Injector Commissioning

Masanori Satoh
(Accelerator Laboratory, KEK)
for the Linac Commissioning Group

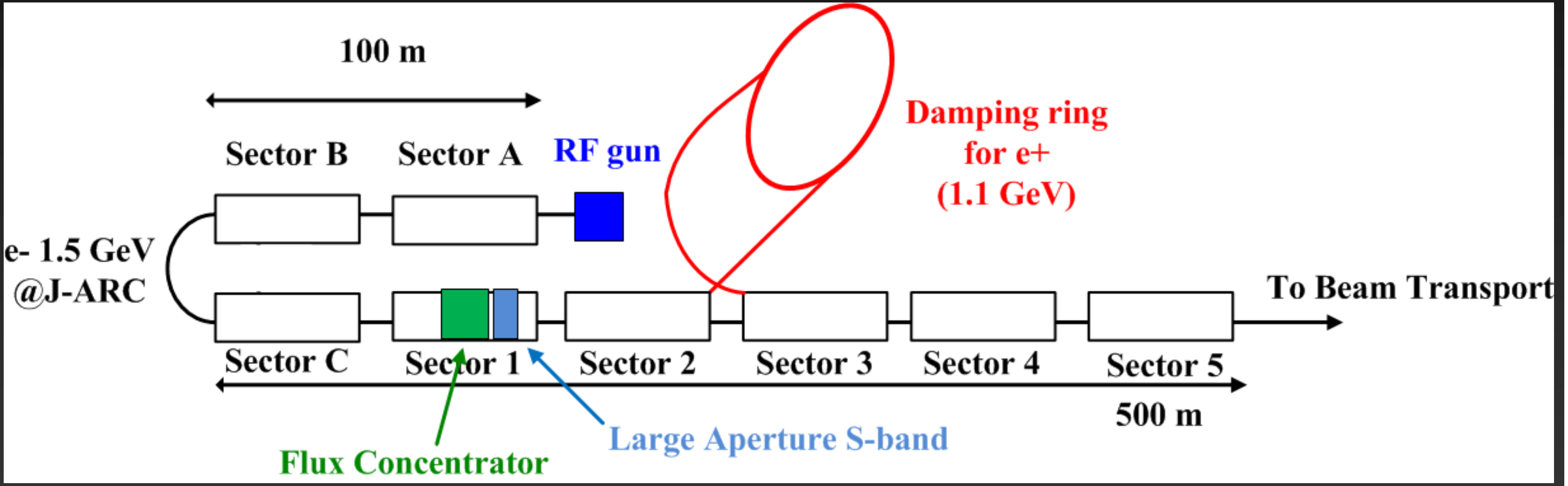
The 19th KEKB Accelerator Review Committee, March 3-5, 2014

Contents

Contents

Injector Upgrade Items

- Low emittance photo-cathode rf gun (M. Yoshida)
- New positron source (T. Kamitani)
- Damping ring (N. Iida, KEKB review 2013)
- Timing system (H. Kaji)
- LLRF development (T. Miura)



e- Linac Beam Parameters

	SuperKEKB	KEKB
Energy (GeV)	7.0	8.0
HER stored current (A)	2.6	1.1
HER beam lifetime (min.)	6	200
Maximum beam repetition (Hz)	50	50
Max. # of bunch in an rf pulse	2	2
Emittance (mm·mrad)	50/20 (Hor./Ver.)	100
Charge (nC)	5	1
Energy spread (%)	0.08	0.05
Bunch length σz (mm)	1.3	1.3
Damping ring	-	-
Simultaneous top-up injection	4 rings (SuperKEKB e-/e+, PF, PF-AR)	3 rings (KEKB e-/e+, PF)

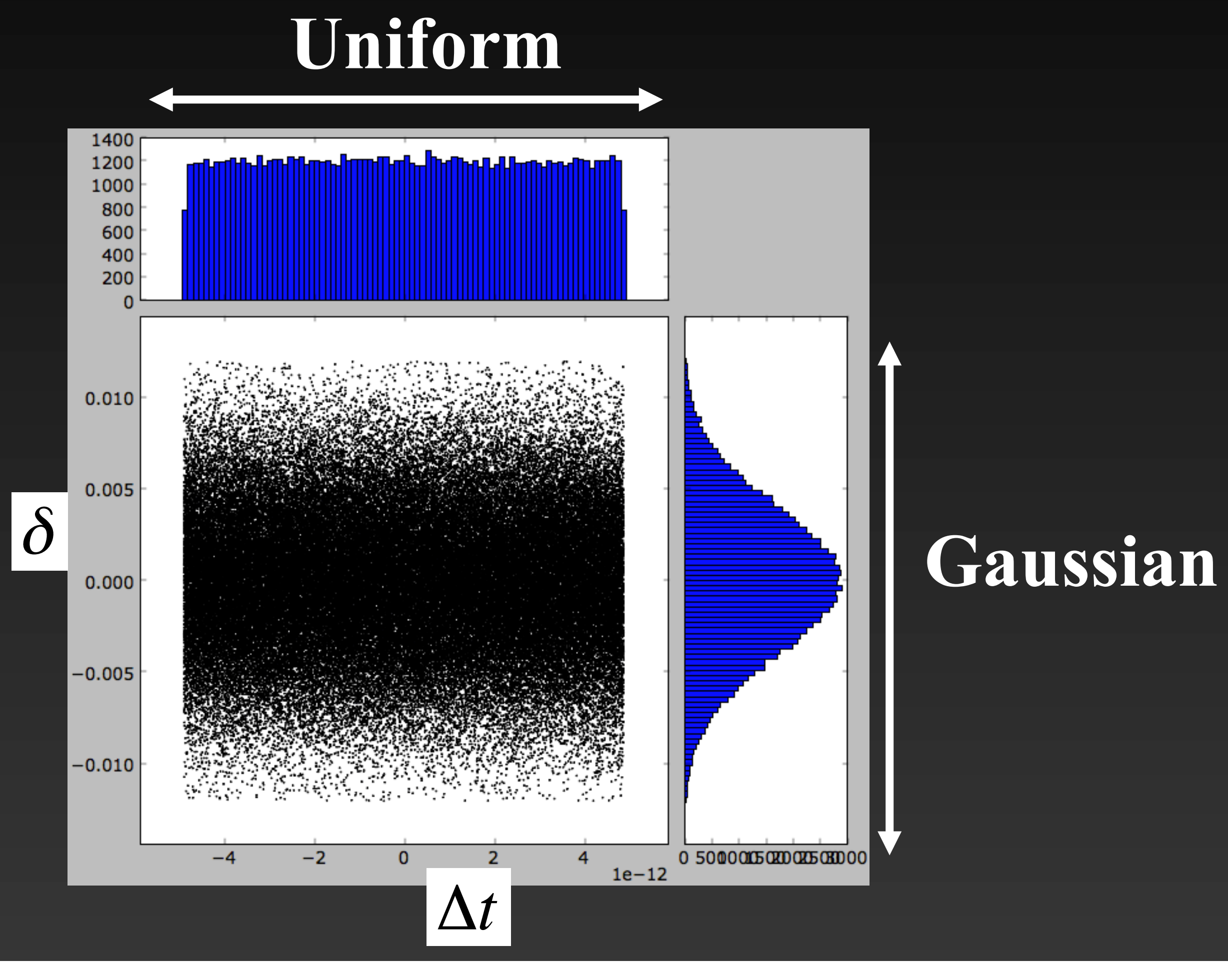
e+ Linac Beam Parameters

	SuperKEKB	KEKB
Energy (GeV)	4	3.5
LER stored current (A)	3.6	1.6
LER beam lifetime (min.)	6	133
Maximum beam repetition (Hz)	50	50
Max. # of bunch in an rf pulse	2	2
Emittance (mm·mrad)	100/20 (Hor./Ver.)	2100
Charge (nC)	4	1
Energy spread (%)	0.07	0.125
Bunch length σz (mm)	0.7	2.6
Damping ring	○	-
Simultaneous top-up injection	4 rings (SuperKEKB e-/e+, PF, PF-AR)	3 rings (KEKB e-/e+, PF)

Contents

Uniform shape of longitudinal beam distribution

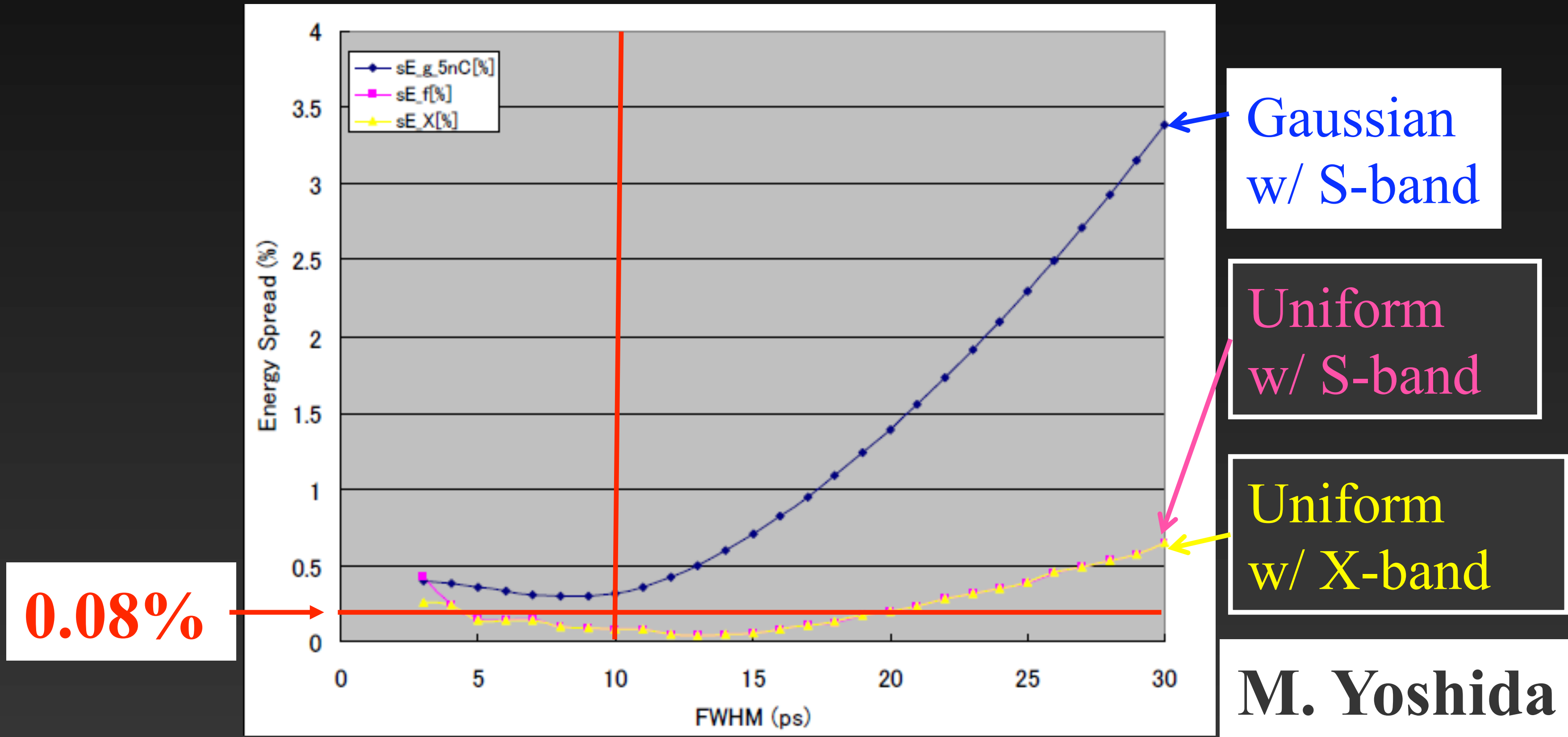
- Energy spread should be less than 0.08%
- Mitigate longitudinal wakefield and reduce energy spread
- Gaussian distribution in momentum space



Energy spread simulation

- For 10 ps bunch length,
  - ∼ 0.3% for Gaussian distribution
  - < 0.08% for uniform distribution
- **Uniform distribution is necessary.**

(Temporal manipulation of rf gun laser)



M. Yoshida

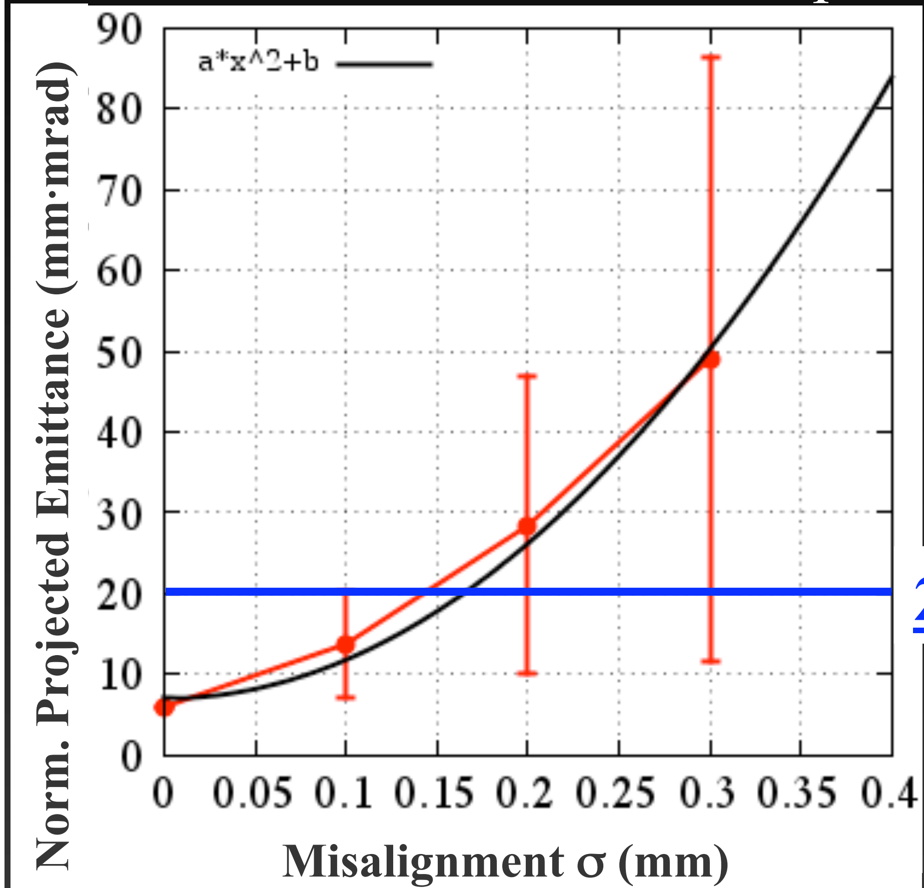
Contents

Low emittance electron

- Low emittance electron beam should be delivered to MR w/o damping ring.
- Emittance preservation is key issue for e- beam.
- Low emittance 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

Emittance growth due to component misalignment

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



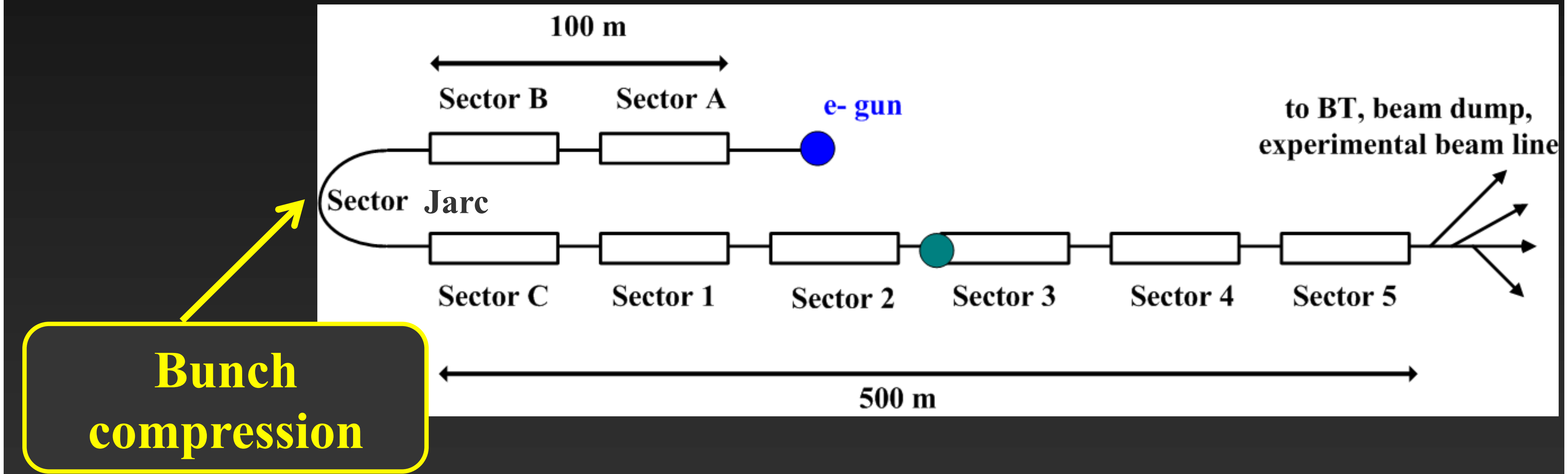
20 mm·mrad

<Emittance growth>

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

Bunch compression at J-ARC

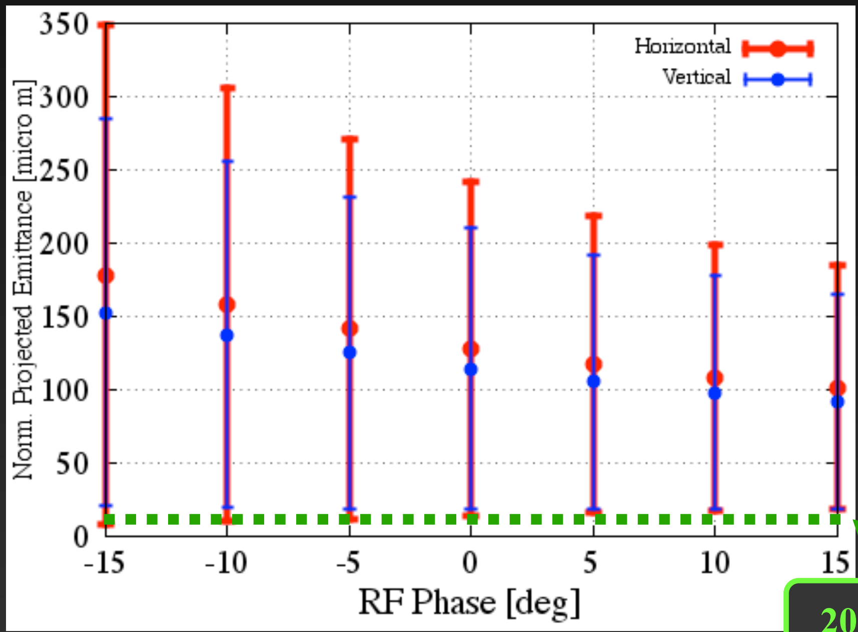
- Mitigate transverse wakefield and emittance growth
- Initial bunch length 10 ps => 5 ps (bunch compression at J-ARC)
  - First stage compression at A1 unit (30 ps => 10 ps)
- Control R56 and energy spread at J-ARC



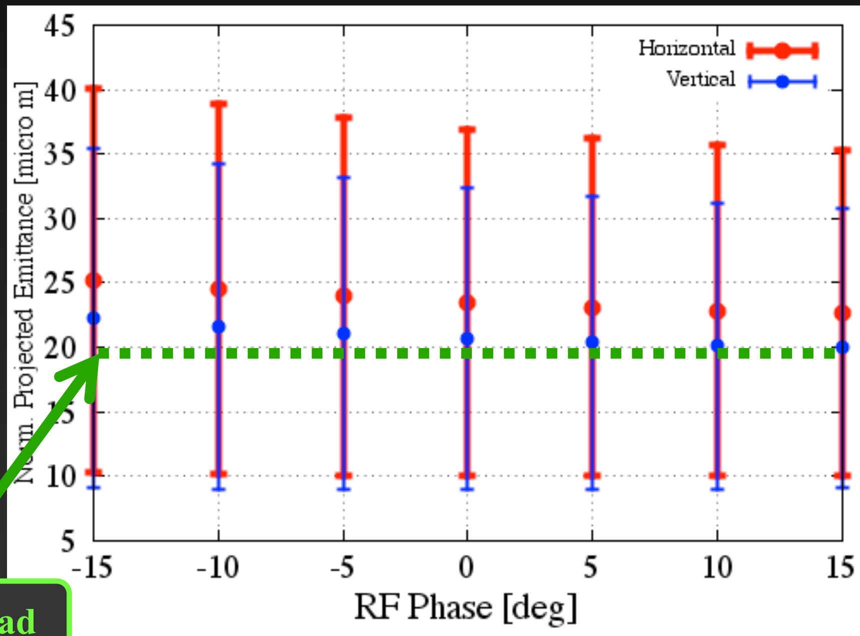
Emittance (misalignment σ = 0.3 mm)

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

R56 = 0 (w/o compression)



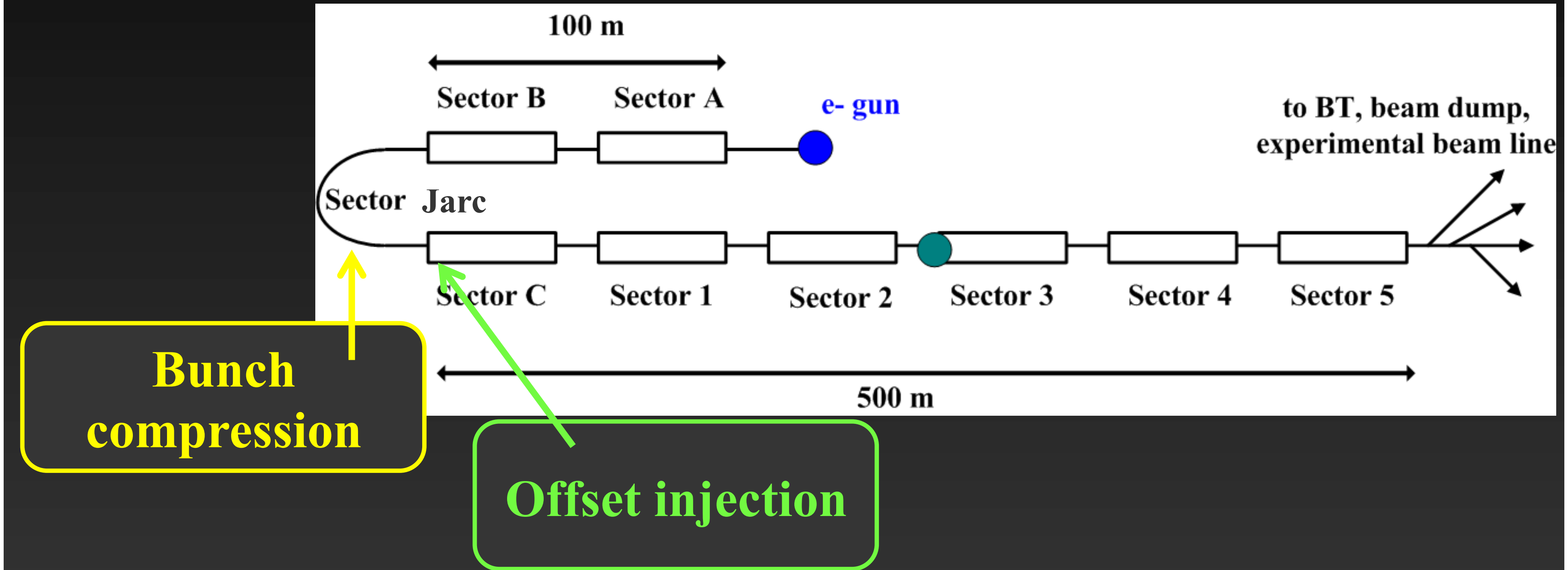
R56 = -0.30 (w/ compression)



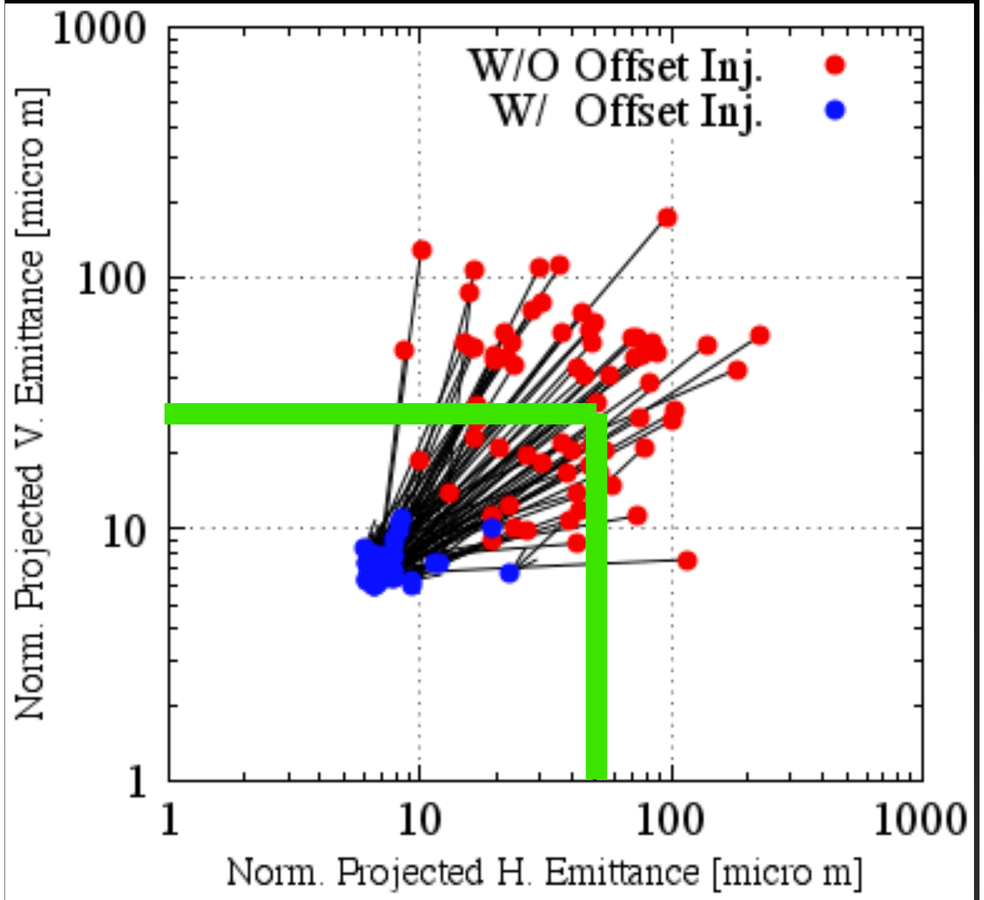
20 mm·mrad

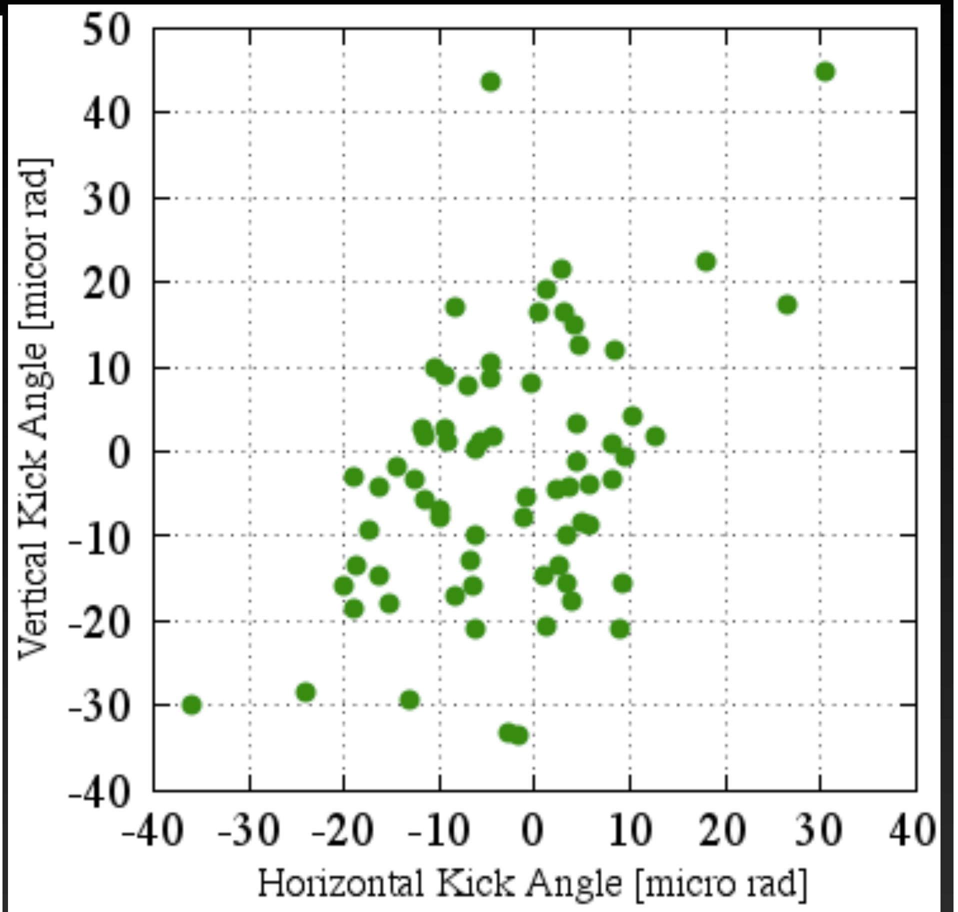
Offset injection for emittance preservation

- Offset injection: intentional change of misalignment seed.
- Control the steering magnet at the beginning of Sector C



Offset injection (simulation)





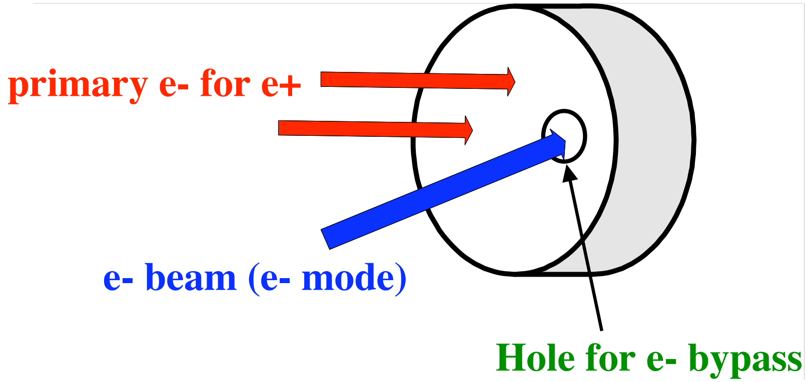
- Kick angle is relatively small.
- Need a high-precision and stable orbit control.

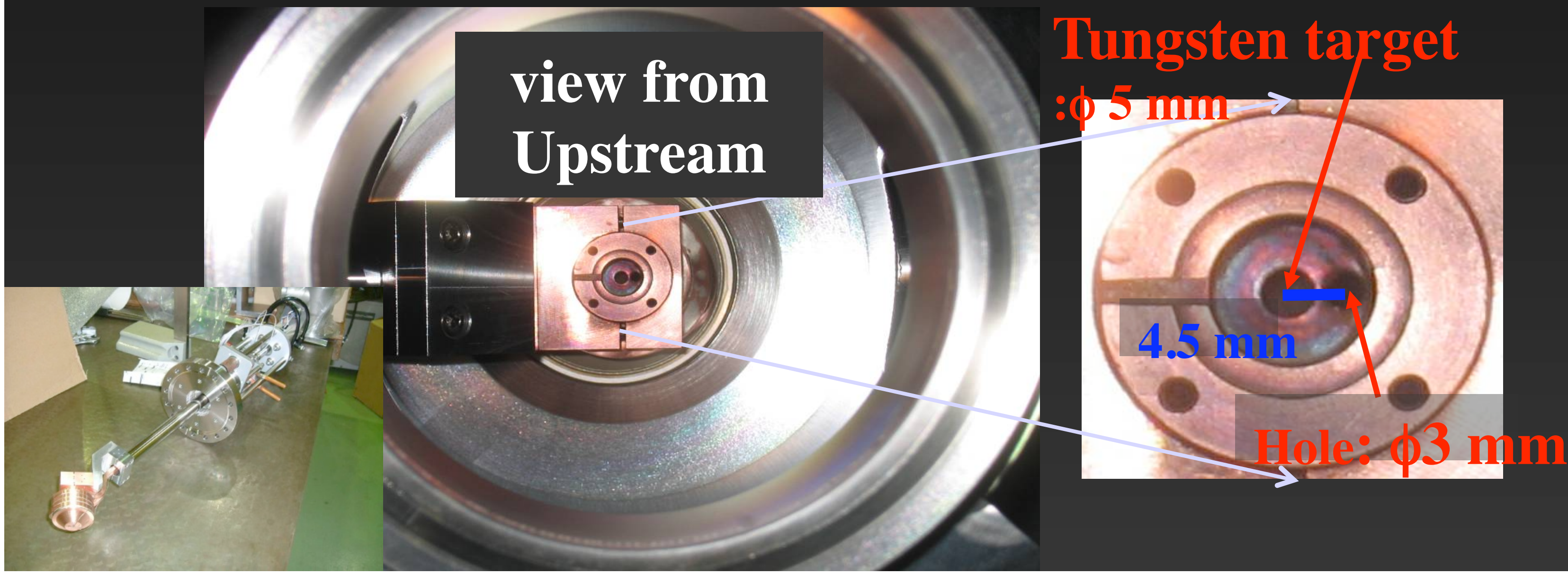
Low emittance electron issue

- Component alignment is important
  - σ < 0.1 mm: enough for emittance (alignment is very difficult)
  - σ > 0.1 mm: beam manipulation is necessary.
- Simulation w/ misalignment σ ~ 0.3 mm
  - Emittance can be preserved by
    - J-ARC: Bunch compression
    - Sector C: Offset injection
  - Simulation w/ measured misalignment
- **Alignment requirement:**
  - **σ < 0.3 mm for global (whole Linac)**
  - **σ < 0.1 mm for local (one Sector ~ 100 m)**

Fast e-/e+ beam switching (KEKB)

- Fast control of e- beam orbit by pulsed steering magnet and e+ target with a hole.
- Similar system will be installed for SuperKEKB.
- Beam position and angle should be fixed at the target location.

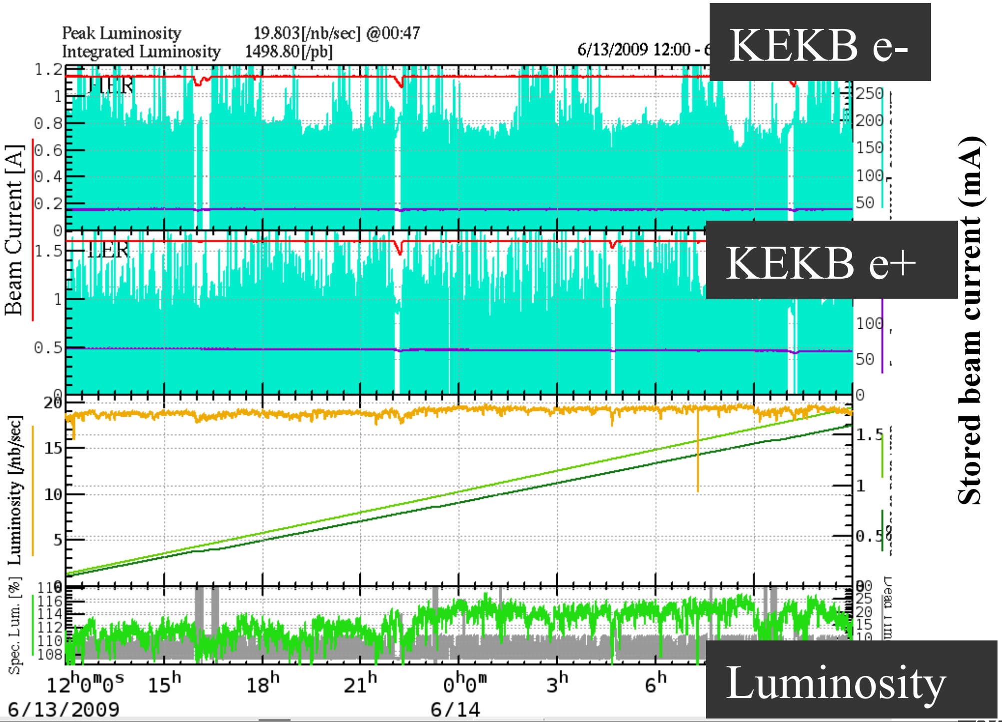


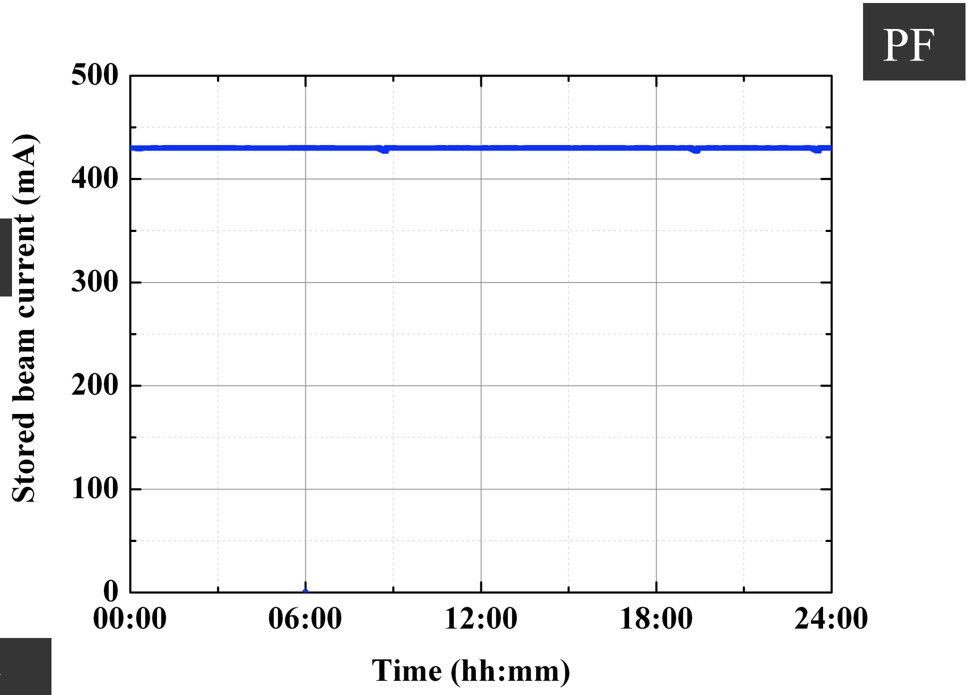


Contents

Simultaneous Top-up Operation for three rings

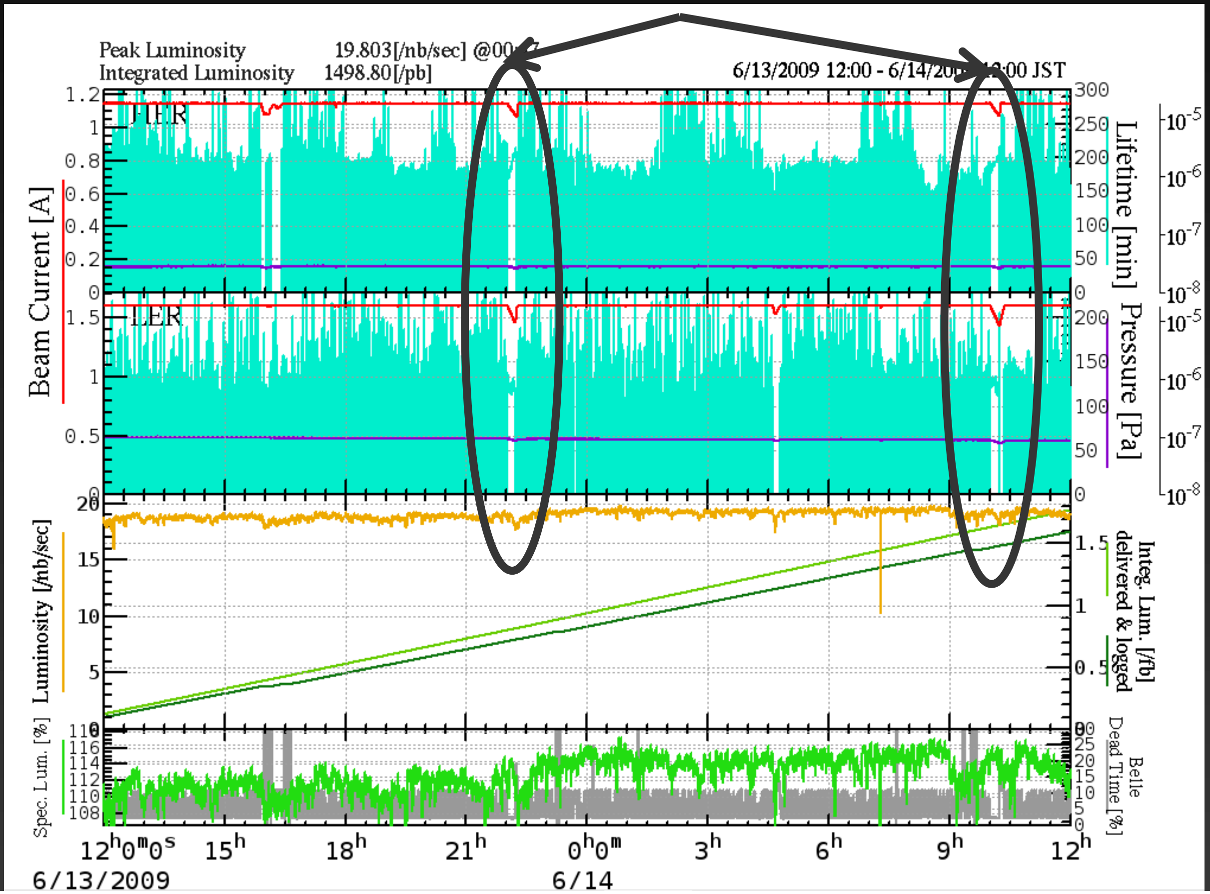
- Stored beam current stability since Apr. 2009
  - KEKB: 1 mA (~ 0.05%) : e-: 12.5 Hz, e+: 25 Hz
  - PF: 0.05 mA (~ 0.01%) : 0.5 Hz





PF-AR injection: 20 min., twice daily

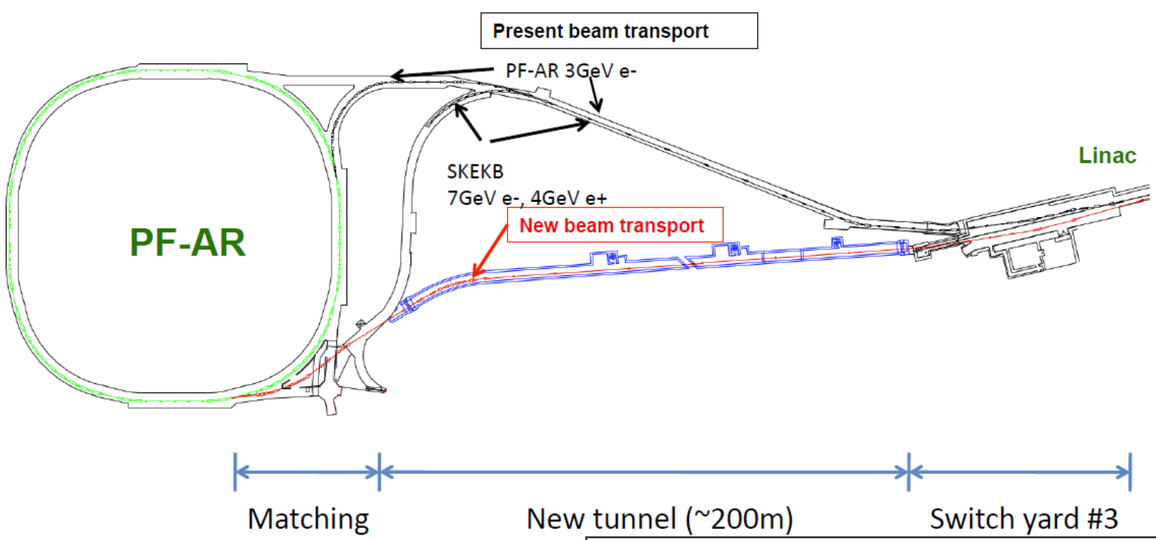
- Interrupt KEKB injection
- Problem for SuperKEKB (beam lifetime: 6 min.)



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.
- New tunnel is under construction. (FY2013)

New beam transport for PF-AR



H. Takaki (KEKB review 2013)

New BT will be available in Jan. of 2016.

Contents

Schedule
- Our goal -

- Beam charge
  - e-: 5 nC (10 nC for e+ production)
  - e+: 4 nC
- Emittance preservation at end of Linac
  - e-: 50/20 mm·mrad w/o DR (Hor./Ver.)
  - e+: 100/20 mm·mrad w/ DR (Hor./Ver.)
- Stability
  - Charge
  - Position
  - Energy
  - Energy spread
  - Emittance
  - Simultaneous top-up for 4 rings

Schedule (cont'd)

- Commissioning Stage 1: Oct. 2013 ~ Mar. 3 2014
  - Nov. 2013: e+ beam line construction
  - Dec. 2013: Daytime: e+ beam line construction (9 ~ 20)

    Night shift: e- beam commissioning
  - Jan., Feb. 2014: Sometimes day shift for e+ beam line construction
  - Beam injection for PF top-up and PF-AR twice daily
    - Sector 3 to Sector 5
  - Full Linac Study: Every Tuesday (Sector A to Sector 5)
  - We have not enough time for study.
  - e+ beam line is not yet completed.

Schedule (cont'd)

- Result of Commissioning Stage 1
  - RF conditioning of gun cavity
  - Laser tuning for e- rf gun
  - 5.6 nC from gun, 0.58 nC at end of Linac
  - Development of commissioning tools

- Next commissioning Stage 2:
  - Apr. 11~ Jul. 1, 2014
    - Mid. of May (daytime) ~ : Commissioning only in Sector A, B (DR construction)
  - Emittance preservation of e-
  - Install Flux concentrator (End of May) and e+ commissioning

Schedule (cont'd)

- Next commissioning Stage 3:
  - Oct. – Dec. 2014
  - e+ commissioning
  - Emittance preservation of e- beam
  - Goal of this stage:
    - e- :1 nC w/ low emittance
    - e+: 1 nC w/o low emittance
    - Stable beam (charge, orbit,…)
- Commissioning Stage 4:
  - Feb. – June 2015
  - Beam Injection to MR (May 2015)

Schedule (cont'd)

- Commissioning Stage 5:
  - Oct. – Dec. 2015
  - During summer shutdown: install pulsed Quadrupole and Steering magnets
  - Pulse-by-pulse switching e-/e+ beam
  - Increase beam charge, Improve beam stability
  - Emittance preservation
  - e+ DR commissioning (Dec. 2015)

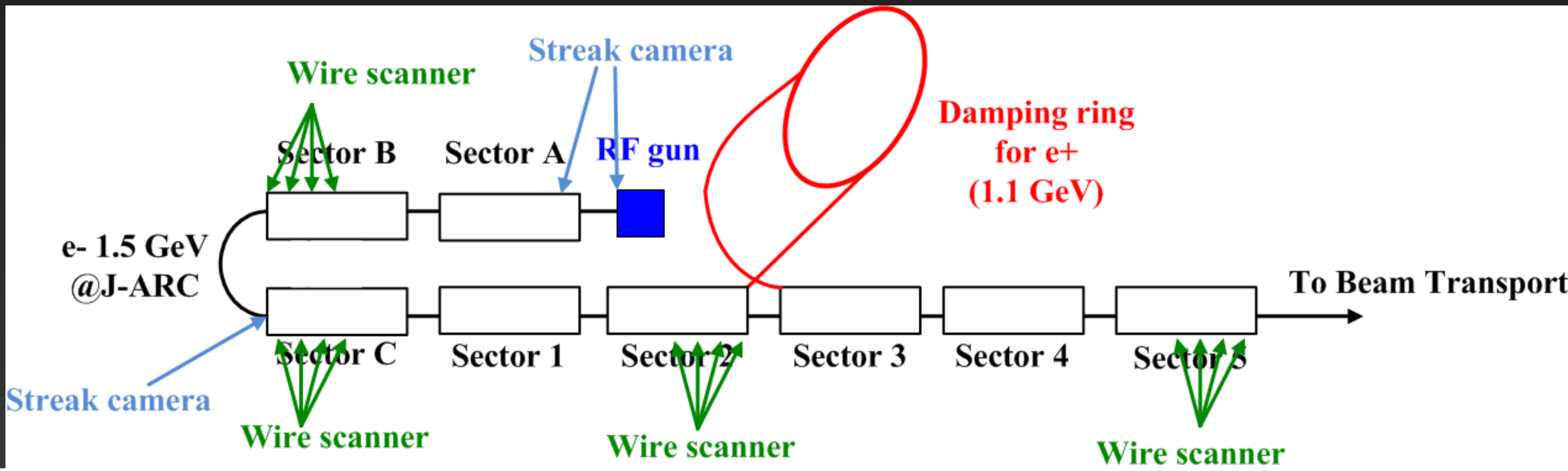
Contents

Recent progress of electron commissioning

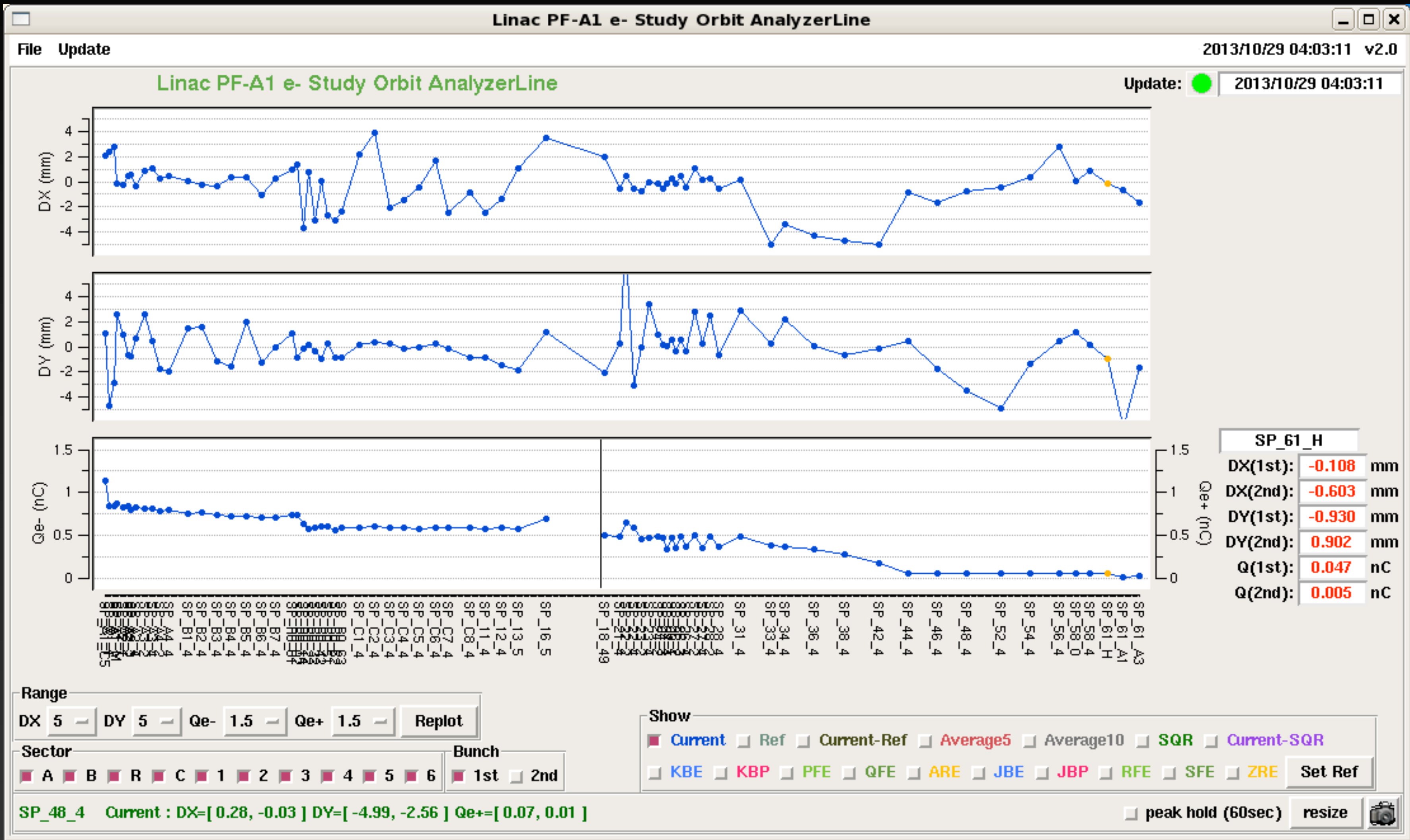
- Commissioning items:
  - RF conditioning of gun cavity
  - Laser tuning for e- rf gun
  - High intensity beam charge up to 5 nC
  - Beam deliver to Linac end
  - Bunch compression @ A1 unit
  - Bunch compression @ J-ARC
  - Emittance measurement
    - A1 unit, Sector B, Sector C, Sector 2, Sector 5

Beam diagnostics

- Beam position measurement
  - BPMs x100 (Strip-line type electrodes)
  - Data processing
    - Oscilloscope (σ 25~50 μm) => VME-based one (σ ~10 μm) is under development
- Beam profile measurement
  - Screen monitors x100
  - Multiple wire scanners x4
- Bunch length measurement
  - Streak cameras x3

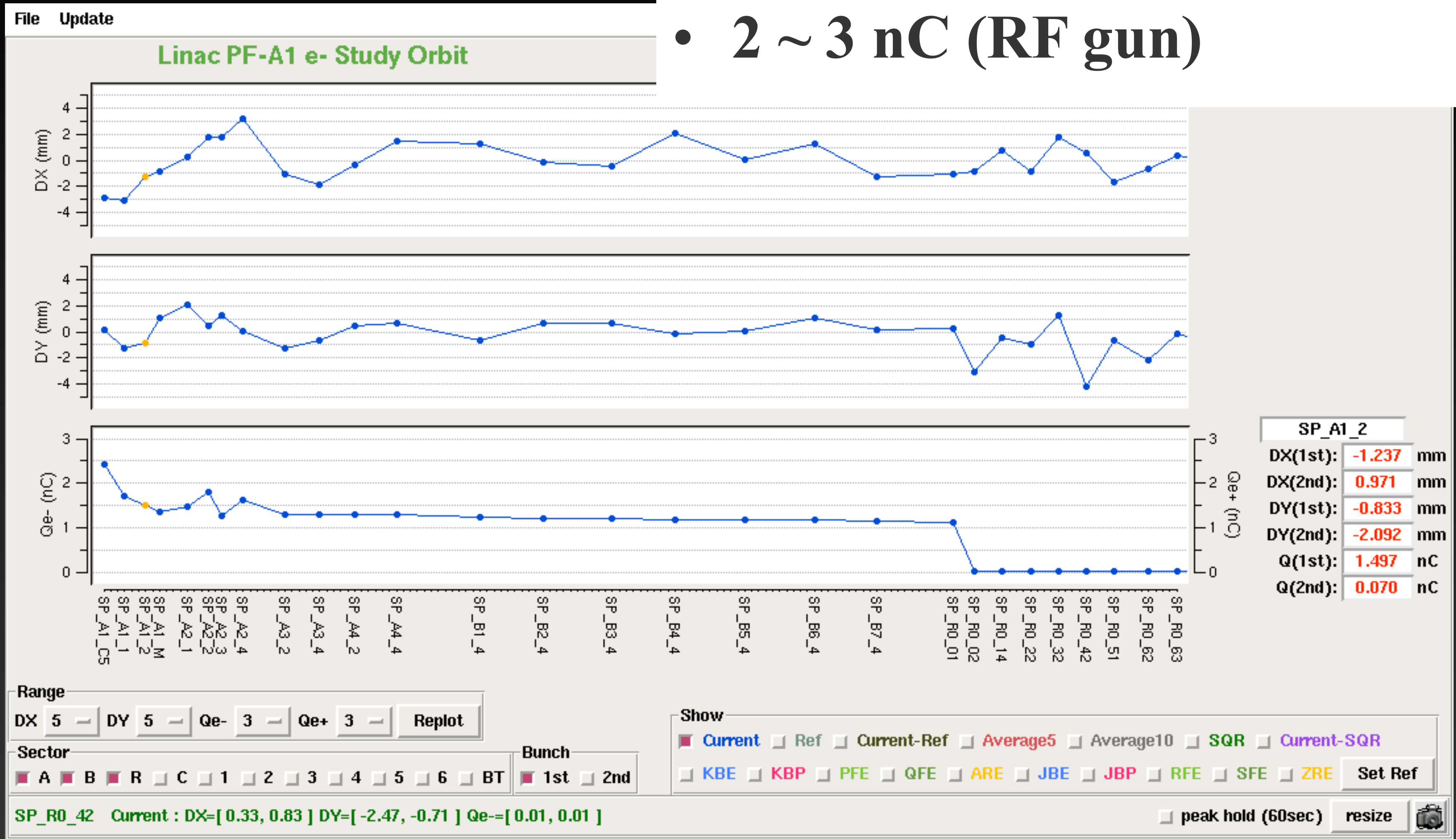


RF gun e- beam (5.12 GeV) in Oct. 2013

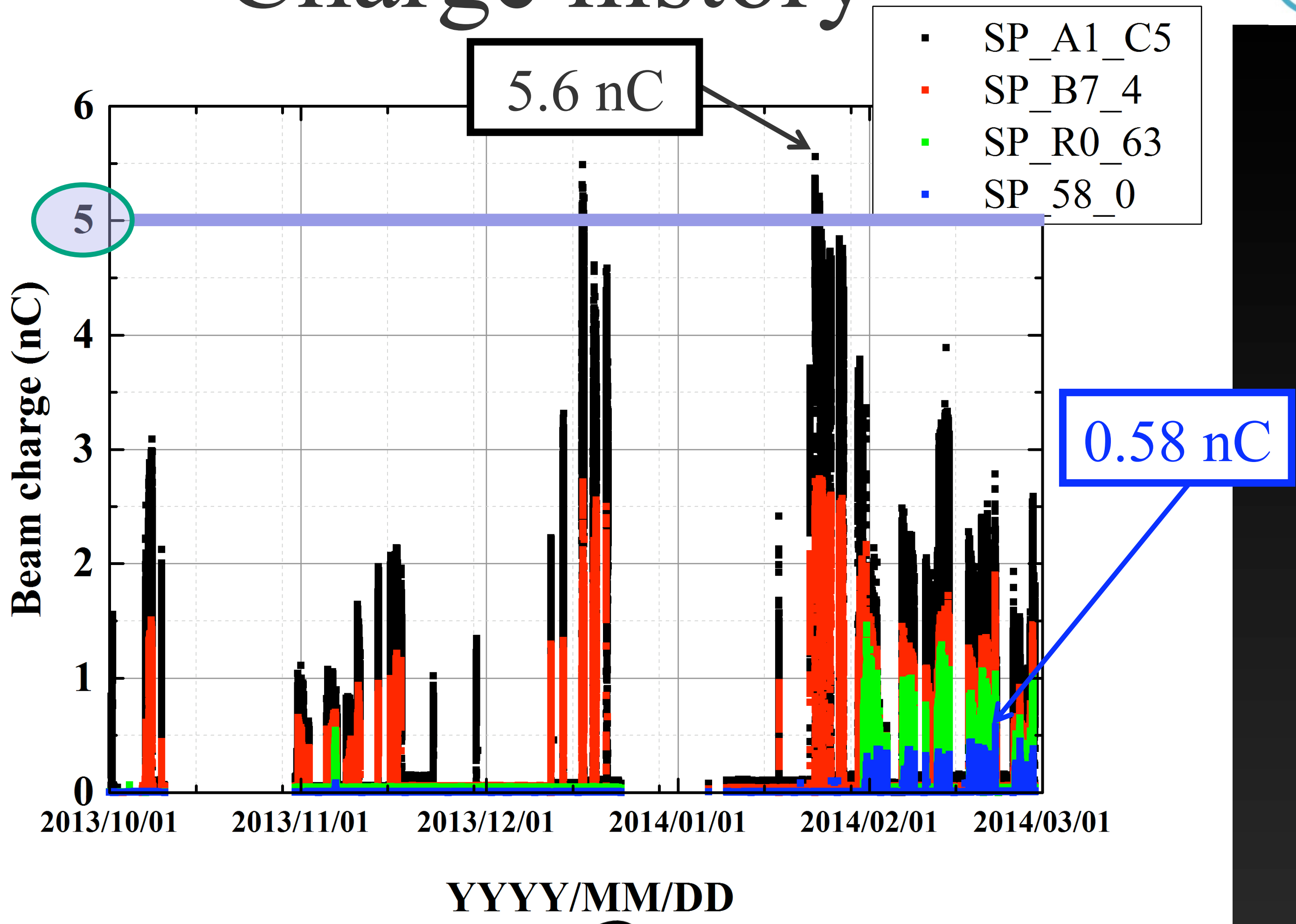


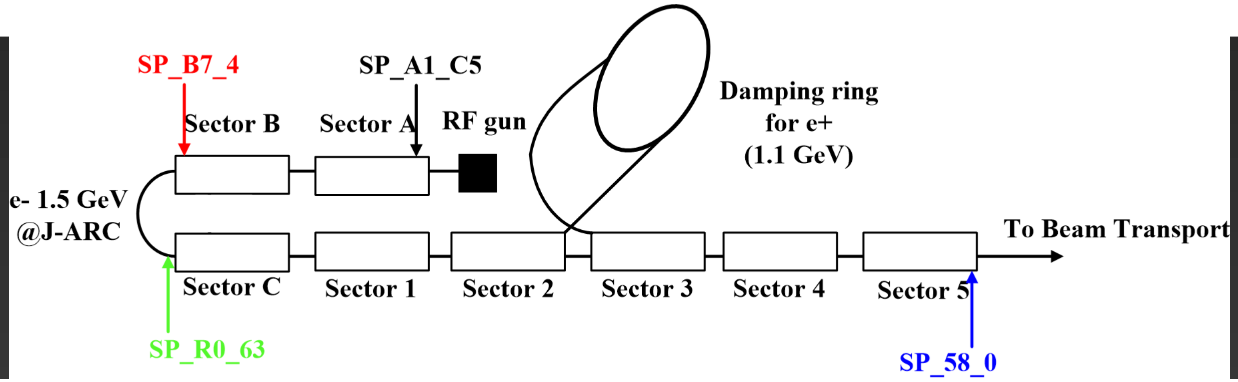
Typical beam charge

- 1 ~ 2 nC (end of Sector B)
- 2 ~ 3 nC (RF gun)

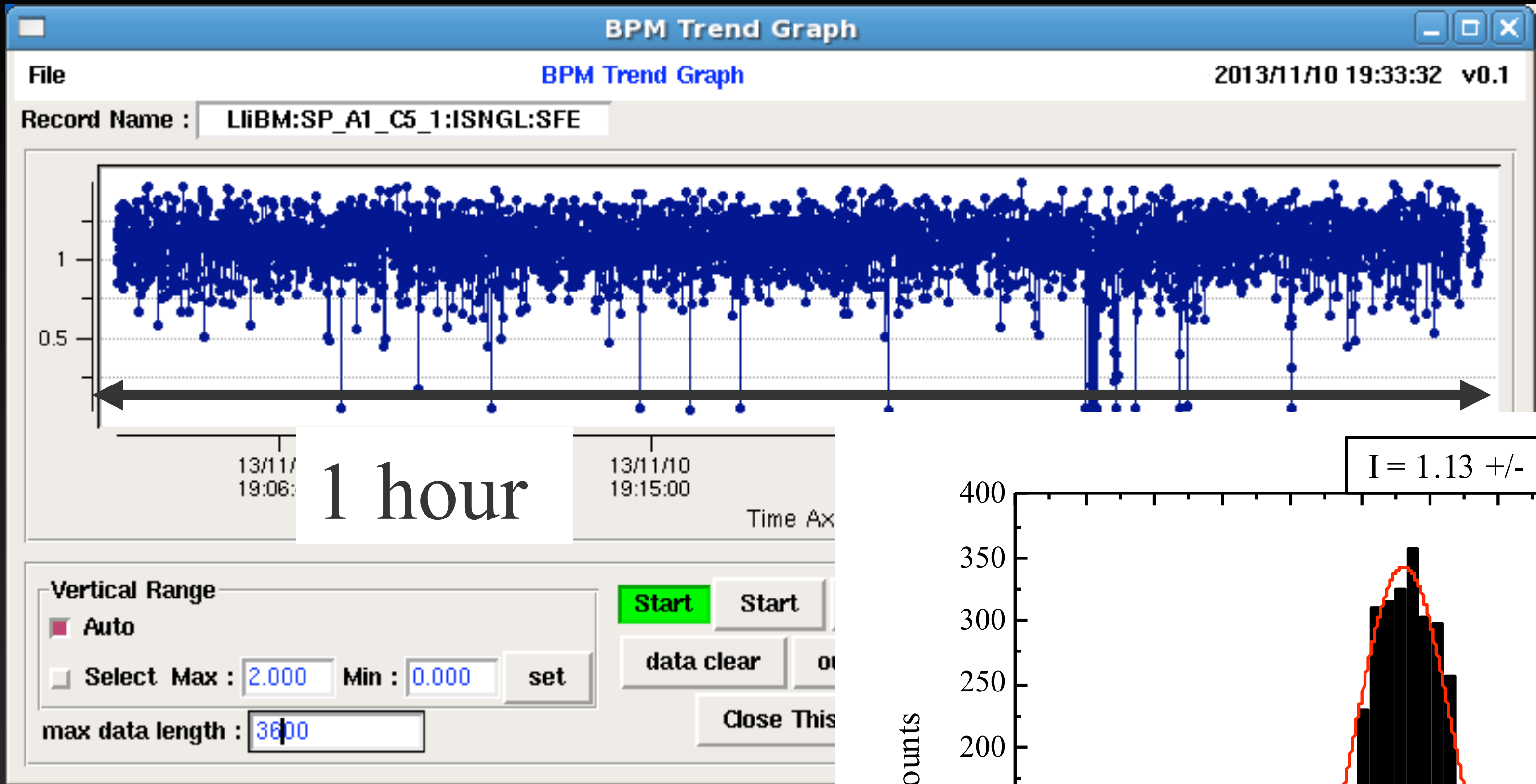


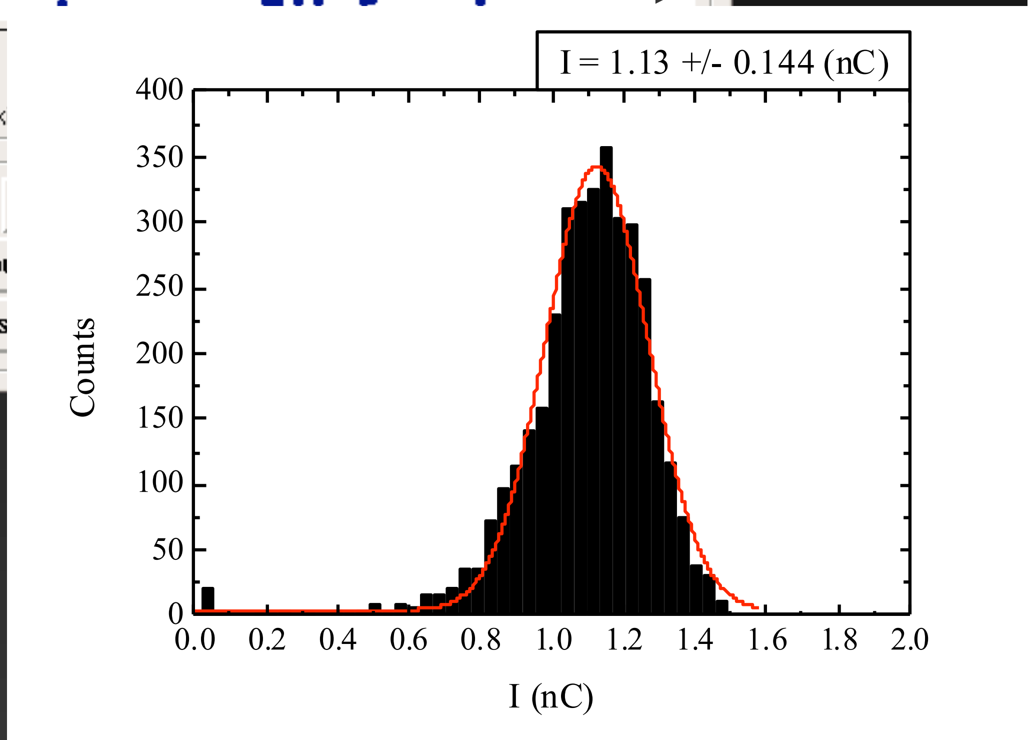
Charge history





Typical beam charge stability



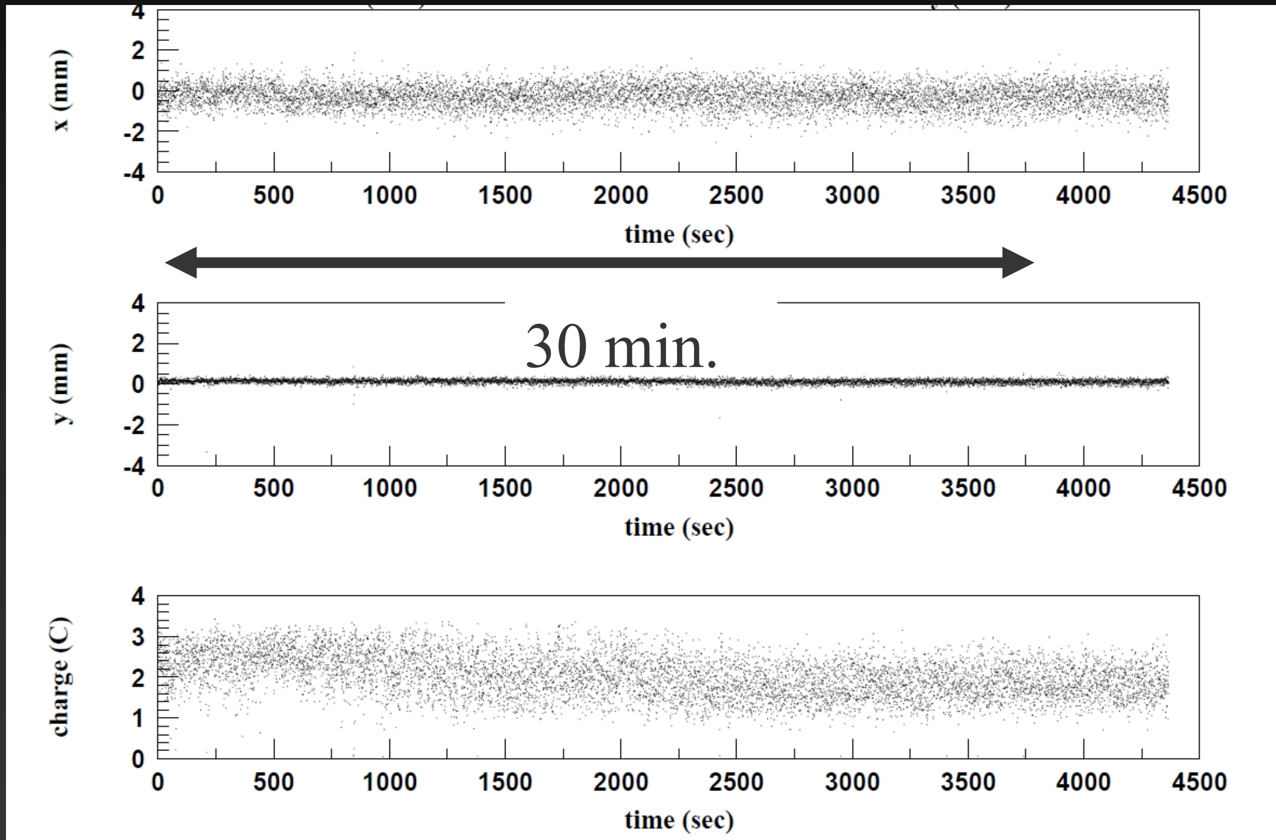


σ_I: 10% ~ 20%

~ 2.5% (KEKB operation)

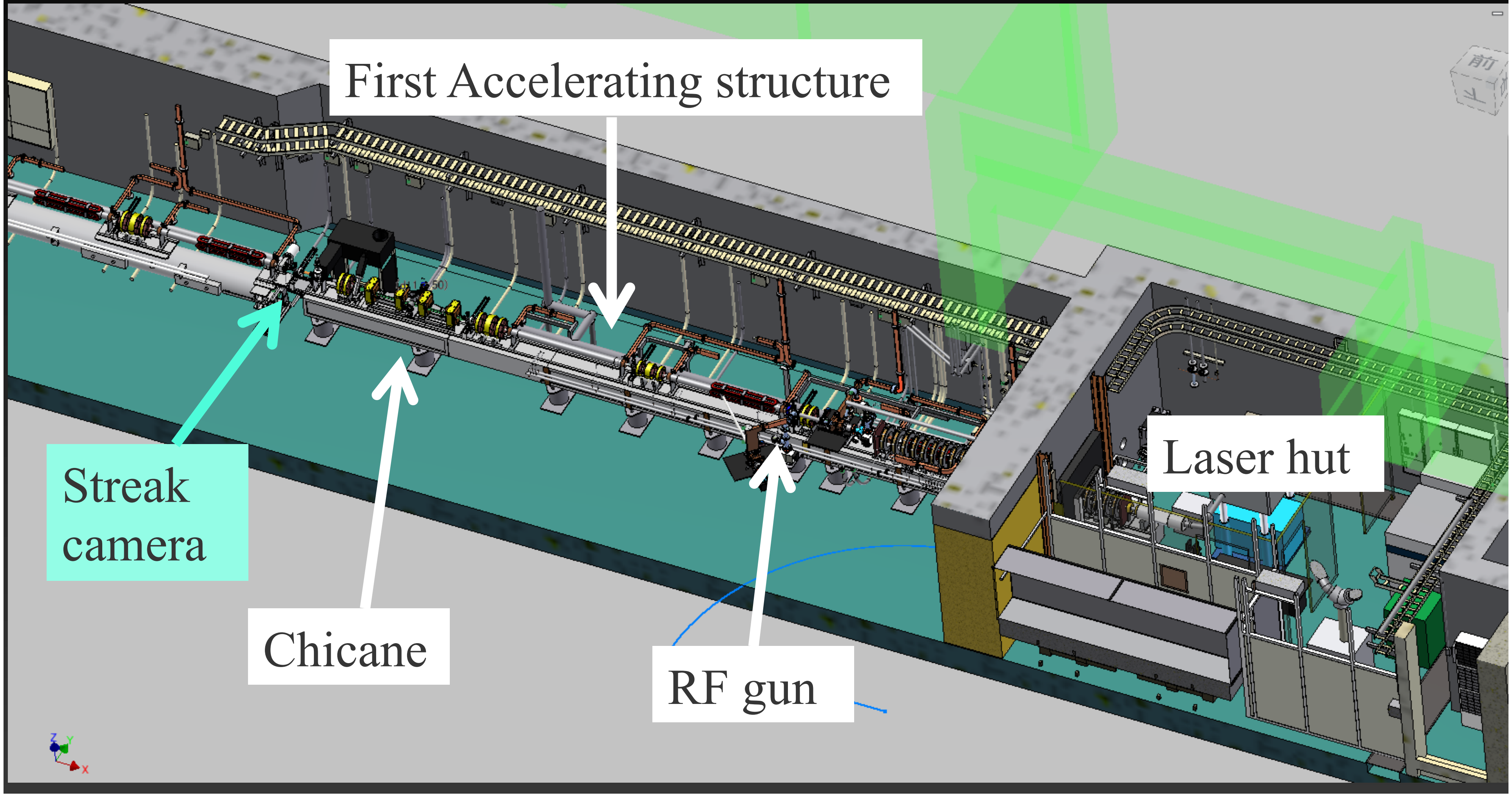
Beam position stability @ SP_A1_C5

- Measured beam position at first BPM (SP_A1_C5)
  - σx ~ 0.57 mm
  - σy ~ 0.11 mm
- Fluctuation of horizontal beam position is larger than vertical one.



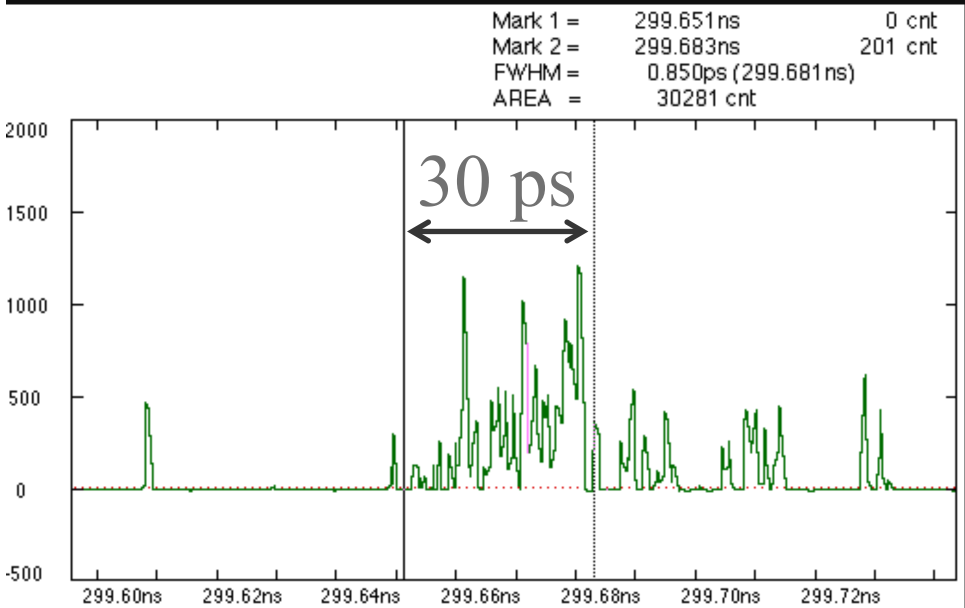
Bunch compression at A1 unit

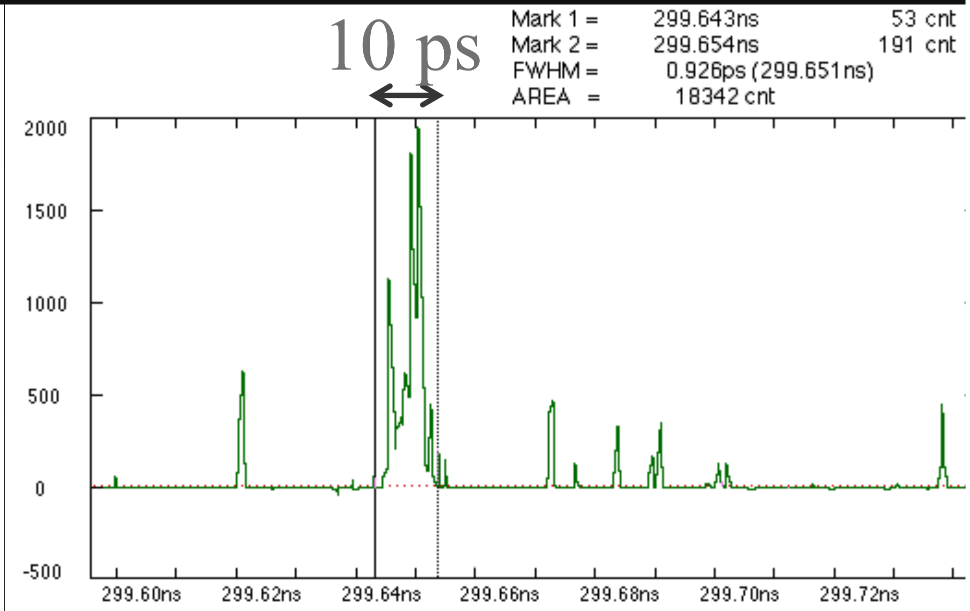
- To mitigate space charge effect, bunch length is compressed from 30 ps to 10 ps.



Single shot bunch length measurement at A1 unit (streak camera)

w/o bunch compression | w/ bunch compression



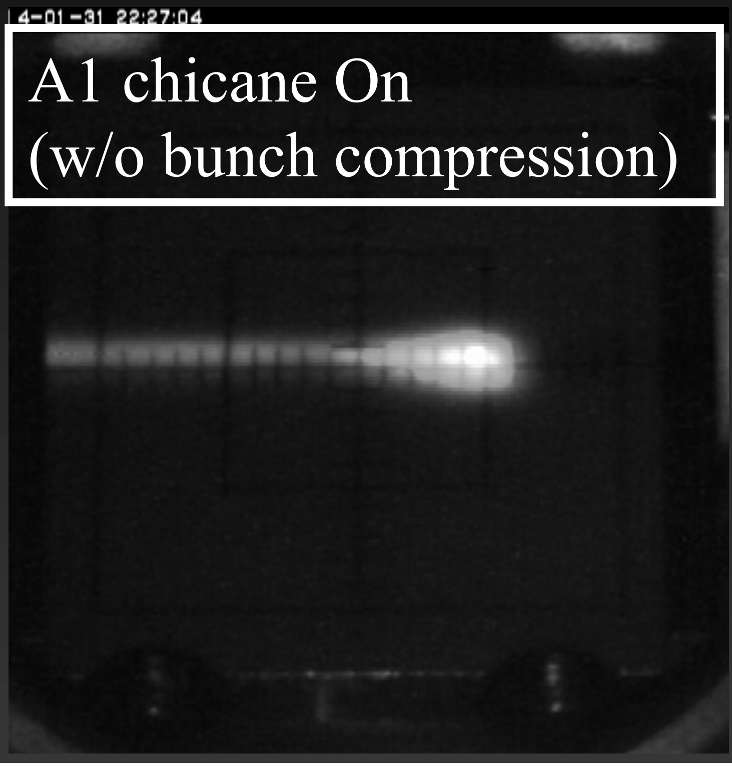


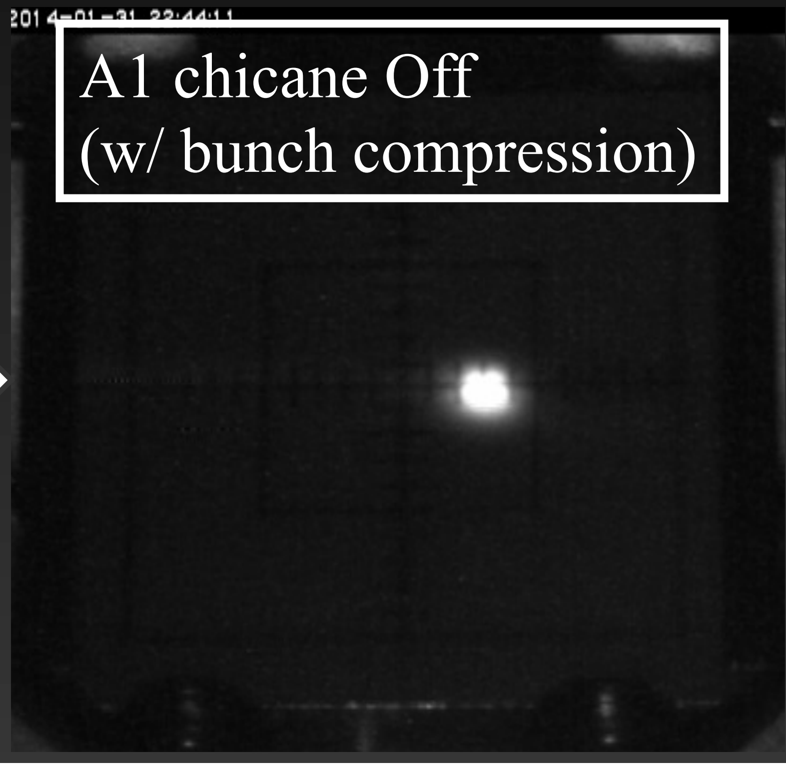
A1 RF Φ 0°: 30 ps

A1 RF Φ -30°: 10 ～ 15 ps

Energy spread measurement @ J-ARC

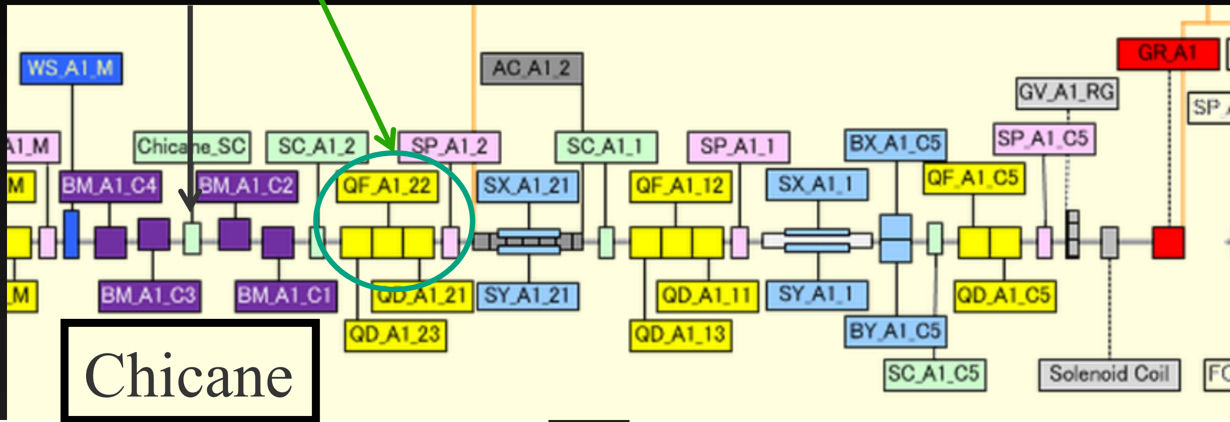
- Measure beam energy spread by screen monitor (middle of J-ARC) w/ and w/o bunch compression at A1 chicane.
- Bunch compression at A1 unit is effective for energy spread compensation.

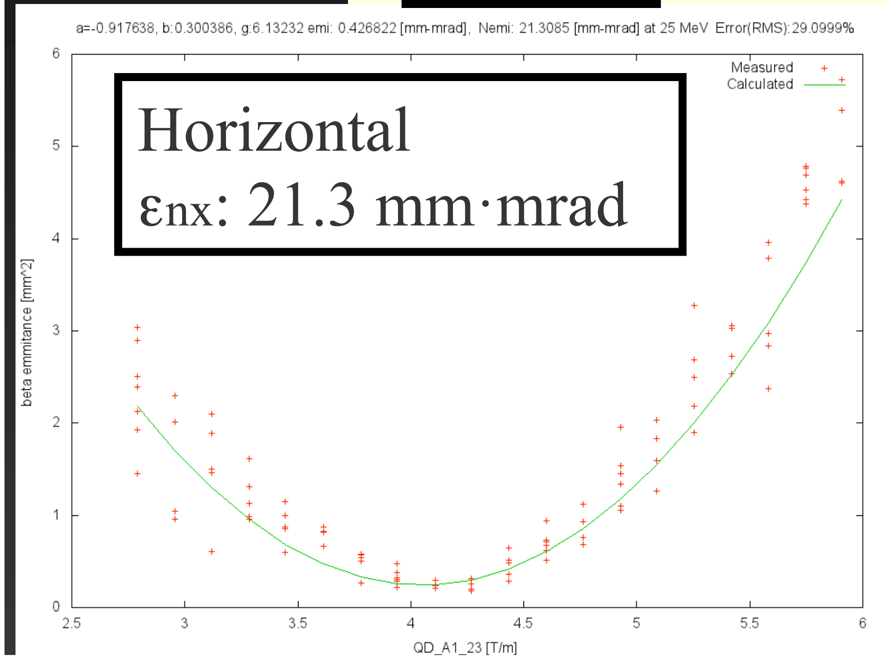


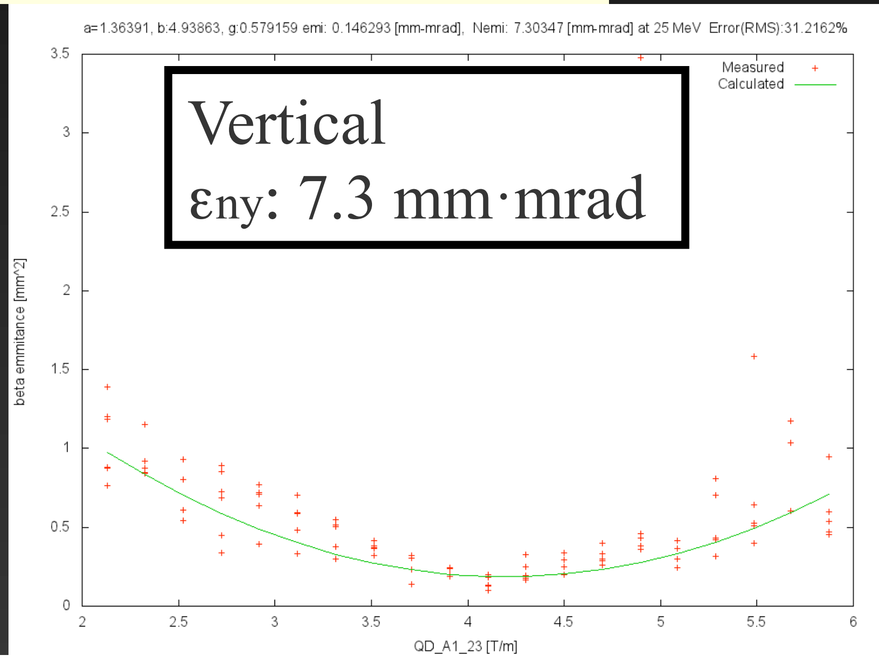


Emittance measurement example (A1 unit)

- Quadrupole scan
- Screen monitor @ middle of chicane

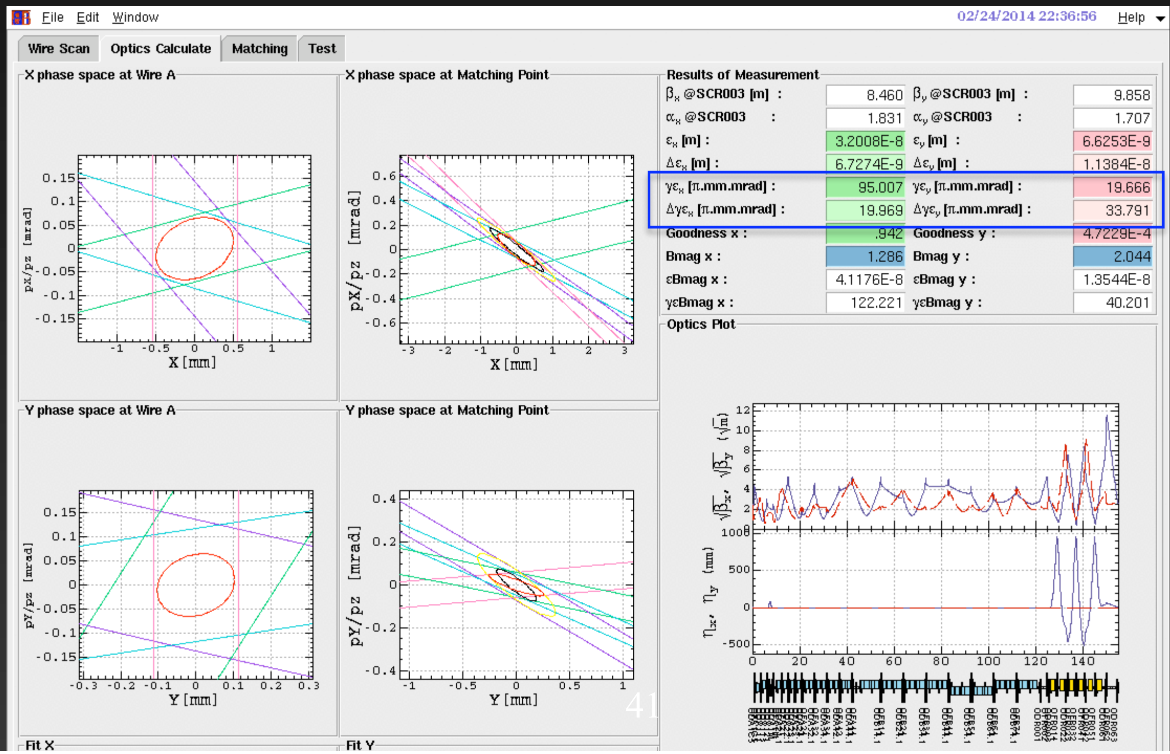






Emittance measurement example (Sector B)

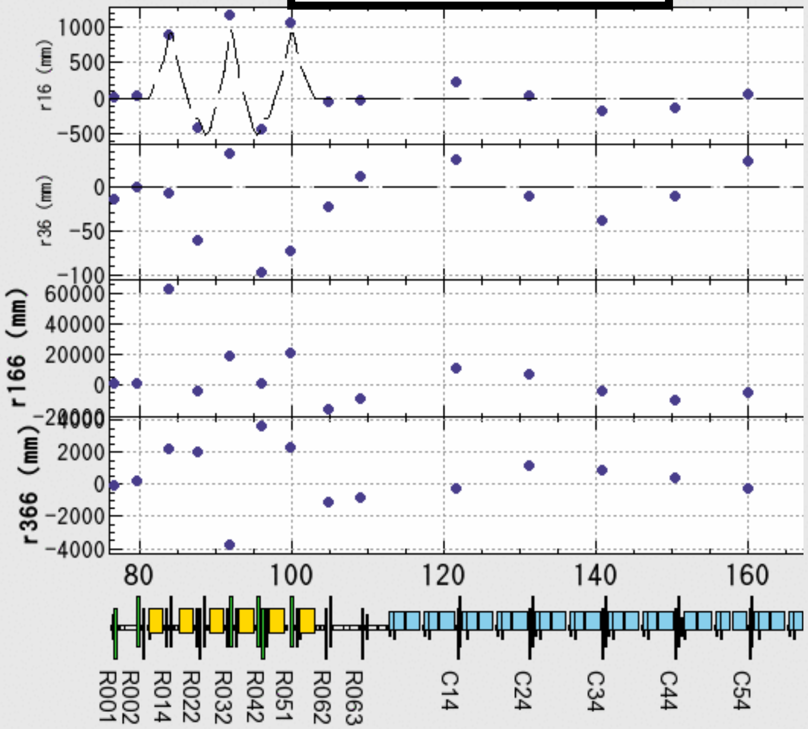
- Multiple wire scanner in Sector B
- Typical result:
  - $\varepsilon_{n,x}$: 95.01 ± 19.97 mm·mrad
  - $\varepsilon_{n,y}$: 19.67 ± 33.79 mm·mrad
- Charge stability is not so small. Software is under development for subtracting shot-by-shot beam fluctuation.



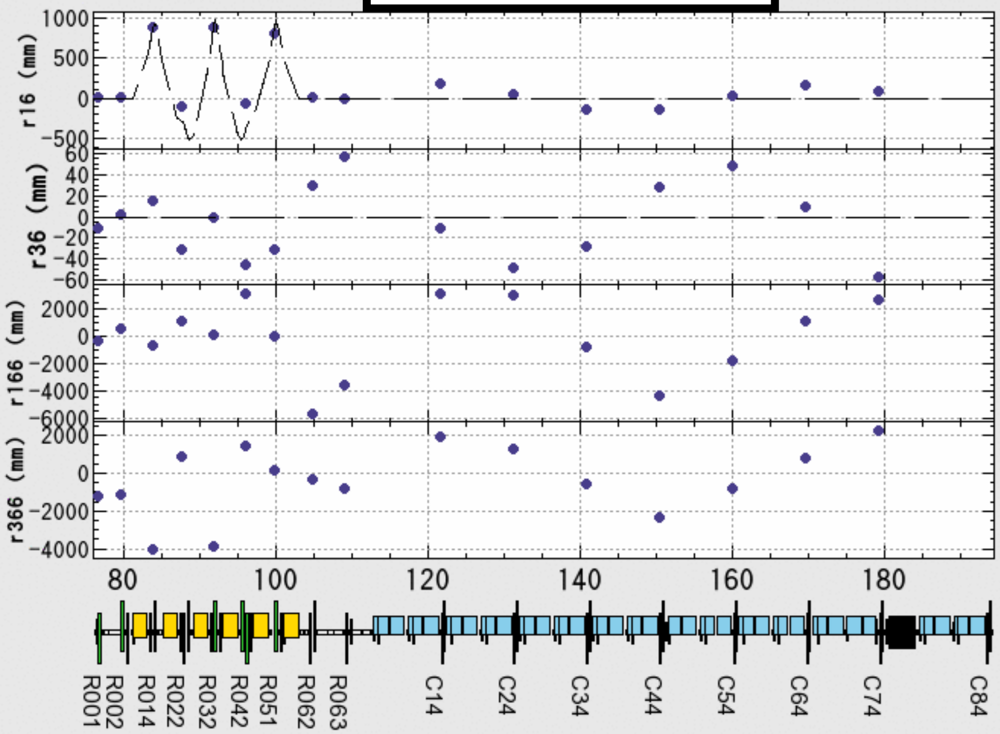
Bunch compression @ J-ARC

- Isochronous, R56 = -0.3 m
- w/ different RF Φ in Sector A, B

Isochronous

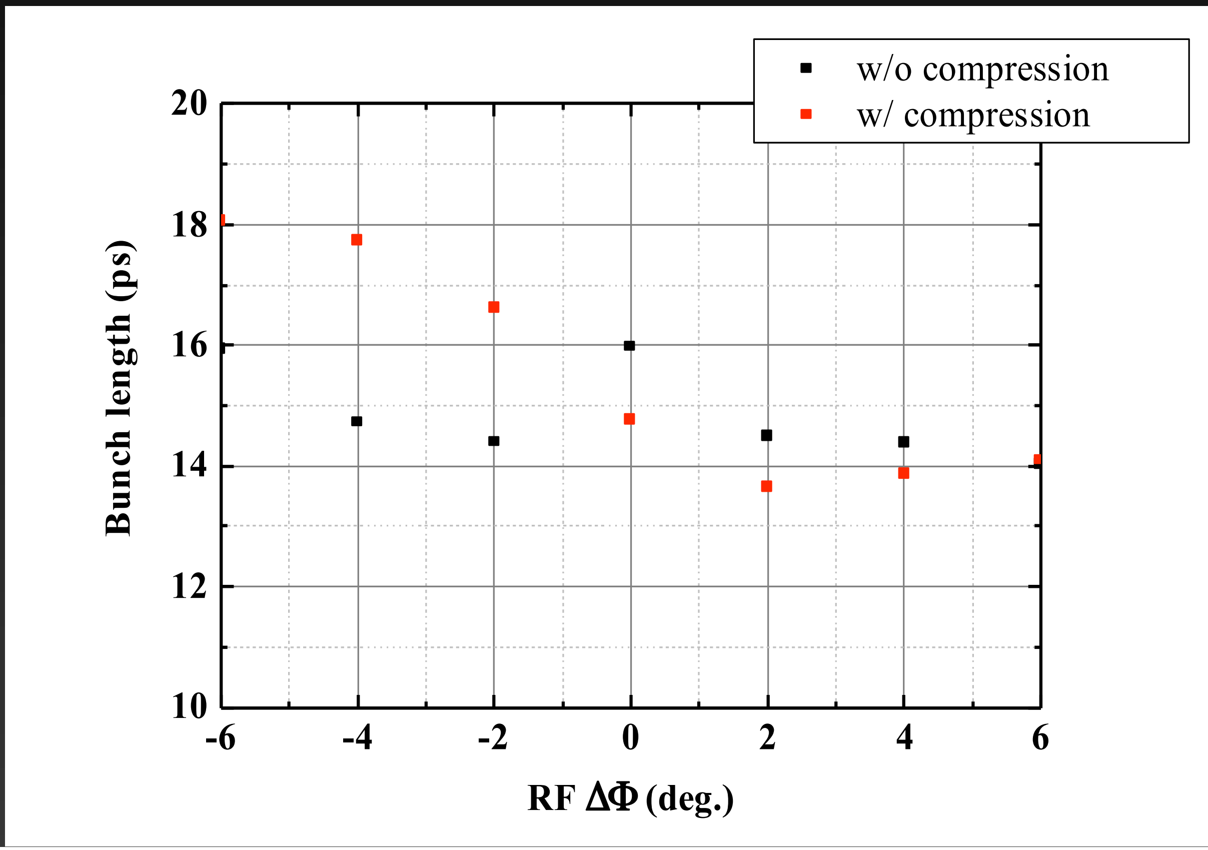


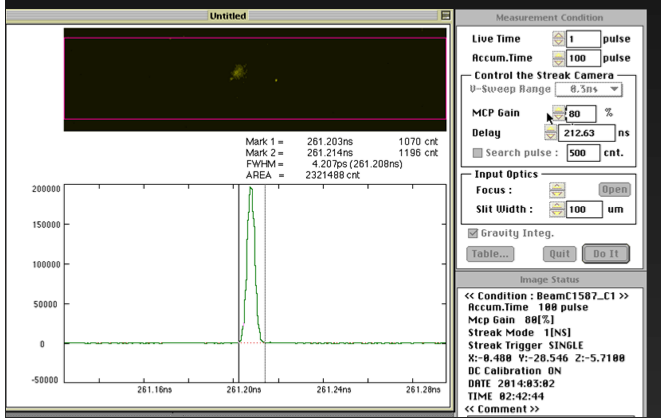
R56 = -0.3 m



Preliminary result of bunch compression @ J-ARC

- Clear bunch compression is not yet measured.
- Continue bunch compression study
- Apr. 2014 ~: Measure emittance by wire scanner @ Sector 2 w/ and w/o J-ARC bunch compression.





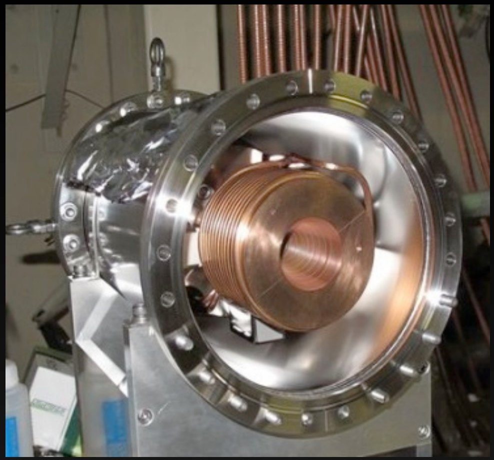
Streak camera @ C1 unit

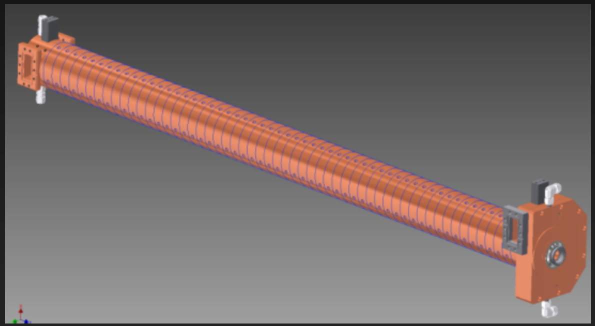
Summary of electron commissioning

Item	Requirement	Current status
Beam charge (nC)	5 (10 for e+ primary)	5.6 (first BPM) 0.58 (Linac end)
Beam energy (GeV)	7	5.12
Normalized emittance (mm·mrad)	50/20 (Hor./Ver.)	20/7 (Hor./Ver.) (@A1 unit)
Beam charge stability	2.5% (KEKB)	10% ~ 20%
Bunch compression @ A1 unit	30 ps => 10 ps	10 ps ~ 15 ps
Bunch compression @ J-ARC	10 ps => 5 ps	n/a
Temporal manipulation of laser	Uniform shape	n/a
Emittance preservation	20 mm·mrad at Linac end	n/a
Max. beam repetition	50	5
# of bunches	2	1
Operation	Simultaneous top-up	n/a

Contents

Issues





- New e+ source
  - Flux concentrator
    - Dec. 2013 => End of May 2014
  - Large aperture S-band structure (LAS)
  - RF conditioning of LAS is not completed.
  - e+ commissioning is delayed.
- e- commissioning:
  - Started in Oct. 2013.
  - Not enough time for injector commissioning
  - Beam stability (charge, position) is not yet enough.

Contents

Summary

- Commissioning stage 1: (Oct. 2013 ~ Mar. 2014)
  - New RF gun commissioning (laser tuning and cavity conditioning)
  - High intensity charge
  - Prepare beam diagnostics and commissioning tools
  - ***New Photo-cathode RF gun has successfully manufactured and installed. (Summer 2014)***
    - ***5.6 nC from New RF Gun***
    - ***0.58 nC at end of Linac***
- Stage 2: (Apr. 11~ Jul. 1, 2014)
  - Emittance preservation of e- at the end of Sector B, Sector 5
    - Bunch compression at J-ARC, offset injection, wake field bump,…..
  - Positron beam commissioning (May 2014 ~)
  - Beam stability
    - Charge, Position, Energy, Energy spread, Emittance

Thank you for your attention!