The 1st International Particle Accelerator Conference
Kyoto, Japan / May 23-28, 2010

Characterization of the THz source at SPARC

ABSTRACT

The region of the spectrum from 0.1 to 10 THz is of great interest for both longitudinal electron beam diagnostics and time and frequency resolved spectroscopy, synchronized pump-and-probe FEL experiments, ...

A linac-driven THz radiation source is currently produced at SPARC as Coherent Transition Radiation (CTR) emitted by both an ultra-short high-brightness electron beam (HBEB) and a longitudinally modulated beam.

Enrica Chiadroni

(INFN-LNF)

on behalf of the SPARC collaboration

OUTLINE

- → INTRODUCTION
  - → The SPARC FEL project
  - → WHY a THz radiation source at SPARC
- → BRIEF OVERVIEW ON COHERENT RADIATION THEORY
- → THE THz RADIATION SOURCE AT SPARC
  - → CTR from ultra-short high-brightness electron bunches
  - → CTR from comb beams
- → FIRST CHARACTERIZATION of the THz radiation
- → CONCLUSIONS

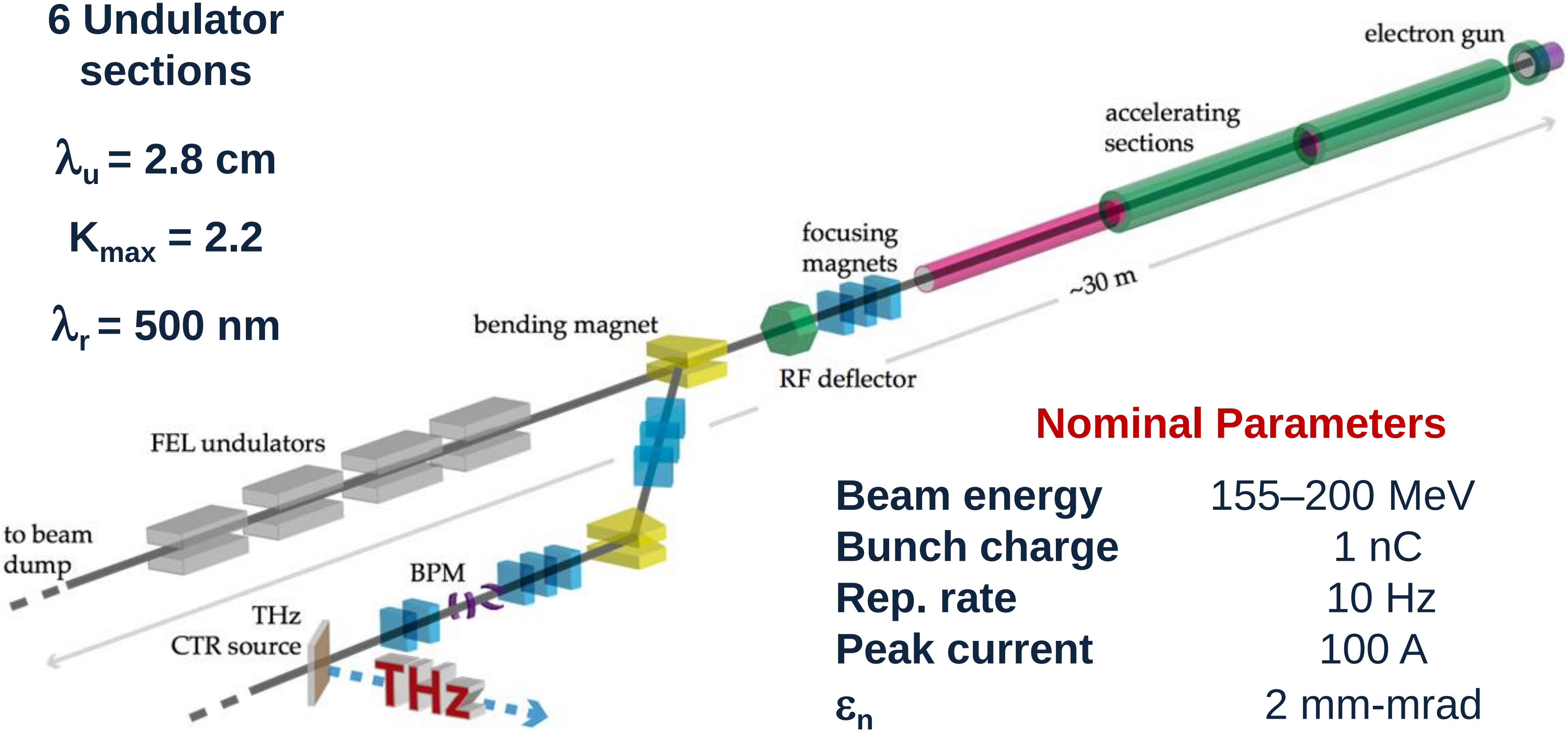
SPARC OVERVIEW

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)

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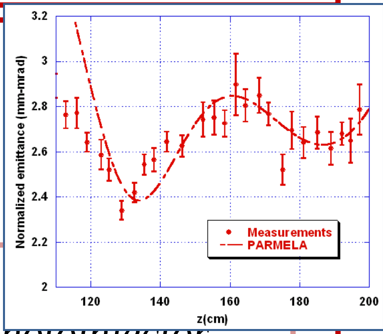
SPARC GOALS



→ **First experimental observation of emittance oscillation after the gun (working point of many LINAC driven FELs)**

M. Ferrario et al.,
"*Direct measurement of double emittance minimum in the SPARC high brightness photoinjector*",
PRL **99**, 234801 (2007)

→ **SASE FEL at 500 nm**

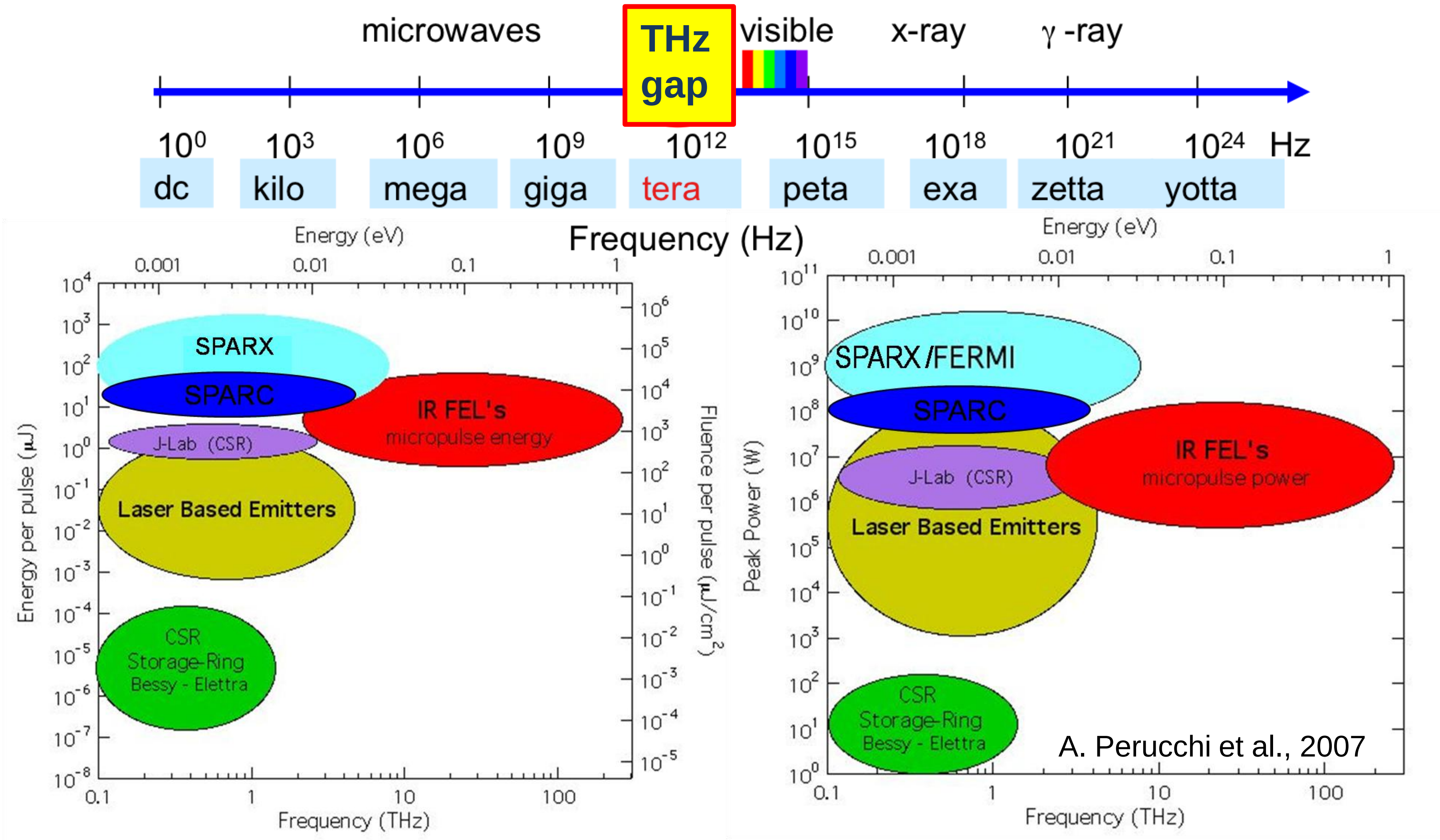
→ **Velocity Bunching with emittance compensation**

M. Ferrario et al.,
"*Experimental Demonstration of Emittance Compensation with Velocity Bunching*",
PRL **104**, 054801 (2010)

→ **Seeded FEL**

→ **THz source**

WHY A THz SOURCE @ SPARC



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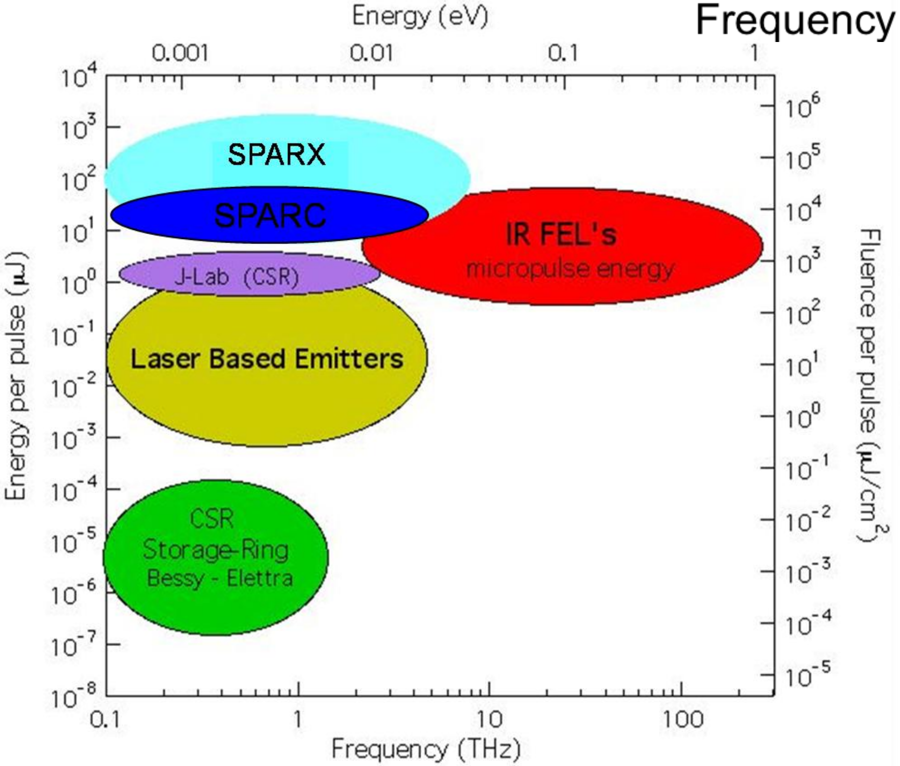
WHY A THz SOURCE @ SPARC

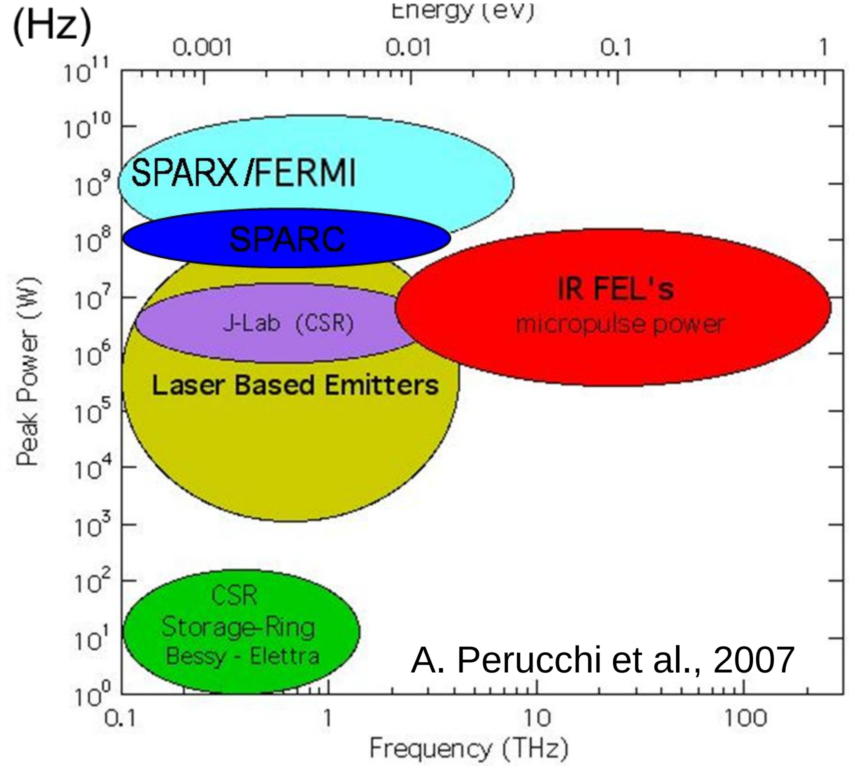
→ **SPECTROSCOPY APPLICATIONS**

→ **Frequency domain measurements on novel electronic materials**
(e.g. superconductors)

→ **Time domain non linear pump and probe spectroscopy**
(e. g. quantum wells lifetime in quantum cascade THz laser)

Frequency (Hz)





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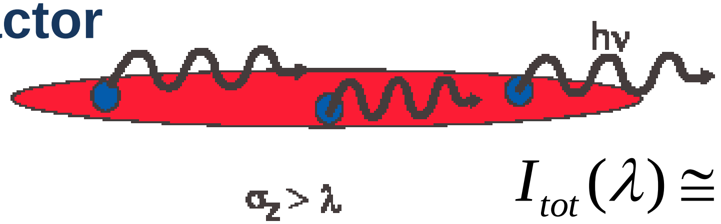
COHERENT RADIATION

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

$$I_{tot}(\lambda) = I_{sp}\left[N + N(N-1)F_{||}(\lambda) \right]$$

in which I_{sp} is the radiation intensity emitted by a single particle and $F_{||}(\lambda)$ the bunch longitudinal form factor

$$F_{||}(\lambda) = \left| \int_{-\infty}^{\infty} S(z) e^{i\frac{2\pi}{\lambda}z} dz \right|^2$$

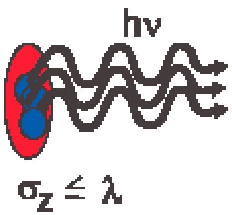


$$I_{tot}(\lambda) \cong I_{sp} N$$

Long bunch emits incoherently

The form factor is typically different from zero for wavelengths equal or longer than the bunch length.

Measuring the **coherent spectrum** it is possible to reconstruct the **bunch length** and even its **longitudinal structure**.



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

Short bunch emits coherently

THE SPARC THz SOURCE

The source is Coherent Transition Radiation (CTR) from a Silicon Aluminated screen.

BROAD BAND
(150 GHz – 5 THz) with
sub-ps high-brightness electron bunches

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RF compression: VELOCITY BUNCHING

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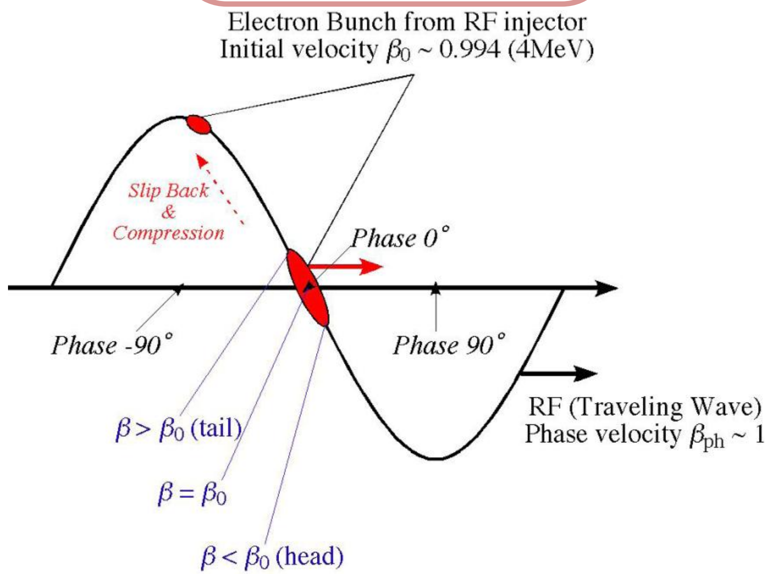
M. Ferrario et al., TUPE082



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MONOCHROMATIC
THz source with a **longitudinally modulated beam, i.e. comb beam**

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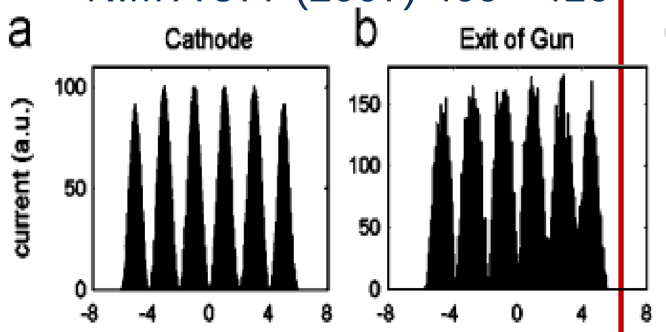
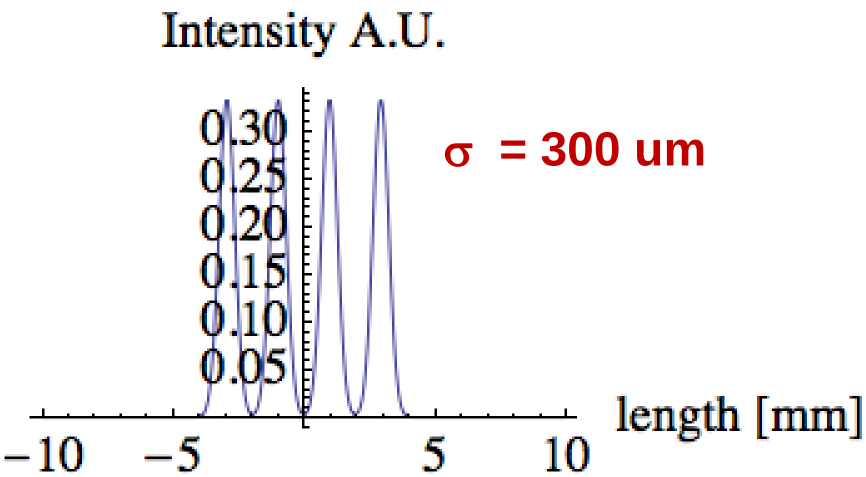
M. Boscolo et al.,
NIM A 577 (2007) 409 - 416



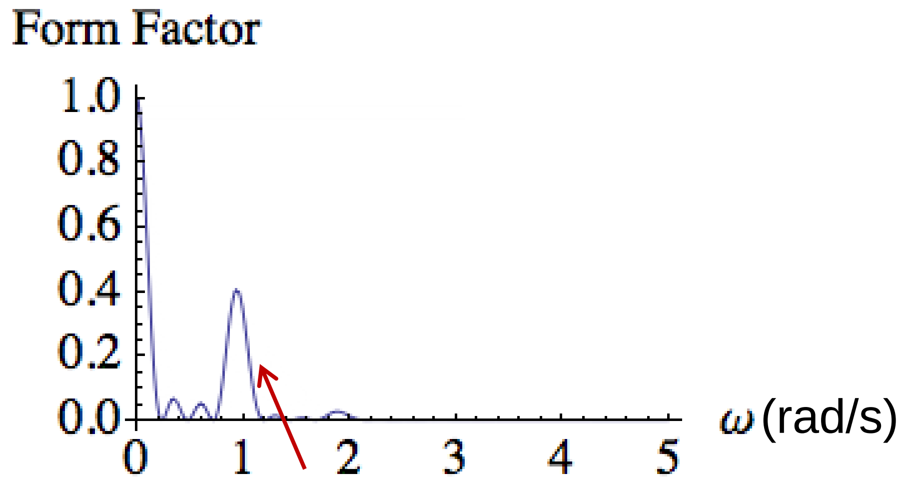
M. Ferrario et al., TUPE082

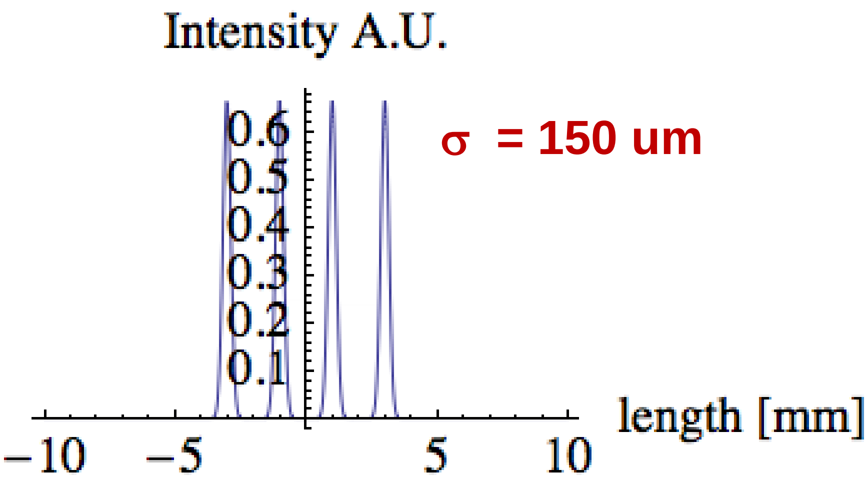
THE SPARC THz SOURCE

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



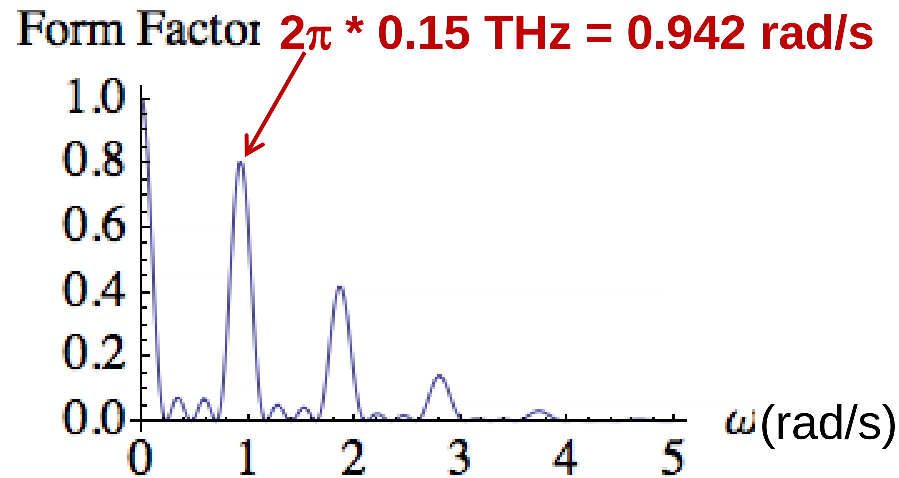
σ = 300 um





σ = 150 um

2π * 0.15 THz = 0.942 rad/s



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THE SPARC THz SOURCE

The source is **Coherent Transition Radiation** (CTR) from a Silicon Aluminated screen.

BROAD BAND
(150 GHz – 5 THz) with **ultra-short high-brightness electron bunches**

MONOCHROMATIC
THz source with a **comb beam**

TUNABLE
THz source combining **velocity bunching and comb beam**

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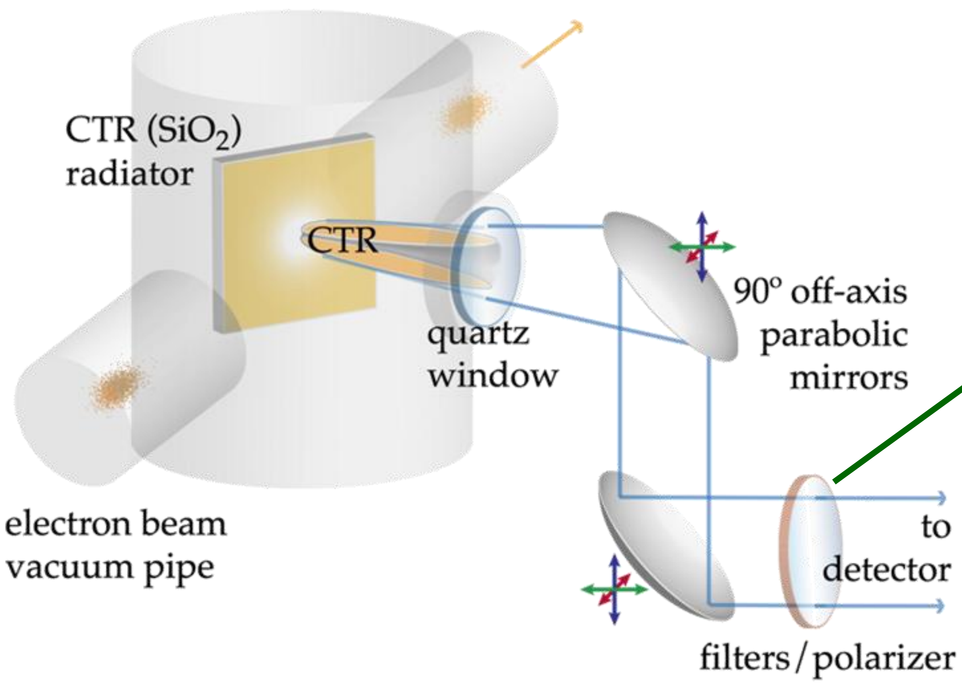
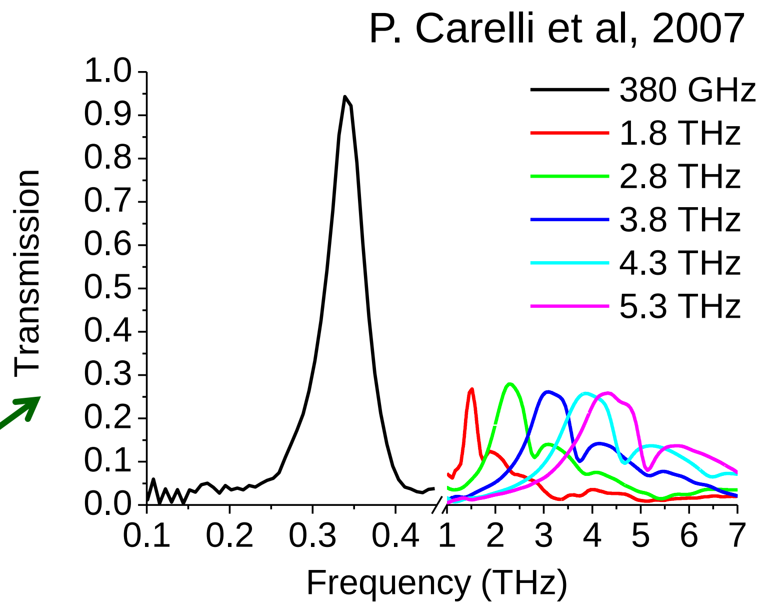
EXPERIMENTAL SET-UP





Golay cell detector

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

Pyroelectric detector

- Operating spectral range: 0.1 – 3 THz
- Active element: 2 mm x 3 mm
- NEP@20 Hz ~ 10^{-8} W/Hz$^{0.5}$

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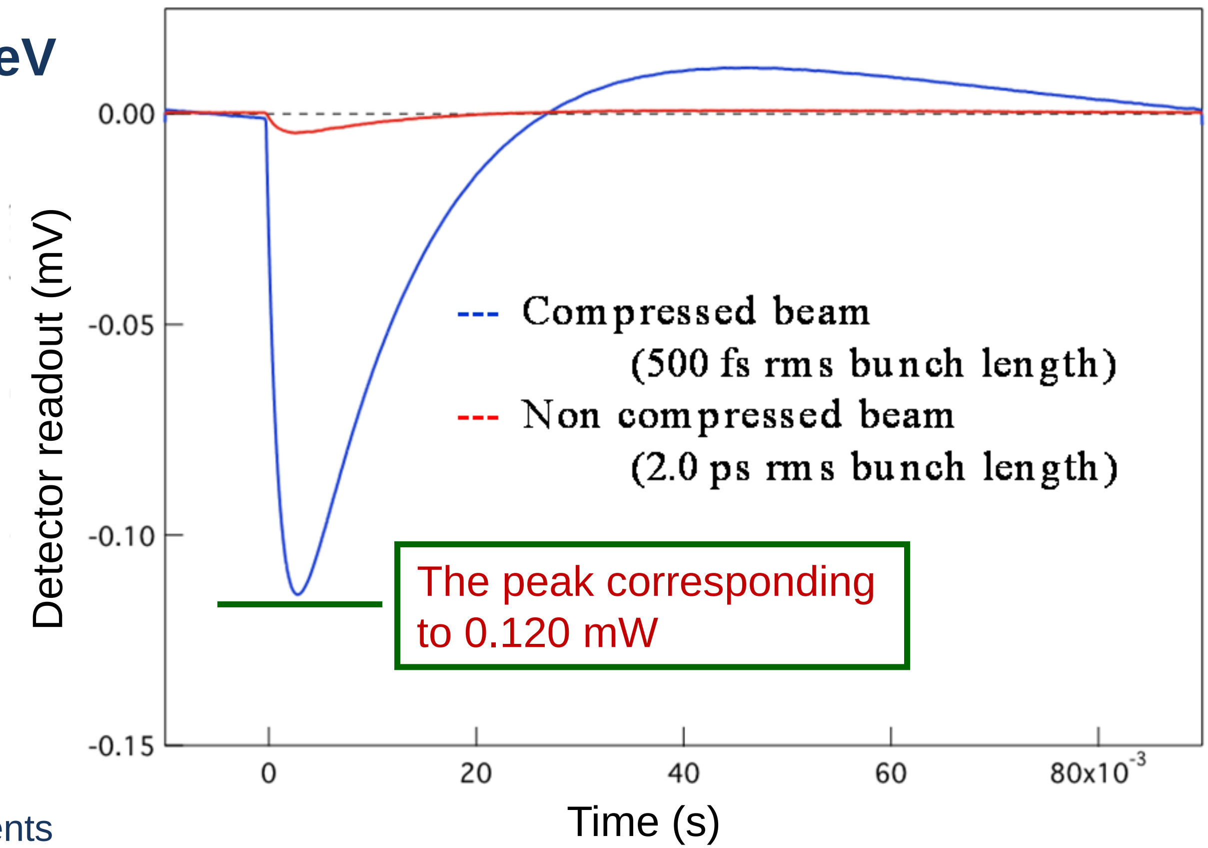
THz BROADBAND EMISSION

Q = 500 pC
σ_t = 2.0 ps **Velocity Bunching** → **σ_t = 0.5 ps**

Beam Energy= 100 MeV

A gain in the average power of a factor of 25 when a 2 ps beam was compressed by a factor 4 down to 500 fs has been measured.



Pyroelectric detector measurements

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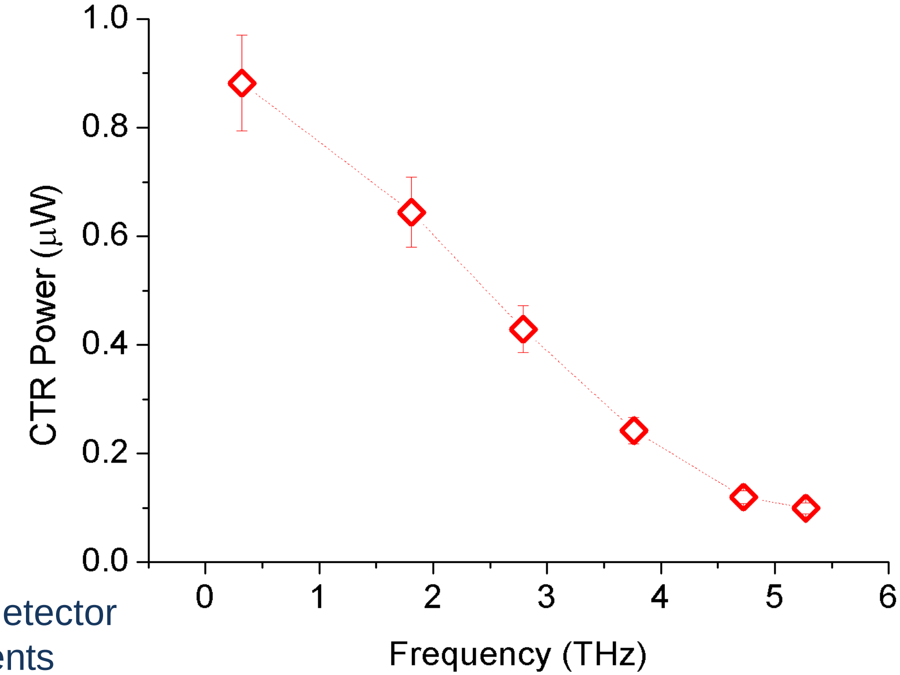
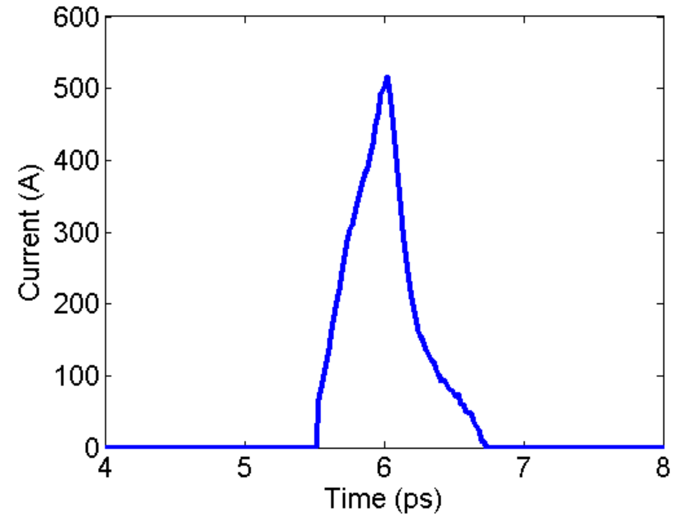
THz RADIATION FROM HBEBs

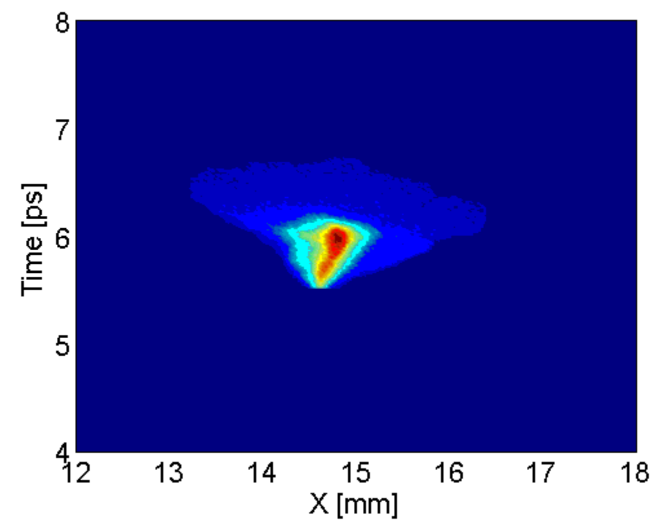
Velocity bunching with compression factor 14 and emittance compensated

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



Golay cell detector measurements





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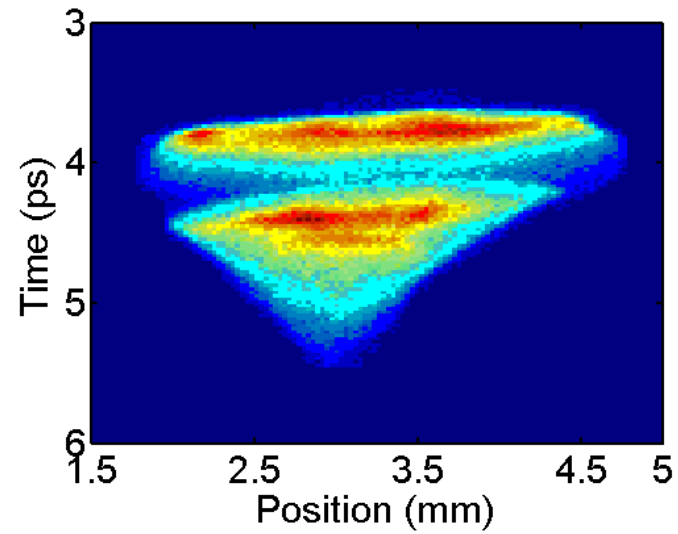
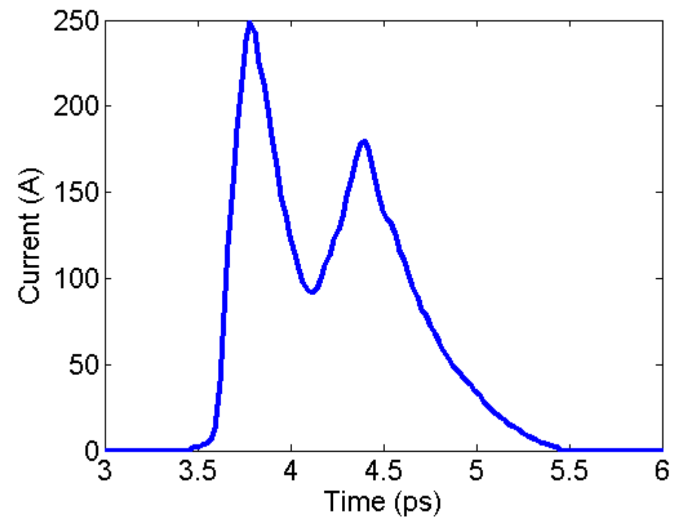
THz RADIATION FROM COMB

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





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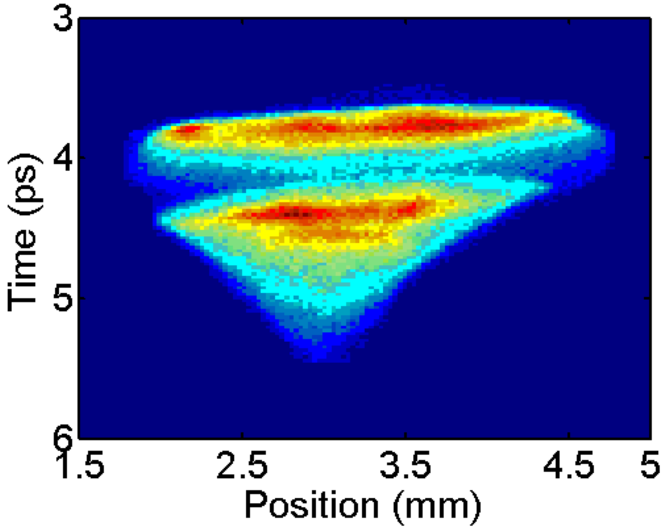

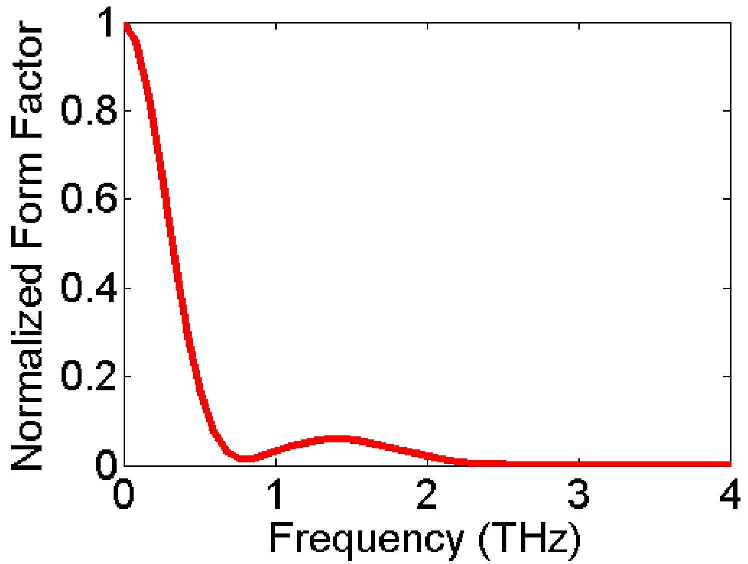

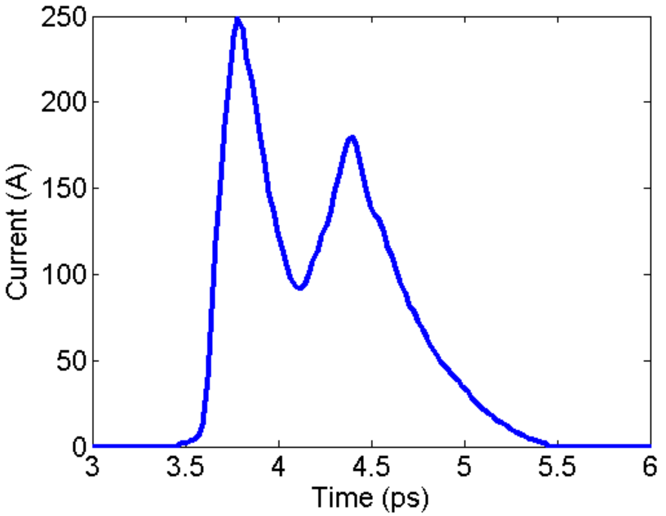

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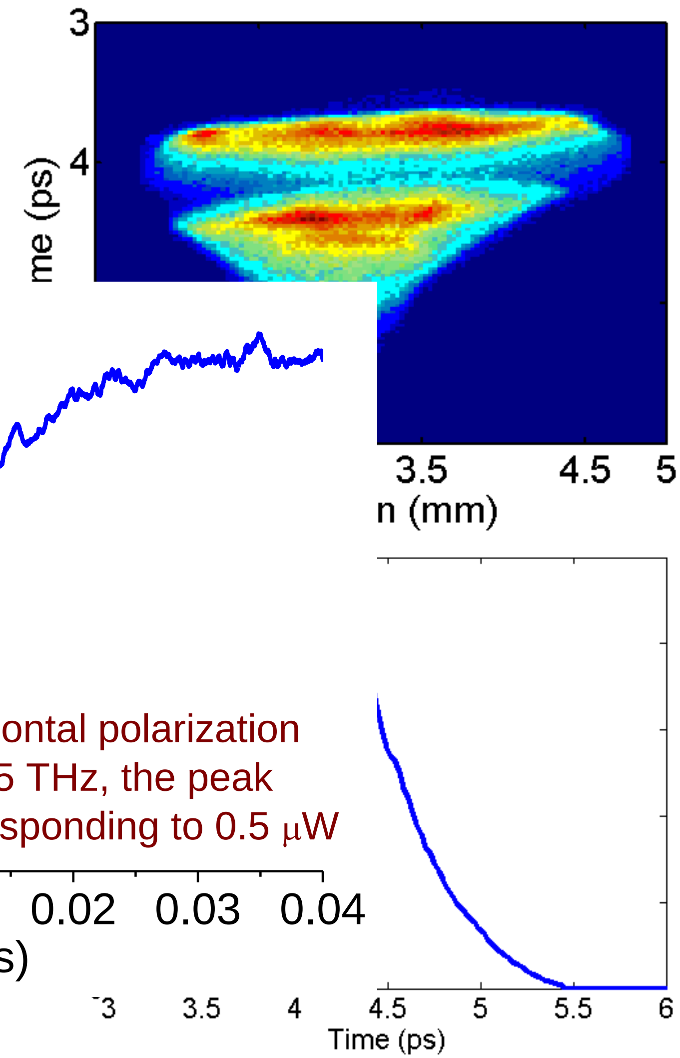

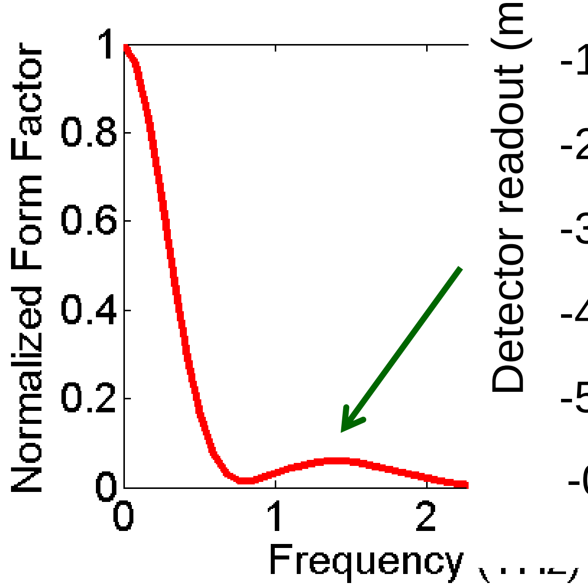

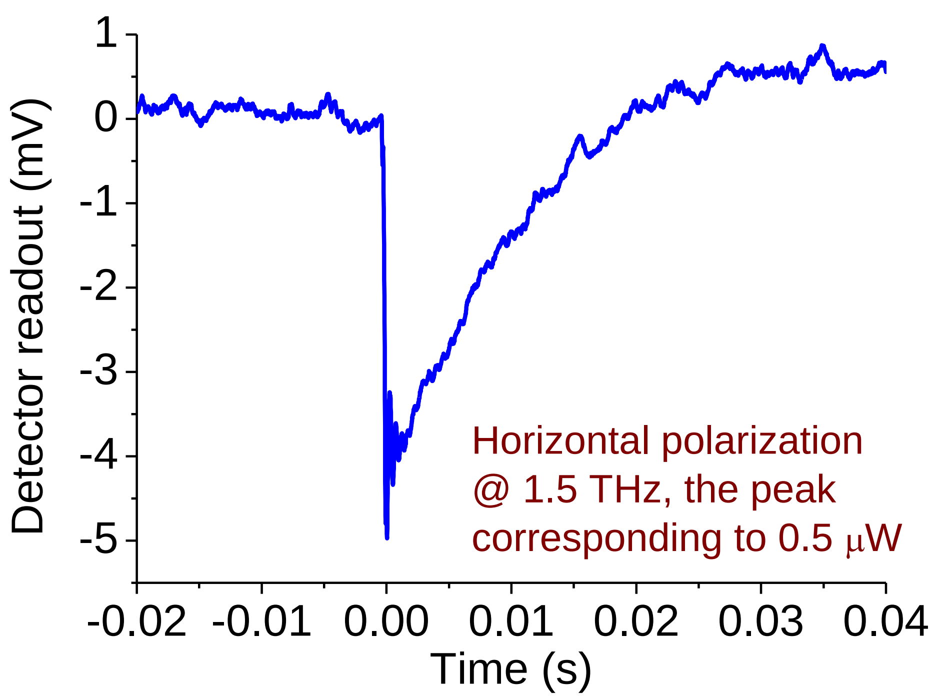

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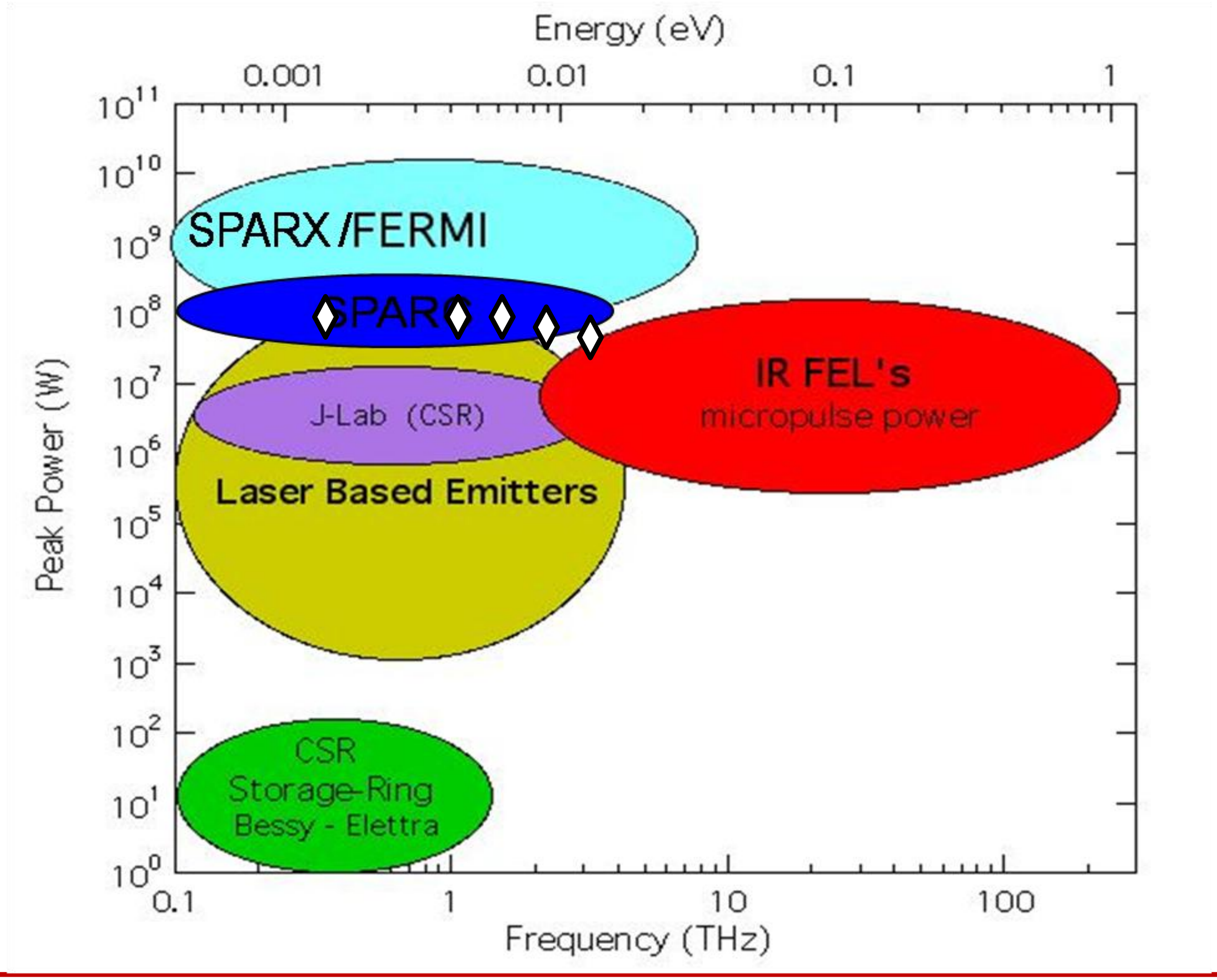
PERFORMANCE ACHIEVED



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CONCLUSIONS

→ A linac-driven high intensity THz radiation source can be produced at SPARC due to HBEB

→ Standard schemes, i.e. ultra-short HBEB, are used to generate high power broadband THz radiation

→ Novel schemes, e.g. Laser Comb, have been developed and ready to be tested in order to produce high power narrow-band, i.e. monochromatic, and tunable THz radiation

→ First experiments using THz are already planned

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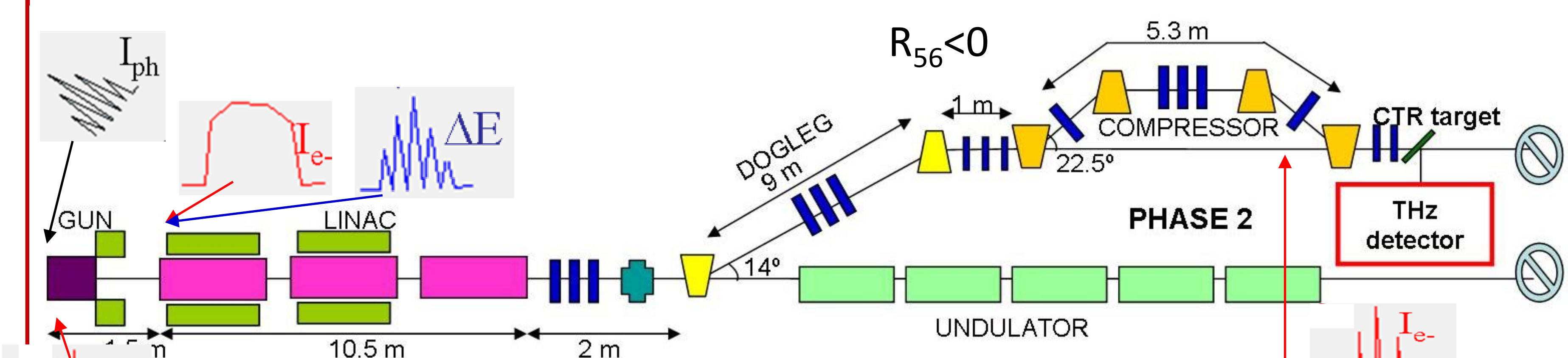

high power narrow-band, i.e. **monochromatic**, **tunable THz radiation**

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感謝