



Recovery of injector linac

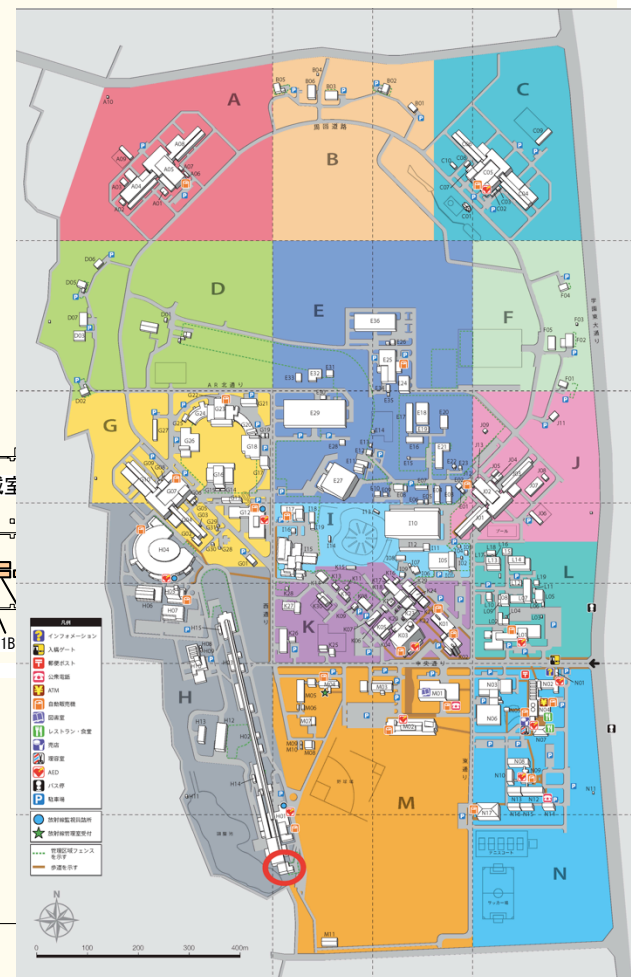
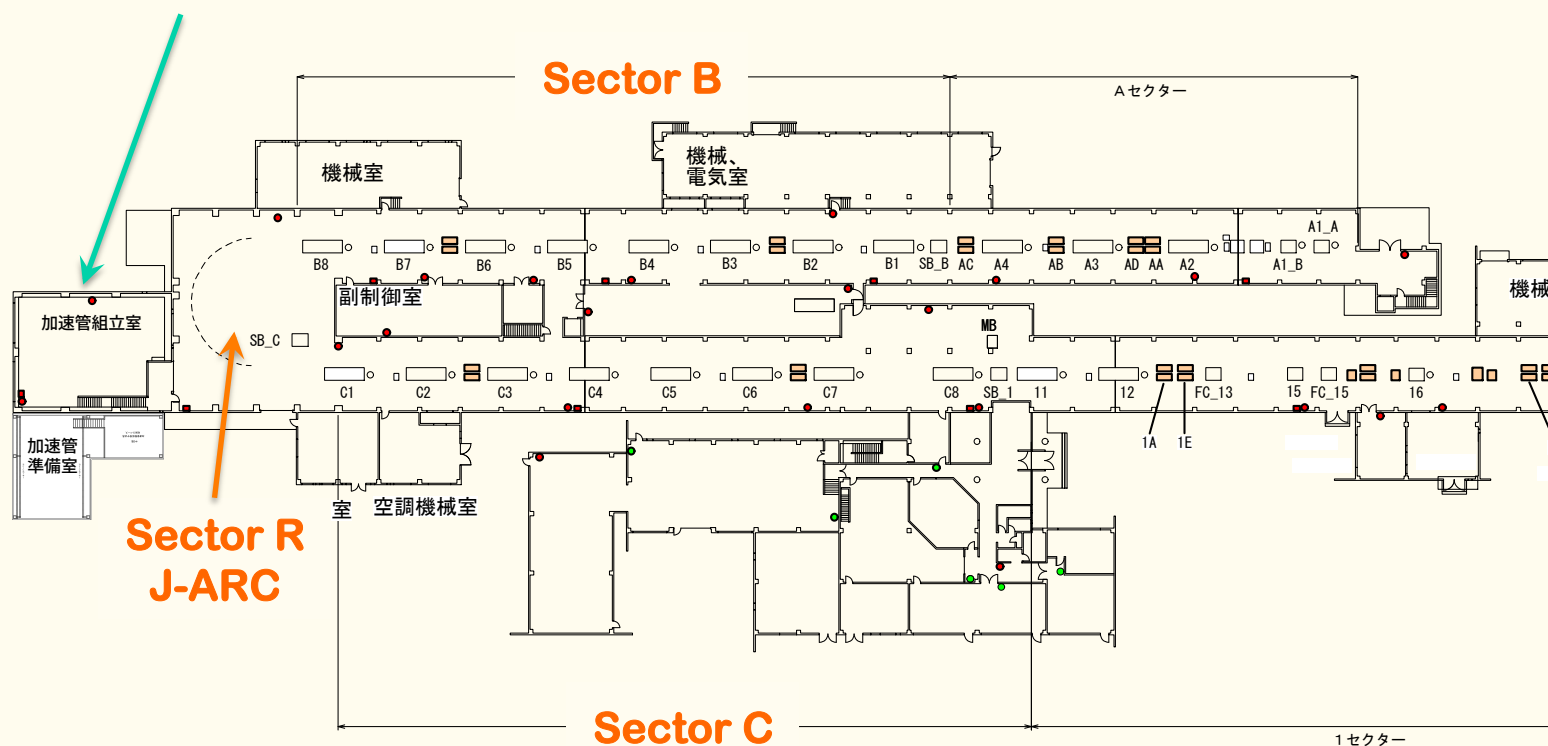
**Kazuro Furukawa
for Injector Linac group
July 9, 2019**



Injector Linac and Accelerating structure assembly room

Accelerating structure
assembly room

Southern 1/3 of Injector



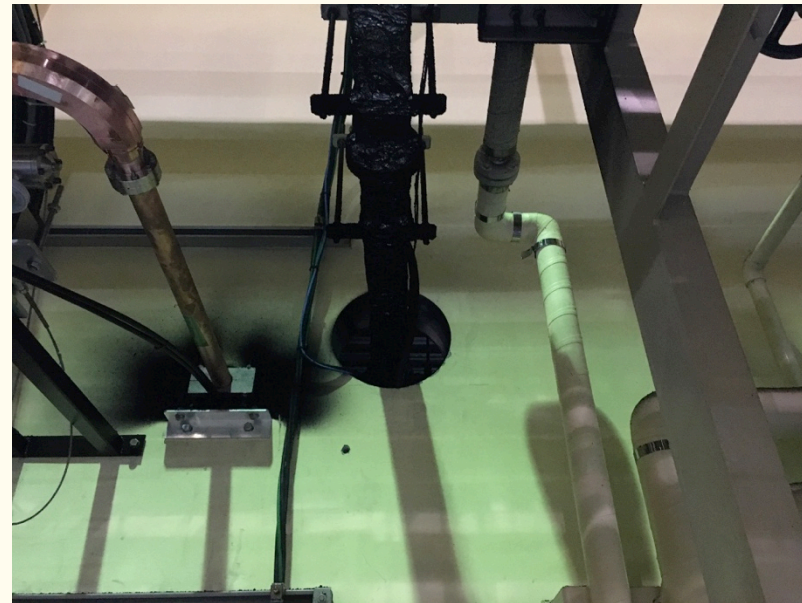
❖ Sectors B, R, C had to be recovered

✧ Approximately 25% of the Injector



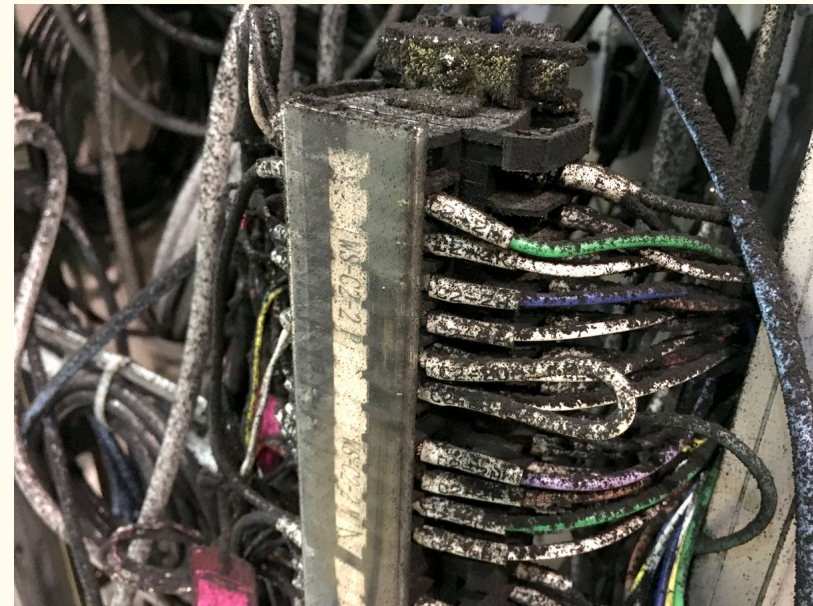
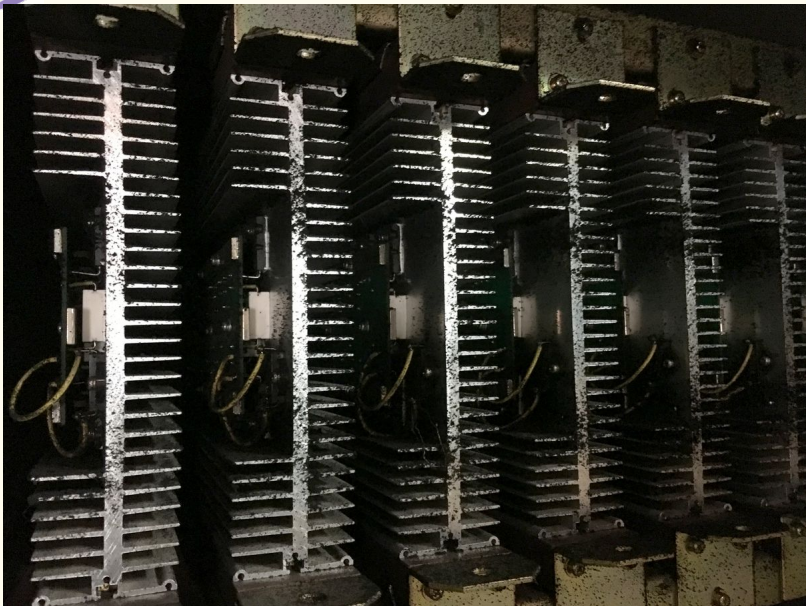
Injector Recovery

- ◆ **No injury**
- ◆ **Fire already extinguished before firemen entered**
- ◆ **No direct fire damage on the injector itself**
- ◆ **However, carbon soot sneaked into the injector**
 - ❖ **Discharge might prevent high-voltage operation of high-power pulsed modulators**
 - ❖ **Short-circuit might prevent high-precision operation of the instrumentation**
- ◆ **Chemical material (Diethyl Phthalate) accompanied with carbon soot**
 - ❖ **Required protective clothing**
- ◆ **Balance between quick recovery and complete cleanup**
 - ❖ **Certain recovery was left for summer shutdown**

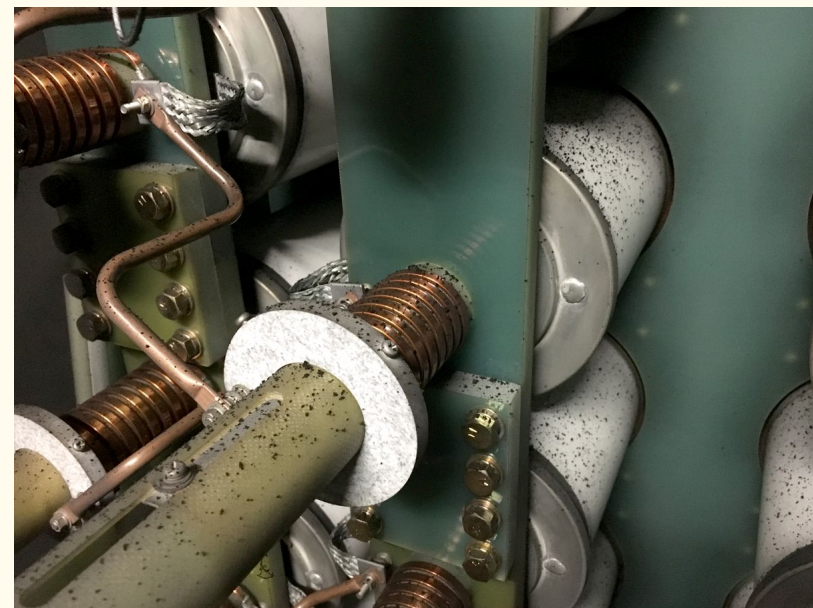


❖ Carbon soot sneaked through holes between rooms





❖ Carbon soot in the equipment





❖ Cleanup one by one



❖ Low-power & high-power tests





◆ Information Sharing via Meeting, Mail and Web

- ❖ Meeting in every morning
- ❖ Group leader meeting in every evening
- ❖ Daily update
- ❖ Mental health
- ❖ Physical health
- ❖ Environmental analysis
- ❖ Recovering strategy
- ❖ Utility recovery
- ❖ Equipment recovery
- ❖ Testing progress
- ❖ Beam schedule

入射器火災復旧について (Linac Fire Recovery, April 2019)

[ストレスイベント後の反応について \(安全衛生推進室、大井雄一産業医\) \(Response after stress event, May.10, **NEW**\) \[pdf\]](#)

[電子陽電子入射器の作業者のみなさまへ \(環境安全管理室、安全衛生推進室\) \(Linac safety reminder, Jul.1, **NEW**\) \[pdf\]](#)

[こころのケアについて \(安全衛生推進室、健康相談室\) \(Mental care, Apr.19\) \[pdf\]](#)

[揮発性有機化合物調査結果と作業管理 \(環境安全管理室、安全衛生推進室\) \(Gas analysis and healthcare, May.27, **NEW**\) \[pdf\]](#) : [\[word\]](#)

[保護具に関する作業管理の質問と回答 \(安全衛生推進室\) \(Gas mask and healthcare Q&A, Apr.22\) \[pdf\]](#)

[保護具に関する作業管理と健康管理 \(安全衛生推進室\) \(Gas mask and healthcare, Apr.19\) \[pdf\]](#)

[入射器棟粉塵濃度測定結果と今後の作業における注意 \(Dust assessment and recovery, Apr.17\) \[pdf\]](#)

[化学物質情報概要 \(Chemical overview, Apr.6\) \[pdf\]](#)

[化学物質情報 \(SDS\) \[pdf\]](#) : [\[Original link\]](#)

[入射器入域安全確保 \(Linac safety, Apr.5, OBSOLETE\) \[pdf\]](#)

[安衛室分析 \(Chemical analysis, Apr.5, OBSOLETE\) \[pdf\]](#)

[安全衛生推進室巡視点検報告 \(衛生管理者、安全衛生管理者\) \(Safety health inspection, May.9, **NEW**\) \[pdf\]](#) : [\[word\]](#)

[安全衛生推進室巡視点検報告 \(産業医、産業看護師\) \(Safety health inspection, May.9, **NEW**\) \[pdf\]](#) : [\[word\]](#)

[安全衛生推進室巡視点検報告 \(Safety inspection, Apr.11\) \[mail\]](#) : [\[word\]](#)

[入射器 Beam 立ち上げ進捗 \(Linac restart progress, Apr.25\) \[pdf\]](#) : [\[excel\]](#)

[入射器復旧作業進捗 \(Linac recovery progress, Apr.19\) \[pdf\]](#) : [\[excel\]](#)

[入射器 Beam 立ち上げ進捗概要 \(Linac restart progress overview, Apr.24\) \[pdf\]](#)

[火災報知設備と加速器運転 \(Fire alarm and operation, Apr.19\) \[pdf\]](#)

[施設部復旧情報 \(Utility recovery daily progress, Apr.26\) \[pdf\]](#)

[施設部復旧情報 \(Utility recovery daily progress, Apr.24\) \[pdf\]](#)

[サブ変電室回復情報 \(Substation recovery progress, Apr.16\) \[pdf\]](#)

[対策会議報告と立上げ打合せ \(Recovery daily progress report, Apr.22\) \[mail\]](#) : [\[powerpoint\]](#)

[対策会議報告 \(Recovery daily progress report, Apr.19\) \[mail\]](#) : [\[powerpoint\]](#)

[火災について \(共同利用者の方へ\) \[KEK News\]](#) : [To KEK Users: On the fire, Apr.25 \[English\]](#)

[火災について \(共同利用者の方へ\) \[KEK News\]](#) : [To KEK Users: On the fire, Apr.11 \[English\]](#)

[火災について \[KEK Press release\]](#) : [Fire at linac, Apr.4 \[English\]](#)

[入射器入域手順 \(Linac entrance procedure, Apr.8\) \[pdf\]](#)

[入射器概略図面 \(Linac floor plan\) \[pdf\]](#)

[Gallery 概略図面 \(Gallery floor plan\) \[pdf\]](#) : [Tunnel 概略図面 \(Tunnel floor plan\) \[pdf\]](#) : [空調範囲図面 \(Airconditioner floor plan\) \[pdf\]](#)

[火災概要 \(Incident overview slide, Apr.8\) \[pdf\]](#)

[火災概要 \(Incident overview slide, Apr.5\) \[pdf\]](#)

[火災概要報告 \(Incident overview 3-page report, Apr.4\) \[pdf\]](#)

[詳細 Mail 共有情報 \(Linac-Update mail archive\)](#)

[入射器復旧写真 \(Linac recovery photo archive\)](#)

[暫定報告 \(Tentative report, May.10, **NEW**\) \[pdf\]](#)

[時系列記録 \(Timeline\) \[html\]](#)

NHK 首都圏 (Apr.4) : [つくば市 \(Apr.4\)](#)

Kazuro Furukawa <linac-request@mail-linac.kek.jp>, Apr.7-Jul.1.2019.
[\[Linac\]](#) [\[Linac-update\]](#) [\[SuperKEKB\]](#) [\[Accelerator\]](#) [\[KEK Staff\]](#) [\[KEK\]](#)



Recovery progress

Apr.3: Fire. Carbon soot was anticipated for high-power and high-precision operation.

Apr.4: During the investigation, hazardous chemical material was found as well as carbon soot.

Apr.5, 6: Partial clean-up was performed as a test, and also for devices to be sent out to maker companies, with limited pieces of protective clothing.

Apr.8: As protective clothing arrived, full clean-up started. Several devices were found to be difficult to fix in a short term, and an operation plan was developed.

Apr.18: Low power test started.

Apr.22, 23: High power test was performed successfully.

Apr.23: Beam test began.

Apr.25: Limited HER injection started.

Apr.26: HER and LER injections, and then collision started.

May.7: PF light source injection as originally scheduled.



Impact on Injector

- ◆ **Recovered with much help from everyone**
 - ❖ All divisions in KEK and outside companies
- ◆ **Certain equipment was postponed to recover**
 - ❖ Energy lowered from 1.5 GeV to 1.35 GeV
 - ✧ at J-ARC, 180 degree bending section
 - ❖ Until summer shutdown
 - ✧ 2 of 60 RF sources would be off
 - ✧ 1 of 2 bending magnet power supplies would be off
 - ❖ Found not to impact much on the injection
 - ✧ with present beam specifications
 - ❖ Should be recovered before autumn operation
- ◆ **Many of backup devices were consumed**
 - ❖ May mean acceleration of renewal for aging devices, actually
- ◆ **Budget may depend on insurance refund**
 - ❖ Planning in this and the next fiscal year



Injector Operation

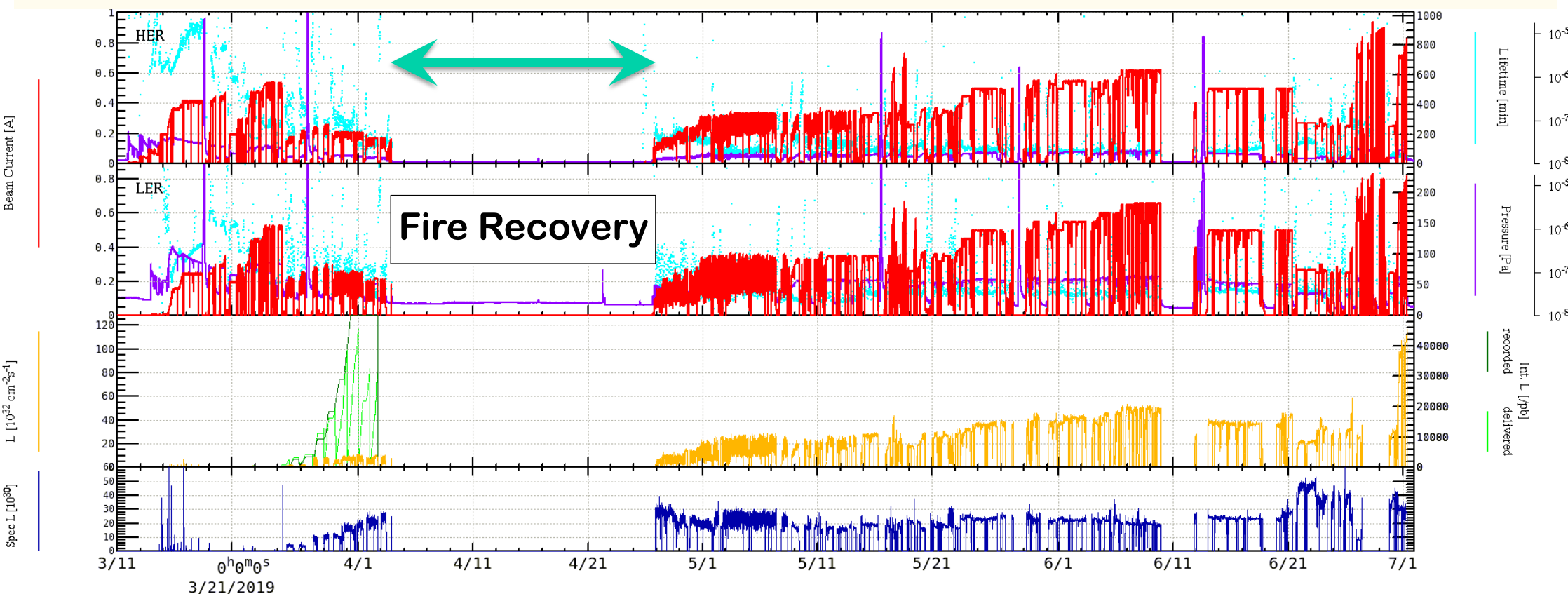
- ◆ **Capacitors at injector are different from Nextef's**
 - ❖ Has ceramic container instead of plastic container
 - ❖ Has lower designed potential gradient (longer lifetime)
 - ❖ Has puncture protection
 - ❖ Performed degradation check every summer
- ◆ **Tentative operation procedure in injector linac**
 - ❖ Local operator investigation is enforced on modulator HV interlock
 - ✧ Observation for any anomalous behavior or capacitor puncture
 - ❖ More frequent observation of southern part of injector
- ◆ **More surveillance devices would be installed**
- ◆ **Important to start S-band structure assembly in 2020**
 - ❖ As originally planned to fight against aging structures
 - ❖ Structure assembly room should be recovered early
- ◆ **Careful knowledge transfer from the original designer to the next generation**



Impact on SuperKEKB Operation

◆ Beam suspension for 3 weeks

- ✧ at the first stage of phase 3 operation
- ✧ at the middle of luminosity development





Impact on SuperKEKB Operation

- ◆ Operation suspension for 3 weeks was unfortunate, but
- ◆ Resultant recovery did not impact the operation much
- ◆ Part of suspension would be compensated in 2020

- ◆ For example of recovering
 - ❖ Simultaneous top-up injection was initiated as originally planned
 - ❖ It is one of the mission of the injector in upgrade



Pulse-to-pulse modulation

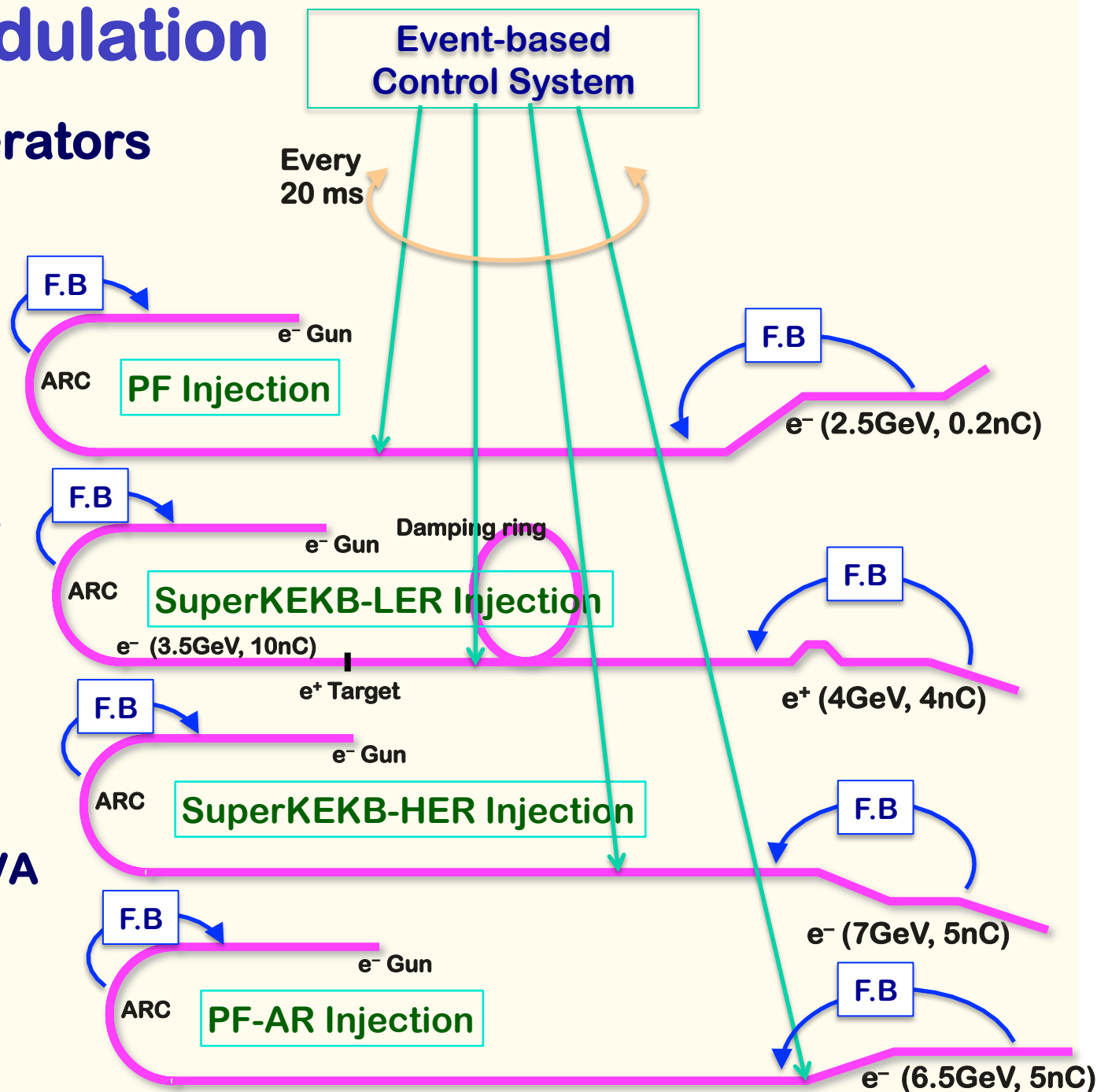
◆ Four PPM virtual accelerators for SuperKEKB project

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

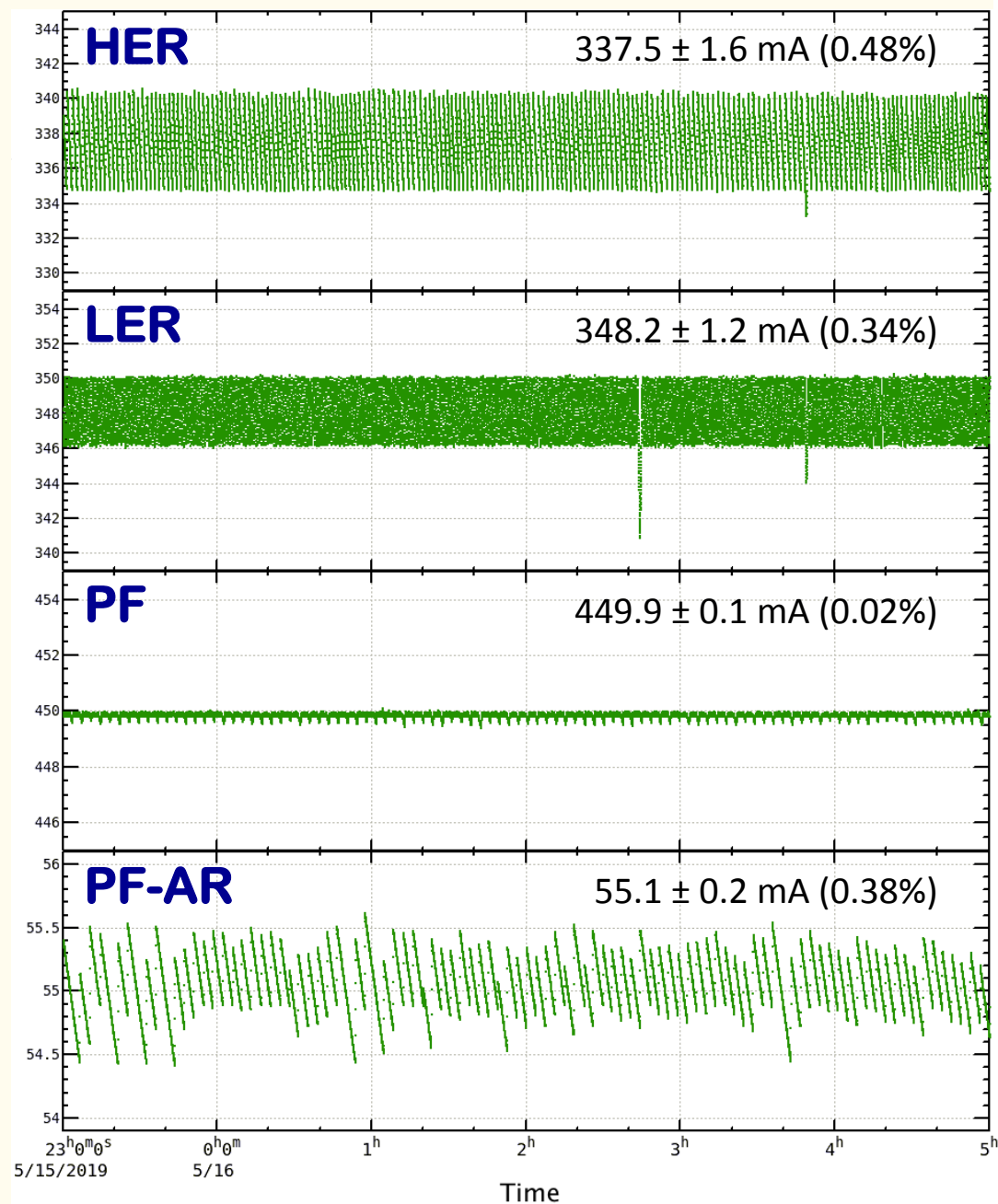




Simultaneous 4 + 1 Ring Top-up Injection

◆ Realized for the first time

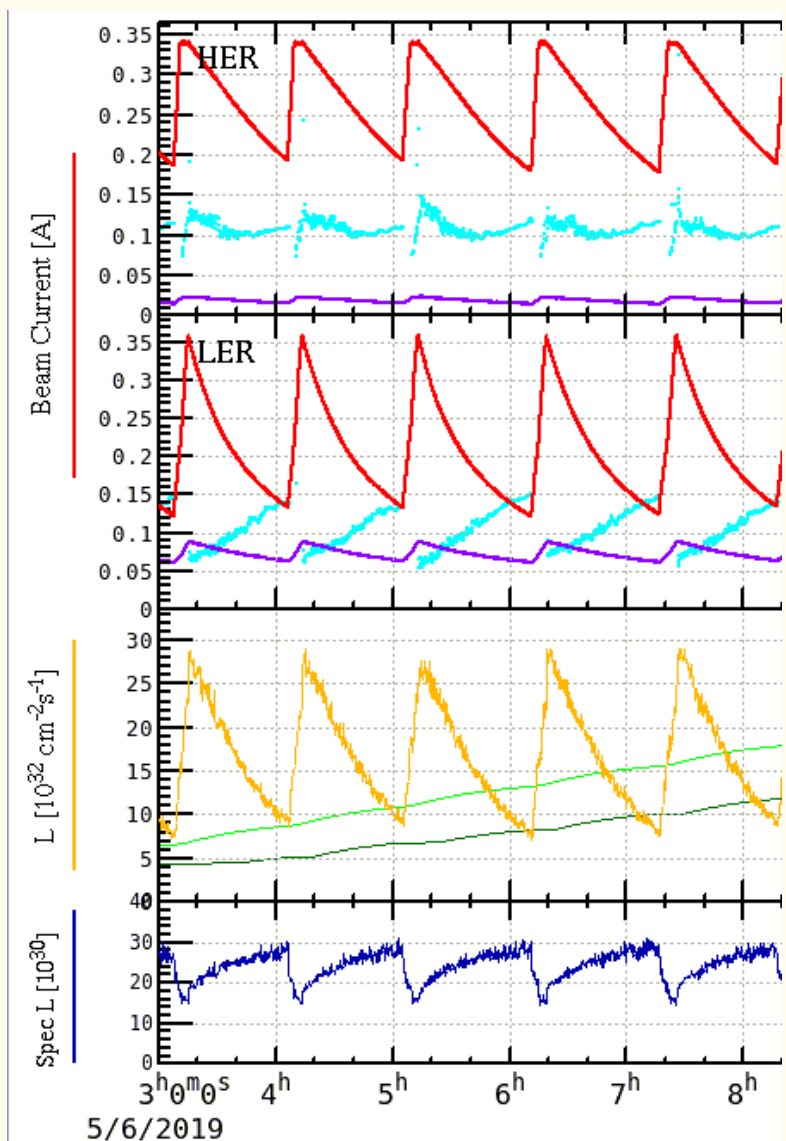
- ✧ SuperKEKB HER 7 GeV e⁻
 - ✧ SuperKEKB DR and LER 4 GeV e⁺
 - ✧ Photon Factory 2.5 GeV e⁻
 - ✧ PF-AR 5.0 / 6.5 GeV e⁻
- ❖ 4 beams are modulated at 20 ms PPM
 - ❖ More than 200 pulsed devices were constructed for SuperKEKB, as well as beam and RF monitors
 - ❖ Injection noise (background) were well studied from the 2nd week of May



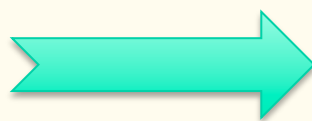


Simultaneous Top-up Injections

◆ Integrated luminosity improvement (example)

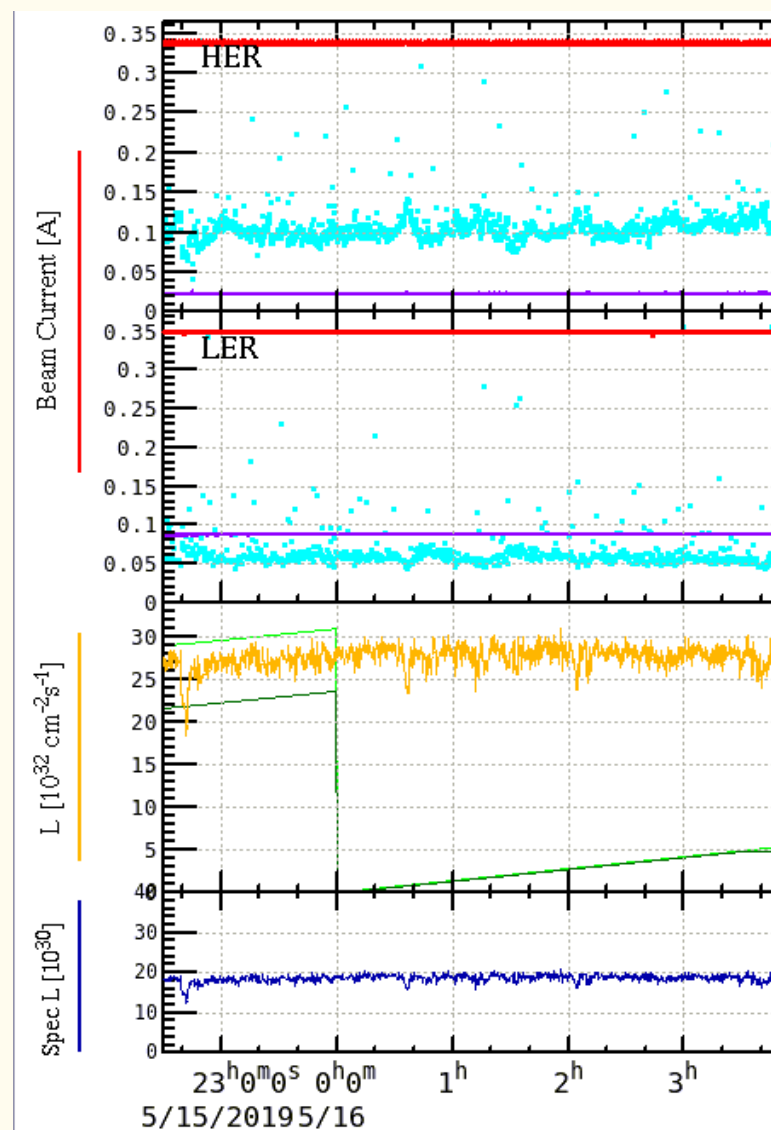


17.54 /pb in 5.15 hr
(5 fills)
on May.6



41.64 /pb in 5.15 hr
(top-up)
on May.16

237%
improvement





Developments

◆ Recommendations in the previous review meeting

- ❖ Still working on them
- ❖ 3. Continue to develop the critical injector systems, including the RF gun and the positron source. Identify the sources of emittance blow up and beam jitters through beam studies. Develop a detailed plan for reducing the injection emittances from about 150 micron for Phase II to the needed 20 to 40 micron for Phase III. (R3.1)
- ❖ 4. Perform a new study to improve the work hardening process of the copper FC coils. Compare with the experience at other laboratories, e.g. at SLAC and BINP. (R7.3)
- ❖ etc.
- ❖ Reports will be provided in the following talks



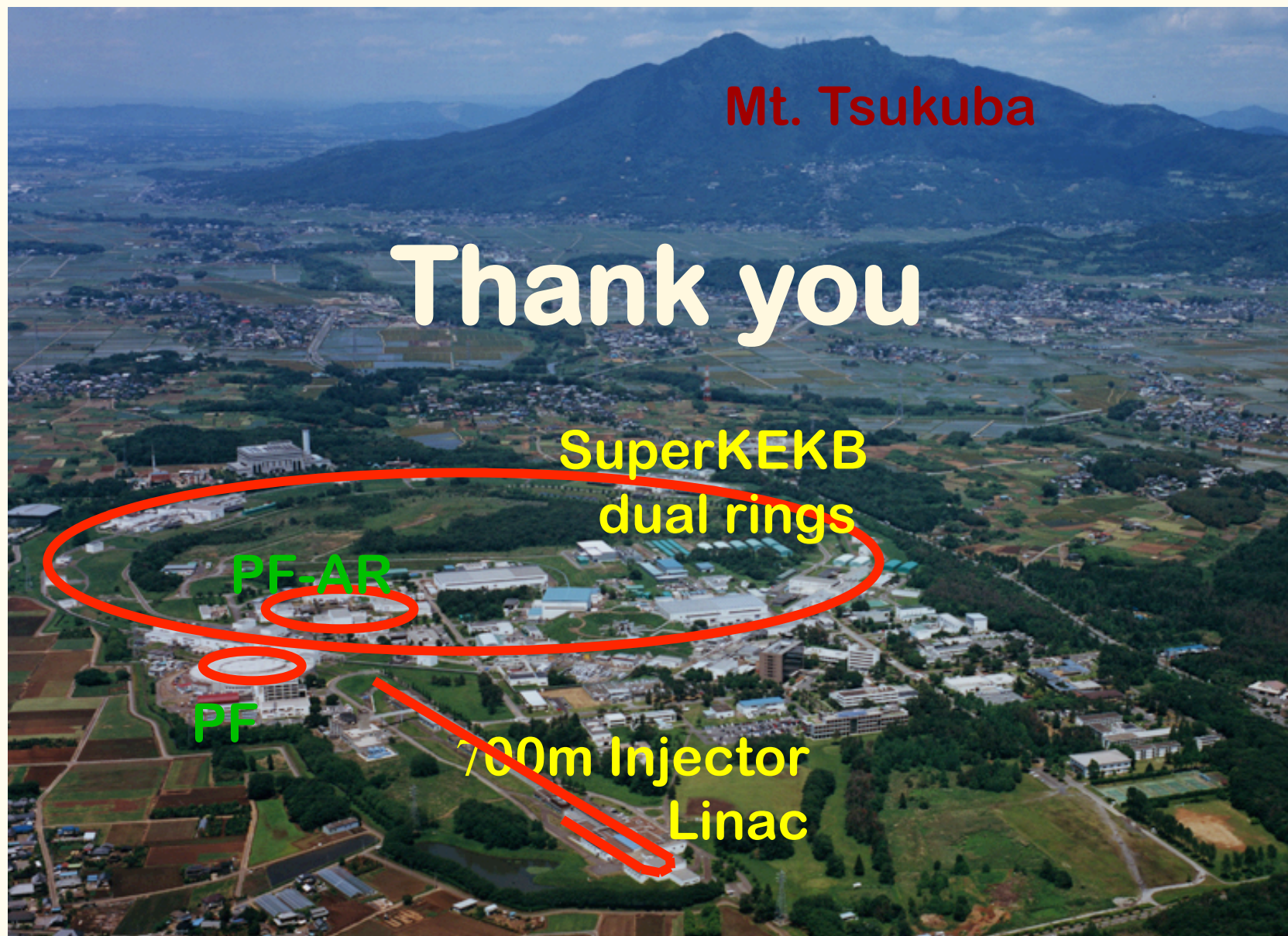
Talks on Injector Linac

- | | |
|--------------------------------------|-------------|
| ◆ Beam background (Injection tuning) | N. Iida |
| ◆ Fire at NexteF | T. Abe |
| ◆ Recovery of injector linac | K. Furukawa |
| ◆ Injector beam operation | M. Satoh |
| ◆ Injector RF and LLRF | T. Miura |
| ◆ Injector beam monitors | F. Miyahara |
| ◆ RF gun | R. Zhang |
| ◆ Positron source | Y. Enomoto |
| ◆ Emittance preservation | Y. Seimiya |



Summary

- ◆ We should not have the same disaster with better preparation
- ◆ We are slowly recovering from the disaster
- ◆ We are improving the injector learning from the beam as well as the past experiences
- ◆ Trial and error for new challenges may be necessary depending on many parameters along the accelerator chain
- ◆ With some Phronesis we can enjoy accelerators
 - ❖ **Phronesis [Greek]: Practical wisdom, Ability to understand the Universal Truth**



Conference papers at <<http://www-linac.kek.jp/linac/>>







Timeline

- ◆ **During SuperKEKB operation in decay mode**
- ◆ **20:58 Last surveillance performed**
- ◆ **21:15 Interlock interrupted the Nextef operation**
- ◆ **21:44 Fire alarm**
- ◆ **21:48 Much smoke found**
- ◆ **21:50 – 22:05 Firemen called and arrived**
- ◆ **23:15 Checked by 6 firemen, radiation manager**
- ◆ **High power modulator was found burnt**
 - ❖ **Accelerator structure assembly room**
 - ❖ **Used for X-band development test facility (Nextef)**



First KEK announce on April 4th

Fire in the accelerator structure assembly room at electron-positron injector linac

At 9:44 pm on April 3rd, on the KEK Tsukuba campus, a fire alarm went off in the accelerator structure assembly room at electron-positron injector linac (a general radiation area) and the fire department was called to the site.

The cause of the alarm was determined to be an electric pulse modulator used in microwave power source, which had suffered a burnout.

This event did not cause any human injuries or radiation leakage. We apologize to everyone for any concern or alarm. For a timeline of the incident and other details, please see the following link.

Timeline

9:44 pm

Fire alarm goes off, 2 researchers from Accelerator division 5 go to the accelerator structure assembly room with the alert and confirm the presence of smoke.

9:52 pm

As a safety precaution, the accelerator's beams are aborted.

11:15 pm (approx.)

Firefighters and KEK Tsukuba Campus Radiation Safety personnel enter

the site, confirm that there is no danger from radiation, heat, etc.

As there was no danger of fire spreading to radioactive isotopes, external shutters were opened and the room was vented naturally.

1:30 am, April 4th

The fire is confirmed to be extinguished.

2. Pre-fire Conditions

A check around 7 pm noticed nothing out of the ordinary. Around 9:30 pm the pulse modulator was remotely confirmed to have stopped unexpectedly.

3. Fire Location and Cause

Performance tests of the accelerating structure require microwaves, and we believe that a pulse modulator used in their generation had an undetermined malfunction that caused it to emit smoke. The exact cause is under investigation.

4. Effect on Accelerator Experiments

The accelerator in the Electron-Positron Injector linac delivers electrons and positrons to the SuperKEKB collider and the Photon Factory light sources, but research carried out in the accelerating structure assembly room is entirely separate from these accelerators.

This effect that this incident will have on on-going experiments is currently under investigation. Once it has been confirmed to be safe, the experiments plan to restart.