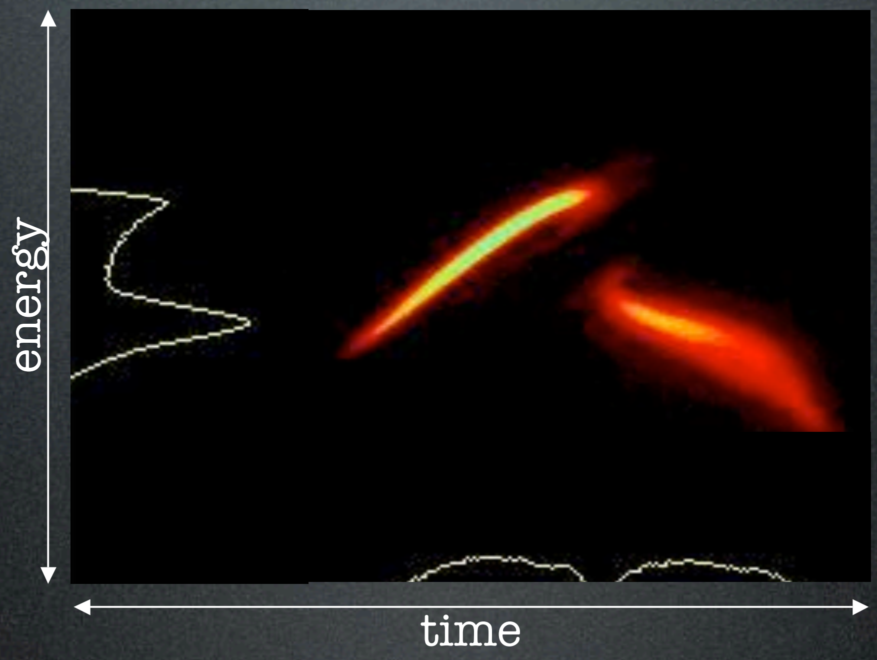
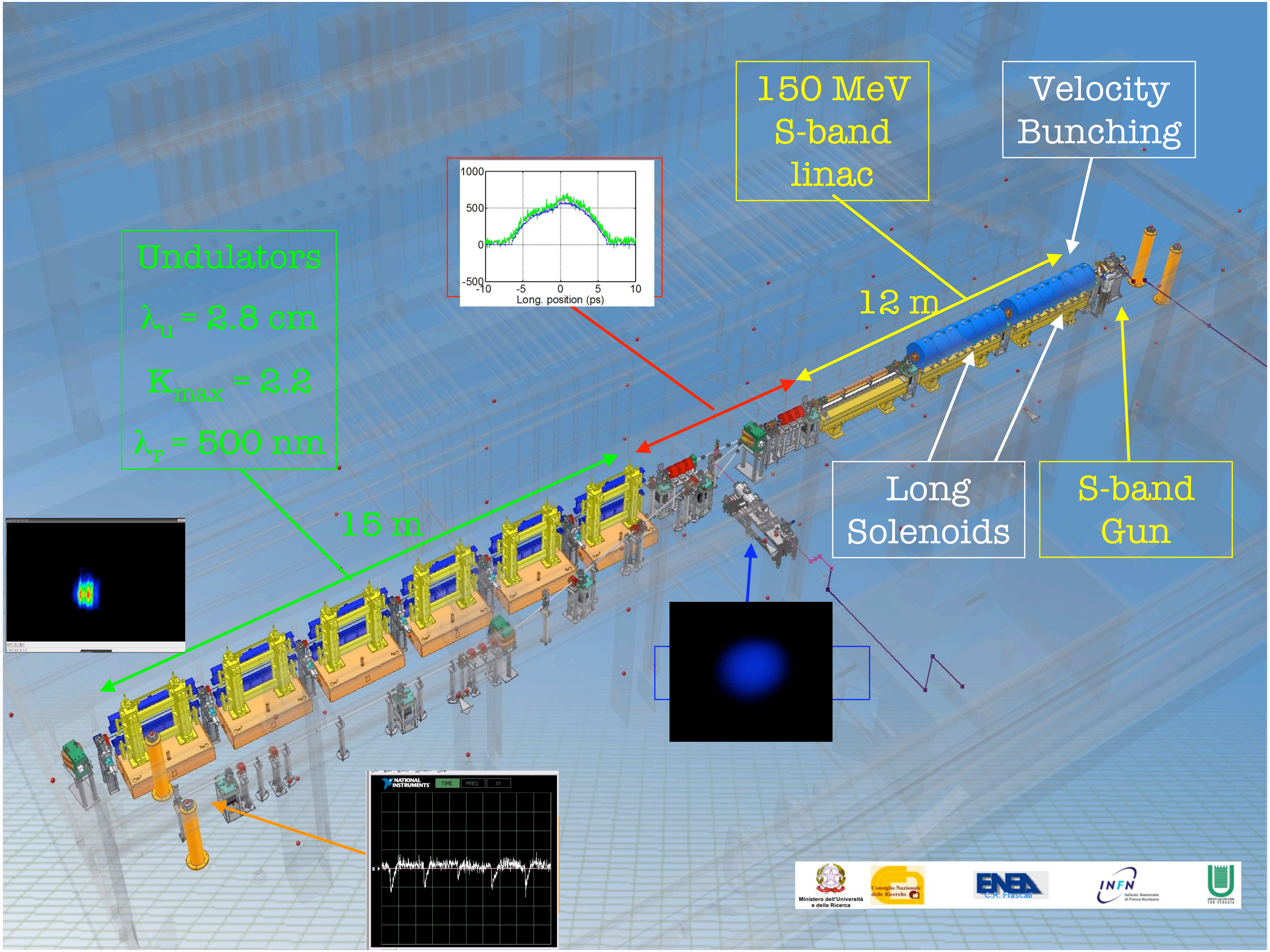
SPARC: fasci di elettroni ad alta brillanza

Massimo Ferrario
on behalf of the SPARC team



LNF meeting on "Prospettive future con gli acceleratori di Frascati" - June 11, 2010

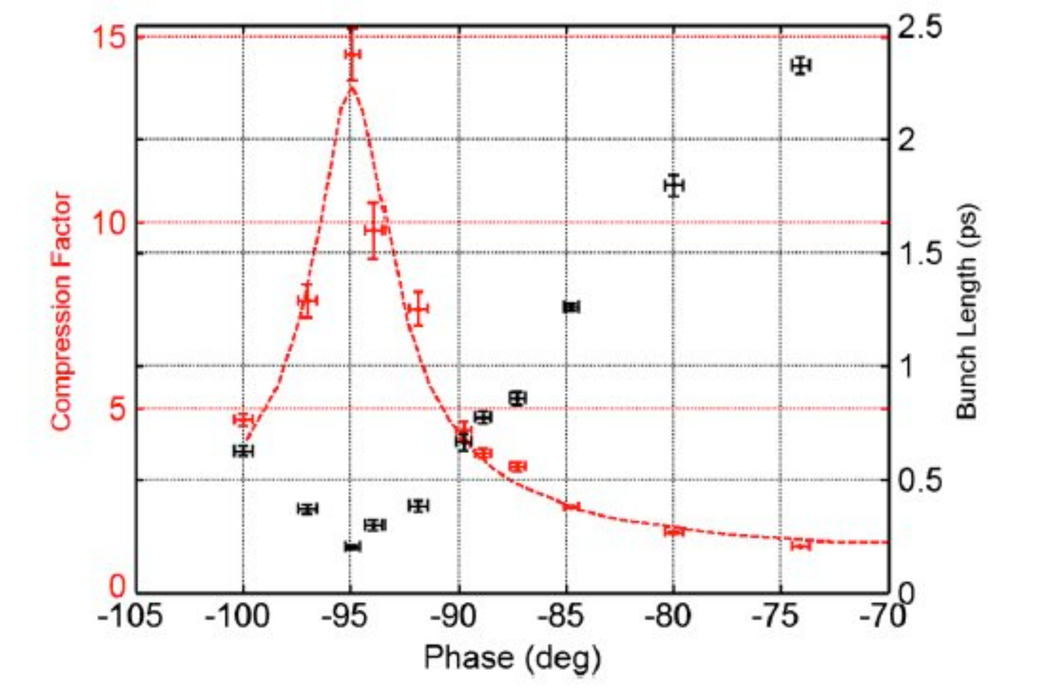

150 MeV
S-band
linac
Velocity
Bunching
Undulators
λ_u = 2.8 cm
K_{max} = 2.2
λ_r = 500 nm
12 m
15 m
Long
Solenoids
S-band
Gun
1000
500
0
-500
-10
-5
0
5
10
Long. position (ps)
NATIONAL INSTRUMENTS
TIME
FREQ
XY
Ministero dell'Università e della Ricerca
ENEA
C.R. Frascati
INFN

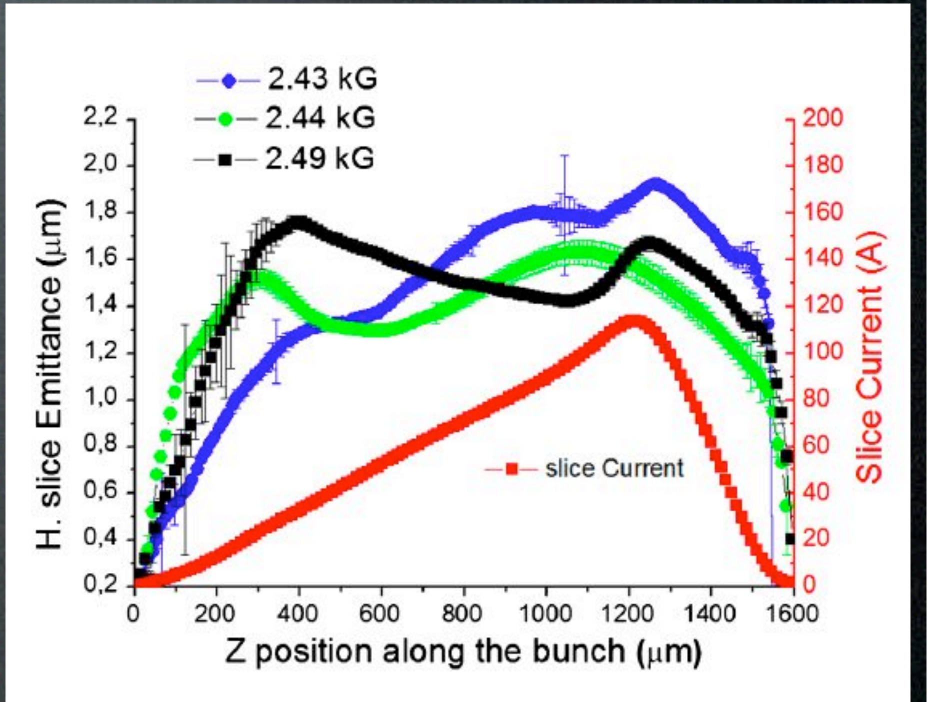
Experiments with Velocity Bunching

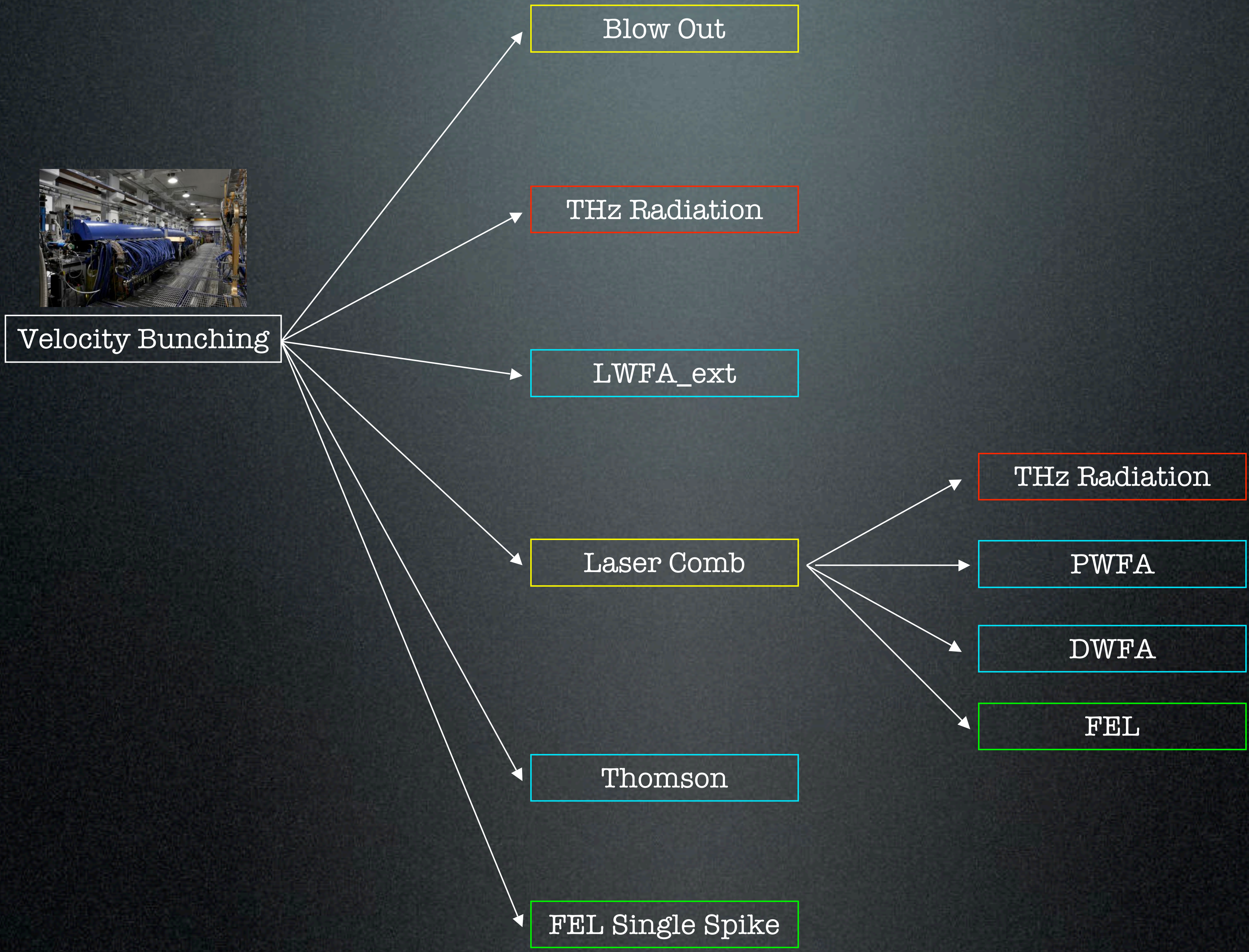
PRL 104, 054801 (2010) PHYSICAL REVIEW LETTERS week ending 5 FEBRUARY 2010

Experimental Demonstration of Emittance Compensation with Velocity Bunching

M. Ferrario,[1] D. Alesini,[1] A. Bacci,[3] M. Bellaveglia,[1] R. Boni,[1] M. Boscolo,[1] M. Castellano,[1] E. Chiadroni,[1] A. Cianchi,[2] L. Cultrera,[1] G. Di Pirro,[1] L. Ficcadenti,[1] D. Filippetto,[1] V. Fusco,[1] A. Gallo,[1] G. Gatti,[1] L. Giannessi,[4] M. Labat,[4] B. Marchetti,[2] C. Marrelli,[1] M. Migliorati,[1] A. Mostacci,[1] E. Pace,[1] L. Palumbo,[1] M. Quattromini,[4] C. Ronsivalle,[4] A. R. Rossi,[3] J. Rosenzweig,[5] L. Serafini,[3] M. Serluca,[6] B. Spataro,[1] C. Vaccarezza,[1] and C. Vicario[1]





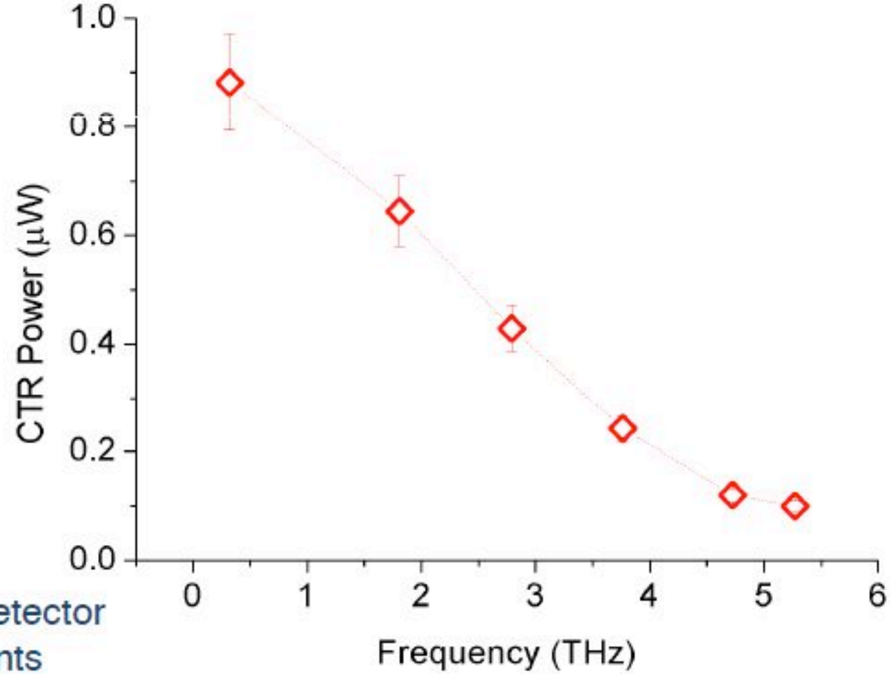

Velocity Bunching
Blow Out
THz Radiation
LWFA_ext
Laser Comb
Thomson
FEL Single Spike
THz Radiation
PWFA
DWFA
FEL

THz radiation

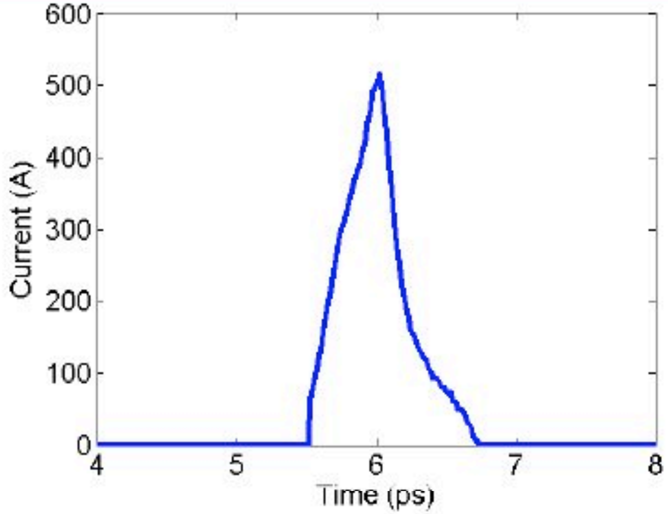
THz RADIATION FROM HBEBs

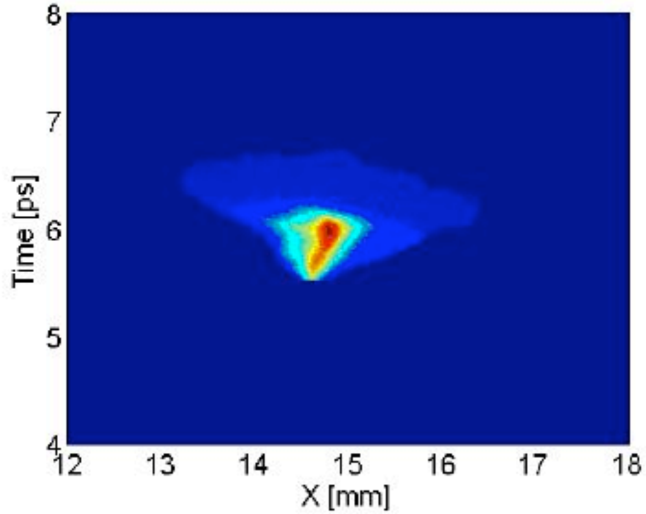
Velocity bunching with compression factor 14 and emittance compensated

Q = 260 pC
σ_t = 260 fs (after compression)
Beam Energy= 100 MeV



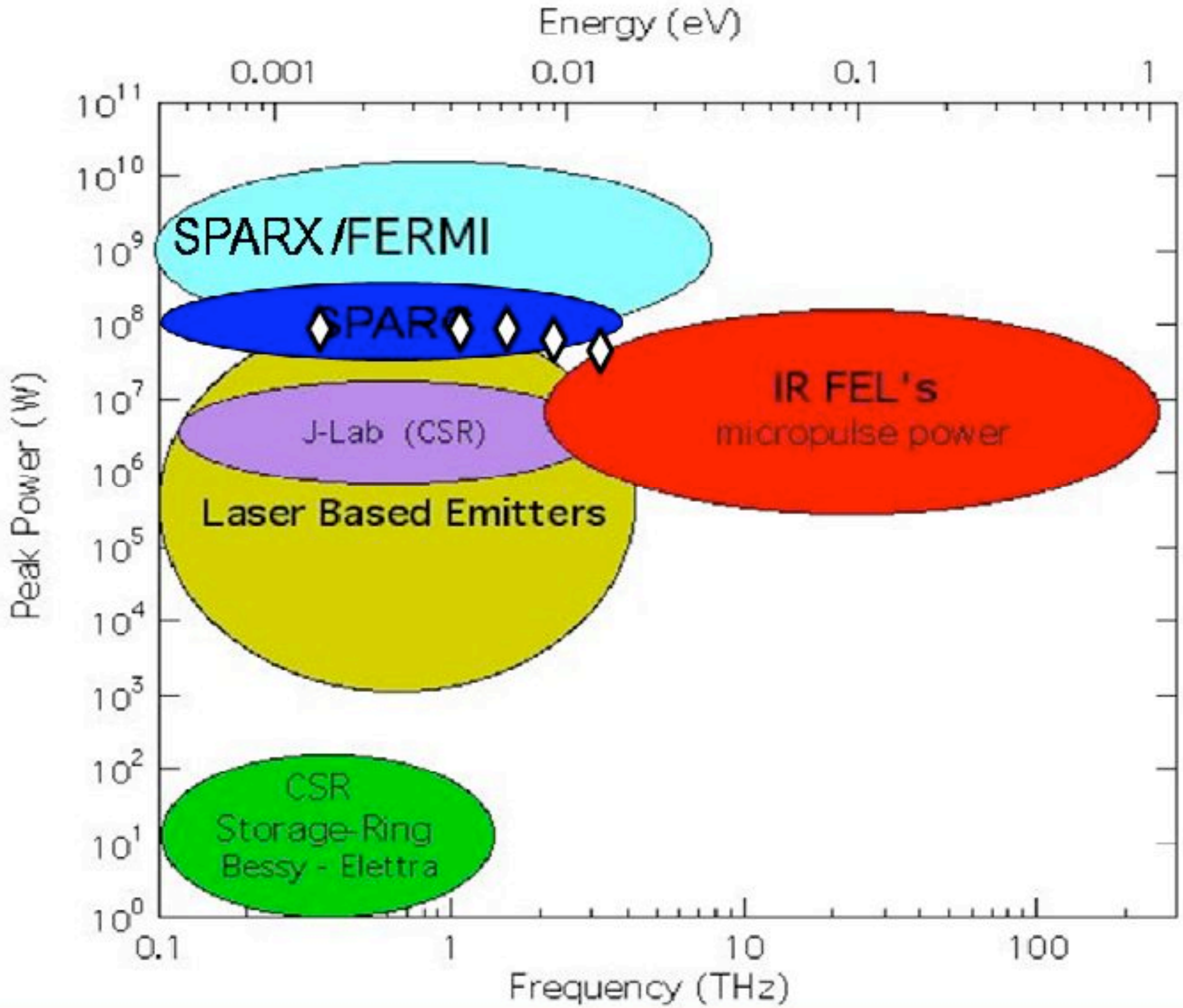
Golay cell detector measurements





Enrica Chiadroni
(INFN/LNF)

PERFORMANCE ACHIEVED



Enrica Chiadroni
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Laser Comb technique

Laser Comb: a train of THz bunches

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

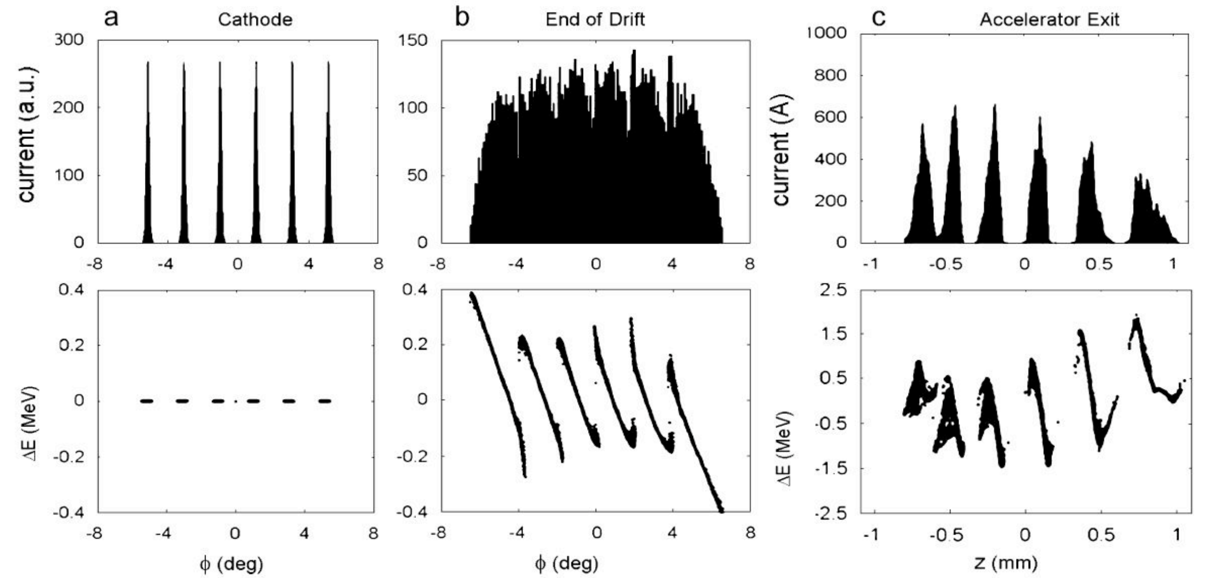
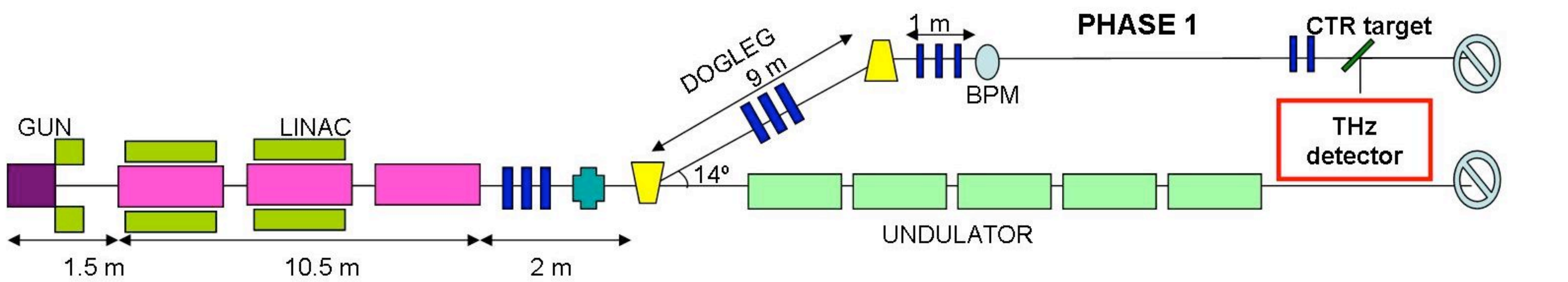


Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).



- 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)

Contents lists available at ScienceDirect

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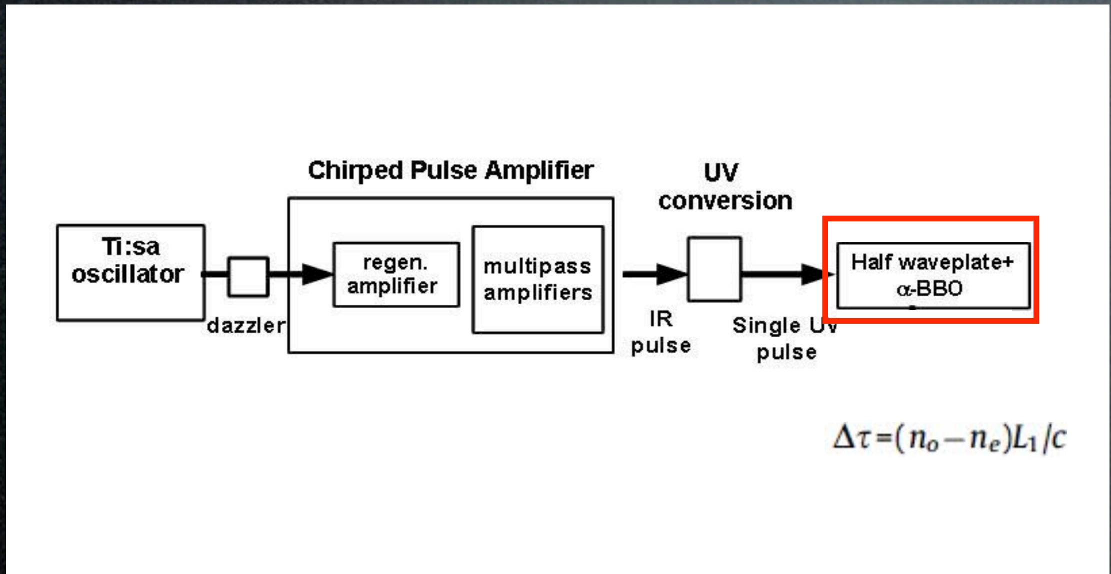
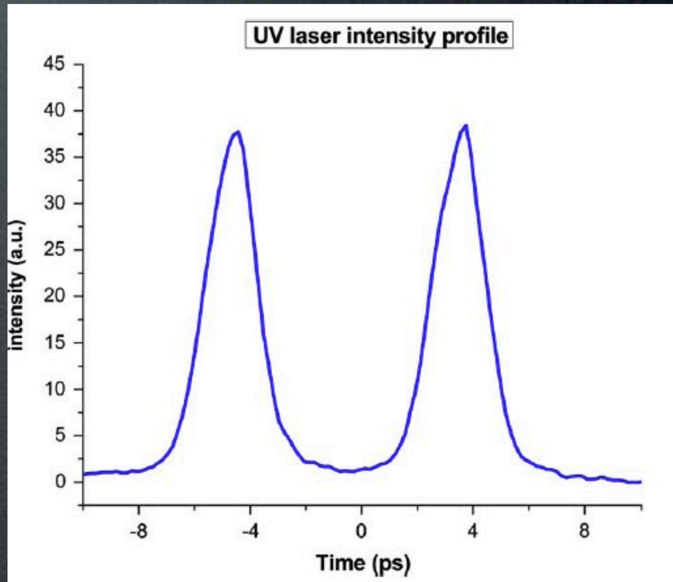
journal homepage: www.elsevier.com/locate/nima

Laser comb with velocity bunching: Preliminary results at SPARC

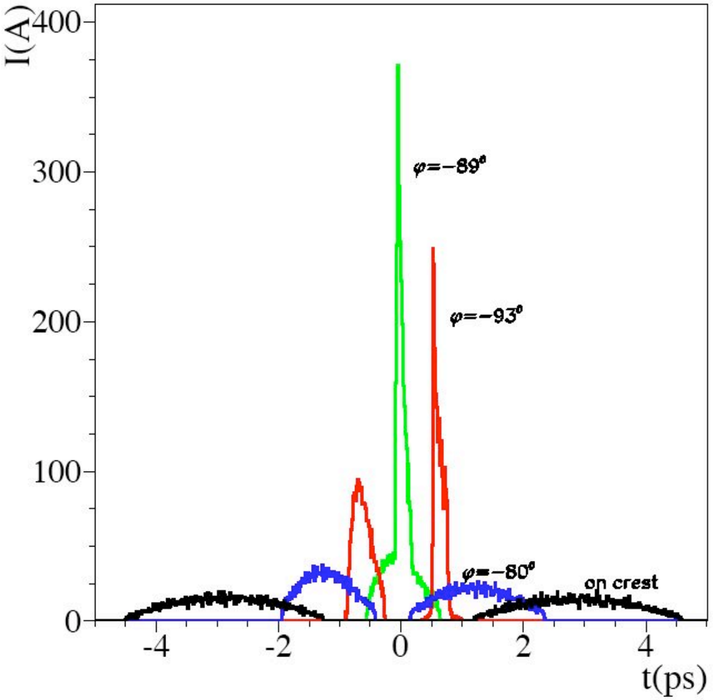


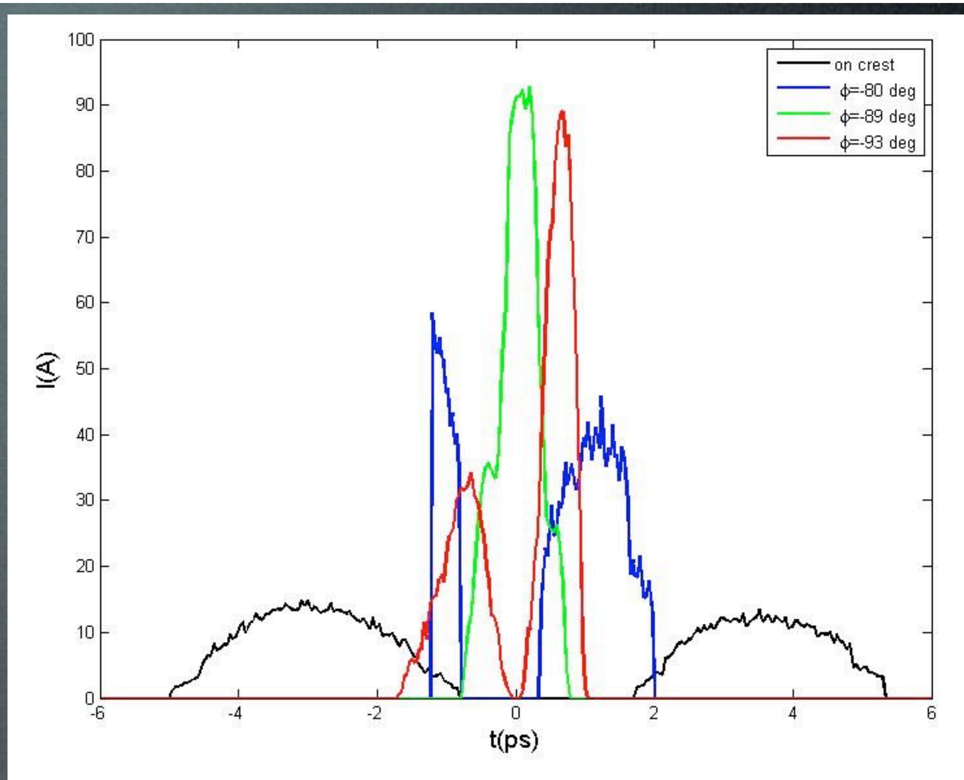


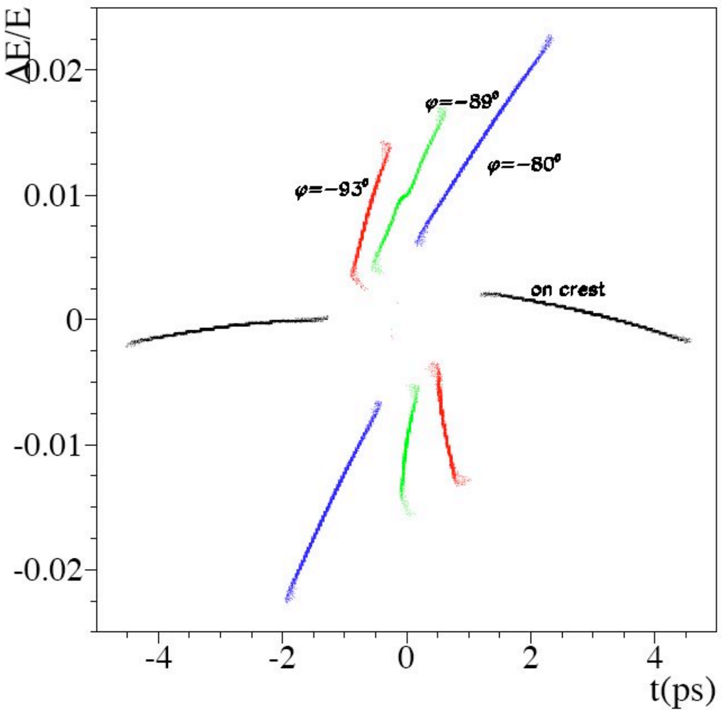
35 pC/pulse

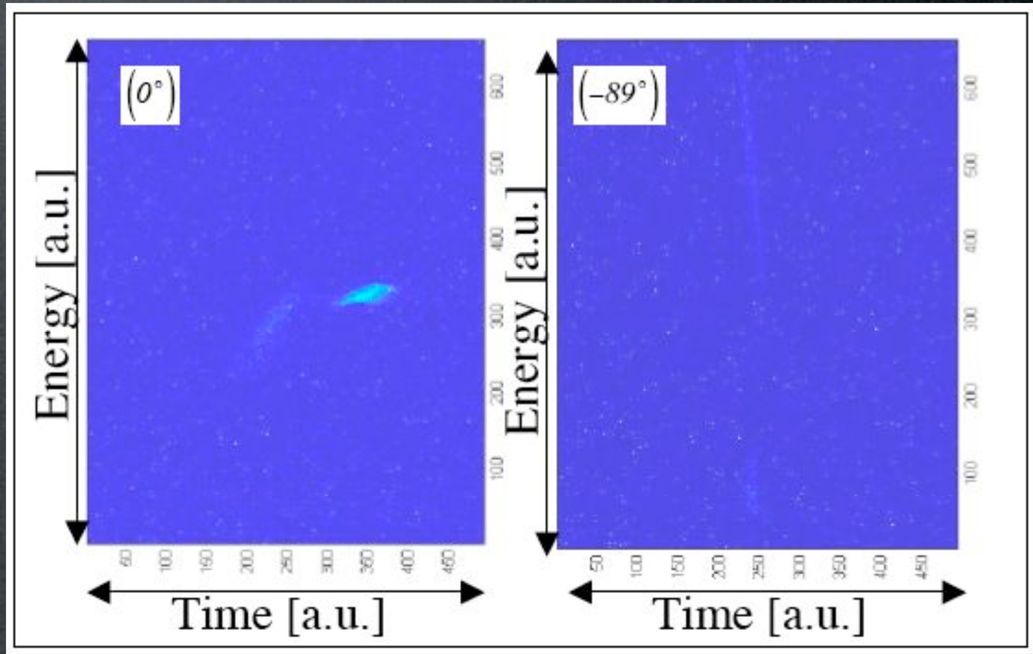
The technique used for this purpose relies on a birefringent crystal, where the input pulse is decomposed in two orthogonally polarized pulses with a time separation proportional to the crystal length.

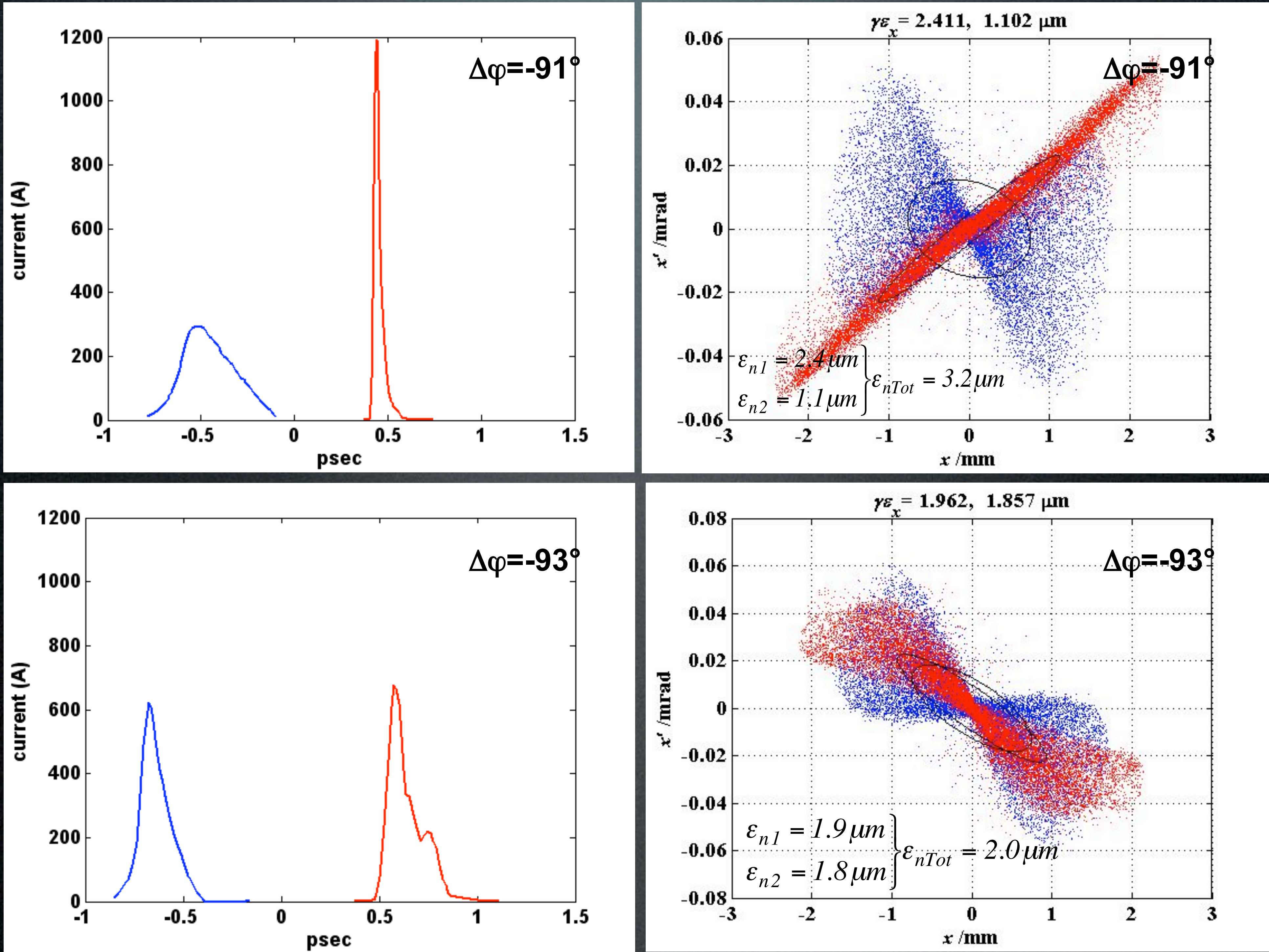
The crystal thickness is 10.353 mm


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


100
90
80
70
60
50
40
30
20
10
0
I(A)
on crest
ϕ=-80 deg
ϕ=-89 deg
ϕ=-93 deg
-6
-4
-2
0
2
4
6
t(ps)

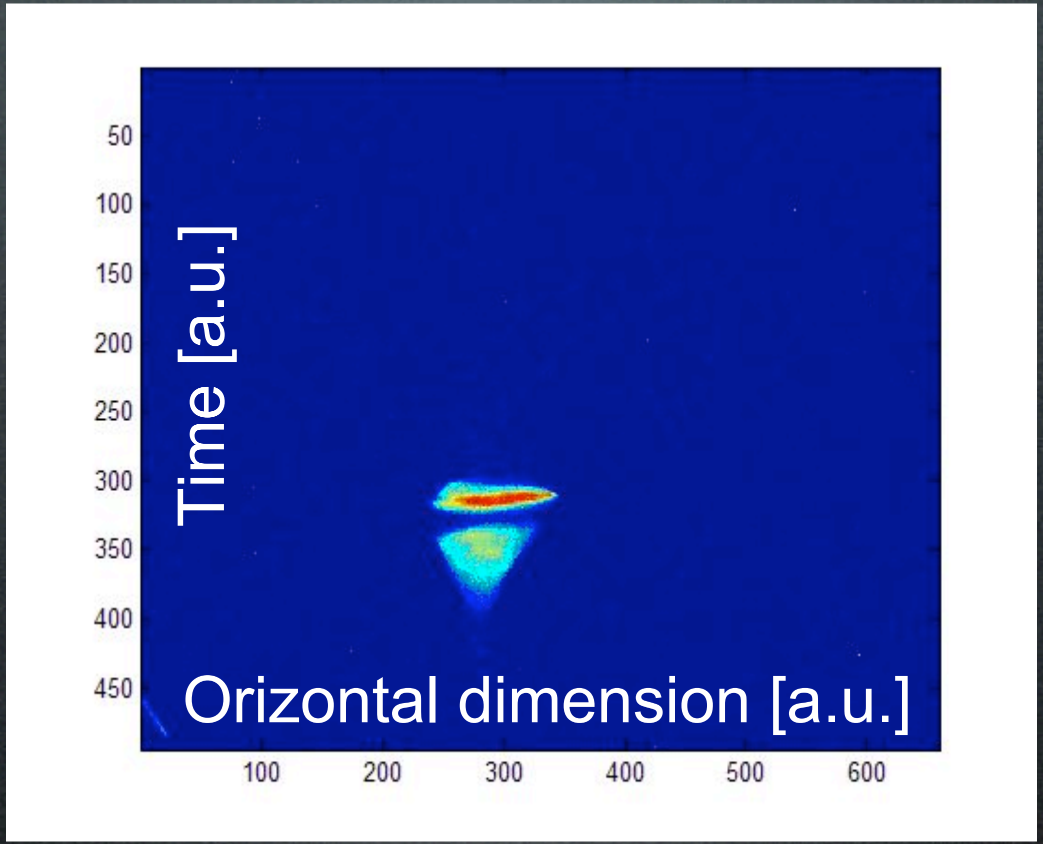

ΔE/E
0.02
0.01
0
-0.01
-0.02
φ=−89°
φ=−80°
φ=−93°
on crest
-4
-2
0
2
4
t(ps)


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



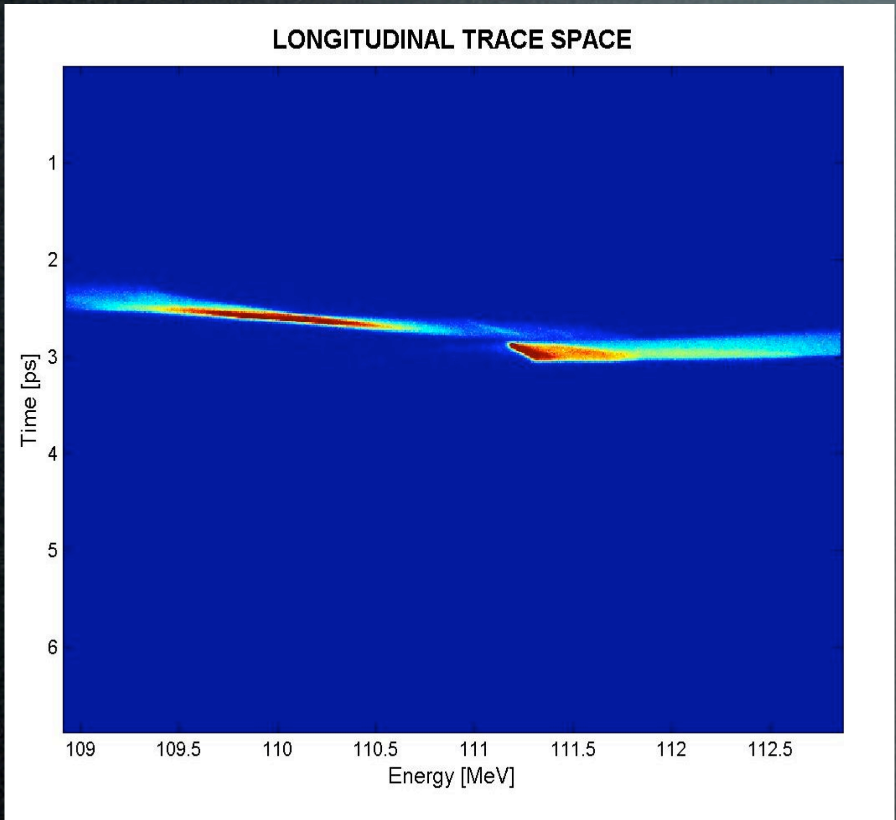
Δφ=-91°
current (A)
psec
γε_x = 2.411, 1.102 μm
Δφ=-91°
x' /mrad
x /mm
$\varepsilon_{n1} = 2.4\mu m$
$\varepsilon_{n2} = 1.1\mu m$
$\varepsilon_{nTot} = 3.2\mu m$
Δφ=-93°
current (A)
psec
γε_x = 1.962, 1.857 μm
Δφ=-93°
x' /mrad
x /mm
$\varepsilon_{n1} = 1.9\mu m$
$\varepsilon_{n2} = 1.8\mu m$
$\varepsilon_{nTot} = 2.0\mu m$

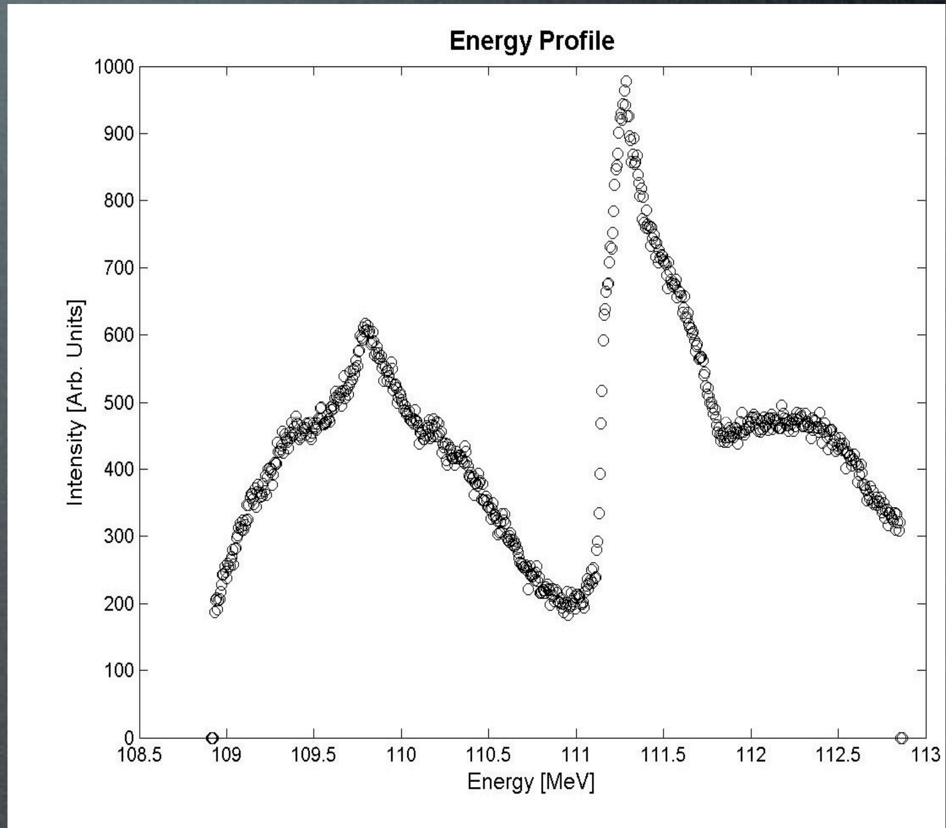
Observation of Pulse Separation in Overcompression Regime



After a tuning of the VB 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%.

Measured Longitudinal Phase Space and Energy Profile





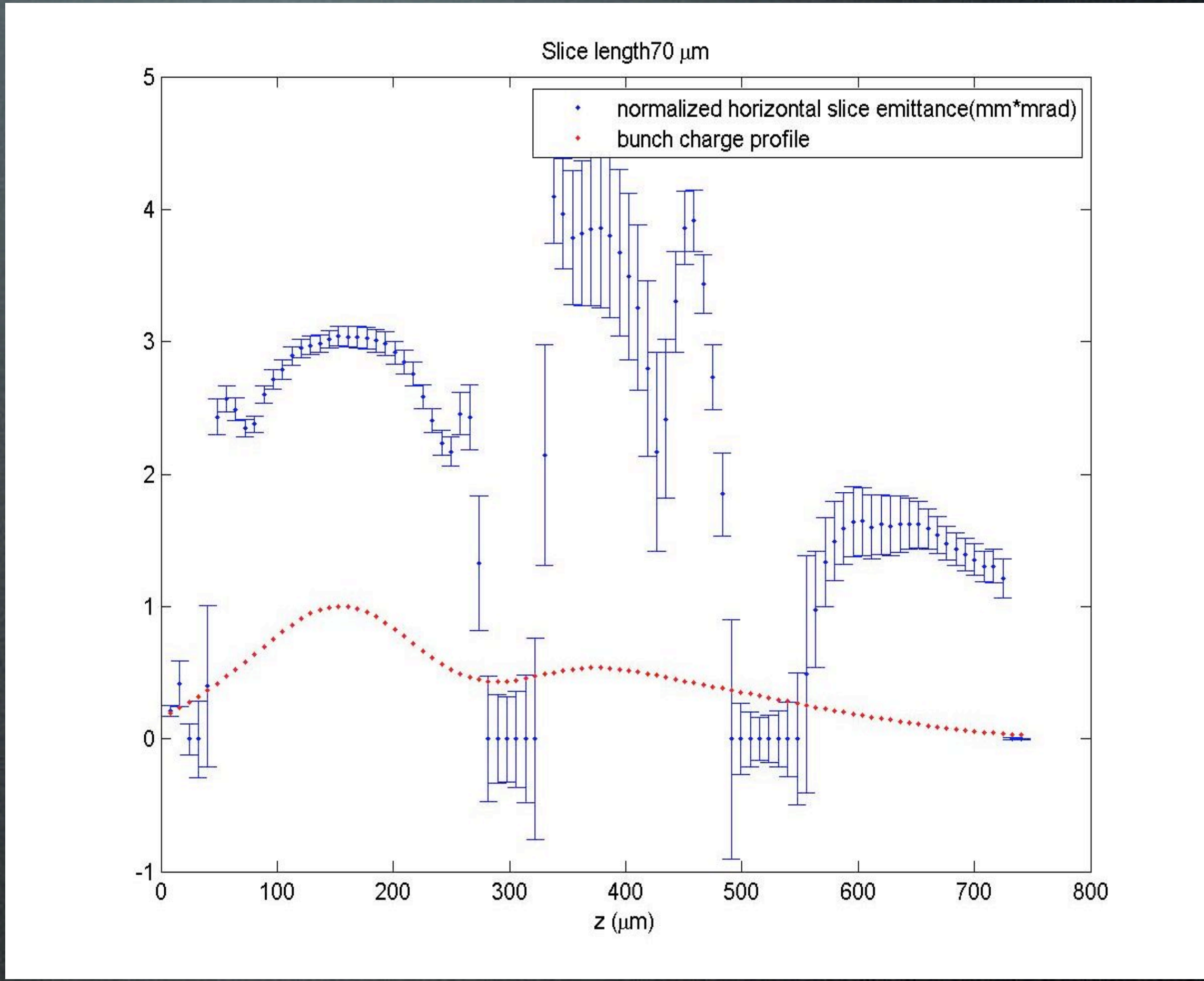
The energy profile shows an energy difference between the two pulses of ~ 2 MeV with a final average energy of 111 MeV.

The rms energy spread of the two pulses was 0.3 % and 0.7 %

Slice emittance Measurement

The slice emittance measuremenet is the only way to get realistic information about the transverse beam quality of the two pulses. Notice that the higer current pulse is probably better matched and results to have the lower emittance.

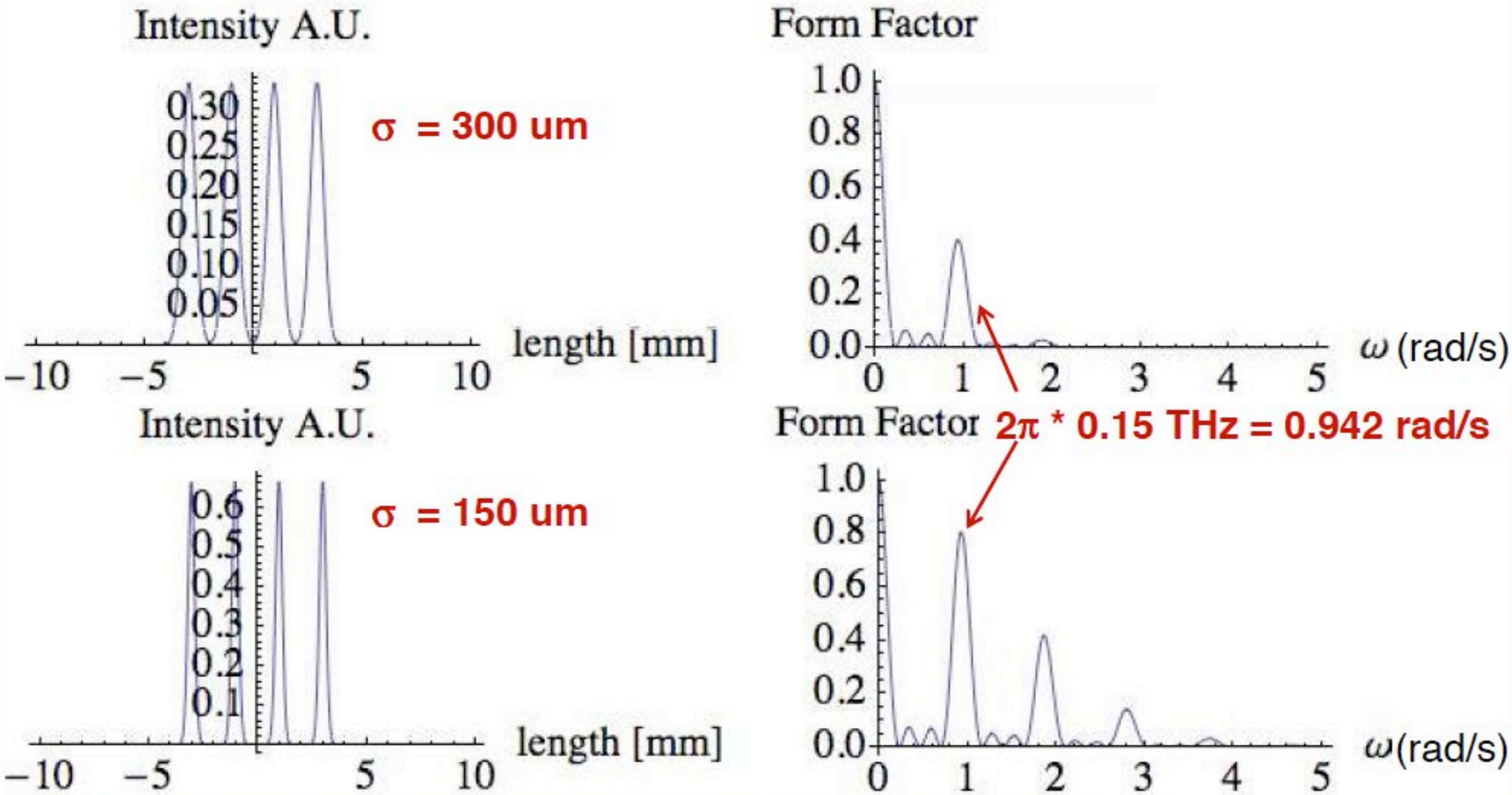
The total projected emittance under this condition was ~ 4 mmrad in both planes



Narrow band THz radiation

THE SPARC THz SOURCE

Pulses Rep. rate: 2 mm (7 ps) ⇔ 0.15 THz

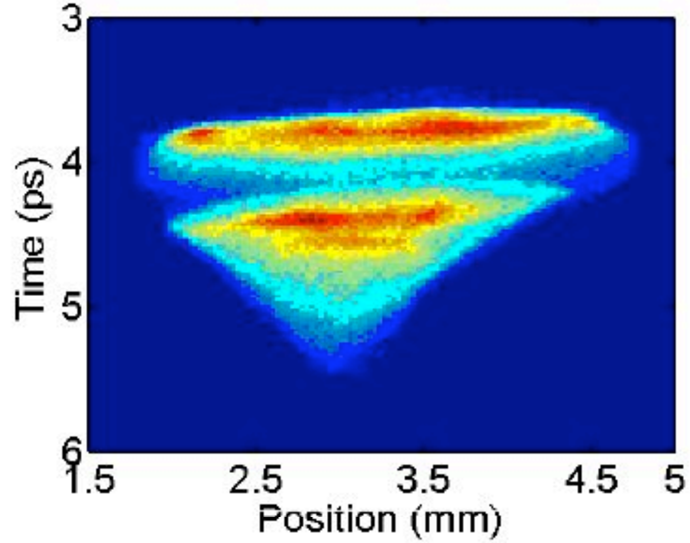


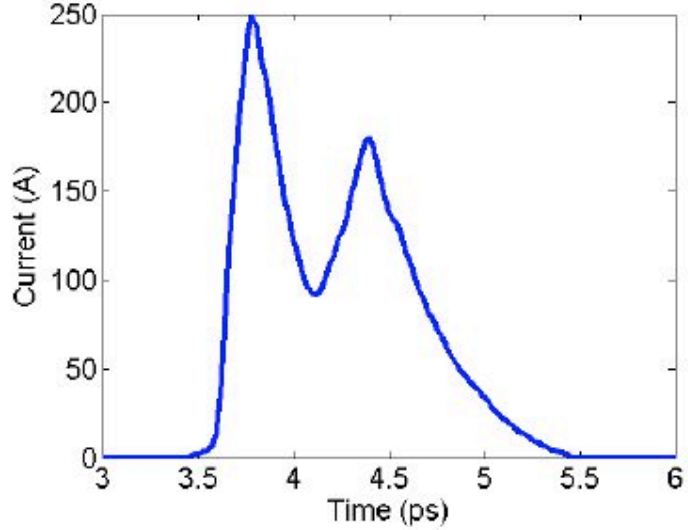
THz RADIATION FROM COMB

Two pulses train electron beam
Velocity bunching (over-compression)

By changing the over-compression factor, the pulses spacing can be adjusted in order to emit at the THz scale.

Beam Energy= 100 MeV
Total charge = 180 pC
Pulses inter-distance = 0.7 ps

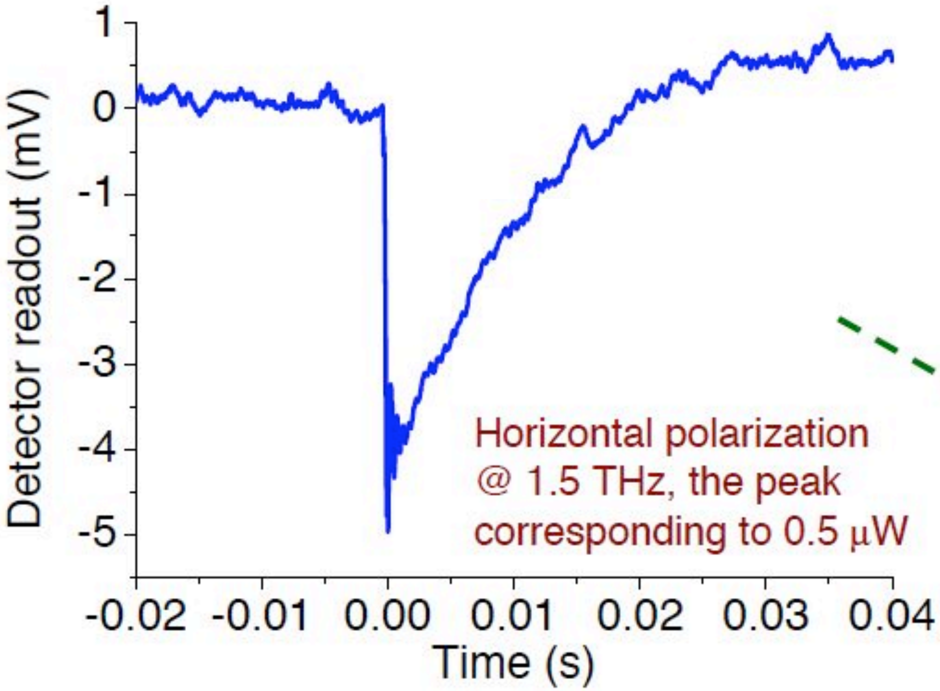


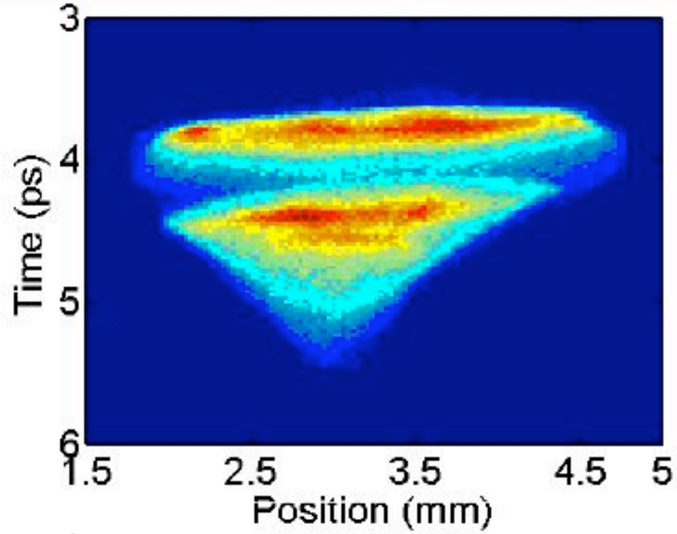


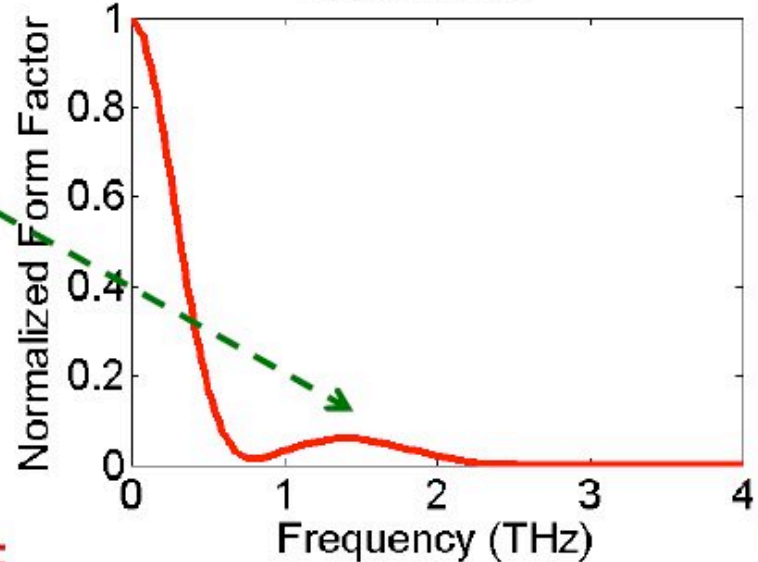
Enrica Chiadroni
(INFN/LNF)

THz RADIATION FROM COMB

Two pulses train electron beam
Velocity bunching (over-compression)







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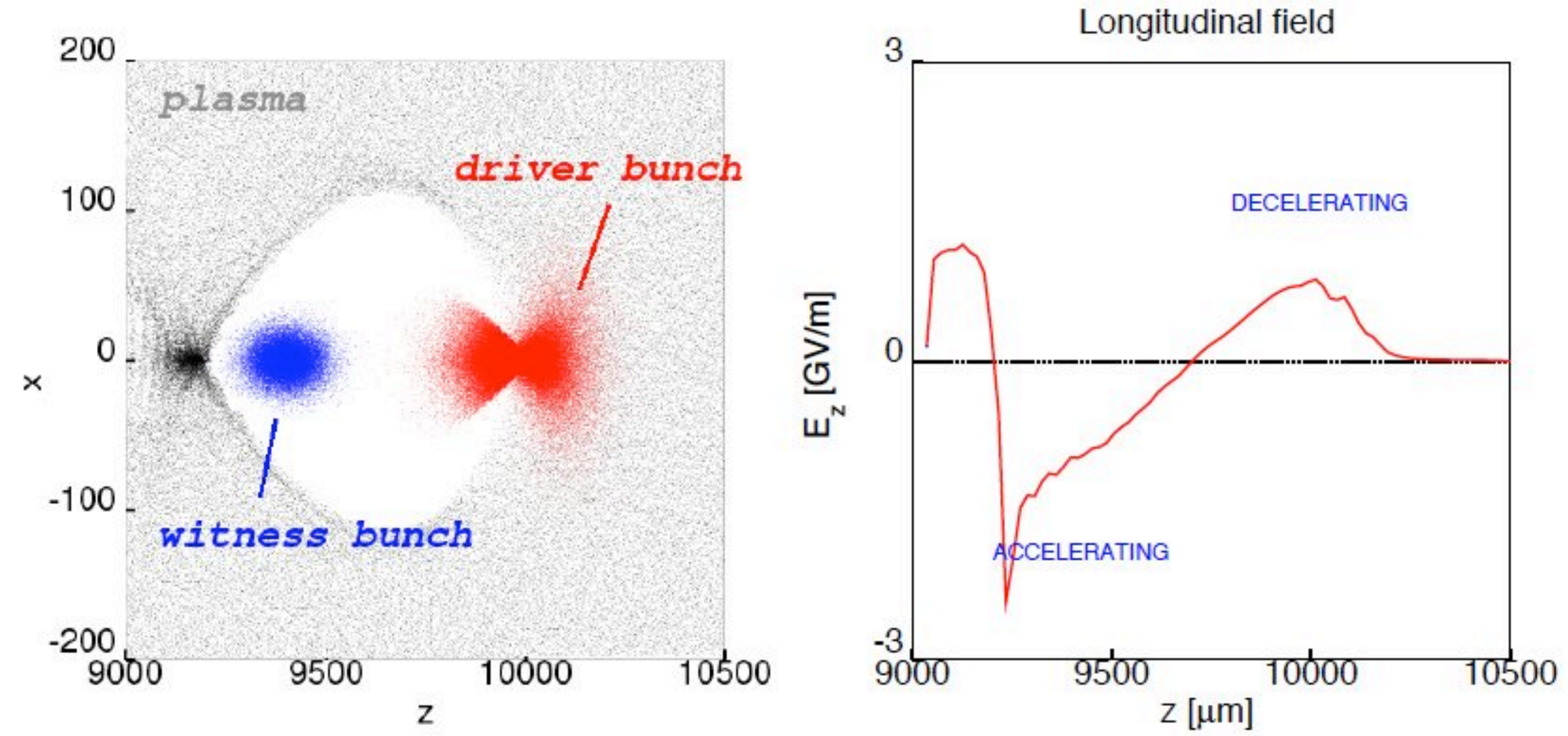
Particle Wake Field Acc.



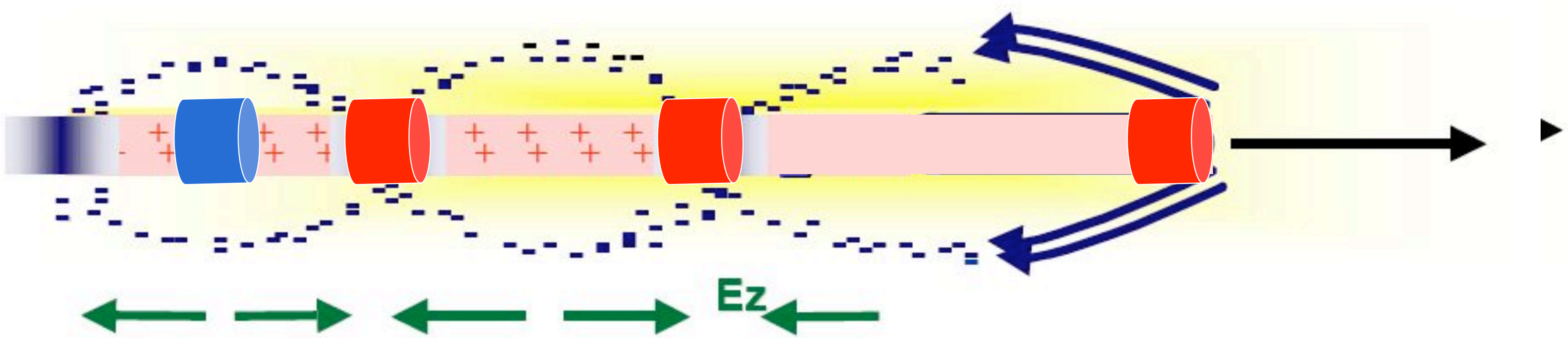
E	145.9 MeV
$\delta E/E$ (rms)	$8.8 \cdot 10^{-3}$
Q	1.75 nC
σ_x	34.74 μm
σ_y	34.80 μm
σ_z	63.08 μm
ϵ_x	3.06 mm mrad
ϵ_u	3.06 mm mrad

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

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

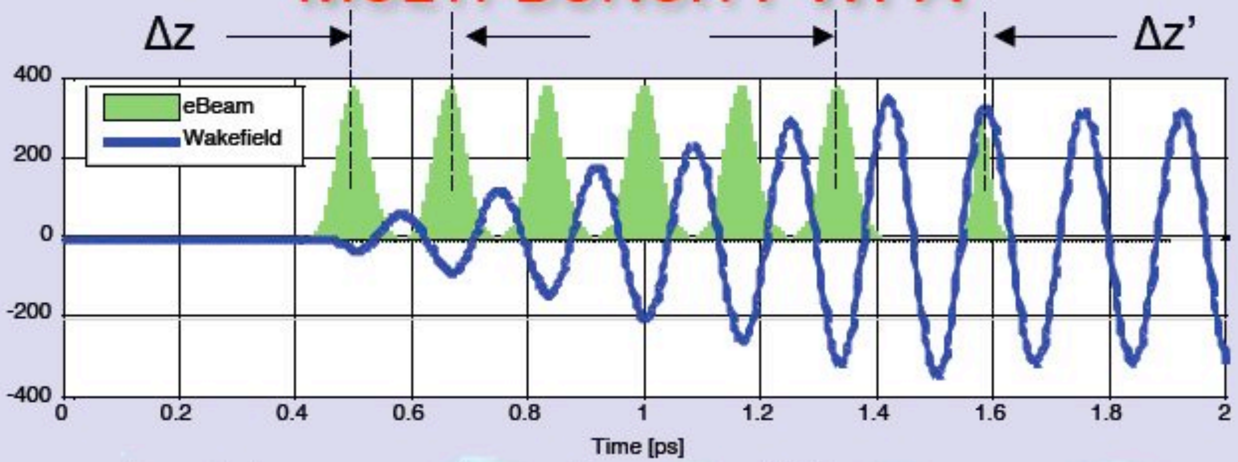
Plasma wakefield multibunch excitation

- 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) $\sigma_z << \lambda_p$

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

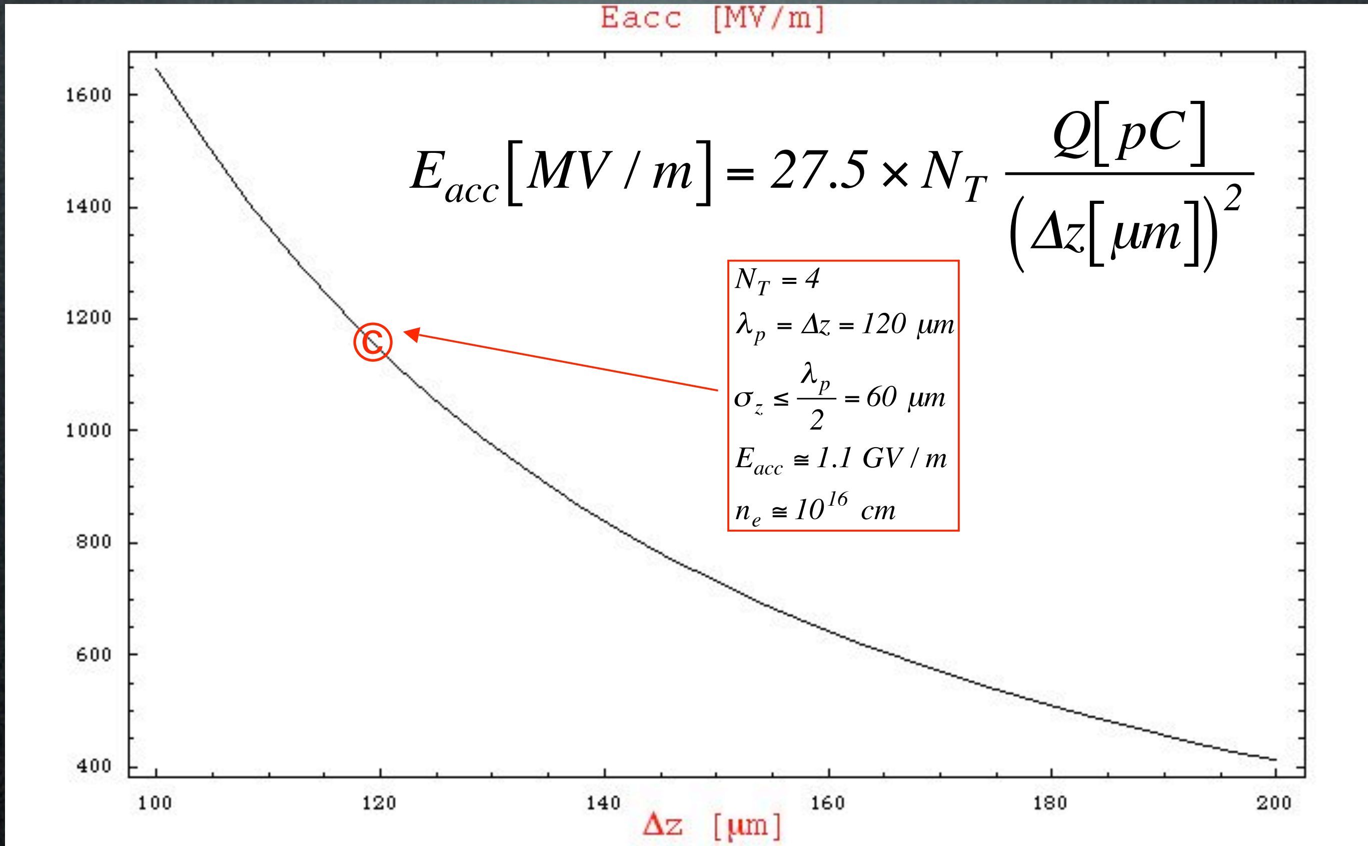
Plasma wavelength: $\lambda_p = \dfrac{2\pi c}{\omega_{pe}}$ Plasma angular frequency, density n_e: $\omega_{pe} = \left(\dfrac{n_e e^2}{\varepsilon_0 m_e}\right)^{1/2}$

- Wake fields add up (linear theory):

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

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

150 pC/pulse x 4 pulses

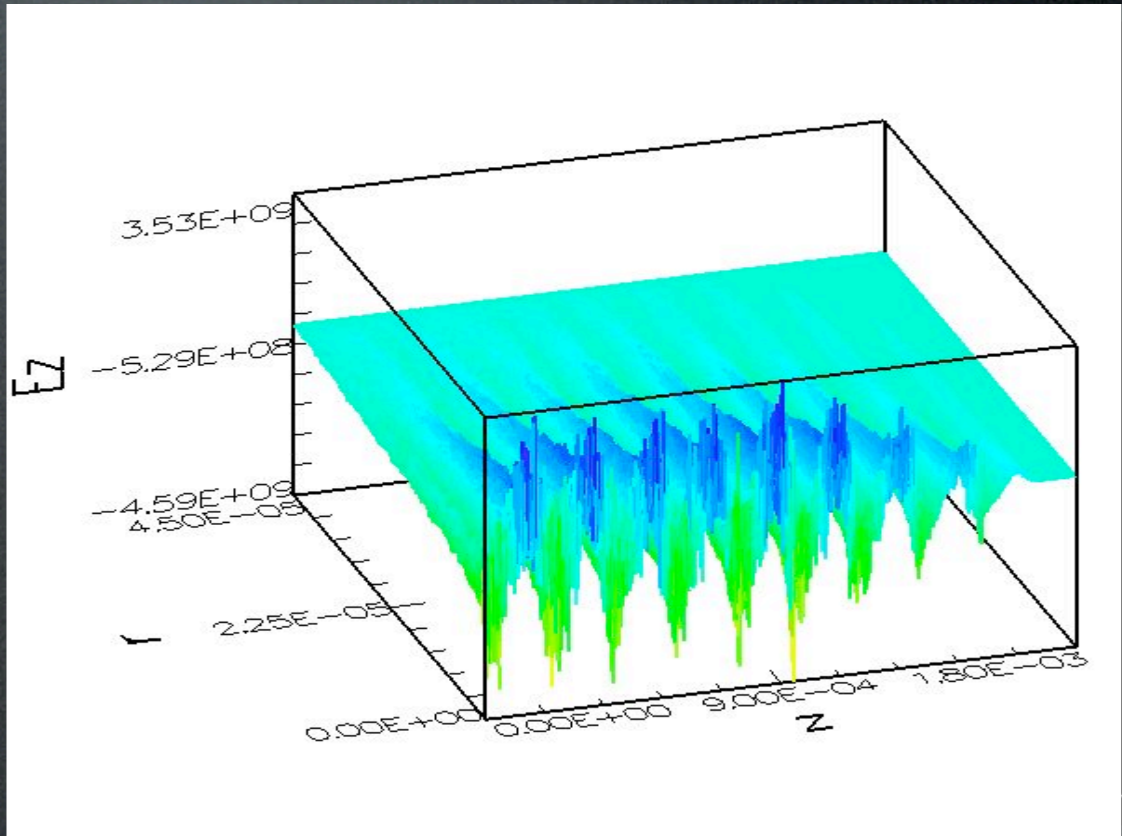


200 MeV in 18 cm

Multipulse operation

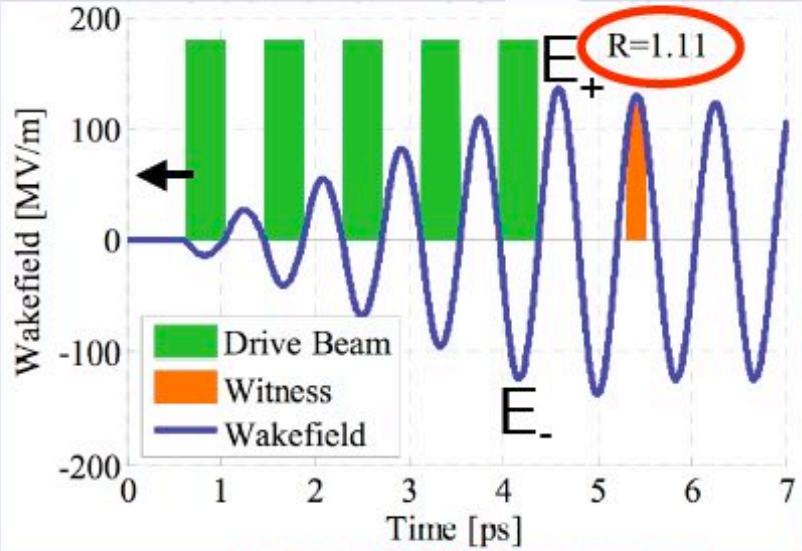
- Resonance works well
- SPARX example gives 3 GV/m

Example:
pulses=4
N_b=1E8
n_e=3E22 m^{-3}
λ_p=190 μm
$\tilde{Q}_1$=0.117



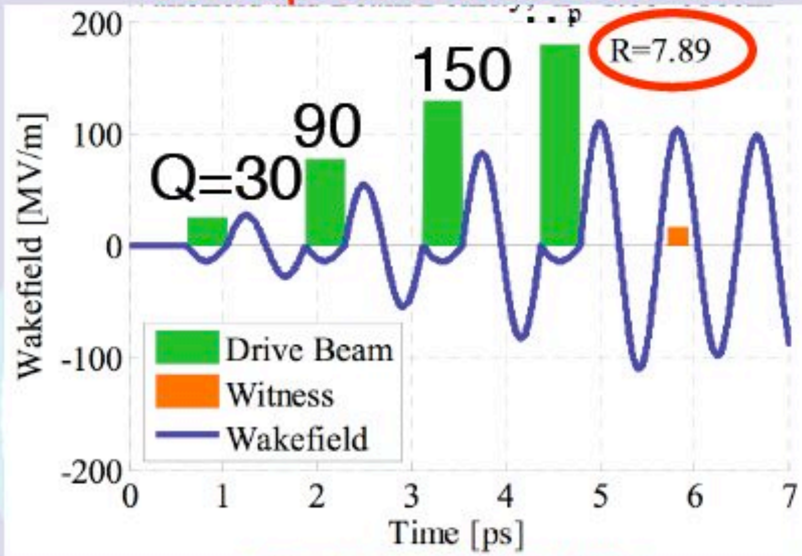
MULTIBUNCH PWFA

Bunch Train @ Resonance



Kallos, PAC'07 Proceedings

Ramped Bunch Train*



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

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

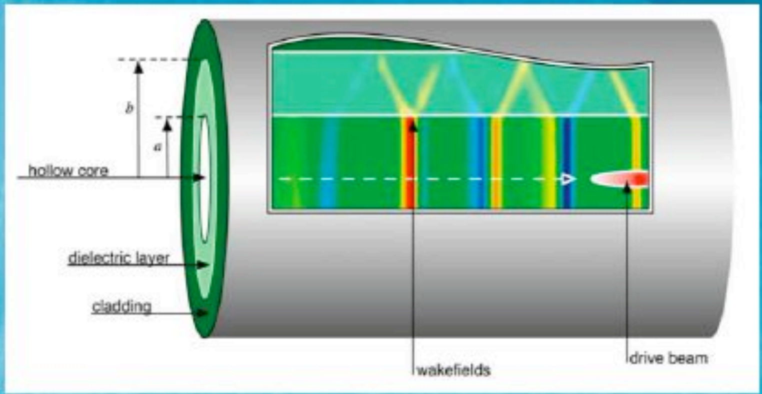
2D Linear Calculations: σ_r=125 μm, n_e=1.8x10^{16} cm^{-3} E_0: incoming energy

Q=30 pC/bunch, Δz=250 μm$\approx\lambda_p$ $\Delta z'$=375 μm$\approx$1.5λ_p

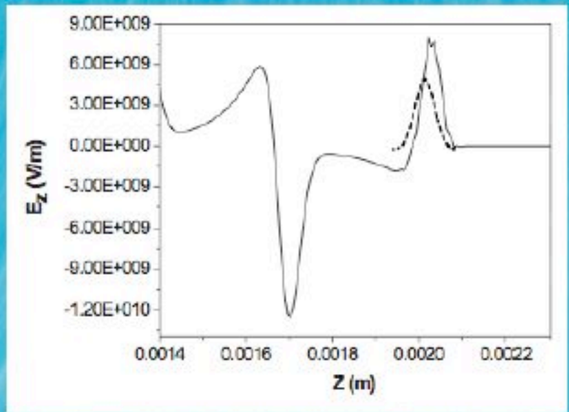
- R=7.9 => gain 8x incoming energy a single PWFA stage!
- Linear regime, theory (n_b/n_e, $\delta n_e/n_e$, E_z/E_{WB}<<1)

Dielectric Wake Field Acc.

Dielectric Wakefield Accelerator
Overview



- Design Parameters $a,b \quad \sigma_z \quad \varepsilon$



Ez on-axis, OOPIC

- Electron bunch (β ≈ 1) drives ***Cerenkov wake*** in cylindrical dielectric structure
  - Dependent on structure properties
  - Multimode excitation
- Wakefields accelerate trailing bunch
  - Mode wavelengths (quasi-optical

$$\lambda_n \approx \frac{4(b-a)}{n}\sqrt{\varepsilon - 1}$$

  - Peak decelerating field

$$eE_{z,dec} \approx \frac{-4N_b r_e m_e c^2}{a\left[\sqrt{\frac{8\pi}{\varepsilon-1}}\varepsilon\sigma_z + a\right]}$$

Extremely good beam needed

  - Transformer ratio (unshaped beam)

$$R = \frac{E_{z,acc}}{E_{z,dec}} \le 2$$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Thank you