First simulation results on laser pulse jitter and microbunching instability at SPARXINO

M. Boscolo, M. Ferrario, V. Fusco, L. Giannessi, M. Migliorati, L. Palumbo, M. Quattromini, C. Ronsivalle, L. Serafini, B. Spataro, C. Vaccarezza

Outline

- The SPARXINO project
- General layout
- Beam optics and working point
- First simulation results on phase jitter
- First simulation results on microbunching instability effects
- Conclusions

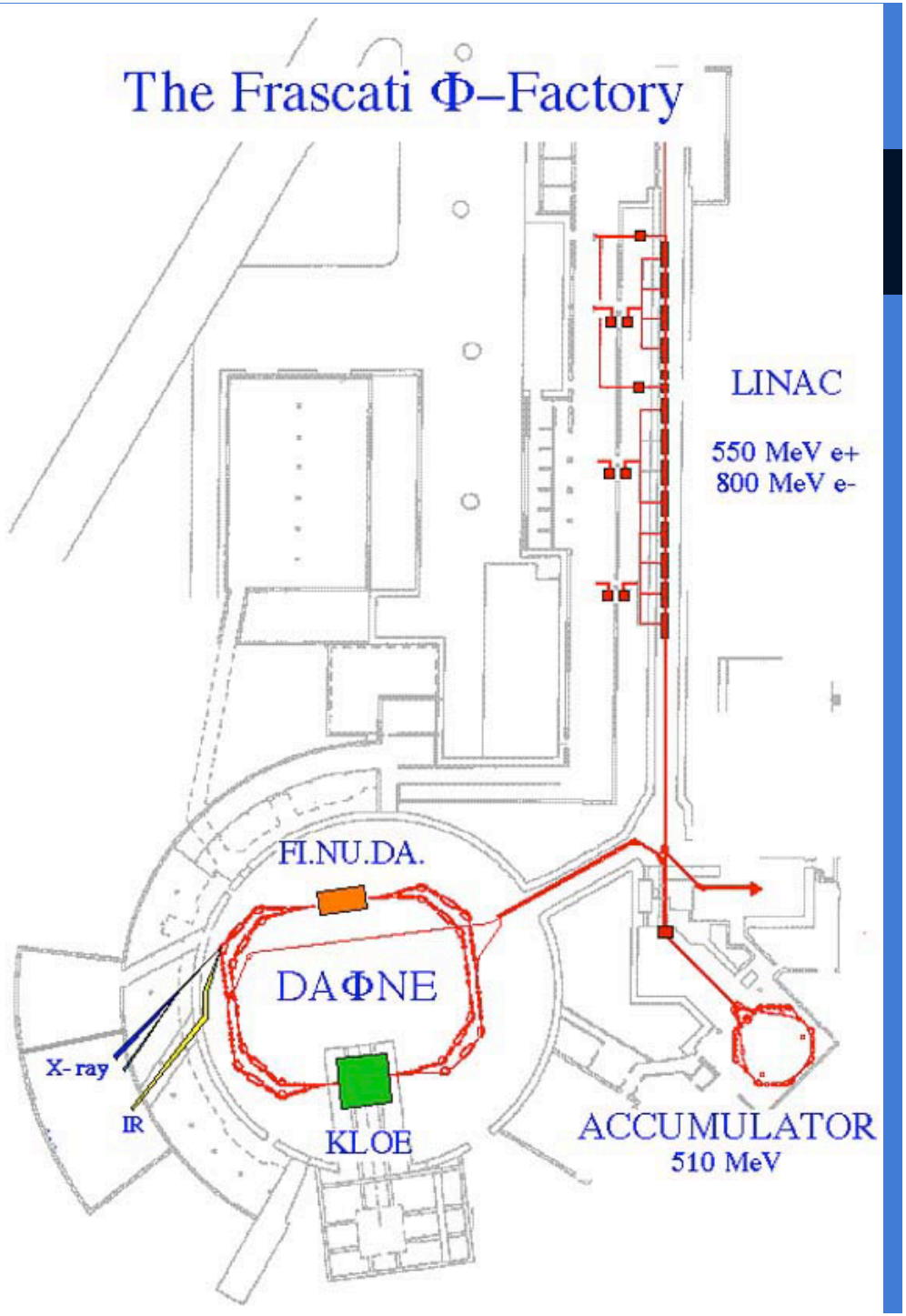
The final decision of the Research Ministry :

SPARX

An R&D program for a (3-10 nm) X-ray FEL test facility

SPARX-*ino* proposal:

- upgrade the DAFNE Linac to drive a 3-10 nm SASE-FEL
- beam energy : 1.2 - 1.5 GeV
- upgrade the injector to a RF photo-injector (SPARC-like)
- Study group is preparing a proposal within 2005



The SPARC project (approved and funded in 2002)

The SPARC project has been proposed by:

Consiglio Nazionale delle Ricerche

ENEA Ente per le Nuove tecnologie, l'Energia e l'Ambiente

INFN Istituto Nazionale di Fisica Nucleare

ULTRAS INFM National Laboratory for Ultrafast and Ultraintense Optical Science

and it is being developed with the collaboration of:

Universita degli Studi di Roma Tor Vergata UTS FIS - Dip. di Fisica

La Sapienza Università degli Studi di Roma

elettra Synchrotron Light Laboratory

Stanford Linear Accelerator Center

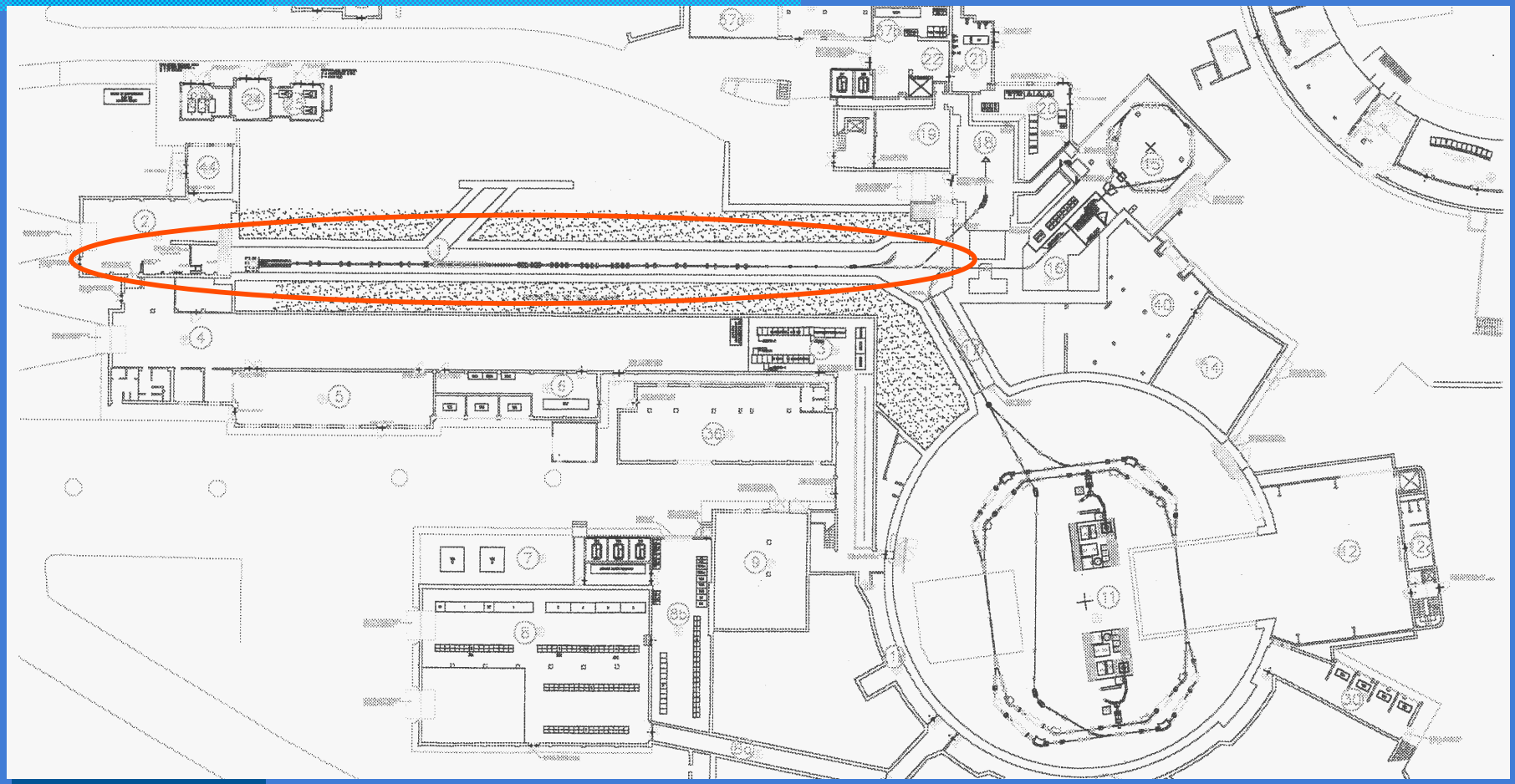
UCLA

- R&D program towards:
- high brightness 150 MeV electron beam,
- a SASE-FEL experiment
- Ultrashort X-ray generation
- X-ray optics & diagnostics

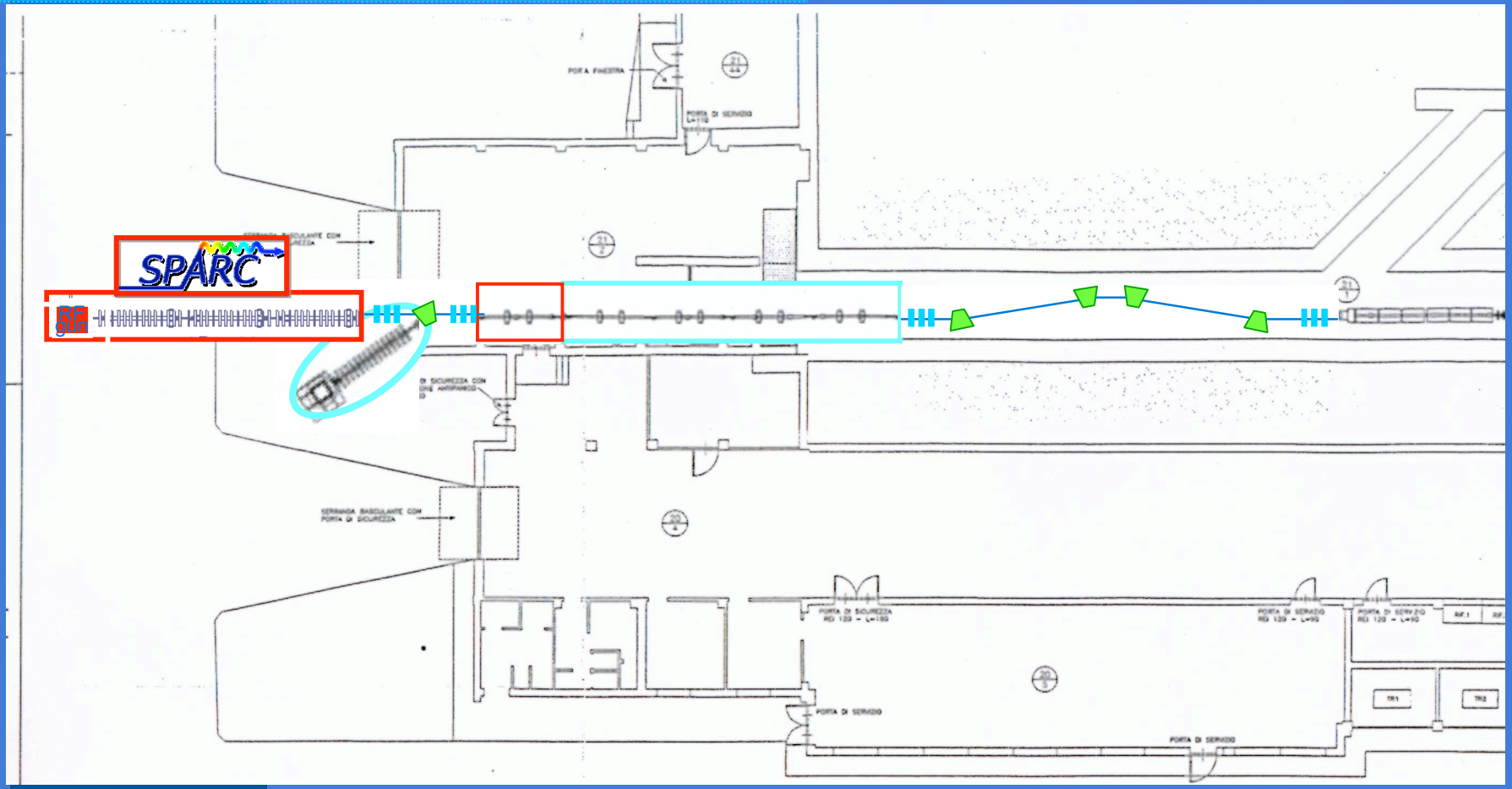
FOR MORE INFO...

http://www.lnf.infn.it/acceleratori/sparc/

The DAΦNE complex



Linac1: Low Energy section

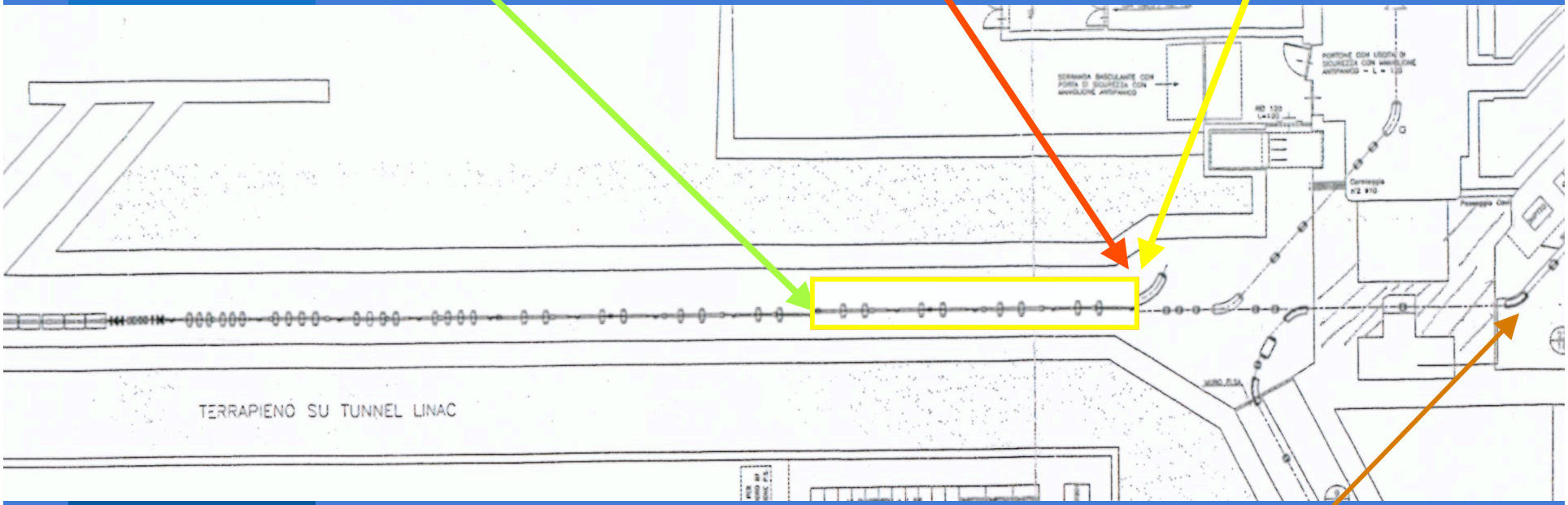


Linac2: High energy section

Now : E_{tot} ~ 1.2 GeV

E_{tot} ~ w 4 S-band :

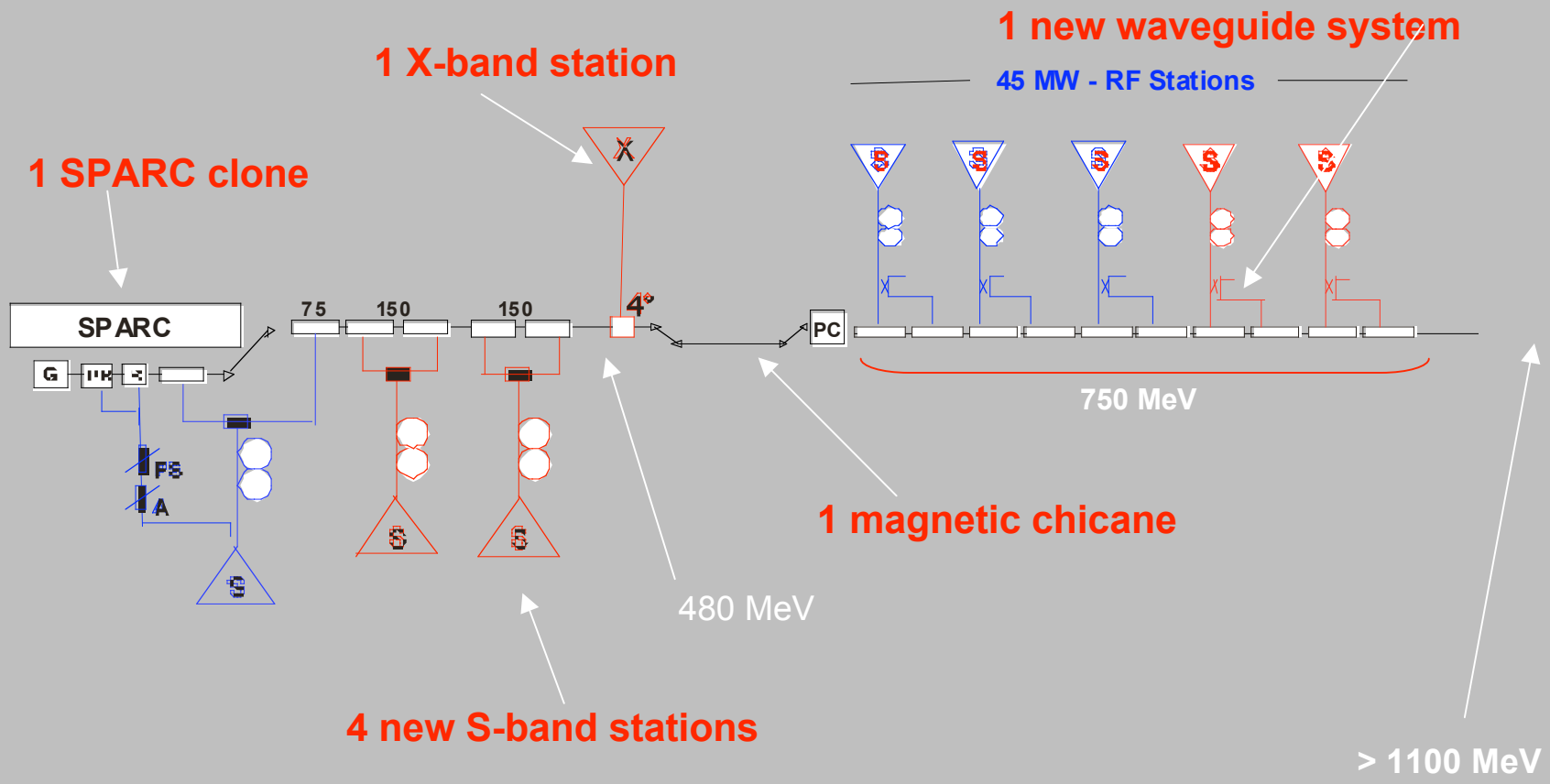
E_{tot} ~ w 4 X-band 2 GeV e^-



dogleg start

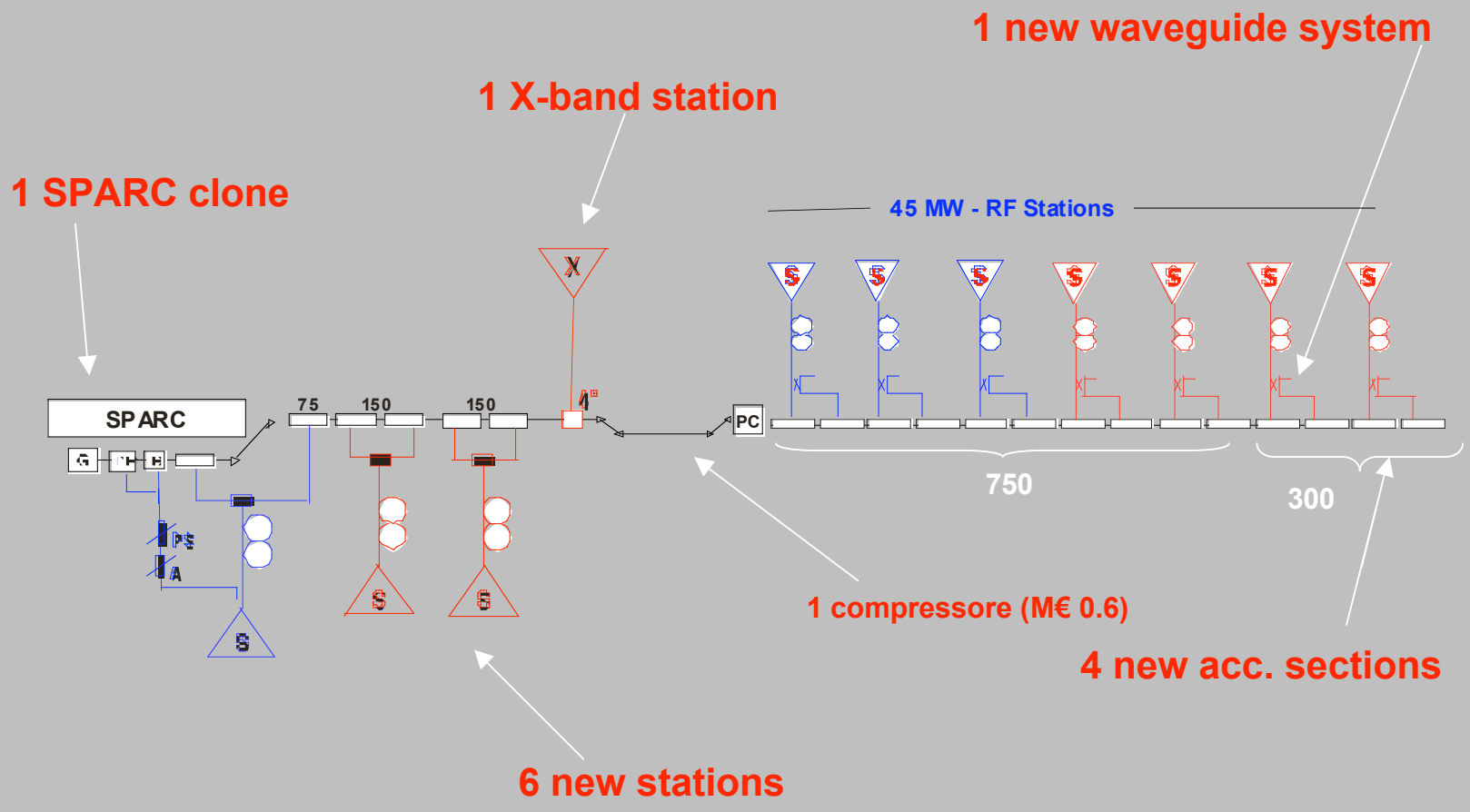
Schematic Linac upgrade

SPARXino – 1.2 GeV S-Band

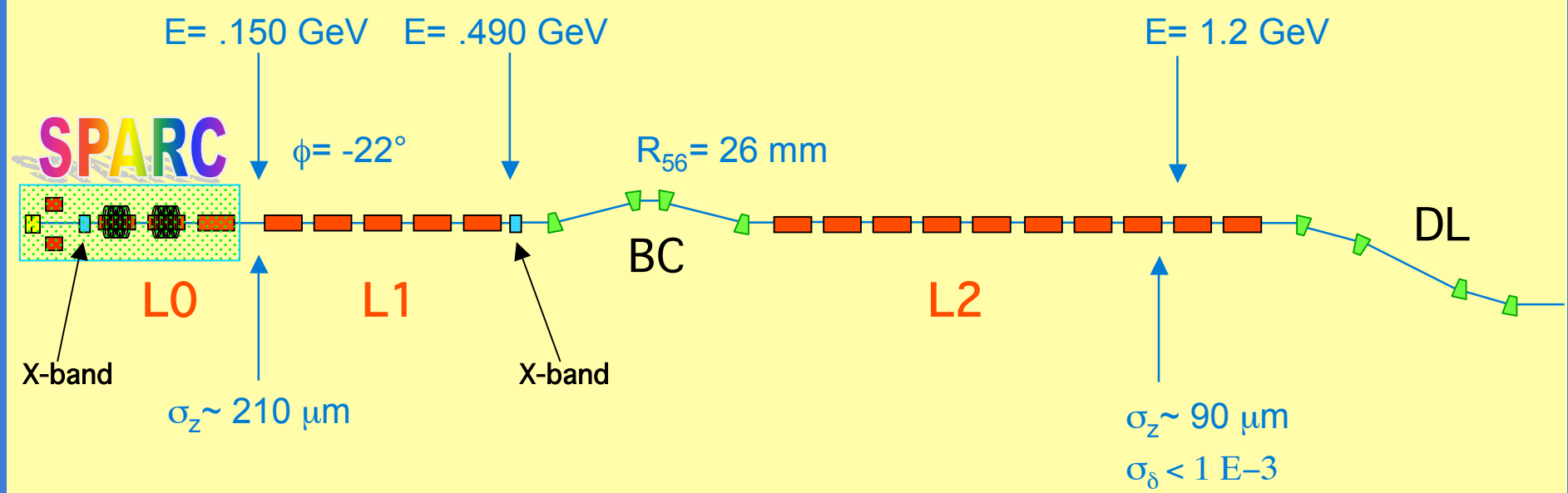


Schematic Linac upgrade

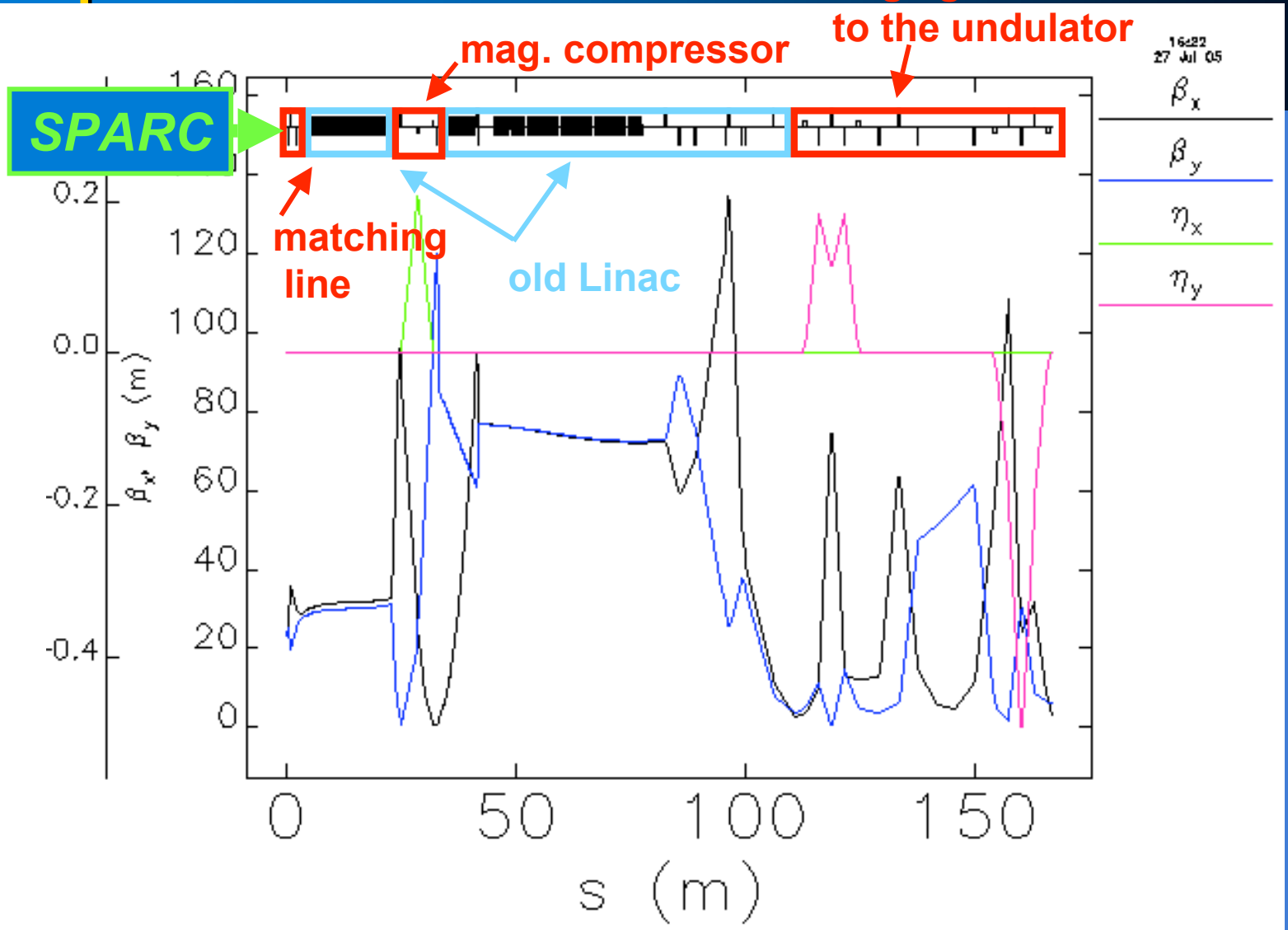
SPARXino – 1.5 GeV S-Band



Schematic layout (1.2 GeV)



Beam optics


dogleg
to the undulator
mag. compressor
SPARC
matching
line
old Linac
16:22
27 Jul 05
β_x
β_y
η_x
η_y
β_x, β_y (m)
0.2
0.0
-0.2
-0.4
160
120
100
80
60
40
20
0
0
50
100
150
s (m)

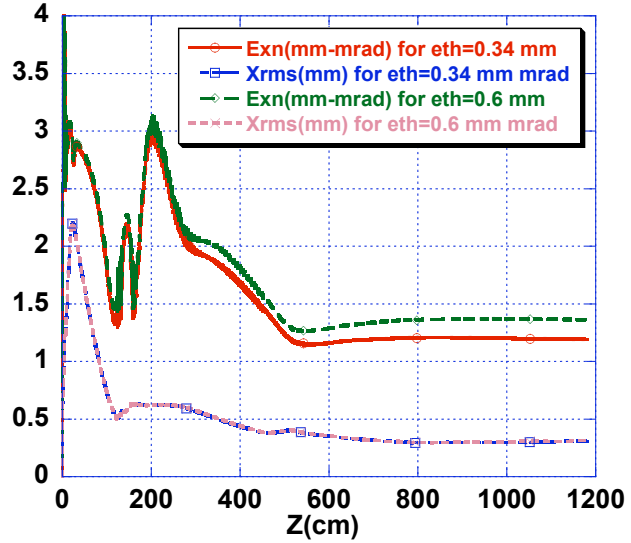
Two possible working
a) $I_{pk\ av}$ 450A w X-ban

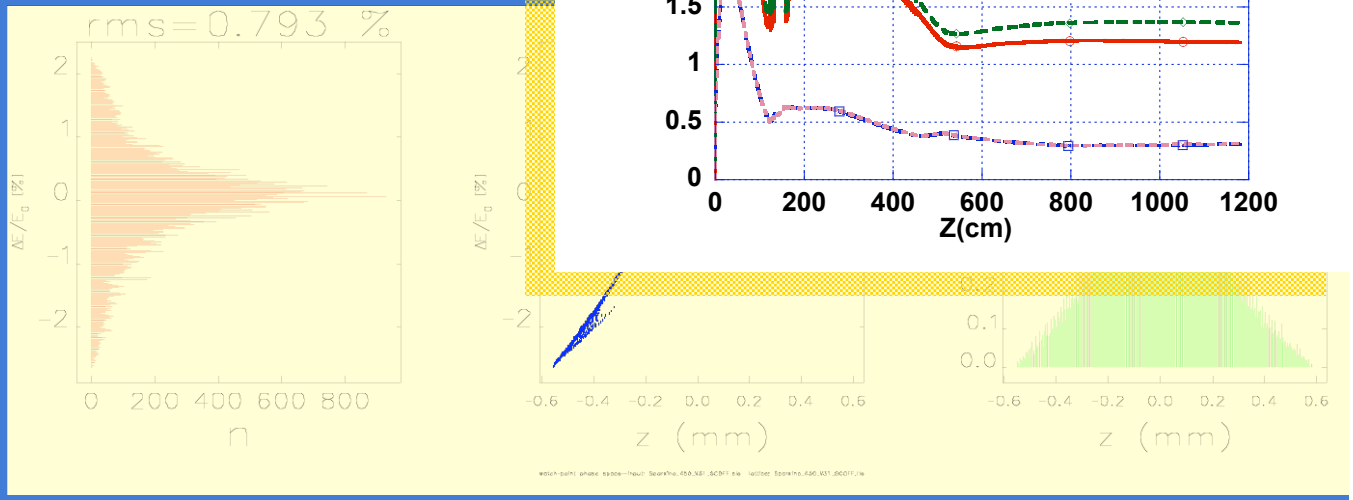
photoinjector exit $I_{pk\text{-}av} \approx$ 450A

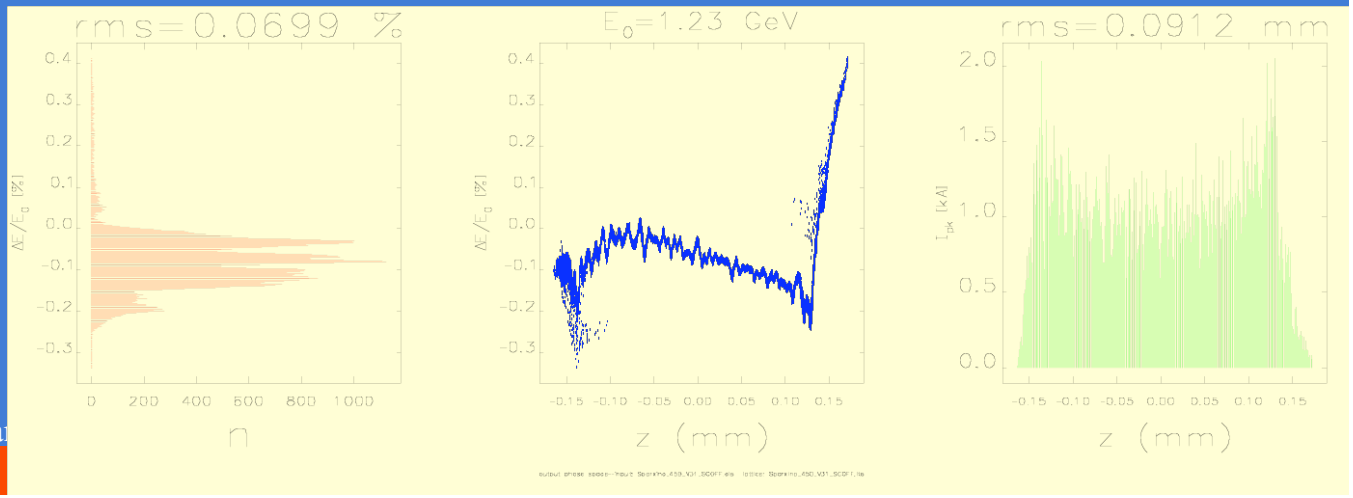
final beam

$I_{pk\text{-}av} \approx$ 1.1 kA

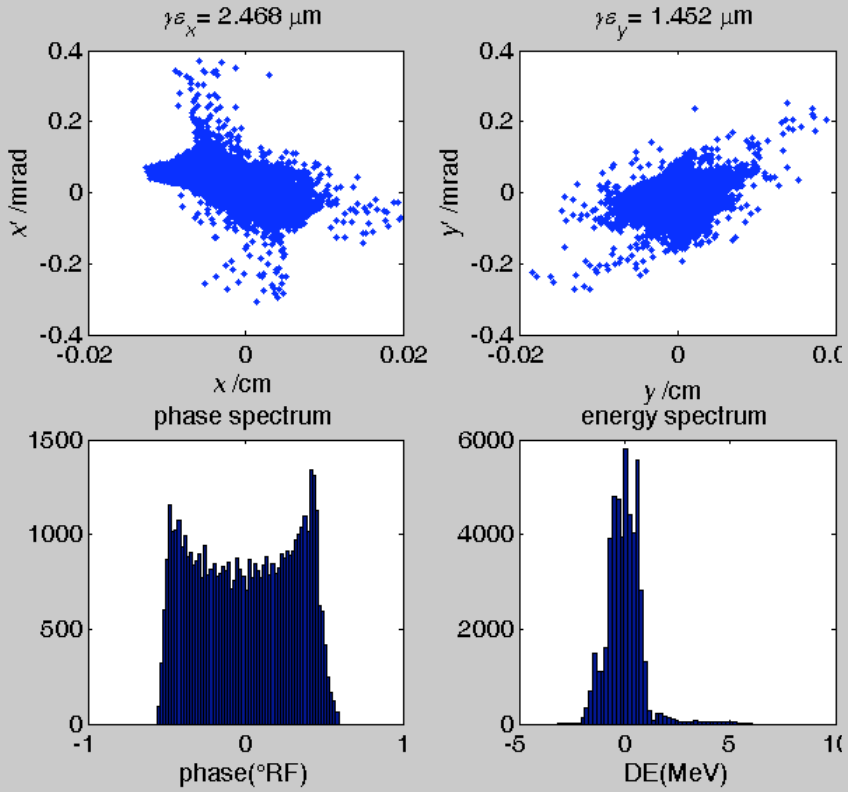
Parmela simulation Np=50k

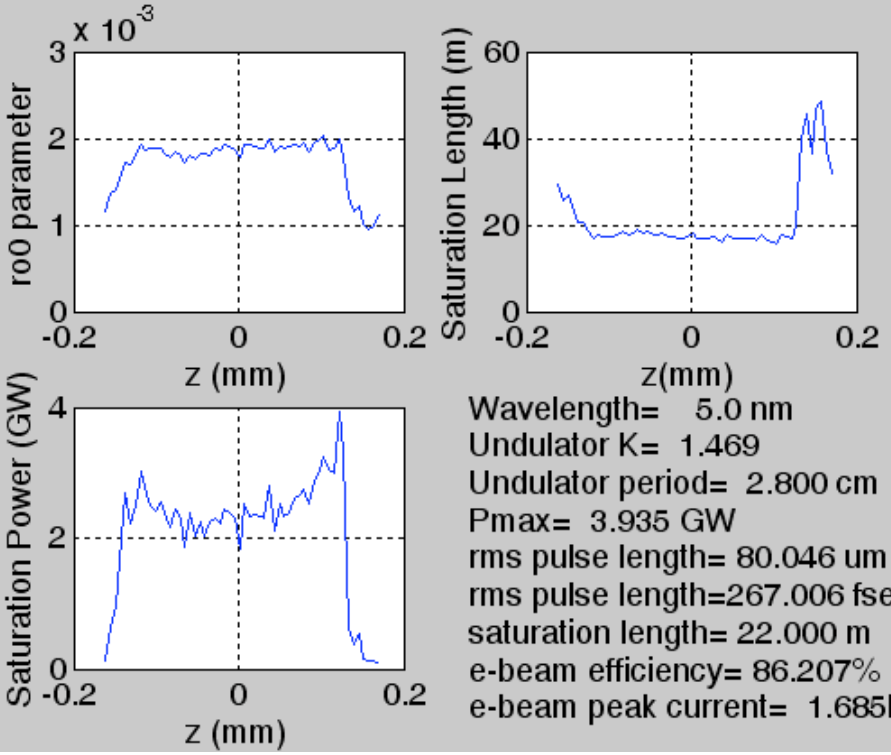






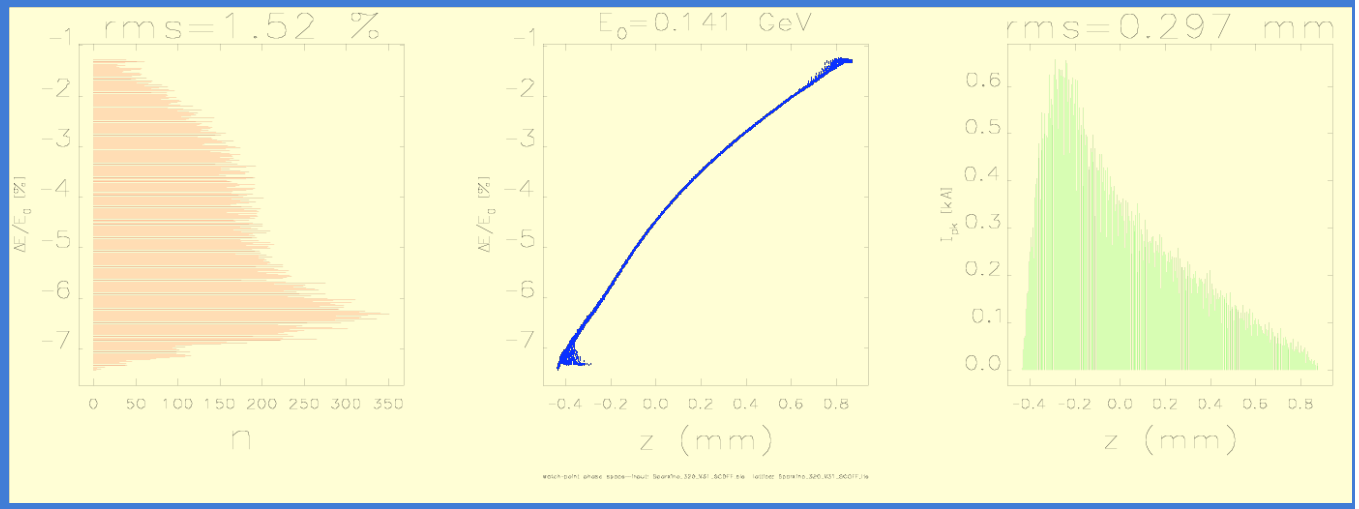
a) $I_{pk\text{-}av}$ 450 A w Xband at gun





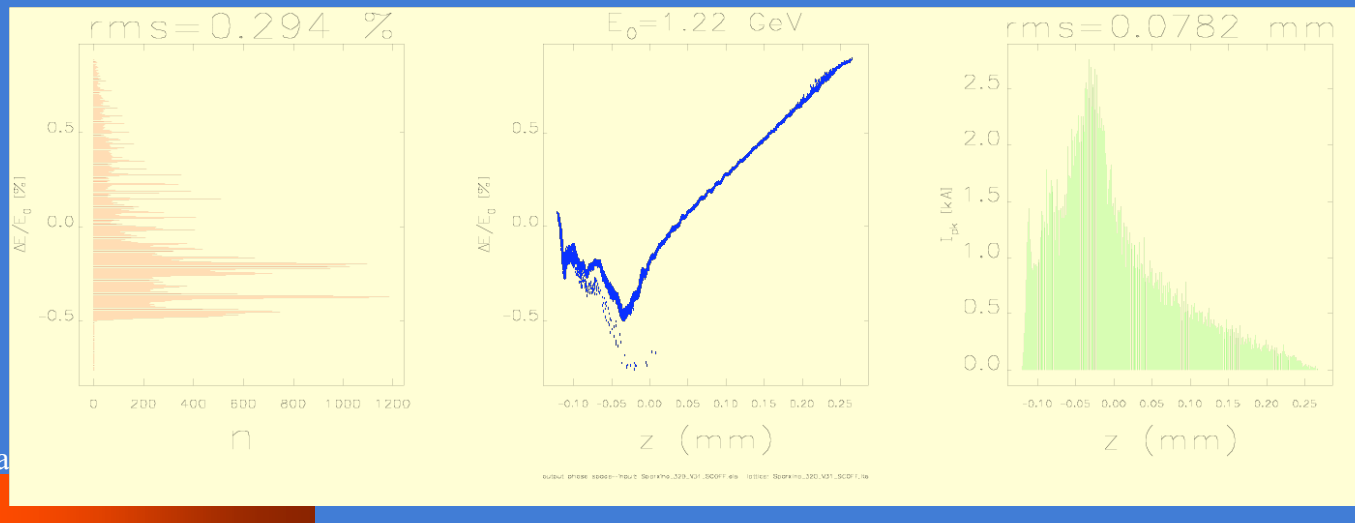
Two possible working points:
b) $I_{pk\ av}$ 300A no X-band at gun exit

photoinjector exit $I_{pk\text{-}av} \approx$ 300A

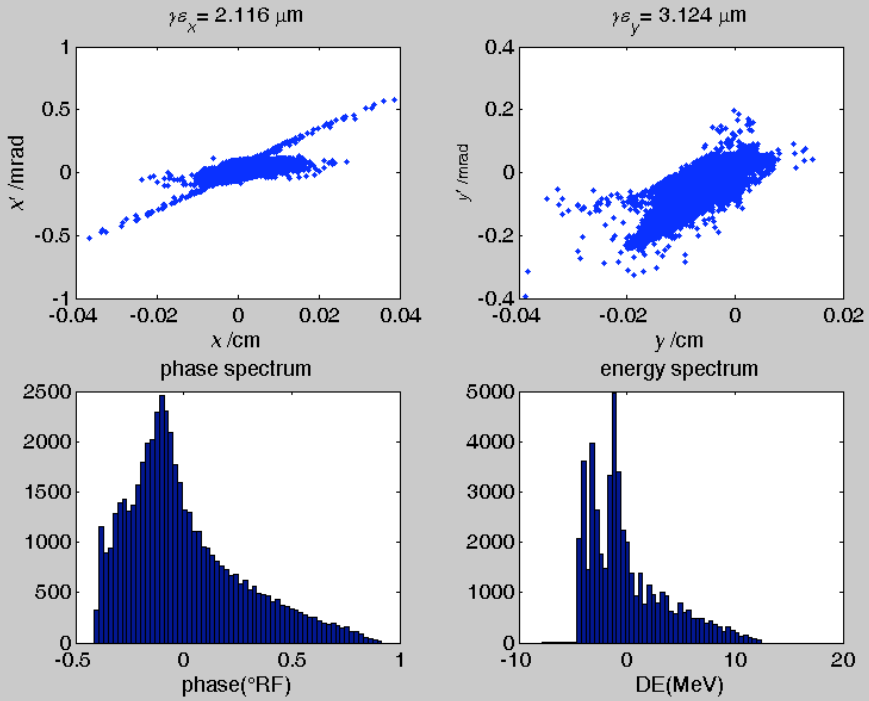


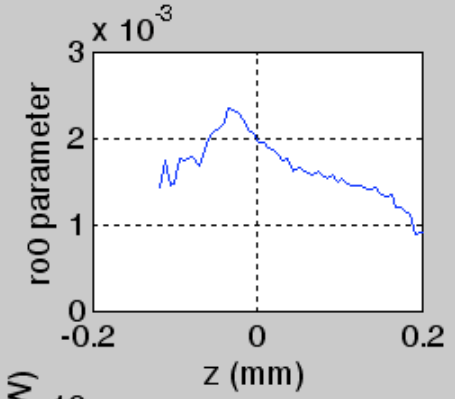
final beam

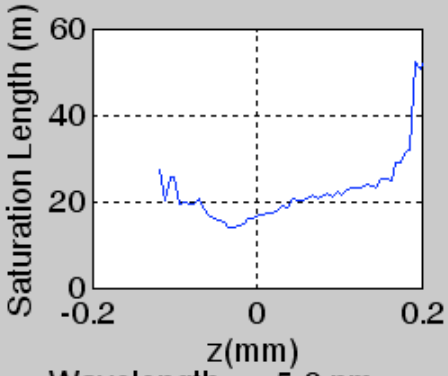
$I_{pk\text{-}av} \approx$ 1.4 kA

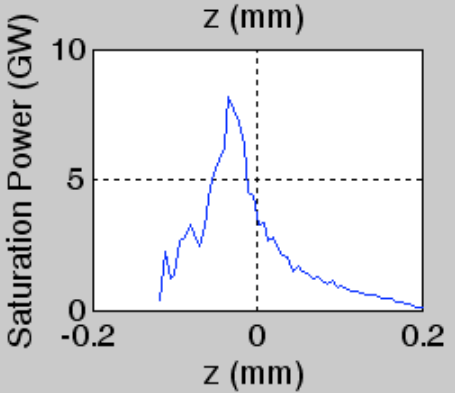


b) $I_{pk\text{-}av}$ 300 A no Xband at gun





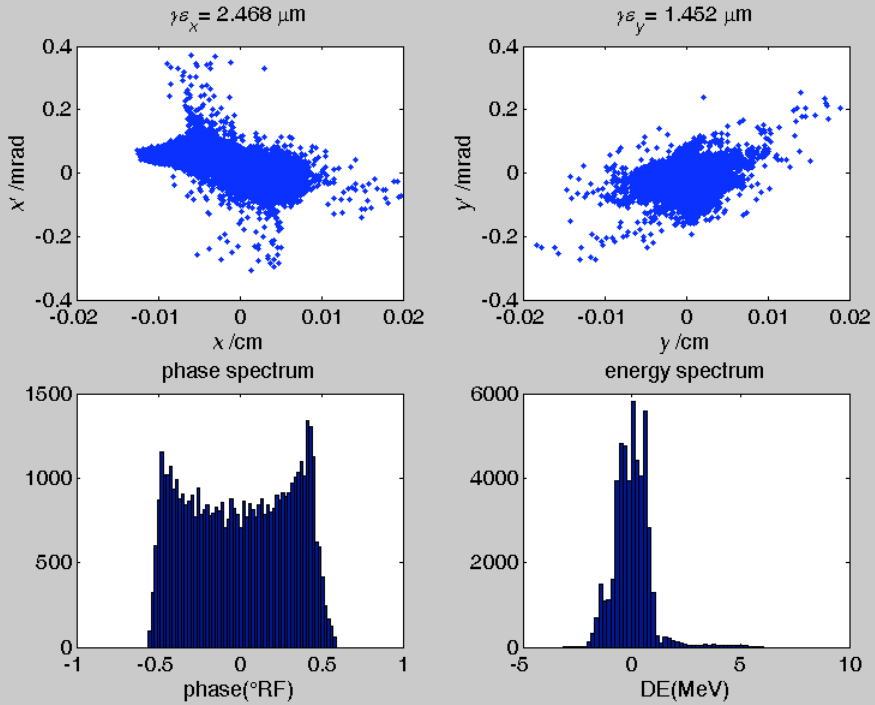




Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 8.147 GW
rms pulse length= 49.434 um
rms pulse length=164.894 fsec
saturation length= 22.000 m
e-beam efficiency= 84.666%
e-beam peak current= 2.584kA

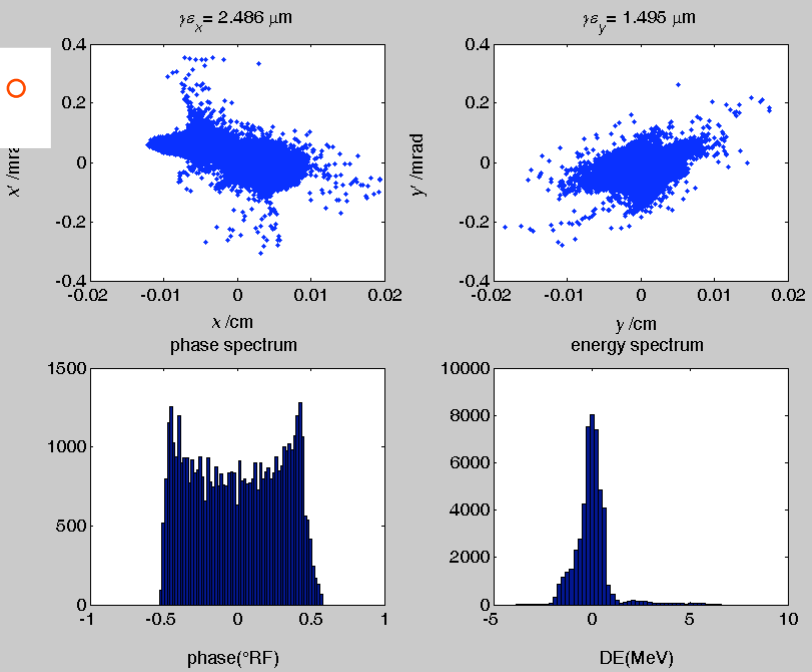
Laser pulse jitter

$I_{pk\text{-}av}$ ~450 A

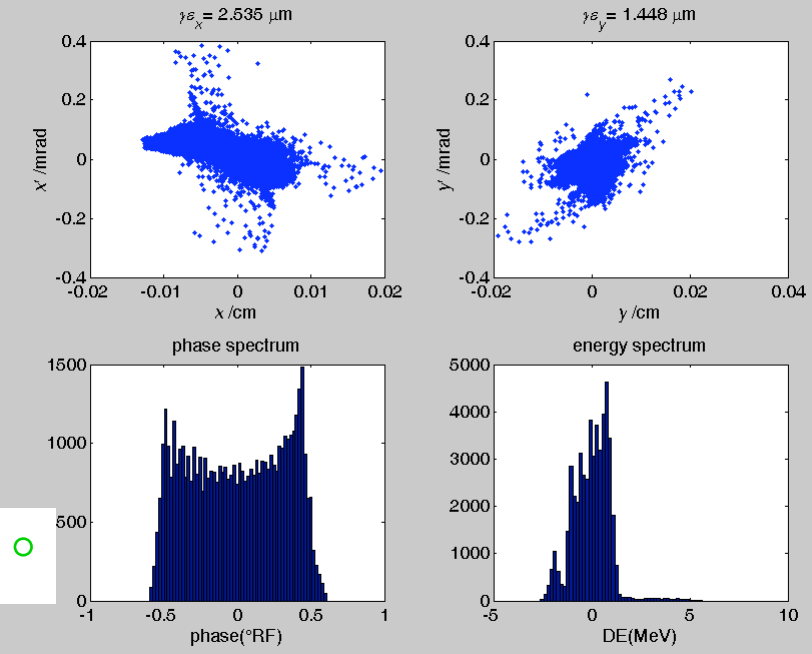


reference

Δϕ= -1°



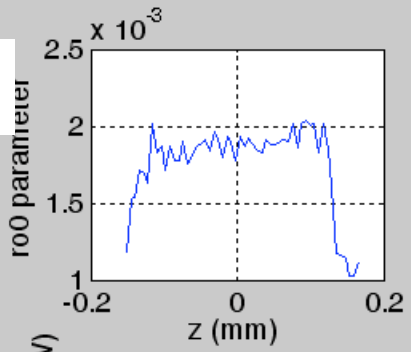
Δϕ= +1°

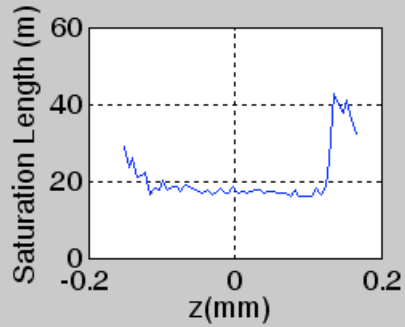


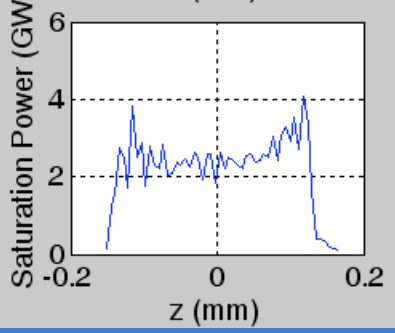
Laser pulse jitter

$I_{pk\text{-}av}$ ~450 A

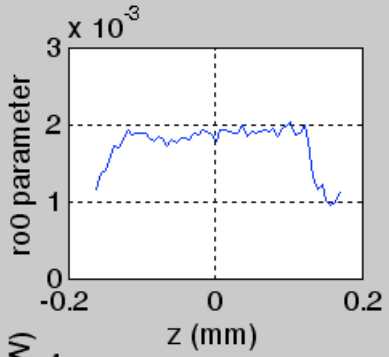
$\Delta\phi$= -1°

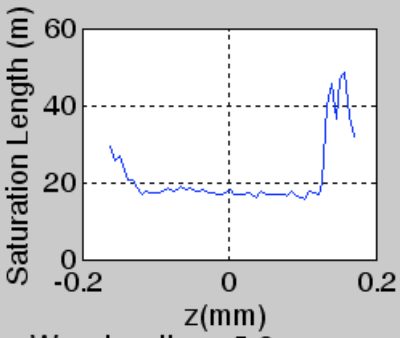


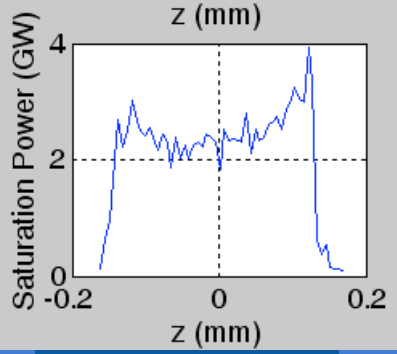




Wavelength= 5.0 nm
Undulator K= 1.469
Undulator period= 2.800 cm
Pmax= 4.059 GW
rms pulse length= 75.024 um
rms pulse length=250.253 fsec
saturation length= 22.000 m
e-beam efficiency= 82.248%
e-beam peak current= 1.595kA

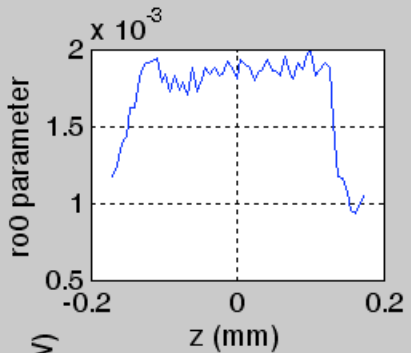


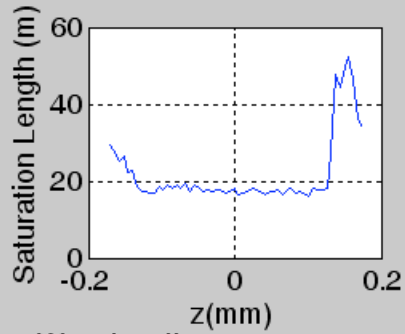


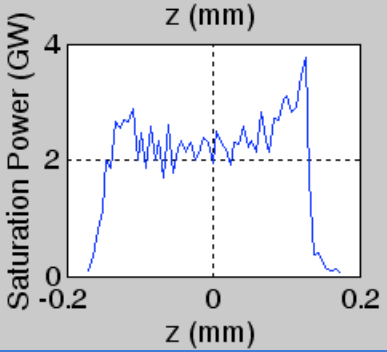


Wavelength= 5.0 nm
Undulator K= 1.469
Undulator period= 2.800 cm
Pmax= 3.935 GW
rms pulse length= 80.046 um
rms pulse length=267.006 fsec
saturation length= 22.000 m
e-beam efficiency= 86.207%
e-beam peak current= 1.685kA

reference





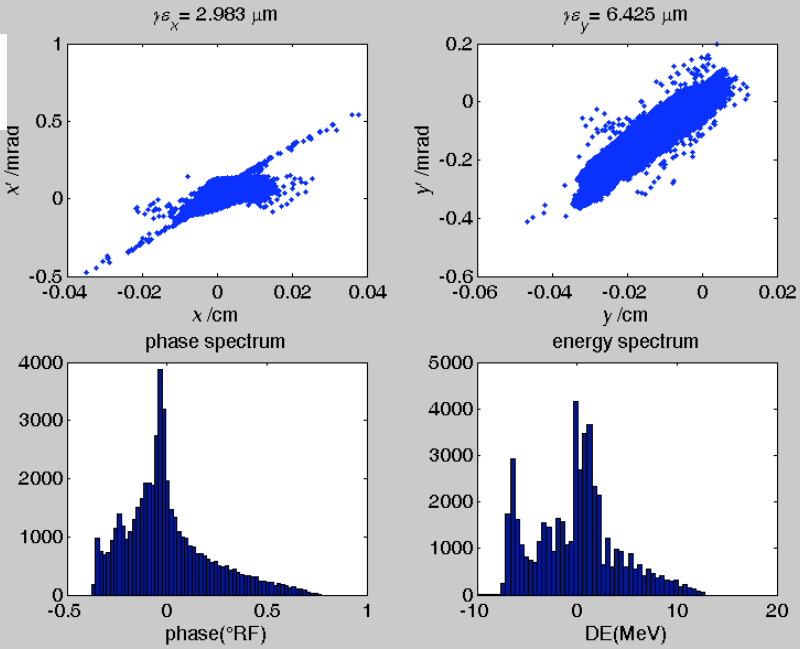


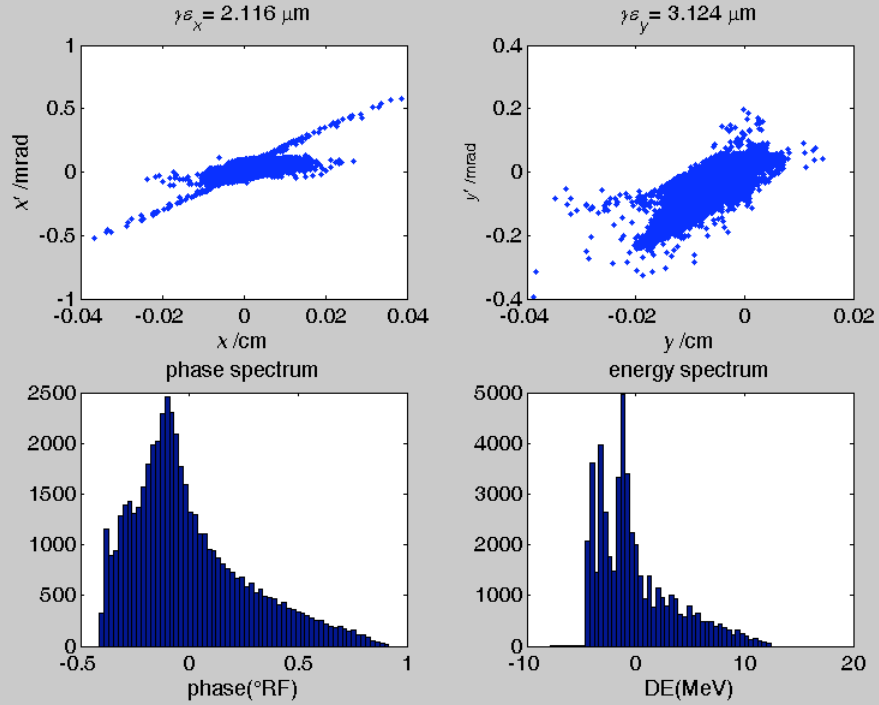
Wavelength= 5.0 nm
Undulator K= 1.469
Undulator period= 2.800 cm
Pmax= 3.761 GW
rms pulse length= 78.089 um
rms pulse length=260.476 fsec
saturation length= 22.000 m
e-beam efficiency= 81.460%
e-beam peak current= 1.668kA

$\Delta\phi$= +1°

Laser pulse jitter
$I_{pk\text{-}av}$ ~300 A

$\Delta\phi$= -1°





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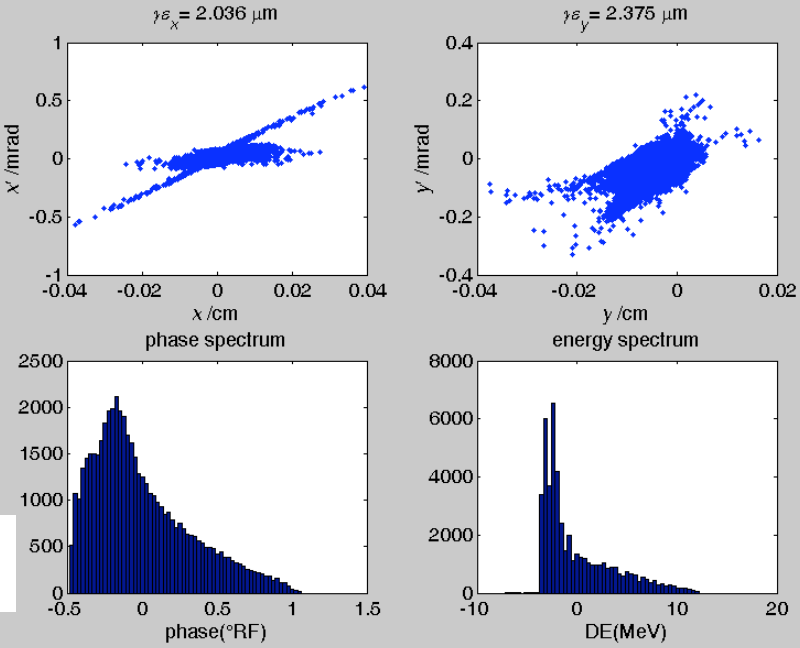
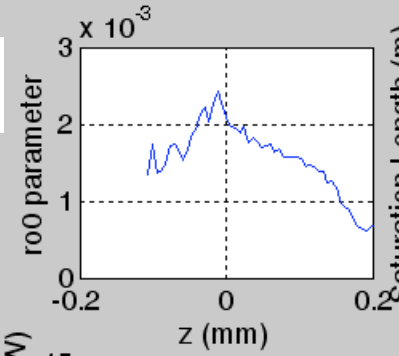


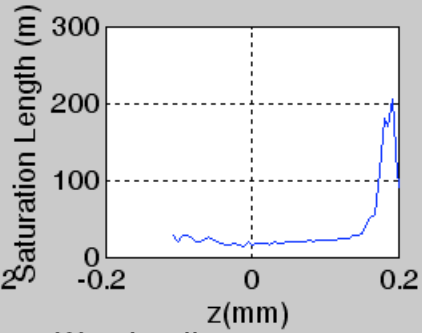
$\Delta\phi$= +1°

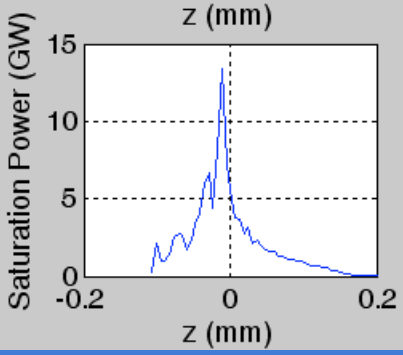
Laser pulse jitter

$I_{pk\text{-}av}$ ~300 A

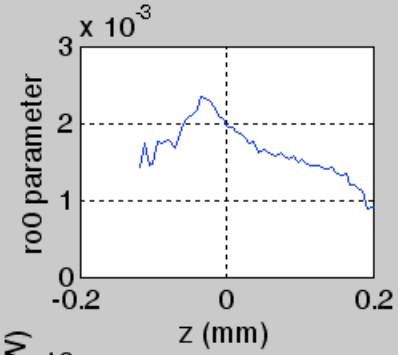
$\Delta\phi$= -1°

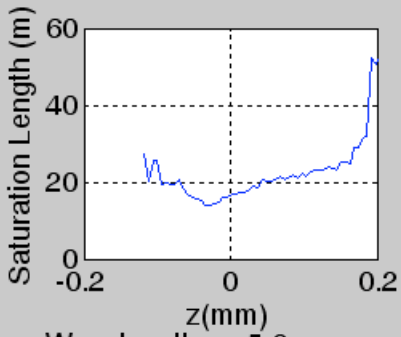


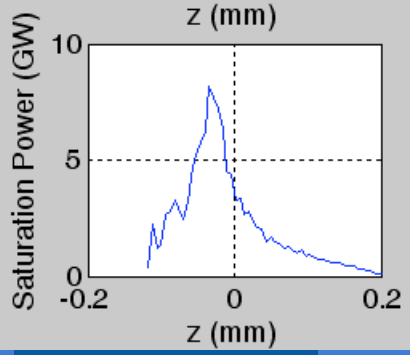




Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 13.431 GW
rms pulse length= 45.798 um
rms pulse length=152.765 fsec
saturation length= 22.000 m
e-beam efficiency= 85.767%
e-beam peak current= 4.490kA

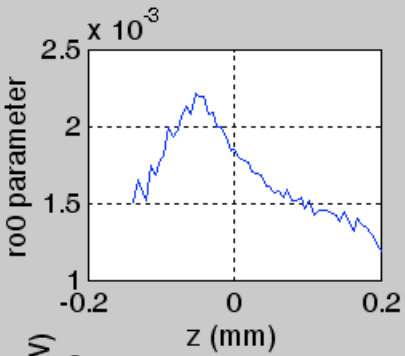


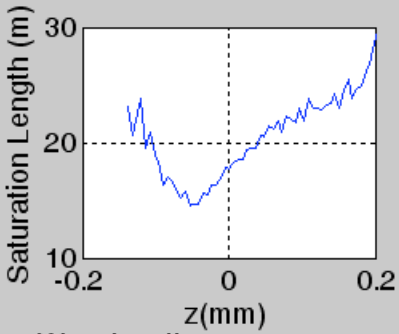


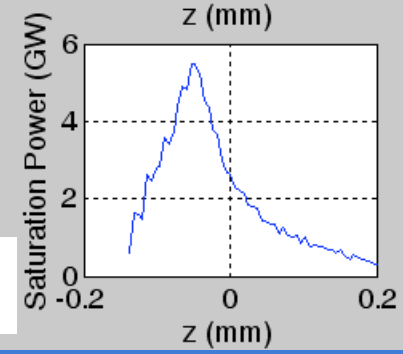


Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 8.147 GW
rms pulse length= 49.434 um
rms pulse length=164.894 fsec
saturation length= 22.000 m
e-beam efficiency= 84.666%
e-beam peak current= 2.584kA

reference







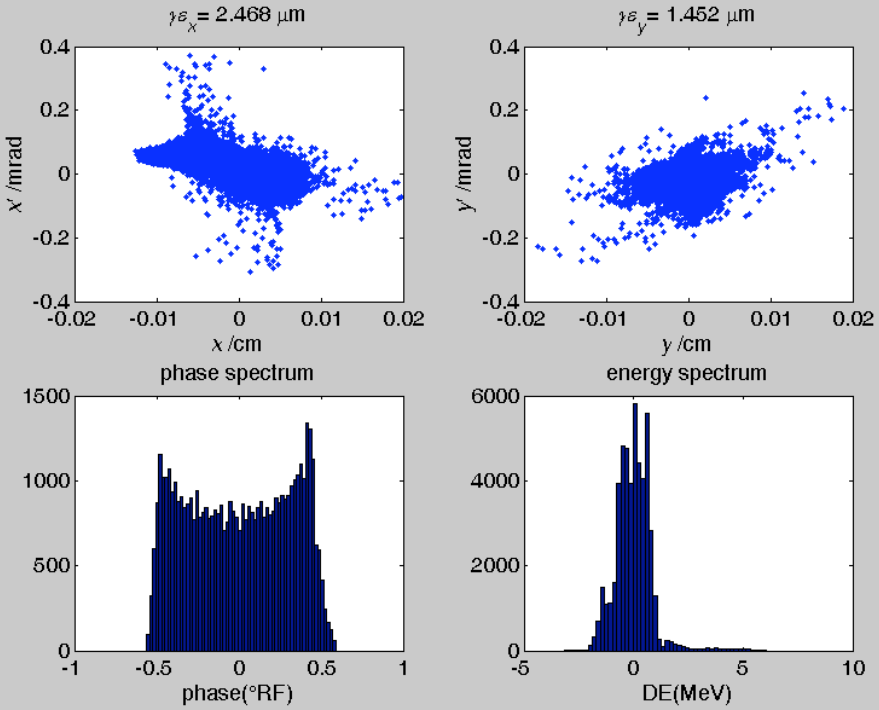
Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 5.498 GW
rms pulse length= 55.748 um
rms pulse length=185.954 fsec
saturation length= 22.000 m
e-beam efficiency= 79.237%
e-beam peak current= 1.883kA

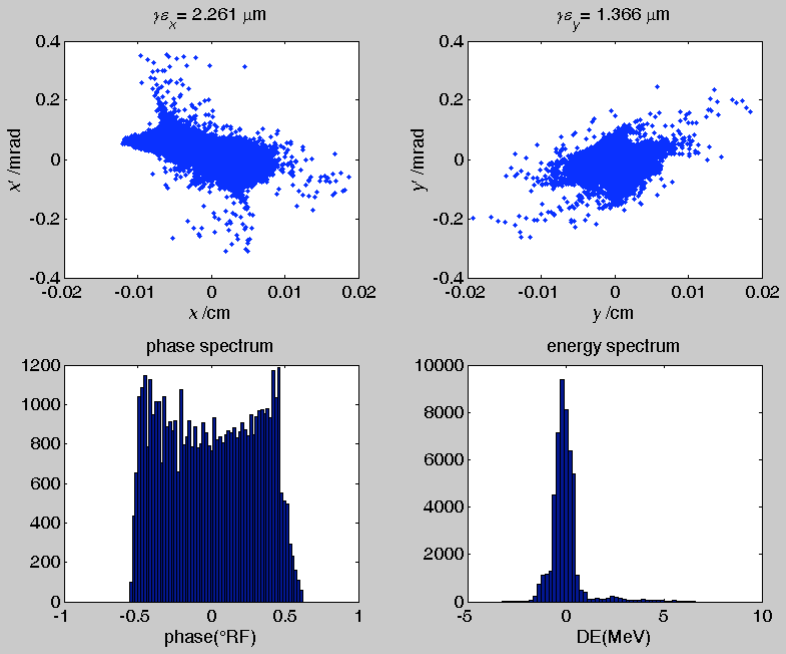
$\Delta\phi$= +1°

L0 jitter

$I_{pk\text{-}av} \sim 450$ A

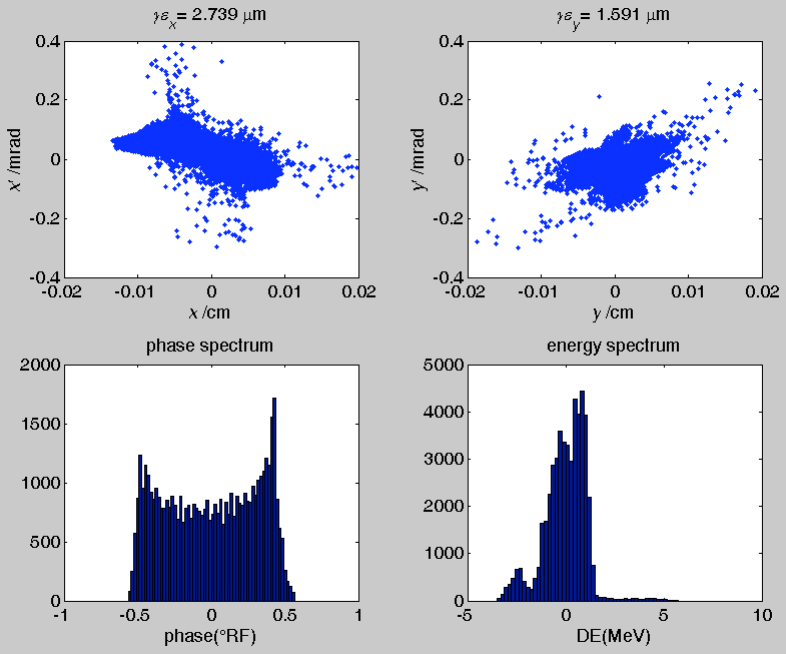
$\Delta\phi = -1°$





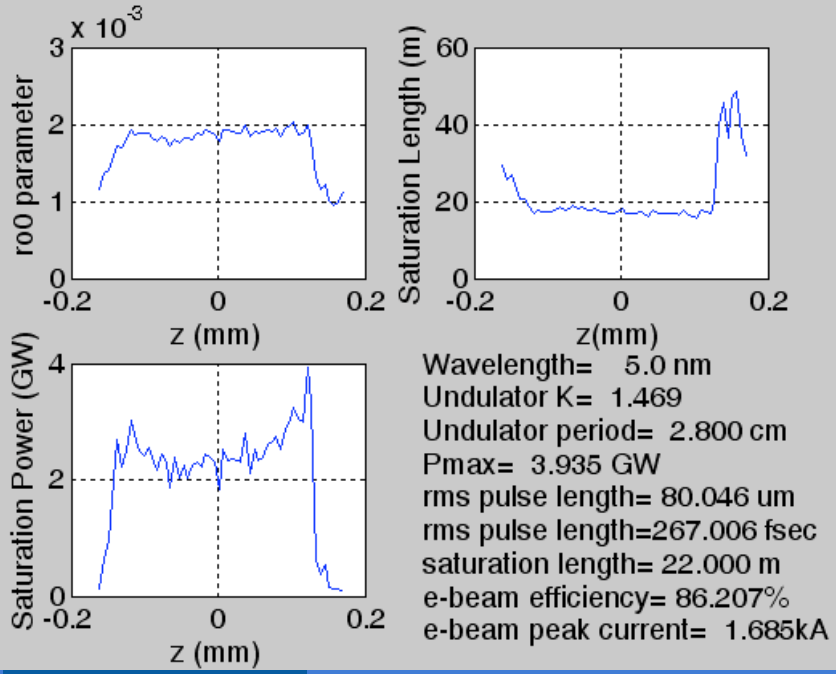
reference

$\Delta\phi = +1°$



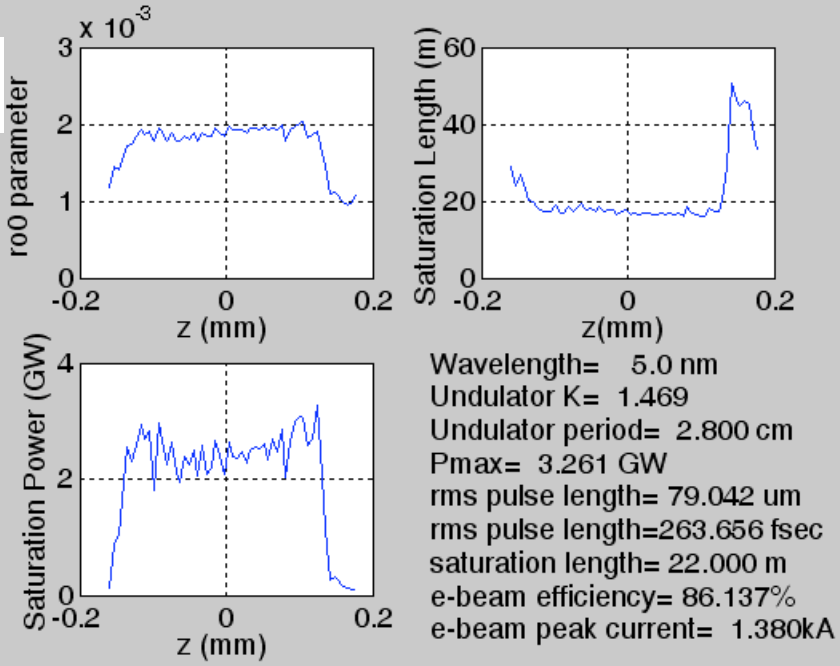
L0 jitter

$I_{pk\text{-}av} \sim 450$ A

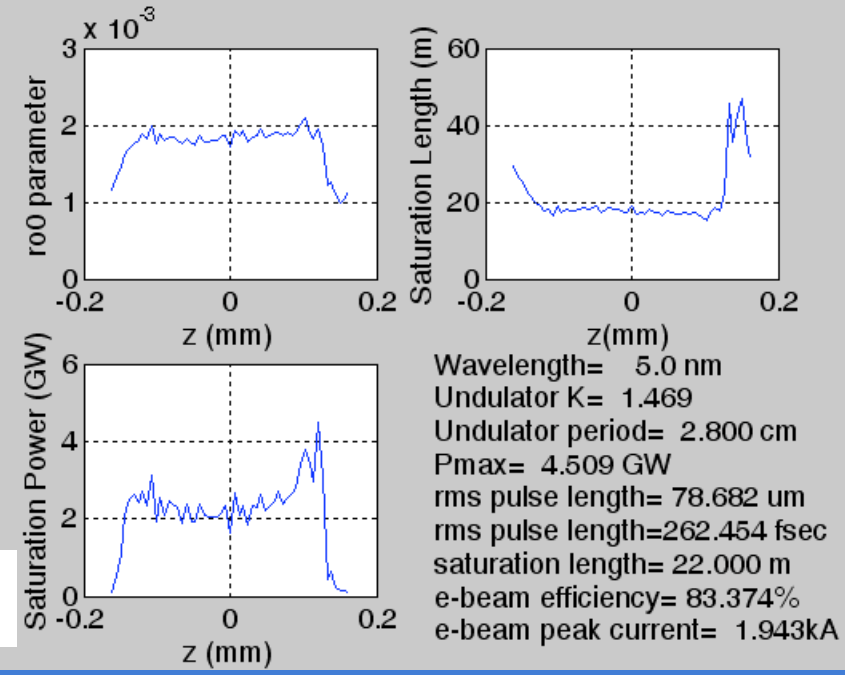


reference

$\Delta\phi = -1°$

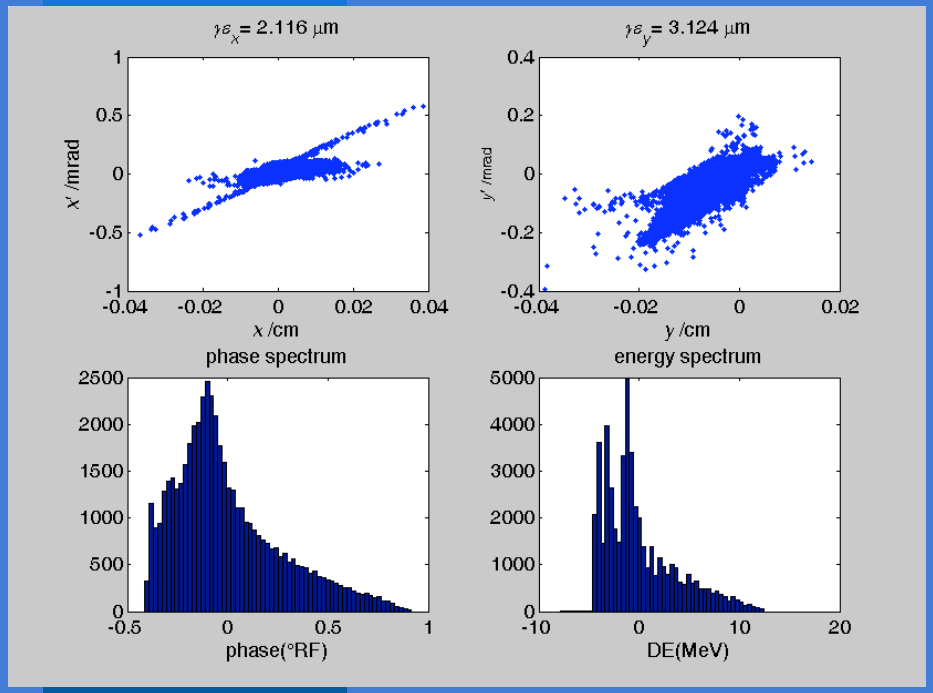


$\Delta\phi = +1°$



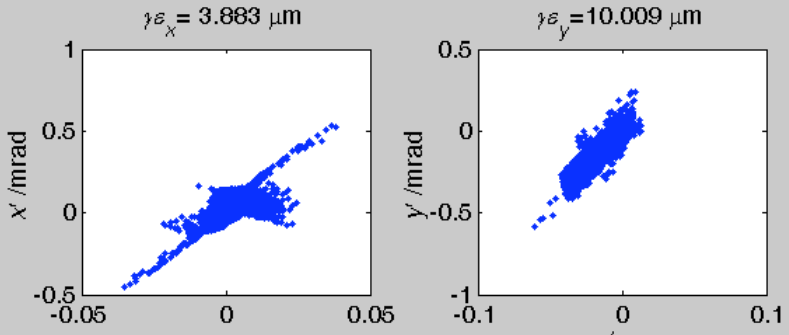
L0 jitter

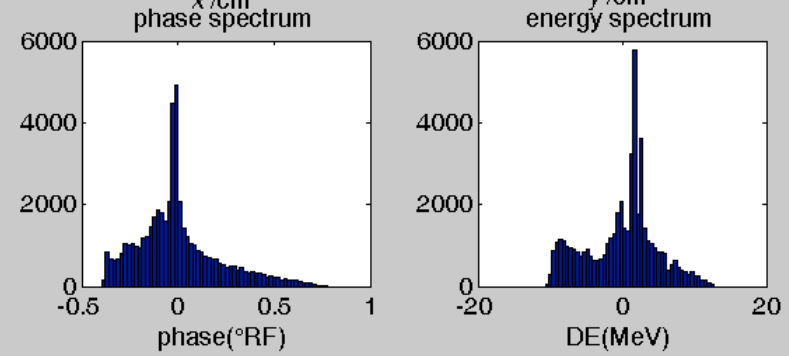
$I_{pk\text{-}av}$ ~300 A

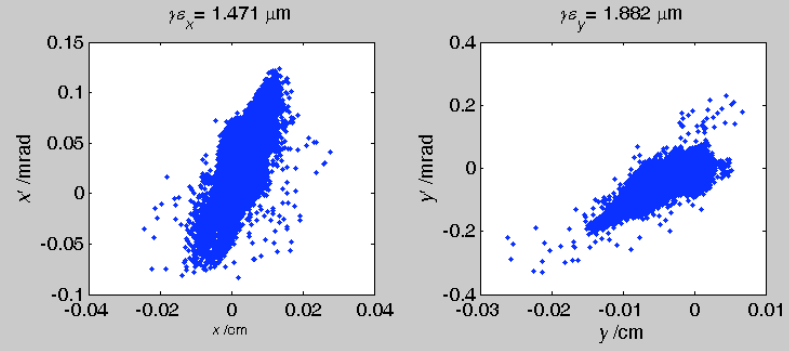


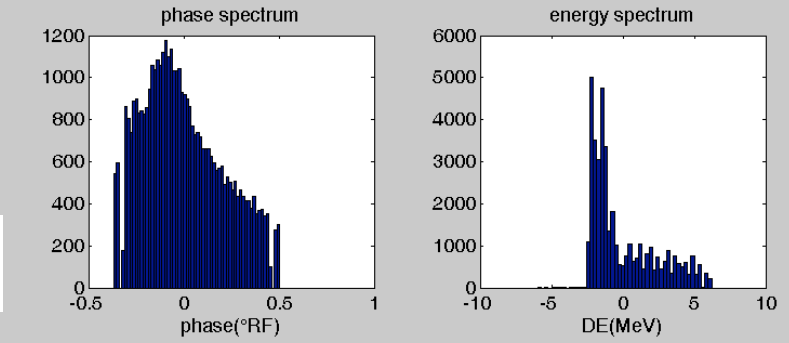
reference

Δϕ= -1°





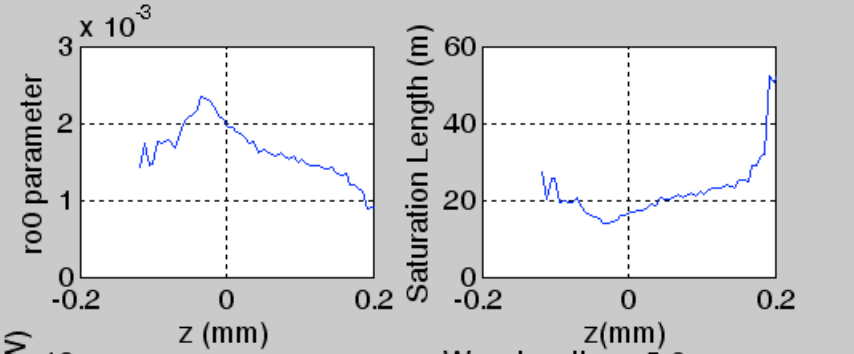




Δϕ= +1°

L0 jitter

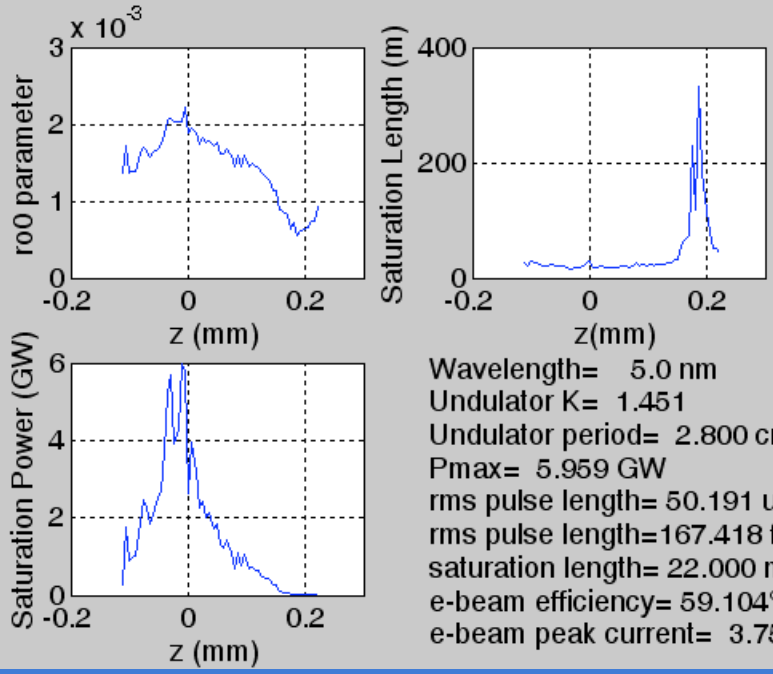
$I_{pk\text{-}av}$ ~300 A



Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 8.147 GW
rms pulse length= 49.434 um
rms pulse length=164.894 fsec
saturation length= 22.000 m
e-beam efficiency= 84.666%
e-beam peak current= 2.584kA

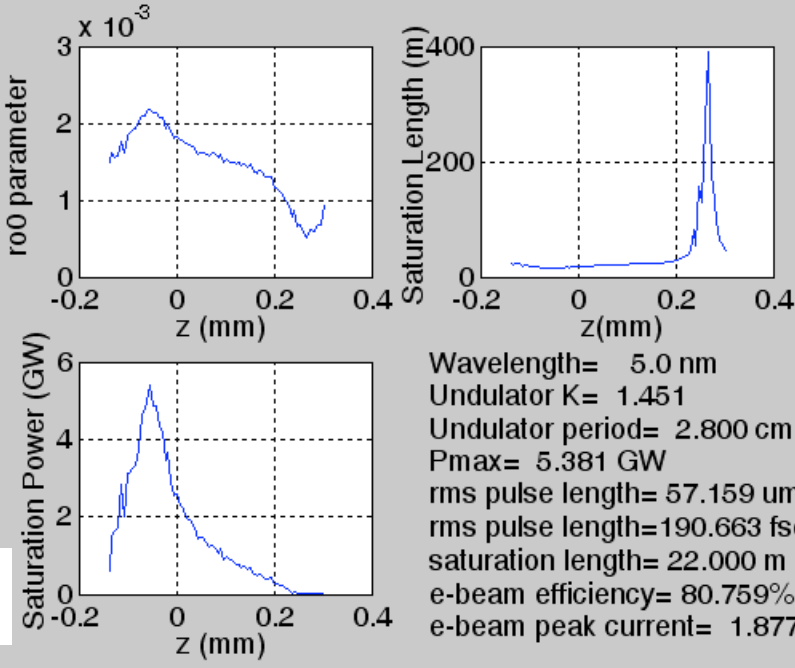
reference

$\Delta\phi$= -1°



Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 5.959 GW
rms pulse length= 50.191 um
rms pulse length=167.418 fsec
saturation length= 22.000 m
e-beam efficiency= 59.104%
e-beam peak current= 3.755kA

$\Delta\phi$= +1°

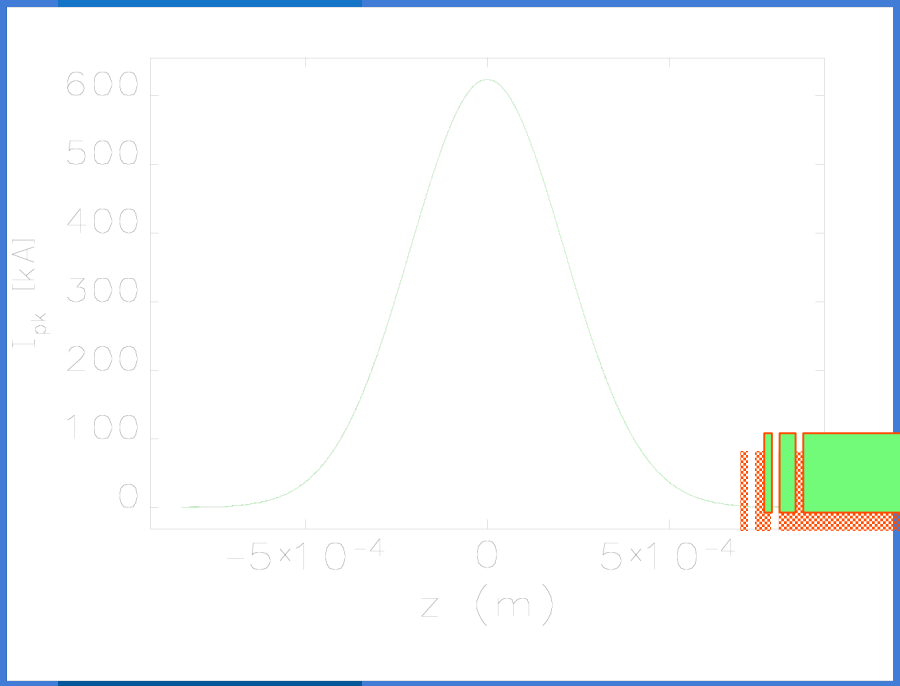


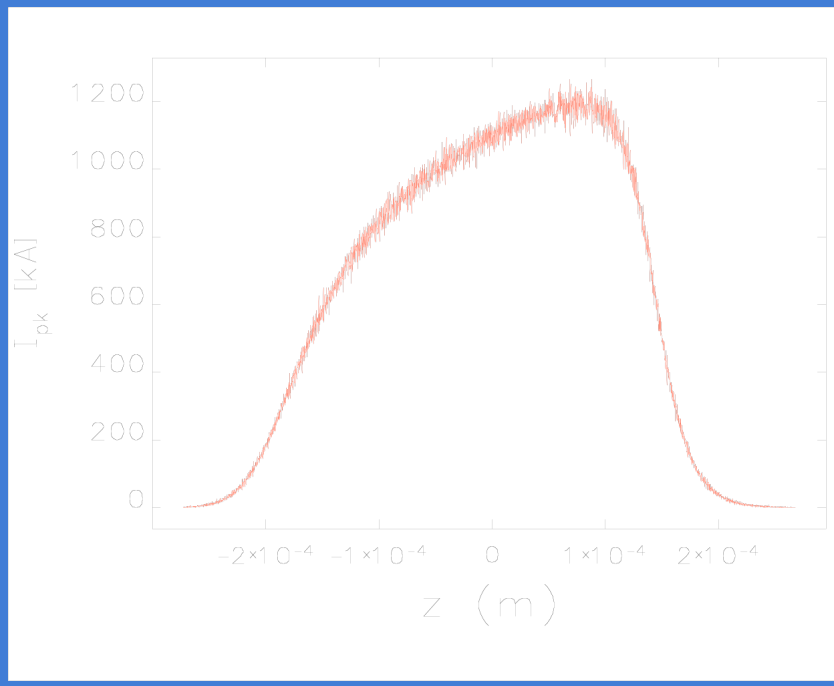
Wavelength= 5.0 nm
Undulator K= 1.451
Undulator period= 2.800 cm
Pmax= 5.381 GW
rms pulse length= 57.159 um
rms pulse length=190.663 fsec
saturation length= 22.000 m
e-beam efficiency= 80.759%
e-beam peak current= 1.877kA

First Microbunching instability simulation results

from Elegant with N_p=2M from the photoinjector exit up to undulator entrance

λ_f =9 μm, A_f= 1 %



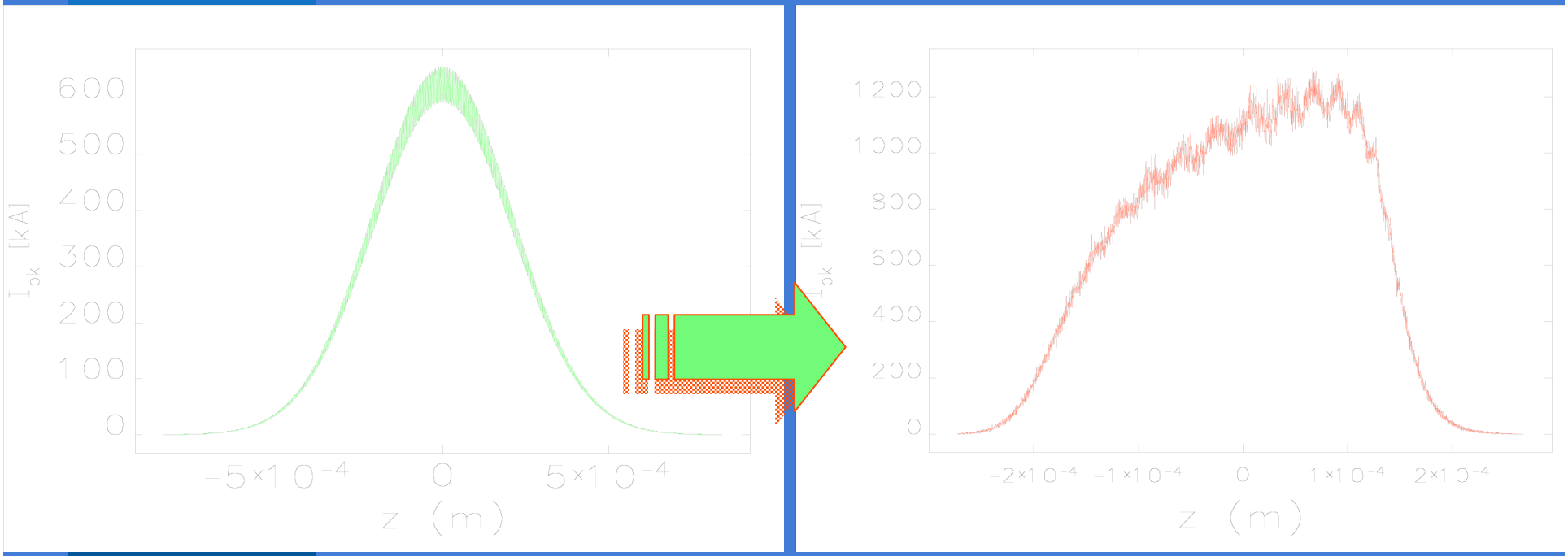


no modulation

from Elegant with N_p=2M from the photoinjector exit up to undulator entrance

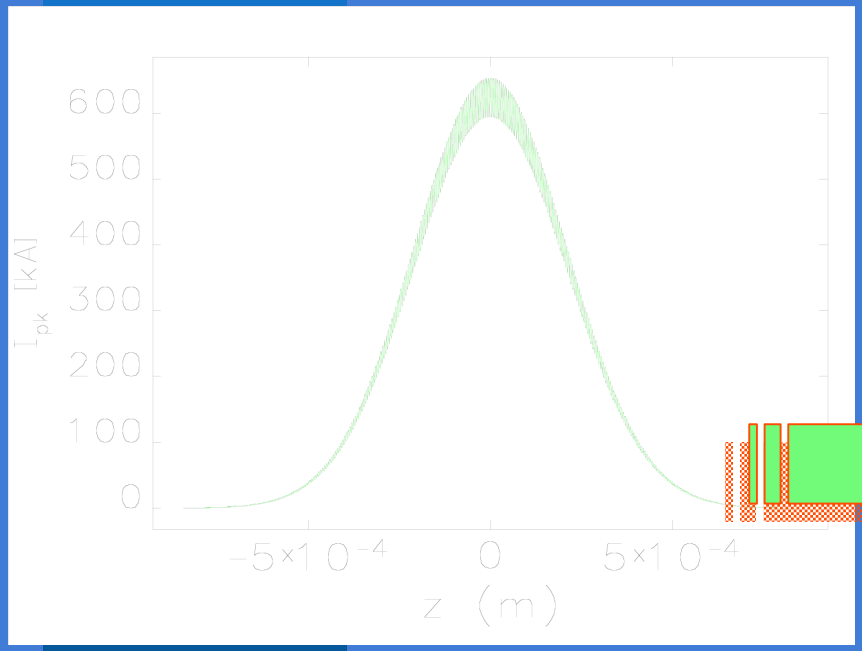
λ_0 =3 μm, A_0= 5 %

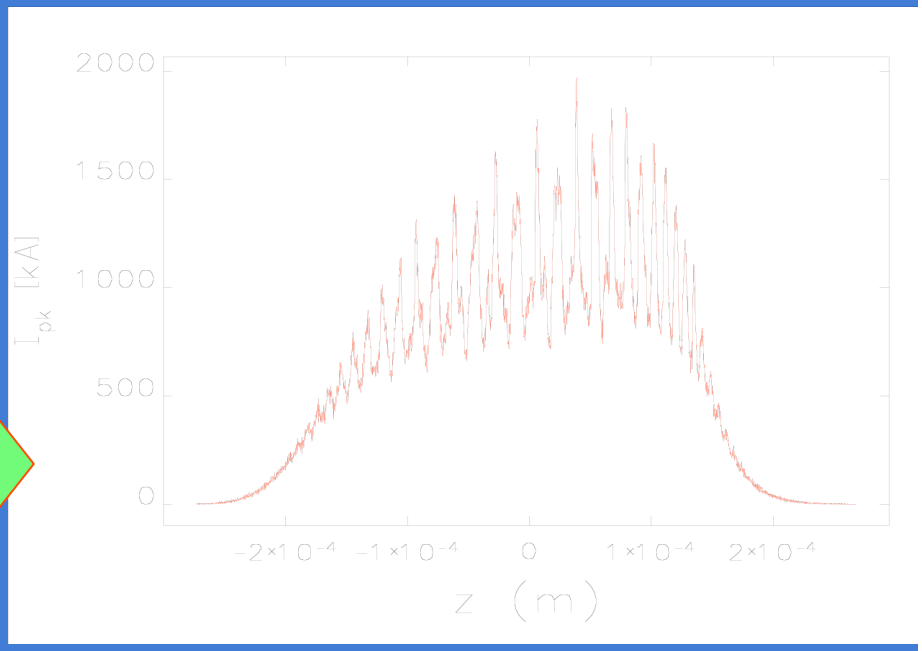
λ_f =26 μm, A_f= 3.7 %



λ_0 =5 μm, A_0= 5 %

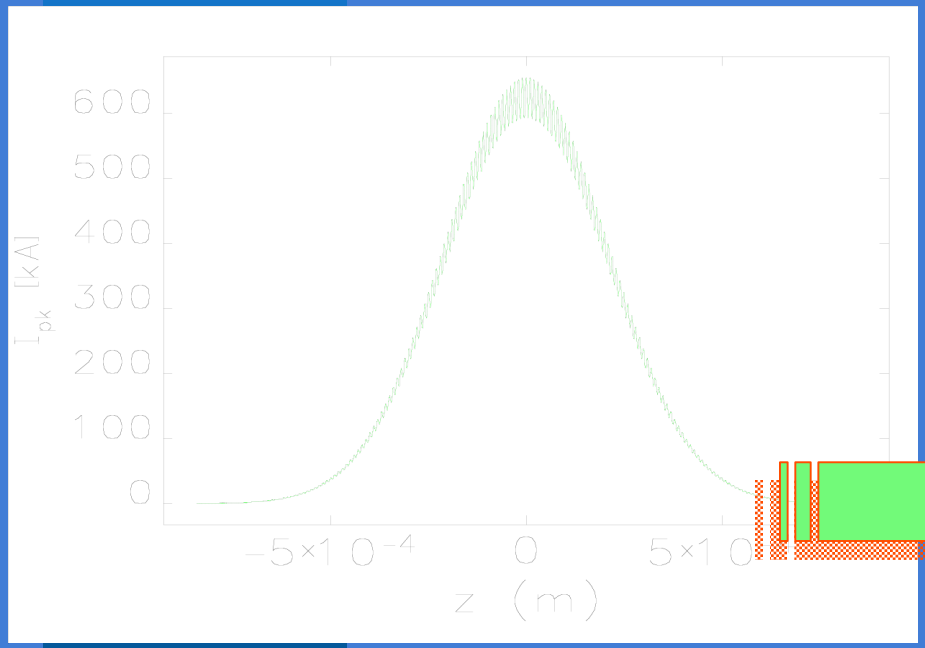
λ_f =15 μm, A_f= 30 %

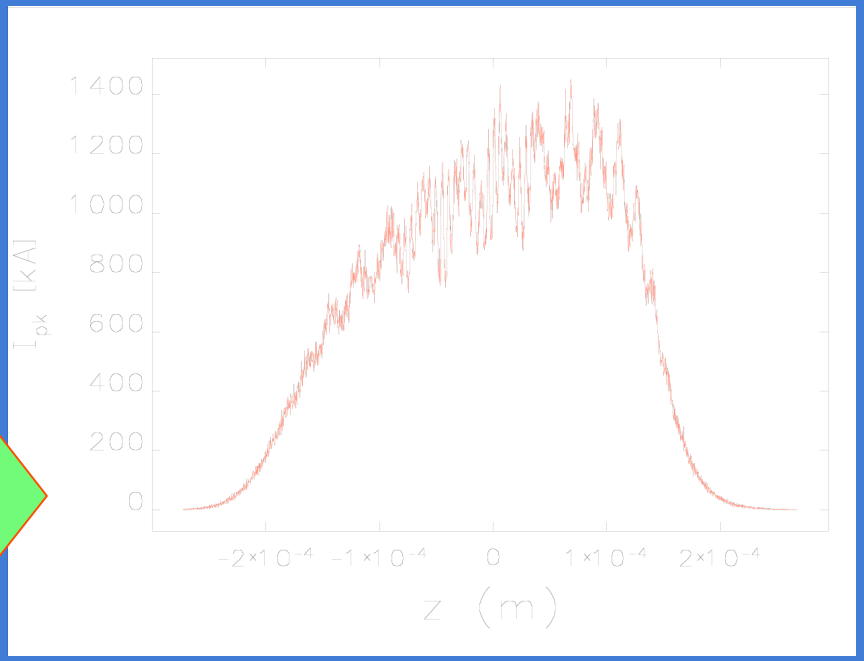




λ_0 =10 μm, A_0= 5 %

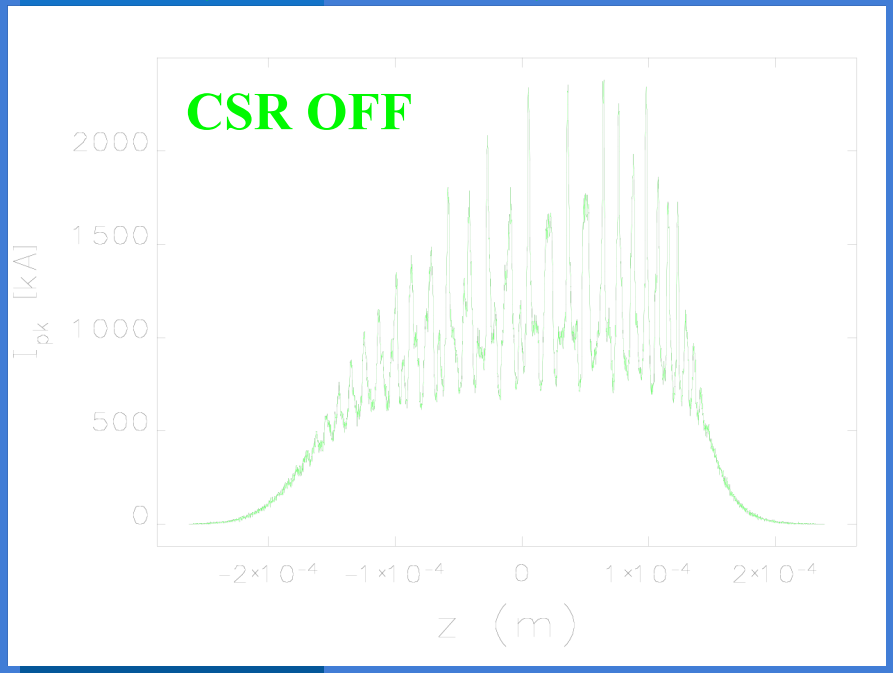
λ_f =25 μm, A_f= 11 %



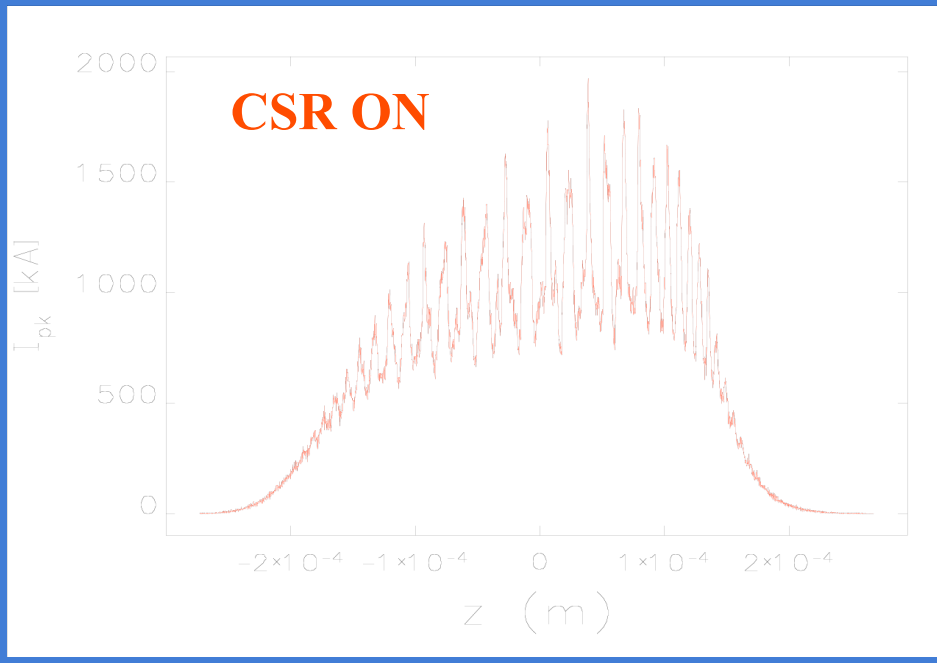


λ_0 =5 μm, A_0= 5 %

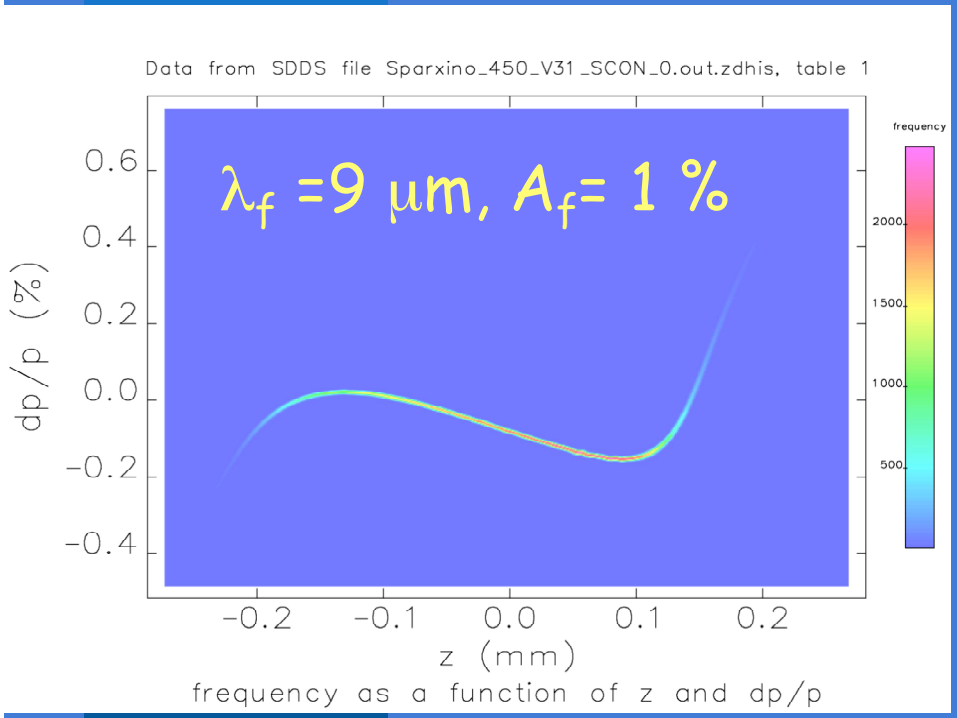
λ_f =13 μm, A_f= 38 %

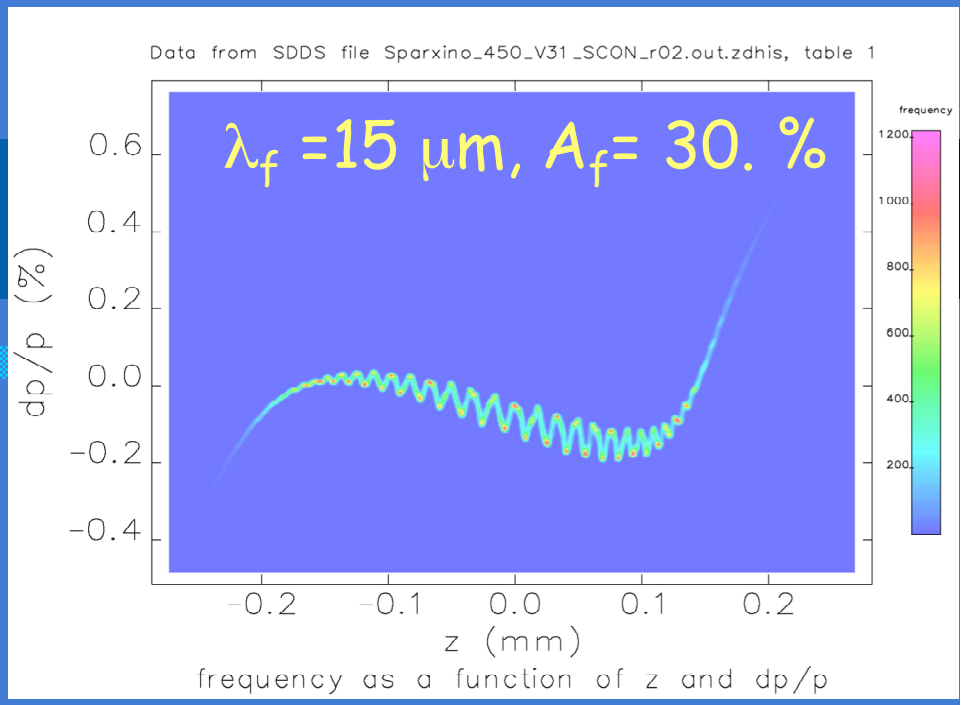


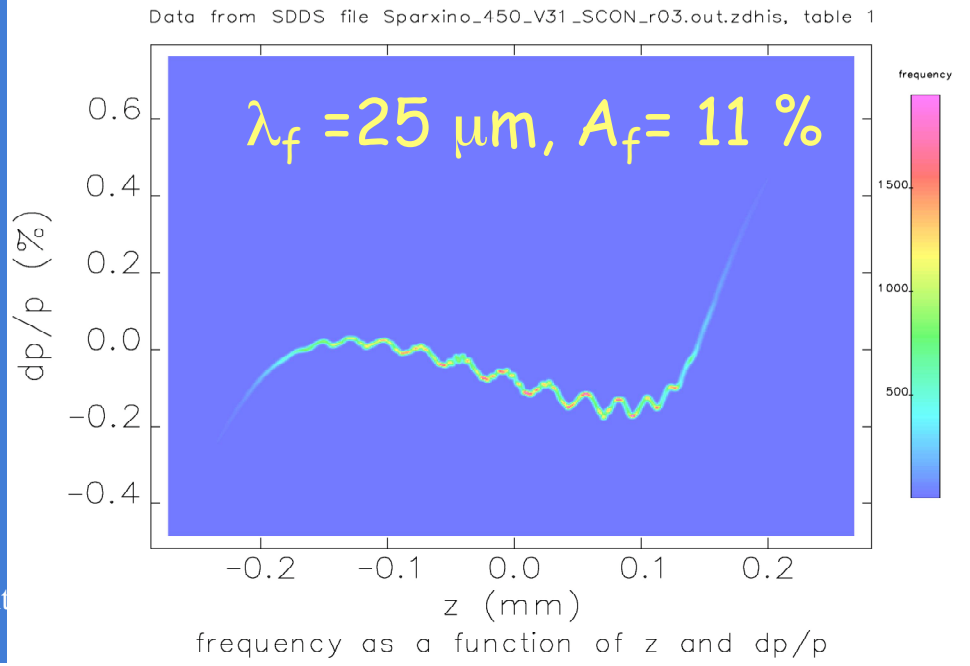
λ_f =15 μm, A_f= 30 %

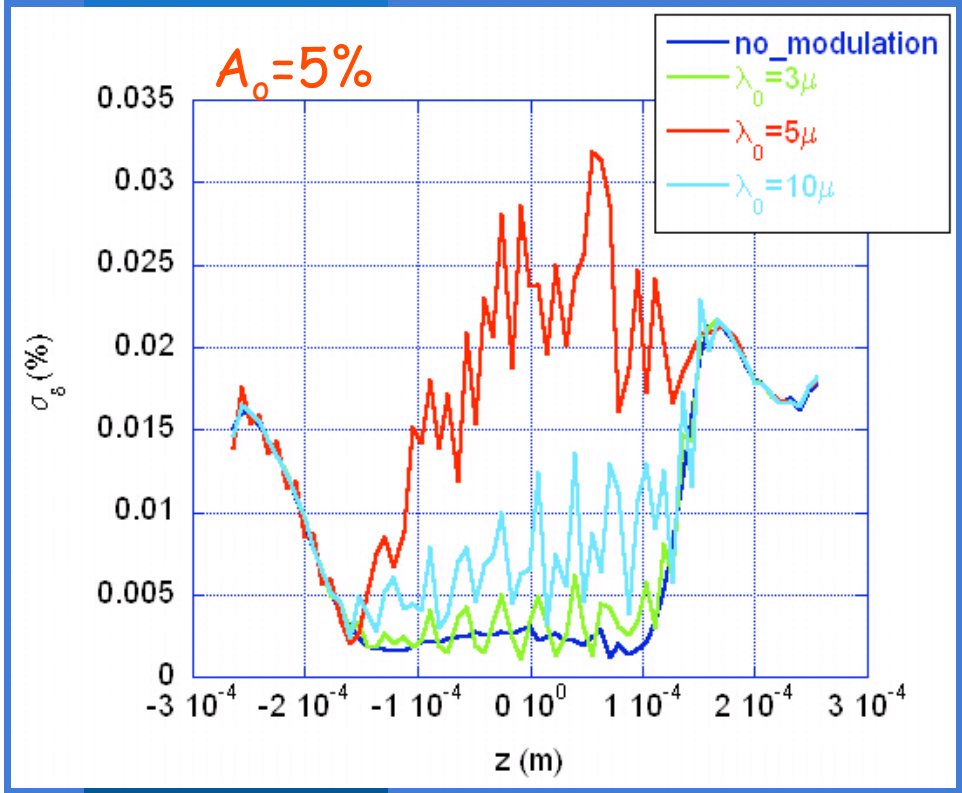


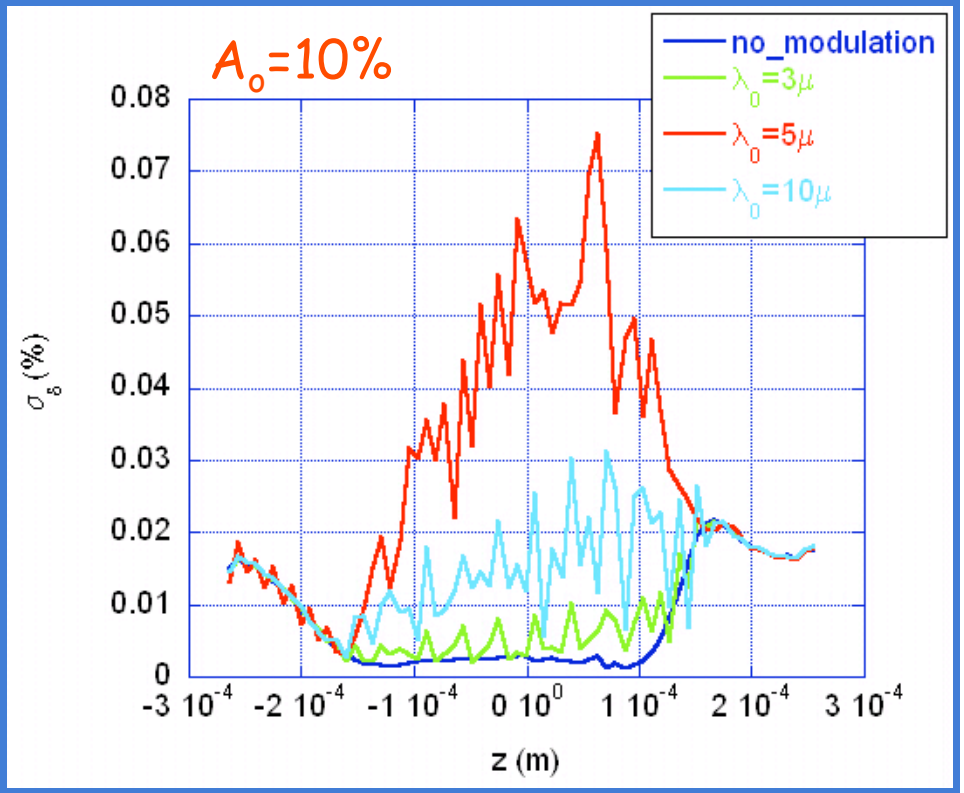
in detail:


Data from SDDS file Sparxino_450_V31_SCON_0.out.zdhis, table 1
λf =9 μm, Af= 1 %
dp/p (%)
z (mm)
frequency
frequency as a function of z and dp/p


Data from SDDS file Sparxino_450_V31_SCON_r02.out.zdhis, table 1
λf =15 μm, Af= 30. %
dp/p (%)
z (mm)
frequency
frequency as a function of z and dp/p


Data from SDDS file Sparxino_450_V31_SCON_r03.out.zdhis, table 1
λf =25 μm, Af= 11 %
dp/p (%)
z (mm)
frequency
frequency as a function of z and dp/p


A_o=5%
no_modulation
λ_0=3μ
λ_0=5μ
λ_0=10μ
σ_δ (%)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-3 10^{-4}
-2 10^{-4}
-1 10^{-4}
0 10^{0}
1 10^{-4}
2 10^{-4}
3 10^{-4}
z (m)


A_o=10%
no_modulation
λ_0=3μ
λ_0=5μ
λ_0=10μ
σ_δ (%)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-3 10^{-4}
-2 10^{-4}
-1 10^{-4}
0 10^{0}
1 10^{-4}
2 10^{-4}
3 10^{-4}
z (m)

Summary table

$\sigma_{\delta 0}$ (%)	λ_0 (μm)	A_0 (%)	λ_f (μm)	A_f (%)
2.0E-5	3	5	26	4.
	5	5	15	30
	10	5	25	11
	3	10	26	8
	5	10	12	58
	10	10	26	24
	5	.1	8.7	1.2^{LSC}

about a laser heater…

- **to increase uncorrelated energy spread**

and….

- **Fast (slice length determined by laser pulse length) control on the longitudinal electron phase space**
- **Convert energy modulation into density modulation. Enhanced SASE. (Ref. Zholents Phys. Rev. ST Accel. Beams 8, 040701, 2005)**
- **Attosecond radiation with a few optical cycle-laser slicing technique (Ref. Zholents and Fawley, PRL 92, 224801, 2004)**
- **Short current spike at the bunch tail to study superradiance regime (Ref. Giannessi, Musumeci, Spampinati, Journal of Applied Physics, 98, 043110 (2005))**
- **Weak FEL detection with a modulated laser-based beam heater (Ref. Emma et al. PAC 2005)**

Conclusions

- **The SPARX-ino project has been funded in 2005.**
- **A possible scheme for the DAFNE LINAC upgrade has been proposed.**
- **A first layout with two working points has been presented together with preliminary results on phase jitter sensitivity and microbunching instability.**
- **A detailed study is in progress**