Expected properties of the radiation from VUV TTF FEL

(Phase I: E = 260 MeV, λ = 95 nm)

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Abstract

This report contains sets of output characteristics of the radiation from VUV TTF FEL (Phase I, E = 260 MeV, λ = 95 nm). Calculations have been performed with three-dimensional, time-dependent FEL simulation code FAST.

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Contents

1. General remarks

The first run of the TTF FEL experiment is performed at the energy of the electron beam of about 260 MeV and three undulator modules. This report presents graphs of expected FEL characteristics at the exit of the undulator for several scenario of the electron beam parameters [1]. Calculations have been performed with three-dimensional, time-dependent FEL simulation code FAST [2]. General parameters of the TTF SASE FEL are given in Table 1. When performing the simulations, we assumed that the distribution of the electrons in the transverse phase space is the Gaussian one with the RMS radius and the RMS angle spread given by

$$\sigma_r = \sqrt{\epsilon_n \beta/\gamma}\ , \sigma_\theta = \sqrt{\epsilon_n/\beta\gamma}\ ,$$

where ϵ_n is rms normalized emittance, β is focusing beta function and $\gamma = \mathcal{E}_0/m_e c^2$ is relativistic factor. Energy spread in the electron beam is assumed to be gaussian with the rms deviation σ_E:

$$dw = \frac{1}{\sqrt{2\pi\sigma_E^2}} \exp[-(\mathcal{E}-\mathcal{E}_0)^2/(2\sigma_E^2)] d\mathcal{E}\ ,$$

Longitudinal bunch profile is also approximated as the Gaussian one,

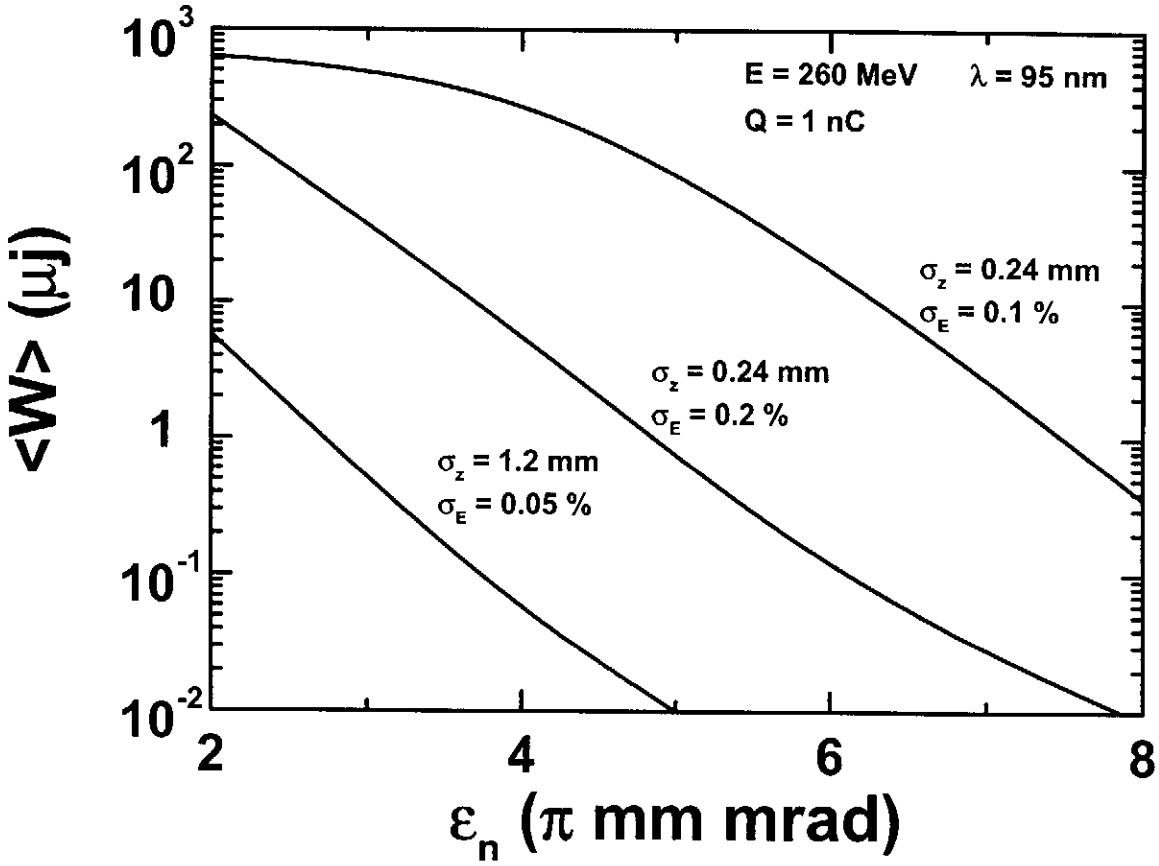
$$I(z) = \frac{I_0}{\sqrt{2\pi\sigma_z^2}} \exp[-z^2/(2\sigma_z^2)]\ .$$

Each set of FEL characteristics contains the plots of typical time and spectral structure of the radiation pulse and the directivity diagram of the radiation intensity in the far zone. Note that the contribution of the incoherent undulator radiation within coherent angle into the total radiation energy is about 1 nJ for all the cases.

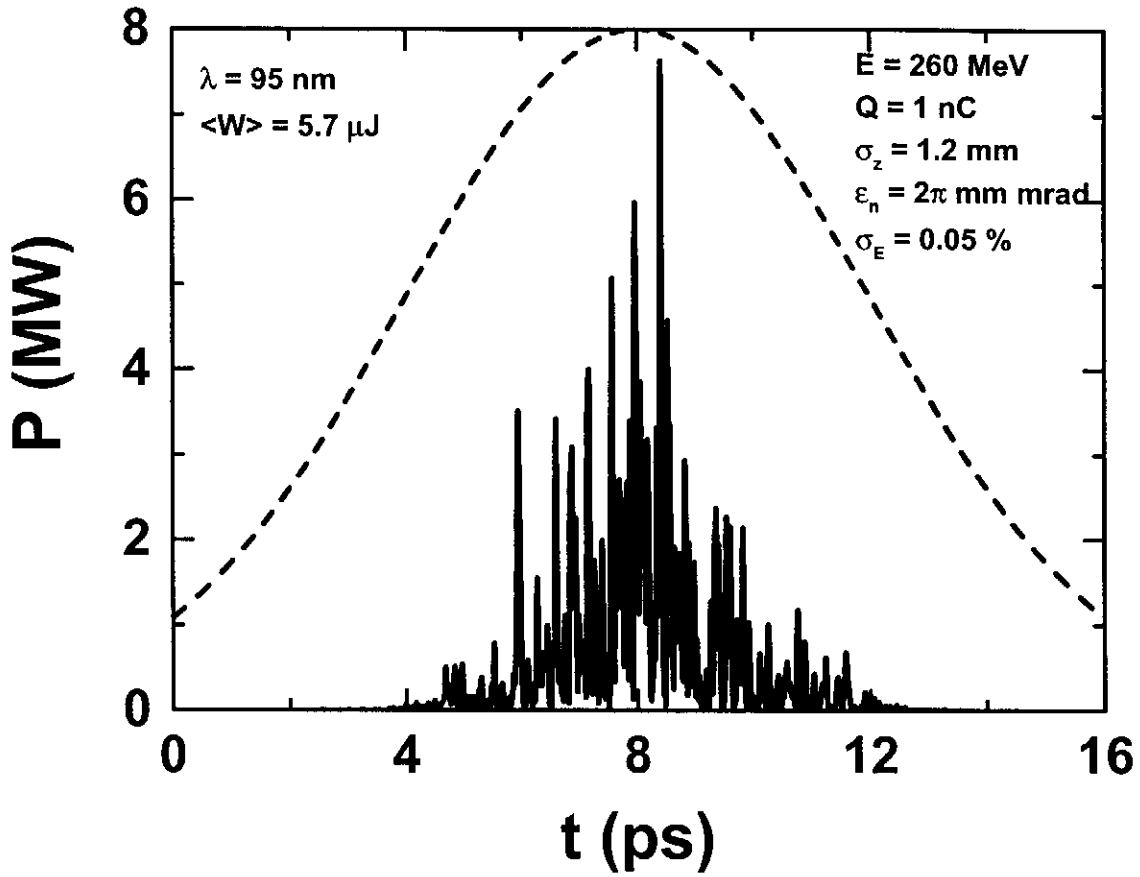
Table 1. Parameters of the 95 nm SASE FEL at DESY

Electron beam	
Energy, $\mathcal{E}_0$	260 MeV
Bunch charge, Q	1 nC
Peak current, I_0	100 / 500 A
rms bunch length, σ_z	1.2 mm / 240 μm
Normalized rms emittance , ϵ_n	2π - 8π mm mrad
rms energy spread, σ_E	0.05 - 0.2 %
External β-function,	110 cm
Undulator	
Type	Planar
Length of undulator	3 modules
Period, λ_w	2.73 cm
Peak magnetic field, H_w	4.97 kGs
Radiation	
Wavelength, λ	95 nm

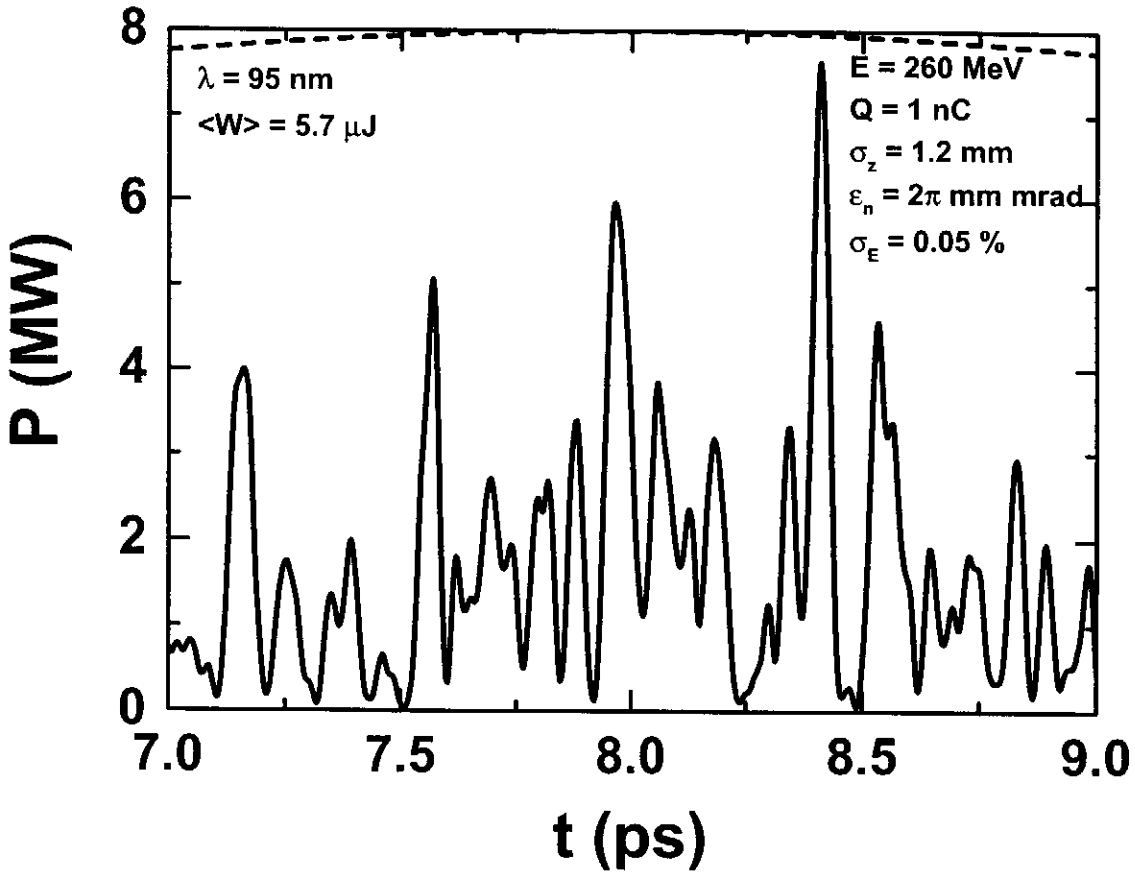
2. Energy in the radiation pulse versus emittance



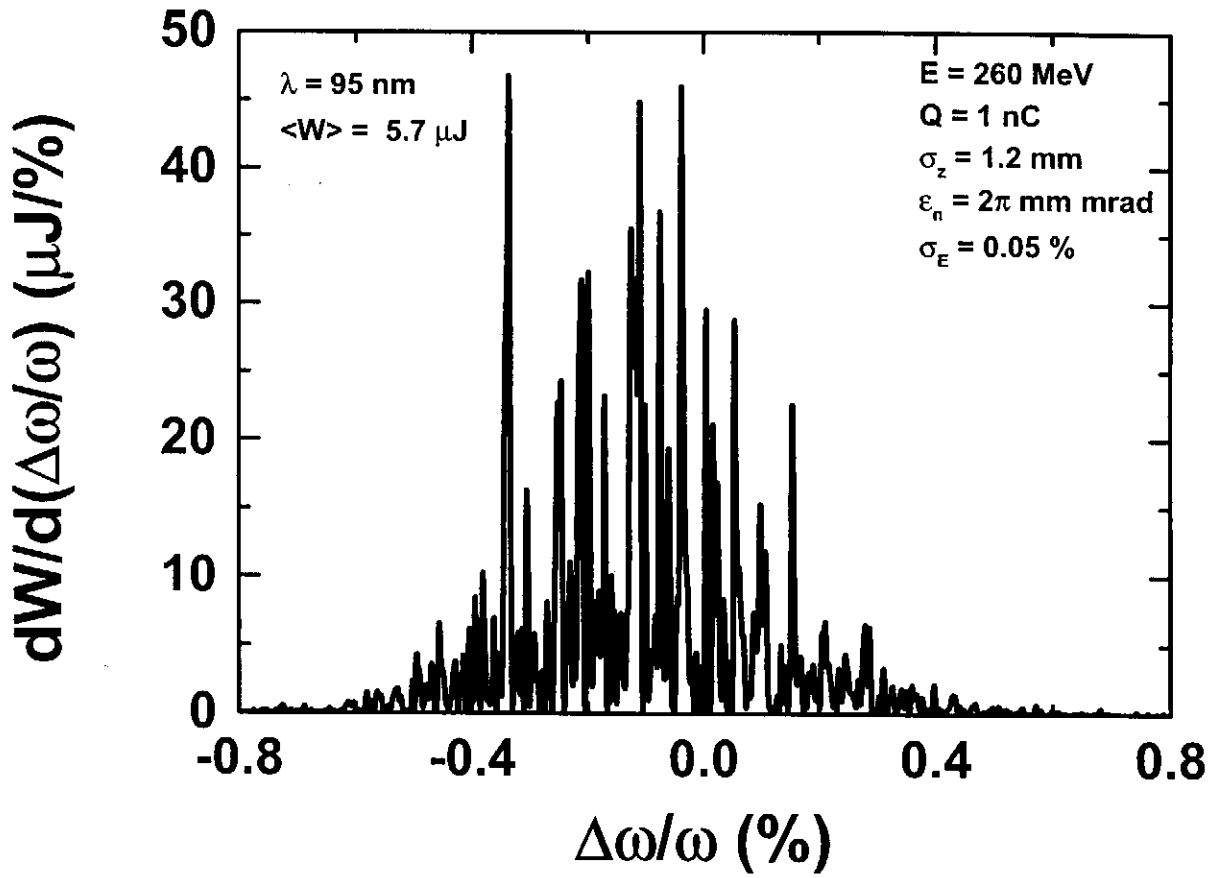
3. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %



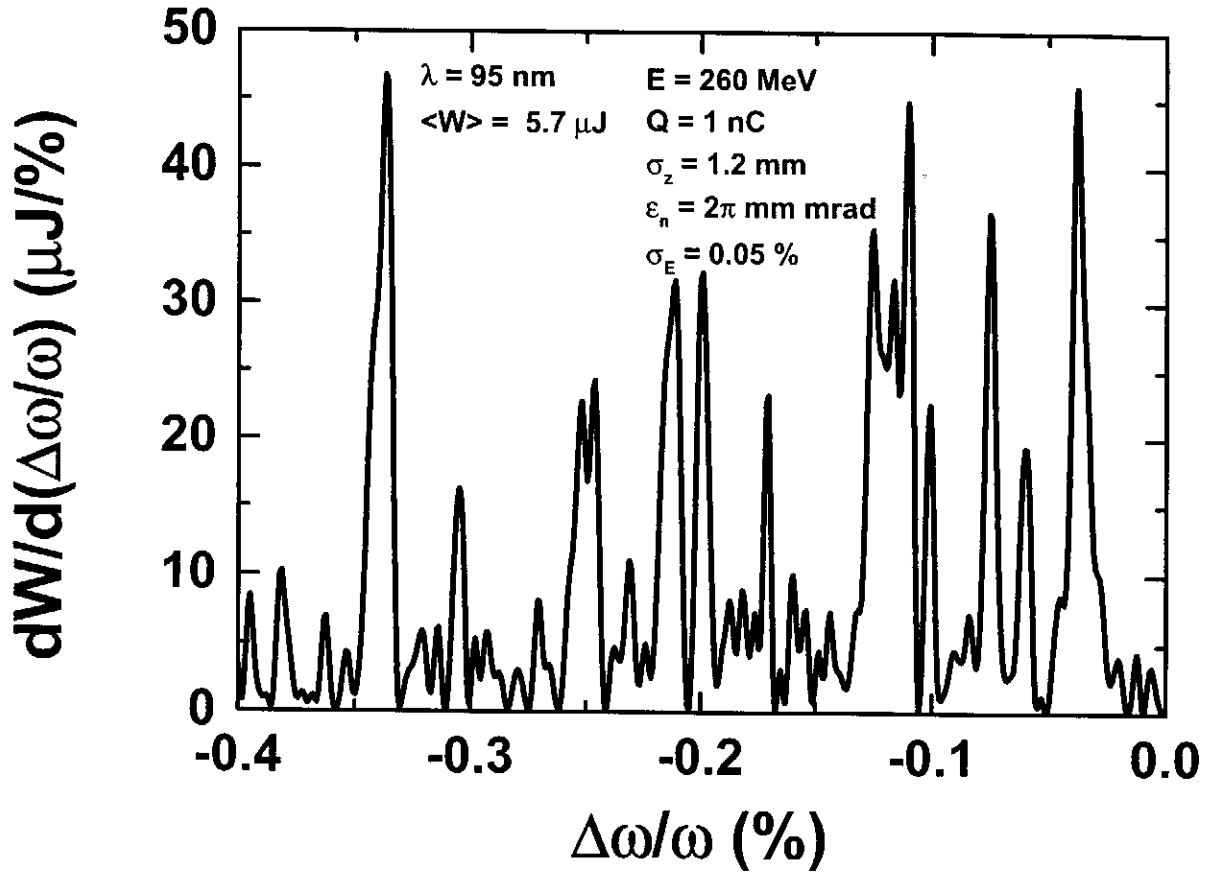
6 3. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %



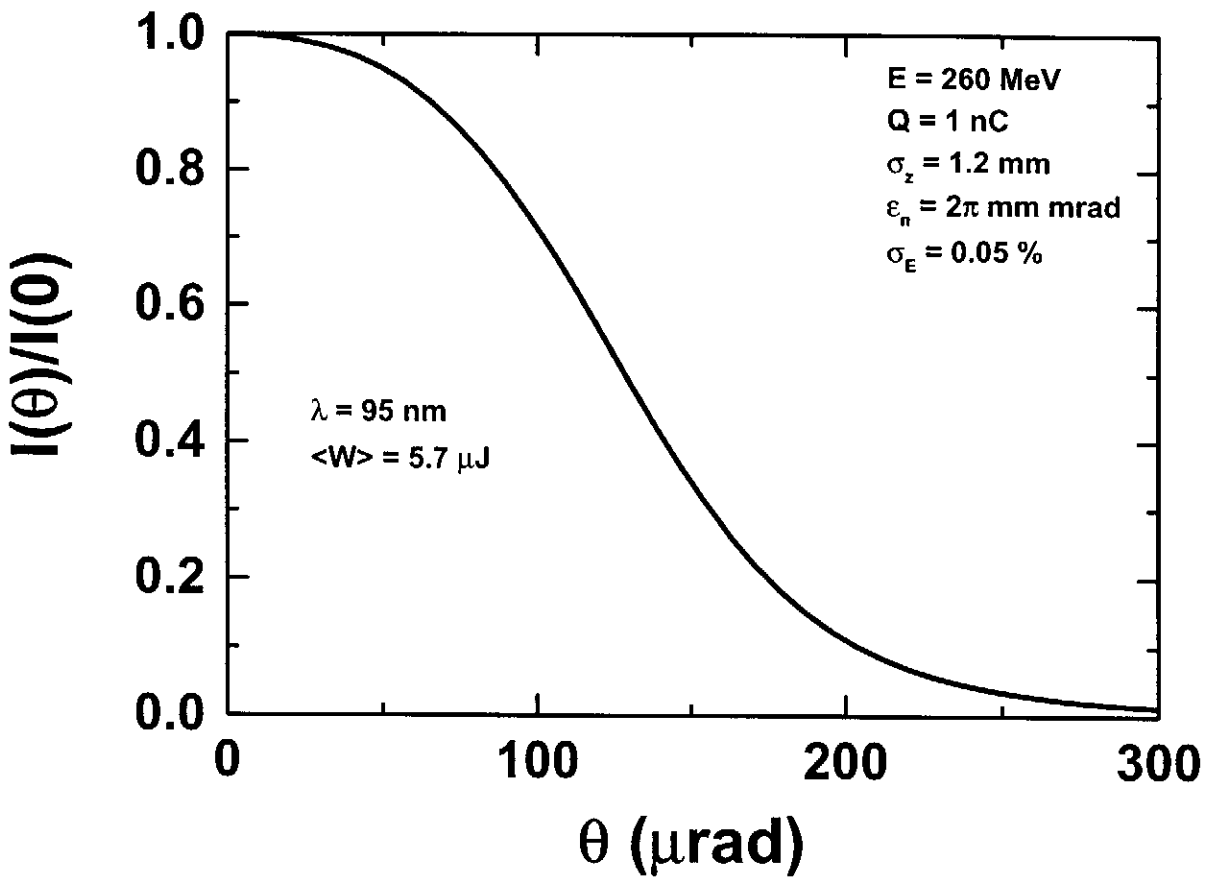
3. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ % 7



8 3. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

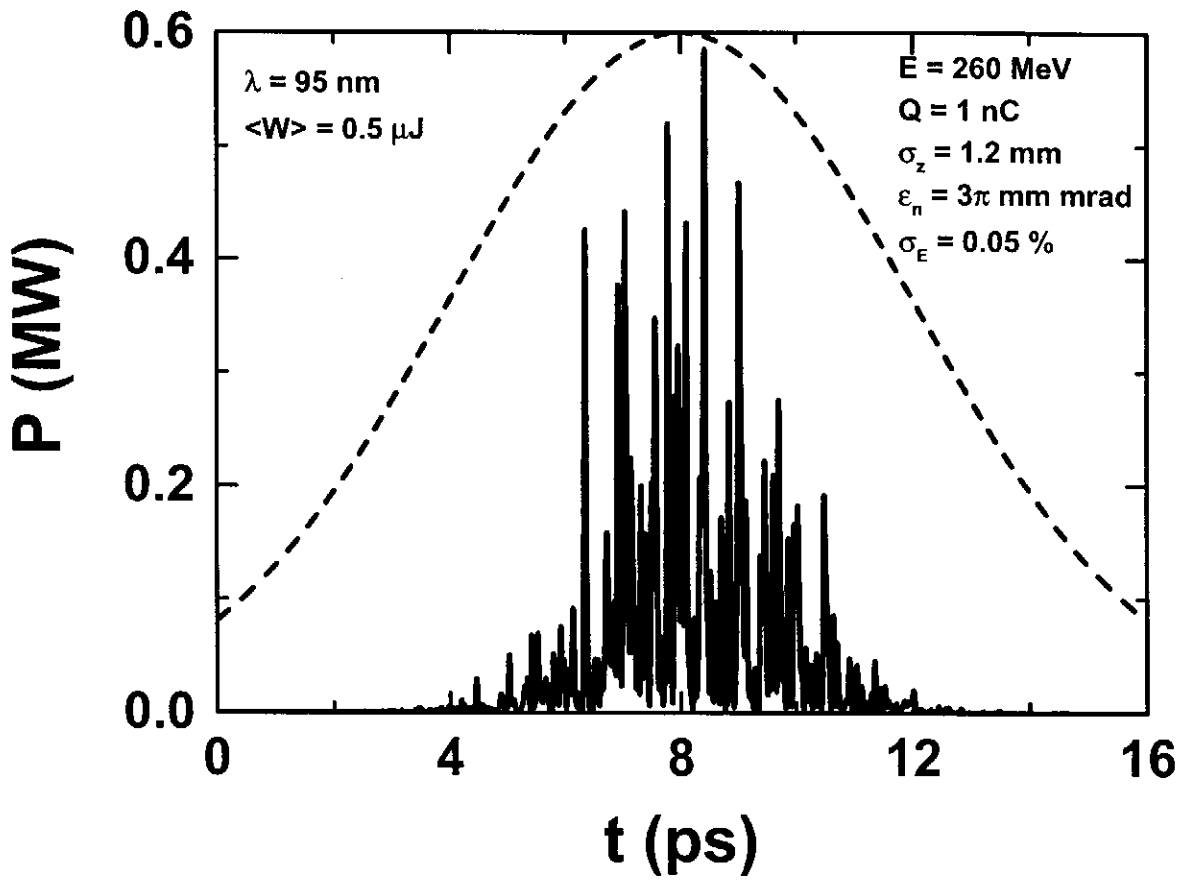


3. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ % 9

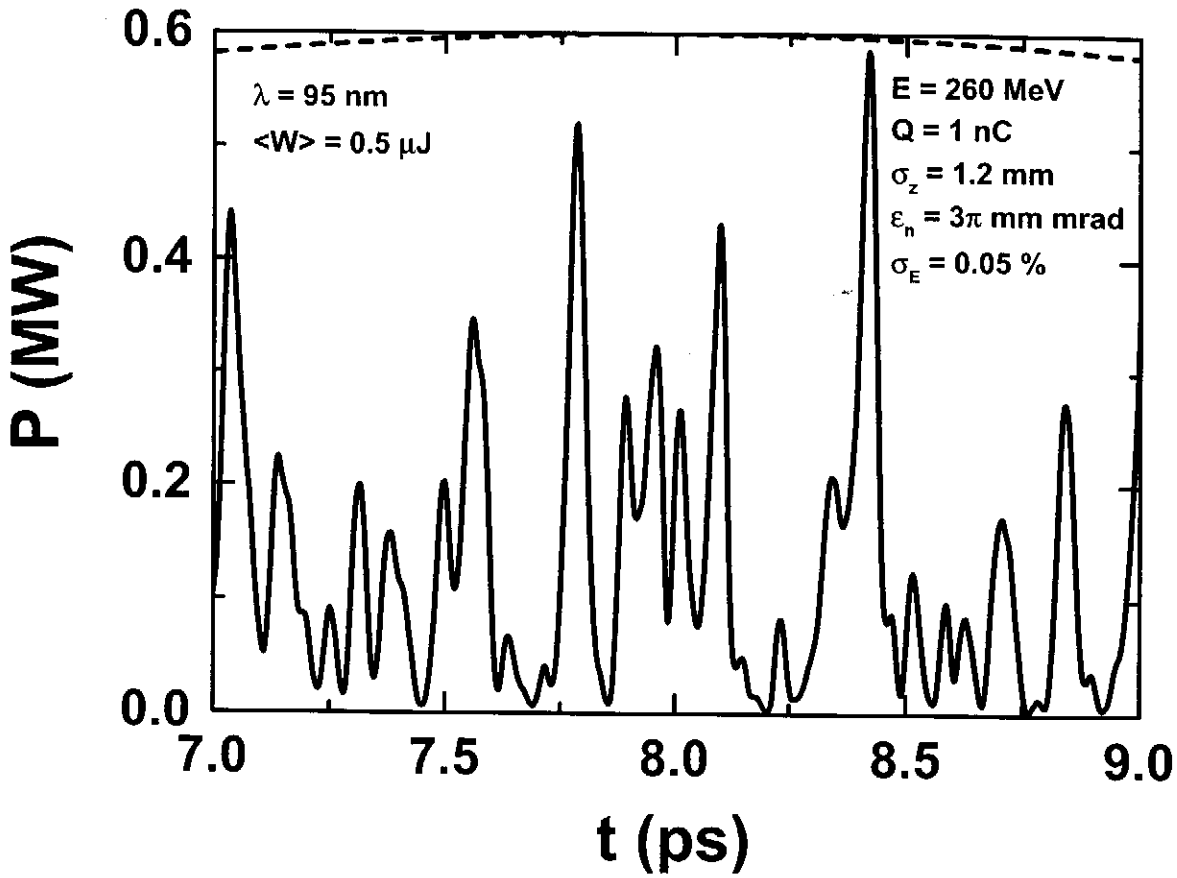


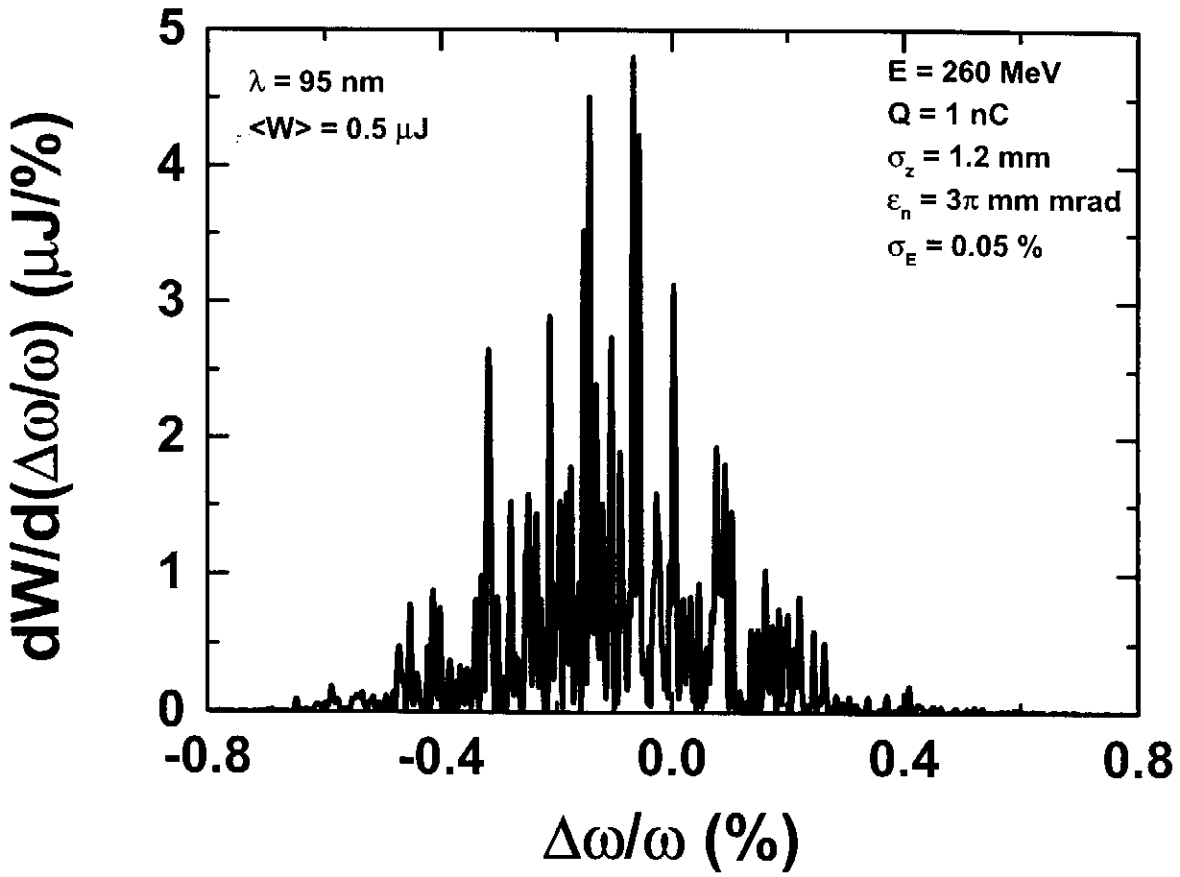
10 3. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

4. $\epsilon_n = 3\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

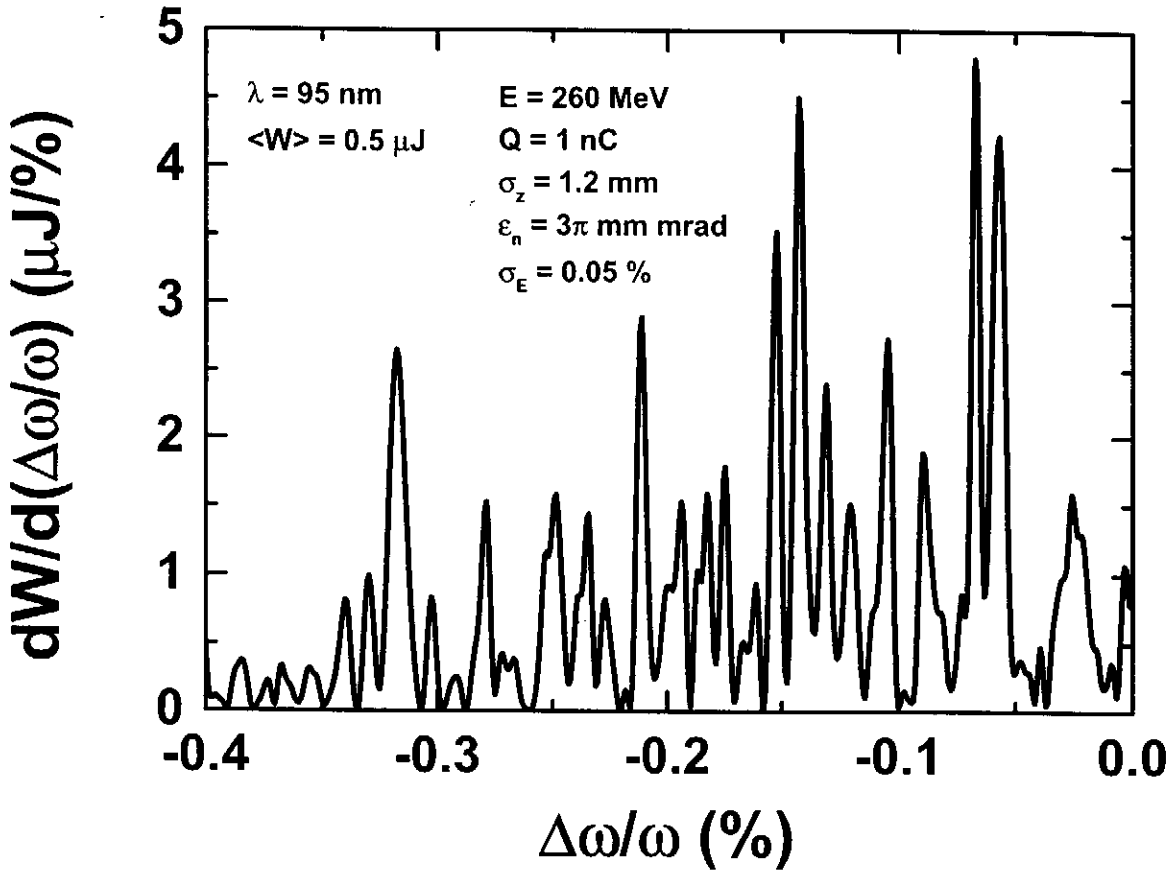


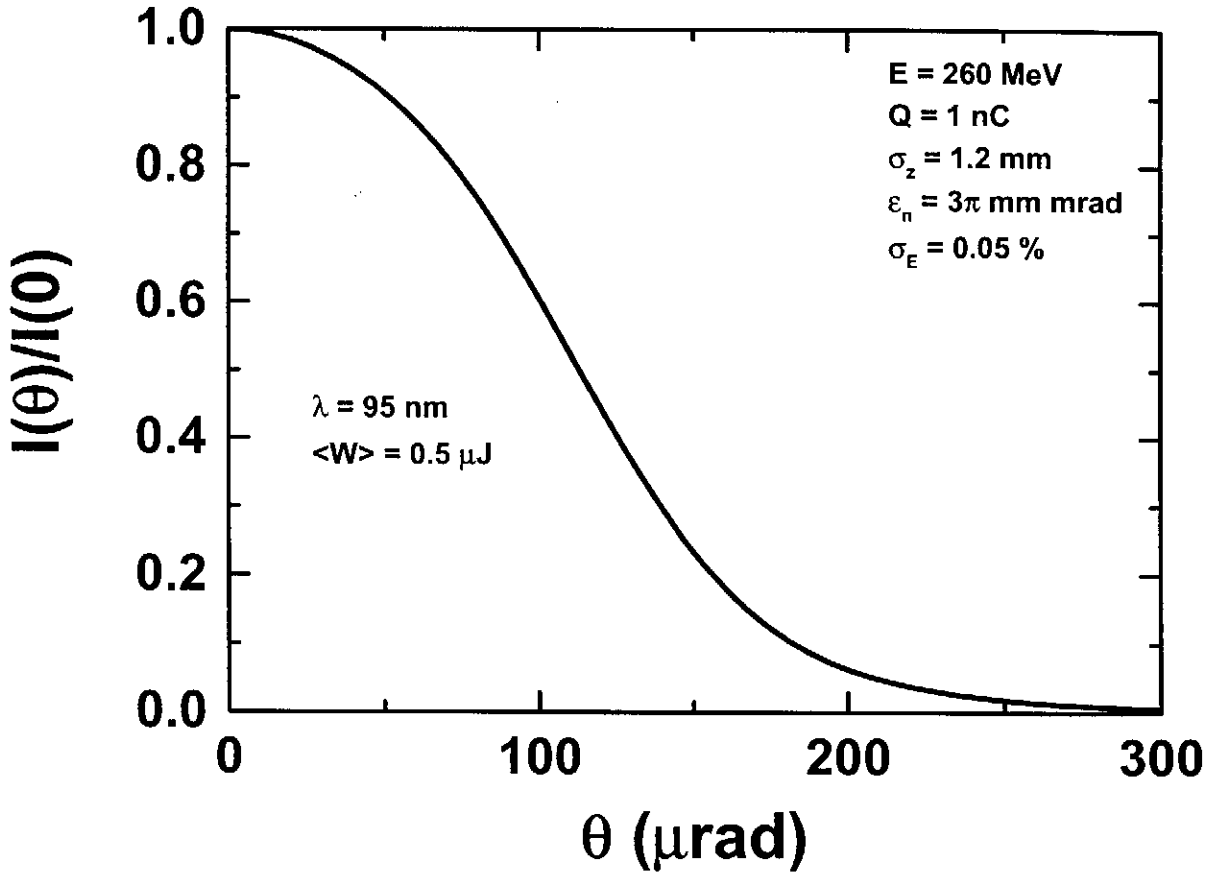
12 4. $\epsilon_n = 3\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %




λ = 95 nm
<W> = 0.5 μJ
E = 260 MeV
Q = 1 nC
σz = 1.2 mm
εn = 3π mm mrad
σE = 0.05 %
dW/d(Δω/ω) (μJ/%)
Δω/ω (%)
0
1
2
3
4
5
-0.8
-0.4
0.0
0.4
0.8

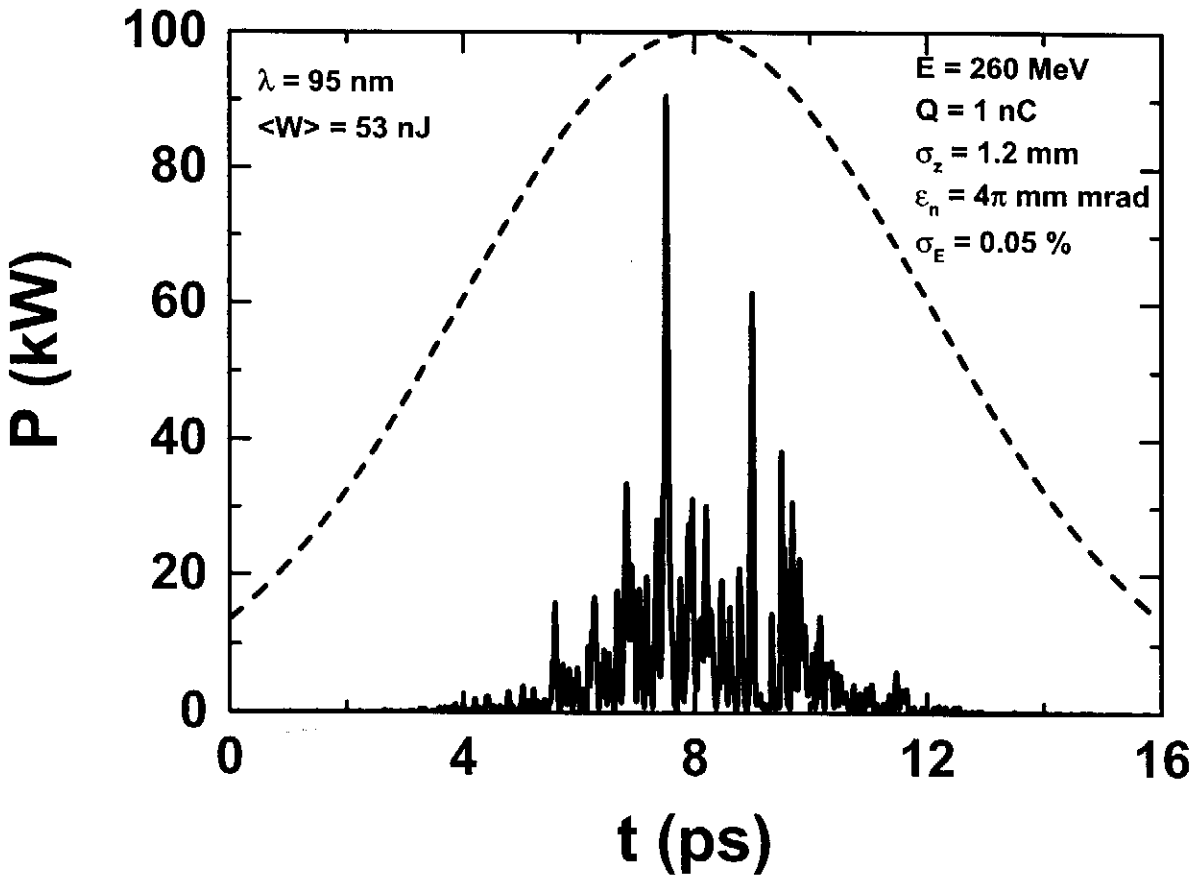
14 4. $\epsilon_n = 3\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %



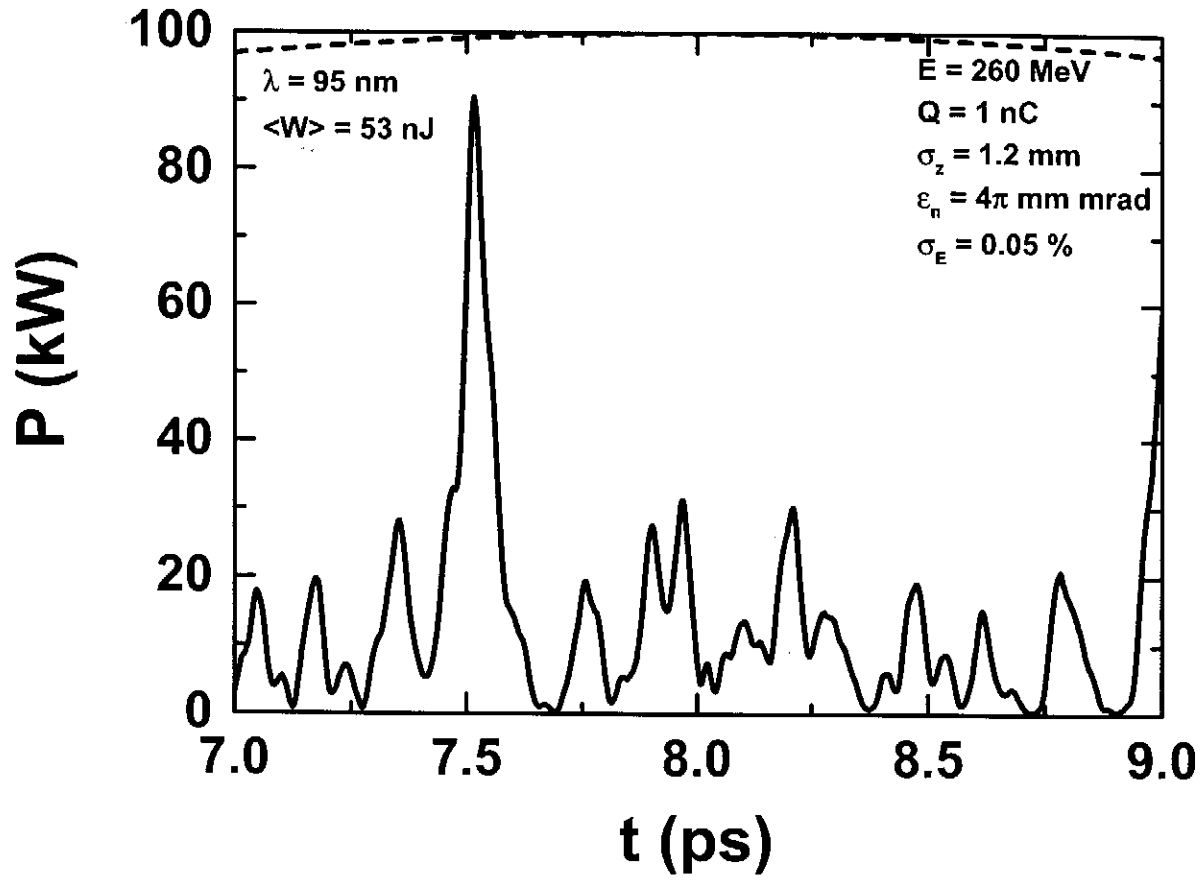

1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
I(θ)/I(0)
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 1.2 mm
εn = 3π mm mrad
σE = 0.05 %
λ = 95 nm
<W> = 0.5 μJ

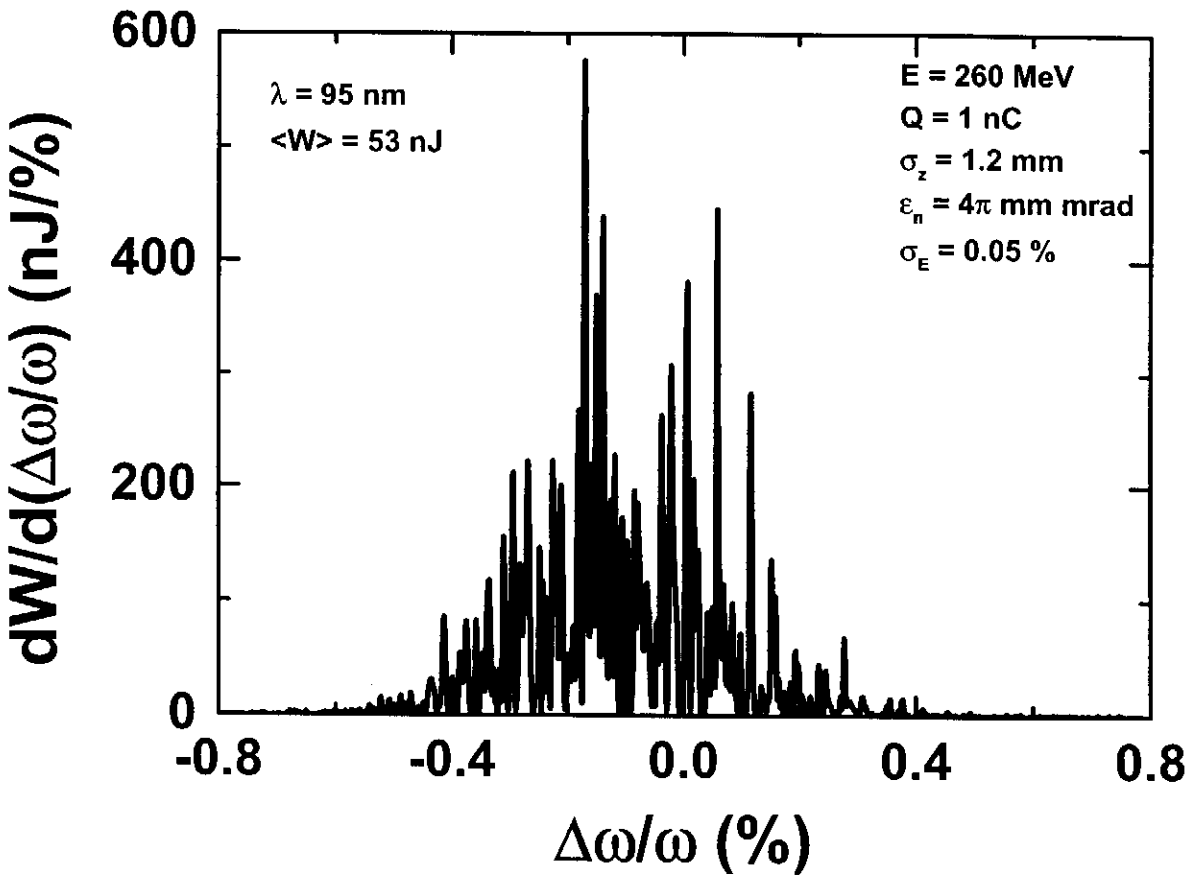
16 4. $\epsilon_n = 3\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

5. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

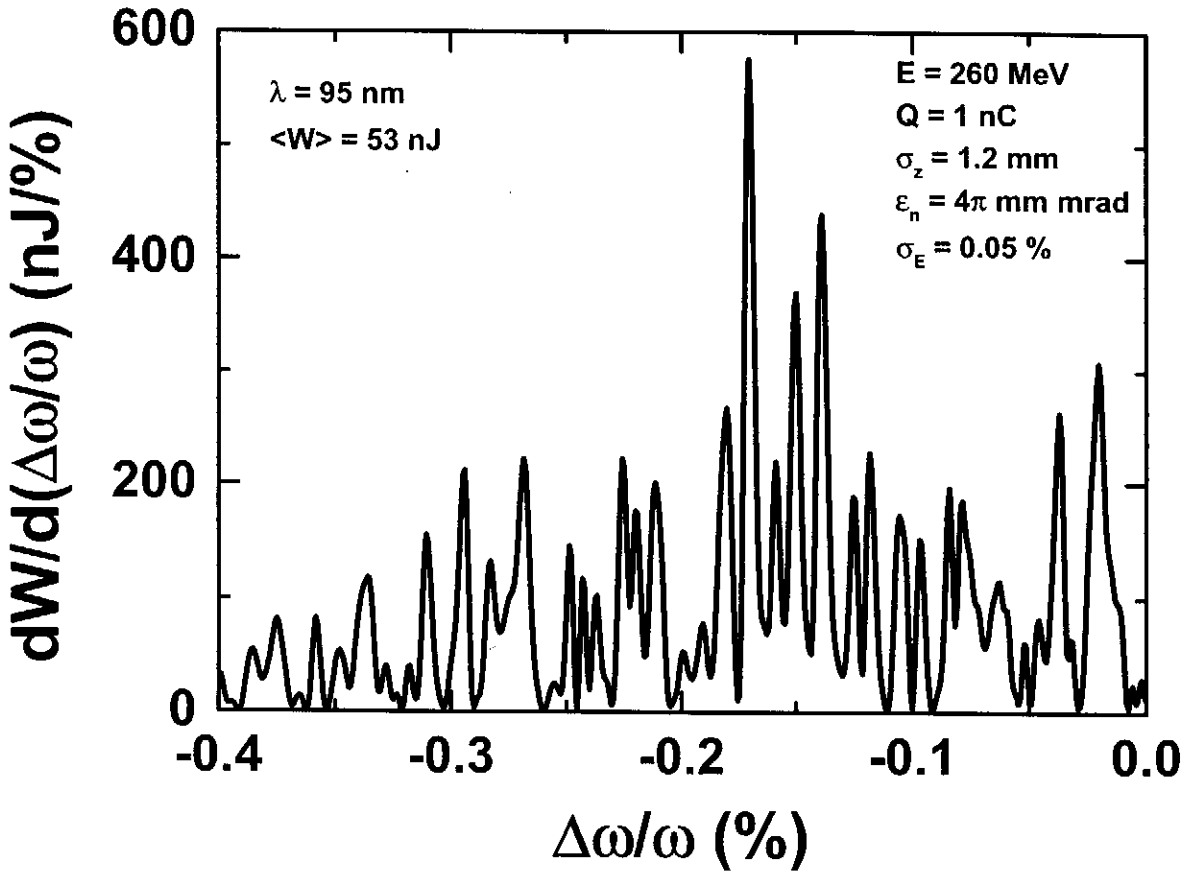


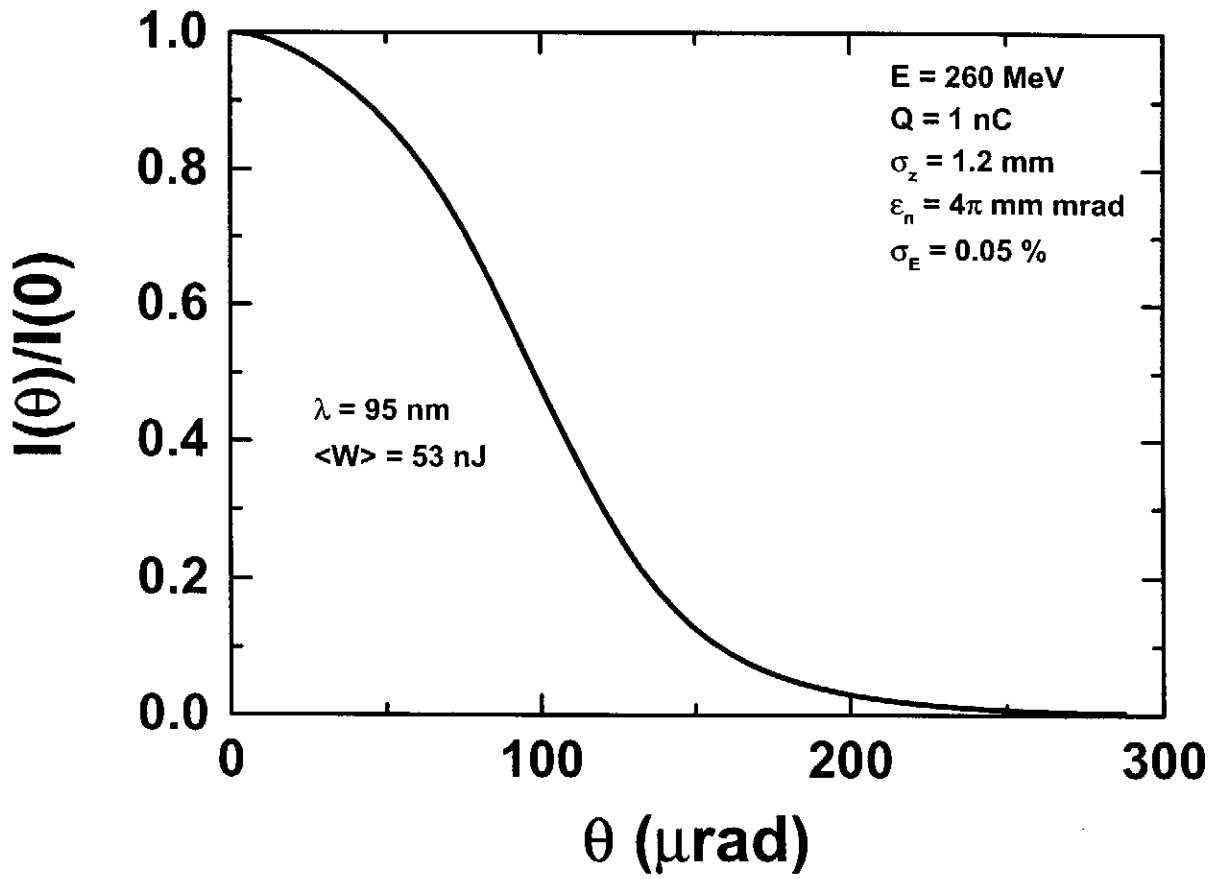
18 5. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %




600
400
200
0
-0.8
-0.4
0.0
0.4
0.8
dW/d(Δω/ω) (nJ/%)
Δω/ω (%)
λ = 95 nm
<W> = 53 nJ
E = 260 MeV
Q = 1 nC
σz = 1.2 mm
εn = 4π mm mrad
σE = 0.05 %

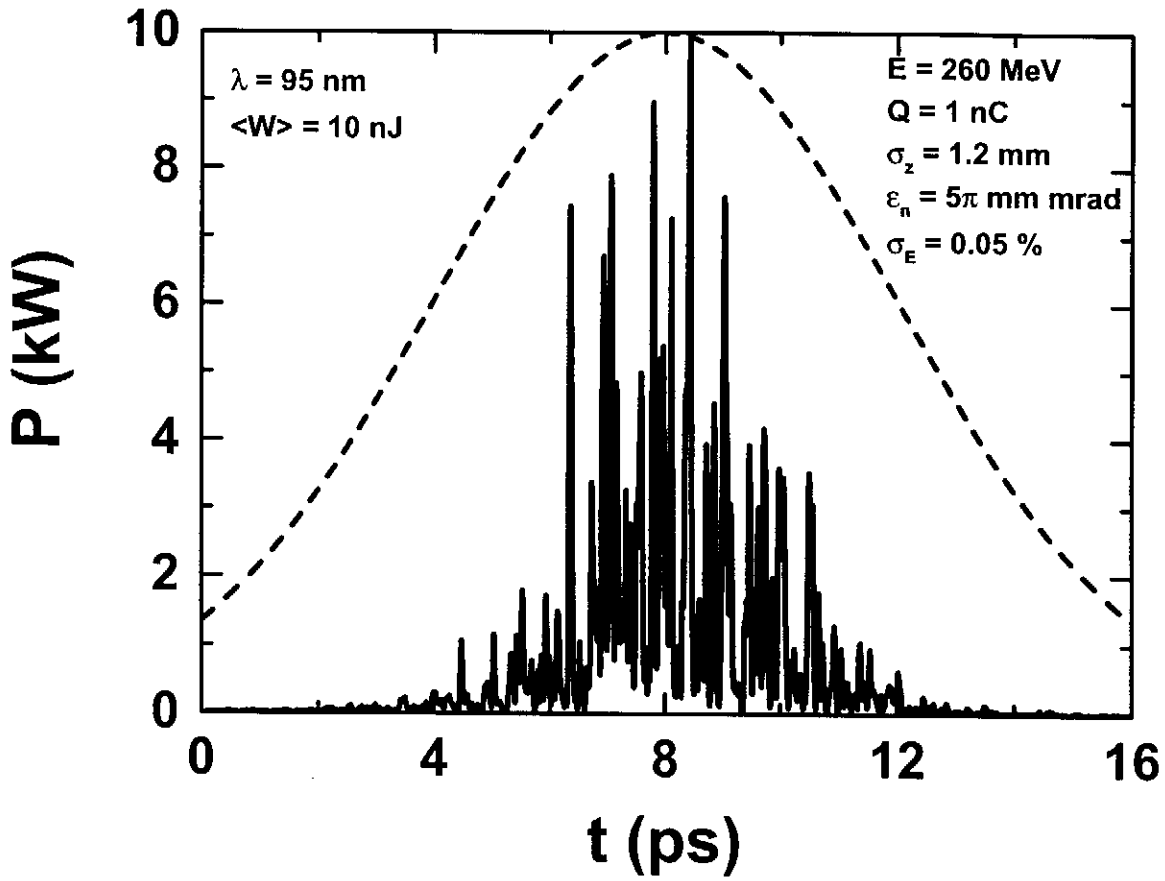
20 5. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %



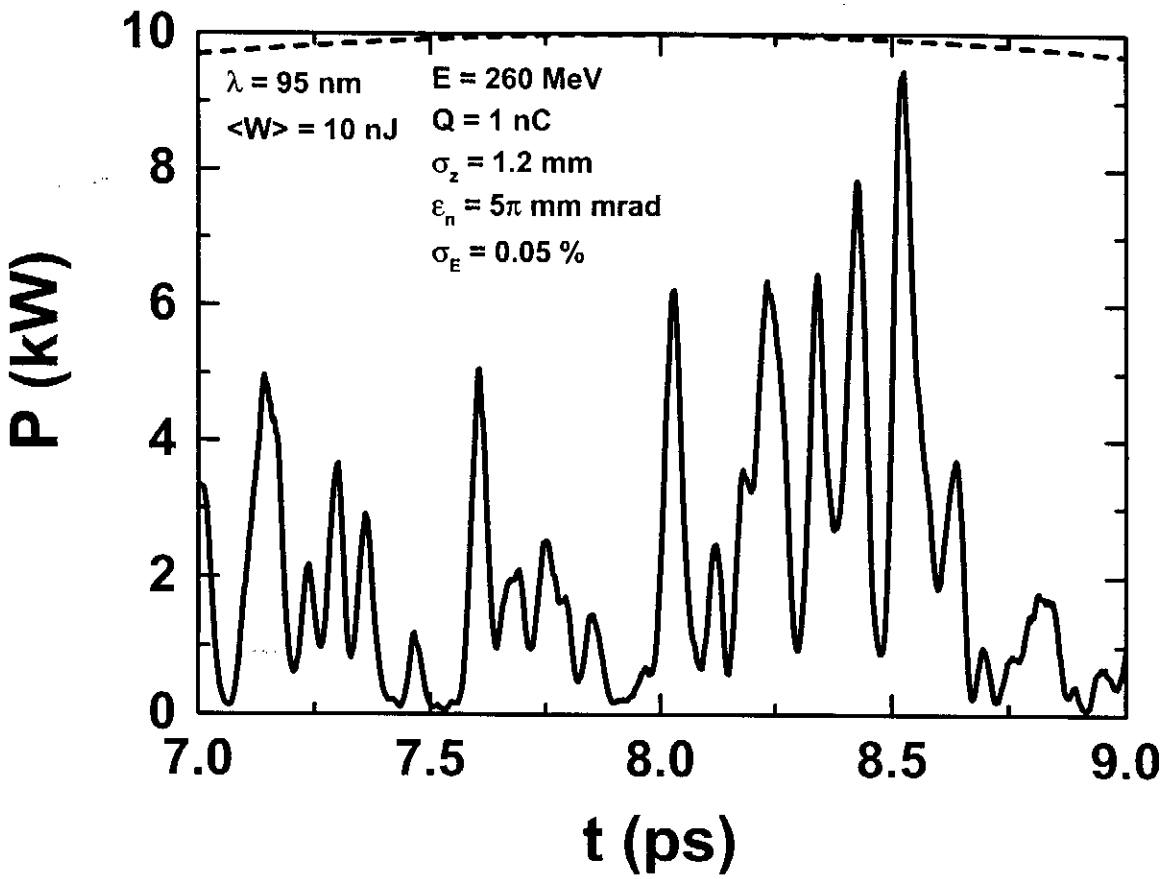

1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
I(θ)/I(0)
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 1.2 mm
εn = 4π mm mrad
σE = 0.05 %
λ = 95 nm
<W> = 53 nJ

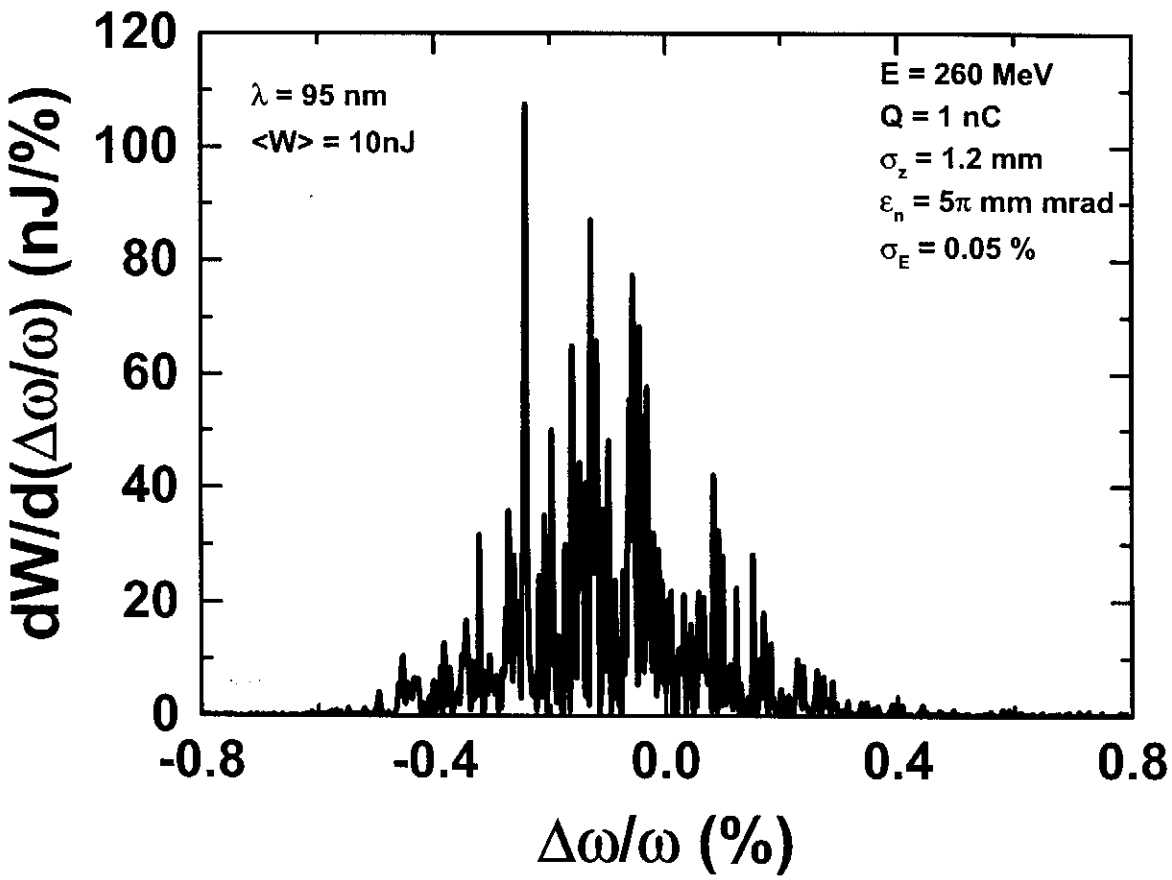
22 5. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

6. $\epsilon_n = 5\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

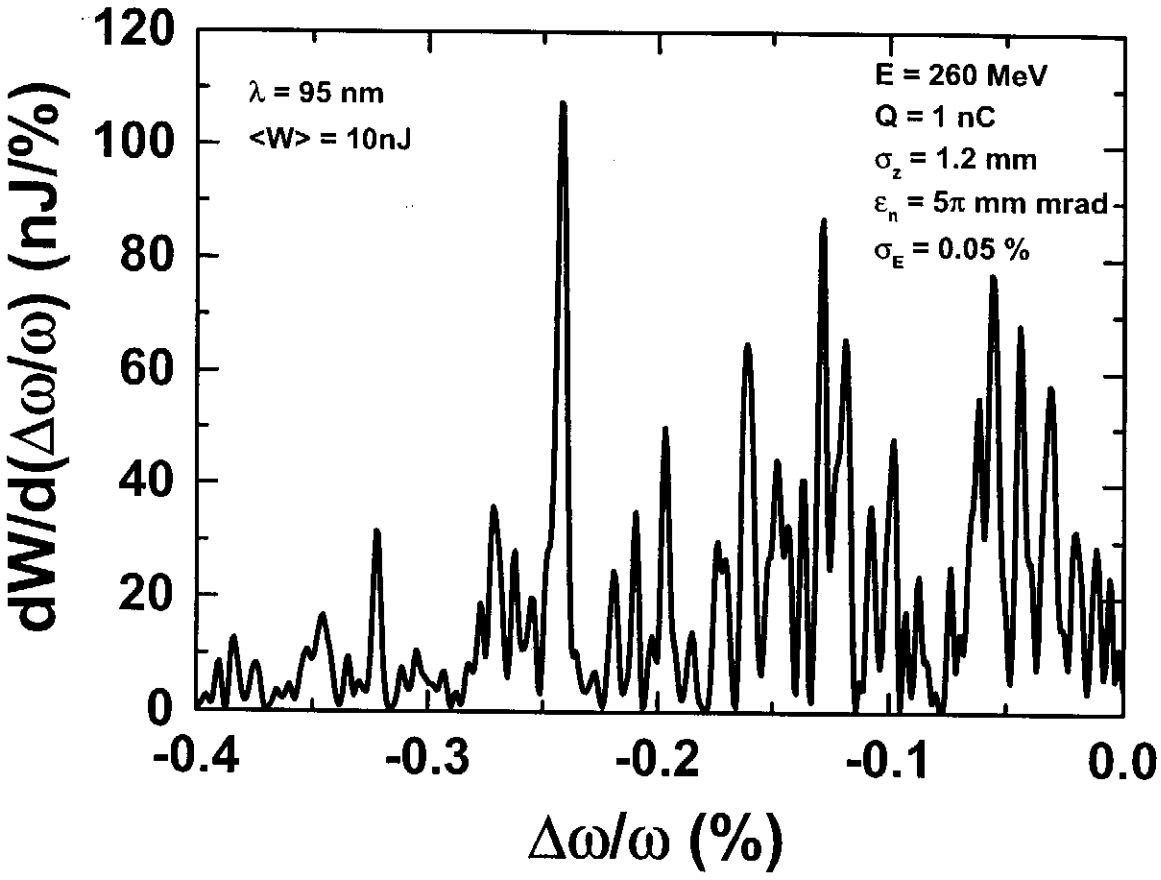


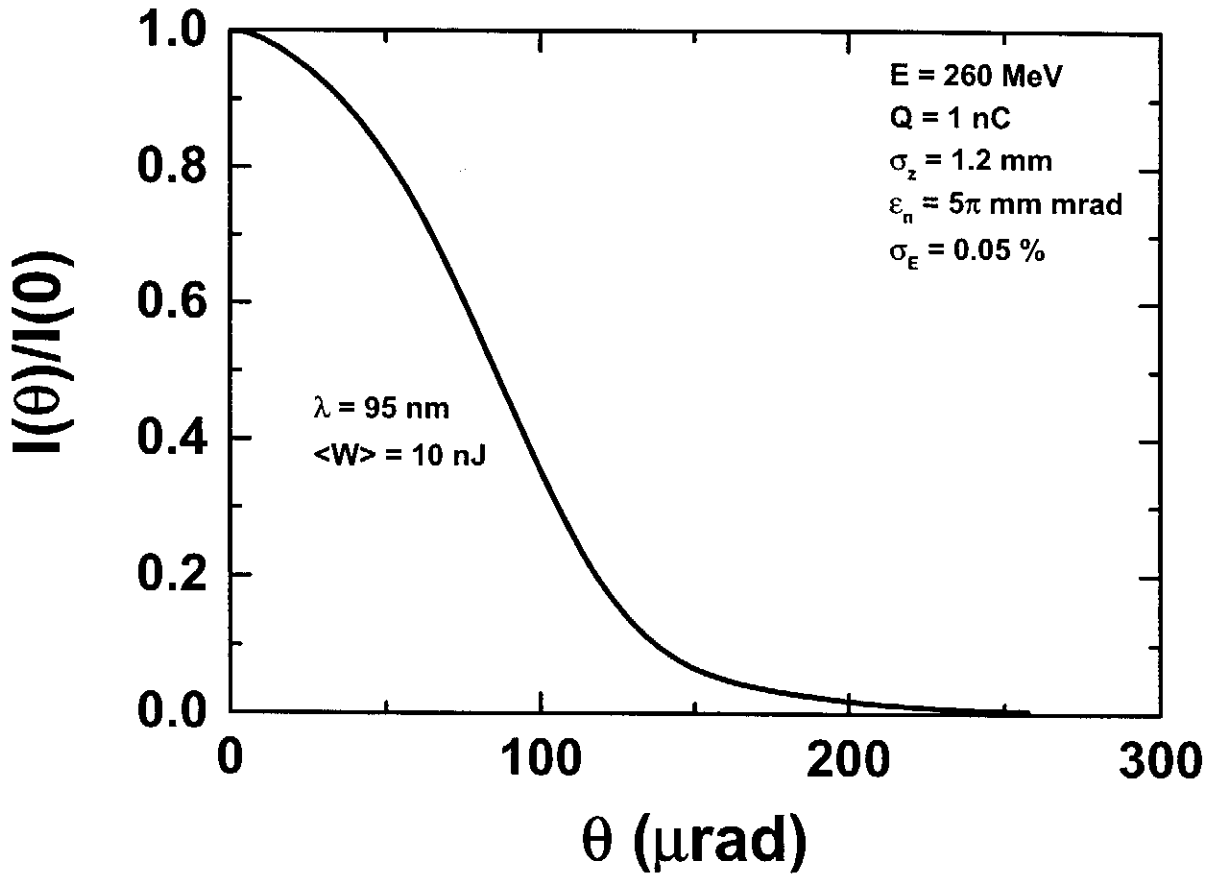
24 6. $\epsilon_n = 5\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %




λ = 95 nm
<W> = 10nJ
E = 260 MeV
Q = 1 nC
σz = 1.2 mm
εn = 5π mm mrad
σE = 0.05 %
dW/d(Δω/ω) (nJ/%)
Δω/ω (%)
120
100
80
60
40
20
0
-0.8
-0.4
0.0
0.4
0.8

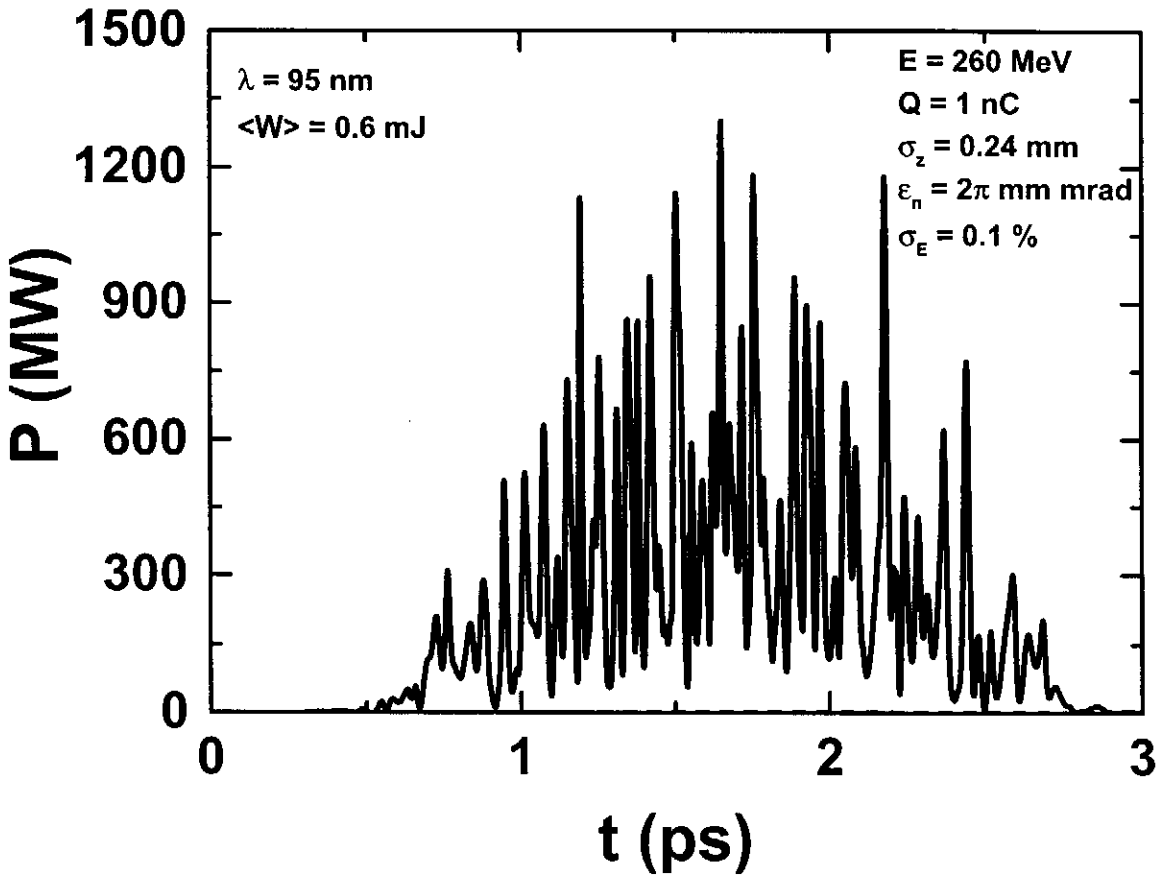
26 6. $\epsilon_n = 5\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %



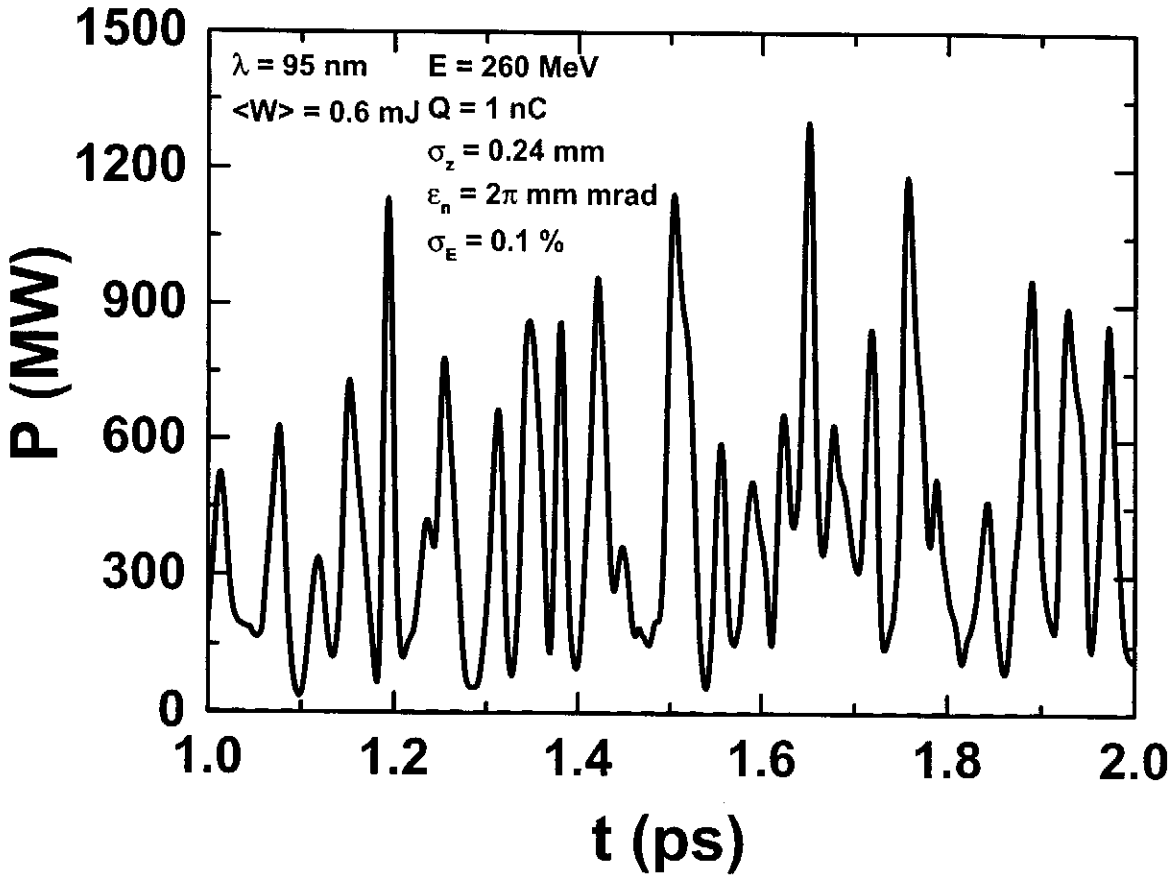

1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
I(θ)/I(0)
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 1.2 mm
εn = 5π mm mrad
σE = 0.05 %
λ = 95 nm
<W> = 10 nJ

28 6. $\epsilon_n = 5\pi$ mm mrad, $\sigma_z = 1.2$ mm, $\sigma_E = 0.05$ %

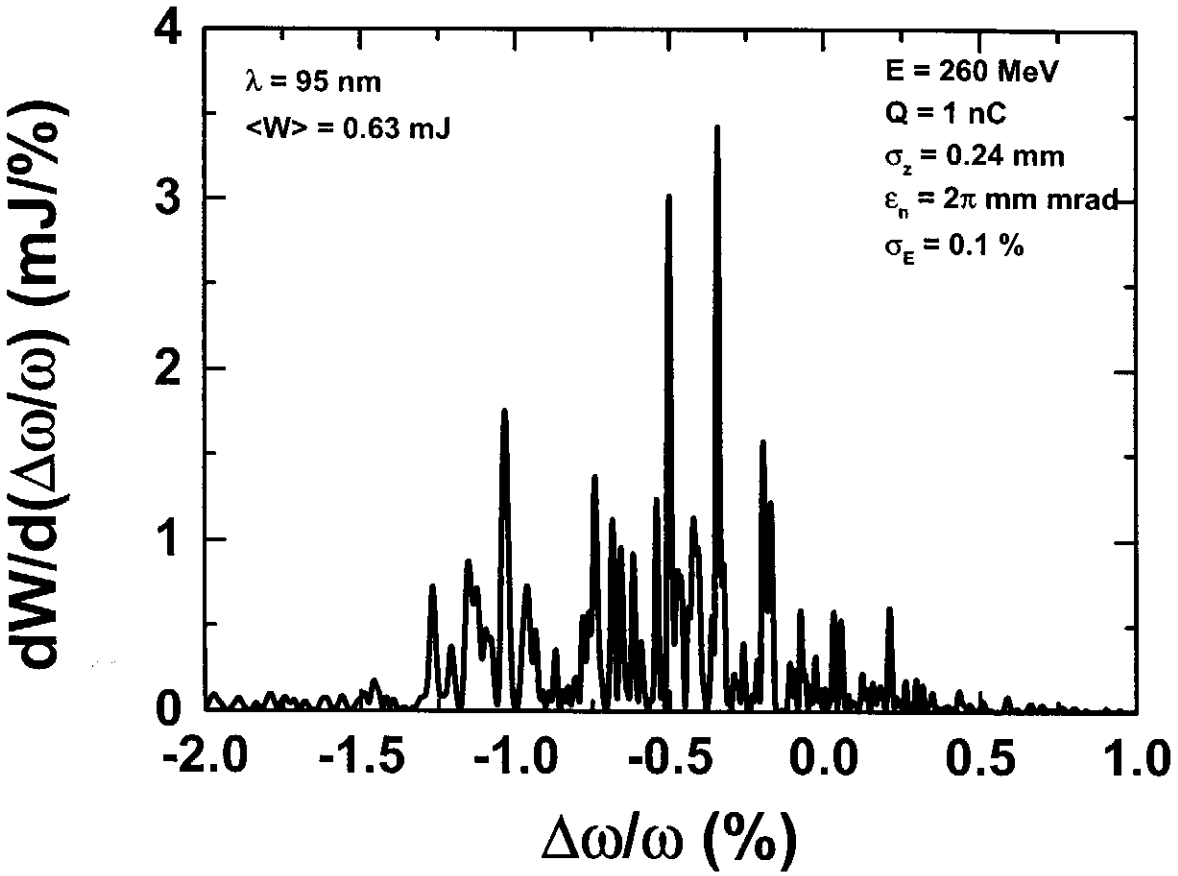
7. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %



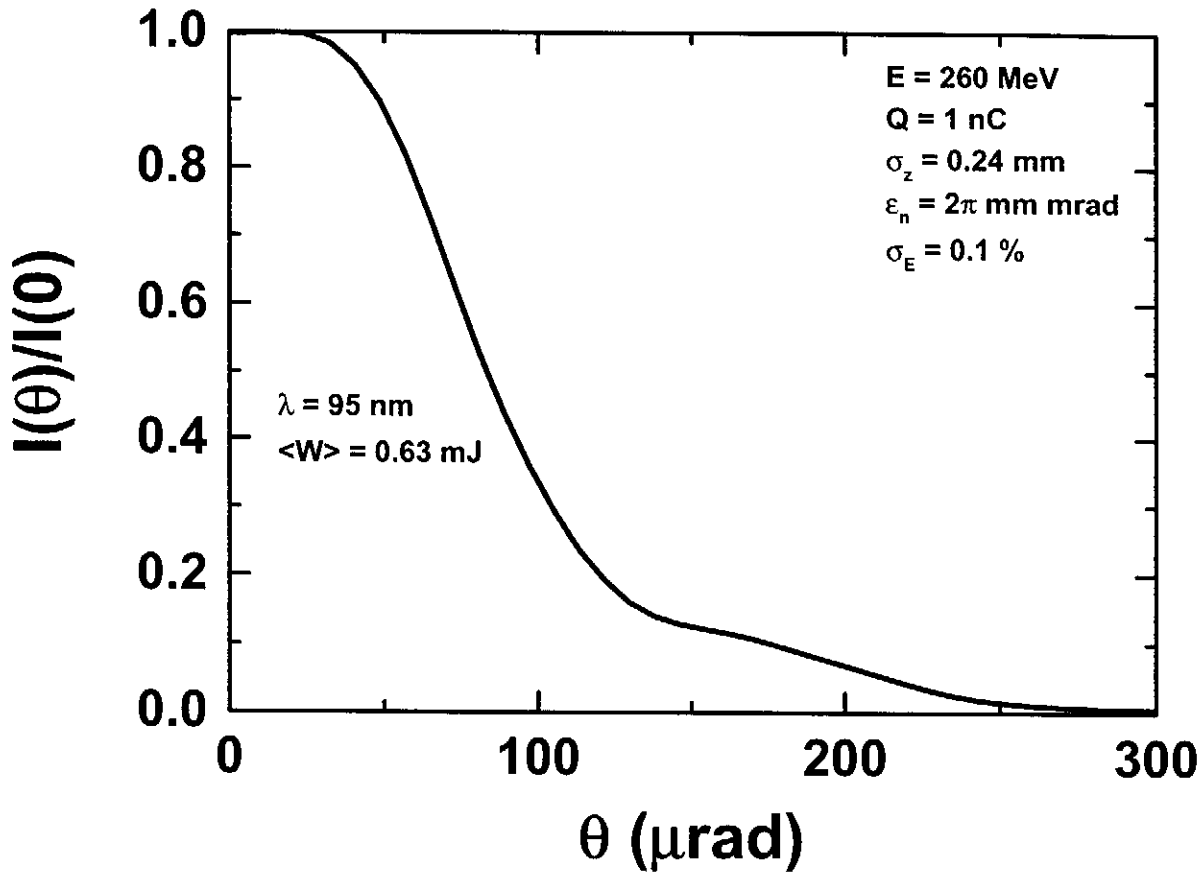
30 7. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %



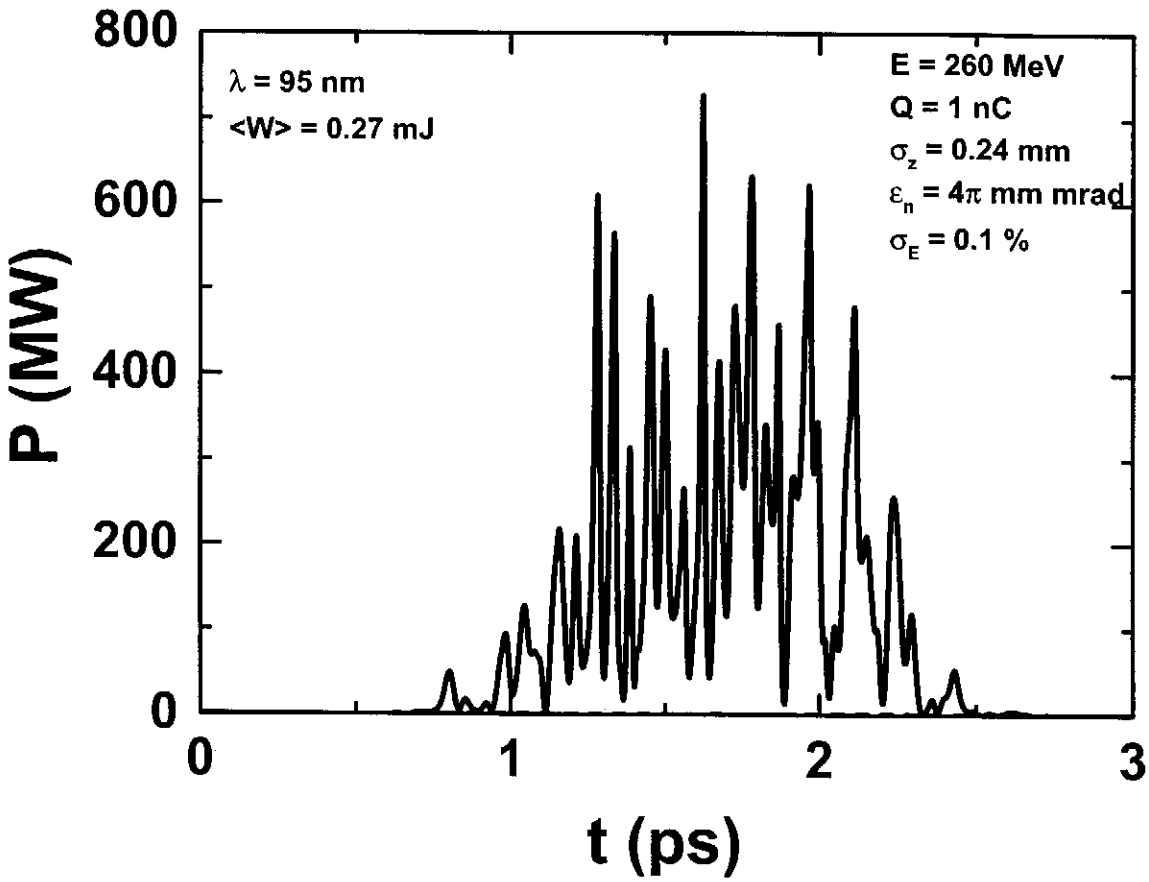
7. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ % 31



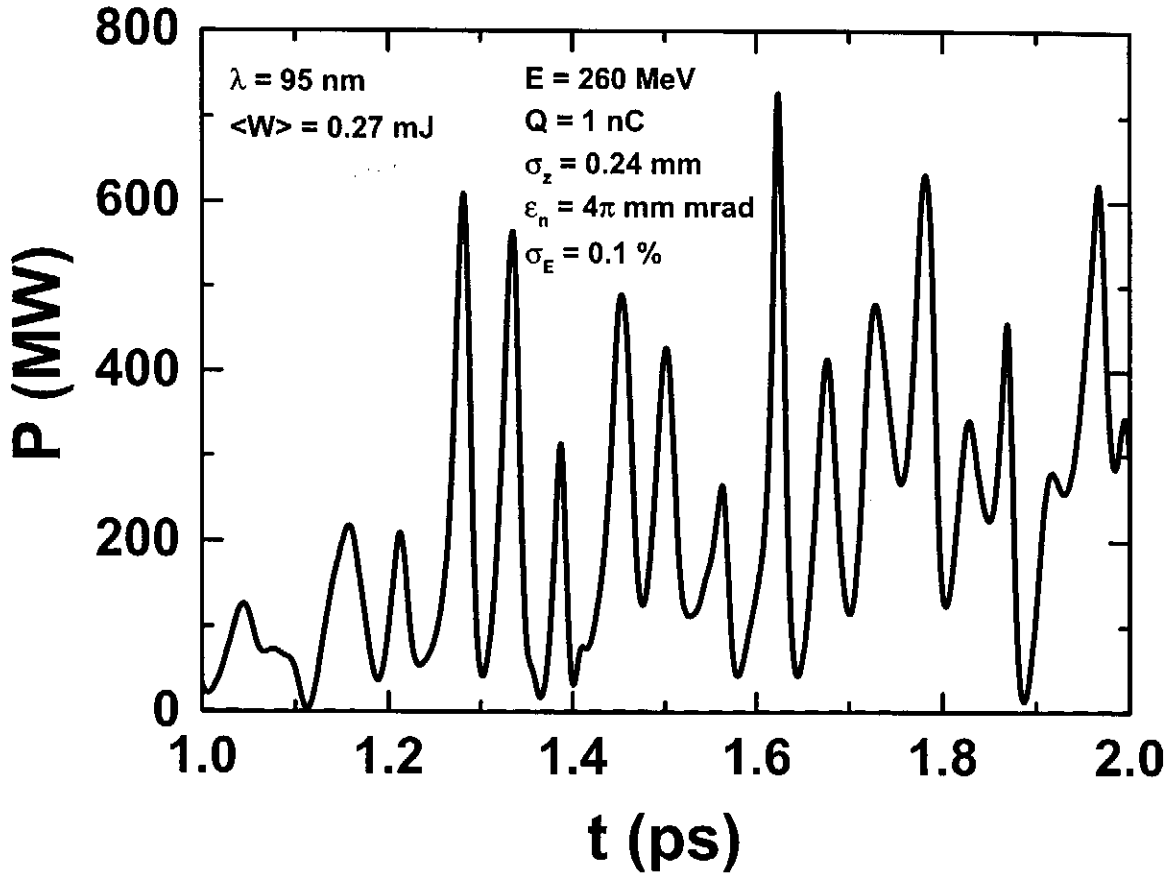
32 7. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %

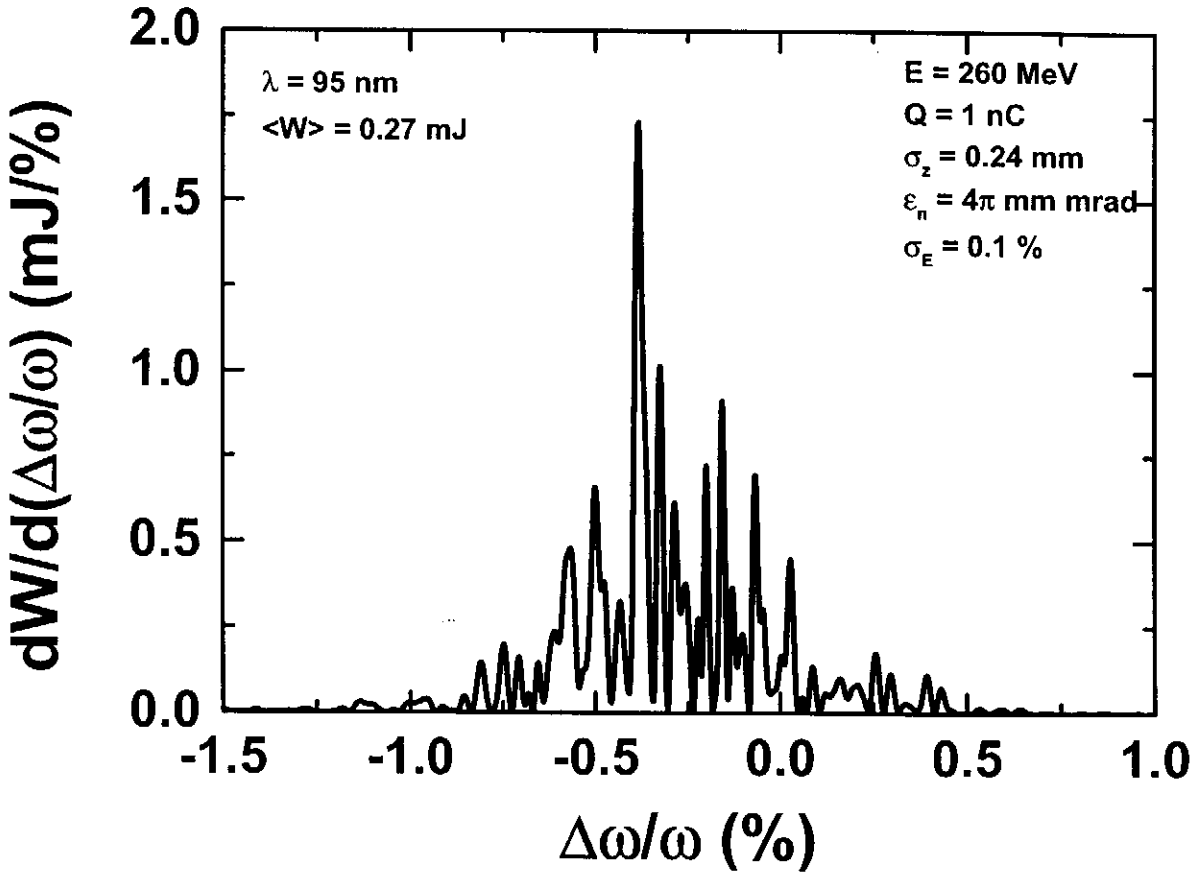


8. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %

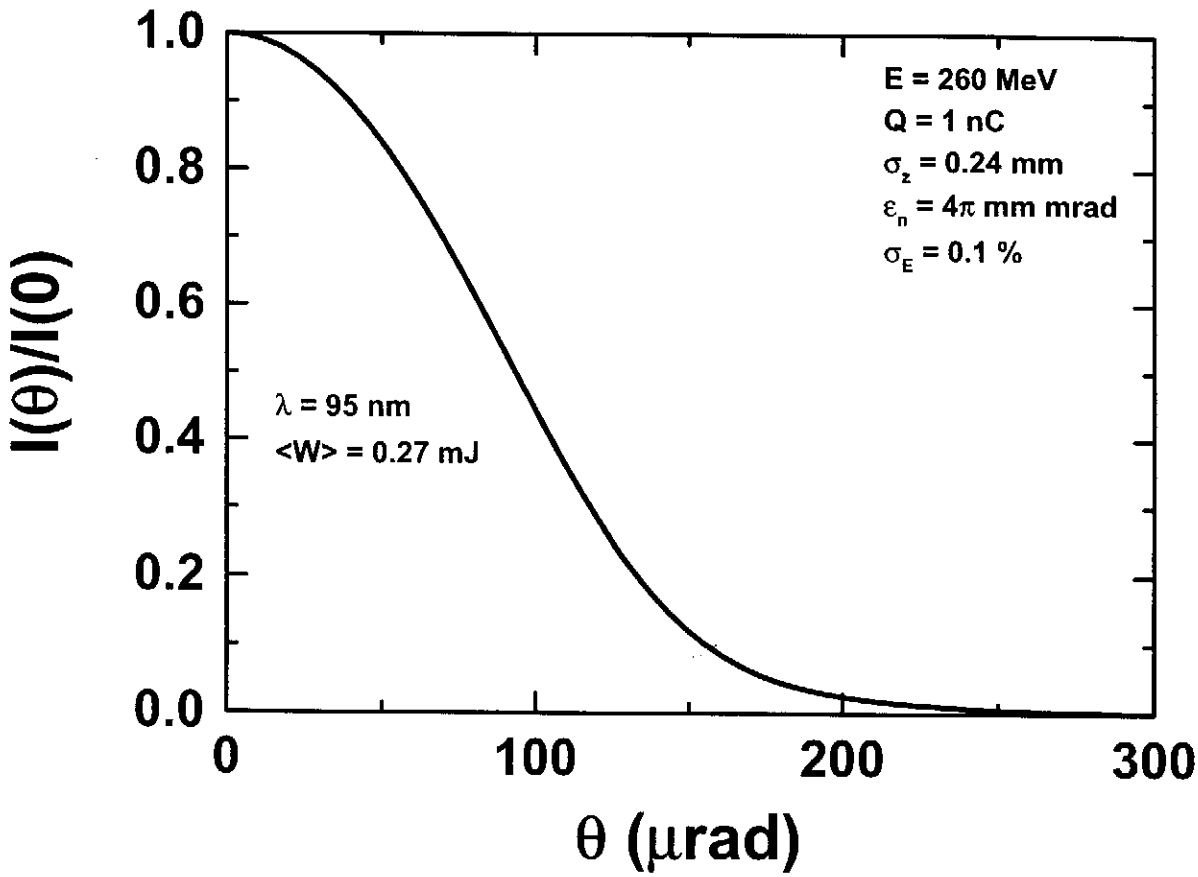


34 8. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %

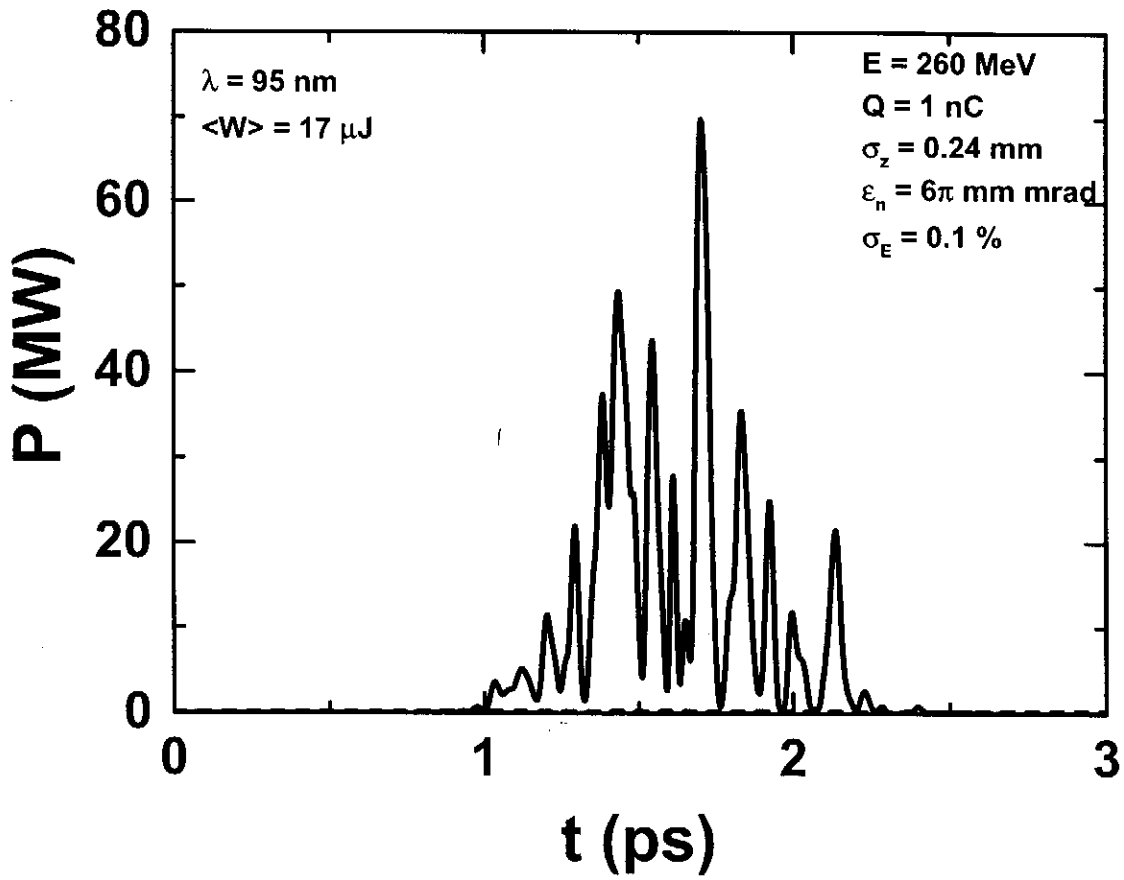



λ = 95 nm
<W> = 0.27 mJ
E = 260 MeV
Q = 1 nC
σz = 0.24 mm
εn = 4π mm mrad
σE = 0.1 %
dW/d(Δω/ω) (mJ/%)
Δω/ω (%)
2.0
1.5
1.0
0.5
0.0
-1.5
-1.0
-0.5
0.0
0.5
1.0

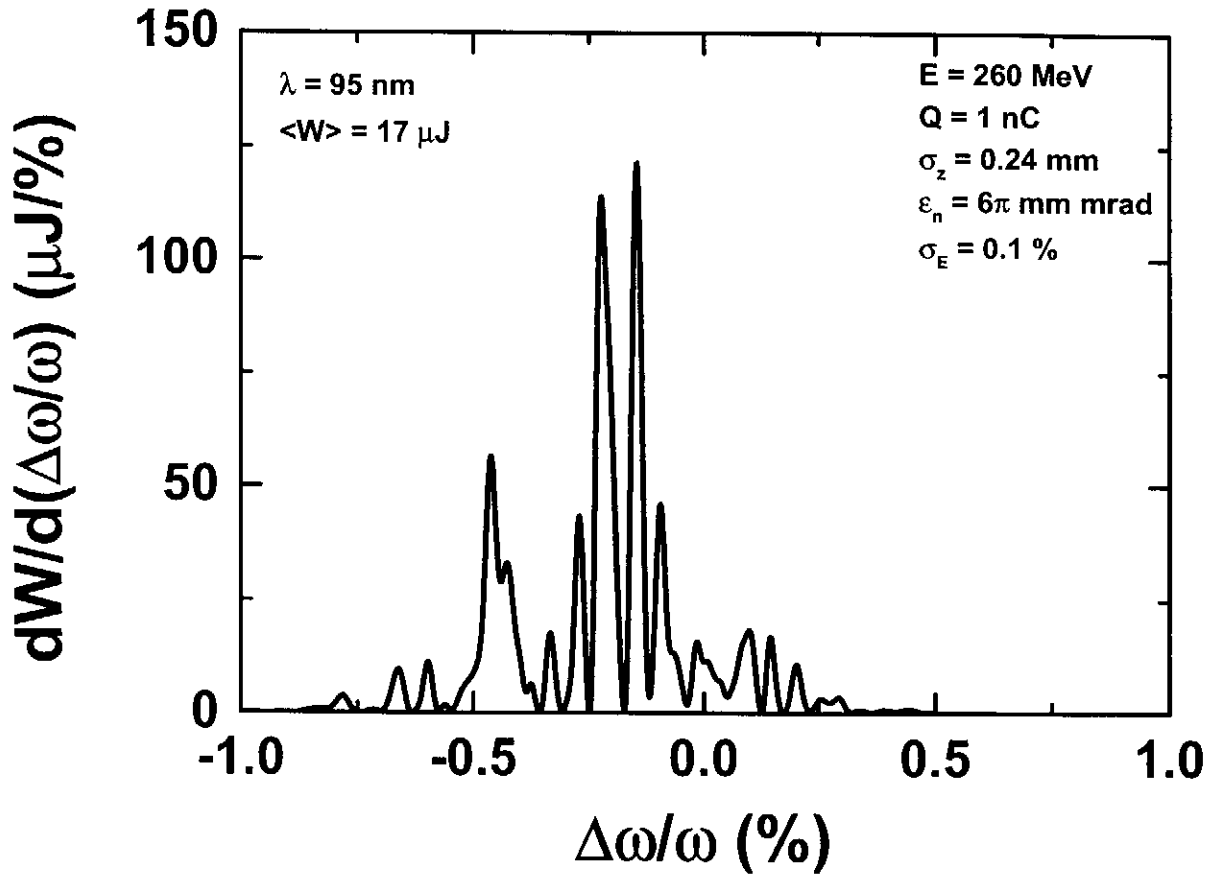
36 8. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %



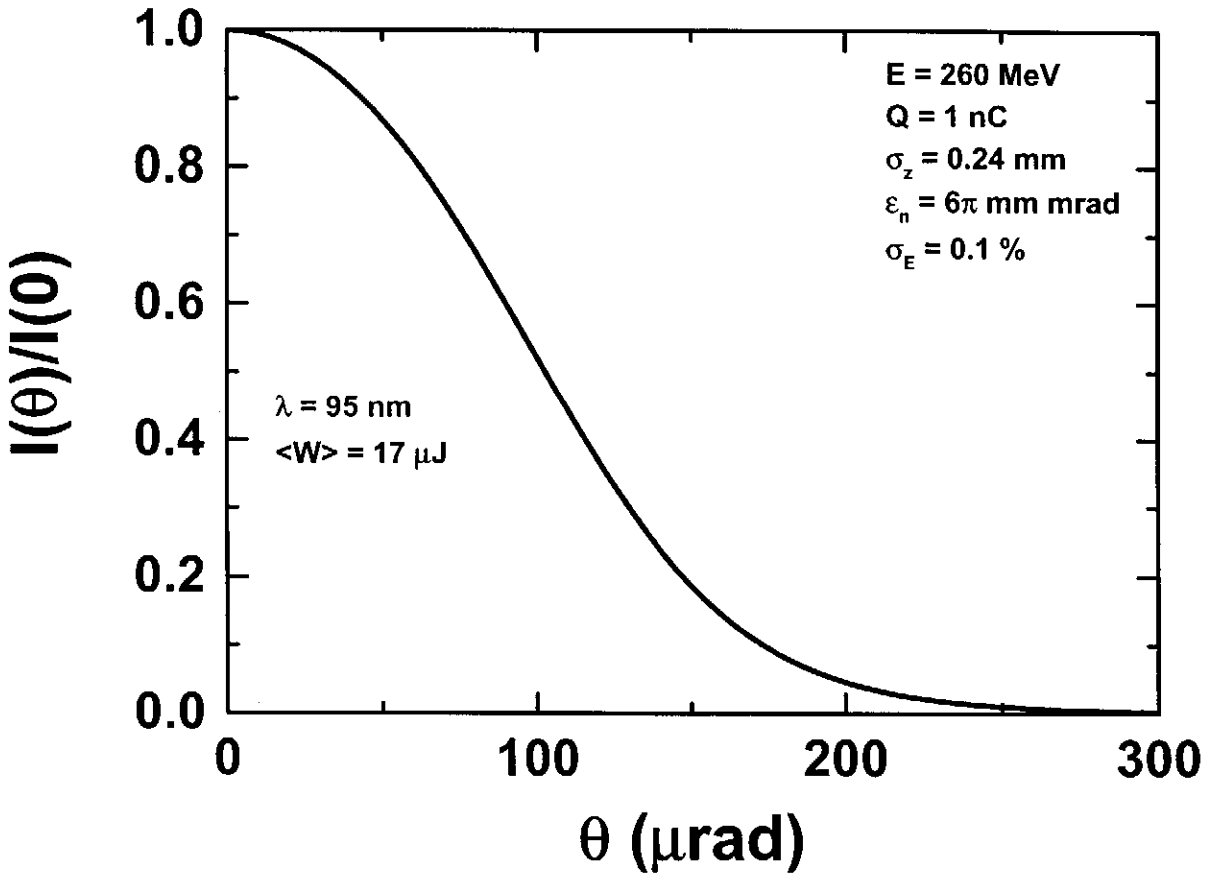
9. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %



38 9. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %

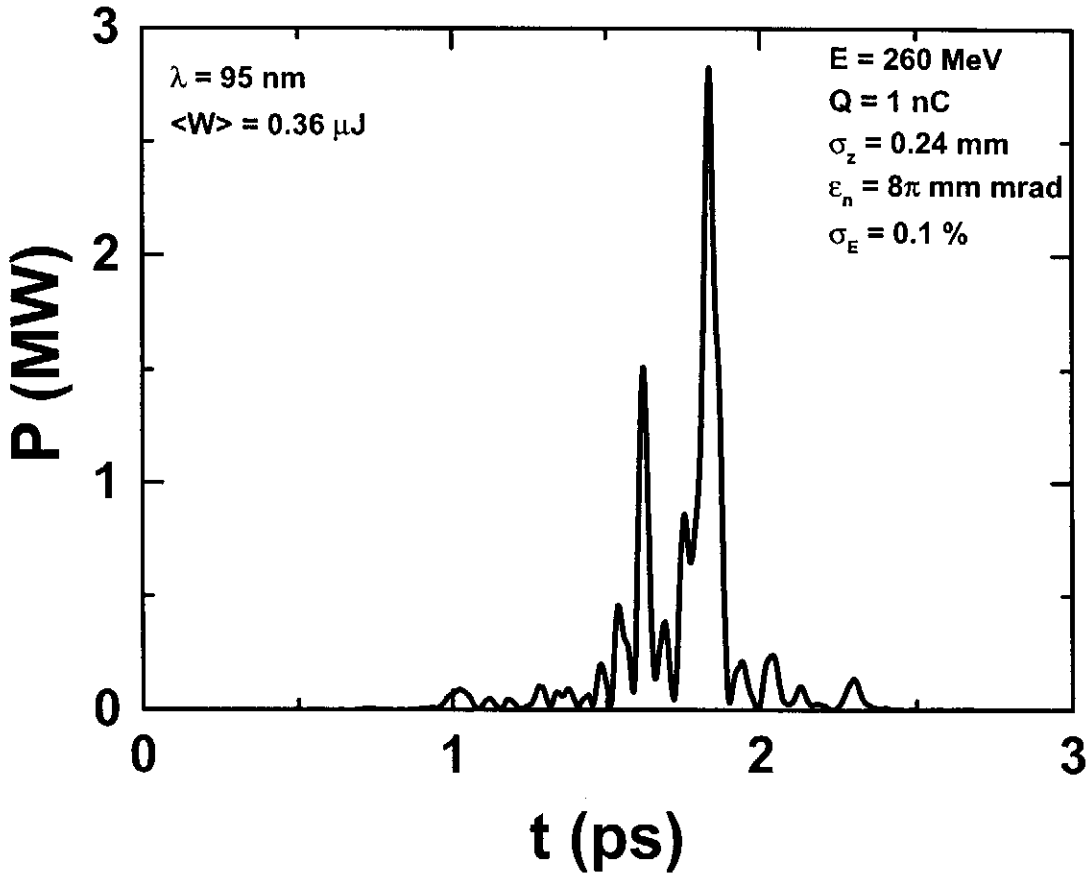


9. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ % 39

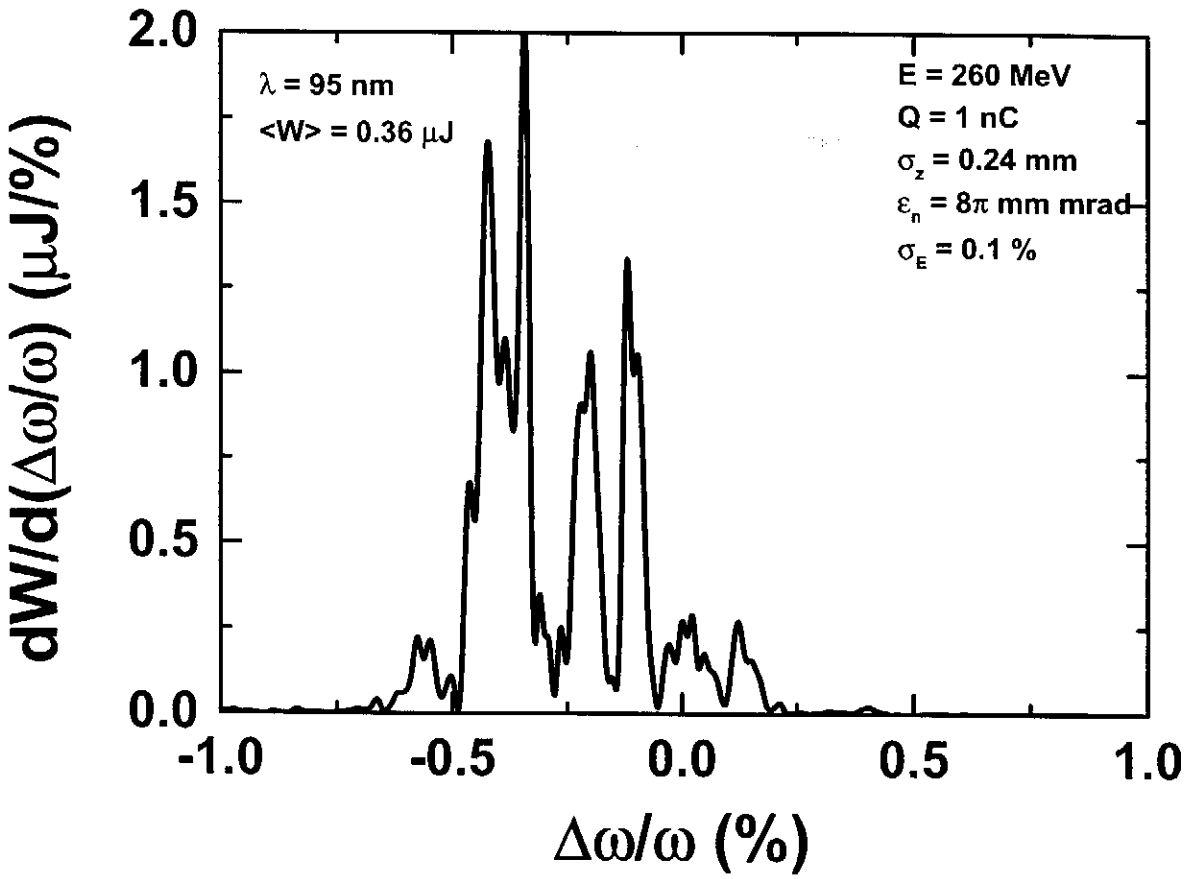


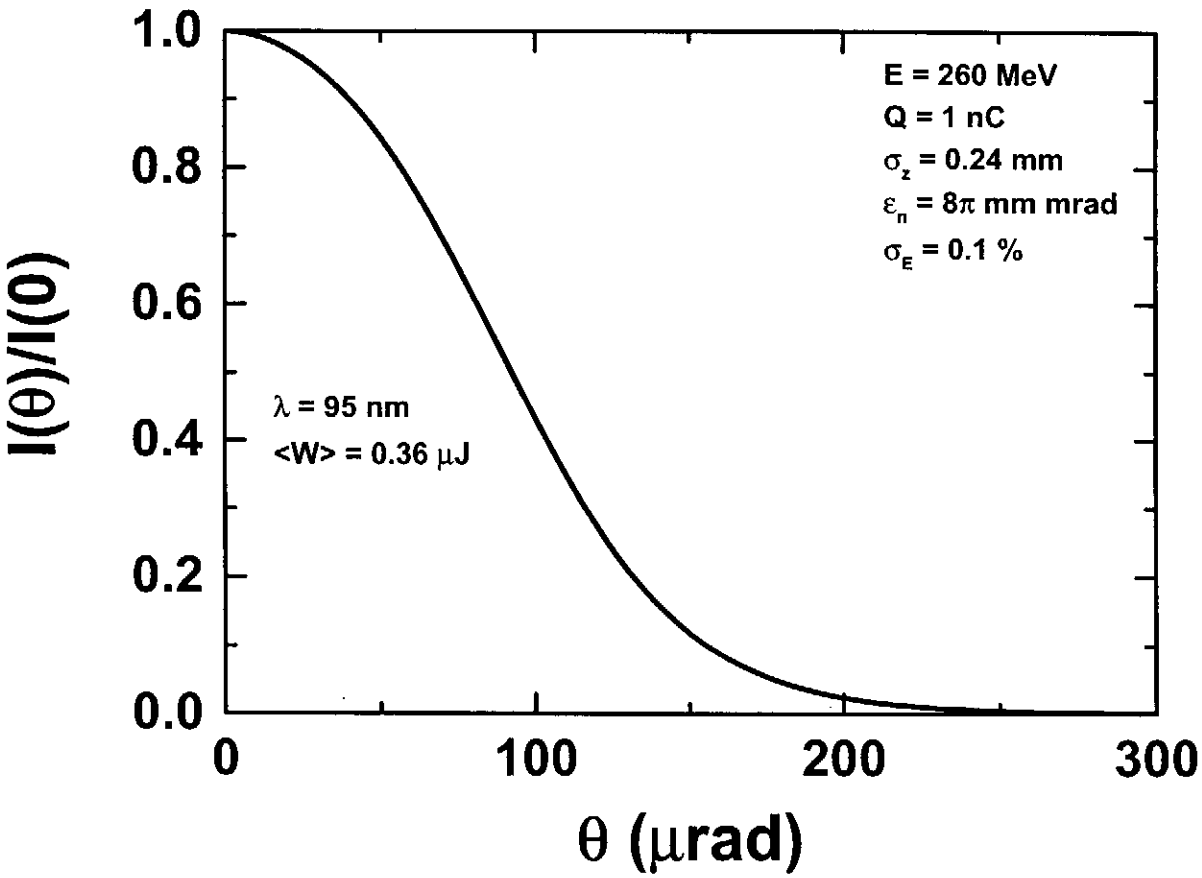
40 9. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %

10. $\epsilon_n = 8\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %



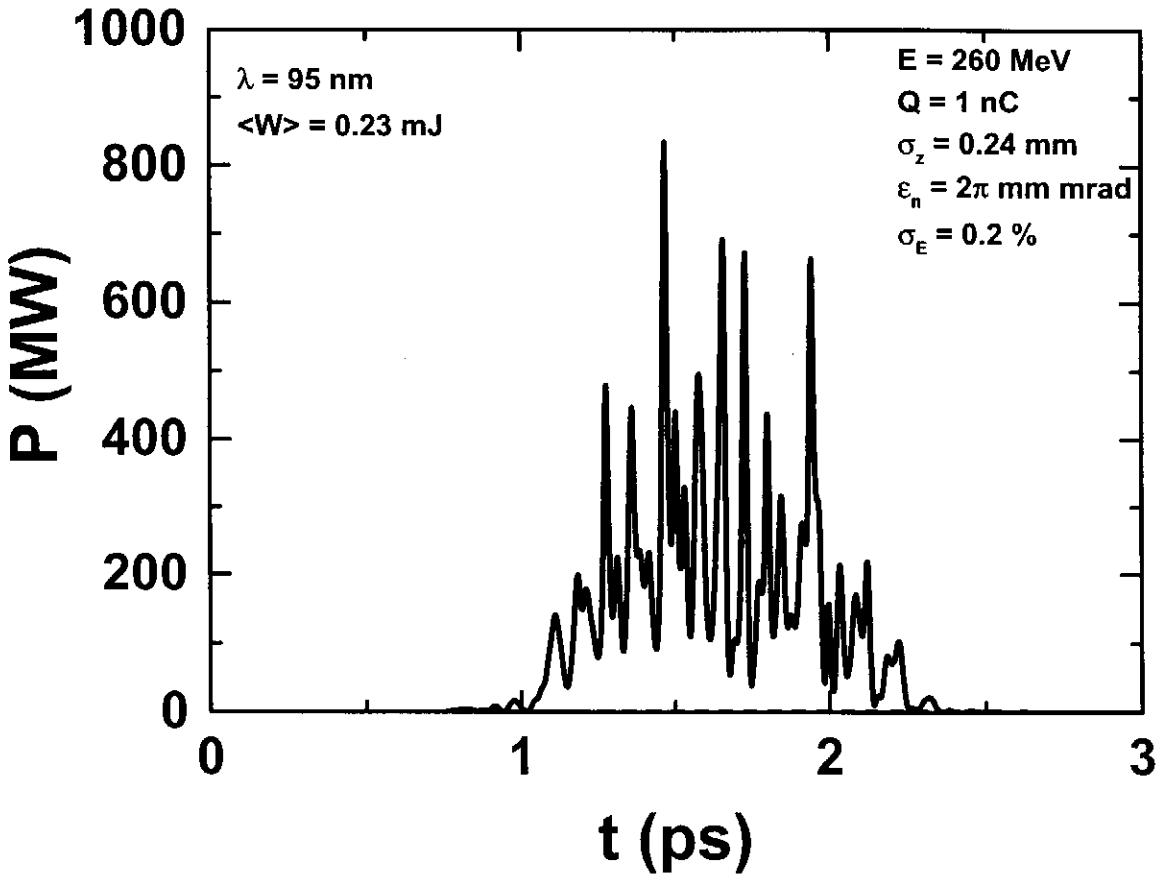
42 10. $\epsilon_n = 8\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %



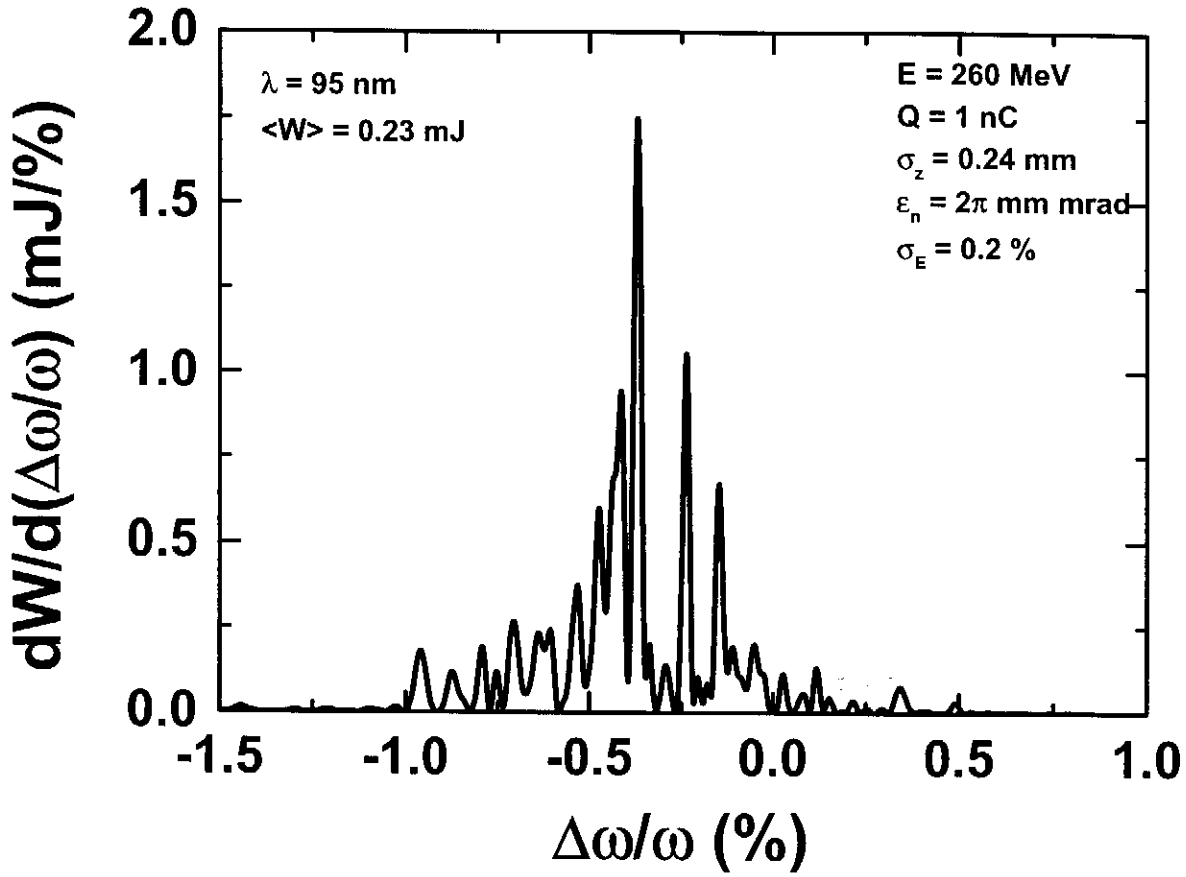

1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
I(θ)/I(0)
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 0.24 mm
εn = 8π mm mrad
σE = 0.1 %
λ = 95 nm
<W> = 0.36 μJ

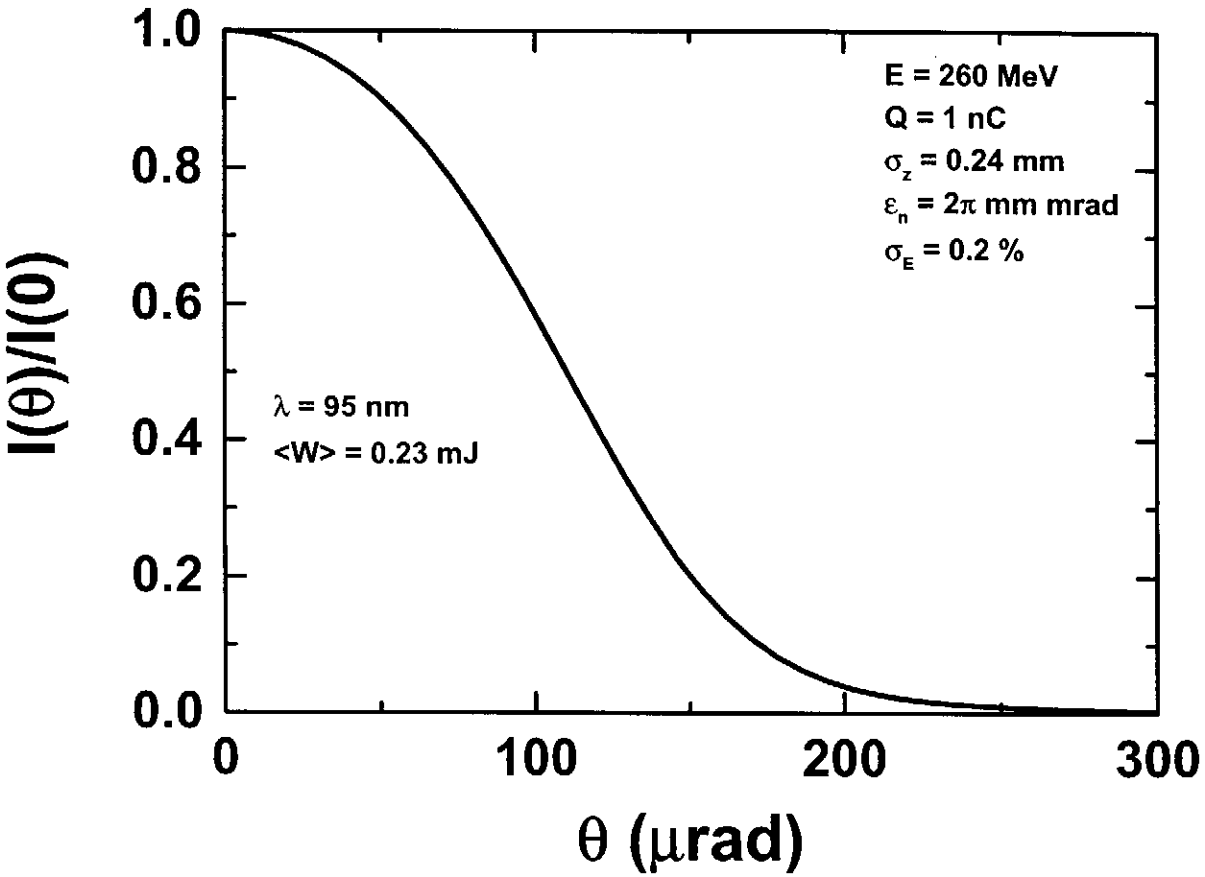
10. $\epsilon_n = 8\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.1$ %

11. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



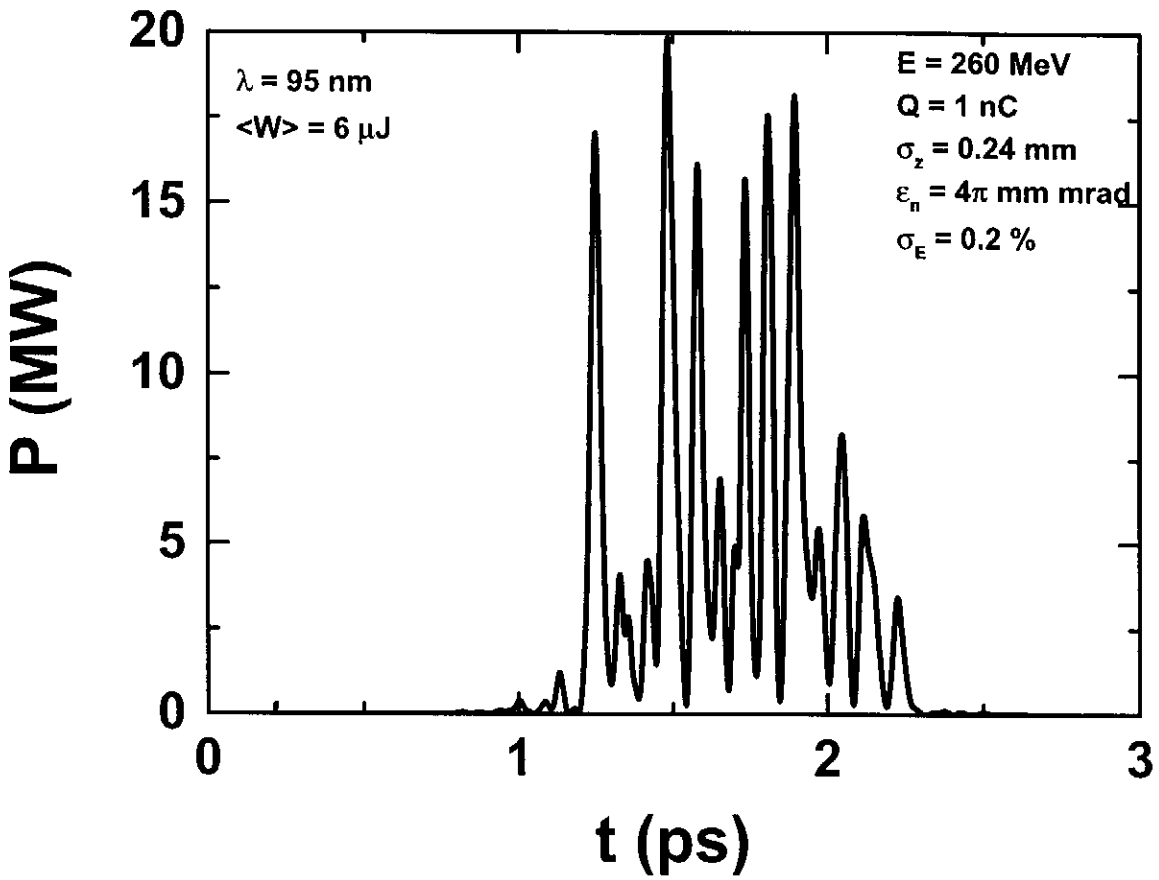
46 11. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



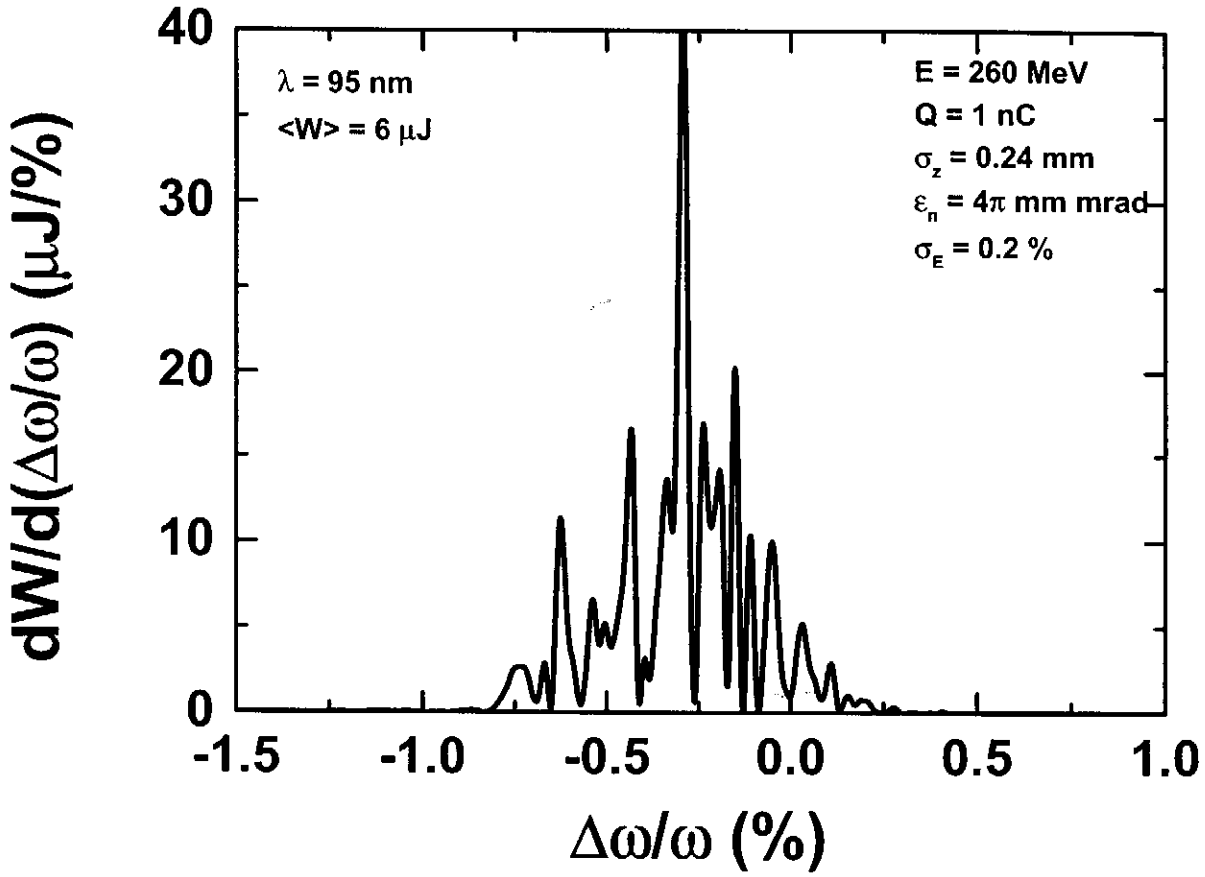

1.0
0.8
0.6
0.4
0.2
0.0
I(θ)/I(0)
0
100
200
300
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 0.24 mm
εn = 2π mm mrad
σE = 0.2 %
λ = 95 nm
<W> = 0.23 mJ

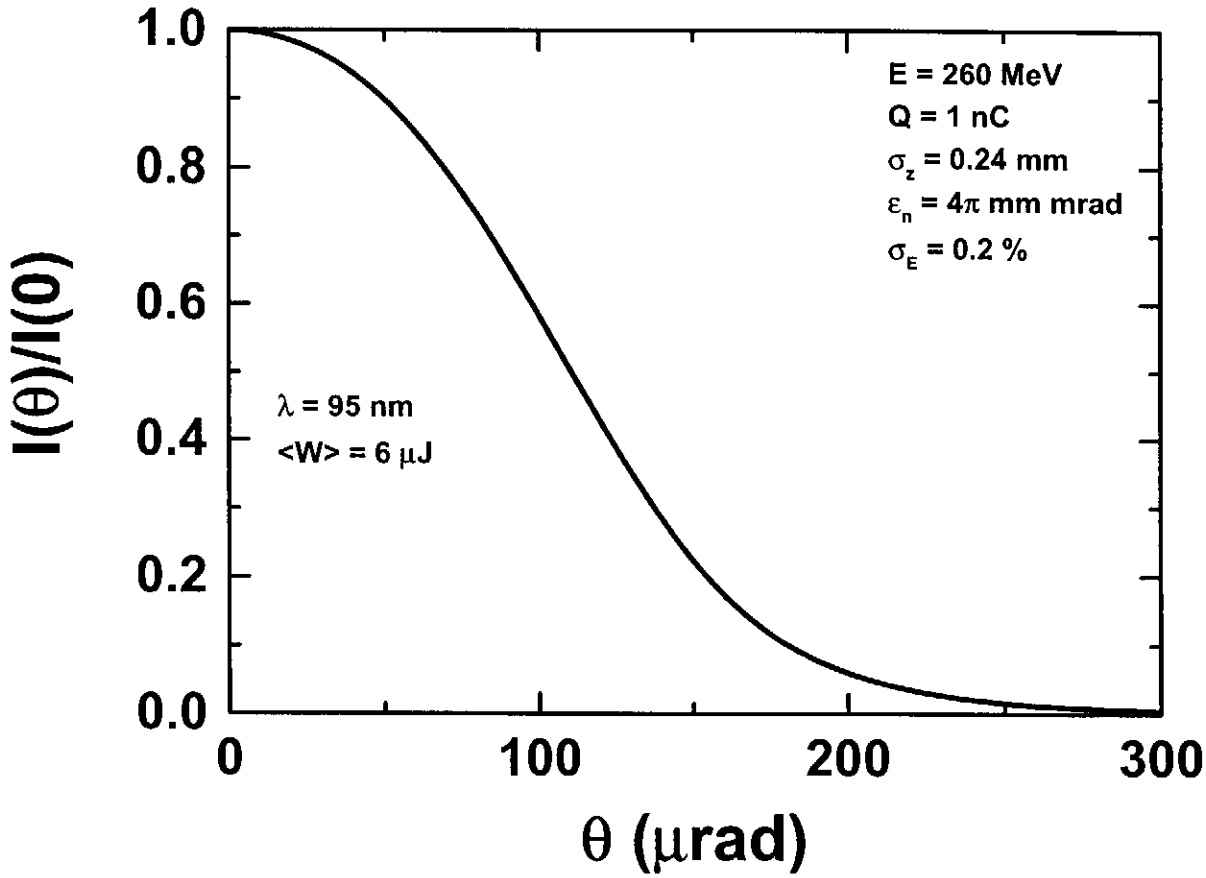
48 11. $\epsilon_n = 2\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %

12. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



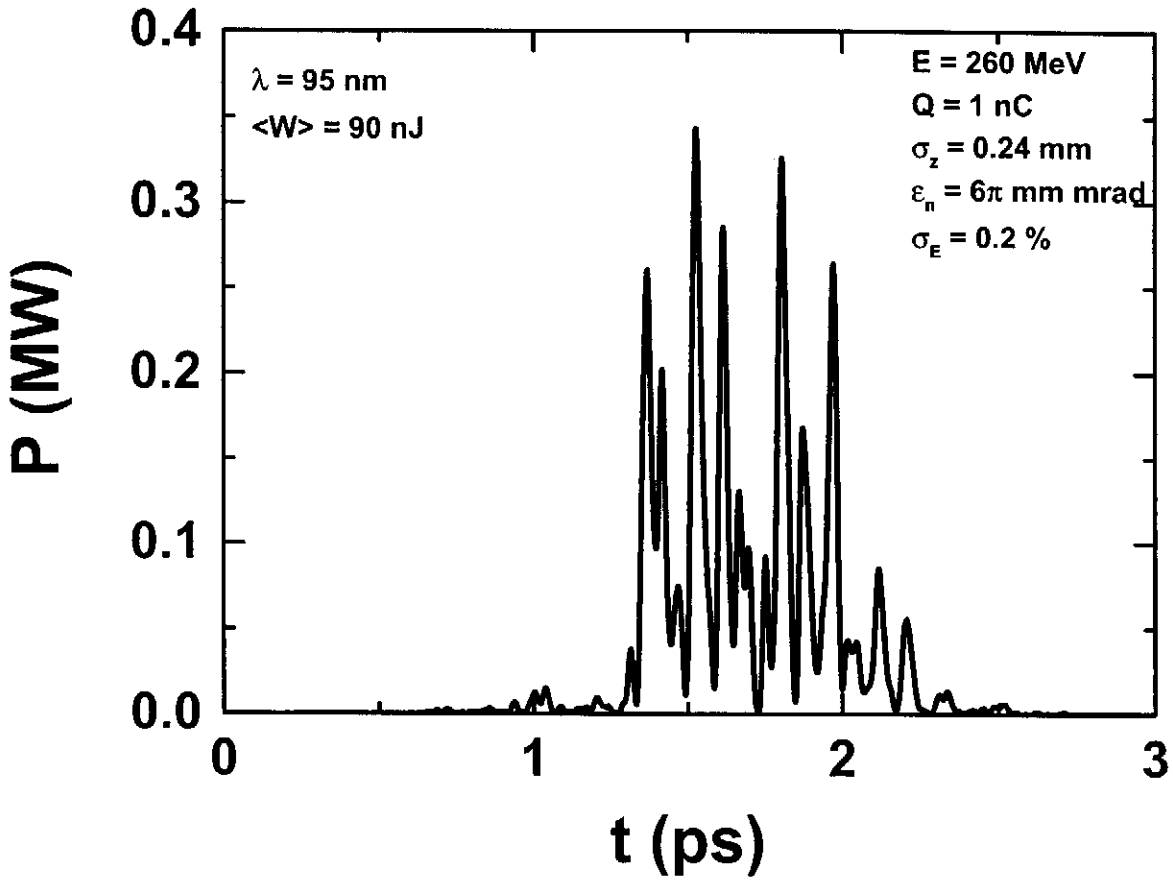
50 12. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



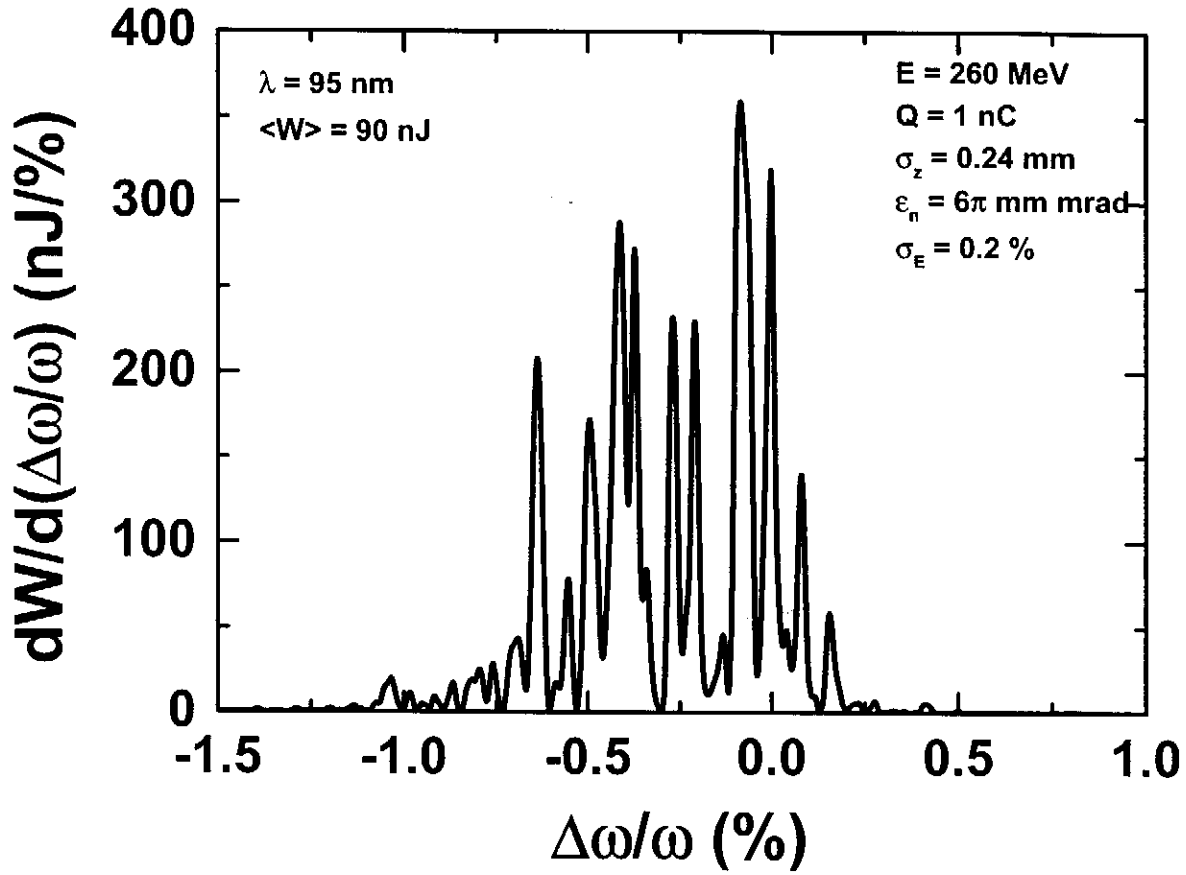

1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
I(θ)/I(0)
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 0.24 mm
εn = 4π mm mrad
σE = 0.2 %
λ = 95 nm
<W> = 6 μJ

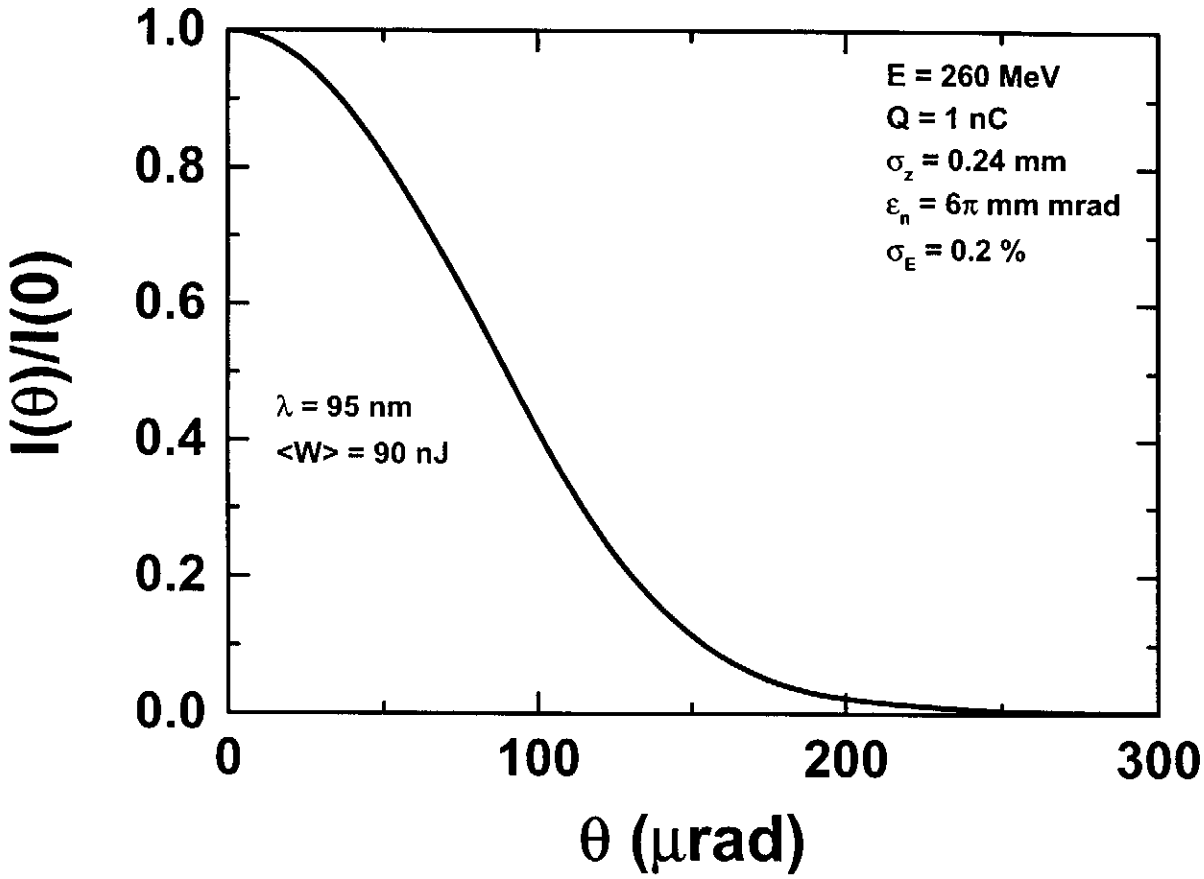
52 12. $\epsilon_n = 4\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %

13. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



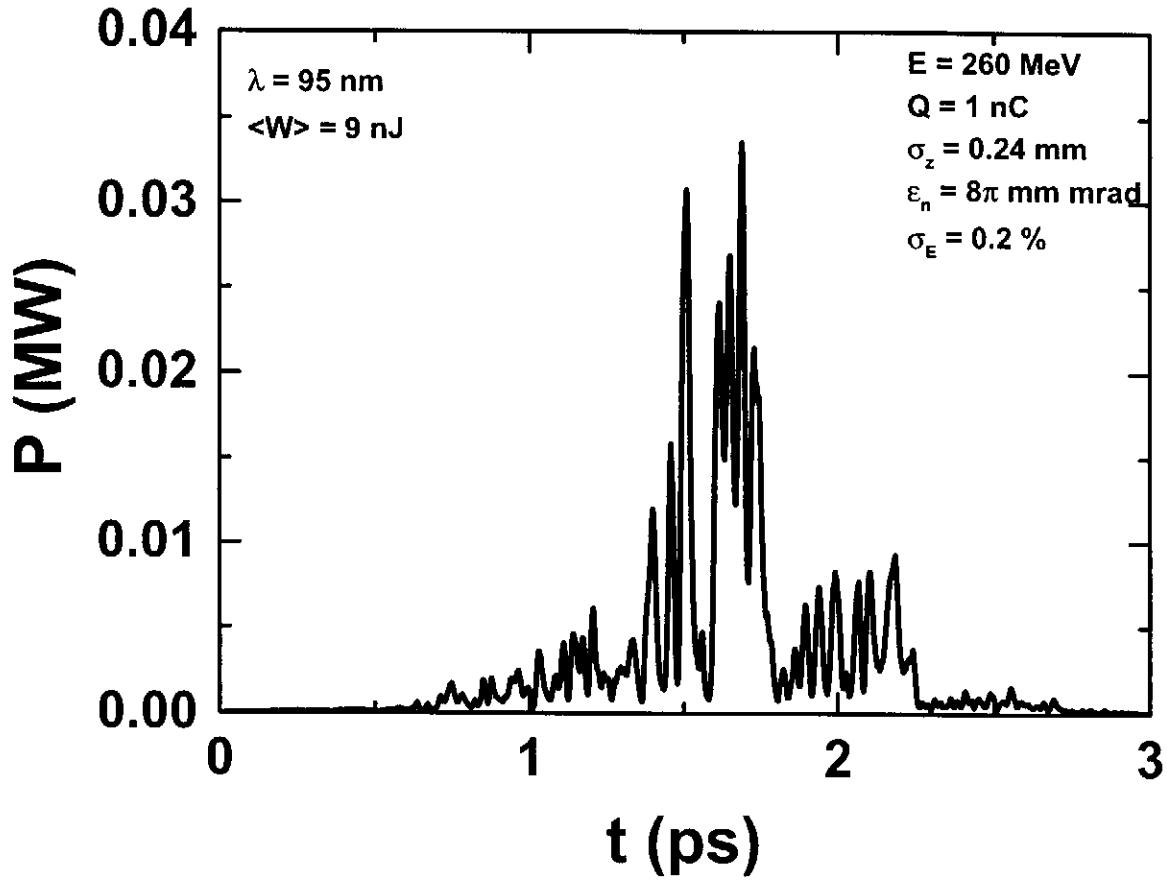
54 13. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



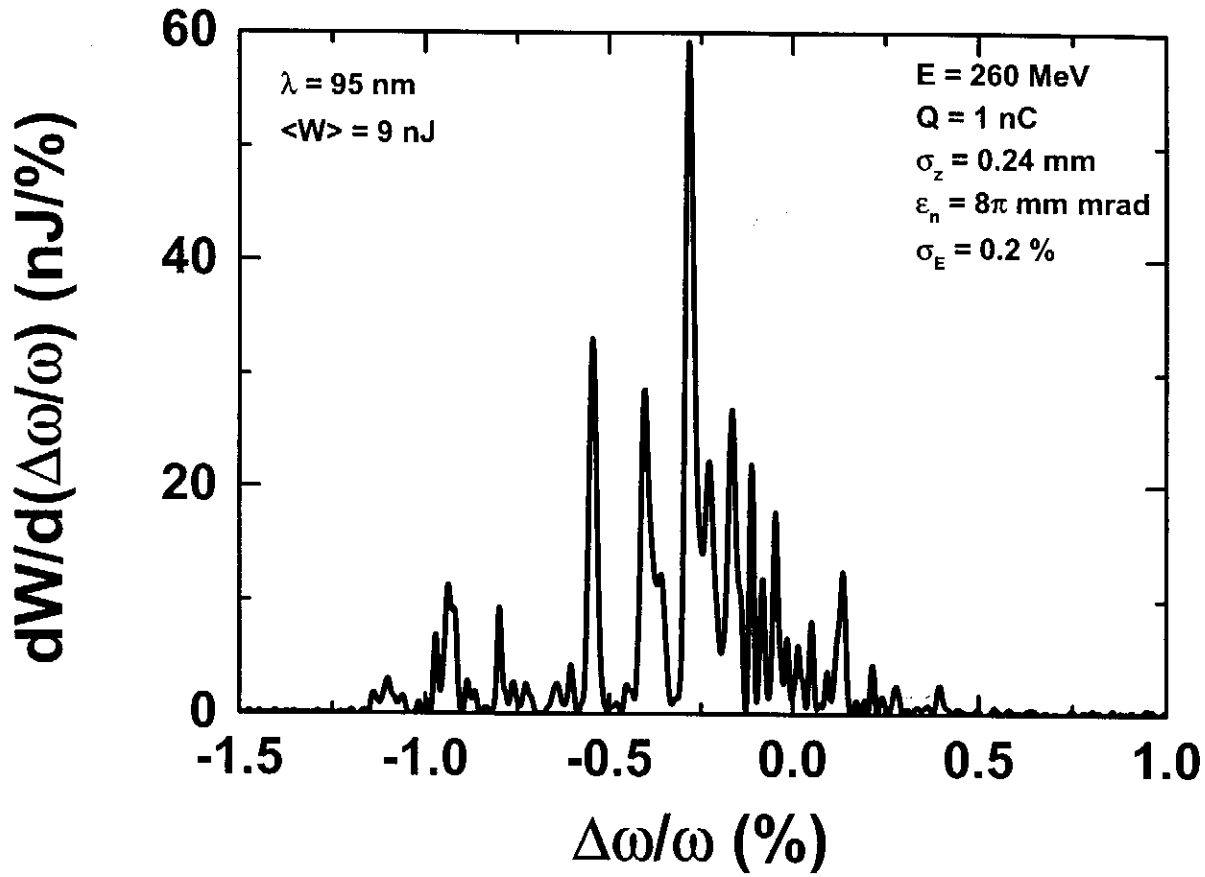

1.0
0.8
0.6
0.4
0.2
0.0
I(θ)/I(0)
0
100
200
300
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 0.24 mm
εn = 6π mm mrad
σE = 0.2 %
λ = 95 nm
<W> = 90 nJ

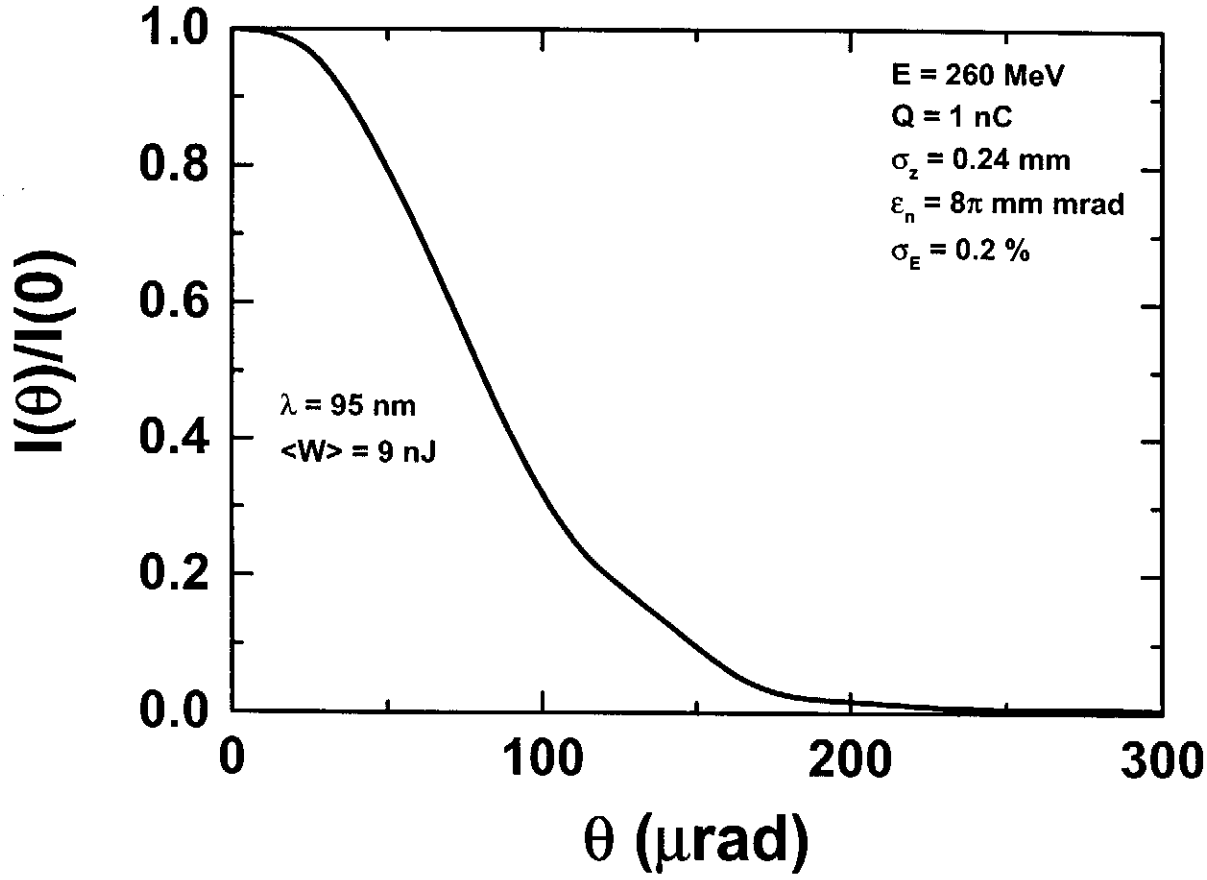
56 13. $\epsilon_n = 6\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %

14. $\epsilon_n = 8\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %



58 14. $\epsilon_n = 8\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %




1.0
0.8
0.6
0.4
0.2
0.0
I(θ)/I(0)
0
100
200
300
θ (μrad)
E = 260 MeV
Q = 1 nC
σz = 0.24 mm
εn = 8π mm mrad
σE = 0.2 %
λ = 95 nm
<W> = 9 nJ

60 14. $\epsilon_n = 8\pi$ mm mrad, $\sigma_z = 0.24$ mm, $\sigma_E = 0.2$ %

References

1. The region of physical parameters under consideration has been fixed on the base of current status of the beam parameters.
2. E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, Nucl. Instrum. and Methods **A429**(1999)233.