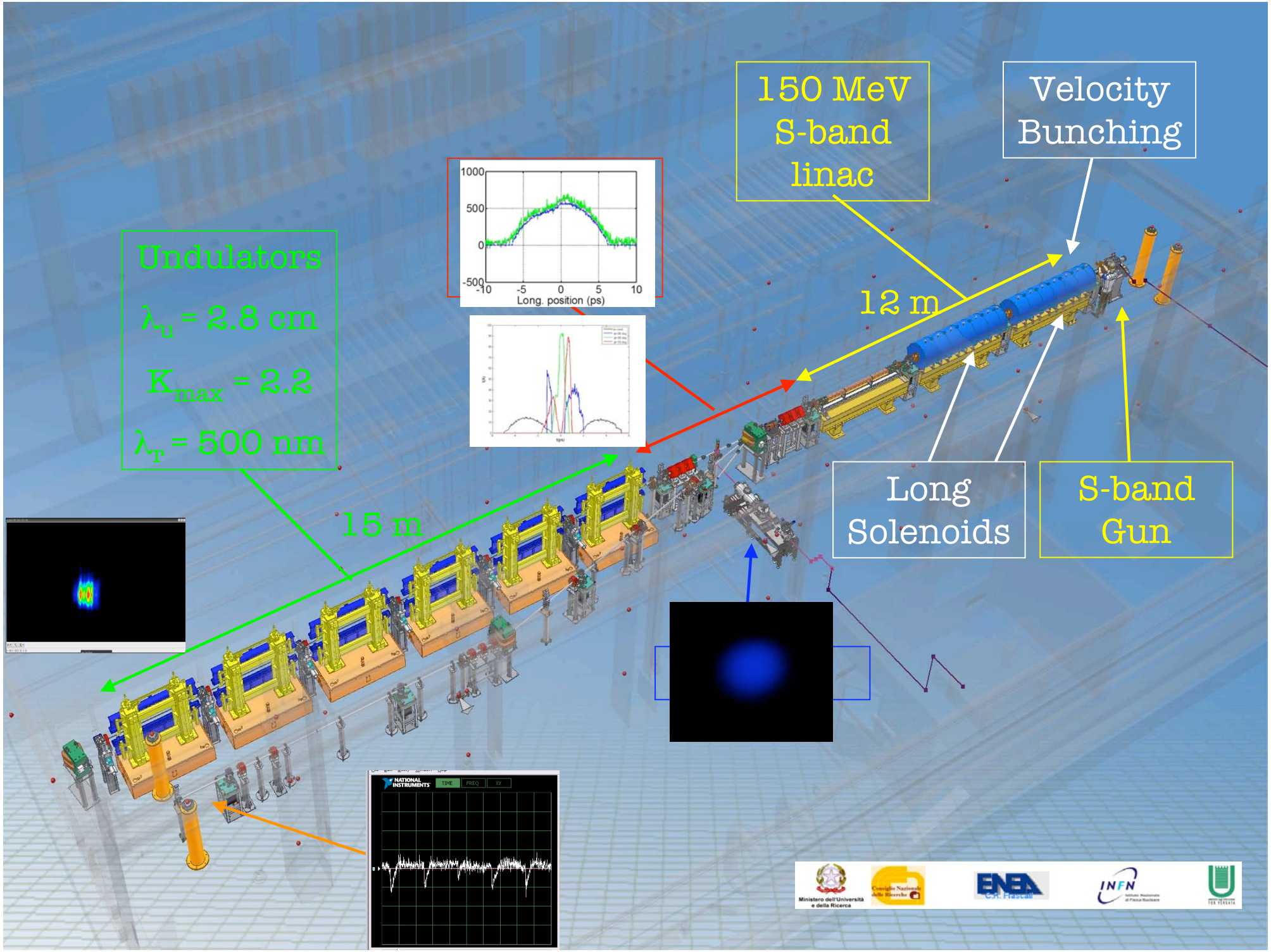
SPARC status and plans

Massimo Ferrario
on behalf of the SPARC team

3rd LI²FE Meeting - March 11, 2010


150 MeV
S-band
linac
Velocity
Bunching
Undulators
λ_u = 2.8 cm
K_{max} = 2.2
λ_r = 500 nm
12 m
15 m
Long
Solenoids
S-band
Gun
1000
500
0
-500
-10
-5
0
5
10
Long. position (ps)

High Brightness beam experiments: Velocity Bunching

PRL **104,** 054801 (2010) PHYSICAL REVIEW LETTERS week ending 5 FEBRUARY 2010

Experimental Demonstration of Emittance Compensation with Velocity Bunching

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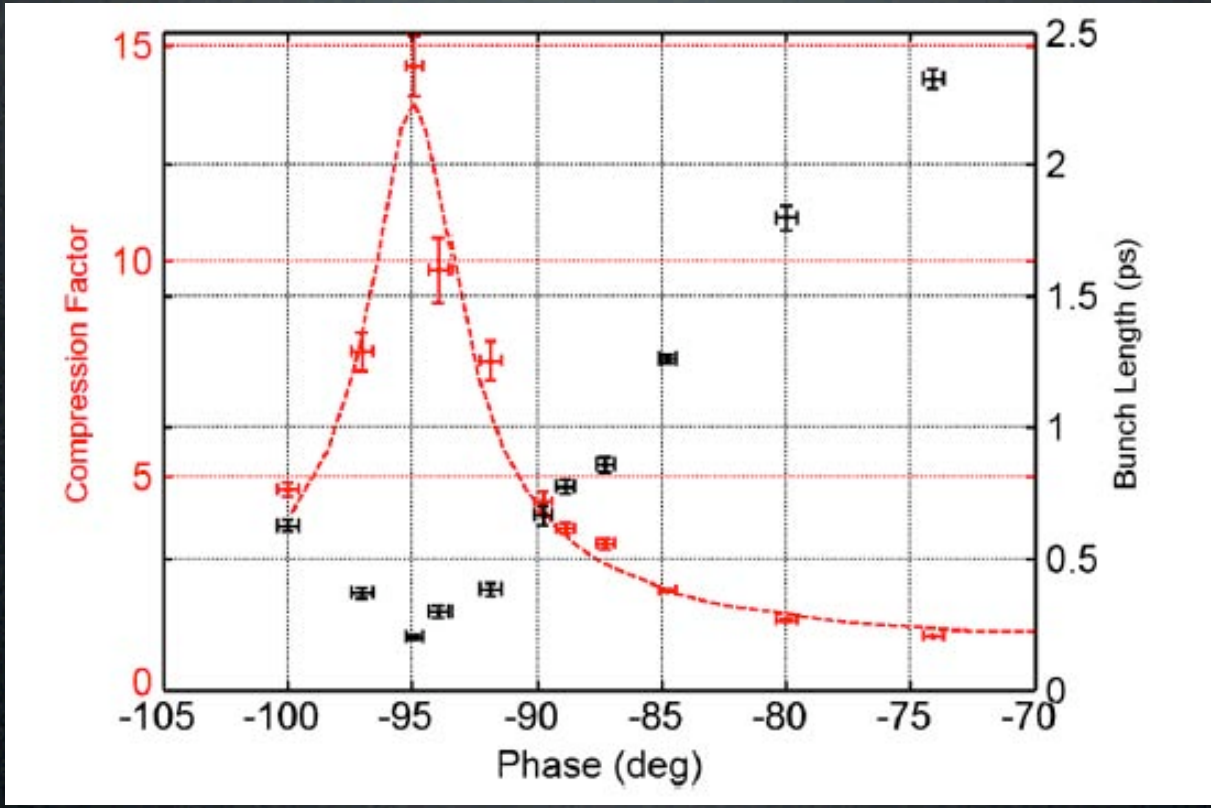
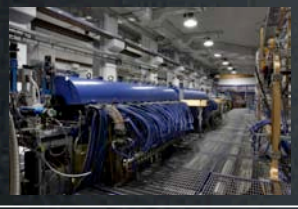




Velocity Bunching

FEL Single Spike

THz Radiation

LWFA_ext

Laser Comb → PWFA

Thomson

Blow Out

Laser Comb

Laser Comb: a train of THz bunches

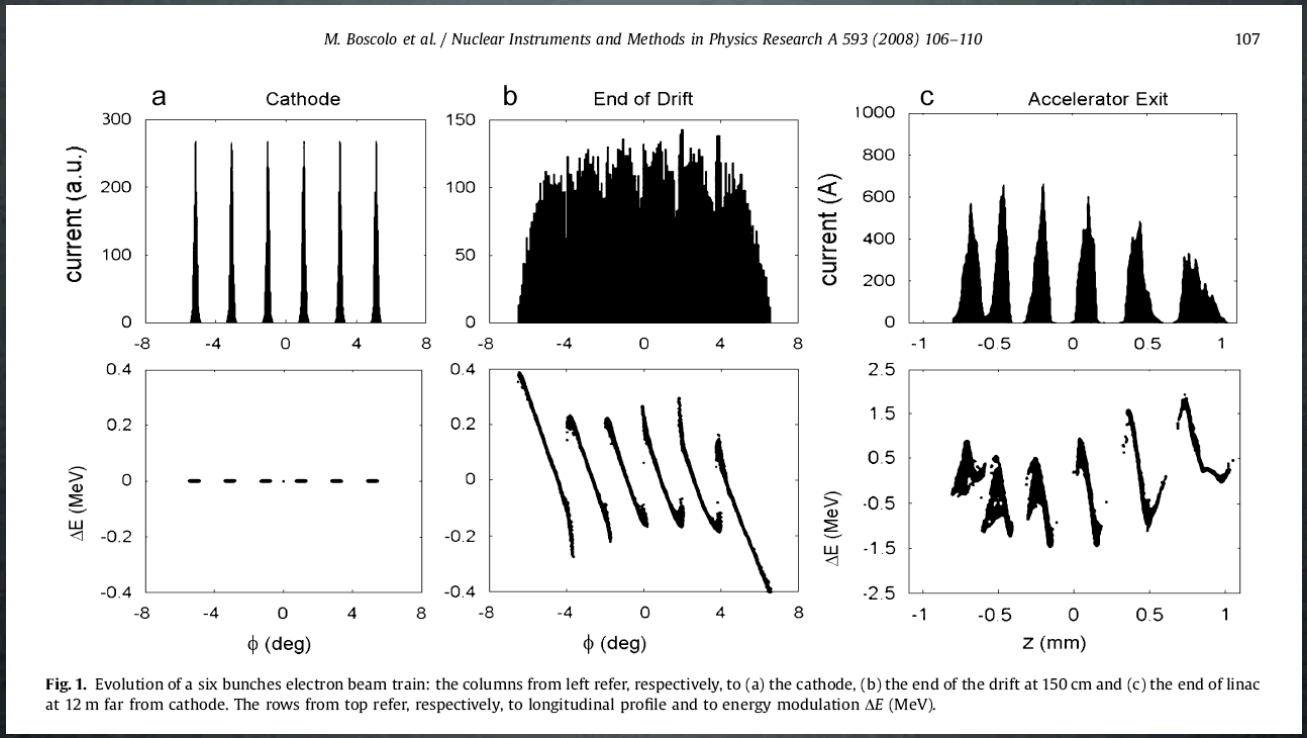
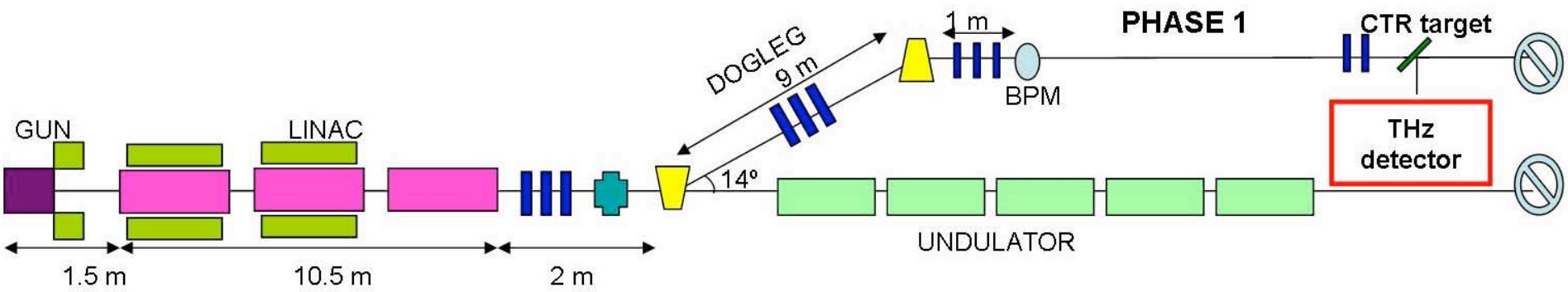
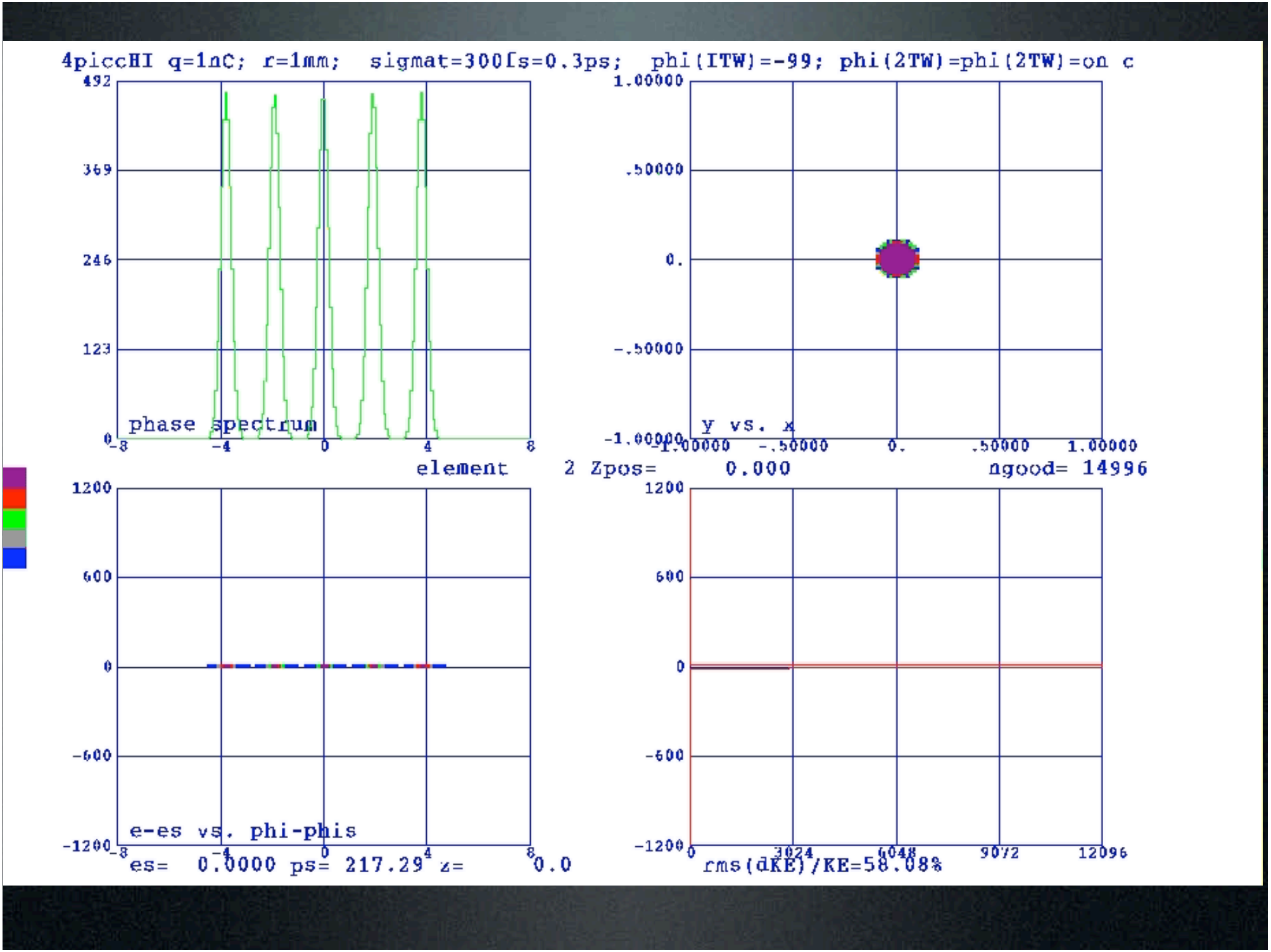


Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).



- 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)

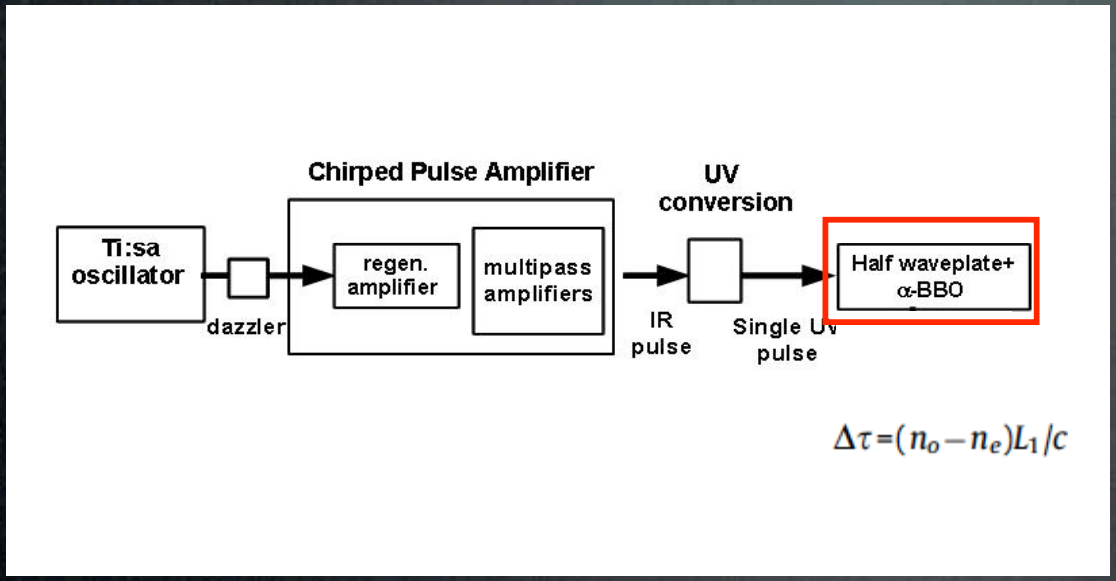

4piccHI q=1nC; r=1mm; sigmat=300fs=0.3ps; phi(1TW)=-99; phi(2TW)=phi(2TW)=on c
492
369
246
123
0
-8
-4
0
4
8
phase spectrum
element
1.00000
.50000
0.
-.50000
-1.00000
-1.00000
-.50000
0.
.50000
1.00000
y vs. x
2 Zpos= 0.000
ngood= 14996
1200
600
0
-600
-1200
e-es vs. phi-phis
es= 0.0000 ps= 217.29 z= 0.0
0
3024
6048
9072
12096
rms(dKE)/KE=58.08%

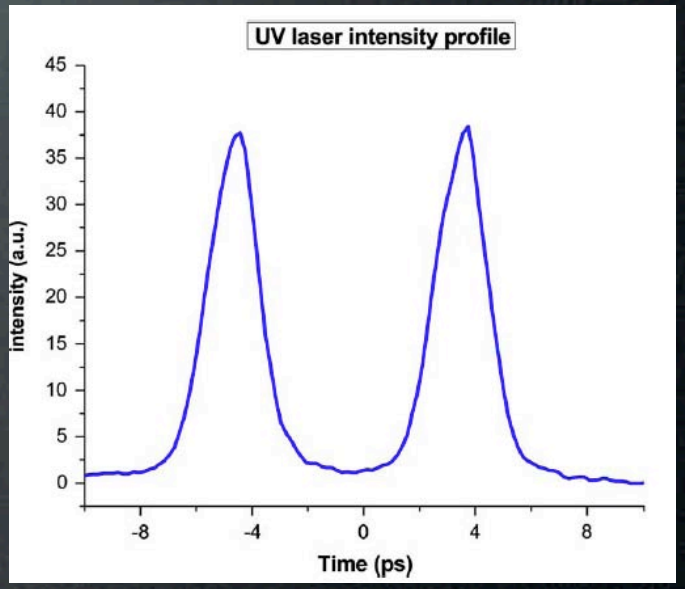
Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

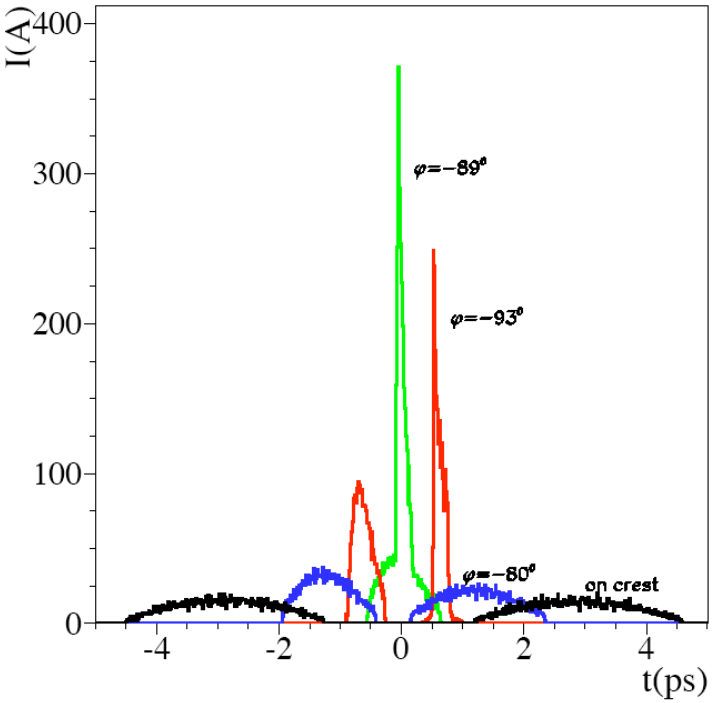
journal homepage: www.elsevier.com/locate/nima

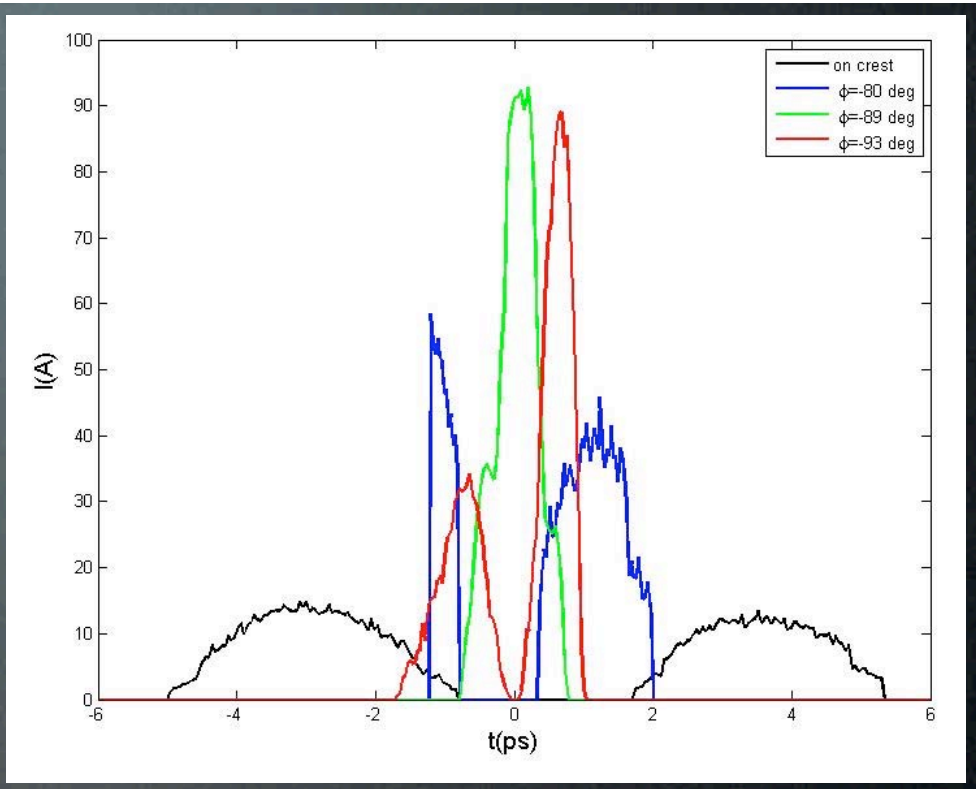
Laser comb with velocity bunching: Preliminary results at SPARC

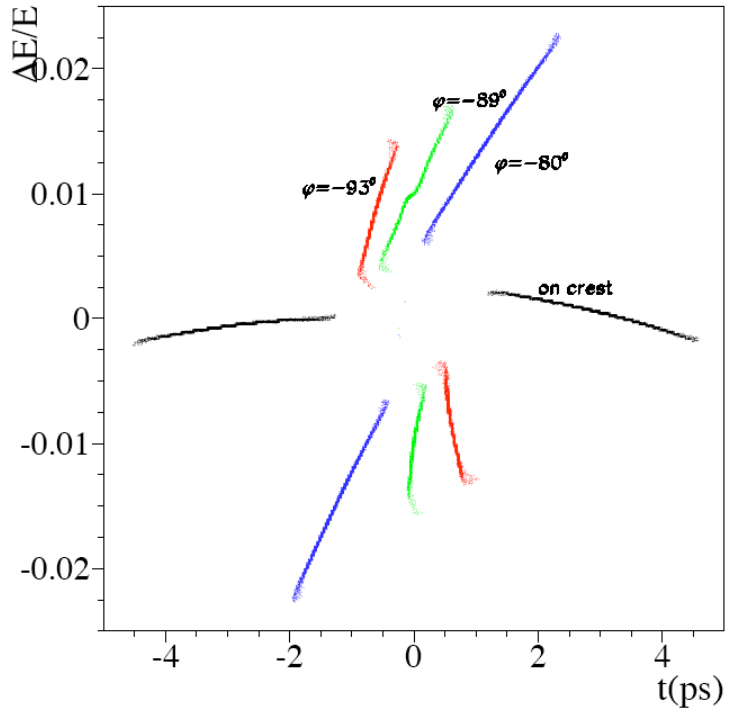


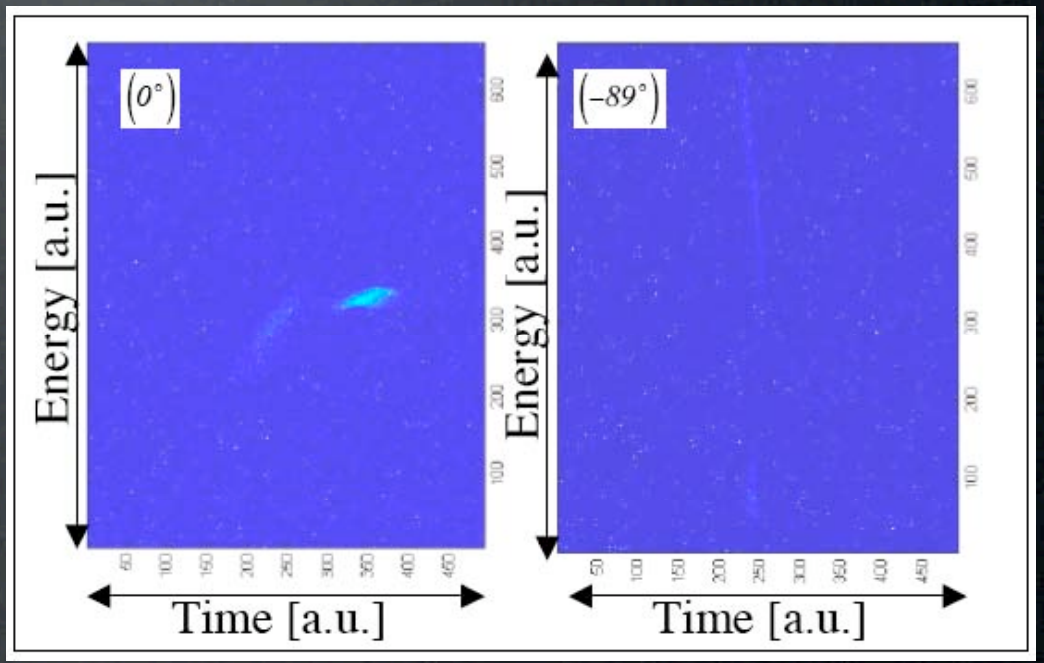


35 pC/pulse


I(A)
400
300
200
100
0
φ=−89°
φ=−93°
φ=−80°
on crest
-4
-2
0
2
4
t(ps)

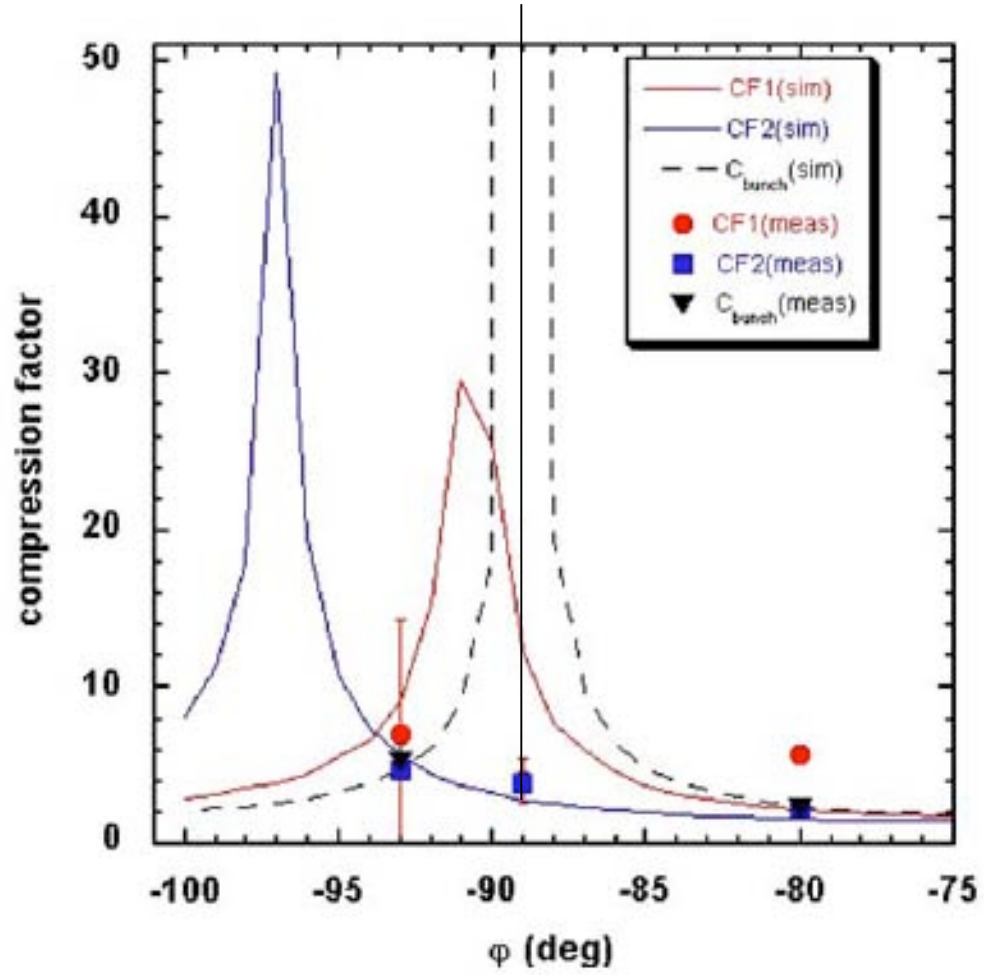

I(A)
on crest
ϕ=-80 deg
ϕ=-89 deg
ϕ=-93 deg
t(ps)

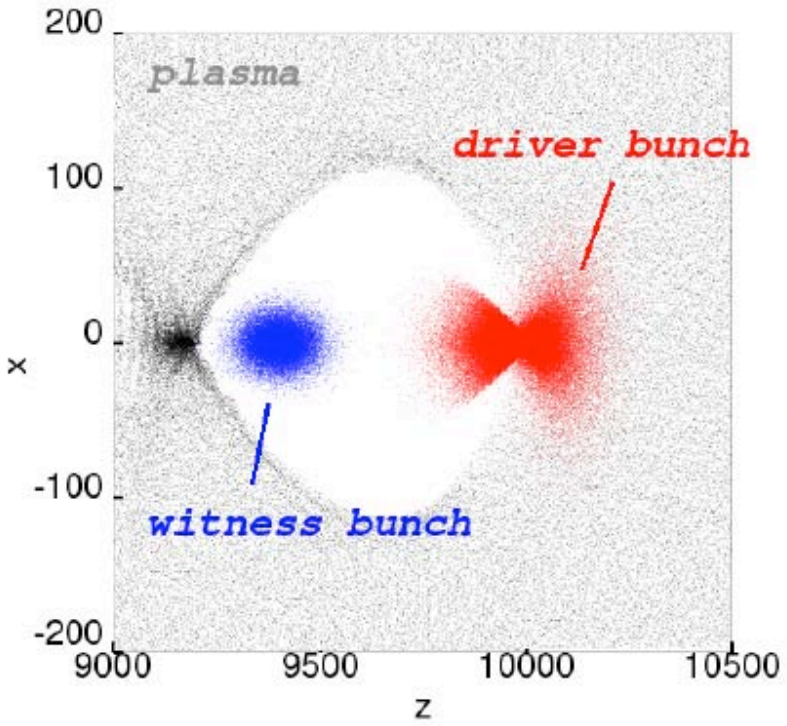

ΔE/E
0.02
0.01
0
-0.01
-0.02
φ=−89°
φ=−93°
φ=−80°
on crest
-4
-2
0
2
4
t(ps)

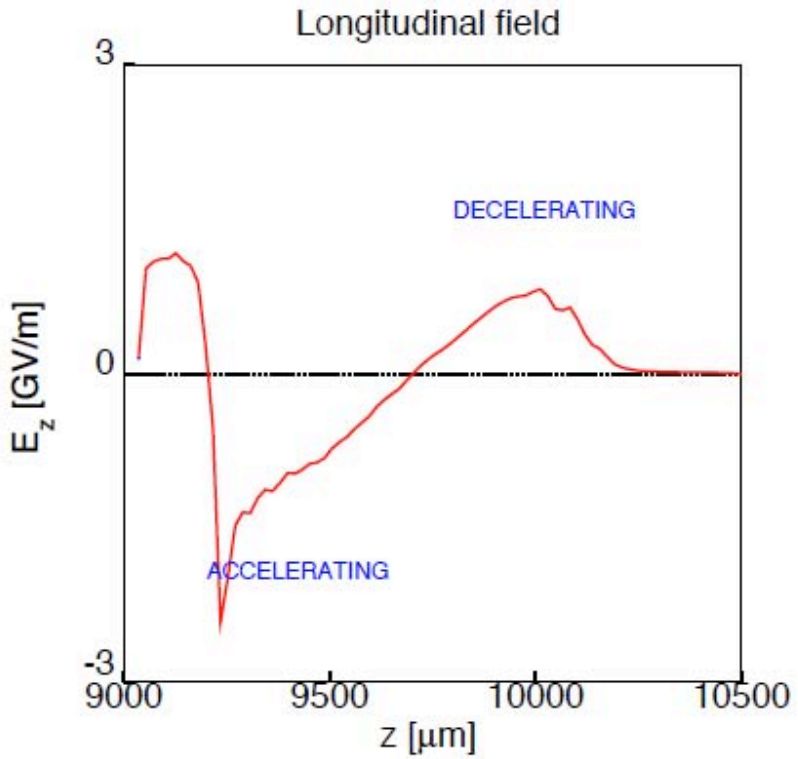

(0°)
(−89°)
Energy [a.u.]
Time [a.u.]
Energy [a.u.]
Time [a.u.]

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







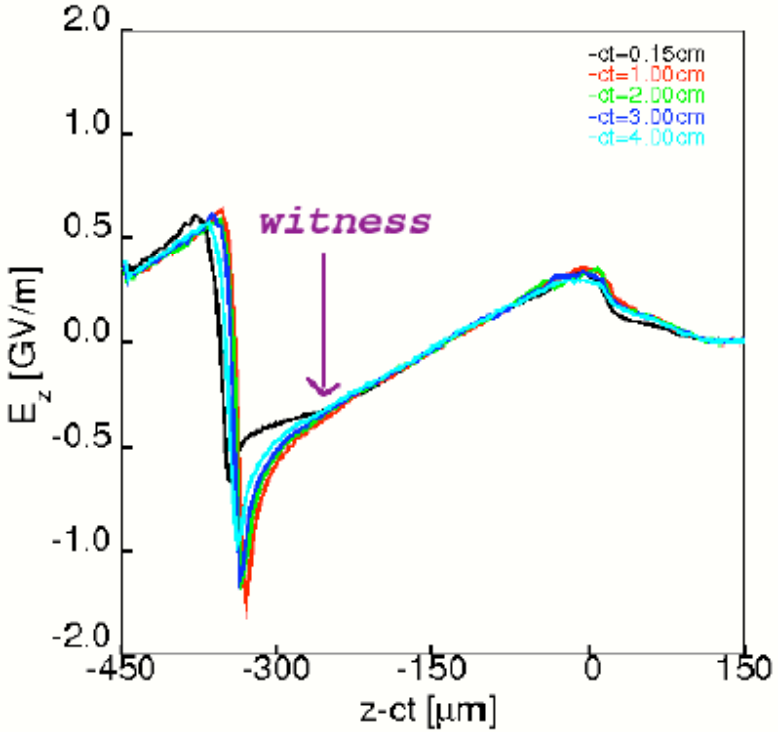
E	145.9 MeV
$\delta E/E$ (rms)	$8.8 \cdot 10^{-3}$
Q	1.75 nC
σ_x	34.74 μm
σ_y	34.80 μm
σ_z	63.08 μm
ϵ_x	3.06 mm mrad
ϵ_u	3.06 mm mrad

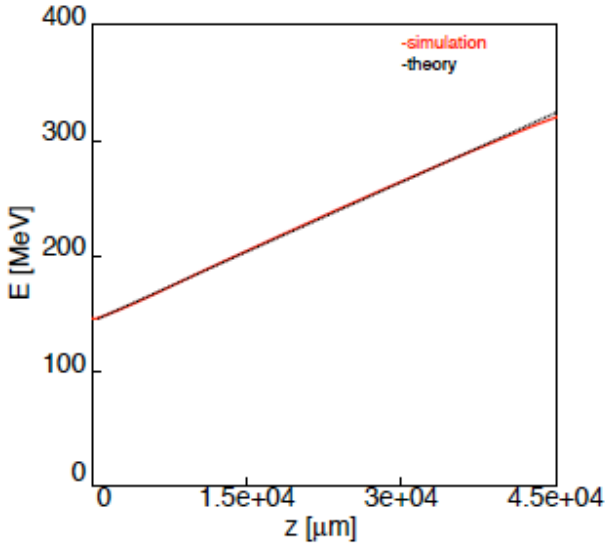
$$E_{acc}\left[MV/m\right] = 27.5\,\frac{Q\left[pC\right]}{\left(\sigma_z\left[\mu m\right]\right)^2}$$

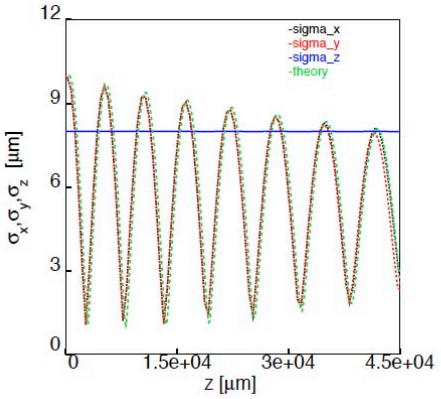
E [MeV]	$\Delta E/E$ [rms]	$\sigma_{x,y}$ [μm]	$\epsilon_{x,y}$ [mm mrad]	Q [pC]	σ_z [μm]
145.9	$5 \cdot 10^{-3}$	7	2	20	2.5

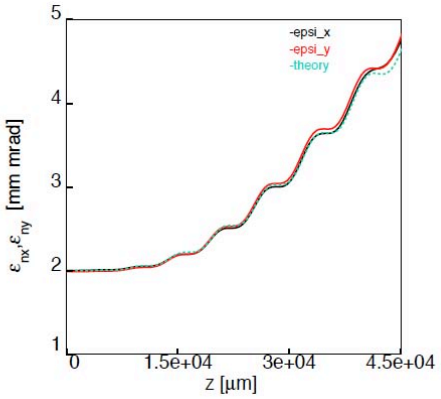
Afterburner experiments with SPARC

- Accelerating field (at different times), energy gain (+170 MeV [final]) & momentum spread ($\sim 3.5\%$ [final]) of the witness



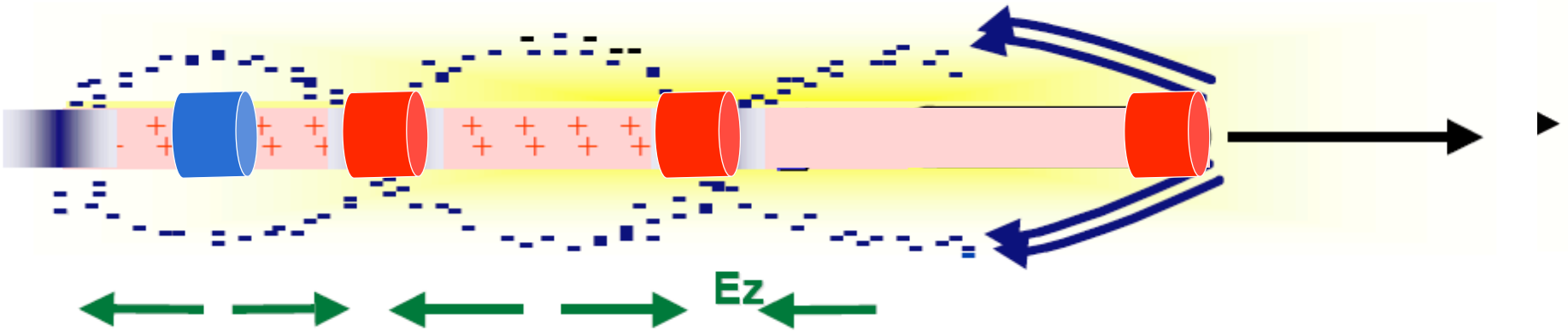






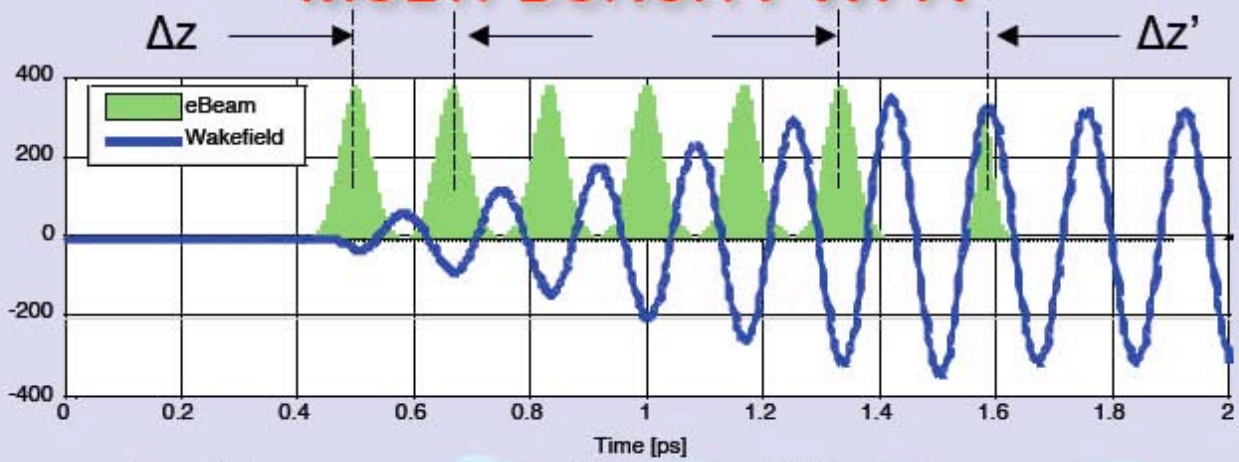
Plasma wakefield multibunch excitation

- Space charge of drive beam displaces plasma electrons



- Plasma ions exert restoring force => Space charge oscillations

MULTI-BUNCH PWFA



- Bunch spacing/plasma density condition:

  $\Delta z=\lambda_p$ (resonance) $\sigma_z \ll \lambda_p$

  $\Delta z' \approx (m+1/2)\lambda_p$, m=0,1,2 ...

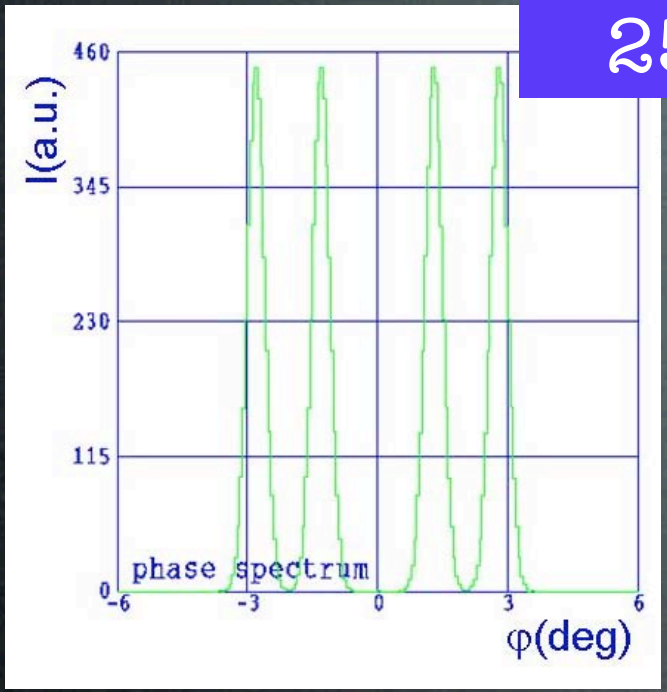
  Plasma wavelength: $\lambda_p = \dfrac{2\pi c}{\omega_{pe}}$ Plasma angular frequency, density n_e: $\omega_{pe} = \left(\dfrac{n_e e^2}{\varepsilon_0 m_e}\right)^{1/2}$

- Wake fields add up (linear theory):

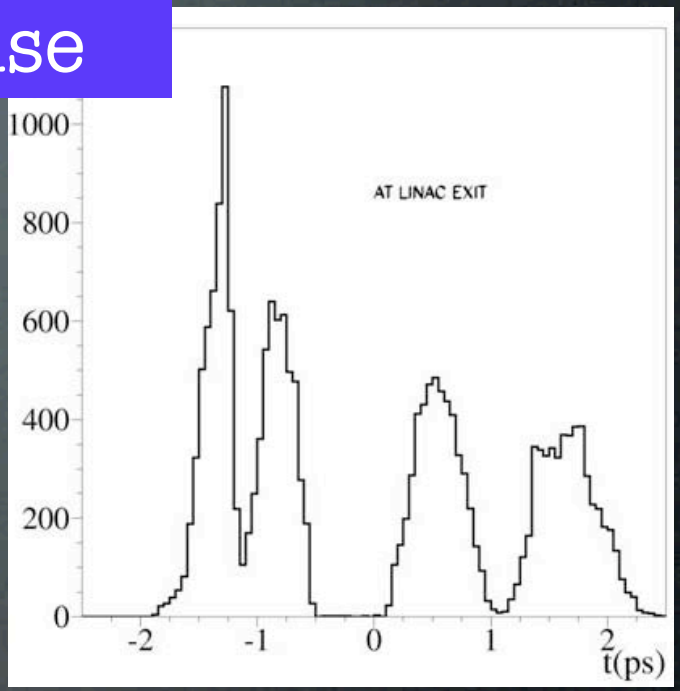
  $E_{z\ N\ bunches} \approx N \times E_{z\ 1\ bunch}$

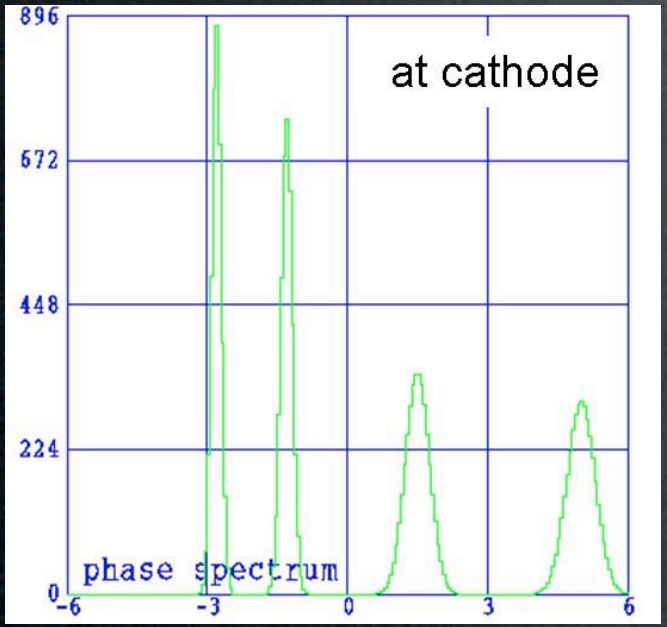
- Finite energy spread $\Delta E/E \ll 1$, beam acceleration

250 pC/pulse

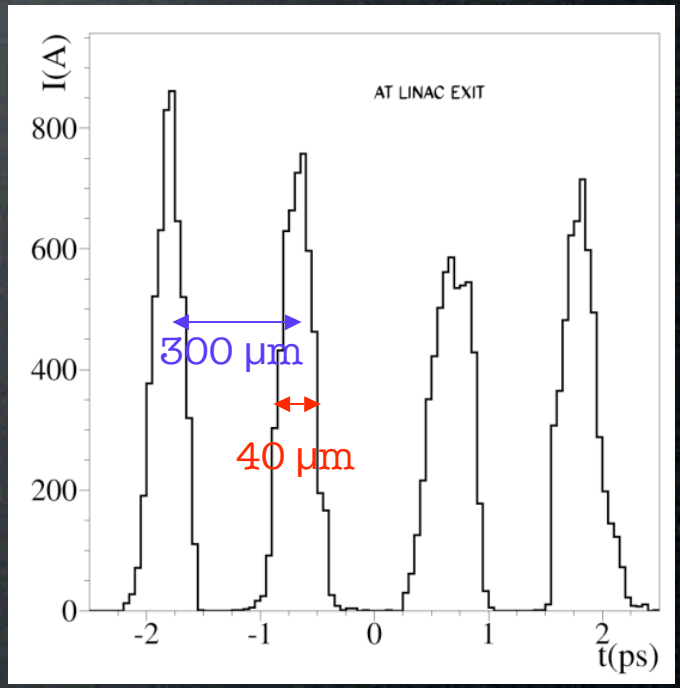

I(a.u.)
460
345
230
115
0
phase spectrum
-6
-3
0
3
6
φ(deg)

==>

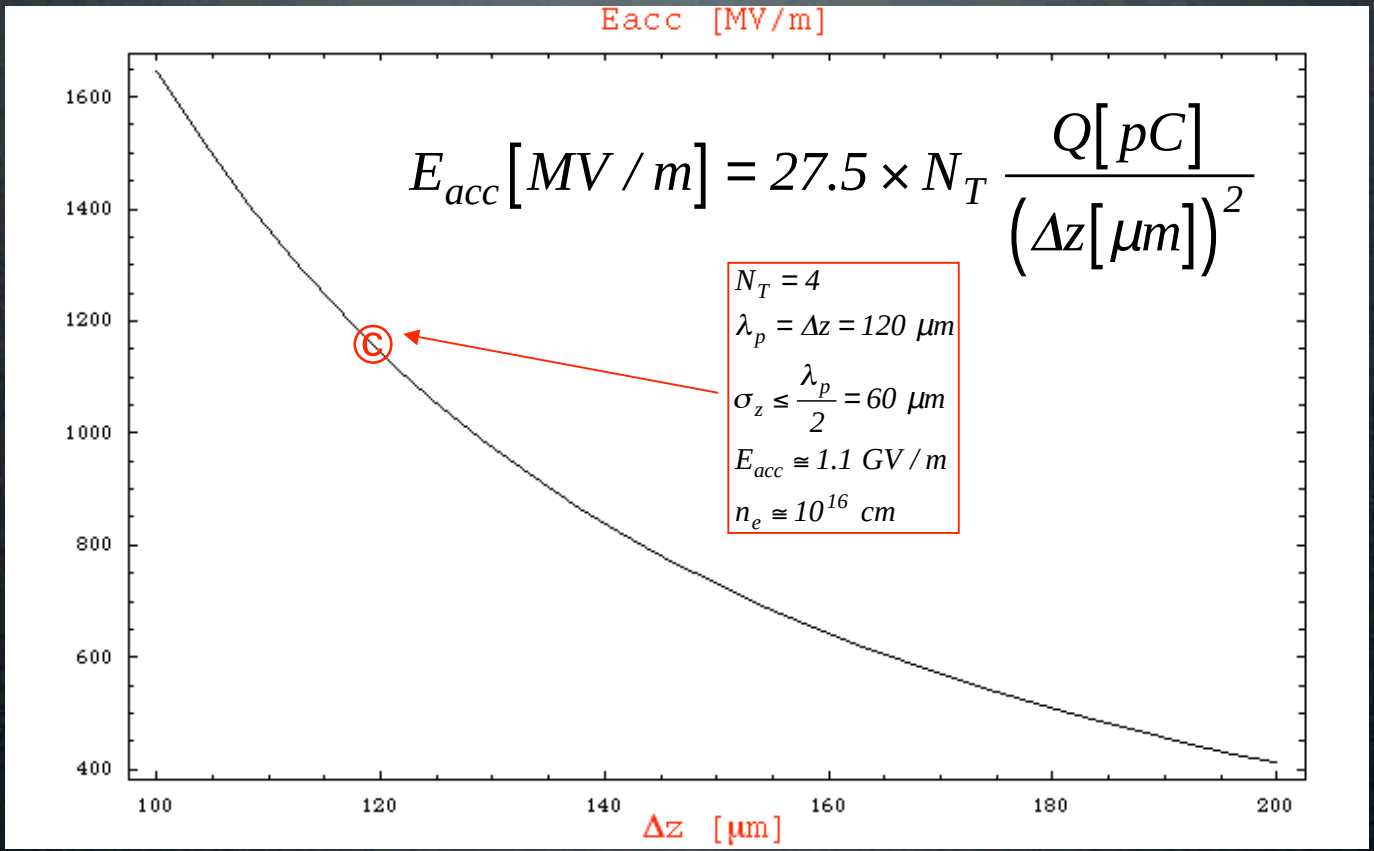

1000
800
600
400
200
0
AT LINAC EXIT
-2
-1
0
1
2
t(ps)


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

==>


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

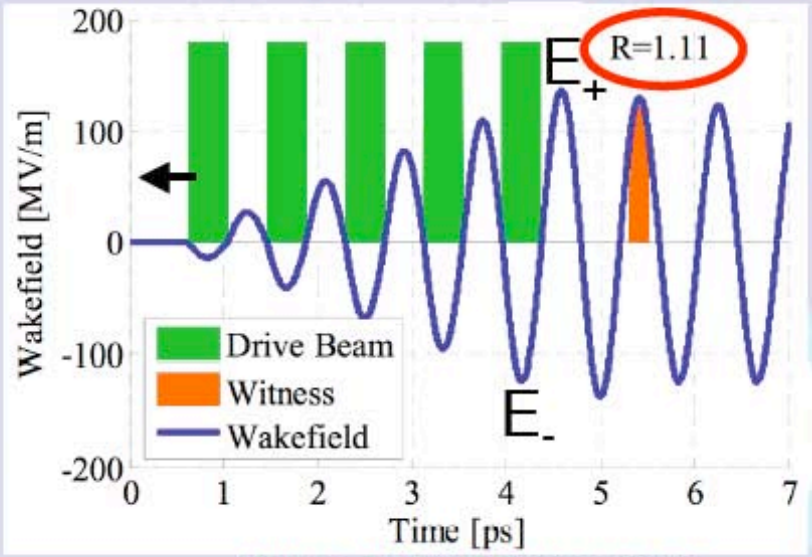
150 pC/pulse x 4 pulses



200 MeV in 18 cm

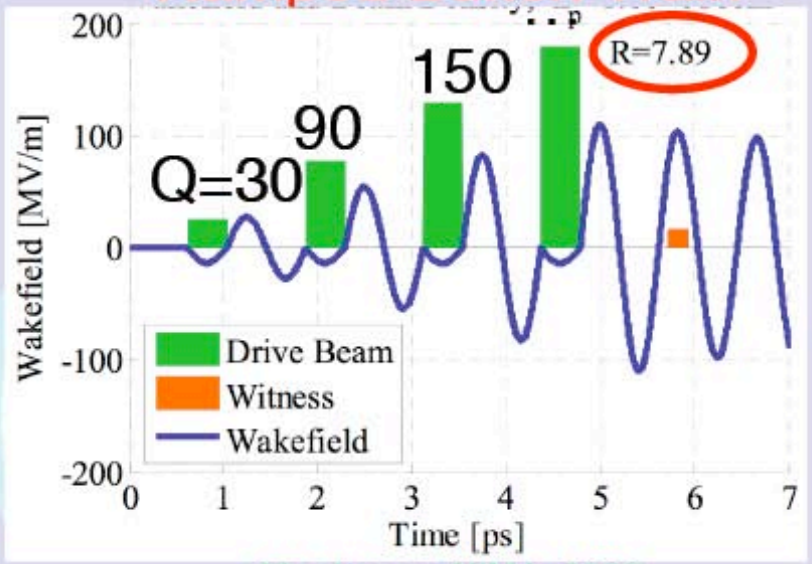
MULTIBUNCH PWFA

Bunch Train @ Resonance



Kallos, PAC'07 Proceedings

Ramped Bunch Train*



*Tsakanov, NIMA, 1999
DWA: Jing, PRL 2007.

Transformer Ratio: $R = E_+ / E_-$ Energy Gain: $\leq RE_0$

2D Linear Calculations: σ_r=125 μm, n_e=1.8x10^{16} cm^{-3}

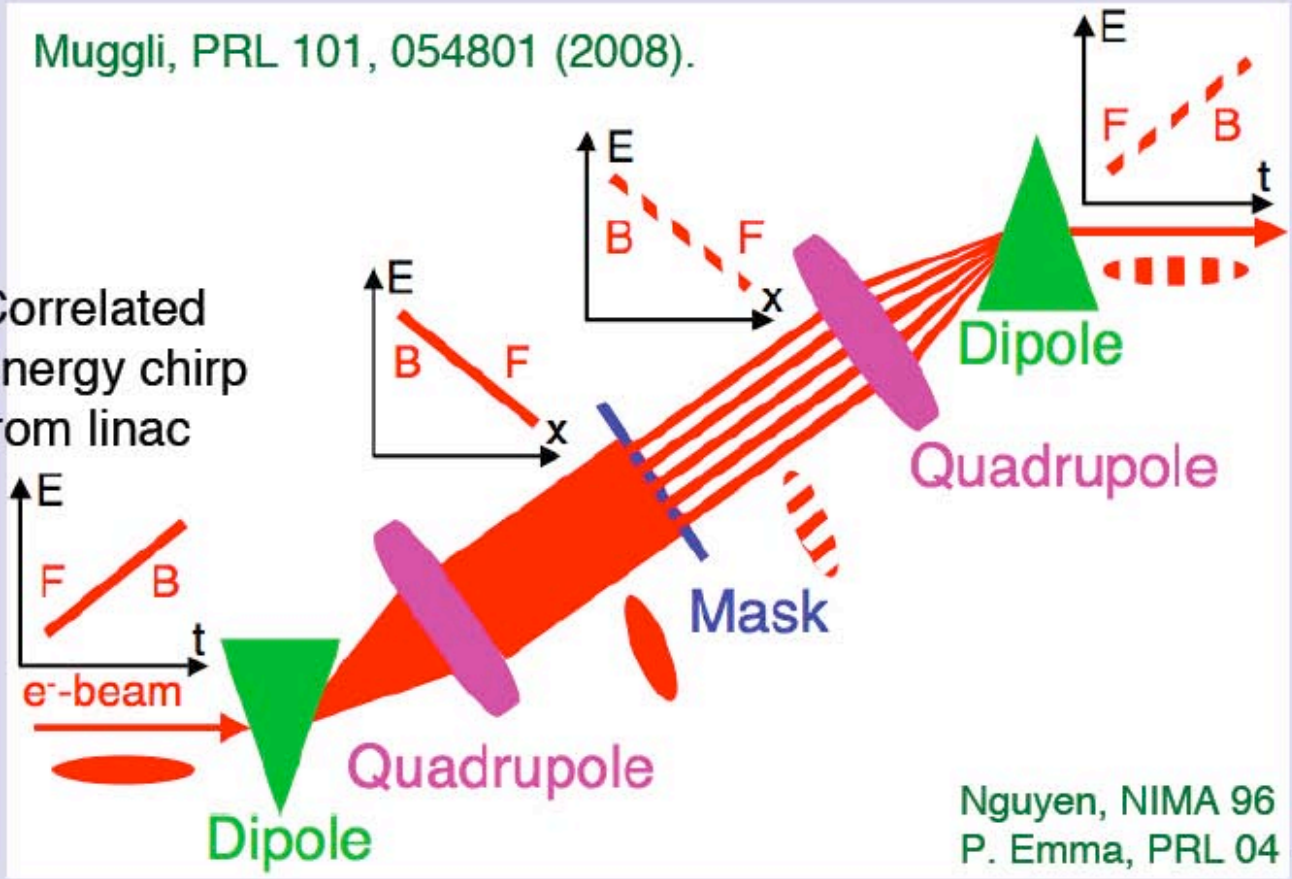
E_0: incoming energy

Q=30 pC/bunch, Δz=250 μm$\approx\lambda_p$

$\Delta z'$=375 μm$\approx$1.5λ_p

- R=7.9 => gain 8x incoming energy a single PWFA stage!
- Linear regime, theory (n_b/n_e, $\delta n_e/n_e$, E_z/E_{WB} <<1)

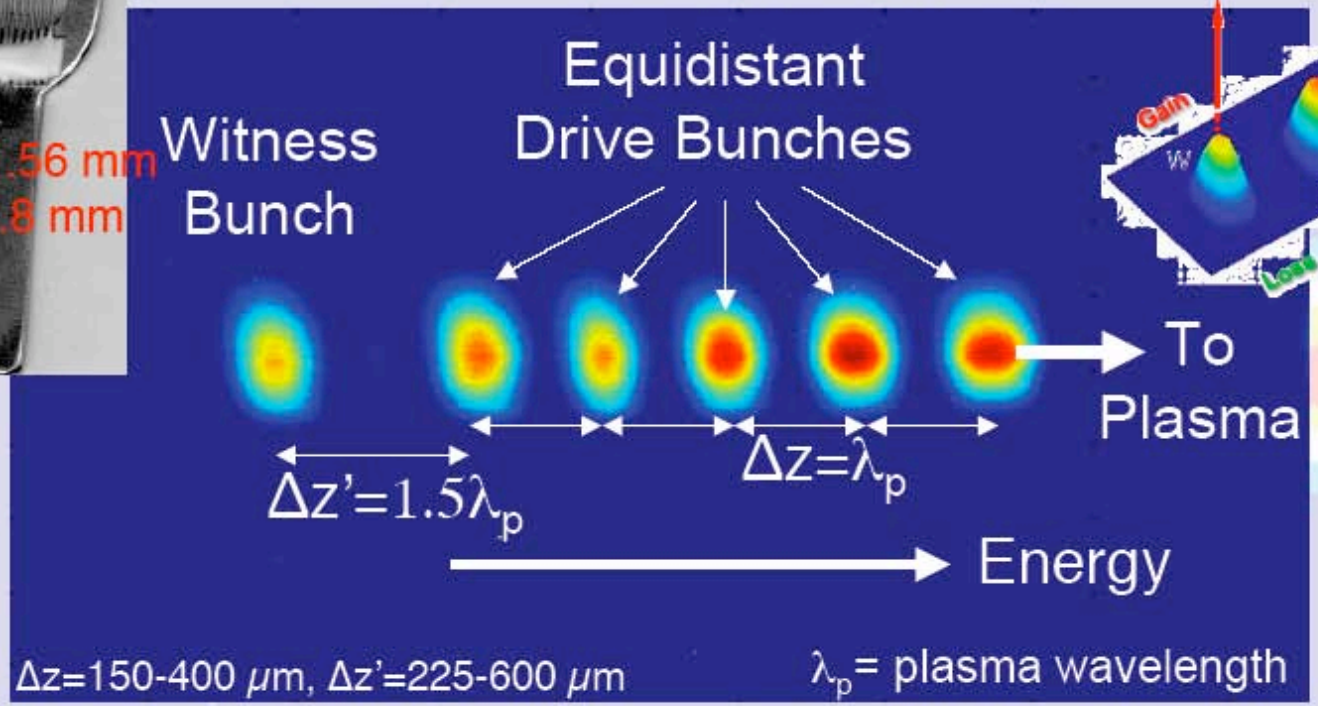
MULTIBUNCH GENERATION

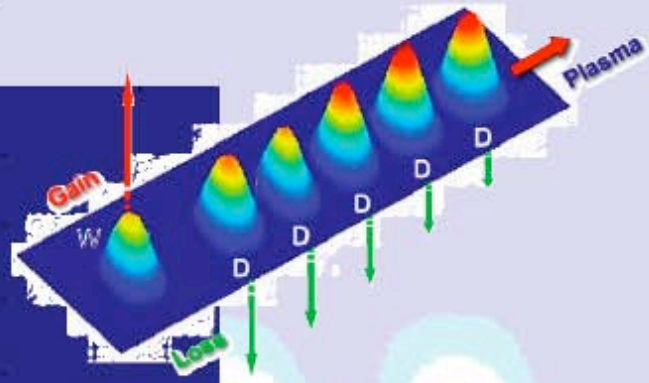


➡ Choose microbunches spacing and widths with mask and beam parameters: N, Δz, σ_z, Q

TRAIN FOR PWFA

Mask with non-equidistant "wires"
Measurement in energy plane

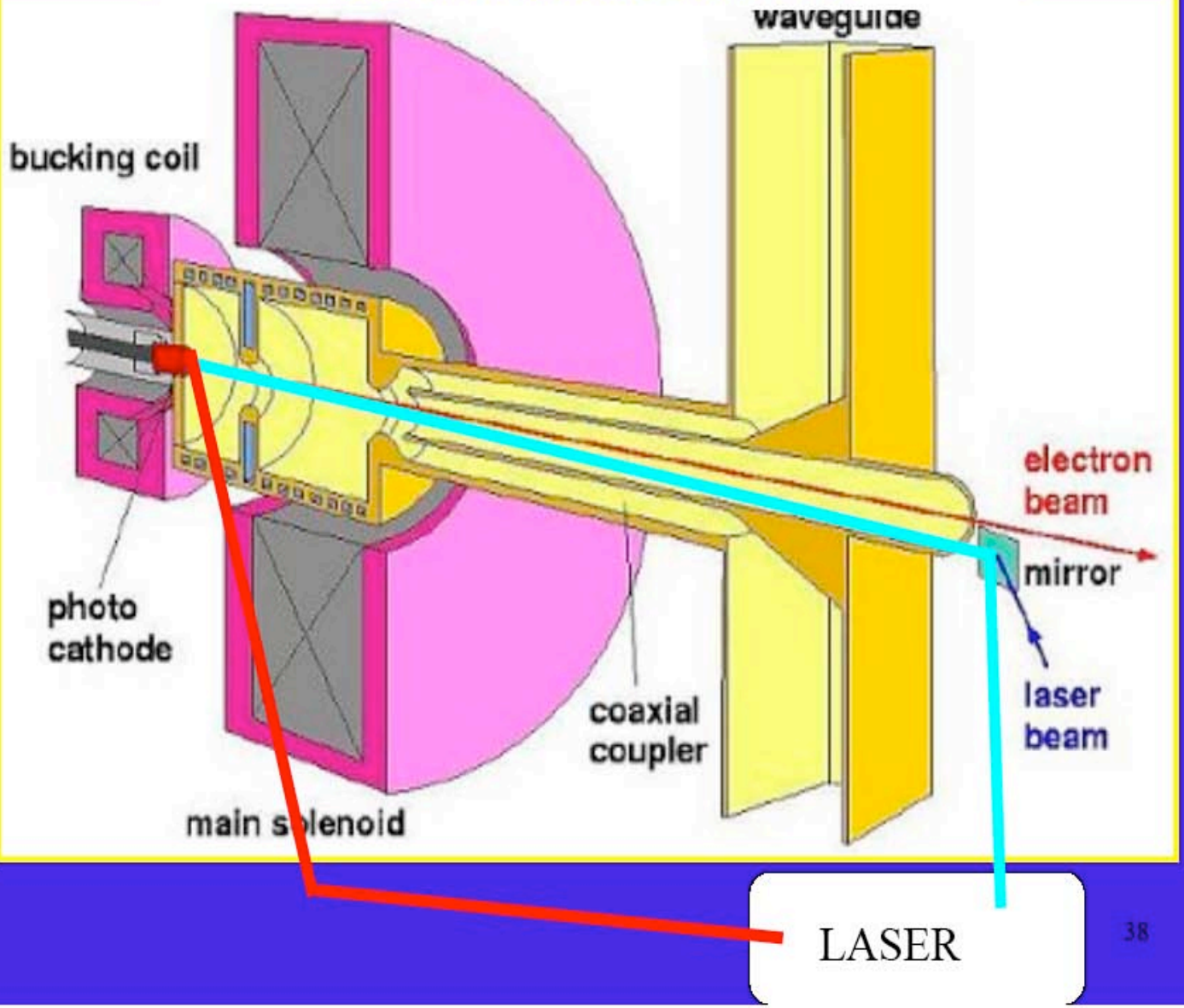




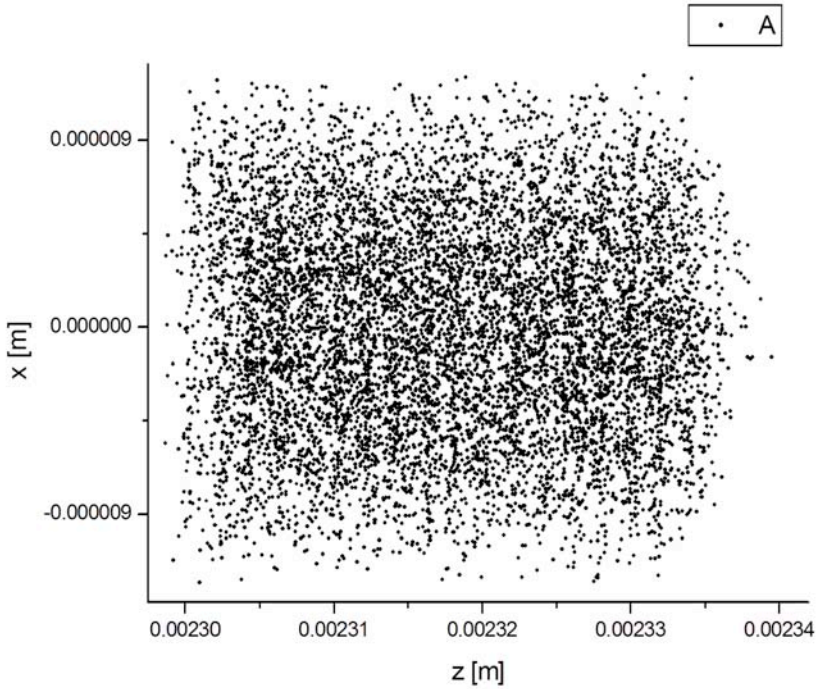
WARNING:
NOT simulations!
Experimental Data!

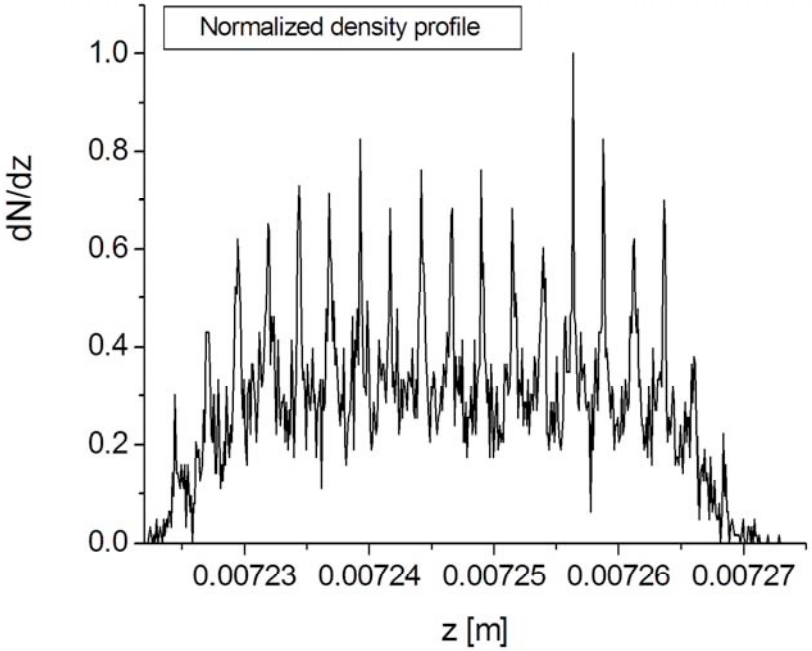
- Generate "ideal" train for resonant PWFA
- Select number of drive bunches (high energy slit): Choose 3D+1W
- Typical bunch separation: $\Delta z \approx 300\text{-}400\ \mu m$
- Expected plasma resonance: $\lambda_{pe}(n_e)=\Delta z$, $n_e \approx 1.2\text{-}0.7 \times 10^{16}\ cm^{-3}$

LASER CONDITIONING



A. Bacci - RETAR

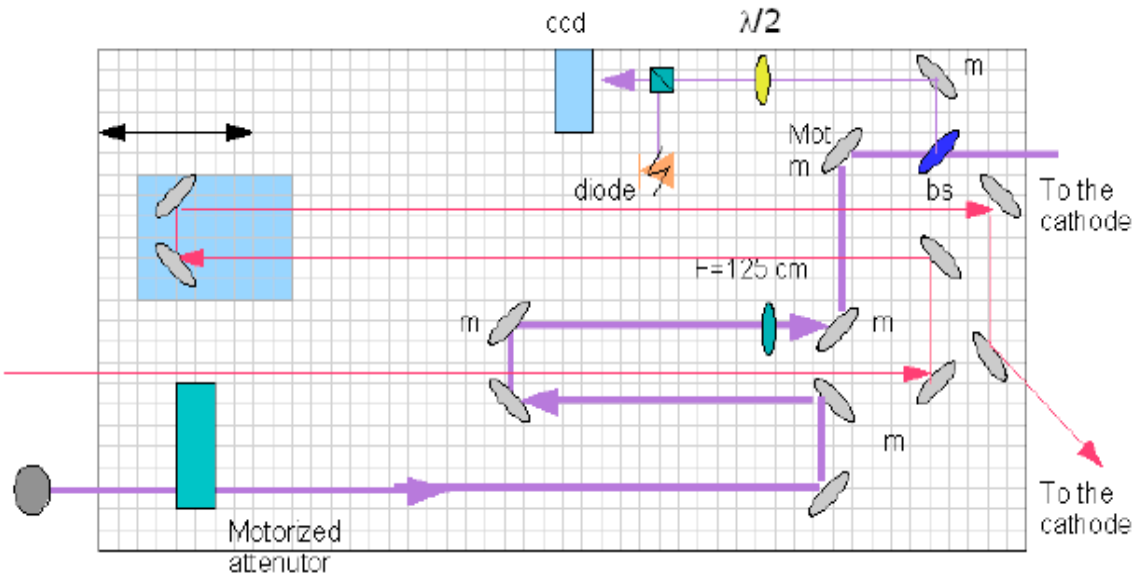




Laser IR 0.8 micron
E0 = 500 MV/m @ 72 Deg
Bunch radius = 5 micron
Laser pulse length = 2 ps
Injection phase= 29.1 Deg

Gun table

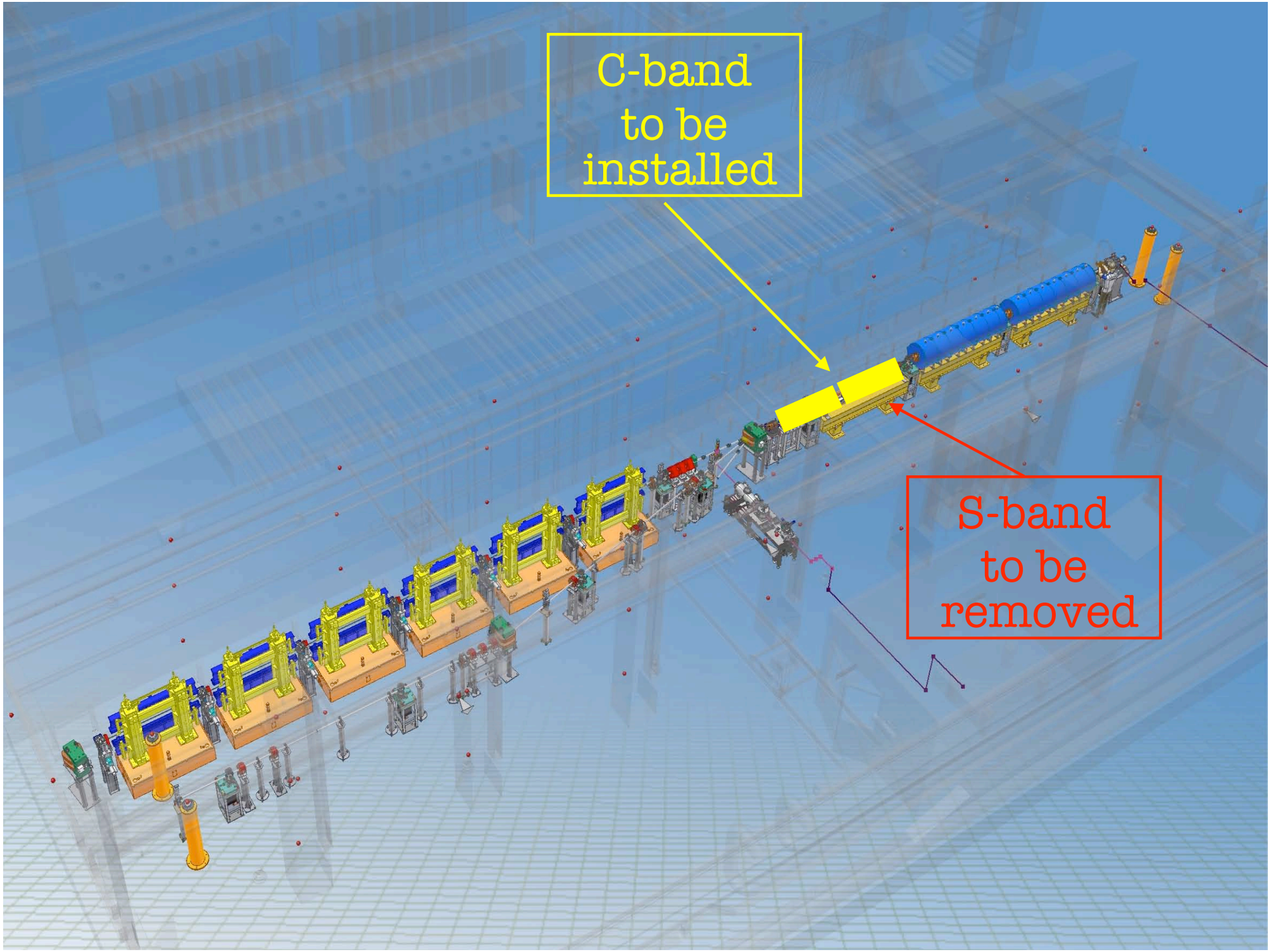
IR optical transfer line



m = hr mirror 45 deg 266 nm

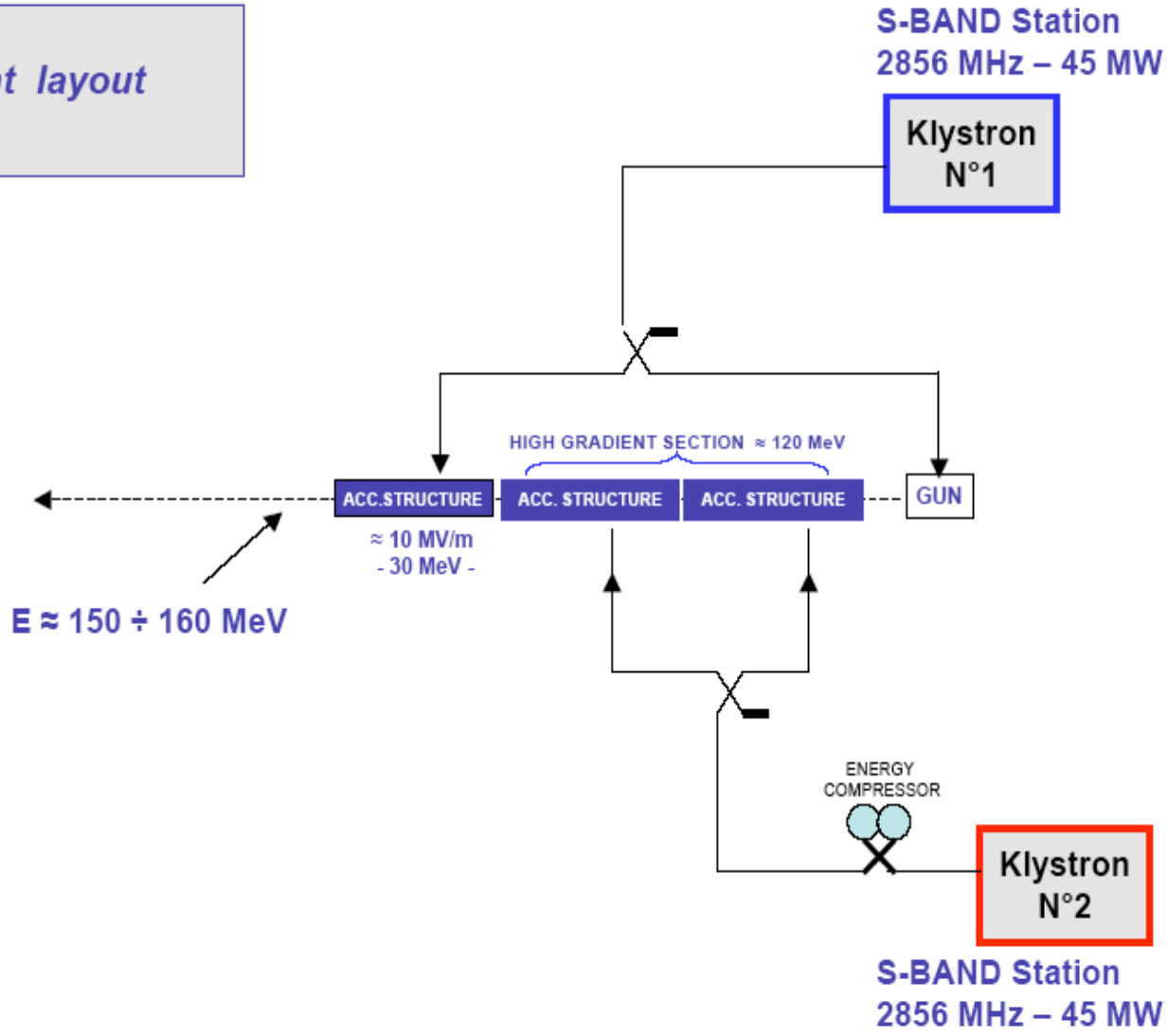
bs = thin beam splitter

SPARC Energy upgrade

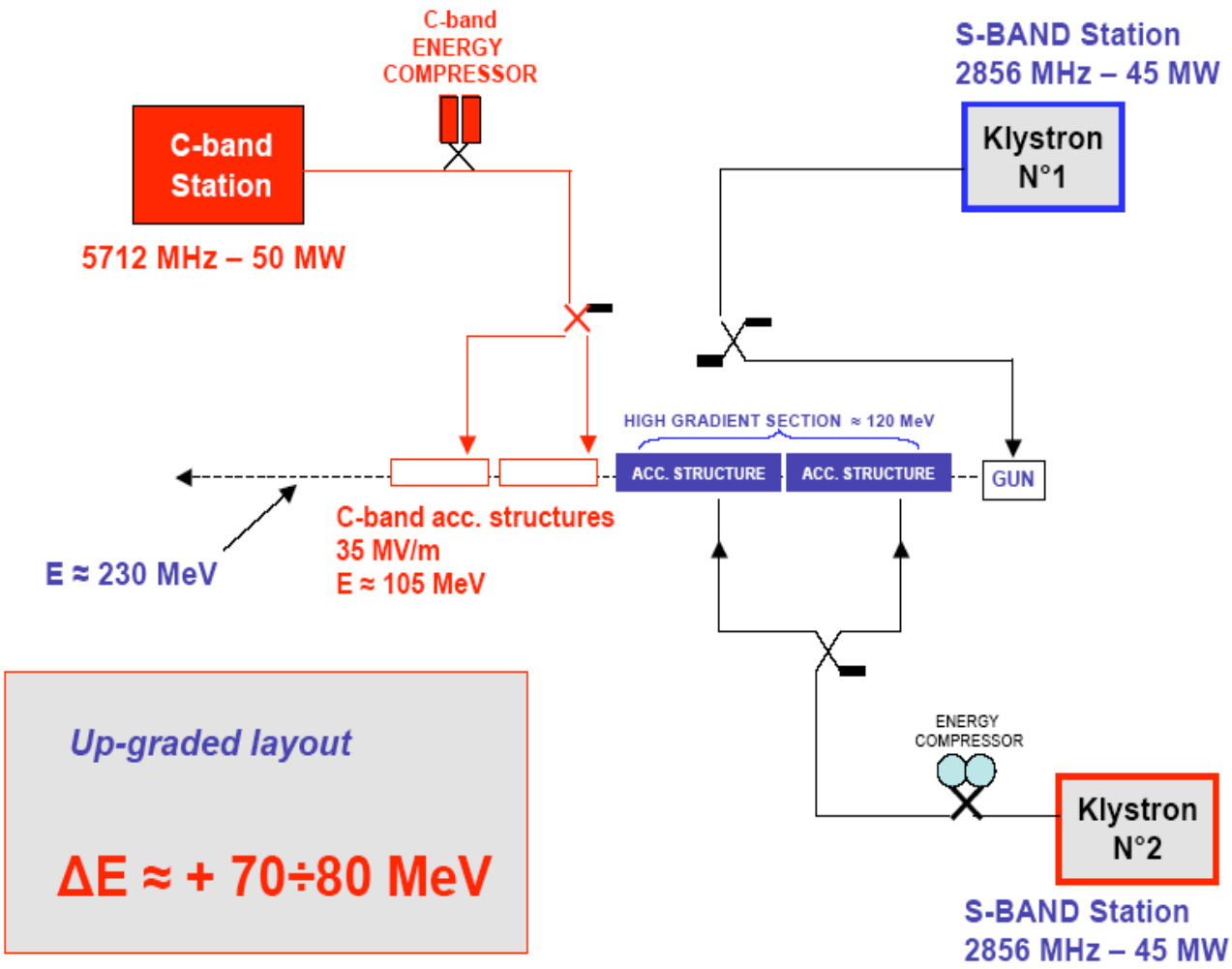

C-band
to be
installed
S-band
to be
removed

SPARC energy up-grading

Present layout



SPARC energy up-grading



Up-graded layout

ΔE ≈ + 70÷80 MeV

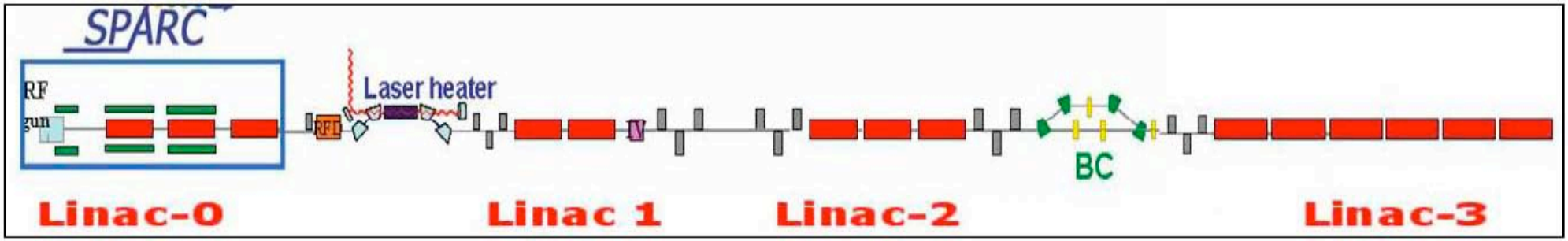
SPARX phase 0 ==> SPARC upgrade

150 MeV

125 A

750 MeV

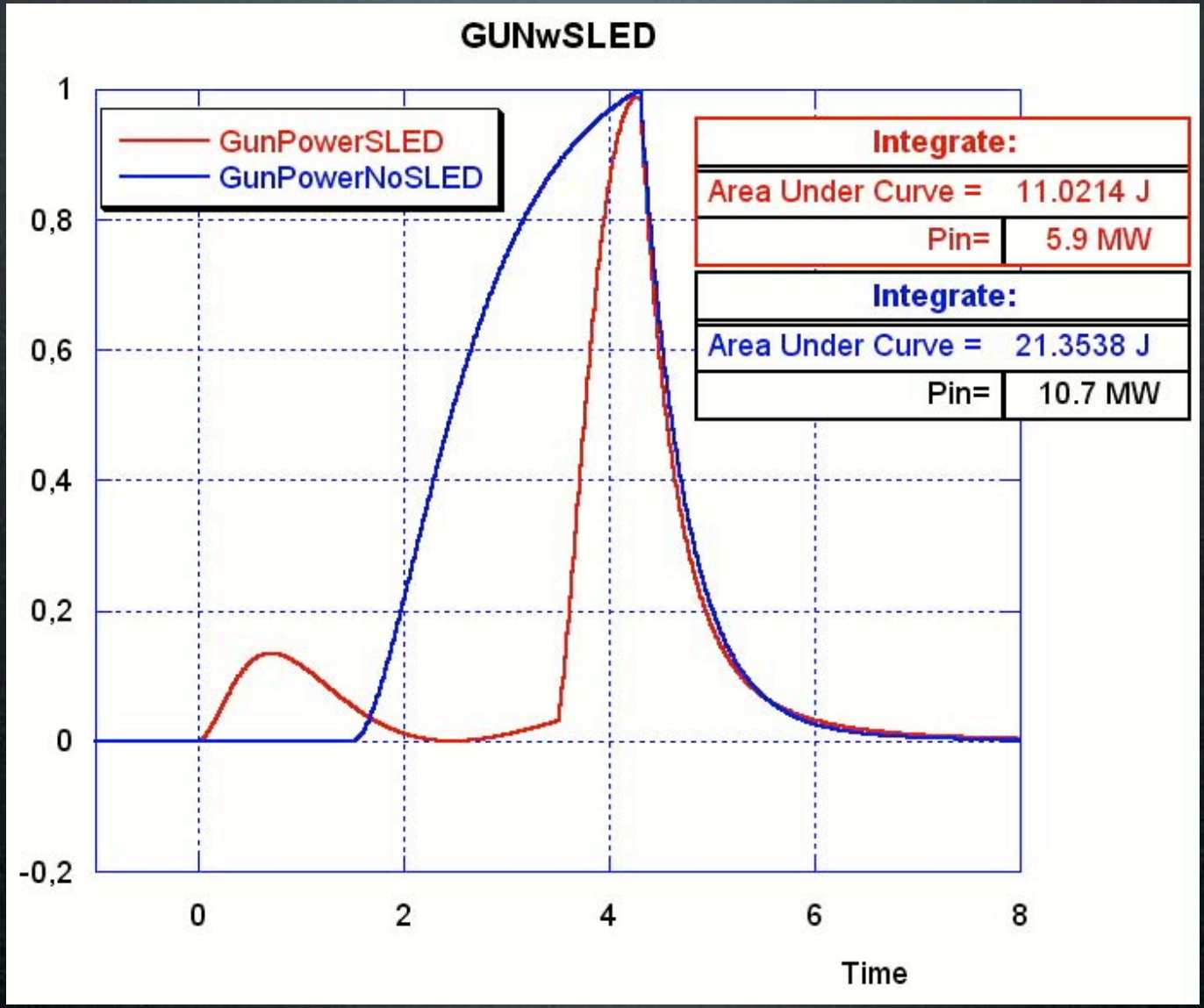
700 A



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

Experiment	Weeks
FEL (SASE - Seeding - Single Spike VB)	16
THz	9
Beam Physics (WP -VB - LC - IR- PlasmonX)	8
Commissioning (Cath. - Solen.)	3
Installation (Cband - Gun)	4


Thank you


GUNwSLED
GunPowerSLED
GunPowerNoSLED
Integrate:
Area Under Curve = 11.0214 J
Pin= 5.9 MW
Integrate:
Area Under Curve = 21.3538 J
Pin= 10.7 MW
1
0,8
0,6
0,4
0,2
0
-0,2
0
2
4
6
8
Time