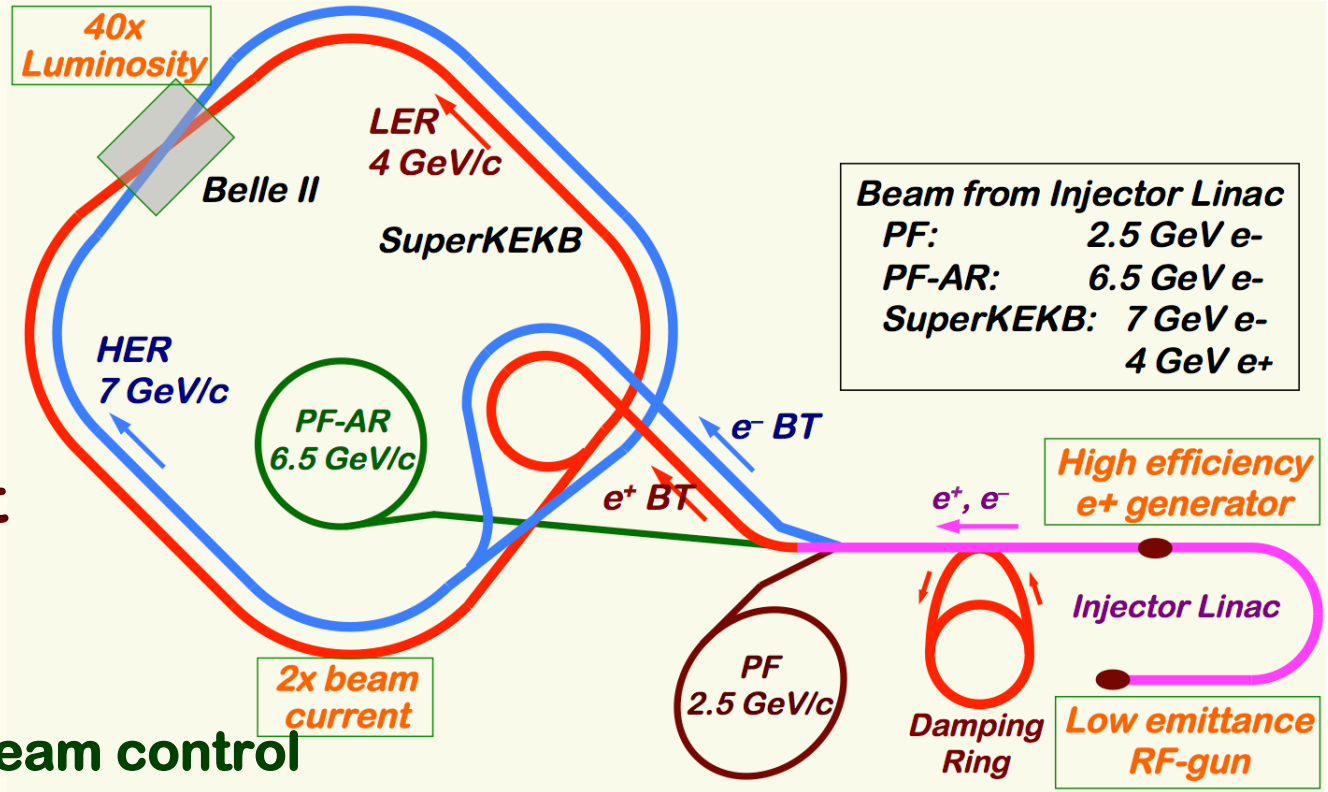
Injector Linac upgrade status towards SuperKEKB

Kazuro Furukawa
Injector Linac, KEK

Mission of electron/positron Injector in SuperKEKB

- **40-times higher Luminosity**
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Linac
    - → Shorter storage lifetime
  - Twice larger storage beam → Higher beam current from Linac
- **Linac challenges**
  - Low emittance e-
    - with high-charge RF-gun
  - Low emittance e+
    - with damping ring
  - Higher e+ beam current
    - with new capture section
  - Emittance preservation
    - with precise alignment & beam control
  - 4+1 ring simultaneous injection



Required injector beam parameters

Stage	KEKB (final)		Present Phase-I		SuperKEKB (final)	
Beam	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1 A	1 A	3.6 A	2.6 A
Life time	150 min.	200 min.	100 min.	100 min.	6 min.	6 min.
Bunch charge	Primary e-10nC → 1 nC	1 nC	Primary e- 8nC → 0.4 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Norm. Emittance ($\gamma\beta\varepsilon$) (μrad)	2100	200	2400	150	100/20 (Hor./Ver.)	50/20 (Hor./Ver.)
Energy spread	0.125%	0.125%	0.5%	0.5%	0.1%	0.1%
No. of Bunch / Pulse	2	2	2	2	2	2
Repetition rate	50 Hz		25 / 50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (KEKB e–/e+, PF)		No top-up		4+1 rings (SuperKEKB e–/e+, DR, PF, PF-AR)	

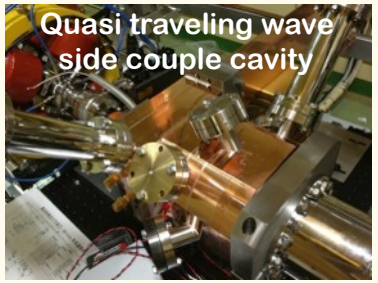
Progress

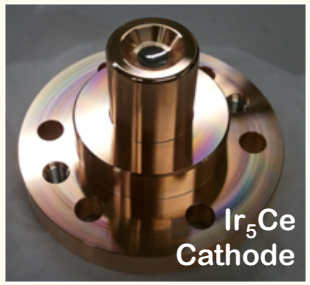
- 2010: Beam design and hardware developments
- 2011-2014: Recovery from earthquake, mainly because of soft-structure girder design
- 2012-: Construction and commissioning
- 2012-: Step-by-step acquirement of beam licenses
- 2016: Phase-1
- Continuous: Light source injections
- …

Linac Upgrade Progress towards SuperKEKB (1)

High-charge low-emittance RF gun development

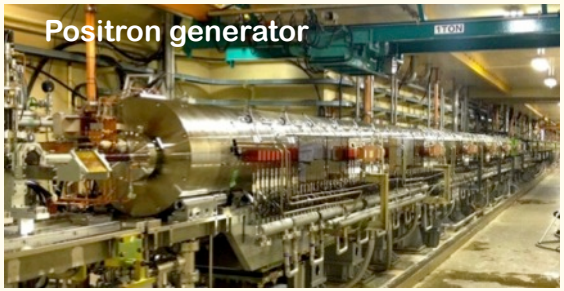
- QTWSC cavity and Ir5Ce photo cathode developments
- Laser development is underway





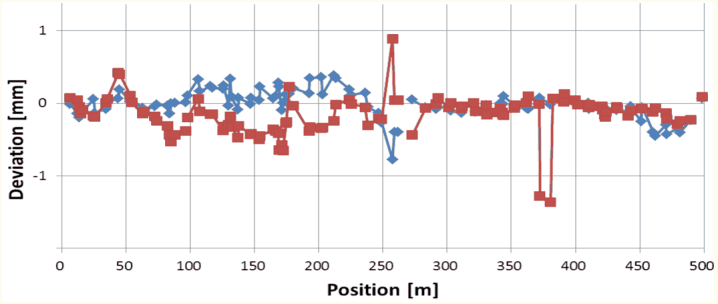
Positron generator commissioning

- Good agreement with the simulation results
- Will solve discharge issues



Precise alignment for emittance preservation

- Recovering after large earthquake in 2011
- Reaching specification of 0.1~0.3mm
- Longer term stability should be solved



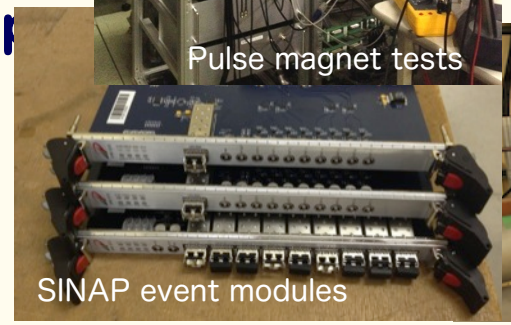
Utility upgrade during FY2014

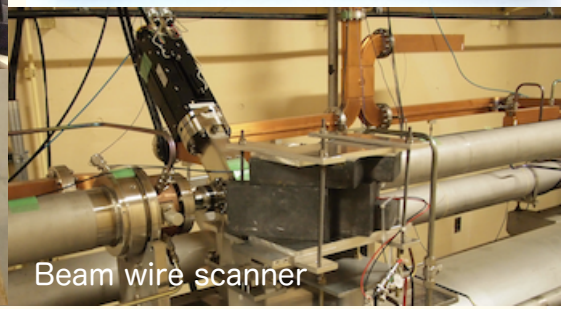
- for electricity (+1.5MW) and cooling water (+1400L/min)

Linac Upgrade Progress towards SuperKEKB (2)

- High-power microwave modulator upgrades
- Low-level RF controls/monitor upgrades
  - Pulse-to-pulse modulation (PPM) between 4+1 rings
  - More spaces for increased number of devices
- Beam instrumentation
  - Large/small aperture beam position monitors (BPM)
  - Precise/fast and synchronized BPM readout system
  - Wire scanners and beam loss monitors
  - Streak cameras
  - (Deflectors, etc.)
- Pulsed magnet developments
  - ~3 bends, ~30 quads, ~40 steerings
  - Even with energy recovery
- Event-based control and timing system up
  - Combination of MRF & SINAP modules
  - Essential for PPM operation
  - Precise timing & synchronized controls
  - Bucket selection at DR and MR

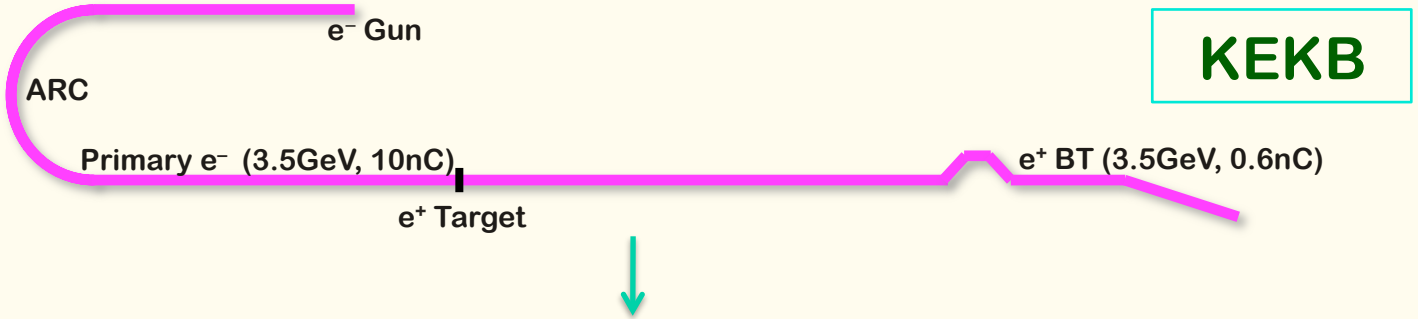

Pulse magnet tests


SINAP event modules

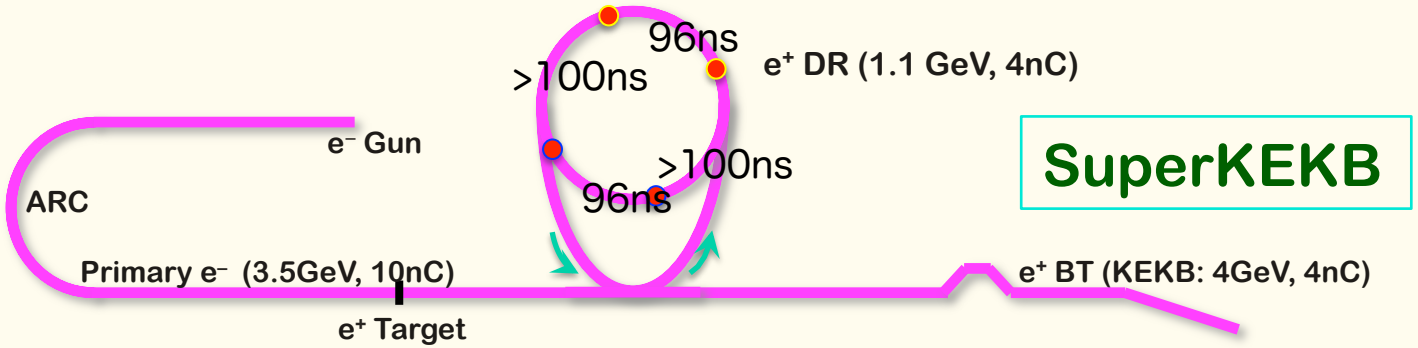

Beam wire scanner

Bucket selection in Phase-2 with DR

- **Without DR, simply wait up to 5120 x 96 ns ~ 490 μs**
  - 96 ns : highest common frequency between linac – ring

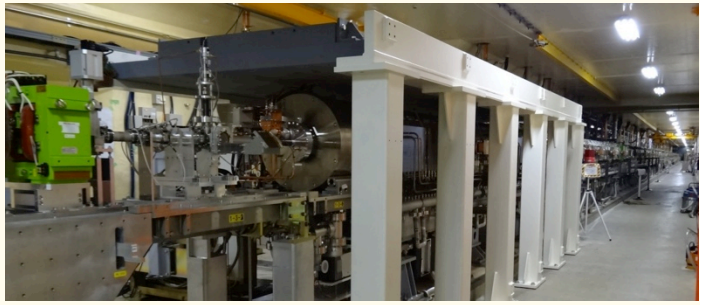


- **With DR, in order to select arbitrary bucket in MR, have to wait up to ~4.5 ms, even if a bucket in DR was carefully selected**
  - Power supply can wait only 2 ms, one of only 2798 buckets in 5120 buckets can be selected, may have to change LLRF condition at latter half of linac every pulse



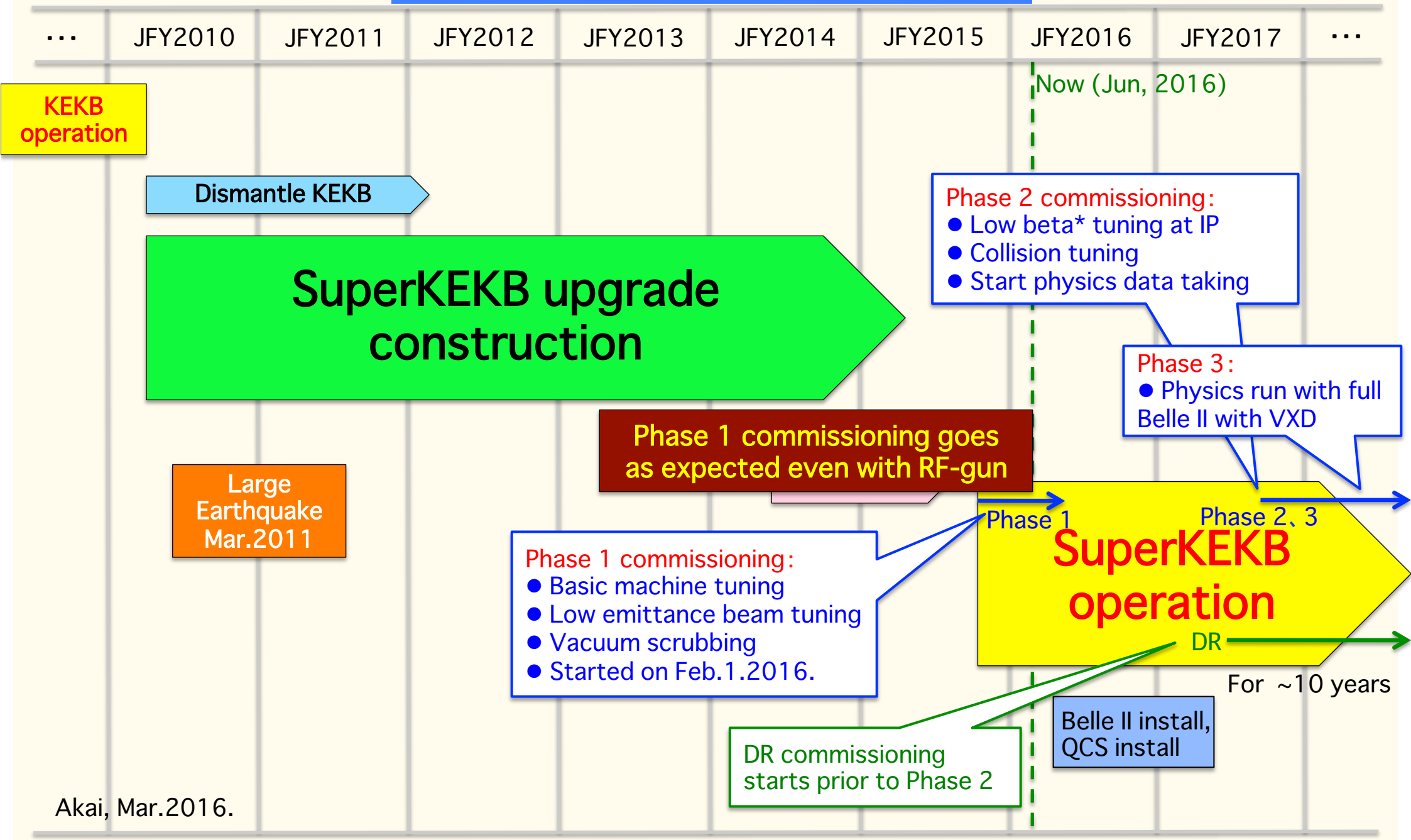
  - Can be a big challenge in LLRF precision

Beam Upgrade and Radiation Controls



- **Step-by-step upgrade of beam limits**
  - Towards 5 nC per bunch in Phase-3
- **Beam license applications**
  - Fall 2013, 10 nA at #28 dump, 1250 nA at #A2 dump
  - Spring 2014, New utility rooms, 50 nA at #61 linac-end dump
  - Summer 2015, 200 nA at #15 positron target
  - Spring 2016, 800 nA at #15 target
  - Before Phase-3, 1250 nA at #15 target, 625 nA at #61 dump
- **Radiation shield additions …**
  - For Gun, 180deg-arc, Target, Electron stopper, Collimator, Damping-ring dump, Linac-end dump, 5 utility rooms, etc
- **Even balancing with PF and PF-AR beam operations**

SuperKEKB master schedule



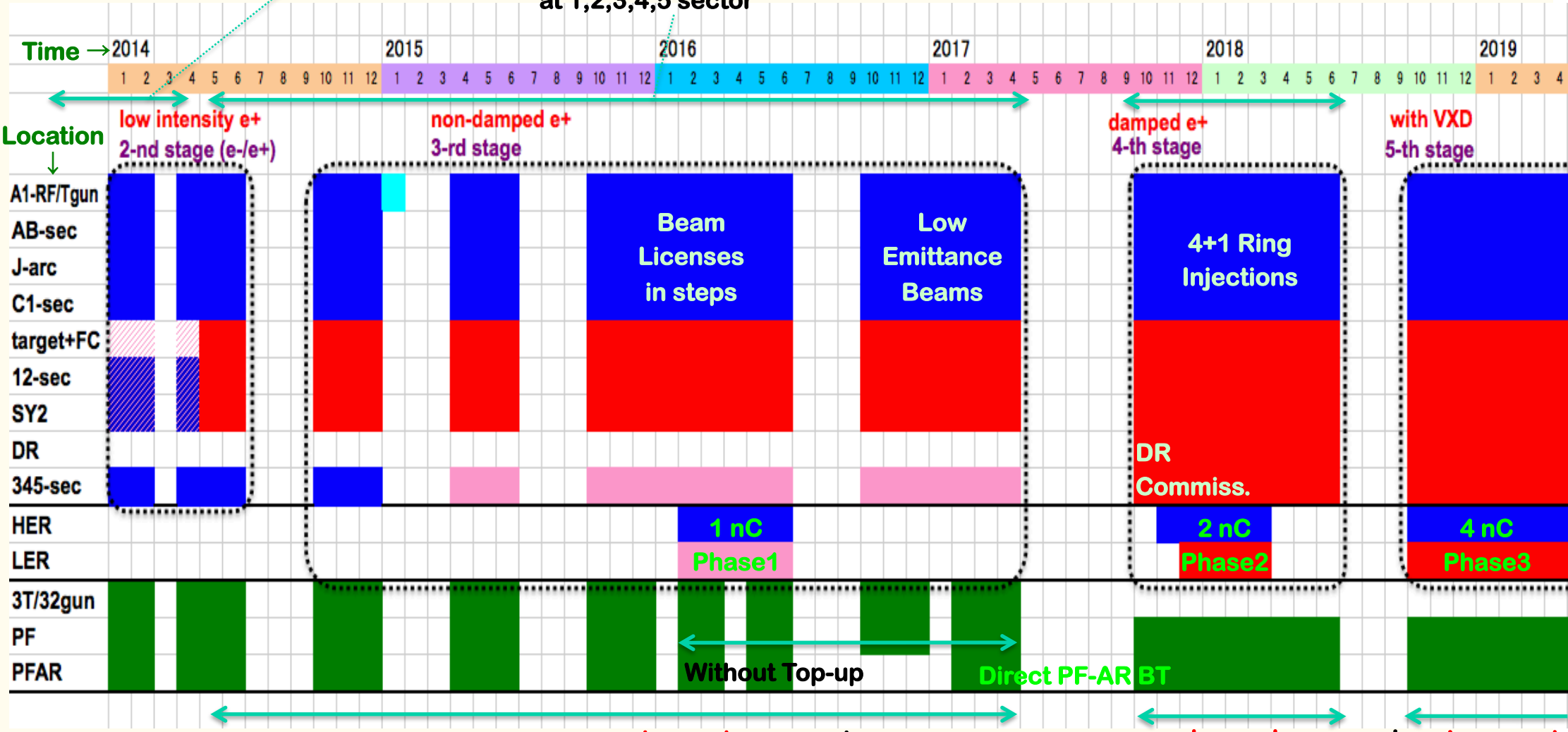
Linac Schedule Overview

RF-Gun e- beam commissioning at A,B-sector

e- commiss. at A,B,J,C,1

e+ commiss. at 1,2 sector (FC, DCS, Qe- 50%)
e- commiss. at 1,2,3,4,5 sector

Phase1: high emittance beam for vacuum scrub
Phase2,3: low emittance beam for collision



: Electron
: Positron
: Low current electron

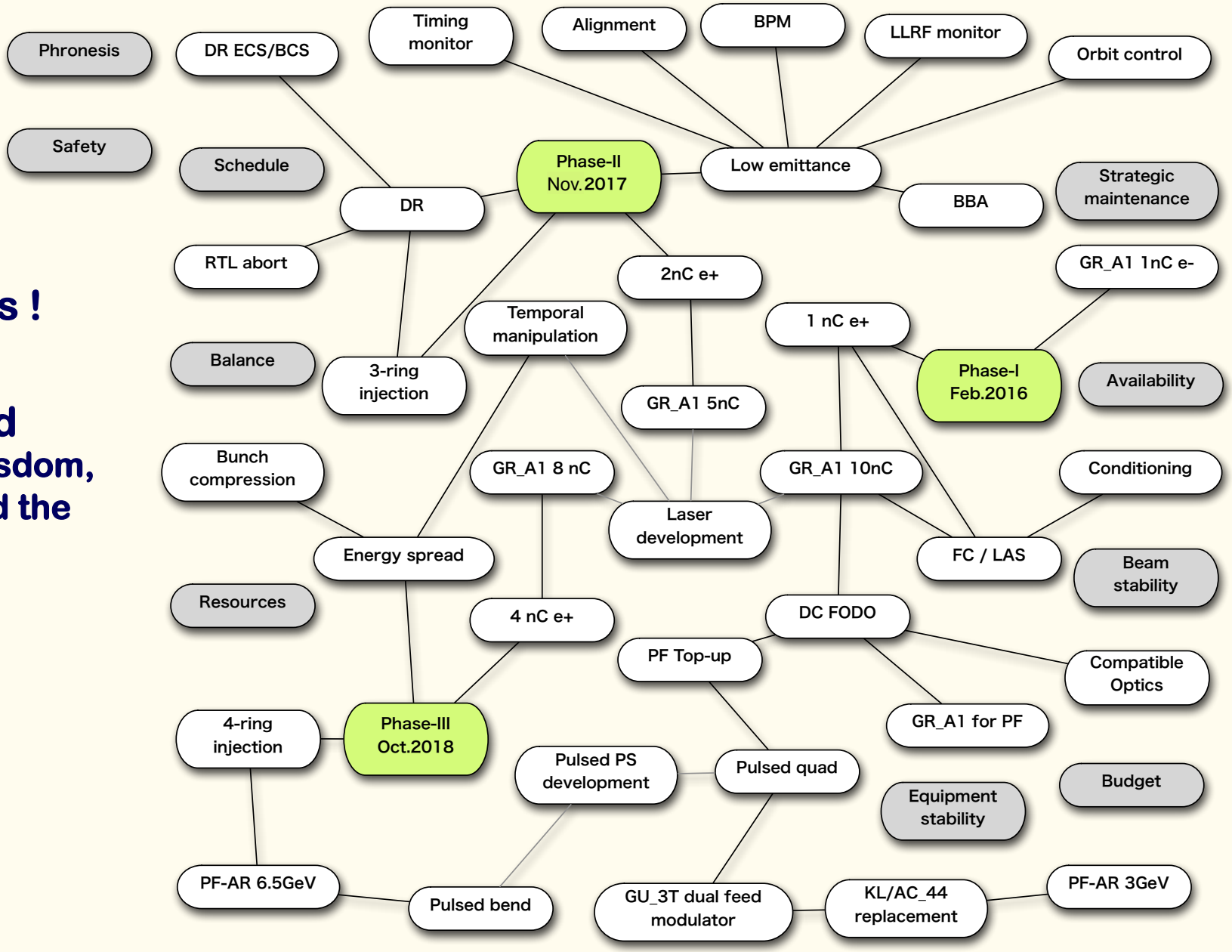
non damped e+ commiss.
at 1,2, 3,4,5 sectors
e- commiss. at A→5 sectors

damped e+ commiss. at 1→5 Qe+ = 1~4nC
e- commiss.
at A→5 Qe- = 1~5nC

Improved RF gun

Subjects to Consider

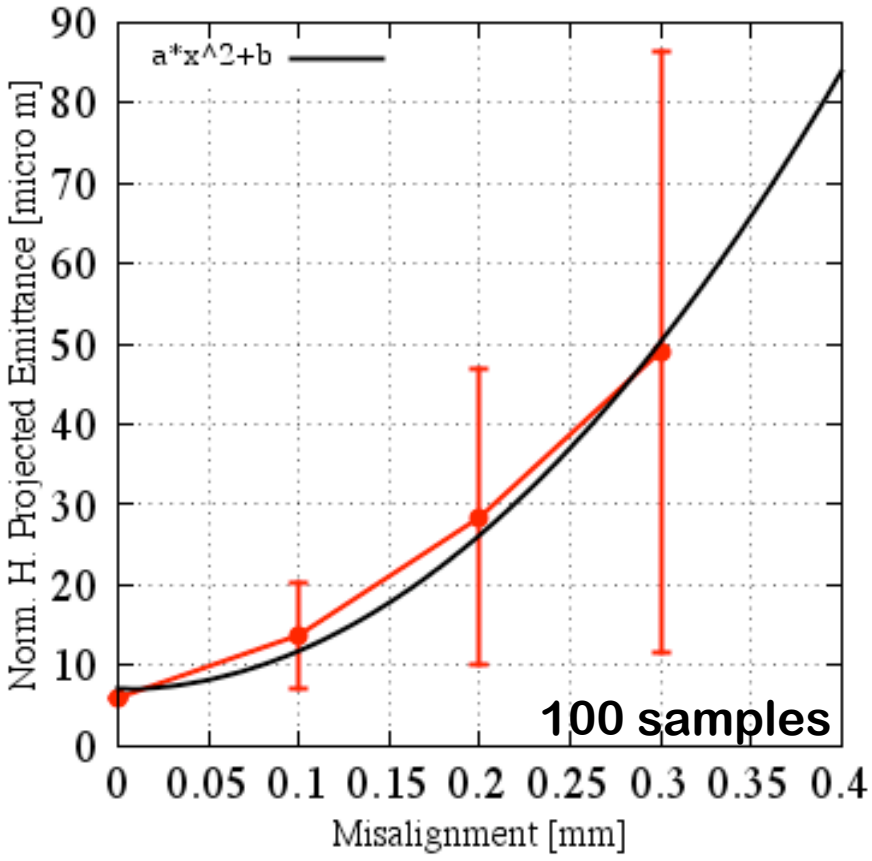
- **Have to consider too many subjects !**
- **Phronesis needed**
  (Greek: Practical wisdom, Ability to understand the Universal Truth)



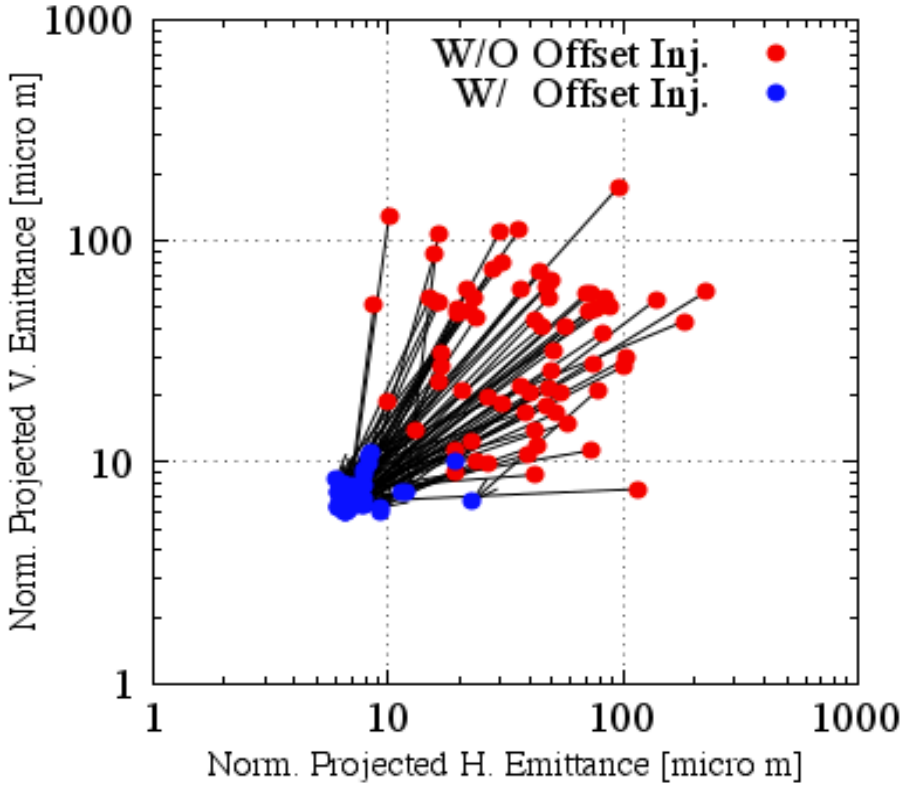
Emittance Preservation

- Offset injection may solve the issue
- Orbit have to be maintained precisely
- Mis-alignment should be <0.1mm locally, <0.3mm globally

Mis-alignment leads to Emittance blow-up

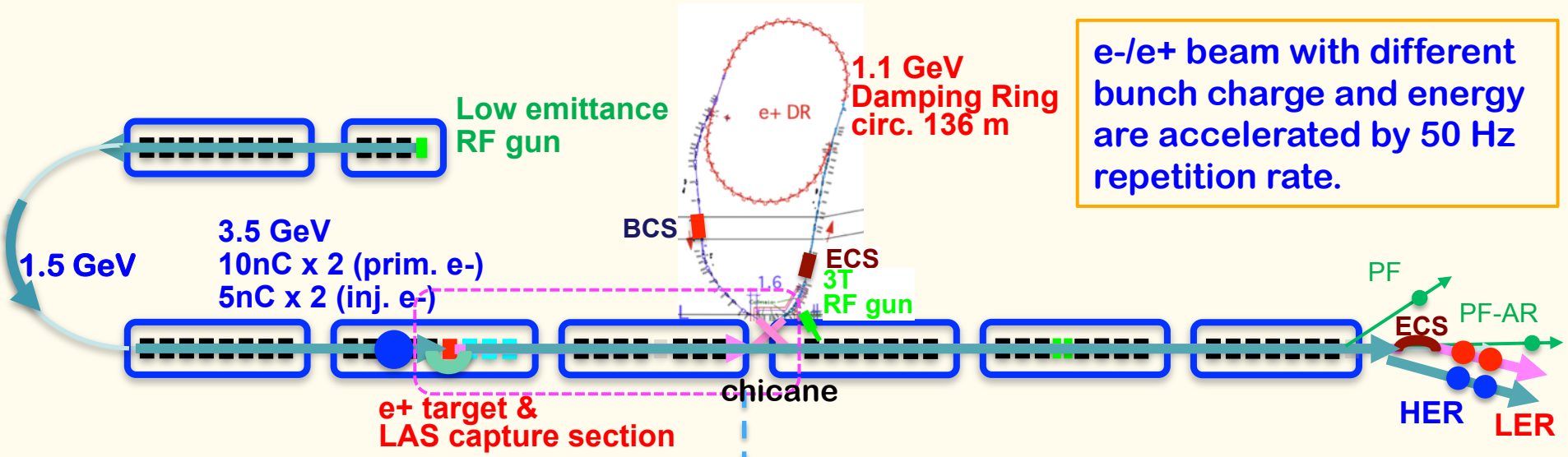


Orbit manipulation compensates it

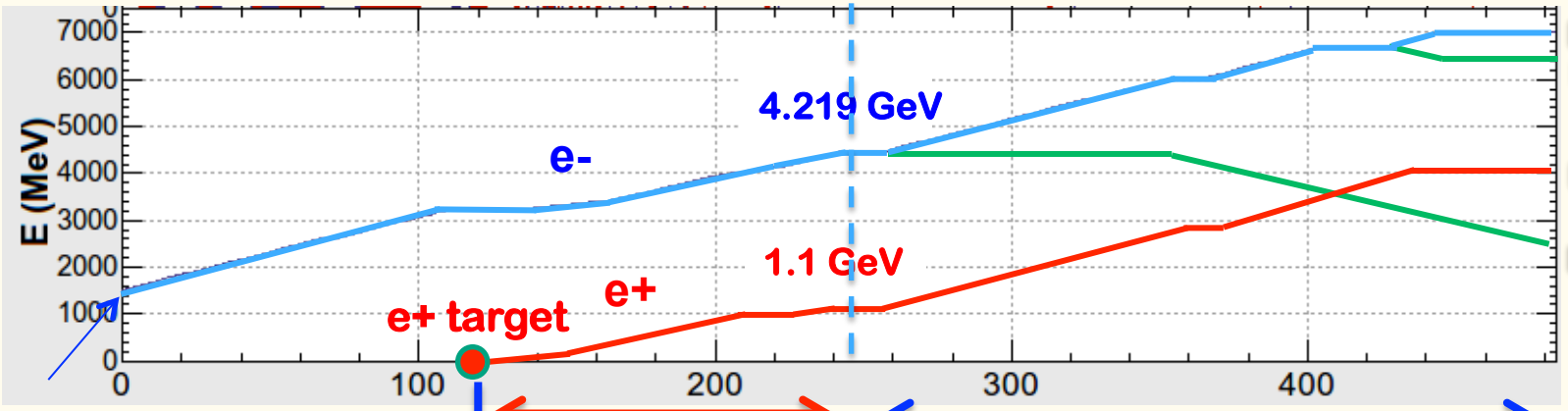


Sugimoto et al.

Injector Linac Energy Management



e-/e+ beam with different bunch charge and energy are accelerated by 50 Hz repetition rate.



5 nC x2
HER: 7GeV e-
PF-AR: 6.5GeV e-
5nCx1
LER: 4GeV e+
4 nCx2
PF: 2.5 GeV e-
0.1nCx1

e-/e+ compatible optics

Optics is changed for each pulse by using pulsed quads (Doublet) & steering magnets

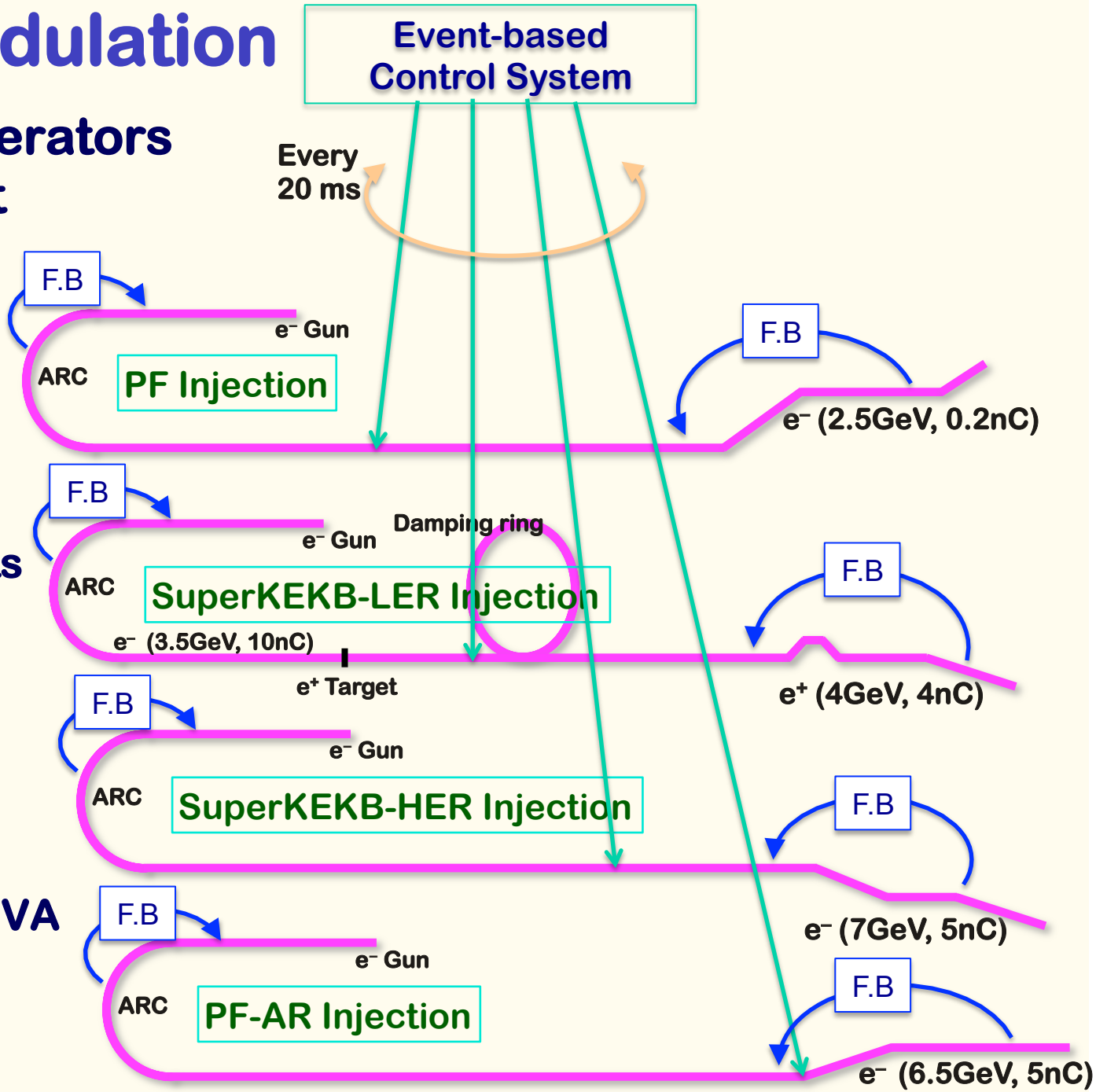
Pulse-to-pulse modulation

- **Four PPM virtual accelerators for SuperKEKB project**

Based on
Dual-tier controls with
EPICS and event-system

Independent parameter sets
for each VA (20ms)
>200 parameters
for equipment controls
many more
for beam controls

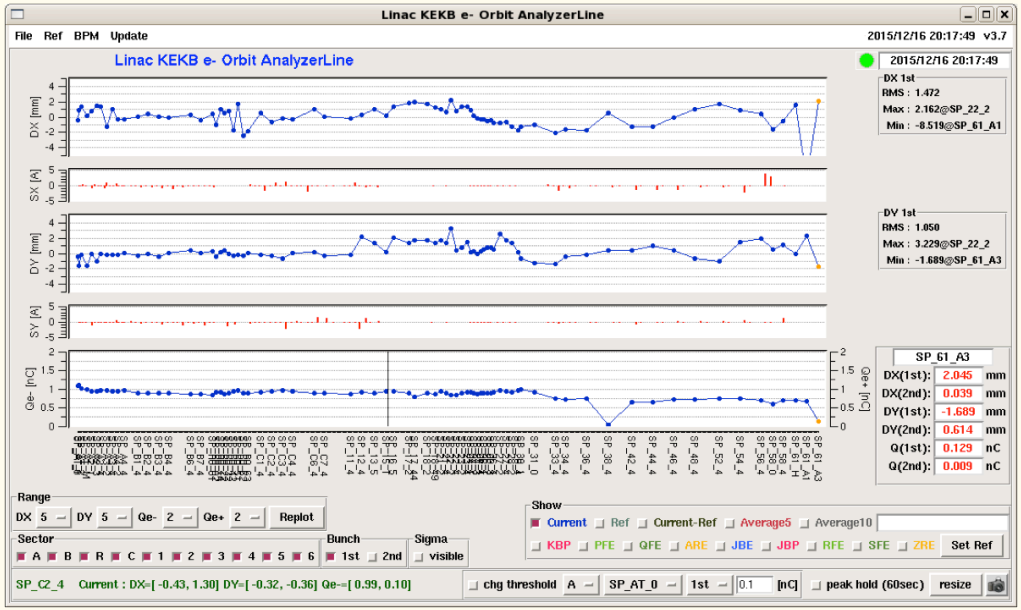
maybe with additional PPM VA
of stealth beam
for measurement



Injector Beam Commissioning for Phase-1

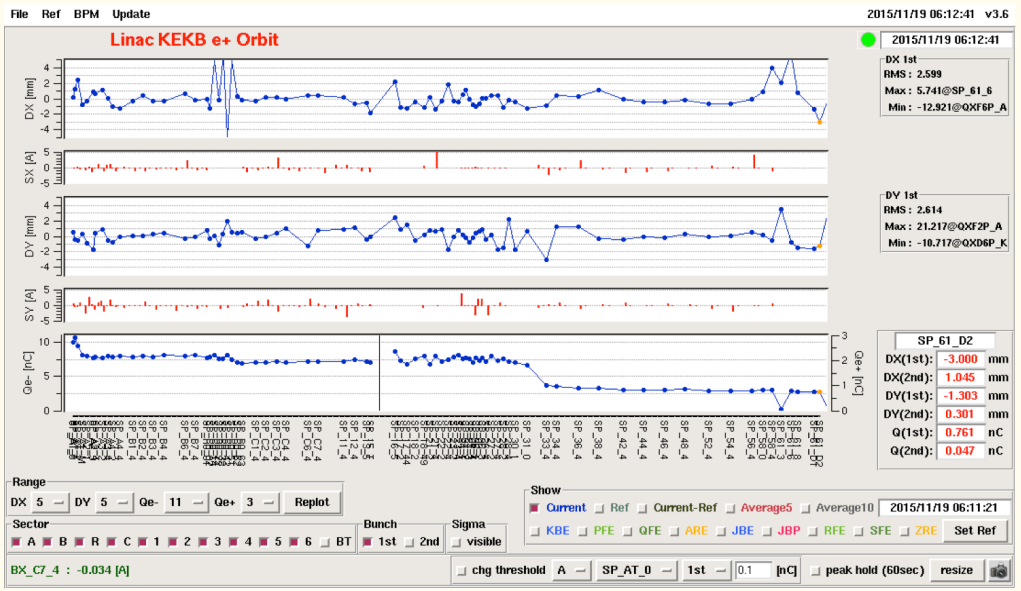
Electron beam

- Thermionic gun at the beginning
- 1 nC per bunch
- 2 bunches per pulse
- 50 pulse per second



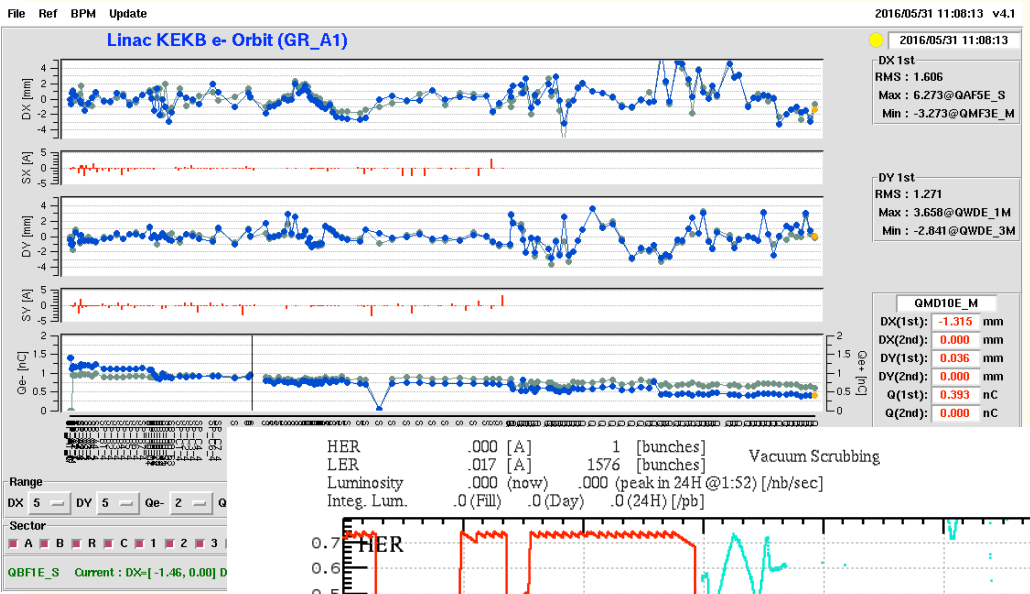
Positron beam

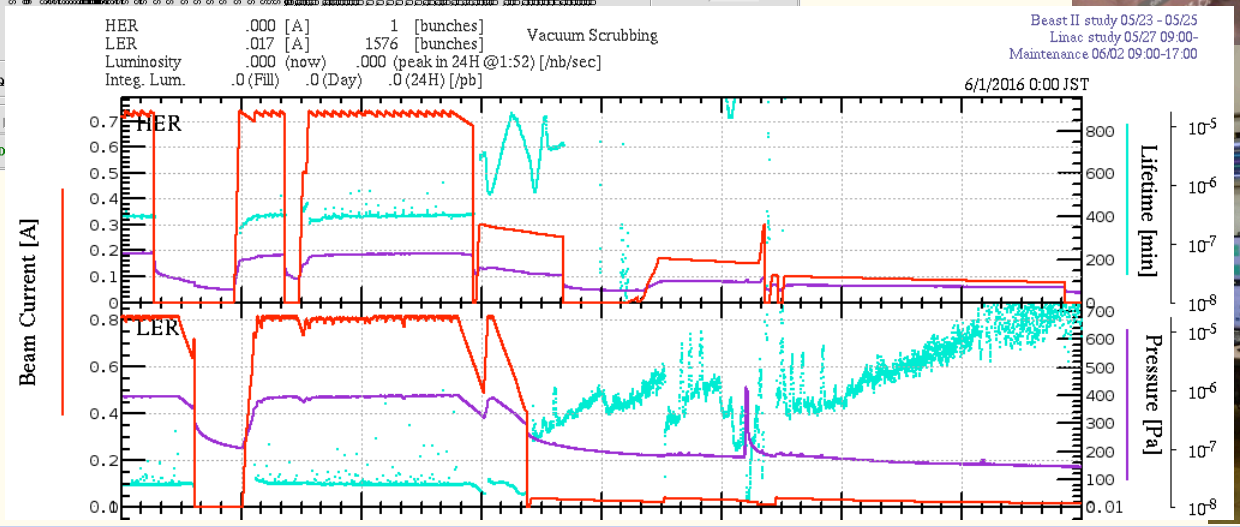
- Primary electron with 7-8 nC per bunch
- Positron of 0.7 nC at linac end without damping ring

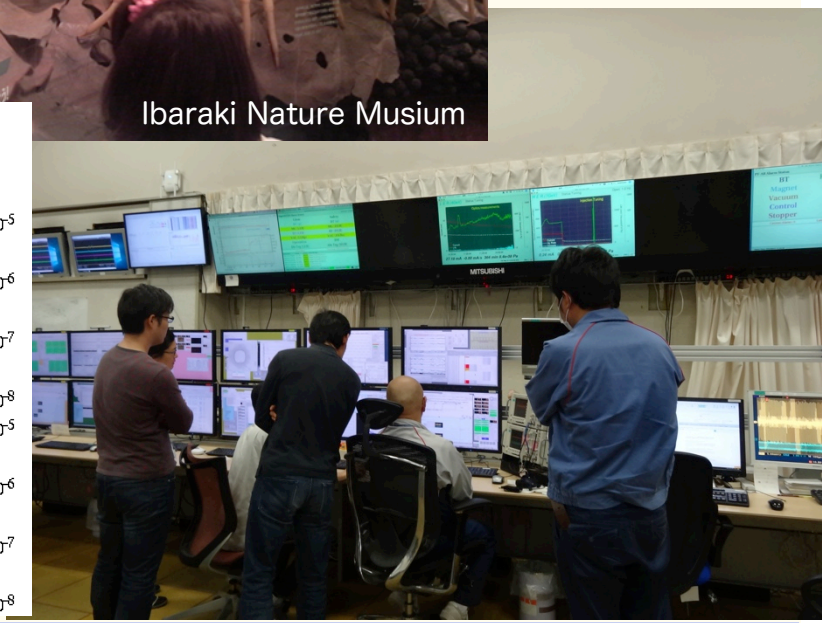


Progress: RF gun

- MR injection from RF gun during Phase-1 was recommended in the last gun review, and was planned for May 2016 since the last year
- On May 31, even an unusual centipede (~15cm!!) managed to visit the operation room to celebrate the first injection into HER

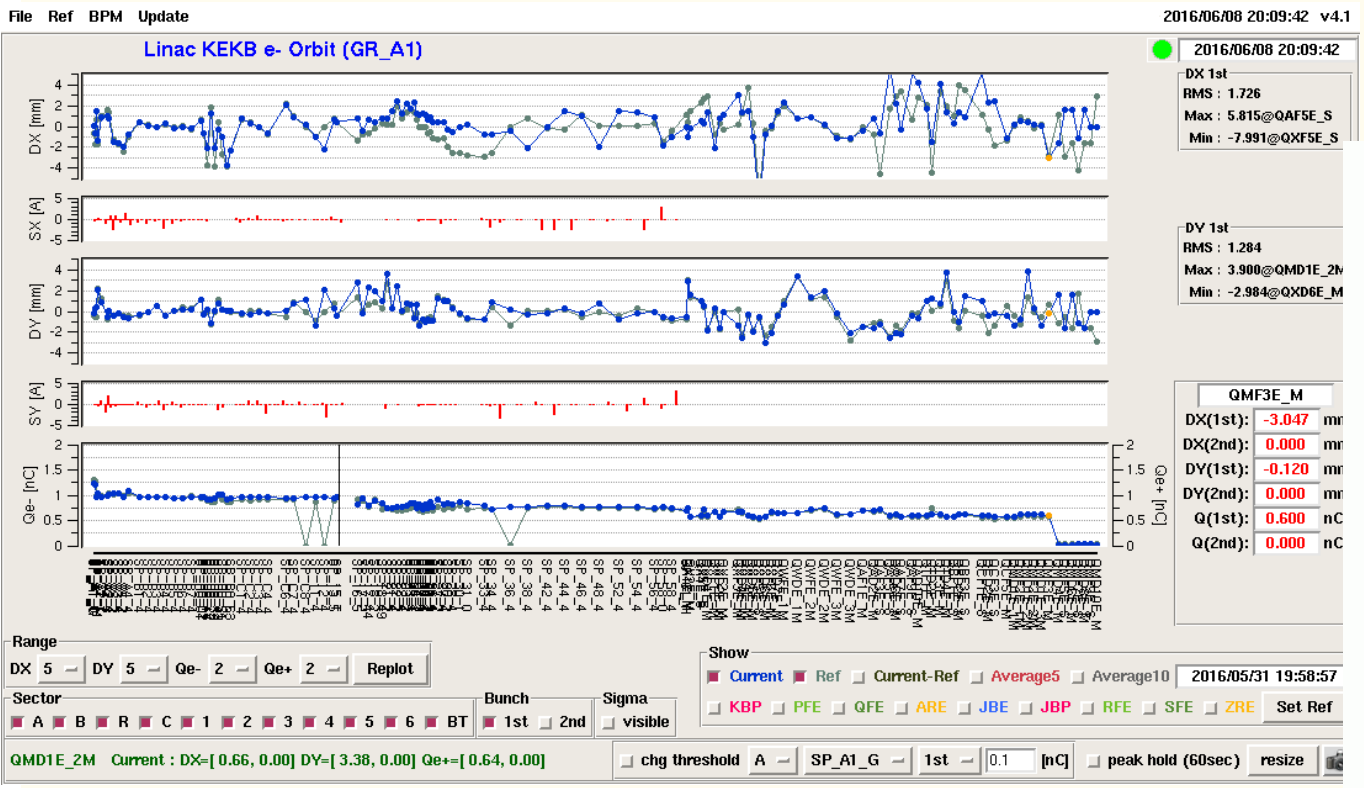


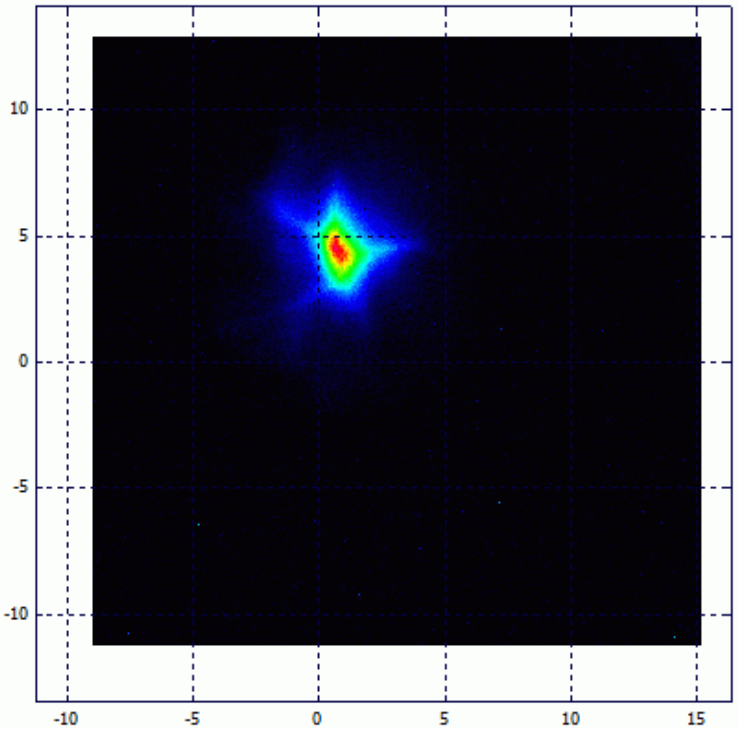




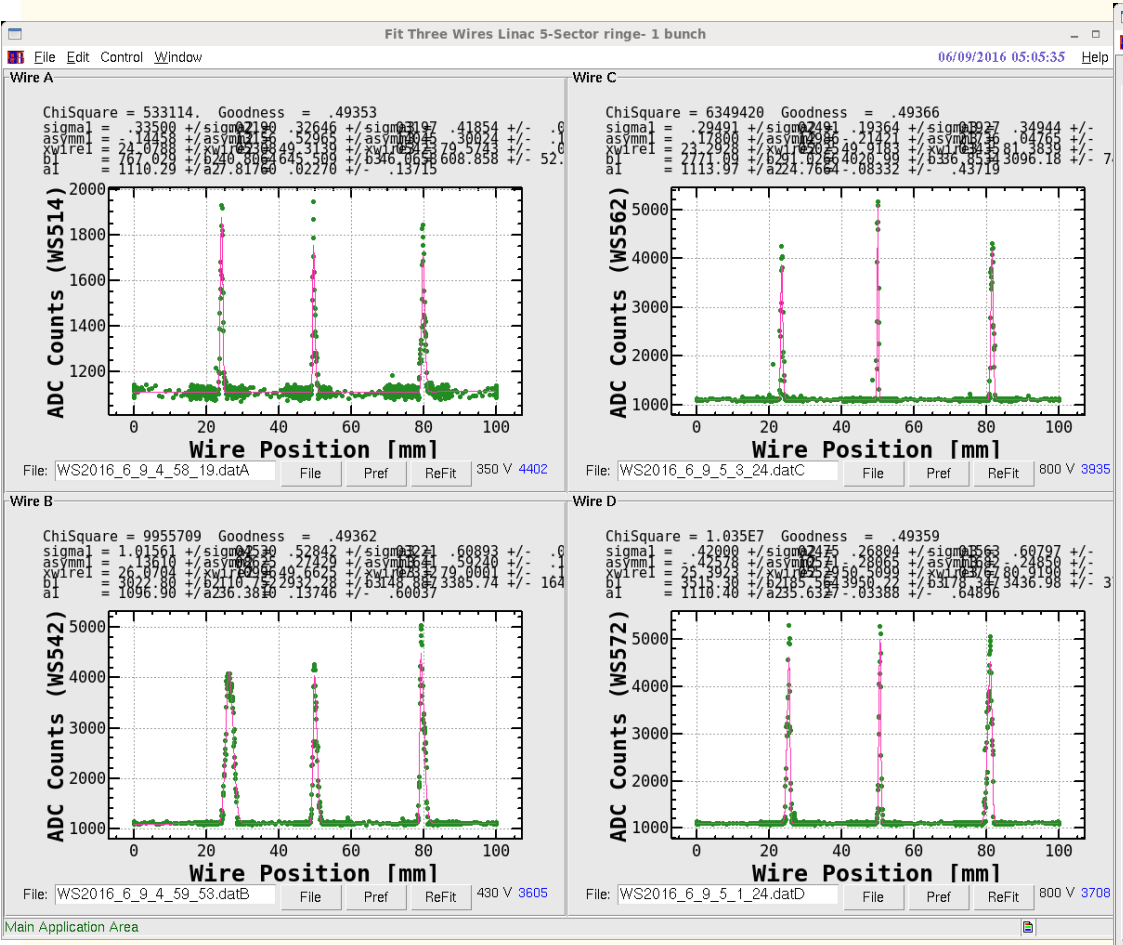
Beam from RF gun

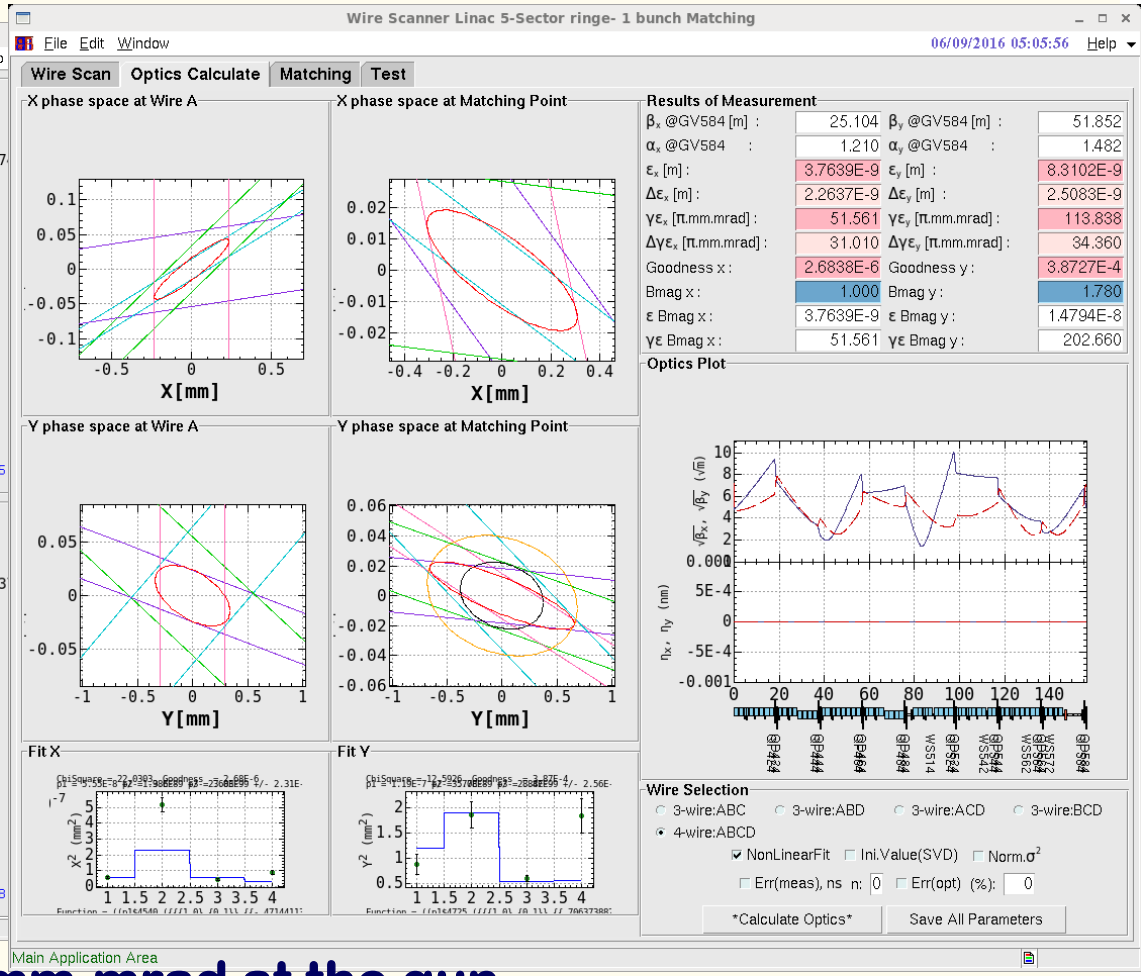
- Successful Injection into MR for the first time, on May.31
- And continuing the RF gun operation since Jun.8





Wire Scanner Measurement





- **Present beam: 1nC/bunch, 25Hz, 20mm.mrad at the gun, 30~200 mm.mrad at the linac end, ? Energy spread**
- **Phase-2: 2nC/bunch, 50Hz, 20 mm.mrad at the linac end, 0.1% energy spread**
- **Phase-3: 4-5nC/bunch**
- **Much room to enjoy the improvements**

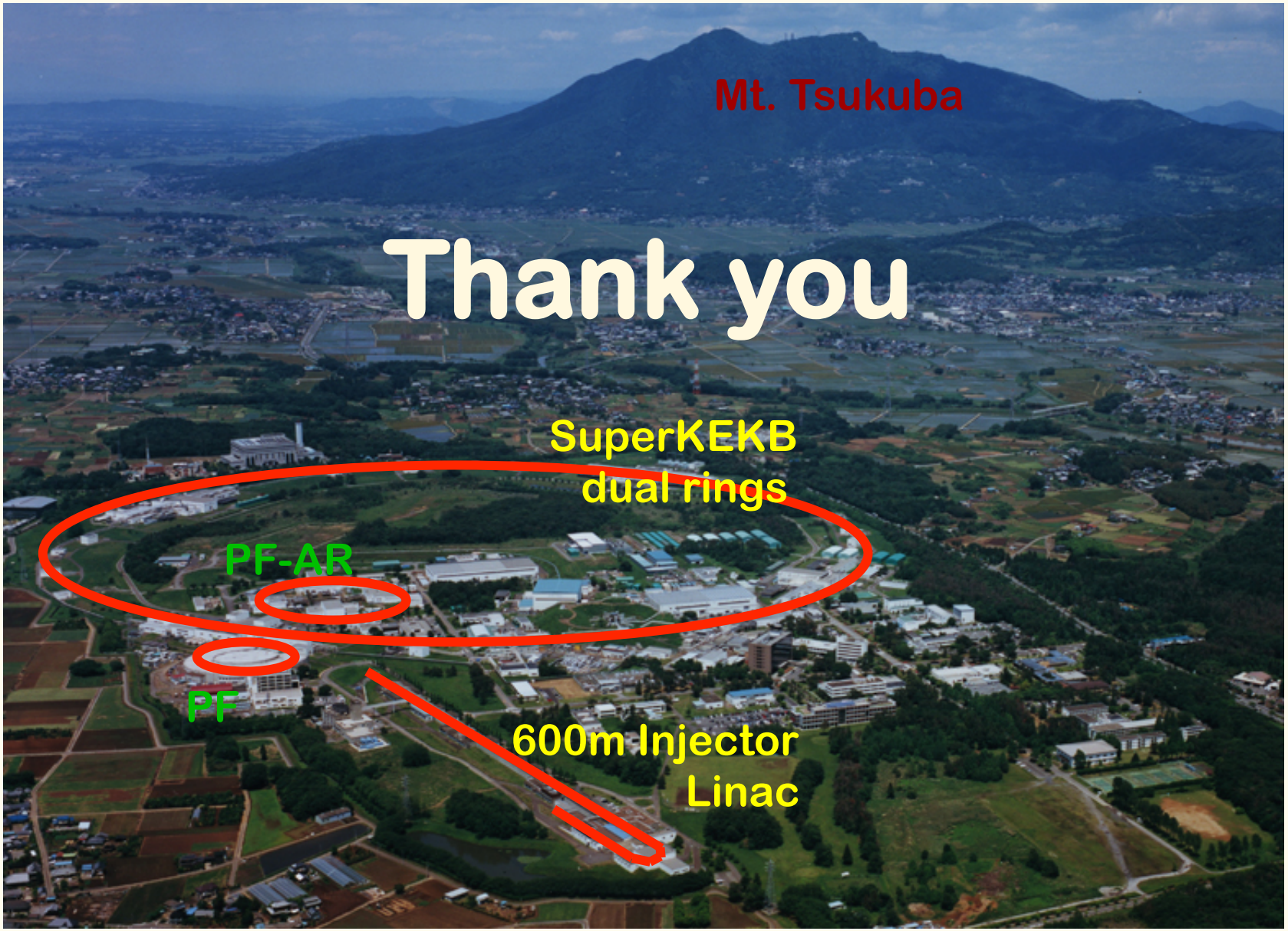
Injector Talks

- RFgun Report, Y. Honda
- RFgun and Electron Beam, M. Yoshida
- Laser and RFgun, X. Zhou
- Positron Generation and Beam, T. Kamitani
- Injector Alignment, T. Higo
- Injector Commissioning, M. Satoh

- (Positron damping ring, M. Kikuchi)

Summary

- We learned a lot during KEKB operation
- Injection into SuperKEKB is another challenge with higher beam charge and lower transverse and longitudinal emittance
- Steady progress towards designed injection beam in steps
  - Alignment: almost confident on the required precision (0.1-mm local, 0.3-mm global), need to maintain for longer term
  - Positron generator: another license test, need discharge analysis
  - Thermionic gun: re-commissioned for primary electron for positron generation
  - RF gun: following recommendations at review meetings
  - Need much more radiation shield
- Will balance between final beam quality and progressive operation
- Will select optimized route depending on available resources
  - Negotiation with light sources
  - Commissioing and development in parallel (no other choices)


Mt. Tsukuba
Thank you
SuperKEKB
dual rings
PF-AR
PF
600m Injector
Linac