Machine plan for 2025c and 2026ab

Gaku Mitsuka (KEK, Accelerator Laboratory)
on behalf of the SuperKEKB commissioning group

B2GM, 29 Sep. 2025

Operational Plan for 2025c-2026b

- **Highest priority in 2025c-2026b is integrated luminosity (recorded) > 425 fb^{-1}.**
- 2025c–2026b run: 5 Nov. 2025 – 1 Jun. 2026
  - Vacuum scrubbing: 5 Nov. 2025 – 17 Nov. 2025 = 13 days
  - Collision run in 2025c: 19 Nov. 2025 – 24 Dec. 2025 = 36 days
  - (Winter shutdown: 24 Dec. 2025 – 7 Jan. 2026 = 15 days)
  - Collision run in 2026a/b: 9 Jan. 2026 – 1 Jun. 2026 = 144 days
  - **Collision run total: 36 days + 144 days = 180 days**
- Physics runs account for 80% of the full collision operation, ~150 days.
  - 4 days per 3-week cycle are allocated to machine tuning, study, maintenance, etc.

December 2025

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Tuning, study, maintenance, etc.

Physics run

Operational Plan for 2025c-2026b

October

Sun	Mon	Tue	Wed	Thu	Fri	Sat
28	29	30	1	2	3	4
	Today		Linac tuning			
5	6	7	8	9	10	11
			Linac tuning			
12	13	14	15	16	17	18
			Linac tuning			
19	20	21	22	23	24	25
	DR/BT start					
26	27	28	29	30	31	1
			Linac/DR/BT tuning			

November

Sun	Mon	Tue	Wed	Thu	Fri	Sat
26	27	28	29	30	31	1
						Linac/DR/BT tuning
2	3	4	5	6	7	8
	Linac/DR/BT tuning		MR start		Vacuum scrubbing	
9	10	11	12	13	14	15
			Vacuum scrubbing			
16	17	18	19	20	21	22
		Collision tuning		Physics run		
23	24	25	26	27	28	29
	Physics run		Maintenance		Physics run	
30	1	2	3	4	5	6
Physics run						

December

Sun	Mon	Tue	Wed	Thu	Fri	Sat
30	1	2	3	4	5	6
				Physics run		
7	8	9	10	11	12	13
		Machine development			Physics run	
14	15	16	17	18	19	20
			Physics run			
21	22	23	24	25	26	27
		Physics run			2-week shutdown	
28	29	30	31	1	2	3
		2-week shutdown				

January 2026

Sun	Mon	Tue	Wed	Thu	Fri	Sat
28	29	30	31	1	2	3
					2-week shutdown	
4	5	6	7	8	9	10
		Linac/DR/BT tuning			Physics run	

9/8 -: Linac operation
- Linac tuning
- New RF gun RF conditioning/commissioning
- New ECS RF conditioning

10/20 -: DR/BT operation
- DR tuning, BT tuning
- New ECS commissioning
- New fast kicker commissioning

11/5 - 11/17: Vacuum scrubbing
- Study on vertical emittance blowup in HER

11/17 - 12/24 (5.5 weeks): Physic run
- Same condition as the 2024c-run end + NLC on
- Operation plan in 3-week increments :
  - 17 days: physics run
  - 4 days: machine development
- 1/5 - Linac, DR, BT operation
- 1/7 - MR operation

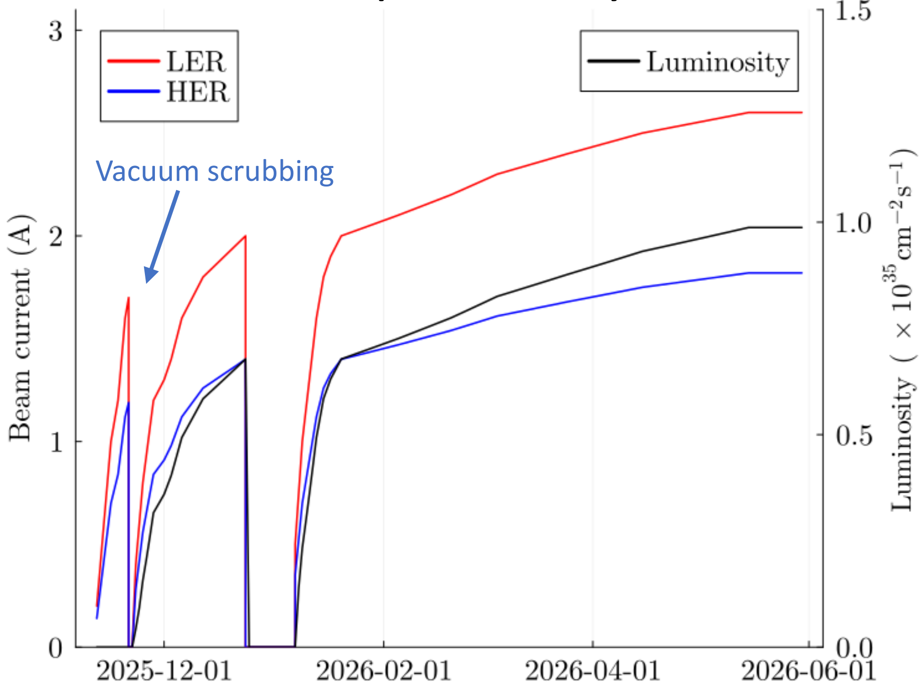
Plan A: basic plan

Target
Peak luminosity = $1 \times 10^{35}\ cm^{-2}s^{-1}$
Integrated luminosity > $425\ fb^{-1}$

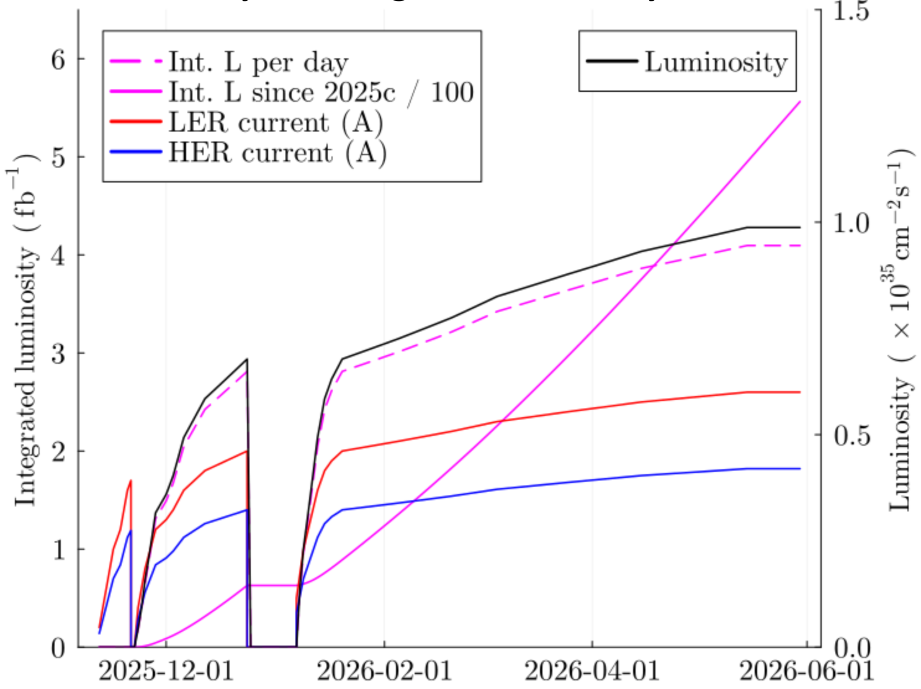
Key parameters
Specific luminosity = $5.0 \times 10^{31}\ cm^{-2}s^{-1}mA^{-2}$ at $0.86\ mA^2$
Accelerator efficiency > 60% (N.B., ~67% at 1.7 A & 1.3A in 2024c)

Requirements
2-bunch injection in HER and LER, β_y^* squeezing to 0.9 mm (plus, possibly β_x^* squeezing)
Mitigation of beam-beam effects

Beam current and peak luminosity



Luminosity and integrated luminosity



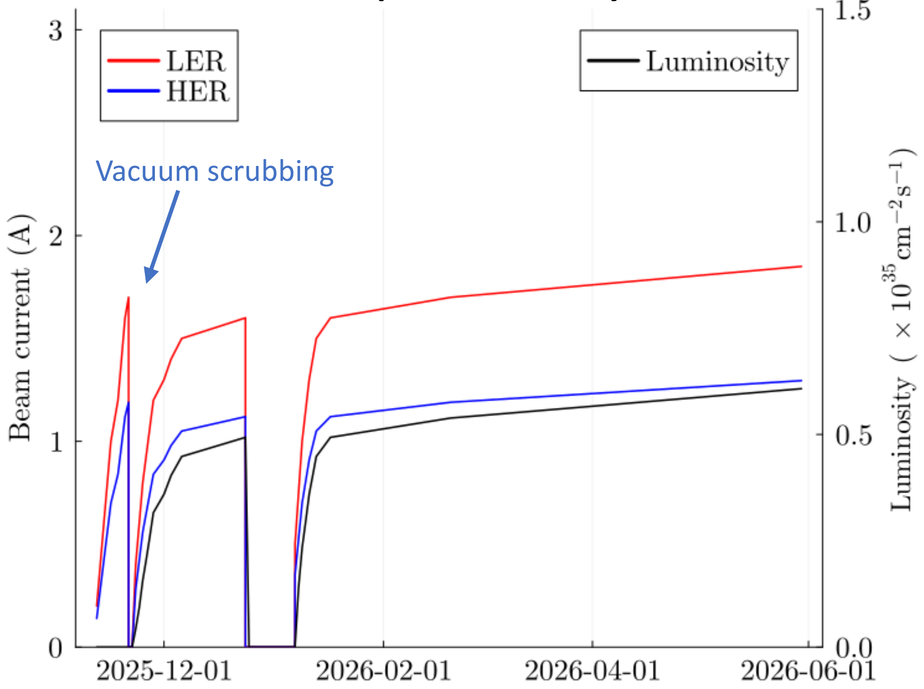
Plan B: optional plan

Target
Peak luminosity = 6×10^{34} cm^{-2}s^{-1}
Integrated luminosity > 425 fb^{-1}

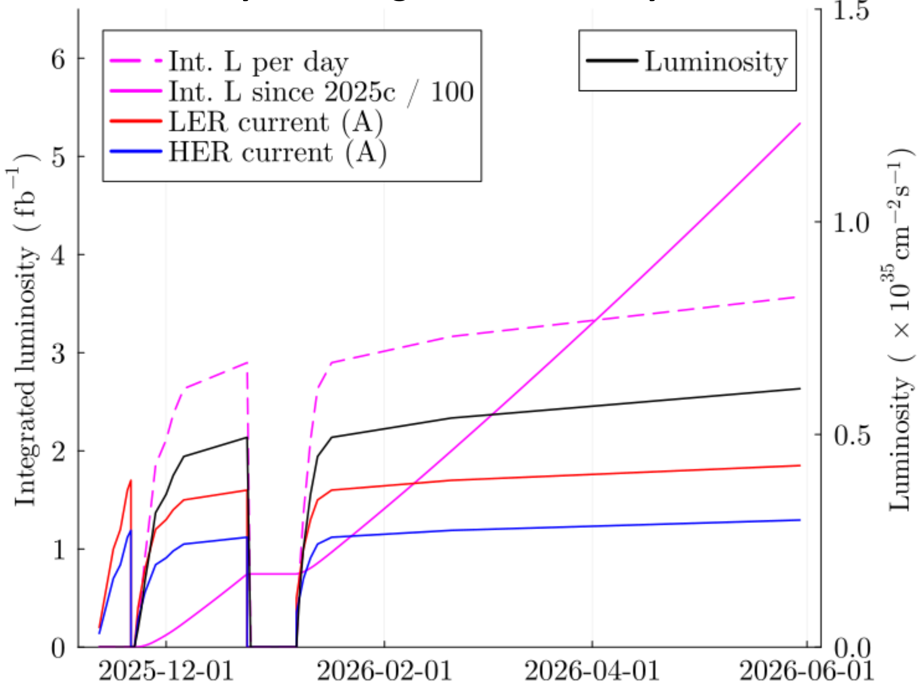
Key parameters
Specific luminosity = 5.9×10^{31} cm^{-2}s^{-1}mA^{-2} at 0.44 mA^2
Accelerator efficiency > 85% (N.B., highest record~88% in 2022c)

Requirements
Stable operation (less SBL, less QCS quench, less machine/detector trouble)
2-bunch injection in LER, Relaxing beam-beam effects

Beam current and peak luminosity



Luminosity and integrated luminosity



Study plan in 2025c operation

- Vacuum scrubbing: 5 Nov. 2025 – 17 Nov. 2025
  - Hardware tuning
    - Sanity check
    - Calibration (timing, monitor gain, beam-based alignment, collimator position, etc.)
  - Optics tuning: ε_y in HER (global orbit, and IR optics & orbit)
  - 1st trial of turn-by-turn BPM measurements in multi-bunch operation
  - 1-bucket spacing pattern vs. SCC HOM power, etc.
- Physics collision run in 2025c: 19 Nov. 2025 – 24 Dec. 2025
  - Correction for cancel coil errors using the QC1RE skew sextupole
  - Nonlinear & D03V4 collimators optimization to reduce BGs, checking pressure rise at NLC (HOM)
  - Betatron tune measurement along bunch train
  - LLRF coupled-bunch instability damper optimization
  - Beam-beam study
- Beam tuning
  - Physical and dynamic aperture measurements by TBT BPMs (sextupole optimization, impedance, ...)
  - σ_y vs. bunch current (bunch-by-bunch FB parameter optimization)

Summary

- 2025c–2026b run: 5 Nov. 2025 – 1 Jun. 2026
  - Highest priority is integrated luminosity (recorded) > 425 fb^{-1}.
  - Plan A (basic) or B (optional) or between A and B
- Full collision operation~180 days
- Physics runs account for 80% of the full collision operation~150 days.
  - 4 days per 3-week cycle are allocated to machine tuning, study, maintenance, etc.
- Beam studies in the vacuum scrubbing run
  - Hardware tuning, Optics tuning for HER ε_y, TBT measurements with multi bunch, etc.
- Beam studies/tuning in physics run
  - Correction for cancel coil error, NLC optimization
  - Physical and dynamic aperture

Backup

Plan A: basic plan

Detailed explanation

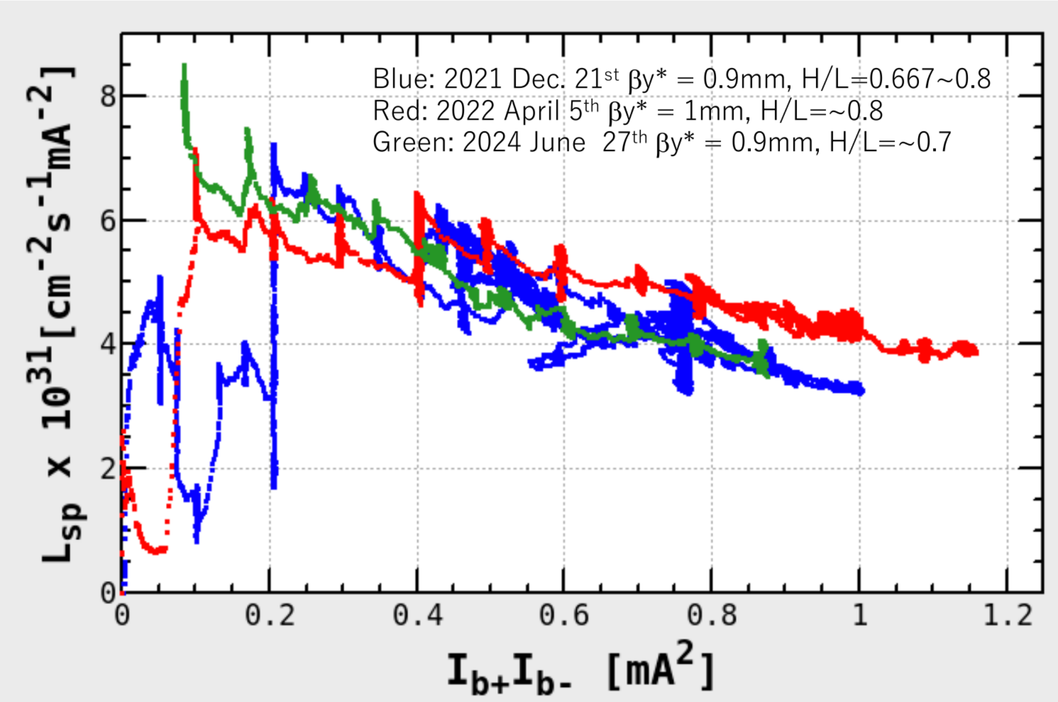
- **Peak luminosity = 5.0 × 10^{31} $cm^{-2}s^{-1}mA^{-2}$ x 0.86 mA^2 x 2346 bunches = 1.0 × 10^{35} $cm^{-2}s^{-1}$**
- **Challenge 1: specific luminosity 5.0 × 10^{31} $cm^{-2}s^{-1}mA^{-2}$** (see p8)
  - Needs to solve the emittance blowup that occurred in HER 2024c
  - Needs squeeze β_y^* to 0.9 mm to lower the beam size at IP
- **Challenge 2: high bunch current 0.86 mA^2 for 2346 bunches** (see p9-11)
  - Corresponds to 1.8 A in HER and 2.6 A in LER
  - Needs to realize 2-bunch injection in LER and HER
  - Needs to mitigate beam-beam effects
  - β_x^* squeezing to 50 mm or lower is planned to avoid σ_x^* blowup harming beam injection.
- **An even relaxed requirement on machine tuning time** (see p12, 13)
  - Accelerator efficiency > 60% is tolerable (N.B., ~67% at 1.6 A & 1.3A in 2024ab.)
  - Namely, machine tuning in the daytime and physics run in the evening and midnight are allowed.

Plan B: optional plan

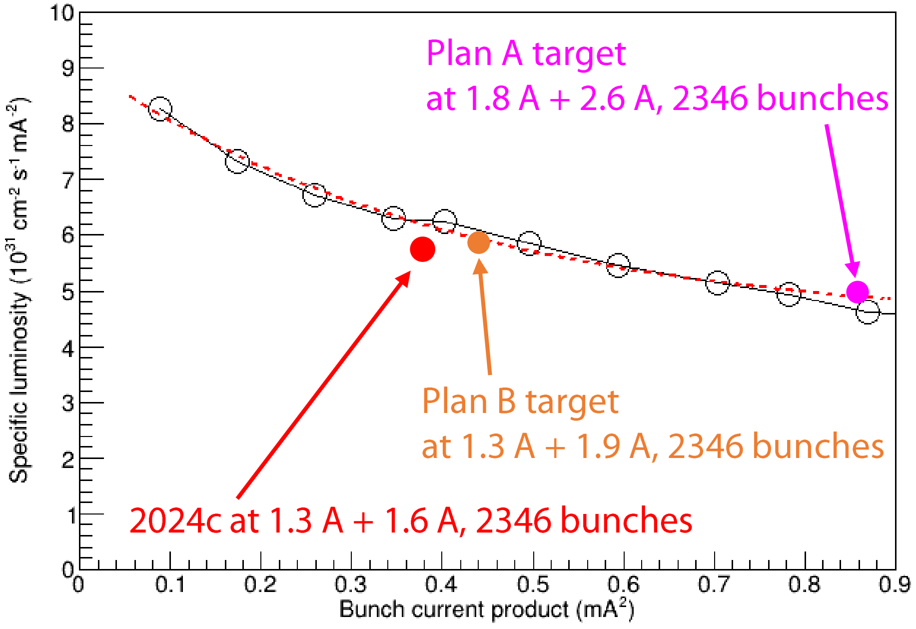
Detailed explanation

- **Peak luminosity = 5.9×10^{31} $cm^{-2}s^{-1}mA^{-2}$ x 0.44 mA^2 x 2346 bunches = 6.0×10^{35} $cm^{-2}s^{-1}$**
- **Challenge 1: very stable physics run, minimizing machine tuning time** (see p12, 13)
  - Needs to avoid beam abort, QCS quench, and machine/detector troubles as low as possible
  - Needs to minimize machine tuning time as much as possible while securing modest luminosity
- **An even relaxed requirement on the high current operation** (see p11)
  - Target current is 1.3 A in HER, 1.9 A in LER with 2346 bunches.
  - Could achieve 1.3 A in HER even with 1-bunch injection since the end of Nov. 2024

Specific luminosity



Combined data (red and green in the left panel)

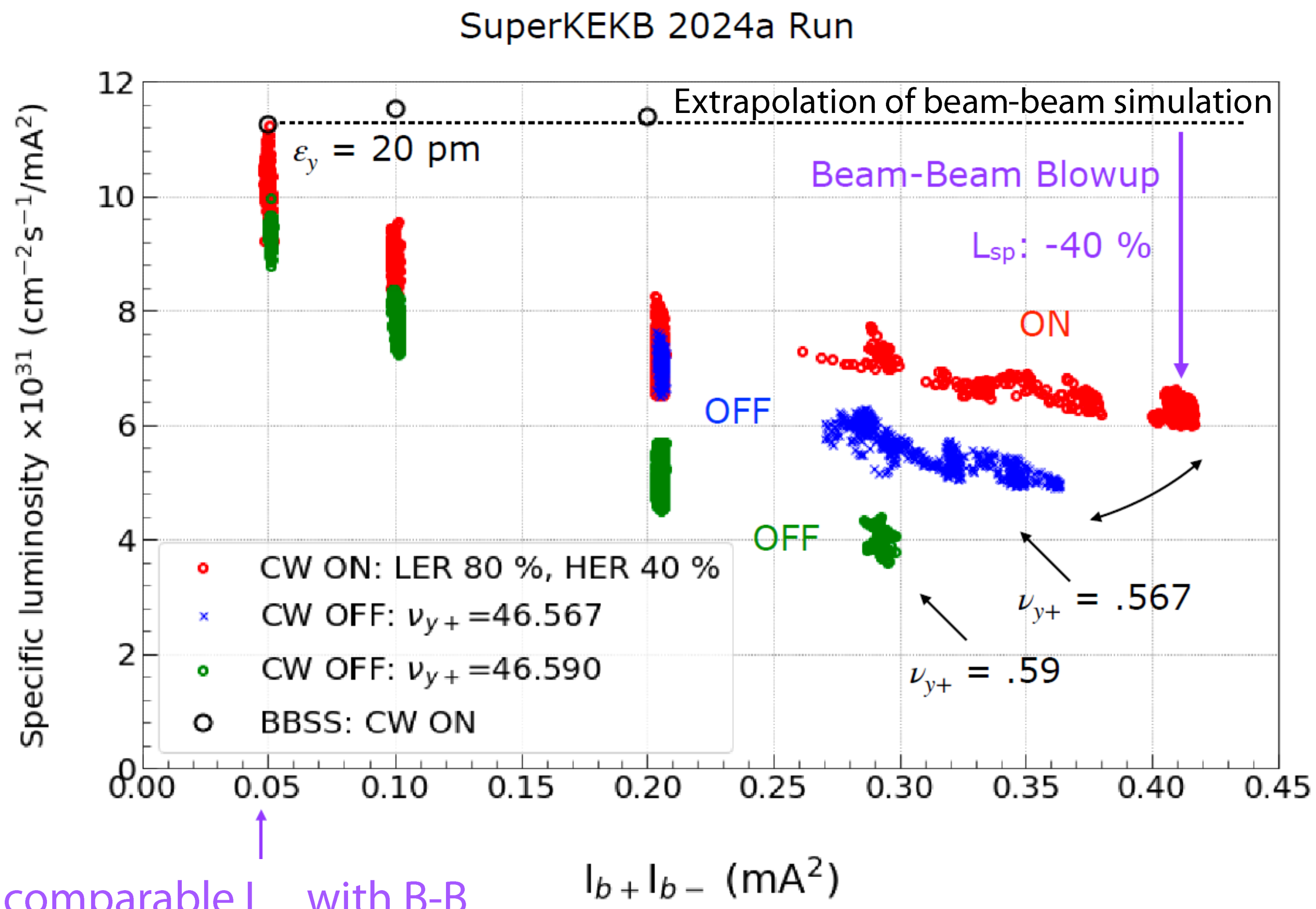


- High specific luminosity could be realized for a small number of bunches, e.g., 393 bunches.
- Challenging to realize it for 2346 bunches due to injection power, chamber-heating induced optics deformation, possibly beam instability, etc.

- 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.

Beam-beam effects

(Y. Ohnishi, eeFACT2025)

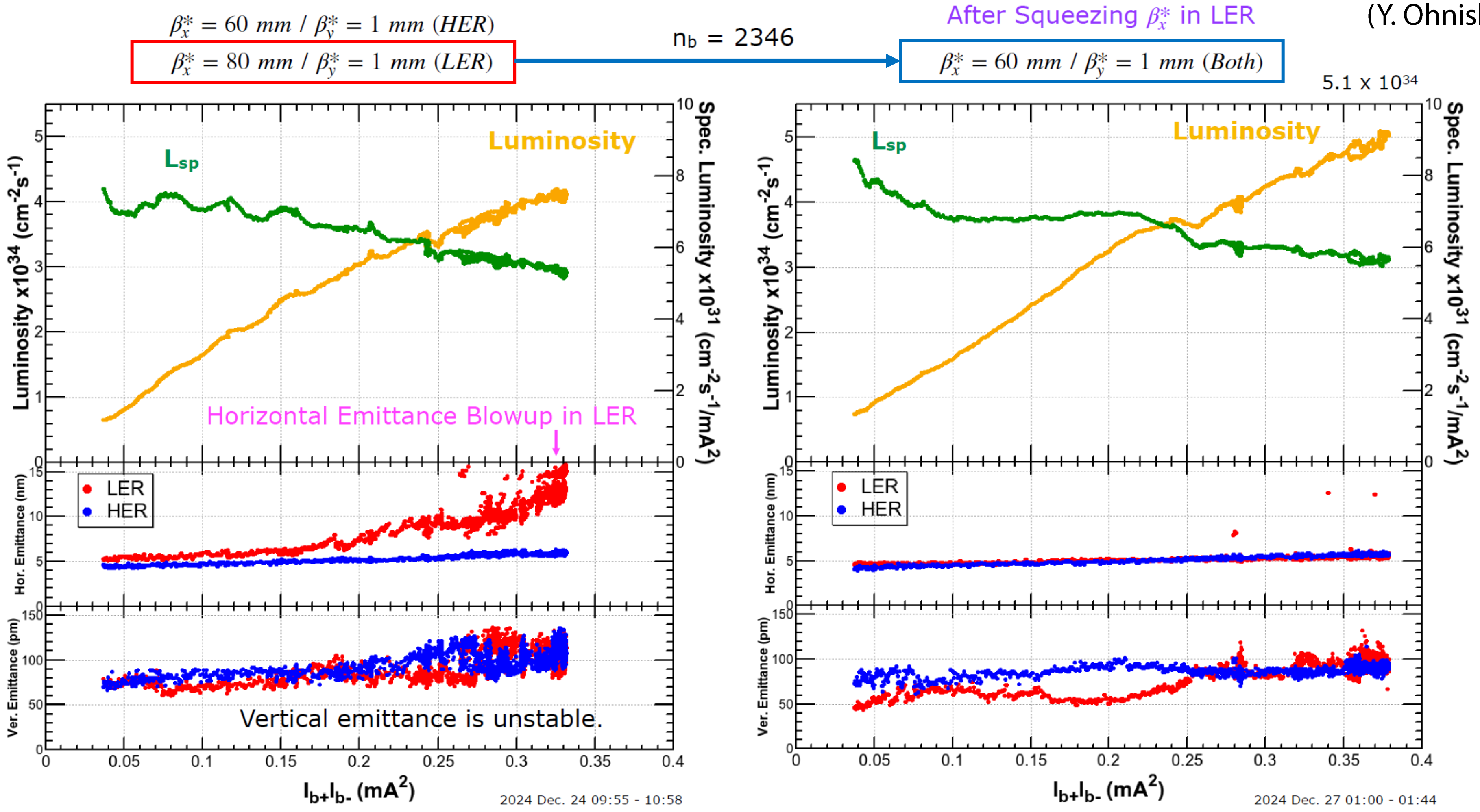


Obtained comparable L_{sp} with B-B simulation at low bunch current

- International collaboration is formed to tackle the beam-beam blowup issue (https://kds.kek.jp/category/1840/).
- Feedback will be applied to machine operation and studies in 2025c.

β_x* squeezing

(Y. Ohnishi, eeFACT2025)



- β_x* squeezing to 60 mm in LER was successful in mitigating σ_x* blowup, then achieving 1.7 A in LER.
- β_x* squeezing to 50 mm or lower is considered to avoid σ_x* blowup harming beam injection.

2-bunch injection

- We could achieve 1.3 A in HER (1-bunch) and 1.7 A in LER (2-bunch) with 2346 bunches in 2024c.
- HER injection started with a 2-bunch scheme. It came to a 1-bunch injection due to the discharge of the RF e- gun.
- Before 2025c, RF e- gun will be replaced with a new type of gun or fixed using a spare cathode plug.
- 2-bunch injection is essential for 1.8 A in HER and 2.6 A in LER in Plan A.

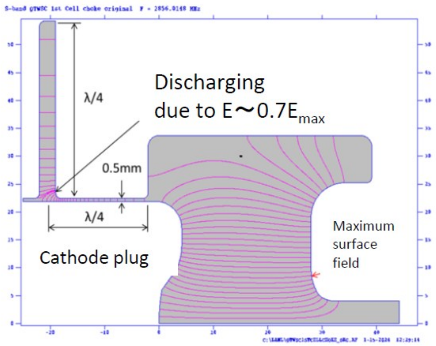
Status of RF Gun (Linac) – Updated QTWSC RF Gun

[M. Yoshida *et al.*]

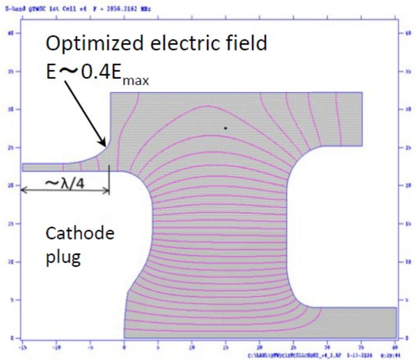
(T. Ishibashi, B2GM, June 2025)

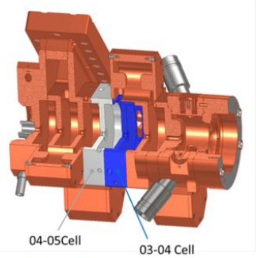
- The current RF gun cathode cell includes a choke structure for thermal cleaning of the cathode.
- The updated cathode cell is designed with:
  - Optimized surface field
  - Additional vacuum pumping
  - A new triplet downstream of the gun
- During brazing, the wrong cavity cell was assembled, resulting in a 10 MHz frequency offset (No tuning required for cathode side cavity chain).
- Tuning of the RF cavity is scheduled this week. RF conditioning will be performed until July.

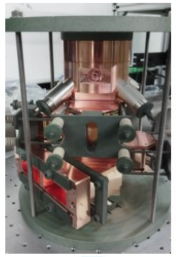
Current



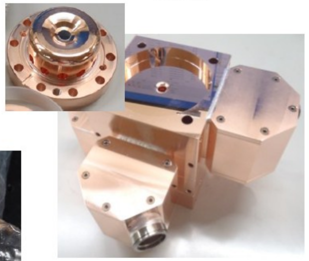
Updated

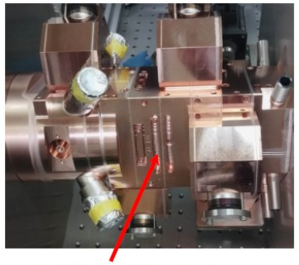






Brazing assembly





Additional machining for tuning

- If tuning cannot sufficiently correct the frequency offset and the schedule is delayed, a new IrCe cathode plug will be installed in the current RF gun.

New IrCe Cathode Plug

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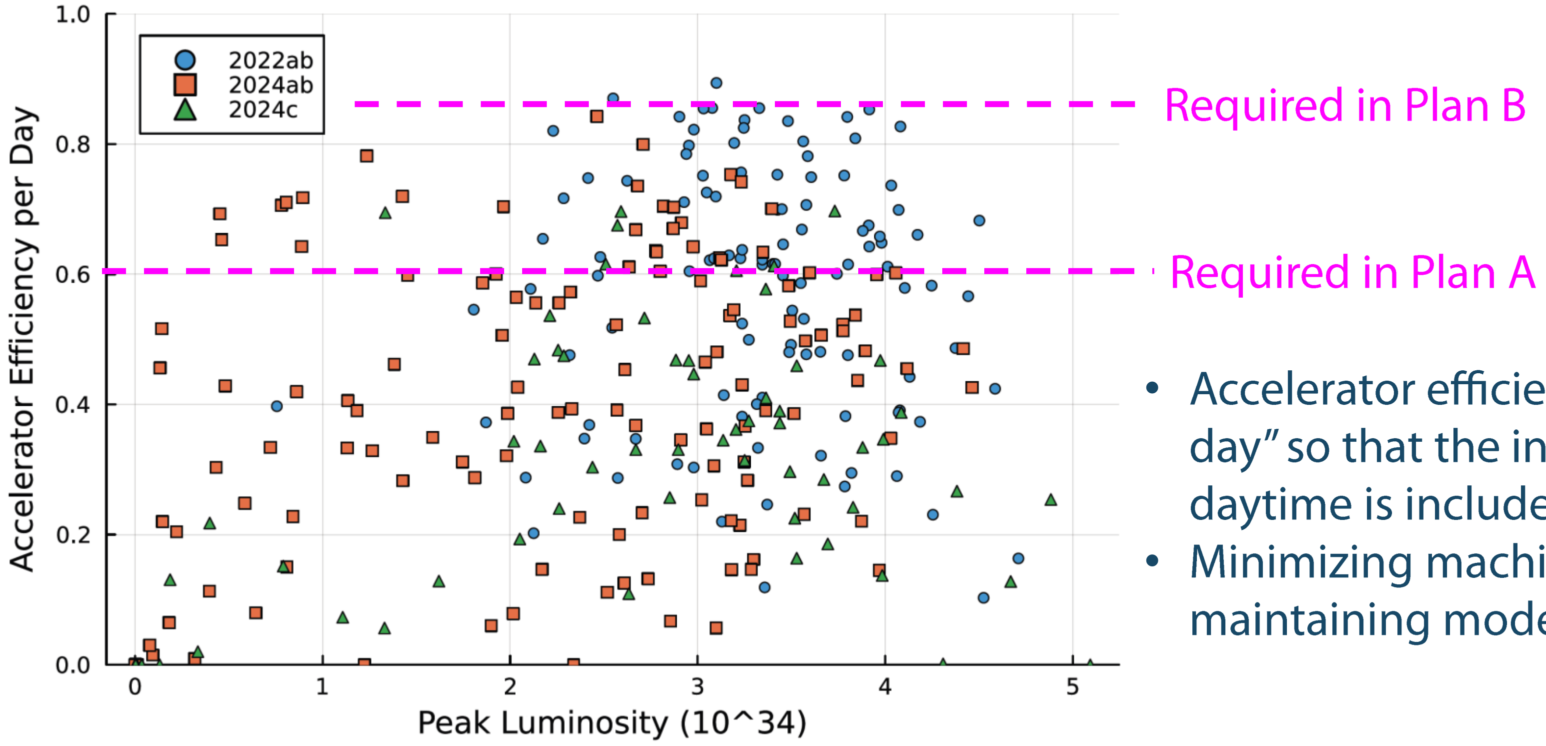
Accelerator efficiency

- A measured quantity of how constantly we can acquire the integrated luminosity while keeping the peak luminosity
- Accelerator efficiency is defined as $\varepsilon_{\mathrm{acc}} \equiv \dfrac{\text{Integrated luminosity}}{\int^{24\text{ hours}} L_{\mathrm{peak}} dt}$
- Cause of low accelerator efficiency: beam aborts, machine tuning inserted in physics run, unstable luminosity, etc.

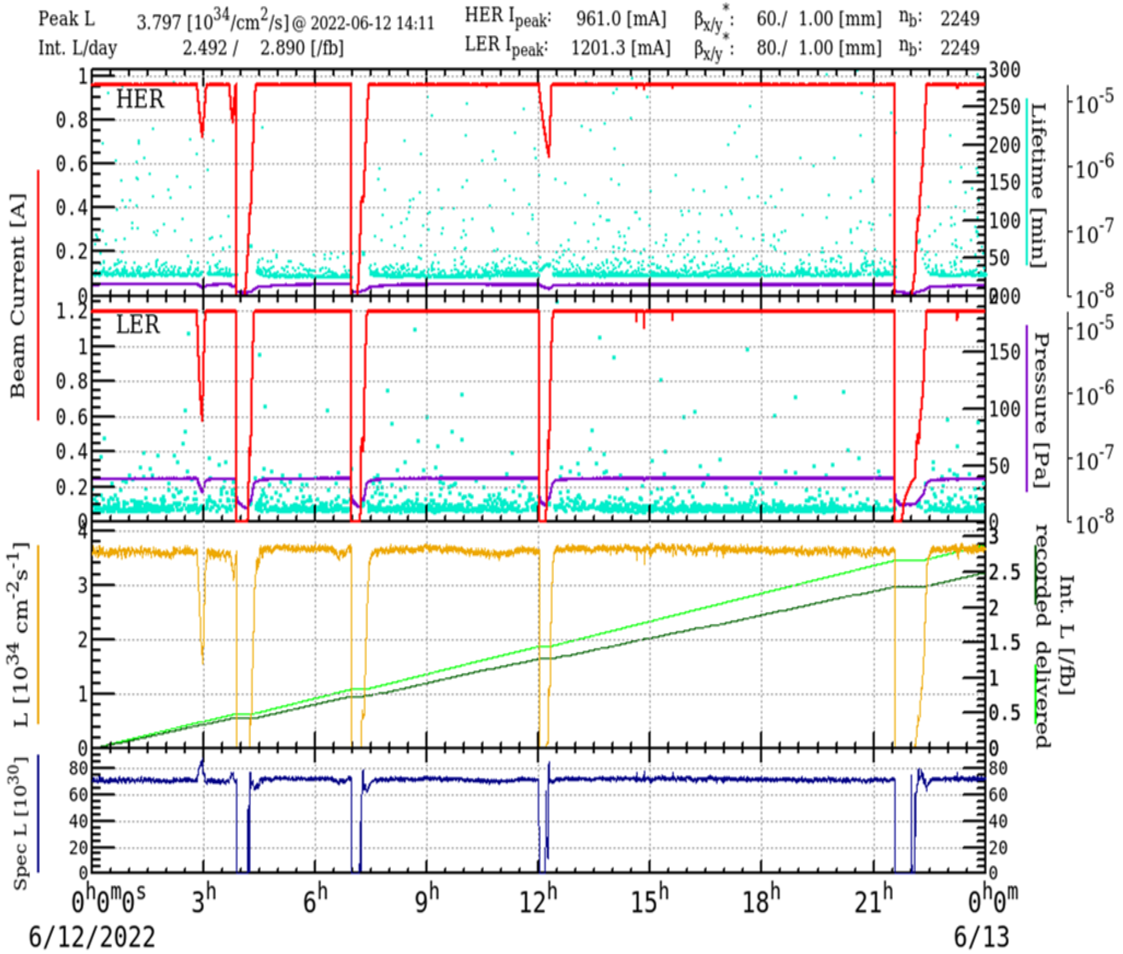


- Accelerator efficiency in the left figure is defined as “per day” so that the inefficiency due to machine tuning in the daytime is included.
- Minimizing machine tuning time as much as possible while maintaining modest luminosity yields high efficiency.

Accelerator efficiency on 12 June 2022

Example of high integrated luminosity/day

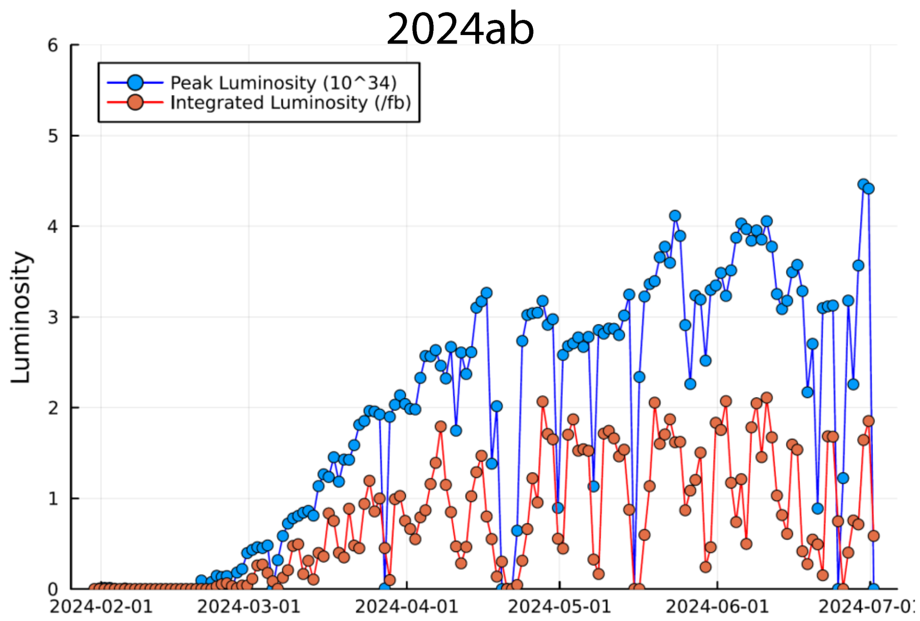
- Date: 2022-06-12, with β_y^*=1 mm
- Beam currents: I_{LER}=1.2 A, I_{HER}=0.96 A (2249 bunches)
- Peak luminosity: 3.8×10^{34} cm^{-2}s^{-1}
- Integrated luminosity (delivered): 2.89 fb^{-1}
  (2.49 fb^{-1} recorded with the DAQ efficiency: ~86%)

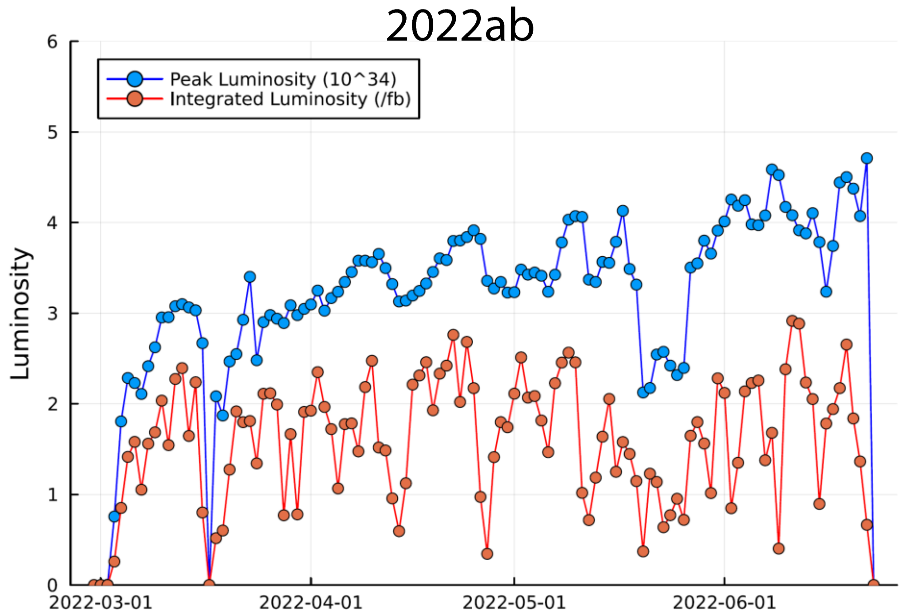


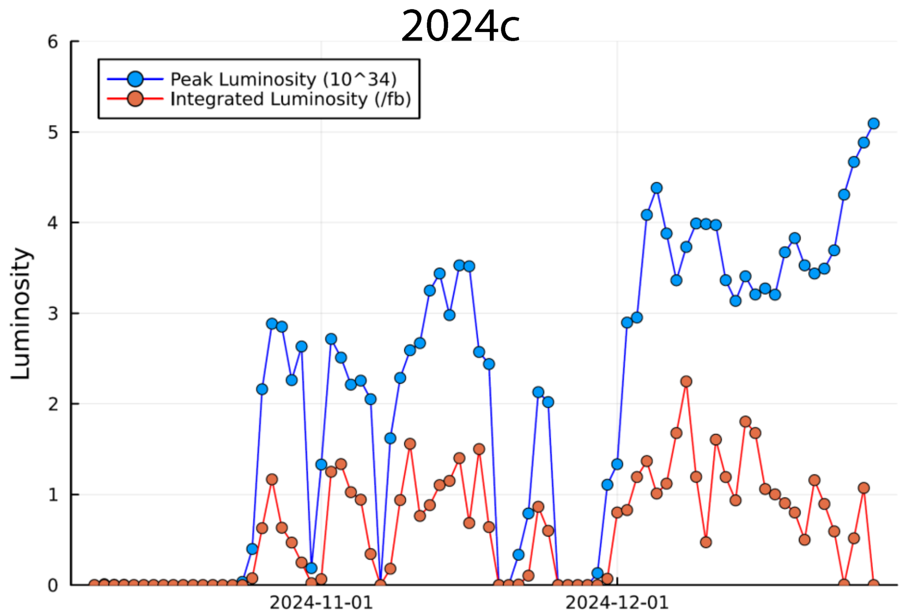
If operated at this luminosity for 24 hours:

- Delivered integrated luminosity = 3.28 fb^{-1}/day
- Accelerator efficiency: (2.89/3.28) × 100 ≈ 88%

Luminosity history







Towards high luminosity

- **Beam current (bunch current)**
  - Single beam: beam lifetime (pressure rising), injection (2-bunch operation)
  - Beam collision: beam-beam effect → narrow dynamic aperture

Obvious at <1.7 A in 2024c

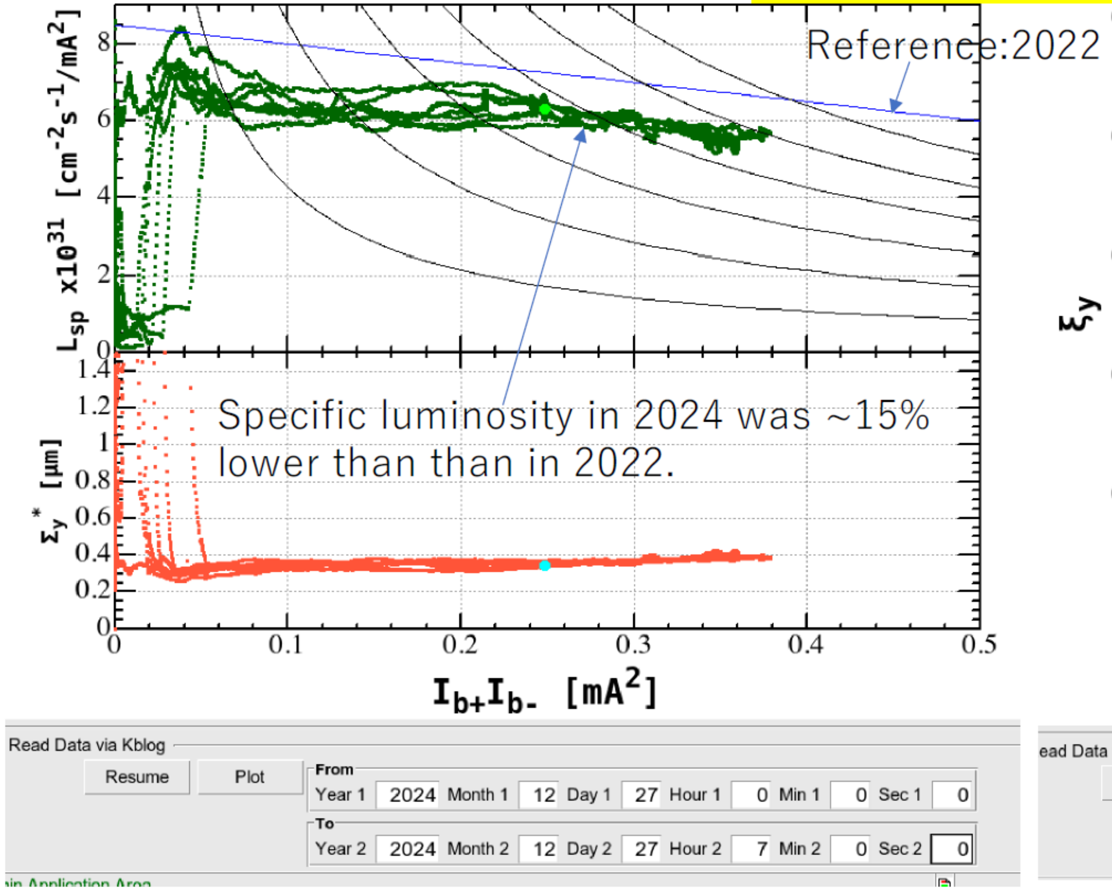
- **Emittance**
  - Single beam
    - Vertical: emittance blowup in HER
    - Horizontal: no problem?
  - Beam collision
    - Vertical: emittance blowup owing to beam-beam effects
    - Horizontal: emittance blowup owing to beam-beam effects
      → solved by lowering β_x^*

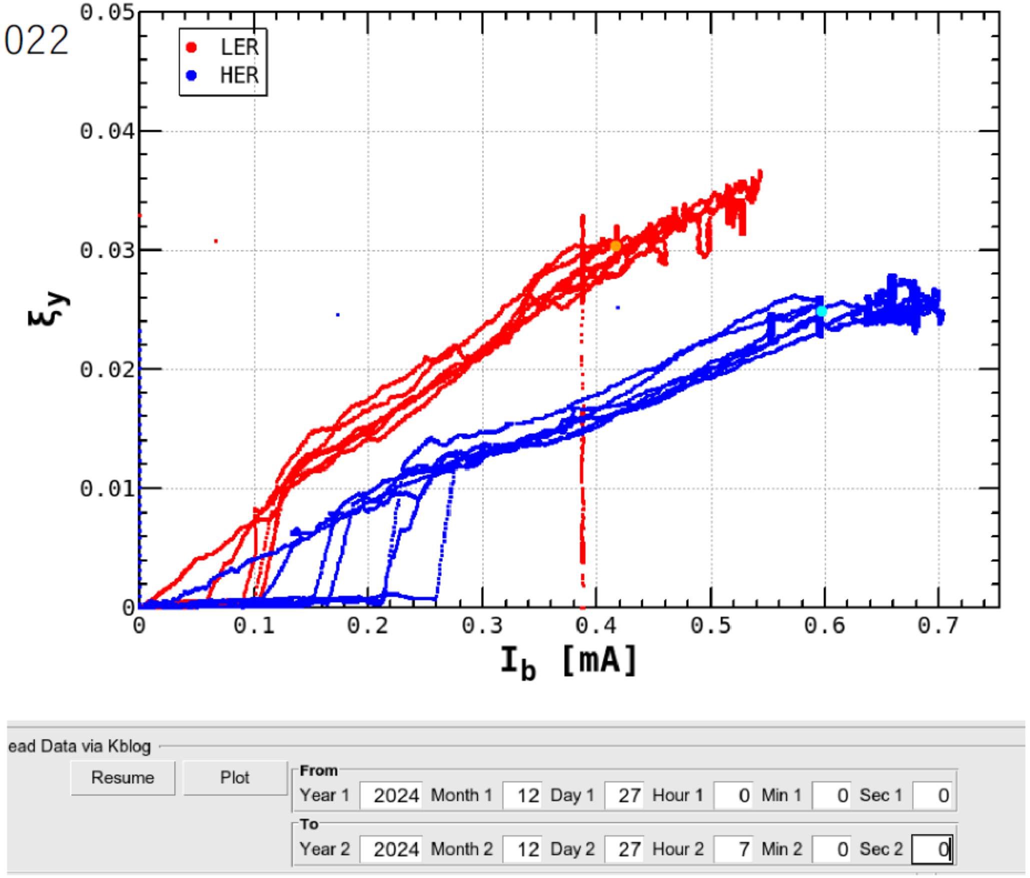
Plan for machine study

- Beam collision with corrects of HER cancel coil errors (1 shift?)
  - 393 bunches /beam
  - Up to higher bunch currents
- Beam collision up to high bunch currents with 393 bunches / beam
  - Reference measurement with good collision performace (1 shift)
  - With collimators open if possible (less transeverse impedance) (1 shift)
- Collision w/ and w/o bunch-by-bunch feedback
  - 31 bunches /beam (1 shift)
- Collision with higher βy^* such as 3 mm (less lattice nonlinearity)(3 days?)
  - We need luminosity tuning.
- Measurement on lattice nonlinearity and impedance (1 shift)
  - Decoherence of dipole oscillation, bunch charge dependence
  - Others?

Specific luminosity and beam-beam parameter

At highest luminosity: Dec.27th 2024





(Courtesy of Y. Ohnishi)

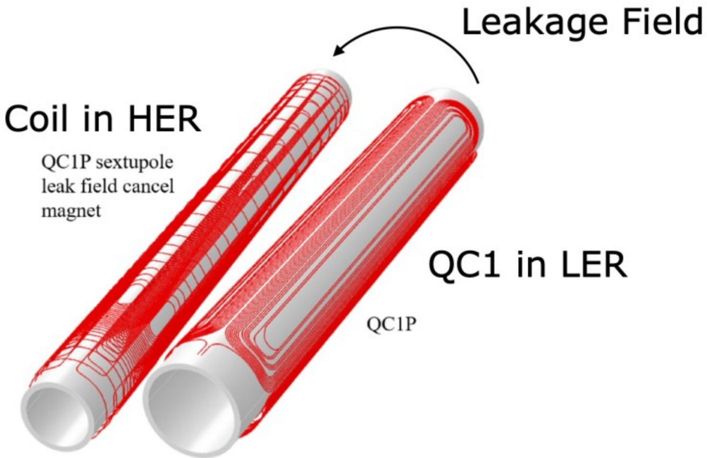
Manufacturing Failure of Cancel Coil in HER

Skew sextupole and skew octupole increase (Not cancelled).

Table 24: Measured integral leak fields at R_{ref}=10 mm

Multipole coefficient	QCSL, Tm without cancelling	QCSL, Tm with cancelling	QCSR, Tm without cancelling	QCSR, Tm with cancelling
b_3	3.36×10^{-3}	2.32×10^{-5}	-3.53×10^{-3}	1.27×10^{-5}
b_4	-7.58×10^{-4}	-2.83×10^{-6}	8.02×10^{-4}	4.39×10^{-6}
b_5	1.57×10^{-4}	3.66×10^{-6}	-1.67×10^{-4}	-3.73×10^{-6}
b_6	-2.98×10^{-5}	7.8×10^{-7}	3.24×10^{-5}	2.35×10^{-6}
a_3	-2.42×10^{-4}	-3.88×10^{-4}	-2.52×10^{-4}	-4.93×10^{-4}
a_4	-5.88×10^{-5}	-1.16×10^{-4}	4.94×10^{-5}	1.71×10^{-4}
a_5	-1.48×10^{-5}	-1.48×10^{-5}	6.26×10^{-6}	-8.31×10^{-6}
a_6	1.88×10^{-5}	1.48×10^{-5}	-4.31×10^{-6}	-1.09×10^{-6}

Definition of the coordinate system seems to be wrong.

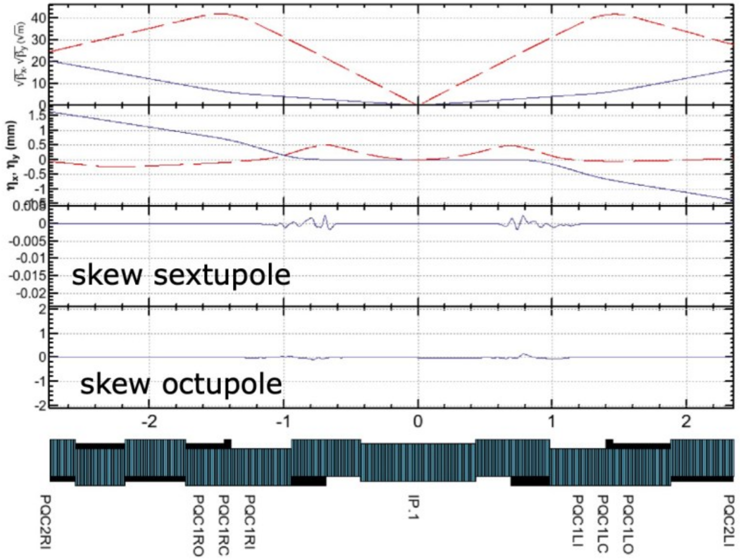


N. Ohuchi, Y. Arimoto

w/o Error

Skew K2 (1/m2)

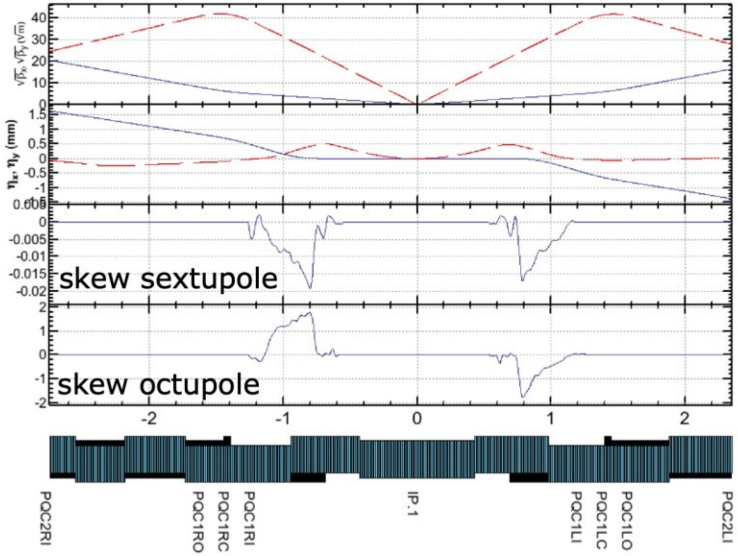
Skew K3 (1/m³)



with Error

Skew K2 (1/m²)

Skew K3 (1/m³)

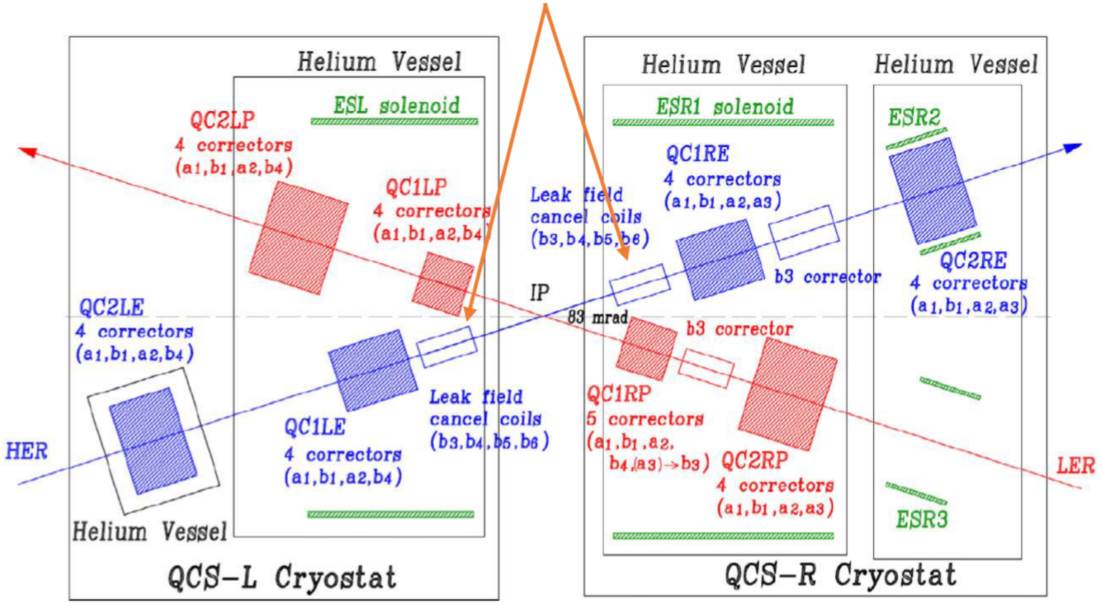


9

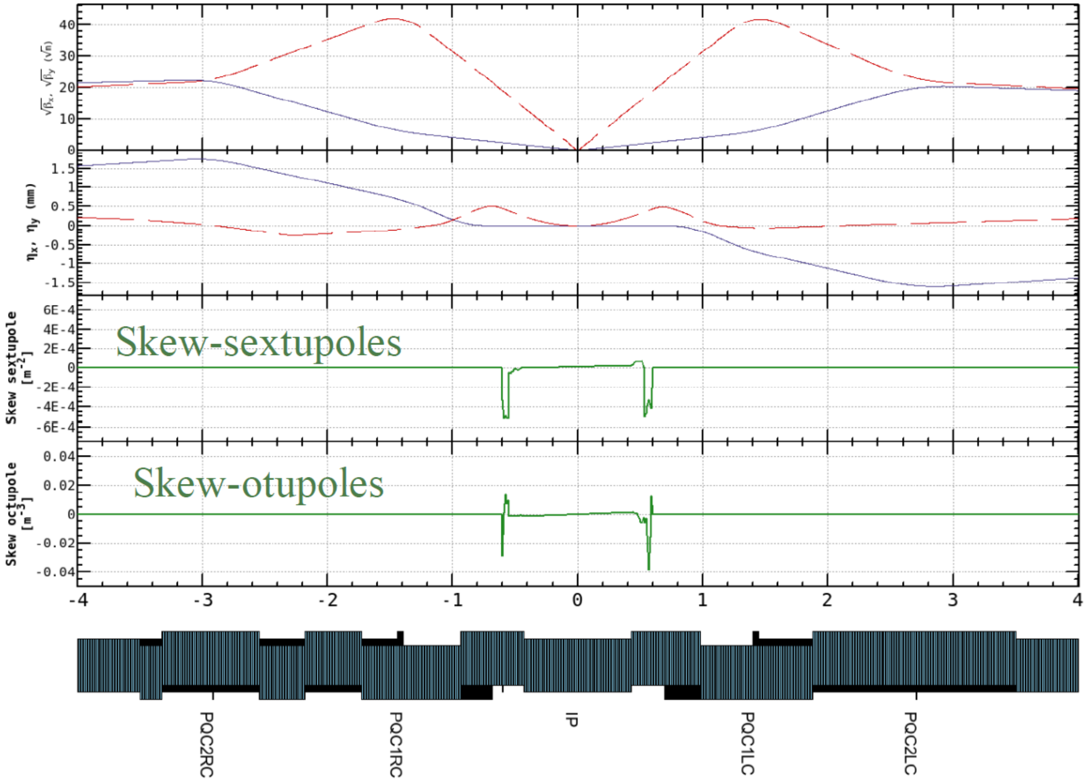
Manufacturing Errors in Leak-Field Cancellation Coils in HER

- The cancellation coils used to compensate the QC1P leakage field in the HER beamline have manufacturing errors.
- These errors introduce additional skew-sextupole and skew-octupole field components into the HER beamline.

Leak Field Cancellation Coils



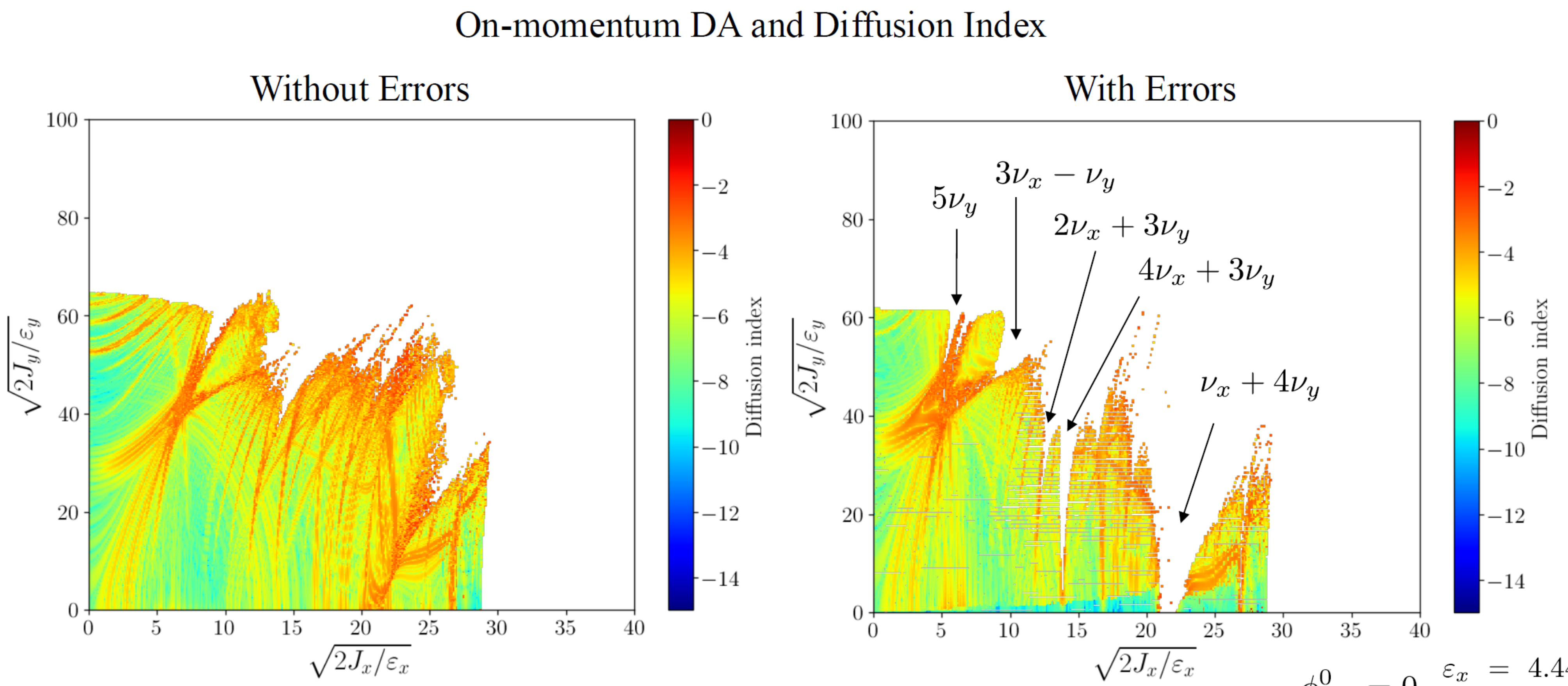
Skew-sextupoles & Skew-octupoles due to Manufacturing Errors



3

Impact on Dynamic Aperture (DA)

- Frequency-map analysis indicates that these errors intensify nonlinear lattice resonances.
- As a result, particles at large amplitudes exhibit chaotic, unstable motion.



$\phi^0_{x,y} = 0$ $\quad \varepsilon_x = 4.44$ nm, $\varepsilon_y = 25$ pm

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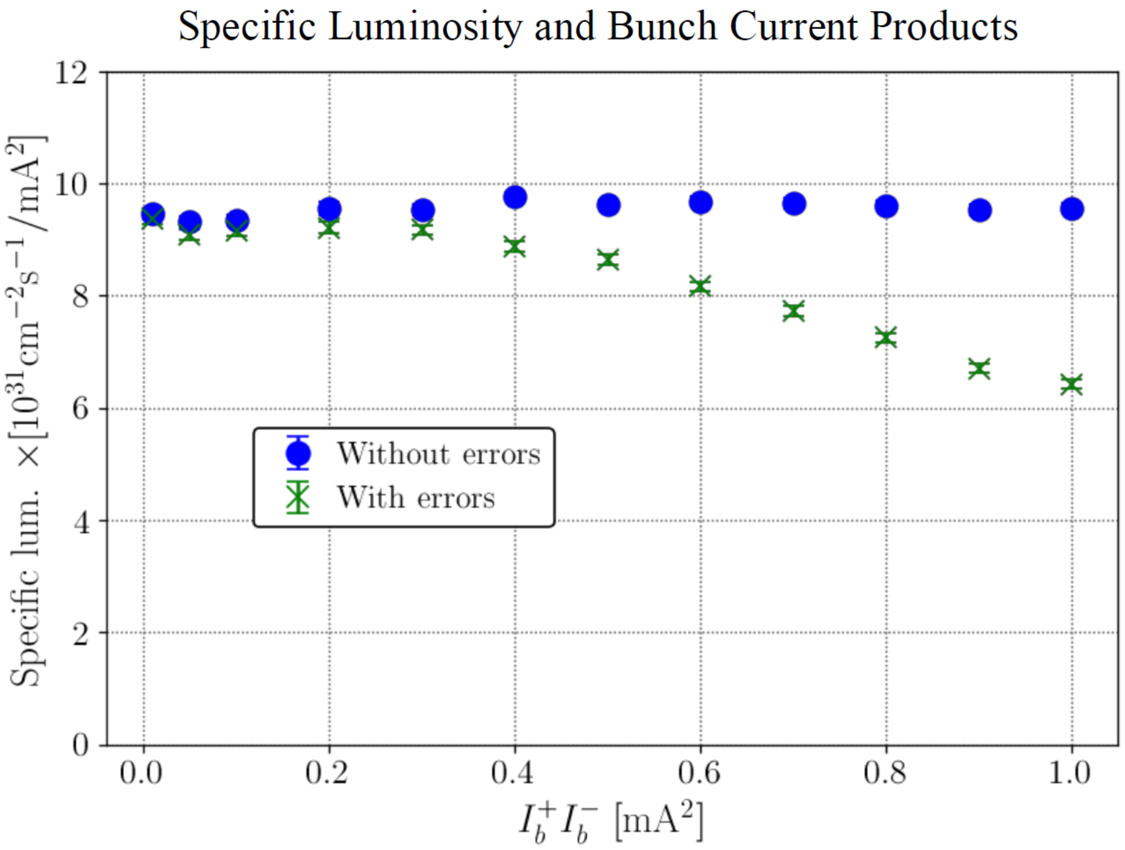
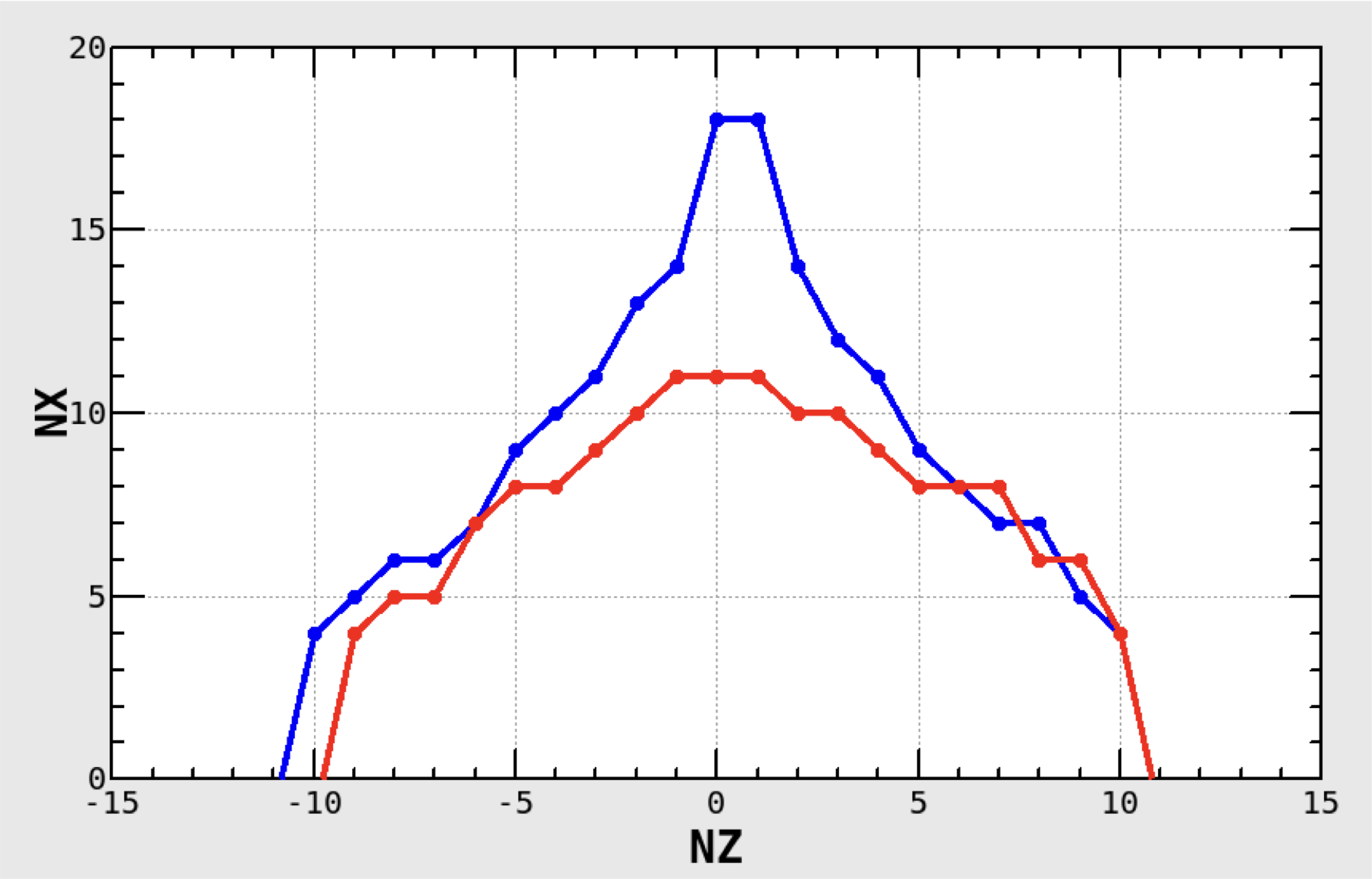
Impact on Luminosity (SAD, Weak-Strong, No wake)

- When cancellation-coil errors are included, vertical beam size increases with beam current.
- The vertical beam blowup arises from the interplay between beam–beam interactions and lattice nonlinearities.
- This report examines the nonlinear terms responsible for luminosity degradation.



(Courtesy of H. Koiso)

キャンセルコイルのエラー有無による力学口径の違い



キャンセルコイルのエラー有無による力学口径の違い

エラーなし

```
 In[8]:= Plus@@LINE["SK2"]
Out[8]:= -.009067889596233848
```

sher_5781_60_1-Y020250213.sad

エラーあり

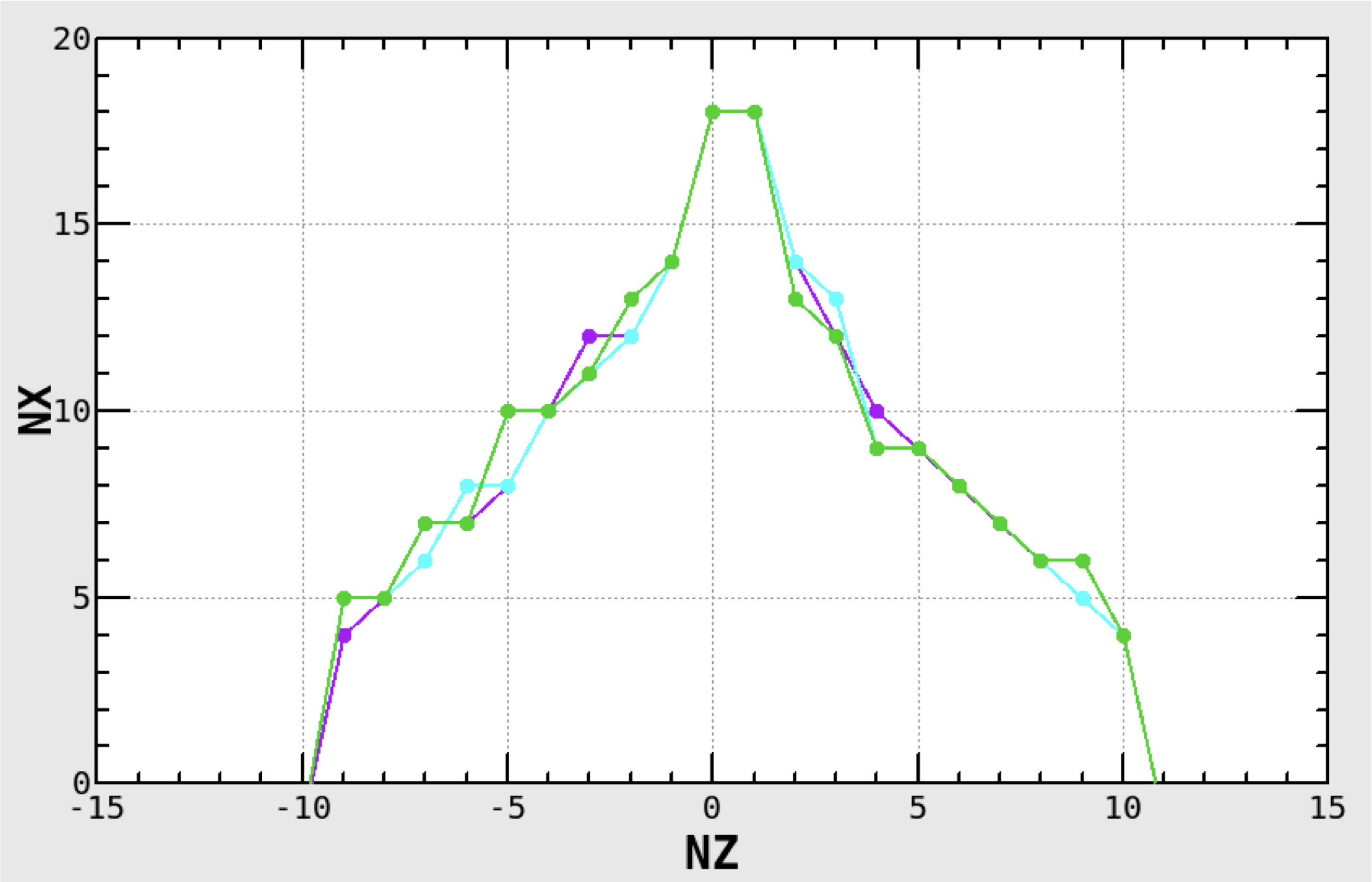
```
 In[26]:= Plus@@LINE["SK2"]
Out[26]:= -.7442901095589288
```

sher_5781_60_1-can2-VSKQC1RE.sad
(VSKQC1RE SK2=0)

EMITY/EMITX
= 25 E-12 / 4.44 E-9
= 0.00563
2/27(木)杉本さんのスライドp.2
と同じ垂直エミッタンス

(Courtesy of H. Koiso)

キャンセルコイルのエラー補正



キャンセルコイルのエラー補正

VKQC1REの直前に thin element
VSKQC1REを置きSK2を調整する。
sher_5781_60_1-can2-VSKQC1RE.sad

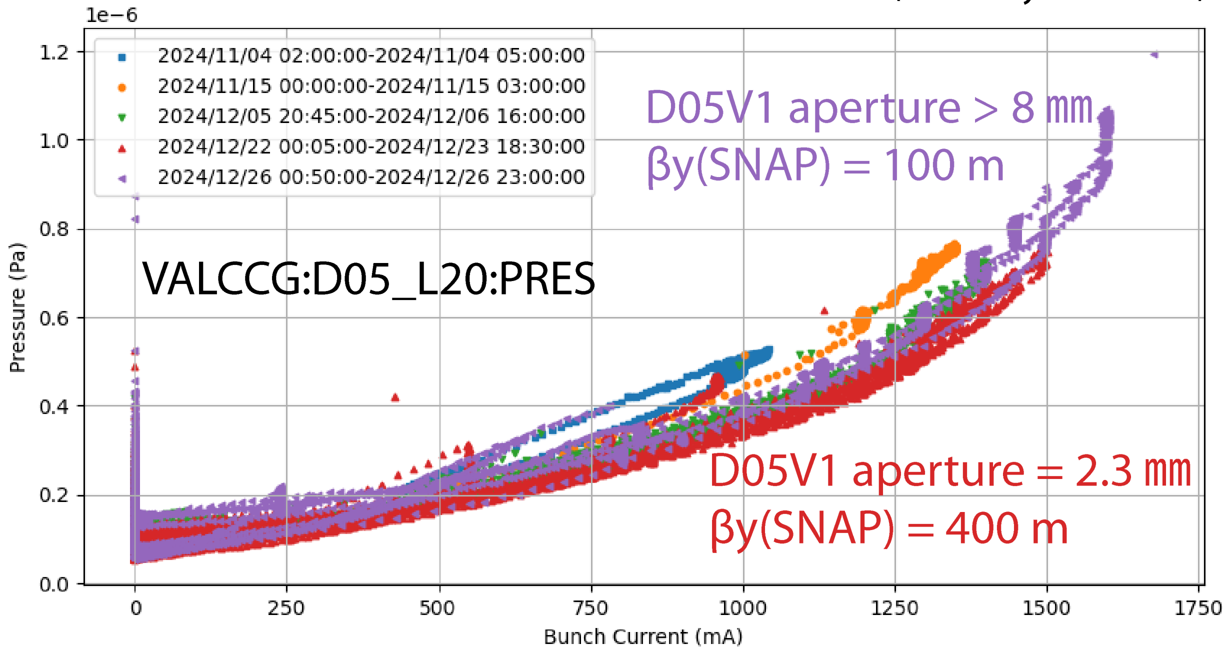
VSKQC1REは軌道上に配置する。
SK2を変えても線形オプティクス
は変化しない。

VSKQC1RE SK2 に
+0.03、+0.04、+0.05
を与えた場合、NZ = -5 ~ +5
あたりの力学口径はほぼ回復する。
これは予想通り IP左右のSK2の
アンバランスを補正する方向。

NLC

NLC aperture	Open	Inj. amplitude of 2nd bunch	Injection BG increases
	Close	Lifetime shortens	

(Courtesy of S. Terui)



- Pressure rising independently of the D05V1 aperture and βy(SNAP)