FEL oscillation with a high extraction efficiency at JAEA ERL FEL

Japan Atomic Energy Agency (JAEA) ERL group

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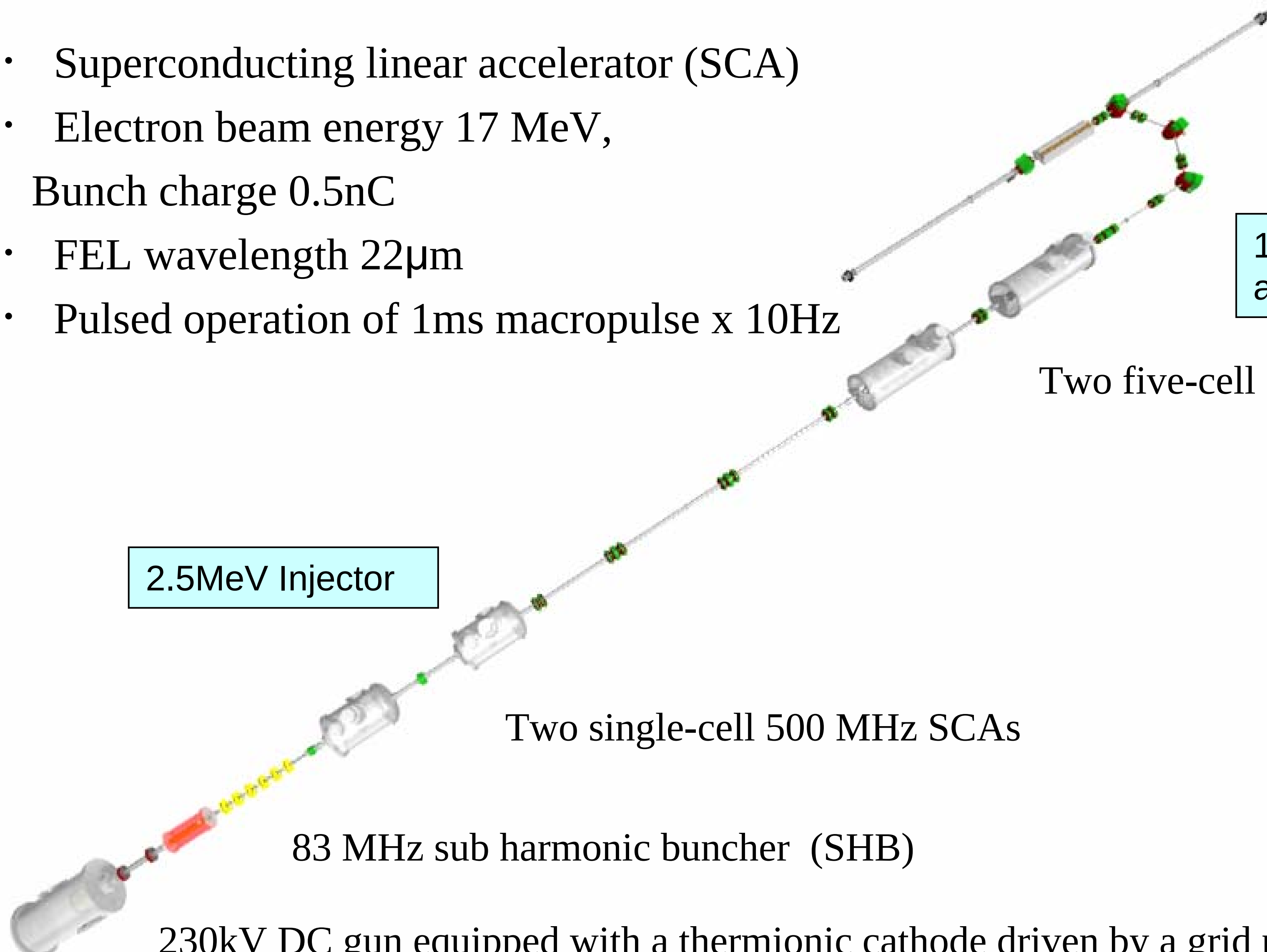
1. Configuration and recent upgrade
2. FEL efficiency measurement in the return arc
3. Magnetic bunch compression in the first arc

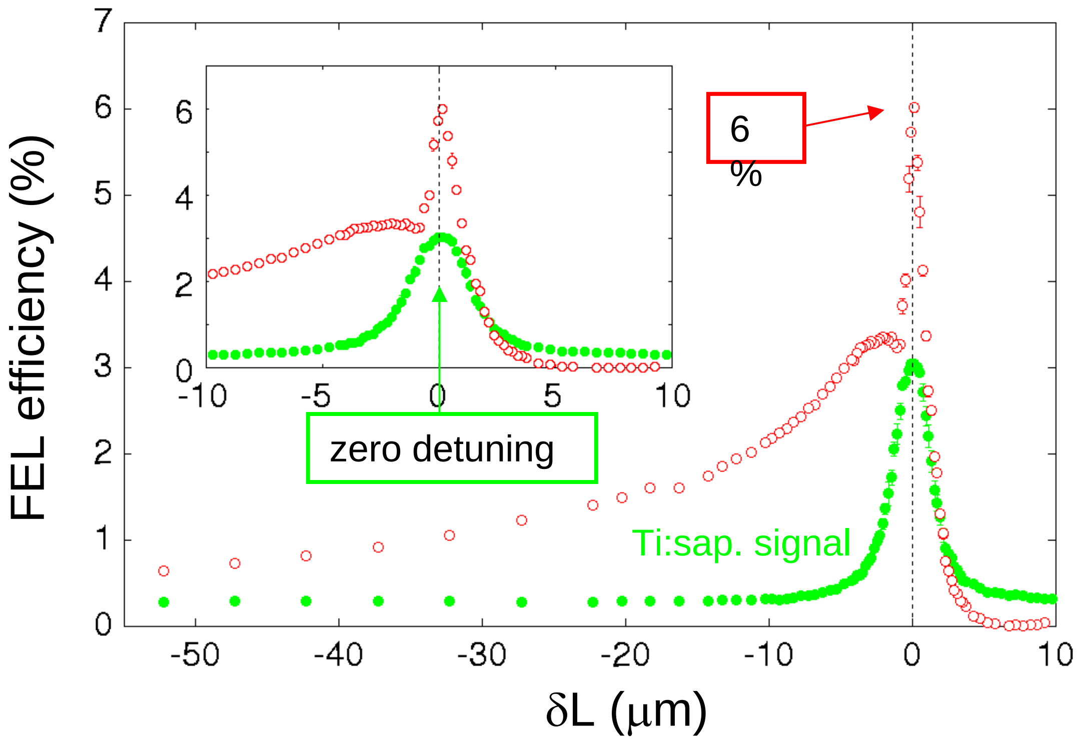
Original JAEA FEL without energy recovery

- Superconducting linear accelerator (SCA)
- Electron beam energy 17 MeV,
  Bunch charge 0.5nC
- FEL wavelength 22μm
- Pulsed operation of 1ms macropulse x 10Hz

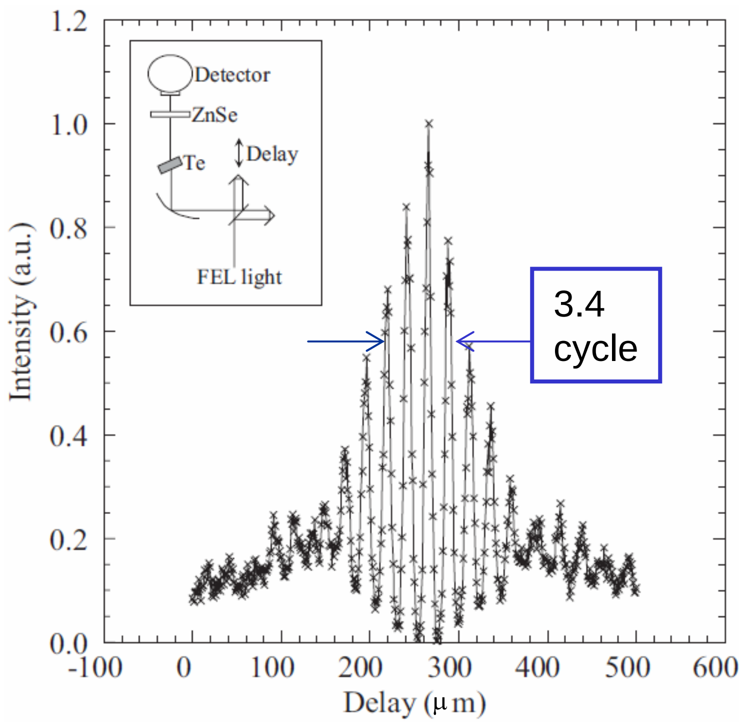


High efficiency FEL without ERL in 2001

FEL efficiency detuning curve



Autocorrelation signal

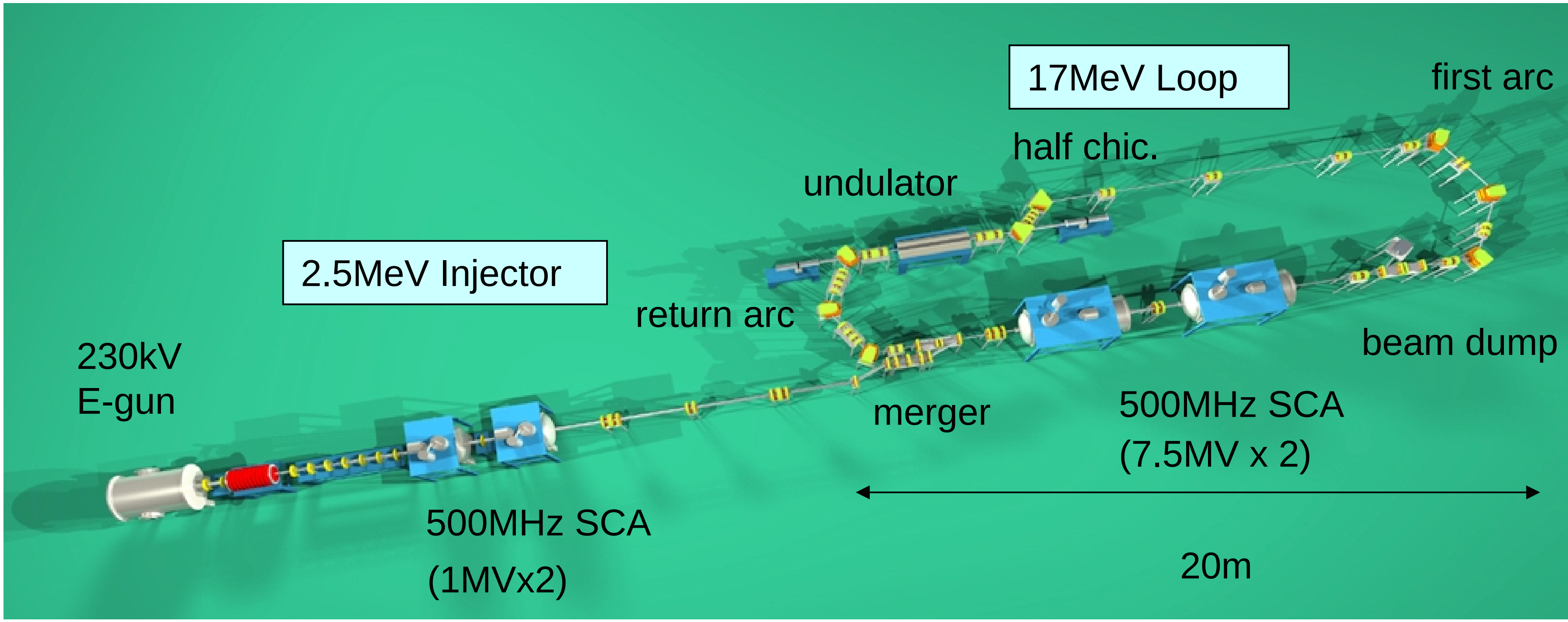


N. Nishimori et al., PRL 86, 5707 (2001).

R. Nagai et al., NIM A 483, 129 (2002).

1. achieved high FEL efficiency of 6 % .
2. observed FEL oscillation at zero detuning length of an optical cavity.
3. generated an intense few-cycle FEL pulse.

A high-power ERL FEL at JAEA



The same injector as the original JAEA FEL

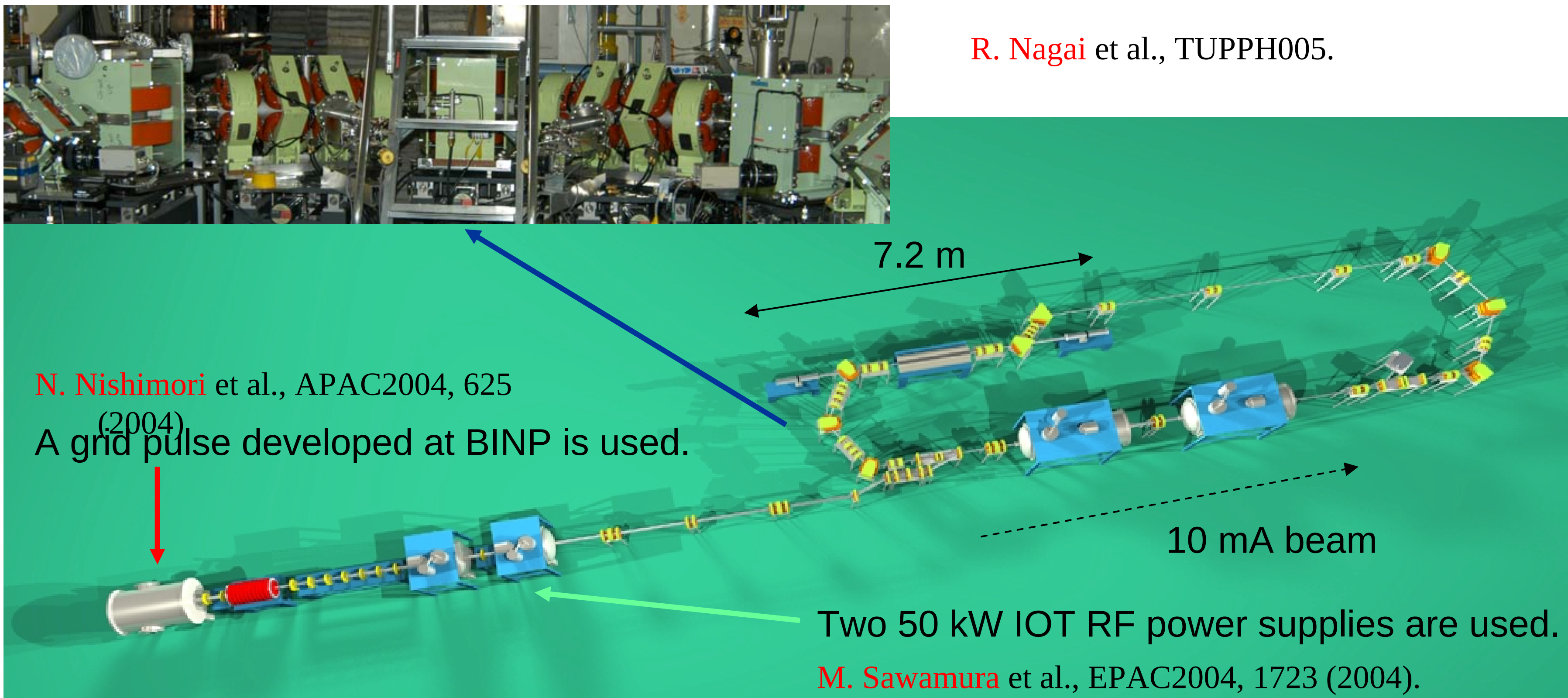
17 MeV loop consists of a merger chicane, two five-cell 500 MHz SCAs, a triple-bend achromat arc, half-chicane, undulator, return-arc, and beam dump.

First lasing in August, 2002.

R. Hajima et al., NIM A 507, 115 (2003).

JAEA ERL upgrade

1. Doubled bunch repetition rate of the gun grid pulser to 20.8 MHz
2. Increase of power supplies for injector SCAs from 8 kW to 50kW
   Improvement of low-level RF controller
3. Doubled energy acceptance of the return arc from 7% to 15%

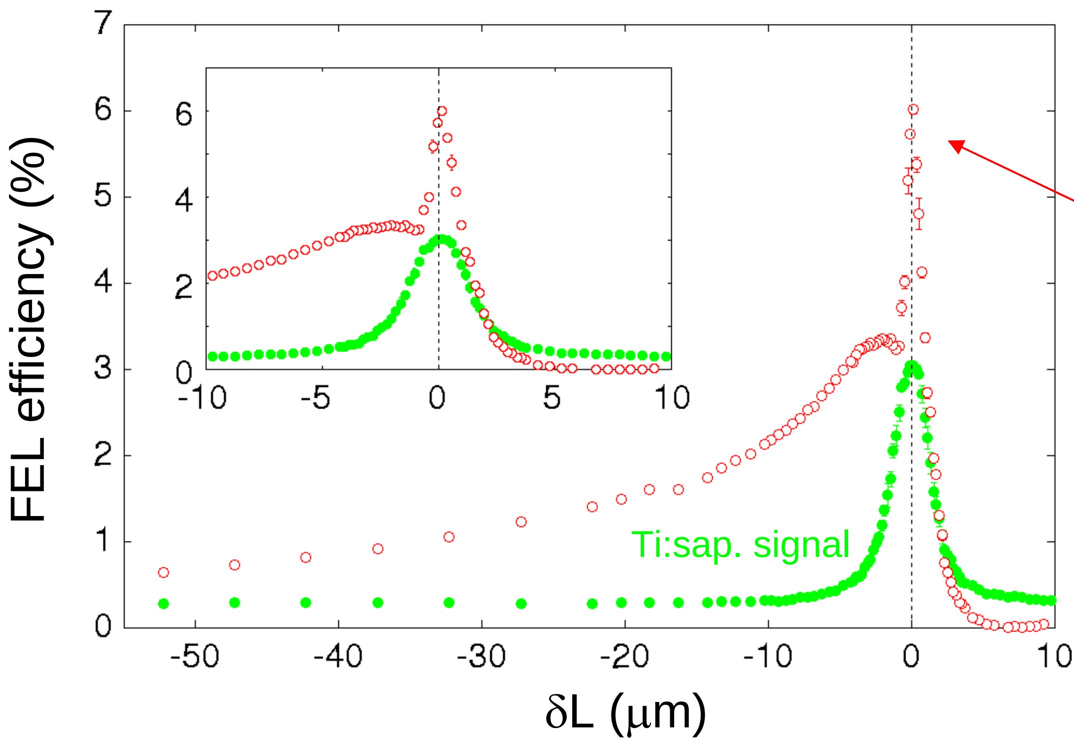


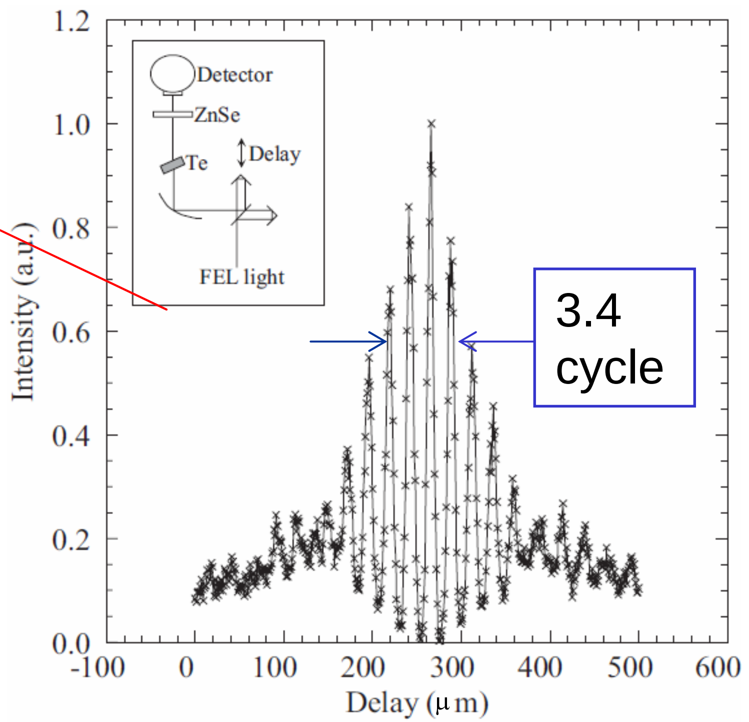
Merits of a high-efficiency FEL

$$P_{FEL} = P_{beam} \eta_{fel}$$

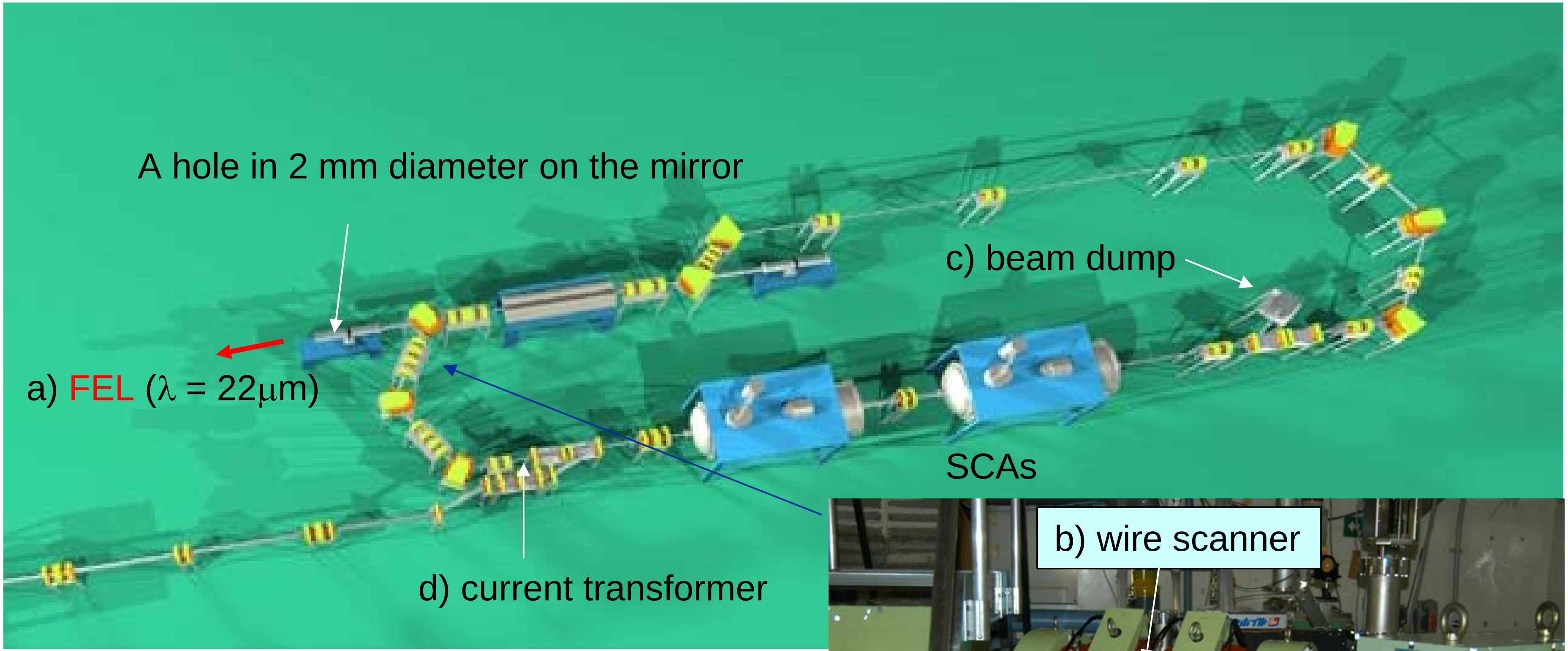
1. Saves the total beam current needed for high-power lasing.
2. Generates broadband ultrashort optical pulses.

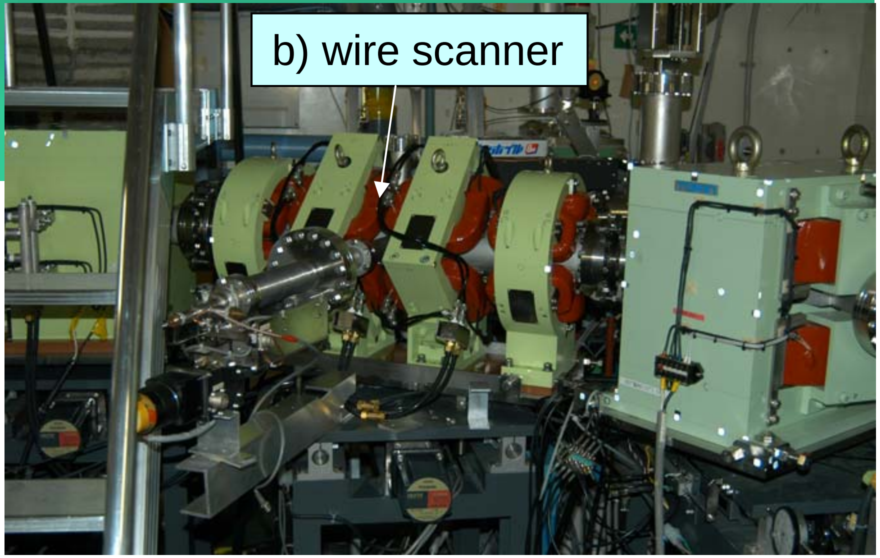
Quantum control of chemical reaciton H. Iijima et al., TUPPH002.





FEL efficiency experiment in the return arc



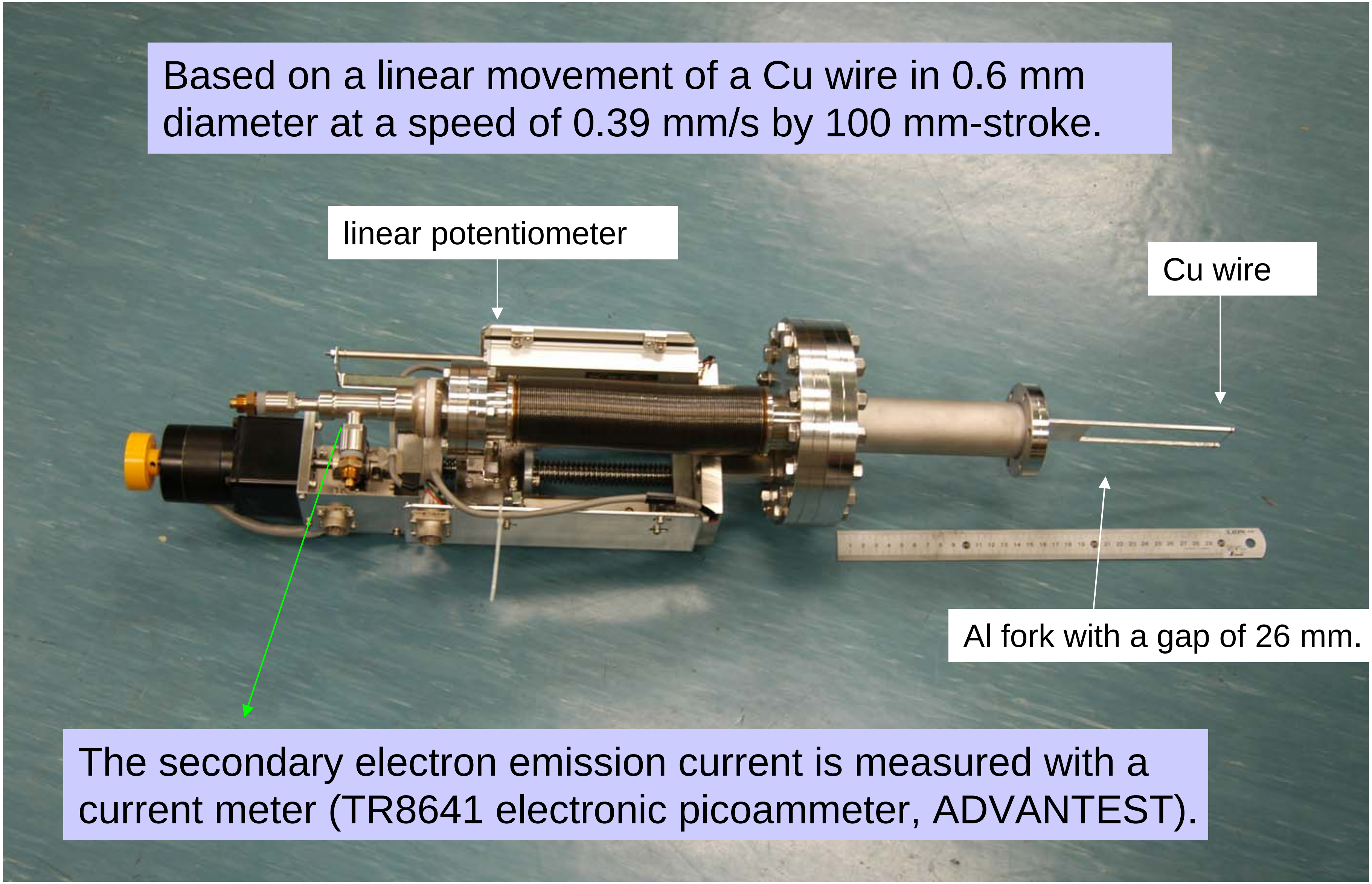


Beam profiles at a dispersive point

Non-destructive beam profile monitors.
1. Synchrotron radiation monitor
2. Beam position monitor
3. **Wire scanner**

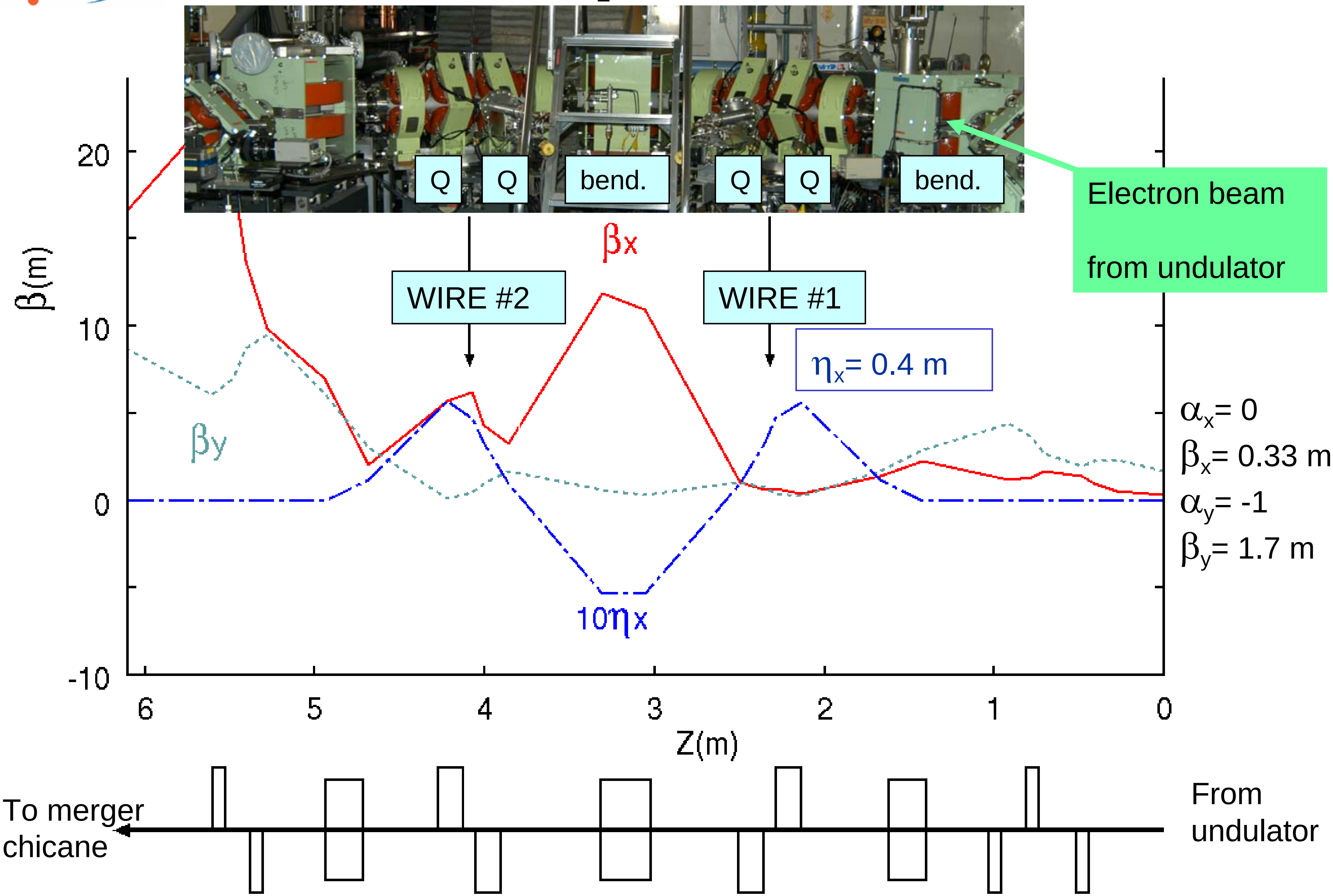
The wire scanner

Based on a linear movement of a Cu wire in 0.6 mm diameter at a speed of 0.39 mm/s by 100 mm-stroke.

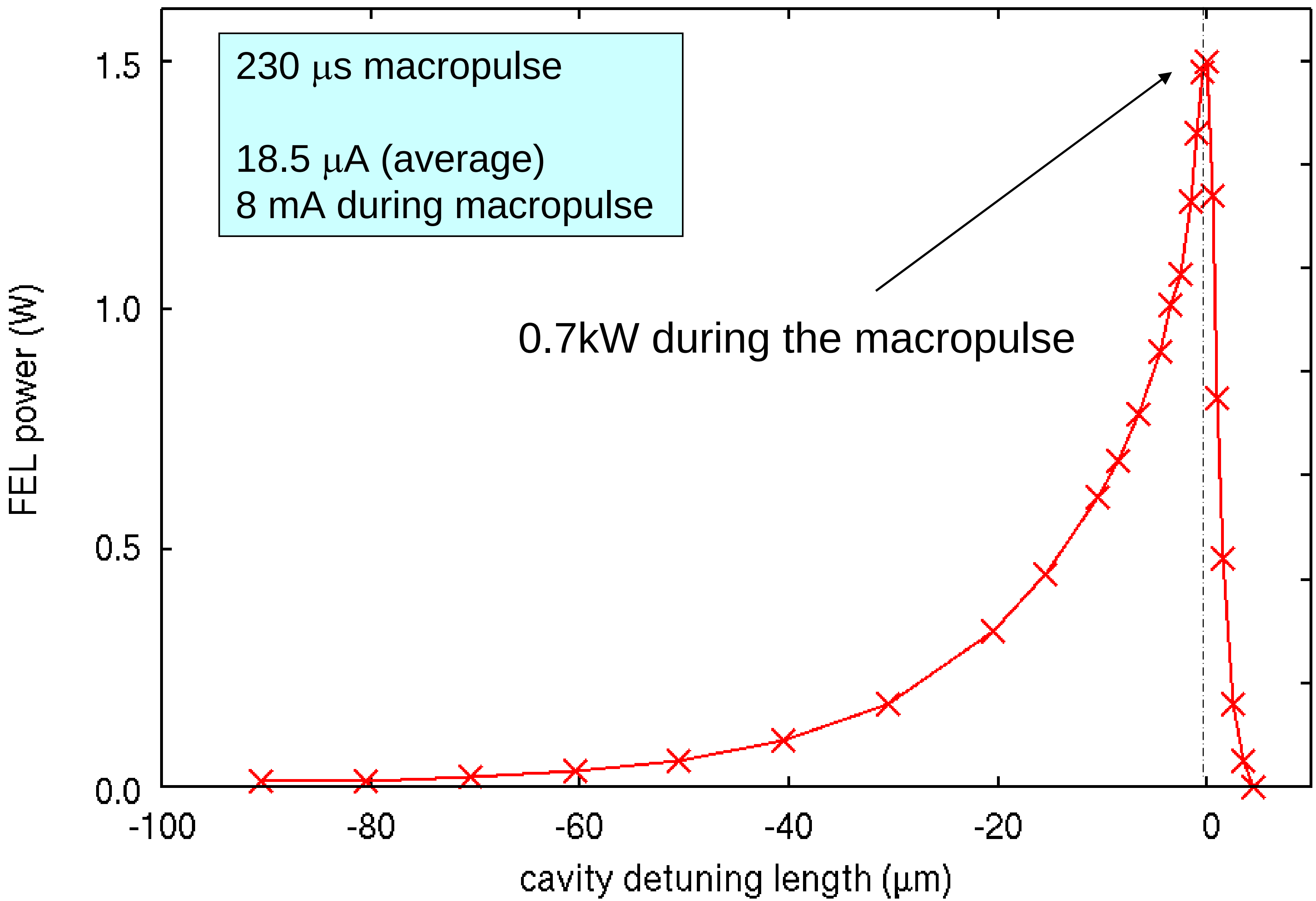


The secondary electron emission current is measured with a current meter (TR8641 electronic picoammeter, ADVANTEST).

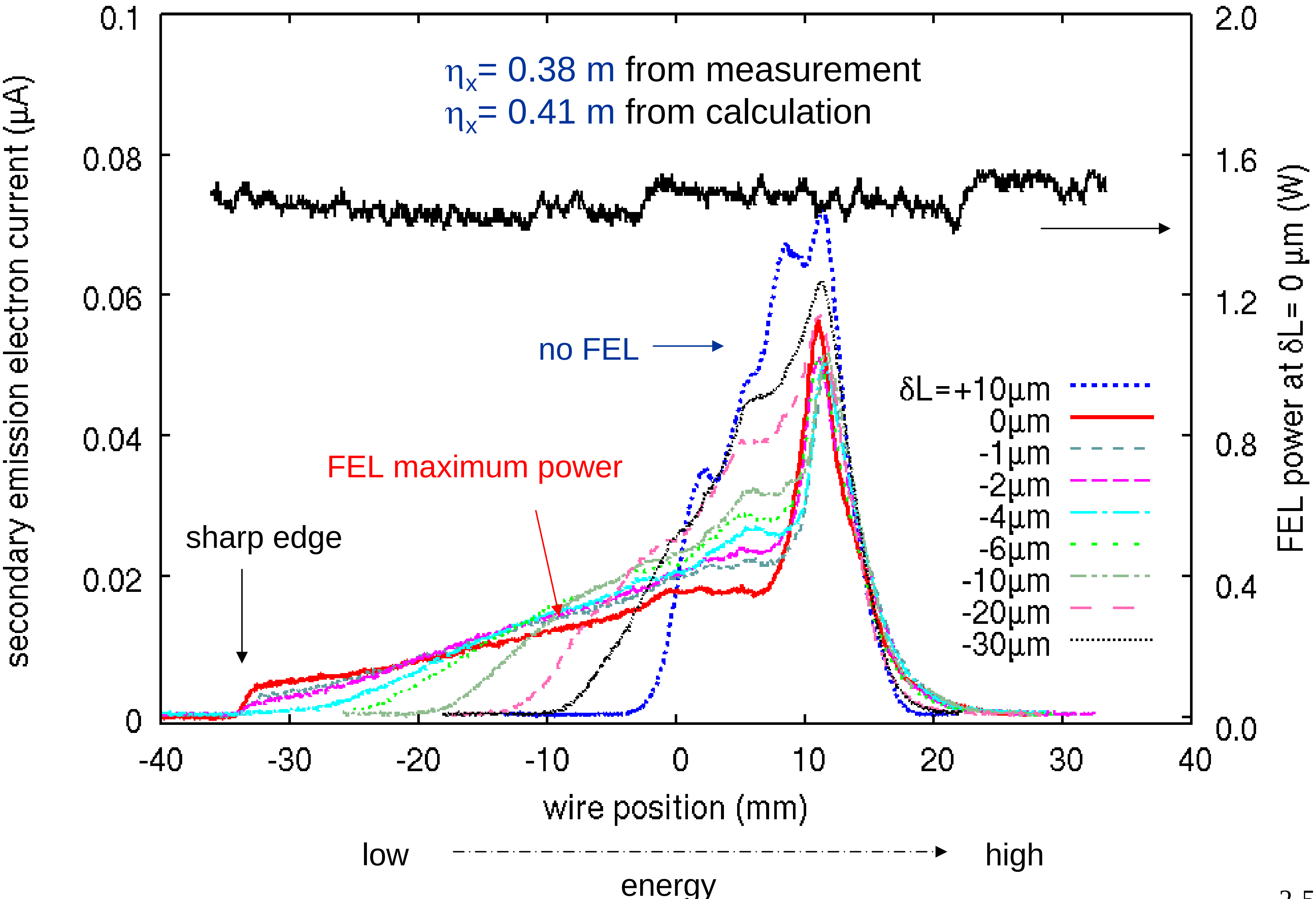
Beam envelopes in the return arc



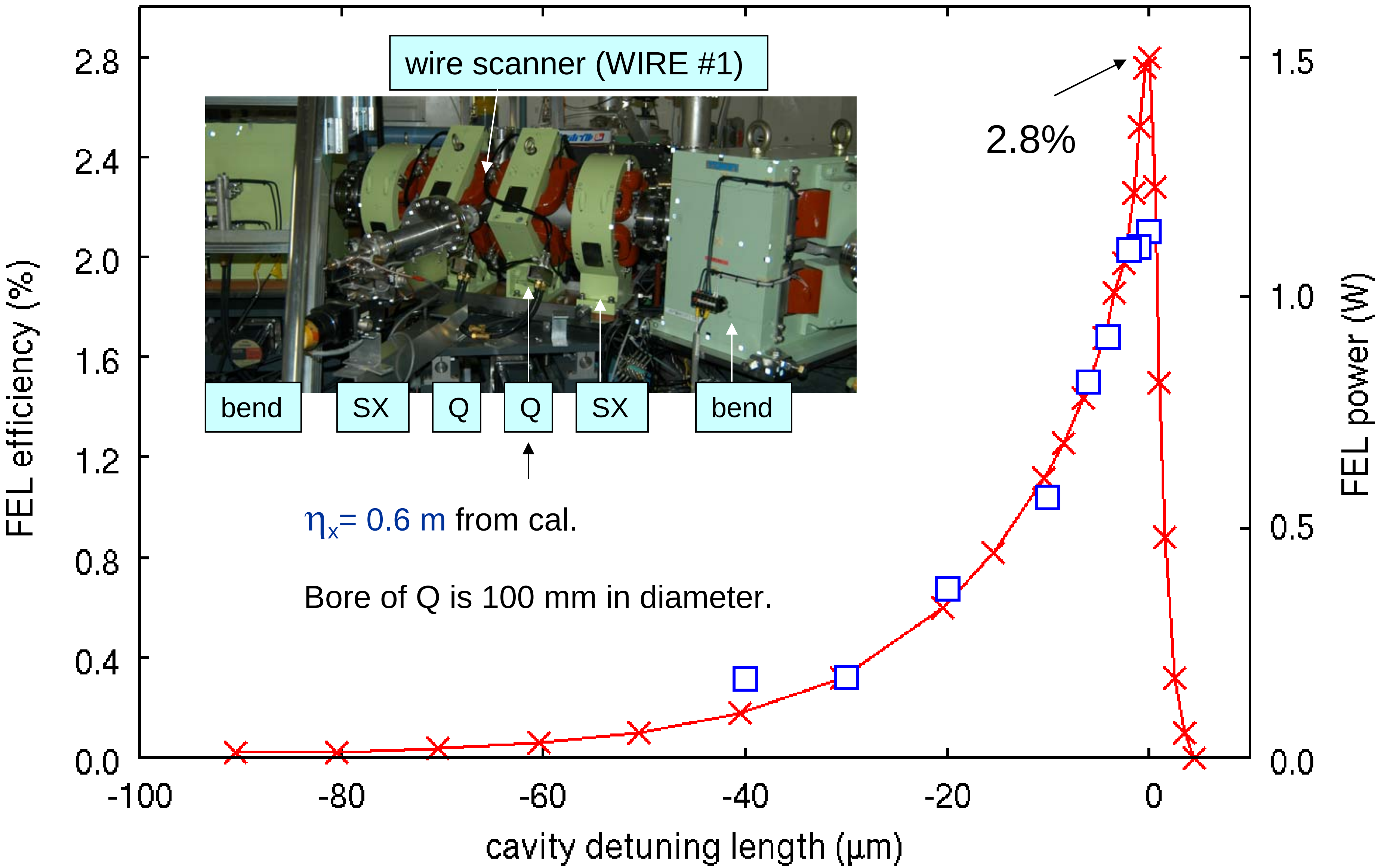
FEL power detuning curve



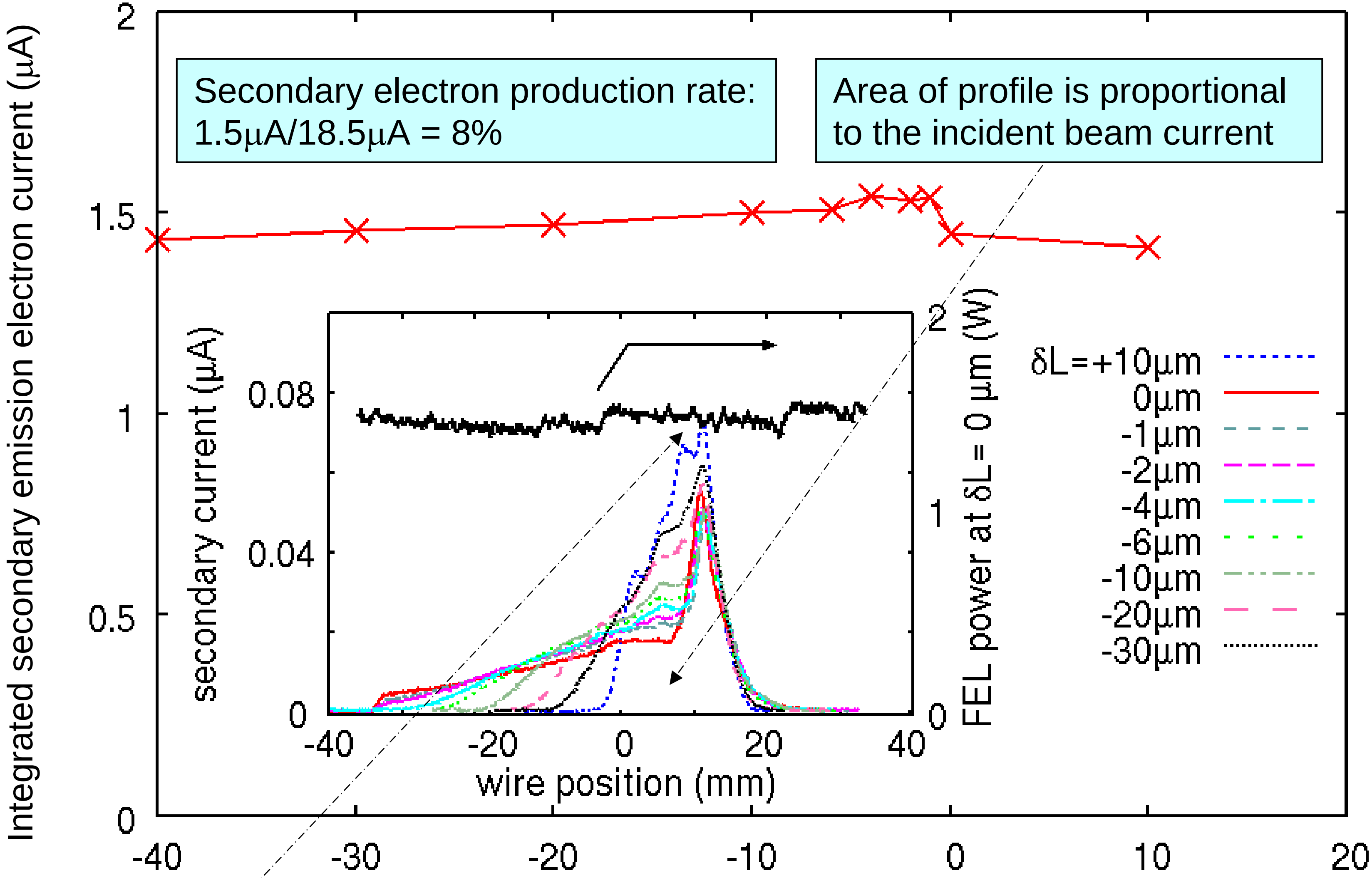
Beam profiles measured with WIRE #1



FEL efficiency detuning curve

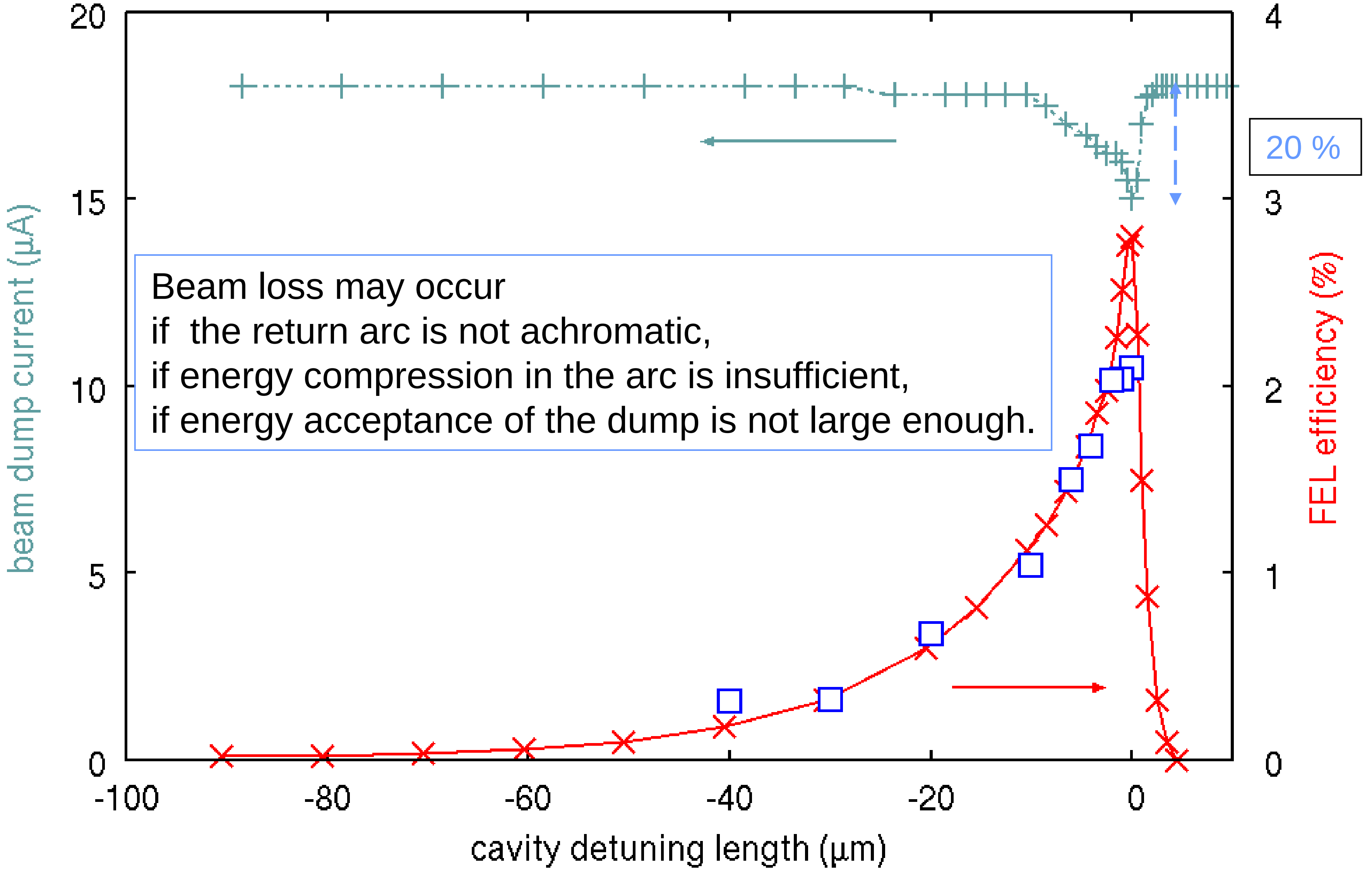


Integrated secondary emission electron current

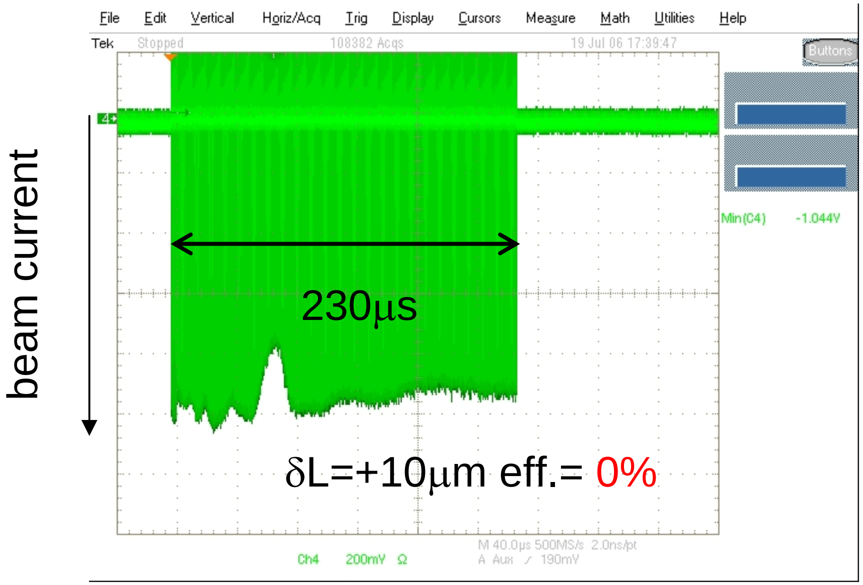


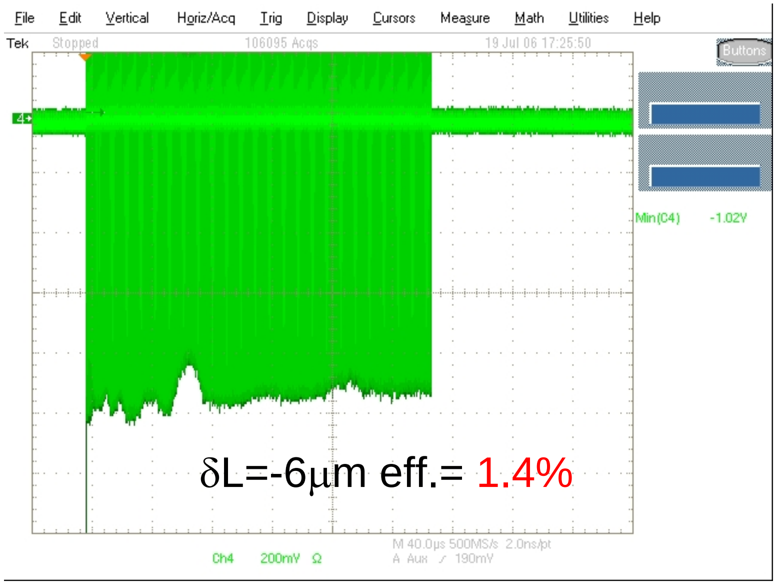
Beam loss due to the presence of wire: 0.08μA/1.5μA = 5%

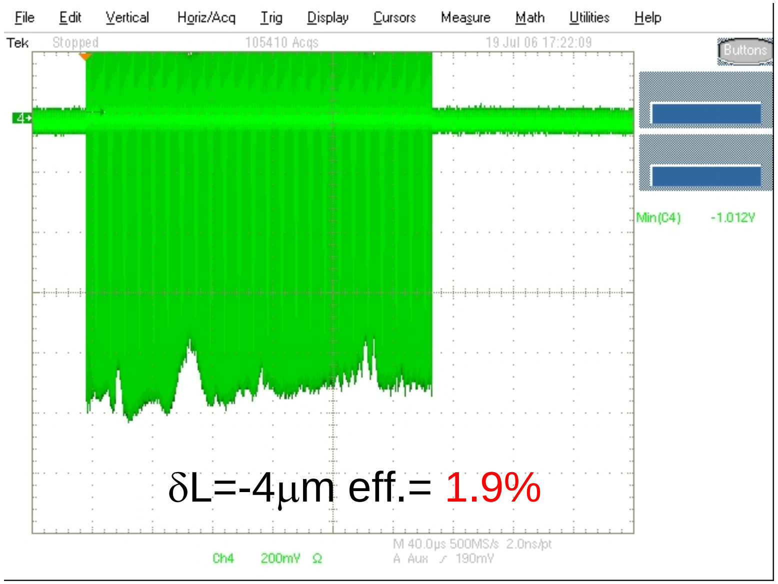
Beam dump current

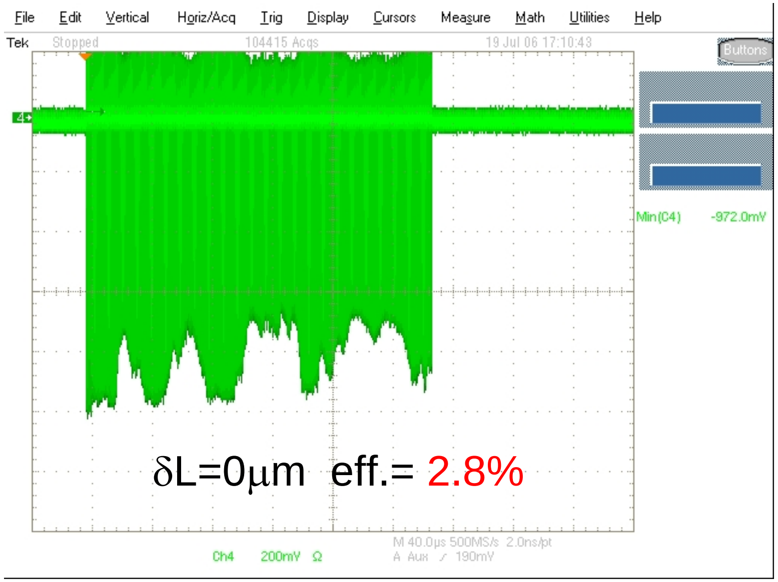


Beam macropulse after the return arc

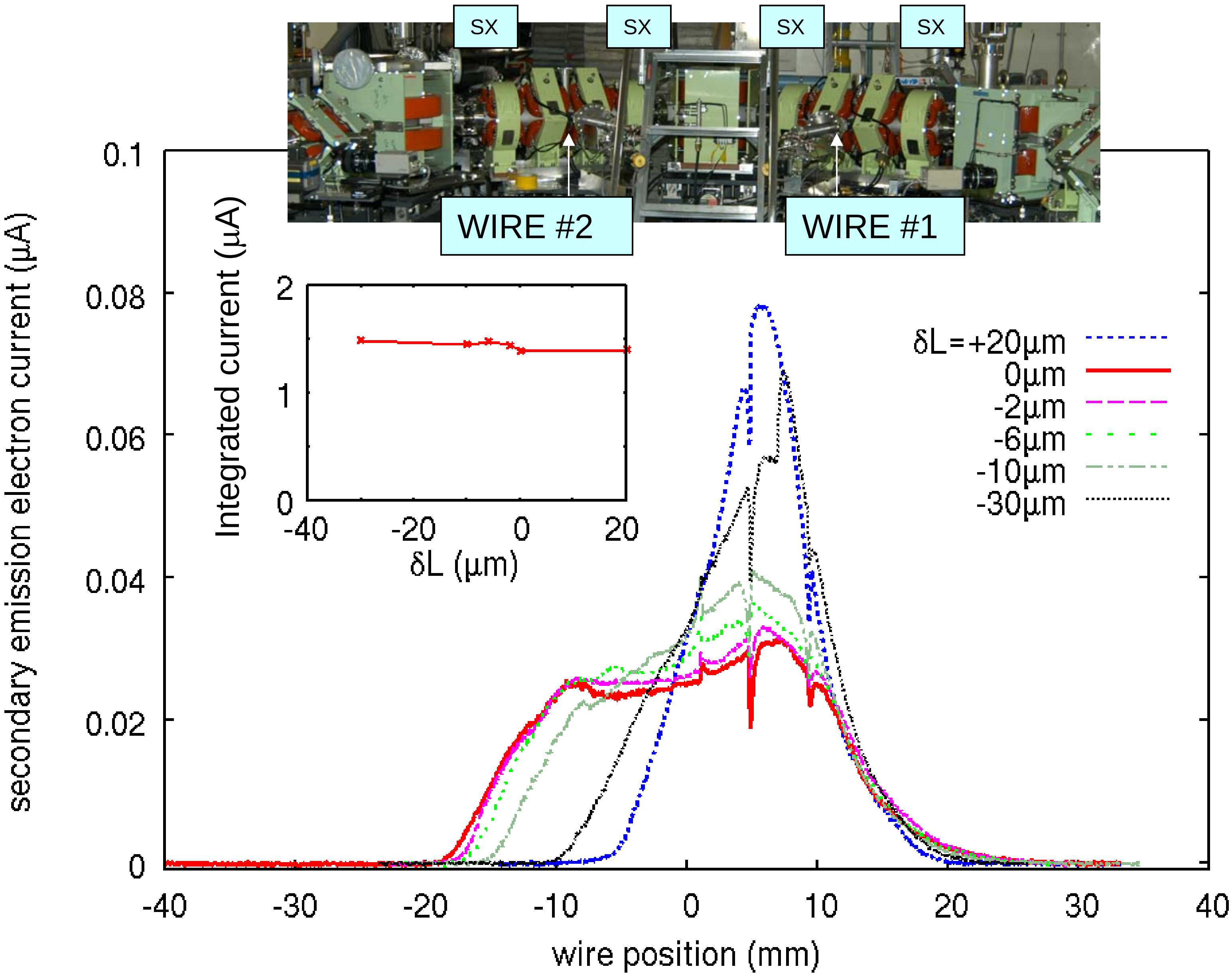




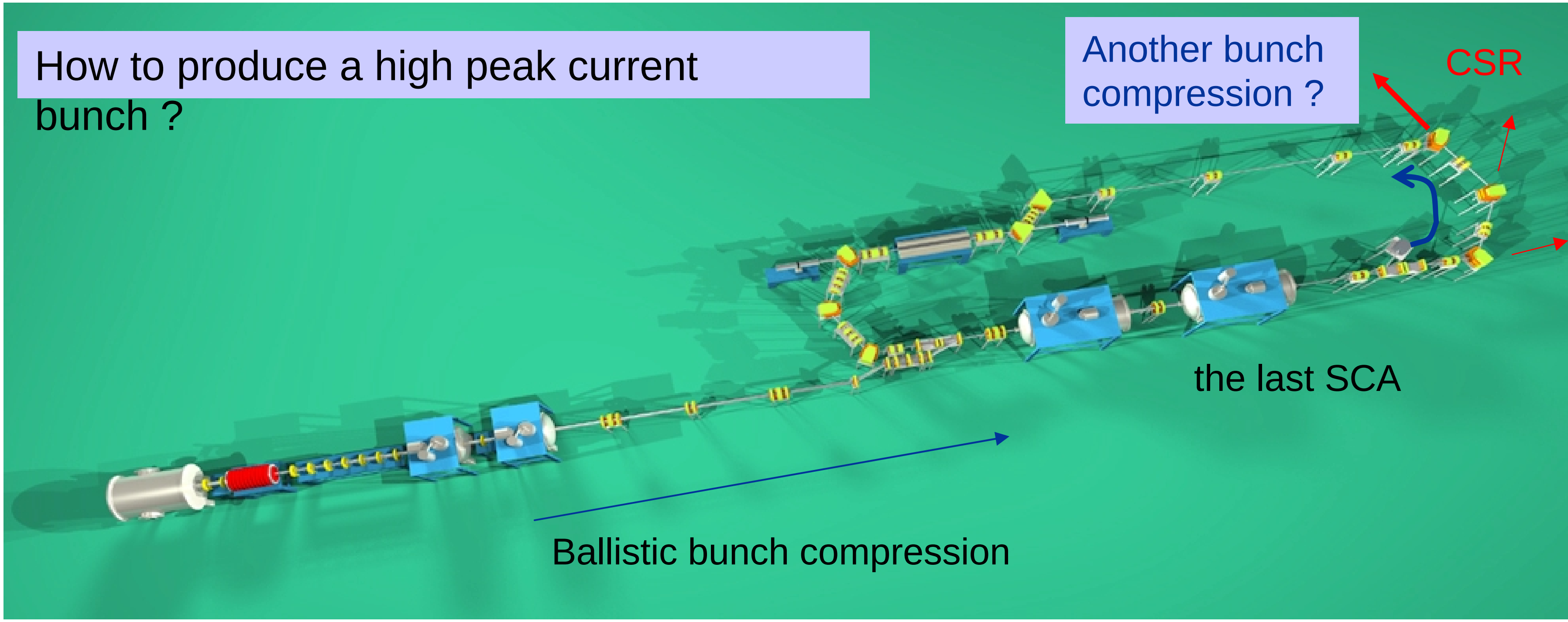




Beam profiles measured with WIRE #2



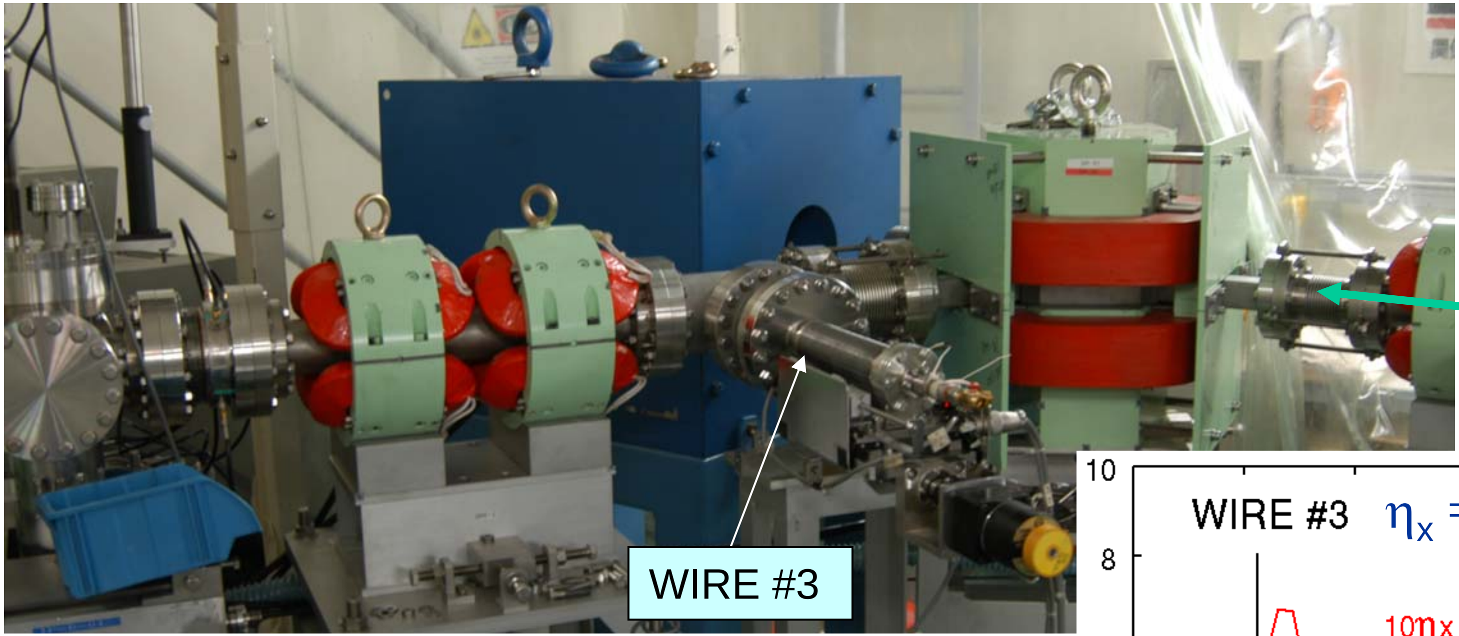
Magnetic bunch compression in the first arc

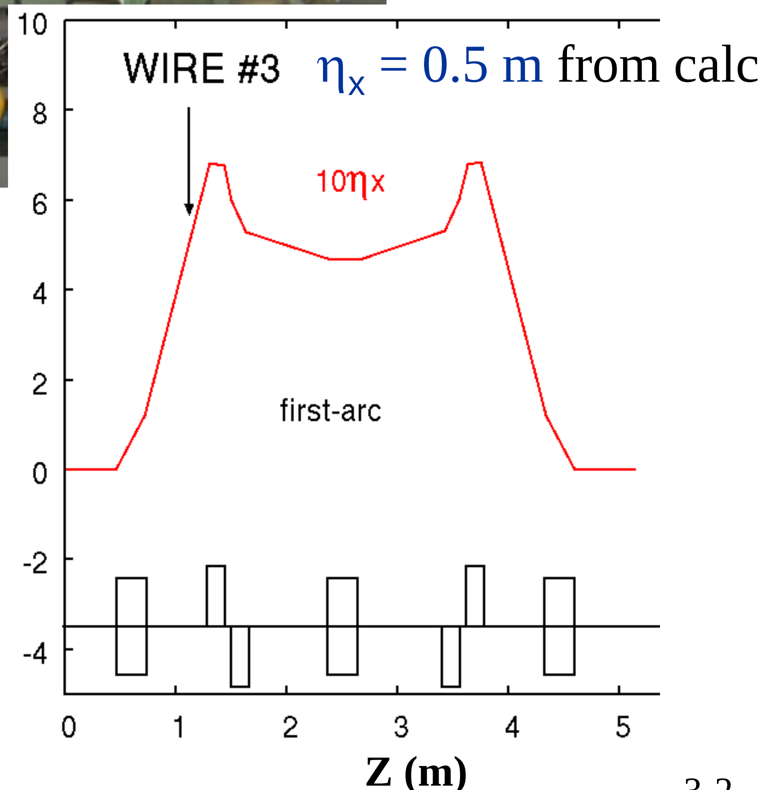


CSR power from the last bending magnet is much higher than the remaining two, indicating another bunch compression in the first arc.

→ Measured horizontal beam profiles with a wire scanner at a dispersive point in the first arc as a function of the RF phase of the last SCA.

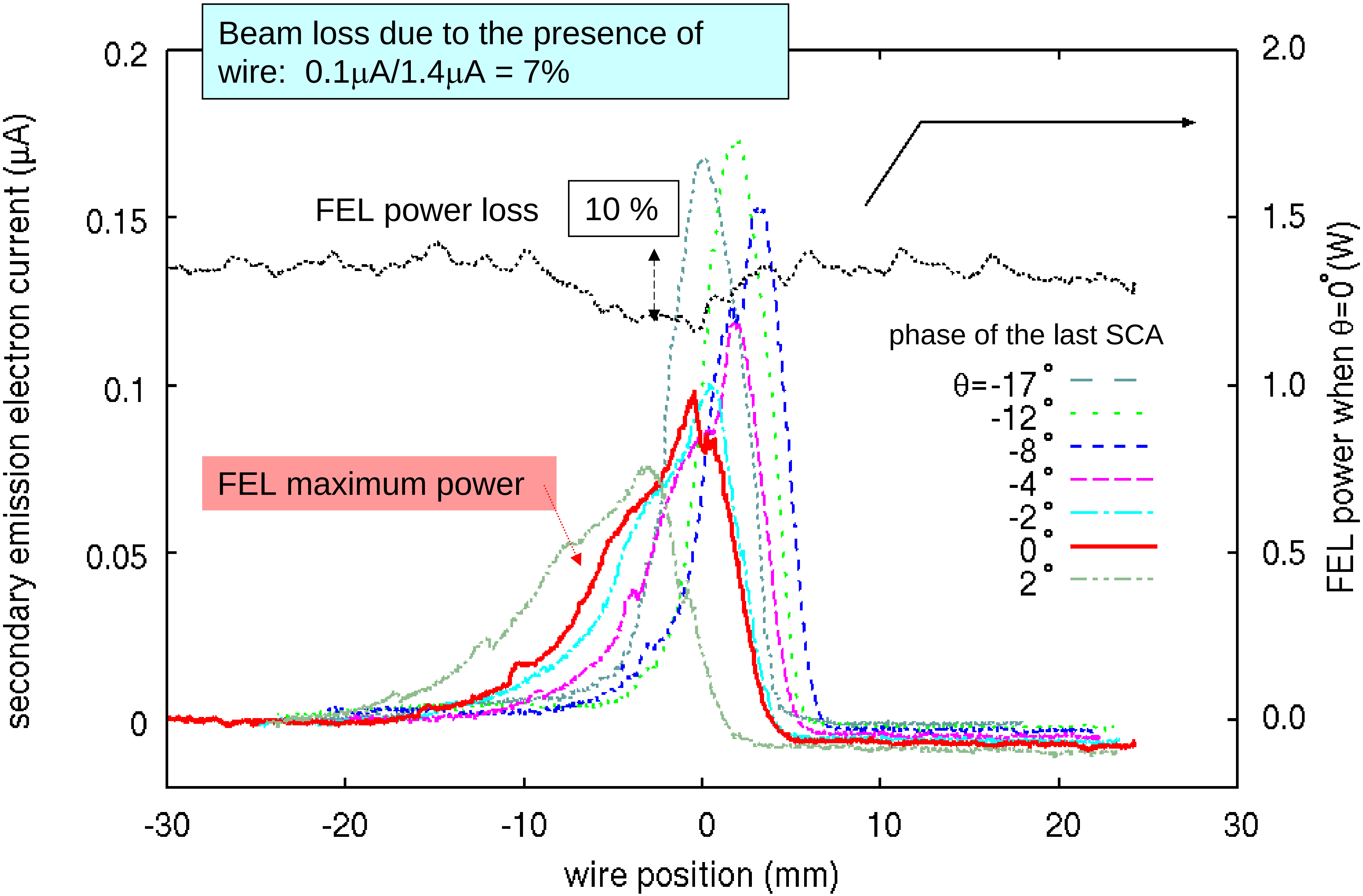
Wire scanner in the first arc



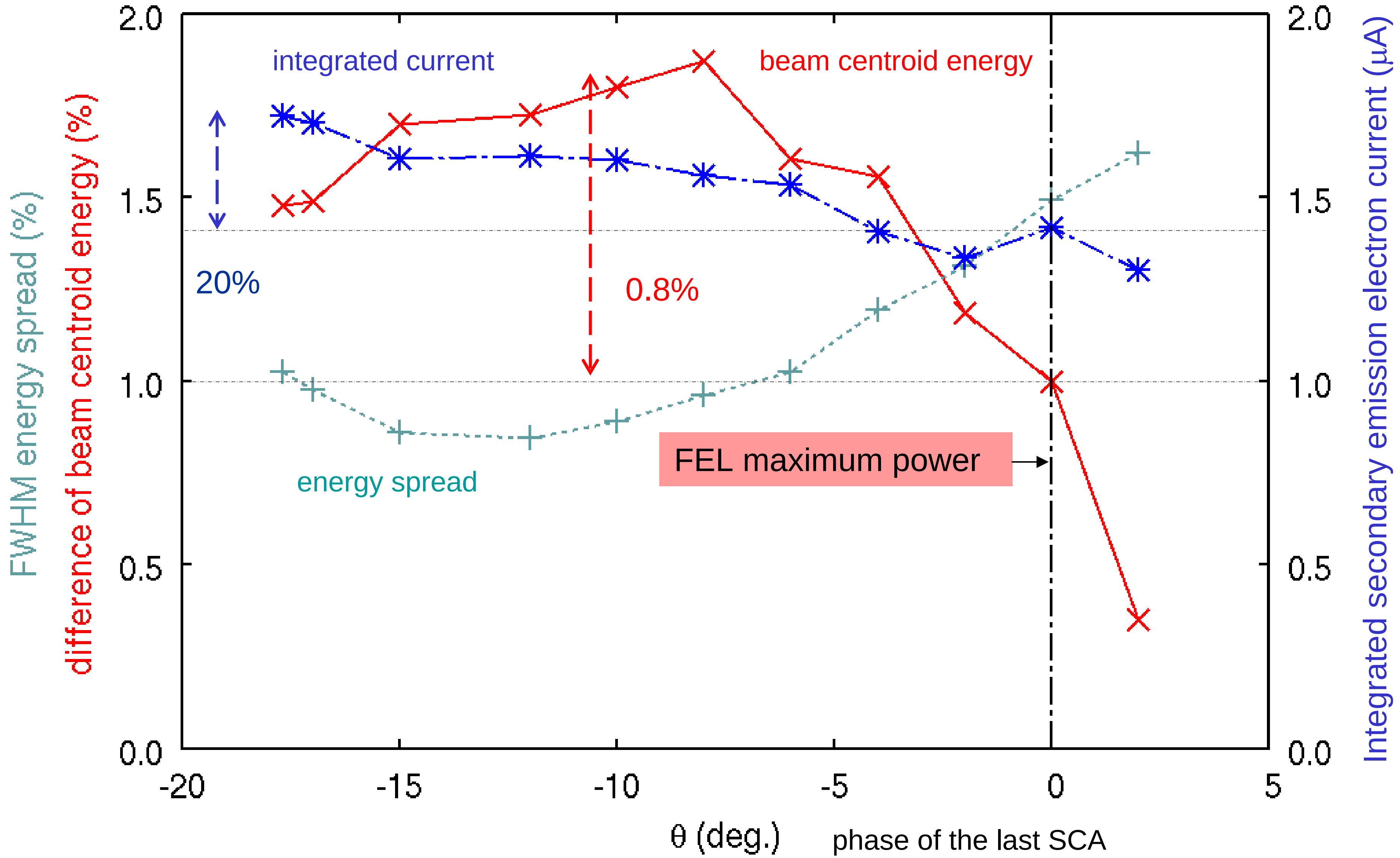


M_{56} = 0.6 m at the exit of the first arc from calc.

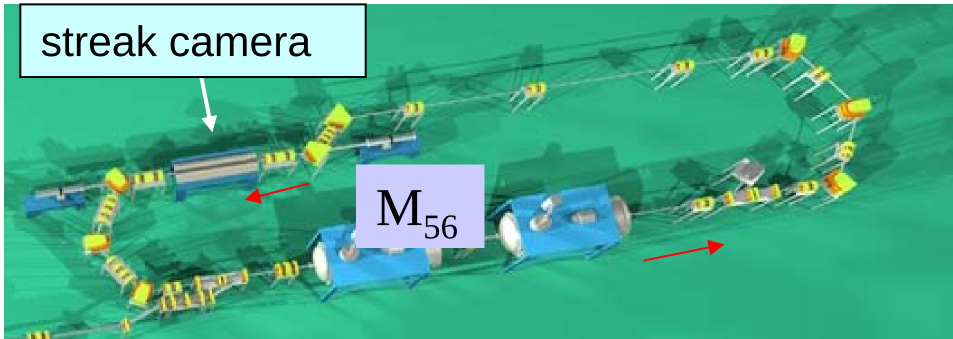
Beam profiles measured with WIRE #3



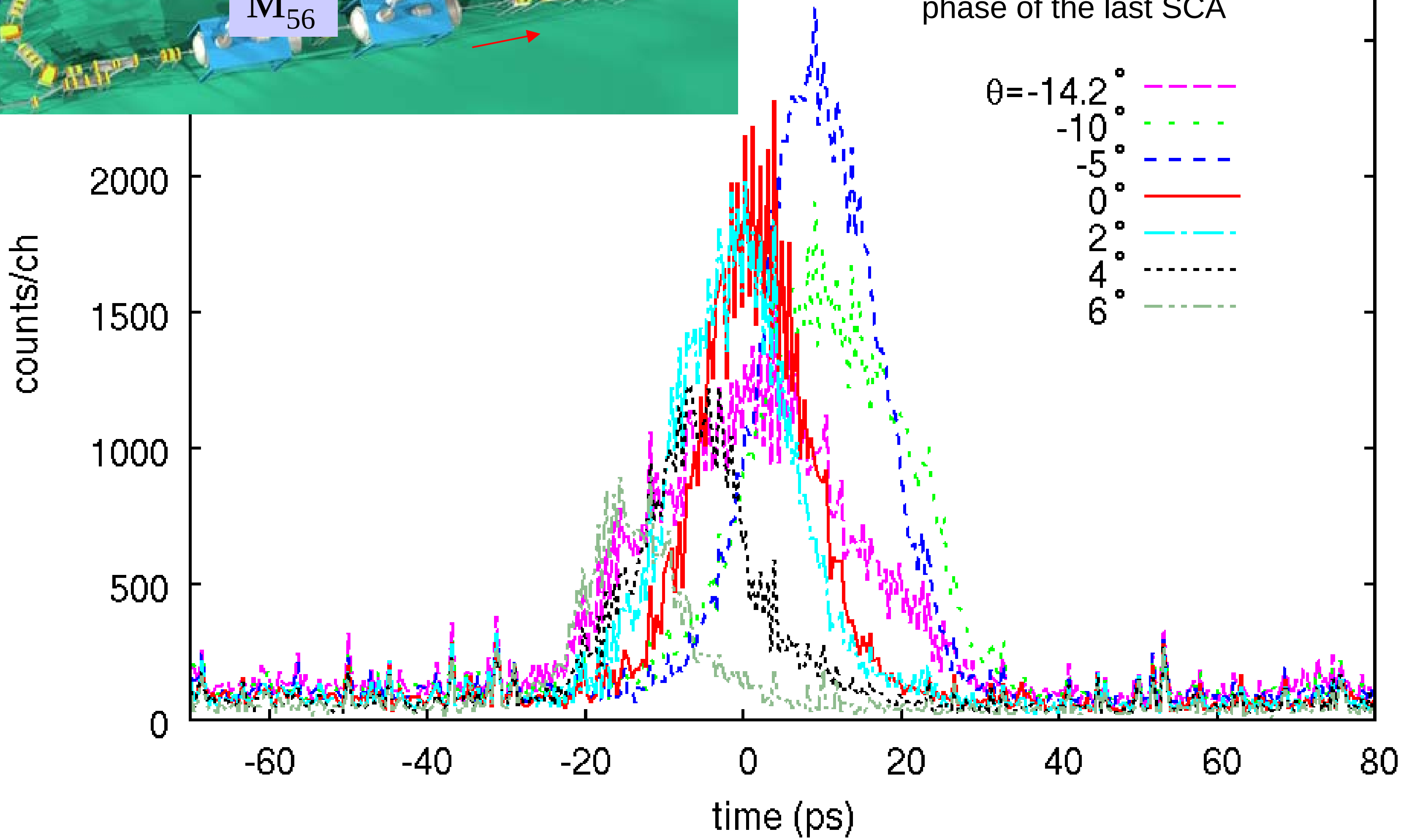
Energy spread, energy of beam centroid, and total secondary electron current



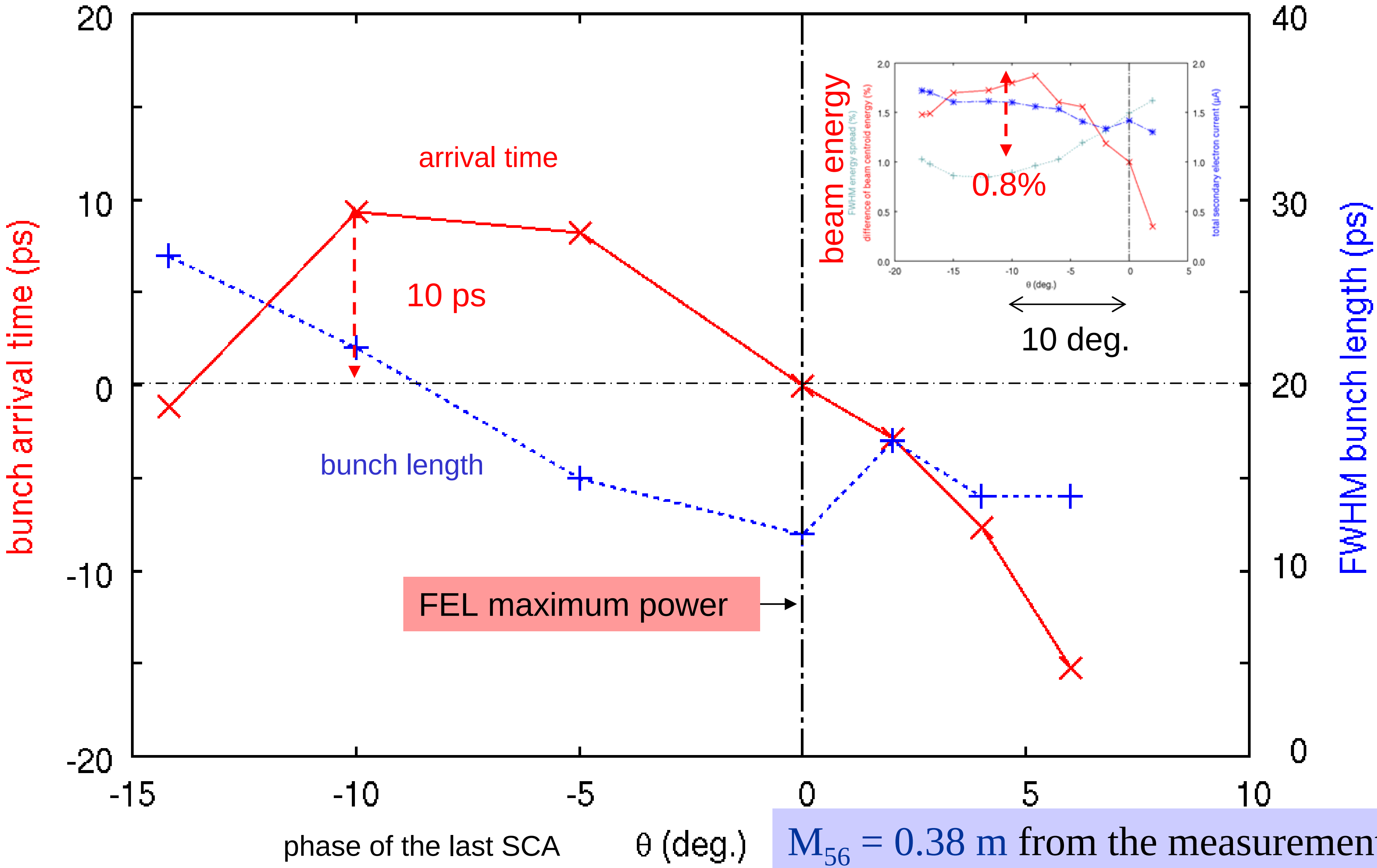
Temporal profiles at the undulator center



30 μs macropulse



Bunch length and bunch arrival time



M_{56} = 0.38 m from the measurement

M_{56} = 0.6 m from the calculation

Poster presentations by JAEA ERL group in FEL06

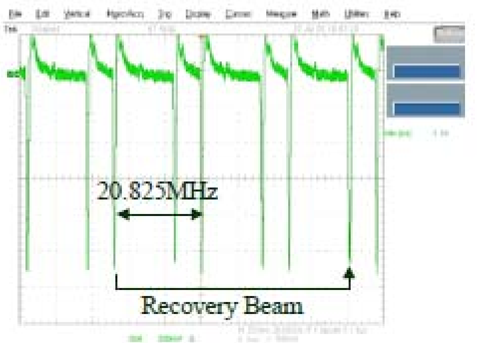


Fig. 2: Typical signal of the current monitor at the entrance of the main linac

[TUPPH005] R. Nagai et al.,

``Beam current doubling of JAEA ERL-FEL''

[TUPPH006] R. Nagai et al.,

``Performance of a conventional analog ϕ-A type low-level RF controller''

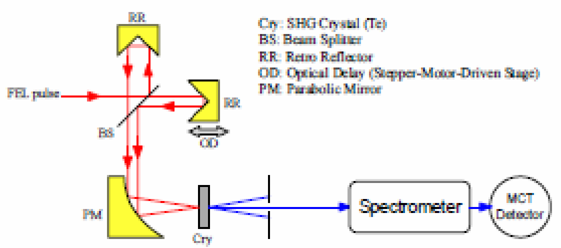


Figure 2: The schematic view of the SHG-FROG setup.

[TUPPH002] H. Iijima et al.,

``Development of frequency-resolved optical gating for measurement of correlation between time and frequency of chirped FEL''

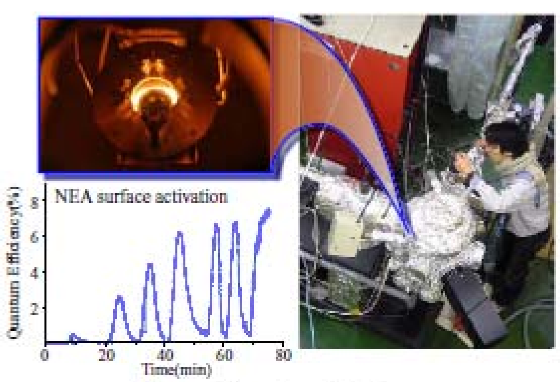


Figure4:Experimental set up

[TUPPH007] T. Nishitani et al.,

``JAEA photocathode DC-gun for an ERL injector''

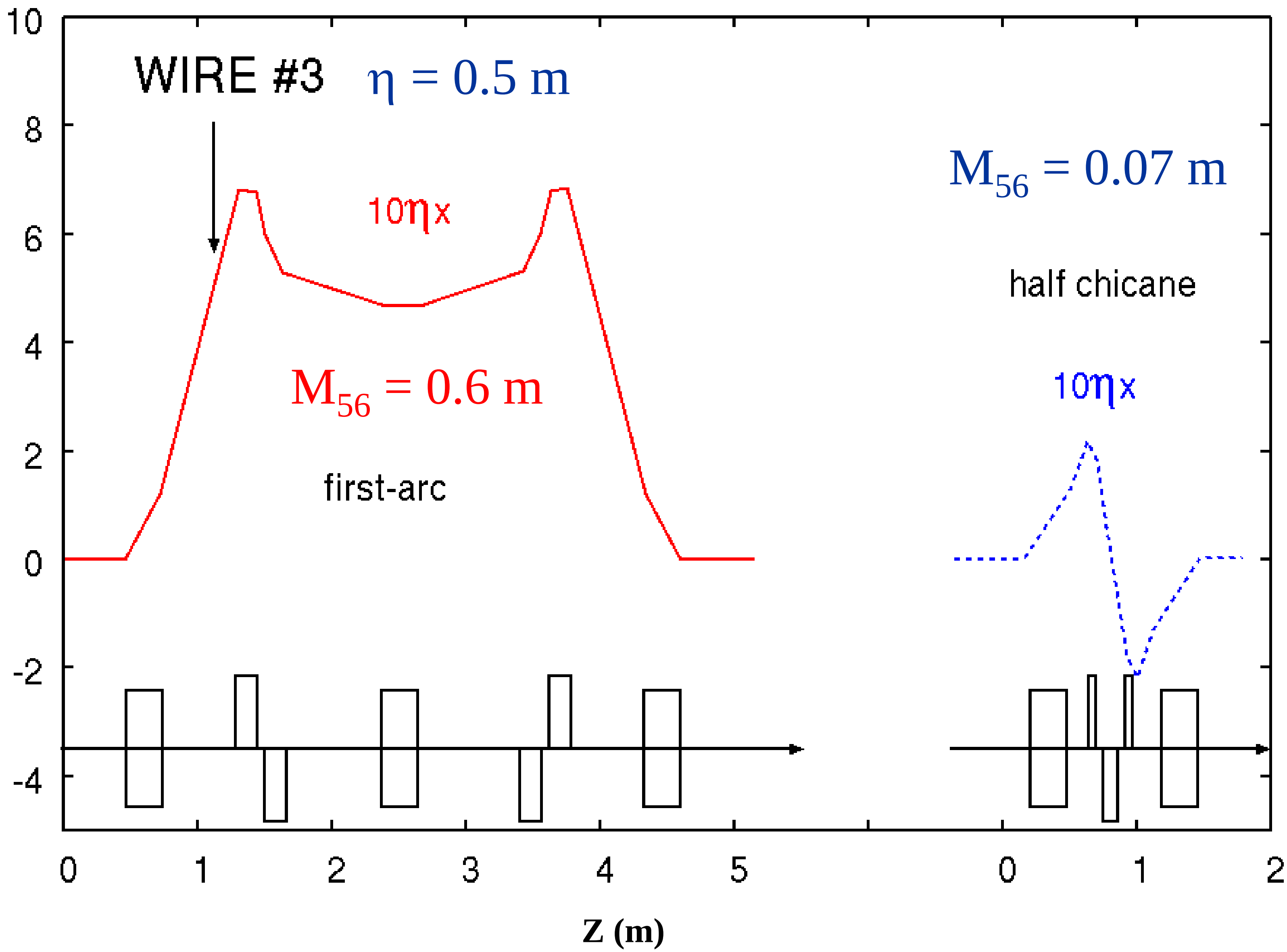
Summary

- We have doubled the electron bunch repetition rate by upgrading the gun grid pulser and RF power supply for injector SCA modules.
- The energy acceptance of the triple bend achromatic return arc has been increased from 7% to 15% by replacing quadrupole magnets and beam ducts.

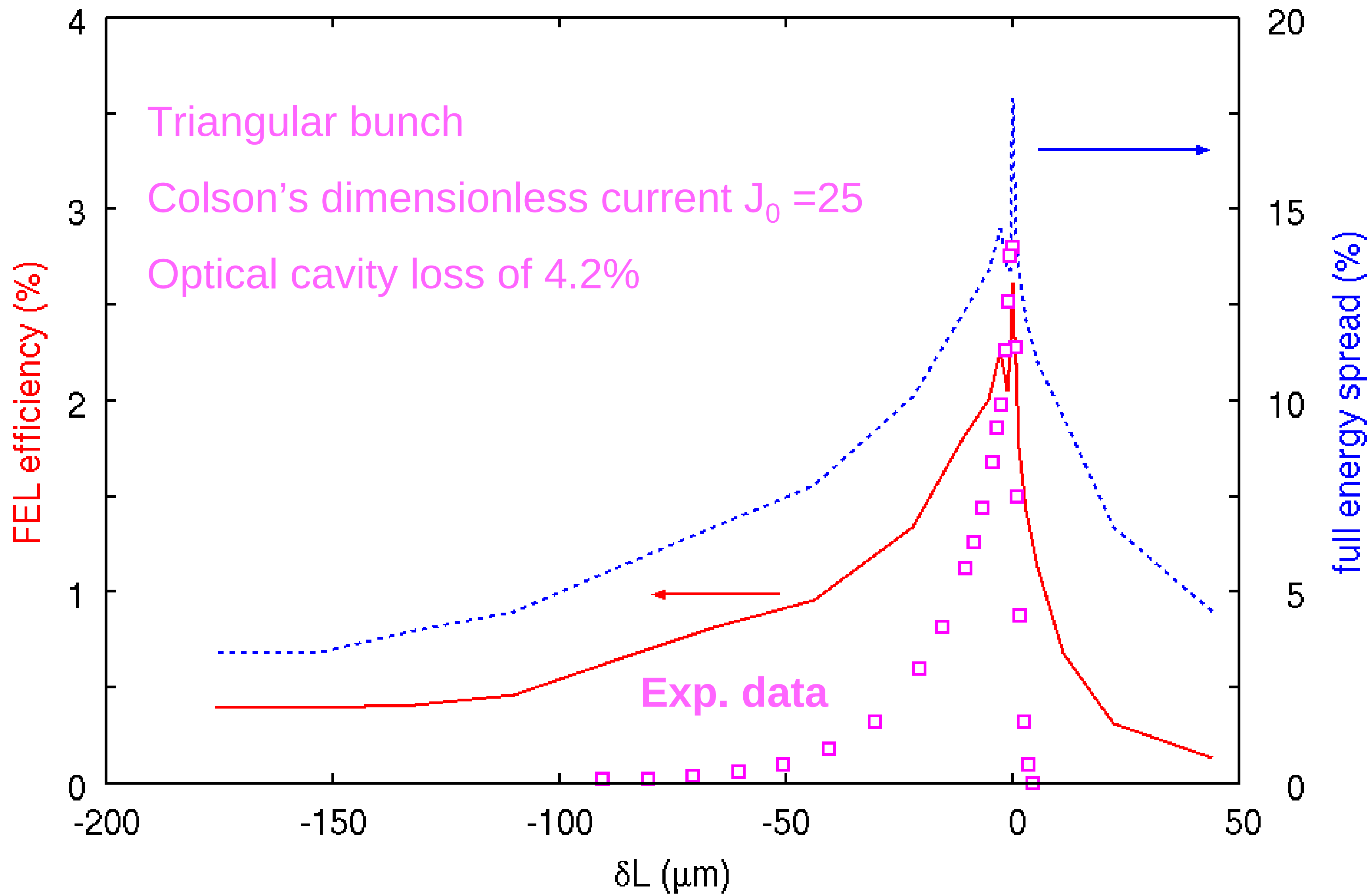
- We have achieved 0.7 kW FEL oscillation during 230 μs macropulse at 22μm wavelength using 8 mA electron beam.
- The FEL extraction efficiency has been measured with a wire scanner and the peak efficiency reaches 2.8%.
- We have found that a magnetic bunch compression in the first arc with off crest acceleration in main SCA modules is indispensable to realize the high-efficiency FEL.

- We will continue our experimental study on the beam dynamics in the triple bend achromatic arcs under high-efficiency FEL oscillation.

1st arc dispersion function



One-dimensional time-dependent FEL simulation



JAEA ERL FEL parameters

Beam energy at undulator	17 MeV
Average current at undulator	8 mA
Bunch charge at undulator	0.4nC
Bunch length at undulator (FWHM)	12 ps
Peak current	35 A
Energy spread before undulator (FWHM)	1.5%
after undulator (full width)	>15%
Normalized emittance (rms)	40 mm mrad
Bunch repetition	20.8 MHz
Macropulse	1ms X 10Hz
Undulator period	3.3 cm
Number of undulator periods	52
Undulator parameter (rms)	0.7
Optical cavity length	7.2 m
Rayleigh range	1.00 m
Cavity mirror radii	6 cm
FEL wavelength	22 μm
FEL extraction efficiency	>2.5%

17MeV ERL loop