SuperKEKB LS1 status and ARC report

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(on behalf of SuperKEK Accelerator Group)

2023.2.13

44th B2GM Plenary Session

Contents

- LS1 status
  - Introduction
    - Challenges and countermeasures
    - LS1 schedule
  - IR status (Tsukuba straight section)
  - NLC status (Oho straight section)
  - Others
- ARC report
- Summary

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  - NLC status (Oho straight section)
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Challenges as a luminosity frontier machine

Challenges recognized in recent commissioning

- To improve the machine further to achieve the goal, however, various challenges as follows should be solved:

1) Severe beam-beam effect (vertical beam size blow-up)
   - Vertical beam size (vertical emittance) blow-up has been observed at high bunch currents.
   - Relaxed by the crab-waist collision scheme, but it still remains.

2) Shorter beam lifetime than expected in the design phase.
   - The maximum bunch currents are limited by the balance between the lifetime and the injection power.
   - The dynamic aperture is very small due to the beam-beam effect and crab-waist sextupoles, while the physical aperture is limited by the beam collimators.

3) Lower bunch-current limit due to TMCI than expected.
   - The cause is higher impedance of beam collimators, where the apertures are smaller than the design values to suppress high background to Belle II.

4) Low machine stability
   - Abnormal beam aborts, sometimes leading to the damage of collimators.
   - Operation efficiency during 2021ab, for example, was almost 0.5, lower than expected one, 0.65. (Main causes: machine tunings, machine troubles, maintenance, etc.).

5) Aging of hardware and facilities, and so on.

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+ 6) Low injection efficiency especially in HER.

Countermeasures against challenges

Planned countermeasures

- Major countermeasures discussed so far.
  - See Appendix C for some details.

	Aim	Possible countermeasures	
(1)	・Increase injection power (efficiency)	Linac upgrade to designed specification	
		Large physical aperture at electron injection point (HER)	During LS1
		Linac upgrade beyond designed specification	
(2)	・Relax beam-beam effect ・Expand dynamic aperture	Utilizing rotatable sextuplole magnets (LER)	Done before LS1
		"Perfect matching"	Under consideration
		QCS modification (Option#1): Move QC1RP to the far side of IP	(It was found that it is not easy.)
		Larger scale QCS modification (Option #8)	Under consideration
(3)	・Suppress BG ・Expand physical aperture	QCS cryostat front panel modification and additional shield to IP bellows	During LS1
		Optimization of collimator location	Done before LS1
		Enlargemen of QCSR beam pipe (Option#3)	Under consideration
(4)	・Relax TMCI limit	"Non-linear collimator"	During LS1
(5)	・Improve stability	Robust collimators	During LS1 (Partially)
		Upgrade of beam abort system and loss monitor system	During LS1 (Partially)
(6)	・Anti-aging measures	Preparation of standby machines and spares, repair of facilities, etc.	During LS1 (Partially)

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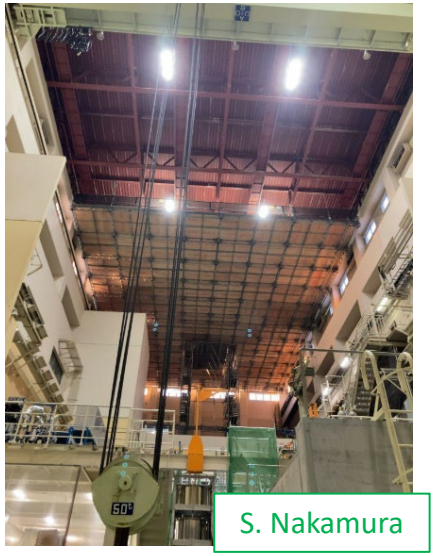
Schedule

- LS1 : ~15 months from July 2022 to autumn 2023
  - 2022b run stopped earlier than planned due to high electricity costs (22nd June), but LS1 major works began on 11th July as scheduled.
  - Beam operation will restart from autumn 2023.
- Major works during LS1 other than accelerator upgrade:
  - Belle II maintenance and reinforcement
    - Replacement of PXD and TOP MCP-PMTs, new IP beam pipes, and so on.
    - IR works are required, including QCS extraction & reinstallation, disassembly & reinstallation of magnets, beam pipes, radiation shields, etc.
  - Aseismic reinforcing work of the ceiling of the laboratory building (Oho Lab. & Fuji Lab.)
    - It took about 5 months and it could be done only during long shutdown.
    - During this work, we could not use ceiling crane required for NLC construction at Oho Lab.!!

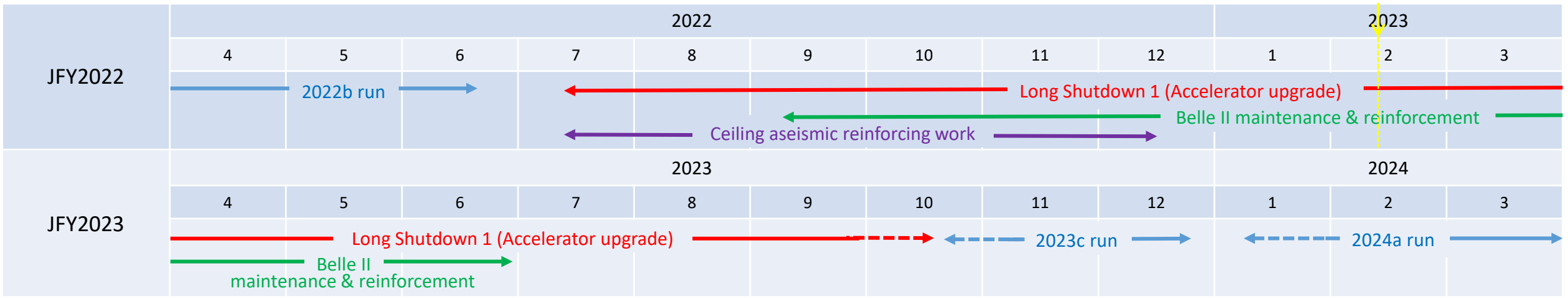
Ceiling aseismic reinforcing work



S. Nakamura

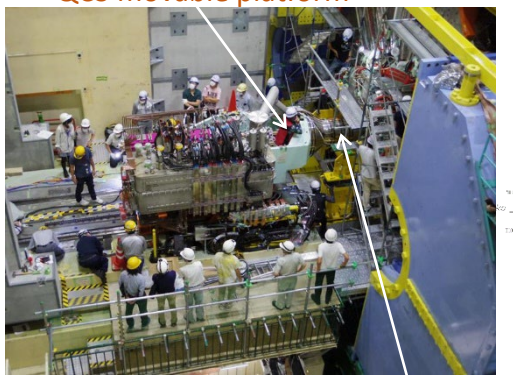
LS1 schedule

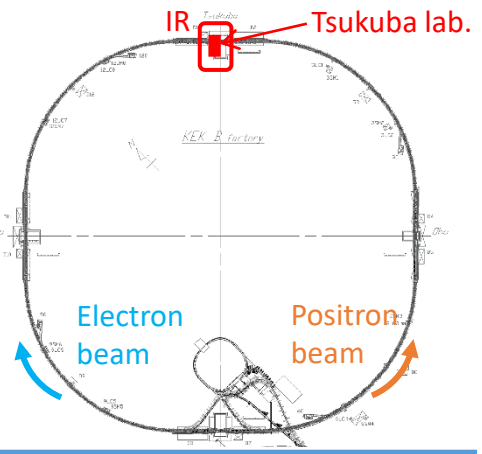
We are here now!!



IR (Tsukuba straight section) #1

- Major work items in accelerator tunnel:
  - Disassembly and reinstallation of concrete radiation shields
  - Belle II maintenance & reinforcement work
  - Disassembly and reinstallation of magnets, beam pipes for QCS work
  - QCS extraction & reinstallation
  - QCSR cryostat leak test
  - QCS cryostat modification





IR (Tsukuba straight section)

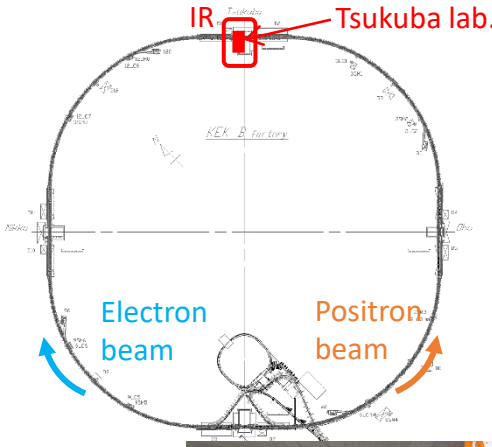
We are here now!!

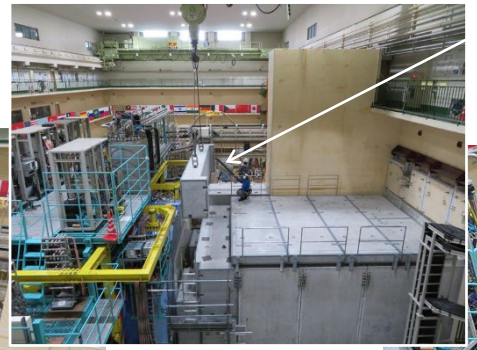
	2022									2023		
JFY2022	4	5	6	7	8	9	10	11	12	1	2	3
	2022b run			Concrete shield disassembly		QCS extraction	QCSR cryostat leak test			QCS cryostat modification		
					Belle II work					Belle II maintenance & reinforcement		

	2023									2024		
JFY2023	4	5	6	7	8	9	10	11	12	1	2	3
	Belle II maintenance & reinforcement			QCS reinstallation		Concrete shield reinstallation						
		Magnet & beam pipe disassembly					2023c run			2024a run		
					Belle II work							

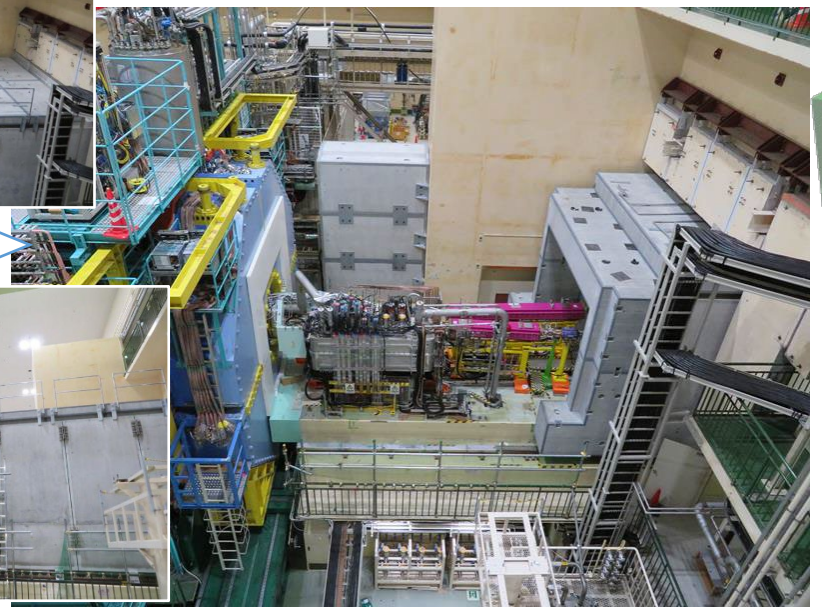
IR (Tsukuba straight section) #2

- Concrete radiation shields disassembly (already done)
  - Concrete radiation shields were temporarily removed for IR works.
  - They will be reinstalled in mid September 2023.
    - To suppress background noise of Belle II, 2 concrete shields will be replaced with new ones.
    - New shields will be delivered in March 2023.



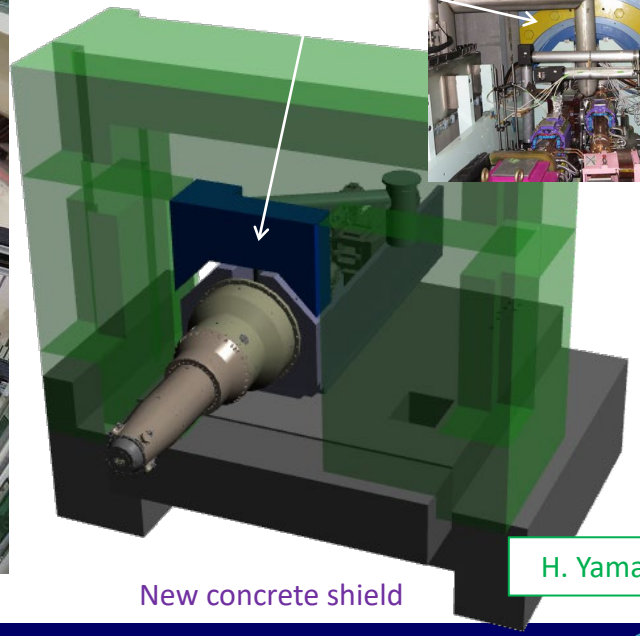


This shield will be replaced with new one.



Concrete shield disassembly work

This space will be filled with concrete.

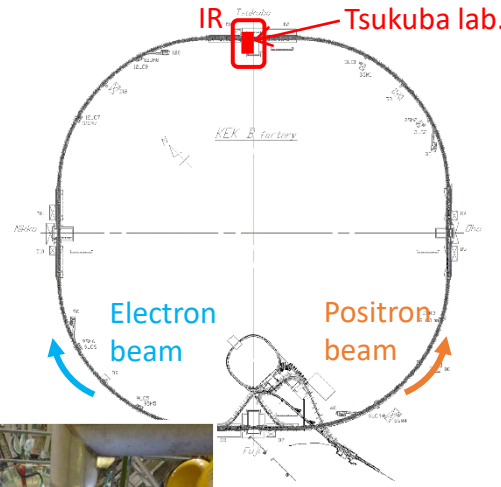


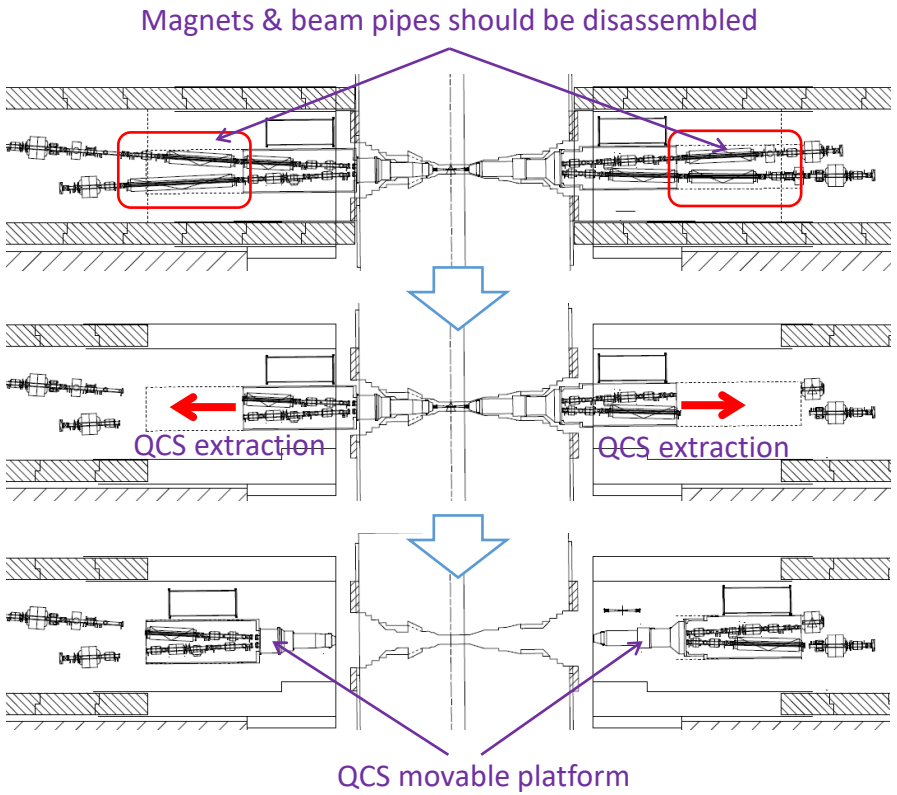
New concrete shield

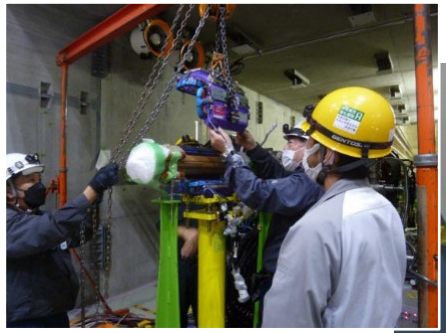
H. Yamaoka

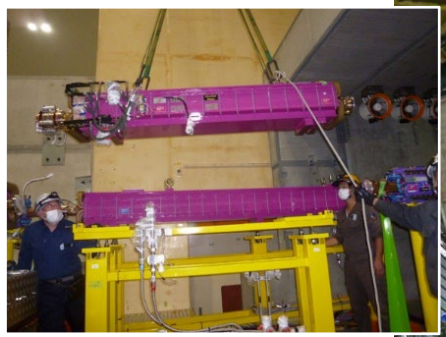
IR (Tsukuba straight section) #3

- Disassembly of magnets & beam pipes for QCS extraction (already done)
  - To make space for QCS extraction, magnets and beam pipes were removed.
  - For QCS cryostat work, some magnets and beam pipes on QCS movable platform were also removed.



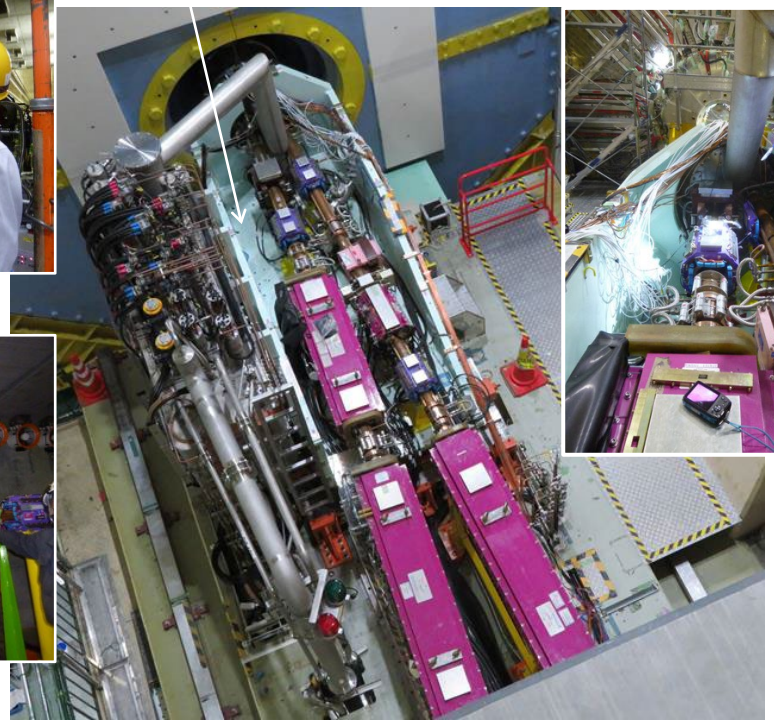


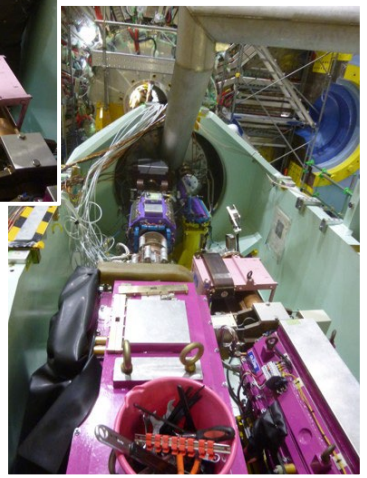




Disassembly work

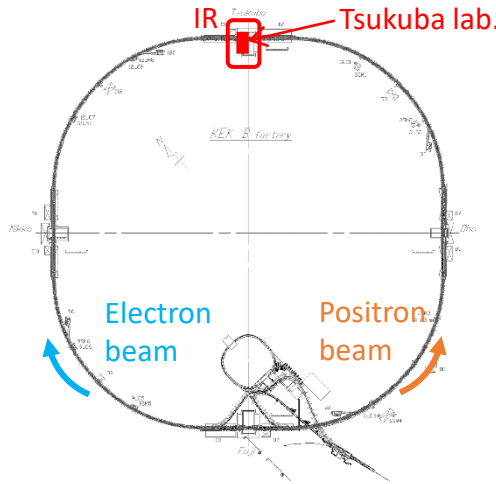
QCS movable platform

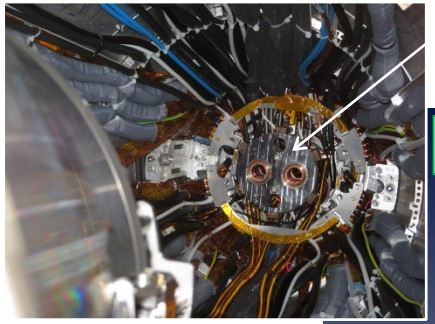




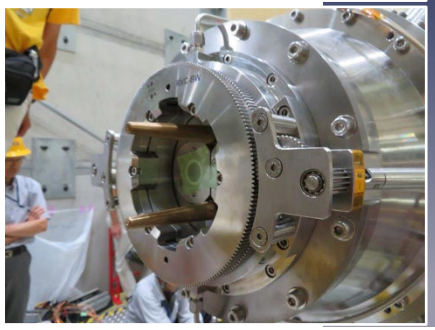
IR (Tsukuba straight section) #4

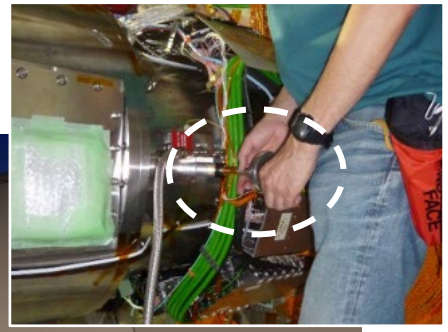
- QCS extraction (already done)
  - RVC disassembly was performed by Belle II and SuperKEKB for the first time.
    - RVC : Remote Vacuum Connection between IP bellows chambers and QCS beam pipes
    - DESY, who is RVC developer and has been in charge of RVC disassembly so far, also joined the work online. Thank you very much for the kind work manual and cooperation!!
    - Although camera for monitoring the RVC movement did not work, disassembly work went well.
  - QCS extractions of both sides were completed successfully in one day!!

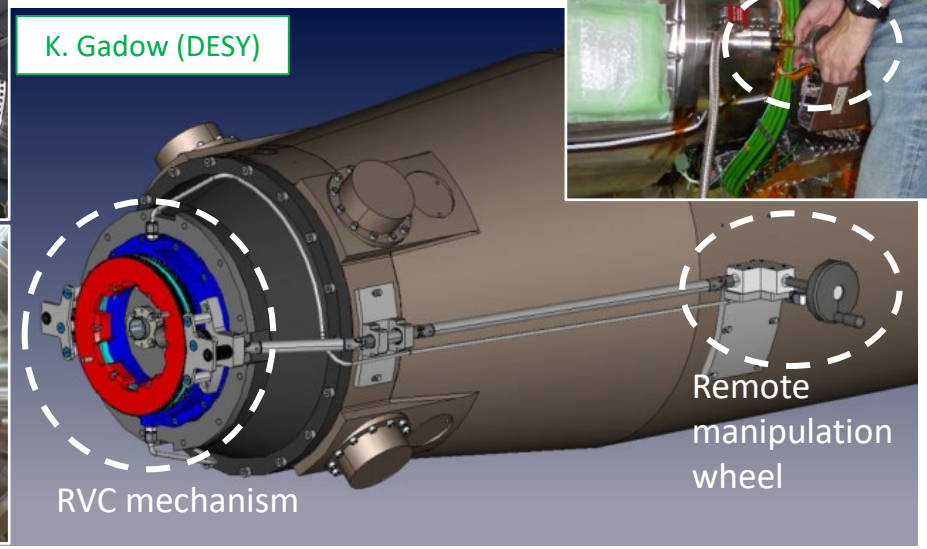


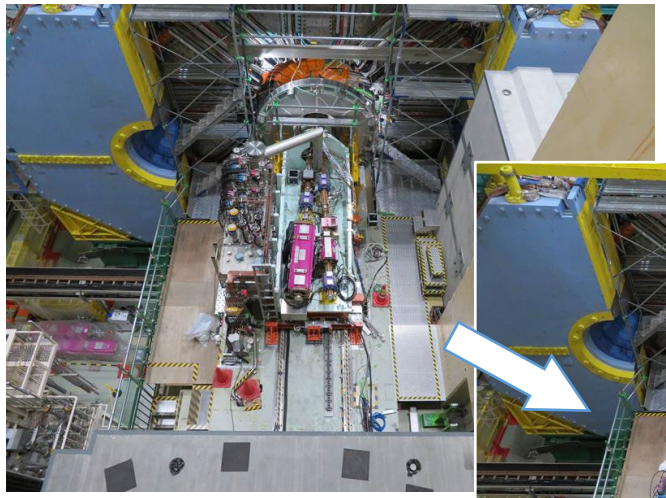


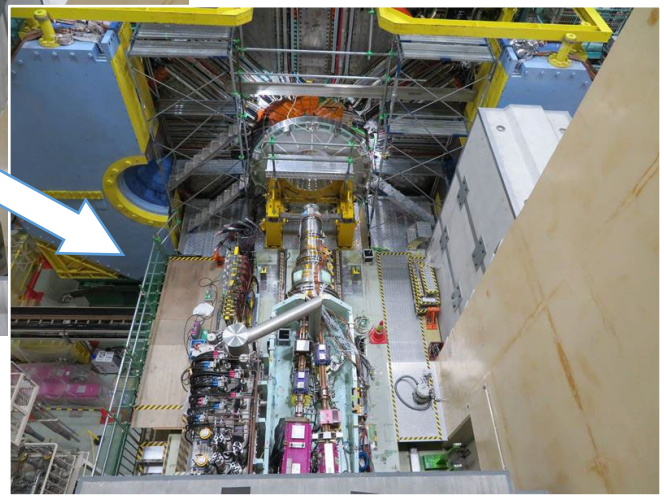
RVC lock flange of IP bellows chamber







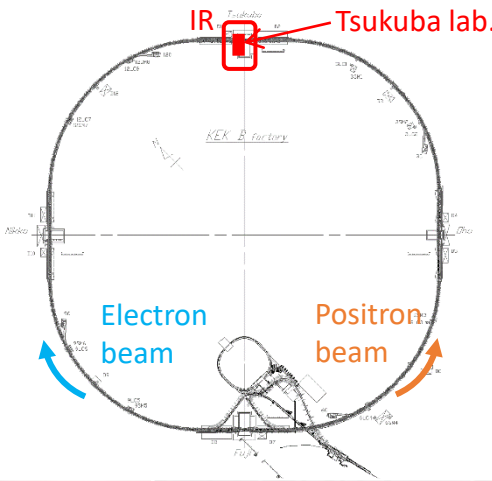


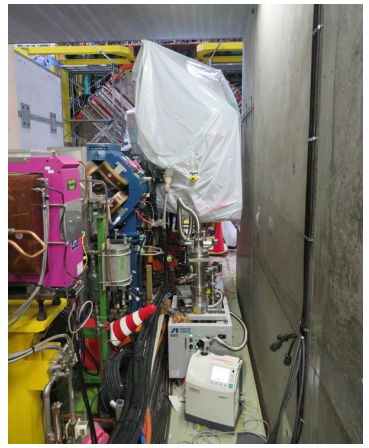


QCS extraction

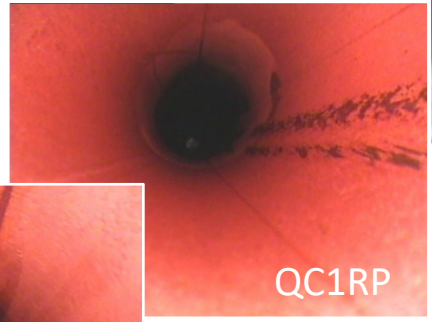
IR (Tsukuba straight section) #5

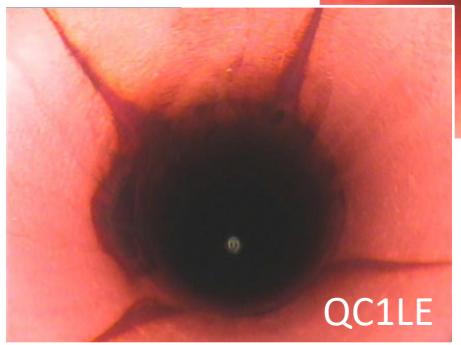
- QCSR cryostat leak test (already done)
  - Pressure in QCSR cryostat has been higher than that in QCSL cryostat.
    - Residual gas analysis showed that vacuum leak has occurred in QCSR cryostat.
    - However, vacuum leak test before LS1 did not detect any vacuum leak.
  - Thorough vacuum leak test was performed after QCS extraction.
    - At last, the location of the vacuum leak was identified!!
    - Vacuum leak will be stopped during LS1.
- Inside observation of beam pipes
  - Inside of IP bellows, QCS beam pipes were observed by fiberscope.
    - Fiberscope observations showed that RF fingers of IP bellows and QCS beam pipes are discolored but healthy.

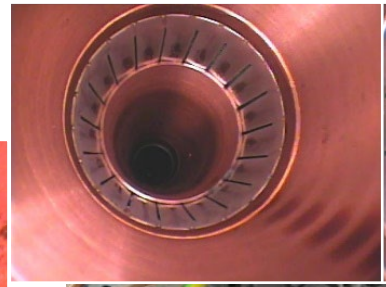


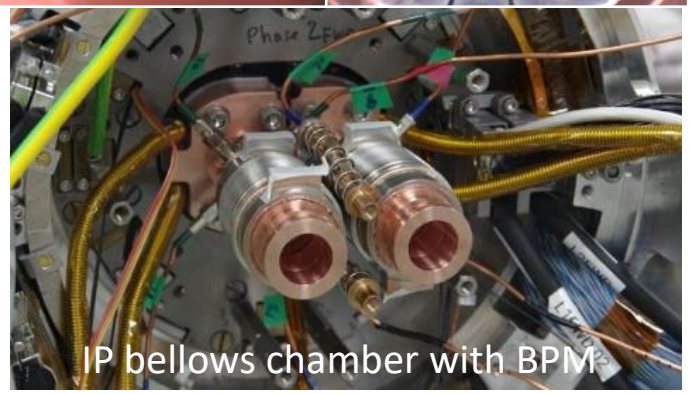


Vacuum leak test of QCSR cryostat



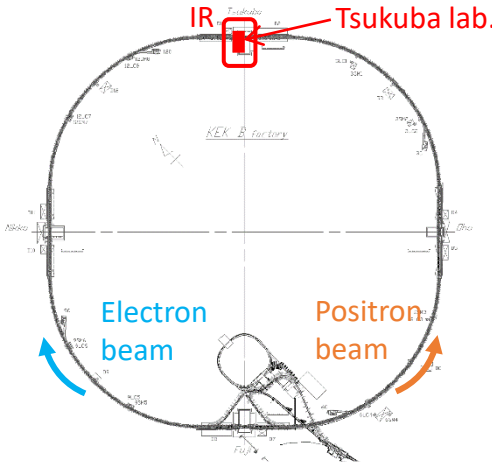


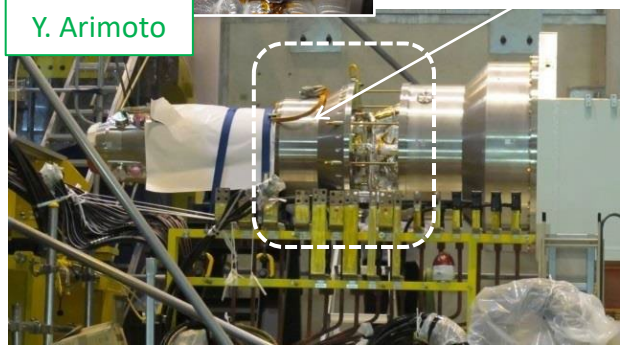


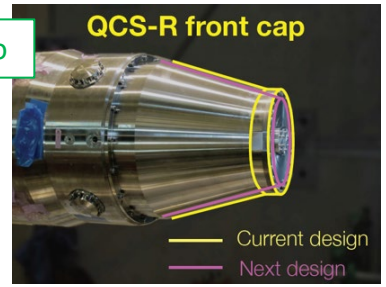


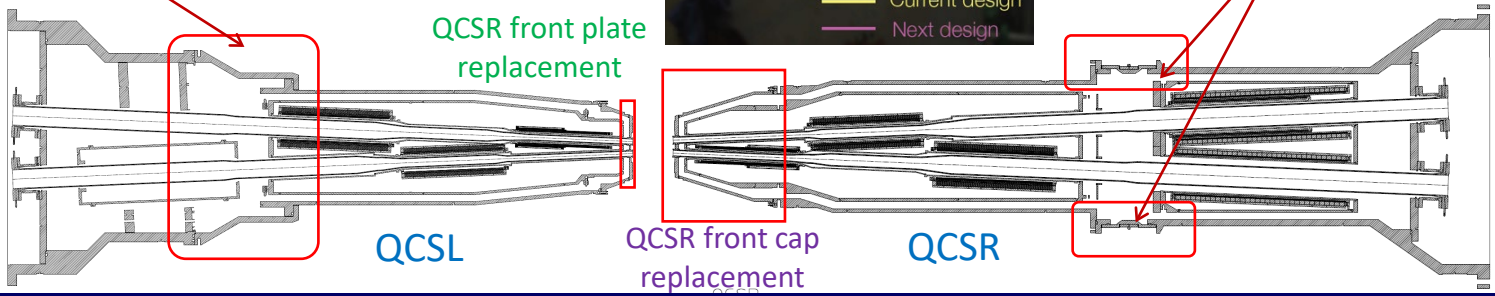
IR (Tsukuba straight section) #4

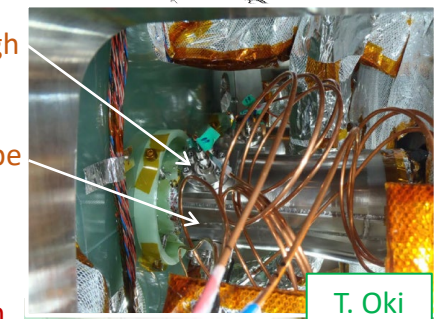
- Future works
  - QCS cryostat modification
    - To reduce Belle II background noise, the material at the tip of QCS cryostat will be changed from W to SUS.
      - QCSR front cap replacement
      - QCSL front plate replacement
    - To make more space for Belle II cables, the tip of QCSR cryostat will be thinner.
      - QCSR cryostat modification including front cap replacement
    - QCS cryostats will be disassembled for these works.
      - It is necessary to shift QCS beam pipes in longitudinal direction.





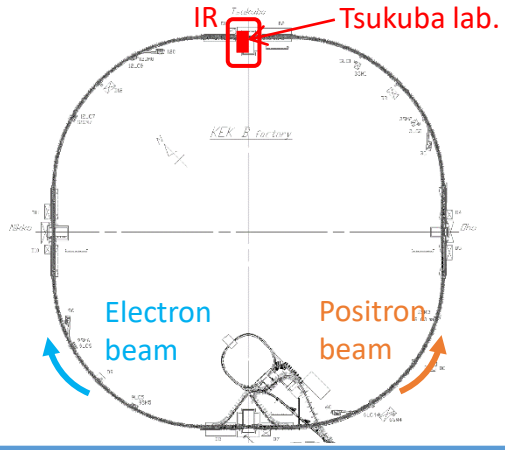






IR (Tsukuba straight section) #5

- Remaining works in accelerator tunnel:
  - Belle II maintenance & reinforcement (~ June 2023, original schedule)
  - QCS cryostat modification (February ~ March 2023)
  - QCS reinstallation (July ~ August 2023)
  - Concrete shield reinstallation (Sep. 2023)
- All works can be completed by the end of September 2023.
  - It is required to coordinate schedule with Belle II work and NLC construction.



IR (Tsukuba straight section)

We are here now!!

JFY2022

2022									2023		
4	5	6	7	8	9	10	11	12	1	2	3

- 2022b run
- Concrete shield disassembly
- Belle II work
- QCS extraction
- QCSR cryostat leak test
- QCS cryostat modification
- Belle II maintenance & reinforcement

JFY2023

2023									2024		
4	5	6	7	8	9	10	11	12	1	2	3

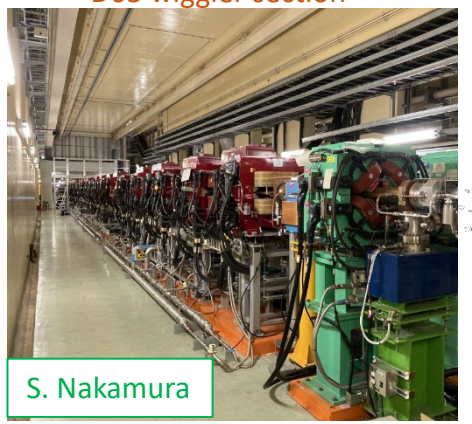
- QCS reinstallation
- Concrete shield reinstallation
- Magnet & beam pipe disassembly
- Belle II maintenance & reinforcement
- Belle II work
- 2023c run
- 2024a run

Oho straight section #1

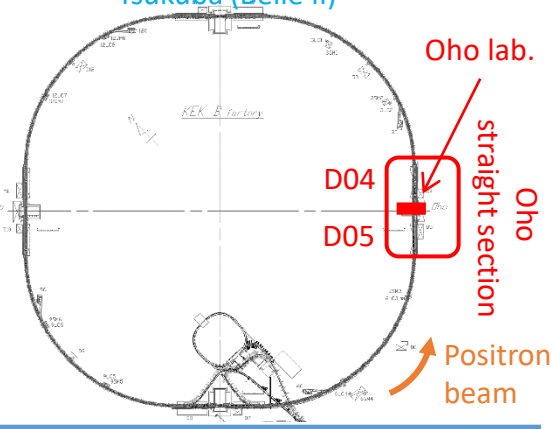
- Major work items in accelerator tunnel:
  - Disassembly and reinstallation of concrete radiation shields
  - NLC construction (LER)
  - RF cavity replacement (LER)
  - Ceiling aseismic reinforcing work
  - Installation of new radiation shields for NLC

Concrete radiation shield

D05 wiggler section

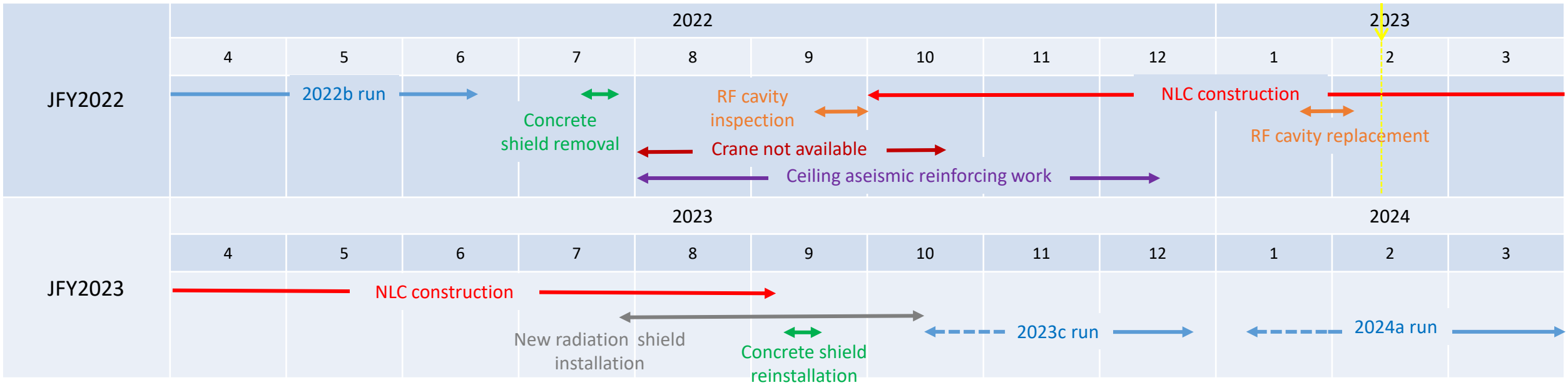


Tsukuba (Belle II)



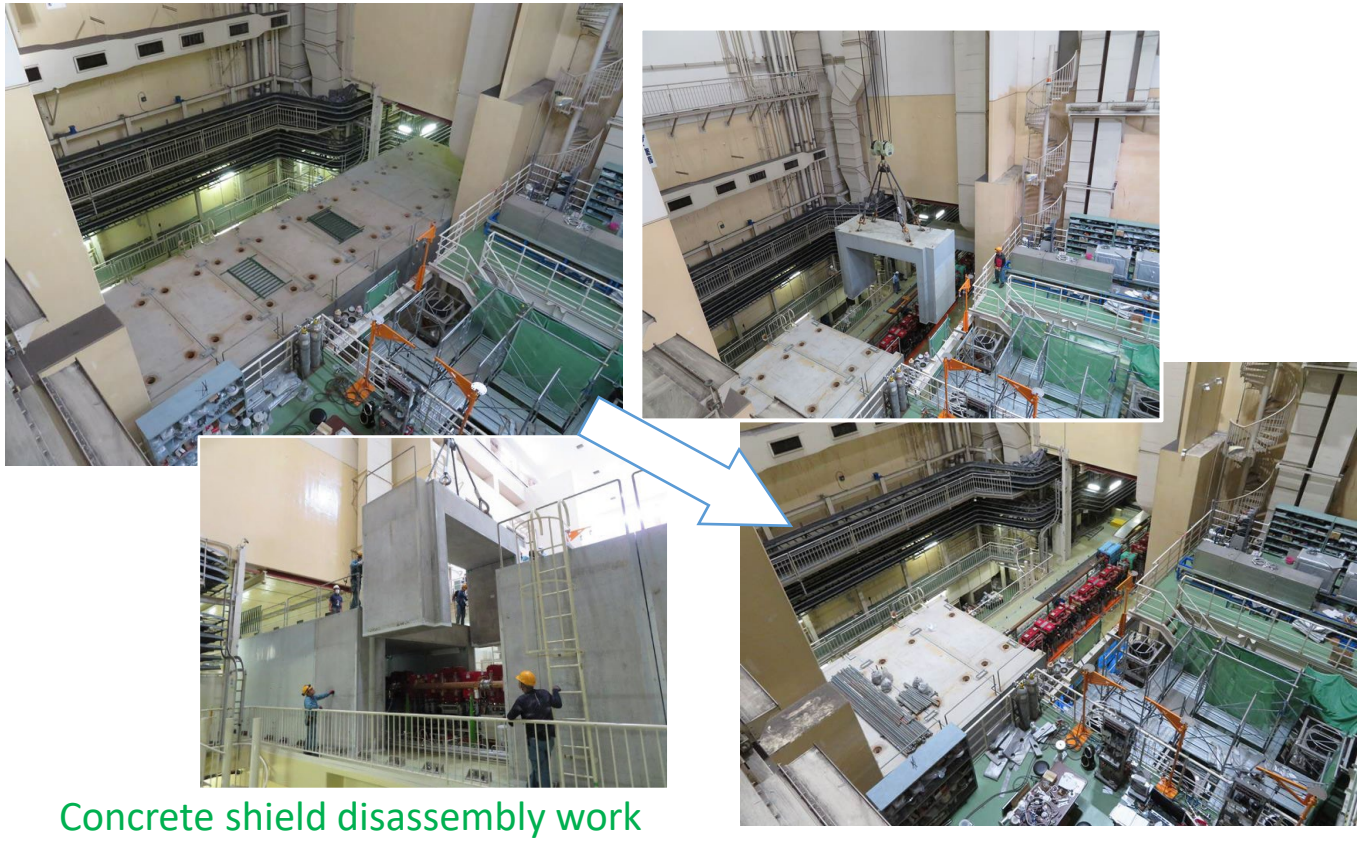
Oho straight section (D05)

We are here now!!

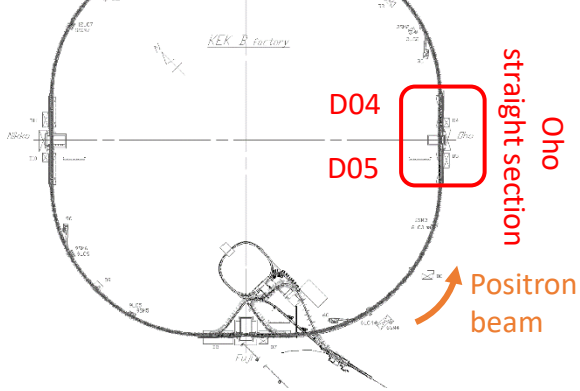


Oho straight section #2

- Concrete radiation shields disassembly (already done)
  - Concrete radiation shields (6/12) were temporarily removed for NLC construction.
    - Concrete shields were placed outside Oho laboratory building.
  - They will be reinstalled in September 2023.



Concrete shield disassembly work

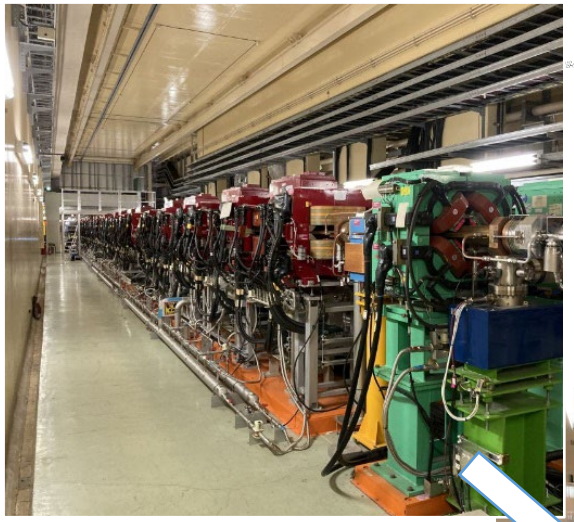


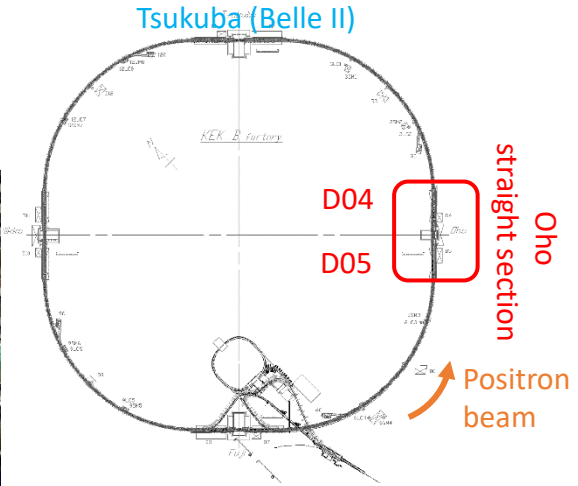
Disassembled concrete shield

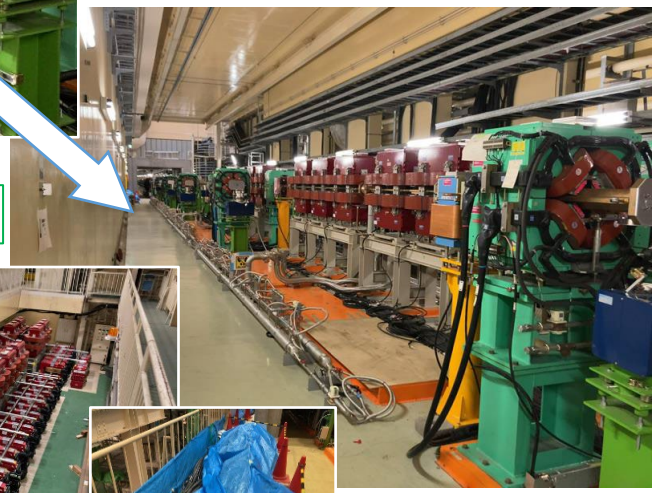
Oho straight section #3

- Wiggler magnets and beam pipe removal (already done)
  - Removed wiggler magnet and cable : 50 magnets and their cables
    - Double pole magnet (3 ton) : 20
    - Single pole magnet (2 ton) : 10
    - Half pole magnet (1.5 ton) : 20
    - Cables : 3 ton
  - Removed beam pipe for wiggler magnet : 10 beam pipes
  - Disassembly procedure
    - Removal of wiggler magnet cables
    - Upper parts of wiggler magnets disassembly
    - Beam pipes removal
    - Upper parts of wiggler magnets reassembly
    - Wiggler magnets removal

10 times







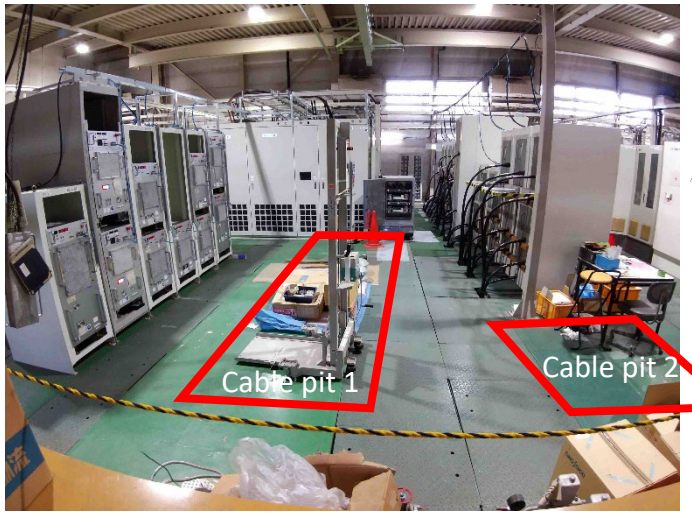
S. Nakamura

Wiggler beam pipe removal work

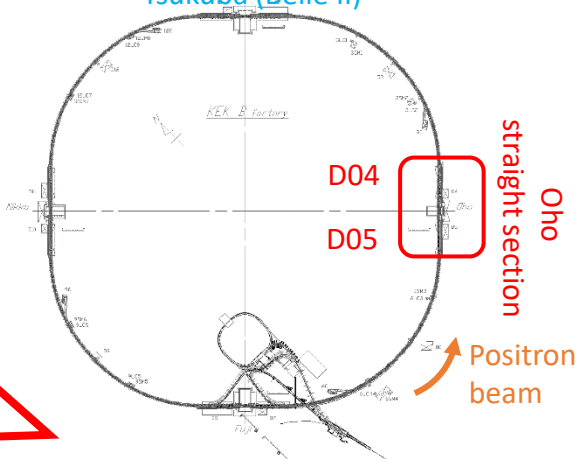
Oho straight section #4

- Future works for NLC construction
  - Collimator relocation from D03V1
  - Q magnet relocation (done) and alignment
  - Skew sextuple magnets installation
  - Beam pipe installation
  - Installation of new power supplies
  - Magnet cabling works
- Future works for radiation shielding enhancement
  - Production & installation of new Pb radiation shields
  - Production & installation of additional concrete shields
  - Reinstallation of concrete shields

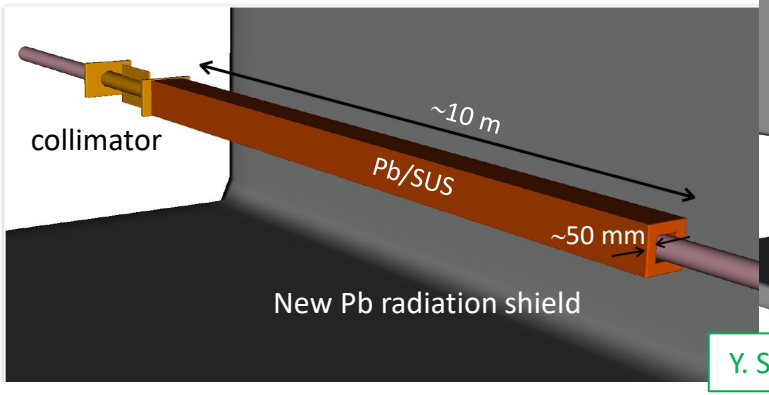
Magnet power supply room (ground level)

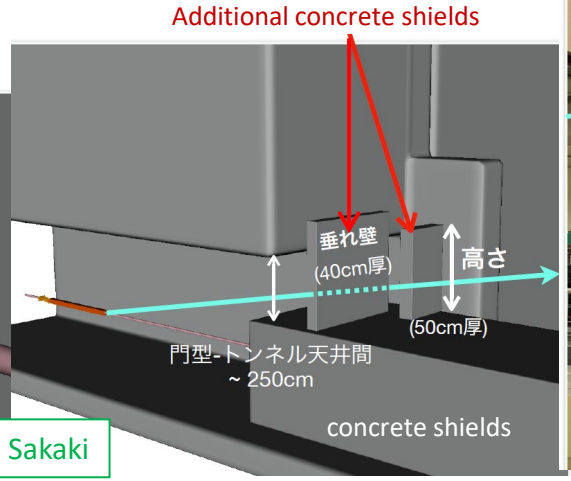


Tsukuba (Belle II)

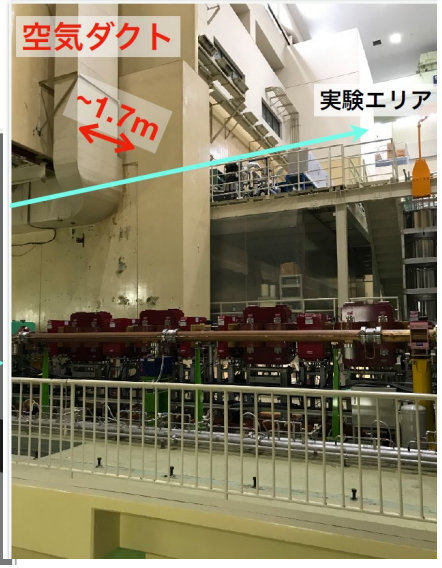


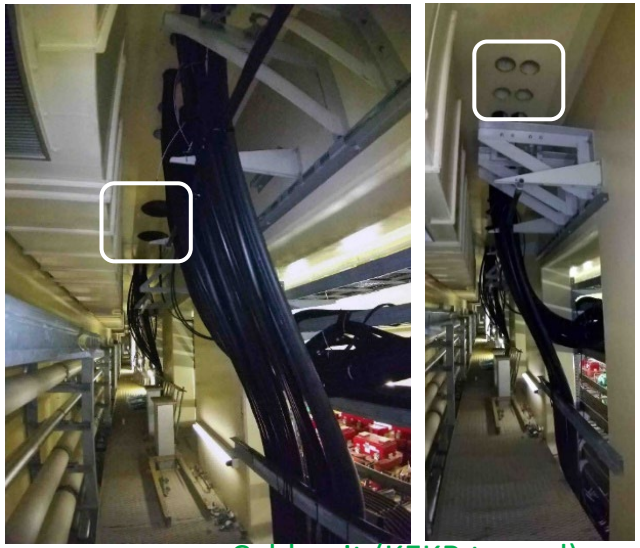
S. Nakamura





Y. Sakaki

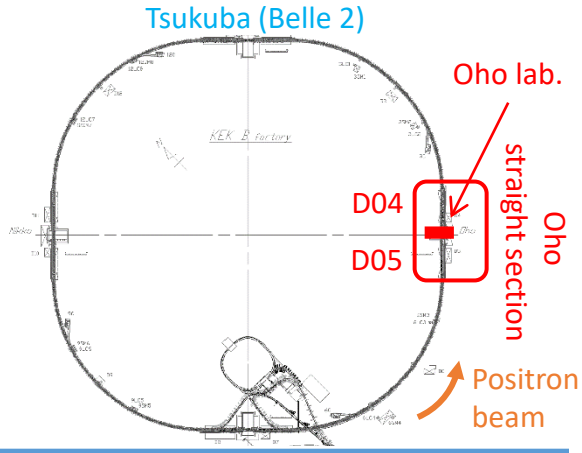




Cable pit (KEKB tunnel)

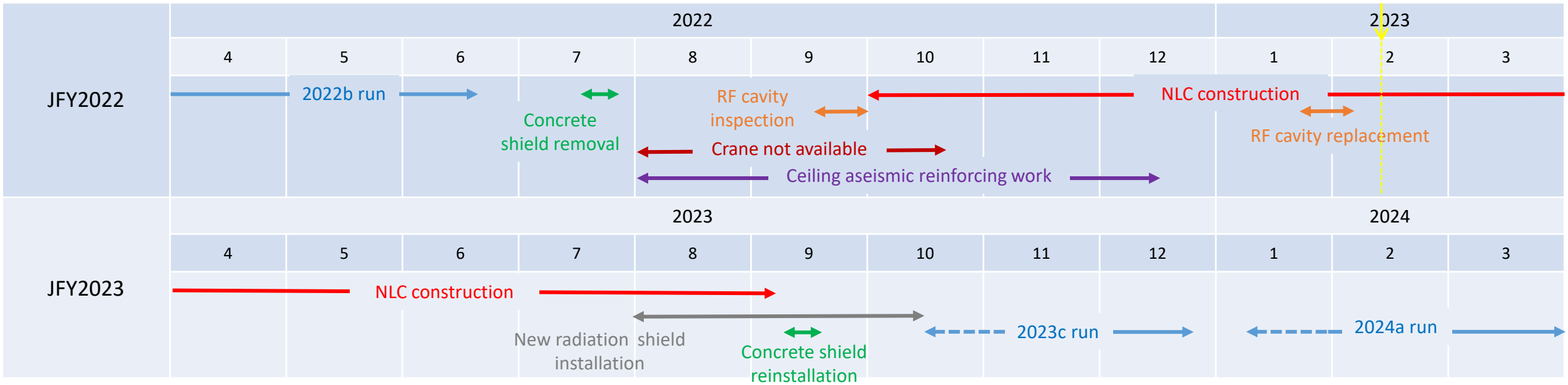
Oho straight section #5

- Remaining works in accelerator tunnel:
  - NLC construction (~ Sept. 2023)
  - RF cavity replacement (Jan. ~ Feb. 2023)
  - New radiation shield installation (August ~ Oct. 2023)
  - Concrete shield reinstallation (Sept. 2023)
- All works can be completed by autumn 2023.
  - Schedule is very tight.

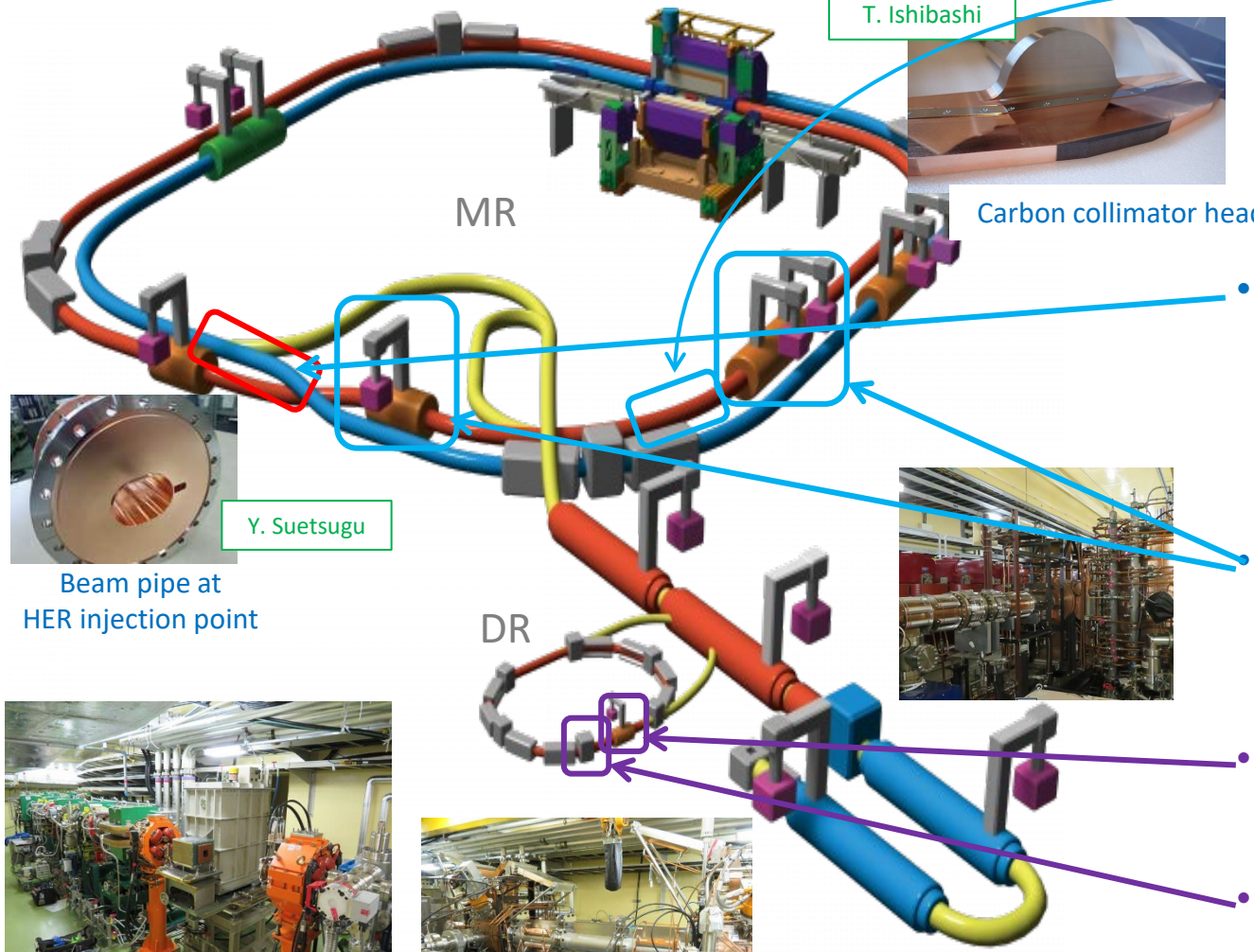


Oho straight section (D05)

We are here now!!



Other major works (excluding Linac)



T. Ishibashi

Carbon collimator head

Y. Suetsugu

Beam pipe at
HER injection point

DR Ext. kicker

DR RF section

- Robust collimator head (LER)
  - As countermeasure against kicker-pulser misfiring and resulting destruction of collimator
    - Replacement with carbon head of horizontal collimator D06H3 and relocation from D06H1 to D06H4
    - Carbon head production : ~ March 2023
    - Head replacement : Spring ~ Summer 2023
    - Collimator relocation : Spring ~ Summer 2023
- New beam pipes with wider aperture at HER injection point
  - For injection efficiency improvement
    - New beam pipes with wider aperture & New BPM for precise measurement of injected beam
    - Beam pipe production : ~ March 2023
    - Beam pipe replacement : Spring ~ Summer 2023
    - Septum baking : ~ Summer 2023?
- RF cavity modification and replacement (LER)
  - For stable operation with larger beam current
    - Modification : Input coupler replacement, cooling power enhancement, coaxial line modification, etc. (done)
    - Cavity replacement (D05A) : January ~ February 2023
- Vacuum seal replacement at RF section (DR)
  - For pressure reduction
    - Replacement from elastomer gasket to metal gasket for dummy pipes (done)
- DR Extraction kicker power supply modification and repair (DR)
  - For stable operation
    - Modification : December 2022 ~ August 2023
- And so on…

Contents

- LS1 status
  - Introduction
    - Challenges and countermeasures
    - LS1 schedule
  - IR status (Tsukuba straight section)
  - NLC status (Oho straight section)
  - Others
- ARC report
- Summary

26th KEKB Accelerator Review Committee

- 26th KEKB ARC meeting was held on 13-14 December 2022.
  - Meeting was held in hybrid mode.
    - 7 committee members : in person
    - Several others : on zoom
  - 22 oral presentations were given by KEKB staff members.
    - The slides of the presentations are available at https://www-kekb.kek.jp/MAC/2022/

KEKB ARC Committee members

Frank Zimmermann	Chair CERN
Ralph Assmann	DESY
Paolo Chiggiato	CERN
Paolo Craievich	PSI
John Fox	Stanford University
Andrew Hutton	JLab (excused)
In Soo Ko	POSTECH
Catia Milardi	INFN-LNF
Evgeny Perevedentsev	BINP
Katsunobu Oide	UNIGE/CERN and KEK (ret.)
Qing Qin	ESRF
Bob Rimmer	JLab
John Seeman	SLAC
Michael Sullivan	SLAC
Tom Taylor	CERN (ret.)
Rogelio Tomas	CERN
Tadashi Koseki	KEK, Director of Acc. Laboratory, Ex Officio Member
Makoto Tobiyama	KEK, Head of Acc. Division III, Ex Officio Member
Mika Masuzawa	KEK, Head of Acc. Division IV, Ex Officio Member
Hiroyasu Ego	KEK, Head of Acc. Division V, Ex Officio Member

Agenda of 26th KEKB ARC meeting

December 13 (Tuesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:10	Welcome	M. Yamauchi
09:10 - 09:40	SuperKEKB Status	M. Tobiyama
09:40 - 10:10	2021c-2022b	Y. Ohnishi
10:10 - 10:30	Belle II Status	K. Matsuoka
10:30 - 11:00	MDI (BG)	H. Nakayama
11:10 - 11:30	Control	H. Kaji
11:30 - 12:10	Monitor	M. Tobiyama
13:30 - 14:00	Injector	M. Satoh
14:00 - 14:30	BT	M. Tawada
14:30 - 15:00	Injection	N. Iida
15:10 - 15:40	Vacuum	K. Shibata
15:40 - 16:10	MR Magnets & QCS	Y. Arimoto
16:10 - 16:40	RF	M. Nishiwaki
16:40 - 17:00	Helium Refrigerator for SRF	K. Nakanishi
17:00 - 19:00	Executive Session	

December 14 (Wednesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:30	Optics Issues	H. Sugimoto
09:30 - 10:00	Collimator Issues	T. Ishibashi
10:00- 10:30	Impedance Issues	K. Ohmi
10:30 - 11:00	Sudden Beam Loss	H. Ikeda
11:00 - 11:30	NLC	A. Morita
11:30 - 12:00	LS1 Status	K. Shibata
13:20 - 13:40	ITF Activity Summary	M. Masuzawa
13:40 - 14:10	Beam-beam	D. Zhou
14:10 - 14:40	LS2, IR modification option 3'	M. Masuzawa
14:40 - 15:30	Others, QCS Tour	
15:00 - 20:00	Report writing / Executive Session	
11:00 - 12:00	Close-out	

Executive Summary

- Executive Summary

In summer 2022, SuperKEKB achieved a new world record luminosity of 4.7×10^{34} $cm^{-2}s^{-1}$, which is a significant accomplishment, more than twice the previous KEKB record.

Among the various issues encountered were

(1) the interplay between a single bunch instability and the feedback system, which was successfully solved by feedback tuning,
(2) still unexplained sudden beam loss, which is tentatively attributed to “fireballs”,
(3) large vertical equilibrium emittances in both rings,
(4) emittance growth in the BT, and
(5) poor or unstable injection conditions.

Many upgrade activities are underway in the current Long Shutdown (LS) 1. Beam operation is expected to resume in October 2023.

The age profile of the SuperKEKB personnel is a concern. About a third of the team is rehired retired staff, which is largely outnumbering the staff below 40 years of age.

Key Recommendations 1

- Key Recommendations

  The Committee has made recommendations throughout the different sections below. The most significant of these recommendations and a few more general recommendations are summarized here:

1. The ARC committee recommends actively recruiting new young staff members to help with the wide-ranging accelerator work of SuperKEKB and to prepare for the next decades of operation (R1.1).
2. Find a mechanism to engage additional PhD students (perhaps also already master students and even undergraduates), from Japanese universities or from abroad in the exciting and real-time accelerator environment of SuperKEKB, in both experimental and theoretical accelerator-physics studies (R1.2).
3. Develop a new algorithm to correct the orbit in a way that is insensitive to possible motion of BPMs without capacitive sensors and their calibrations (R2.4).
4. Simulate the effect of the measured vertical floor deformation by up to 40 mm on the vertical emittance in the LER and HER (R11.1).
5. Consider realigning the whole ring, especially the Southern part (R11.2).
6. Simulate the injection efficiency to the LER, by changing the injection offset, which may affect the efficiency or the lifetime for large amplitude particles (R9.6).

Key Recommendations 2

- Key Recommendations
  7. Quantify the expected integrated luminosity improvements for all specifically proposed LS2 projects. Update annually (R21.2).
  8. Investigate through a combination of electro-magnetic, mechanical and shower simulations (as performed for LHC collimators) whether a sudden collimator jaw deformation by ~100 micron could occur, triggered by HOM heating or small beam impact, which could then lead to a self-amplifying increasing deformation and catastrophic sudden beam loss (R17.5).
  9. Given the ongoing extremely high concern for the cost of electrical power, study configurations for the RF system in SuperKEKB that will allow for full or nearly full beam operation while significantly lowering the cost of RF power generation (R12.2).
  10. Complete a comprehensive study of the possible advantages coming from inserting an ECS in the e^- BT before proceeding with the real device construction (R8.2).

See “(C) Findings, Comments, Recommendations” for details.

Summary

- Many upgrade works are done during Long Shutdown 1 (LS1).
  - LS1 started in July 2022 and will end in autumn 2023. (~15 months)
  - “Belle II maintenance & reinforcement” and “Aseismic reinforcing works of the ceiling of the laboratory building” are also done during LS1.
- Status of “IR works” & “NLC construction” were reported in detail.
  - Both works are progressing as planned so far.
  - It is possible to complete all works by October 2023 and resume beam operation from autumn 2023.
  - It takes much longer time for some materials and devices to be delivered, so more careful coordination of LS1 schedule until the end of LS1 is required.
- 26th KEKB ARC meeting was held on 13-14 December 2022 in hybrid mode.
  - ARC report and slides of the presentations are available at

    https://www-kekb.kek.jp/MAC/2022/

Fin.

Thank you for your attention.

Backup