Overview of SuperKEKB Status

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- Brief review since the last KEKB review (2018/3/14-16)
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    and Phase-3 2019 spring run (2019/3/11-2019/7/1)
- Key challenges for higher luminosity
  - Specific luminosity
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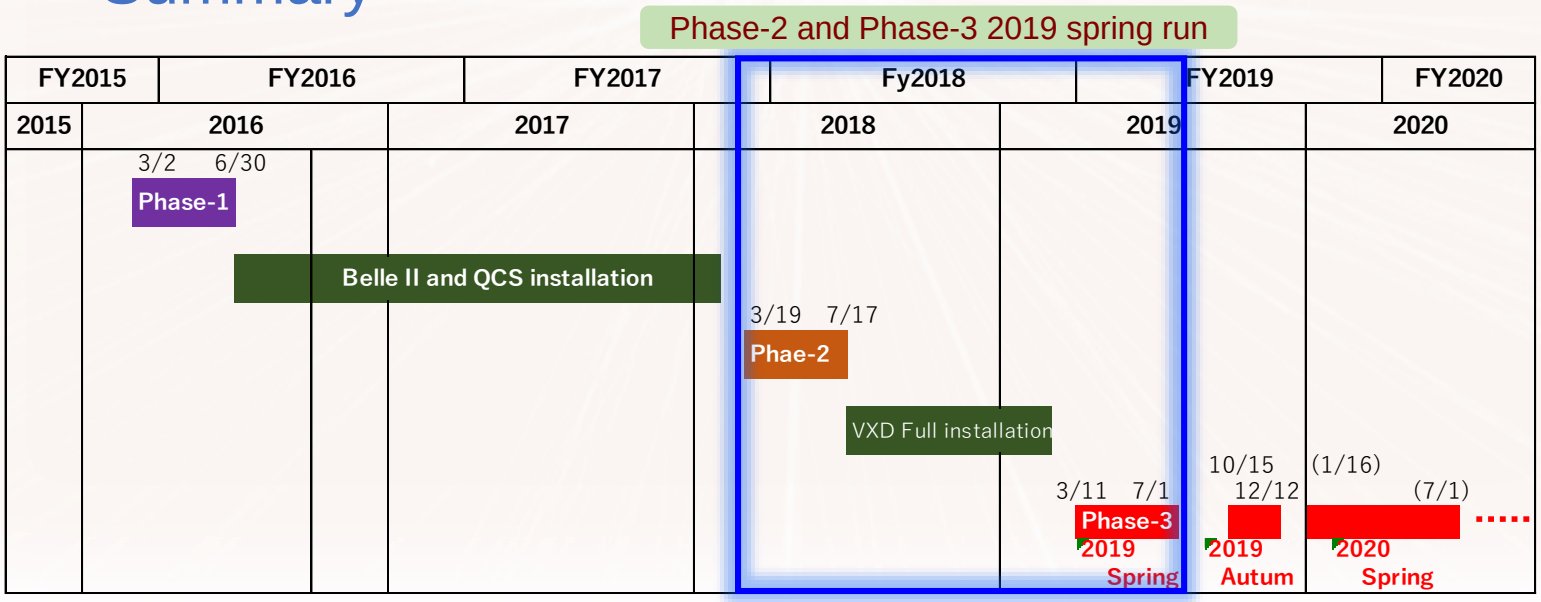
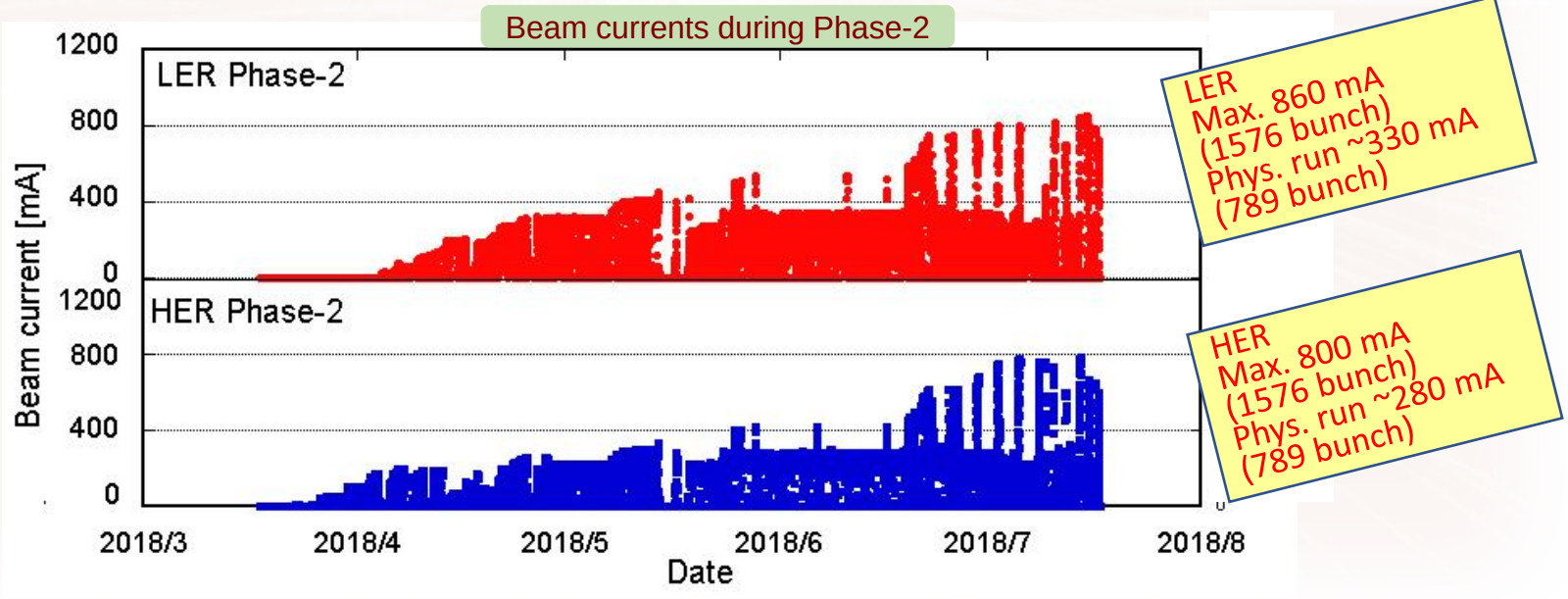
  - QCS quench and beam aborts
- Commissioning plan
- Summary



Highlights in Phase-2

- Phase-2 commissioning started from 19th, March, and ended 17th, July, 2018.
- Aims of Phase-2:
  - Positron injection through the damping ring (DR)
  - Collision tuning with QCS (final focusing quadrupole magnets) and Belle II detector.
  - Demonstrate “nano-beam” collision scheme.
  - Confirm that the background is tolerable level for the vertex detector (VXD) to be installed in Phase-3.

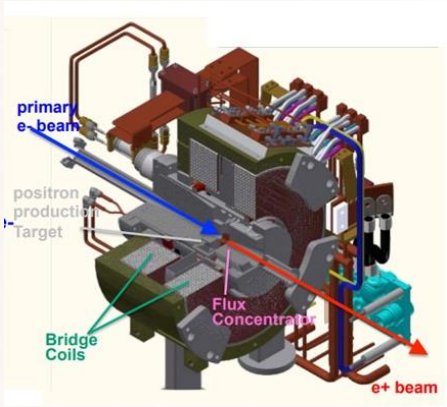


Highlights in Phase-2

- The injector linac has been working stably.
- Simultaneous bean injection to five rings (HER, LER, Damping ring, PF, and PF-AR) was realized in Phase-2.
  - Pulsed magnet system is working well.
- Photo-cathode RF gun has been regularly used for HER injection.
- Flux concentrator has been also functioning as expected.
  - These will be reported by Satoh-san, Zhang-san, and Enomoto-san.

Layout of injector linac

Flux concentrator for e+

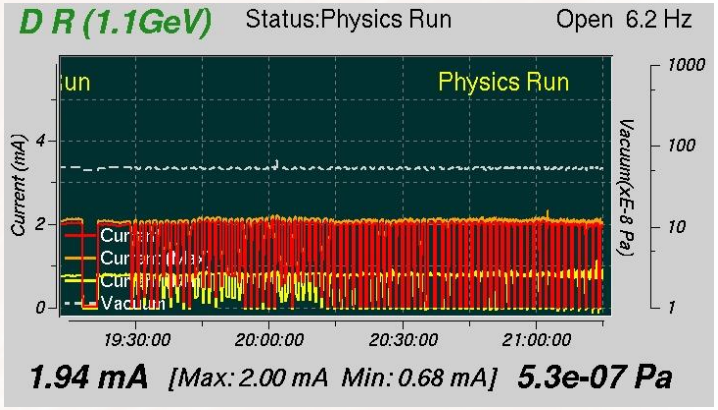


Highlights in Phase-2

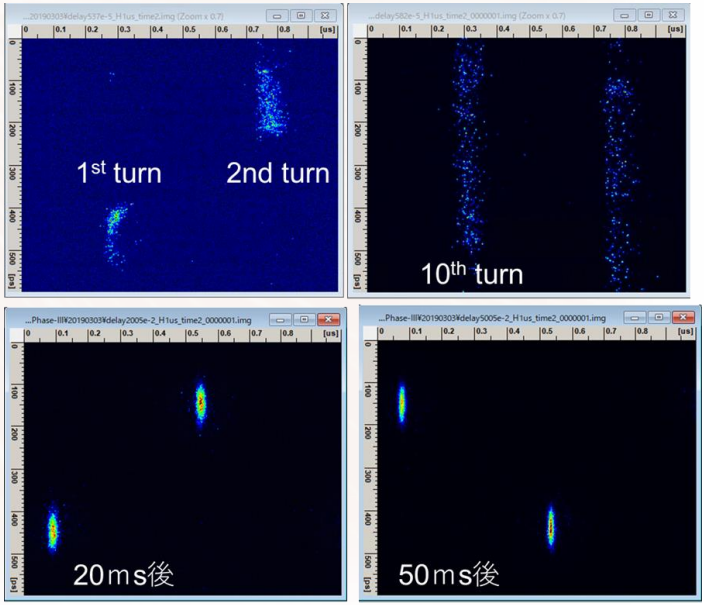
- Commissioning of DR was very successful.
  - It took only a few days for injection, storage, and extraction.
- DR has been working well since Phase-2.
  - Will be reported by Mori-san.
- Emittance issues in the beam transport (BT) line have been continuously investigated.
  - Will be reported by Seimiya-san.
- Damping of bunch (Phase-3): by Ikeda

  While the beam at first blows up just after the injection to the ring, the longitudinal and horizontal beam sizes well damped after 20 ms by the radiation damping.

Operation status of DR (Phase-3)



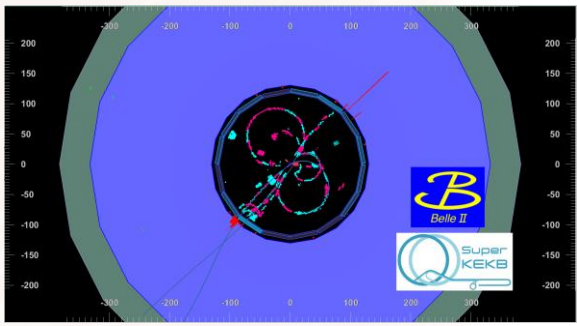
Longitudinal beam size (vertical) and horizontal beam size (horizontal) after injection [Streak camera] (Phase-3)



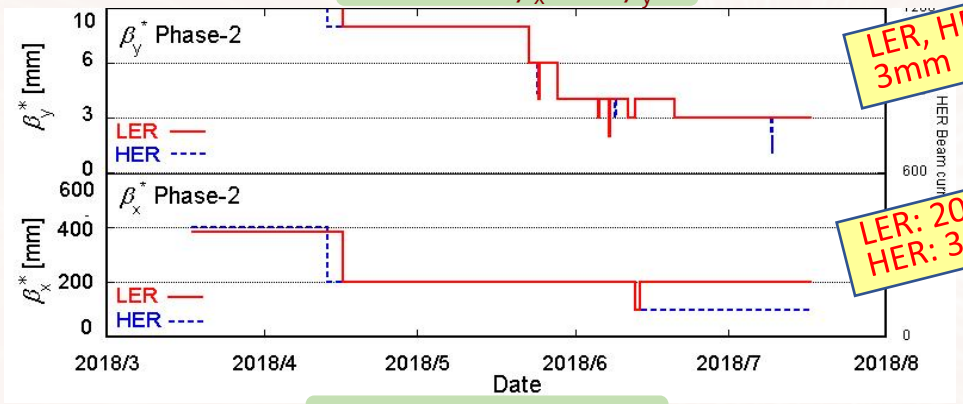
Highlights in Phase-2

- In MR, the collision tuning was proceeded squeezing β_x^*/β_y^* gradually.
- The first physics event was observed on 26th, April, 2018.

The first event on 26th, April 2018.



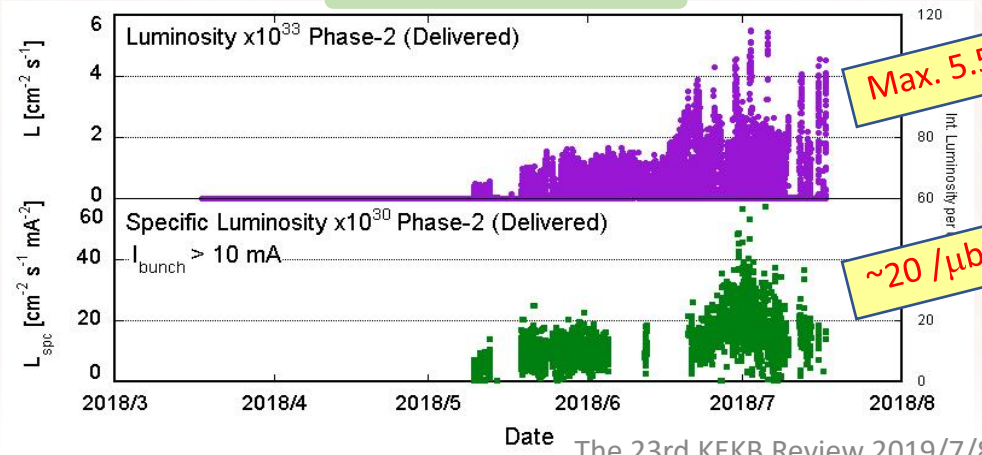
Trends of β_x^* and β_y^*



LER, HER: 3mm

LER: 200 mm
HER: 300 mm

Trends luminosities



Max. 5.5 /nb/s

~20 /μb/s/mA^2

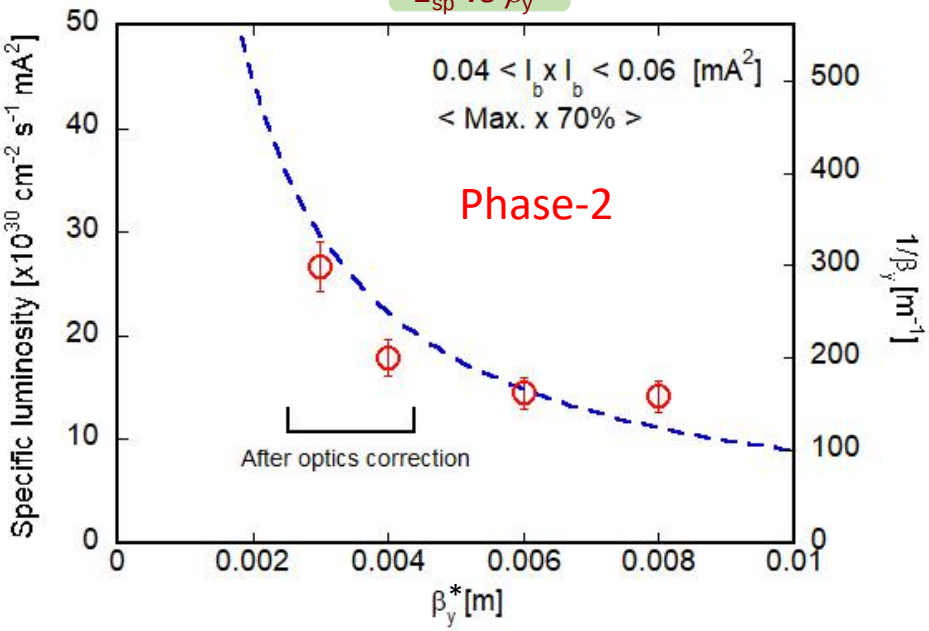
Highlights in Phase-2

- Specific luminosity (L_{sp}) increased in proportion to $1/\beta_y^*$.
- This demonstrated the "nano-beam scheme" collision for the first time in a practical machine.
- But, decrease in the specific luminosity with bunch current product has been observed due to beam-size blowup.

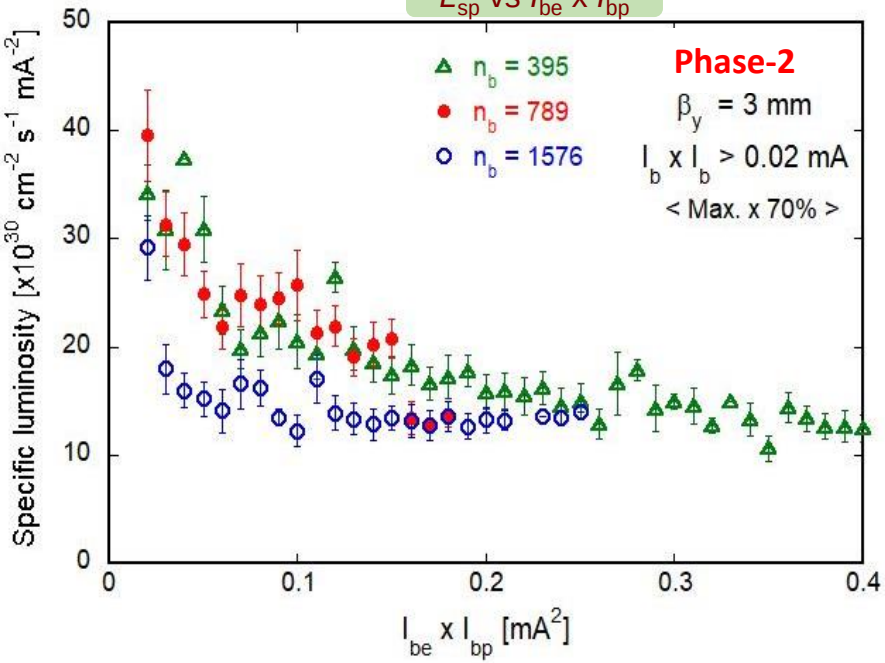
$$L_{sp} = \frac{L}{n_b I_{be} I_{bp}} \propto \frac{1}{\beta_y^*} \quad \text{for} \quad \frac{\beta_y^*}{\varepsilon_y} = \text{const.}$$

$$L_{sp} \propto \frac{1}{\langle \sigma_y^* \rangle} \quad \text{for} \quad \sigma_z^* = \text{const.}$$

L_{sp} vs β_y^*



L_{sp} vs $I_{be} \times I_{bp}$



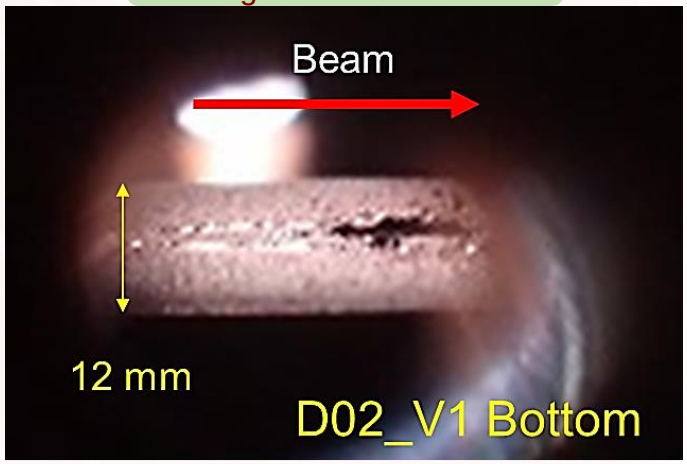
Highlights in Phase-2

- QCS has been working stably since Phase-2.
- Lots of quenches were triggered by beams in Phase-2 .
- The quenches due to injection beams were avoided by tuning beam collimators and injection parameters.
  - Narrower apertures at collimators than those in QCS.
  - Fast beam abort system using VXD diamond sensors.
- The quenches, which might be induced by beam-dust collision, occurred twice.
  - The head of a beam collimator was heavily damaged.
  - The similar event was again experienced in Phase-3.

List of quench events

Date	Time	Quenched Magnet	Beam Line		電流遮断後のビームアボート (HER)	(LER)	← In	Corrector name			→ Out	← In	Corrector current [A]		→ Out	
2018/4/1	20:55	QC1LP	LER				a1	b1	a2	b4		-1.13	2.97	-0.11	-0.36	
2018/4/2	19:29	QC1LP	LER				a1	b1	a2	b4		-1.13	2.97	-0.11	-0.36	
2018/4/9	17:31	QC1LE-b1	HER				b1	a1	a2	b4		-32.57	-11.19	3.98	-0.03	
2018/4/9	20:06	QC1LE-b1	HER				b1	a1	a2	b4		-32.57	-11.19	3.98	-0.03	
2018/4/9	20:53	QC1LE-b1	HER				b1	a1	a2	b4		-32.57	-11.19	3.98	-0.03	
2018/4/9	21:40	QC1LE-b1	HER				b1	a1	a2	b4		-32.57	-11.19	3.98	-0.03	
2018/4/10	17:44	QC1LE-b1	HER				b1	a1	a2	b4		-32.57	-11.19	3.98	-0.03	
2018/4/10	21:56	QC1RE-b1	HER				b1	a1	a2	a3		33.20	-2.22	-1.26	0.12	
2018/4/11	14:21	QC1RE-b1	HER				b1	a1	a2	a3		33.20	-2.22	-2.42	0.12	
2018/4/11	15:25	QCSL-Can-b3	HER				b3	b4	b5	b6		-40.30	-25.60	-17.60	14.40	
2018/4/11	18:45	QC1RE-b1	HER				b1	a1	a2	a3		33.20	-2.22	-2.42	0.12	
2018/4/11	20:23	QC1RE-b1	HER				b1	a1	a2	a3		33.20	-2.22	-2.42	0.12	
2018/4/11	21:15	QC1RE-b1	HER				b1	a1	a2	a3		33.20	-2.22	-2.43	0.12	
2018/4/20	14:33	QC1RP	LER	at the same instance			a1	b1	a2	b4	b3	0.12	-13.88	-3.96	0.27	-0.46
2018/4/20	14:33	QC1LP	LER				a1	b1	a2	b4		1.33	2.97	-1.22	-0.36	
2018/4/20	14:33	QC1RP-b1	LER				a1	b1	a2	b4	b3					
2018/4/21	02:49	QC1LP	LER	at the same instance			a1	b1	a2	b4		1.33	2.97	-1.22	-0.36	
2018/4/21	02:51	QC1RP	LER				a1	b1	a2	b4	b3	0.12	-13.88	-3.96	0.27	
2018/4/21	02:13	QC1RP-b1	LER				a1	b1	a2	b4	b3					
2018/5/6	11:28	QC1LE-b1	HER		マイナス11ms	No abort	b1	a1	a2	b4		-32.57	-11.02	4.82	-0.03	
2018/5/13	2:45	QC1RP-b1	LER				a1	b1	a2	b4	b3	No data	No data	No data	No data	
2018/5/17	2:09	QC1RP-b1	LER		No abort	22.35ms	a1	b1	a2	b4	b3	0.12	-13.88	-3.96	0.27	-0.46
2018/5/17	4:06	QC1RP-b1	LER		No abort	34.85ms	a1	b1	a2	b4	b3	0.12	-13.88	-3.96	0.27	-0.46
2018/5/24	17:17	QCSL-Can-b3	HER				b3	b4	b5	b6		-40.30	-25.60	-17.60	14.40	
2018/6/25	11:20:34	QC1RP	LER													
2018/6/25	11:20:34	QC1RP-b1	LER				a1	b1	a2	b4	b3					
2018/6/25	11:20:34	QC1LP	LER													
2018/7/3	5:14:17	QC1RP-b1	LER	入射中		285.9 mA	a1	b1	a2	b4	b3					

Damage of collimator head



Highlights in Phase-2

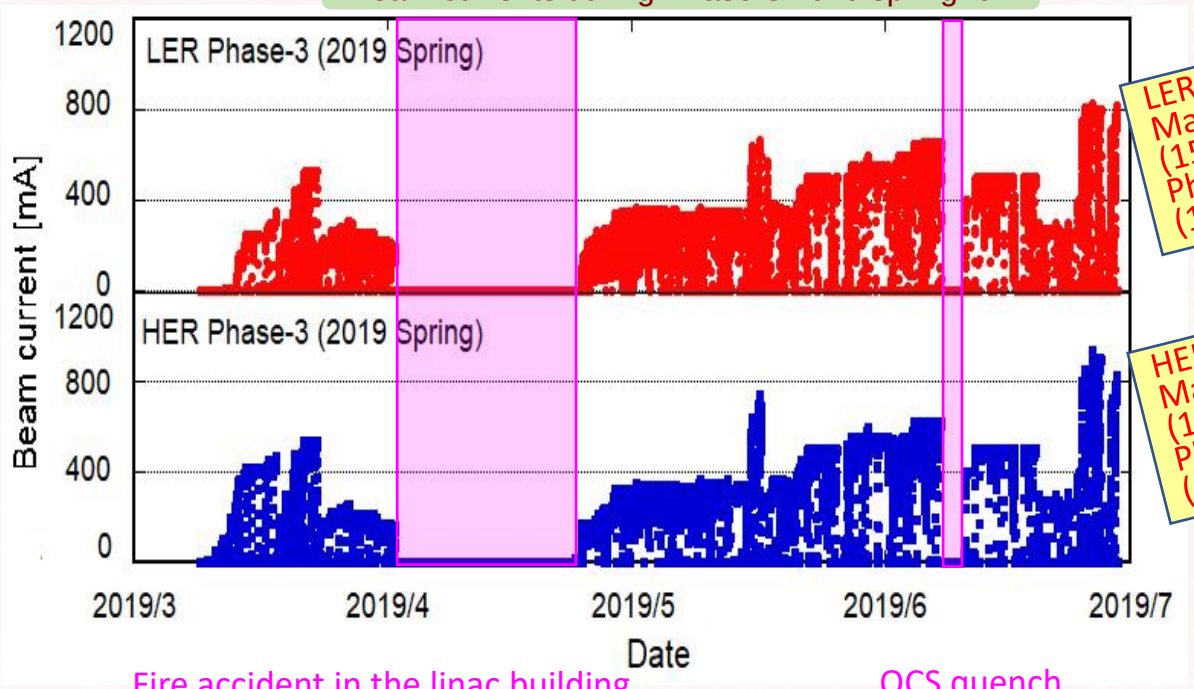
- Summaries of major results in Phase-2

Major results in Phase-1 and Phase-2				
Parameters	Phase-1 (3/2/2016–6/30/2016)		Phase-2 (3/19/2018–7/17/2018)	
	LER	HER	LER	HER
Max. beam current [mA]	~1010	~870	~860	~800
Beam dose [Ah]	775.0	661.5	337.5	340.2
Min. β_x^*/β_y^* in physics run (non phys.) [mm/mm]	-	-	200/3 (200/2)	100/3 (100/1.5)
Min. ε_x / ε_y [nm/pm]	~-/10 . (single)	~-/10 (single)	~1.7/160 (in col.)	~4.6/80 (in col.)
Max. bam beam param.			0.0244	0.0141
Max. lumi. L [$\times 10^{33}$ cm^{-2} s^{-1}]			5.55 (@1/1576/3.06)	
Specific lumi. @Max. L [$\times 10^{31}$ cm^{-2} s^{-1} mA^{-2}]			1.43	

Highlights in Phase-3 2019 Spring

- Phase-3 commissioning started from 11th, March, and ended 1st, July, 2019.
- Aims of Phase-3 2019 Spring run:
  - Starting full-scale physics run with complete VXD in Belle II.
  - Accelerator and collision tunings with lower β^* for higher luminosity.

Beam currents during Phase-3 2019 spring run



LER
Max. 830 mA
(1576 bunch)
Phys. run ~660 mA
(1576 bunch)

HER
Max. 940 mA
(1576 bunch)
Phys. run ~620 mA
(1576 bunch)

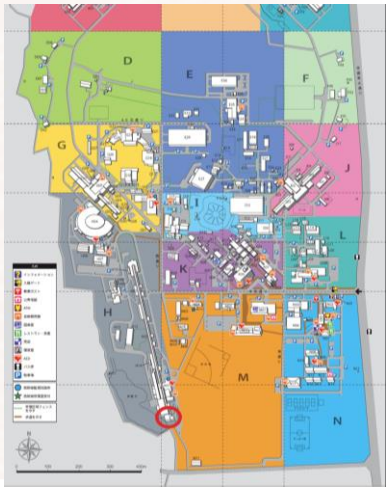
Highlights in Phase-3 2019 Spring

- Fire accident in the linac building on 3rd, April.
  - The fire occurred at a room separated by a wall from the injector linac used by SuperKEKB, but lots of carbon soot in the power pulsed-modulators should be cleaned up before restart.
- MR operation stopped for approximately 3 weeks during the recovery work of the linac, and the operation finally restarted from 25th and 26th.
  - Details will be presented by Abe-san and Furukawa-san.

Soot at terminal block

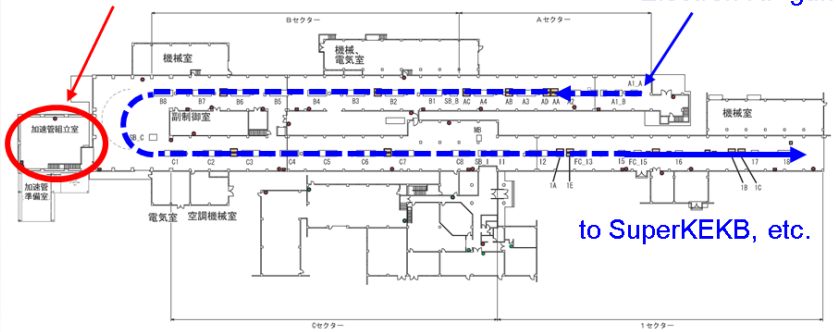
Burnt pulse modulators

Injector linac



Accelerating structure assembly room

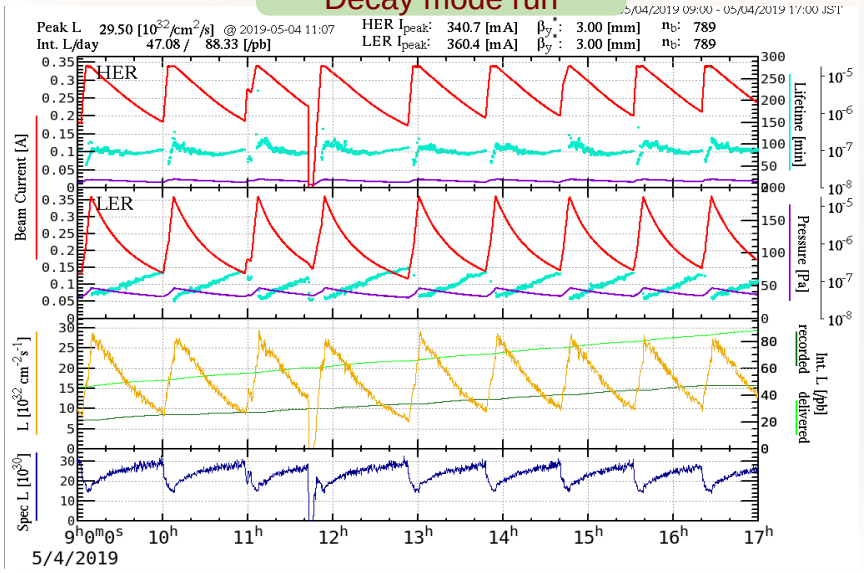
Electron RF gun



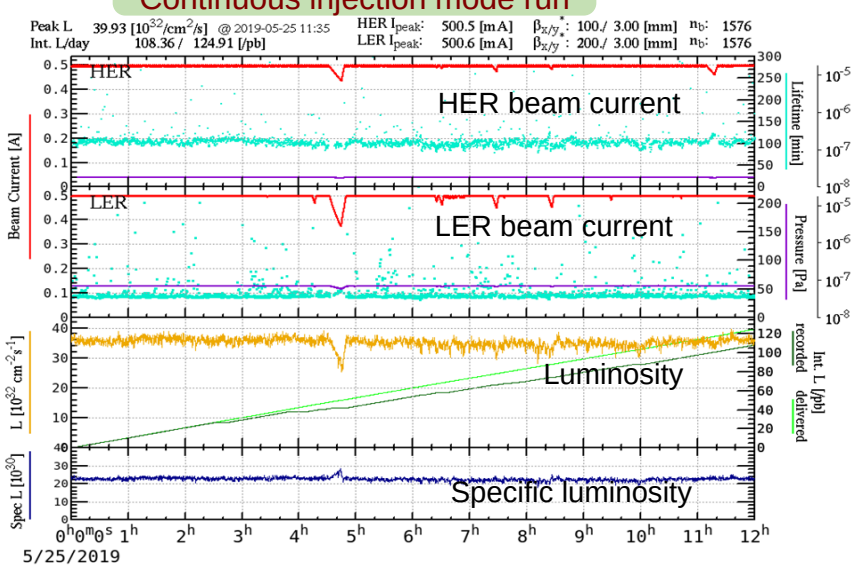
Highlights in Phase-3 2019 Spring

- β_y^* was gradually squeezed and the optics with β_y^* = 3 mm was established on 1st, April.
- LER and HER continuous injection started from May.
  → Increase in int. luminosity.
  - Realized after successful background reduction by elaborate tunings of injection parameters and collimators.
- Most of physics run was operated with β_x^* = 200/100 mm (LER/HER) and β_y^* = 3 mm.
  - L ~ 0.5x10^{34} cm^{-2}s^{-1} at ~600 mA.

Decay mode run

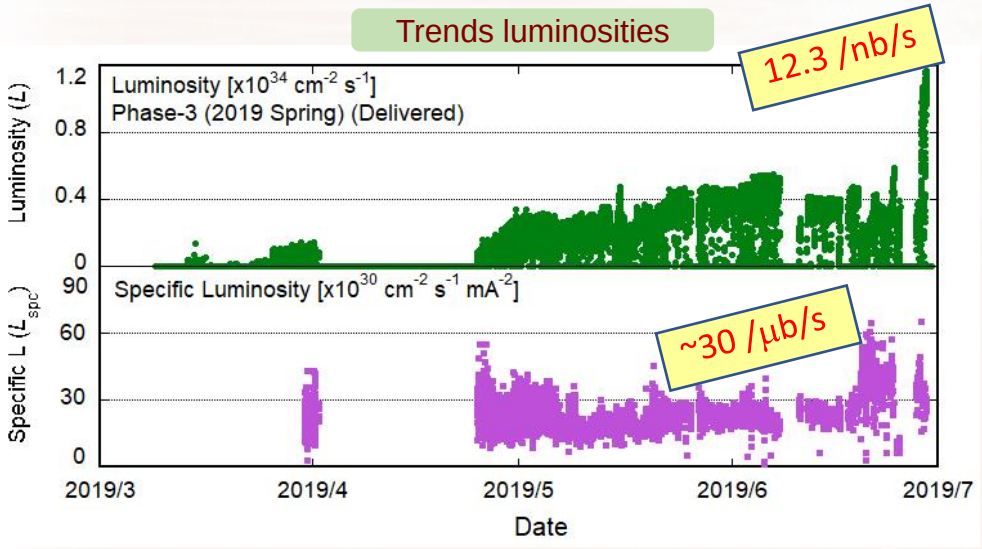


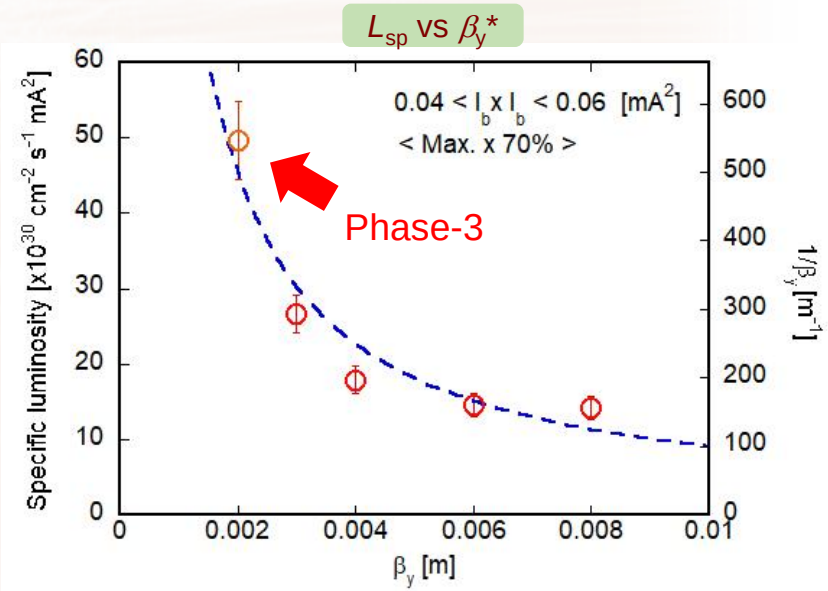
Continuous injection mode run



Highlights in Phase-3 2019 Spring

- β_x^*/β_y^* were squeezed to 80/2 mm on 21st, June.
- After collision tuning, the max. luminosity of 1.23×10^{34} $cm^{-2}s^{-1}$ was recorded at approximately 820/830 mA (LER/HER, 1/1576/3.06RF), although the Belle II HV was off due to high background.
- Specific luminosity increased in proportion to $1/\beta_y^*$.
  - Satisfied even for β_y^* = 2 mm.





Highlights in Phase-3 2019 Spring

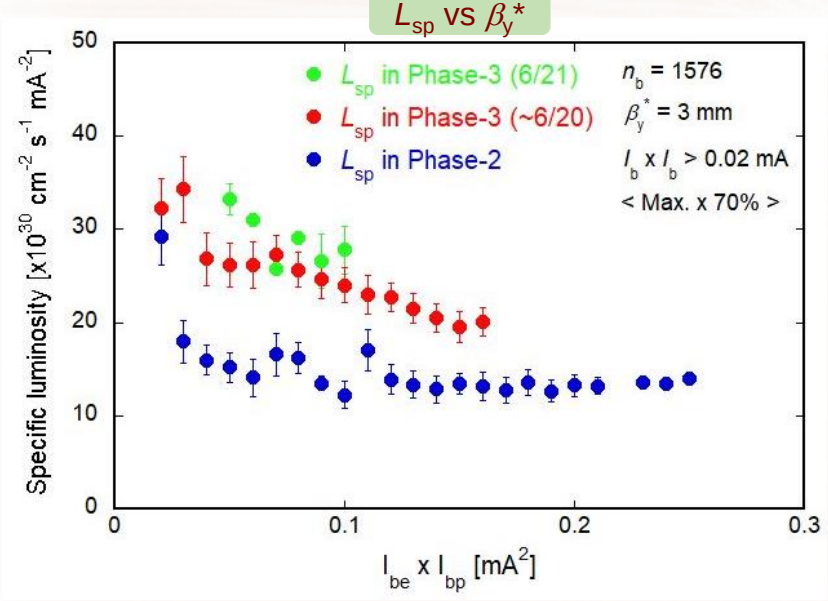
- Summary of major results

Major results in Phase-1, Phase-2 and Phas-3 2019 Spring run						
Parameters	Phase-1 (3/2/2016–6/30/2016)		Phase-2 (3/19/2018–7/17/2018)		Phase-3 2019 Spring run (3/11/2019–7/11/2019)	
	LER	HER	LER	HER	LER	HER
Max. beam current [mA]	~1010	~870	~860	~800	~830	~940
Beam dose [Ah]	775.0	661.5	337.5	340.2	500.4	539.1
Min. β_x^*/β_y^* in physics run (non phys.) [mm/mm]	-	-	200/3 (200/2)	100/3 (100/1.5)	100/3 (80/2)	100/3 (80/2)
Min. ε_x / ε_y [nm/pm]	~-/10 . (single)	~-/10 (single)	~1.7/160 (in col.)	~4.6/80 (in col.)	~2.0/88 (in col.)	~3.8/61 (in col.)
Max. bam beam param.			0.0244	0.0141	0.0355	0.0197
Max. lumi. L [$\times 10^{33}$ cm^{-2} s^{-1}]			5.55 (@1/1576/3.06)		12.3 (@1/1576/3.06, β_y^*=2mm)	
Specific lumi. @Max. L [$\times 10^{31}$ cm^{-2} s^{-1} mA^{-2}]			1.43		2.9	

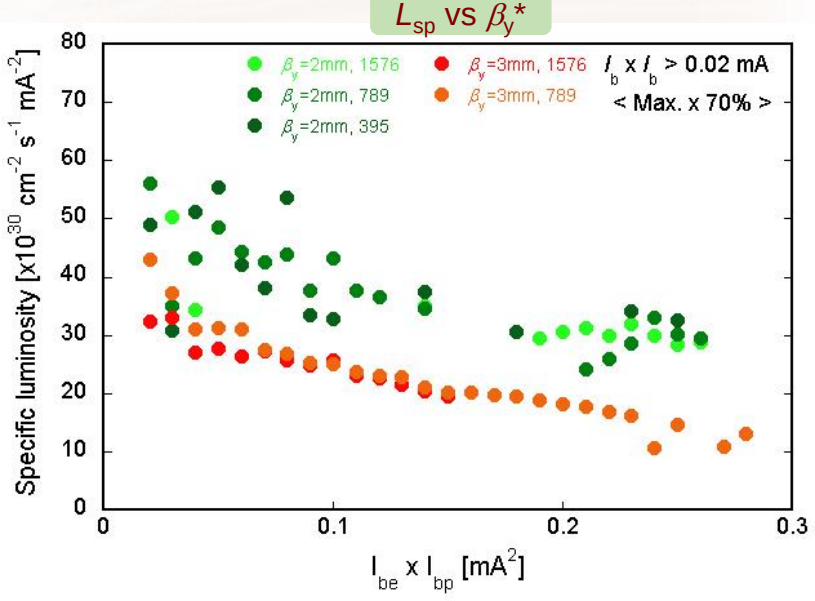
Key challenges for high luminosity

- Decrease in L_{sp} with bunch current product.
- Caused by the beam-size blowup due to beam-beam effect.
  - Ex. LER ε_y 6.1 →88 pm, HER ε_y 20 →61 pm. (β_y^*=2mm, ~700 mA)
  - Although L_{sp} has been improved by elaborate collision tunings, but the tendency does not change.
- The mechanism has not been well understood yet.
- To be reported by Ohnishi-san and Ohmi-san.

L_{sp} vs β_y^*



L_{sp} vs β_y^*



Key challenges for high luminosity

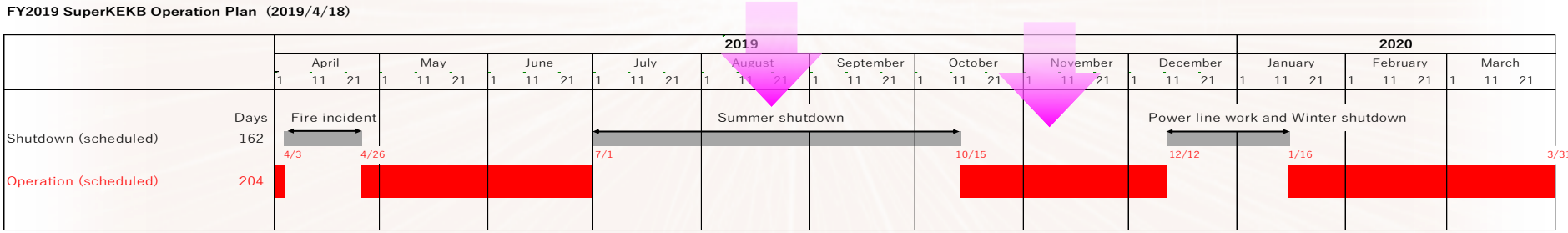
- High background (BG)
- From LER stored beam
  - Main BG source in LER storage mode was found to be the beam-gas Coulomb scattering. This raised the base of BG, and limited the beam currents during physics run.
- Bursts from stored beam
  - Induced CDC trips and/or beam aborts. Dusts?.
- Bursts from Injection beams
  - Induced CDC trips and/or beam aborts. Changes in energy or orbit at the linac?
- Slow change in injection condition
  - BG as well as the injection efficiency degraded gradually, even in a shift (8hours), and it was difficult to keep good injection condition.
  - Temperature dependence?
- Background issues will be reported by Nakayama-san and Iida-san.

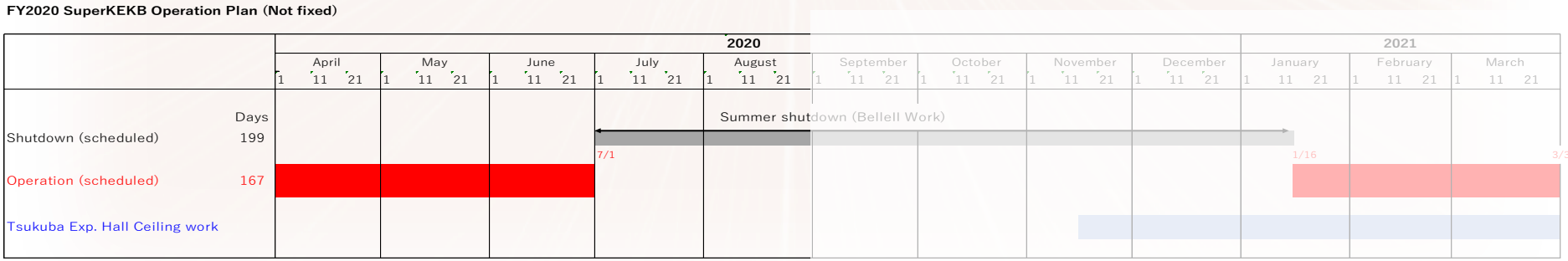
Key challenges for high luminosity

- QCS quenches and beam aborts
- Frequency of QCS quenches in Phase-3 decreased compared to that in Phase-2.
- However, seven quenches (two types) happened.
- [Type-1]: Caused by the malfunction of QC2LE power supply.
- [Type-2]: Very fast (3～4 turns) beam loss event! Suspected to be caused by the steered or blown-up beam which lost energy by a collision with dusts (LER).
  - Stored beam was steered or blown up abruptly and damaged a vertical-type collimator head. Similar to the case in Phase-2.
  - Also gave high radiation dose to VXD.
- Quenches, beam aborts and dust events will be reported by Ohuchi-san, Ikeda-san, Nakamura-san, and Ishibashi-san

Commissioning plan

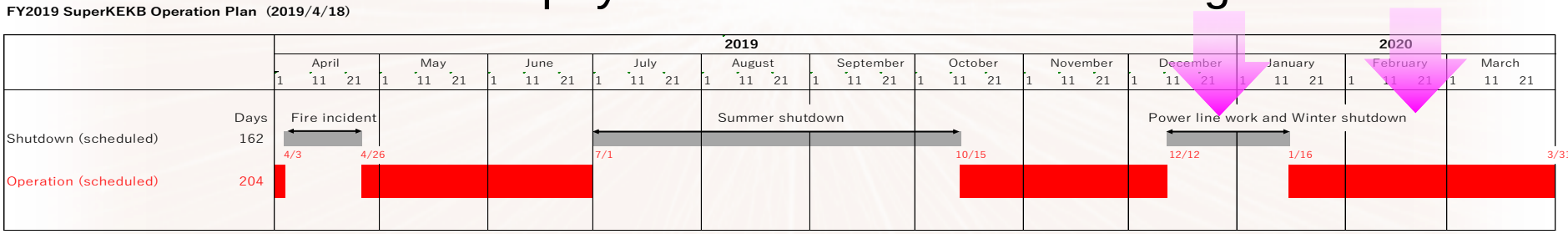
- Summer shutdown (2019/7/1~2019/10/15)
  - Replacement of the bellows at IP
  - Replacement of QC1L BPM cables at IP
    - These works require the retraction/insertion of QCS-L.
  - Any measures against QCS quenches if available.
  - Many other works in the machine and the Belle II.
- Autumn run (2019/10/15~2019/12/12)
  - Continue the physics run and machine tunings.

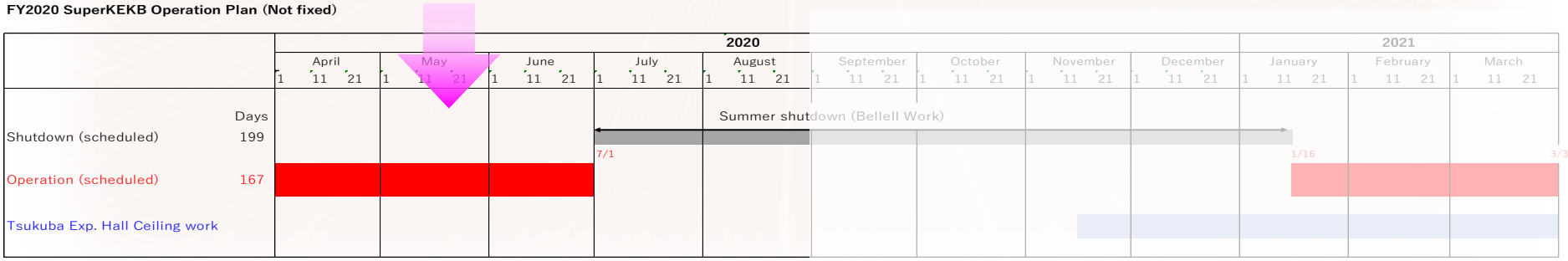




Commissioning plan

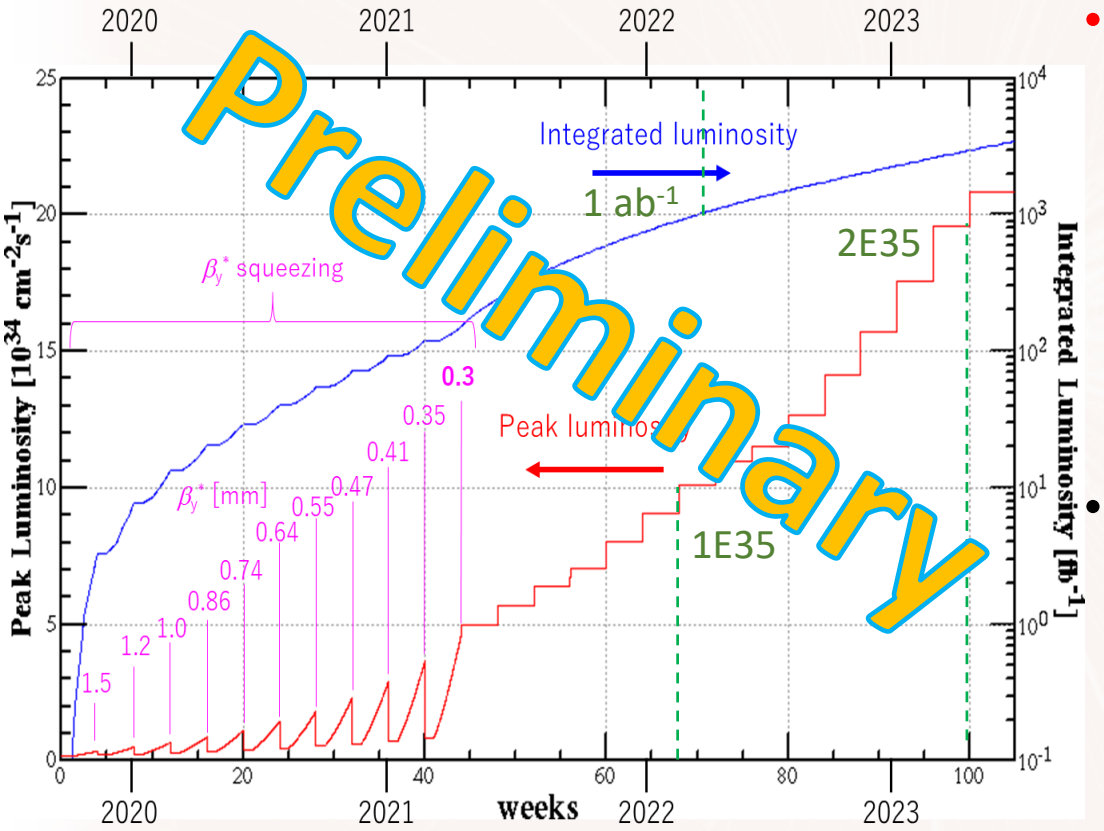
- Winter shutdown (2019/12/12～2020/1/16(not fixed))
  - 150 kV power line work by TEPCO
    - The electric power in KEK was restricted to less than 50 MW.
    - The MR have to be stopped. Linac, DR, and BT can be operated.
  - A vertical-type collimator will be installed into LER.
- 2020 Spring run (2020/1/16~2020/6/30 (under consideration))
  - Operation in January will be for mainly BT tuning and vacuum scrubbing.
  - Continue the physics run and machine tunings.





Commissioning plan

- Luminosity projection
- Discussion about the strategy to increase the luminosity has just started, on the basis of the results in this run.



- We need more discussions together with Belle II group to find the best way.

- **As a case study,** here the machine study to squeeze β_y^* is highly prioritized.
  - β_y^* is squeezed step by step every four weeks.
  - Two weeks for machine study and two for physics run
  - 28 weeks operation/year
  - 1576 bunches.
- Notes
  - No improvement in beam-beam parameter.
  - Keep the present $L_{sp} \times \beta_y^*$ dependence on I_b^2.
  - No improvement in BG situation, i.e., I_{max} was limited by the present pressure (scrubbing effect is included).

Summary-1

- Phase-3 has just finished.
  - Full-scale physics run has finally started.
  - The “nano-beam scheme” collision was demonstrated up to $\beta_y^* = 2$ mm.
  - Continuous injections for both rings are available in regular operation.
  - The max. luminosity of 1.23×10^{34} cm^{-2}s^{-1} was recorded at $\beta_y^* = 2$ mm (LER 820 mA, HER 830 mA, 1576 bunches).
  - The injector linac and DR have been working well.
- Key challenges to increase luminosity
  - Low specific luminosity at high bunch current product
    - Essential issue to realize high luminosity.
  - High background
    - Limit beam currents.
  - QCS quenches and beam aborts
    - Fast abort system is indispensable for stable high-current operation.

Summary-2

- Commissioning plan
  - Plan in FY2019 is almost fixed, and we will expect ~ 7 months' operation.
    - 2019 Summer shutdown: 7/1 ~ 10/14
      - Replacement of bellows at IP, repair of QCS BPM.
    - 2019 Autumn run: 10/15 ~ 12/12
    - 2019 Winter shutdown: 12/12 ~2020/1/16
      - Power line work in Tsukuba campus
      - Installation of a vertical-type collimator into LER
    - 2020 Spring run: 2020/1/16 (not fixed) ~ (7/1)
  - The schedule of 2020～2021 are under discussion.
  - Discussion about the strategy to increase the luminosity has just started.

Thank you for your attention.

Backup