Electron / Positron Injector Linac

K. Furukawa
for Linac division

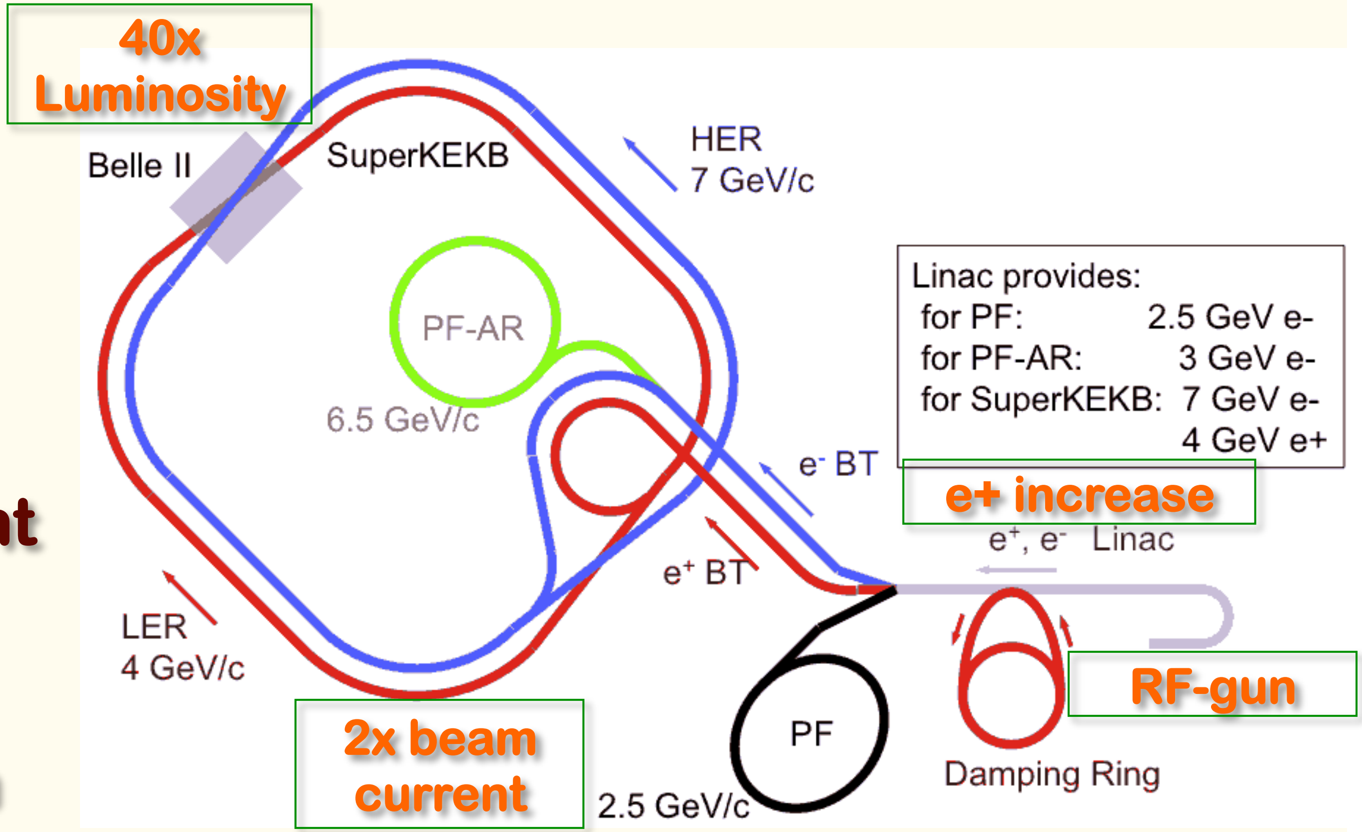
Linac in SuperKEKB Project

40-times higher Luminosity

- Twice larger storage beam → Higher Linac beam current
- 20-times higher collision rate with nano-beam scheme
  - → Low-emittance Linac injection beam
  - → Shorter storage lifetime → Higher Linac beam current

Linac challenges

- Low emittance e-
  - High-charge RF-gun
- Low emittance e+
  - Damping ring
- Higher e+ beam current
  - New capture section
- Beam transport
- Four ring manipulation

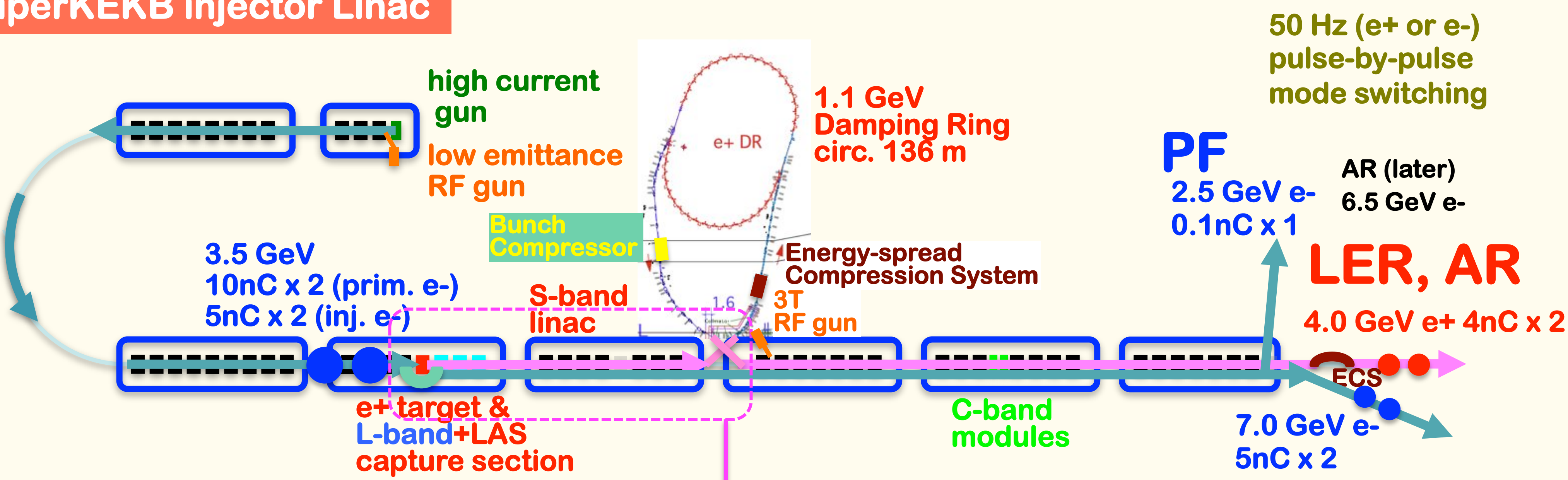


SuperKEKB Injector Linac

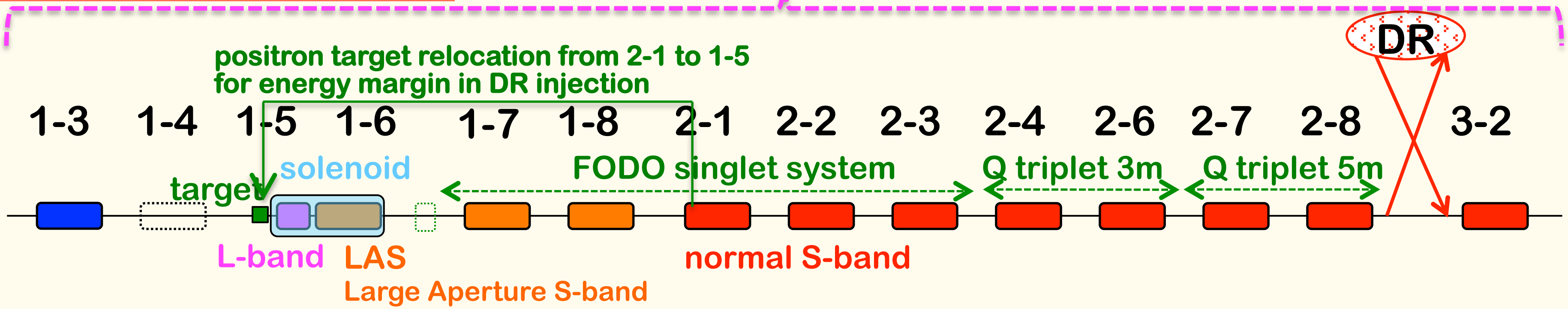
- **Higher Injection Beam Current**
  - To Meet the larger stored beam current and shorter beam lifetime in the ring
  - 4~8-times larger bunch current for electron and positron
  - Reconstruction of positron generator, etc
- **Lower-emittance Injection Beam**
  - To meet nano-beam scheme in the ring
  - Positron with a damping ring
  - Electron with a photo-cathode RF gun
  - Emittance preservation by alignment and beam instrumentation
- **Quasi-simultaneous injections into 4 storage rings**
  - SuperKEKB e^-/e^+ rings, and light sources of PF and PF-AR
  - Improvements to beam instrumentation, low-level RF, controls, timing, etc

Linac and Positron Capture Section

SuperKEKB injector Linac

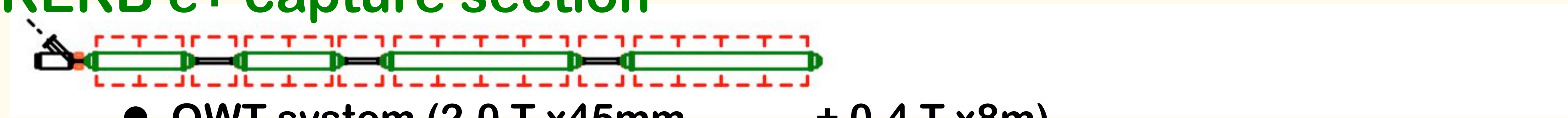


Positron Capture Section



Design of Positron Capture Section

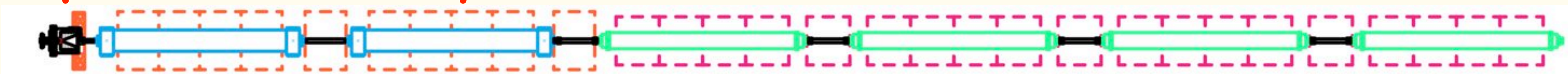
KEKB e+ capture section



- QWT system (2.0 T x45mm + 0.4 T x8m)
  air-core pulse coil DC solenoids
- KLY1 (S-band) -> 2 x 1m 12 MV/m, aper 2a = 27 -> 25 mm
- KLY2 (S-band) -> 2 x 2m 10 MV/m, aper 2a = 25 -> 21 mm
- beam energy at capture section exit : 80 MeV

N(e+)/N(e-) = 10 % at 3.5 GeV linac-end
N(e+)/N(e-)/E(e-) = 2.5 %/GeV

SuperKEKB e+ capture section



- AMD system (6.0 T x200mm + 0.4 T x15m)
  flux concentrator DC solenoids
- L-band -> 2 x 2m 10 MV/m, aper 2a = 39 -> 35 mm
  LA S-band -> 4 x 2m 10 MV/m, aper 2a = 32 -> 30 mm
- beam energy at capture section exit : 110 MeV

N(e+)/N(e-) = 65 % at 1.1 GeV DR
N(e+)/N(e-)/E(e-) = 19 %/GeV

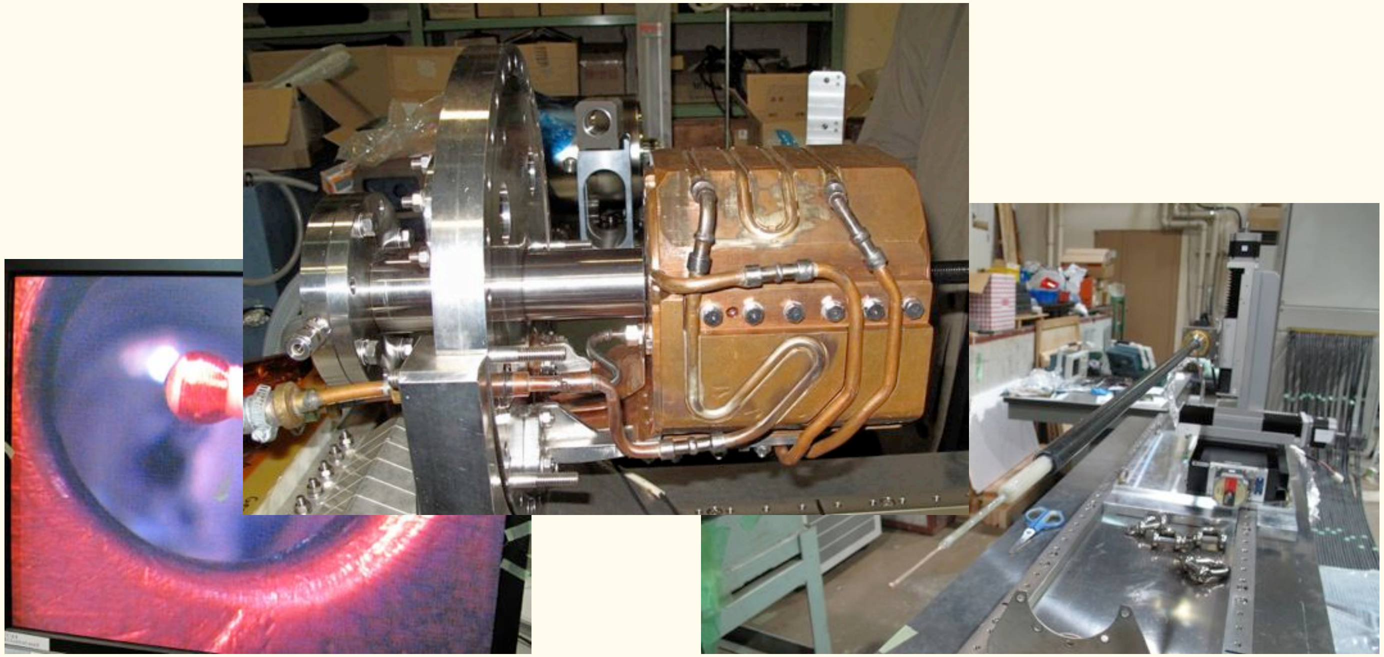
Deceleration mode

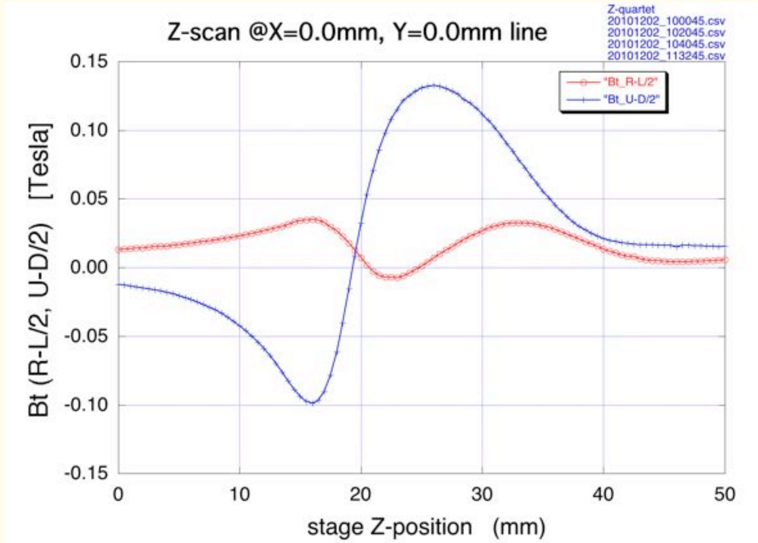
full L-band configuration

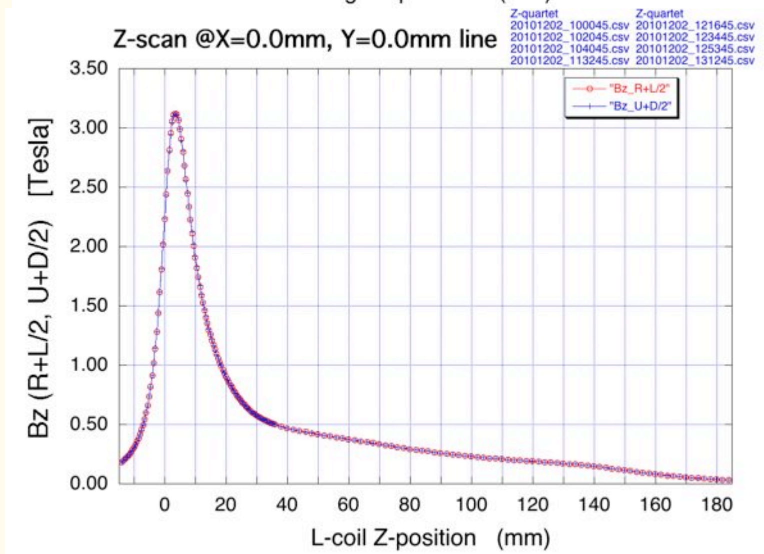
L-band + LAS configuration
for comparable performance
with reduced cost

Flux Concentrator BINP-type

- In collaboration with BINP, prototype field measurement & high-power operation test performed at KEK from Nov. 2010 to March 2011.
- Breakdown issue with vacuum burst above 7 Tesla was identified. However, the investigation with BINP experts was interrupted by the Earthquake.

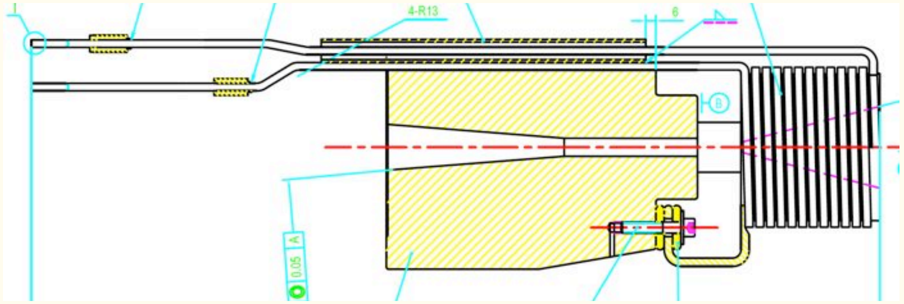


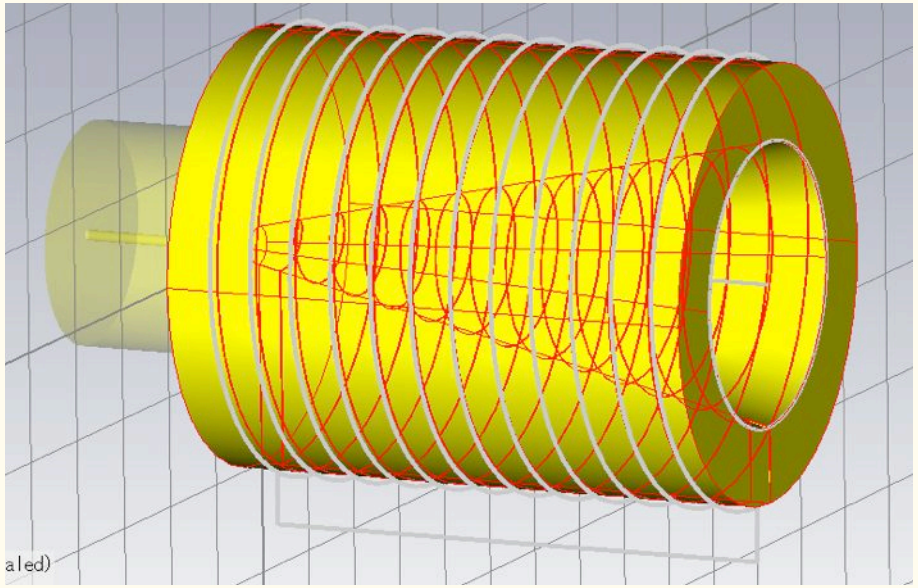


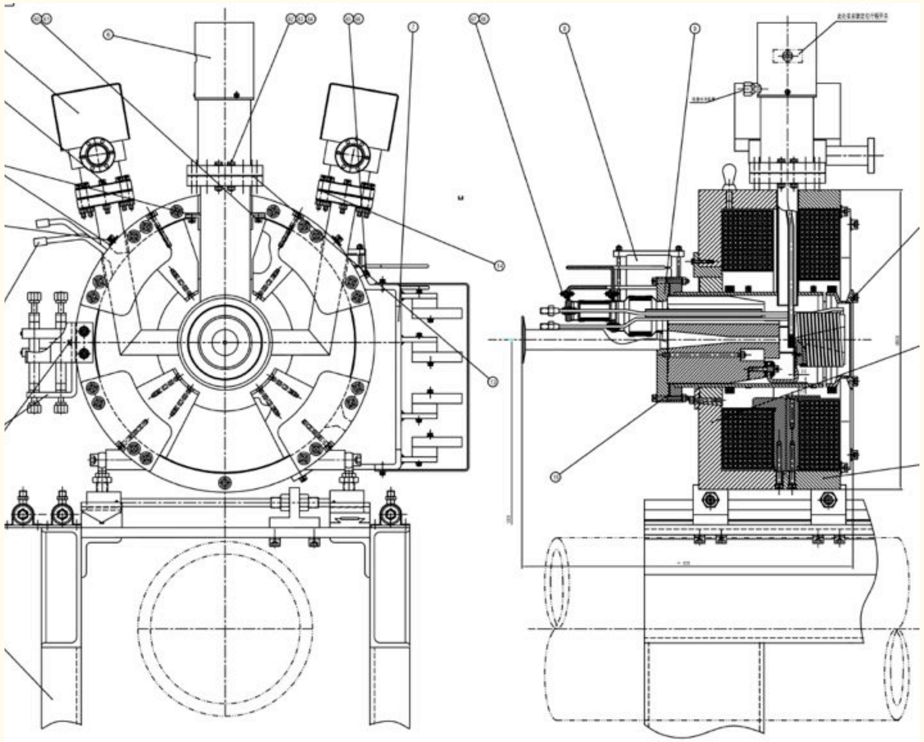


Flux Concentrator SLAC-type

- with helps from SLAC and IHEP we are going to fabricate SLAC-type FC for linac commissioning from 2013 autumn and stable operation at T=0.
- Final optimization of field design and mechanical design as well as fabrication system design







SLAC-type FC at IHEP

Capture by L-band and LAS structures

- **L-band**
  - Large aperture (d=39~35mm) of accel. structure is desirable for transverse acceptance of Positron Capture Section
  - Coprime (5:11) frequency relation is effective to sweep out satellite bunches critical to DR radiation shield issue. Full S-band (LAS) capture section gives comparable e+ yield, but with plenty of satellite particles
- **LAS (Large Aperture S-band)**
  - Medium large aperture (d=32~30mm) is desirable for transverse acceptance of PCS and quad focusing system
  - Existing S-band rf source, SLED, DC solenoids are available & compact Q at FODO (reduction in initial cost)

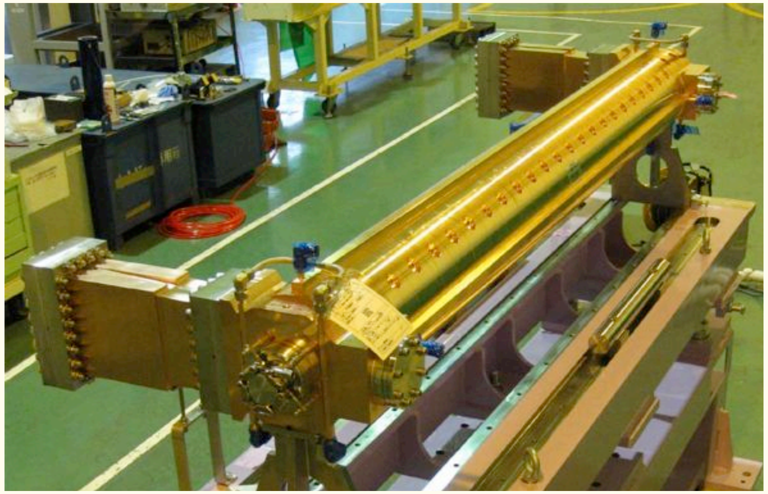
L-band Klystron

- 40 MW L-band(1298 MHz) klystron PV-1040 designed by KEK and Mitsubishi Electric
- compatible with existing S-band modulator and KLY tank in KEKB linac
- first PV-1040 delivered in March 2010
- performance test since June 2011
- KLY operation spec. at SKB linac
  30 MW x 1.5 us x 50 pps achieved !
- another two PV-1040 will be delivered, we will have three L-band klystrons for
  (1) positron capture section
  (2) bunch compressor at DR
  (3) spare

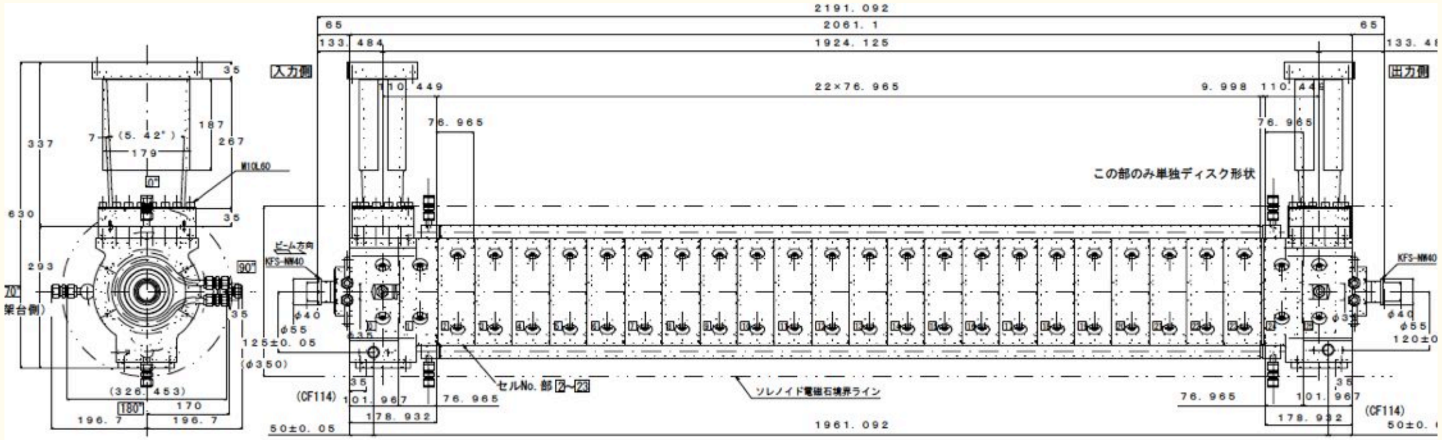
(KLY data by S. Matsumoto)

L-band Accelerating Structure

- first L-band structure completed in March 2010
- operation test at test stand from April 2012



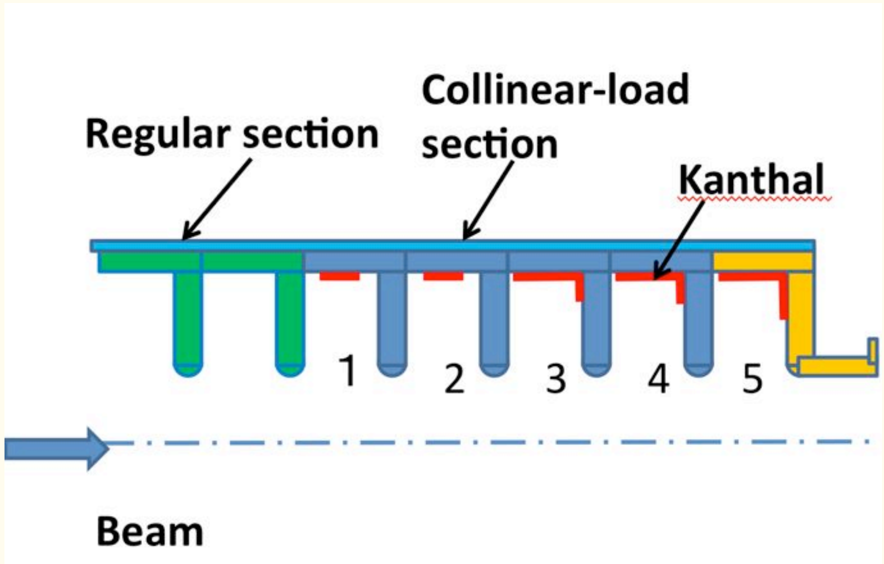
- RF frequency 1298 (=2856 x5/11) MHz
- traveling-wave structure (short rf pulse)
- constant gradient
- (2/3)pi phase advance per cell
- structure length 2.2 meter
- disk aperture 2a = 39.4 ~ 35.0 mm
- field strength 12 MV/m@15 MW input
- single feed coupler (with field symmetrized)
- attenuation constant tau = 0.26

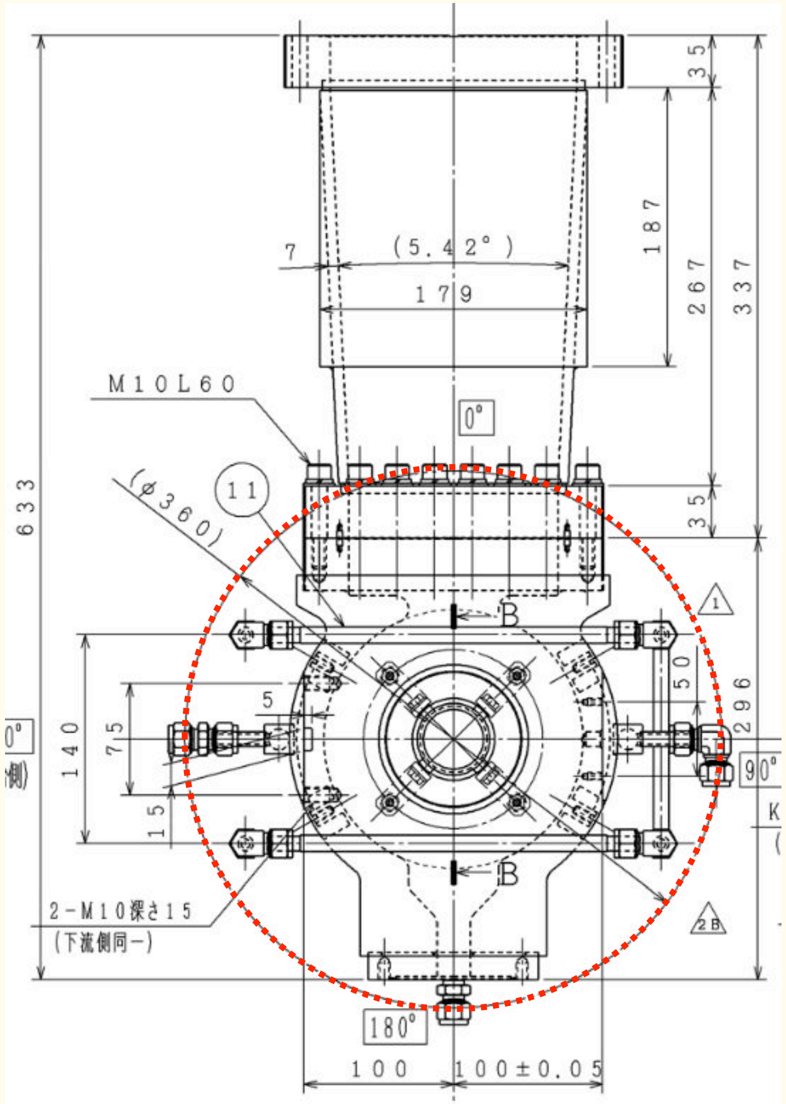


(structure data by T. Higo)

Built-in Collinear RF Power Load

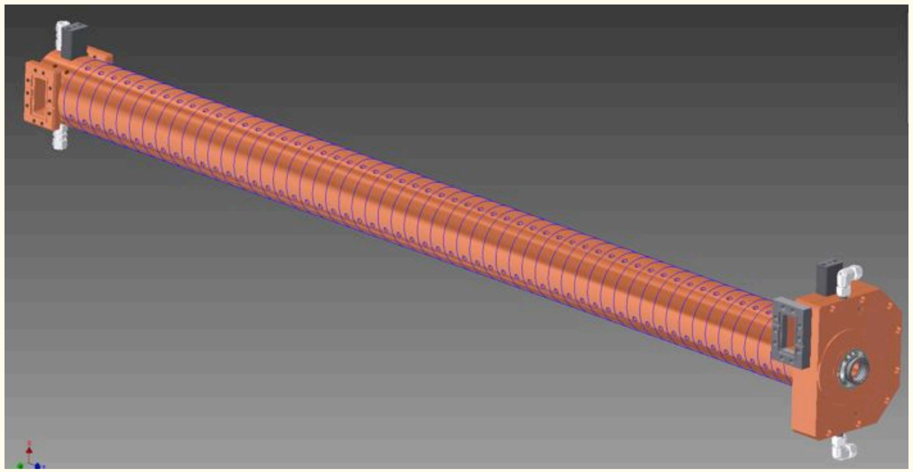
- L-band rf coupler limits DC solenoid inner radius >= 180 mm
- for regular cell region, the radius can be 130 mm
- with built-in collinear power load, the output coupler can be omitted and end-tail becomes thin





Large Aperture S-band Structure

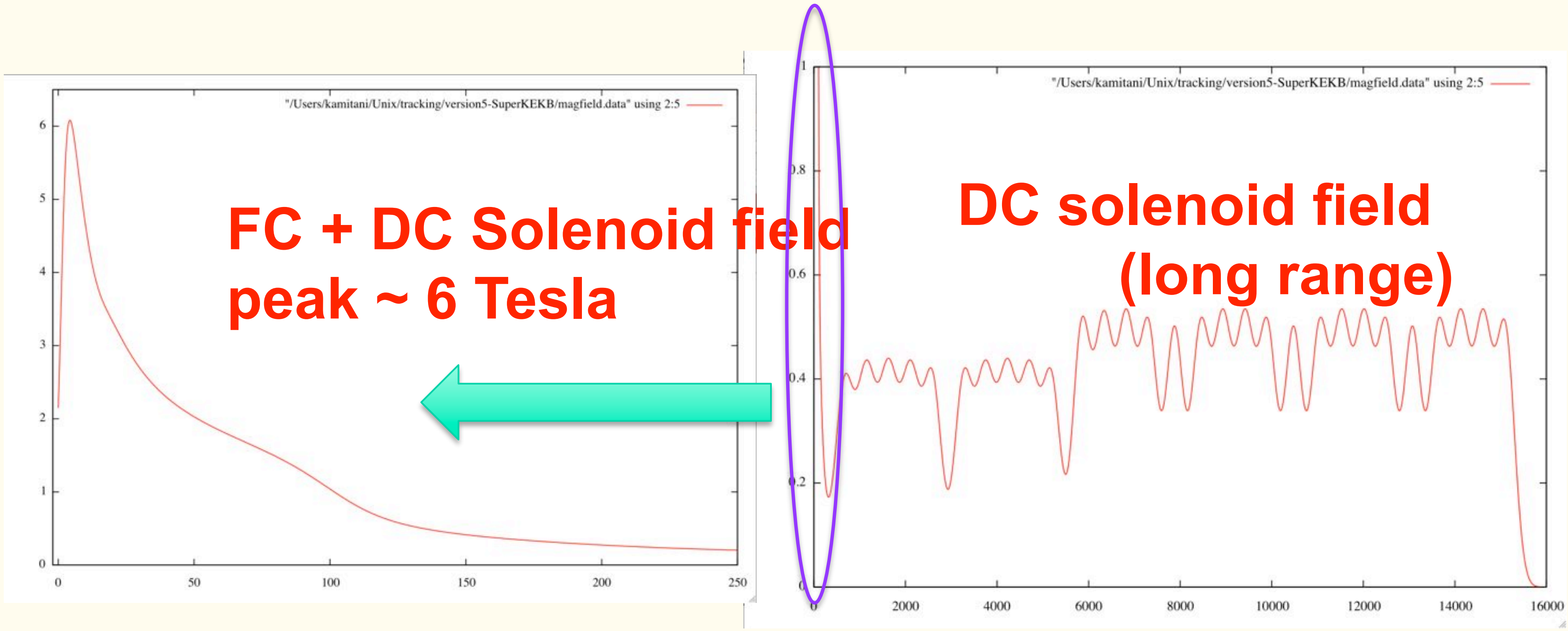
- **LAS structures are used,**
  - **in second unit of capture section**
  - **in two accelerator modules just behind capture section**
- **Large aperture and compact outer diameter**
  - **existing rf source available**
  - **existing DC solenoid available**
  - **compact quad outside LAS structure compared with L-band**
- **Cost-performance balance**

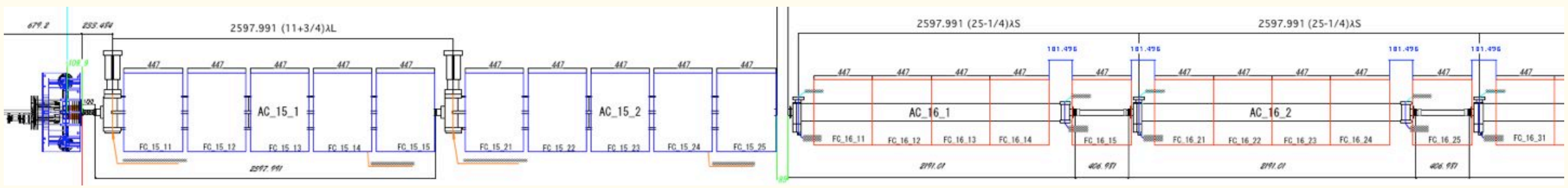


- traveling-wave structure
- constant gradient
- (2/3)pi phase advance per cell
- structure length 2.2 meter
- disk aperture 2a = 31.9 ~ 30.0 mm
- field strength 16.4 MV/m with SLED
  6.9 MV/m w/o SLED
- two port input coupler (J-shape side-couple)
  two port output coupler (ordinary shape)
- attenuation constant tau = 0.112

Solenoid Field Design

- FC + DC solenoid field distribution determines transverse acceptance of capture section and e+ initial emittance.



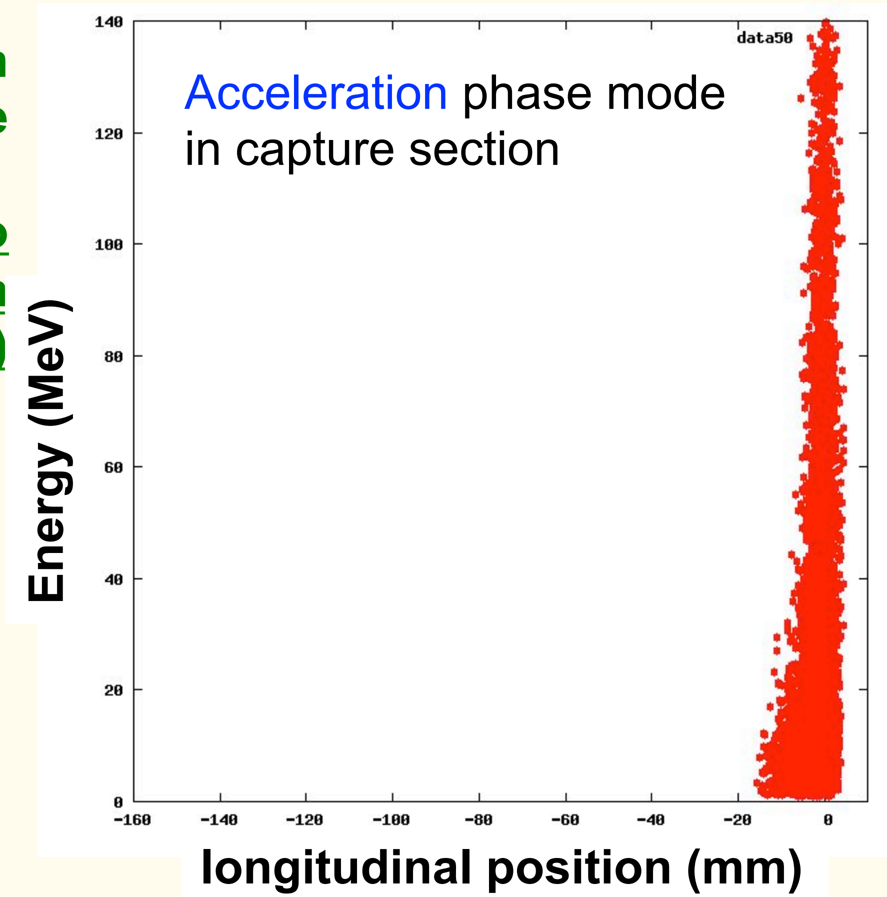


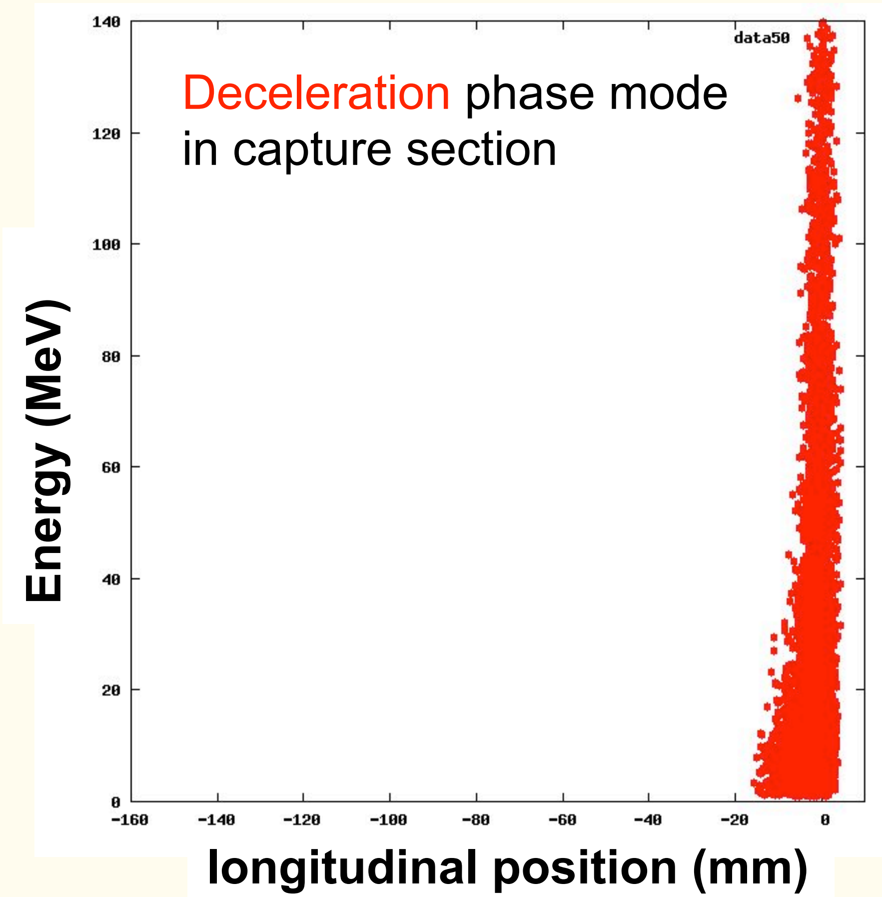
Particle Simulation

- capture section : Zang Lei (GPT), T.Kamitani(EGS4, CST)
- linac 1~2 sector + LTR : T.Miura, N.Iida (SAD)
- DR beam dynamics : H.Ikeda
- RTL + linac 3~5 sector + BT-line : N.Iida (SAD)

Simulation Example

from target to capture section exit (120 MeV)





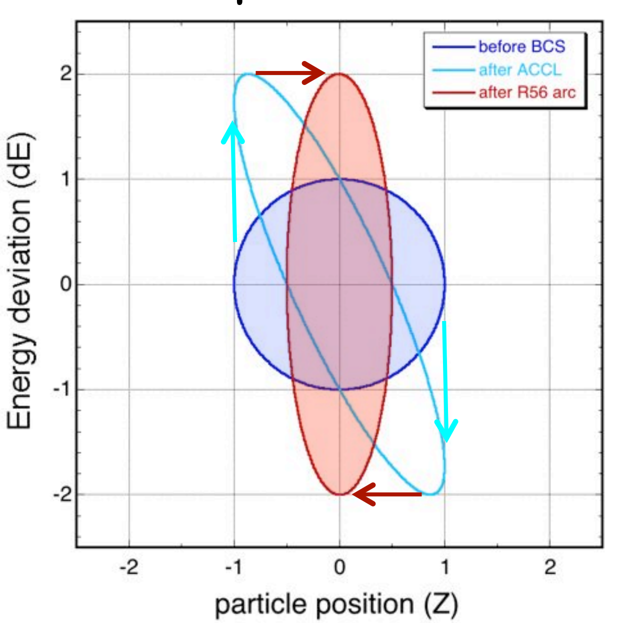
ECS at LTR & BCS at RTL

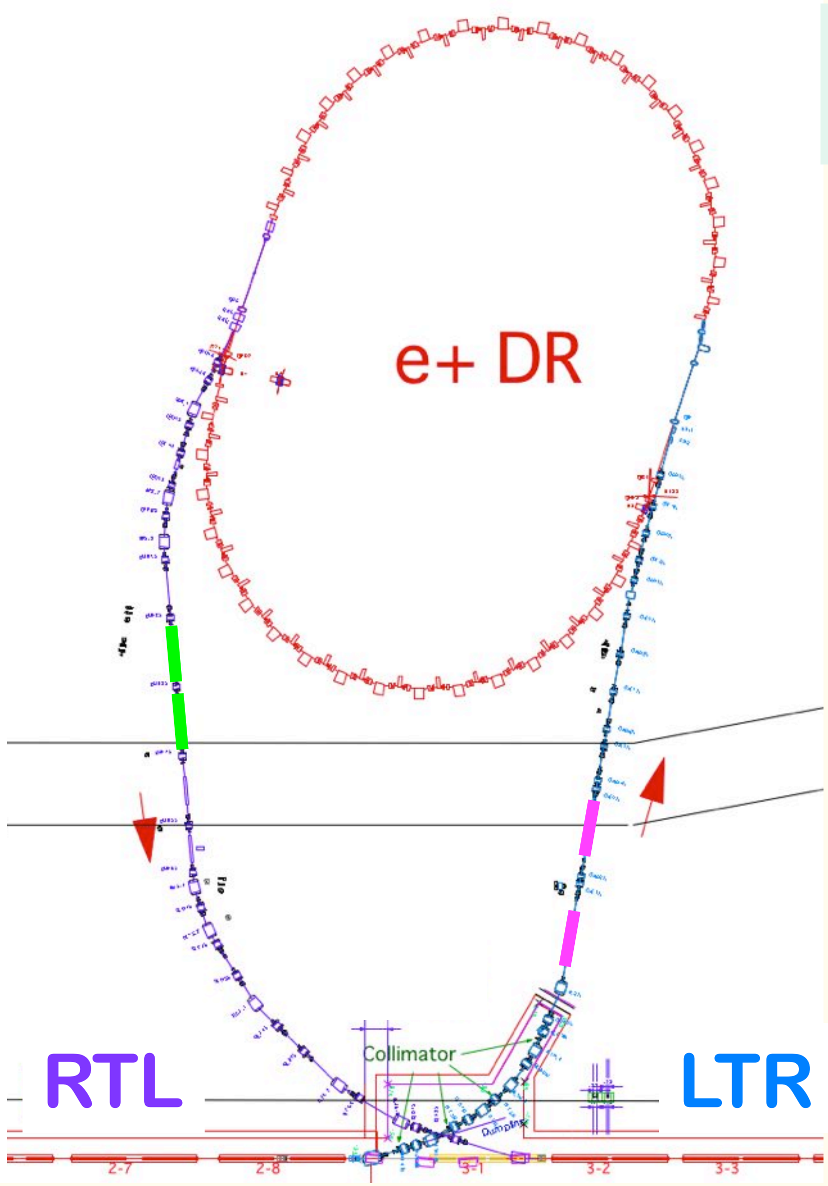
Bunch Compression System

BCS reduce bunch-length of e+ extracted from DR

energy gradient by RF field + non-isochronous arc

Vc = 37 MV (L-band)
R_{56} = -1.05 m
compression 1/9



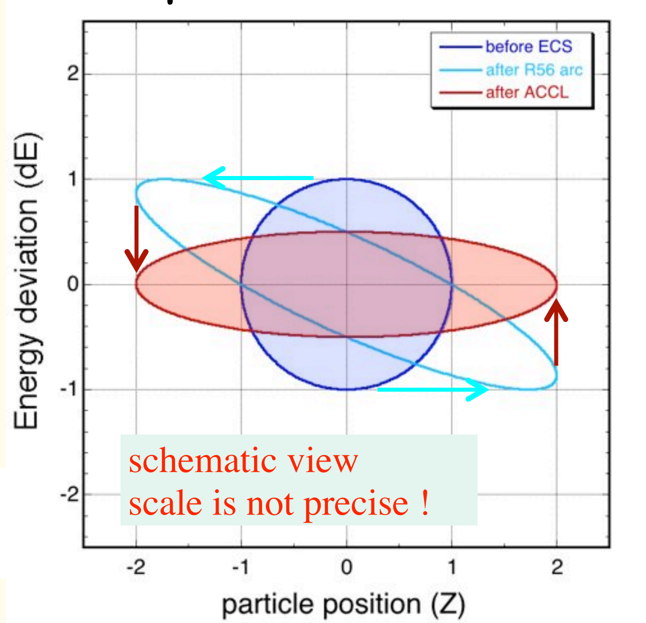


Energy-spread Compression System

ECS reduce energy-spread of e+ entering DR

non-isochronous arc + energy correction by RF field

R_{56} = -0.61 m
Vc = 41 MV (S-band)
compression 1/3

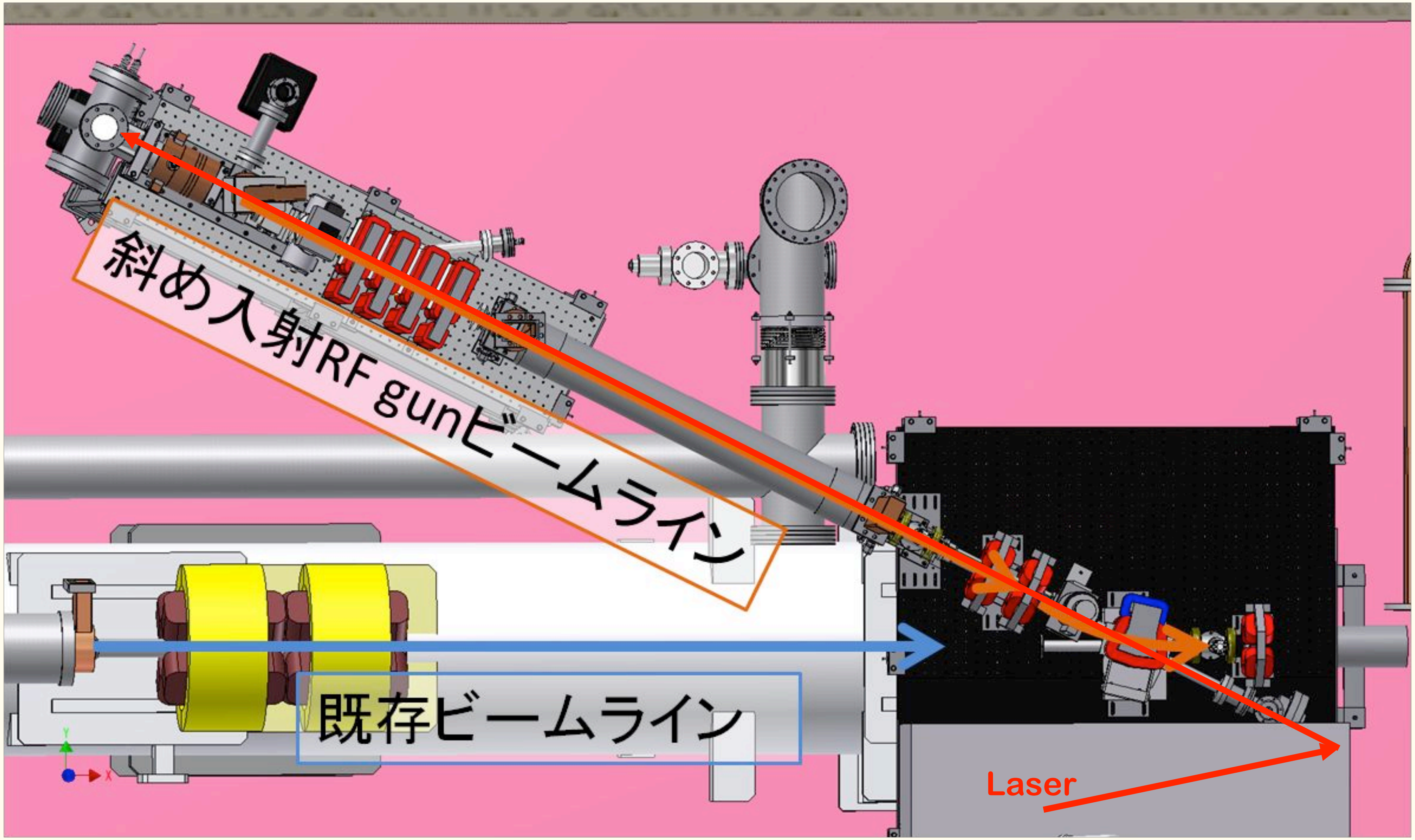


Injector Positron Source Status

- Fabricating SLAC-type FC for T=0
- Need consideration on target protection
- 1st L-band structure to be high-power tested soon
- Design of L-band collinear load fixed
- Waveguides & loads in fabrication
- L-band klystron 1st tube ready
- Large Aperture S-band structures in fabrication
- DC solenoid field dips are moderated by huge solenoids
- Beam optical design almost OK
- Particle tracking simulation is ongoing for e+ yield and hardware parameter optimization
- Damping Ring, ECS, BCS are in construction

RF Gun at 32 unit for 5nC / 20mm-mrad

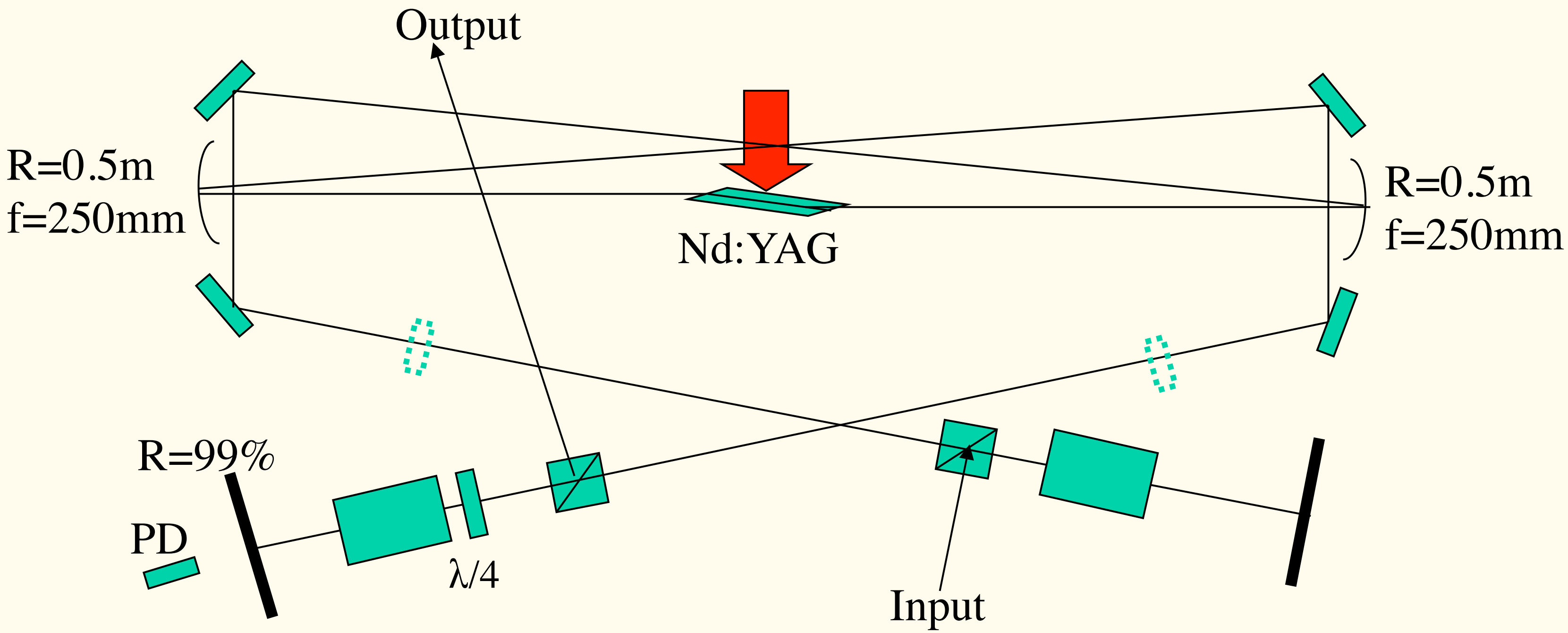
Emittance of 300μm in KEKB should be reduced to 20μm

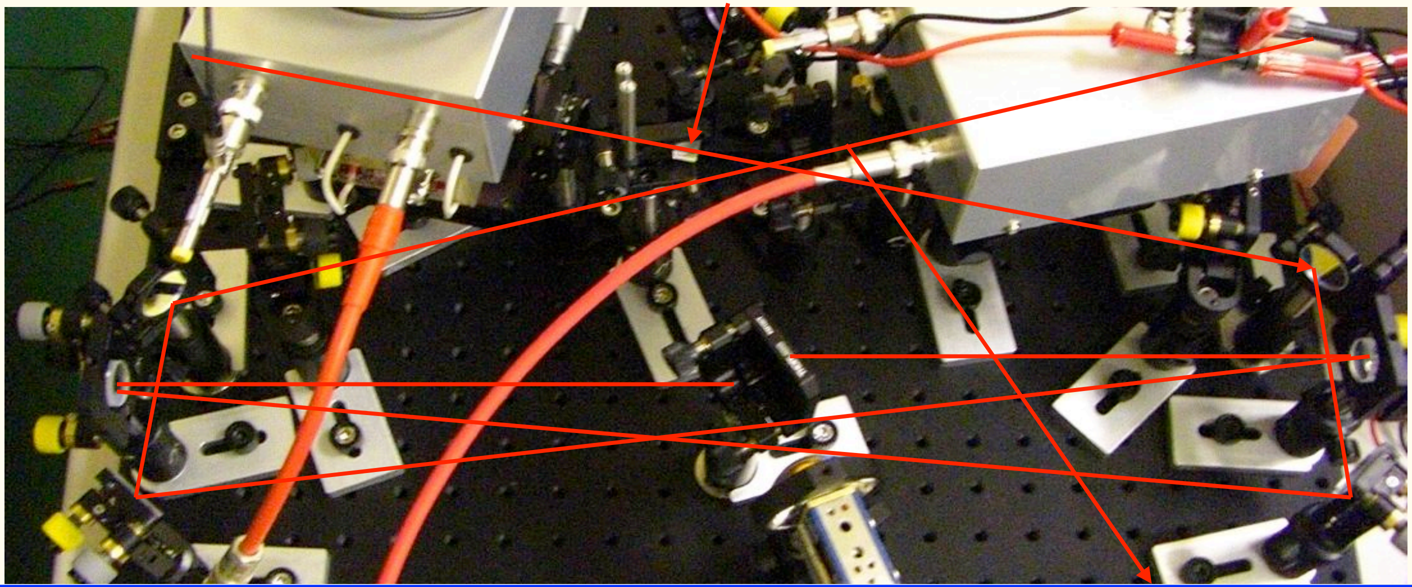


Laser Development

- **Oscillator**
  - Nd:YAG medium, LD excitation
  - Change frequency from 114MHz to 52MHz
    - Synchronized through 10.39MHz Clock
  - Successful stable excitation
- **Amplifier improvements**
  - ~1.5mJ / 30ps / pulse at 266nm

Laser Amplifier Development





Laser Amplifier Development

Multi-pass Amplification

Cleaner Amp. with EO and AO components

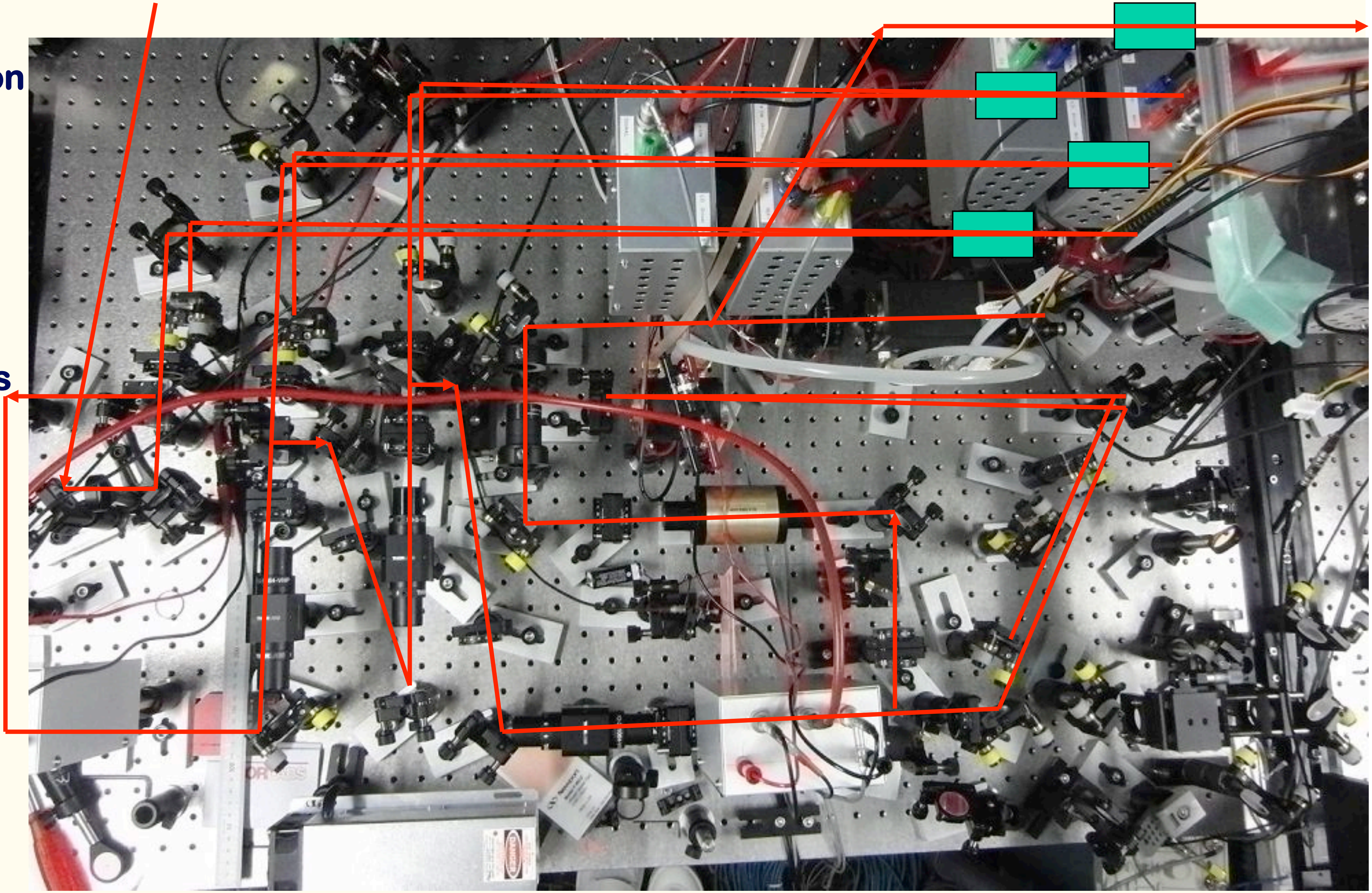


Photo Cathode Development

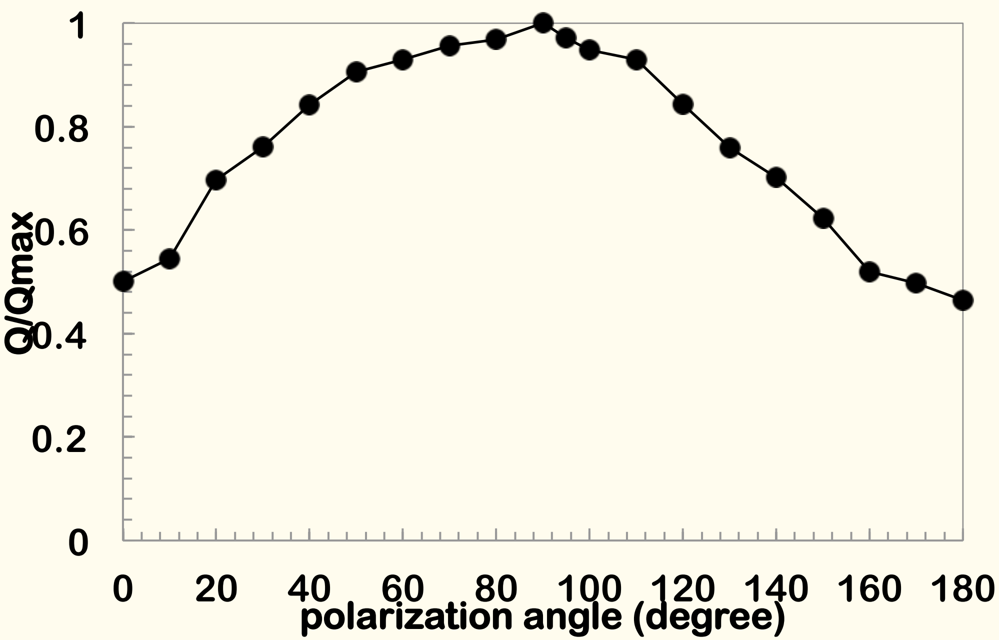
- Started with LaB_6
  - Successful up to ~0.3nC before April
- Replaced with Ir_5Ce
  - For better quantum efficiency
  - Achieved up to ~1nC / bunch in April
- Surface cleaning cut & try
  - With high power laser with/without RF
  - LaB6 and Ir5Ce are rather stable
- Other possibilities in the future
  - CsTe, etc

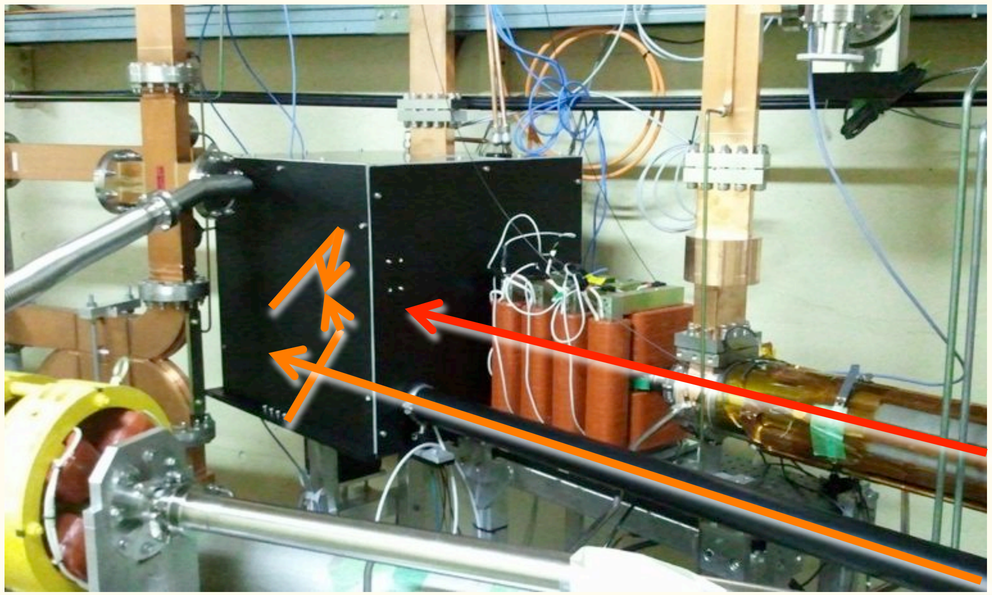
Slant Laser Injection

- **Perpendicular laser injection**
  - **Before May.2012**
- **Slant laser injection through CaF2 windows**
  - **Non-zero perpendicular electric field (?)**
  - **Increased up to ~3nC / bunch**
  - **Emittance should be confirmed**

Polarization dependence (Ir5Ce)

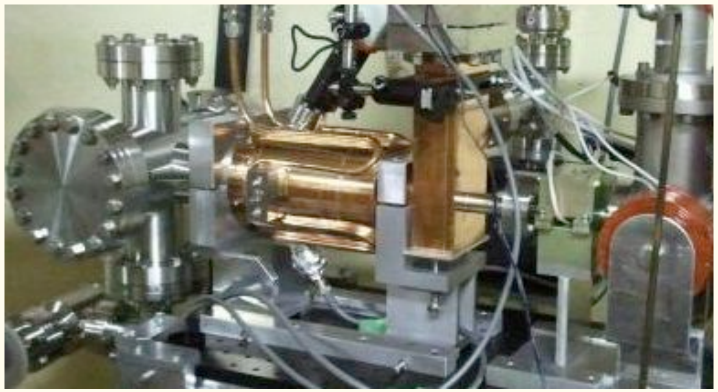
(東工大/佐藤)

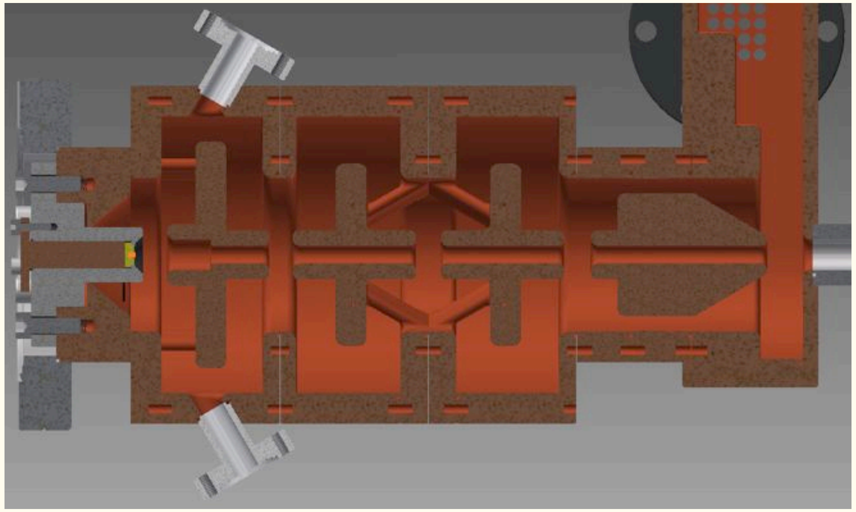


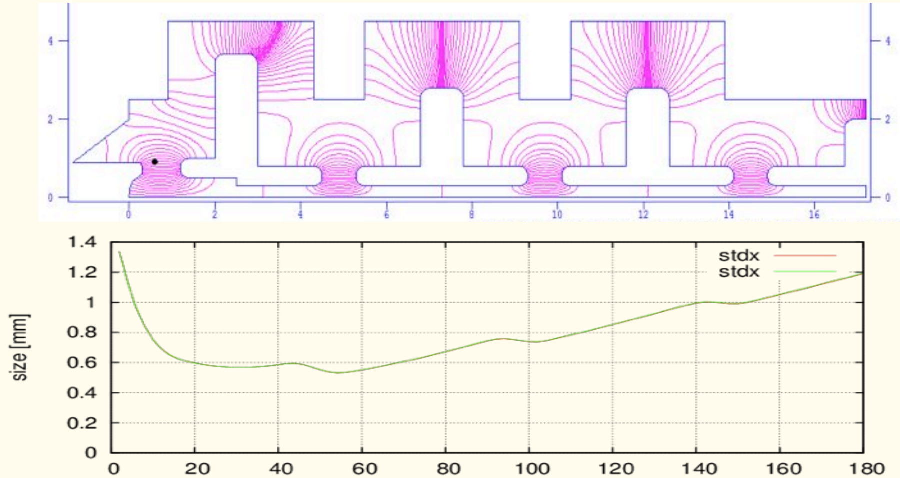


Stable Operation of RF Gun

- DAW (Disk and washer) type photo cathode RF gun
  - Strong RF beam focusing
  - With stable cathode
  - Should experience continuous PF injection in autumn 2012
  - With backup laser





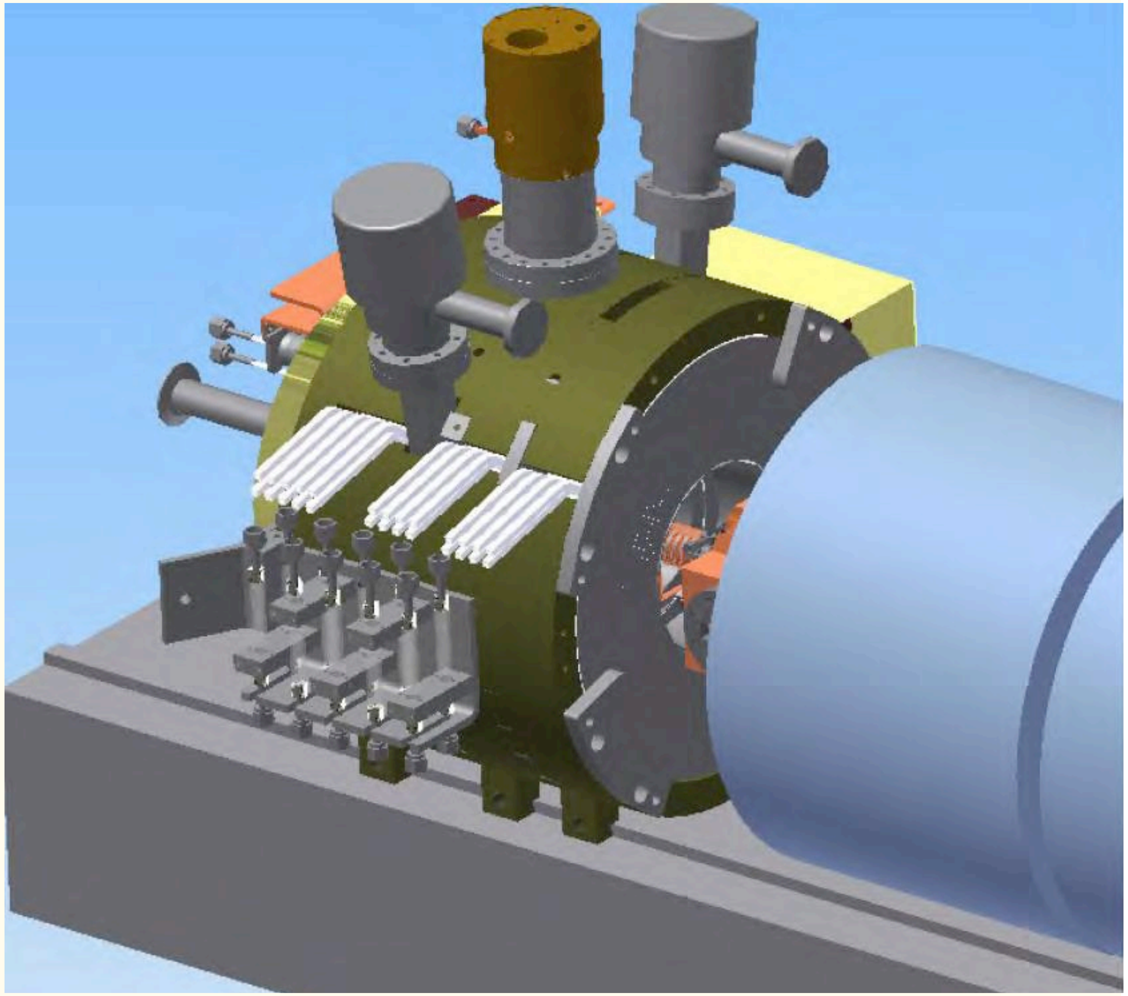


Electric field and beam tracing simulation

Fast Recovery at Failure of Positron Generator

◆ Positron capture section replacement

- How components should be designed/installed in order to be replaced under high radiation condition? (replaced twice in KEKB)
- Positron target, Flux concentrator, Bridge coil, Acceleration structure, Solenoid, Girders, Vacuum components, etc.
- Large unit should be replaced with special links
- Under discussion



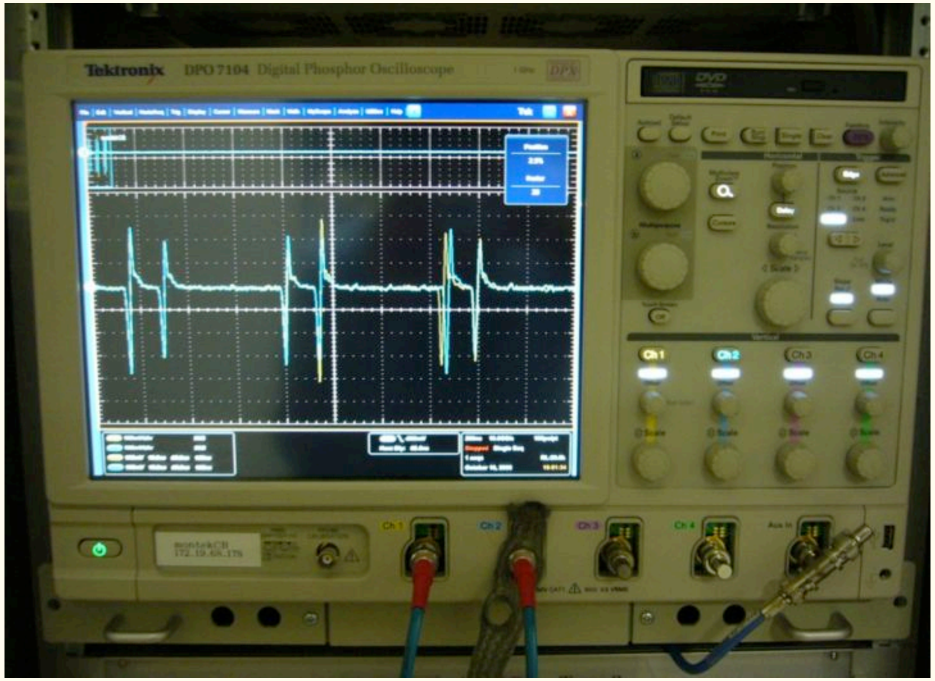
Reliability with Failed Acceleration Unit

◆ Linac Beam Energy Management

- At least one backup acceleration unit should available with two units for an energy knob in regions of ;
  - Before 180deg arc
    before damping ring
    after damping ring
- In each of electron and positron modes (and PF/PF-AR)
- The plan was fixed
- While troubles at several important units (like capture section) can prevent operation, others should be backuped

Beam Position Monitor Development

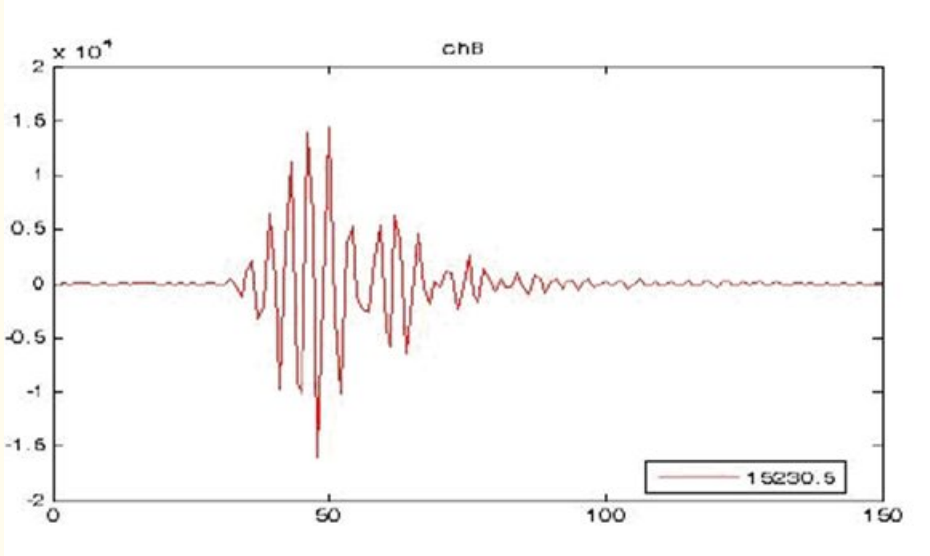
- **Requirement**
  - 50Hz with event synch., 2bunchs 96ns apart, 10micron resolution, 0.1~10nC variation at 50Hz
- **Present system**
  - 8bit oscilloscope, Windows-EPICS, 50Hz,
  - 50~100micron resolution
- **BPM is essential for**
  - Low-emittance transport with wakefield compensation
  - Beam stability monitor



BPM Development

- **Modifications to commercial module Libera**
  - Event-based control capability and embedded EPICS
  - Fast attenuator for variable beam modes
  - Modifications to filters and ADCs for 2-bunches 96ns apart
- **New development at local company**
  - In VME form factor, with external CPU and event-based controls
  - Additional on-line pulse test capability
- **Both evaluations in this year**
  - Lab tests during summer
  - Beam tests in autumn
  - Resolution, price, reliability, flexibility, manageability, etc
  - Installation in 2014

band-pass + saw filters

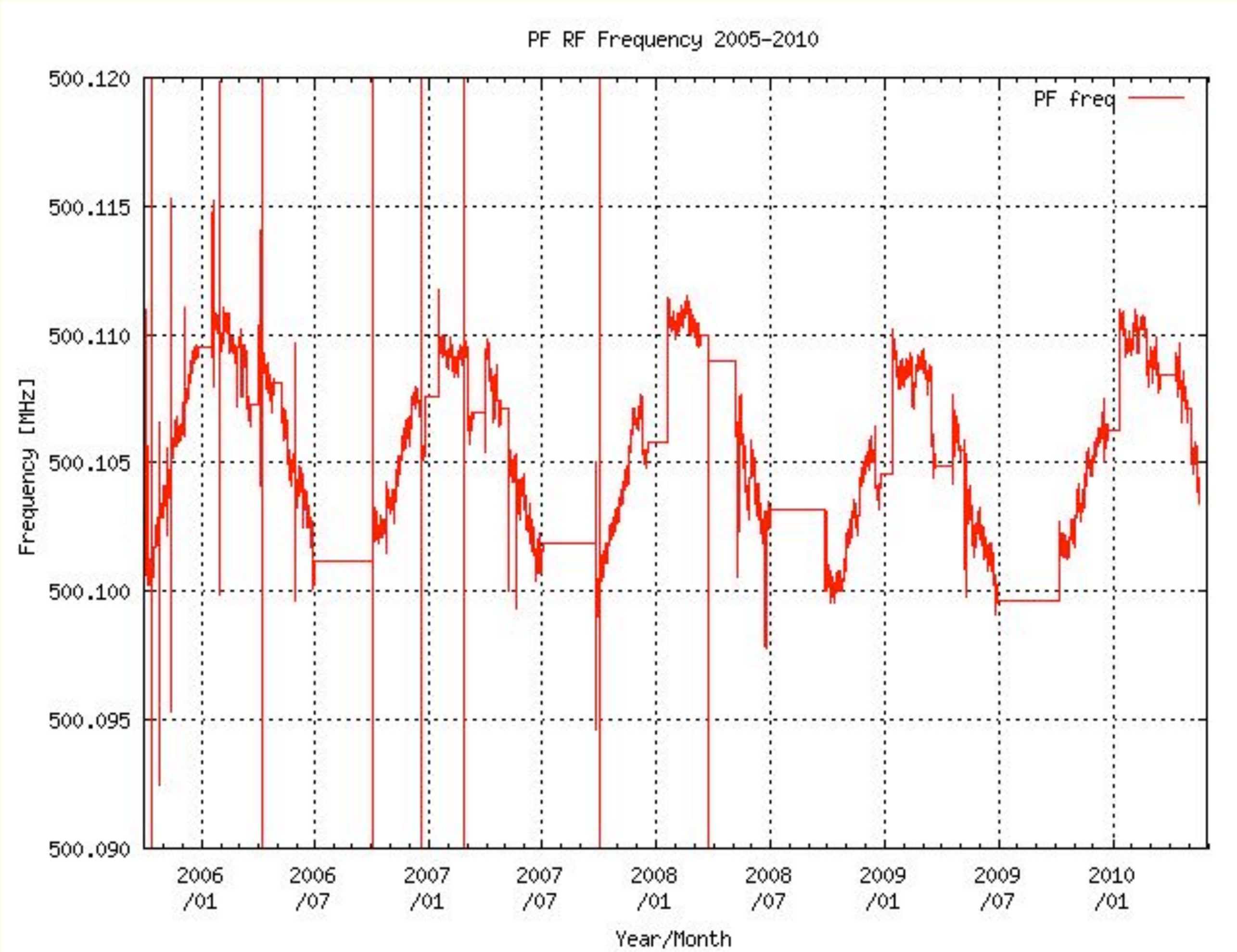


4 Ring Injection Timings

- **SuperKEKB will have integer RF clock relation with Linac**
  - Needs ring circumference compensation with frequency modulation
- **PF / PF-AR will not have common clock with Linac**
  - As they need independent circumference compensation
  - Linac injects beams at accidental synchronization
  - No synchronization opportunity if integer relation
- **Damping ring and L-band introduction**
  - Requires further condition restrictions

PF Synchronization

- **PF Frequency modulation in a year**
  - Approx. 2 x 10^-5



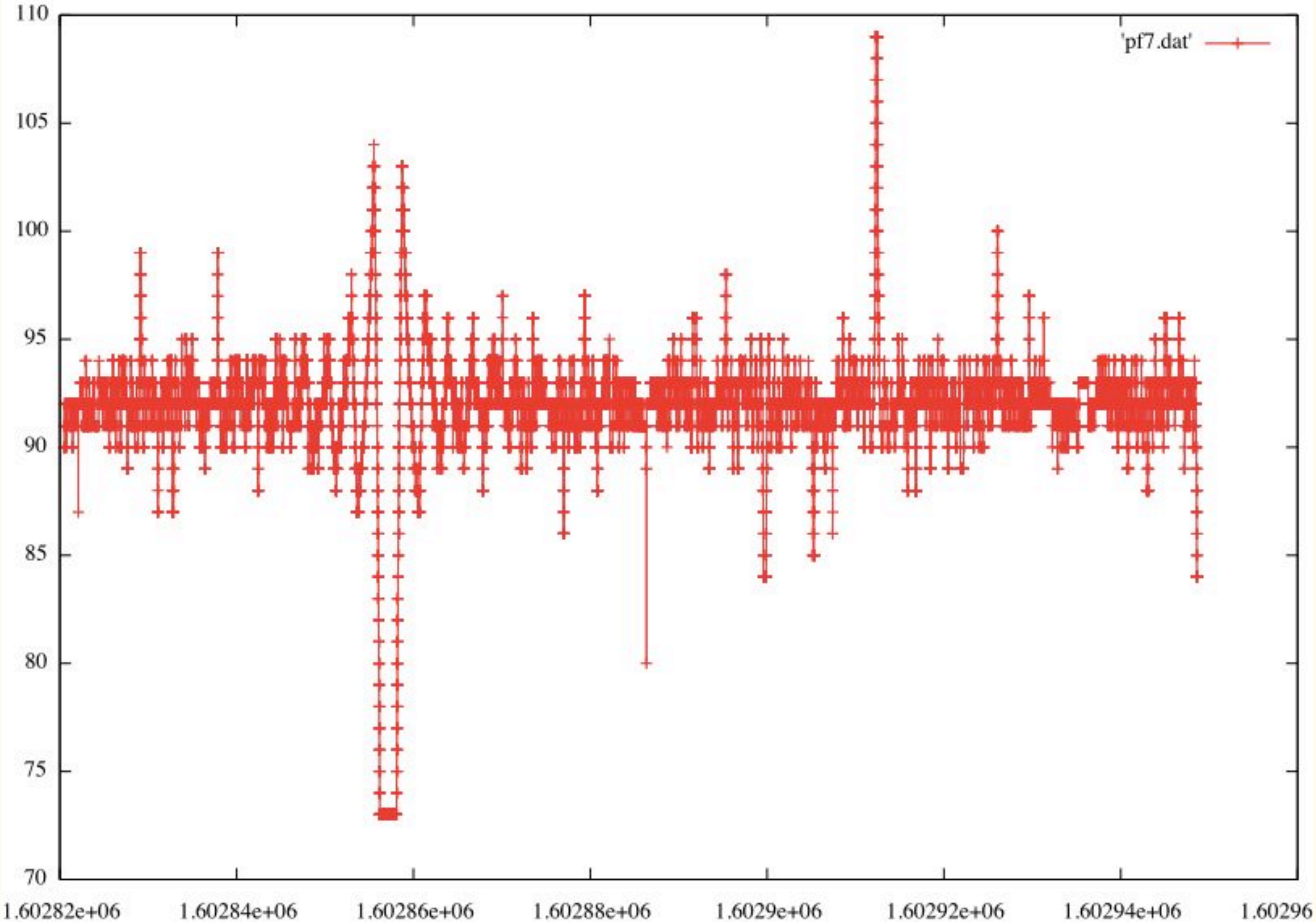
Injection Synchronization with 114MHz

For PF
with KEKB

Duration Jitter
20ms
+/-500 μs
Clock Jitter
500 ps

Plot in 10^{-4}

No problems



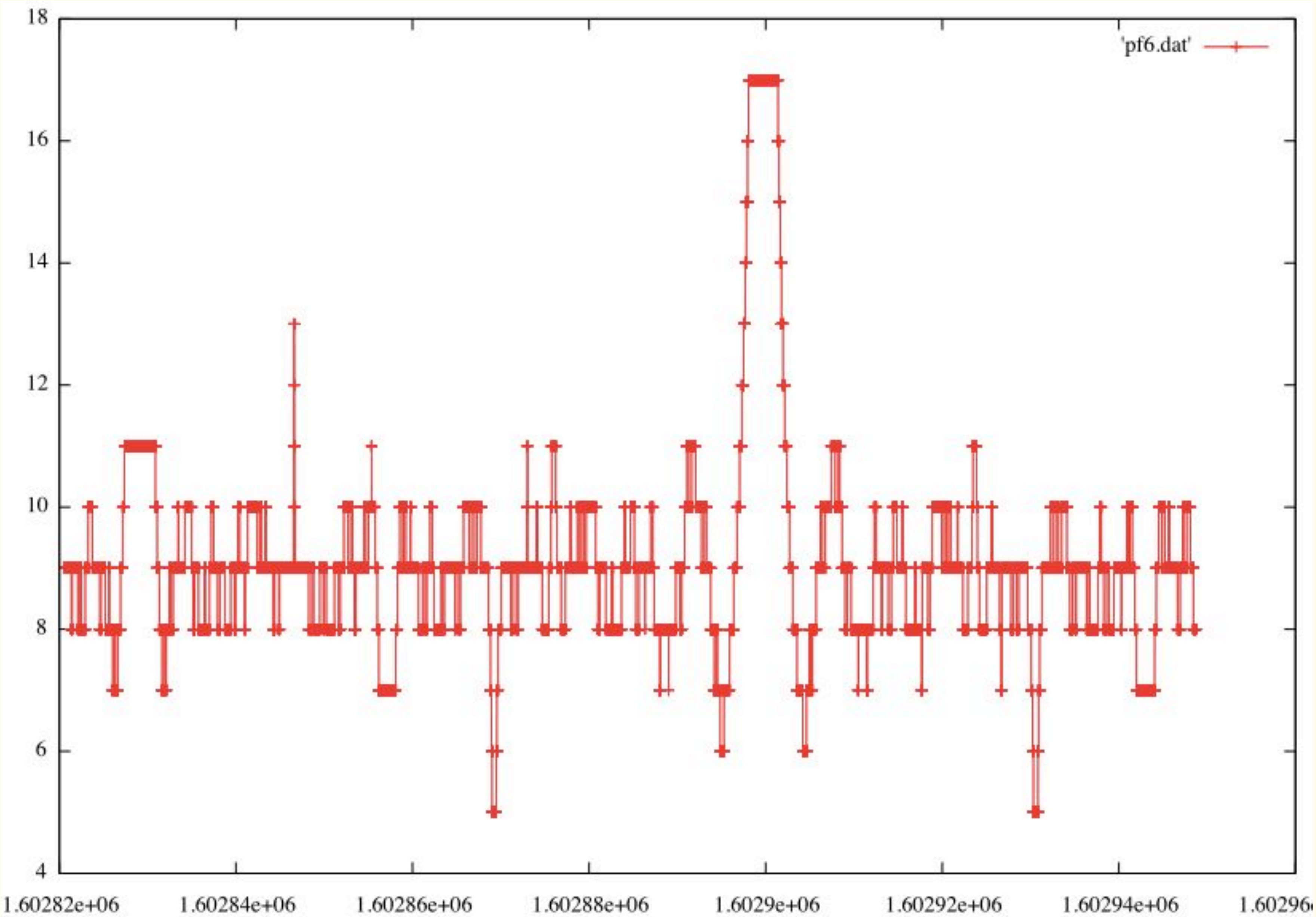
Injection Synchronization with 10.39MHz

For PF with SuperKEKB

Duration Jitter
20ms
+/-500μs
Clock Jitter
500 ps

Plot in 10^{-4}

Bad region have to be avoided

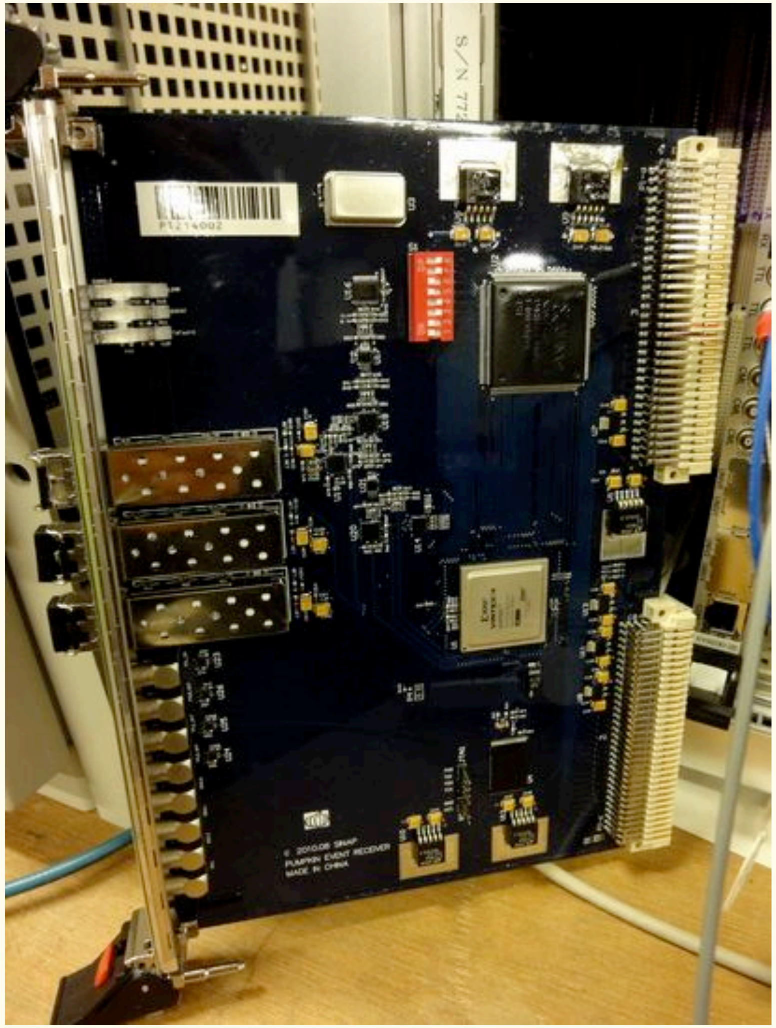


Investigation

- This issue is different than the bucket selection challenges at SuperKEKB
  - Bucket selections both at DR and MR
- Was not well investigated under 10.39MHz
  - May require pulse-to-pulse LLRF manipulation between RF systems of PF / PF-AR / SuperKEKB
  - Should be investigated further

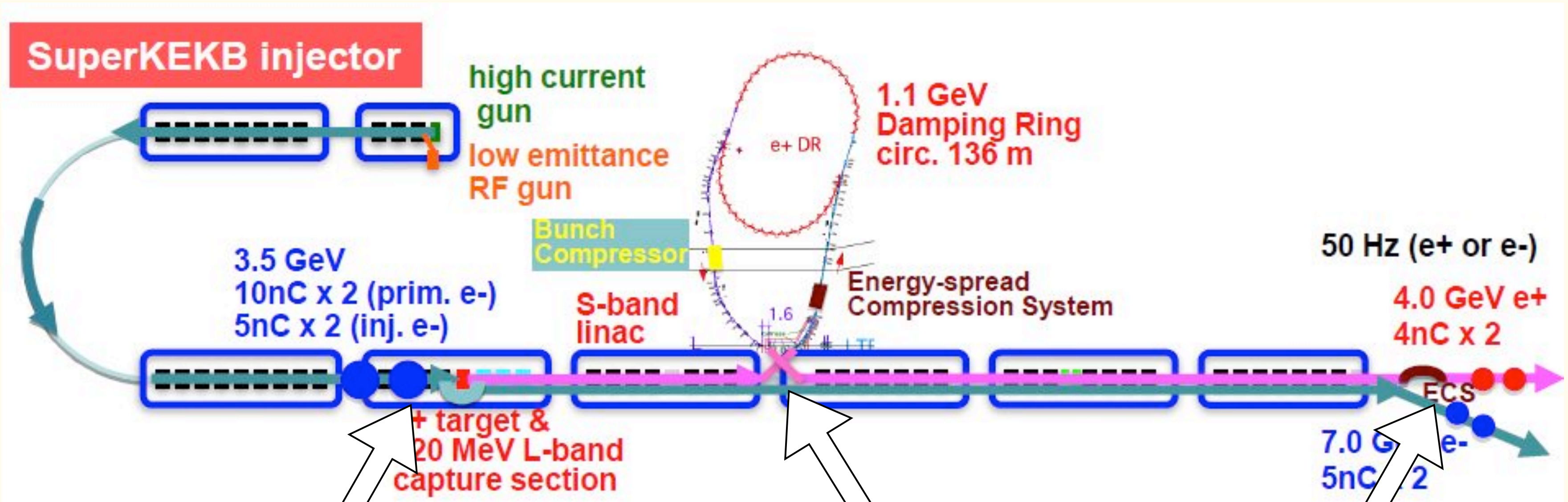
Event System Development Collaboration with SINAP

- For PLC (F3RP61 Linux CPU) as well as VME
- Under testing
- Many more synchronous controls at a reduced cost



Facility for Electric Power and Cooling Water

- **Linac needs electricity and cooling water extensions, especially for positron generator upgrade**
- **First estimation was performed, and was found that it may impact the construction**
- **Under discussion how to extend the facility**



[I] 第1〜2セクター
陽電子ビーム強度の５倍化に向けて、収束用電磁石の数と強度が大幅に増加する。
増加分920 kVA, 900 L/min
現状　401kVA
1211 / 1430 L/min

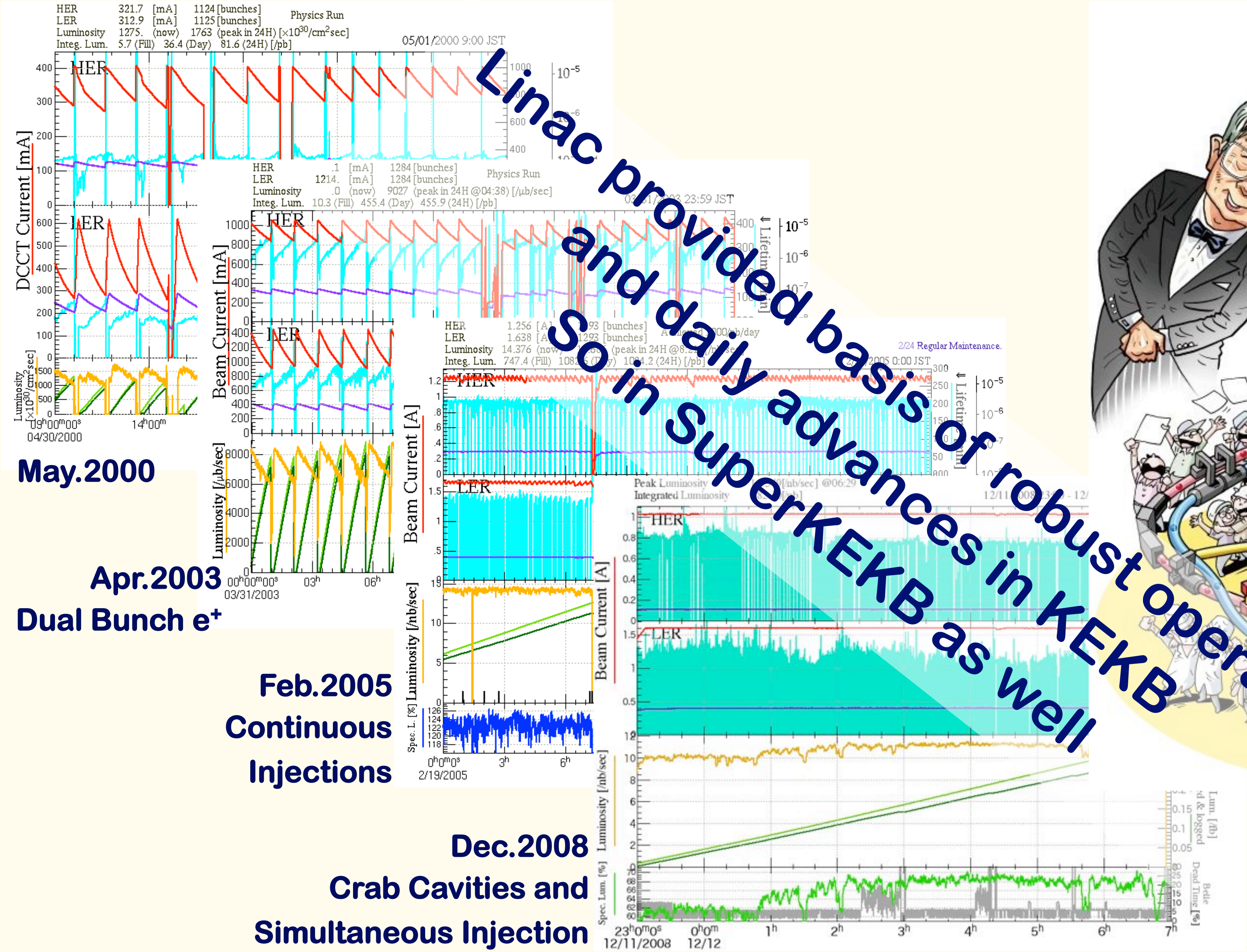
[II] 第3セクター
DRの入射＆出射路の新設に伴って、その電磁石の一部が入射器トンネルに新たに設置される。
増加分310 kVA
現状　6.7kVA
136 / 500 L/min

[III] 第３スイッチヤード
１）陽電子エネルギーの増大（3.5GeV→4GeV）に伴う偏向磁石系の電力増及び　２）RF偏向によるエミッタンスモニターの新設に伴って熱負荷が増大する。
増加分300 kVA, 460 L/min
現状　158kVA
（587+α）/ 750 L/min

Schedule

- Summer 2012 : Alignment, SY3, 3T-gun, 32-gun
- Autumn 2012 : 32-RF-gun, A1-gun(0.2nC)
- Winter 2013 : SY2 / DR
- Spring 2013 : A1-gun
- Summer 2013 : Installation of many components
- Autumn 2013 : e– then e+ commissioning
  - Half Linac: PF injection, Day: construction, Night: commissioning
- Spring 2014 : Pulsed Quad, Steering, Alignment
- Summer 2014 : Installation of remainings
- Autumn 2014 : Possible ring injection (?)
- Winter 2015 : DR then MR injection commissioning
- …

Change in Operation Modes at KEKB



May.2000

Apr.2003
Dual Bunch e+

Feb.2005
Continuous
Injections

Dec.2008
Crab Cavities and
Simultaneous Injection

Linac provided basis of robust operation and daily advances in KEKB

So in SuperKEKB as well

Belle/KEK


Thank You for Your Patience