SuperKEKB MR Status and Plans

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Acc. Lab , KEK

Outline

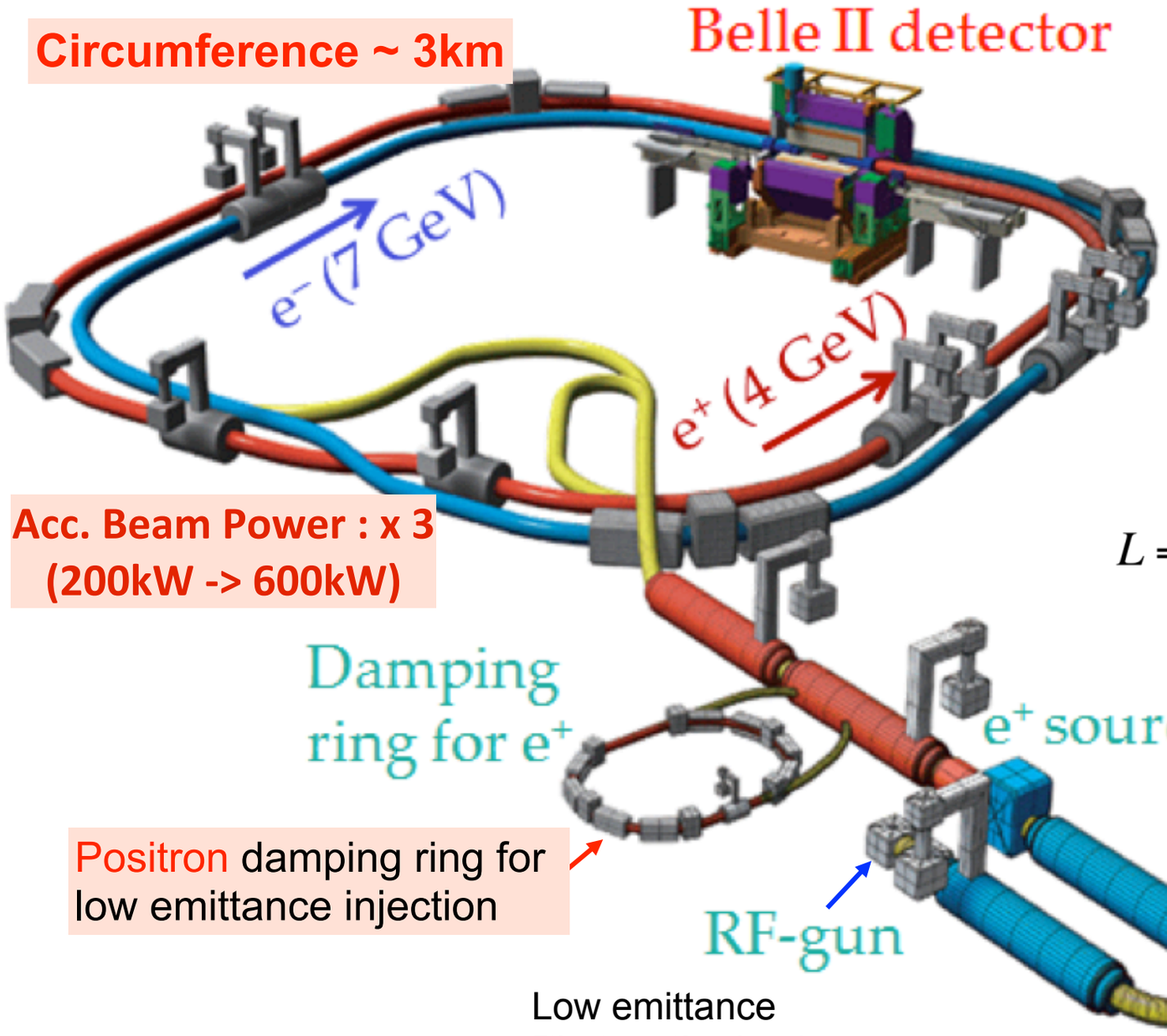
- **Simple Introduction of SuperKEKB Accelerator**
- **Brief Summary of Phase-3 2019 Spring (Mar.~Jun)**
  - **Recent Remarkable Results**
- **Concerned Issues and Troubles**
- **Improvements for Quick Abort Kicker Firing**
- **Commissioning Plans for Next Runs (2019 Oct. ~ 2020 June)**
- **Summary**

SuperKEKB Accelerator

An upgraded acc. from the KEKB acc.

Luminosity : KEKB x 40 !

Circumference ~ 3km



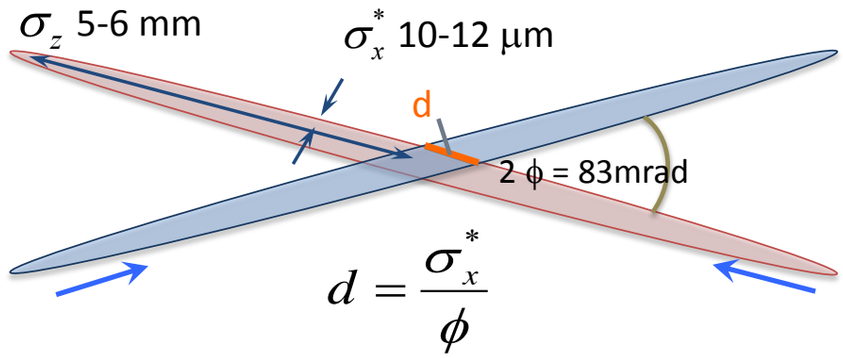
Acc. Beam Power : x 3
(200kW -> 600kW)

Positron damping ring for low emittance injection

Low emittance Photocathode electron gun

P. Raimondi

Nano-Beam Scheme SuperKEKB



Half crossing angle: ϕ

overlap region << bunch length

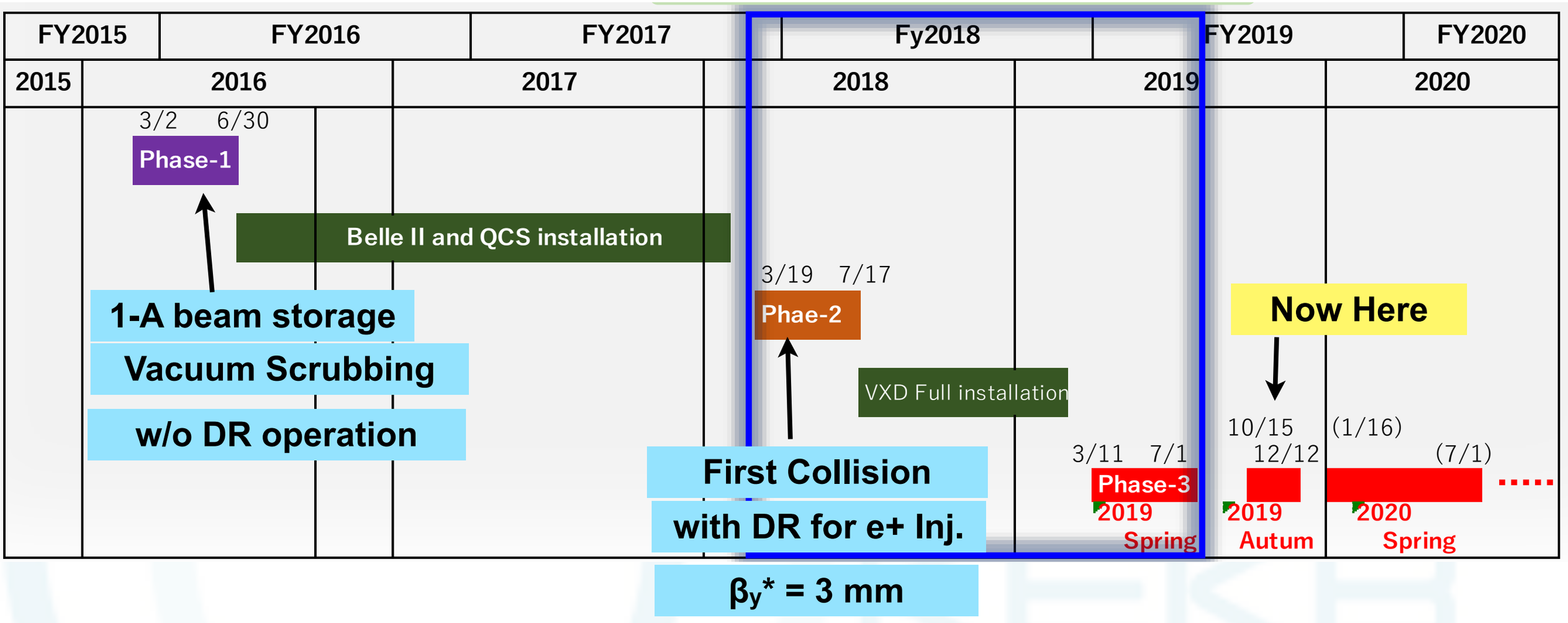
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Beam Current: x 2

β_y @IP: 1/20

	KEKB Acieved		SuperKEKB Nano-Beam	
	LER	HER	LER	HER
I_{beam} [A]	1.6	1.2	3.6	2.6
β_y^* [mm]	5.9	5.9	0.27	0.30
ξ_y	0.09	0.12	0.088	0.081
Luminosity [cm^{-2} s^{-1}]	2.1×10^{34}		8.0×10^{35}	

Timeline of Commissioning Steps



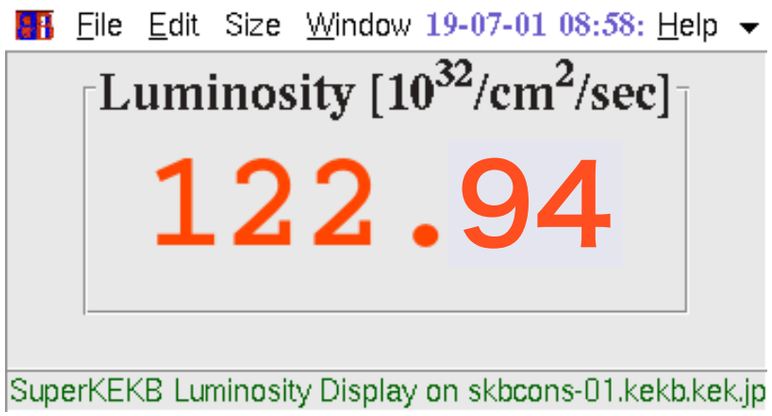
Brief Summary
of Phase-3 2019 Spring (Mar.~Jun)

- Recent Remarkable Results -

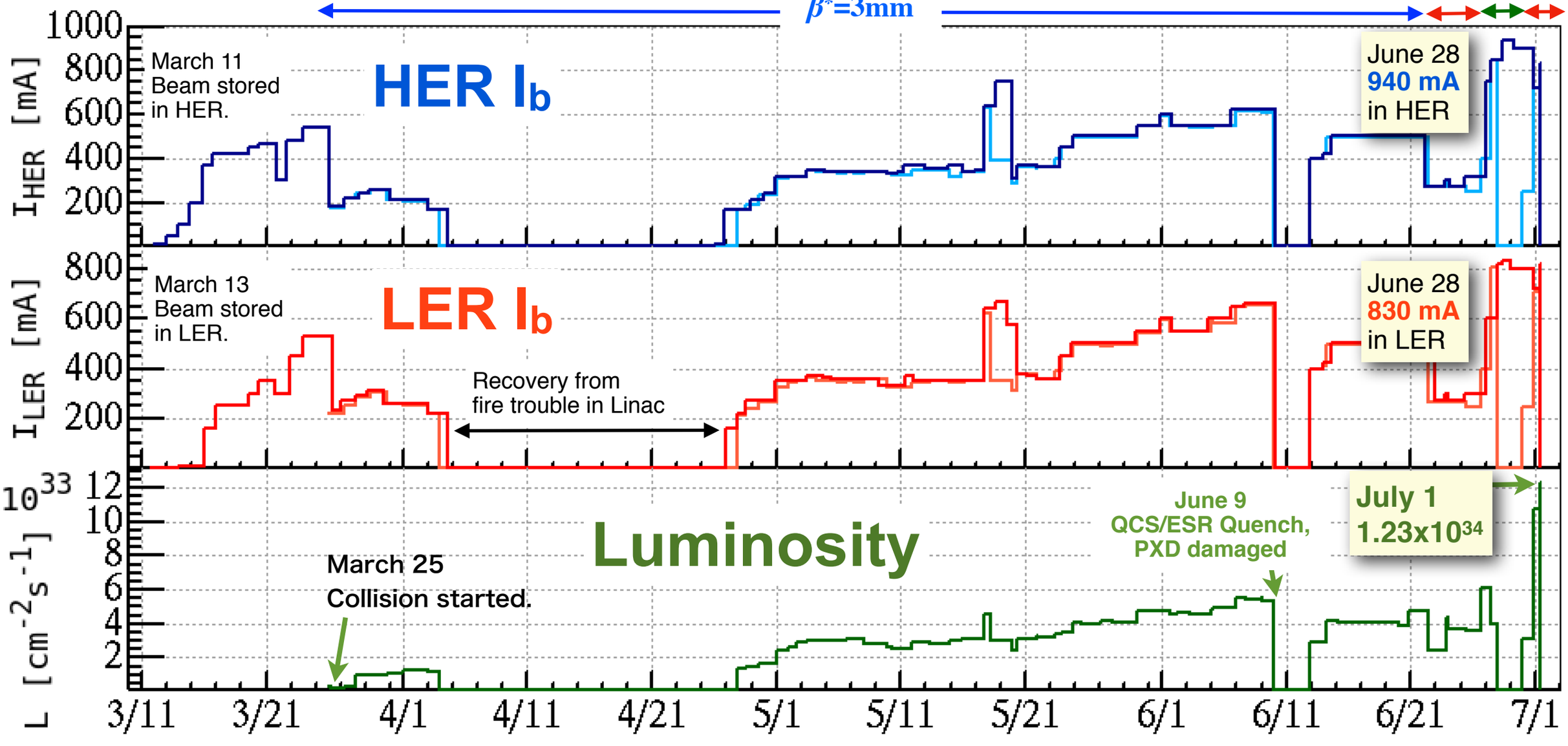
Brief Summary of Phase-3, 2019 Spring

Y. Ohnishi, ARC, July 8, 2019

Peak luminosity at Phase 3 Spring Run 2019

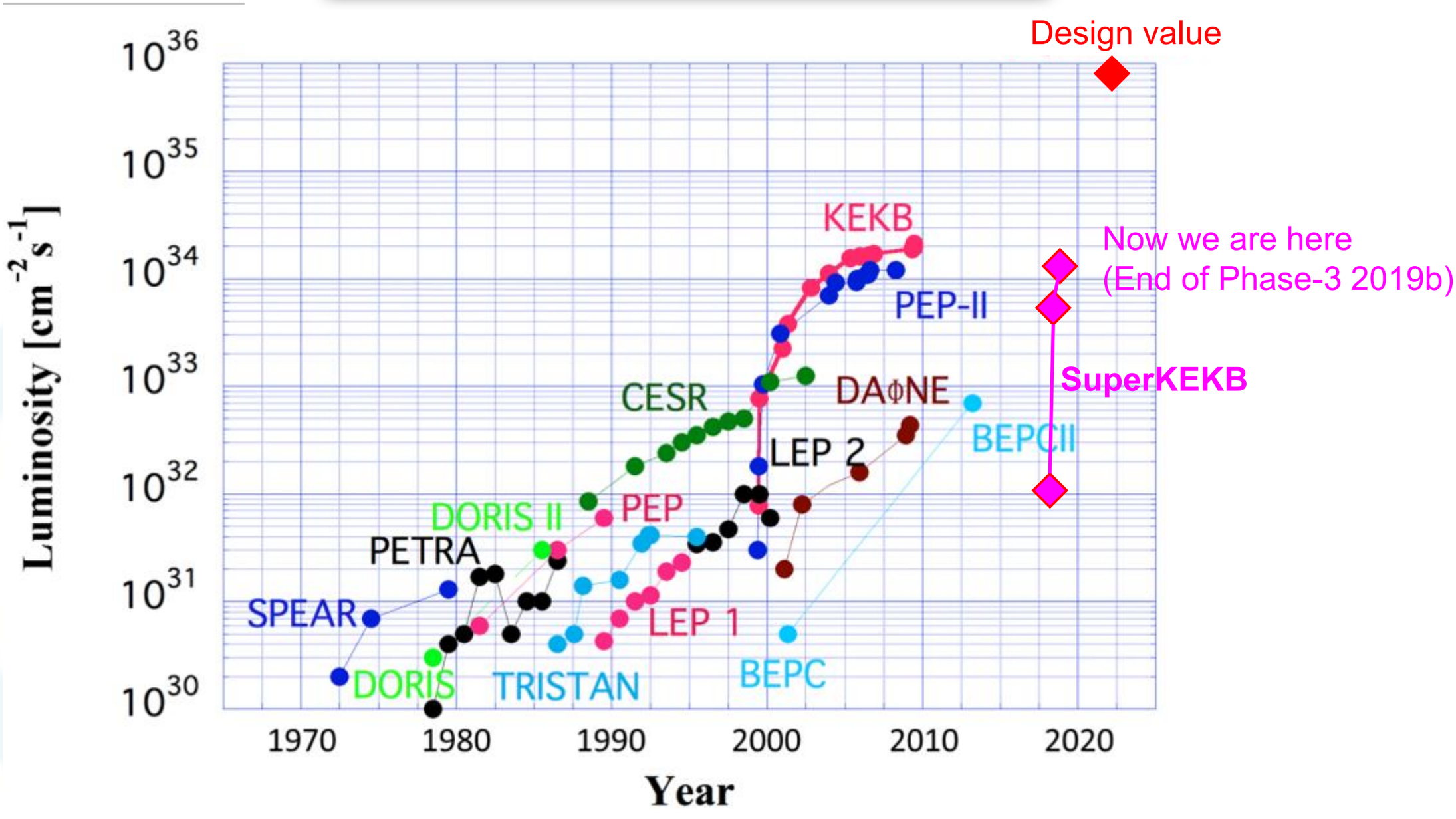


High current sturdy w/o Physics Run



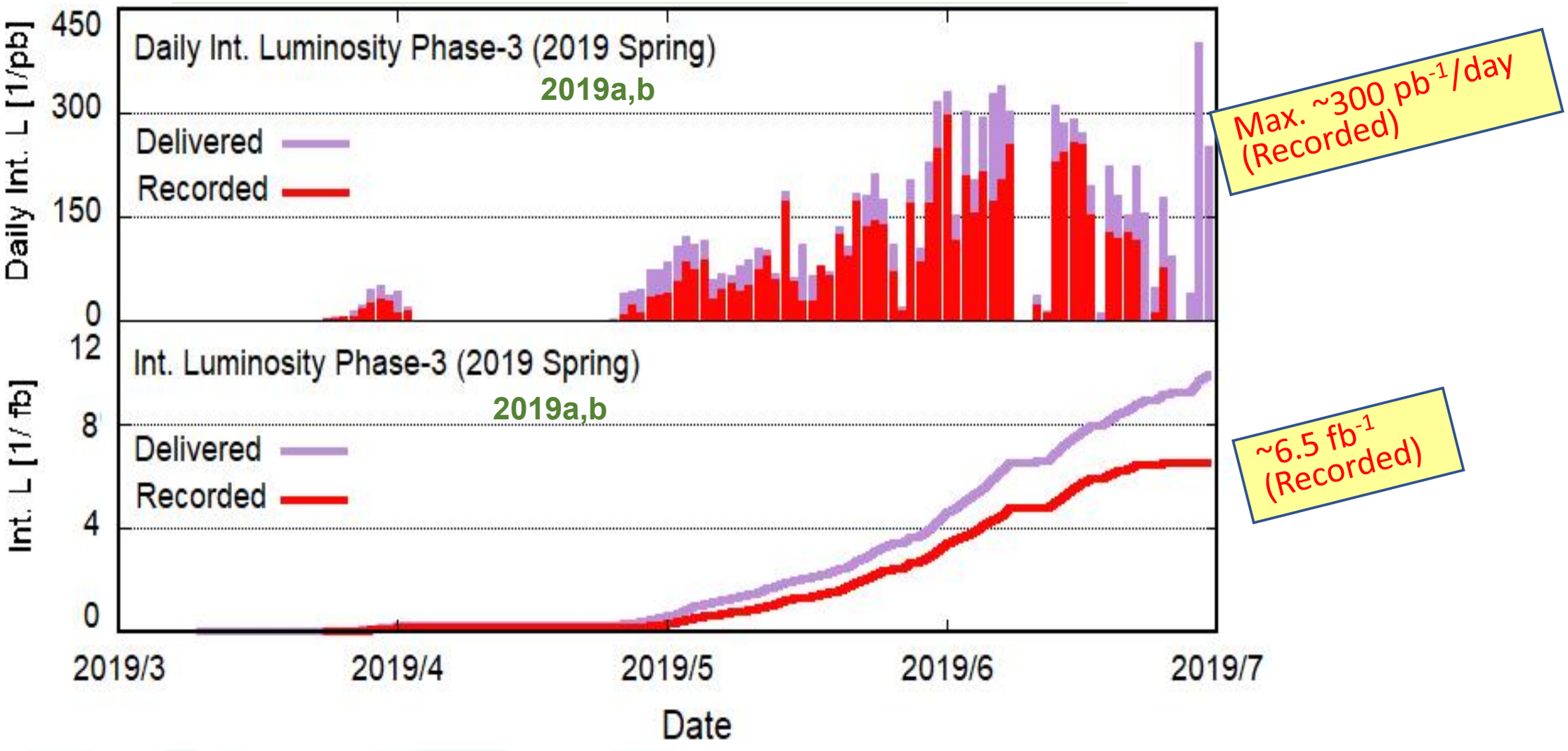
Brief Summary of Phase-3, 2019 Spring

Achieved Luminosity



Brief Summary of Phase-3, 2019 Spring

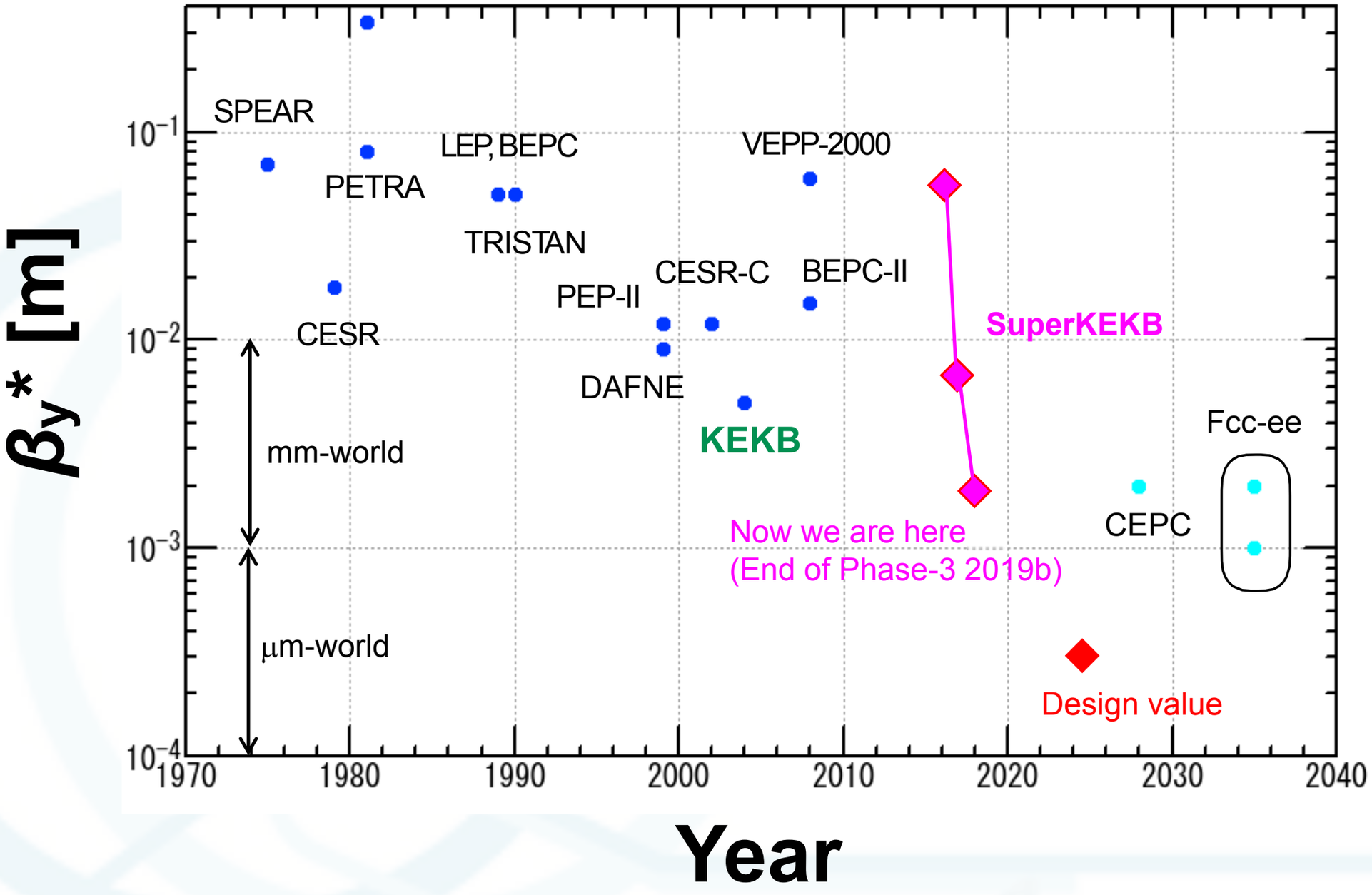
Integrated Luminosity



Max. recorded luminosity per day was ~300 pb^{-1}/day.
Recorded integrated luminosity of ~6.5 fb^{-1} were accumulated.
Delivered integrated luminosity ~9.6 fb^{-1}.

Brief Summary of Phase-3, 2019 Spring

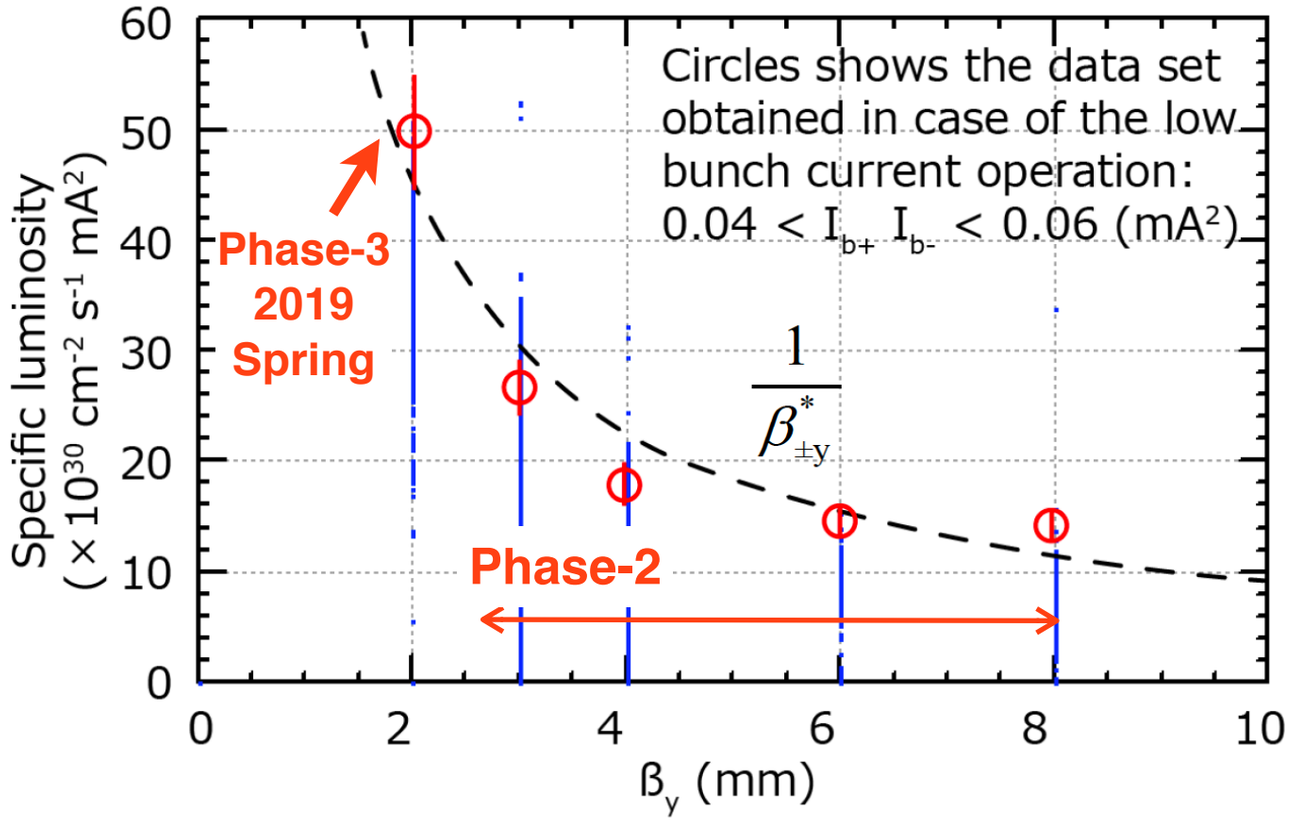
Achieved β_y^*



Brief Summary of Phase-3, 2019 Spring

Demonstration of the nano-beam scheme for β_y^* = 2 mm

Y. Ohnishi, Y. Funakoshi

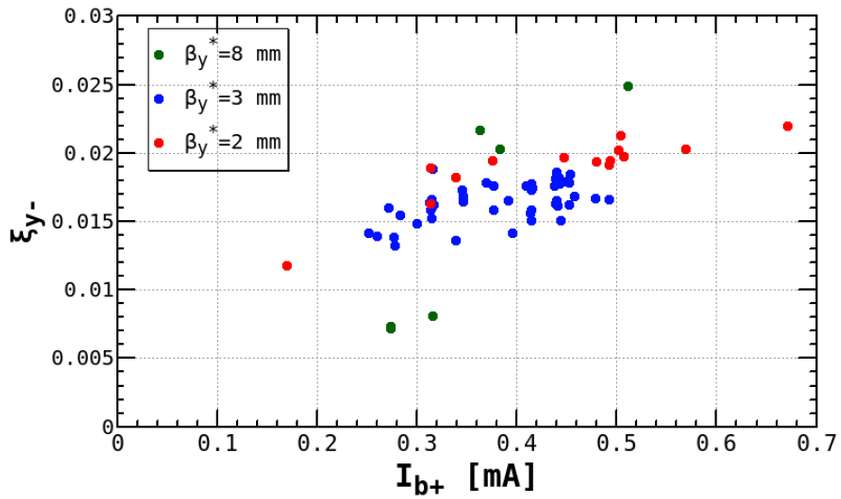


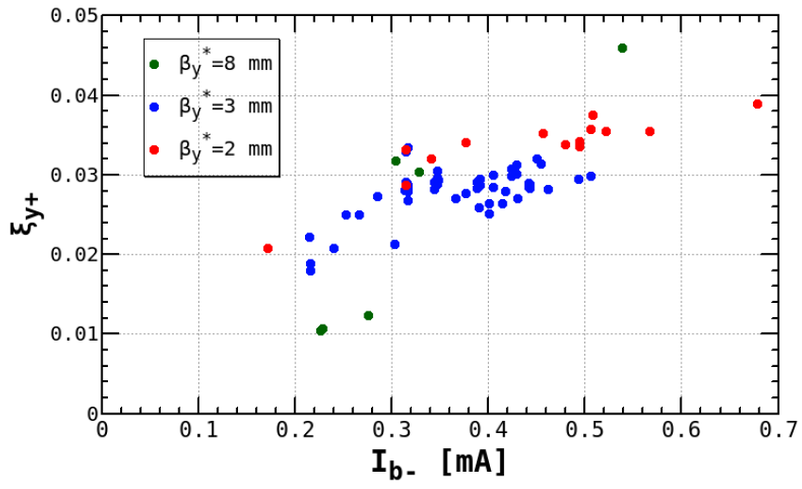
The specific luminosity is increased by squeezing β_y^*.

It is well proportional to $1/\beta_y^*$ at a constant bunch current.

The beam-beam parameter can be also kept while squeezing β_y^*.

$\xi_{y\pm}$ **: Beam-Beam Param.**





$$\xi_{y\pm} = \frac{r_e N_{\mp}}{2\pi\gamma_{\pm}\phi_x\sigma_{z\mp}}\sqrt{\frac{\beta_y^*}{\varepsilon_{y\mp}}}$$

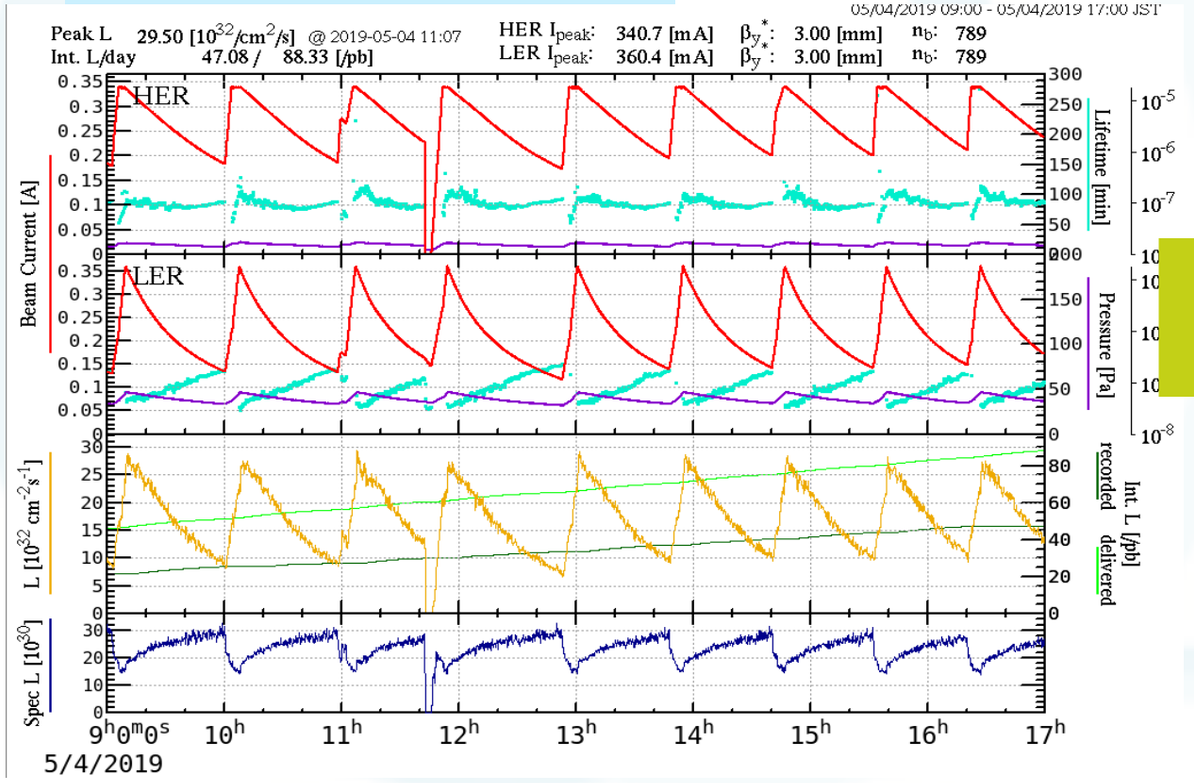
Brief Summary of Phase-3, 2019 Spring

Continuous injections started from May, 2019 in both LER and HER

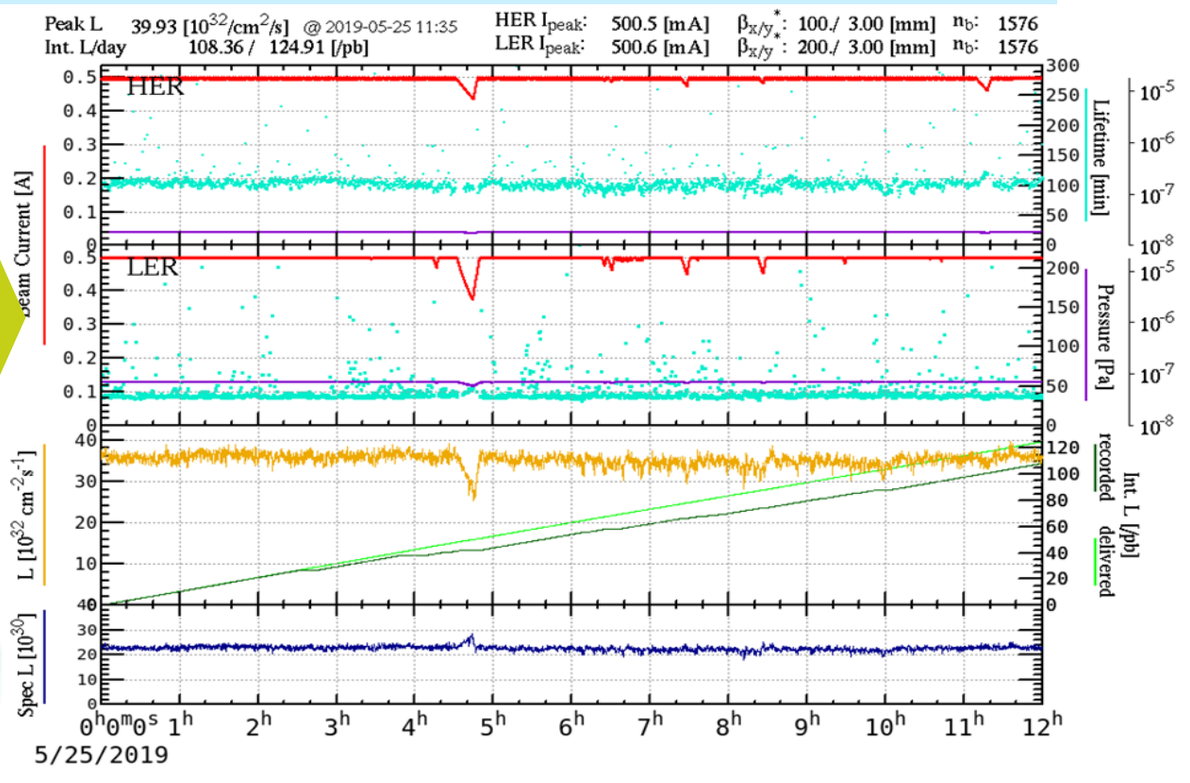
The injection BG was drastically **reduced by the elaborate tuning of collimator**s and new injection tuning method, then, **continuous injection mode** was realized.

This improvement
Contributed to higher integrated luminosity.
Efficiency was increased by ~50% .

Decay mode run



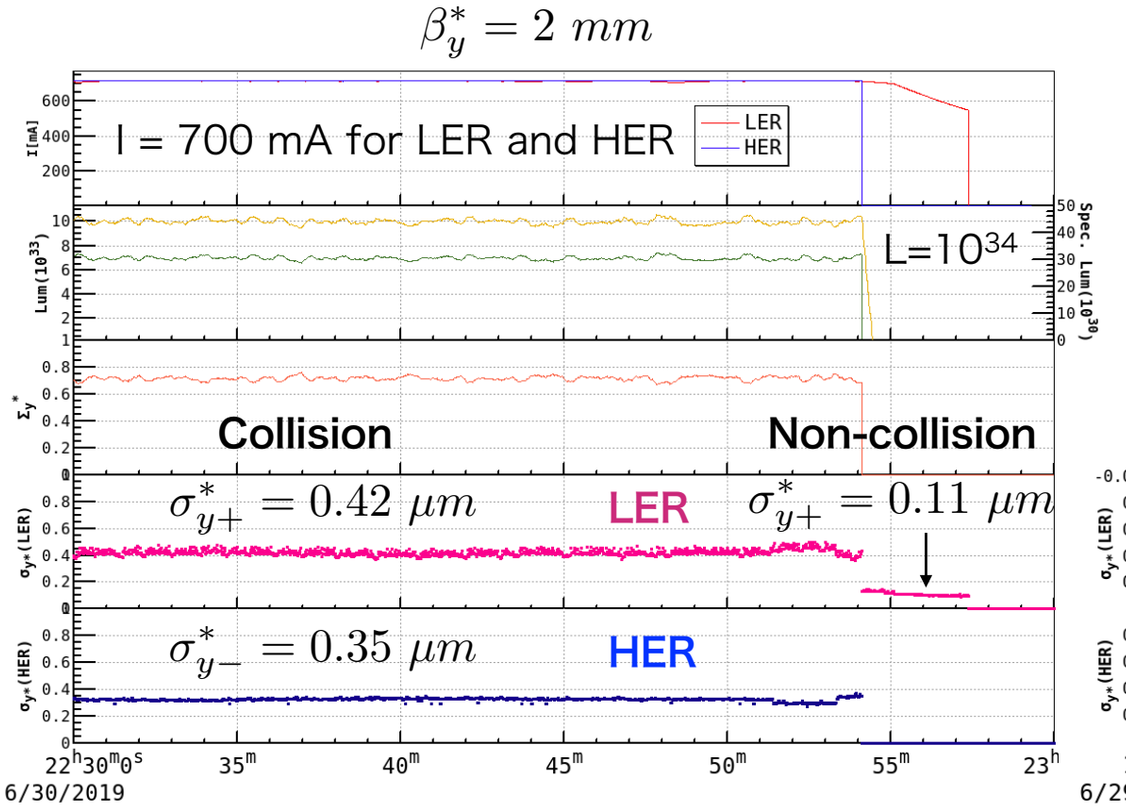
Continuous injection mode run

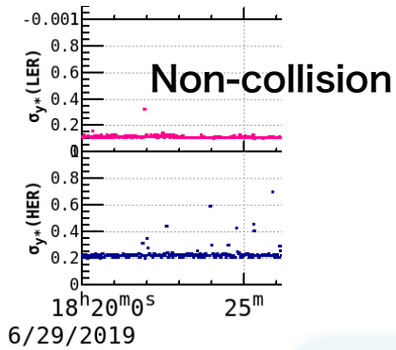


Concerned Issues and Troubles

Beam-Beam Blow-Up

Y. Ohnishi, ARC, July 8, 2019

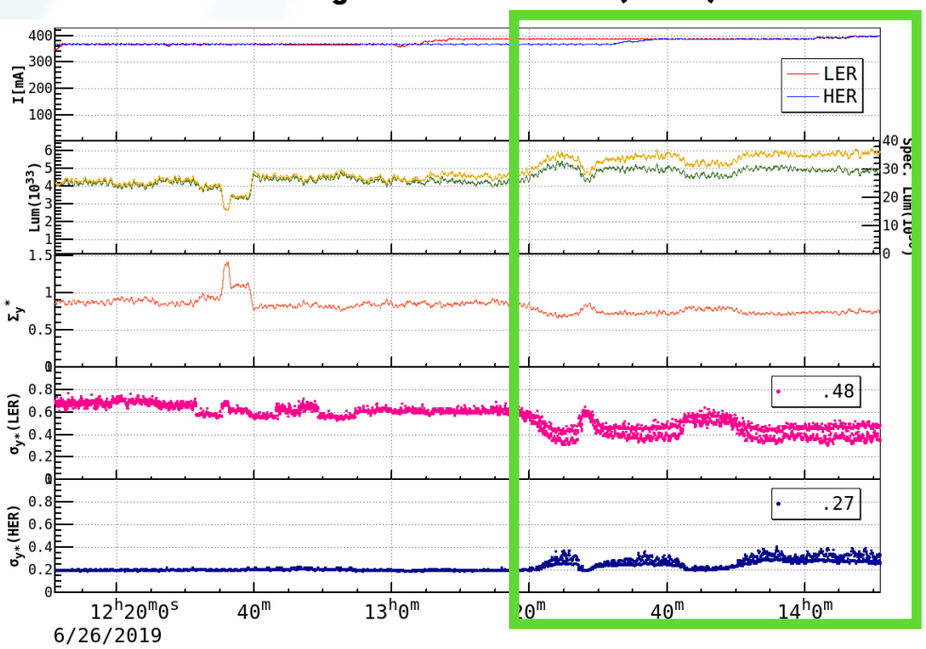




Beam-Beam blow-up was observed, and also flip-flop phenomena in beam sizes.

The blow-up in the LER is significantly larger than the HER.

Continuous Injection Mode (CIM)



Luminosity was improved
by increasing vertical emittance in HER

However, beam size was unstable.
It seems like flip-flopping between beam sizes of HER and LER.

These phenomena are not yet understood well.
Detailed study will be necessary.

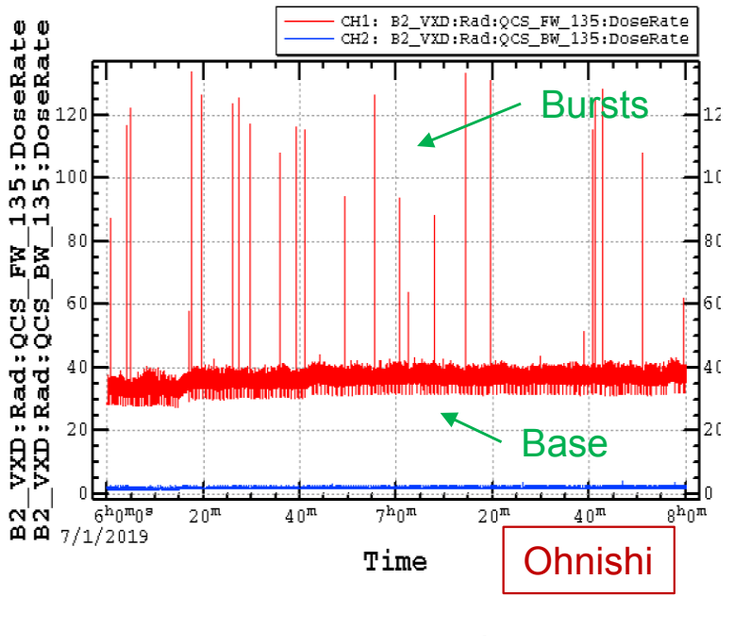
Beam Background Issue

In the 2019 spring run

Injection spikes in the LER

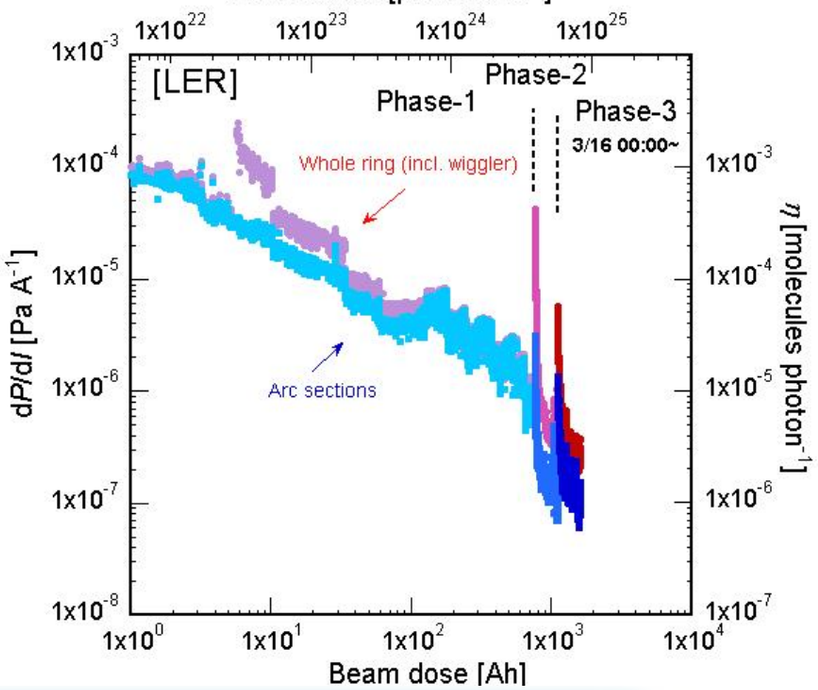
Background from injection beams was decreased by adjusting beam orbits, energy spreads, emittances and injection parameters. However, the quiet situation did not continue.

Background bursts by injection beams were also observed.
From recent studies, it was found that the bursts in LER were likely to occur at the timing of a klystron down or of a mis-triggering of pulse magnets at Linac.
But it was not always. The cause of these bursts have not been fully understood yet.



Storage beam background in the LER

Main background source in LER storage mode was the beam-gas Coulomb scattering from the stored beam.
Vacuum scrubbing in LER was proceeding steadily, but the pressure was still high, especially compared to HER.
Number of collimators for LER was insufficient.



Background studies should be continued.

Optimization of collimator settings are important.
and additional collimators are needed.
And also more vacuum scrubbing in the LER is needed.

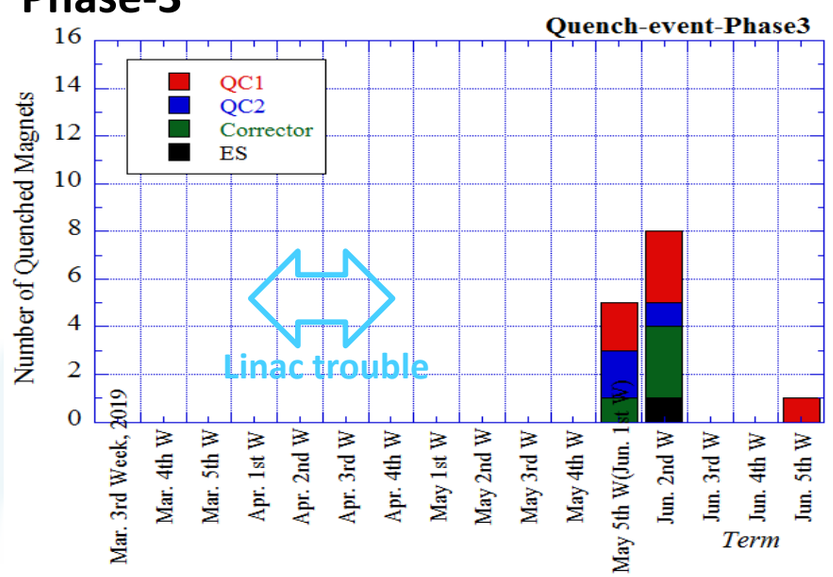
QCS Quench in Spring Operation 2019

N. Ohuchi, ARC, July 8, 2019

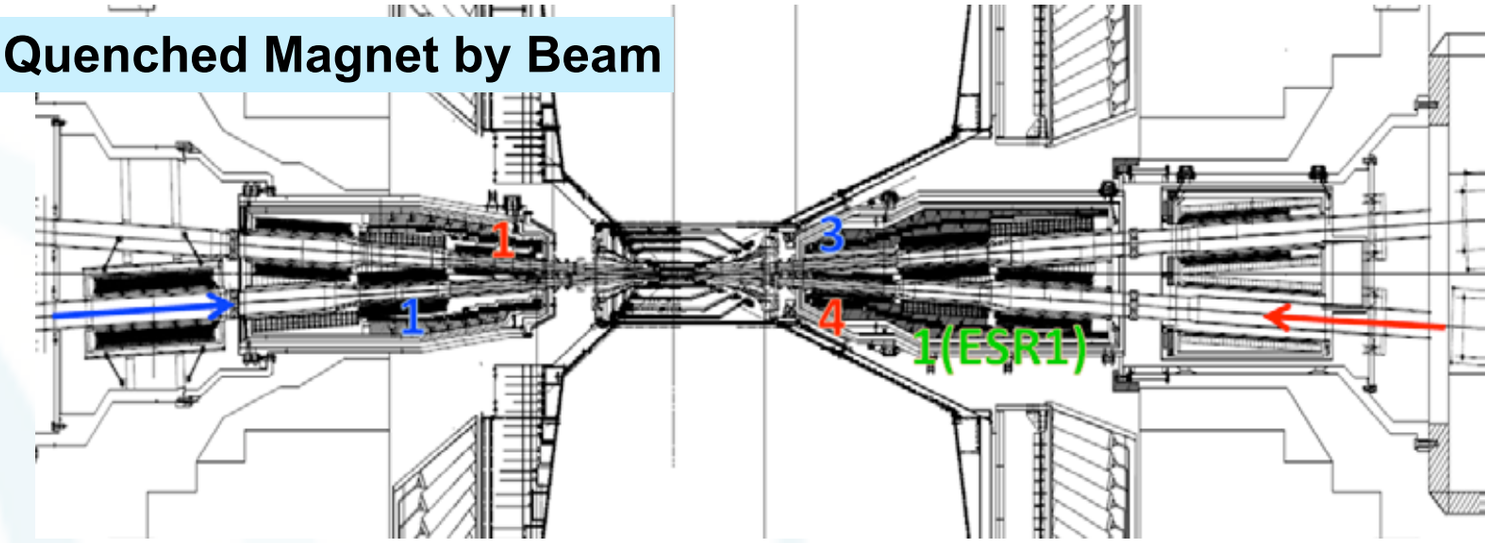
During the Spring operation 2019, 6 magnet quench events occurred.

– 3 events are beam induced quench (due to beam loss).
– 3 events are due to QC2LE power supply failure. SVD had serious damaged.

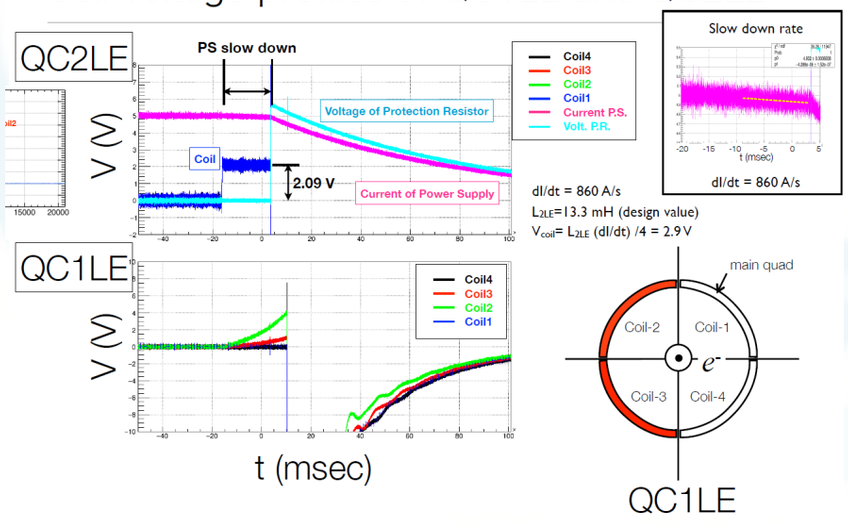
Phase-3



Quenched Magnet by Beam



Coil-voltage profiles of QC1LE and QC2LE



As one of the countermeasures to avoid QCS quench due to steered beams, shortening the delay time to abort kicker firing is important,

→ Abort trigger system was improved in this summer. Details will be presented later.

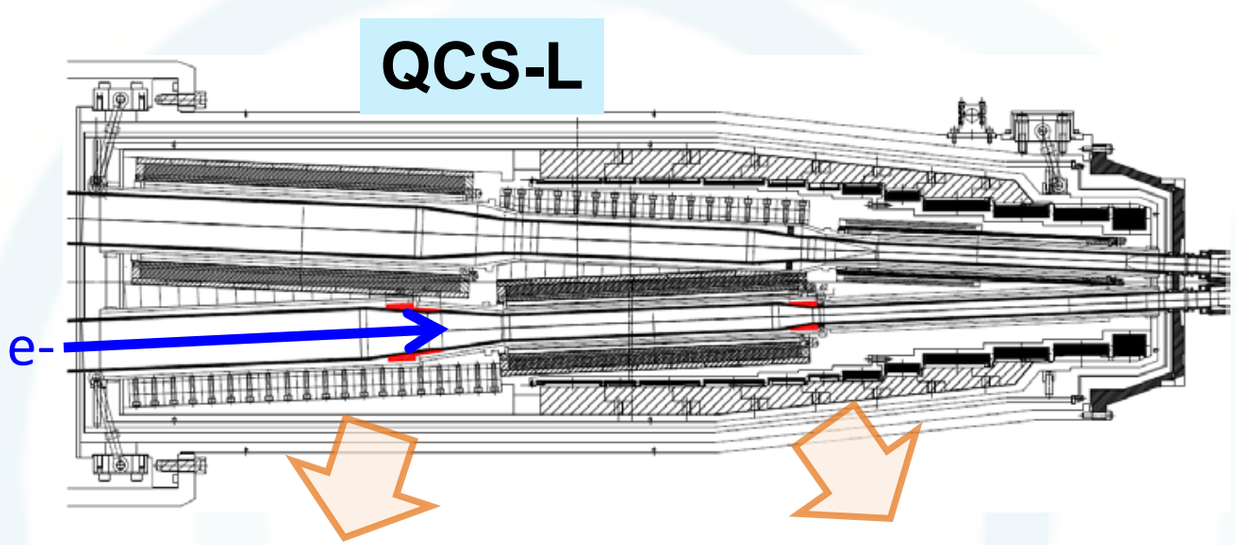
Protect Shields agains Quench

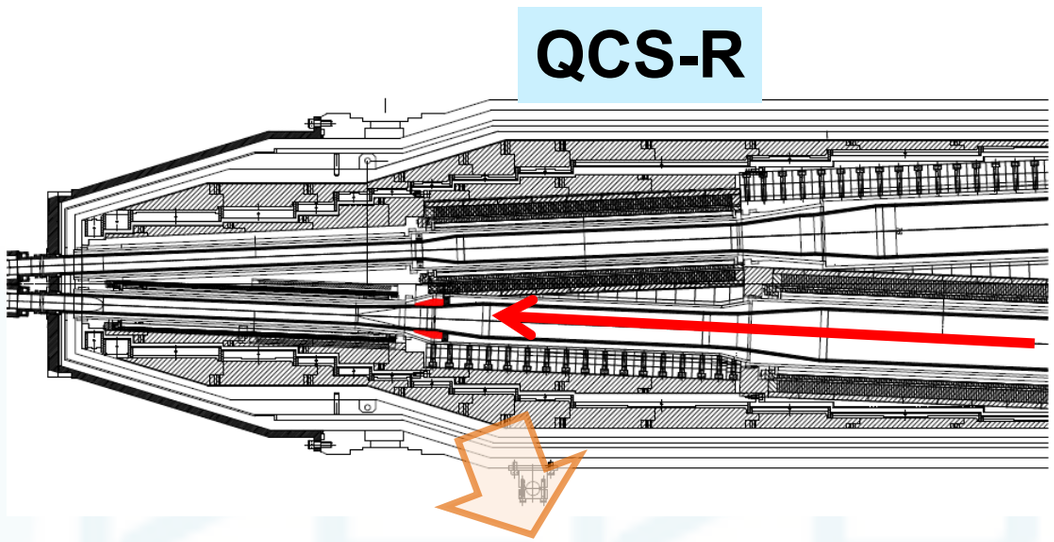
N. Ohuchi, ARC, July 8, 2019

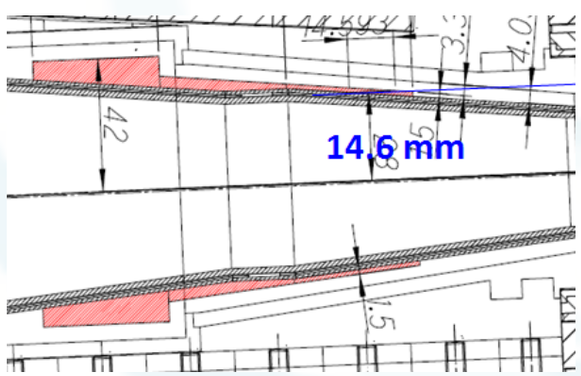
Future Issue

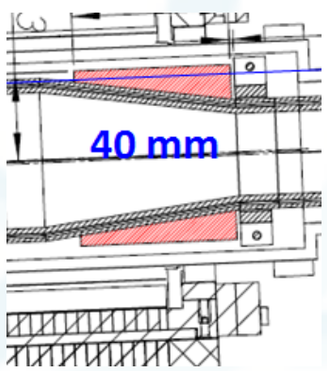
The countermeasure to the quenches of the QC1 magnets has been proposed to assemble the W alloy shield on the incoming beam pipes by the QCS group.

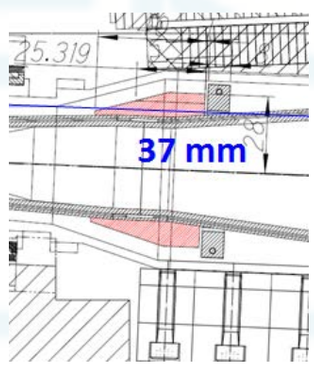
– TheQCS group is waiting for the beam simulation results including these shields concerning for the effectivity of the magnet quench protection.











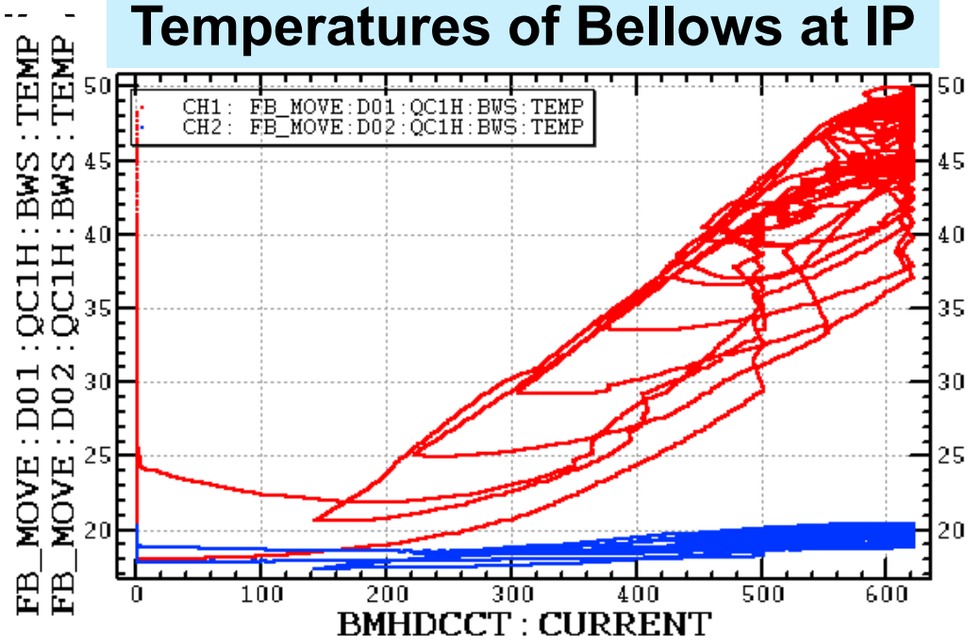
IR Chamber Trouble (1)

- Troubles of bellows chamber at backward side of IP -

The HER bellows was heated up: The temperature increased to ~50°C at ~ 600 mA.
It was very concerned for high currents.

Bellows at IP

Temperatures of Bellows at IP



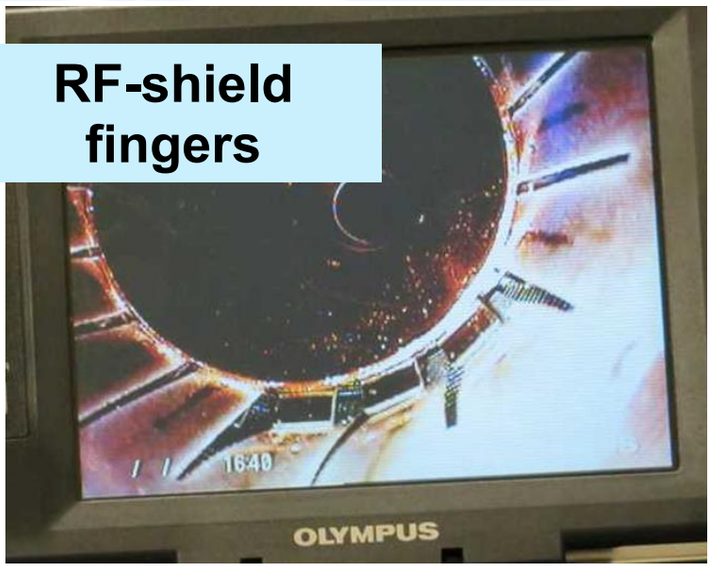
In this Summer Work

QCSL was retracted ,
and the bellows chamber was replaced during this summer shutdown.

Three RF-shield fingers inside the bellows were dislocated.
The cause of the finger-dislocation is not clear.

The bellows was replaced with a spare.
No abnormal movement was seen during this work.

RF-shield fingers

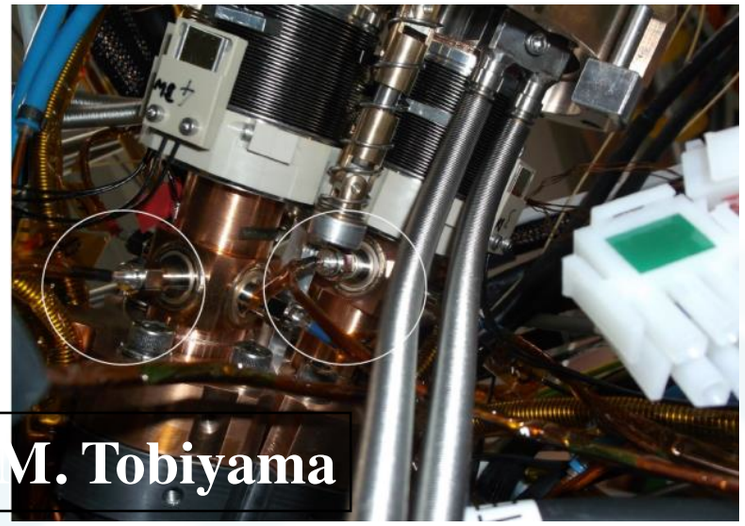


No temperature increase has been observed in the present operation (last 2 weeks) at 700-mA storage (Oct. 15th 2019~).

IR Chamber Trouble (2)

- Troubles of bellows chamber at backward side of IP -

Damage at QC1L BPM connectors



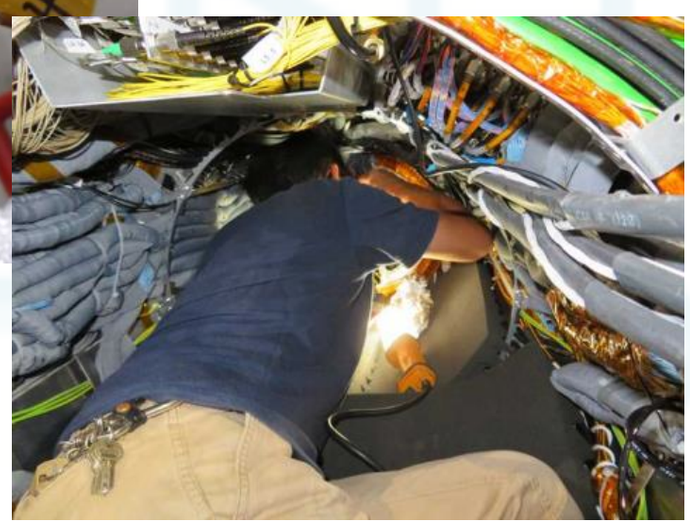
Two QC1L BPMs (Downside) were unusable due to disconnections of cables in the operation (Reported in last BPAC).

TDR measurements suggested damage at the SMA connectors.

In this Summer Work

It was found that downside BPM connectors were broken.
→ **They were replaced to improved ones.**

The cabling paths were changed to upside to avoid tensions on connectors during various works in the detector.

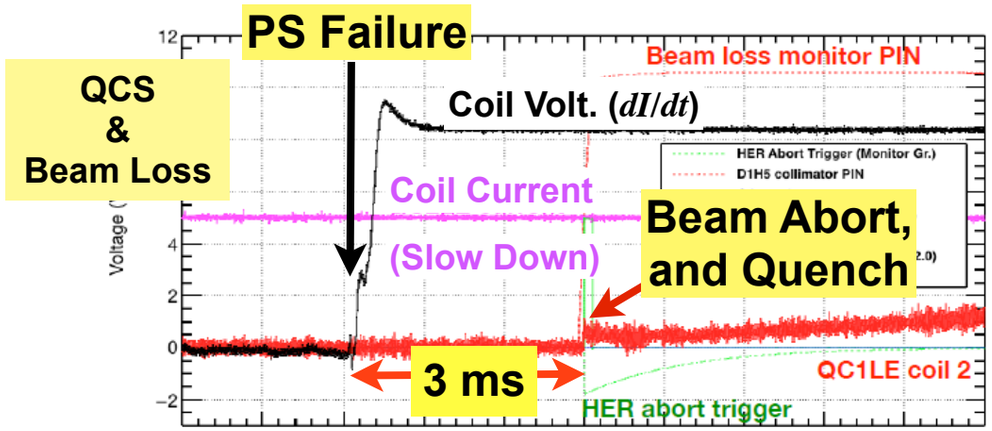


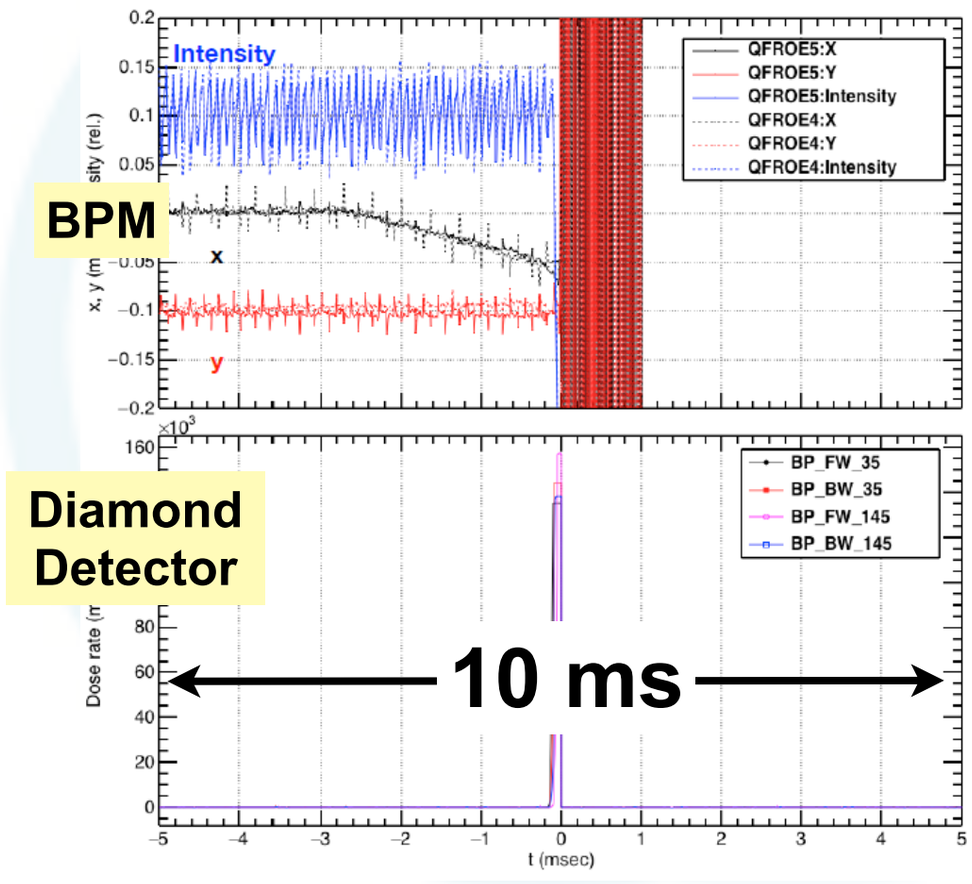
Improvements
of Shortening Delay time of Abort Trigger
for Quick Abort Kicker Firing

QCS Quench in Spring Operation 2019

During the Spring operation 2019, 6 magnet quench events occurred.

- **3 events are due to QC2LE power supply failure. SVD had serious damaged.**
- **3 events are beam induced quench (due to beam loss).**





When the magnet PS was failed (I/L worked), the PS slow down started.

After ~3 ms, the beam was aborted by the loss monitor signal, then the steered beam hit and QCS was quenched. During this 3 ms, the beam orbit was deviated.

One of the reason of the delay (~3ms) to the abort timing: Abort request signal from PS system of the magnet was very slow because it was transmitted via relay switches of PLC modules (it took ~60 ms).

Improved in this summer:

In the improved system, the abort request signal is transmitted directly from FPGA in the PS system as optical signal. As the result, the delay was reduced to ~10μs, which is ~50μs before starting slow down of PS.

From the autumn run 2019, accordingly, beams will be immediately aborted after PS failure in ~30 μs before beam orbits are deviated.

QCS Quench in Spring Operation 2019

During the Spring operation 2019, 6 magnet quench events occurred.

– 3 events are due to QC2LE power supply failure (IMP abnormal work).

– 3 events are beam induced quench (due to beam loss).

The beam was aborted at 30~40 μs (3~4 turns) after the large beam loss started. (T_{rev}=10μs)

-> The delay time between the abort request and the abort kicker firing was about (max.) ~40 μs.

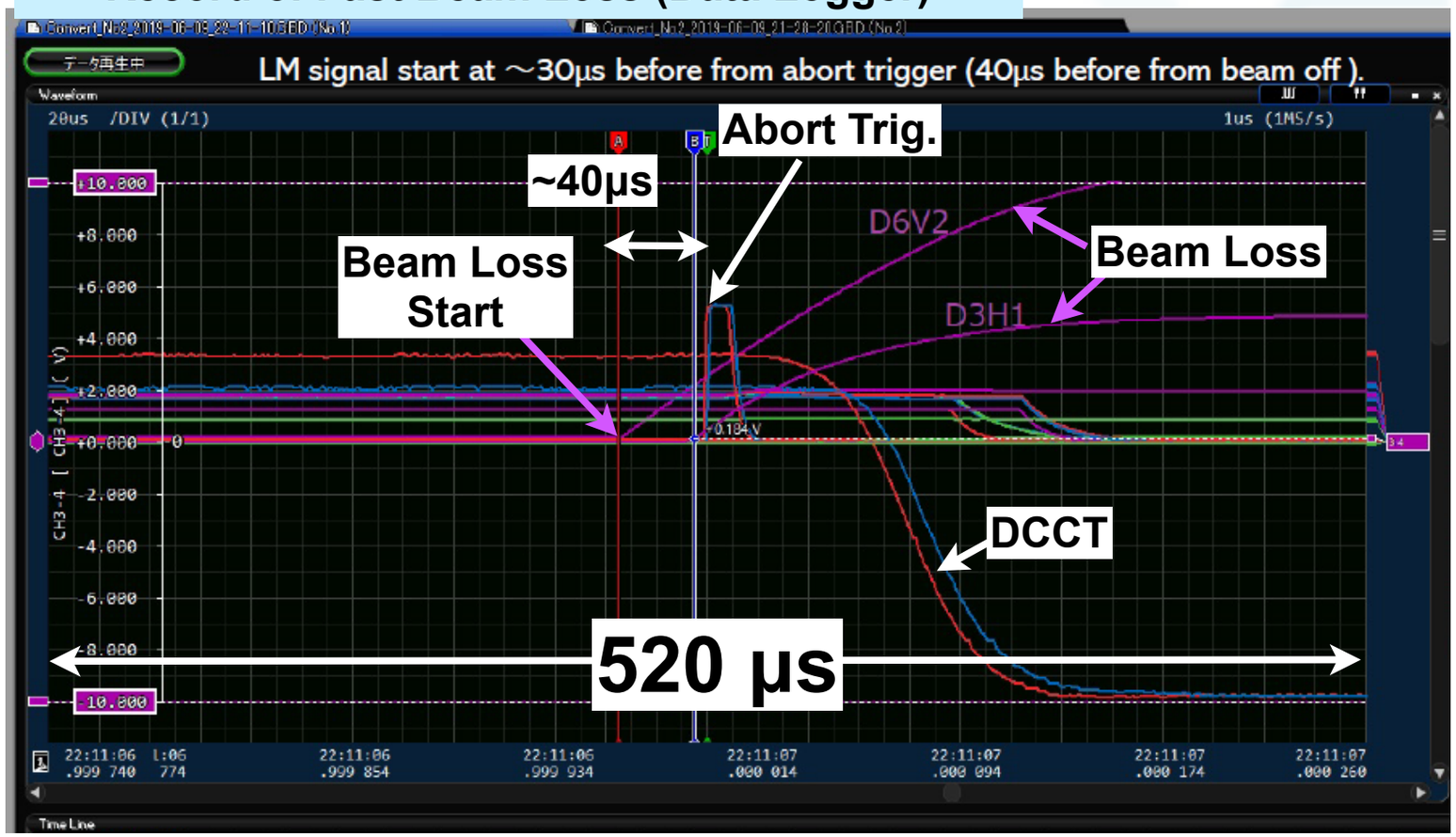
- ~1/3 of beam current was lost until the beam abort.
- High radiation dose damaged PXD.
- Collimator head of D02_V1 (V-type collimator, just upstream of IP) was heavily damaged.

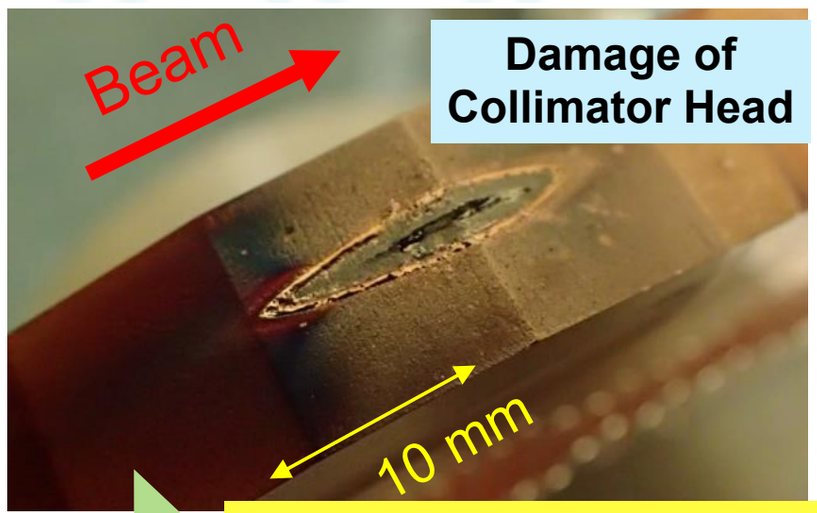
• The beam loss leaded to QCS quench.

The stored beam was steered or blew up suddenly!

Reduction of time lag to abort kicker firing will be effective.

Record of Fast Beam Loss (Data Logger)





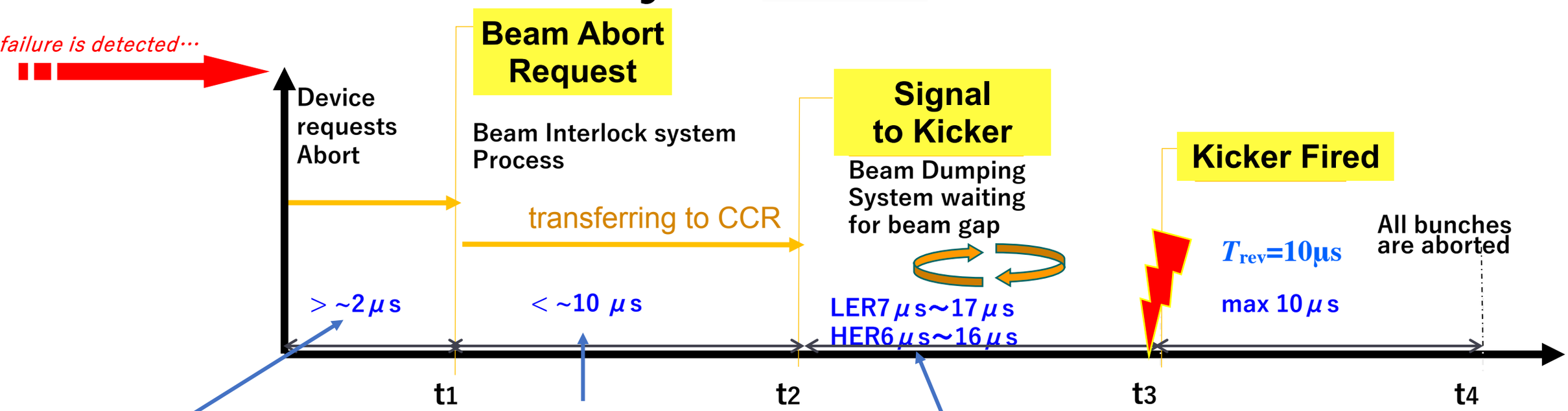
This collimator was replaced with new one.

And also, additional collimator will be installed in winter 2019.

Delays in Beam Abort System

Beam Abort Delays

H. Ikeda



Hardware dependent

To summarize the abort request on the beam abort system.

Depends on the optical cable length from the local control room to CCR.

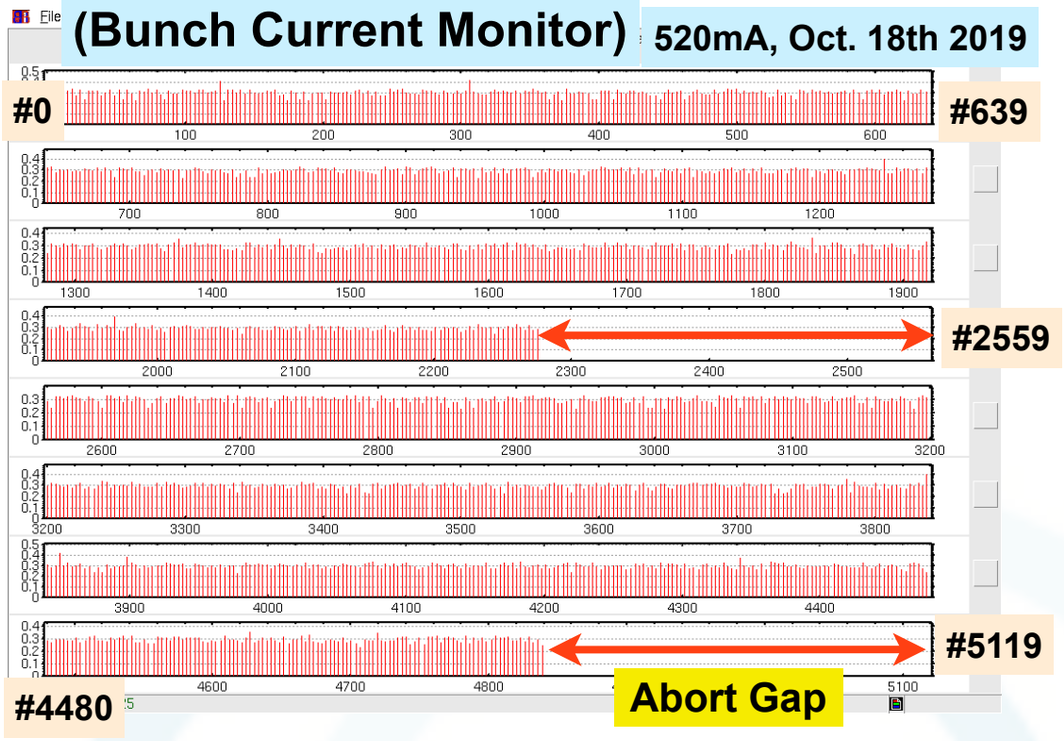
10μs for D1, D2(near Belle-II),

2μs for D7 or D8

Synchronization of the abort request signal with revolution in FPGA.：Max delay=10μs
Delay to synchronize to the abort gap(fixed delay) : 4.2μs for LER, 2.8μs for HER
Delay from CCR to kicker (400m) : 2μs
Thyratron ON :1μs
Rise time for the kicker : 200ns

2 Abort Gaps and New Trigger System

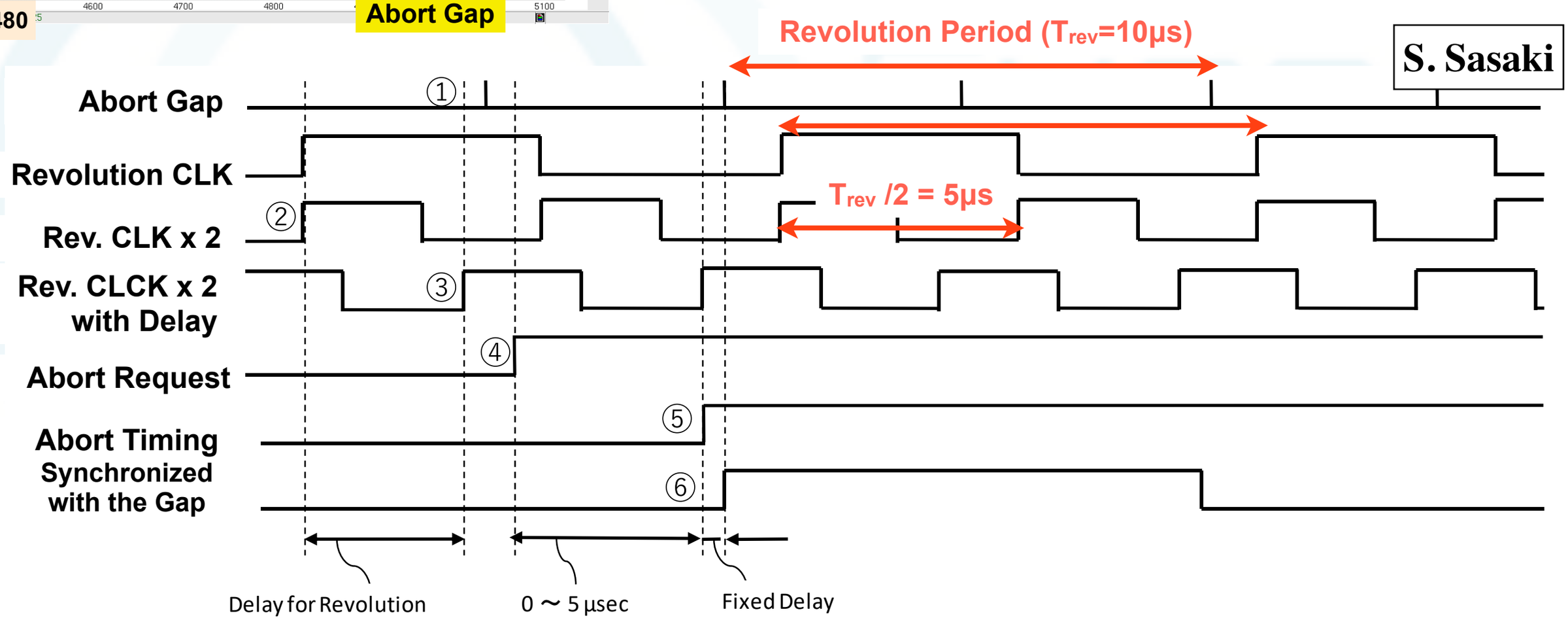
Fill Pattern of Train (Bunch Current Monitor) 520mA, Oct. 18th 2019



In order to shorten the time lag to the abort kicker,

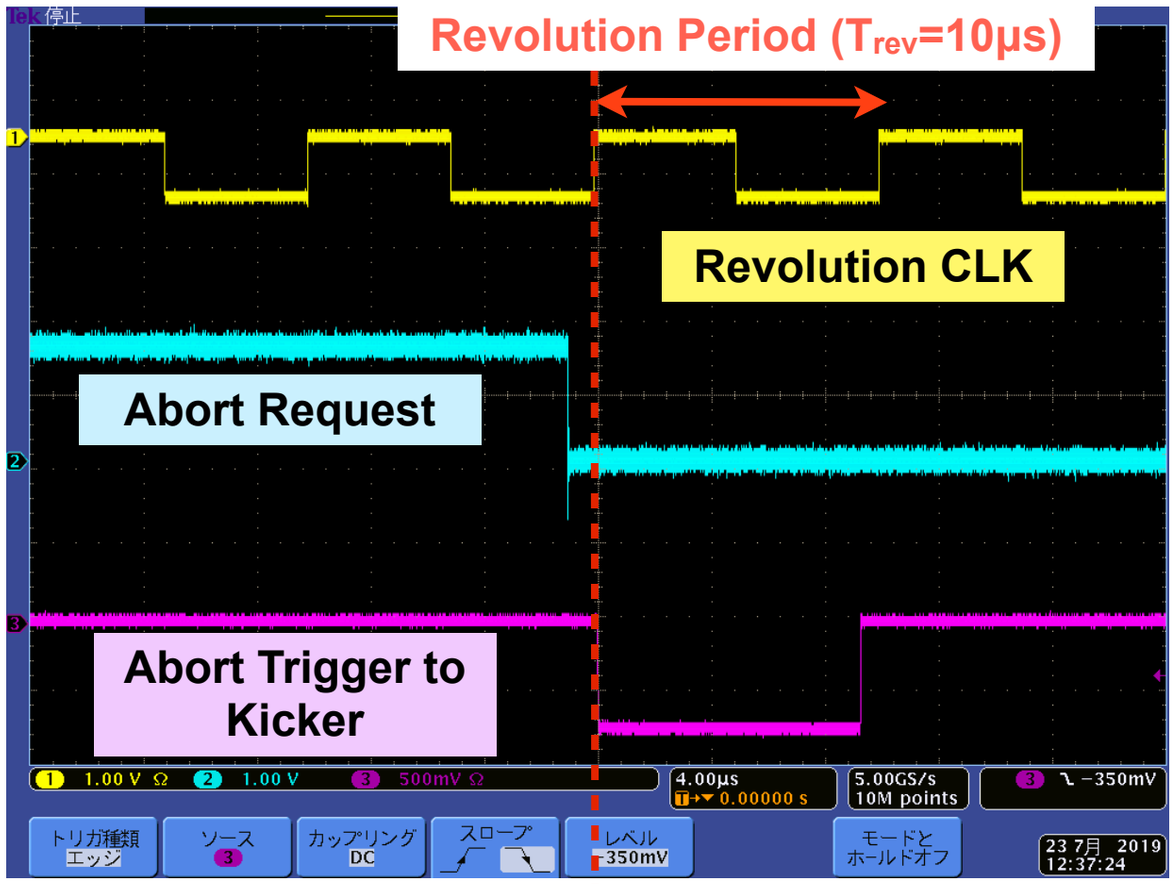
- **Number of abort gaps was increased to 2 in the train.**
- **Abort trigger system was improved to synchronize with the half revolution period.**

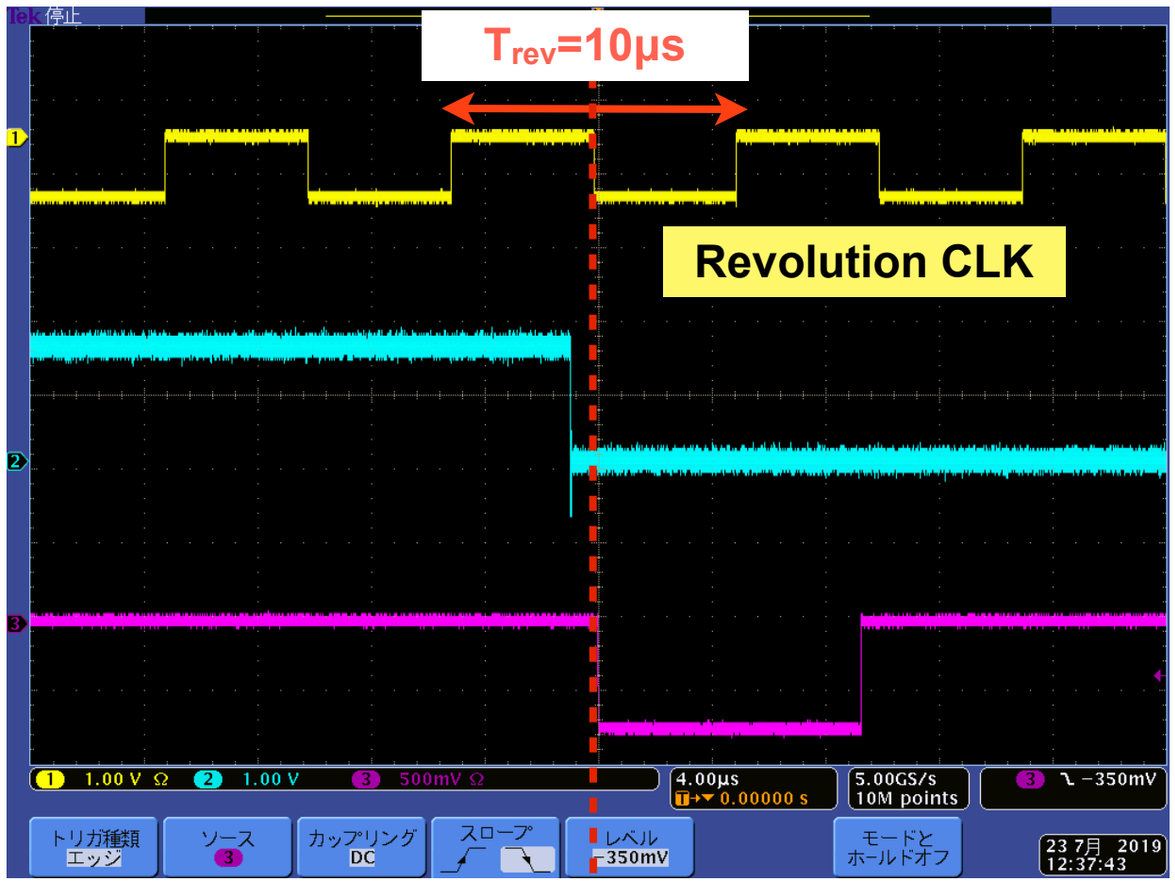
① Number of the abort gap is increased to 2 in the revolution time.
② Multiplied revolution is used to sync an abort request to the increased abort gap timing.
③ Multiplied revolution can be delayed with MR RF clock. This allows to decrease fixed delay.
④ Receive an abort request.
⑤ Synchronize the abort request to the multiplied revolution.
⑥ Wait for the abort gap timing with the digital delay. It would be very short time.



Abort Trigger Synchronization with 2 Gaps

ch1：Revolution　ch2：Abort request　ch3：Abort trigger
(Revolution delay = 0 clock, Digital Delay(TD4) = 1 clock)





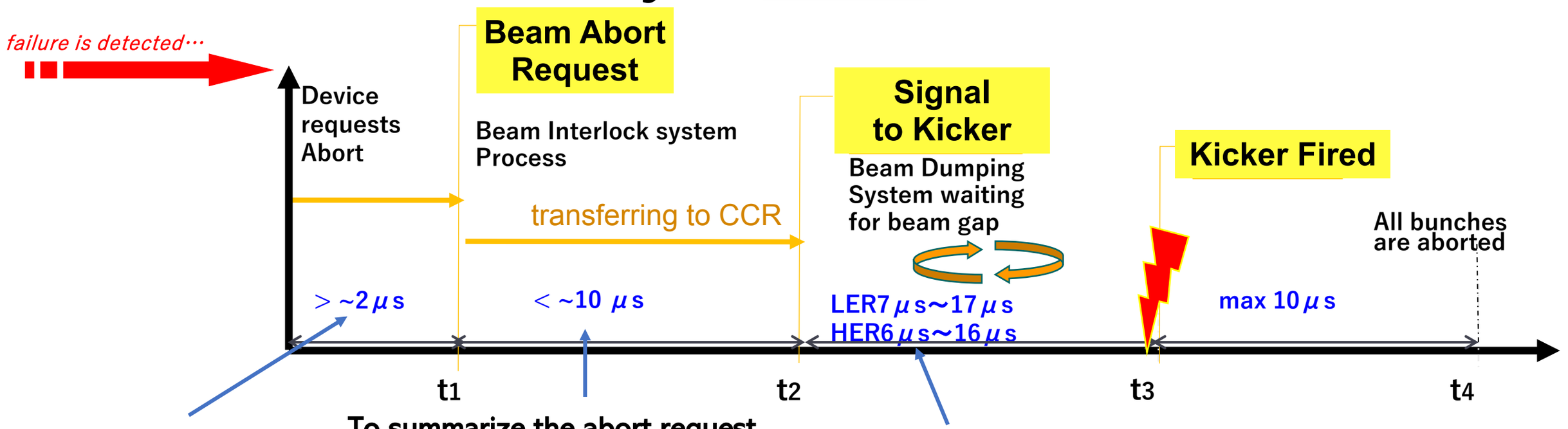
Synchronization with Gaps #1

Synchronization with Gaps #2 (at timing of the half period)

Reduction of Abort Trigger Delay

Beam Abort Delays

H. Ikeda



Hardware dependent

To summarize the abort request on the beam abort system.

Depends on the optical cable length from the local control room to CCR.

10μs for D1, D2(near Belle-II),

2μs for D7 or D8

Synchronization of the abort request signal with revolution in FPGA.：Max delay=10μs → **5μs**

Delay to synchronize to the abort gap(fixed delay) : 4.2μs for LER, 2.8μs for HER → **0μs**

Delay from CCR to kicker (400m) : 2μs

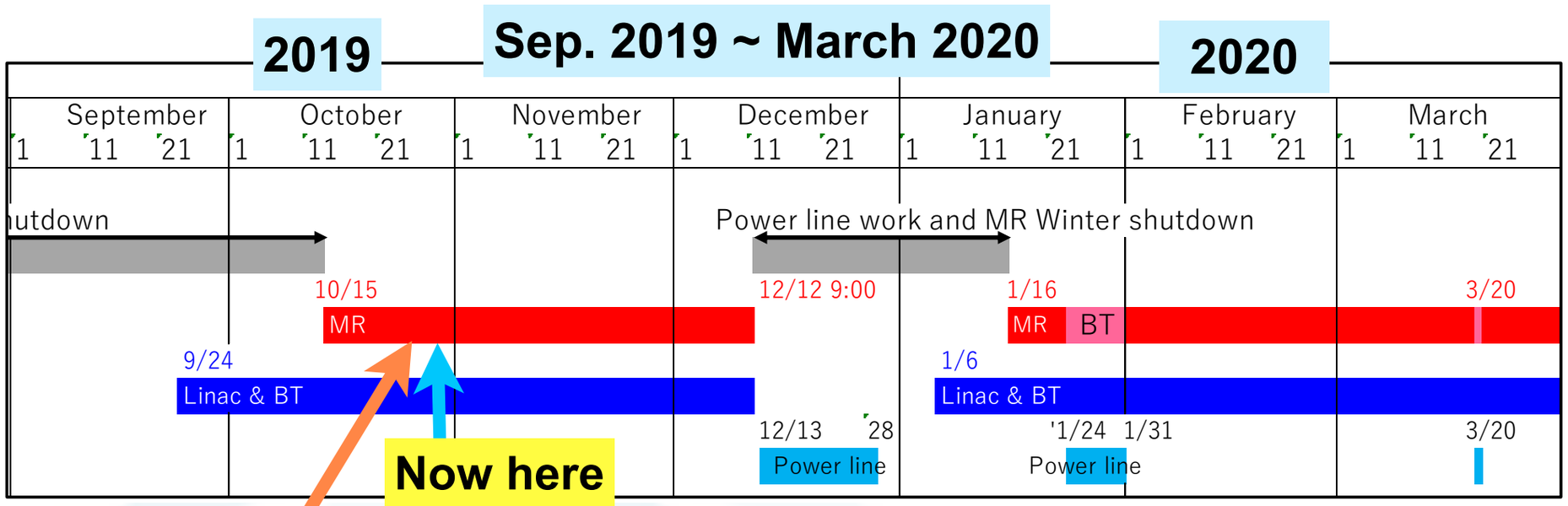
Thyratron ON :1μs

Rise time for the kicker : 200ns

The delay will be shorten by ~10 μs (1-turn) in total.

Commissioning Plan of Next Runs (2019 Oct. ~ 2020 June)

Schedule of Next Runs



2020-Spring operation will be concentrated to physics run to accumulate luminosity.

General goal

- Luminosity goal by the summer 2020: ~200 fb^{-1}.
- 2019-Autumn operation will be devoted to increase the peak luminosity mainly by squeezing β_y^*, and to reduce the beam background.
- Peak luminosity of 2~3 x10^{34} $cm^{-2}s^{-1}$ is required from the beginning of 2020 to achieve ~200 fb^{-1} by the summer.

2019 Autumn Plan (Oct. ~ Dec.)

Base Plan: β_y^* 2.0→1.0

First 3 weeks are devoted for recovery of machine and beam studies at β_y^* = 2 mm.

After that,

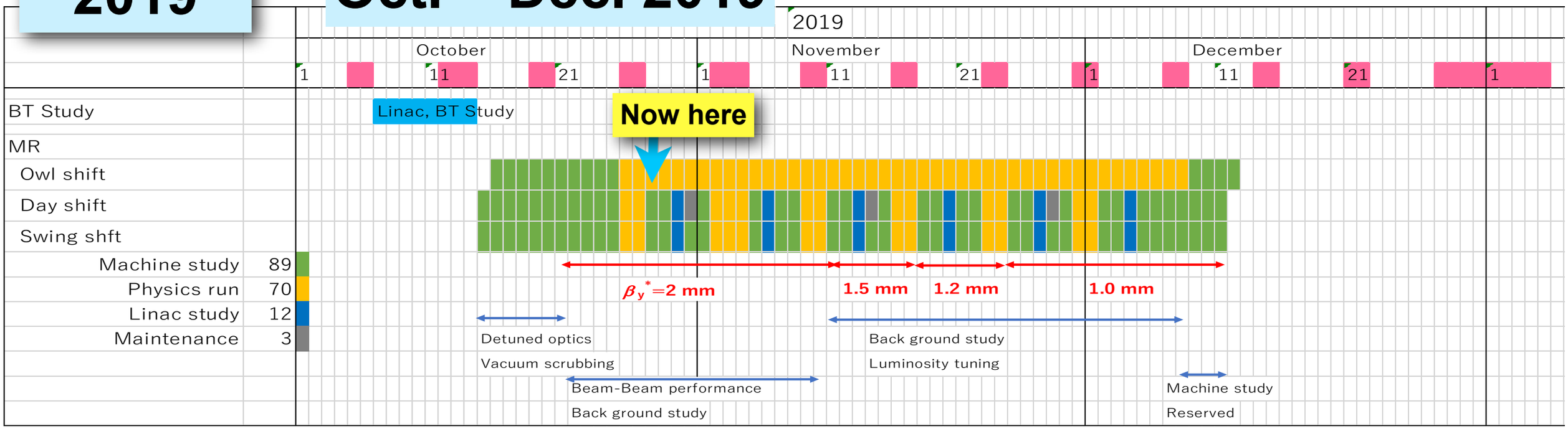
- Machine tuning is planned in day and swing shift of working day.
- Physics run or vacuum scrubbing in owl shift of working day, and whole of holiday.

β_y^* will be squeezed to 1 mm by the end of November.

The last week of this run will be machine study (reserve).

2019

Oct. ~ Dec. 2019



2020 Spring Plan (Jan. ~ June)

Base Plan: β_y^* =1.0

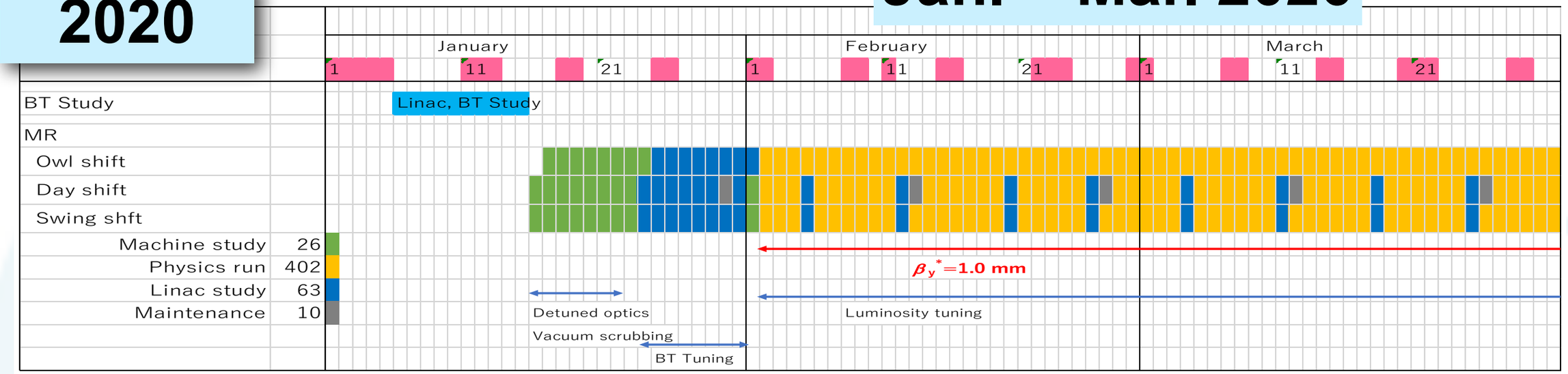
Operation in January will be devoted for vacuum scrubbing, machine studies and Linac studies.

Operation after from February will be basically for physics run with β_y^*=1.0mm.

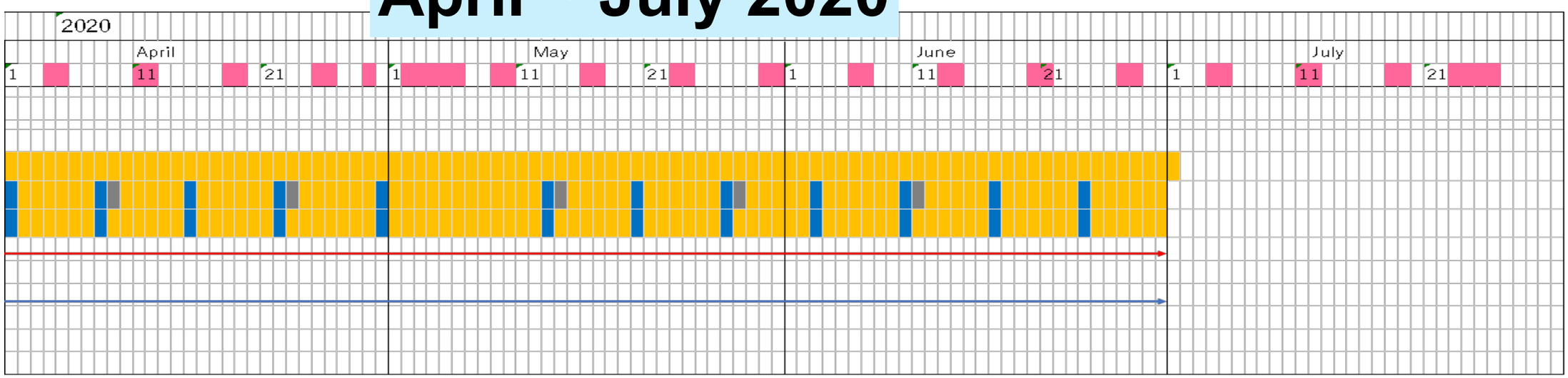
Linac study is scheduled on every Wednesday (1.5 shift)

2020

Jan. ~ Mar. 2020



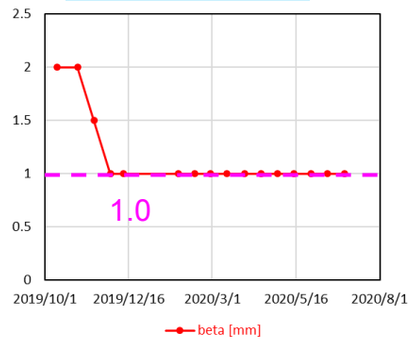
April ~ July 2020



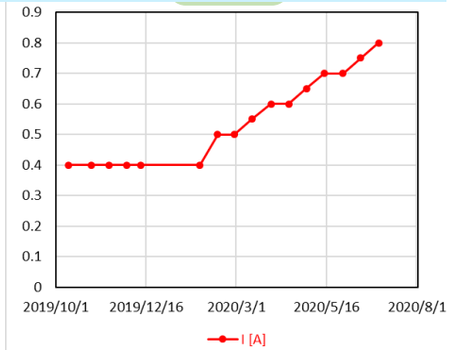
Expected Luminosities by Summer 2020

for the Base Plan: β_y^* =1.0

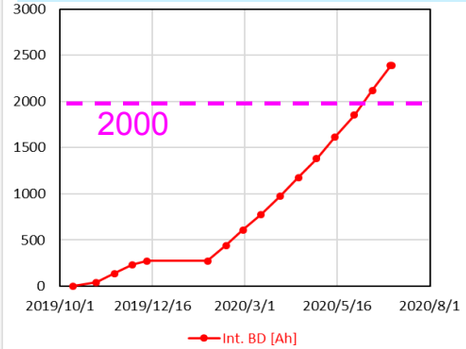
β_y^*[mm]



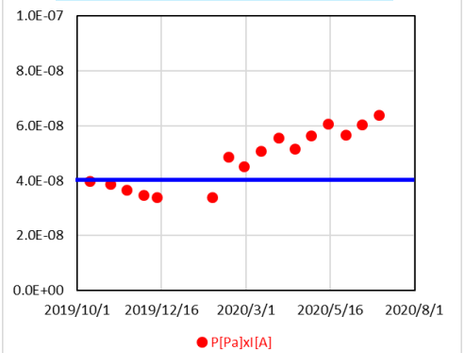
Beam Current [A]



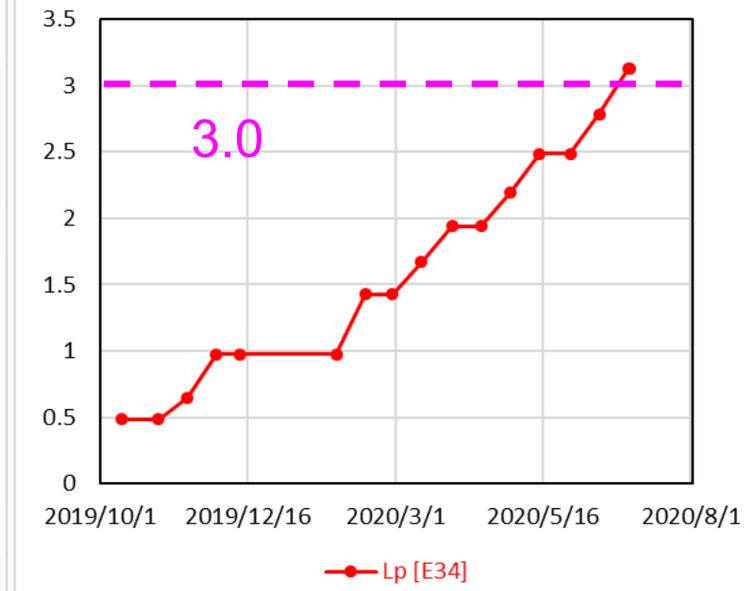
Beam Dose [Ah]



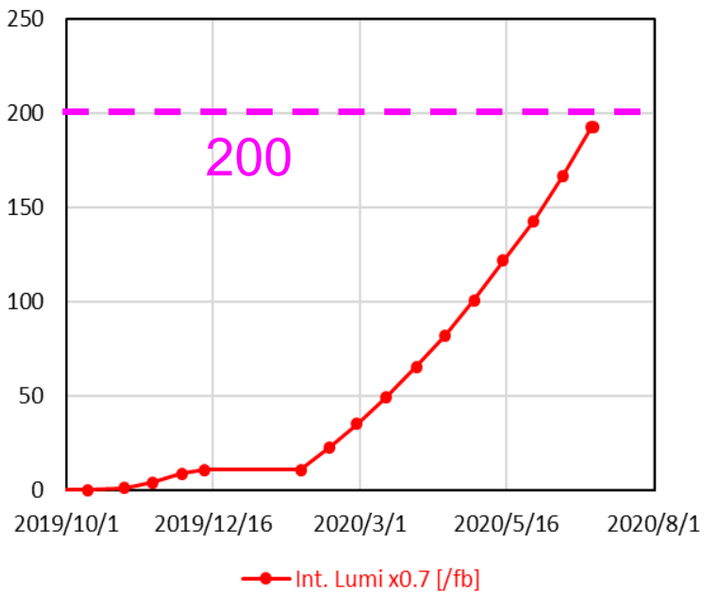
PxI [Pa A]



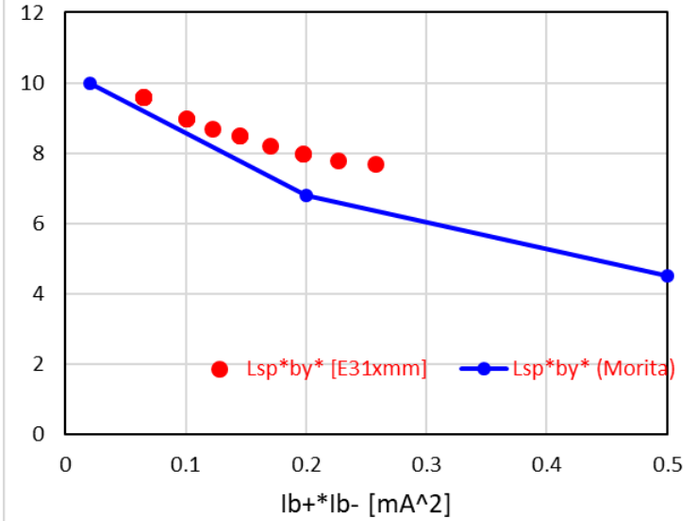
L [x10^{34} $cm^{-2}s^{-1}$]



Int. L [fb^{-1}]



L_{sp} x β_y^* [x$10^{31}cm^{-1}s^{-1}$] vs $I_{b+}I_{b-}$ [mA^2]



Assumptions:

1) Specific luminosity will be proportional to $1/\beta_y^*$. **(in low bunch current condition)**
2) Similar background level as 2019 Spring run, with slightly improvement by 50%.
3) Similar beam-beam effects as 2019 Spring run, with slightly improvement by 20%.
4) Beam background is independent of β_y^*.
4) Expecting vacuum scrubbing of LER during operation: decrease in dP/dI proportional to 1/BD.
5) Efficiency of integrated luminosity is 70%.

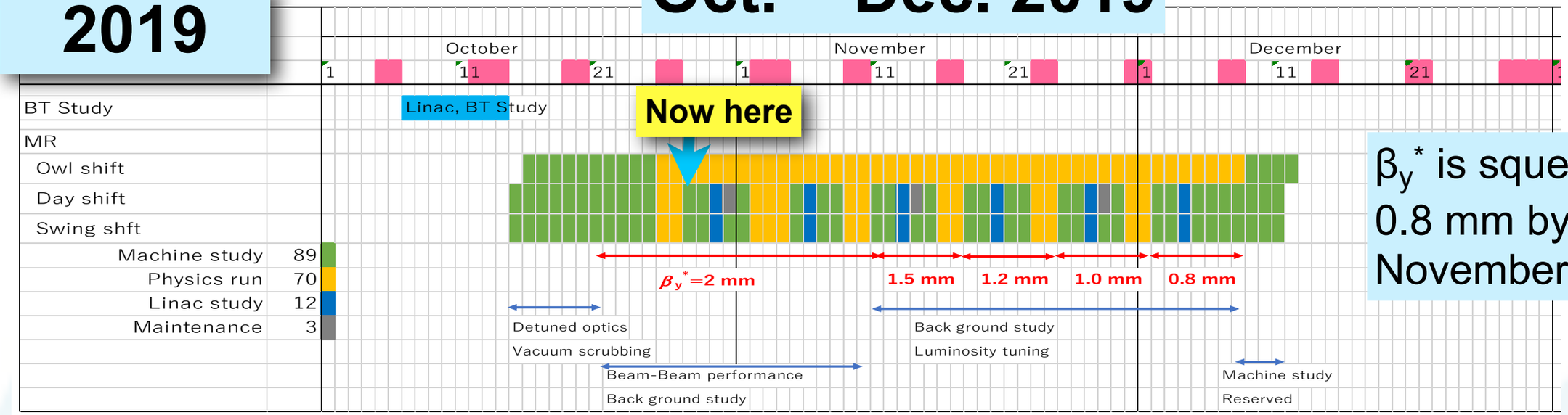
Option Plan for 2020 Spring Operation

Option Plan: β_y^* 2.0→ 0.8 in autumn 2019

If the commissioning would favorably-progressed beyond expectation.

Oct. ~ Dec. 2019

2019

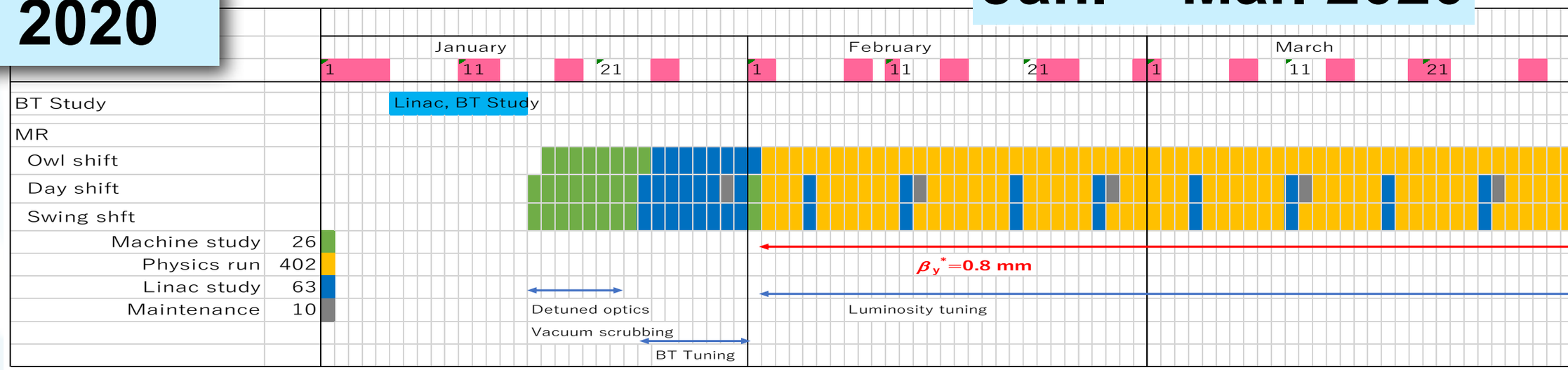


β_y^* is squeezed to 0.8 mm by the end of November.

The run of 2020 will be operated with β_y^* = 0.8 mm

Jan. ~ Mar. 2020

2020

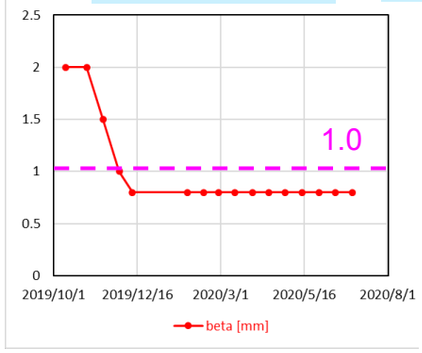


However, in the present state, the schedule was already delayed due to the BT magnet trouble.

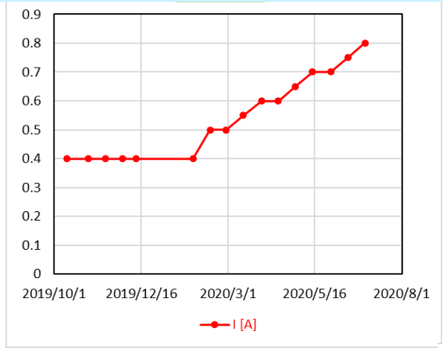
Expected Luminosities by Summer 2020

for the Option Plan: $\beta_y^* = 0.8$

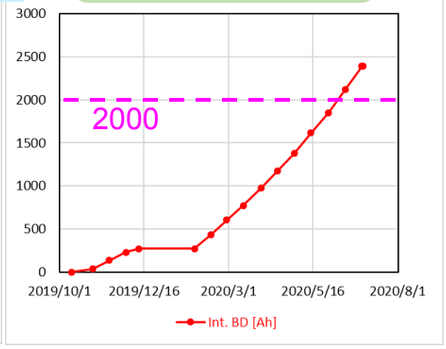
β_y^*[mm]



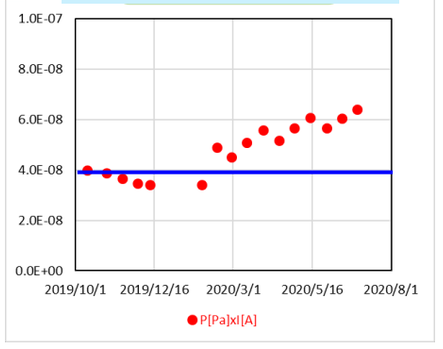
Beam Current [A]



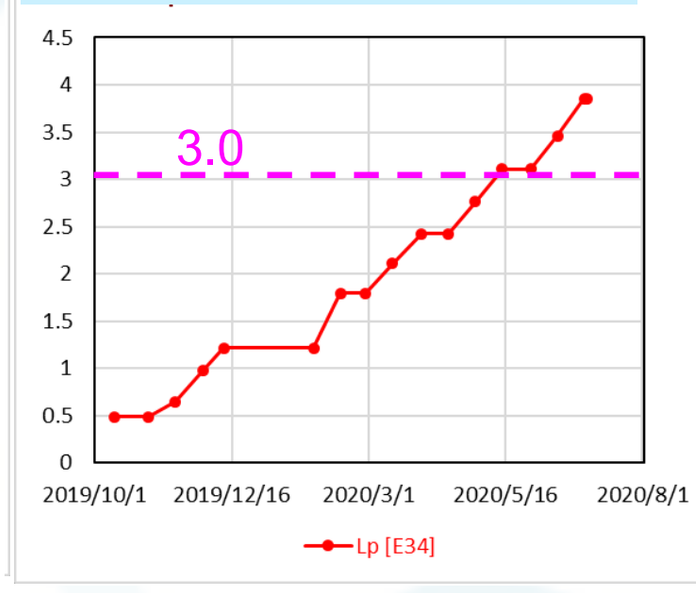
Beam Dose [Ah]



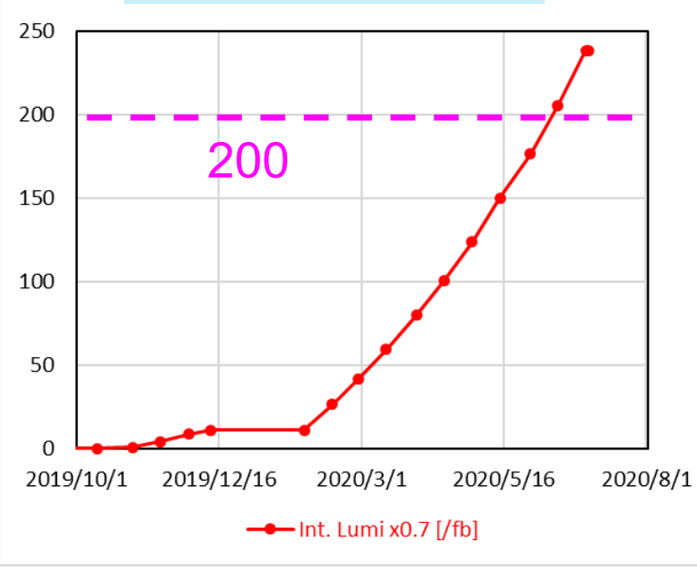
Pxl [Pa A]



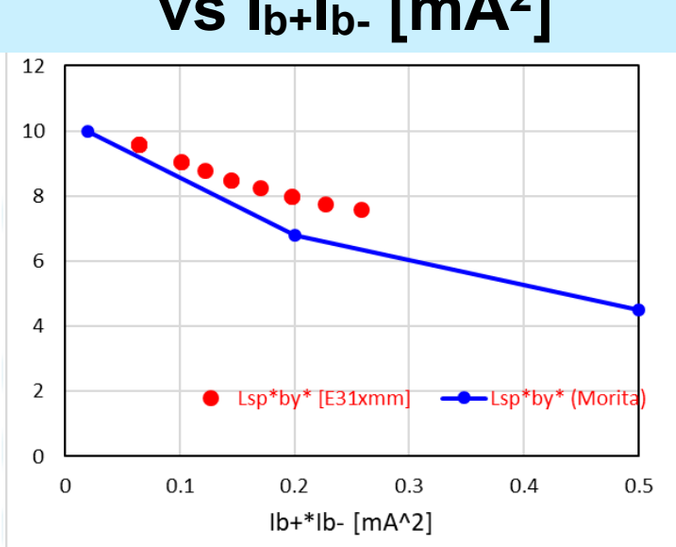
L [x10^{34} cm^{-2}s^{-1}]



Int. L [fb^{-1}]



$L_{sp} \times \beta_y^*$ [x10^{31}cm^{-1}s^{-1}] vs $I_{b+}I_{b-}$ [mA^2]



Assumptions:

1) Specific luminosity will be proportional to $1/\beta_y^*$. **(in low bunch current condition)**
2) Similar background level as 2019 Spring run, with slightly improvement by 50%.
3) Similar beam-beam effects as 2019 Spring run, with slightly improvement by 20%.
4) Beam background is independent of β_y^*.
4) Expecting vacuum scrubbing of LER during operation: decrease in dP/dI proportional to 1/BD.
5) Efficiency of integrated luminosity is 70%.

Summary

- Phase-3, 2019 Spring Commissioning (Mar.~Jun)

  Peak luminosity of 1.23×10^{34} was obtained with $\beta_y^* = 2$ mm.
  Recorded integrated luminosity of 6.5 fb^{-1} was accumulated.
  Nano-beam scheme for $\beta_y^* = 2$ mm was demonstrated.
  Continuous injection for both rings became available : 50%-increase of efficiency

- Concerned Issues

  Beam-Beam blow-up and flip-flop phenomena are observed in beam sizes. Detailed sturdy will be needed.
  Beam background is one of the significant problems. Many countermeasures will be required.
  HER bellows chamber and BPM connectors in IR were broken in 2019-spring operation. They were replaced with new ones.

- Improvements for Quick Abort Kicker Firing

  In order to avoid QCS quench, abort trigger system was improved, and delay of Abort request signal to the kicker firing was significantly reduced:
  - QCS Magnet Failure Abort Request : 60 ms → 50μs
  - Abort Gap : 1 → 2
  - Synchronization with gap timing : 17μs → 5μs

- Plans for Next Operation (2019 Oct. ~ 2020 June)

  Goal : Integrated Luminosity of ~200 fb^{-1} by the summer 2020
  → L = 2~3 $\times 10^{34}$ $cm^{-2}s^{-1}$ is required from the beginning of 2020
  - Base Plan: β_y^* 2.0 → 1.0 in 2019 : Expected L ~ 3 $\times 10^{34}$ $cm^{-2}s^{-1}$
  - Optional Plan: β_y^* 2.0 → 0.8 in 2019 : Expected L ~ 3 $\times 10^{34}$ $cm^{-2}s^{-1}$

  2020-Spring operation will be concentrated to physics run.

Thank you for your attention !

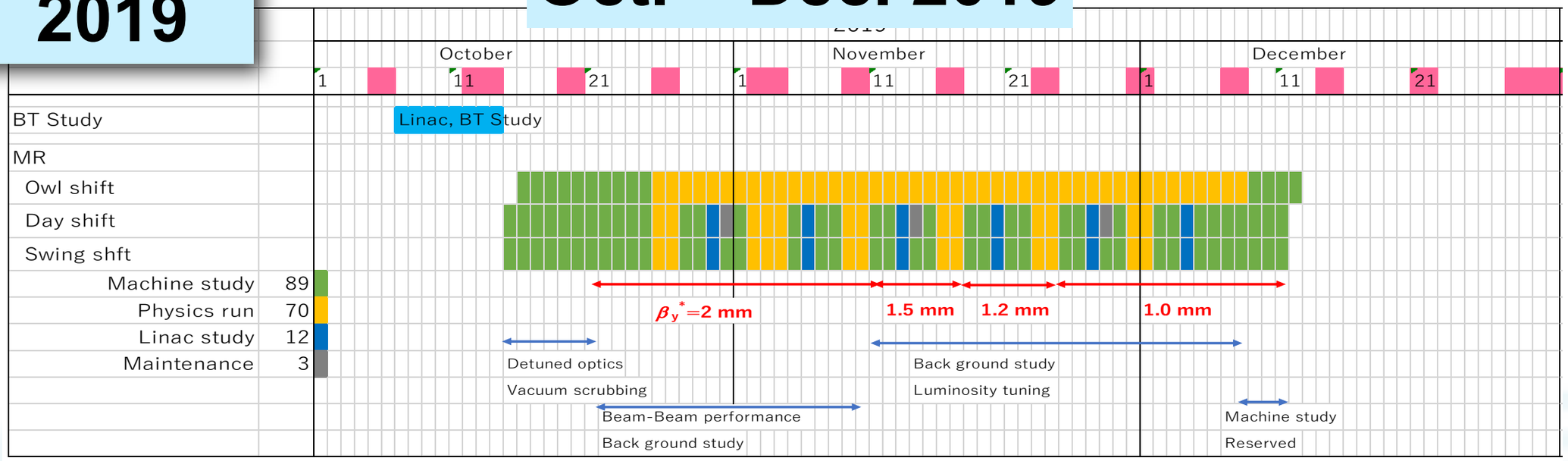
Backup Slides

2020 Spring Plan (Jan. ~ June)

Option Plan-2: β_y^* 2.0→ 1.0 (2019) → 0.8 (2020)

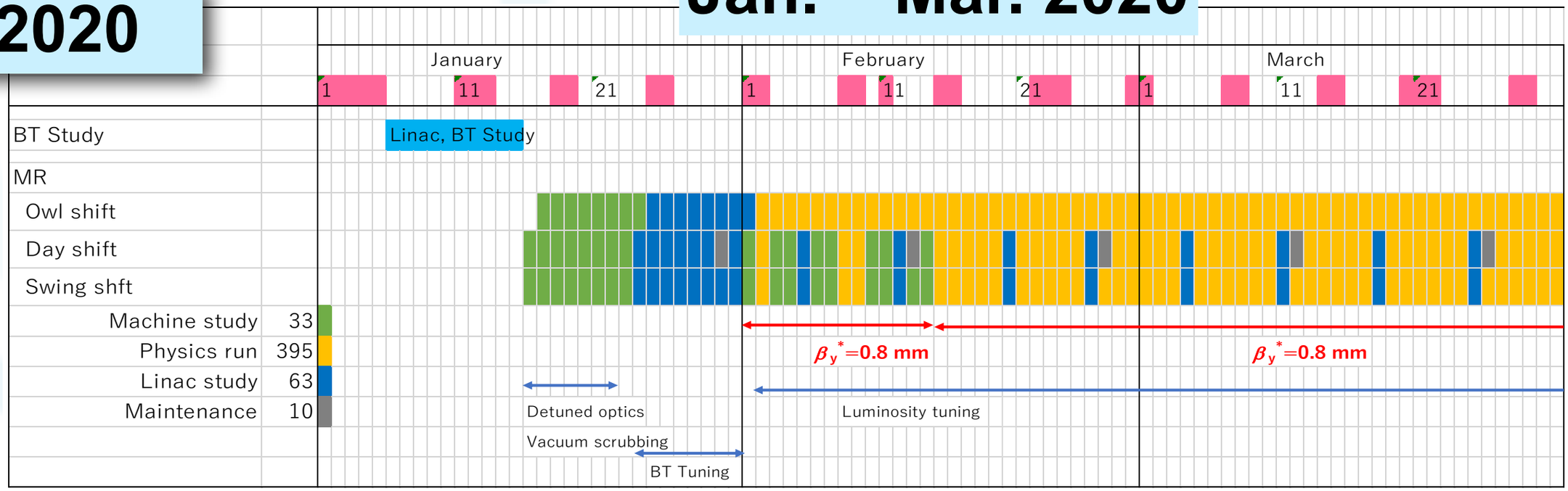
2019

Oct. ~ Dec. 2019



2020

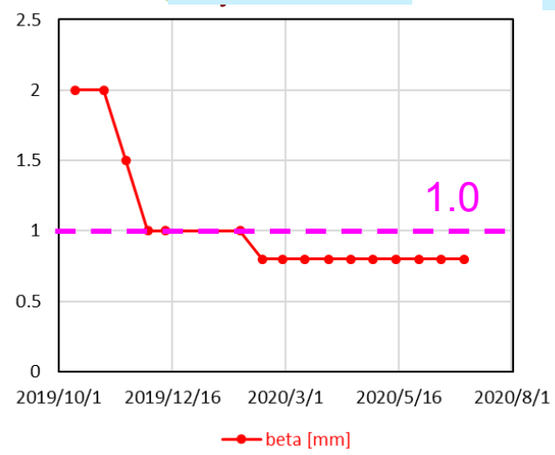
Jan. ~ Mar. 2020



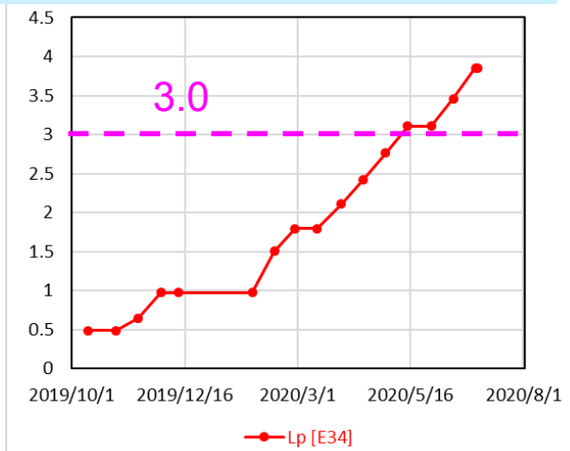
Expected Luminosities by Summer 2020

for Option Plan-2: $\beta_y^* = 2 \rightarrow 1 \rightarrow 0.8$

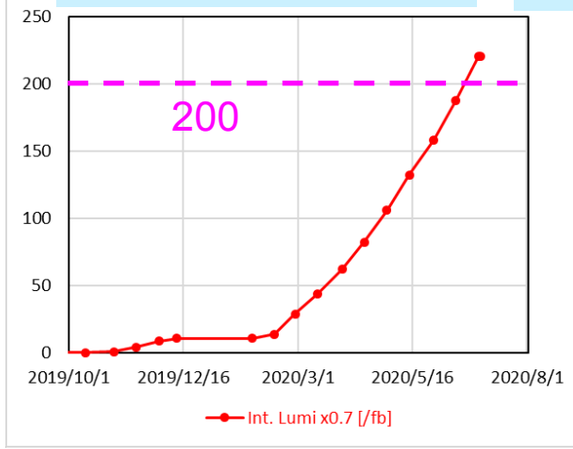
β_y^*[mm]



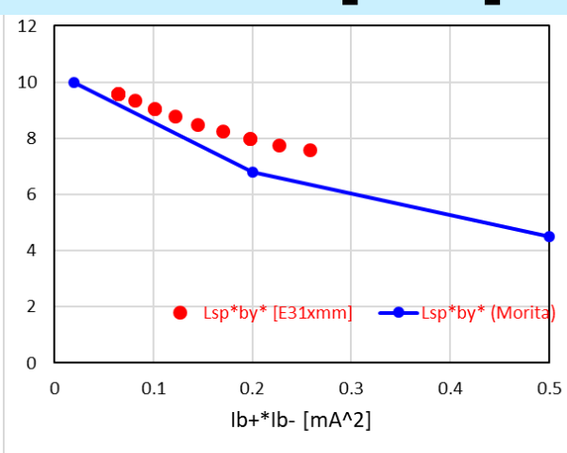
L [x10^{34} cm^{-2}s^{-1}]



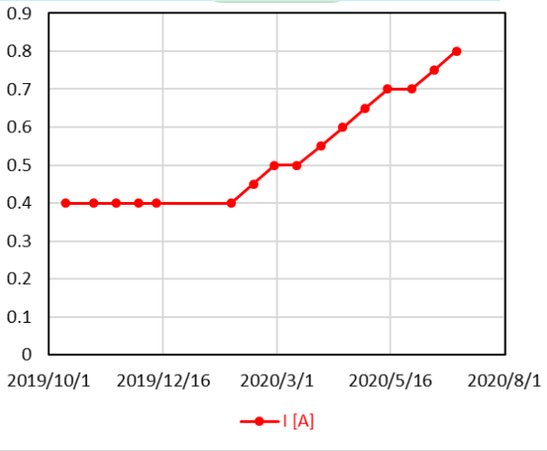
Int. L [fb^{-1}]



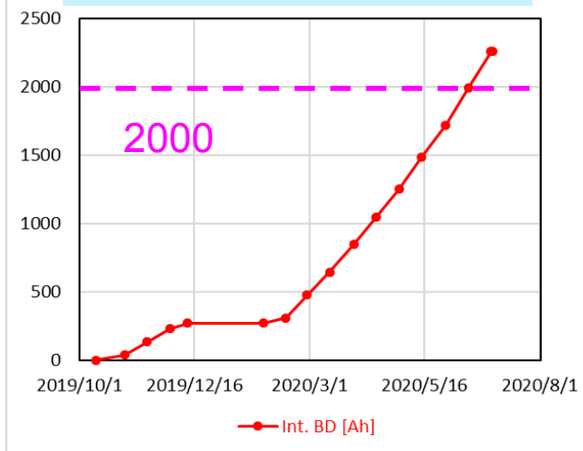
$L_{sp} \times \beta_y^*$ [x10^{31}cm^{-1}s^{-1}] vs $I_{b+}I_{b-}$ [mA^2]



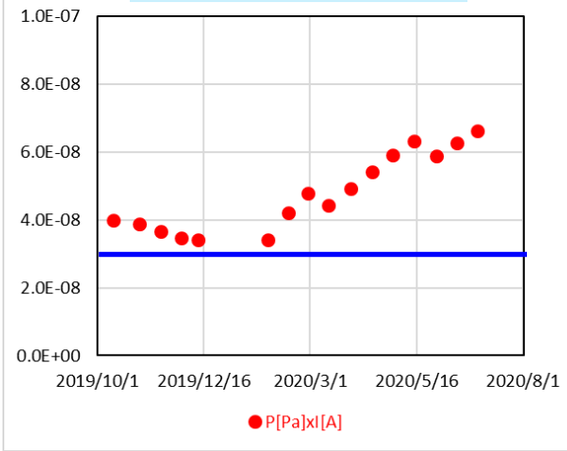
Beam Current [A]



Beam Dose [Ah]



PxI [Pa A]



Assumptions:

1) Specific luminosity will be proportional to $1/\beta_y^*$.
2) Similar background level as 201b, with slightly improvement by 50%.
3) Similar beam-beam effects as 201b, with slightly improvement by 20%.
4) Expecting vacuum scrubbing of LER during operation: decrease in dP/dI in proportion to 1/BD. 5) Efficiency of integrated luminosity is 70%.