Bunch compression at the SPring-8 linac for successive generation of THz pulse train in the isochronous ring

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- Demonstration Experiment
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Introduction

Applications of Short Electron Bunch

- Short Pulsed X-Ray

  For time resolving experiments

  → Sub-ps (femto-second) pulse

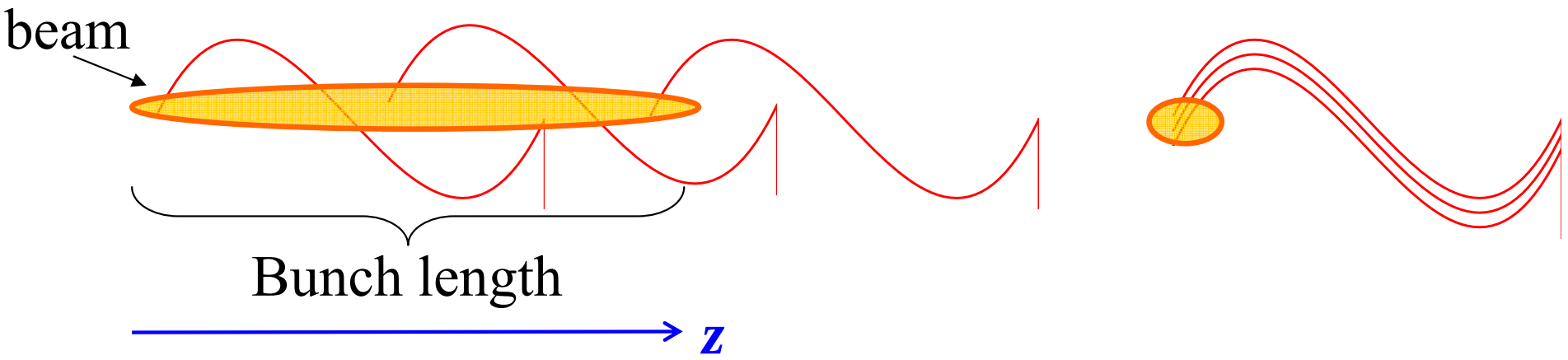
  → Intense ps pulse is still valuable

- Coheremt synchrotron radiation (CSR)

  → extremely strong THz radiation

  → stable radiation

Coherent Synchrotron Radiation (CSR)



Radiation power from *N* electrons in a bunch

$$P_{tot}(\omega) = p(\omega)\left[N + (N^2 - N)\left|f(\omega)\right|^2\right]$$

($p(\omega)$: power from an electron
$f(\omega)$: form factor)

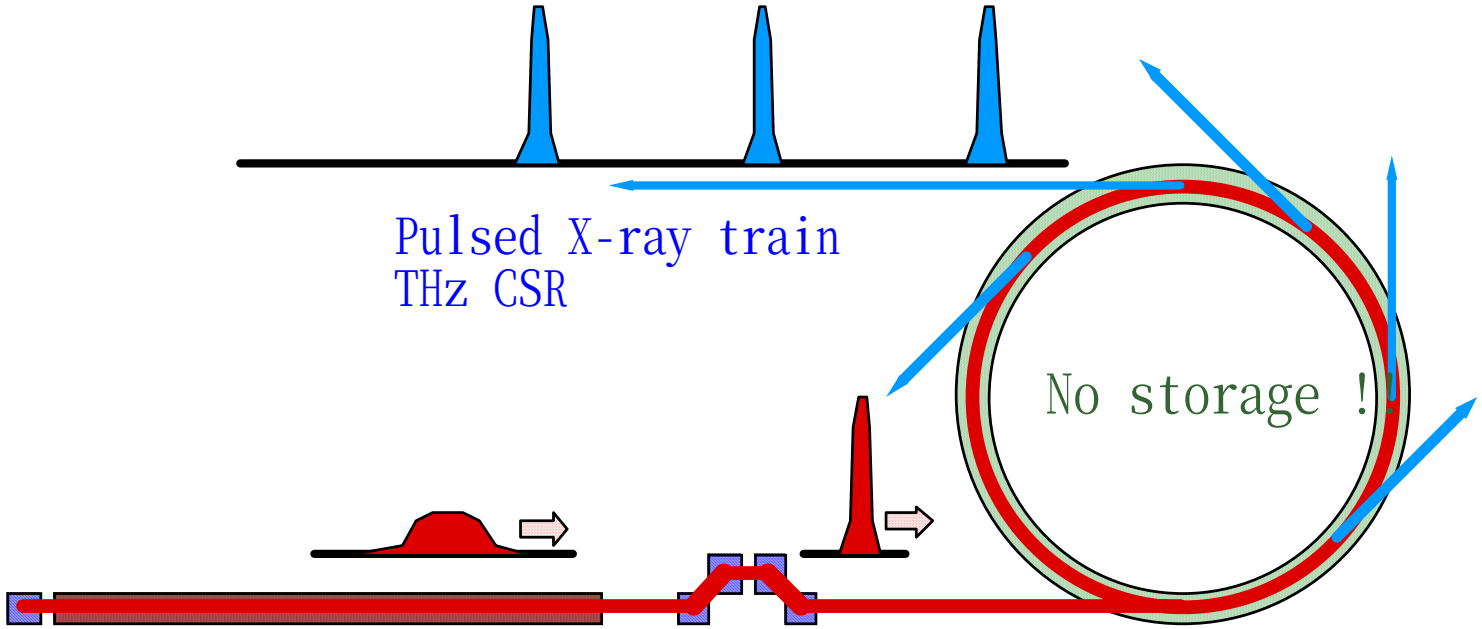
Form factor

$$f(\omega) = \int \rho(z)\exp(i\omega z/c)dz$$

($\rho(z)$: charge density, $\int \rho(z)dz = 1$)

The Concept

1. Make short and intense bunch in a linac
2. Let the bunch circulate in an isochronous ring
3. Use short pulsed X-ray train or THz CSR



Merits

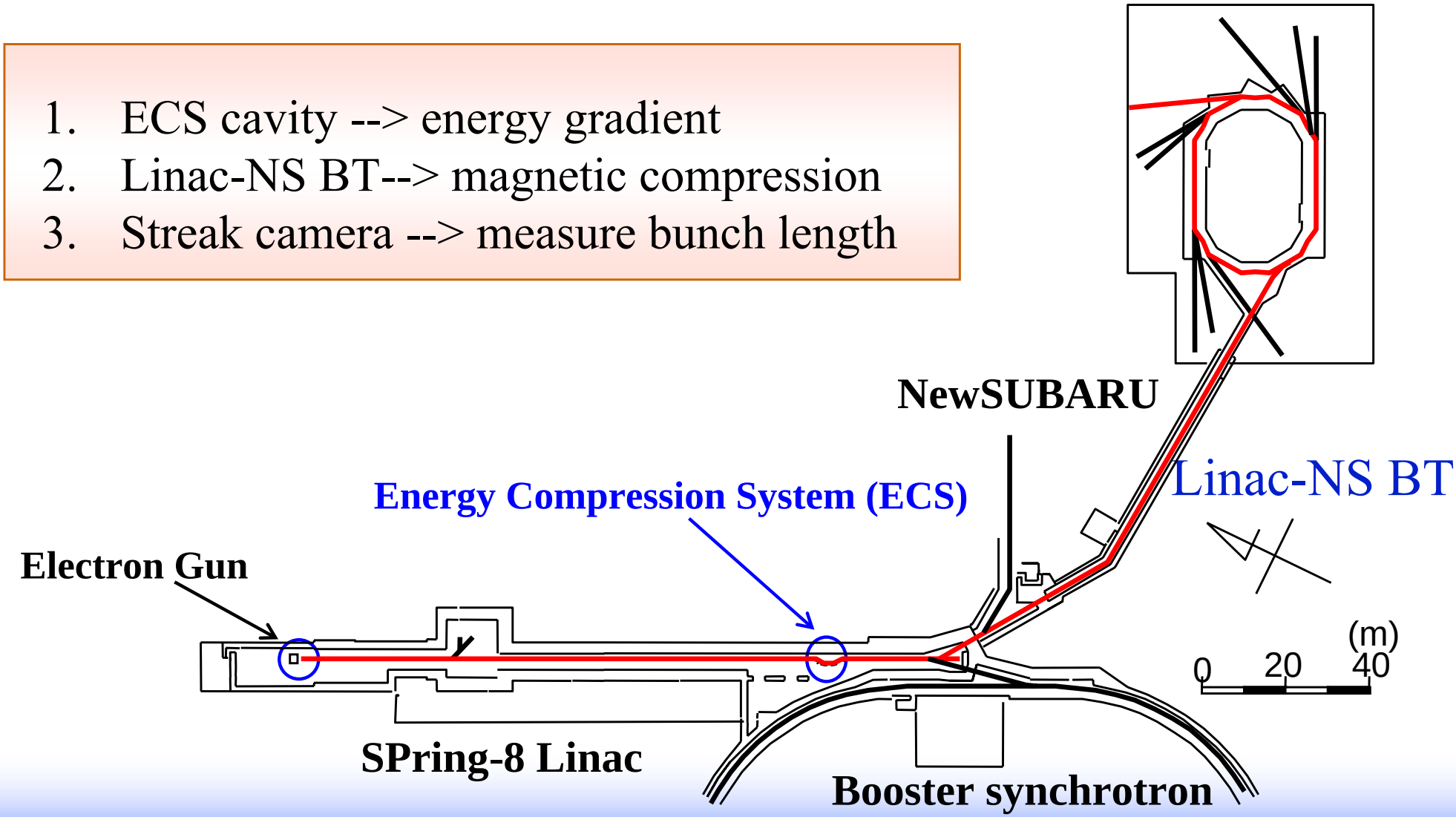
(i) Short and intense pulse is obtained at ring BL.
--> Light for many BLs at the same time

(ii) Short pulse train with fixed period
--> It helps to confirm the synchronization.

(iii) Existing accelerators are enough for a few ps pulse.
--> No special expense is required

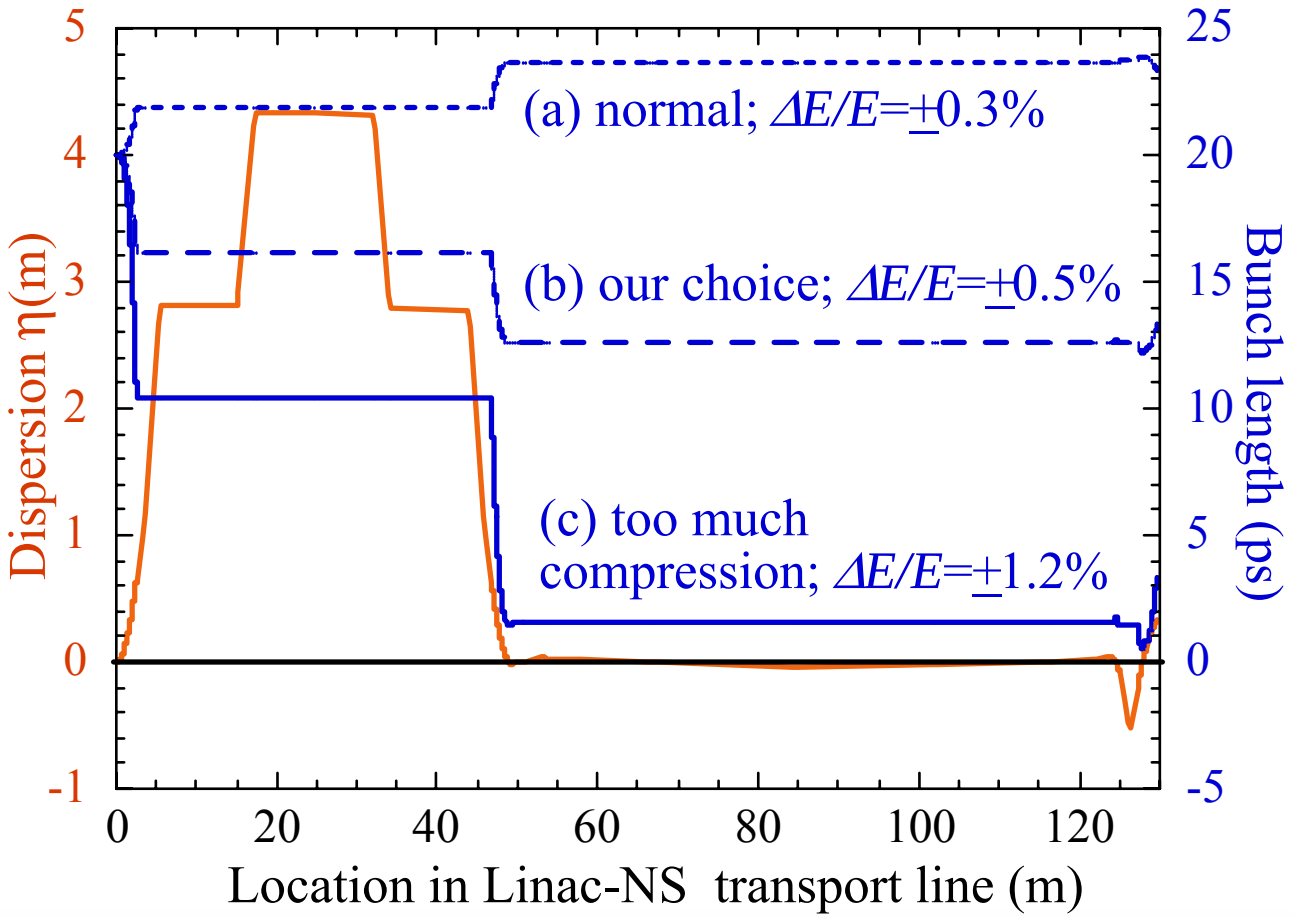
Demonstration Experiment

1. ECS cavity --> energy gradient
2. Linac-NS BT--> magnetic compression
3. Streak camera --> measure bunch length



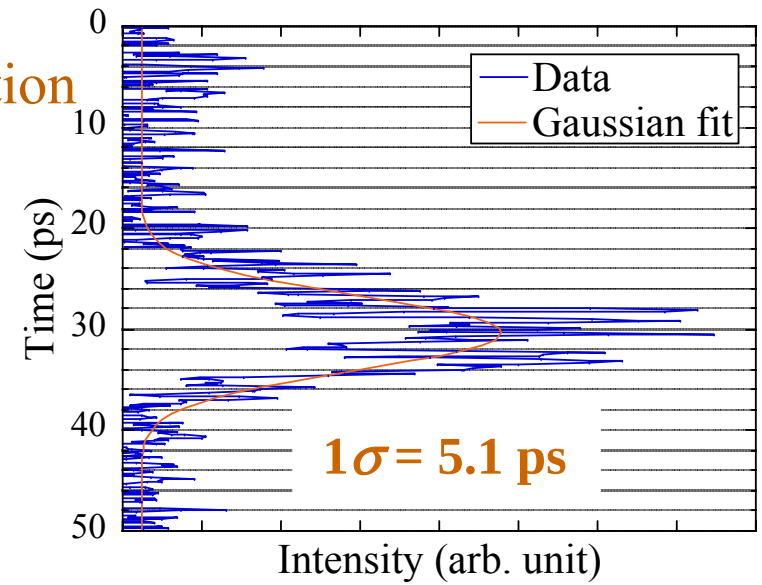
Simulation of bunch compression

Magnetic compression along the Li-NS transport



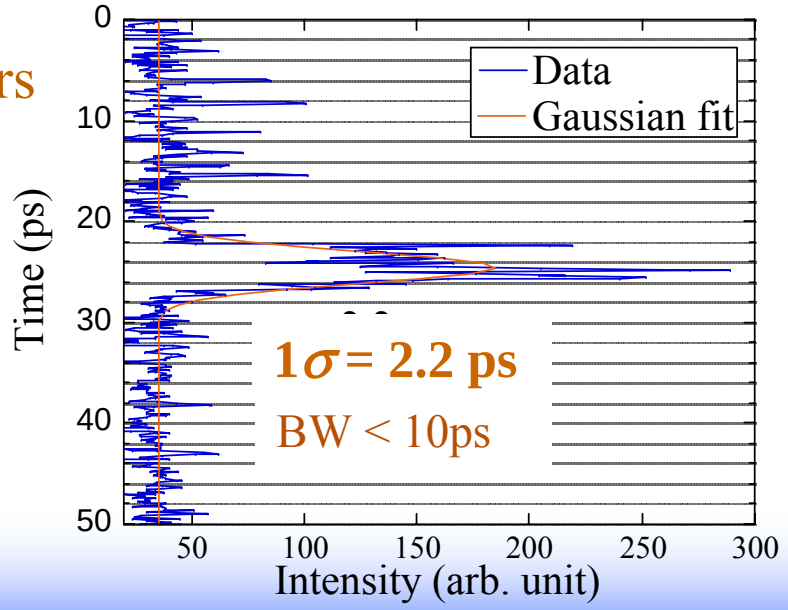
Bunch Length Measurement

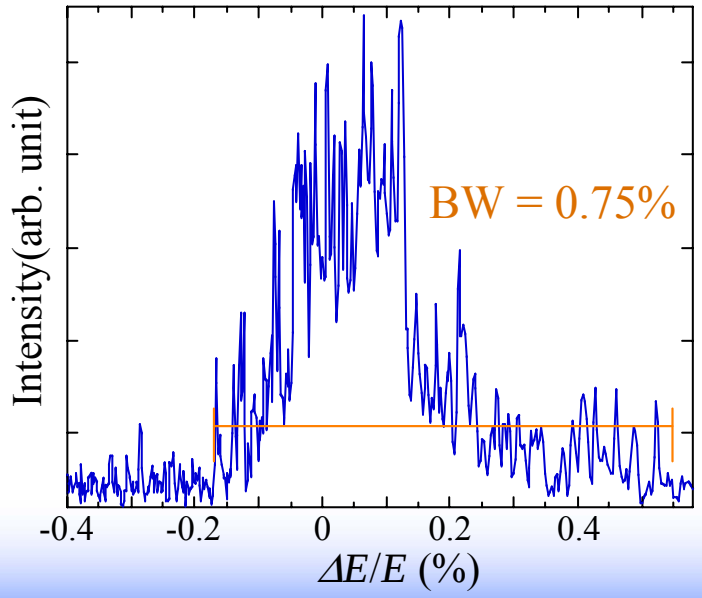
Normal Operation Parameters



Time profile at the initial turn in the ring

ECS parameters Optimized





Multi-turn Circulation

Energy dependence of path-length

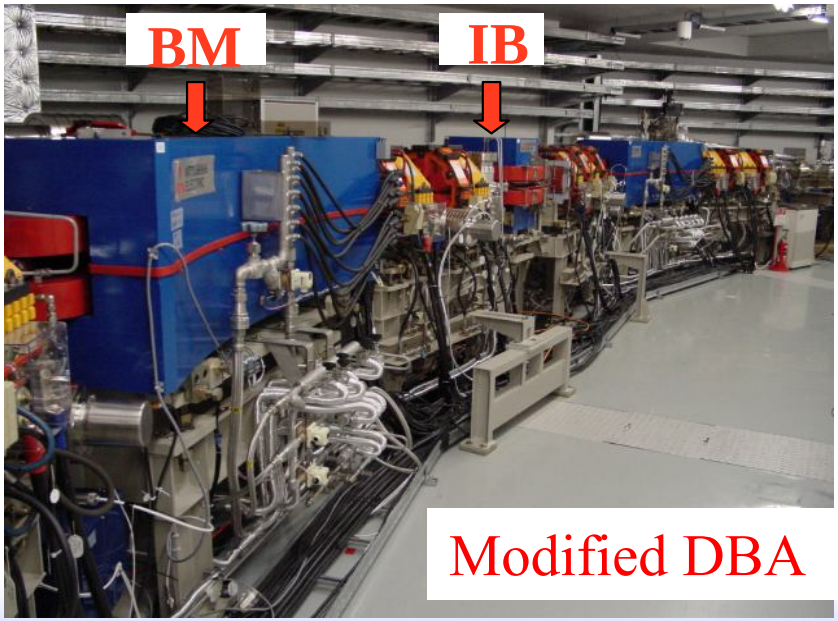
$$\Delta L/L = \alpha_1\delta + \alpha_2\delta^2 + \alpha_3\delta^3 + \ldots \qquad (\text{here} \quad \delta = \Delta E/E$$

α_n : n-th momentum compaction factor

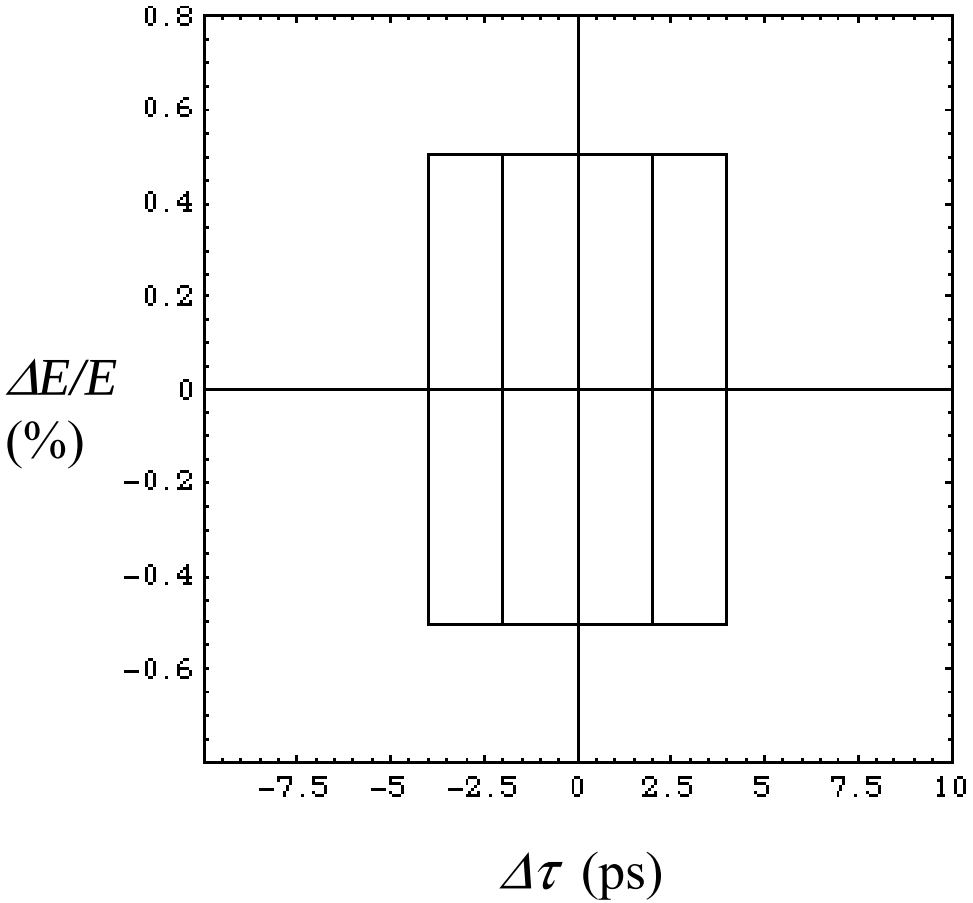
NewSUBARU storage ring

Invert Bend →control α_1

- $\alpha_1 = 1.3 \times 10^{-3} \rightarrow \approx 0$
- $\alpha_2 = 0$ (setting accuracy ≈ 10^{-3})
- α_3 no control knob ($\alpha_3 \approx 0.5$)



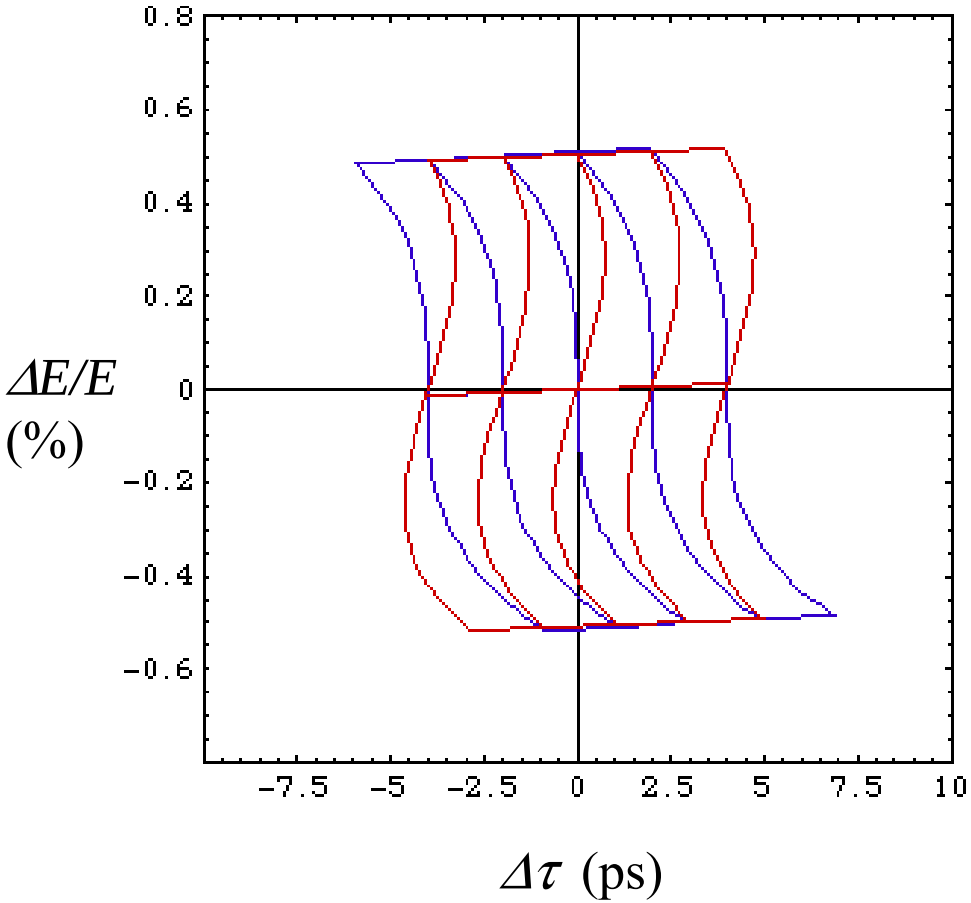
Tracking simulation in the non-linear rf bucket



Initial state; just after injection

$\Delta E/E = \pm 0.5\%$ $\Delta\tau = \pm$ 4ps

Tracking simulation in the non-linear rf bucket



Initial state; just after injection

$\Delta E/E = \pm 0.5\%$ $\Delta\tau = \pm$ 4ps

. $\alpha_1 = 0$ After 100 turns

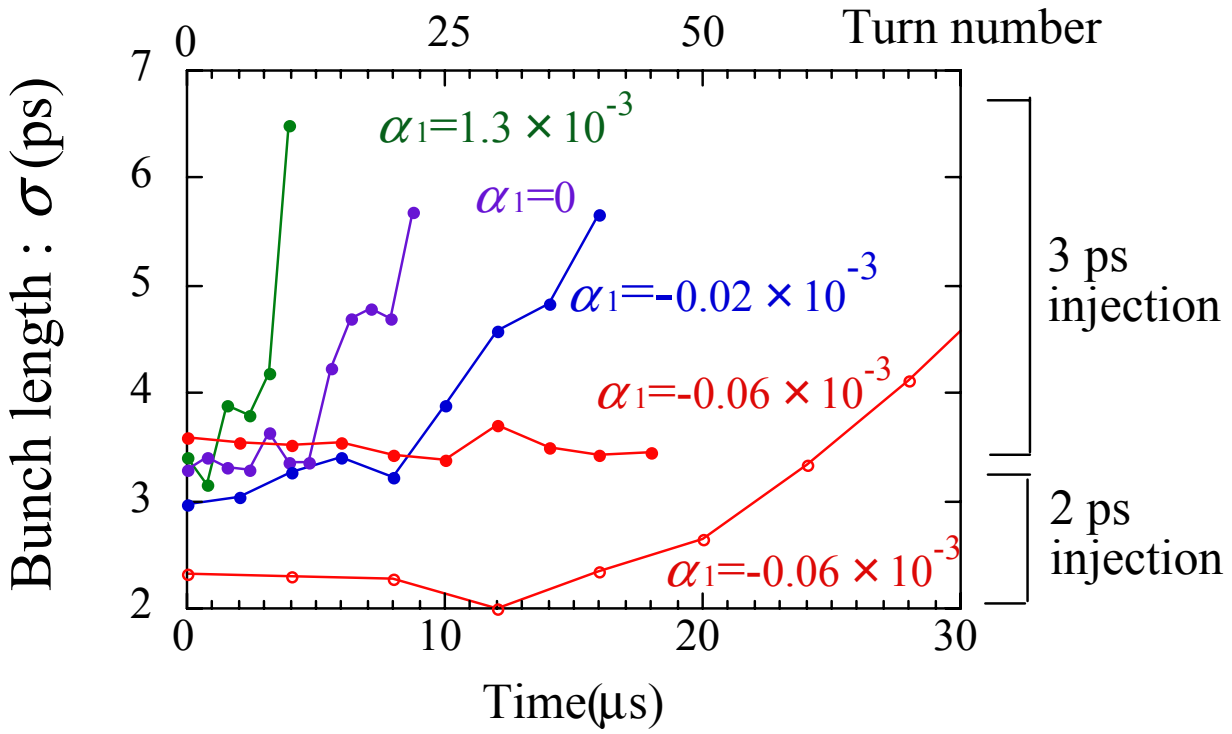
. $\alpha_1 = -1 \times 10^{-5}$ After 100 turns

. $\alpha_2 = 0$

. $\alpha_3 = 0.5$

. $\alpha_4 = -20$

Quasi-isochronous ring

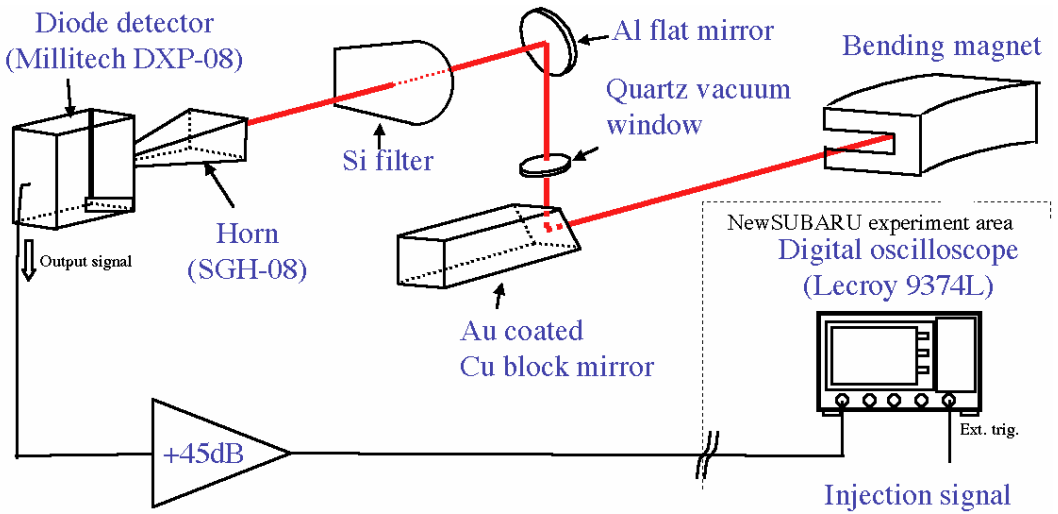


Optimum α_1 was larger than the expected
Bunch elongation was faster than the expected

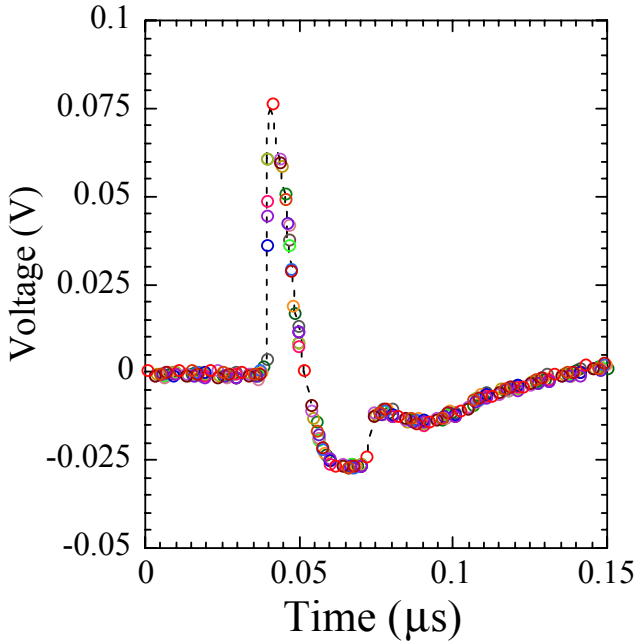
50 turns with $\sigma < 3$ps

CSR detection

Set-up of micro-wave detector (90-140GHz)

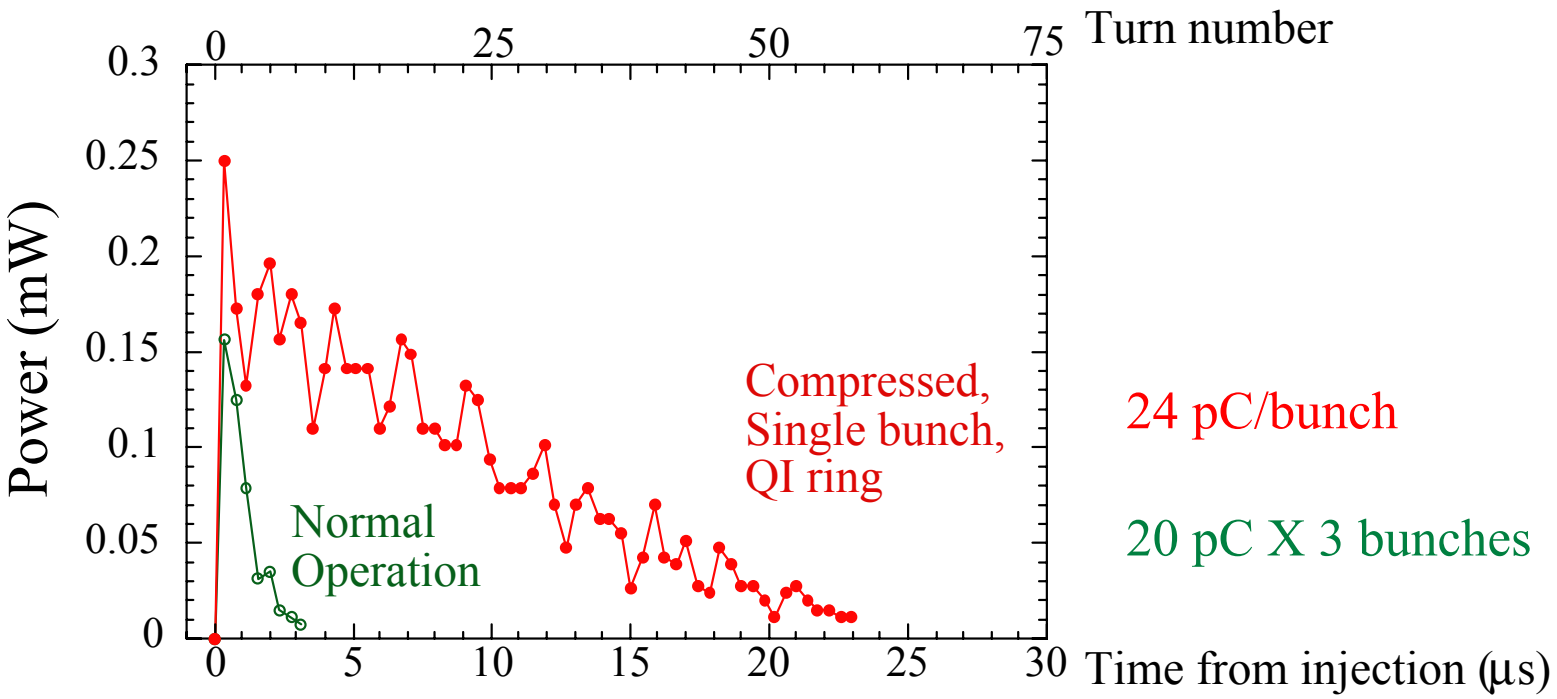


Signal waveform



Revolution period=0.4μs

Turn by turn CSR power

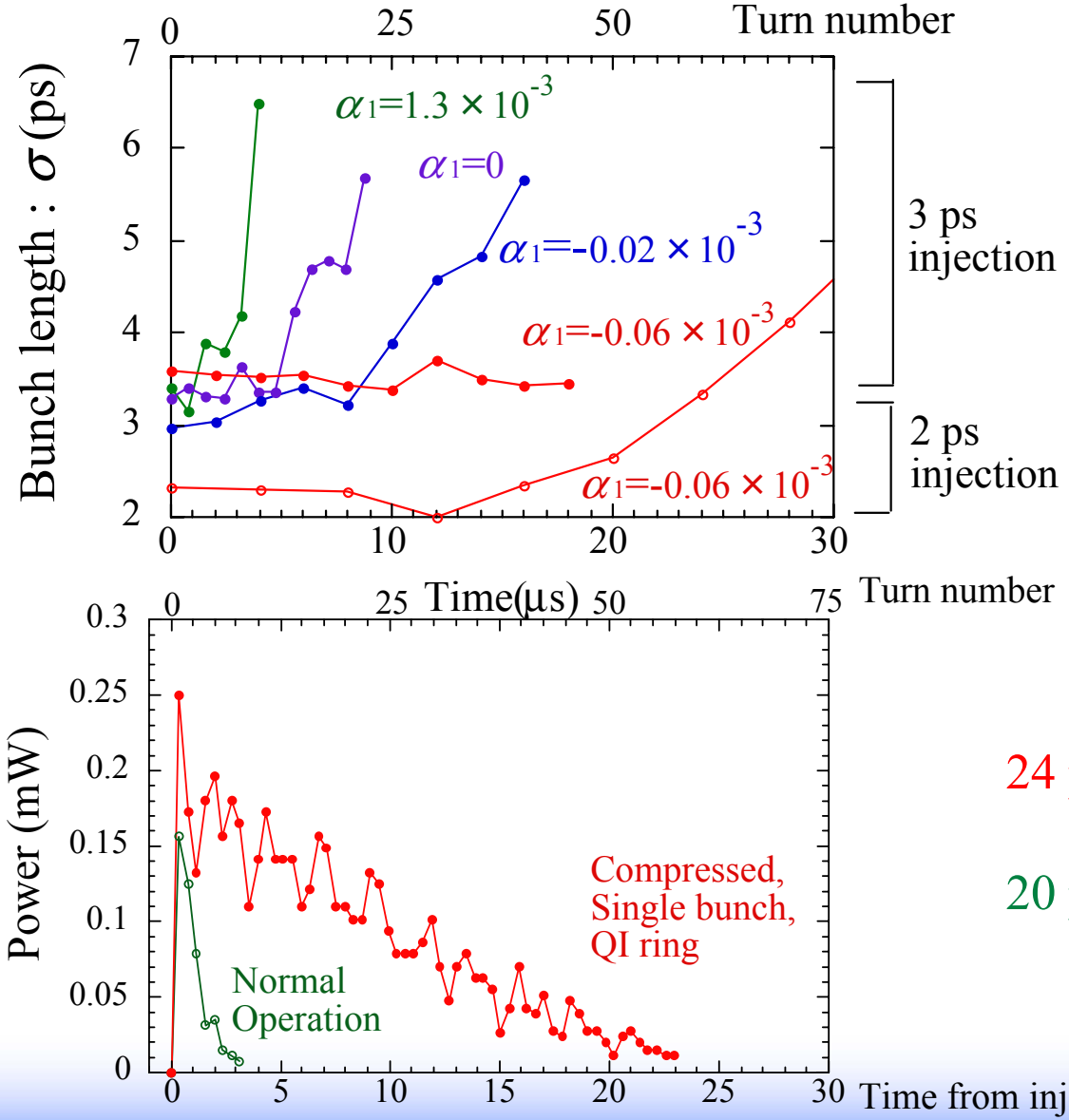


24 pC/bunch

20 pC X 3 bunches

Stronger CSR at the injection
It lasted longer than the normal condition

Bunch length & CSR power



24 pC/bunch

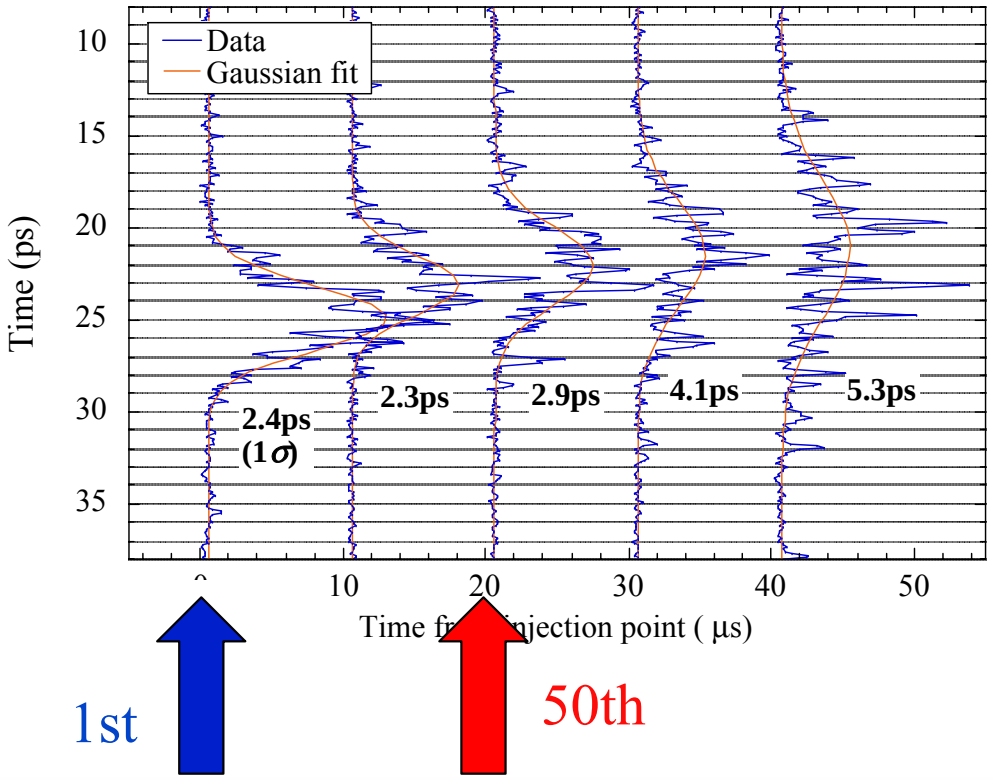
20 pC X 3 bunches

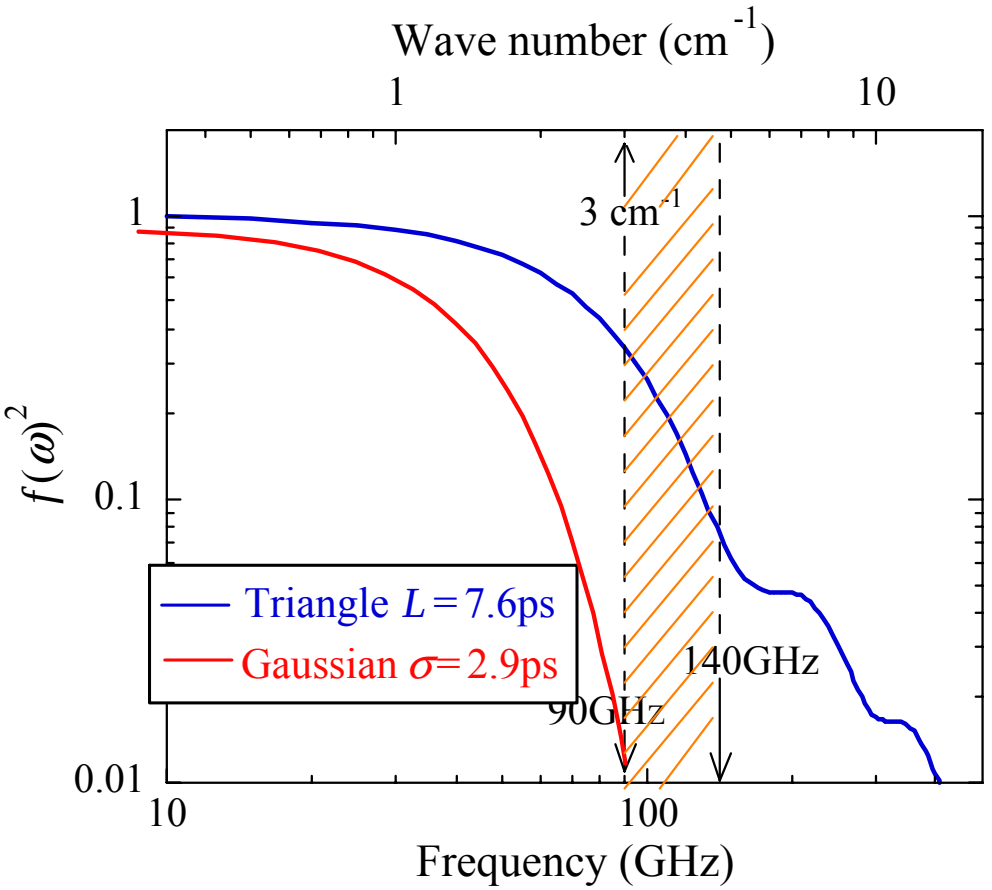
Reduction of CSR

contribution of form factor $f(\omega)$

Sensitive to a
small change of the bunch length

Evolution of time profile after injection





Summary of Experiment

Short Bunch Circulation

- succeeded to keep $1\sigma < 3$ps for 50 turns
  - larger CSR lasted longer

Of course, still there are many problems …

Future Improvement

Ring (magnet system)

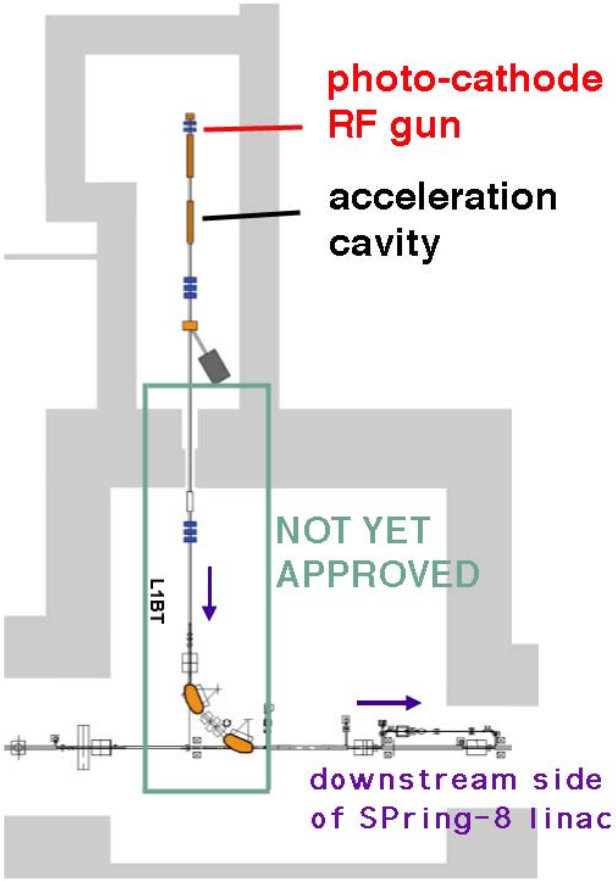
- improve stability ; temperature control
  ; magnetic field
  ; better tuning

  = improvements for the daily operation

Linac (electron gun)

- thermionic gun --> photo-cathode RF gun

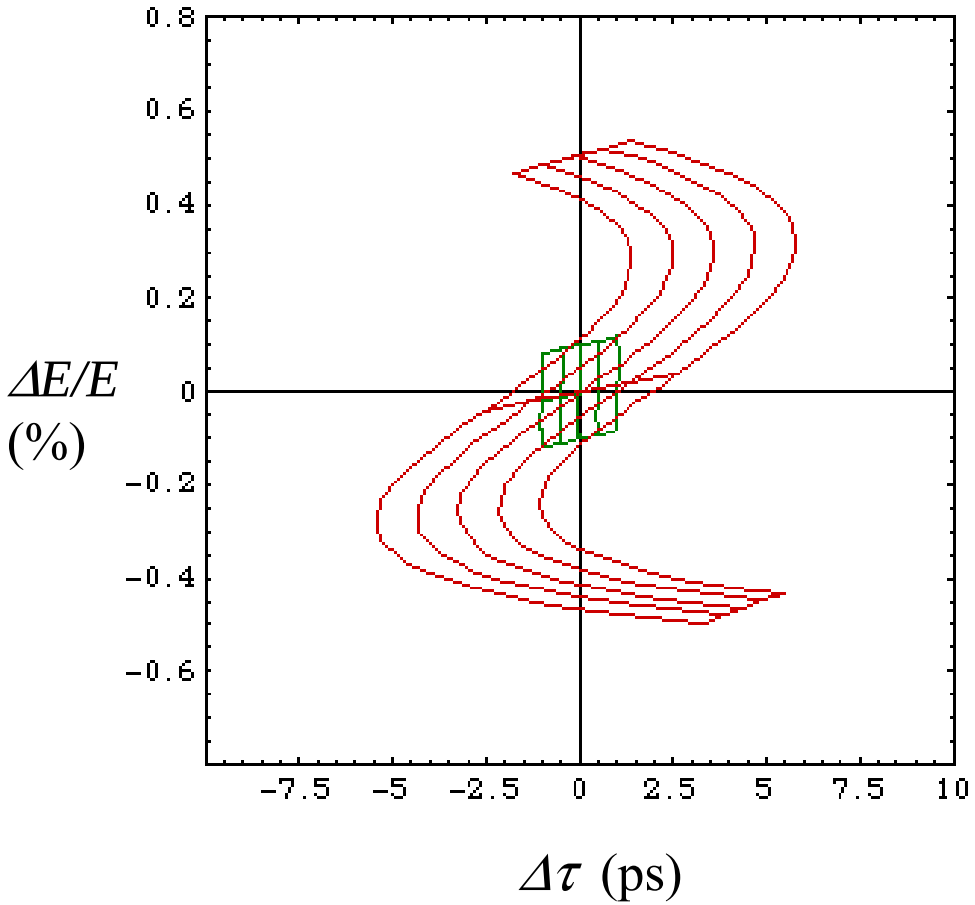
Photo-cathode RF gun



RF gun R&D room

Thermionic Gun

Photo-cathode rf gun



Electron Gun	Thermionic	Photo-Cath
Energy Spread	± 0.5%	± 0.1%
Bunch Length	2.2 ps	< 1 ps
Bunch Charge	< 0.1 nC	> 1 nC

Initial state

$\Delta E/E = \pm 0.5\%$; $\Delta\tau = \pm$ 2.2ps

. $\alpha_1 = -1.5 \times 10^{-6}$; after 500 turns

Initial state

$\Delta E/E = \pm 0.1\%$; $\Delta\tau = \pm$ 1ps

. $\alpha_1 = -0.5 \times 10^{-6}$; after 500 turns

Comparison with other methods

Beam Parameters	QI operation (BESSY-II)	Laser Slicing (ALS)	Short Bunch Circulation (SPring-8 Linac & NewSUBARU) Demonstration	Photo-cathode gun
bunch length (ps)	1.0 (1σ)	0.16 (1σ)	3 (1σ)	<1.0
charge (pC/bunch)	~ 1	~ 10	24	1000
Pulses per shot	quasi-dc	1	~ 50	>100 ?
	stable	short		strong

Beam physics study

1. Stable operation of quasi-isochronous ring

2. Circulation of an extreme beam
   - Similarity with ERL's arc
   - Problem would be enhanced with multi-turn circulation
   - Ring parameter can be tuned using stored beam

3. Future project at Tohoku Univ.
   - Circulation of sub-mm pulse
   - [H. Hama, 27th International FEL Conference (2005)].