MODE LOCKED OPTICAL KLYSTRON CONFIGURATION IN AN FEL CAVITY RESONATOR

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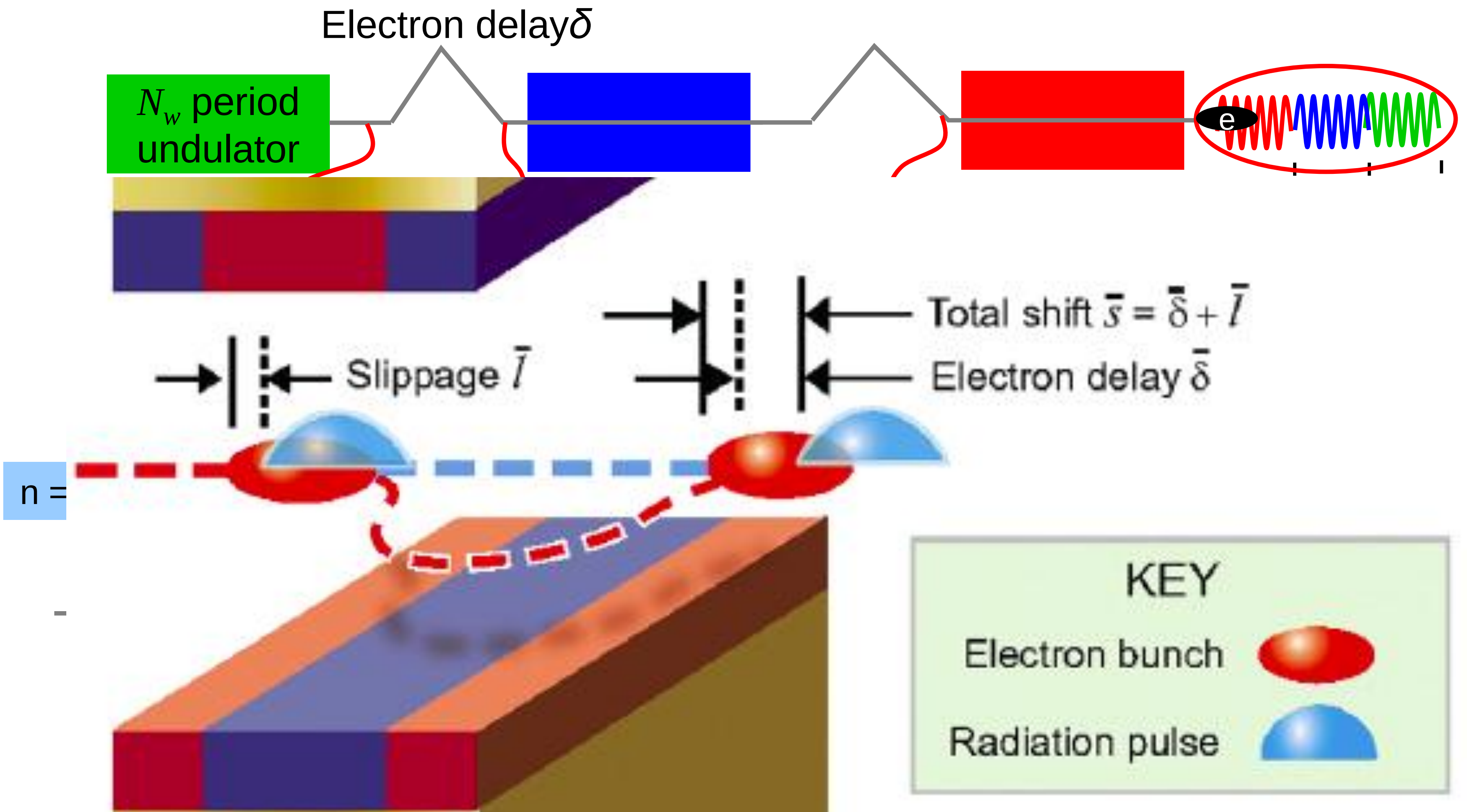
Outline

- Mode Locked Optical Klystron - brief review
- Further development:
  MLOK in an cavity resonator
  - RAFEL *without* MLOK – interesting case of short electron pulse: $l_b \sim l_c$
  - RAFEL with MLOK – short electron pulse
  - IR-FEL cavity resonator with MLOK
- Conclusions

Mode Locked Optical Klystron – brief review

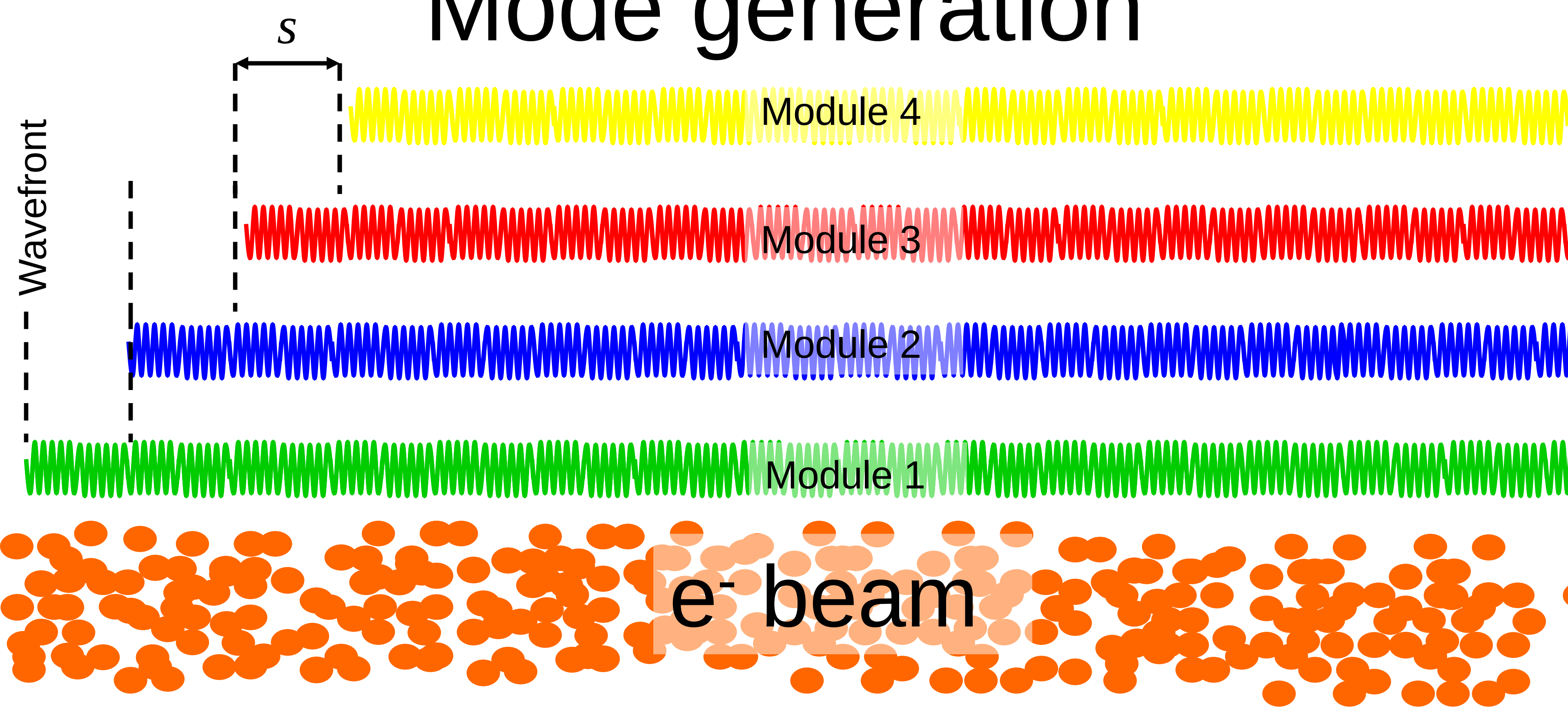
Axial Modes from an *amplifier* FEL

- ***Synthesise axial mode spectrum <u>without cavity</u>***



each undulator/chicane module has been synthesized

Mode generation

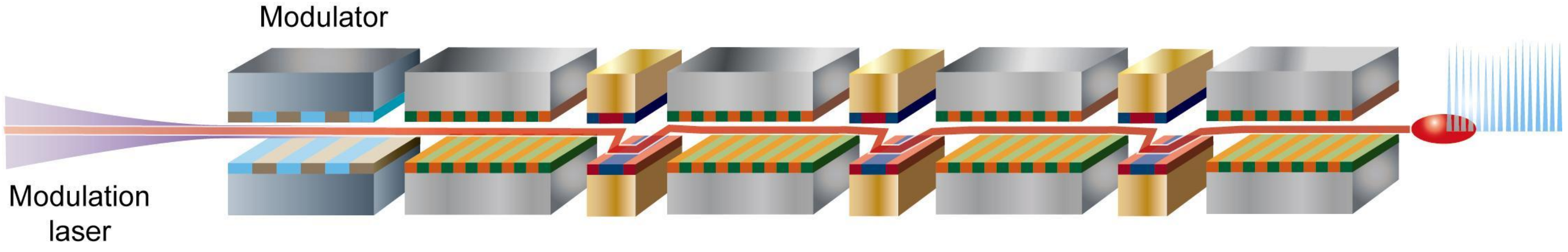


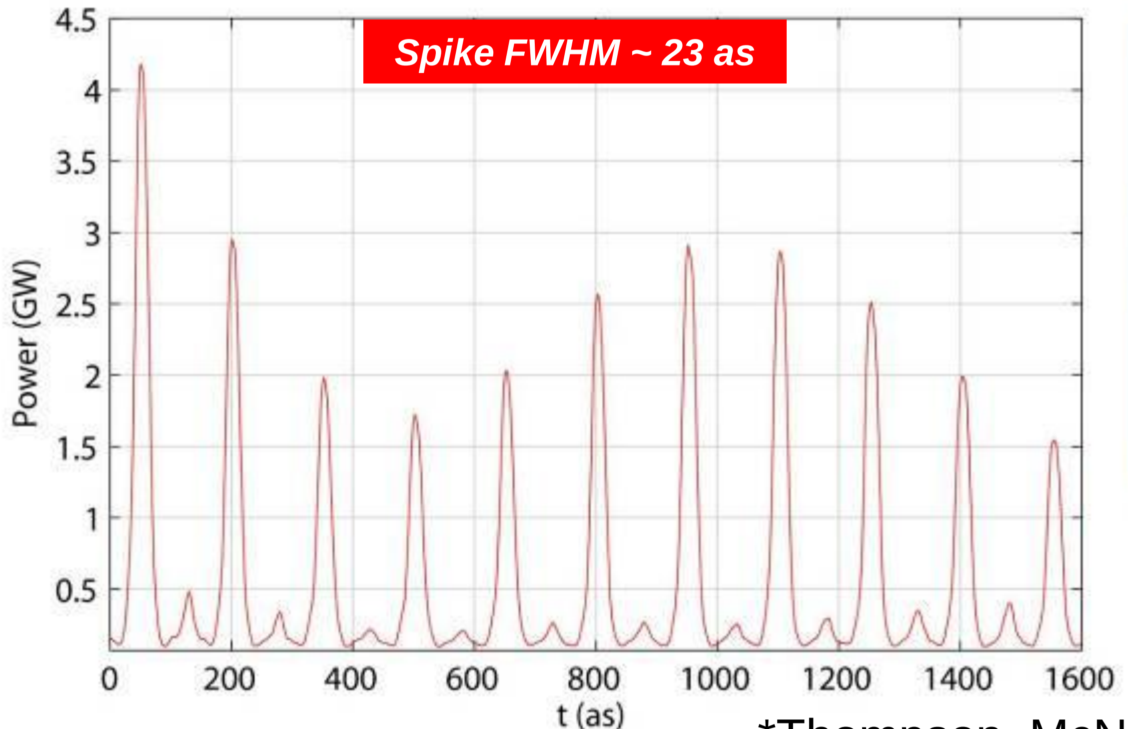
For continued slips of distance s, only those wavelengths with an integer number of periods in distance s will survive after many such slips. For s an integer of λ_r :

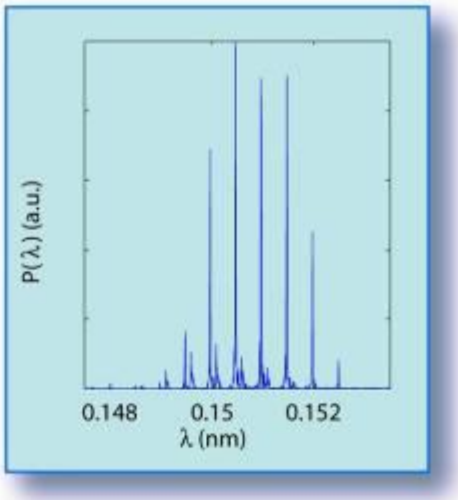
$$s = N\lambda_r = (N+1)\lambda_-$$

$$\Rightarrow \omega_r = \frac{2\pi c N}{s}; \omega_+ = \frac{2\pi c\left(N+1\right)}{s} \quad \Rightarrow \Delta\omega_s = \omega_+ - \omega_r = \frac{2\pi c}{s}$$

X-ray SASE MLOK amplifier with mode-locking*

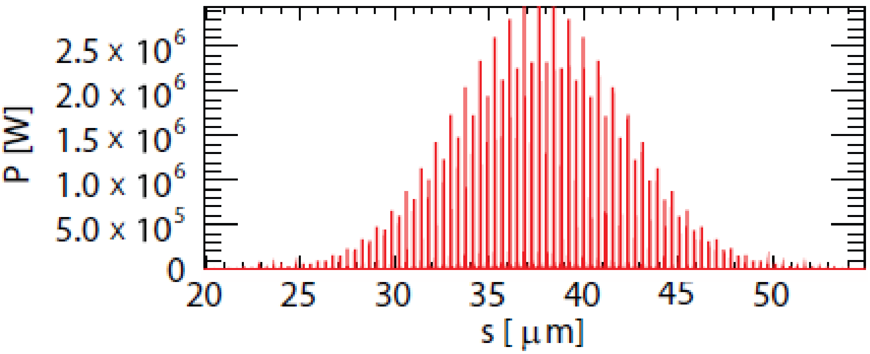


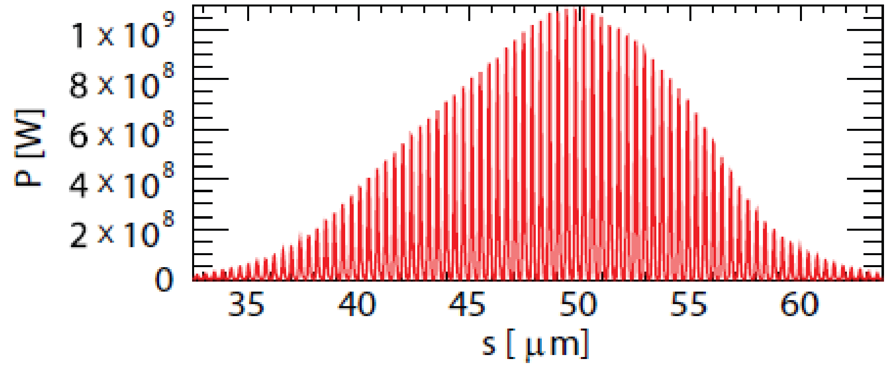


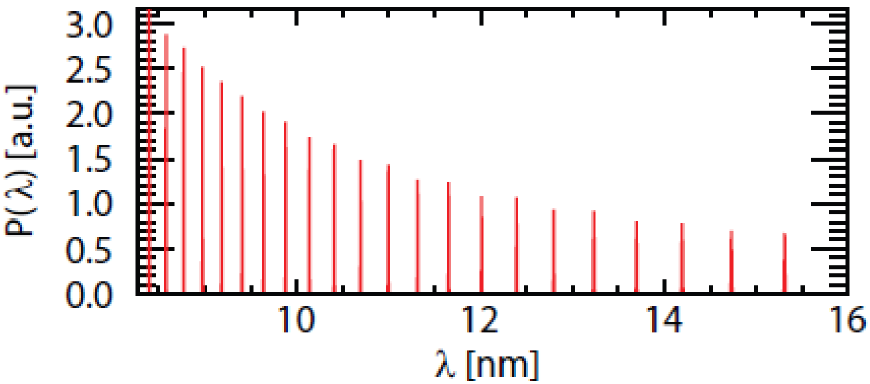


*Thompson, McNeil, PRL **100,** 203901 (2008)

Amplified HHG – retaining structure with MLOK via initial electron beam energy modulation*







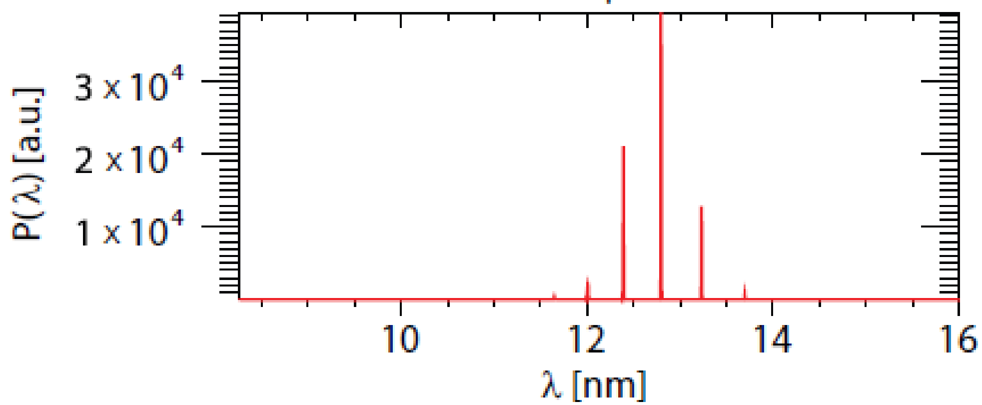
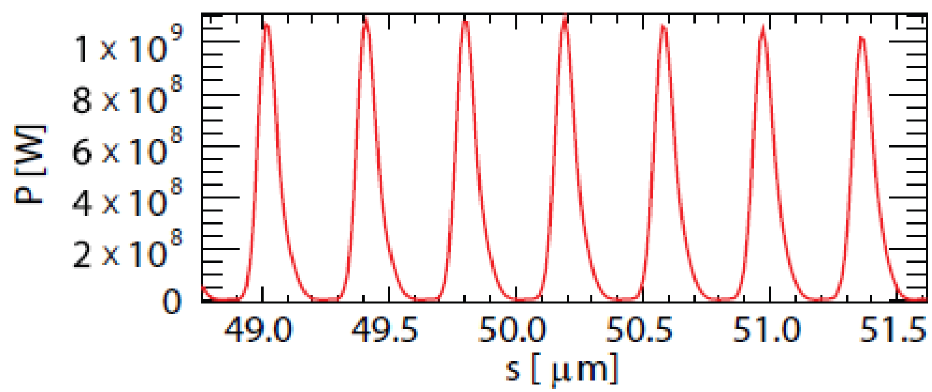


Figure 6: Longitudinal intensity profile (top) and spectral power distribution (bottom) of the HHG seed in 3D simulations.



* B. W. J. McNeil, N. R. Thompson, D. J. Dunning, B. Sheehy, Proceedings of FEL conference 2008 (MOCAU04)

Improved temporal coherence by increasing cooperation length*

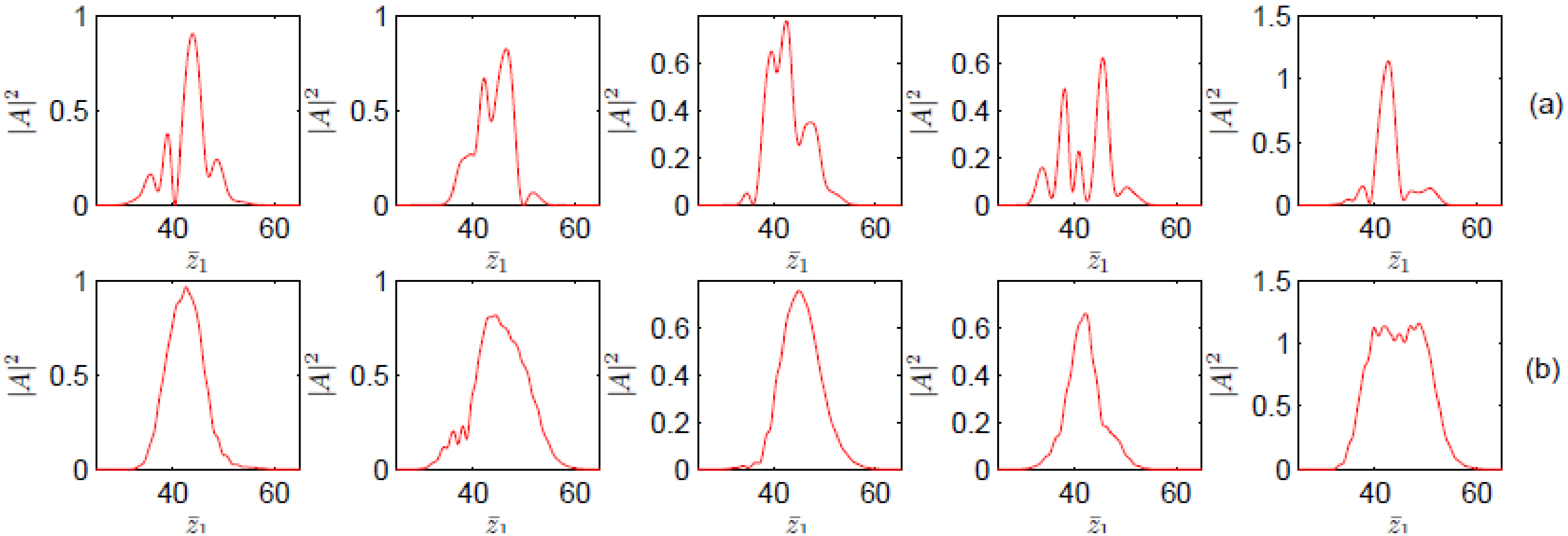


Figure 3: Short Pulse Regime: Scaled power pulse profiles at saturation for (a) $S_e = 1.0$ and (b) $S_e = 4$ with delays randomised and terminated prior to saturation.

*Thompson, Dunning & McNeil,
IMPROVED TEMPORAL COHERENCE IN SASE FELS
Proceedings of IPAC'10, Kyoto, Japan, TUPE050, 2010

Why bother with APTs?

[1] P. Johnsson, R. López-Martens, S. Kazamias, J. Mauritsson, C. Valentin, T. Remetter, K. Varjú, M. B. Gaarde, Y. Mairesse, H. Wabnitz, P. Salières, Ph. Balcou, K. J. Schafer and A. L'Huillier, *Attosecond Electron Wave Packet Dynamics in Strong Laser Fields*, PRL **95,** 013001 (2005).

[2] T. Remetter, P. Johnsson, J. Mauritsson, K. Varjú, , Y. Ni, F. Lépine, E. Gustafsson, M. Kling, J. Khan, R. López-Martens, K. J. Schafer, M.J.J. Vrakking and A. L'Huillier, *Attosecond electron wave packet interferometry,* Nature Physics **2,** 323-326 (2006).

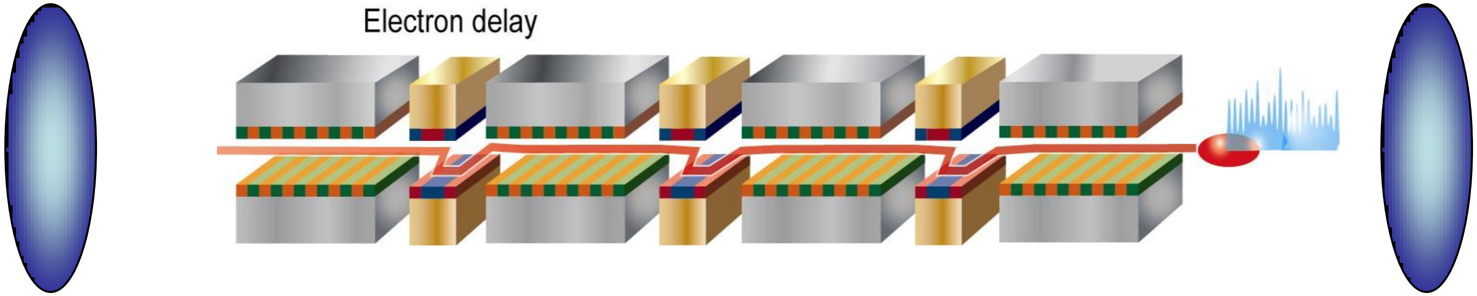
[3] K. Varjú, P. Johnsson, J. Mauritsson, T. Remetter, T. Ruchon, Y. Ni, F. Lépine, M. Kling, J. Khan, K. J. Schafer, M.J.J. Vrakking and A. L'Huillier *Angularly resolved electron wave packet interferences*, J. Phys. B: At. Mol. Opt. Phys. **39,** 3983–3991 (2006).

[4] J. Mauritsson P. Johnsson, E. Mansten, M. Swoboda, T. Ruchon, A. L'Huillier, and K. J. Schafer, *Coherent Electron Scattering Captured by an Attosecond Quantum Stroboscope*, PRL **100**, 073003 (2008).

[5] M. Klaiber, K.Z. Hatsagortsyan, C. Müller and C.H. Keitel, *Coherent hard x rays from attosecond pulse train-assisted harmonic generation*, Optics Lett. **33**, 411-413 (2008).

[6] K. P. Singh, F. He, P. Ranitovic, W. Cao, S. De, D. Ray, S. Chen, U. Thumm, A. Becker, M. M. Murnane, H. C. Kapteyn, I.V. Litvinyuk, and C. L. Cocke, *Control of Electron Localization in Deuterium Molecular Ions using an Attosecond Pulse Train and a Many-Cycle Infrared Pulse*, PRL **104**, 023001 (2010).

Further development:
MLOK in an cavity oscillator

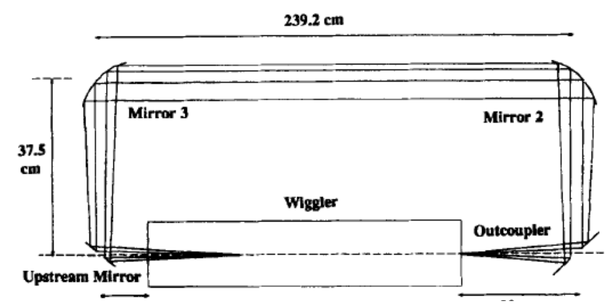


Regenerative Amplifier FEL

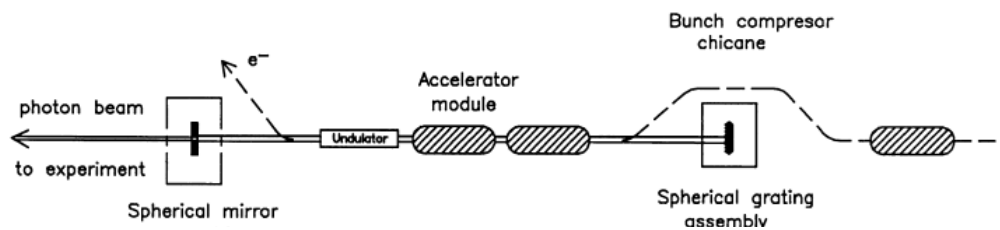
As well as these experiments in the infrared region of the spectrum, this high-gain regime of the FEL oscillator is also of interest in FEL designs for the ultraviolet and higher frequencies. The lack of high mirror reflectivities for these frequencies severely restricts the design of low-gain oscillators.

- High Gain Low Feedback concept (Low-Q cavity)
  McNeil B W J 1990 *IEEE J. Quantum Electron.* **26** 1124

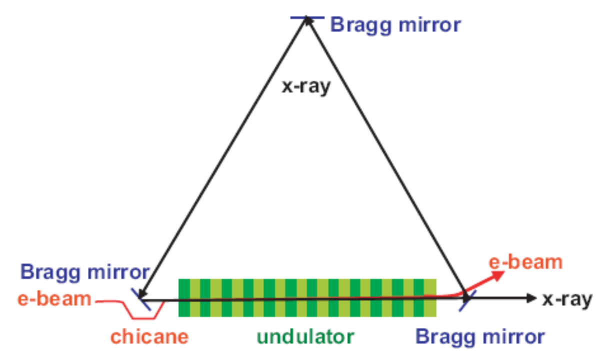
- Los Alamos IR-RAFEL
  Nguyen D C, Sheffield R L, Fortgang C M, Goldstein J C, Kinross-Wright J M and Ebrahim N A 1999 *Nucl. Instrum. Methods Phys. Res.* A **429** 125–30



- TTF VUV-RAFEL
  Faatz B, Feldhaus J, Krzywinski J, Saldin E L, Schneidmiller E A and Yurkov M V 1999 *Nucl. Instrum. Methods Phys. Res.* A **429** 424–8



- LCLS X-RAY RAFEL
  Huang Z and Ruth R D 2006 *Phys. Rev. Lett.* **96** 144801



New Journal of Physics
The open-access journal for physics

A design for the generation of temporally-coherent radiation pulses in the VUV and beyond by a self-seeding high-gain free electron laser amplifier

B W J McNeil[1,4], N R Thompson[1,2], D J Dunning[2],
J G Karssenberg[3], P J M van der Slot[3] and K-J Boller[3]

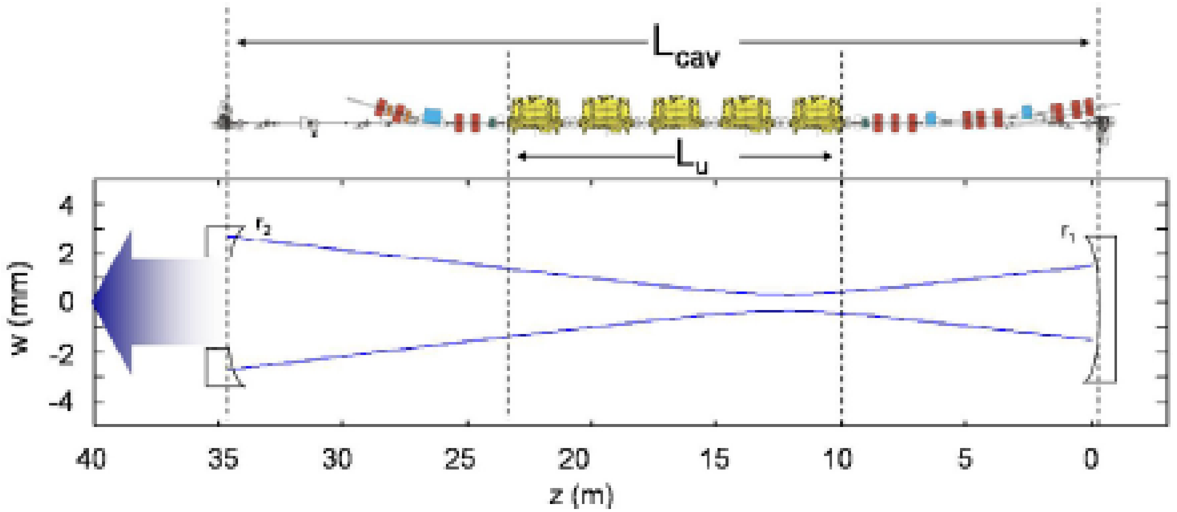


Figure 5. A schematic of the 4GLS VUV-FEL with the baseline design parameters. The fundamental cavity mode at $1/e^2$ of the on-axis intensity is shown in blue on the same longitudinal scale as the engineering representation. Electron beam transport is right to left.

WHY A RAFEL?

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Short wavelength regenerative amplifier free electron lasers

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[b] SUPA, University of Strathclyde, Glasgow G4 0NG, UK

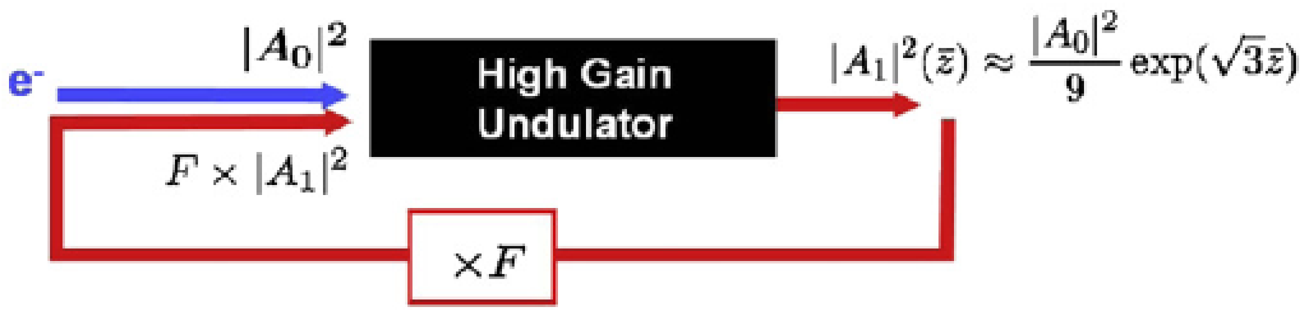


Fig. 1. Schematic representation of a generic high gain RAFEL system.

- Robust FEL cavity design able to generate close to Fourier Transform limited tunabla output from feedback factors $F \sim 10^{-5}$: a self-seeding high gain FEL ideal for short wavelength generation

RAFEL ***without*** MLOK – interesting case of short electron pulse: $l_b \sim l_c$

Example short-pulse RAFEL simulation

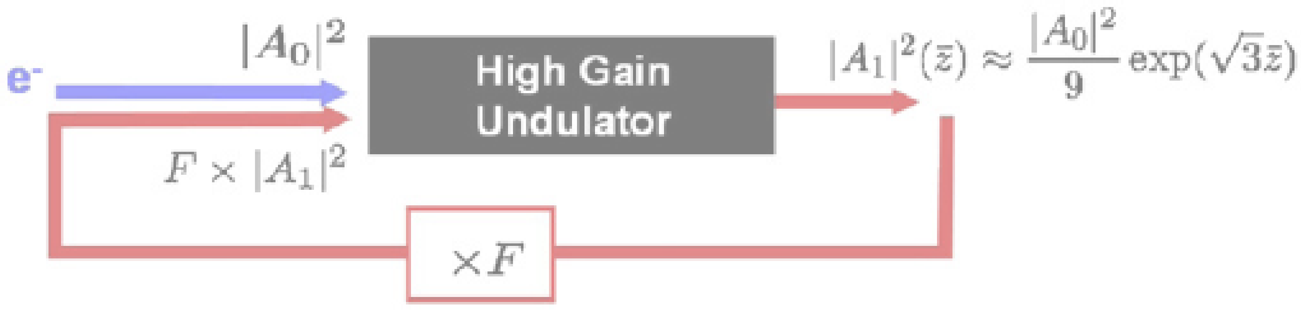
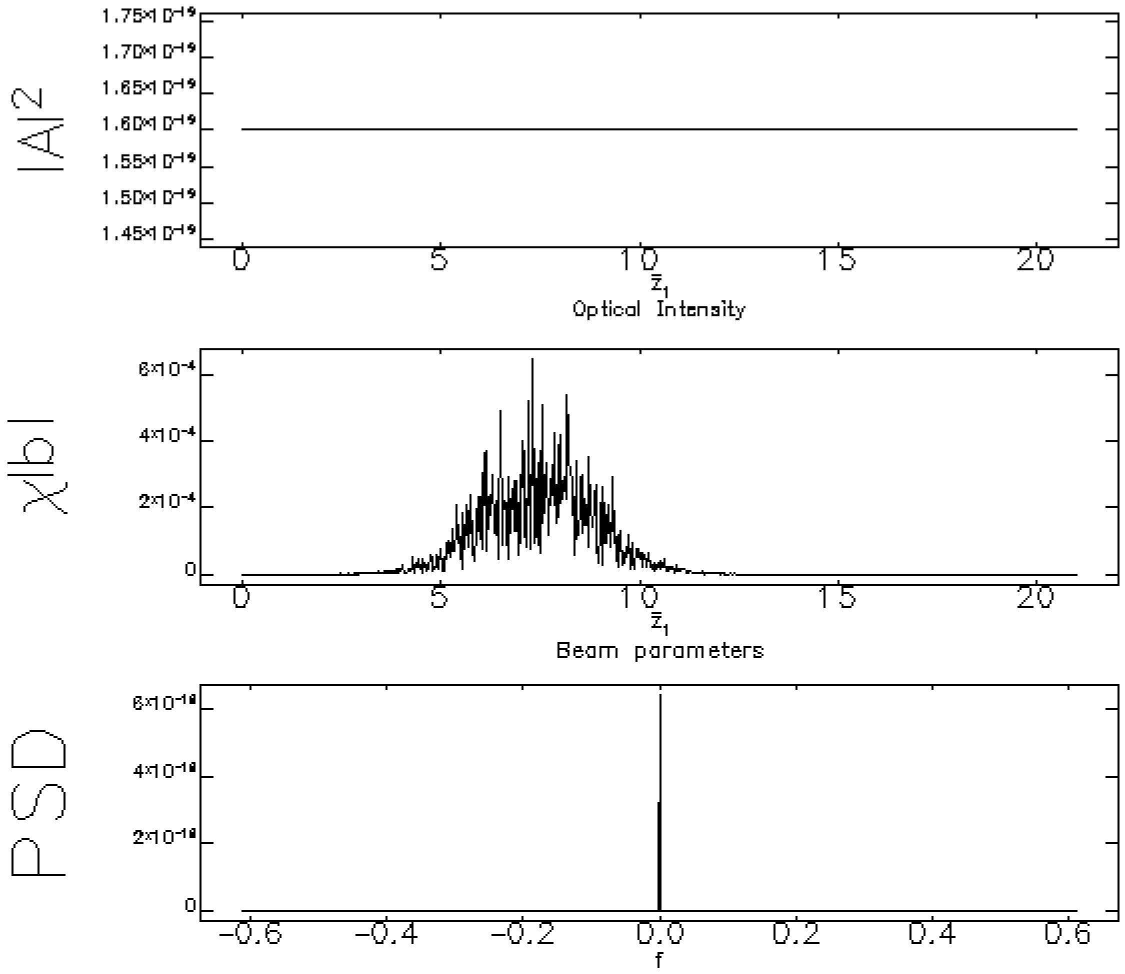


Fig. 1. Schematic representation of a generic high gain RAFEL system.

Parameters are typical for a soft x-ray FEL:

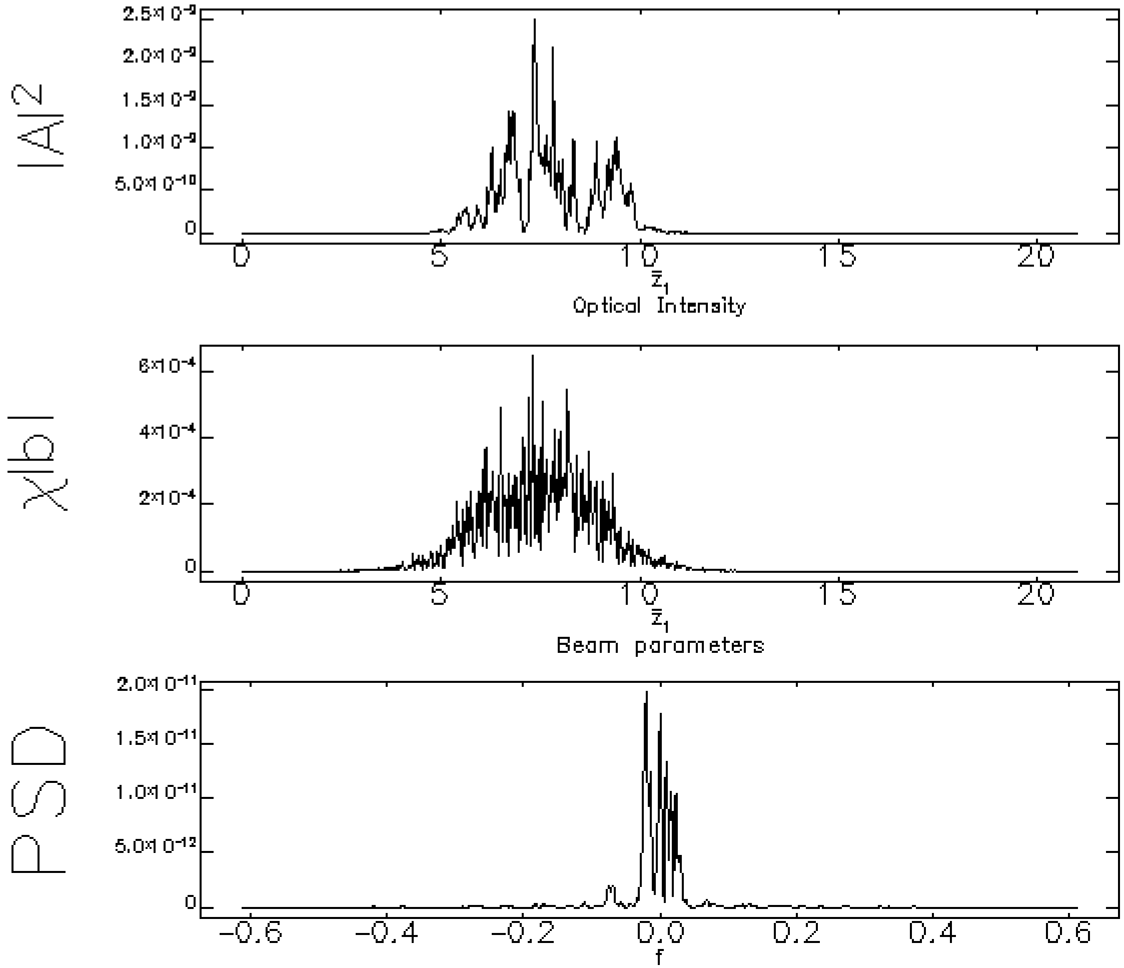
Gaussian current electron pulse:	$\sigma_z = l_c \qquad (l_c = \lambda / 4\pi\rho)$
FEL parameter:	$\rho = 2 \times 10^{-3}$
Undulator length:	$L_u = 6\, l_g \quad (l_g = \lambda_u / 4\pi\rho)$
Cavity feedback factor:	$F = 4 \times 10^{-3}$
Cavity detuning:	lengthened by l_c

Pass=1



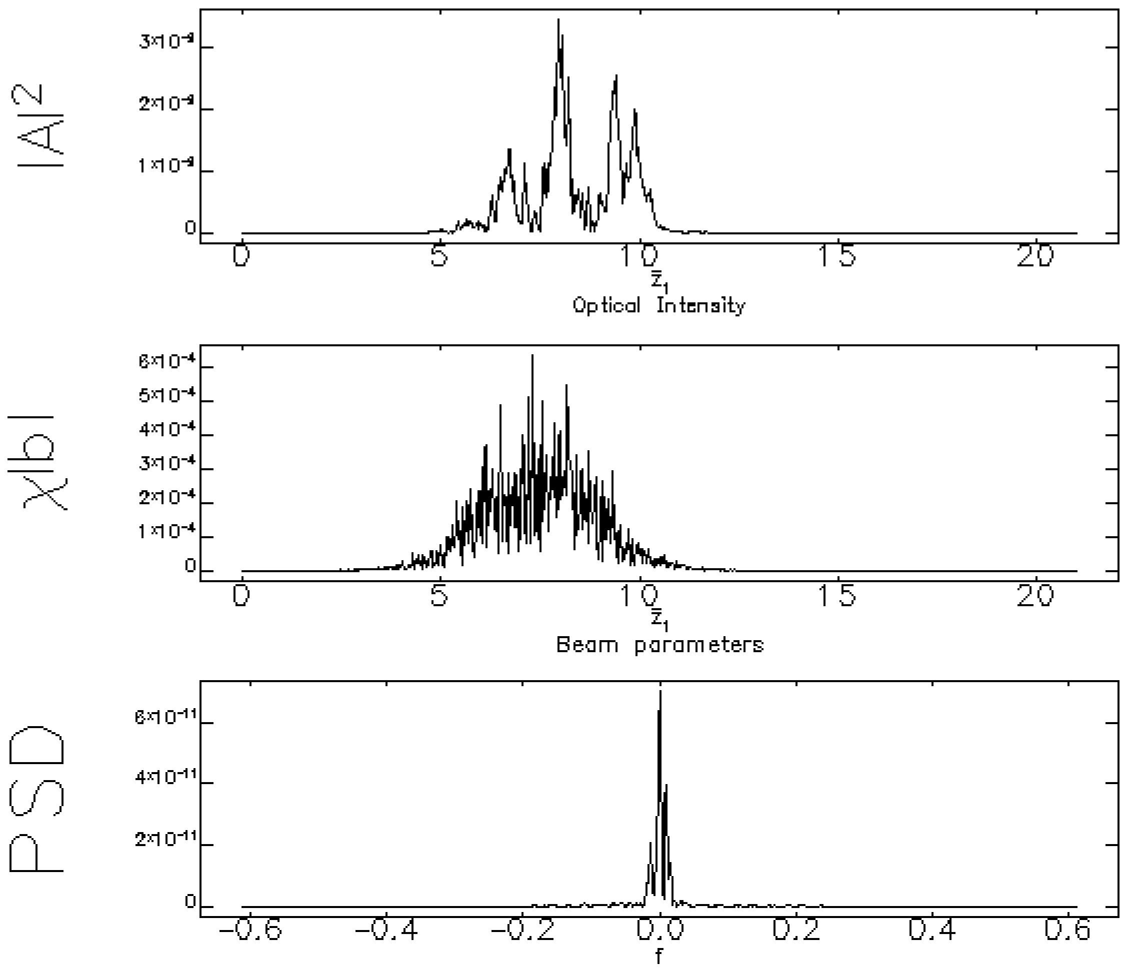
|A|2
1.75×10^-19
1.70×10^-19
1.65×10^-19
1.60×10^-19
1.55×10^-19
1.50×10^-19
1.45×10^-19
0
5
10
15
20
z1
Optical Intensity
χ|b|
6×10^-4
4×10^-4
2×10^-4
0
0
5
10
15
20
z1
Beam parameters
PSD
6×10^-18
4×10^-18
2×10^-18
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1

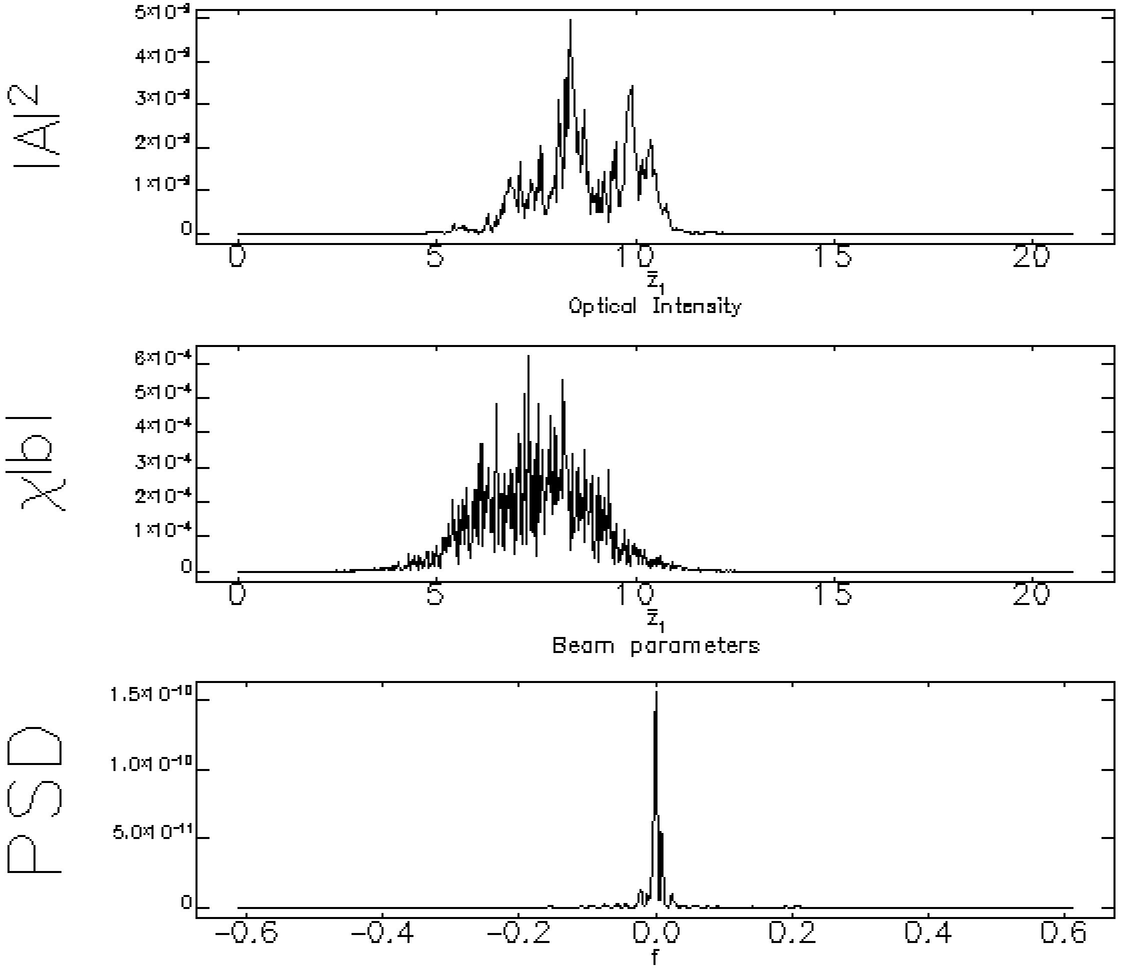


|A|2
2.5×10⁻⁹
2.0×10⁻⁹
1.5×10⁻⁹
1.0×10⁻⁹
5.0×10⁻¹⁰
0
0 5 10 15 20
z̄1
Optical Intensity
χ|b|
6×10⁻⁴
4×10⁻⁴
2×10⁻⁴
0
0 5 10 15 20
z̄1
Beam parameters
PSD
2.0×10⁻¹¹
1.5×10⁻¹¹
1.0×10⁻¹¹
5.0×10⁻¹²
0
−0.6 −0.4 −0.2 0.0 0.2 0.4 0.6
f

Pass=1

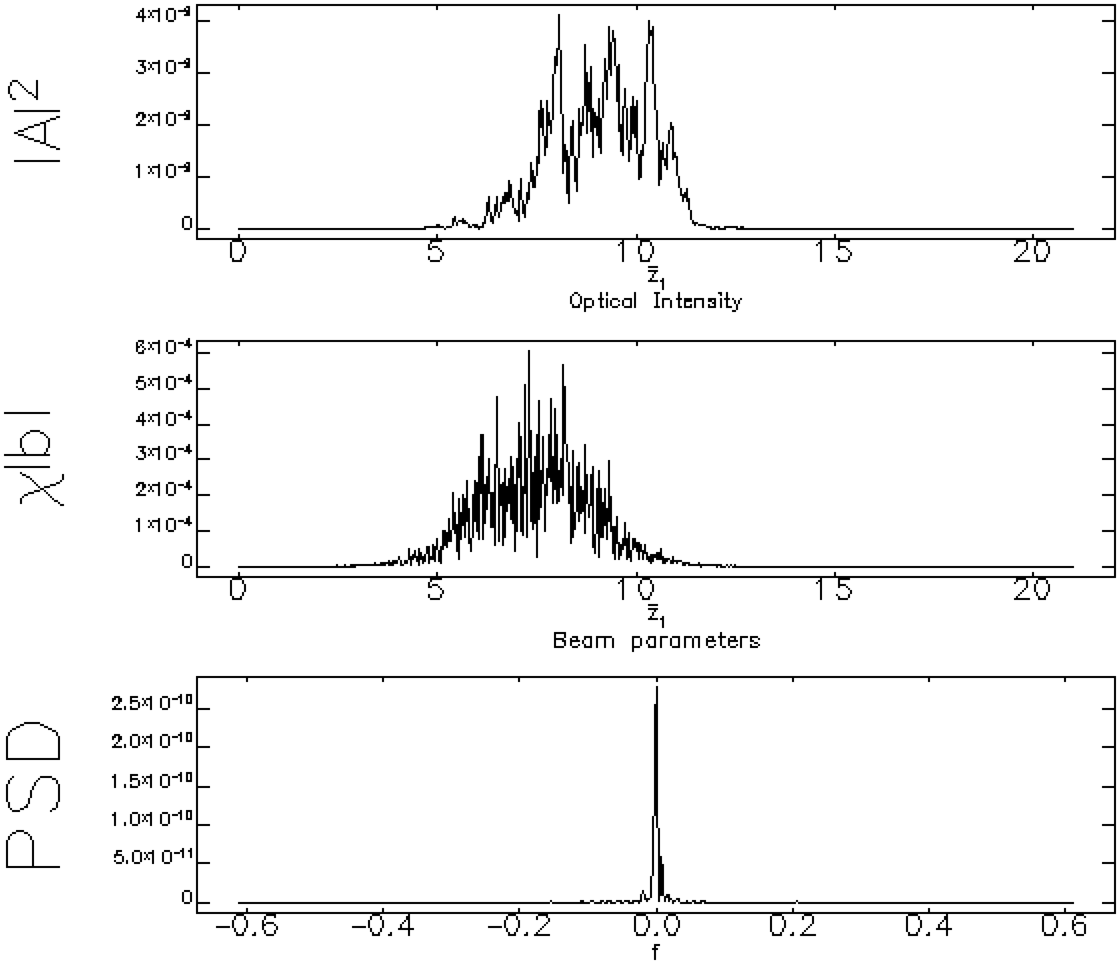

|A|^2
3×10⁻⁹
2×10⁻⁹
1×10⁻⁹
0
0 5 10 15 20
z̄1
Optical Intensity
χ|b|
6×10⁻⁴
5×10⁻⁴
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
1×10⁻⁴
0
0 5 10 15 20
z̄1
Beam parameters
PSD
6×10⁻¹¹
4×10⁻¹¹
2×10⁻¹¹
0
−0.6 −0.4 −0.2 0.0 0.2 0.4 0.6
f

Pass=1



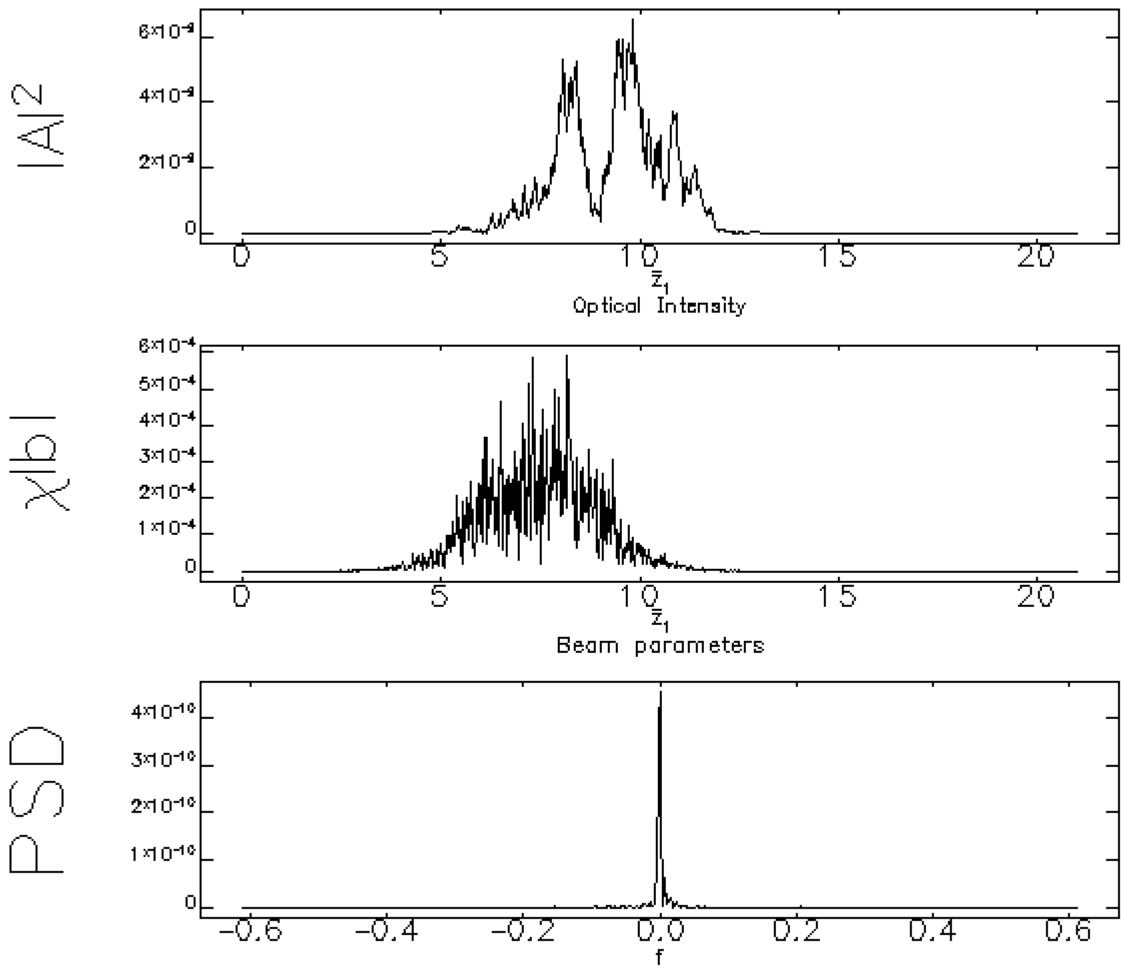
|A|2
5×10⁻⁹
4×10⁻⁹
3×10⁻⁹
2×10⁻⁹
1×10⁻⁹
0
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
6×10⁻⁴
5×10⁻⁴
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
1×10⁻⁴
0
0
5
10
15
20
z̄1
Beam parameters
PSD
1.5×10⁻¹⁰
1.0×10⁻¹⁰
5.0×10⁻¹¹
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
f

Pass=1



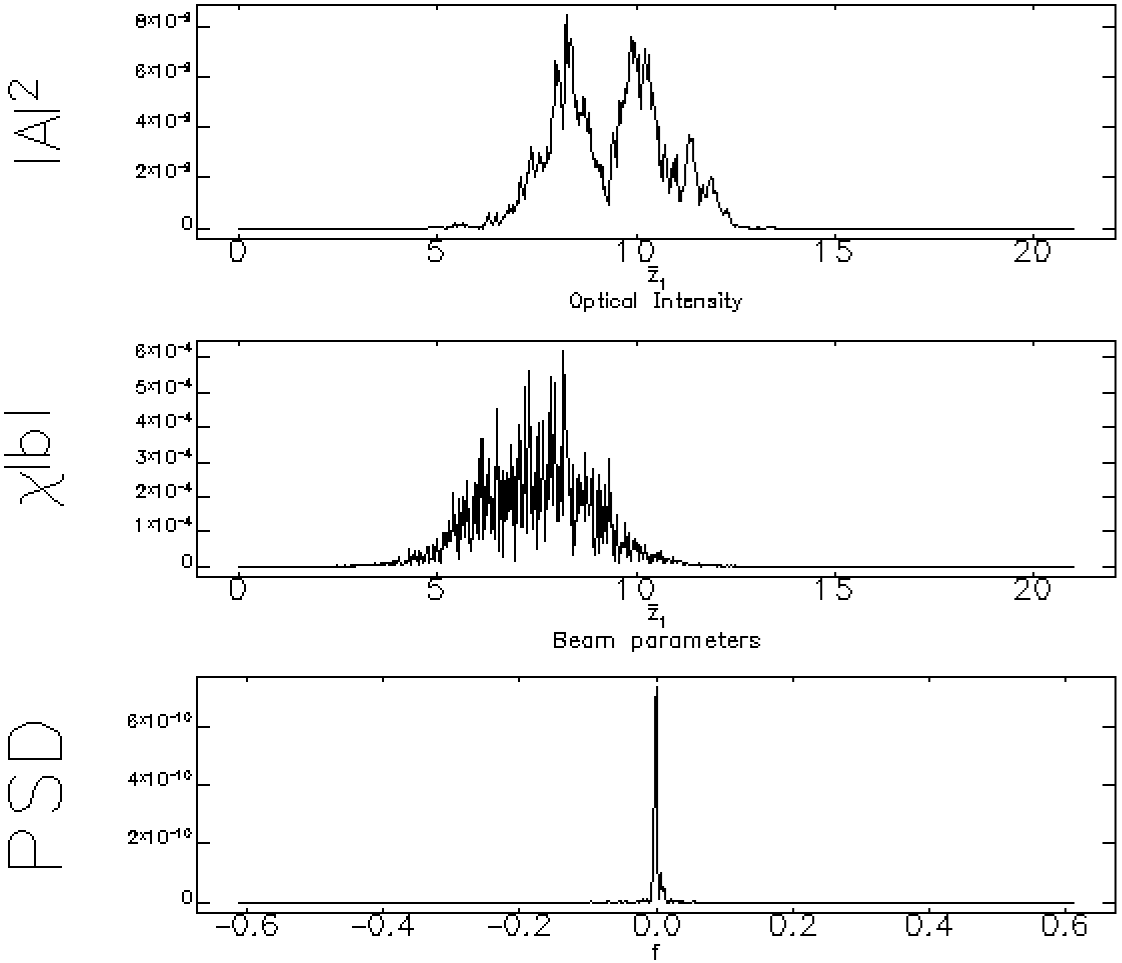
|A|2
4x10-9
3x10-9
2x10-9
1x10-9
0
0
5
10
15
20
z1
Optical Intensity
χ|b|
6x10-4
5x10-4
4x10-4
3x10-4
2x10-4
1x10-4
0
0
5
10
15
20
z1
Beam parameters
PSD
2.5x10-10
2.0x10-10
1.5x10-10
1.0x10-10
5.0x10-11
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1



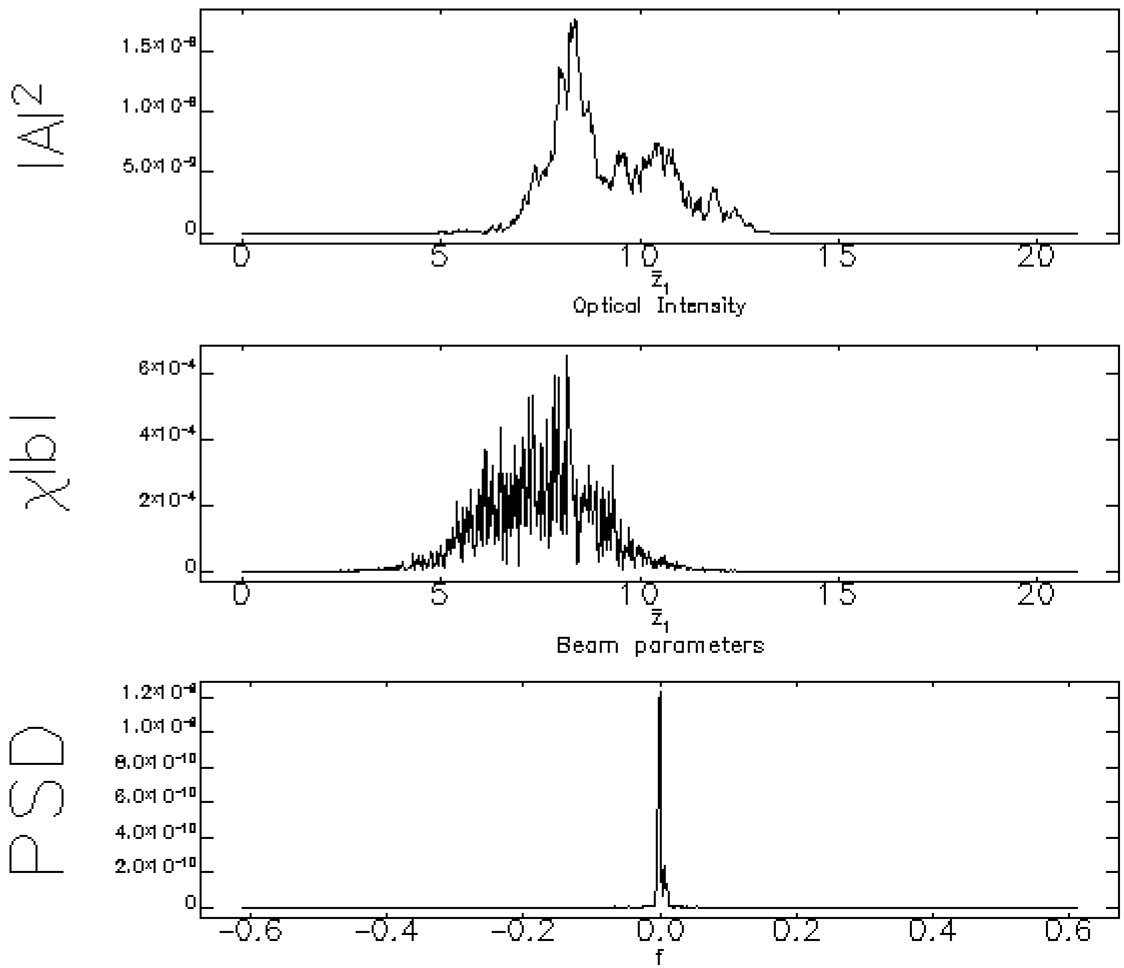
|A|2
0
0
5
10
15
20
$\bar{z}_1$
Optical Intensity
χ|b|
6×10⁻⁴
5×10⁻⁴
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
1×10⁻⁴
0
0
5
10
15
20
$\bar{z}_1$
Beam parameters
PSD
4×10⁻¹⁰
3×10⁻¹⁰
2×10⁻¹⁰
1×10⁻¹⁰
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
f

Pass=1



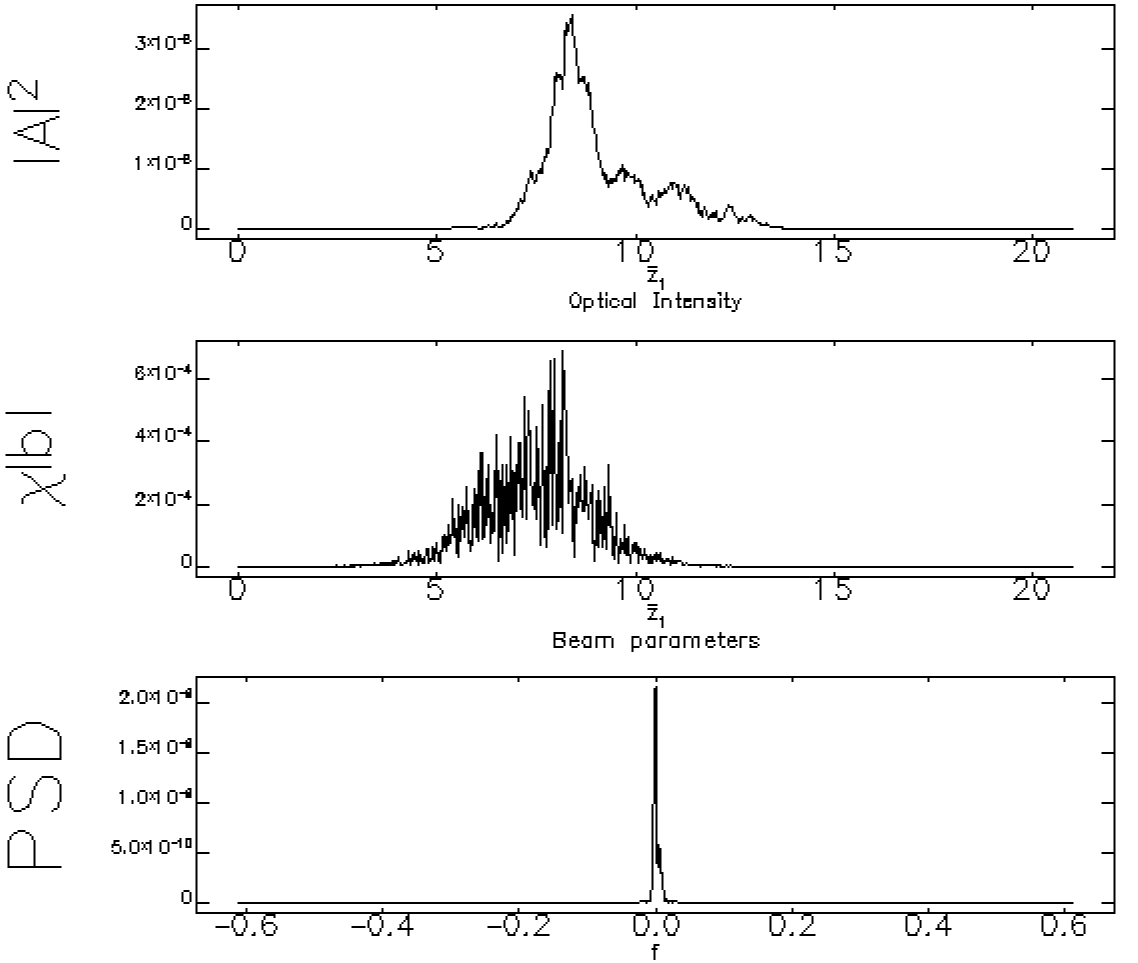
|A|2
Optical Intensity
χ|b|
Beam parameters
PSD
0
5
10
15
20
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1



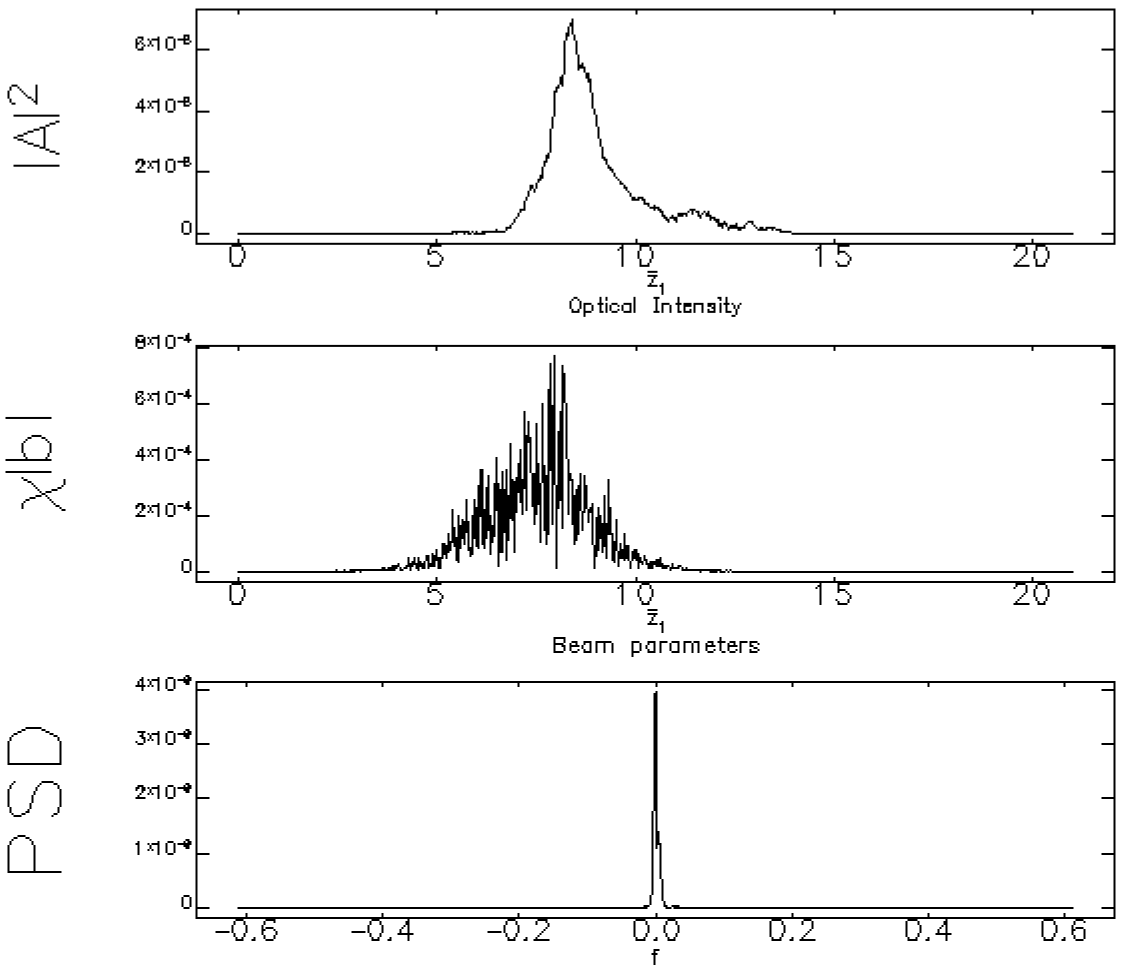
|A|2
0
0
5
10
15
20
Optical Intensity
χ|b|
6x10-4
4x10-4
2x10-4
0
0
5
10
15
20
Beam parameters
PSD
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1



|A|2
3×10-8
2×10-8
1×10-8
0
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
6×10-4
4×10-4
2×10-4
0
0
5
10
15
20
z̄1
Beam parameters
PSD
2.0×10-9
1.5×10-9
1.0×10-9
5.0×10-10
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1



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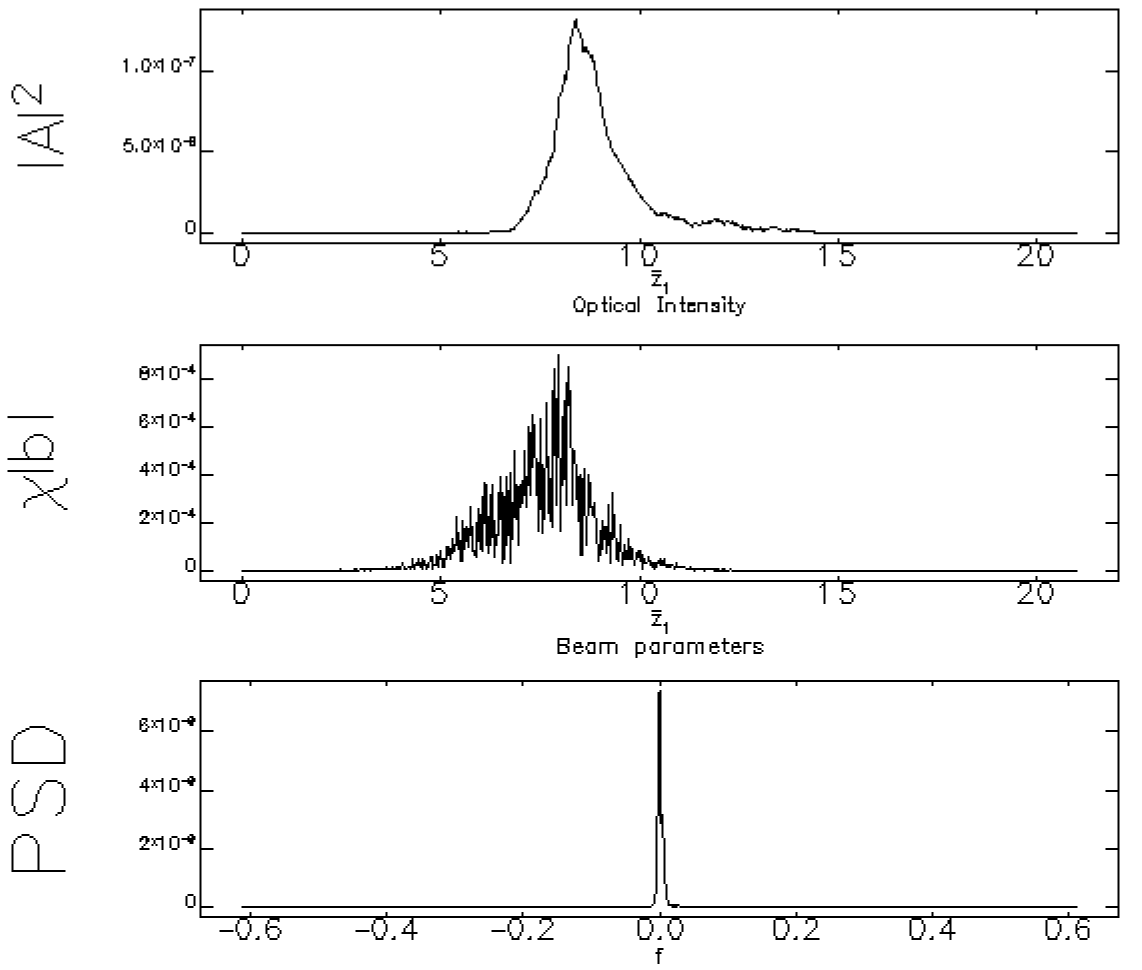
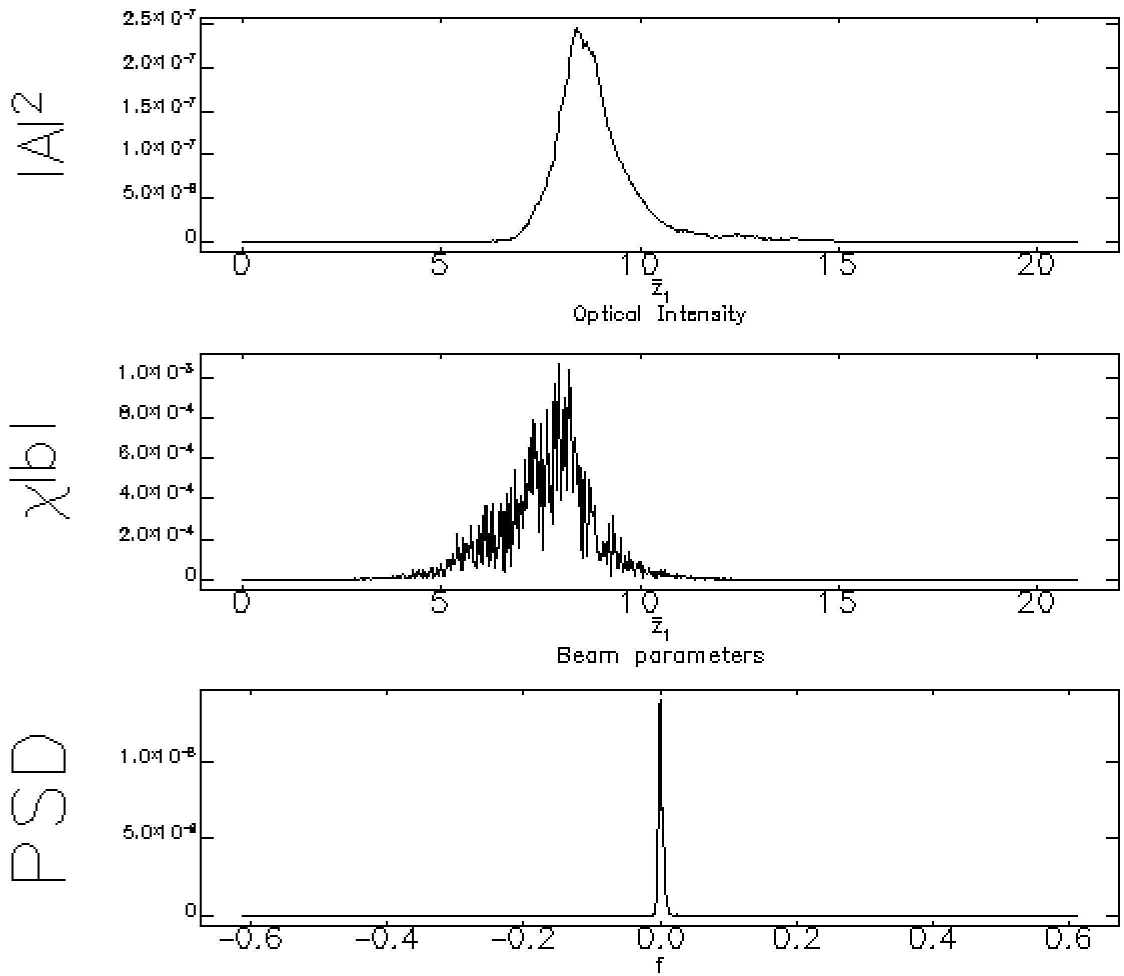


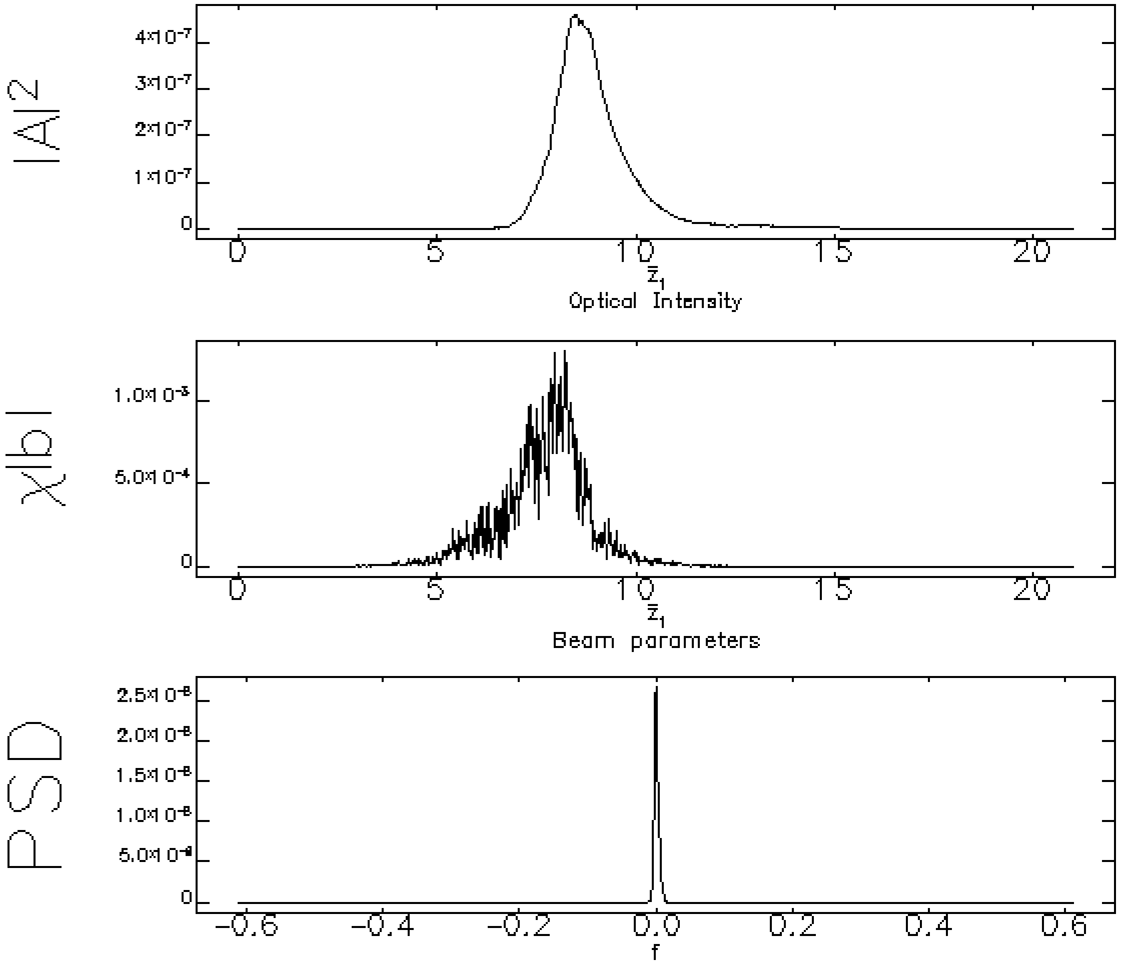
|A|2
1.0x10-7
5.0x10-8
0
0
5
10
15
20
$\bar{z}_1$
Optical Intensity
χ|b|
8x10-4
6x10-4
4x10-4
2x10-4
0
0
5
10
15
20
$\bar{z}_1$
Beam parameters
PSD
6x10-8
4x10-8
2x10-8
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1



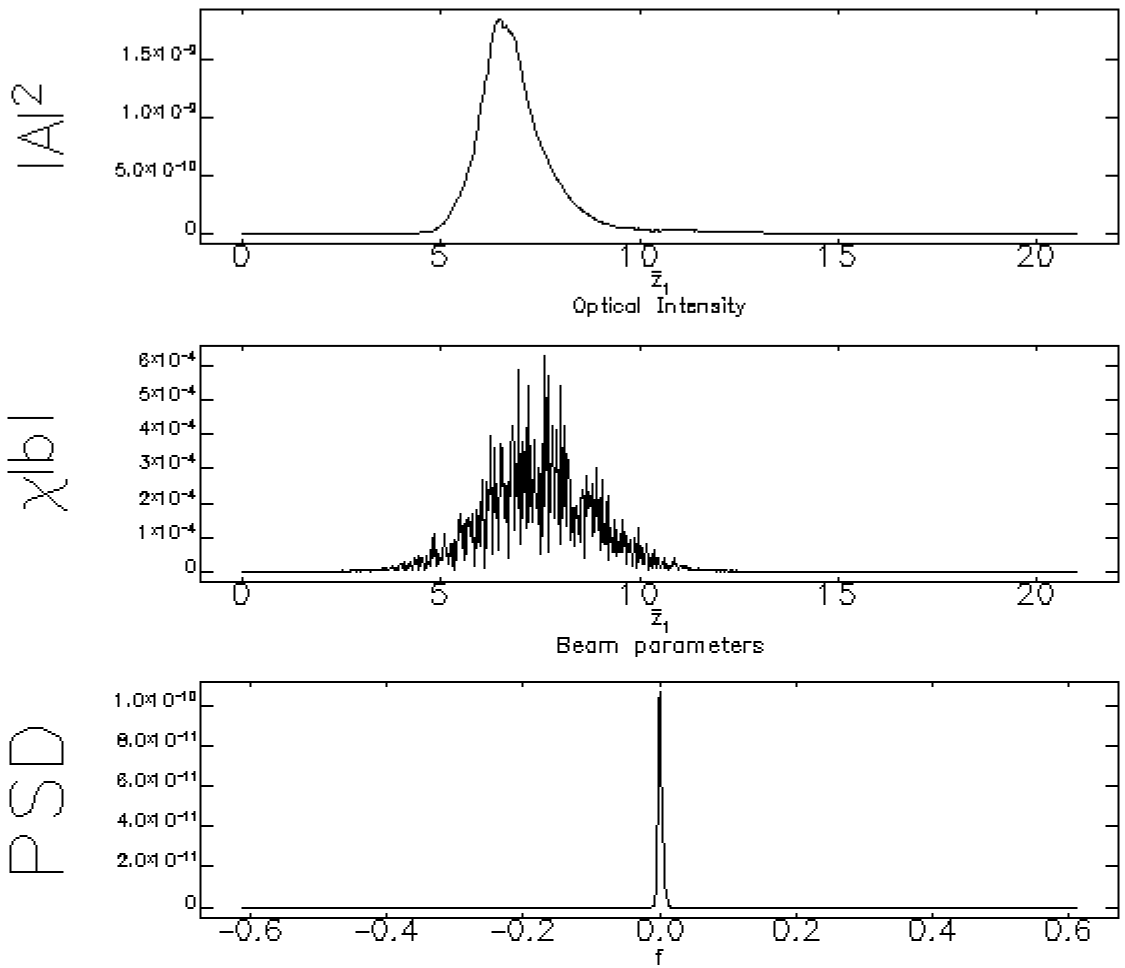
|A|2
2.5x10-7
2.0x10-7
1.5x10-7
1.0x10-7
5.0x10-8
0
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
1.0x10-3
8.0x10-4
6.0x10-4
4.0x10-4
2.0x10-4
0
0
5
10
15
20
z̄1
Beam parameters
PSD
1.0x10-8
5.0x10-9
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=1



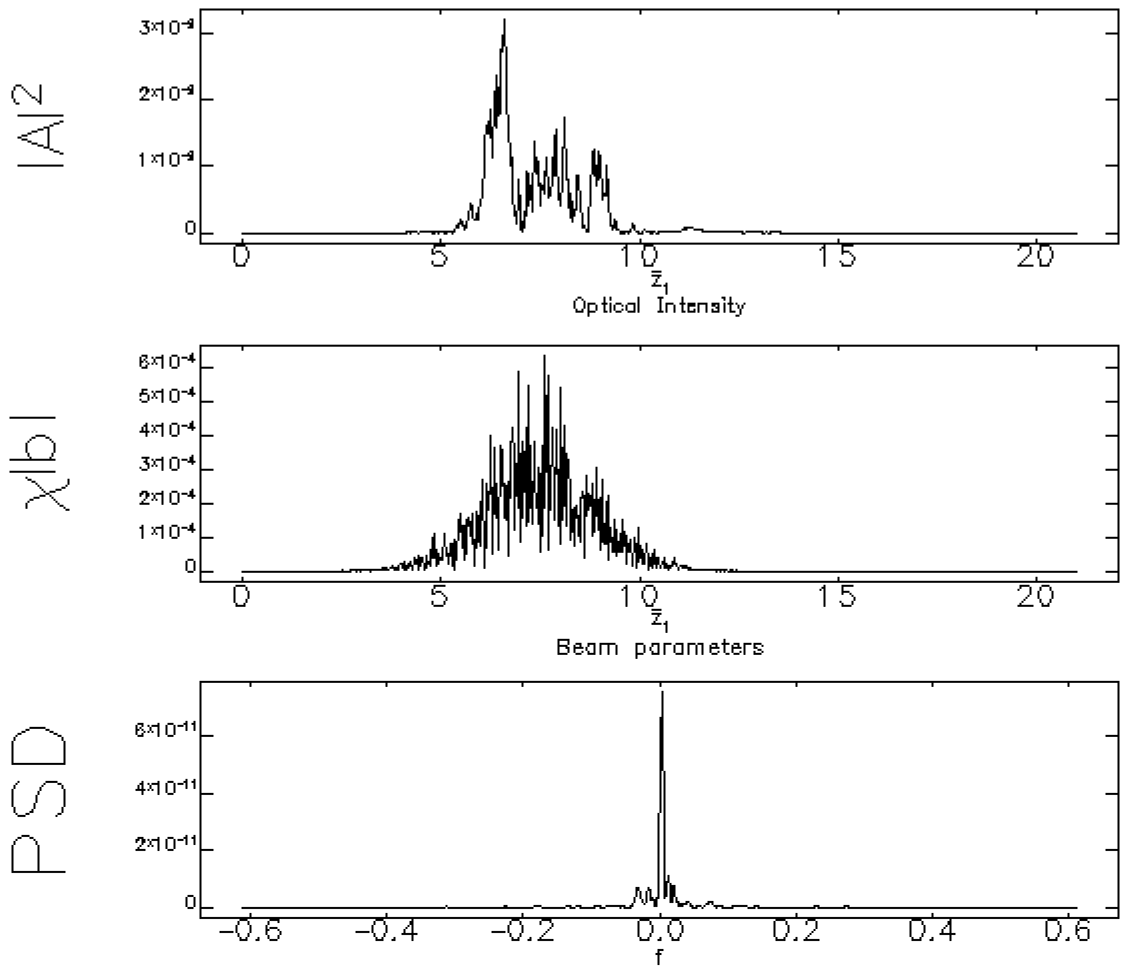
|A|2
4×10-7
3×10-7
2×10-7
1×10-7
0
0
5
10
15
20
z1
Optical Intensity
χ|b|
1.0×10-3
5.0×10-4
0
0
5
10
15
20
z1
Beam parameters
PSD
2.5×10-8
2.0×10-8
1.5×10-8
1.0×10-8
5.0×10-9
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=2



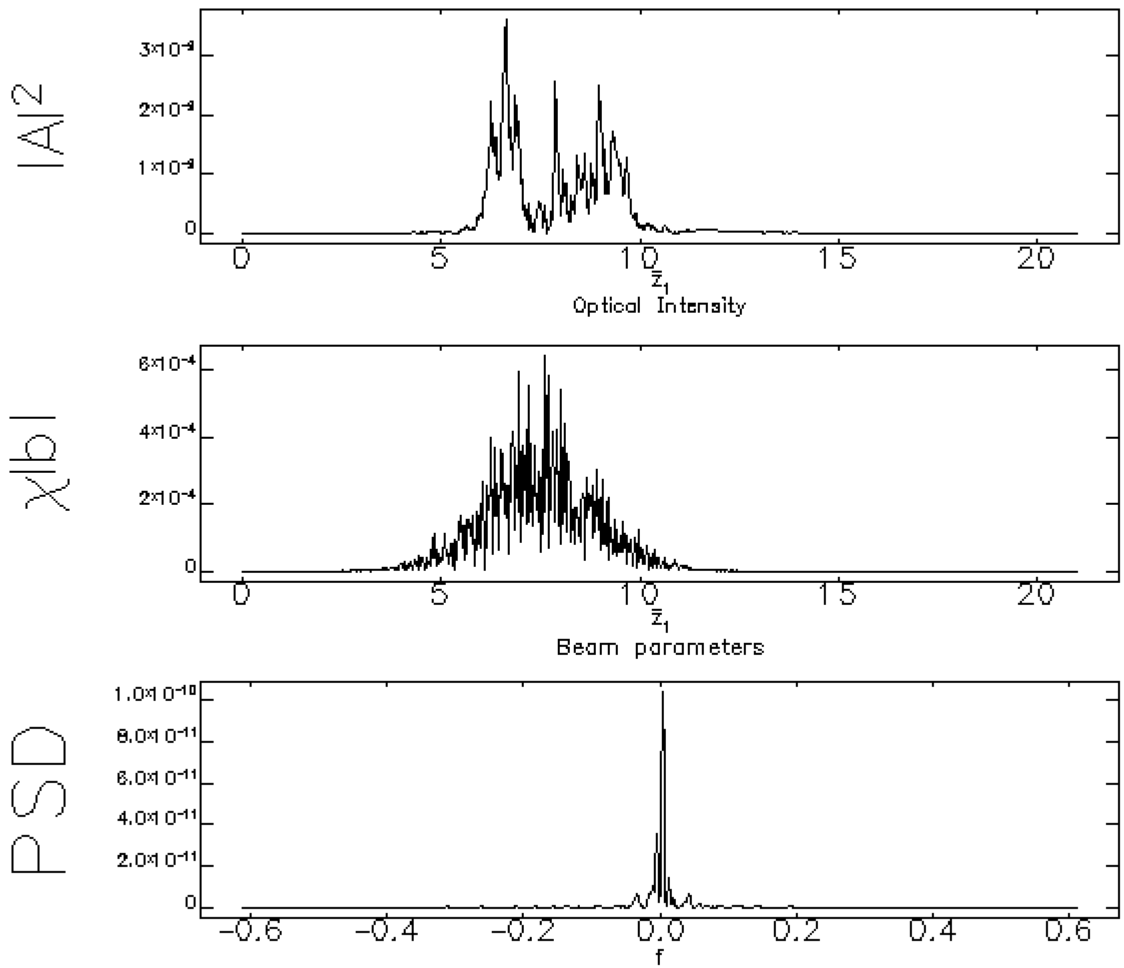
|A|2
1.5×10⁻⁹
1.0×10⁻⁹
5.0×10⁻¹⁰
0
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
6×10⁻⁴
5×10⁻⁴
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
1×10⁻⁴
0
0
5
10
15
20
z̄1
Beam parameters
PSD
1.0×10⁻¹⁰
8.0×10⁻¹¹
6.0×10⁻¹¹
4.0×10⁻¹¹
2.0×10⁻¹¹
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
f

Pass=2

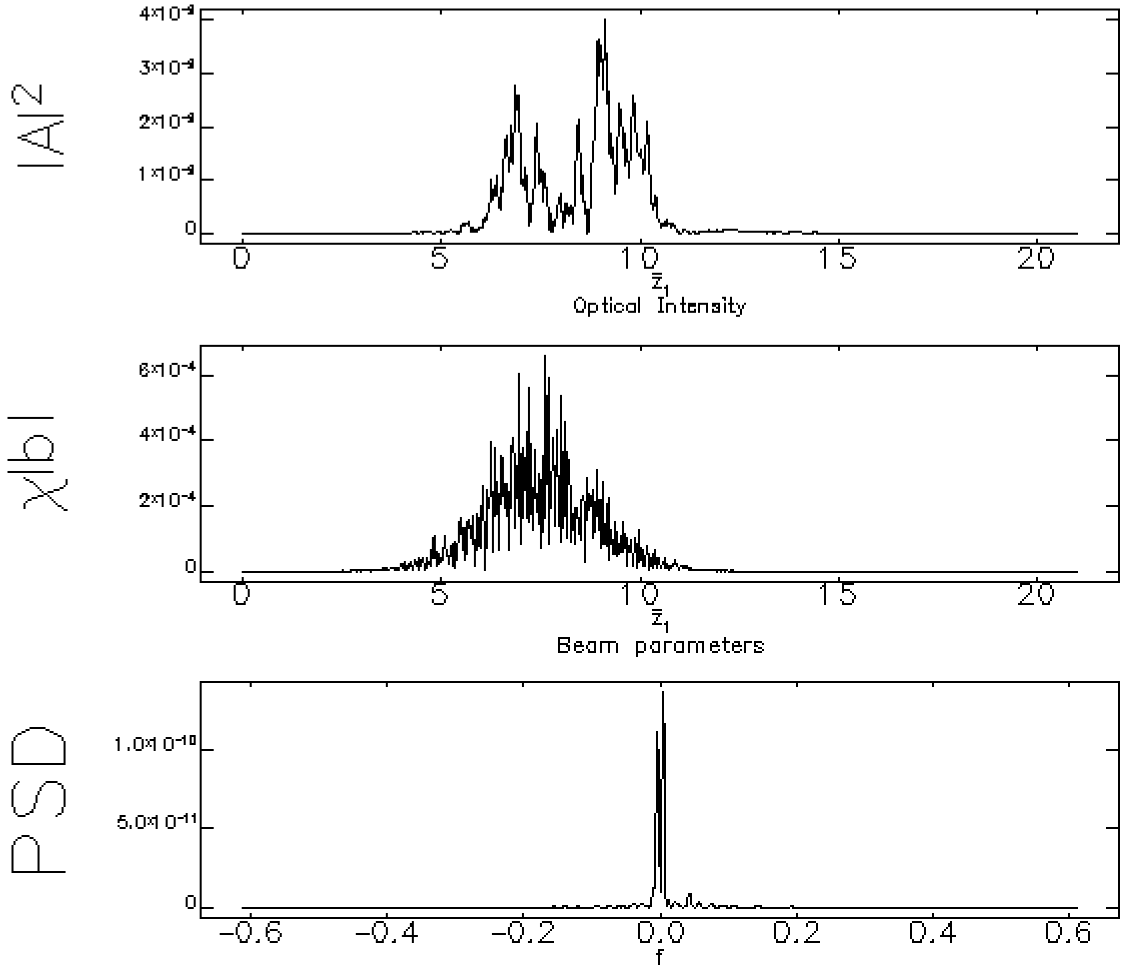


|A|2
3×10⁻⁹
2×10⁻⁹
1×10⁻⁹
0
0
5
10
15
20
z1
Optical Intensity
χ|b|
6×10⁻⁴
5×10⁻⁴
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
1×10⁻⁴
0
0
5
10
15
20
z1
Beam parameters
PSD
6×10⁻¹¹
4×10⁻¹¹
2×10⁻¹¹
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
f

Pass=2

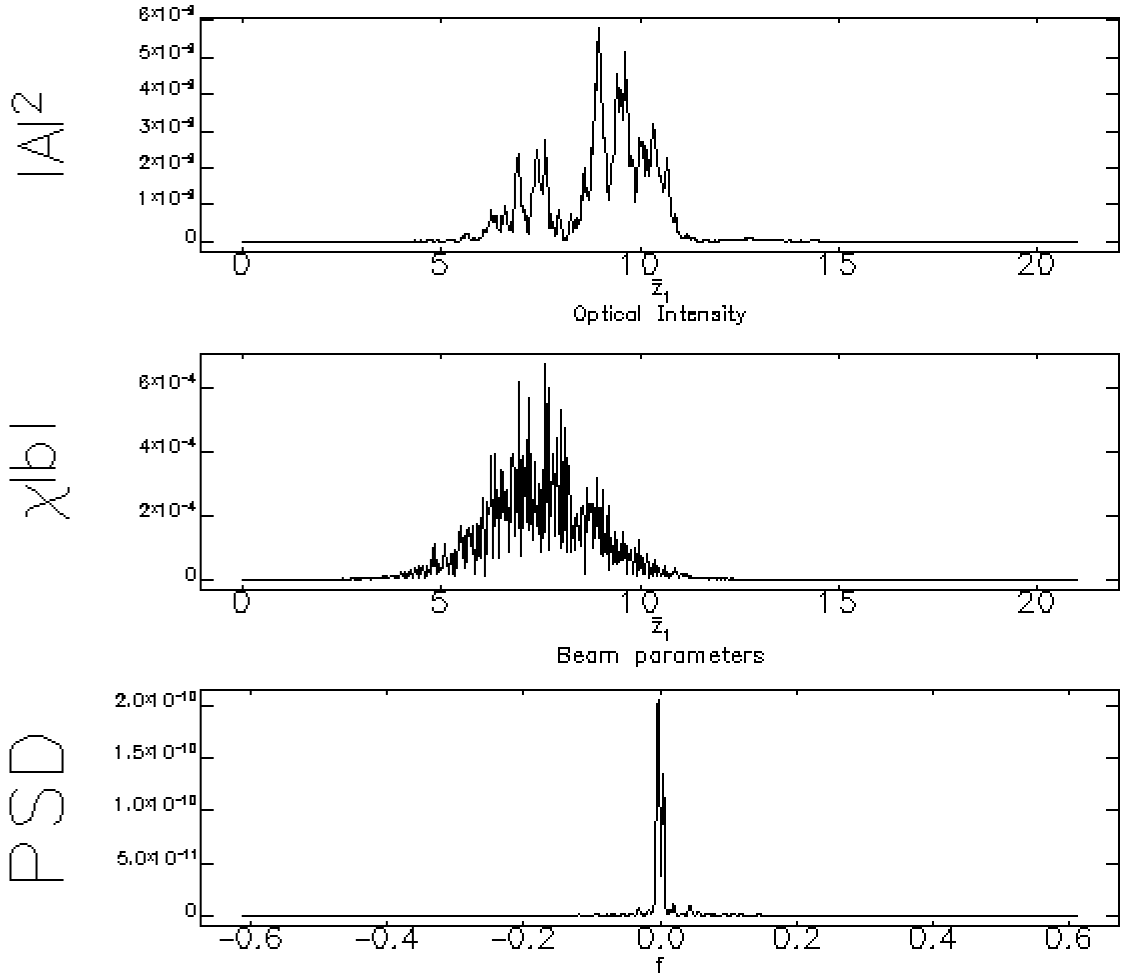

|A|2
3×10⁻⁹
2×10⁻⁹
1×10⁻⁹
0
0
5
10
15
20
$\bar{z}_1$
Optical Intensity
χ|b|
6×10⁻⁴
4×10⁻⁴
2×10⁻⁴
0
0
5
10
15
20
$\bar{z}_1$
Beam parameters
PSD
1.0×10⁻¹⁰
8.0×10⁻¹¹
6.0×10⁻¹¹
4.0×10⁻¹¹
2.0×10⁻¹¹
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
f

Pass=2

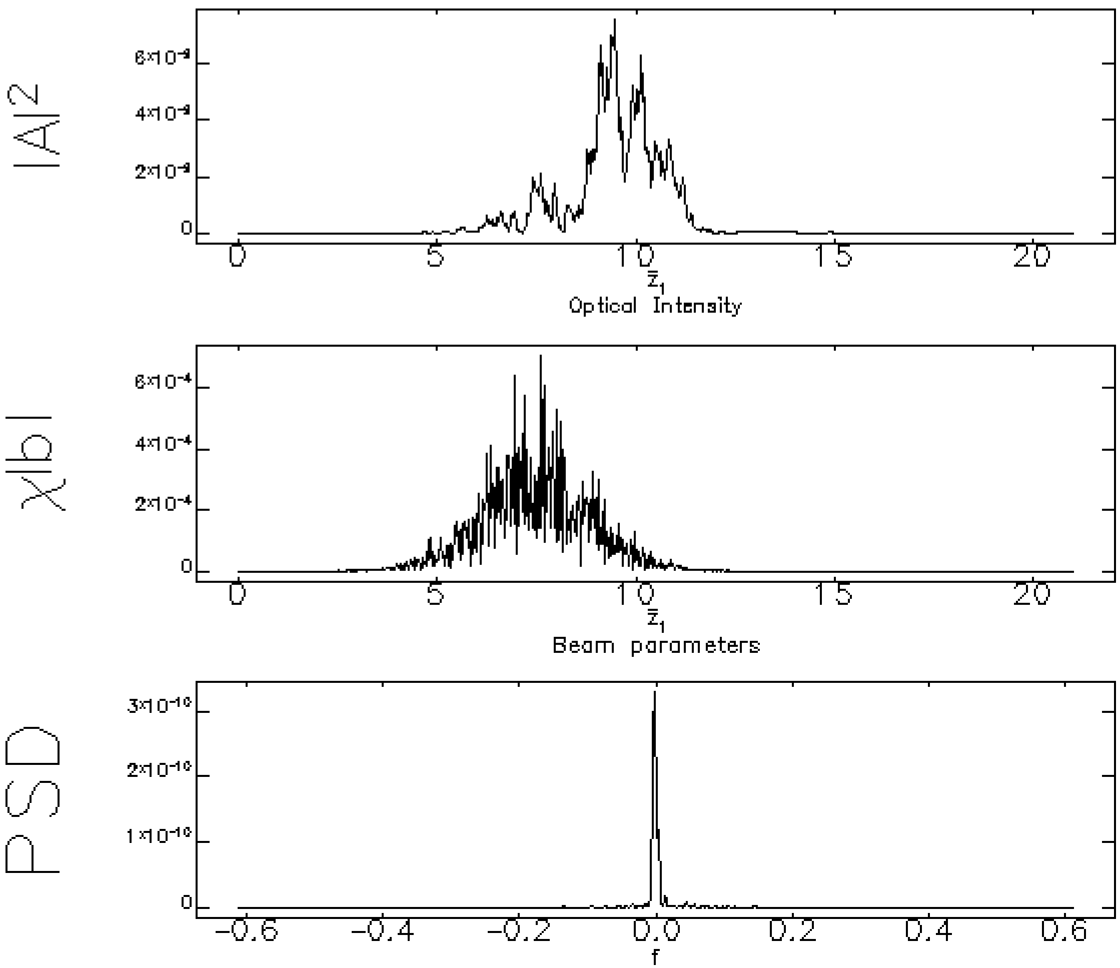


|A|2
Optical Intensity
χ|b|
Beam parameters
PSD
f
0
5
10
15
20
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6

Pass=2

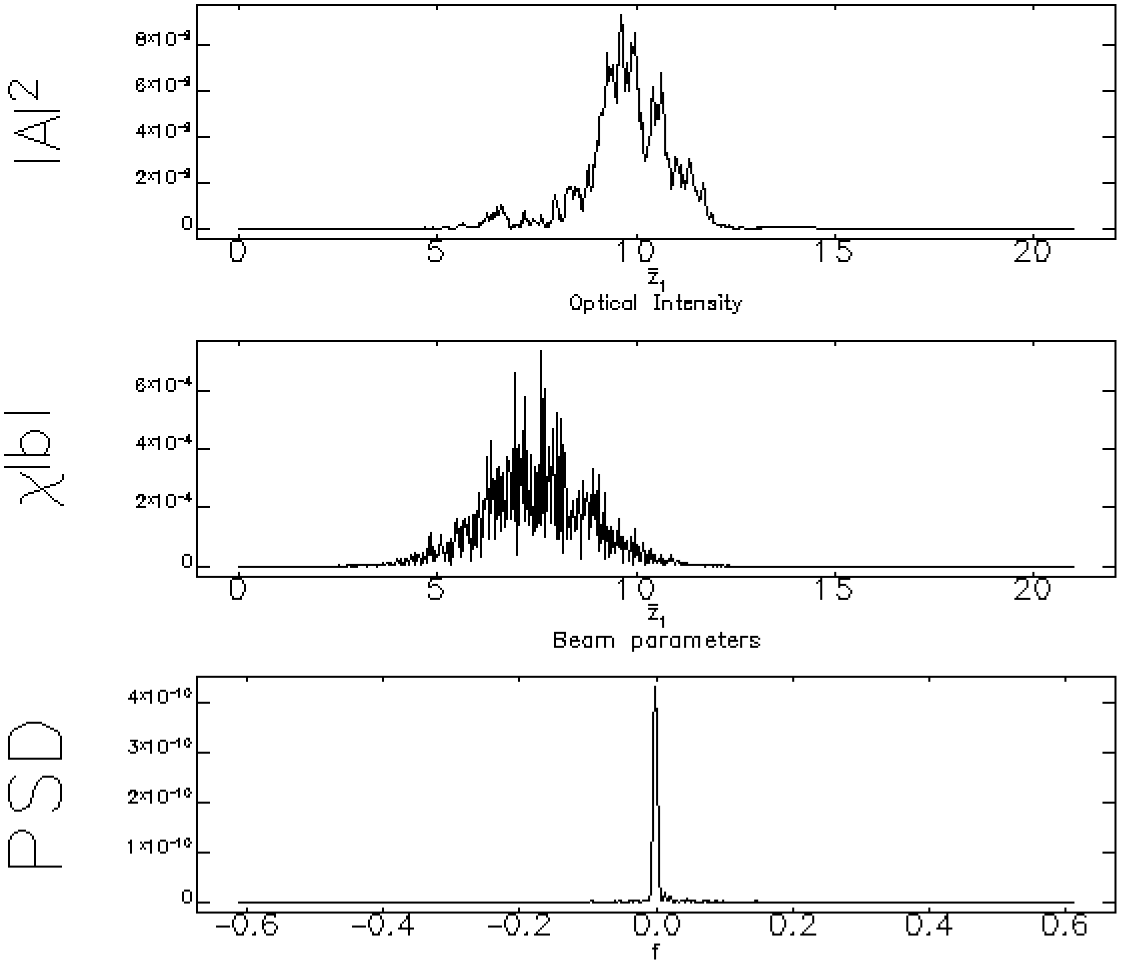

|A|2
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
6×10-4
4×10-4
2×10-4
0
5
10
15
20
z̄1
Beam parameters
PSD
2.0×10-10
1.5×10-10
1.0×10-10
5.0×10-11
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=2



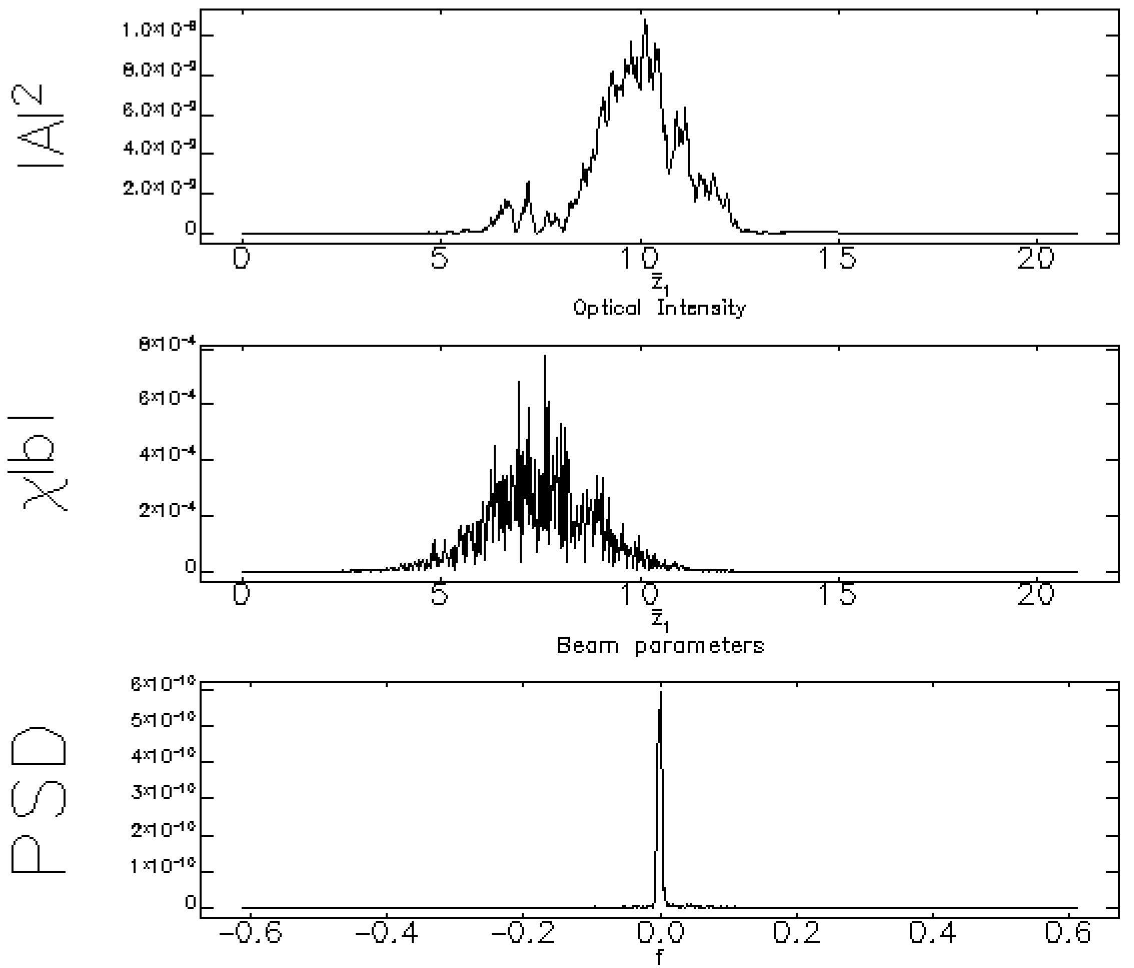
|A|2
0
0
5
10
15
20
$\bar{z}_1$
Optical Intensity
χ|b|
6×10-4
4×10-4
2×10-4
0
0
5
10
15
20
$\bar{z}_1$
Beam parameters
PSD
3×10-10
2×10-10
1×10-10
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=2



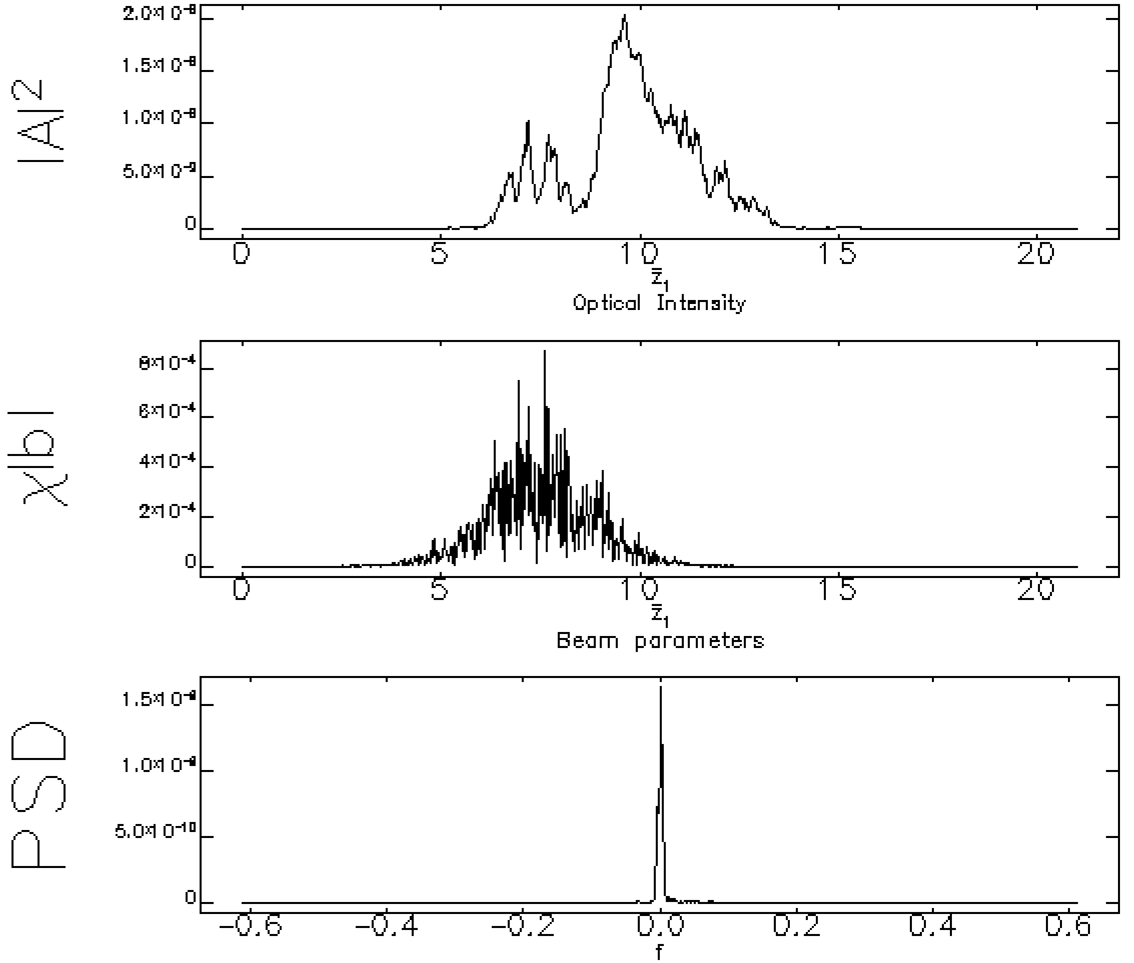
|A|2
0
5
10
15
20
Optical Intensity
χ|b|
Beam parameters
PSD
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=2



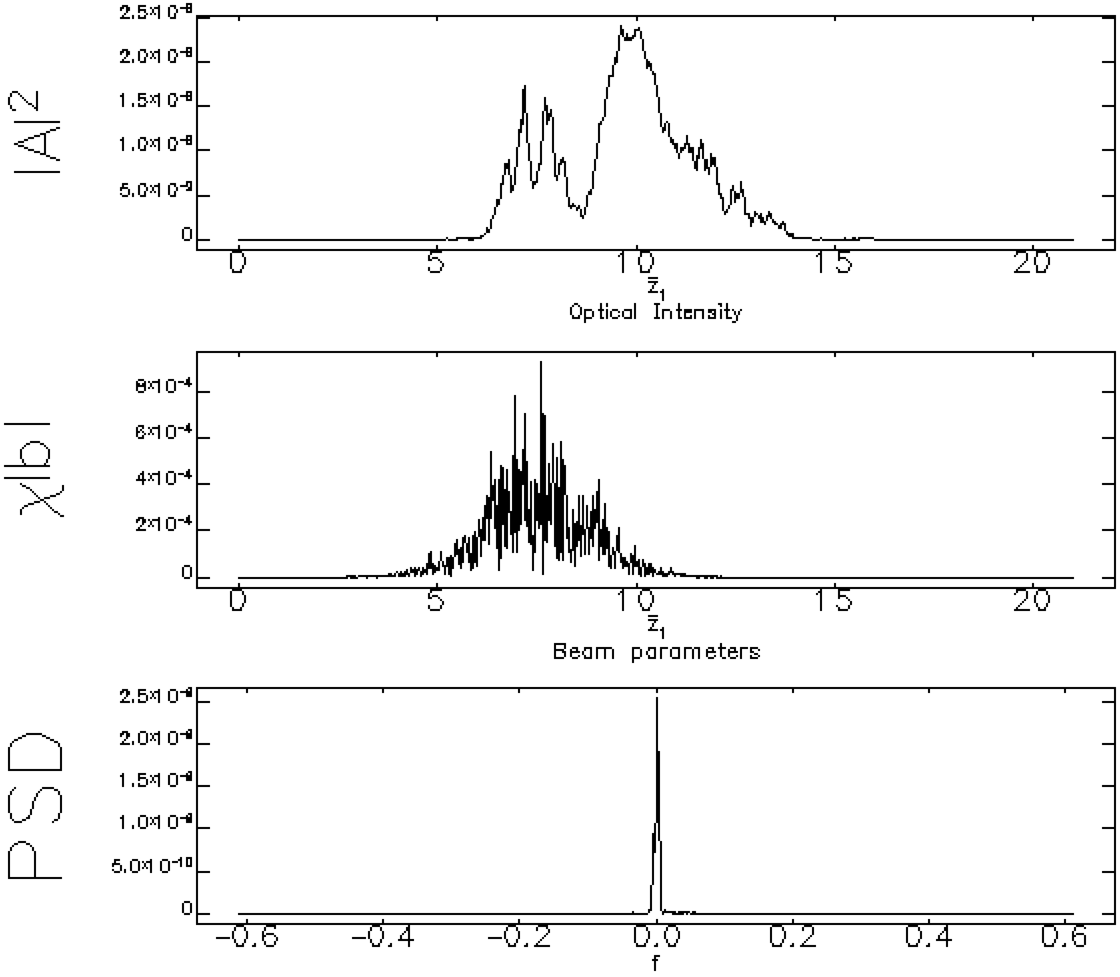
|A|2
1.0x10-8
8.0x10-9
6.0x10-9
4.0x10-9
2.0x10-9
0
0
5
10
15
20
z1
Optical Intensity
χ|b|
8x10-4
6x10-4
4x10-4
2x10-4
0
0
5
10
15
20
z1
Beam parameters
PSD
6x10-10
5x10-10
4x10-10
3x10-10
2x10-10
1x10-10
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=2

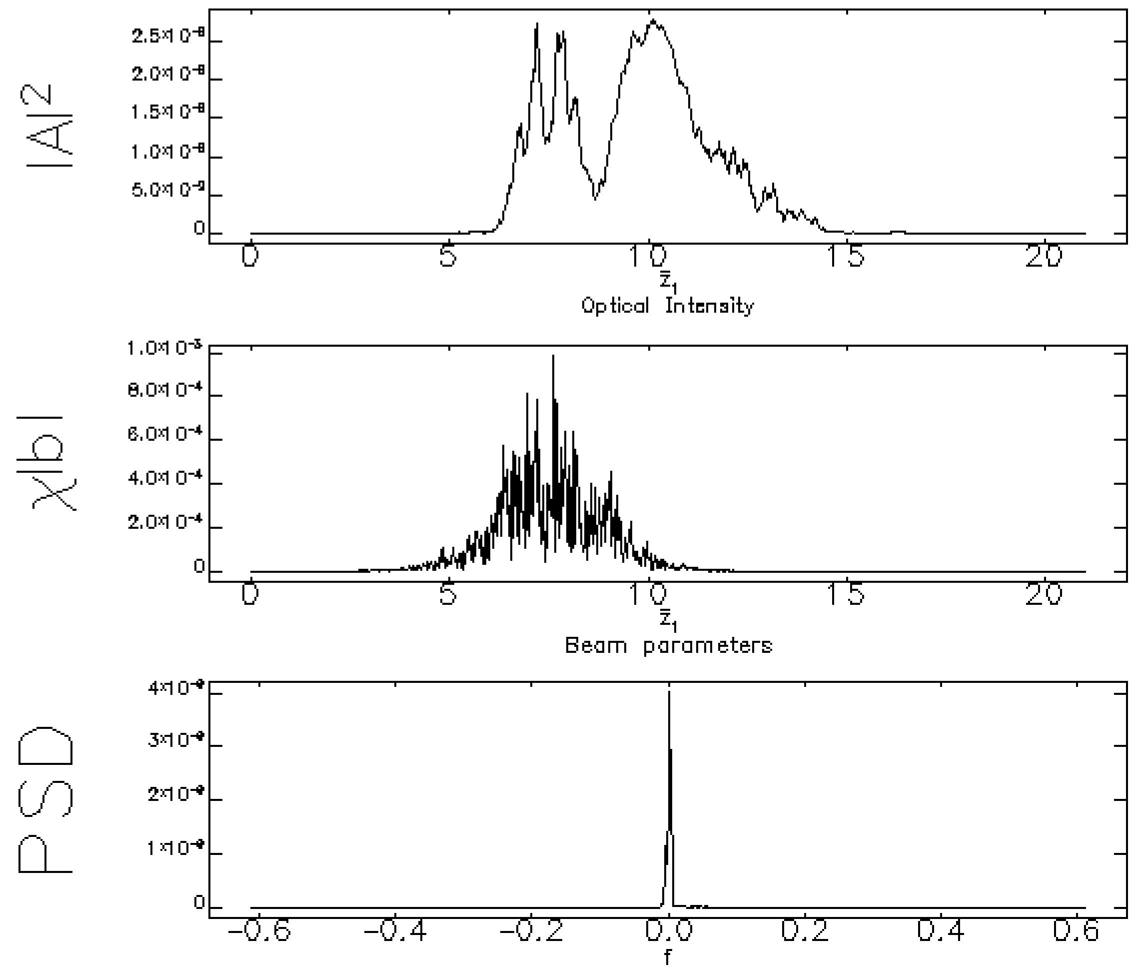


|A|2
2.0x10-8
1.5x10-8
1.0x10-8
5.0x10-9
0
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
8x10-4
6x10-4
4x10-4
2x10-4
0
0
5
10
15
20
z̄1
Beam parameters
PSD
1.5x10-9
1.0x10-9
5.0x10-10
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

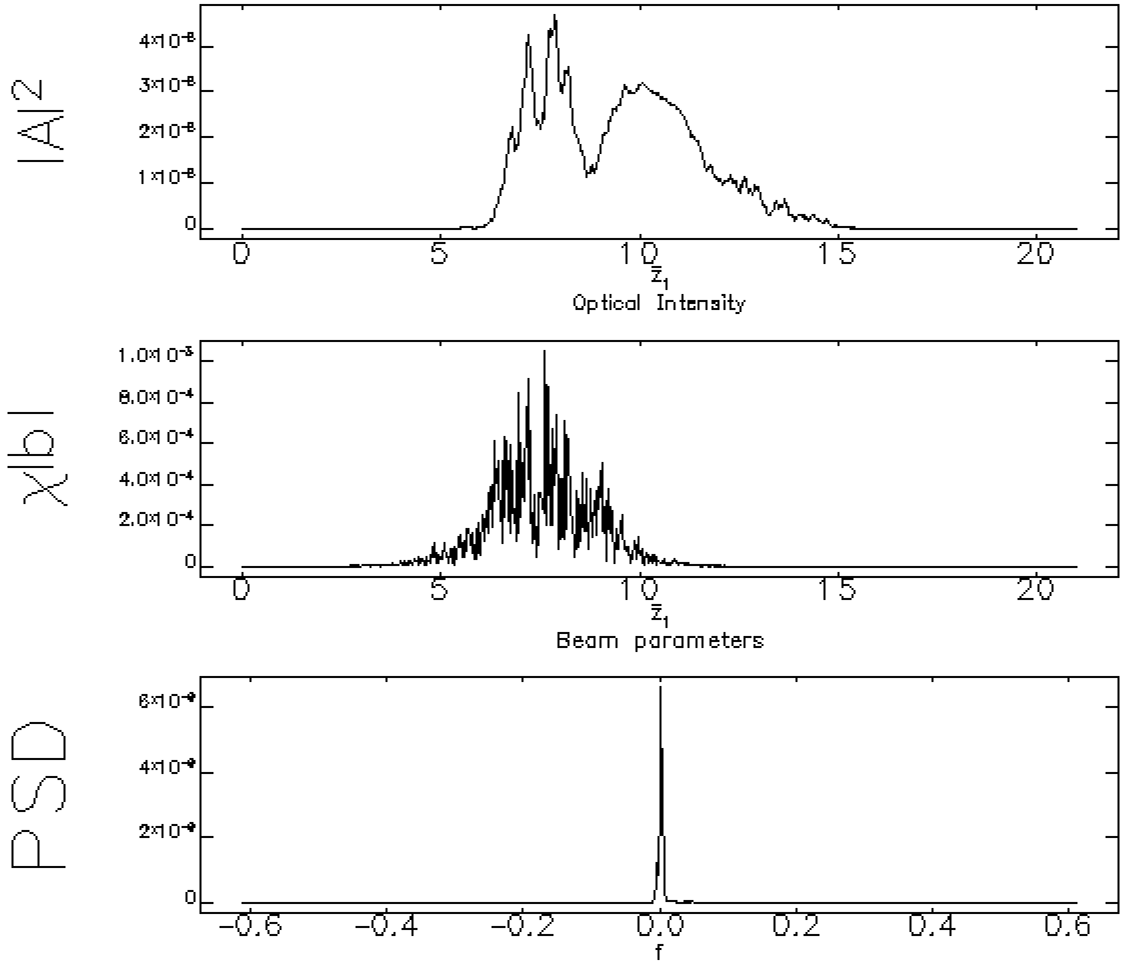
Pass=2



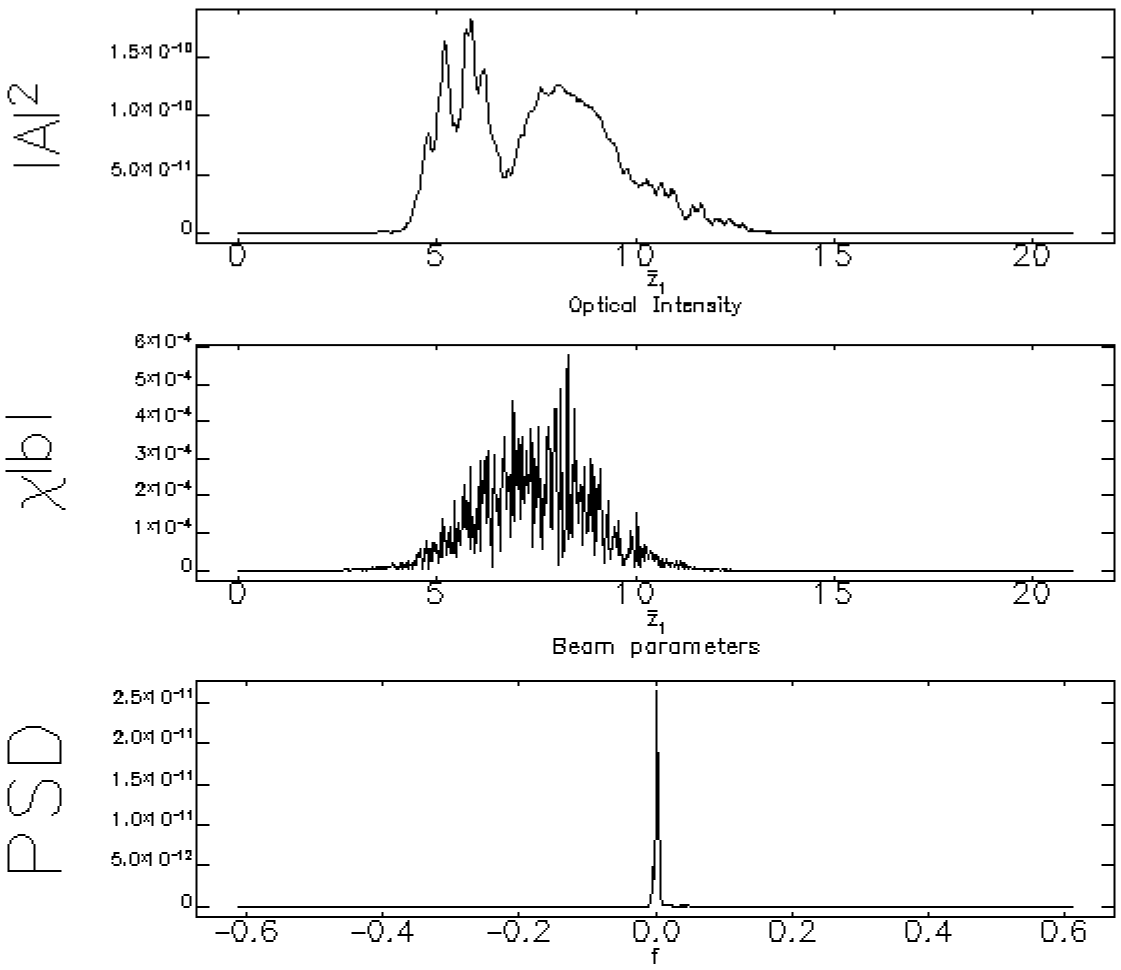
Pass=2


|A|2
0
5
10
15
20
Optical Intensity
χ|b|
0
5
10
15
20
Beam parameters
PSD
0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
f

Pass=2

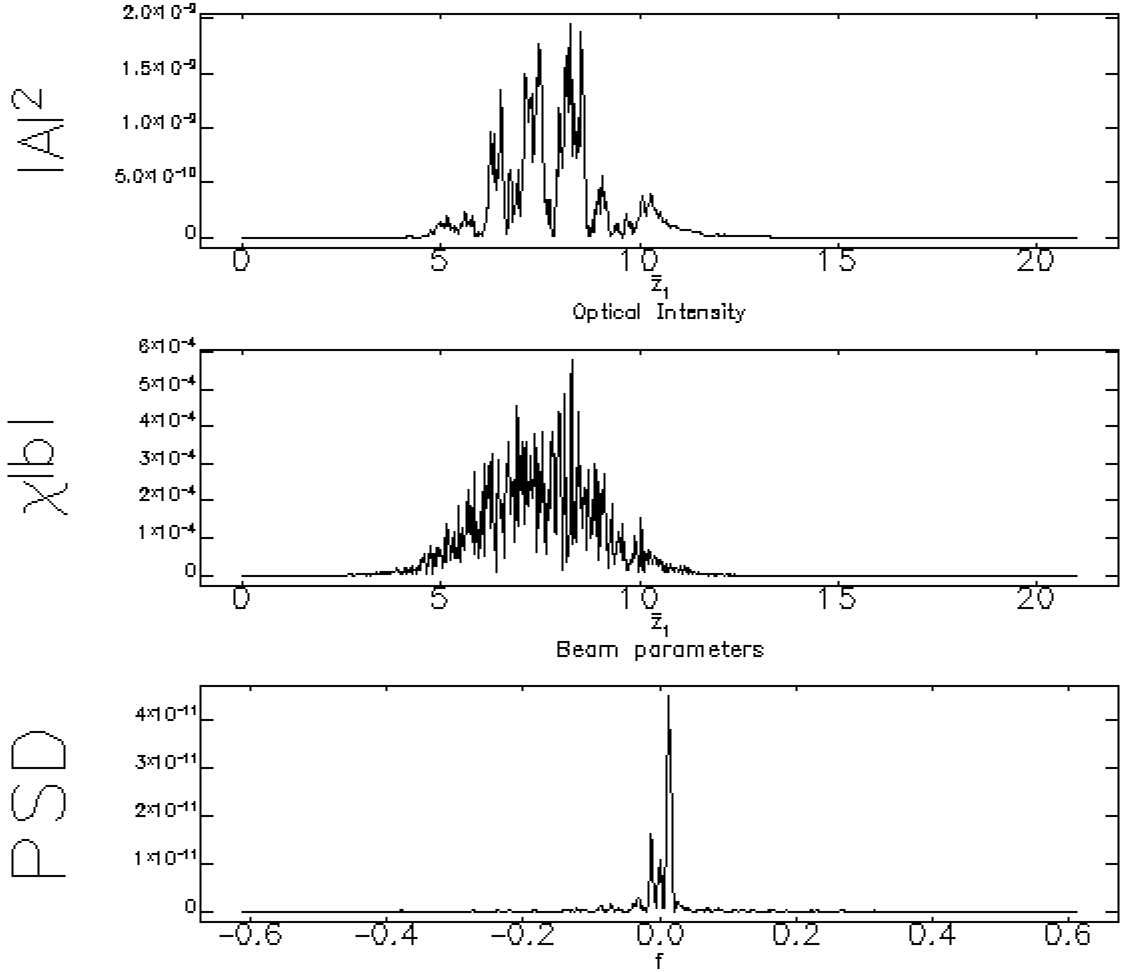


Pass=2



|A|2
1.5×10⁻¹⁰
1.0×10⁻¹⁰
5.0×10⁻¹¹
0
0
5
10
15
20
z̄1
Optical Intensity
χ|b|
6×10⁻⁴
5×10⁻⁴
4×10⁻⁴
3×10⁻⁴
2×10⁻⁴
1×10⁻⁴
0
0
5
10
15
20
z̄1
Beam parameters
PSD
2.5×10⁻¹¹
2.0×10⁻¹¹
1.5×10⁻¹¹
1.0×10⁻¹¹
5.0×10⁻¹²
0
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
f

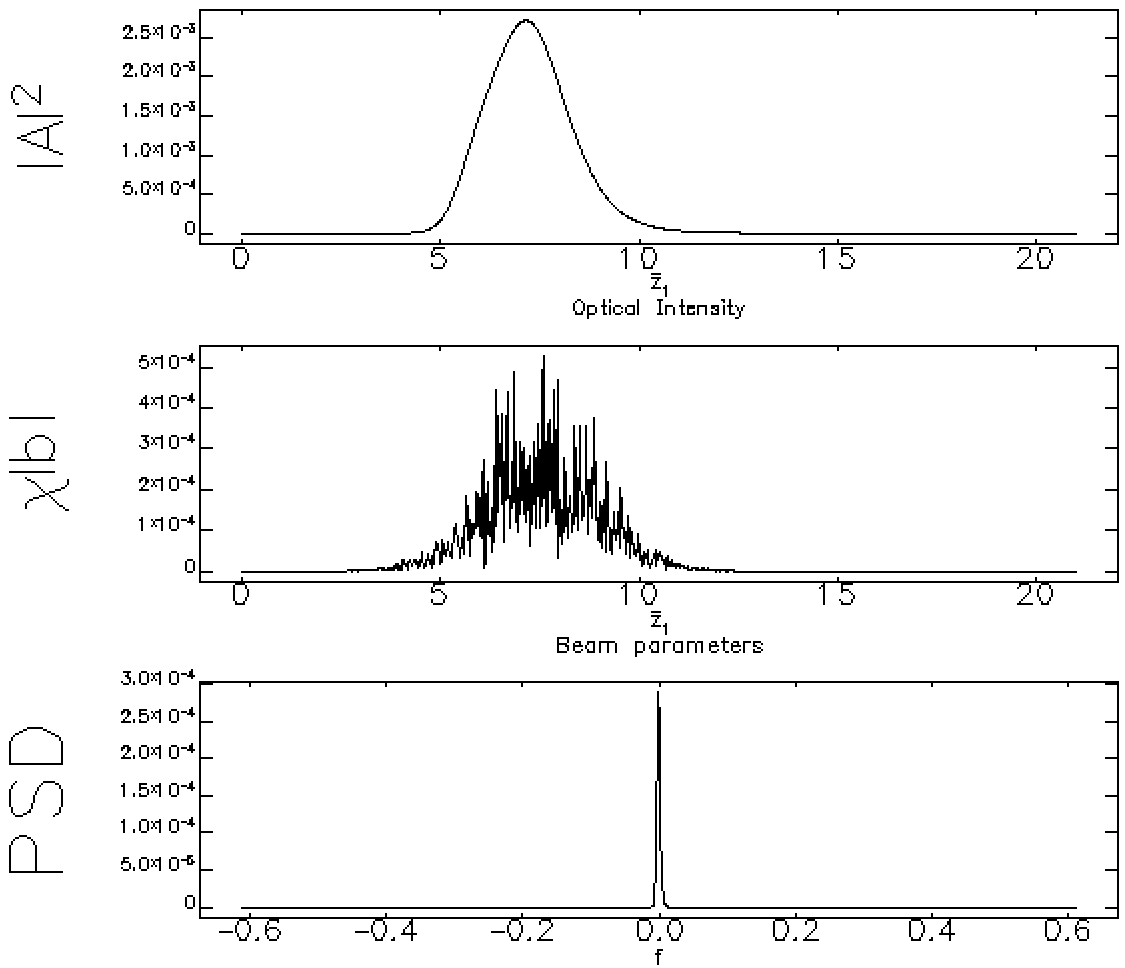
Pass=3



And so on until sometime later….

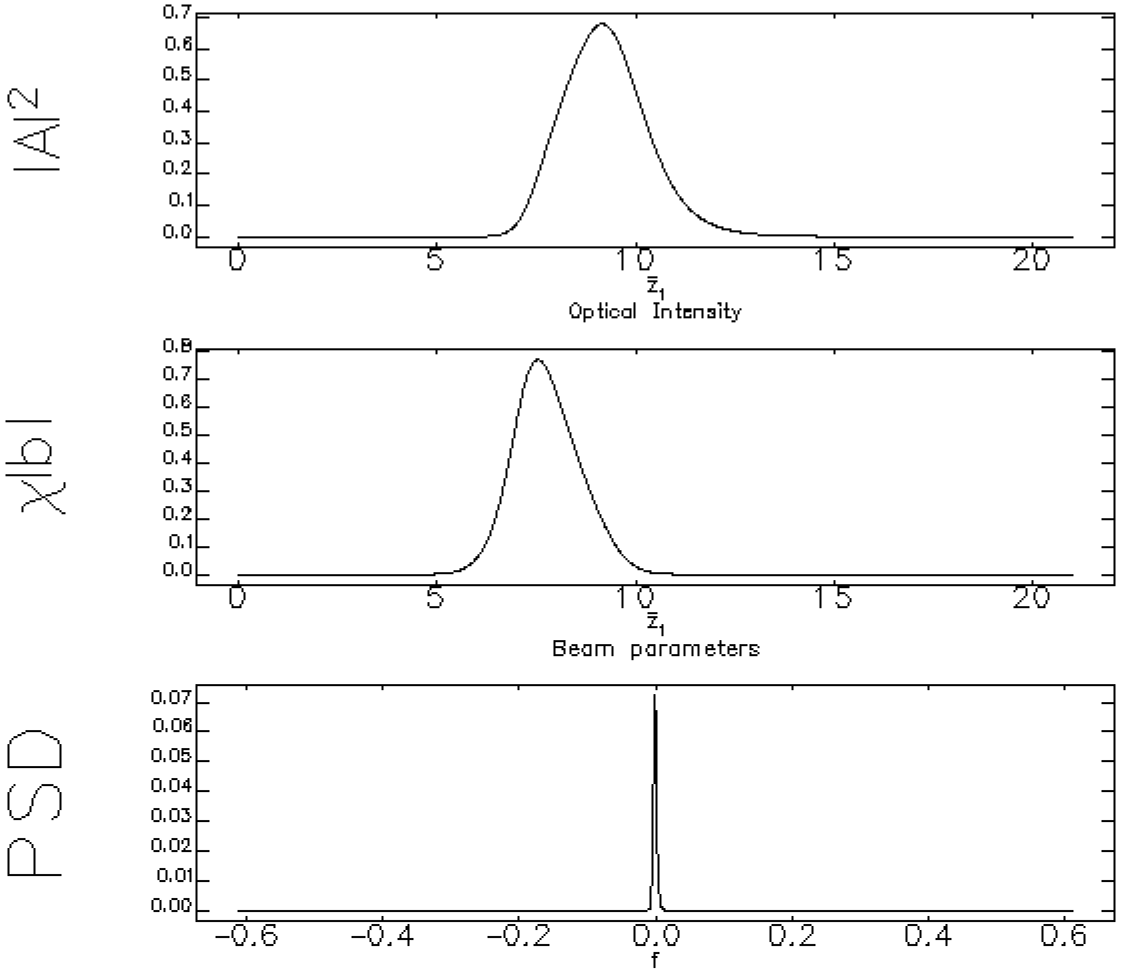
Pass = >> 1

Start wiggler



Pass = >> 1

End wiggler



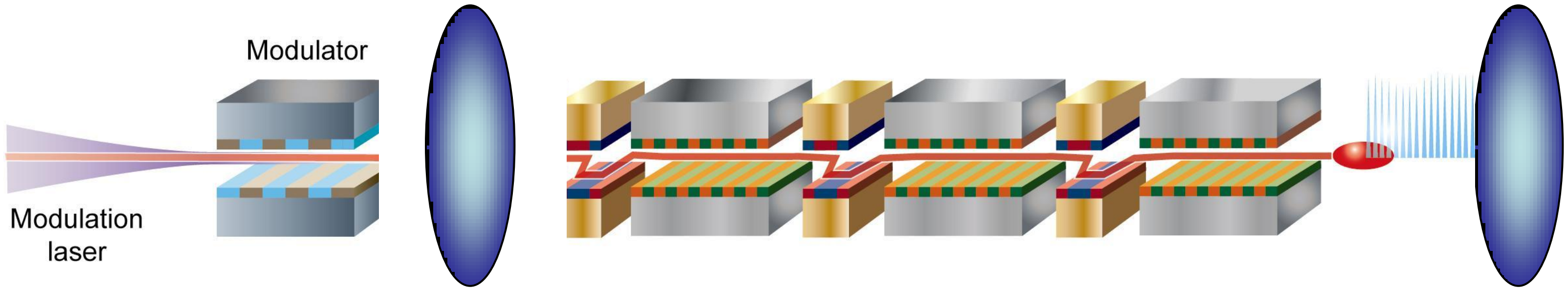
This output is stable, with very little temporal jitter or power jitter, pass to pass :

A great candidate for generating single, stable, attosecond pulses in the x-ray.

RAFEL ***with*** MLOK –

with short electron pulse: $l_b \sim l_c$

Example short-pulse MLOK RAFEL simulation

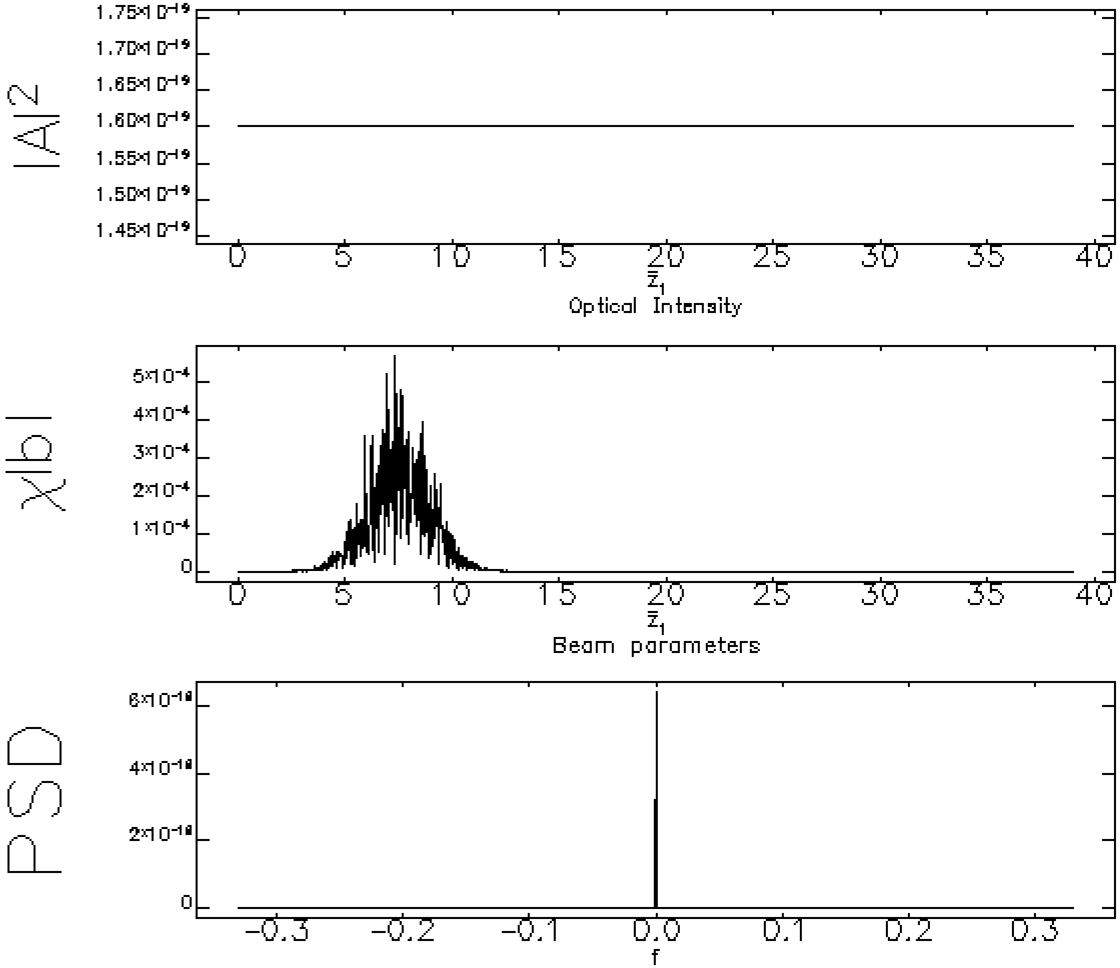


Parameters are typical for a soft x-ray FEL:

Gaussian current electron pulse:	$\sigma_z = l_c$
FEL parameter:	$\rho = 2\times10^{-3}$
Undulator module length X 16:	$L_u = l_g / 4$
Chicane induced slippage X 16:	$\delta = 1.25 l_c$
Beam energy modulation amplitude: (can also use current modulation)	$\gamma_{\text{mod}} = \rho\gamma$
Cavity feedback factor:	$F = 3.5\times10^{-2}$
Cavity detuning:	lengthened by $3\times l_c$

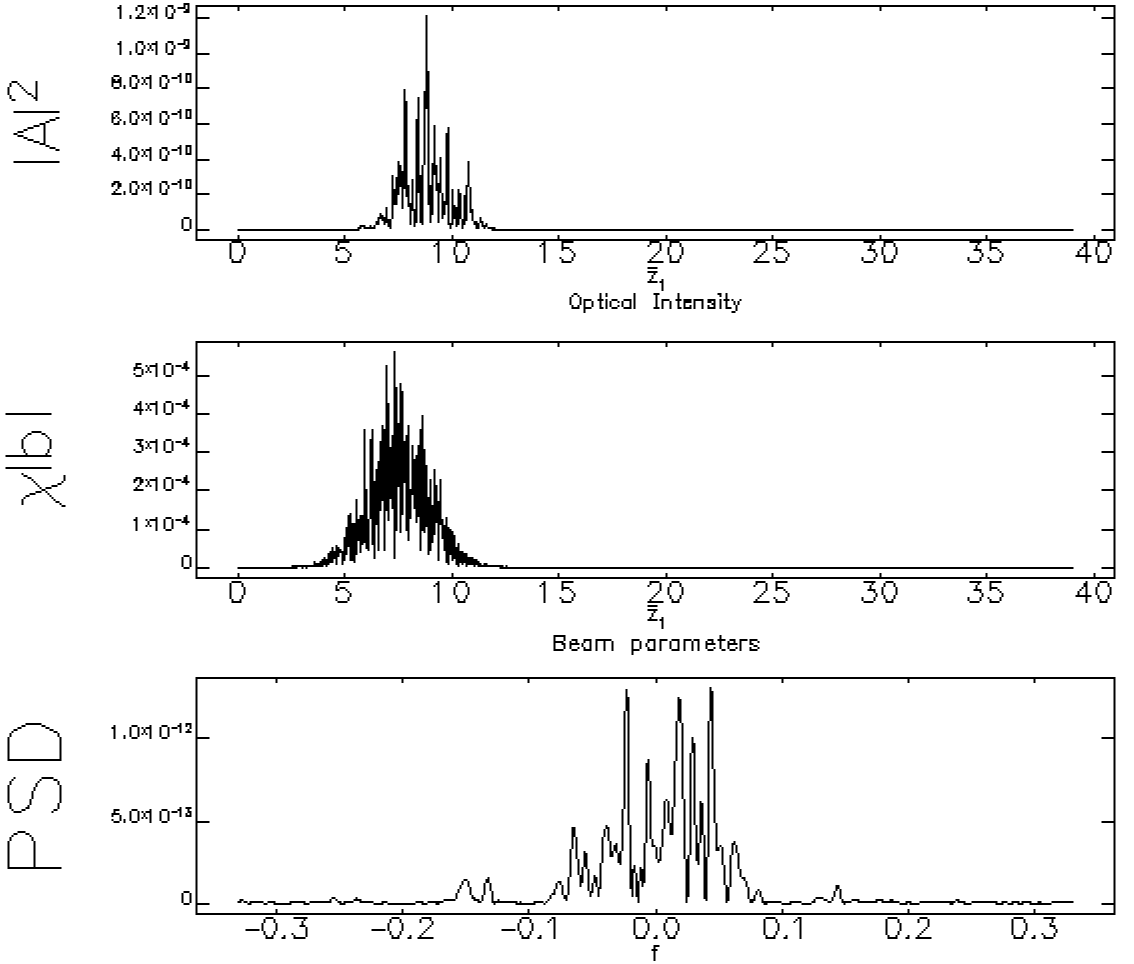
Pass=1

Module 0



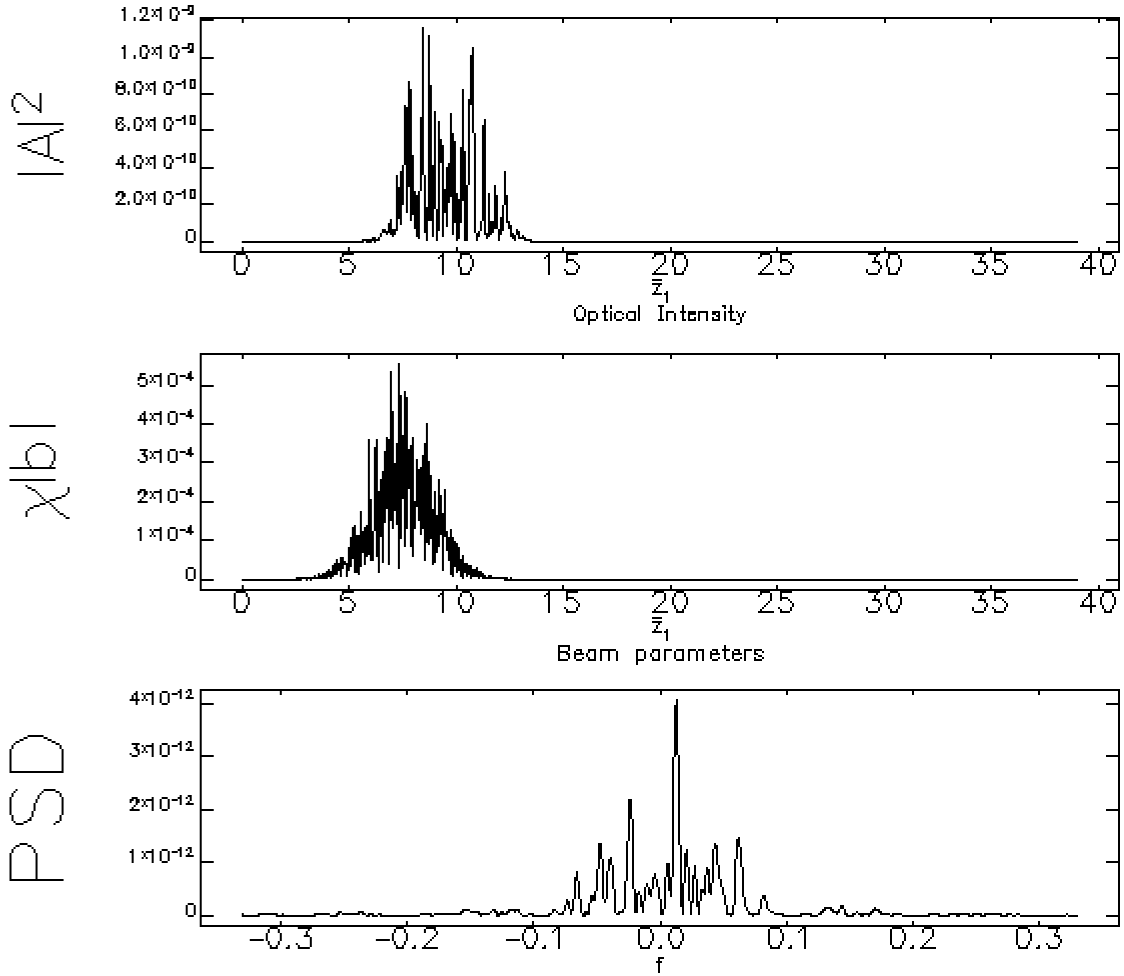
Pass=1

Module 1



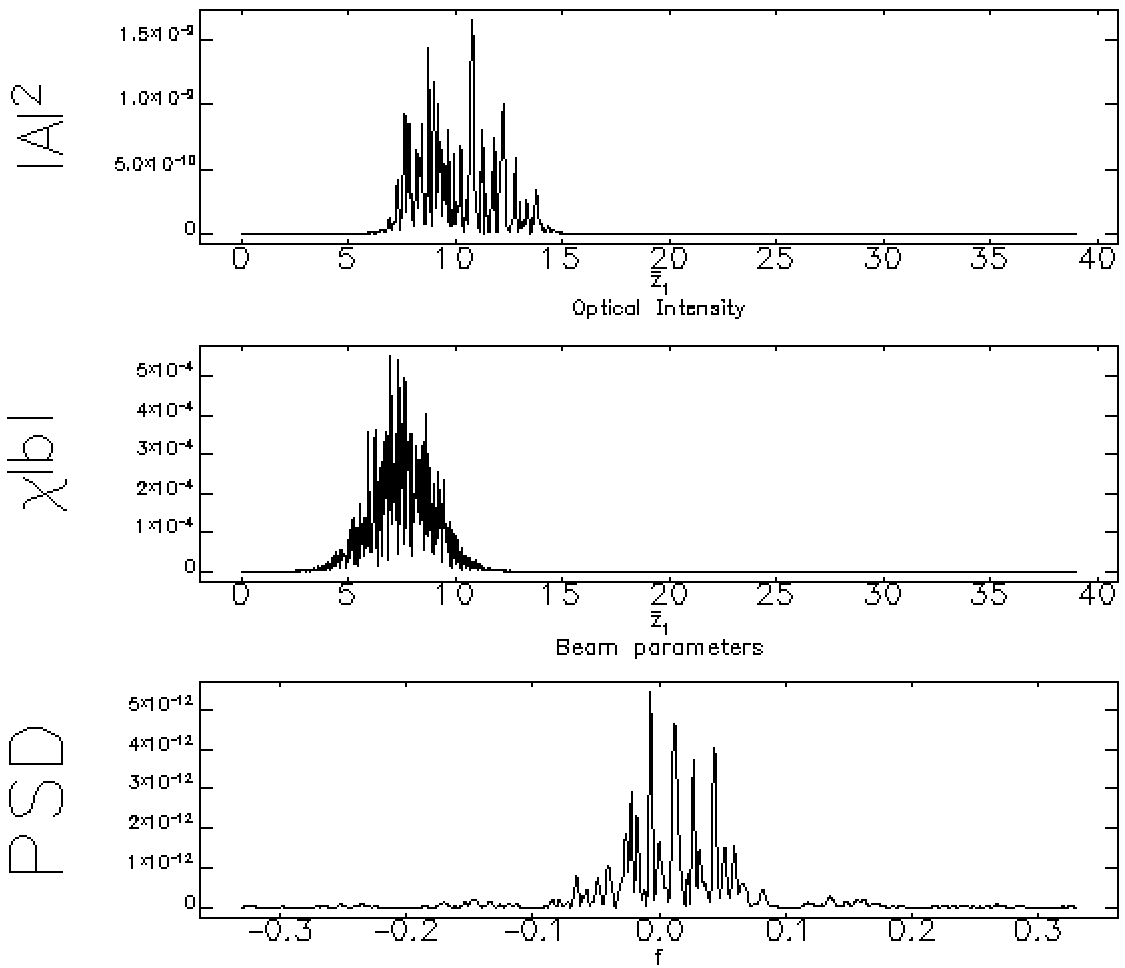
Pass=1

Module 2



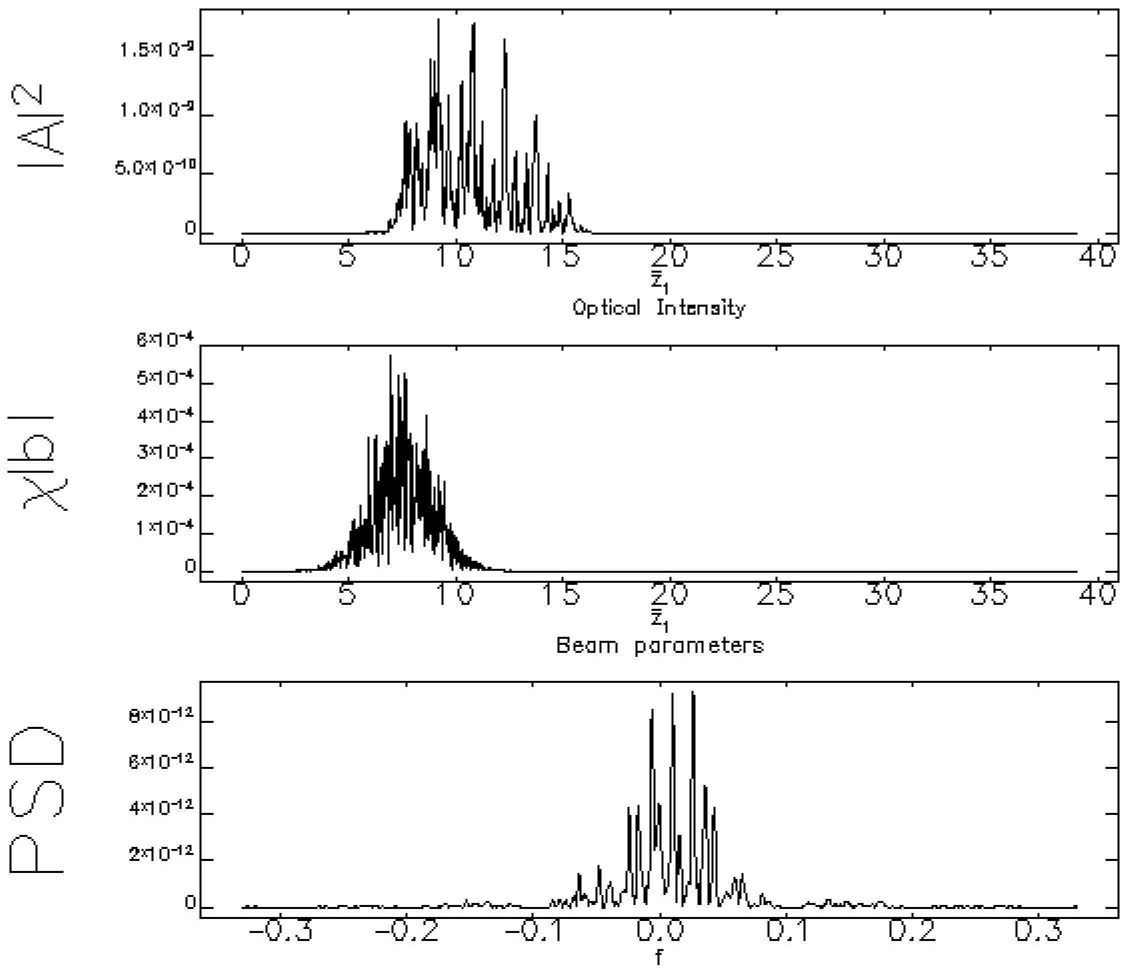
Pass=1

Module 3



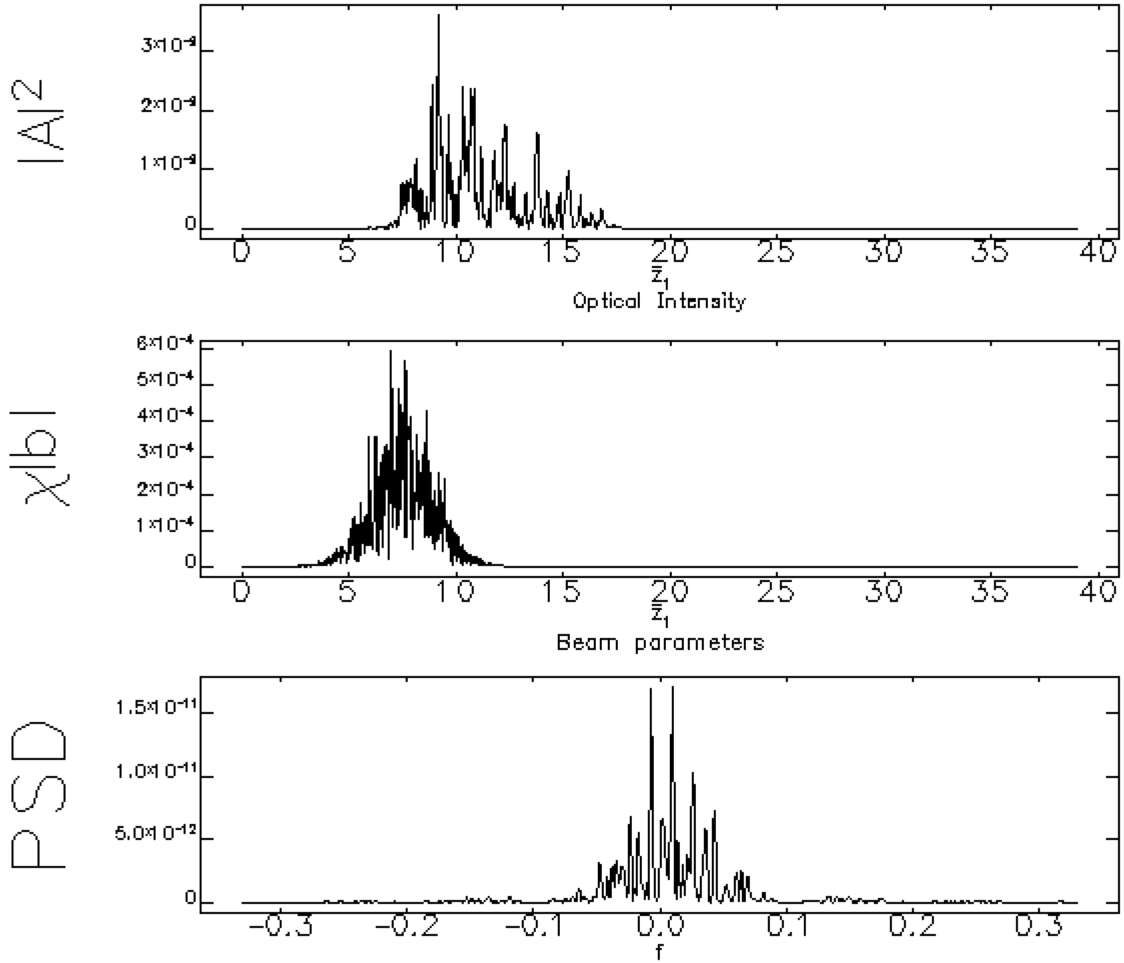
Pass=1

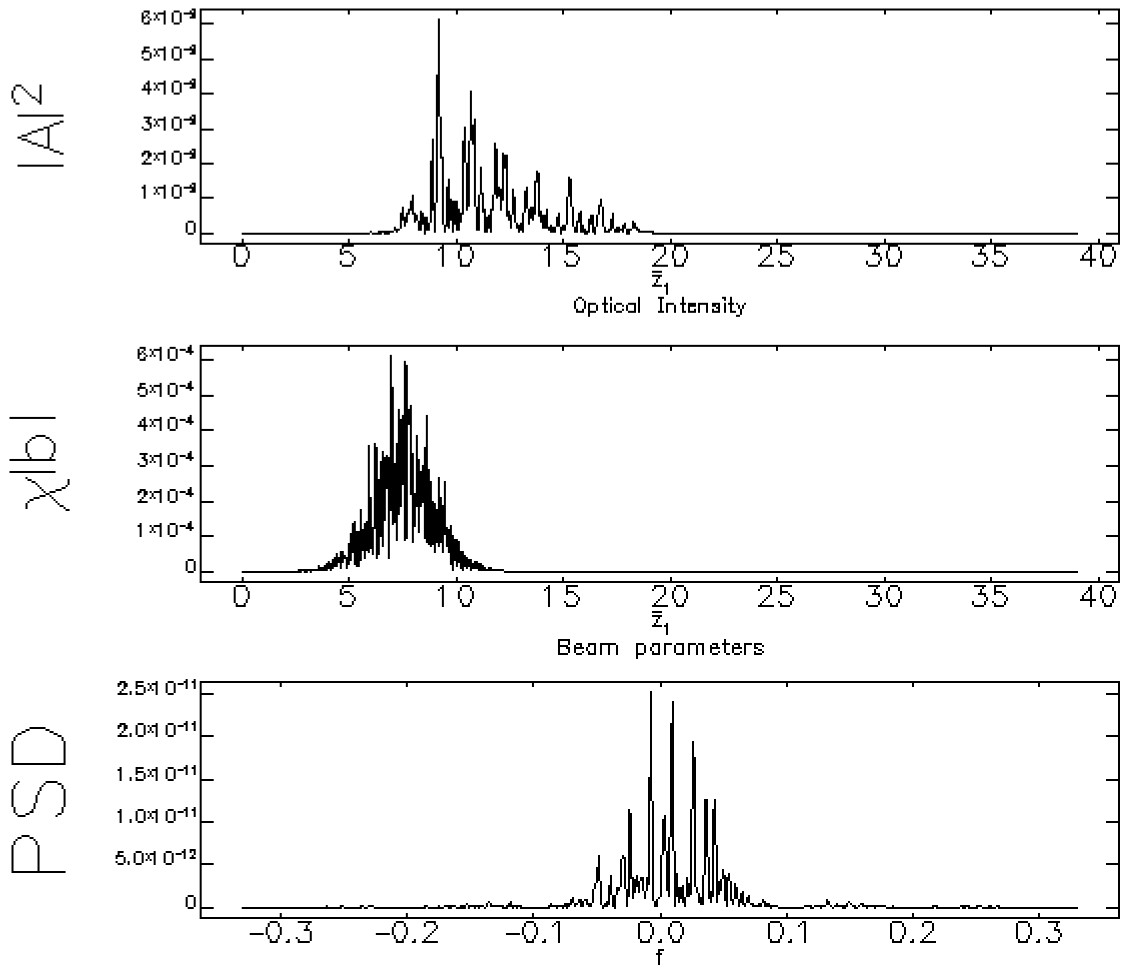
Module 4



Pass=1

Module 5



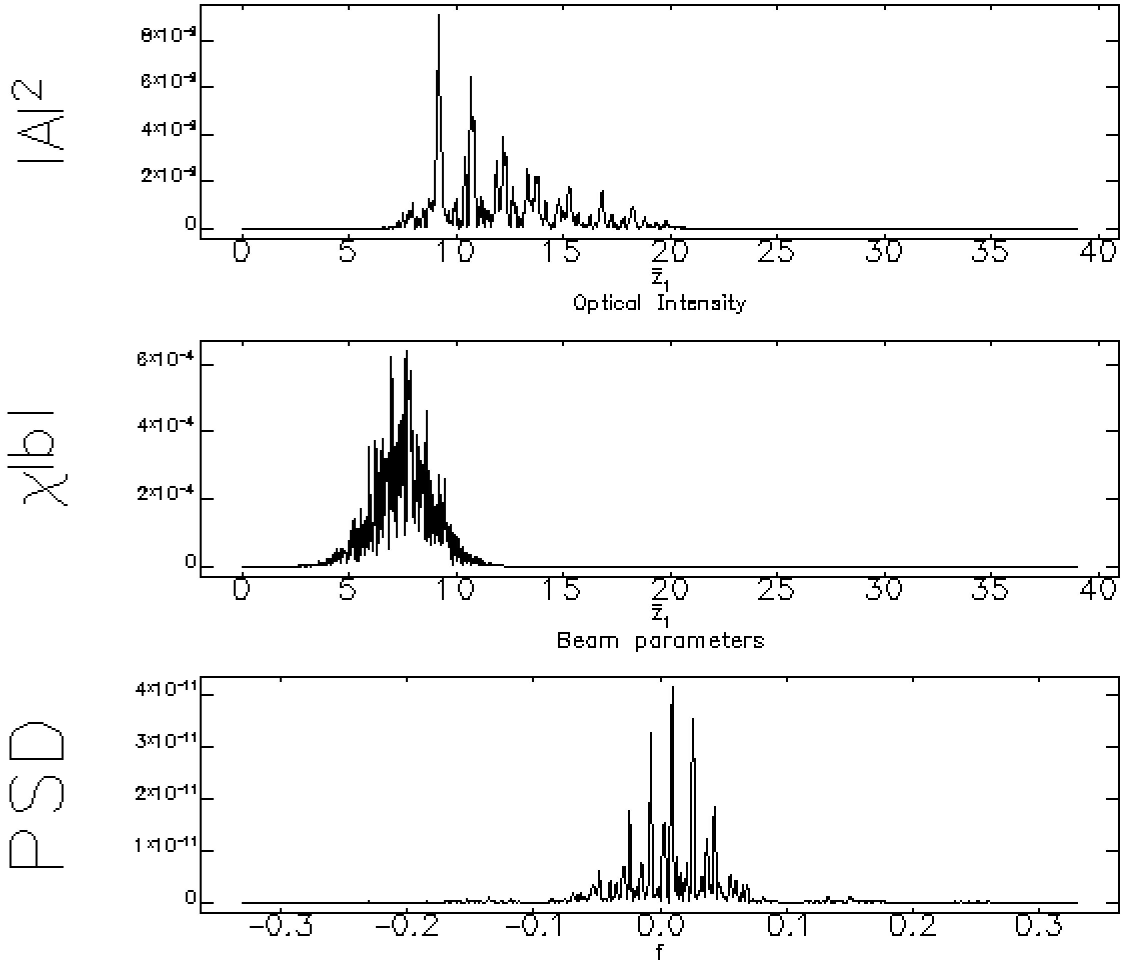


Pass=1

Module 6

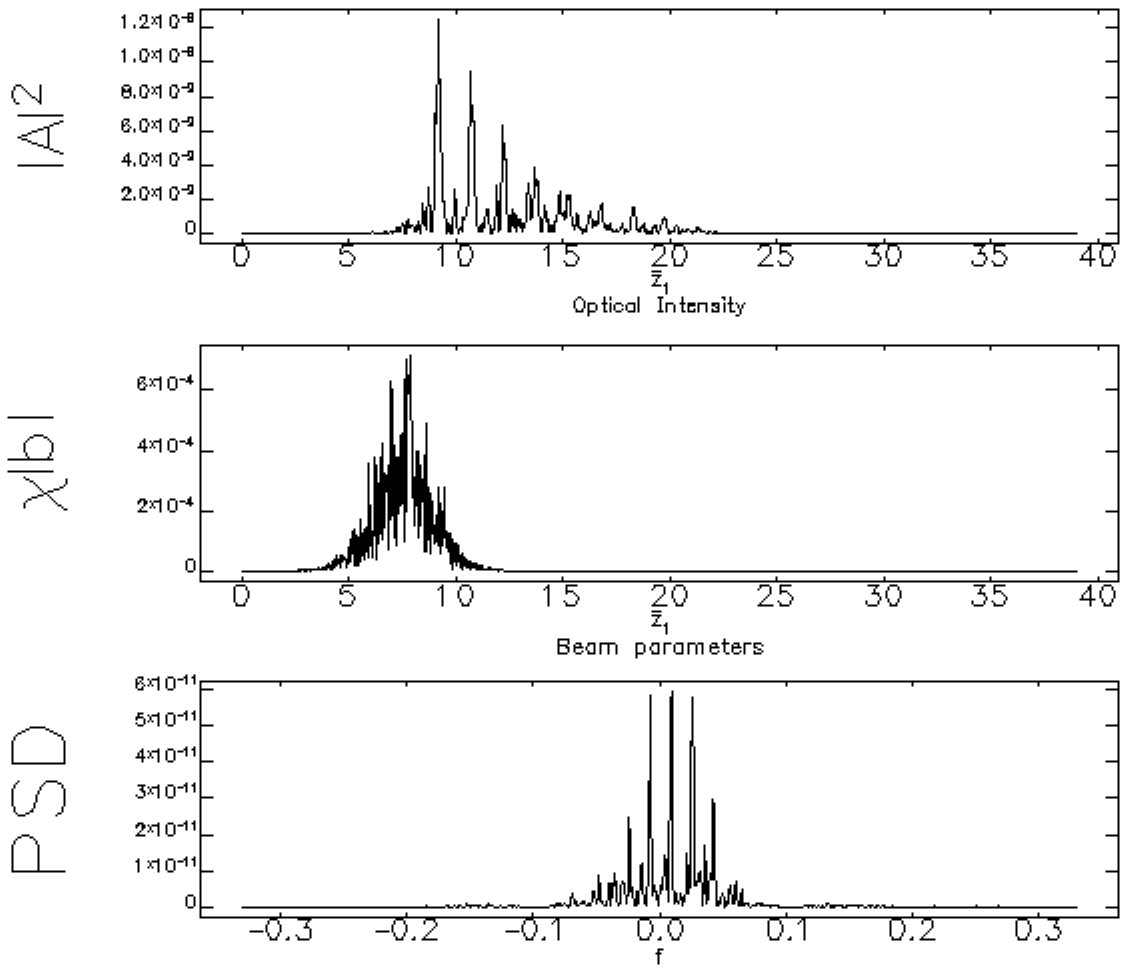
Pass=1

Module 7



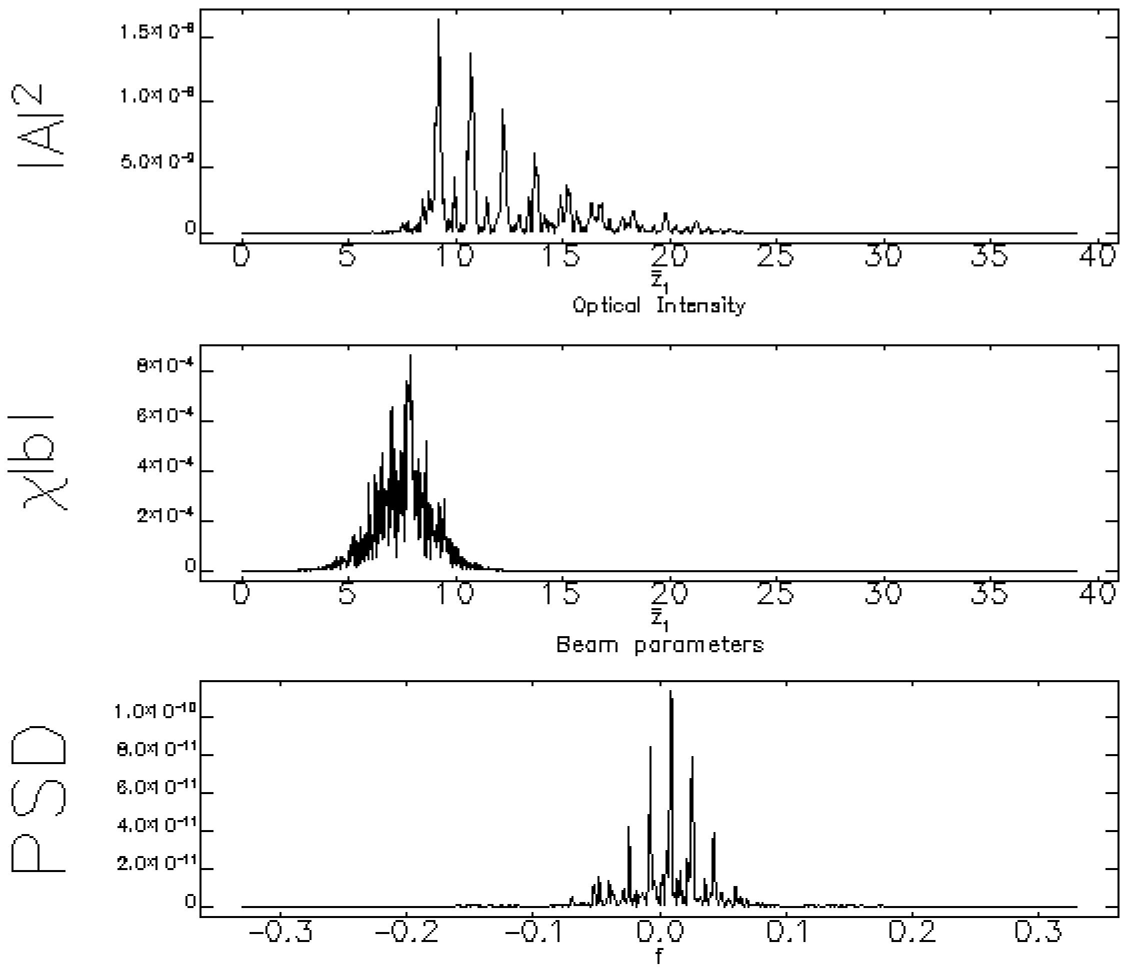
Pass=1

Module 8



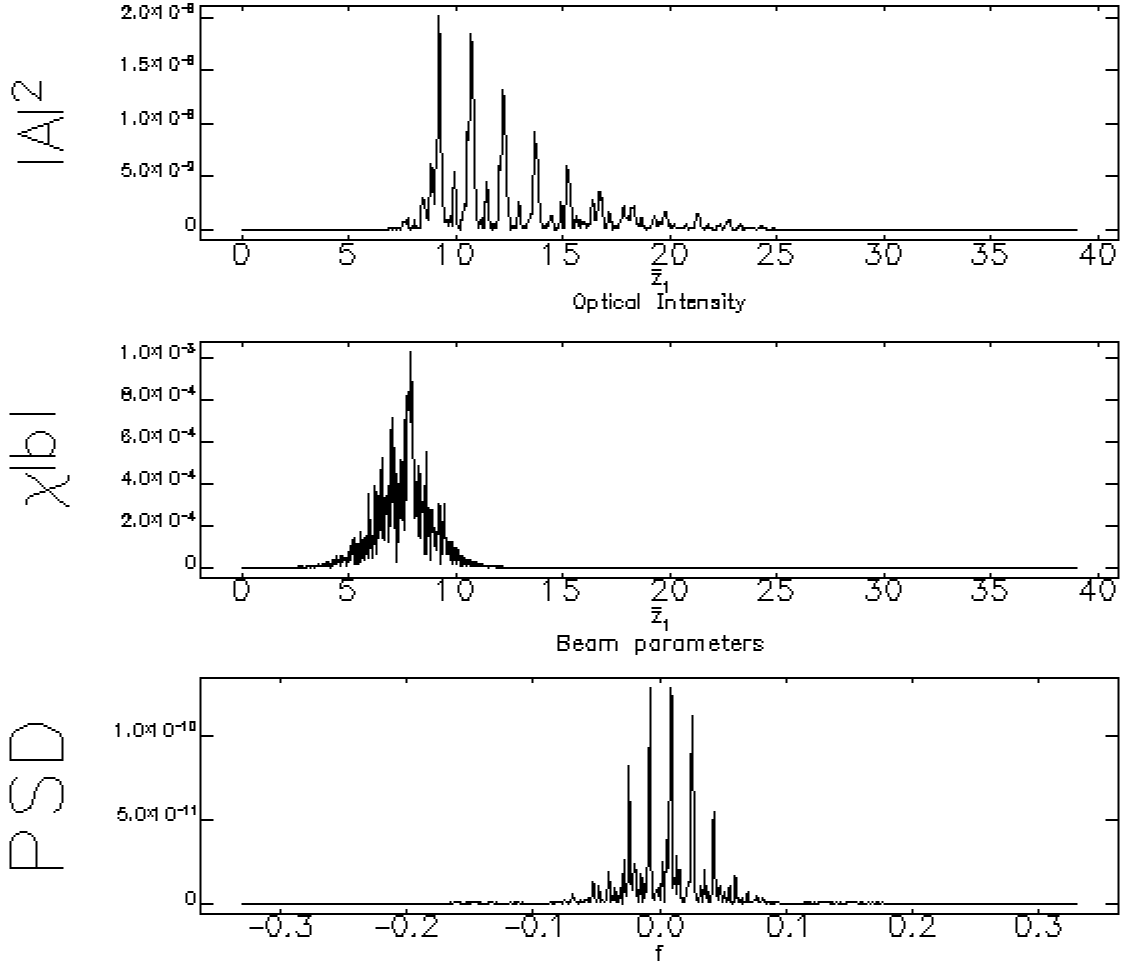
Pass=1

Module 9



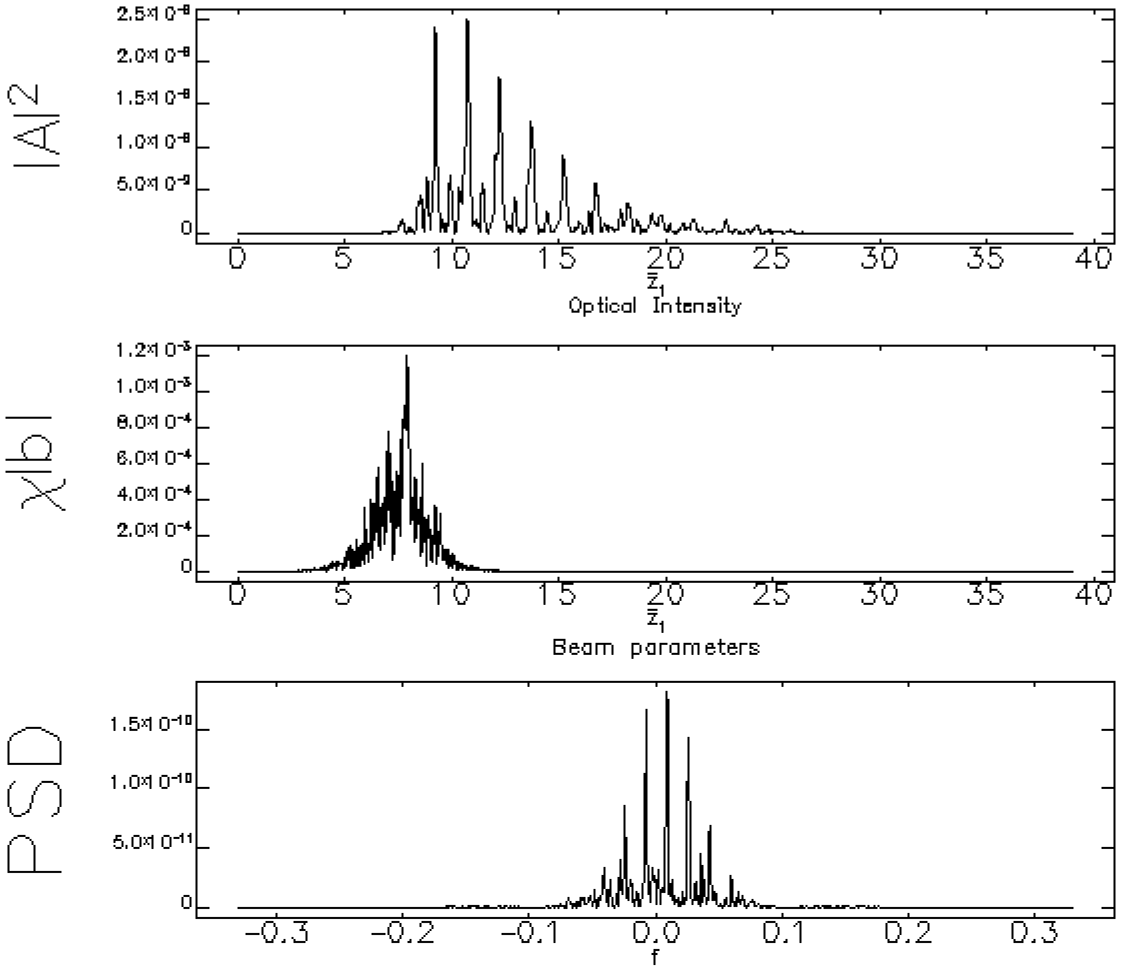
Pass=1

Module 10



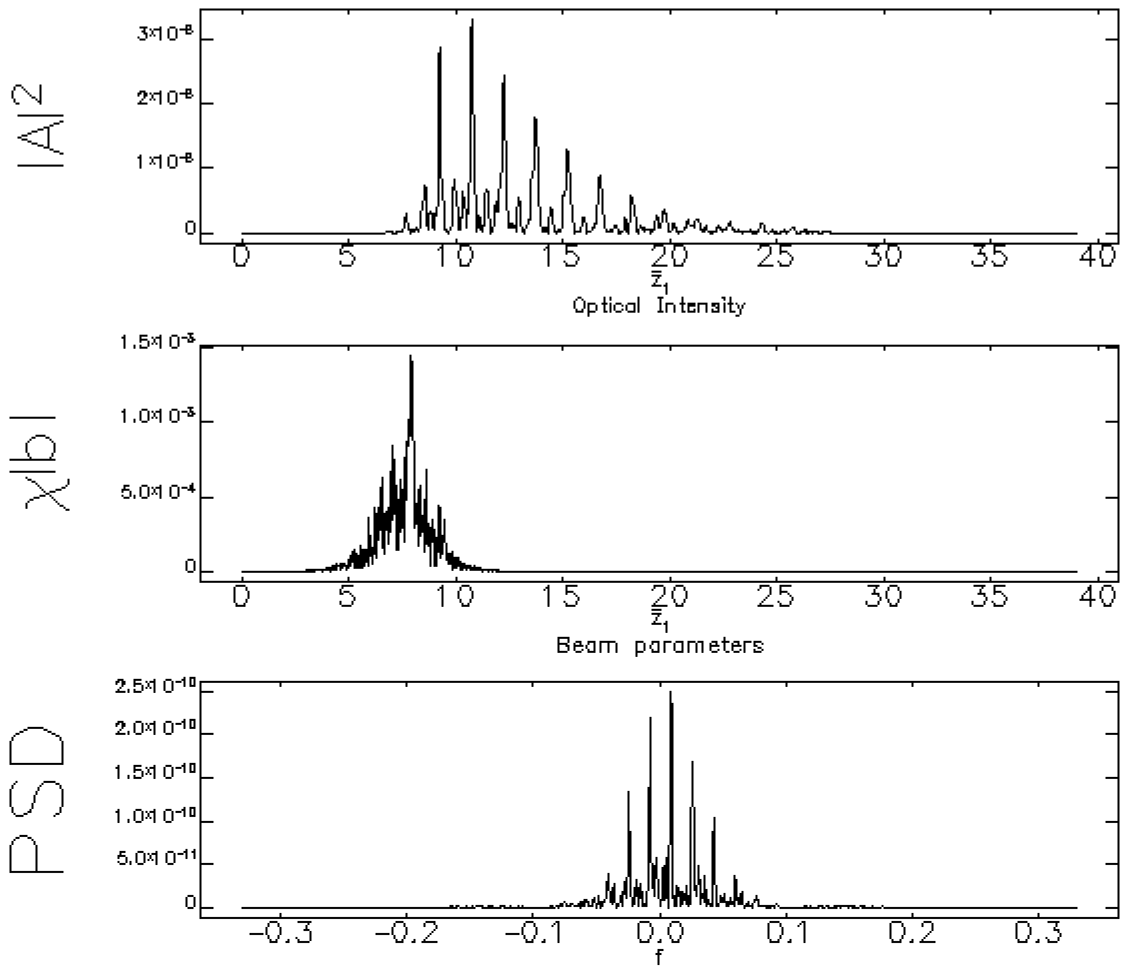
Pass=1

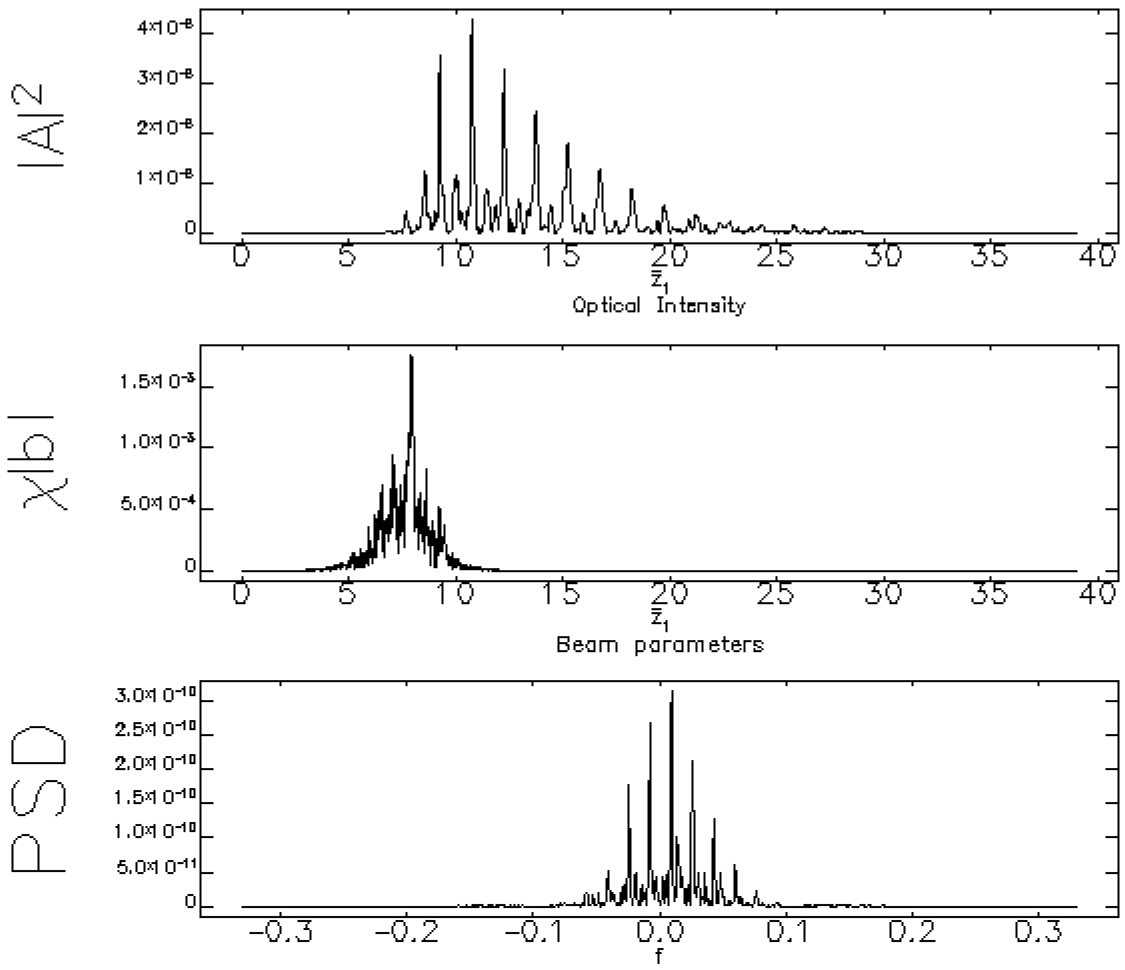
Module 11



Pass=1

Module 12



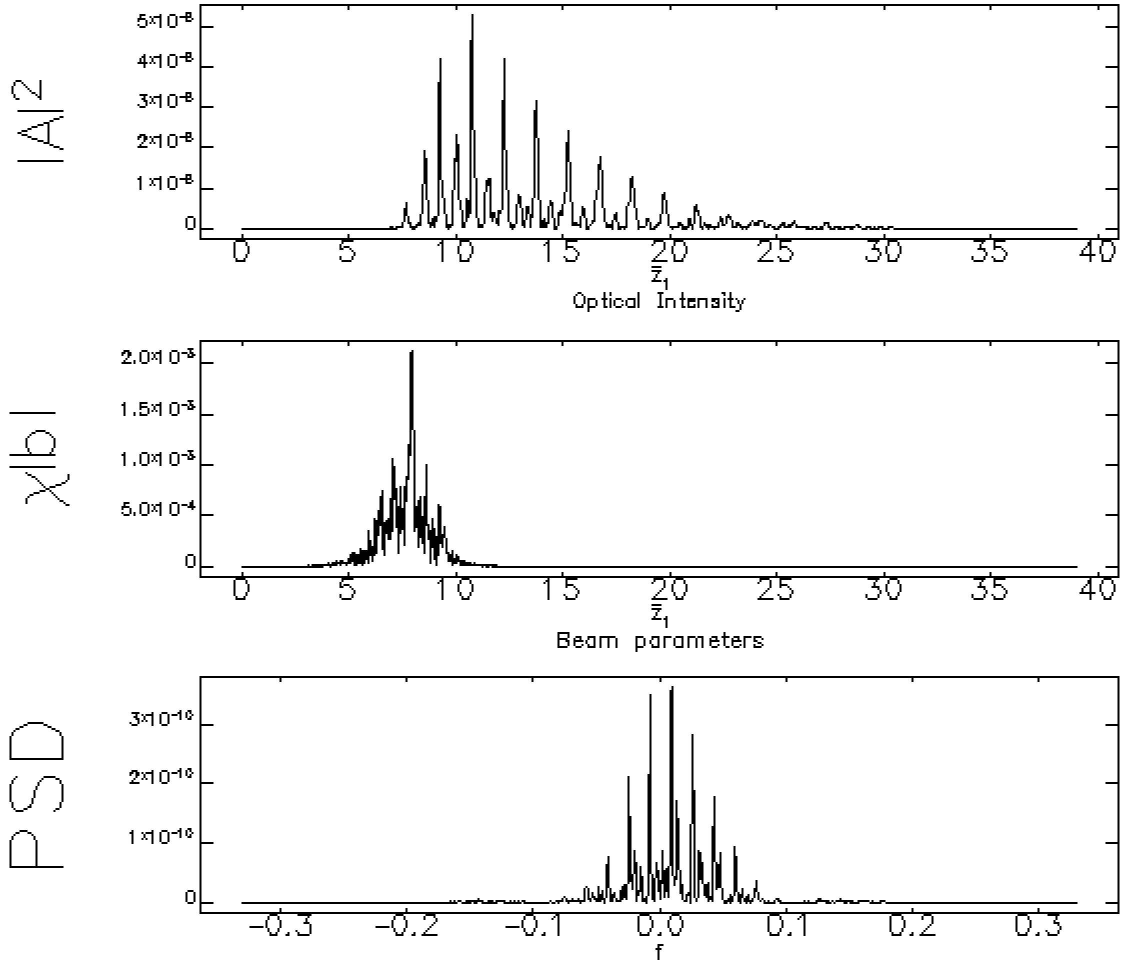


Pass=1

Module 13

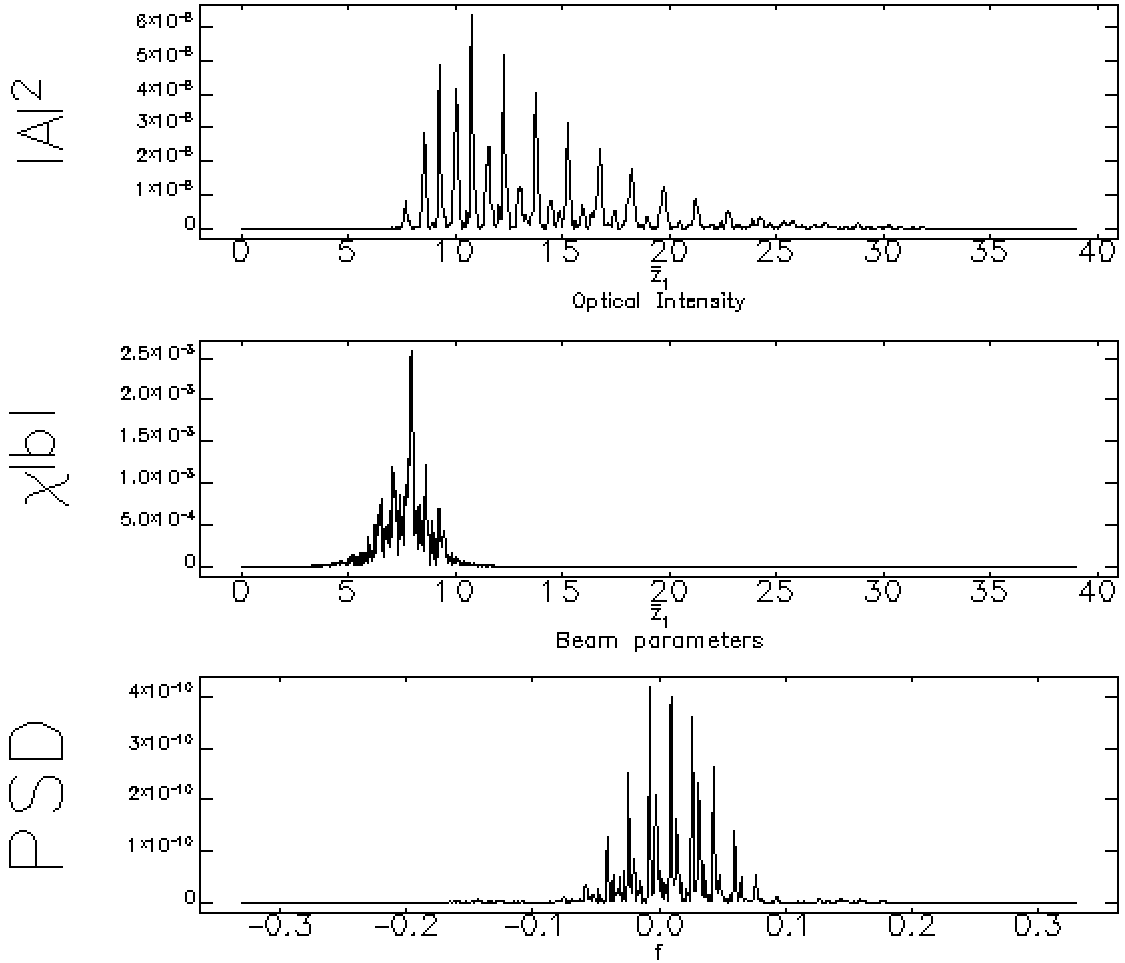
Pass=1

Module 14



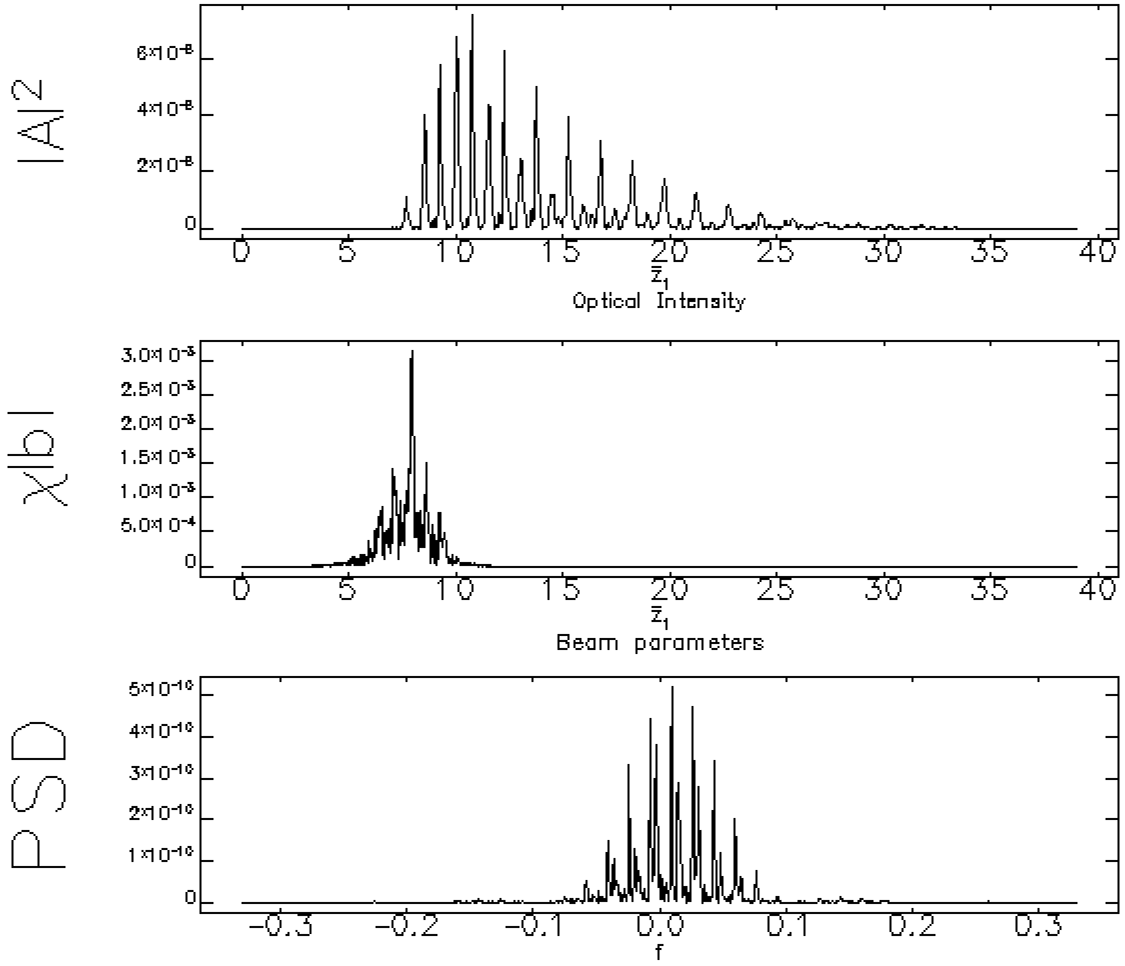
Pass=1

Module 15



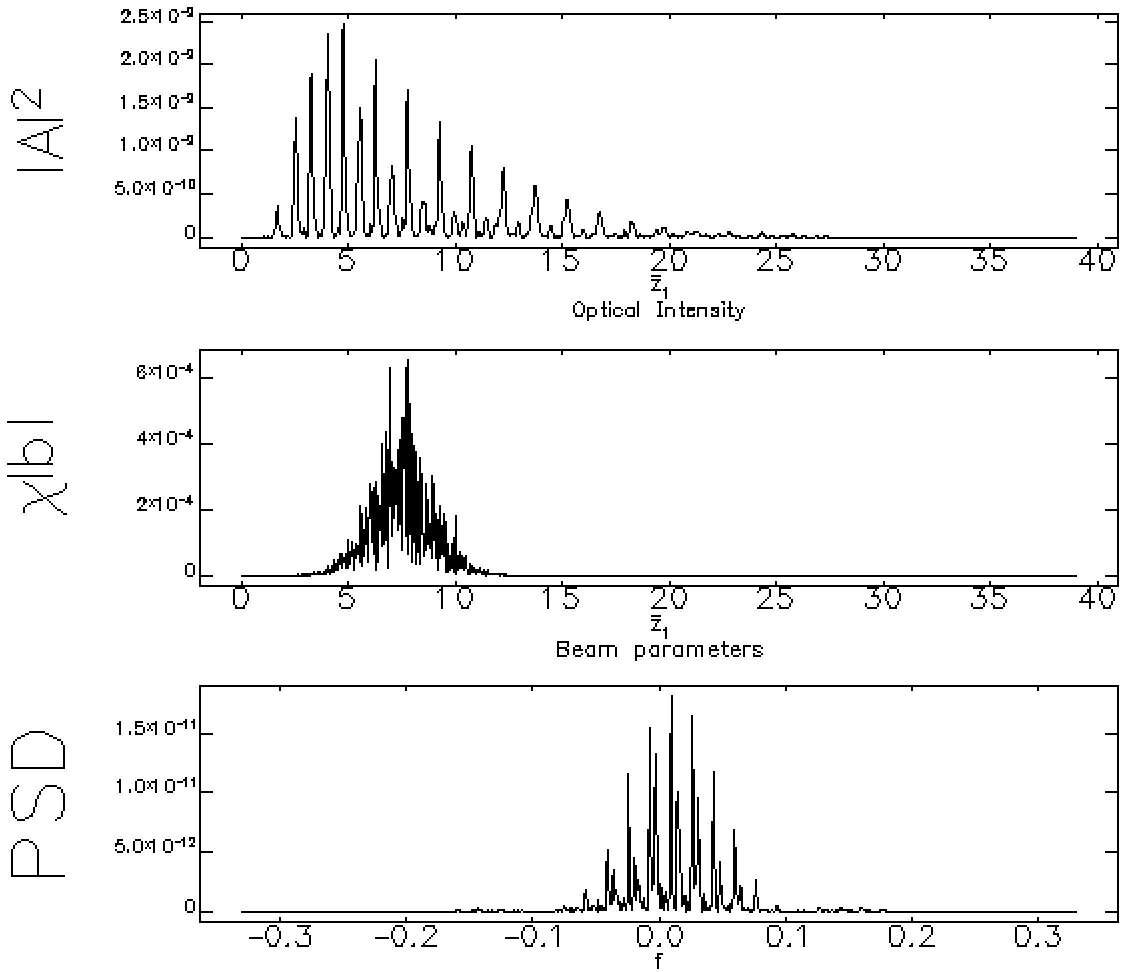
Pass=1

Module 16



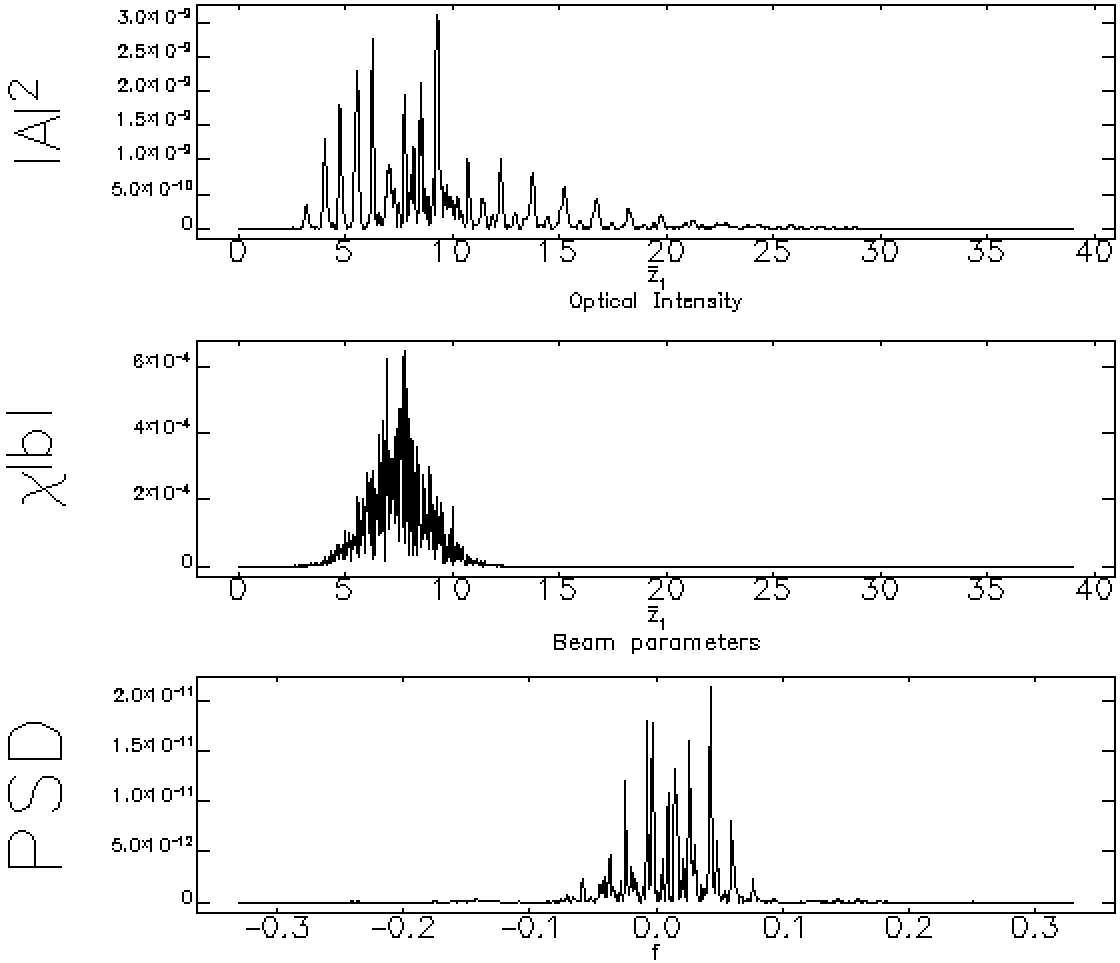
Pass=2

Module 0



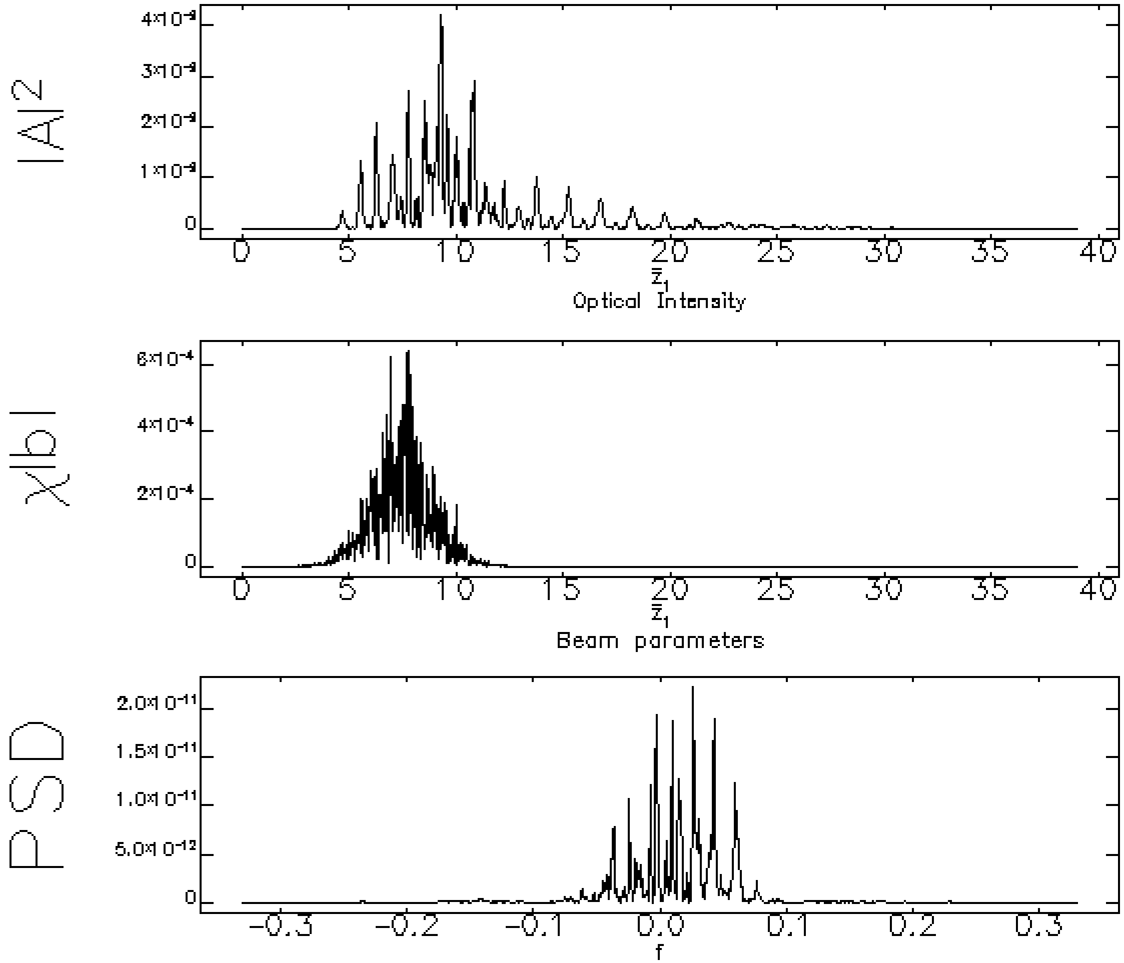
Pass=2

Module 1



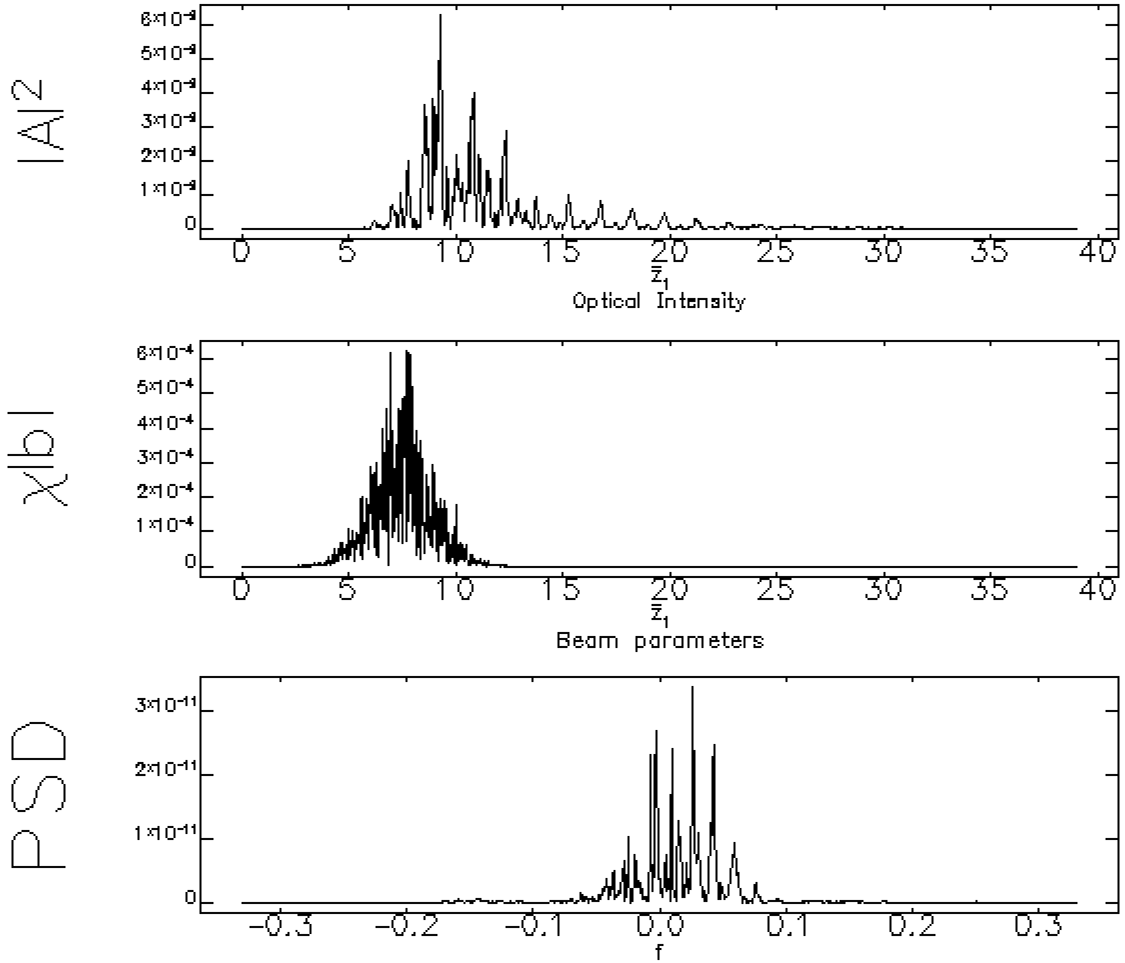
Pass=2

Module 2



Pass=2

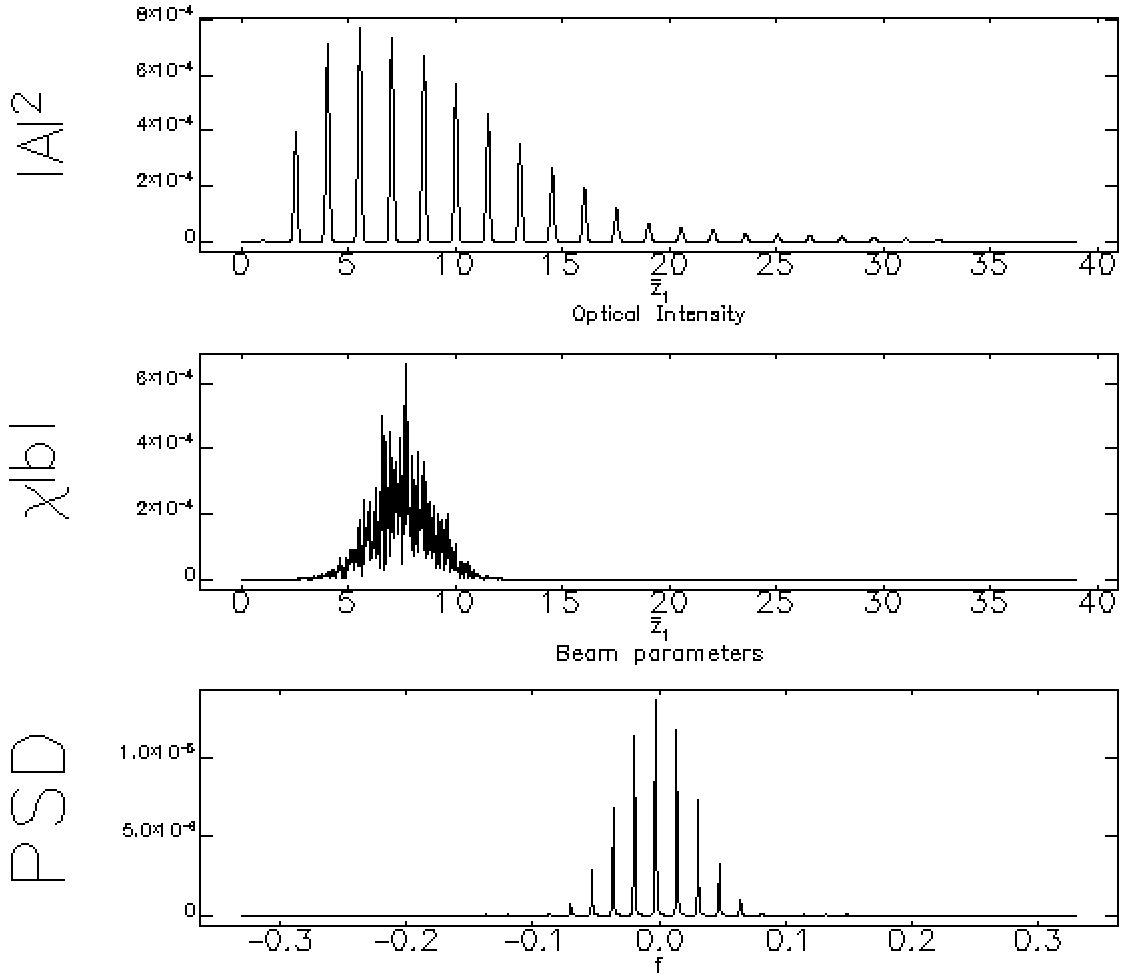
Module 3



And so on until sometime later….

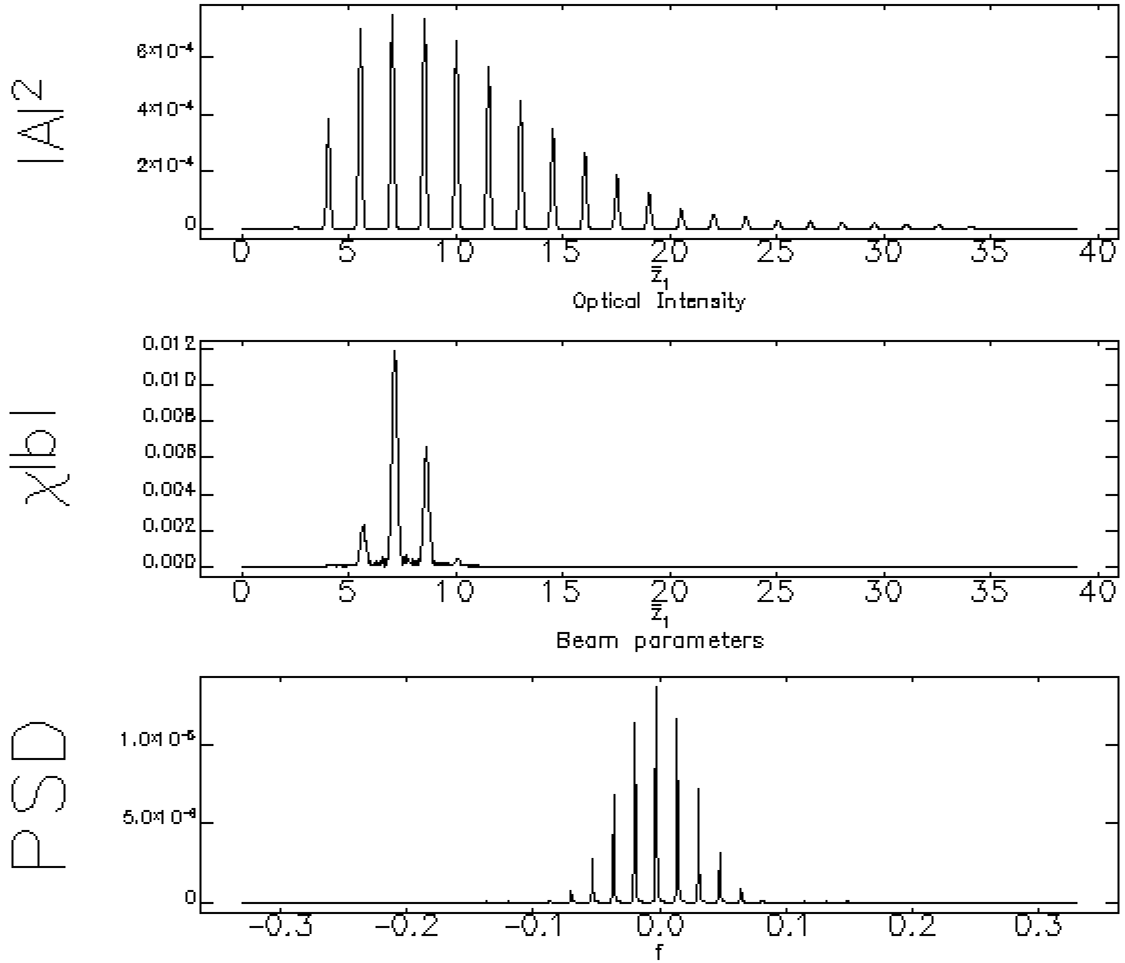
Pass >>1

Module 0



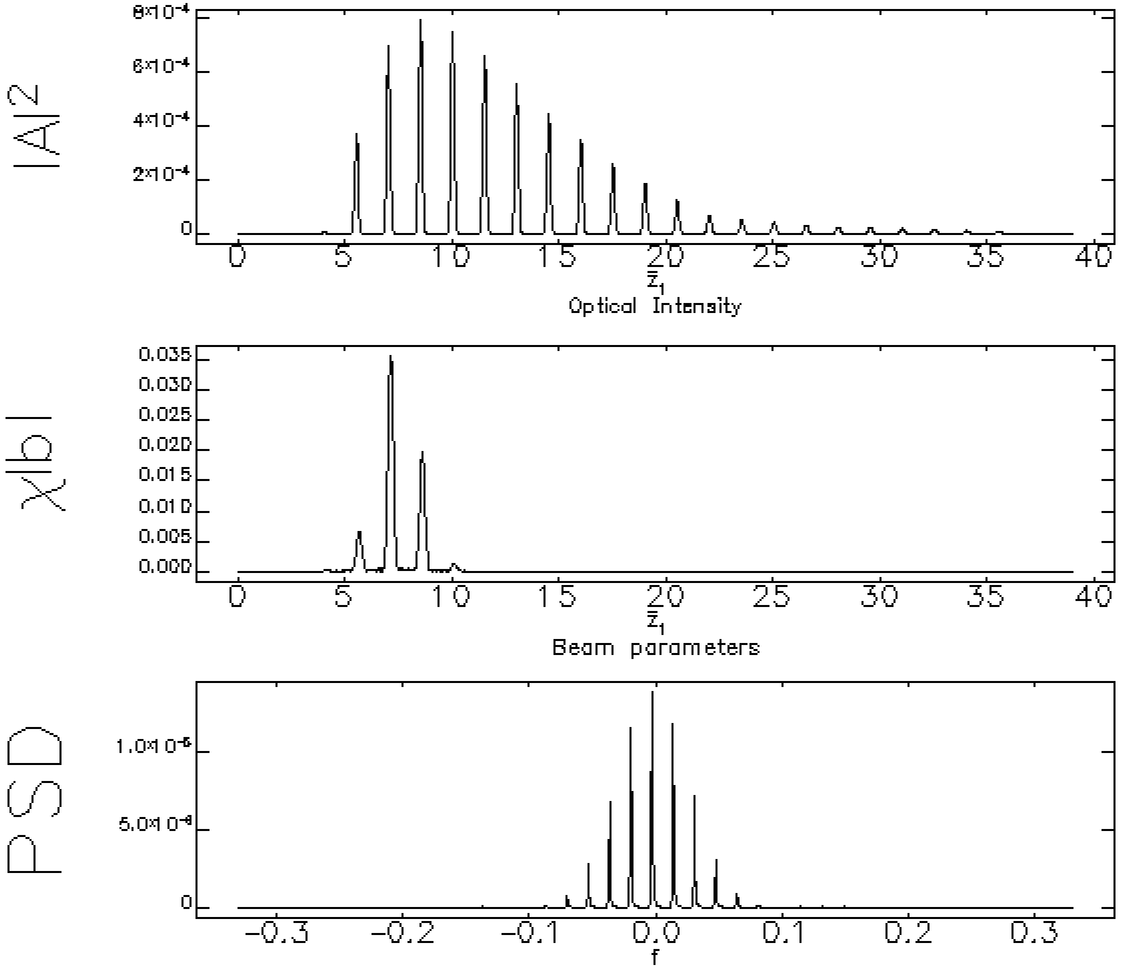
Pass >>1

Module 1



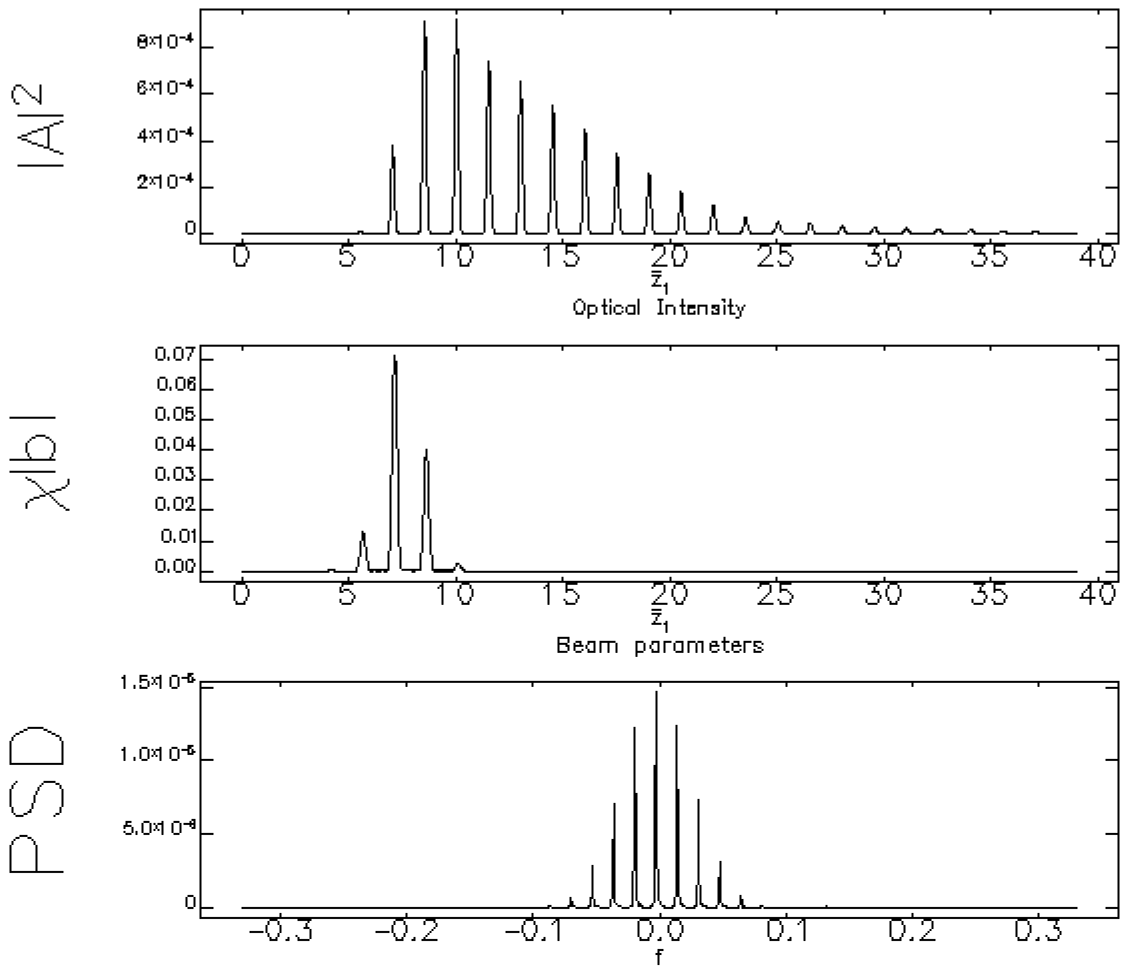
Pass >>1

Module 2



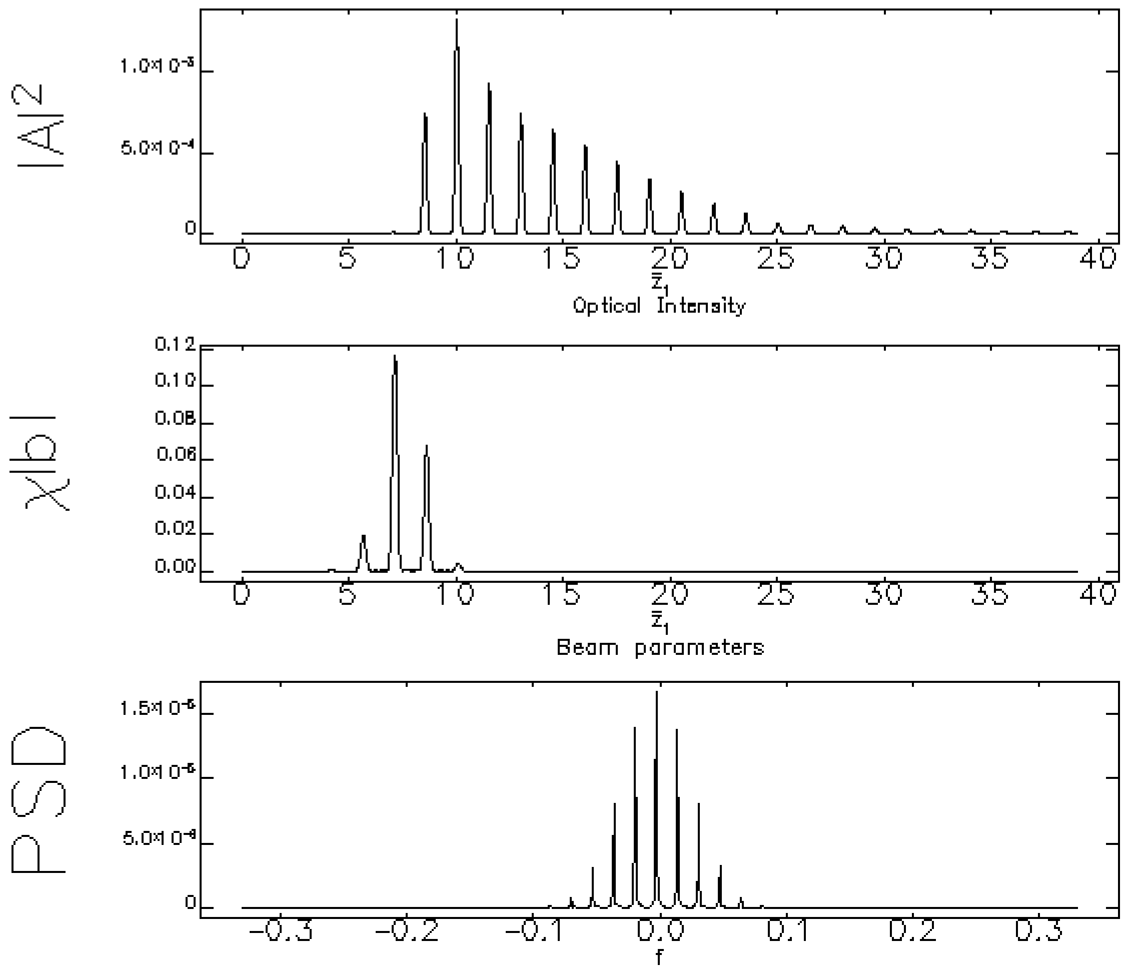
Pass >>1

Module 3



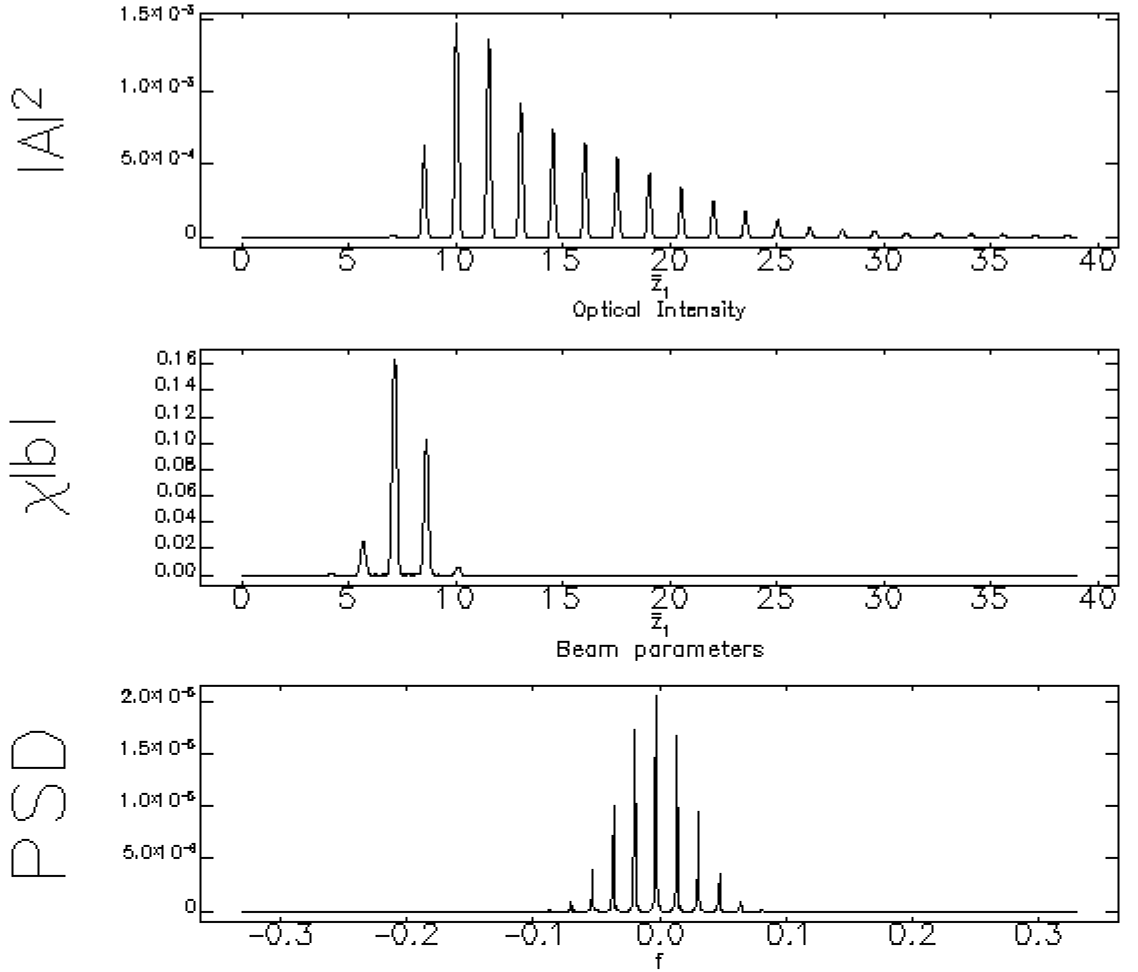
Pass >>1

Module 4



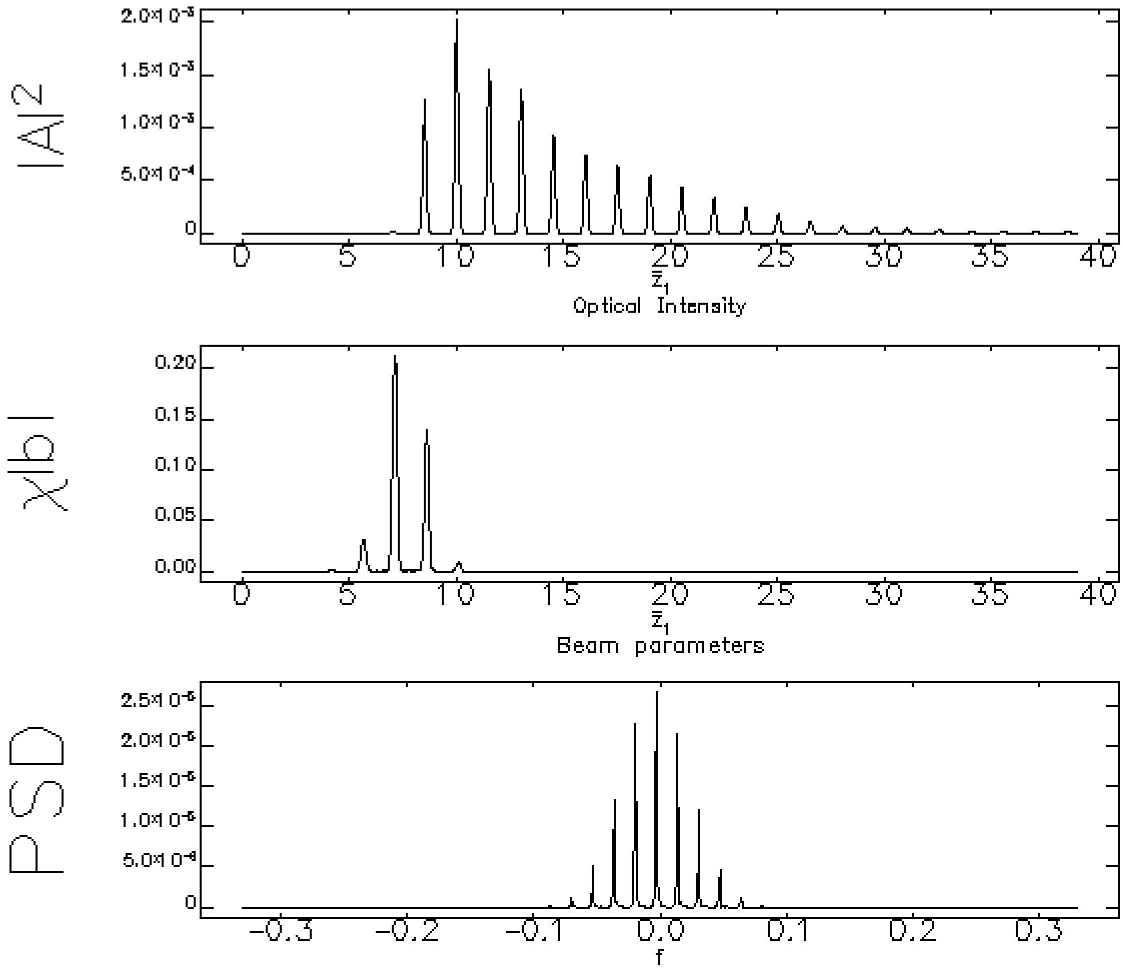
Pass >>1

Module 5



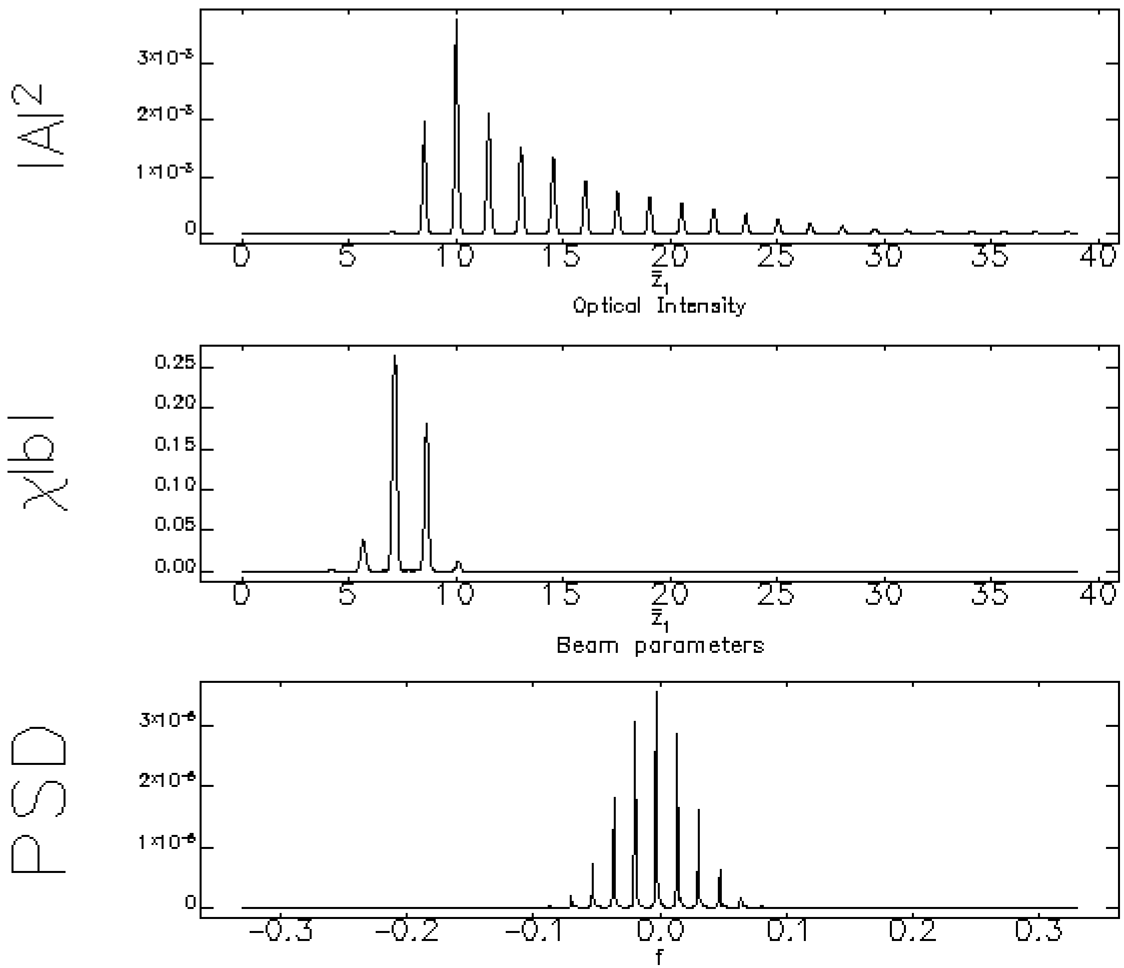
Pass >>1

Module 6



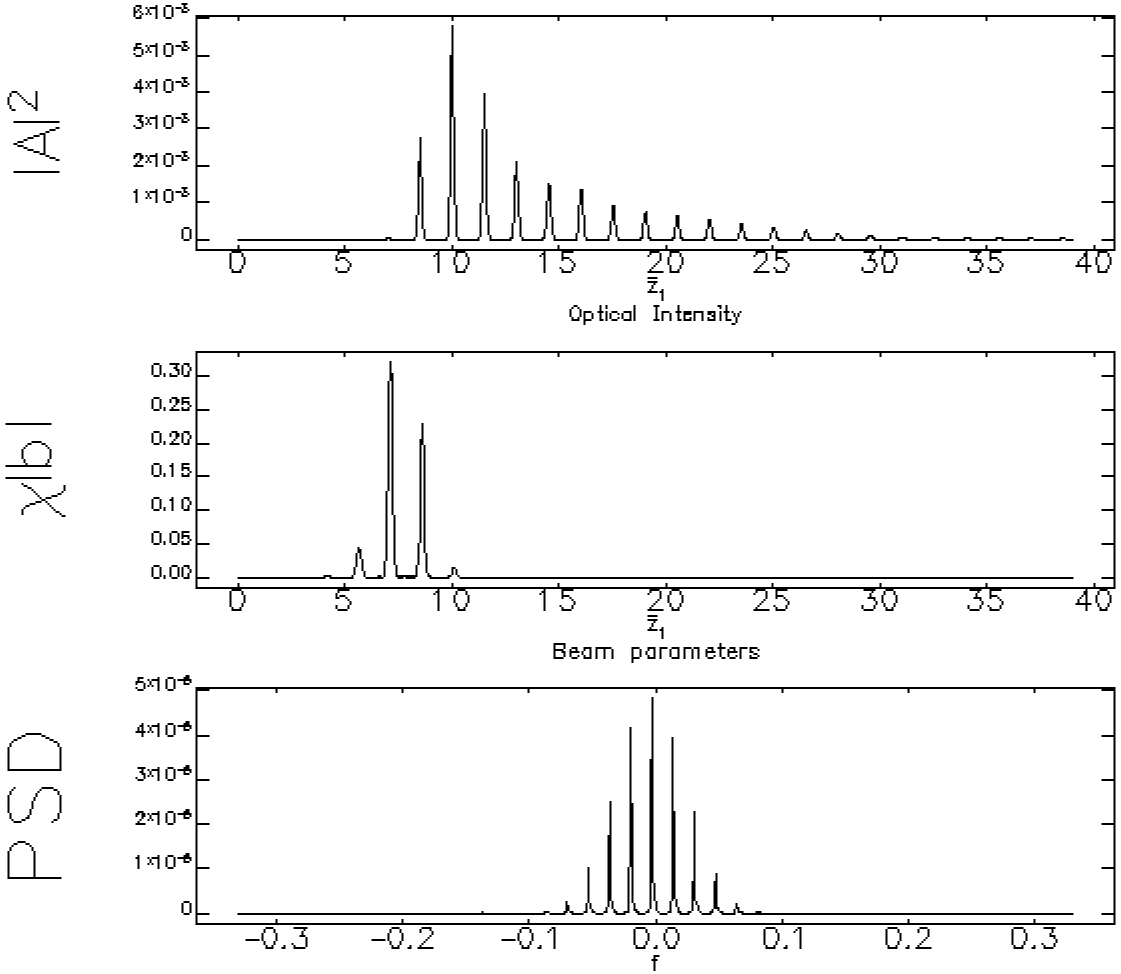
Pass >>1

Module 7



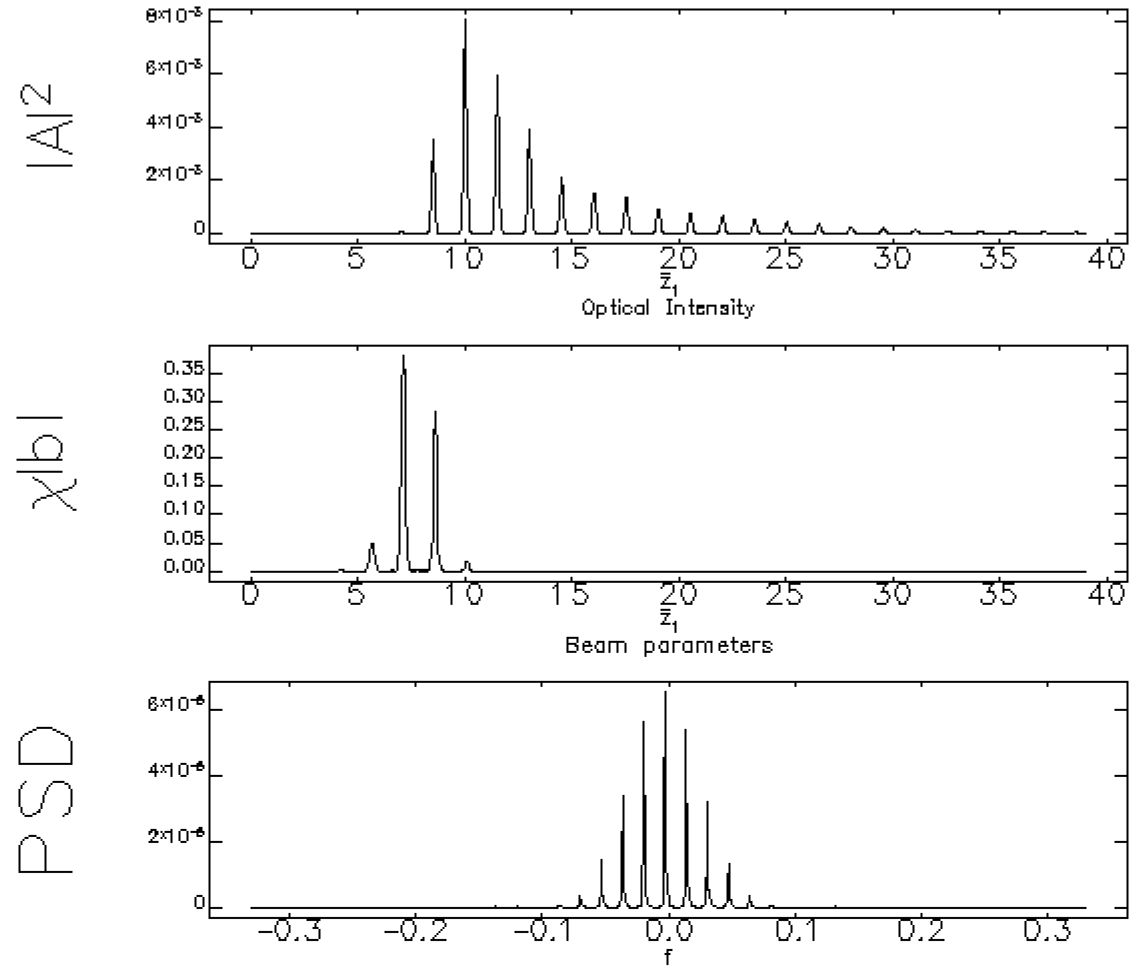
Pass >>1

Module 8



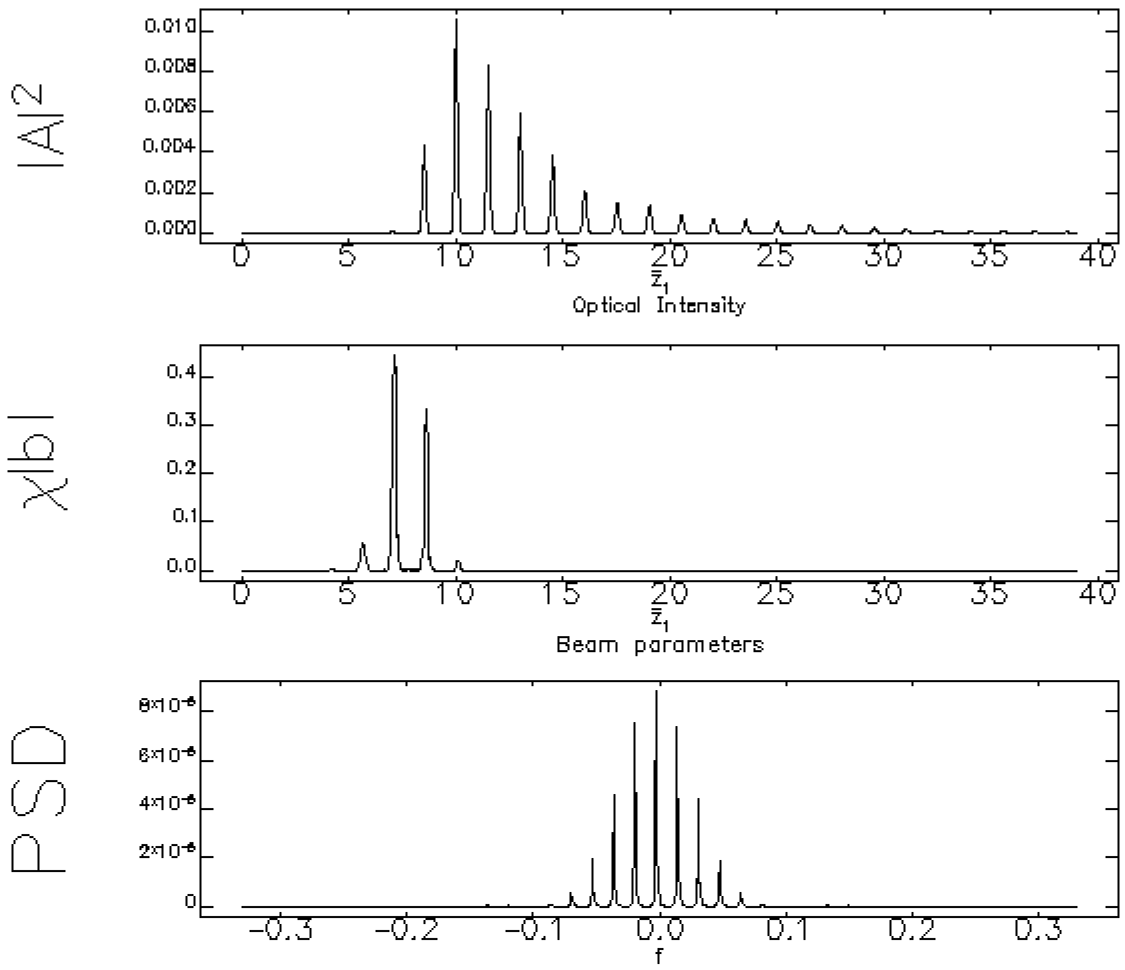
Pass >>1

Module 9



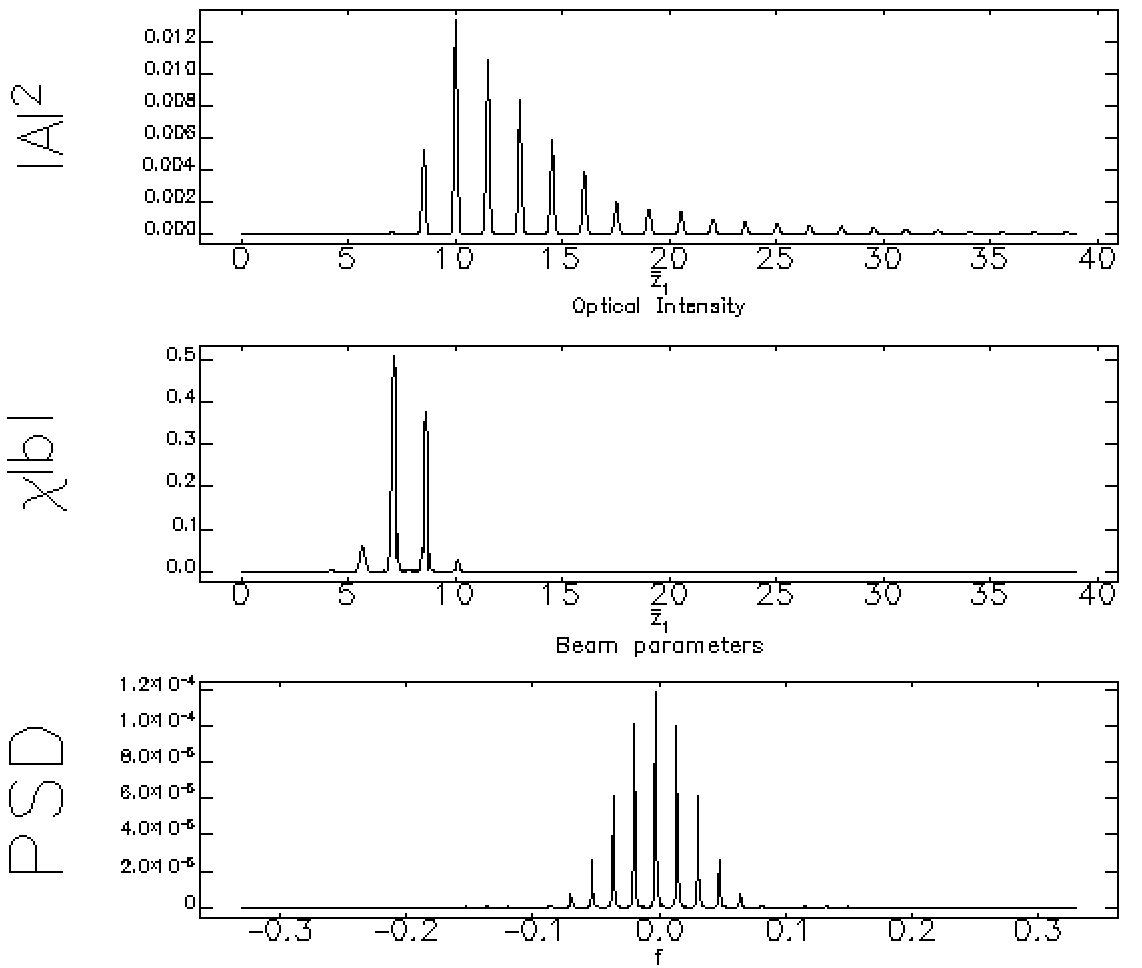
Pass >>1

Module 10



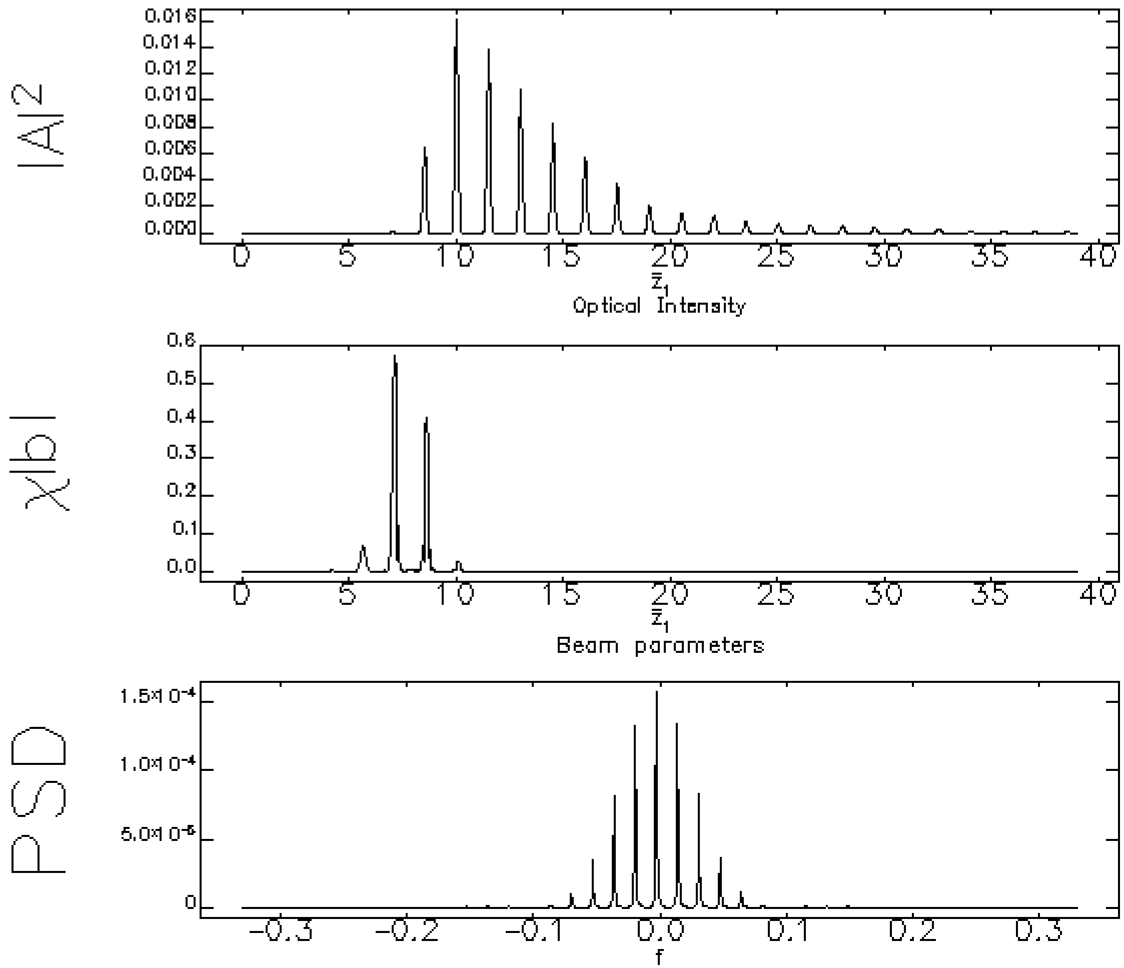
Pass >>1

Module 11



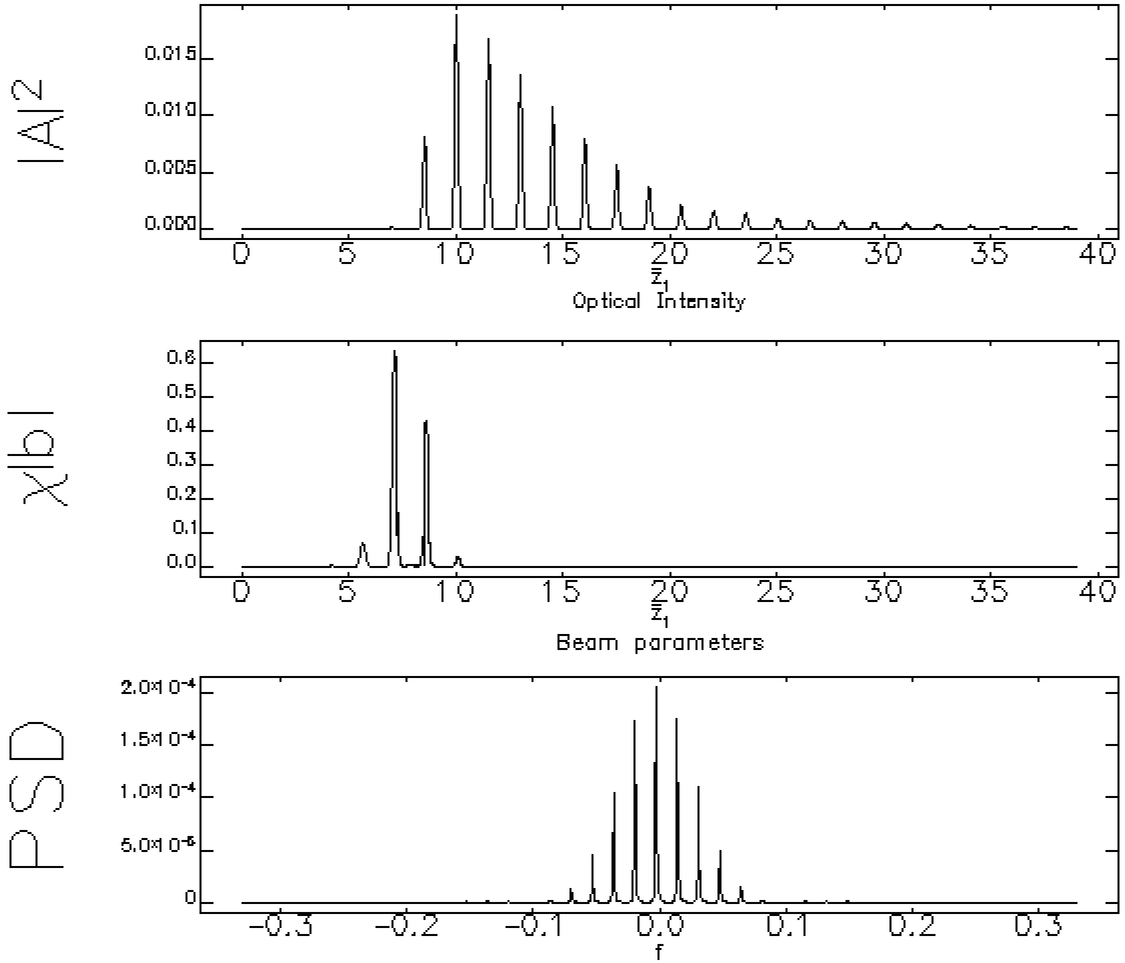
Pass >>1

Module 12



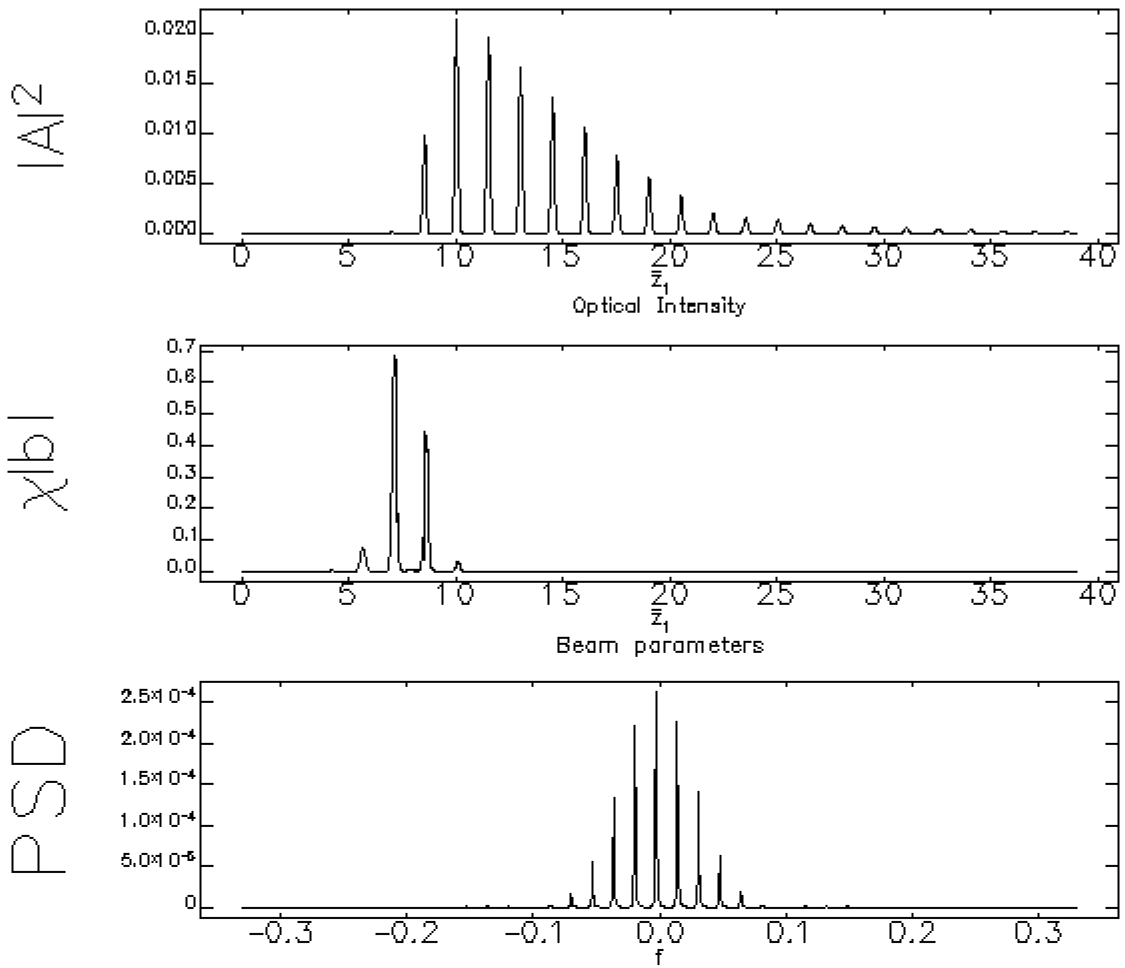
Pass >>1

Module 13



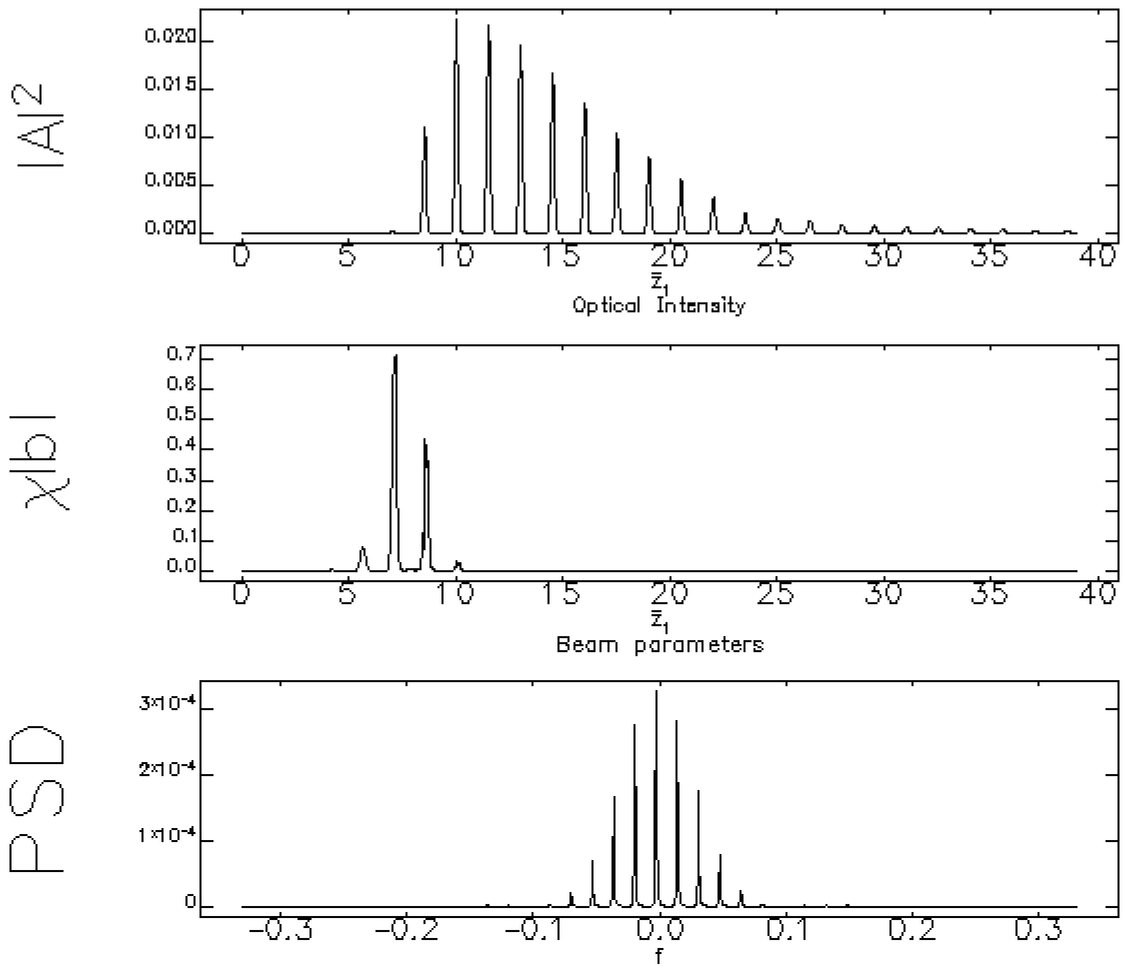
Pass >>1

Module 14



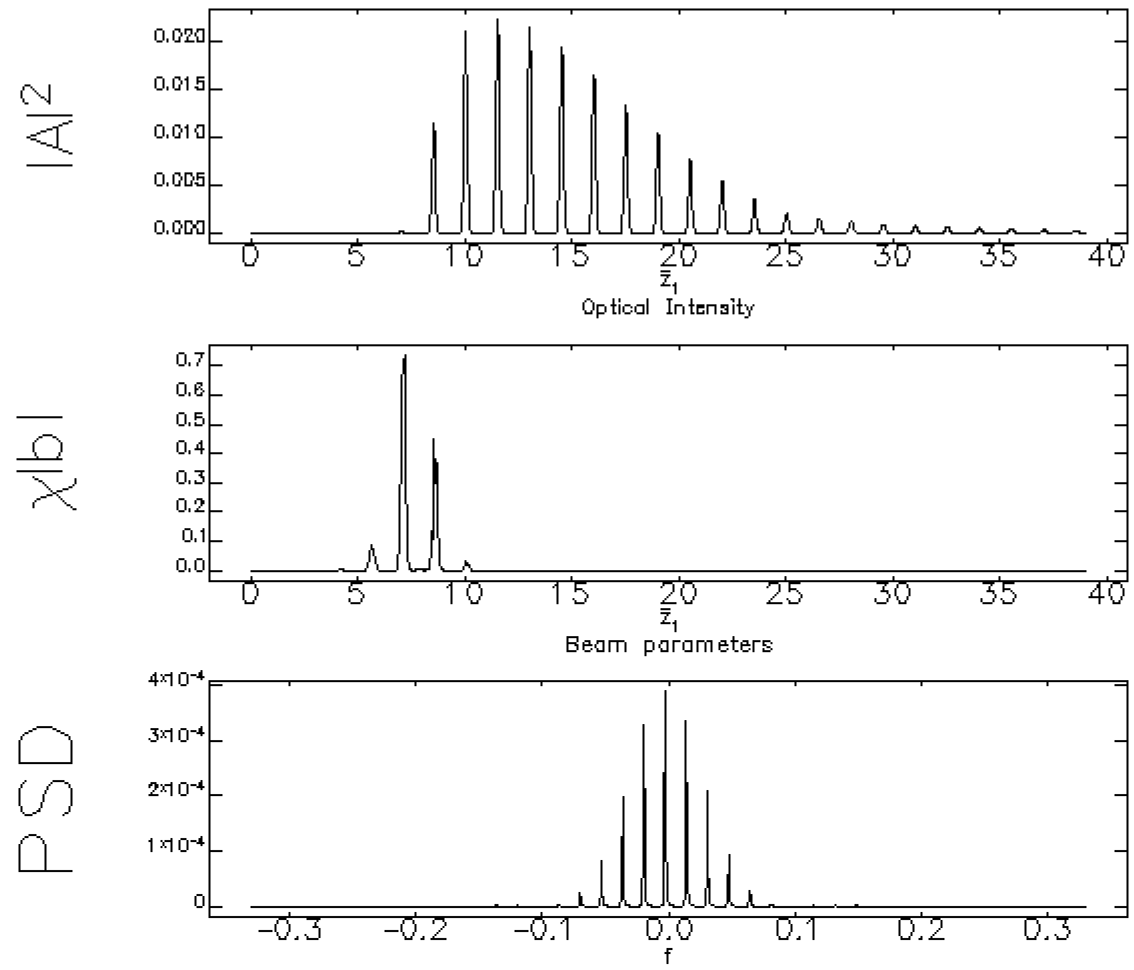
Pass >>1

Module 15



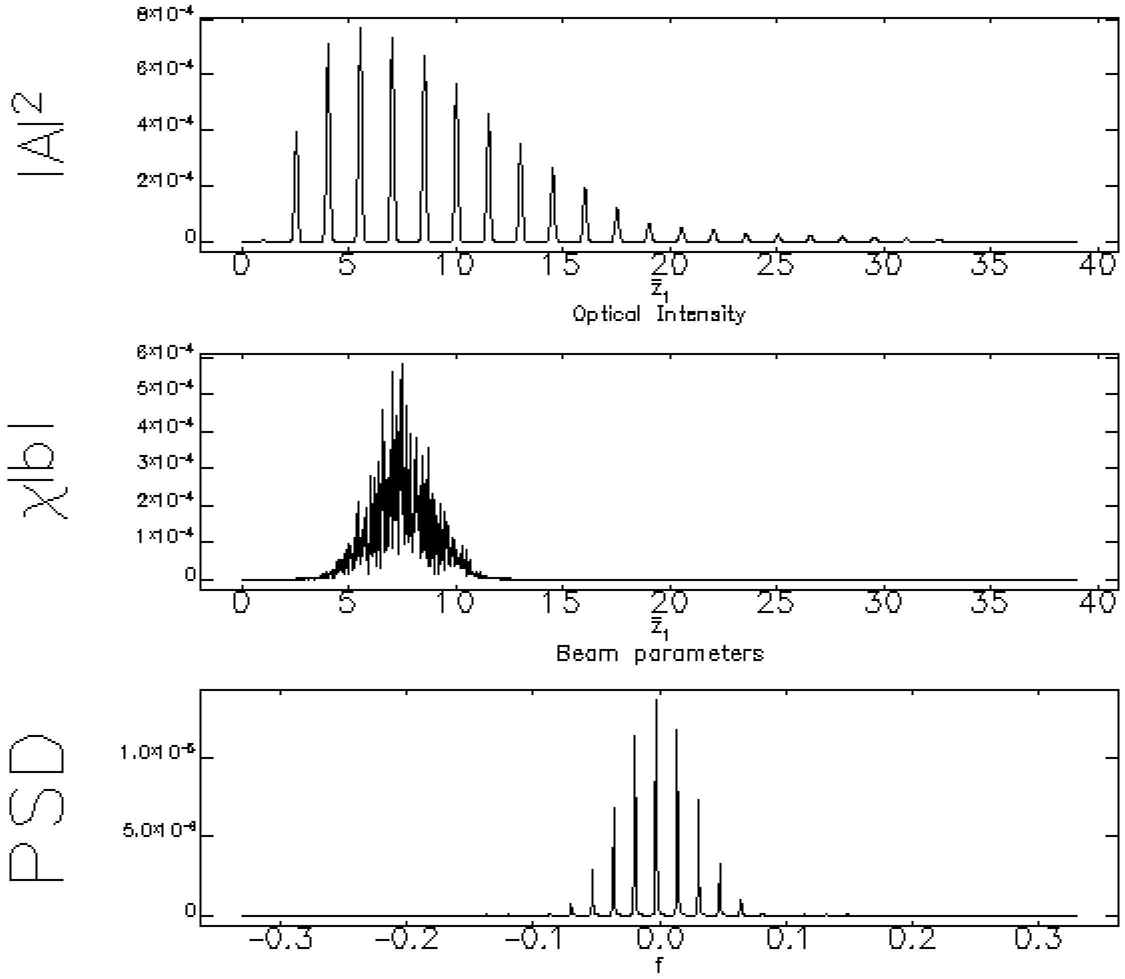
Pass >>1

Module 16



Pass >>1 + 1

Module 0



ALICE IR-FEL

J.A. Clarke et al. - MOPA08

Table 1: Nominal ALICE Electron Beam Parameters

Electron beam energy	35 MeV
Bunch charge	80 pC
Normalised emittance	10 mm-mrad
Bunch length (rms)	0.6 ps
Energy spread (rms)	0.1%

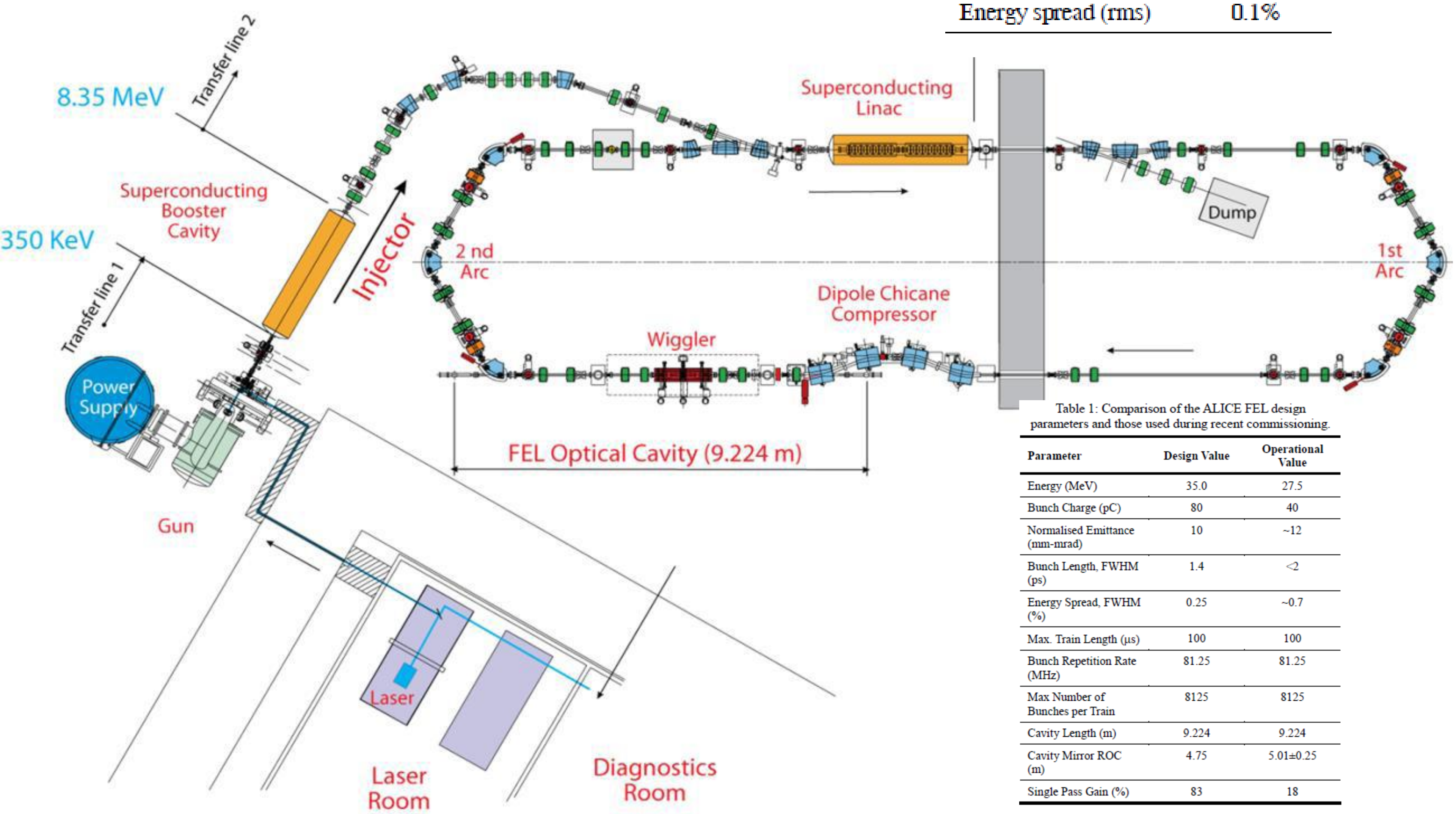


Table 1: Comparison of the ALICE FEL design parameters and those used during recent commissioning.

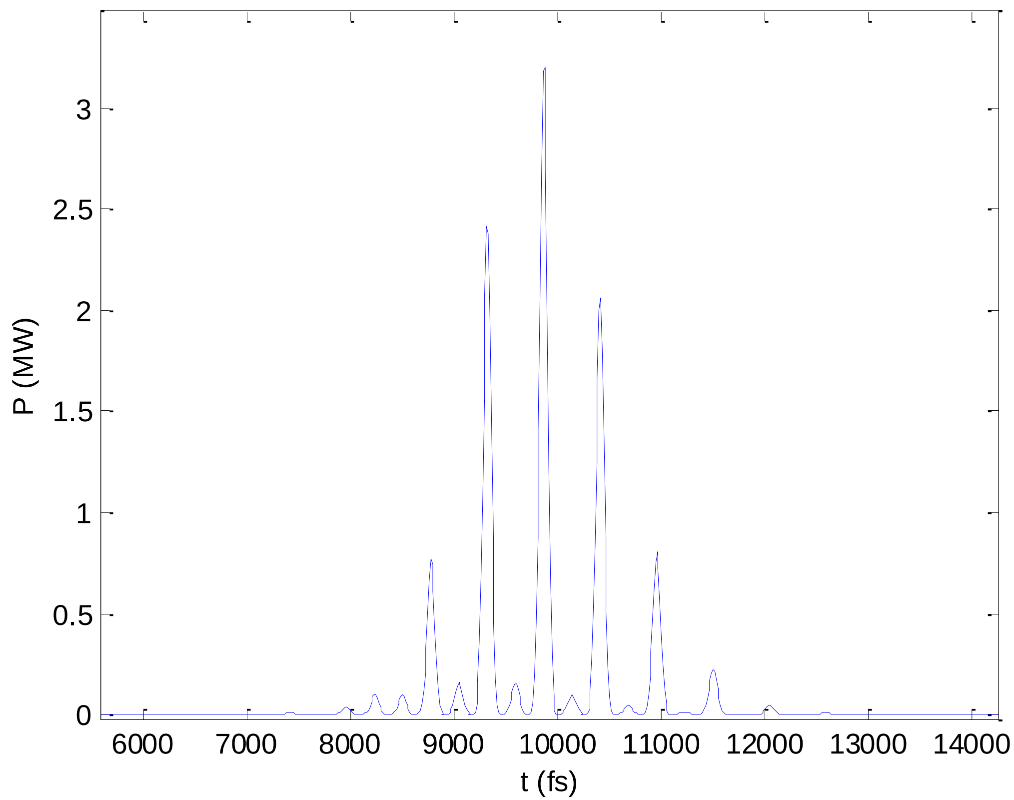
Parameter	Design Value	Operational Value
Energy (MeV)	35.0	27.5
Bunch Charge (pC)	80	40
Normalised Emittance (mm-mrad)	10	~12
Bunch Length, FWHM (ps)	1.4	<2
Energy Spread, FWHM (%)	0.25	~0.7
Max. Train Length (µs)	100	100
Bunch Repetition Rate (MHz)	81.25	81.25
Max Number of Bunches per Train	8125	8125
Cavity Length (m)	9.224	9.224
Cavity Mirror ROC (m)	4.75	5.01±0.25
Single Pass Gain (%)	83	18

ALICE MLOK IR-FEL scaled parameters

Gaussian current electron pulse:	$\sigma_z = 2.37\, l_c$
FEL parameter:	$\rho = 2.3 \times 10^{-3}$
Undulator module length X 10:	$L_u = 0.22\, l_g$
Chicane induced slippage X 10:	$\delta = 0.88\, l_c$
Beam energy modulation amplitude: (can also use current modulation)	$\gamma_{\mathrm{mod}} = \rho\gamma$
Cavity feedback factor:	$F = 0.9$
Cavity detuning:	lengthened by ~$5 \times l_c$

ALICE MLOK IR-FEL – not really optimised yet

- 80pC, 35MeV, 1ps rms electron bunch.
- Resonant at 4.3µm.
- ALICE FEL undulator rebuilt as ten 4-period sections with integrated delay/matching sections between
- 150kV electron beam energy modulation and ~165µm period.
- Gives 3MW 100fs (FWHM) spikes (7-cycle)



Currently investigating if such an experiment is feasible and fundable.

Conclusions

- Simulations of Mode Locked Optical Klystron configuration predict pulse trains/multi-frequency mode output in both amplifier and cavity resonator FELs.
- RAFEL with short electron pulses gives stable, coherent output of ‘single’ attosecond pulses in x-ray – will investigate how low feedback factor can be ($F \lesssim 10^{-5}$?)
- RAFEL in MLOK configuration gives APT output
- Simulations of low gain IR-FEL oscillator in MLOK configuration also predict mode locking.
- Investigating a possible proof-of-principle experiment on the ALICE IR-FEL.

Thank you for listening.