Commissioning of Electron Beam for SuperKEKB Injector Linac

Masanori Satoh (KEK, Linac Control G.)
for the Linac Commissioning Group

The 18th KEKB Accelerator Review Committee, Mar. 4-6, 2013

Requirement

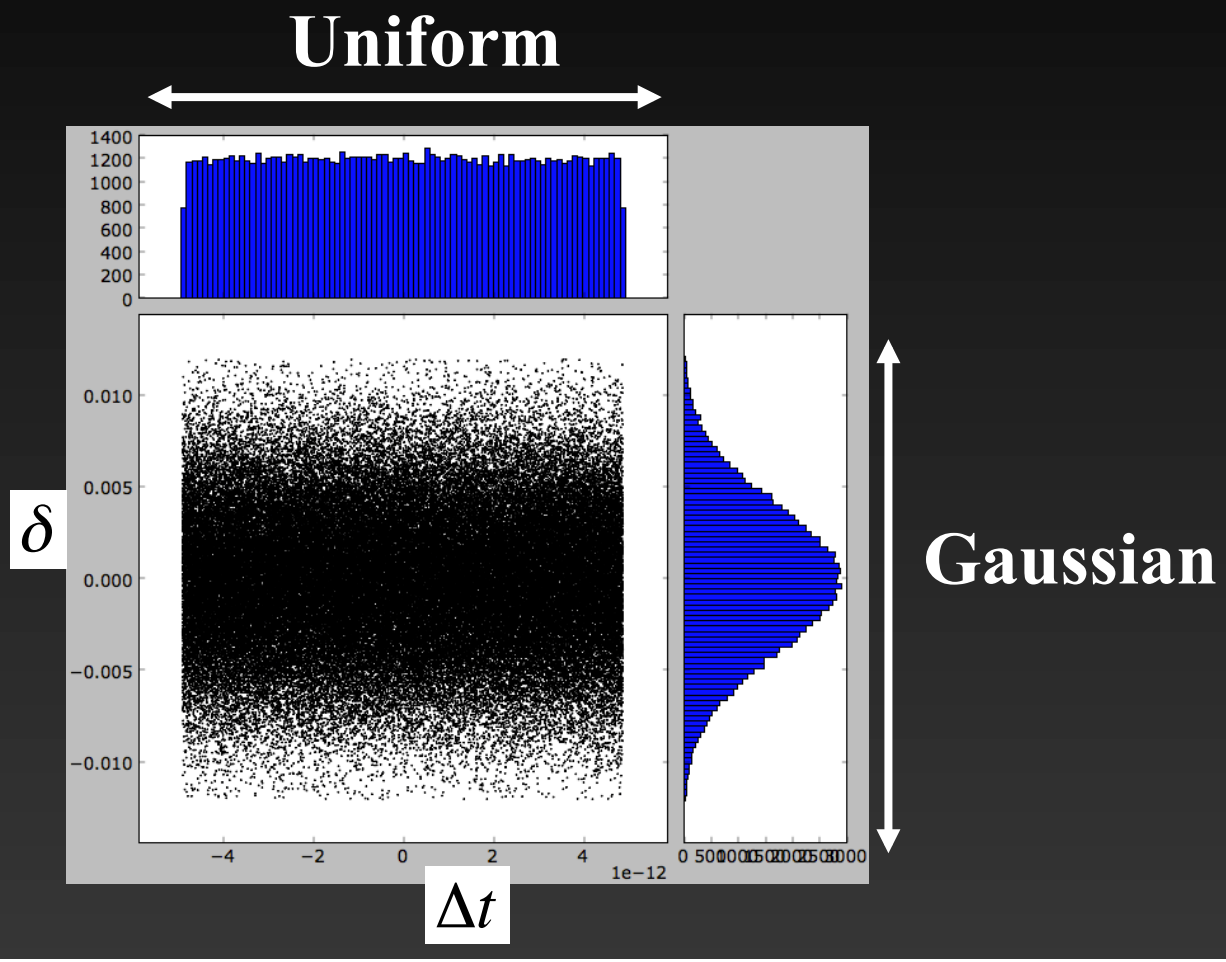
Electron Beam Parameters

	SuperKEKB Linac	KEKB Linac
Energy (GeV)	7	8
HER stored current (A)	2.6	1.2
HER beam lifetime (min.)	10	200
Maximum beam repetition (Hz)	50	50
Max. # of bunch in a rf pulse	2	2
Emittance (mm·mrad)	20	100
Charge (nC)	5	1
Energy spread (%)	0.08	0.05
Bunch length σz (mm)	1.3	1.3
Simultaneous top-up injection	4 rings (SuperKEKB e-/e+, PF, PF-AR)	3 rings (KEKB e-/e+, PF)

Energy Spread

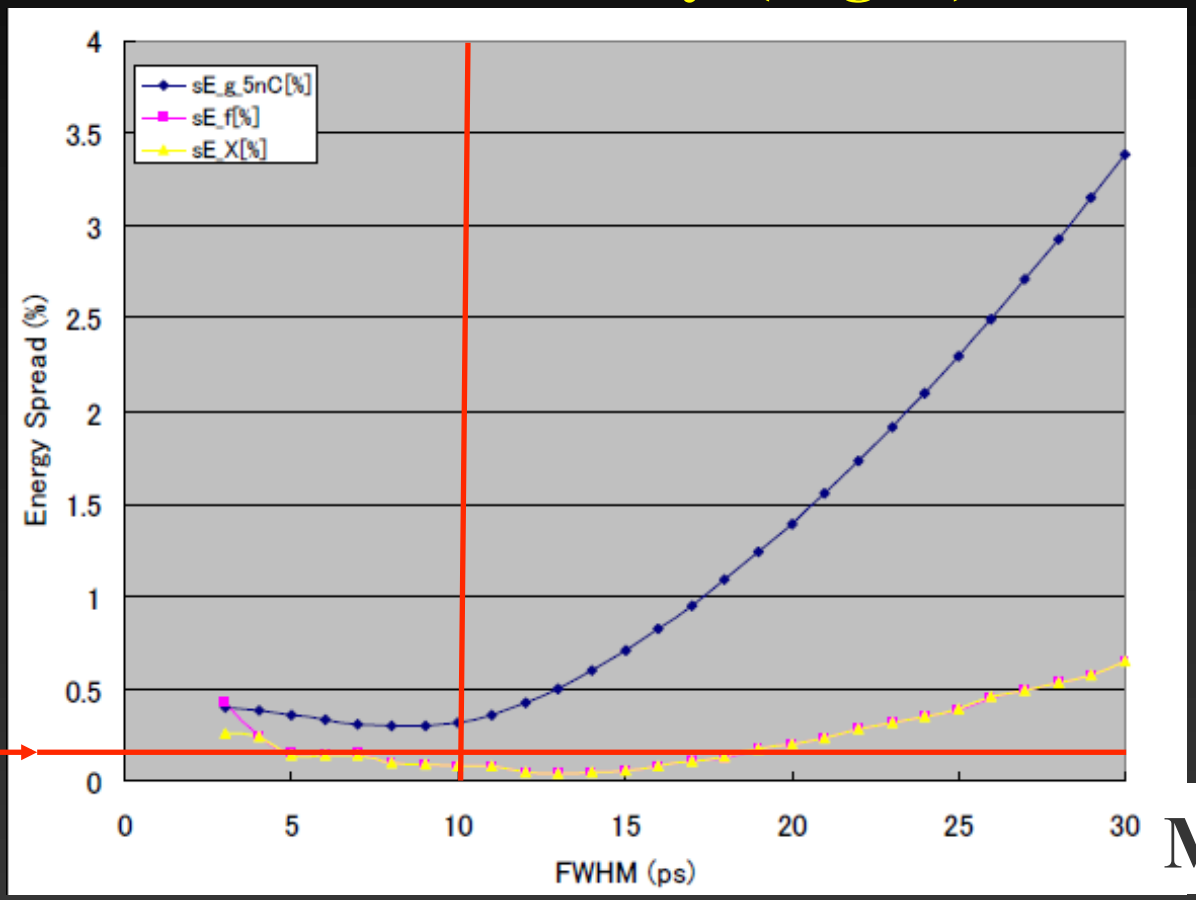
Uniform shape of longitudinal beam distribution

- Energy spread should be less than 0.08%
- Mitigate longitudinal wakefield and reduce energy spread
- Gaussian distribution in momentum space



Energy spread

- For 10 ps bunch length,
  - ~ 0.3% for Gaussian distribution
  - < 0.08% for uniform distribution
- **Uniform distribution is necessary. (rf gun)**



0.08%

M. Yoshida

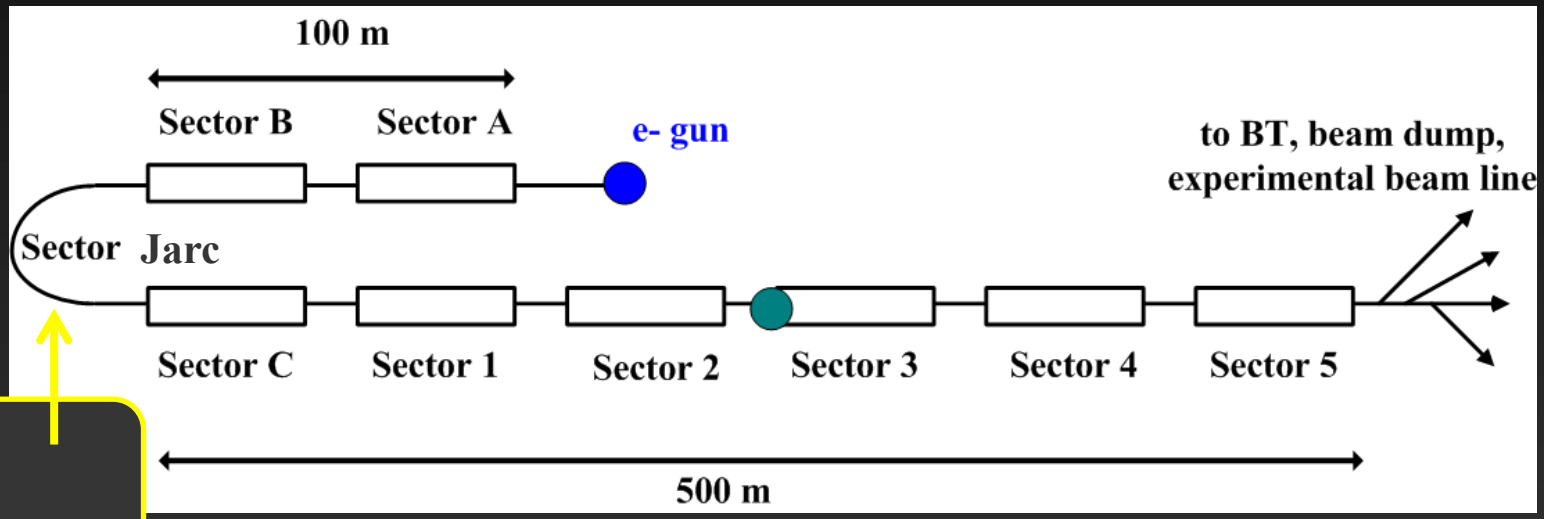
Low Emittance

Low emittance electron

- Low emittance electron beam should be delivered to MR w/o damping ring.
- Emittance preservation is key issue
- RF gun (M. Yoshida, T. Natsui, X. Zhou)
- Emittance growth simulation (H. Sugimoto)
  - SAD code, Elegant
  - Initial bunch charge: 5 nC
  - Initial emittance: 6 mm·mrad
  - Initial bunch length: 10 ps (FWHM)
  - Initial energy spread : 0.4%
  - Initial beam energy: 20 MeV
  - Uniform longitudinal beam distribution

Bunch compression at Jarc

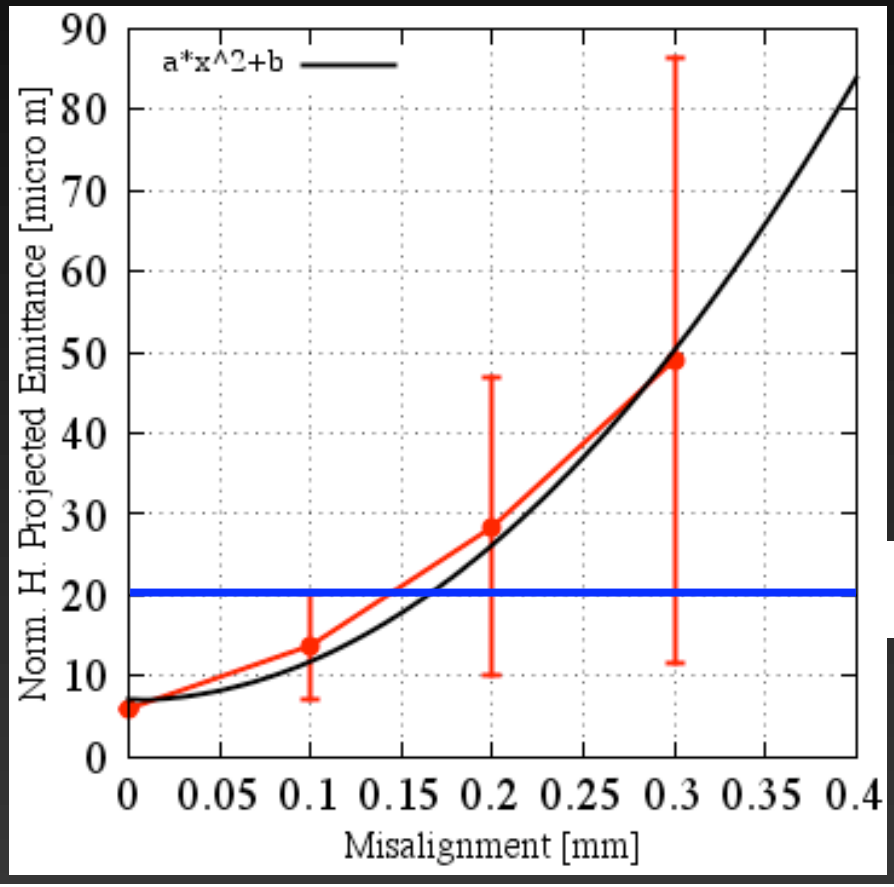
- Mitigate transverse wakefield and emittance growth
- Initial bunch length 10 ps => 5 ps (bunch compression at Jarc)
- Control R56 at Jarc



Bunch compression

Emittance growth due to component misalignment

- Simulation results from 100 different seeds
- Misalignment of Quadrupole magnets and Accelerating structure:
  - σ < 0.1 mm: ε 20 mm·mrad is almost satisfied.
  - σ > 0.1 mm: emittance preservation is very difficult.



<Emittance growth>

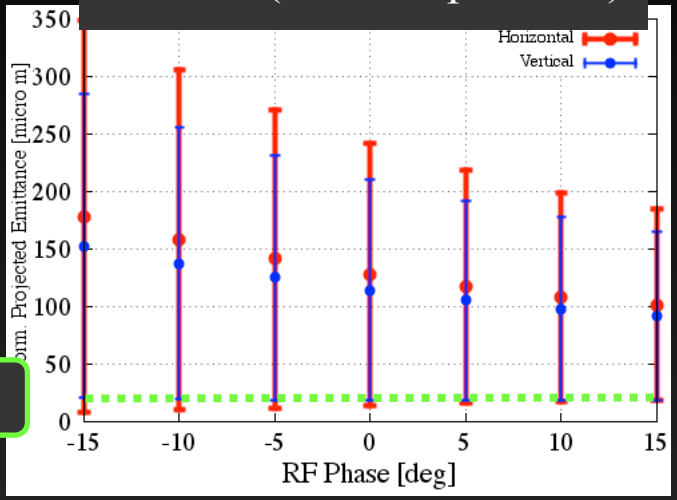
- quadratic curve as a function of misalignment
- strongly depend on error seed

requirement

Emittance (misalignment σ = 0.3 mm)

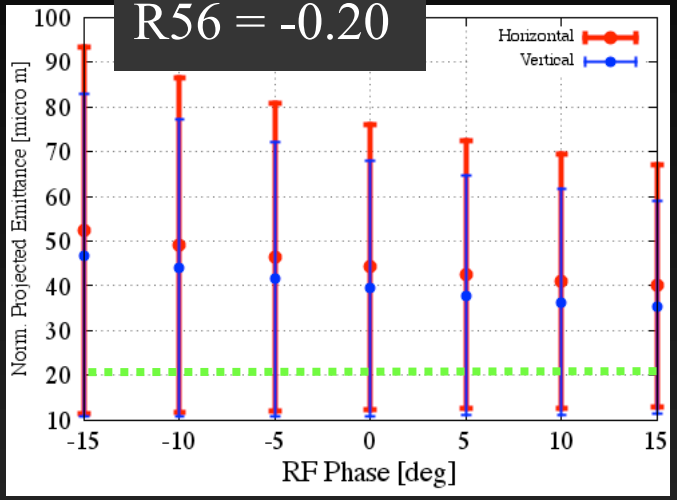
Bunch compression is effective. However, still not enough for 20 mm·mrad

R56 = 0 (w/o compression)



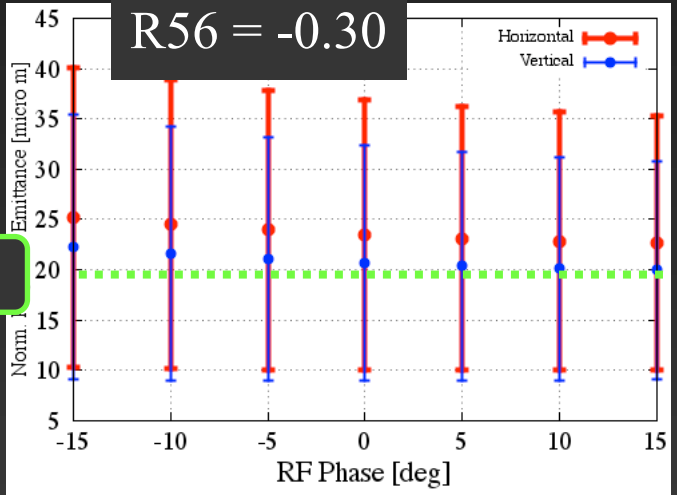
20 mm·mrad

R56 = -0.20



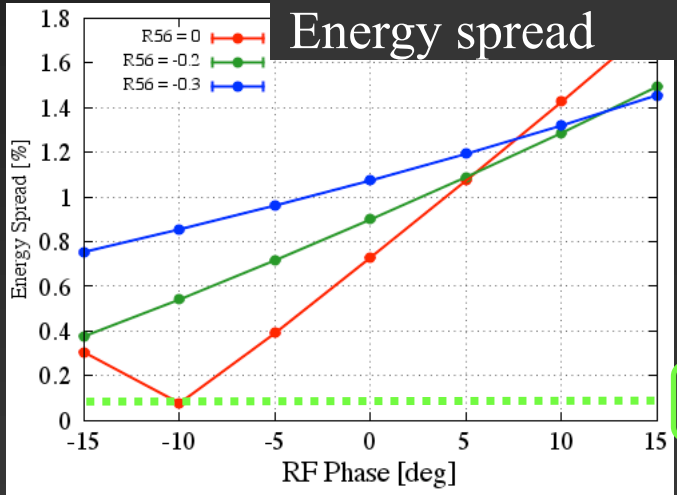
20 mm·mrad

R56 = -0.30



20 mm·mrad

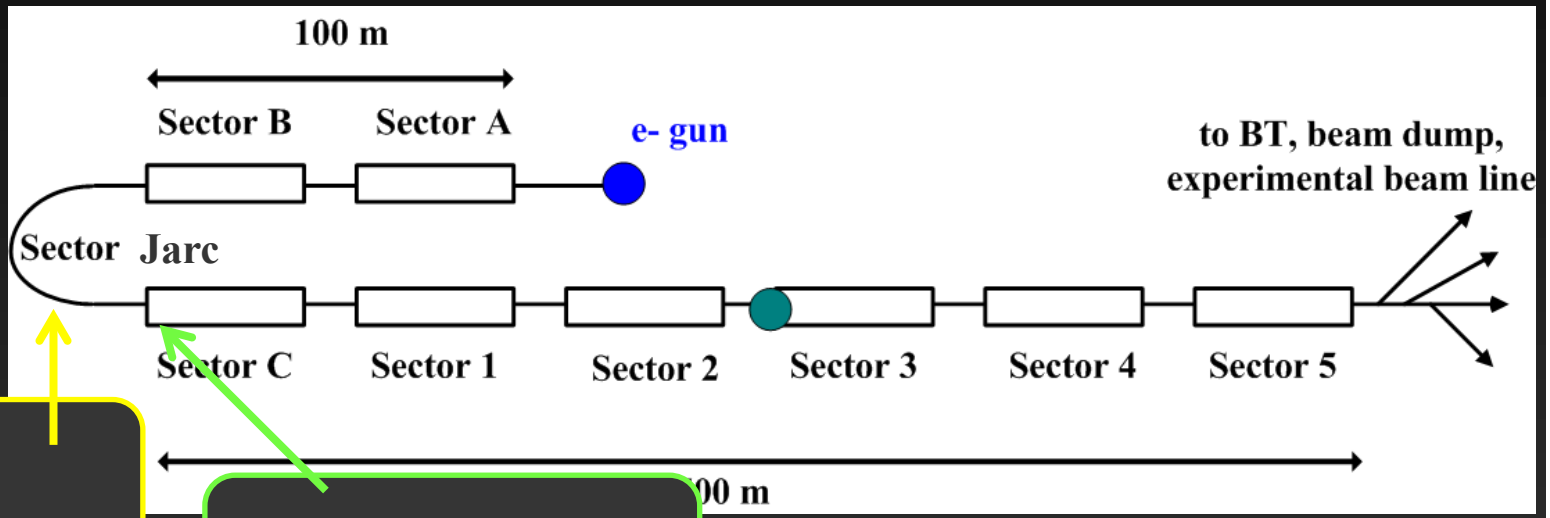
Energy spread



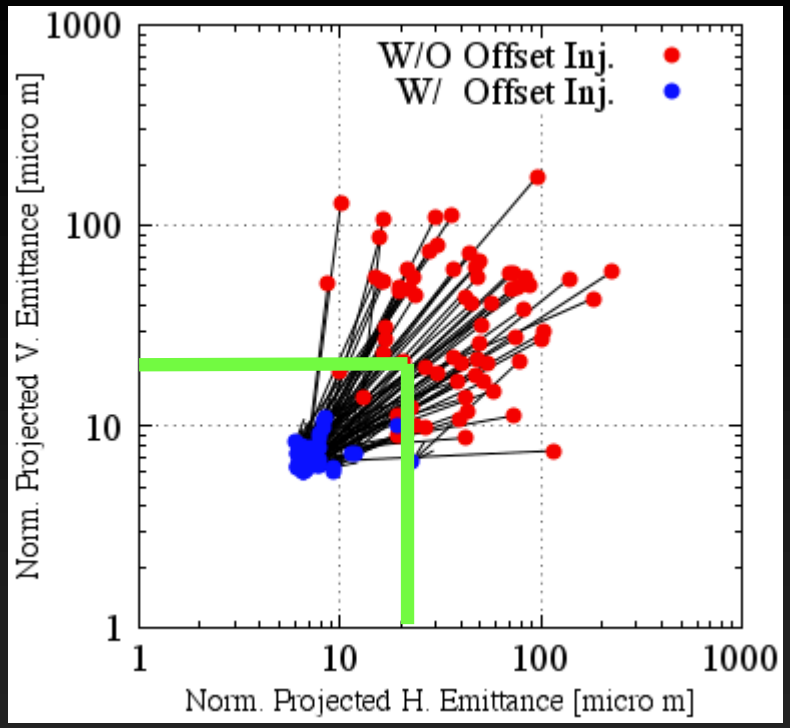
0.08%

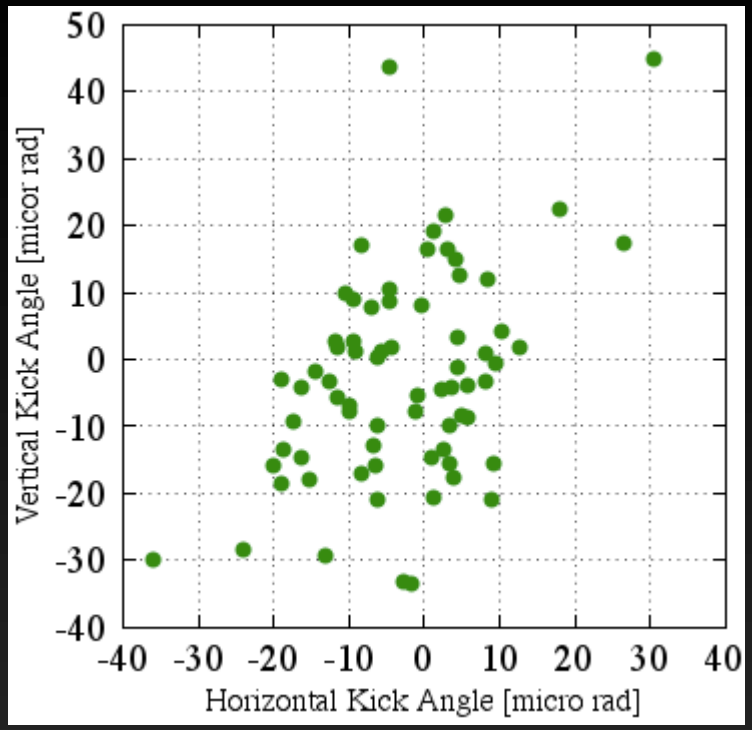
Offset injection for emittance preservation

- Offset injection: intentional change of misalignment seed
- Kicks at the beginning of Sector C



Offset injection (simulation)



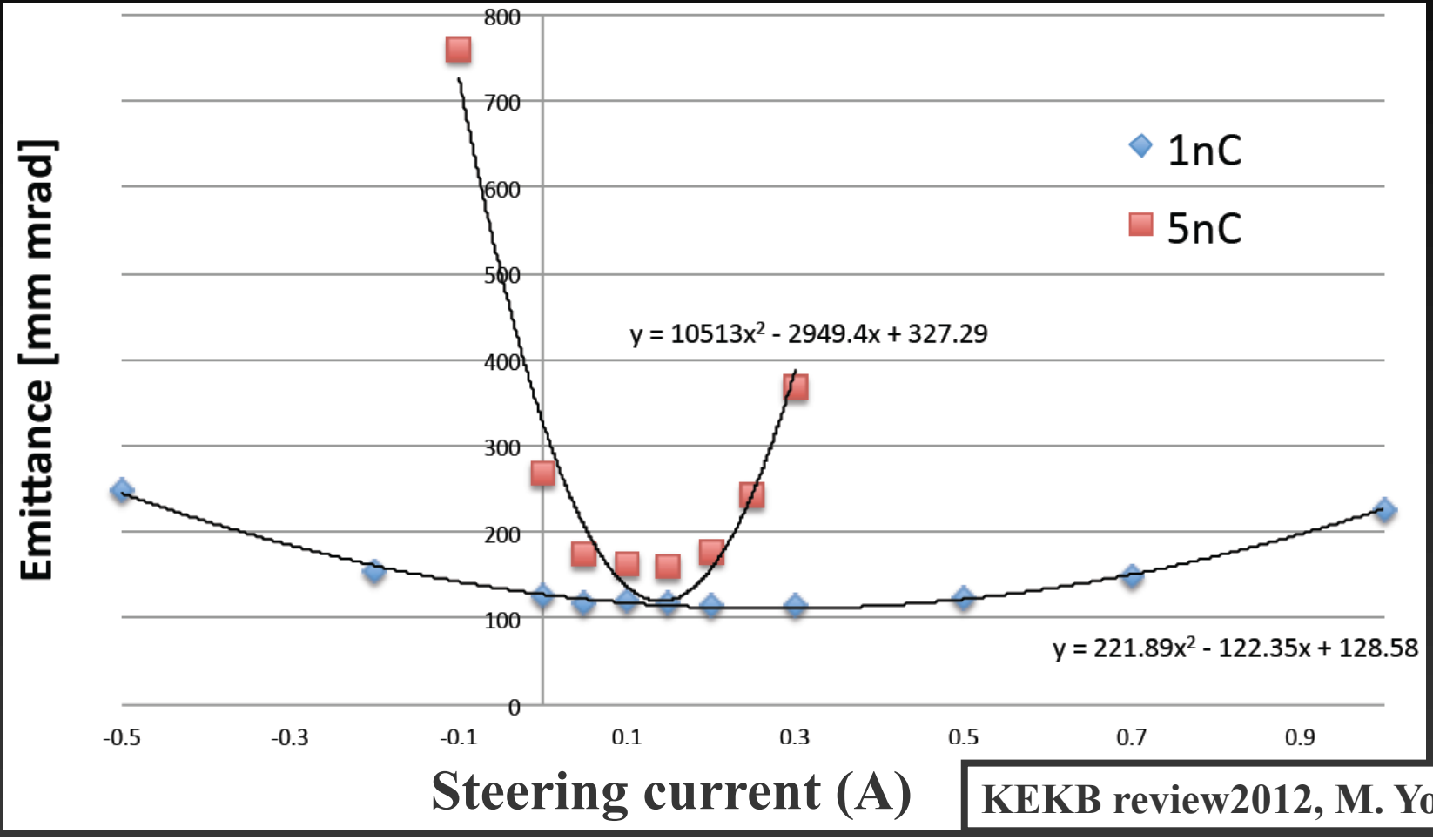


	Average (mm·mrad)	Standard Deviation (mm·mrad)
W/O Offset Inj.	43	28
W/ Offset Inj.	7.4	2.9

- Kick angle is relatively small compared to the case of orbit correction.
- Need a high-precision and stable orbit control.

Offset injection (experiment at Sector A, B)

Effective for high-intensity bunch



KEKB review2012, M. Yoshida

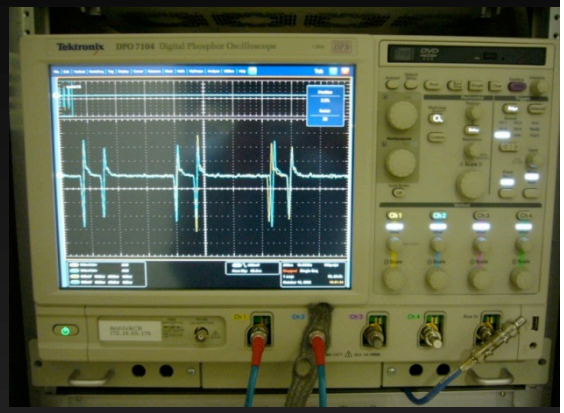
Low emittance electron issue

- Component alignment is important
  - $\sigma < 0.1$ mm: good for emittance (alignment is very difficult)
  - $\sigma > 0.1$ mm: Beam manipulation is necessary.
- $\sigma \sim 0.3$ mm
  - Jarc: Bunch compression
  - Sector C: Offset injection
  - Emittance can be preserved.
  - Small energy spread is difficult.

- **Alignment requirement**
  - **$\sigma < 0.3$ mm for global (whole Linac)**
  - **$\sigma < 0.1$ mm for local (one Sector ~ 100-m-long)**

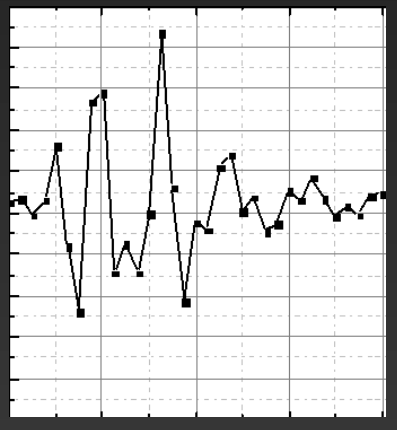
High Precision Beam Position Measurement

- **Current system:**
  - WindowsXP-based digital oscilloscope
    - 10 GSa/s, 8 bits, 1 GHz bandwidth, 4 channels
    - Acquisition speed: 50 Hz
    - Twenty four systems process 100 BPMs
    - Position measurement precision: 50 μm (3-BPM)



- More precise orbit measurement < 10 μm

- New system based on band-pass sampling scheme is under test and development.



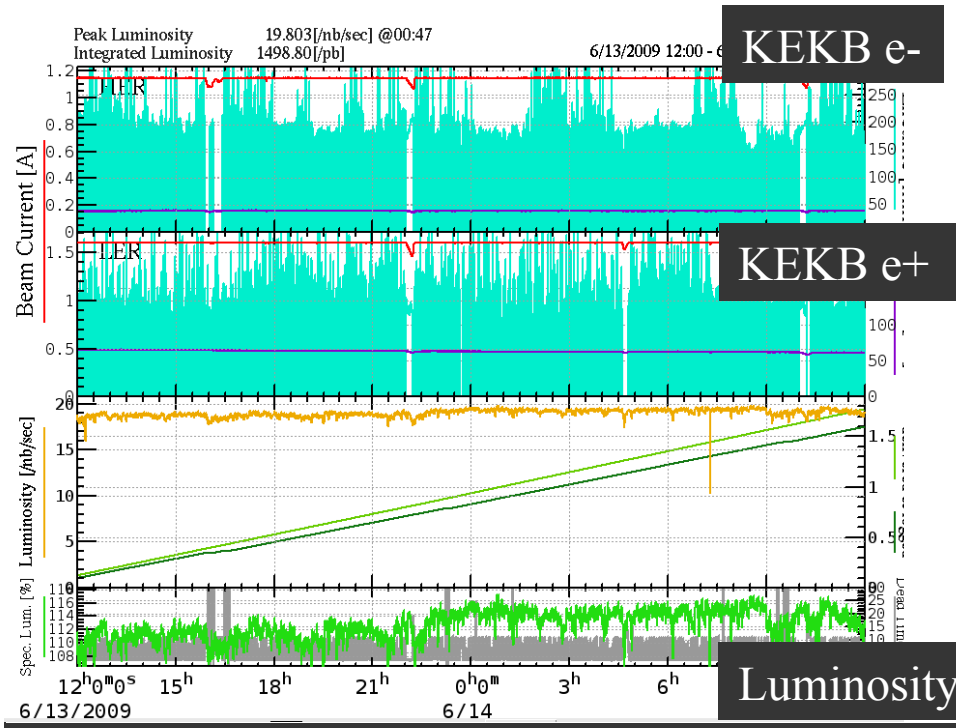
New system:

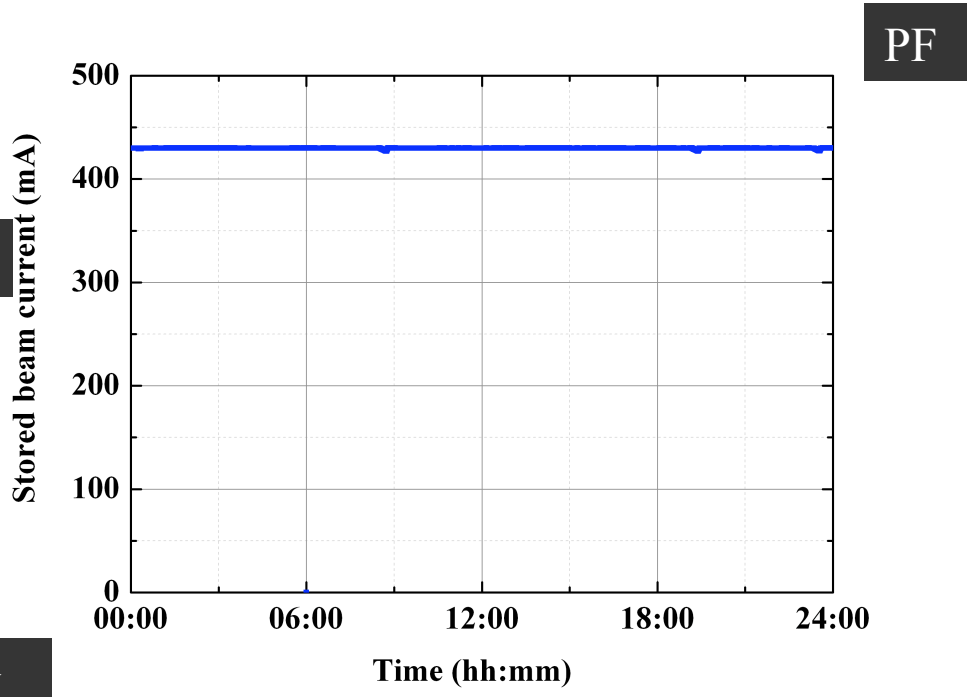
	Oscilloscope (current)	Libera Brilliance SP	Libera SPE (under test)	KEK-VME based (under development)
Signal generator (gain calibration)	N/A	N/A	N/A	○
Band-pass filter	N/A	fc: 522 MHz BW: 24 MHz	fc: 522 MHz BW: 24 MHz	Fc: 300 MHz BW: 30 MHz
A/DC	8 bits, 10 GSa/s	16 bits, 125 MSa/s	16 bits, 160 MSa/s	16 bits, 250 MSa/s
Software (EPICS)	○	○	○	× (need development)
Event system	via network	via network	EVR inside (μ-TCA-like)	VME-EVR
Precision	50 μm (3BPM)	10 μm (test pulser) 20 μm (3BPM, 0.1 nC)	3.5 μm (test pupulser) ? (3BM)	?
Remarks	FY2015 End of support	Discontinued	Candidate	Candidate

Simultaneous Top-Up for 4 Rings

Simultaneous Top-up Operation for three rings

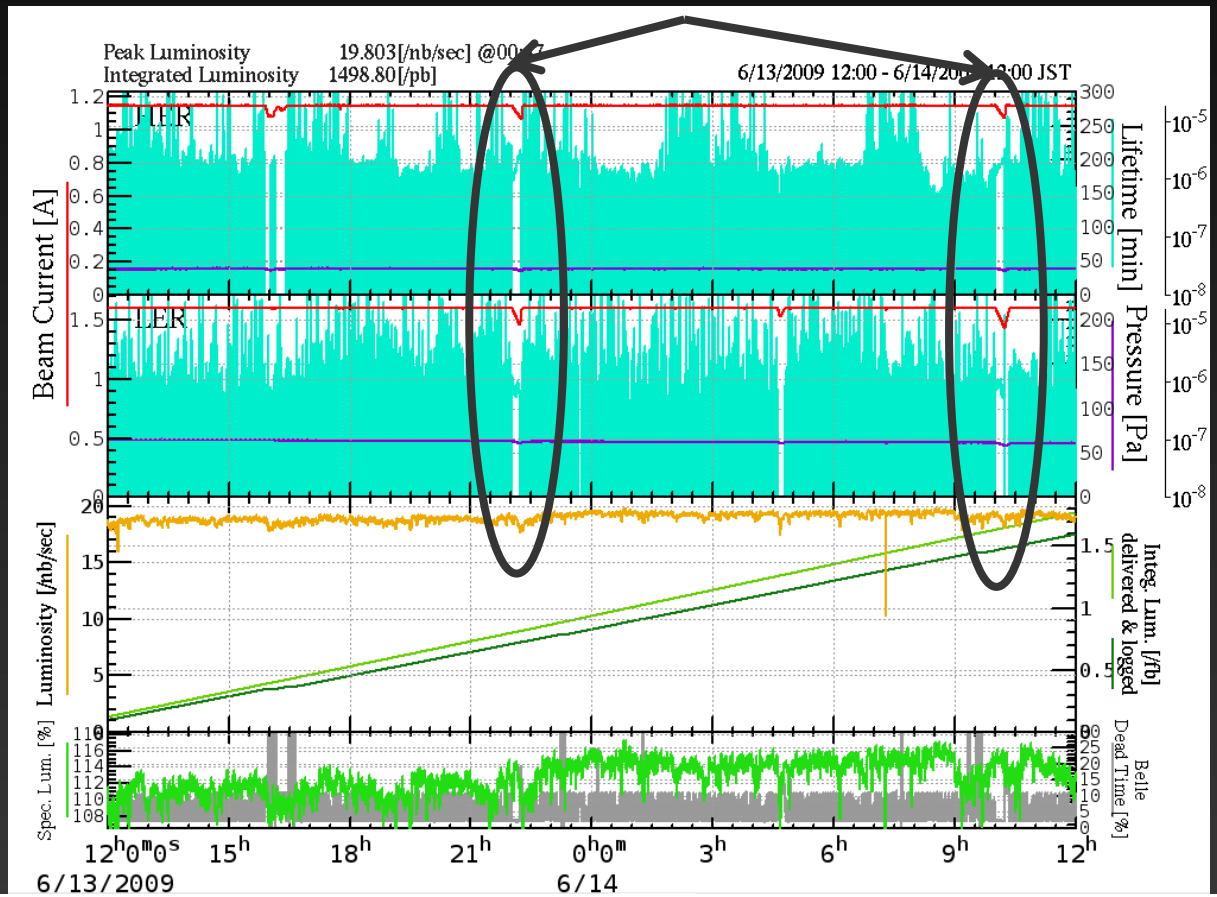
- Stored beam current stability since Apr. 2009
  - KEKB: 1 mA (~ 0.05%) : e-: 12.5 Hz, e+: 25 Hz
  - PF: 0.05 mA (~ 0.01%) : 0.5 Hz





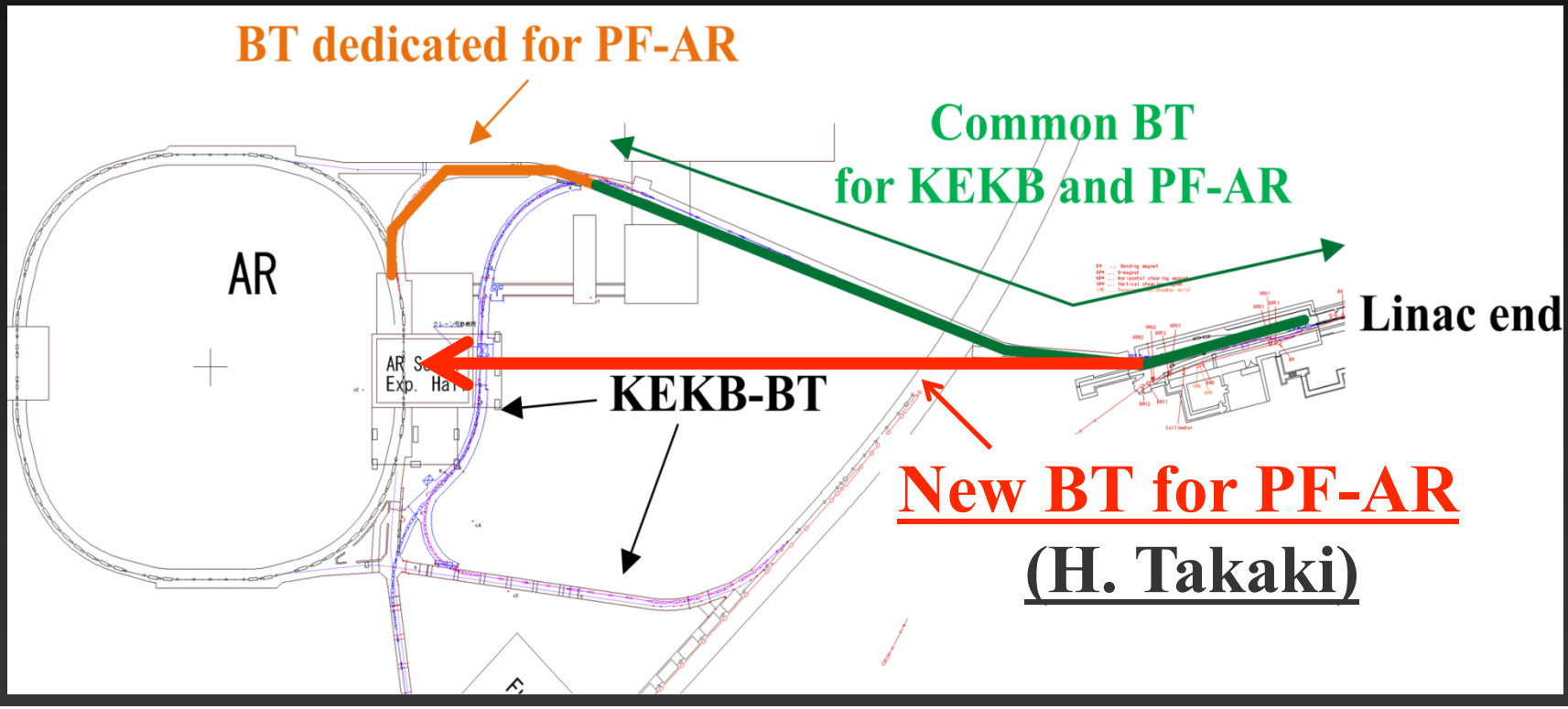
PF-AR injection: 20 min., twice daily

- Interrupt KEKB injection
- Problem for SuperKEKB (beam life: 10 min.)



Simultaneous top-up including PF-AR injection

- PF-AR and KEKB share the long part of beam transport line.
- Existing tunnel space is very tight.
- New beam transport line is required for PF-AR top-up injection.



Summary

Stable beam operation
(simultaneous top-up for 4 rings)

Feedback loops (energy, orbit , energy spread)
Precise beam diagnostic and control
Commissioning tools

Low emittance
(20 mm·mrad)

Small energy spread
(0.08%)

rf gun
Alignment
Bunch compression
Offset injection

Uniform longitudinal beam distribution

High bunch charge (5 nC)

Future plan

- **Low Emittance Preservation**
  - Simulation study
    - Including BPM reading, steering setting errors, and timing jitter
  - Beam study
    - Bunch compression at Jarc
      - **Streak camera required**
    - Emittance preservation study
      - Wire scanner (Sector2) will be installed
    - **Pulse-to-pulse beam stability**
- High precision BPM data processing system
  - Evaluation, 3-BPM (beam test)
- Simultaneous top-up 4 rings (including PF-AR)

Thank you for your attention!