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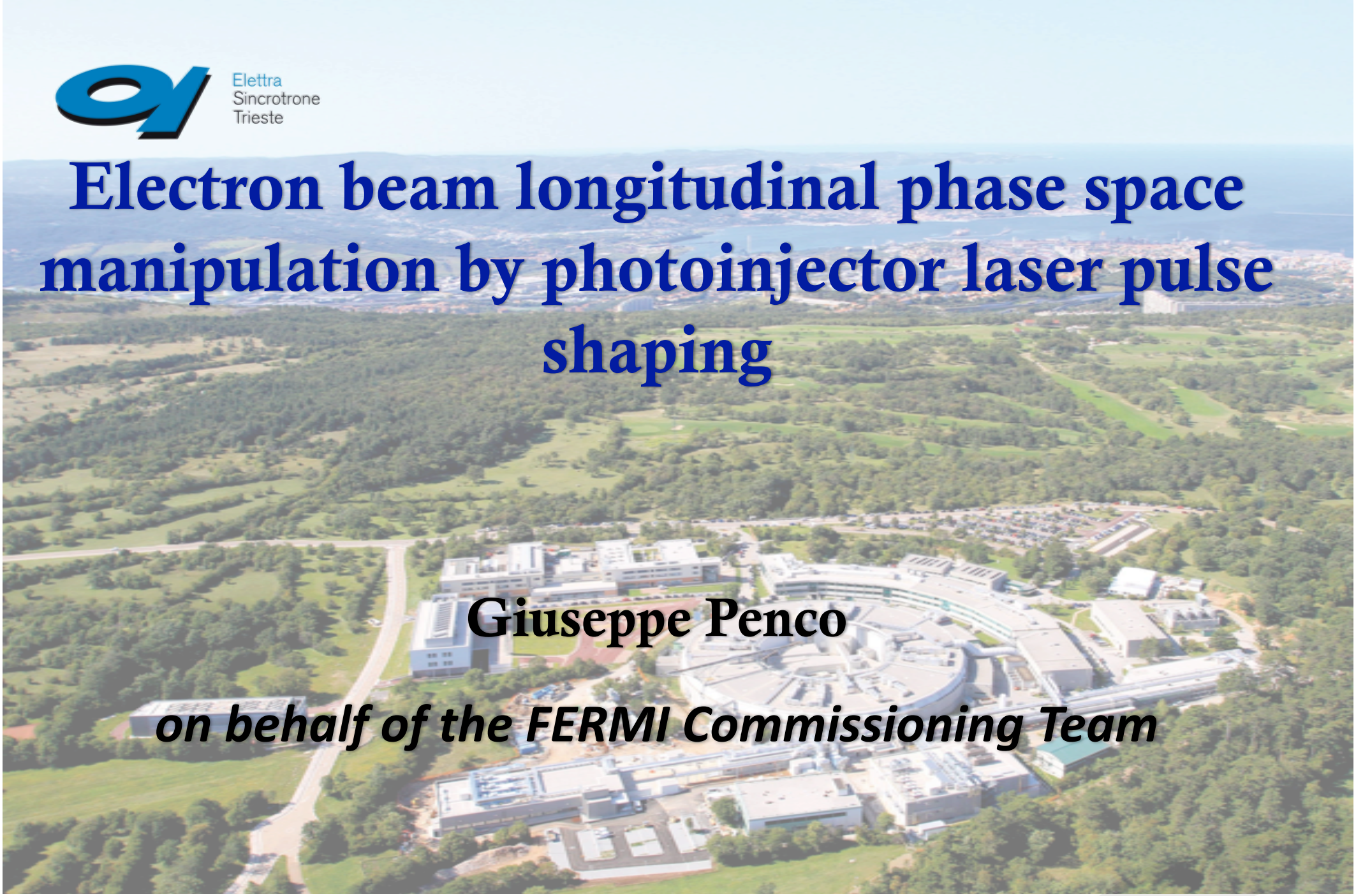
Trieste

Electron beam longitudinal phase space manipulation by photoinjector laser pulse shaping



Giuseppe Penco

on behalf of the FERMI Commissioning Team

FEL 2013 | Manhattan, USA
35th International Free-Electron Laser Conference
August 26-30, 2013

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Outline

- Introduction: impact of the longitudinal phase space on the FEL performance
- Who are the main "linac players" in defining the longitudinal phase space (LPS)
- An additional free parameter: shaping the bunch current profile at the injector
- Experimental evidence of LPS linearization
- Conclusion

Impact of the e- long. phase space (LPS) on FEL

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SASE

PRL **106,** 144801 (2011) PHYSICAL REVIEW LETTERS week ending 8 APRIL 2011

Self-Amplified Spontaneous Emission Free-Electron Laser with an Energy-Chirped Electron Beam and Undulator Tapering

L. Giannessi,[1,*] A. Bacci,[2,4] M. Bellaveglia,[2] F. Briquez,[10] M. Castellano,[2] E. Chiadroni,[2] A. Cianchi,[8] F. Ciocci,[1] M. E. Couprie,[10] L. Cultrera,[2] G. Dattoli,[1] D. Filippetto,[2] M. Del Franco,[1] G. Di Pirro,[2] M. Ferrario,[2] L. Ficcadenti,[2] F. Frassetto,[6] A. Gallo,[2] G. Gatti,[2] M. Labat,[10] G. Marcus,[9] M. Moreno,[5] A. Mostacci,[5] E. Pace,[2] A. Petralia,[1] V. Petrillo,[3,4] L. Poletto,[6] M. Quattromini,[1] J. V. Rau,[7] C. Ronsivalle,[1] J. Rosenzweig,[9] A. R. Rossi,[2,4] V. Rossi Albertini,[7] E. Sabia,[1] M. Serluca,[5] S. Spampinati,[11] I. Spassovsky,[1] B. Spataro,[2] V. Surrenti,[1] C. Vaccarezza,[2] and C. Vicario[2]

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **6**, 050702 (2003)

Frequency chirped self-amplified spontaneous-emission free-electron lasers

S. Krinsky* and Z. Huang

Stanford Linear Accelerator Center, Stanford, California 94309

(Received 31 January 2003; published 5 May 2003)

$$\lambda_0 = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

…and others

Seeded (HGHG)

Journal of the Optical Society of America B: Optical Physics

Volume 24, Issue 3, March 2007, Pages 484-495

Interplay of the chirps and chirped pulse compression in a high-gain seeded free-electron laser

Wu, J.[a], Murphy, J.B.[b], Emma, P.J.[a], Wang, X.[b], Watanabe, T.[b], Zhong, X.[c]

PHYSICAL REVIEW E **71**, 046501 (2005)

High-gain harmonic generation free-electron laser with variable wavelength

Timur Shaftan and Li Hua Yu

J. Phys. A: Math. Theor. **42** (2009) 085405 (13pp) doi:10.1088/1751-8113/42/8/085405

Impact of an initial energy chirp and an initial energy curvature on a seeded free electron laser: free electron laser properties

Alberto A Lutman[1], Giuseppe Penco[2], Paolo Craievich[2] and Juhao Wu[3]

J. Phys. A: Math. Theor. **42** (2009) 045202 (13pp) doi:10.1088/1751-8113/42/4/045202

Impact of an initial energy chirp and an initial energy curvature on a seeded free electron laser: the Green's function

Alberto A Lutman[1], Giuseppe Penco[2], Paolo Craievich[2] and Juhao Wu[3]

Nuclear Instruments and Methods in Physics Research A 712 (2013) 113–119

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

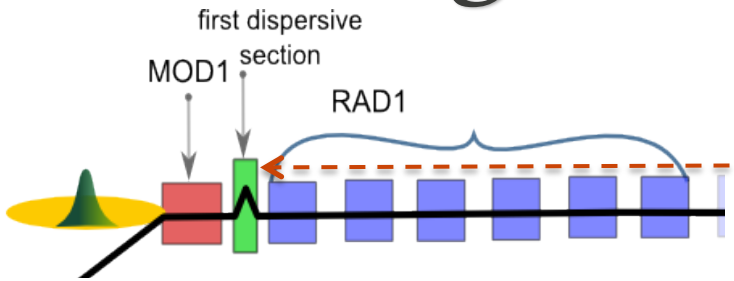
Chirped pulse amplification in a seeded free-electron laser for generating high-power ultra-short radiation

Chao Feng[a,b], Lei Shen[a], Meng Zhang[a], Dong Wang[a], Zhentang Zhao[a,*], Dao Xiang[c]

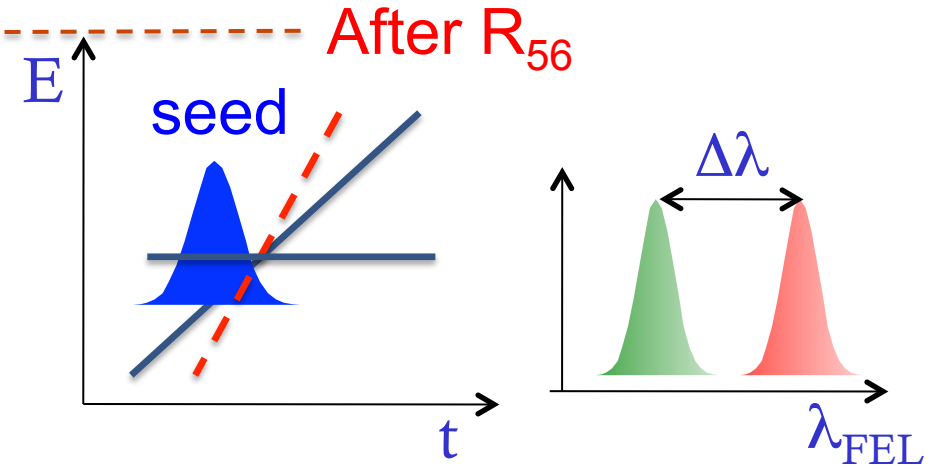
…and others

Giuseppe Penco – giuseppe.penco@elettra.eu |

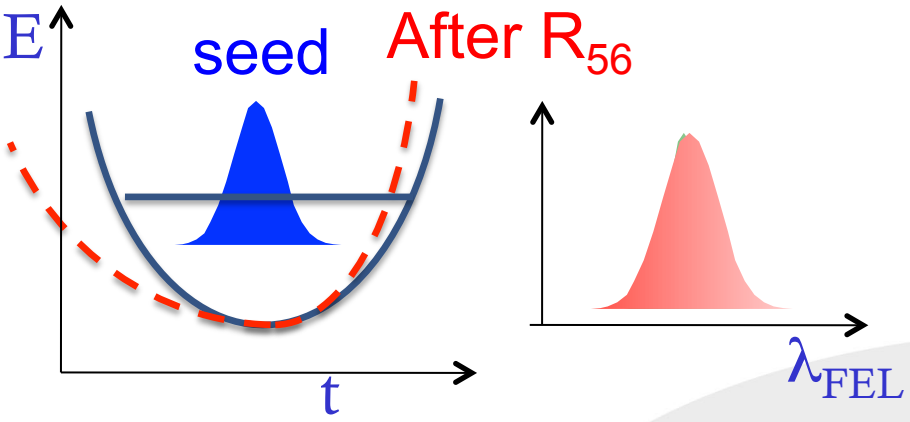
Impact of the electrons LPS on High Gain Harm. Gen. FEL



- A **linear energy chirp** in the e-beam couples with the dispersive section R_{56} and it **shifts the FEL wavelength** radiation: it can be compensated by retuning the undulators wavelength.



- A **quadratic energy chirp** results in a **spectral broadening** of the FEL radiation. In principle it can be compensated with a negative chirp seed pulse.



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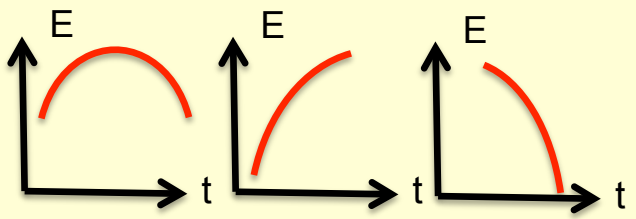
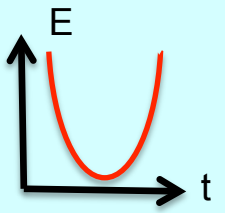
Linac elements defining e- LPS

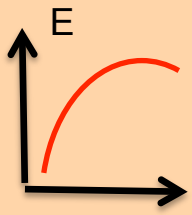
Accelerating sections



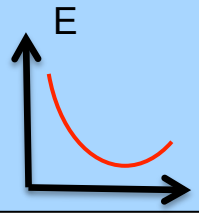
X-band

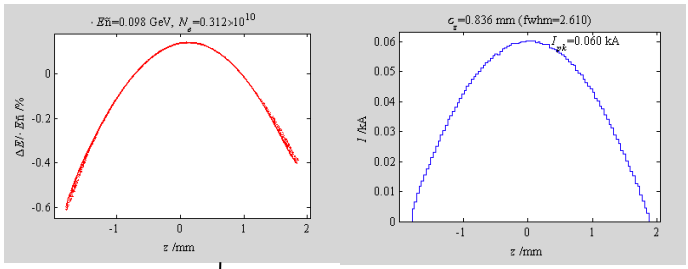


Chicane R_{56} and T_{566}



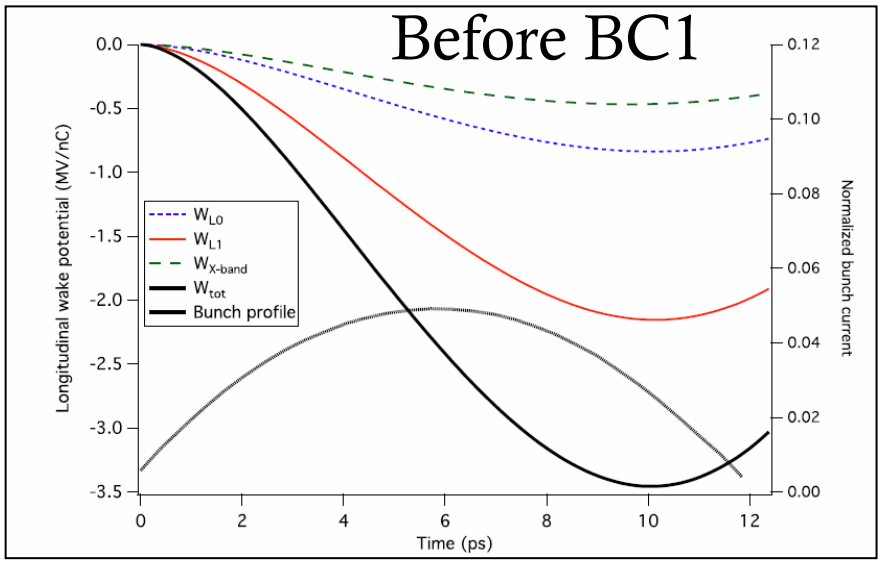
Long. Wakes (*that strongly depend on the current profile)





FERMI linac
Q=500 pC

Longitudinal wakes

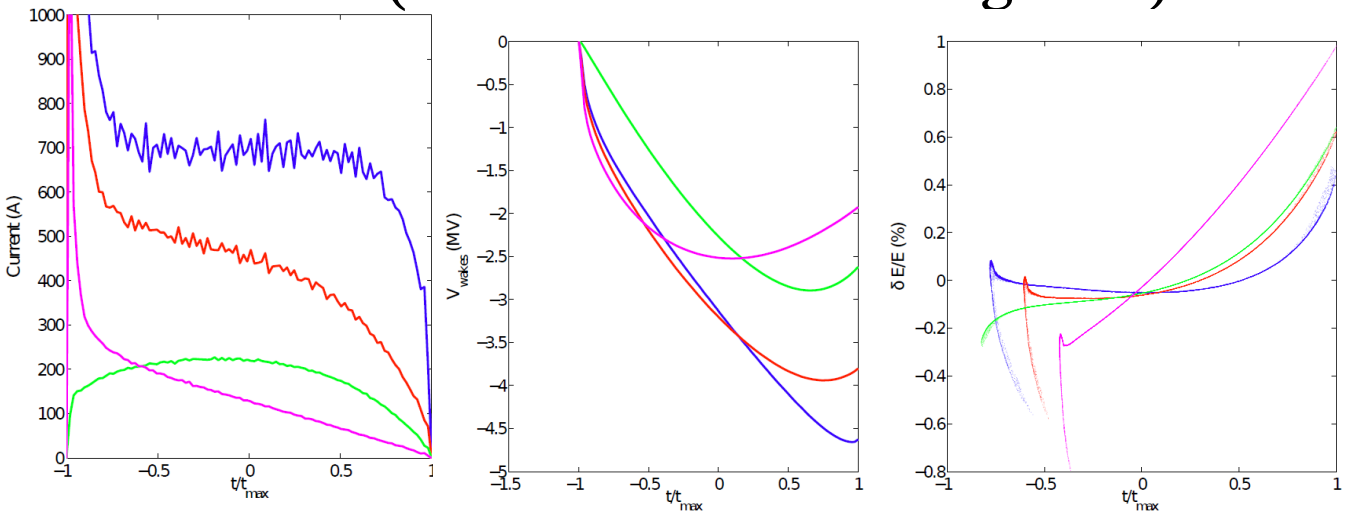


Wakes potential is fitted by a 3rd order polynomial:

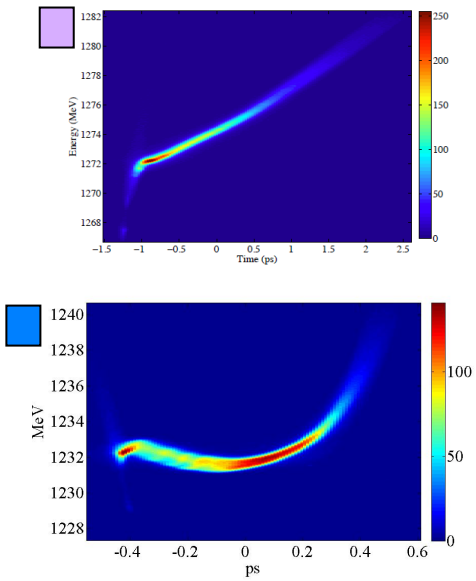
$$W_z(\tau) = \frac{1}{6}\omega_{rf}^3 a_3 \tau^3 + \frac{1}{2}\omega_{rf}^2 a_2 \tau^2 + \omega_{rf} a_1 \tau + a_0$$

	a_0	a_1	a_2	a_3
X-band off ($\sigma_t = 700fs$)	-2.49	-0.17	0.19	0.12
X-band on ($\sigma_t = 700fs$)	-2.27	-0.97	0.29	0.04
X-band on ($\sigma_t = 300fs$)	-3.18	-1.03	0.13	0.15
X-band on ($\sigma_t = 200fs$)	-3.11	-1.26	-0.04	0.10

After BC1 (and without activating BC2)



Measurements:



Nominal FERMI configuration (500 pC/flat-top at the inj & only BC1)

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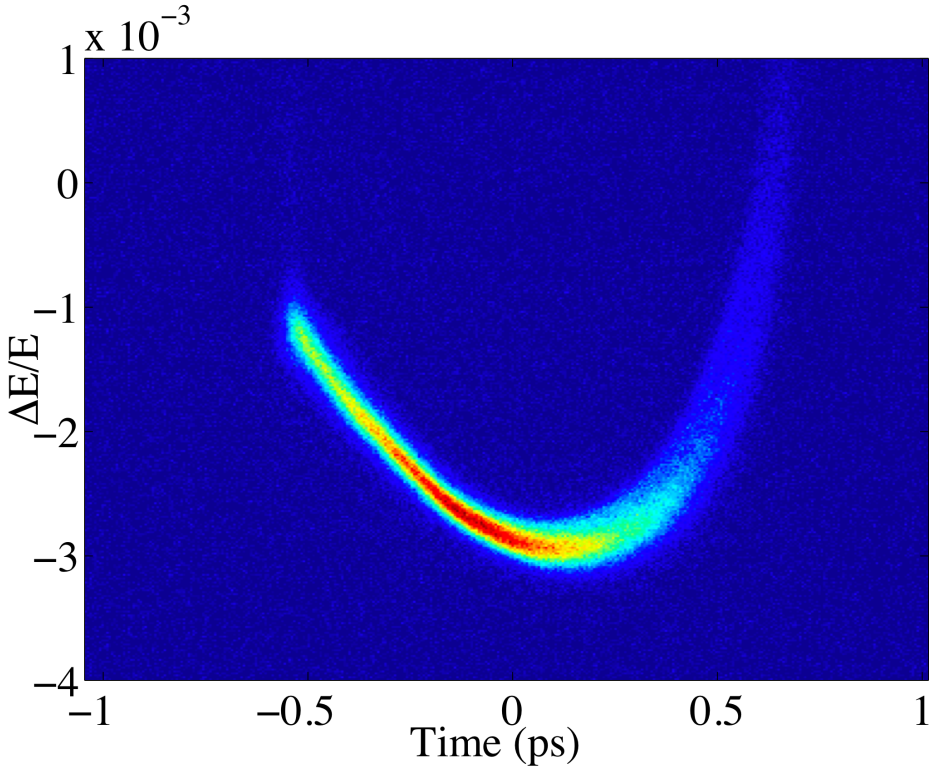
LPS measurement at the end of the linac
(by RF Defl. Cavity + En spectr.)

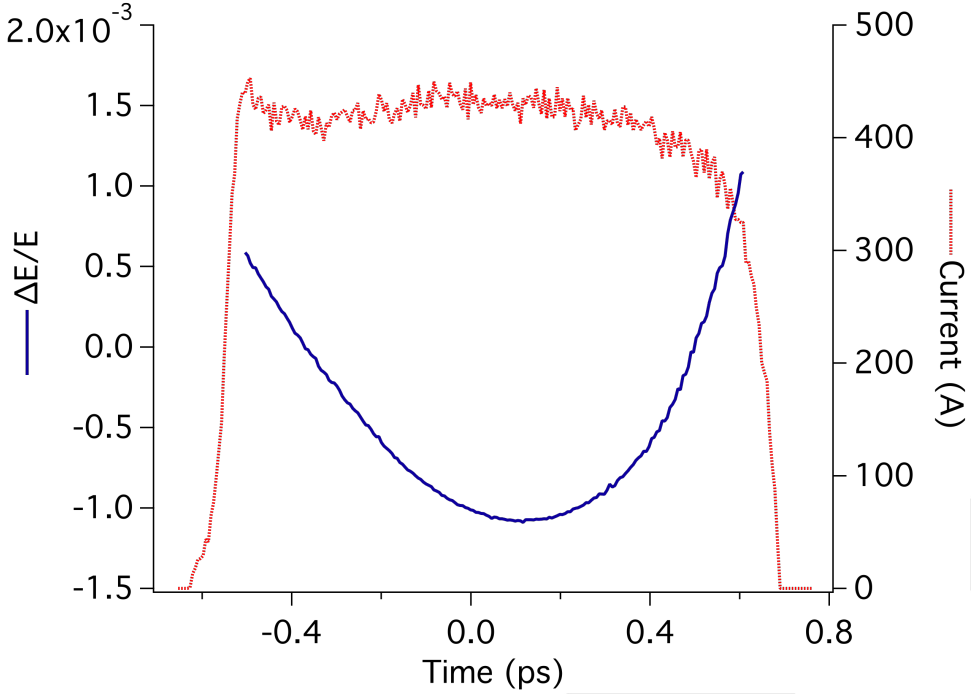


$$E(t) = E_0 + \chi_1 \cdot t + \frac{1}{2}\chi_2 \cdot t^2 + \frac{1}{6}\chi_3 \cdot t^3$$

χ_1=-1.2 MeV/ps

χ_2=17 MeV/ps^2

χ_3=36 MeV/ps^3



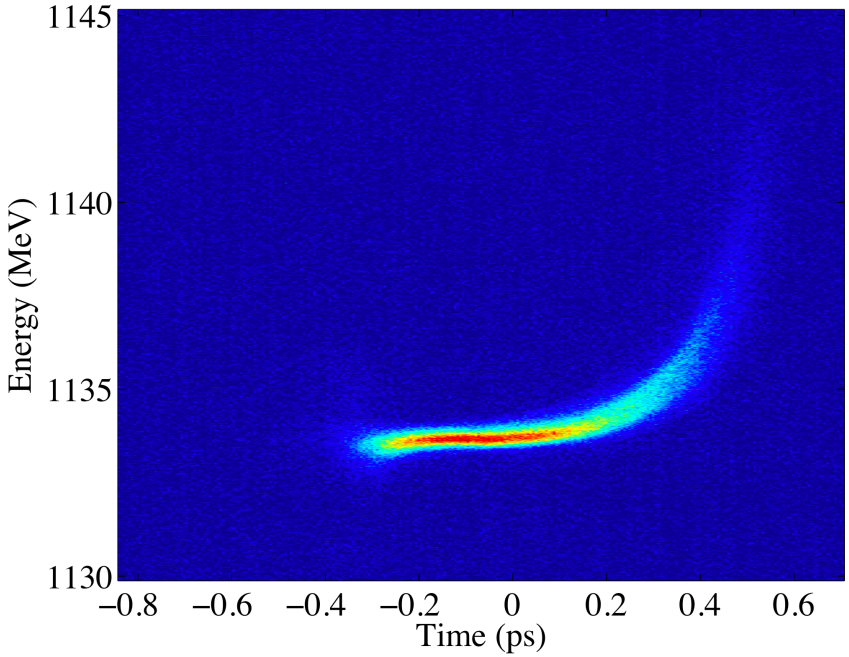
Two-stage compression helps

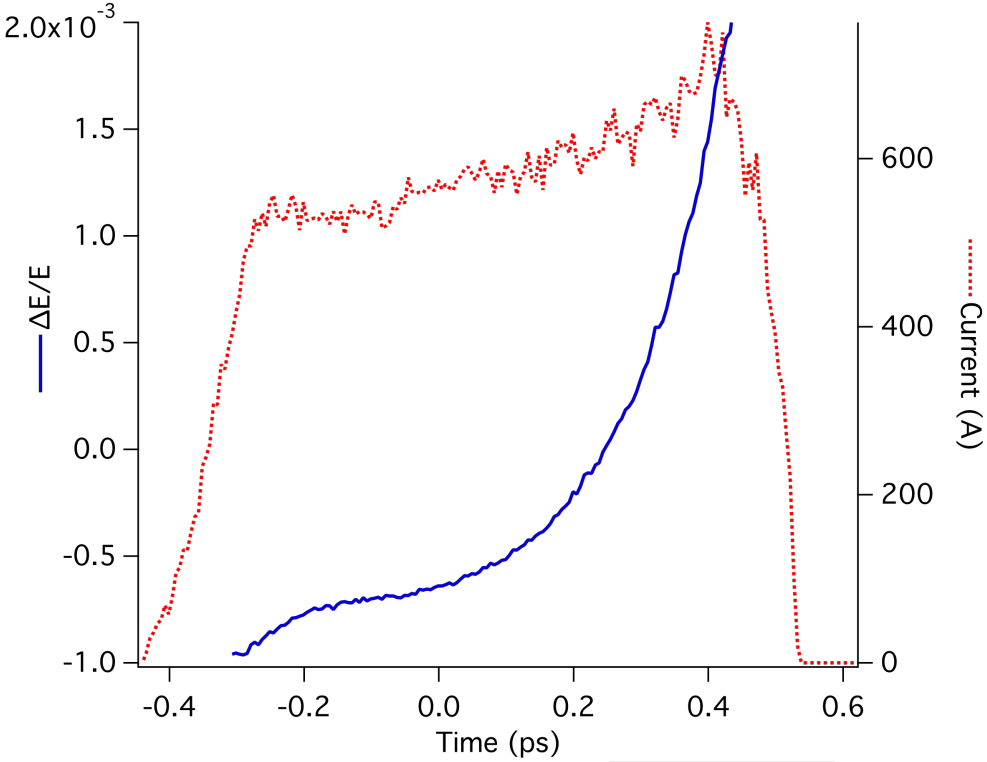
If considering the wakes contribution as a quadratic chirp, it can be compensated with the T_{566} of BC2: this translates in higher CF in BC2 (R_{56}=41mm, i.e. θ=80mrad)

χ_1=1.6MeV/ps

χ_2=10 MeV/ps^2
(improves by a factor 2)

χ_3=67 MeV/ps^3





Backtracking of a "flat-flat" profile

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 9, 120701 (2006)

Formation of electron bunches for harmonic cascade x-ray free electron lasers

M. Cornacchia, S. Di Mitri, and G. Penco
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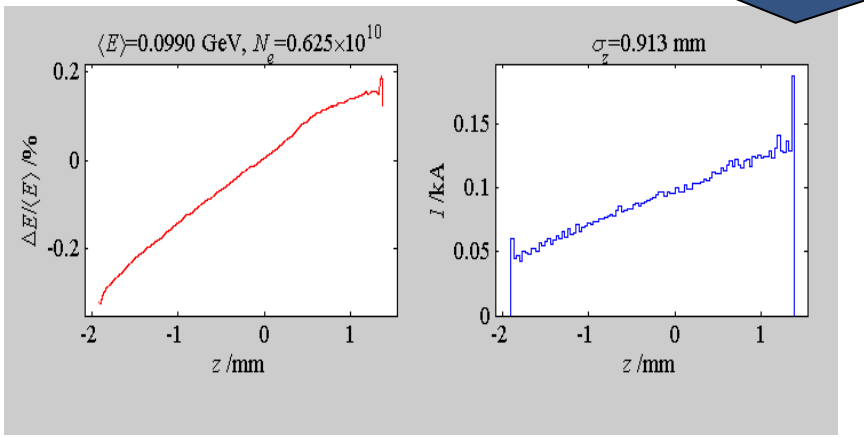
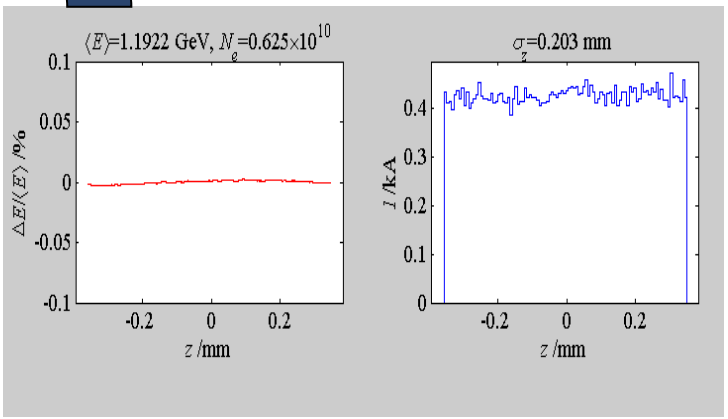
A. A. Zholents
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
(Received 11 August 2006; published 6 December 2006)

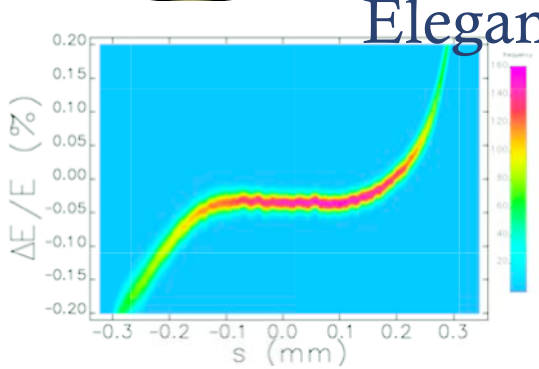


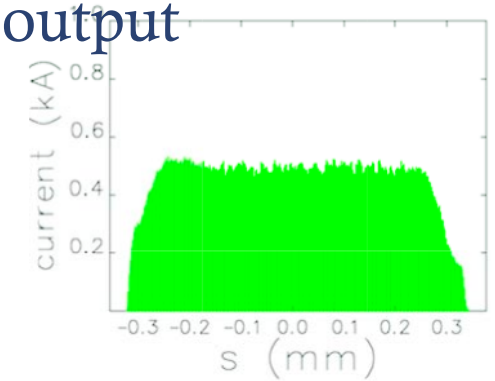
LiTrack Backtracking



100 MeV — e^- → **1.2 GeV**

Elegant output





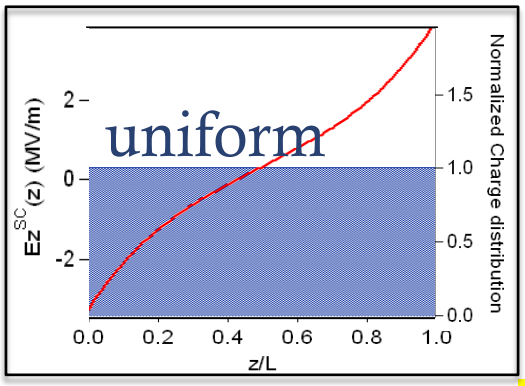
Which current distribution at the cathode ?

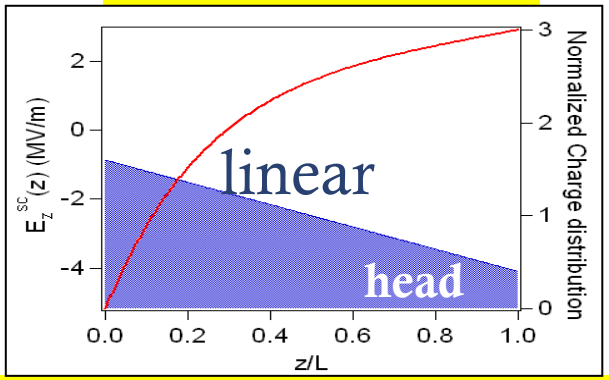
Long. Space charge field on axis:

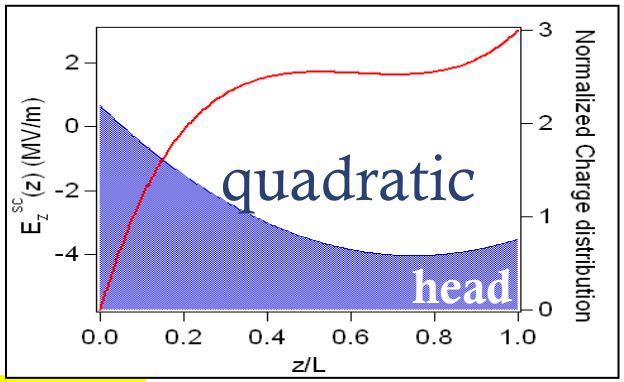
$$E_Z^{SC}(z) = \int_0^L \frac{1}{2\varepsilon_0} \cdot \rho(z') \left[\frac{z'-z}{\sqrt{(z'-z)^2 + R^2}} - \frac{|z'-z|}{z'-z} \right] \cdot dz'$$

Q=500pC
R~0.6-0.9mm

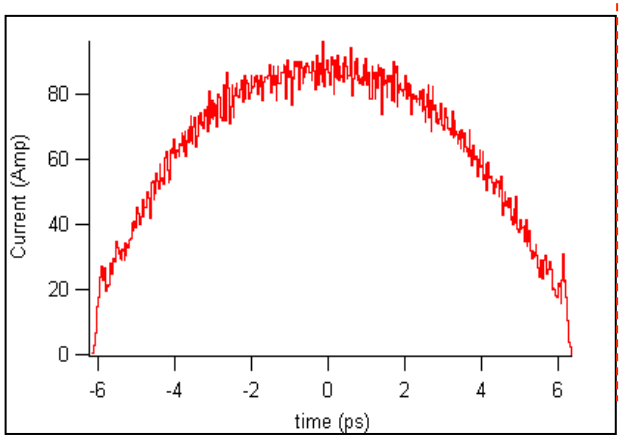
At the cathode

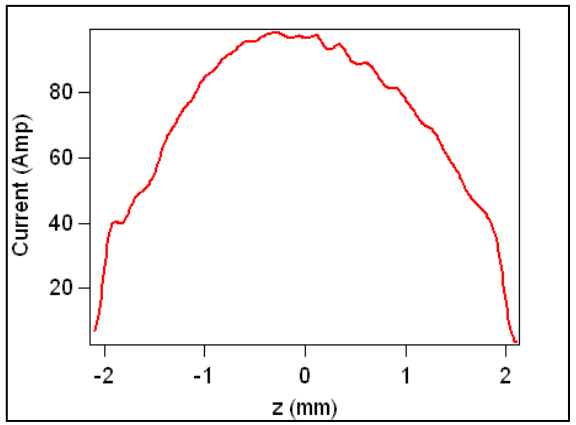


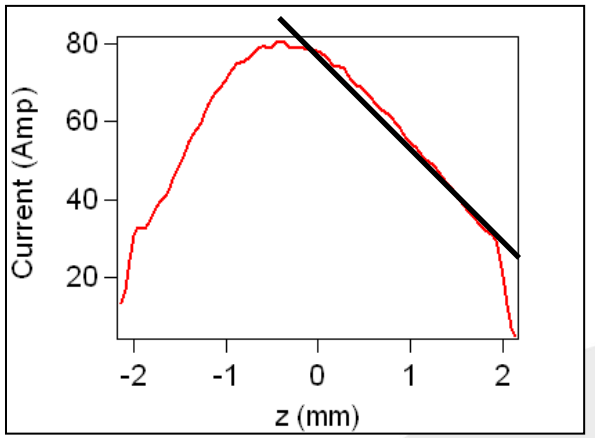




At the injector exit (100 MeV)







G. Penco, M. Trovo',S. Lidia, THPPH027, FEL '06

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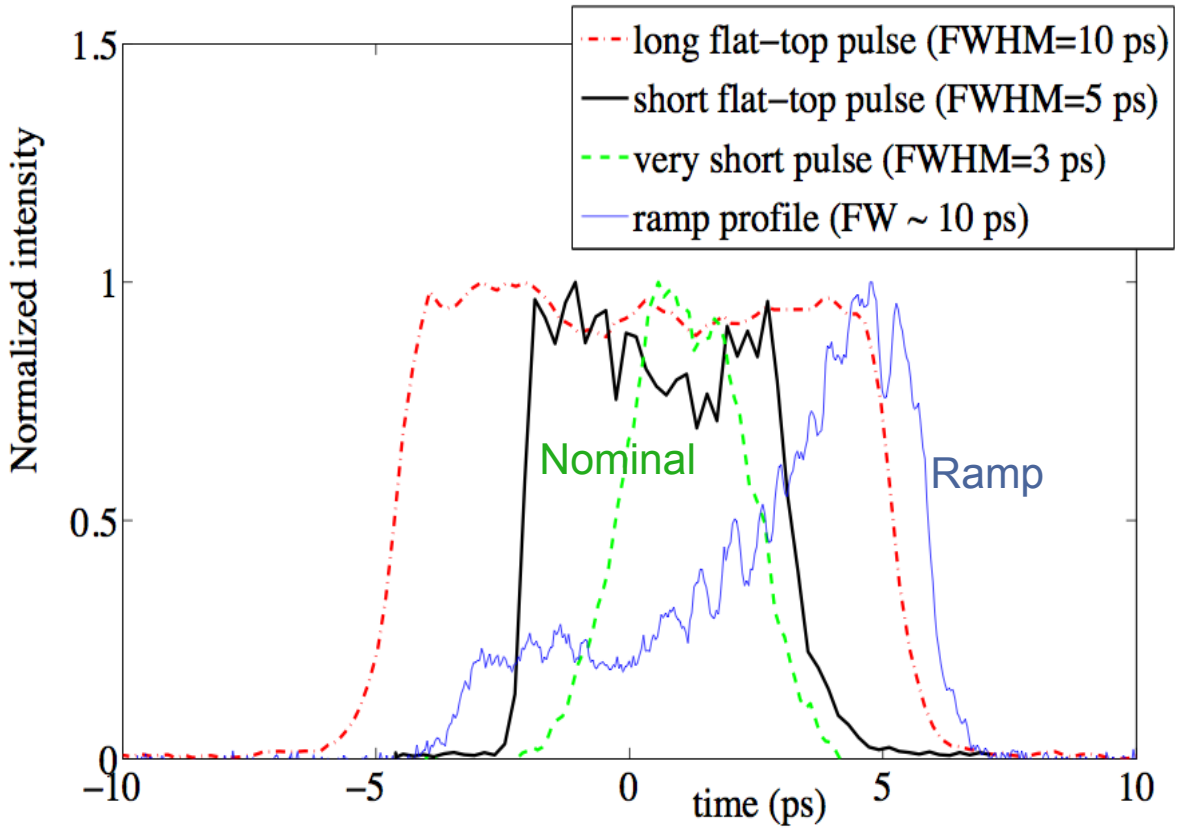
Photo-Injector Laser pulse shaping



G. Penco et al., JINST **8**, P05015 (2013)

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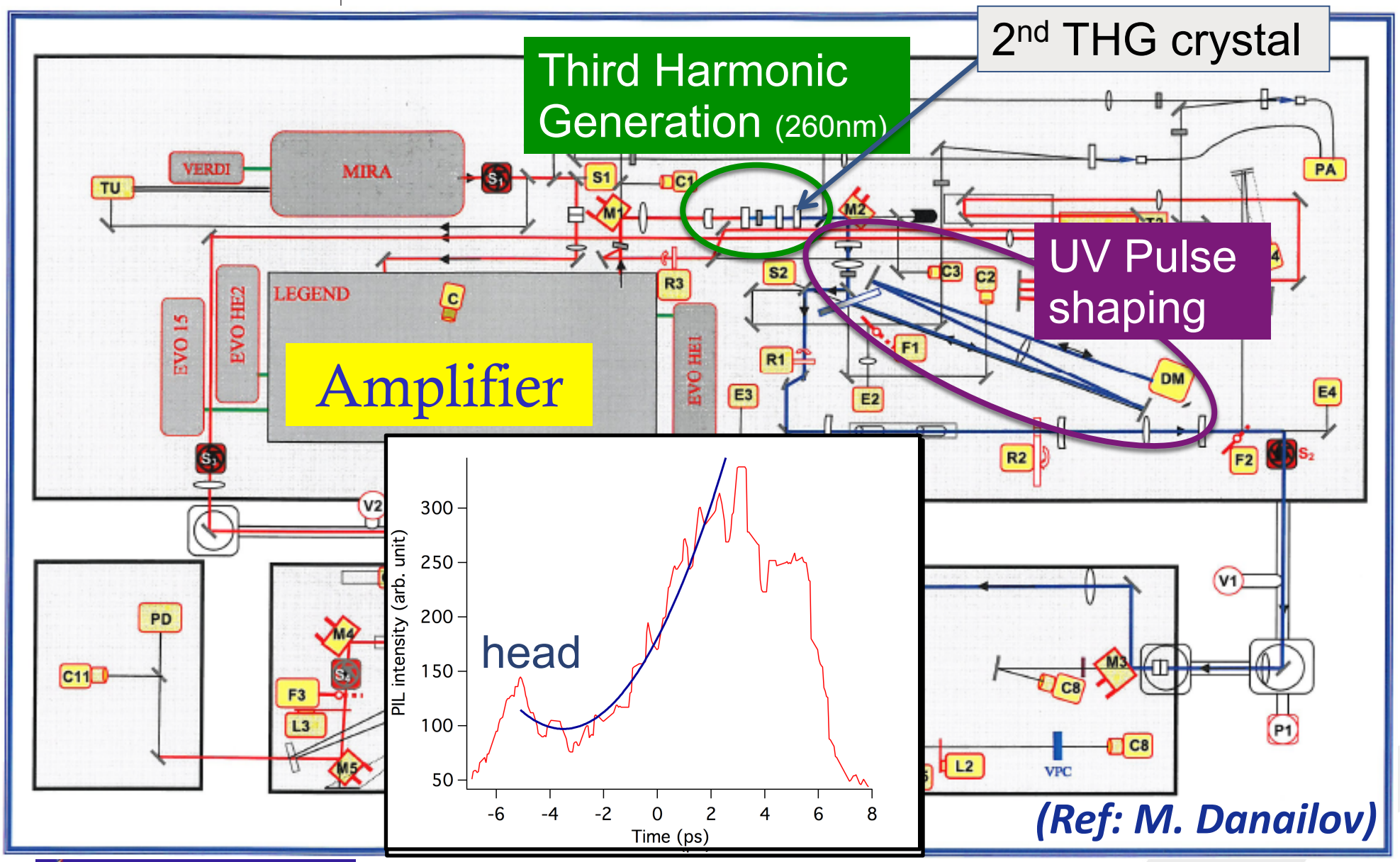
PIL shaping system



(Ref: M. Danailov)

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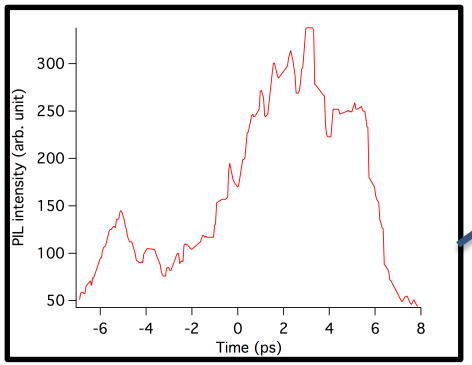
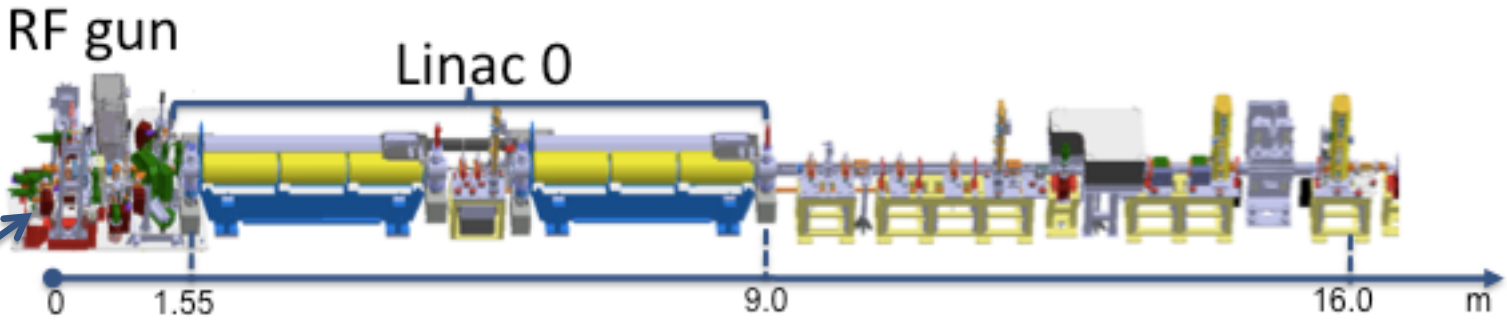
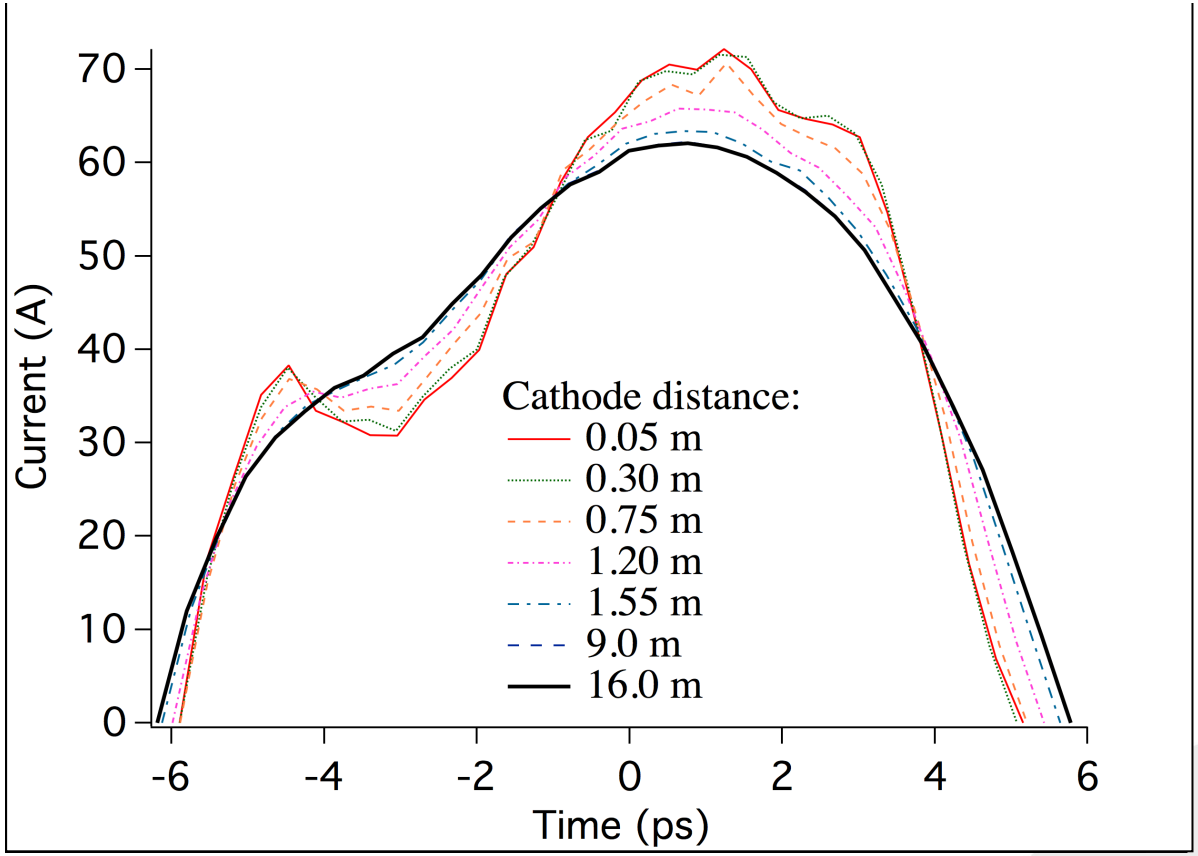
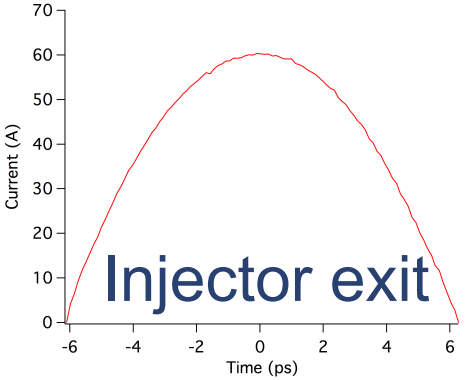
GPT simulation

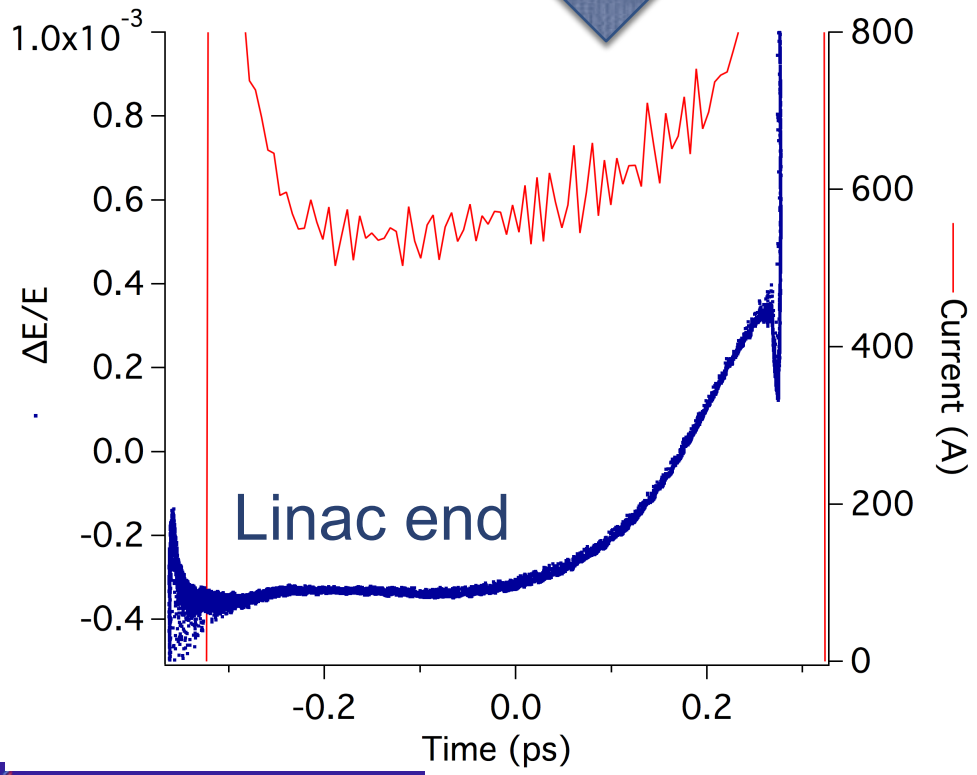


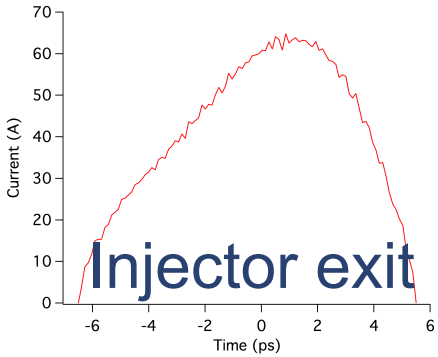


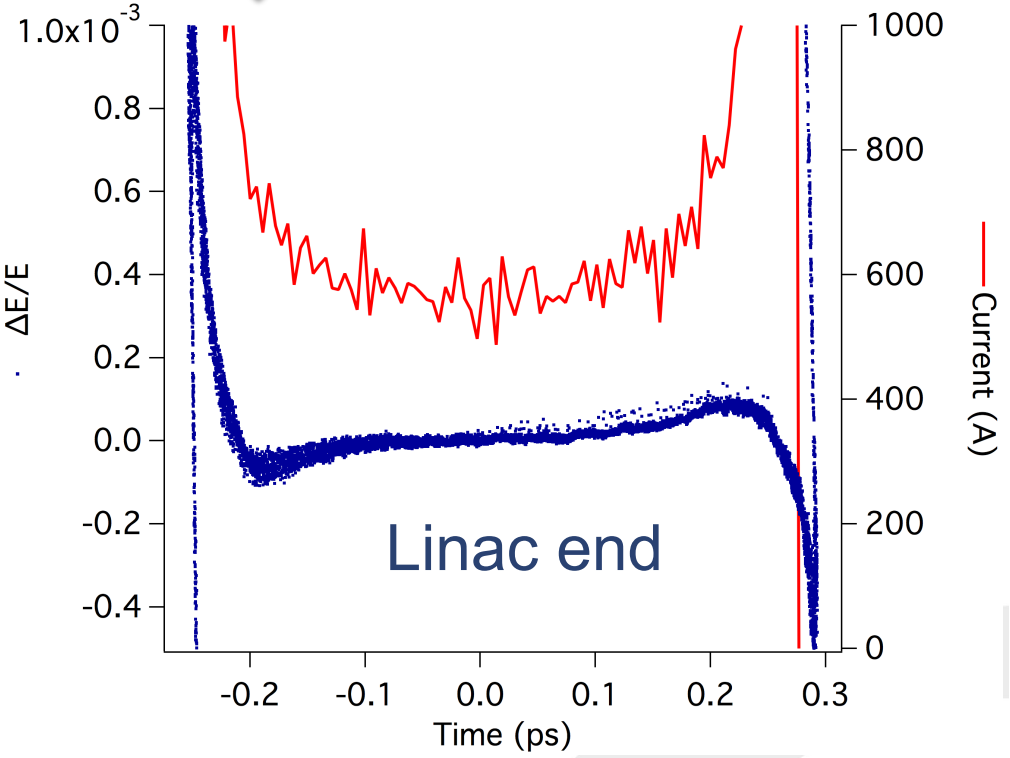


1-D tracking (BC1+BC2)



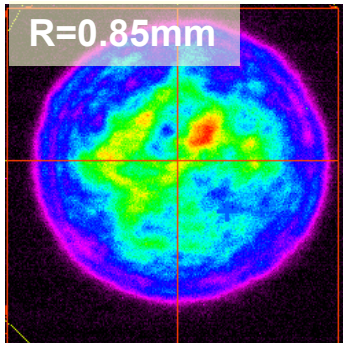


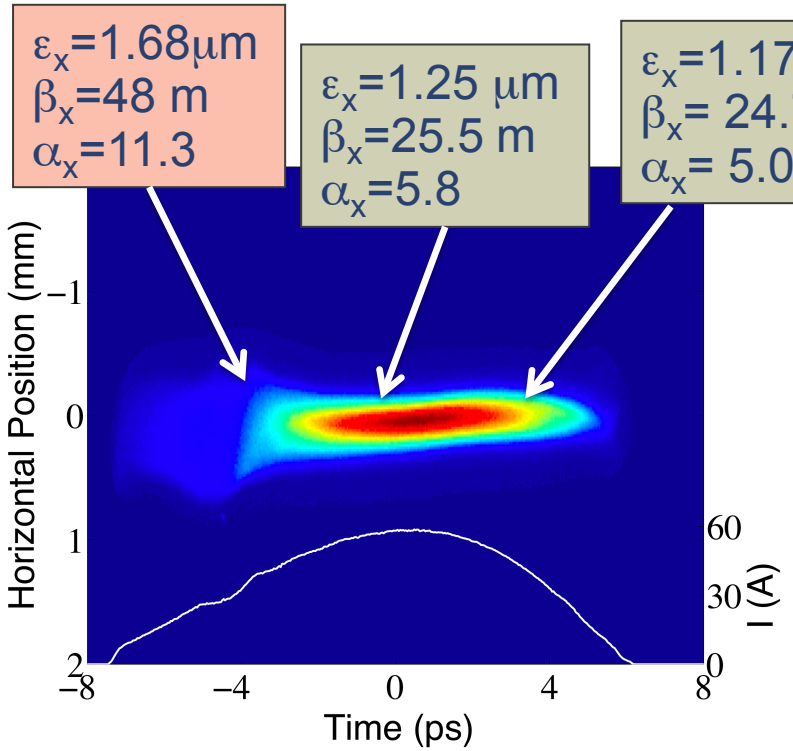


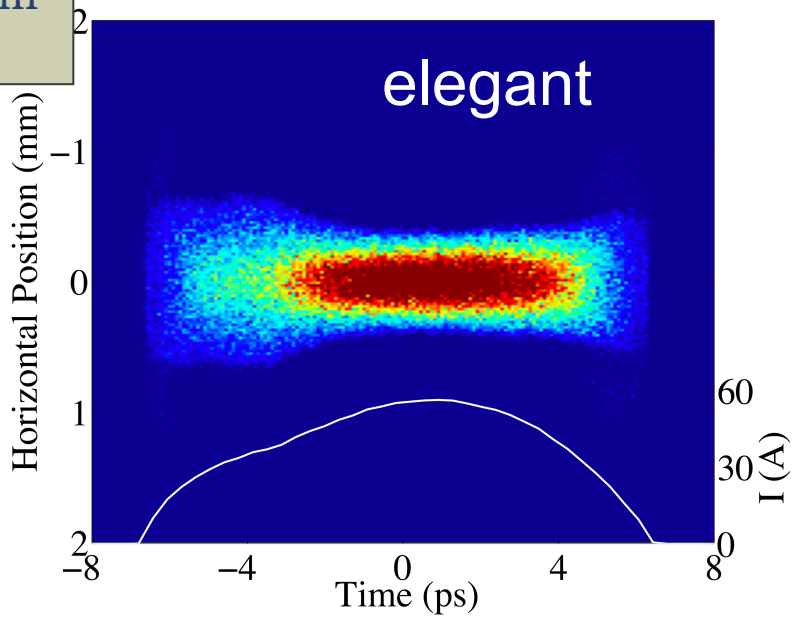


Experimental studies on the ramped current bunch

PIL spot size has been increased from the nominal radius of 0.65 mm to 0.85 mm to limit the risk of cathode surface damaging due to the high energy peak in the temporal profile tail. The consequence is an unavoidable increment of the beam thermal emittance, that is expected to be enhanced proportionally.

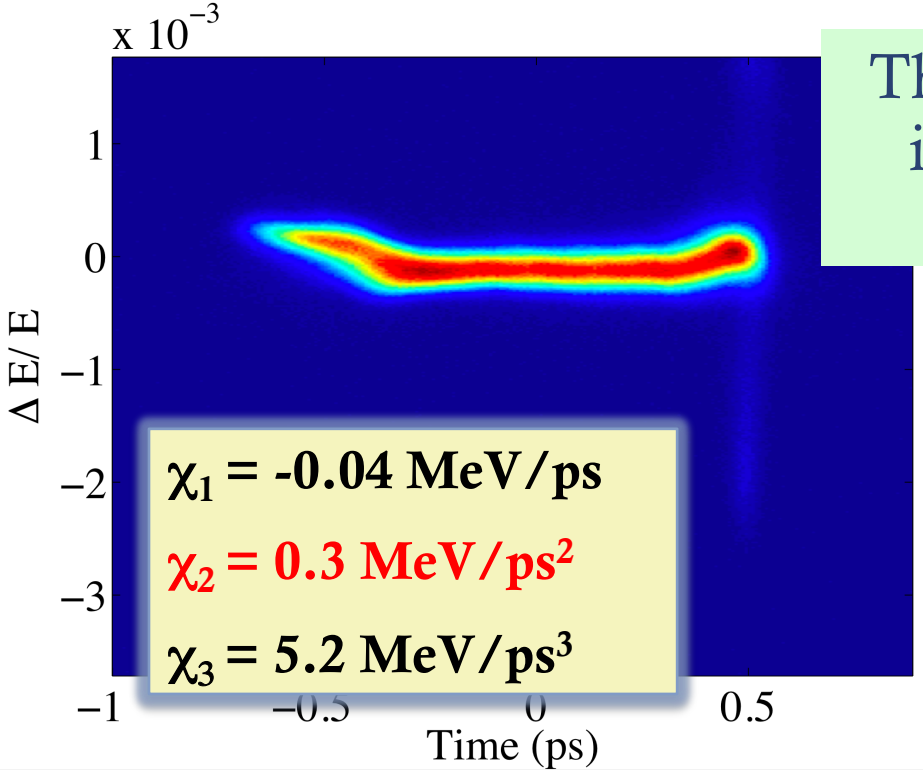






LPS Linearization

BC1 at 85mrad (CF~3) & BC2 at 70 mrad (CF~3)

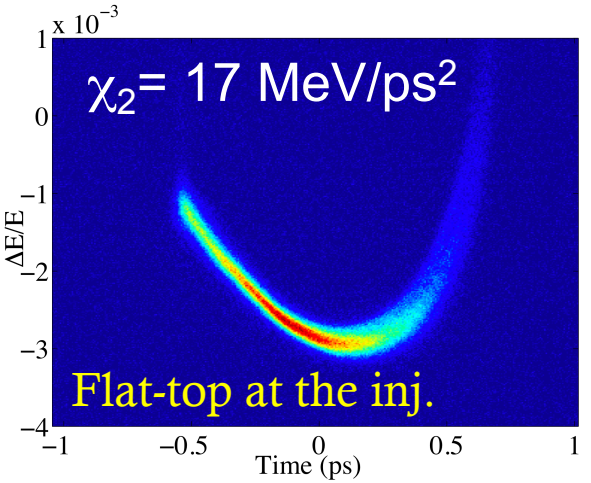


χ_1 = -0.04 MeV/ps

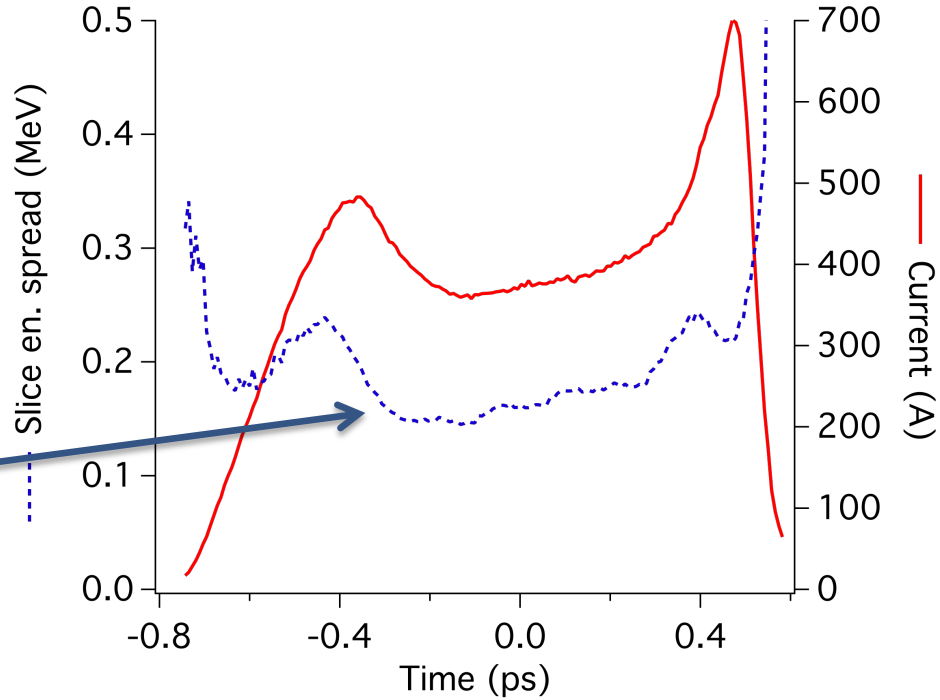
χ_2 = 0.3 MeV/ps^2

χ_3 = 5.2 MeV/ps^3

The quadr. chirp is completely suppressed



Core bunch has slice en. Spread of about 150keV



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Conclusion

- A linearly ramped current bunch profile has been generated by temporal shaping the photoinjector laser (quadratic ramp).
- Injector transverse emit. increases (1.1-1.2 μm) but it remains under control and meets the FERMI specification (1.5μm).
- The "ramped" bunch has been longitudinally compressed in two stages (BC1 and BC2).
- Full linearization of the electrons longitudinal phase space at the end of the linac has been experimentally demonstrated !
- The "ramped" bunch has been sent in the FEL-2 line (HGHG double-stage cascade) and few μJ at 8nm has been measured. A detailed characterization of the FEL performance in this configuration is going to be carried on in the next future.

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Thank You

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