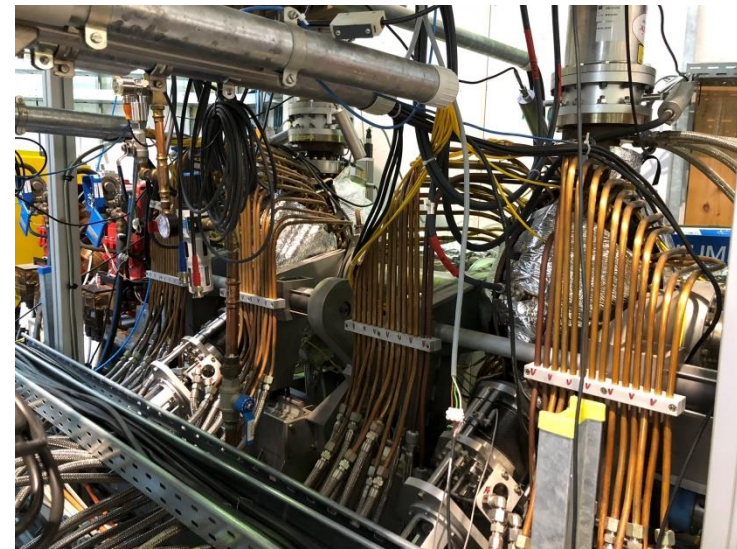
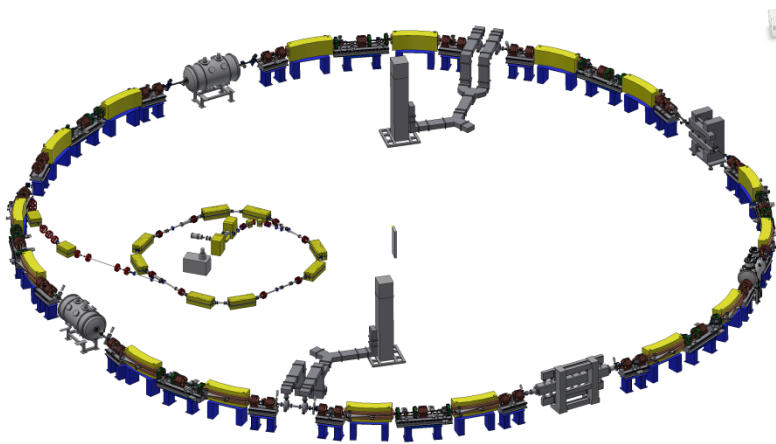


# Present Status of RF System in KARA

Akira Mochihashi on behalf of IBPT and LAS team in KIT

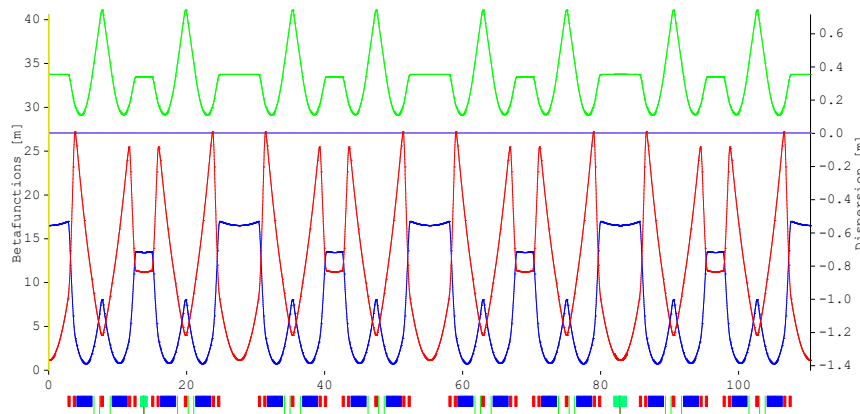
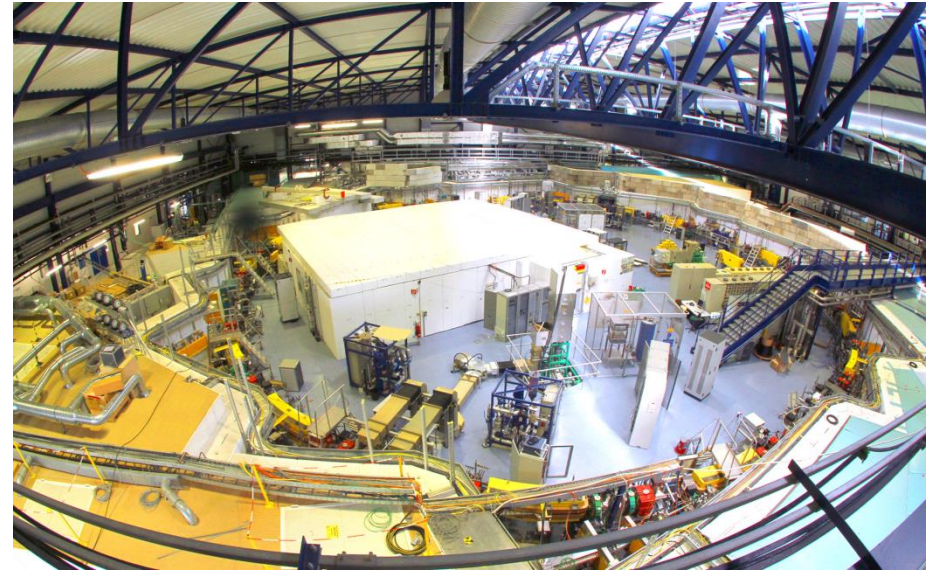
Laboratory for Applications of Synchrotron Radiation (LAS),  
Karlsruhe Institute of Technology (KIT)



# Contents

- Introduction -- The Karlsruhe Research Accelerator (KARA) --
  - Microtron, Booster Synchrotron and Storage Ring
- Trouble Report in 2018
  - Failure in Microtron Linac
- RF System in KARA Storage Ring
  - Overview
  - RF Control System
  - Beam Loading Effect
  - RF Modulation Scheme
- Outlook: Running Plan NOW

# Introduction (1) Karlsruhe Research Accelerator



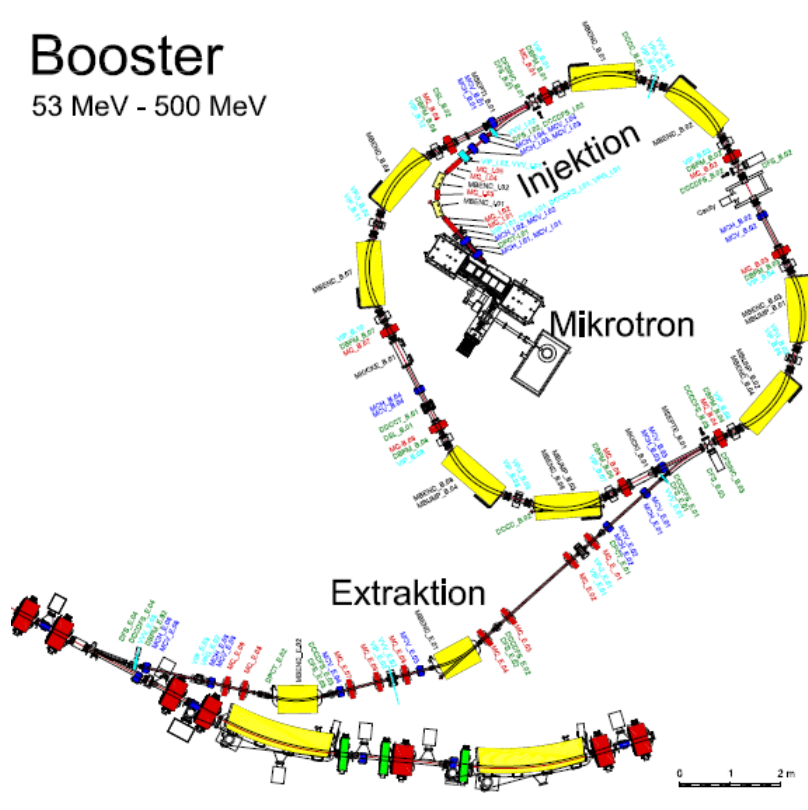
**Extended DBA Lattice**  
**(Dispersion > 0 in straight section)**  
**Designed Emittance = 59 nm-rad**

Beam Energy	< 2.5 GeV
Circumference	110 m
RF Frequency	499.7 MHz
Harmonic Number	184
Number of RF Station	2
Number of Cavity in 1-Station	2
Acc. Voltage	1.4 MV (2.5 GeV)
Ring Lattice	DBA

# Introduction (2) Karlsruhe Research Accelerator

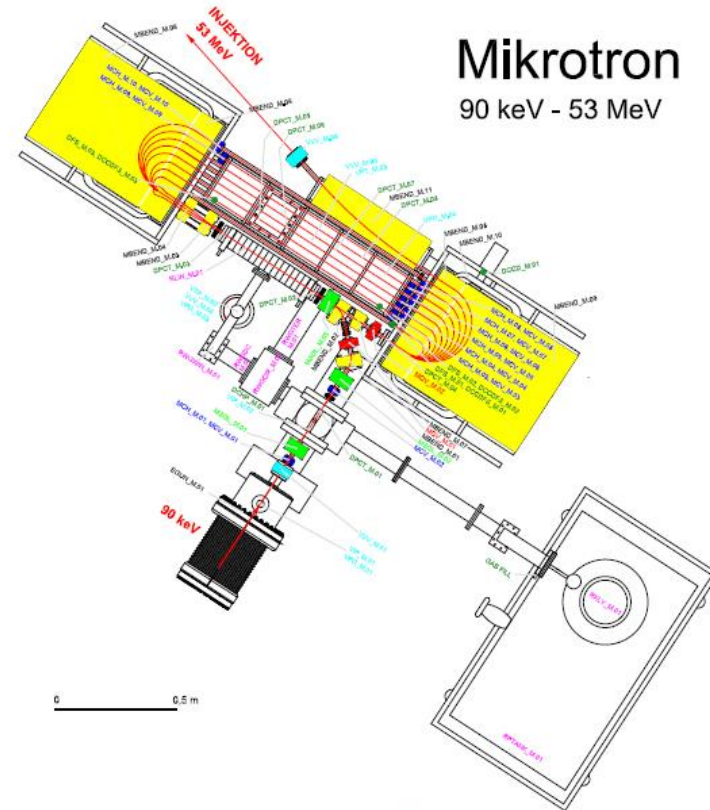
## Booster

53 MeV - 500 MeV



## Mikrotron

90 keV - 53 MeV



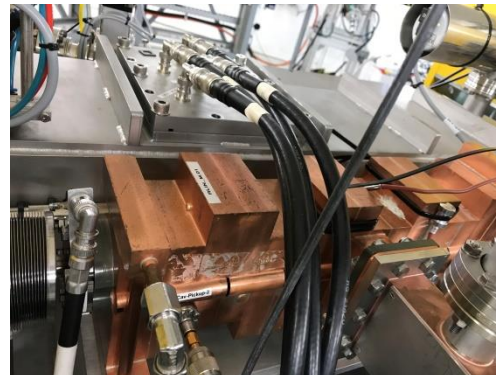
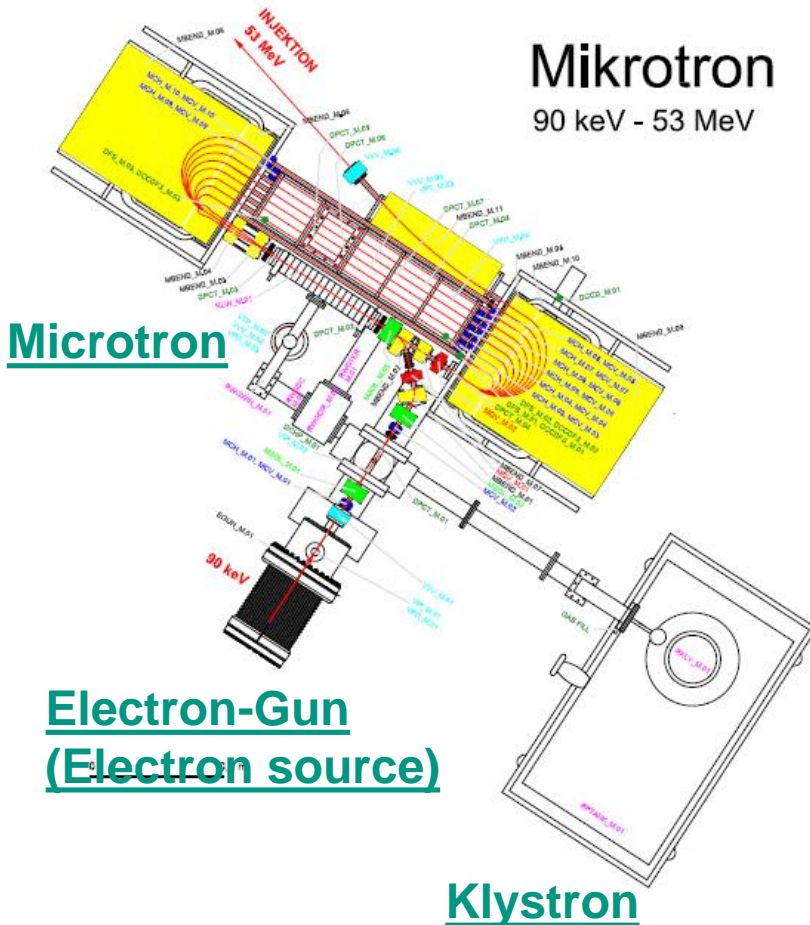
Beam Energy	< 500 MeV
Circumference	24 m
Harmonic Number	44
Number of RF Station	1
Operation Rep. Rate	1 Hz

Beam Energy	< 53 MeV
RF Frequency	2.999 GHz
Number of Turns	10 (up to 53 MeV)
Linac Structure	(1/2+7+1/2)Cells, Side Couple
Mode	$\Pi/2$ mode

# Trouble Report in 2018 (1)

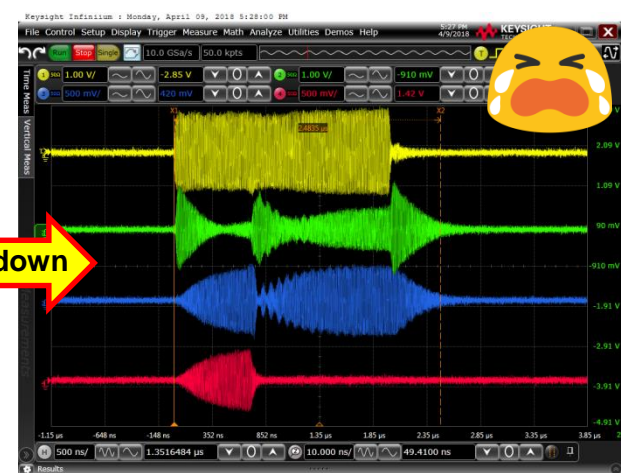
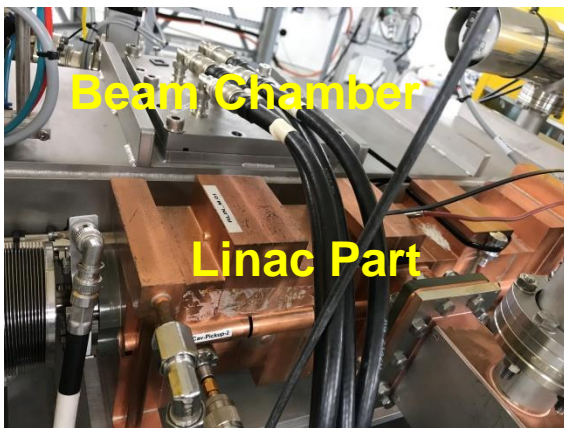
## RF-Breakdown in Microtron Linac

- Klystron
  - 2.999GHz, Pulse-modulation
  - Peak power ~ 2MW (4MW maximum)
  - Pulse length: 5 $\mu$ s, Rep.rate: 1Hz
- Waveguide
  - From Kly. to Linac: Filled with SF6 gas
  - 1 Ceramic window (water-cooled)
- Microtron Linac
  - Water-cooled
  - 2 pick-up antennas



# Trouble Report in 2018 (2)

- RF-Breakdown in Microtron Linac (about 20 years old)
  - 15.March.2018, RF-reflection power from the microtron linac became higher and intra-cavity power decreased drastically.



- The reflection power obviously increased.
- 2 pick-ups on the linac in different position had different pattern.

This could be from a local discharge inside the linac.

\*Initially we suspected a discharge on the ceramic window in the waveguide, so we polished/cleaned it but it could not help us.

# Trouble Report in 2018 (2)

- Time line from **the failure** until **its recovery**

Date	Events
<a href="#"><u>2018-03-15</u></a>	RF Problem in microtron linac
2018-03-19	Open waveguide system and cleaned ceramic window
2018-03-21	RF power test with load ... The window was fine.
2018-03-23	Closed waveguide system and started bake-out
2018-03-26,27	RF commissioning: Not good condition.
2018-03-28	Dismount the linac for visual inspection (fiber scope)
2018-04-04	Cleaning with dry N2 gas
2018-04-06	Installed linac again and bake-out over weekend
2018-04-09	Started again RF commissioning
<a href="#"><u>2018-04-19</u></a>	Started commissioning with beam

We could receive a lot of helpful and kind comments and information from many accelerator facilities in the world.

**Thank you very much!**

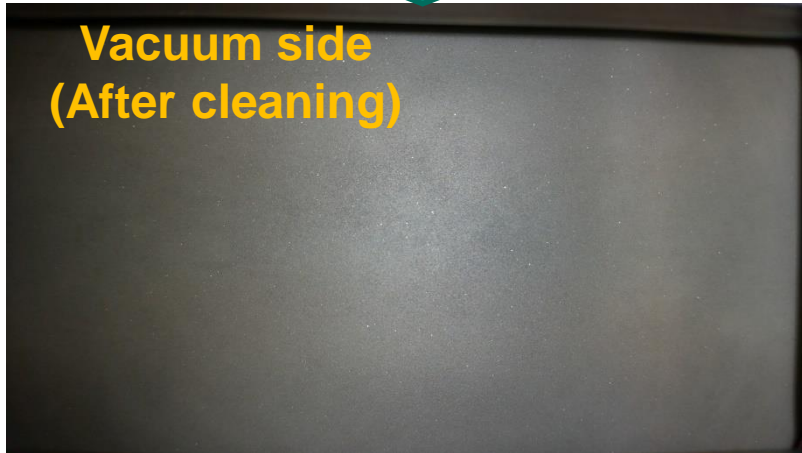
# Trouble Report in 2018 (3)

## Ceramic window in waveguide

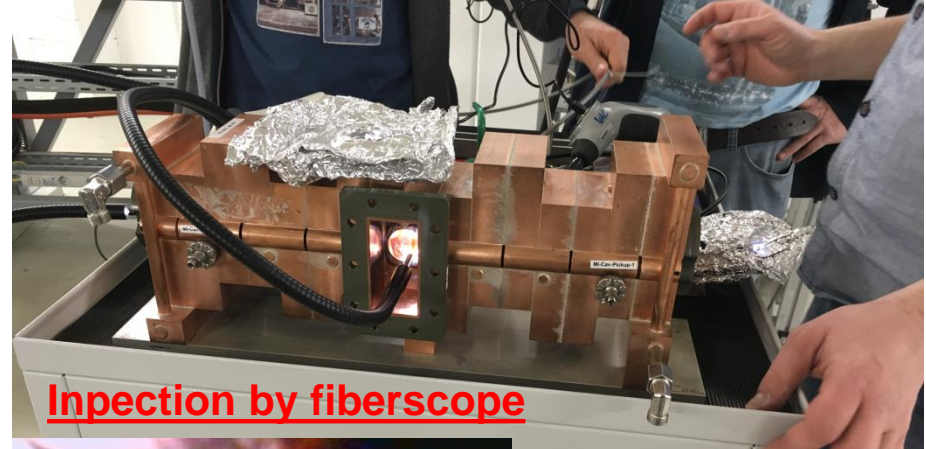
Vacuum side  
(Before cleaning)



Vacuum side  
(After cleaning)



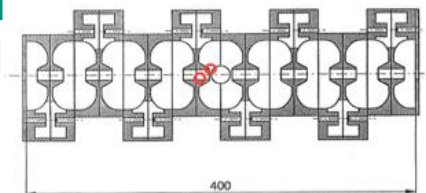
## Linac dismant...



Inspection by fiberscope



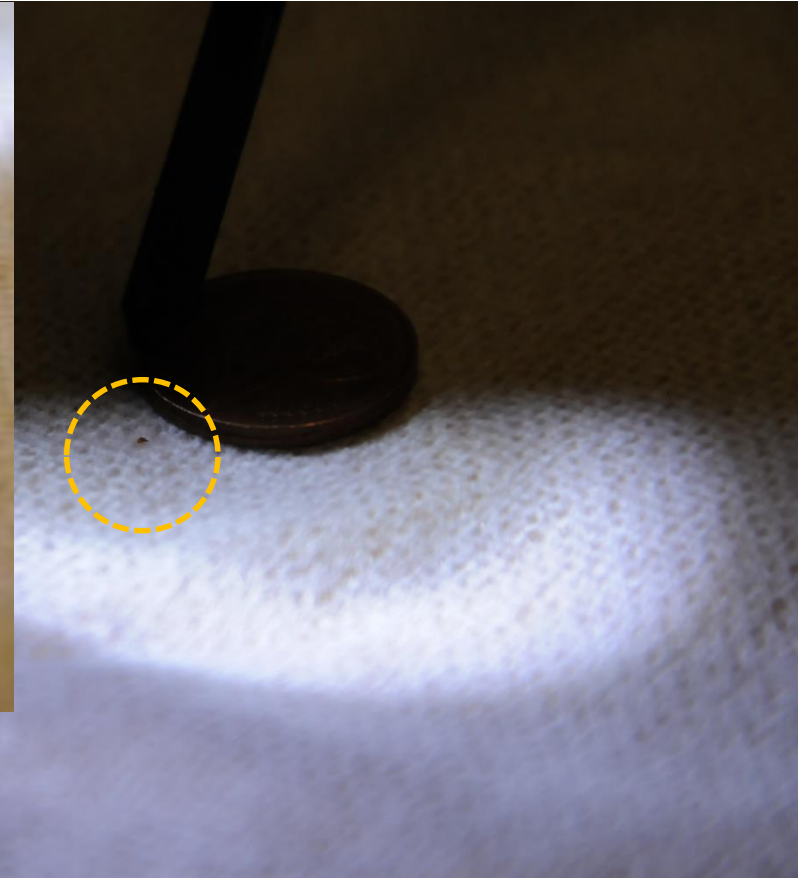
Some (discharge?) mark and a scratch were found around the nose cone.





# Trouble Report in 2018 (4)

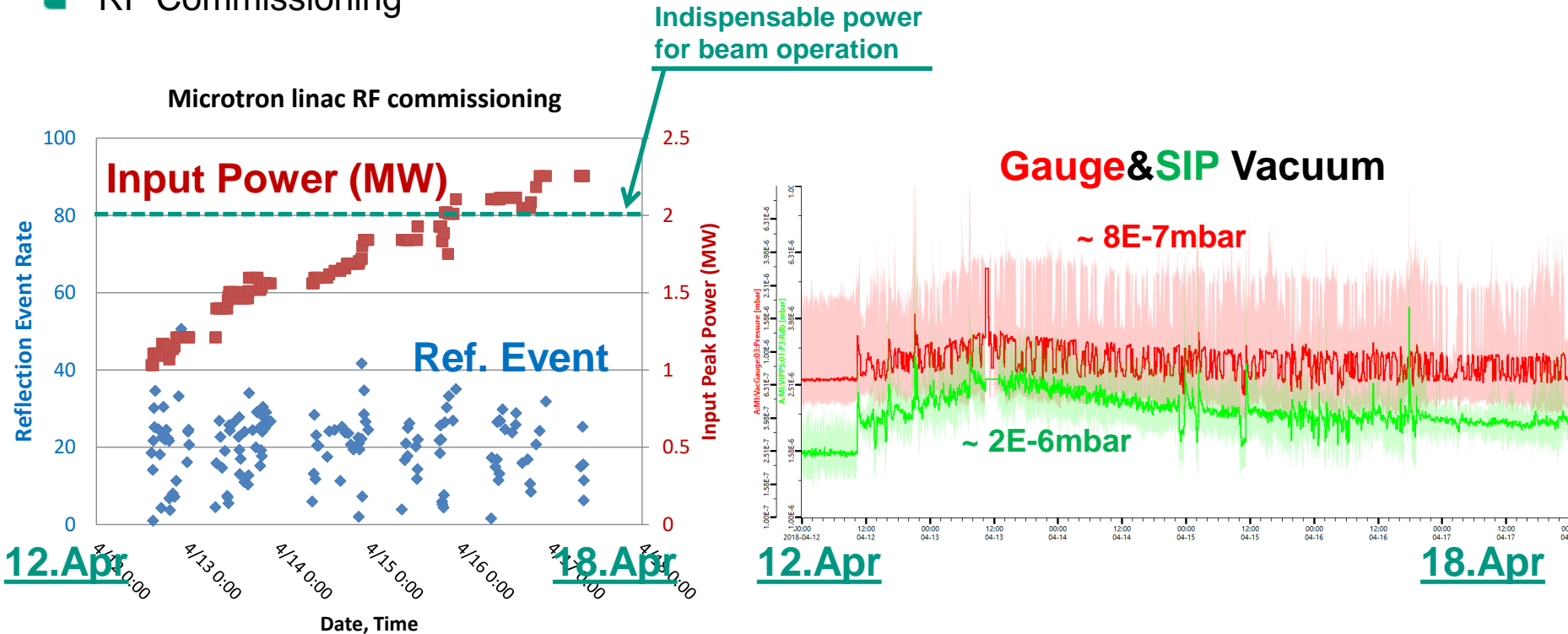
## Blow cleaning with dry N<sub>2</sub> gas



Copper-like grains came out of linac.  
...where did it come from?

# Trouble Report in 2018 (4)

## RF Commissioning

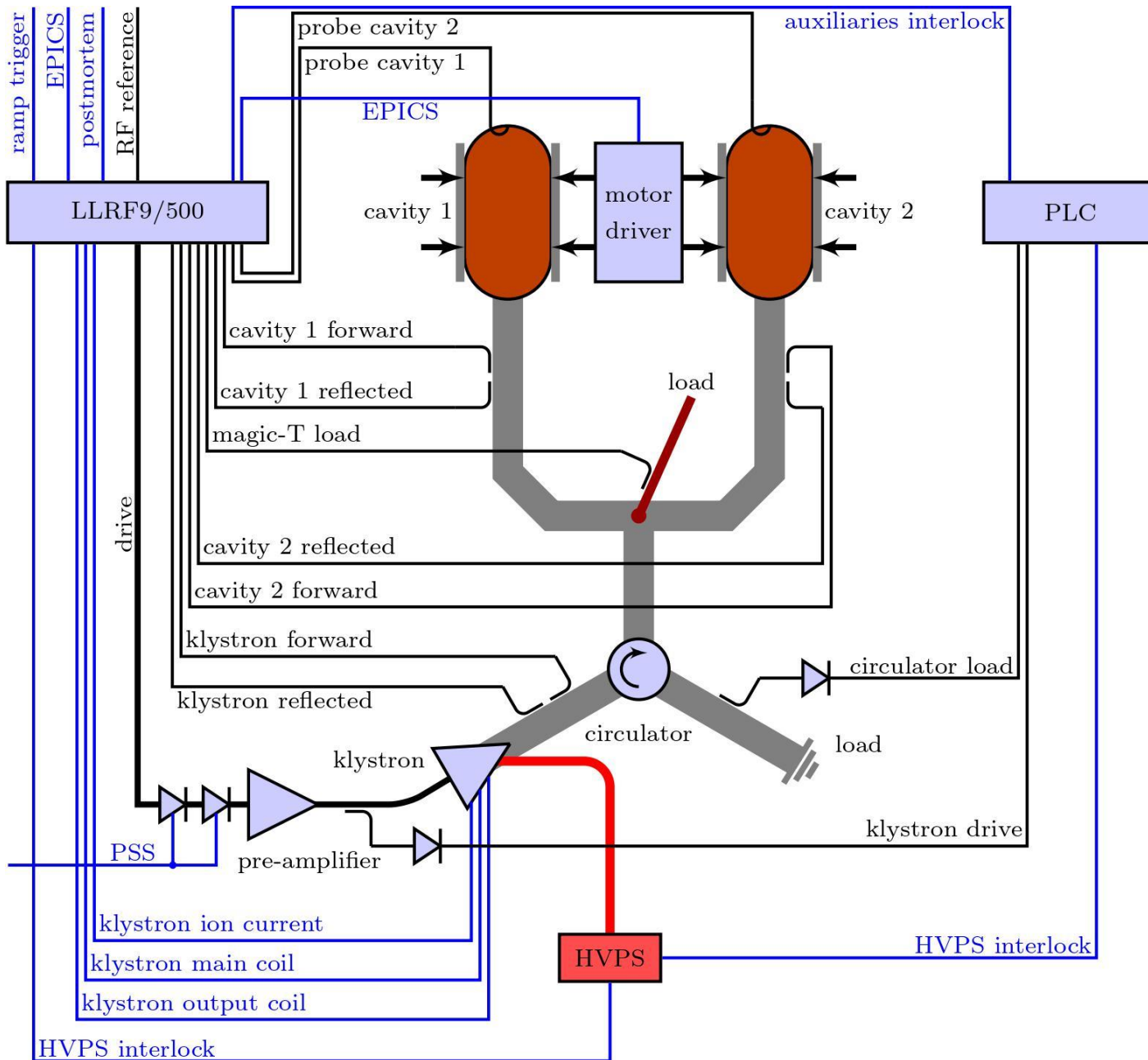


- The commissioning took about 1 week from very low to sufficient power.
- Making a reflection-event counting system (by digital oscilloscope): commissioning by looking at the statistics.

**The microtron has been recovered and is in operation now.**

# RF System in KARA Storage Ring (1)

Parameters	500MeV (Injection)	2.5GeV (User Operation)
RF / Revolution Freq.	499.7MHz / 2.72MHz	
Harmonic Number	184	
Total RF Voltage	300kV (Typ.)	1.4MV (Typ.)
Energy Loss per Turn	995.9eV	622.4keV
Synchronous Angle	0.05deg.	6.38deg.
Momentum Compaction	0.0105	0.00867
Synchrotron Frequency	35.0kHz	34.0kHz
Energy Spread (rms)	$1.82 \times 10^{-4}$	$9.08 \times 10^{-4}$
Bunch Length (rms)	8.67ps	36.9ps
Total Klystron Output	5.2kW (150mA)	140kW (140mA)
Ramping Time	-	3 minutes
Tuner Dead Band	0.1~0.5deg.	0.1~0.5deg.
Filling Pattern	Partical (30~33x3 bunches) or (30~33x4 bunches)	



# RF Control in KARA

# RF System in KARA Storage Ring (3)

## LLRF Controller: DIMTEL LLRF9/500

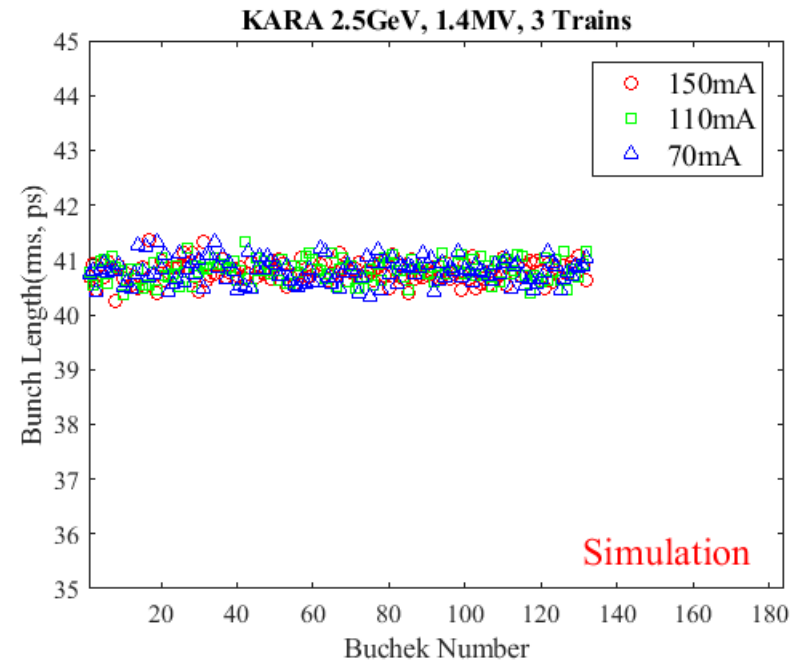
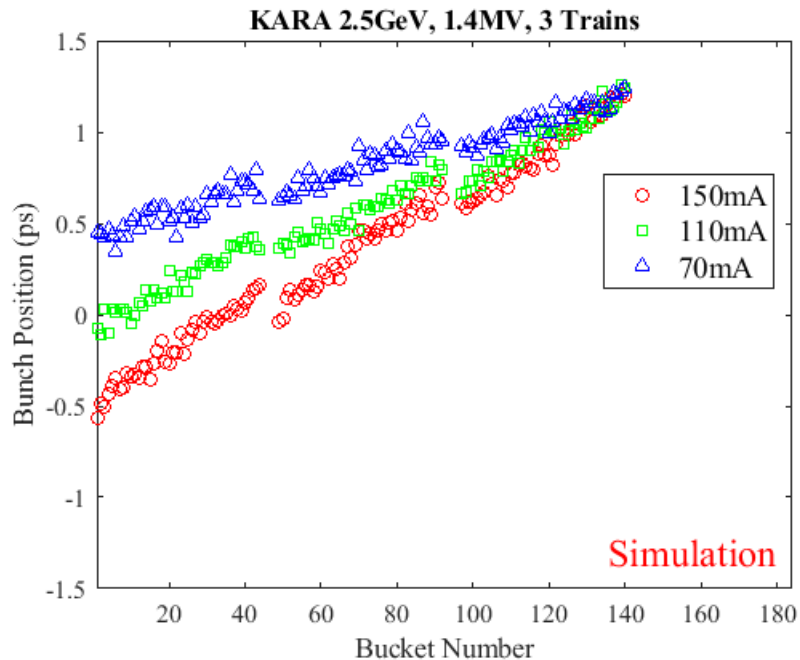


- 1-Module per 1-Station(2Cavs.)
  - Cavity pickups are vector-summed and processed in LLRF.
  - Phase adjustment between 2 stations are necessary.

Signal	Symbol	Ratio to $f_{rf}$	Frequency (MHz)
Reference	$f_{rf}$	1	499.654
IF	$f_{IF}$	$\frac{1}{12}$	41.6378
Local oscillator	$f_{LO}$	$\frac{11}{12}$	458.0162
ADC clock	$f_{ADC}$	$\frac{11}{48}$	114.5040
DAC clock	$f_{DAC}$	$\frac{11}{24}$	229.0081

# RF System in KARA Storage Ring (4)

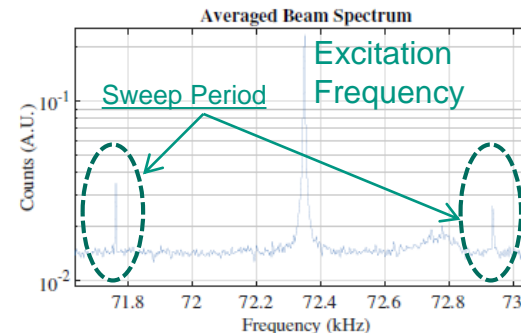
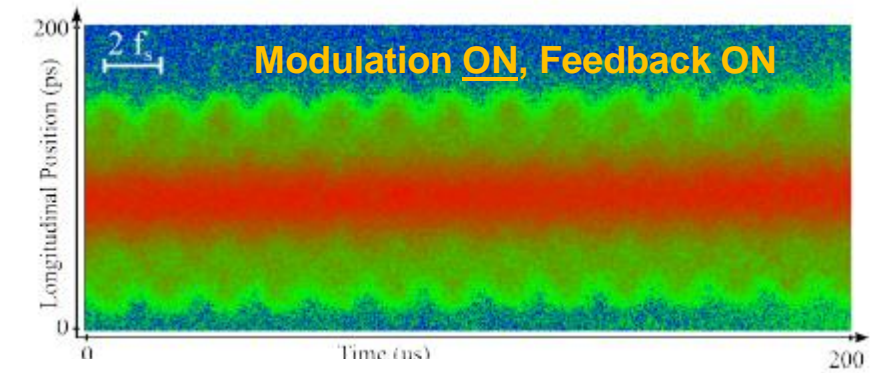
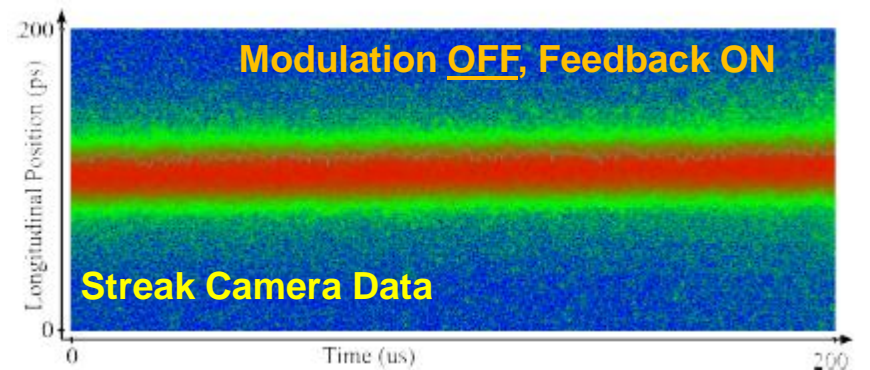
- Transient Beam Loading in Partial Filling (Simulation)
  - Bunch Arrival Timing: **1.5 ps** difference in 150 mA.
  - Natural Bunch Length **~40 ps** (rms)



Difference in the arrival timing is negligible in KARA 2.5 GeV normal operation.

# RF System in KARA Storage Ring: Operation(1)

- 2 Longitudinal Modulation Schemes
  - Modulation by Kicker Cavity
  - Phase Modulation by Main Cavities



**Additional simulation would be necessary.**

E. Blomley, M. Schedler and A-S. Müller, Proceedings of IPAC2016, p.2658-2660

- At the beam injection (**500MeV**), the kicker cavity is driven to excite quadrupole mode on the beam.
- The bunch lengthening occurs and the injection rate tends to be stabilized/improved.

# RF System in KARA Storage Ring: Operation(2)

## ■ 2 Longitudinal Modulation Schemes

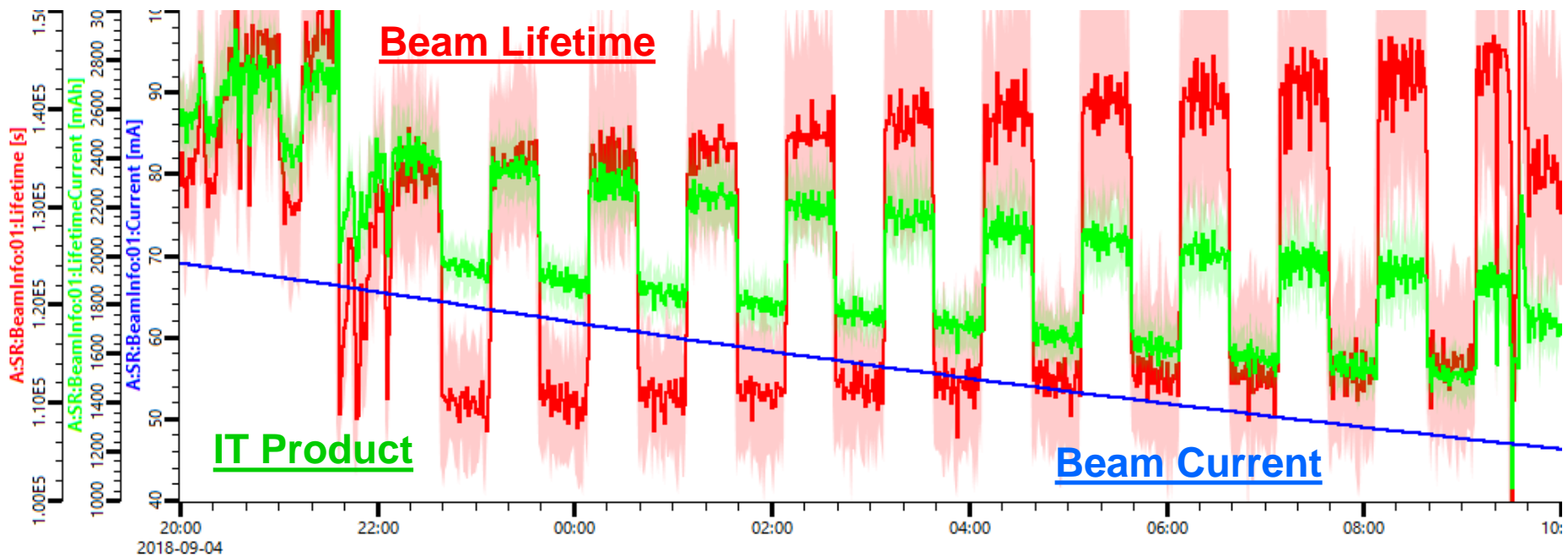
■ Modulation by Kicker Cavity

■ Phase Modulation\* by Main Cavities (R&D is now in progress)

In 2.5GeV, the kick by the kicker cavity is too weak to excite the oscillation.

We have introduced a function of the phase modulation into the KARA LLRF on September 2018.

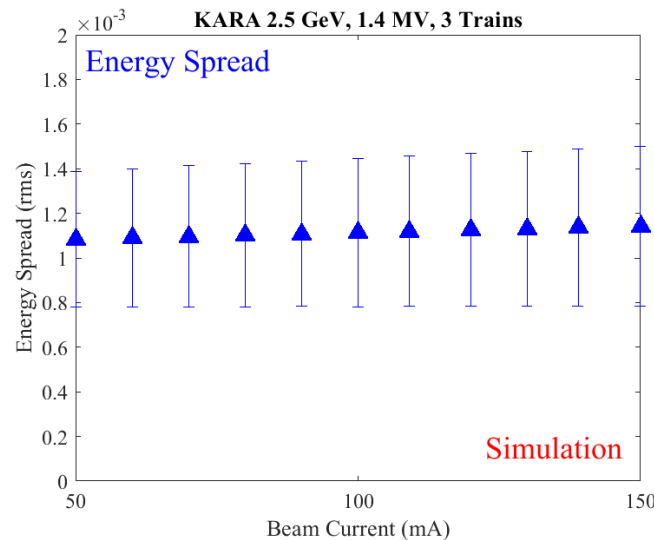
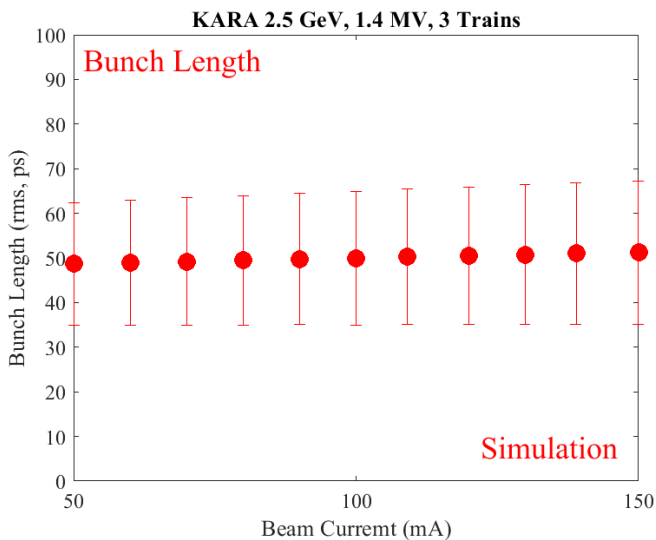
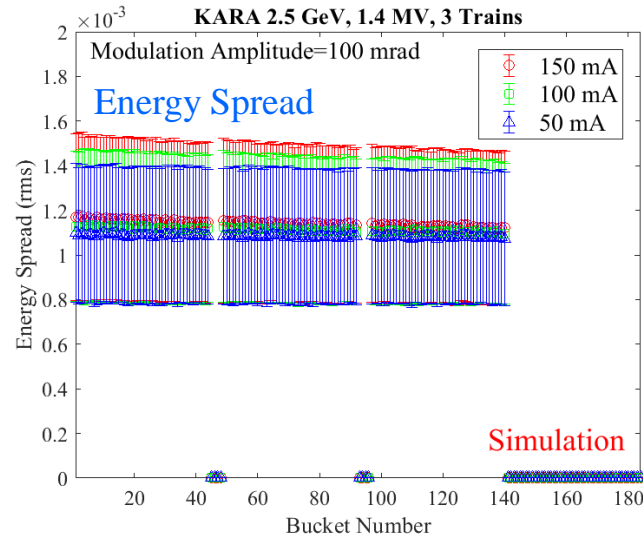
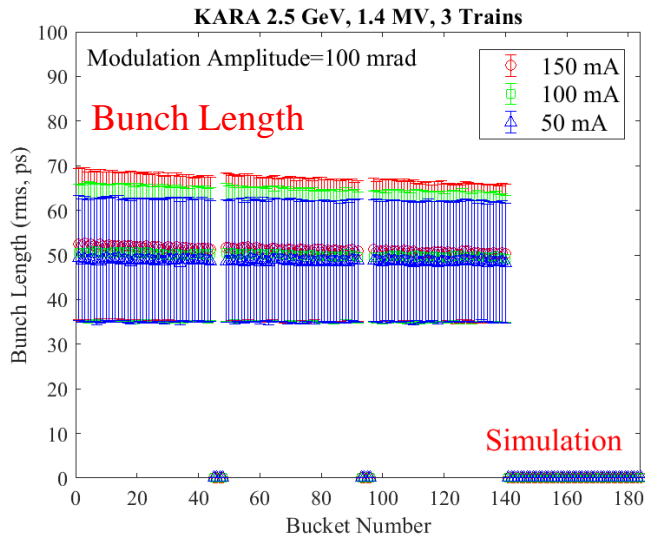
### The First Trial of RF-PM in 2.5GeV



\*S.Sakanaka et al., PRST-AB **3** 050701 (2000).



# RF System in KARA Storage Ring: Operation(3)



The experiments to find an optimized condition are now under way...

We have to check:

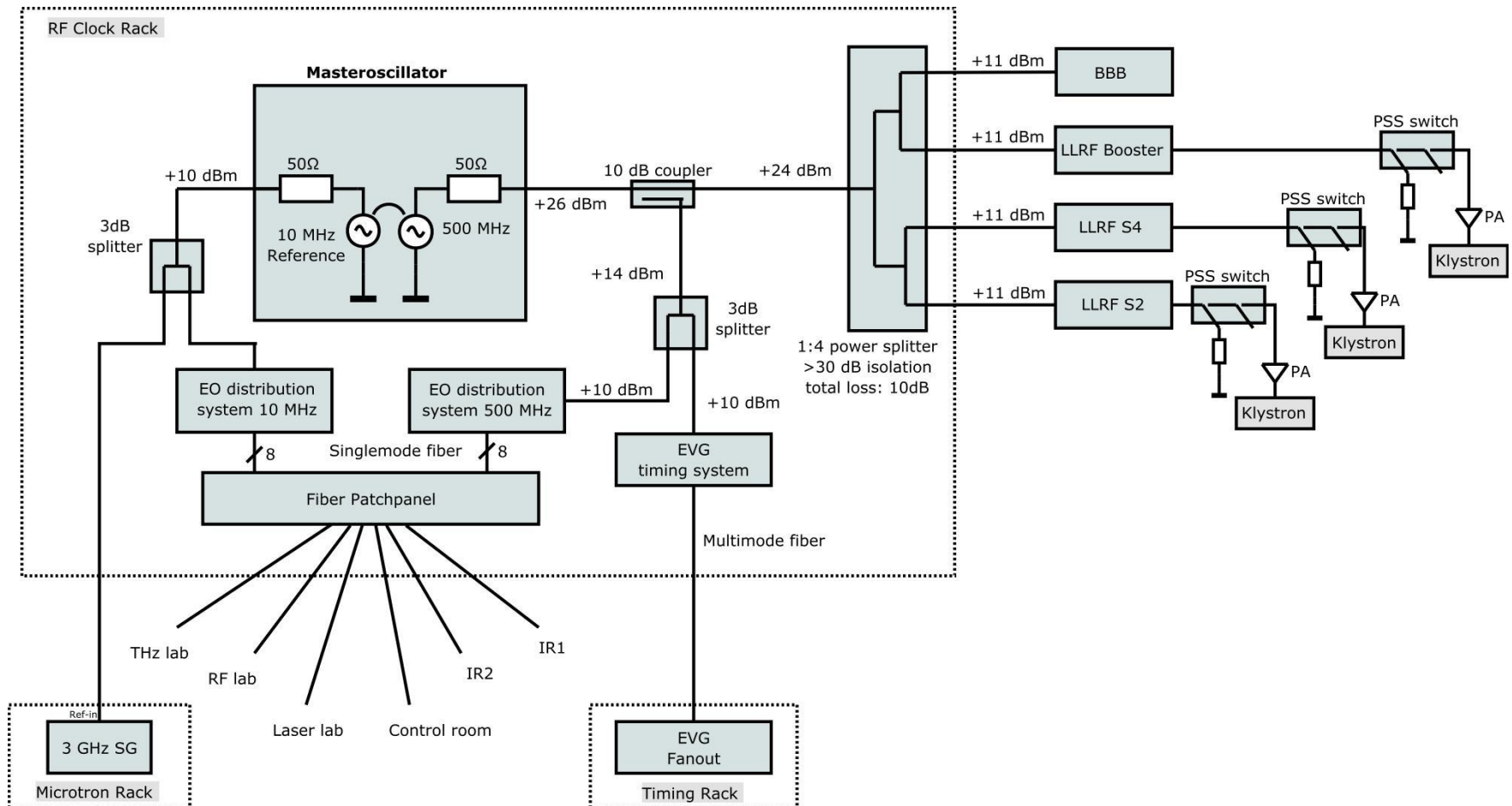
- Influence on the beamline (IDs).
- The other beam dynamics issues such as coupled bunch instabilities.

# Outlook: Running Project NOW (1)

- Renewal of RF Cabinets, Re-cabling of LLRF System
  - Re-calibration of RF power from each component is needed: power meter, calorimetry / beam measurement
- New Master Oscillator
  - Rohde&Schwarz SMA100B: Low Phase Noise...-155 dBc/Hz (7.1 femto-sec. in 500 MHz)
- New Pre-amplifiers
  - Storage Ring: 500 MHz CW  $P_{max}=50$  W
  - Microtron / FLUTE: 2.999 GHz Pulse(Rep.Rate<10 Hz)  $P_{max}=250$  W(Peak)
  - Personal Safety System Interlock: The amplifier turns off when an alarm happens.
- Renewal of Klystron Protection System
  - Now: HVPS for KLY...PLC for water&air, self-made system for other issues
  - Plan: replacing the self-made system to LLRF, optical fiber for solenoid interlock

# Outlook: Running Project NOW (2)

## Renewal of 500MHz Distribution System



# Thank you very much for your attention!



In Black Forest...



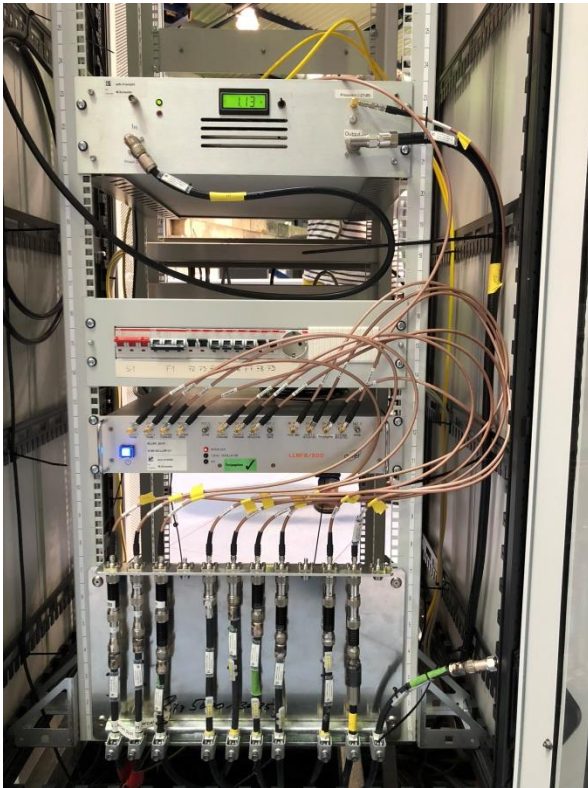
Karlsruhe Palace...



Rick(y)

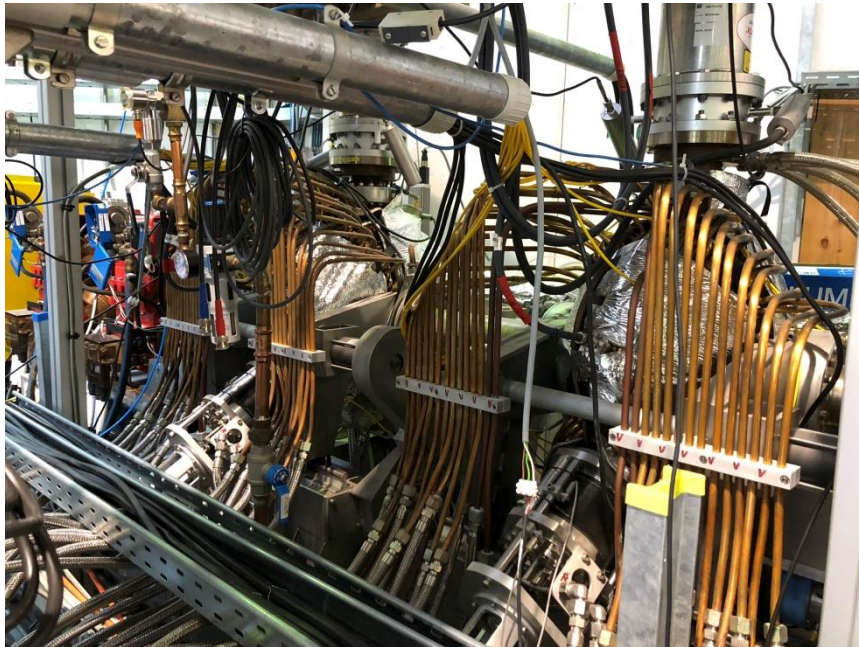
# Backups

# RF System in KARA Storage Ring (1)



- Low Level RF System (19inch,1-rack)
  - Based on DIMTEL LLRF System
  - (Klystron, Cavity tuner) control
- Klystron, Circulator and Waveguides
  - 250kW Klystron (EEV), 1Klystron/Station
  - Circulator (AFT), Magic-T ... Split into 2 ports

# RF System in KARA Storage Ring (2)



## ■ RF Cavity (2Cavs/Station)

- ELETTRA Type Cavity
- $Q_0 \sim 40000$ ,  $R_{sh} \sim 3.3M\Omega$
- $V_c = 350kV/Cavity$  (@2.5GeV)



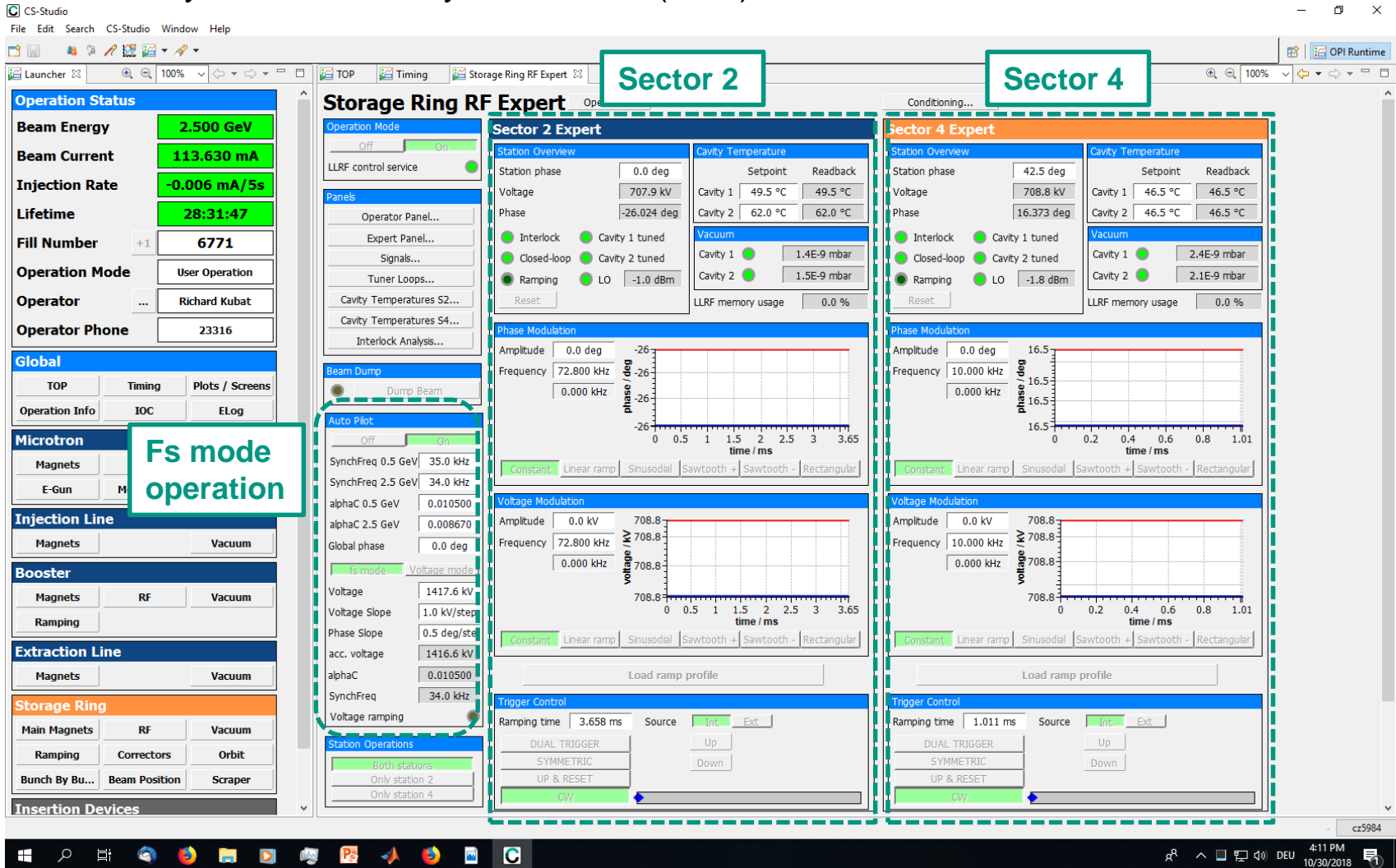
## ■ Cavity Cooling System

- 1-Chiller for each Cavity
- Settled Temp. = 40~50degree
- Controllable for each Cavity independently

**The RF System in KARA is stably operated in daily beamtime.**

# RF System in KARA Storage Ring (3)

## Control System: Control System Studio (CSS) & EPICS



**Operation Status**

- Beam Energy: 2.500 GeV
- Beam Current: 113.630 mA
- Injection Rate: -0.006 mA/5s
- Lifetime: 28:31:47
- Fill Number: 6771
- Operation Mode: User Operation
- Operator: Richard Kubat
- Operator Phone: 23316

**Global**

- TOP | Timing | Plots / Screens
- Operation Info: IOC | ELog

**Microtron**

- Magnets | E-Gun

**Injection Line**

- Magnets | Vacuum

**Booster**

- Magnets | RF | Vacuum
- Ramping

**Extraction Line**

- Magnets | Vacuum

**Storage Ring**

- Main Magnets | RF | Vacuum
- Ramping | Correctors | Orbit
- Bunch By Bu... | Beam Position | Scraper

**Insertion Devices**

**Storage Ring RF Expert**

**Sector 2 Expert**

Station Overview: Station phase 0.0 deg, Voltage 707.9 kV, Phase -26.024 deg

Cavity Temperature: Cavity 1 49.5 °C, Cavity 2 62.0 °C

Vacuum: Cavity 1 1.4E-9 mbar, Cavity 2 1.5E-9 mbar

Phase Modulation: Amplitude 0.0 deg, Frequency 72.800 kHz

Voltage Modulation: Amplitude 0.0 kV, Frequency 72.800 kHz

Trigger Control: Ramping time 3.658 ms

**Sector 4 Expert**

Station Overview: Station phase 42.5 deg, Voltage 708.8 kV, Phase 16.373 deg

Cavity Temperature: Cavity 1 46.5 °C, Cavity 2 46.5 °C

Vacuum: Cavity 1 2.4E-9 mbar, Cavity 2 2.1E-9 mbar

Phase Modulation: Amplitude 0.0 deg, Frequency 10.000 kHz

Voltage Modulation: Amplitude 0.0 kV, Frequency 10.000 kHz

Trigger Control: Ramping time 1.011 ms

**Auto Pilot**

Off | On

SynchFreq 0.5 GeV: 35.0 kHz

SynchFreq 2.5 GeV: 34.0 kHz

alphaC 0.5 GeV: 0.010500

alphaC 2.5 GeV: 0.008670

Global phase: 0.0 deg

**Fs mode operation**

Voltage: 1417.6 kV

Voltage Slope: 1.0 kV/step

Phase Slope: 0.5 deg/step

acc. voltage: 1416.6 kV

alphaC: 0.010500

SynchFreq: 34.0 kHz

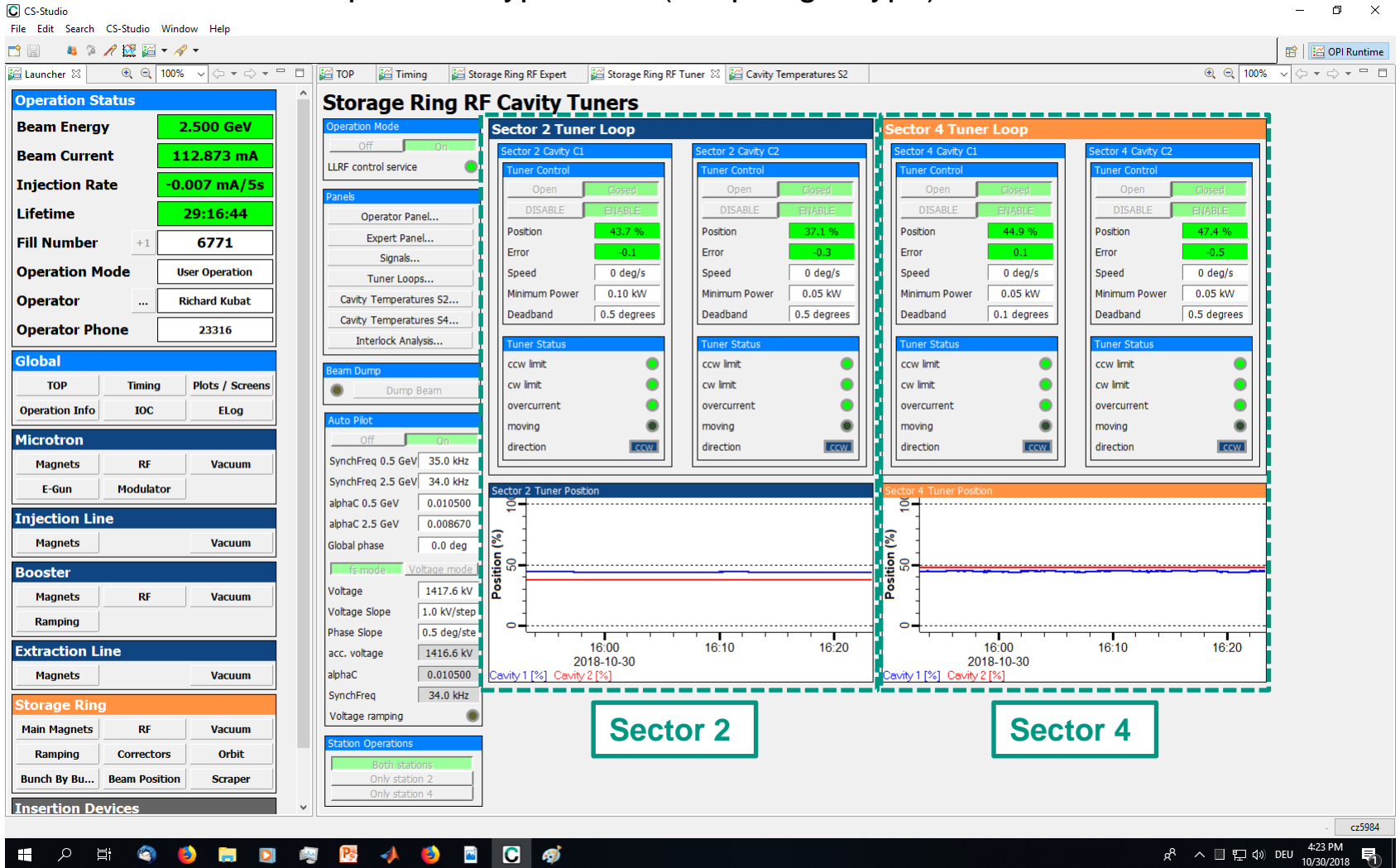
Voltage ramping

Station Operations: Both stations, Only station 2, Only station 4



# RF System in KARA Storage Ring (4)

## Tuner Control: Compression-type tuner (not plunger-type)



**Operation Status**

- Beam Energy: 2.500 GeV
- Beam Current: 112.873 mA
- Injection Rate: -0.007 mA/5s
- Lifetime: 29:16:44
- Fill Number: 6771
- Operation Mode: User Operation
- Operator: Richard Kubat
- Operator Phone: 23316

**Storage Ring RF Cavity Tuners**

**Sector 2 Tuner Loop**

Parameter	Sector 2 Cavity C1	Sector 2 Cavity C2
Tuner Control	Open: Closed	Open: Closed
DISABLE	ENABLE	ENABLE
Position	43.7 %	37.1 %
Error	-0.1	-0.3
Speed	0 deg/s	0 deg/s
Minimum Power	0.10 kW	0.05 kW
Deadband	0.5 degrees	0.5 degrees

**Sector 4 Tuner Loop**

Parameter	Sector 4 Cavity C1	Sector 4 Cavity C2
Tuner Control	Open: Closed	Open: Closed
DISABLE	ENABLE	ENABLE
Position	44.9 %	47.4 %
Error	0.1	-0.5
Speed	0 deg/s	0 deg/s
Minimum Power	0.05 kW	0.05 kW
Deadband	0.1 degrees	0.5 degrees

**Position Graphs**

**Sector 2 Tuner Position**

Position (%) vs Time (2018-10-30)

**Sector 4 Tuner Position**

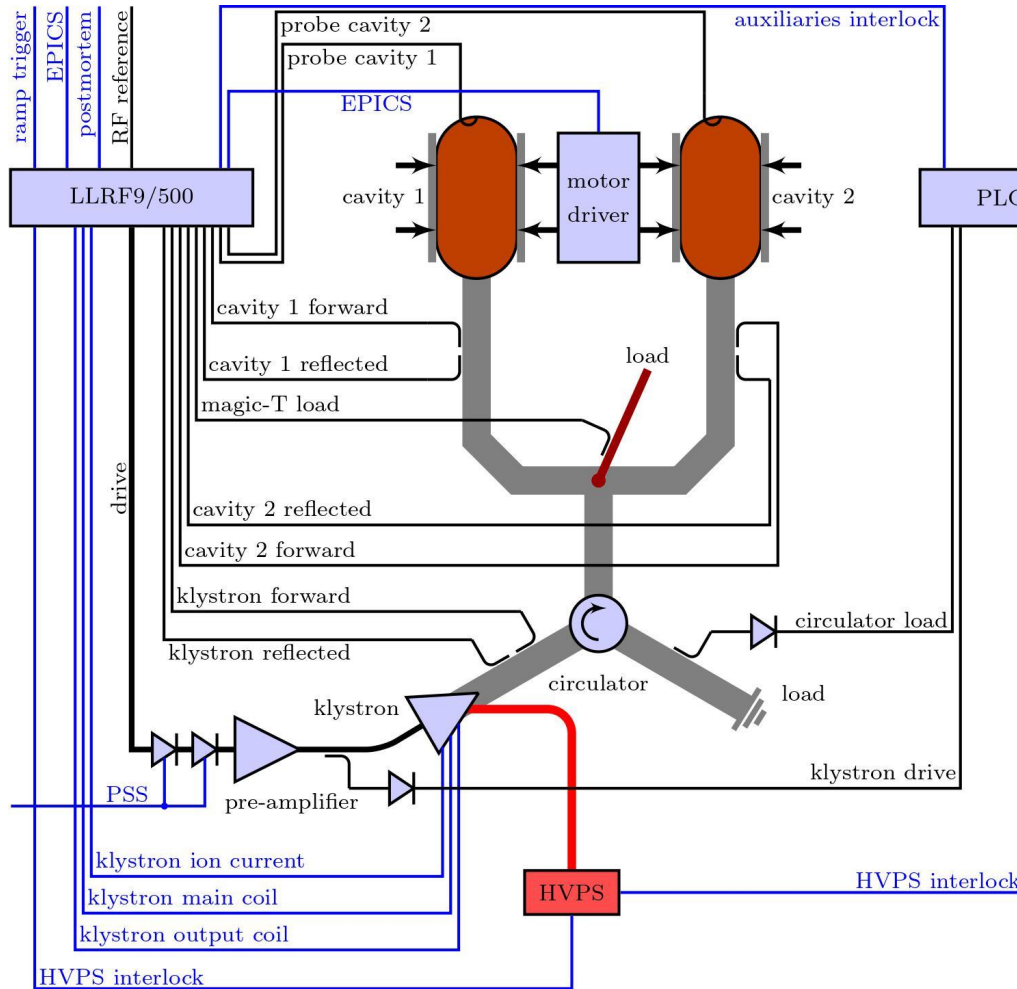
Position (%) vs Time (2018-10-30)

**Station Operations**

- Both stations
- Only station 2
- Only station 4

# RF System in KARA Storage Ring (2)

## RF Control System in KARA



### LLRF Controller: DIMTEL LLRF9/500



Signal	Symbol	Ratio to $f_{rf}$	Frequency (MHz)
Reference	$f_{rf}$	1	499.654
IF	$f_{IF}$	$\frac{1}{12}$	41.6378
Local oscillator	$f_{LO}$	$\frac{11}{12}$	458.0162
ADC clock	$f_{ADC}$	$\frac{11}{48}$	114.5040
DAC clock	$f_{DAC}$	$\frac{11}{24}$	229.0081

- 1-Module per 1-Station(2Cavs.)
  - Cavity pickups are vector-summed and processed in LLRF.
  - Phase adjustment between 2 stations are necessary.