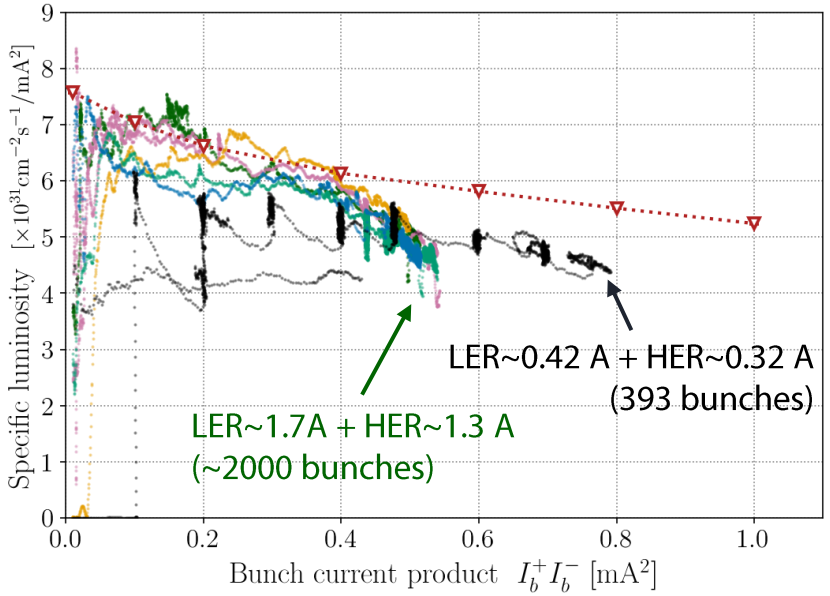
Strategy for beam lifetime and injection rate at 1e35 $cm^{-2}s^{-1}$

Gaku Mitsuka (KEK, Accelerator Lab)

The 29th KEKB Accelerator Review Committee
27 Oct. 2026

Case study: parameters for L=1x10^{35} cm^{-2}s^{-1}



- Case study assumes 2346 bunches.
- Specific luminosity: fit of high-bunch-current test data (black, right figure).

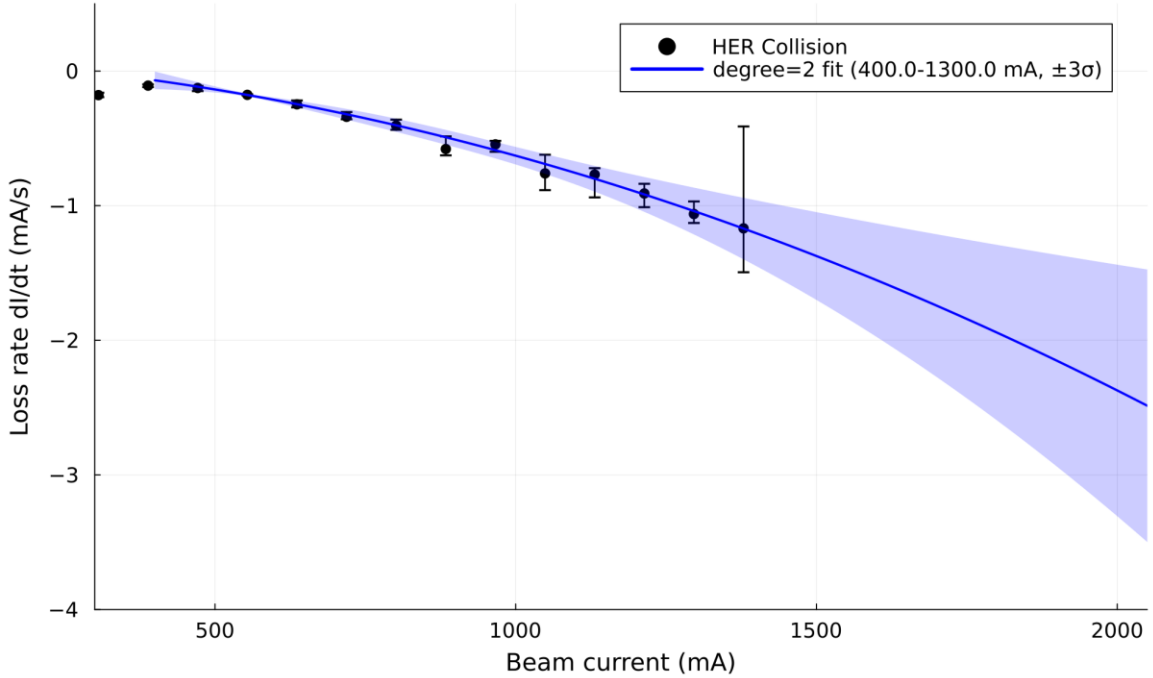
Main issues:

1. **Beam lifetime and injection power**
2. Reduce backgrounds to Belle II
3. Understand/suppress specific luminosity degradation
4. Suppress beam instabilities

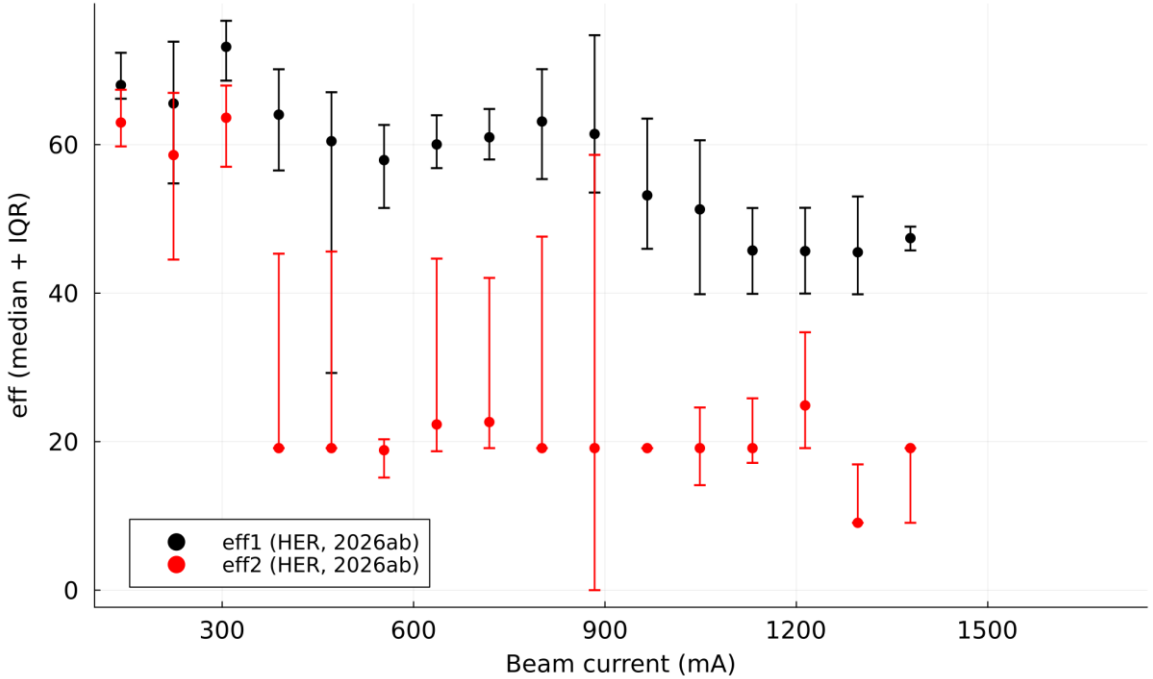
	2024/12 reached					Next target
Peak luminosity	5e34	6e34	7e34	8e34	9e34	10e34
Specific luminosity	5.5	5.3	5.1	4.8	4.5	4.4
HER beam (A) / bunch (mA) current	1.31/0.56	1.46/0.62	1.62/0.69	1.77/0.75	1.93/0.82	2.00/0.85
LER beam (A) / bunch (mA) current	1.64/0.70	1.83/0.78	2.02/0.86	2.21/0.94	2.41/1.03	2.60/1.11

HER beam storage

Minimum required injection current = 3.3 mA/s, can be reached with, e.g., 3.0 nC (BT end) × 2 × 25 Hz × 25%



HER loss rate vs beam current (collision, 2nd-order fit ±3σ)



HER injection efficiency vs beam current (black: 1st bunch, red: 2nd bunch)

Linac and BT

- Higher 2nd-bunch efficiency (new RF gun, fast kickers, orbit/energy spread FB)
- More precise beam-position measurement with the upgraded BT-BPM detectors → clues to the emittance growth
- SY3 diagnostic line (SR monitor)

Main ring

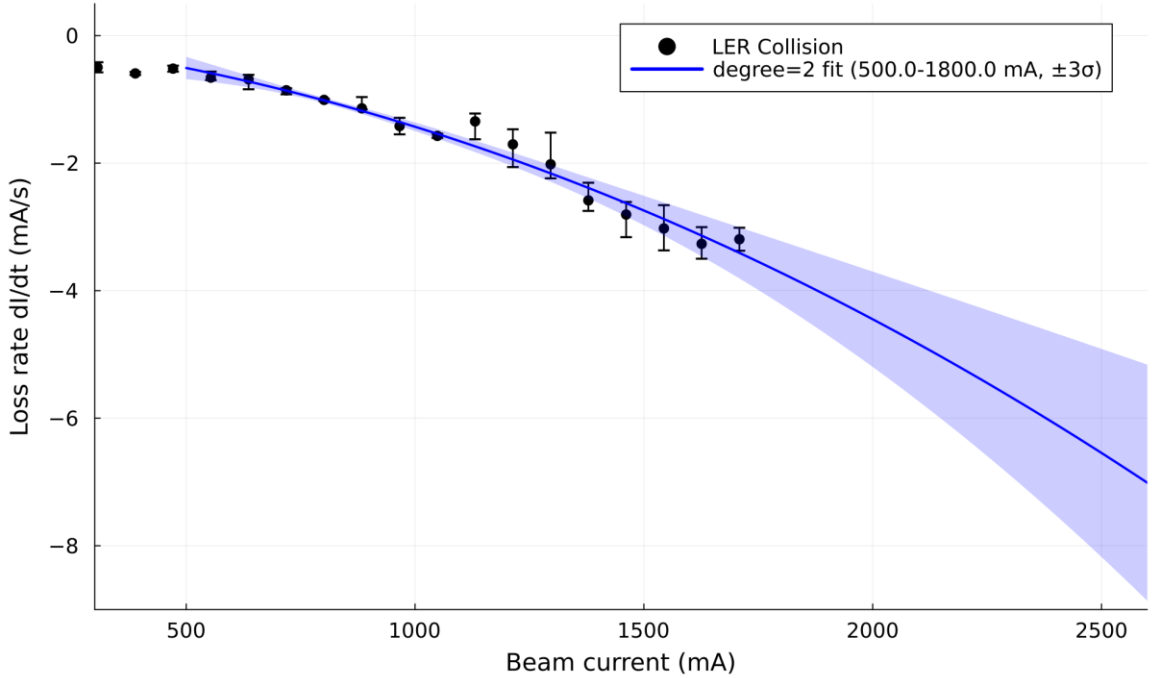
- Understand the tune dependence of injection
- Beam-beam effects



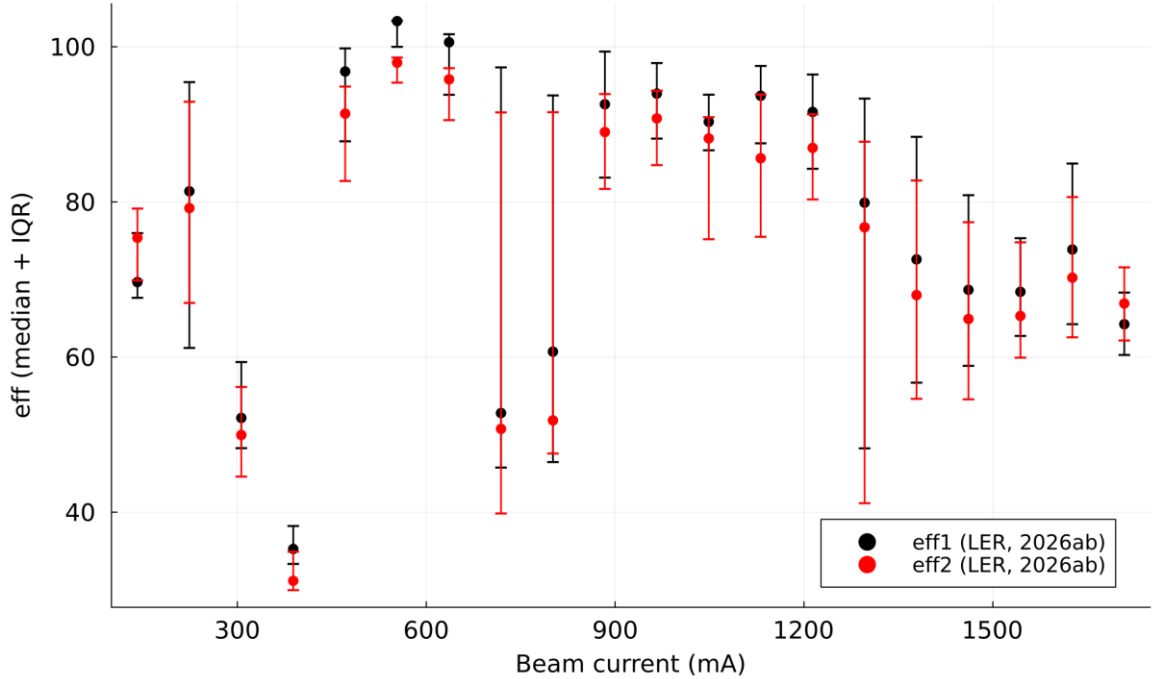
New RF electron gun installed

LER beam storage

Minimum required injection current = 9.0 mA/s, can be reached with, e.g., 3.5 nC (BT end) × 2 × 25 Hz × 55%.



LER loss rate vs beam current (collision, 2nd-order fit ±3σ)



LER injection efficiency vs beam current (black: 1st bunch, red: 2nd bunch)

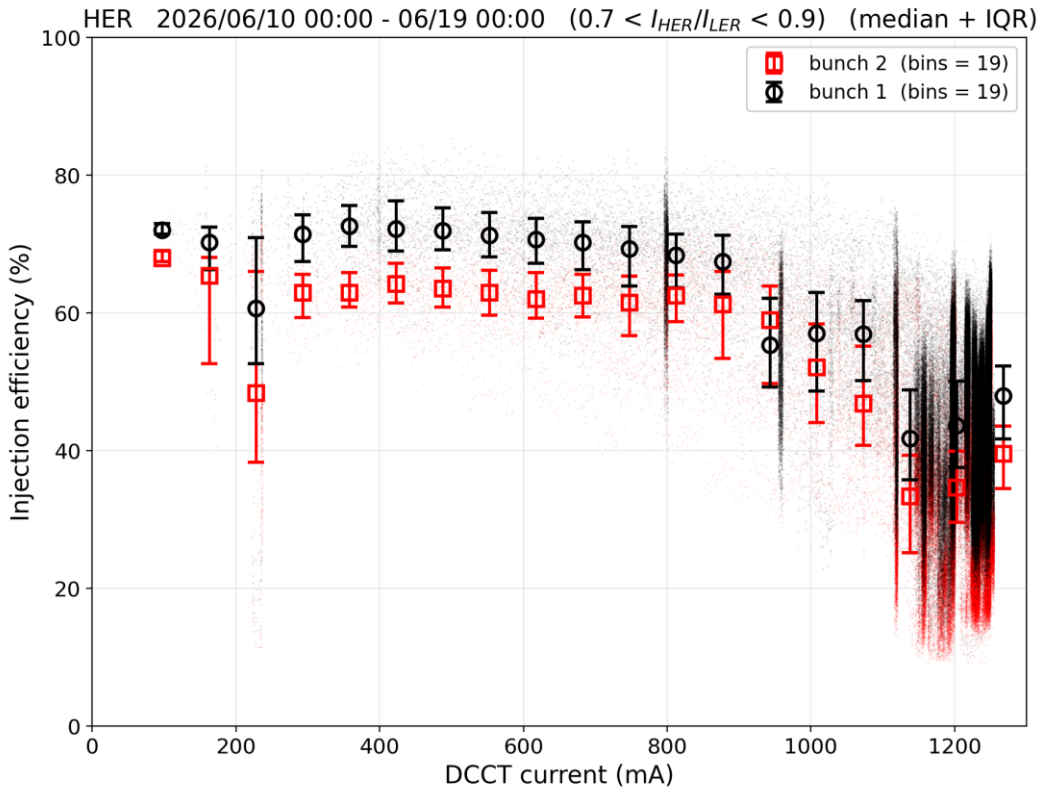
Linac and BT

- Horizontal emittance reduction
- Higher positron charge: 3 nC → 3.3, 3.6 nC …
  (higher electron-beam charge, ML-based orbit optimization)

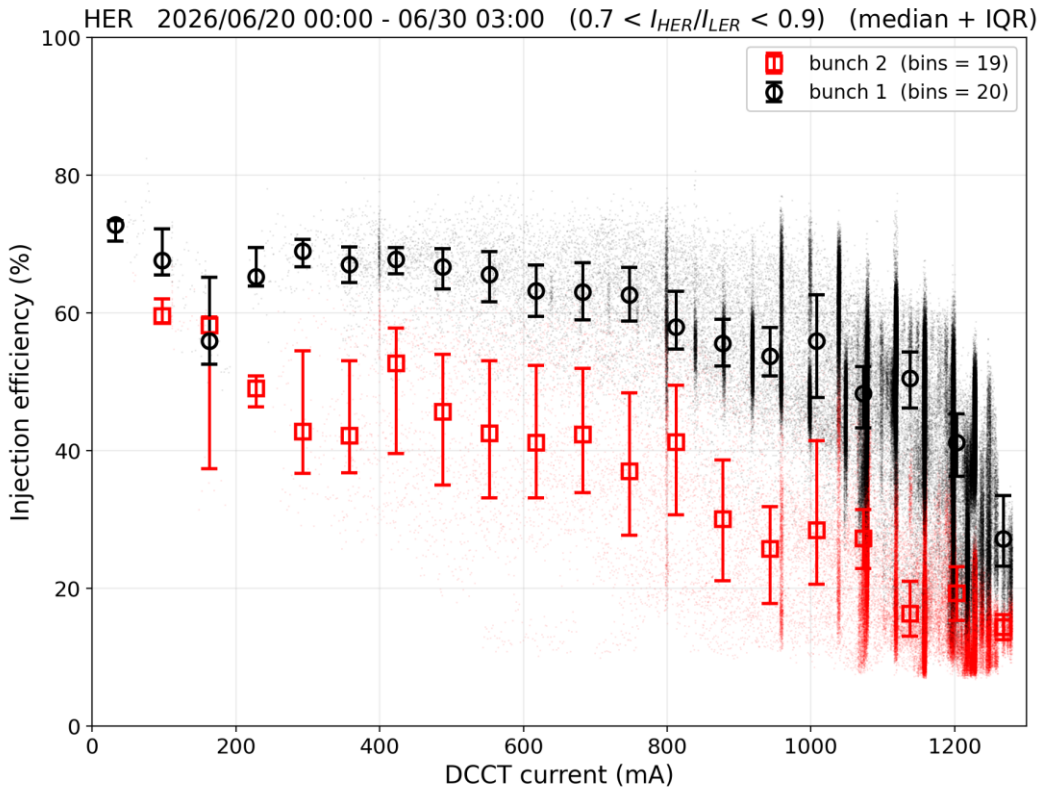
Main ring

- Beam lifetime dominated by beam-gas scattering
  → better vacuum quality is mandatory
- Larger dynamic aperture by sextupole optimization

HER injection efficiency (collision): before and after power outage on 6/19



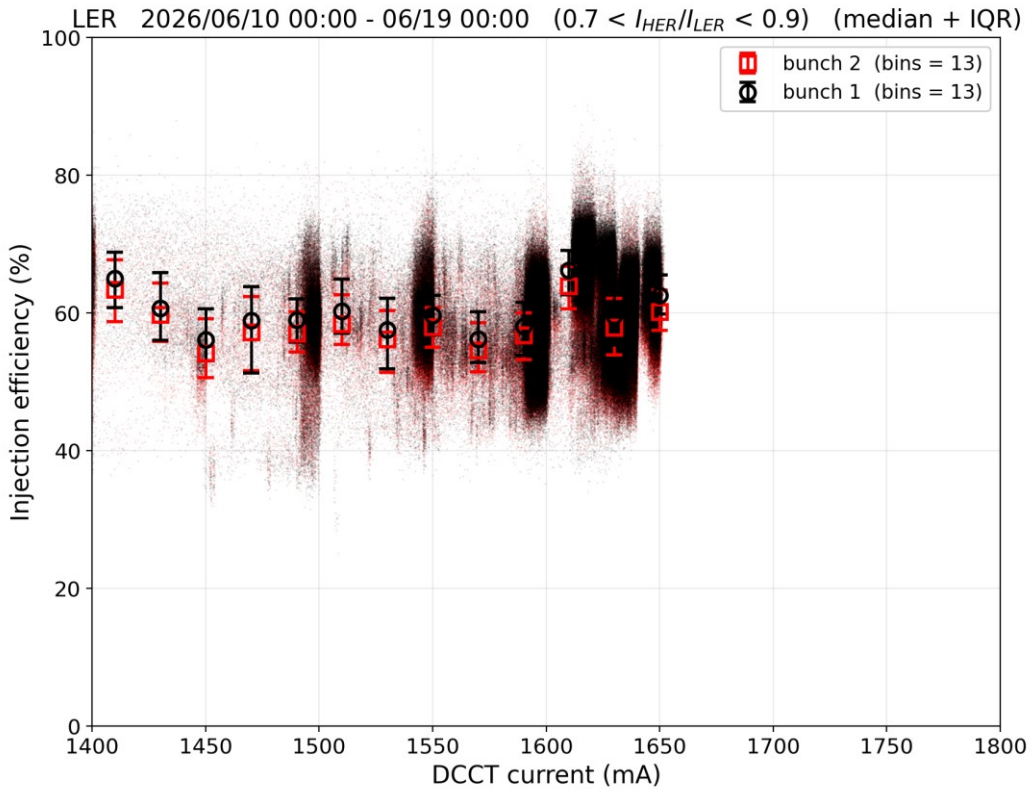
6/10–6/19



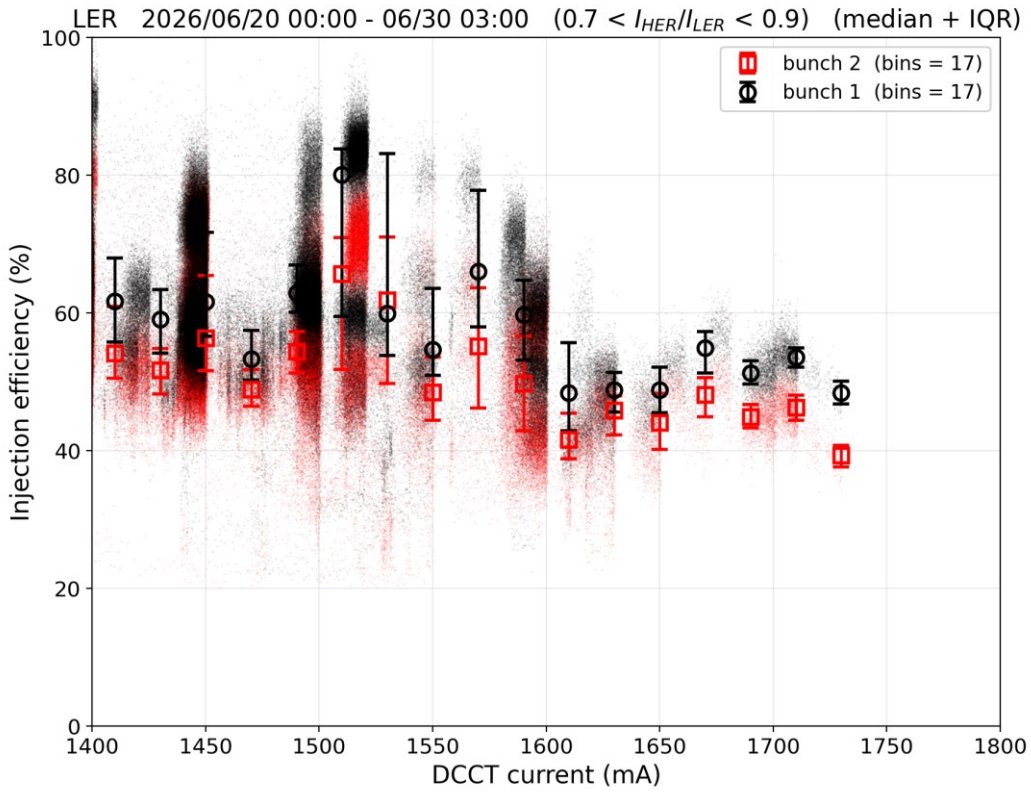
6/20–6/30

- Around the 6/19 power outage, the 2nd-bunch (red) efficiency changed greatly. Before 6/19, below 0.9 A: 1st bunch ~70%, 2nd ~60%. After: 2nd bunch ~40% (0.4–0.9 A), ~15–25% above 1 A.
- In good conditions, at least the pre-6/19 efficiency is achievable. Keeping the 2nd bunch in the same condition as the 1st with the 2nd-bunch kicker is the key.
- In HER, the injection efficiency decreases with beam current above 0.8–0.9 A.

LER injection efficiency (collision): before and after power outage on 6/19



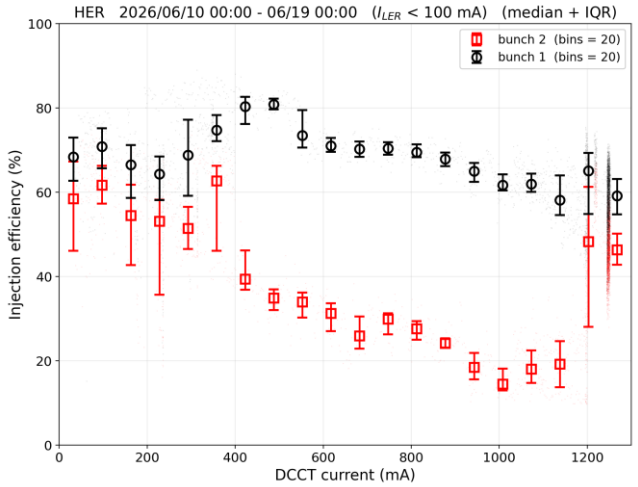
6/10–6/19



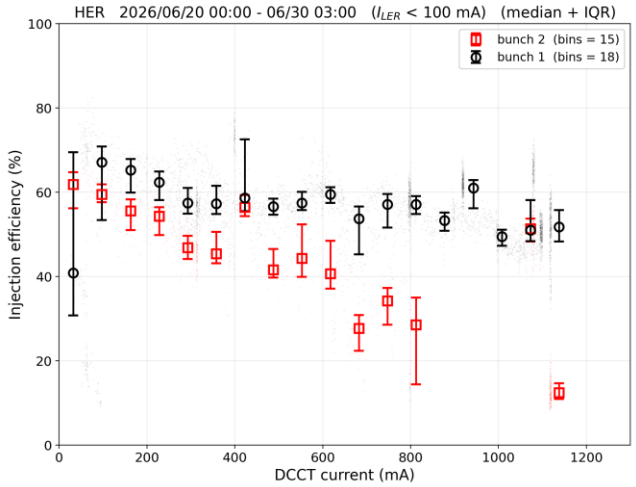
6/20–6/30

- Before 6/19: both bunches ~55–65% at 1.4–1.65 A. After: 1st bunch ~50–55%, 2nd ~40–48% at 1.6–1.73 A.
- Toward the LER target (75%), check the effect of the QI6P exchange and BT emittance reduction early in 2027ab.
- In LER, the injection efficiency shows no clear decrease with beam current, or only a gradual one.

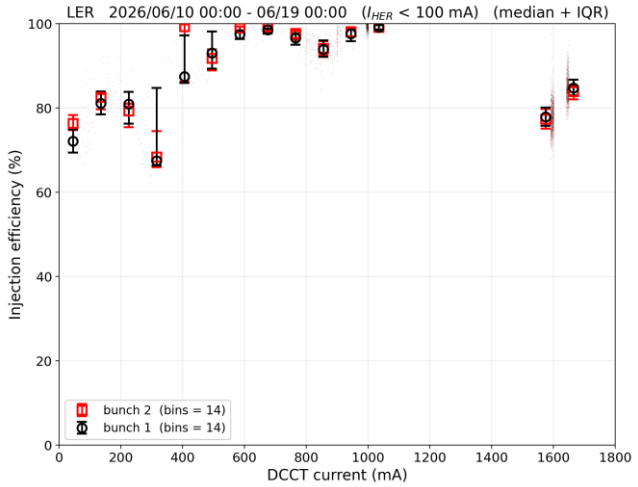
Injection efficiency (single beam): before and after 6/19



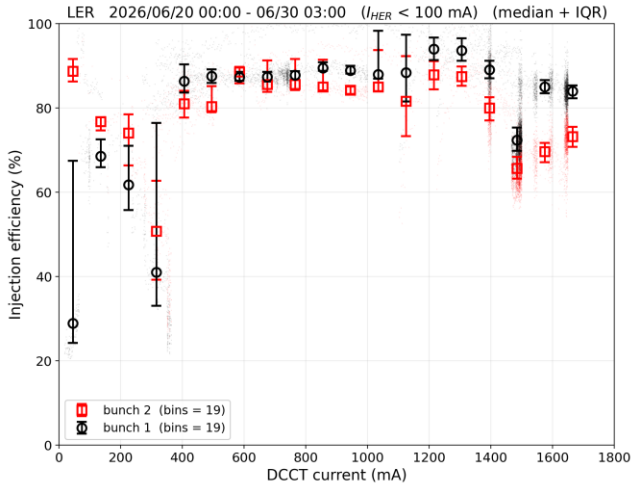
HER 6/10–6/19



HER 6/20–6/30



LER 6/10–6/19



LER 6/20–6/30

- In HER single beam, the 2nd-bunch efficiency drops with current even before 6/19 (~60% near 0.4 A to ~15% near 1 A). The 2nd-bunch condition needs to be understood, including differences from collision (collimator settings, bunch pattern).
- After 6/19, the HER 1st-bunch efficiency also dropped to ~55–60%.

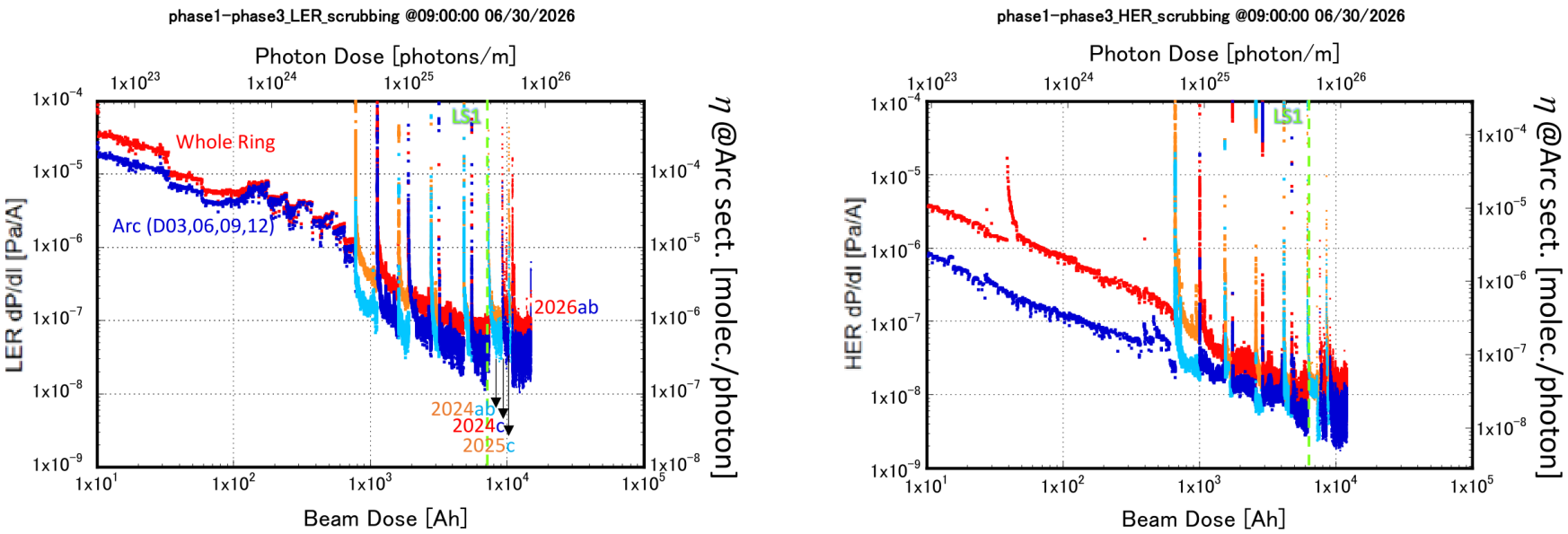
Injection Beam (from Linac to BT)

		2026ab present	Target	Item	Person in charge
HER injection beam	**Charge (BT end)**	**1.8 nC**	**3.0 nC**	**RF gun: laser phase, upstream emittance minimization**	**Yoshida**
	γεx (BT end)	230 μm	130 μm	BT orbit, energy spread optimization BPM precision upgrade: 2-bunch signal separation Orbit feedback Energy spread feedback New in FB: •Fast kicker, SY3 SR monitor, •SY3 diagnostic line	Injection & high current TF
	γεy (BT end)	140 μm	130 μm	BT orbit, energy spread optimization	Injection & high current TF
	Background	~70-85 μA	~17 μA	BT collimator optimization: position vs loss Radiation BG measurement Jitter, long-term stability Injection BG measurement (2027-)	Injection & high current TF, Uno
LER injection beam	**Charge (BT end)**	**2.6 nC**	**e- gun → BT 12 nC → 4.0 nC (11 nC → 3.65nC)# (#: present cathode limit, new one summer 2027)**	**Thermionic gun**	**Yoshida**
				Capture section optimization; capture section to DR optics optimization	**Natsui, Miyahara**
	γεx (BT end)	210 μm	150 μm	BT orbit, energy spread optimization (same as HER)	Injection & high current TF
	γεy (BT end)	50 μm	50 μm	BT orbit, energy spread optimization (same as HER)	Injection & high current TF
	Background	~30-35 μA	~8 μA	BT collimator optimization (same as HER)	Injection & high current TF, Uno

Injection Beam (MR)

		Present	Target	Item	Person in charge
HER injection beam	Injection efficiency (1st bunch)	50% (1.3 A)	70% (2.0 A)	Countermeasures to emittance growth	Injection & high current TF
	Injection efficiency (2nd bunch)	20% (1.3 A)	70% (2.0 A)	Fast kicker for 2-bunch control	Okayasu, Kamitani, Injection & high current TF
	Loss rate	-1.3 mA/s (1.2 A)	-0.9 mA/s (1.2 A) -3.3 mA/s (2.0 A)	FB? Beam-beam? DA?	Tobiyama, Funakoshi, Koga, Mitsuka, etc.
LER injection beam	Injection efficiency (1+2 bunches)	65% (1.7 A)	75% (2.6 A)	Countermeasures to emittance growth	Injection & high current TF
				QI6P chamber replacement	Vacuum G
	Loss rate	-3.5 mA/s (1.6 A)	-3.0 mA/s (1.6 A) -9.0 mA/s (2.6 A)	Vacuum? FB? DA?	Ishibashi, Terui, Koga, Mitsuka, etc.

Impact of the ring pressure on the beam lifetime



dP/dI vs beam dose (left: LER, right: HER). Red: whole ring, blue: arc sections

- Whole-ring dP/dI in 2026ab: LER (left) about 7×10^{-8}–1×10^{-7} Pa/A, HER (right) about 1.5–2.5×10^{-8} Pa/A.
  The LER, with many new Al chambers, is 3–5 times higher.

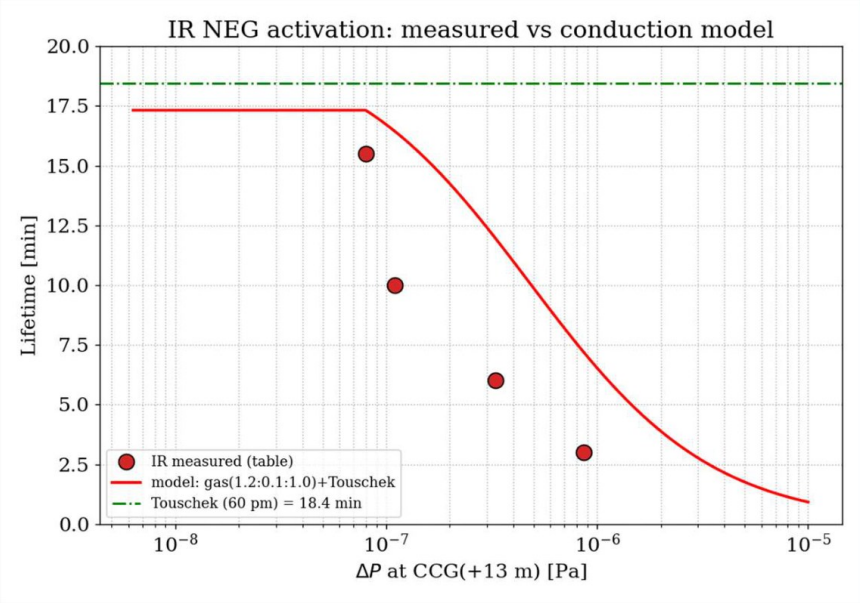
- Of the LER loss, residual-gas scattering (Coulomb loss) is about 55–60% at 1.6 A; the remaining ~40% is Touschek loss.
- The Coulomb scattering rate scales inversely with the square of the energy, so at the same pressure the LER (4 GeV) would lose about 3 times more than the HER (7 GeV).

Coulomb loss from the IR (further investigation needed in 2027ab)

Table 1: Calculated Coulomb loss rate and lifetime for different IR vacuum models at 1400 mA. IR pressure is assumed to be 67 % of the 722 Ah simulation to match the 1400 Ah measurement condition in June 2024.

Parameters	Case 1 (No IR)	Case 2 (IR: CO)	Case 3 (IR: CO_2)
IR Pressure Assumption	0	Calc. × 0.67	Calc. × 0.67
Calculated τ_C [min]	31.8	17.2	13.6
Calculated Loss Rate [mA/s]	0.84	1.55	1.96
IR Contribution [%]	0	45.9	57.2

Coulomb loss calculated at 1400 mA: including the IR brings it close to the measured 2.2 mA/s



Raising the IR pressure by activating the IR NEG shortens the lifetime from 15.5 to 3 min

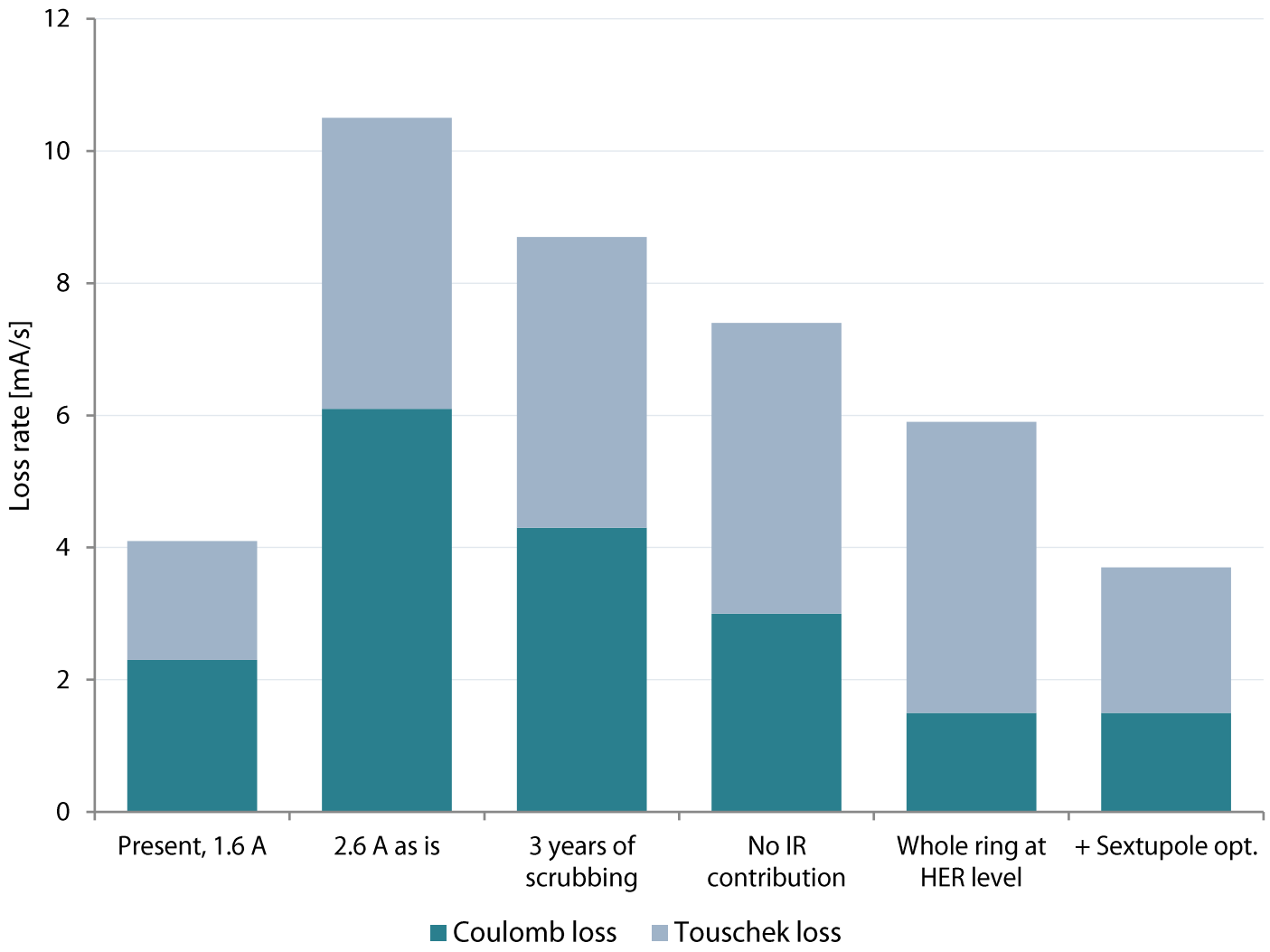
Summary of the study report

- The Coulomb loss is set by "the ring integral of pressure × βy". The IR is only ~1/100 of the ring length, but with βy* ~1.0 mm, βy reaches several hundred meters there, so its impact is large.
- The average-pressure model deviates from the measurement by more than a factor of 2. Including the IR explains it: above 1.6 A, about half of the Coulomb loss (over 30% of the total) originates in the IR.
- A higher IR pressure also raises the storage background. The IR vacuum affects both lifetime and background.

Caveats

- The vacuum gauge closest to the IP is 12 m away; the IR pressure cannot be measured directly.
- Existing pumps and NEG coating cannot solve this; new technology must be developed. Whether it can be ready for LS2 is uncertain.
- The analysis assumptions seem rough (chamber apertures and pumps are approximate; partial-pressure ratios estimated from D04). A re-study with N_2 injection is planned; further investigation is needed.

LER loss-rate estimate (2.6 A, 2346 bunches, ε_y 80 pm)



Scenario	Total	Lifetime
Scaled to 2.6 A	**-10.5 mA/s**	~4 min
Scrubbing, 3 yr	-8.7 mA/s	~5 min
No IR contribution	-7.4 mA/s	~6 min
Ring = HER level	-5.9 mA/s	~7 min
+ Sextupole opt.	**-3.7 mA/s**	~12 min

- Extrapolating the Coulomb and Touschek losses at 1.6 A: −10.5 mA/s.
  - Scaling: Coulomb ∝ I^2; Touschek ∝ I × I_bunch / √εy.
- DCCT-fit extrapolation: about −7 mA/s (−9 mA/s at −3σ assuming bad conditions).
- With an injection capacity of ~11 mA/s (3.2 nC, 70%), 2.6 A should be reachable.

- Sextupole optimization: Touschek lifetime 325→729 s (simulation with full-open collimators); little effect unless the Coulomb loss is also reduced…

Injection-rate balance and background limit

Required injection rate (25 Hz, f_rev = 99.4 kHz, dI/dt = Q × (η1+η2) × 25 Hz × f_rev)

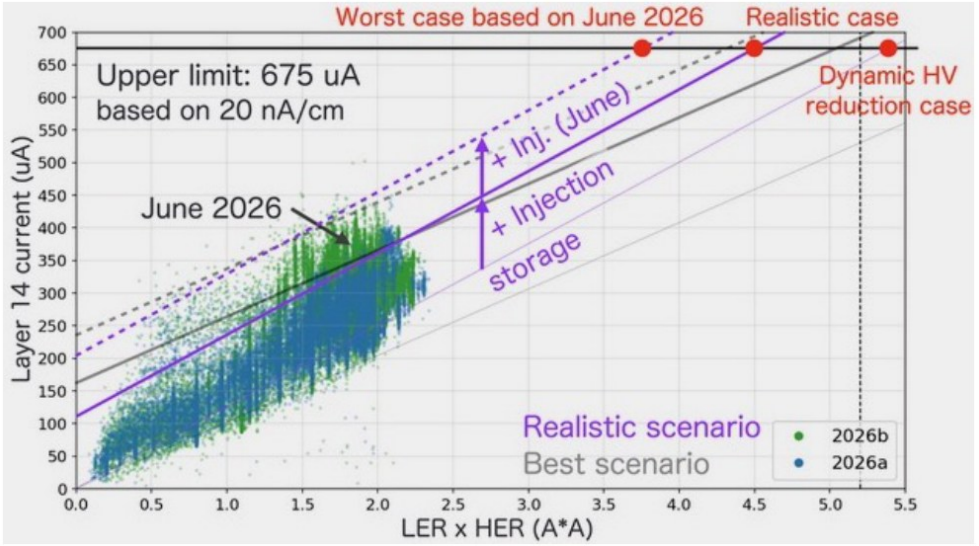
	Required at target current	Present performance	List targets as written	Realistic outlook (assumed)
HER 2.0 A	3.3 mA/s (list assumption) DCCT extrapolation ≈ 2.5 mA/s	**1.8 nC × (50+20)%** **→ 3.1 mA/s (short)**	**3.0 nC × (70+70)%** **→ 10.4 mA/s (~3× margin)**	**2.0 nC × (65+50)%** **→ 5.7 mA/s (sufficient)**
LER 2.6 A	9.0 mA/s (list assumption) DCCT extrapolation ≈ 7 mA/s	**2.6 nC × (65+65)%** **→ 8.4 mA/s (short)**	**4.0 nC × (75+75)%** **→ 14.9 mA/s (margin)**	**3.2 nC × (70+70)%** **→ 11.1 mA/s (sufficient)**

Observations

- For the injection rate alone, more charge is not required if efficiency reaches its target.
- The charge lost for a given supply scales as (1−η)/η: HER 35%→70% average cuts the lost charge to about 1/4 (−77%); LER 65%→75% cuts it by ~40%.
- If background scales with the lost charge, efficiency (attributed to large emittance) matters more than charge.

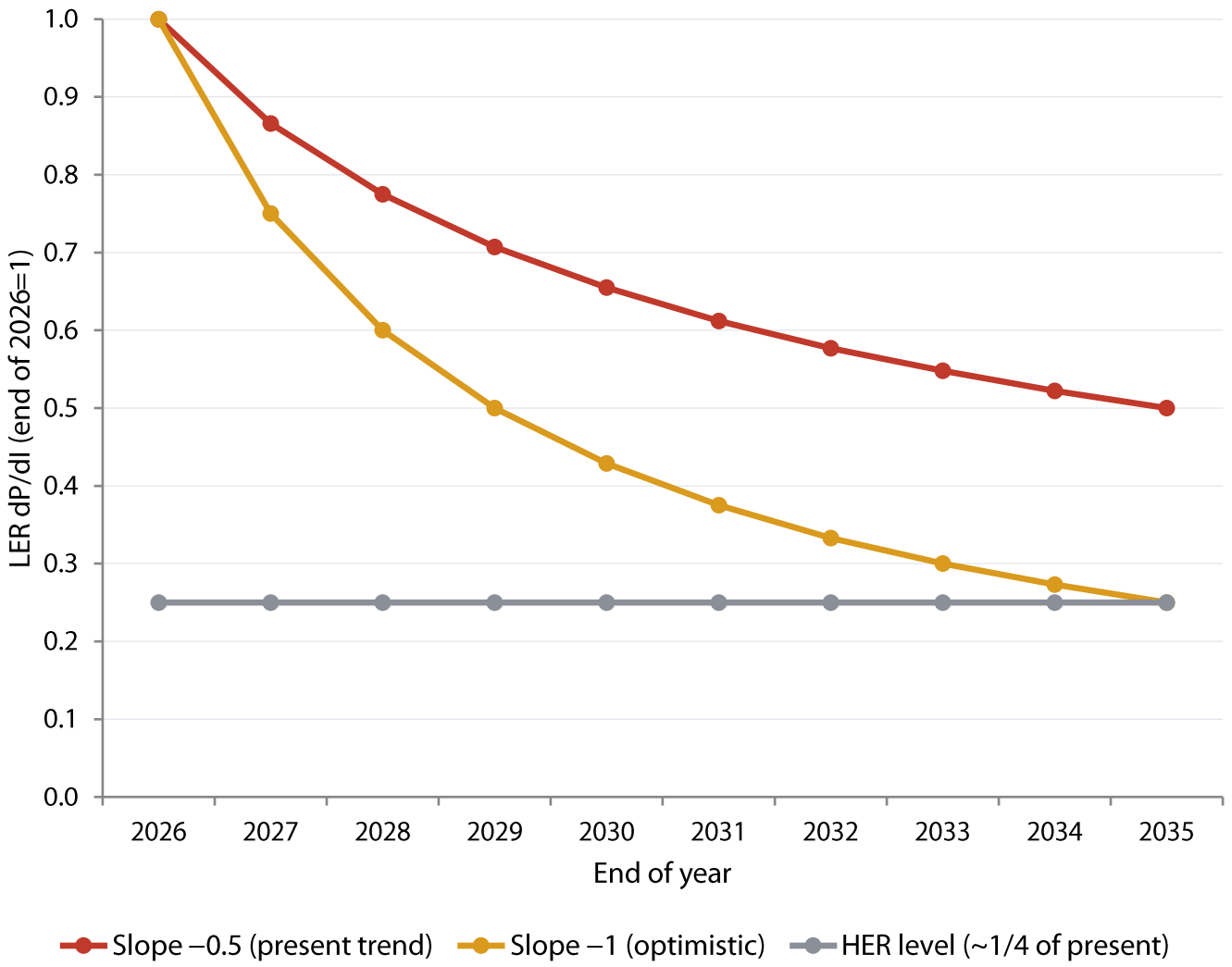
Proposals

- It could also be interpreted that the stored-beam background limits the current that L14 can accommodate. Reducing this stored-beam background is important.



CDC Layer 14 current vs current product (Uno); limit 675 μA

Estimated improvement rate by vacuum scrubbing



Assumptions

- LER integrated dose: about 1.5×10^4 Ah at the end of 2026ab, then about 5,000 Ah per year (6 months × 60% efficiency × 2 A).
- dP/dI at the CCG closest to the IP decreases as (dose)^−α. Reading the fit on p.3 plot gives α≈0.5.

Estimated pressure improvement by scrubbing

- With α≈0.5, after 3 years (end of 2029) dP/dI is still about 0.7 of the present value. Reaching the HER level (~1/4) would take about 45 years?
- Even in the optimistic case α=1, the HER level is reached around 2035.