Statistical properties of radiation in TTF2 (Genesis simulations)

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5.12.05

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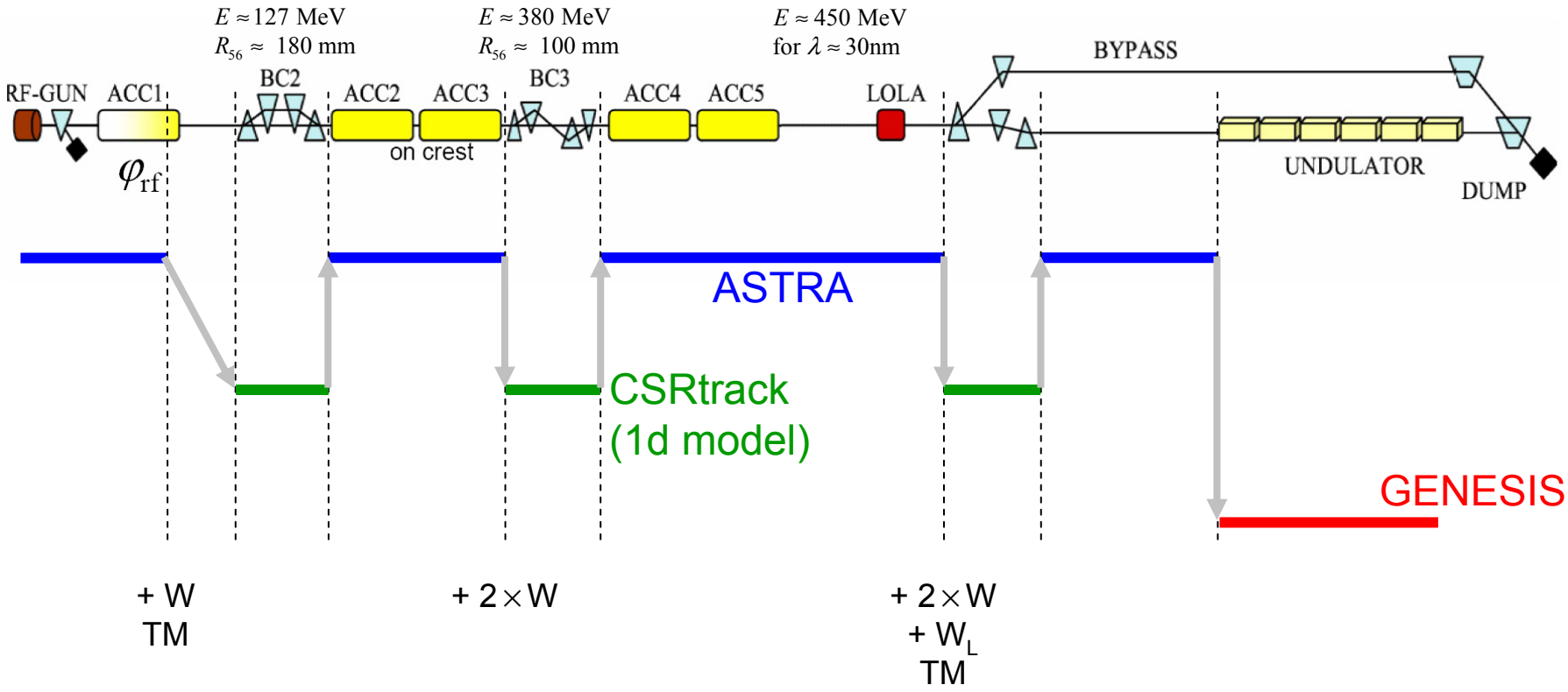
TTF2 – s2e

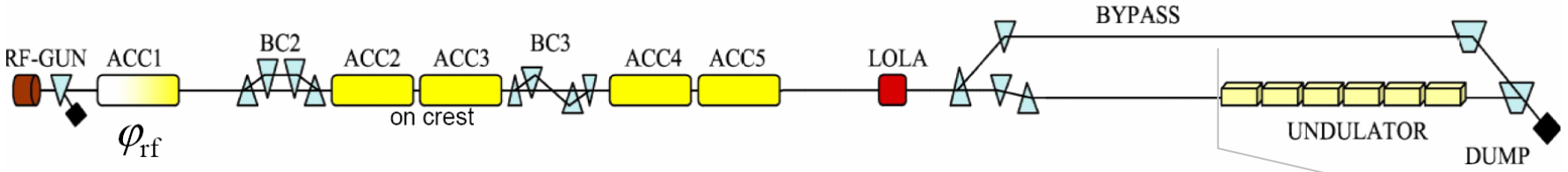


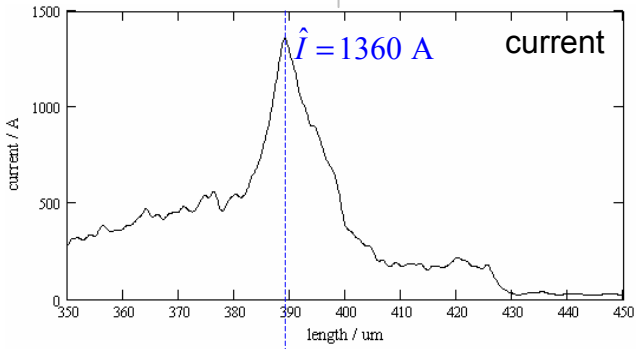
W = wake of one TTF module

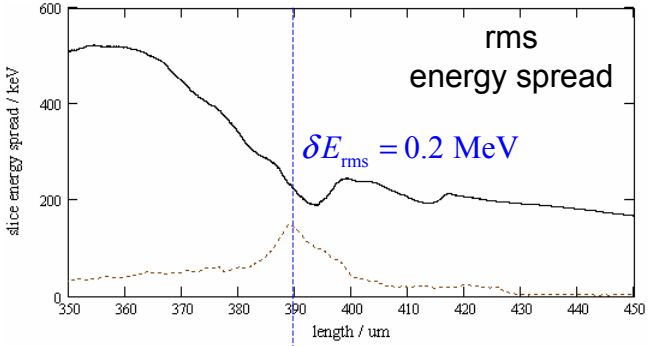
W_L = wake of LOLA structure

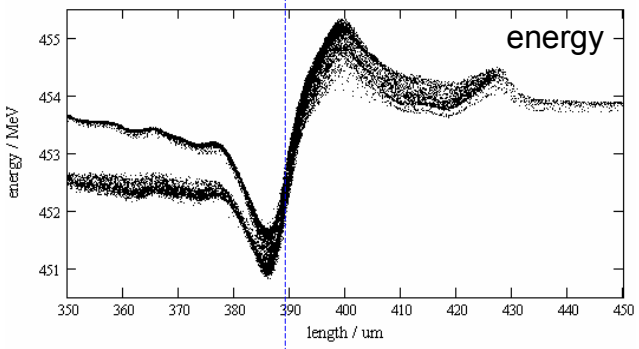
TM = transverse matching to design optic

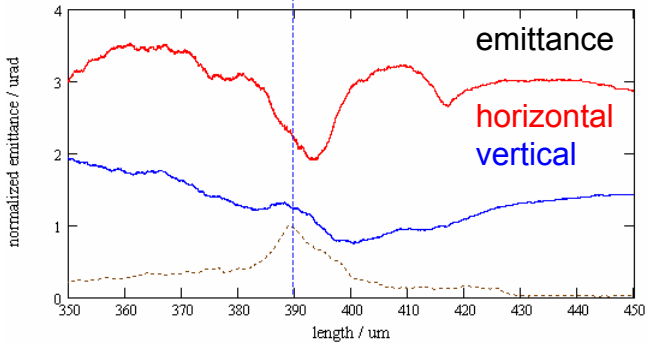
M.Dohlus

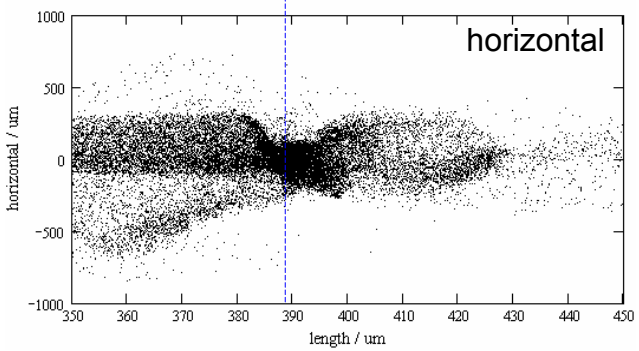

RF-GUN
ACC1
BC2
ACC2
ACC3
BC3
ACC4
ACC5
LOLA
BYPASS
UNDULATOR
DUMP
on crest
φ_{rf}

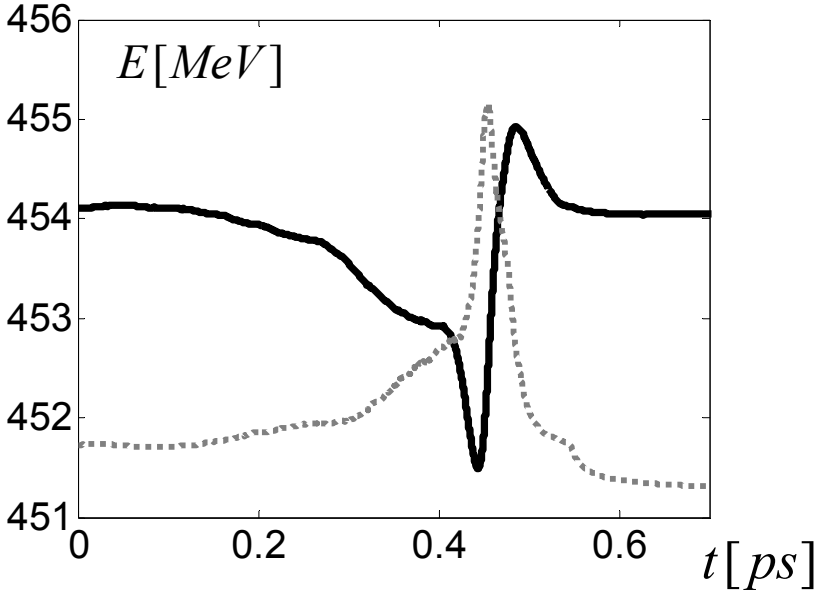

current
$\hat{I} = 1360$ A
current / A
length / um

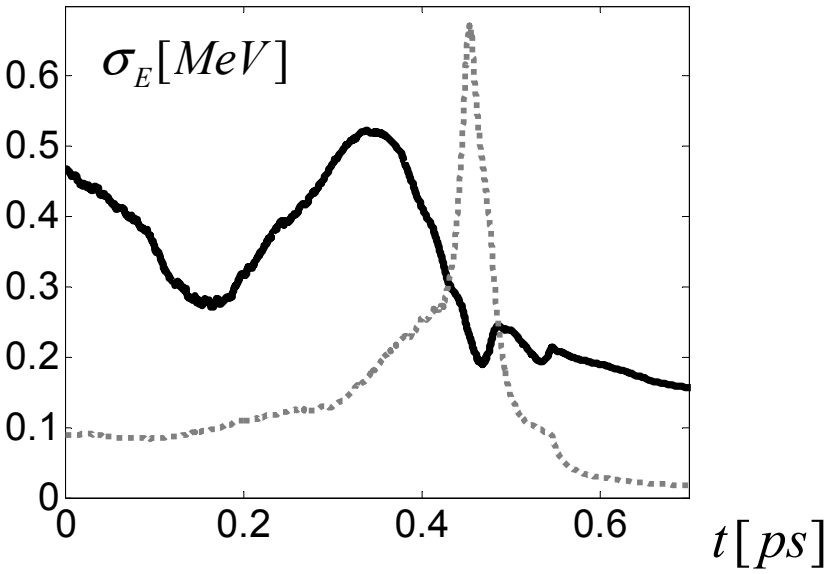

rms
energy spread
$\delta E_{rms} = 0.2$ MeV
slice energy spread / keV
length / um

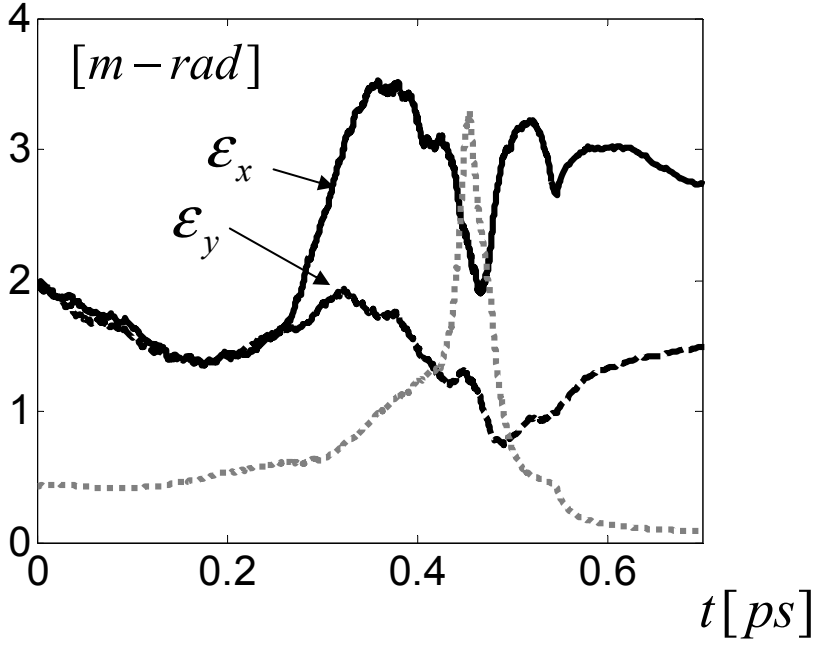

energy
energy / MeV
length / um

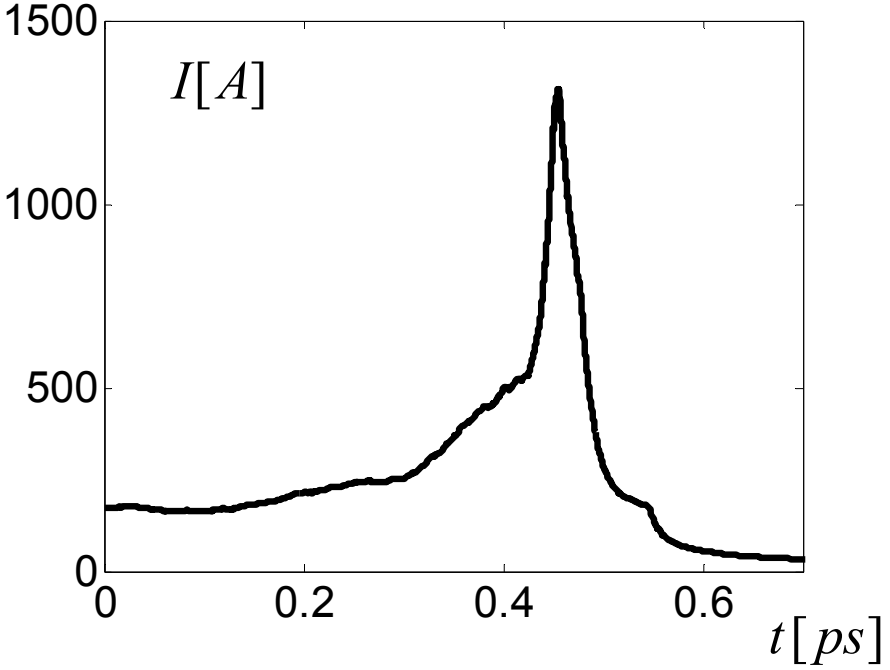

emittance
horizontal
vertical
normalized emittance / urad
length / um


horizontal
horizontal / um
length / um

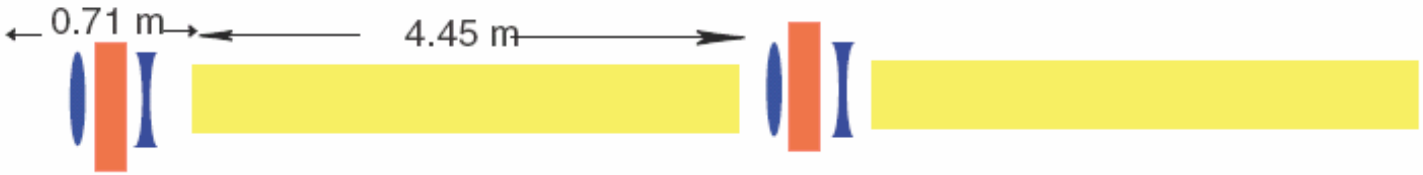

456
455
454
453
452
451
$E[MeV]$
0
0.2
0.4
0.6
$t[ps]$


0.6
0.5
0.4
0.3
0.2
0.1
0
$\sigma_E[MeV]$
0
0.2
0.4
0.6
$t[ps]$


4
3
2
1
0
$[m-rad]$
ε_x
ε_y
0
0.2
0.4
0.6
$t[ps]$


1500
1000
500
0
$I[A]$
0
0.2
0.4
0.6
$t[ps]$

TTF2 Undulator layout



Undulator segment 4.45 m/163.5 periods, undulator period: 27.3 mm

Focusing Defocusing quadrupole 37 T/m with optical length 82 mm

Diagnostic block 327 mm

Total effective (magnetic) undulator length: 26.78 m (6 segments)
Total geometrical length: 31.16 m
Doublet period: 5.17 m
Separation between quadrupole centroids in doublet: 385 mm

parameters

name	symbol	unit	value
energy	γ		886
energy spread	σ_γ		0.47
emmitance	ε_x ε_y	π mm-mrad	2.4 1.14
bunch charge	Q	nC	1
peak current	I_P	kA	1.3
undulator period	λ_u	cm	2.73
undulator parameter	a_u		0.896
quadrupole length	L_Q	cm	12.716
quadrupole gradient	G_F G_D	T/m	10.6 -9.1
section length	L_{sect}	m	4.45+0.75=5.2
total length	L_{total}	m	31.2
beta function (waist)	$\beta_{x,}$ $\beta_{y,}$	m	3.4 5.63

Parameters of the FEL theory

$$\lambda_s = \frac{\lambda_u}{2\gamma^2}\left(1 + a_u^2\right) = 31.348\text{e}\,[\text{nm}]$$

$$z_R = \frac{\pi w_0^2}{\lambda_s} = \frac{2\pi\sigma_r^2}{\lambda_s} = 1.64\,[m]$$

Parameters of the FEL theory

Gain parameter

$$\Gamma_3 = \left[\left(\frac{A_{JJ}\omega_s\theta_l}{c\gamma_l} \right)^2 \frac{I_P}{2\gamma I_A} \right]^{1/2} = 2.5 \qquad \Gamma_1 = \Gamma_3 B^{-1/3} = 1.56$$

Efficiency parameter

$$\rho_3 = \frac{c\gamma_l^2\Gamma_3}{\omega} = 5.4\text{e-}3 \qquad \rho_1 = \frac{c\gamma_l^2\Gamma_1}{\omega} = 3.4\text{e-}3$$

Diffraction parameter

$$B = \Gamma_3\sigma_r^2\frac{\omega_s}{c} = 4.1$$

Effective power of the input signal

$$P_{sh} = 3\rho_1 \frac{W_b}{N_c\sqrt{\pi \ln N_c}} = 20.3\,[W]$$

Gain length*

$$L_g = L_{g0}(1+\delta) \approx 0.767\,[\mathrm{m}]$$

Optimal beta-function

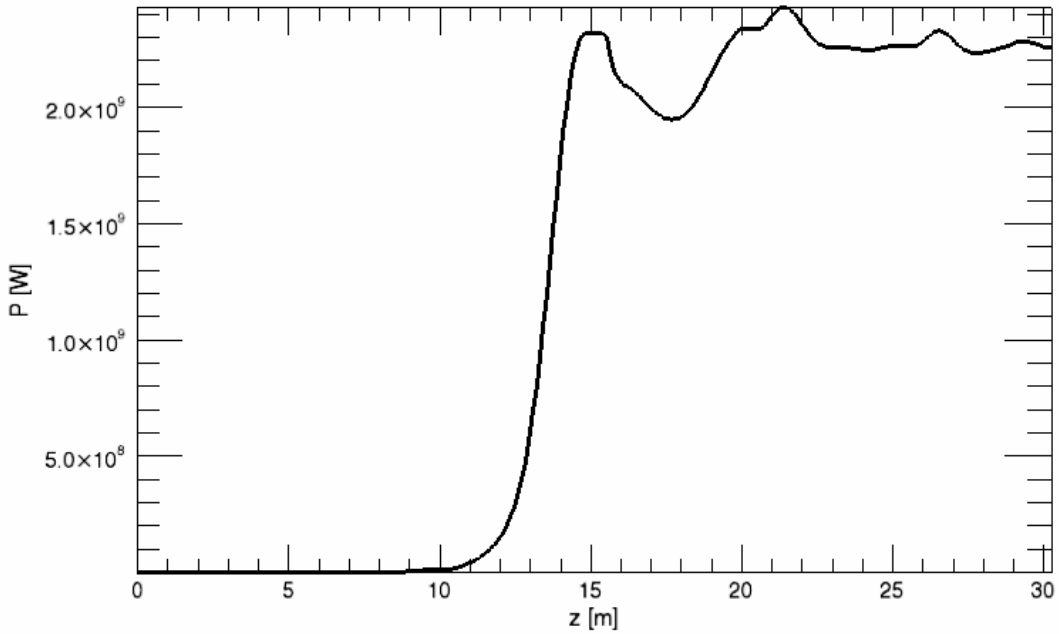
$$\beta_{opt} \approx 0.6\,[\mathrm{m}]$$

Saturation length

$$L_{sat} \approx 10 \div 20 L_{g0} = 8 \div 15\,[\mathrm{m}]$$

* E.L.Saldin et al./Optics Communications 235 (2004) 415-420

Genesis steady state simulation



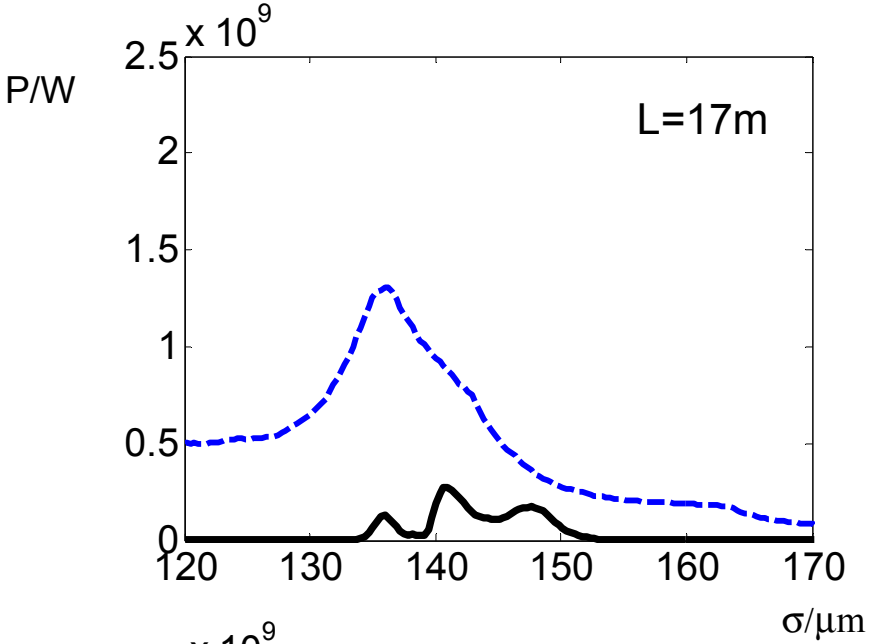
$$\lambda_s^{num} = 31.54\,[\mathrm{nm}]$$

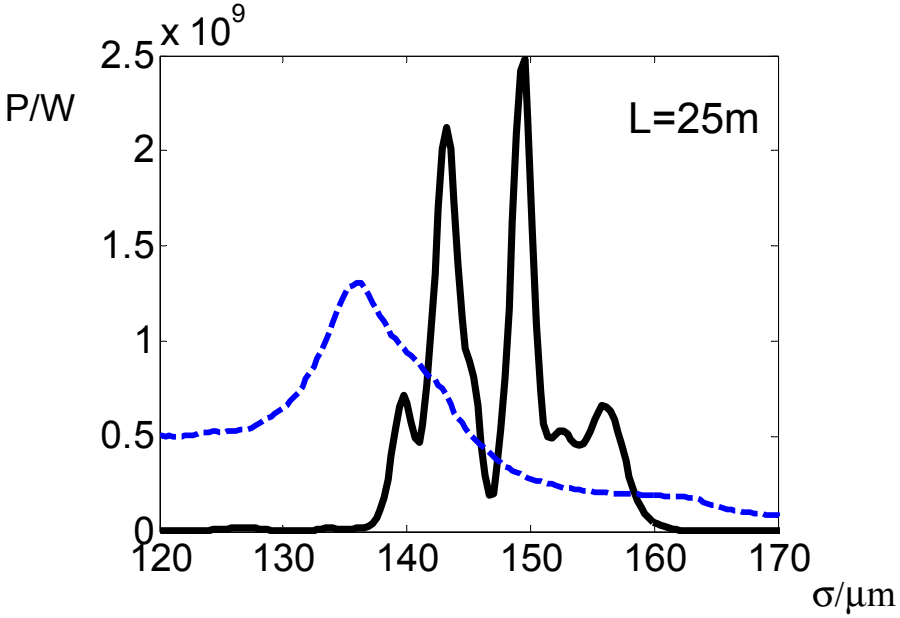
$$L_{sat} = 15\,[\mathrm{m}]$$

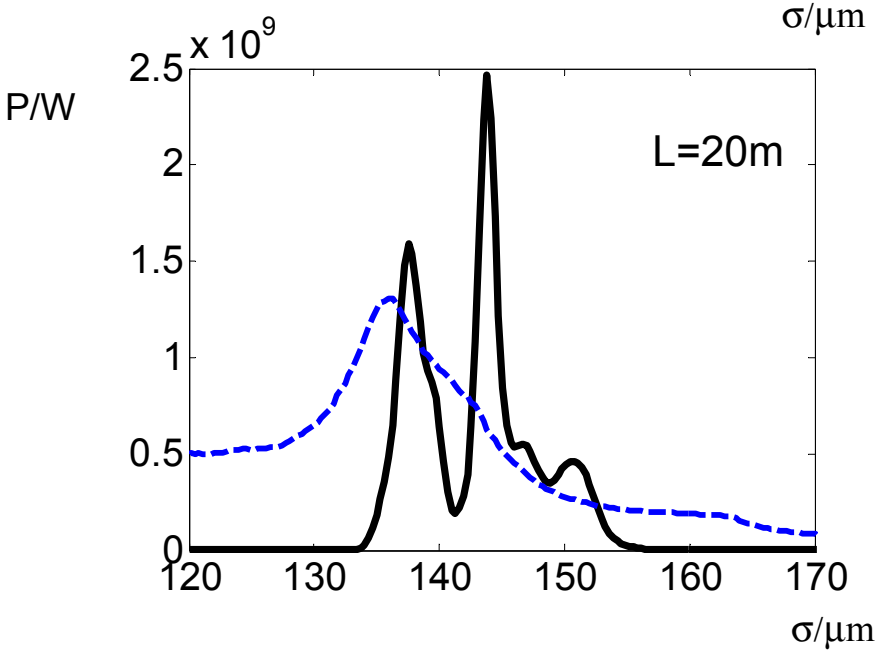
$$L_{slippage} = 37\mu m$$

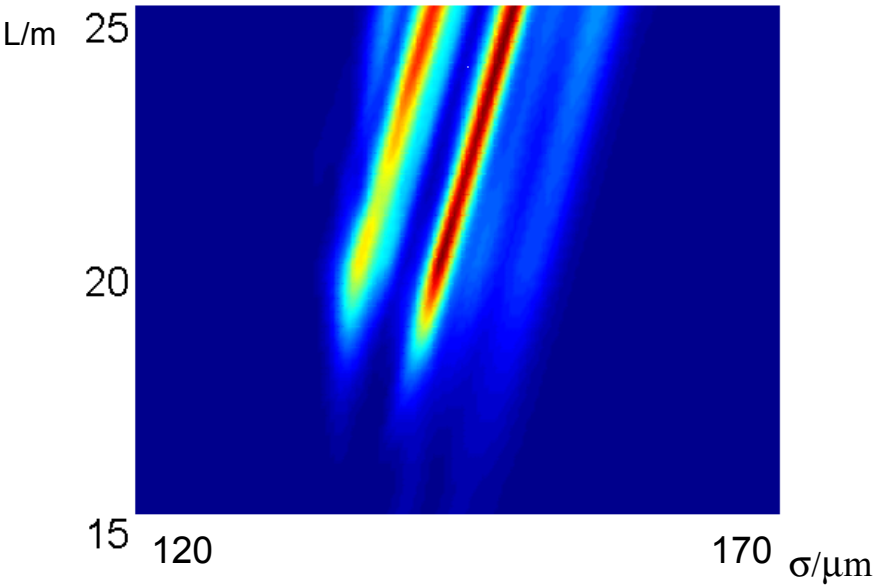
$$L_{cooperation}\ ;\ 2L_g\lambda_s / \lambda_u = 1.76\mu m$$

Genesis (SASE)

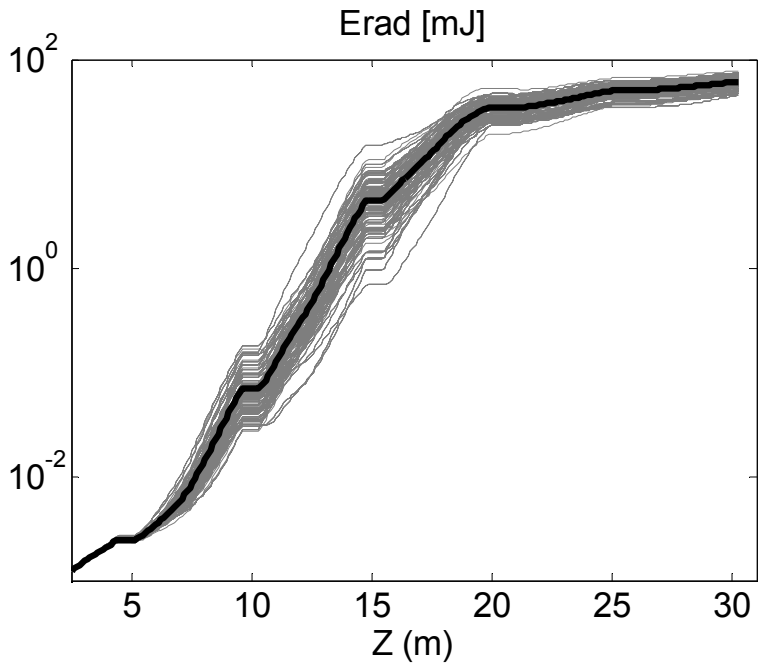


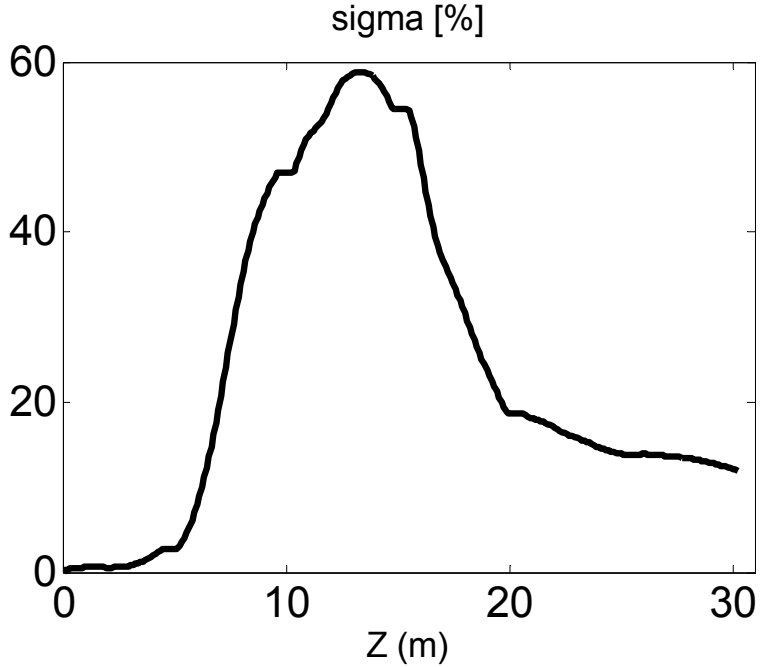


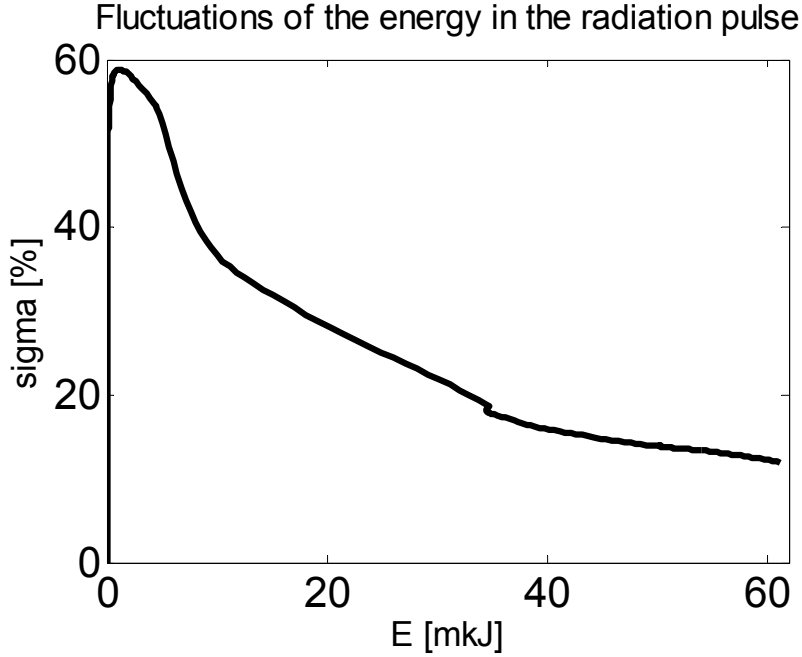




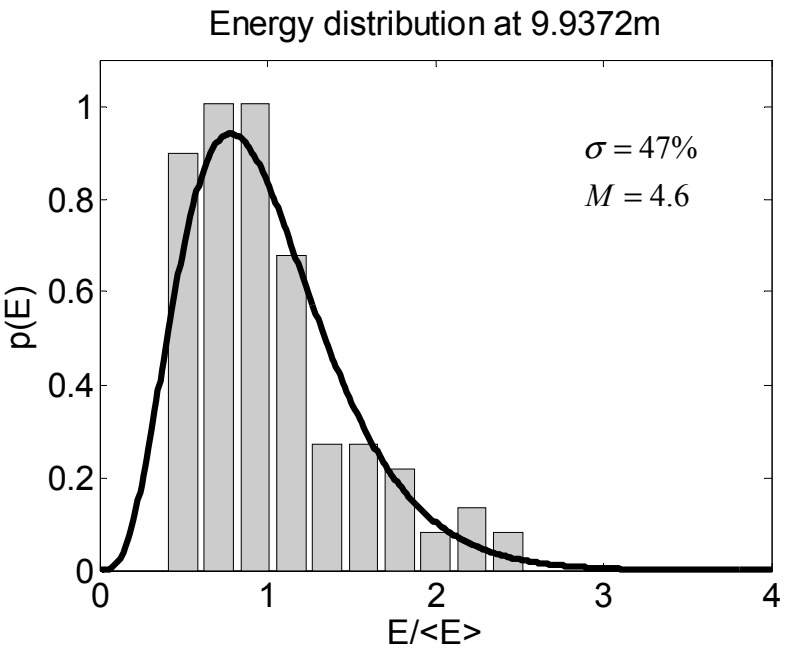
Genesis (SASE, N=170)

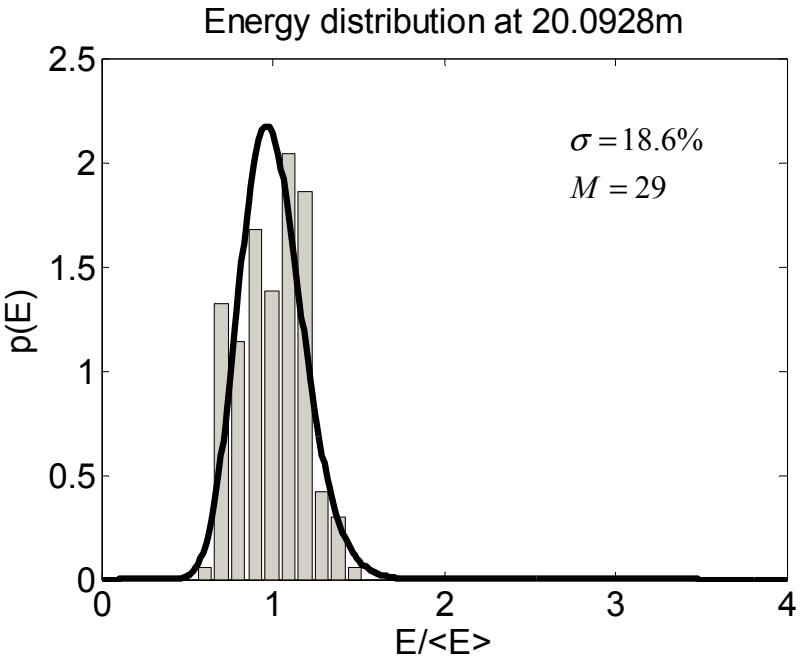


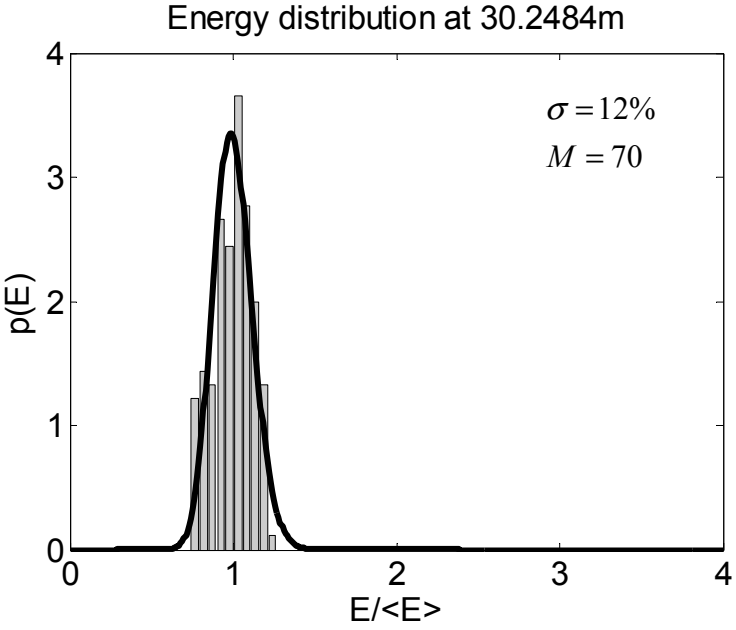




Probability distribution of energy in the radiation pulse (Genesis, N=170)

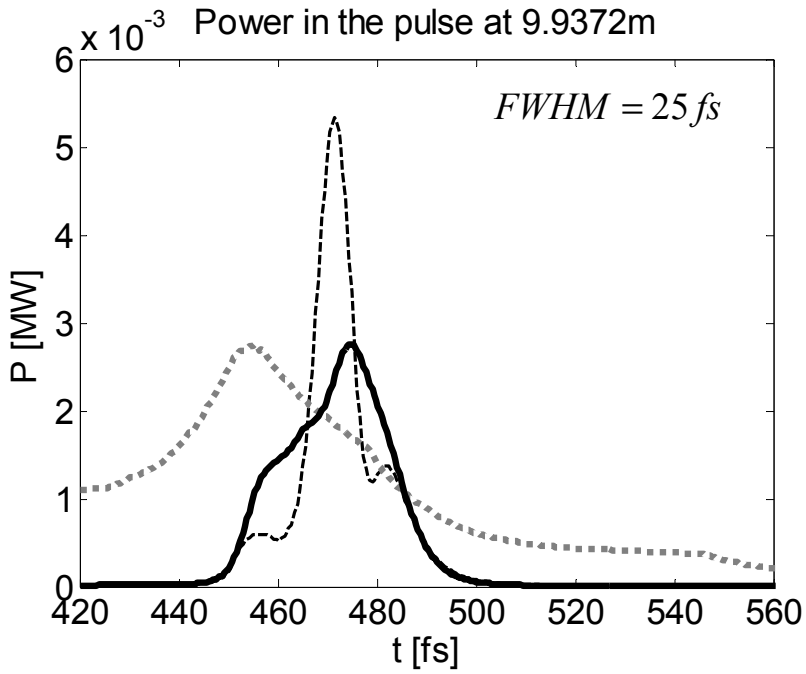


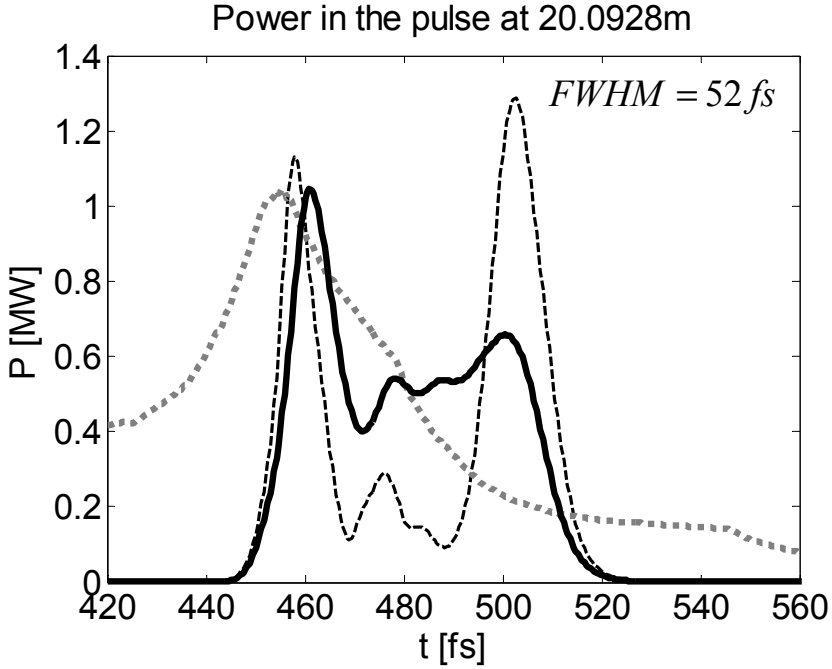


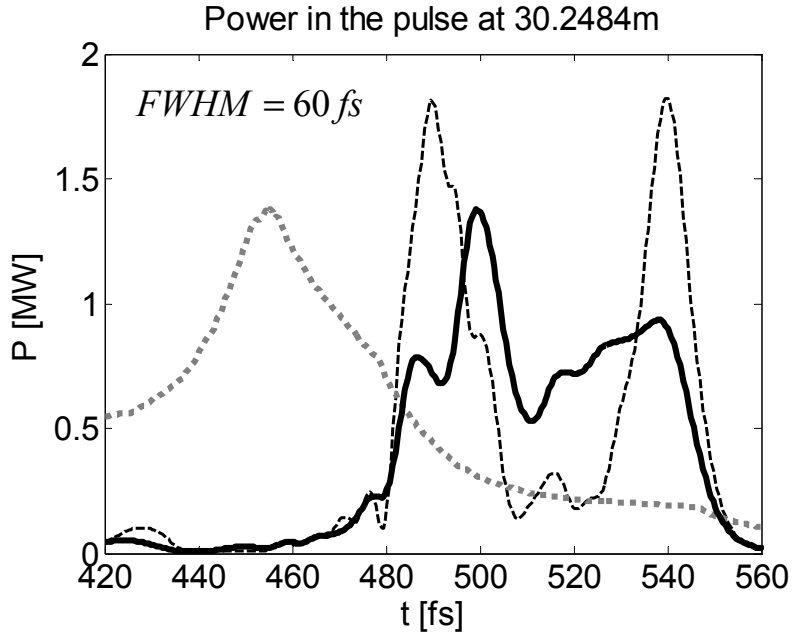


$$p(E) = \frac{M^M}{\Gamma(M)} \left(\frac{E}{\langle E \rangle} \right)^{M-1} \frac{1}{\langle E \rangle} \exp\left(-M \frac{E}{\langle E \rangle} \right)$$

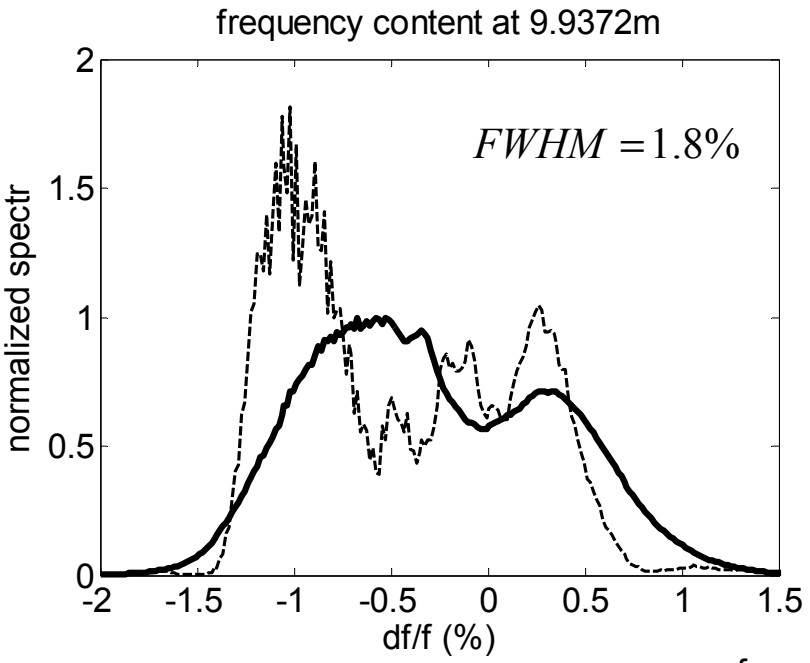
Radiation power in the pulse and pulse duration (Genesis, N=170)

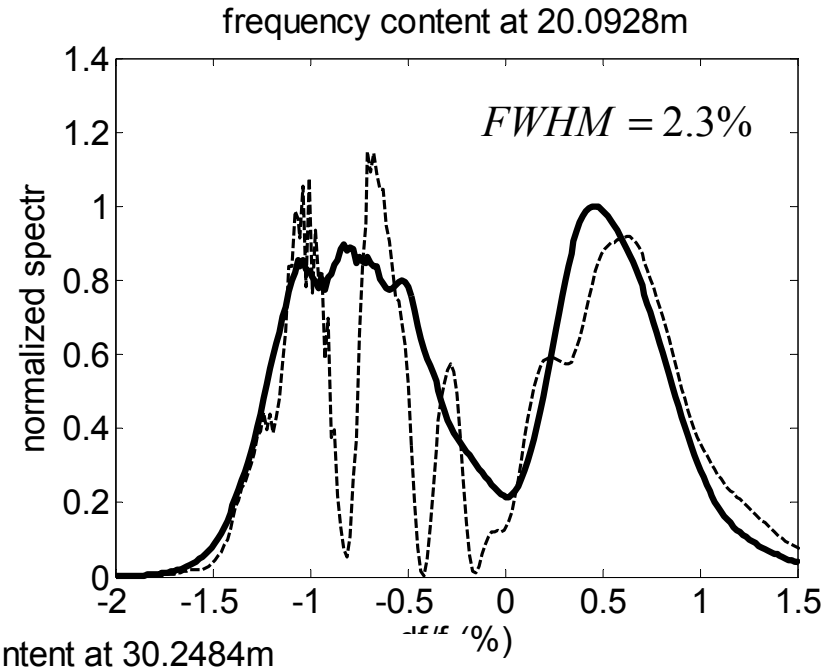


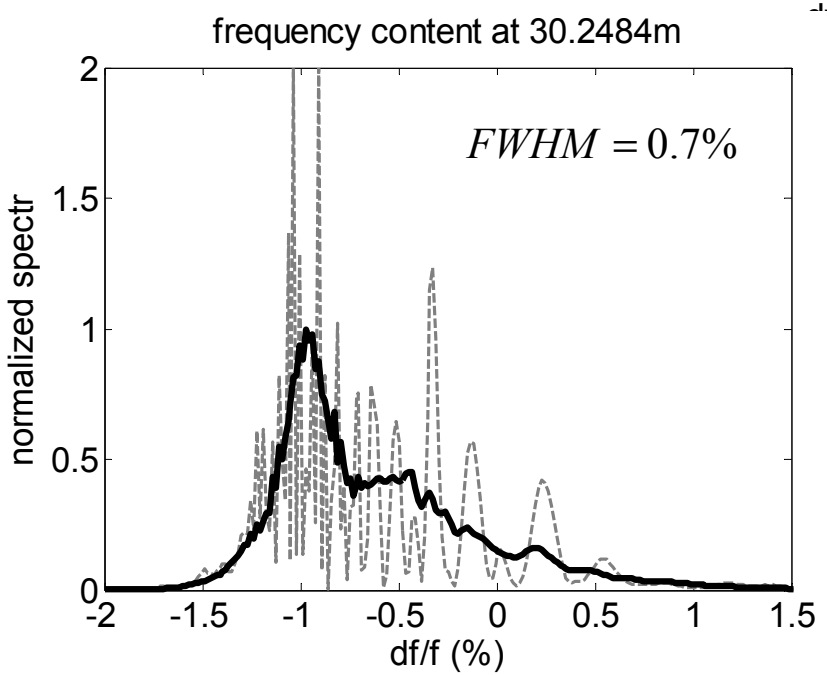




Spectrum of the radiation (Genesis, N=170)



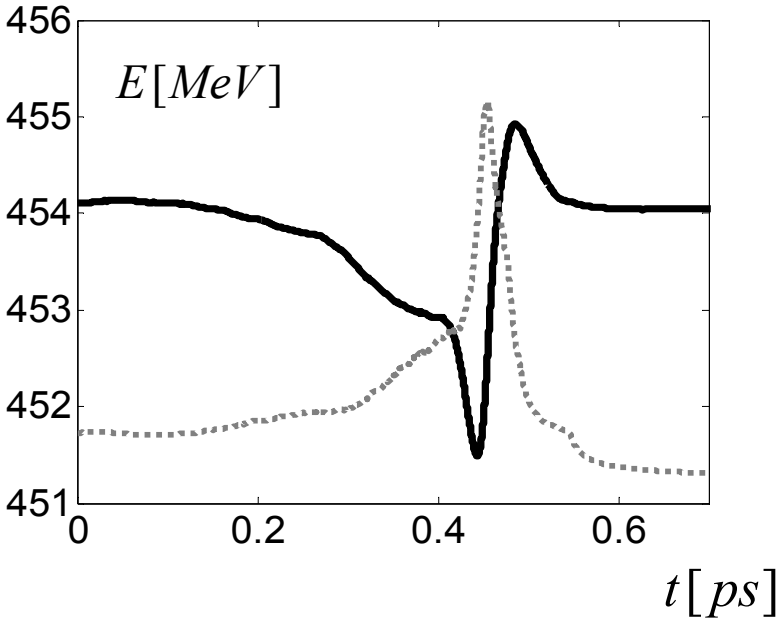


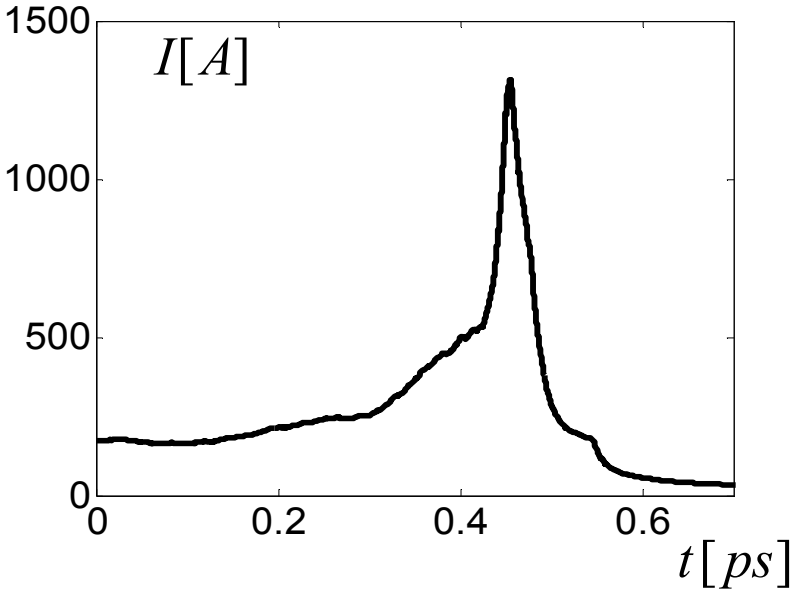


	SSY*	Genesis
Energy, MeV	450	454
Bunch charge, nC	0.5-1	1
Current, kA	1.3-2.2	1.3
Emmitance,mm-mrad	1.5-3.5	2.4/1.4
Saturation length	18-22	~25
Energy in the rad. pulse	50-150	~60
Radiation pulse duration, fs	15-50	60
Radiation peak power, GW	2-4	3.8
Spectrum width, %	0.8	0.7

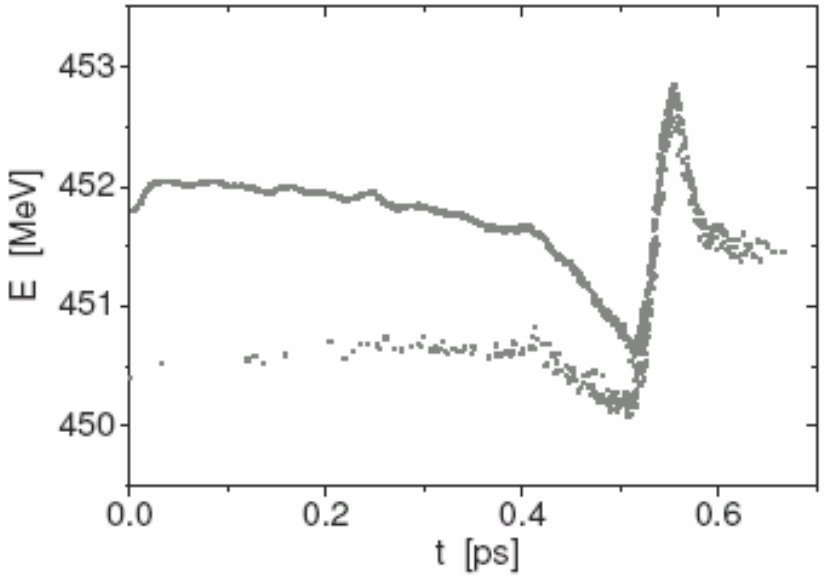
SSY*- E.L.Saldin et al, TESLA FEL 2004-06

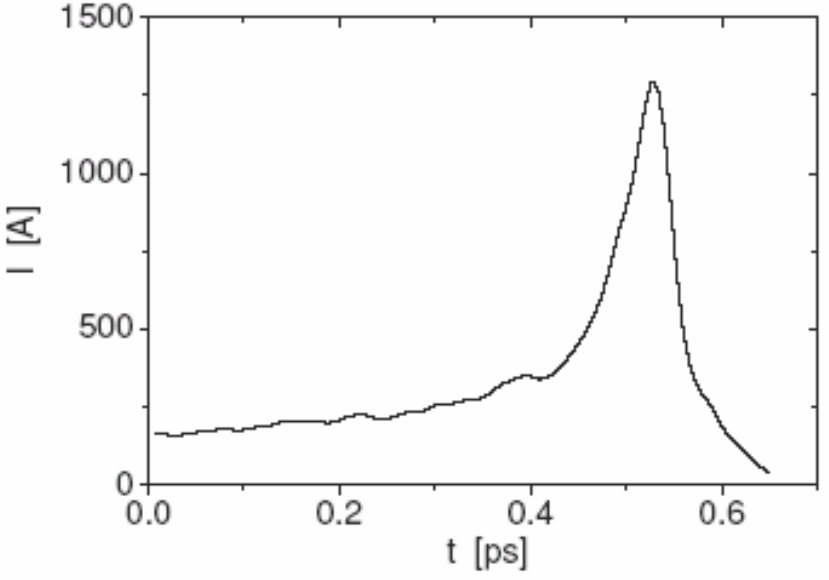
Genesis
30 m with intersections



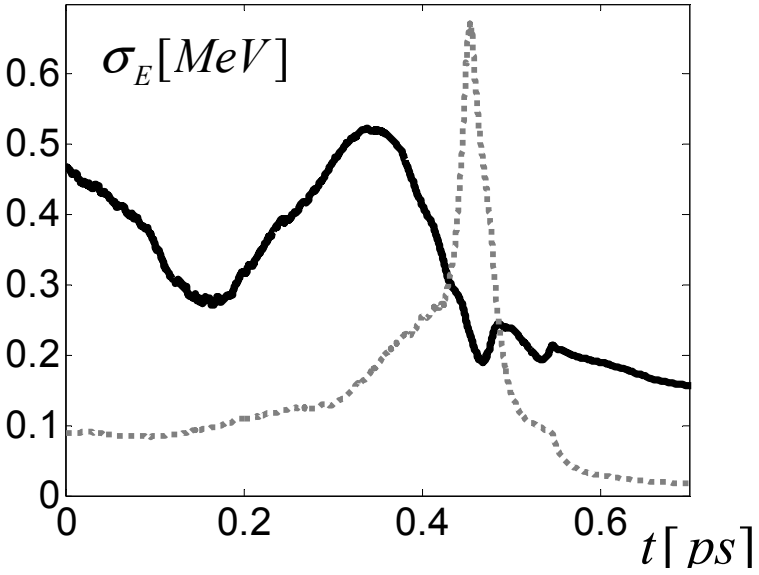


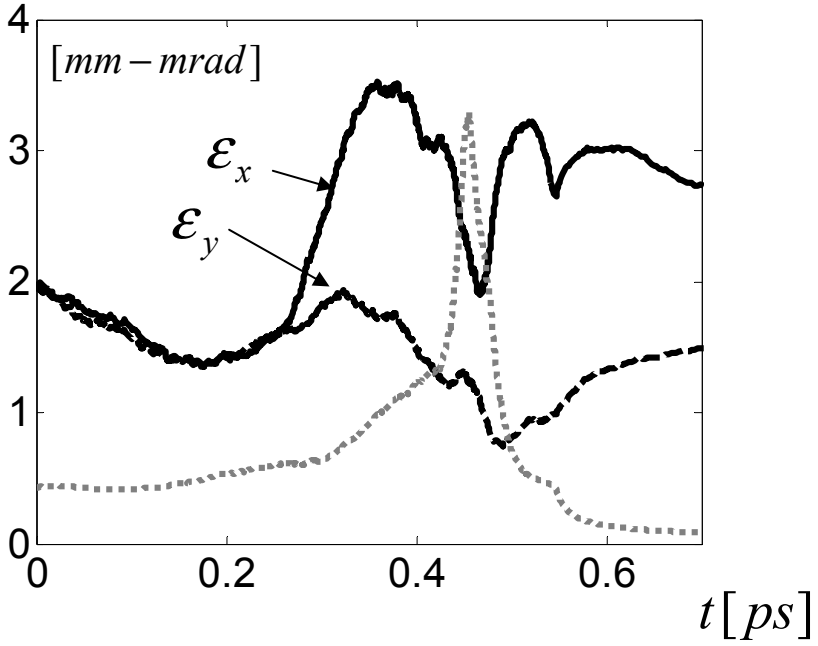
FAST (E.L.Saldin et al., DESY 05-239)
21 m without intersection



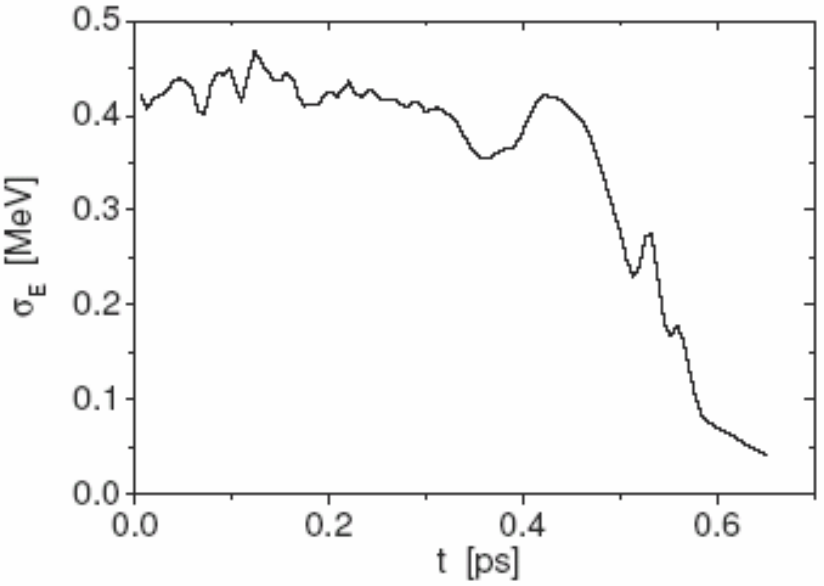


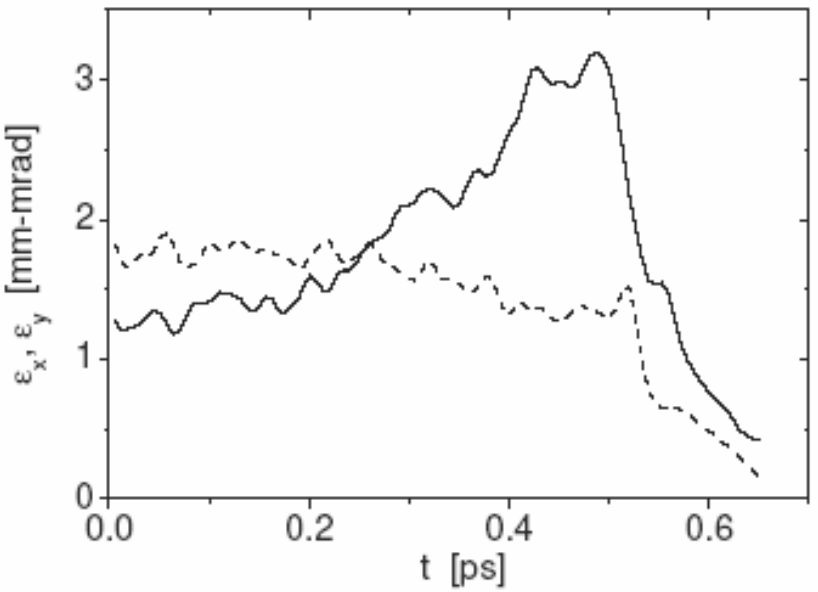
Genesis





FAST (E.L.Saldin et al., DESY 05-239)





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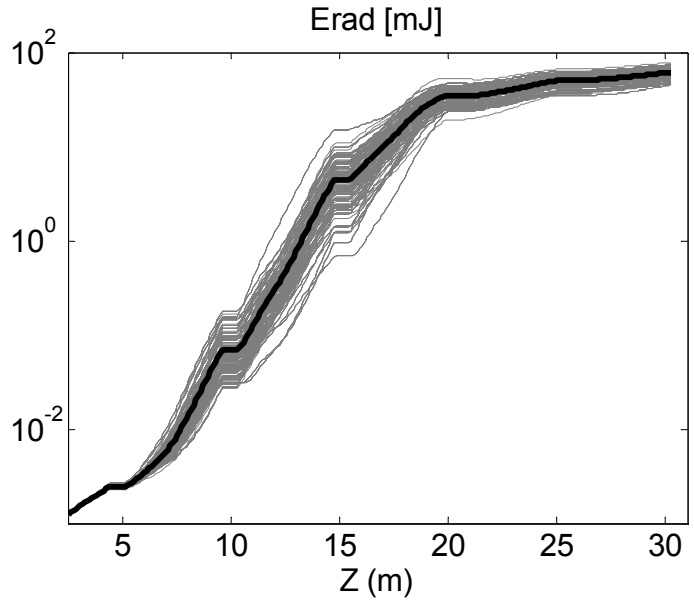
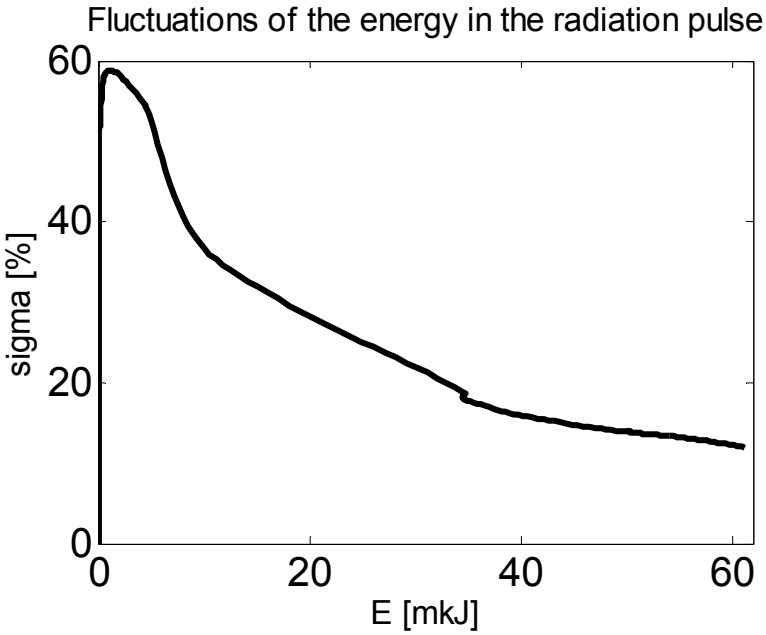
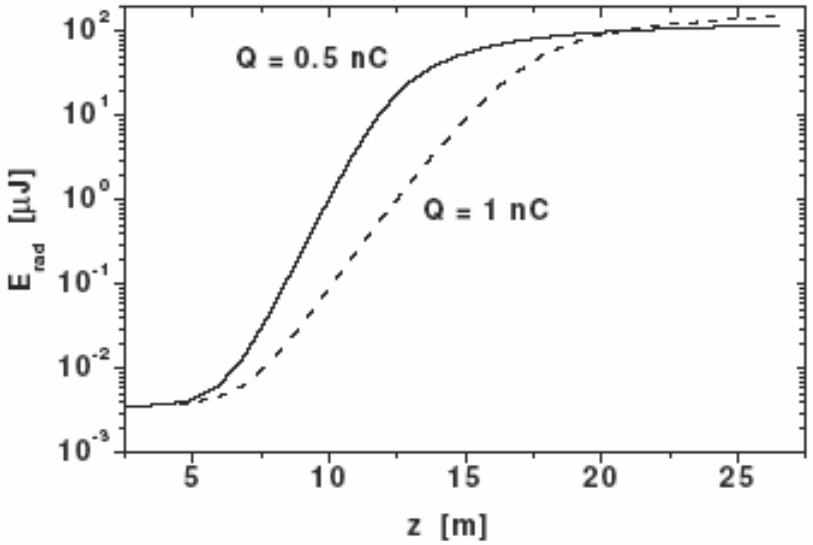
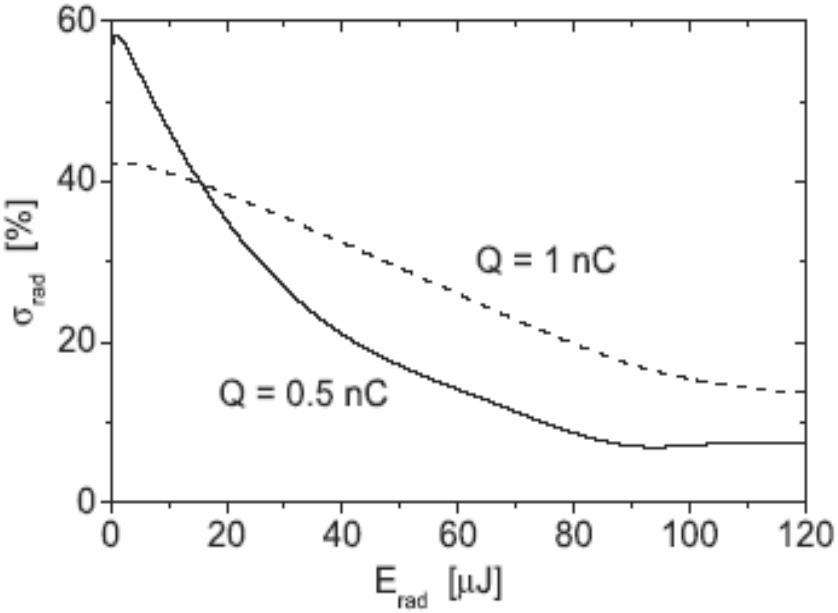




FAST (E.L.Saldin et al., DESY 05-239)





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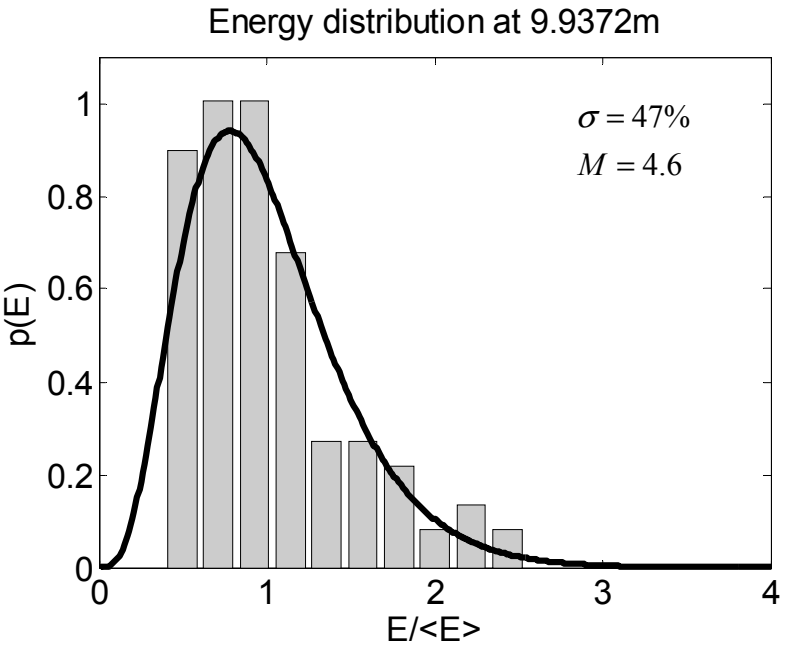
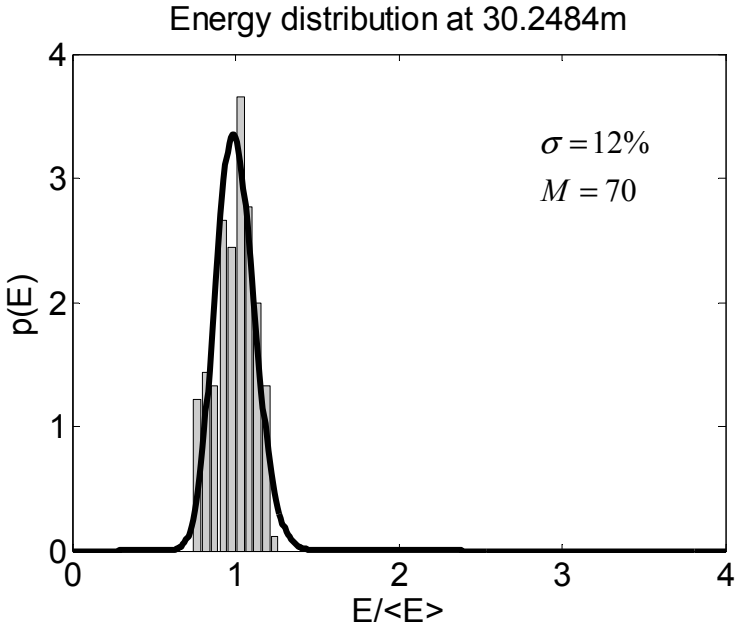
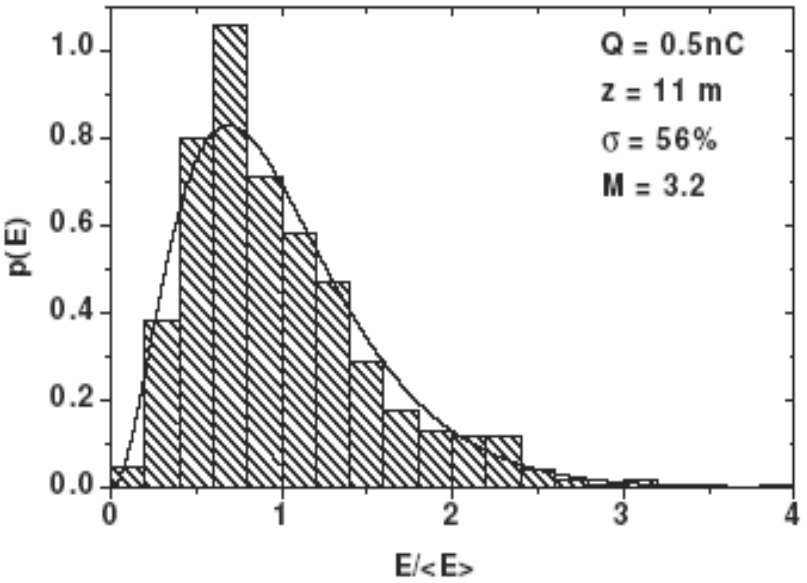
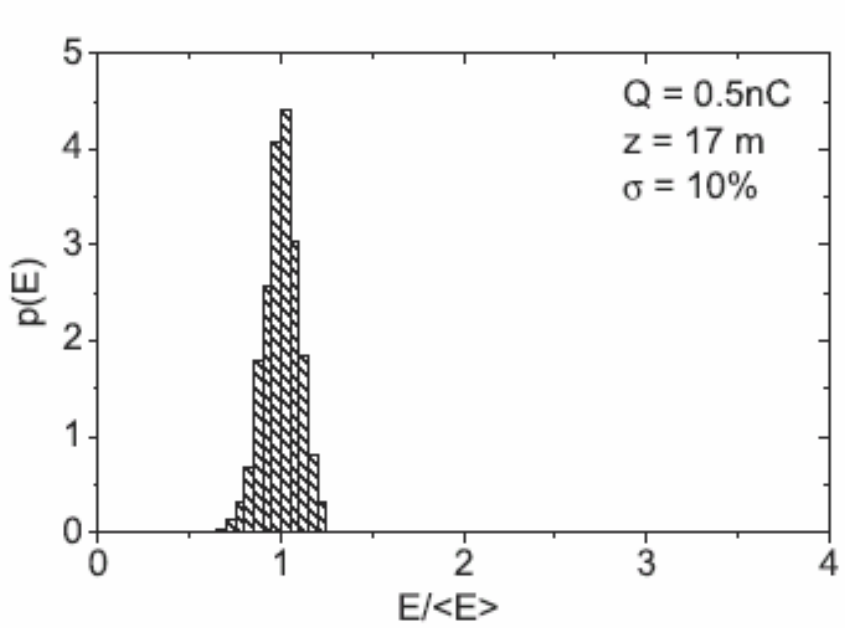




FAST (E.L.Saldin et al., DESY 05-239)





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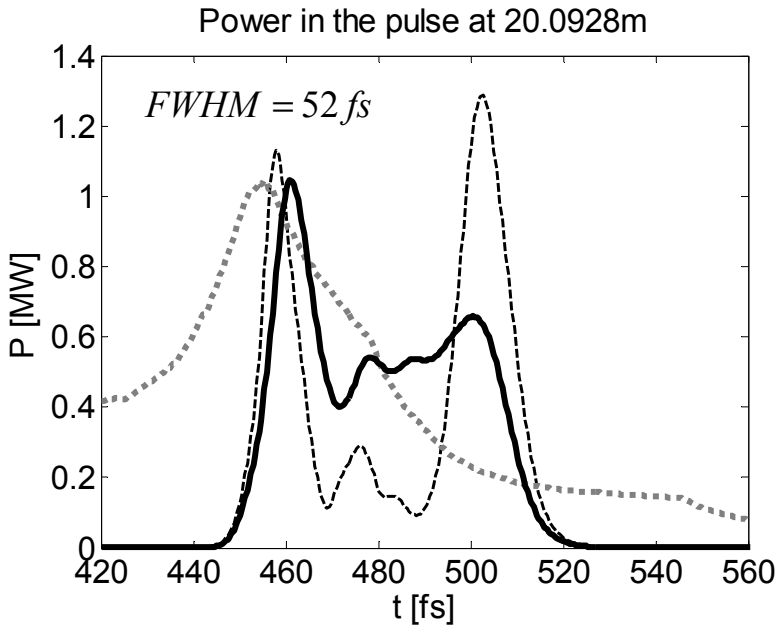
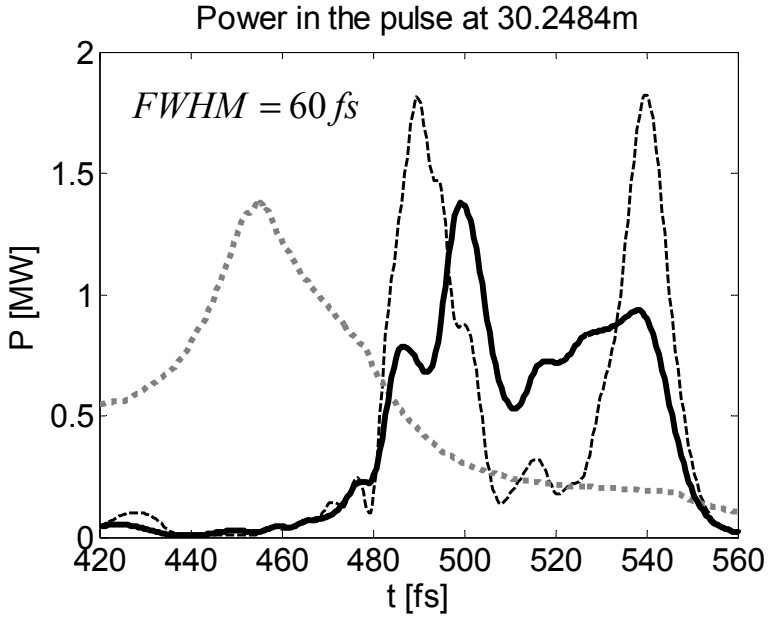
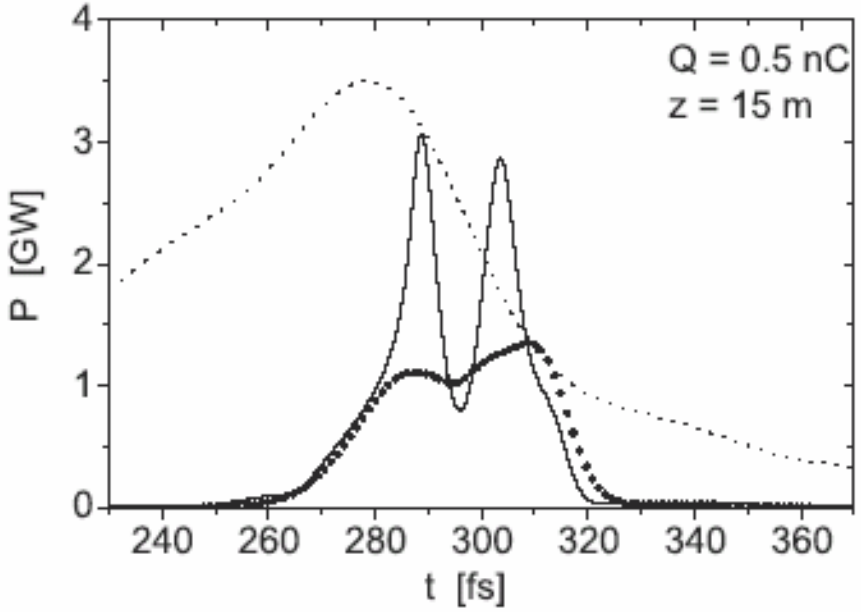
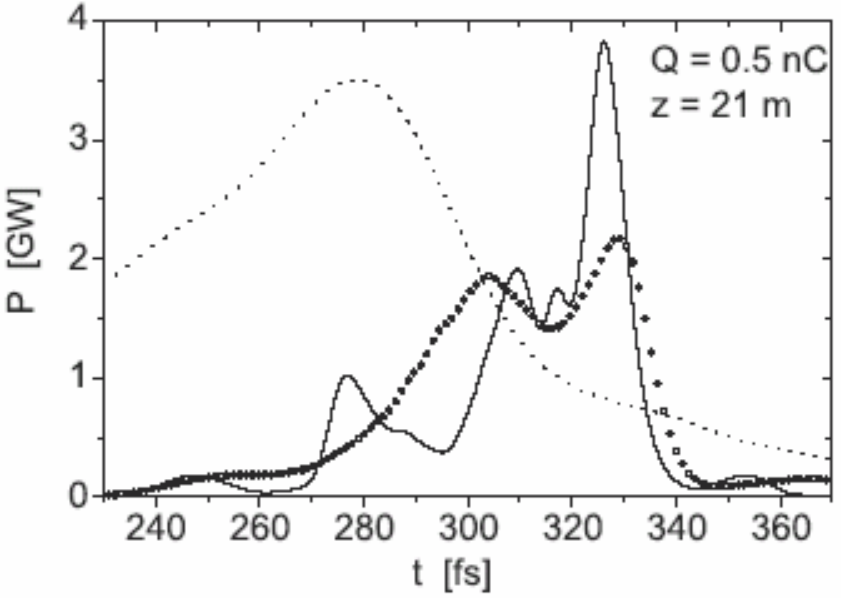


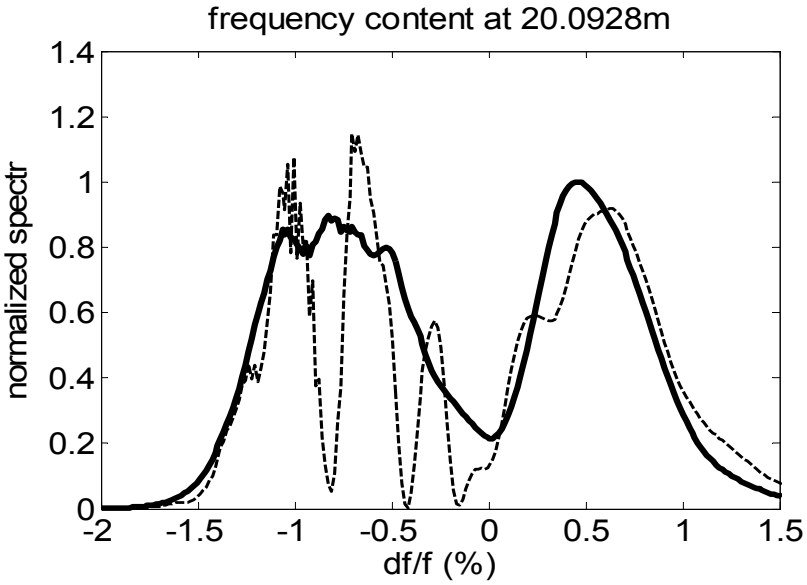


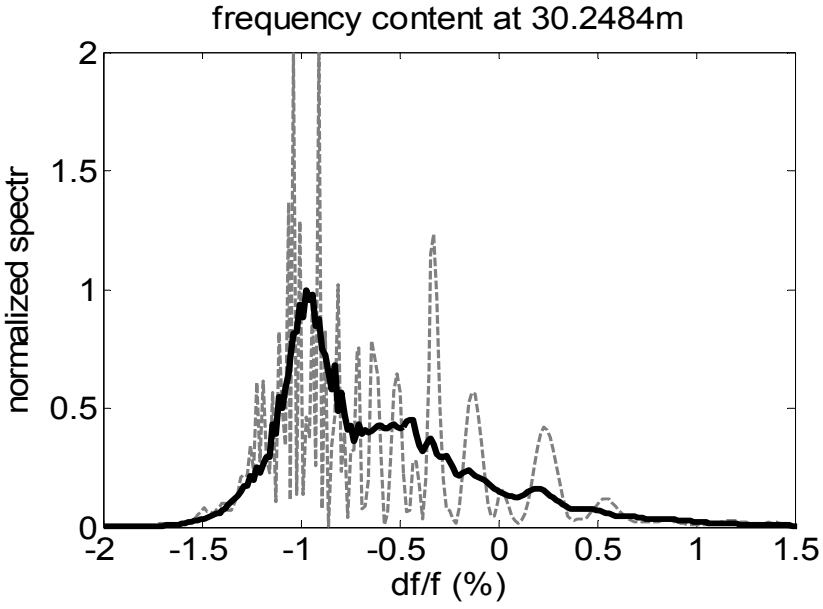
FAST (E.L.Saldin et al., DESY 05-239)



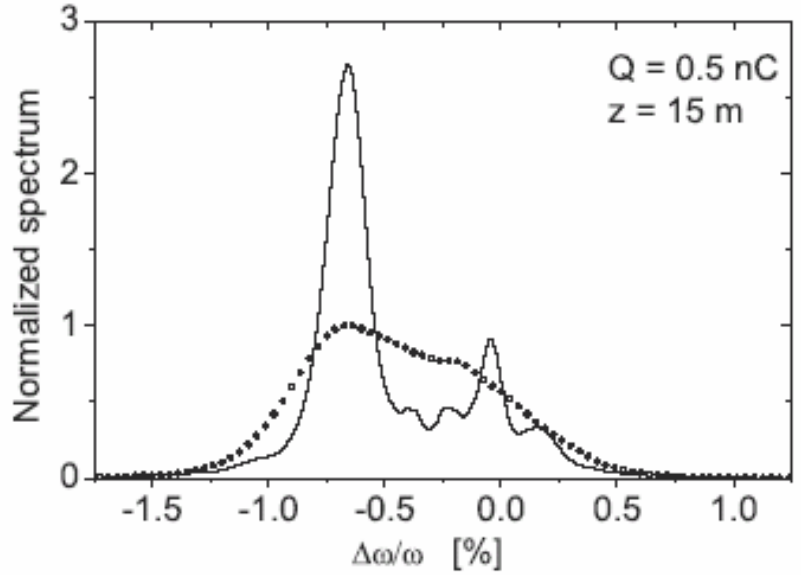


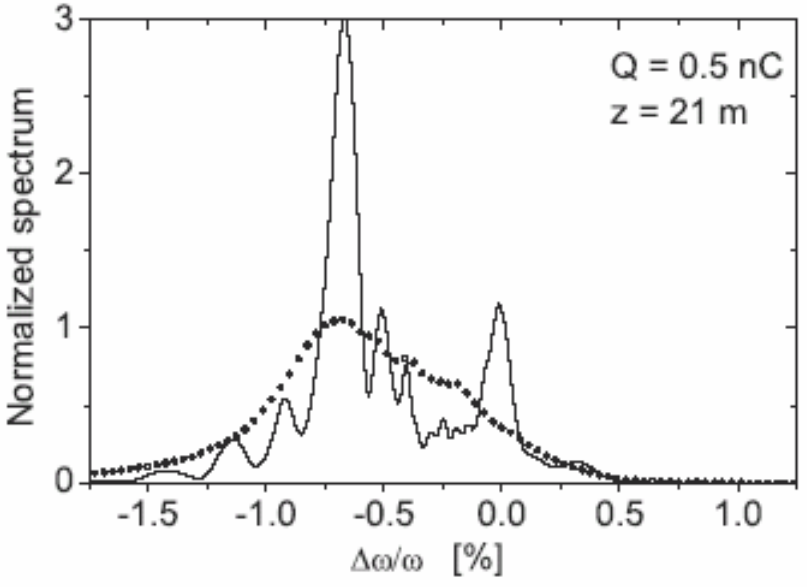
Genesis





FAST (E.L.Saldin et al., DESY 05-239)





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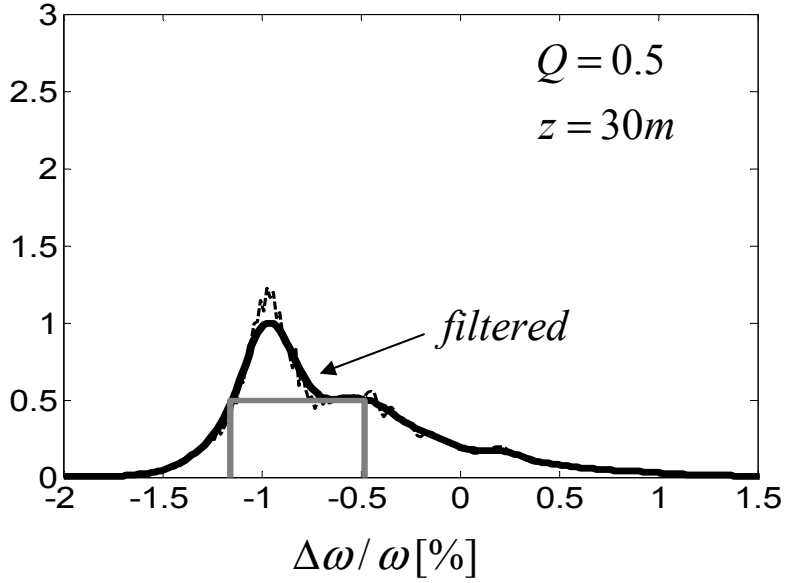
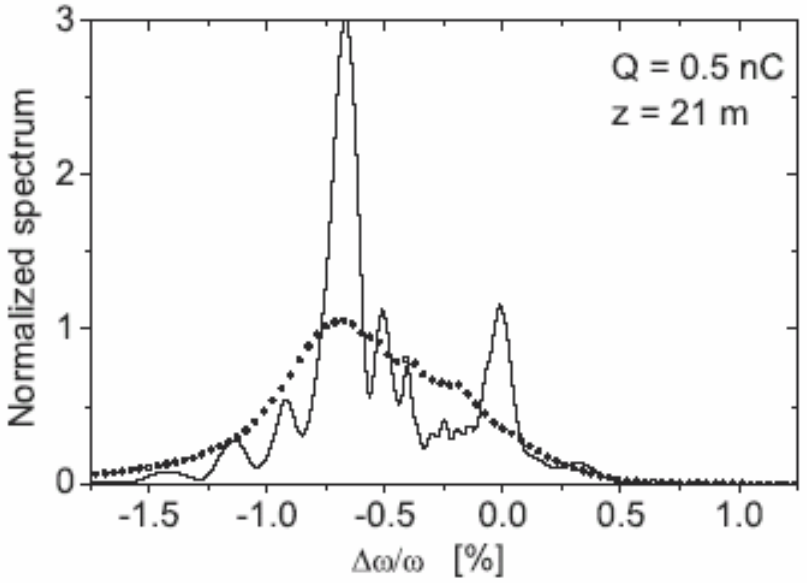
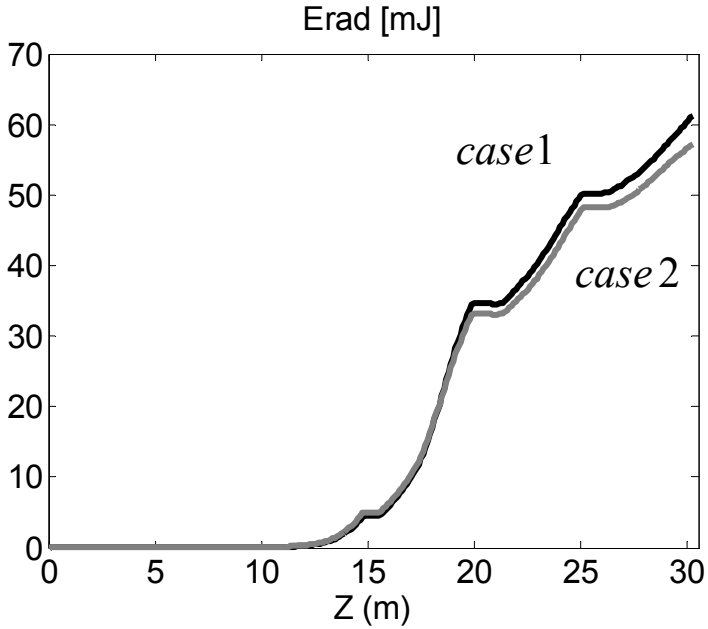


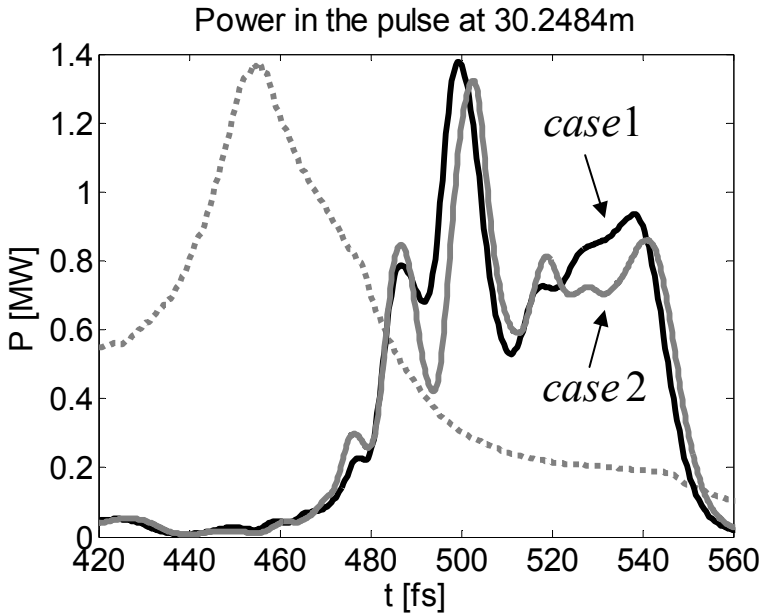
$FWHM = 0.7\%$

FAST (E.L.Saldin et al., DESY 05-239)



Genesis accuracy check





$case1:\quad slice\ width = 4\lambda_s,\quad N\ of\ particles/slice = 8192,\quad N\ runs = 170$

$case2:\quad slice\ width = 2\lambda_s,\quad N\ of\ particles/slice = 16384,\quad N\ runs = 17$

Conclusions

1. The pulse energy is smaller by factor 2 compared to FAST simulations

2. The possible reasons:
   - higher energy chirp,
   - smaller width of the current pulse
   - including of intersections in the lattice

3. Other statistical properties are in good agreement

4. The impact of wakefields?