E-cloud observations and simulation at J-PARC

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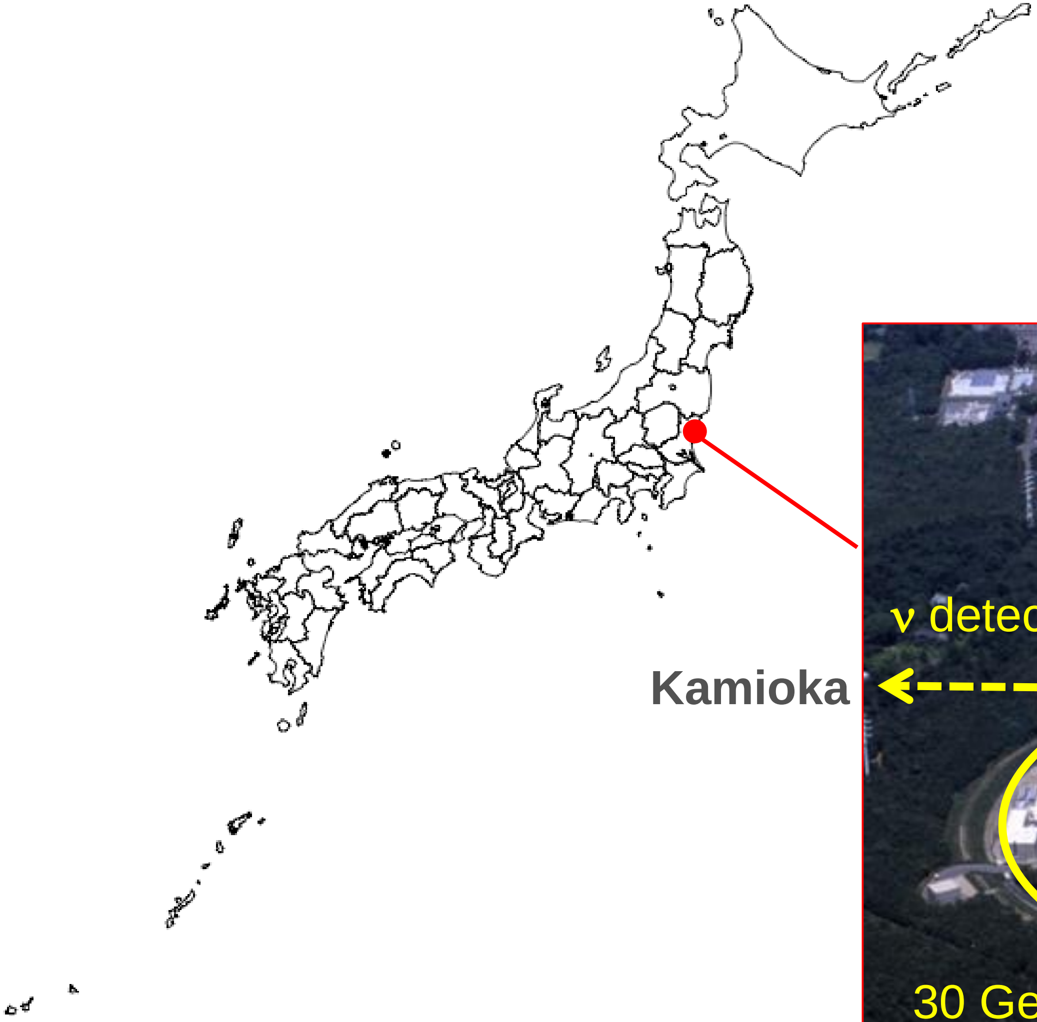
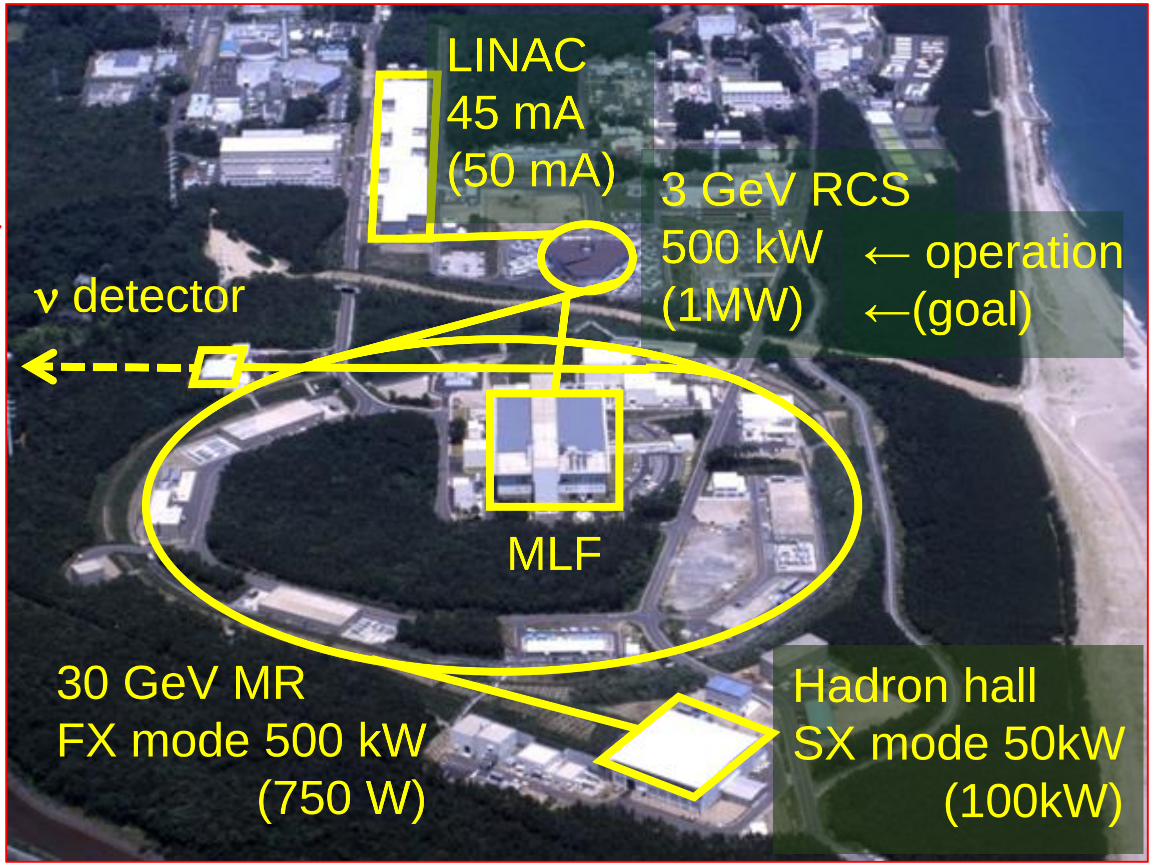
Japan Proton Accelerator Research Complex



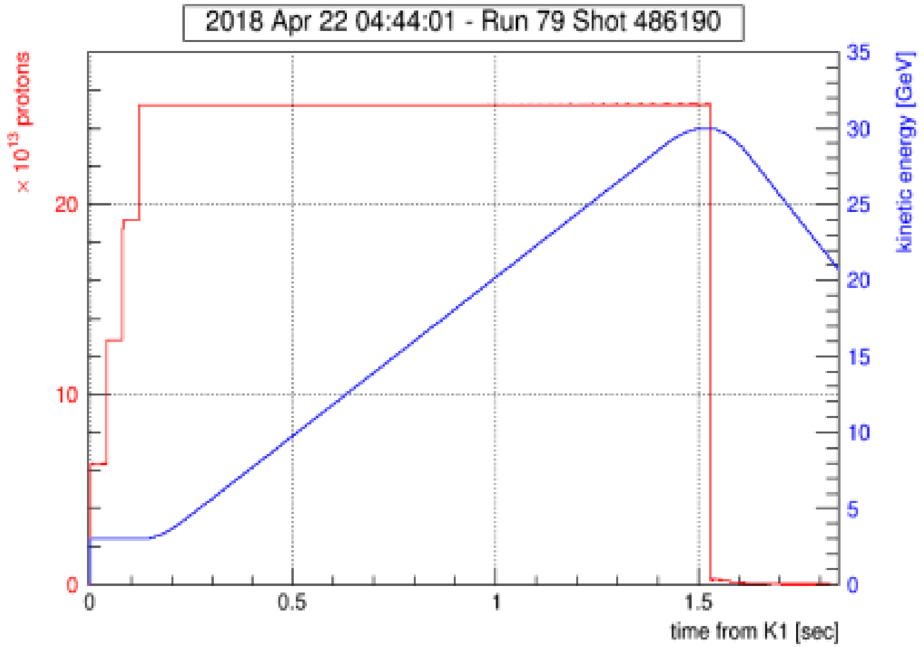
Kamioka

Tokai, Ibaraki



Two operation modes

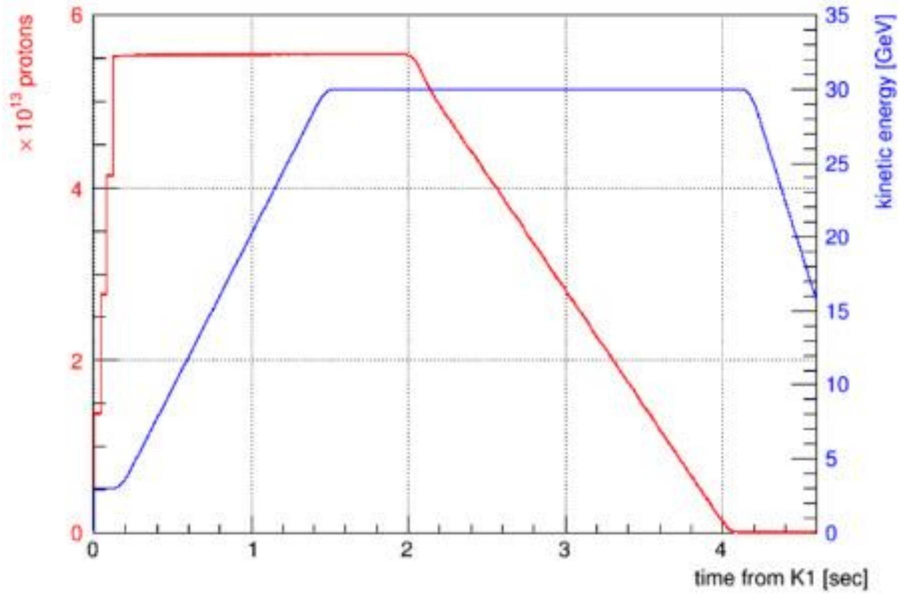
Fast Extraction (FX)



Red line: DCCT
Blue line: Kinetic energy
Beam power: 490 kW
Machine cycle: 2.48 s
Top energy: 30 GeV

Slow Extraction (SX)

(1) Coasting beam slow extraction



Red line: DCCT
Blue line: Kinetic energy
Beam power: 51 kW
Machine cycle: 5.20 s
Top energy: 30 GeV

(2) Bunched beam slow extraction

Electron Cloud appears . . .

FX mode

- after large modification of vacuum components (usually long shutdown)
  - accompanying vacuum pressure rise,
  - scrubbing run of a few days is effective to reduce the pressure rise
- no issue during routine operations
- Beam intensity will increase from 2.5×10^{14} ppp → 3.3×10^{14} ppp in future
  - e-cloud is not foreseen because of higher incident e^{-} energy

SX mode

- at the debunching process at the flat-top
  - accompanying vacuum pressure rise,
  - connection to transverse instabilities is not clear (only one sample)
- very slow decrease of the electron signal ~ a few % reduction / year
- still potential risk
- Beam intensity will increase from 5.5×10^{13} ppp → 1.1×10^{14} ppp in future

Electron cloud detectors (ECD)

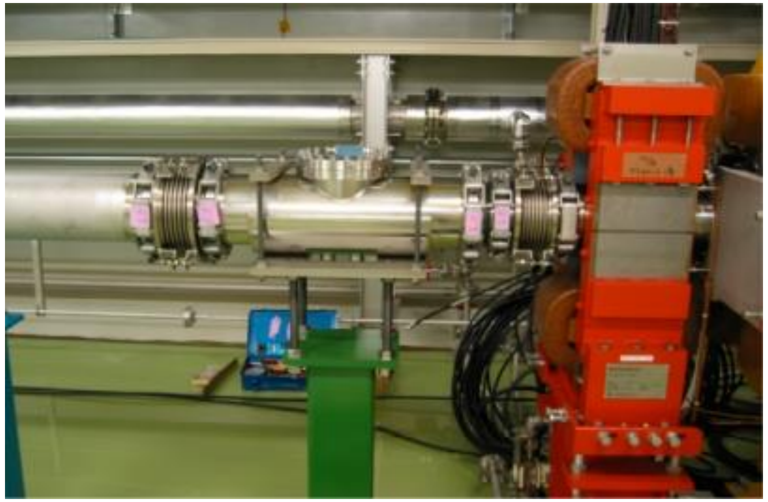


Figure 1: The ECD installed at MR of J-PARC.

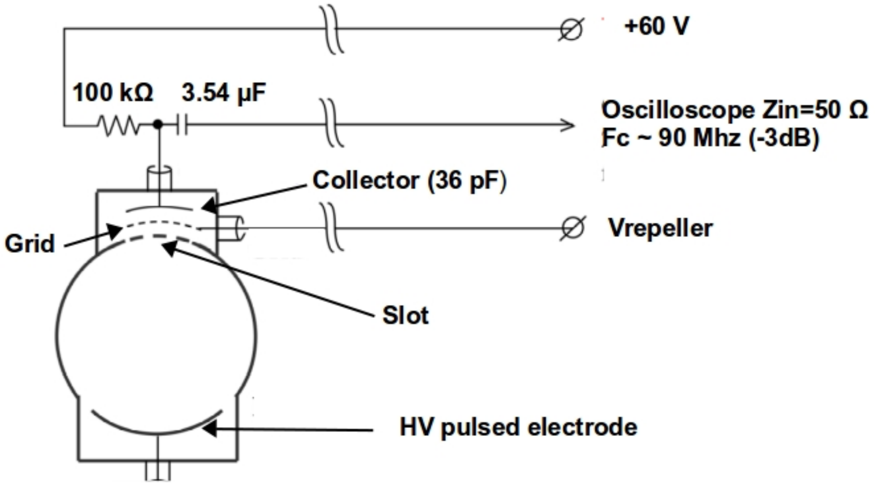
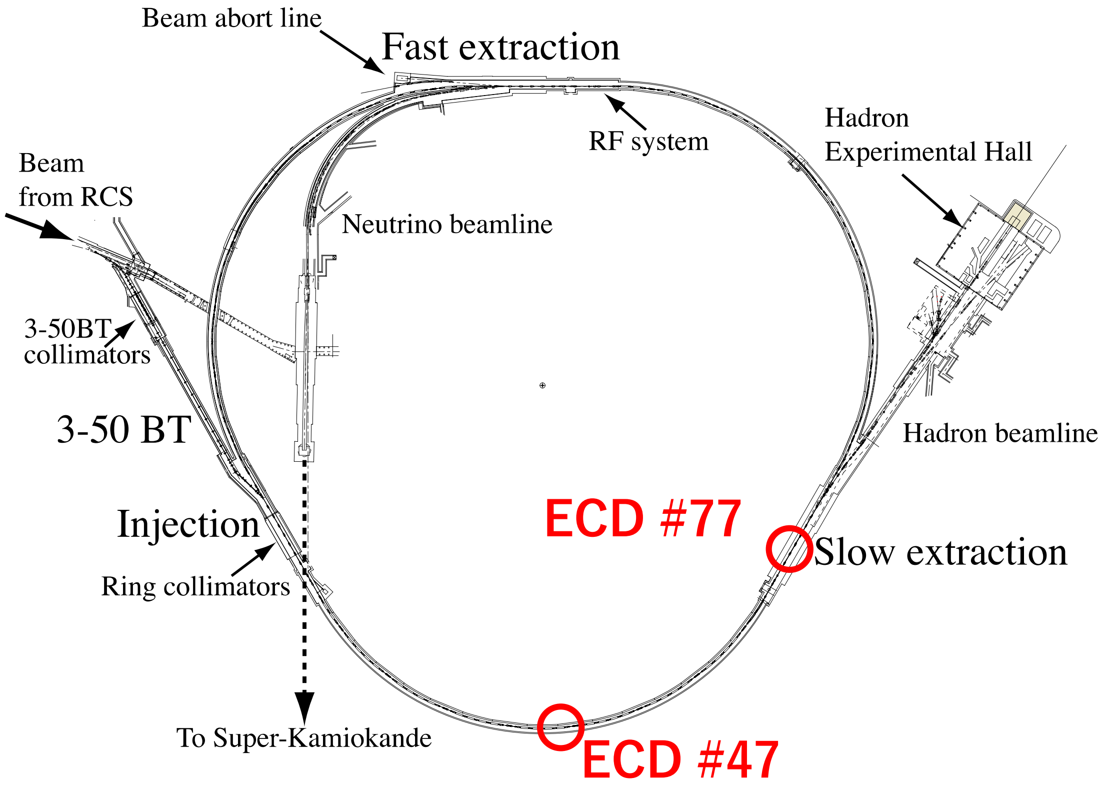
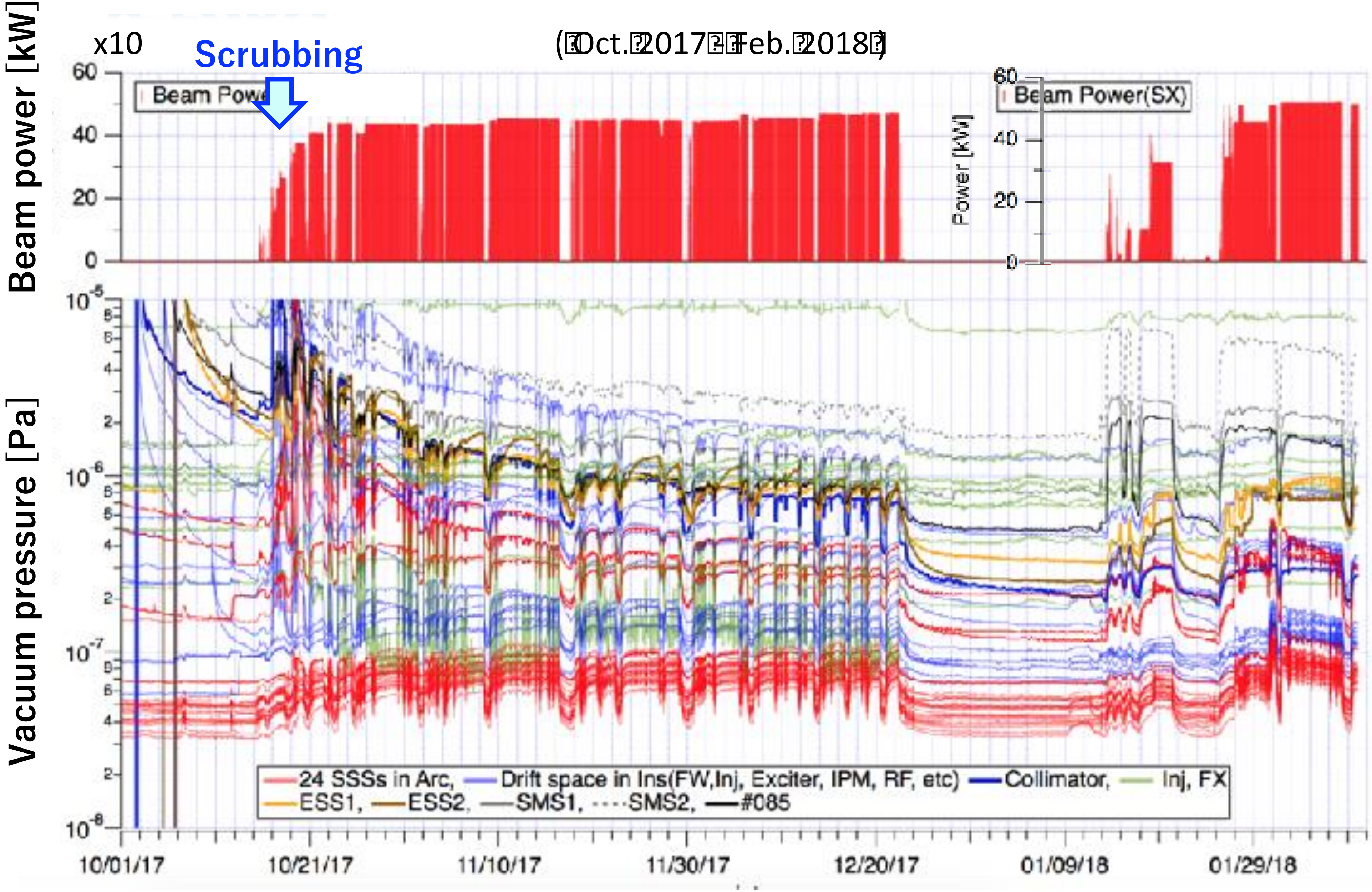


Figure 2: Schematic view of the ECD at J-PARC MR. Courtesy of R. J. Macek.

MR layout

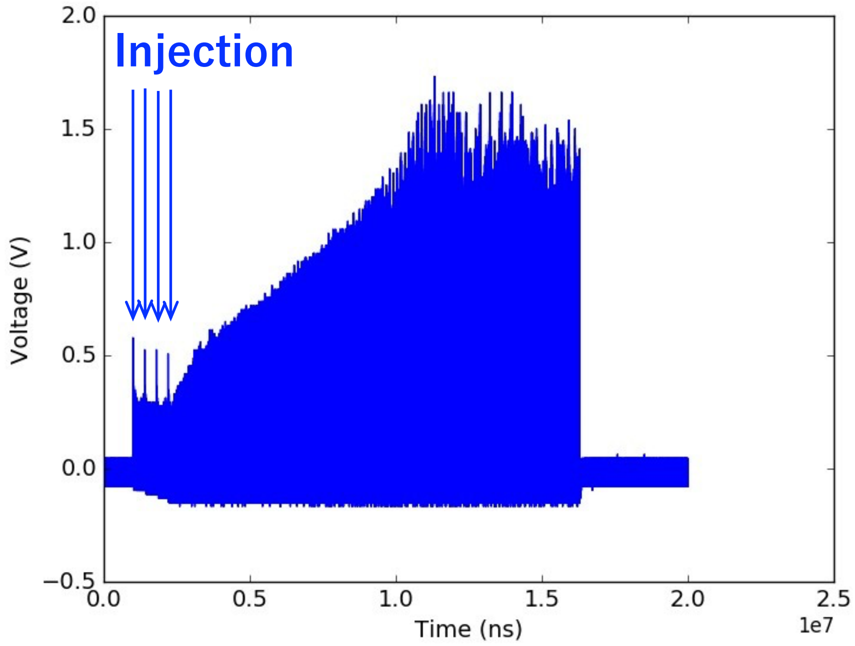


FX mode

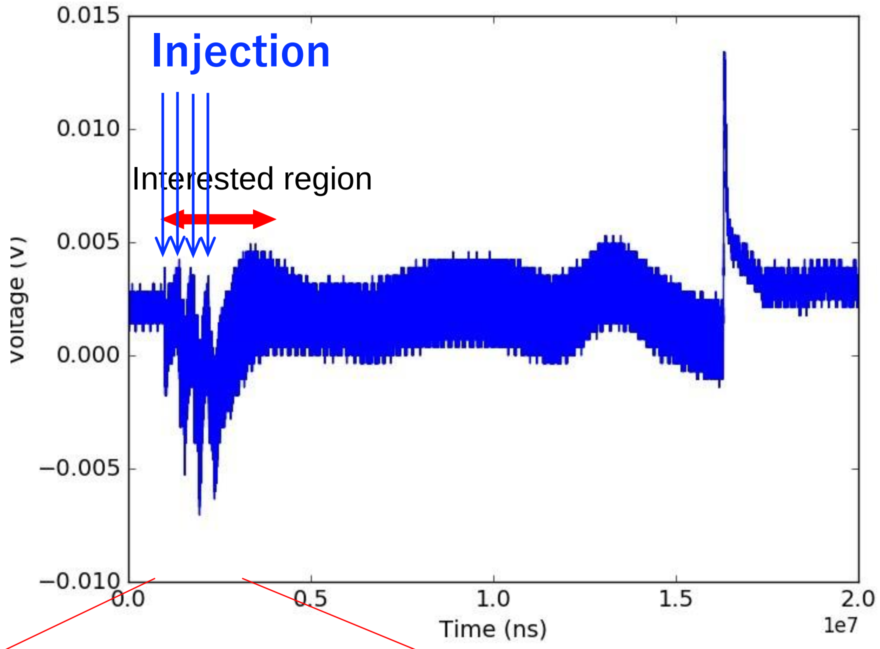


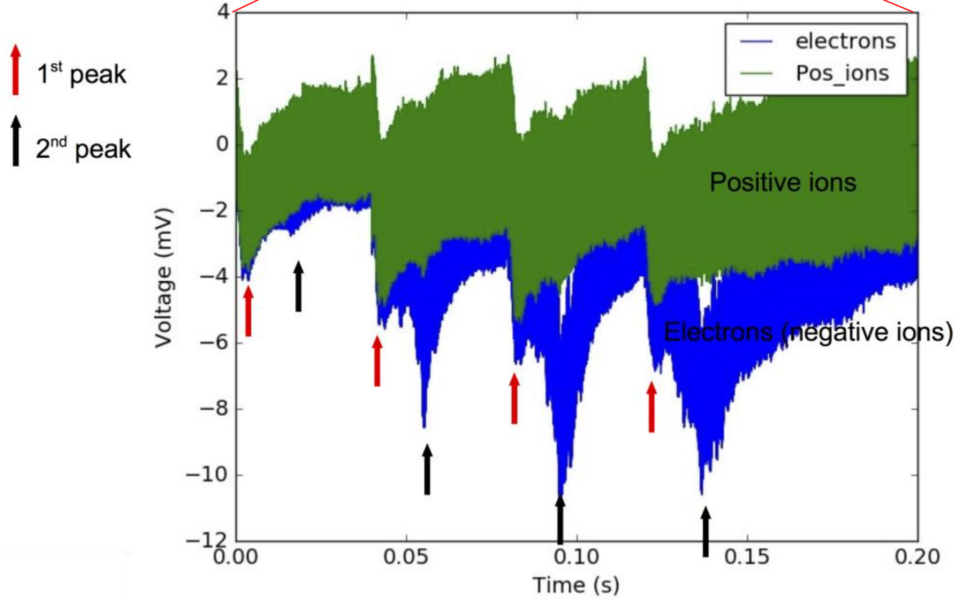
Beam power [kW]
x10
Scrubbing
(Oct. 2017 Feb. 2018)
Beam Power(SX)
Power [kW]
Vacuum pressure [Pa]
24 SSSs in Arc, Drift space in Ins(FW,Inj, Exciter, IPM, RF, etc) Collimator, Inj, FX
ESS1, ESS2, SMS1, SMS2, #085
10/01/17
10/21/17
11/10/17
11/30/17
12/20/17
01/09/18
01/29/18

FCT signal



Electron cloud detector signal





Input impedance = 1 MΩ

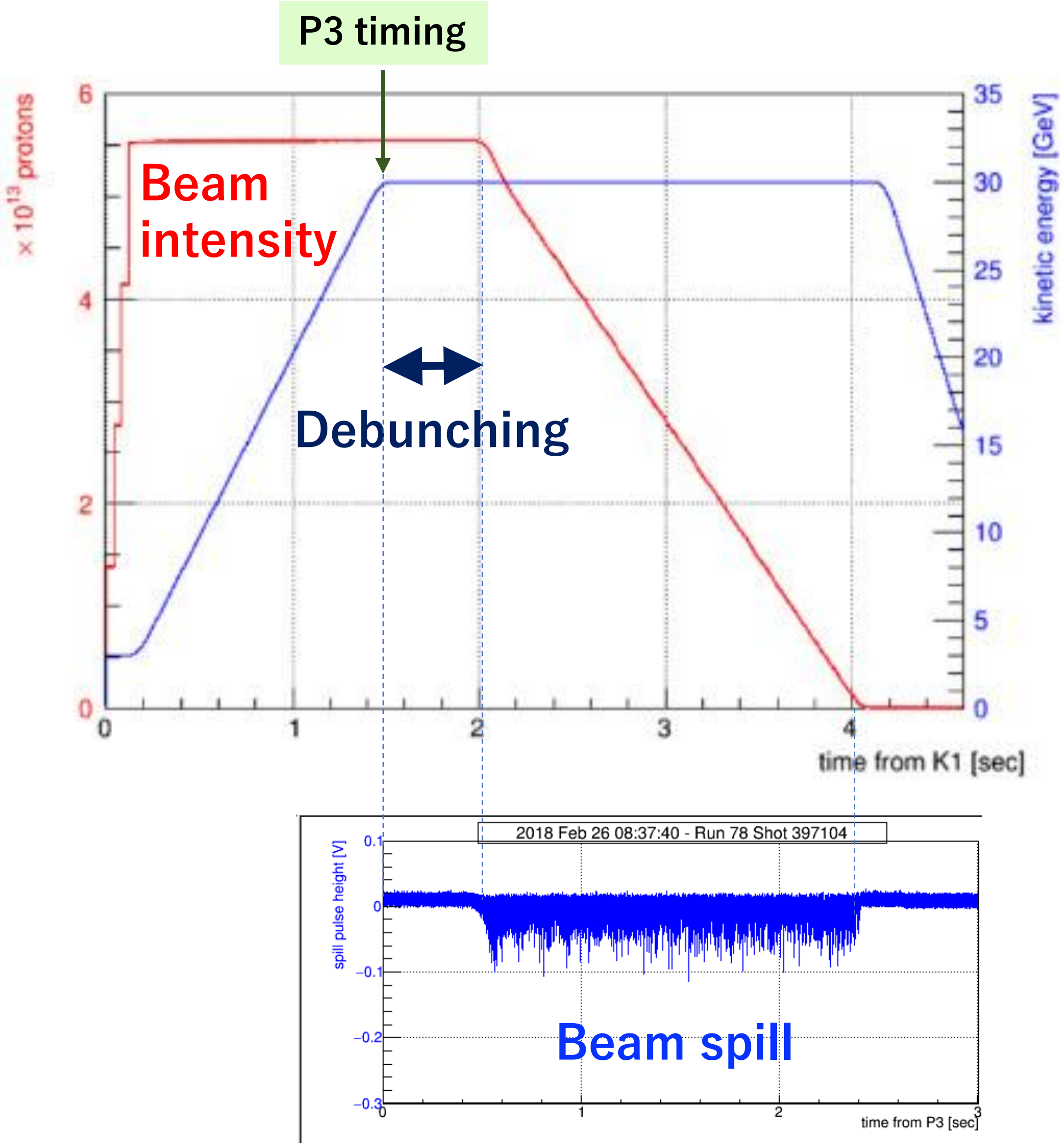
10 mV → 10 μA

EC peaks at four injections

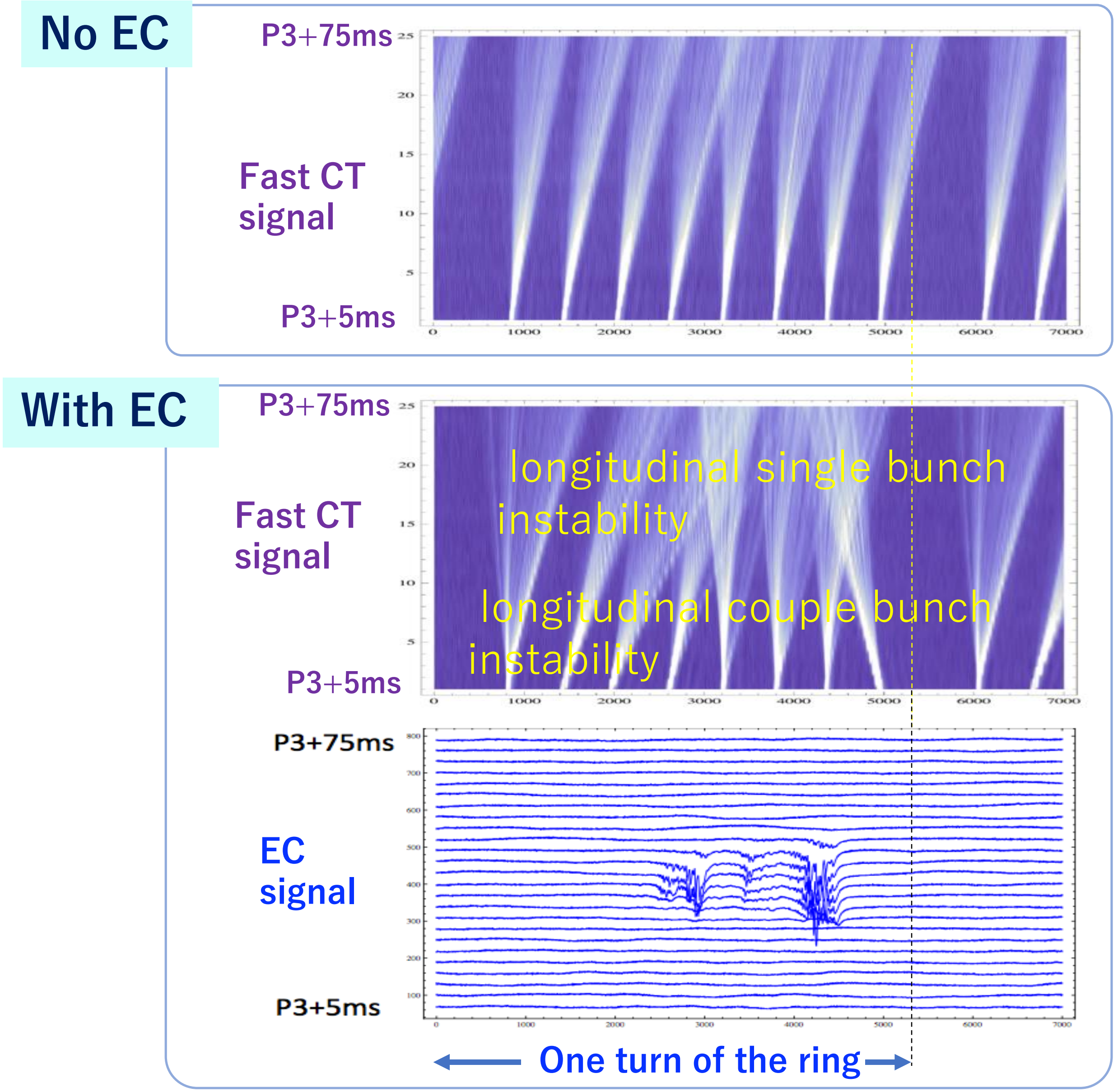
EC signal decreases after a few days

SX mode

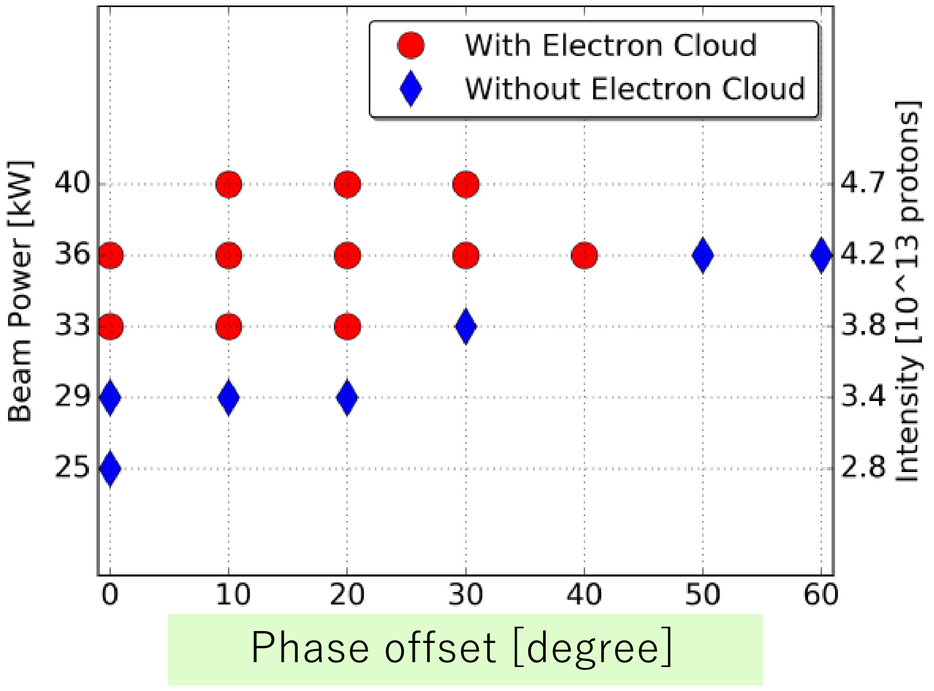
EC at the debunching process at the flat-top



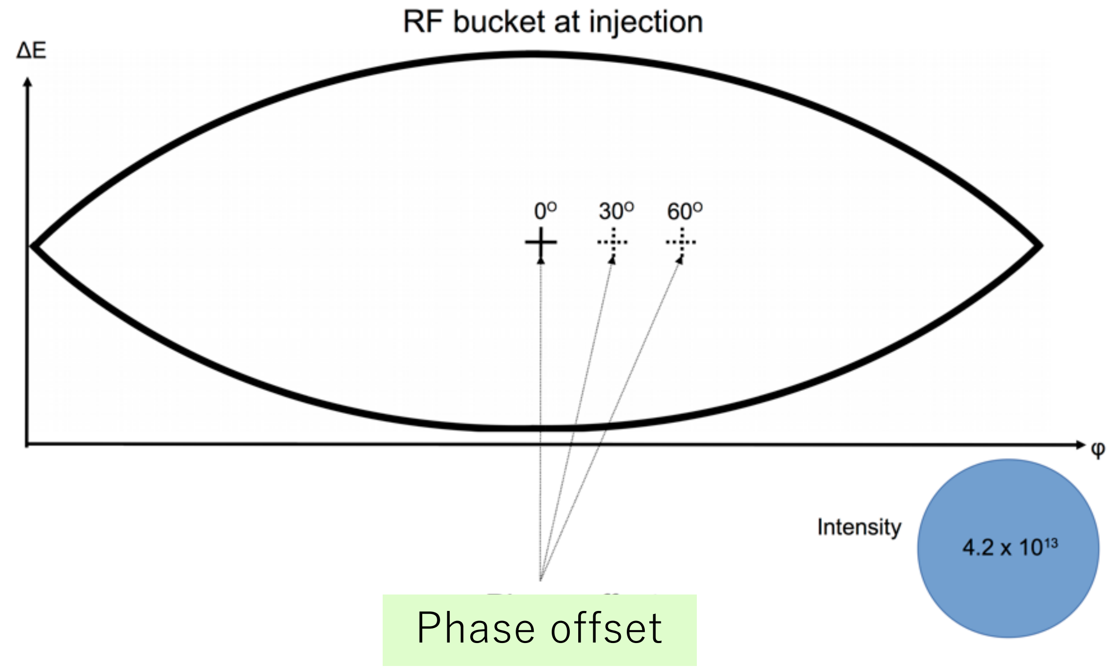
Beam intensity ~ 4 10^{13} protons



Beam conditions where EC appears



Injection at RF phase



EC presence depends on the RF phase at MR injection and the beam intensity / beam power

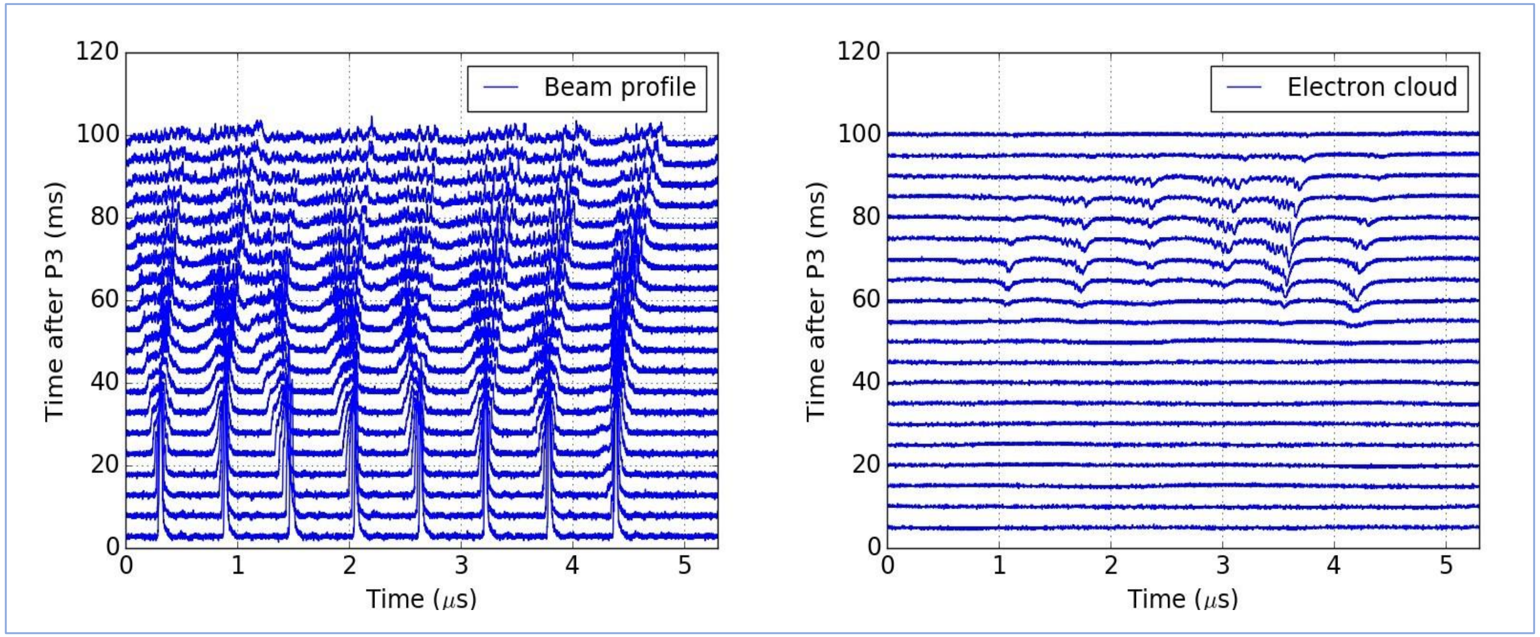
Larger RF phase results longer bunch length before debunching.

Electron cloud build up is triggered by longitudinal single bunch instability which is induced by longitudinal couple bunch instability.

a, Ibaraki, Japan

ble 1: Relevant beam parameters during the SX operat MR.

Parameters	Units	Value
Circumference	m	1567.5
Energy	GeV	30
Power	kW	38.2
Bunch population	10^{13} p	4.2



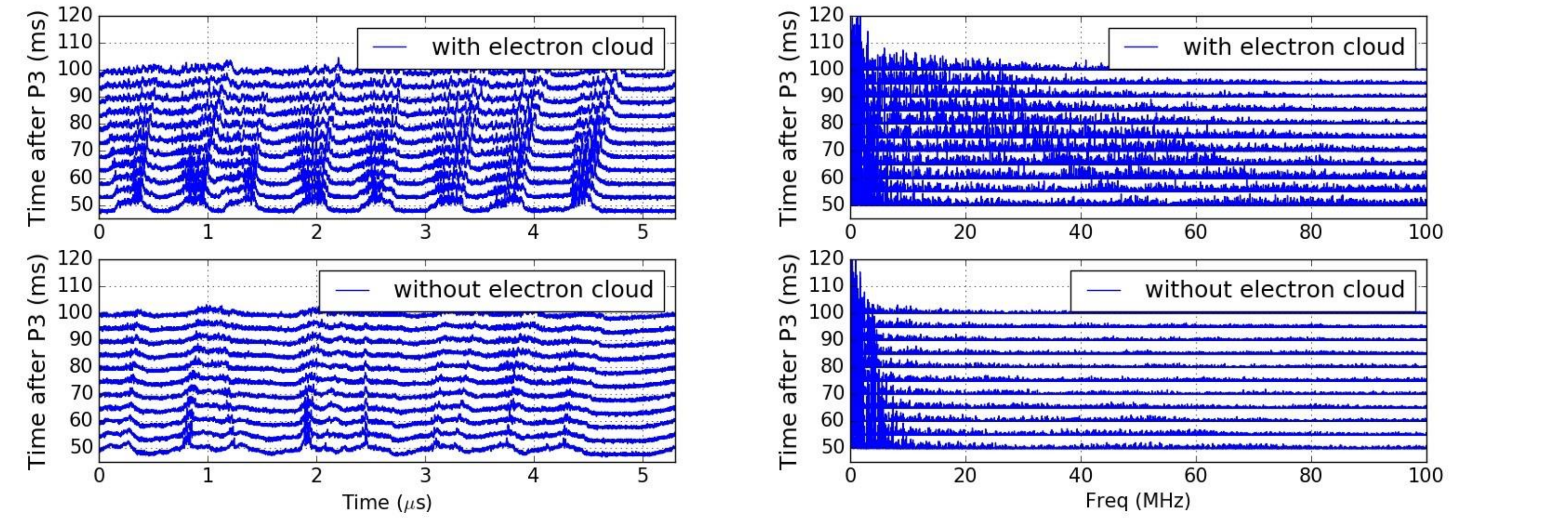


Figure 4: The beam current signals for events with and without electron cloud in the time domain, top and bottom left, respectively. The corresponding Fourier transform plots are shown in right side in the same order.

Simulation for SX mode (debunching)

- **PEI**

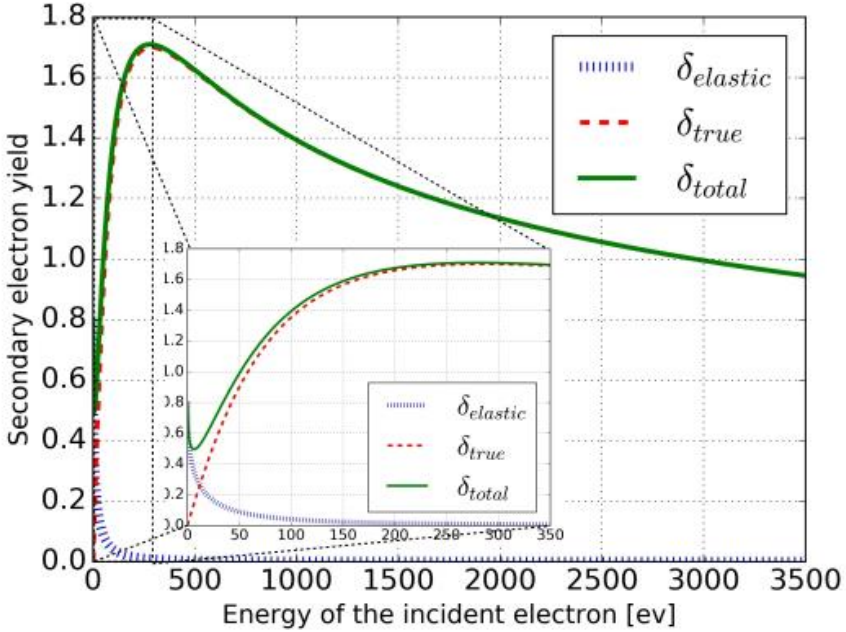


Figure 1: The total SEY (δ_{total}, green solid line) is the sum of the contribution for the elastic part ($\delta_{elastic}$, blue dot line) and the true secondaries (δ_{true}, red dot line).

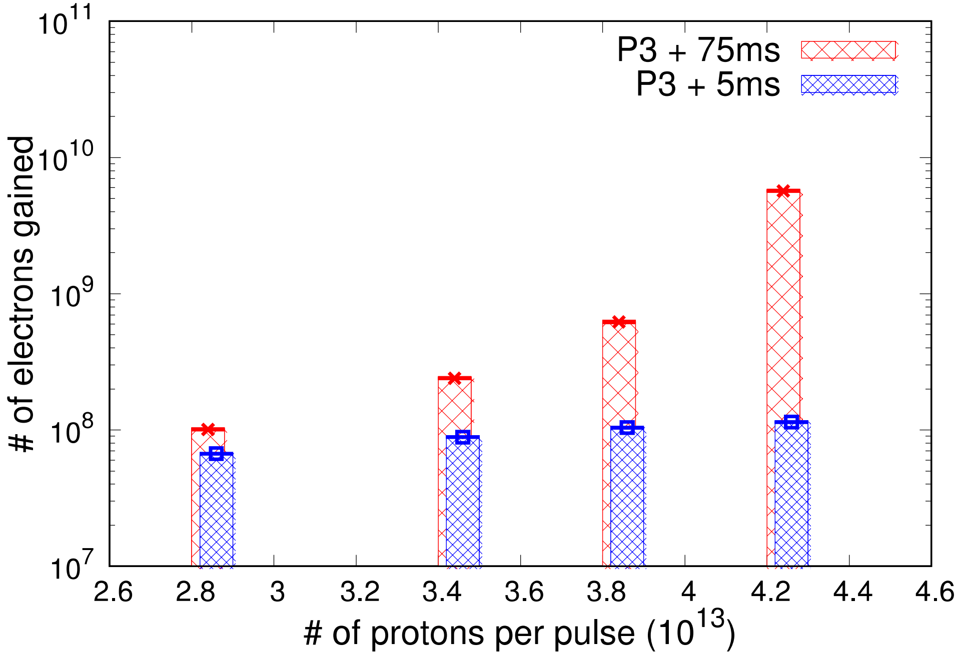


Figure 4: The comparison of the total electrons generated by the four intensities simulated at the two different times (5 ms and 75 ms after P3). The model used a δ = 1.6 and E_{max} = 200 eV.

Simulation for SX mode (debunching)

Simulation
with the sinusoidal beam density modulation

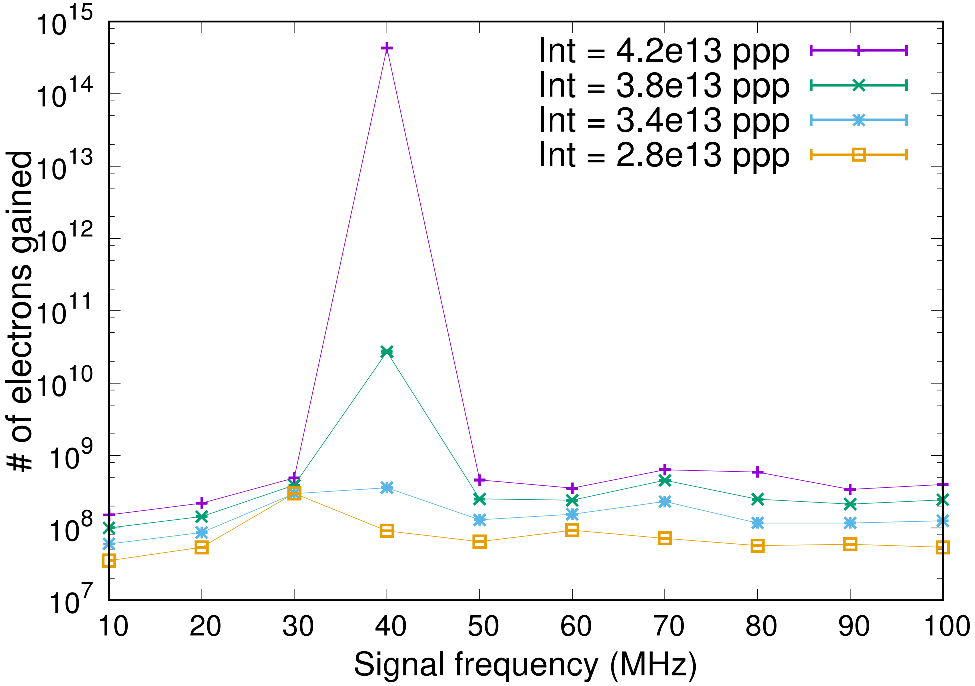
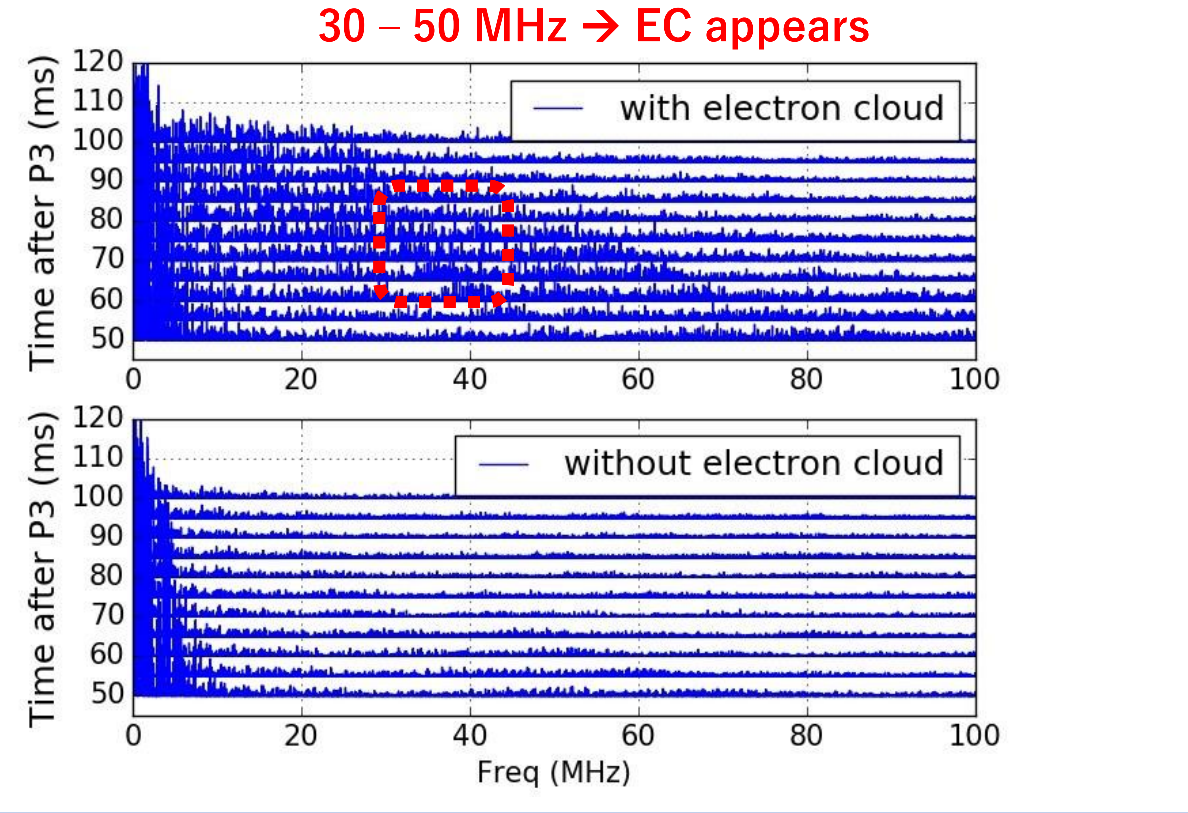


Figure 6: Electrons produced in the simulations vs. the frequency of the sine signal at different intensities, using $\delta = 1.1$ and $E_{max} = 200\ eV$.

Frequency spectrum of the beam
measured by the Fast CT



"Multipactor condition" may be satisfied

Electron frequency and instability threshold

- Electron frequency bounded in proton beam potential

$$\omega_{e,y}^2 = \frac{\lambda_p r_e c^2}{(\sigma_x + \sigma_y)\sigma_y}$$

- $\omega_{e,x}=\omega_{e,y}$=32MHz ($2.8\times10^{13}$ppp), 40 MHz ($4.2\times10^{13}$ppp) for σ_{xy}=7.5mm.
- λ_p=averaged proton line density=1.8×10^{10}-2.7×10^{10} m^{-1}.
- These frequencies are consistent with the electron amplification in the previous page.

- Threshold of the beam instability

$$\lambda_{e,th} = \frac{2\gamma\omega_e|\eta_p|\sigma_p(\sigma_x + \sigma_y)\sigma_{x,y}}{\sqrt{3}cQr_p\beta_y} = 7.6\times10^7\ m^{-1}$$

Simulation for SX mode (debunching)

- **PyECLOUD**

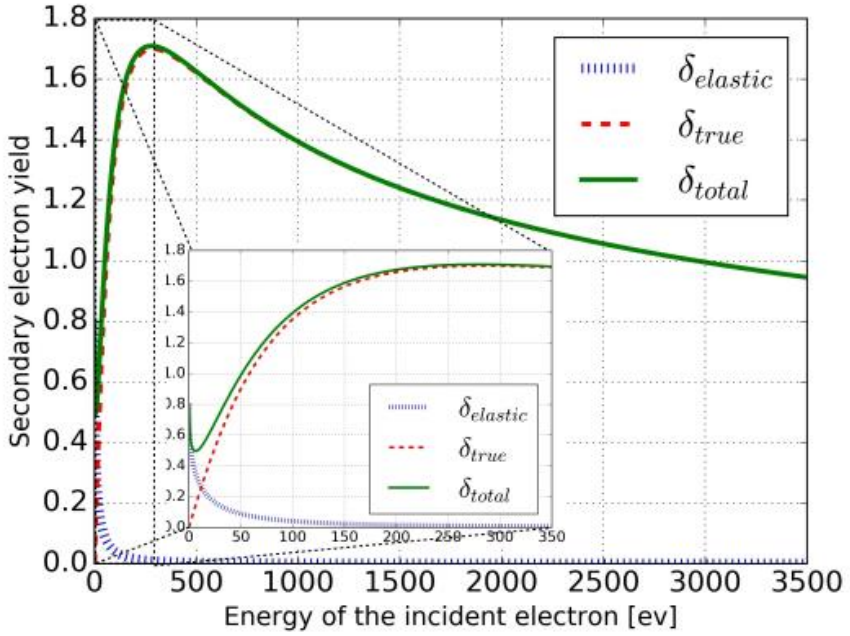


Figure 1: The total SEY (δ_{total}, green solid line) is the sum of the contribution for the elastic part ($\delta_{elastic}$, blue dot line) and the true secondaries (δ_{true}, red dot line).

- Seed: Ionization Gas* (H was used as residual gas).
- Beam profile: FCT measurements at SX mode.
- SEY: δ=1.7, Emax= 287 eV, Ro=0.8.
- Tracking simulations: 15 turns.

Result of the EC simulation

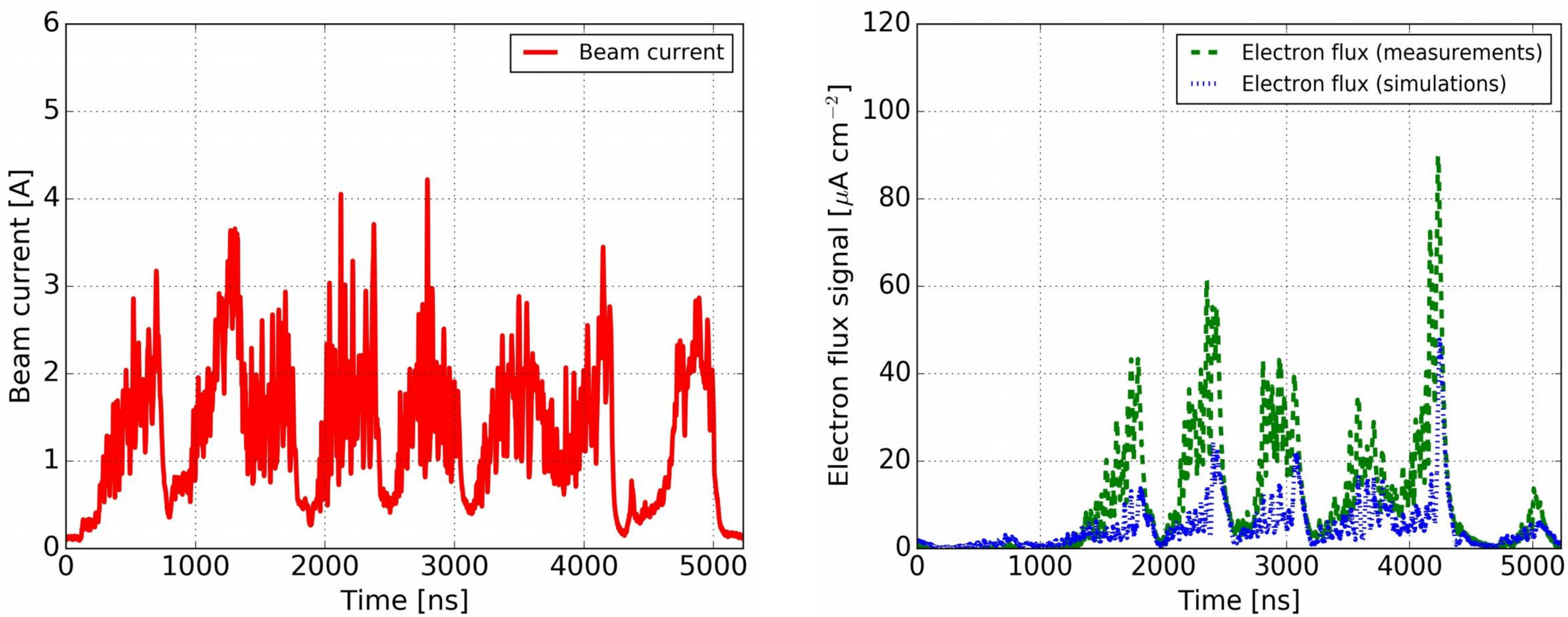
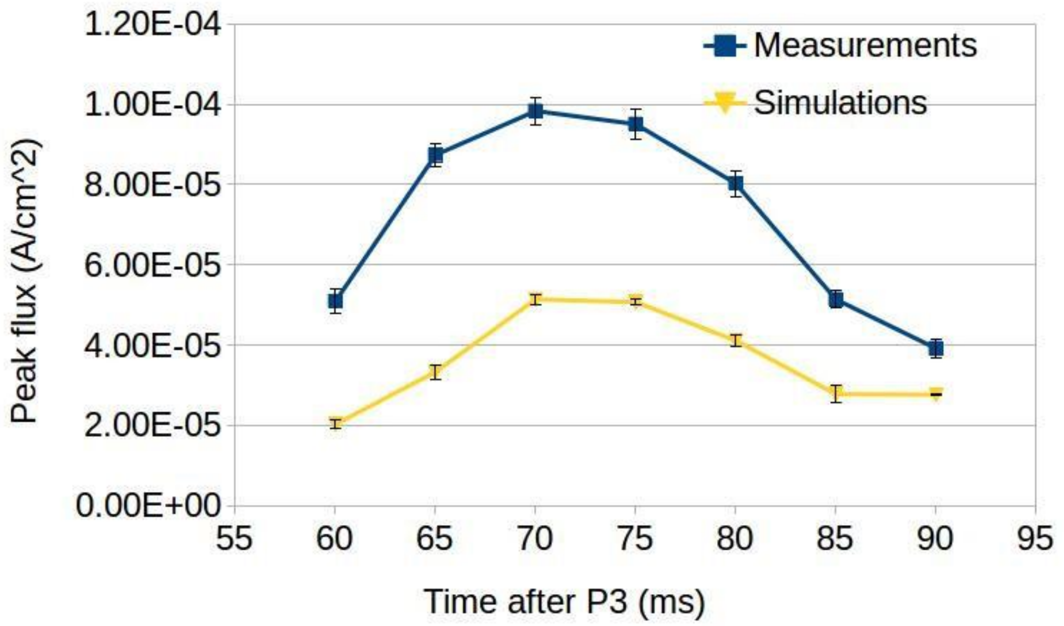


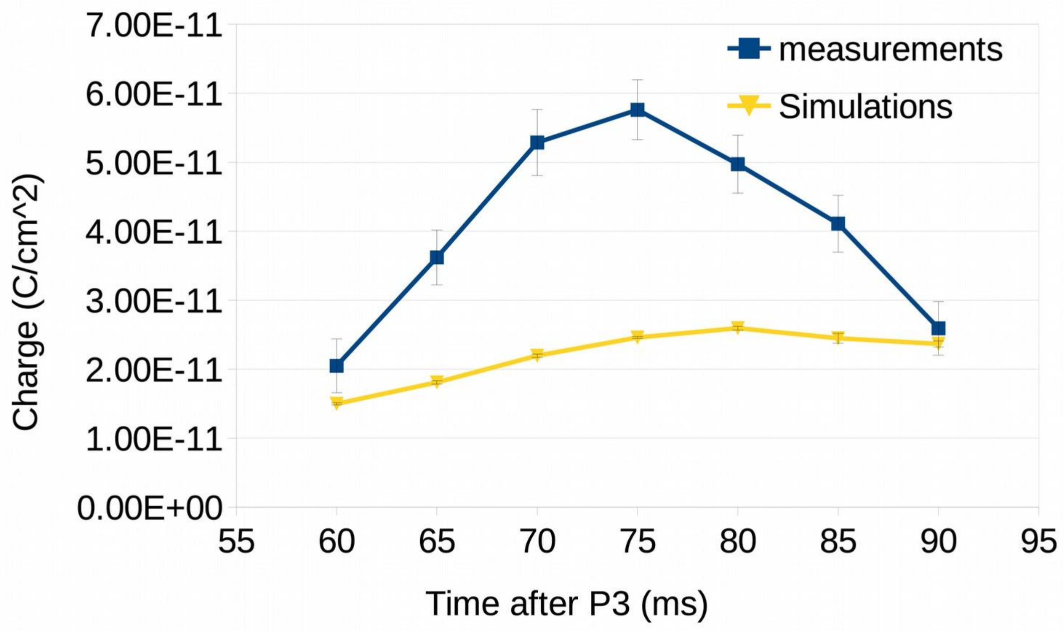
Figure 5: Left: the beam current; right: the comparison of the electron flux signals measured (green dot line) and the simulated (blue dot line). The values corresponded at 75 ms after the beginning of debunching.

Time evolution of the EC

Peak flux



Total charge



Trend is reproduced.

This suggests the longitudinal beam profile affects the EC growth.

The discrepancy may come from the estimation error of detector efficiency *etc*.

Simulation for FX mode

Parameters

δ =1.7.

Emax= 300 eV.

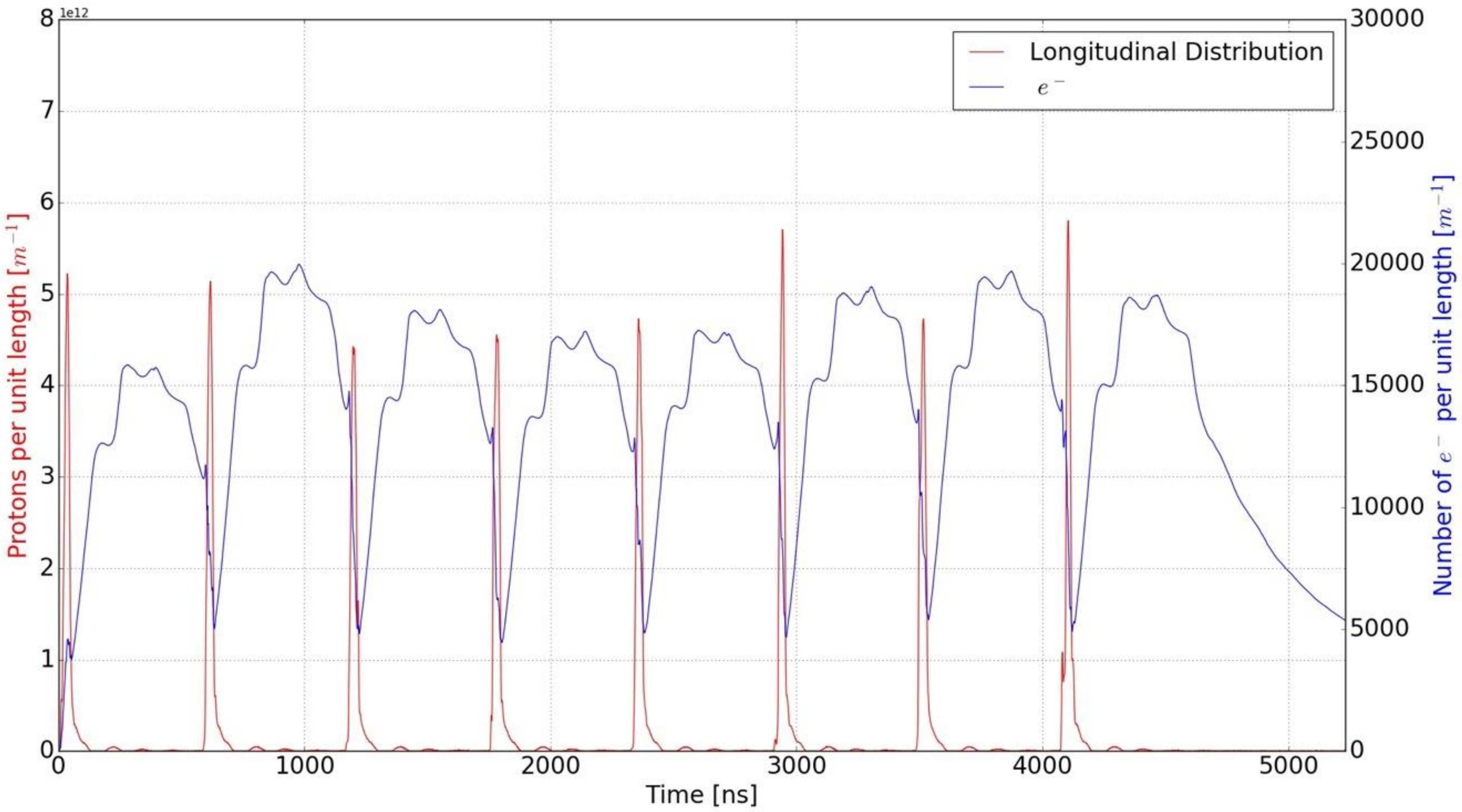
Ro = 1.

Proton per bunch~ **$4.2\mathrm{x}10^{13}$**. (Bunch length ~ 54 ns)

Measured longitudinal profile by Fast CT

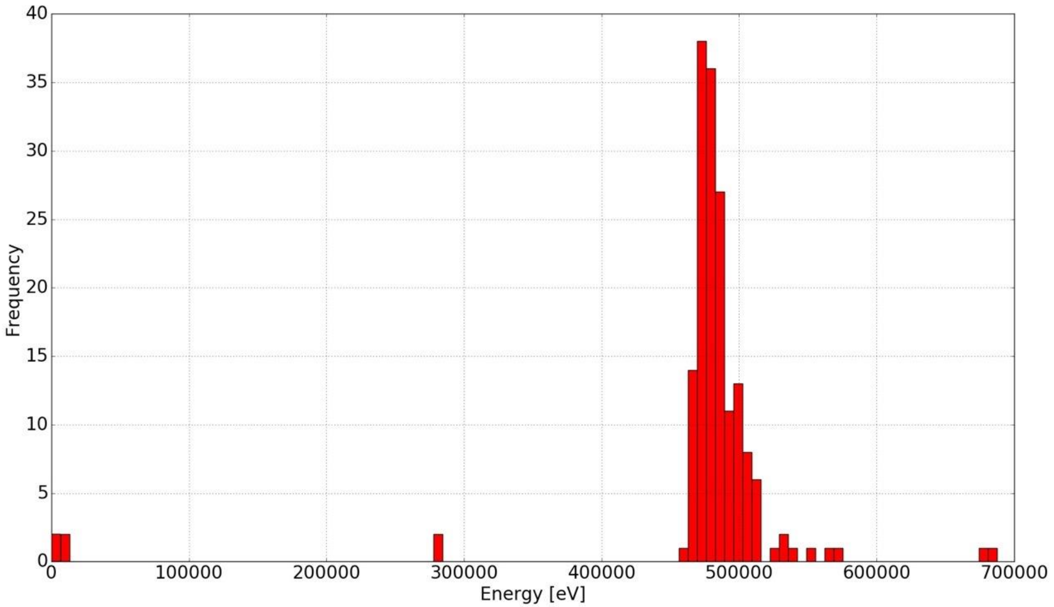
Tracking turns = 6.

Proton density vs Electron density



Electron cloud density is very small comparing to the proton density.

Electron energy distribution



Electron energies are in higher energies at which SEY is less than 1

Summary

- **Measurements**

  ✓ **SX mode:** **EC appears during debunching process.**
  EC and vacuum pressure rise in the whole ring.
  Larger initial RF phase offset suppresses the EC growth.
  possible scenario:
  → suppresses longitudinal coupled-bunch oscillation
  → smoother debunching
  → no EC

  ✓ **FX mode:** **EC only appears after vacuum component modification.**
  EC & vacuum pressure rise decrease after a few days.

- Simulation

✓ SX mode: EC growth is reproduced with spiky beam profiles.

Details of the spiky beam profiles affects the EC growth

Beam profile structure around 40 MHz seems to satisfy multipactor condition at the beam intensity ~ 4×10^{13} protons.

✓ FX mode: EC estimated to be negligibly small with the beam profile at 4.2×10^{13} p/bunch, 8 bunches.

References

B. Yee-Rendon et al., “ELECTRON CLOUD STUDIES AT J-PARC MAIN RING”,
presented in ICFA mini-WORKSHOP ON IMPEDANCES AND BEAM INSTABILITIES IN PARTICLE ACCELERATORS,
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B. Yee-Rendon et al., “Electron cloud simulations for the main ring of J-PARC”, J. Phys.: Conf. Ser. 874 012065 (2017).

B. Yee-Rendon et al., “PyECLOUD SIMULATIONS OF THE ELECTRON CLOUD FOR THE J-PARC MR”,
Proceedings of the 14th Annual Meeting of Particle Accelerator Society of Japan, August 1-3, 2017, Sapporo, Japan, p.197.

B. Yee-Rendon et al., “MEASUREMENTS OF THE ENERGY DISTRIBUTION OF THE ELECTRON CLOUD AT J-PARC MR”,
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B. Yee-Rendon et al., “ELECTRON CLOUD STUDY AT SX OPERATION MODE AT J-PARC MR”,
Proceedings of 13th Particle Accelerator Society of Japan, Chiba, Japan, August 8 - 10, 2016, p.149.

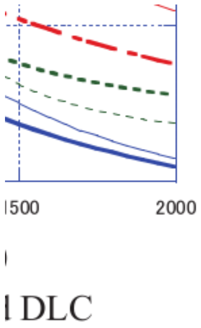
B. Yee-Rendon et al., “ELECTRON CLOUD MEASUREMENTS AT J-PARC MAIN RING”,
Proceedings of 7th International Particle Accelerator Conference, Busan, Korea, May 8 - 13, 2016, pp. 137–139.

F. Naito, “Status of MR”, ATAC2018, Mar. 1, 2018.

and references therein.

APPENDIX

Model for low electron energy PyECLOUD



G. Landarola. PhD Thesis, CERN-THESIS-2014047.

Okada et al." *CONTROL OF THE MULTIPACTORING BY THE SURFACE COATING OFTHE EXCITER ELECTRODES IN J-PARC MR",* PASJ10

Spectrum energy secondary electrons

G. Landarola. PhD Thesis, CERN-THESIS-2014047.

J. J. Scholts, D. Dijkkamp, and R. W. A. Schmitz, “Secondary electron emission properties,” Philips J. Res., vol. 50, pp. 375–389, 1996

ss steel.

Observation of the instability

One event during SX mode
Transverse instability triggered the e-cloud or vice versa → not clear

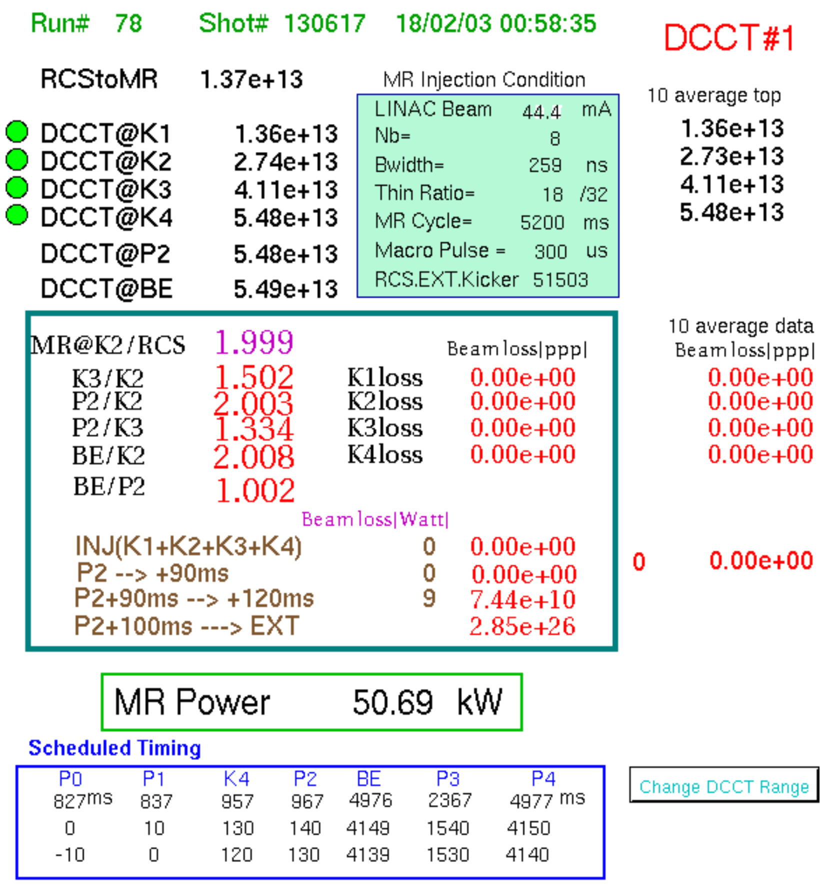
Beam intensity = 5.5 10^{13} protons (51 kW)

Electron cloud signals larger than normal shots

Beam loss MPS stops the operation

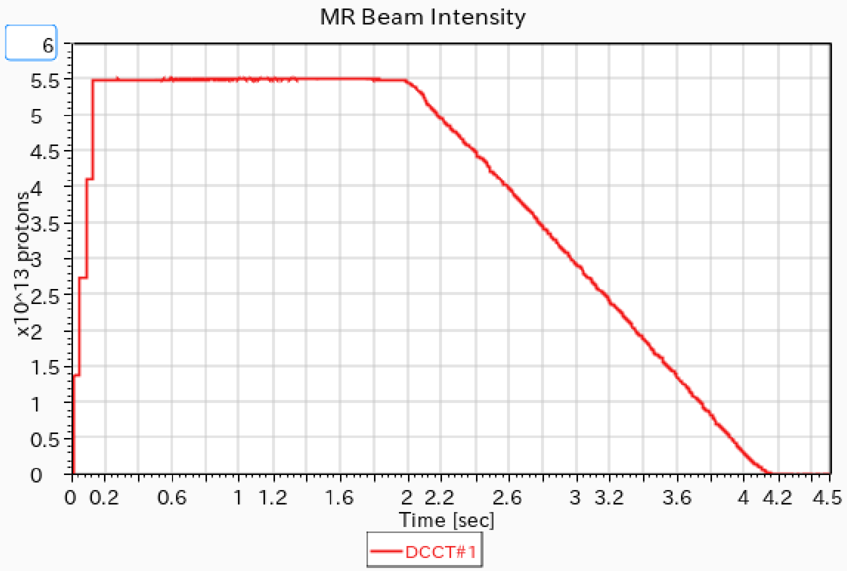
Pressure rise larger than normal shots

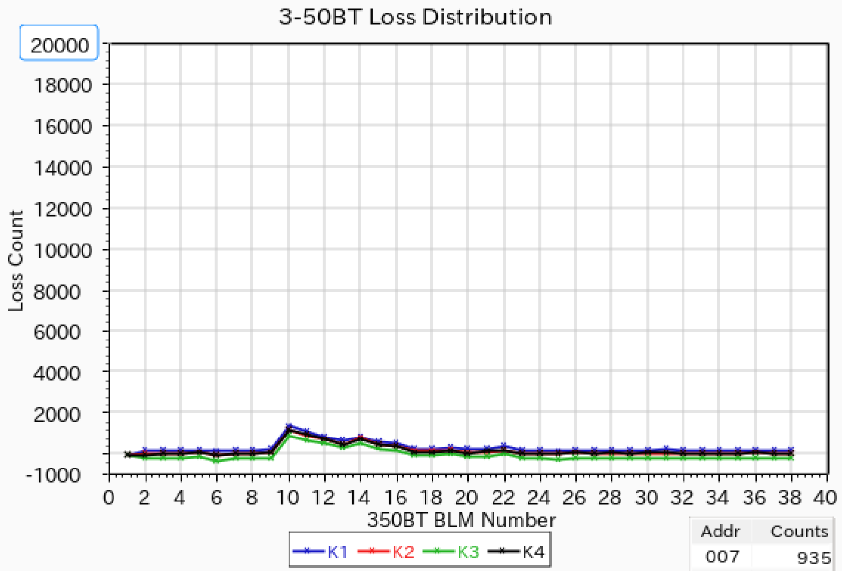
Vertical oscillation observed

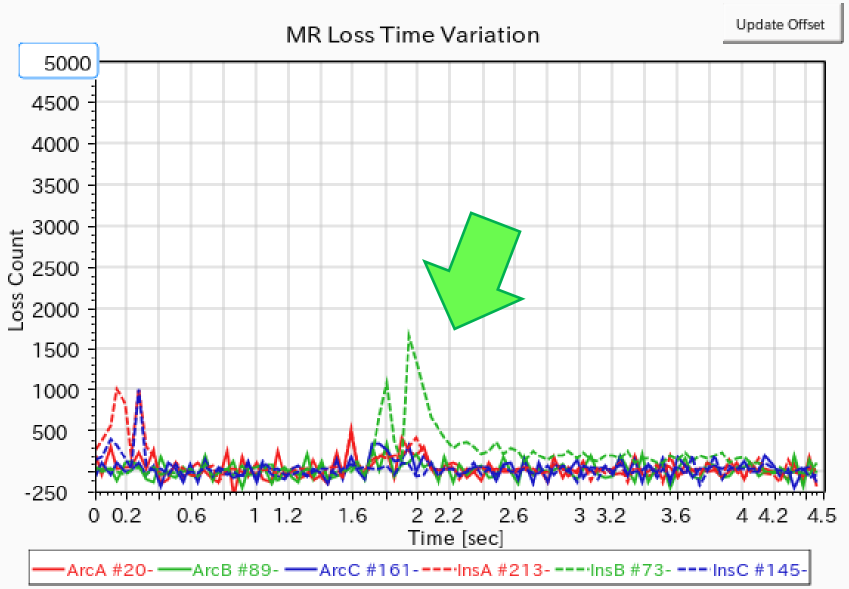


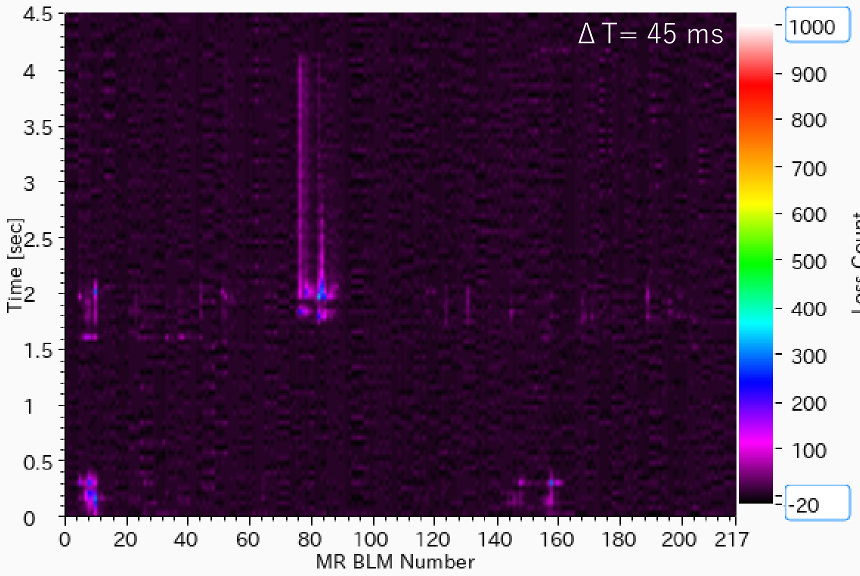
18/02/03 00:59:52 Run 78 Shot 130617 at 18/02/03 00:58:37

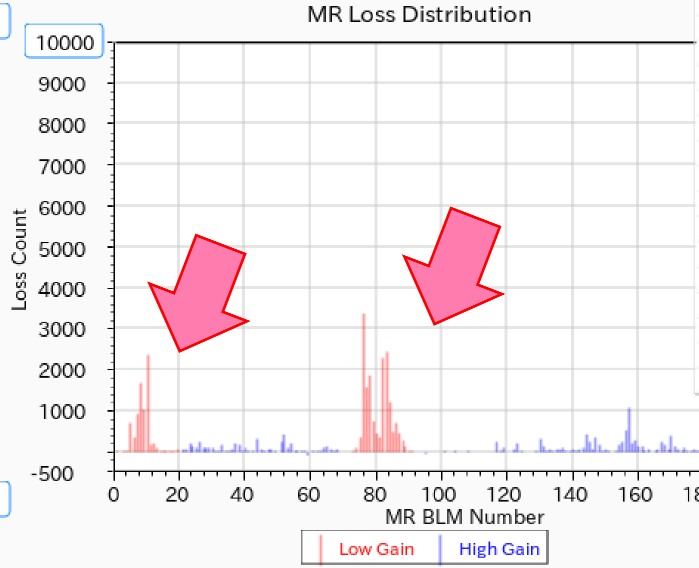
Latest Offset Run 78 Shot 38220 at 18/01/25 14:51:20



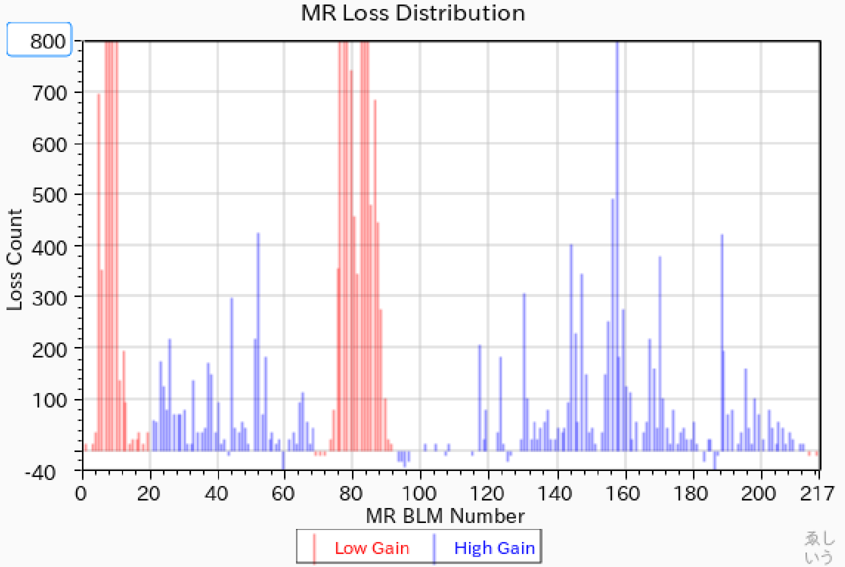




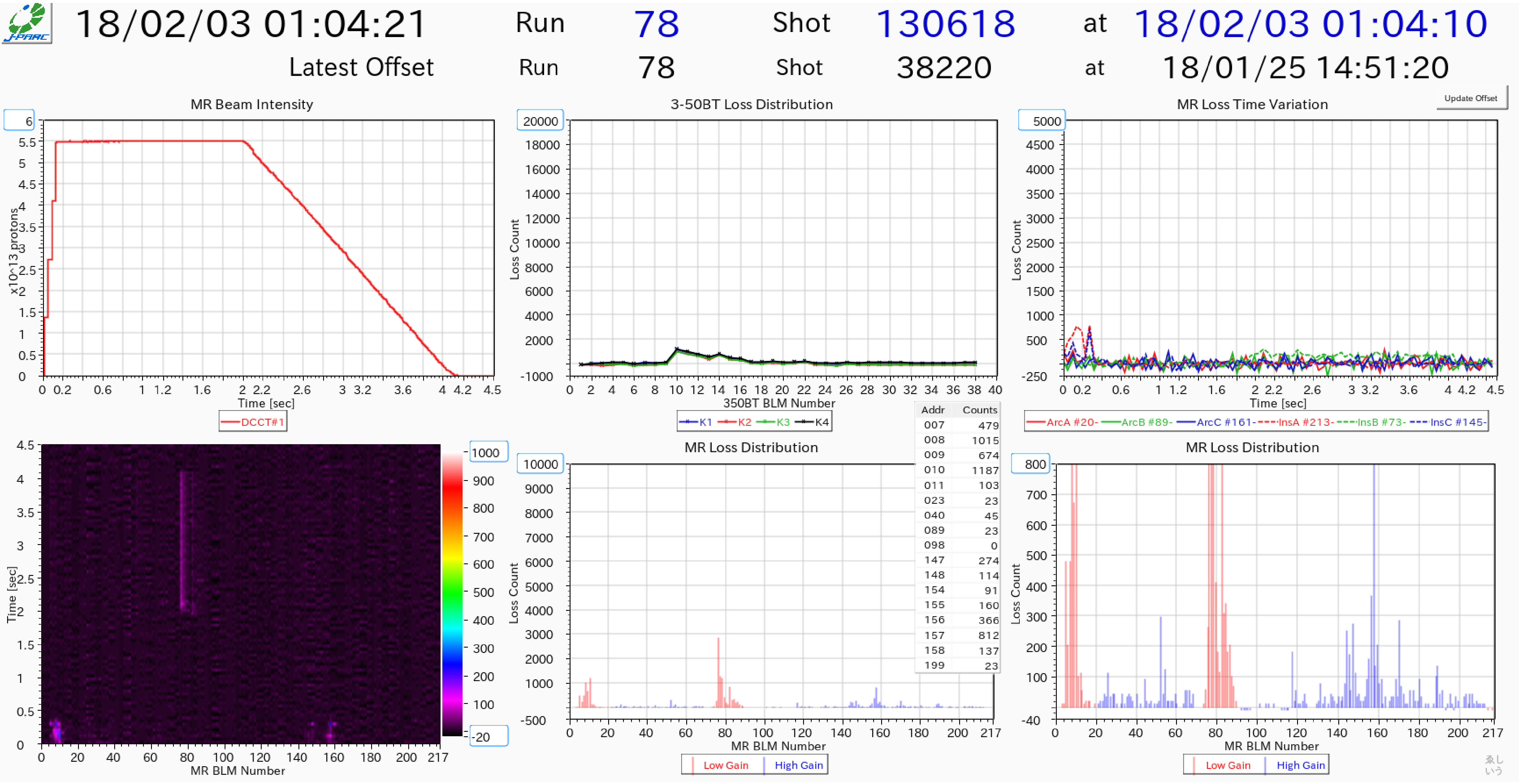




Addr	Counts
007	935
008	1676
009	1016
010	2363
011	137
023	172
040	91
089	103
098	0
147	343
148	149
154	148
155	251
156	491
157	1053
158	182
199	69



Next shot (to check if the machine comes back to the normal condition)

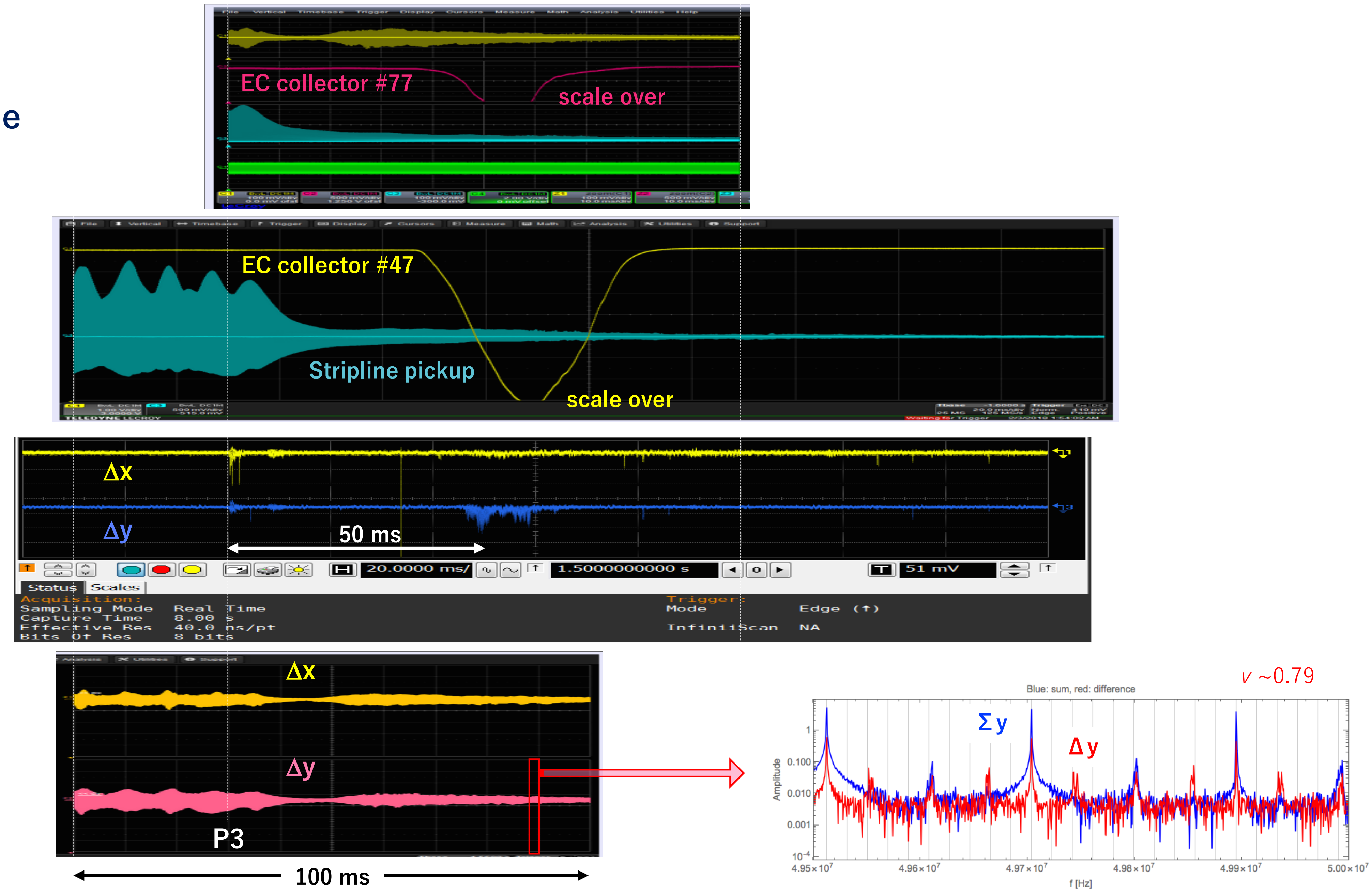


Addr	Counts
007	479
008	1015
009	674
010	1187
011	103
023	23
040	45
089	23
098	0
147	274
148	114
154	91
155	160
156	366
157	812
158	137
199	23

EC signal and Δx, Δy signals

Shot *130617* at *18/02/03 00:58:35*
50.69 kW 18/02/03 01:02:47

All relevant signals are lined up in the same time scale



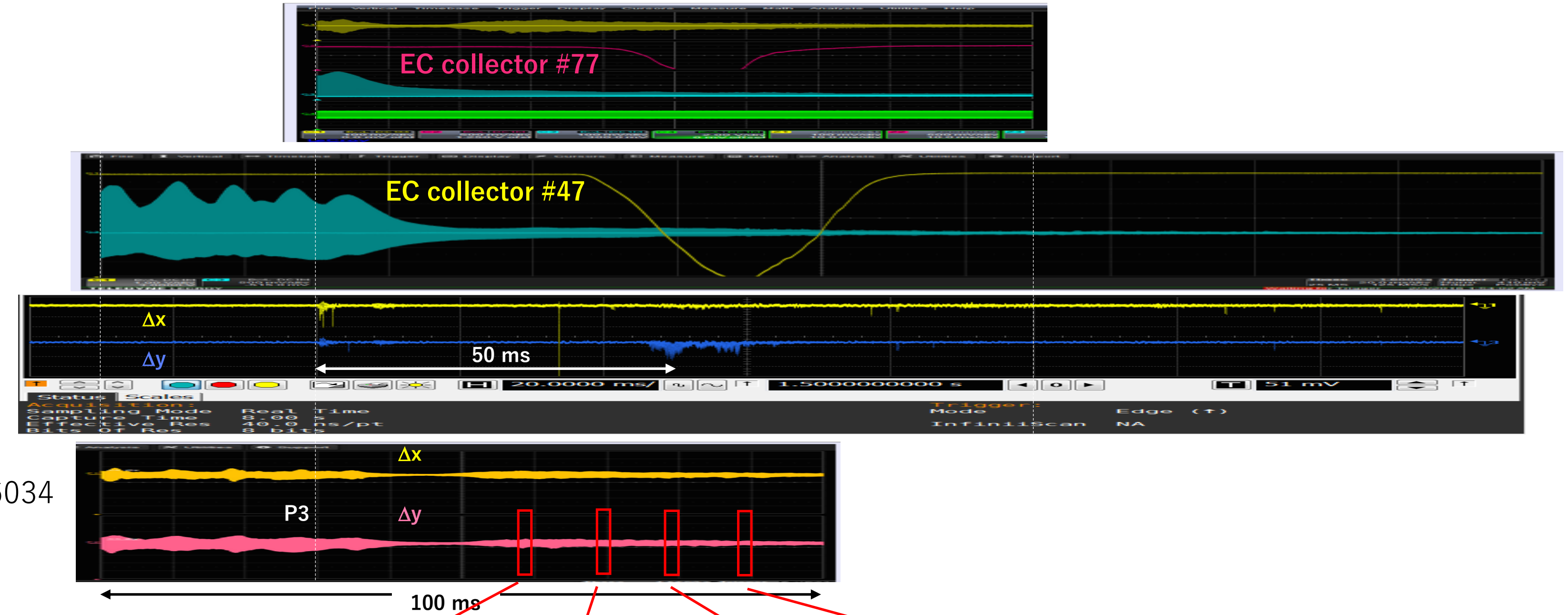
EC signal and Δx, Δy signals

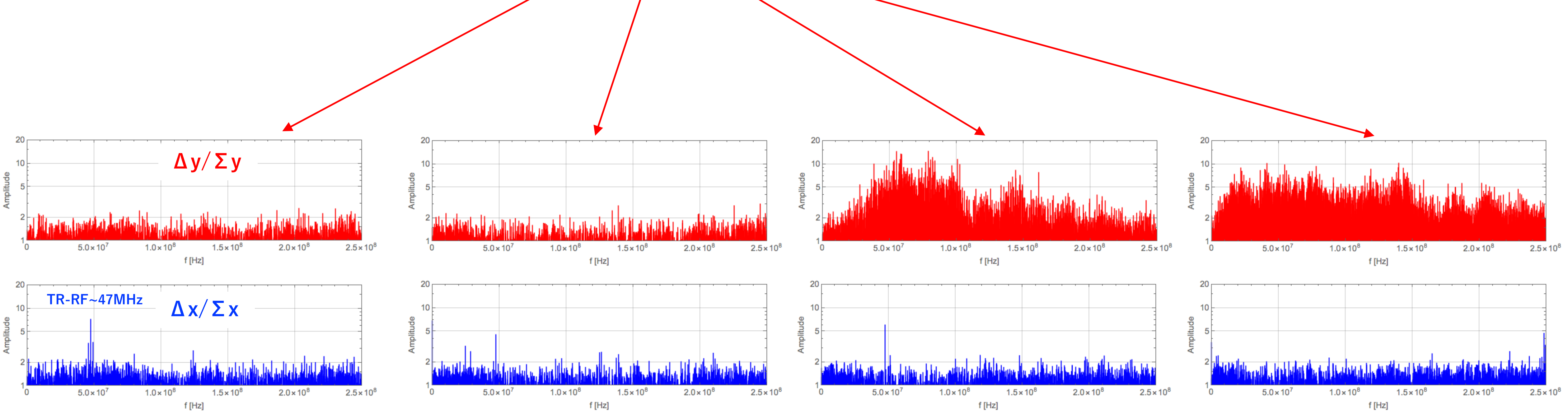
Shot *130617* at *18/02/03 00:58:35*
50.69 kW 18/02/03 01:02:47

Hor. / Ver. oscillation

frequency analysis

Oscilloscope: LeCroy HDO6034
500 MS/s, LPF=200MHz





Vacuum Pressure