LINAC Upgrade Status

Takako Miura / Kazuro Furukawa
(Accelerator Laboratory, KEK)
on behalf of Injector LINAC group

Injector LINAC

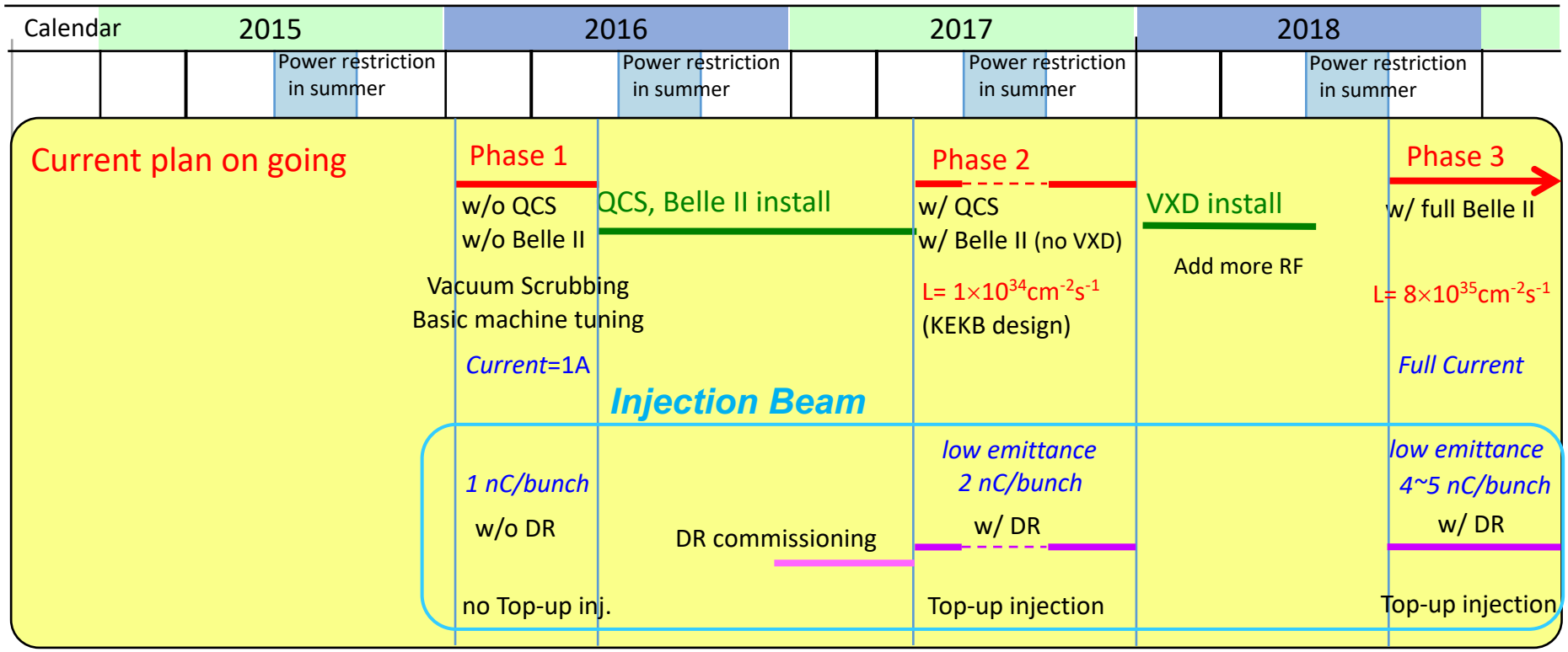
High-current and **low-emittance** injection beams are required for SuperKEKB. The LINAC has been upgraded for SuperKEKB, and beam commissioning has been performed during the upgrading.

LINAC Beam Parameters

	for KEKB		for SuperKEKB	
	e+	e-	e+	e-
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV
Bunch charge	Primary e-10nC →1 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Norm.Emittance ($\gamma\beta\varepsilon$)	2100 (mm·mrad)	100 (mm·mrad)	100/20 (Hor./Ver.) (mm·mrad)	50/20 (Hor./Ver.) (mm·mrad)
Energy spread	0.125%	0.125%	0.1%	0.1%
Num. of Bunch / Pulse	2	2	2	2
Repetition rate	50 Hz		50 Hz	
Simultaneous top-up injection	3 rings (KEKB e-/e+, PF)		4 rings (SuperKEKB e-/e+, PF, PF-AR)	

Schedule

SuperKEKB commissioning is divided into three stages. (phase1, phase2, phase3)

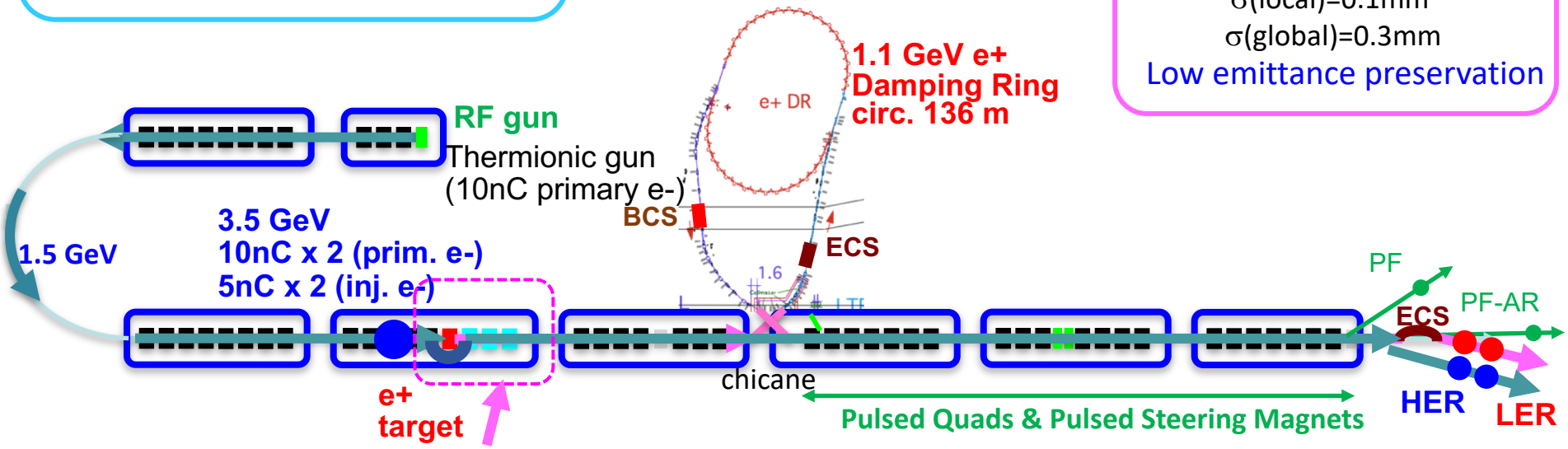


Major Upgrades of Injector LINAC

Photo-cathode RF gun system
< e- beam>
Low emittance ($\gamma\varepsilon \leq 20$ mm·mrad)
high bunch charge ($\geq$ 5nC)

Positron Damping Ring (DR)
Low emittance e+ beam

Alignment error tolerance
σ(local)=0.1mm
σ(global)=0.3mm
Low emittance preservation



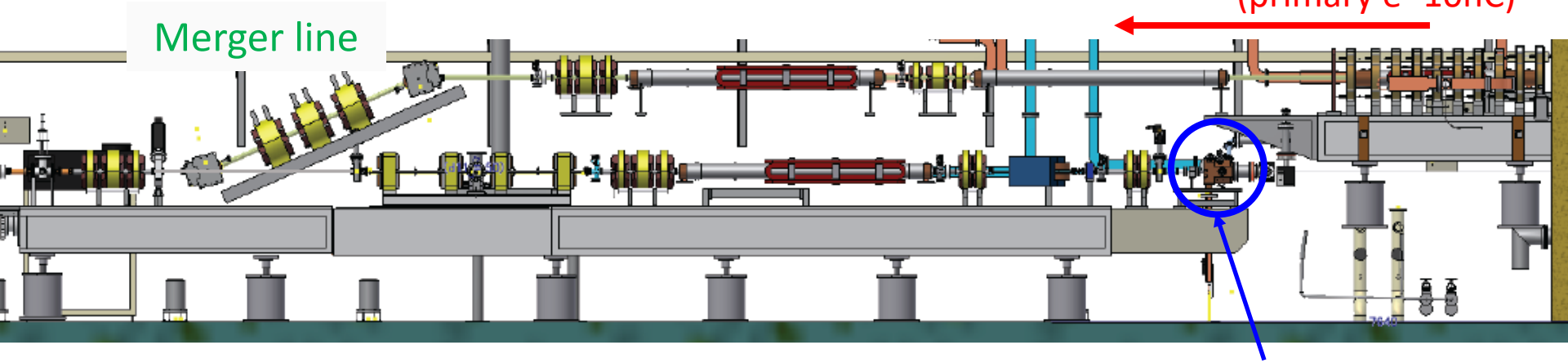
Positron Capture Section
- Flux concentrator (FC)
- Large aperture S-band accel. Structures (LAS)

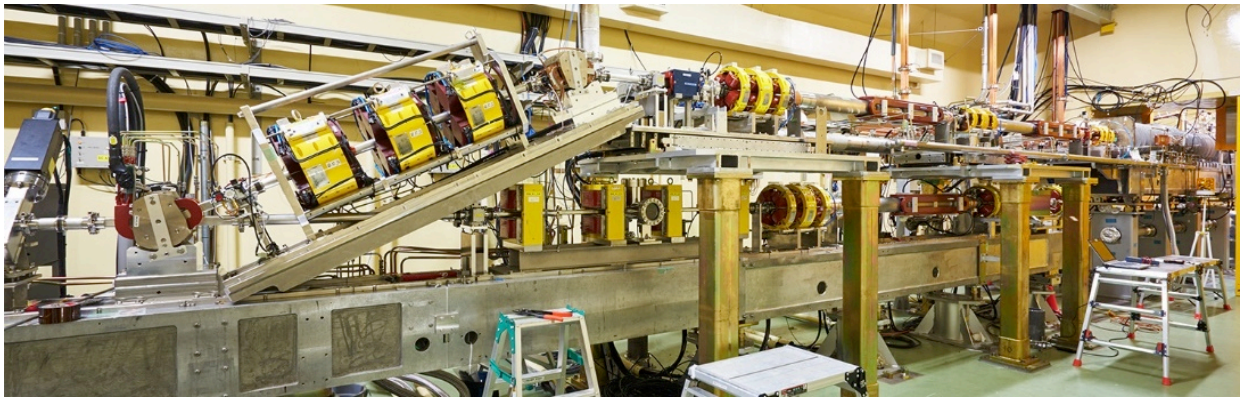
4 times higher e+ yield

Event Timing System and Pulsed Modules
- Synchronization for 5-rings including DR
- 200 parameters are switched at 50Hz each mode
- Optics at the downstream of DR is switched by using pulsed magnets

Layout of Electron Guns

- Thermionic electron gun are located upstairs to produce ~10 nC primary electrons for positron production.
- Photocathode RF gun for low emittance e- production is located on the straight line.

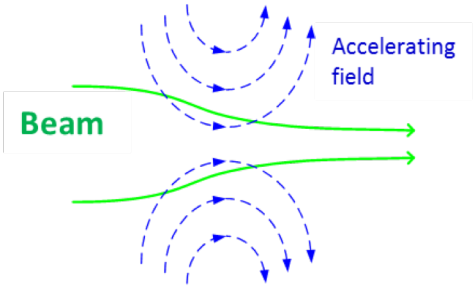




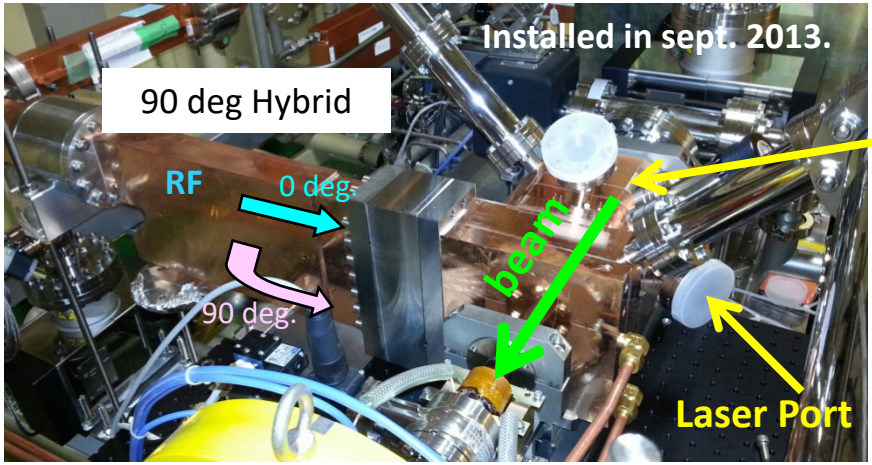
Thermionic gun: commissioning was started from June 2015.

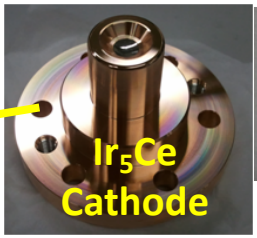
Quasi Traveling Wave Side Couple RF GUN

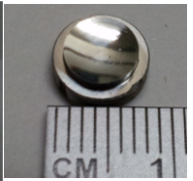
Strong focusing force using accelerating field



Quasi traveling wave (QTW) side couple RF gun

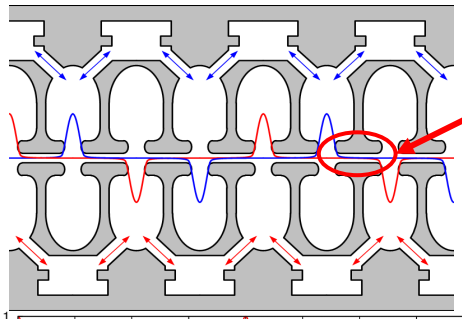






QE=1 × 10^{-4} @266nm
Long lifetime

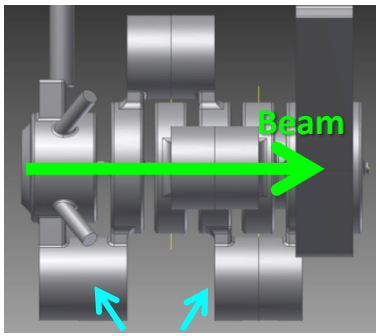
Incident angle: 60deg to the cathode surface.

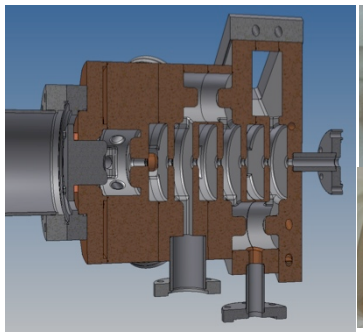


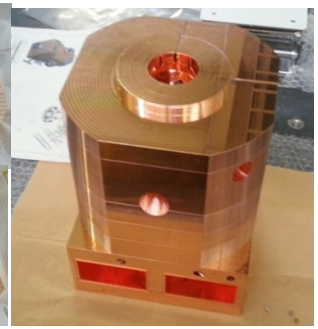
QTW type is adopted to make drift space short.

Drift space = no focus field

7 cell, 13.5 MeV@design
Emittance: 5.5 mm-mrad @5 nC (by simulation)
This RF gun can generate e- up to 10 nC







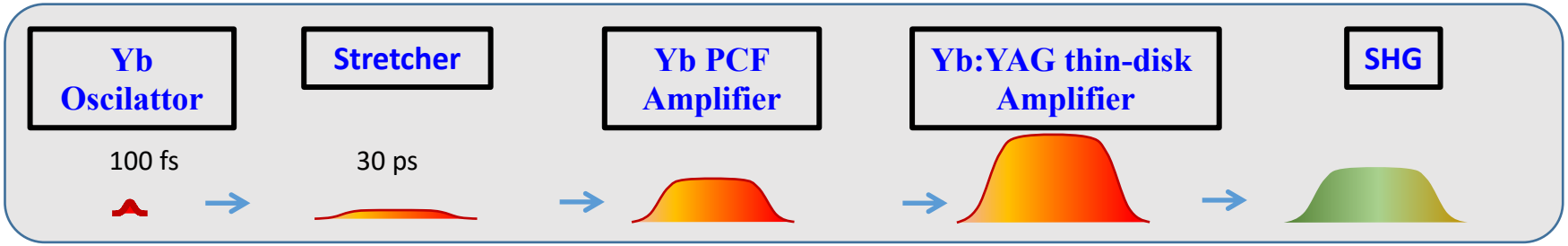
QTW is made by two standing waves with 90deg phase difference.

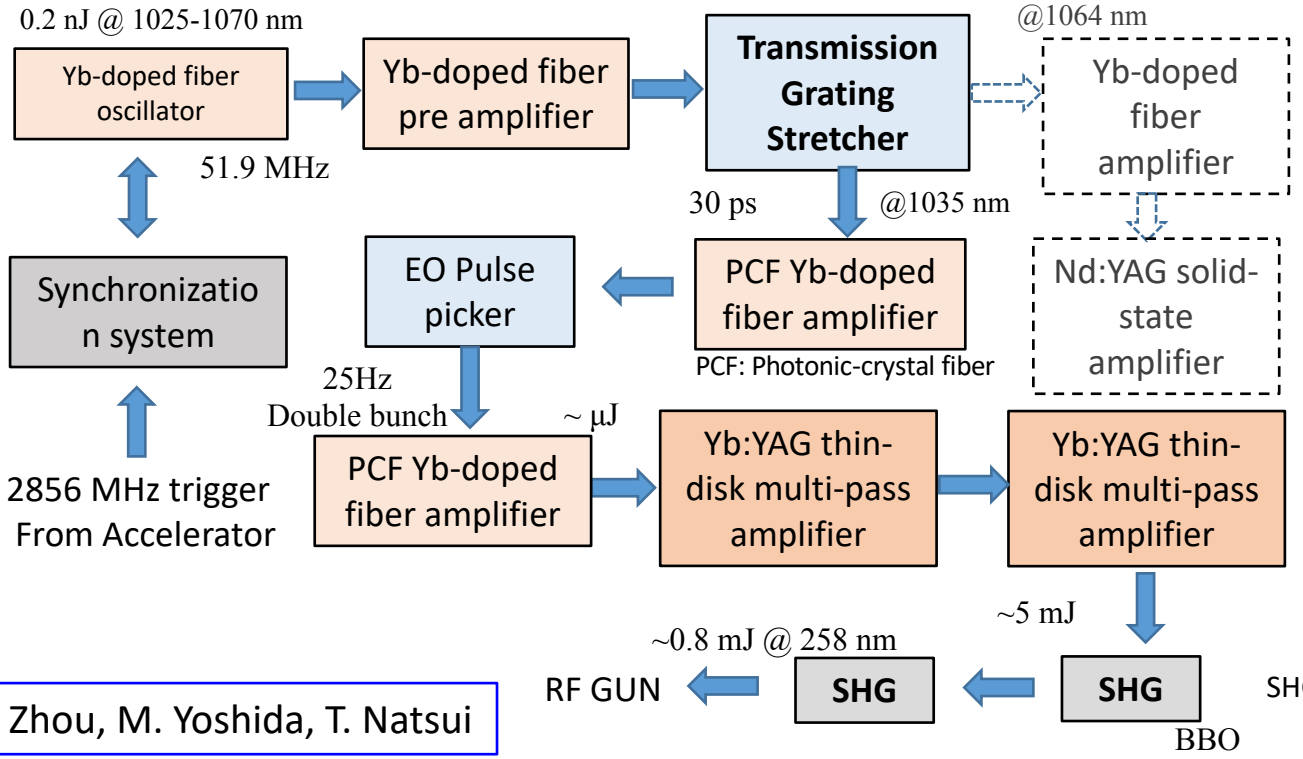
coupling cavities

T.Natsui, M.Yoshida

Yb:YAG/Nd:YAG Laser System for RF-Gun

Yb:YAG (1025-1070 nm) broad band →Pulse shape manipulation is possible.





2 bunch, 25 Hz achieved (limited by thermal effect)

Final goal is 50 Hz.

X. Zhou, M. Yoshida, T. Natsui

Beam Commissioning of RF Gun

Operation Condition

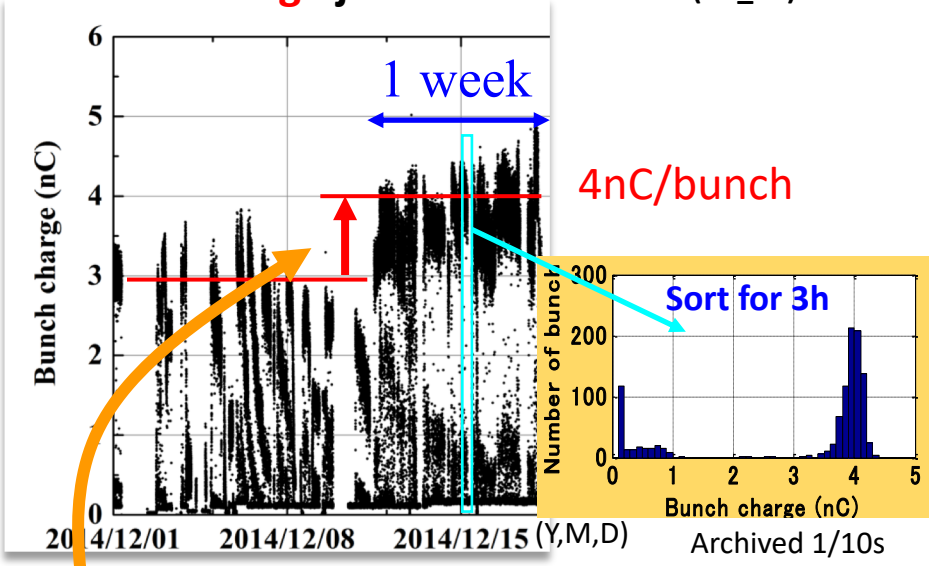
- Laser: 2bunch, 25 Hz
- RF gun acc. voltage: limited to 6.5 MV by breakdown (13.5 MV@design)

Target : 5nC

$\gamma\varepsilon_x$=50 mm·mrad, $\gamma\varepsilon_y$=20 mm·mrad @ LINAC end

$\gamma\varepsilon_x$, $\gamma\varepsilon_y$ = 10 mm·mrad @ Gun

Bunch charge just after RF GUN (A1_C5)



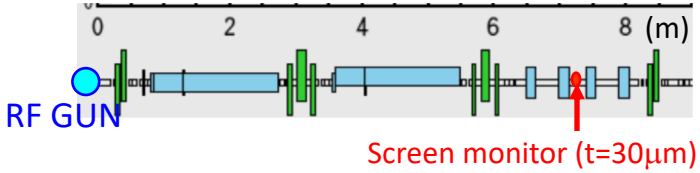
Bunch charge stability depends on the laser stability.

Yb:YAG Thin-disk cooling by soldering Cu plate was Improved.

R. Zhang, TUPWA071

Laser power increased and stability was also improving.

Emittance measurement by Quad-scan

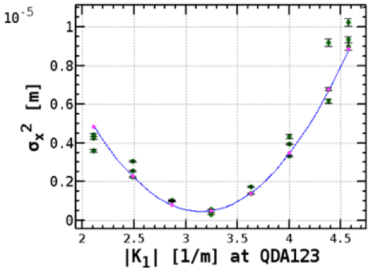


Bunch charge: 3nC@Screen

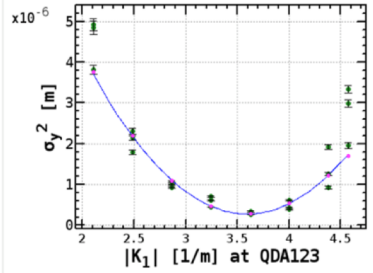
Beam size was measured shot by shot.

=> Position jitter is not included

$\gamma\varepsilon_x$=49.2 mm·mrad±10%



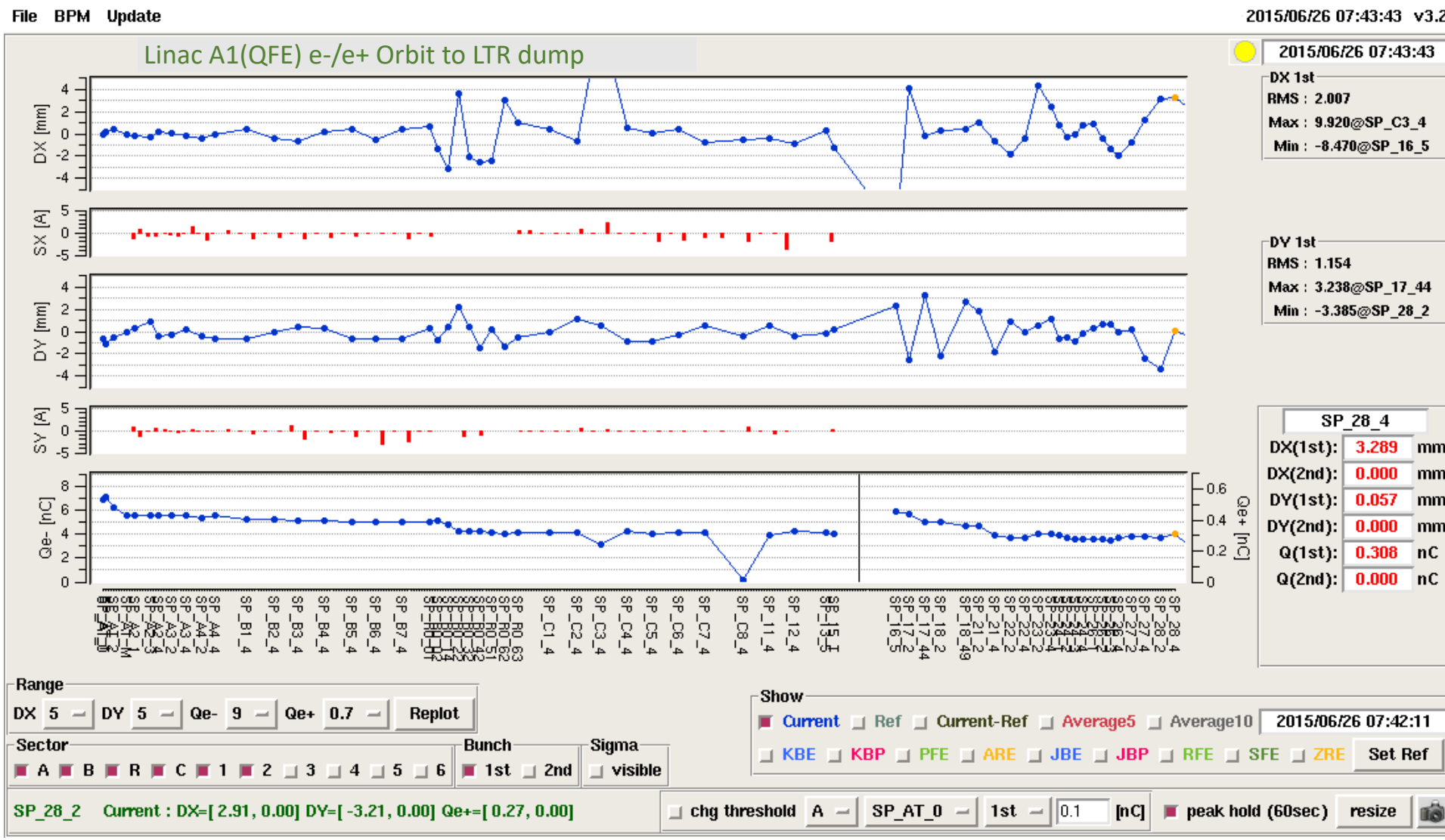
$\gamma\varepsilon_y$=26.2 mm·mrad±10%



- Measured emittances were higher than target values.
- Higher horizontal emittance is due to laser incident angle.

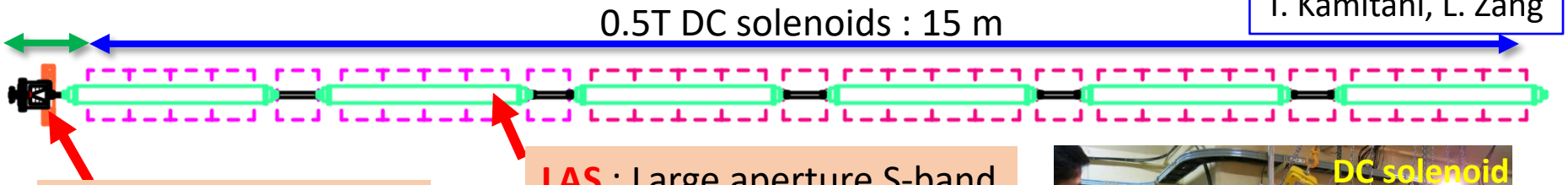
Need high acc. voltage of RF gun for small emittance

Beam Commissioning of Thermionic e- Gun



Positron Capture Section

T. Kamitani, L. Zang



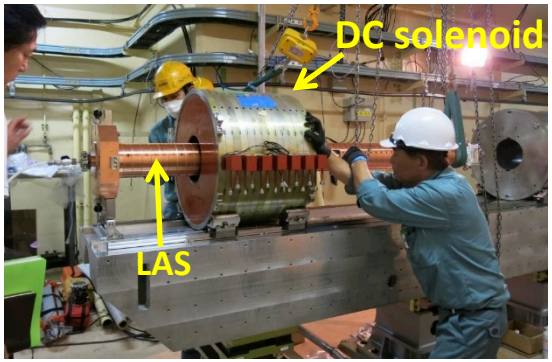
FC : Flux concentrator

Large energy acceptance

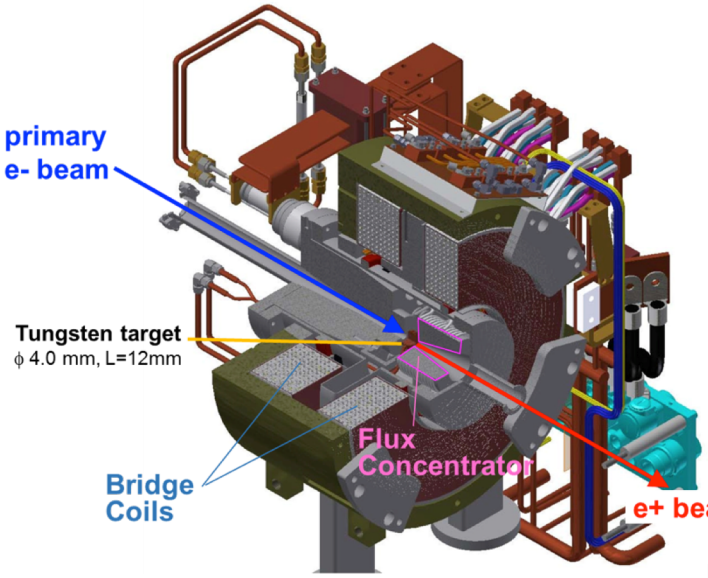
LAS : Large aperture S-band accel. Structures

Aperture ϕ20mm $\rightarrow$ ϕ 30mm

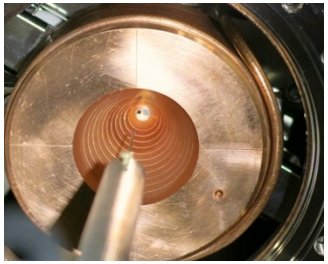
Large transverse acceptance



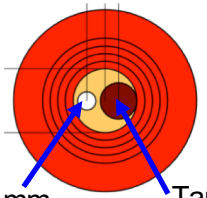
Solenoid field at e+ production target
= 3.5T(FC)+1T(Bridge coil) = 4.5 T

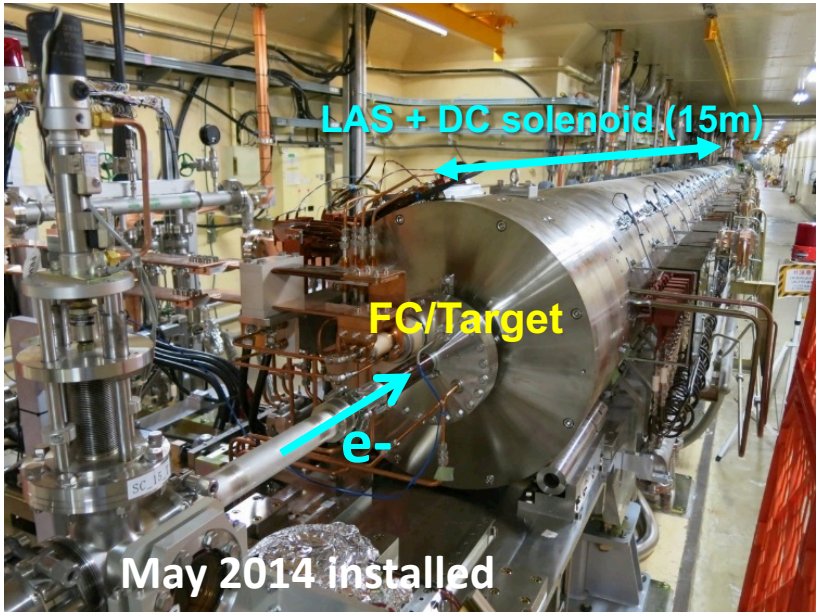


FC viewed from downstream



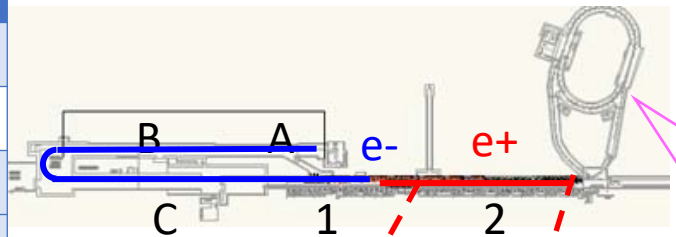
3.5T@12kA, 6μs (half sine)





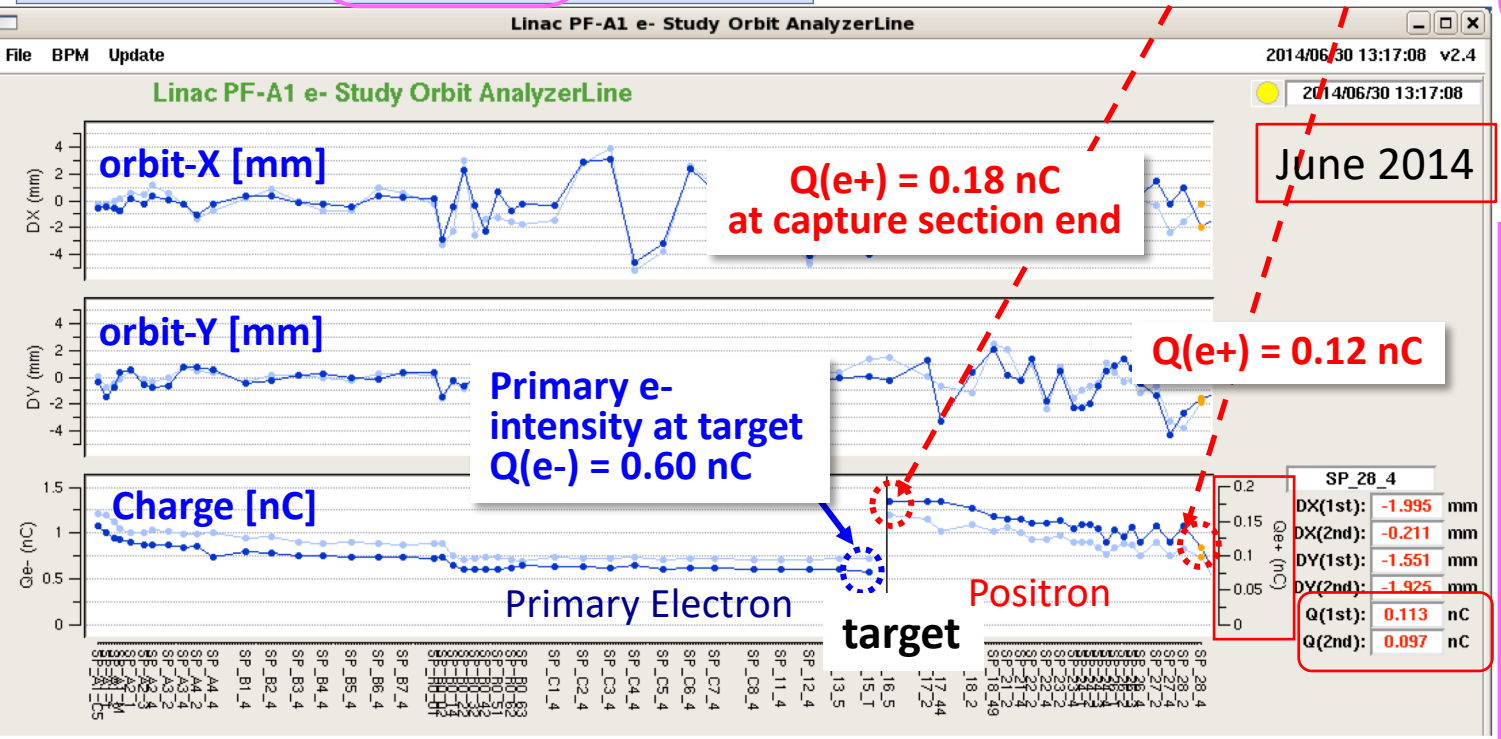
Positron beam commissioning @June 2014

	Design	6/2014
Flux Concentrator	**12 kA**	6.4 kA
Bridge Coil	**600 A**	600 A
DC Solenoids	**650 A**	370 A
Acc Field	**14, 12MV/m**	10, 12MV/m



T. Kamitani

Ye+ > 40 % is necessary at DR entrance.



June 2014

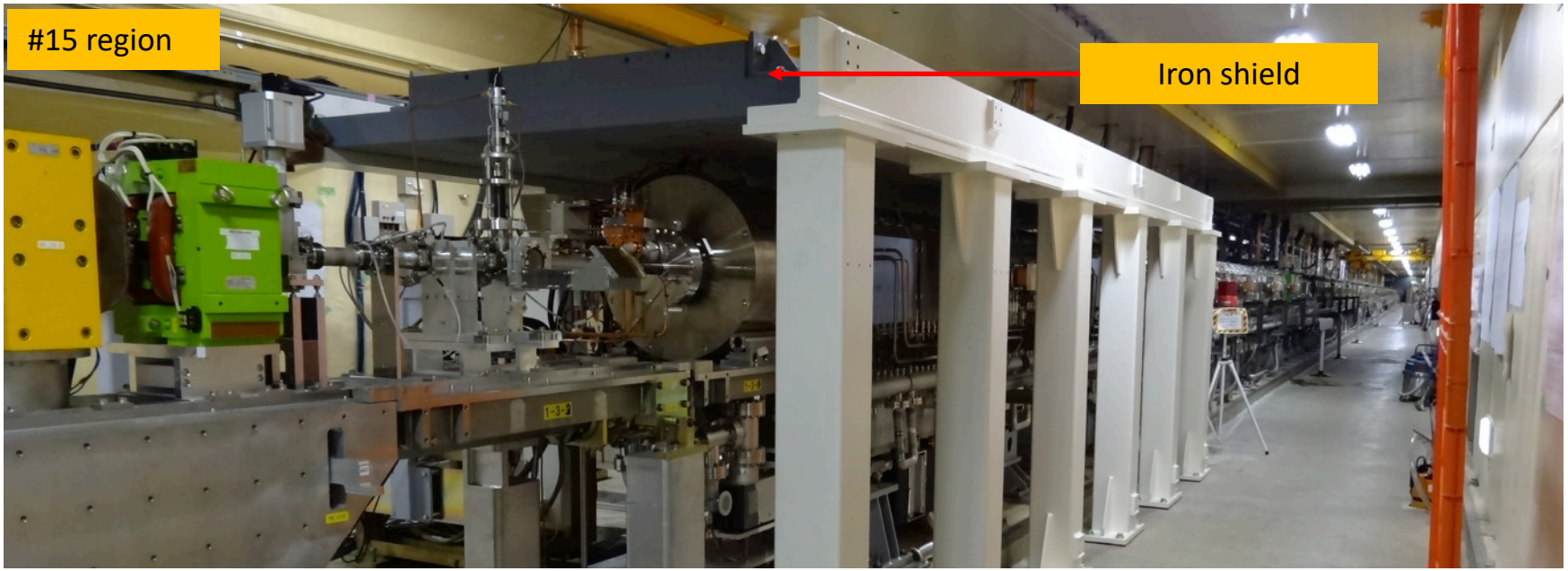
Commissioning with design parameters will be started from Oct. 2015.

So far, the commissioning data agrees the design well

e+ yield (Ye+) = e+ charge (Qe+) / primary e- charge (Qe-)

Ye+@Jun.2014 = 30 % at capture section end, 20% at the end of Sector2 with limited ele/mag fields

Radiation shield for higher beam current



Gradual increase of beam current / shield and corresponding radiation license applications are planned

Summary

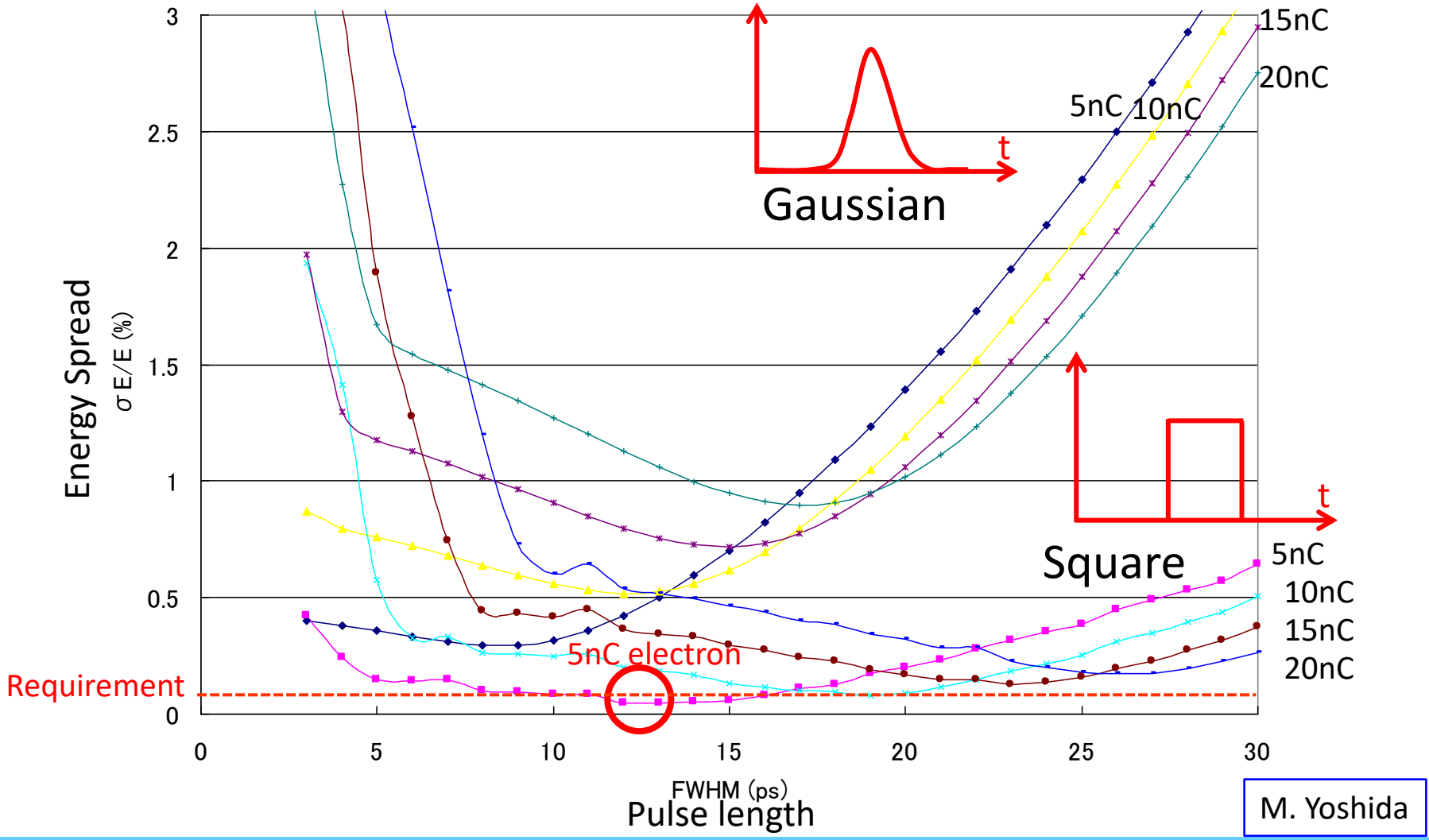
- Steady progress towards first MR injection in JFY2015
- Finished earthquake disaster recovery in JFY2014
- Will make gradual improvements up to Phase-III
  - Alignment: almost confident on the required precision (0.1-mm local, 0.3-mm global), need to maintain for longer term
  - RF gun: following recommendations at review meetings with commercial devices and Nd-based lasers
  - Thermionic gun: under commissioning
  - Positron generator: waiting for license tests
- Will balance between final beam quality and operation in phases
- Will select optimized route depending on available resources


Mt. Tsukuba
Thank you
SuperKEKB
dual rings
PF-AR
PF
Injector
Linac

Back-up slides

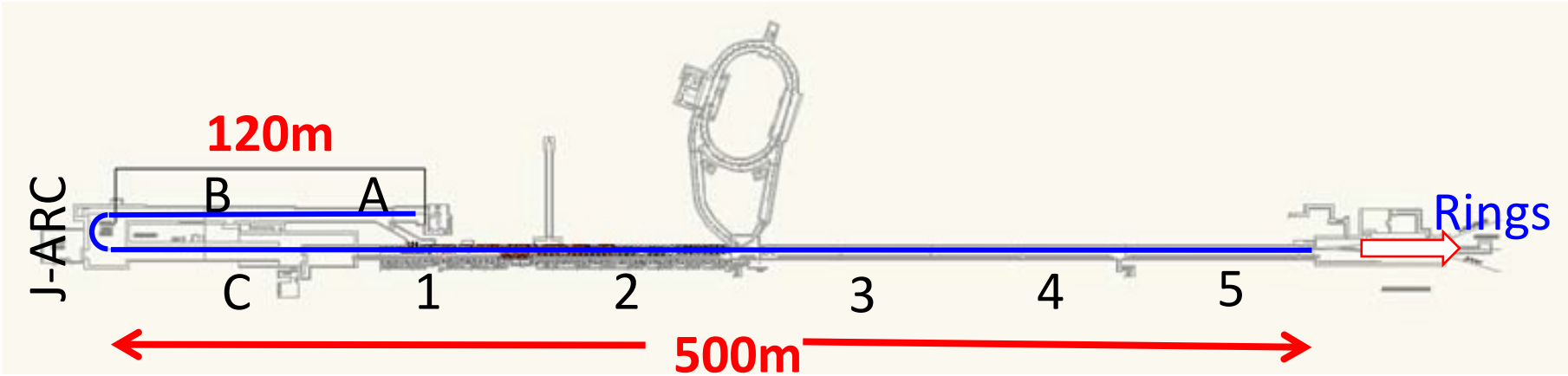
Why need longitudinal pulse-shape manipulation?

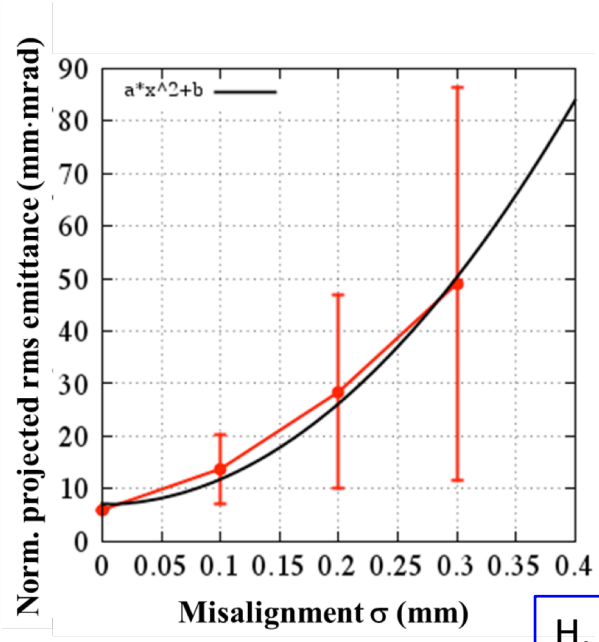
Energy spread of 0.1% is required for SuperKEKB synchrotron injection.



M. Yoshida

Alignment Requirement





H. Sugimoto

$\sigma < 0.1$ mm: $\beta\gamma\varepsilon$ 20 mm·mrad is almost satisfied.

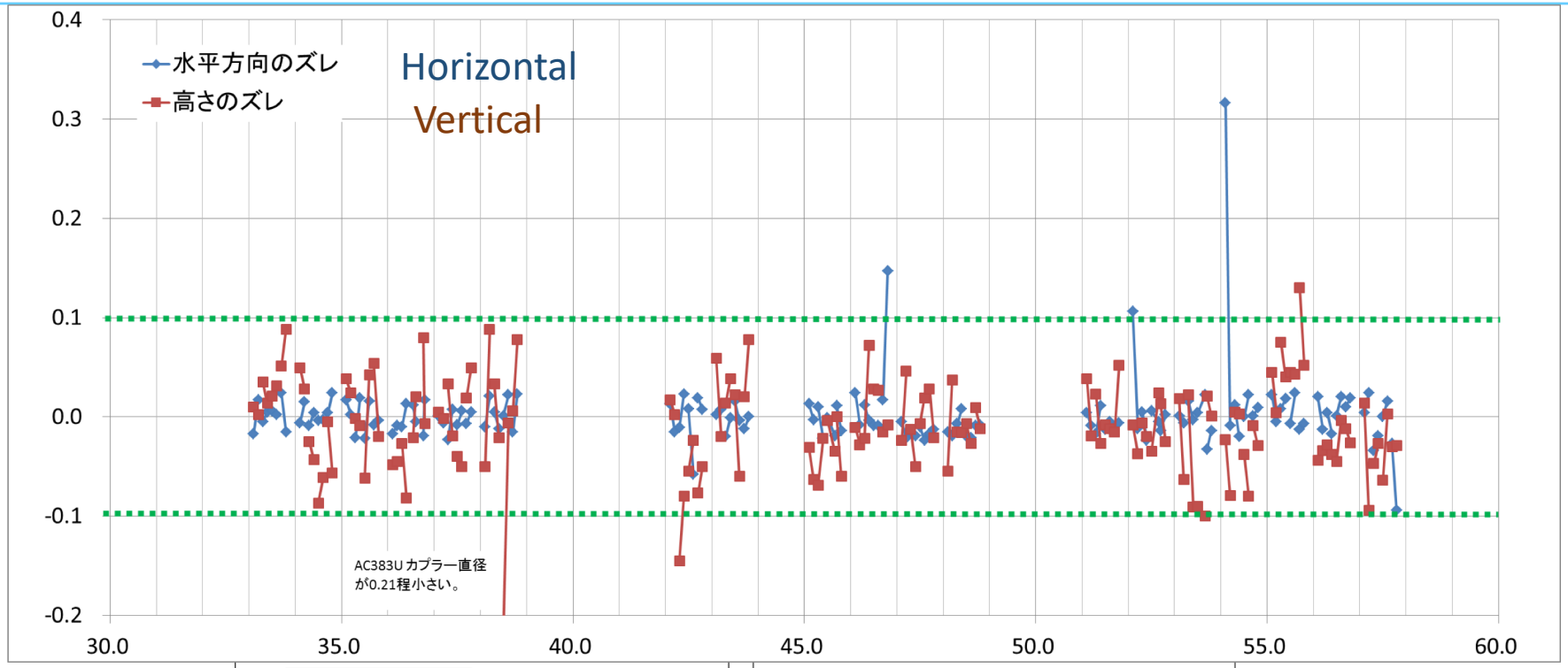
$\sigma > 0.1$ mm: emittance preservation is required by some methods.

Requirement

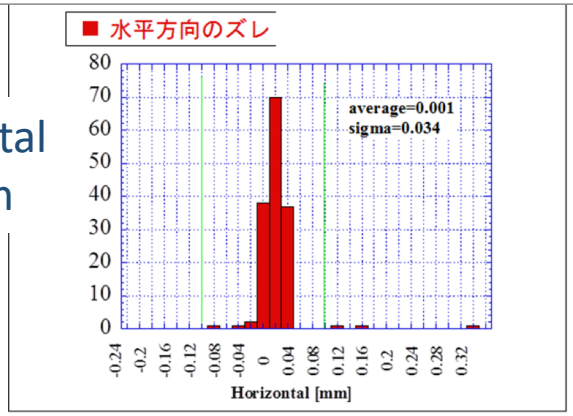
Local $\sigma < 0.1$mm

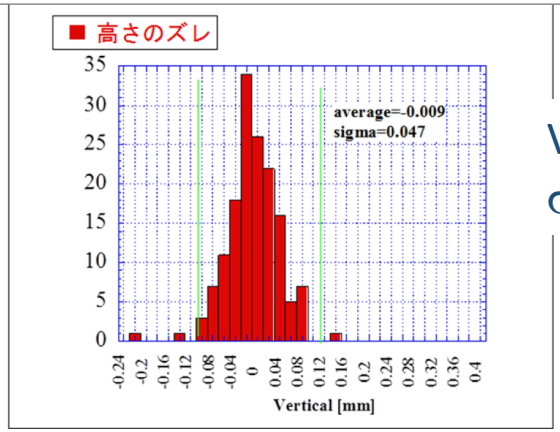
Global $\sigma < 0.3$mm

Hard ware alignment on a girders in sector 3 - 5



Horizontal
σ=34μm





Vertical
σ=47μm

T. Higo

Floor Movement in a Half Year

straight laser of 500m + Position Detector (PD)

T. Suwada

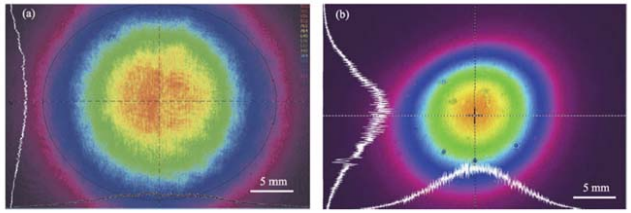
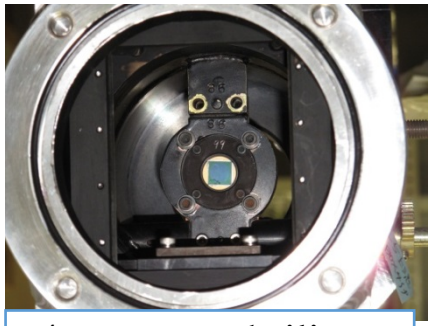
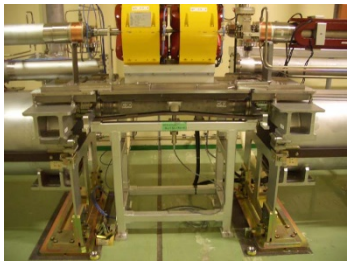


FIG. 5. Intensity profiles of the laser beam at (a) $z = 0$ m and (b) $z = 500$ m. Scale bars are 5 mm.

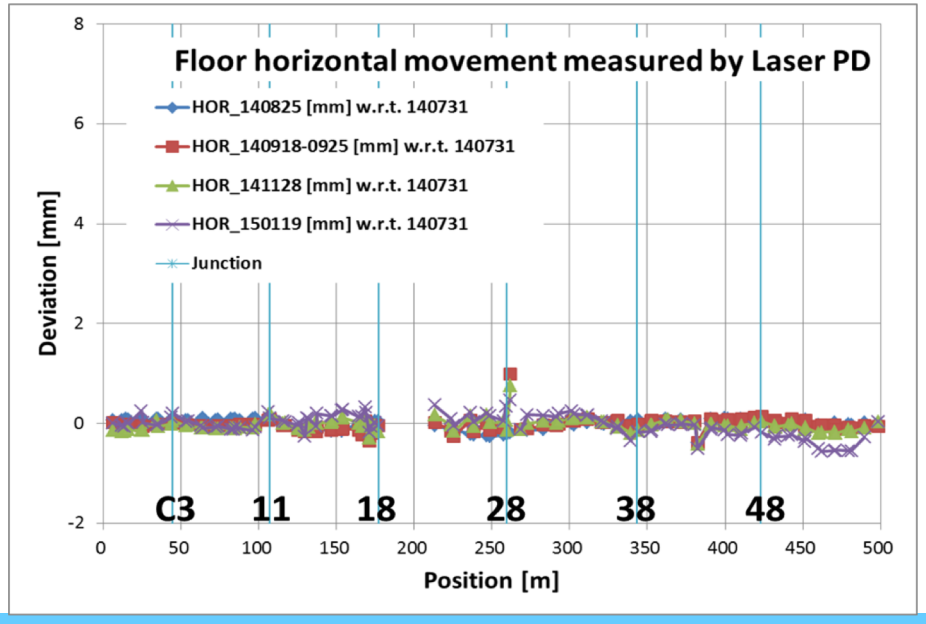


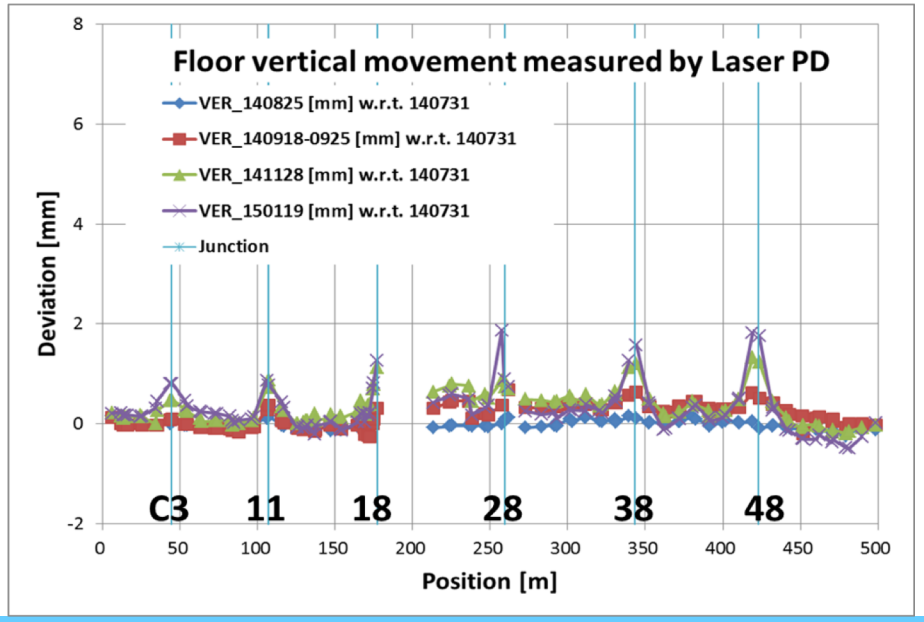
4-segmented silicon PD (dia.=10mm)

At expansion joint in tunnel, large movement is observed.



T. Higo

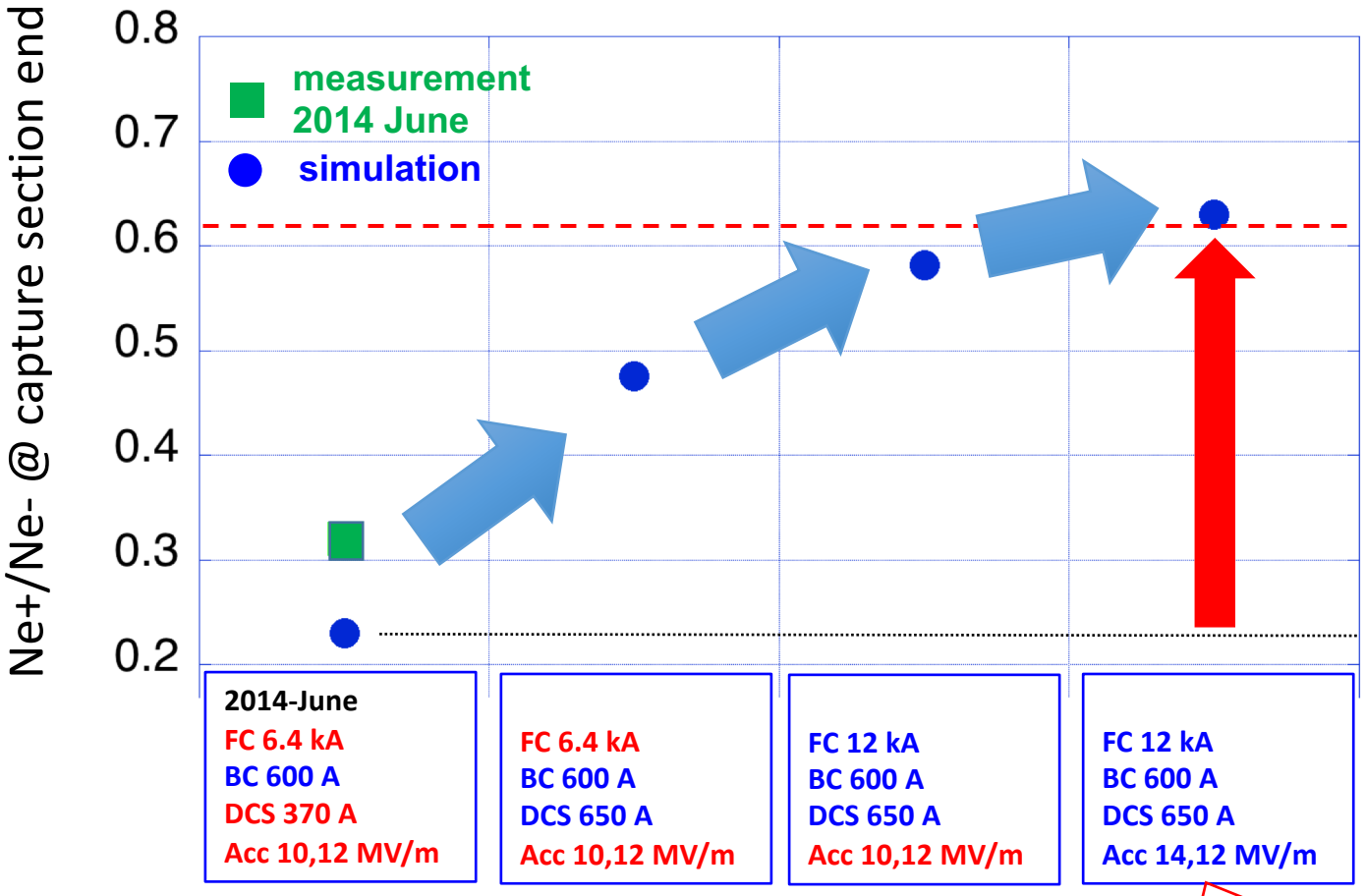




Expected e+ Yield improvement

T. Kamitani, F. Miyahara

At the entrance of LER, 4nC e+ is necessary for 10nC primary e- .



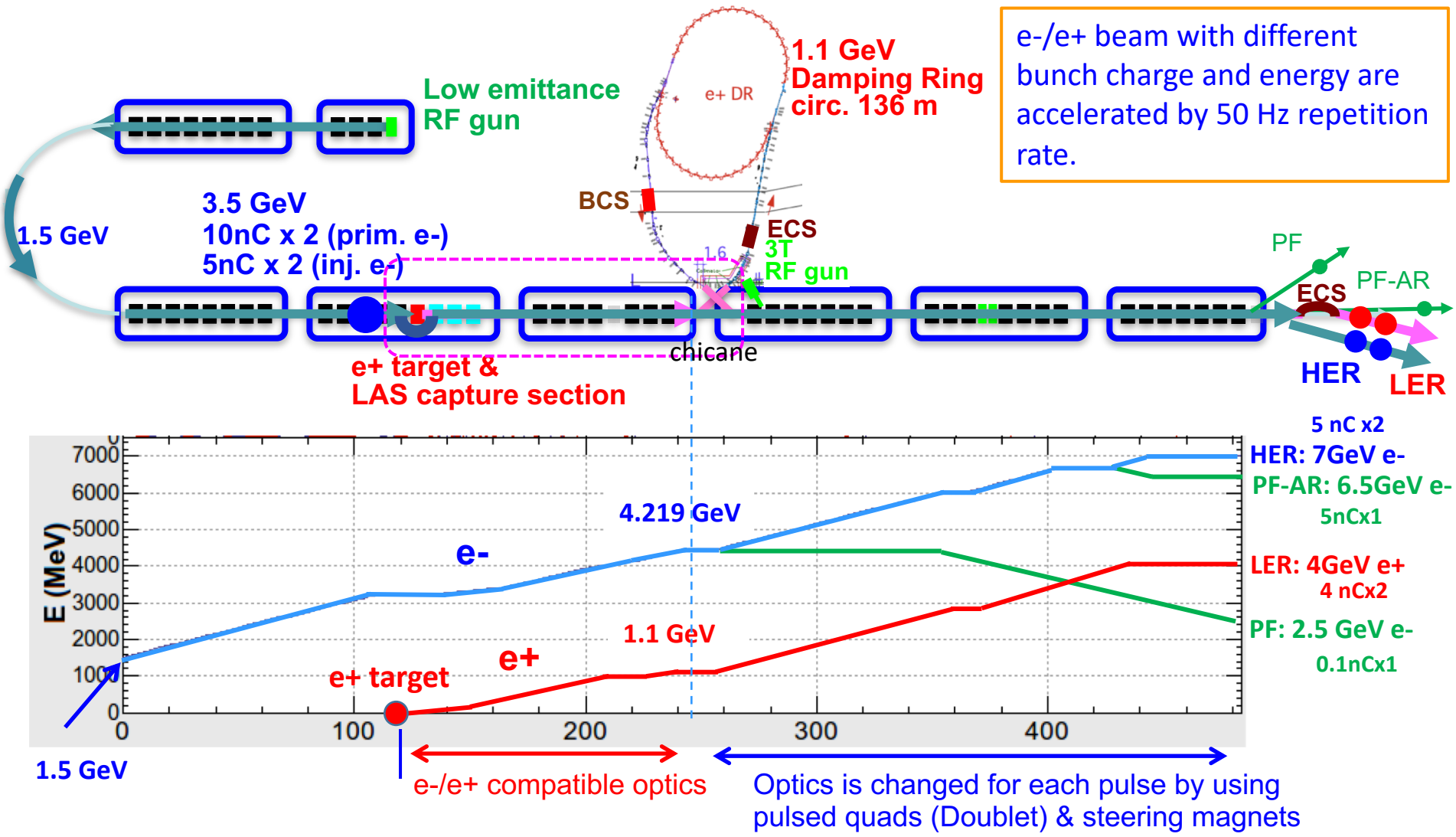
Designed yield at capture section end

By raising
DC Solenoid field
FC field and
acceleration field,

2.7 times Improvement expected.

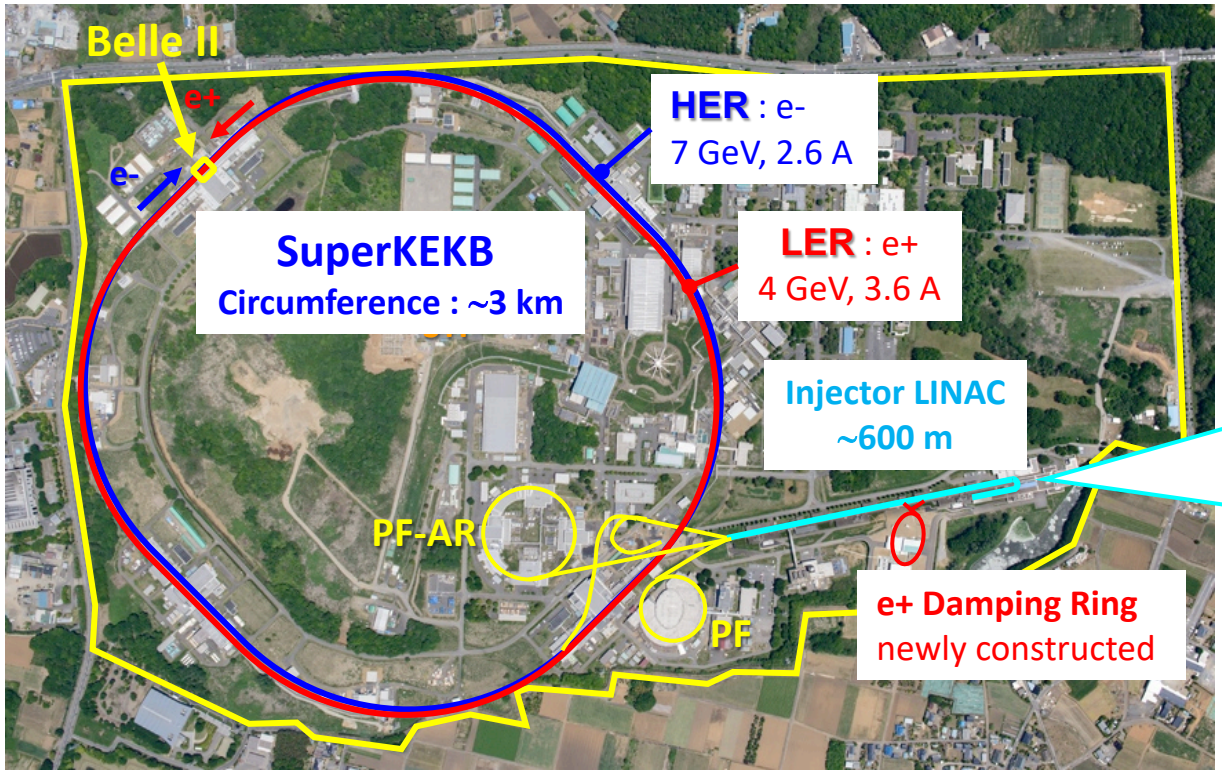
Start from Oct. 2015

LINAC Beam Acceleration Scheme



Injector LINAC

The upgrade construction toward SuperKEKB has been started from 2010.
High-current and low-emittance injection beams are required for SuperKEKB.
Upgrade of injector LINAC for SuperKEKB is in progress.



LINAC Provides:

LER:	**4 GeV e+**	**4nC × 2**
HER:	**7 GeV e-**	**5nC × 2**
PF:	**2.5 GeV e-**	**0.3nC ×1**
PF-AR:	**6.5 GeV e-**	**5nC × 1**

LINAC is the injector for four storage rings (LER, HER, PF, and PF-AR).
The pulse by pulse beam mode switching in 50 Hz which is repetition rate of the LINAC is necessary for top-up injections into these four rings.

Beam Lifetime

Y. Funakoshi

	KEKB (design)		KEKB (operation)		SuperKEKB Design	
	LER	HER	LER	HER	LER	HER
Radiative Bhabha	21.3h	9.0h	6.6h	4.5h	28min.	20min.
Beam-gas	45h[a)]	45h[a)]			24.5min.[b)]	46min.[b)]
Touschek	10h	-			10min.	10min.
Total	5.9h	7.4h	~2.2h	~3.3h	6min.[c)]	6min.[c)]
Beam current	2.6A	1.1A	1.6A	1.1A	3.6A	2.6A
Loss Rate	0.12mA/s	0.04mA/s	0.23mA/s	0.11mA/s	10mA/s	7.2mA/s

a) Bremsstrahlung
b) Coulomb scattering, sensitive to collimator setting
c) w/o beam-beam effect

Revolution freq~100kHz

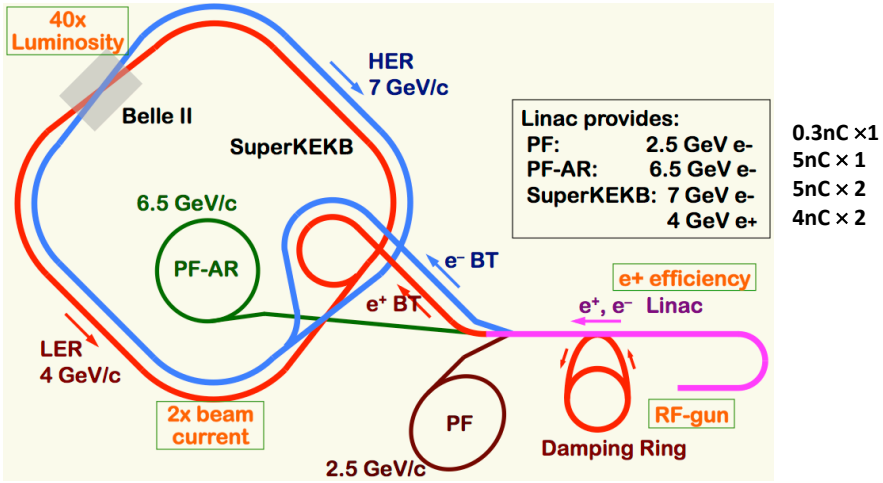
For compensation of the particle loss
4nC@25Hz 2.9nC@25Hz
injection rate are required.

Low emittance and high current injection beams are necessary.

LINAC is a key component of SuperKEKB.

LINAC Beam Parameters

	for KEKB		for SuperKEKB	
	e+	e-	e+	e-
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV
Bunch charge	Primary e-10nC →1 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Num. of Bunch / Pulse	2	2	2	2
Norm.Emittance ($\gamma\beta\varepsilon$)	2100 (mm·mrad)	100 (mm·mrad)	100/20 (Hor./Ver.) (mm·mrad)	50/20 (Hor./Ver.) (mm·mrad)
Energy spread	0.125%	0.125%	0.1%	0.1%
Repetition rate	50 Hz		50 Hz	



Beam modes are switched in pulse to pulse for 5-rings including Damping Ring (DR).

High charge and low emittance are required for SuperKEKB

	for KEKB		for SuperKEKB	
	e+	e-	e+	e-
Energy (GeV)	3.5	8.0	4.0	7.0
Bunch charge (nC)	1	1	4	5
Norm.Emittance ($\gamma\beta\varepsilon$) (mm·mrad)	2100	100	100 (H) / 20 (V)	50 (H) / 20 (V)
Energy spread (%)	0.125	0.125	0.1	0.1