

# Operation of accelerators at KEK e-/e+ injector linac

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# KEK (since 1971)



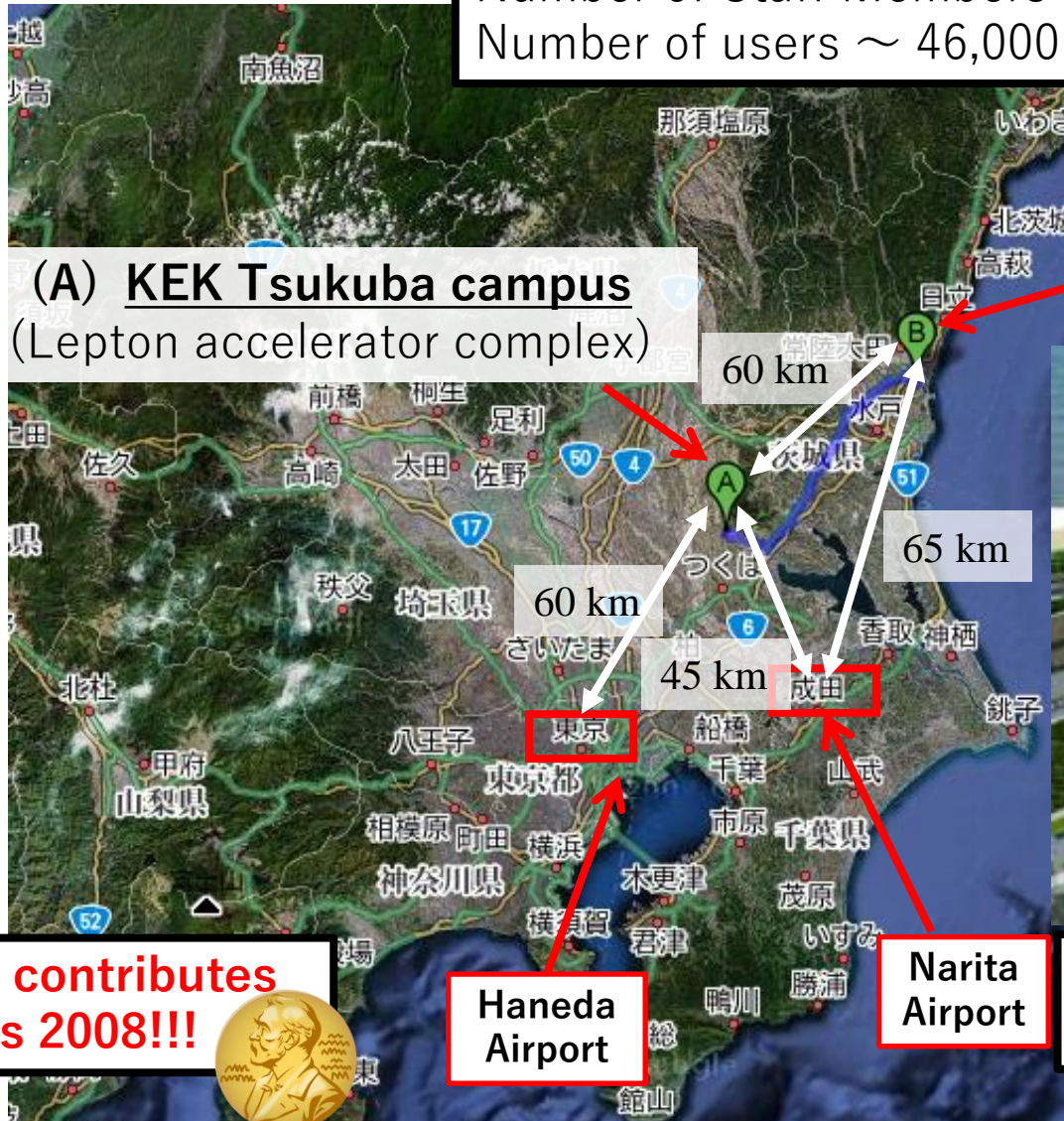
Number of Staff Members ~ 700  
Number of users ~ 46,000



Japan

(A) KEK Tsukuba campus  
(Lepton accelerator complex)

(B) KEK Tokai campus  
(J-PARC)



- SuperKEKB
- Photon factory (PF, PF-AR)
- Injector linac
- Accelerator Test Facility (ATF)
- Compact ERL (cERL)
- Superconducting Test Facility (STF)

**KEKB/Belle experiment contributes to Nobel Prize in Physics 2008!!!**



Haneda Airport

Narita Airport

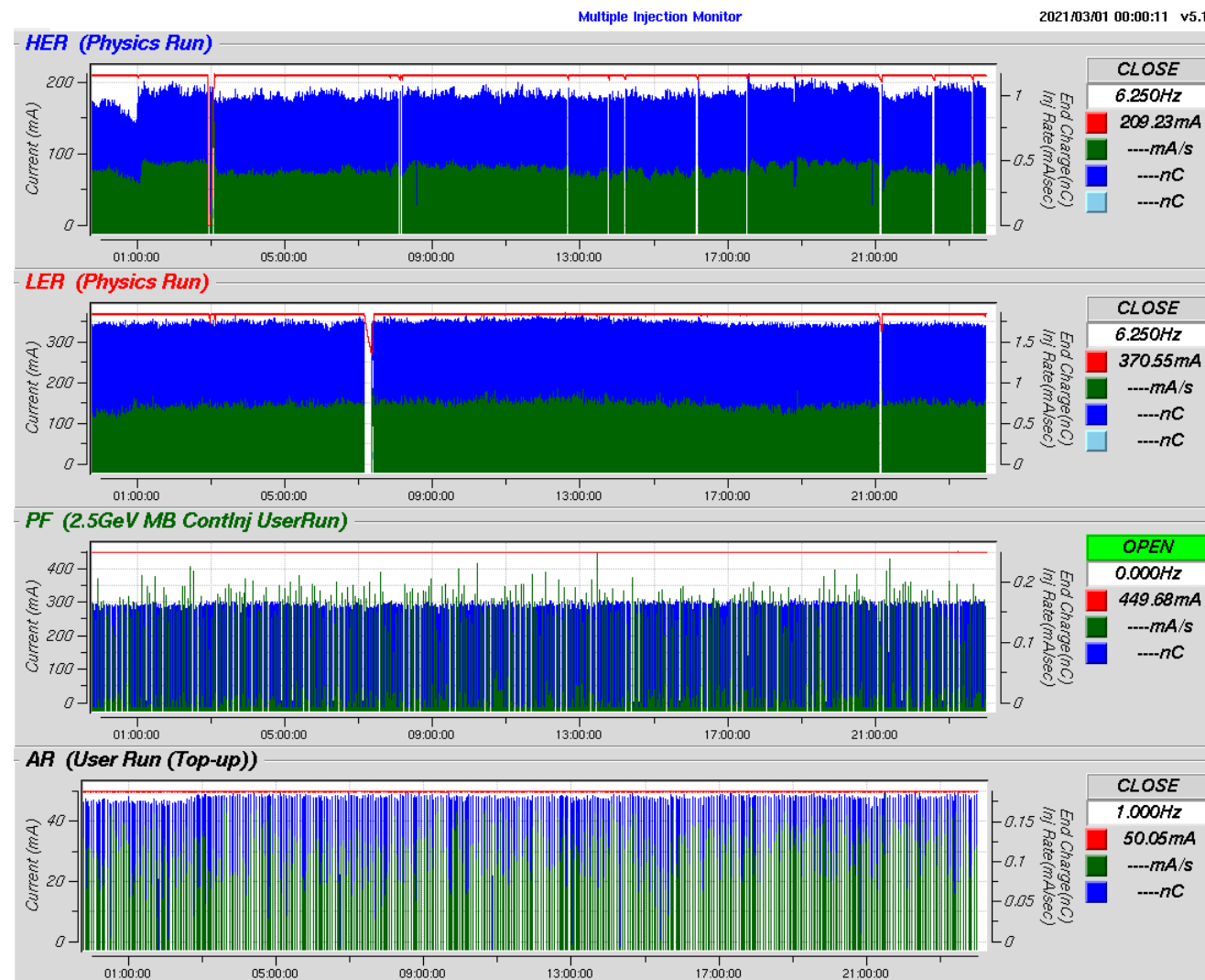
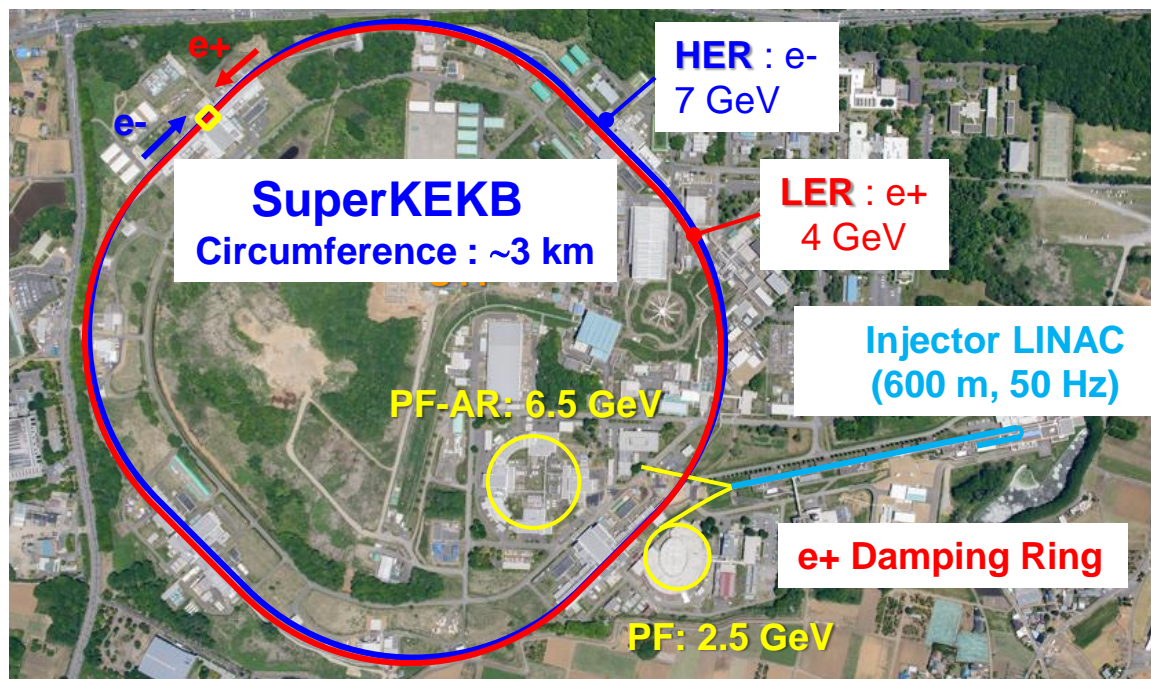
**J-PARC/T2K experiment contributes to Nobel Prize in Physics 2015!!!**



# Lepton accelerator complex in Tsukuba campus

## - simultaneous top-up since 2019 -

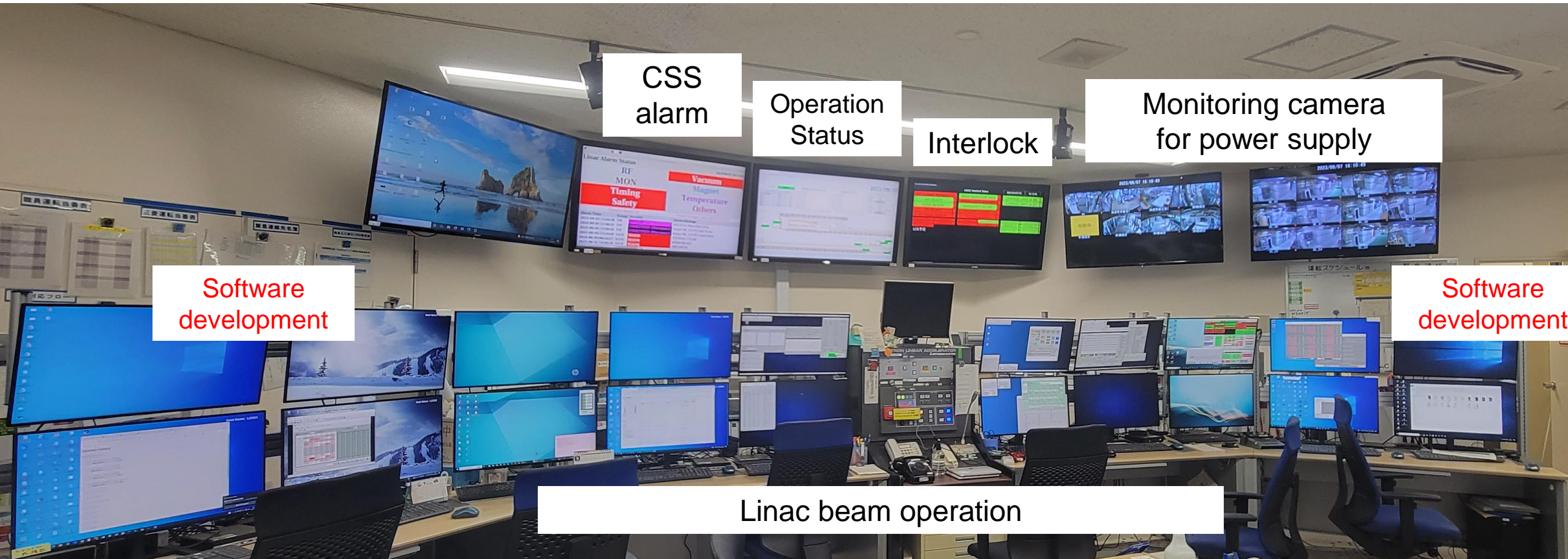
- Complex operation has been conducted with the high-performance accelerator control systems.



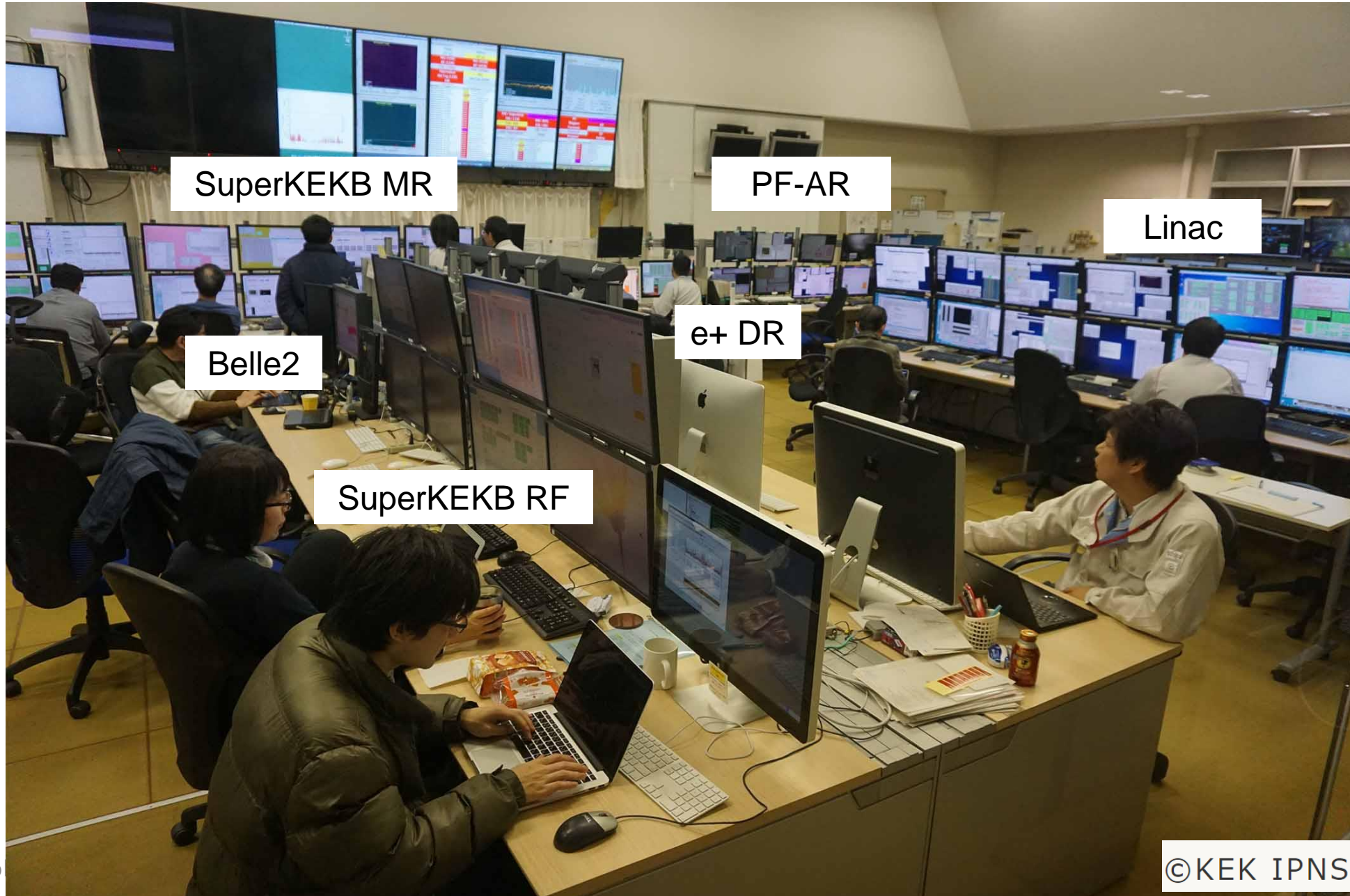
Stored current (red lines) (24 hours)

# Linac local control room

- Twenty 27-inch LCD and six 55-inch LCD for linac operation
- Large LCD show alarm status, interlock status, and operation status
- Monitor size is gradually improved: 15-inch -> 18-inch -> 21-inch -> 27-inch



# Central control room



SuperKEKB MR

PF-AR

Linac

Belle2

e+ DR

SuperKEKB RF

# # of operators for accelerator operation

- A three shift operation, one or two operators and one safety shift (KEK staff) are assigned in each shift.
- In addition, some operators are also assigned to the maintenance work in weekday dayshift.
  - prepare and/or fix spare power supply, software development, assist R&D work

Accelerator (# of operators in total)	Morning shift (0:00 – 9:00)	Day shift (9:00 – 17:00)	Evening shift (17:00 – 0:00)
Linac (12)	2	2	2
SuperKEKB/PF-AR (12)	2	2	2
PF (7)	1	1	1

# Contact book for troubleshooting

- Linac operator can fix most troubles.
- Safety shift staff call expert staff when serious trouble occurs.
- Contact book is prepared for each group and device.

Device name		Person in charge		
各種機器		担当職員（敬称略）()内はPHS番号 ※トラブル発生時は先頭から連絡する。青字は代表者。		
サブプースターユニット関係	クライストロン	松本（利）（4701）	松本（修）（4645）	
	パルス変調器	中島（4087）	夏井（4862）	川村（4523）
	半導体スイッチ	中島（4087）	夏井（4862）	川村（4523）
	HV 電源	中島（4087）	夏井（4862）	川村（4523）
クライストロン関係	クライストロンアセンブリ	松本（修）（4645）	川村（4523）	
	集束電磁石電源	松本（修）（4645）	川村（4523）	
	高周波窓	松本（修）（4645）	松本（利）（4701）	
	SHB アンプ	荒川（4049）	松本（利）（4701）	矢野（4376）
LLRF 関係	マスターオンレータ	松本（利）（4701）	三浦（4798）	矢野（4376）
	恒温槽本体	荒川（4049）	松本（利）（4701）	矢野（4376）
	恒温槽内部機器	片桐（4410）	松本（利）（4701）	矢野（4376）
	小型励振器	三浦（4798）	片桐（4410）	矢野（4376）
	600W RF アンプ	荒川（4049）	松本（利）（4701）	矢野（4376）
	RF Monitor	片桐（4410）	三浦（4798）	矢野（4376）
モジュレータ関係	モジュレータ 各種ユニット	中島（4087）	川村（4523）	夏井（4862）
	サイラトロン	夏井（4862）	中島（4087）	川村（4523）
	インバーター電源	川村（4523）	中島（4087）	夏井（4862）
	CONT1	中島（4087）	片桐（4410）	松本（利）（4701）
FC 関係	パルス変調器（伝送・スナバ回路含む）	夏井（4862）	中島（4087）	川村（4523）

2022/4/22 更新

RF group  
contact book

# Operation panel

- In the beginning of KEKB project, all panels were developed with Tcl/Tk and in-house backend
- Currently, most of operation panels are implemented with Python (Tkinter or Qt) and EPICS
- Many feedback software (beam orbit, RF phase, beam energy, ...)

The 'binfo (monitor)' panel displays the status of various linac components. It includes sections for 'READY' (AR, KEKB, DR, PF), 'Safety Key' (OFF, RF, OK, READY), 'LINAC' (KEKB), and 'GR A1' (Protection Shutter: OPEN, Laser Mode: GR A1). It also shows 'SKEKB Bucket Selection' (ON) and 'Linac mode/BT dump mode' (SY2 Chicane: OFF). A 'Bunch Control' section lists parameters like HER, LER, Linac1st, Linac2nd, KBE, and KBP. A 'Main Trigger Station' section shows 'A1 Beam KEKB', 'A1 Beam PF', 'A1 Gate KEKB', 'A1 Gate PF', and 'A1 Gate AR'. A table at the bottom shows 'PumpA' and 'PumpB' values for various beam lines.

Interlock, beam gate status panel

The 'Linac Parameters (using Channel Access)' panel allows for configuring the linac. It includes a 'Device' section with checkboxes for 'Es', 'Phase', 'QMAG', 'STC', 'BEND', 'DELAY', 'ACCSTB', 'PHASE', 'FB', 'RF', and 'RM'. A 'Sector' section has checkboxes for 'A', 'B', 'R', 'C', '1', '2', '3', '4', '5', '6', '0', and 'S'. A 'Beam Mode' dropdown is set to 'ALL'. The panel also features a file browser showing a directory structure with folders for years from 2017 to 2023. At the bottom, there are buttons for 'Save', 'Load', 'Load(Q Stdz)', 'Copy', 'Show File', and 'Show Cur'.

Linac parameter management panel

The 'InjPattern Multi - newevg' panel is used for managing beam repetition. It features a 'Rep' section with 'SKEKB: Open' and 'Linac: Close' buttons. A 'Beam' section contains multiple tables for different beam lines (KEKB e- (KBE), KEKB e- (KBP), PF-3T e- (PFE), PF-A1 e- (QFE), AR e- (ARE), KEKB e- Study (JBE), KEKB e- Study (JBP), PF-3T e- Study (RFE), PF-A1 e- Study (SFE), AR e- Study (ZRE), Septum (KLY HV), and GR A1 LASER (GR A1 Pump A, GR A1 Pump B)). Each table has columns for 'write' and 'read' values and 'Set' buttons. A 'Bucket Selection' dropdown is set to 'ON'. At the bottom, there are buttons for 'Read', 'Set Beam ALL 0', 'open pat info', 'EVG setting', 'Set Beam ALL', and 'Set ALL'.

Beam repetition management panel

The 'Linac KEKB e- Orbit (GR\_A1)' panel displays beam orbit data. It features four plots showing 'DX (mm)', 'SX (mm)', 'DY (mm)', and 'Qx (pc)' over time. A 'DV 1st' section shows 'RMS: 0.731', 'Max: 2.478@QMD1E\_2M', and 'Min: -2.711@QMD1E\_3M'. A 'QMD10E\_M' section shows 'DX(1st): -0.863 mm', 'DX(2nd): -3.321 mm', 'DY(1st): 0.188 mm', 'DY(2nd): 2.850 mm', 'Q(1st): 1.167 nC', and 'Q(2nd): 0.094 nC'. At the bottom, there are control buttons for 'Beam Gate', 'Bucket Sel', 'Bunch', 'BT Collimator', 'BT LossMonitor', 'Beam Rep', and 'Sector'. A 'Show' section includes 'Range DX 5', 'DY 5', 'Qe 2.5', 'Qe+ 2.5', and 'Replot'. A 'Sector' section has checkboxes for 'A', 'B', 'R', 'C', '1', '2', '3'. A 'Set Ref' section includes '2022/06/09 10:30:04' and 'Set Ref' buttons.

Beam orbit panel

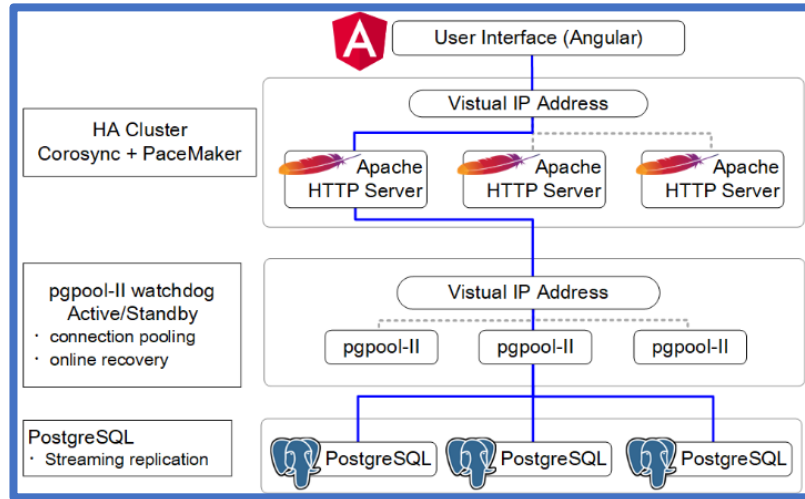
The 'Virtual Touch Panel (sbbct72)' panel is used for managing magnet parameters. It features a table with columns for 'Name', 'SET', 'DAC', 'ASC', 'DAC', 'ASC', 'SMB 001', 'Status', and 'FB'. The table lists parameters for various magnets (e.g., QD\_11\_4, QF\_11\_4, QD\_12\_4, QF\_12\_4, etc.). A 'Magnet - Q' section shows a table with columns for 'Name', 'SET', 'DAC', 'ASC', 'DAC', 'ASC', 'SMB 001', 'Status', and 'FB'. A 'Beam Mode' dropdown is set to 'KBE'. A 'Type' dropdown is set to 'Q'. A 'Sector' dropdown is set to '1'. A 'Num' input field is set to '5'. At the bottom, there are 'Set' and 'Reset' buttons.

Magnet parameter management panel



# Electrical operation logbook

- Web-based e-Log (in-house)
- Angular, PHP, PostgreSQL
- For each shift, it includes operator name, operation outline, trouble, schedule, .....
- Image file is available.
- Many information can be automatically updated in real time.
  - e.g.) Beam on/off status, high voltage setting, beam gate, beam repetition, .....



**KEK e+/e- LINAC Operation page**

Information  
Shift table  
LCG Report  
KCG Report  
Other log  
RF data  
ACC data  
LINAC status  
Linac Study

**HER (7GeV) Status: Open 12.5 Hz**

Current (mA): 178.70 mA  
Life (min): 0.32 mA/s  
Inj. Rate: 0 min  
Vacuum: 1.1e-08 Pa  
L 0.225 [10<sup>24</sup>/cm<sup>2</sup>/sec]

17:50:51  
17:51:53.708355

<KEKB e+>  
DR 蓄積電流が増加するように調整実施。  
GU AT KEKB e+ Delay 1st 1.880ms → 1.880ms  
PX A1 M-KBP -0.230A → -0.240A (-0.010A)  
PY A1 M-KBP -0.470A → -0.450A (+0.020A)  
PV RD 01-KBP -1.650A → -1.450A (+0.200A)  
PV RD 03-KBP 0.200A → 0.400A (+0.200A)

SKEKB LER 入射状況

16:30 ~ 00:30 シフトリーダー: 荒川 大 オペレーター: 豊富 直之, 鈴木 和彦

## List of operators and shift staff

[運転日誌\(詳細\)](#) [運転日誌\(概要\)](#) [運転日誌\(LCG\)](#) [運転日誌\(概要+LCG\)](#)

## Operation outline

概況	SKEKB e-/e+ 入射 PF-RING e- 入射 (HB) AR e- 6.5GeV 入射
LCG	折りたたまれています。
引継ぎ	折りたたまれています。
入射時間	折りたたまれています。
チャージ量	折りたたまれています。
パラメータ変更	折りたたまれています。

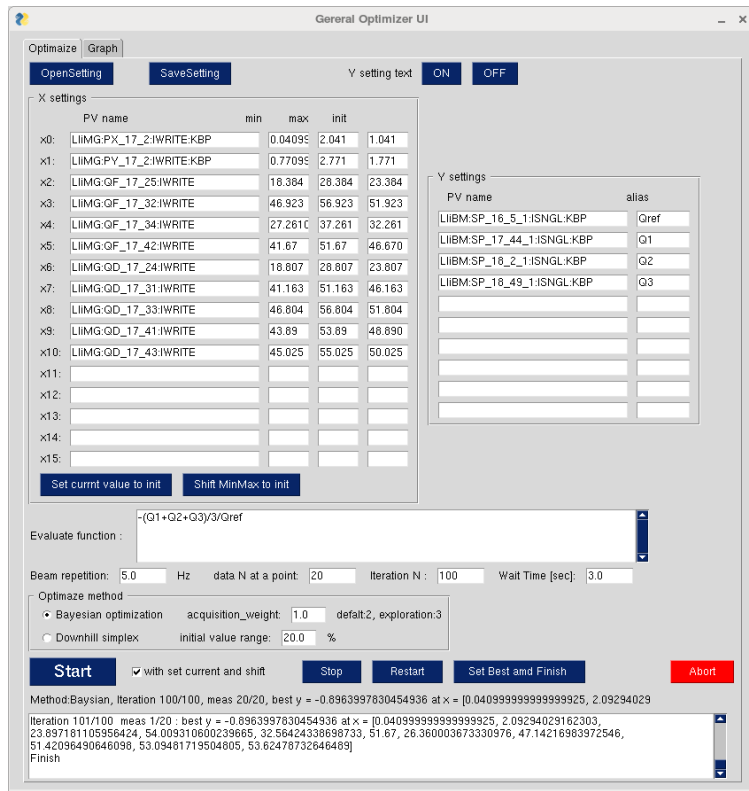
- トラブル (3件)**
- ギャラリー移動中、1CB 筐体天井 FAN から異音が発生していることに気付いた件 (16:30:00 ~ 16:50:19)
  - CSS Alarm で、LiIMG:QD.C1\_4.CONNECTION\_ALARM が MAJOR 表示となっていることに気づく。(19:15:58) (19:41:42)
  - KL\_32 IPL(H) でダウン。RF OK NG のまま。(21:08:23 ~ 21:37:23)

## Troubles

## Detail information of shift

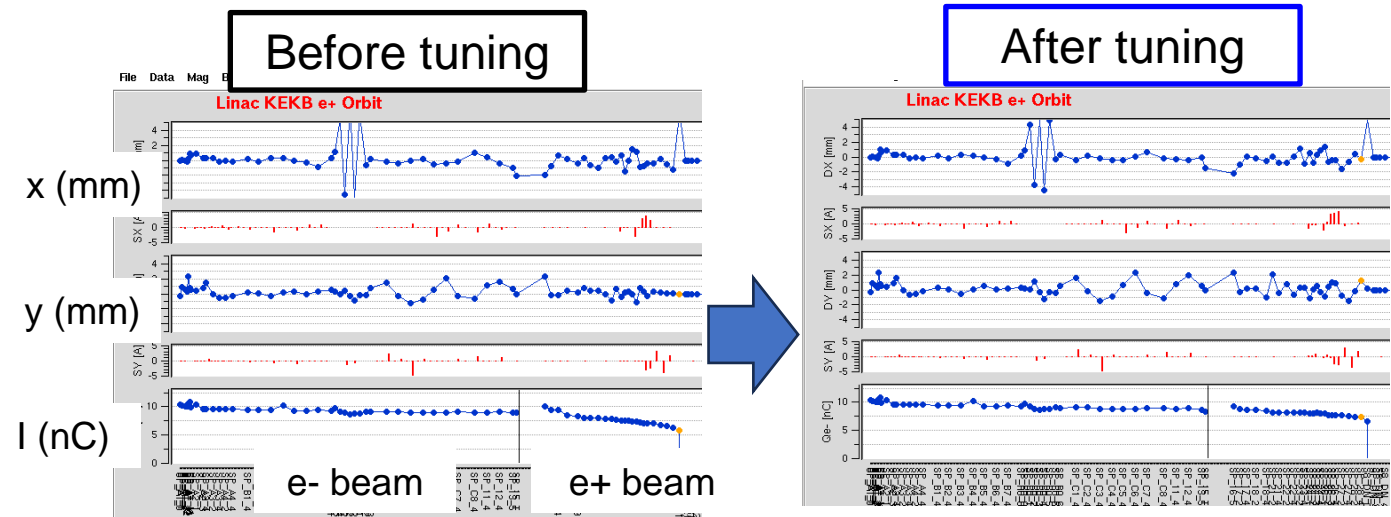
# Machine learning for automatic beam tuning

- Auto tuning with Bayesian Optimization has been tested since Oct. 2022. (T. Natsui, G. Mitsuka)
- Implementation was done by using GPyOpt and PySimpleGUI.
- To increase e+ yield and transmission efficiency with 16 parameters (pulsed steering, RF phase)
- Expand auto-tuning to two bunch tuning, dispersion correction, injection tuning, and more
- (\*) more details will be given by Miho Shimada in machine learning session.

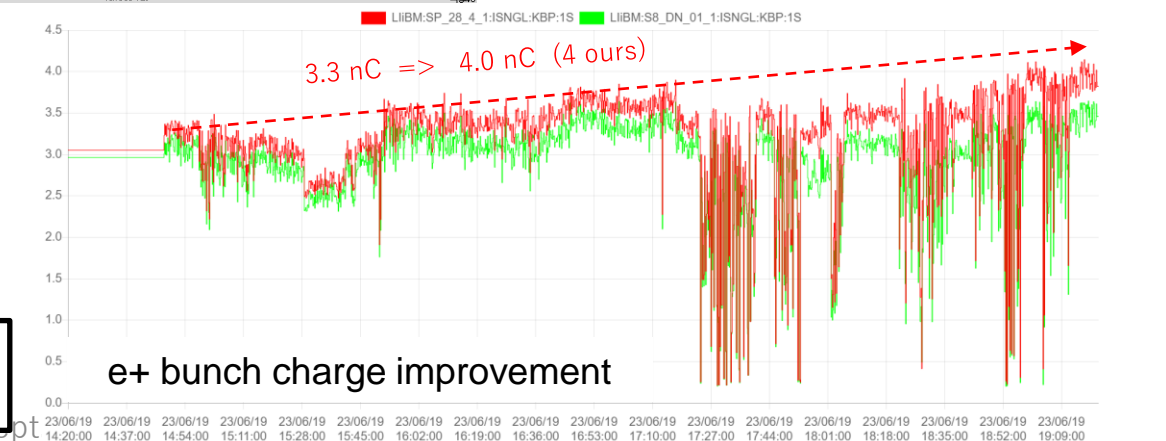


Automatic beam tuning panel

Masanori Satoh (KEK)



T. Natsui



e+ bunch charge improvement

# Summary

- **At the KEK e-/e+ injector linac, simultaneous top up injection operation of 5 rings (SuperKEKB HER/LER/PDR, PF, PF-AR) has successfully established.**
  - **Pulse to pulse beam control based on the event based timing system, low level rf phase control, pulsed magnet (Quad, Steering, Bend)**
  - **50 Hz monitoring (BPM, rf, pulsed magnet PS) and analysis tools**
  - **Many People's Continuous Contributions and Efforts over 15 years**
- **Issues and Future improvements**
  - **Training cost of operator is increasing (complex operation scheme, large # of OPI)**
  - **Expand AI-based auto-tuning to reduce the load of operator**

**Thank you for your attention!**