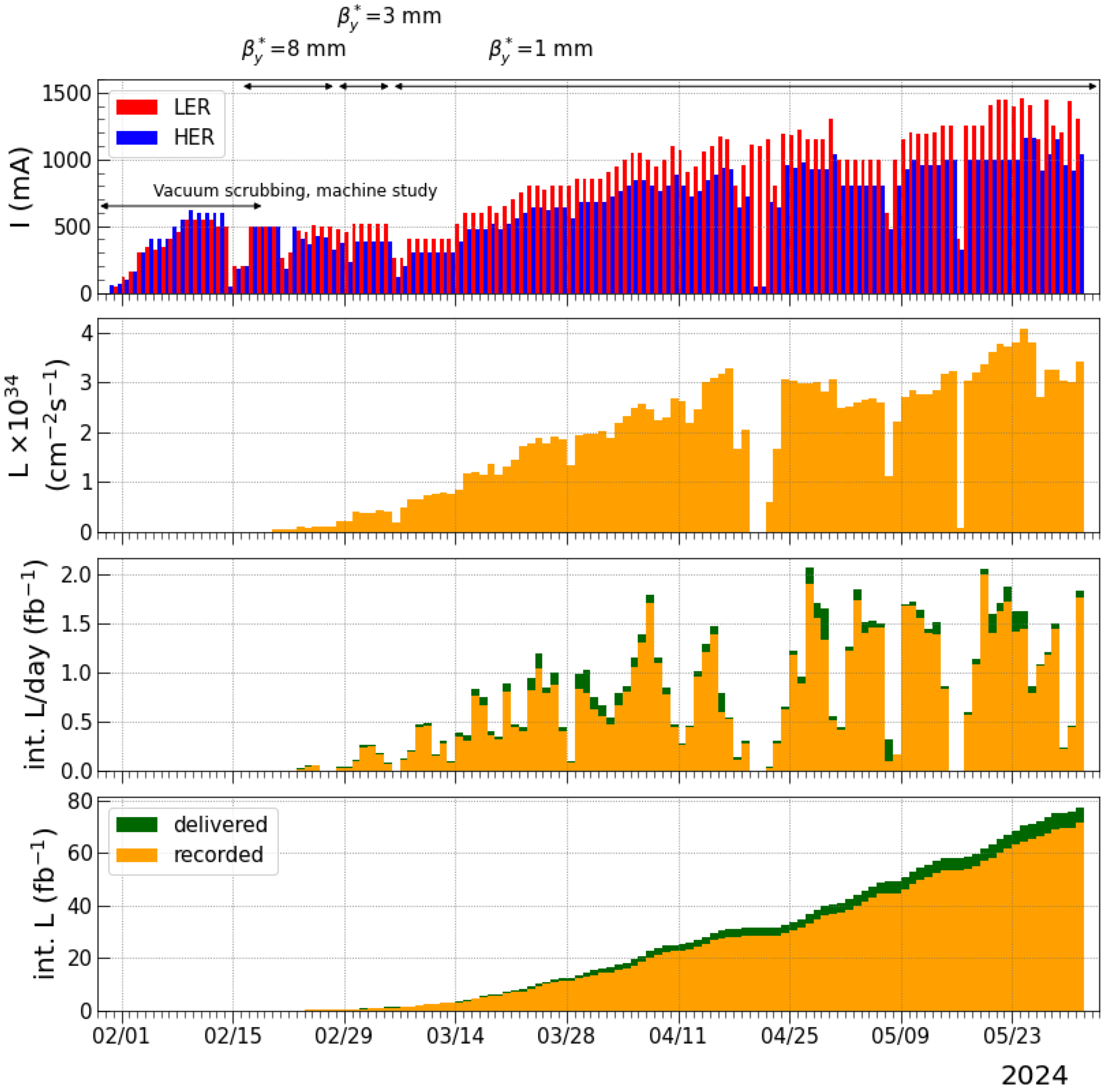
SuperKEKB during 2024a/b

Y. Ohnishi

48th B2GM
June 3 - 7, 2024 at KEK

2024ab Operation



- Achievements until May 31
  - LER Current: 1450 mA
  - HER Current: 1160 mA
  - Number of Bunches: 2346
  - Peak Luminosity: 4.08 x 10^{34} $cm^{-2}s^{-1}$
  - Integrated Luminosity: 71.4 fb^{-1} / 77.4 fb^{-1}
- Issues
  - Sudden Beam Loss (SBL)
  - Short Lifetime in LER
  - Beam Pipe Deformation due to SR Heating
  - Poor Injection Efficiency in HER

Measure Against Seven Major Issues

1. Sudden Beam Loss

    ➡ Copper Coating of Collimator Head, Additional Monitors (Acoustic Sensors, Loss Monitors, Specific TBT BPM)

2. Beam-Size Blowup due to Beam-Beam Interactions

    ➡ Chromatic X-Y Coupling Correction, Reduction of Machine Error in IR

3. Beam-Related Background

    ➡ More IR Radiation Shields

4. Injection Efficiency and Emittance Blowup in the Beam Transport Line

    ➡ Wider Aperture at Injection Point, Suppression of CSR by using Beam Pipe Offset (Shielding Effect) in BTp

5. Difficulties to Keep Beam Orbit Stable

    ➡ Beam Pipe Deformation due to SR Heating, BPMs Push Quadrupole Magnets. Isolation of BPM Is Tested.

6. Short Lifetime and Narrow Dynamic Aperture with β_y^* Squeezing

    ➡ Sextupole and Octupole Optimization

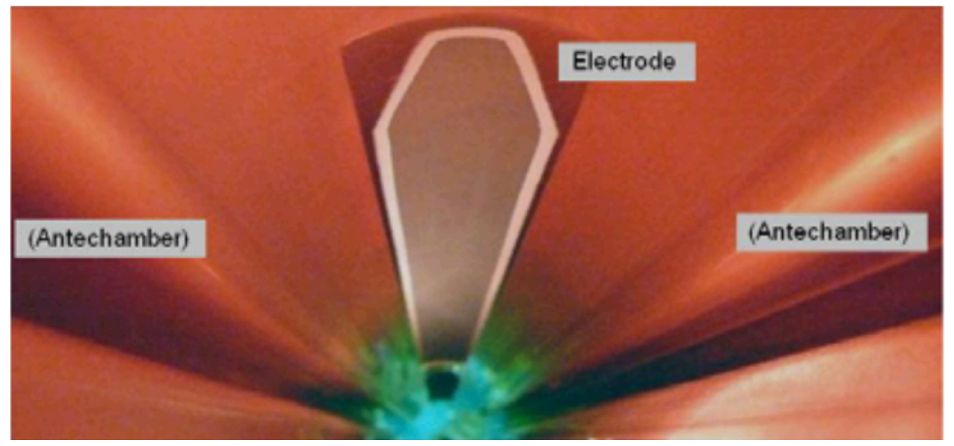
7. Beam-Size Blowup due to -1 Mode Instability in LER → Reduce Impedance and BxB FB Optimization

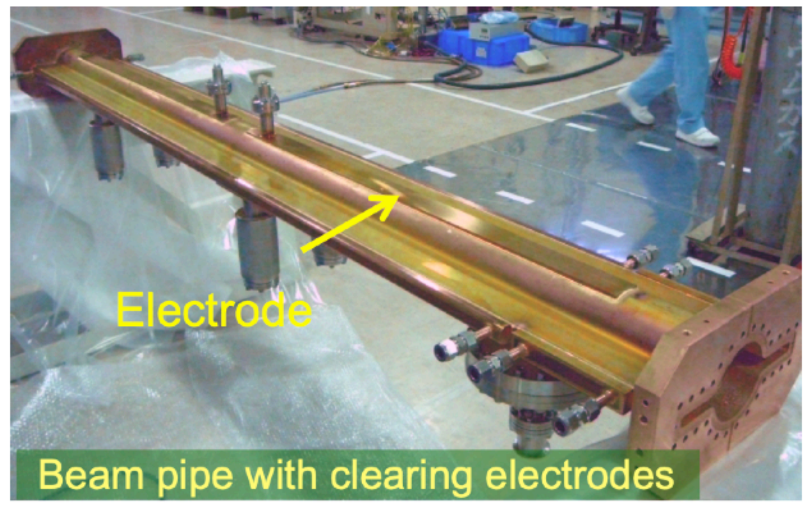
SBL → the Next Talk

Candidates of SBL Source

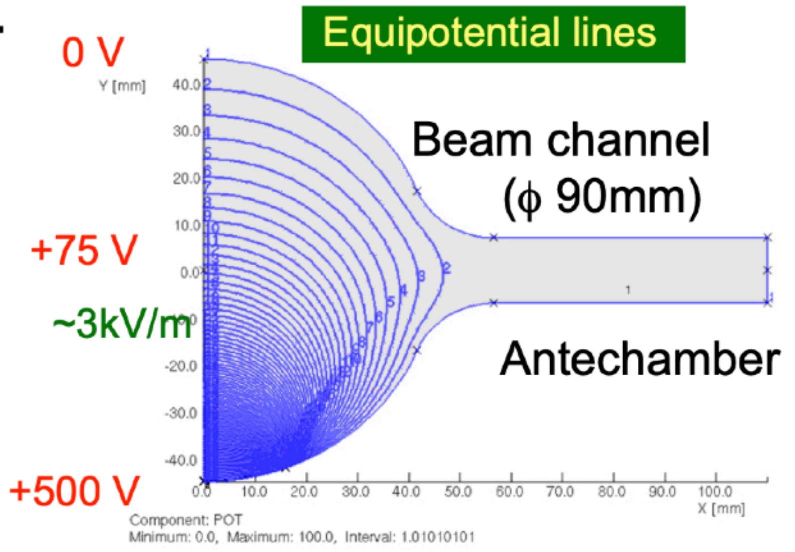
Sections	L [m]	L [%]	Countermeasure	Material
Total	3016	100		
Drift space (arc)	1629 m	54	TiN coating + Solenoid	Al (arc)
Steering mag.	316 m	10	TiN coating + Solenoid	Al
Bending mag.	519 m	17	TiN coating + Grooved surface	Al
Wiggler mag.	154 m	5	Clearing Electrode New	Cu
Q & SX mag.	254 m	9	TiN coating	Al (arc)
RF section	124 m	4	(TiN coating +) Solenoid	Cu
IR section	20 m	0.7	(TiN coating +) Solenoid	Cu or ?

- **Clearing electrode** for wiggler section.
  - Attract electrons by electrostatic field
  - Very thin electrode has been develop
    - 0.1 mm tungsten on 0.2 mm Al_2O_3
    - Small impedance and effective heat transfer
  - Have been tested in KEKBdeveloped
    - Expected reduction ratio: 1/100
  - Also demonstrated in CesrTA
  - Manufacturing has already started.



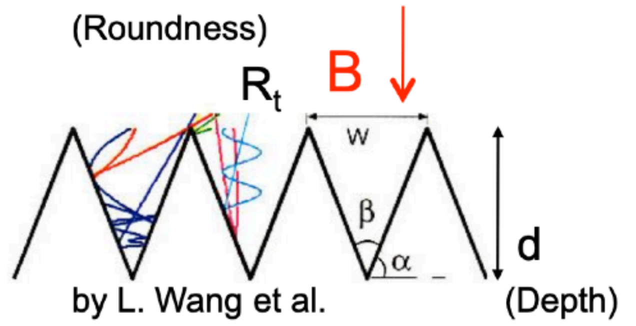


Beam pipe with clearing electrodes

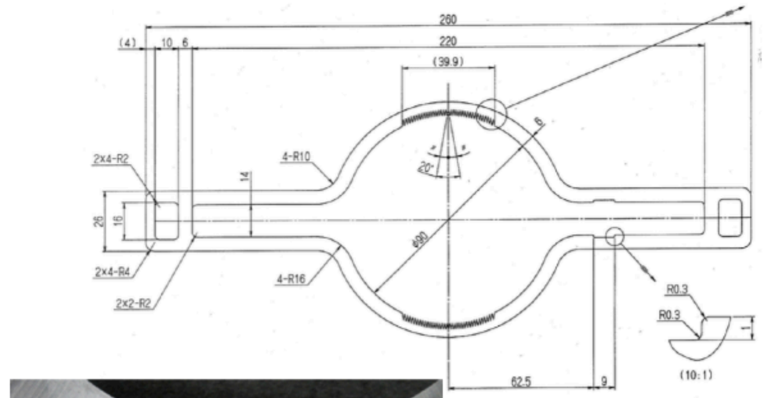


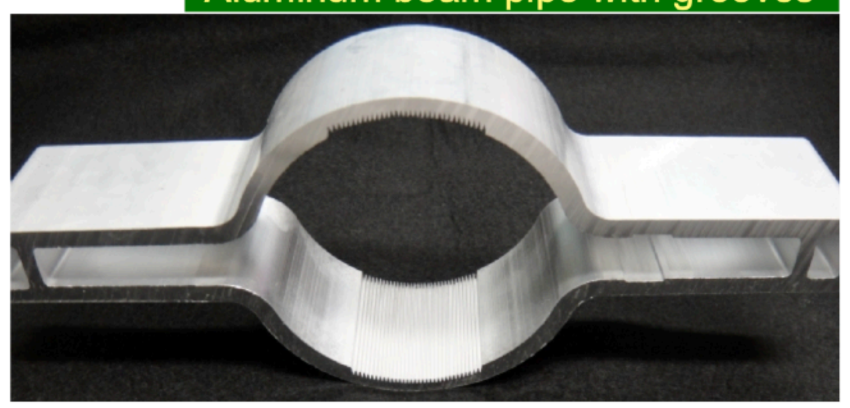
Equipotential lines

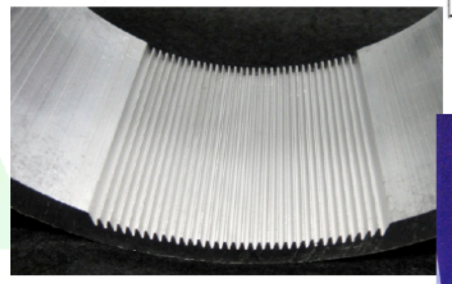
- **Grooved surface** for bending magnets section
  - Reduce effective SEY structurally
  - Have been tested in KEKB, and also in CesrTA
  - Extrusion test of aluminum beam pipe was successful.
  - With TiN coating

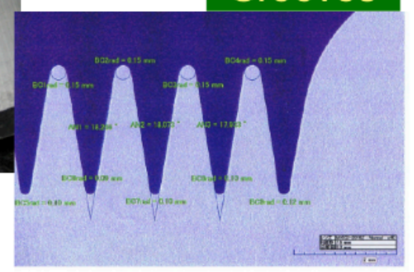


by L. Wang et al.




Aluminum beam pipe with grooves



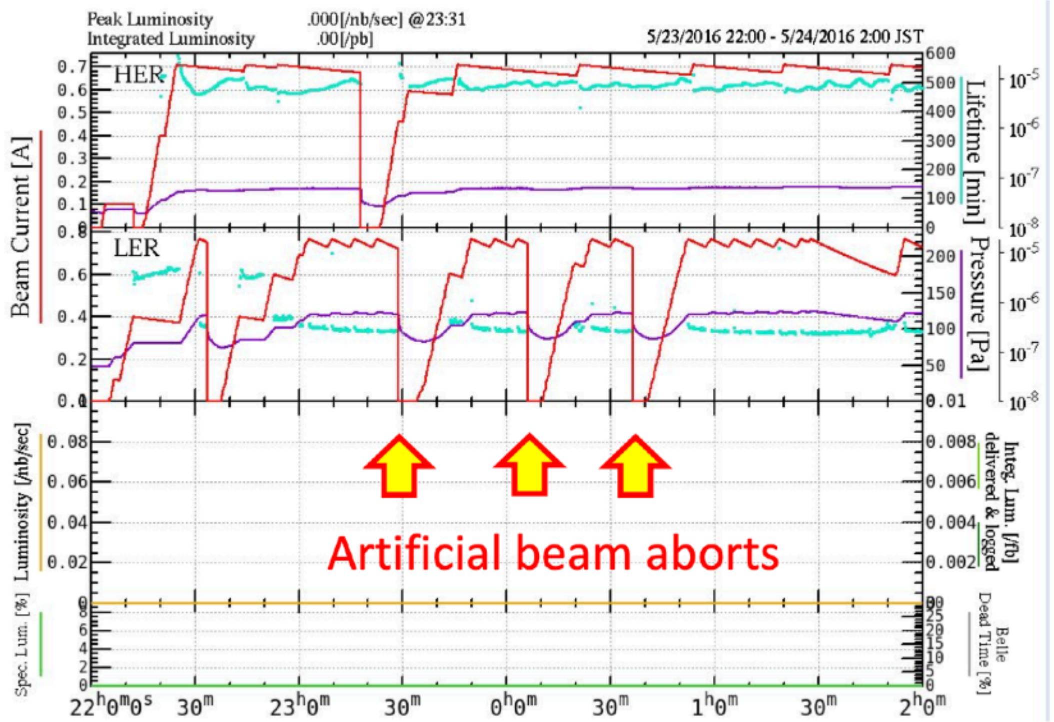

Grooves

Valley : R0.1~0.12
Top : R0.15
Angle : 18~18.3°

2011/2/8 KEKB Review 2011 @KEK 14

Knocker Study in 2016

- Pressure bursts accompanying beam loss in LER - 7
- Knocking test
  - A "knocker" was set at a beam pipe in a bending magnet, where the burst had been observed frequently.
  - We succeeded in reproducing the phenomena three times by knocking the beam pipe!



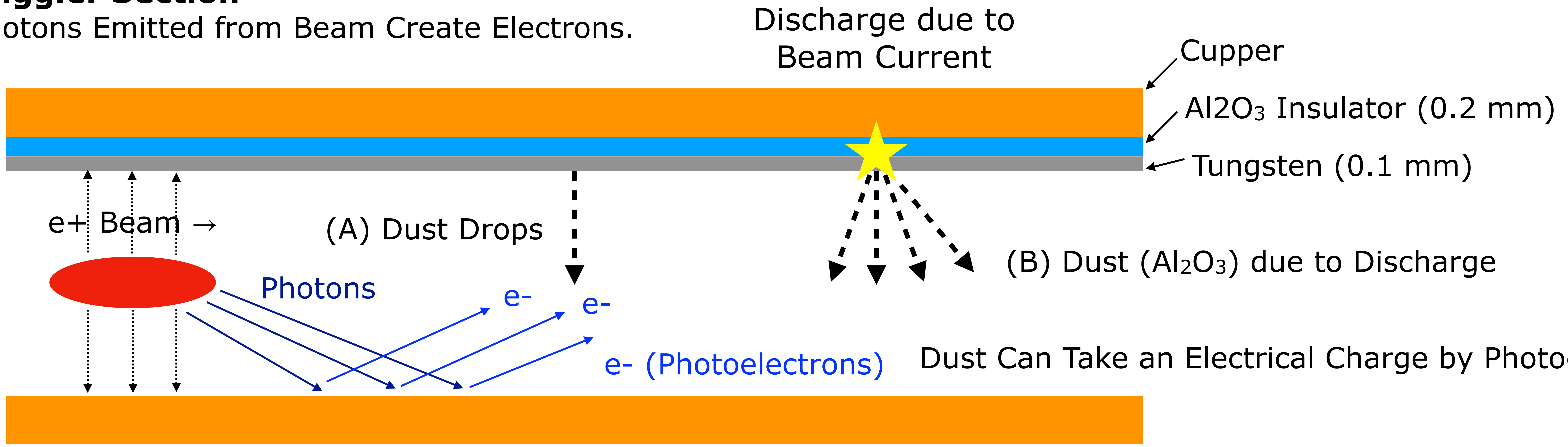
Knocker
at the Dipole Magnet

Y. Suetsugu, MAC 2011, 2016

Clearing Electrode

Wiggler Section

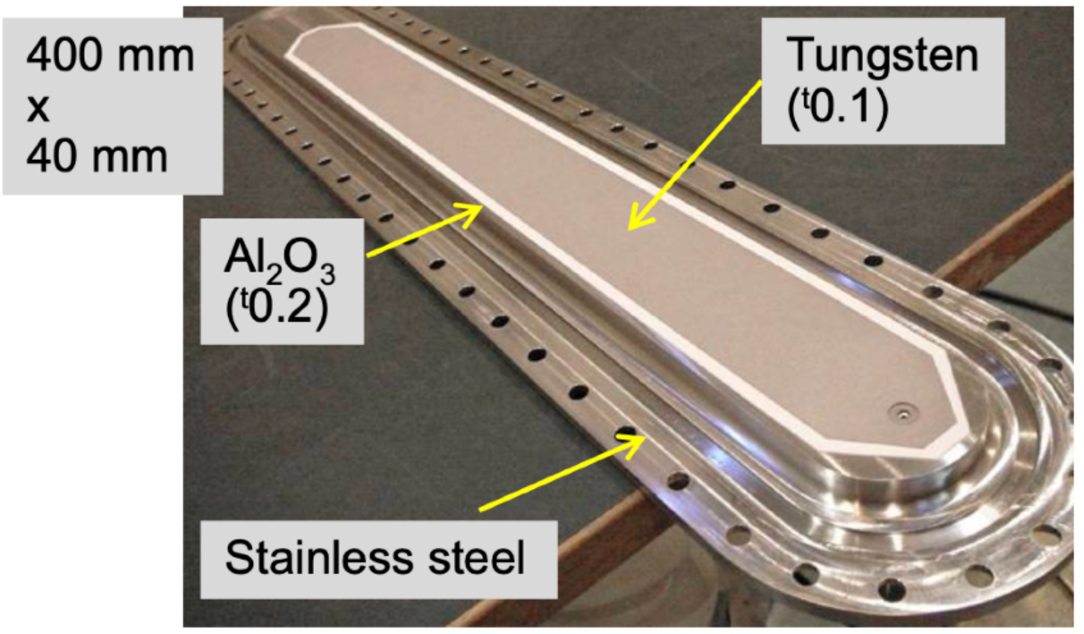
Photons Emitted from Beam Create Electrons.

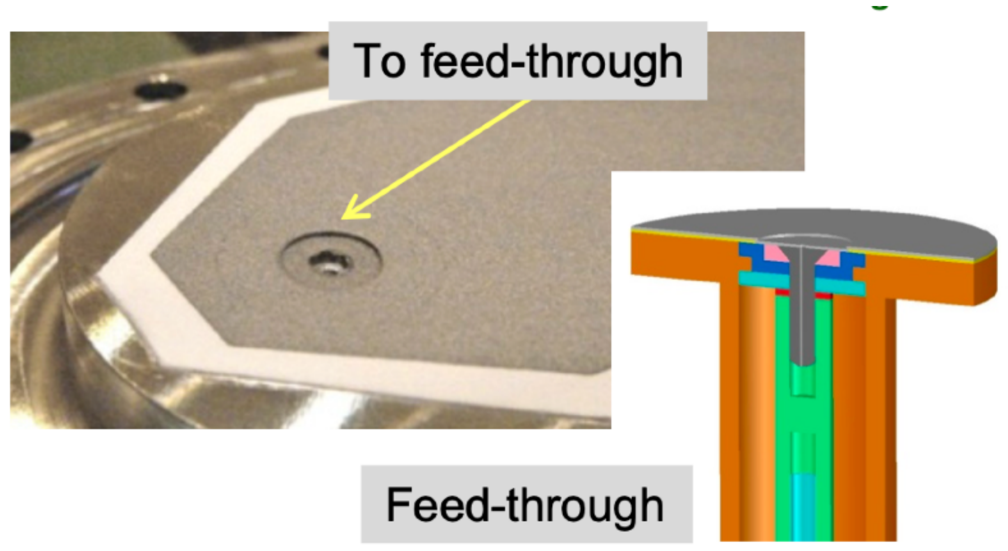


Dust Can Take an Electrical Charge by Photoelectrons.

Clearing Electrode (Prototype)

Low Beam Impedance





Y. Suetsugu, H. Fukuma, M. Pivi and L. Wang, NIM-PR-A, 598 (2008) 372

(A) Drop due to Gravity

Dust → Turn Over the Top and Bottom

(B) Discharge → Dust → Cupper Coating ?

Dust in the Vacuum

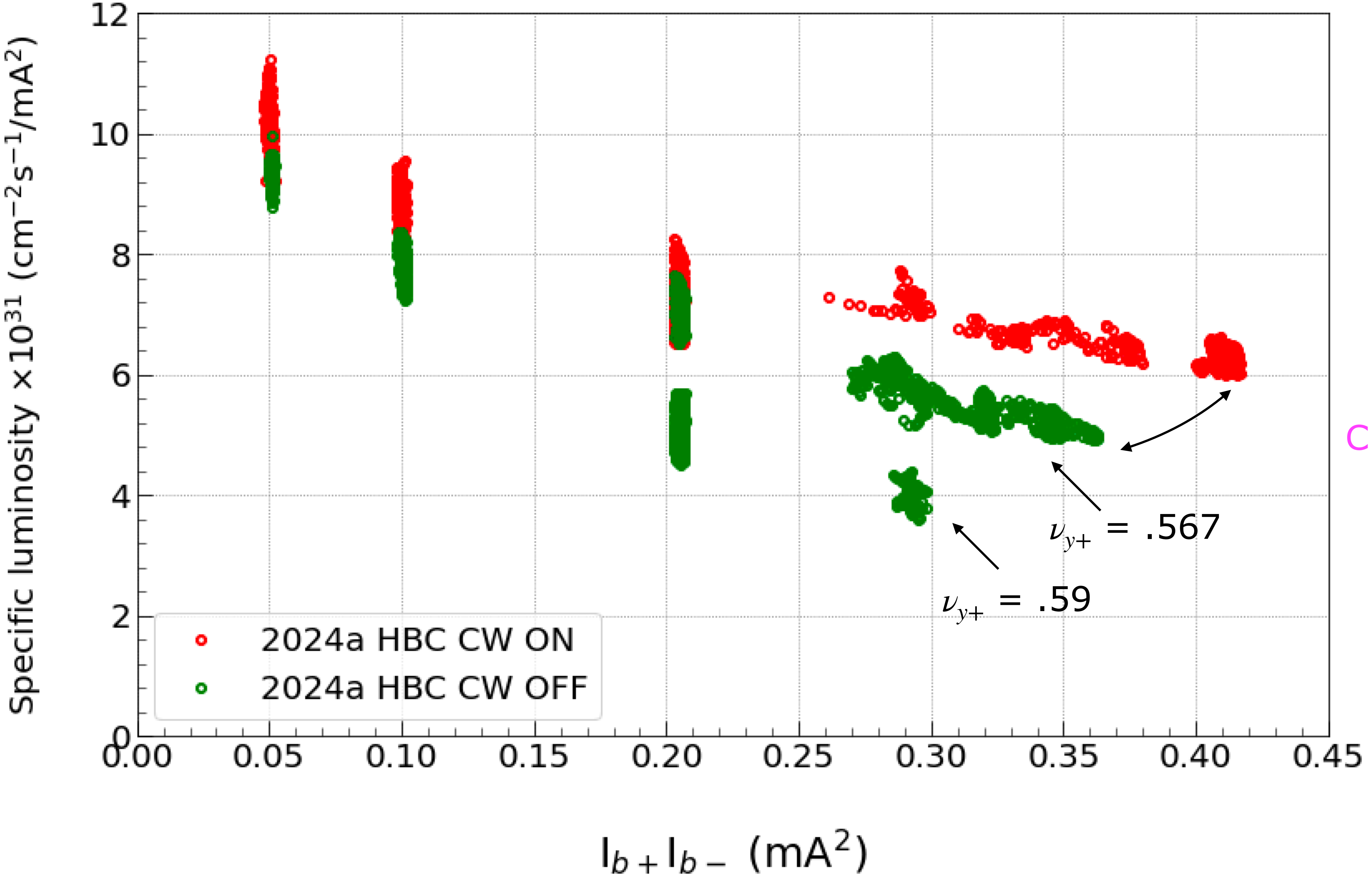
"Dust in the Wind" is a song recorded by American progressive rock band Kansas and written by band member Kerry Livgren, first released on their 1977 album "Point of Know Return".

Beam-Beam Performance

Crab Waist ON and OFF

LER: CW 80 % / HER: CW 40 %

Try HER → 60 %



Crab Waist Is Effective.

* HBC = High Bunch Current (393 Bunches)

Nonlinear Collimator

Reduction of Impedance: Nonlinear Collimator

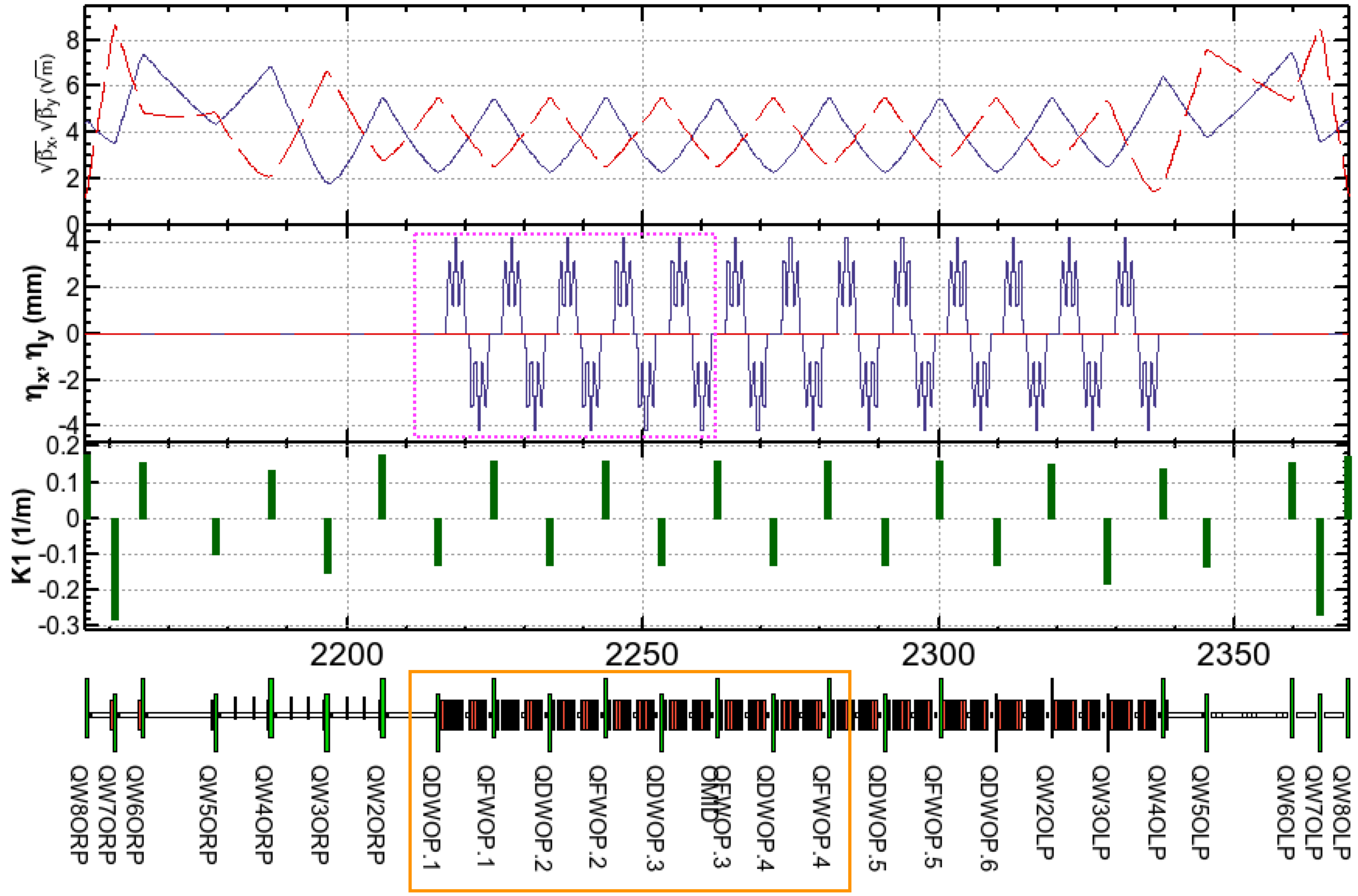
Nonlinear Collimator (D05V1) to Reduce Impedance (vertical)

Drop Beam Halo with Larger Aperture. → Low Impedance

About 60 % Improvement for BG Reduction
20 % Reduction of Impedance

OHO Section

Before LS1

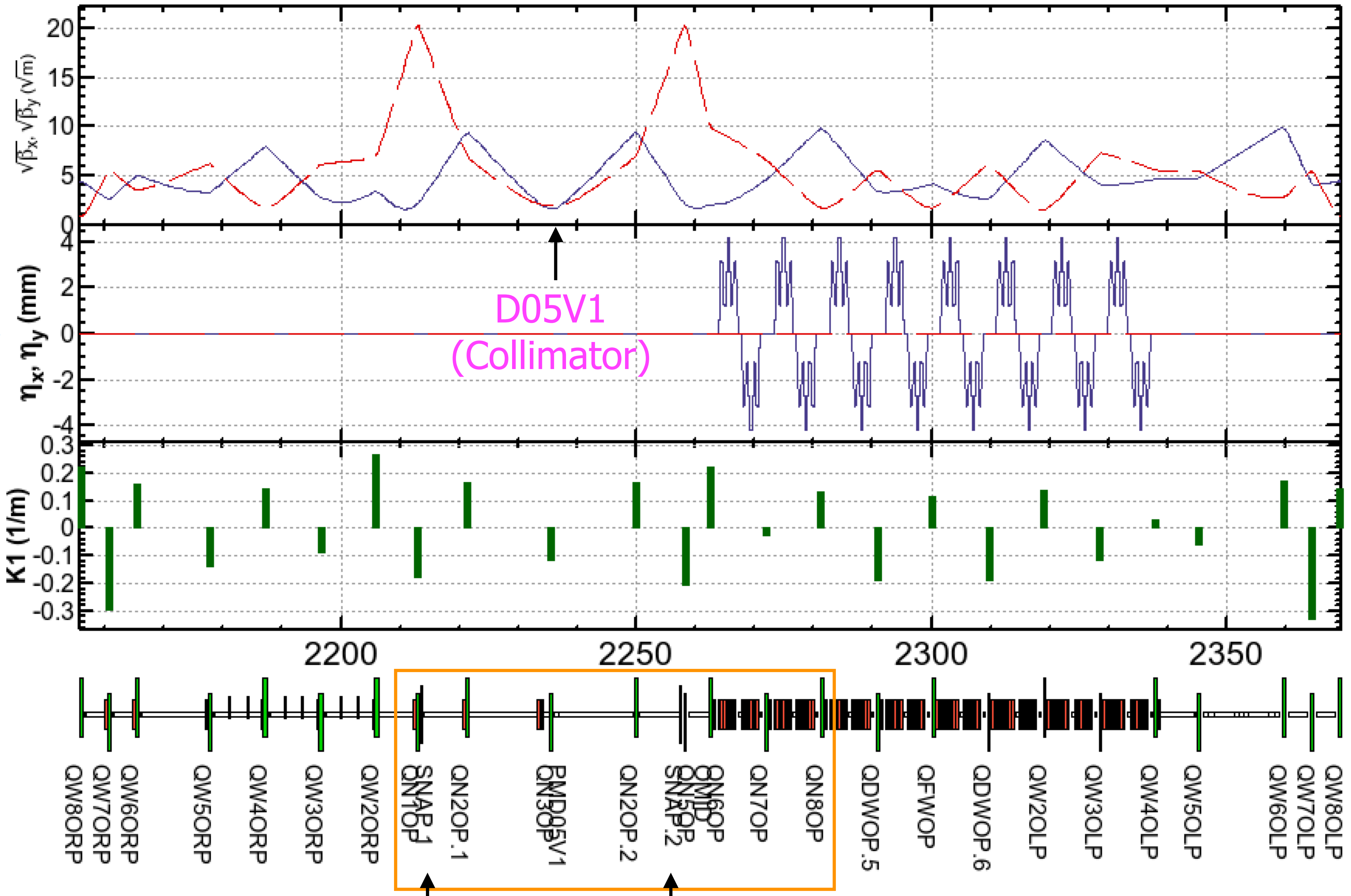


wiggler Section

Positron →

$$\Delta p_y = \frac{K_2}{2}\Delta y^2$$

After LS1



Skew Sextupole Pair (SNAP)

Positron →

$\Delta\psi_y = 2\pi$ to QC1RP

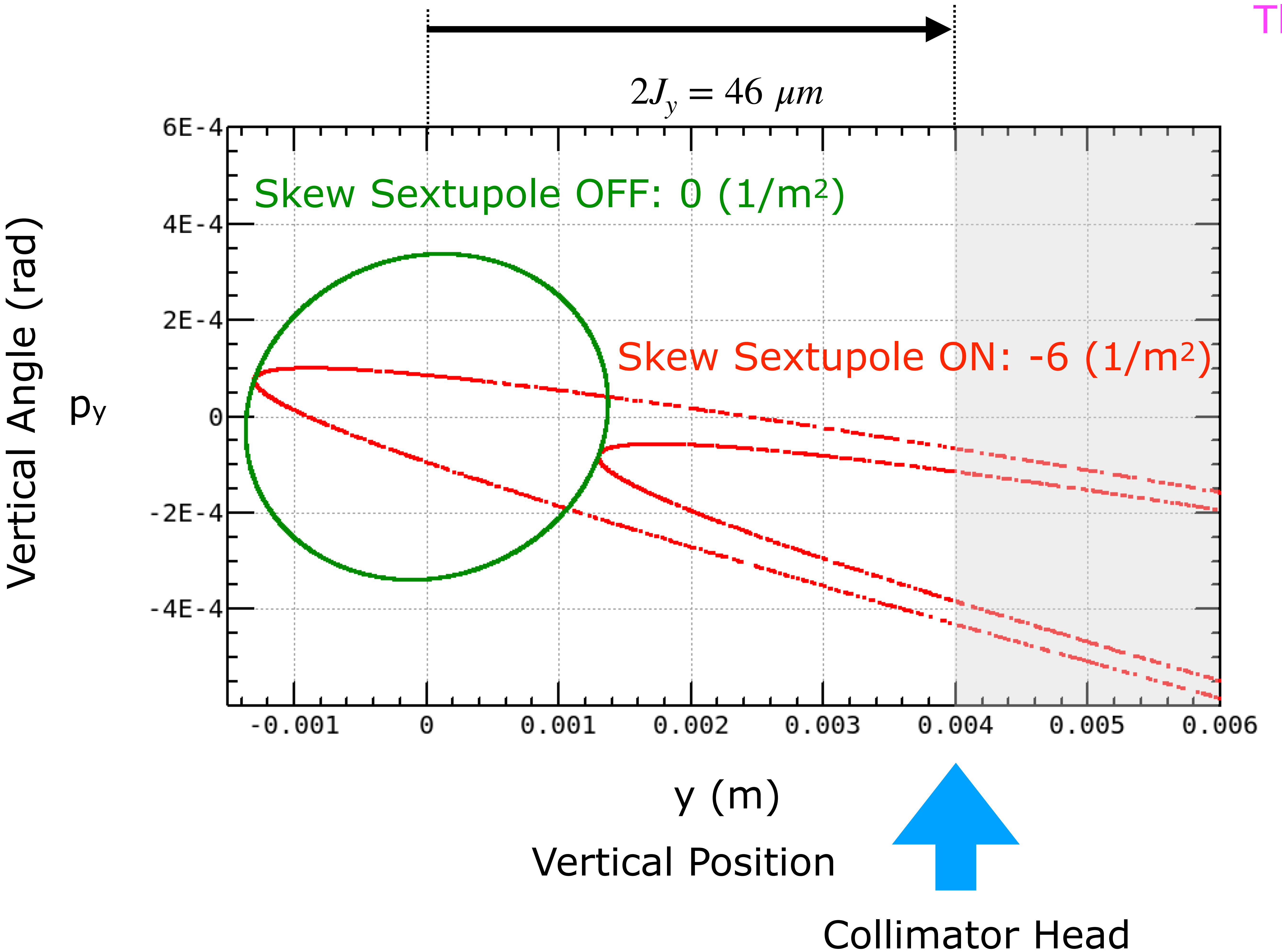
M = -I'

```
Damping time (msec):
X :  45.67757    Y :  45.68328    Z :  22.84954
```

```
Damping time (msec):
X :  52.99557    Y :  53.00312    Z :  26.50934
```

Beam Halo Can Be Scraped by Larger Collimator Aperture.

This Can Reduce Impedance.



Beam Loss and Radiation Dose at OHO Experimental Area

D05V1 Works to Reduce Stored Beam Background.

Nonlinear Collimator (D05V1) Can Not Be Closed Very much due to High Radiation Dose at OHO Experimental Area.

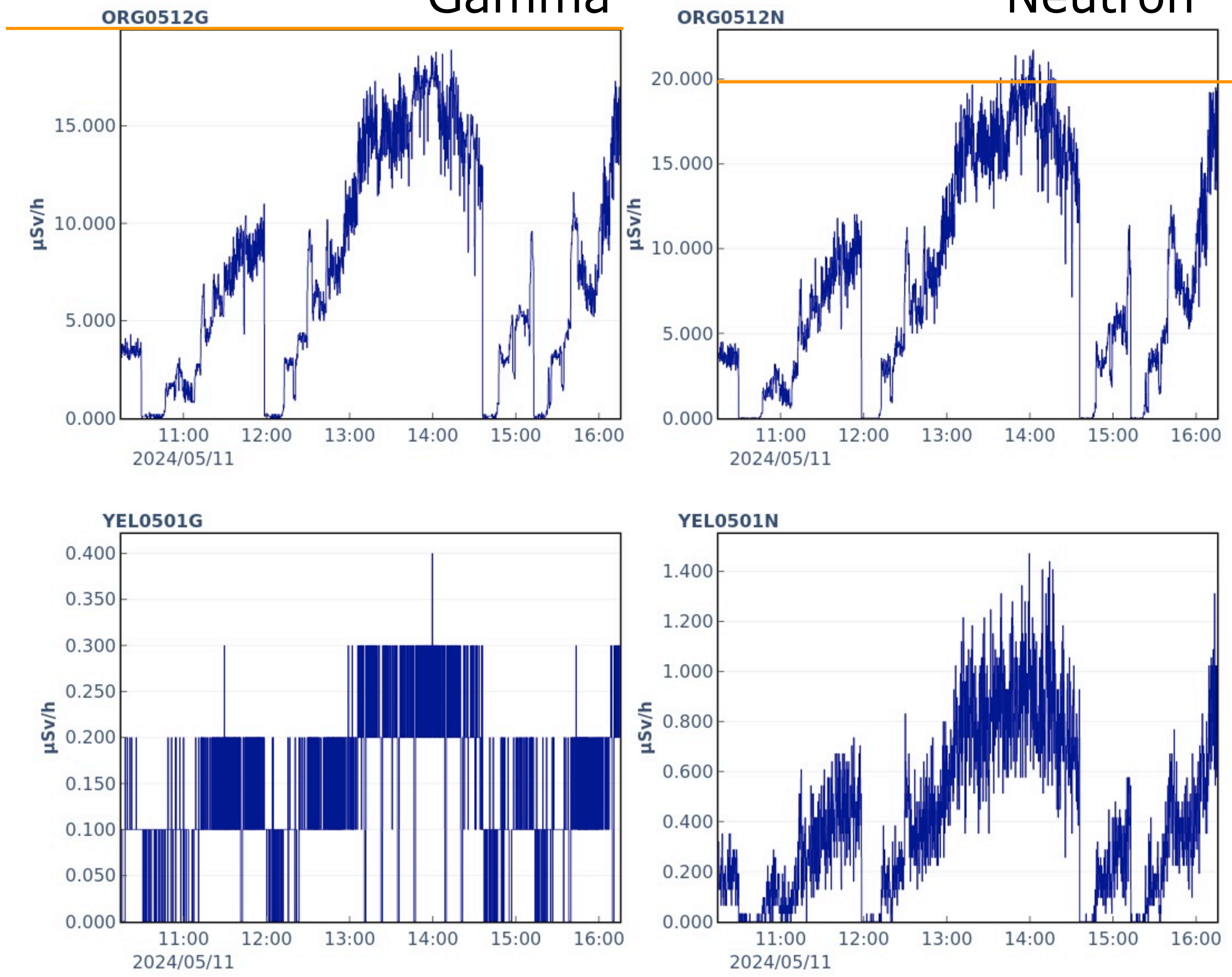
We have to Use D06V1 to Reduce Radiation Dose. We Consider More Radiation Shield.

Gamma

Neutron

20 μSv/h

Larger than What We Expected !



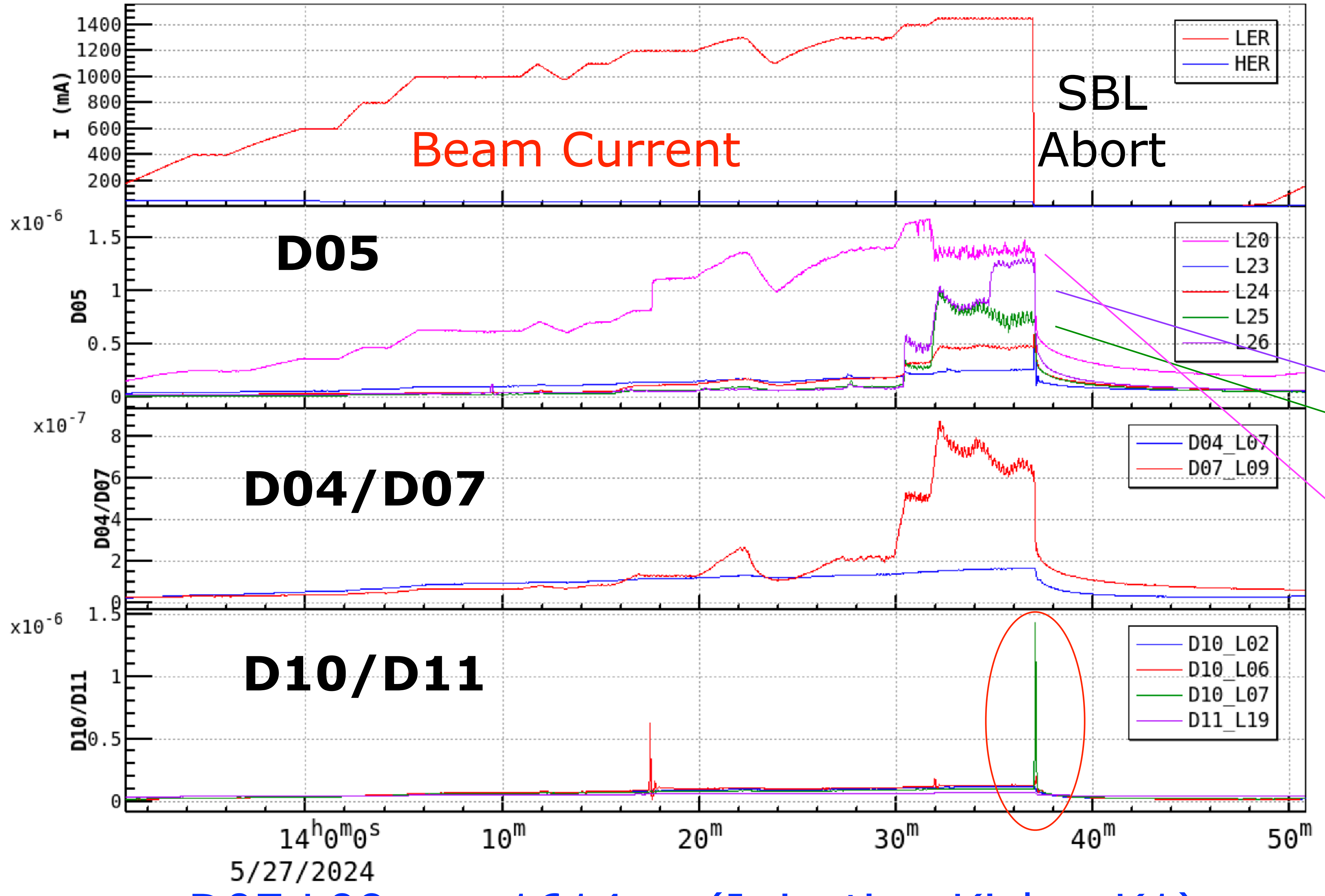
20 μSv/h

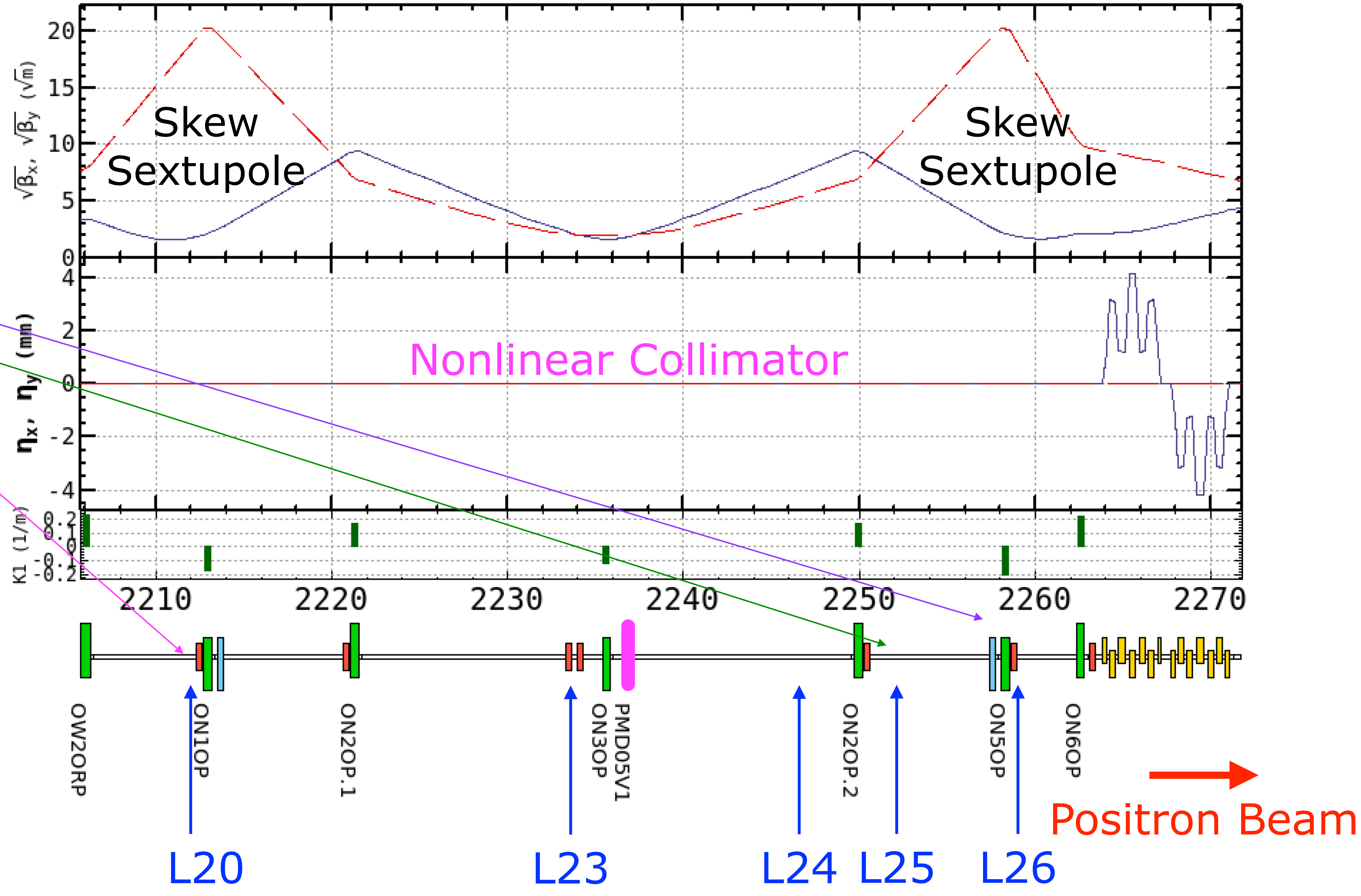
Radiation Dose Rate < 20 μSv/h

Pressure Burst at Wiggler Section and near D05V1 Collimator in LER

LER

Vacuum Sensors (CCG)

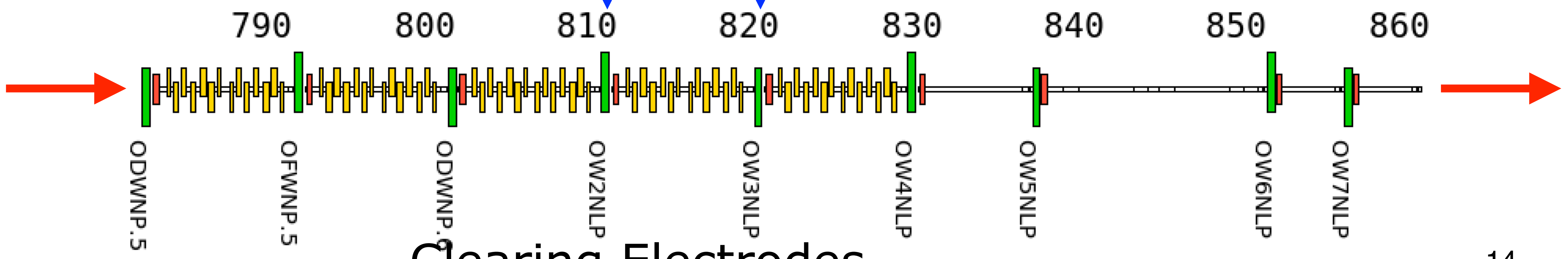




D07 L09: s= 1614 m (Injection Kicker K1)

Higher Order Mode Effect due to Pipe Structure ?

D10 L06: s = 811 m (QW2NLP, Wiggler Section)
D10 L07: s = 820 m (QW3NLP, Wiggler Section)



Clearing Electrodes

D05 L23: s= 2213 m
D05 L23: s= 2234 m
D05 L24: s= 2246 m
D05 L25: s= 2252 m
D05 L26: s= 2259 m

Beam Pipe Deformation due to SR Heating

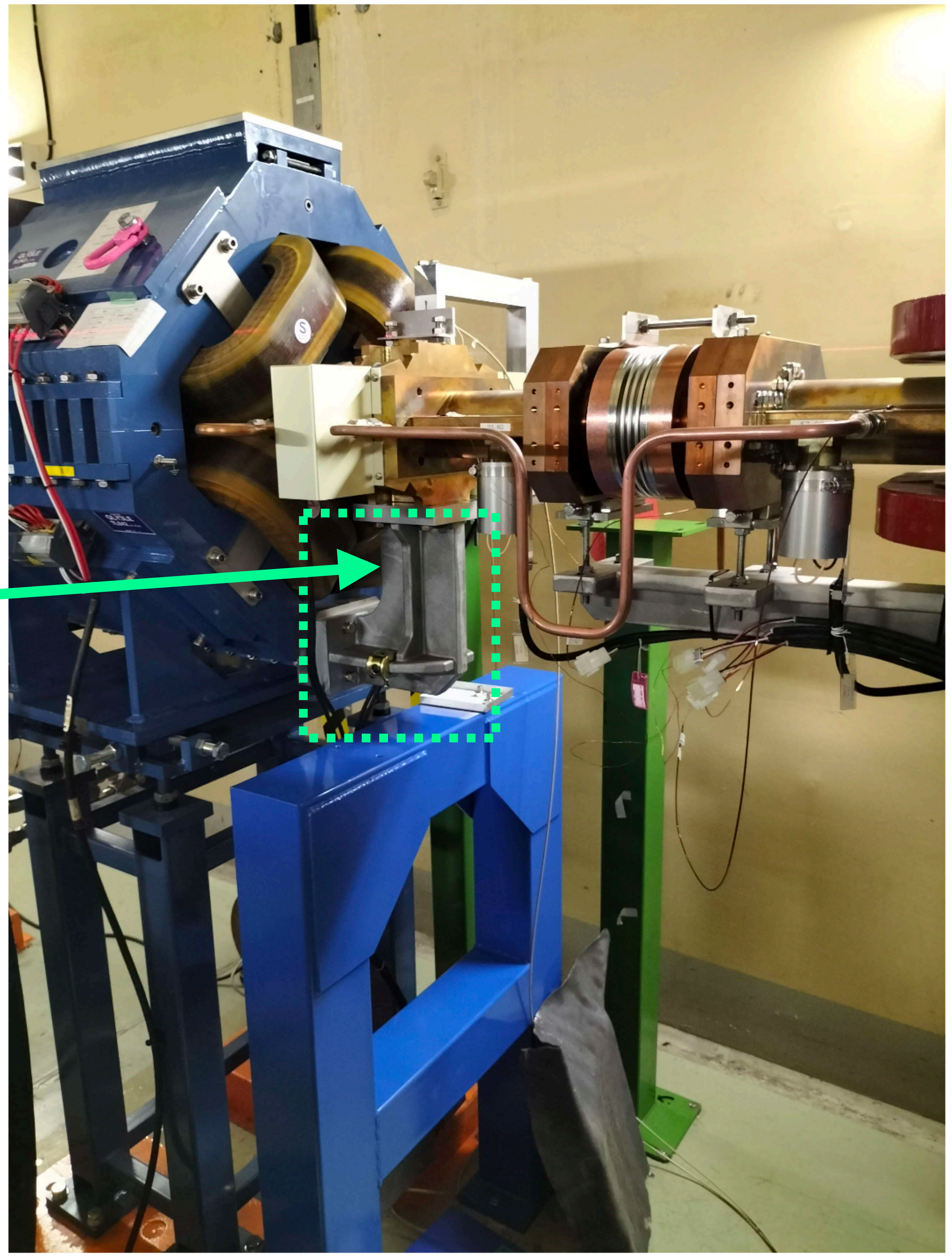
Isolation Between BPM Block and Quadrupole Magnet

BPM Block (Beam Pipe) Moves in the Horizontal Direction due to SR Heating.

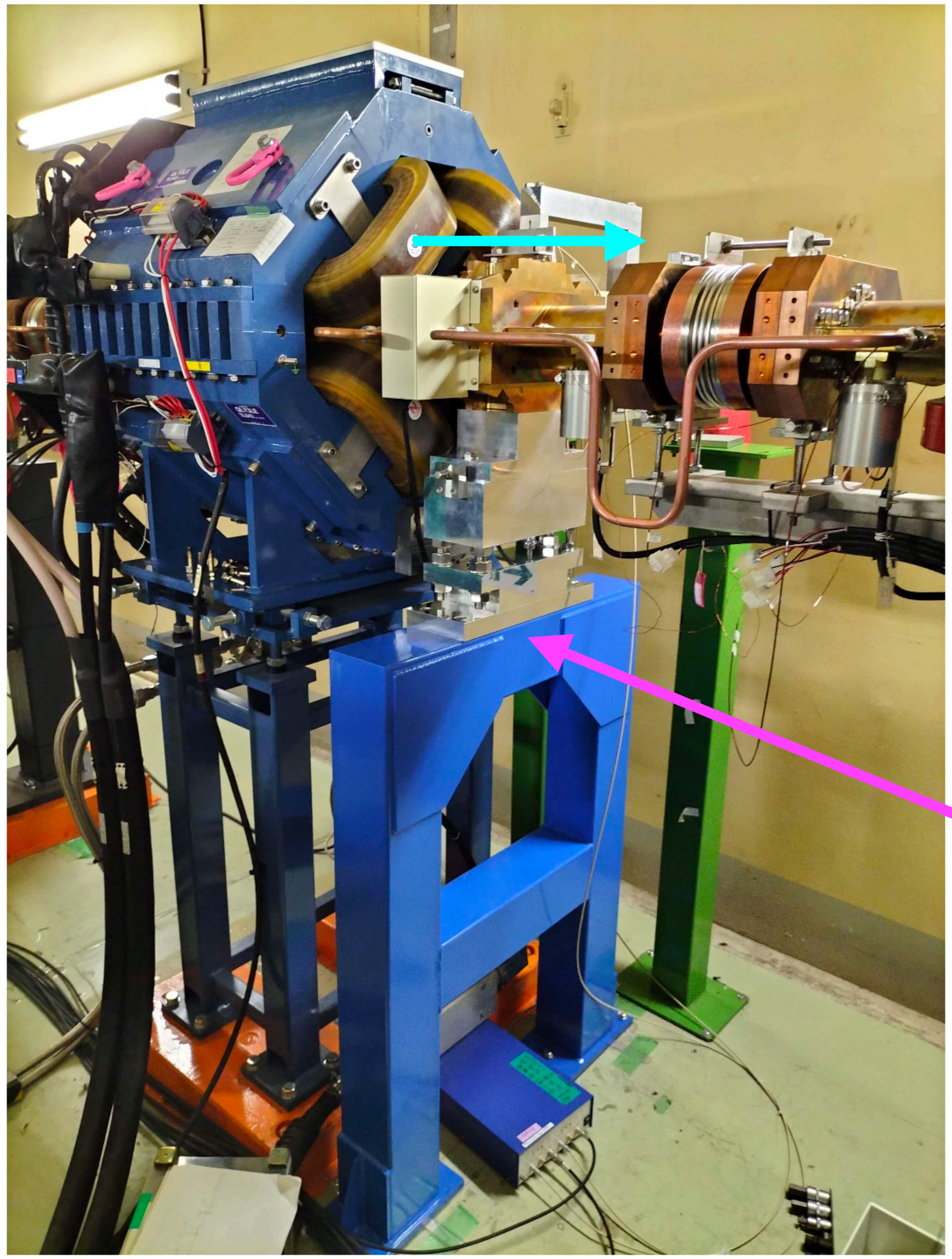
HER

BPM Block (Beam Pipe) Pushes Quad.

BPM Block is supported by Quadrupole Magnet.

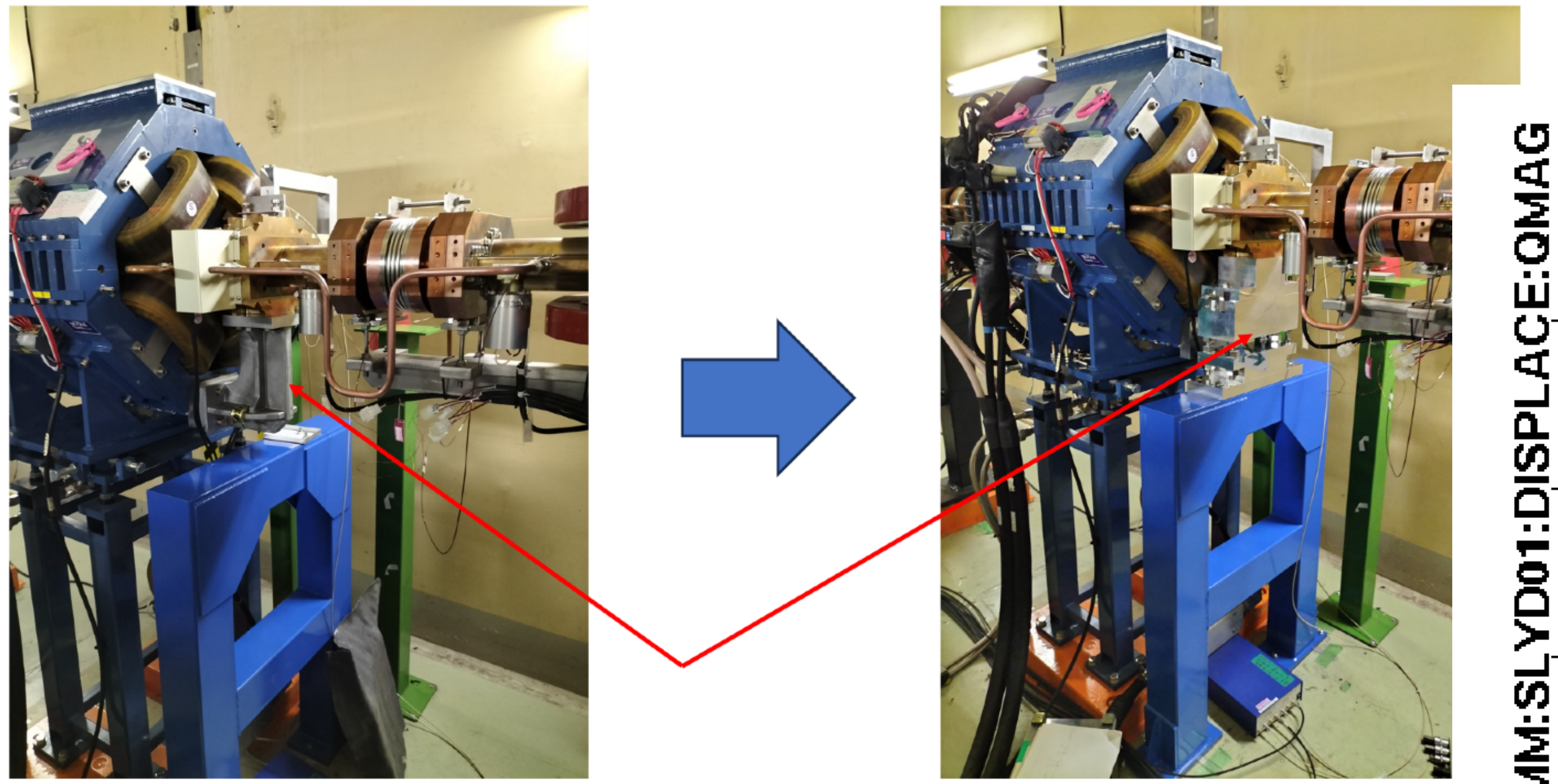


BPM Block (Beam Pipe) Doesn't Touch Quad.



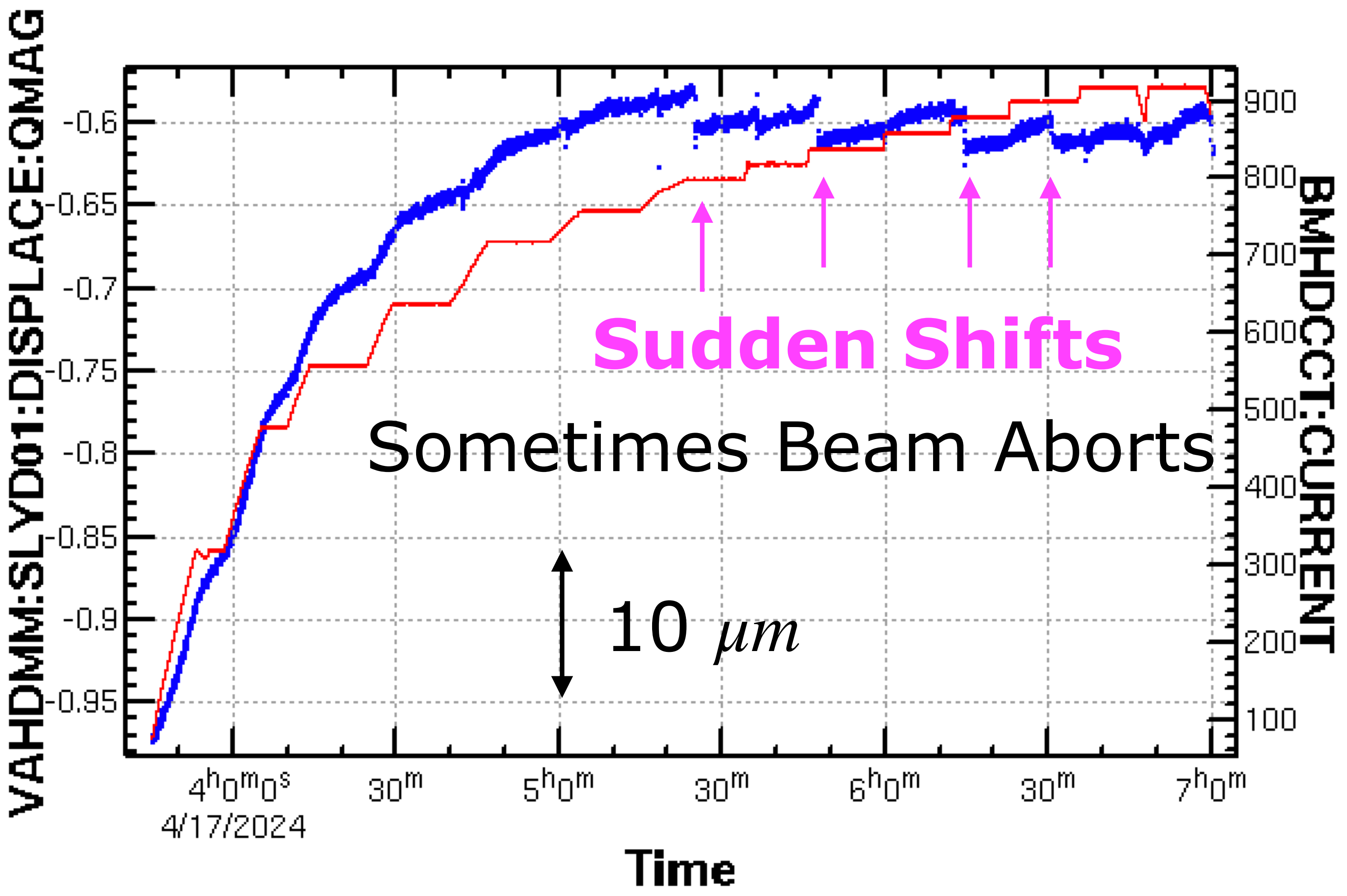
New Support

Before After

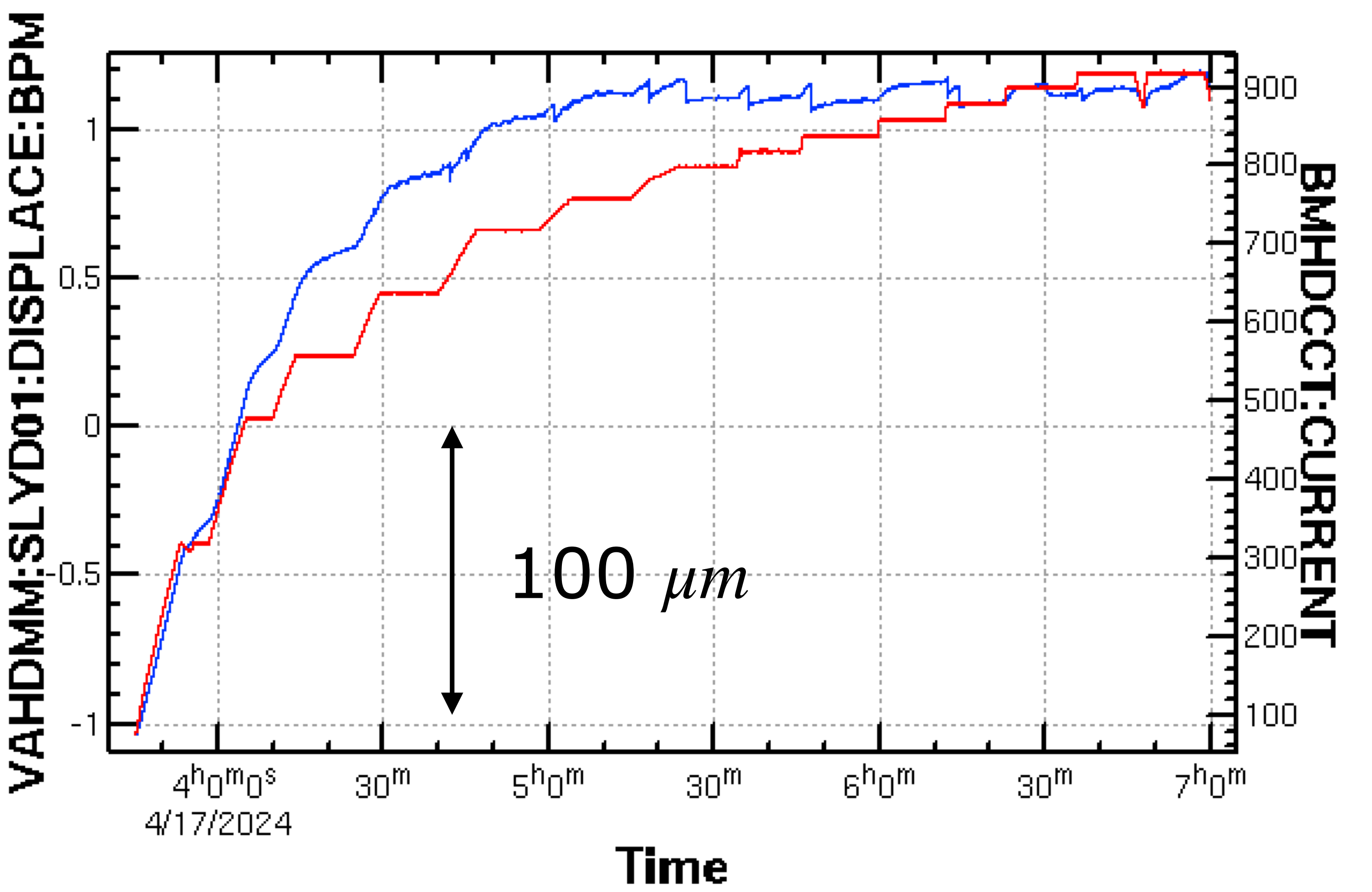


BPM Support Was Separated
from Quadrupole Magnet.

Quad. Displacement



BPM Block Displacement



HER

Isolation Works Very Well.

In addition,
Optics Feedback Systems Are Working.

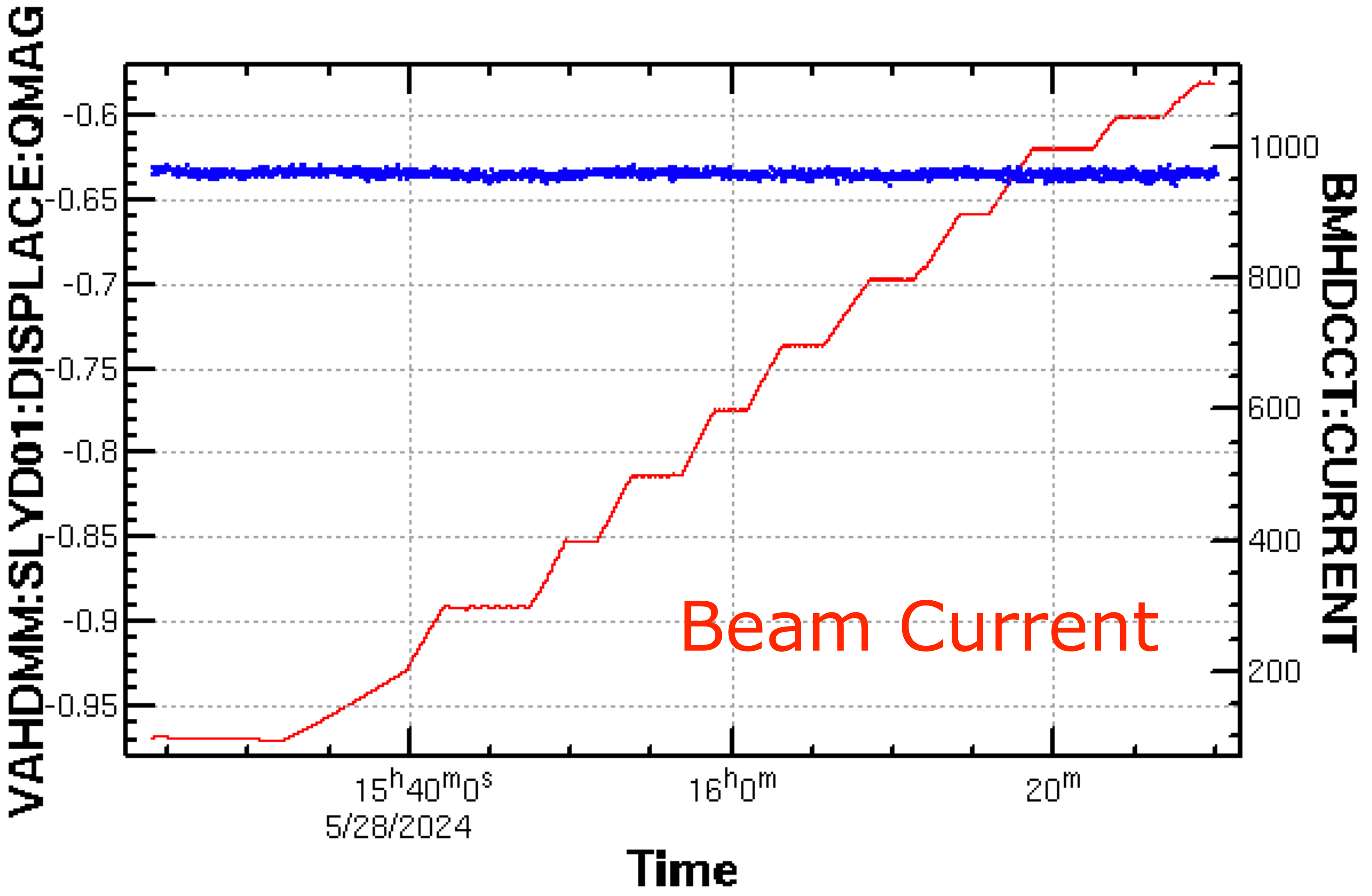
Orbit Offset Induces Optics Degradation.

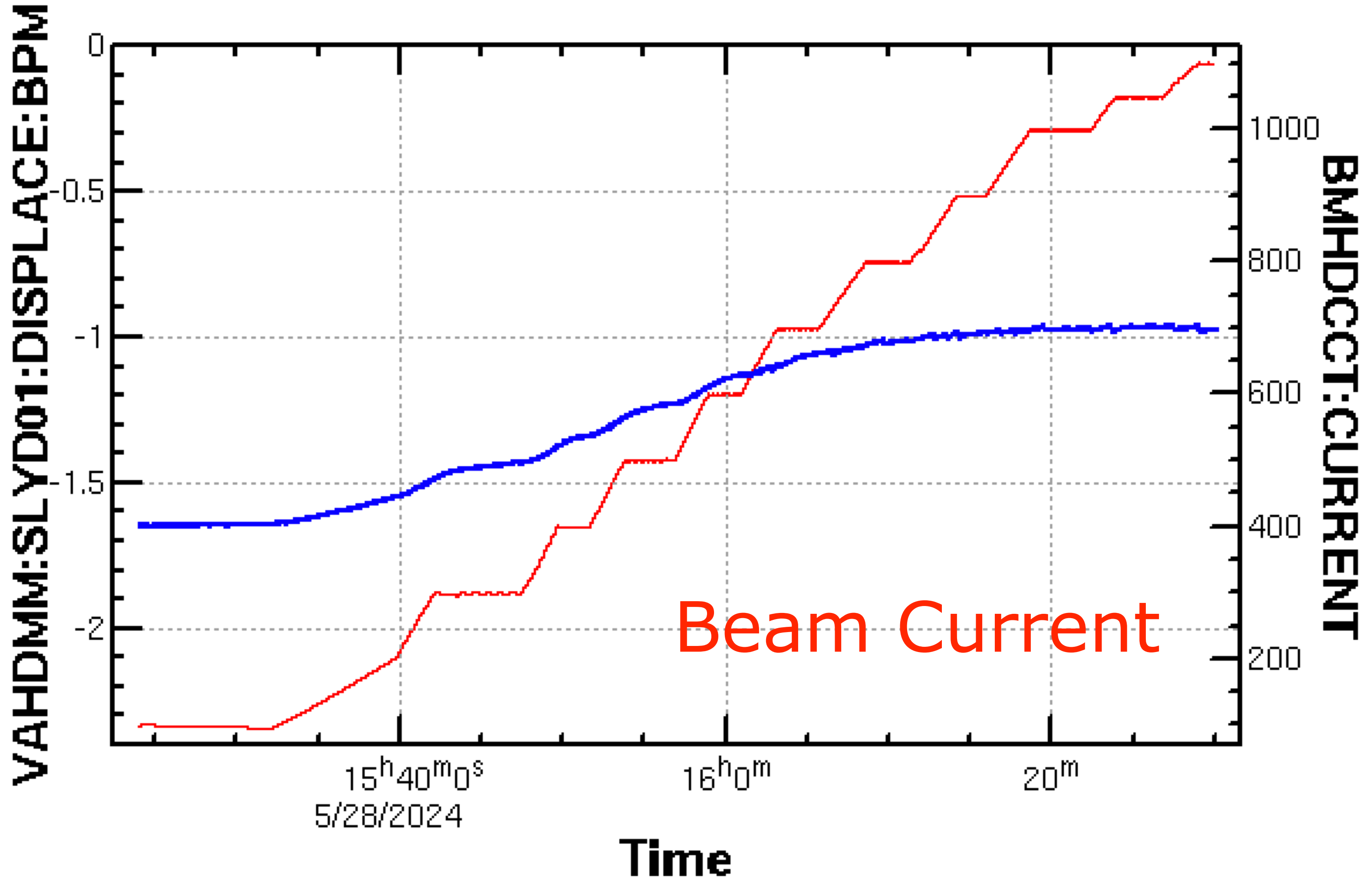
LER also Has Similar Problem.

After Modification

1 V = 100 μm

No Displacement at I > 1 A

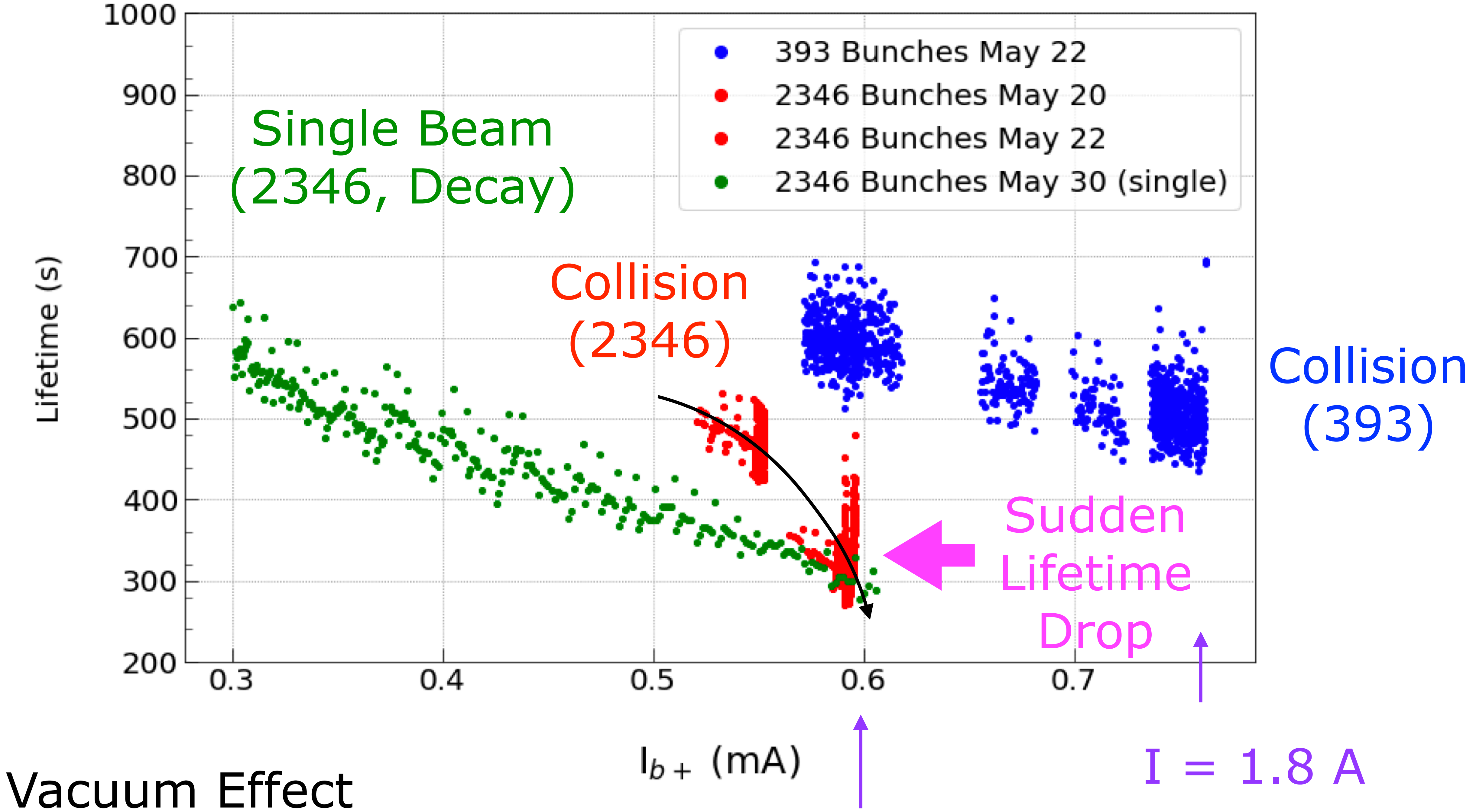




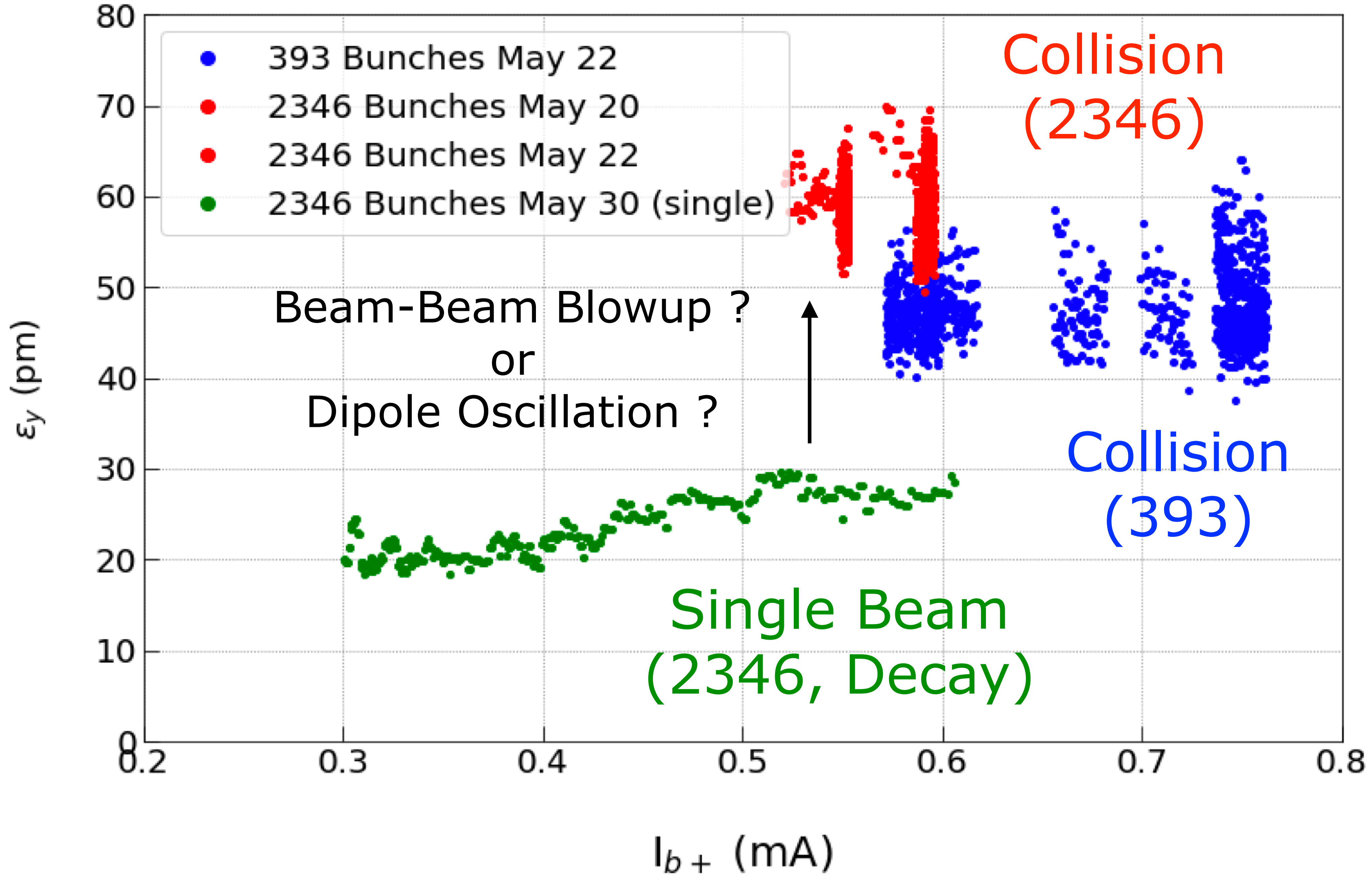
Lifetime

LER

Lifetime VS Bunch Current



Vertical Emittance VS Bunch Current



Lifetime at 1.4 A for Collision (2346) is about 300 s
(Sudden Lifetime Drop) even though Beam Blowup. Beam-Beam ?

Vacuum Effect

$$\tau_V \propto \frac{1}{n_b I_{b+}}$$

Touschek Effect

$$\tau_T \propto \frac{\sqrt{\varepsilon_y}}{I_{b+}}$$

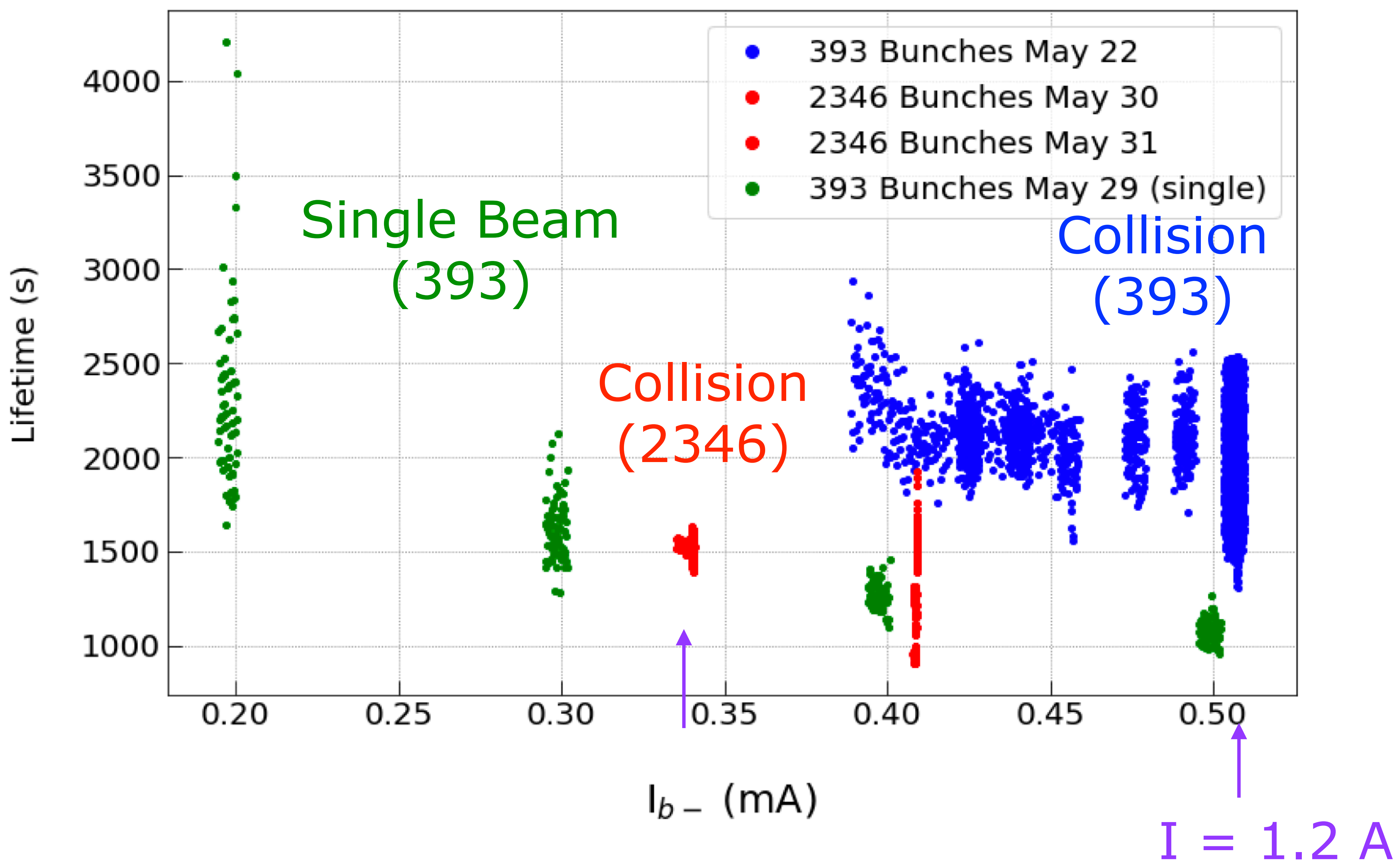
Lifetime: 300 s = Loss Rate: -4.7 mA/s at 1.4 A.

6.9 mA/s Can Be Provided by Linac > 4.7 mA/s
2-Bunch Injection: 2.7 nC (80% eff.) and 1.8 nC (60% eff.) with 23 Hz Repetition (BCE: -5 %)
But It is Difficult to Increase Beam Current Larger than 1.4 A. The Reason is Unclear.

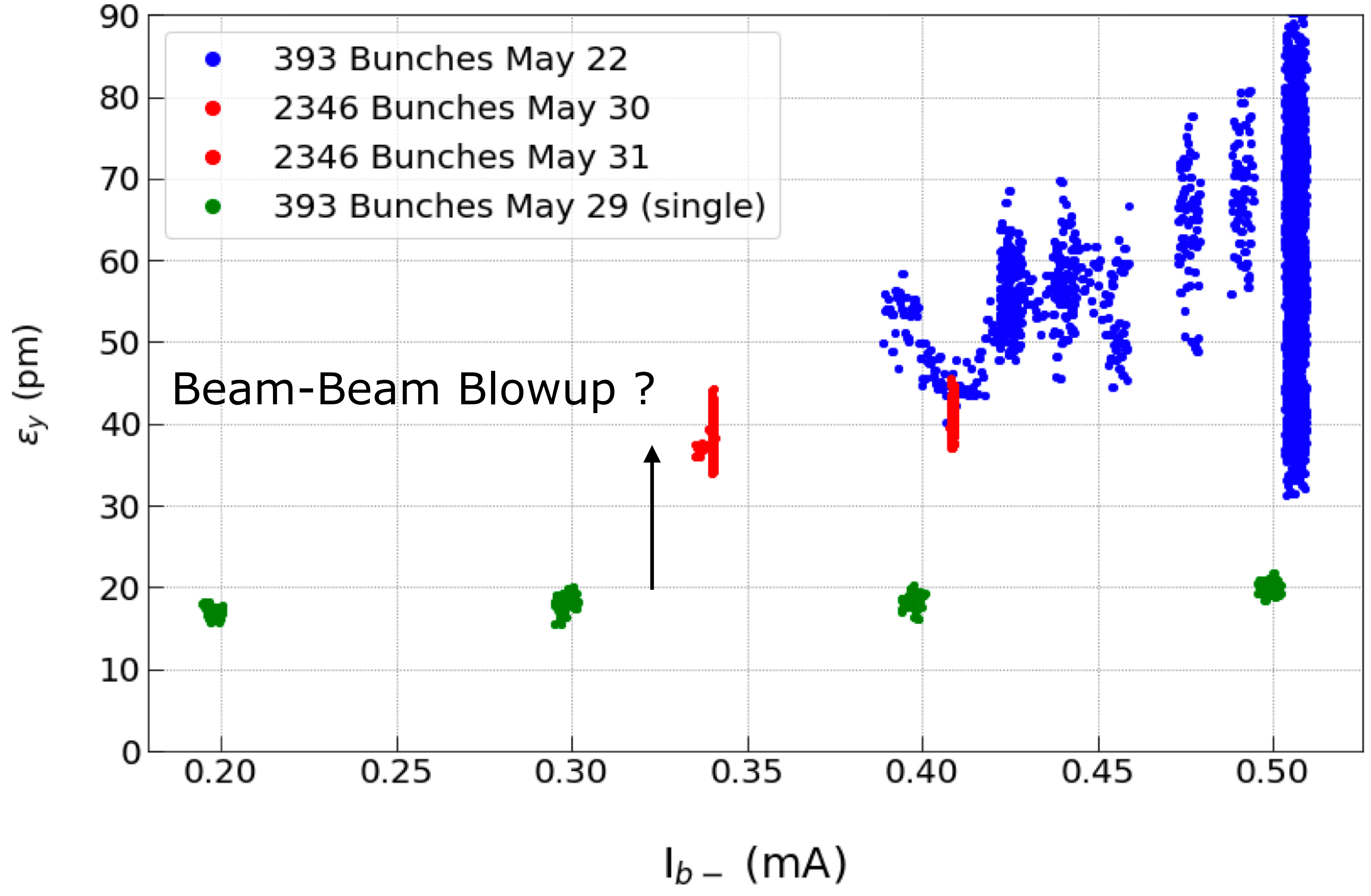
Lifetime in HER

HER

Lifetime VS Bunch Current



Vertical Emittance VS Bunch Current



I = 0.8 A with 2346 Bunches

Vacuum Effect

$$\tau_V \propto \frac{1}{n_b I_{b+}}$$

Touschek Effect

$$\tau_T \propto \frac{\sqrt{\varepsilon_y}}{I_{b+}}$$

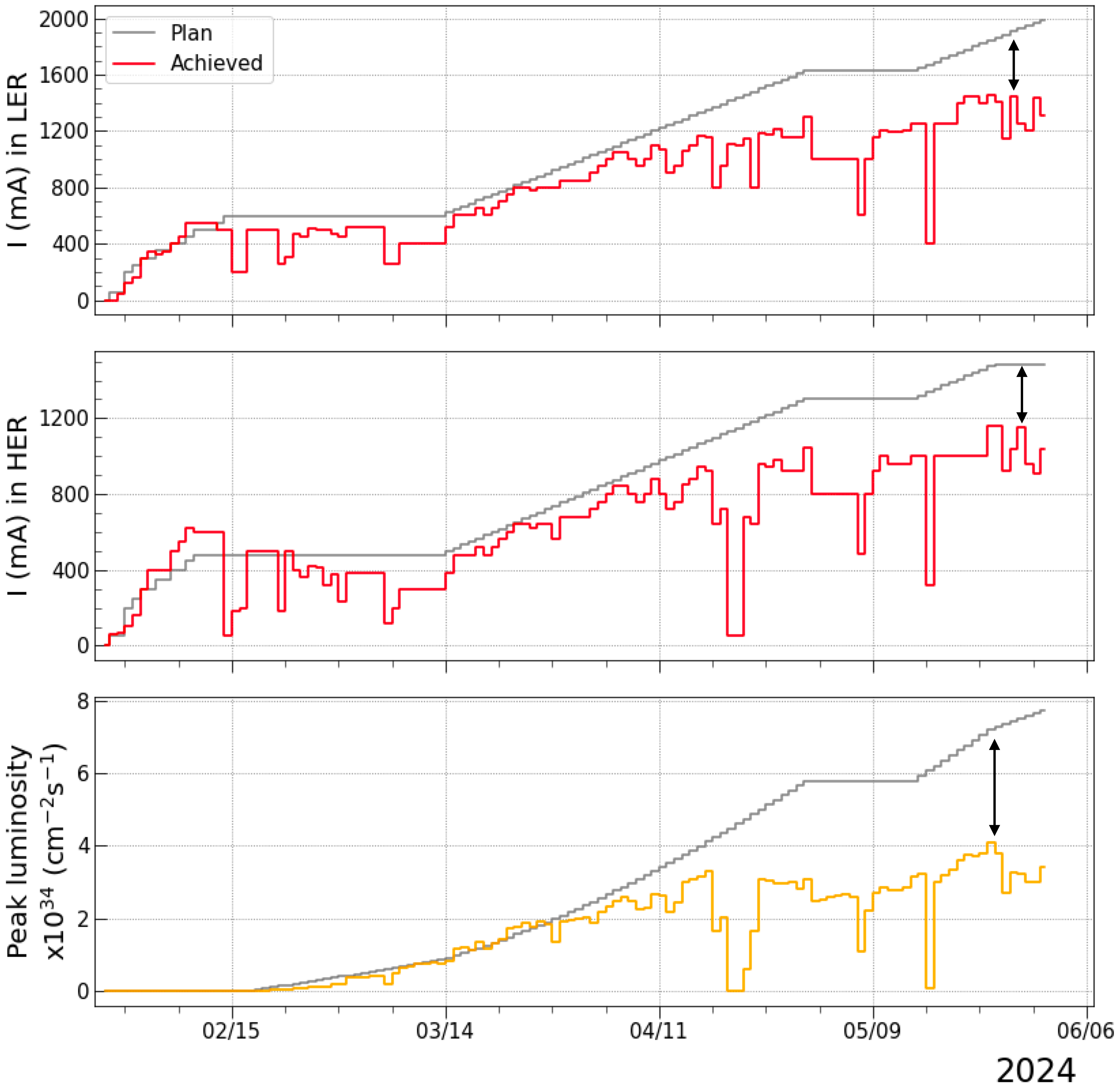
Lifetime at 1.2 A is about 1000 s.
Loss Rate is -1.2 mA/s.

1.8 nC, 2-Bunch Injection with 23 Hz Repetition
→ 15 % Injection Efficiency

Linac: 1st Bunch 1.9 nC, 35 % eff. 2nd Bunch 1.4 nC 20 % eff.
23 Hz Repetition → 2 mA/s

Plan

Plan and Achieved Beam Currents



A) High Current Plan
LER: 1.8 - 2.0 A / HER: 1.2 - 1.4 A

B) Beta Squeezing Plan → 2nd Week until End
β_y^* = 0.8 mm (includes Adiabatic Squeezing)

First Week in June

We Need to Investigate the Reason
that We Can't Increase Currents
Larger than 1.4 A in LER.

Dynamic Aperture, Physical Aperture, Beam-Beam,
Vacuum, Instabilities, etc.

Poor Injection Efficiency in HER
Dynamic Aperture, Physical Aperture

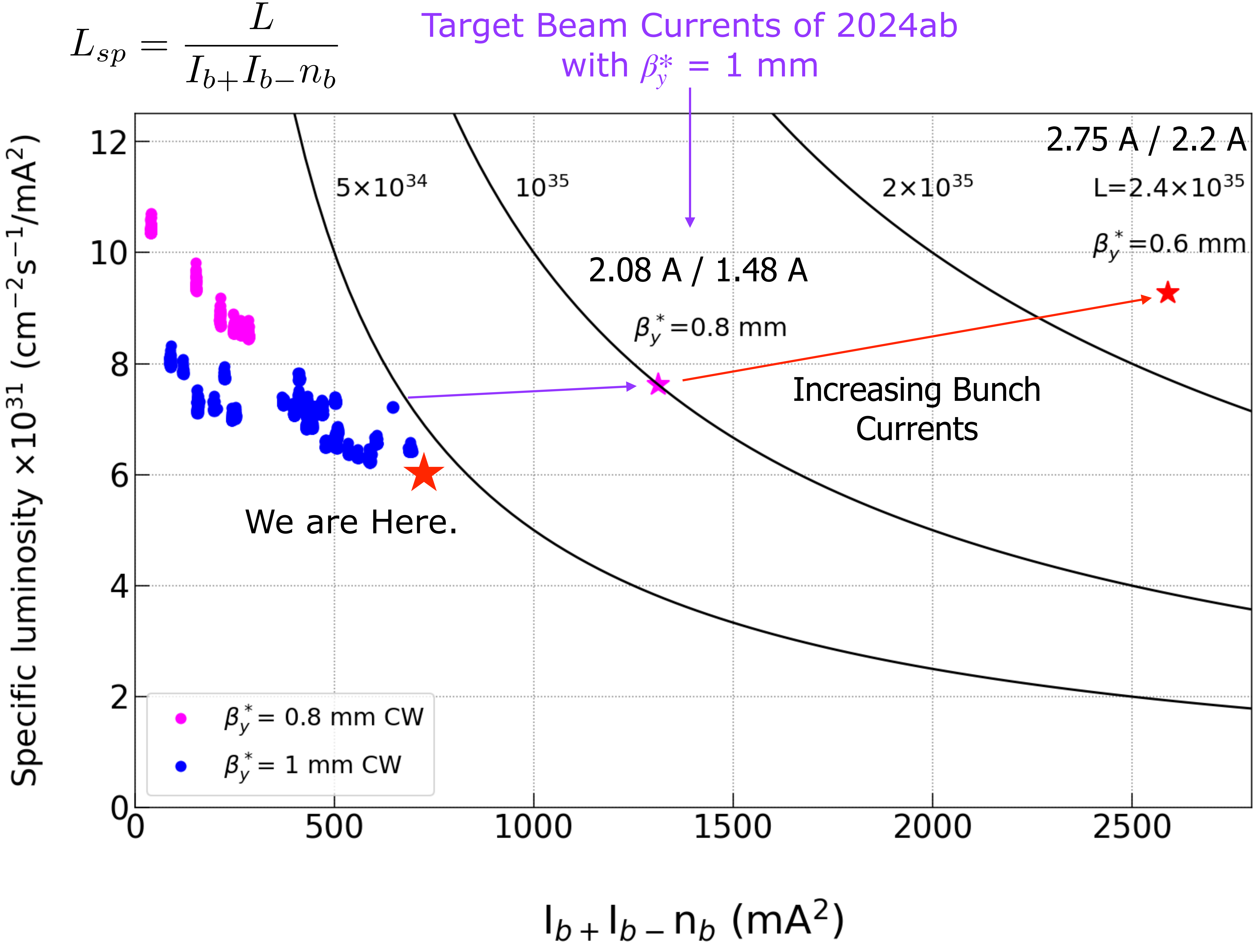
Improve Luminosity Performance

Vertical Angle Scan in LER, CW 60 % in HER

+ SBL Study

Strategy Toward 2.4 x 10^{35} $cm^{-2}s^{-1}$

$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b}$$



Strategy for 10^{35}

- Increase Bunch Current. Max. Number of Bunches is 2346 (Design Value).
  - Sudden Beam Loss Problem Has to Be Fixed. Clearing Electrode Is SBL Source ? How to ?
  - Sudden Lifetime Drop in LER (Found in 2024b Run)
  - Larger Dynamic Aperture and Physical Aperture Should Be Realized by Sextupole Setting and Better Detector Background Controls. (Trial and Error)
- Beam Injection
  - Emittance Blowup in the Beam Transport Line (BT) Has to Be Fixed. No Concrete Solution so far.

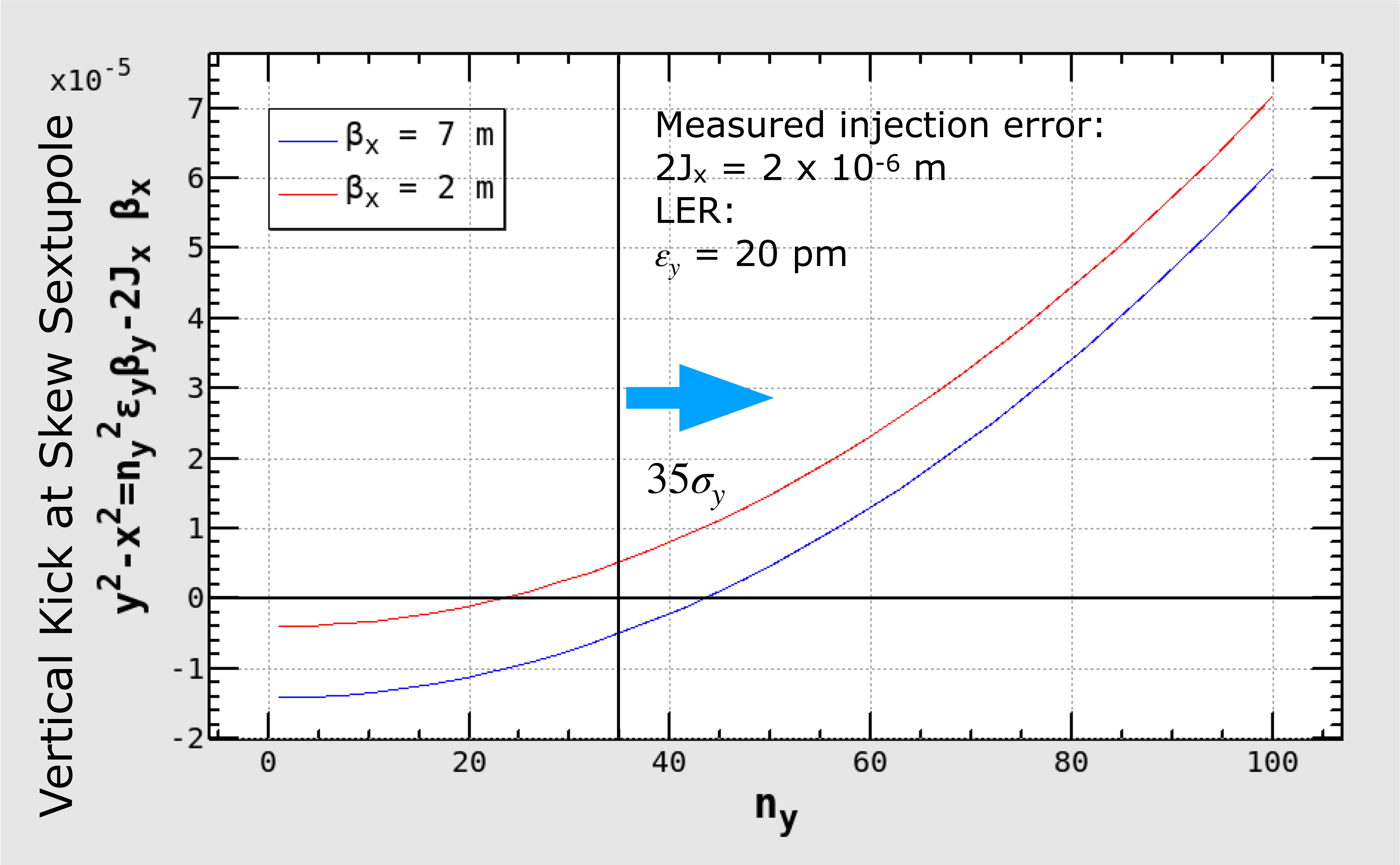
Nonlinear Magnetic Field in BTp

- Luminosity Performance at High Beam Currents
  - Single Beam Blowup Has to Be Suppressed Enough.
  - Reduce Machine Error (SR Heating Problem, also LER)
- How to Squeeze Beta Function at IP ?
  - First Target is 0.8 mm. Then, Try 0.6 mm.
  - Machine Study Is Needed to Make Larger Dynamic Aperture (Longer Lifetime).

Appendix

We Consider Lower β_x at Skew Sextupoles to Reduce Injection Beam Background as well as Stored Beam Background.

β_x at skew sextupole for D05V1 (nonlinear collimator)

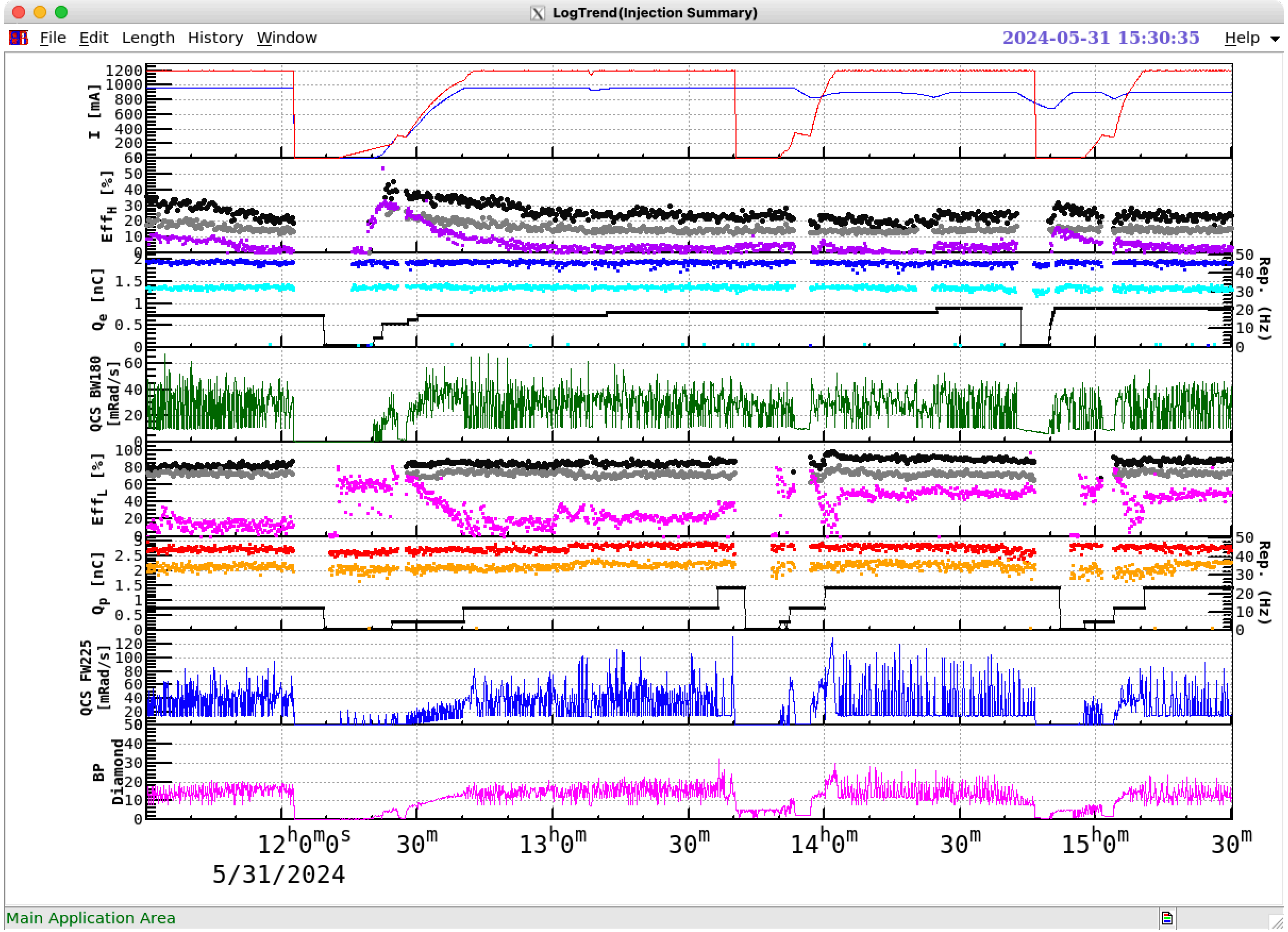


$$n_y = \frac{\Delta y}{\sigma_y}$$

Lower β_x at the skew sextupole is preferable for the vertical size larger than $35\sigma_y$.

Y. Ohnishi

Injection



LogTrend(Injection Summary)
File Edit Length History Window
2024-05-31 15:30:35
Help
I [mA]
Eff_H [%]
Q_e [nC]
Rep. (Hz)
QCS BW180 [mRad/s]
Eff_L [%]
Q_p [nC]
QCS FW225 [mRad/s]
BP Diamond
12h0m0s
5/31/2024
30m
13h0m
14h0m
15h0m
Main Application Area