SPARX

Patrizio Antici

On behalf of the SPARC/X collaboration

From SPARC to SPARX:

From R & D to experiments

From SPARC to SPARX

2003 - MIUR Funding of SPARC-Test Facility

2005 - MIUR Funding of R&D for a soft X-ray FEL
(SPARX R & D)

2007 - Agreement with MIUR & Regione Lazio for the development of soft X-ray FEL
(SPARX-FEL)

SPARX Goals

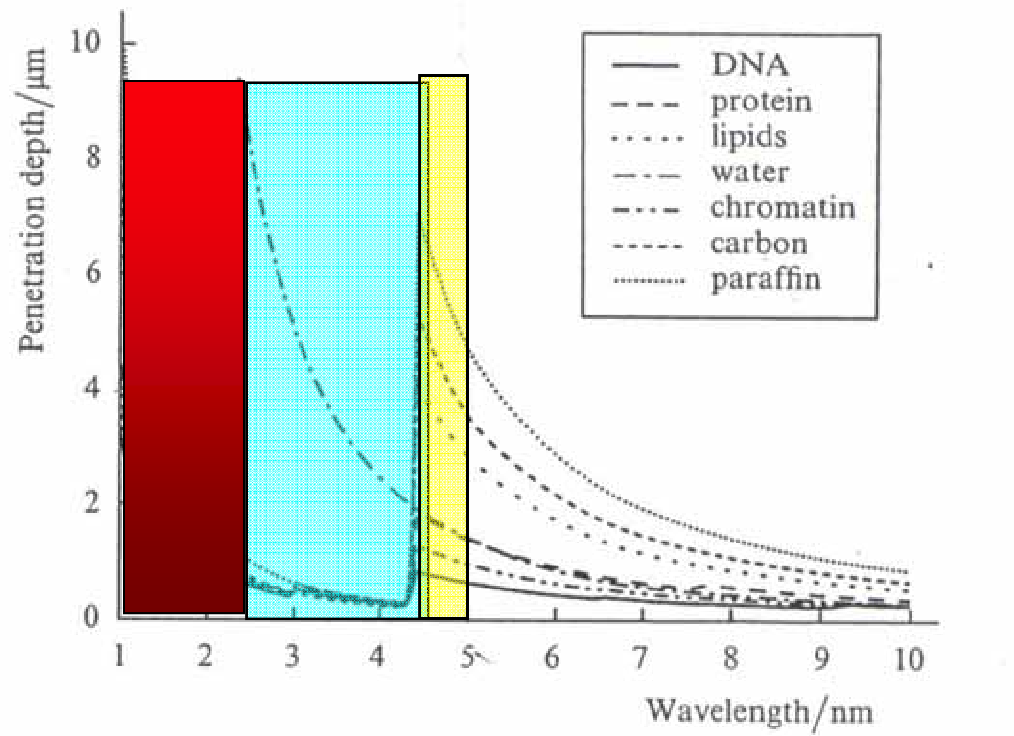
The needs of different user-communities have identified in several workshops

SPARX workshops	***- INFN-LNF***	***09.05.2005***
	- INFN-LNF	***19.06.2007***
SIMPOSI SPARX	**March, June and October 2008**	
Bio&Medical Sciences workshop	**- Rome**	**March 2009**
Bio&Medical Sciences workshop	**- London**	**March 2010**

Wavelength range :
0.6 - 40 nm

- water window
  (~ 2.5 – 4.5 nm)

- carbon window
  (~ 4.5 – 5.0 nm)



Funding

National funds:

MIUR FISR 2003	2.5 M€
SPARX-MIUR Part 1+2	~10.0 M€
Regione Lazio	15.0 M€

EU-Funding (ca. 2 M€)

Obtained:
EuroFEL (FP6)
CARE (JPA PHIN)
IA-SFS
IRUVX-FEL (FP7)
ELISA (JRA FELINS)
EuCARD (WP ANAC)

Foreseen:
TIARA
CECILIA
CRISP

Initial decision adjusted

- SPARX-FEL Facility shall be firstly constructed at INFN Frascati National Laboratories

UNIVERSITÀ DEGLI STUDI DI ROMA "TOR VERGATA"

ENEA

Consiglio Nazionale delle Ricerche

INFN

Roma, 02 DIC. 2010

OGGETTO: Progetto SPARX.

Dichiarazione d'intenti

Sulla scorta di quanto emerso nella riunione tenutasi il 10 settembre u.s. presso la sede dell'Istituto Nazionale di Fisica Nucleare (INFN) fra i sottoscritti: prof. Renato Lauro, Rettore dell'Università degli Studi di Roma "Tor Vergata", ing. Giovanni Lelli, Commissario dell'ENEA, prof. Luciano Maiani, Presidente del CNR, prof. Roberto Petronzio, Presidente dell'INFN, si ribadisce quanto segue.

Tenuto conto dello sforzo profuso dalla collaborazione nella realizzazione del progetto SPARX, in termini di studio, sperimentazione e sviluppo del citato progetto da parte dei ricercatori delle istituzioni coinvolte, nonché dei risultati già ottenuti ed altresì del mutato scenario internazionale che suggerisce lo studio di soluzioni innovative nello sviluppo dei sistemi di Free Electron Laser (FEL), riteniamo che quanto deciso nell'ambito della riunione suddetta sia la soluzione più appropriata per le fasi successive del progetto.

Preso, dunque, atto dell'interesse dell'Università di Roma "Tor Vergata" di ospitare SPARX nella sua versione finale, risulta opportuno, per ragioni tecniche ed economiche, avviare la realizzazione di una sorgente - che offra le prestazioni di una facility per l'utenza e di R & D per nuove soluzioni nell'ambito della Fisica dei laser ad elettroni liberi - presso i laboratori dell'INFN di Frascati per poi realizzare le successive azioni presso il Campus di "Tor Vergata" attraverso la stipula di una apposita convenzione, fermo restando la disponibilità delle risorse economiche.

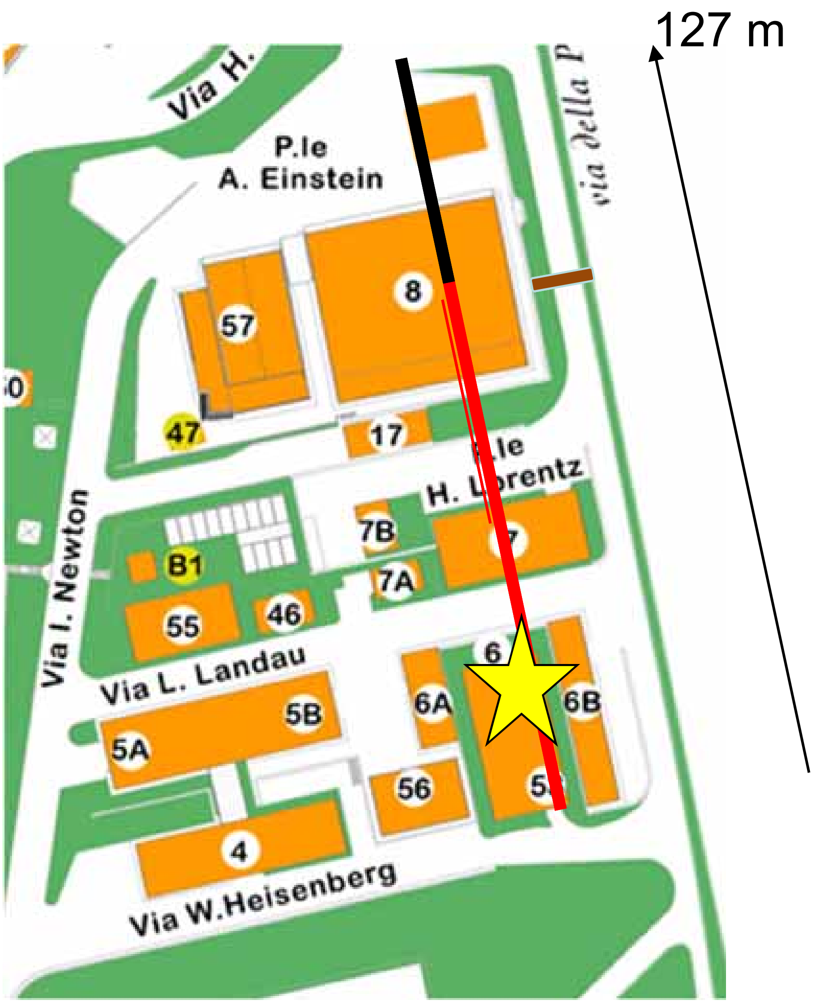
Resta inteso che, per rendere concreta l'iniziativa, è necessario avviare immediatamente l'iter di costituzione del Consorzio LUCE con lo scopo di gestire le necessarie azioni e regolamentare i rapporti reciproci tra le Parti e tra esse e i Soggetti finanziatori.

In fede,

Renato Lauro | Giovanni Lelli | Luciano Maiani | Roberto Petronzio

Dec. 2010

SPARX-750 MeV @ LNF

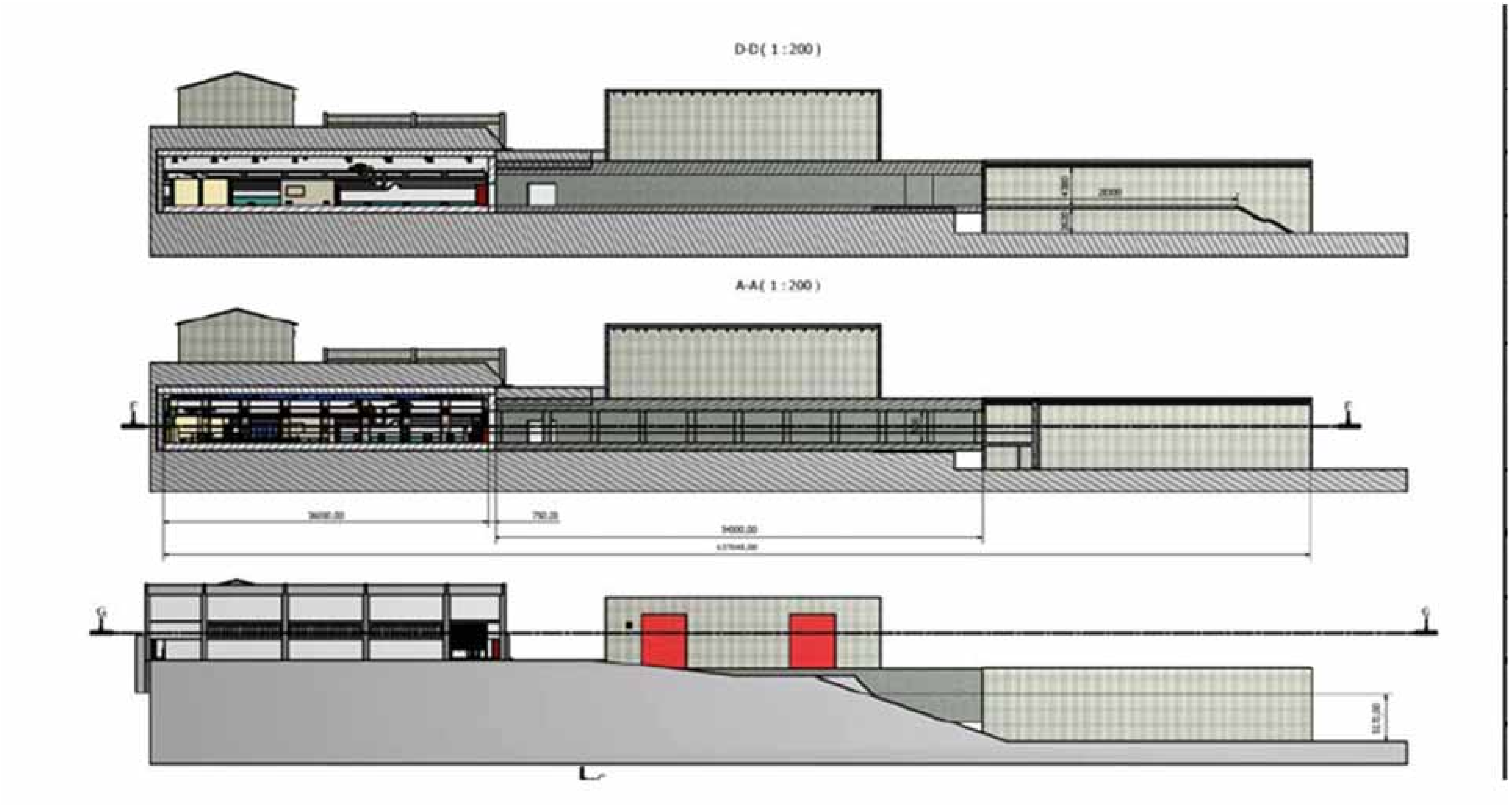


4 Puls - Servizio Meccanica ed Impianti
(Aula Master, Aula Puls)
5 Officine Servizi Ingegneria Meccanicas - 5a Laboratorio Servizi Vuoto
6 SPARC - 6a Sala Controllo - 6b Sala Macchine
7 Laboratorio Tecnologie - 7a & 7b Sala Compressori
8 Laboratori Gran Sasso ed Antenna Gravitazionale NAUTILUS

53 Capannone deposito materiale
54 Sala controllo BTF
55 Uffici SPARC
56 Laboratorio FLAME in assetto provvisorio
57 Ampliamento Laboratorio GRAN SASSO e annessi uffici

SPARX Linac+undulators

SPARX VUV optical line


D-D(1 : 200)
A-A(1 : 200)

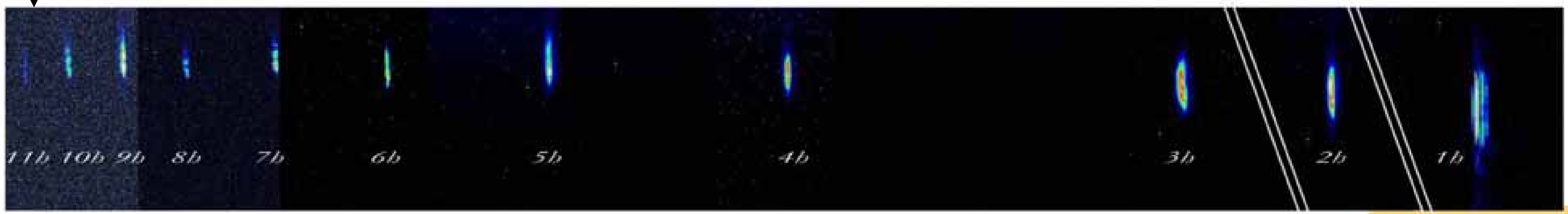
Scientific Highlights

SPARC FEL Highlights (2010)

- SASE operation at 500 nm *(2009 - SPARC design wavelength)*
- SASE with tapered undulator compensating energy chirp – single coherence region from SASE *(PRL, L. Giannessi et al., to be published)*
- Generation of laser COMB structures *(in prep.)*
- Generation of high harmonics in a seeded FEL operating at saturation *(in prep.)*
- Superradiant cascade (400nm-> 200nm + harmonics down to 40nm) *(in prep.)*
- Direct seeding with HHG of an FEL amplifier at 160nm (in prep.)
- One stage cascaded FEL amplifier seeded with harmonics generated in gas (266nm -> 133nm) (in prep.)

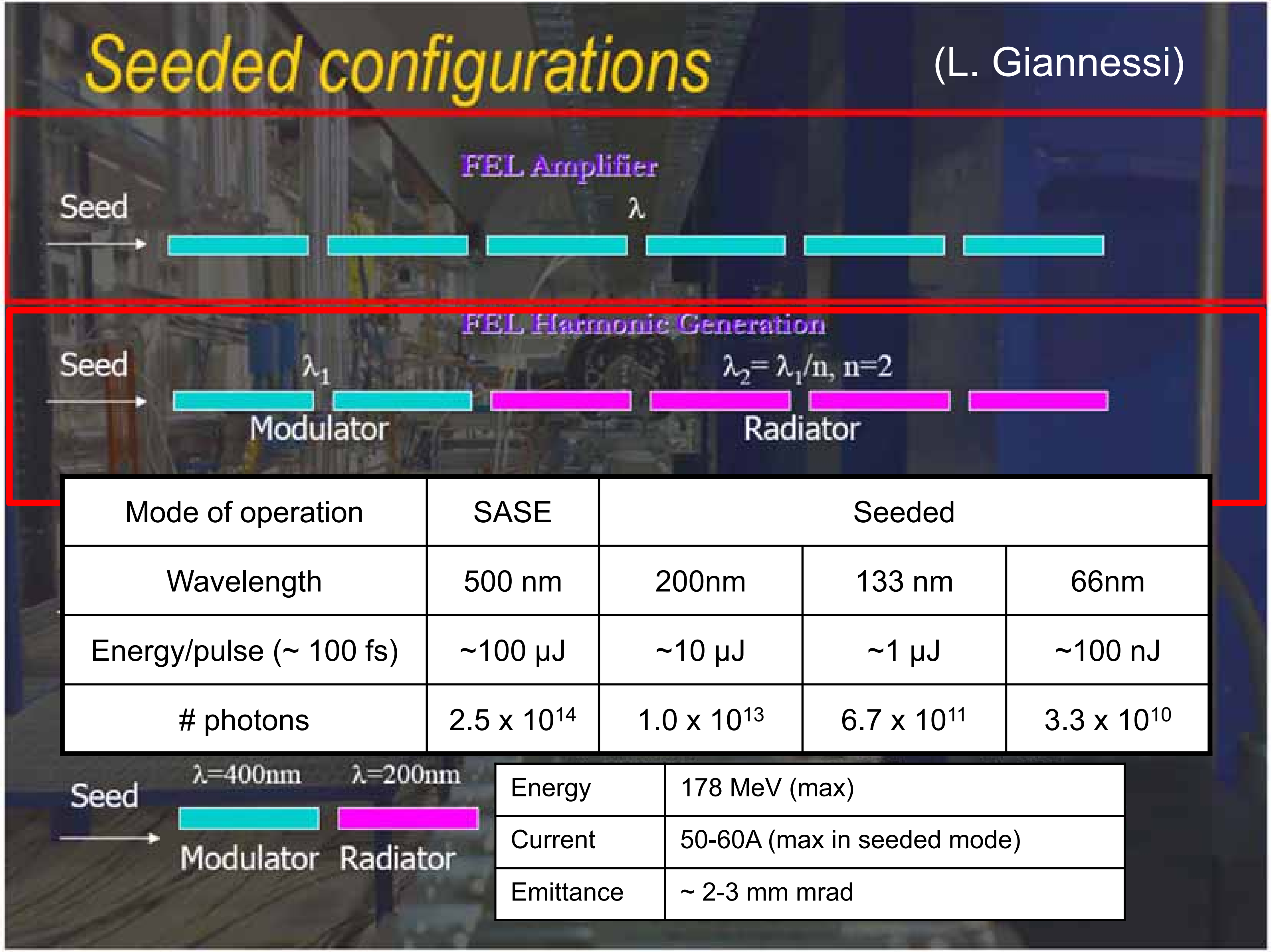
36.18 nm

High harmonics simultaneously generated in a superradiant FEL amplifier



L.Giannessi

Testing of different seedings



Mode of operation	SASE	Seeded		
Wavelength	500 nm	200nm	133 nm	66nm
Energy/pulse (~ 100 fs)	~100 µJ	~10 µJ	~1 µJ	~100 nJ
# photons	2.5×10^{14}	1.0×10^{13}	6.7×10^{11}	3.3×10^{10}

Energy	178 MeV (max)
Current	50-60A (max in seeded mode)
Emittance	~ 2-3 mm mrad

Laser-Comb

M. Boscolo et al. / Nuclear Instruments and Methods in Physics Research A 593 (2008) 106–110 107

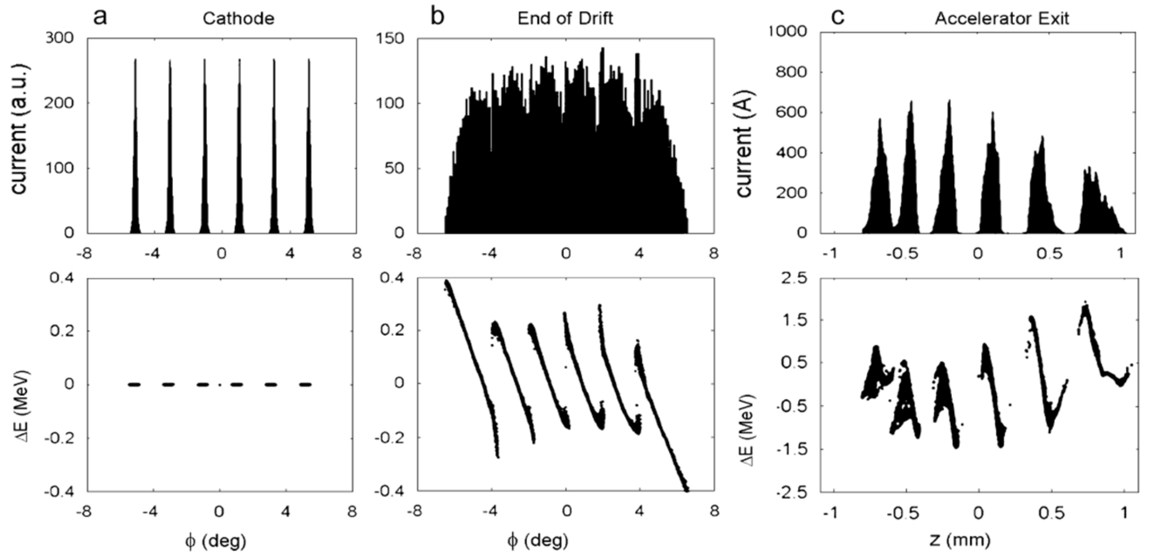
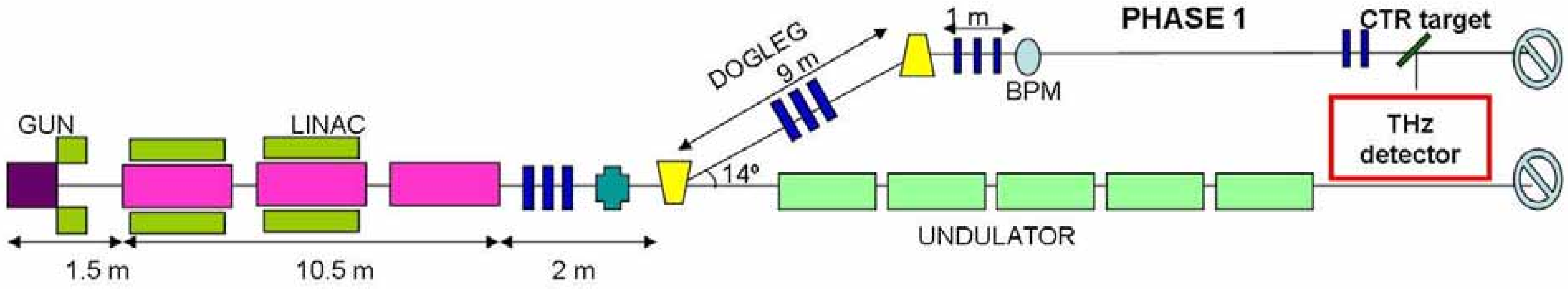


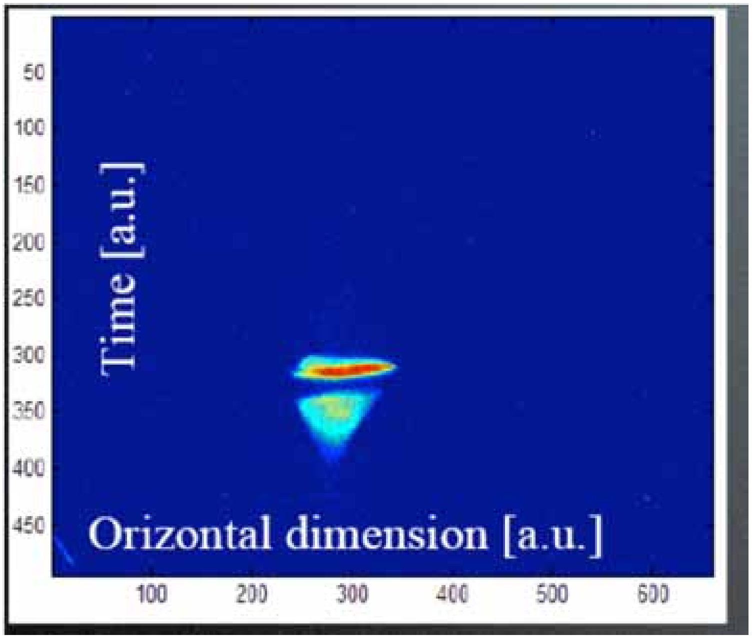
Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).

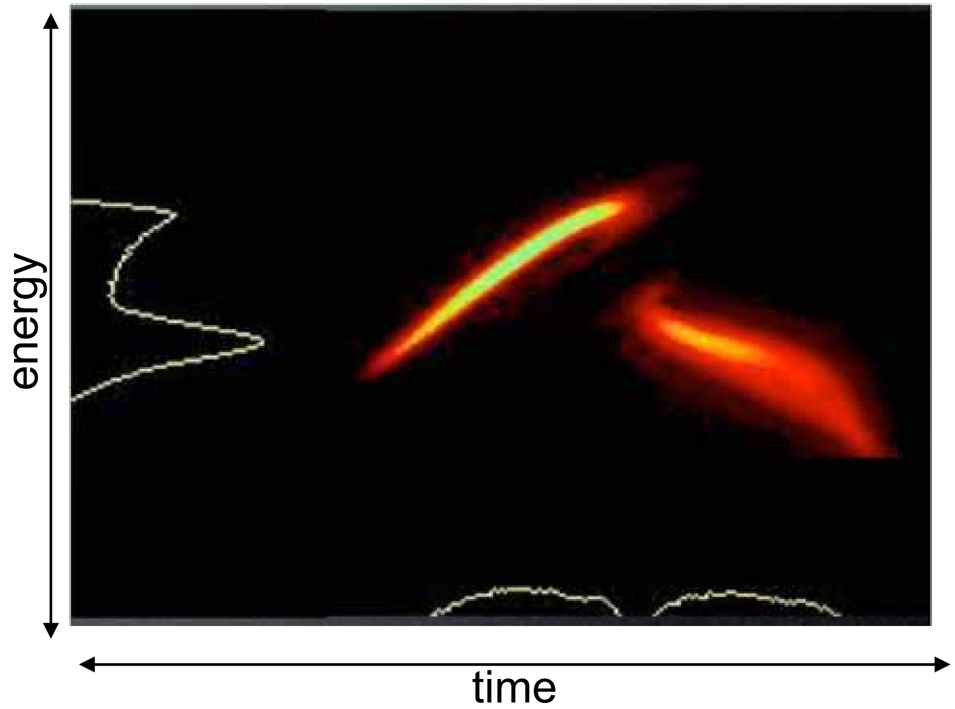


- P.O.Shea et al., Proc. of 2001 IEEE PAC, Chicago, USA (2001) p.704.
- M. Ferrario. M. Boscolo et al., Int. J. of Mod. Phys. B, 2006 (Taipei 05 Workshop)

Pulse separation by COMB

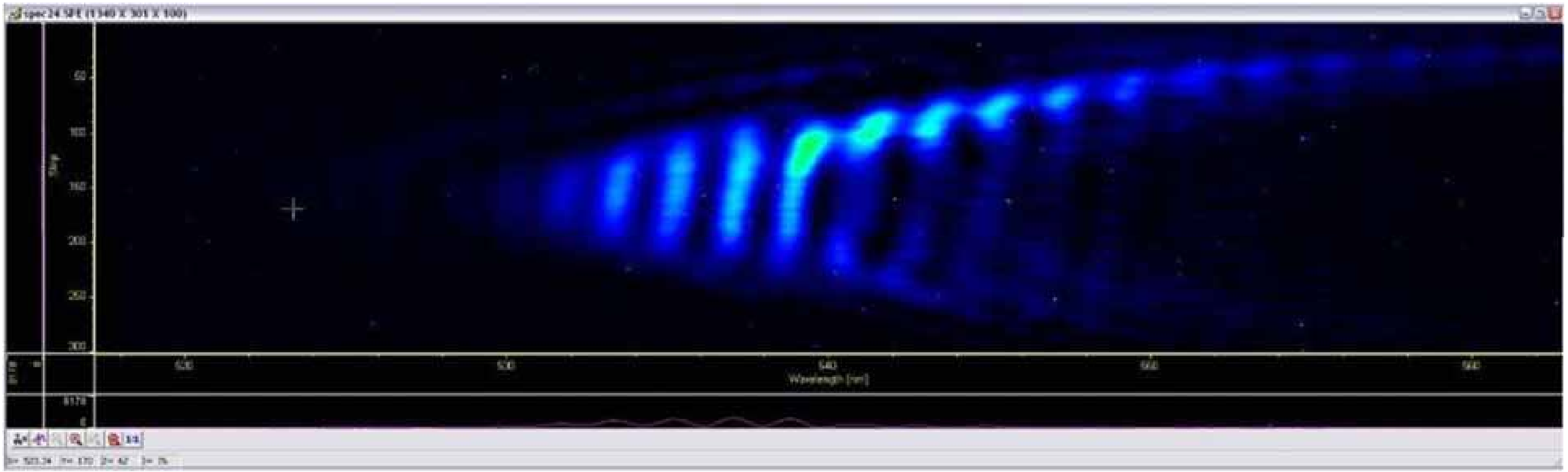
Observation of Pulse Separation in Overcompression Regime

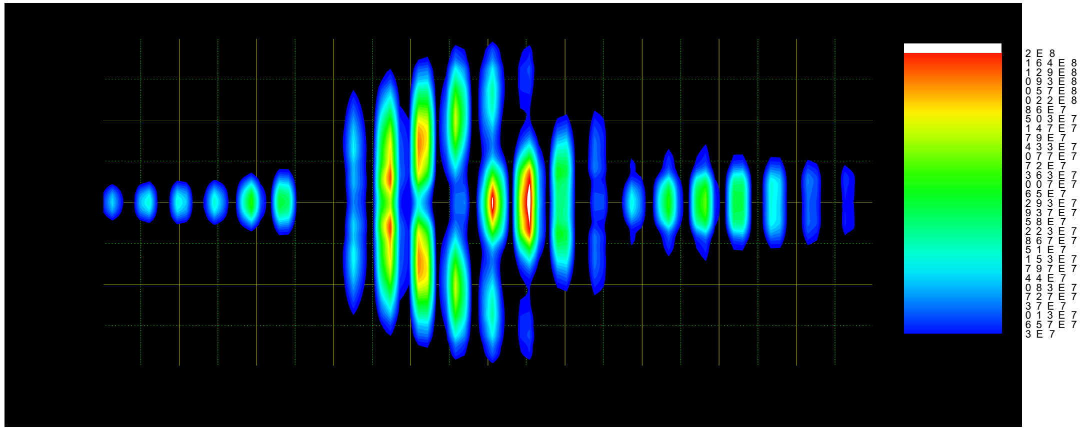




After a tuning of the Velocity Bunching injection phase we observed on the screen downstream the RF Deflector two distinct pulses separated by ~1 ps with σ_{t1} = 0.24 ps
and σ_{t2} =0.29 ps respectively.
The charge unbalance was ~ 40%.

Two pulses from FEL





Genesis 1.3 code

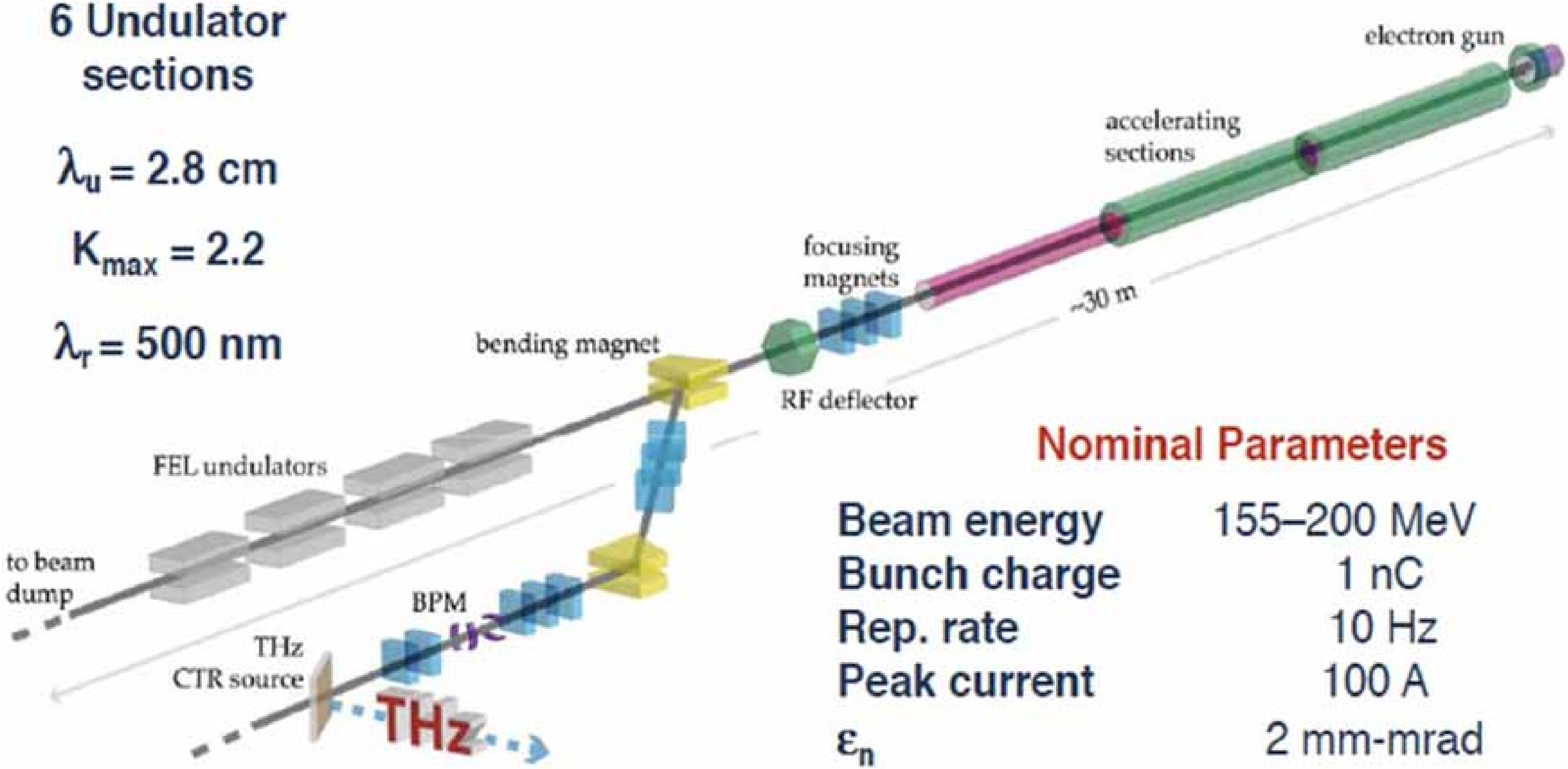
THz-radiation at SPARC

6 Undulator sections

$\lambda_u = 2.8$ cm

$K_{max} = 2.2$

$\lambda_r = 500$ nm



Nominal Parameters

Beam energy	155–200 MeV
Bunch charge	1 nC
Rep. rate	10 Hz
Peak current	100 A
ε_n	2 mm-mrad
ε_n(slice)	1 mm-mrad
σ_γ	0.2%
Laser Pulse length	<10 ps (FWHM)

Effect of Bunch Compression

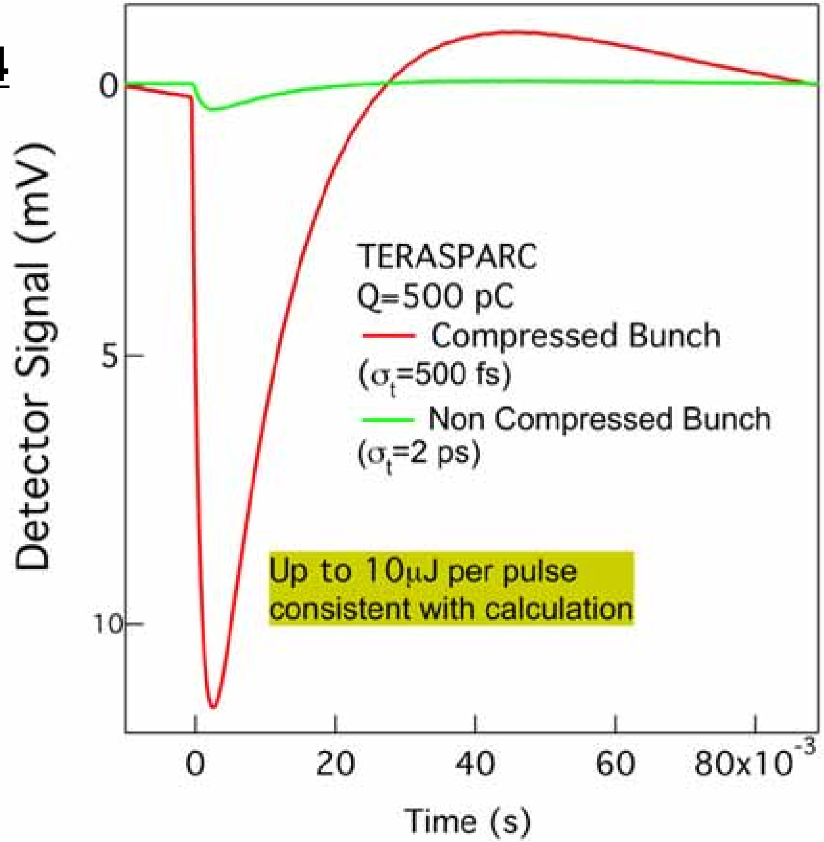
A gain of a factor 25 in intensity with respect to the on crest operation has been detected in the RF compression mode

On crest operation

Q = 500 pC
Energy= 167 MeV
energy spread = 0.1%
e_x= 3.5 mm mrad
b_x = 17.73 m
a_x = -1.17
e_y = 4.1 mm mrad
b_y = 25 m
a_y = -2.78
σ_t = 2.0 ps

Compression Factor 4

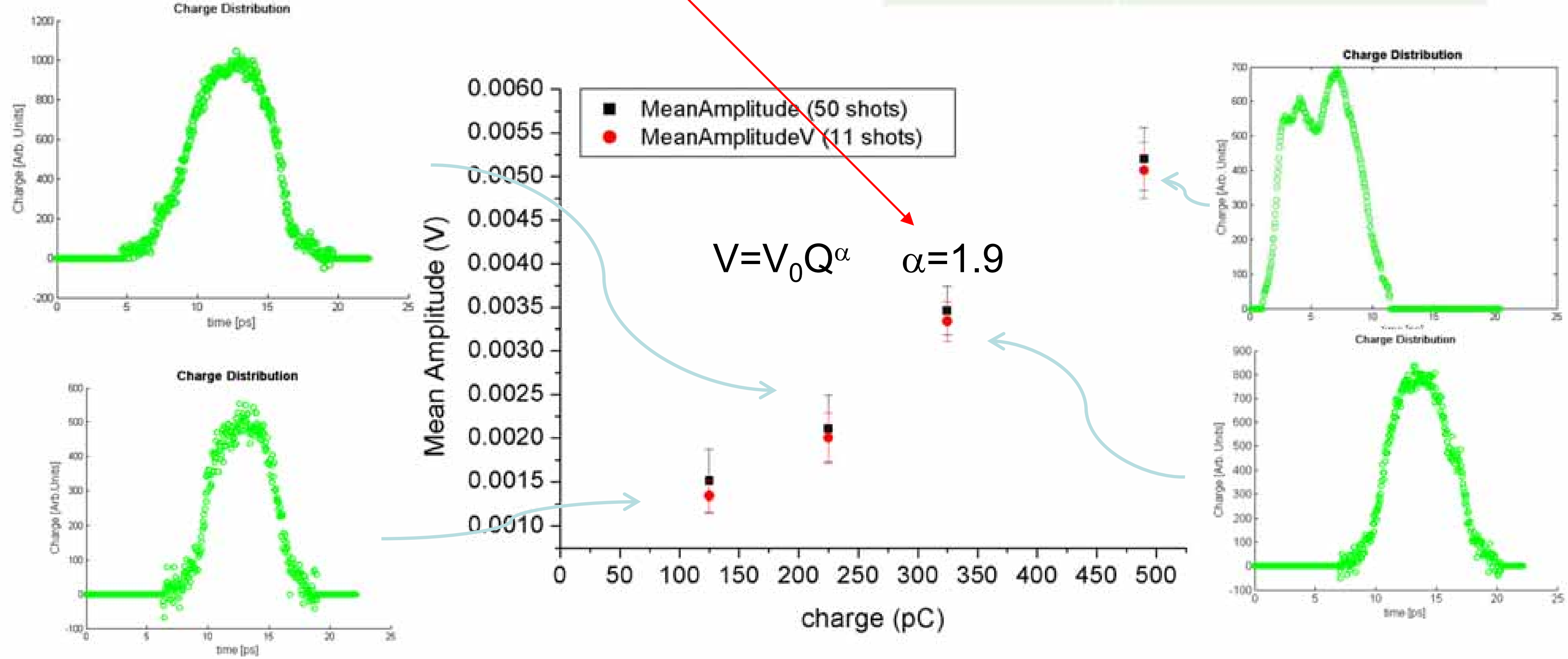
Q = 500 pC
Energy= 94 MeV
energy spread = 1%
e_x= 6.4 mm mrad
b_x = 28.4 m
a_x = -2.774
e_y = 3.3 mm mrad
b_y = 33.83 m
a_y = -2.539
σ_t = 0.5 ps



N^2 dependency

$$I_{tot}(\lambda)=I_{sp}\, N^2\, F_{||}(\lambda)$$

Charge (pC)	Bunch Length (ps)
125	1.81+/-0.019
225	1.96+/-0.018
335	2.22+/-0.021
490	2.49+/-0.034

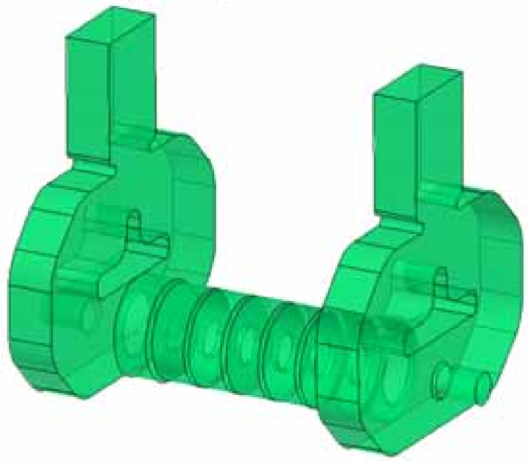


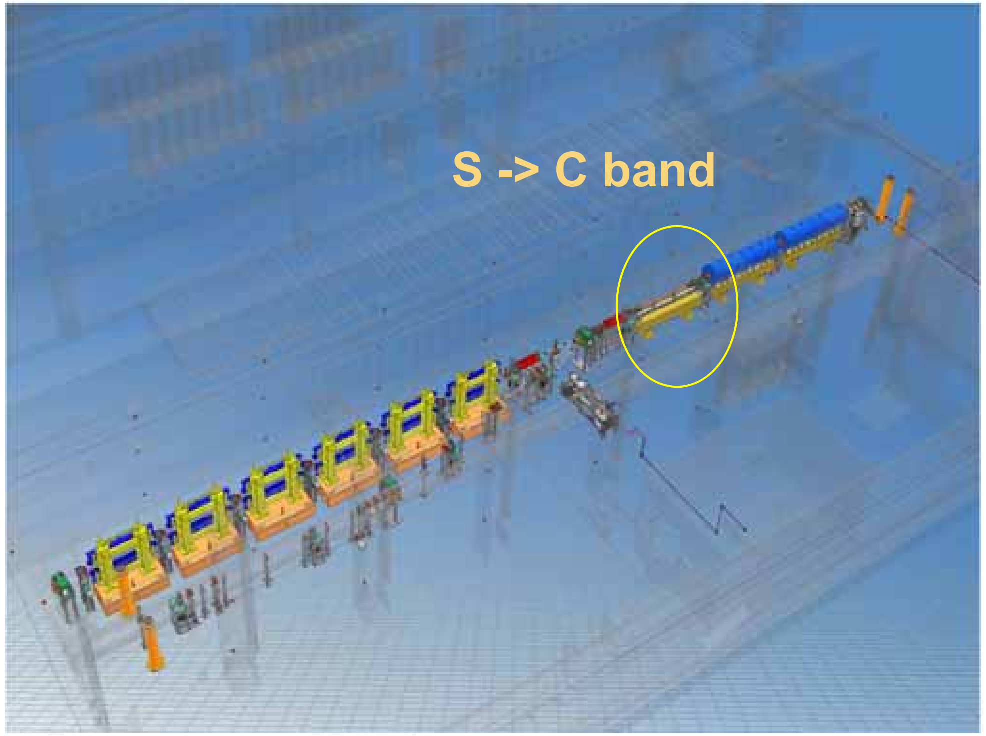
Future developments

Energy Up-grade - C-band

main Motivation: to increase the SPARC beam energ *from ≈ 180 MeV to ≈ 250 MeV* to lase closer to the UV and improve the seeding experiment

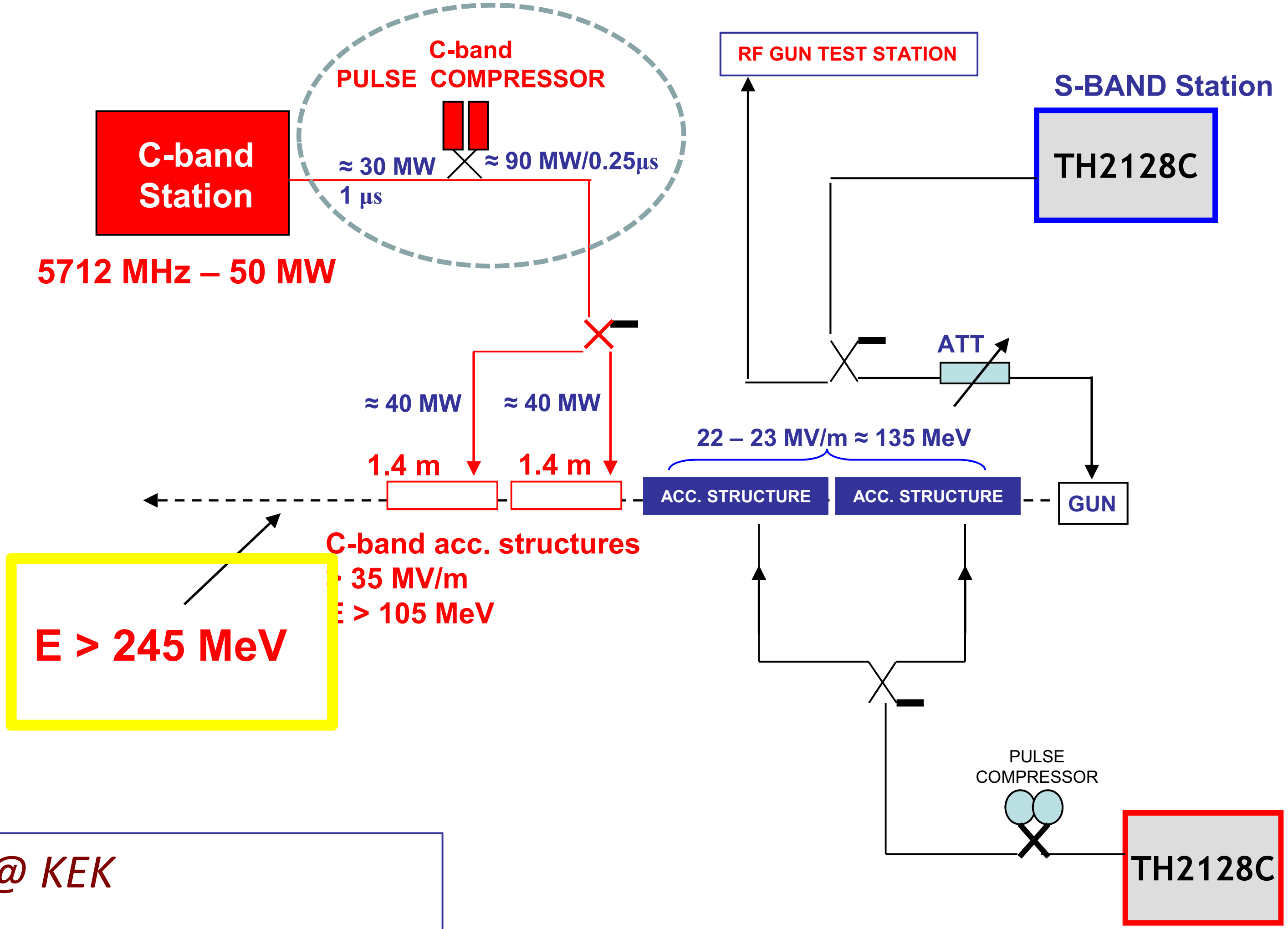
2nd Motivation: to gain experience with a rather new RF technology, in the light of possible future developments





PARAMETERS	
Frequency (f_{RF})	5.712 [GHz]
Phase advance per cell ($\Delta\phi$)	$2\pi/3$
Number of accelerating cells (N)	86
group velocity (vg):	0.0278*c
Field attenuation (α)	0.22 [1/m]
Filling time (τ)	180 [ns]
Average accelerating field @ $t=\tau$	35 [MV/m]
Average diss. Power @ 10 Hz	46 [W]

SPARC with C-Band

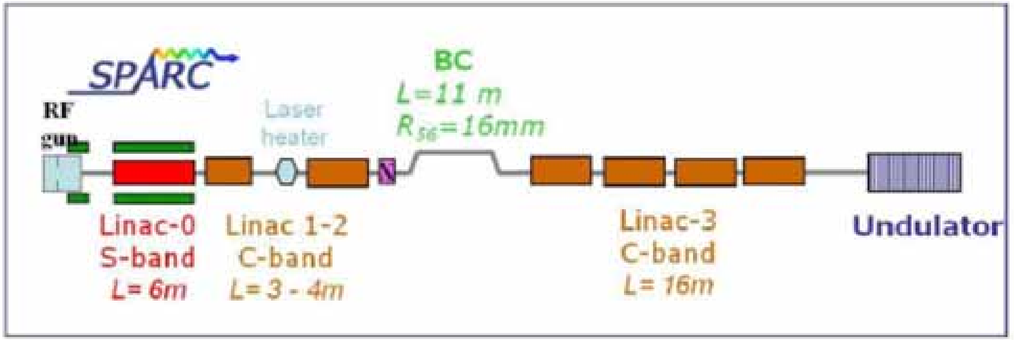


Test of C-band 50 cm @ KEK
RF power is ***110 MW***
'breakdown rate' of a few discharges/hour
Acceleration >40 MeV/m

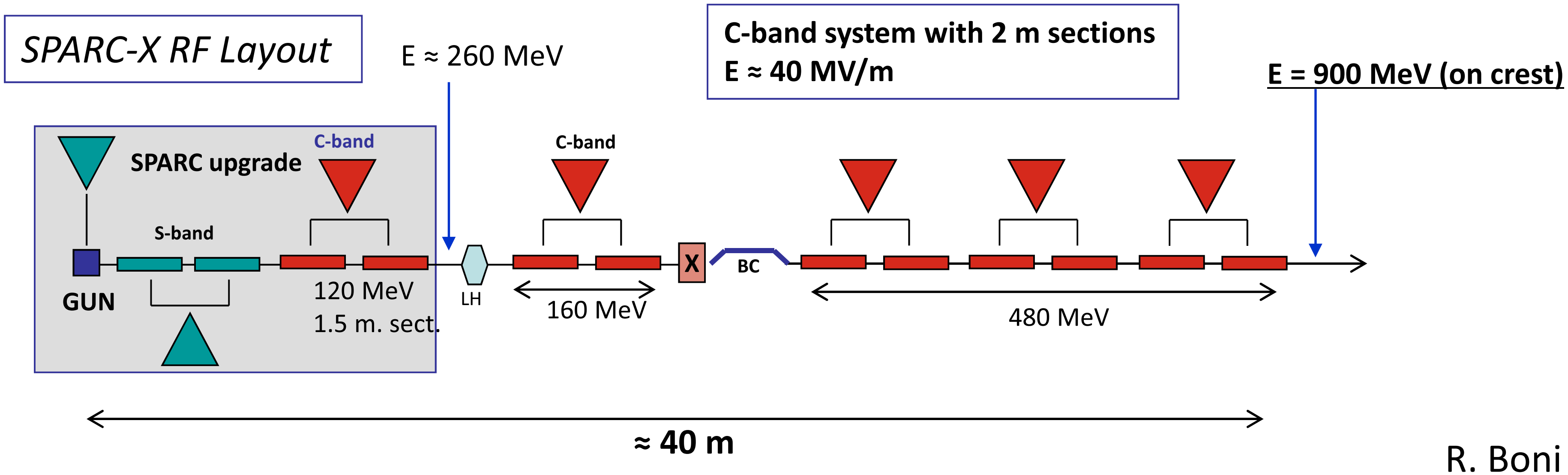
R. Boni

Energy upgrade to 750 MeV

Following the successful result of the prototype power test, an average C-band RF gradient of 40 MV/m can be considered for the SPARC energy upgrade to 750 MeV.



General layout of SPARC-X-750



R. Boni

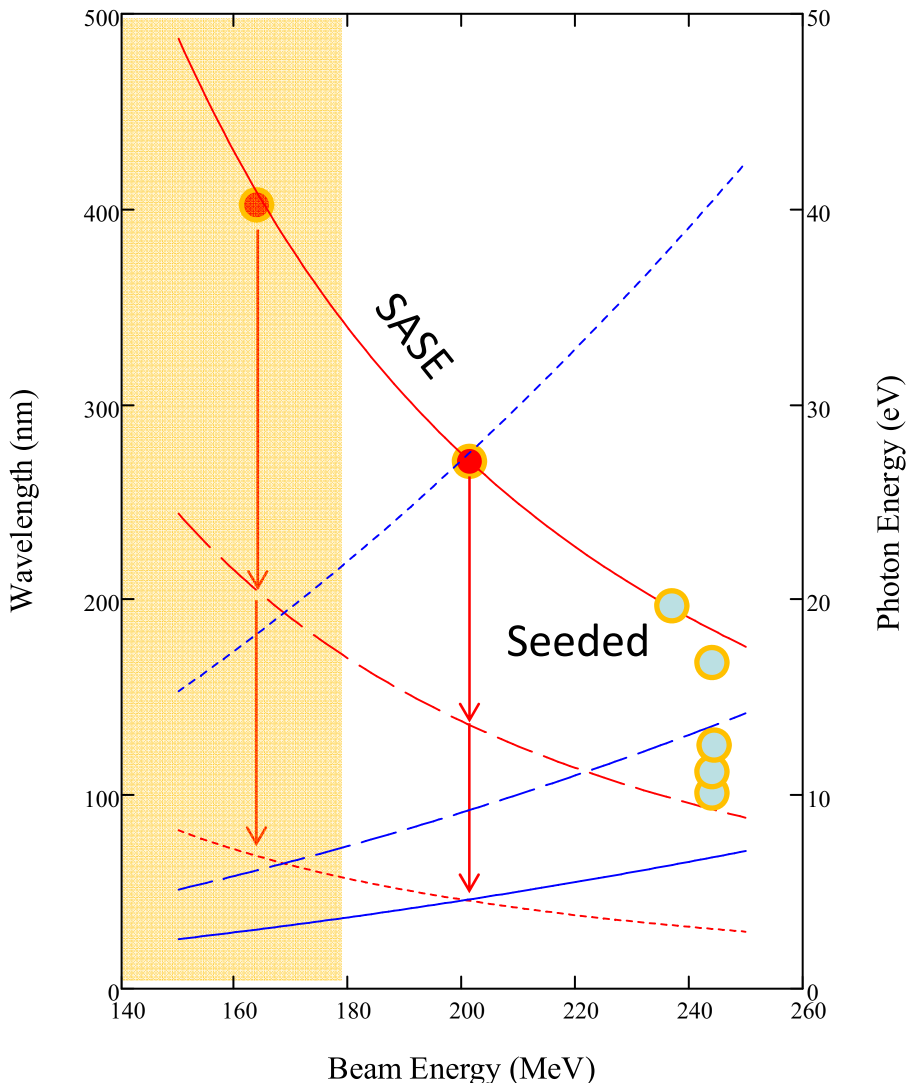
C-Band for lower wavelength

- Cascaded FEL amplifier seeded with harmonics generated in gas *(in progress)*

Seeding with a 1 stage cascade
@ 400 nm & 266 nm

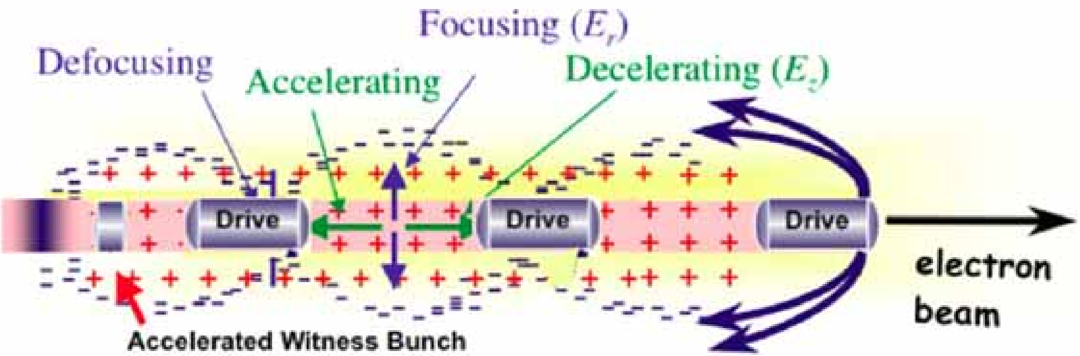
3° harmonic in the cascade

Direct Seeding
with harmonics generated in gas
@ 200nm,
160nm,
133nm,
114nm,
100nm



Plasma WFA by COMB

Coherent plasma Oscillations by Multiple electron Bunches
for FEL and Linear Collider applications

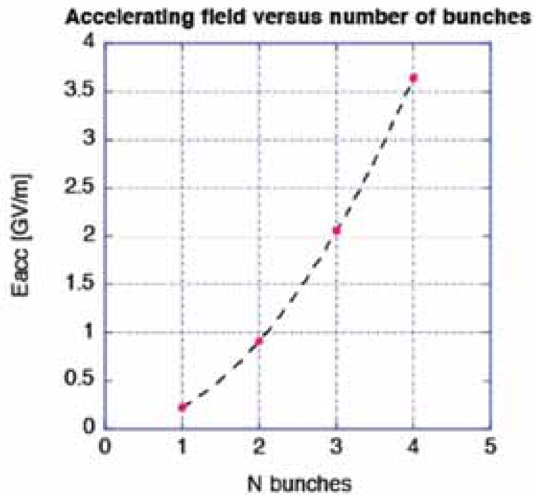


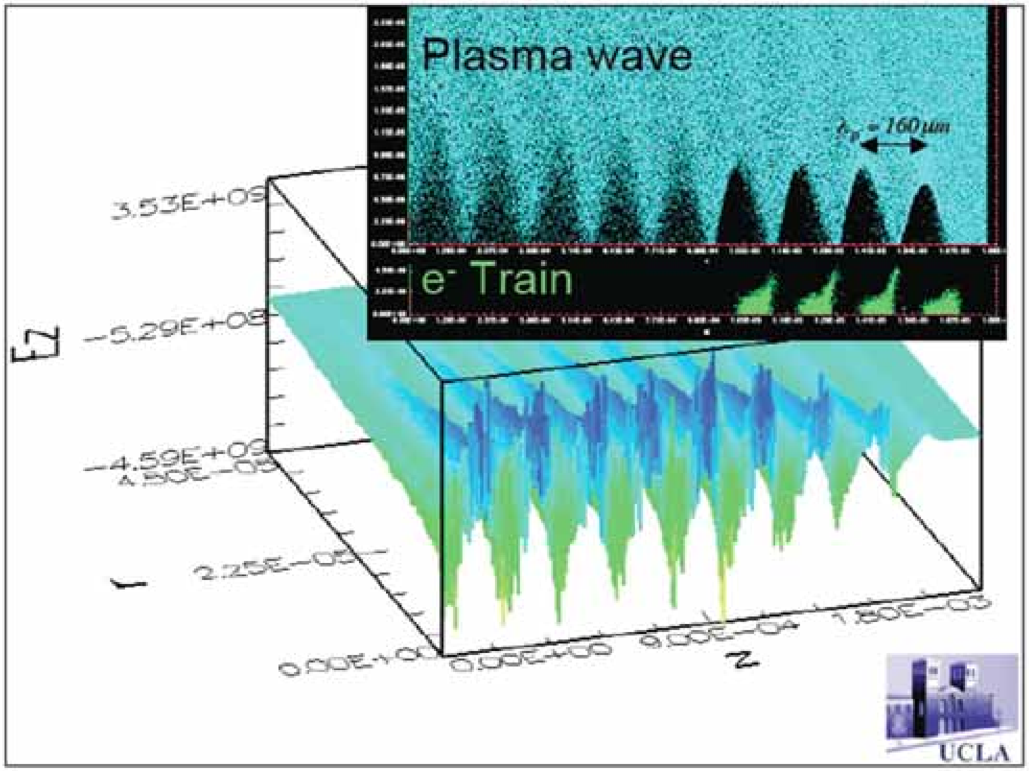
- **Weak blowout regime** (new!) with resonant amplification of plasma wave by a train of high Brightness electron bunches produced by **Laser Comb** (new!) technique ==> **5 GV/m** with a train of 3 bunches, 100 pC/bunch, 50 μm long, 20 μm spot size, in a plasma of density 10^{22} e^-/m^3 at λ_p=300 μm ?
- **Strong blowout regime** (new!) with pC/fs bunches ==> TV/m regime ?
- Acceleration of a train of bunches for high Luminosity Colliders

Promising Simulations

Weak Blowout Regime: operation in the quasi-nonlinear regime, where one uses beam with relatively low charge and longitudinal and transverse beam size smaller than a plasma wavelength $\sigma_z, \sigma_r << \lambda_p$ In this case, the beam density may exceed that of the plasma, producing blowout, but due to the small total charge, producing a disturbance that behaves in many ways as linear, having frequency essentially that of linear plasma oscillations.

N_b=4
Q=16 pC
N_e=10^8
n_e=3 10^{22} m^{-3}
λ_p=190 μm
==> 3 GV/m





$$E_{acc}[GV/m] = 76 \times 10^{-33} \times n_p[m^{-3}] \times N_e \times N_b^2$$

comb

SPARX@LNF Future Strategy

- SPARX@LNF:
  - Compactness: C-X band accelerators – short-undulator (7-9 mm)
  - Ultra-short radiation bunches (bunch length <10 fs)
  - High repetition rate (from 50 Hz – multi-100 Hz)
  - Integration of novel acceleration technologies (plasma injector)
  - Combination of FEL radiation (0.1 – 10 keV) with Compton scattered photons (100 keV – 20 MeV)

Thank you !