Proton beam accelerations with MA loaded RF systems in J-PARC RCS and MR synchrotrons

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   c. Cavity impedances
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Introduction

1. J-PARC RCS has a transition energy above 3 GeV top accelerating energy and 50 GeV MR has an imaginary transition energy.

2. The RF stations of both RCS and MR use Magnetic alloy loaded cavities and Full digital LLRF based on DDS.

3.RCS beam commissioning started in October 2007 with 10 RF systems. Protons were accelerated successfully up to 3 GeV in 31 October 2007. The RCS 11th RF station has been installed in November 2008.

4.MR beam commissioning started with 4 RF stations in May 2008. Proton beam acceleration started in December 2008. Protons were successfully accelerated up to 30GeV in 23 December 2008.

a. RF System Status

	RCS	MR
# of stations	11 (12)*	4 (7)*
typical total peak accelerating voltage	400kV	160kV

* the numbers in ( ) shows the design number of stations.

b. Diagnosis of system failures

1. RCS system failures: 117 times/3200-hrs

   MR system failures: 6 times/2000-hrs

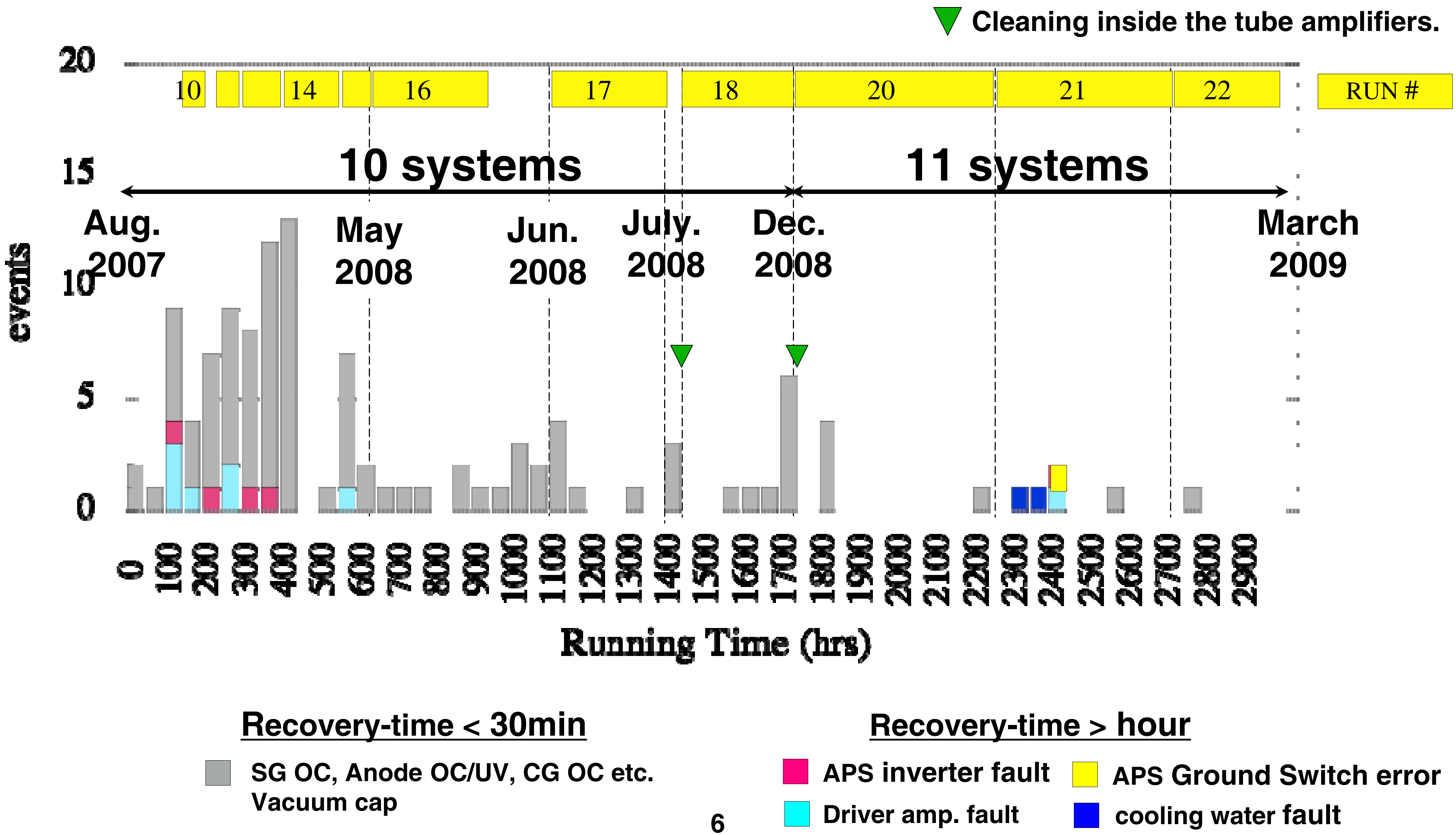
2. In RCS, 87% of failures were caused by “OC/UV” interlock of the screen grid, anode and/or control grid dc-power supplies.

3. The screen grid voltage of RCS RF station is 1750V and higher than that of MR. “Sparking” at the screen grid circuit is considered as a source of this failure.

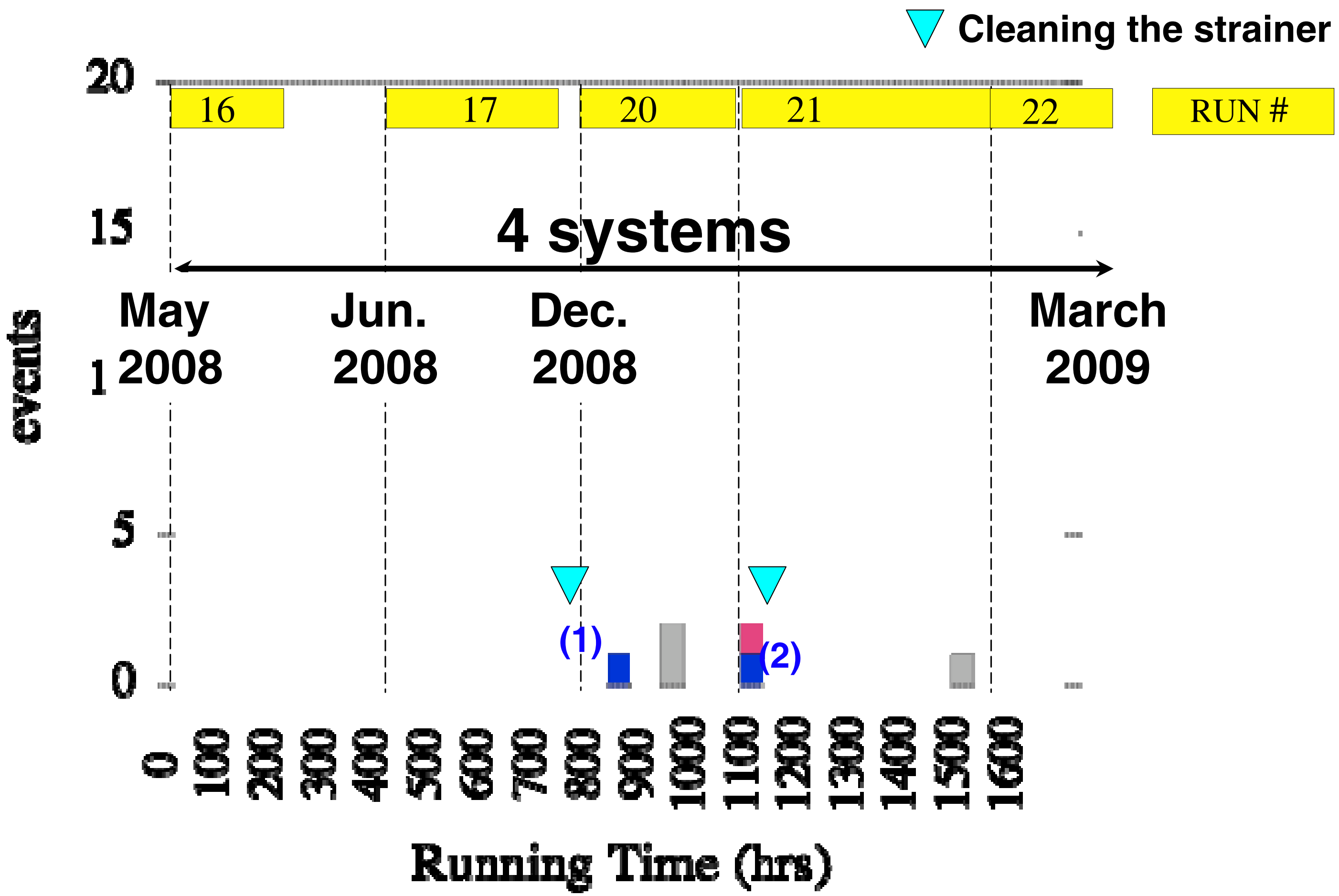
4. Dust, moisture and dew inside the amplifier could trigger sparking. Cleaning is periodically tried.

5. The percentage of downtime due to the rf system faults is 3%.

Summary of RCS RF system failures



Summary of MR RF system failures



Recovery-time < 30min

SG OC, Anode OC/UV, CG OC etc.
Vacuum cap.

Recovery-time > hour

APS inverter fault
cooling water fault
(1) APS, (2) Cav.

c. Cavity Impedance

1. In order to check the condition of each system, each cavity temperature and each cathode current of tube-amplifier are monitored and recorded during operation.

2. And also, the impedance measurement during the maintenance period by using the network analyzer is useful as a direct method.

¶ During this regular measurement, the impedance reduction was found at one of the 11 RCS cavities.

This reduction seems to be starting slowly in August 2008. In December 2008, the impedance dropped down by 5%.

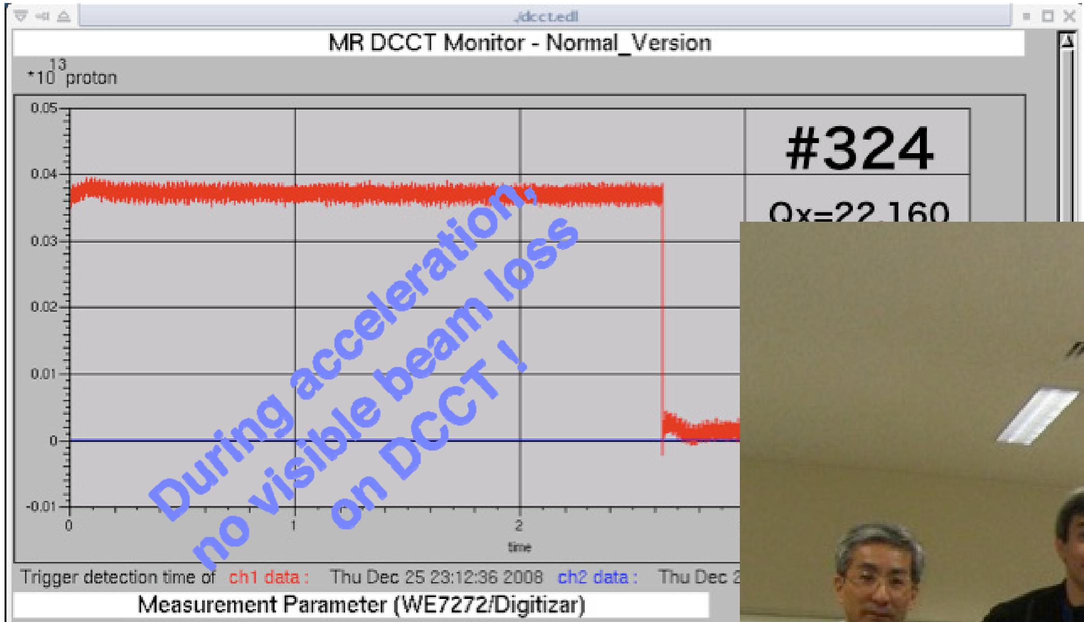
- ✓ **One of the 6 water-tank vessels consisting the cavity had a large impedance reduction.**
- ❡ **The system was rearranged to 2-gaps instead of 3-gaps and operated to retain the RCS operation in January and February 2009.**
- ❡ **In March 2009, the cavity was opened to investigate the cores inside and the three damaged cores were replaced with new cores to put the cavity back into the tunnel for the next beam operation in April.**

- ✓ **The change in impedance originates from the further progressing of the buckling in the core, leading to destruction of the layer structure.**

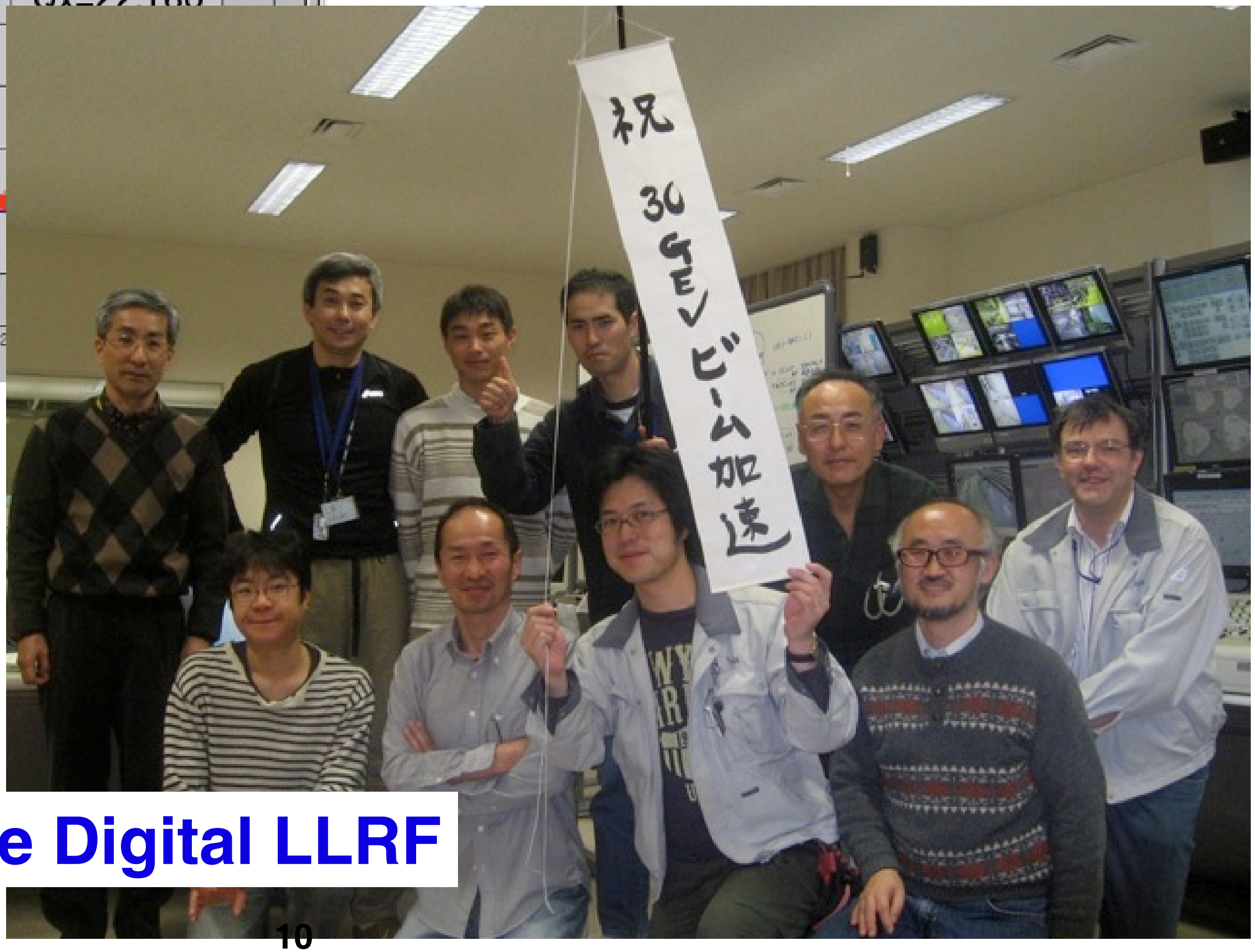
- ❡ **The details are described at the poster session "WE5PFP002".**

2. Beam commissioning

First 30GeV proton acceleration

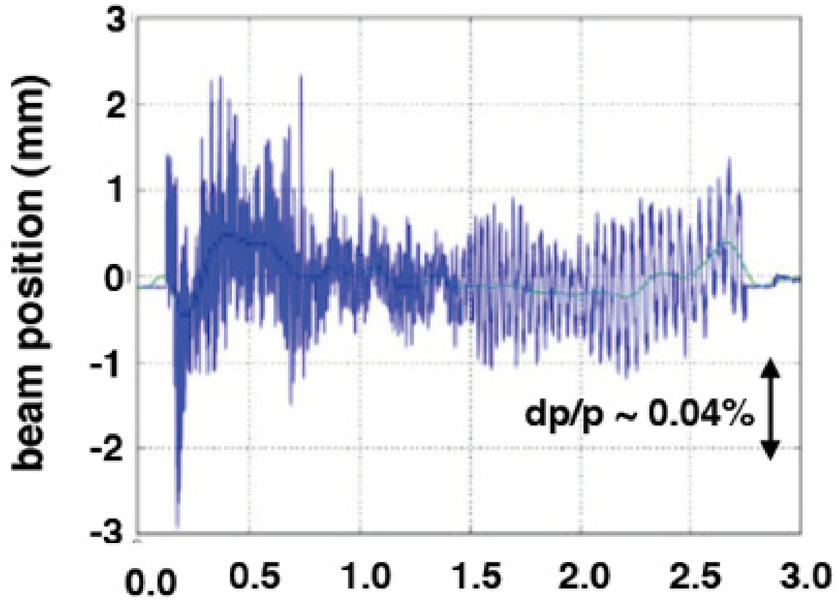


Dec. 23, 2009



1. imaginary γ_t
2. MA cavity
3. precise / flexible Digital LLRF

a. 30GeV proton acceleration

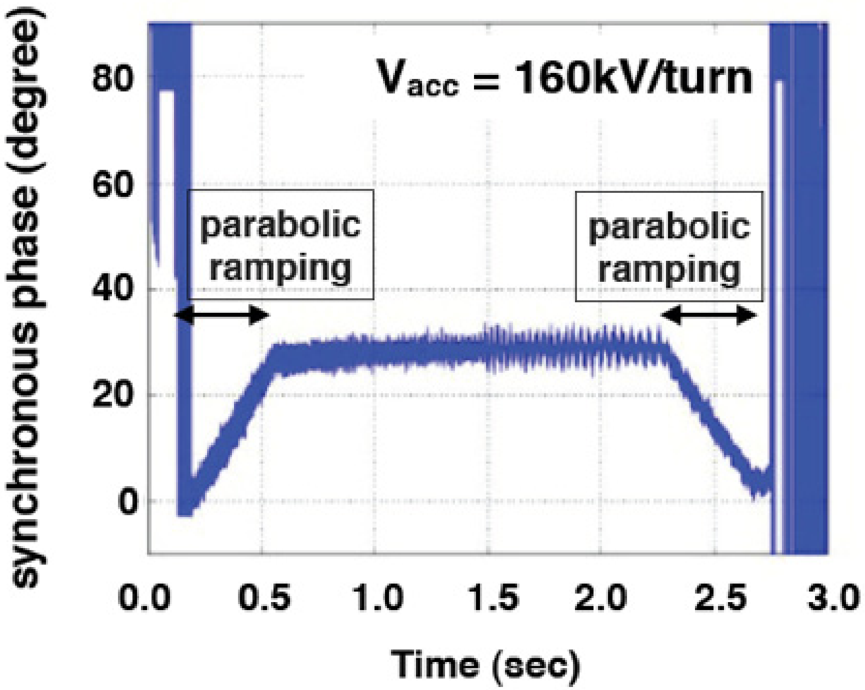


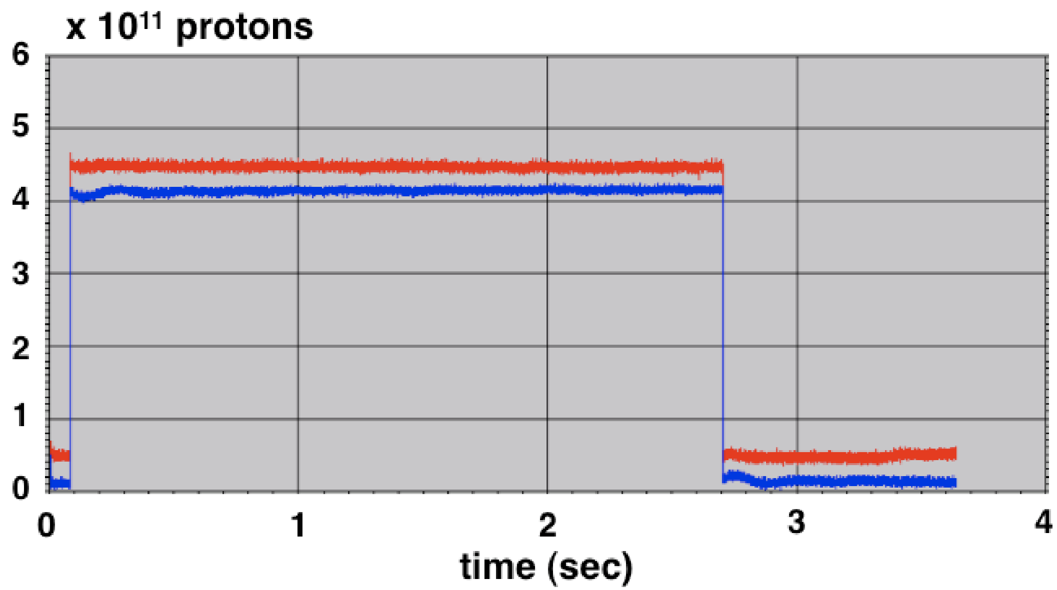
single bunch, 4 x 10^{11} protons

a. 2.5s accl. in 6.0s cycle

b. radial feedback: not closed

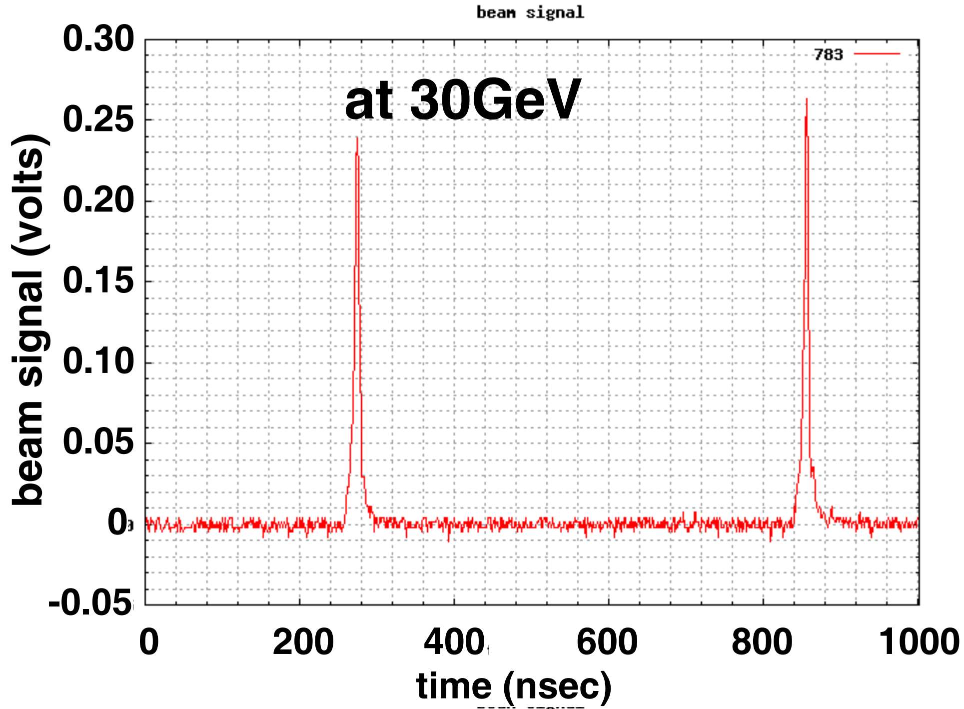
c. 160kV/turn with 4 RF stations



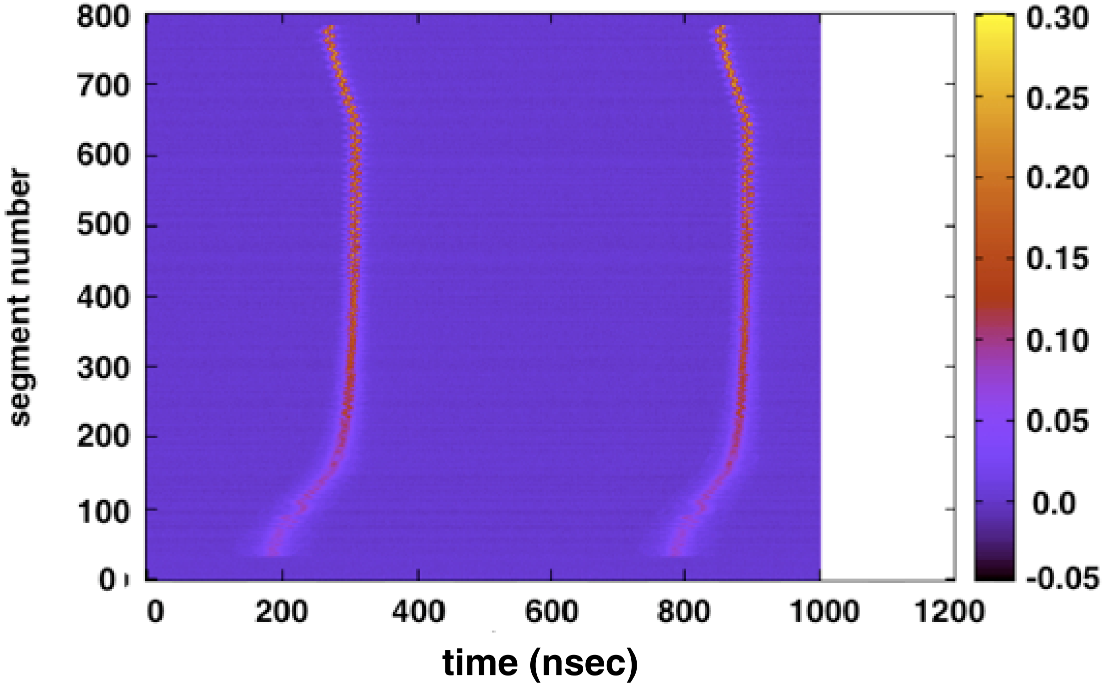


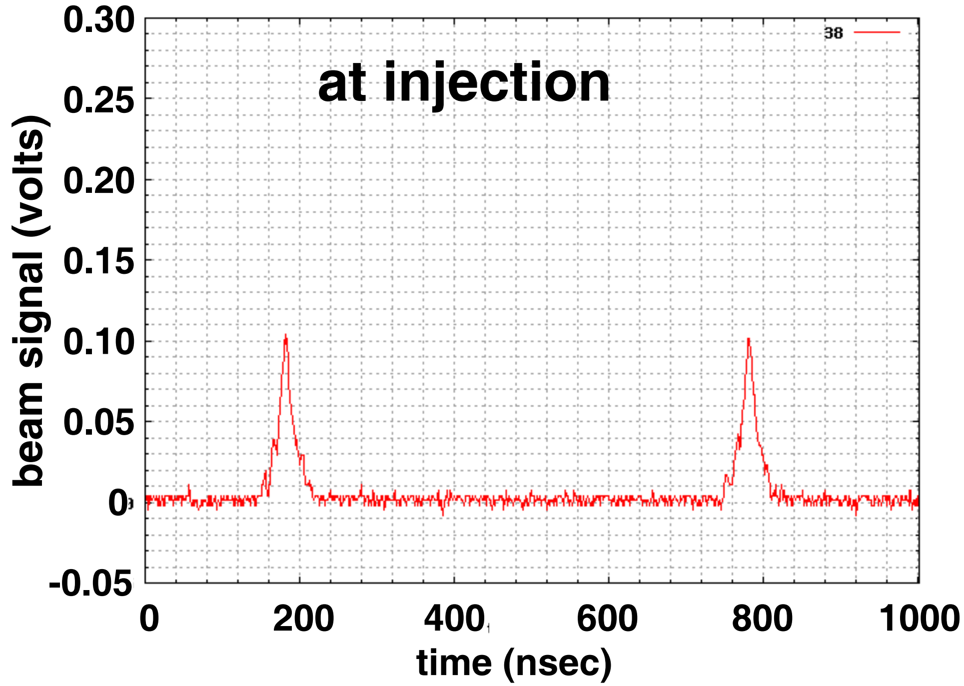
Two-bunch protons acceleration in MR

a. Two bunches from RCS were accelerated in MR, April 23 2009
b. 8 x 10^{11} protons/pulse
c. (upper) WCM signals at 30 GeV
d. (lower) WCM signals at injection.



mountain view plot





b. RCS beam commissioning

1. RCS beam commissioning started in October 2007.

2. RCS rf system: dual-harmonic AVC is working properly.

3. radial feedback: not closed in RCS/MR, because it is not necessary.

- reproducible B-field and rf frequency

- frequency pattern is modified offline.

• phase feedback: closed when RCS operates with high current, but MR not yet

b-1 Longitudinal painting

1. Transverse and longitudinal paintings are the key issue for aiming to reduce beam loss during RCS acceleration.

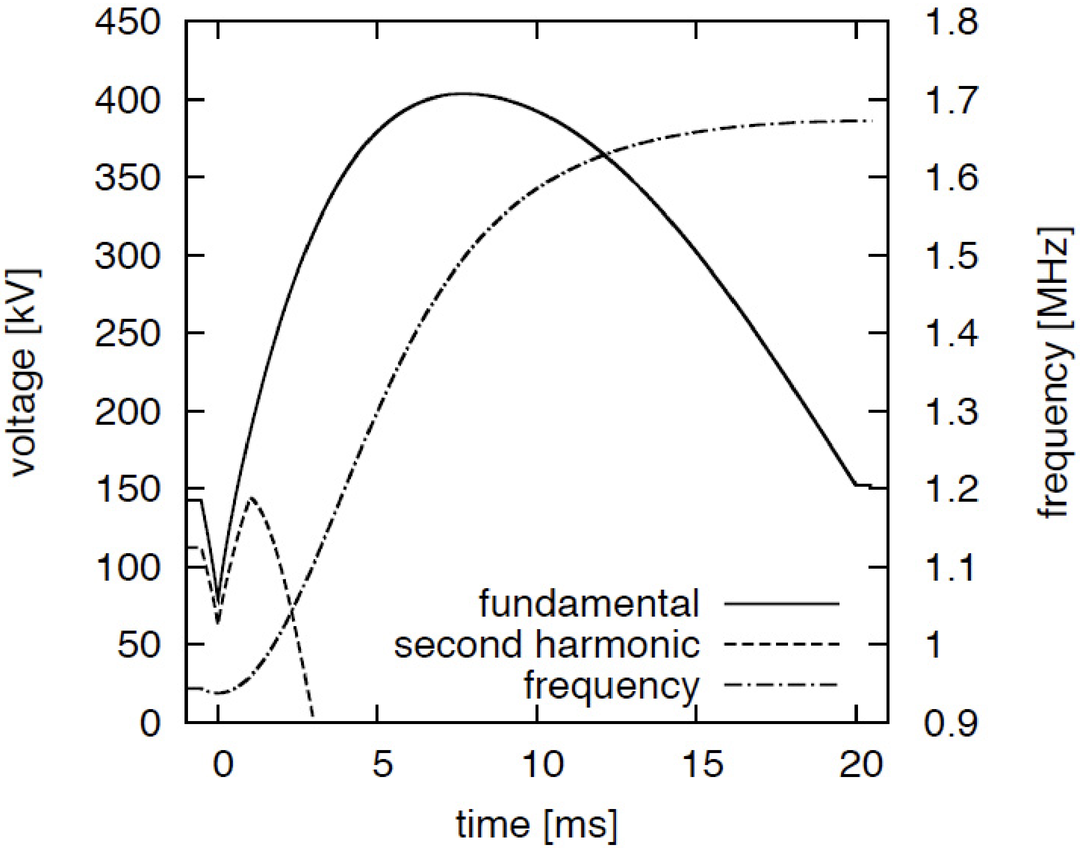
2. Longitudinal painting is purposed for increasing the bunching factor (more than 0.4 at injection) to alleviate space charge effect.

methods

- momentum offset
- vary amplitude of 2^{nd} harmonic rf
- 2^{nd} harmonic phase sweep (new)

¶ to modify bucket shape during injection

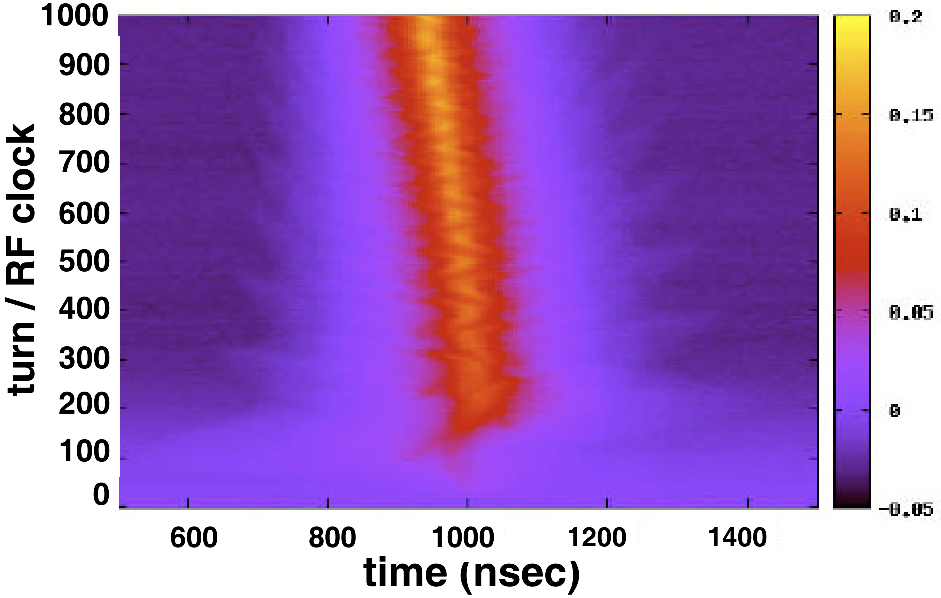
Voltage pattern example

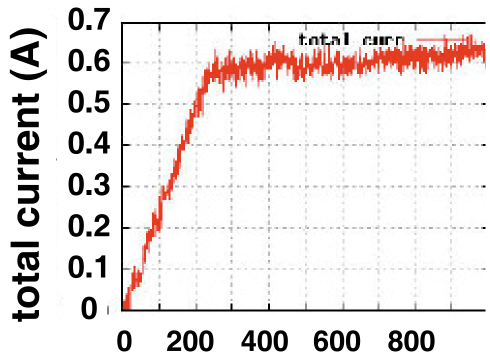


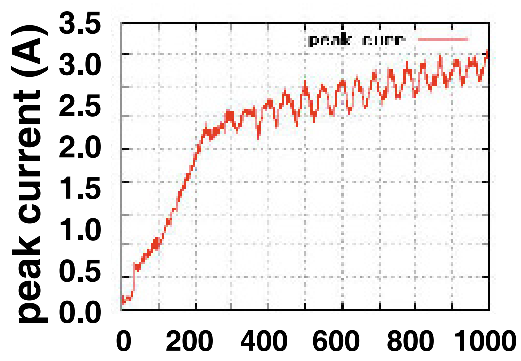
Caption: voltage pattern with 2nd harmonic rf (80% amplitude)

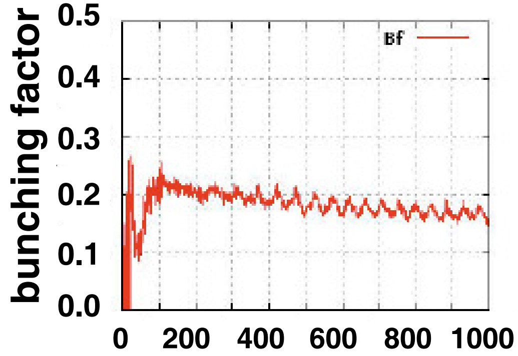
- ~ 1ms: 80% to fundamental
- amplitude linearly reduced, zero at 3msec

Longitudinal painting (1)







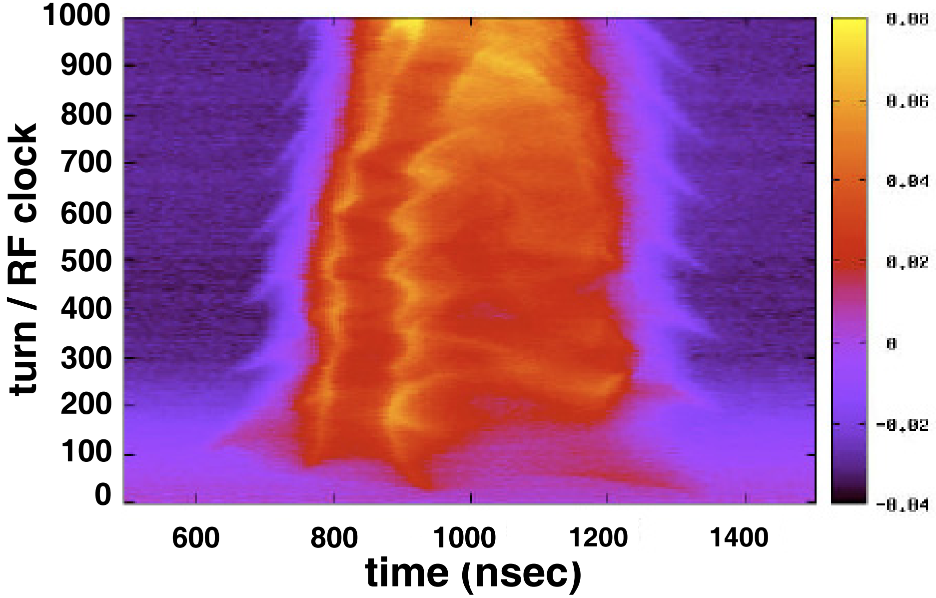


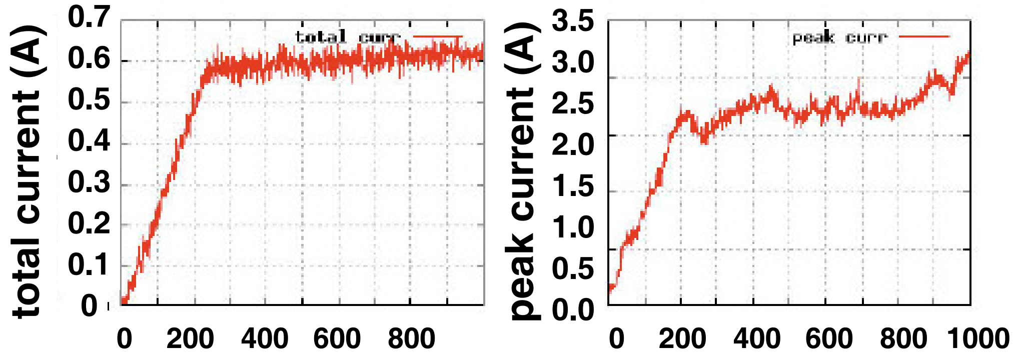
horizontal scale:
turn / RF clock

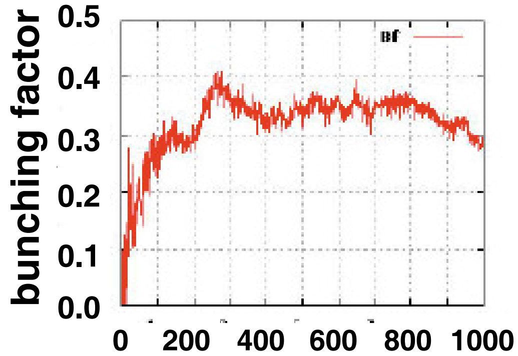
- linac 5mA, chopping width 560ns
- phase feedback on, 200μs~extraction
- no momentum offset
- ❡ bunching factor (250-th turn): 0.2
- 8.25 x 10^{12} protons
- DCCT transmission: 0.995

fundamental rf only

Longitudinal painting (2)





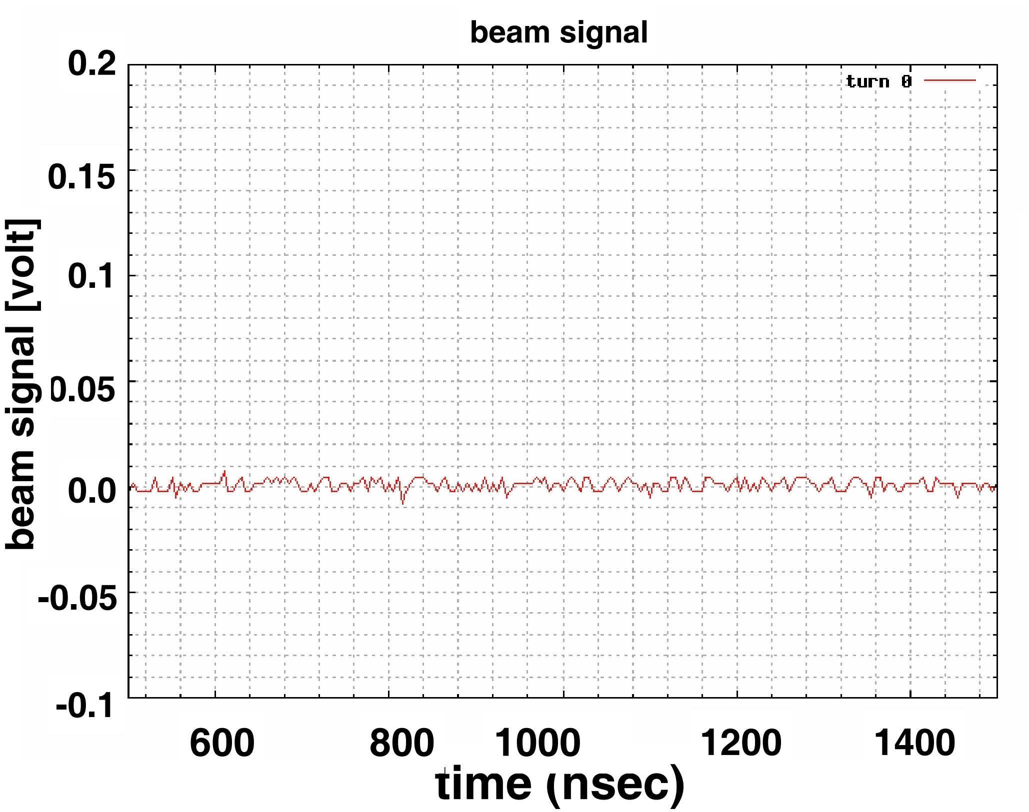


horizontal scale:
turn / RF clock

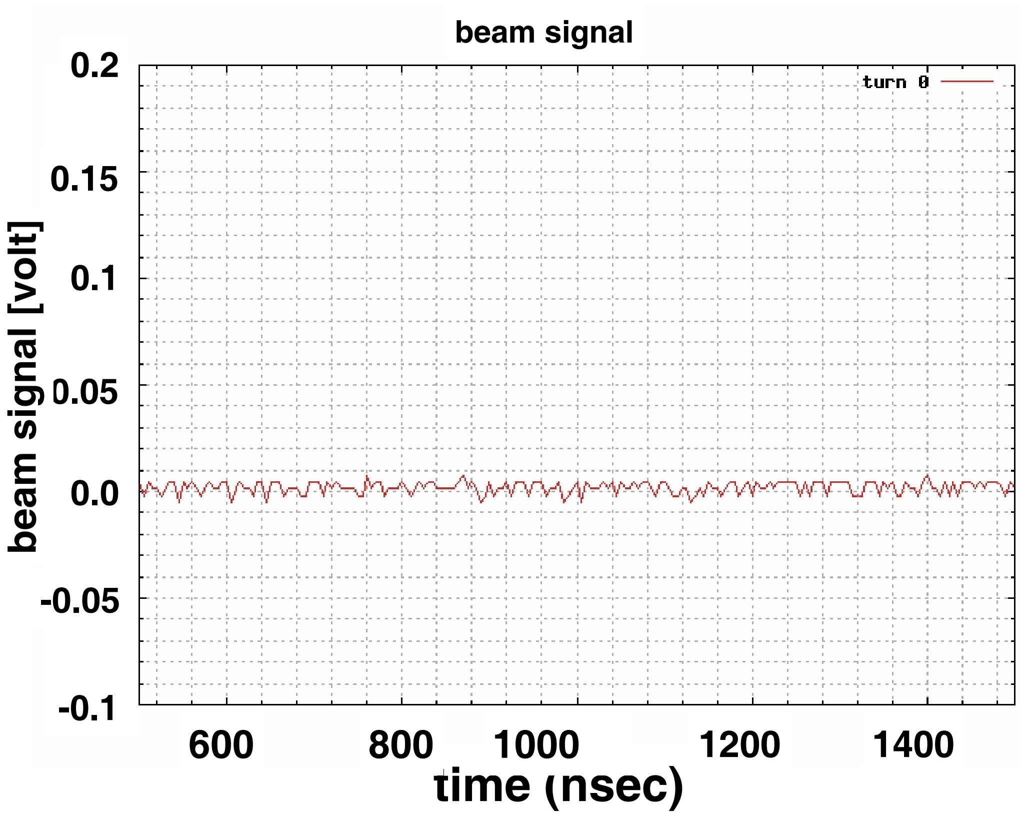
- linac 5mA, chopping width 560ns
- phase feedback on, 200μs~extraction
- dp/p = -0.2%
- 2nd harmonic phase sweep: 80 degrees
- bunching factor (250-th turn): 0.37
- 8.32 x 10^{12} protons
- DCCT transmission: 1.00

80% 2nd harmonic rf

Longitudinal Painting Summary



fundamental only



+ 2nd harmonic 80%
+ momentum offset
and phase sweep

b-3 high intensity trial and longitudinal manipulations in RCS

Overview

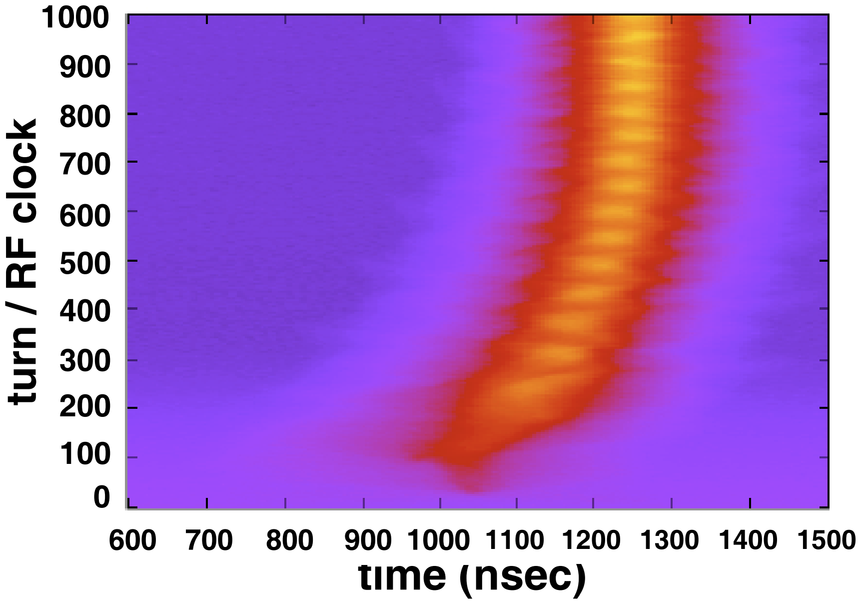
- high-intensity trial (~350kW)
- bunch lengthening/shortening at extraction

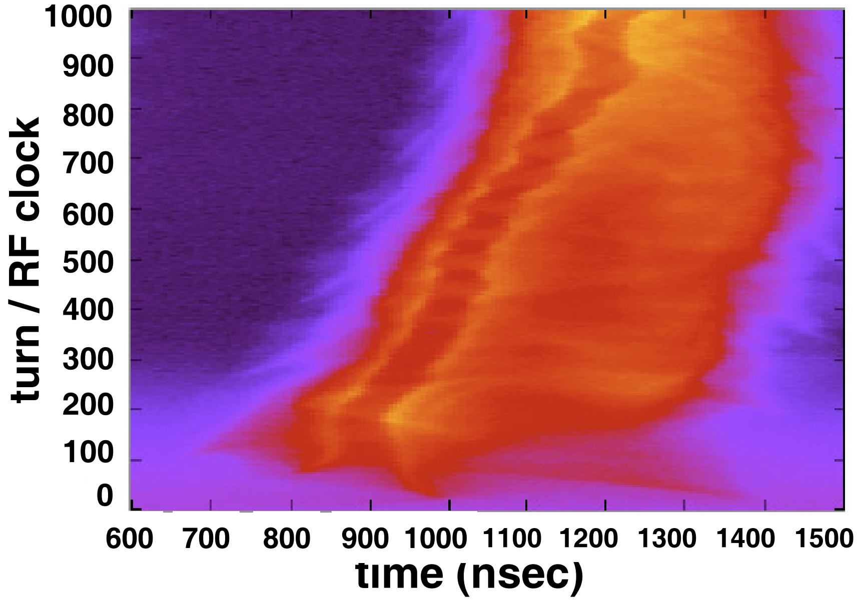
Date: 080917

linac parameters: peak current 15mA, macro pulse 500 μsec

two bunch operation (one bunch operation is not possible, because of beam loading)

high intensity trial



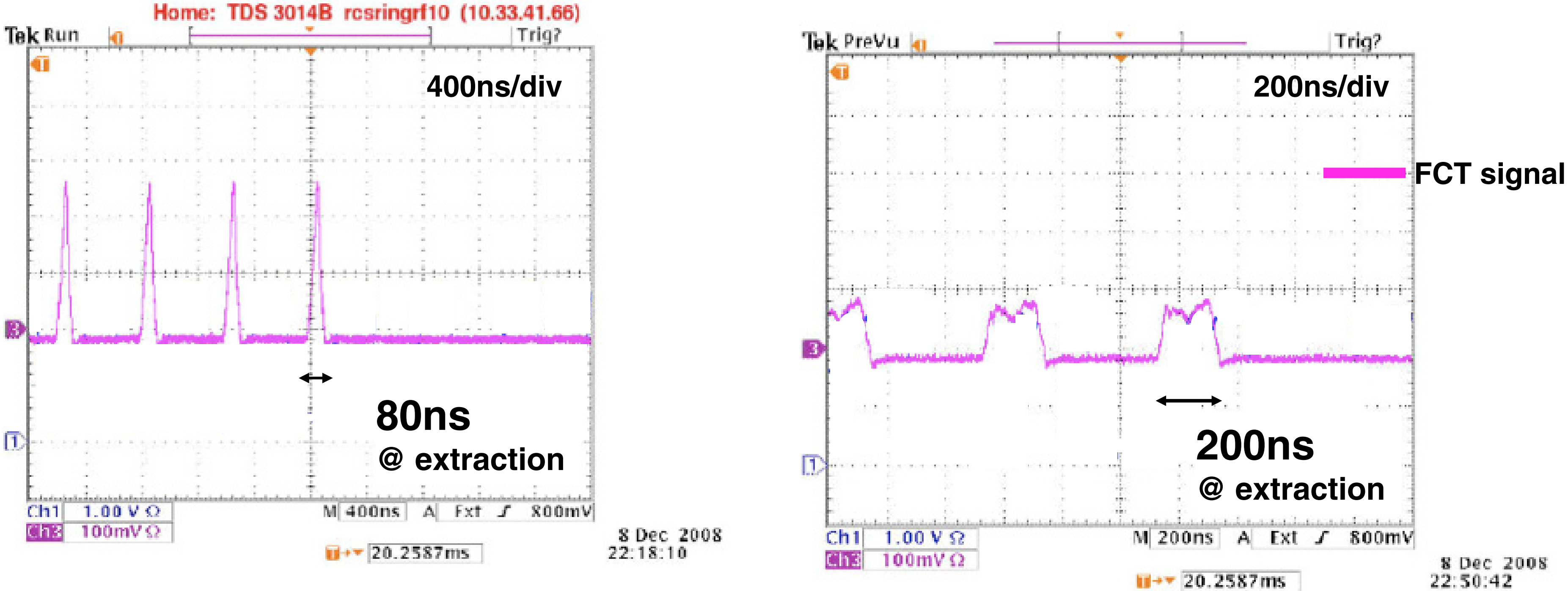


- date: 080917
- linac 15mA, chopping width 560ns, 270kW
- phase feedback on, 200μs~extraction
- no momentum offset
- 2.25 x 10^{13} protons
- DCCT transmission: 0.95
- limit at 95% without 2nd harmonic rf

- date: 080917
- linac 15mA, chopping width 700ns, 353kW
- phase feedback on, 200μs~extraction
- dp/p = -0.2%
- 2nd harmonic phase sweep: 80 degrees
- 2.93 x 10^{13} protons
- DCCT transmission: 0.961

b-4 Bunch lengthening

“necessary for matching and increasing a bunching factor for MR injection”



Caption: (left) ext. voltage = 150kV. (right) ext. voltage = 60kV and apply 2nd harmonic rf with the amplitude ratio 50% to the fundamental. (Note: different time axis scale)

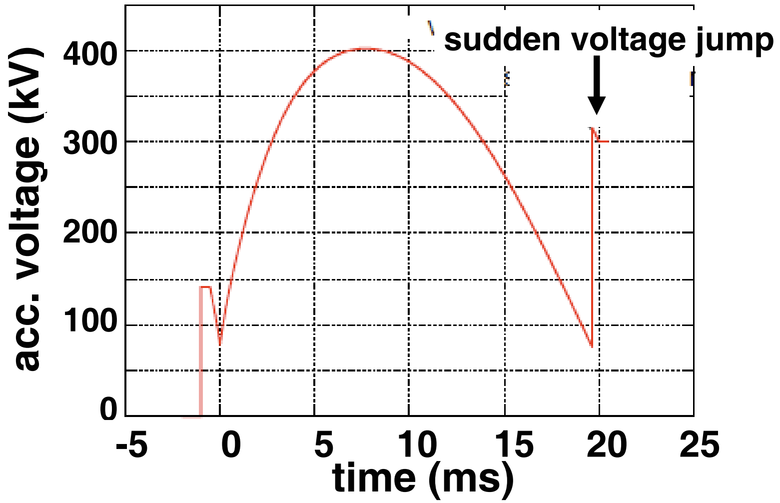
- Clearly the bunch is lengthened (80ns ⟶ 200ns)
- voltage pattern optimization is necessary to avoid beam loss in latter part of the acceleration

b-5 Bunch shortening

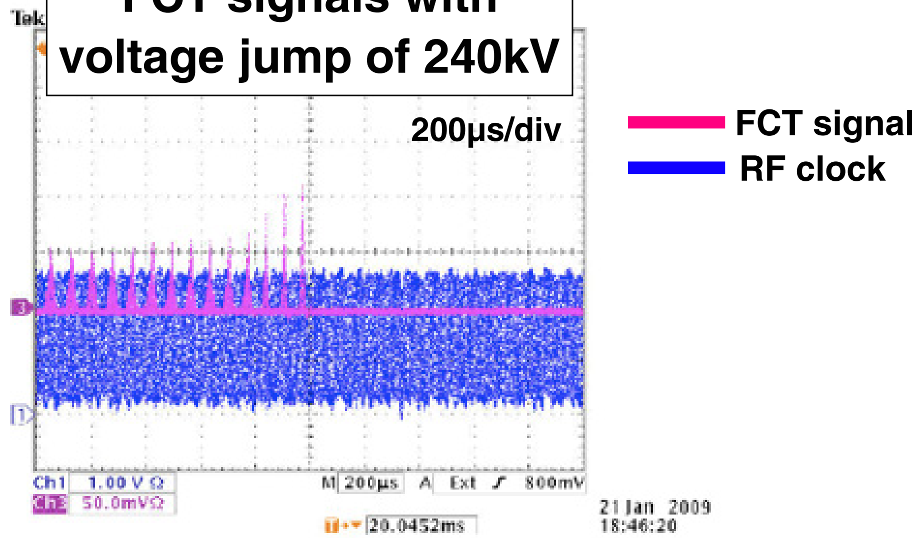
"required for MLF muon users"

- apply "voltage jump" just before the extraction so that the bunch starts quadrupole oscillation.

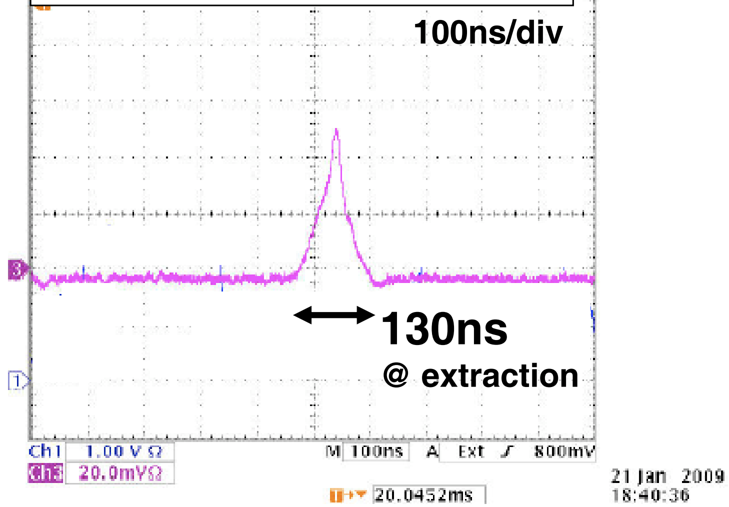
voltage pattern

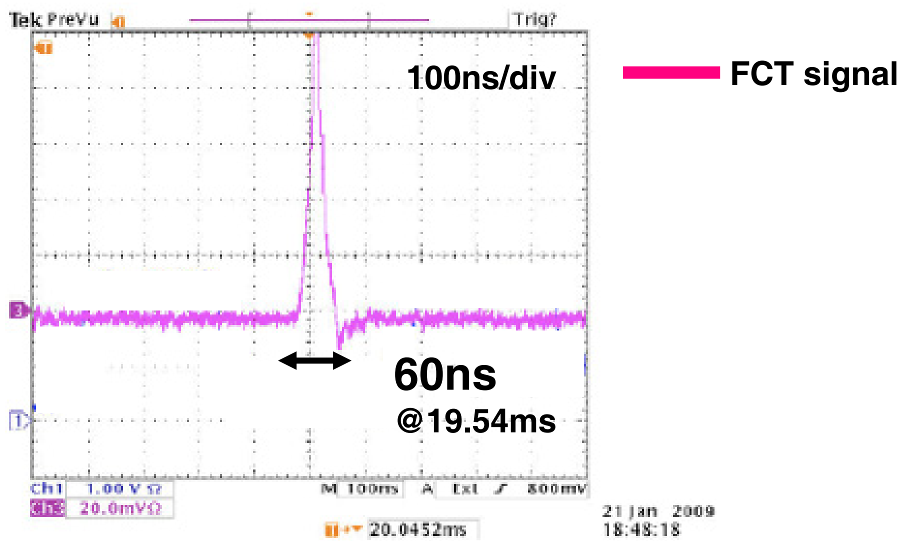


FCT signals with voltage jump of 240kV



FCT signal with 60kV





3. Summary (1)

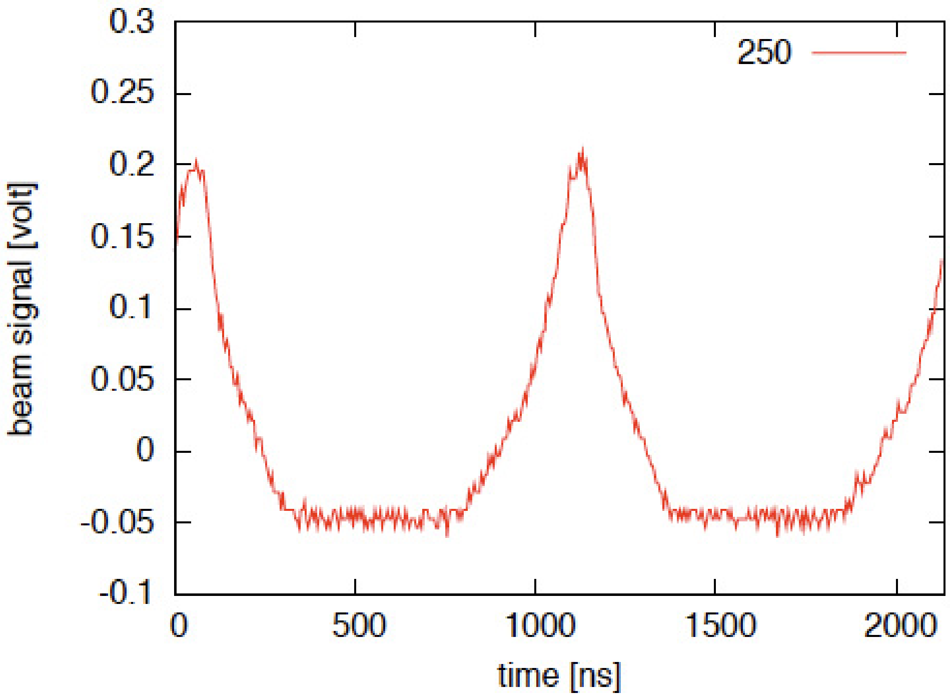
1. In both 50GeV MR and 3GeV RCS, protons were successfully accelerated to the designed energy.

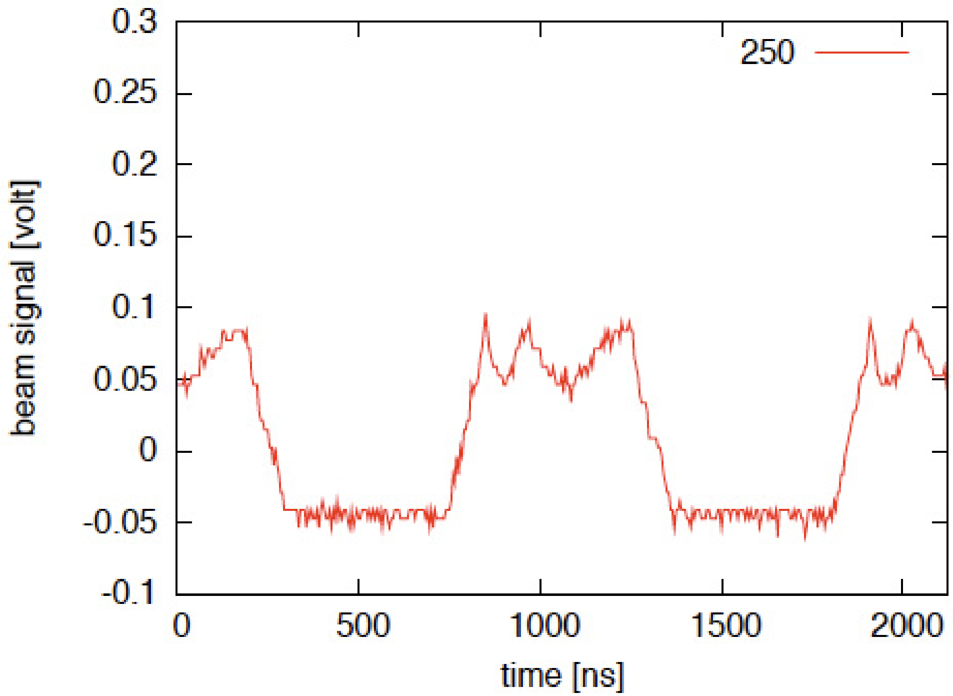
2. 30 GeV protons are extracted to the Hadron experimental hall with a 3rd resonance scheme and to the Neutrino line with a fast extraction scheme.

• Imaginary γ_t, MA loaded RF systems and Digital LLRF made easy acceleration in MR.

• In RCS, the longitudinal painting based on the particle tracking was researched, and the agreement with a good outcome of an experiment and calculation was confirmed. ☞ TH5PFP028

3. Summary (2)





Caption: (left) fundamental only (right) 2nd harmonic rf 80% + momentum offset + phase sweep.

5. 2nd harmonic rf 80% with its phase sweep and "momentum offset" improve the bunching factor and the bunch shape

6. Also, in high intensity trial, the equivalent beam power of 350kW was demonstrated successfully.

3. Summary (3)

7. The system works stable during operation. The percentage of downtime due to the rf system faults is 3%.

8. At one of the 11 RCS cavities, the impedance reduction was found.

9. The impedance reduction is due to the buckling of the core.

10. The damaged cores have been already replaced with the new cores to put the cavity back into the tunnel for the beam operation.

11. The mechanism and the prevention plan of the buckling are being examined.

☞ WE5PEP002