SPARC/X status and plans

Massimo Ferrario
on behalf of the SPARC/X team

Microbunch instability workshop - March 25, 2010

SPARX Technical Design Report ready ==> 1.4 - 2.5 GeV

SPARX Scientific Case ready

CONSORTIUM preliminary agreement signed by all partners

CONSORTIUM operating from ?

Available funding (10 M€ + 15 M€) ==> 750 MeV , 27 nm

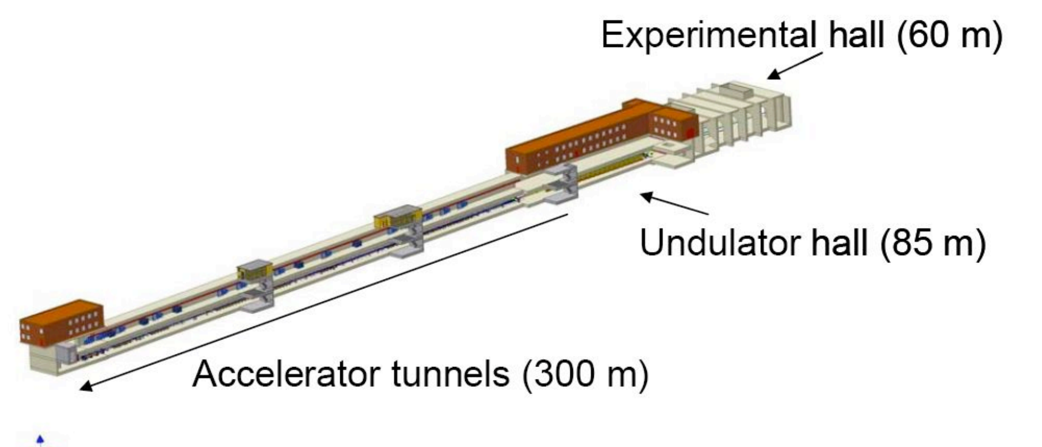
Site choice: Uni ToV or LNF

40nm - 10 nm

15nm - 5nm

5nm -1nm

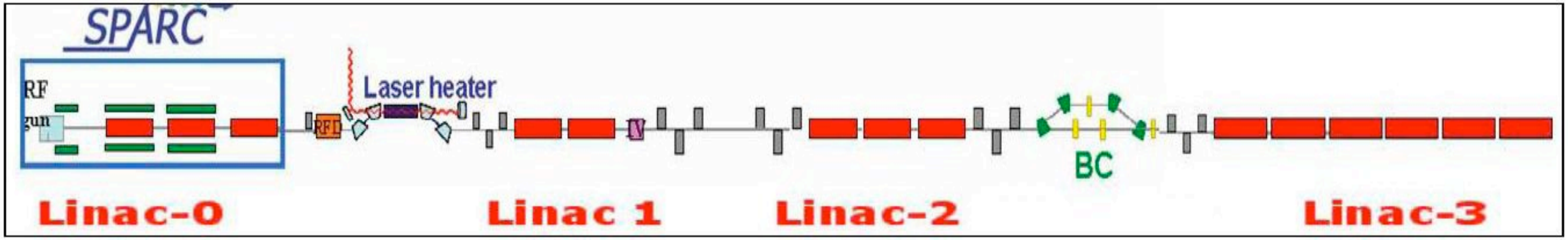
1.2nm-0.6nm



SPARX phase 0 ==> SPARC upgrade

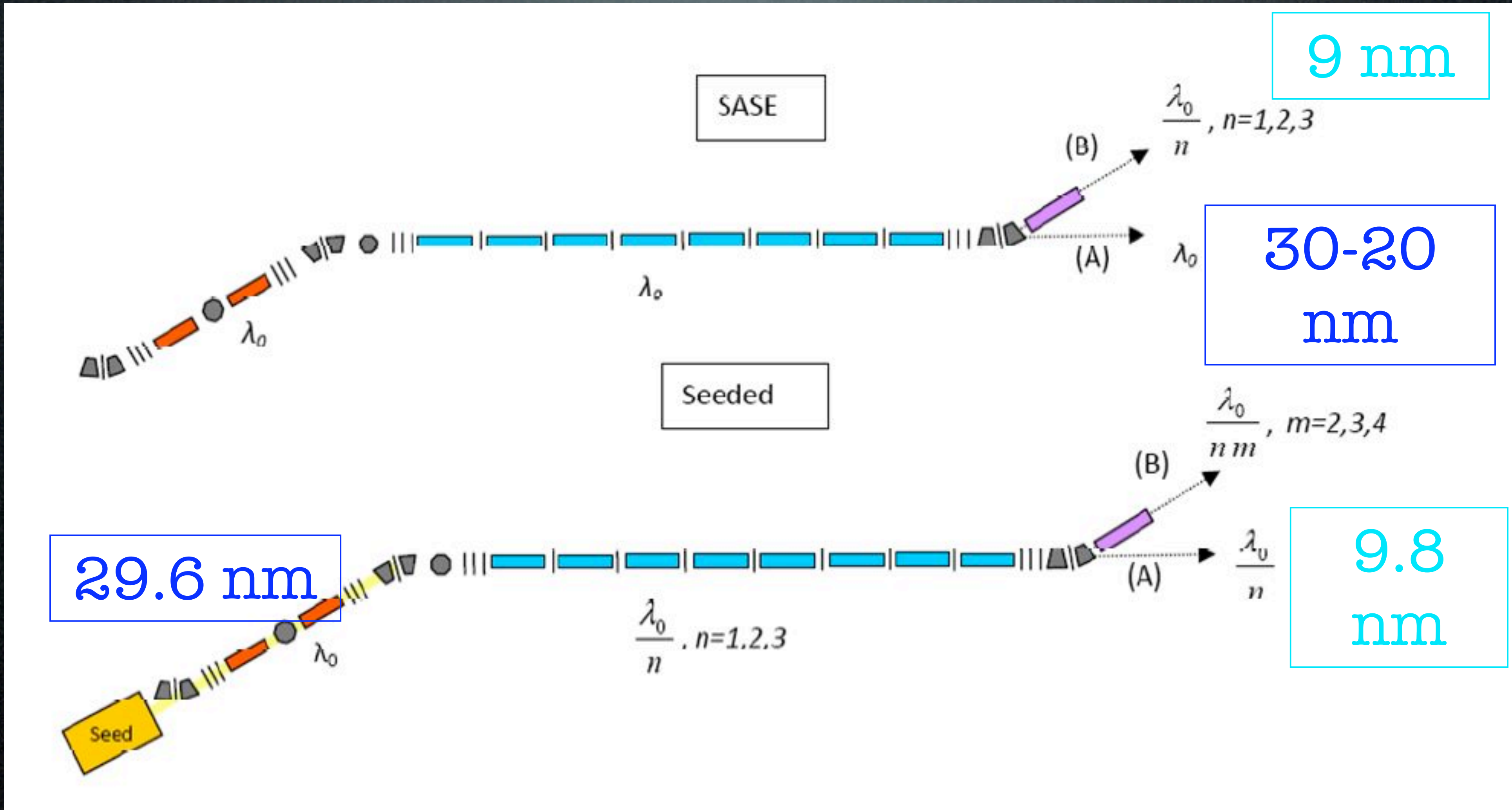
150 MeV
125 A

750 MeV
700 A



S-band injector with VB ==> C-band linac option

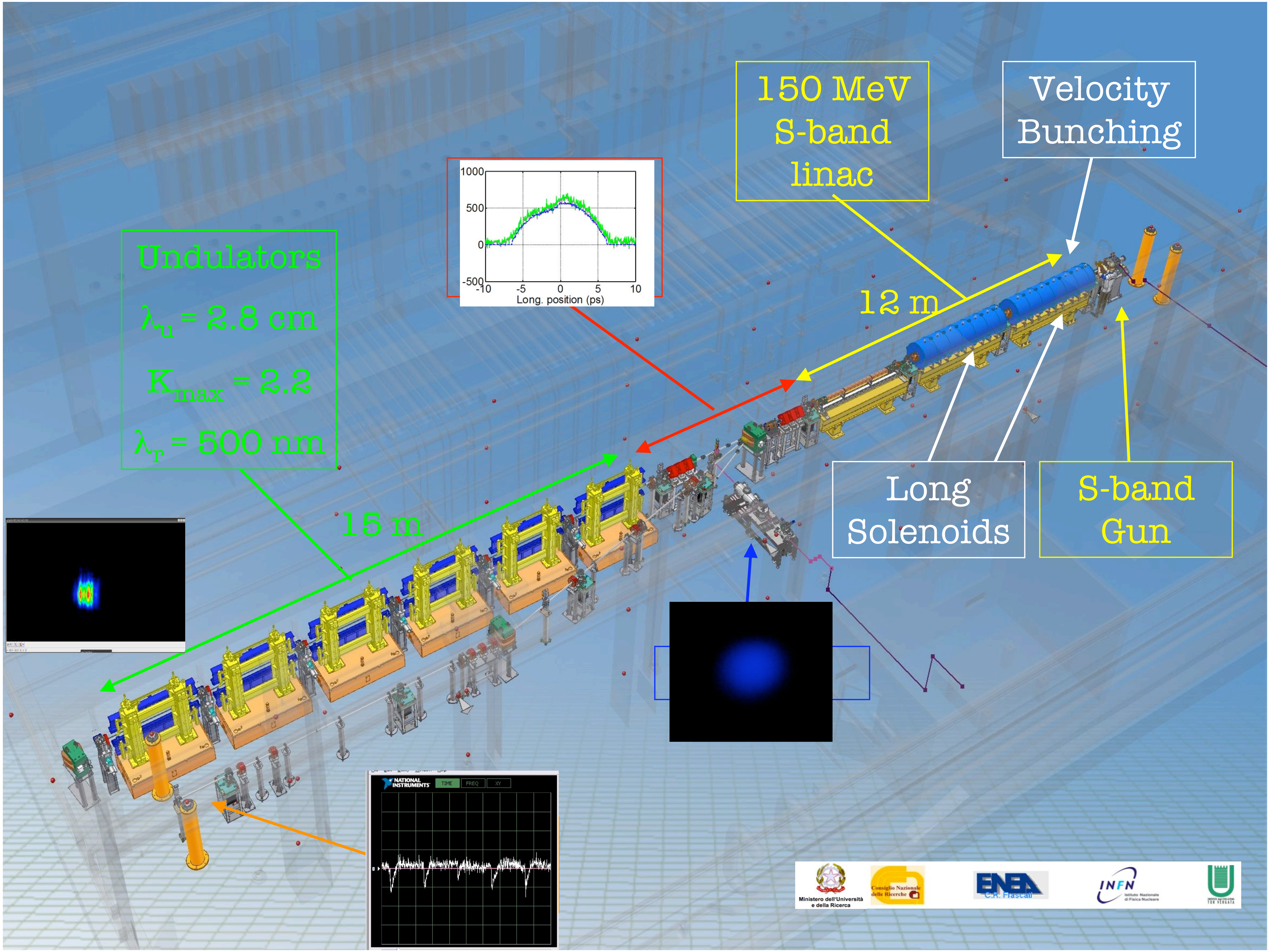
SPARX phase 0 ==> Undulators scheme



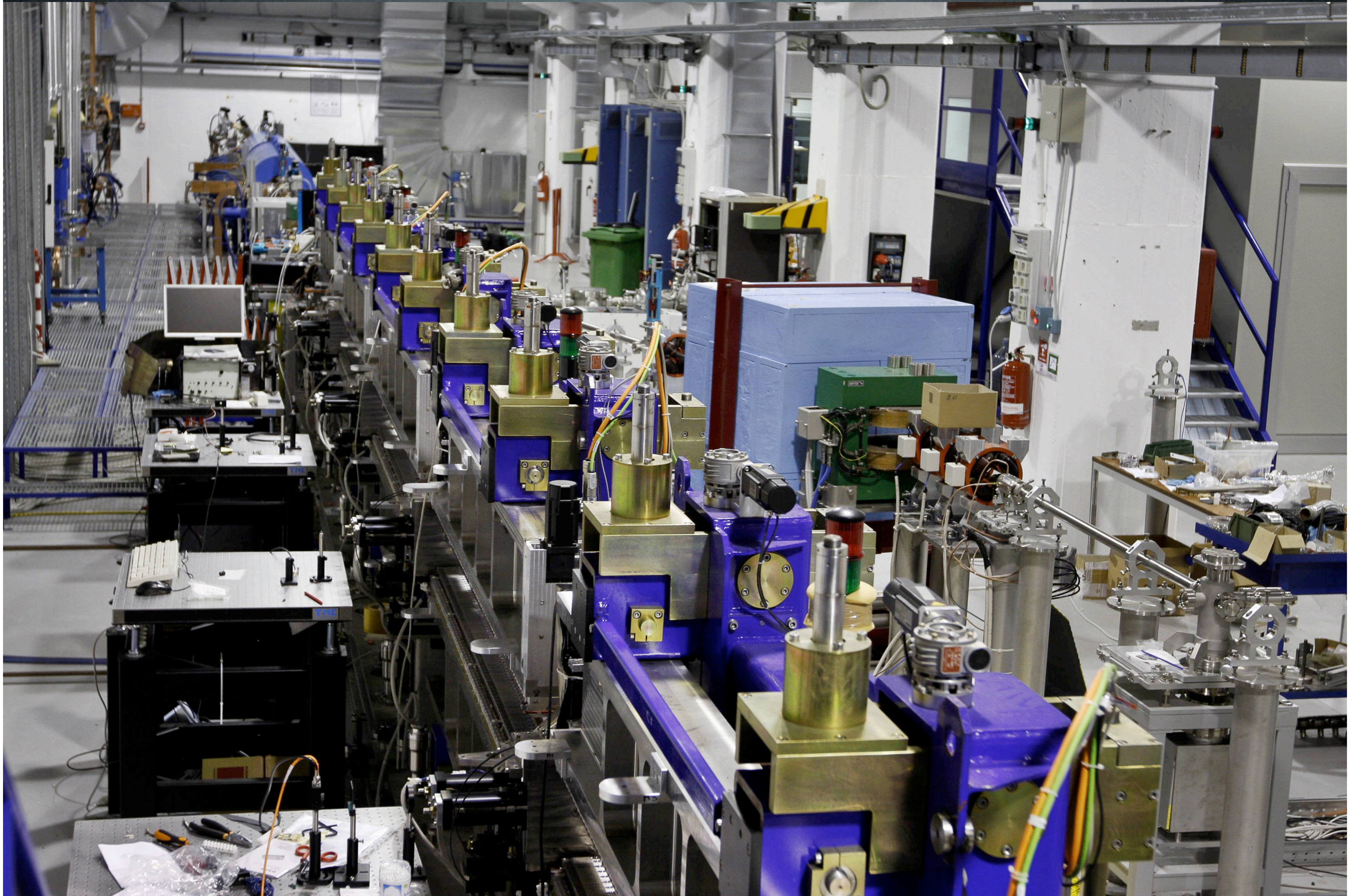
8xUndulator: 75 periods, λ_u=28mm (SPARC like)

2xUndulator: 45 periods, λ_u=44mm

1xUndulator: 150 periods, λ_u=17mm



150 MeV S-band linac
Velocity Bunching
1000
500
0
-500
-10
-5
0
5
10
Long. position (ps)
Undulators
λ_u = 2.8 cm
K_{max} = 2.2
λ_r = 500 nm
12 m
15 m
Long Solenoids
S-band Gun
NATIONAL INSTRUMENTS
TIME
FREQ
XY
Ministero dell'Università e della Ricerca
Consiglio Nazionale delle Ricerche
ENEA
C.R. Frascati
INFN
Istituto Nazionale di Fisica Nucleare



FEL experiments:
seeding and synchronization

Ti:Sa Regenerative amplifier
800 nm - 2.5 mJ – 1 kHz
+
High order harmonics
400 & 266 nm
+
High order armonics in gas:
266, 160, 114 nm
High Energy
Short duration
Spatial and temporal Coherence

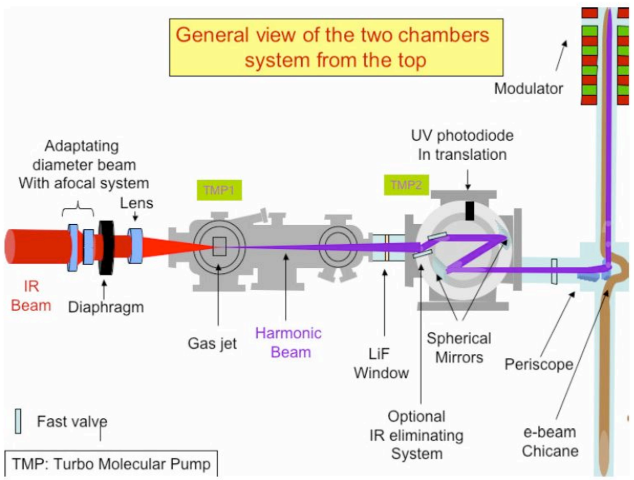
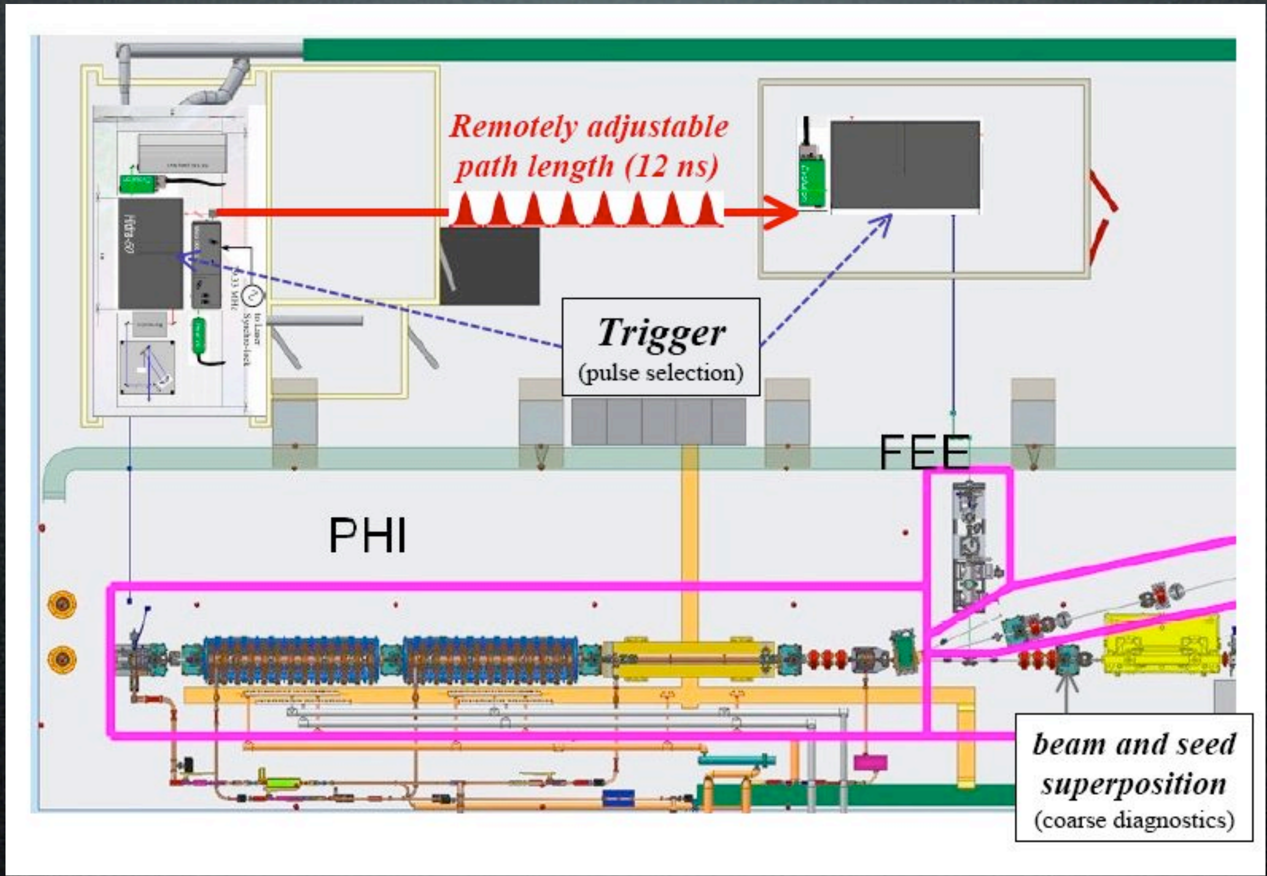


Fig. 31. *Lay-out of the harmonic chamber for the seeding experiment at SPARC. The first chamber is dedicated to the production of harmonics in gas. The second chamber is required for the opical mode adaptation.*

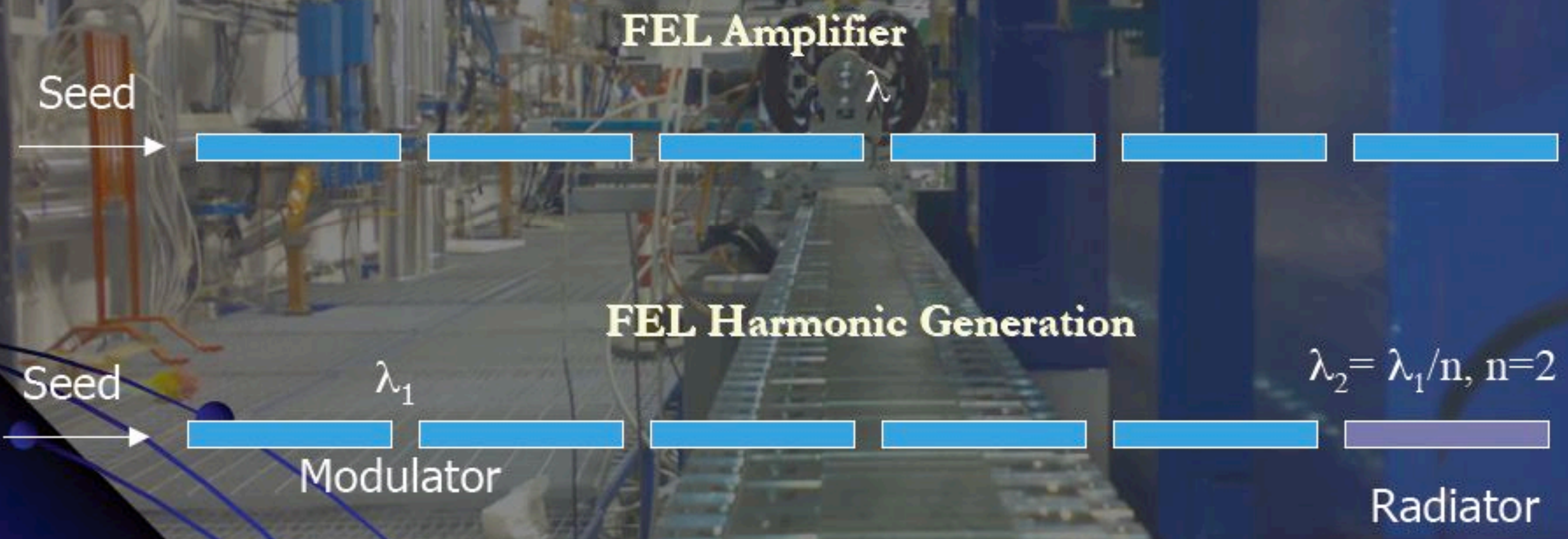
1) The seeding laser system is a regenerative amplifier, making use of a sample of the optical IR pulse train produced by the oscillator of the photocathode laser system. This makes the two lasers 100% time correlated.
2) The pulse of the laser oscillator are spaced by 12.6 ns (79.33 MHz). An optical delay line with a dynamic range > 12.6 ns allows shifting in time the 2 laser systems (and therefore the seed respect to the beam).



3) The trigger system allows to select the same pulse in the 2 laser systems for amplification .
4) A coarse (few ps) superposition of the beam and seed can be obtained by looking at the relative position of the pulses at the same target on a strek camera. SASE light (with seeding off) is the best candidate to identify the beam arrival time.
5) Fine tuning will be driven by observation and optimization of the seeding process.

2 days of beam

- 1° day - synchronization e-beam & laser
- 2° day - first seeding tests:

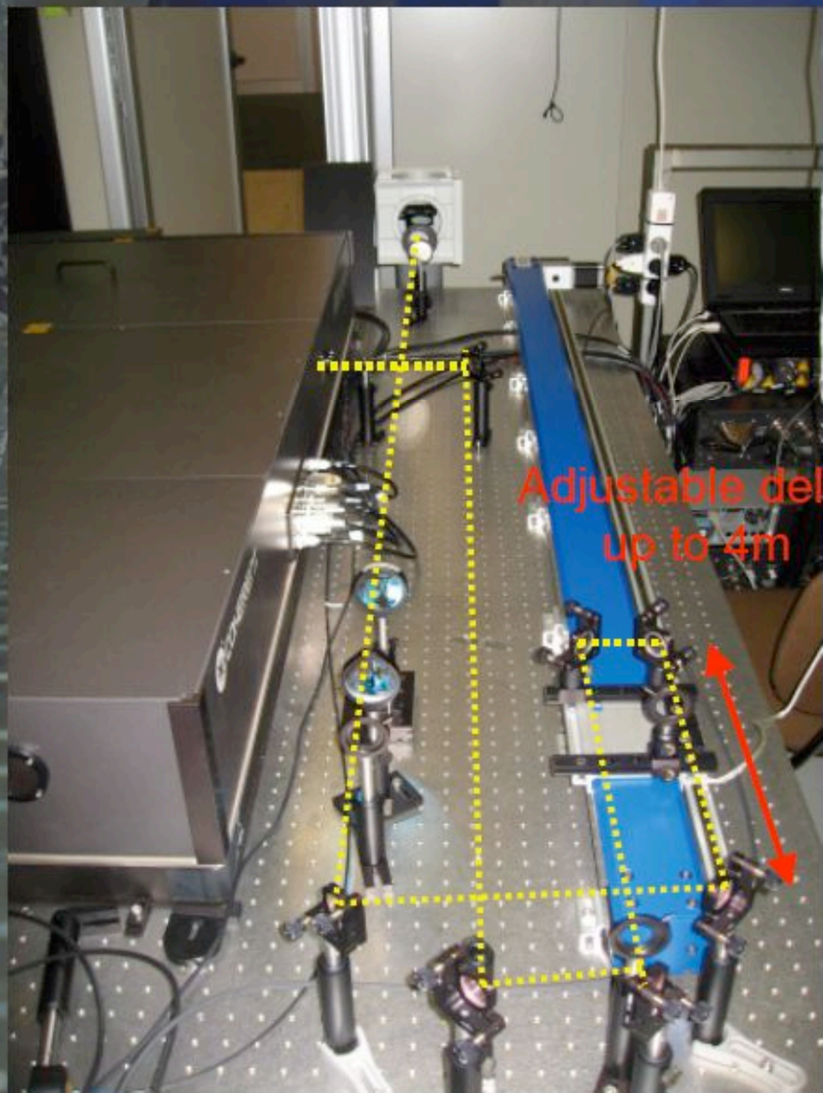


Very preliminary results

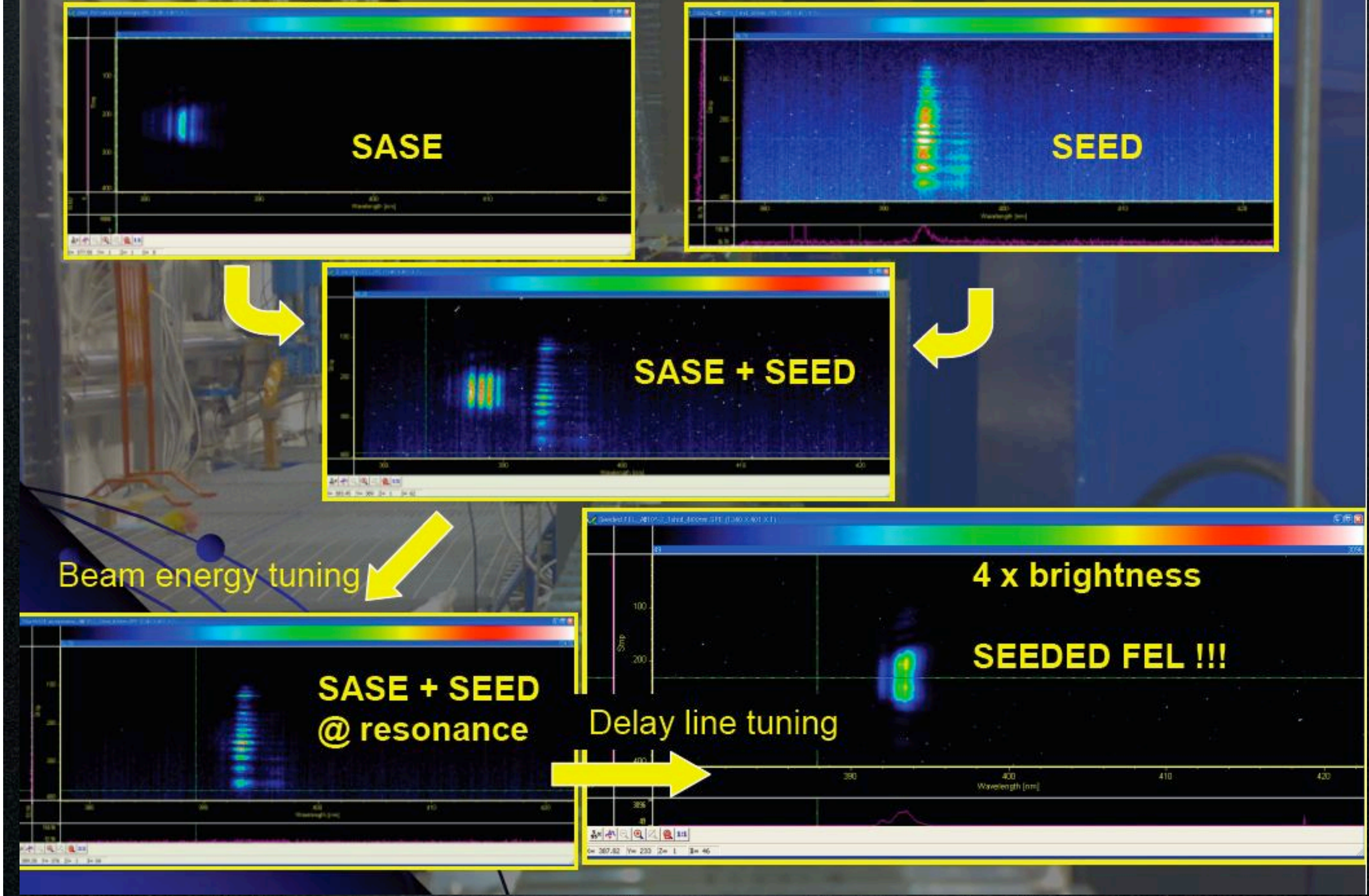
1° Day

Adjust delay line

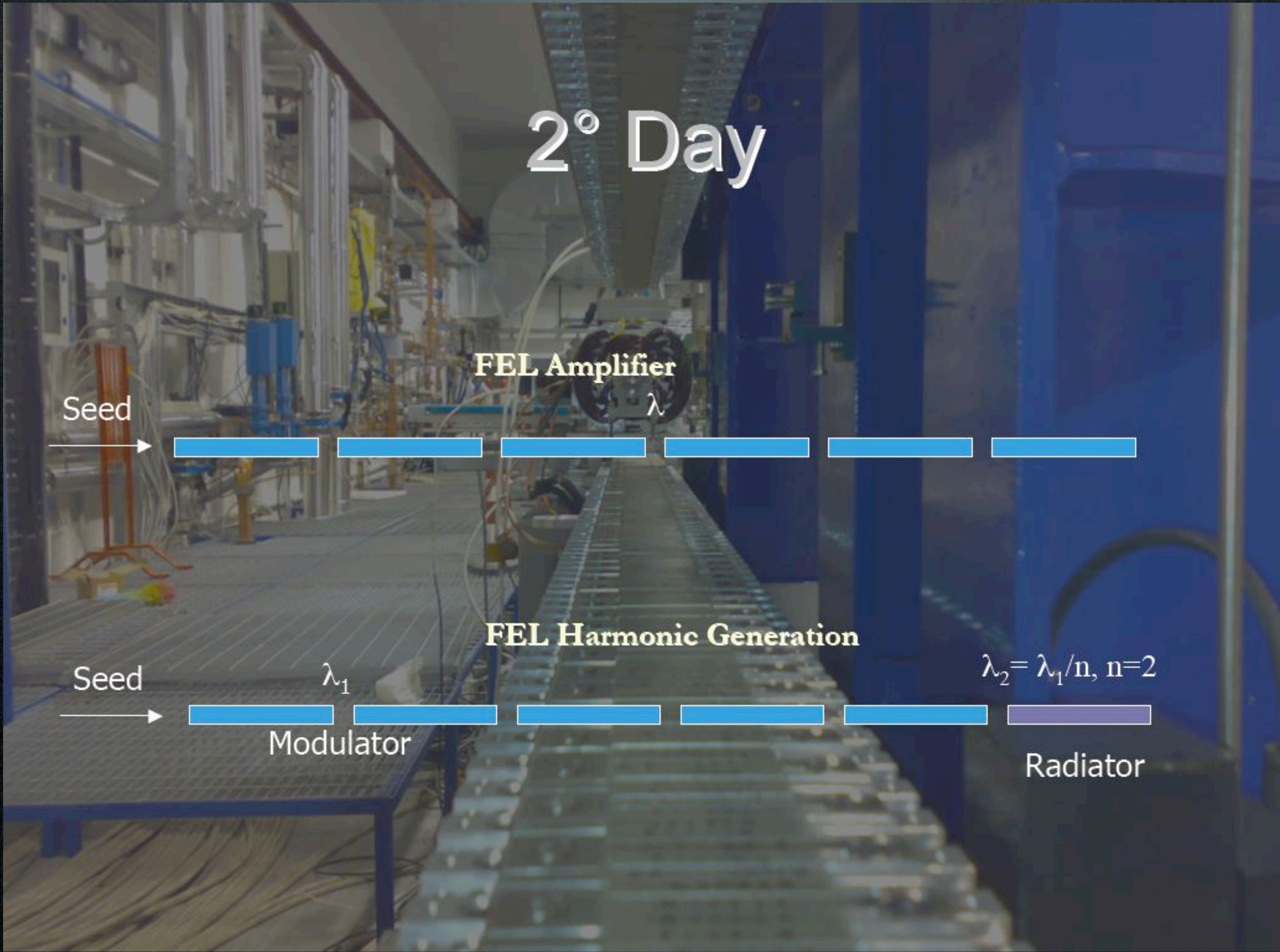
- Align seed to reference in UM (1.5 uJ)
- Tune resonance @400 nm
- Adjust electronic delay better than 1 ns (photodiode)
- Move the delay line until amplification is observed



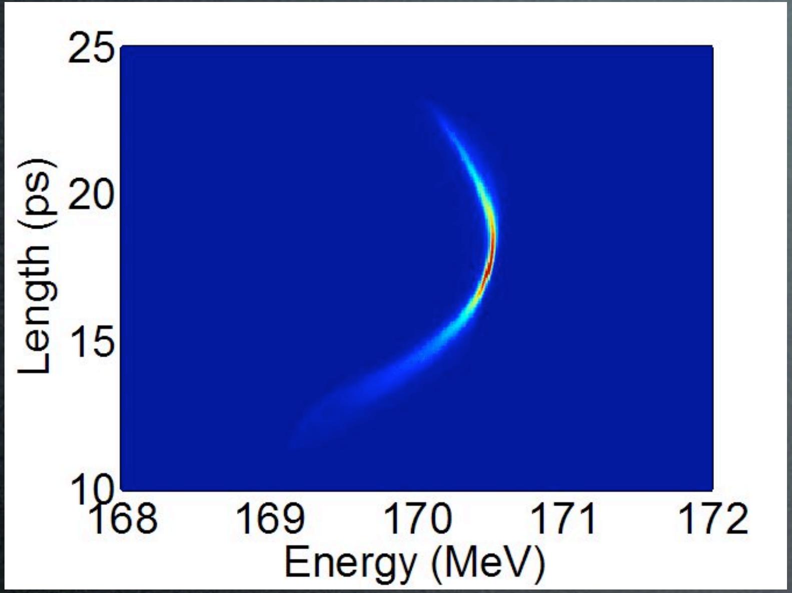
Synchronization (11-02-2010)

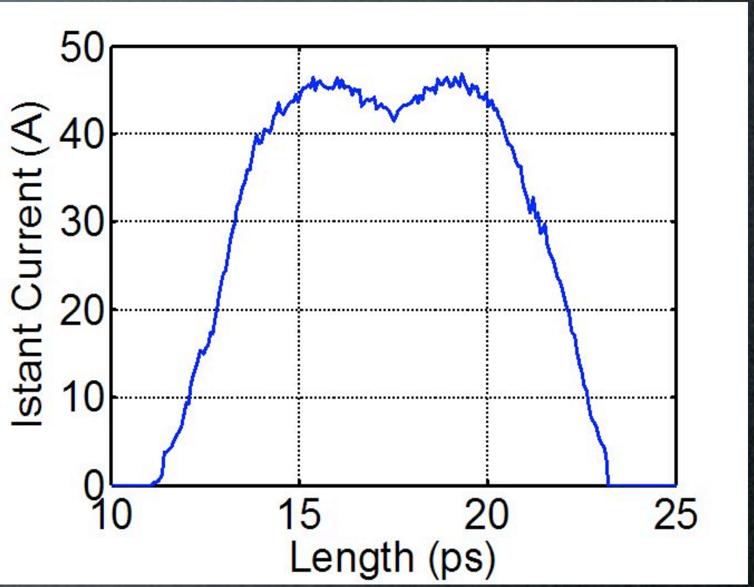


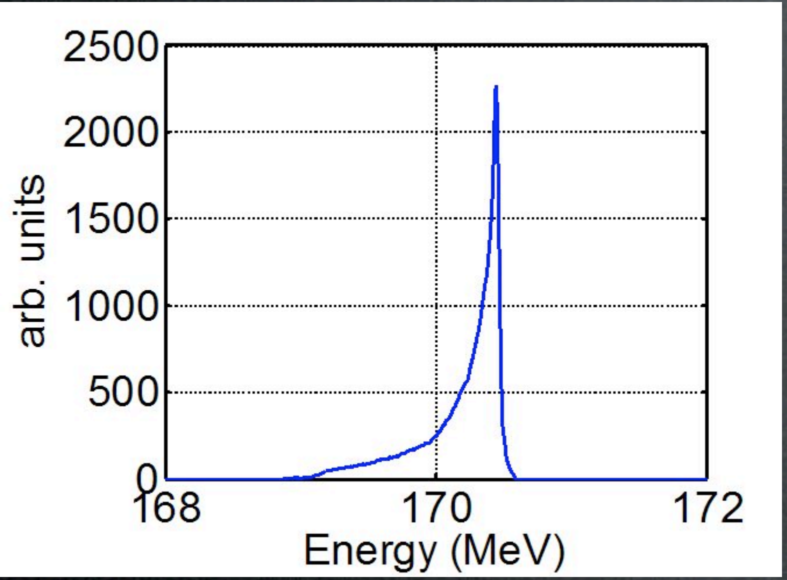
2° Day


FEL Amplifier
Seed
λ
FEL Harmonic Generation
Seed
λ1
λ2= λ1/n, n=2
Modulator
Radiator

Beam parameters



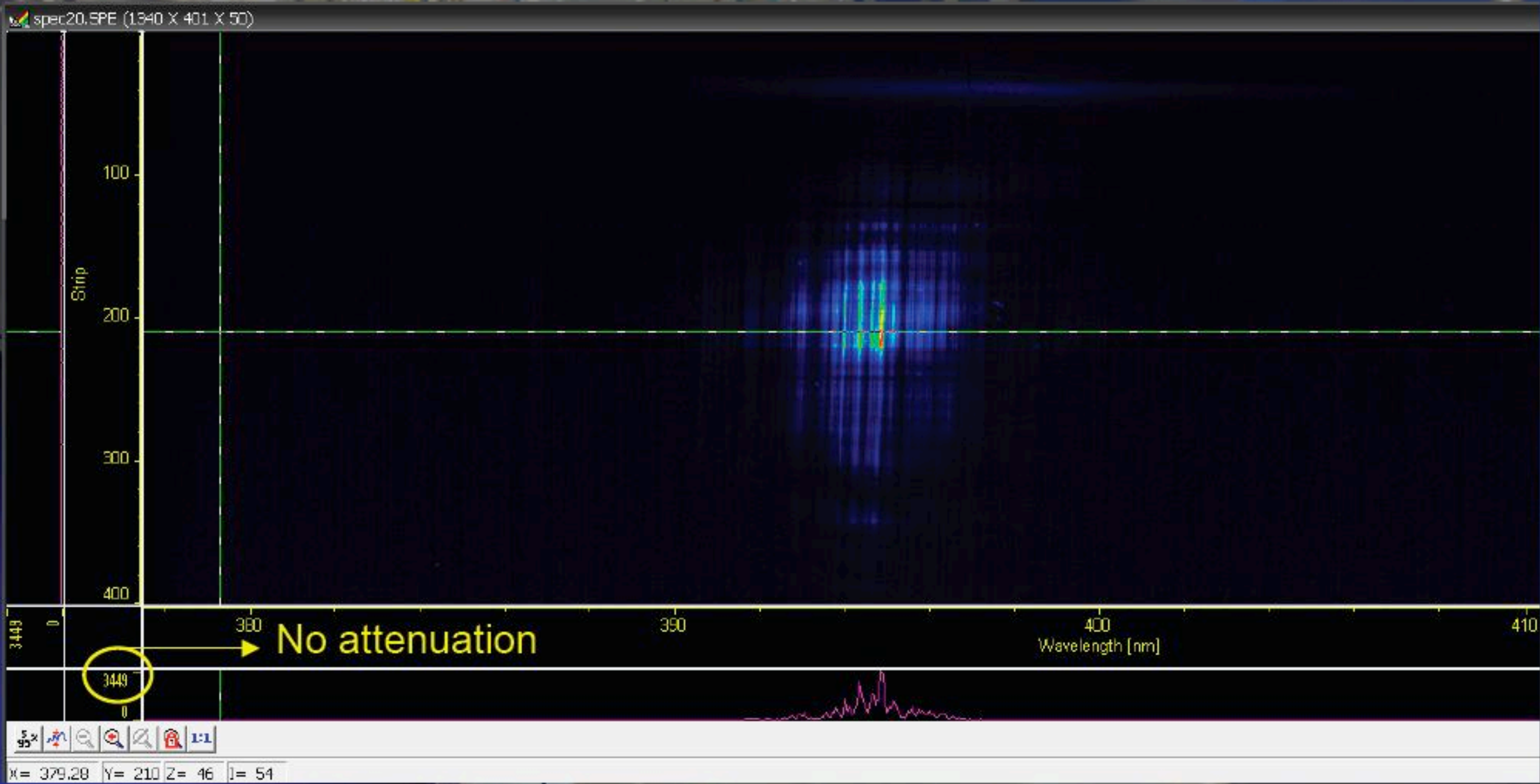




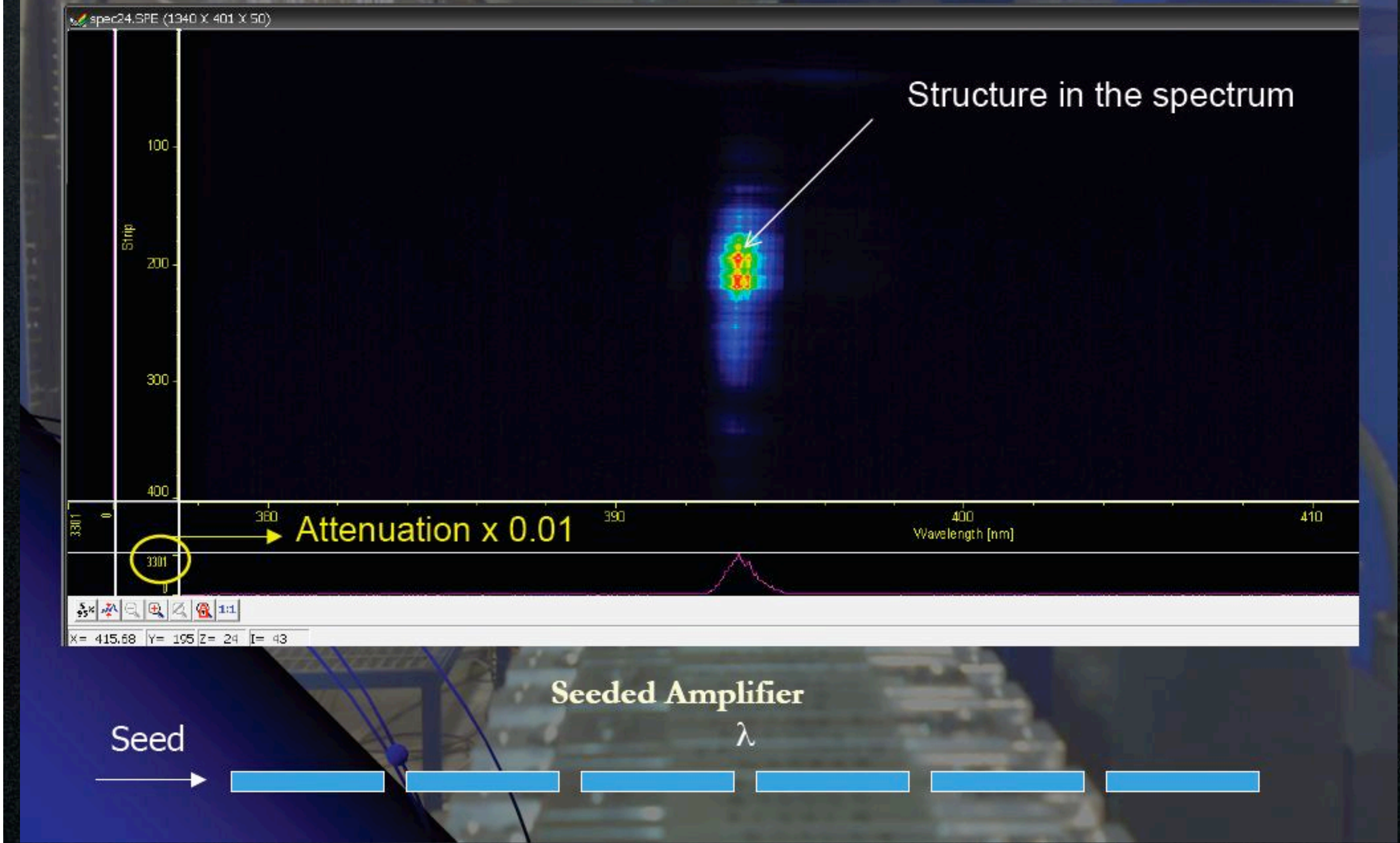
Beam parameters	
Emittance (mm-mrad)	3-4
Slice En.Spread ($\times 10^{-4}$)	2-3

SASE @ 400 nm

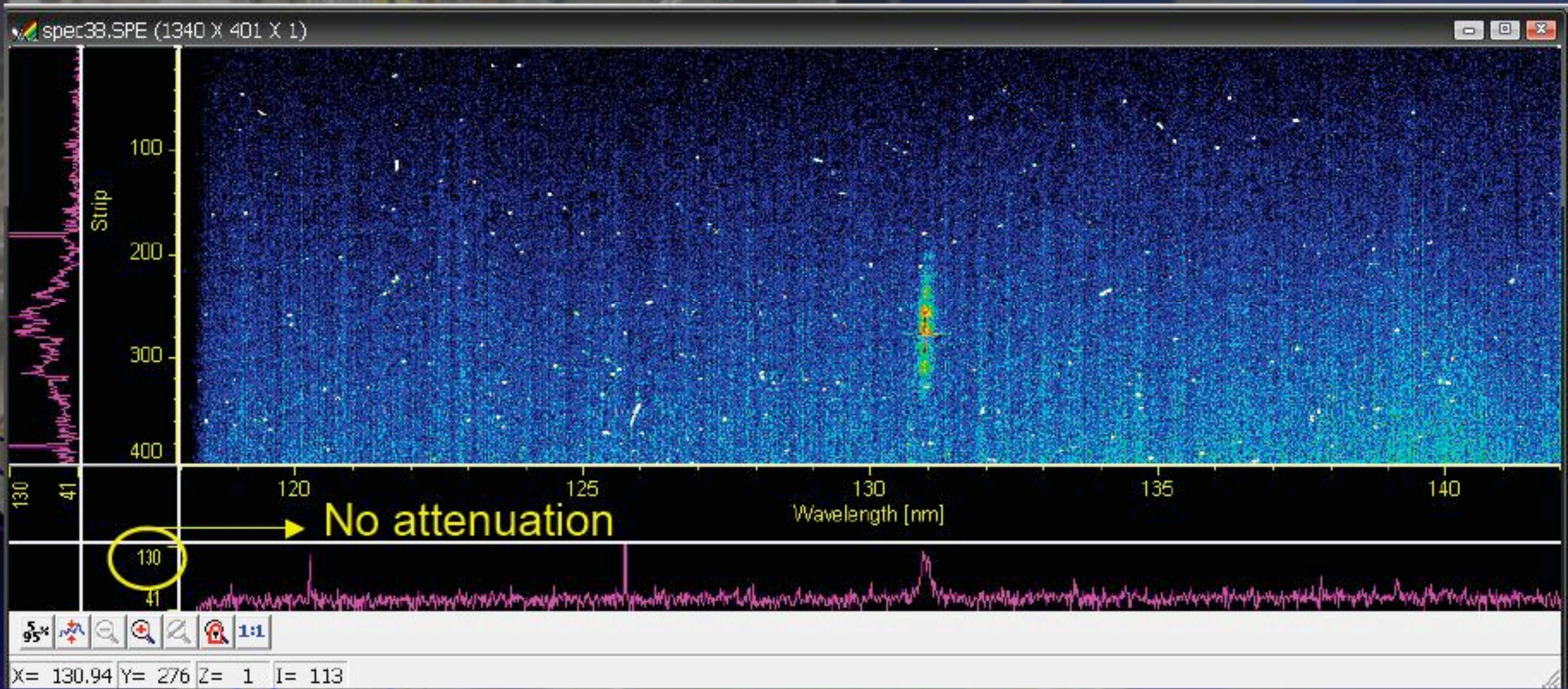
typical spectrum



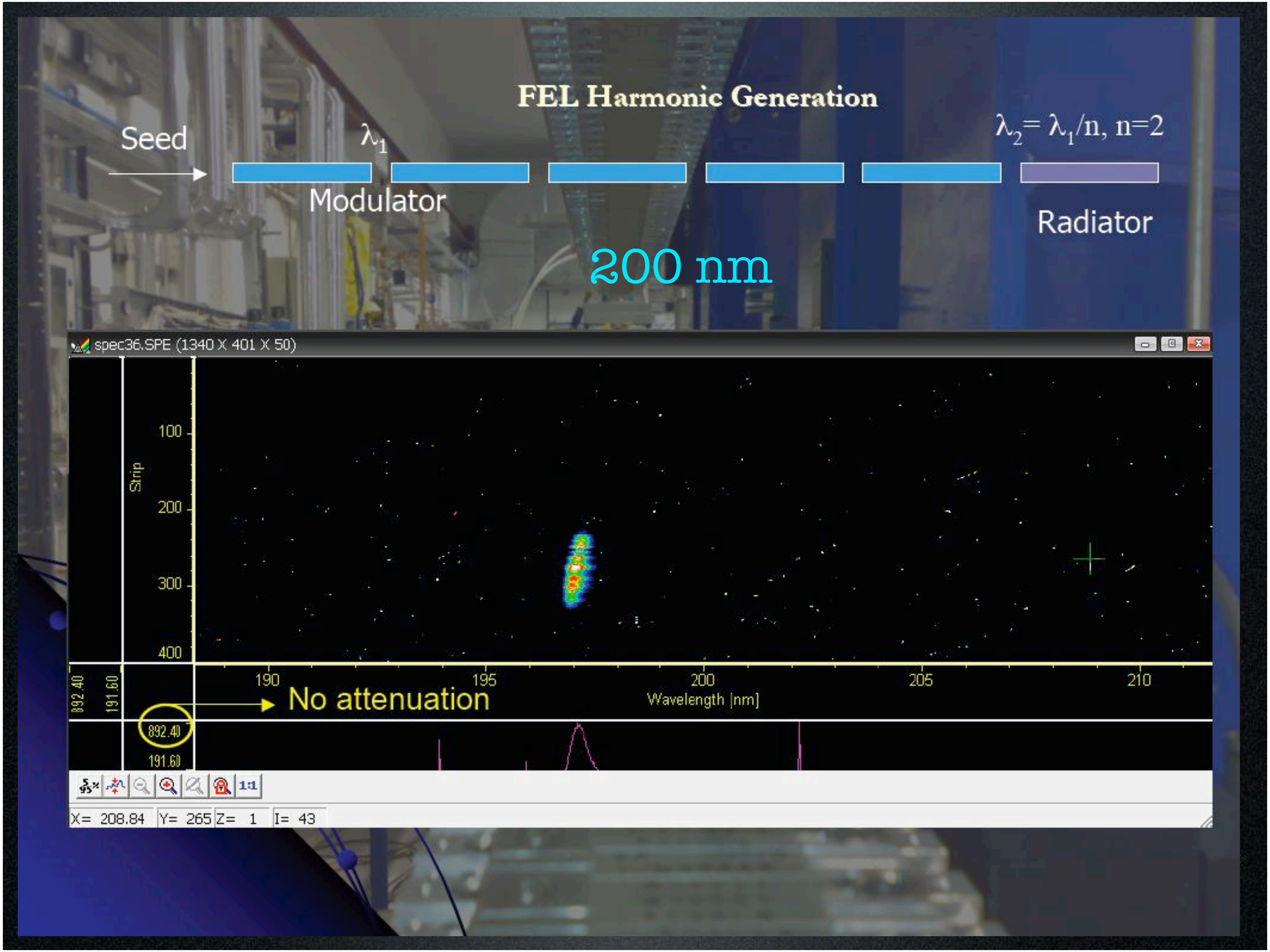
Seeded FEL


spec24.SPE (1340 X 401 X 50)
Structure in the spectrum
Strip
100
200
300
400
380
390
400
410
Wavelength [nm]
Attenuation x 0.01
3301
X= 415.68 Y= 195 Z= 24 I= 43
Seeded Amplifier
λ
Seed

3° harmonic



spec38.SPE (1340 X 401 X 1)
Strip
100
200
300
400
130
41
120
125
130
135
140
Wavelength [nm]
No attenuation
130
41
X= 130.94 Y= 276 Z= 1 I= 113


FEL Harmonic Generation
Seed
λ_1
$\lambda_2 = \lambda_1/n$, n=2
Modulator
Radiator
200 nm
spec36.SPE (1340 X 401 X 50)
Strip
100
200
300
400
190
195
200
205
210
Wavelength [nm]
No attenuation
892.40
191.60
X= 208.84
Y= 265
Z= 1
I= 43

Laser Comb

(Giant microbunch instability)

Laser Comb: a train of THz bunches

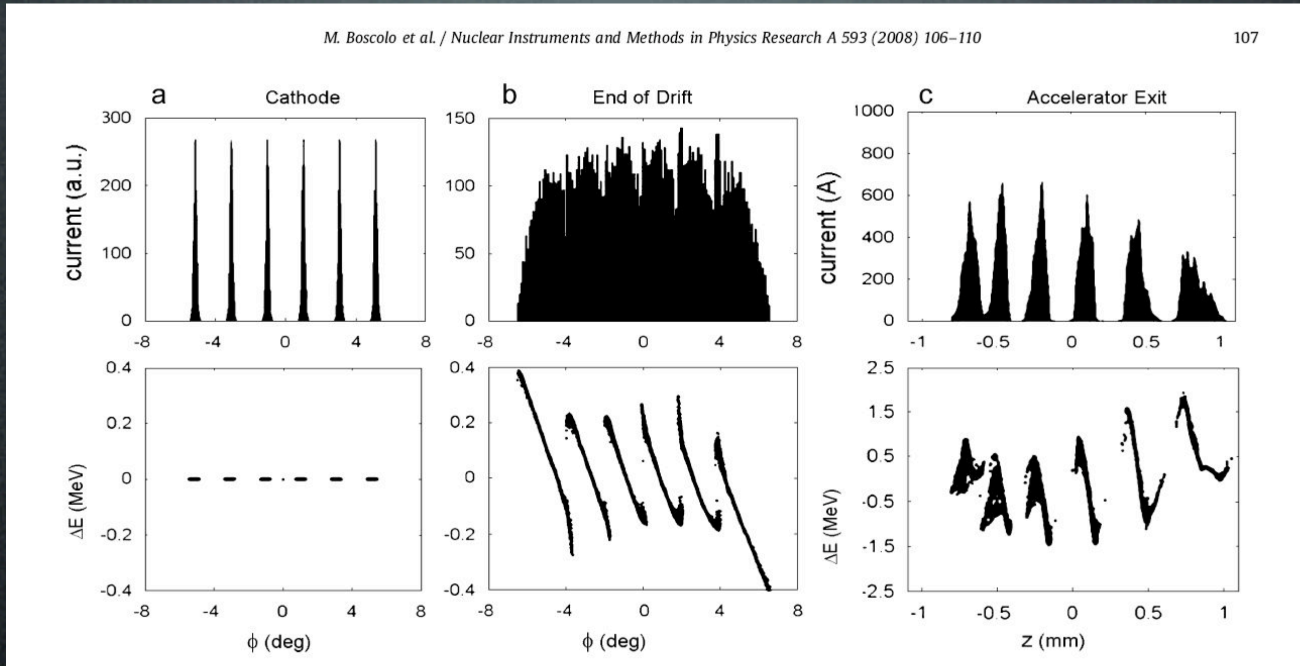
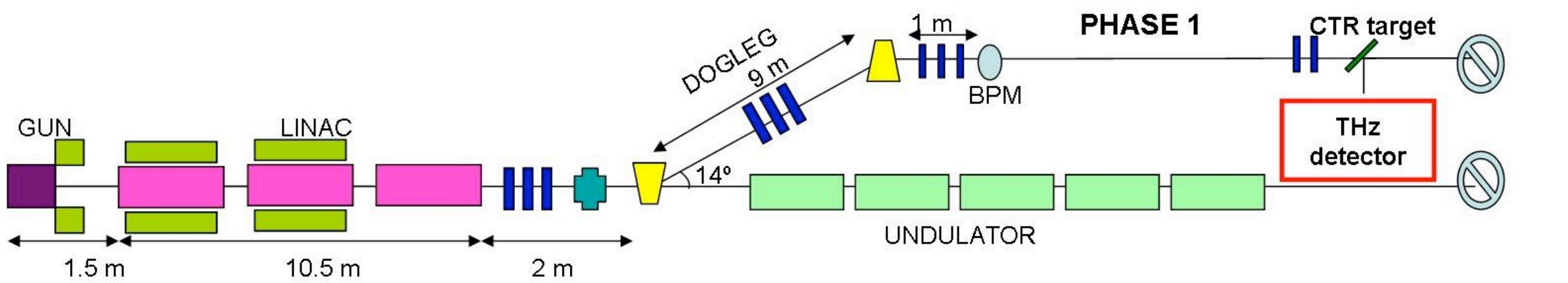
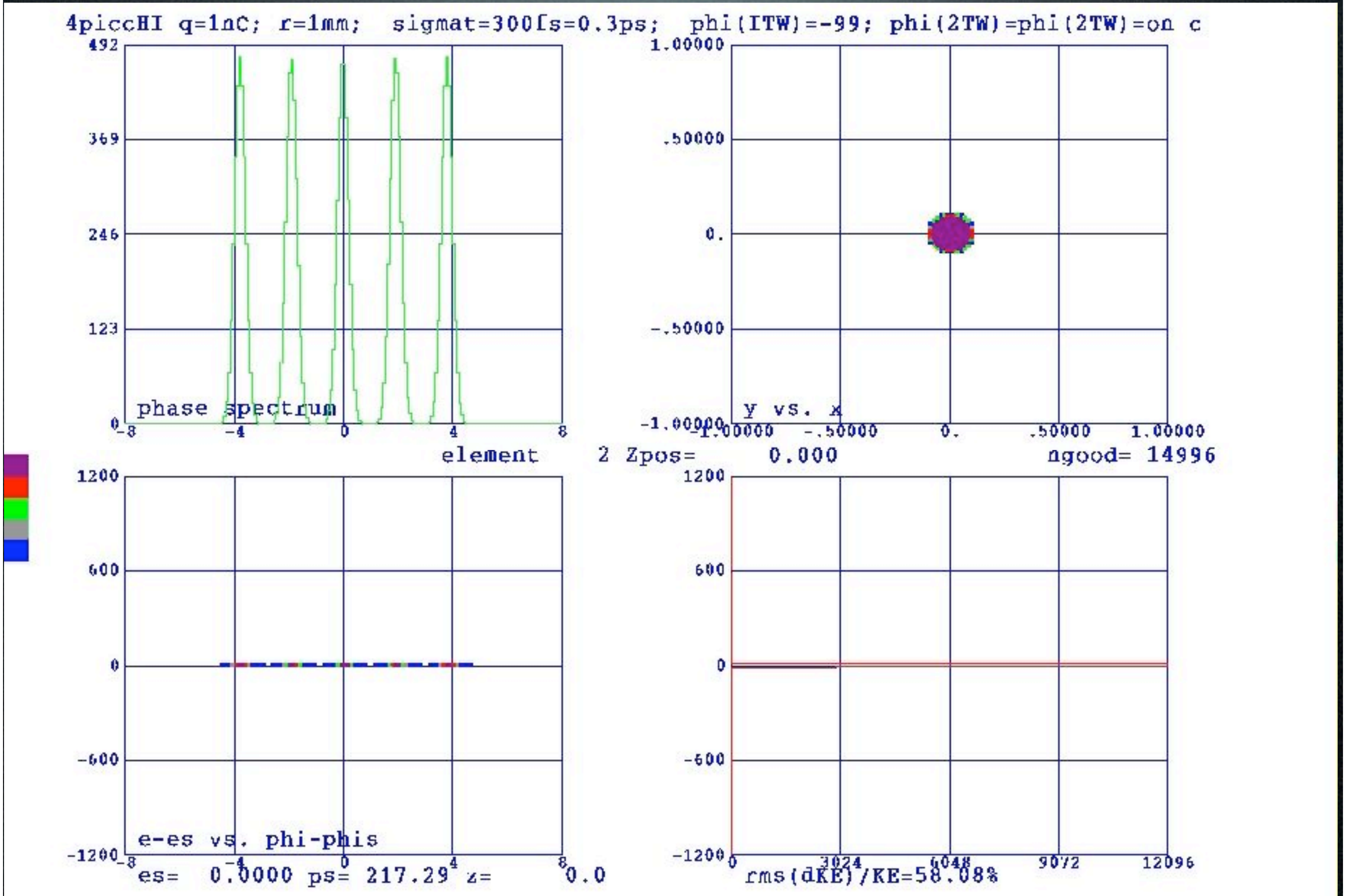


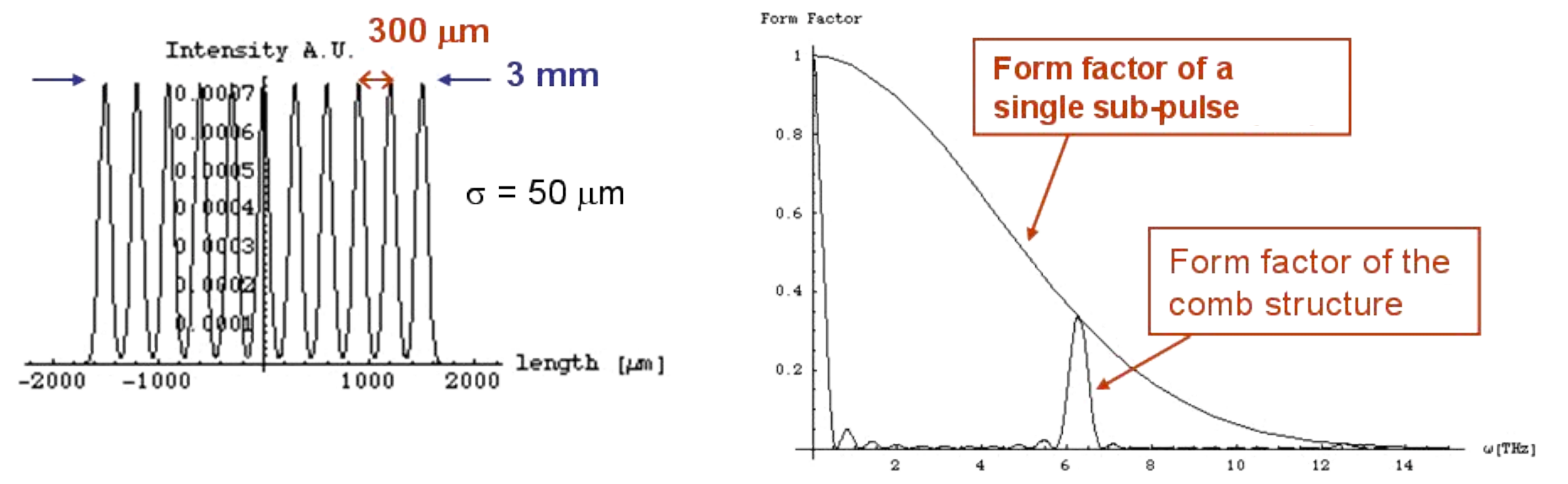
Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).



- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)


4piccHI q=1nC; r=1mm; sigmat=300fs=0.3ps; phi(1TW)=-99; phi(2TW)=phi(2TW)=on c
phase spectrum
y vs. x
element 2 Zpos= 0.000
ngood= 14996
e-es vs. phi-phis
es= 0.0000 ps= 217.29 z= 0.0
rms(dKE)/KE=58.08%

THz source



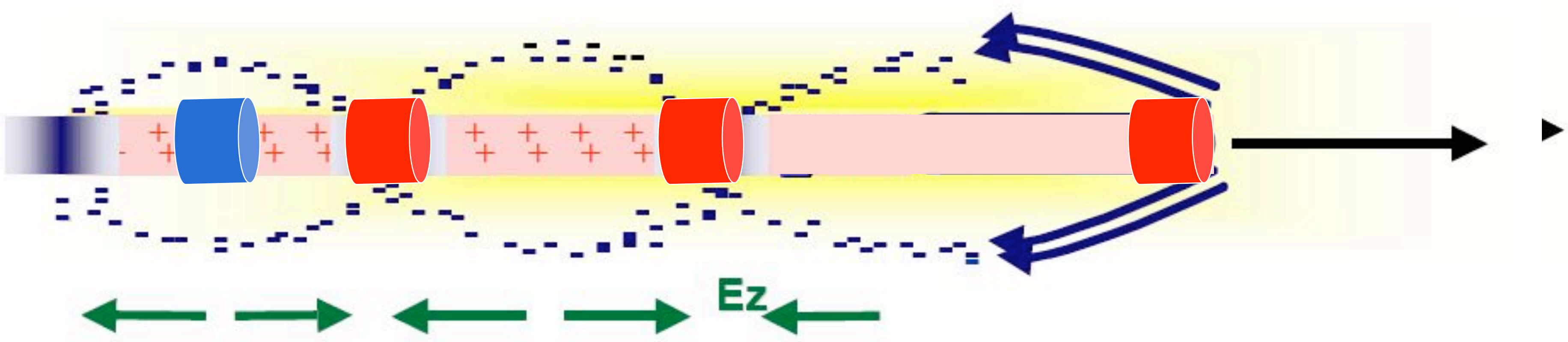
THz radiation can be easily produce by means of CTR

It is difficult to put high charge in sub-ps bunches

A laser comb structure in the longitudinal laser profile can solve this problem

Plasma wakefield coherent excitation

- Space charge of drive beam displaces plasma electrons



- Plasma ions exert restoring force => Space charge oscillations

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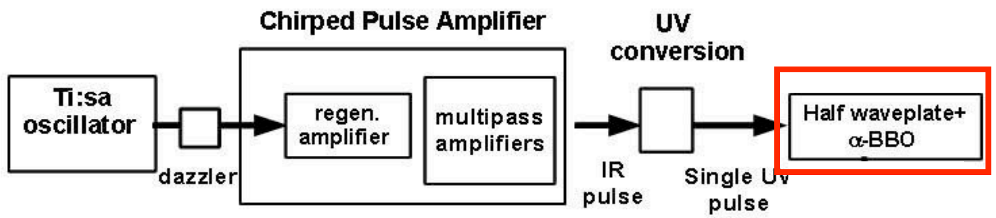
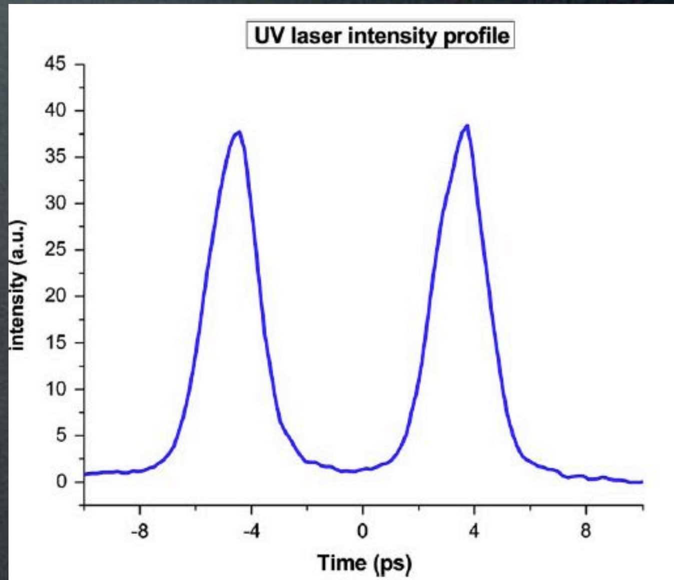
Laser comb with velocity bunching: Preliminary results at SPARC



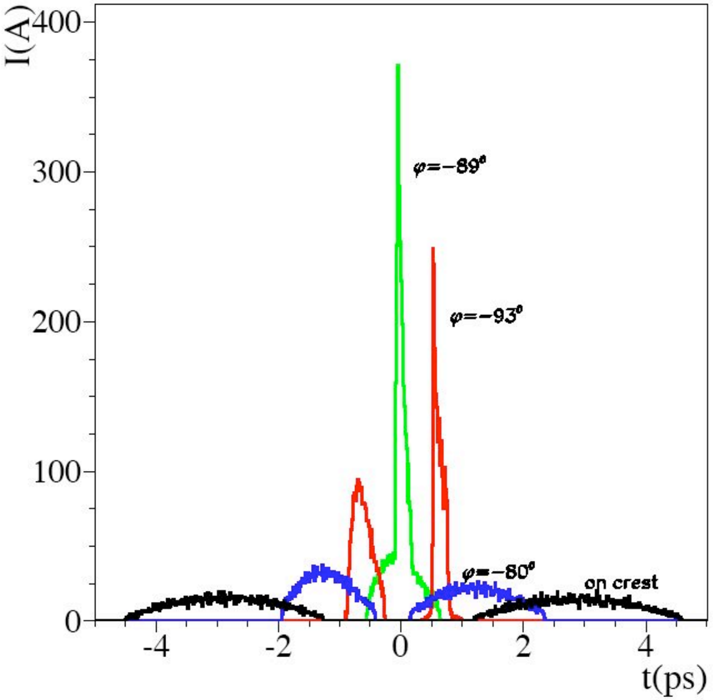
$$\Delta\tau = (n_o - n_e) L_1 / c$$



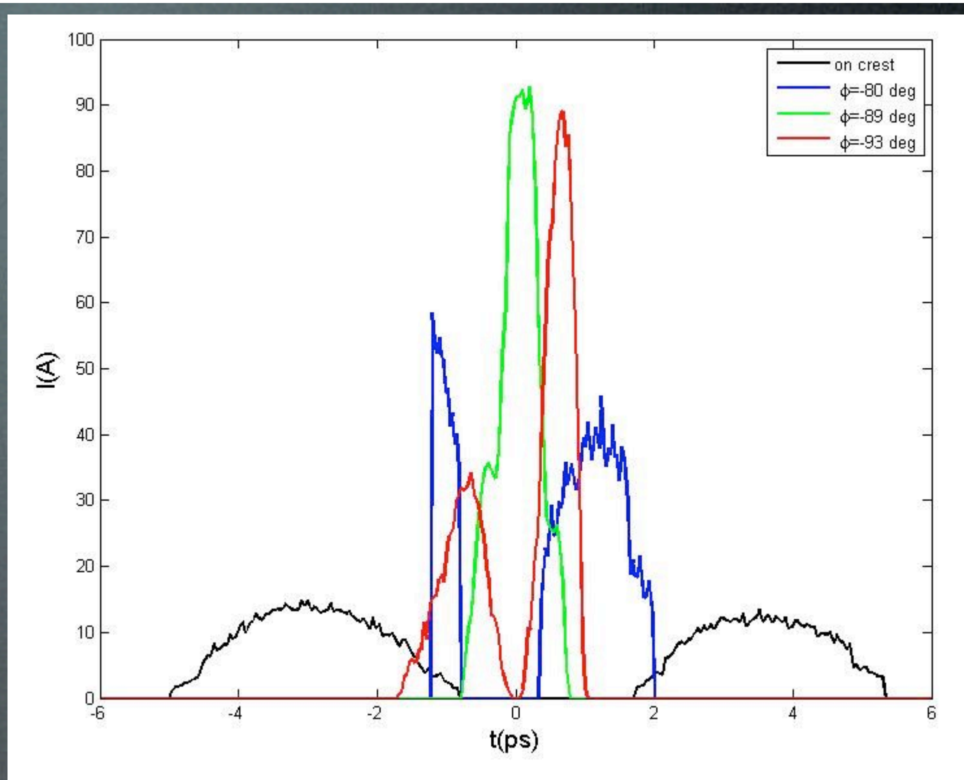
35 pC/pulse

The technique used for this purpose relies on a birefringent crystal, where the input pulse is decomposed in two orthogonally polarized pulses with a time separation proportional to the crystal length.

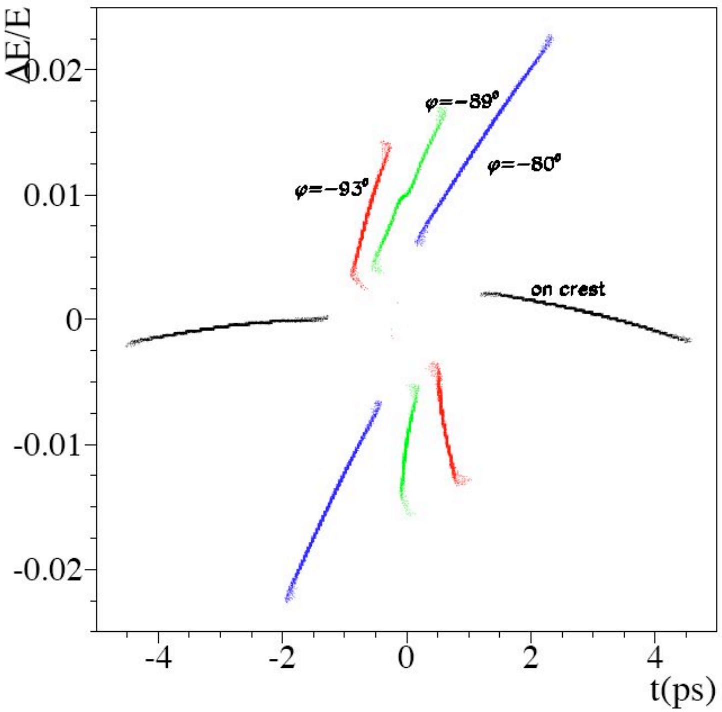
The crystal thickness is 10.353 mm



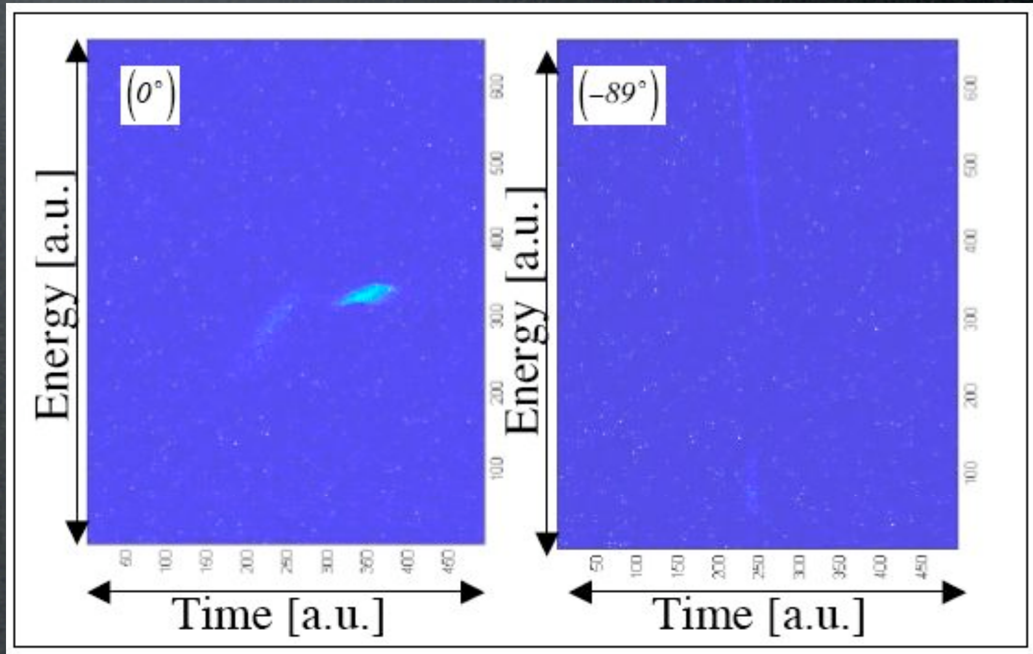
I(A)
t(ps)
φ=−89°
φ=−93°
φ=−80°
on crest



on crest
ϕ=-80 deg
ϕ=-89 deg
ϕ=-93 deg
I(A)
t(ps)



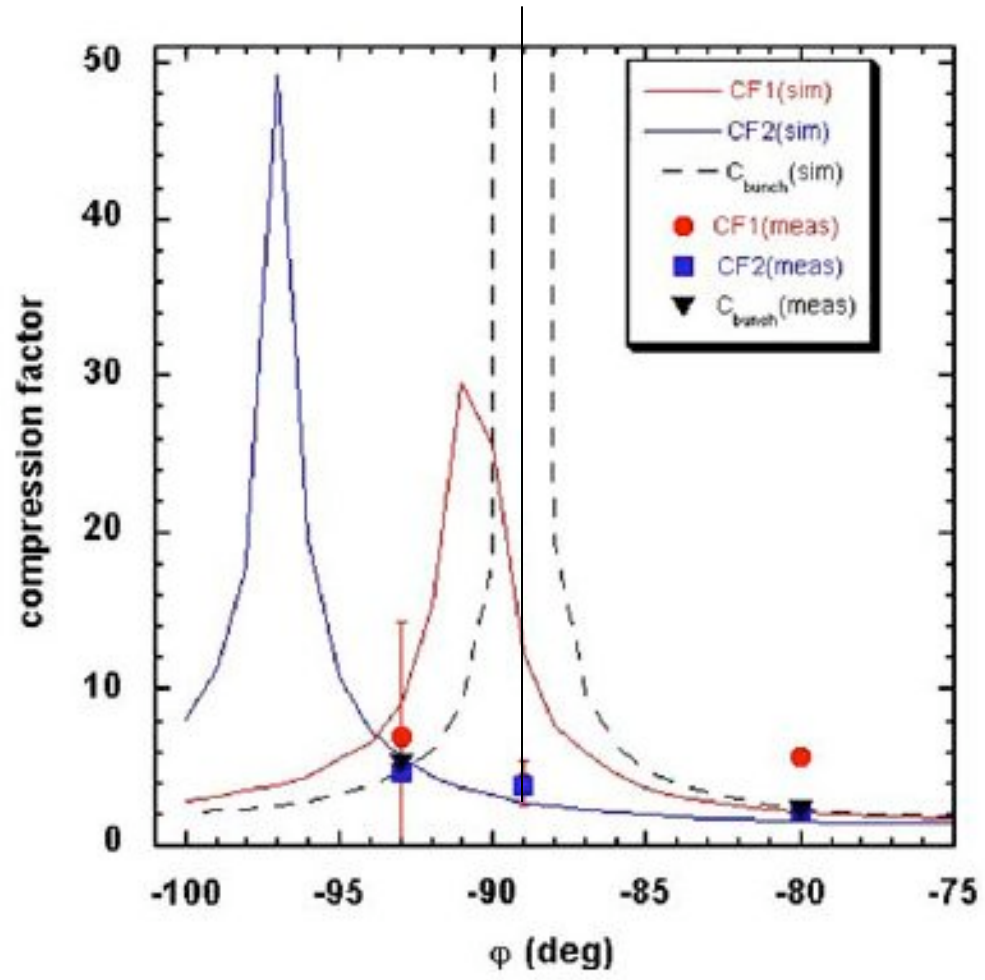
ΔE/E
t(ps)
φ=−89°
φ=−93°
φ=−80°
on crest



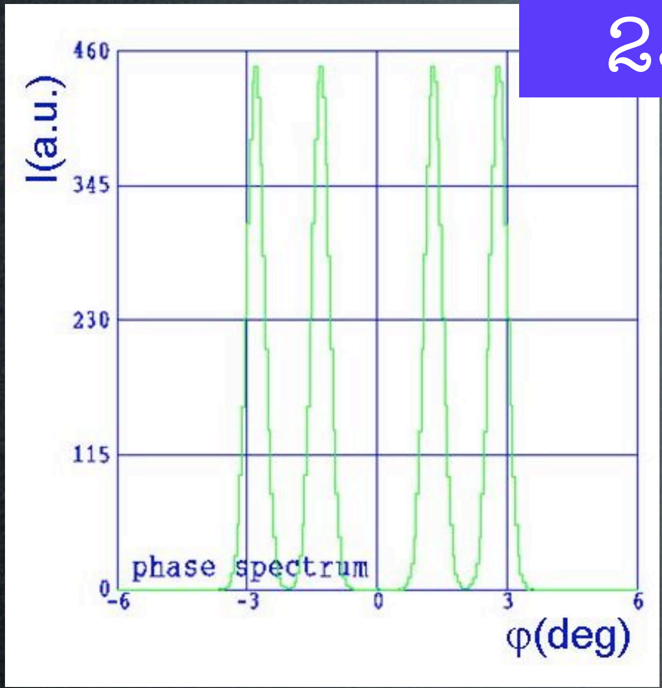
(0°)
(−89°)
Energy [a.u.]
Time [a.u.]
Energy [a.u.]
Time [a.u.]

Measured pulse length [ps].

Phase	Trailing pulse	Leading pulse	Pulse distance
0°	0.73 ± 0.01	0.83 ± 0.04	6.50 ± 0.02
−80°	0.13 ± 0.01	0.40 ± 0.01	2.79 ± 0.24
−89°	0.19 ± 0.07	0.22 ± 0.02	Overlapped
−93°	0.11 ± 0.11	0.17 ± 0.02	1.24 ± 0.24

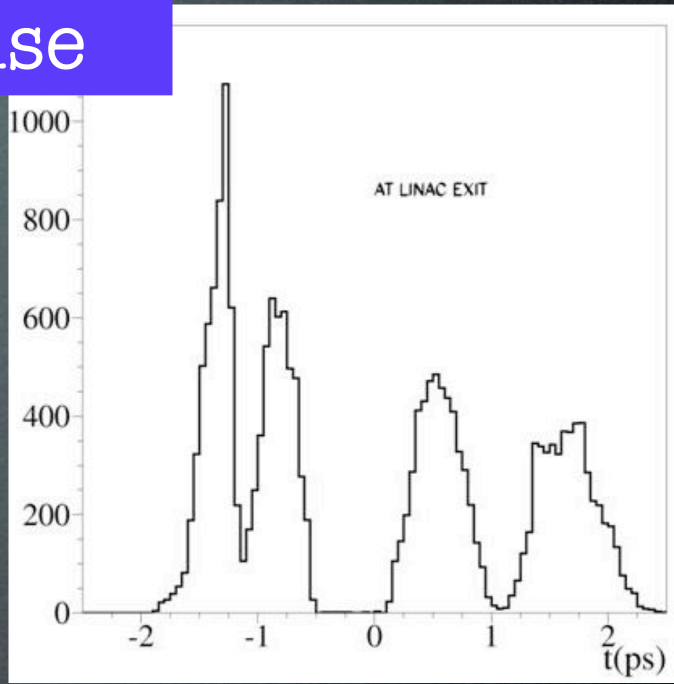


250 pC/pulse

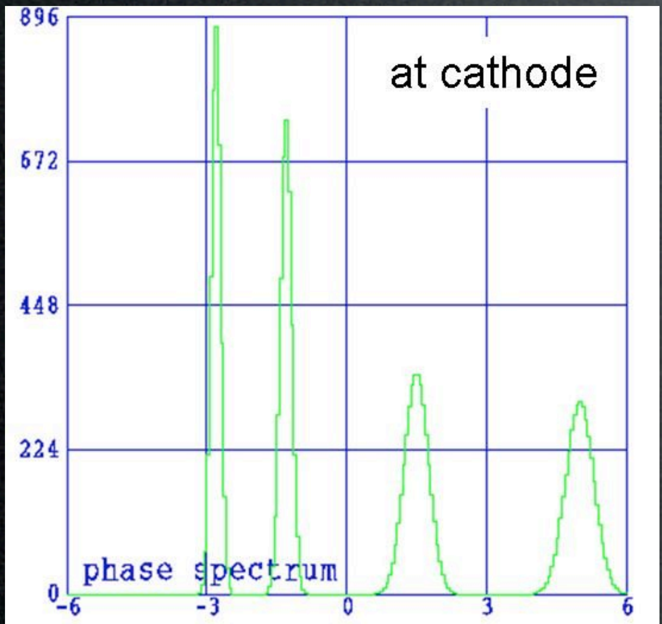


I(a.u.)
460
345
230
115
0
phase spectrum
-6
-3
0
3
6
φ(deg)

==>

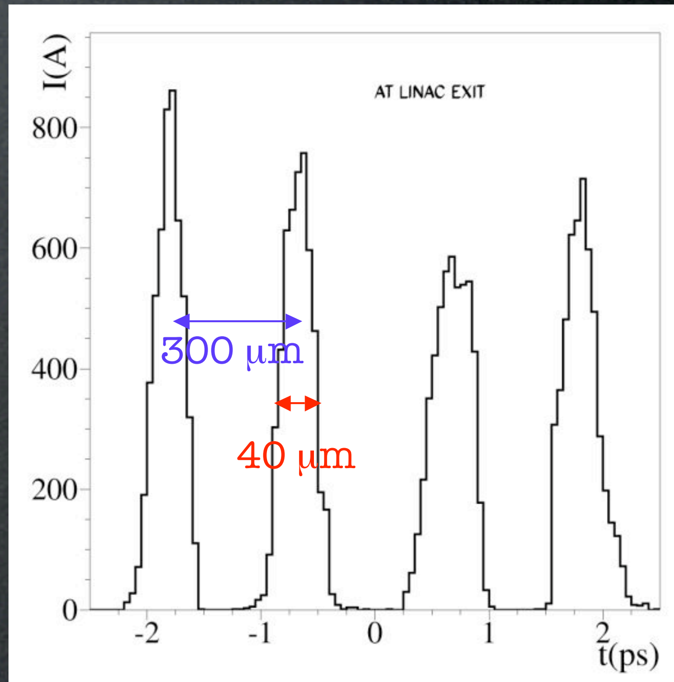


AT LINAC EXIT
1000
800
600
400
200
0
-2
-1
0
1
2
t(ps)



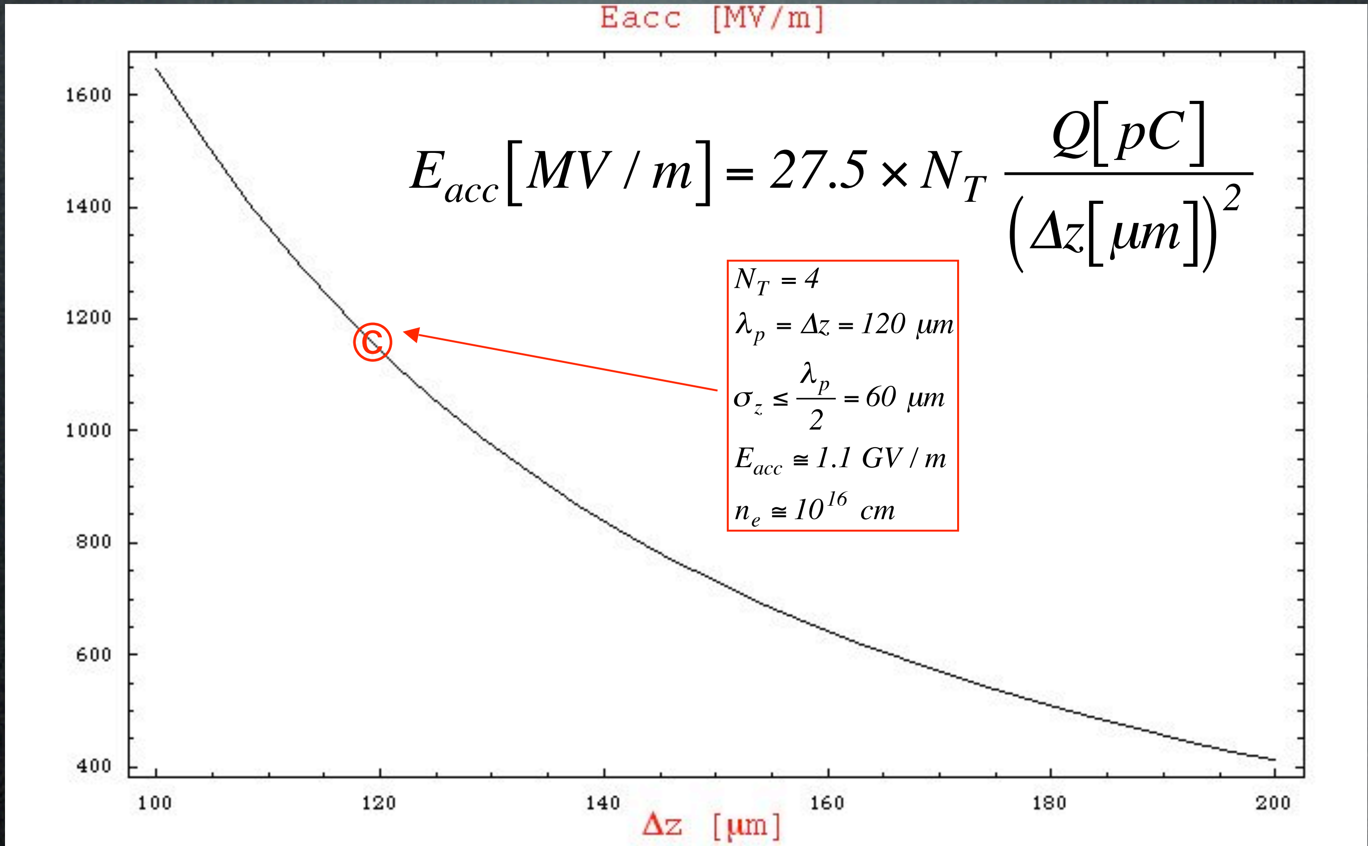
896
672
448
224
0
at cathode
phase spectrum
-6
-3
0
3
6

==>



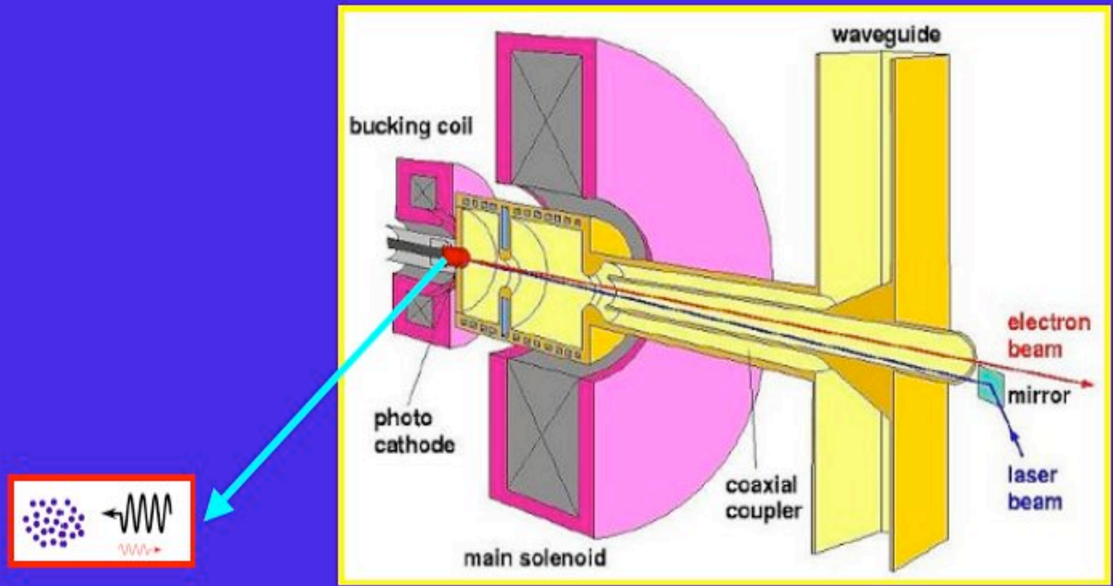
I(A)
AT LINAC EXIT
800
600
400
200
0
300 μm
40 μm
-2
-1
0
1
2
t(ps)

PWFA ==>150 pC/pulse x 4 pulses



200 MeV in 18 cm

Electron-Laser interaction near the cathode



$\lambda = 266$ nm ==> $T = 8.9\ 10^{-16}$ sec

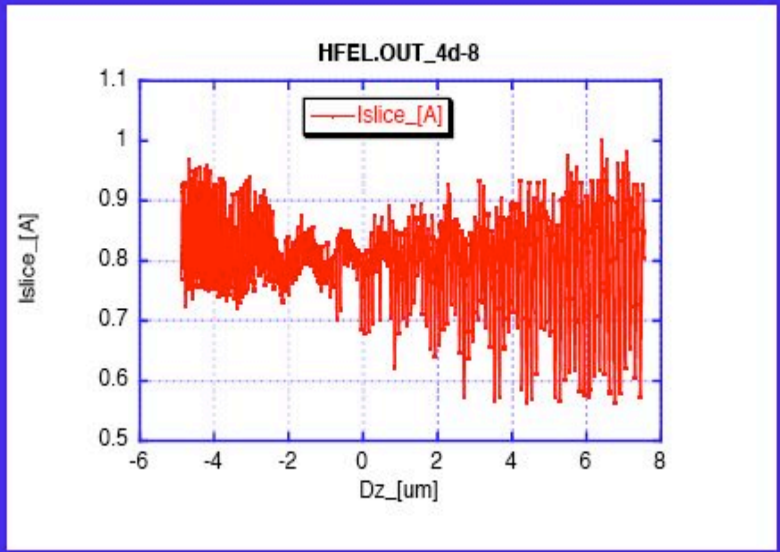
ELECTRON BEAM-LASER INTERACTION NEAR THE CATHODE IN A HIGH BRIGHTNESS PHOTOINJECTOR

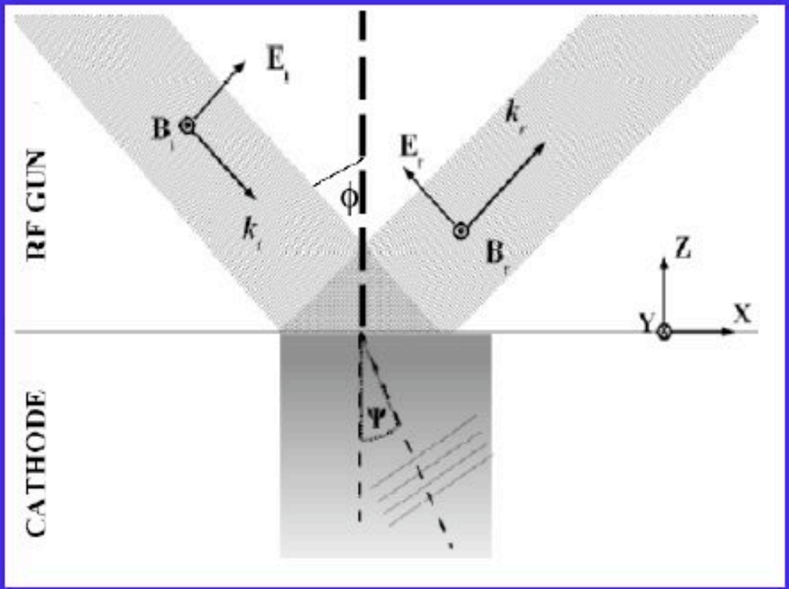
M. Ferrario, G. Gatti, INFN-LNF, Frascati, Italy; L. Serafini, INFN-Mi, Milano, Italy;
J. B. Rosenzweig, UCLA, Los Angeles, USA

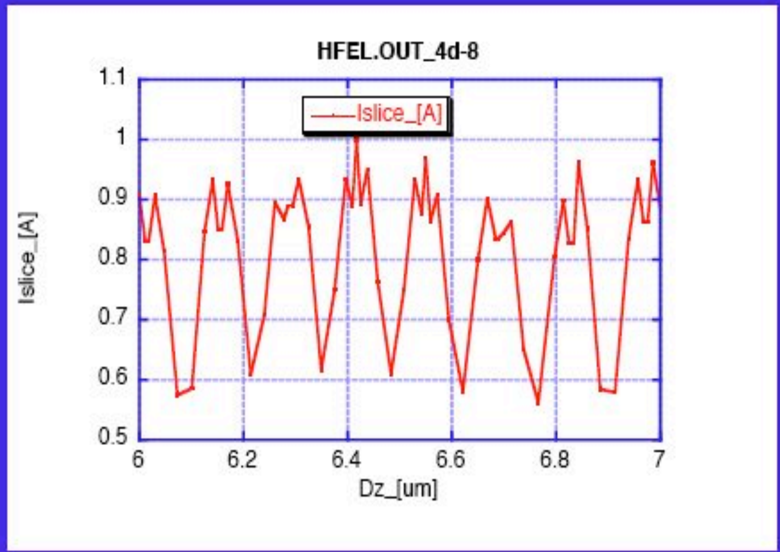
70º illumination

==> E_z = 180 MV/m

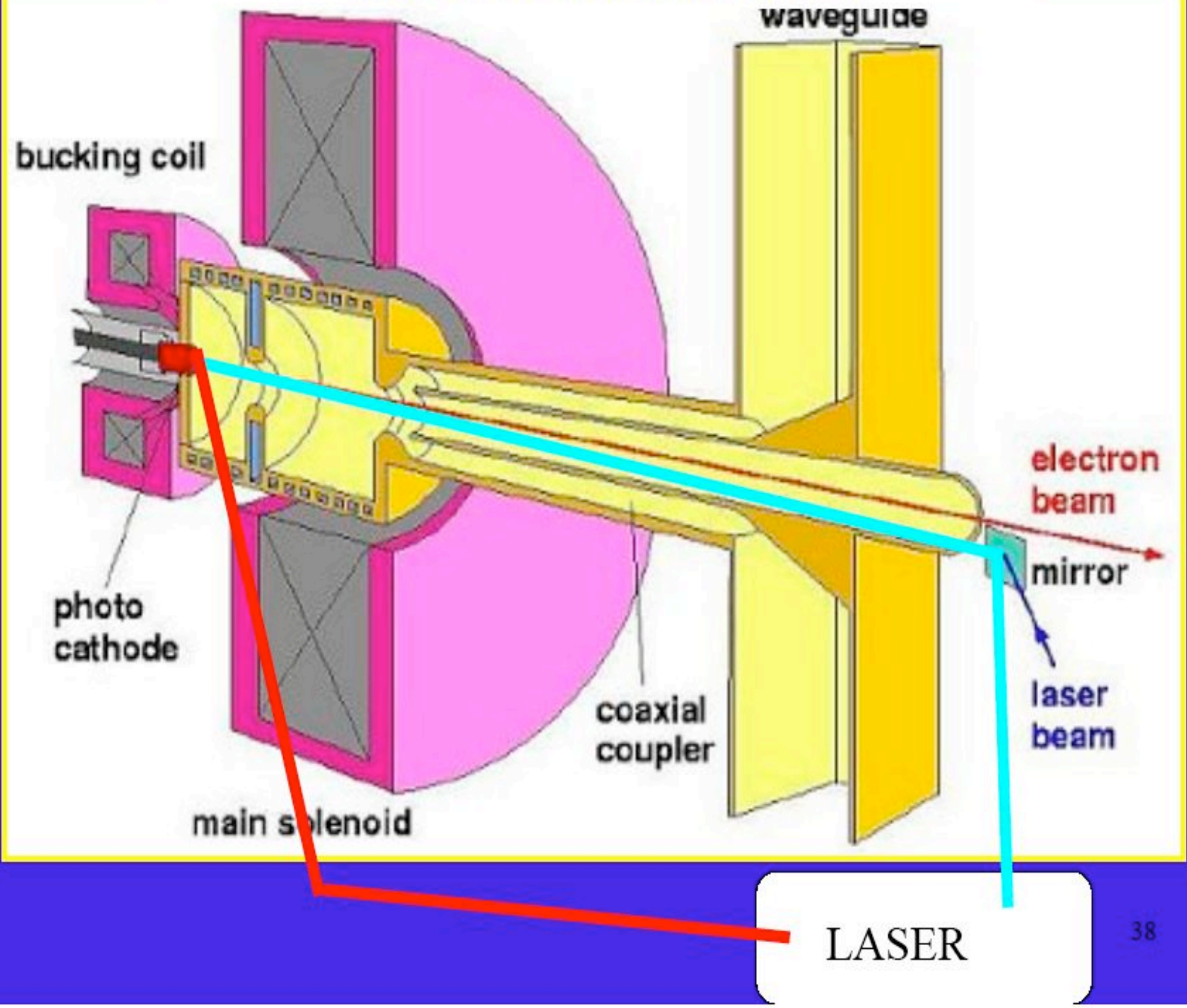
Microbunching at λ scale

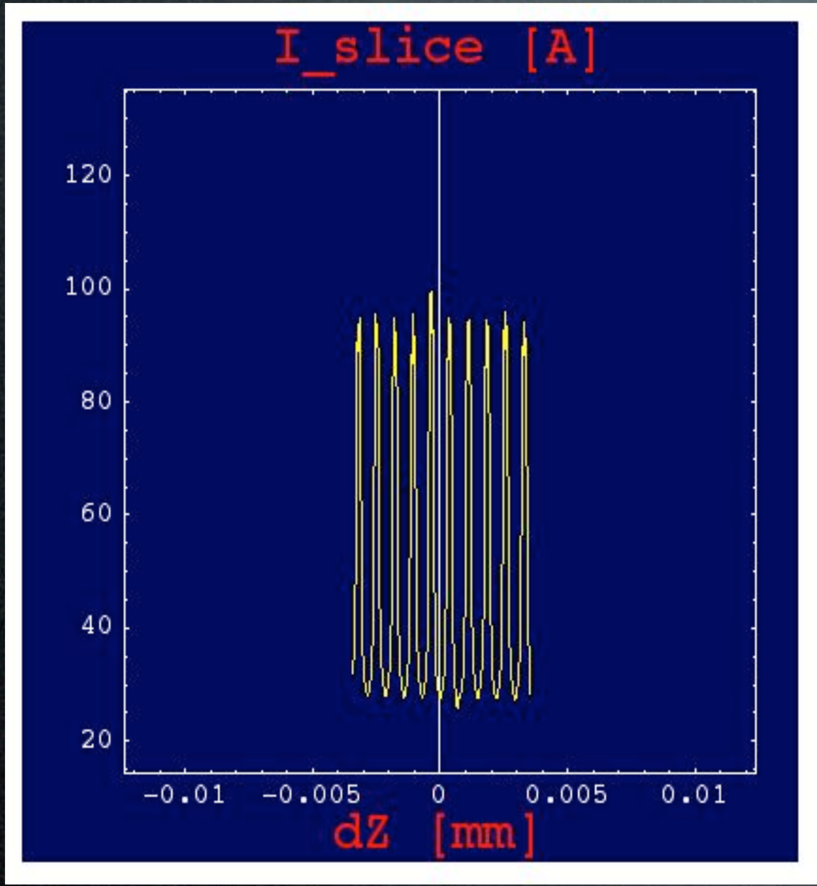


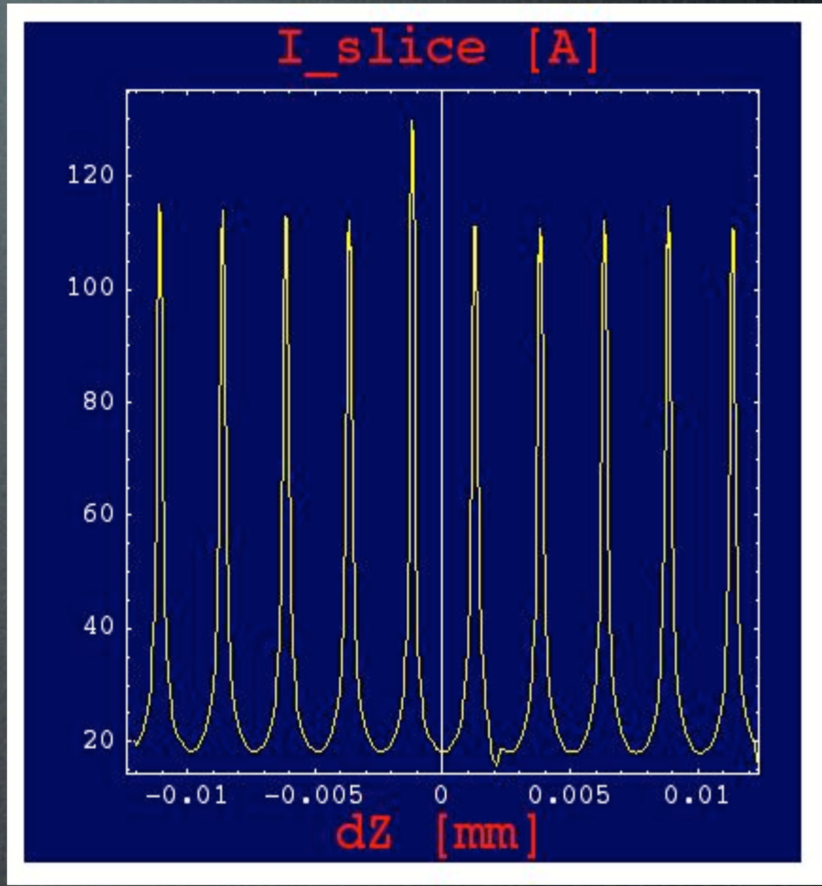


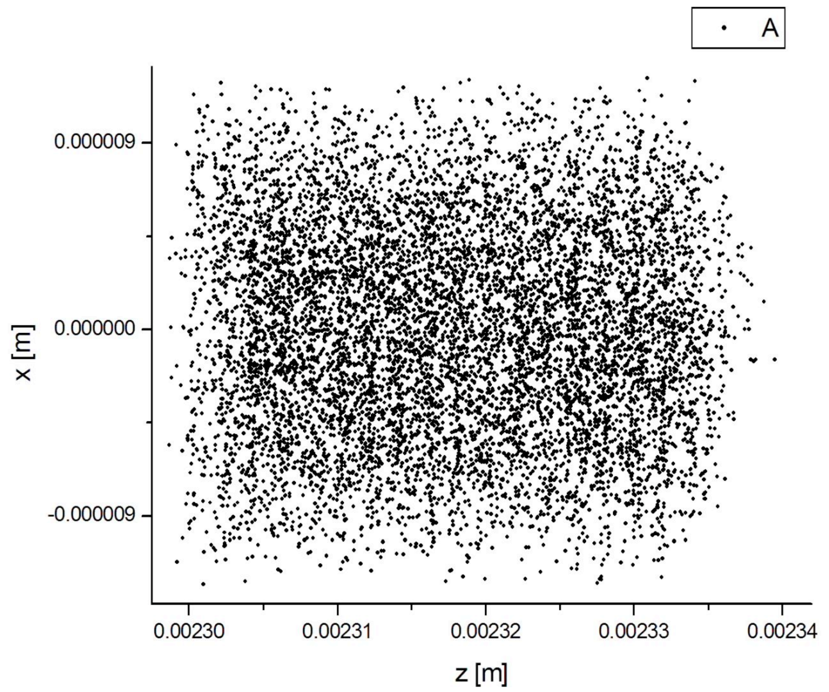


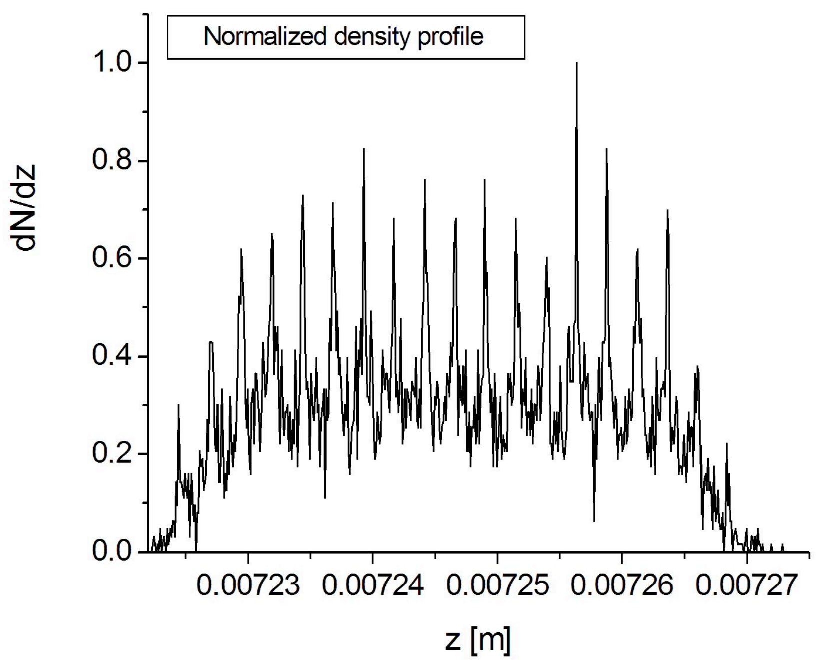
LASER CONDITIONING




I_slice [A]
120
100
80
60
40
20
-0.01
-0.005
0
0.005
0.01
dZ [mm]

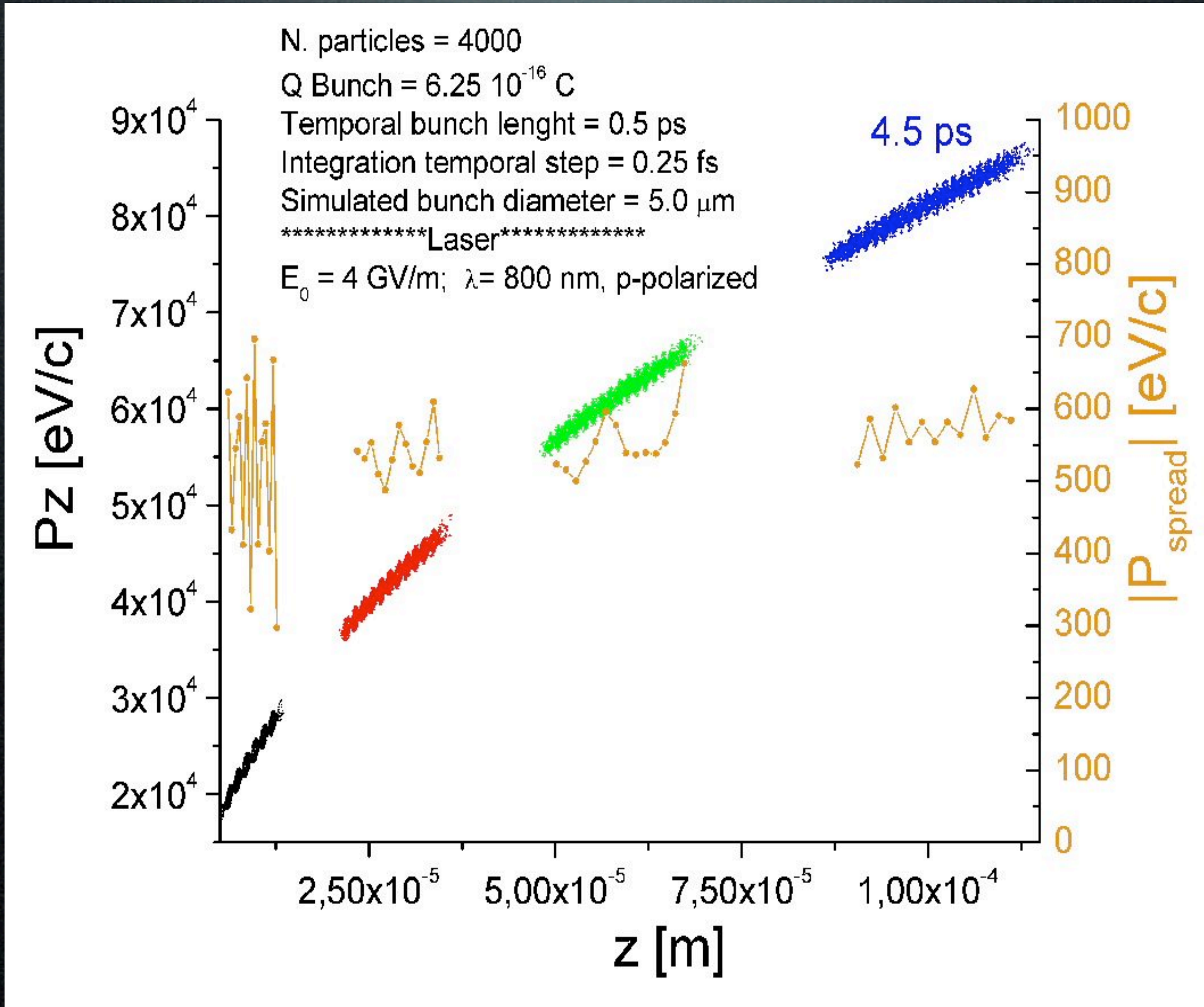

I_slice [A]
120
100
80
60
40
20
-0.01
-0.005
0
0.005
0.01
dZ [mm]



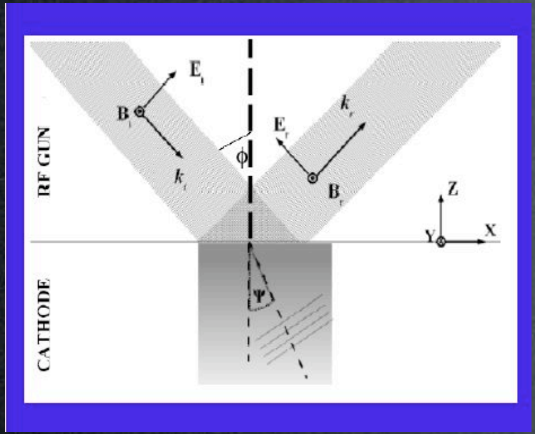


A. Bacci - RETAR

Laser IR 0.8 micron
E0 = 500 MV/m @ 72 Deg
Bunch radius = 5 micron
Laser pulse length = 2 ps
Injection phase= 29.1 Deg



N. particles = 4000
Q Bunch = 6.25 10^-16 C
Temporal bunch lenght = 0.5 ps
Integration temporal step = 0.25 fs
Simulated bunch diameter = 5.0 μm
*************Laser*************
E_0 = 4 GV/m; λ= 800 nm, p-polarized
4.5 ps
Pz [eV/c]
|P_spread| [eV/c]
z [m]
9x10^4
8x10^4
7x10^4
6x10^4
5x10^4
4x10^4
3x10^4
2x10^4
2,50x10^-5
5,00x10^-5
7,50x10^-5
1,00x10^-4
1000
900
800
700
600
500
400
300
200
100
0



Setting

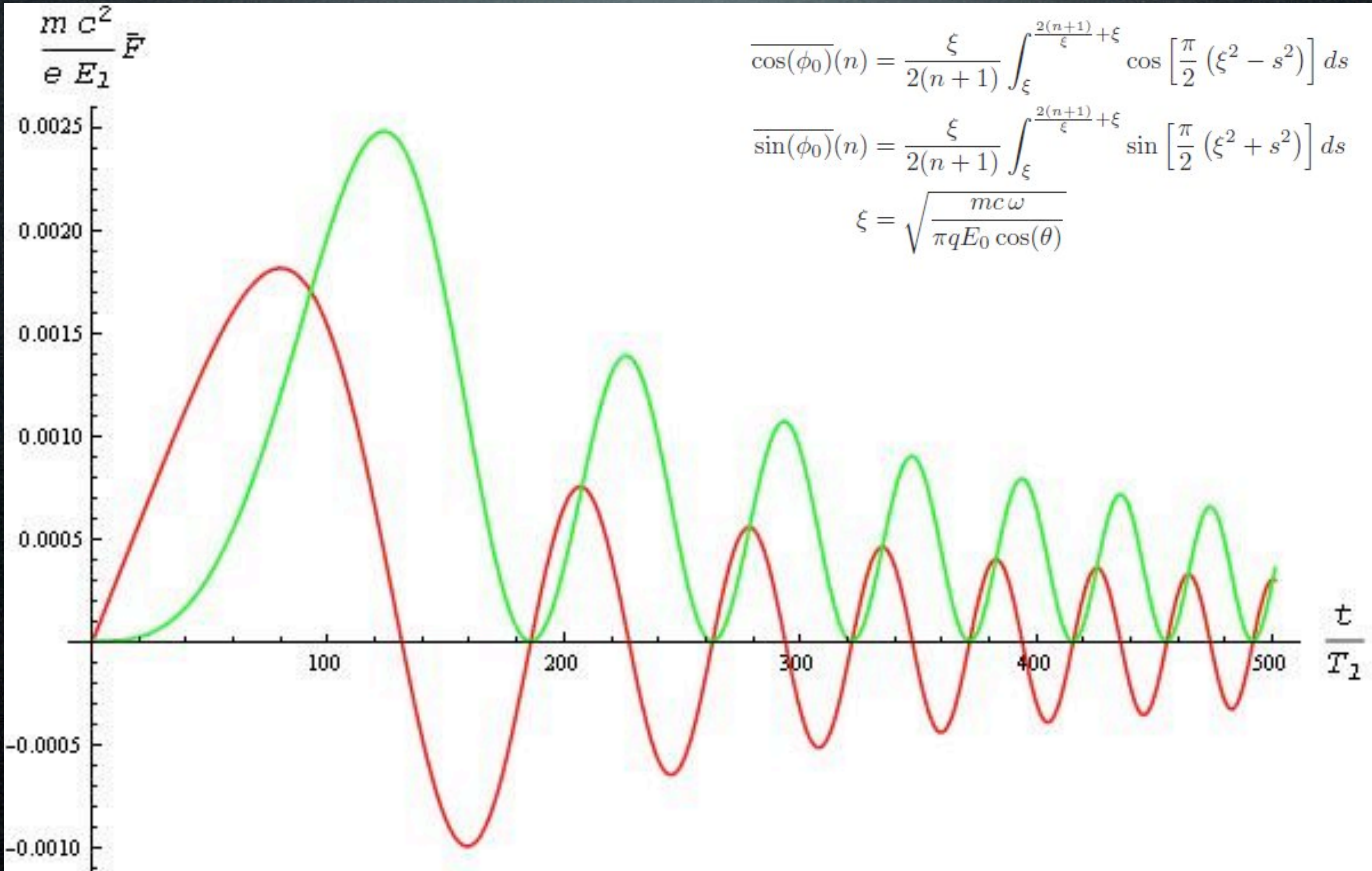
$$E_z = E_0\left[1 - \alpha \sin(\phi)\right]$$

where $\alpha = \frac{E_0 \sin(\theta)}{E_{\text{laser}}}$ and $\phi = \omega t + \frac{\omega \cos\theta}{c} z(t)$, the relative equation of motion reads:

$$\frac{1}{mc^2}\frac{d}{dz}(\Delta E_{\mathrm{T}}) = \frac{qE_0\alpha}{mc^2}\left[\sin\left(\phi_0 + \Delta\phi\right) - \sin\left(\phi_0\right)\right]$$

$$(\Delta E_{\mathrm{T}})^2 = -2mc^3 \frac{\beta_0^3\gamma_0^3}{\omega} qE_0\alpha \sin(\theta)\left\{\overline{\sin(\phi_0)}(n)\left[\sin(\Delta\phi) - \Delta\phi\right] - \overline{\cos(\phi_0)}(n)\cos(\Delta\phi)\right\} + C$$

A. R. Rossi

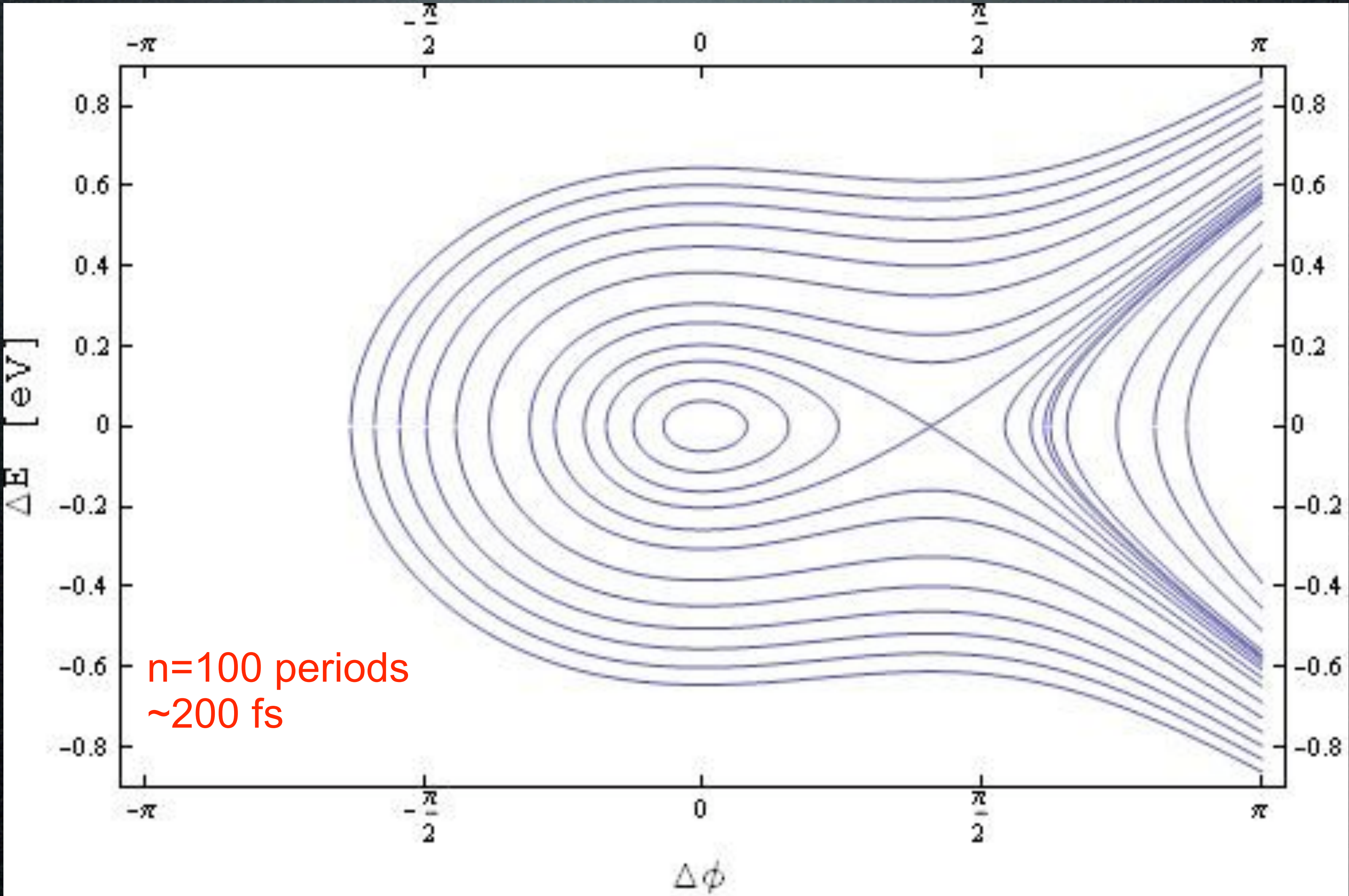


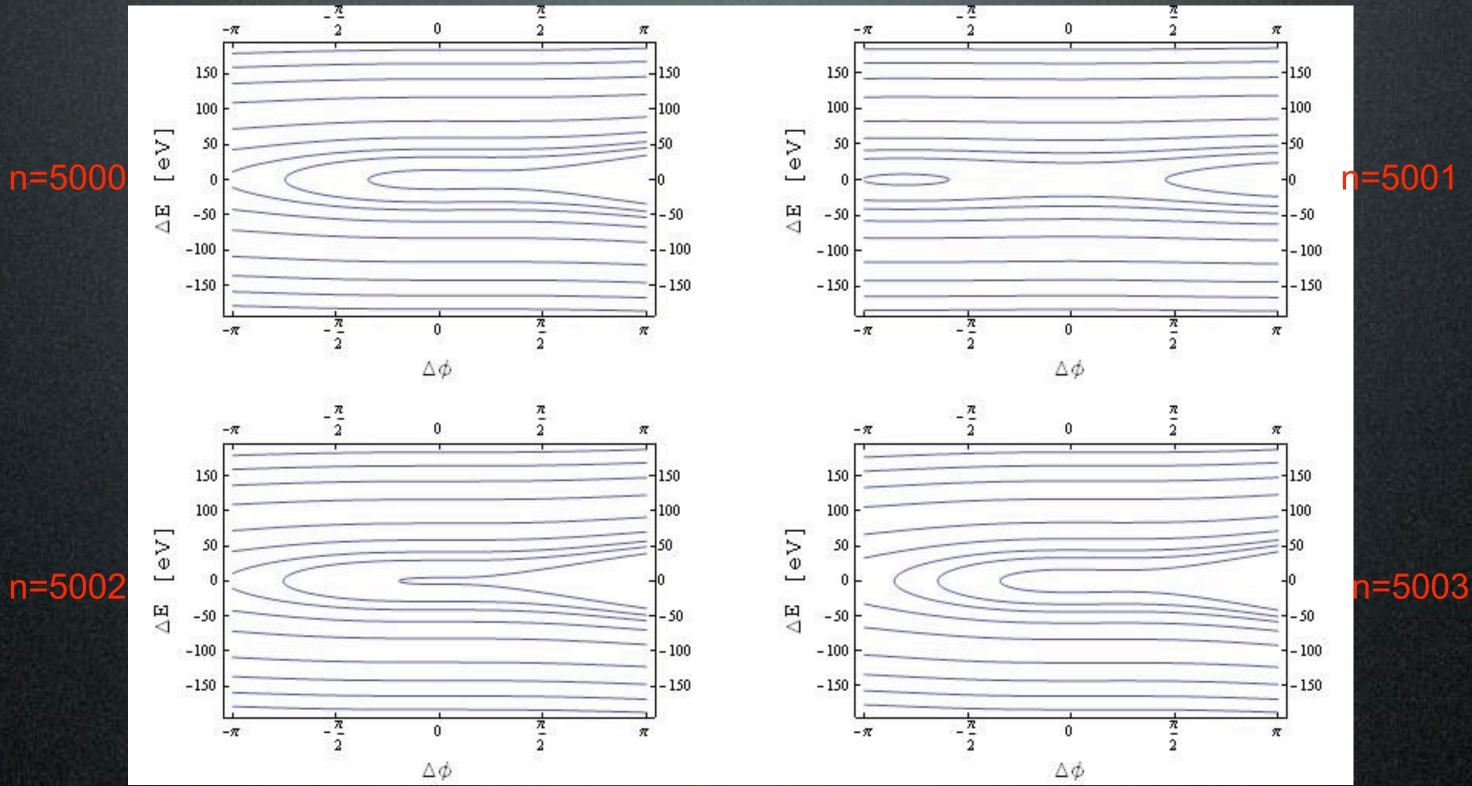
$$\overline{\cos(\phi_0)}(n) = \frac{\xi}{2(n+1)} \int_{\xi}^{\frac{2(n+1)}{\xi}+\xi} \cos\left[\frac{\pi}{2}\left(\xi^2 - s^2\right)\right] ds$$

$$\overline{\sin(\phi_0)}(n) = \frac{\xi}{2(n+1)} \int_{\xi}^{\frac{2(n+1)}{\xi}+\xi} \sin\left[\frac{\pi}{2}\left(\xi^2 + s^2\right)\right] ds$$

$$\xi = \sqrt{\frac{mc\,\omega}{\pi q E_0 \cos(\theta)}}$$

$$(\Delta E_{\mathrm{T}})^2 = -2mc^3\frac{\beta_0^3\gamma_0^3}{\omega}qE_0\alpha\sin(\theta)\left\{\overline{\sin(\phi_0)}(n)\left[\sin(\Delta\phi)-\Delta\phi\right]-\overline{\cos(\phi_0)}(n)\cos(\Delta\phi)\right\}+C$$





Changes every laser period

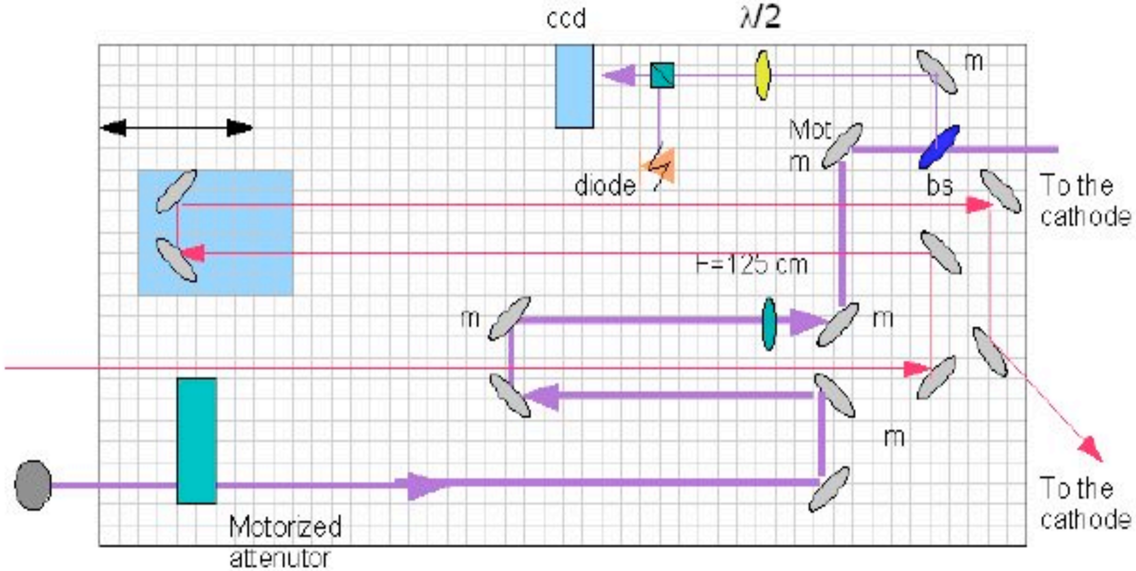
IR pulse as modulating E field

- The IR on the cathode synchronous with the UV pulse can be used to generate energy/charge modulation

- IR present characteristics:
  - Length < 1 ps
  - Energy > 10 mJ
  - Dimension diameter 10 – 0.1 mm
  - E field 2-200 MV/m

Gun table

IR optical transfer line



m = hr mirror 45 deg 266 nm

bs = thin beam splitter

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Multiphoton Photoemission from a Copper Cathode Illuminated by Ultrashort Laser Pulses in an rf Photoinjector

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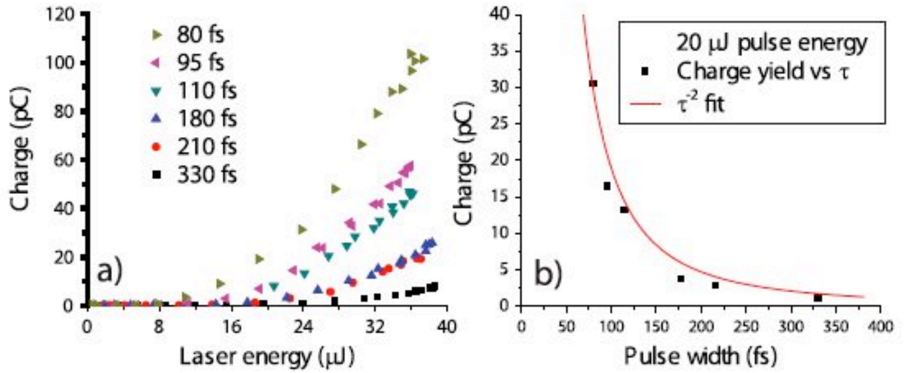

FIG. 3 (color online). (a) Yield vs different laser pulse length for 700 μm spot size at the cathode. (b) Charge as a function of pulse length for constant 20 μJ laser energy.

$$Q = J\tau A = CI^3\tau A = C\frac{E^3}{\tau^2 A^2}$$

Accelerated @ SPARC

	IR e-beam	UV e-beam
Energy	158.9 MeV	158.8 MeV
Energy spread	$7*10^{-4}$	$1*10^{-3}$
Charge	150 pC	600 pC
Charge fluctuation	15% ptp	6% ptp
Bunch length	0.9 ps rms	1.85 ps rms


Thank you