Belle II status

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Belle II operation strategy

- Data taking with a high efficiency (≥ 90%)
  - ・・・ Mission of the luminosity frontier experiment
  - Establish sustainable operation system (labor-saving, automation, …)
  - Along with the luminosity increase, in a step-by-step manner, solve issues of the detectors, trigger, computing, etc. which arise from the high luminosity and beam background.

- Mitigate the beam background without interfering the accelerator performance.
  - Suppress the detector degradation by the radiation and performance degradation by the huge beam background within the acceptable level until accumulating 50 ab^{-1}.
    ・・・ Necessary for high precision measurements

- Safe operation without damaging the detectors
  - Occasional huge beam losses damaged the innermost PXD.

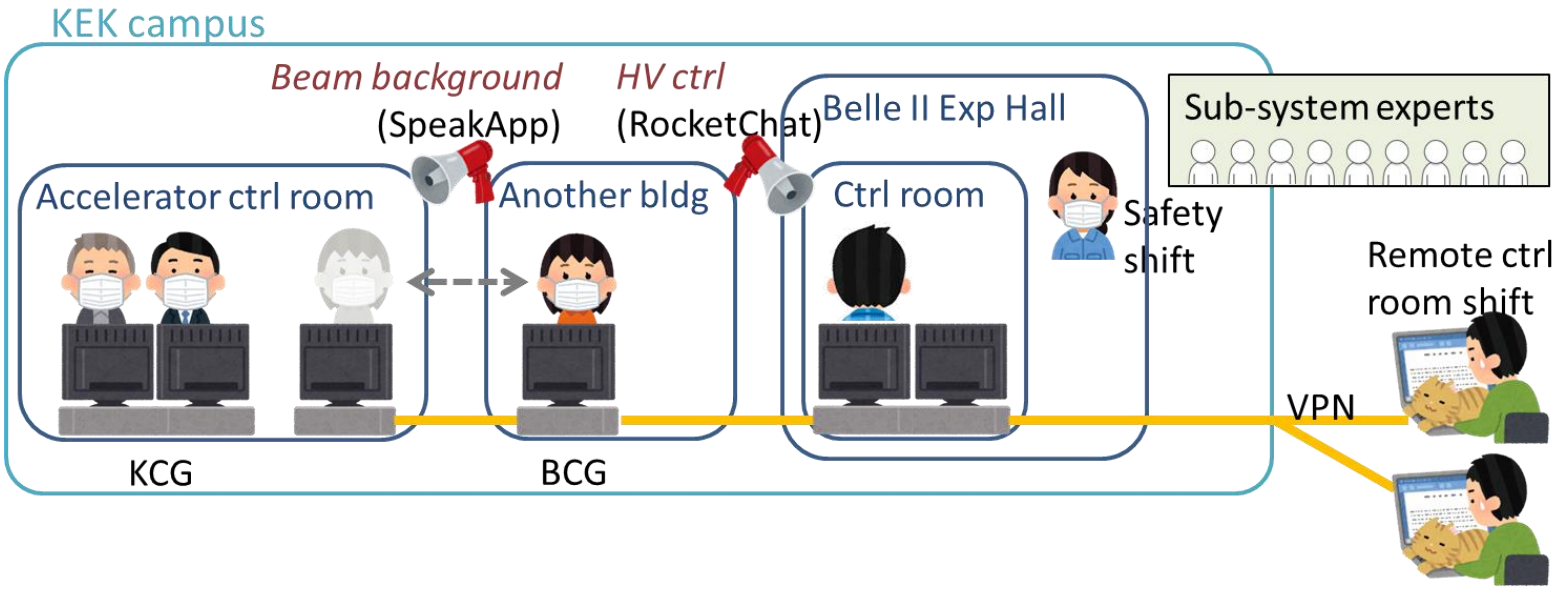
Belle II operation shifts under COVID-19

Limited number of people (~50) in KEK staying for several months or longer.

- Keep minimizing person-to-person contact, avoiding 3C, and taking hygiene.

Operation by people traveling to KEK in turns → mainly by remote people.

- Control room shift: 2 local → 2 remote + 1 local shifters
  … Remote shifters are actively working, and load on local people has been reduced.
- BCG shift: accelerator control room → another bldg.



Tireless efforts for a higher data taking efficiency

Iteration

Understand the existing situation

- Monitors (ELK; Elasticsearch, Logstash, Kibana)
  - We can easily know how well we are doing.

Find what should be improved

- Lesson of errors
  - Review of every major downtime longer than 30 min

Work on the issues

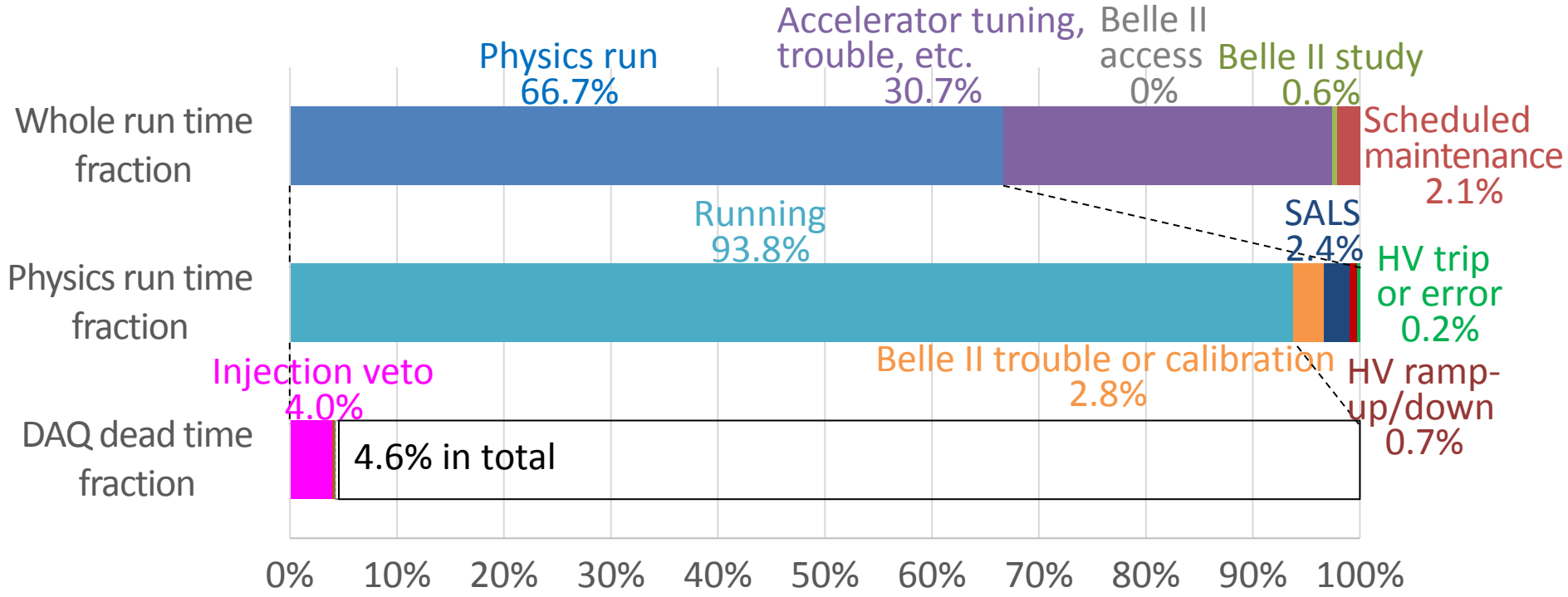
- Fix the cause of the error
- Speed up the recovery procedure from the error
- Documentation, instructions, trainings for subsystem experts

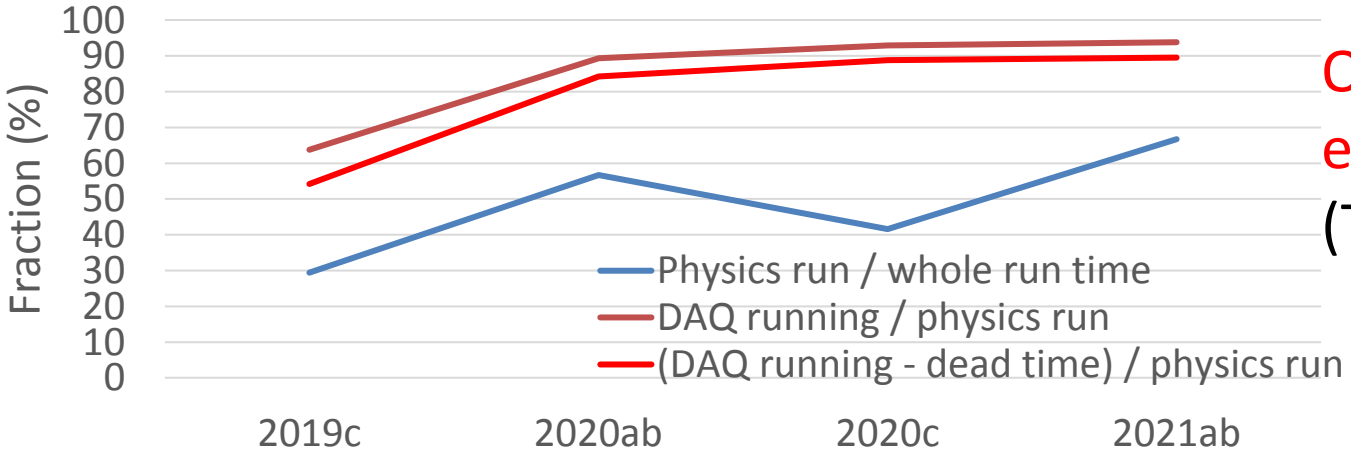
Quality of operation shifters

- Documentation, instructions, trainings for shifters
- Experienced local shifters (special situation under Covid-19)

Feb 16 - Jul 5, 2021

Data taking efficiency in 2021ab





Overall data taking efficiency = 89.5%

(Target 90%)

Toward 90% data taking efficiency

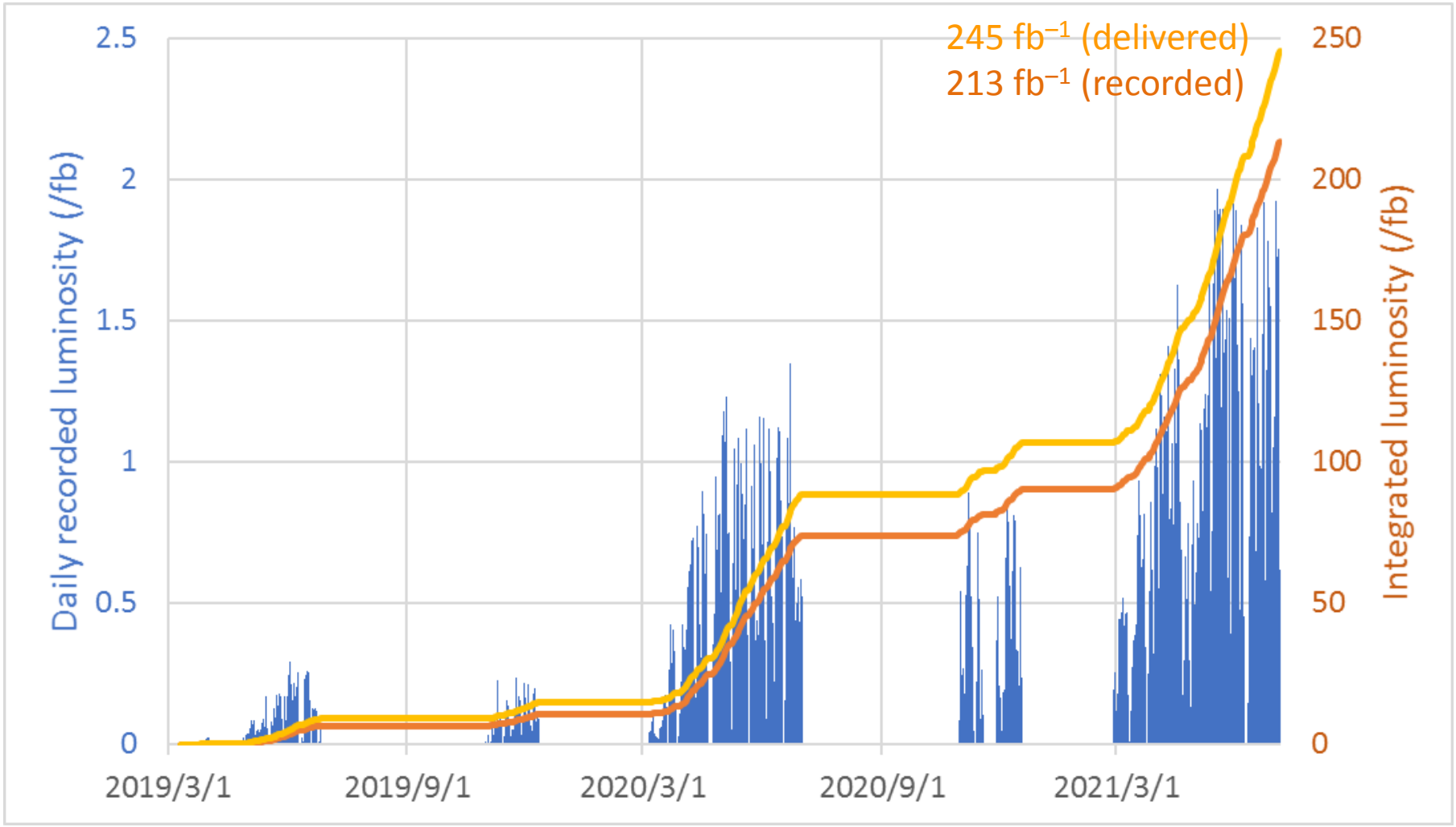
- Data taking efficiency has been improved slightly in 2021ab in spite of more frequent DAQ stops due to a higher beam background, thanks to
  - ✓ More automation, recovery tools
  - ✓ Improved documentation, training
  - ✓ Experienced local CR shifters
- To achieve 90% eff, we should continue improving our system:

  [Short term]
  - Reduce recovery time (e.g. recovery GUI) and time for SALS (e.g. auto-mode)

    (Reduction by 1 min will increase the efficiency by 0.7%.)

  [Long term]
  - Make our system robust against the beam background.
  - Mitigate the neutron background by adding shields and machine/collimator tuning.

Recorded/delivered luminosity



Mitigation of the beam background

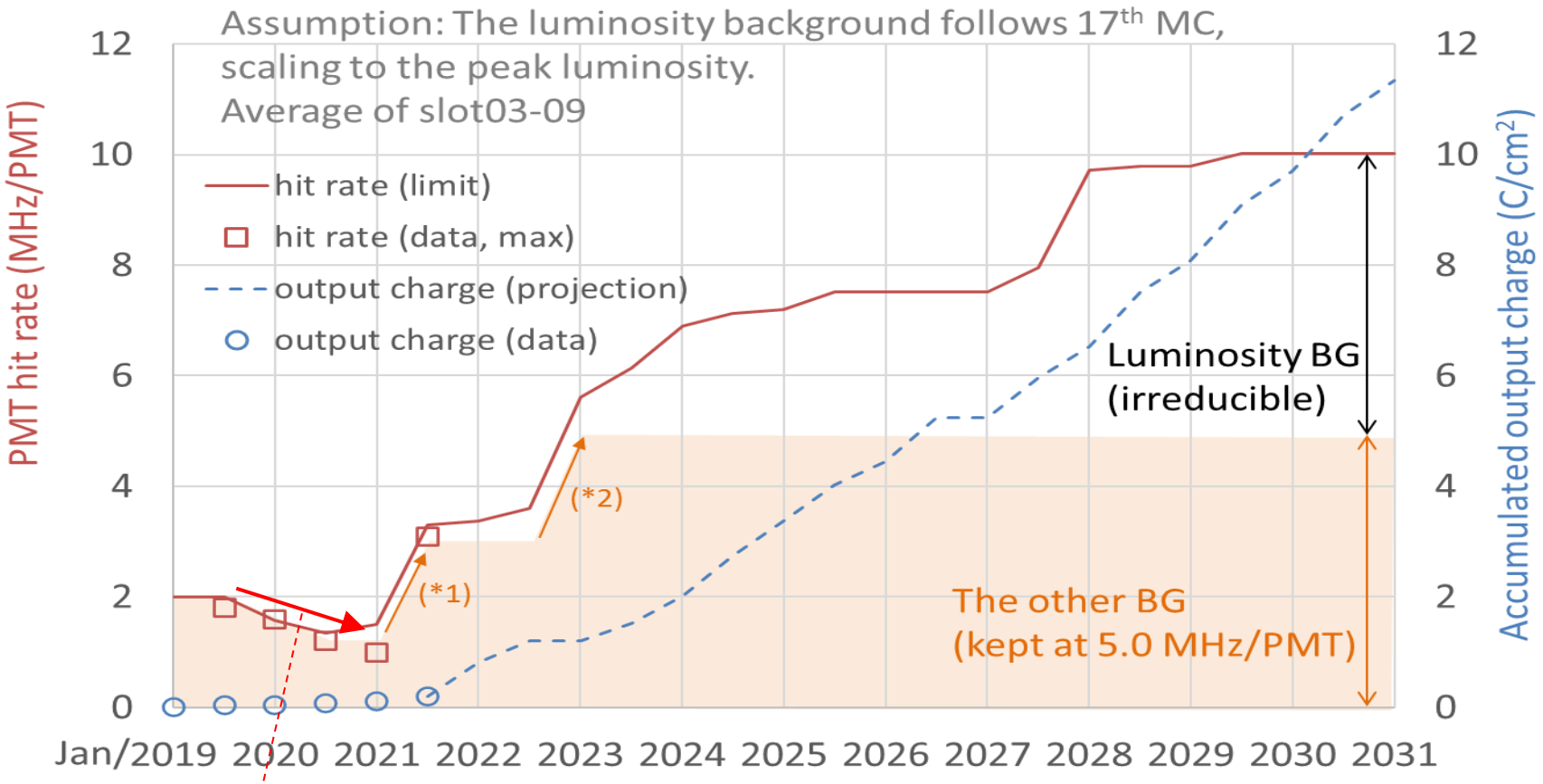
- If the beam background level reaches Belle II limit, the beam current cannot be increased any more. So far, the beam background did not limit the beam current.

- Strategy for the beam background mitigation
  - Understand the beam background
  - ~~Close and add collimators~~
    - ~~Better injection performance will allow tighter collimator settings.~~

  → Need to open collimators to relax TMCI
    - but cannot open them now to avoid frequent beam aborts by bad injections.
  - Optimize collimators
  - Introduce a non-linear collimator
  - Add shield around the QCS bellows
  - (QCS modification)

Most stringent limit on the beam background by TOP

due to degradation of MCP-PMT photocathode caused by background photon detection



(*1) Accepted a higher background at the cost of the 2nd replacement of the MCP-PMTs around 2026.
(*2) The other BG is limited to 3.0 MHz until the replacement of the conventional MCP-PMTs in 2022.

Reduction mainly by LER vacuum scrubbing and by adding/closing collimators

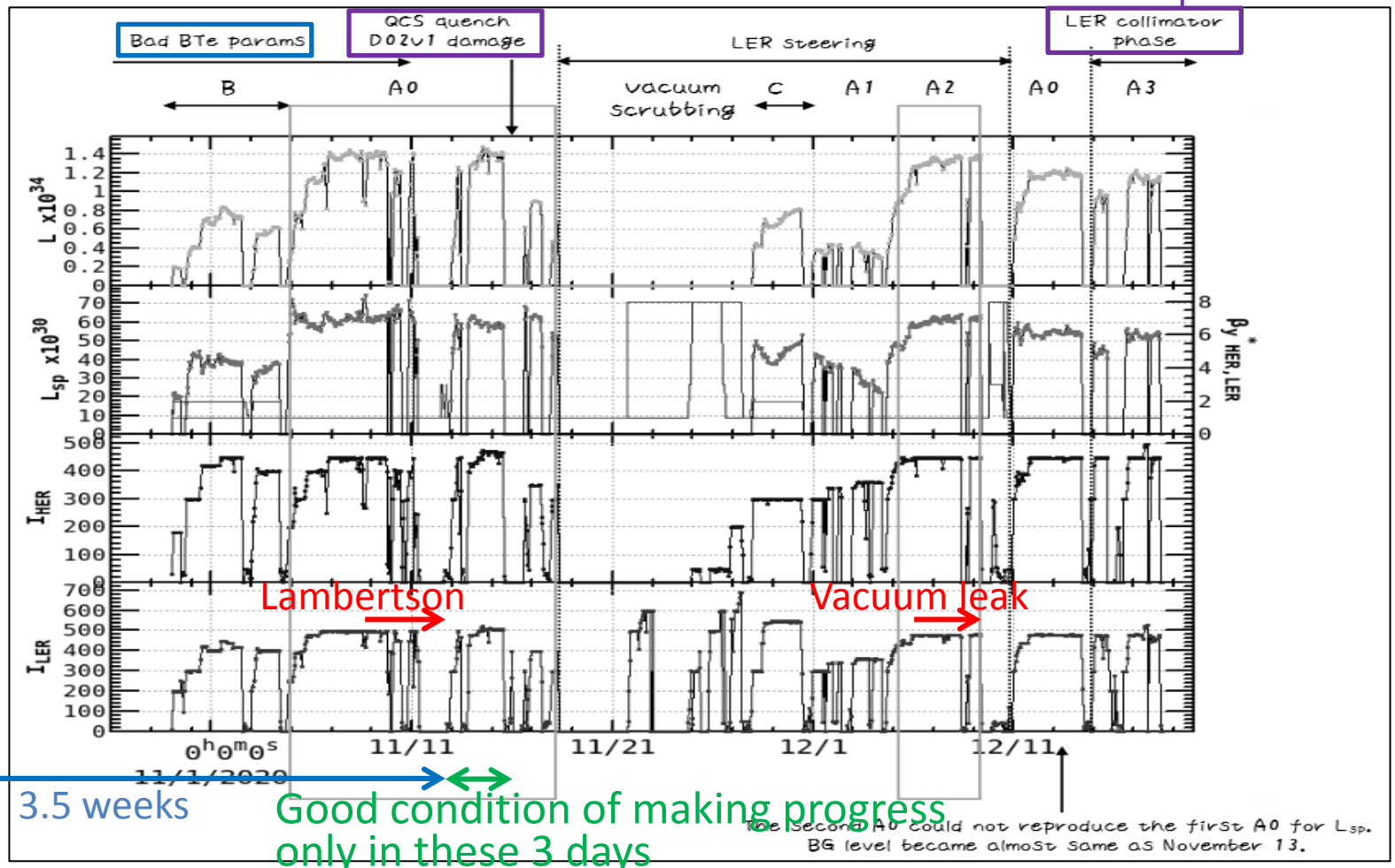
Storage background (Touschek and beam gas) will increase with I_{beam}^2 unless any improvements are anticipated.

Original run plan in 2020c

- Accelerator tuning (squeeze β_y^* from 1.0 to 0.8, 0.7 and 0.6 mm).
  - Target luminosity: 4 x 10^{34} /cm^2/s with 750-1000 mA.

However, many troubles prevented the progress.

To protect D2V1

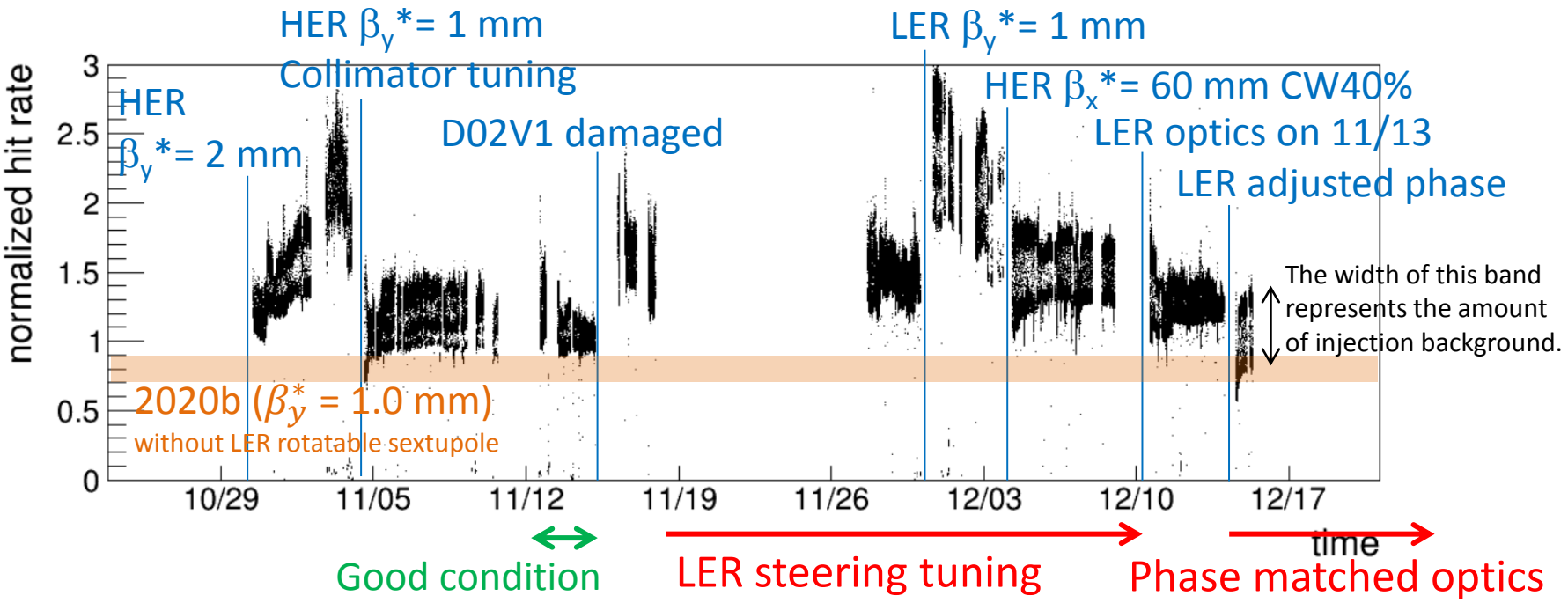


10/19

3.5 weeks

Good condition of making progress only in these 3 days

Beam background (TOP) in 2020c



- The LER steering tuning increased the injection background a lot. That was why the collimators had to be closed for stable operation.
- The phase matched optics was tried to protect D02V1 by D03V1, which eventually increased TMCI.

PMT hit rate normalized by the expectation based on the measurement on May 9:

$$\left(1.1E^{-2}\frac{I^2}{\sigma_y n_b}+1.9E^{-4}I+1.8E^{-7}I^2\right)_{HER}+\left(3.0E^{-2}\frac{I^2}{\sigma_y n_b}+2.4E^{-4}I+9.1E^{-7}I^2\right)_{LER}+7.85E^{-2}\mathcal{L}\,[10^{34}/cm^2/s]$$

Strategy in 2021

- Collect as much data as possible to produce as many physics results of publication quality as possible during LS1.
  - In 2021, we should exceed at least 424 fb^{-1} = BaBar at Y(4S).

Mar.

➢ Restore the same luminosity performance as June 2020,
2.4×10^{34} /cm^2/s at LER 712 mA, HER 607 mA, 978 bunches
with the same optics and collimator settings. (→ ~1.4 fb^{-1}/day incl. eff.)

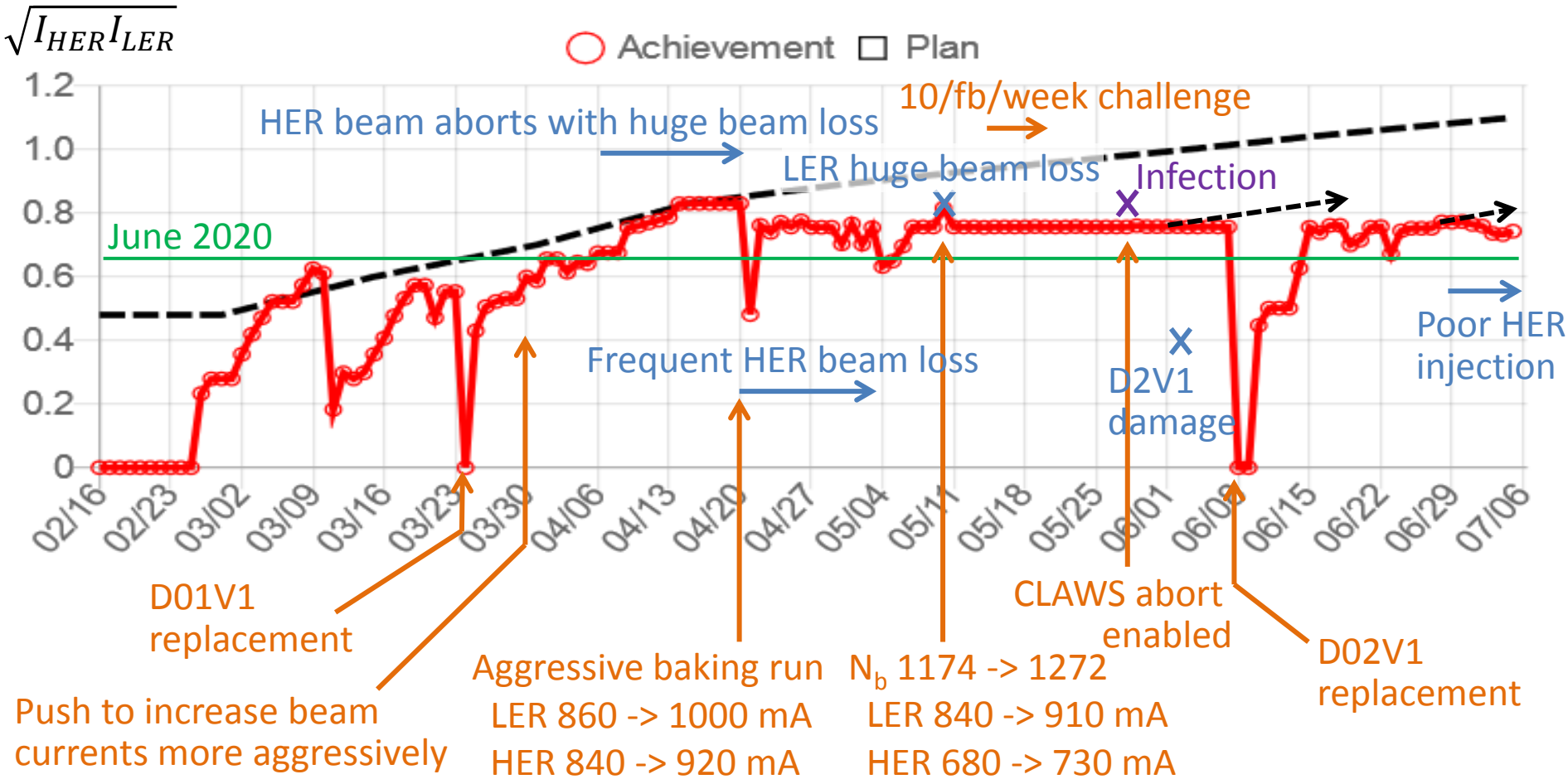
Apr.

➢ Change 978 → 1565 bunches and increase the total beam currents.

→ Target: 3.8×10^{34} /cm^2/s (~2.1 fb^{-1}/day incl. eff.)

- We put priority on the luminosity rather than the beam background reduction in terms of the accelerator tuning/operation.
  - Limits: L1 rate < 13-14 kHz for DAQ, TOP PMT hit rate < 3 MHz + luminosity

Daily max beam current (A) during physics run

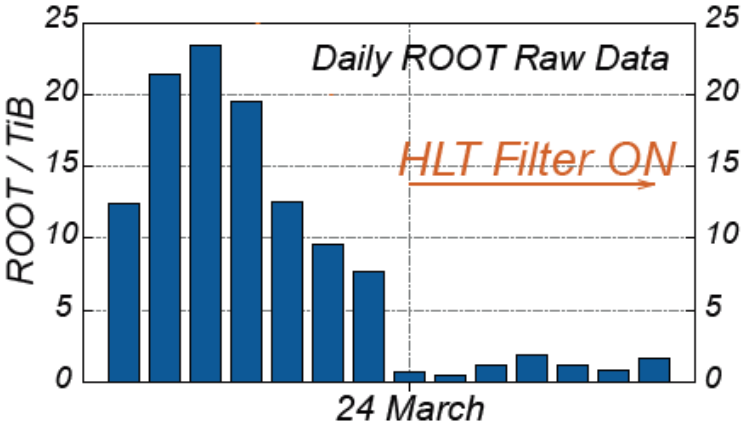


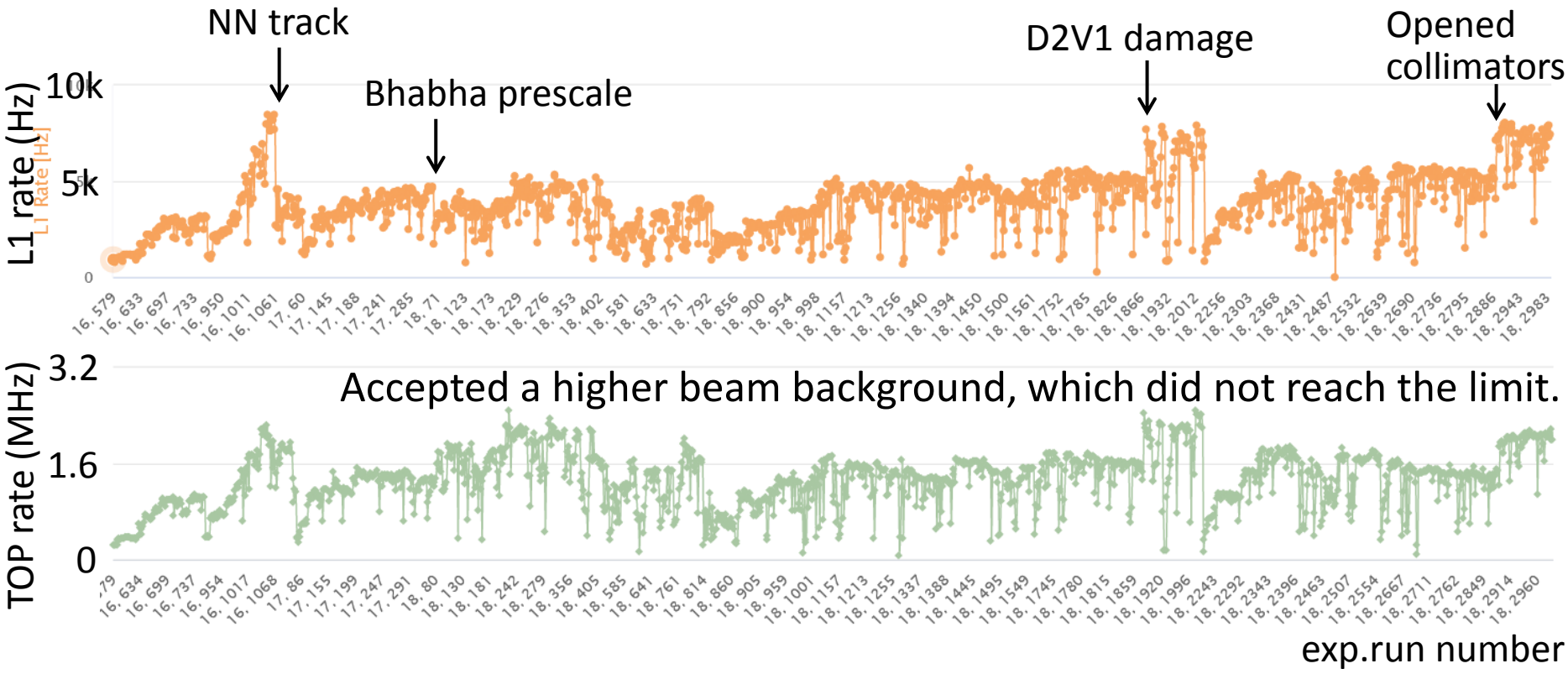
Increasing the beam current is a tough challenge.

- PXD, diamond readout and collimators were damaged by the huge beam loss on May 10.
- It is yet unresolved what is the cause of huge beam losses.

Trigger rate and beam background in 2021ab

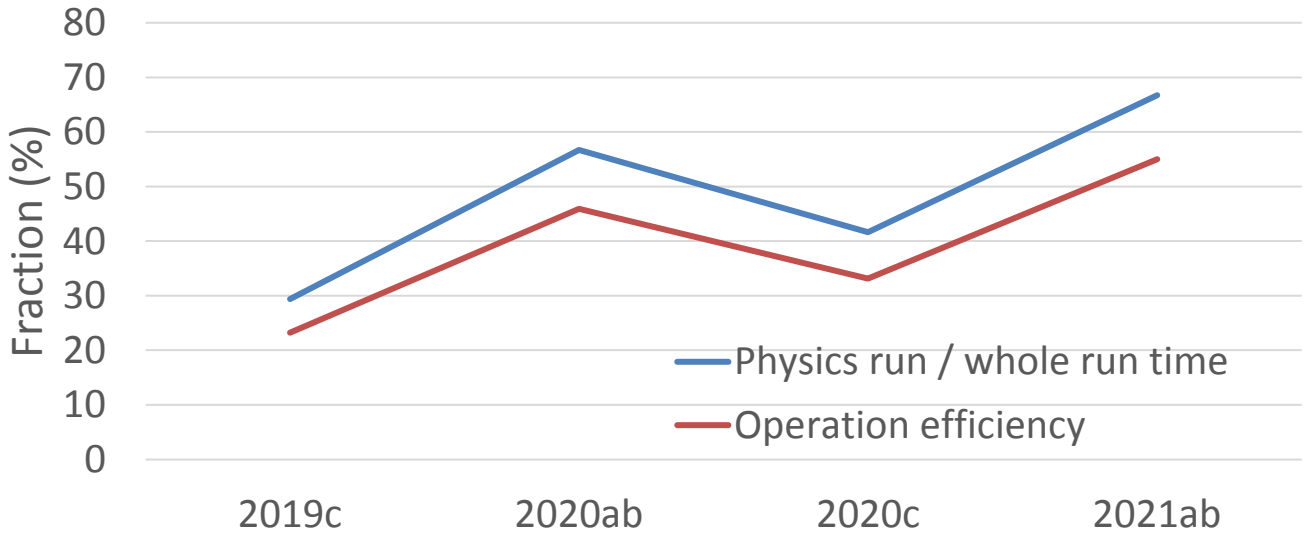
- L1 NN track trigger since 3/20
- HLT filtering since 3/24 (exp17)
- Prescale of L1 Bhabha trigger since 4/7 (exp18)
  - L1 rate was kept below the DAQ limit without applying prescales to the main trigger bits.





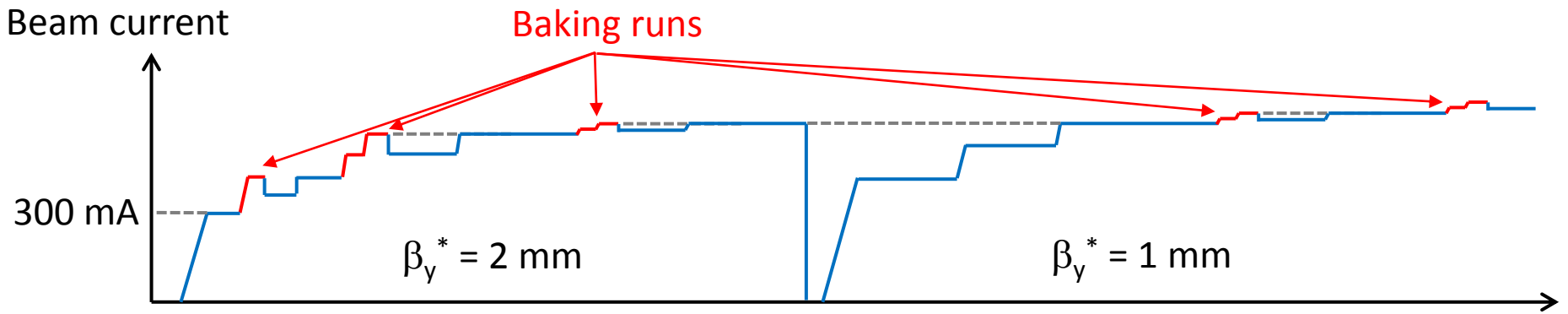
Stable operation is a key

- To integrate the luminosity, to make progress in the accelerator tuning, to reduce risk of damaging the detectors and machine components.
- Operation efficiency $= \frac{\text{Delivered luminosity}}{\int \mathcal{L}_{\max}(t) \cdot \mathrm{d}t}$
  - Represent operation stability at a high luminosity
  - Assumption in the MEXT 2020 load map: 70% operation efficiency



Baking run

- When the beam current is increased above the max current in each run period, Belle II HV is kept at STANDBY for safety (to avoid risk of detector damage by dust event **or beam instability**) until the accelerator is stabilized.
  - **Baking run for 30 min** at the new high current above 300 mA.
    - The step size of the current increase in the baking run is determined by the accelerator experts. **The current should not be far from the one during physics run.**
    - **Baking run should be done in the same collision condition as physics run.**
  - Start physics run at a lower beam current by 20 mA or less than the max of the baking run. Gradually increase the current up to the max of the baking run. Meanwhile accelerator tuning is necessary at a constant current.
    - The beam current at physics run is determined by Belle II in consultation with KCG.



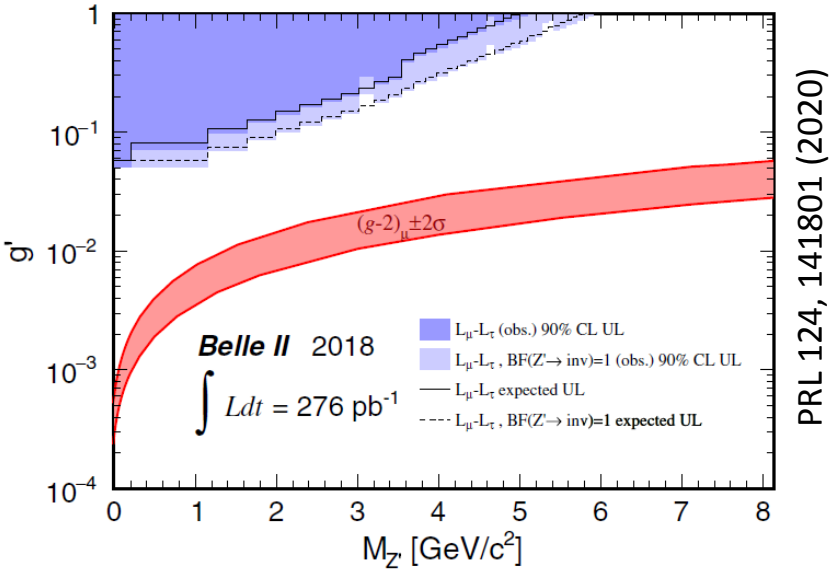
The first threshold (300 mA) should be revisited.

Physics results

Only publications are shown here.

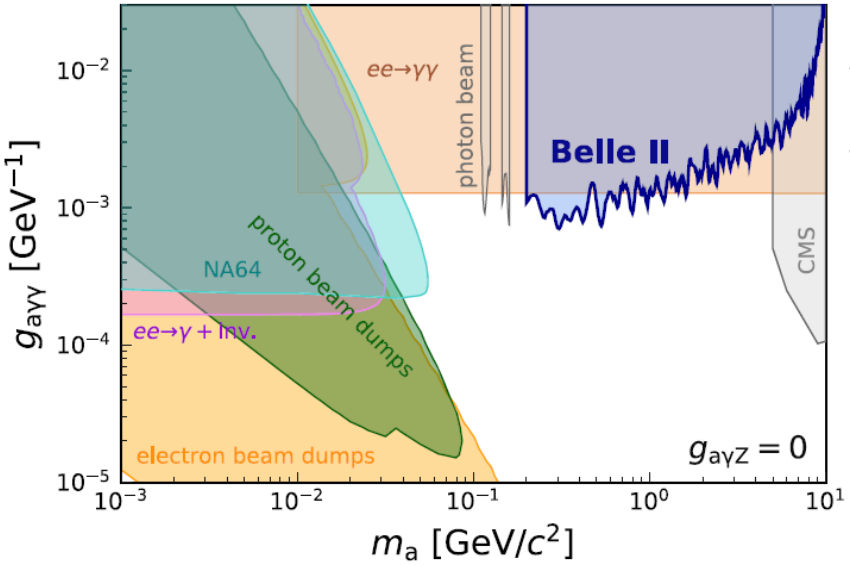
World-leading/competitive results with the data up to last summer.

Search for $e^+e^- \to \mu^+\mu^- Z', Z' \to$ invisible



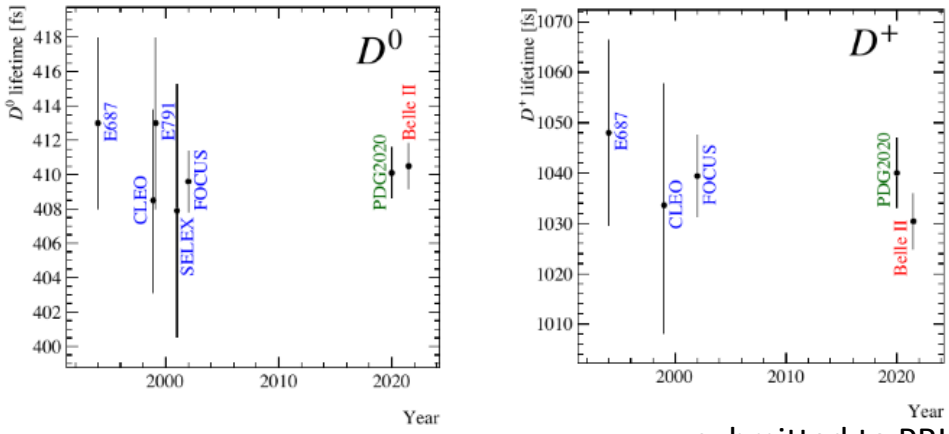
PRL 124, 141801 (2020)

Search for $e^+e^- \to \gamma a, a \to \gamma\gamma$

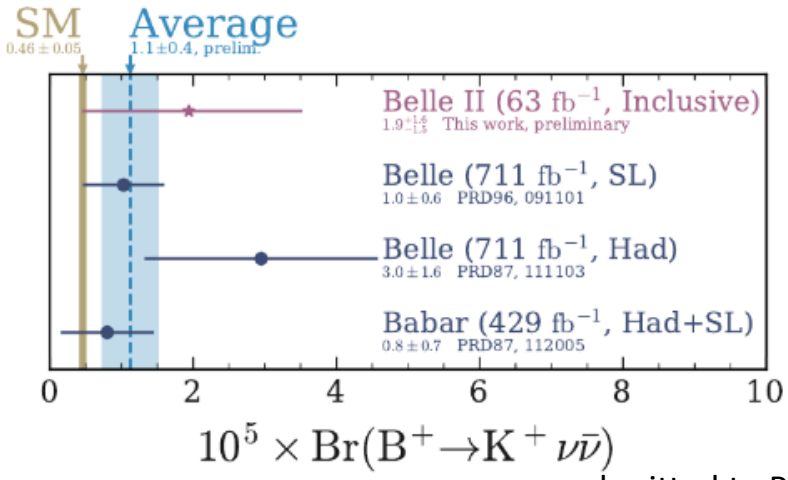


PRL 125, 161806 (2020)

Measurement of D^0 and D^+ lifetime



submitted to PRL



submitted to PRL

Need more data

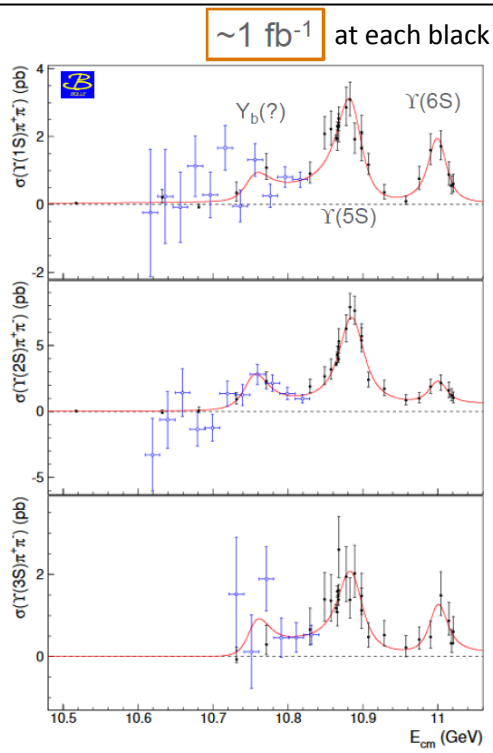
- Before the long shutdown in 2022, we need data comparable to 711 fb^{-1} = Belle at Y(4S) or more to be fully back in the game.
  - Data in a timely manner is essential to compete with LHCb.
- Short runs in 2021c around 10.75 GeV, which is almost unexplored and promising for O(10) publications.

Pacific Northwest NATIONAL LABORATORY

Motivation: "$Y_b(10750)$"

- Recent Belle analysis of $\pi^+\pi^-\Upsilon(\ell\ell)$ transitions
  JHEP 10 (2019) 220
- Observation of enhancement @ 10.75 GeV
- Decays similar to $\Upsilon(56S)\to\pi^+\pi^-\Upsilon(123S)$
  - Could there be a Z_b enhancement?
  - Could it be $\Upsilon(3D)$ bottomonium or a tetraquark?
  - Near $B^{(*)}B^*\pi$ threshold regions

Wang, CPC 43, 123102 (2019)
Ali et al., PLB 802, 135217 (2020)
Bicudo, Cardoso & Wagner, arXiv:2008.05605 (2020)
Chen, Zhang & He, PRD 101, 014020 (2020)
Giron & Lebed, PRD 102, 014036 (2020)
Li et al., EPJC 80, 59 (2020)
Liang, Ikeno & Oset, PLB 803, 135340 (2020)
…



Beyond ϒ(4S) / B2GM / 2020.11.09 6

B. Fulsom

Plan of the above-Y(4S) runs in 2021c

Integrated luminosity projection at each energy

	Day 1 Wed	2 Thu	3 Fri	4 Sat	5 Sun	6 Mon	7 Tue
Owl		(0.2/fb)	(1.5/fb)	(0.5/fb)	(2.0/fb)	(3.5/fb)	(0.5/fb)
Day	Maintenance	(0.5/fb)	**10.706 GeV**	(1.0/fb)	(2.5/fb)	**10.751 GeV**	(1.0/fb)
Swing	**10.657 GeV**	(1.0/fb)	(0.2/fb)	(1.5/fb)	(3.0/fb)	(0.2/fb)	(1.5/fb)
	8 Wed	**9 Thu**	**10 Fri**	**11 Sat**	**12 Sun**	**13 Mon**	**14 Tue**
Owl	(2.0/fb)	(3.5/fb)	(5.0/fb)	(6.5/fb)	(8.0/fb)	(9.5/fb)	(0.5/fb)
Day	(2.5/fb)	(4.0/fb)	(5.5/fb)	(7.0/fb)	(8.5/fb)	**10.810 GeV**	(1.0/fb)
Swing	(3.0/fb)	(4.5/fb)	(6.0/fb)	(7.5/fb)	(9.0/fb)	(0.2/fb)	(1.5/fb)
	15 Wed	**16 Thu**	**17 Fri**	**18 Sat**	**19 Sun**	**20 Mon**	**21 Tue**
Owl	(2.0/fb)						
Day	Maintenance		Contingency			Y(4S)	
Swing	**Y(4S)**						

Summary

- Belle II has improved the operation system and 89.5% of the data taking efficiency was achieved in 2021ab.
  - Even 1 min loss concerns us now.
  - We will continue efforts to improve it.
- Compromise on the beam background mitigation by opening the collimators will be necessary to achieve a higher luminosity.
  - Belle II can still accept a higher beam background until it hits the limit.
  - Once the injection quality gets better, the collimators can be opened.
- Increasing the beam current while keeping the stable condition is challenging.
  - Need to understand the cause of huge beam losses and prevent it.

  → Nakayama-san's talk for more detail
- Belle II needs more data to produce physics results, which are the driving force of this project.