

Accelerator operation plan

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on behalf of the SuperKEKB commissioning group

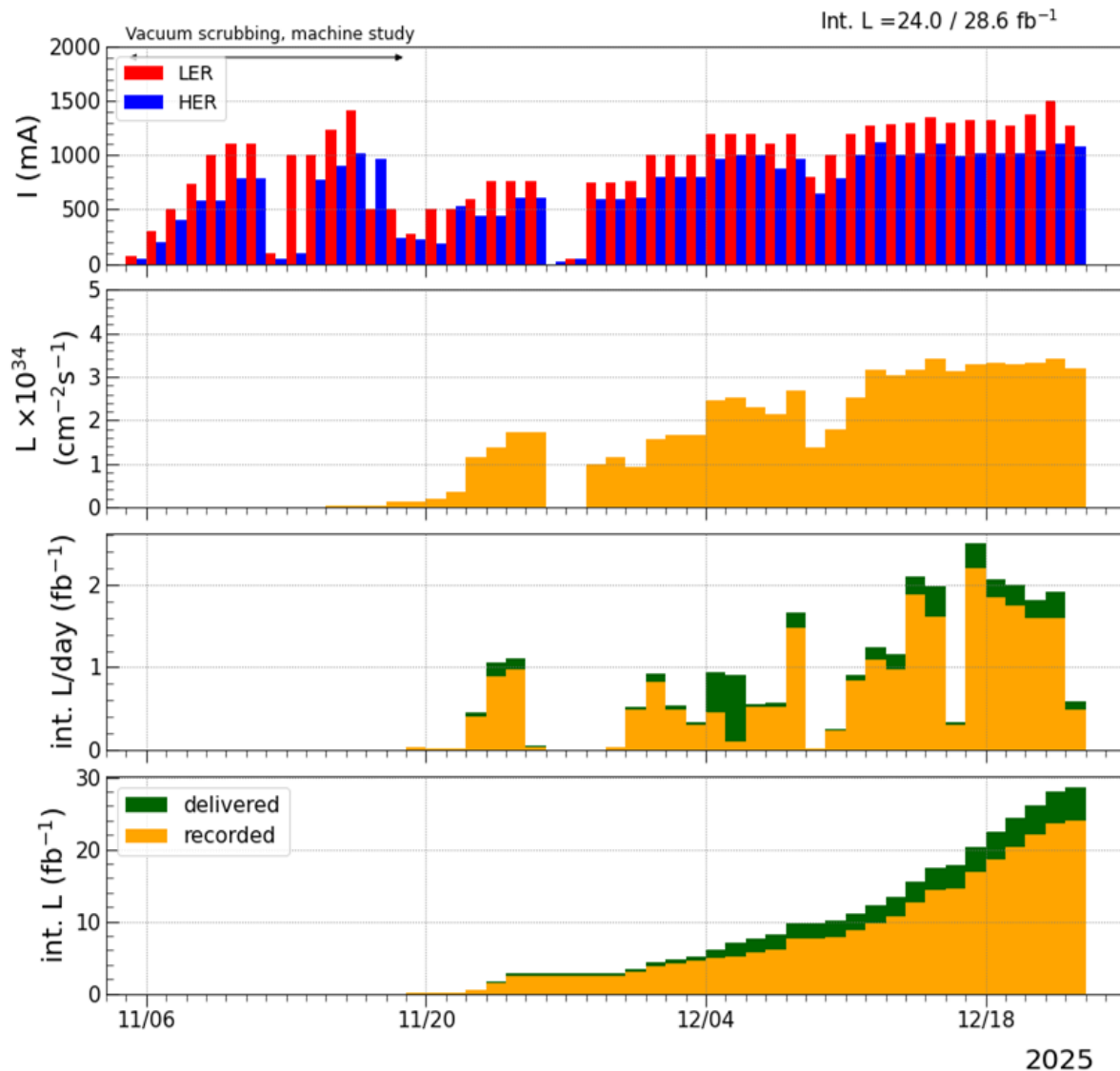
Joint review focusing on the operation plan
17 April 2026



Outline

- Response to 2025 Dec. review's recommendations and 2026ab operation plan
- 2026ab status
 - Integrated luminosity
 - Instantaneous luminosity, specific luminosity, and beam current
 - Linac and beam injection
 - Beam abort
 - Machine trouble
- Plans for 2026b April-June operation
 - How high will the beam current be increased?
 - How high will the instantaneous/integrated luminosity be Increased?
 - Abort countermeasures
 - Machine trouble countermeasures
- Summary

2025c operation



- **5 Nov. – 22 Dec. 2025, total of 47 days**

- Peak luminosity : **$3.4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$**

- β_y^* -squeezing : 1.0 mm

- Maximum beam current : HER/LER = 1.35/1.49 A

- Total Integrated luminosity(deli./reco.) = **681/599 fb⁻¹**.

- **QCS-L liquid helium level recovery**

- By adjusting the cooling scheme, we successfully eliminated the liquid helium level drop during the 2025c run.

- The run was terminated two days earlier than planned, and we investigated a cause of the QCS issue.

- No leak was found at the QCS-L cryostat.

- 2026a operation resumed on January 26th after performing Belle II solenoid cooling and QCS cooling.

Reminder of 2025 Dec. review's recommendations

- **1st stage:** The committee considers that a staged approach to luminosity increase should be adopted. Based on machine and detector operating parameters that have been achieved in previous runs, the committee recommends that, after successfully reaching a peak luminosity of $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, a first operational stage should target a peak luminosity of $6 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ with a machine operation efficiency of 80% and a Belle II data-taking efficiency of 0.85.
- **2nd stage:** The next operational stage is expected to begin once the accumulated integrated luminosity approaches the 1 ab^{-1} goal, for example at the level of approximately 90%. At this point, machine studies aimed at increasing the peak luminosity to $1 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ and beyond, with a machine operation efficiency of 65% or better, should take priority in order to address the secondary goal.

Plan for achieving 1 ab^{-1} with $6.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Target

Peak luminosity = $6.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Integrated luminosity = 430 fb^{-1}

Requirements

Stable operation (less SBL, less QCS quench, less machine/detector trouble)

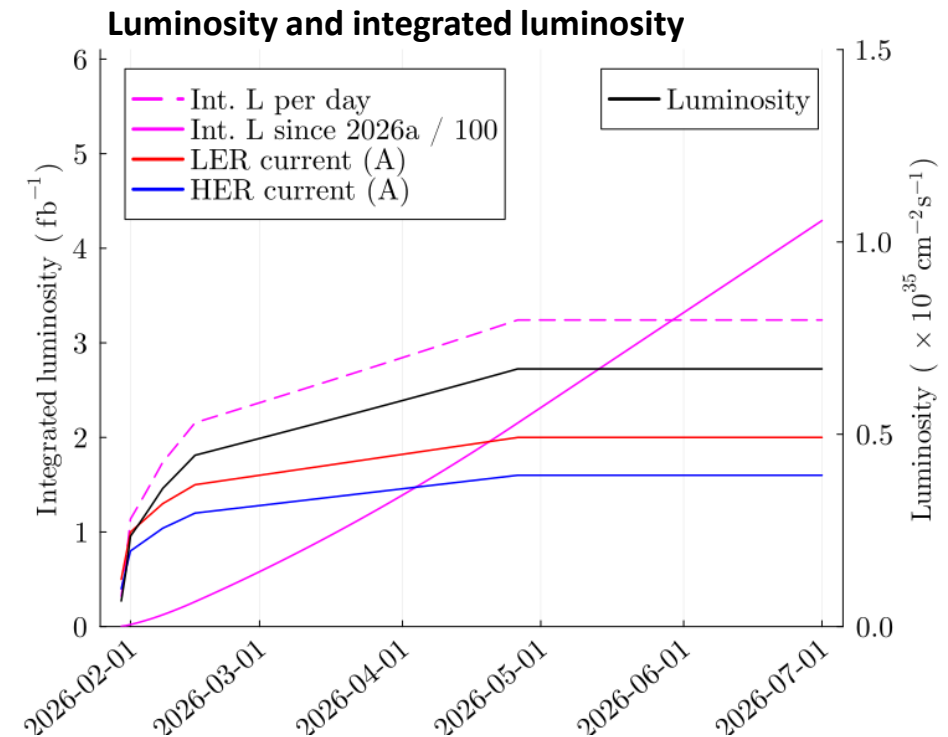
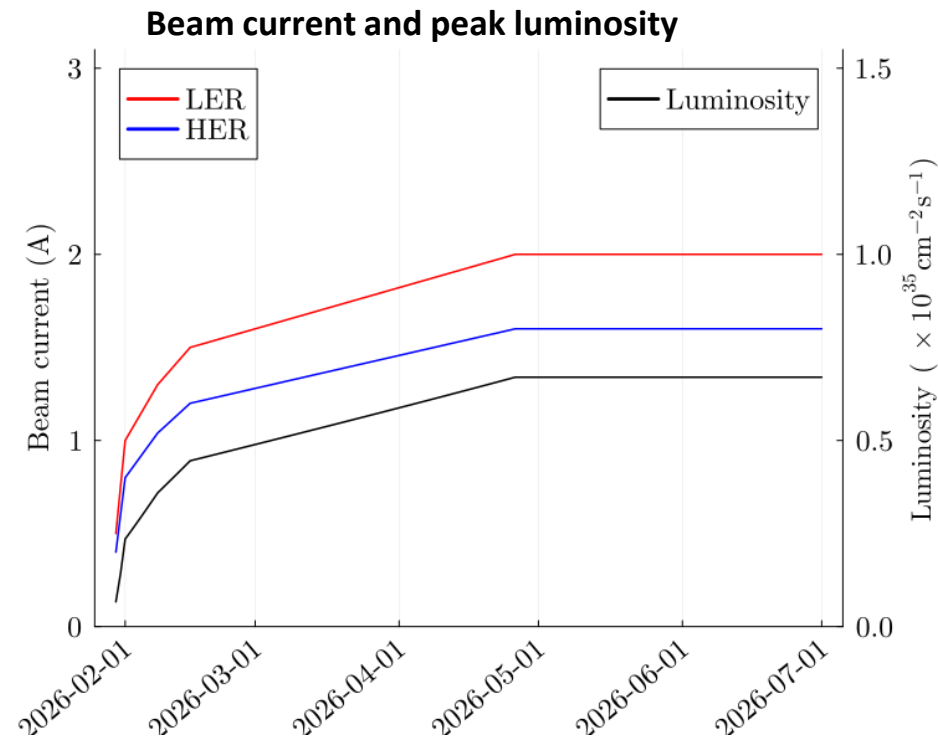
2-bunch injection in LER, Relaxing beam-beam effects

Key parameters

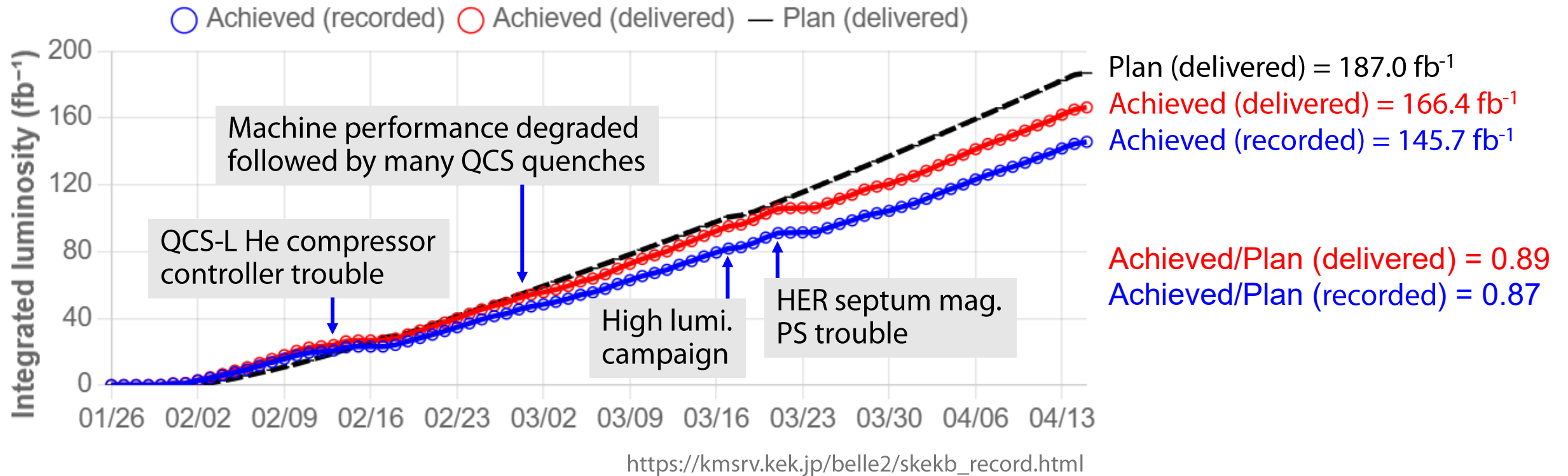
Specific luminosity = $4.9 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1} \text{ mA}^{-2}$ at 0.58 mA^2

Fraction of physics run/machine time = 75%

Average operation efficiency > 80%, Belle II DAQ = 90%



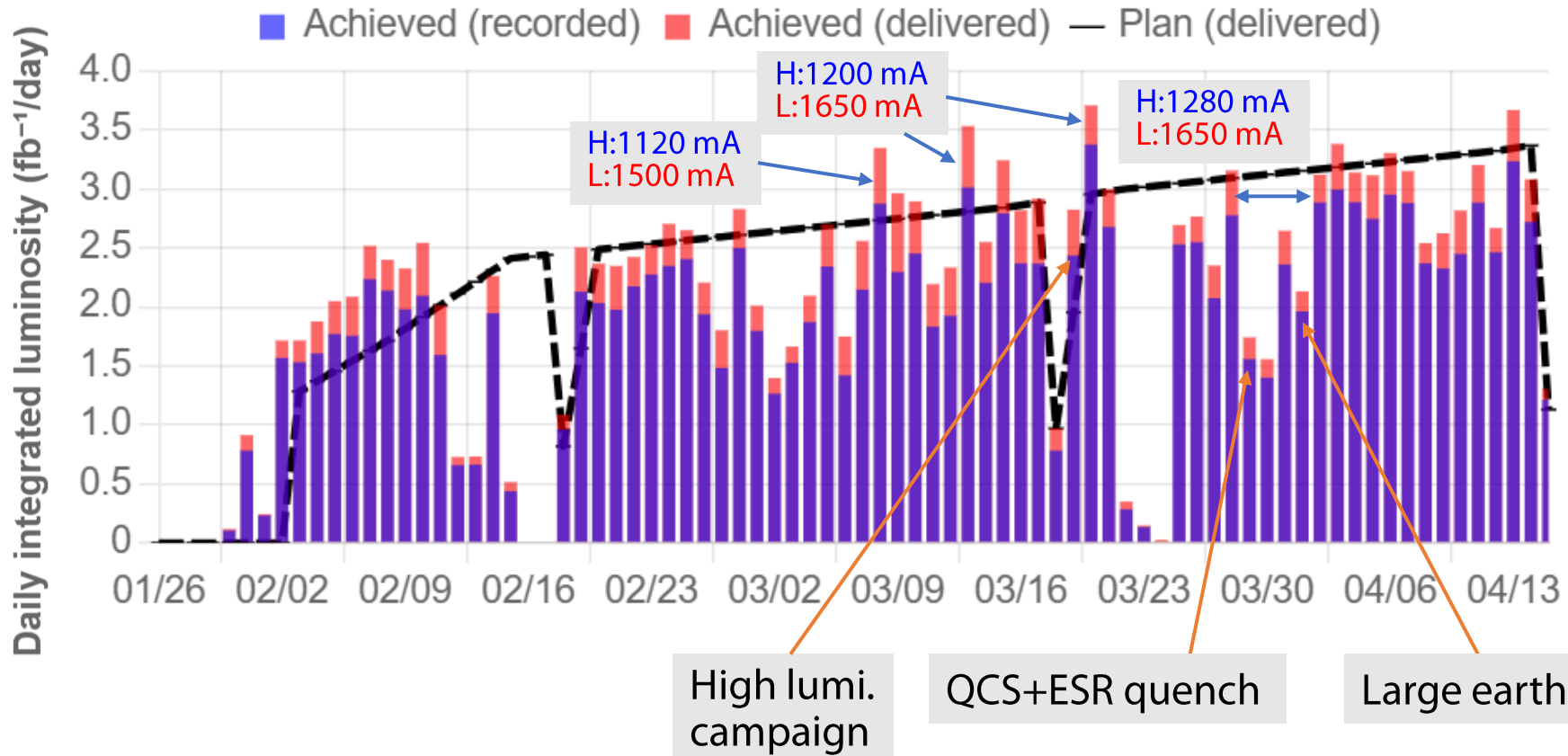
Integrated luminosity



Reasons hindering the increase in integrated luminosity and instantaneous luminosity:

1. The beam current is set lower than the planned value to keep abort frequency low.
2. Specific luminosity is lower than planned.

Daily integrated luminosity

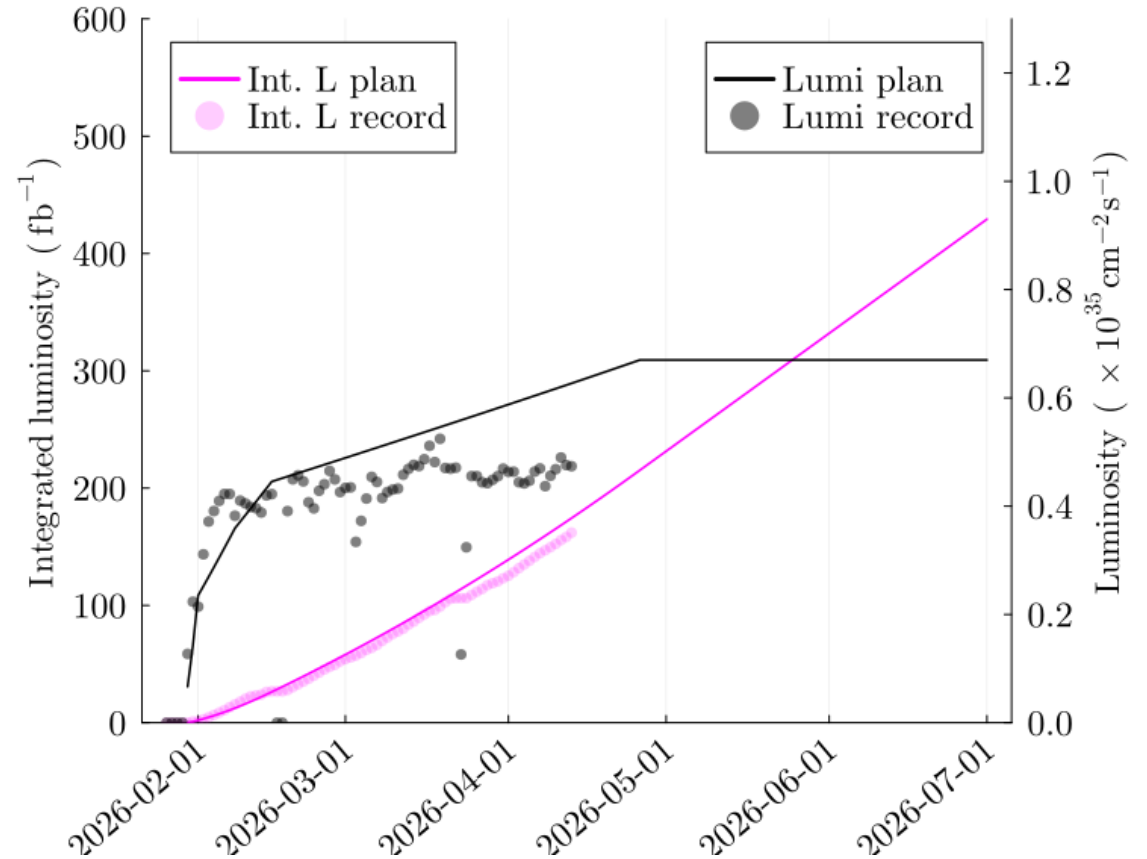
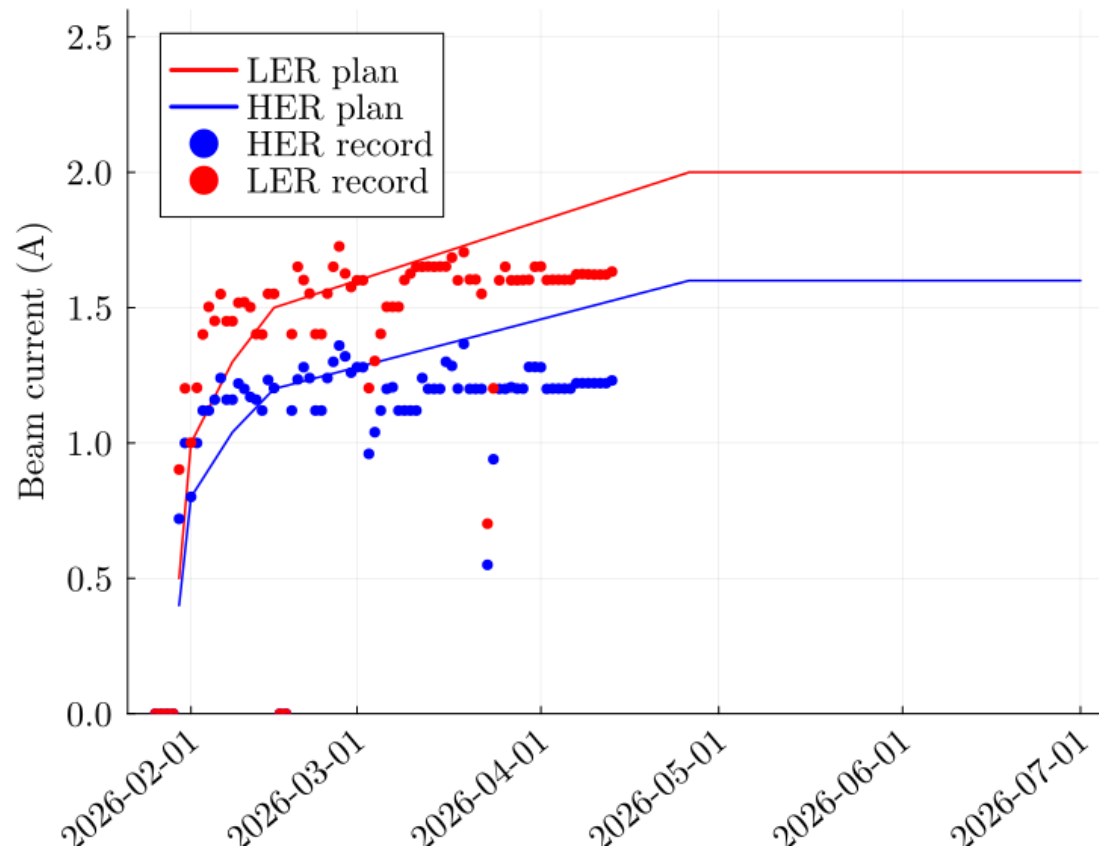


- 745.2 fb⁻¹ (recorded) was accumulated as of Apr. 15.
- ~3.4 fb⁻¹ (recorded) is needed to reach 1 ab⁻¹ by Jun. 30. N.B. >3.3 fb⁻¹ was achieved on Mar. 20.

Reasons hindering the increase in integrated luminosity and instantaneous luminosity:

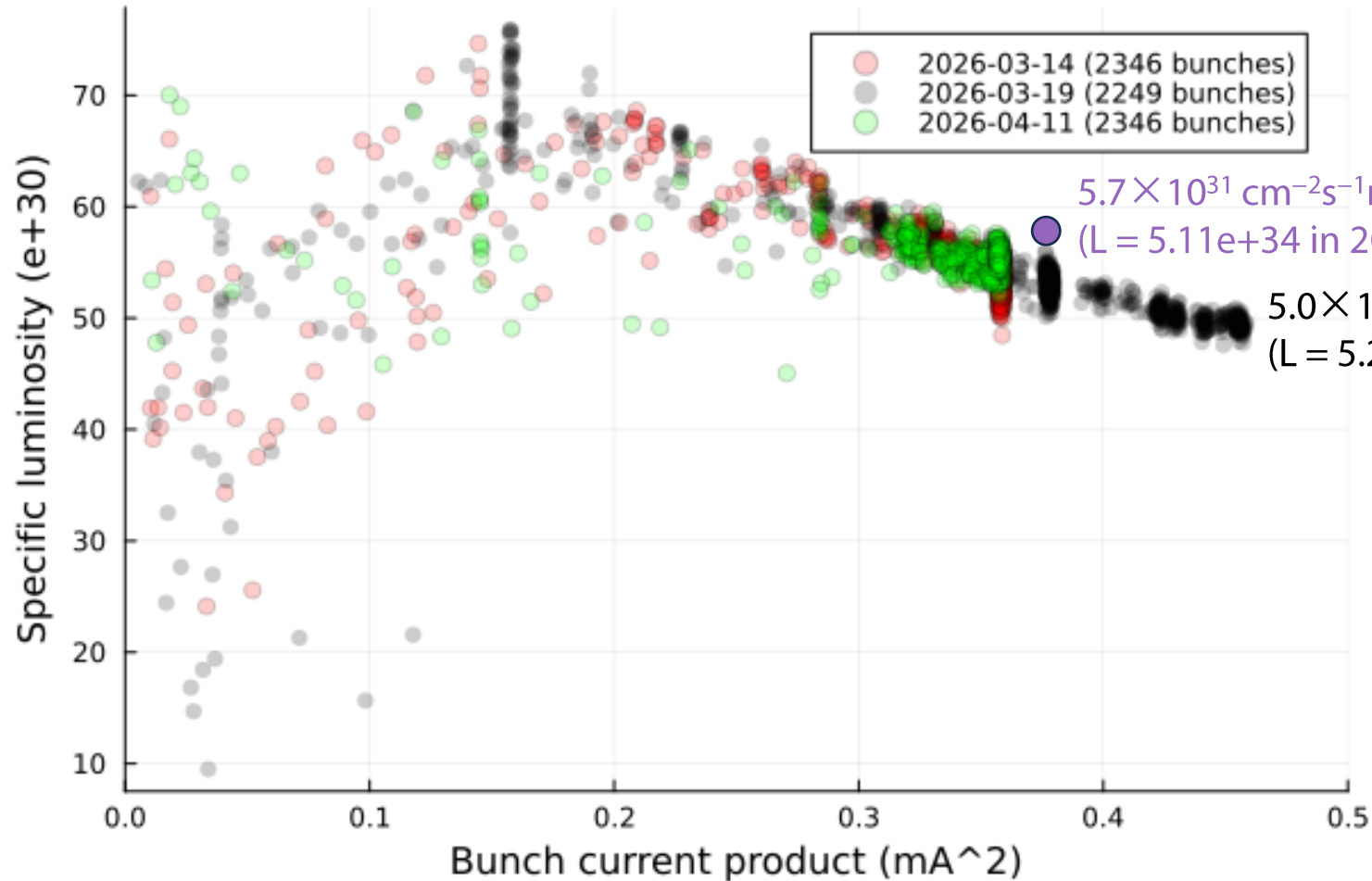
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2. Specific luminosity is lower than planned.

Beam current and luminosity



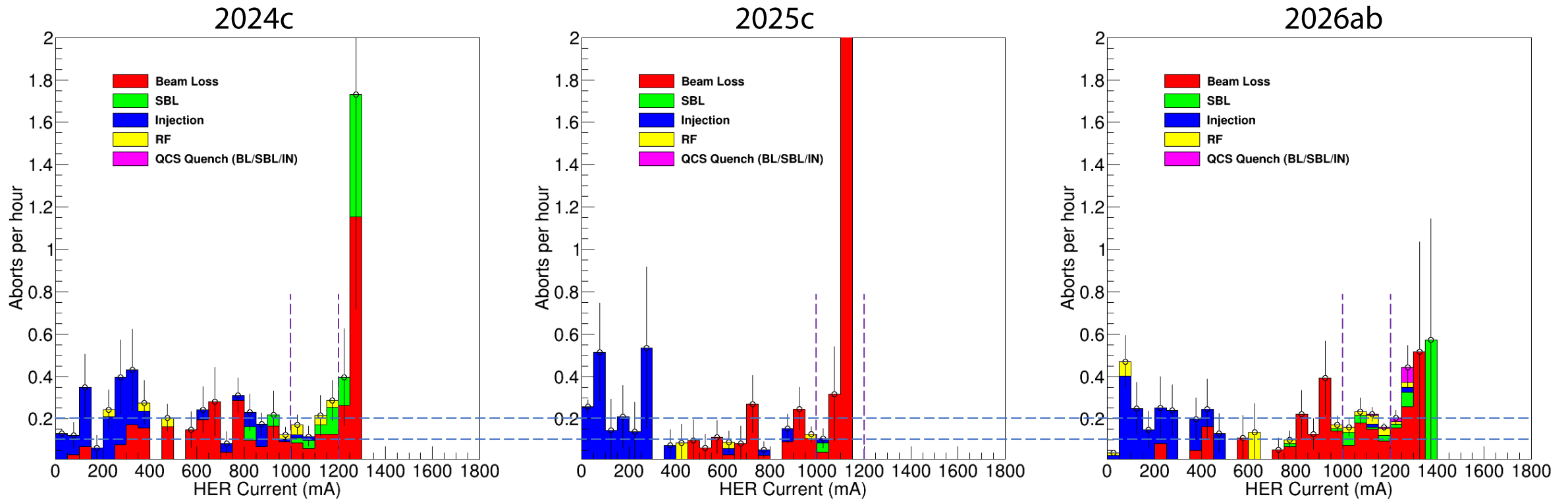
Since mid-March, HER and LER have been operating with a lower current than planned because increasing it as planned would result in frequent beam aborts and prevent the accumulation of integrated luminosity.

Specific luminosity



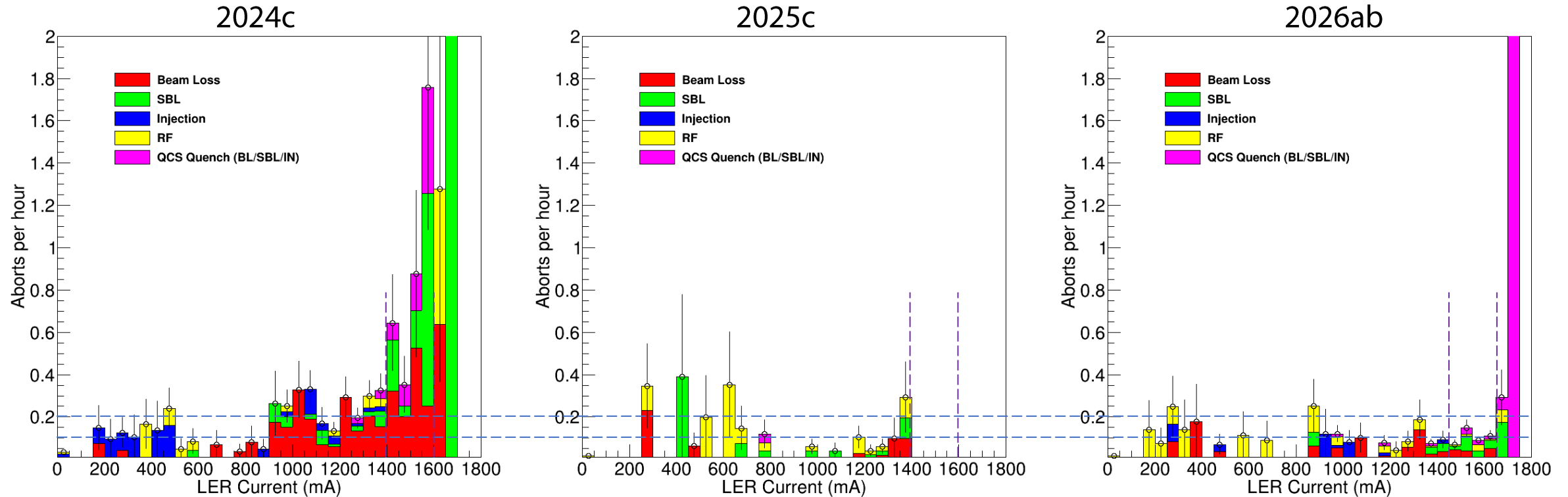
- The specific luminosity in 2026ab is generally lower than that in 2024c-end (the 2024c emittances in HER and LER were larger than those in 2026ab).
- The target specific luminosity = $4.9 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}\text{mA}^{-2}$ at 0.58 mA^2 .
- If $L_{sp} = 5.7\text{e}+31$ can be maintained, $L \sim 6.0\text{e}+34$ can be achieved with the present beam current.

Beam abort statistics in physics run (HER)



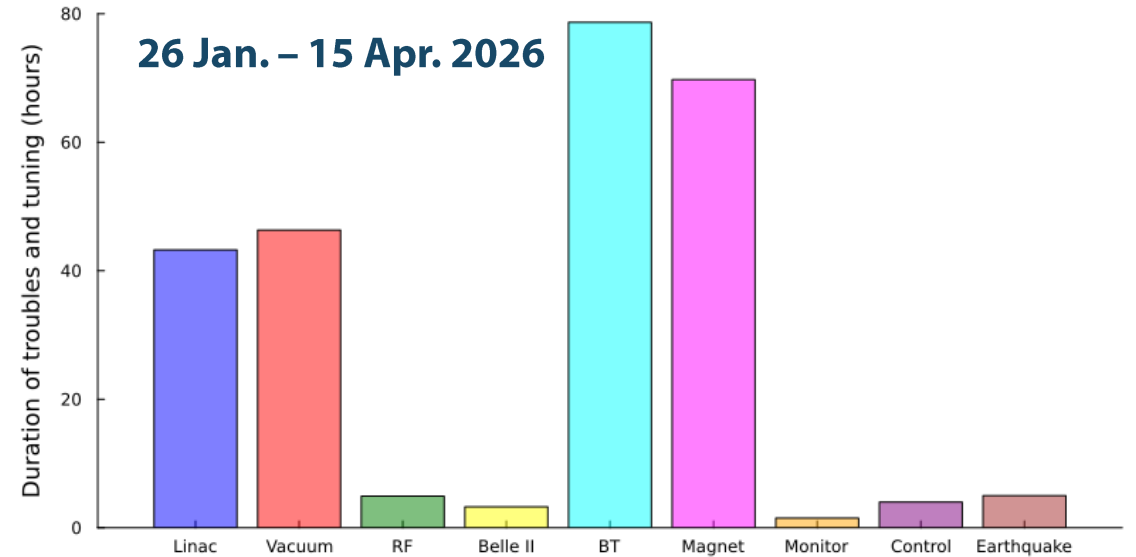
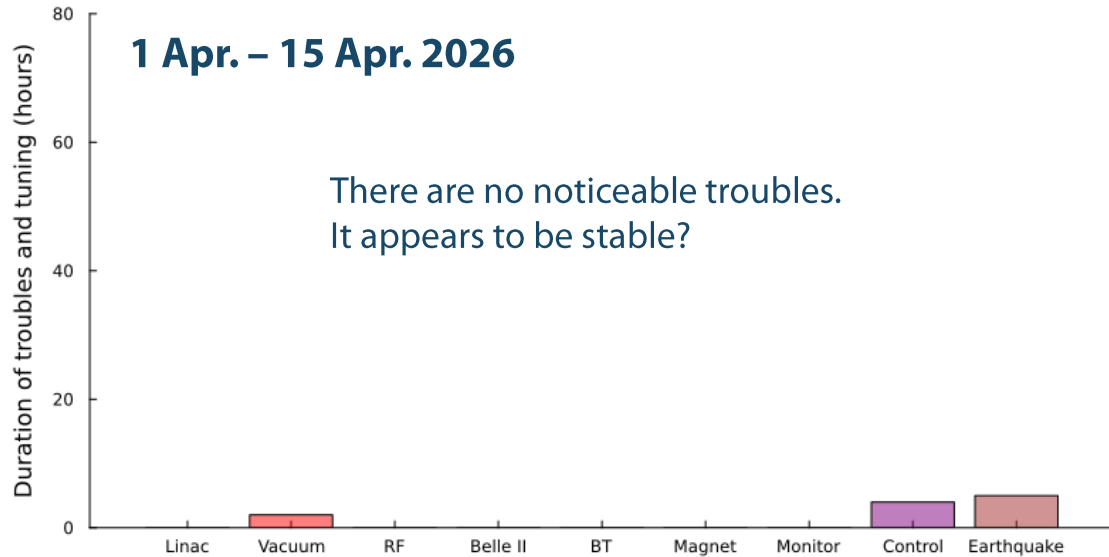
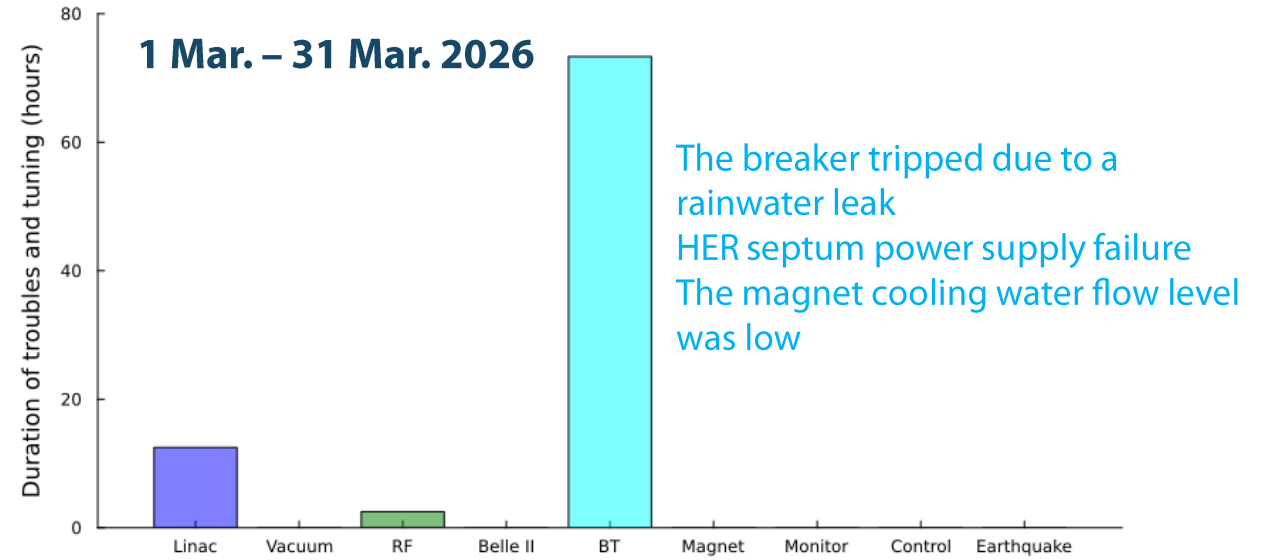
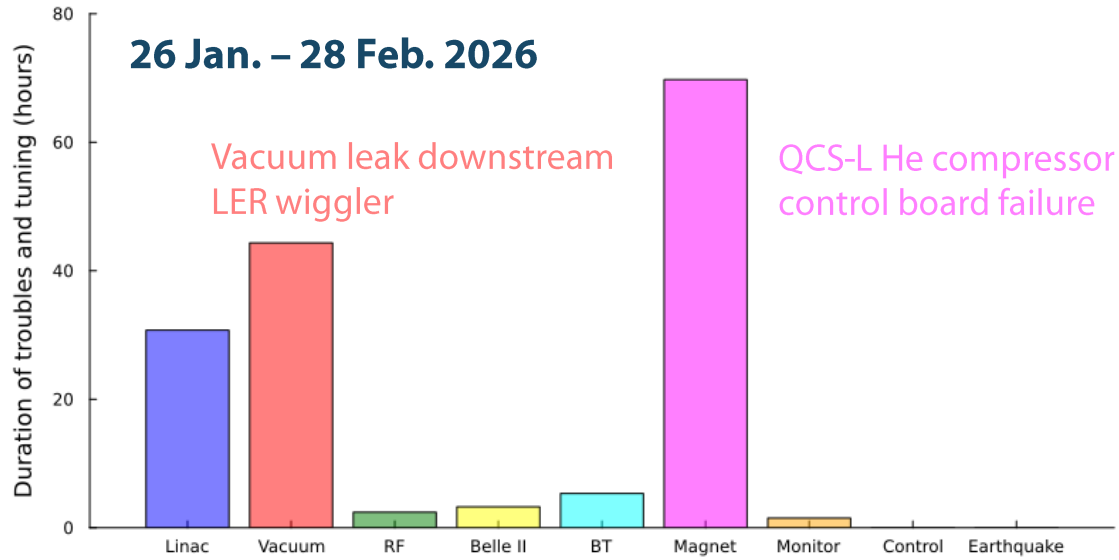
- The HER beam abort situation remained largely unchanged from 2024c to 2026ab.
- The total abort frequency at 1.0-1.2 A is approximately 0.2/hour and seems to increase above 1.2 A. Reducing it to 0.1 times/hour will be a challenge for increasing the integral luminosity in the future.
- The abort frequency is higher than that of LER, but the reason is unclear.

Beam abort statistics in physics run (LER)



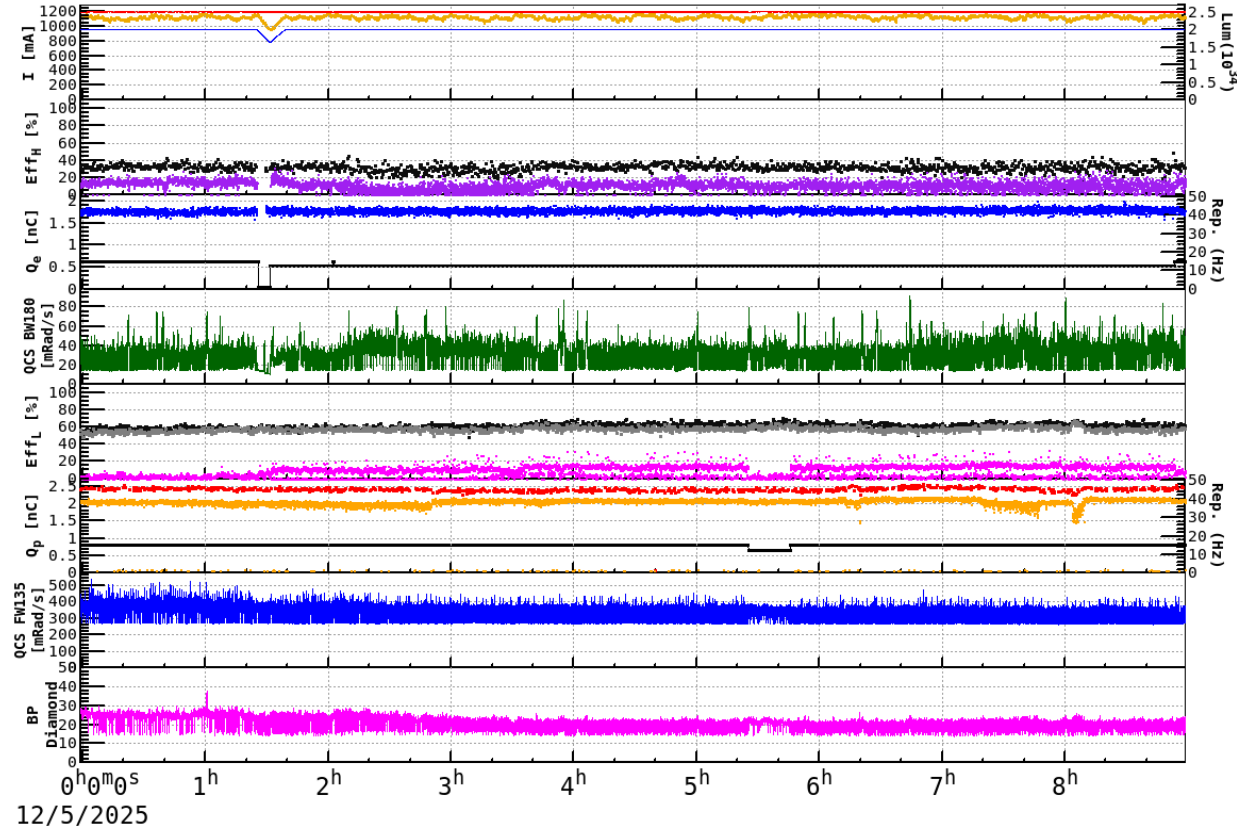
- VACSEAL removal was performed between the middle of 2024c and the start of 2025c. The abort frequency decreased dramatically, about 0.1/hour, approximately half that in HER.
- The proportion of QCS quenches, requiring about four times longer than the normal BL abort to recover beam operation, to total beam loss aborts (BL + SBL) is approximately 20% at > 1.5 A.
- To achieve the target accelerator efficiency of 90%, the challenge is to reduce beam loss to IR.

Machine troubles

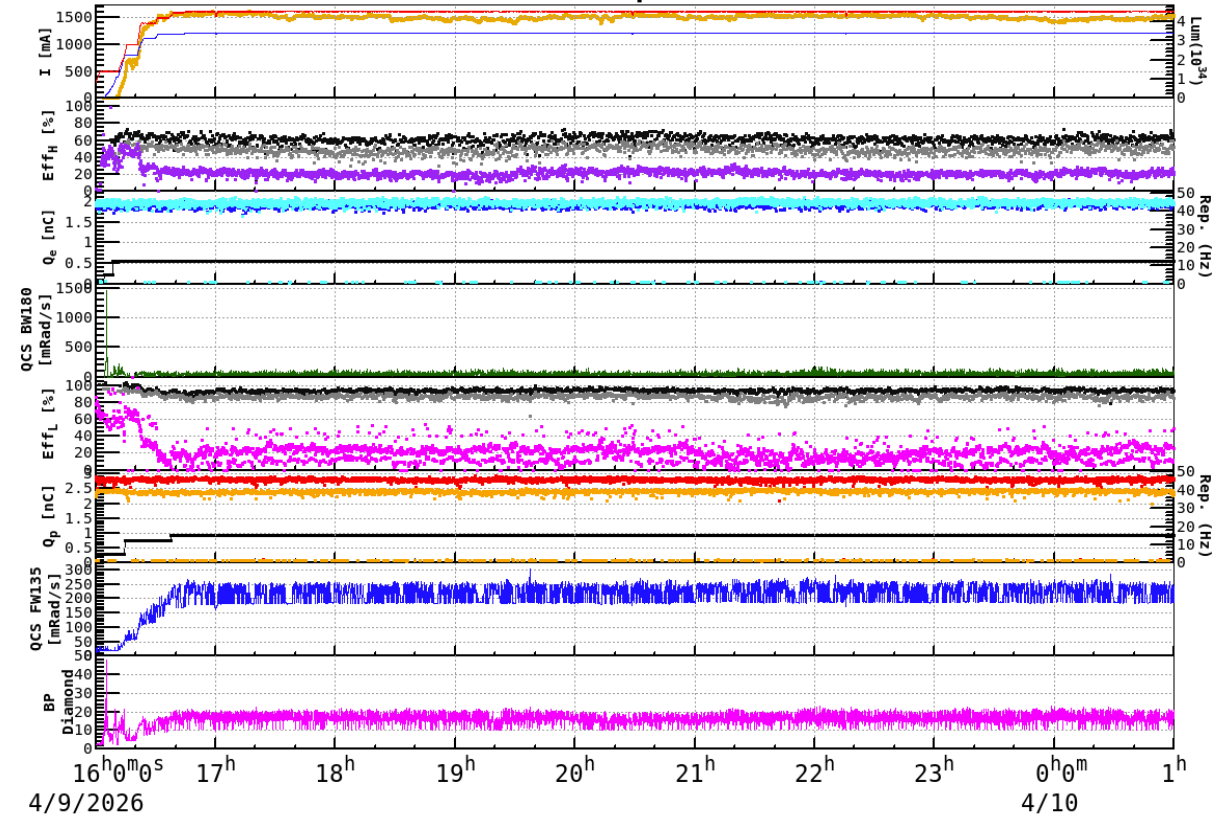


Injection comparison 2025c vs. 2026b

2025c (5 Dec. 2025)



2026b (9 Apr. 2026)



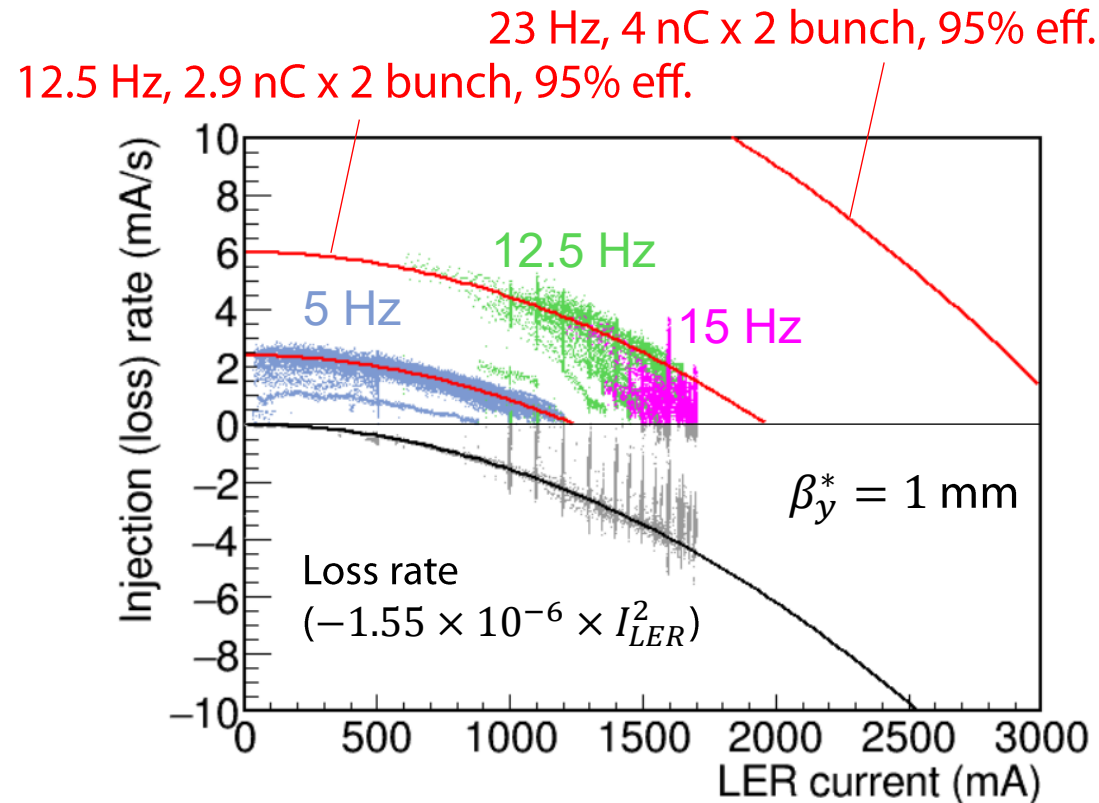
HER in 2026ab: Because emittance and beam orbit jitter have been suppressed, the injection efficiency improves to 40-60% at >1.2 A. Two-bunch operation is commonly used.

LER in 2026ab: We maintain the same injection efficiency for the 1st and 2nd bunches, thanks to continuous beam tuning. The injection efficiency remains 80-90% (was 60% in 2025c).

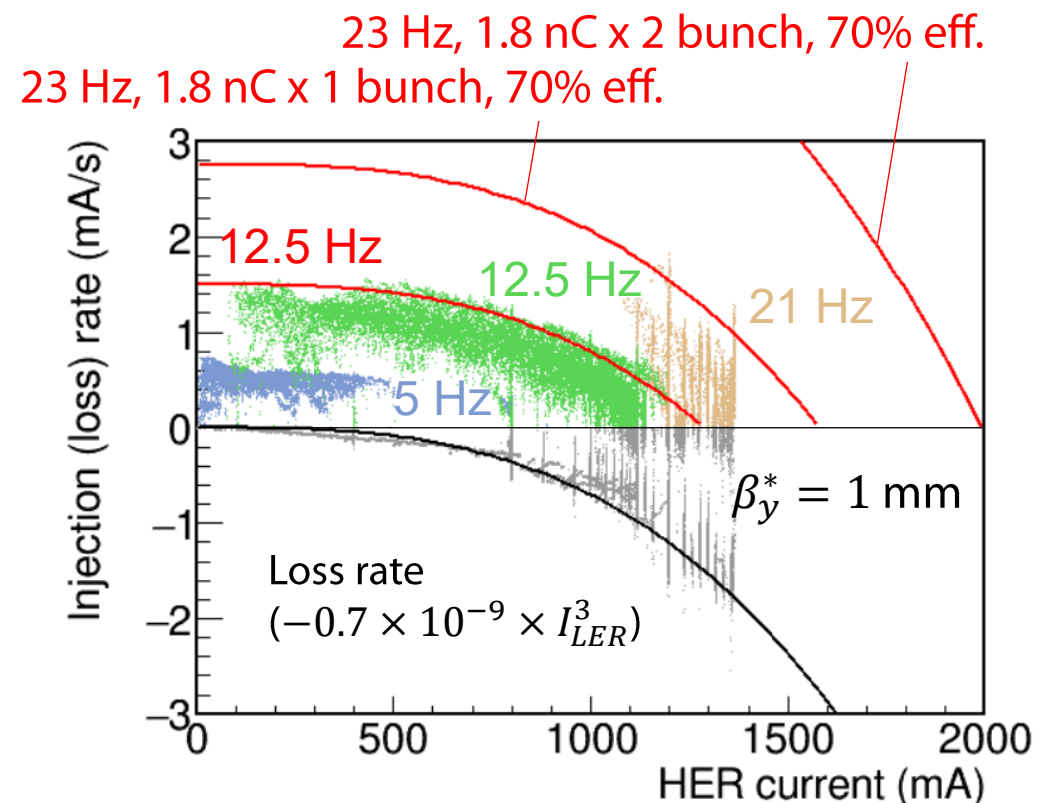
Improvements in the beam transport (BT) line

- The visible-light beam size monitor (SRM) in the electron line, which had not been adjusted during the 2025c operation, has resumed operation. HER SRM has enabled the operation of Linac beam orbit feedback to continue suppressing emittance at BT.
- BT orbit feedback has also been fully implemented for both electron and positron lines. The beam orbit and, consequently, the injection efficiency have stabilized.

How high will the beam current be increased?

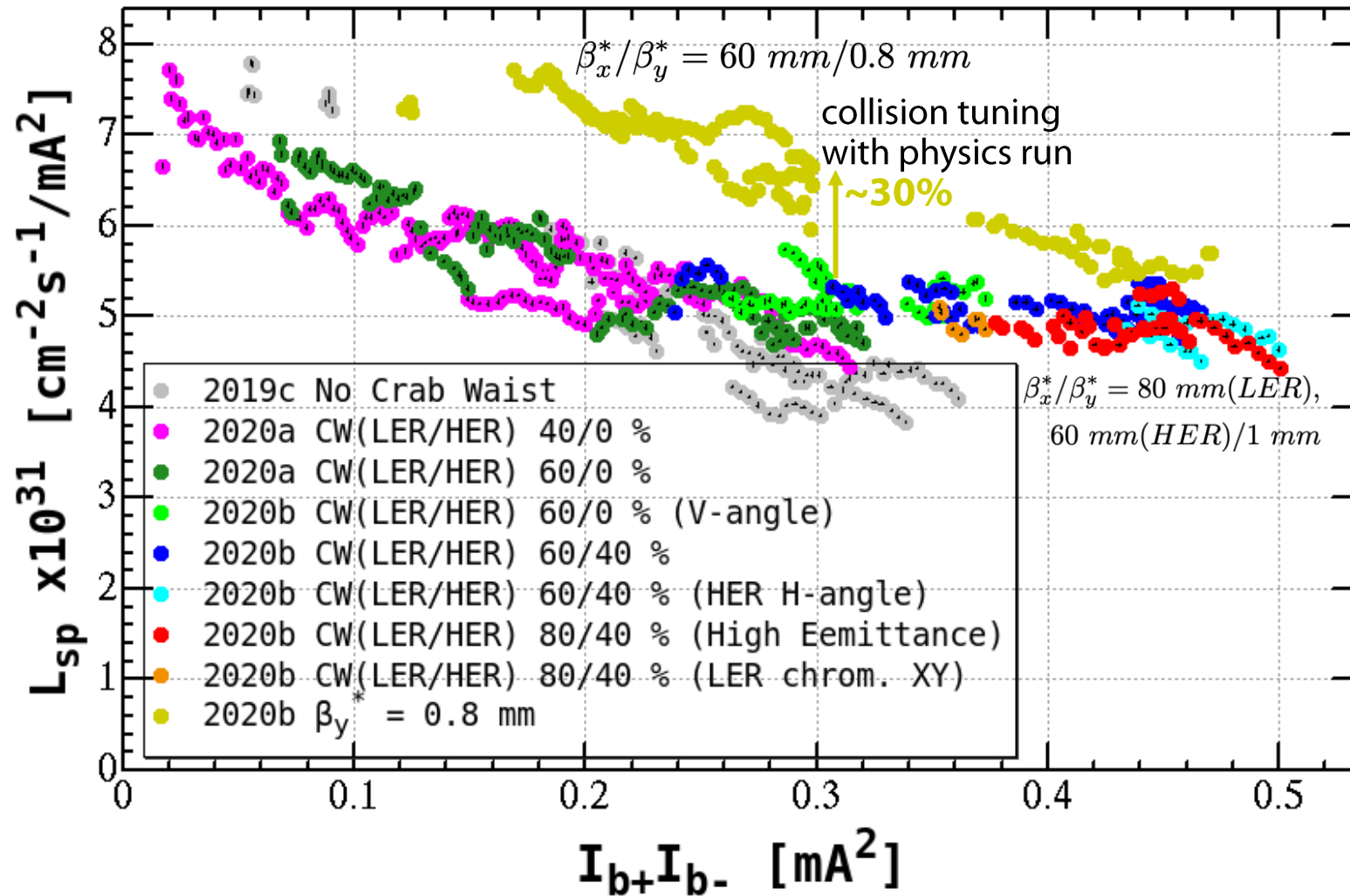


LER current reached 1.70 A with 2 bunch x 15 Hz.
If the repetition rate is increased to 21 Hz, it may reach 2.0 A.



HER current reached 1.36 A with 1 bunch x 21 Hz.
If the efficiency of the 2nd bunch is comparable to that of the 1st bunch, it is possible to reach 1.6A.

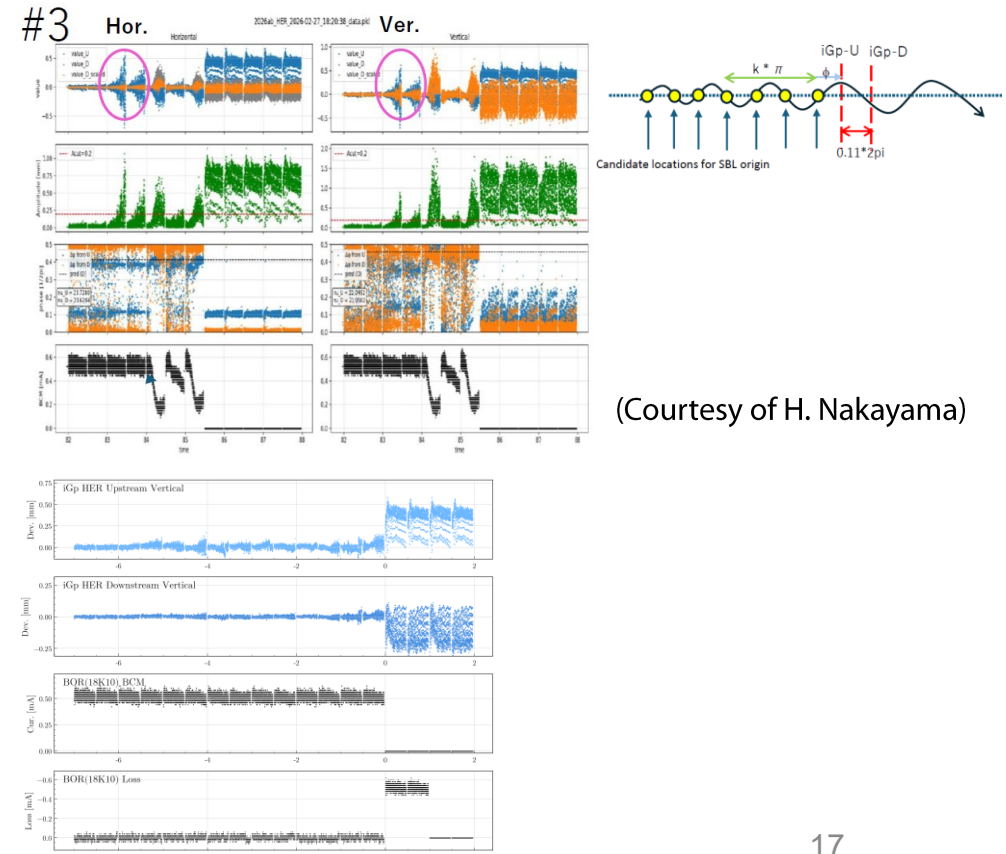
How high will the luminosity be increased?



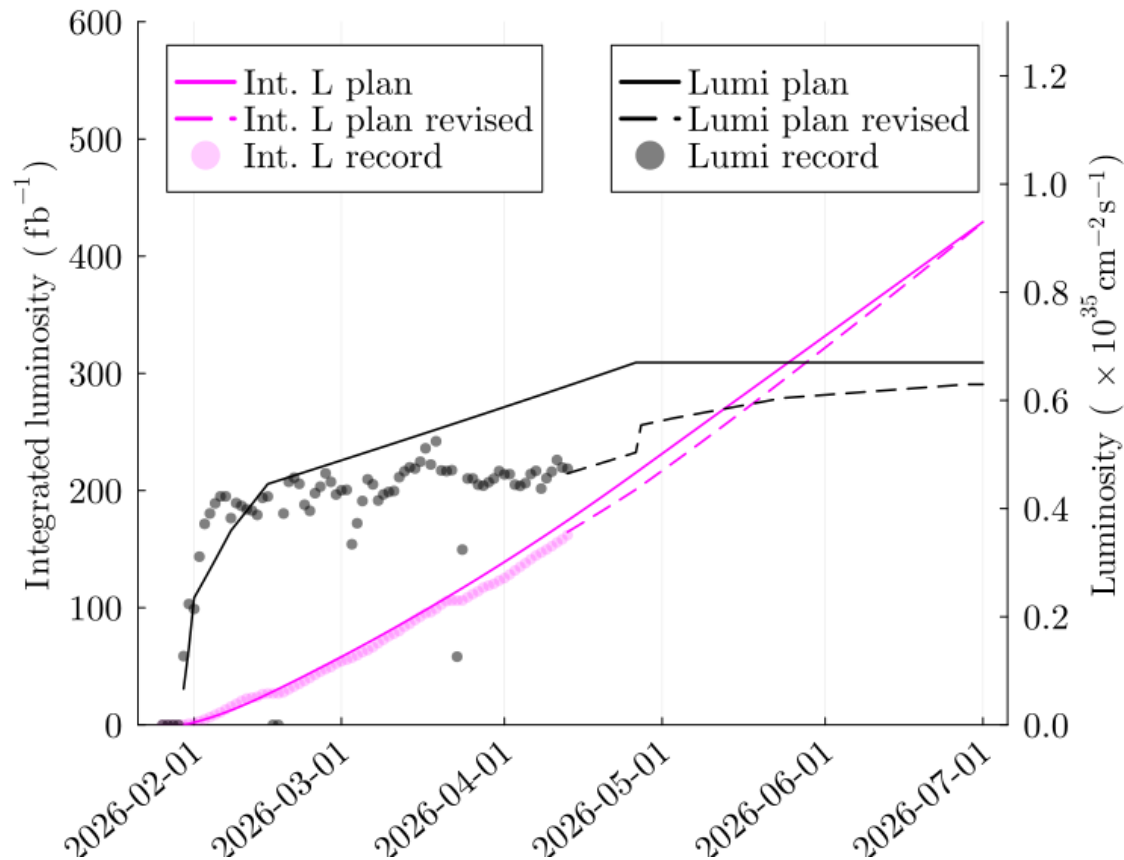
- Until the end of April (i.e., end of the off-resonance run), we will gradually increase the beam current while keeping the abort frequency enough low.
- After the off-resonance run is completed, we plan to reduce β_y^* and increase the luminosity while keeping the current at 1.6A/1.2A.

Abort countermeasures

- The approaches to preventing aborts differ between HER and LER.
 - For HER, the focus is on reducing the number of aborts $\sim 0.2/\text{hour}$ to $\sim 0.1/\text{hour}$.
 - For LER, the focus is on identifying the source of SBLs and on preventing radiation from reaching the IR to avoid QCS quenches.
- Abort data analysis
 - Bunch oscillation recorder, loss monitor, CCG, etc.
- Beam study proposals
 - HER: can small gaps be interleaved within the bunch train to suppress the development of vertical oscillations?
 - LER: can weakening the wiggler magnets and reducing the intensity of synchrotron radiation hitting the chamber eventually reduce dust generation?
 - Further investigation is needed as these could affect beam stability and luminosity.



Plans for 2026b April-June operation



	2025 Dec. plan	Revised plan	Present status
Physics run/total	75%	80%	68.0%
Acc. operation eff.	80%	83%	81.4%
HER current max	1.60 A	1.40 A	1.36 A
LER current max	2.00 A	1.75 A	1.70 A
β_y^*	1.0 mm	1.0 mm \rightarrow 0.9 mm	1.0 mm
Specific luminosity (10^{31})	4.9 at 0.58 mA ² (2346 bunches)	6.0 at 0.45 mA ² (2346 bunches)	5.0 at 0.46 mA ² (2249 bunches)
Peak luminosity (10^{35})	6.7	6.3	5.25
Int. luminosity (fb ⁻¹)	430	430	166.4

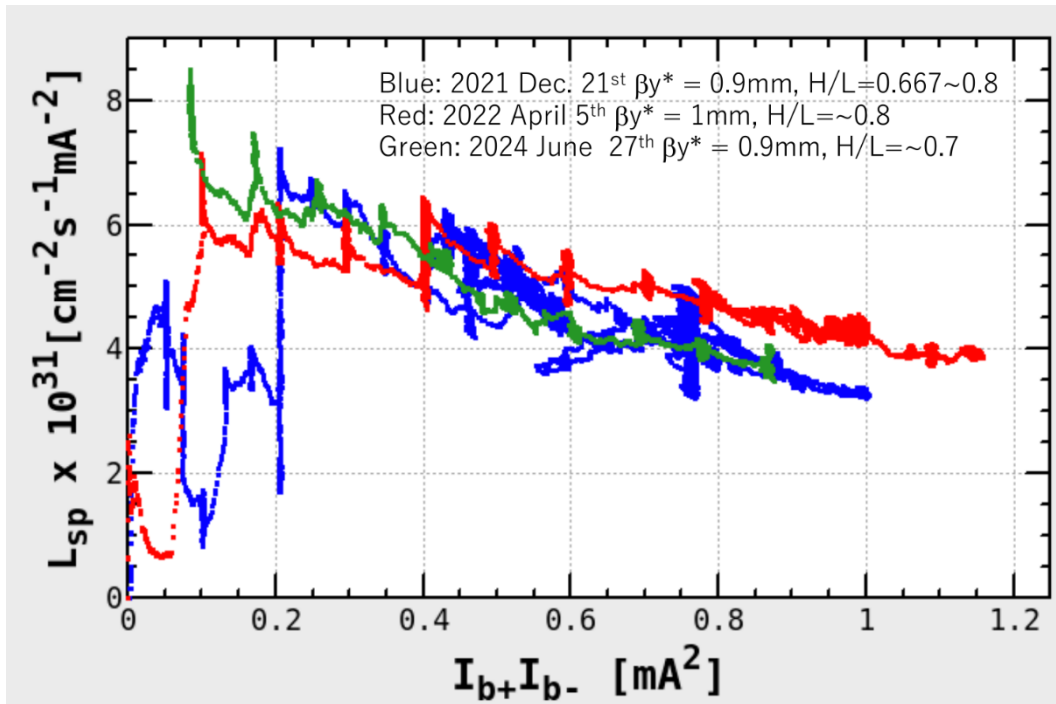
- Because aborts and QCS quenches occur frequently with increasing beam current, we cannot increase the current significantly.
- Therefore, we will keep the current below 1.75 A/1.40 A, and will squeeze β_y^* from 1.0 mm to 0.9 mm (possibly via 0.95 mm) to increase the instantaneous luminosity.
- Furthermore, we aim to minimize time spent on work other than physics runs (e.g., machine studies, troubleshooting) to maximize integrated luminosity.

Summary

- The Linac electron beam condition has improved significantly. As a result, HER injection efficiency has also increased, and 2-bunch operation is currently underway.
- Beam current in MR has reached 1.70 A in LER and 1.36 A in HER, with instantaneous luminosity reaching 5.24×10^{34} . Due to low specific luminosity, the instantaneous luminosity is somewhat low relative to the value expected with the operating beam current.
- Above LER 1.6 A and HER 1.2 A, the frequency of beam aborts increases, hindering integrated luminosity.
- We will revise the operating plan from mid-April onwards based on the following points: 1) Limiting the maximum current to 1.75 A/1.40 A to prevent an increase in abort frequency, and 2) Reducing β_y^* to increase luminosity.

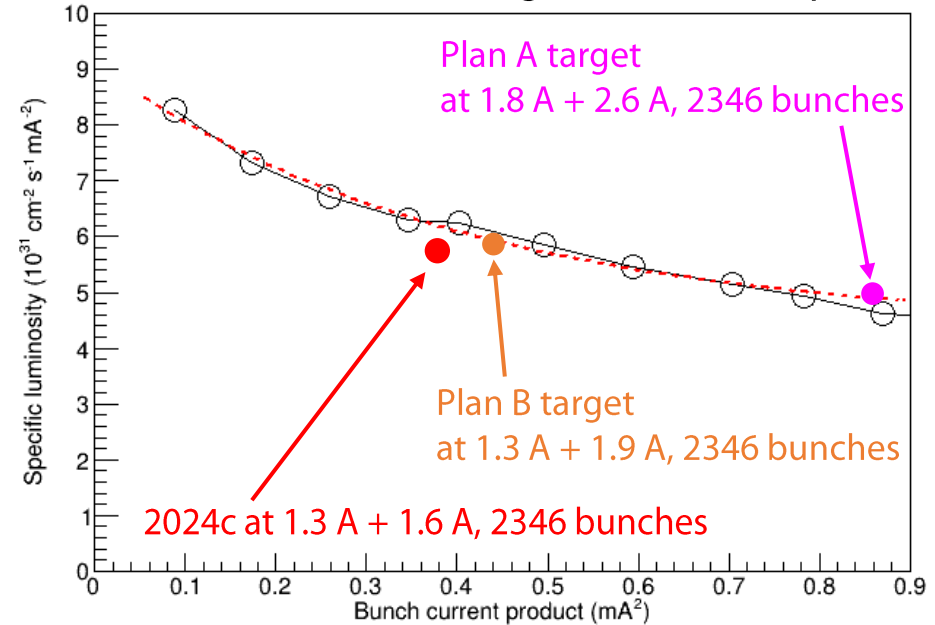
Backup

Specific luminosity with small number of bunches



- High specific luminosity could be realized for a small number of bunches, e.g., 393 bunches.
- Challenging to realize it for 2346 bunches due to injection power, chamber-heating induced optics deformation, possibly beam instability, etc.

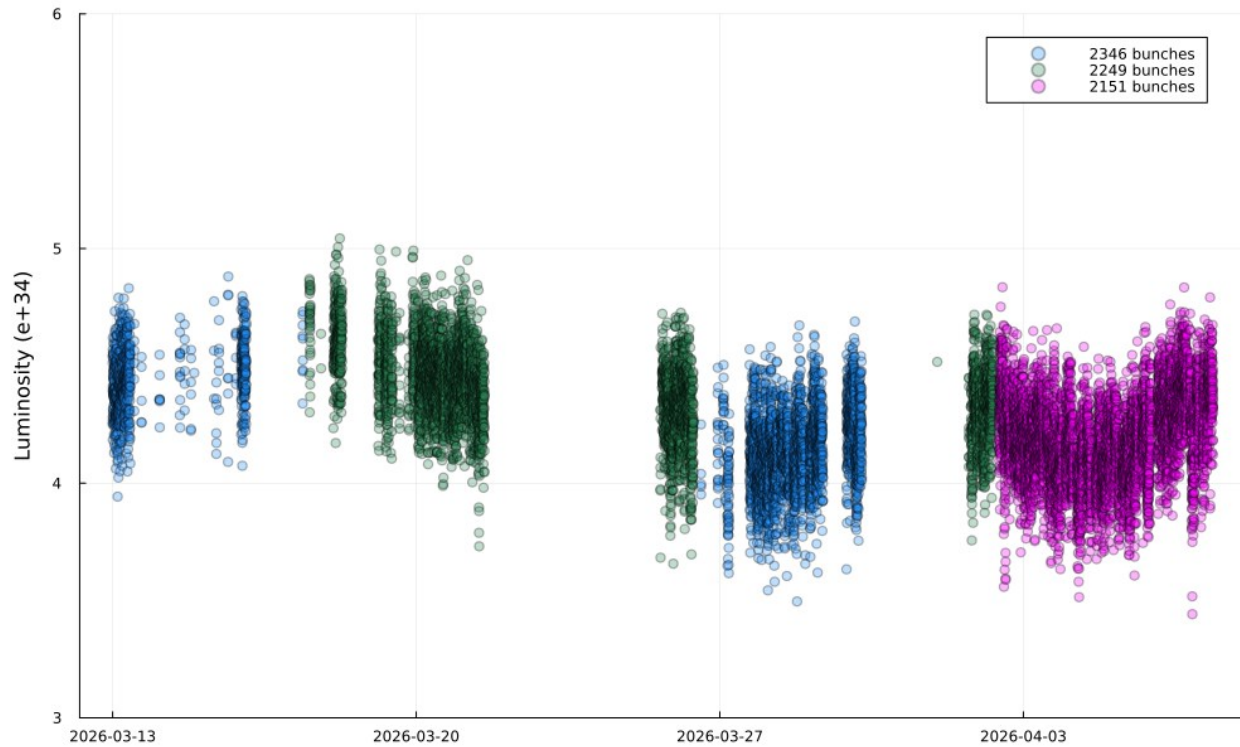
Combined data (red and green in the left panel)



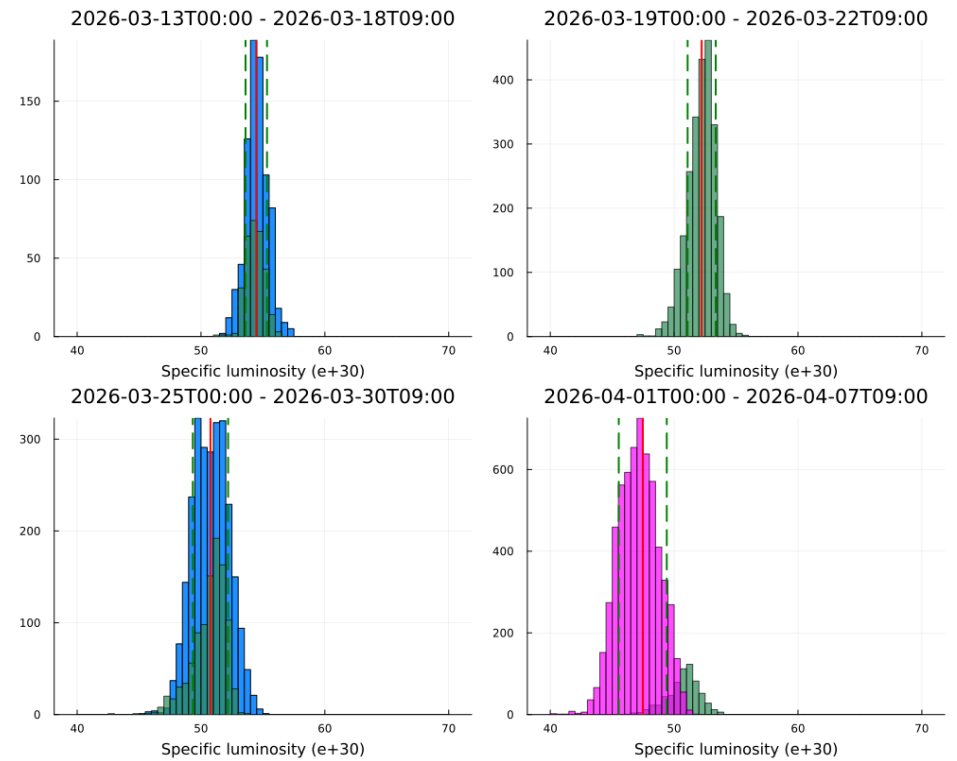
- Specific luminosity lying on the red dashed curve could be realized if HER emittance blowup in 2024c was solved (though not solved.)
- Optics study is planned for early 2025c to address emittance blowup if it reappears.

Luminosity with various filling patterns

LER 1.6 A, HER 1.2 A

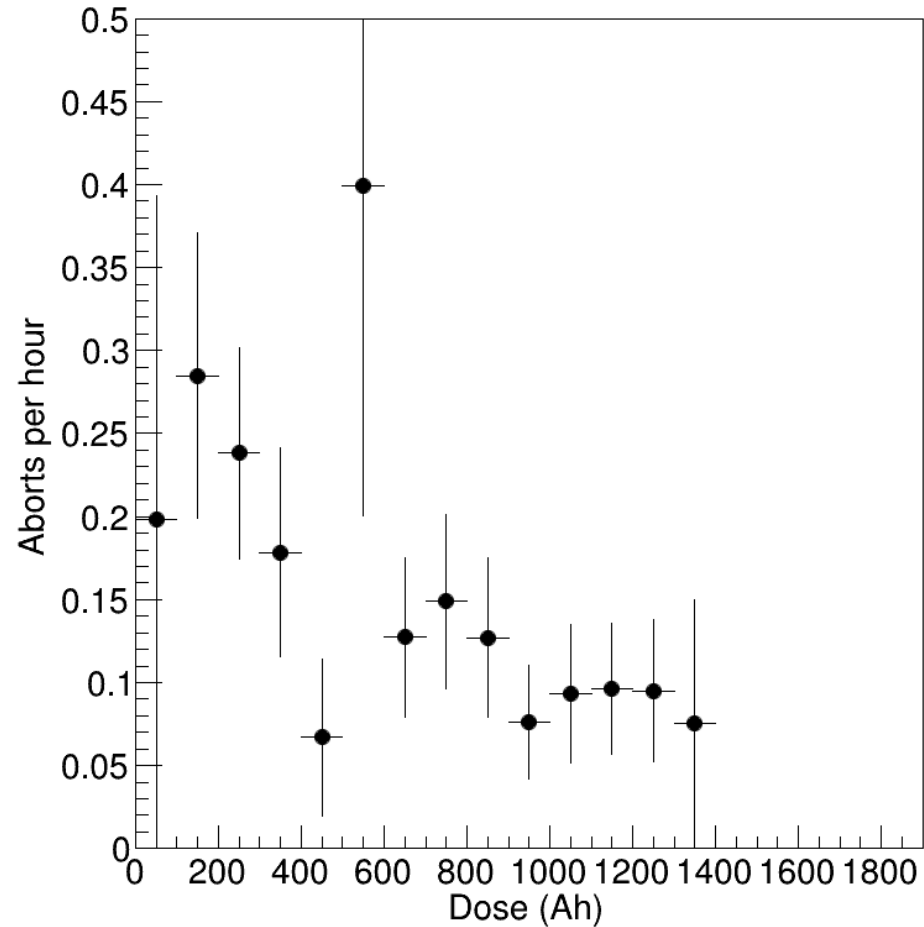


LER 1.6 A, HER 1.2 A

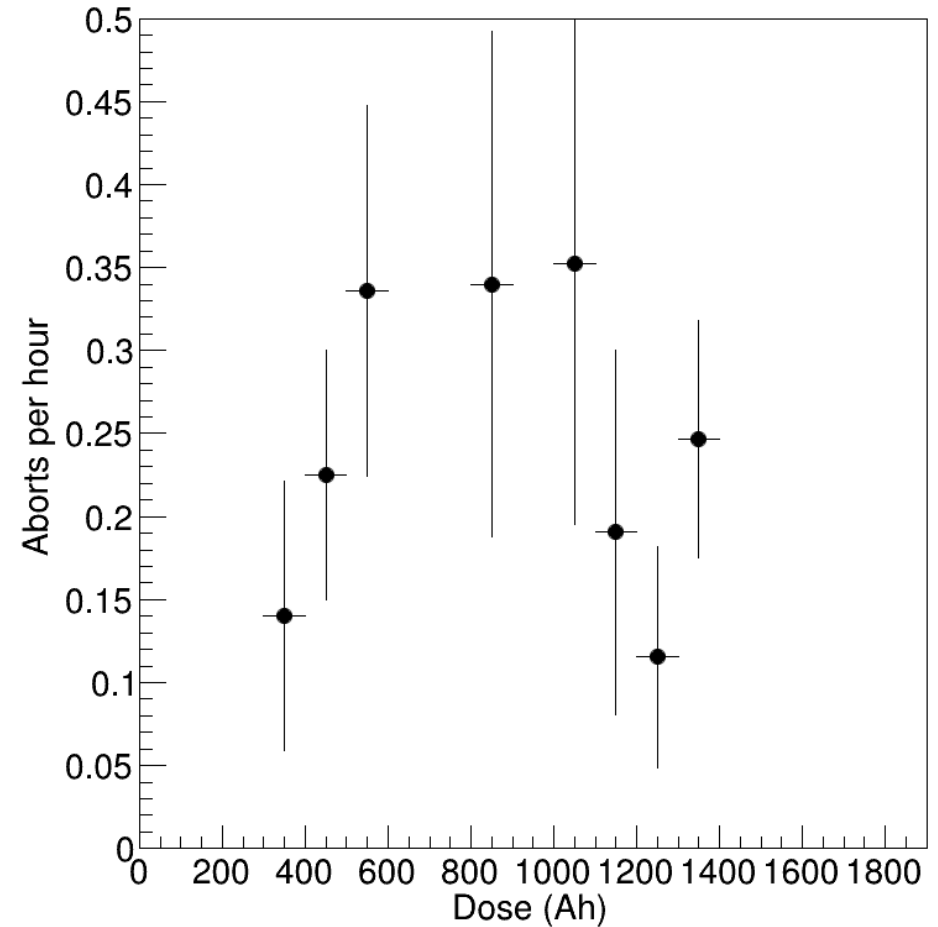


HER abort frequency (/hour)

HER (1.1-1.2 A)

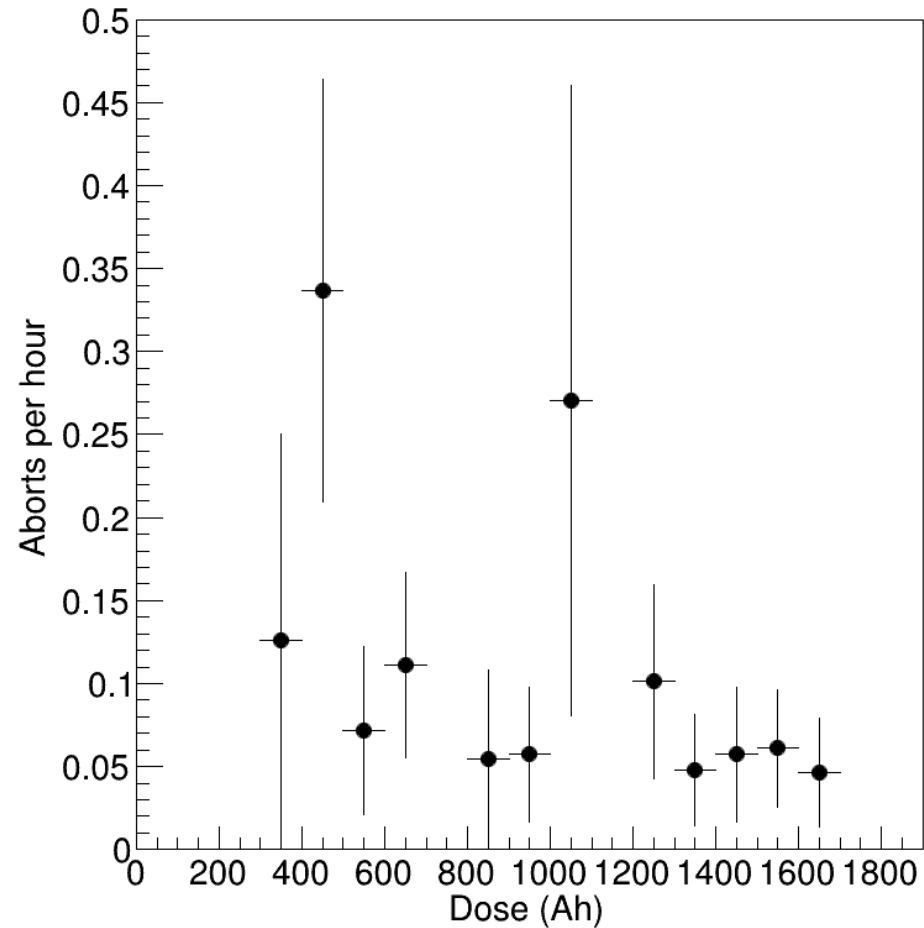


HER (1.2-1.3 A)

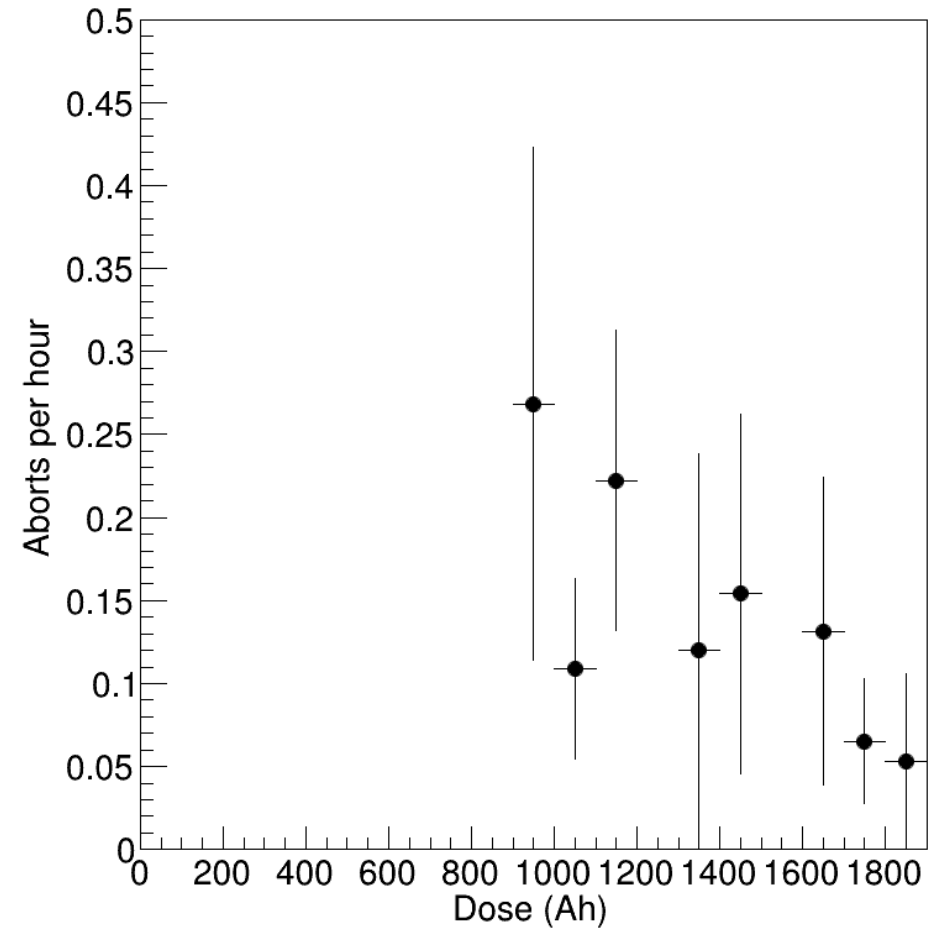


LER abort frequency (/hour)

LER (1.5-1.6 A)

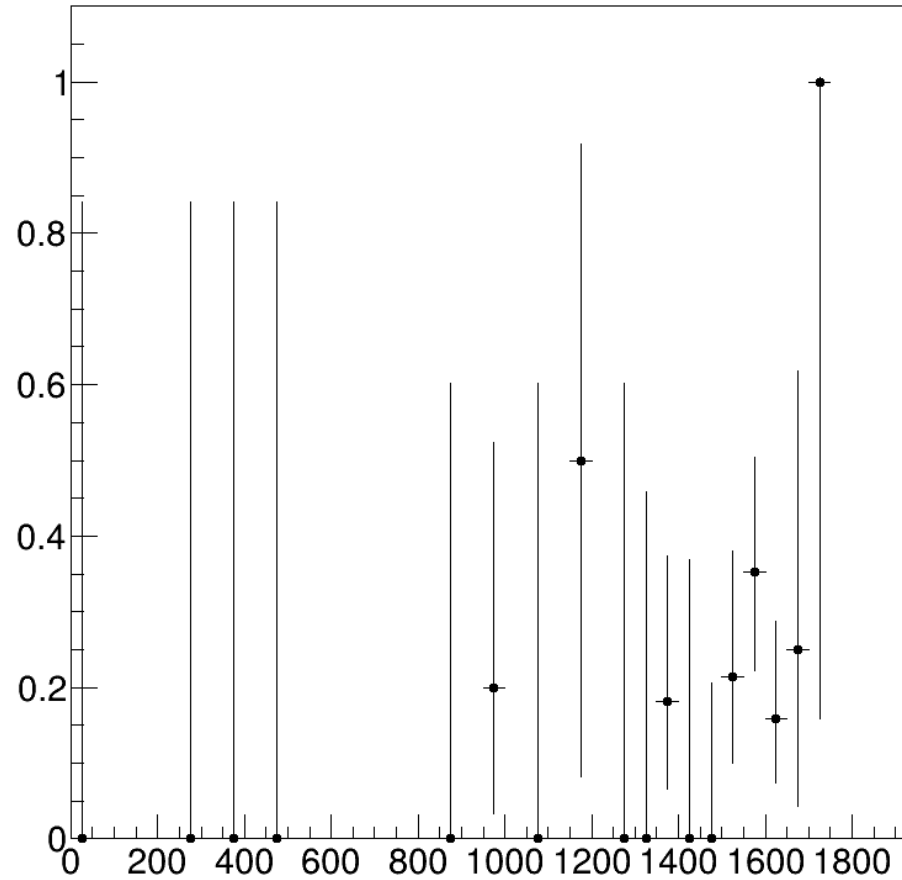


LER (1.6-1.8 A)



Fraction of QCS/(SBL+BL aborts)

LER



HER

