Beam Physics Highlights of the FERMI@Elettra Project

S. Di Mitri

on behalf of the Accelerator Optimization Group:

M. Cornacchia, P. Craievich, S. Di Mitri, G. Penco, M. Trovo', ST
I. Pogorelov, J. Qiang, M. Venturini, A. Zholents, LBNL
P. Emma, Z. Huang, R. Warnok, J. Wu, SLAC
D. Wang, MIT

FLS Workshop, May 2006, Hamburg

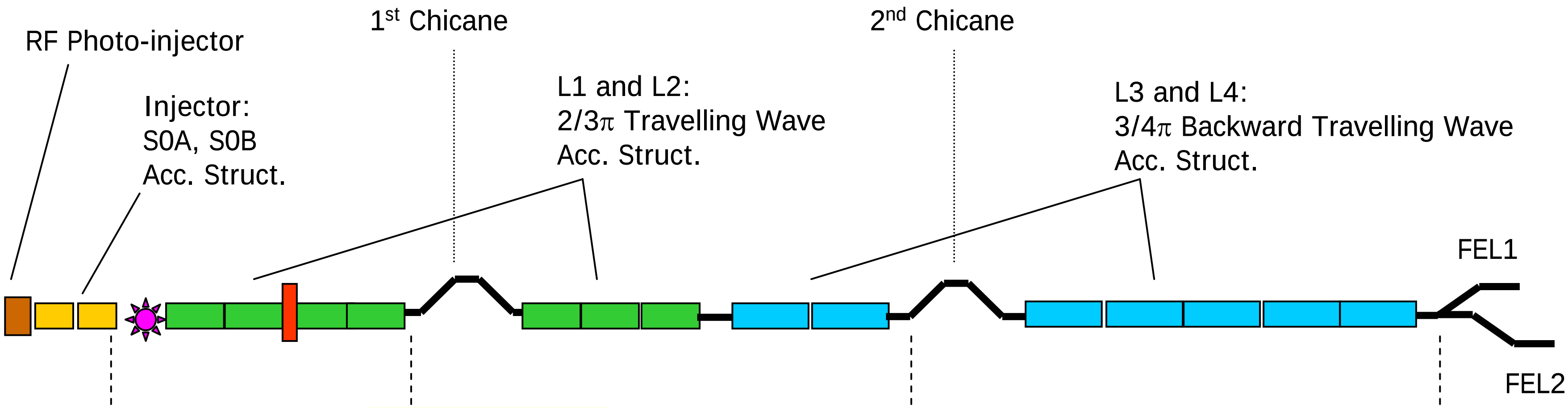
Plan

- Outlook
  - FEL Performances
  - The Accelerator
  - Wakefields
- Electron Beam Physics
  - Quadratic energy chirp
  - Cubic energy chirp
  - Reverse tracking
  - Jitter in the longitudinal phase space
  - Beam breakup
- Simulation results
  - “Medium” bunch
  - “Long” bunch
- References

Outlook - FEL PERFORMANCES

- Seeded Harmonic Cascade FEL for EUV and Soft X-rays
- Single Pass FEL User Facility:
  - 100-40 nm single stage
  - 40-10 nm two stages cascade
- 100's MW to GW's of peak power with 10^{13} to 10^{14} photons per pulse and rep. rate from 10Hz to 50 Hz
- 50 fs to 1 ps photon pulse length
- Electron beam energy fixed to 1.2 GeV

Outlook – THE ACCELERATOR



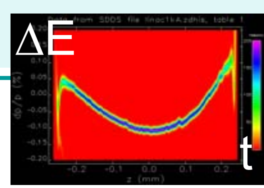
$E_0 \approx 100$ MeV
$I \approx 60$ A (10ps)

$E_1 \approx 220$ MeV
$R_{56} \approx -0.03$ m
c.f. = 3.5

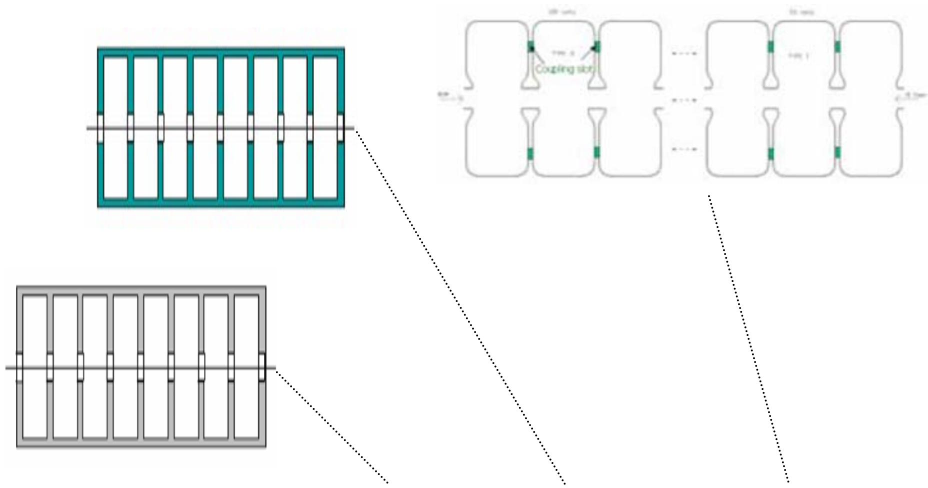
$E_2 \approx 600$ MeV
$R_{56} \approx -0.02$ m
c.f. = 3.0

$E_3 \approx 1200$ MeV
$I \approx 800$A (700fs)
$I \approx 500$A (1.4ps)

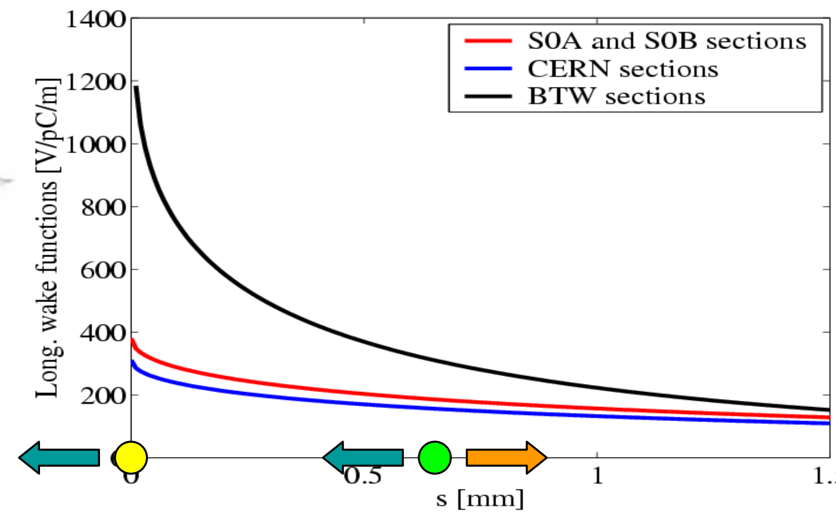
	"Short" bunch	*"Medium" bunch*	*"Long" bunch*
Bunch length	200 fs (flat part)	700 fs (flat part)	1.4 ps (flat part)
Peak current	800 A	800 A	500 A
Emittance(slice)	1.5 μm	1.5 μm	1.5 μm
Energy spread(slice)	<150 keV	<150 keV	<150 keV
Flatness, $\|d^2E/dt^2\|$		<0.8 MeV/ps^2	<0.2 MeV/ps^2

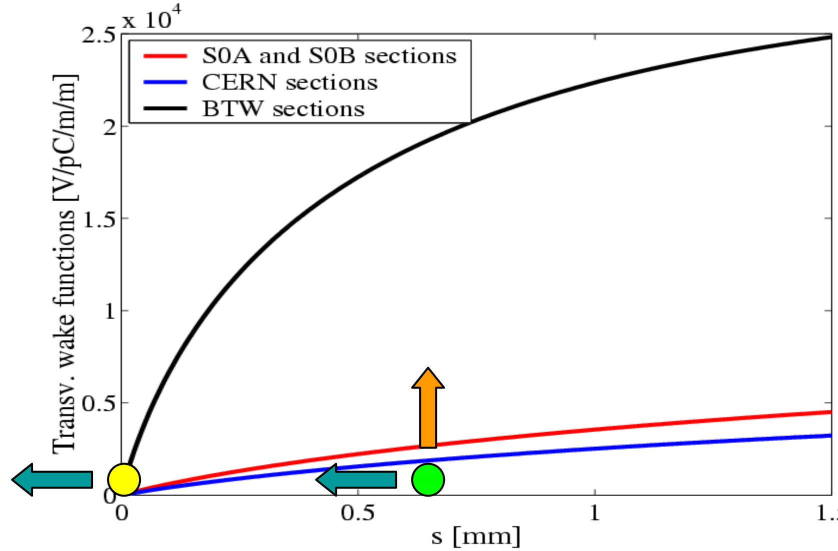


Outlook - WAKEFIELDS



	S0A, S0B	CERN 2/3π	BTW 3/4π
f [MHz]	2997.74	2997.74	2997.74
R iris [mm]	9.7 (avg)	10.8 (avg)	5.0
# cells	93	135	162
Lcell [mm]	33.33	33.32	37.50
G [MV/m]	14.1	10.4	19.5





courtesy P. Craievich, I. Zagorodnov, T. Weiland

E-Beam Physics - QUADRATIC ENERGY CHIRP

- *Sources:* RF waveform and longitudinal wakefields
- *Effects:* less efficient compression
- *Solution:* increase the amplitude of the harmonic linearizer, while phase is locked at $\Delta\phi$ = - 90°
- *Cons:* beam energy lowered, high phase sensitivity, tight alignment

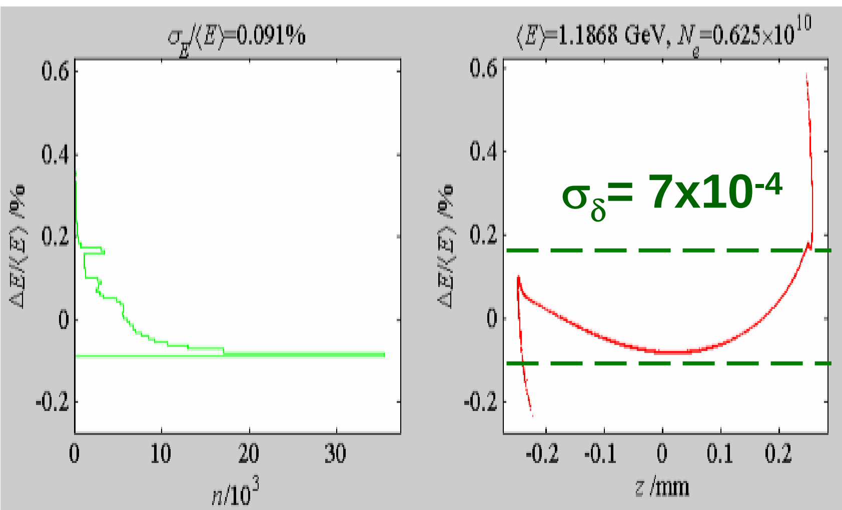
1st step

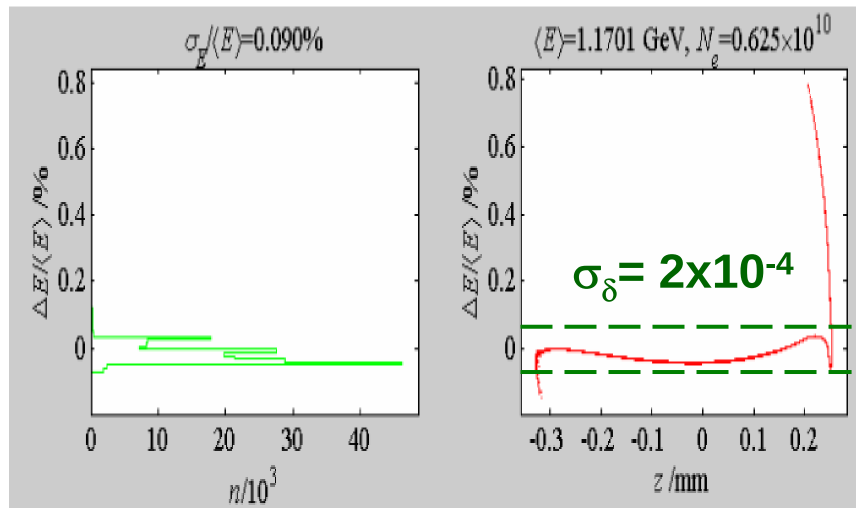
ϕ(Linac1) = - 39°
V(X-band) = 14 MV

→

ϕ(Linac1) = - 44°
V(X-band) = 20 MV

2nd step

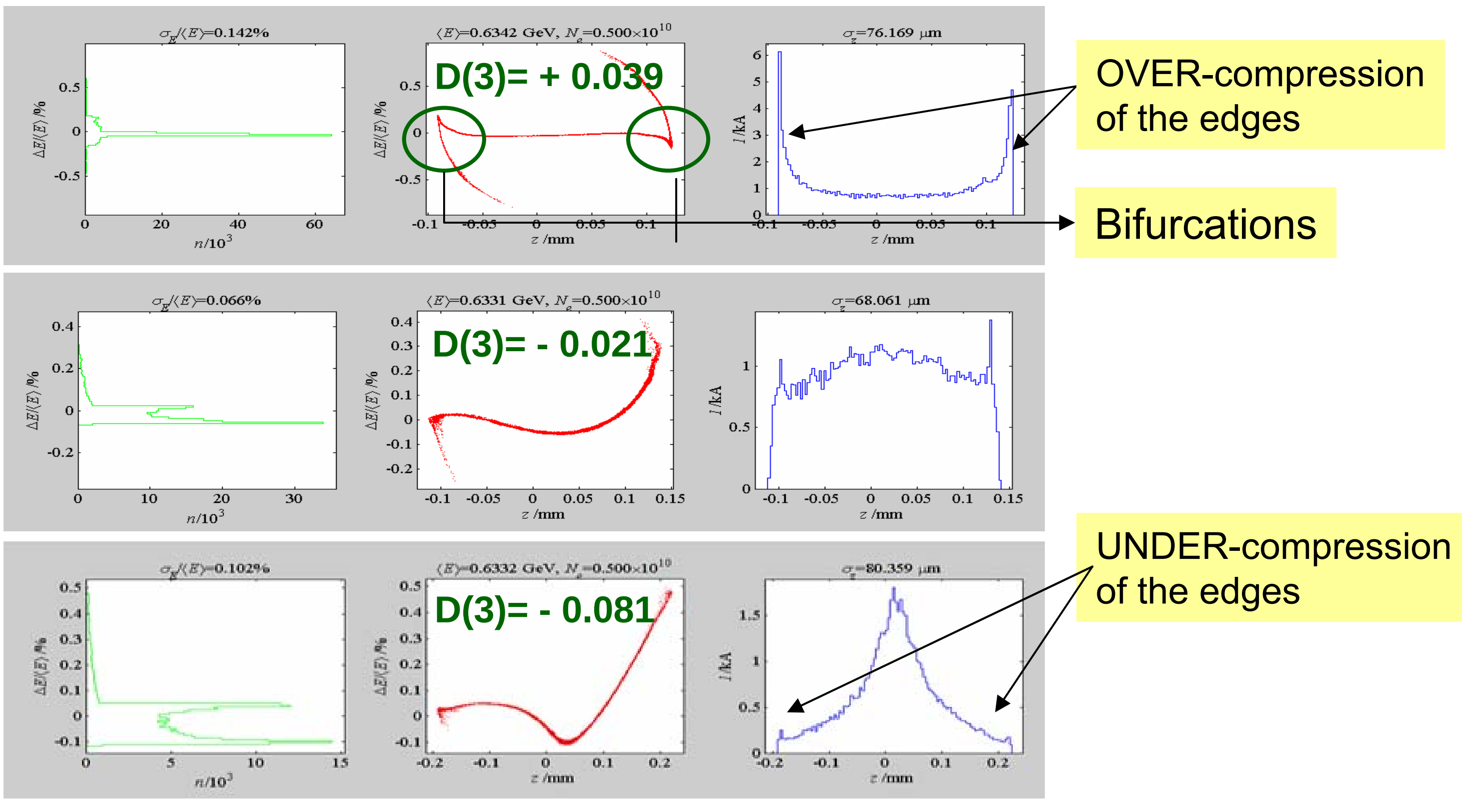




FERMI @elettra

E-Beam Physics - CUBIC ENERGY CHIRP

- *Sources:* space charge dynamics and longitudinal wakefields
- *Effects:* bifurcations in phase space and current spikes
- *Solution:* phase of the harmonic linearizer set off-crest
- *Cons:* the knob is weak

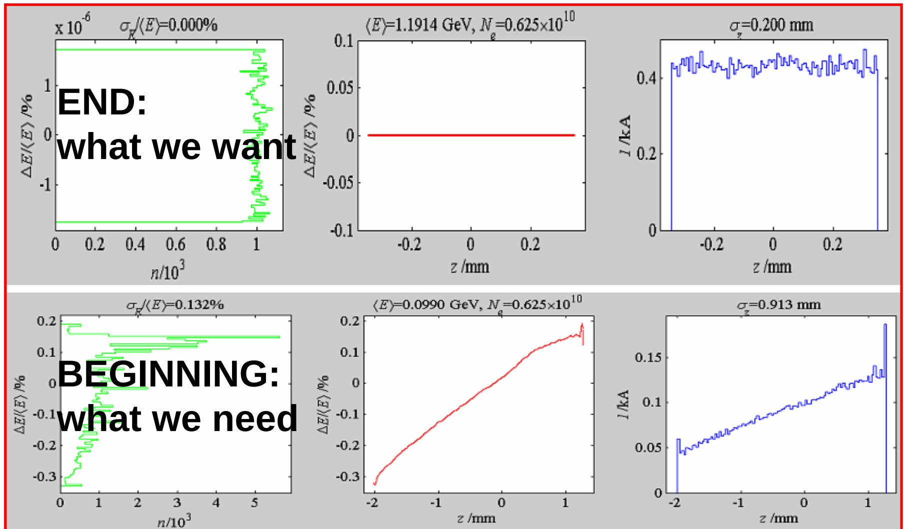


The cubic component D(3) of δ(z) changes sign

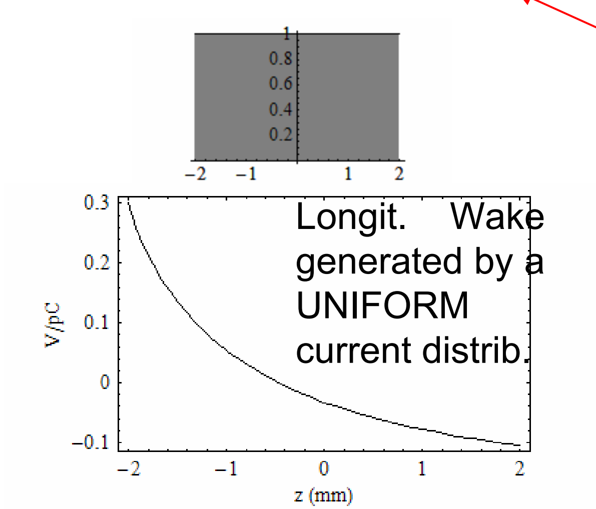
courtesy M. Cornacchia, P.Emma, A. Zholents

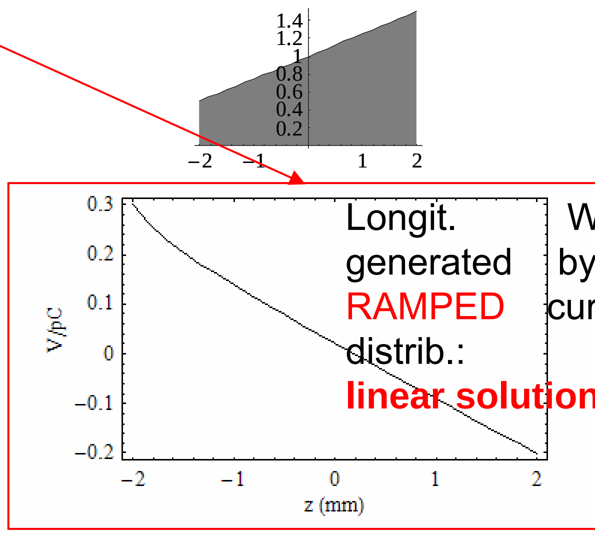
FERMI @elettra

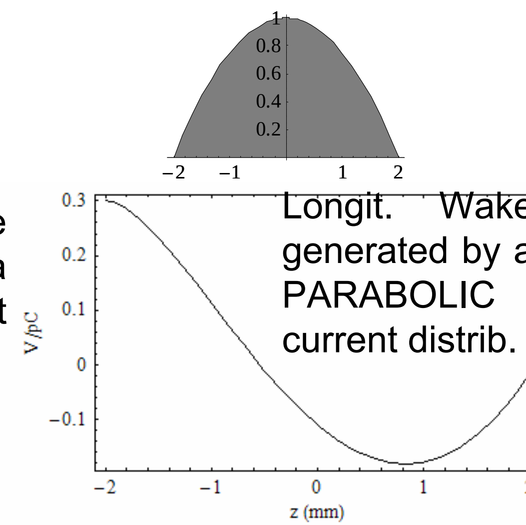
E-Beam Physics - REVERSE TRACKING



- Valid for “frozen” beams (see, Appendix)
- It predicts a ramped current profile from the Injector.
- Confirmed by the forward tracking.





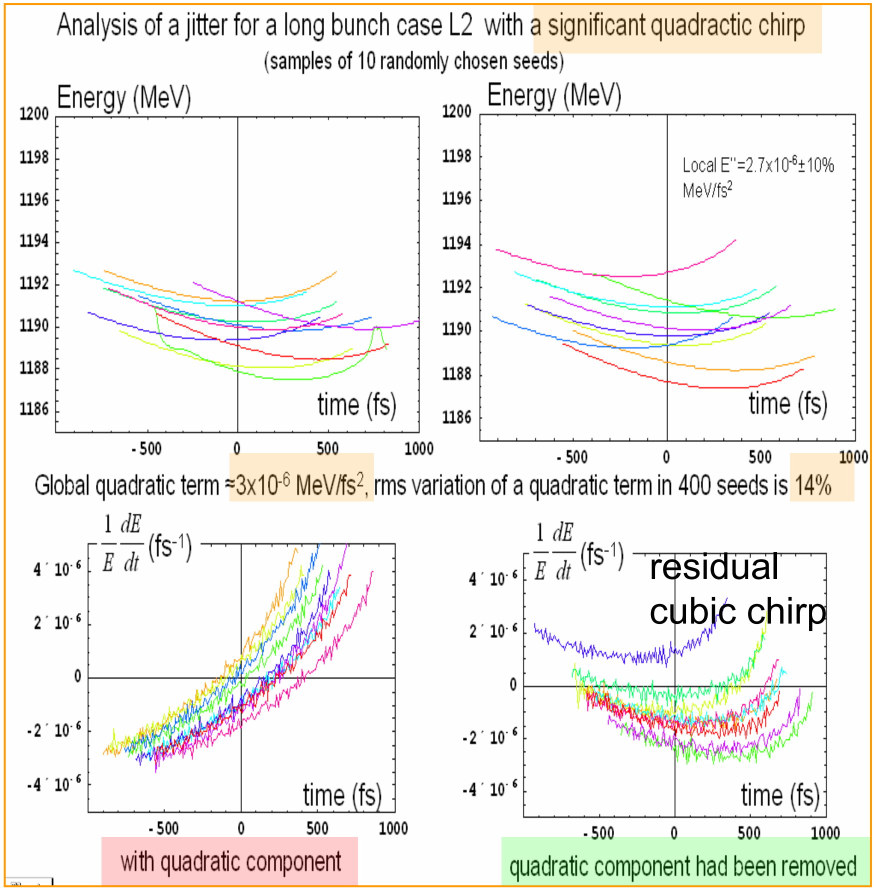


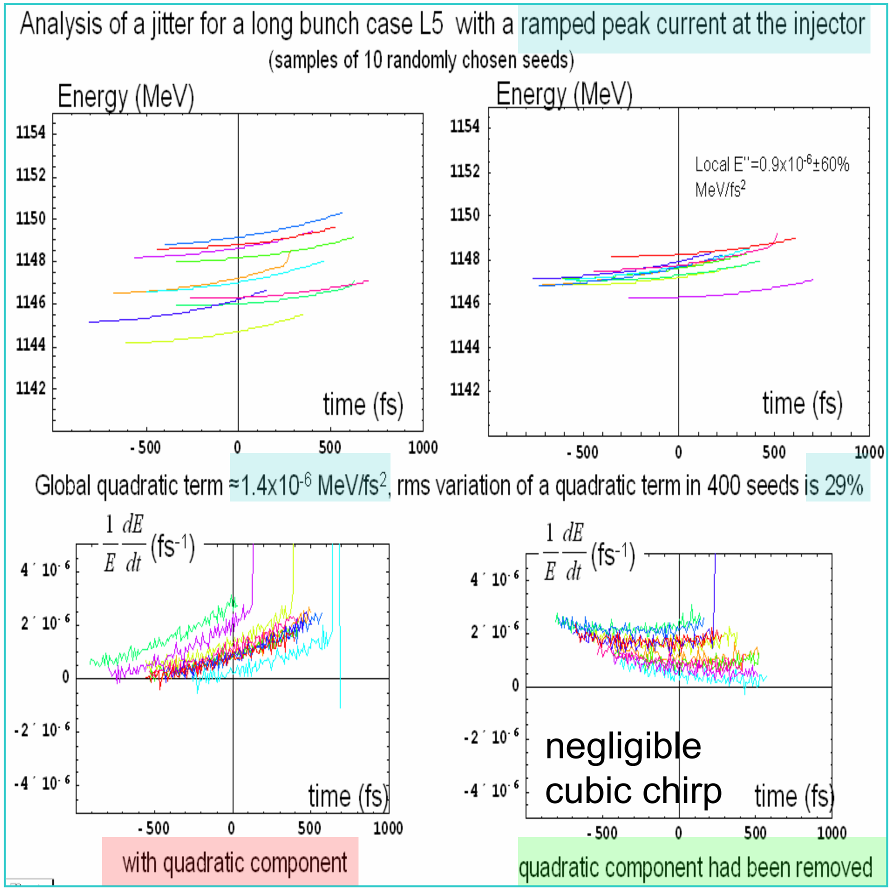
 courtesy M. Cornacchia, P.Emma, G. Penco, A. Zholents

FERMI @elettra

E-Beam Physics - PHASE SPACE JITTER

- A seed laser with a linear frequency chirp will allow for compensating for a frequency chirp due to a quadratic energy variation in the electron ($\Delta\omega \sim \Delta E/\Delta t$) $\Rightarrow$ a small jitter of the 2nd order component is required.

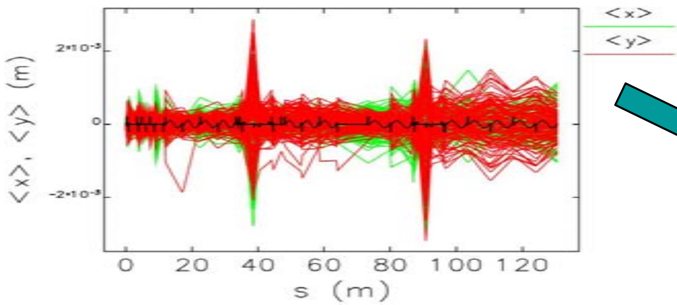


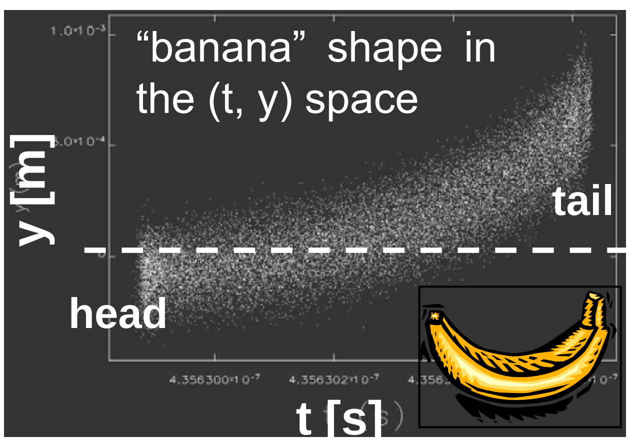


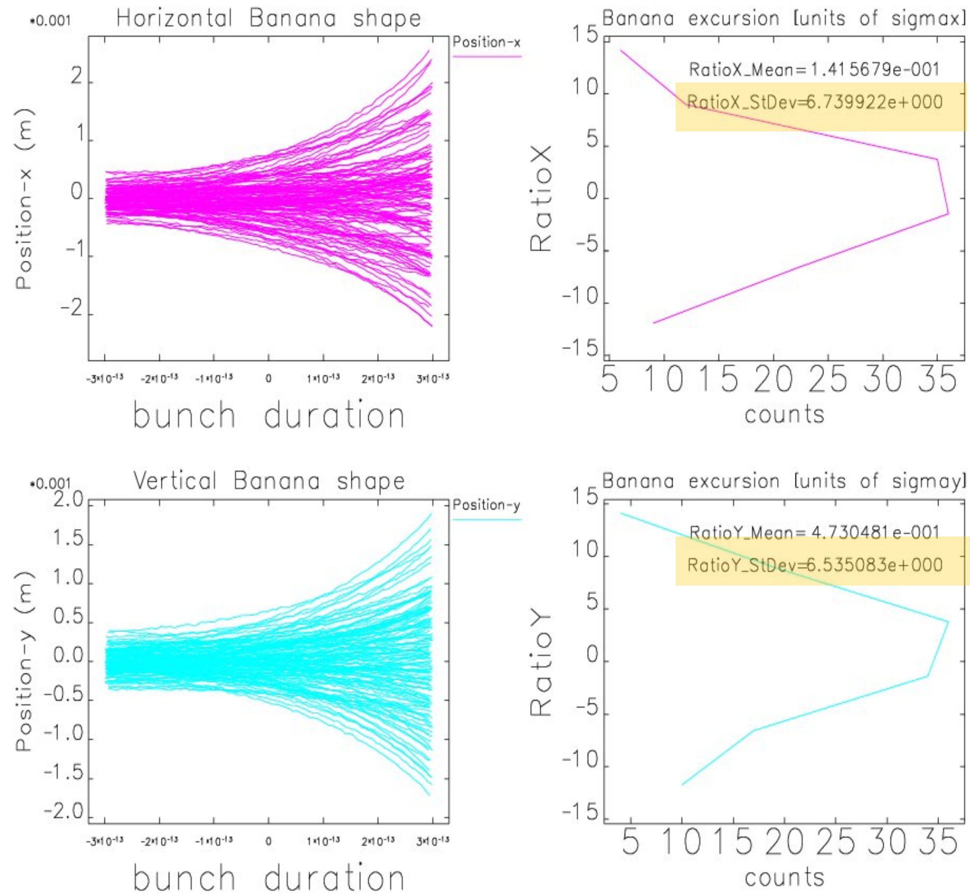
courtesy P. Craievich, A. Zholents

E-Beam Physics - BEAM BREAKUP (1)

120 trajectories in the Linac. The conventional correction is NOT sufficient to avoid the BBU instability.



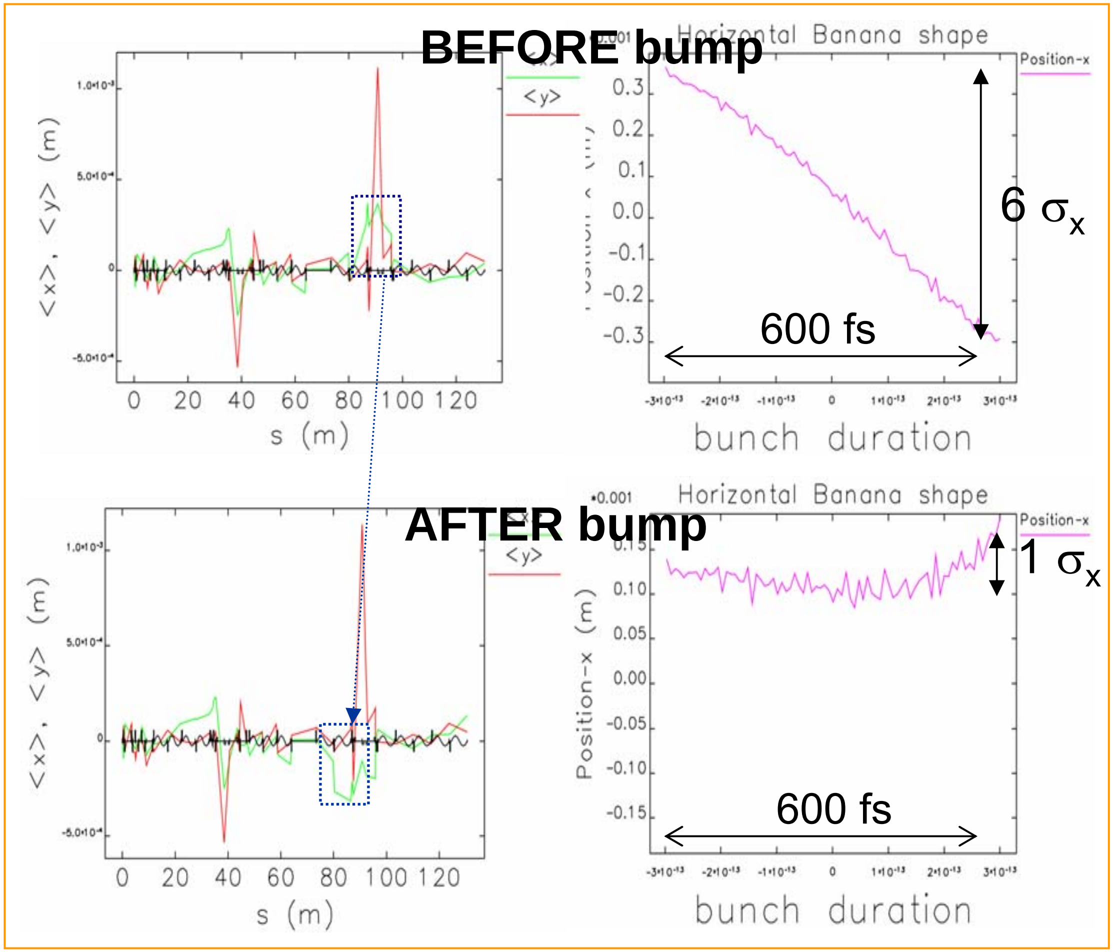




"Banana" shapes (in x and y plane) for 120 trajectories in the Linac. The bunch tail deviates from the head of about 6 $\sigma_{x,y}$ at the Linac end.

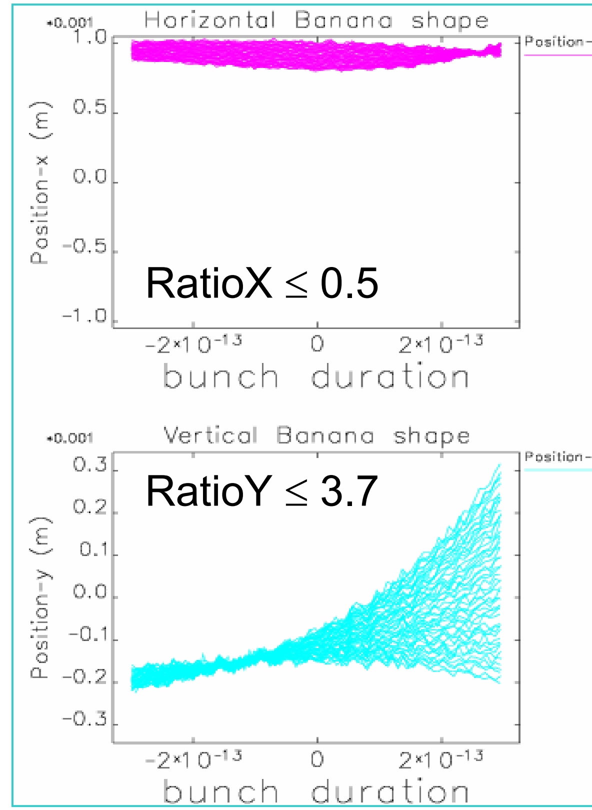
FERMI @elettra

E-Beam Physics - BEAM BREAKUP (2)



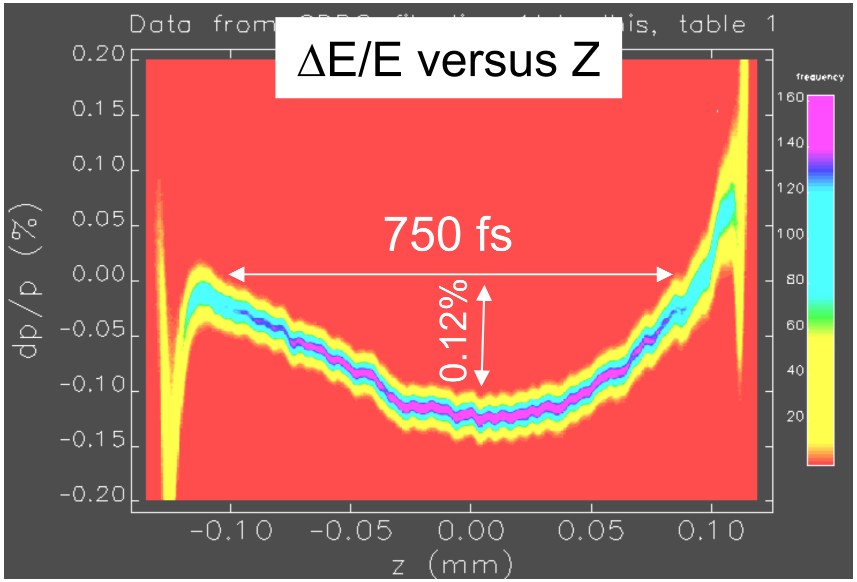
Trajectory **local bumps** cancel "banana" shape.

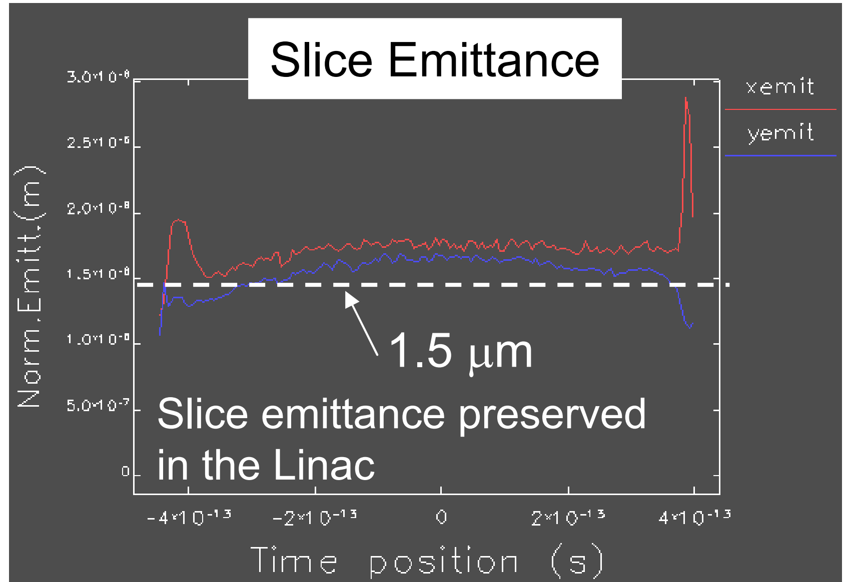
Jitters of the launching error does not affect a "banana" previously compensated.

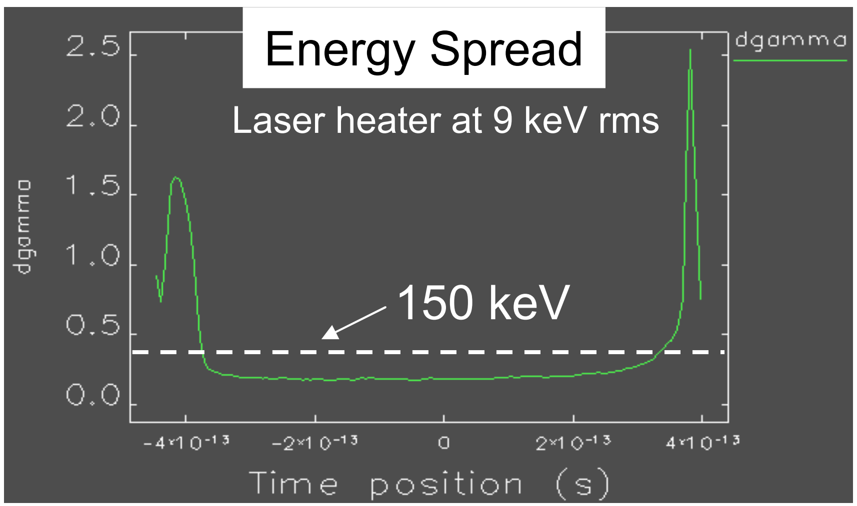


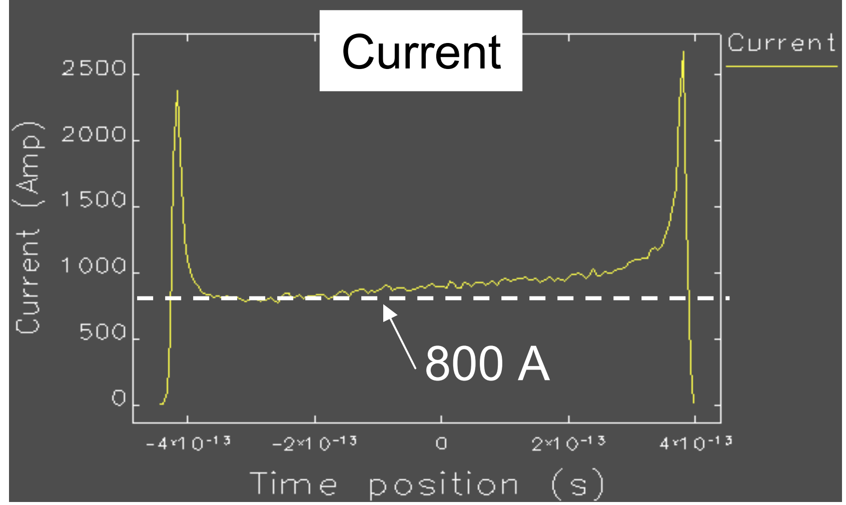
FERMI @elettra

Simulation Results - MEDIUM BUNCH



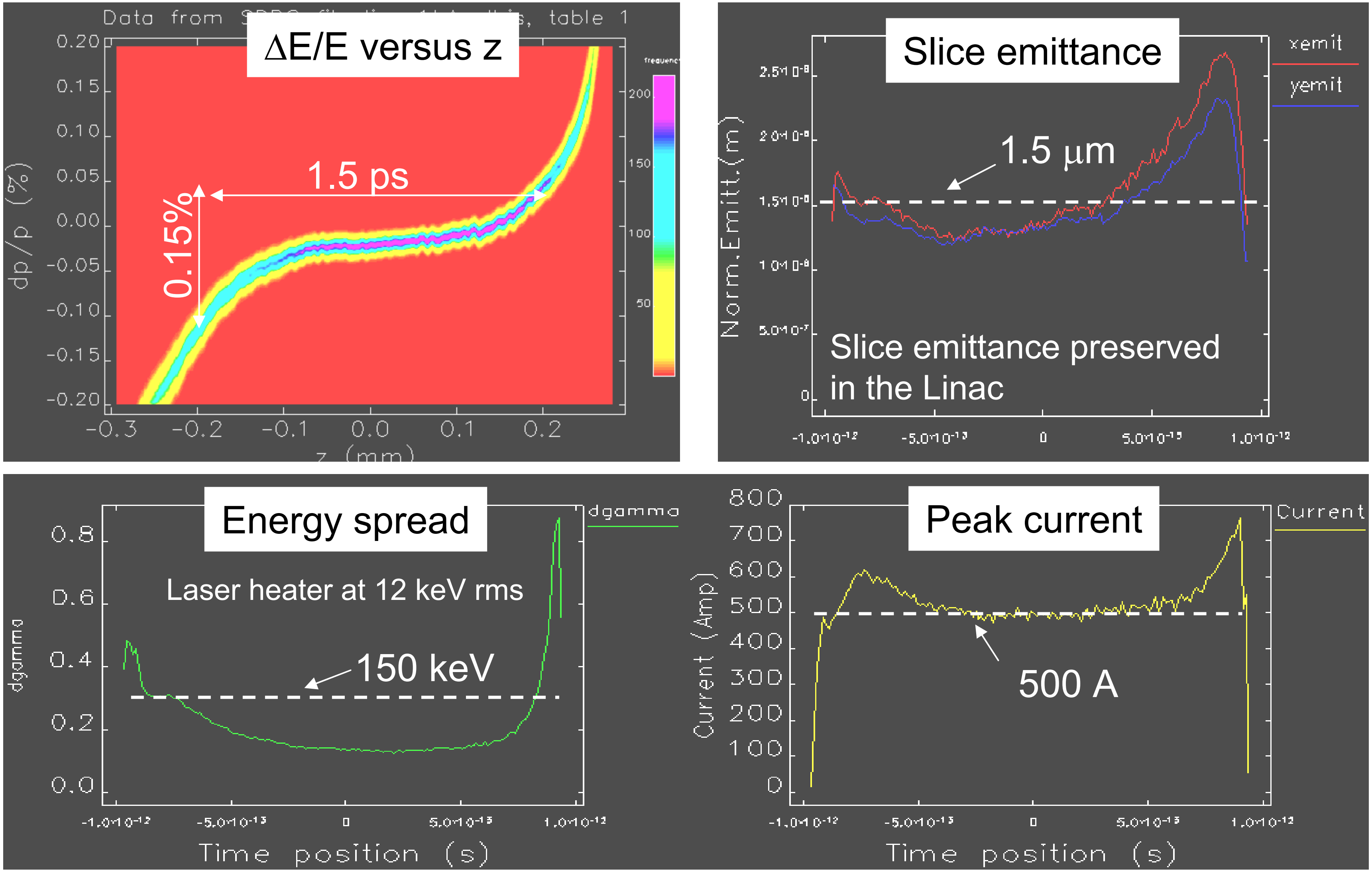






courtesy M. Cornacchia, A. Zholents

Simulation Results - LONG BUNCH



S. Di Mitri – FLS2006 courtesy M. Cornacchia, M. Trovo', A. Zholents

FERMI @elettra

References

- C. Bocchetta *et al.*, Proc. of the EPAC06 Conf., Edinburgh, UK (June 2006)
- M. Cornacchia *et al.*, ST/F-TN-05/24 (ST Tech. Note, November 2005)
- P. Craievich and S. Di Mitri, ST/F-TN-05/26 (St Tech. Note, November 2005)
- S. Di Mitri *et* al., Proc. of the FEL05 Conf., SLAC, CA (August 2005)
- P. Craievich and S. Di Mitri, Proc. of the FEL05 Conf., SLAC, CA (August 2005)
- P. Craievich *et* al., ST/F-TN-05/01 (St Tech. Note, March 2005)
- Z. Huang *et. al*, Phys. Rev. ST – Acc. and Beams, v.5, 074401(2002)
- Z. Huang *et. al*, Phys. Rev. ST – Acc. and Beams, V.7, 074401, (2004).

Acknowledgement

The author thanks M. Borland for his fundamental support using the Elegant tracking code and Sdds post-processing.

Thank you for your attention

APPENDIX: Justification for a reverse tracking

1) Transformation through linac for a “frozen” longitudinal density distribution:

$$\delta_f(z_f) = \delta_i(z_i) + eU\cos(k_{rf} z_i) + e\int_{-\infty}^{z_i} \rho(s) W(s - z_i)\, ds$$

Since ρ(s) is the same at the beginning and at the end of the linac, then $\delta_i(z_f = z_i)$ at the beginning can be found from above equation for a given δ_f

2) Transformation through a chicane for a “frozen” energy distribution:

$$z_f(\delta_f) = z_i + R_{56}\delta_i + T_{566}\delta_i^2 + \ldots$$

Since δ(z) is the same at the beginning and at the end of the chicane ($\delta_f = \delta_i$), then z_i at the beginning can be found from above equation for a given z_f

courtesy A. Zholents