SuperKEKB Highlights of 2026ab and Plans for 2027ab

2026-07-06 B2GM

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On behalf of SuperKEKB commissioning

Outline

Goals and status of 2026ab operation. (: complete, ✓ : incomplete or in progress)

Top priority of 2026ab operation was to accumulate integrated luminosity to above $400\ \mathrm{fb}^{-1}$ during this run.

Delivered integrated luminosity has been recorded over $314\ \mathrm{fb}^{-1}$ and total is $914\ \mathrm{fb}^{-1}$

✓ Total integrated luminosity achieved over $1\ a\mathrm{b}^{-1}$ has been postponed next operation (2027a)

Update peak luminosity record

update the highest luminosity : $5.32 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ without Belle II data taking (2026-06-29)
: $5.28 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ with Belle II data taking (2026-05-30)
(cf. $5.1 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ in the previous run)

Reduction of number of beam aborts and investigation of Sudden Beam Loss (SBL)

Number of SBL events in the LER was significantly reduced compared with 2024 due to beam pipe cleaning during the 2025 shutdown.

This enabled longer operation at higher beam currents and contributed to achieving more than $300\ \mathrm{fb}^{-1}$ of integrated luminosity in this run.

✓ However, SBL and beam-loss events still occurred at high beam currents, often leading to QCS quenches. To address this issue, the SBL Task Force was launched in May to investigate the root causes. Details will be shown later.

Accelerator Status

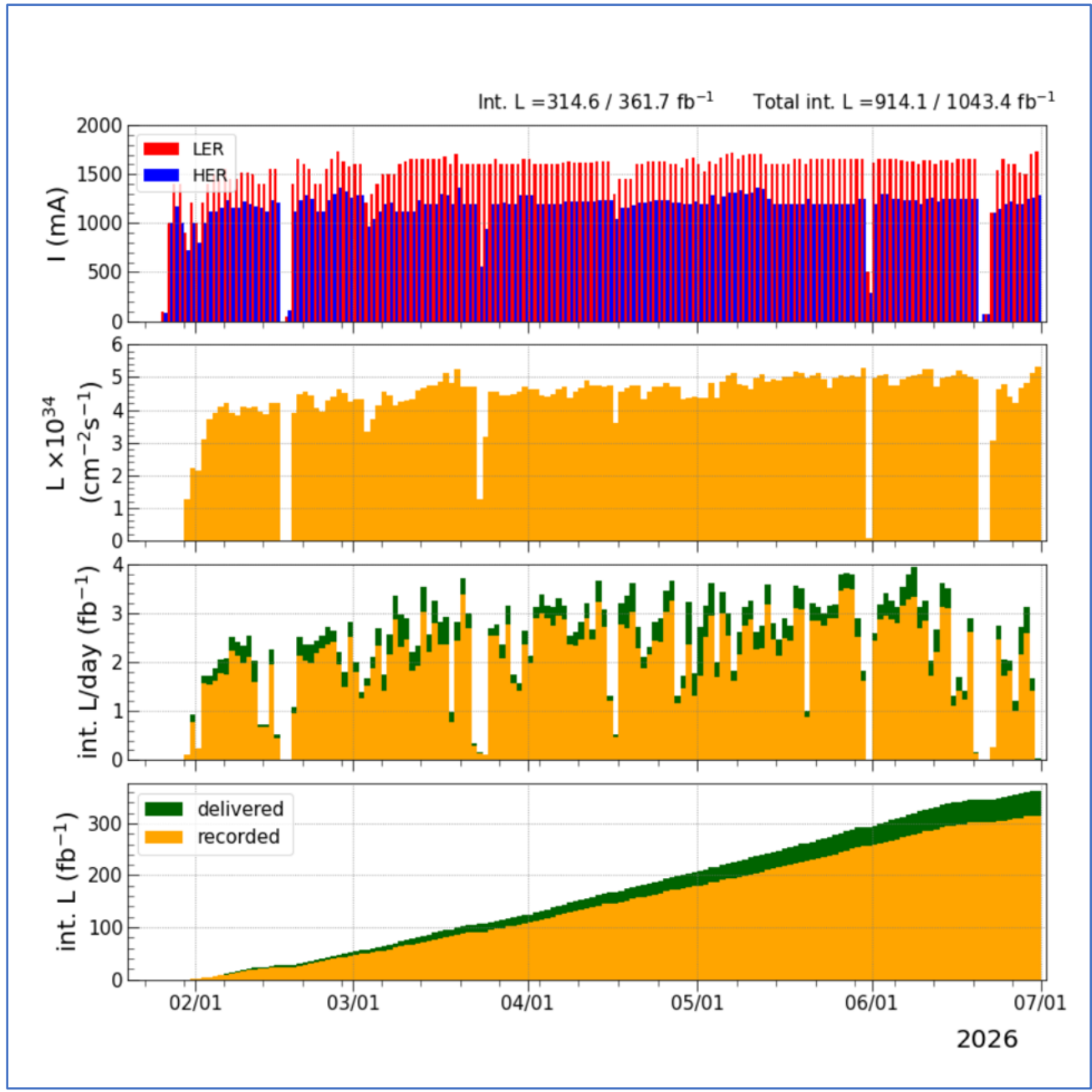
- 2-bunch injection for both rings
- β_y^*: $0.9\ \mathrm{mm}$ operation

  Increase specific luminosity at high current

High bunch current operation

2026ab operation history

- 2026ab operation period was from Jan. 26 to Jun. 30
  - 155 days with 4 maintenance days
- Vacuum scrubbing with detuned optics: Jan. 26/Jan. 29
  - LER: 1.2 A/HER : 1.0 A
- Off-resonance run on Apr. 15/Apr. 27
- Integrated Luminosity
  - Recorded/Delivered : $314/361\ \mathrm{ab}^{-1}$ (total $900\ \mathrm{ab}^{-1}$ has been reached since 2026-06-18)
- Peak Luminosity
  - 5.32x10^34 at 2026-06-29 with $\beta_y^* = 0.9\ \mathrm{mm}$
  - 5.28x10^34 at 2026-05-30 w/ Belle II data taking
- Maximum beam current in 2026ab
  - LER maximum : 1.73 mA (2026-06-30)
  - HER maximum : 1.36 mA (Physics run 2026-03-19)
- (Infrastructure trouble)



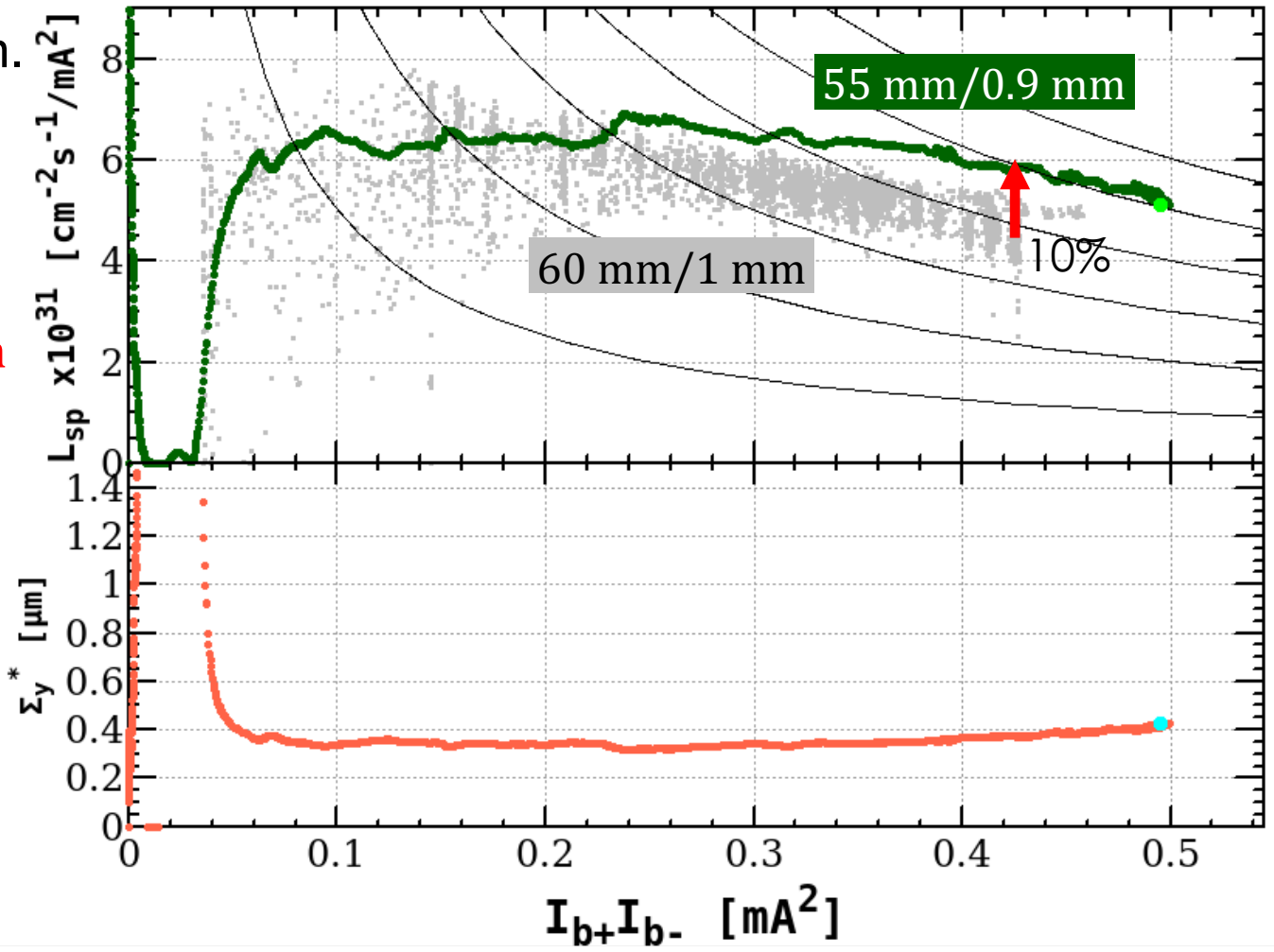
Stable operation with $\mathcal{L} > 5\times10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

High current operation with 2-bunch injection in the HER started on Apr. 1.

Increase peak luminosity and accumulate integrated luminosity

- Stable high-current operation with $\beta^*_{x,y} = 60, 1\ \mathrm{mm}$ started since beginning this run.
- Beam current with $\beta^*_{x,y} = 55, 0.9\ \mathrm{mm}$ was further increased after Apr. 30 (after off-resonance run)
- Specific luminosity with $\beta^*_{x,y} = 55, 0.9\ \mathrm{mm}$ (green) is 10% higher than $\beta^*_{x,y} = 60, 1\ \mathrm{mm}$ (gray).

2026-05-30
Peak luminosity (w/ Belle II)
$5.28\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$



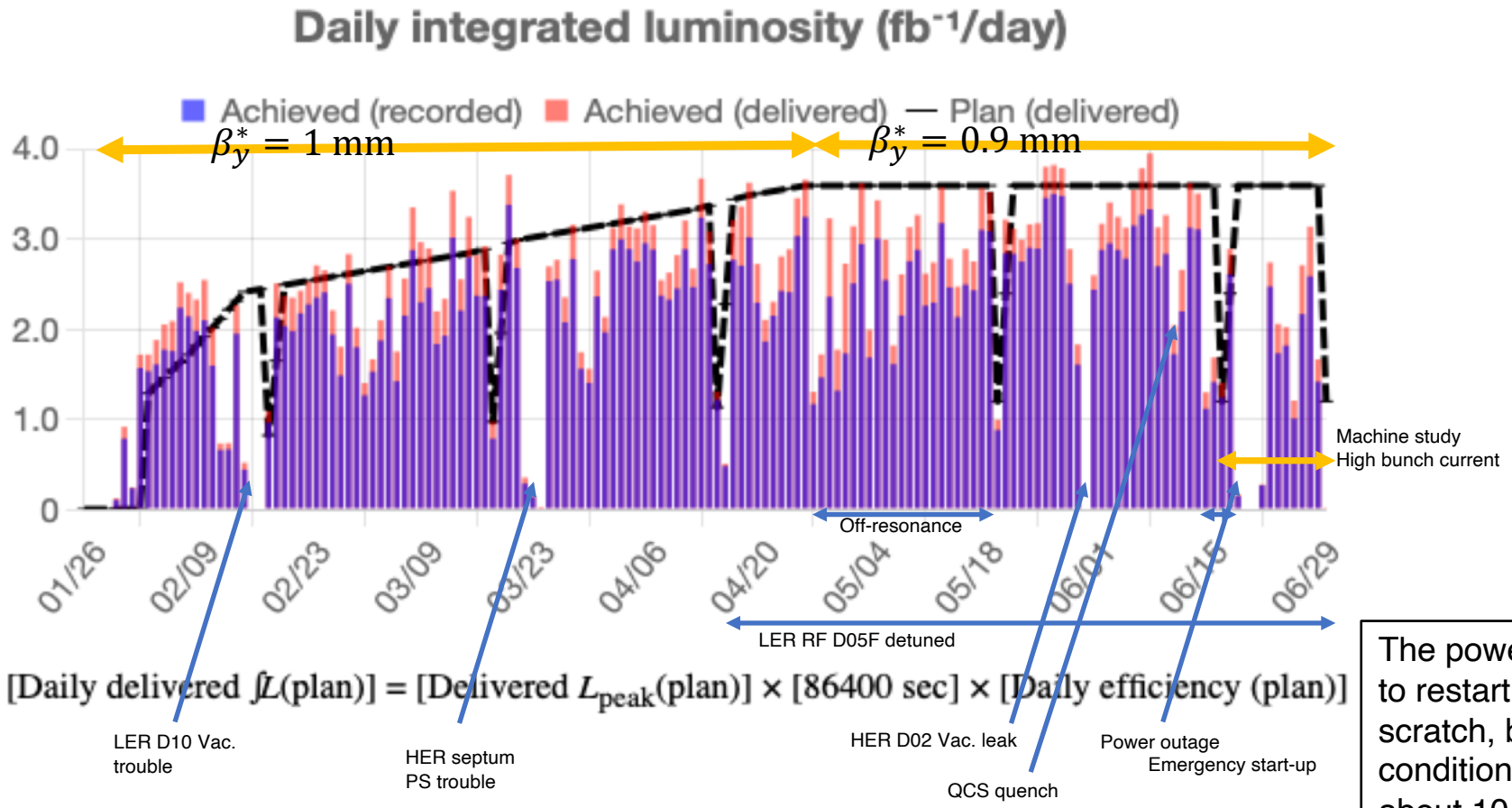
$\beta^*_y = 0.9\ \mathrm{mm}$ is highly effective in increasing spec. luminosity compared with $\beta^*_y = 1\ \mathrm{mm}$.

Dynamic aperture reduction was small, and the injection rate was maintained by auto and manual tuning.

However, emittance growth remains an unresolved issue.

In addition, luminosity was unstable, and fluctuation mechanism need further investigation. For example, we found that even slight temperature fluctuations in the control room were correlated with luminosity. We will continue working with other departments to explore ways to reduce these fluctuations.

Increase peak luminosity and accumulate integrated luminosity



The power outage forced us to restart the recovery from scratch, but the machine condition was restored within about 10 days through emergency efforts.

- 2346 bunches were base of number of bunches on 2026ab run.
- Integrated luminosity with $\beta_y^* = 0.9$ mm was comparable to that with $\beta_y^* = 1$ mm
- Highest recorded and delivered daily integrated luminosity : $3.5\ \mathrm{fb}^{-1}$ and $3.9\ \mathrm{fb}^{-1}$ on May 27 and Jun. 8, respectively
- 1.7 A and 1.3 A were mainteined with 2-bunch x 12.5 Hz injection rate.

Trouble statistics and dead time

- Vacuum leak (solved)
  - LER Nikko wiggler section (D10_L7)
  - Tsukuba straight section downstream SS chamber for iBump (D02_H16)

  It took 1-2 days to resume the physics run.
- QCS Helium compressor solenoid valve trouble on 2026-02-15 (solved)

  It took two days to refill liquid Helium.
- SBL and Beam loss

  RF recovery, increase beam current, injection tuning

  It took around 10 min.

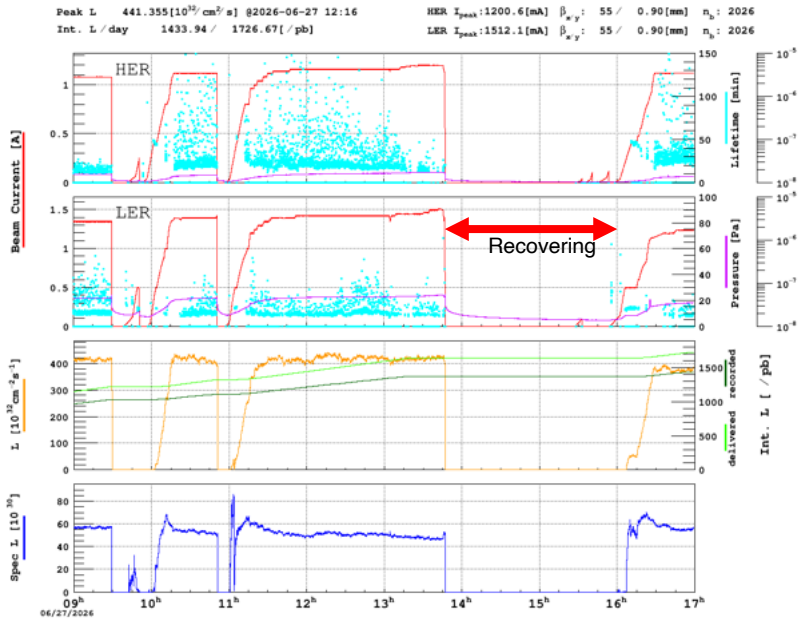
  QCS quenches

  LER: 37, HER : 22, Both :2, Total 61
- Air conditionar failure at D07 control room (solved)
- Injection septum power supply trouble (solved)
- LER Injection kicker miss fire (PS will be replaced this summer)
- LER RF D05F cavity leak (Cavity will be replaced this summer)

  Two cavities (D05A, D05F) were detuned during 2026ab
- Electric power outage 2026-06-20

  A long time recovery was required (emergency recovery)

QCS quench example



QCS recovery time is around 2 hour.
Operational improvements have reduced the recovery time.

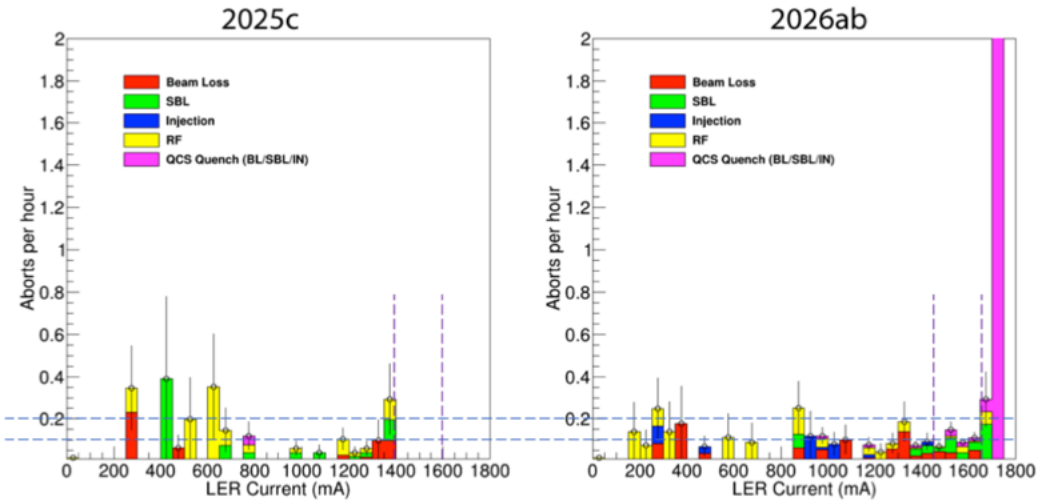
Abort statistics

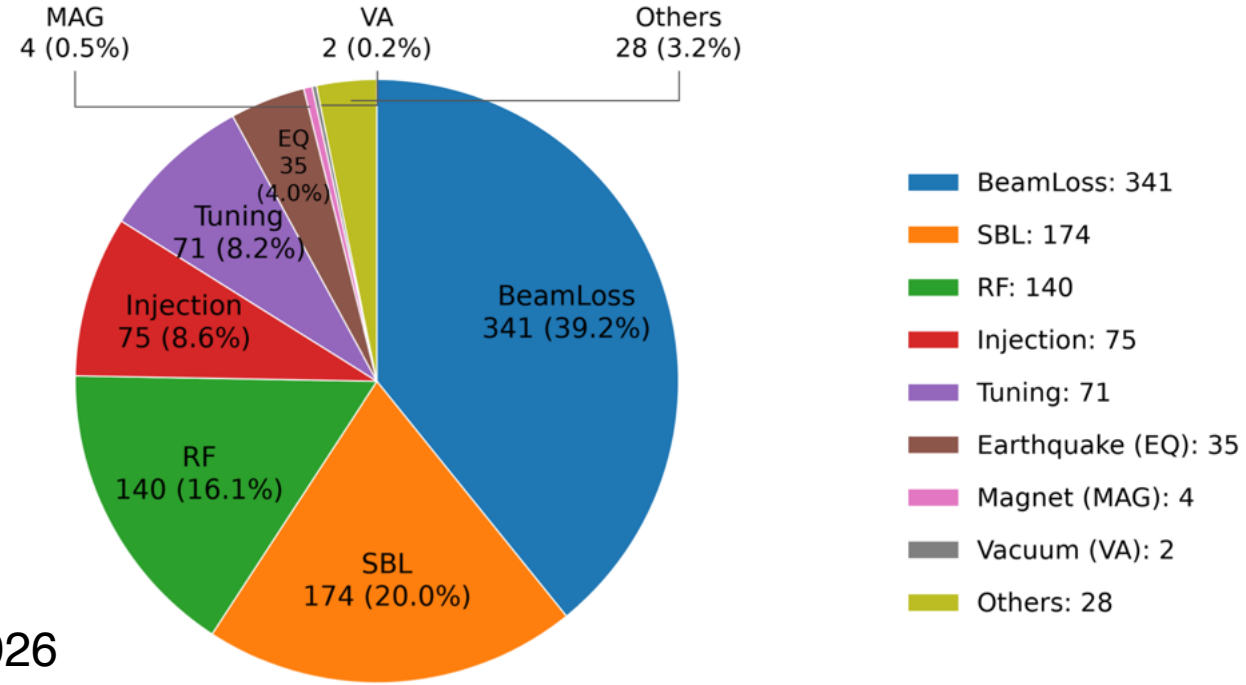
- Number of SBLs of the LER has been reduced since beam pipe cleaning during 2025 shutdown.
- Number of SBLs of the HER is comparable to that in the LER, but many HER beam-loss aborts observed.
- Reducing abort frequency is require for increase the beam current and luminosity.
- Further improvement requires high-current operation and extended running time.

2026-01-26 09:00:00 ~ 2026-06-30 09:00:59

ring	SBL	BeamLoss	EQ	Injection	MAG	Manual	Others	RF	Tuning	VA	Uncategorized	TOTAL
TOTAL	174	341	35	75	4	-	28	140	71	2	-	870
Both(LER)	88	44	-	13	1	-	11	4	2	-	-	163
Both(HER)	81	216	1	58	1	-	2	-	58	-	-	417
Both(Both)	-	1	9	1	2	-	3	2	1	1	-	20
Both	-	-	-	-	-	-	-	-	-	-	-	-
LER	3	14	5	1	-	-	6	75	4	1	-	109
HER	2	66	20	2	-	-	6	59	6	-	-	161

Beam currents >1 mA, hide manual abort





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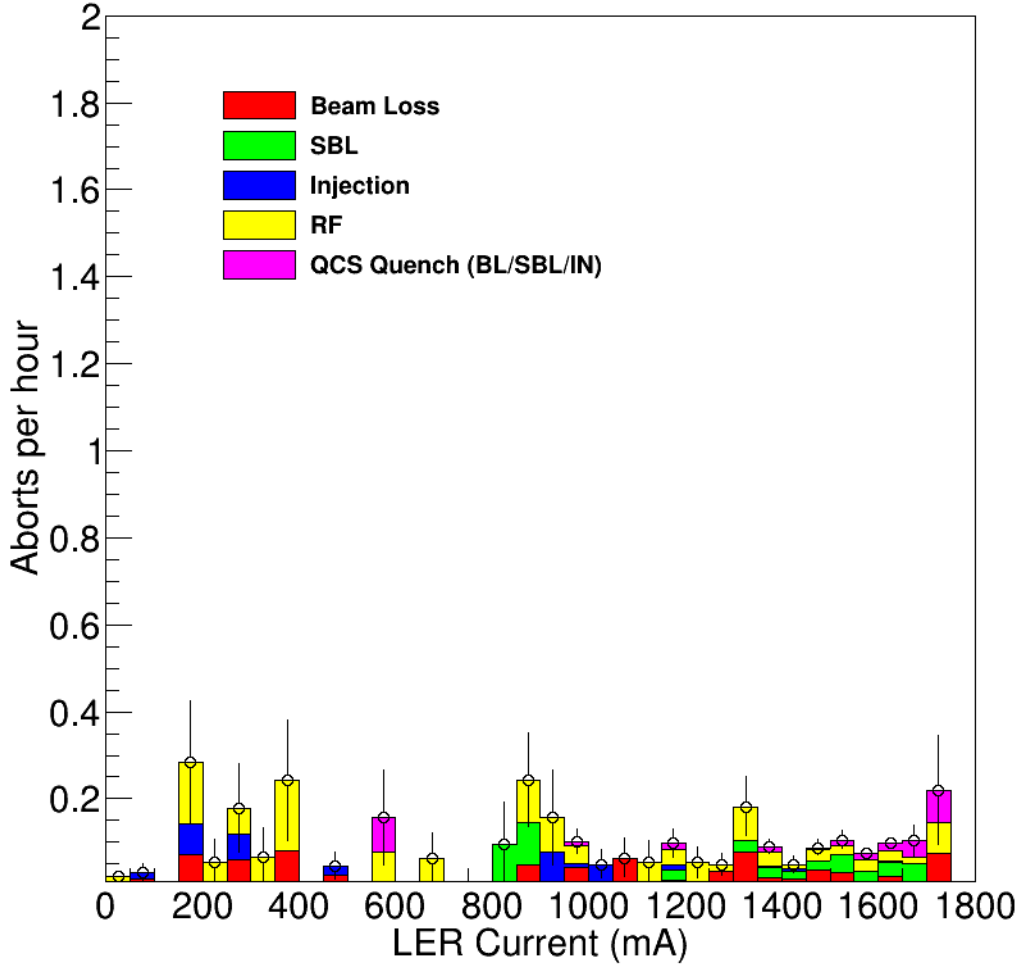
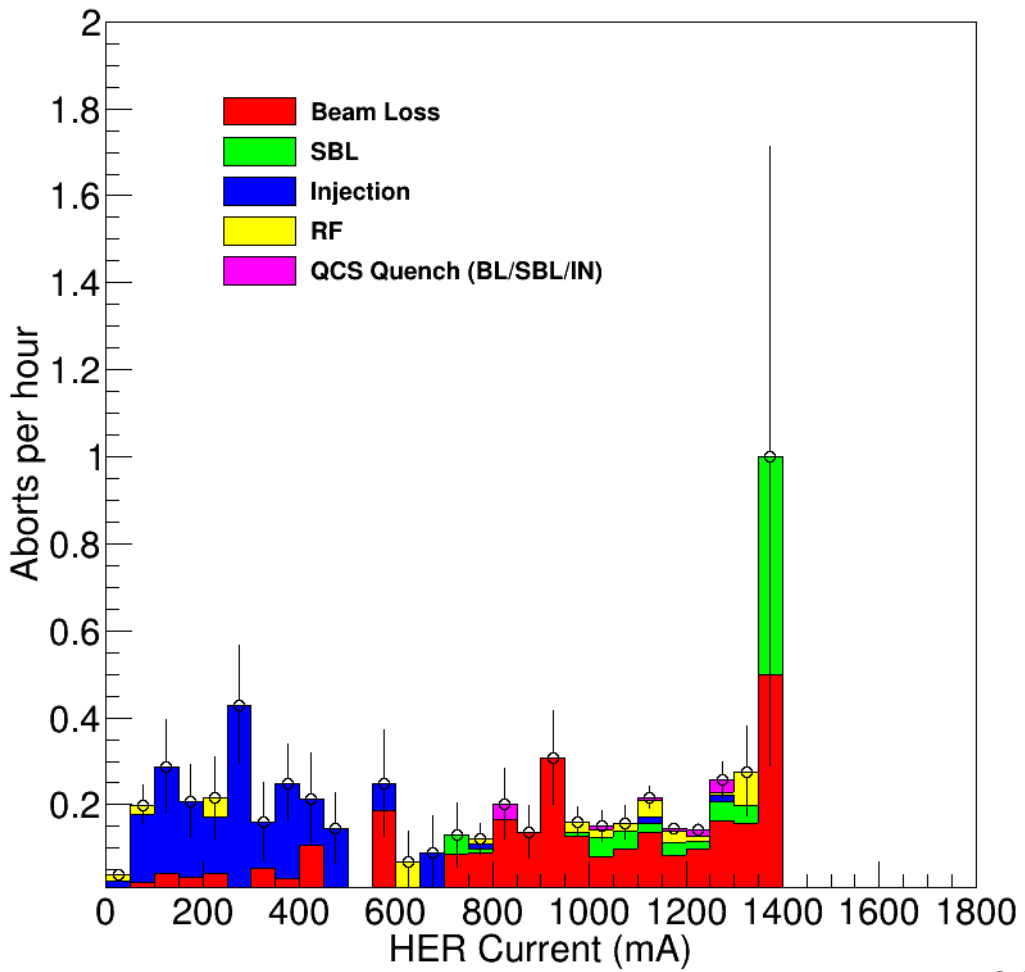
Frequency of SBLs and QCS quenches increase with beam current





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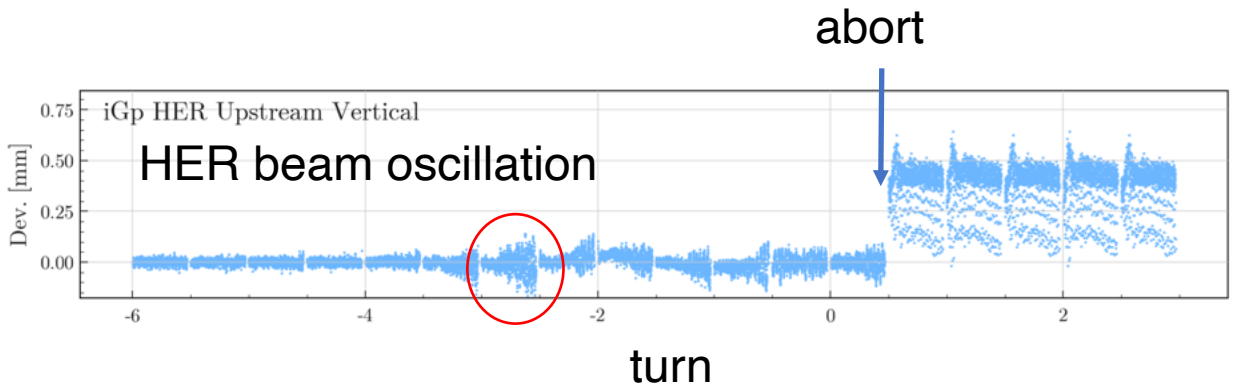
SBL frequency of the HER increases with beam current.

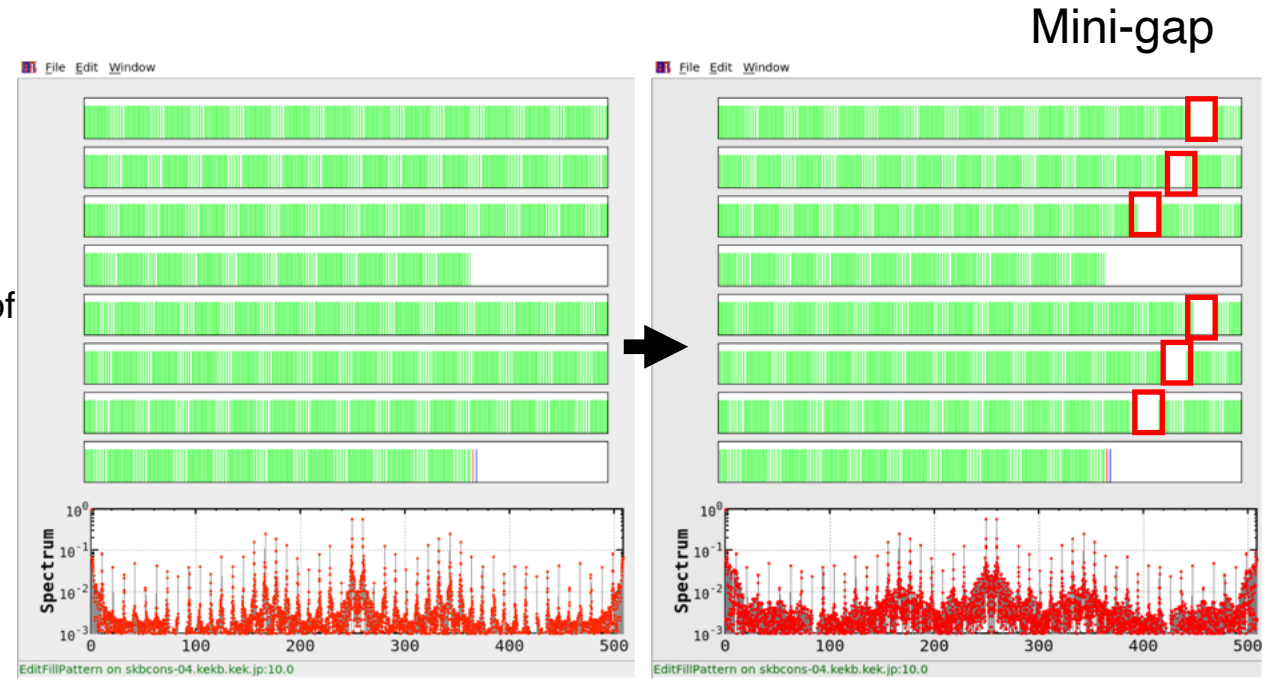
SBLs of the LER often involves QCS quenches.

Reducing the SBL frequency in both rings is essential, and SBL Task Force is currently investigating possible countermeasures.

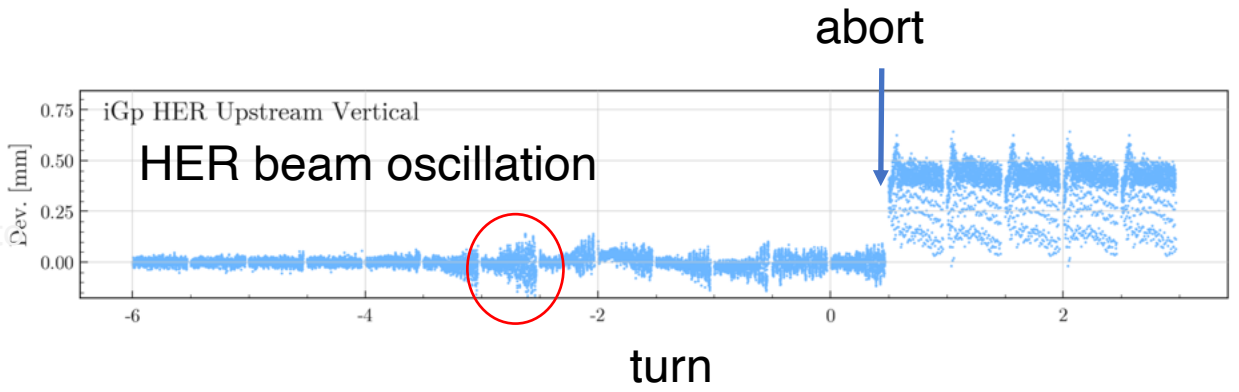
SBL countermeasures

- Belle II & Acc. established a SBL task force (K. Uno)
  - In 2026ab, TF focused on understanding SBL phenomena and developing strategy
    - Systematic evaluation by categorization, BOR data analysis identify location and source, Pressure burst event analysis, beam study (mini-gap fill pattern), mitigation of QCS quenches
- LER
  - Cleaning **Vacseal**® (2025 summer) reduced the total number of events.
  - Not all causes have been identified yet. Further BOR analysis will continue this summer to identify the location.
  - Development of methods to prevent QCS quenches
- HER
  - Cleaning **Vacseal**® reduced SBL count, however, the number of SBLs remains high.
  - The causes may differ from those of SBLs in the LER.
  - Vertical oscillations were observed using BOR data in about 1/3 of SBL events.
- Approaches
  - Bunch train with mini-gap study (T. Yamaguchi, K. Uno)
    - Multibunch effect is one suspected cause of SBL in HER
    - Short bunch train will mitigate the multibunch effect.
  - BOR analysis (H. Nakayama)
    - Location identify (Betatron phase) using big data.





SBL countermeasures

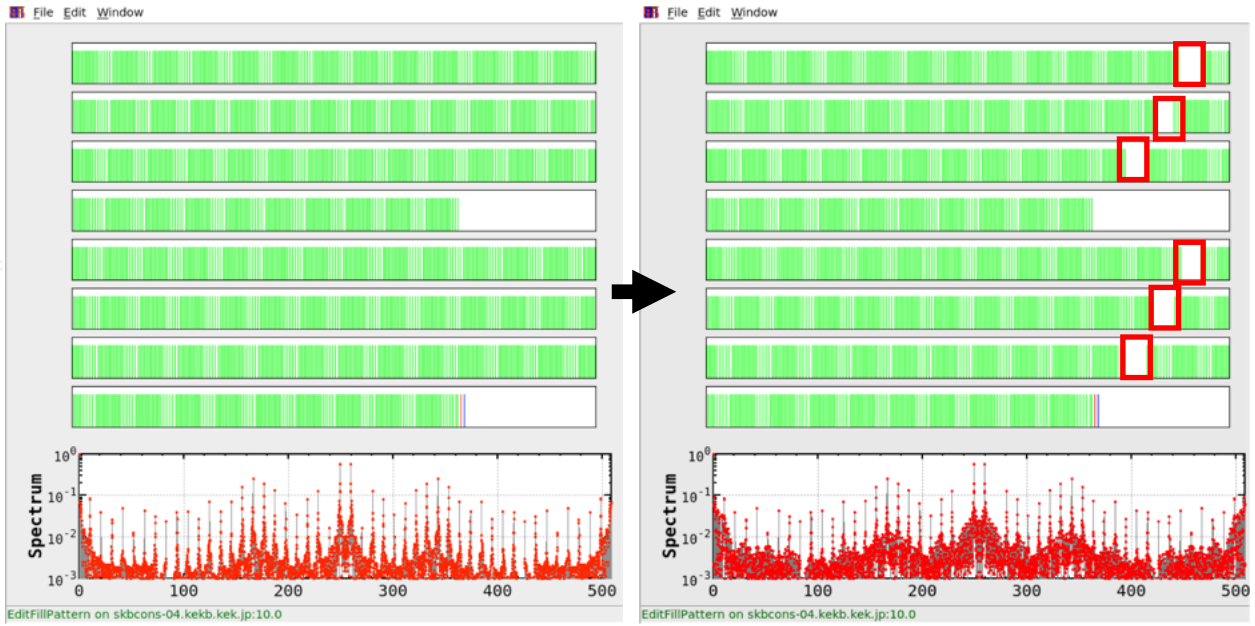


A characteristic oscillation was observed in some SBL events of the HER.

A mini-gap study was performed, and although the conclusion is not yet clear due to the short operation time, the number of characteristic aborts decreased.

SBL TF will analyze the data during the summer and optimize the fill pattern, which may help reduce SBL events.

Mini-gap



Approaches

- Bunch train with mini-gap study (T. Yamaguchi, K. Uno)
  - Multibunch is one suspected cause of SBL in HER
  - Short bunch train will mitigate the multibunch effect.
- BOR analysis (H. Nakayama)
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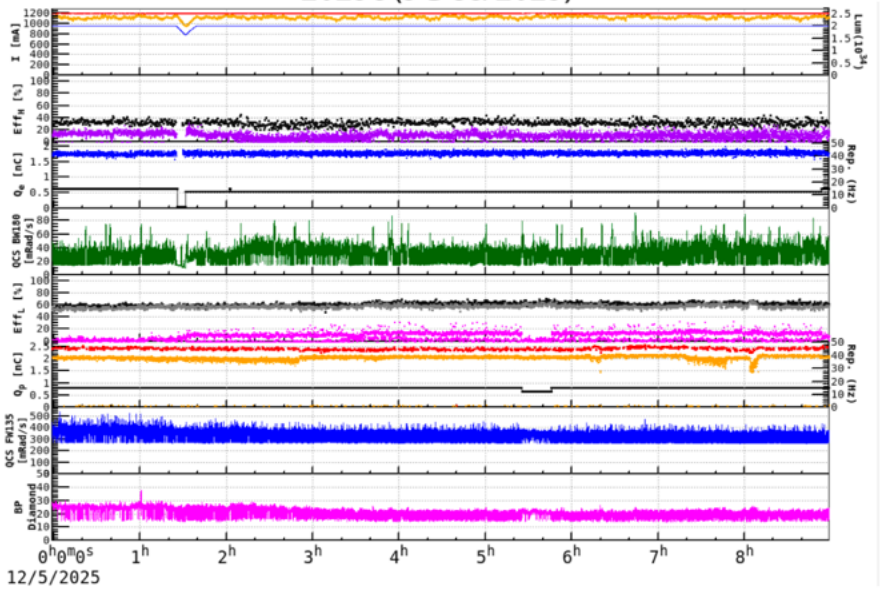
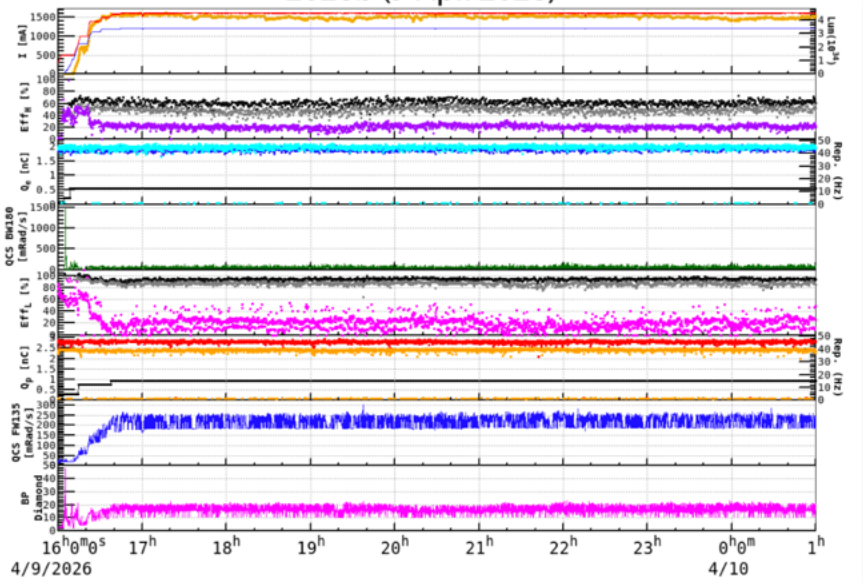
Injection comparison

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).

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G. Mitsuka, Review 17 Apr. 2026

e- RF-gun operation remained stable, and bunch charge was consistently above 2 nC at injection.

Automatic emittance tuning (Y. Seimiya), BT orbit feedback (Y. Shimosaki) and manual phase tuning stabilized Linac and BT and improved LER and HER injections.

High bunch current study

- β_y^*: 0.9 mm

HER single beam ε_y

ε_y increases linearly as bunch current I_b to 0.5 mA and then saturates at around $\varepsilon_y \sim 100$ pm.

LER single beam ε_y

ε_y increases only slightly up to bunch current I_b to 0.8 mA, then rises sharply.

Consistent with TMCI instability simulation at around $I_b = 1$ mA.

Impedance increase is probably caused by collimator damage.

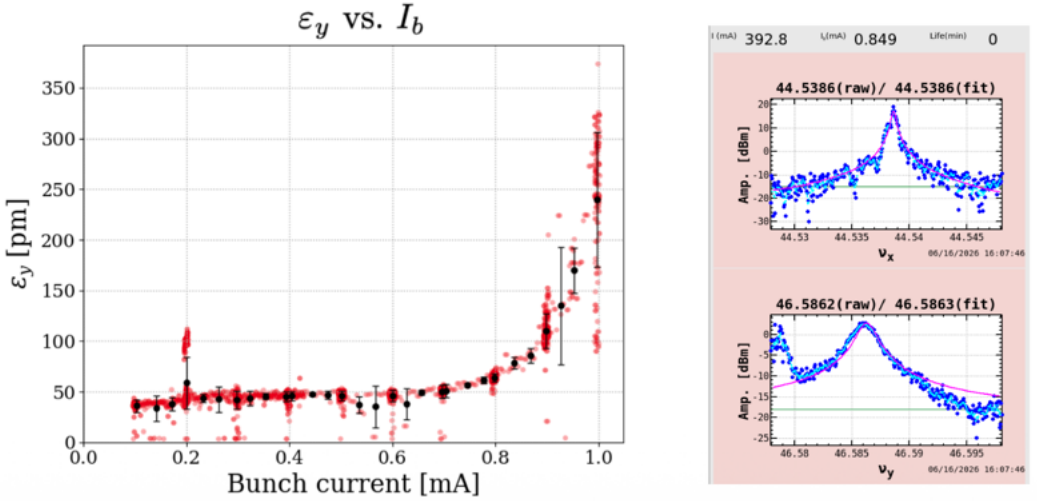
Damaged collimator (LER D03V4) is scheduled to be replaced this summer shutdown.

High bunch current collision up to $I_b^+ I_b^- = 0.8\ \mathrm{mA}^2$

Specific luminosity showed little dependence on bunch current

LER 単独ビームの垂直エミッタンス

- I_b= 0.8 mA ~1.0 mA でエミッタンス増大。
- コリメーター損傷によるインピーダンス増加が原因と考えられる。



H. Sugimoto, commissioning meetings

2026ab, the operating point was kept close to the threshold of blow-up while maintaining the best performance.

The single beam LER beam-size blow-up must be resolved to increase the beam current.

Major Troubles during 2026ab

- Vacuum leak (fixed during 2026ab, Countermeasures this summer)
  - LER Nikko wiggler section (D10_L7) (Replace new water-cooling type chamber this summer)
  - Tsukuba straight section downstream SS chamber for iBump (D02_H16) (Replace modified SS chamber to reduce the risk of vacuum leak this summer)

  Needs to tunnel work, it takes around a few hour or a few days to activate NEG
- QCS Helium compressor solenoid valve trouble at 2026-02-15 (solved temp., Replace new valve this summer)

  It takes 2 days to fill liquid He
- SBL, Beamloss

  Recovering RF, increase current, injection tuning

  It takes around 10 min.

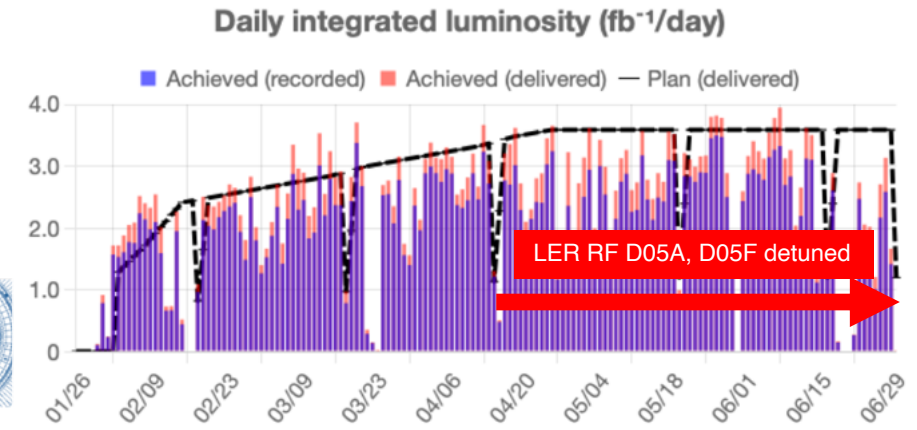
  QCS quenches

  LER: 36, HER : 22, Both :2, Total 61
- Air conditionar failure at D07 control room (Repaired during 2026ab)
- Injection septume power suppy trouble (Repaired during 2026ab)
- LER Injection Kicker miss fire (PS wii be replaced this summer)
- LER RF D05F cavity leak (Cavity will be replaced this summer)

  Two cavities (D05A, D05F) was detuned during 2026ab
- Electric power outage 2026-06-20

  Needs a long time recovery (emergency recovering)

RF D05F trouble



[Daily delivered $\int \mathcal{L}$(plan)] = [Delivered L_{peak}(plan)] × [86400 sec] × [Daily efficiency (plan)]

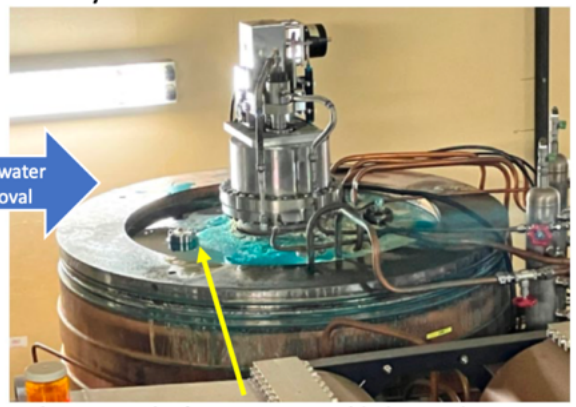
LER D05F abnormal pressure increase

cooling water leak

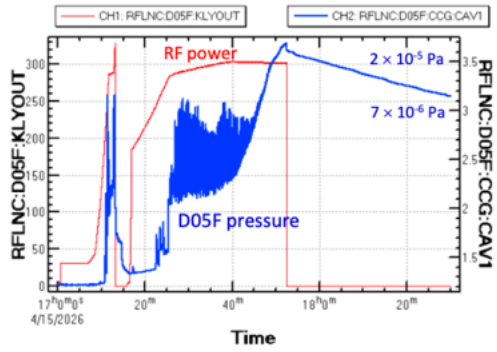
D05F ARES Cavity

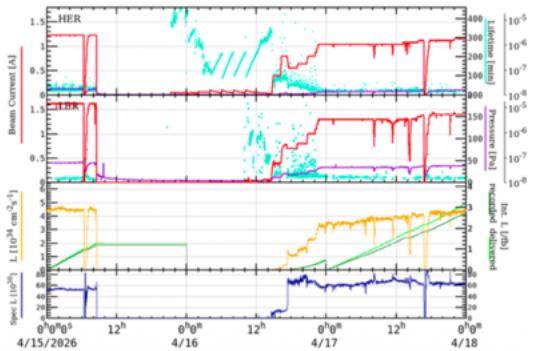
Water accumulation above the storage cavity due to a water leak.

After water removal



There is a risk of corrosion at welded parts due to residual water trapped in gaps.





6th May 2026 B2EB 8

- Vacuum leak found in the RF D05F cavity during maintenance conditioning.
- Caused by localized corrosion from a cooling water leak.
- Pressure rises when RF power is applied. Two ARES cavities of the LER operated in detuned during this 2026ab run.
- D05A, D05A cavities are currently conduting RF test and leak check.
- D05F will be replaced during the summer shutdown to increase the current limit for the 2027 run.

Summer shutdown major activities

- Damaged collimators will be replaced during this summer shutdown.
  - Mitigate beam size blow-up and TMCI.
- Replace beam pipe for vacuum leak countermeasures
  - Beam pipes at wiggler section will be replace new water-cooling type chamber
  - SS chamber at tsukuba will be replace the modified chamber with improved SR mask.
- Reinforce radiation shielding at OHO
  - To utilize NLC at higher beam currents
- Replace LER injection chamber
  - Improve LER injection efficiency
- Replace or repair RF D05F and D05A cavities
  - Increase beam current
- QCS quench countermeasures
  - Upgrade the loss monitors and acoustic sensors (under discussion).
  - Continue data analysis in the SBL TF to reduce quenches.

Plan for next operation (**under discussion**)

- Target for the 2027 Run **under discussion**
  - Target peak luminosity: > $1\times10^{35}\ \mathrm{cm^{-2}s^{-1}}$
  - Target beam currents : LER 2.6 A / HER 2.0 A
  - Baseline operating conditions (plan A)
    - β_y^*: 0.9 mm
    - 2346 bunches
  - Why β_y^*: 0.9 mm
    - Dynamic aperture is too small at 0.8 mm (observed in 2022).
    - The specific luminosity was about 10% higher at 0.9 mm than at 1.0 mm in this run.
    - β_y^*: 0.8 mm is optional and under discussion
  - Why 2346 bunches?
    - Lower bunch current helps suppress emittance blow-up, as observed in the high-bunch-current study.
    - Favors higher integrated luminosity.
  - Is LER 2.6 A reachable?
    - The RF hardware limitation is on the HER (2.0 A), and corresponding upgrades are planned at LS2.
    - The LER current limitation this run was due to RF cavities failures.
    - 1.7 A was achived by 2-bunch injection at 12.5 Hz. With 21 Hz injection, LER >2.6 A may be achievable.

Achieving $1\times10^{35}\ \mathrm{cm^{-2}s^{-1}}$ is a milestone; pursuing higher integrated luminosity remains the first priority.

Summer shutdown work will focus on resolving the issues that limit beam-current increase.

In parallel, we will continue efforts to reduce SBL frequency and maximize the integrated luminosity.

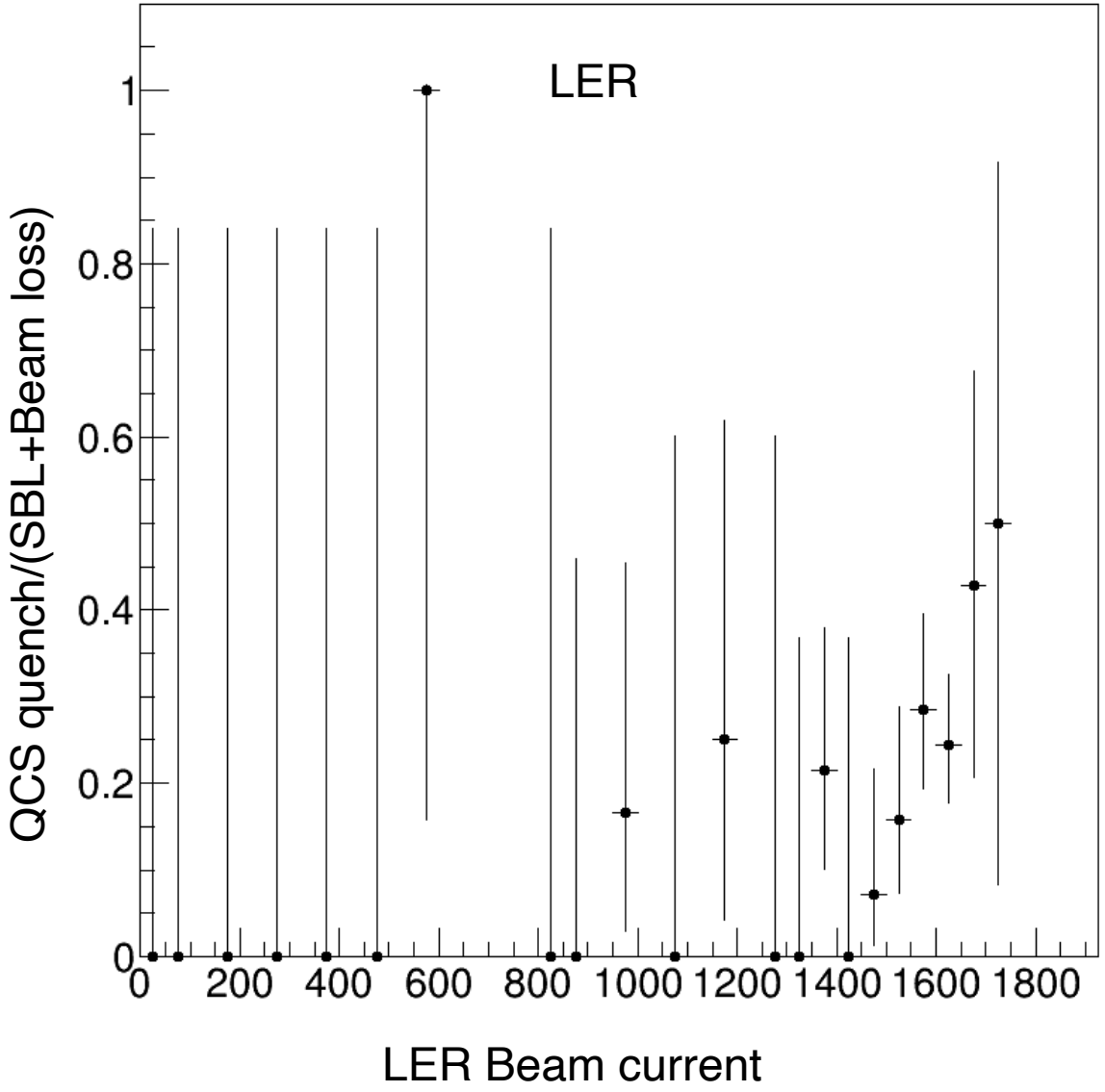
- SBL and Quench Countermeasures
  - Dedicated Task Force continues investigations and countermeasure studies.
- Schedule
  - 2026c will be postponed due to cavity replacement work aimed at increase beam current next run.
  - Mid-December: BT tuning and Linac machine studies start
  - January 12: Main Ring operation start (Earliest case)

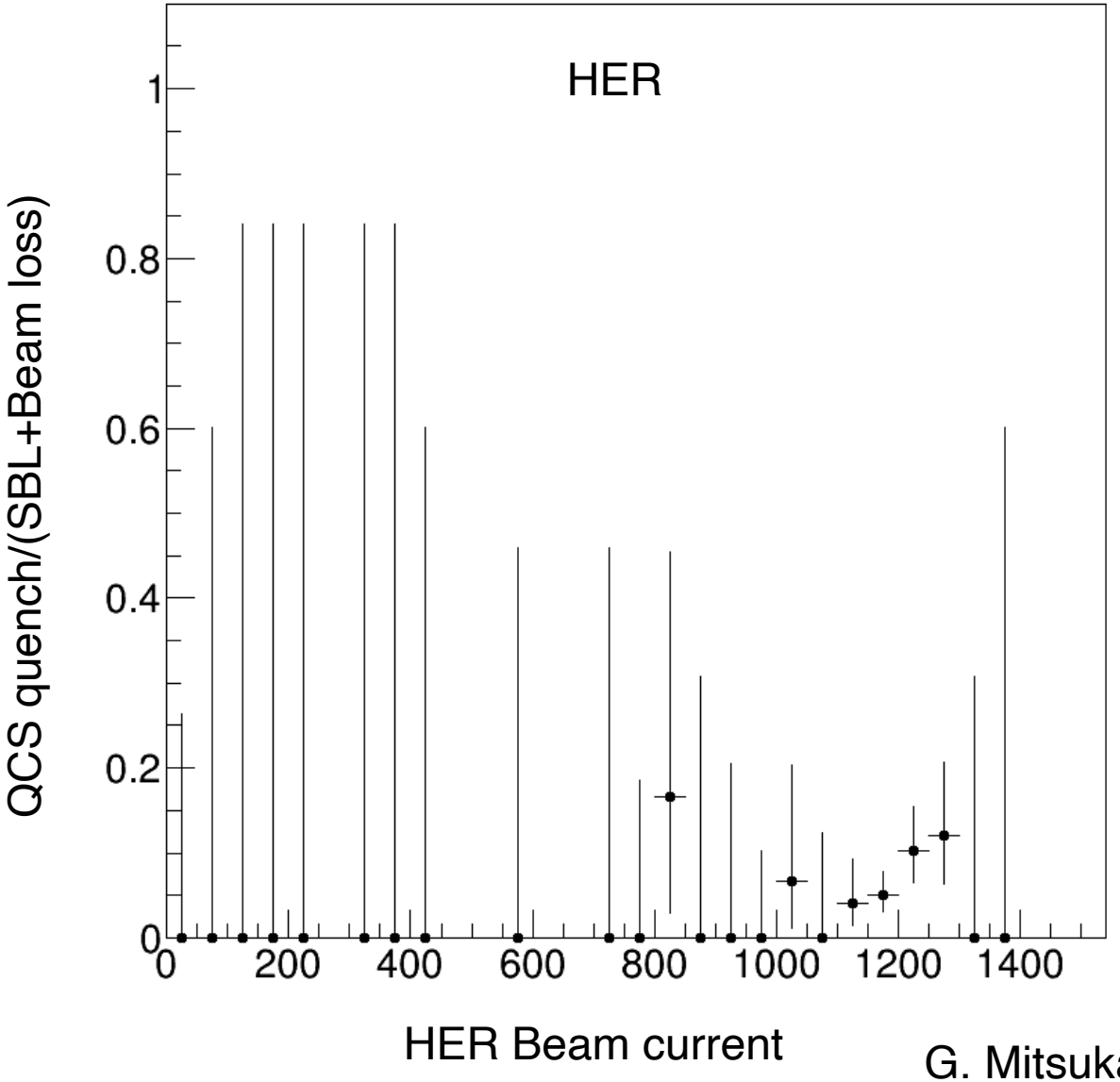
Summary

- 2026ab operation achieved stable high current operation and updated peak luminosity record.
  - HER 2-bunch injection and BT emittance tuning & orbit FB enabled stable high current operation.
  - Peak luminosity reached $5.32 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$ w/o Belle II, $5.28 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$ w/ Belle II.
  - Total delivered integrated luminosity reached $914\ \mathrm{fb^{-1}}$.
- SBL, beam loss aborts, and QCS quenches remain the major problem for high current operation
  - SBLs of the LER were significantly reduced after beam pipe cleaning during 2025 shutdown.
  - SBL TF is continuing cause analysis and countermeasure studies.
- RF cavities, collimators and other failure components will be replace or repair this summer shutdown.
  - 2026c will be postponed because of the replacement works.
- Beam size blow-up and beam-beam effect are key issue to further increase specific luminosity.
- 2027ab plan is still under discussion.

Backup

Backup QCS quench frequency





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Backup

Optional Operating plan

If the specific luminosity does not improve:

- Squeeze βy to 0.8 mm.
- Reduce the number of bunches.
  - Accept some emittance blow-up if beneficial.
  - The choice will depend on the achieved specific luminosity.
  - Collision performance may improve.
  - Additional machine study time will be required.

Backup

Established Task Force

- Beam-Beam
- SBL
- AI/ML beam
- High current/Injection

High bunch current study

HBC Study　- 目的と測定項目 -

- 単独ビームの垂直エミッタンスのバンチ電流依存性の素性を確認した上で、
  Specific Luminosity (Lsp) のバンチ電流積依存性を調べる。
- また、衝突ありなしの両方でTune scan scan を 行う。

- 測定項目 (時系列)

(1) 単独ビーム、393 bunches
- 垂直ビームサイズのバンチ電流依存性
- Horizontal / Vertical tune scan

(2) 衝突状態、393 bunches
- Lsp vs bunch current products
- Horizontal / Vertical tune scan

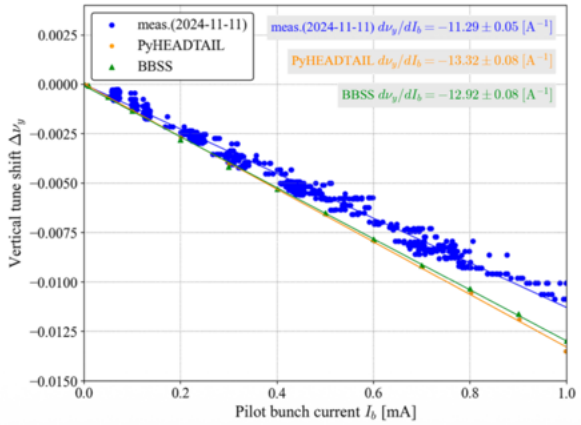
Nominal Condition

Parameters	LER (e^+)	HER (e^-)	Units
N_{bunch}	393		
Bunch Current I_b	$I_b^+ = 0.8$	$I_b^- = 0.75 \times I_b^+$	mA
$(\nu_x,\ \nu_y)$	(44.538, 46.585)	(45.532, 43.606)	

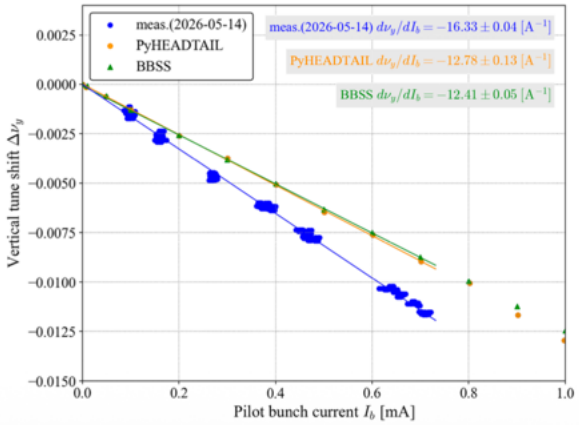
Single Bunch Vertical Tune Shift Measurement

- 2026/05/14 の測定では、2024/11/11 の測定に比べて vertical tune shift が明らかに大きい。
- PyHEADTAIL の結果と比較しても大きい。計算に使うWake data は石橋氏に提供して頂いた。
- コリメータ損傷の影響が疑われる。

11/11 2024 by* = 1.0 mm



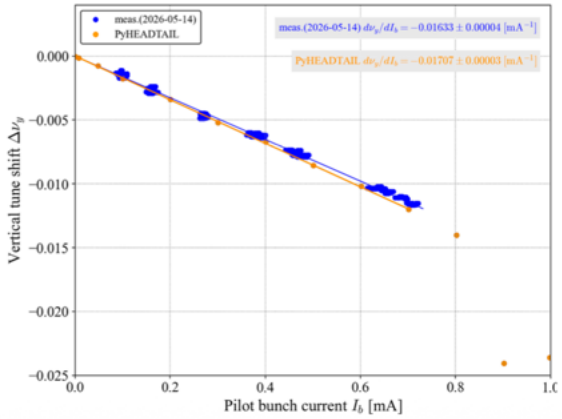
05/14 2026 by* = 0.9 mm

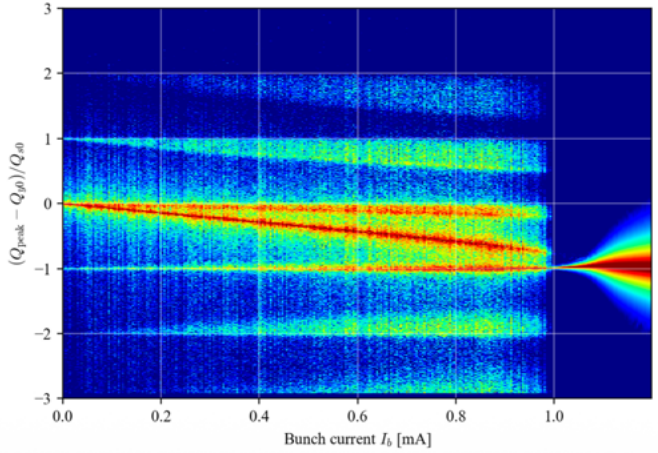


Transverse Mode Coupling Instability の閾値

- 測定を再現するように wake field をスケールし、閾値電流を概算した。
- 現状の wake model では、バンチ電流 1 mA は厳しい可能性がある。

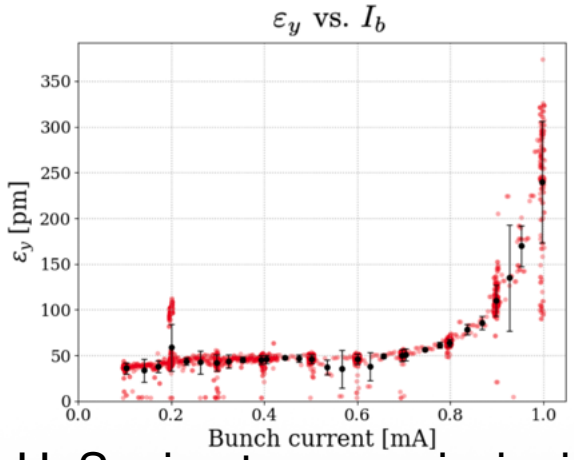
Vertical Tune Shift

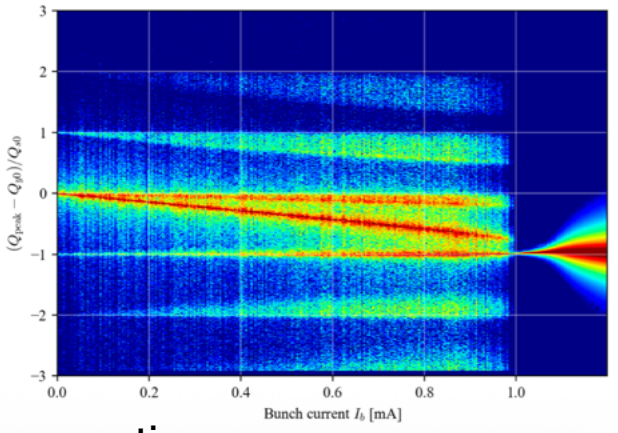




Transverse Mode Coupling Instability の閾値

- 測定された tune shift を再現するように ウェイクのデータをスケーリングして計算。
- バンチ電流 1 mA は厳しいという予測であった。
- 今回のスタディ結果と整合している。

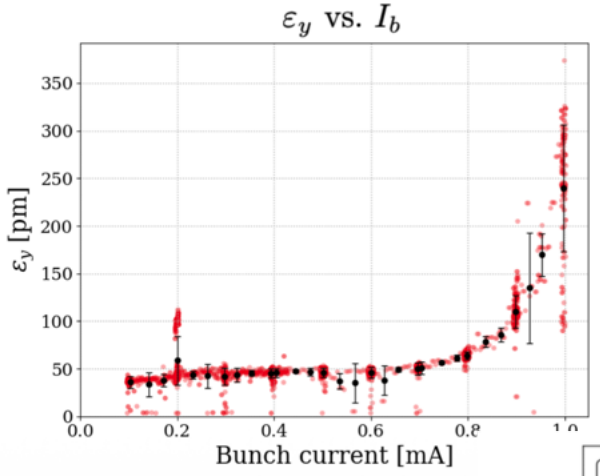


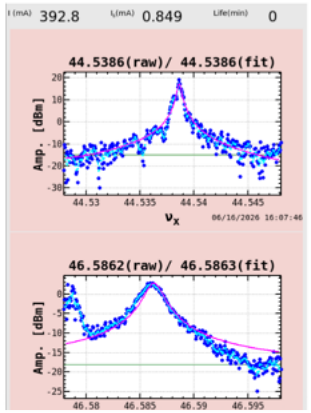


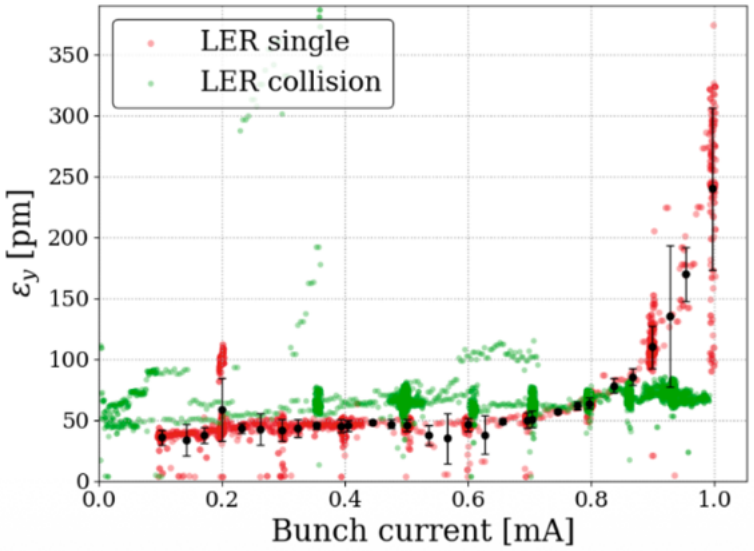
High bunch current study

LER 単独ビームの垂直エミッタンス

- I_b = 0.8 mA ~1.0 mA でエミッタンス増大。
- コリメーター損傷によるインピーダンス増加が原因と考えられる。

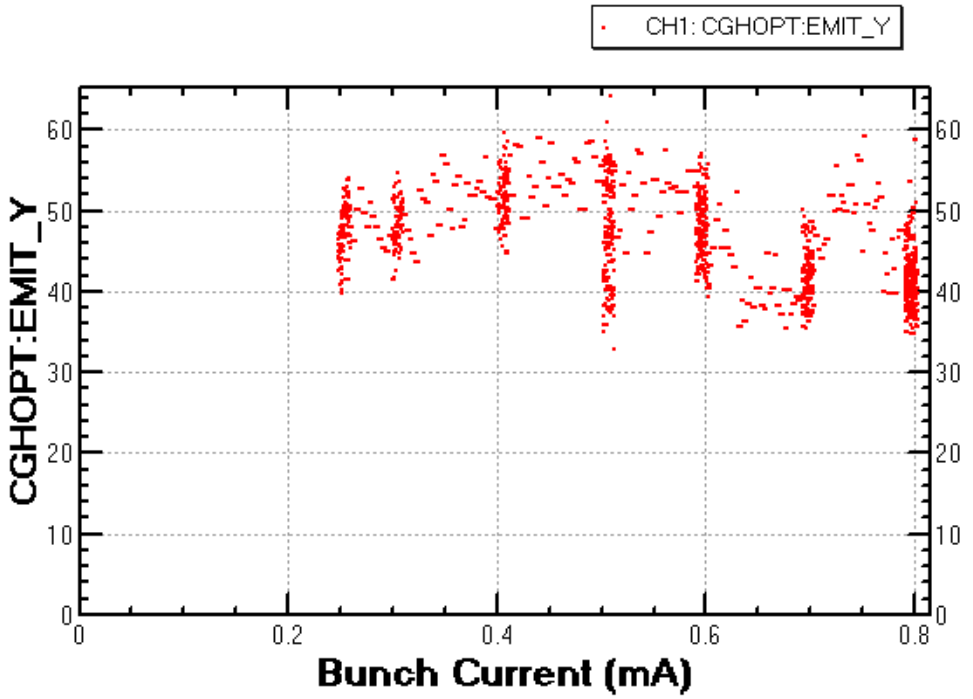






The reason why the beam-size blow-up was mitigated under collision conditions remains unsolved.

HER 単独ビームの垂直エミッタンス

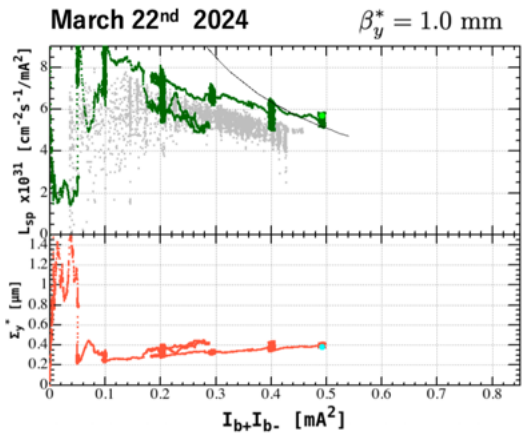


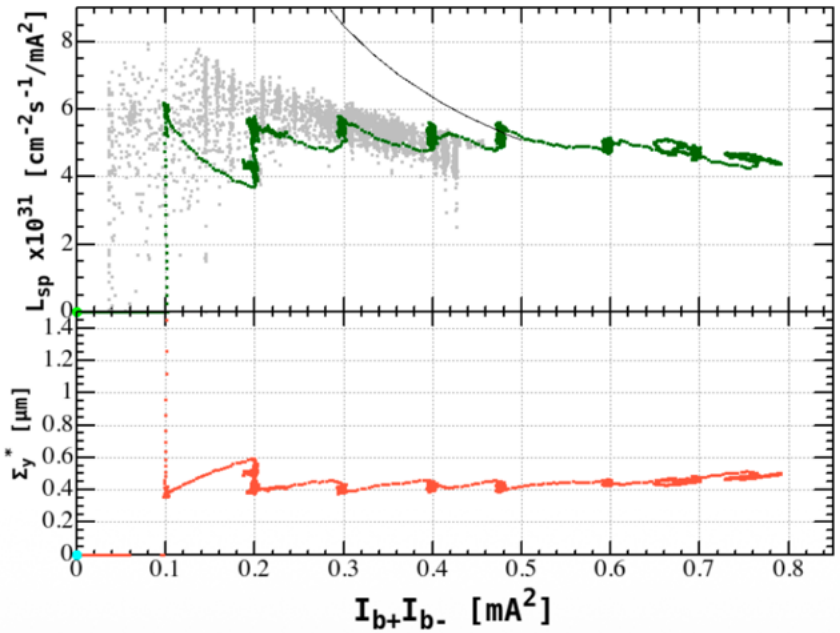
H. Sugimoto, commissioning meetings

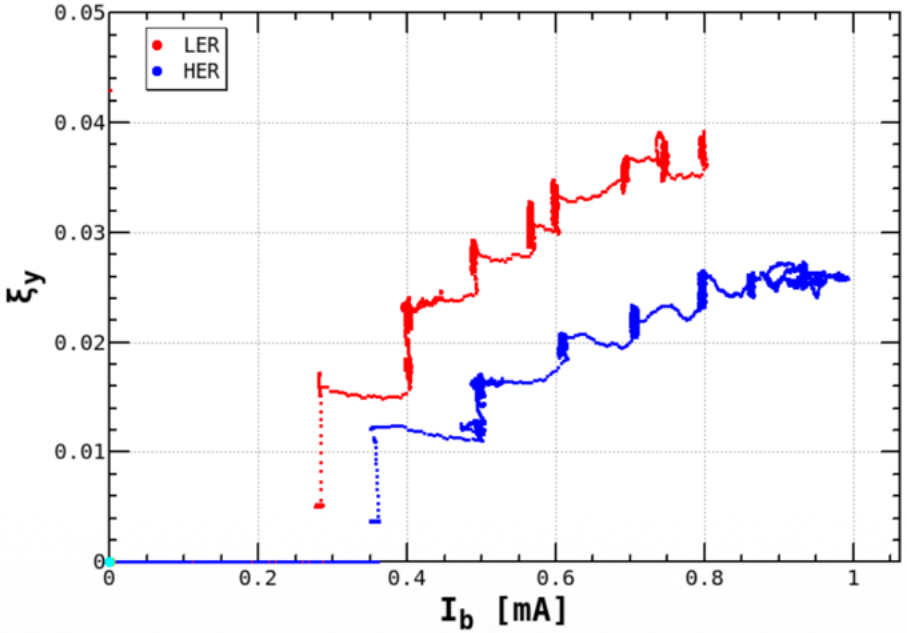
High bunch current study

Lsp vs. Bunch Current Products

- IPKnobは $I_b = 0.5$ mA^2 で一通りスキャン。他の電流はiBump voffsetのみスキャン
  (R1 Knobのバンチ電流依存性あり。低バンチ電流積ではLER R1 Knobが設定限界に。)
- Spec. Lumi. はバンチ電流積にあまり依存しない。







Countermeasures for wiggler leak at the LER

Mitigation leak damage

Clamshell method

Mitigate the damage to leak by installing clamshell chamber at the flange.
This method cannot prevent vacuum leaks.

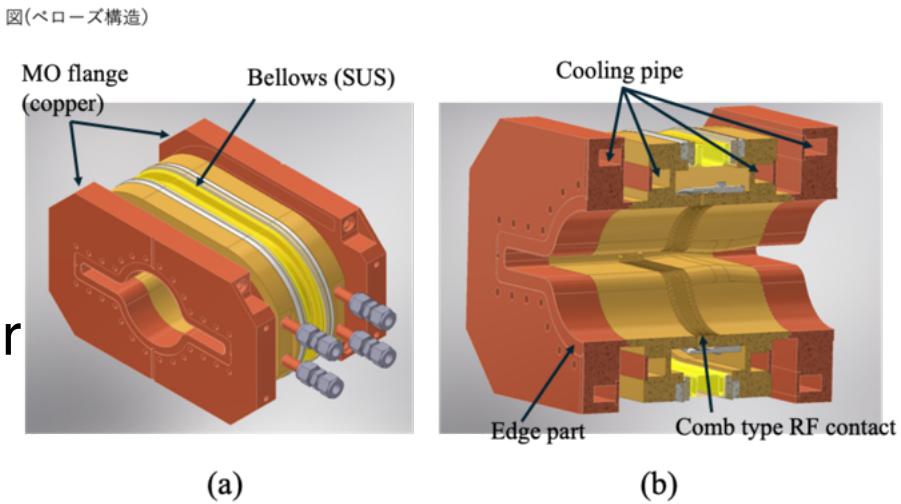
Shield the flange from radiation by a deforming chamber.

This is expected to reduce the probability of vacuum leaks.

Fundamental countermeasure

New water-cooled bellows chamber

Reduce the flange temperature using water cooling.
10 chambers are planned to be installed this summer



S. Terui, commissioning meetings