What Next@LNF: Fisica della Materia
Laboratori Nazionali di Frascati
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The SPARC_LAB THz Source

Abstract
High peak power THz radiation with tunable spectral bandwidth is produced at SPARC_LAB as coherent radiation (CR) from relativistic, short (~100 fs) electron bunches. The CR spectrum is characterized through frequency domain techniques.

Riccardo Pompili and Enrica Chiadroni on behalf of the SPARC_LAB team

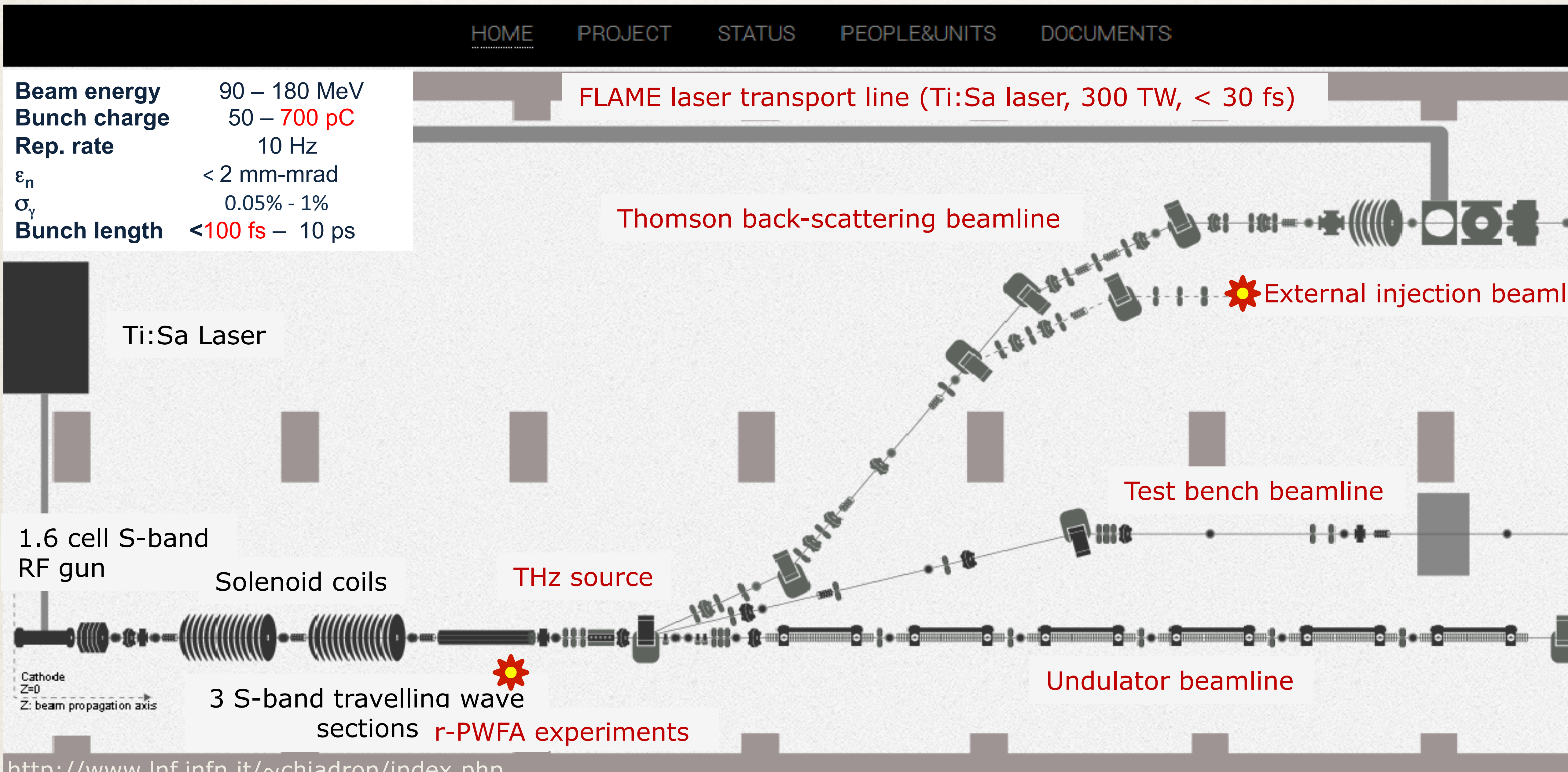
Outline

- **Introduction**
  - The SPARC_LAB test facility
    - High brightness photo injector
- **The SPARC_LAB THz Radiation**
  - Electron-beam based source
    - *Coherent radiation from sub-ps beams*
  - Tailoring THz emission
    - *Manipulation of electron beam longitudinal shape*
  - Figures of merit of the THz source
- **Scientific Case**
- **Conclusions**

The SPARC_LAB Test Facility

Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

High brightness photo-injector



Electron beam-based source

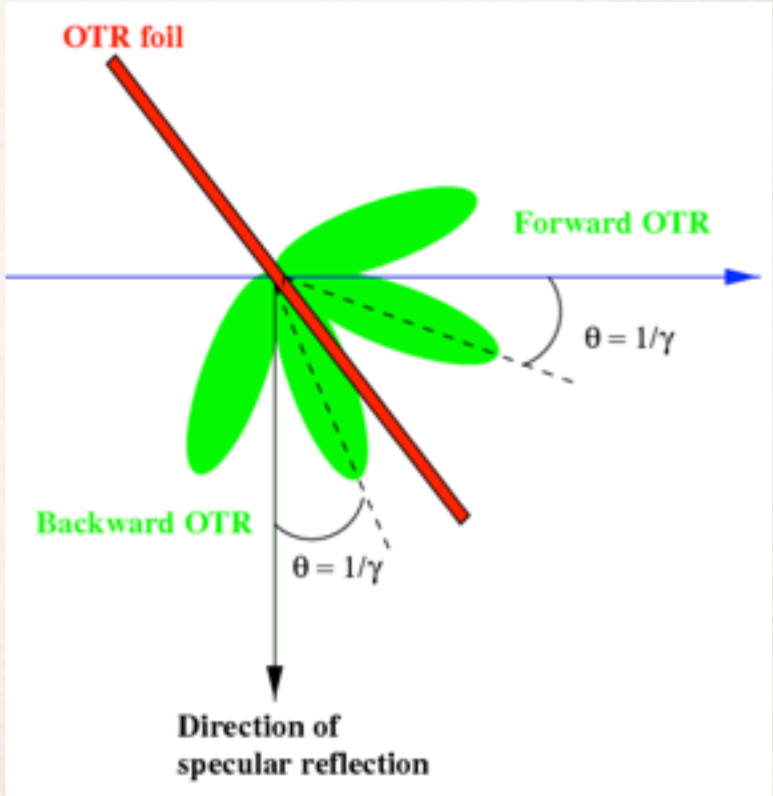
- A **new generation of sources** that boost the peak power available in the THz region up to more than 10^2 MW
- The **key for high efficiency** in a beam-based radiation source is to exploit the **coherence enhancement effect by beam profile tailoring**
- Short, sub-ps, electron bunches produce coherent radiation in the THz range

Tailoring THz Emission

- The total radiation intensity emitted by a bunch of N electrons is given

$$\frac{dU}{d\lambda} = \frac{dU_{sp}}{d\lambda}\left[N + N(N-1)|F(\lambda)|^2\right]$$

- $\frac{dU_{sp}(\lambda)}{d\lambda}$ is the radiation intensity emitted by a single particle
- Transition Radiation (TR) is emitted, both in forward and backward direction, when a charged particle crosses the boundary between two media with different optical properties



- The radiation results from the prompt change of the boundary conditions for the electromagnetic (EM) field carried by the relativistic particle in the first and second media

Tailoring THz Emission

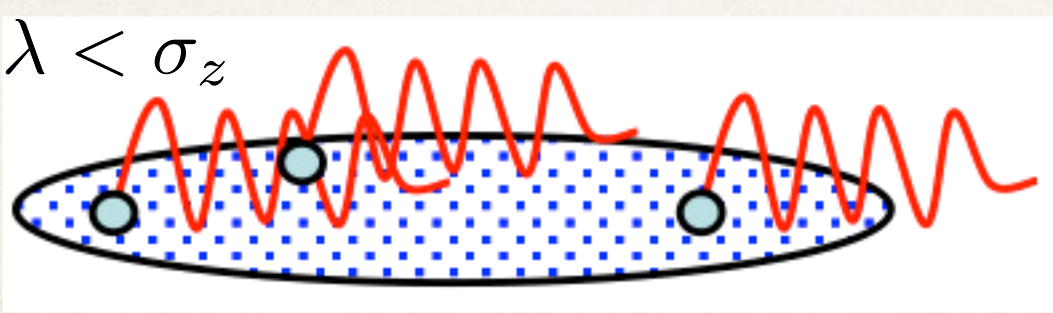
- The total radiation intensity emitted by a bunch of *N* electrons is given

$$\frac{dU}{d\lambda} = \frac{dU_{sp}}{d\lambda}[N + N(N-1)|F(\lambda)|^2]$$

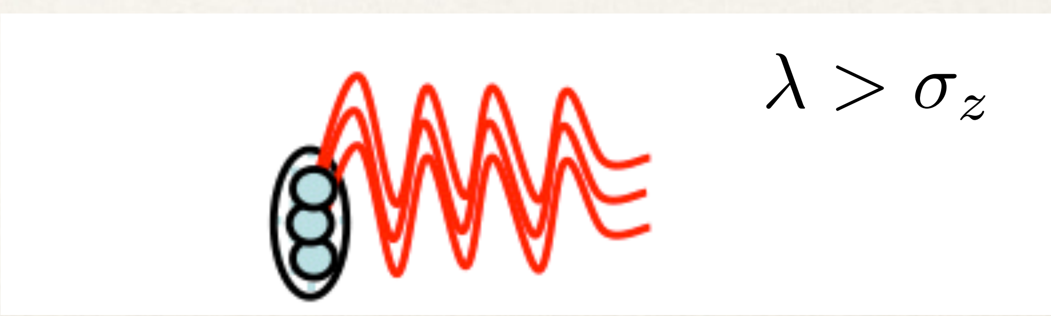
$F(\lambda) = \int_{-\infty}^{\infty} S(z) e^{i\frac{2\pi z}{\lambda}} dz$ is the bunch form factor, defined as the Fourier transform of the electron bunch longitudinal profile, *S(z)*.

$$0 \leq F(\lambda) \leq 1$$

Incoherent emission $\propto N$

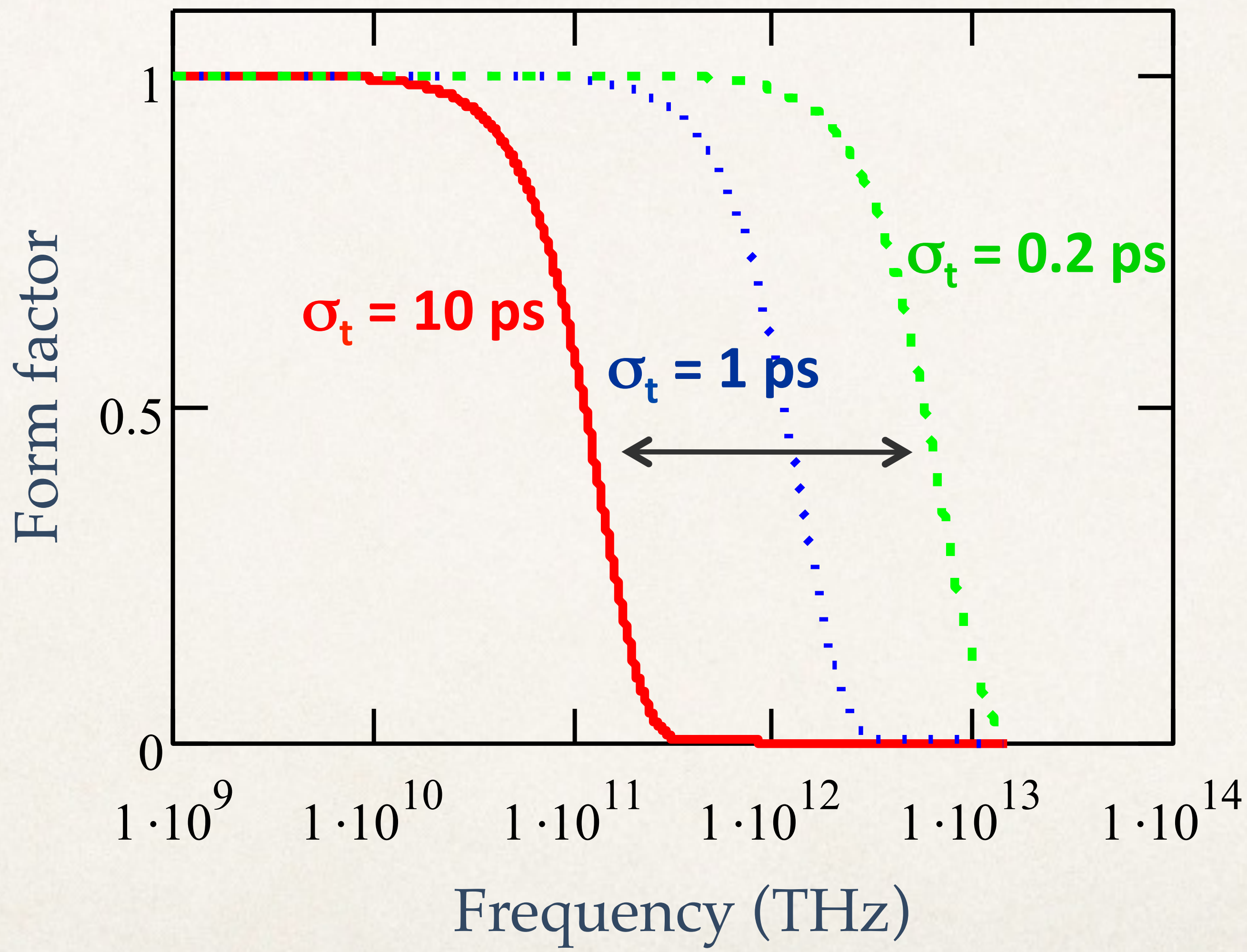


Coherent emission $\propto N^2$



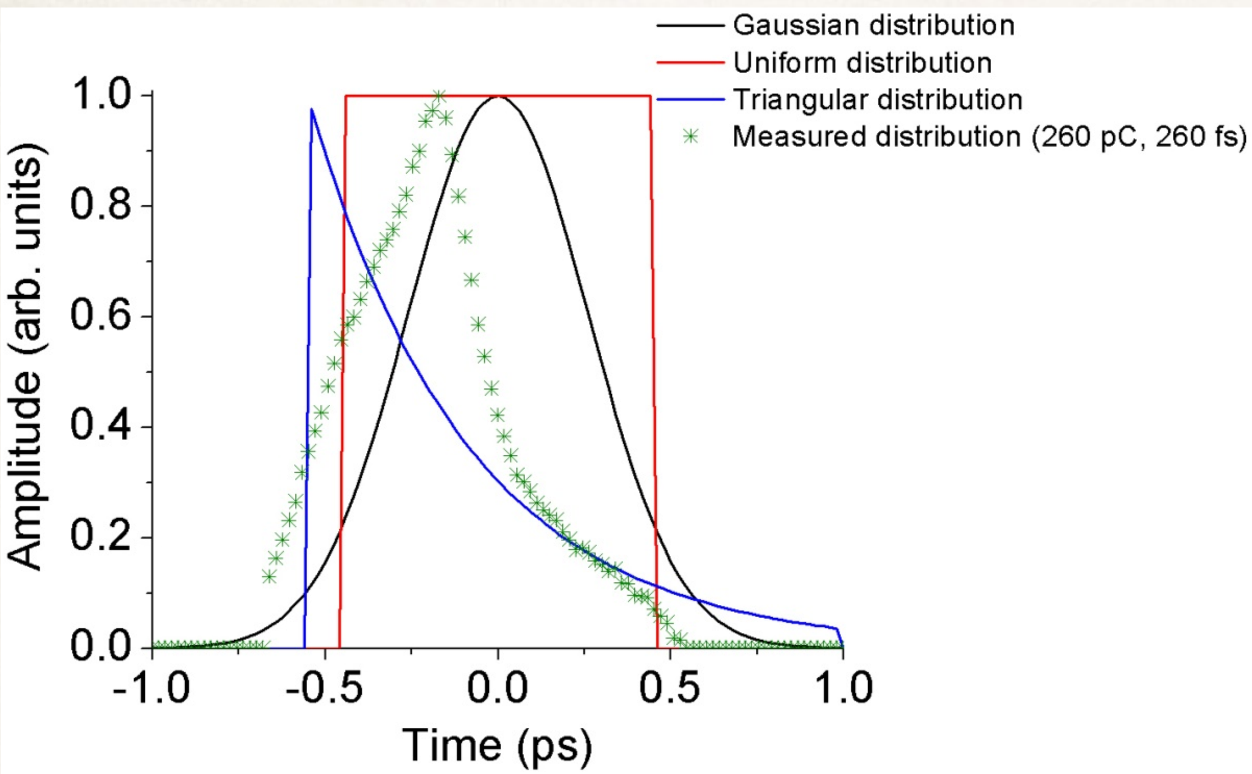
Broad-band THz Source

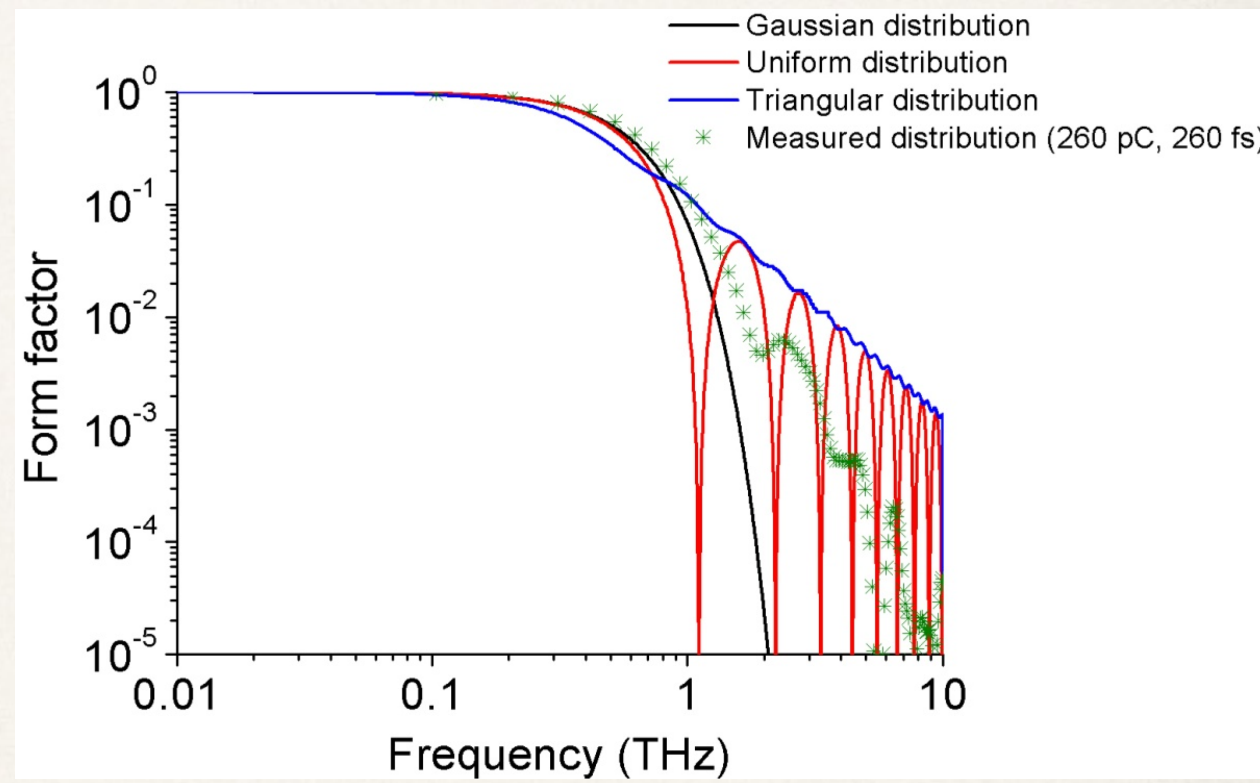
- To extend the Coherent Radiation spectrum towards higher THz frequencies the bunch must be shortened down to 10-100 fs



Broad-band THz Source

- To extend the Coherent Radiation spectrum towards higher frequencies the triangular (saw-tooth) distribution is the best

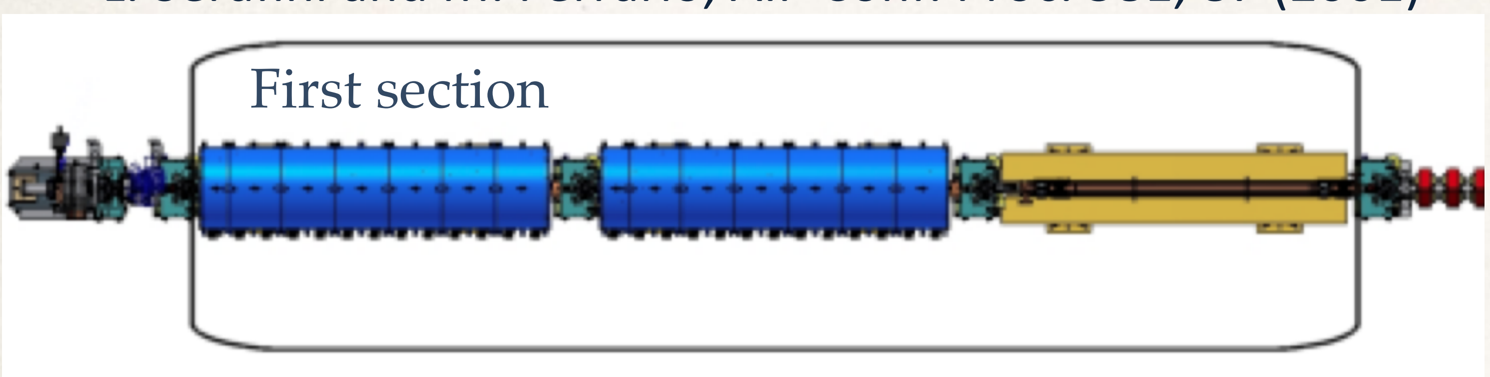


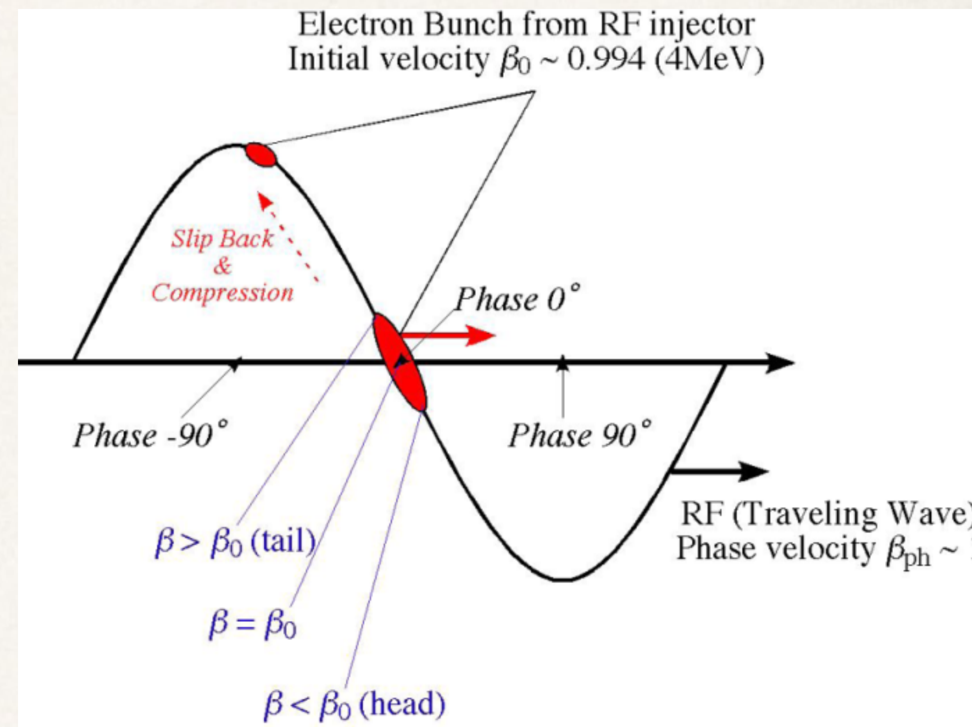


Longitudinal compression techniques are mandatory to enhance coherence effects and increase the radiation bandwidth

Velocity Bunching (VB) Technique

L. Serafini and M. Ferrario, AIP Conf. Proc. 581, 87 (2001)



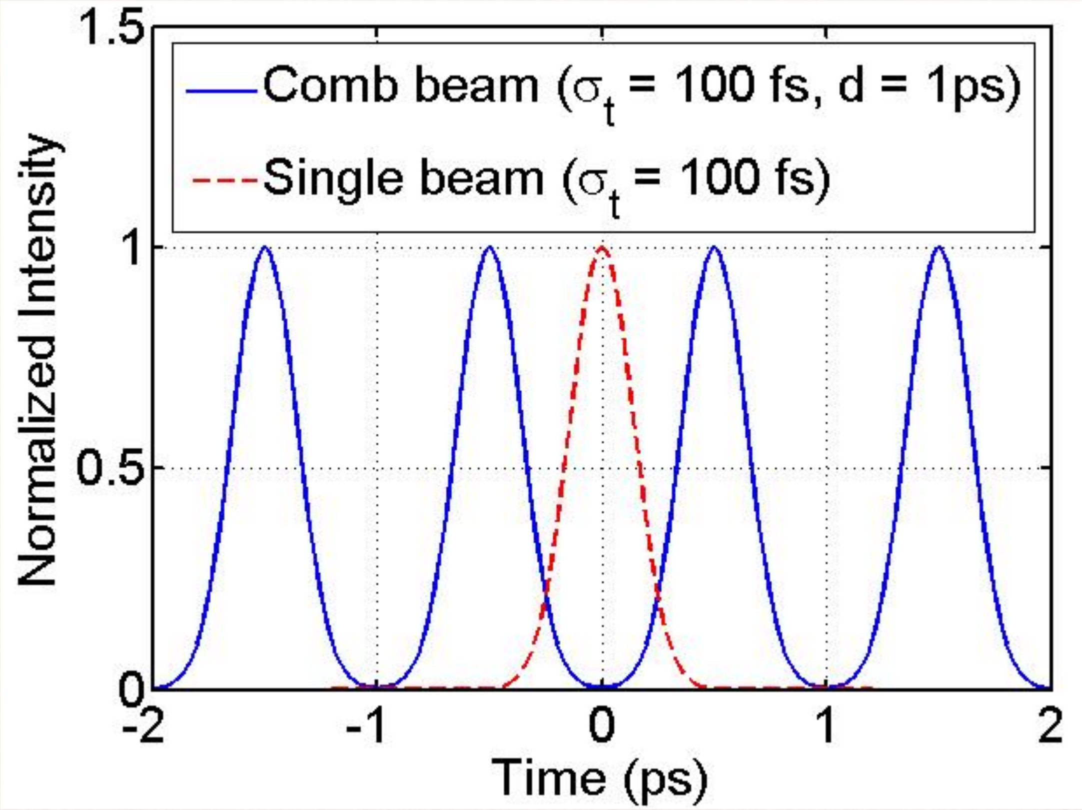


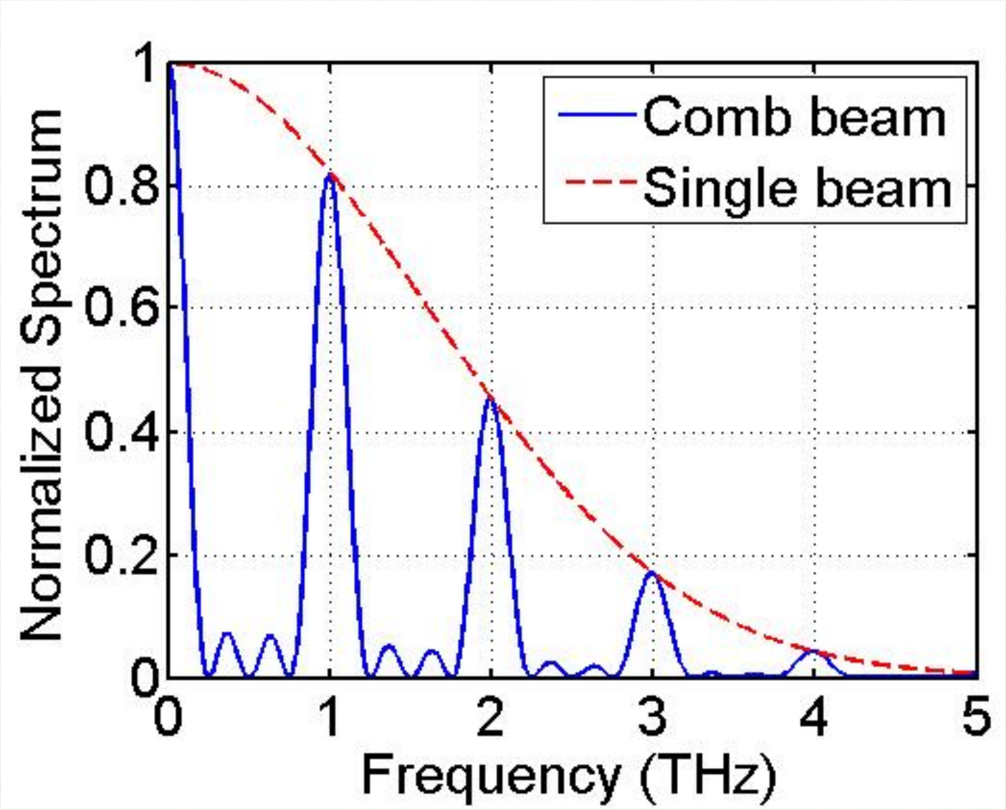
- The beam is injected in the I linac section at the 0-crossing field phase.
- Injection takes place at low energies where the beam is slower than the phase velocity of the RF wave.
- The beam will slip back to phases where the field is accelerating, but at the same time it will be chirped and compressed.
- Compression and acceleration take place at the same time within the same linac section.

Tunable and Narrow-band THz Source

- If a **longitudinally modulated beam**, i.e. a ***comb* beam**, interacts with an aluminum target, being the emission a surface phenomenon, and therefore instantaneous, the bunch structure is frozen during the emission process

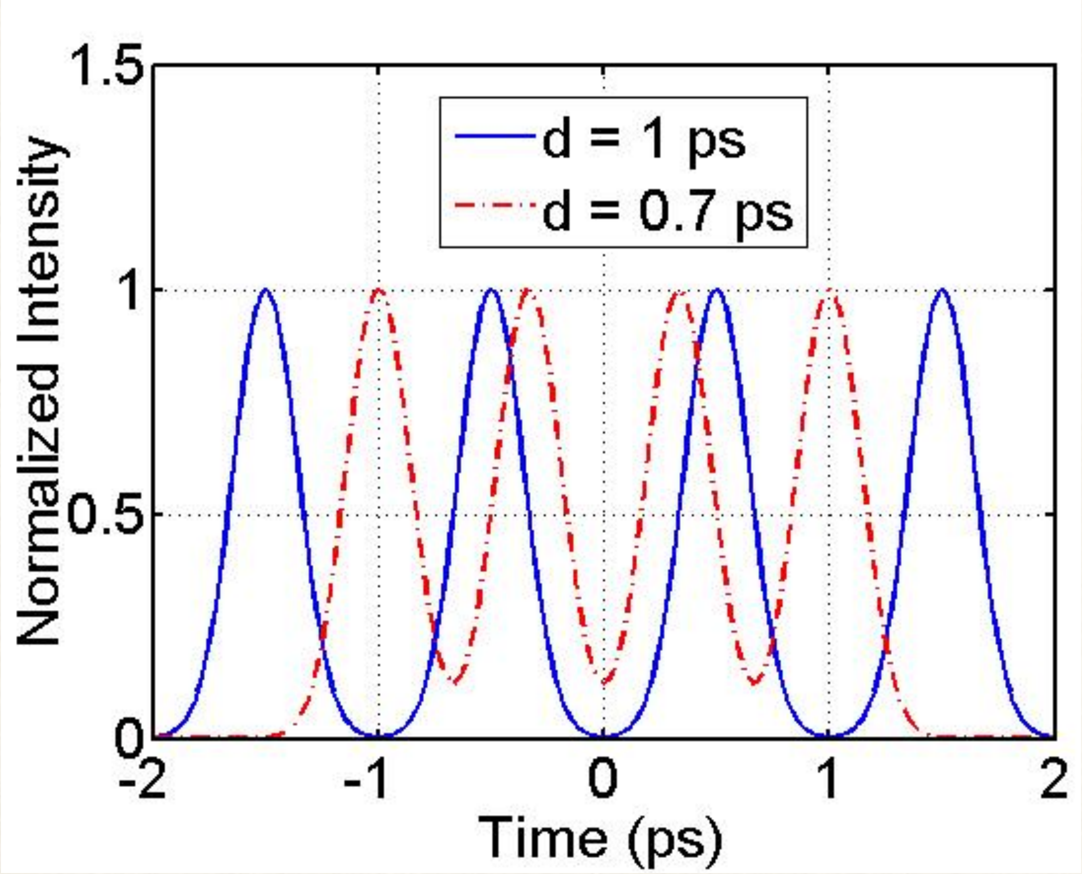
- If the width of the micro-pulses that constitutes the comb is reduced, the single pulse spectrum becomes larger, and more harmonics of the micro-pulse repetition frequency appears in the comb spectrum

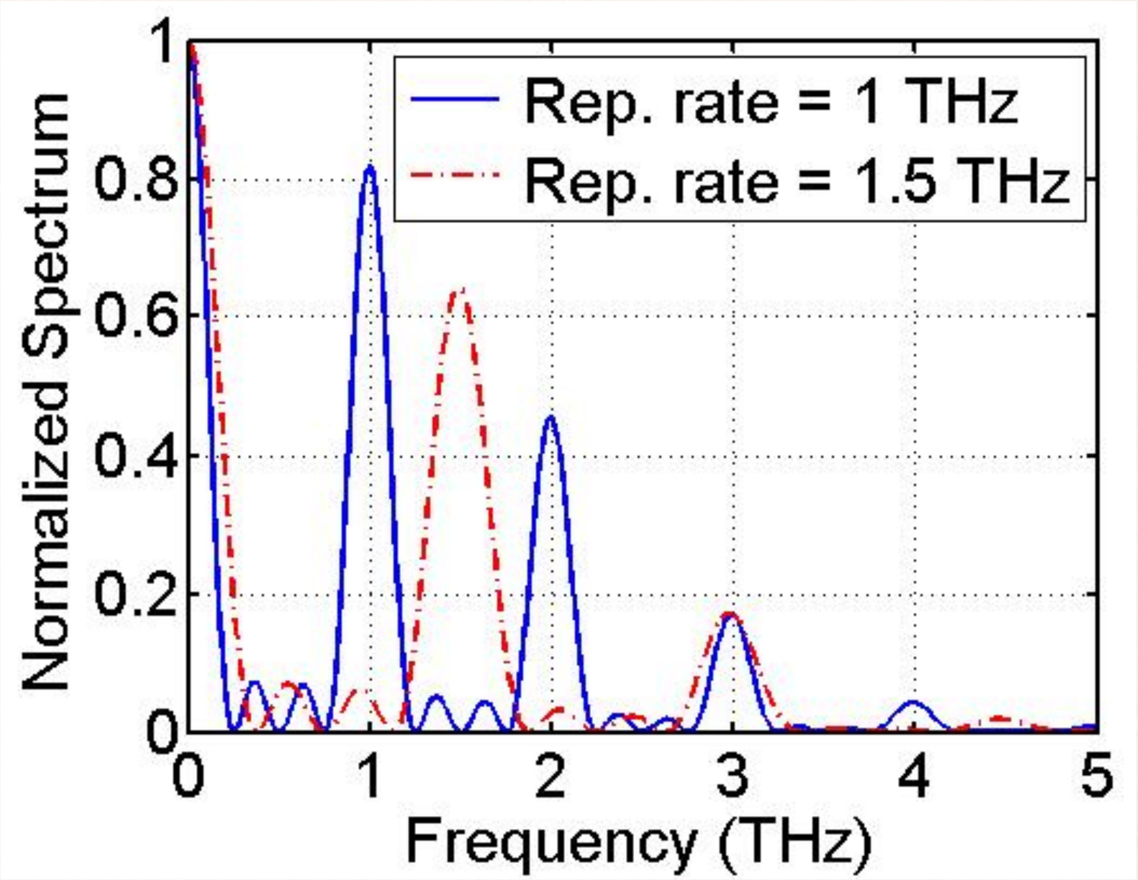




Tunable and Narrow-band THz Source

- By changing the time separation between micro-pulses, emission occurs at different THz frequencies





Laser Comb and VB Technique

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

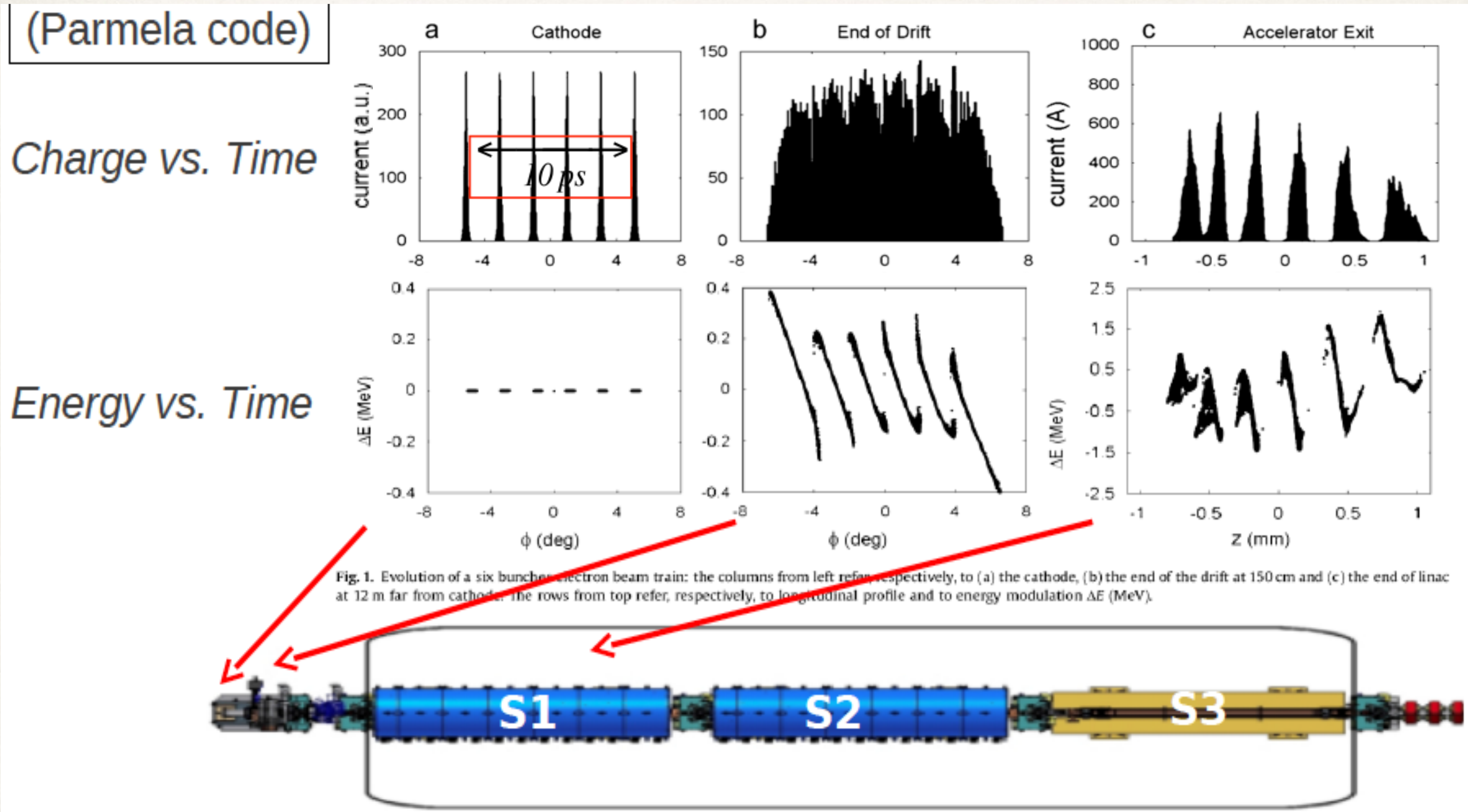
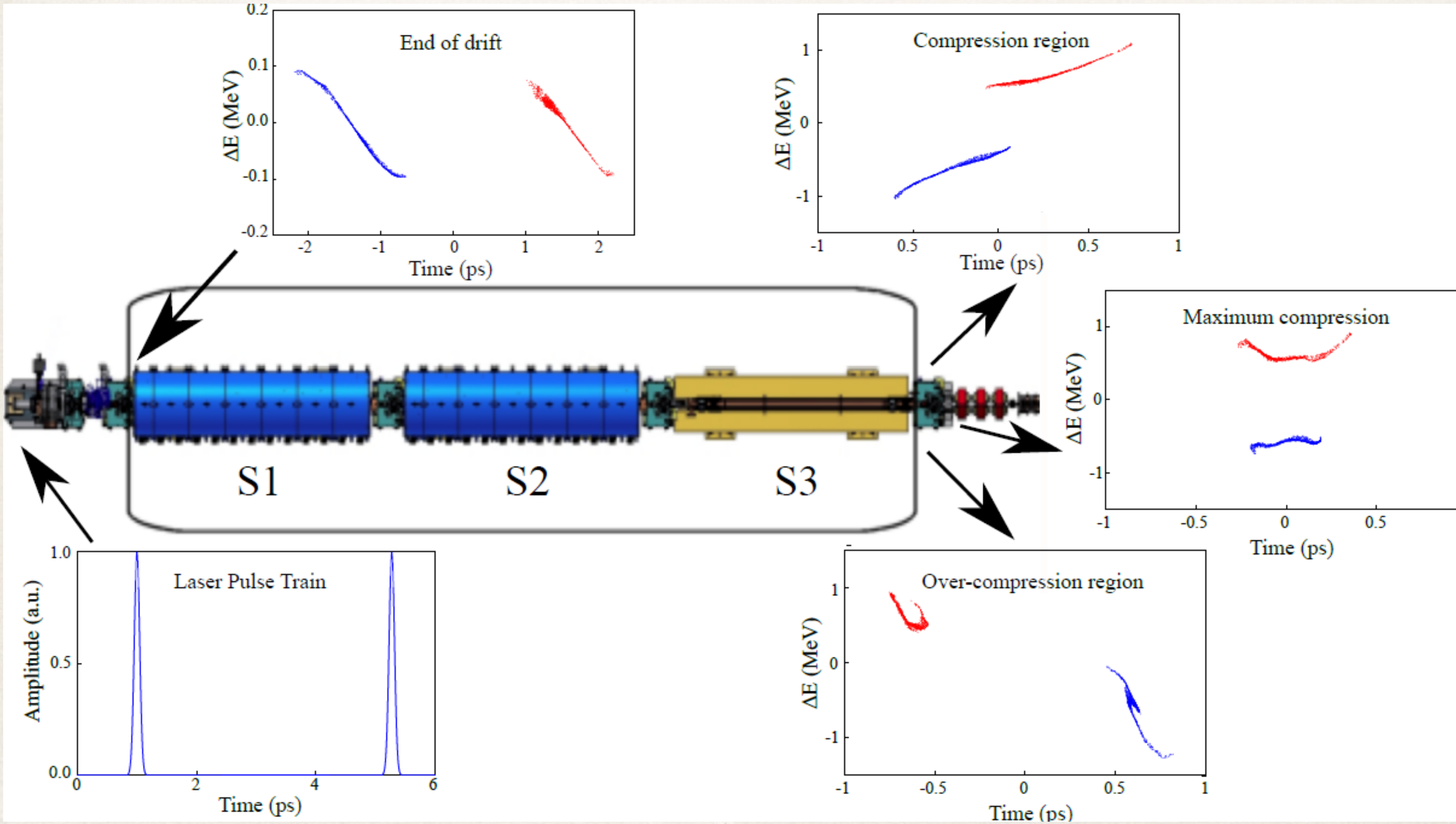
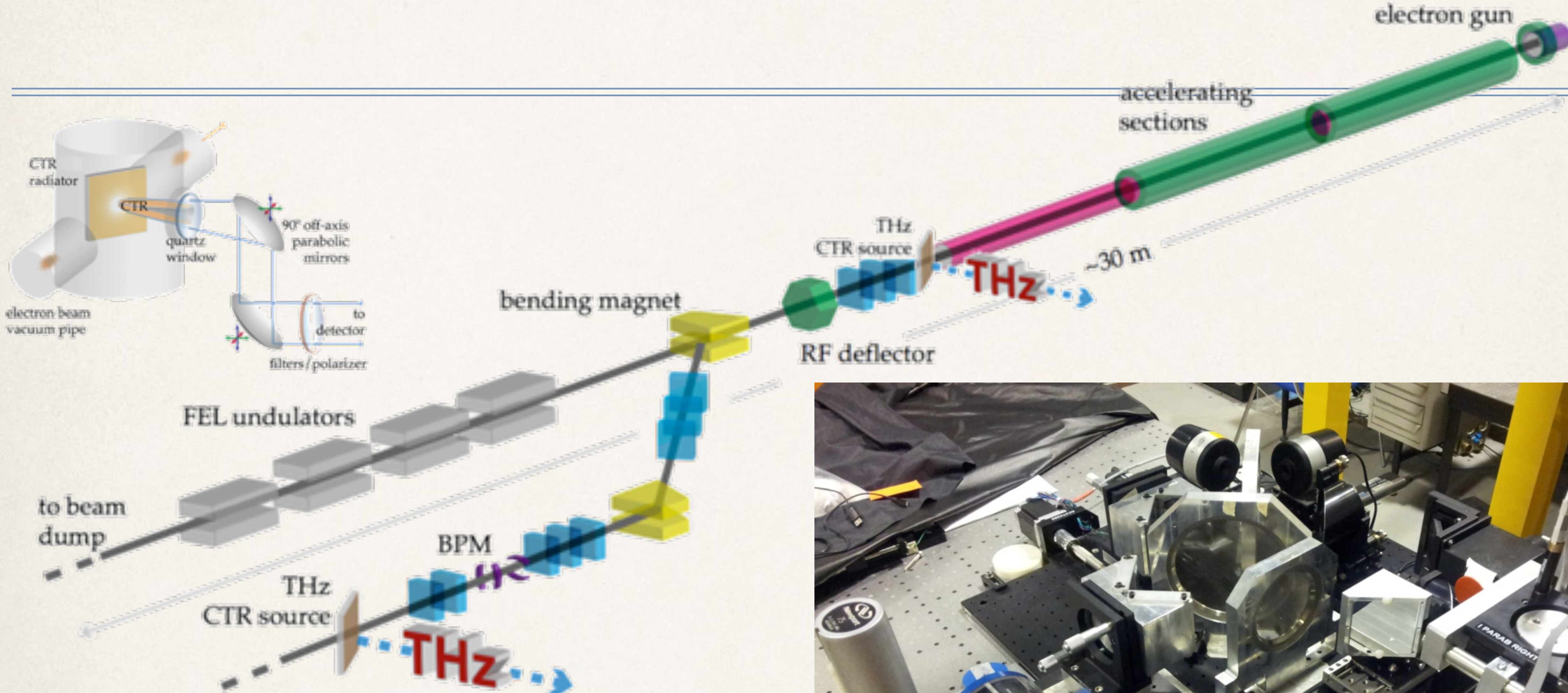


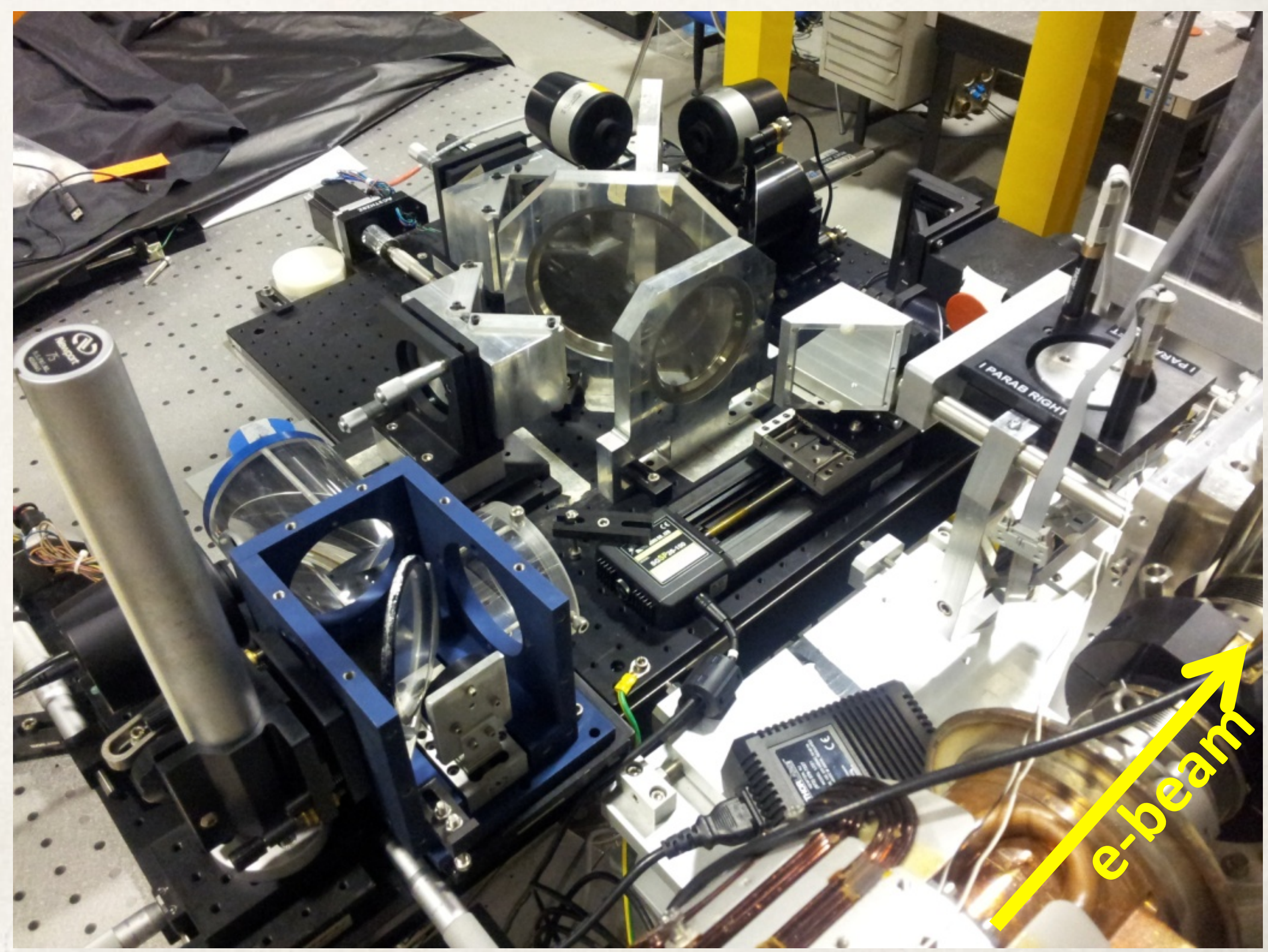
Fig. 1. Evolution of a six bunches electron beam train: the columns from left refer, respectively, to (a) the cathode, (b) the end of the drift at 150 cm and (c) the end of linac at 12 m far from cathode. The rows from top refer, respectively, to longitudinal profile and to energy modulation ΔE (MeV).

Train Evolution along the linac as function of the compression phase



The SPARC_LAB THz Source





Two stations are dedicated to THz applications and electron beam longitudinal diagnostics by measuring the autocorrelation function of CR through either Martin-Puplett or Michelson interferometer

Detection Apparatus

- The experimental apparatus for detecting the frequency spectrum consists of
  - a set of customized band-pass mesh filters placed in front of a either Golay cell or pyroelectric detectors

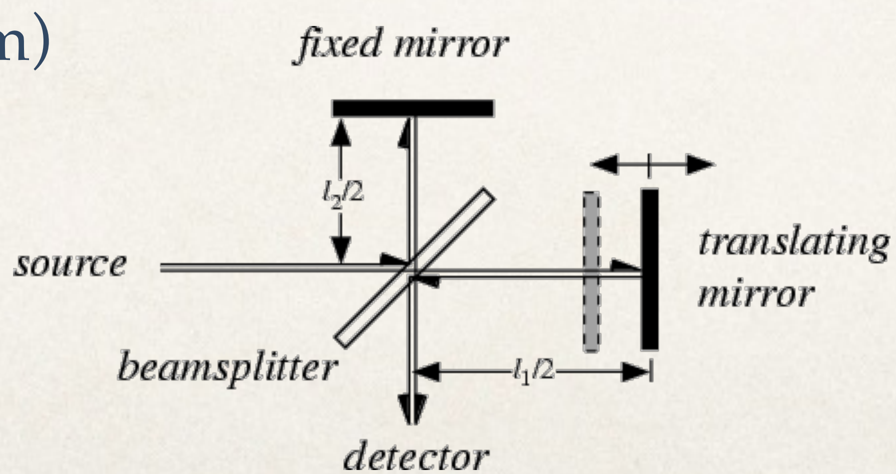
Pyrodetector

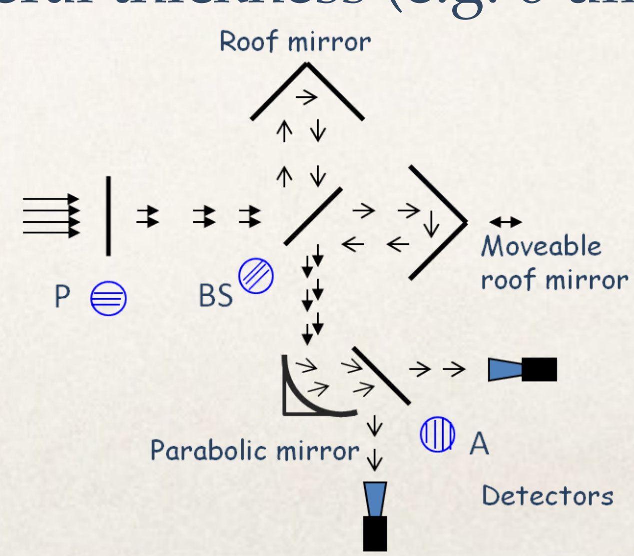
Operating spectral range: 0.1 – 30 THz
Active element: ø 2 mm
R ~ 140 kV/W
NEP@20 Hz ~ $4\ 10^{-10}$ W/Hz$^{0.5}$

Golay detector

Operating spectral range: > 40 GHz
Active element: ø 6 mm
R ~ 35 kV/W
NEP@20 Hz ~ 10^{-10} W/Hz$^{0.5}$

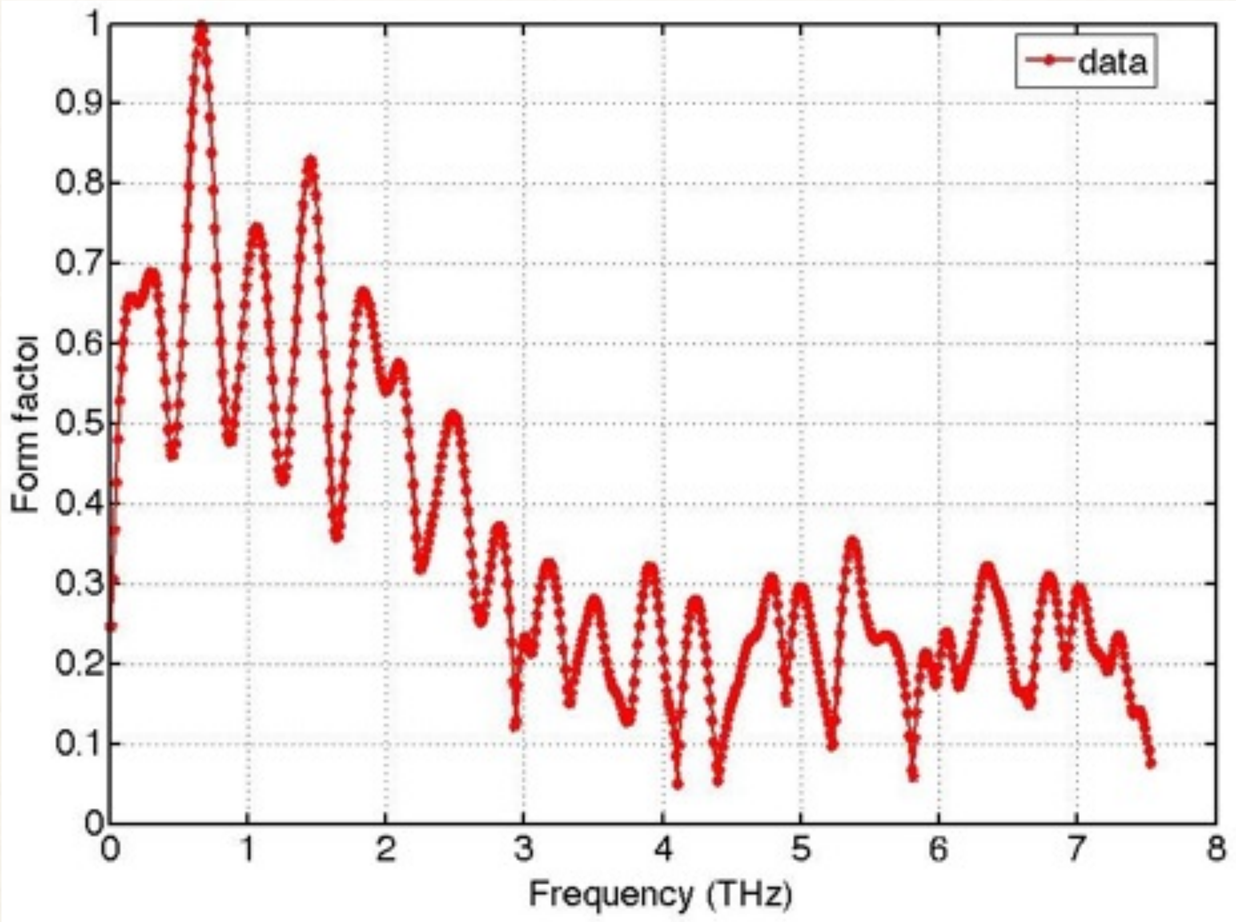
  - a Martin-Puplett interferometer, with wire grids to select polarizations
  - a Michelson interferometer with a Mylar BS of several thickness (e.g. 6 um, 12 um, 24 um)



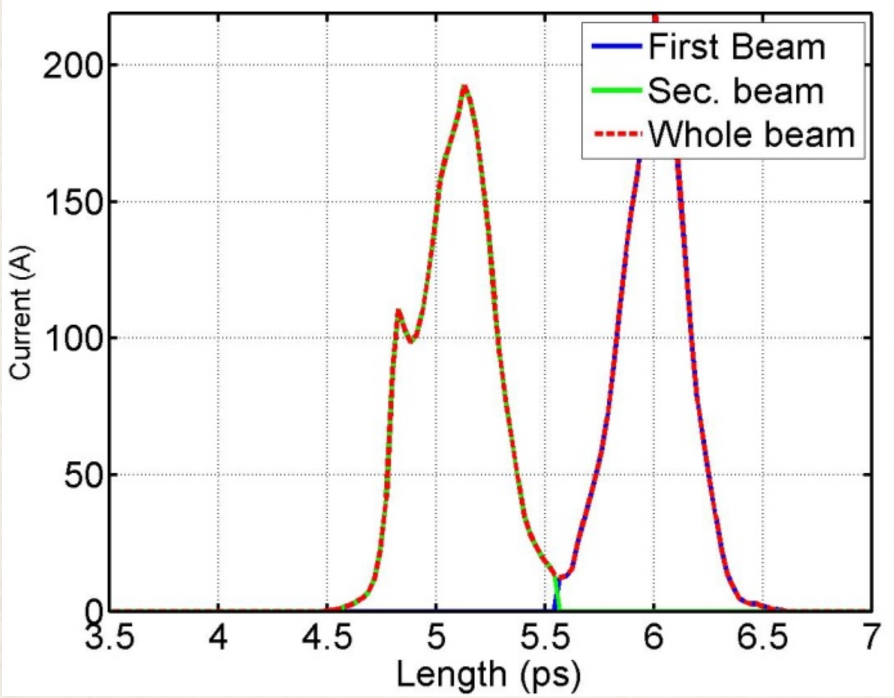


Figures of Merit: Broad-band

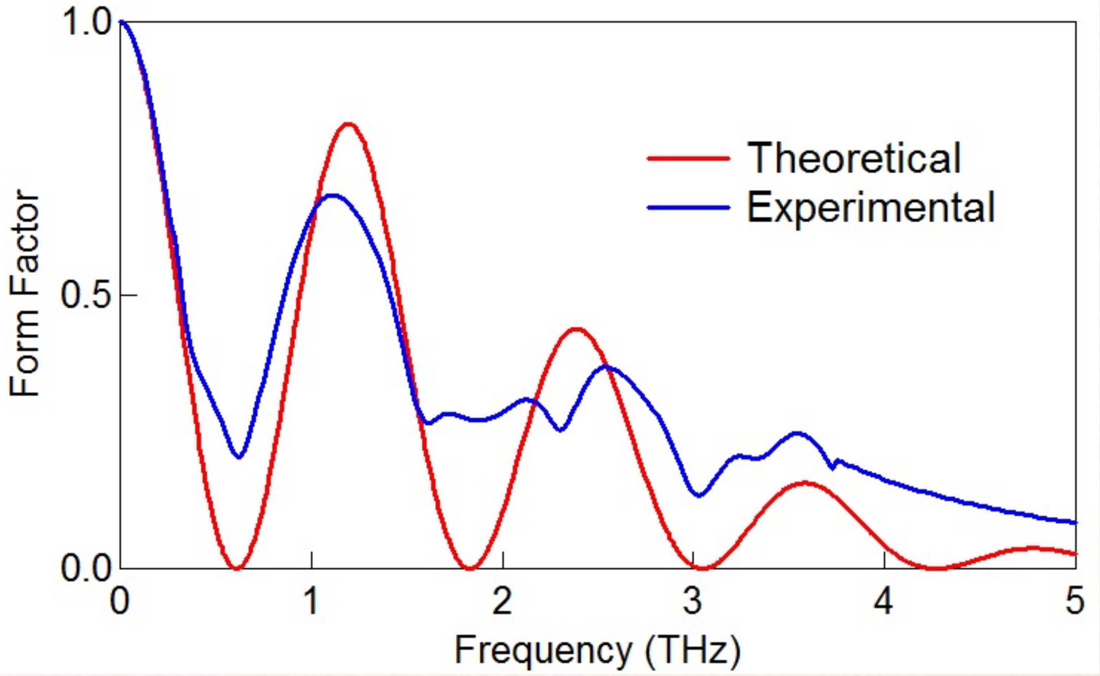
THz radiation parameters	
Energy/pulse (uJ)	25
Electric field (MV/cm)	>1.3
Pulse duration (fs)	~100
Bandwidth (THz)	0.3 - 7

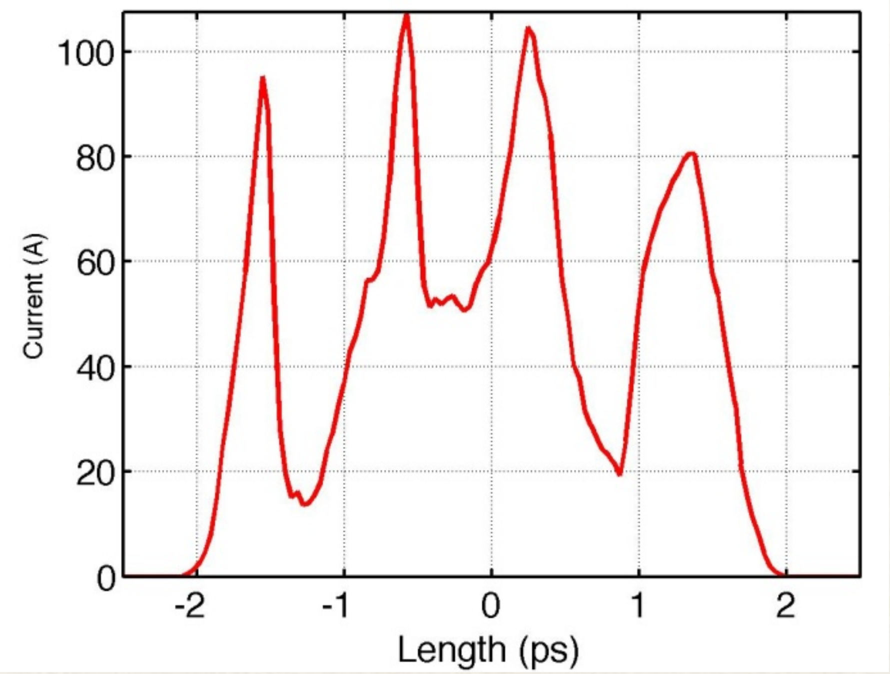


Figures of Merit: Narrow-band

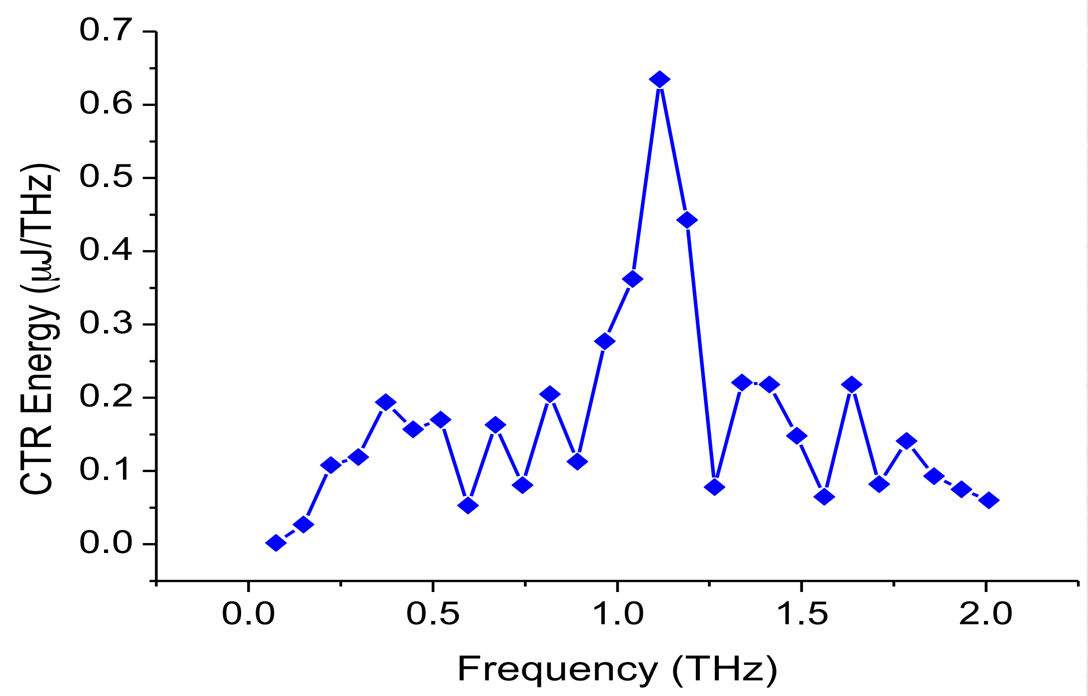


Electron beam parameters	
Energy (MeV)	122
Charge (pC)	160
RMS bunch 1 length (fs)	150
RMS bunch 2 length (fs)	165
Time distance (ps)	0.91 (0.019)





Electron beam parameters	
Energy (MeV)	110
Charge/bunch (pC)	50
RMS single bunch length (fs)	200



Scientific Case

- **Coherent radiation from sub-ps, high brightness electron beams**
  - as a **powerful longitudinal diagnostics** of electron bunches that drive FELs, plasma-based accelerators
  - as an **intense source of THz radiation** for
    - **ultra-fast and non-linear phenomena**
      - Peak electric fields greater than 1-10 MV/cm
    - **THz pump - THz probe experiments**

Conclusions

- **SPARC_LAB is a test bench for advanced high brightness beam applications**, e.g. novel FEL schemes, high peak power THz radiation production, x-ray generation via Thomson back-scattering, advanced plasma-based acceleration techniques

- **Coherent THz radiation is currently produced and optimized at SPARC_LAB** through ultra-short relativistic beams

- **Different THz emission regimes** have been achieved by properly control electron bunch shaping, length, charge, therefore **by properly set photo-injectors parameters**

- **First, successful, users experiments have been performed** showing the SPARC_LAB THz source is strongly competitive for spectroscopic applications in non-linear physics and pump-probe experiments

Acknowledgment

- All of you for the attention
- SPARC_LAB houses a dedicated INFN-funded experiment in collaboration with the Univ. of Rome La Sapienza and CNR/IFN
  - S. Lupi and F. Giorgianni (Phys. Dept. University of Rome "La Sapienza")

References

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