

$\hat{\sigma}_b = 8$

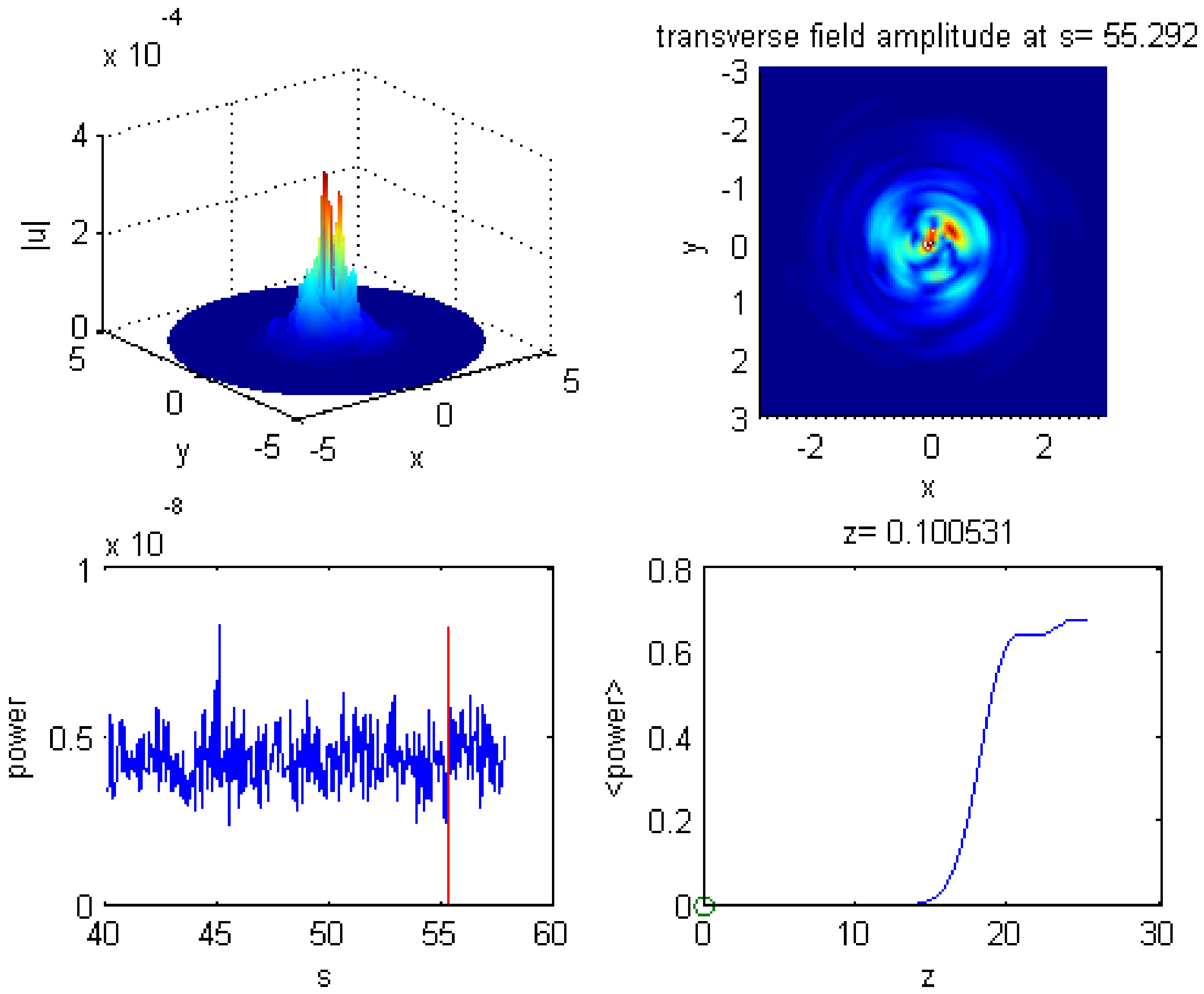


FAST*

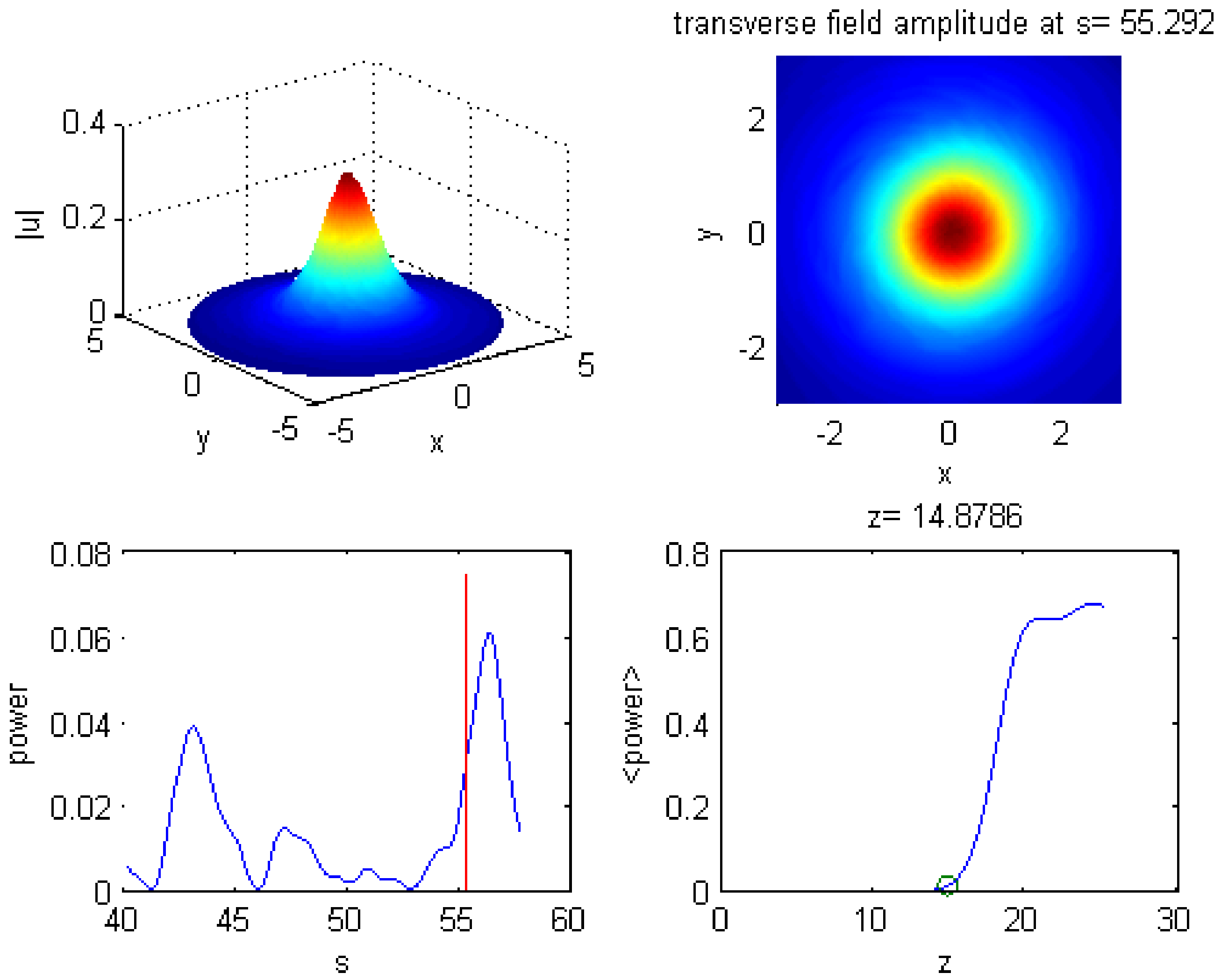


*[SSY, 1999] E.L.Saldin, E.A.Schneidmiller, M.Y.Yurkov, The Physics 0f Free Electron Lasers, Springer, 1999

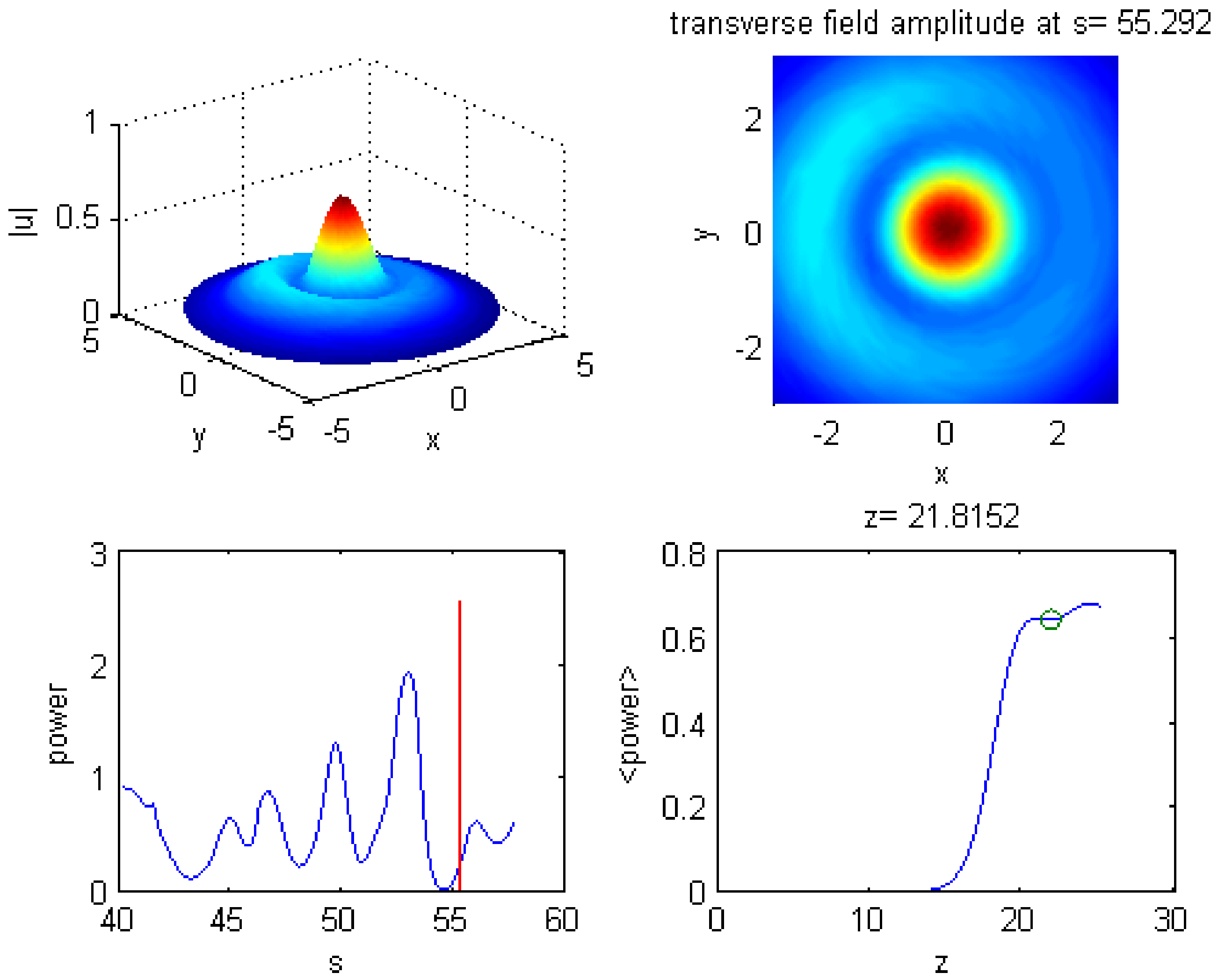
Longitudinal and transverse coherence (SASE, 3D)



Longitudinal and transverse coherence (SASE, 3D)



Longitudinal and transverse coherence (SASE, 3D)



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