Electron / Positron Injector Linac

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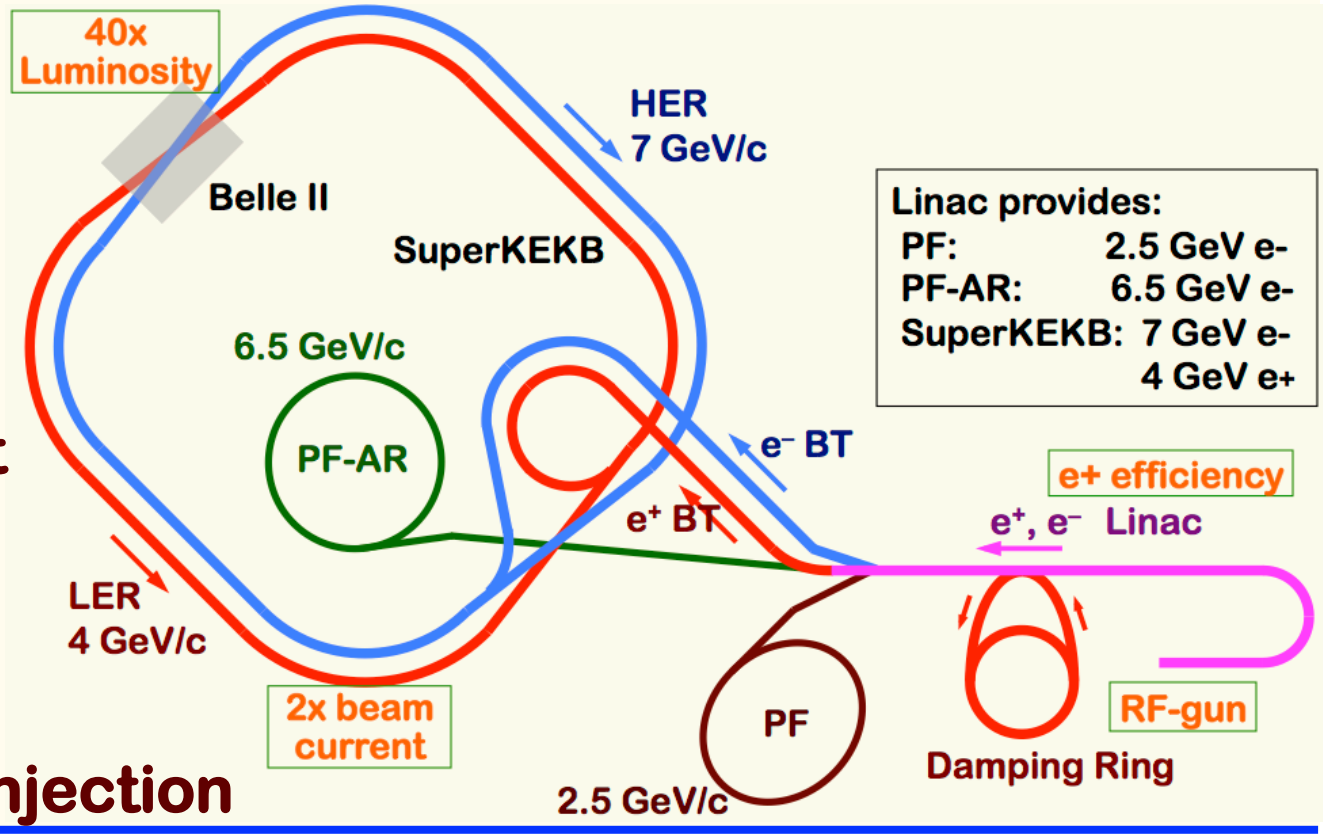
for Injector Linac

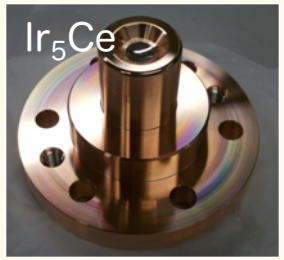
Mission of electron/positron Injector in SuperKEKB

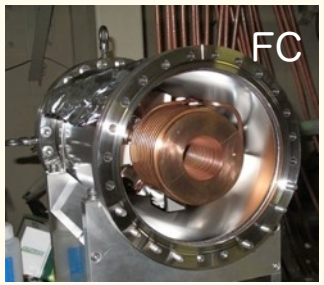
- **40-times higher Luminosity**
  - Twice larger storage beam → Higher beam current at Linac
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Linac
    - → Shorter storage lifetime (→ Higher Linac beam current)
- **Linac challenges**
  - 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 beam control
  - 4+1 ring simultaneous injection



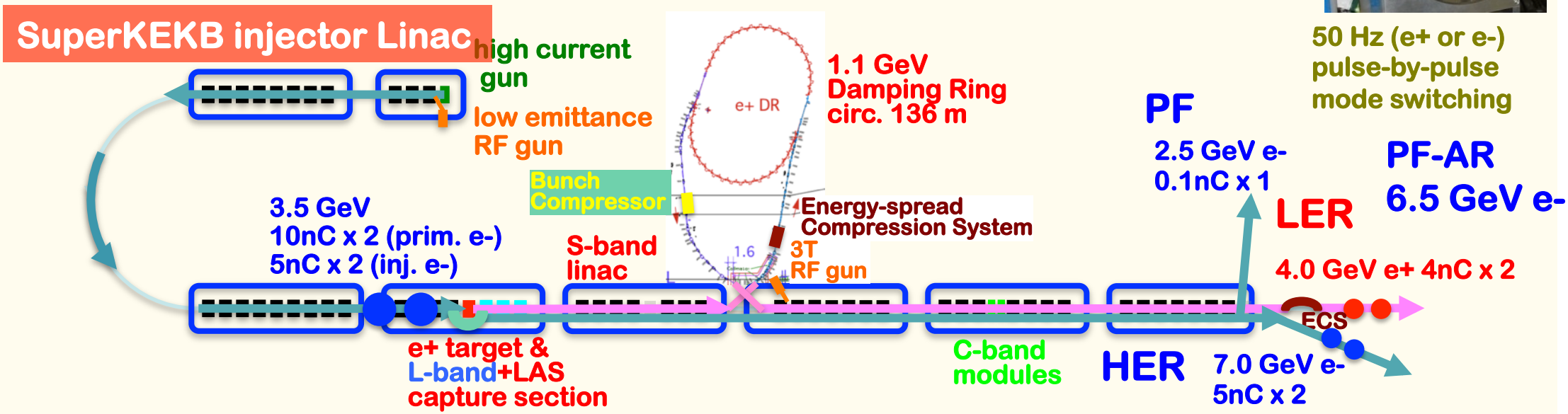
Linac Upgrade for SuperKEKB

- **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
- **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 (PPM)**
  - SuperKEKB e^-/e^+ rings, and light sources of PF and PF-AR
  - Improvements to beam instrumentation, low-level RF, controls, timing, etc

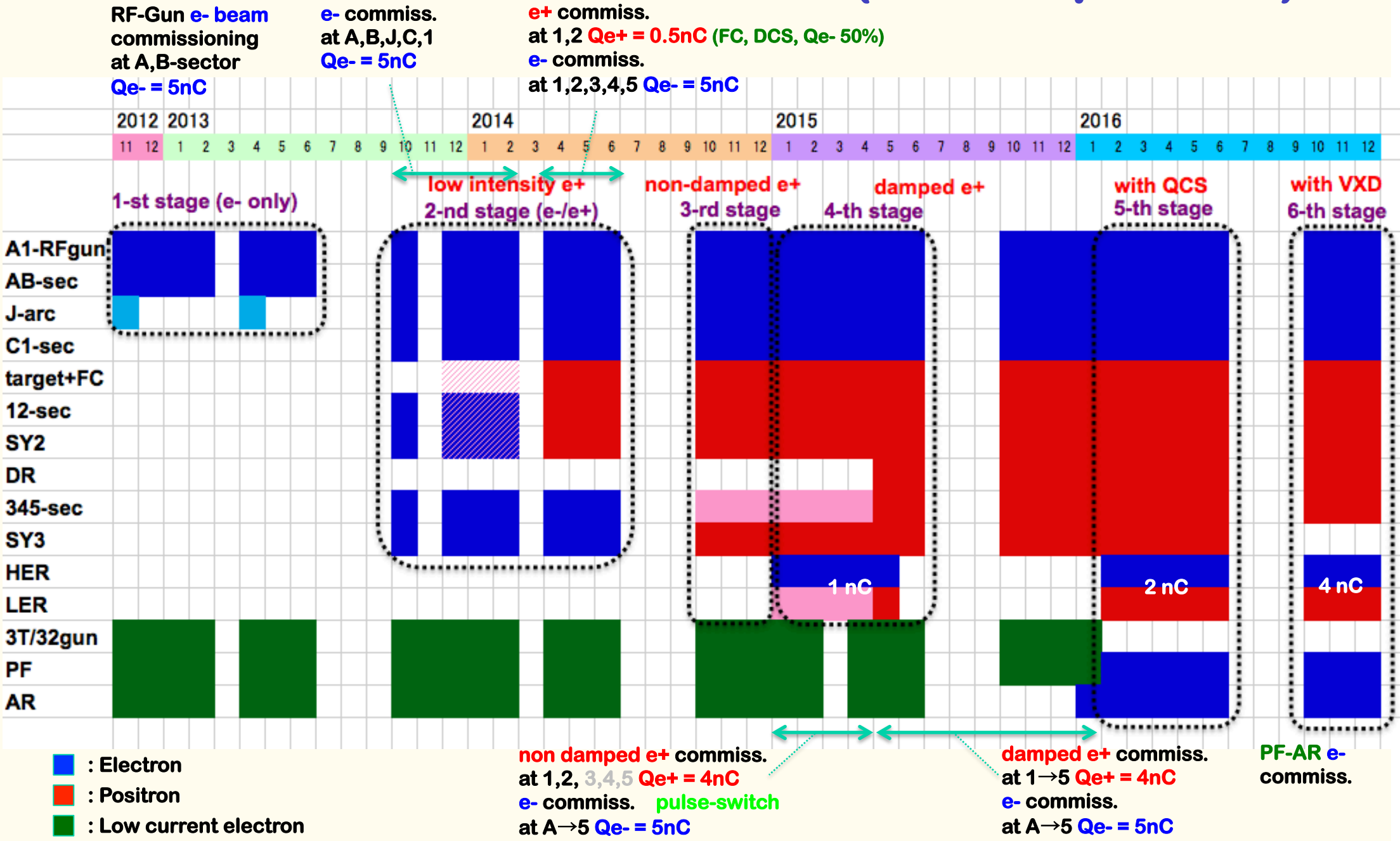




50 Hz (e+ or e-)
pulse-by-pulse
mode switching

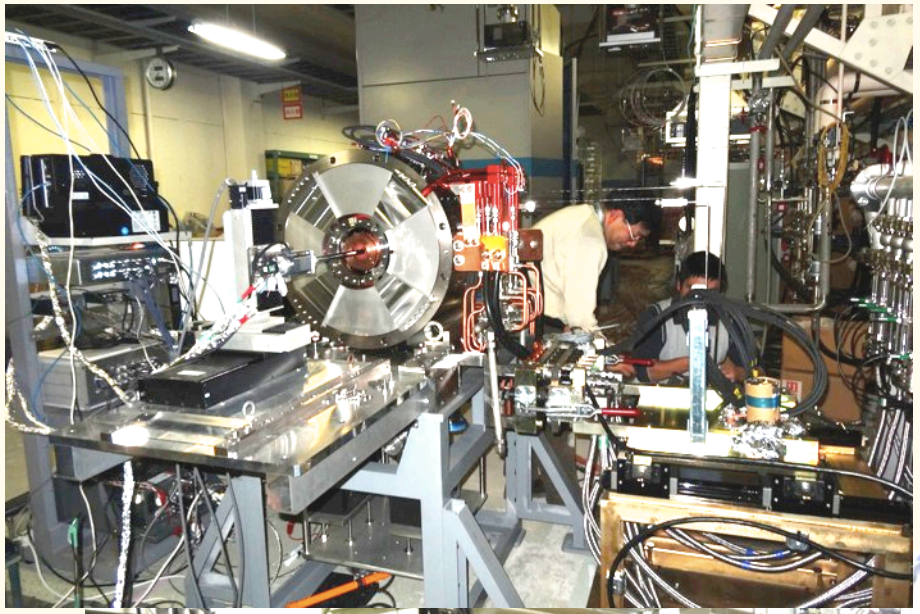


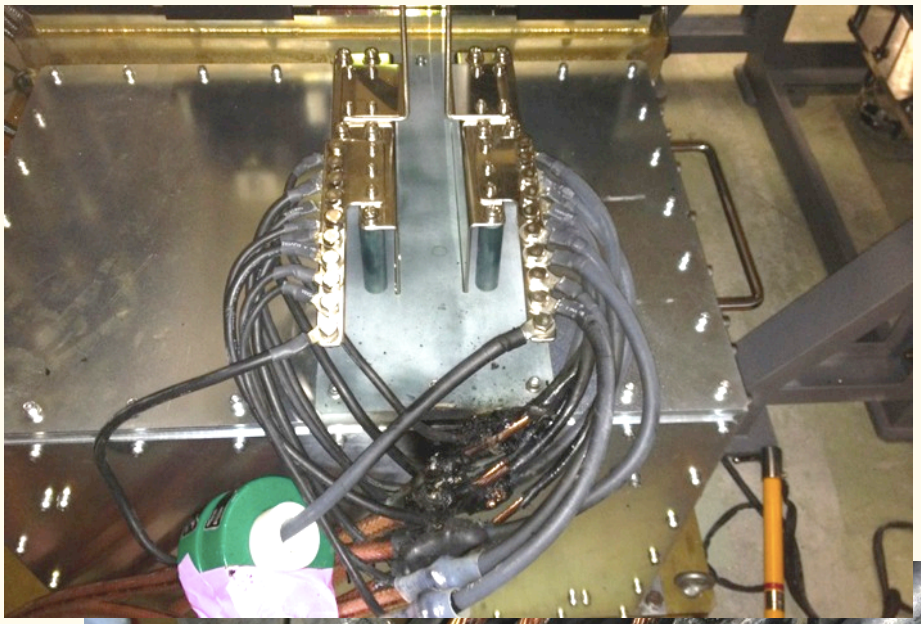
Linac Schedule Overview (to be updated)

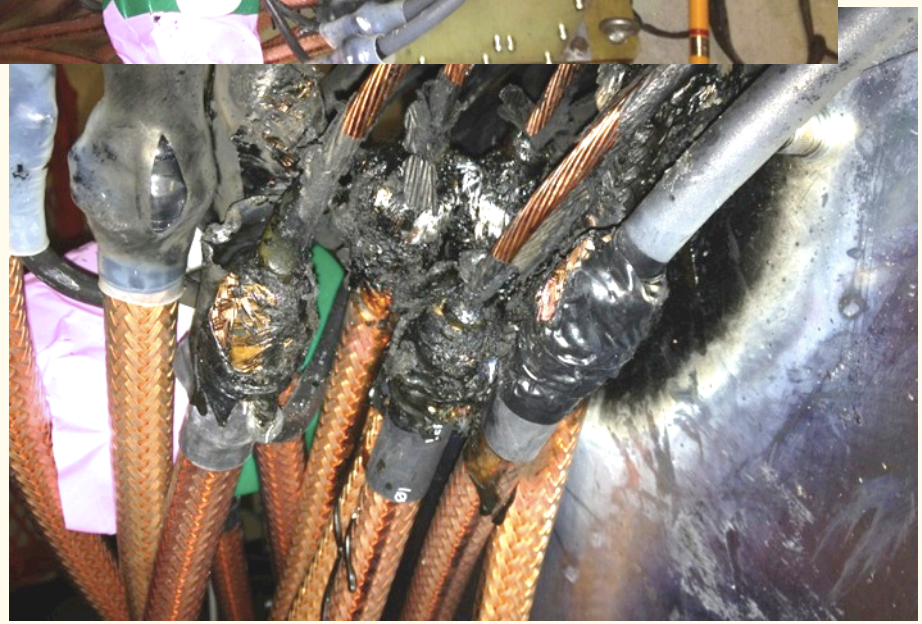


Fire during flux concentrator development

- One of small problems – Cables burned by 20cm







SLAC-SuperKEKB Workshop (Injector Linac)

- **Injector commissioning and issues *30'***
  - Speaker: Masanori Satoh (KEK)
- **Photo-cathode RF gun *20'***
  - Speaker: Takuya Natsui (KEK)
- **Positron source *30'***
  - Speaker: Takuya Kamitani (KEK)
- **Timing synchronization *20'***
  - Speaker: Hiroshi Kaji (KEK)
- **Linac alignment *20'***
  - Speaker: Toshiyasu Higo (KEK)
- **Beam optics design for simultaneous injection *20'***
  - Speaker: Takako Miura (KEK)

Questions and Answers

- PEDD dependent on beam repetition?
  - SLAC study was on single-pulse energy density
    - may need further investigation
- Fiber loss monitor blackening around target?
  - Can be replaced routinely
- Diamond loss detector?
  - Is worth comparing in the future
- Orbit stability tolerance against beam size?
  - Pinhole 2mm and beam sigma 0.3mm are possible
    Beam orbit jitter will be studied, as well as for emittance preservation
- Rotating target/spoiler?
  - Should be studied for the beam current larger
- Frequency synchronization btw. linac/ring?
  - All SKEKB frequencies are generated from common freq. with ring circumference compensation
- Beam charge variation pulse-pulse?
  - Can be important
  - Technically possible with different event assignment
  - Means different injection modes with different orbit stabilization for wakefield
- Target quad – pulsed ?
- Beam jitter should be small
- DR extraction angle jitter
  - Offset injection position/angle jitter should be small

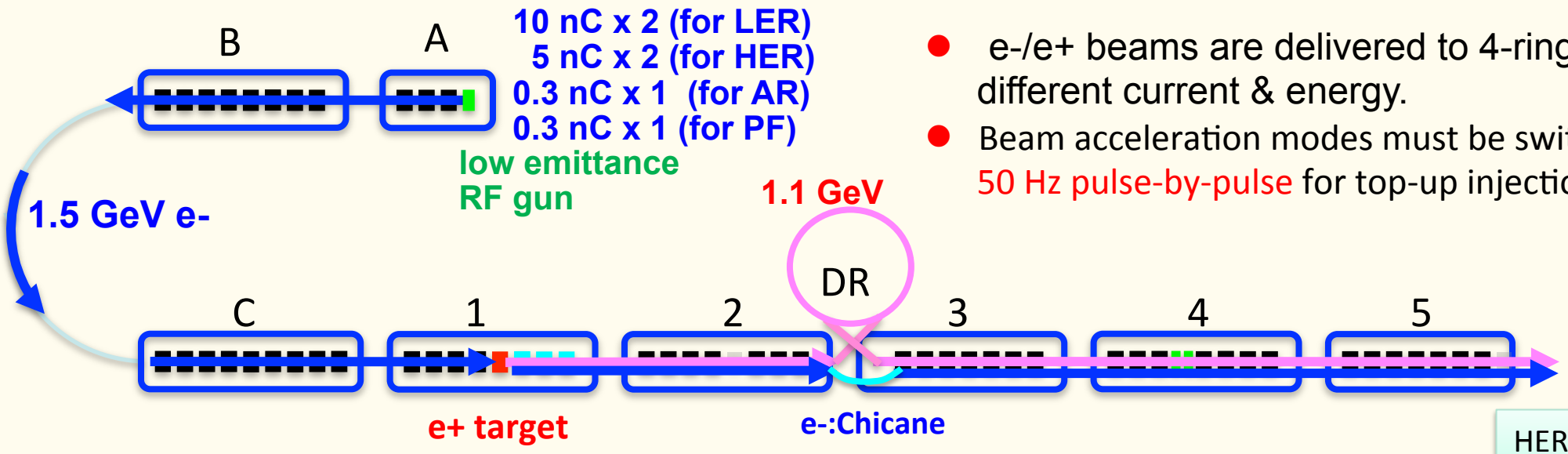
Several Workshop around Injector Linac

- **Technology choice for beam position monitor (BPM)**
  - Indispensable for emittance preservation
  - ~10micron precision (~100micron in KEKB linac), about 100 BPMs, event controls
  - Experts from SLAC, Steve Smith and Andrew Young
  - Many valuable discussions for filter design, digital signal processing, etc.
  - One of the developments was chosen for performance, operation, and budget
- **Laser and photo-cathode RF gun workshop**
  - 6 presentations, 16 participants
  - The same objectives of low emittance and higher stability
  - Injector linac is unique on higher beam charge and lower energy spread
  - Should exchange technology/information continuously
- **Accelerator structure processing workshop**
  - 22 participants
  - Many discussions on duration (more than a month), and the system
  - No baking necessary, longer processing and better monitors, better interlock needed

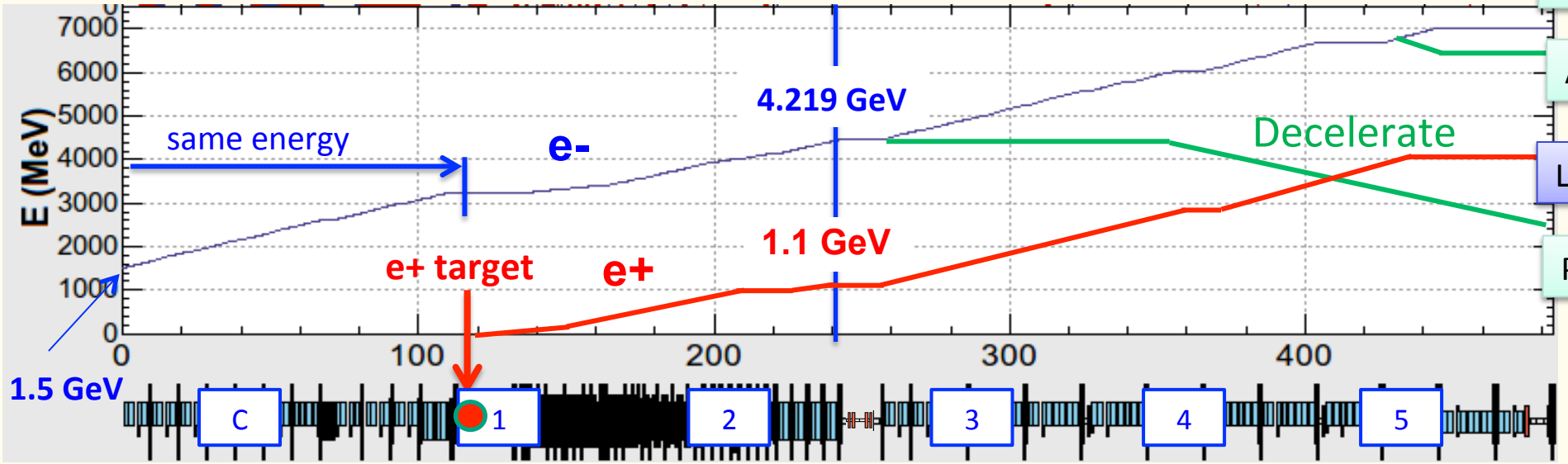
Improved beam optics design

- Pulsed quad addition – Simultaneous injection
- FODO → Doublet – Emittance preservation
- Orbit correction simulation
- Further emittance preservation even with alignment tolerances
- Optimization for budget …

KEK e-/e+ Injector LINAC



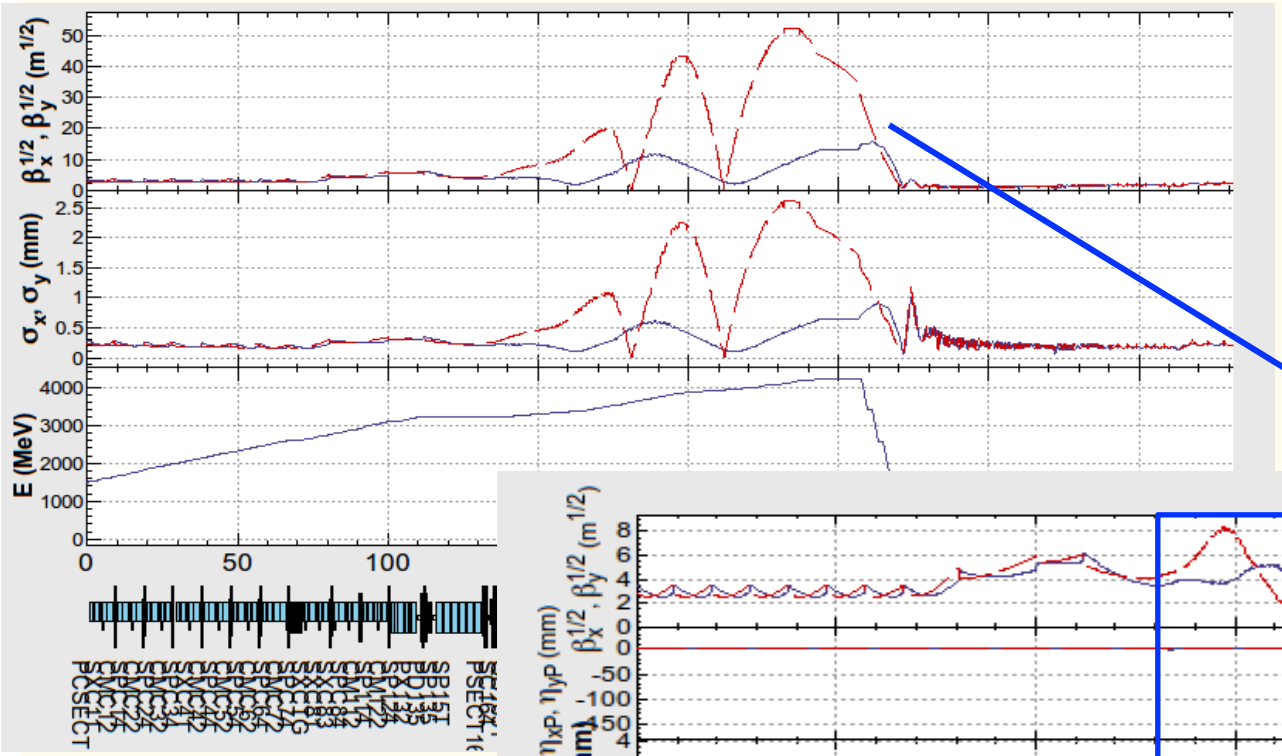
- e-/e+ beams are delivered to 4-rings with different current & energy.
- Beam acceleration modes must be switched by 50 Hz pulse-by-pulse for top-up injection.

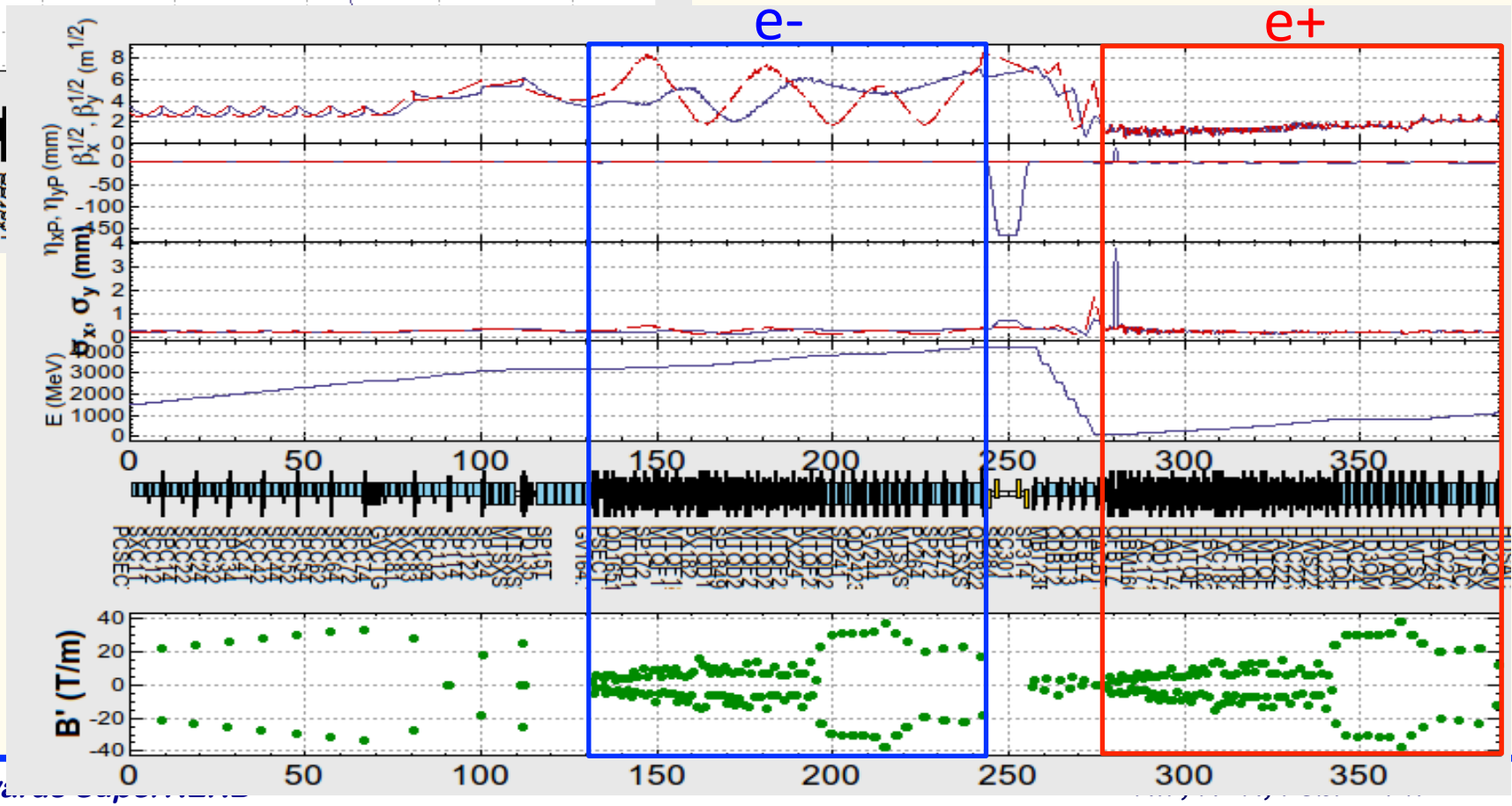


HER: 7 GeV e-
5 nC x2
AR: 6.5 GeV e-
0.3 nC x1
LER: 2.5 GeV e+
4 nC x2
PF: 2.5 GeV e-
0.3 nC x1

Beam optics should satisfy the fast beam-mode switching.

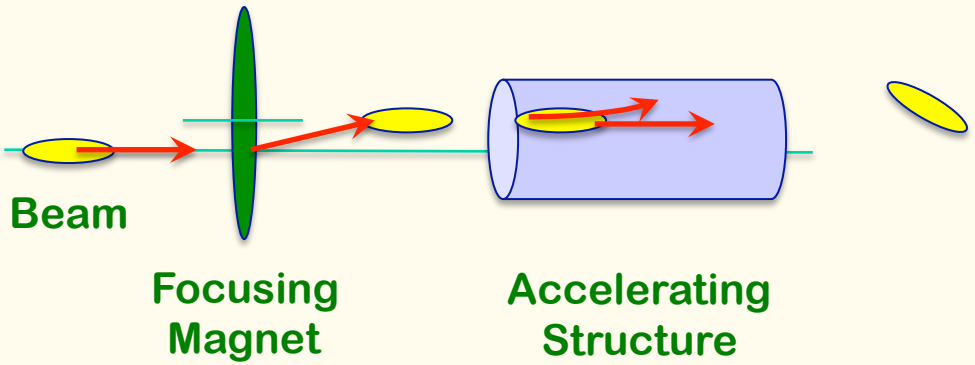
Result of e-p fitting



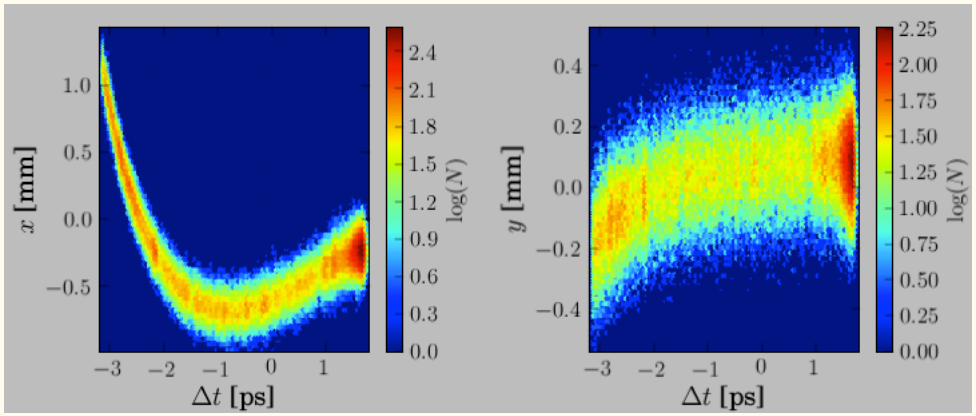


Emittance Preservation

- If Device is off center of the beam
  - Focusing magnet (quad) kicks the beam bunch
  - Accelerating structure (cavity) excites wakefield, to bend the tail
- Distorted bunch in banana shape
  - Emittance dilution or blow-up
  - Depending on the beam optics and the beam charge
- Orbit correction is crucial to preserve the emittance



Sugimoto et al.

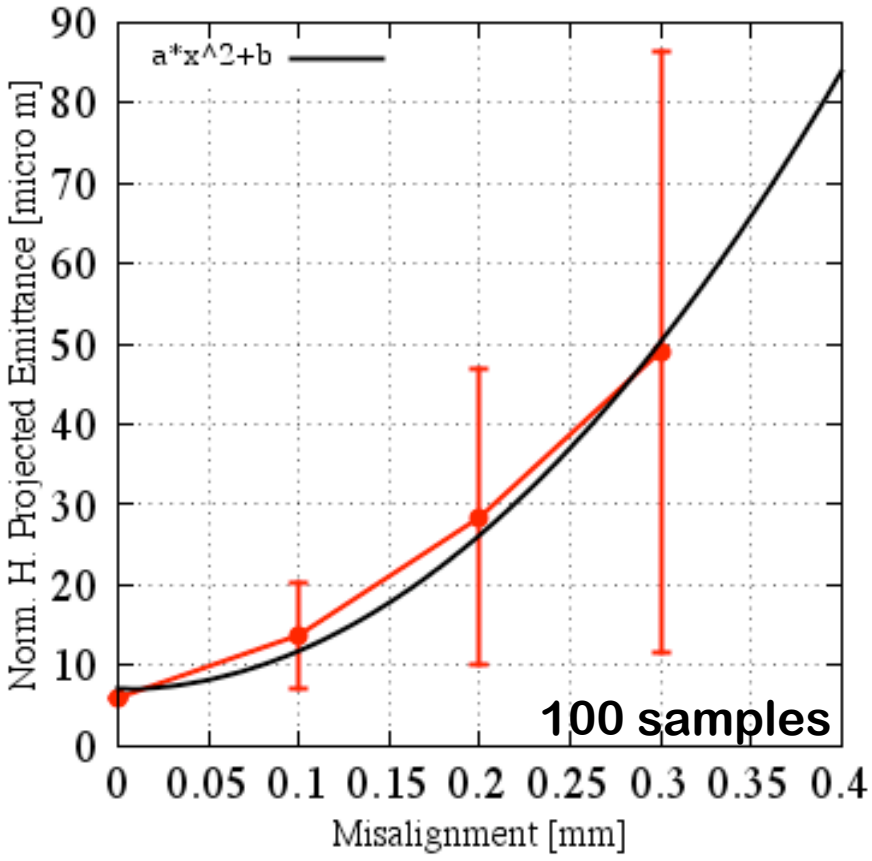


Transverse distribution in time direction

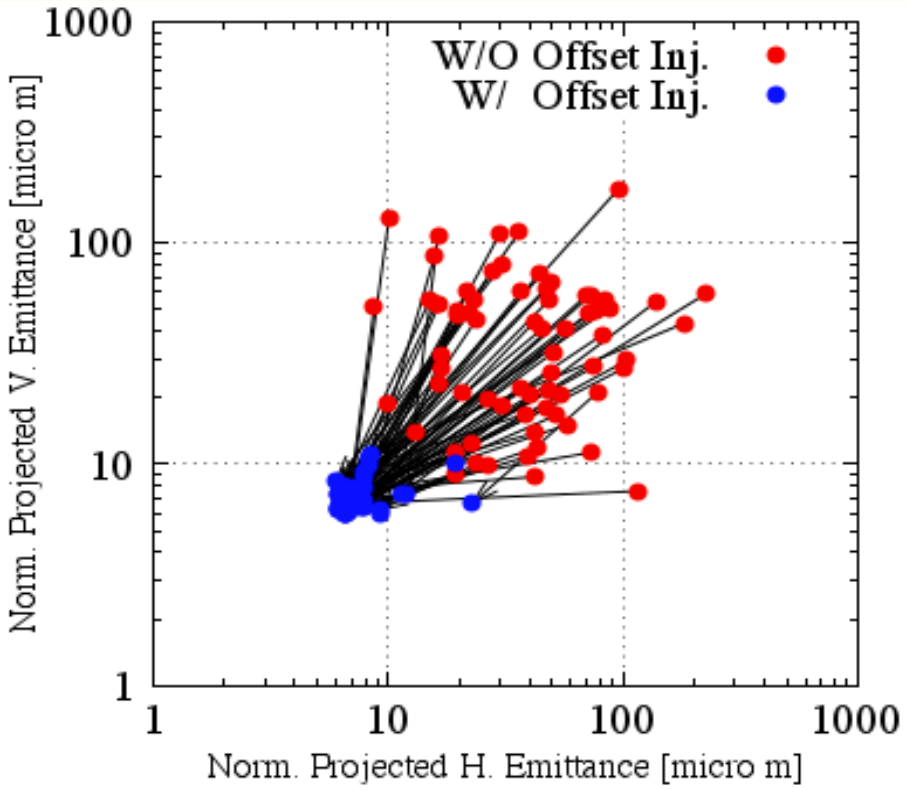
Emittance Dilution

- Offset injection may solve the issue
- Orbit have to be maintained precisely

Mis-alignment leads to Emittance blow-up



Orbit manipulation compensates it



Sugimoto et al.

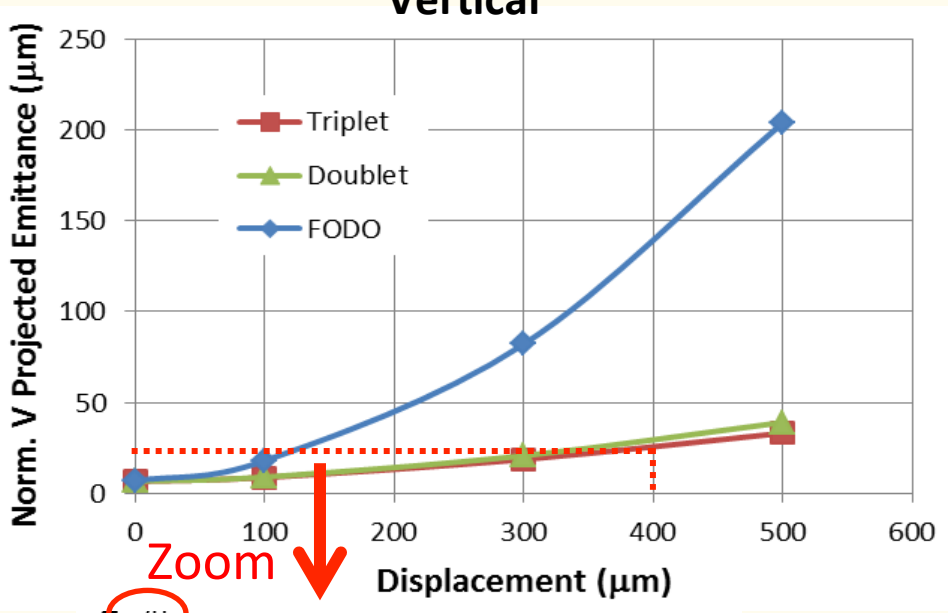
Alignment Error vs. Emittance Growth

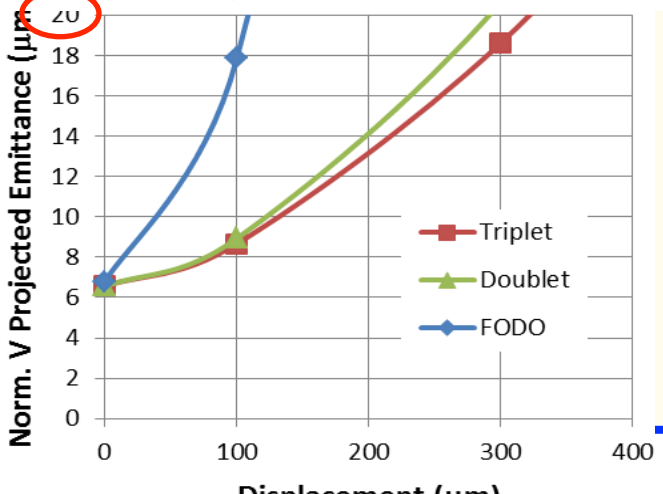
Calculated by H. Sugimoto

<Tracking Condition>

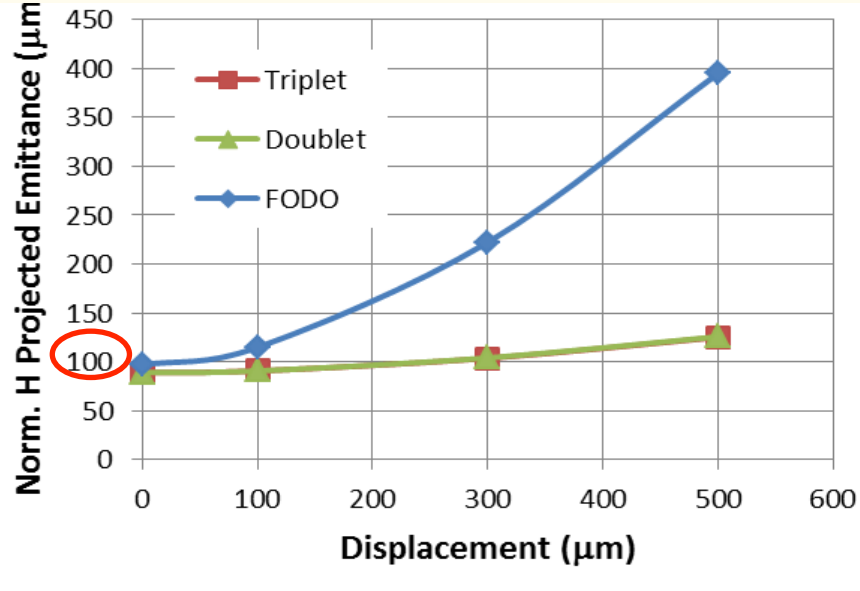
- Positron is transported from DR outlet to LINAC end.
- Alignment error is given in quads and cavities.
- The orbit correction is performed by assuming the center of the quads and BPM are exactly the same.
- Initial Emittance@Outlet of DR =6.5 μm / 89 μm (Vertical / Horizontal)

Vertical





Horizontal



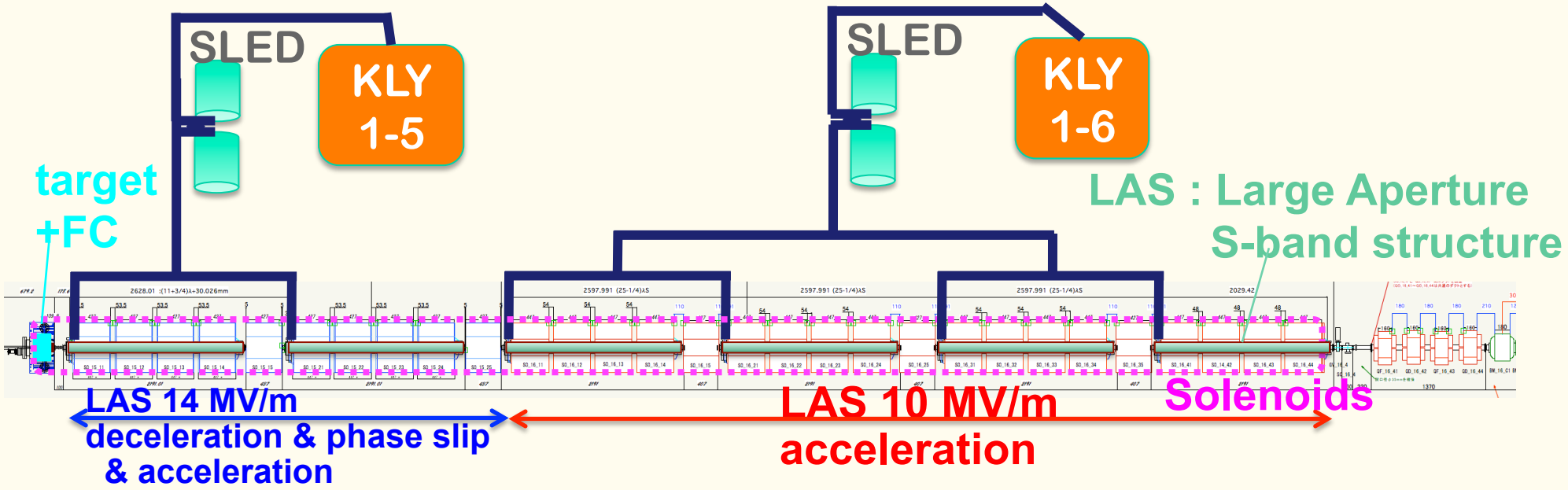
e+ norm. ε at LINAC-end should be less than
20 μm / 100μm (Ver. / Hor.)

- Triplet and doublet give almost same results.
- In triplet and doublet, misalignment of 300μm is acceptable.
- In FODO lattice, significant emittance growth is seen.

Positron Source

- High current positron is required
- Positron capturing with flux concentrator (FC) and large aperture s-band structure (LAS)
- Deceleration field to reduce satellite bunches
- Pinhole beside target for electron beam
- Protection system with beam spoilers

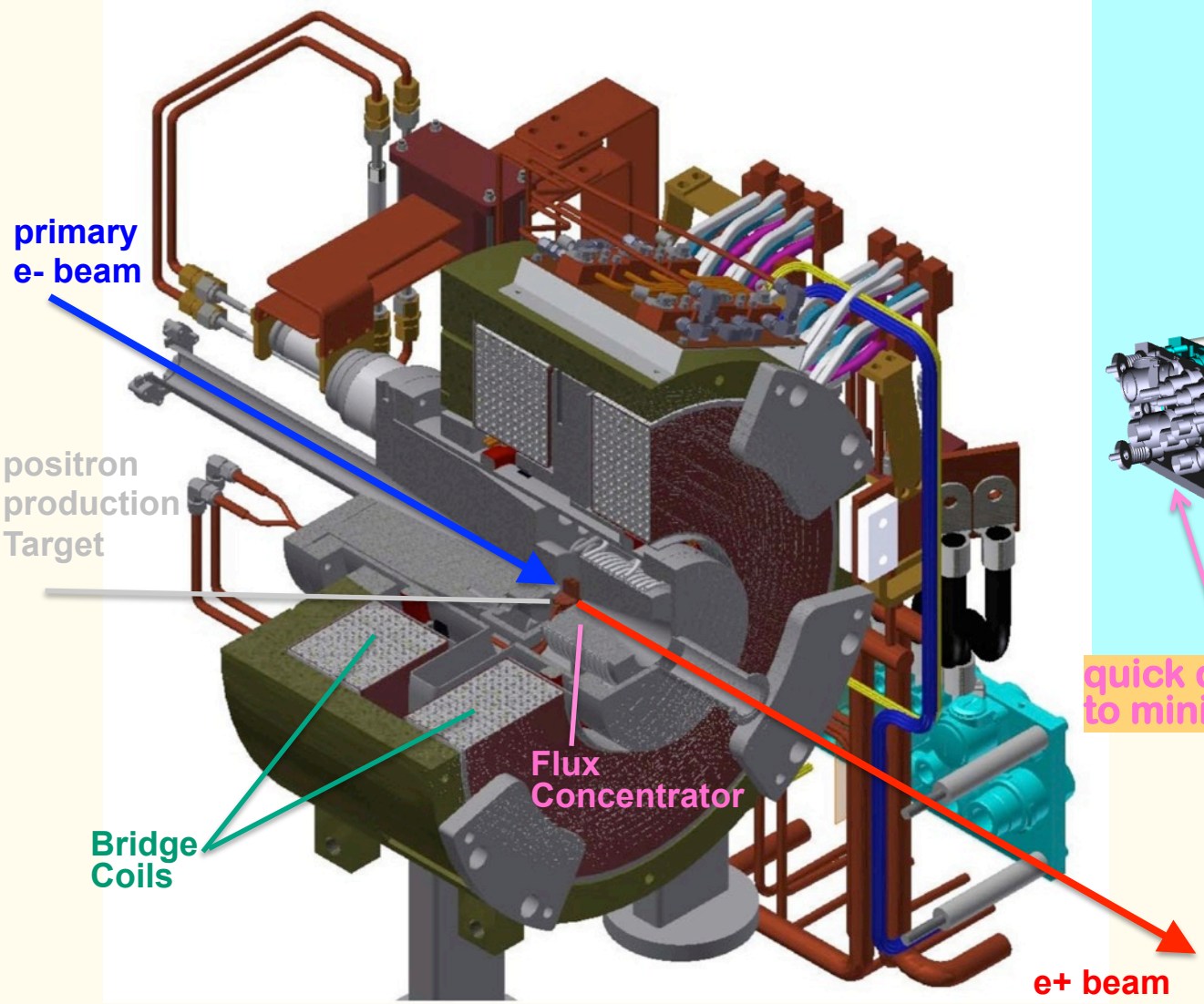
Positron beamline under construction

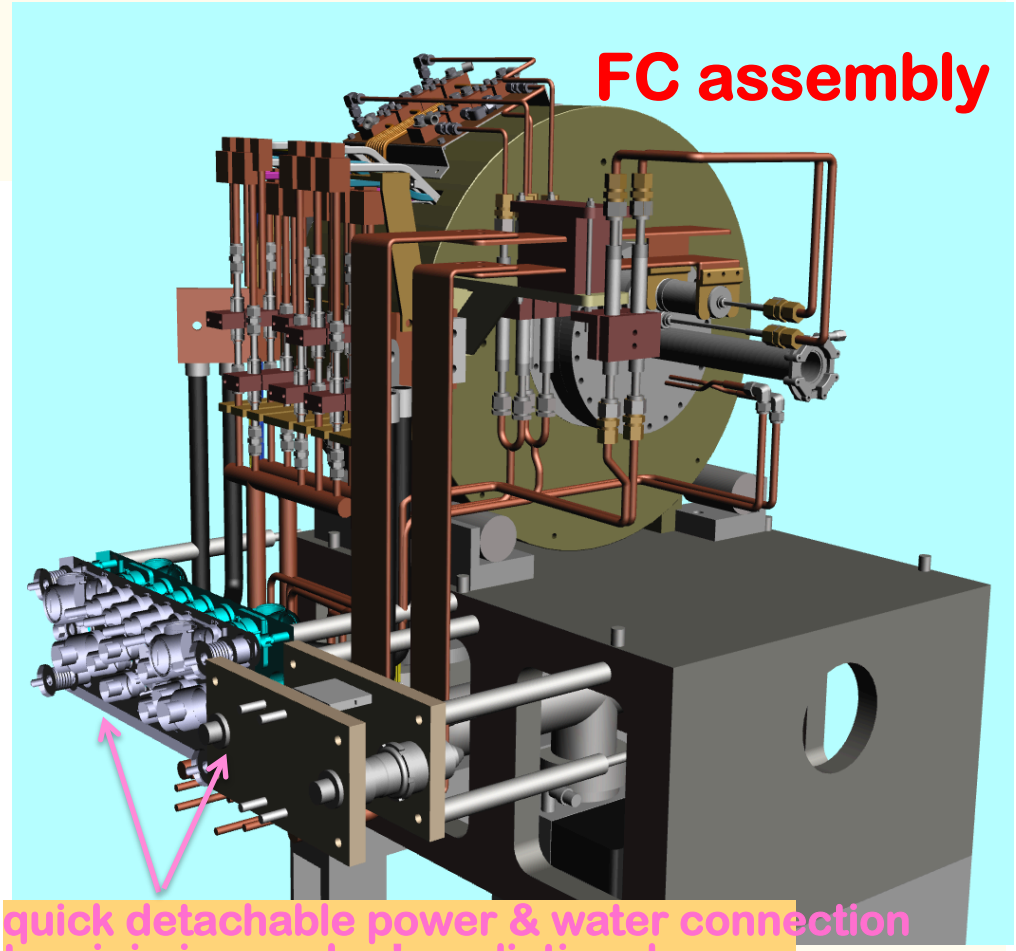


- primary e- 3.2 GeV, 10 nC x 2 bunch, 50 Hz
- tungsten target
- AMD system (5.0 T x 200mm Flux Concentrator + 0.4 T x 15m DC solenoids)
- KLY1 2m LAS x 2 (14 MV/m), aperture 2a = 32 -> 30 mm (typical S-band ~20 mm)
- KLY2 2m LAS x 4 (10 MV/m), aperture 2a = 32 -> 30 mm Deceleration capture
- e+ beam energy at capture section exit : 110 MeV

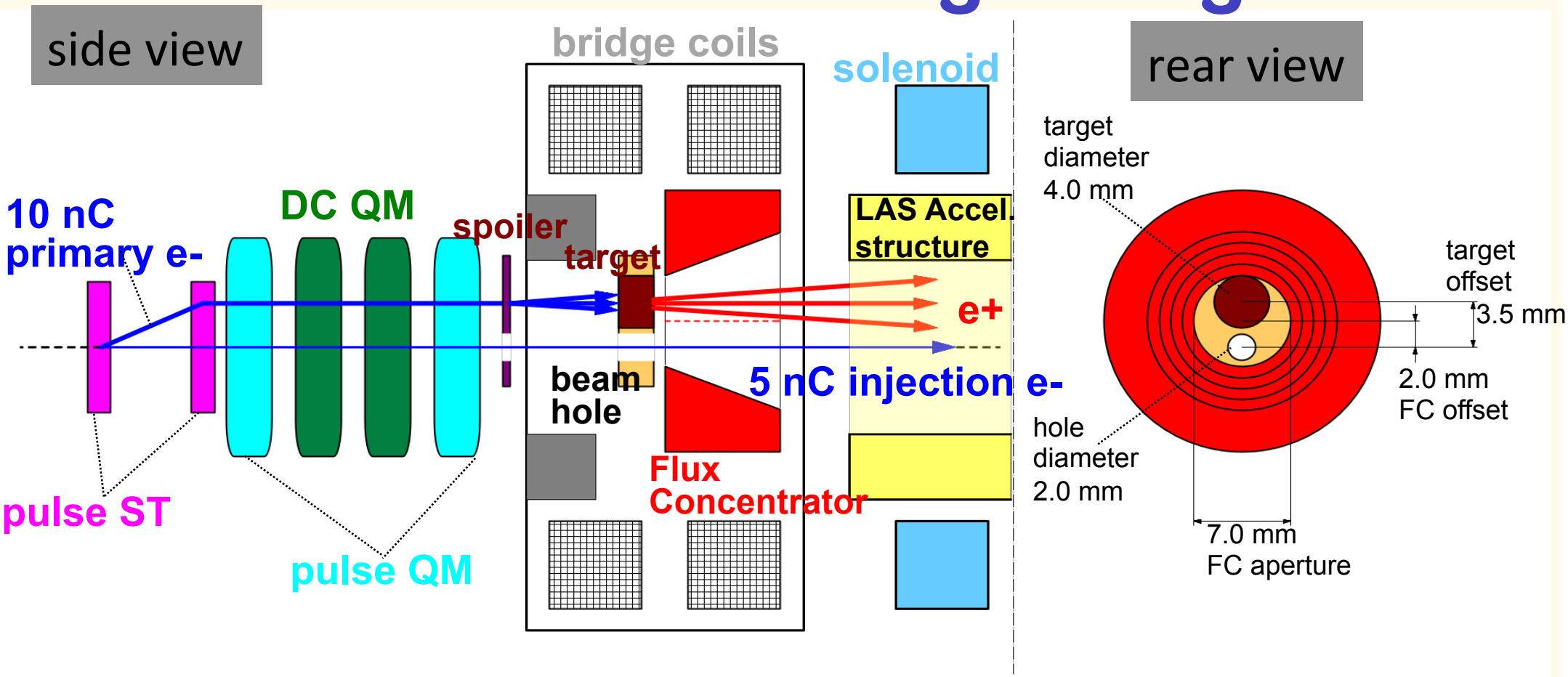
e+ yield: N(e+)/N(e-) = 49 % at 1.1 GeV DR

Flux Concentrator Assembly





e+/e- beam switching at target



Two possible schemes of beam switching by orbit bump

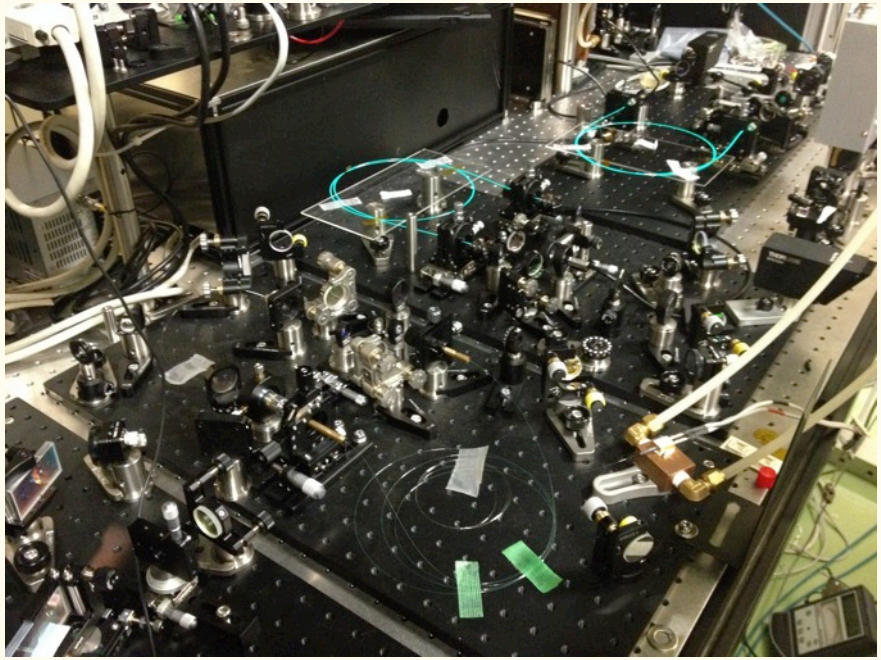
1) **e+ on-axis, e- offset**
   -> e- **emittance growth** by solenoid kick induced orbit
2) **e- on-axis, e+ offset**
   -> e+ **yield degradation** (50% -> 10%)

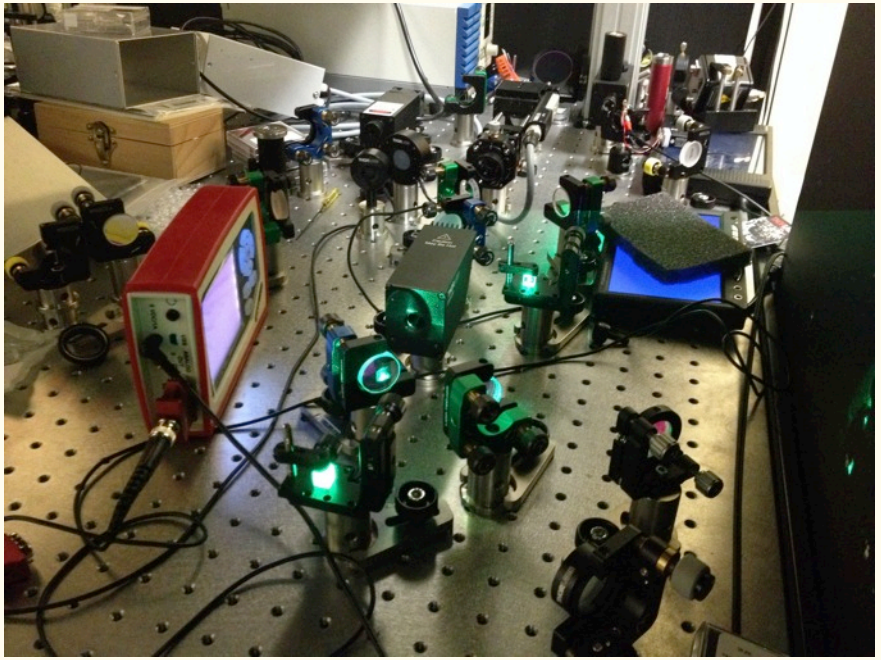
we take this scheme.

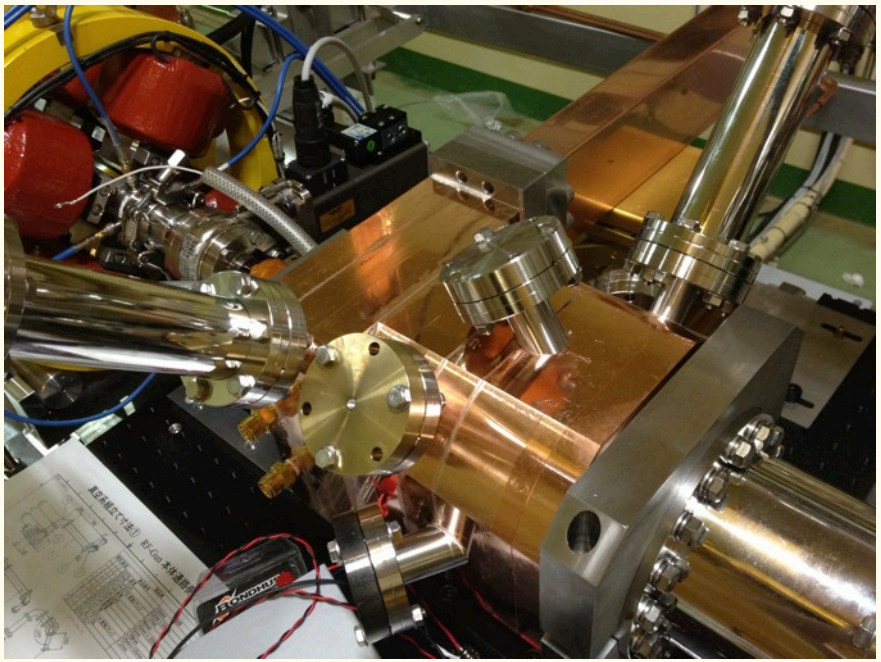
T.Kamitani

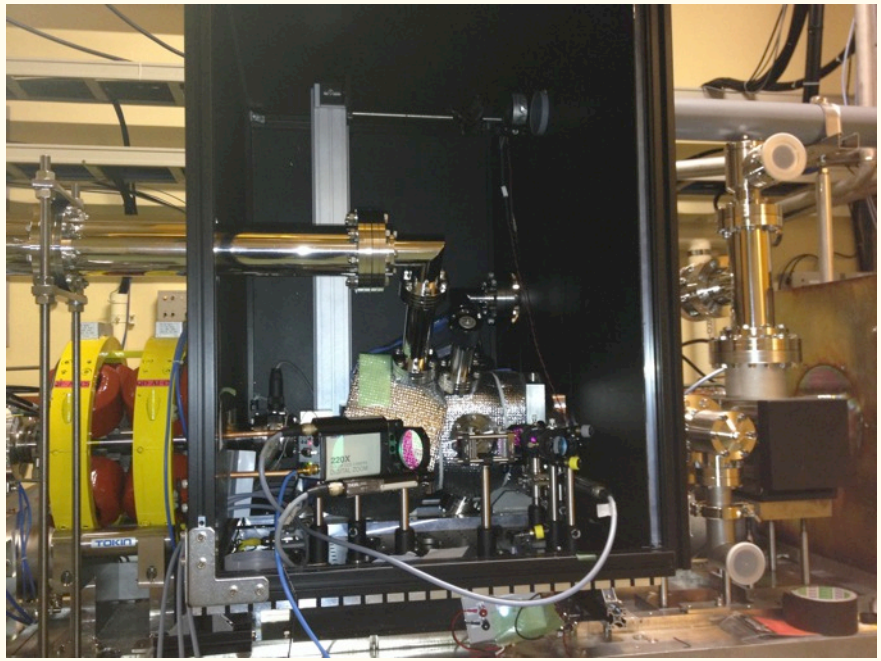
Photo-cathode RF-gun Development

- **A1 RF-gun (GR_A1) under test**
  - Big progresses are quasi-traveling wave side-coupled cavity, Ir5Ce photo-cathode, Yb fiber laser
  - Longitudinal laser pulse manipulation is necessary for energy-spread and stability management
  - Should understand those many new components for real stable operation
  - 5-nC per bunch was re-confirmed with new configuration
  - 600-m transport was confirmed (with small charge)

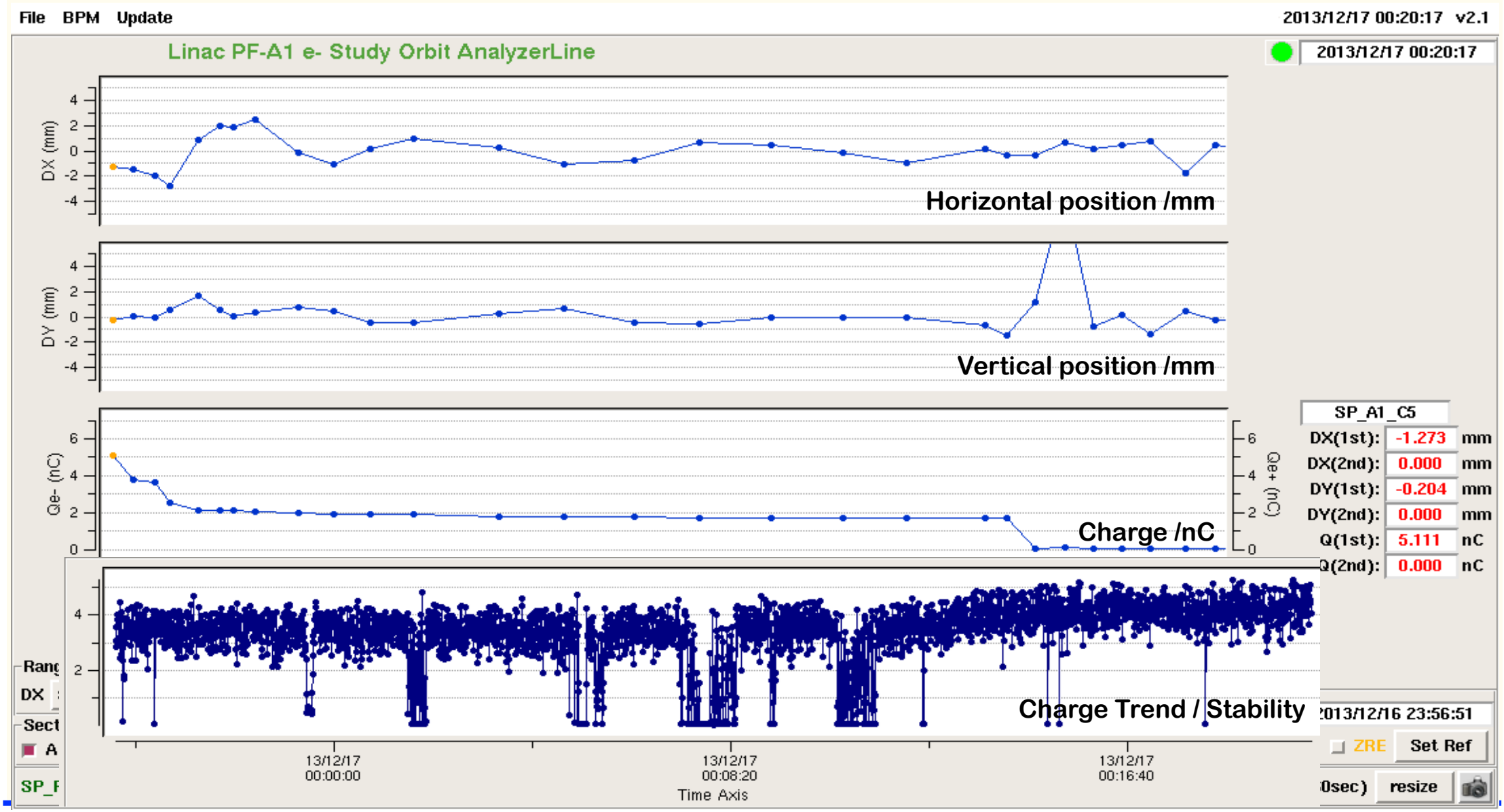




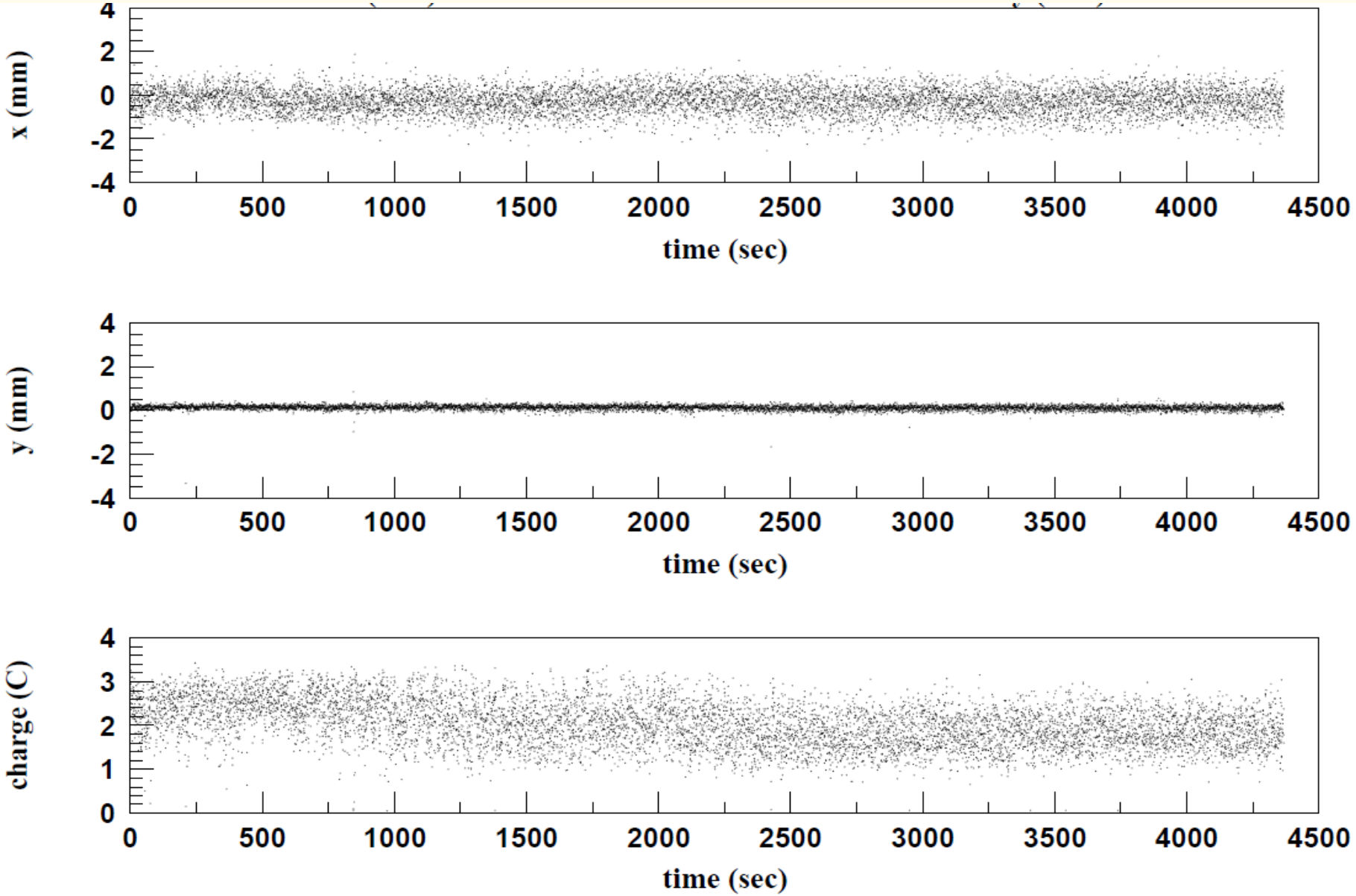




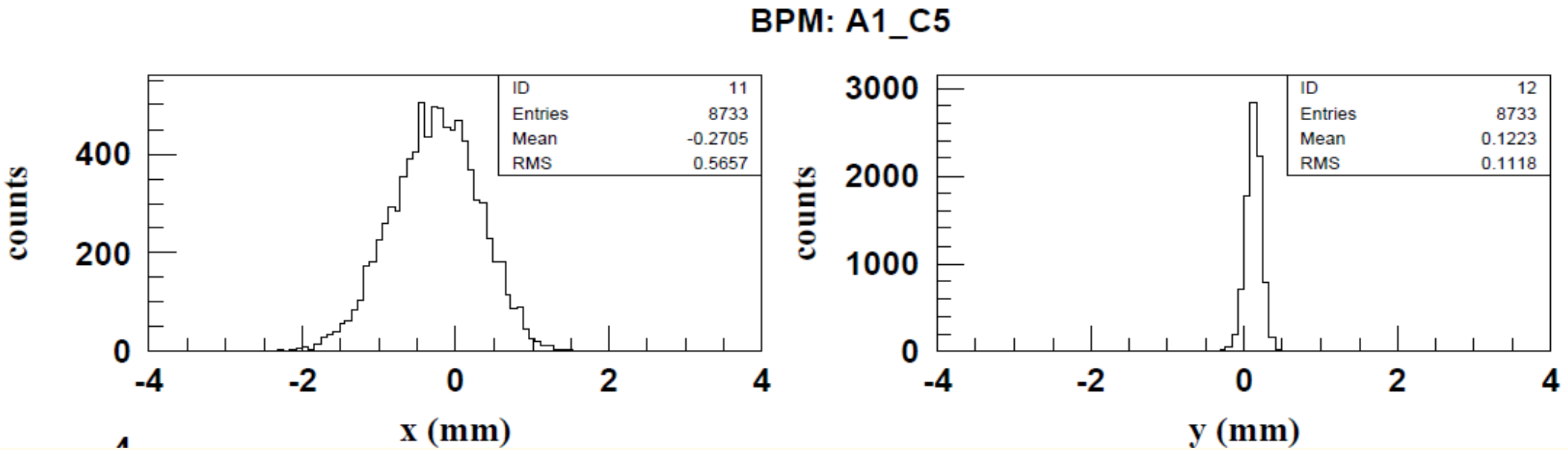
GR_A1 : 5.1 nC / bunch



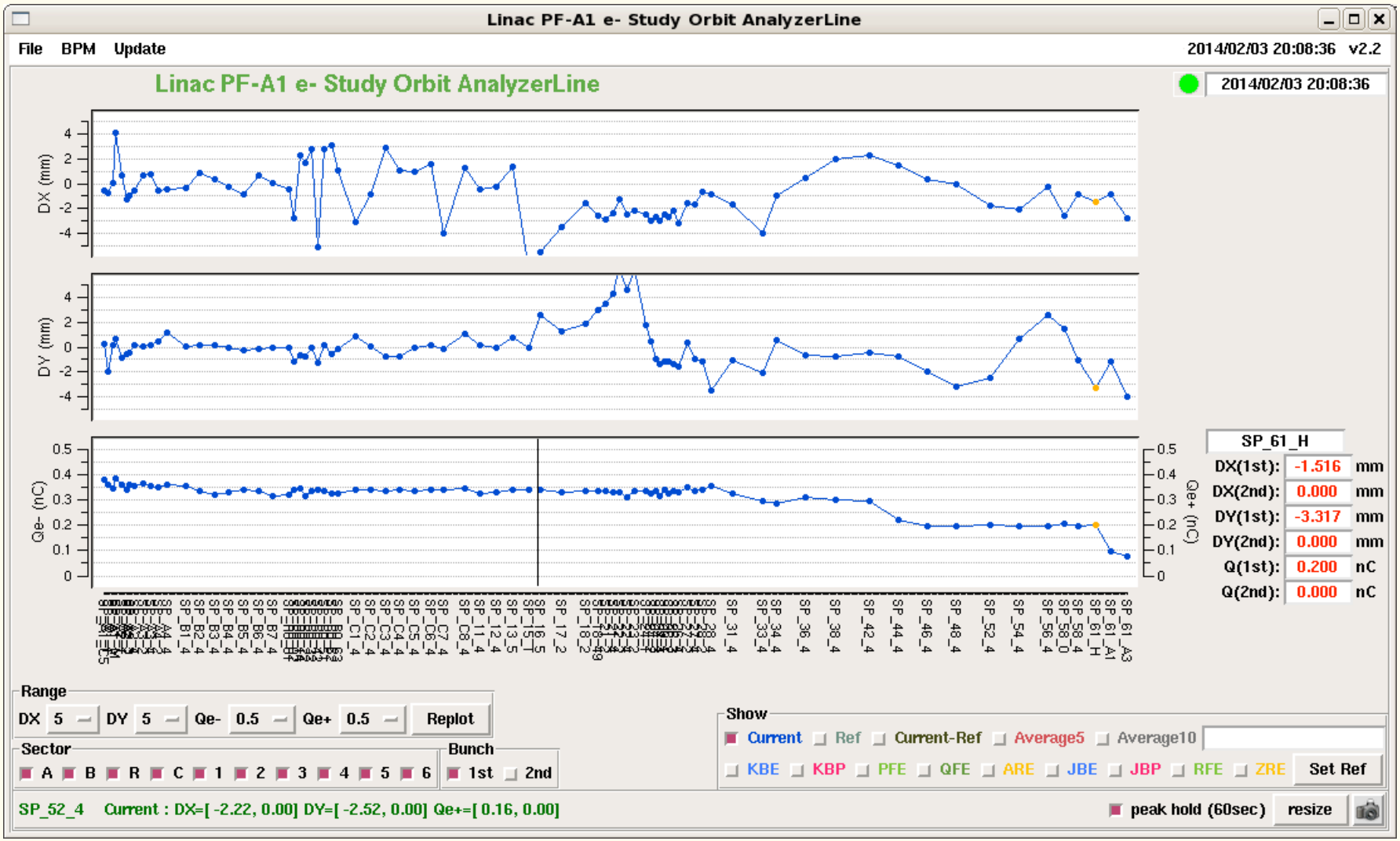
Beam Trend / Stability



Horizontal / Vertical stability

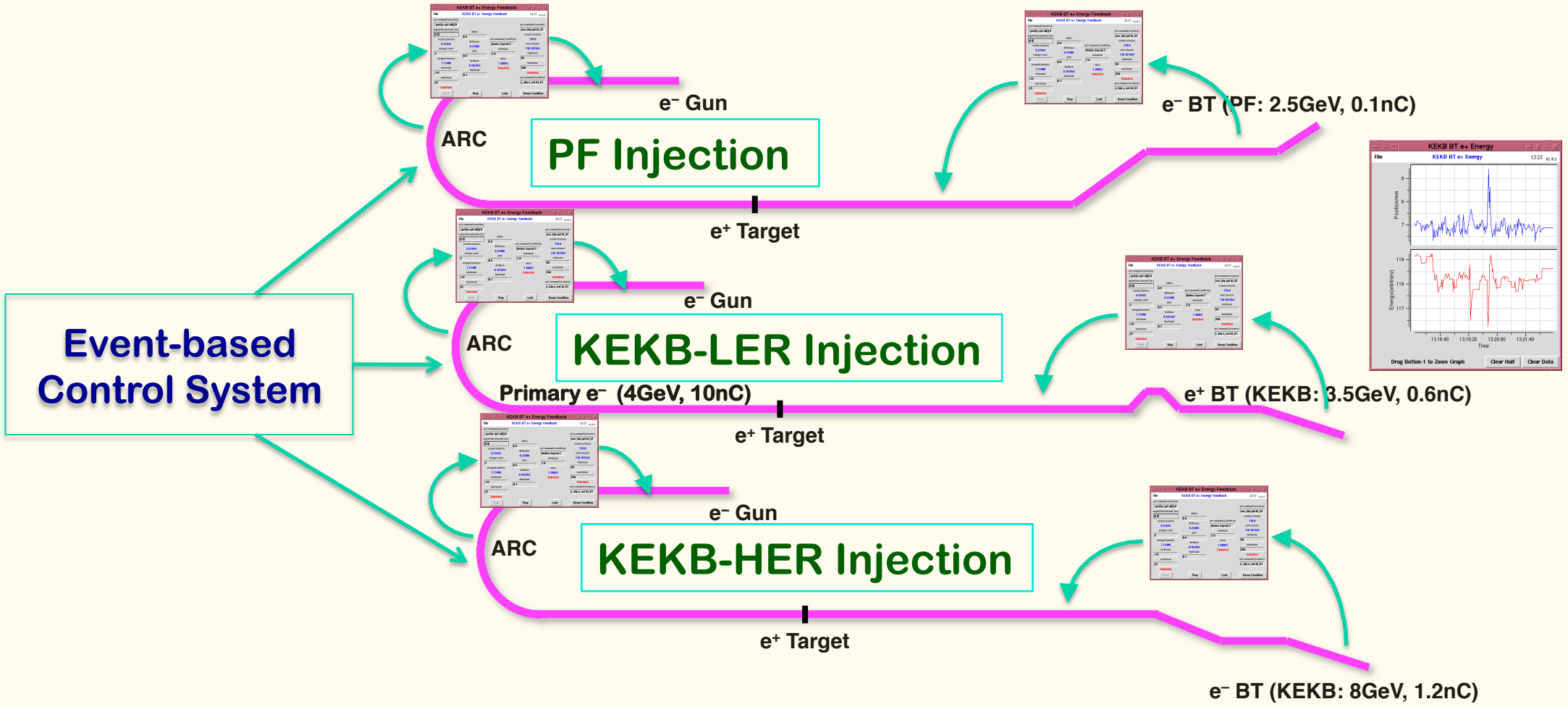


◆600m beam transport from RF-gun with QTWSC



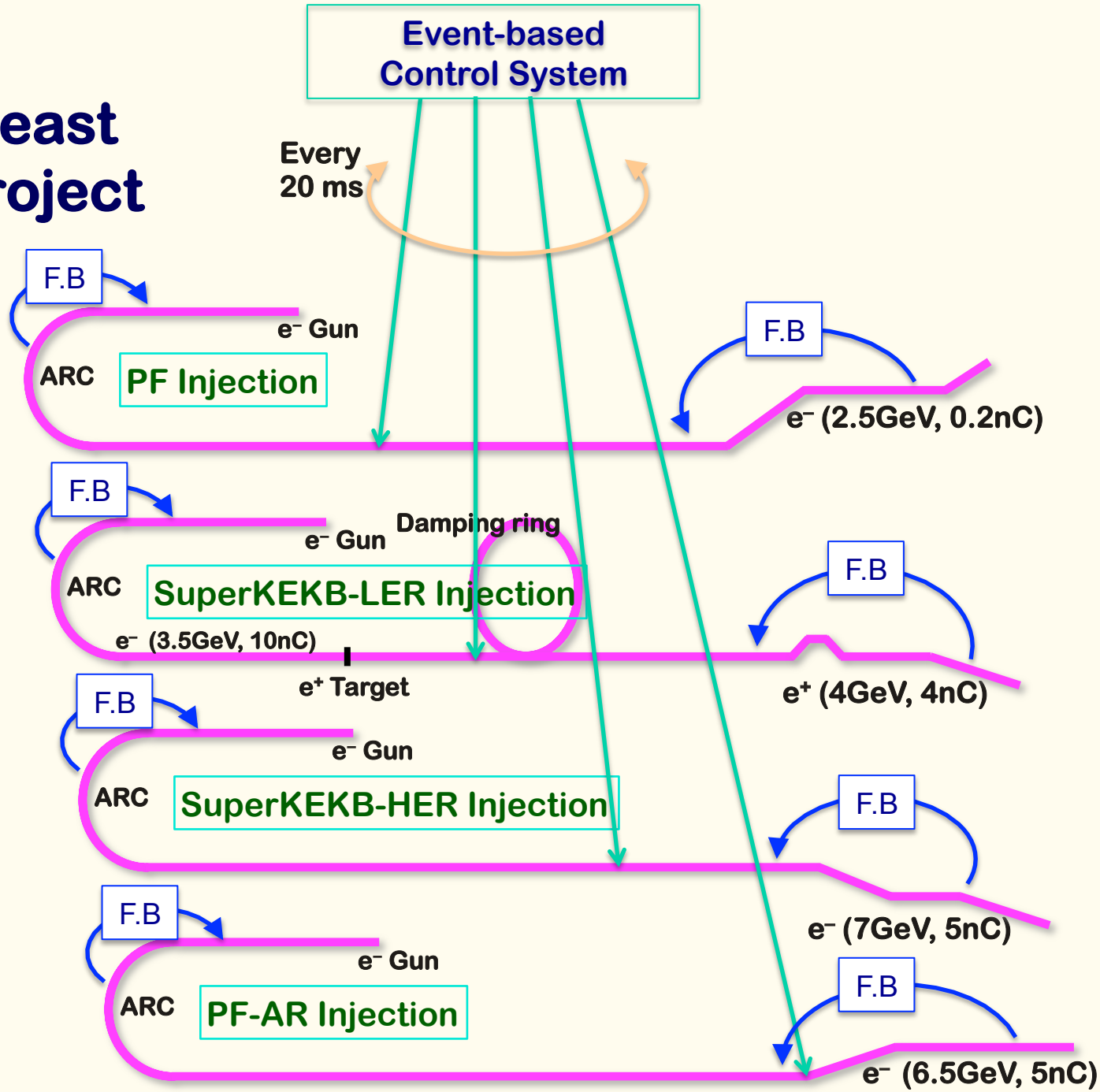
Virtual Accelerator-based Controls

- **Multiple closed loops were installed on each PPM VA independently**
  - **Tested at KEKB**



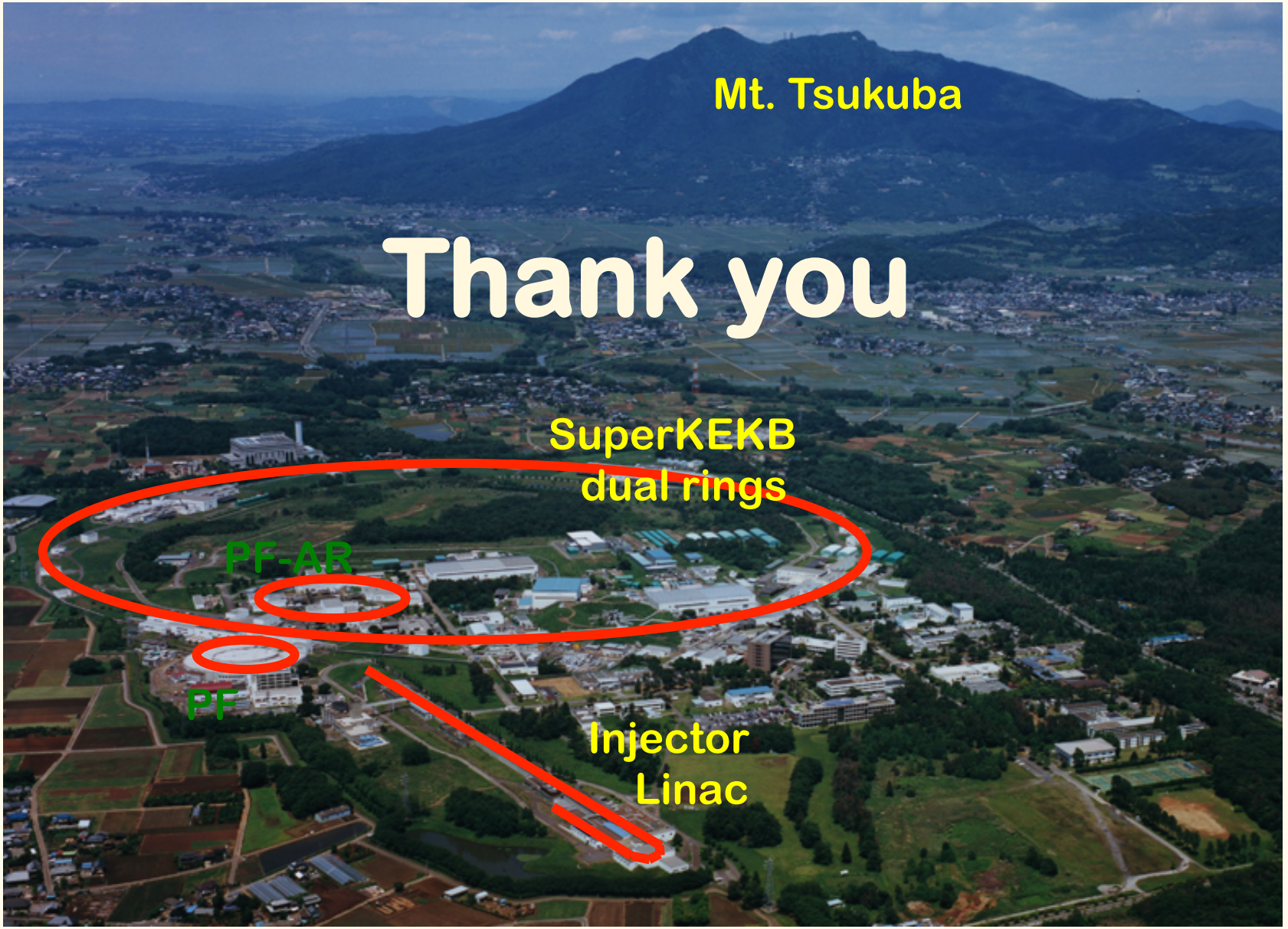
- **Four PPM VAs at least for SuperKEKB project**

  (maybe with additional PPM VA for stealth beam)



Summary

- Steady progress towards first MR injection in 2015
- Will make staged improvements before 2017
- Will finish disaster recovery in 2014
- Will balance between final beam quality and stable and staged operation
- Will select optimized route depending on available resources


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