Beam Stabilization in SPring-8 Linac

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Beam energy instability of SPring-8 linac is
***0.01%** rms.*
How have we achieved it …

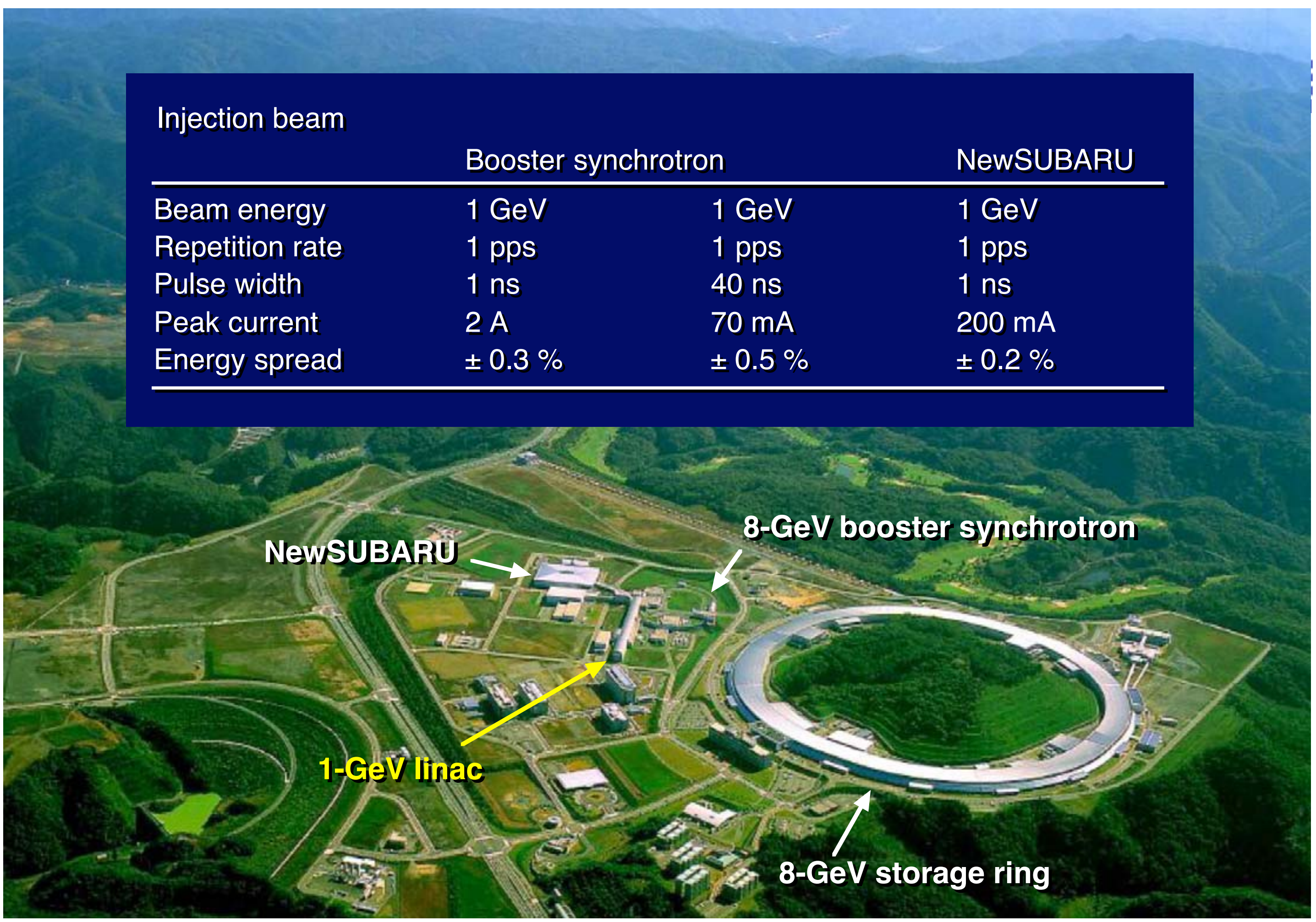
1 Overview of SPring-8 linac

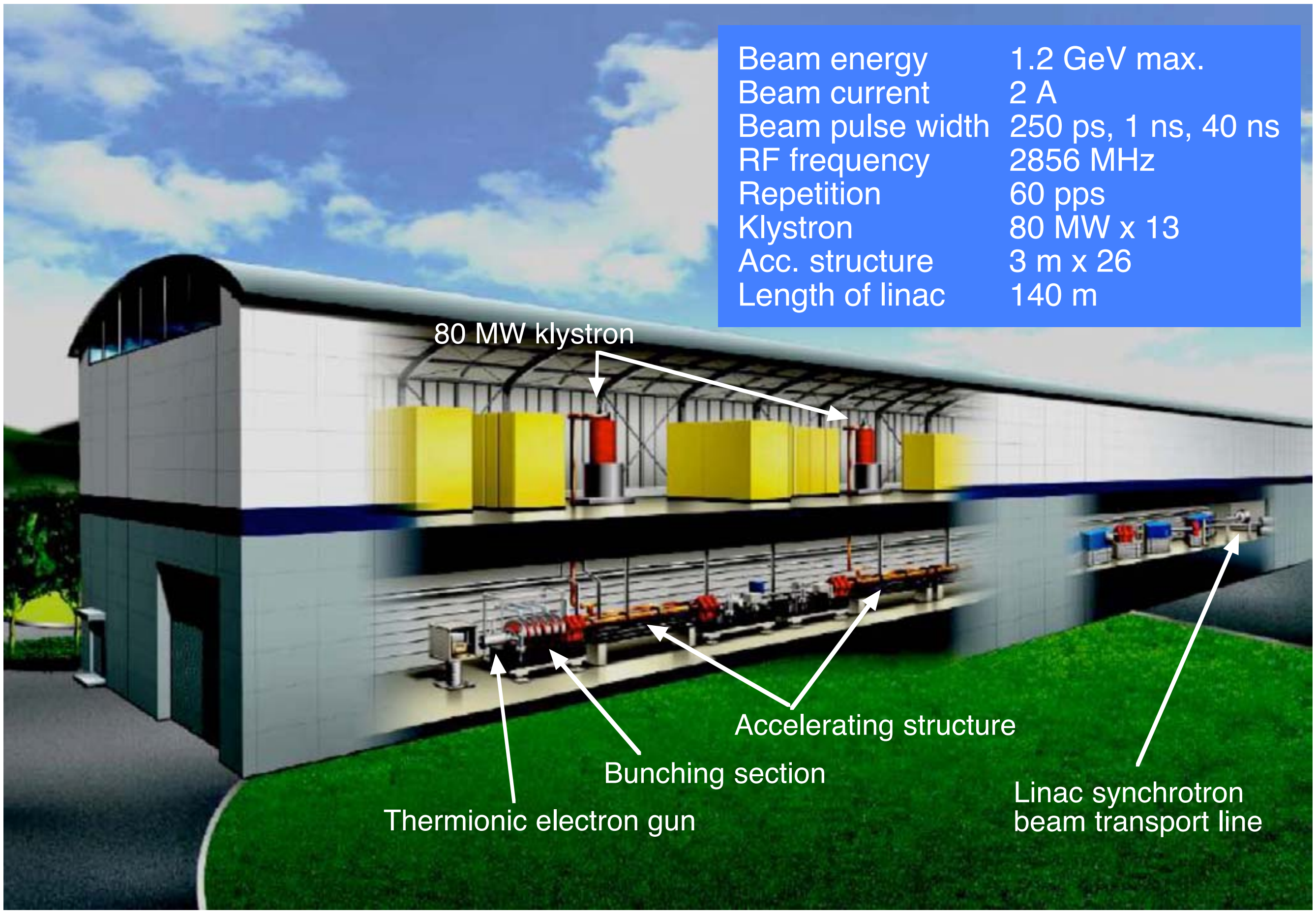
2 Beam stabilization
- Stabilization of RF amplitude & phase
- Synchronization of linac RF with ring RF
- Energy compression system (ECS)
- Feedback control

3 Summary

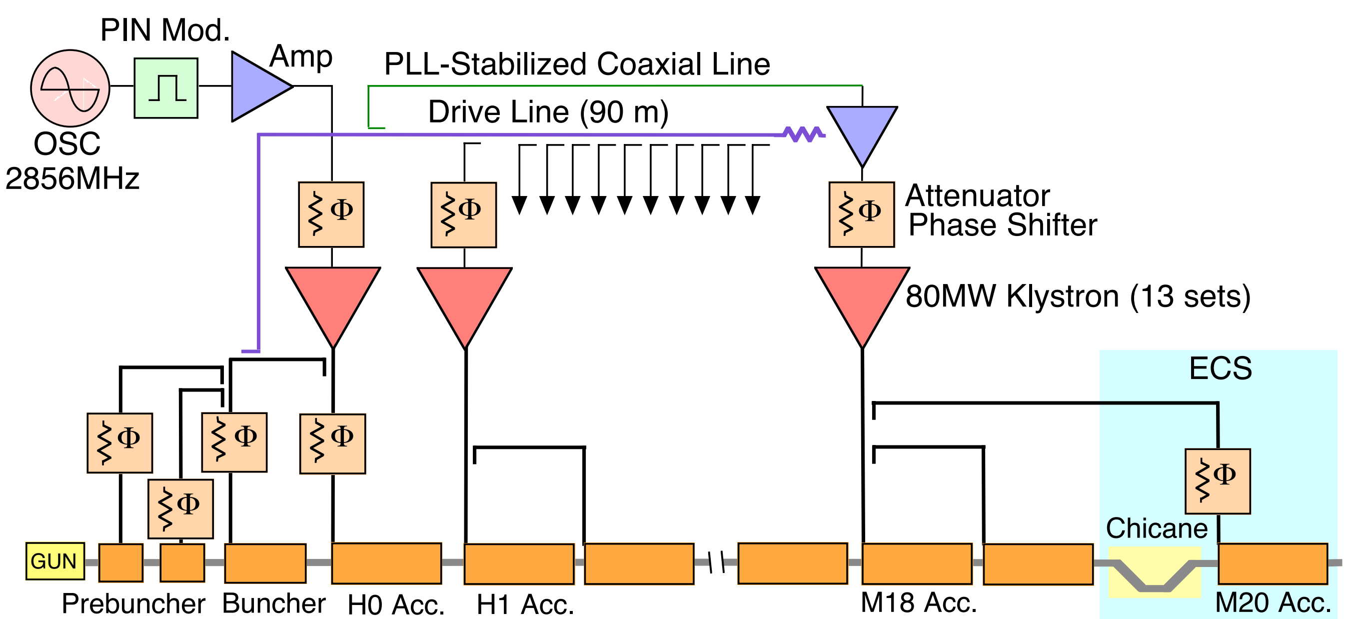
Injection beam

	Booster synchrotron		NewSUBARU
Beam energy	1 GeV	1 GeV	1 GeV
Repetition rate	1 pps	1 pps	1 pps
Pulse width	1 ns	40 ns	1 ns
Peak current	2 A	70 mA	200 mA
Energy spread	± 0.3 %	± 0.5 %	± 0.2 %

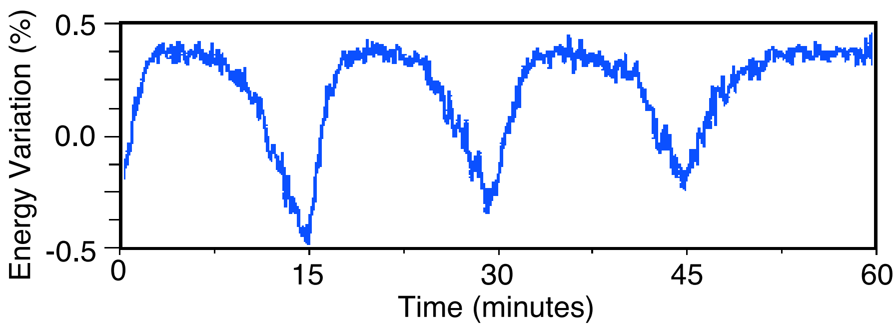


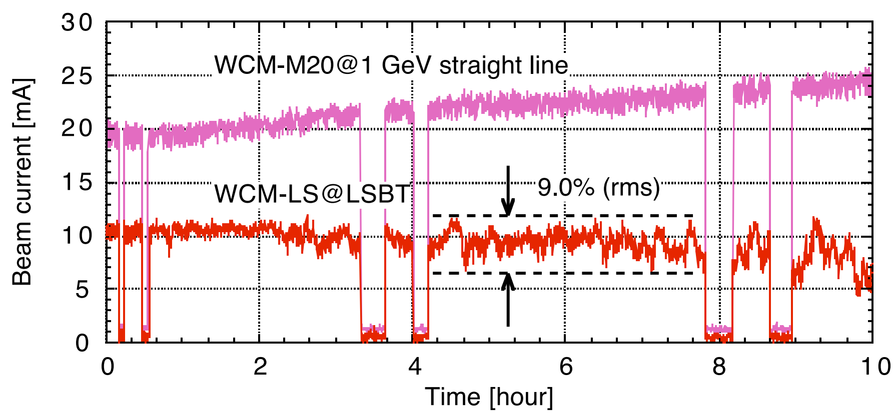


Present Linac RF System



Beam Injection Instability in 1998





Strategy for stabilizing beam energy

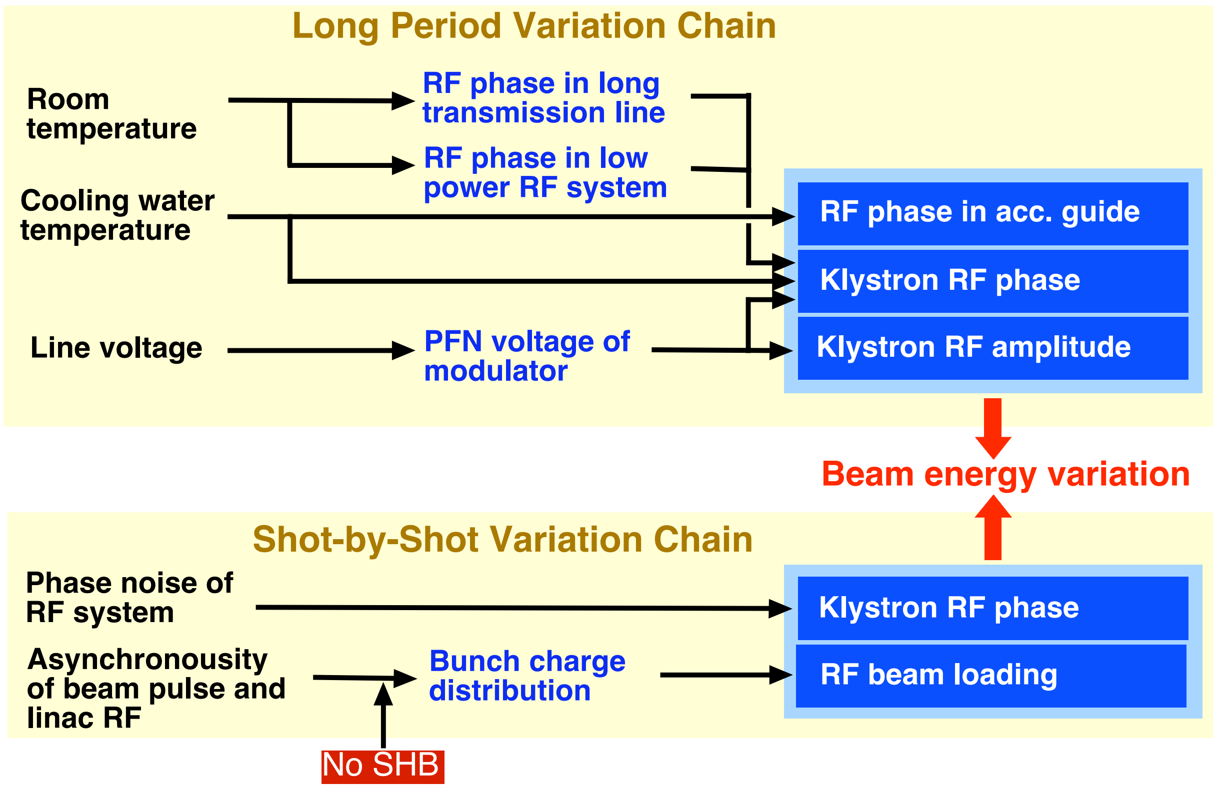
1 Stabilization of RF amplitude & phase
➡ Investigate variation chains
Stabilization of their origins or devices

2 Reduce beam loading fluctuation ◀ ***No SHB!***
➡ Synchronization of linac RF with ring RF

3 Compensate accidental energy variation
➡ Introduce Energy Compression System (ECS)

4 Reduce residual beam position drift
➡ Introduce feedback control

Variation chains in SPring-8 linac

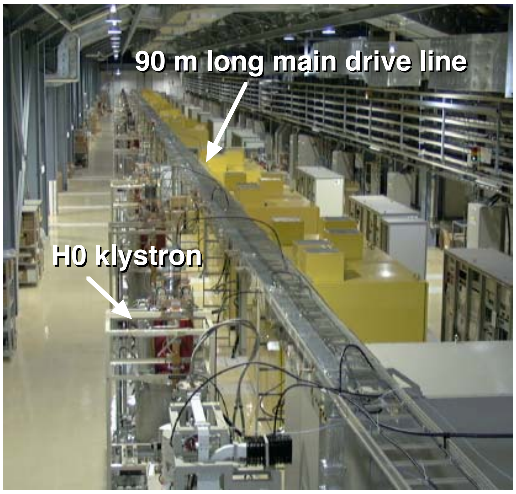


Reduction of long-period RF variation

- **Room temperature stabilization**
  - Readjustment of air conditioners
  - Covering the long drive line with heat jackets
  - Circulating temperature stabilized water inside the jackets
- **Klystron temperature stabilization**
  - Improvement of water cooling system
- **Isolate line voltage variation**
  - Stabilization of Pulse Forming Network (PFN) voltage by improving modulator regulation circuits

Room temperature stabilization

SPring-8

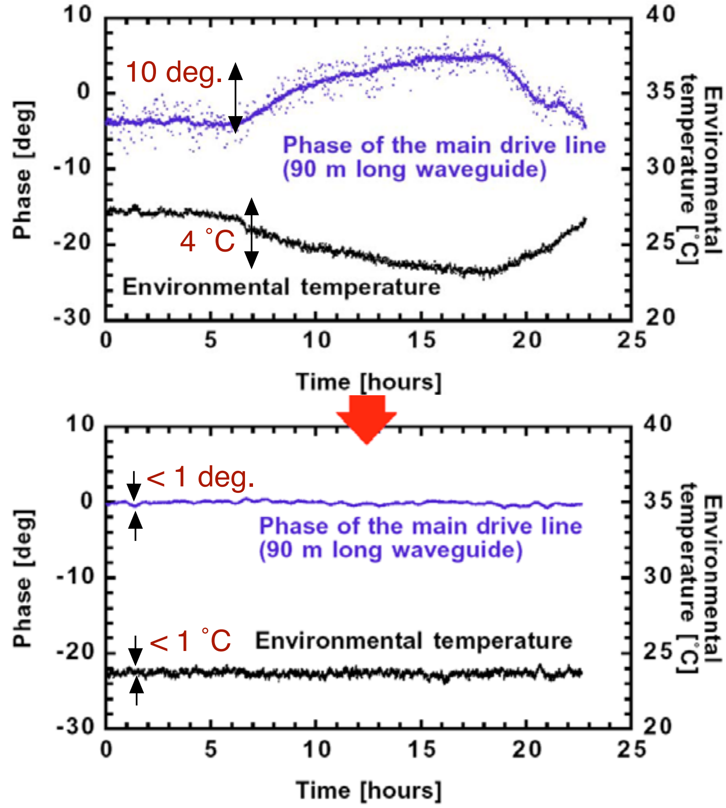


Phase variation

10 deg. / 4˚C

↓

< 1 deg. / 1˚C



Klystron temperature stabilization

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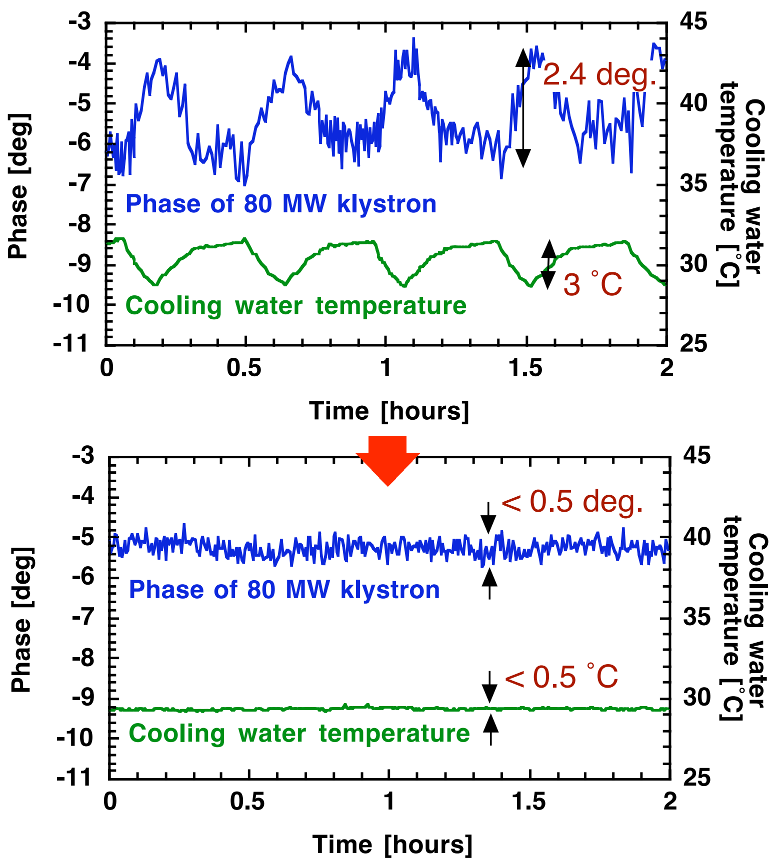

Phase variation

2.4 deg. / 3˚C

↓

< 0.5 deg. / 0.5˚C

Calculated temperature coefficient: 0.74 deg. / ˚C

Improvement of modulater regulation

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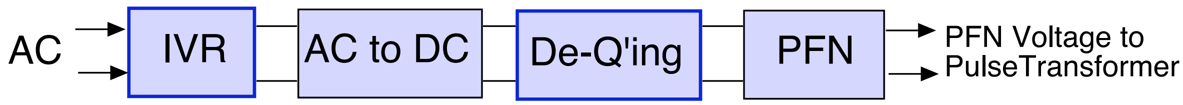
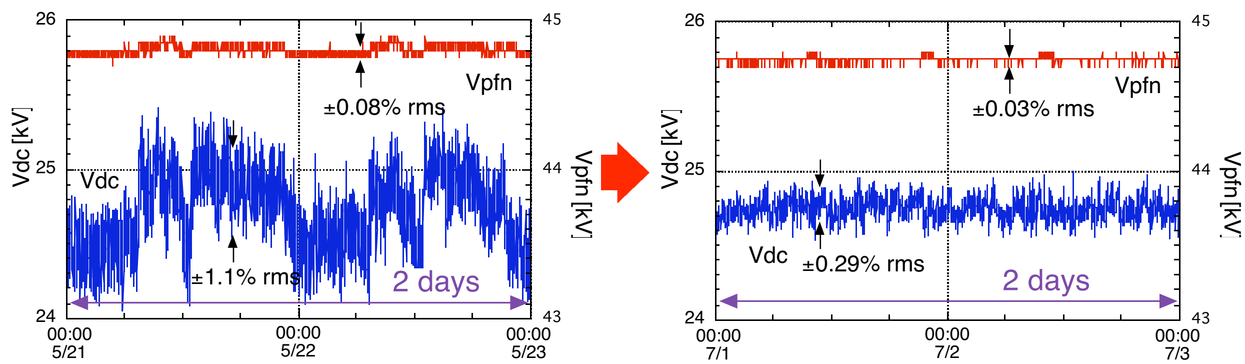


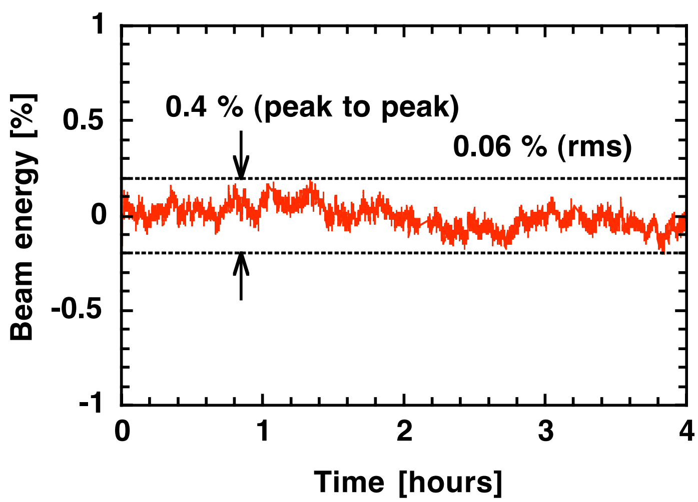
- Control Induction Voltage Regulator (IVR) to compensate line voltage variation
- Optimization of de-Q'ing rate
  7% ⟶ 4%

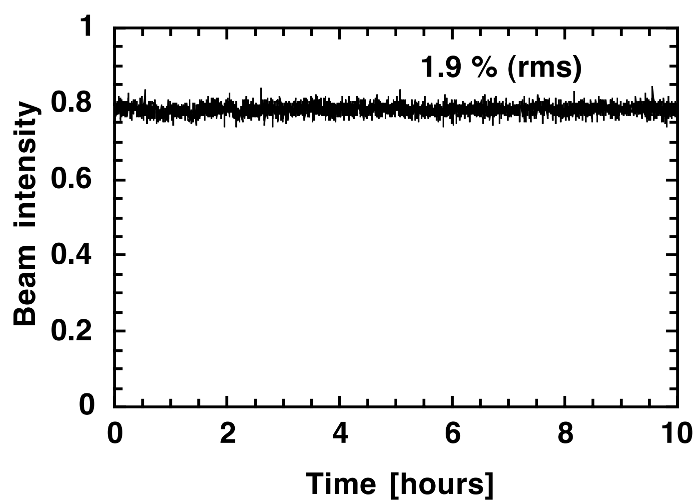
PFN voltage
0.3 % (rms)
⬇
0.03 % (rms)



Improved beam stability

SPring-8





Beam energy
> 1 % (10 h)
⬇
0.06 % (rms) (4 h)
0.03 % (rms) (10 min)

Beam current
> 20 %
⬇
1.9 % (rms)

Strategy for stabilizing beam energy

1. Stabilization of RF amplitude & phase
   ➡ Investigate variation chains
   Stabilization of their origins or devices
2. Reduce beam loading fluctuation ← ***No SHB!***
   ➡ Synchronization of linac RF with ring RF
3. Compensate accidental energy variation
   ➡ Introduce Energy Compression System (ECS)
4. Reduce residual beam position drift
   ➡ Introduce feedback control

Asynchronous RF issue before 2001

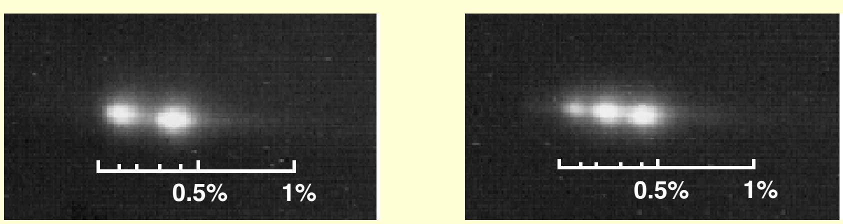
Ring 508.58 MHz → Counter → 1-Hz beam trigger

Linac 2856 MHz

Asynchronous relation (between the 1-Hz beam trigger and Linac 2856 MHz)

No Sub-harmonic buncher

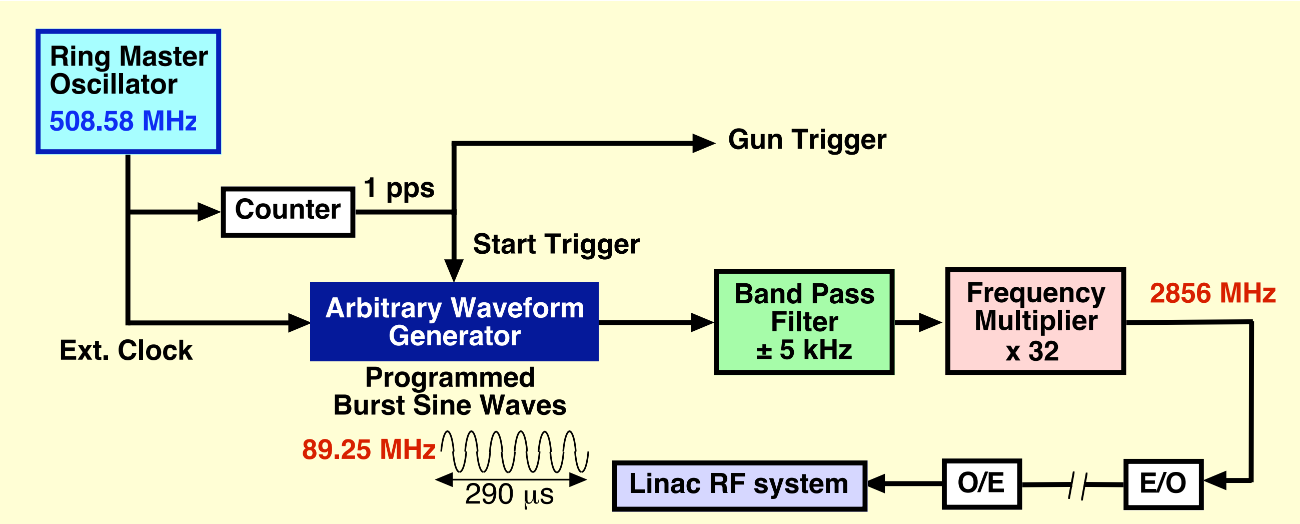
Asynchronous 2856-MHz RF forms two or three bunches along with beam trigger timing referred to the RF phase.



Energy distribution of 1-ns beam (@1.9A)

- Unstable beam energy at high current
- Unstable current of single-bunch beam

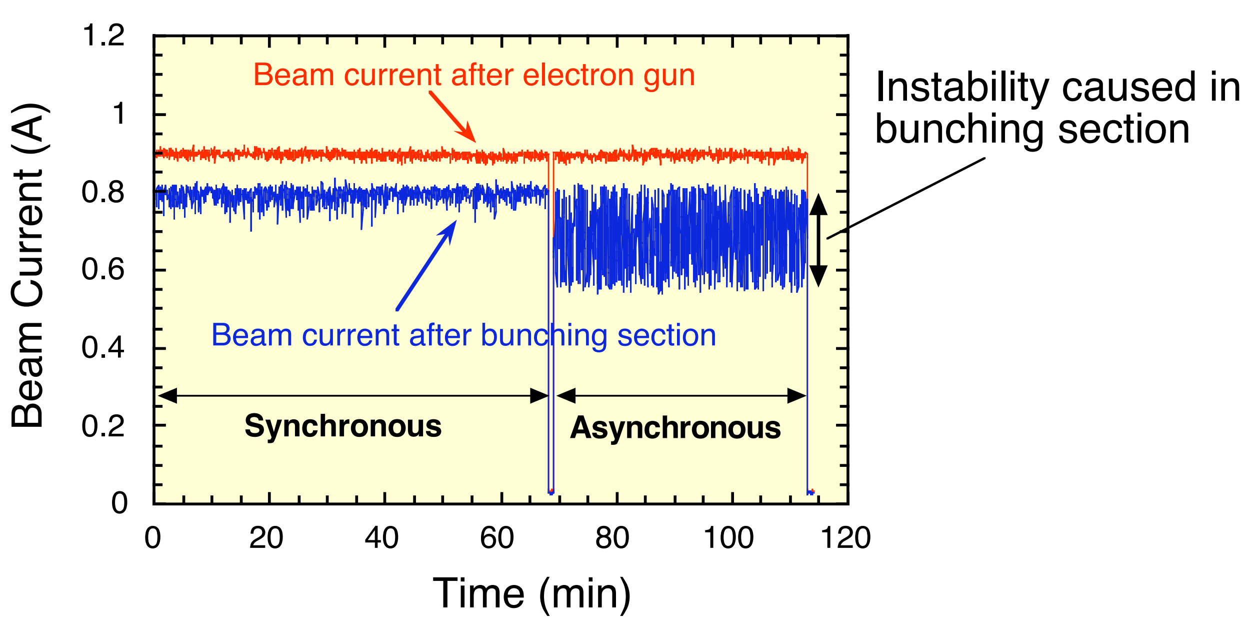
New synchronous oscillator



- A start signal synchronous to 508.58 MHz starts the AWG to generate a **burst wave** of 89.25 MHz
- A narrow band pass filter reduces phase noises

Single-bunch current stability

Beam pulse width : 250 ps



Beam energy stability at high current

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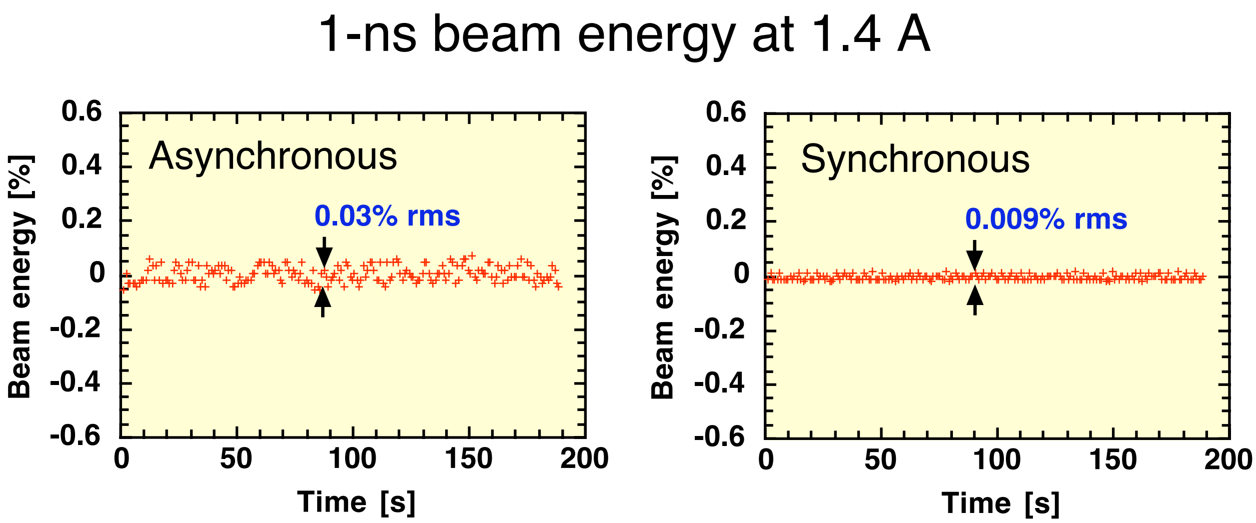
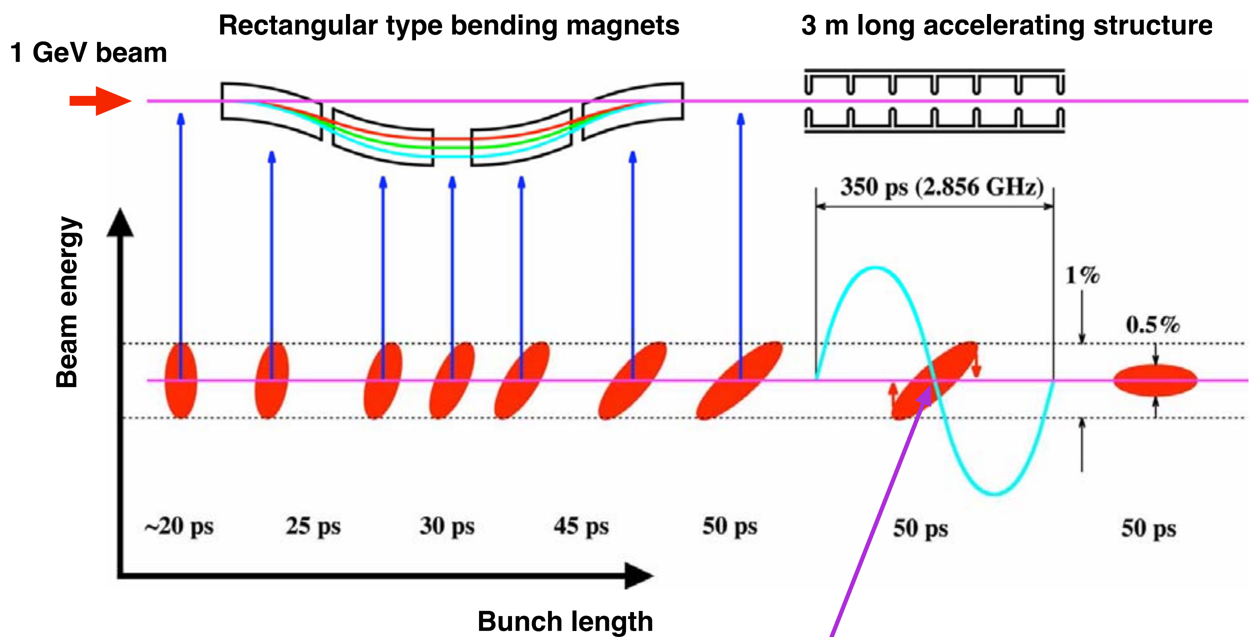


Strategy for stabilizing beam energy

SPring-8

1. Stabilization of RF amplitude & phase
   ➡ Investigate variation chains and fix their origins
2. Reduce beam loading fluctuation
   ➡ Synchronization of linac RF with ring RF
3. Compensate accidental energy variation
   ➡ Introduce conventional Energy Compression System (ECS)
4. Reduce residual beam position drift
   ➡ Introduce feedback control

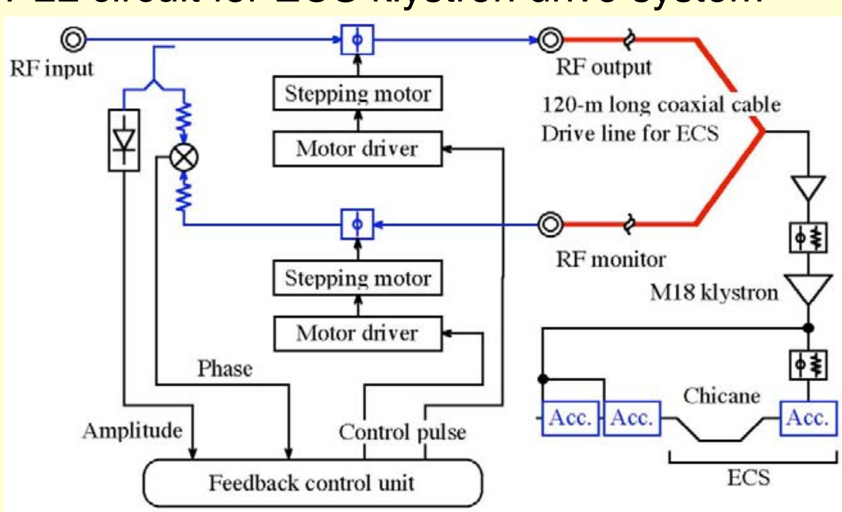
Energy Compression System (ECS)



- ▶ Chicane expands bunch length along with beam energy.
- ▶ ECS compresses beam energy spread and variation.
- ▶ ECS requires RF phase stability

ECS requires RF phase stability

1) PLL circuit for ECS klystron drive system



2) Klystron voltage > 350 kV

Phase variation
0.2 deg. rms

New synchronous Oscillator

Phase variation
0.2 deg. rms

ECS Phase instability: 0.3 deg. rms
Energy instability : ~ **0.01%** rms

ECS compressed beam energy spread

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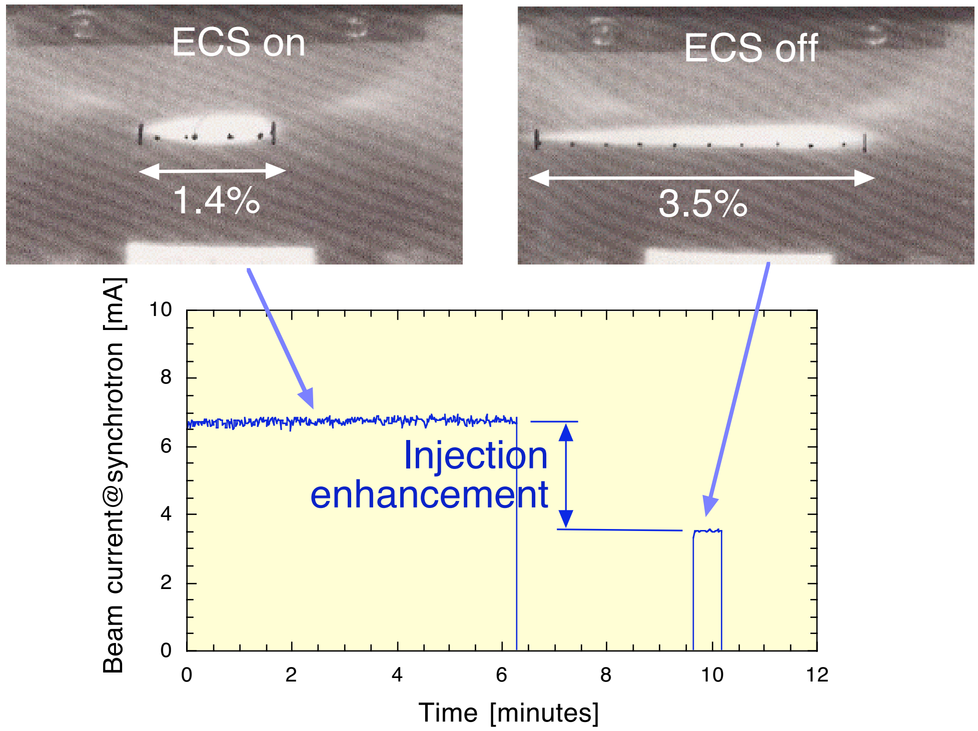
40-ns beam at 350 mA



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Feedback control of beam trajectory

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Problem: beam position drift

Beam position drift at the linac upstream
→ Small betatron oscillation
→ Beam position drift at the injection points

Solution: beam position feedback control

Beam position stabilization at BT lines
- Injector part
- Linac end
- Long BT to the NewSUBARU storage ring

Control steering magnets reffering to BPM data
- Position window: 60μm
- Response time: a few minutes

Beam Position Feedback Control

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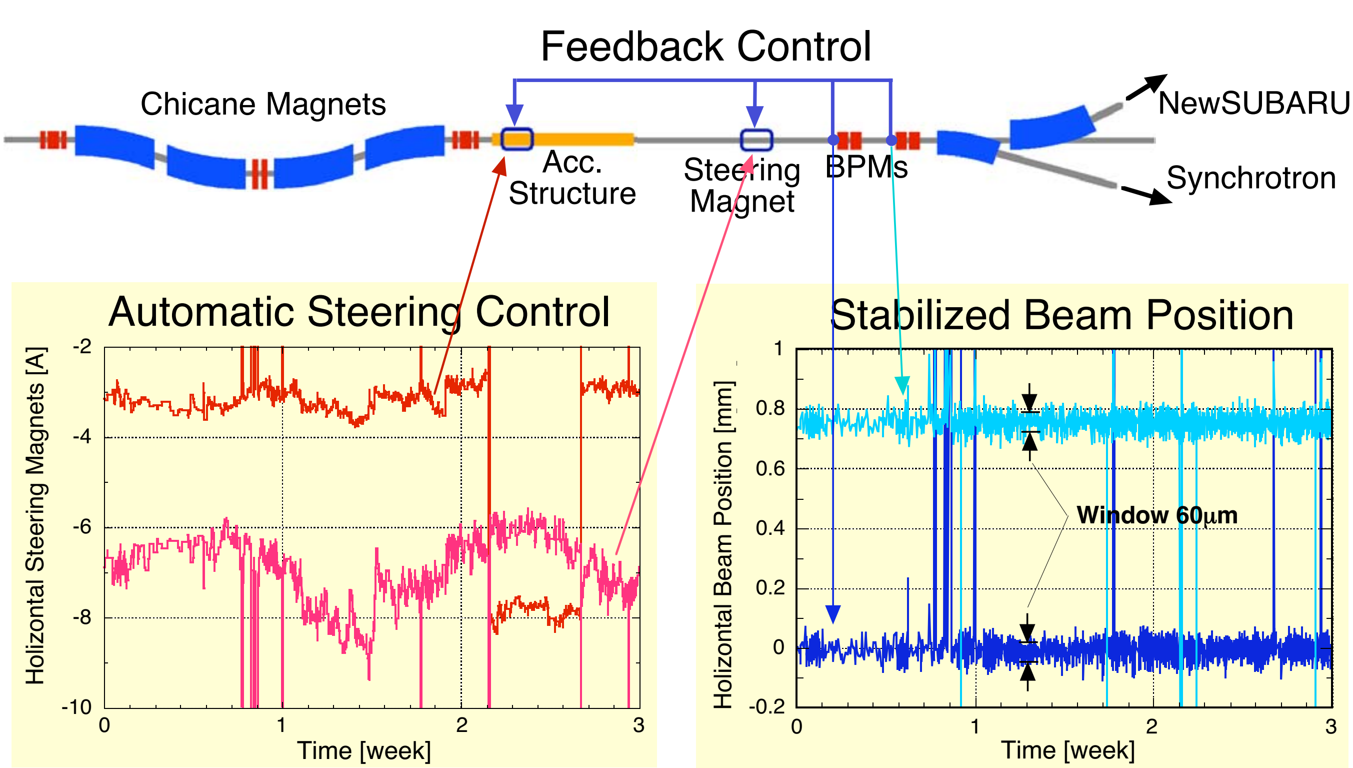

Summary

1 Stabilization of RF amplitude & phase

➡ Investigate variation chains
Stabilization of their origins or devices

➡ **Energy instability: 0.03% rms**

2 Reduce beam loading fluctuation

➡ Synchronization of linac RF with ring RF

➡ **Energy instability: < 0.01% rms**

3 Compensate uncontrolable energy variation

➡ Introduce Energy Compression System (ECS)

➡ **Long and short term stability**

➡ **High current injection**

4 Reduce residual beam position drift

➡ Introduce feedback control

➡ **Position stability: 60 μm**