Electron cloud instability in J-PARC experimental observations

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J-PARC / KEK

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Acknowledgements

- SX study

  R. Muto, Y. Arakaki, T. Kimura, S. Murasugi, M. Okada, K. Okamura, T. Shimogawa, Y. Shirakabe, M. Tomizawa, E. Yanaoka, A. Matsumura

- Machine tuning

  Y. Sato, S, Igarashi, Y. Sugiyama, M. Yoshii, C. Ohmori, F. Tamura, K. Hasegawa, K. Hara et al.,

- Coupling impedance studies

  A. Kobayashi, T. Nakamura, M. Yoshii, C. Ohmori, K. Hasegawa, Y. Sugiyama, T. Shibata, K. Ishii, Y. Shobuda, F. Tamura, K. Hanamura, T. Kawachi

- E-cloud simulation

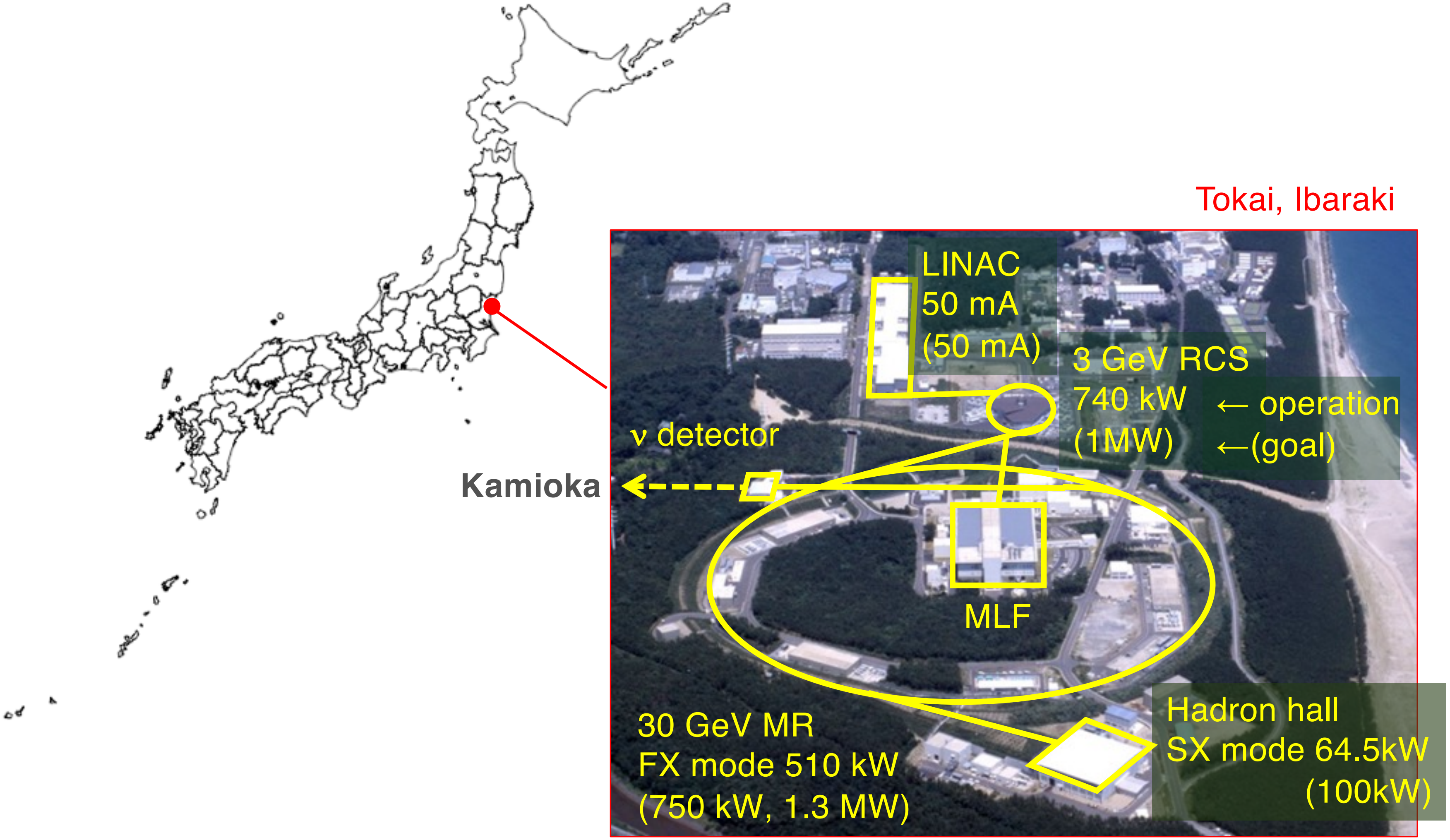
  K. Ohmi, B. Yee-Rendon, M. Tomizawa

- Test bench of concentric cylinder

  M. Okada

and J-PARC staff

Japan Proton Accelerator Research Complex



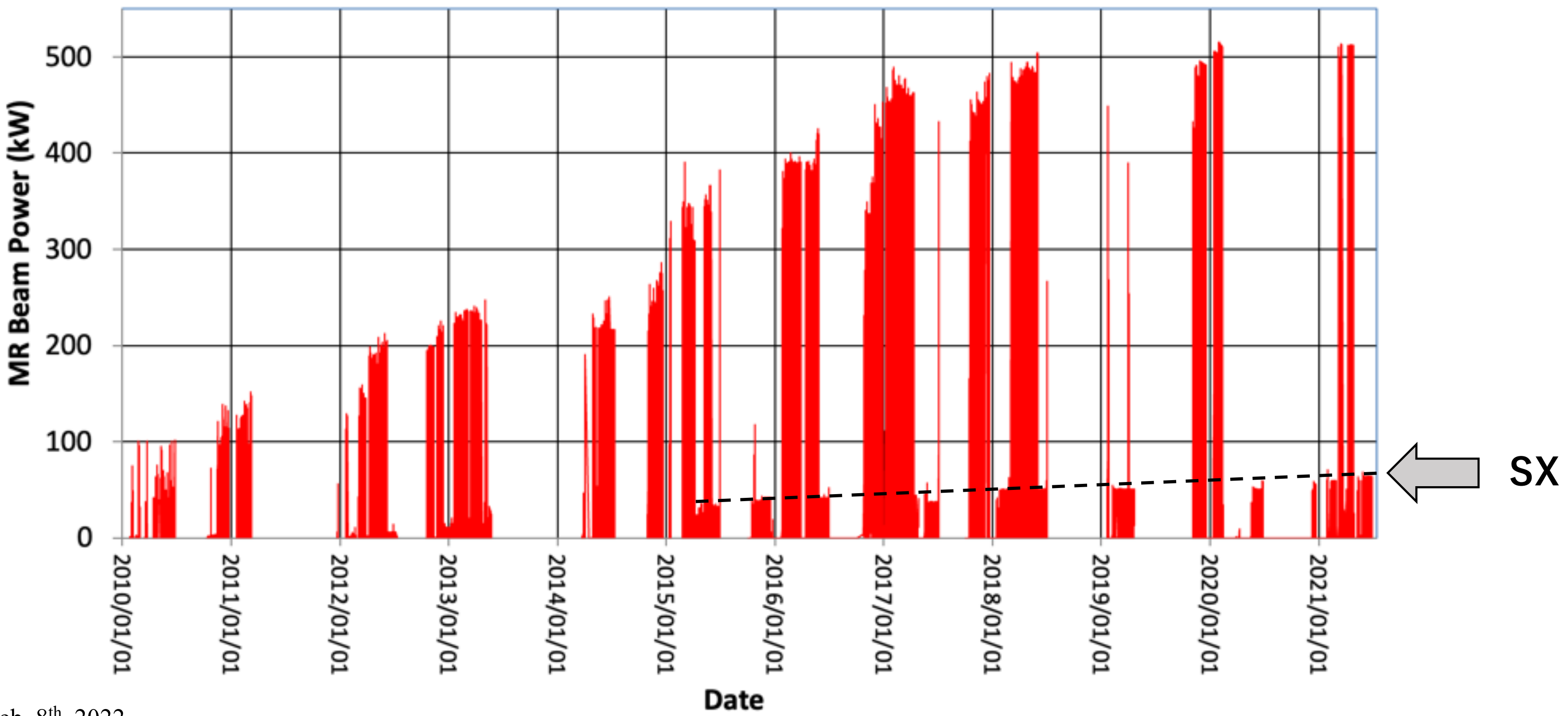
MR Beam Power

FX operation (Mar. and Apr. 2021)

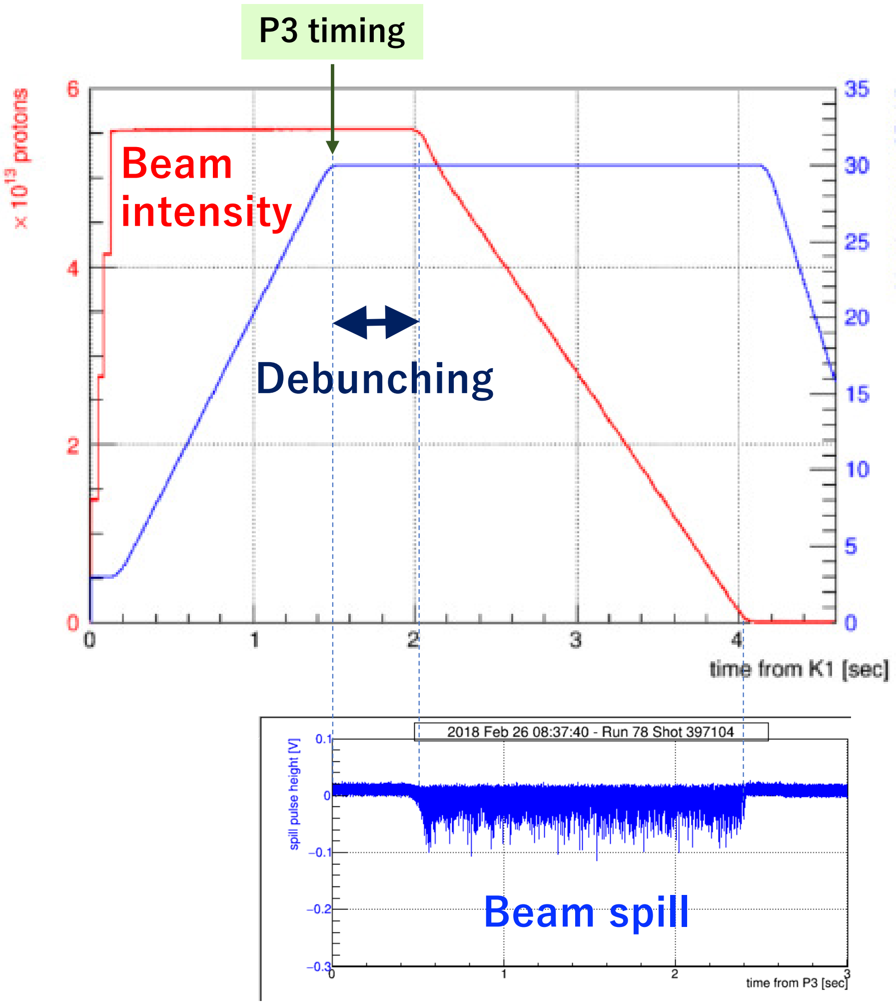
- Beam power (max.) : **510 kW**
  (2.63E+14 ppp)

- Run 87 (May 10 – June 29)
- **SX 30 GeV Extraction**
  - Beam Power： **64.5 kW** (6.98E+13 ppp)
  - Extraction Efficiency： 99.5 %
  - Spill Duty : 50 – 55%
- **SX 8 GeV Extraction (May 20 – 25)**
  - Beam Power： **1.8 kW** (7.30E+12 ppp)
  - Extraction Efficiency : 99.1% (It was 97.3 % in 2018)
  - Spill Duty : 55% (It was 16% in 2018)

As of June 29, 2021

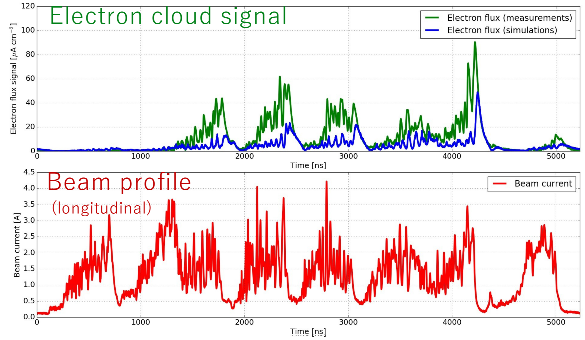


Current understanding of the phenomenon



Longitudinal microwave instability produces microstructure of the longitudinal distribution

During debunching process at the beginning of the slow extraction, an electron cloud grows up



Bruce Yee-Rendon et al.,, PASJ2017, THOM07, p.19

Vacuum pressure rise

Instability

Beam loss

Limiting the SX beam power

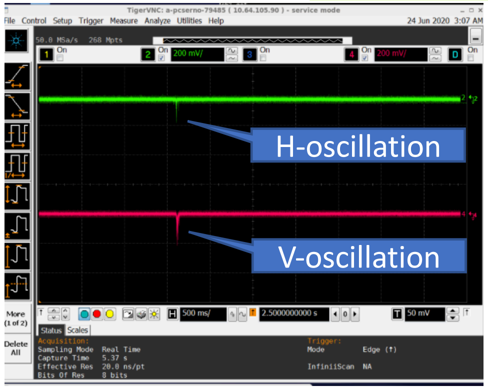
Foreseen similar phenomena at the FX mode during RF gymnastics

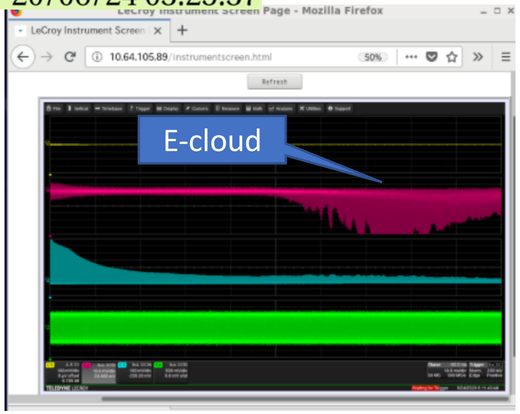
Encountered Beam Instability at debunch timing

Currently Limiting SX beam intensity (large beam loss for SX)

Abort destination, 60kW debunch , RF offset 65deg

Shot 311512 at 20/06/24 03:24:49
60.06 kW 20/06/24 03:25:37

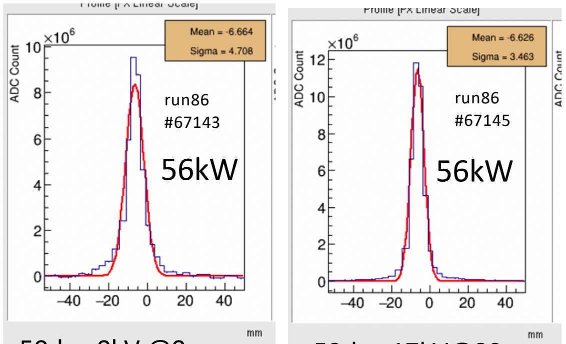




H, V beam size growth

56kW

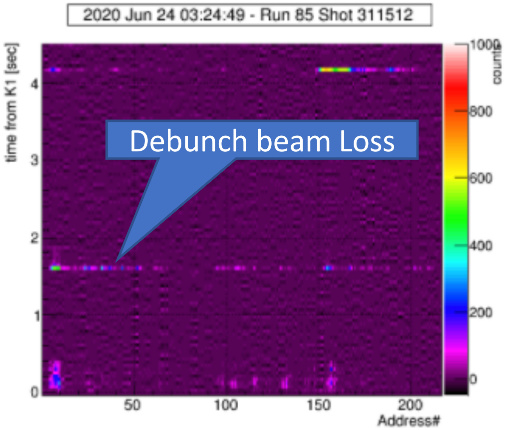
w/Insta. w/o Insta.



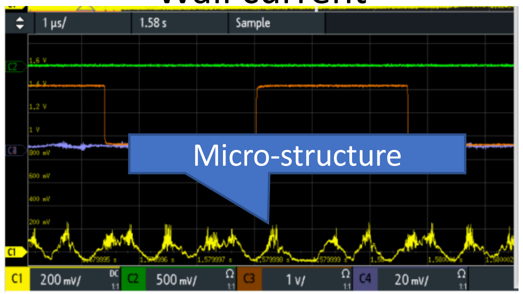
50deg 0kV @0ms 53deg 17kV@80ms

Beam power
50 kW @ 2018
⬇
now 64.5 kW

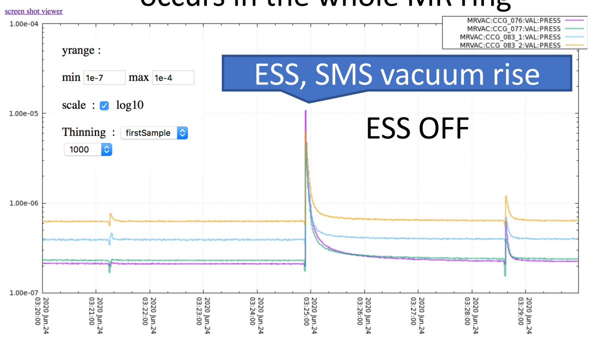
EC is frequently accompanied by transvers instabilities
⬇
Limiting factor of power upgrade



Wall current



occurs in the whole MR ring



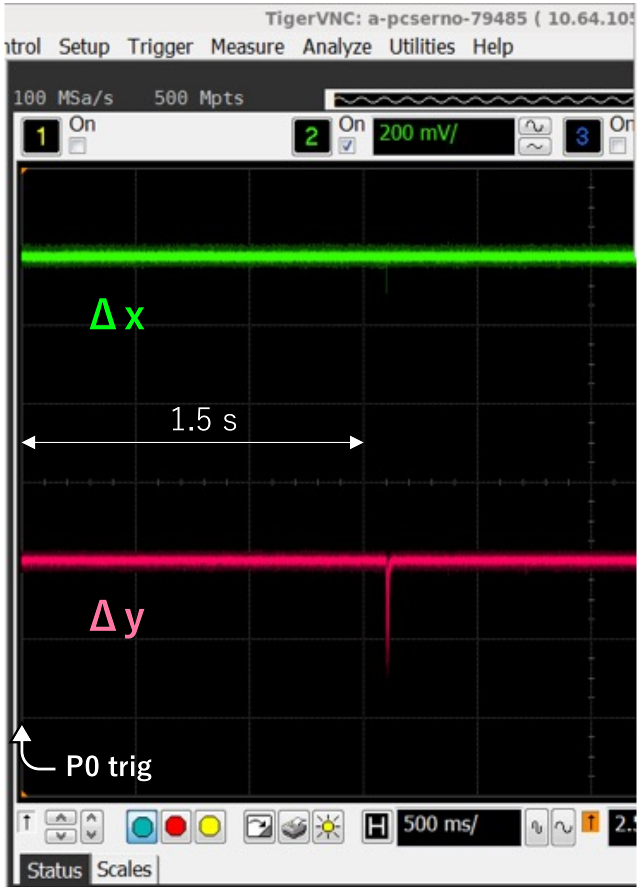
seen at debunch end timing (～60ms from start)

M. Tomizawa,
ICFA Mini-Workshop
on Slow Extraction, 2022

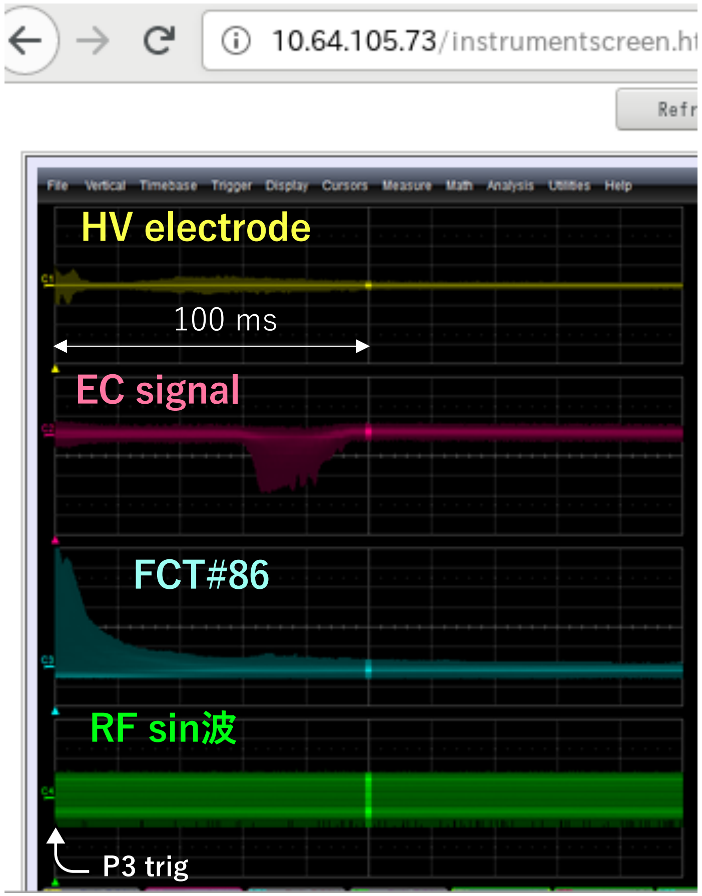
Beam monitor signals

2020. 6. 5　11:05:03　shot#76096

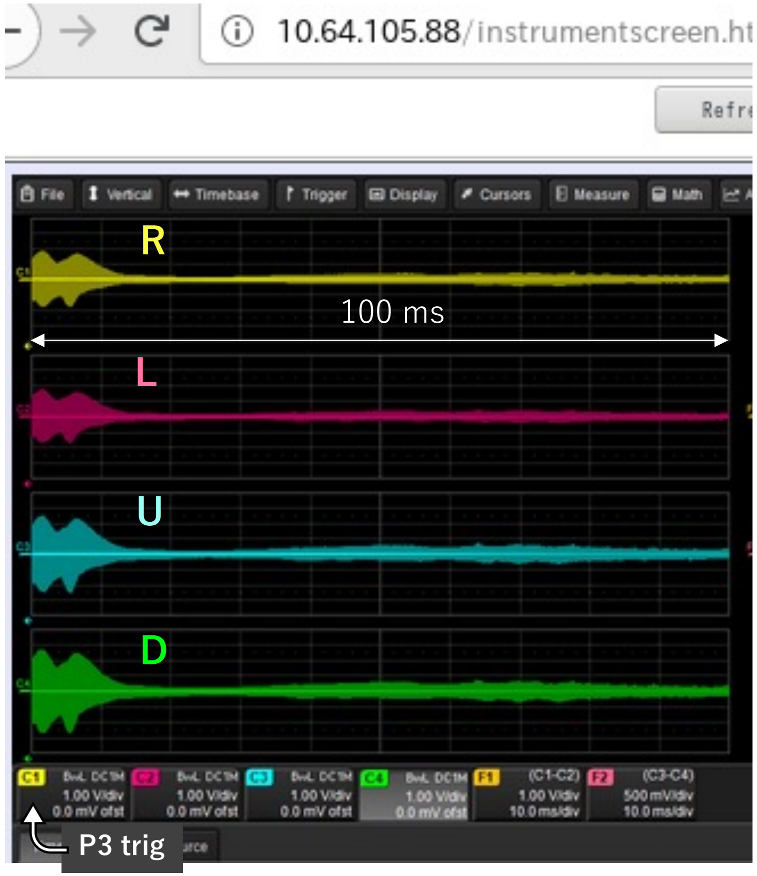
Diode detection signal of a BPM



EC detector @#77

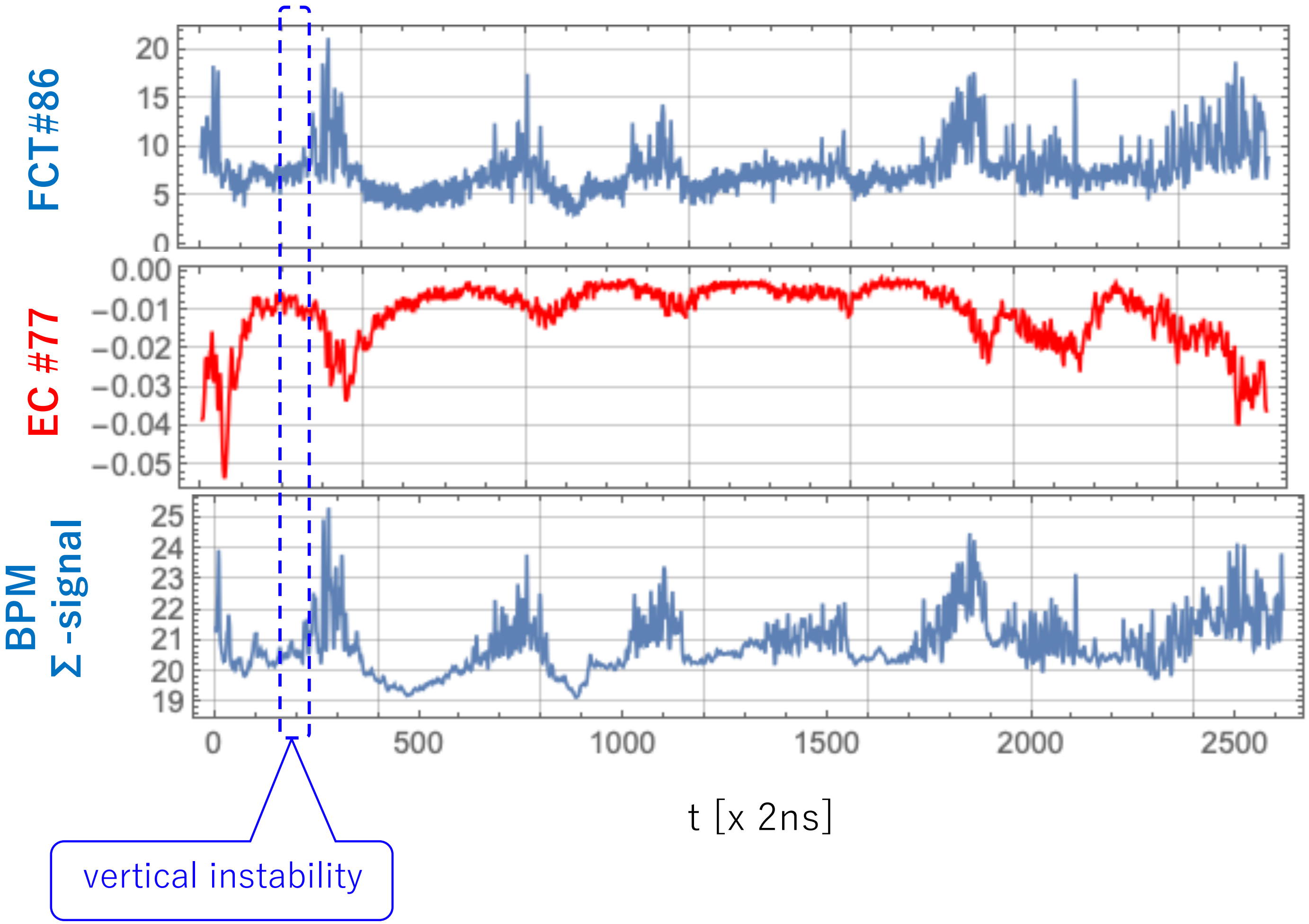


Tapered coupler BPM @#15



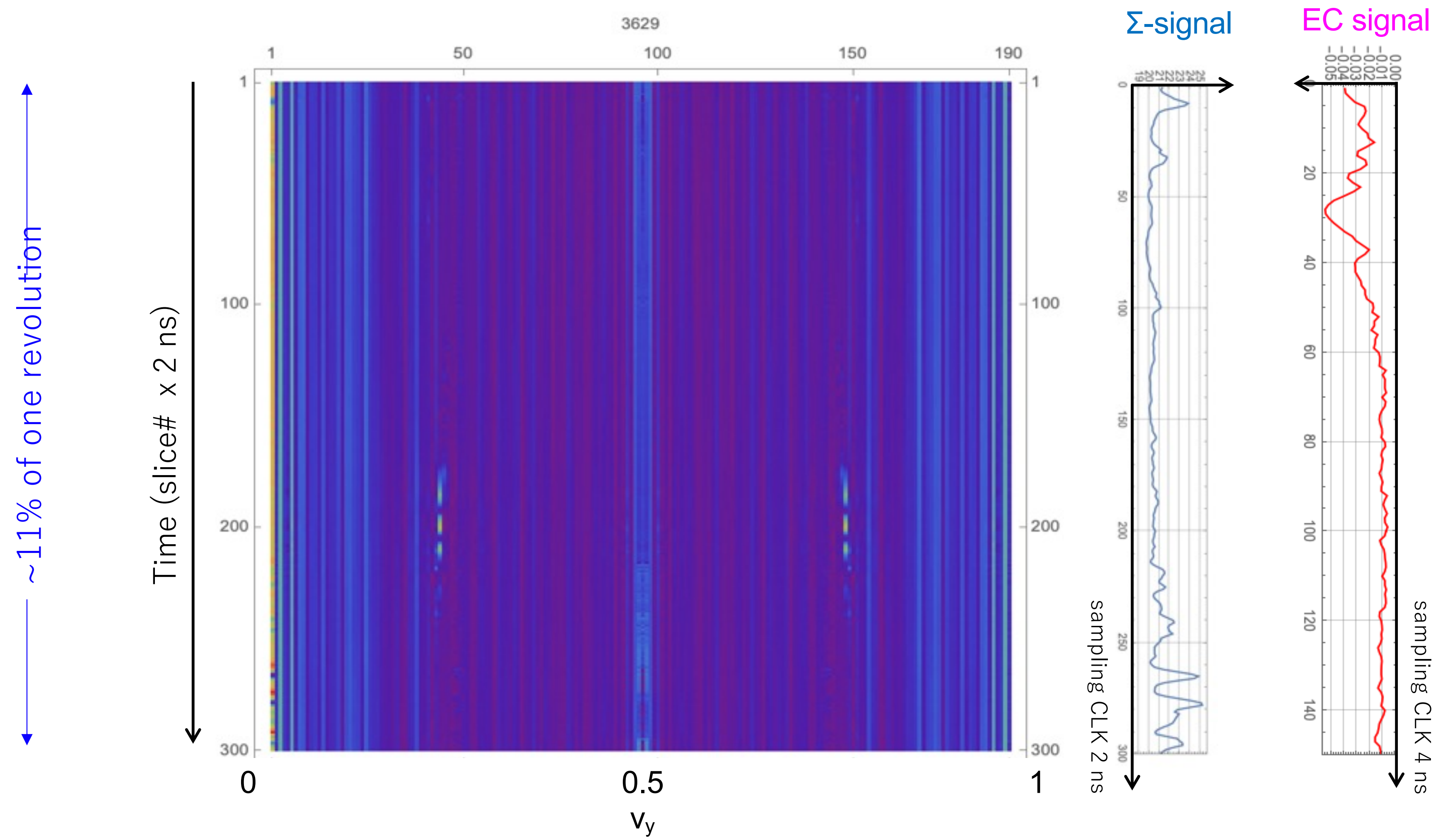
2020. 6. 5 11:10:21 shot #76096
Beam power = 51.0 kW

3629-th turn from P3+50ms (around P3+69ms)



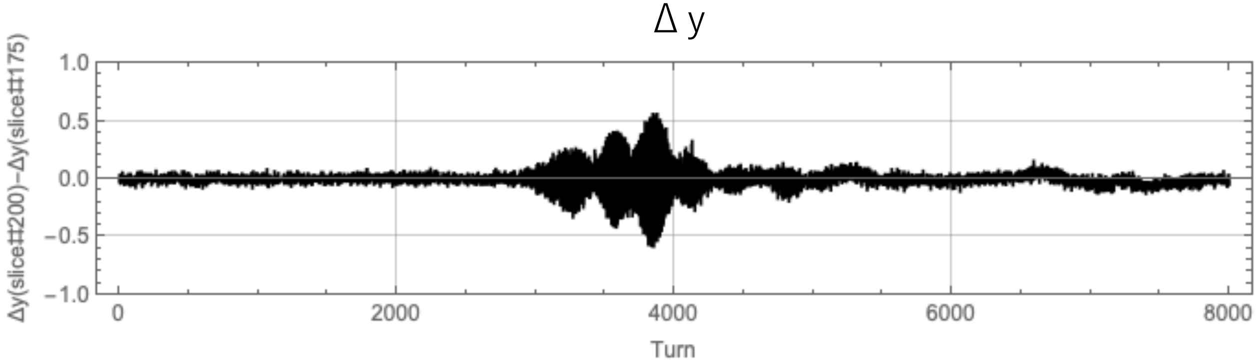
2020. 6. 5 11:10:21   shot#76096

Δy : 190 turn Fourier transform at each slice @ around P3+69ms
Oscillation occurs very local places, not necessarily at the beam density peak nor EC peak.



2020. 6. 5 11:10:21   shot#76096

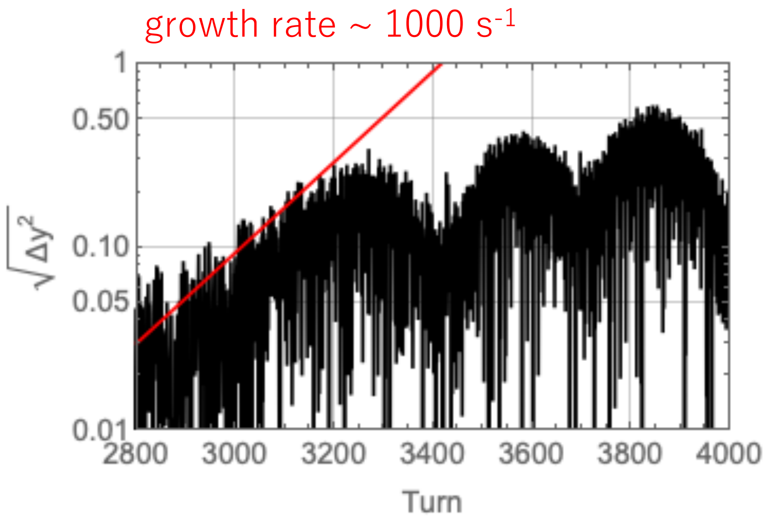
Growth of local oscillation

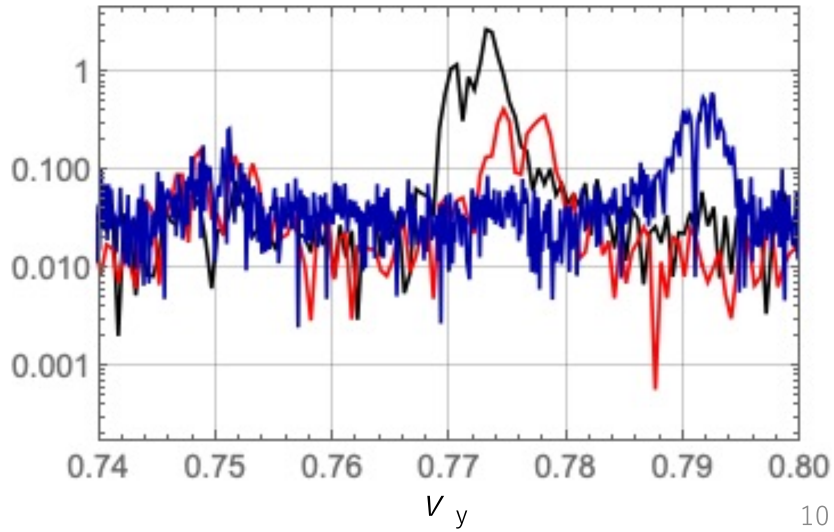


Black: 3001th - 4000th turn, #200-#175

Red: 4501th - 5500th turn , #200-#175

Blue: 1th - 8000th turn , #650-#600

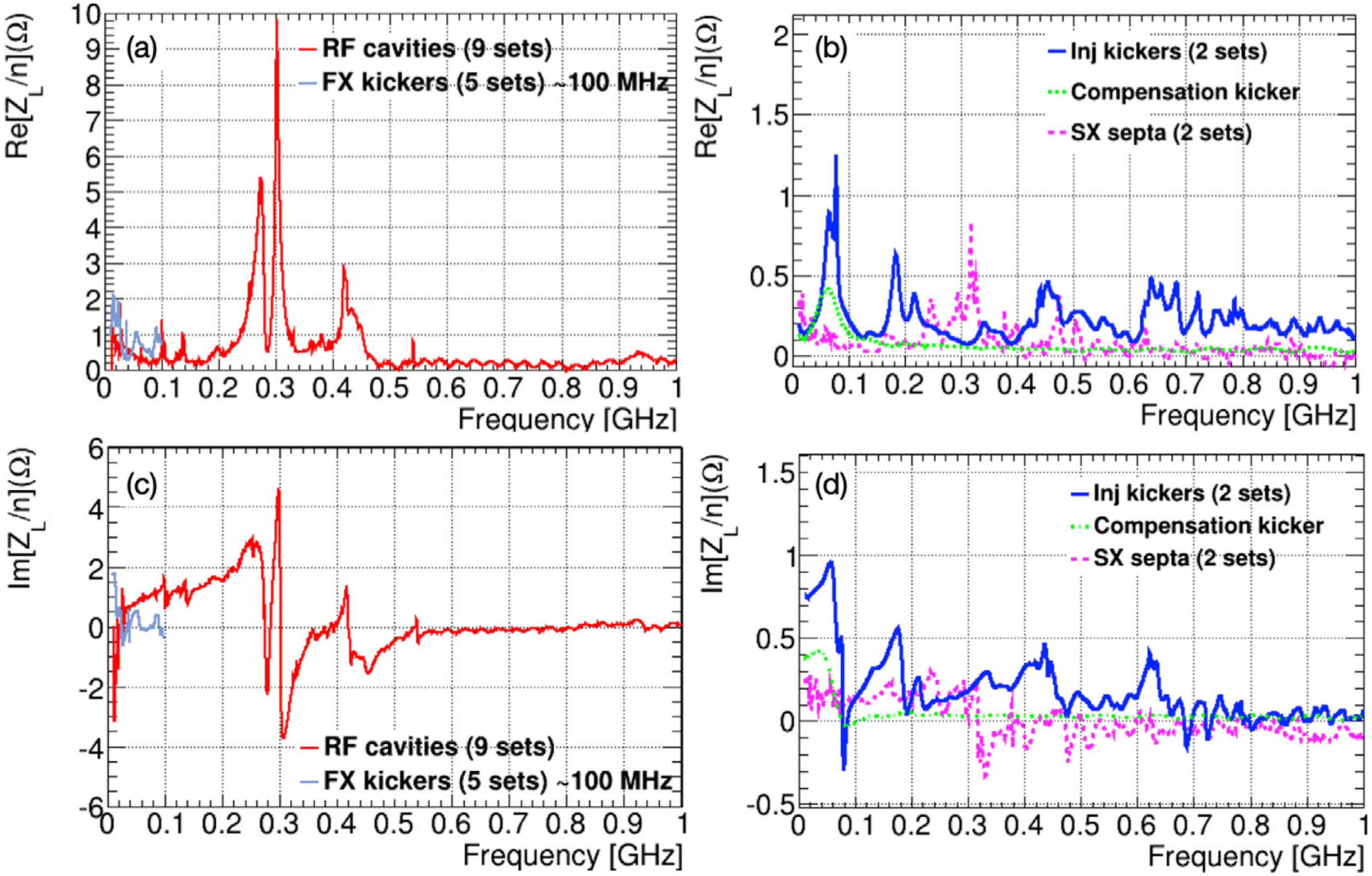




Countermeasures against electron clouds

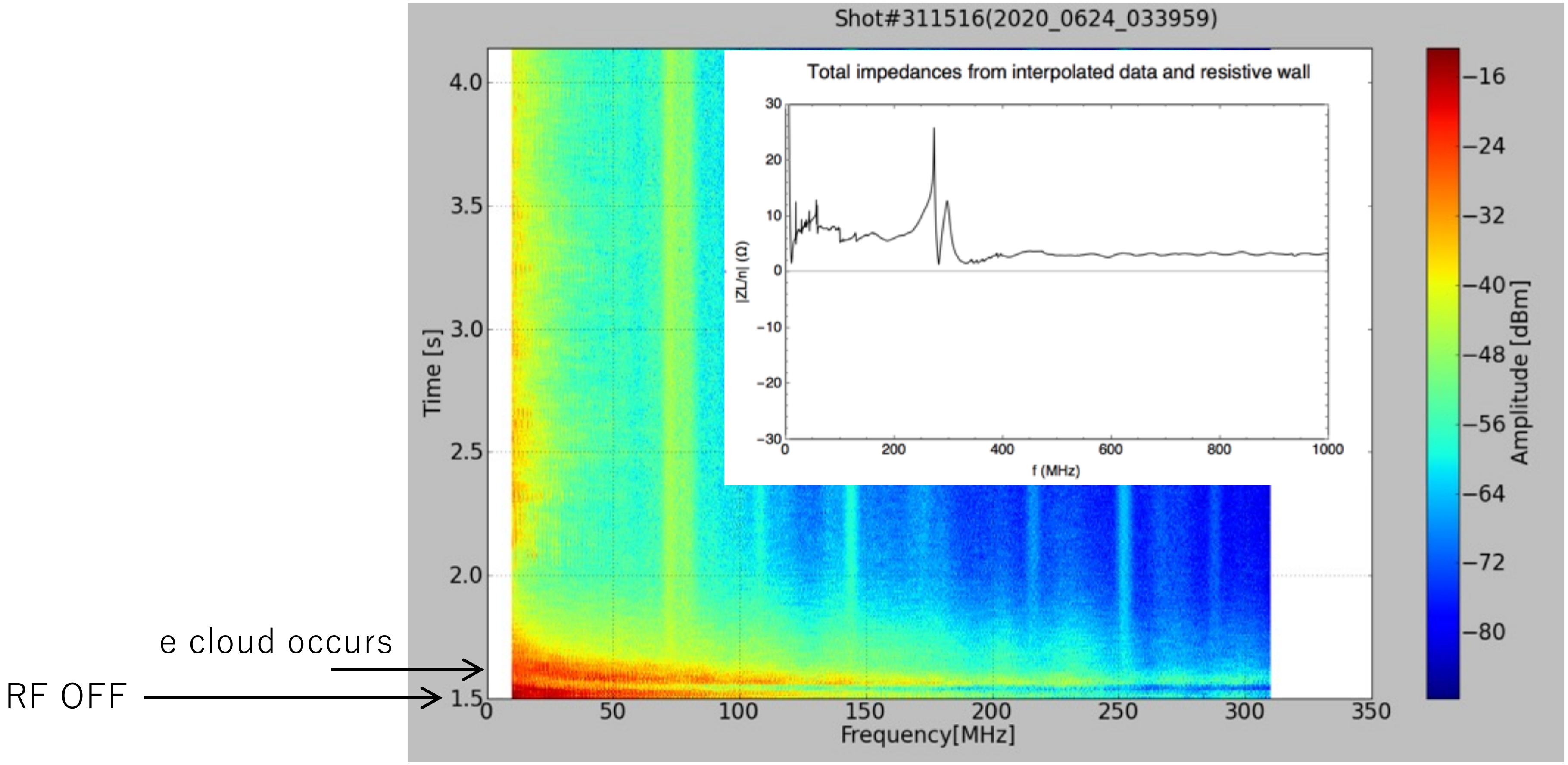
- ✓ Suppress the longitudinal microwave instability
  - Evaluate and reduce longitudinal impedances
    - ✓ Evaluation of longitudinal impedances
    - ✓ Reduction of Z_L of new septa
      - ➢ inserting SiC-loaded flanges
  - Blowup the longitudinal emittance
    - ✓ Phase-offset injection to the RF buckets
    - ✓ Step reduction of the RF voltage
    - ✓ Designing a new VHF cavity

Longitudinal impedance of the J-PARC MR



A. Kobayashi et al., NIM A1031 (2022) 166515

Spectrogram plot of the wall current monitor



courtesy of
Y. Sugiyama

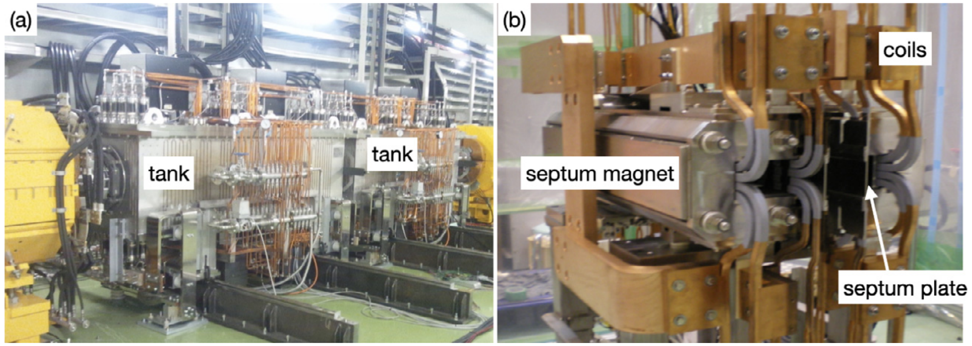
Microstructure in the longitudinal distribution may relate with the longitudinal impedance

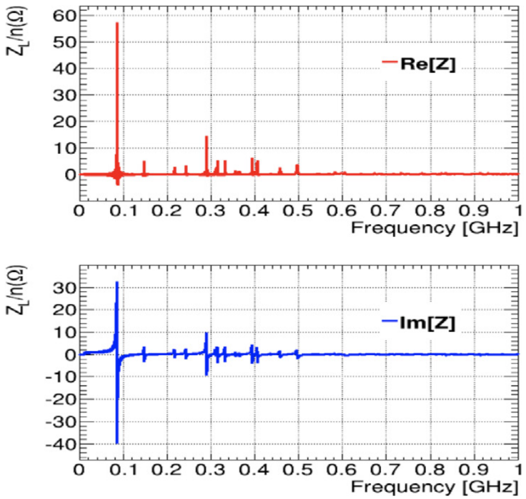
Under study with simulation → Tomizawa-san's talk

Impedance reduction

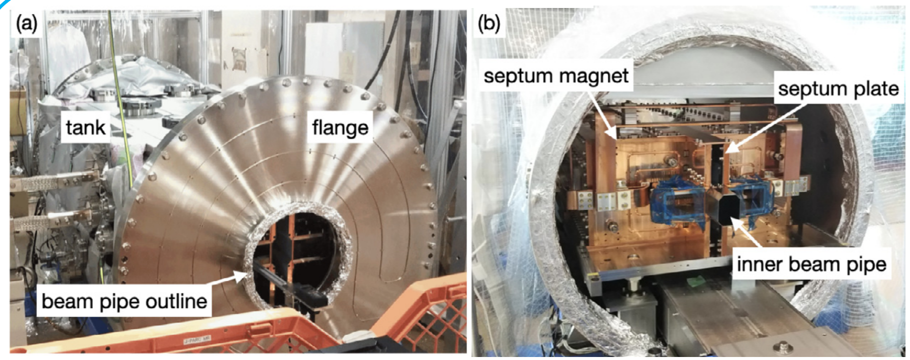
FX in vacuum septa, replaced in 2021 summer
a SiC-loaded flange partially inserted in 2022 summer and fully inserted in 2023 summer

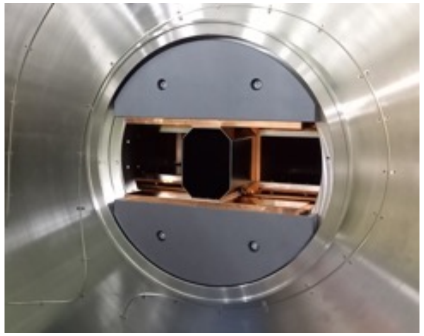
Before 2021





After 2022





SiC-loaded flange is set

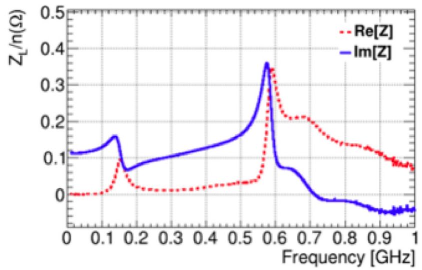


Fig. 12. Longitudinal impedance of the septa with copper plates and SiC added for impedance reduction, calculated in the CST studio suite.

A. Kobayashi et al., NIM A1031 (2022) 166515

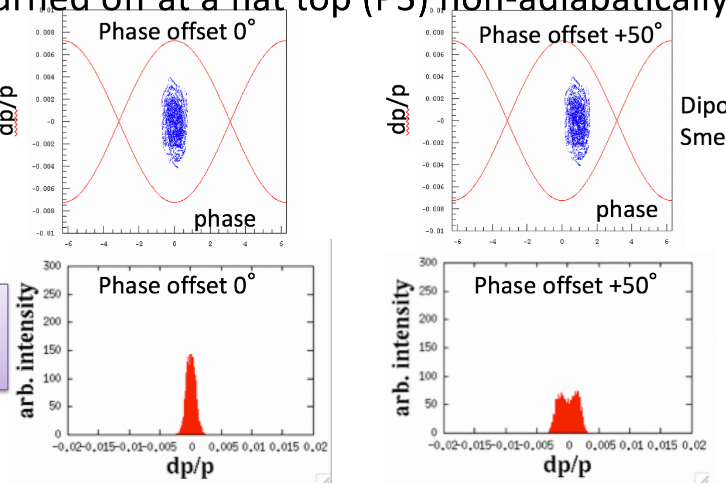
Current Mitigations of Beam Instability

- Beam injected to MR RF buckets with a phase offset (effective up to 50 kW)

  256kV RF turned off at a flat top (P3) non-adiabatically

160kV Injection

256kV Flat top Before debunch



Dipole oscillation Smear

- 2-step (voltage) debunch in combination with the phase offset injection

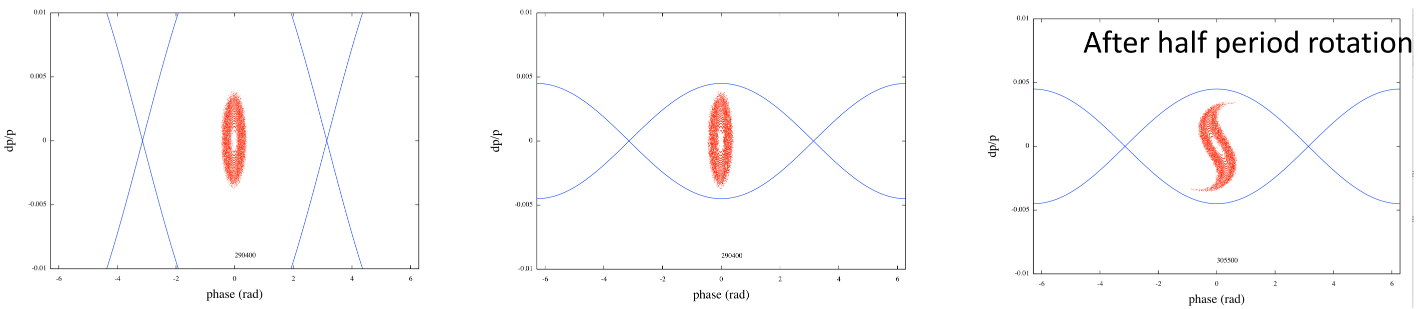
  Newly introduced from Dec., 2020

  ramped up the beam power for the user run from 50kW to 64.6 kW.

P3 256kV

P3 17kV (non-adiabatically)

P3+80ms 17 -> 0 kV



M. Tomizawa, ICFA Mini-Workshop on Slow Extraction, 2022

VHF RF cavity for emittance blowup

Table I. Parameters of the simulation for the longitudinal emittance blow-up.

f_b [MHz]	117.95
V_b [kV]	100
$\Delta\phi_m$ [rad]	π
f_m	$16 \times f_s$
Harmonic number of fundamental RF	9
Number of bunches	8
Particles per bunch	2×10^{13}
Macroparticles per bunch	1×10^{5}
Slices per bucket	100
σ_t for every bunch [ns]	30
VHF operation period from K1 [s]	0 - 0.13

f_s: synchrotron frequency
$f_b/f_{rev} = 635$ (f_{rev}: beam revolution frequency)

Y. Morita et al., JPS Conf. Proc. **33**, 011032 (2021)

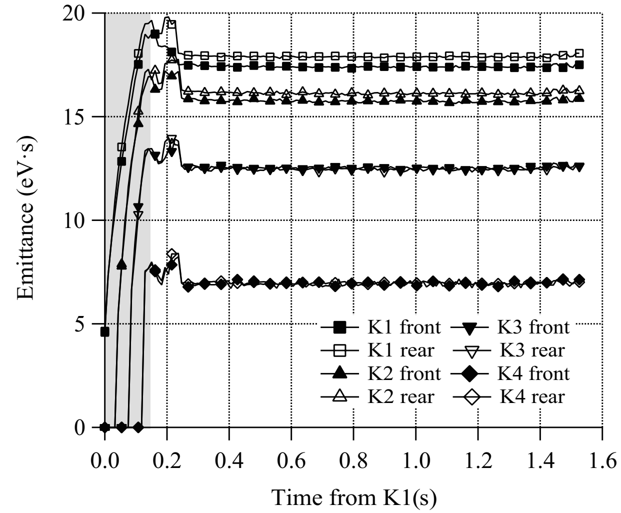
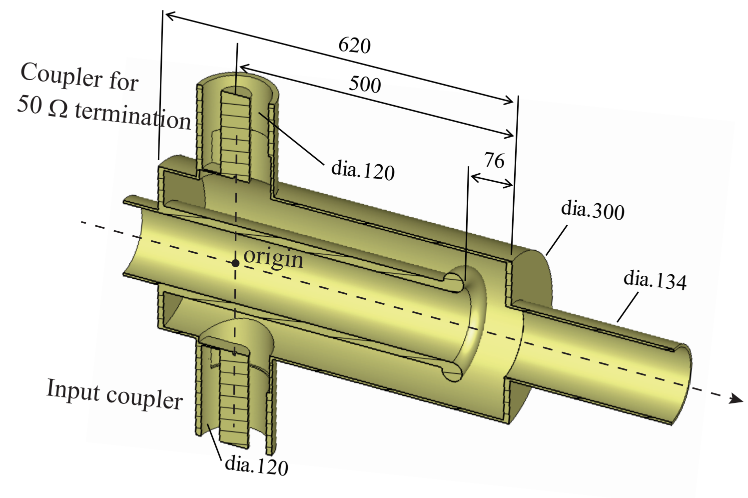


Fig. 1. Simulated longitudinal emittance blow-up.

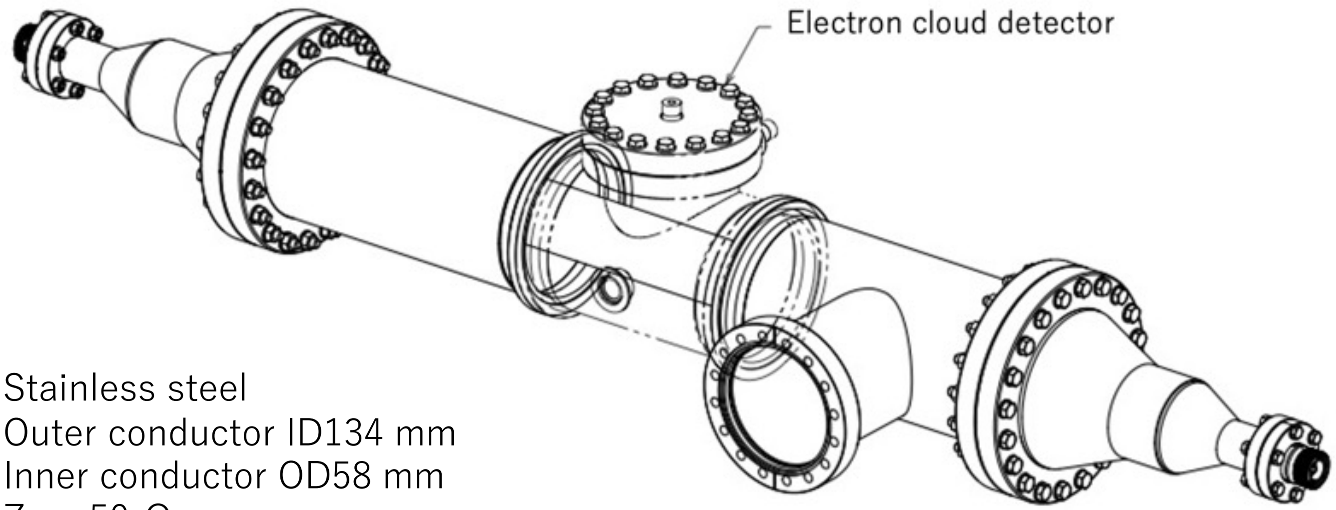


Test Bench of multipactors

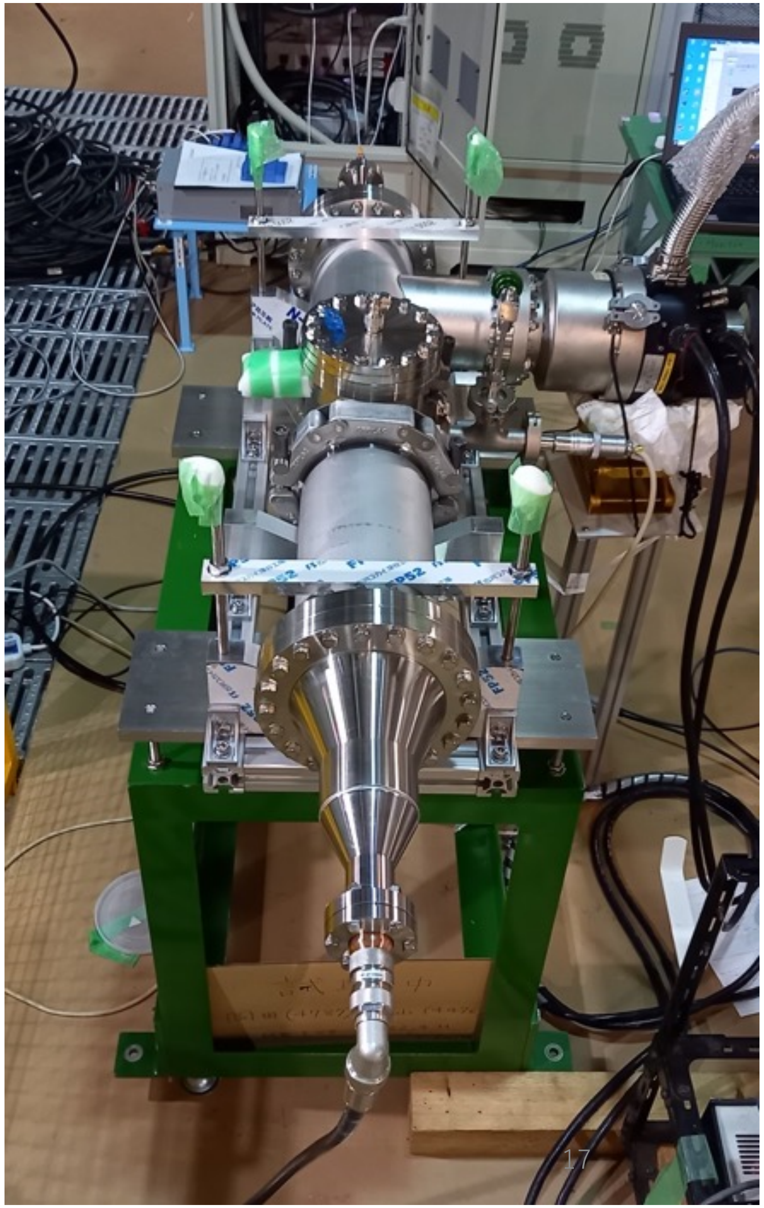
Goal

- Understanding multipacting in concentric cylinder
- Evaluation of the electron cloud detector
- Evaluation of surface coatings (amorphous carbon)

Setup



Stainless steel
Outer conductor ID134 mm
Inner conductor OD58 mm
$Z_C = 50\ \Omega$



Simulation by CST studio

Preliminary

f_{RF} = 50 MHz

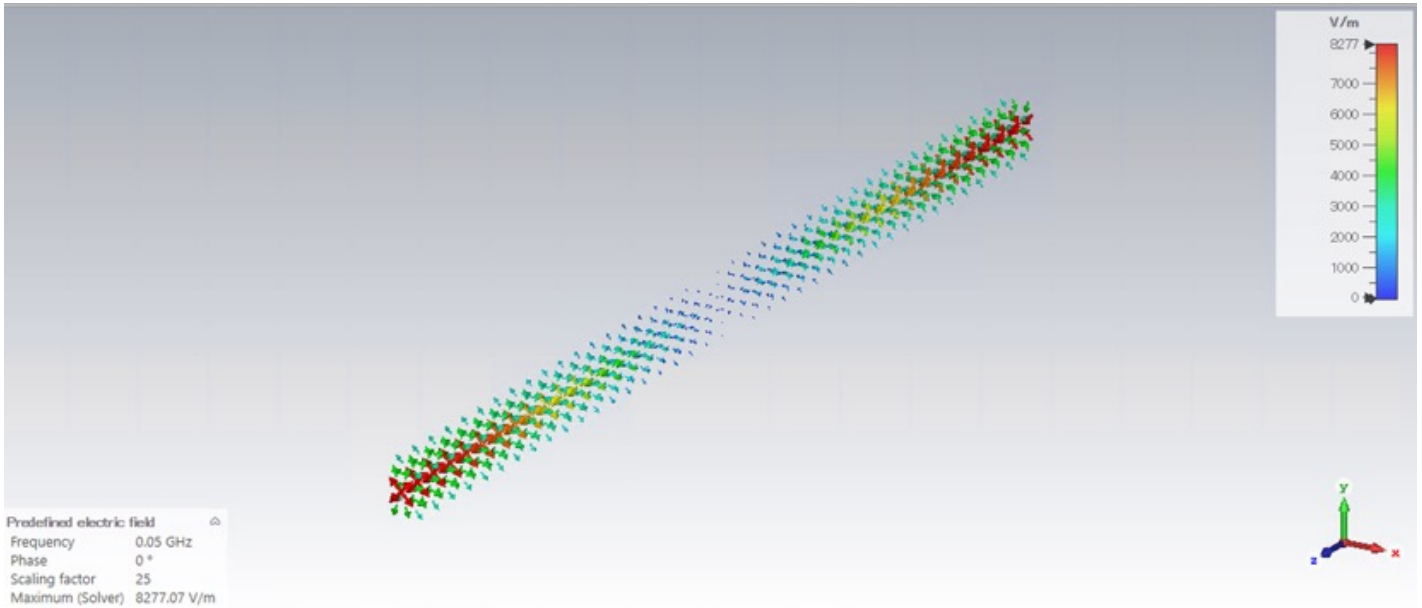
V_{RF} = 200 V

E_{max} = 384 eV, δ_{max} = 1.32

Vaughan model

Evolution of the Electric field

phase = 0 deg



length = 3 m
Concentric cylinder with PEC

Simulation by CST studio

Preliminary

f_{RF} = 50 MHz

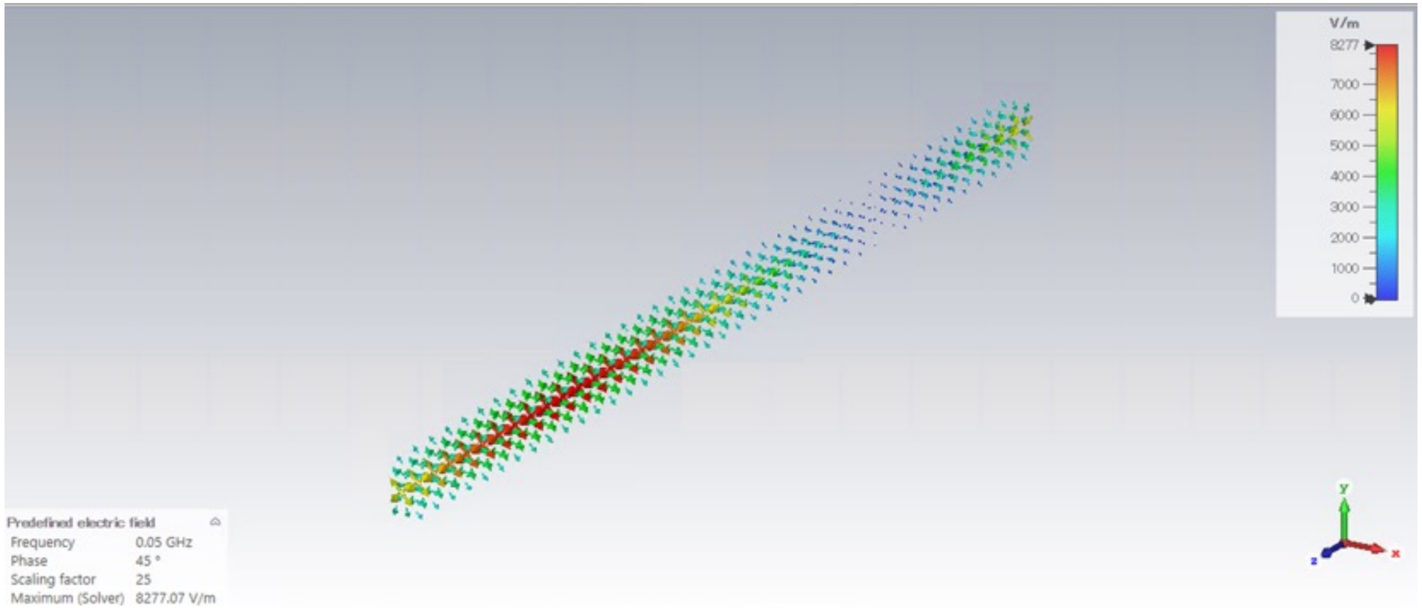
V_{RF} = 200 V

E_{max} = 384 eV, δ_{max} = 1.32

Vaughan model

Evolution of the Electric field

phase = 45 deg



length = 3 m
Concentric cylinder with PEC

Simulation by CST studio

Preliminary

f_{RF} = 50 MHz

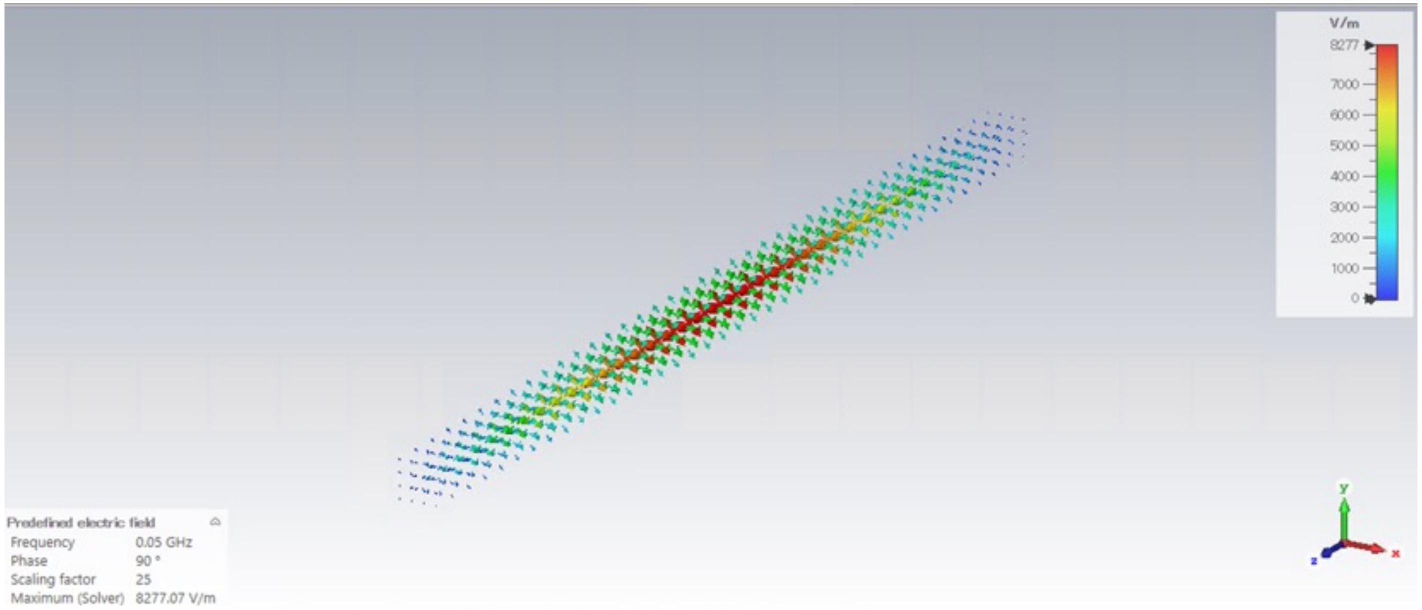
V_{RF} = 200 V

E_{max} = 384 eV, δ_{max} = 1.32

Vaughan model

Evolution of the Electric field

phase = 90 deg



length = 3 m
Concentric cylinder with PEC

Simulation by CST studio

Preliminary

f_{RF} = 50 MHz

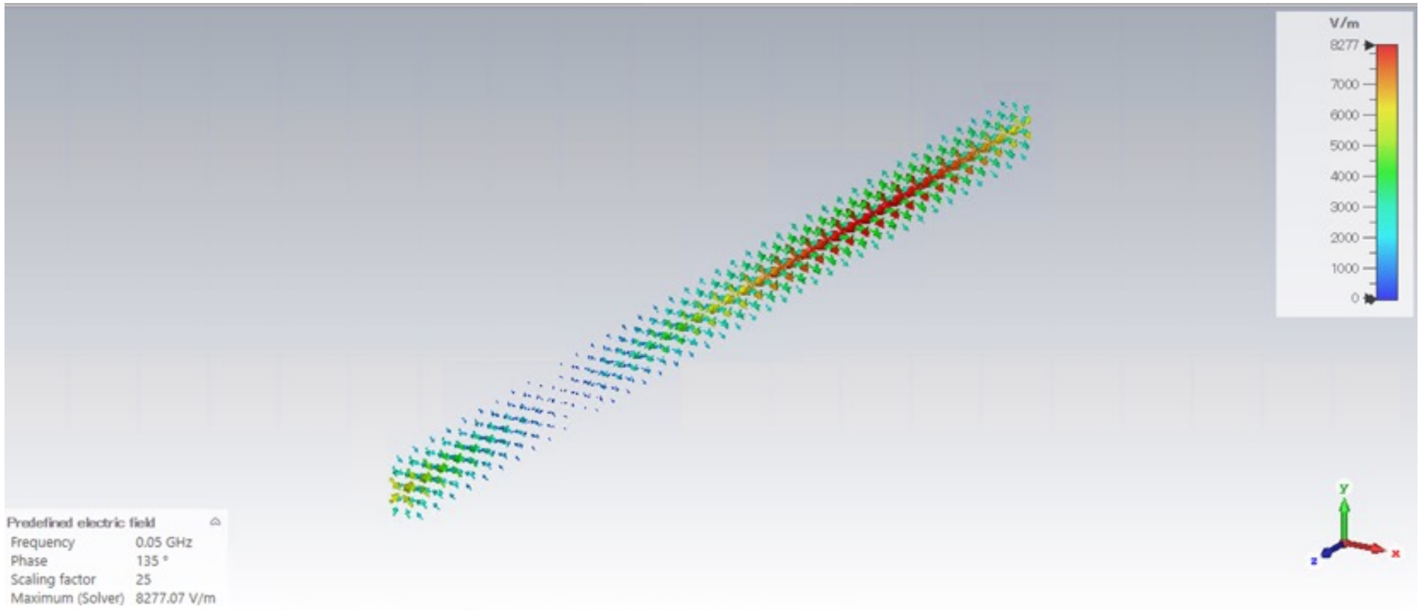
V_{RF} = 200 V

E_{max} = 384 eV, δ_{max} = 1.32

Vaughan model

Evolution of the Electric field

phase = 135 deg



length = 3 m
Concentric cylinder with PEC

Simulation by CST studio

Preliminary

f_{RF} = 50 MHz

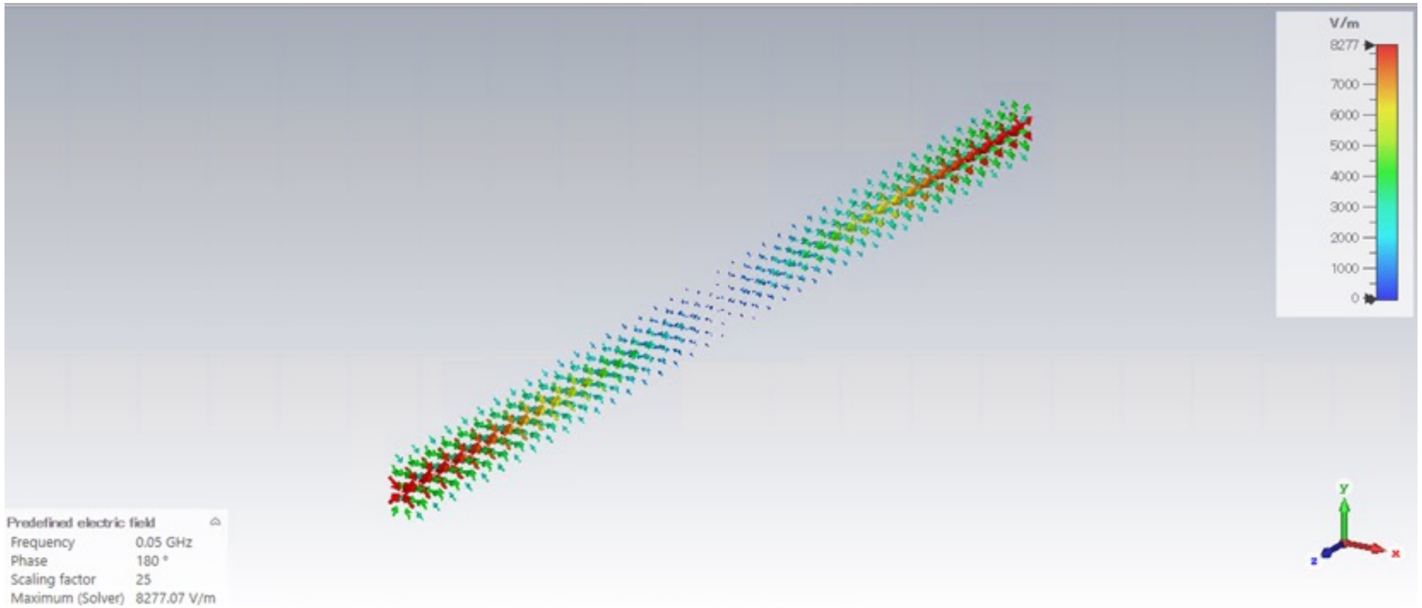
V_{RF} = 200 V

E_{max} = 384 eV, δ_{max} = 1.32

Vaughan model

Evolution of the Electric field

phase = 180 deg



length = 3 m

Concentric cylinder with PEC

Simulation by CST studio

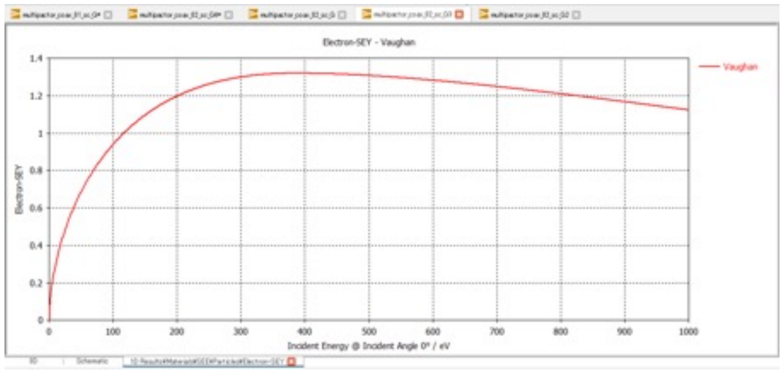
Preliminary

f_{RF} = 50 MHz

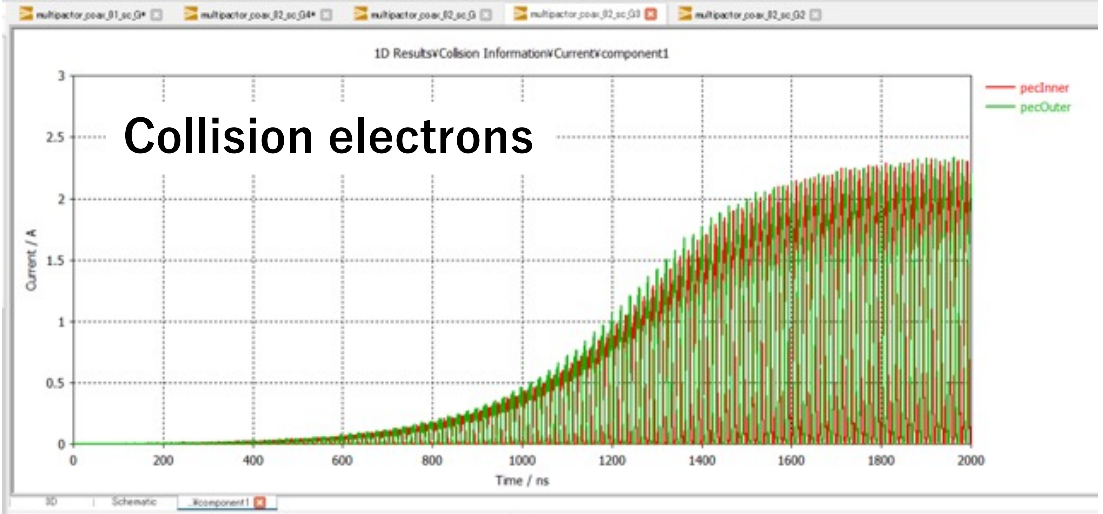
V_{RF} = 200 V

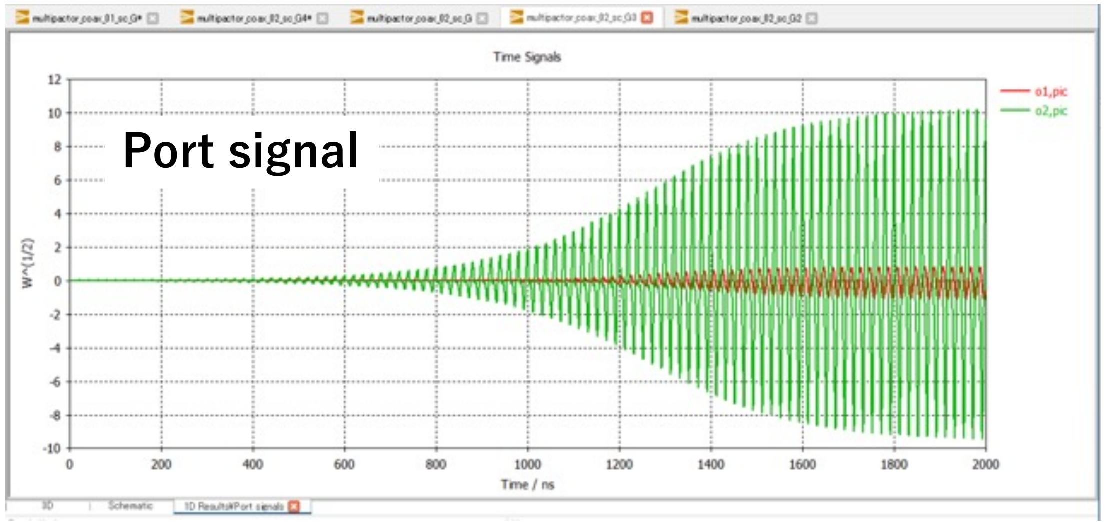
E_{max} = 384 eV, δ_{max} = 1.32

Vaughan model

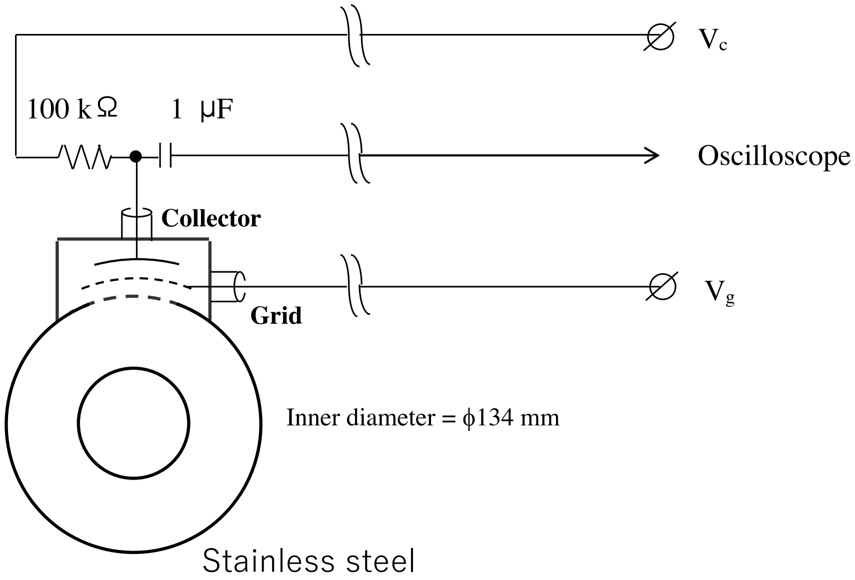


Space Charge ON

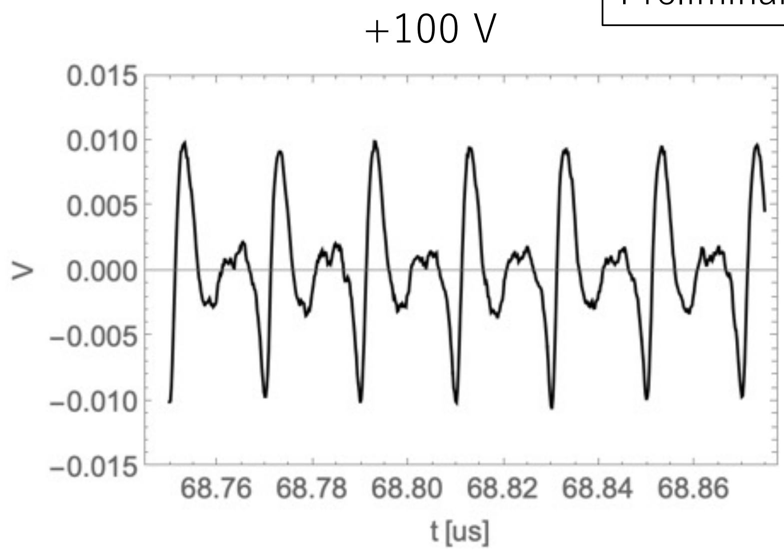




Measurements



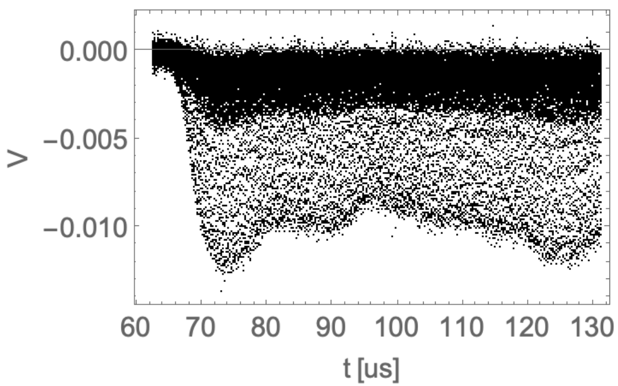
Preliminary

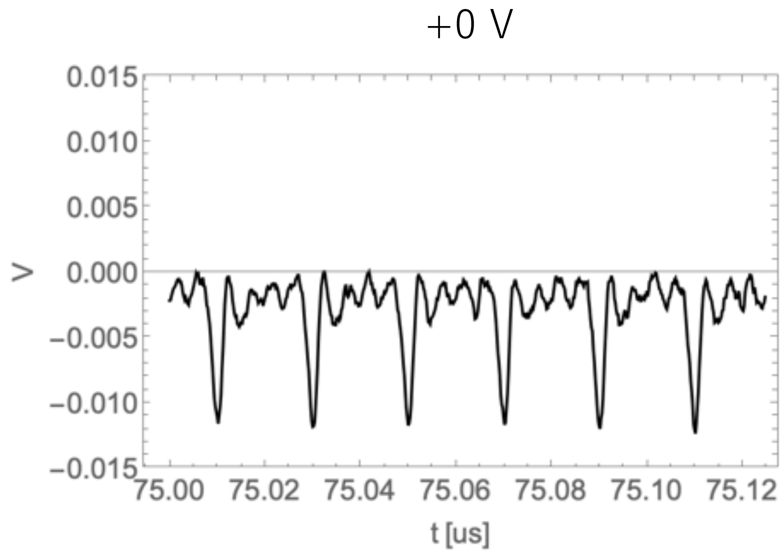


f_{RF} = 50 MHz

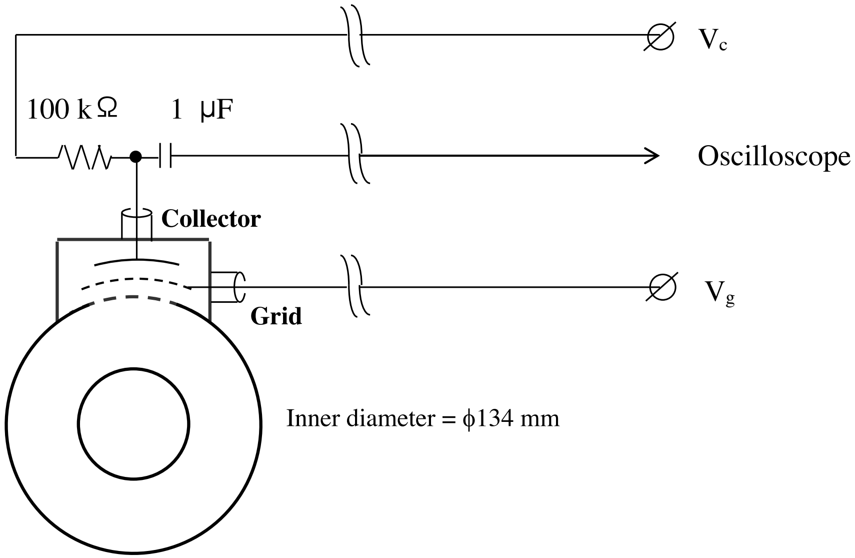
V_{RF} = 200 V

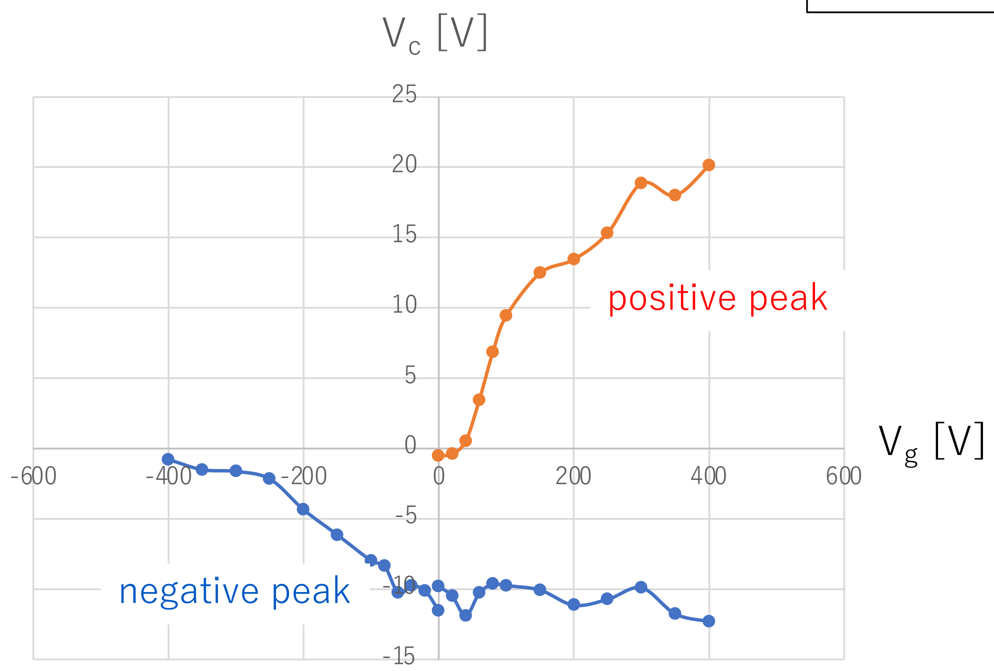
Vacuum pressure ~ 7E-6 Pa





Preliminary





- ✓ Electron is suggested by the signal suppression with a permanent magnet
- ✓ Negative and positive signal peaks are observed depending on the V_g and at different timings

  positive signals are suspected secondary electrons from collector
- ✓ The signal saturates in a few microseconds

  Time scale is consistent with the CST simulation

  Additional study is needed on signal magnitude

Summary (1)

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**
- ✓ **The EC possibility during bunch manipulation at the top energy is under study**

Summary (2)

SX mode

✓ **During the debunching process at the flat-top**

EC, vacuum pressure rise, and beam loss occur

connection to transverse instabilities:

not yet direct correlation between EC and instability

because EC signal is a local measurement at the drift space,

while instability is caused by global effects (?)

→ EC may be large at Q, B?

Summary (3)

SX mode

- ✓ **EC is now a limiting factor**
- ✓ **Beam intensity will increase from 7.0x10^{13} ppp → 1.1x10^{14} ppp in future**

  Reducing the longitudinal microstructure with

  - **phase offset injection to the RF bucket**
  - **step switching-off of the RF voltage**
  - **coupling impedance reduction (Z_L)**

  Preparing the VHF cavity for emittance blowup

Summary (4)

Test bench with concentric cylinder

- ✓ **Electron is suggested with the signal suppression with a permanent magnet**
- ✓ **Negative and positive signal peaks are observed depending on the V_g and at different timings**
  - **positive signals are suspected secondary electrons from collector**
- ✓ **The signal saturates in a few microseconds**
  - **Time scale is consistent with the CST simulation**
  - **Additional study is needed on signal magnitude**
- ✓ **Coated cylinder will be tested, with the same material as the sample for in-situ measurement @Fermilab (amorphous carbon)**

Thank you!