Positron Source Upgrade

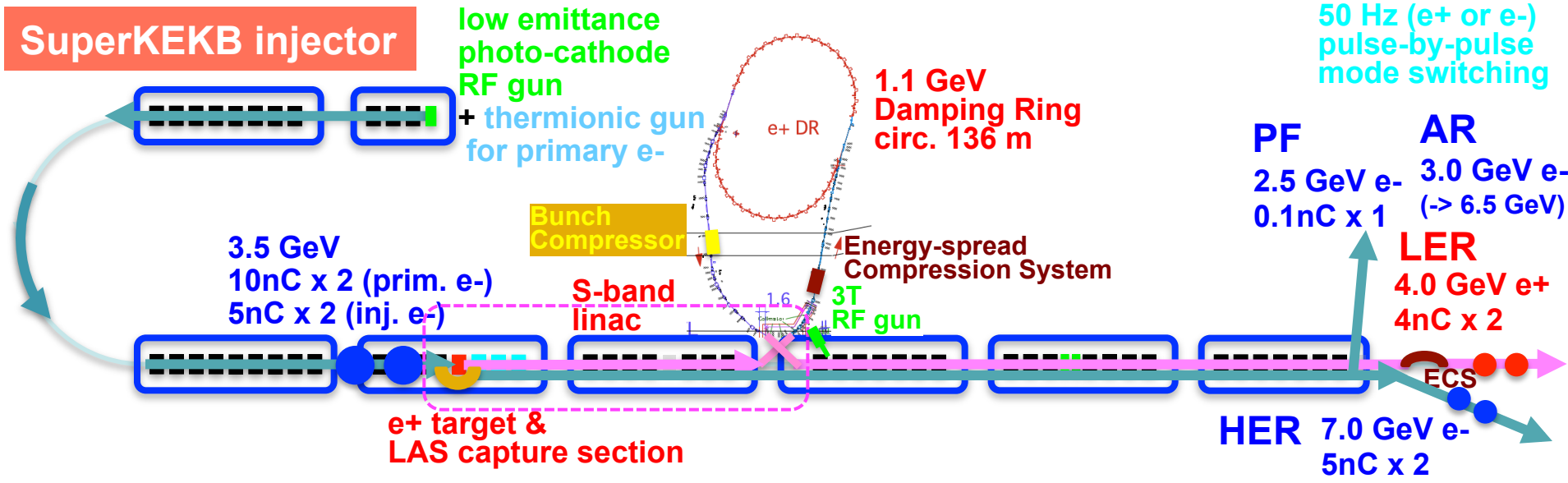
(2015 February 25)

KEKB injector linac

Takuya Kamitani

(1) SuperKEKB Positron Source Overview

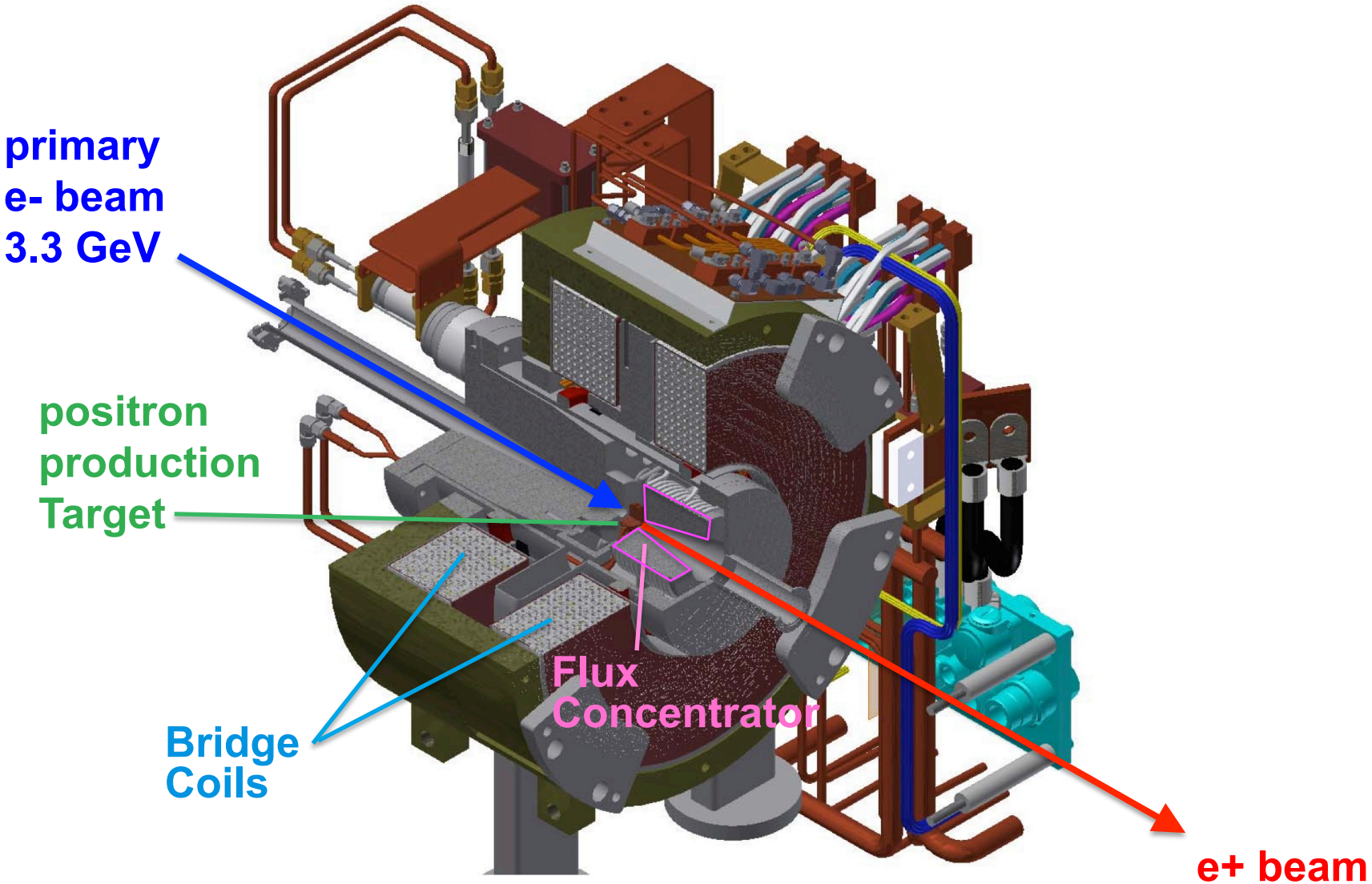
SuperKEKB Injector



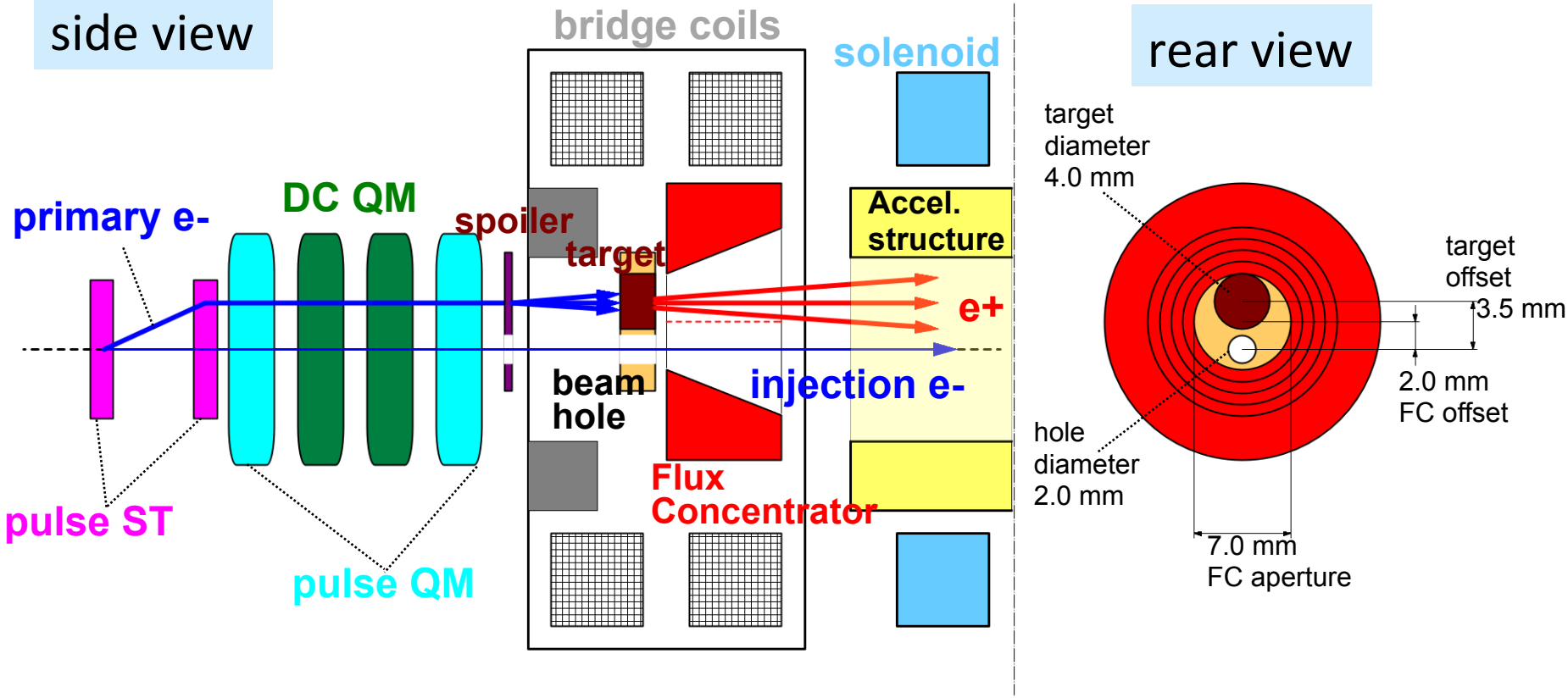
Upgrade items in positron source

- positron damping ring introduced
- new positron focusing lens: flux concentrator (3.5 T) + bridge coils (1.0 T)
- large-aperture (2a=30mm) accelerating structure (LAS) in capture section
- positron focusing beam line layout reorganized with 100 new quad. magnets

SuperKEKB positron source

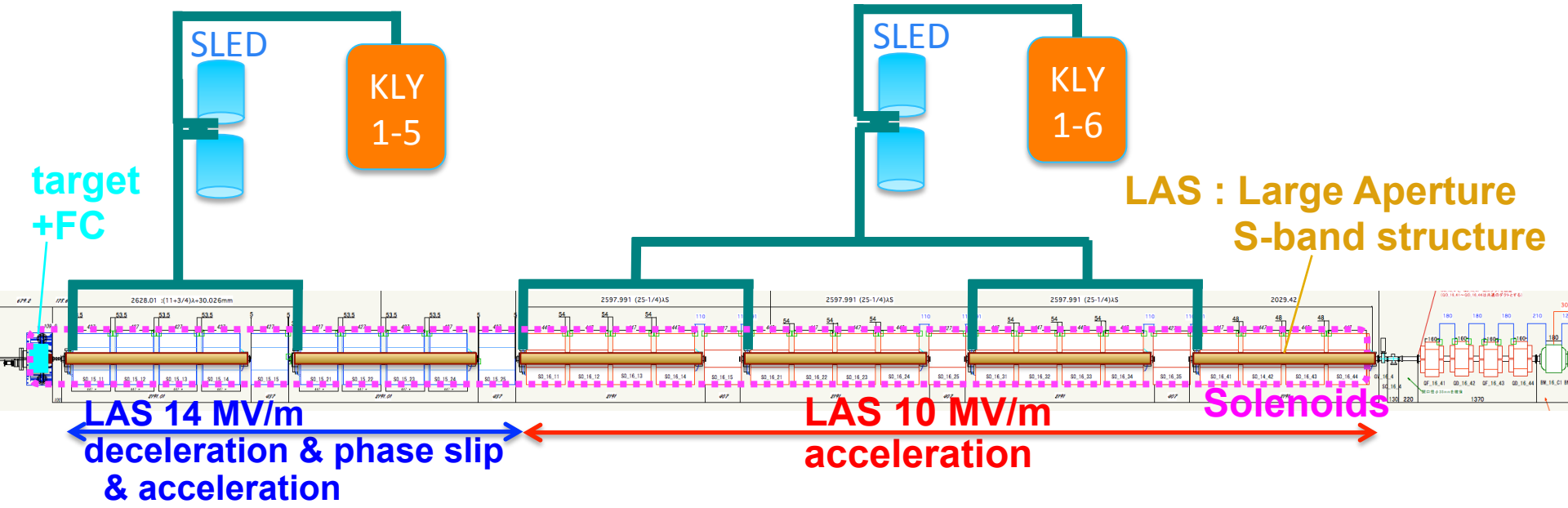


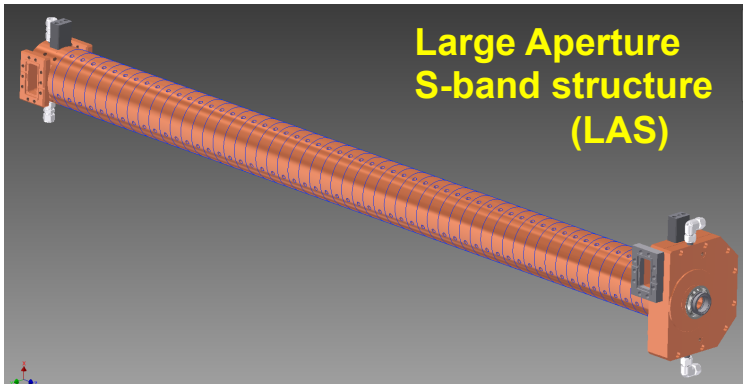
target offset & beam hole



- injection e- beam : on axis to preserve low emittance
- primary e- beam : 2.5 mm off axis to minimize e+ yield degradation
  (target offset 3.5 mm, FC offset 2.0mm)

Positron Capture Section

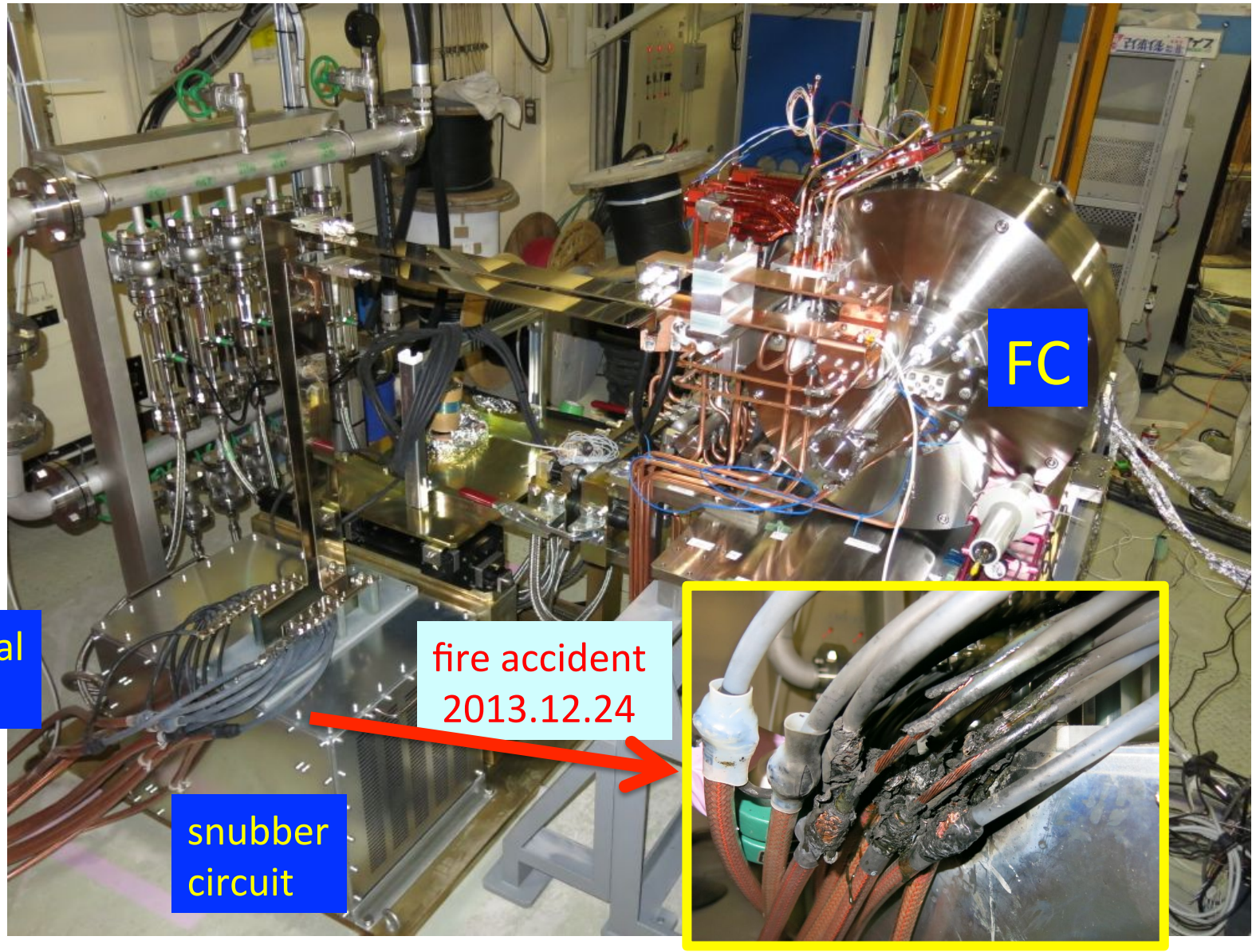




- LAS with SLEDs for sufficient field gradient
- breakdown issue of LAS in solenoid field
- needs careful RF conditioning

(2) FC operation test at test stand (2014 April)

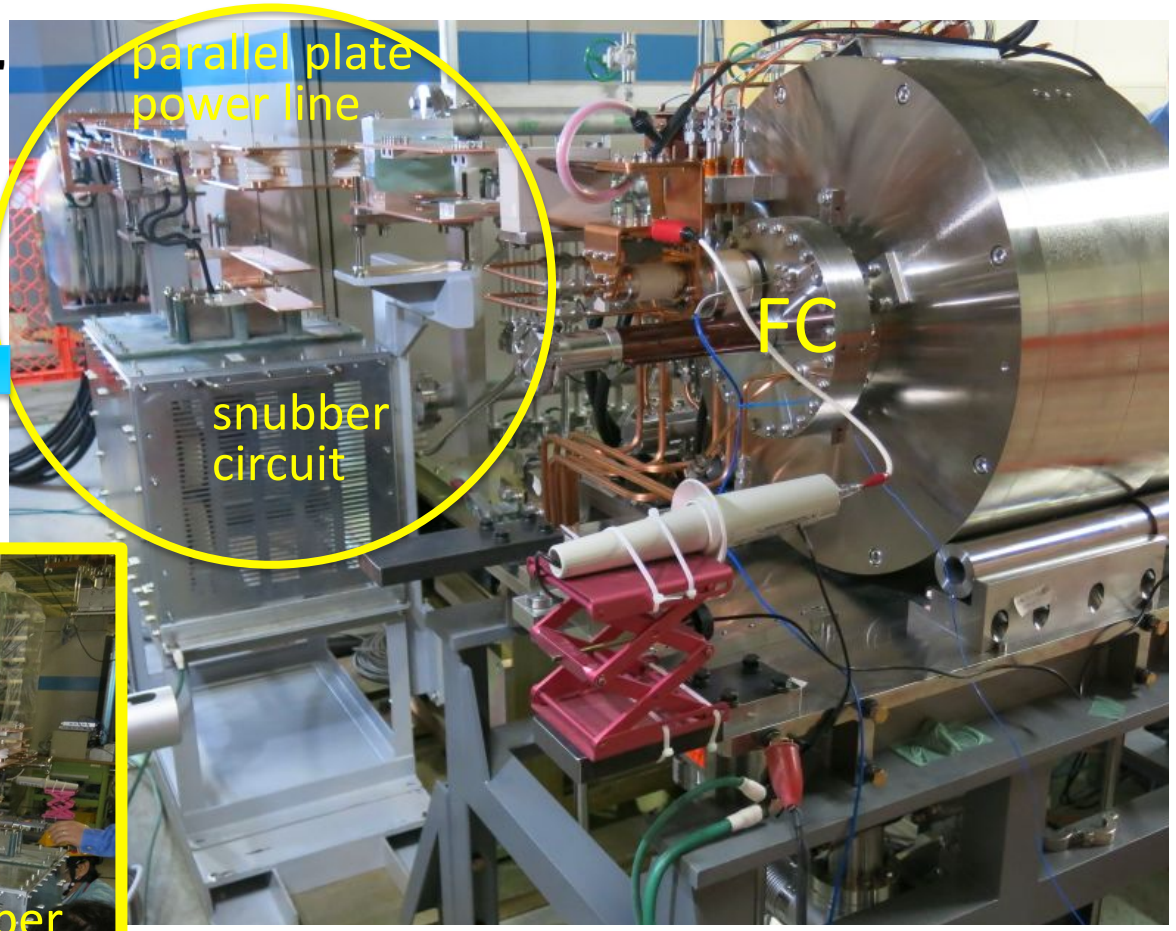
FC Test-stand at 2013 Dec.

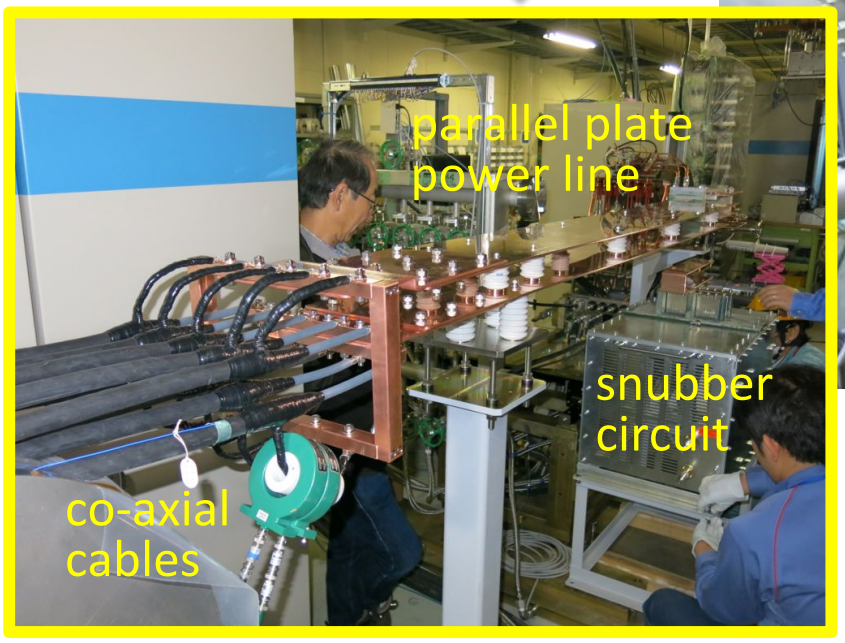


reformed FC test stand
with parallel plate power line (2014.04.18)

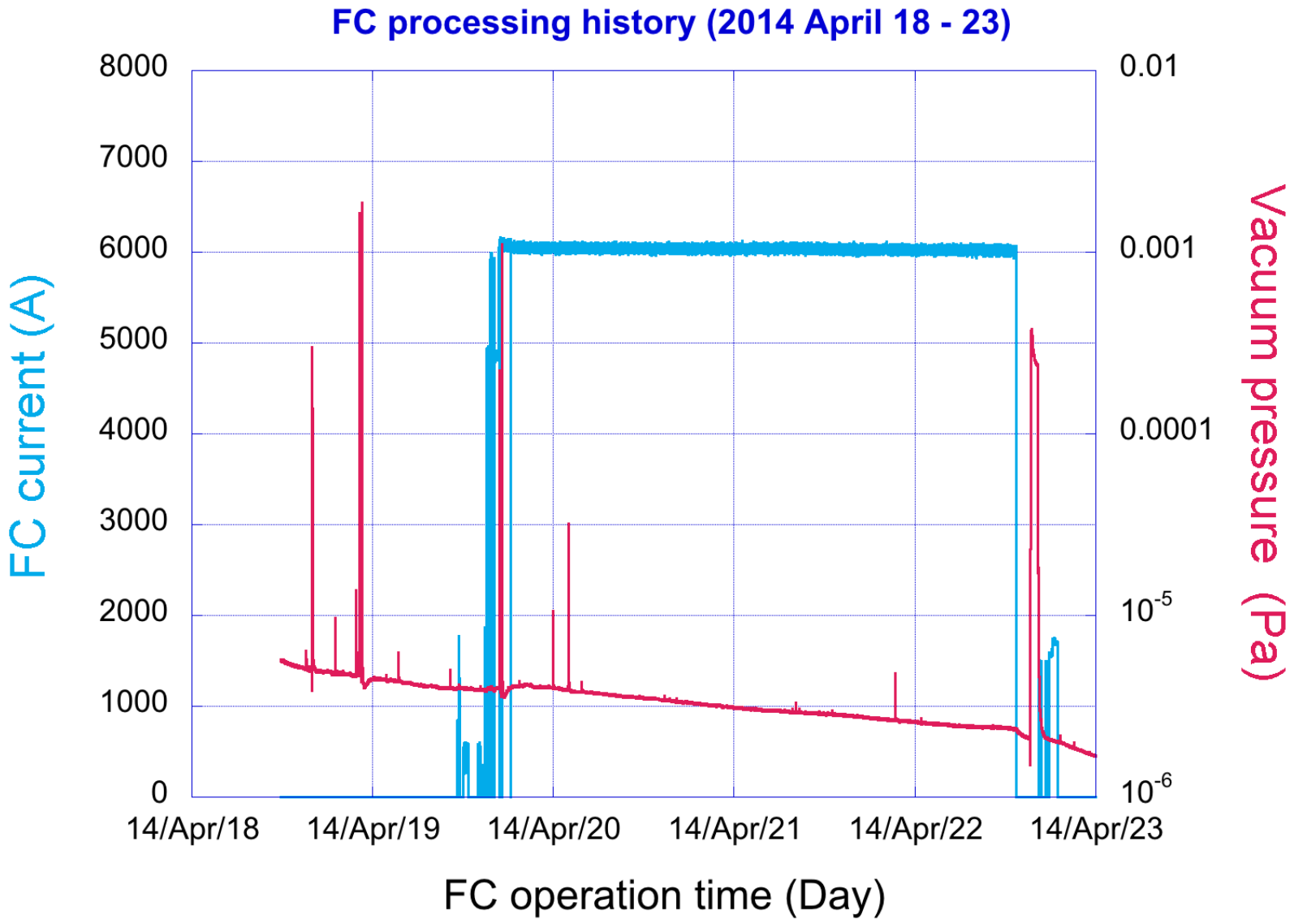
Careful treatment of cable terminals against discharging using "stress cone" made of butyl rubber and well arranged layout.

A parallel plate power line was introduced to put the cable terminal far away from high-radiation area (target).



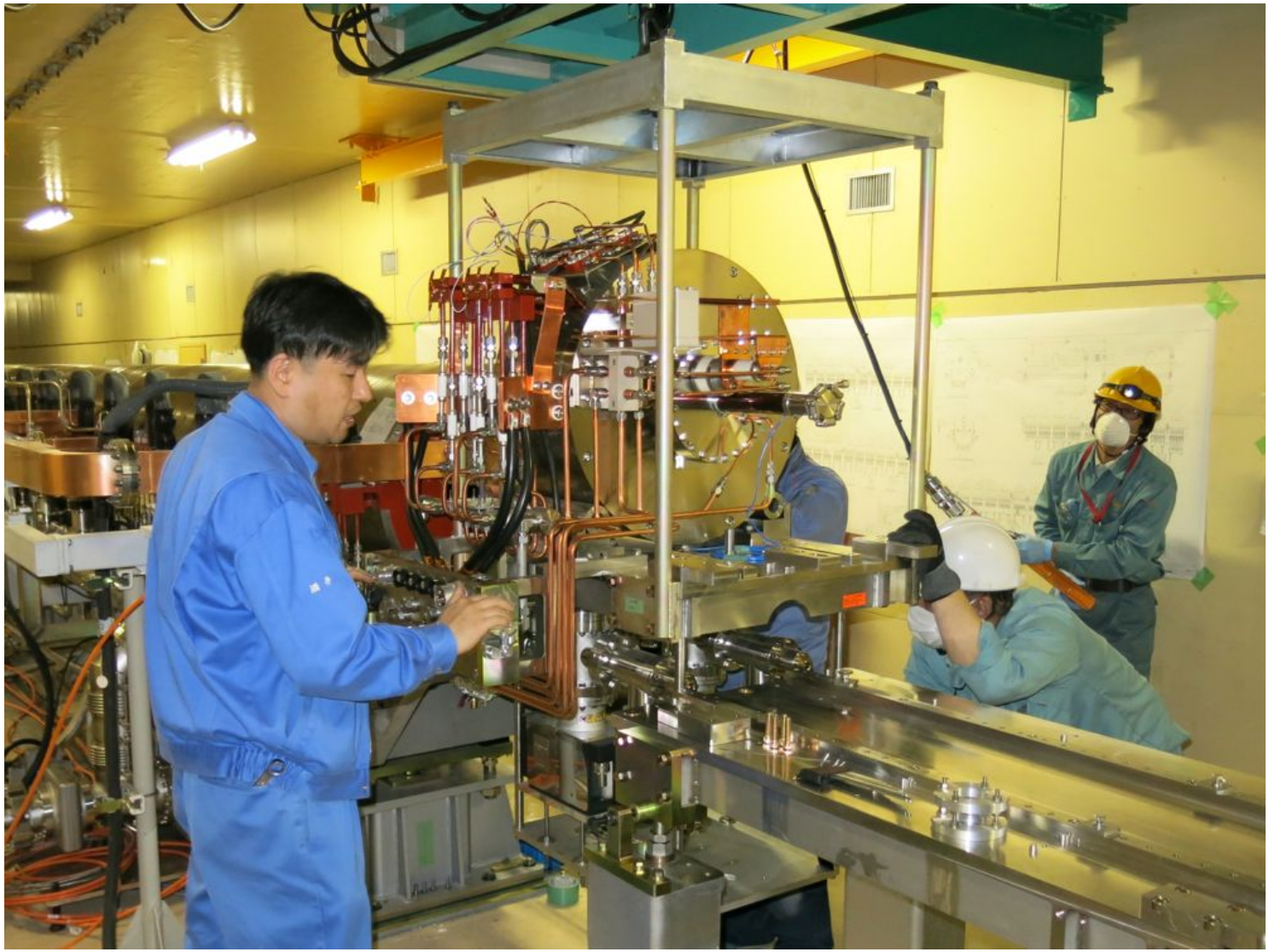


FC stand-alone operation test

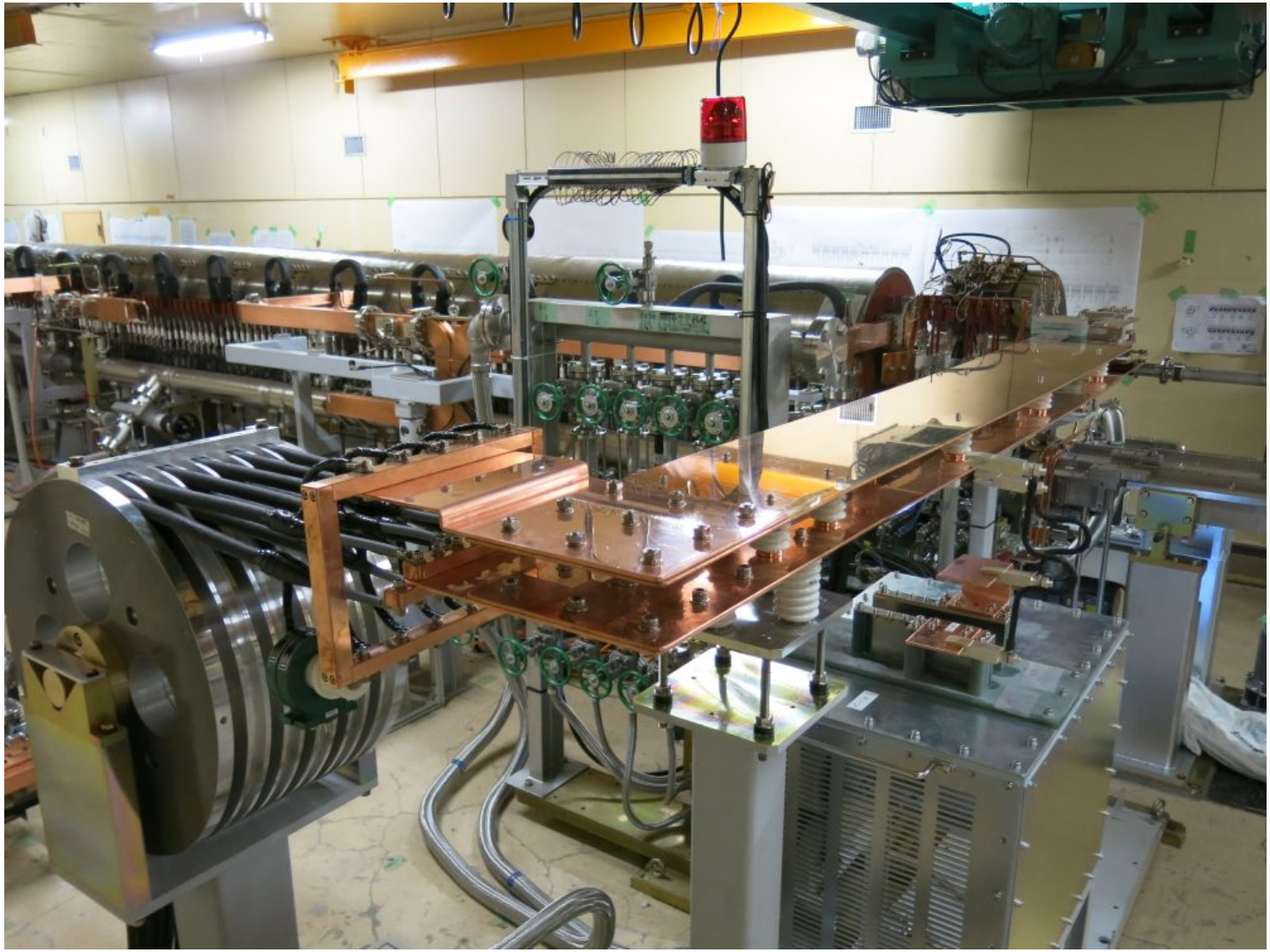


(3) FC installation & beam spoiler beam separator (2014 April)

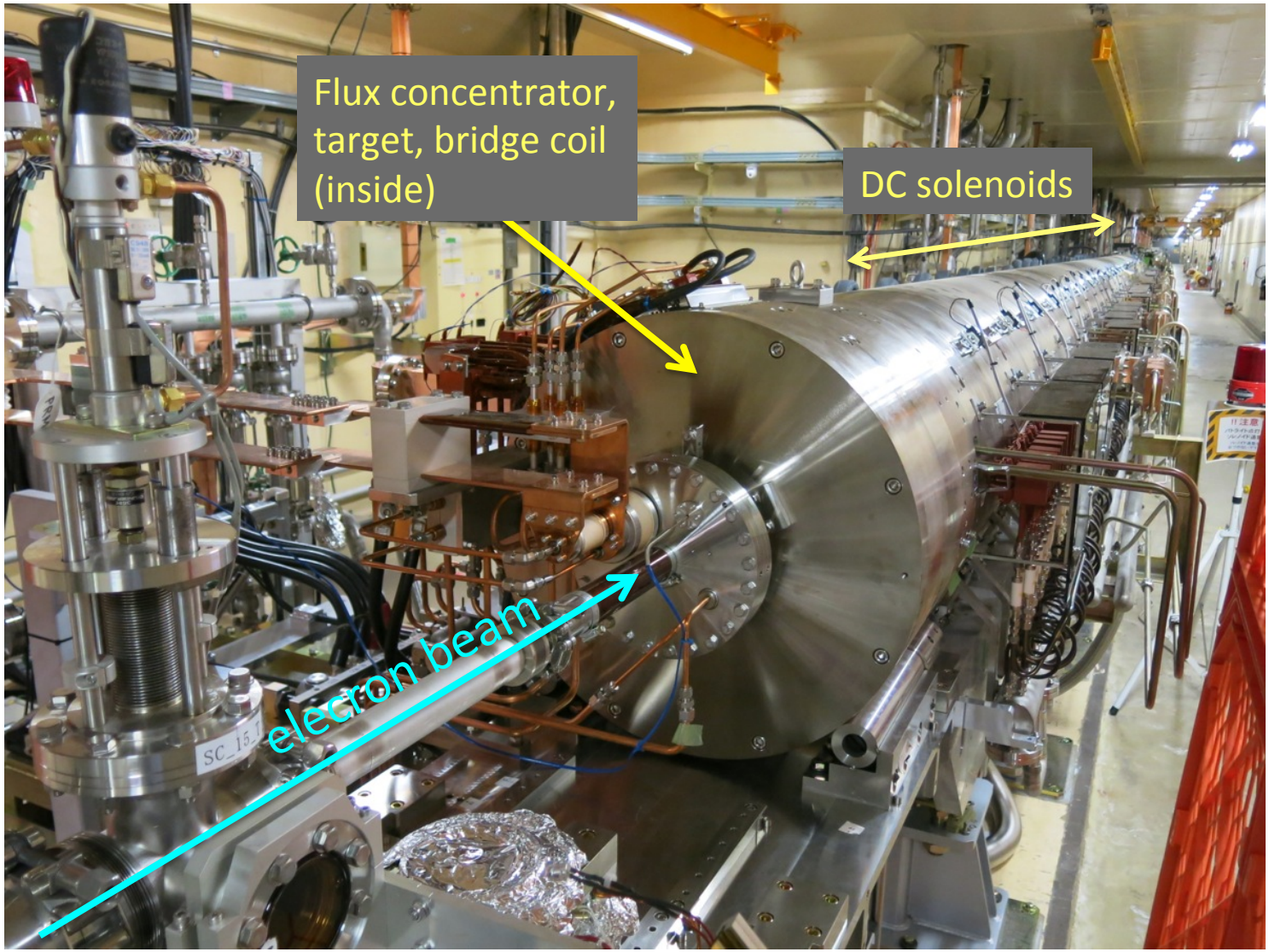
FC installation



power feed line (first model)

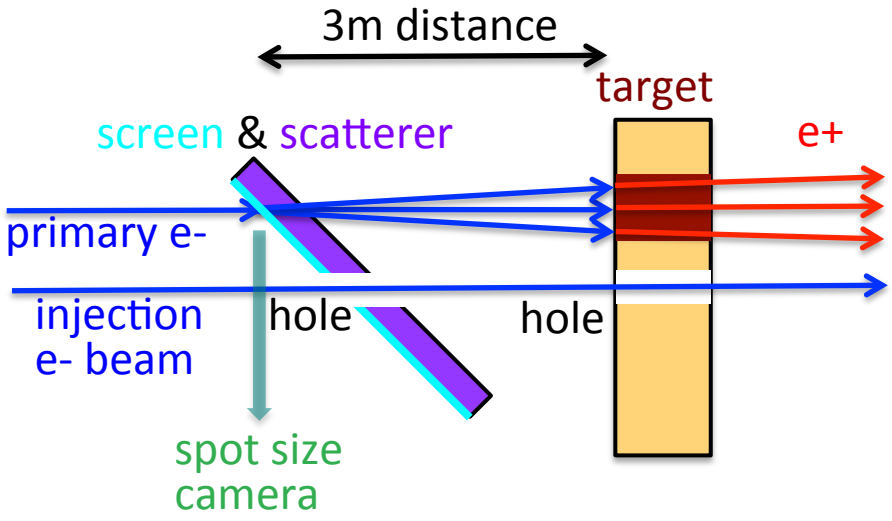


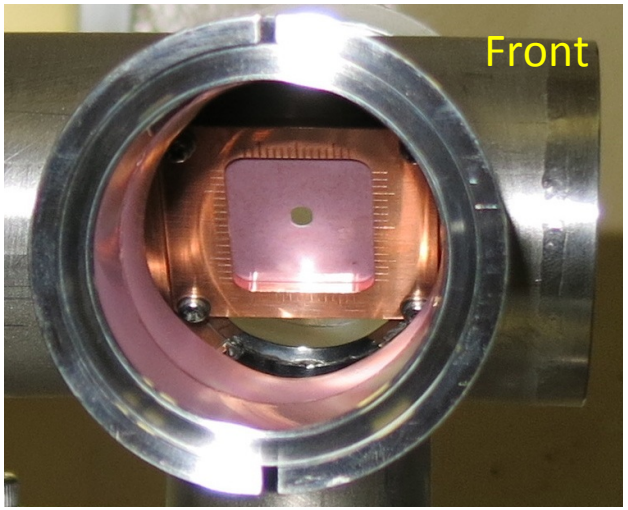
e+ capture section in linac tunnel

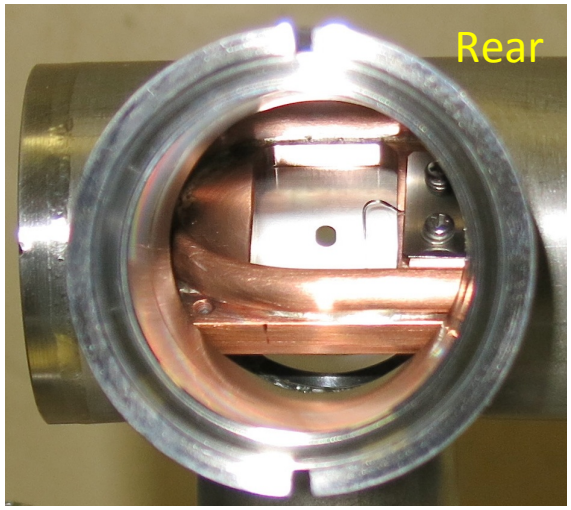


beam spoiler

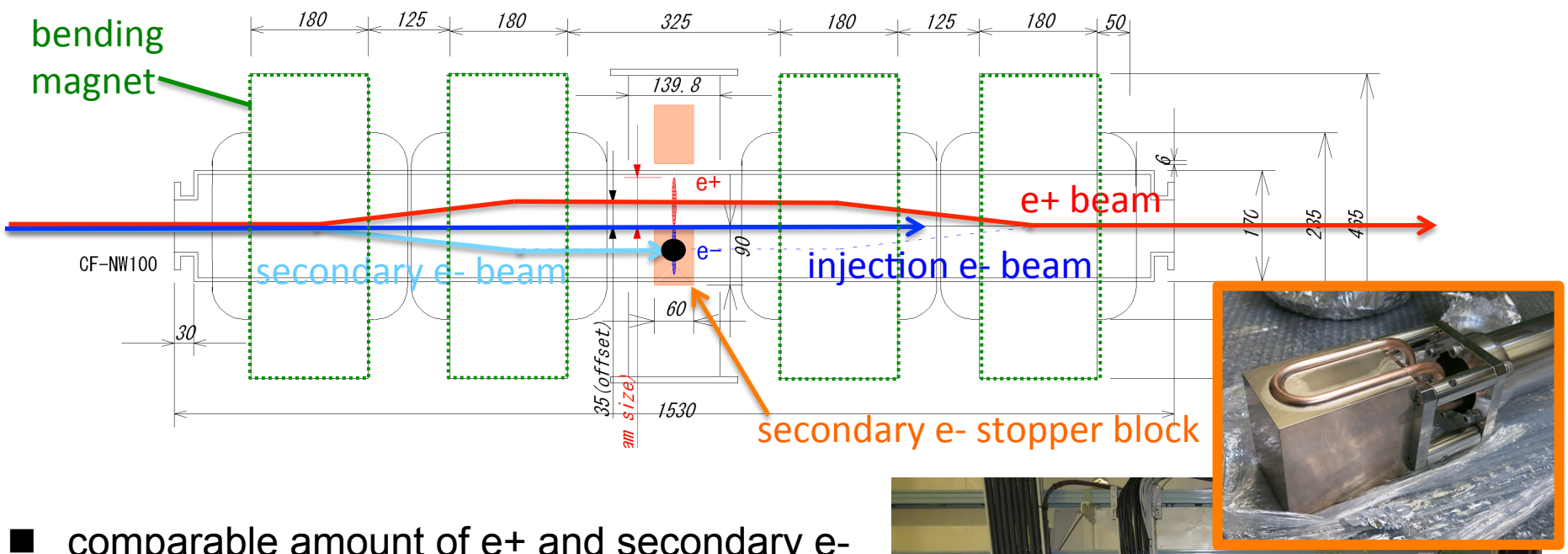
- **beam spoiler** to enlarge beam spot on target to be σ_x , σ_y> 0.7 mm to avoid target destruction
- spot size monitoring screen Al_2O_3 (0.14 mm thick)
  + scattering Al foil (0.25 mm thick)
  [total material thickness = 0.05 X_0]
- beam hole for injection e-
- In the initial commissioning, primary e- also bypassed spoiler

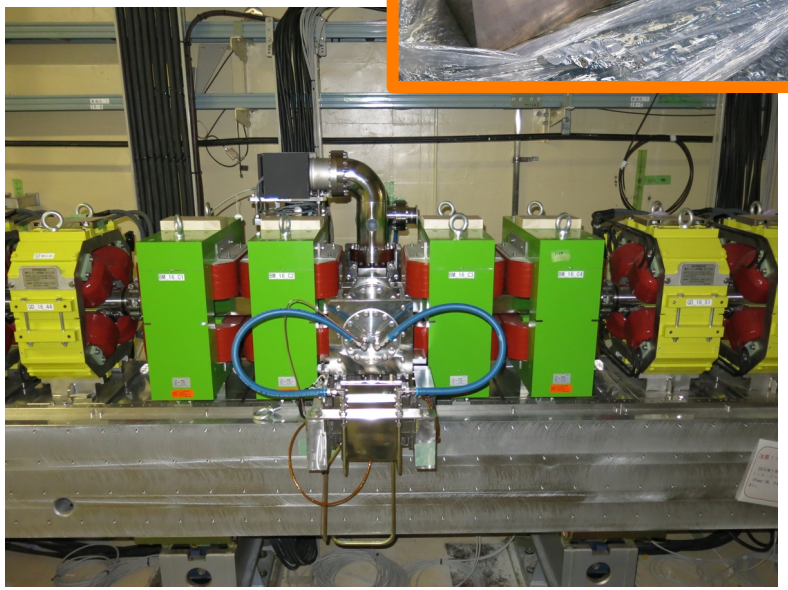






e-/e+ separator chicane





- comparable amount of e+ and secondary e- emerge from the capture section
- Beam-Position Monitor (BPM) signals spoiled by secondary e- !
  => needs e- elimination
- secondary e- stopped by W(70%)-Cu(30%) alloy block
- injection e- (3.3GeV) pass beside the block

(4) Positron beam commissioning (2014 June)

Limited parameters of capture section

- Initial e+ commissioning (2014 June) started with limited magnetic/electric field parameters of capture section due to hardware constraint at this stage.

	2014 June achieved	Design
Flux Concentrator current/field	6.4 kA / 1.9 T with temporary PS 6kA spec	12 kA / 3.5 T with full spec PS 12 kA
Bridge Coil current/field	600 A / 1.0 T	600 A / 1.0 T
DC solenoid current/field	370 A / 0.22 T power line capacity limit	650 A / 0.4 T
LAS Acceleration field	10, 12 MV/m Acc1,2 Acc3,4,5,6 outgas in RF processing	14, 10 MV/m Acc1,2 Acc3,4,5,6

LAS structure RF processing

- LAS structure in the capture section took longer time for RF processing
  - higher surface field
    surface/accel. field ratio is higher (2.42) than ordinary S-band structure (2.14)
  - non-flat RF waveform with SLED cavity
  - solenoid field initiate multipacting and outgassing
    -> 2D scanned (in accel. field gradient and solenoid field strength) RF processing needed !

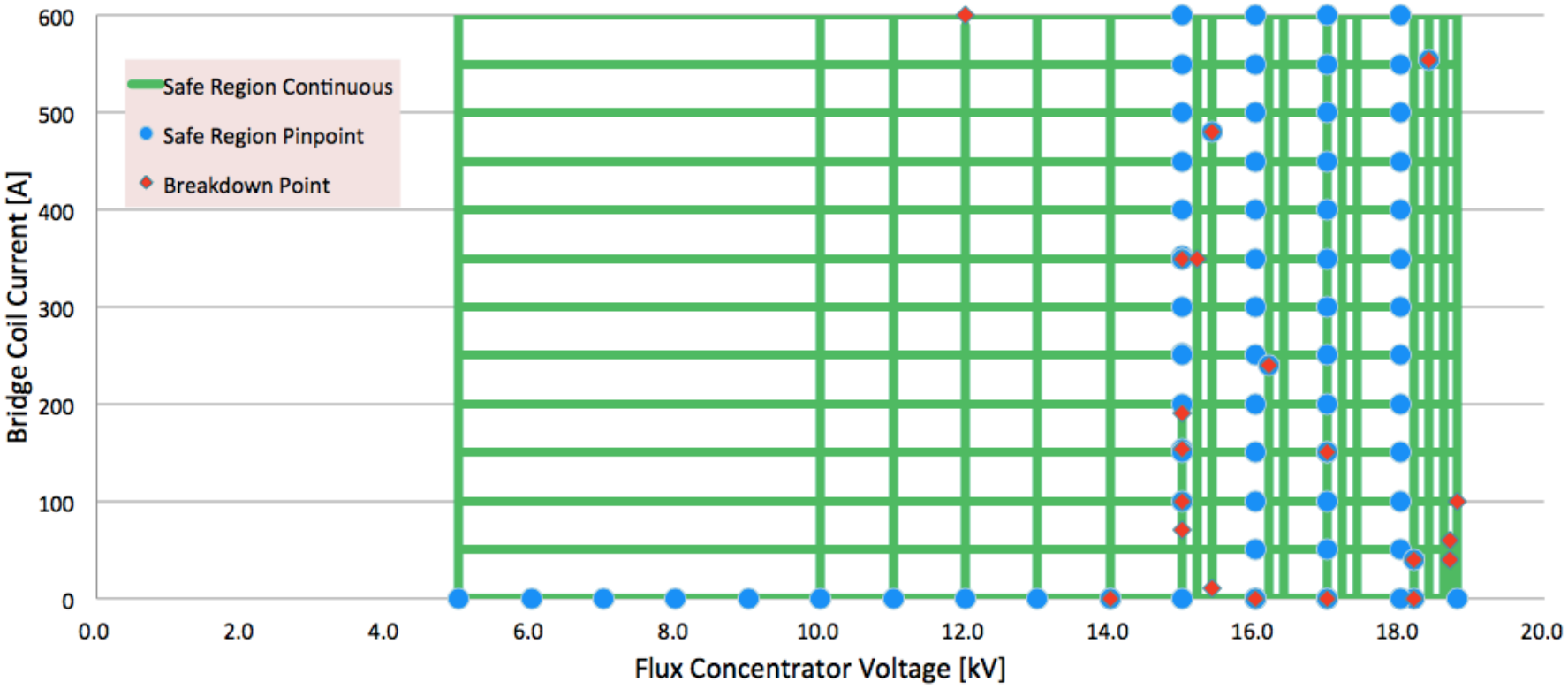
Finally, LAS structure 3, 4, 5, 6 achieved 12 MV/m !!

- First two LAS structures behind the target notably suffered from outgassing
  - shower particles from target irradiate structure surface ?
  - problem in wave guide ?

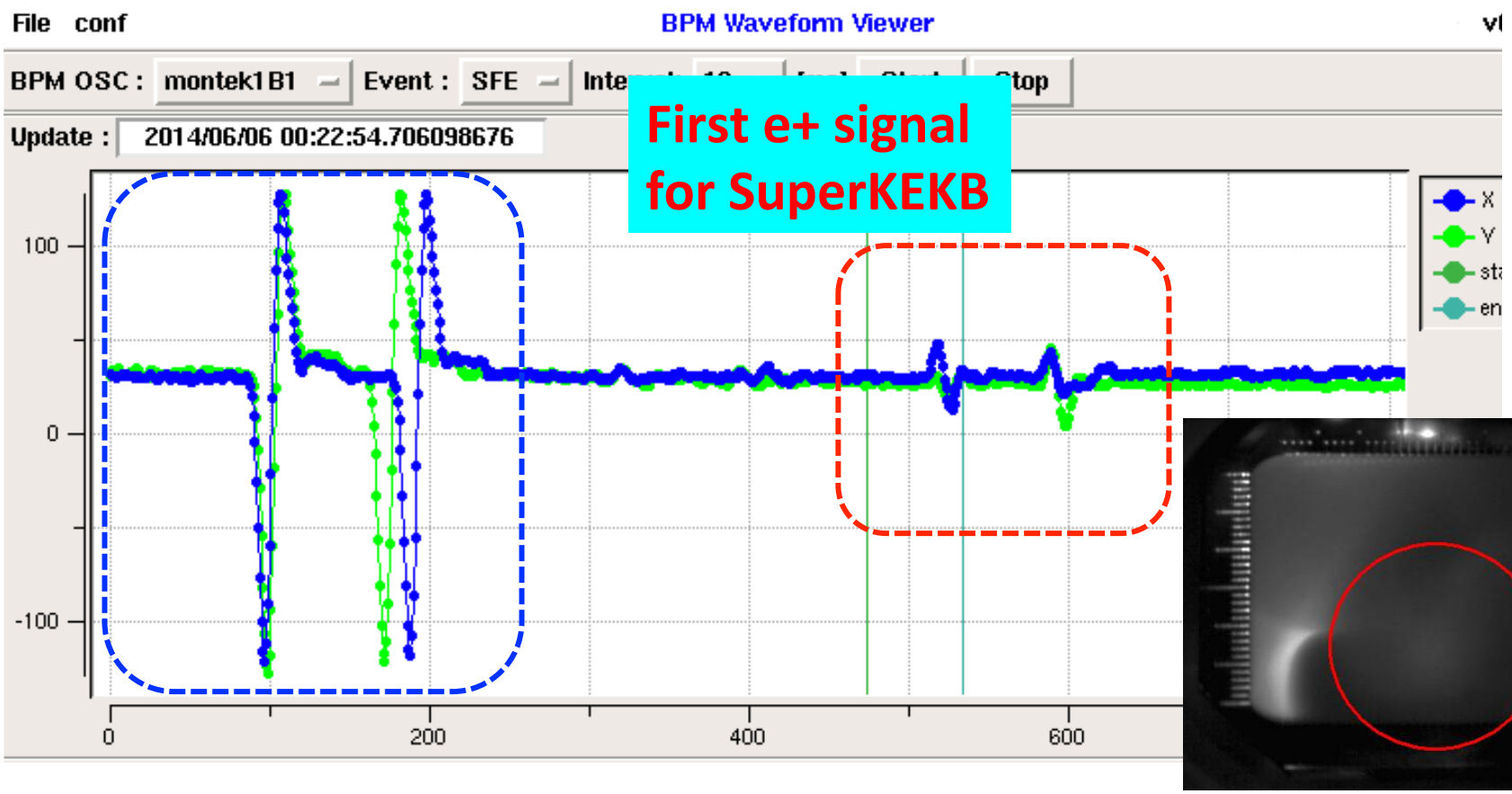
LAS structure 1, 2 remained ~10 MV/m

HV processing of FC with BC field

- FC needs gradual high-voltage processing (training)
- DC magnetic field by the bridge coils affects FC resulting in gas-bursts (-> 2D scanned processing)
- beam irradiation to target makes occasional gas-bursts



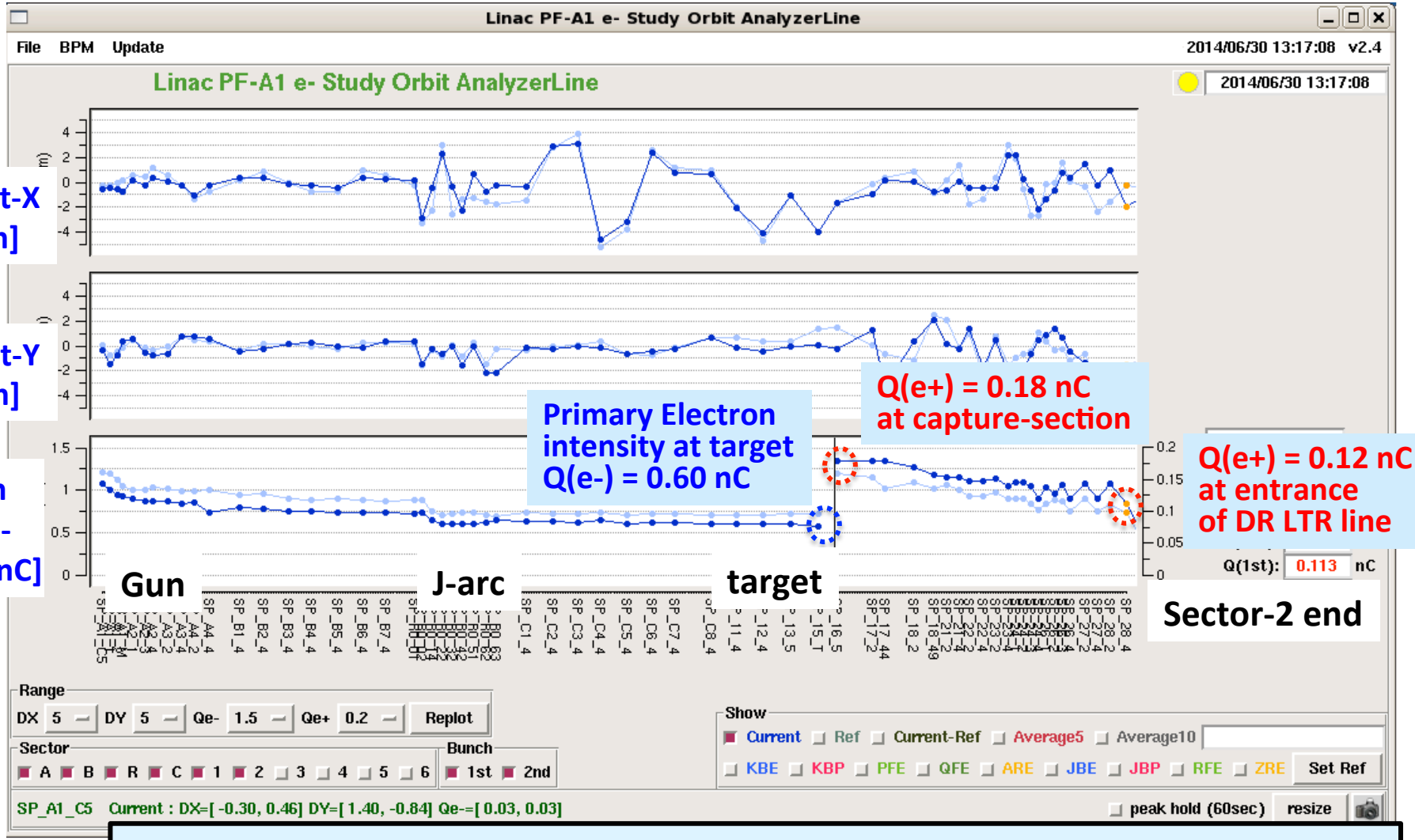
The first positron beam after the upgrade



BPM: SP_15_T in front of target
negative charged particles (e- beam)
give (−)(+) bipolar signal

BPM: SP_16_5 after e+ capture section
(+)(−) signal indicates
positive charged particles (e+) !

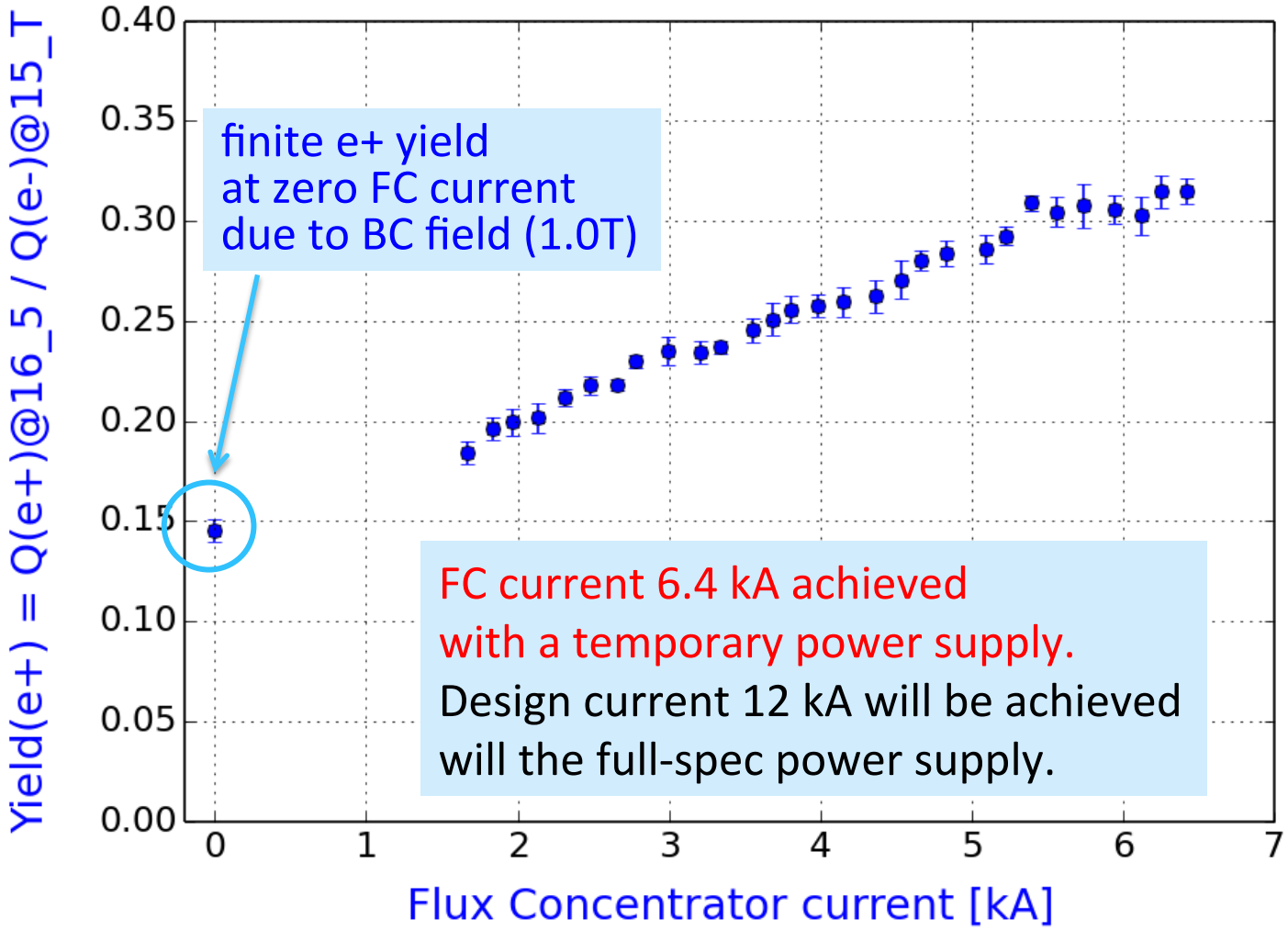
e+ yield (achieved 2014 June)



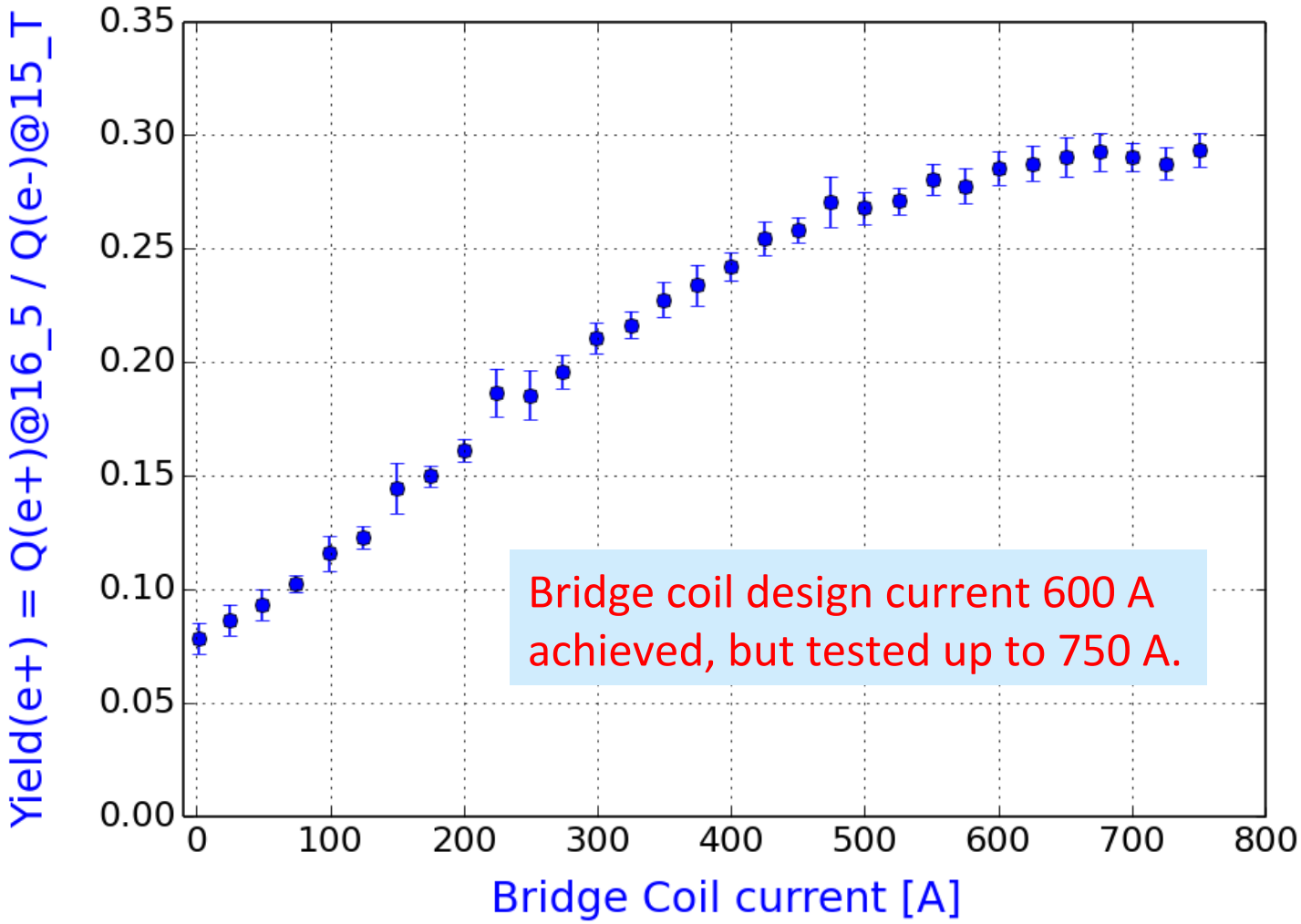
e+ yield (Ye+) = e+ charge (Qe+)/primary e- charge (Qe-)

Ye+ = 30% at capture section、Ye+ = 20% at SY2 for damping ring

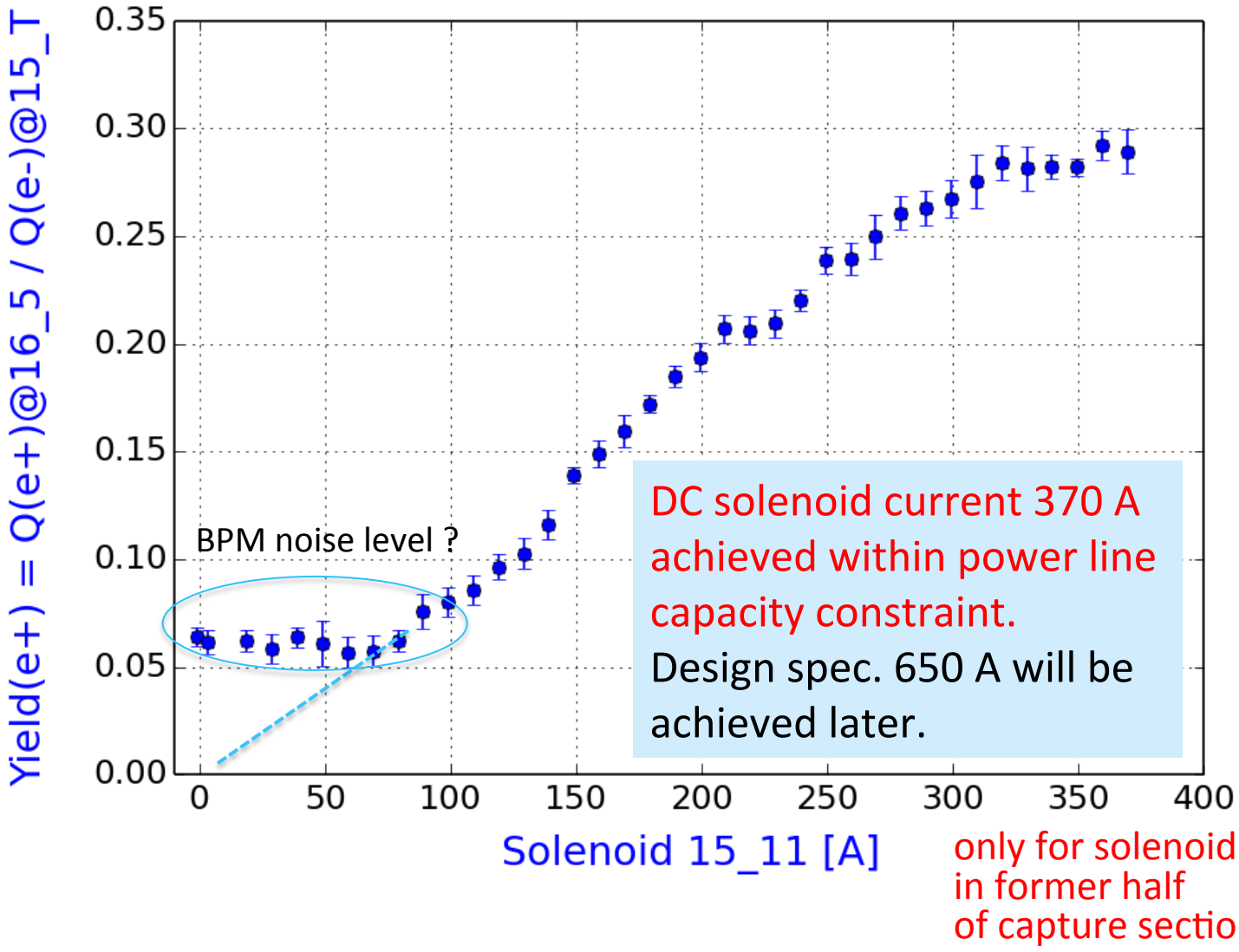
e+ yield vs. FC current



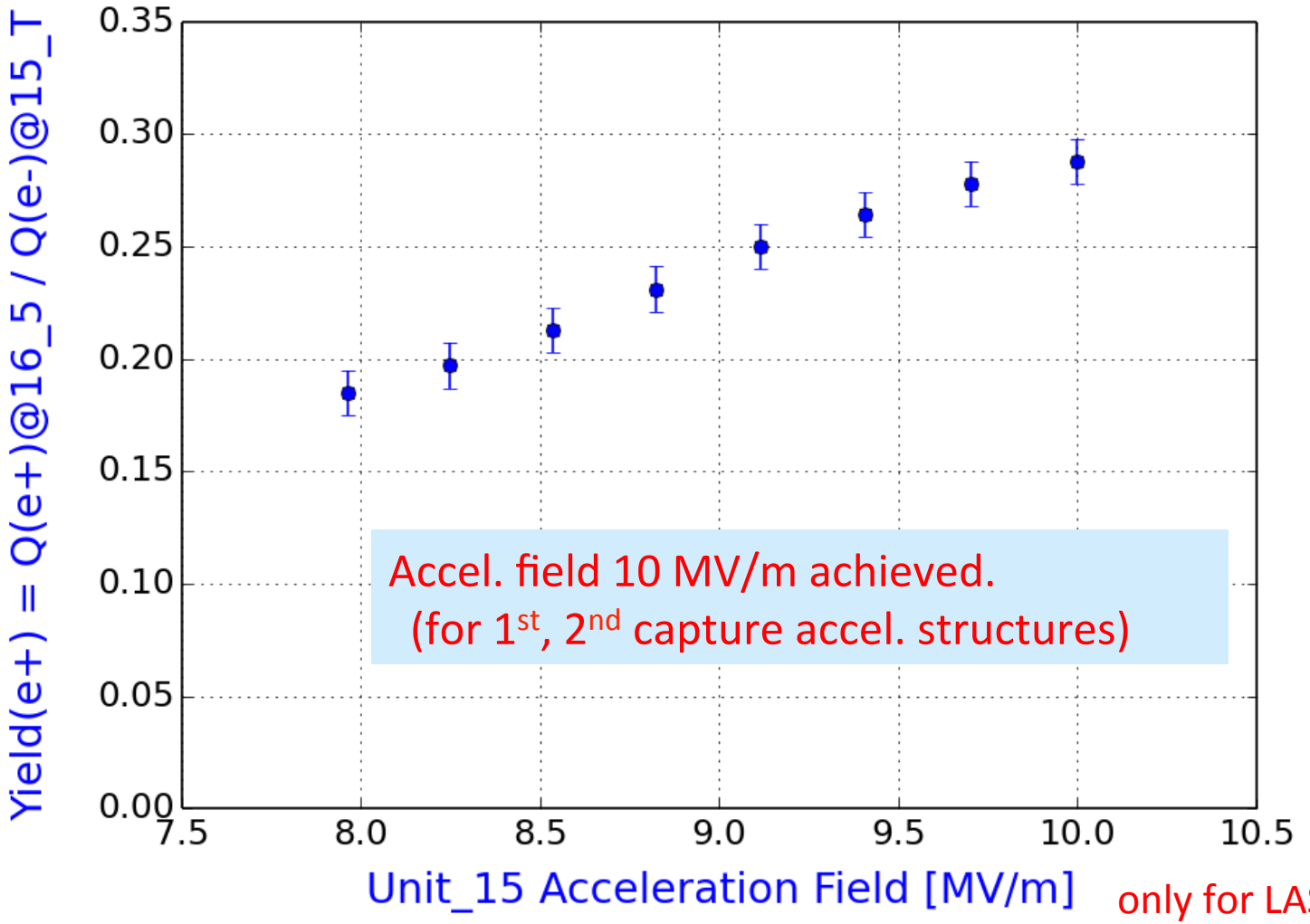
e+ yield vs. bridge coil current



e+ yield vs. DC solenoid current



e+ yield vs. accel. field strength

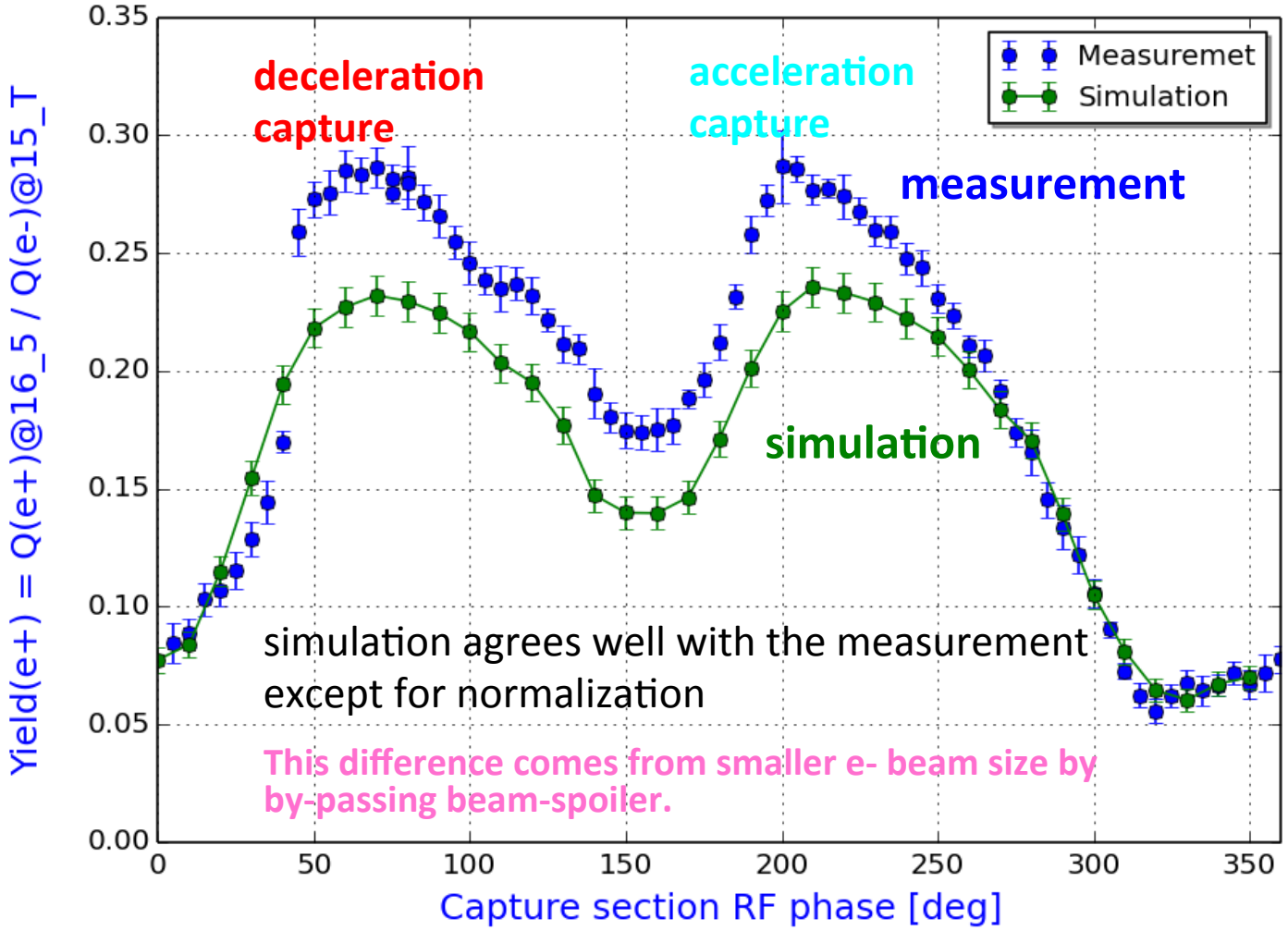


only for LAS #1, #2
in capture section

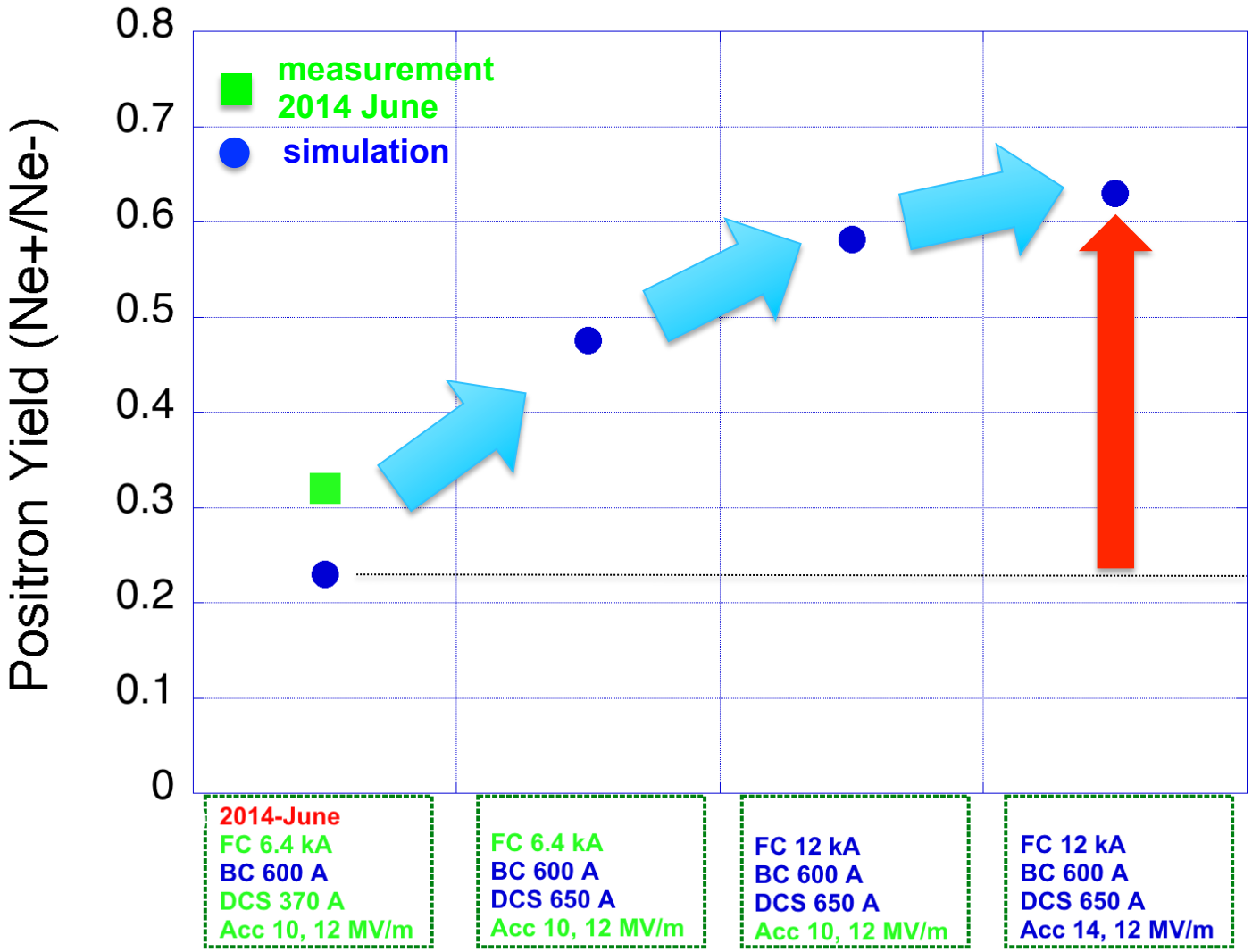
e+ yield vs. capture RF phase

deceleration/acceleration captures give comparable e+ yields

shorter bunch length and smaller energy spread for deceleration capture



Expected e+ yield improvement

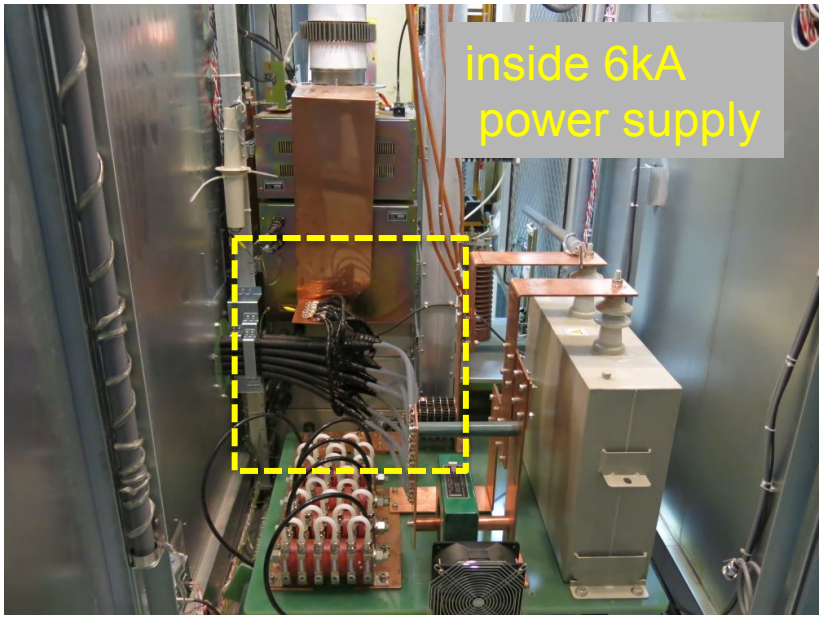


By raising
DC Solenoid field
FC field and
acceleration field
2.7 times
improvement
expected !!

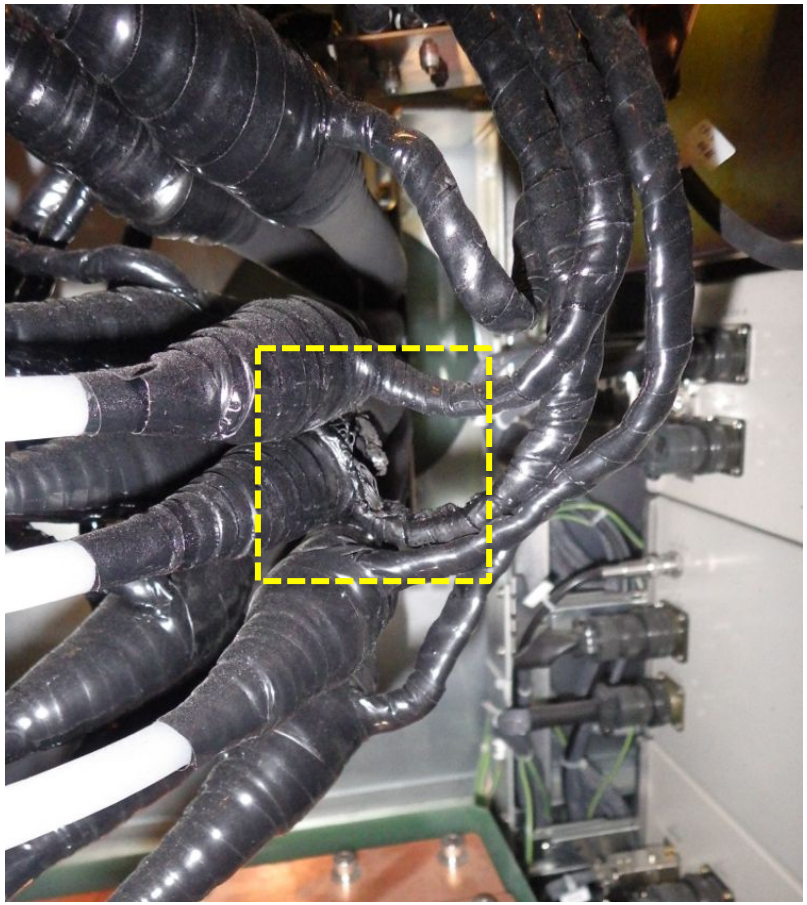
(5) FC cable accident & cable + power-line renovation

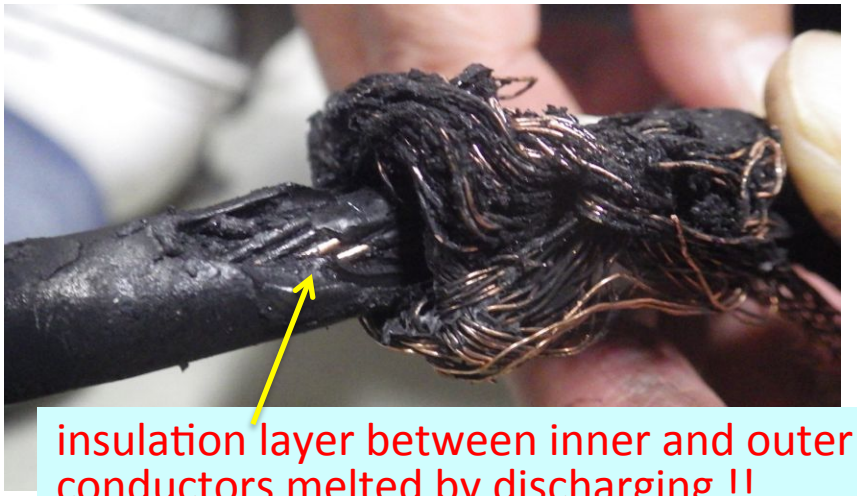
(2014 Dec. -> now)

FC power cable accident



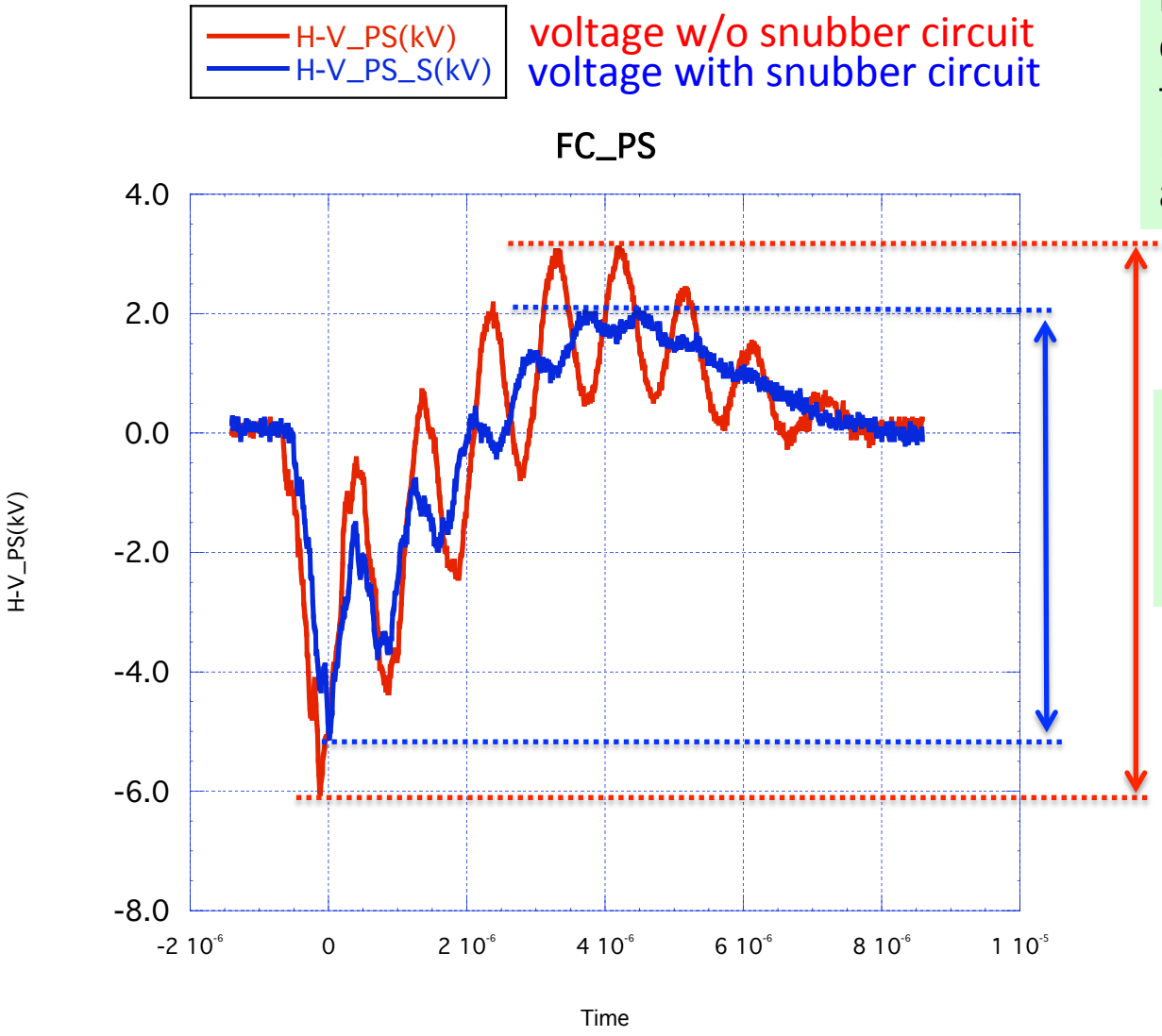
We started e+ commissioning in 2014 Dec.
Cable burning accident stopped FC operation.
It occurred at already-experienced 6kA,
due to the operation w/o snubber circuit.





operation w/o snubber circuit

voltage wave shape at power supply terminal



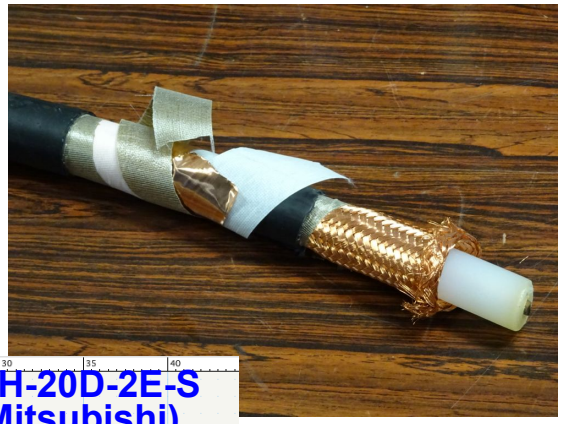
Before start of 2014 autumn run, we removed snubber circuit for convenience of future FC exchange work.
It should triggered the cable accident.

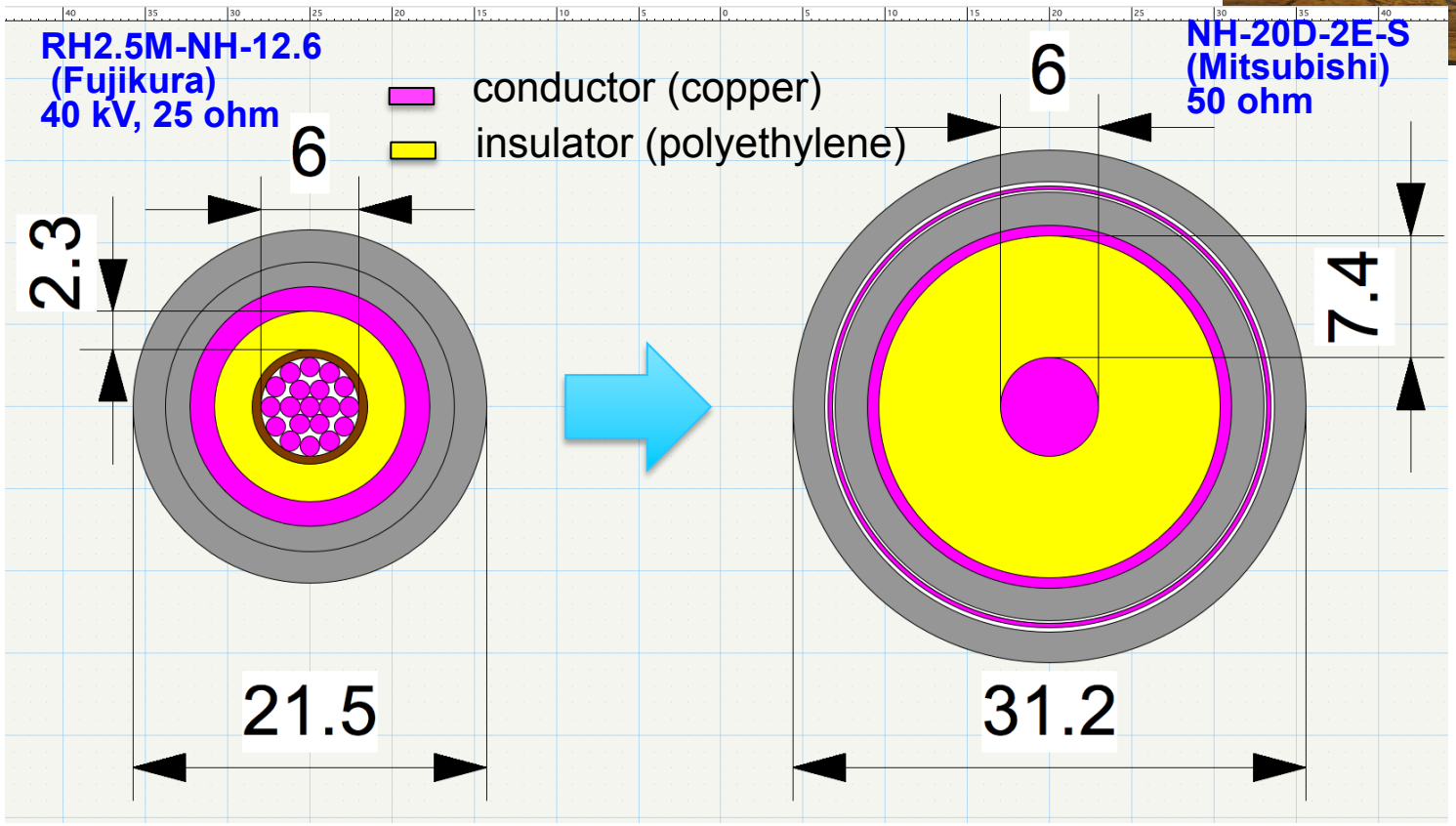
peak-to-peak voltage
at power-supply terminal
became 30% higher
by removing snubber circuit

Even with snubber circuit,
it is safer to have
much more voltage limit
margin of the HV cable !!

New FC cable

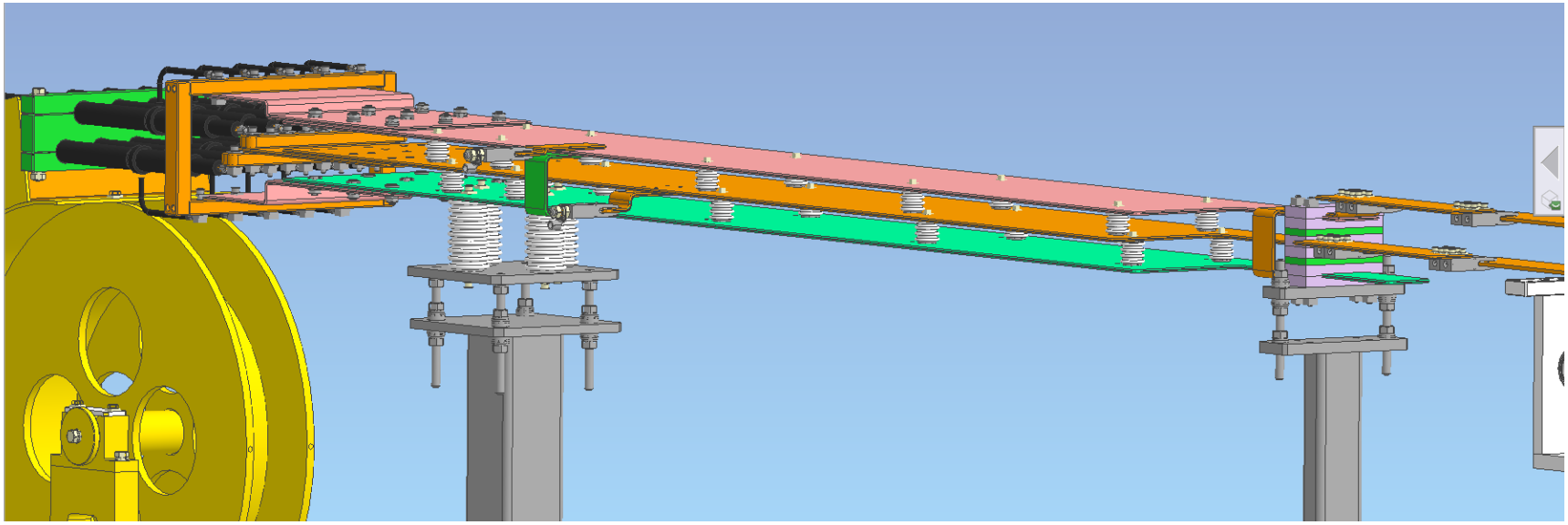
We will replace FC power cables to those have thicker insulation layer and higher-voltage limit.





triplate power line

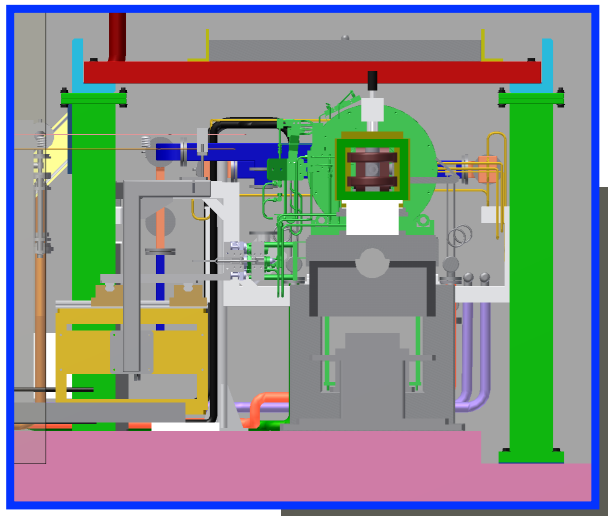
- In increasing FC current from achieved 6 kA to designed 12 kA, it is desirable suppress PS voltage (~ 18 kV) by circuit parameter tuning in order to avoid discharge problem.
- Reduce power line inductance from 4.2 uH to 3.2 uH by
  - modifying parallel plate from parallel plate to triplate
  - reducing plate gap from 60 mm to 34 mm
- Increase PS capacitance from 1.0 uF to 1.4 uF
- Trade-off is larger pulse width (4.7 us -> 6.7 us) which gives larger vibration in FC body.



Recovery & step-up of FC operation

- Reconstruction of FC test stand with (2015 February -> March)
  (1) spare FC (#4), (2) new 12kA power-supply, (3) new cables,
  (4) modified parallel-plate power line, (5) snubber circuit
- Test operation of FC (#4) at the test-stand for (2015 March->May)
  - High-voltage processing up to 12kA
    (especially at un-experienced level 6kA -> 12kA)
  - HV check against discharge
  - mechanical stability check of FC
- Power line reconstruction for FC (#3) in the beam line (2015 May)
  - (1) relocation of the 12kA power-supply to designed position
  - (2) installation of the new cables, power line & snubber to tunnel
- Positron beam commissioning (2015 June ->)

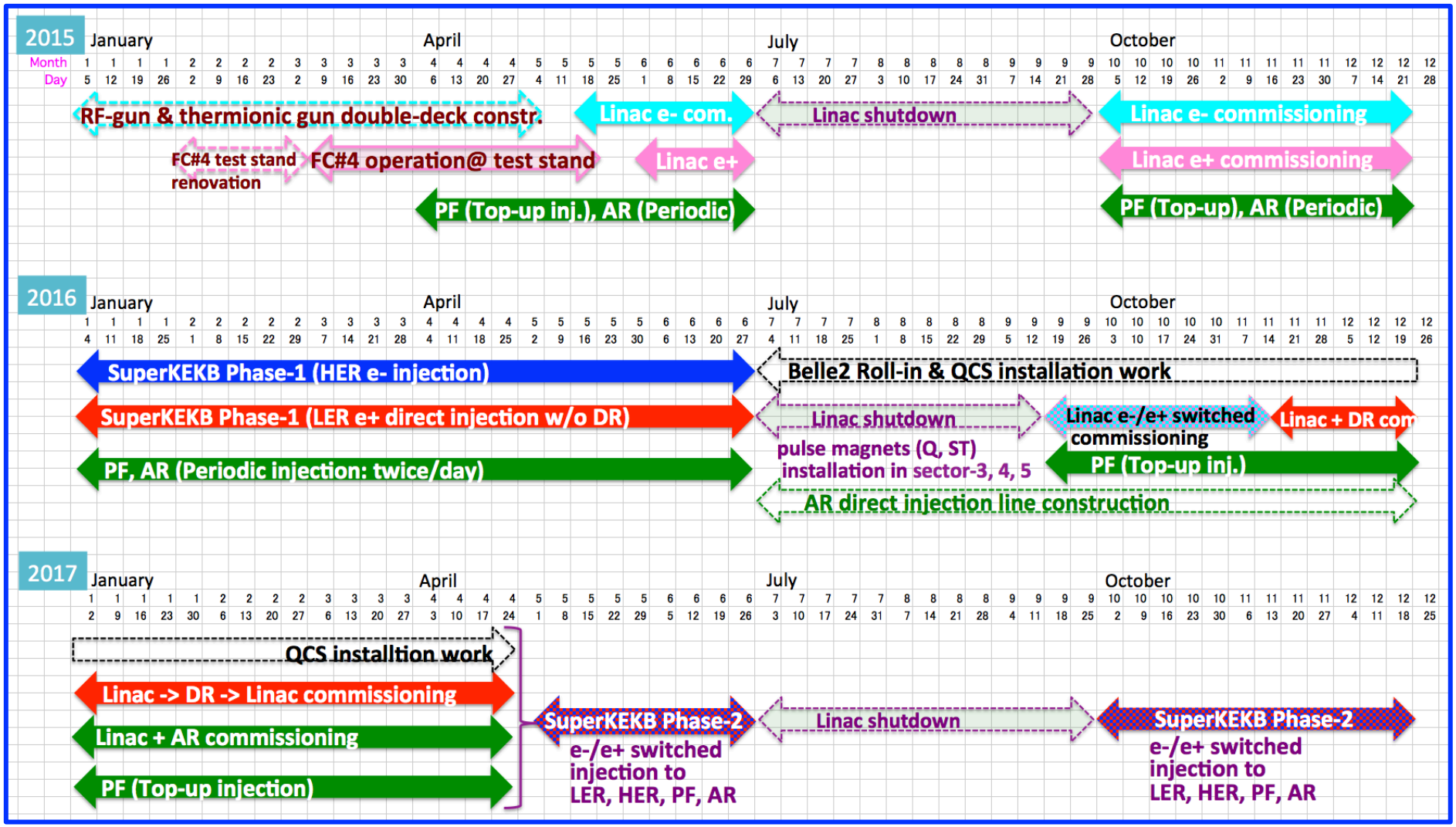
radiation shield installation



Radiation shield structure (200-mm thick iron) to be installed in 2015 March. Later, increased to 400 mm thickness.

(6) Schedule & Summary

schedule


2015
January
April
July
October
Month
Day
RF-gun & thermionic gun double-deck constr.
Linac e- com.
Linac shutdown
Linac e- commissioning
FC#4 test stand renovation
FC#4 operation@ test stand
Linac e+
Linac e+ commissioning
PF (Top-up inj.), AR (Periodic)
PF (Top-up), AR (Periodic)
2016
January
April
July
October
SuperKEKB Phase-1 (HER e- injection)
Belle2 Roll-in & QCS installation work
SuperKEKB Phase-1 (LER e+ direct injection w/o DR)
Linac shutdown
Linac e-/e+ switched commissioning
Linac + DR com
pulse magnets (Q, ST) installation in sector-3, 4, 5
PF, AR (Periodic injection: twice/day)
PF (Top-up inj.)
AR direct injection line construction
2017
January
April
July
October
QCS installtion work
Linac -> DR -> Linac commissioning
Linac + AR commissioning
PF (Top-up injection)
SuperKEKB Phase-2
e-/e+ switched injection to LER, HER, PF, AR
Linac shutdown
SuperKEKB Phase-2
e-/e+ switched injection to LER, HER, PF, AR

Summary

1) All the components of positron capture section have been installed in the beam line. (2014 April)
   (positron production target, flux concentrator, bridge coil, DC solenoid coils, LAS structures, beam spoiler, e+/e- separator)

2) Initial positron beam commissioning started (2014 June) with limited magnetic/electric field strength and the first positron observed after the positron source upgrade.

3) Positron yield Y(e+) = 20% (Q(e+)=0.20nC/Q(e-)=0.60nC) achieved at entrance of DR-LTR line. Design yield 50% will be achieved by improving parameters which is lower than the specifications.

4) Renovation of FC cables and power line is on-going after the cable burning accident (2014 Dec.).

5) Next positron commissioning will start in 2015 May after sufficient FC operation test at test stand for checking electrical/mechanical stability.