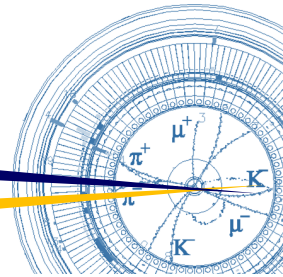


SuperKEKB

current status and future plan



K. Shibata

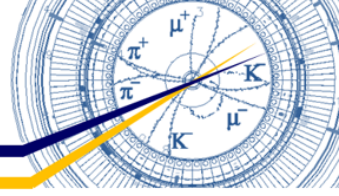
(on behalf of SuperKEKB Accelerator Group)

2020.11.09

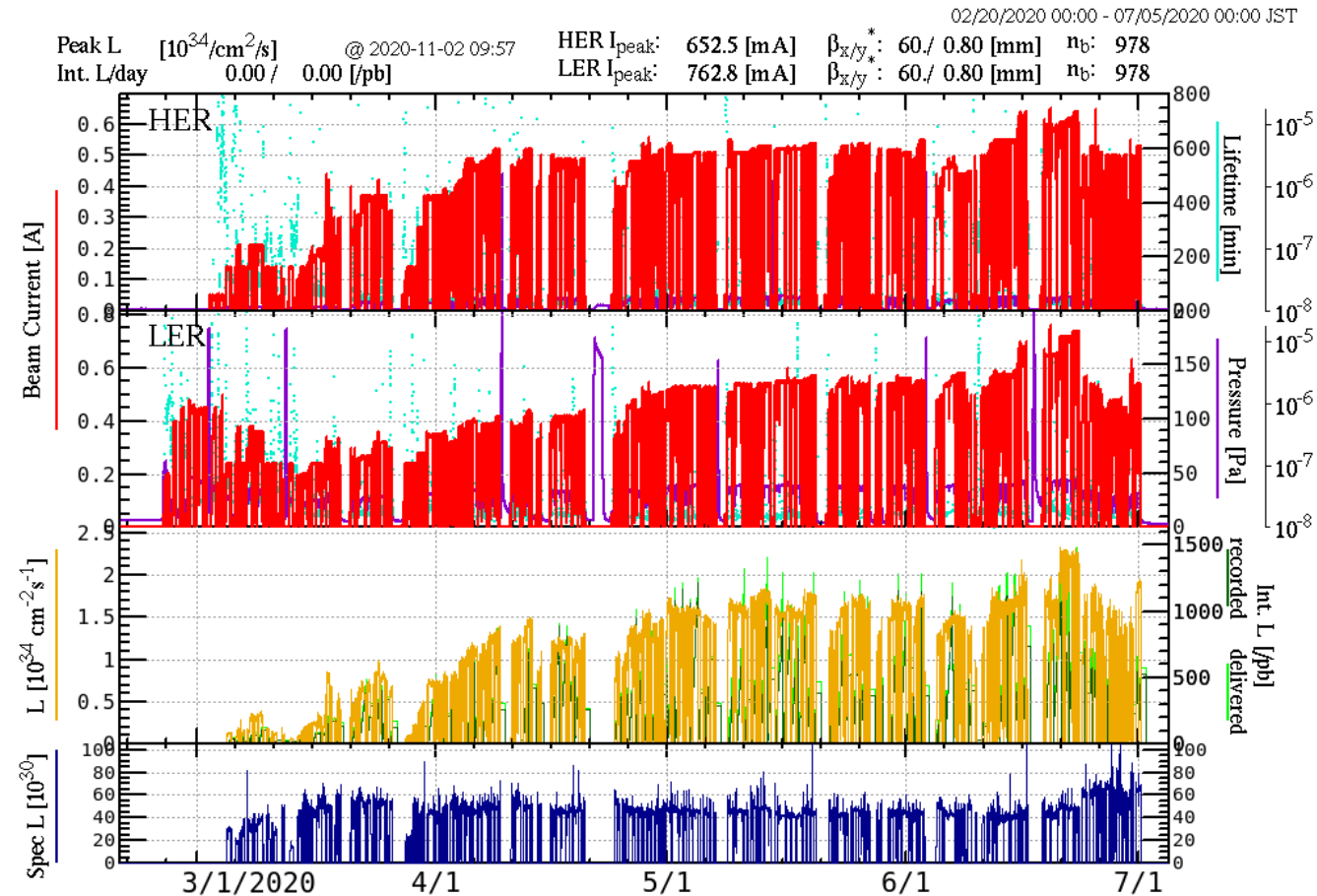
B2GM



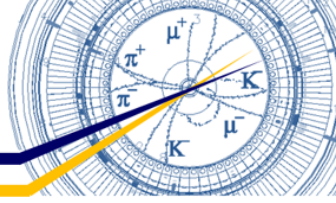
Highlight from 2020ab run



- Main missions of 2020ab run;
 - Physics run toward more than 100 fb^{-1}
 - Demonstration of crab-waist collision scheme
- Overview of 2020ab run;
 - From 25/Feb. to 1/July.
 - Beta squeezing:
 - Mainly $\beta_y^* = 1 \text{ mm}$, $\beta_x^* = 60(\text{HER})/80(\text{LER}) \text{ mm}$
 - Finally $\beta_y^* = 0.8 \text{ mm}$, $\beta_x^* = 60 \text{ mm}$
 Smallest β_y^* in the world !!
 - Crab-waist:
 - Cabling work for HER crab-waist (20-23/April)
 - LER : 0 % \rightarrow 40 % \rightarrow 60 % \rightarrow 80 %
 - HER : 0 % \rightarrow 40 %
 - Luminosity:
 - Peak Lumi. : $2.4 \times 10^{34} \text{ cm}^{-2} \cdot \text{s}^{-1}$ (NEW World Record!!)
 - $\beta_{x/y}^*$: 60/1mm (HER), 80/1 mm(LER)
 - Crab Waist : 40% (HER), 80% (LER)
 - Current : 610 mA (HER), 720 mA (LER)
 4.9 spacing (3-6 mix), 2 trains, 978 bunches
 - Delivered Integrated Lumi : $\sim 74 \text{ fb}^{-1}$



Specific luminosity (2020ab)



Luminosity

$$L = \frac{N_+ N_- n_b f_0}{4\pi \sigma_{x,\text{eff}}^* \sqrt{\epsilon_y \beta_y^*}}$$

Specific luminosity

$$L_{\text{sp}} = \frac{L}{I_{b+} I_{b-} n_b} \propto \frac{1}{\sqrt{\epsilon_y \beta_y^*}} \sigma_y^*$$

- L_{sp} depends on $1/\sigma_y^*$.
- L_{sp} doesn't depend on I_{b+}/I_{b-} .

- However, it was observed that L_{sp} decreases as I_{b+}/I_{b-} increases.



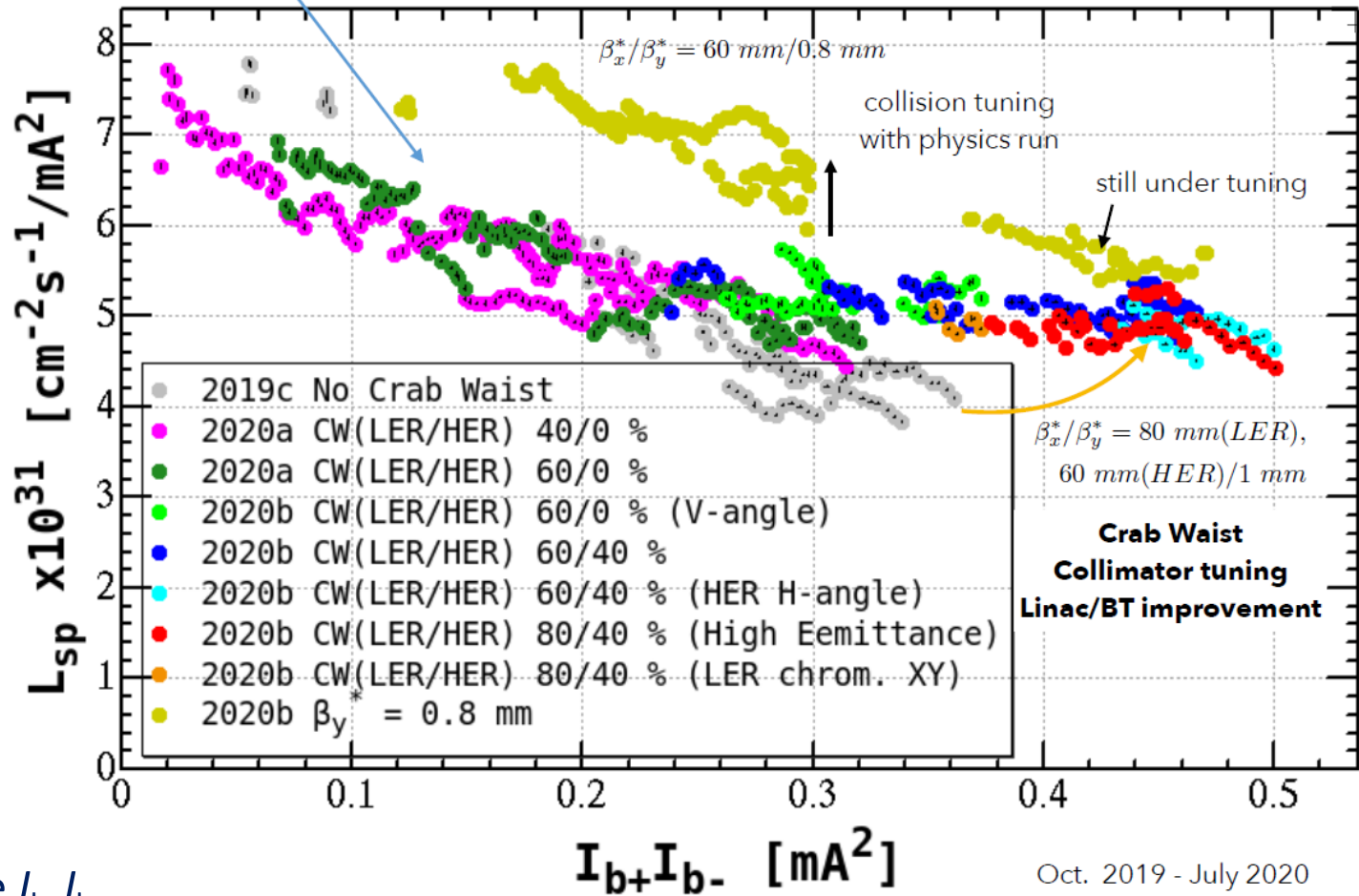
Beam blowup due to Beam-Beam effect at large I_{b+}/I_{b-} .

Beam blowup due to Beam-Beam effect

- $\sigma_y^* = 0.19 \mu\text{m}$
- $\sigma_y^* = 0.22 \mu\text{m}$
- $\sigma_y^* = 0.26 \mu\text{m}$
- $\sigma_y^* = 0.31 \mu\text{m}$

$\beta_y^* = 1 \text{ mm}$ and 0.8 mm

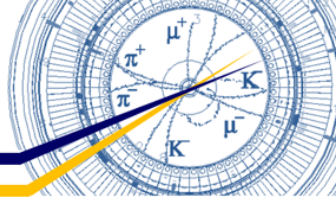
Y. Ohnishi



Oct. 2019 - July 2020



Luminosity performance



Y. Ohnishi

	Phase 2 2018a/b	Phase 3.1 2019a/b	Phase 3.2 2019c	Phase 3.3 2020a/b	
Date	March 19 - July 17 2018	March 11 - July 1 2019	Oct. 15 - Dec. 12 2019	Feb. 25 - July 1 2020	Remarks
Operation time (days)	120	91 (fire : 21)	57	127	~ 6 months per year
Beta Function at IP β_x^* / β_y^* (mm)	LER : 200 / 3 HER : 100 / 3	LER : 80 / 2 HER : 80 / 2	LER : 80 / 1 HER : 60 / 1	LER : 60 / 0.8 HER : 60 / 0.8	The minimum horizontal / vertical value
Beam Currents (mA)	LER : 860 HER : 800	LER : 940 HER : 840	LER : 880 HER : 700	LER : 770 HER : 660	The maximum values during the operation
Peak Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	2.62×10^{33}	5.50×10^{33}	1.14×10^{34}	2.40×10^{34}	w Belle II
	5.55×10^{33}	1.23×10^{34}	1.88×10^{34}	-	w/o Belle II

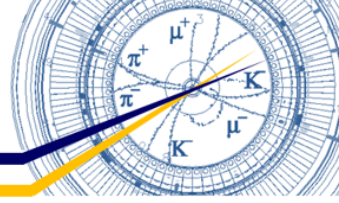


Major works during summer shutdown

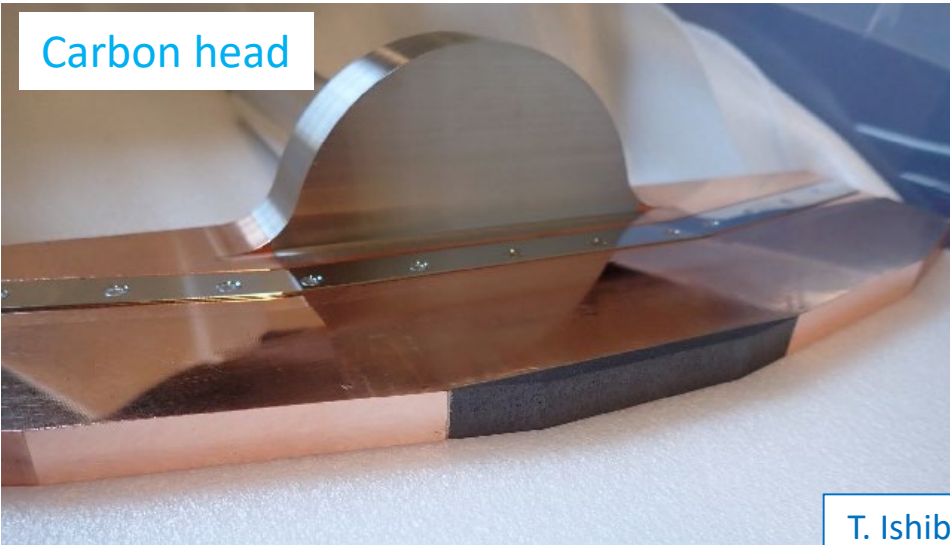
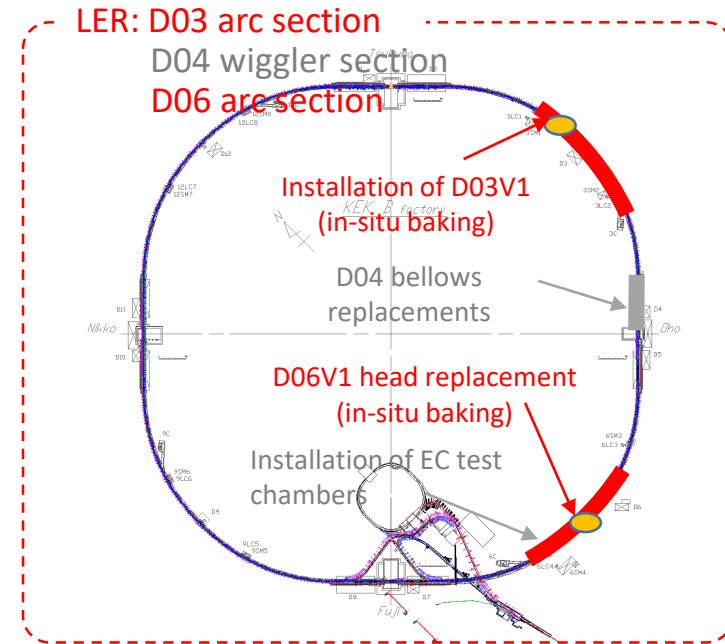
- Installation of new D03V1 collimator in LER
- Replacement of Tantalum jaws in D06V1 to Carbon jaws (Low-Z collimator)
- Installation of new skew-quadrupole (skew-Q) magnet in injection kicker section of LER
- Preparation and improvement of various beam tuning knobs to control rotatable sextupole magnets of LER
- Visual inspection of the inside of beam pipes of electron beam transport line.
 - Already reported by Mori_san
- Others
 - Regular maintenance of various power supplies and components
 - Visual check of jaws in HER collimators
 - Removal of gate valves that may cause vacuum pressure spikes in HER
 - Installation of new bellows chambers with high SR-masks into Wiggler Sections in LER
 - Replacement of mirror of SR beam size monitor in HER
 - Etc.



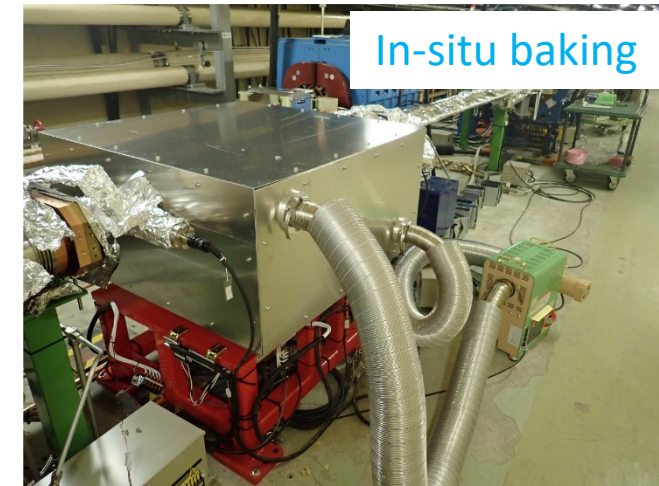
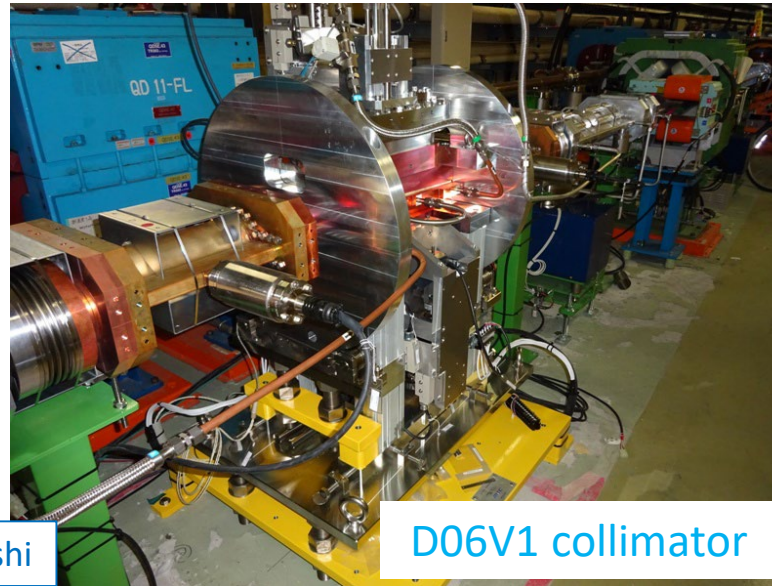
Collimator works



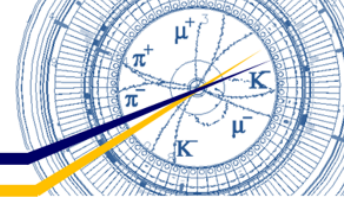
- Installation of new D03V1 collimator in LER
 - In-situ baking was performed after installation to reduce the pressure.
 - Conventional Tantalum jaws are installed into D03V1 collimator.
- Replacement of Tantalum jaws in D06V1 to Carbon jaws (Low-Z collimator)
 - In-situ baking was performed after installation to reduce the pressure.
 - Removed Tantalum jaws were damaged during Phase-3 2020ab.
- Visual check of jaws in HER collimators
 - It was found that there are many damaged jaws, though it is unknown when they were damaged.



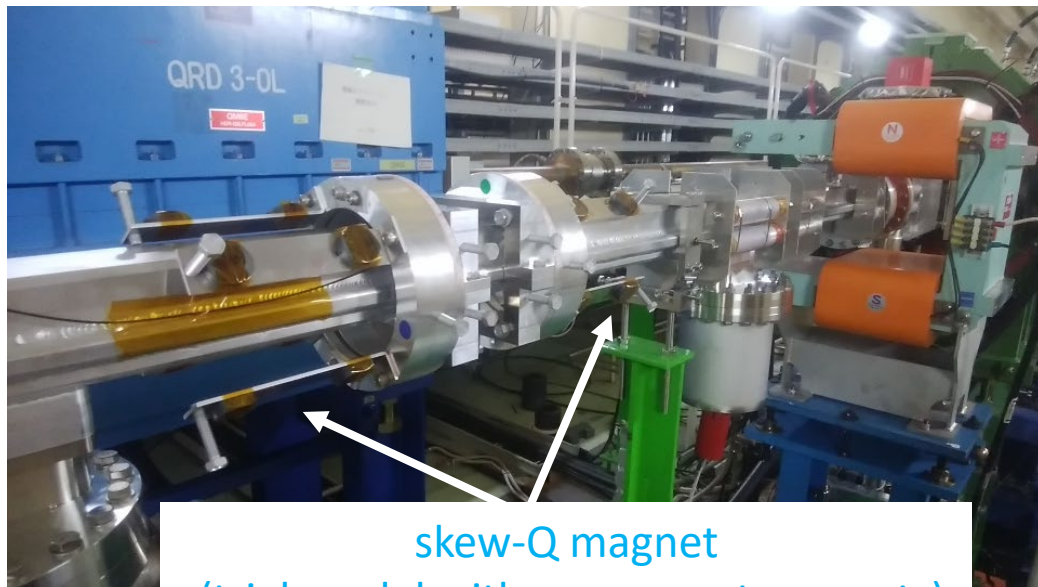
T. Ishibashi



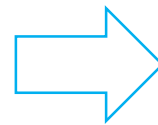
Installation of skew-Q magnet in LER



- Installation of new skew-quadrupole (skew-Q) magnet in injection kicker section of LER.
 - For correction of X-Y coupling due to Injections kickers.
 - Its effectiveness has been proven with permanent magnets during Phase-3 2020ab.
 - Improvement of injection efficiency
 - Reduction of injection BG duration
 - Suppression of luminosity drop during injection
 - etc.

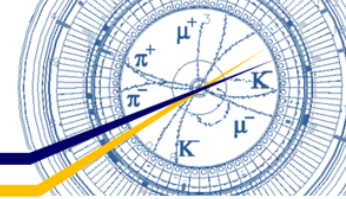


skew-Q magnet
(trial model with permanent magnets)

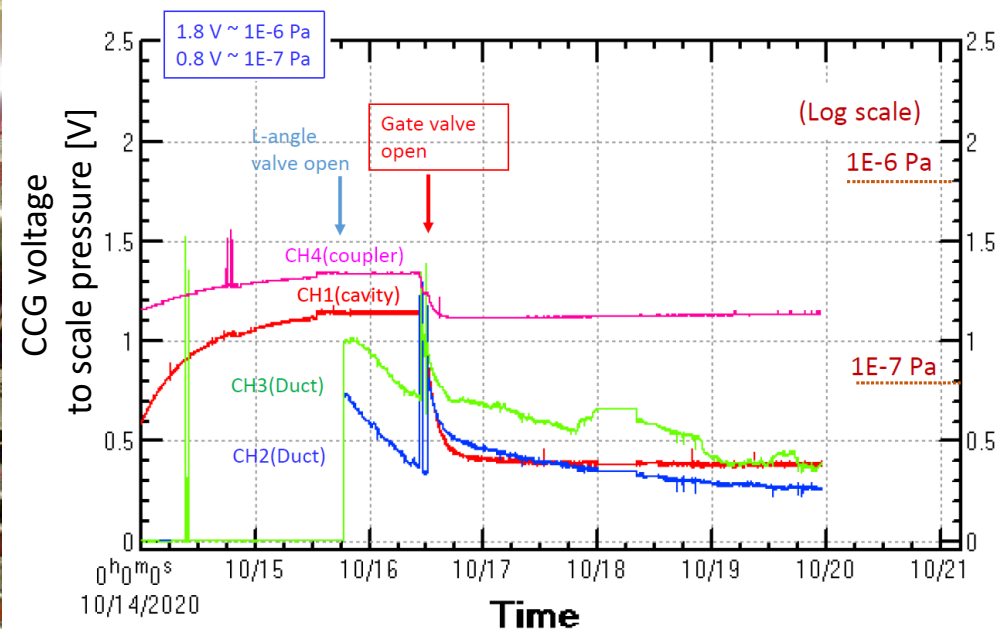
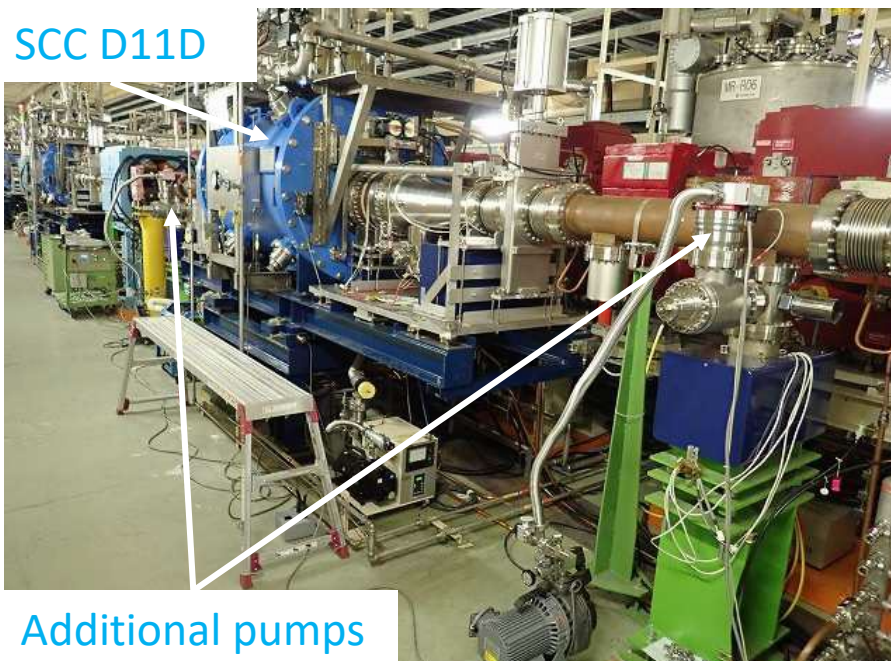
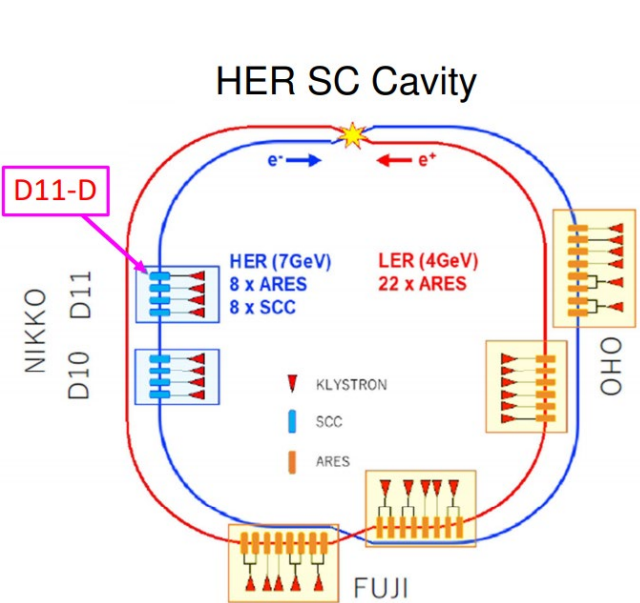
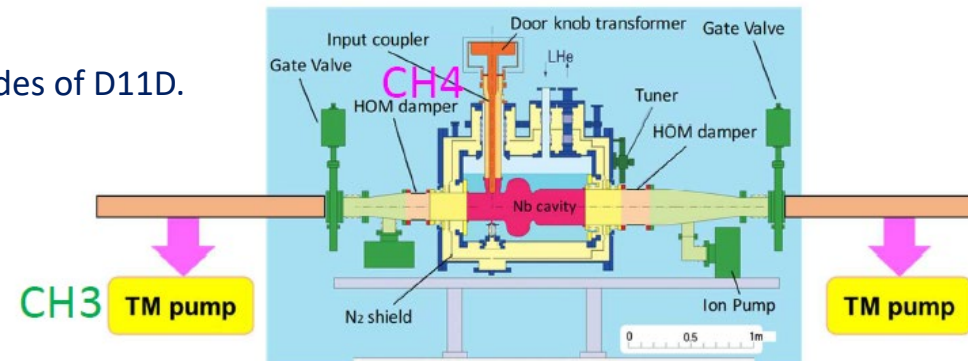


New skew-Q magnet

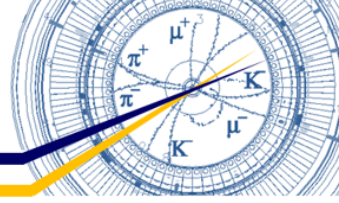
Superconducting Cavity problem (HER)



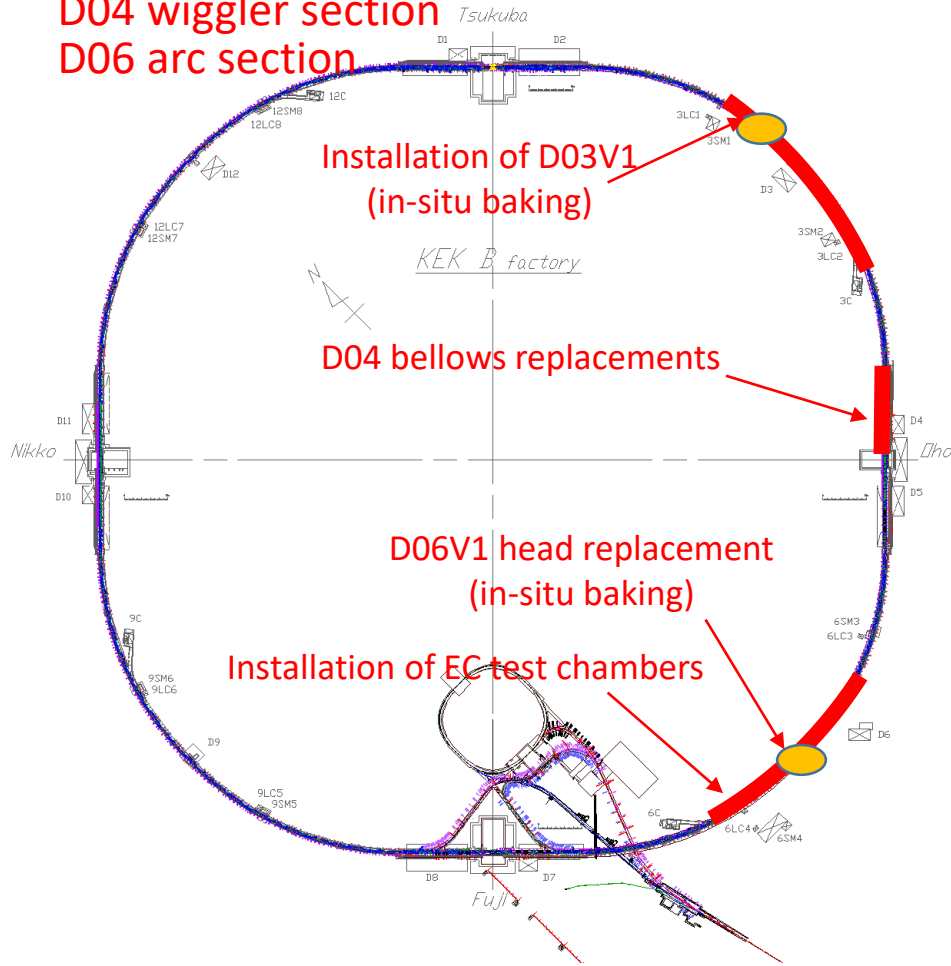
- Abnormal high pressure was observed in Superconducting Cavity (SCC) D11D in HER immediately before 2020c run.
 - Small leakage was detected in D11D.
 - In order to reduce the pressure near D11D, two additional pumps were installed on both sides of D11D.
 - The pressure in D11D has been kept low enough to operate HER normally so far.
- It was decided not to use D11D for beam operation
 - D11D is detuned during 2020c operation.
 - Accelerating voltage is compensated by other SCCs.
 - D11D will be replaced with a spare cavity during this winter shutdown.



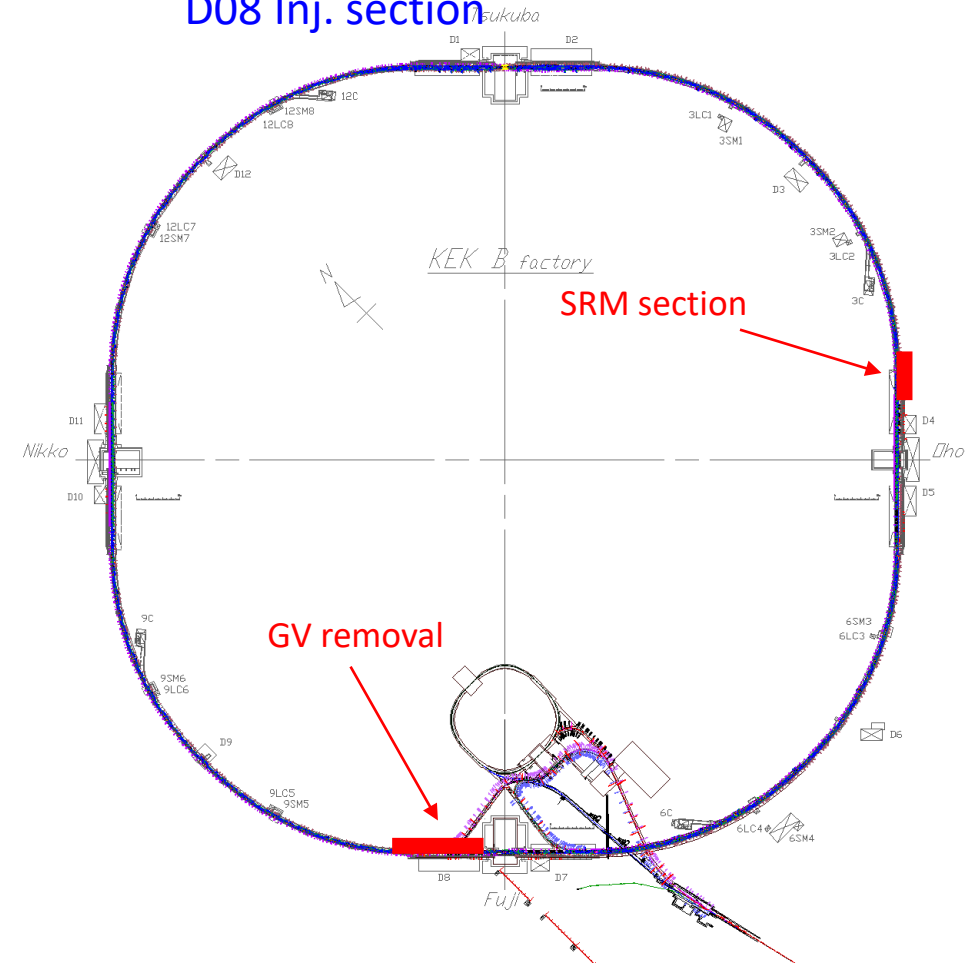
Vacuum work locations during summer shutdown



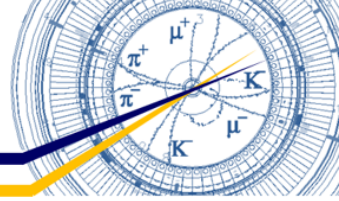
LER: D03 arc section
D04 wiggler section
D06 arc section



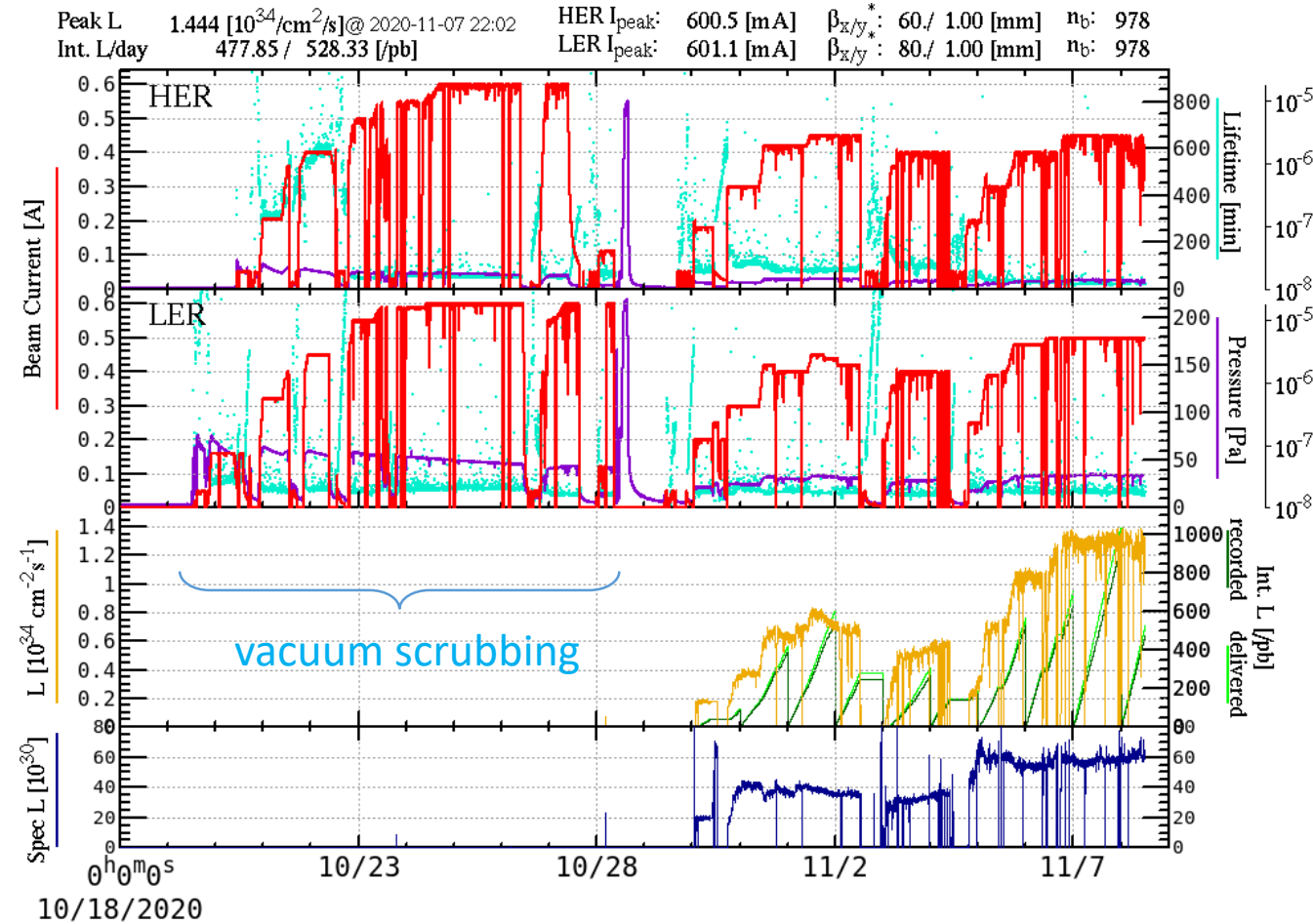
HER: D04 SRM section
D08 Inj. section



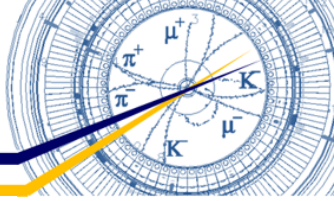
Phase-3 2020c Beam Commissioning



- Main missions of Phase-3 2020c run;
 - Physics run toward more than 40 fb^{-1} (only in 2020c)
 - Challenge to Peak Lumi. of $\sim 4 \times 10^{34} \text{ cm}^{-2} \cdot \text{s}^{-1}$
 - Doubling luminosity world record
 - With beam currents of 0.75 – 1 A
 - Beta squeezing : $\beta_{x/y}^* = 60/0.6 \text{ mm}$
- Overview of 2020c run (until 8/Nov.);
 - Operation time : 60 days (19/Oct. - 18/Dec.)
 - Vacuum scrubbing : 19/Oct. - 27/Oct.
 - Beta squeezing & Crab waist:
 - HER $\beta_y^* = 1 \text{ mm}$, $\beta_x^* = 80 \text{ mm}$, Crab-waist 40 %
 - LER $\beta_y^* = 1 \text{ mm}$, $\beta_x^* = 60 \text{ mm}$, Crab-waist 60 %
 - Finally we came back to Physics Run with 1mm- β_y^* .
 - Luminosity (until 8/Nov. 12:00):
 - Peak Luminosity : $1.4 \times 10^{34} \text{ cm}^{-2} \cdot \text{s}^{-1}$
 - Integrated Luminosity (delivered) : 4.7 fb^{-1}



Luminosity performance



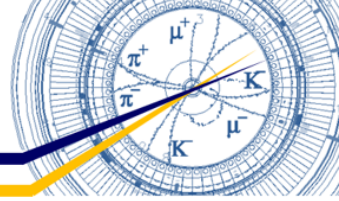
Y. Ohnishi

	Phase 2 2018a/b	Phase 3.1 2019a/b	Phase 3.2 2019c	Phase 3.3 2020a/b	Phase 3.4 2020c	
Date	March 19 - July 17 2018	March 11 - July 1 2019	Oct. 15 - Dec. 12 2019	Feb. 25 - July 1 2020	Oct. 19 - Dec. 18 2020	Remarks
Operation time (days)	120	91 (fire : 21)	57	127	60	~ 6 months per year
Beta Function at IP β_x^* / β_y^* (mm)	LER : 200 / 3 HER : 100 / 3	LER : 80 / 2 HER : 80 / 2	LER : 80 / 1 HER : 60 / 1	LER : 60 / 0.8 HER : 60 / 0.8	LER : 60 / 0.8 - 0.6 HER : 60 / 0.8 - 0.6	The minimum horizontal / vertical value
Beam Currents (mA)	LER : 860 HER : 800	LER : 940 HER : 840	LER : 880 HER : 700	LER : 770 HER : 660	750 - 1000	The maximum values during the operation
Peak Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	2.62×10^{33}	5.50×10^{33}	1.14×10^{34}	2.40×10^{34}	4×10^{34}	w Belle II
	5.55×10^{33}	1.23×10^{34}	1.88×10^{34}	-	-	w/o Belle II

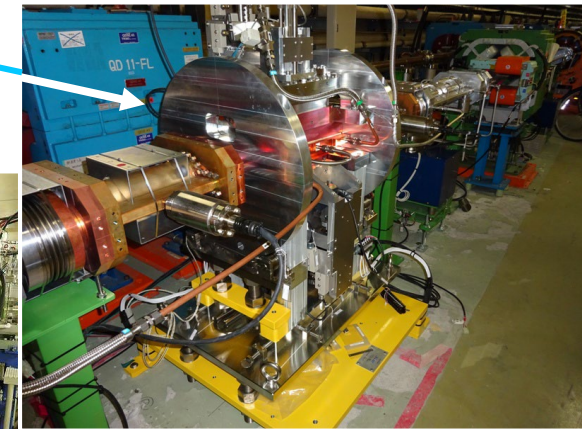
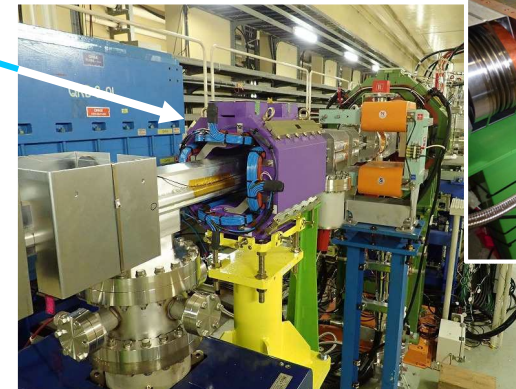
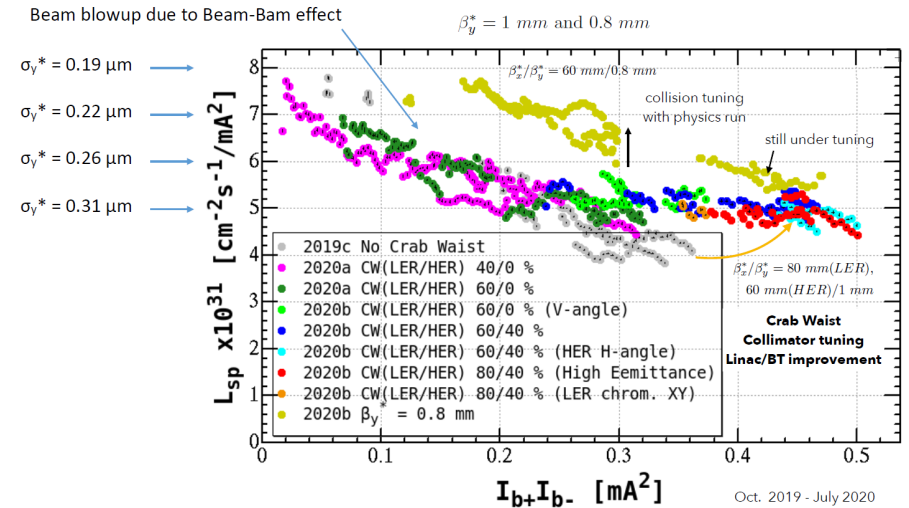
- Target stability of machine performance : $1.5 \text{ fb}^{-1}/\text{day}$

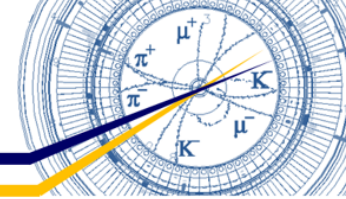


Challenges in 2020c



- Raising peak luminosity
 - Further β_y^* squeezing down to 0.6 mm
 - Collision tuning to suppress beam-beam blow-up at high bunch current products
 - Raising beam current
- Reduction of background noise to Belle II detector
 - New vertical collimator D03V1 in LER
 - New carbon jaws of D06V1 (low-Z collimator) in LER
- Suppression of X-Y coupling at injection kicker section of LER
 - New skew-Q magnet at injection kicker section
- Extension of very short beam lifetime
- Overcoming difficulties in correction of beam optics
- Maintaining aged hardware including buildings
- Etc.

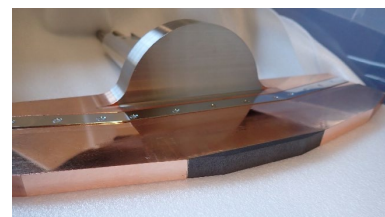




News flash of recent machine studies

1. Carbon-head (Low-Z) collimator D06V1 in LER

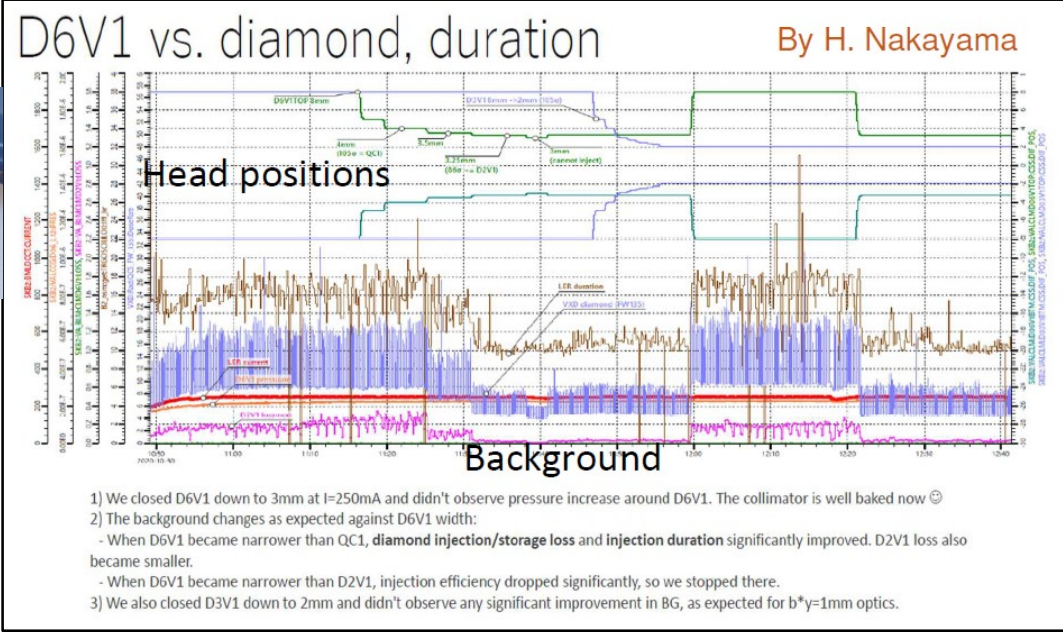
- It was confirmed that low-Z collimator worked well to suppress BG.



Carbon head

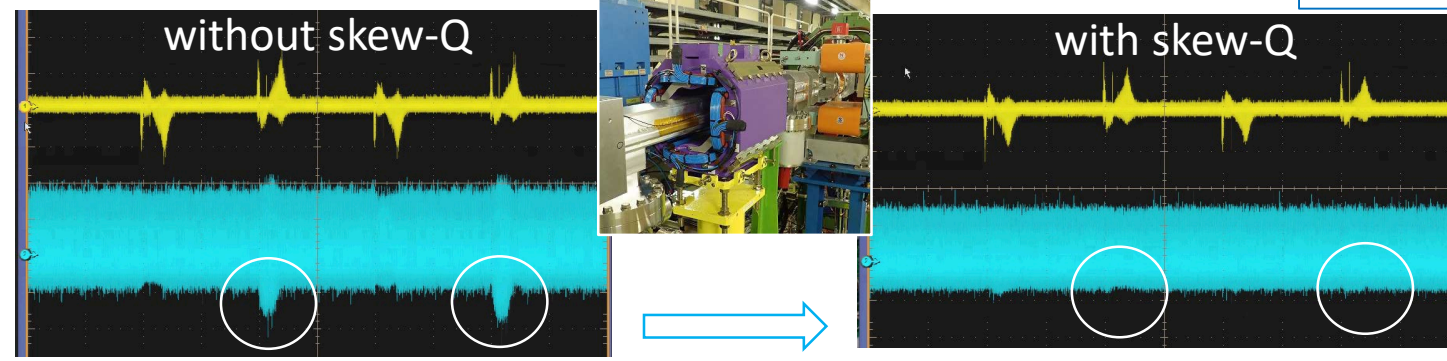
2. Skew-Q magnet at injection section in LER

- It was confirmed that new skew-Q magnet installed at injection section of LER worked well to suppress X-Y coupling of injected beam.
- BG due to injected beams were reduced.
- BG duration was also reduced.



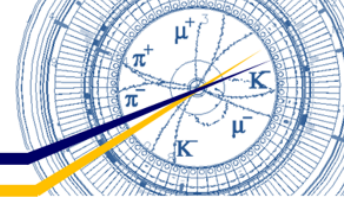
New skew-Q magnet

S. Terui



Vertical oscillation of injected beam was well suppressed.

Maintaining aged hardware



- Anti-aging measures for old components and facilities are indispensable for stable operation of SuperKEKB.
 - Potential risk of long-term failure increases rapidly.
 - Budget for beam operation will have to be allocated to maintenance costs.
 - This is not a problem just for this term, but a long-term problem.

Examples of aging:

Erosion of Klystron cooling towers



Water leakage from old flow sensors

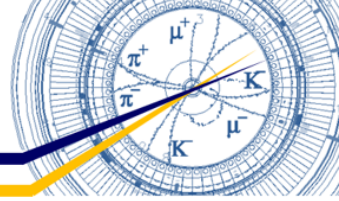


Leakage of roof of power supply buildings



Others: Frequent failures of old power supplies for magnets
Heat up of power supply building due to poor thermal barrier
etc.

Long-term plan



Y. Suetsugu

Plan proposed for MEXT Roadmap2020

MEXT : Ministry of Education, Culture, Sports, Science and Technology

- Based on results obtained so far and expected budgeted.
- QCS upgrade is newly proposed.

New goals:

- Integrated luminosity : 50 ab^{-1} around 2030
- Peak luminosity : $\sim 6 \times 10^{35} \text{ cm}^{-2} \cdot \text{s}^{-1}$
- β_y^* squeezing: 0.5 mm before IR upgrade, 0.3 mm after that
- Beam currents (LER/HER):
 $\sim 2.5\text{A}/\sim 1.8\text{A}$ before RF upgrade
 $\sim 2.9\text{A}/\sim 2.1\text{A}$ after that

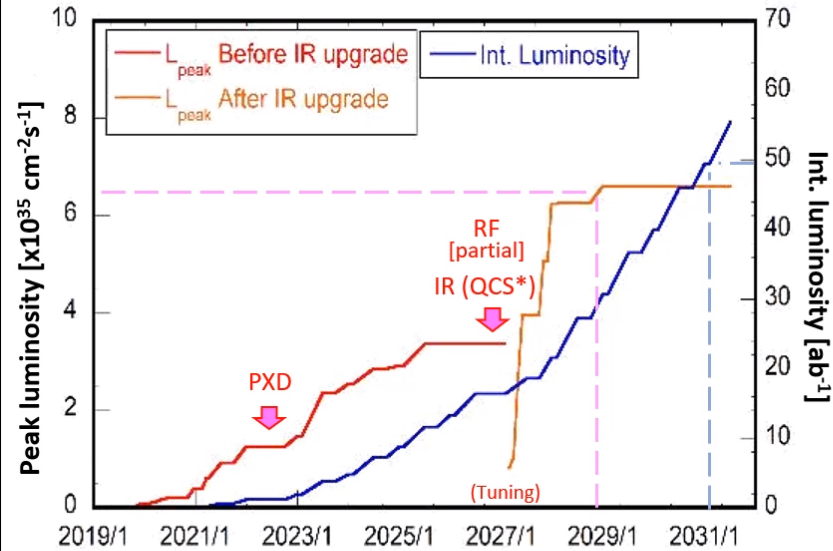
Required investment in equipment

- IR upgrade(QCS, its beam pipes, etc.)
- Partial RF-power upgrade (2 stations)
- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade



Update of operation plan and its reasons

- Updated plan
 - Proposed in Roadmap 2020



*QCS:

Superconducting final focusing quadrupole magnet

- Peak luminosity $\sim 6E35 \text{ cm}^{-2} \cdot \text{s}^{-1}$ in ~ 2028
- Integrated luminosity 50 ab^{-1} in ~ 2030 (40 ab^{-1} in ~ 2029)
- PXD exchange in 2021~2022
- Partial RF-power upgrade (2 stations) in 2026
- IR (QCS and its beam pipes etc.) upgrade in 2026
- $\beta_y^* = 0.3 \text{ mm}$ in 2026 after IR upgrade, and $\sim 0.5 \text{ mm}$ before that
- Max. beam currents: LER 2.8 A, HER 2.0 A (1761 bunches) in 2027
- Basically, 8 months operation per year.

[Investment in equipment]

- IR (QCS and its beam pipes etc.)
- Partial RF-power upgrade (2 stations)
- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade

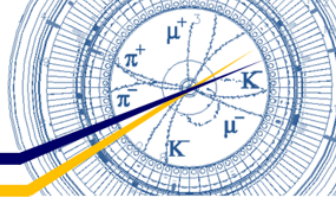
2020/6/29

BPAC 2020 0629

21



IR upgrade plan

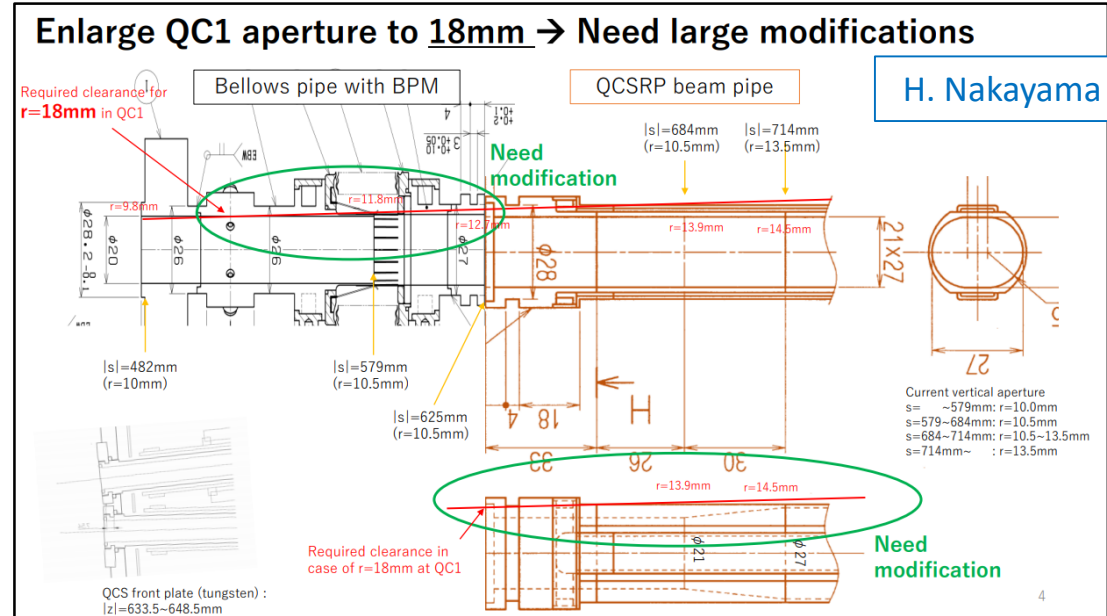


Motivation

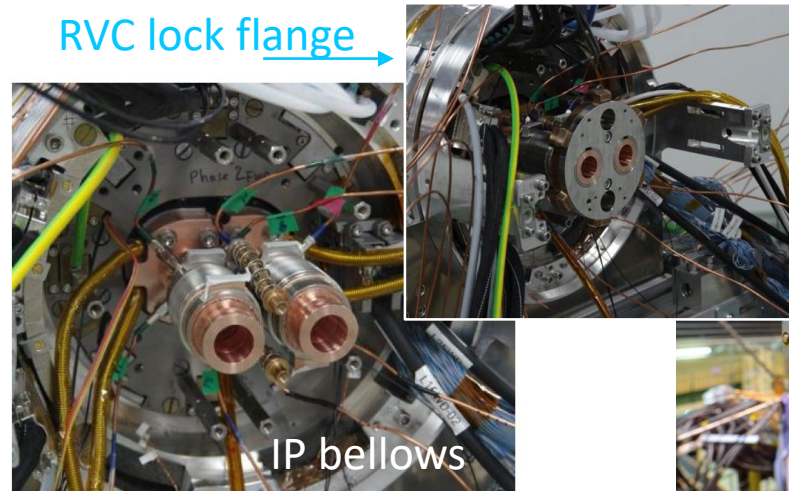
- Strong beam-beam effects in high bunch current region
 - Recent studies indicate that one promising countermeasure is modification of QCS to avoid interference between its magnetic field and Belle II solenoid field for LER.
- Narrow physical aperture in QCS beam pipes
 - QCS quenches caused by unstable beam hits have been observed.
 - If we squeeze βy^* to less than 0.5 mm, it will be difficult to protect QCS by using collimators.
- Large background noise from QCS beam pipes
 - At present, background in Belle II is larger than expected.
 - One of main background sources is hit of beam halo on the QCS beam pipes.
 - Background will become larger as βy^* is further squeezed.

→ Modification of QCS magnets and QCS beam pipes with large aperture is required.

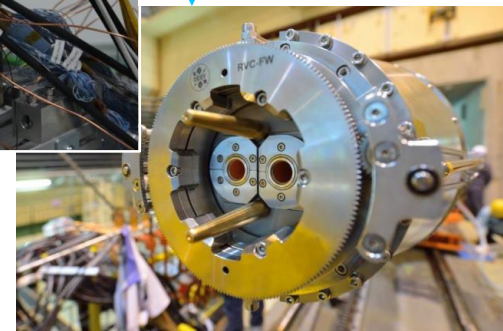
- Accelerator Review Committee requested an investigation into the feasibility and effectiveness of IR upgrade plan before making final decision. (within ~2 years)
- Design works of new QCS and its beams pipes started, and they are ongoing now.
- IP bellows, RVC lock flanges and QCSR front plate should be modified too.



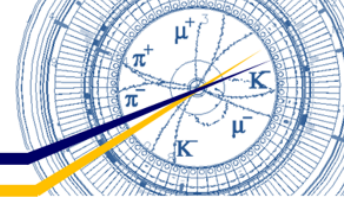
RVC lock flange →



QCS beam pipes (front end) ↓



2021a operation plan



• Winter shutdown

- From 18/Dec./2020 to 16/Feb./2021
- Replacement of SCC D11D
- Replacement of 66 kV high-voltage power supply lines

• 2021a run

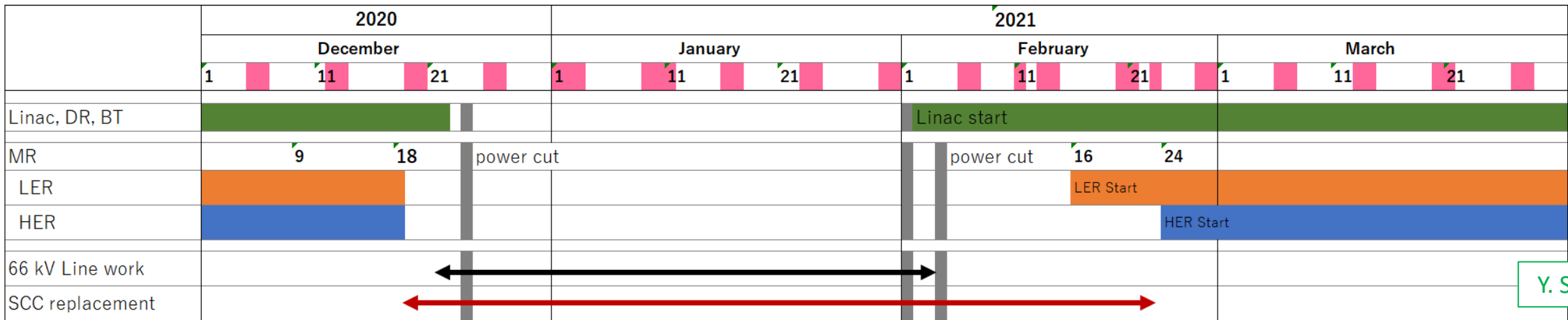
- From 16/Feb. to 31/Mar.
 - Operation cost will be covered with an extra budget from Director.
- LER operation will start on 16/Feb.
- HER operation will start on ~24/Feb.
 - It depends on D11D replacement work.

• By the end of March 2021

- Operation time of this JFY (Apr. 2020 –Mar. 2021) will be ~6.5 months.
- Toward more than 240 fb⁻¹ in total
- Target peak lumi. : ~6.5 × 10³⁴ cm⁻².s⁻¹
 - Beam currents : ~ 0.9 A
 - Beta squeezing : $\beta_{x/y}^* = 60/0.6$ mm

	Parameters			
	Int. L [fb ⁻¹]	L _p [E34]	I _{max} [A] (ave.)	β _y [*] [mm]
Base plan until 2020c	~110	~4	0.74	0.6
Base plan until 2021a (Depend on operation time)	240~140	6.5~4.5	0.9~0.75	0.6

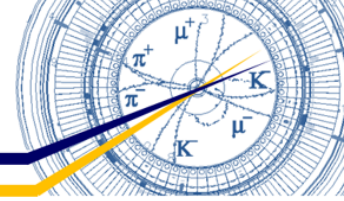
SuperKEKB 2020c&2021a Operation Plan



Y. Suetsugu



JFY2021 run plan



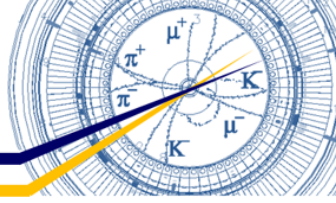
- JFY2021 budget request process is ongoing.
- MEXT has asked to align JFY2021 budget request to the plan submitted for the MEXT Roadmap2020.
 - 5.7 months of operation in JFY2021
 - Taking account of long shutdown for PXD replacement from Jan. 2022.

JFY: Japanese Fiscal Year, from April to March of next year.
 MEXT : Ministry of Education, Culture, Sports, Science and Technology

FY2020	2020										2021			Y. Suetsugu
	4	5	6	7	8	9	10	11	12	1	2	3		
Present plan (20th Oct.)	← 2020b → ~3M						← 2020c → ~2M				← 2021a → ~1.5M		Total ~6.5M/y	
FY2021	2021										2022			Total ~5.7M/y
	4	5	6	7	8	9	10	11	12	1	2	3		
Original plan (not fixed) [MEXT Road Map]	← 2021b → ~3M						← 2021c → ~2.7M			PXD exchange				
	4/1		7/1				10/4		12/24					

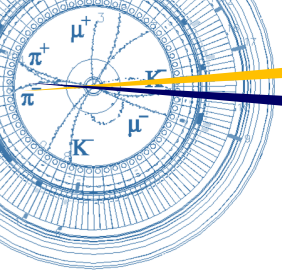


Summary

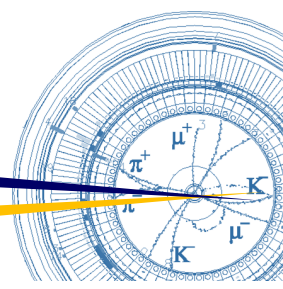


- 2020c run
 - From 19/Oct. to 18/Dec.
 - Vacuum scrubbing before physics run completed successfully.
 - Physics run with $\beta_y^* = 1$ mm has been resumed.
- 2020 winter shutdown
 - SCC D11D will be replaced with a spare cavity.
- 2021a run
 - From 16/Feb. to 31/Mar.
 - Target peak luminosity : $\sim 6.5 \times 10^{34} \text{ cm}^{-2} \cdot \text{s}^{-1}$
 - Beam currents : ~ 0.9 A
 - Beta squeezing : $\beta_{x/y}^* = 60/0.6$ mm
- Long-term plan proposed for MEXT Roadmap2020
 - New luminosity targets :
 - Integrated luminosity : 50 ab^{-1} around 2030
 - Peak luminosity : $\sim 6 \times 10^{35} \text{ cm}^{-2} \cdot \text{s}^{-1}$
 - IR upgrade & Partial RF-power upgrade are required.
 - JFY2021 budget request process is ongoing.





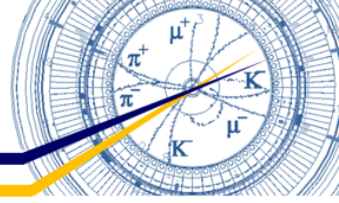
Fin.



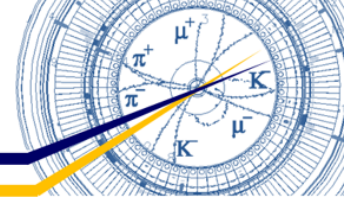
Thank you for your attention.



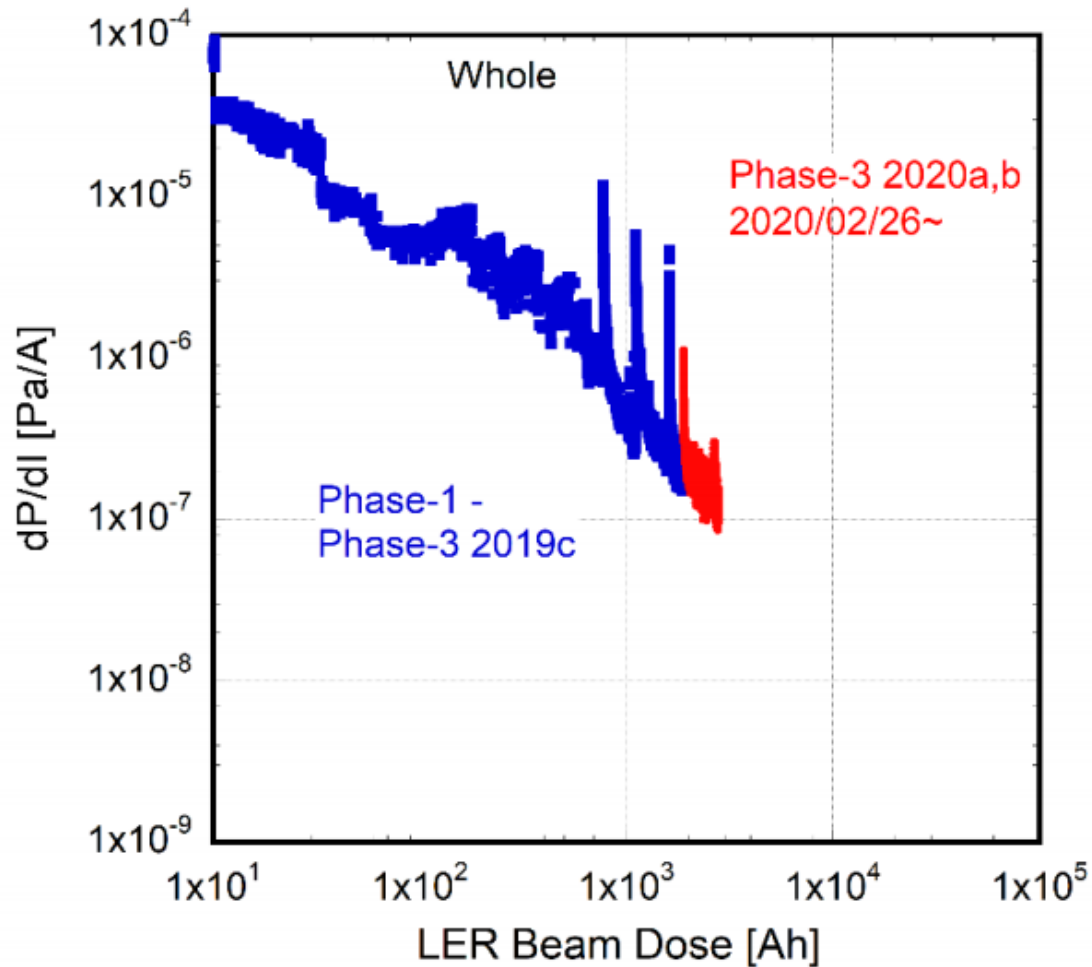
Backup



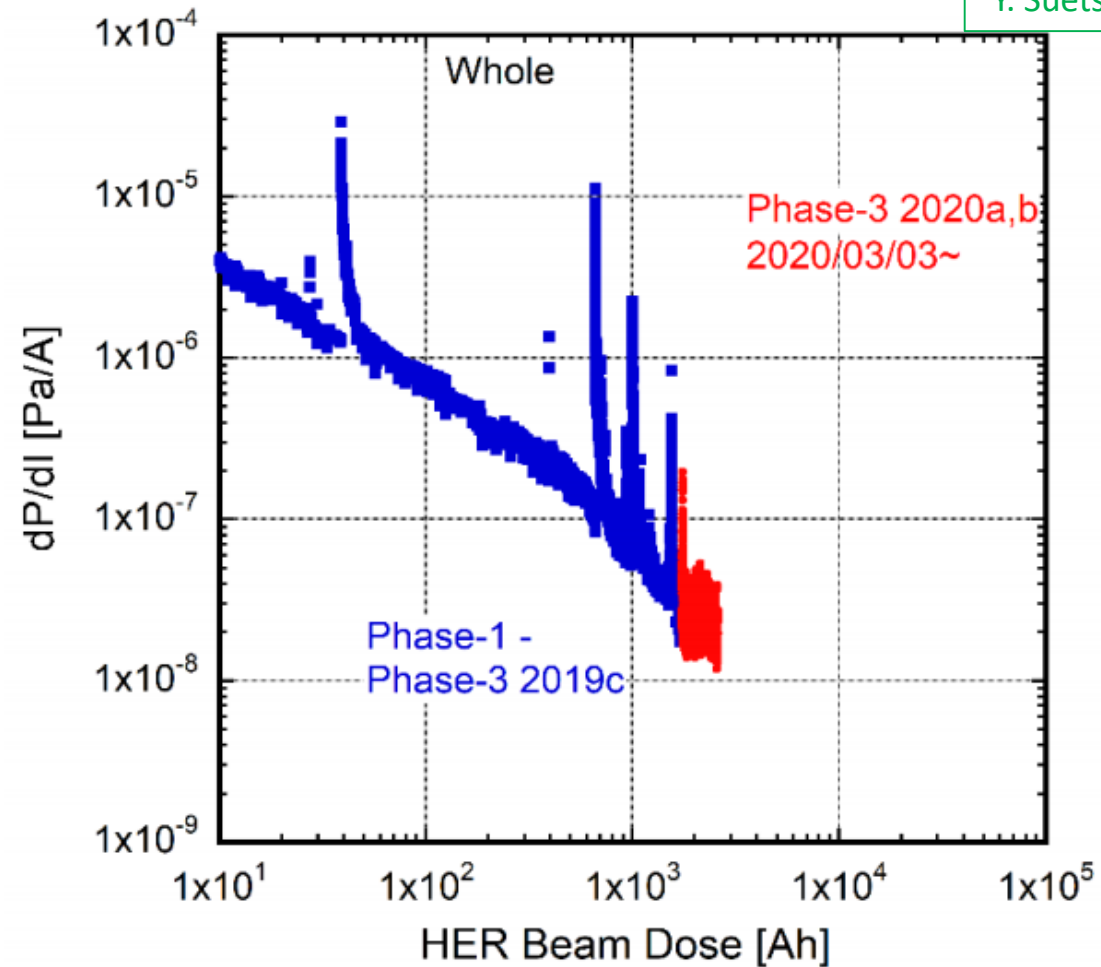
Vacuum scrubbing since Phase1



LER



HER



Y. Suetsugu

