Beam Instrumentations

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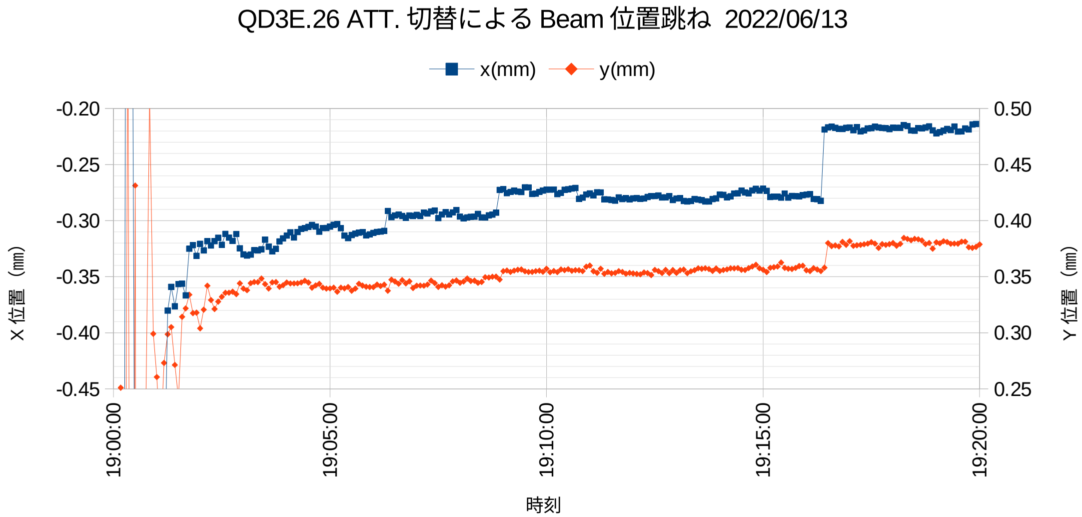
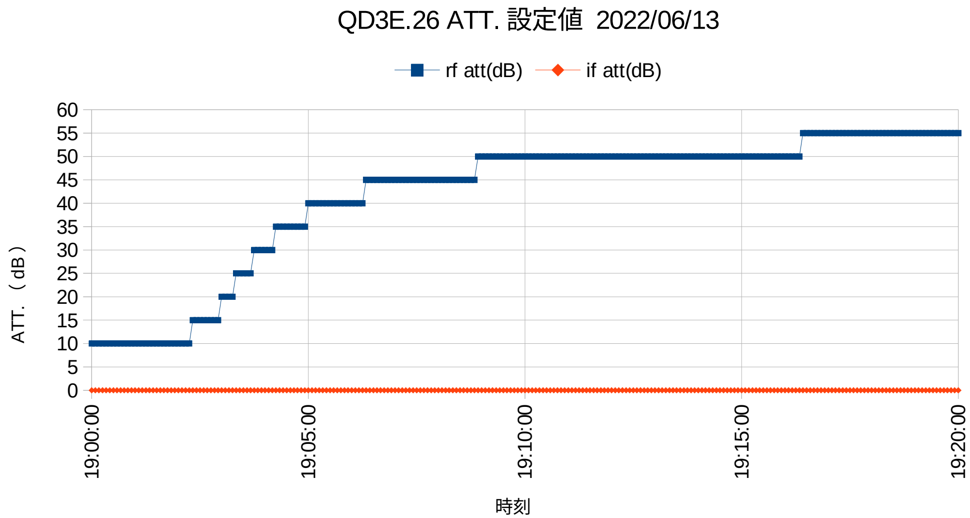
for SuperKEKB Beam Instrumentation Group

- **COD monitor**
  - Change of measured beam position with beam current
- **X-ray beam size monitor**
- **Visual synchrotron radiation monitor**
  - Replacement of first mirror
  - Coronagraph
  - Injection beam monitor
- **Bunch feedback system**
  - FIR filter effect
  - Broadband noise in the front-end circuit
- **Tunnel environment monitors**

HER beam position change with beam current

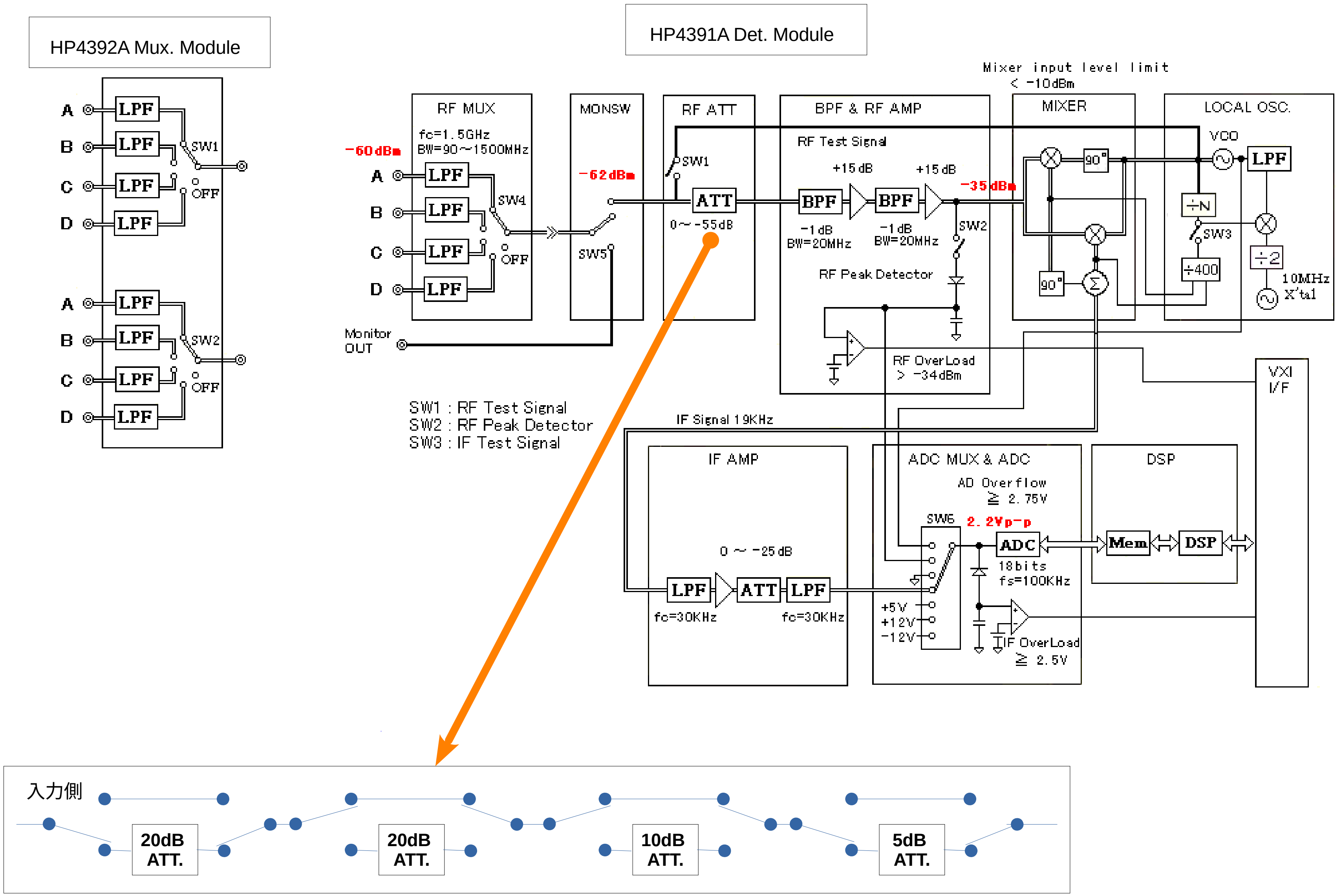




Similar behavior of four BPMs in the same narrowband detector (D6 QF2E32 QD3E26 QF4E26 QD1E16) have been observed.

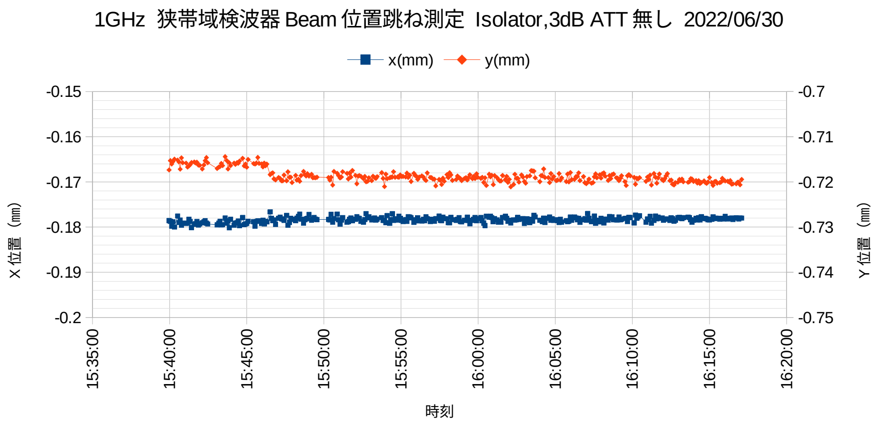
Suspected to be caused by the HP 1GHz narrowband detector's characteristics.

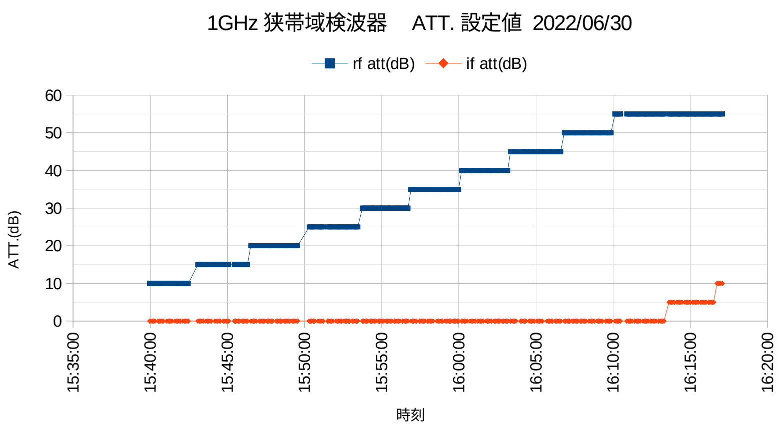
HER 1GHz BPM detector



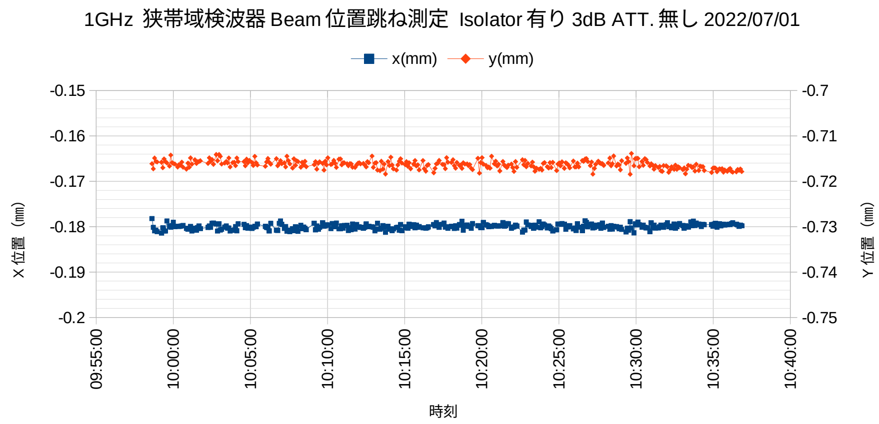
Suspected source: Impedance mismatch

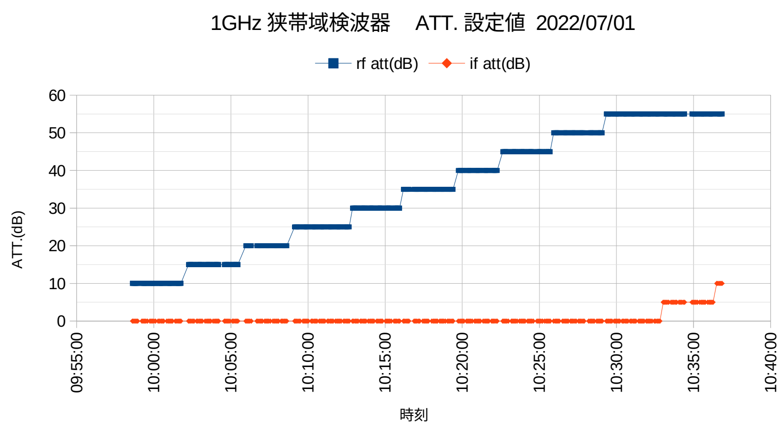
w/o 1GHz isolator





with isolator

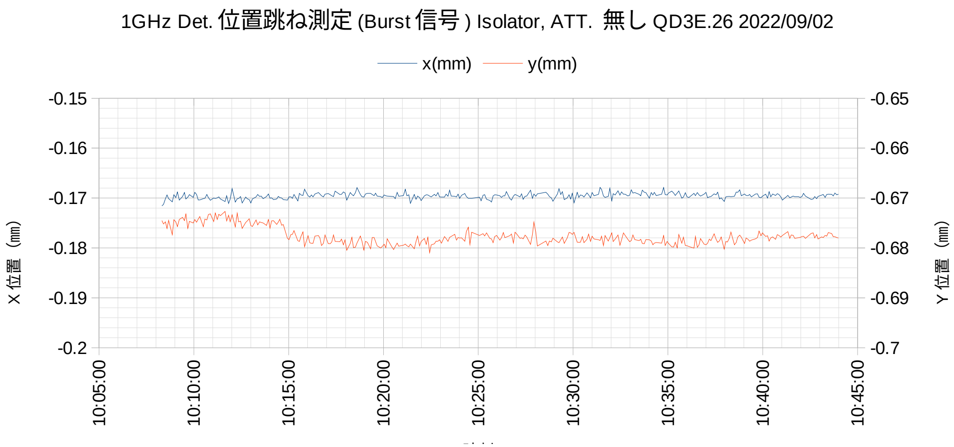


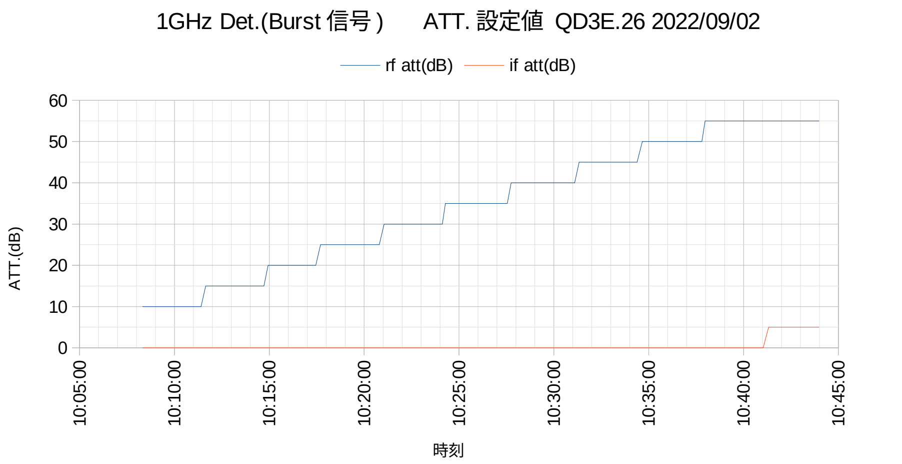


CW measurement at the bench did not show large position jump

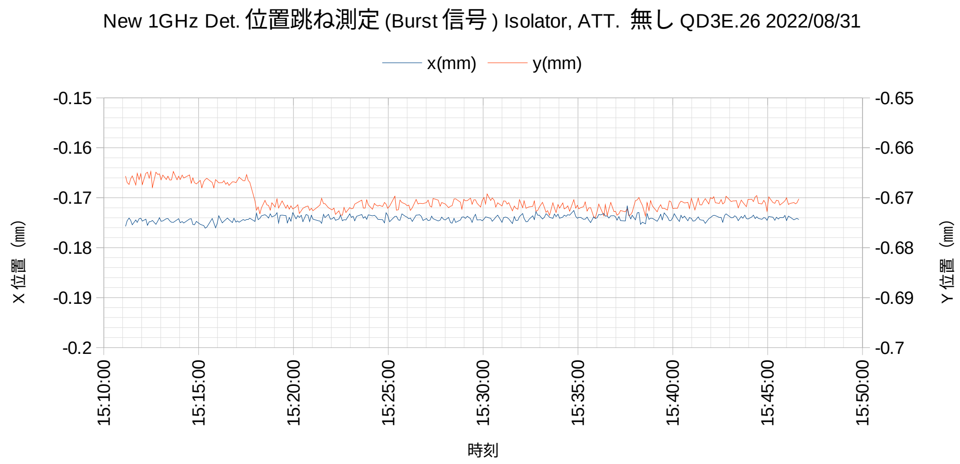
Burst signal response

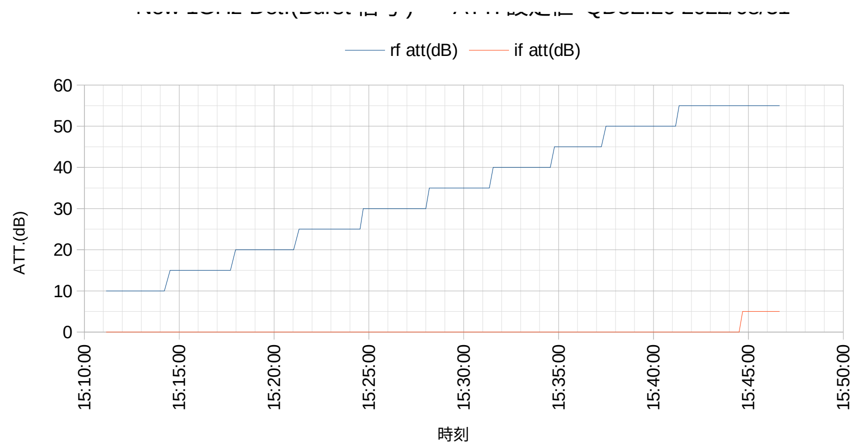
Original detector





Spare detector

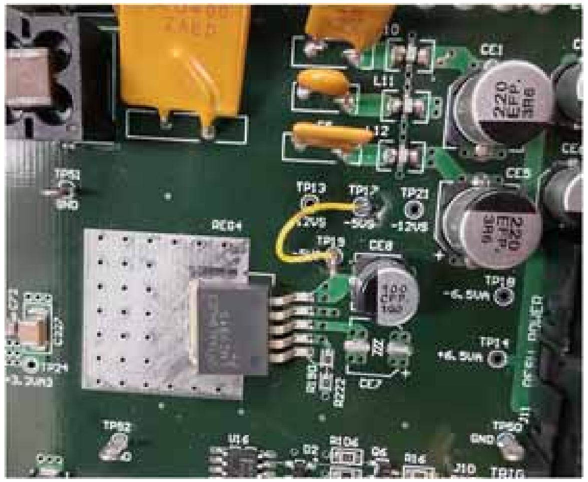




- **We will try to insert 1GHz isolators between the MUXs and the detectors at the "important" BPMs.**
  - 30 isolators have been ordered. Waiting for delivery.
- **Another way might be to use 500MHz detectors (newly developed for SuperKEKB) used for LER BPMs.**
  - 6 spares are available now.

Turn-by-Turn BPMs

Building	BPM	Date	Broken	Repaired date	Repaired parts
LC5	QD3E18	2022/1/4	PS	2022/1/4	PS replacement
D07	QEAP25	2022/3/23	PS	2022/3/23	PS replacement
LC4	QD3E23	2022/3/23	LAN	2022/3/23	Power on/off & IOC reboot
D7	QM2E	2022/5/3	Gated sw.	2022/5/11	Under investigation



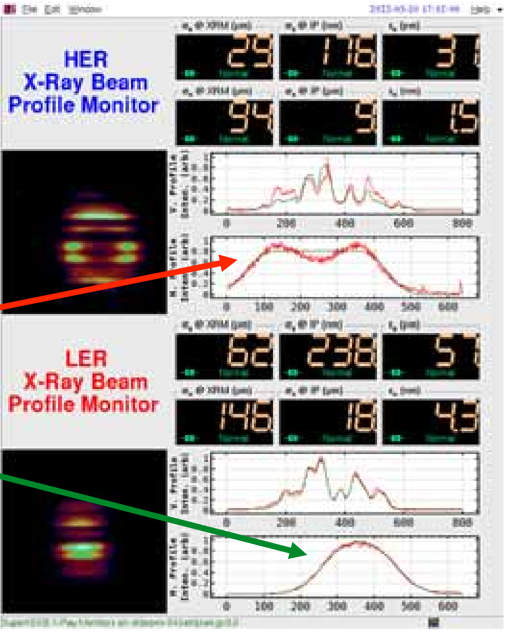
- The power supplies have been malfunctioning for the recent two years; 3 BPMs in 2021abc and 2 BPMs in 2022ab. Broken PSs were replaced every time by us (not in a beautiful way).
- PSs of 55 BPMs in total (1/3 of all turn-by-turn BPMs) were replaced by a circuit maker.
  The rest of the replacements are planned for the next FY.

X-ray beam size monitors

X-ray irradiation inside the detector box was so severe at ~1 A.

- Malfunctioning of the CMOS cameras became frequent, and we replaced the cameras two times in HER and once in LER in 2022ab.
  - The new “big” detector box makes enough room for the Pb shielding.
- Scintillation efficiency of the YAG:Ce scintillator in HER decreased above 0.9 A. A visible check on maintenance day found no significant damage on the scintillator and the CMOS camera.
  - Quick solution: we added the Cu filter upstream from the scintillator, and it looked OK.
  - A diamond scintillator would be a good alternative.

The copper filter reduced X-ray intensity by 30%, which was consistent with the calculation overall.



A large leak in the HER X-ray line

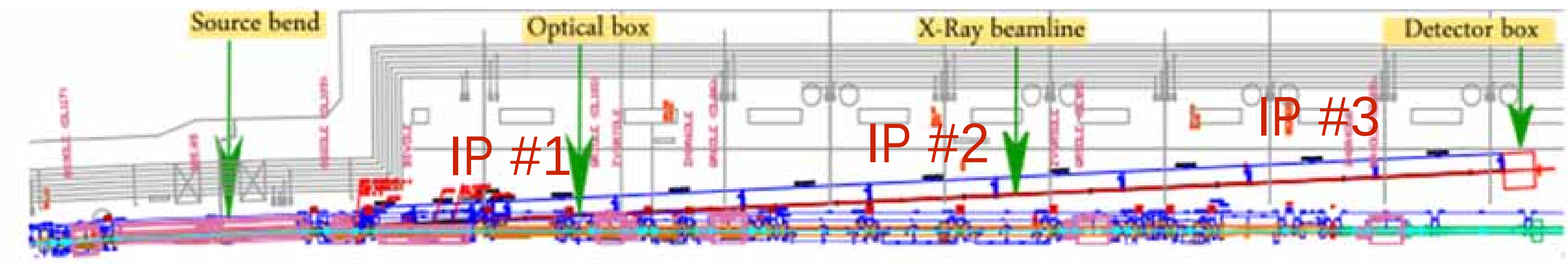
1. Two (middle #2 and downstream #3) out of the three ion pumps didn't turn on at the beginning of August after the power maintenance.
2. We suspected the humid atmosphere in the OHO straight section, where ceiling repair work has been ongoing, caused an electrical leakage around the HV connector.
3. We tried to turn on the ion pump #2 and #3 several times, and finally, the ion pump #2 started though the ion pump #3 still stopped.
4. Shortly later, we replaced the detector box as scheduled and found a significant leak in the downstream Be window.
5. Once we stopped all the ion pumps and replaced the leaked downstream Be window with a new one. At the same time, we replaced the upstream Be window (confirmed to be healthy) for sure. In this work, we found that the ion pumps #2 and #3 were failing.
6. After replacing the ion pump #2 and #3, we believed everything was OK and tried to turn on all the pumps. But the upstream ion pump #1 didn't wake up and turned out to be broken.
7. Consequently, we replaced two Be windows and three ion pumps #1-#3.

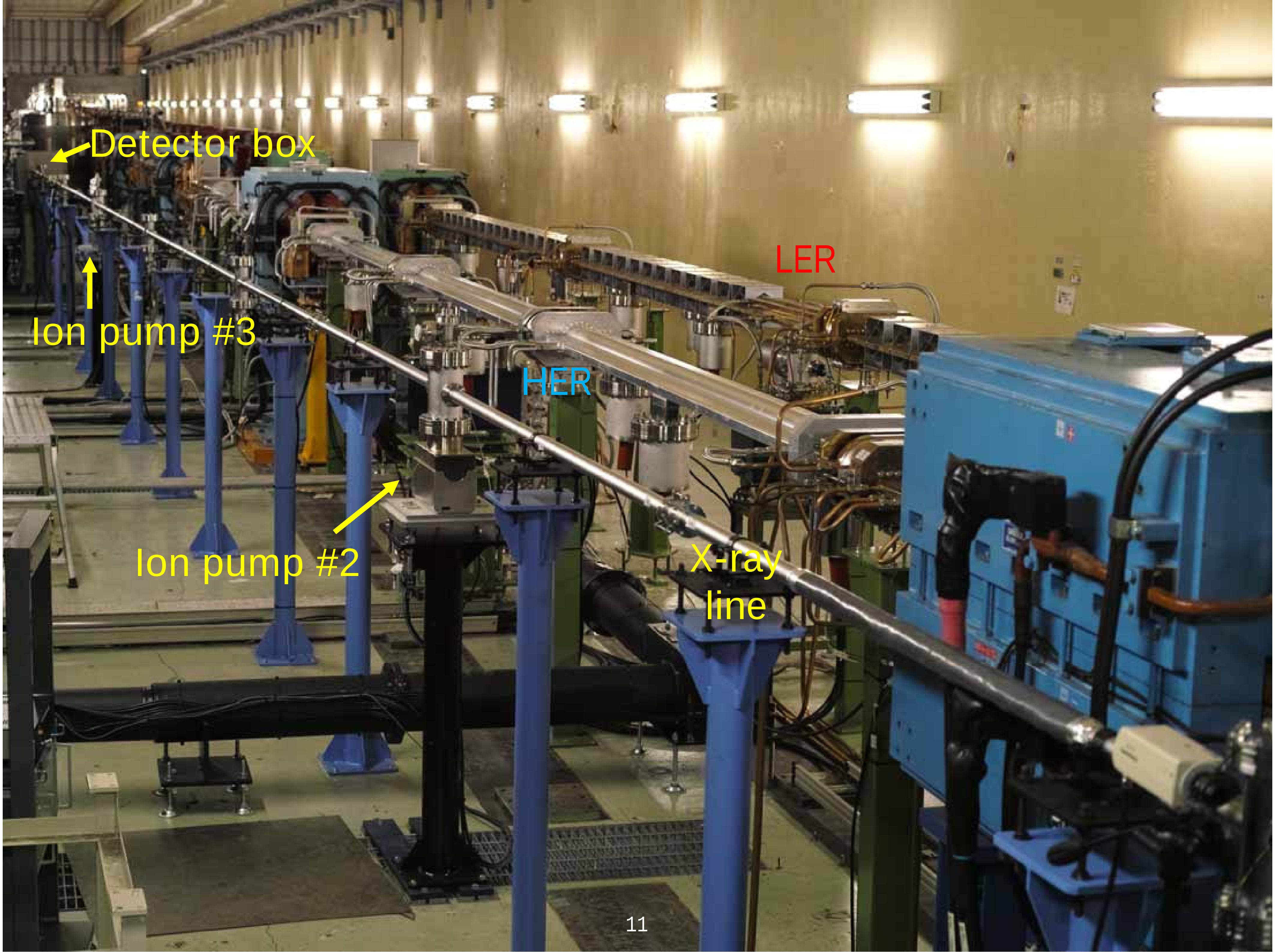
← Though the pressure was good, there should have been a small leak in 2020b.

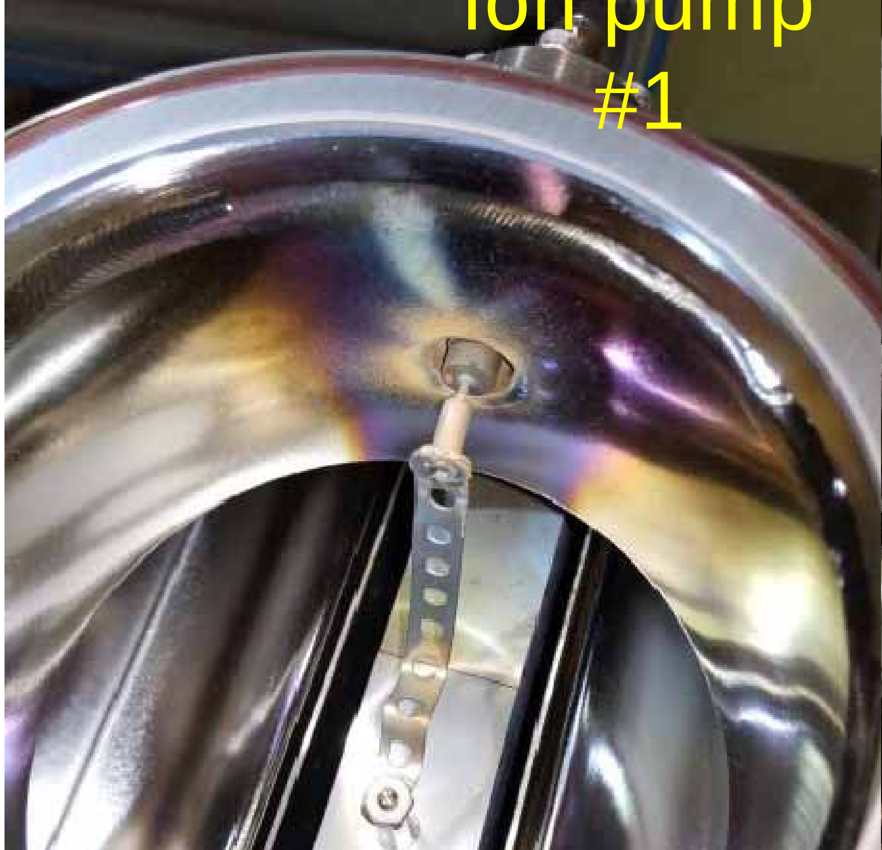
← This trial was a problematic action to make the ion pump #2 and #3 broken.

← Did something make a big hole, or did a small hole widens gradually?

← It seems natural to think the pressure inside the X-ray line has been at the atmospheric level since 3.




Detector box
Ion pump #3
LER
HER
Ion pump #2
X-ray
line


Ion pump
#1


New detector
box


Be window (upstream)


Be window (downstream)

A large leak in the HER X-ray line

- We don't yet clearly understand when and why a large leak occurred.
- We got where the leak occurred on the Be window: brazing between the Cu holder and the Be window.
  - Did severe copper oxide make the Be window peel off?
  - A Be-window maker investigates a reason for leakage in detail.
- What we must do in LS1:
  - Production of spare Be windows
  - CCG-based interlock systems to protect the ion pumps

SRM

2022/12/13 SuperKEKB Review

SRM 1: Diamond Mirror

- Developed a single crystal diamond mirror and made efforts to suppress the current dependence of thermal deformation, but the mirror had not only the current dependence of the deformation at high currents, but also some deformations made during manufacturing at beginning of SuperKEKB.

- Made a new thick polycrystalline diamond mirror that is not easily deformed by heat and installed it in 2020.

  - Resistance to thermal deformation is similar to single crystal.

  - Reflectance is high because the coating is changed from gold to platinum.

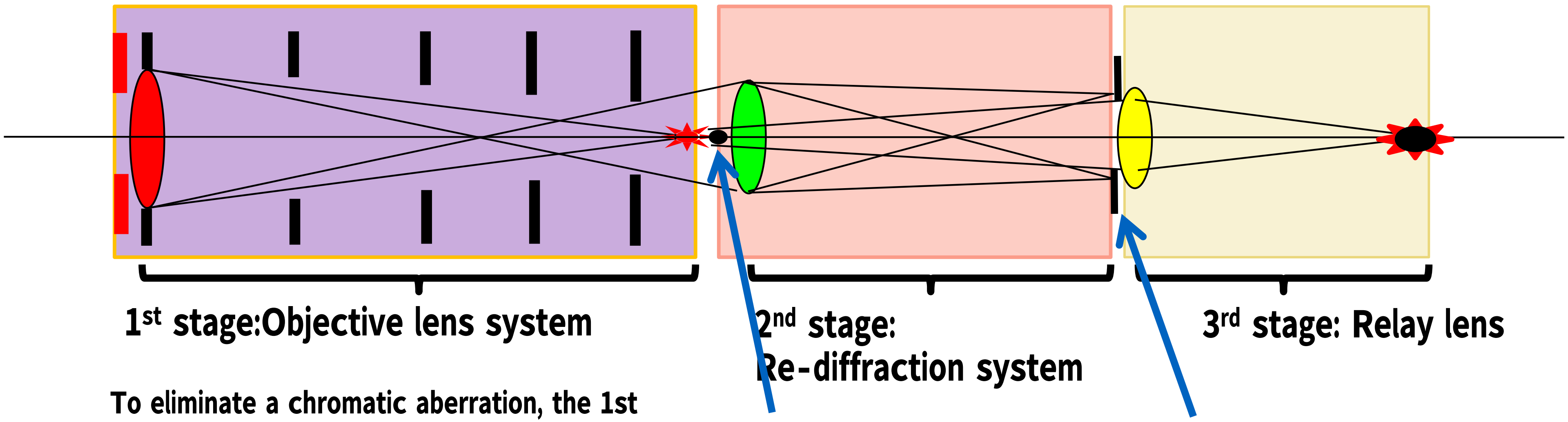
  ⇒ obtain a sufficient amount of light for beam profile measurement for each bunch, and it became possible to measure the beam halo and injection beam for each turn.

- Measured surface flattens of the new diamond mirrors have been confirmed less than $\lambda/5$ with beam current larger than 1A, that enabling to create diffraction-limited image at the optics station.

  - Imaging using fast gated camera, streak camera measurements, coronagraph... etc.

SRM 2: Coronagraph

- Beam halo may cause unexpected beam loss or long-term irradiation leading to luminosity degradation and damage to accelerator components.
- Introduced Coronagraph to SRM.
- Sensitivity of the measurement : Ratio of beam halo/Core ~ 2e-3 x 2e-3 ~ O(1e-6)



1st stage:Objective lens system

2nd stage:
Re-diffraction system

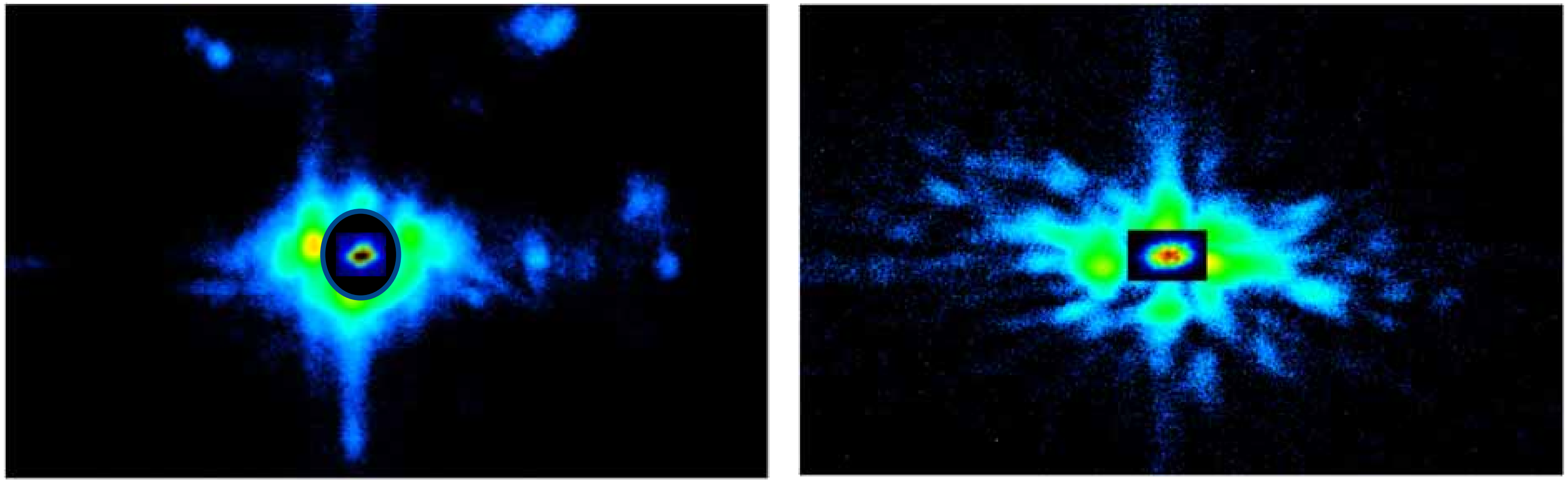
3rd stage: Relay lens

To eliminate a chromatic aberration, the 1st system adopts a reflective mirror system rather than a refractive lens system.

Input opaque disk to hide beam core.

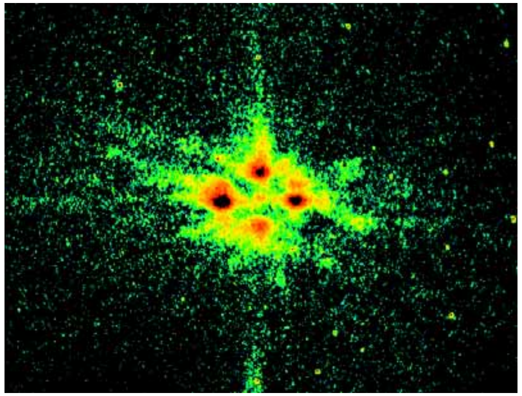
blocked by the Lyot stop

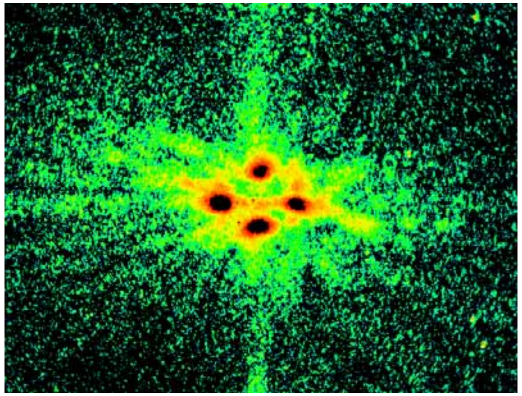
HER 0.57mA **LER 0.61mA**

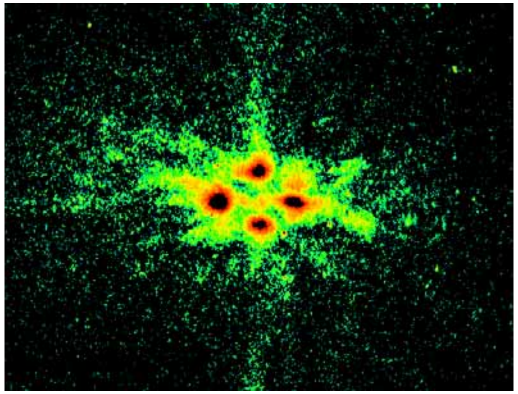


Results for the observation of beam halo in HER and LER. The beam core image and shadow of opaque mask are superimposed in the halo image.

Gate width=100ns,Log, mask=1mm×2mm
Delay changed (position @ train)


1874


1974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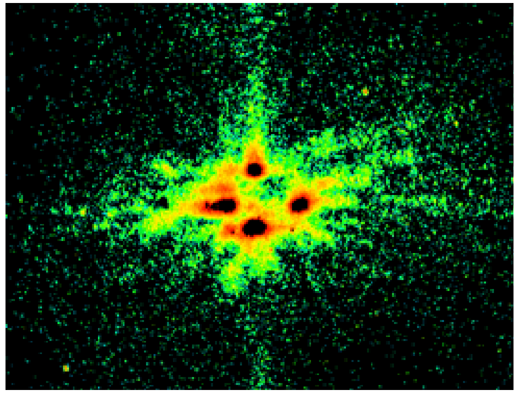
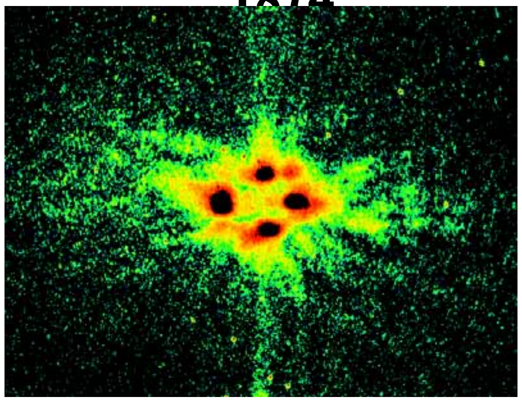

2274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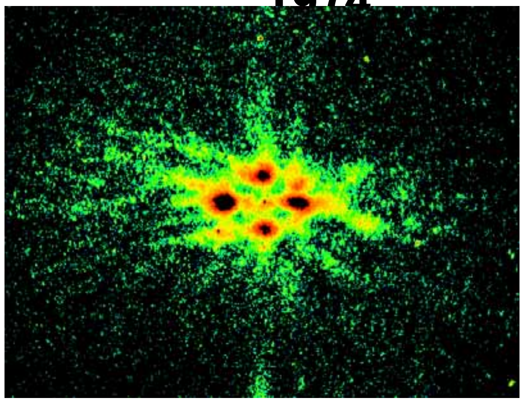
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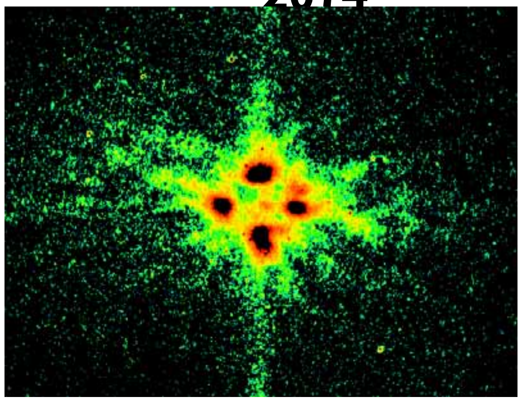
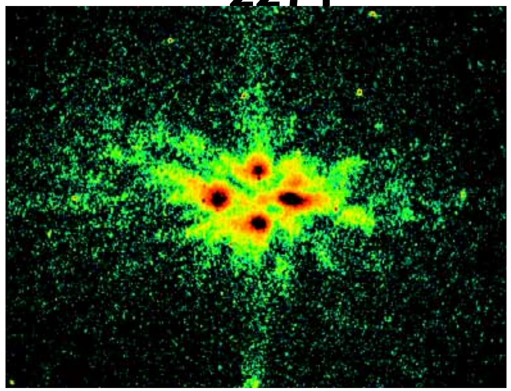
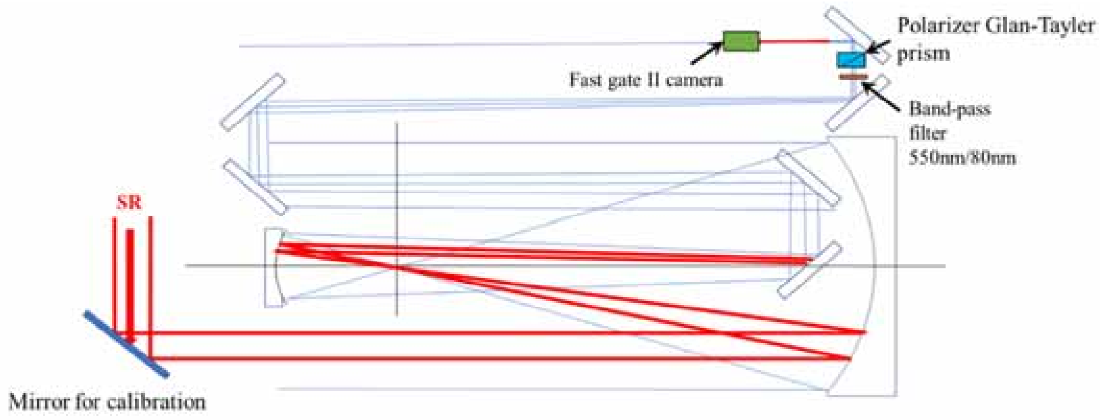

4074


5274

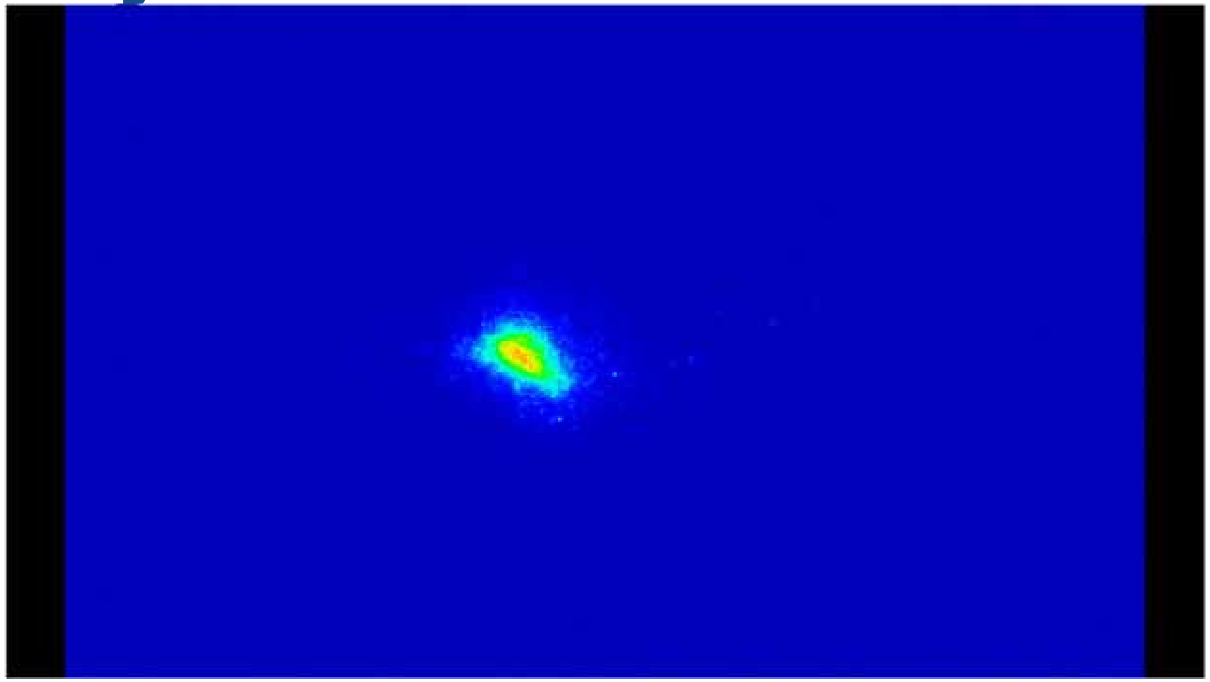
SRM 3 : Injection beam measurement

- It is important to observe how the injection beam turn in the ring usually and prepare for the measurement of difference with worth efficiency injection beam.
- Since it became possible to measure the beam for bunch by bunch, we tried to see the state of the injection beam.
- Object system which designed for coronagraph is used to measure the injection beam.
- Single-turn injection was applied on the HER beam. (Each injection bunch kicks out the previous injected bunch. Then the ring always has only one bunch).



Injection Beam Measurement Result : HER injection beam

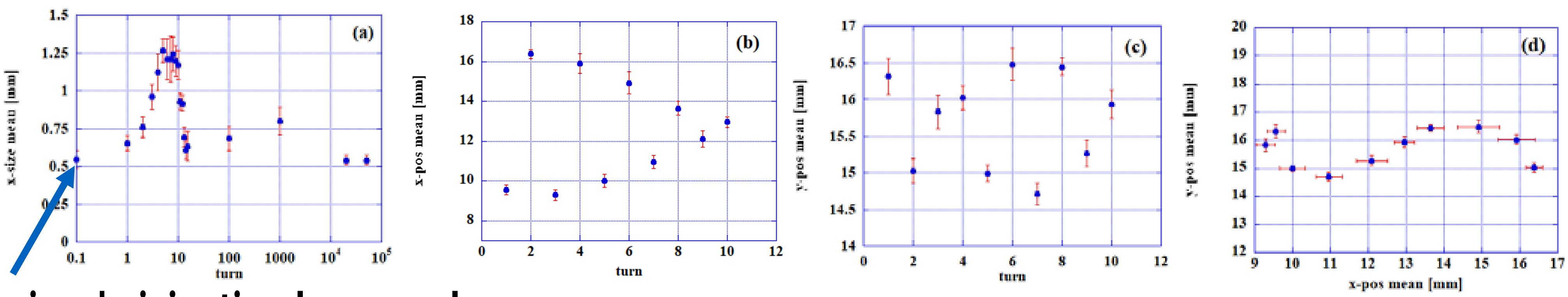
- The beam just after the injection repeatedly oscillation.
- Since SuperKEKB operating tune is close to a half-integer, it can be seen that the bunch moves left and right at every turn.
- The beam size does not shrink monotonically, but shrinks while repeating oscillation.



- Gate width : one turn (10 μ s).
- Trigger was applied at the injection timing

Injection Beam Measurement Result : HER injection beam

- Horizontal beam size for each turn of the injection beam after calibration.
  - The injection beam repeatedly expands and contracts and damped after 10,000 turns (10 ms).
  - The beam size is including the diffraction effect.
- The injection beam oscillation
  - it can be seen that the amplitude becomes stable while oscillate with a width of about ± 4.5 mm at the maximum.

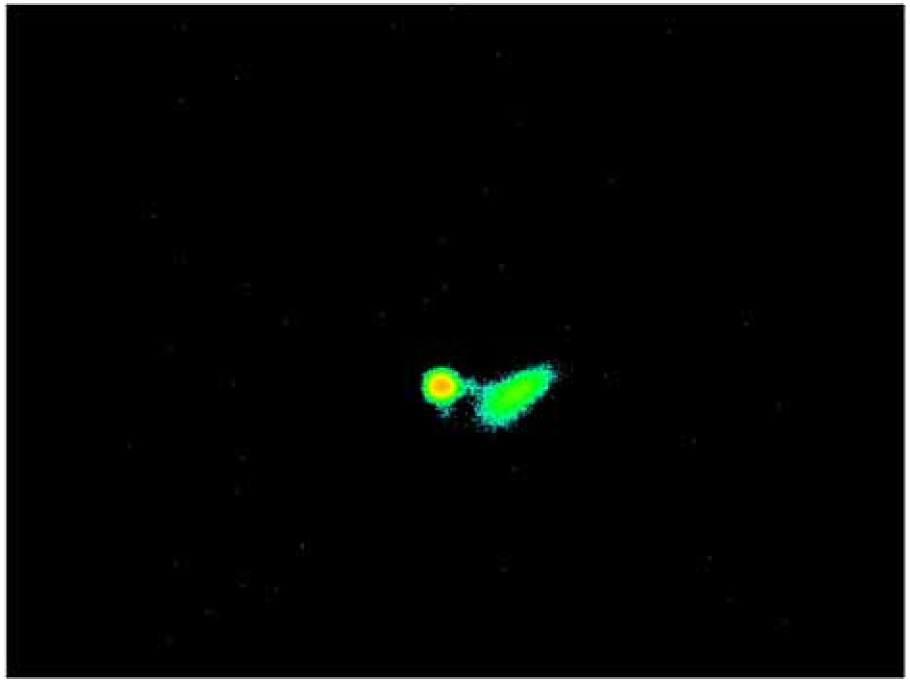


previously injection beam and corresponds after a complete dump for comparison

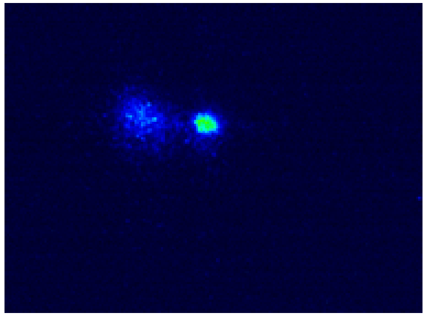
Injection Beam Measurement Result: LER injection with stored beam

- We also observed the injection beam when stacking normal collision beams.

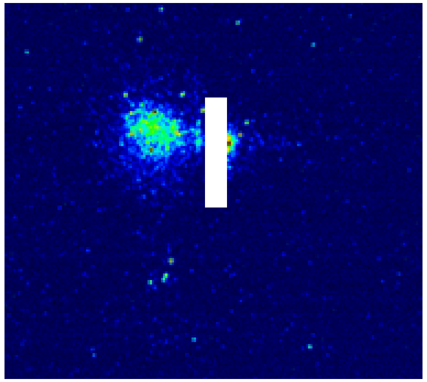
- In order to see the injection beam during the collision, we put a mask in front of the camera to hide the stored beam.
- Some measurement is possible.



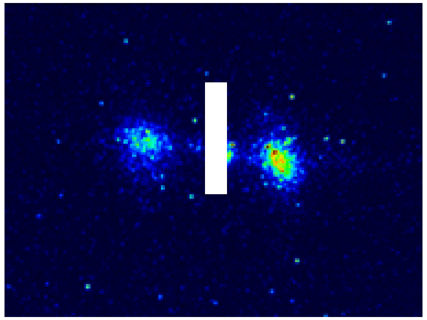
LER



(a) Stored beam and Injected 1st turn beam



(b)Masked stored beam and injected 1st turn beam

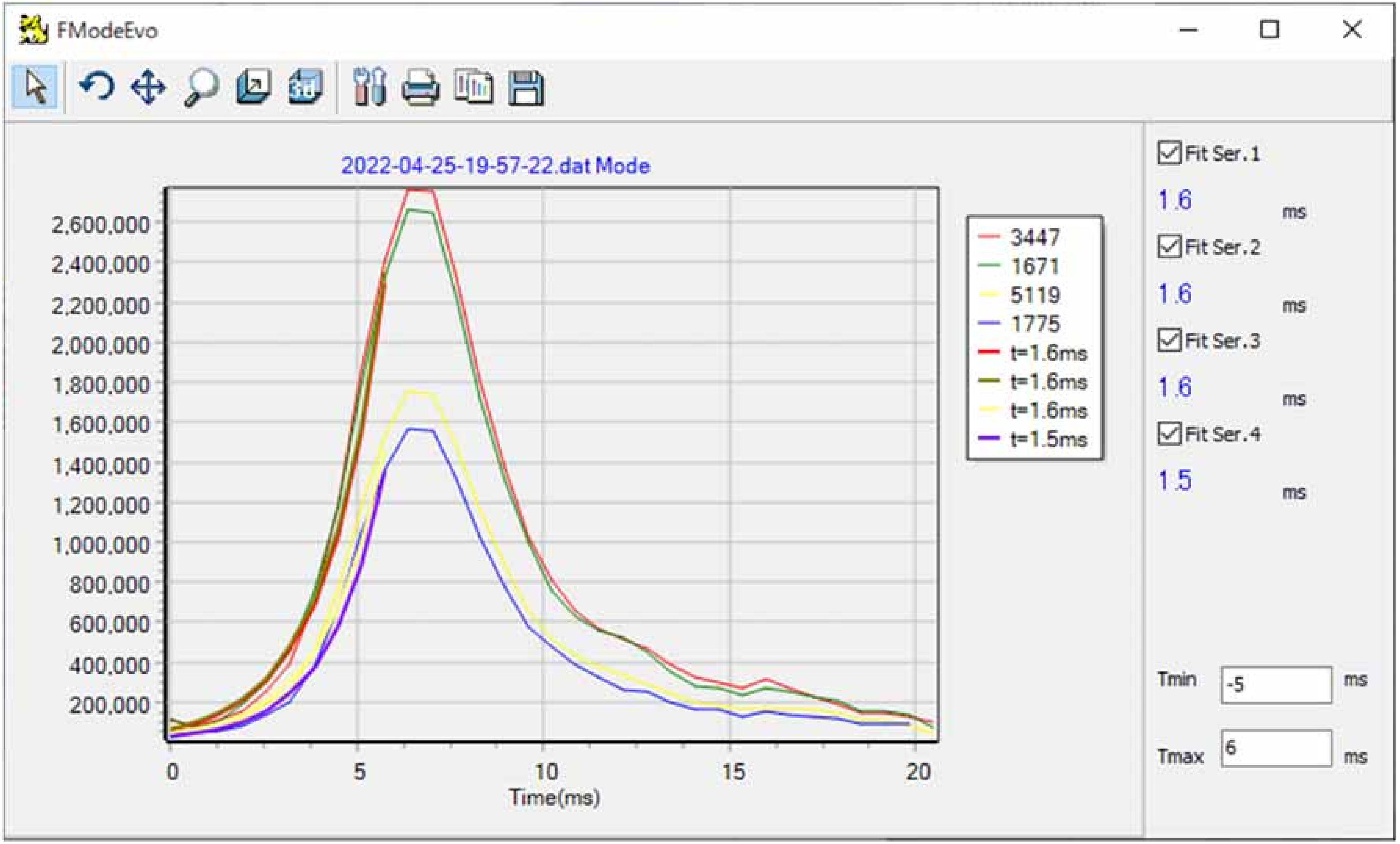


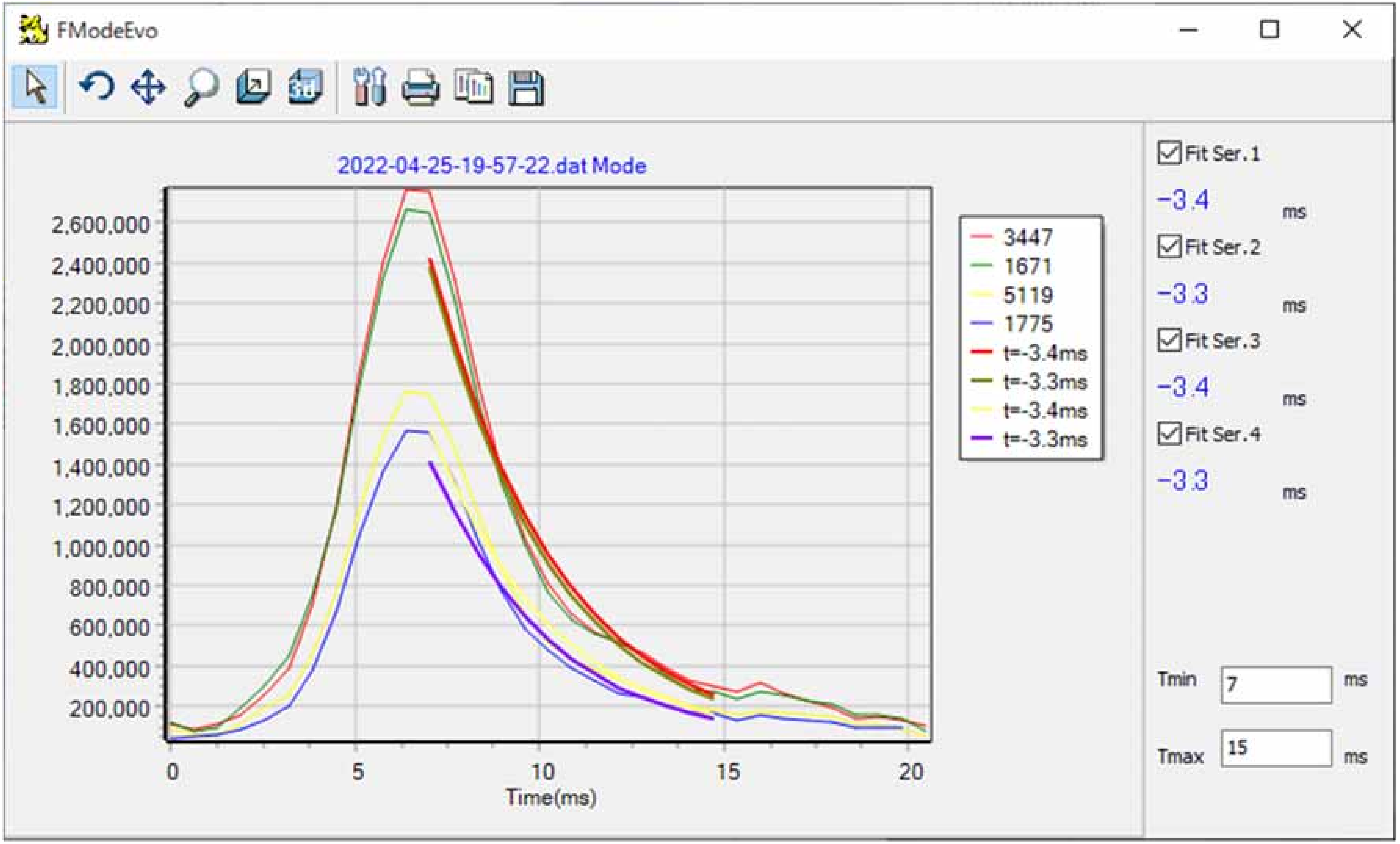
(c) Masked stored beam and injected 1st,2nd turn beam

Bunch FB system (HER)

- **With increasing number of bunches**
  - Feedback gain drops
  - Total beam current increase (growth rate of the instability might be increased)

  Found vertically unstable behavior: tried to increase vertical FB gain step by step (around 0.5dB step)
- **Finally, we have increased the FB gain of upstream loop around 6dB.**
  - Checked the luminosity behavior before and after change of the gain– no significant change have been observed.
  - Checked the grow-damp behavior during collision.


FModeEvo
2022-04-25-19-57-22.dat Mode
2,600,000
2,400,000
2,200,000
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
5
10
15
20
Time(ms)
3447
1671
5119
1775
t=1.6ms
t=1.6ms
t=1.6ms
t=1.5ms
Fit Ser.1
1.6 ms
Fit Ser.2
1.6 ms
Fit Ser.3
1.6 ms
Fit Ser.4
1.5 ms
Tmin -5 ms
Tmax 6 ms

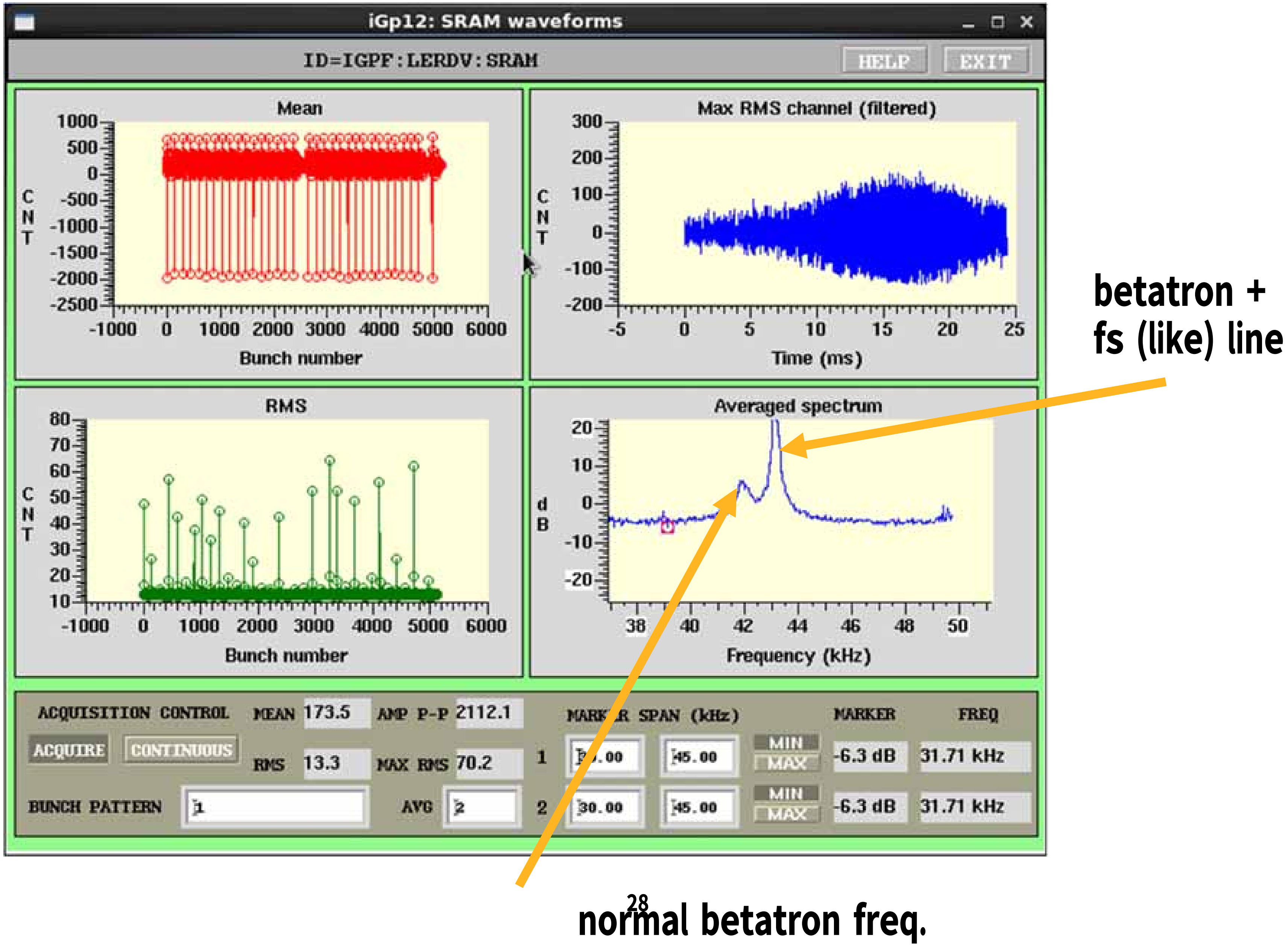


Found 1 failed HER Final amplifier after 2022b run.

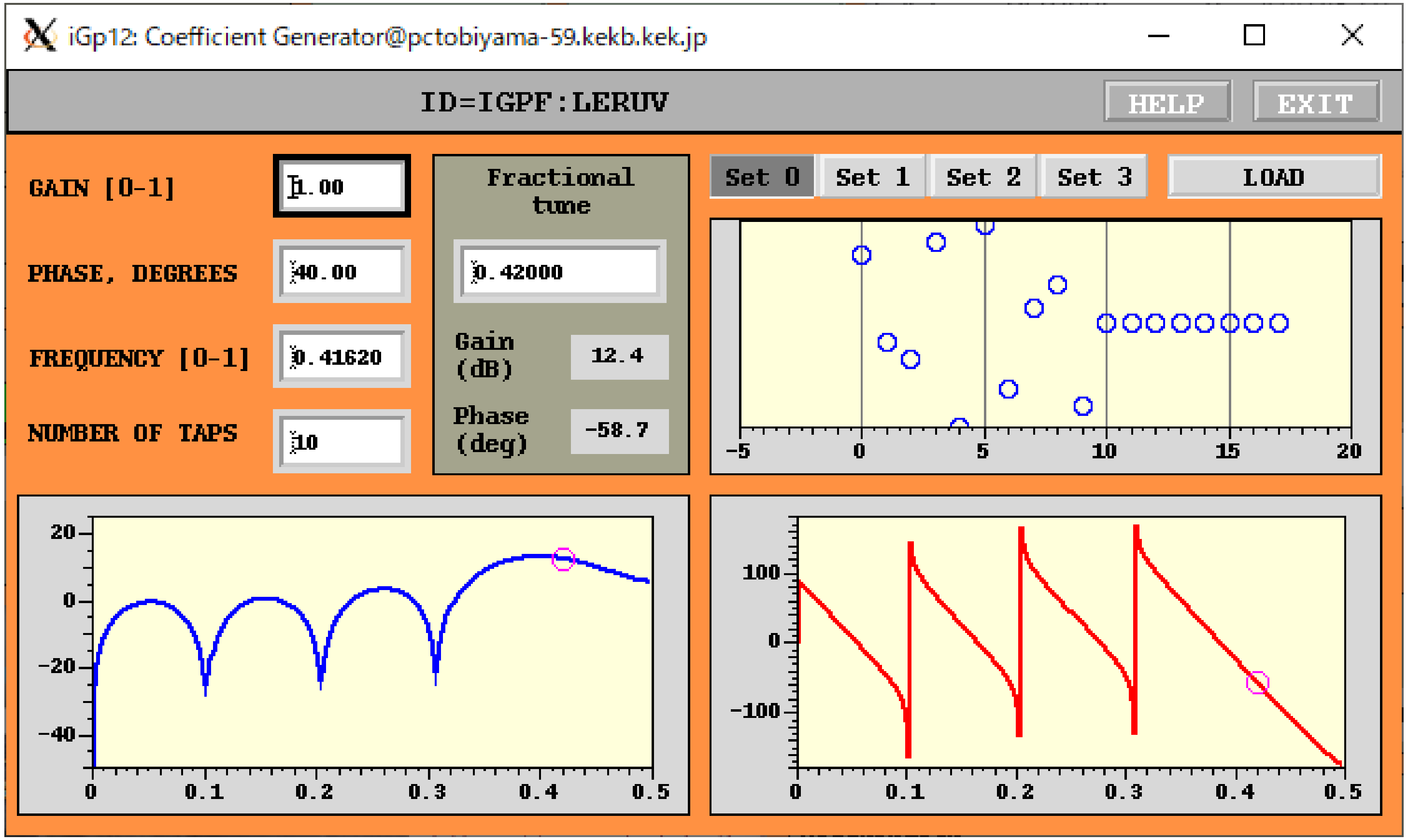
LER

- Changed the FIR filter from 10 Tap FIR to 4 Tap FIR (upstream), 8 Tap FIR to 6 Tap FIR (downstream) on 11/Mar.
- Tuned the FB phase and tool several GD data on 28/Mar with LER single beam.

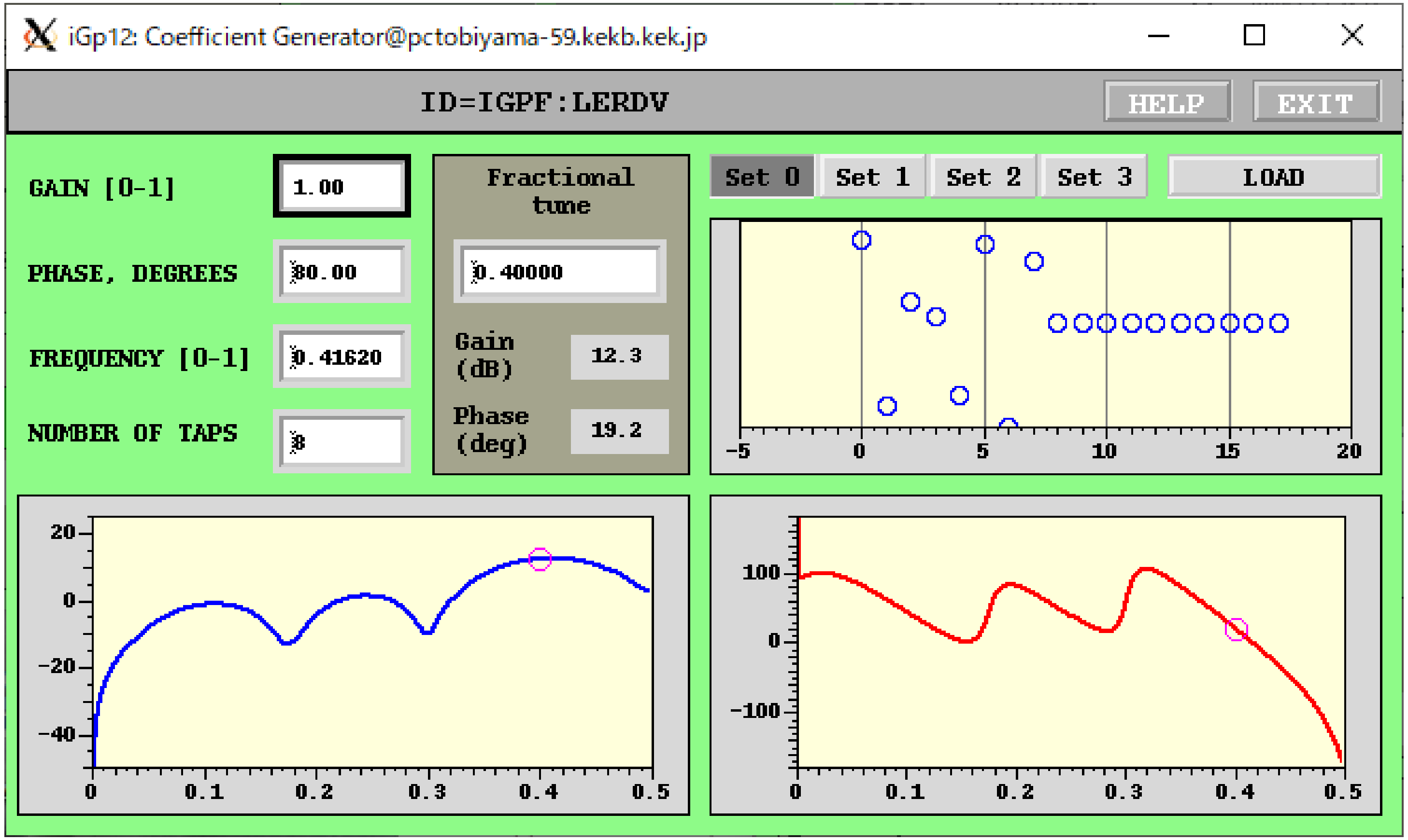
FB off at few bunch, high bunch current operation



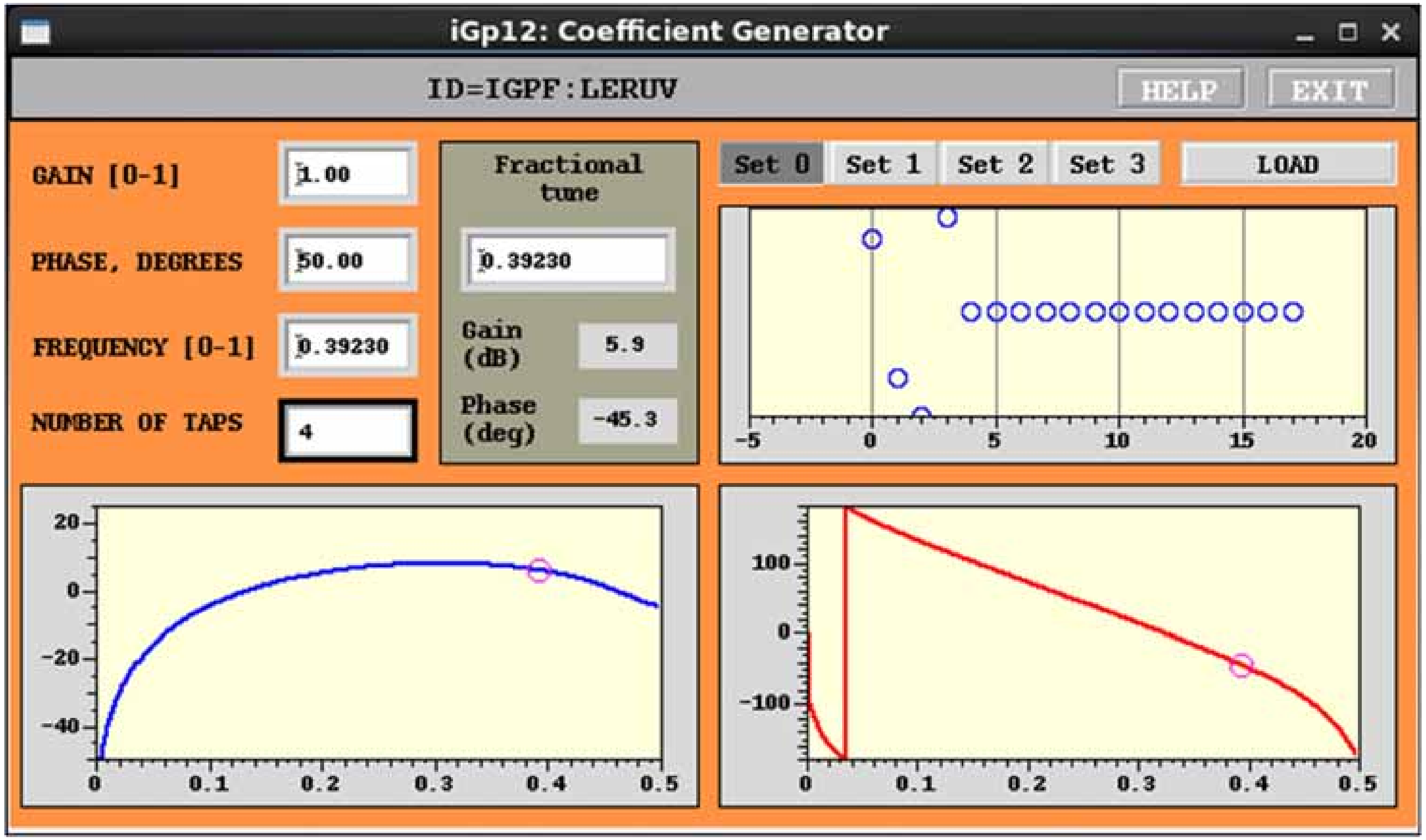
FB filter (Uppersterem V)



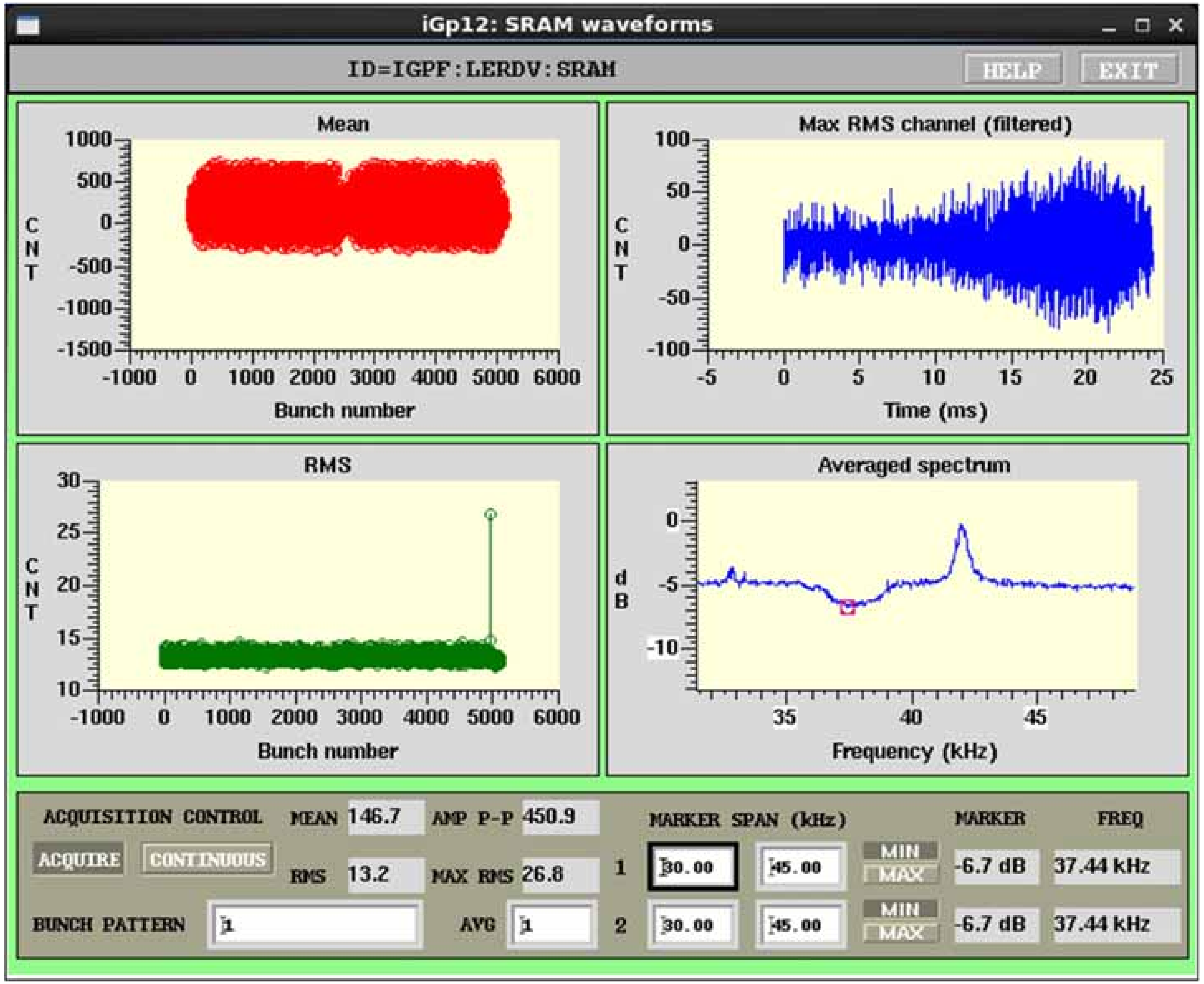
FB filter (Downstrem V)

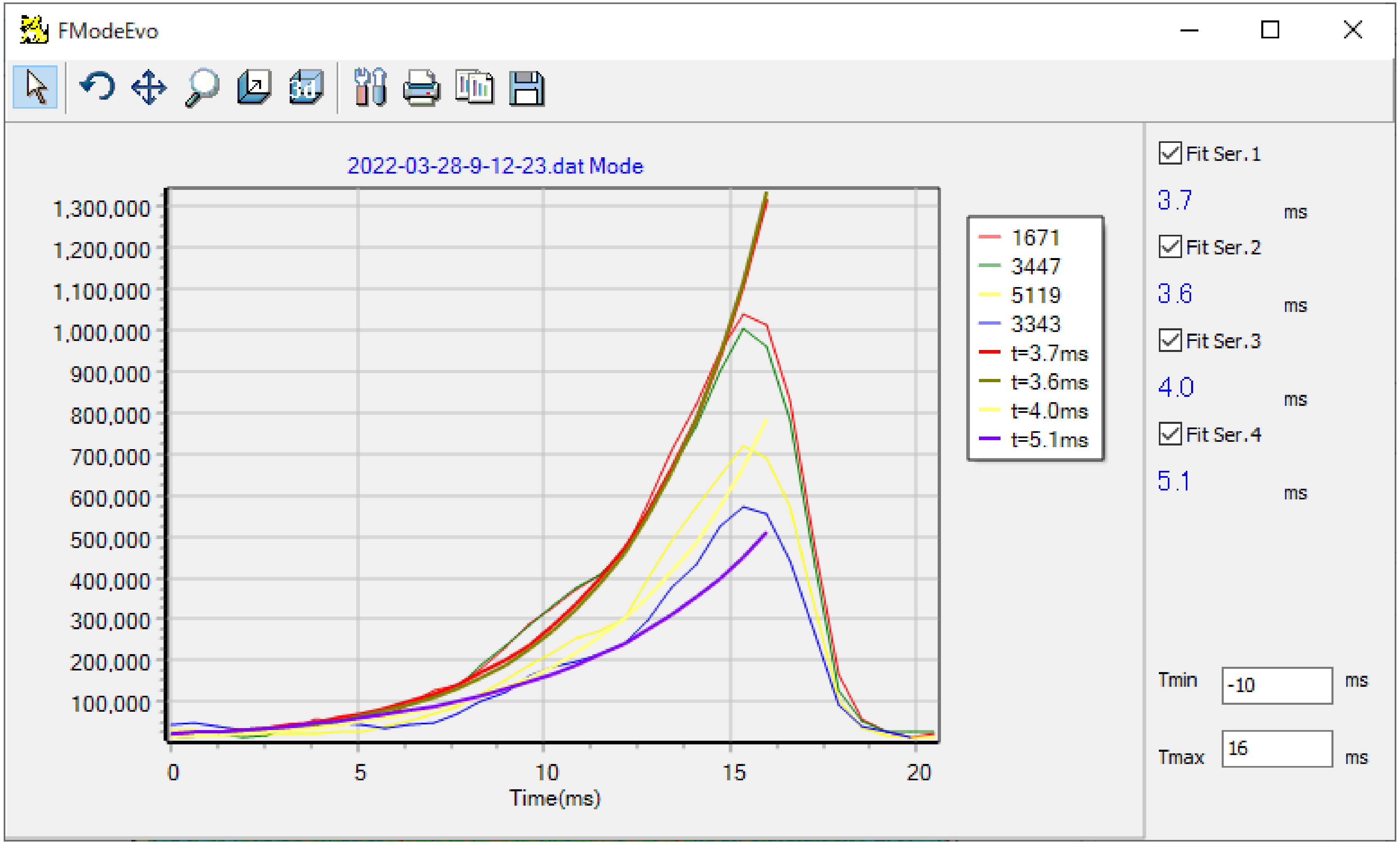


4 Tap filter

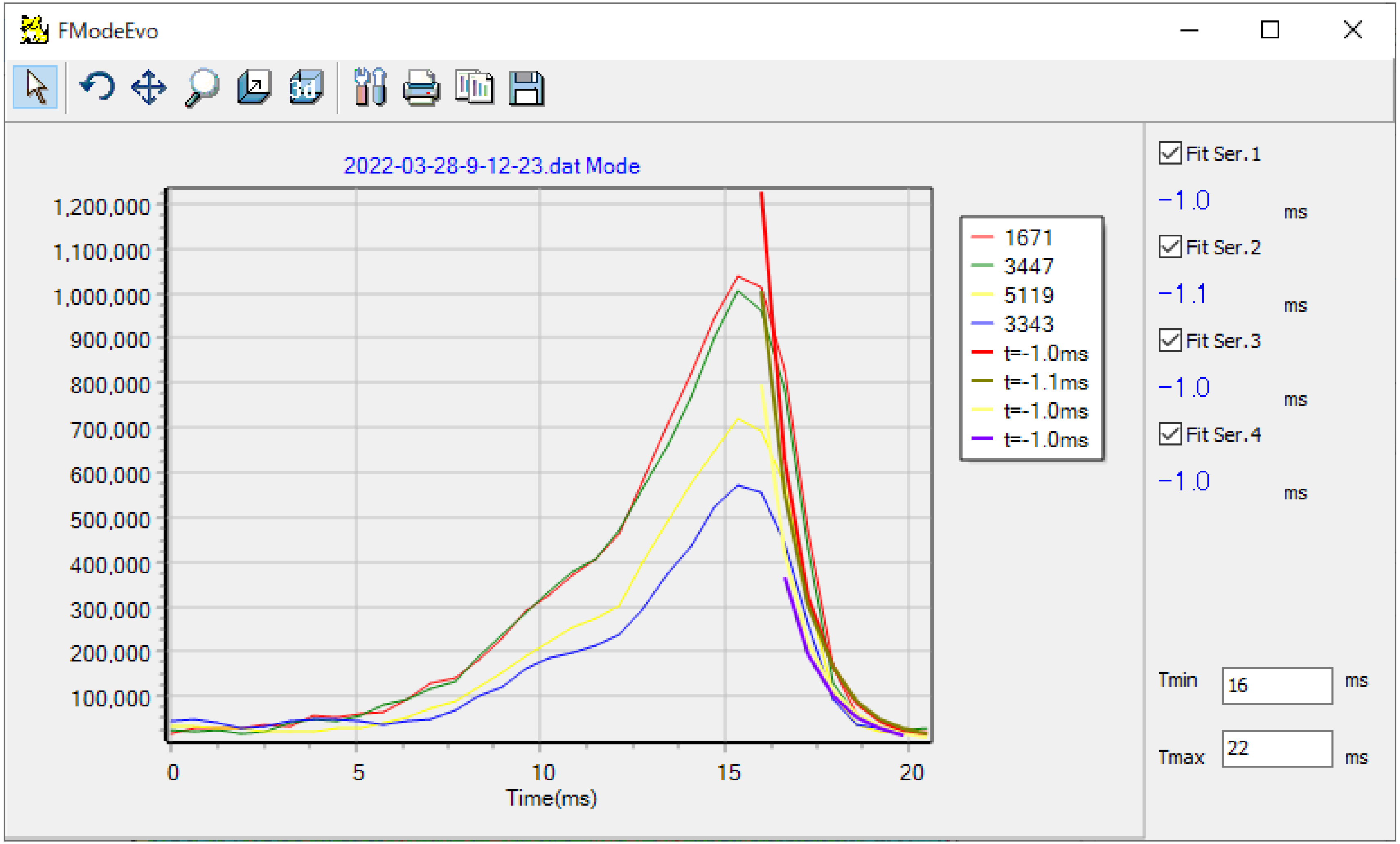


iGp12: Coefficient Generator
ID=IGPF:LERUV
HELP
EXIT
GAIN [0-1]
1.00
PHASE, DEGREES
50.00
FREQUENCY [0-1]
0.39230
NUMBER OF TAPS
4
Fractional tune
0.39230
Gain (dB)
5.9
Phase (deg)
-45.3
Set 0
Set 1
Set 2
Set 3
LOAD


iGp12: SRAM waveforms
ID=IGPF:LERDV:SRAM
HELP
EXIT
Mean
CNT
Bunch number
Max RMS channel (filtered)
Time (ms)
RMS
Averaged spectrum
dB
Frequency (kHz)
ACQUISITION CONTROL
ACQUIRE
CONTINUOUS
MEAN 146.7
AMP P-P 450.9
RMS 13.2
MAX RMS 26.8
BUNCH PATTERN 1
AVG 1
MARKER SPAN (kHz)
MARKER
FREQ
1 30.00 45.00 MIN MAX -6.7 dB 37.44 kHz
2 30.00 45.00 MIN MAX -6.7 dB 37.44 kHz



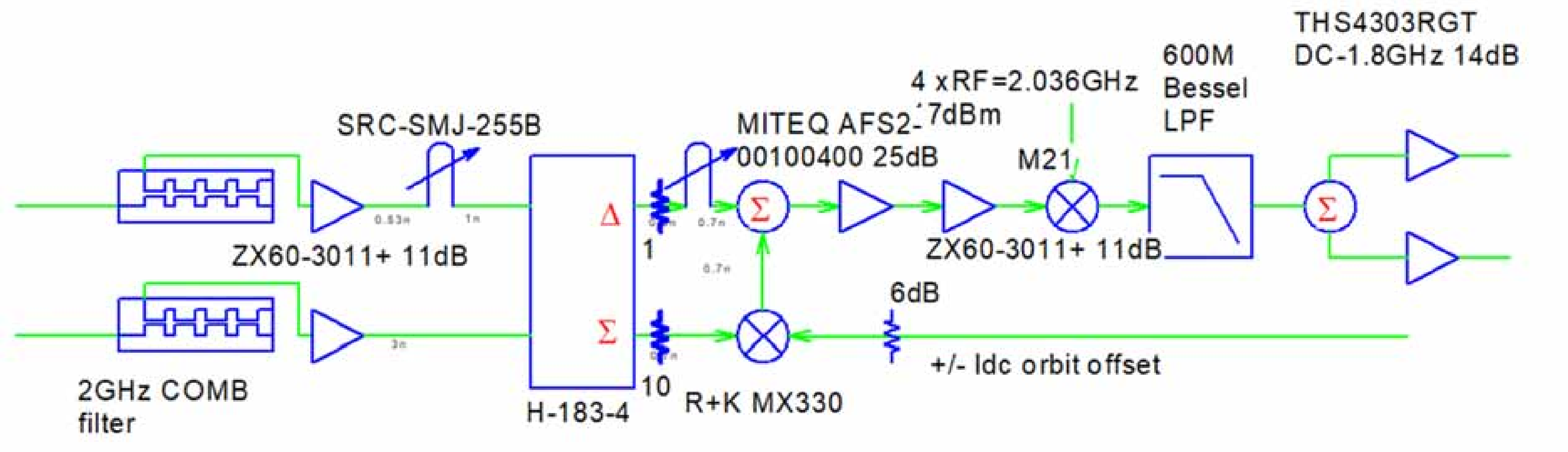
Mode -1 faster than e-cloud related mode


FModeEvo
2022-03-28-9-12-23.dat Mode
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
5
10
15
20
Time(ms)
1671
3447
5119
3343
t=-1.0ms
t=-1.1ms
t=-1.0ms
t=-1.0ms
Fit Ser.1
-1.0
ms
Fit Ser.2
-1.1
ms
Fit Ser.3
-1.0
ms
Fit Ser.4
-1.0
ms
Tmin
16
ms
Tmax
22
ms

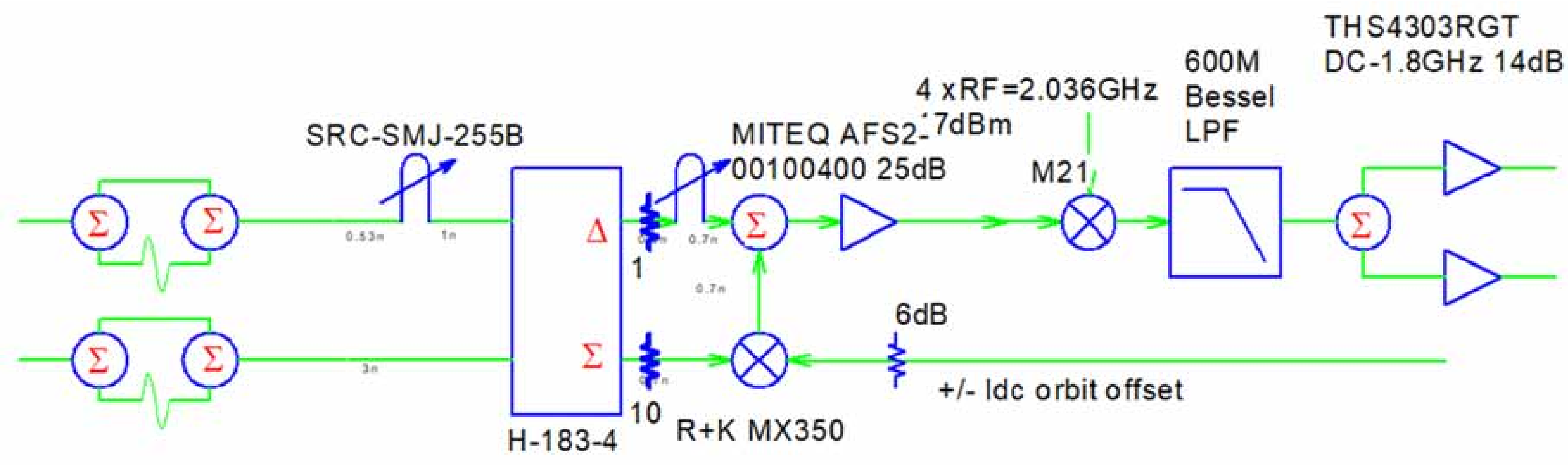
During LS1

- **Planned to reduce broadband noise in the FB front-end circuit by changing the first 2GHz BPF.**
  - Replace 2GHz-3tap comb filter with 2tap cable-type comb filter.
  - Similar gain at the front-end
  - Expected to have ½ of broadband noise
  - Much severe timing margin– need much longer tuning time after restart of the beam operation.

-22+11+25+11=+25dB



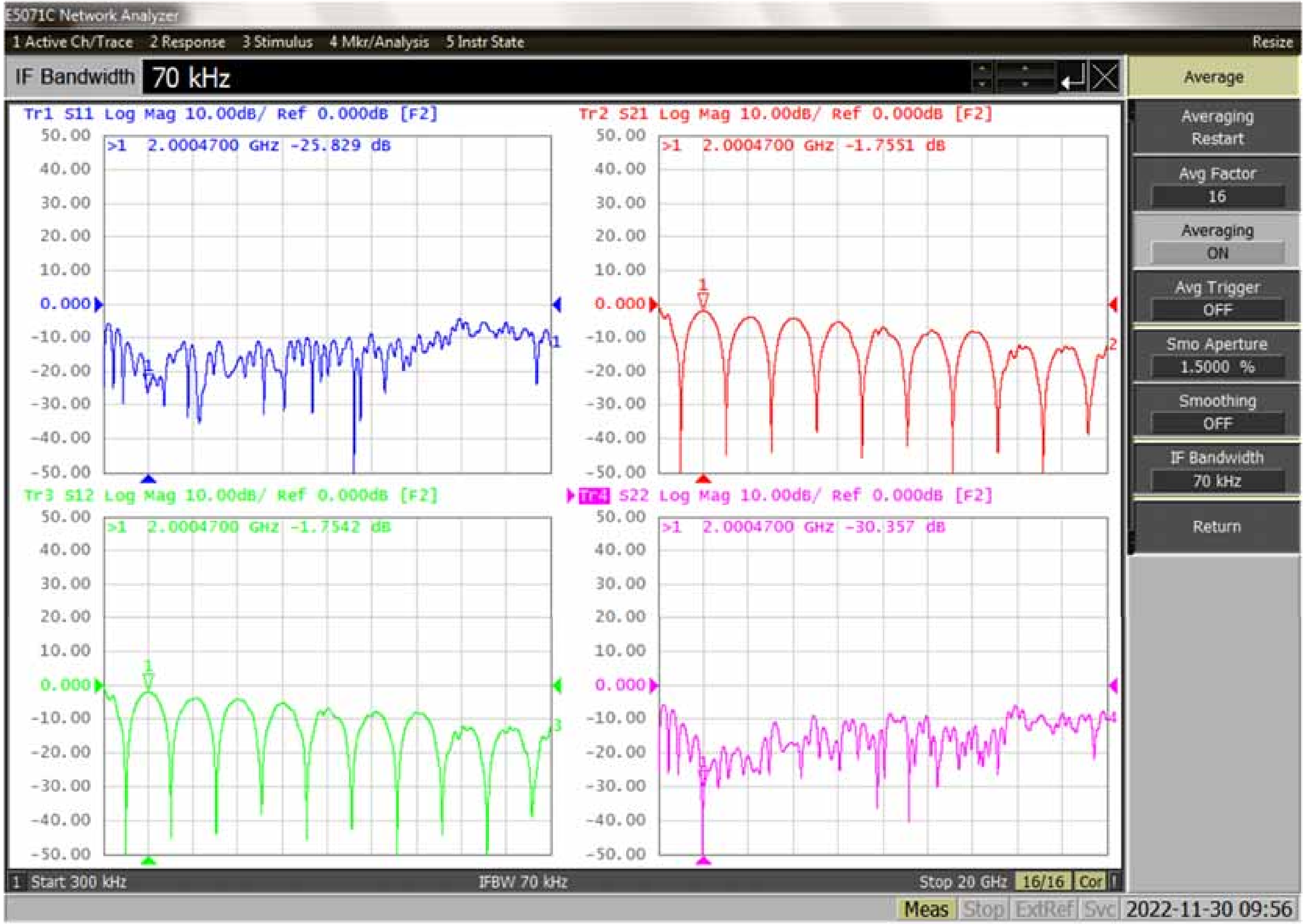
-4+25=+21dB



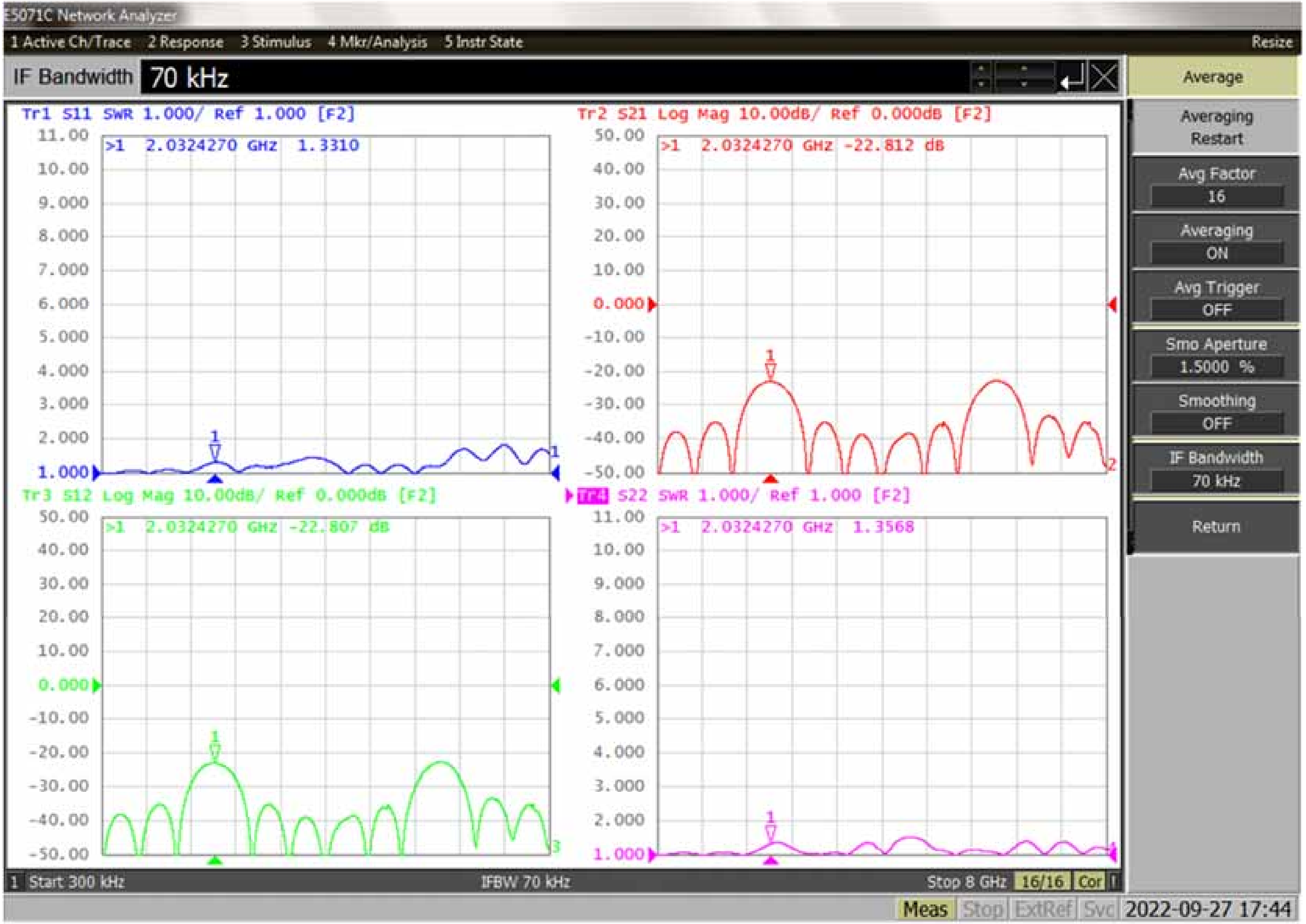
RMS counts at iGp12s: 14 counts -> 6.5 counts

New cable BPF

2 tap 2GHz BPF (up to 20GHz)

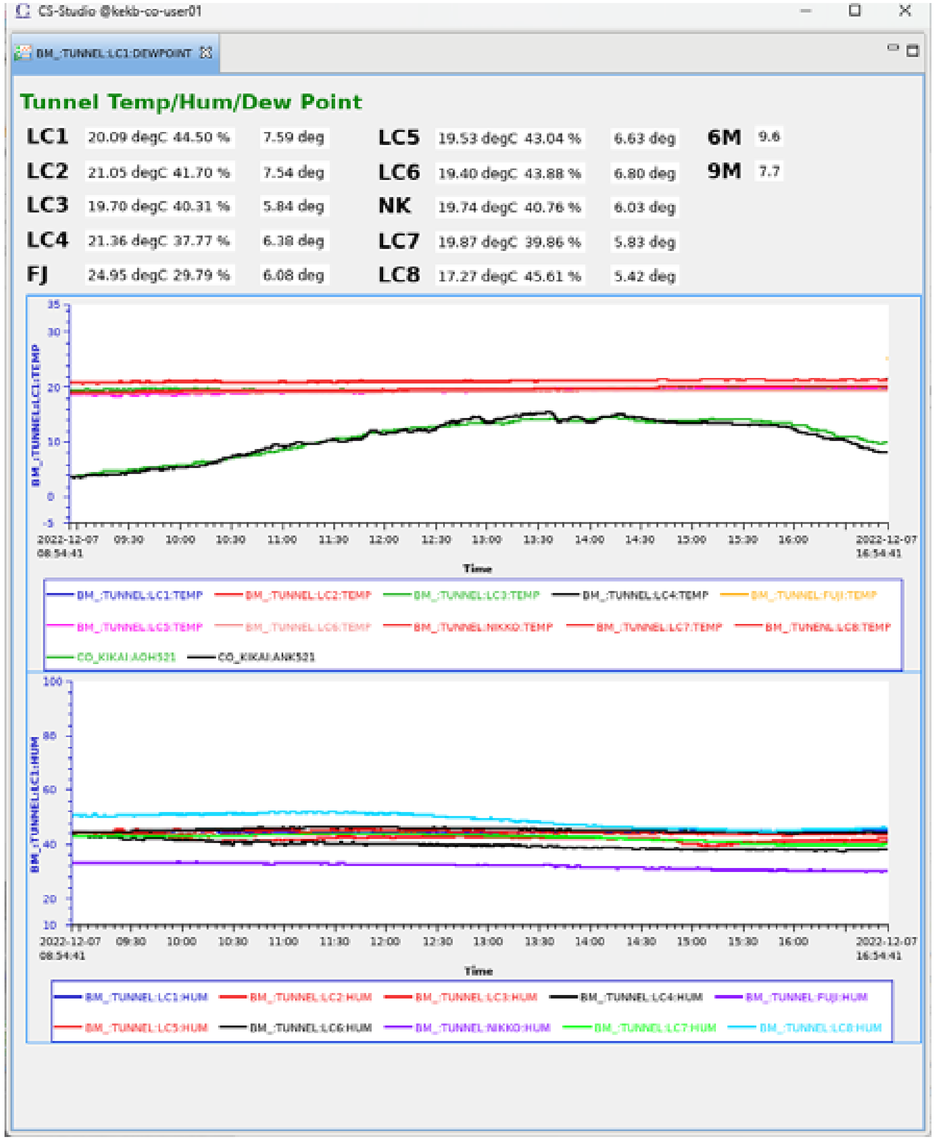


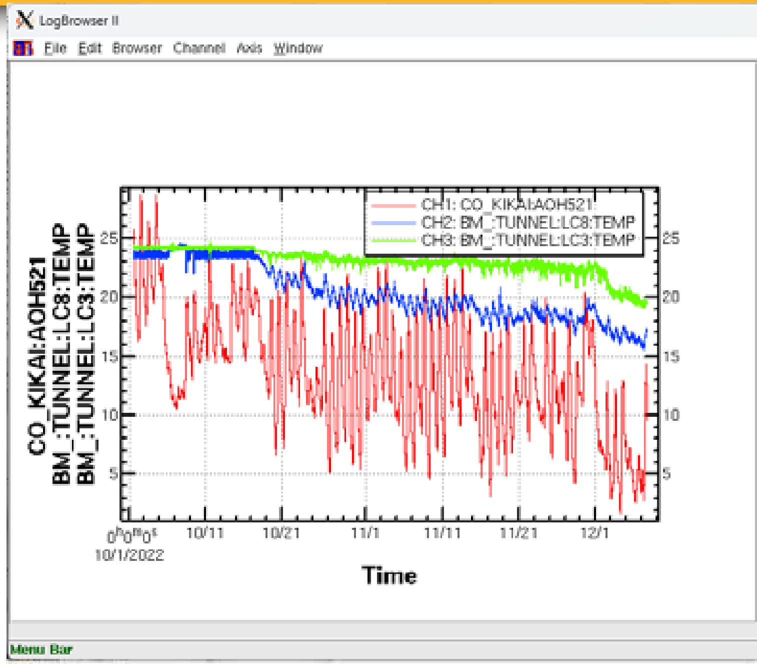
Original 3 tap stripline-coupled comb BPF

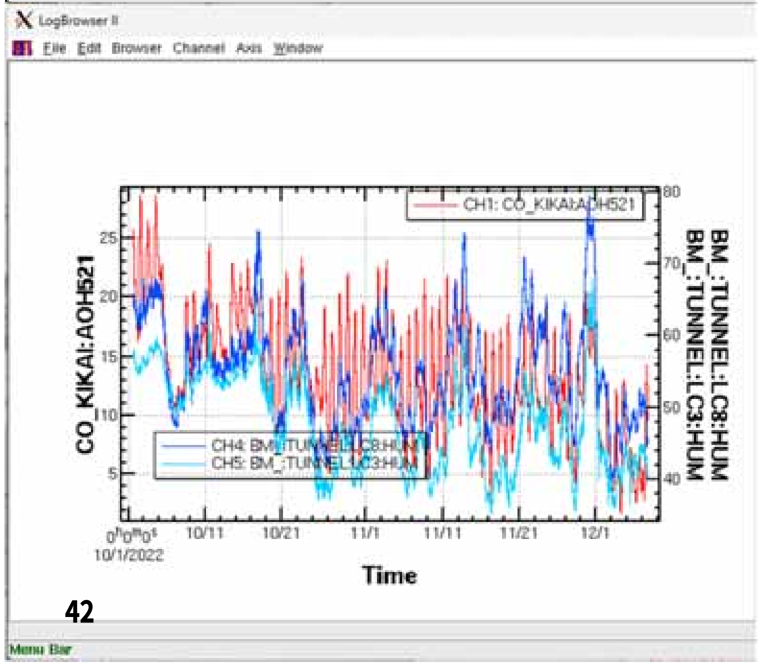


Environment monitor

- Raspberry Pi + home made USB sensor (temperature and humidity)
- LC1-LC8, Nikko, Fuji (planned OHO and Tsukuba)
- Easily hanged-up during beam operation (LC6 and LC7), even with thick Lead radiation shield.


CS-Studio @kekb-co-user01
BM_:TUNNEL:LC1:DEWPOINT
Tunnel Temp/Hum/Dew Point
LC1 20.09 degC 44.50 % 7.59 deg
LC2 21.05 degC 41.70 % 7.54 deg
LC3 19.70 degC 40.31 % 5.84 deg
LC4 21.36 degC 37.77 % 6.38 deg
FJ 24.95 degC 29.79 % 6.08 deg
LC5 19.53 degC 43.04 % 6.63 deg
LC6 19.40 degC 43.88 % 6.80 deg
NK 19.74 degC 40.76 % 6.03 deg
LC7 19.87 degC 39.86 % 5.83 deg
LC8 17.27 degC 45.61 % 5.42 deg
6M 9.6
9M 7.7
Time
Time


LogBrowser II
File Edit Browser Channel Axis Window
CH1: CO_KIKAI:AOH521
CH2: BM_:TUNNEL:LC8:TEMP
CH3: BM_:TUNNEL:LC3:TEMP
CO_KIKAI:AOH521
BM_:TUNNEL:LC8:TEMP
BM_:TUNNEL:LC3:TEMP
10/1/2022
10/11
10/21
11/1
11/11
11/21
12/1
Time
Menu Bar

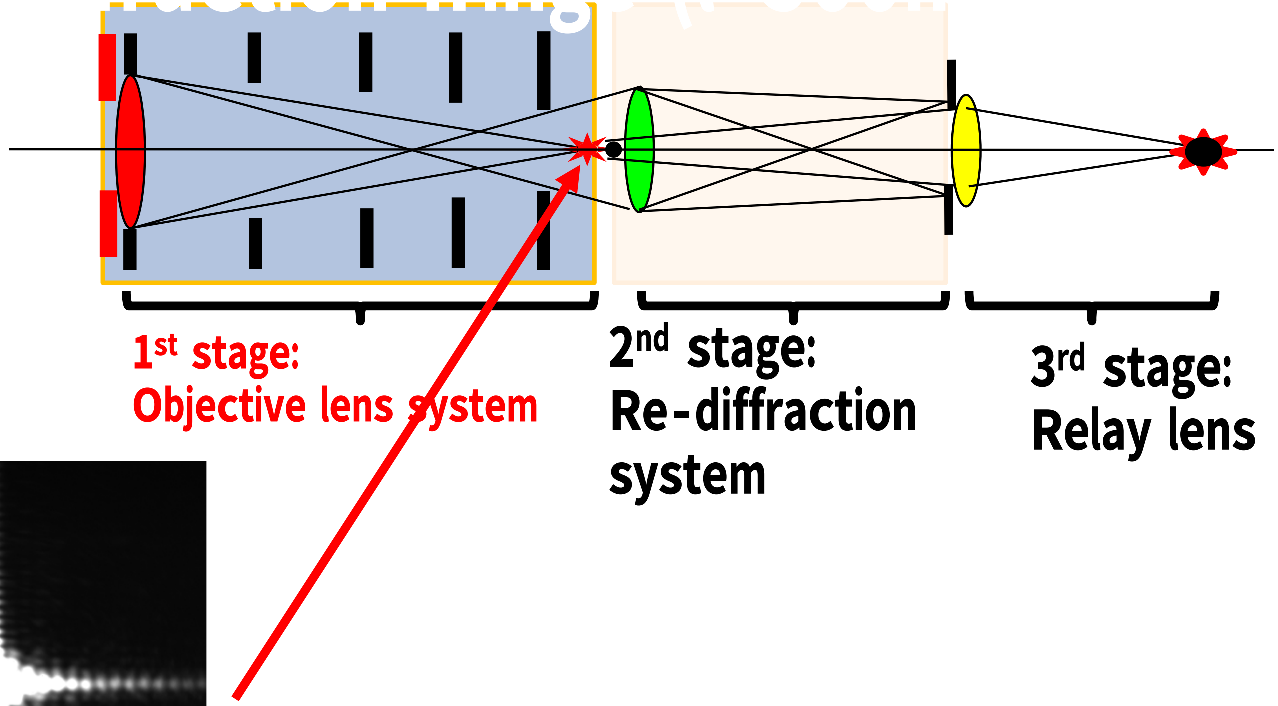

LogBrowser II
File Edit Browser Channel Axis Window
CH1: CO_KIKAI:AOH521
CH4: BM_:TUNNEL:LC8:HUM
CH5: BM_:TUNNEL:LC3:HUM
CO_KIKAI:AOH521
BM_:TUNNEL:LC8:HUM
BM_:TUNNEL:LC3:HUM
10/1/2022
10/11
10/21
11/1
11/11
11/21
12/1
Time
Menu Bar

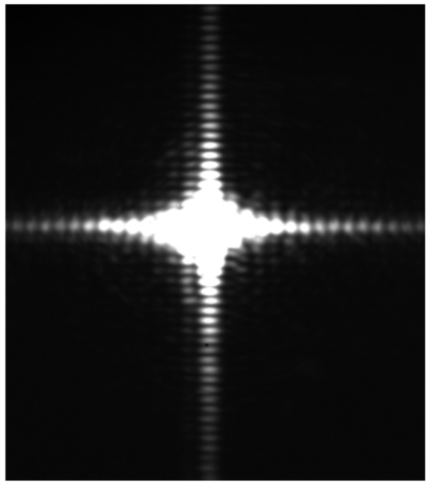
Summary

- Beam instrumentation of SuperKEKB rings are almost working, without severe failures.
- HER COD measurement systems (original KEKB circuits) will be needed to be improved.
  - SWR effects with change of internal attenuators.
  - Day-night effects (cable temperature).
  - Will try to install isolators on several important BPMs.
- Re-built HER X-ray monitor box
- Replaced first optical mirrors (polycrystal diamond, HER and LER).
  - Much better image, much higher photon intensity.
  - Injection bunch measurement
  - Coronagraph
- Effect of bunch feedback side-effects
  - Lower number of FIR taps in the digital filter
  - Much better NF with cable BPF
- Environment monitors are working.

backup

To eliminate a chromatic aberration, the 1st system adopts a reflective mirror system rather than a refractive lens system.

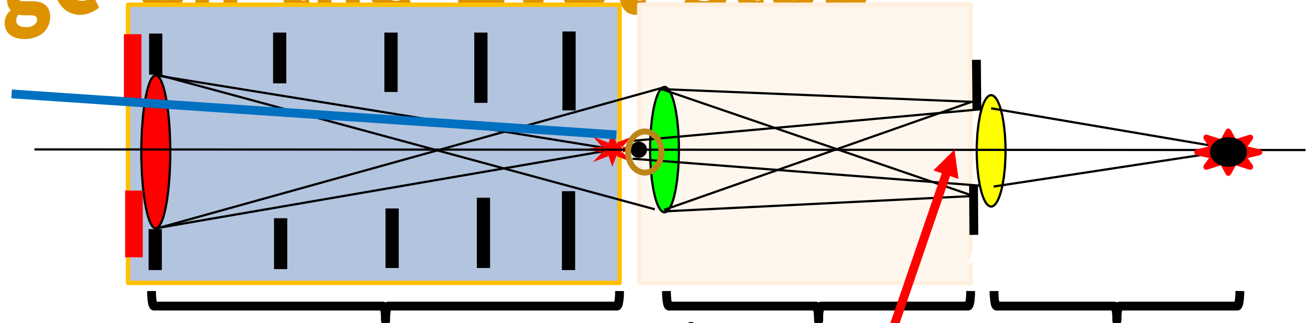


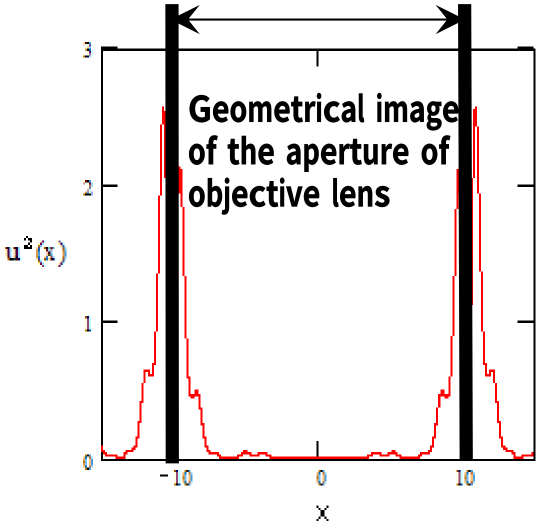


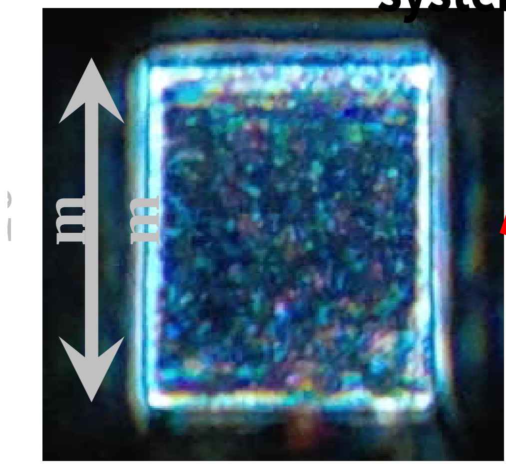
Clearly observed ~18th order fringes

Diffraction image on the Lyot stop

- Input **opaque disk** to hide beam core.
- Diffraction fringes of objective lens aperture is shown.

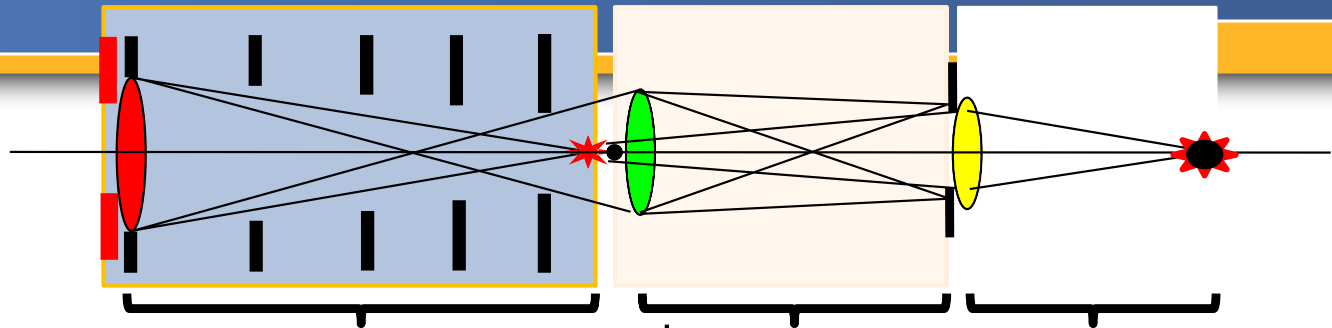




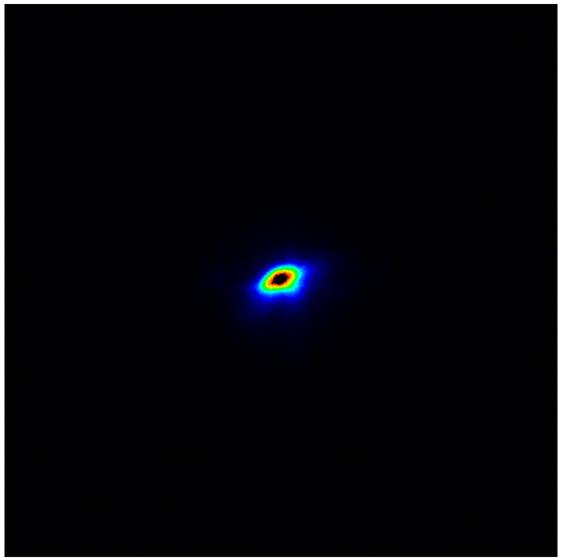


Observed image

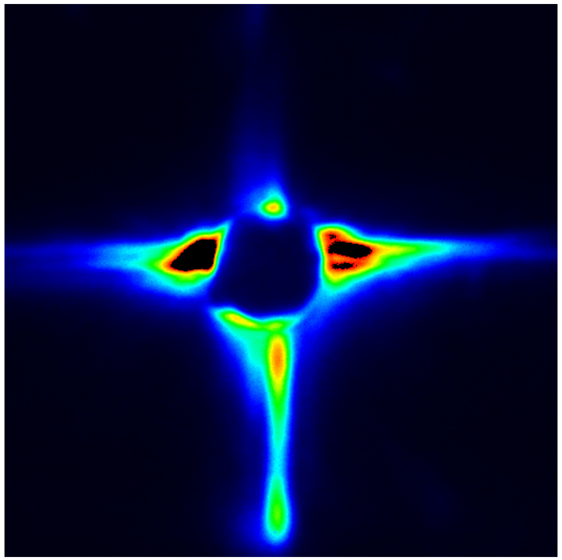
Observation of beam halo



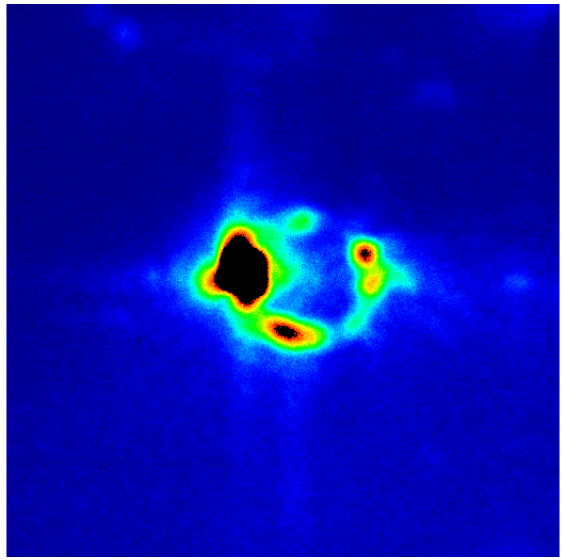
Beam core



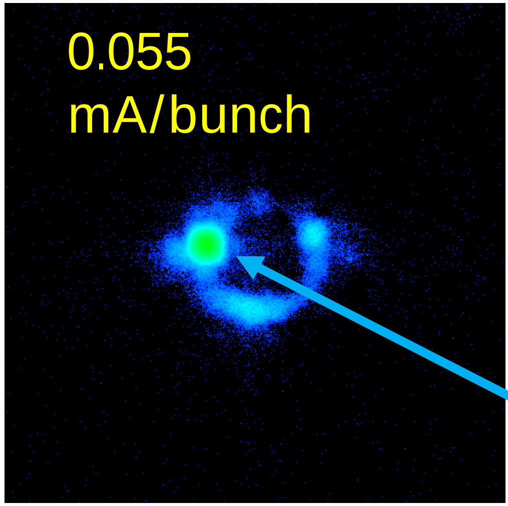
Core blocked by a Φ3mm disk



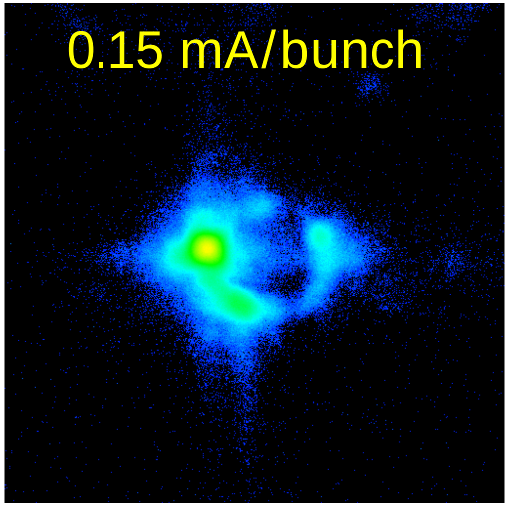
Re-diffraction fringes blocked by the Lyot stop

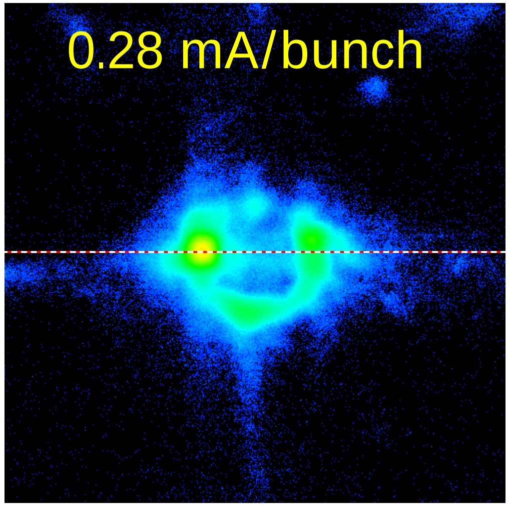


Observation : Bunch-current dependence in HER



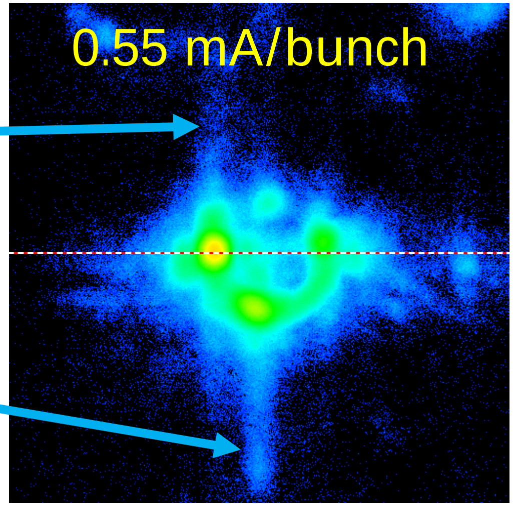
Due to beam orbit changes





Diffraction fringes made by the latter optics than the Lyot stop

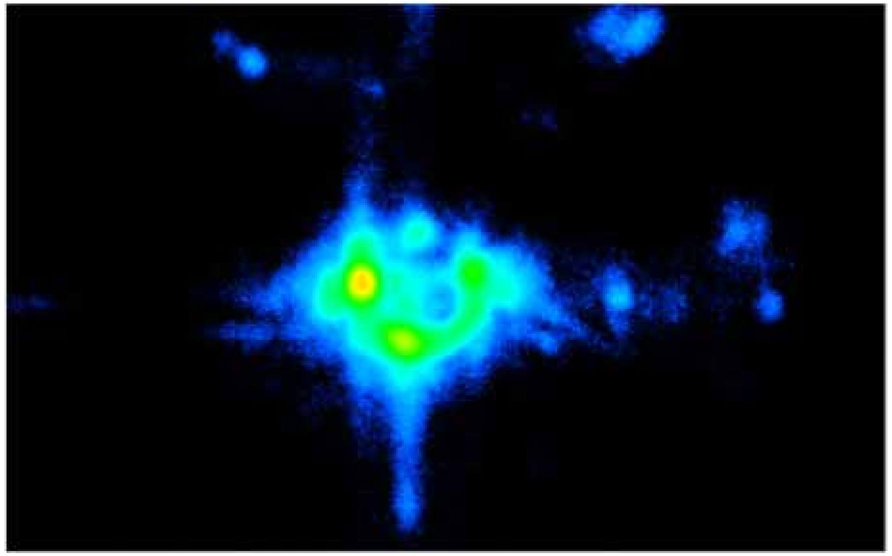
Leakage of diffraction fringes by the diamond mirror



Comparison of halos between HER and LER

Gate width 10msec

HER 0.57mA



LER 0.61mA