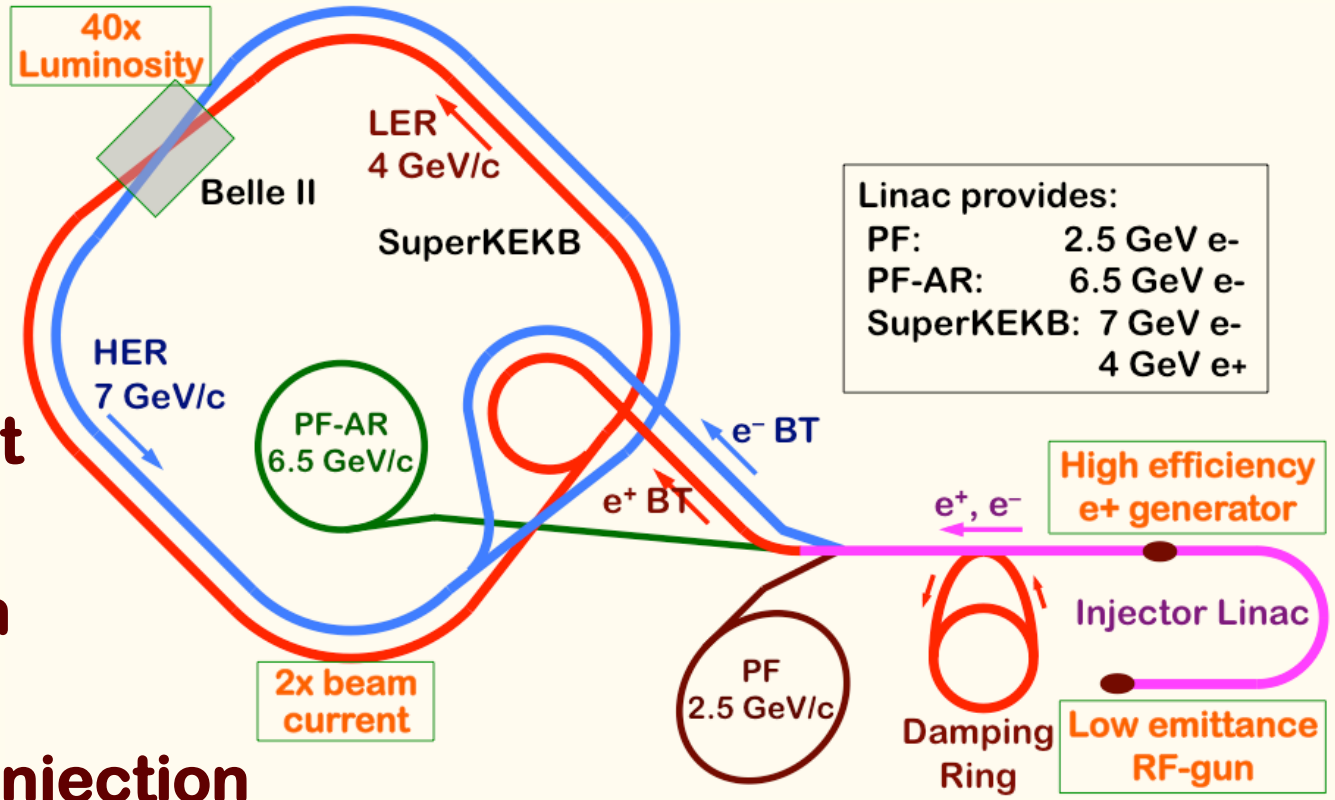
Progress of Injector Linac

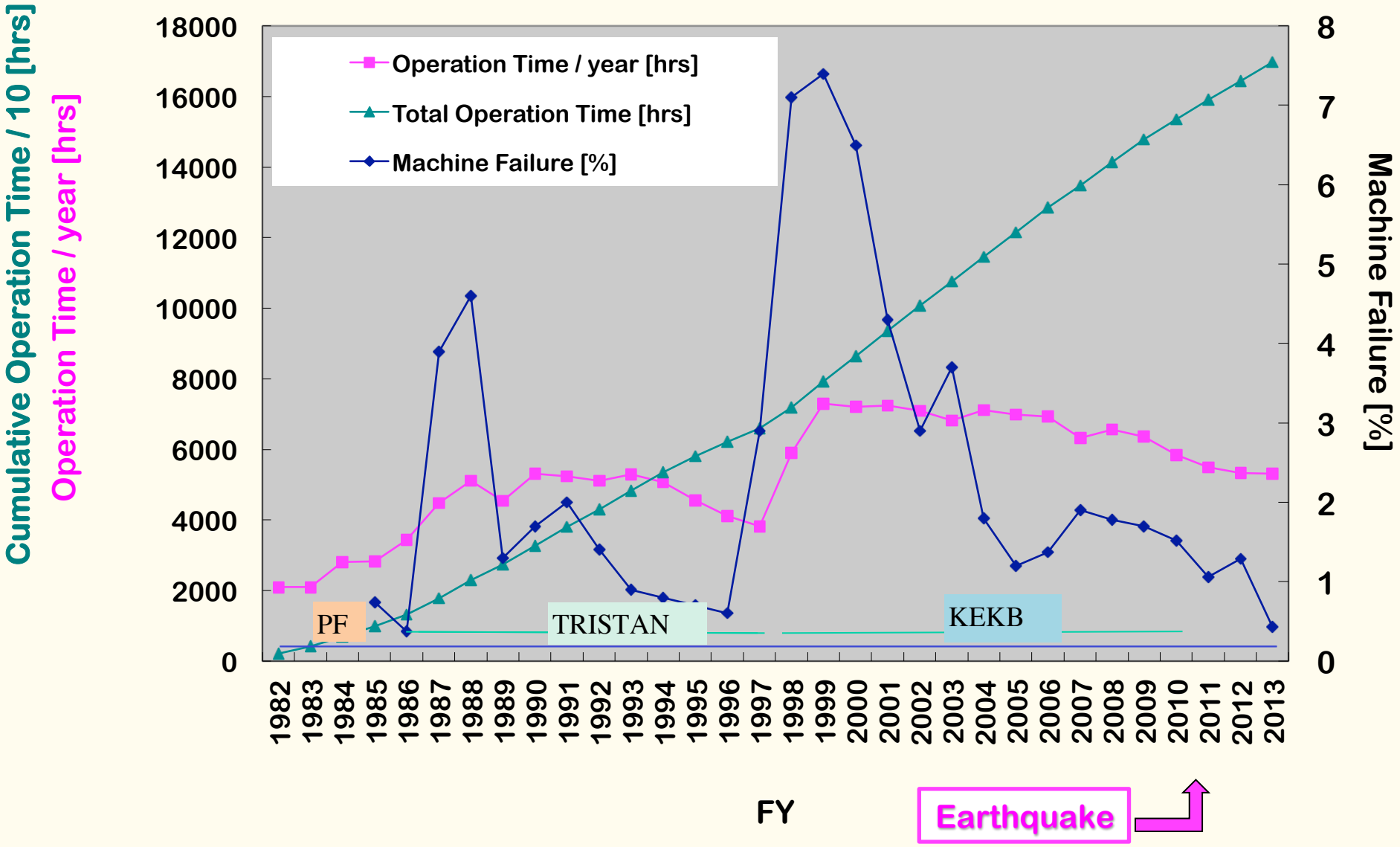
Kazuro Furukawa
for Injector Linac

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



Injector Linac Operational History



Operation Statistics

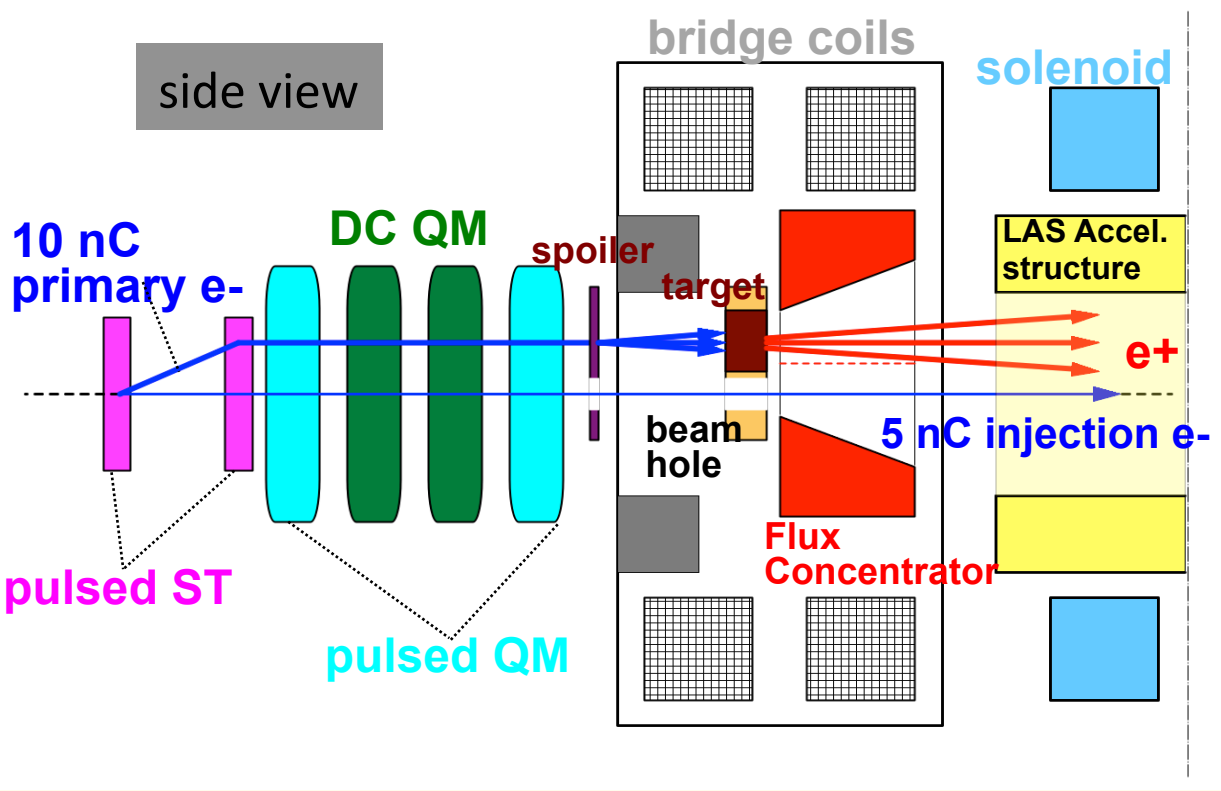
FY2013 Statistics

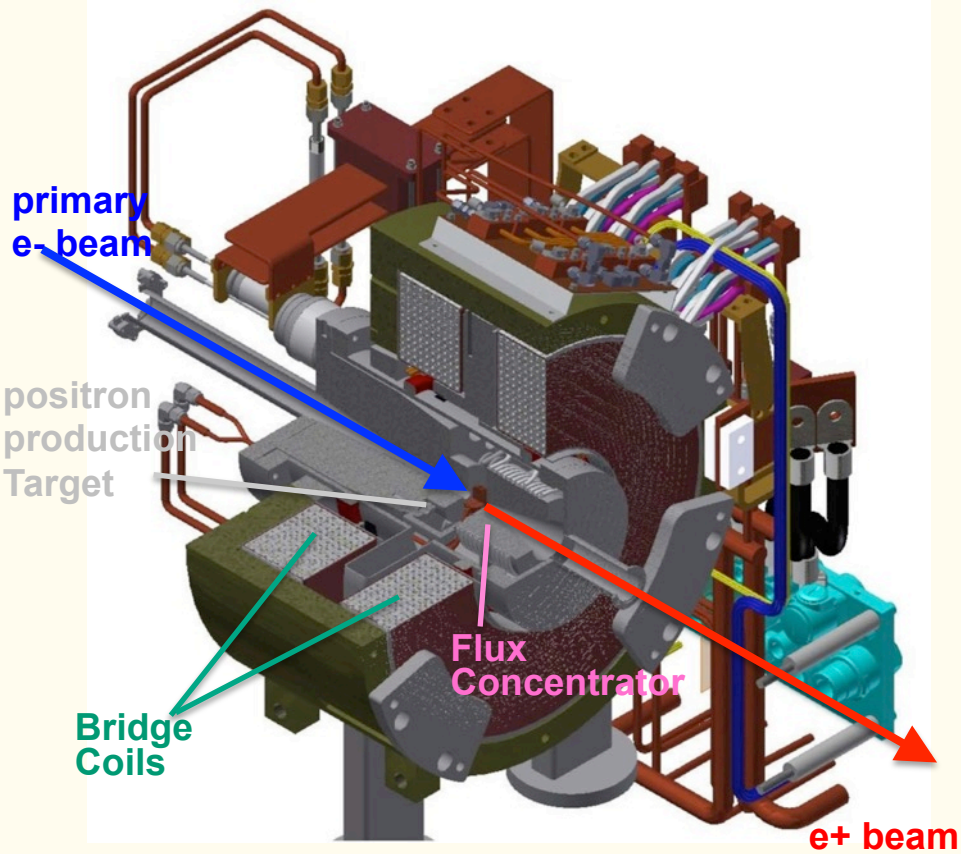
- Operation time: 5315 hours (FY2012 -0.3%)
  - PF/PF-AR Injection and Commissioning for SuperKEKB
- Failure rate: 0.43% (FY2012 -0.87 point)
  - Failures include stand-by devices
  - Not all of failures affected the injections
- Failure rate was the best in these 20 years
  - Earthquake recovery goes well
  - Old devices do not reach their lifetimes yet
  - Commissioning for SuperKEKB is performed deliberately

Positron Generation

- **4-times more positron is required at SuperKEKB than KEKB**
  - **Safety measure was taken after cable fire during the test of Flux Concentrator (FC)**
  - **New components in 100-m capture section were tested in steps**
  - **High voltage tests in tunnel in April**
  - **Beam tests with electron in May**

Positron generation for SuperKEKB

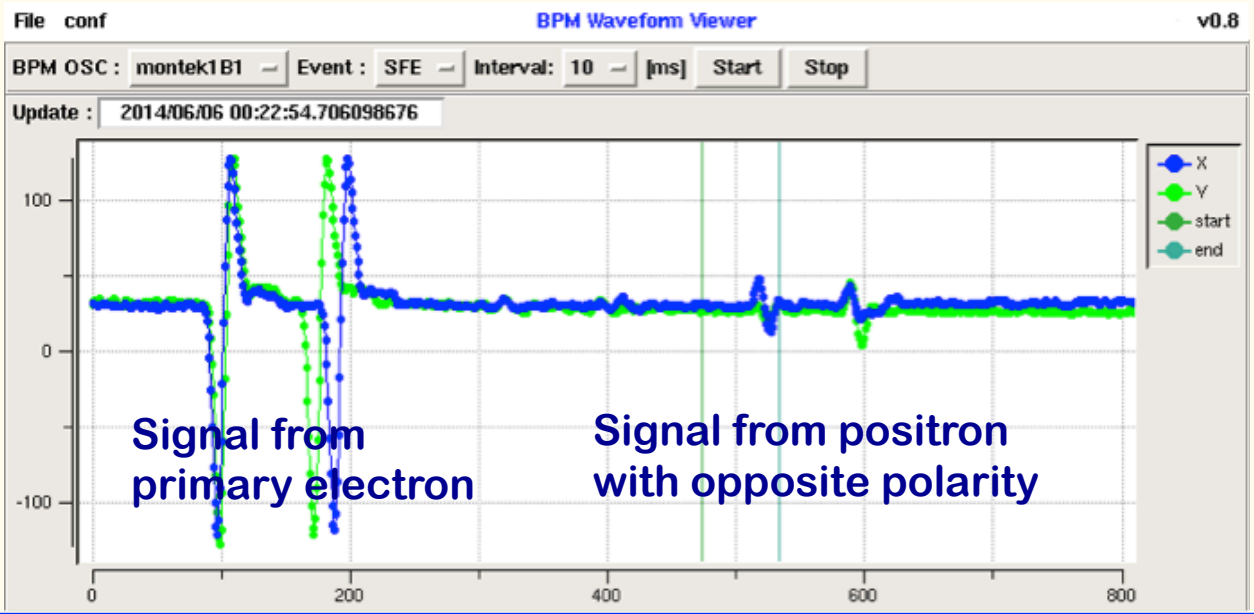




New positron capture section after target with
Flux concentrator (FC) and large-aperture S-band structure (LAS)
Satellite bunch (beam loss) elimination with velocity bunching
Pinhole (2mm) for electrons beside target (3.5mm)
Beam spoiler for target protection

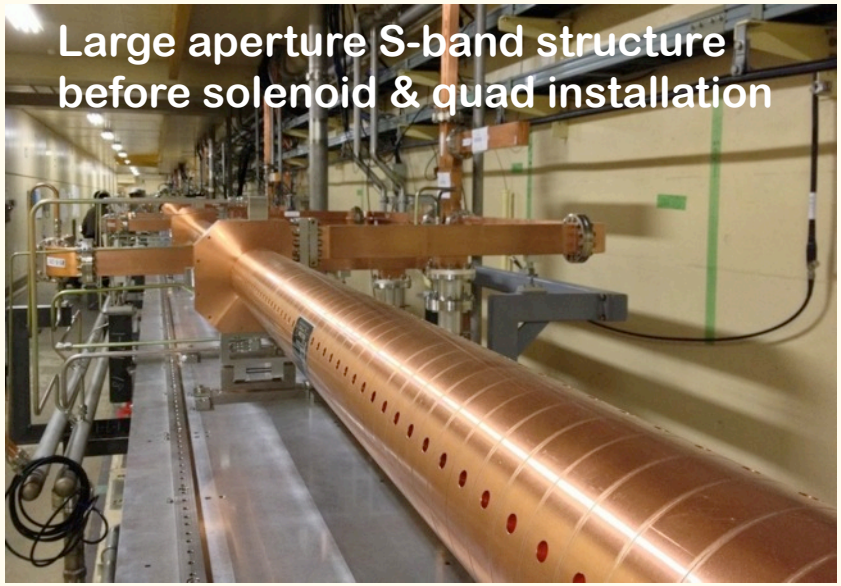
First Positron Observation from New Generator

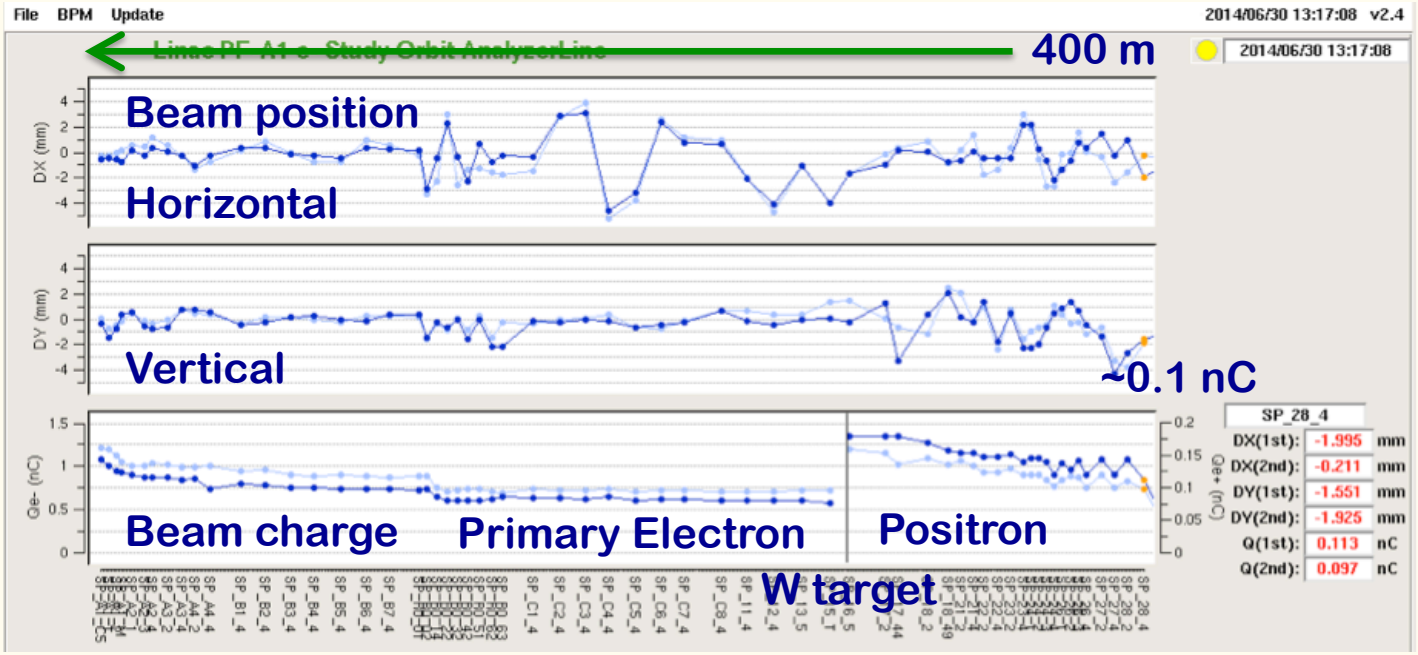
- Devices and primary electron beam studied
- First positron signal confirmed on Jun.5
- Positrons transferred to the beam dump on Jun.6
- Consistent with simulation designs
- Expect design achievement after full constructions



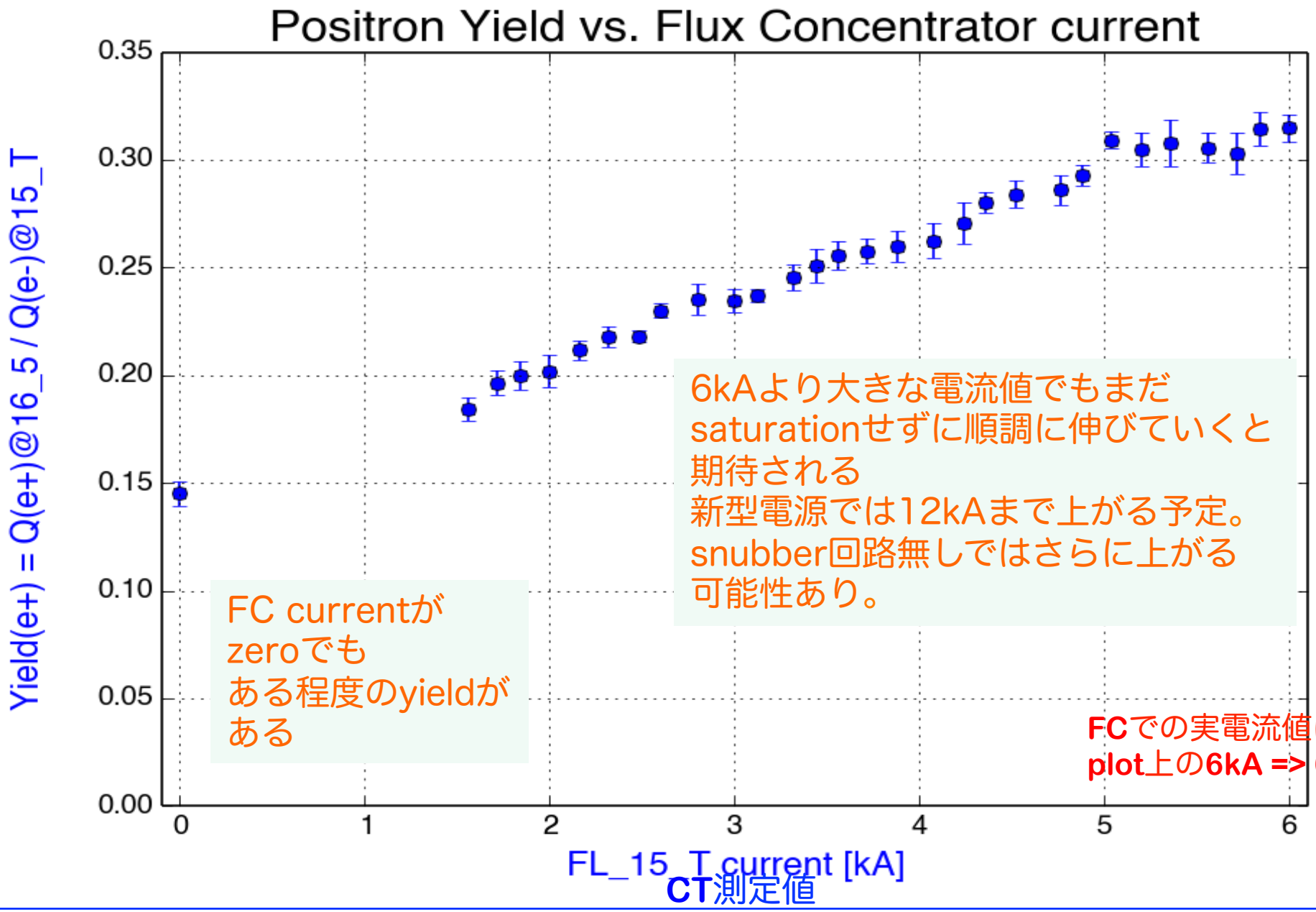
Positron from New Positron Capture Section

- Generated positron ~0.1nC was transferred to the entrance of damping ring
- With higher magnetic and electric field, 4-nC positron will be generated
- Target shield (40cm x 6m long) will be finalized
- Alignment will be improved 3mm → 0.1mm

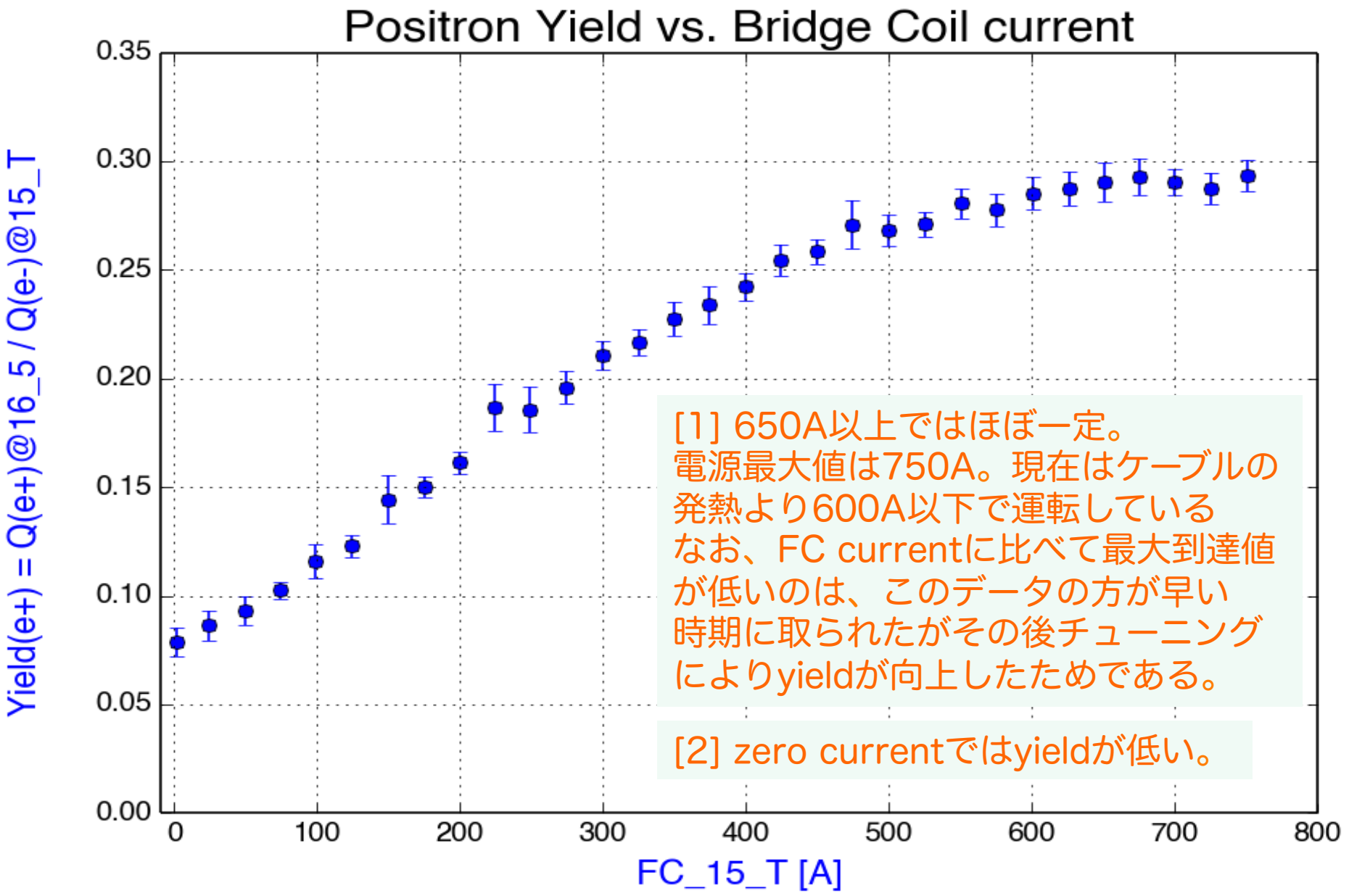




(1) FC current


Positron Yield vs. Flux Concentrator current
Yield(e+) = Q(e+)@16_5 / Q(e-)@15_T
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
FL_15_T current [kA]
CT測定値
6kAより大きな電流値でもまだ
saturationせずに順調に伸びていくと
期待される
新型電源では12kAまで上がる予定。
snubber回路無しではさらに上がる
可能性あり。
FC currentが
zeroでも
ある程度のyieldが
ある
FCでの実電流値は1.07倍
plot上の6kA => 6.42 kA

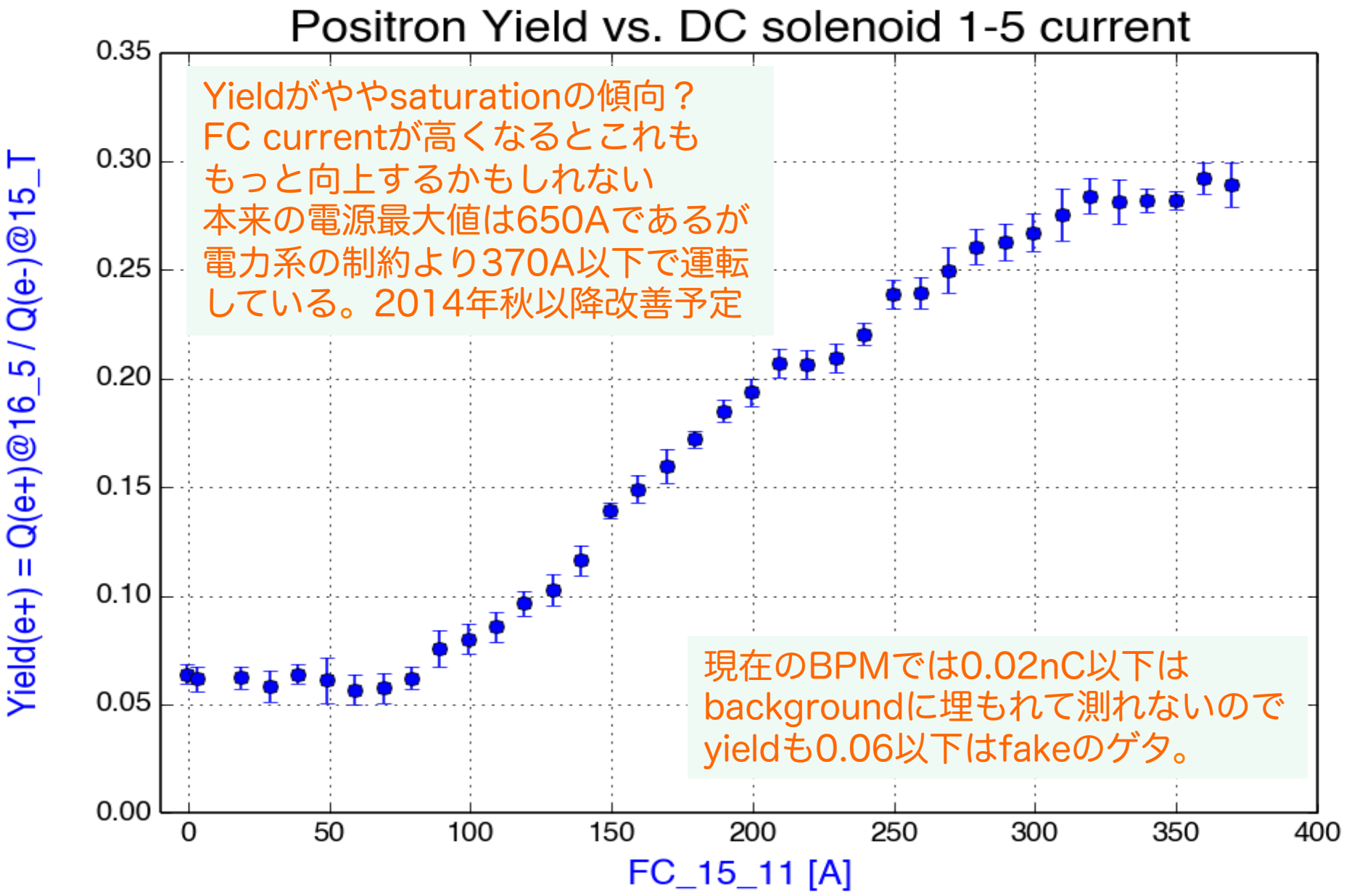
(2) Bridge Coil current



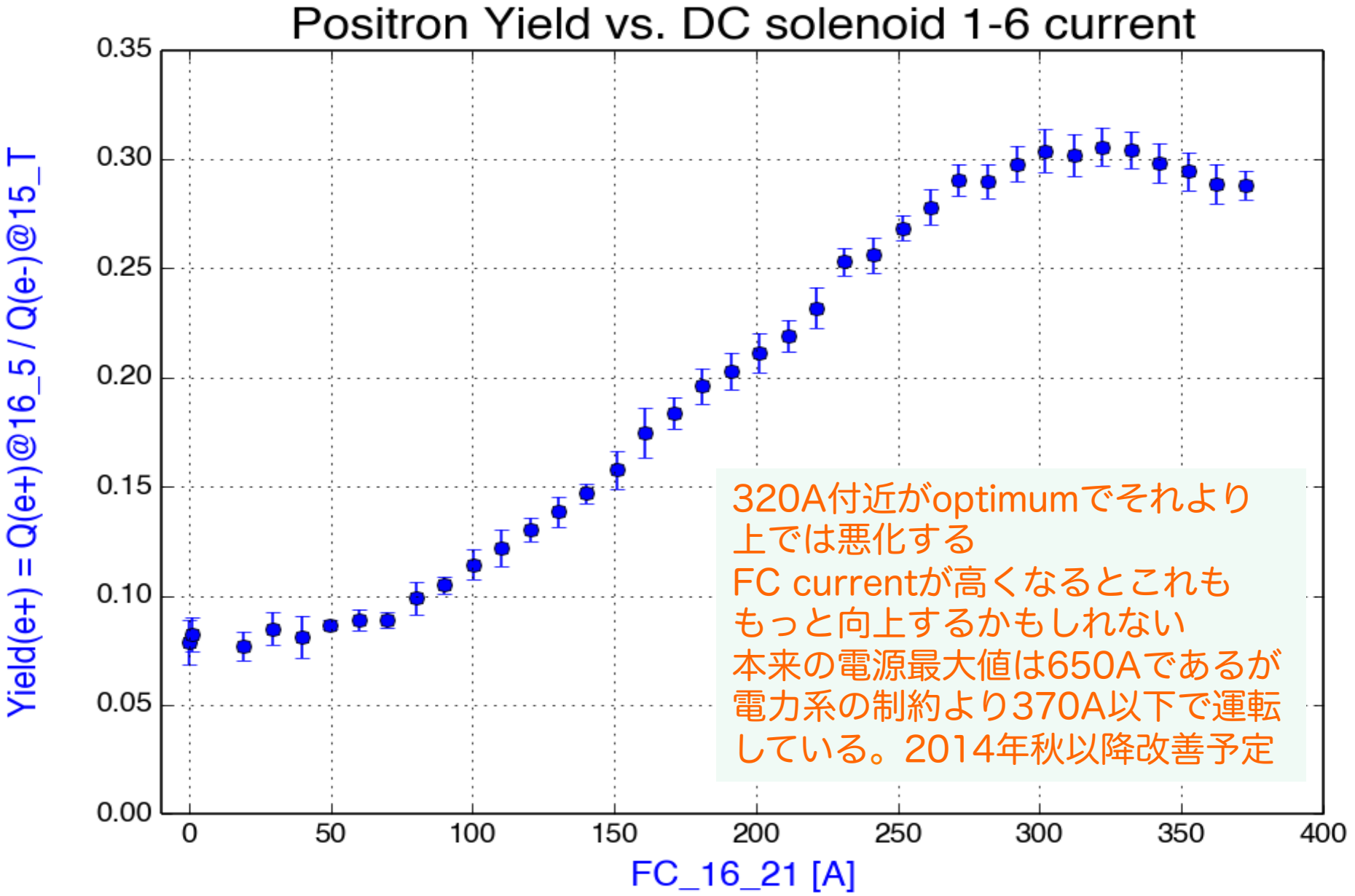
[1] 650A以上ではほぼ一定。
電源最大値は750A。現在はケーブルの発熱より600A以下で運転している
なお、FC currentに比べて最大到達値が低いのは、このデータの方が早い時期に取られたがその後チューニングによりyieldが向上したためである。

[2] zero currentではyieldが低い。

(3) DC solenoid 1-5 current



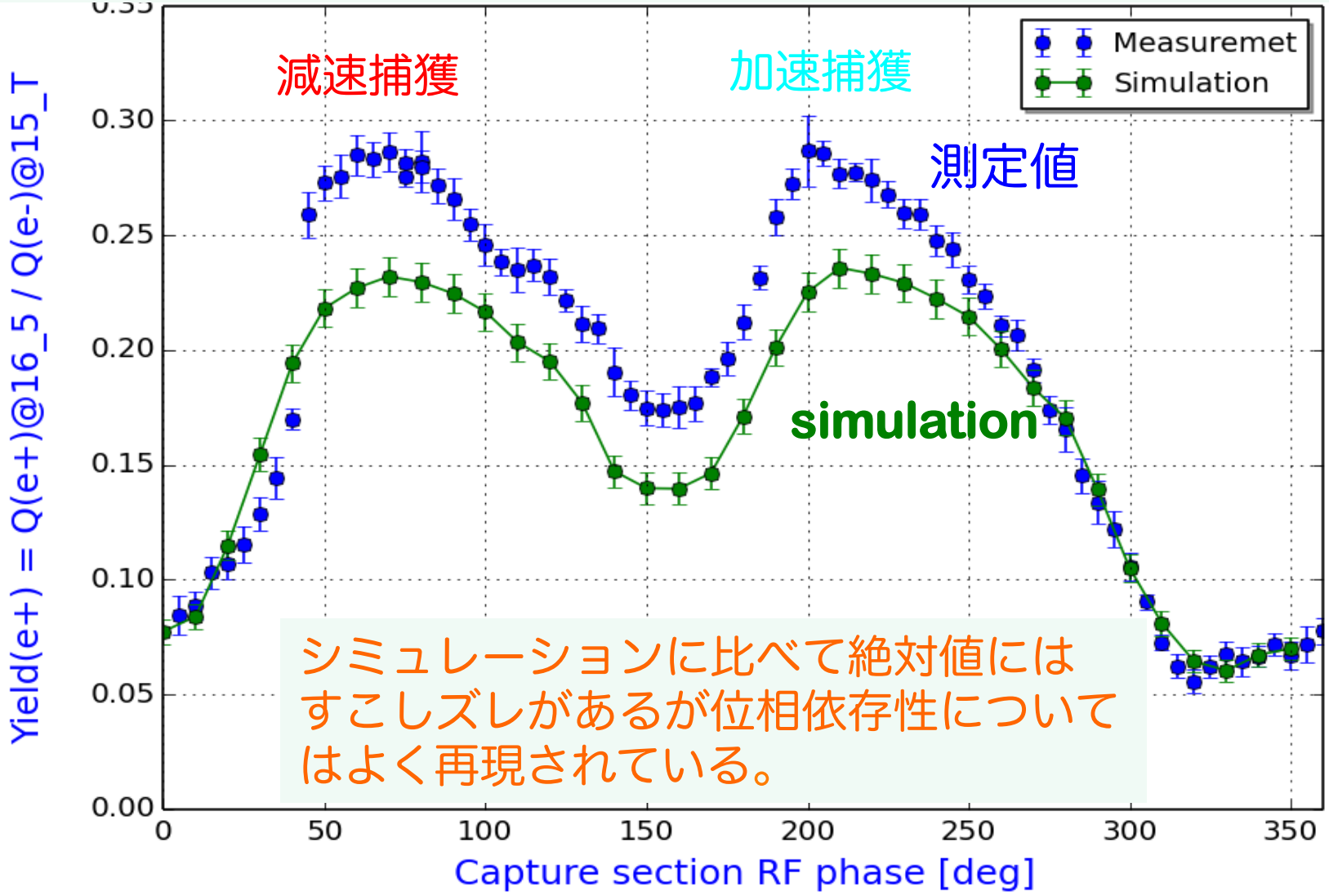
(4) DC solenoid 1-6 current



320A付近がoptimumでそれより上では悪化する
FC currentが高くなるとこれももっと向上するかもしれない
本来の電源最大値は650Aであるが電力系の制約より370A以下で運転している。2014年秋以降改善予定

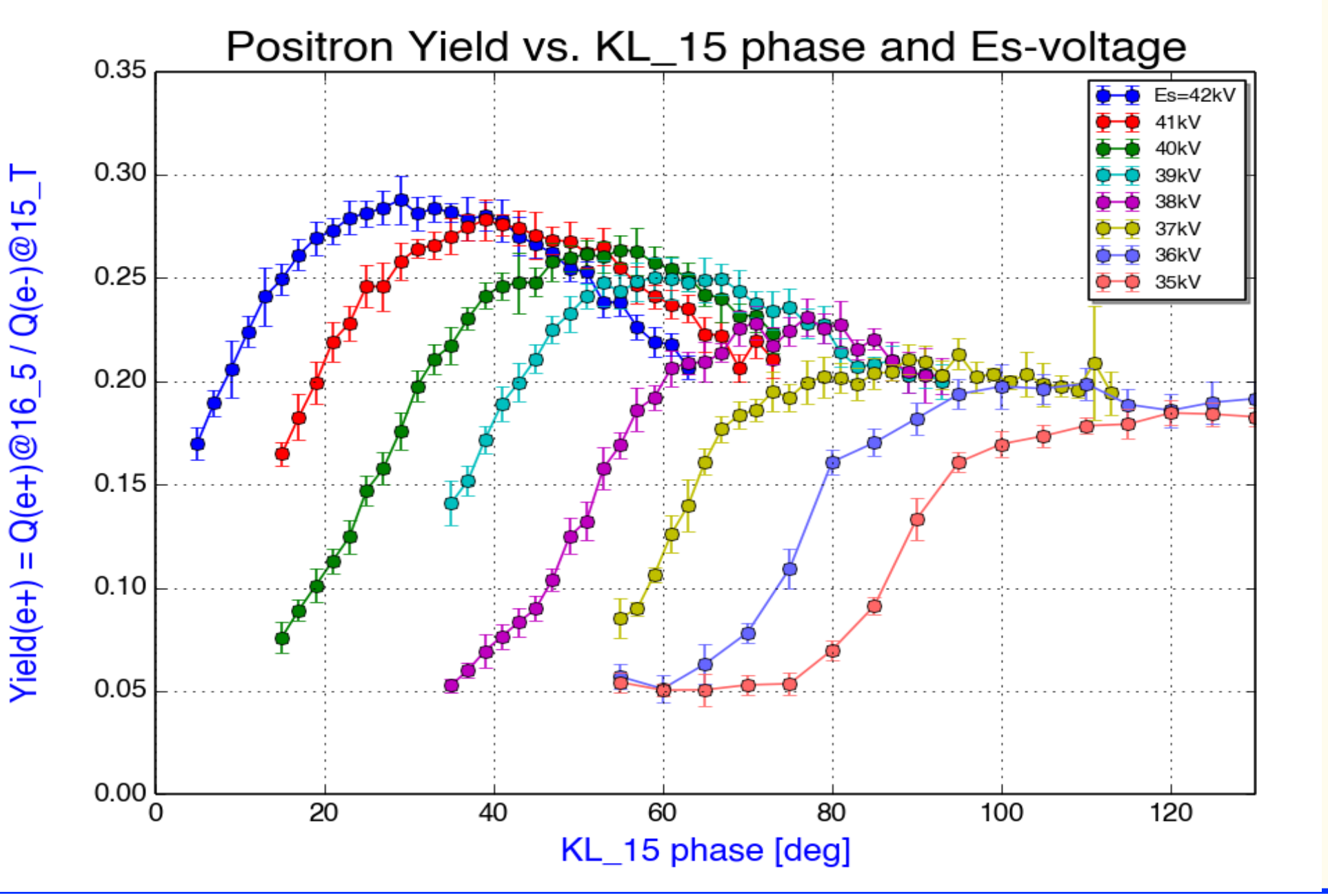
(5) e+ RF phase [1-5と1-6の位相関係は固定]

FCの広いアクセプタンスのおかげで減速捕獲でもほぼ同じ収量が得られる。
減速捕獲の方が陽電子のバンチ長、エネルギー広がりが小さい。

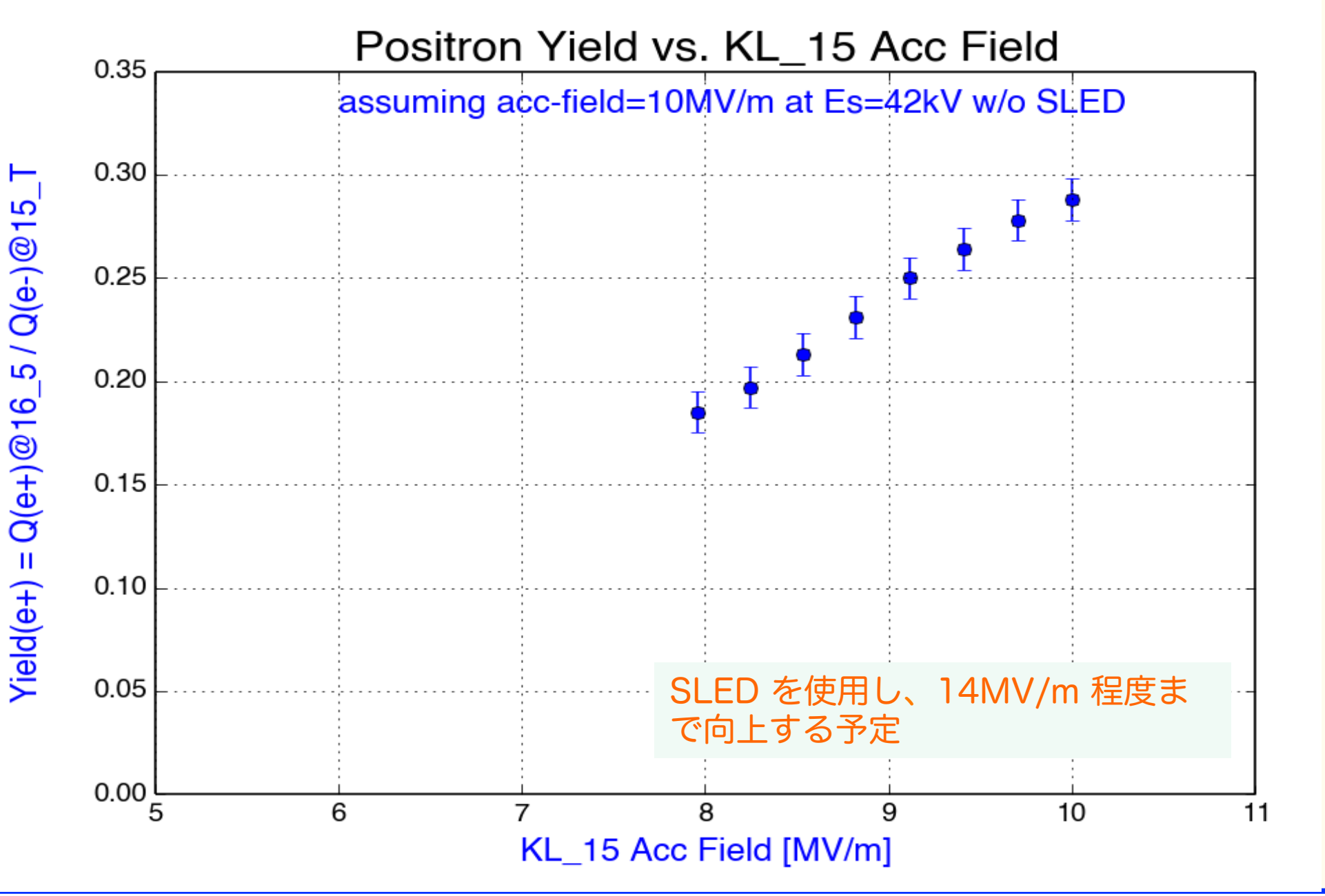


(6) Acc-field grad./phase at 1-5

T.Kamitani



(6-2) Acc-field grad. [MV/m] at 1-5



Positron Generation

1) **Installation of positron generator for SuperKEKB in April 2014**
   (Beamline construction since summer 2013)
   (positron target, spoiler, Flux Concentrator, bridge coils, LAS structures [x6], DC solenoids [16+13], e+/e- separator, quads [>90])

2) **Commissioning of positron beam, observation of the first positron after reconstruction for SuperKEKB, further improvements expected**

	Primary e- [nC]	Positron [nC]	Efficiency	Parameters
June 2014	0.6	0.12	20%	FC 6.4kA, Solenoids 370A, LAS capture field 10 MV/m
	x17	x42	x2.5	
Specification (at SY2)	10.0	5.0	50%	FC 12kA, Solenoids 650A, LAS capture field 14 MV/m
DR injection (2016?)		4.0	40%	Energy spread acceptance 0.5%

3) Oct.~Dec.2014 : Linac commissioning
   Jan.~Mar.2015 : Construction
   Jul.~Sep.2015 : Construction
   Apr.~Jun. : Linac commissioning
   Oct. : LER injection

Facility for Electric Power and Cooling Water

- Linac needs electricity and cooling water extensions, especially for positron generator upgrade, that was planned in FY2012
- Separate building construction in FY2013 not to impact PF/PF-AR
- Facility extensions performed during summer 2014

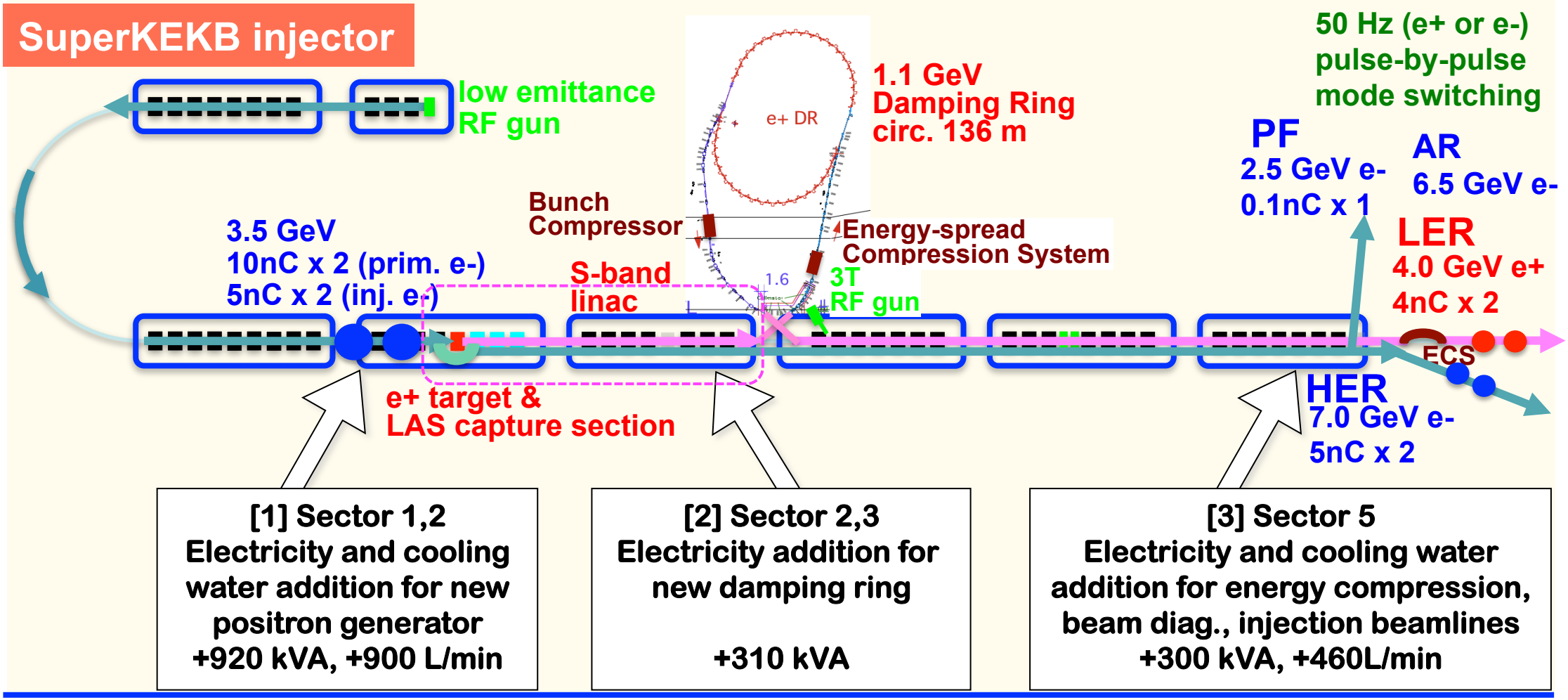
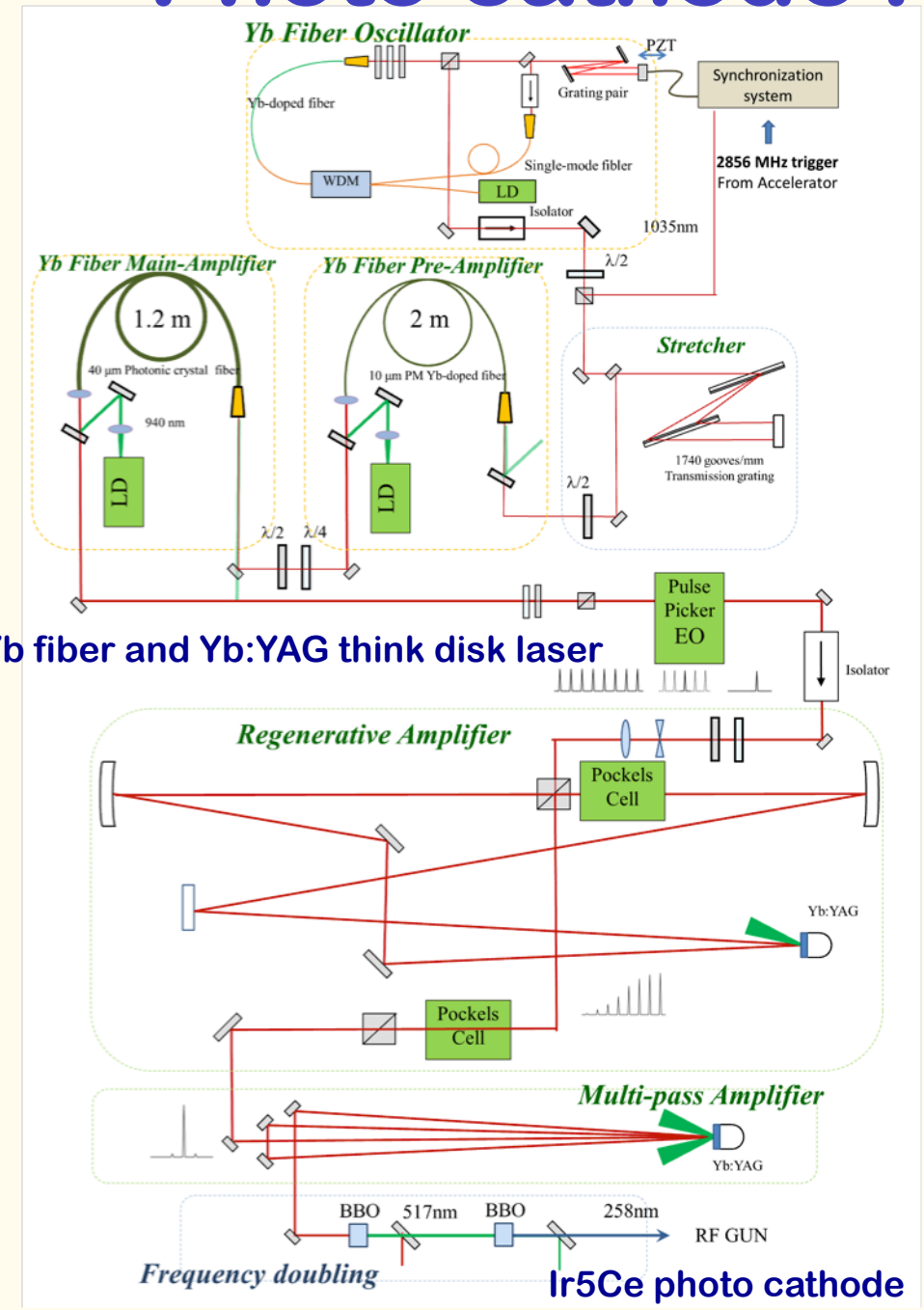
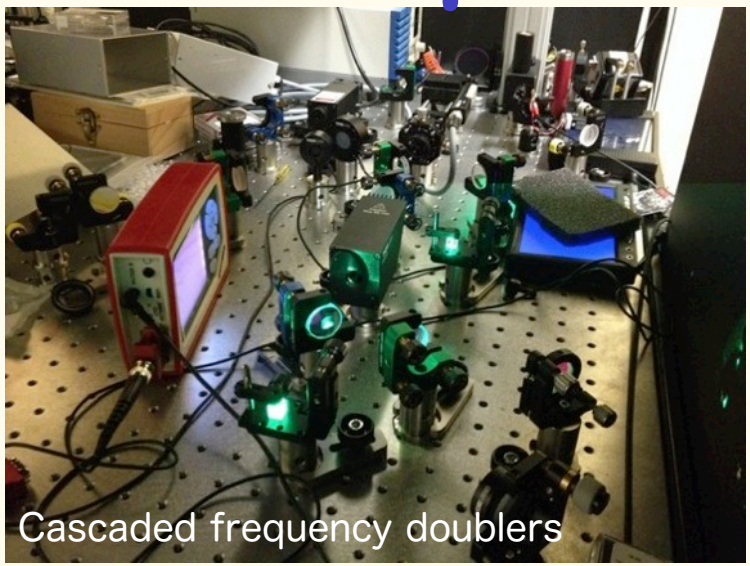


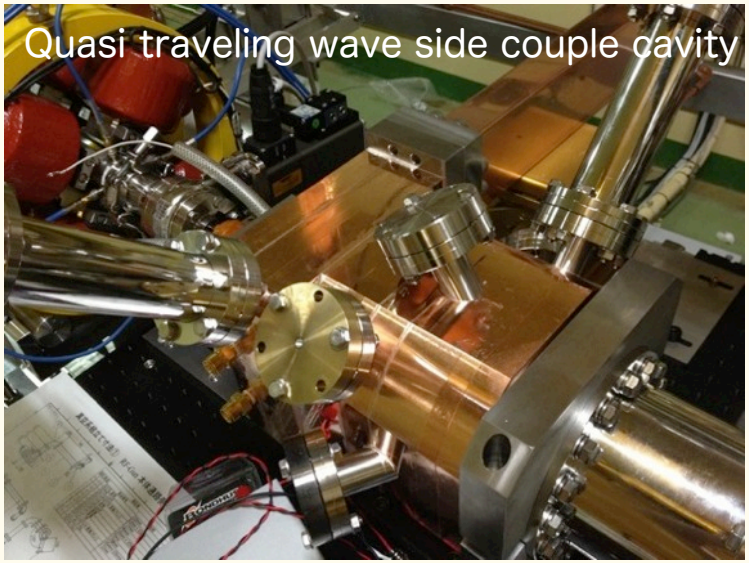
Photo cathode RF gun development

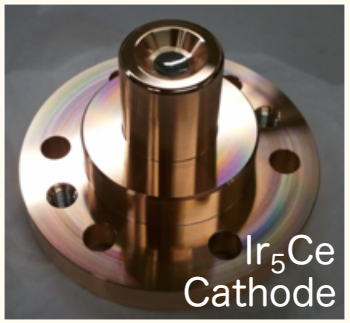


Yb fiber and Yb:YAG think disk laser

Ir5Ce photo cathode







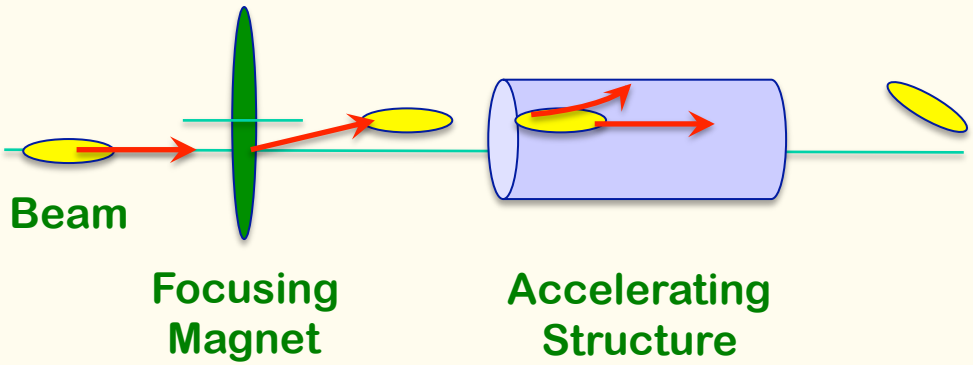
- 5.6 nC / bunch was confirmed
- Next step: 50-Hz beam generation & Radiation control

Photo cathode RF gun improvement

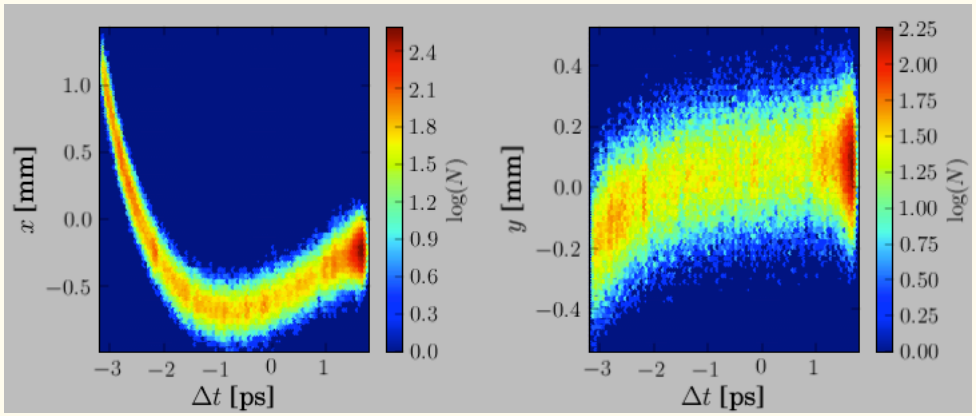
- Crucial for high-current low-emmittance beam
- New Ir5Ce cathode and new cavity QTWSC were successful
- Basic features were confirmed at 2 ~ 5 Hz
- Expect beam parameter and stability performance at 50 Hz
- Staged laser system improvements with beam measurements
- Regenerative amplifiers were replaced with multi-pass amplifiers for their heat to achieve 25 Hz then 50 Hz

Emittance Preservation and Alignment

- 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, even 100 times larger
    - Depending on the beam optics and the beam charge
- Alignment and orbit correction is crucial to preserve the emittance



Sugimoto et al.

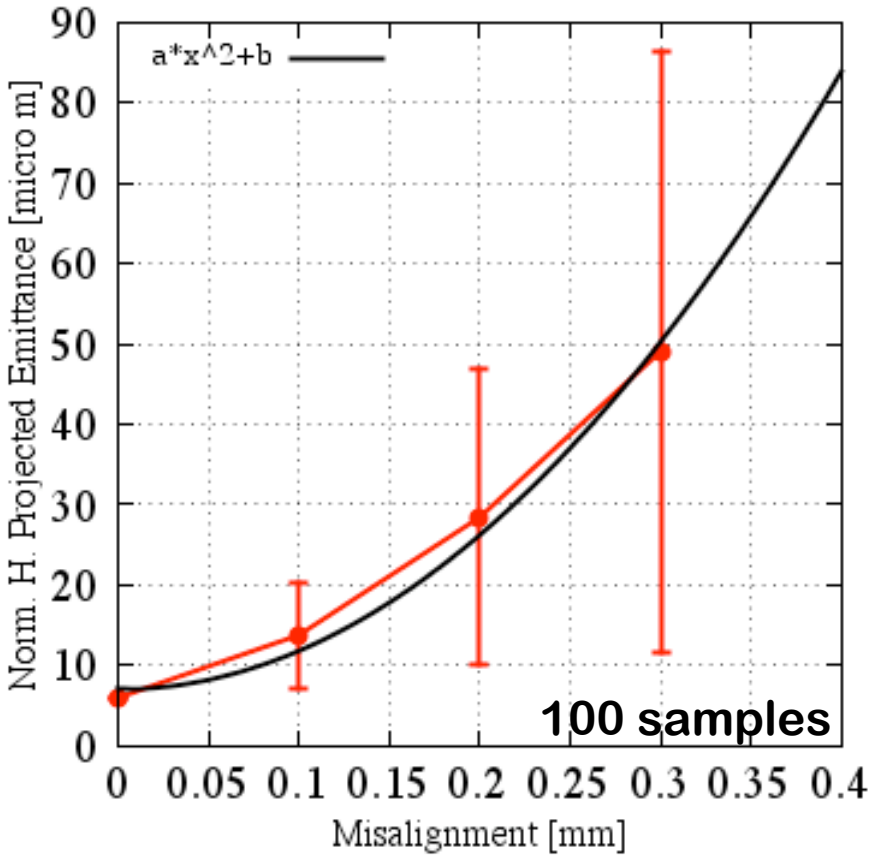


Transverse beam distribution in time direction

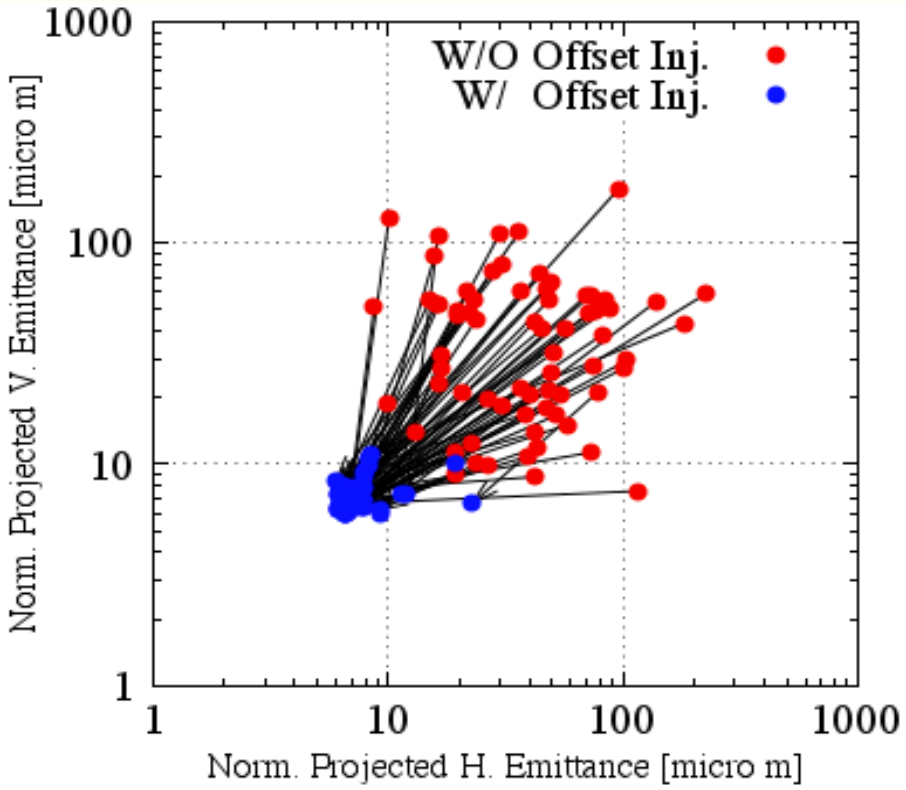
Emittance Preservation

- 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



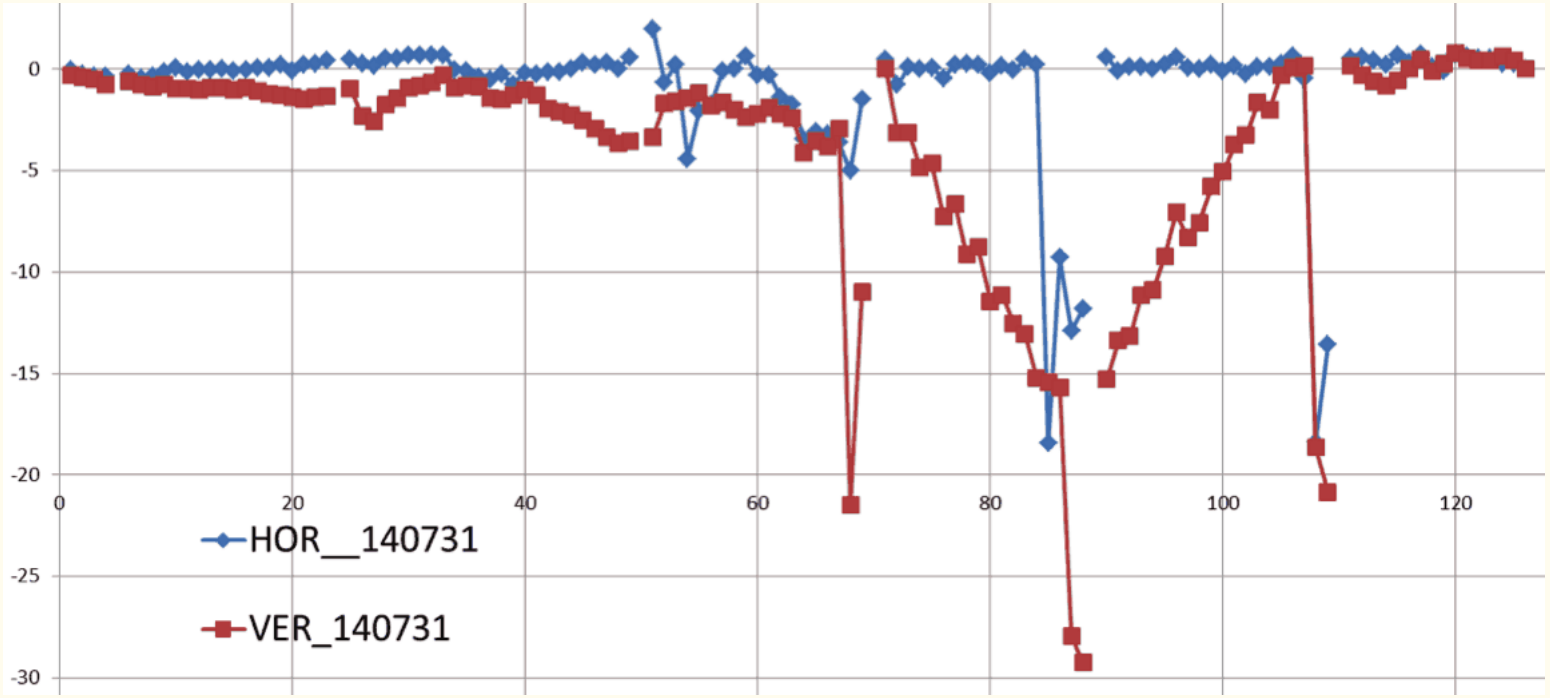
Sugimoto et al.

Alignment

- High-precision alignment was not necessary in PF and KEKB injections, and it was much damaged by earthquake in 2011.
- Instead of flexible-structure girder before earthquake, rigid-structure was adopted with jack-volts and fixed supports.
- Reflector pedestals are mounted onto quad magnets and accelerating cavities for laser-tracker measurement.
- Iterative measurement and adjustment with 500-m straight laser and position sensors should enable 0.3-mm global alignment.
- Laser tracker should enable 0.1-mm measurement within 10-m girder unit.
- Displacement gauges, hydrostatic leveling, inclinometer are also employed.
- Remote measurement system and girder mover system will be necessary for longer term, and are under development.

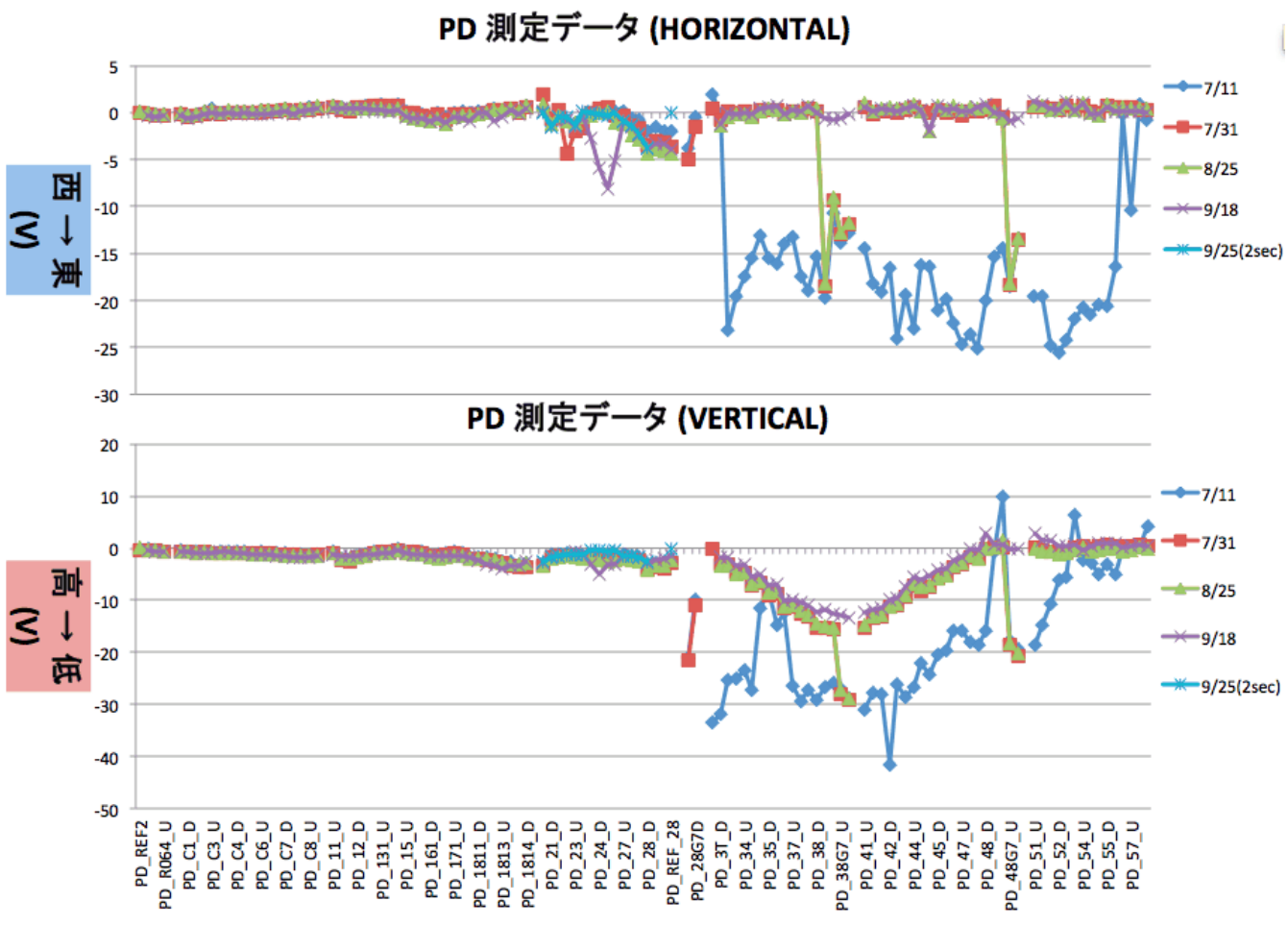
Alignment work at summer 2014

- For the first time at 3-5 sectors
- Horizontal axis: sensor number from sector C, 1-4, to sector 5 (~80 m/sector)
- Vertical axis: voltage (~displacement at 0.25~0.5mm/V)
- Some girders were not yet upgraded
- Moved up to 3 mm not to break vaccuum



Alignment work during summer 2014

- Several measurements during summer
- Measurement reproducibility was confirmed up to ~0.2 mm
- While there existed many conflicting measurements, consistent scheme has been established
- Movement of tunnel by several 10's of micrometer was observed (→ mover)



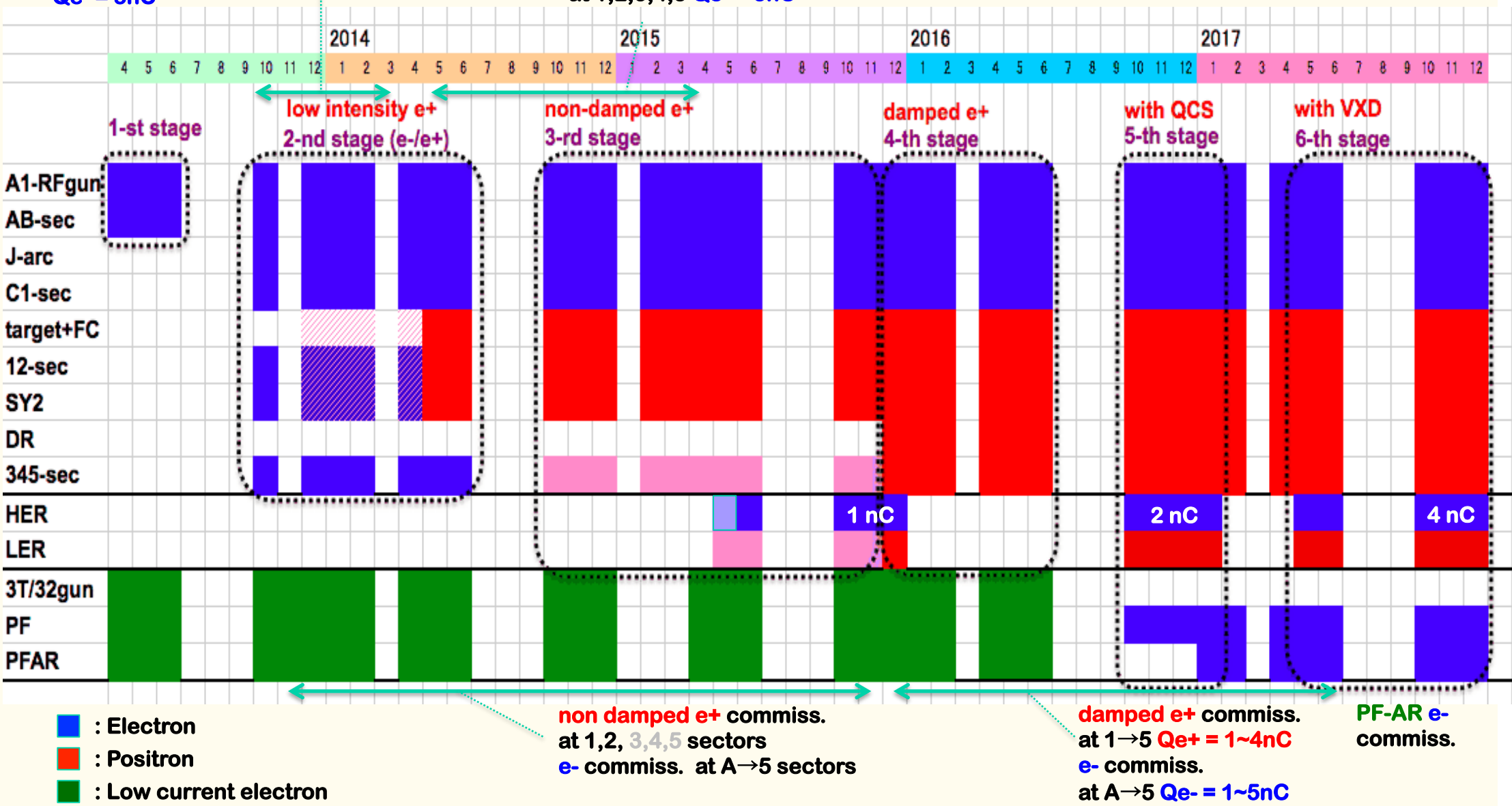
Instrumentation

- **RF stability is crucial for the beam**
  - LLRF monitor is being developed
  - 60 high-power klystrons and 10 middle-power systems
  - 50Hz synchronized data acquisition with event (beam-mode) recognition
  - 0.1% amplitude and 0.1degree phase resolution
- **BPM precision improvement**
  - 100 μm → 50 μm → < 10 μm
  - Event recognition
  - Mass production is underway
- **Other beam monitors**

Staged Radiation Control License towards SuperKEKB

- Two licenses were approved in June 2014
- [1] Beam diagnostic station at #A2 just after gun
  - for 1250nC/s at 50Hz 2bunches
- [2] Beam dump at #28 just before damping ring
  - for 10nC/s with positrons
- Radiation measurements especially at positron generator
  - Indispensable to estimate radiation at >100 times higher beam
- Both approved
- Soon apply for the next license at ~May.2015

Linac Schedule Overview (as of Mar.2014)

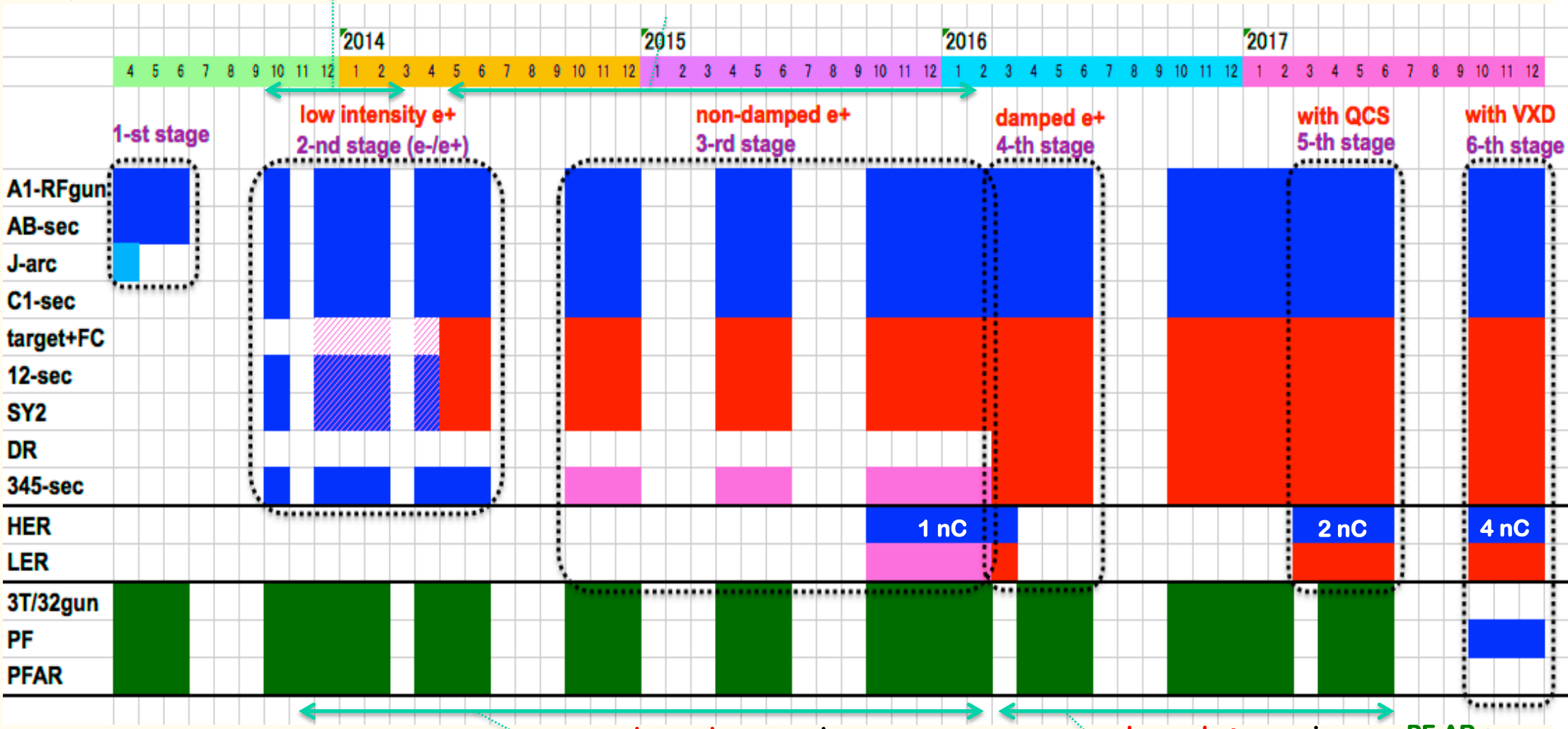


Linac Schedule Overview (Newer)

RF-Gun e- beam commissioning at A,B-sector
Qe- = 5nC

e- commiss. at A,B,J,C,1
Qe- = 5nC

e+ commiss. at 1,2 Qe+ = 0.5nC (FC, DCS, Qe- 50%)
e- commiss. at 1,2,3,4,5 Qe- = 5nC



: Electron
: Positron
: Low current electron

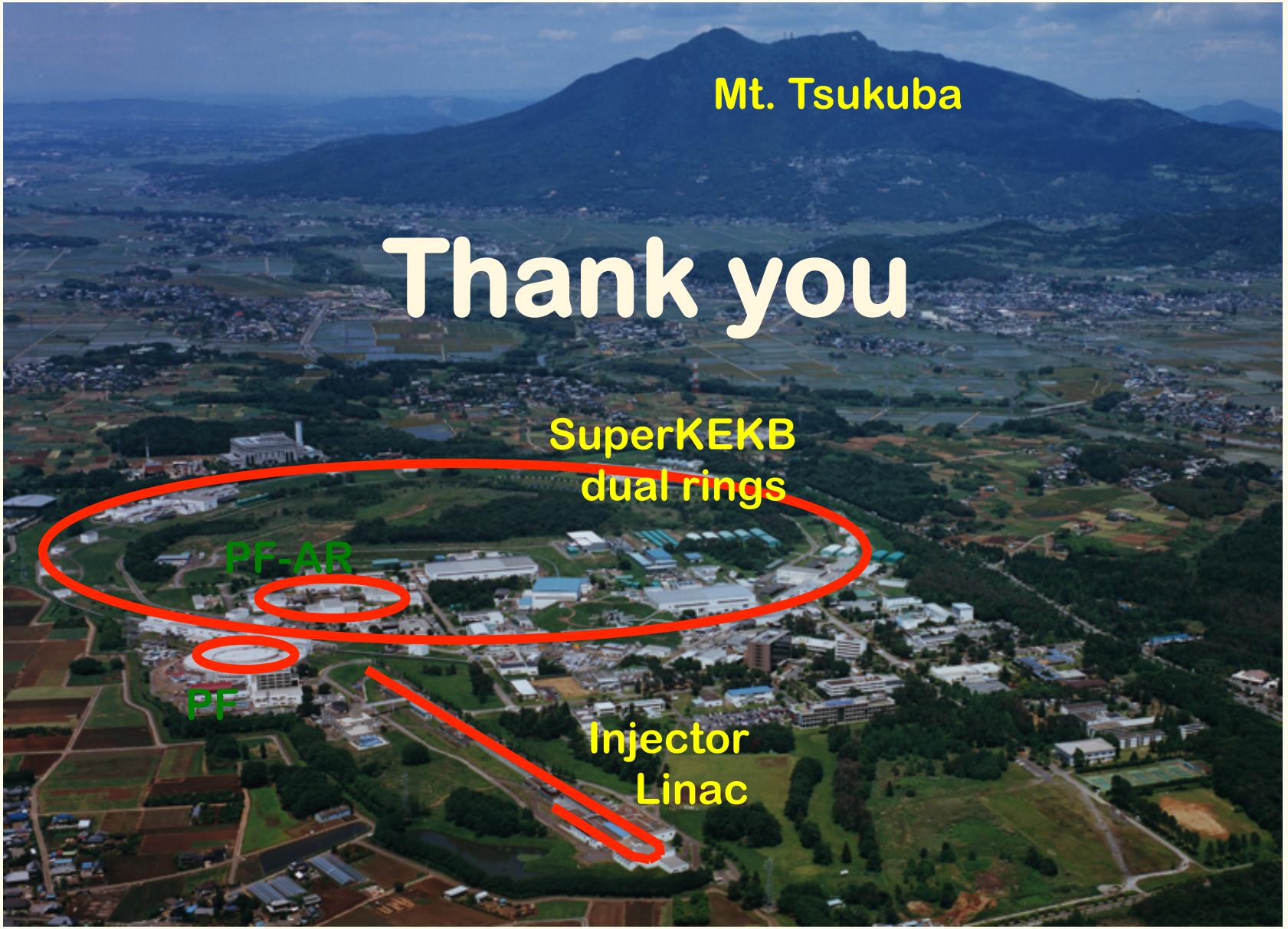
non damped e+ commiss.
at 1,2, 3,4,5 sectors
e- commiss. at A→5 sectors

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

PF-AR e- commiss.

Summary

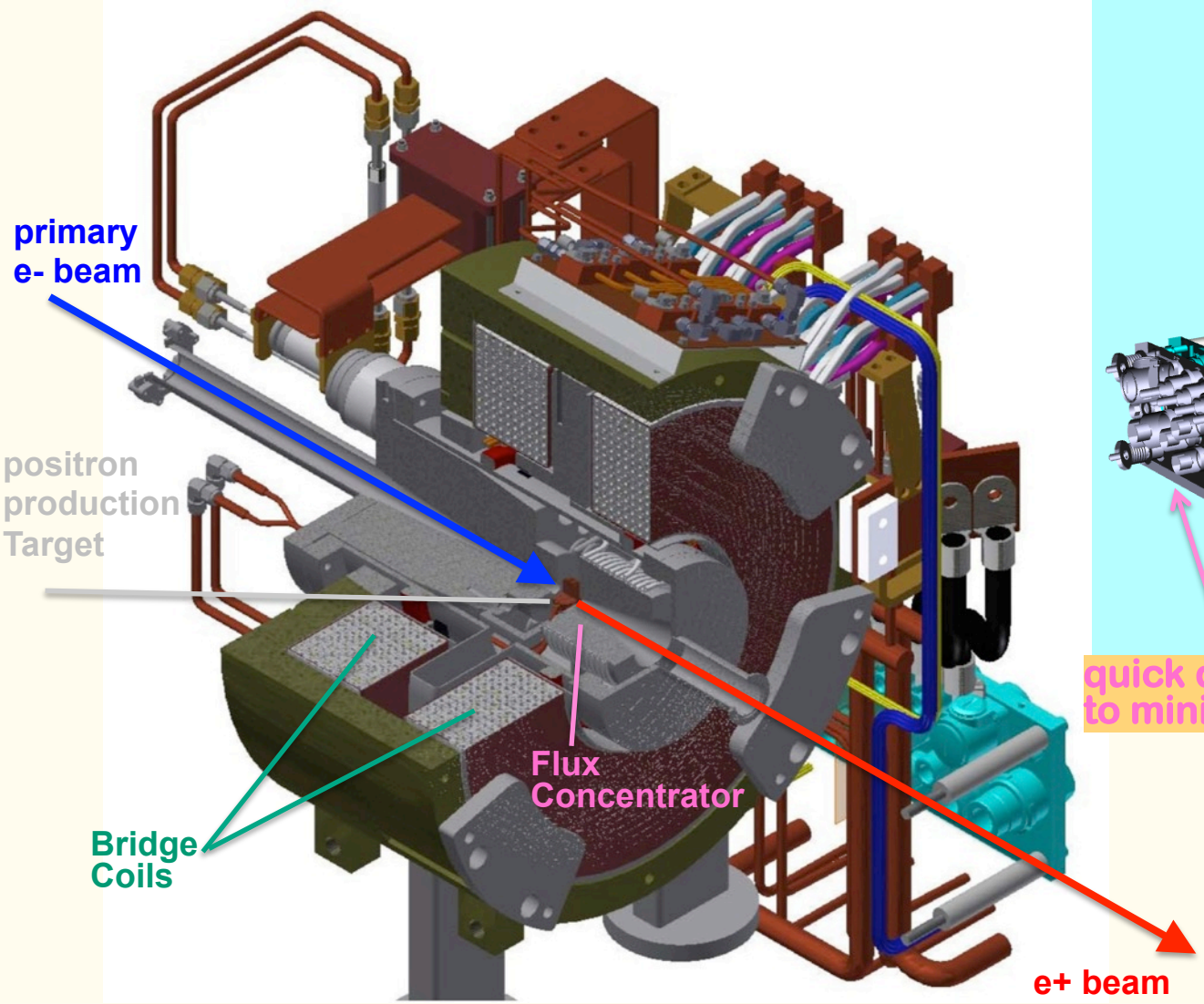
- Steady progress towards first MR injection in 2015
- Will finish earthquake disaster recovery in 2014
- Will make staged improvements before 2017
- Will balance between final beam quality and stable/staged operation
- Will select optimized route depending on available resources

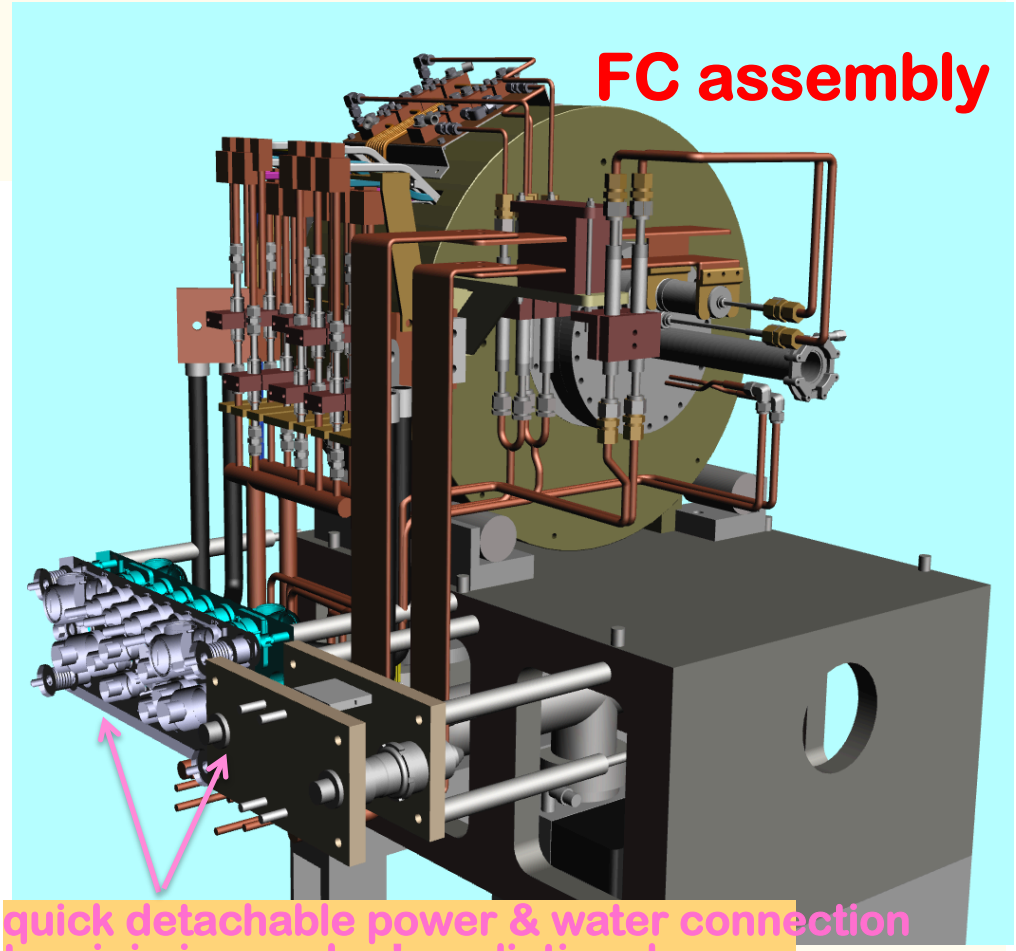

Mt. Tsukuba
Thank you
SuperKEKB
dual rings
PF-AR
PF
Injector
Linac

Positron Source

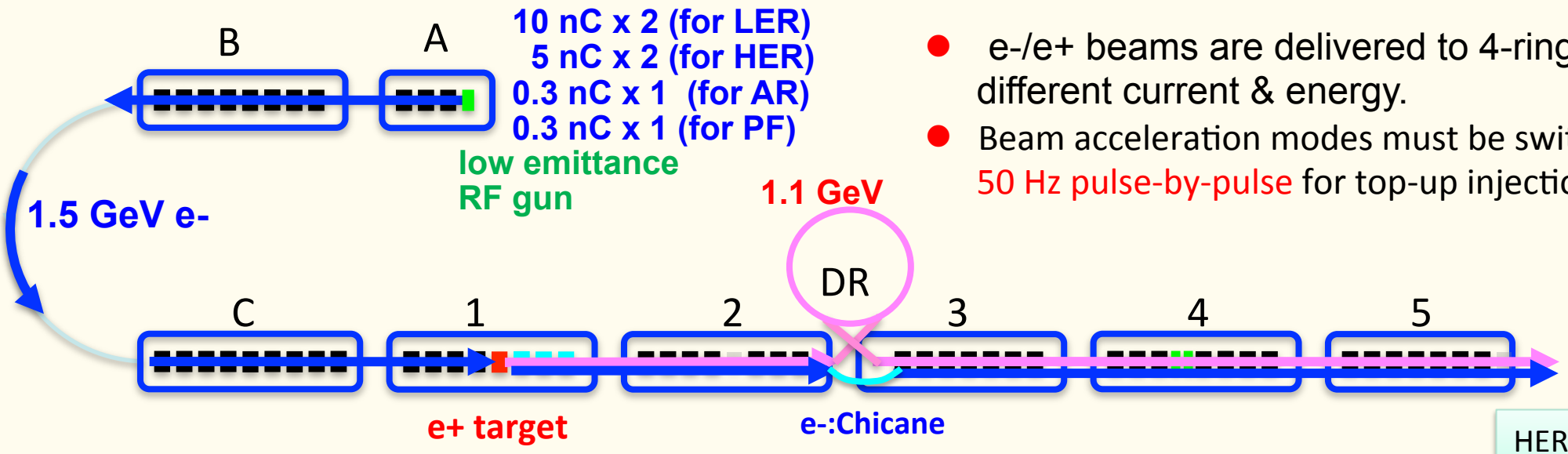
- High current positron is required
- Positron capturing with flux concentrator (FC) and large aperture s-band structure (LAS)
- Deceleration field to reduce satellite bunches
- Pinhole beside target for electron beam
- Protection system with beam spoilers

Flux Concentrator Assembly

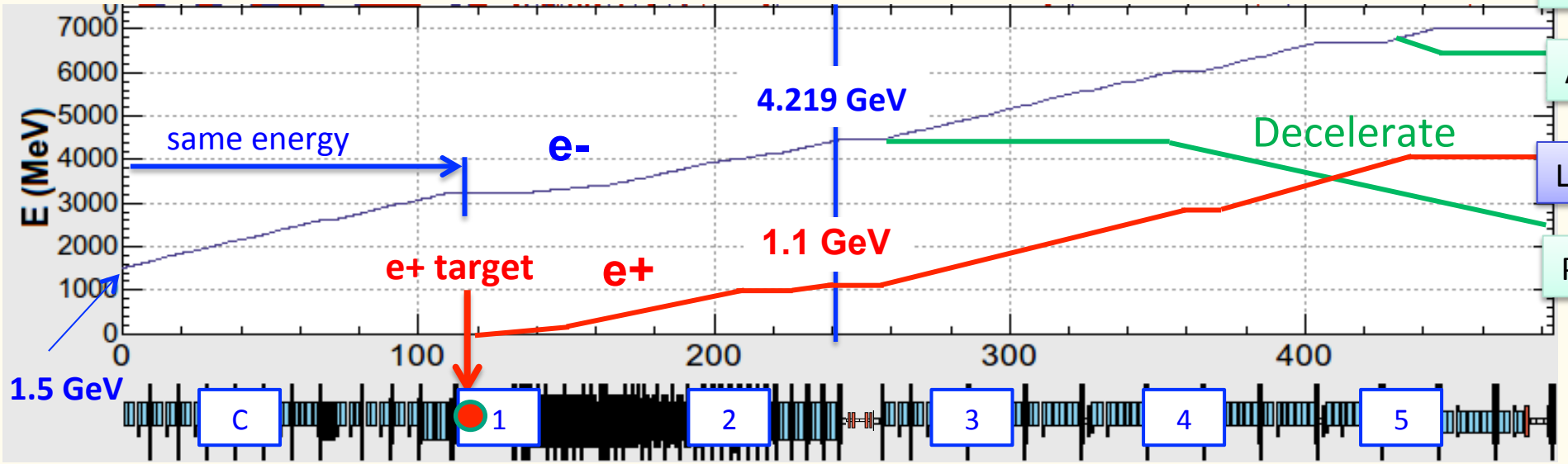




Energy profiles and beam properties



- 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.

Pulse-to-pulse modulation

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

maybe with additional PPM VAs for stealth beam measurements

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