HB2016
57th ICFA Advanced Beam Dynamics Workshop on
High-Intensity and High-Brightness Hadron Beams
Malmö, Sweden, 3-8 July 2016

Operational Experience at KOMAC

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on behalf of the KOMAC team

7 July, 2016

KOMAC, KAERI

KAERI

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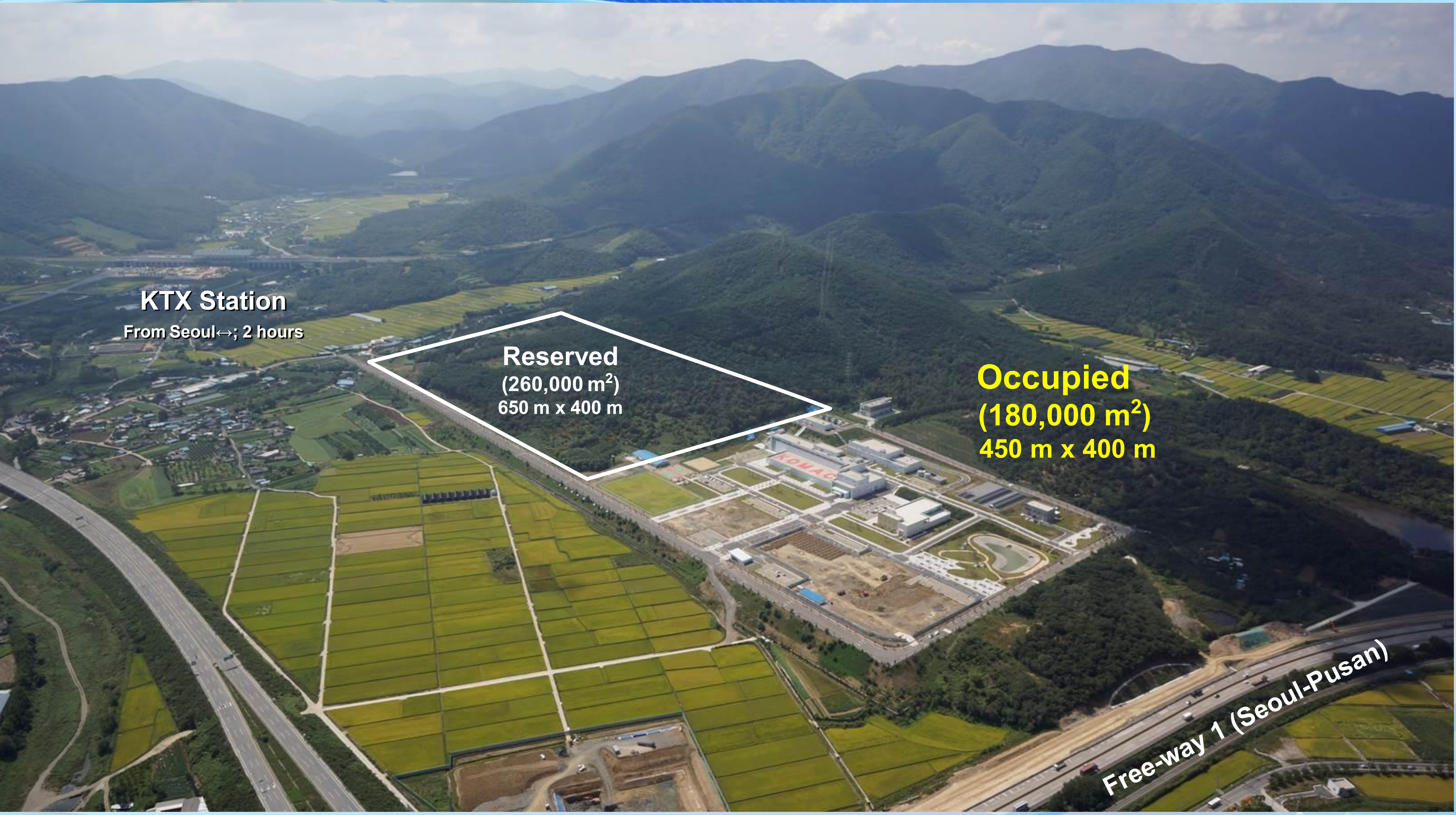
Outline

- Introduction
- 100-MeV Linac & Beam Lines
- Operational Issues
- Summary

KOMAC Site : Gyeong-ju, Korea



Main Facility

Linac and Beam Lines

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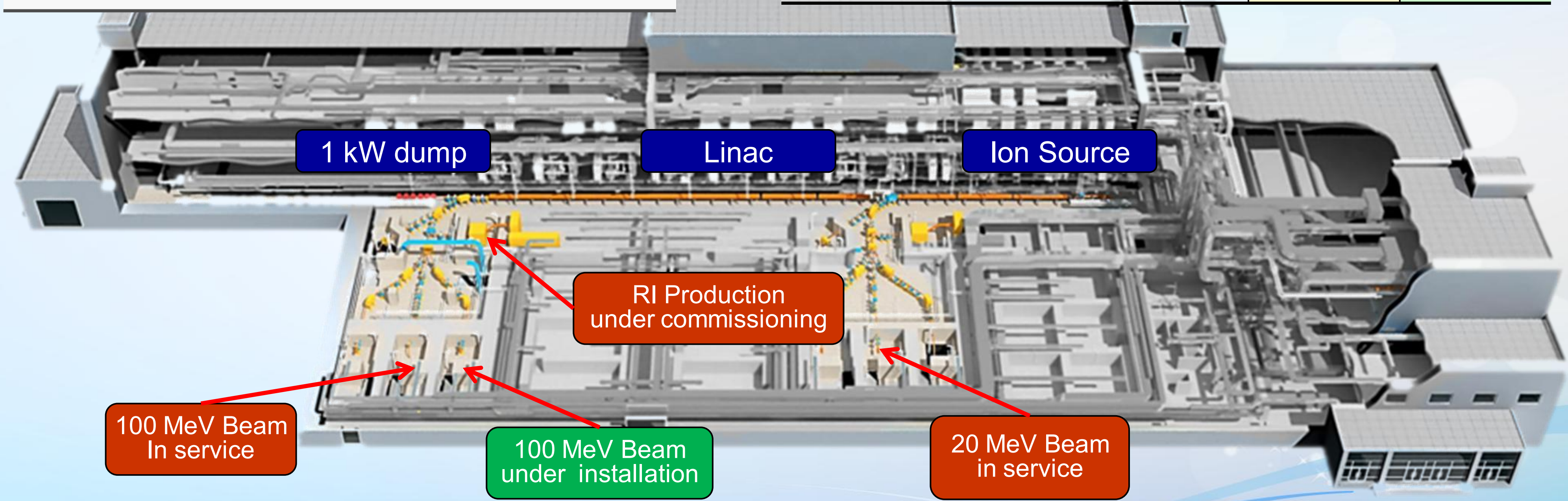
Features of KOMAC 100-MeV linac

- 50-keV Injector (Ion source + LEBT)
- 3-MeV RFQ (4-vane type)
- 20 & 100-MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160



Beam power is being ramped up with target room preparation

Accelerator Development

- Developed proton linac technologies
  - 2.45-GHz Microwave ion source
  - 350-MHz RFQ
  - 350-MHz DTL
  - 700-MHz Elliptical SC cavity for future
  - Digital LLRF and EPICS

5-cell SCC prototyping

- Built KOMAC 100-MeV proton linac with domestic companies

DTL

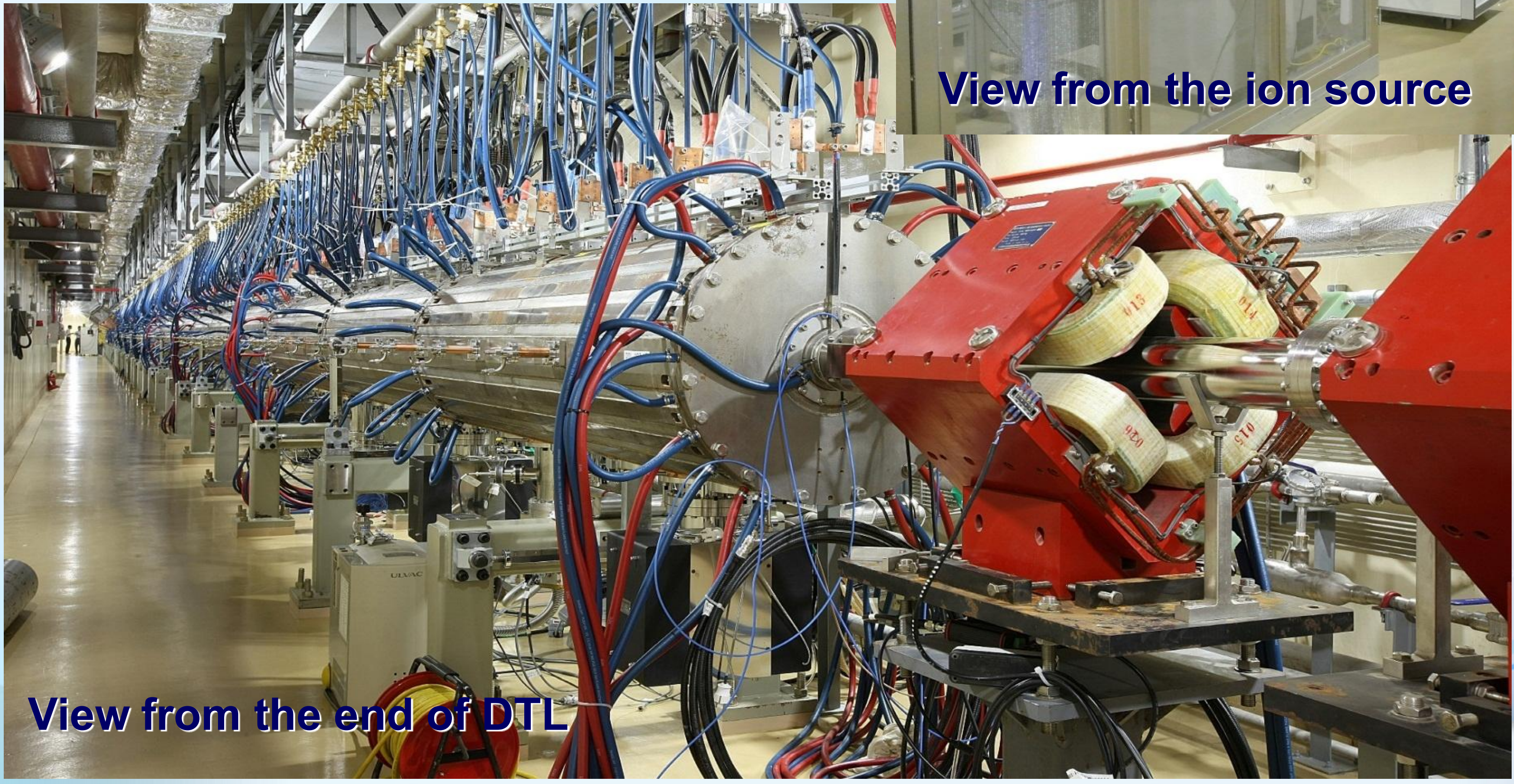
Ion source

RFQ

100-MeV proton linac

- Tunnel : 100 m
- 100-MeV linac : 75 m

View from the ion source



View from the end of DTL

Linac Configuration

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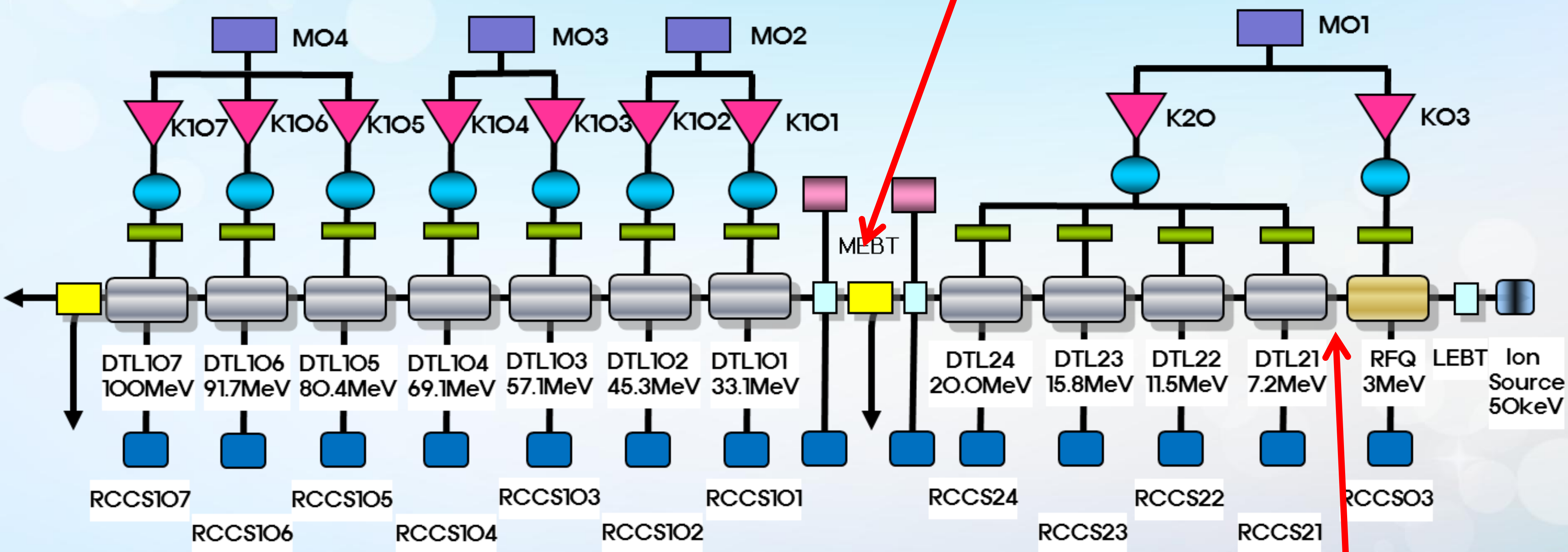
- 4 modulators drive 9 klystrons (350 MHz, 1.6 MW)
- Modulators: 3-set of 5.8 MW and 1-set of 8.7 MW

- MEBT @ 20 MeV for switch magnet

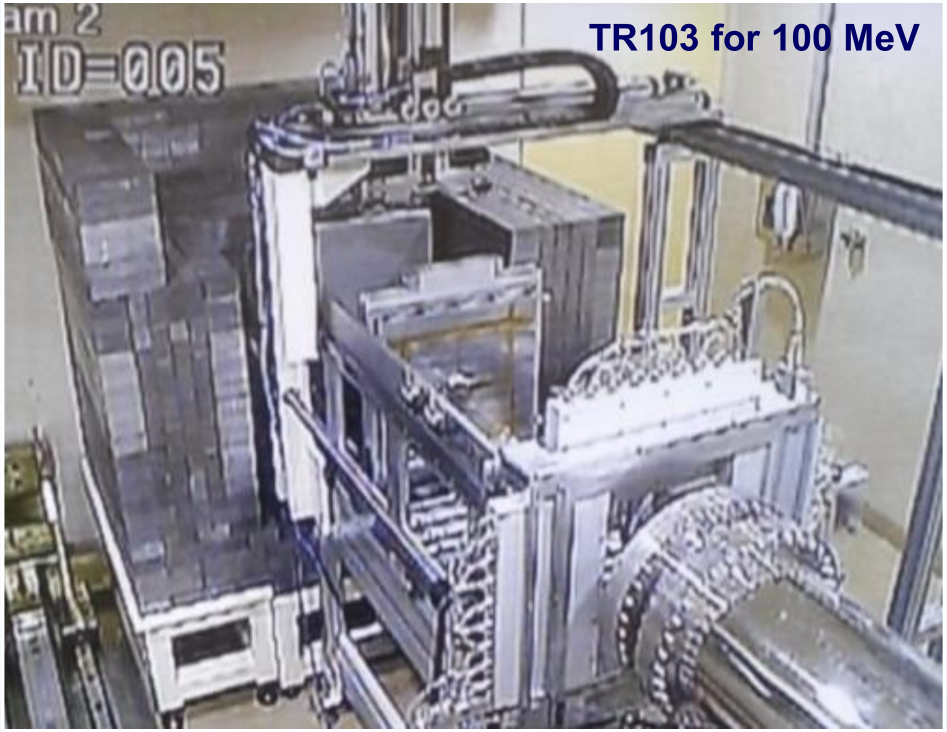


- No MEBT between RFQ and DTL (as close as possible)

Target Room

- 2 beam lines and 2 target rooms are installed and in services
  - 1 for 20 MeV, 1 for 100 MeV
- Irradiation: in air through 0.5-mm Al-Be alloy window

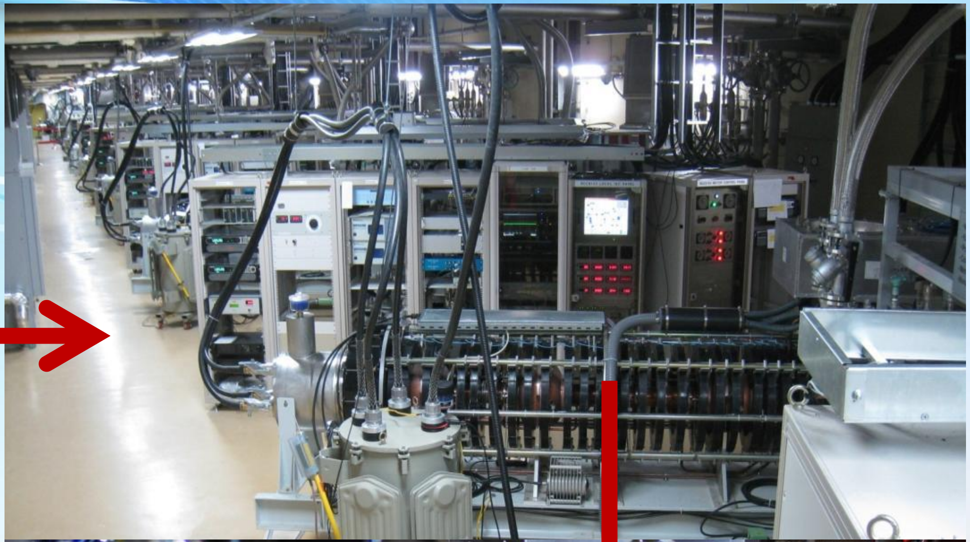
Beam line



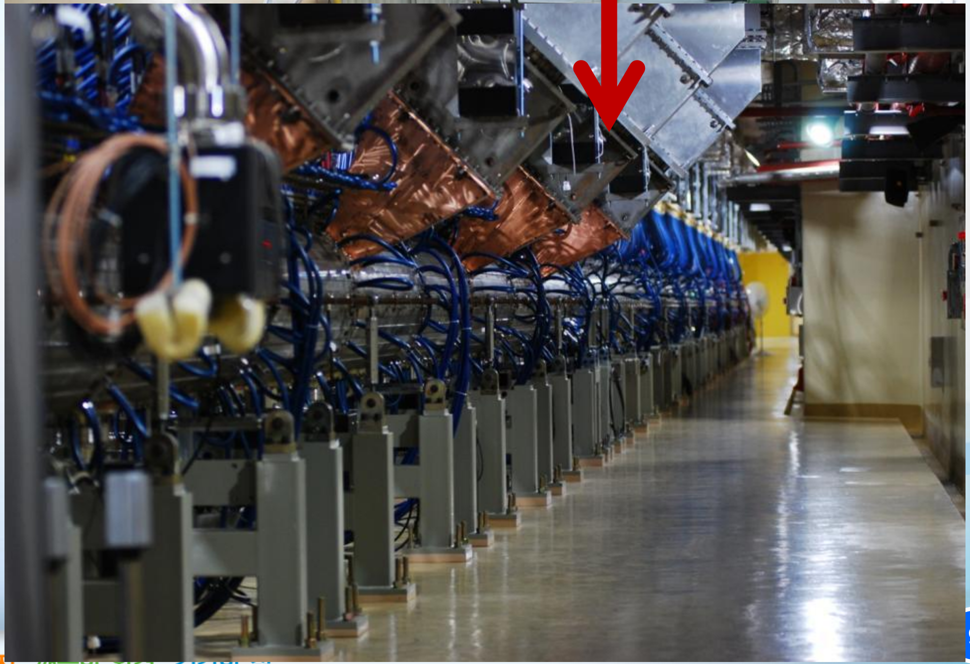
Target room

HPRF

Klystrons on 2nd floor



Modulators on 3rd floor



Linac in tunnel

Control Room & Operator

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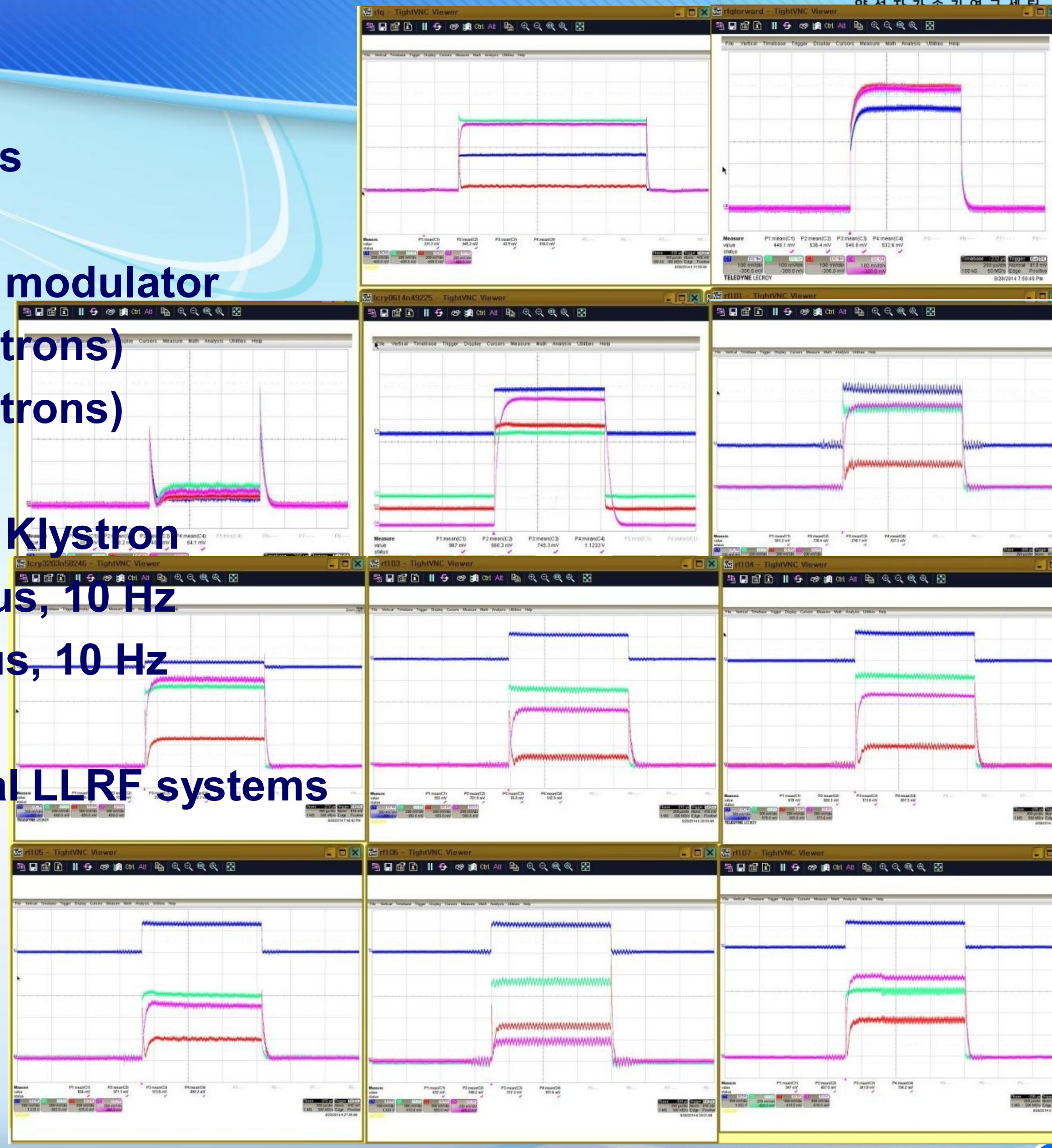
- EPICS based control system
  - Accelerator / Utilities / PSIS / RMS are controlled in the main control room
- Operators/shift : 2 for accelerator, 2 for beam service in target room

RF Power Conditioning



- Number of HPRF systems : 9 sets

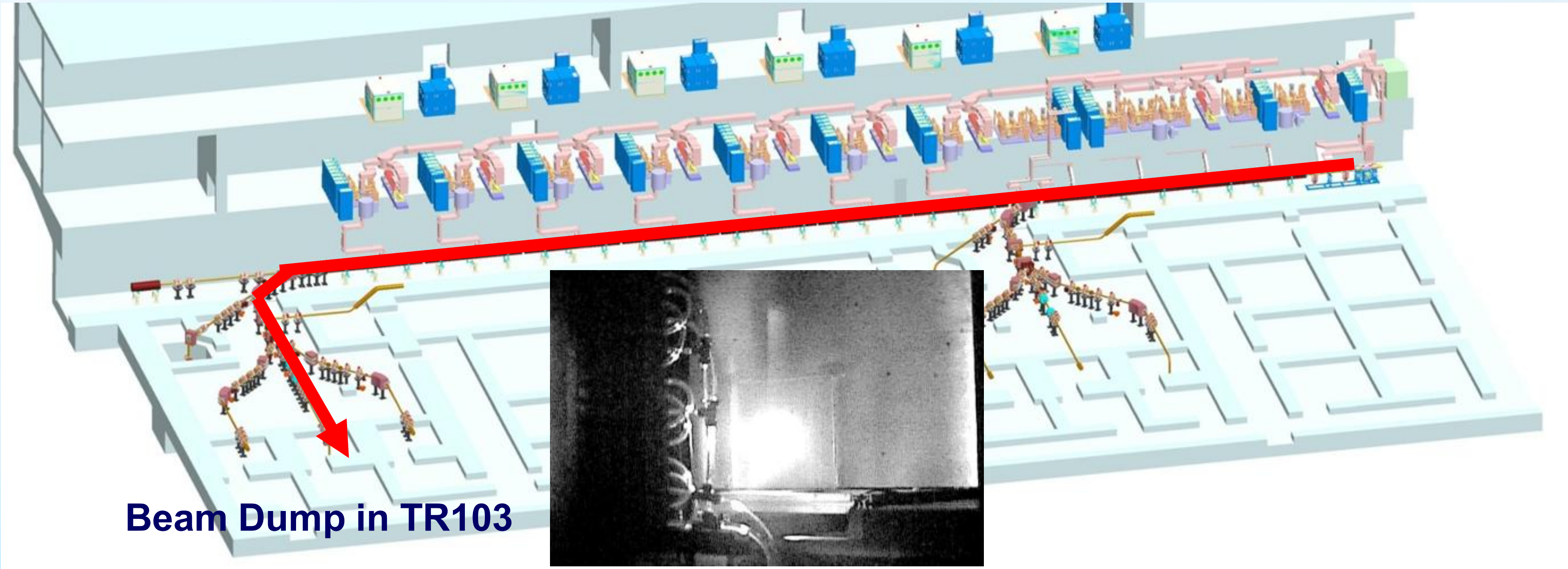
- Nominal operation conditions of modulator
  - 5 MW @ 1 ms, 10 Hz (for 2 klystrons)
  - 7 MW @ 1 ms, 10 Hz (for 3 klystrons)

- Nominal operation conditions of Klystron
  - RFQ Klystron : 500 kW @ 550 us, 10 Hz
  - DTL Klystron : 1.2 MW @ 700 us, 10 Hz

- RF system is controlled by digital LLRF systems

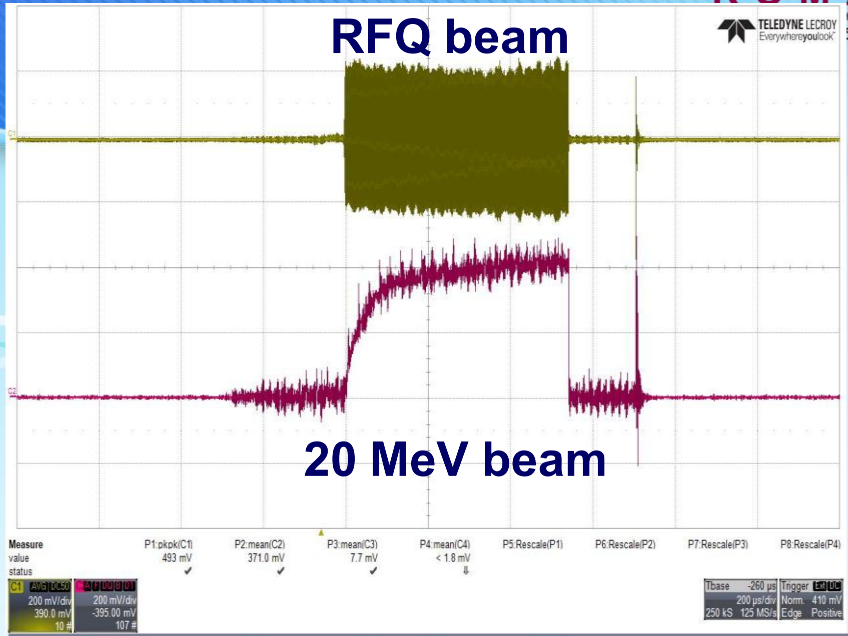
Commissioning in 2013

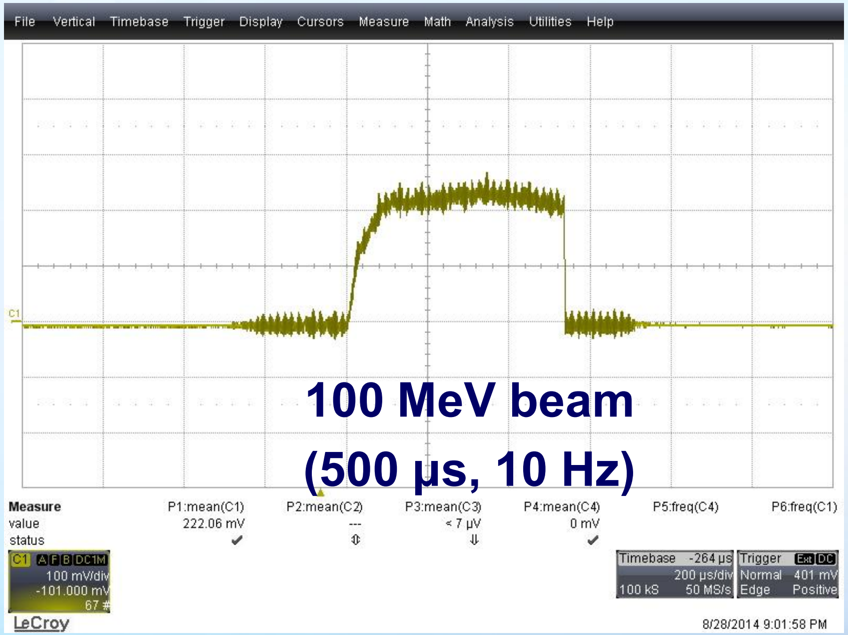
- RF set point was tuned by
  - Scanning beam phase by BPM
  - Monitoring radiation along the linac and in the target room
- Commissioning in 2013
  - Delivered 1-kW beam into TR103 in July, 2013
  - Checked beam energy change by turning off 7 DTL tanks one-by-one
- Operation license from the Nuclear Safety and Security Commission of Korea
- Started user beam services with 1-kW beam from July 22, 2013

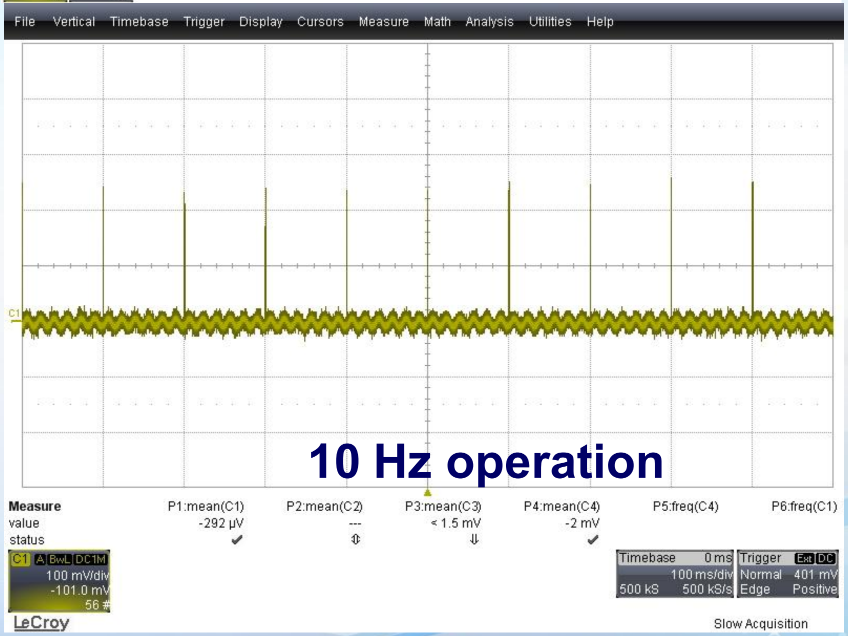


Commissioning in 2014

- Goal : 10-kW beam @ 100 MeV
- Delivered 10-kW beam in August 2014:
  550 μs, 10 Hz
- Normal operation with 10-kW
  with revised operation license







RF Network Issue

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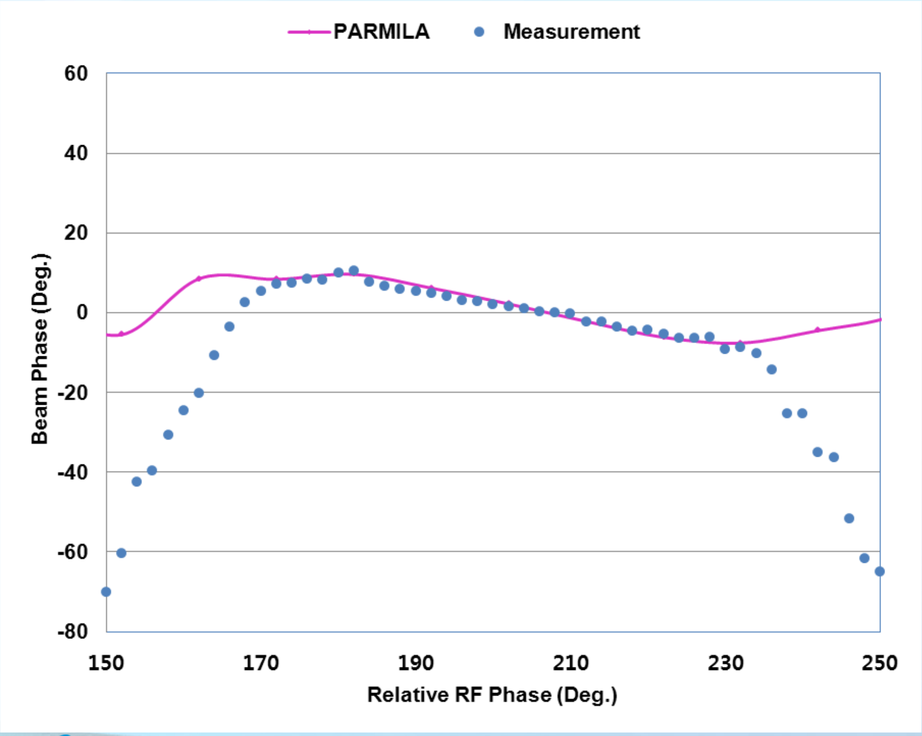
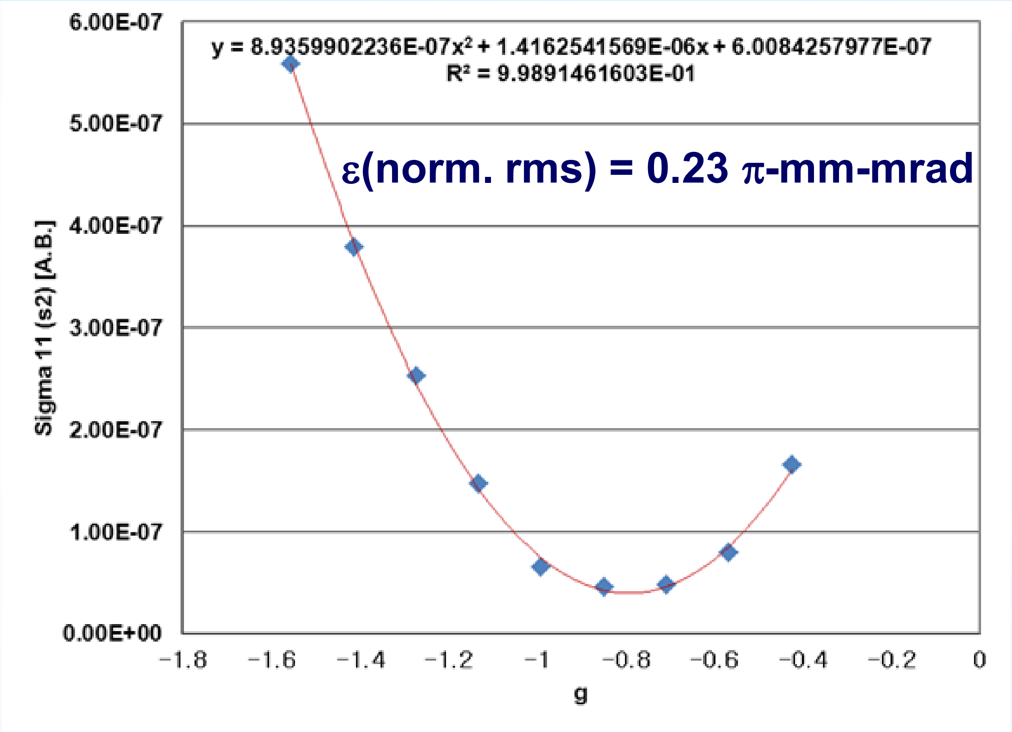
- **4 DTL tanks driven by 1 klystron**
  - Feeding equal power into each of 4 tanks was accomplished from design stage
  - Phase of each RF transmission line is adjusted by separated phase shifter
  - Resonant frequency of each tank is controlled by separated RCCS
- **Works well so far**



Phase scan with 20 MeV beam



Quad scan with 20 MeV beam

Management of the Component

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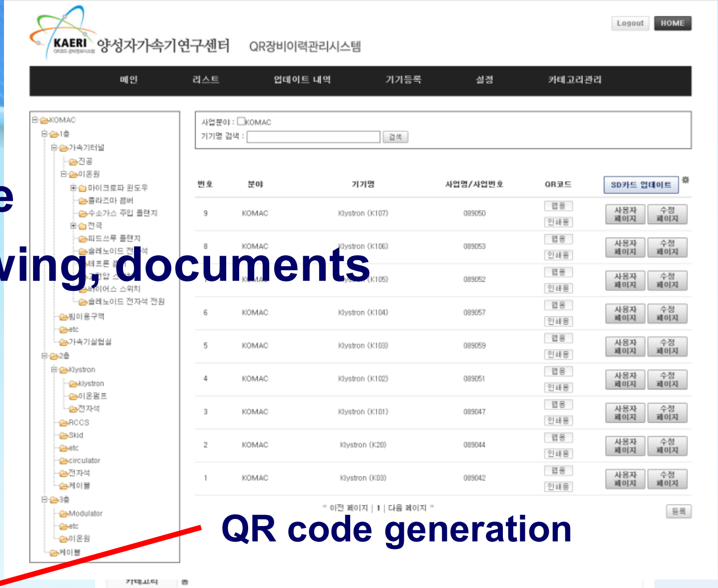
- QR code & Tablet based system
- Spare parts management, preventive maintenance
- Including specification, maintenance history, drawing, documents



QR code generation

QR code scan with Tablet

(Possible scan distance depends on QR code size)

General information

Maintenance history

Component information

Summary of Operation History

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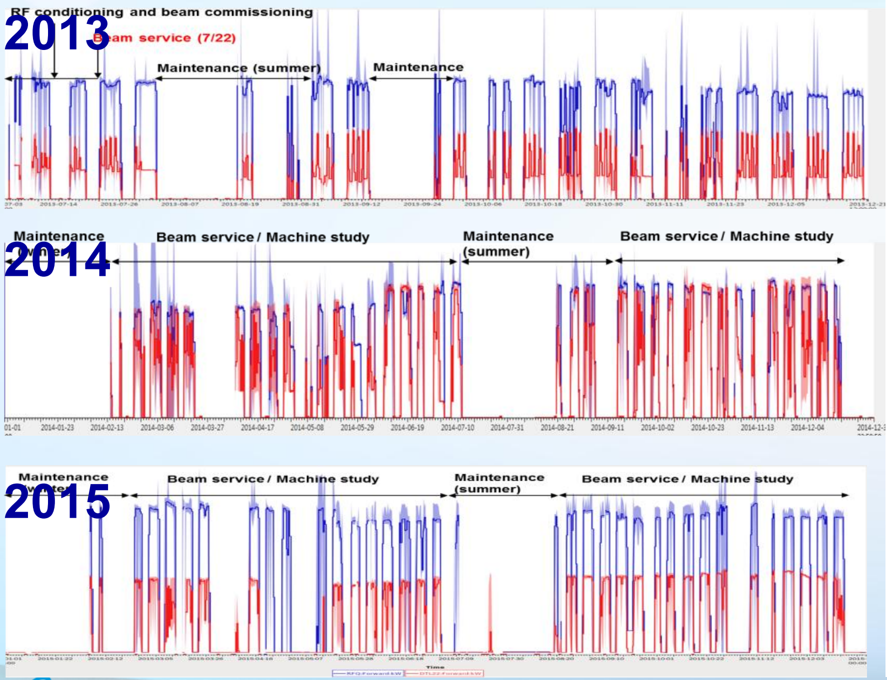
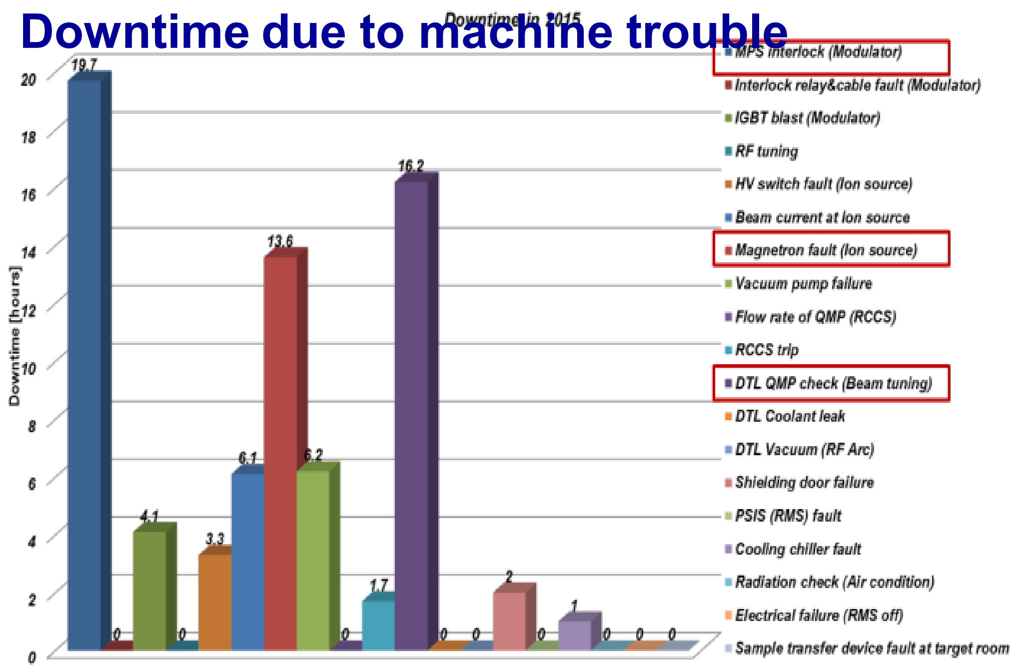
- ❖ Operated in weekly-based schedule through a yearly plan
  - ▪ Beam service: Monday 13:00 ~ Friday 12:00
- ❖ Operation statistics

	2013	2014	2015	Sum
Operation hours	2,290	2,863	2,948	8,101
Beam service	432.7	700.9	704.1	1,837.7
Availability	82.0%	86.3 %	90.5%	86.8%



Downtime due to machine trouble

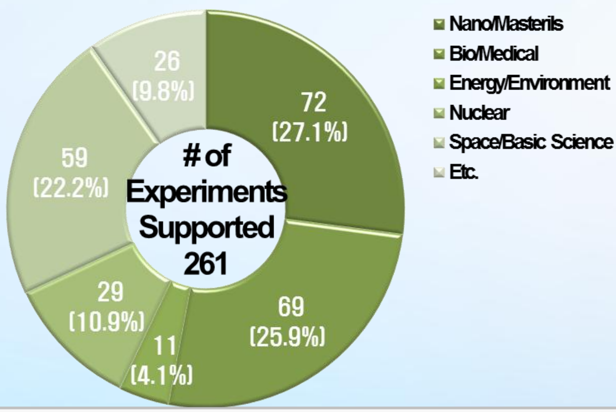


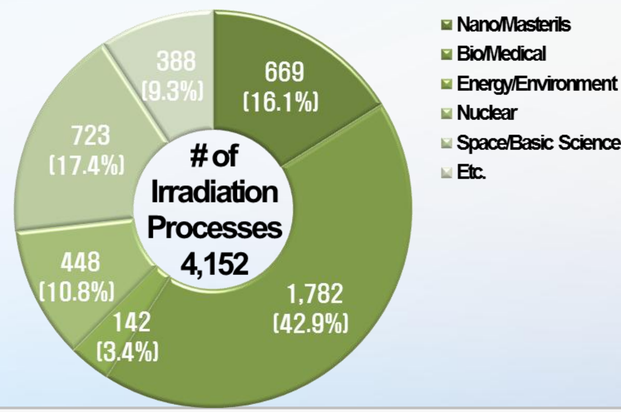
Beam Service Stat. (July 2013 ~ Dec. 2015)

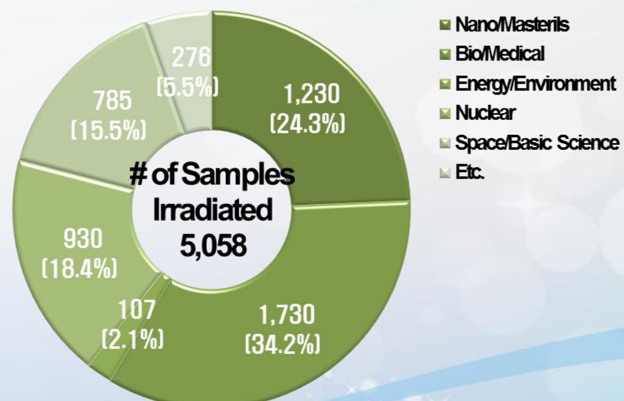
❖ Increasing beam time requests

Year	Research Projects			Beam Time (day)			Users
	Proposed	Served	Ratio(%)	Requested	Served	Ratio(%)	
2013	56	39	69.6	182	96	52.7	84
2014	121	103	85.1	275	203	73.8	223
2015	153	124	81.0	311	193	61.2	349
Sum	330	261	79.1	768	460	59.9	656

- **R&D Fields: Nano/Materials(26.4%), Bio/medical(26.4%), Space/Basic Sci.(22.6%) etc.**







- **KOPUA: Korea Proton Beam User Association (Self-organized user network) reviews proposals & allocates beam-time**

New Beam Line (1) under commissioning

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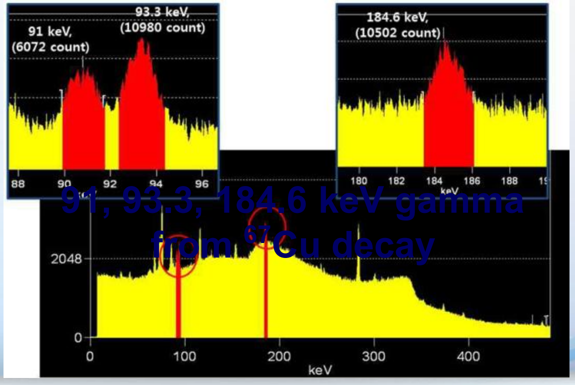
❖ RI Beamline: 100-MeV Proton

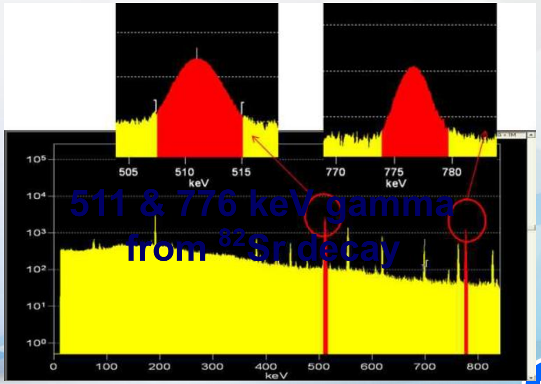
- **Application**
  - RI production: Cu-67, Sr-82, etc.
- **Proton beam**
  - Energy: 33 ~ 100 MeV
  - Beam power: 30 kW @ 100MeV
- **Status**
  - Completed installation: Dec. 2015
  - Under Commissioning
  - Operation: September 2016

Target Preparation

^{68}Zn(p,2p)^{67}**Cu**



^{nat}Rb(p,x)^{82}**Sr**



User Beam Requirements

- Users from various fields
  (nano/materials, bio/medicine, space, basic science and so on)

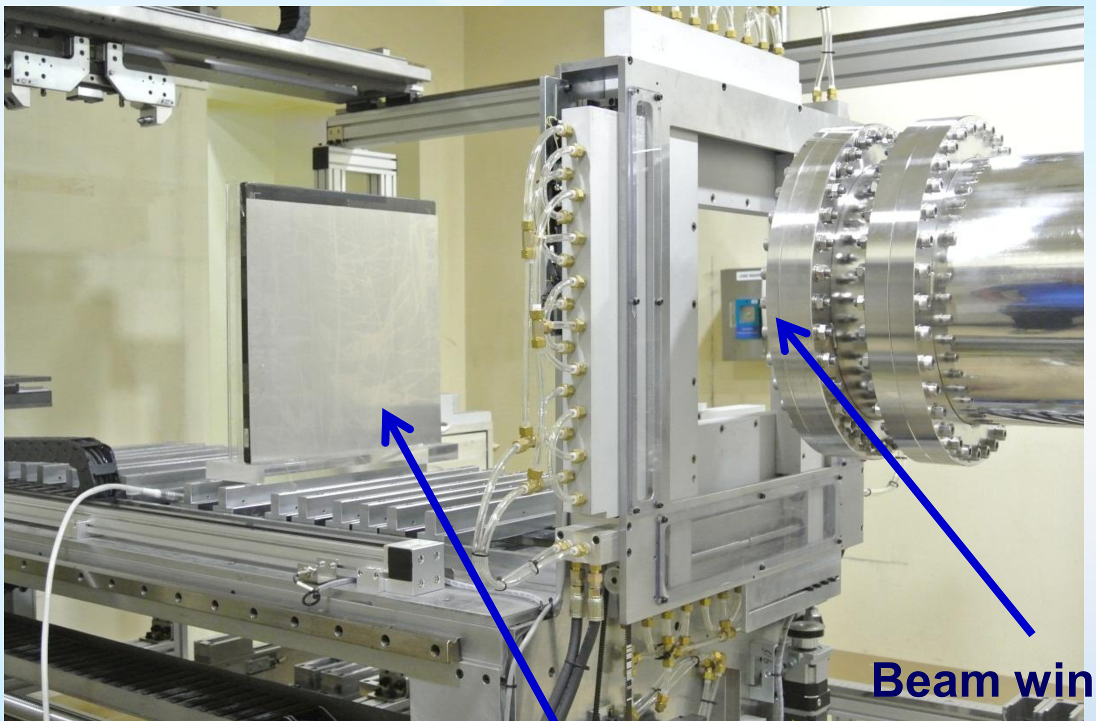
- Their requirements
  - Energy: 20 MeV ~ 100 MeV (controlled by DTL tank RF on / off)
  - Peak current: 0.1 ~ 20 mA (controlled by ion source rf power and defocusing)
  - Beam size: 5 mm ~ 300 mm (controlled by QMs in beam lines)
  - Pulse width: 50 μs ~ 5 ms
  - Number of pulses: 1 ~ ∞
  - Dose uniformity: < ±5%
  - Dose stability: < ±5%
  - Flux: $1 \times 10^2 \sim 1 \times 10^8/cm^2$

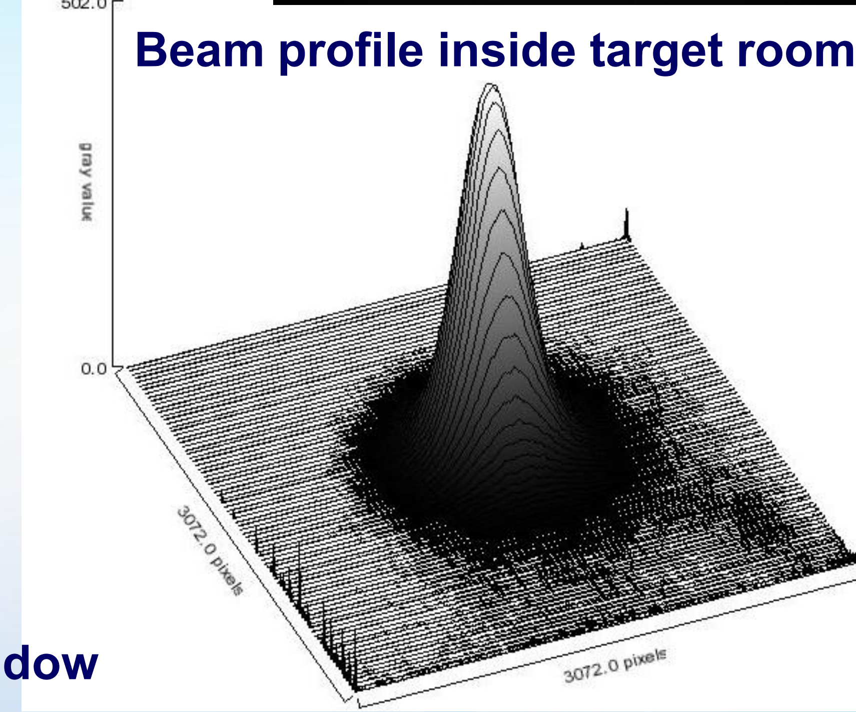
  Especially single shot operation after long preparation is not easy.

- In some cases, the irradiation conditions are not clear.
  They decide the conditions during beam service.

Beam Profile at Target Room

- User requirement for beam size: max. 300-mm diameter
- Monitoring beam profile
  - Flat panel detector with CsI scintillator
  - Panel size 430 mm × 430 mm, pixel size 139 μm





Beam Service Issue

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- Current beam service
  - Frequent shielding door open-close operation (20~30 / day)
    -> failure in the shielding door system (weight 6 Ton)
- Grouping high-flux beam services and low-flux beam services and to install low-flux beam line without shielding door

Shielding door of a 100 MeV target room

A failure of the shielding door controller

New Beam Line (2) under installation

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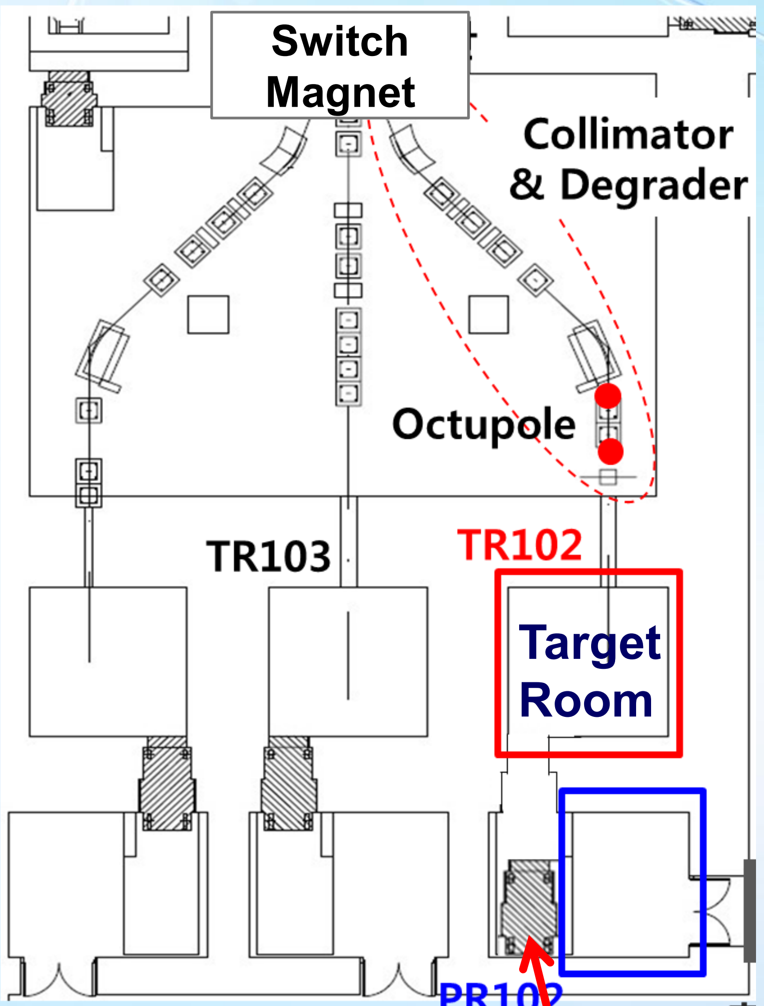
❖ Low-flux beamline: 100-MeV proton



- **Application**
  - Space radiation simulation, Detector R&D, etc.
- **Proton beam**
  - Beam power: 8 kW @ 100MeV (1mA peak, duty 8%)
- **Requirements**
  - Energy: 33 ~ 100 MeV
  - Flux: $1\times10^{2} \sim 1\times10^{8}/cm^{2}$ @ peak
  - Uniformity: < 5%, 100 mm X 100 mm
- **Status**
  - Under installation & to be commissioned in 2017

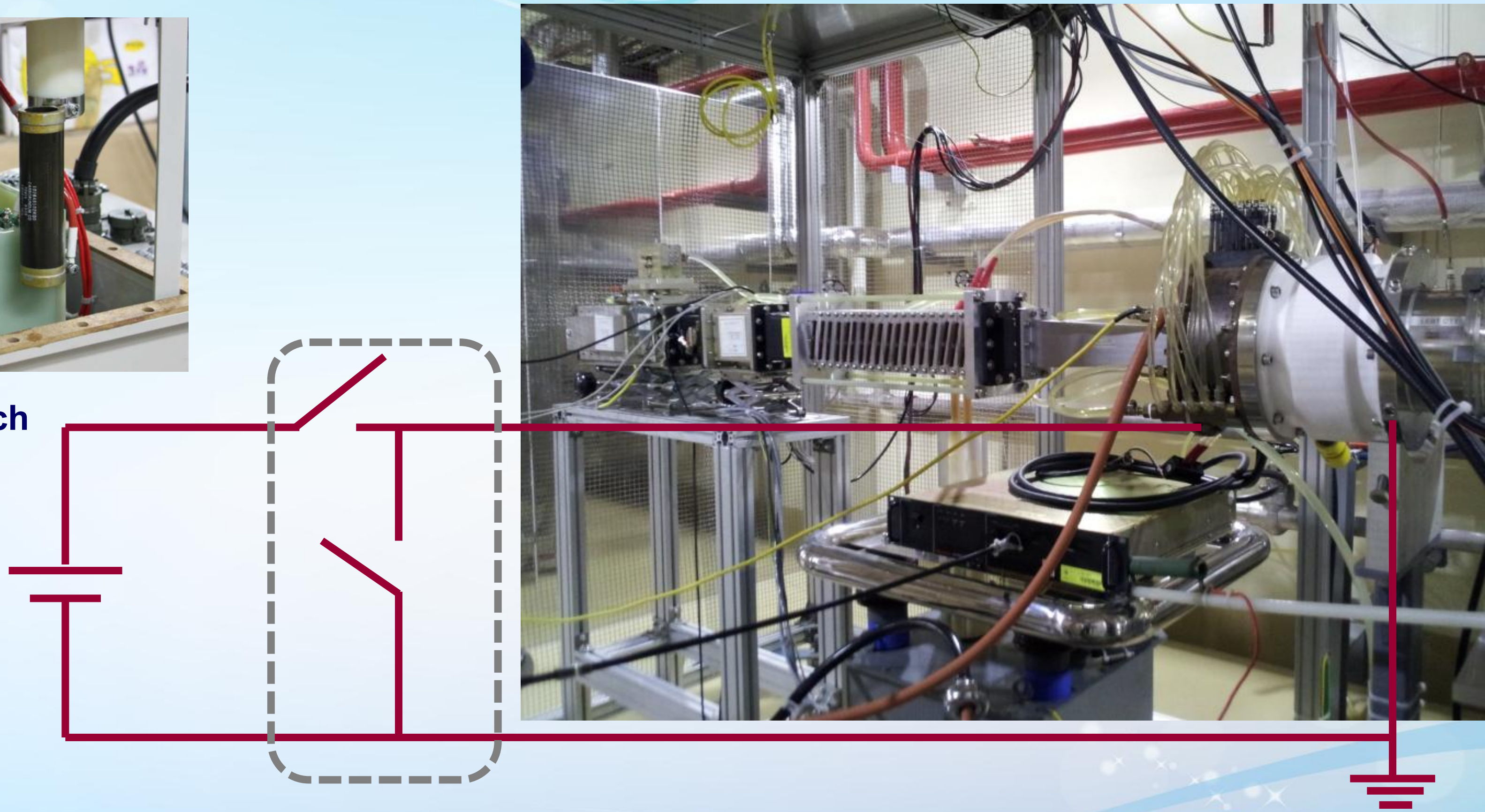
Exit

Shielding door open

Ion Source Issue 1

- Specification: 50 keV, 20 mA peak, 2.5 ms, 120 Hz (30 % duty)
- Type: Microwave ion source 2.45 GHz, 1 kW
- Operation mode: CW plasma, pulsed extraction

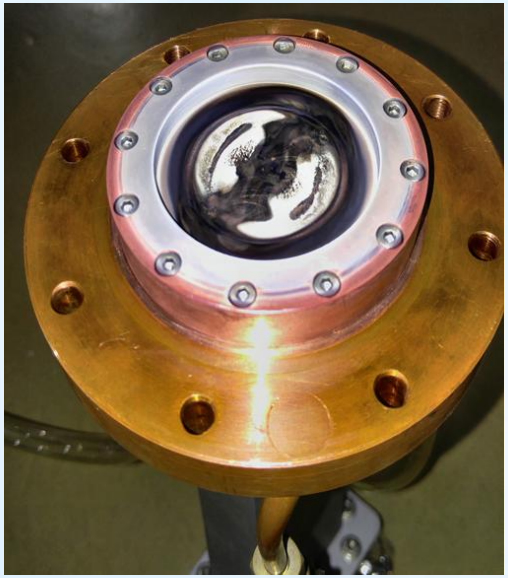
Semiconductor switch (push-pull type, 80 IGBTs connected in series)



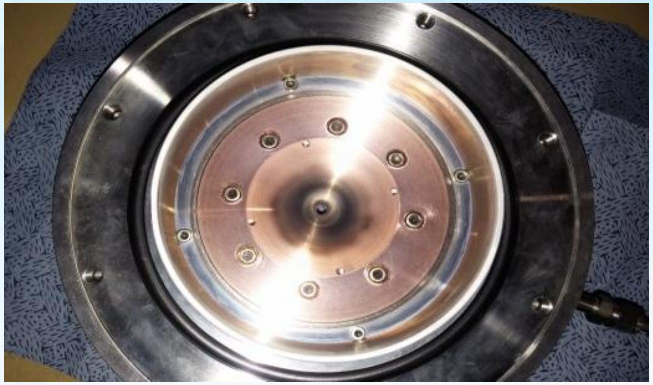
- Failure of the switch was a problem. Now fixed.

Ion Source Issue 2

- CW plasma operation: electrode being coated BN
  - BN from the microwave window
  - Frequent arcs between electrode: Switch failure

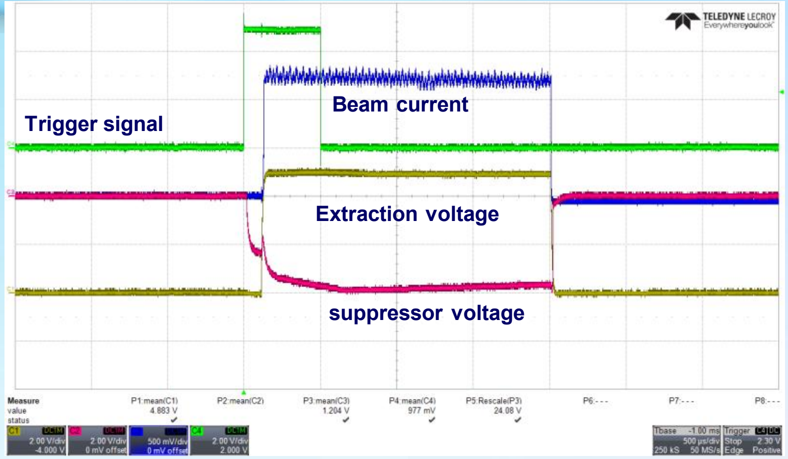


BN window after 1,000-hour operation

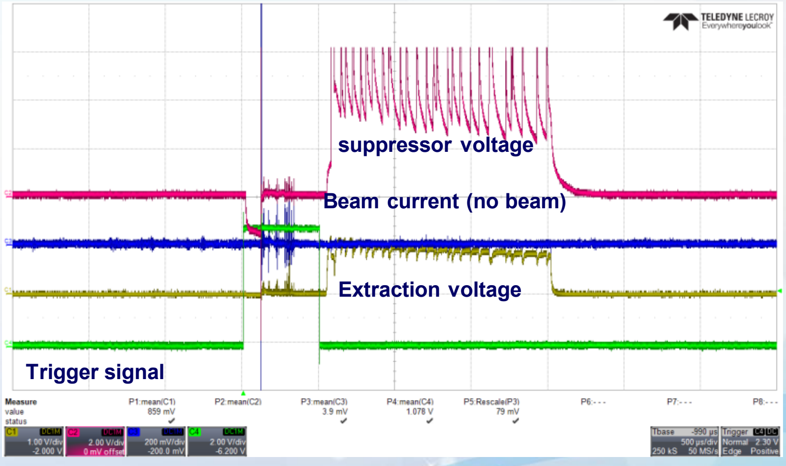


Plasma electrode coated by BN

- Over-all after 500-hour operation



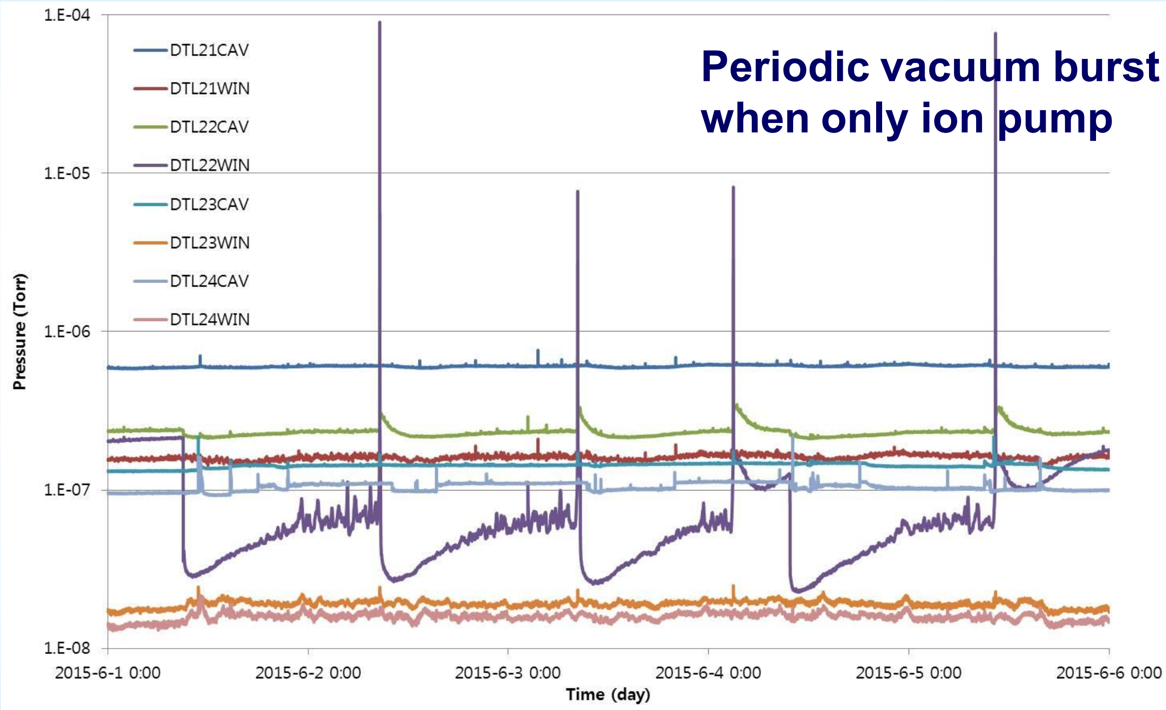
Normal operation waveform



Abnormal waveform due to coating

DTL Pump Issue

- Vacuum pump operation
  - 1 TMP + 3 IPs per DTL tank, 1 IP per DTL window
  - TMP: initial evacuation and turned off when ion pumps are operating
  - Normal vacuum level: ~5 E-8 Torr
  - Occasional vacuum burst during operation with only ion pump
- Vacuum burst was not observed with the TMP in operation
- Plan to replace 1 ion pump with 1 TMP (2 TMP + 2 IP per tank)

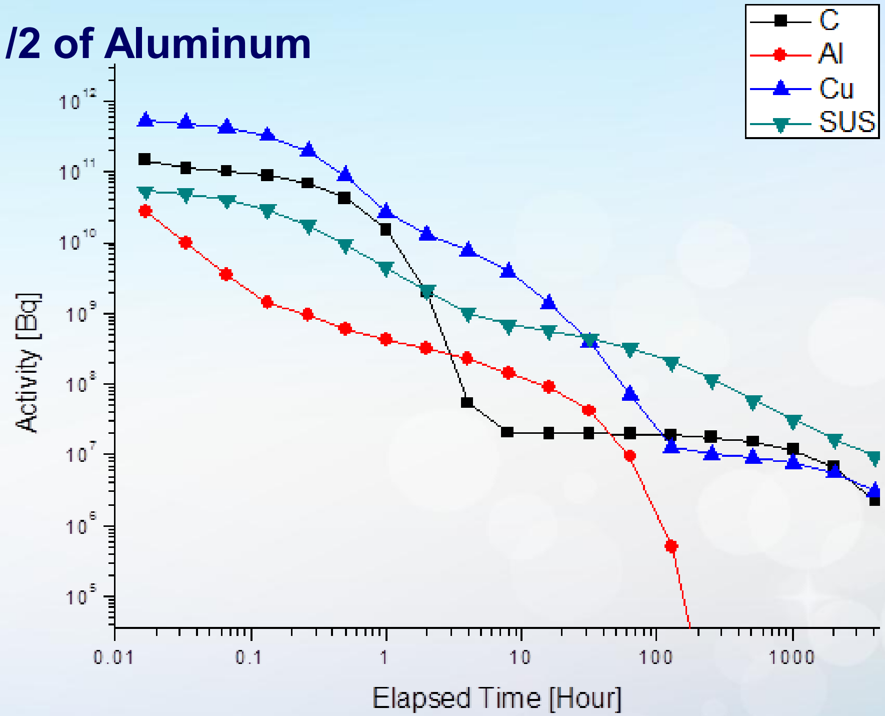


Beam Dump Issue

- Copper is used for the beam dump. But for high power, neutron is problem.
- High power proton beam dump material
  - Graphite is a good candidate with viewpoint of radiation issues
  - Neutron yield is less than 1/4 of copper, 1/2 of Aluminum
- Plan to change copper dump to graphite

Neutron yield depending on proton energy

Proton Energy	Cu	C	Al
33 MeV	1.88E-02	7.69E-04	9.32E-03
100 MeV	2.29E-01	5.54E-02	1.25E-01



Residual radiation change after 1-hour irradiation with 100 MeV, 1 μA proton beam

Summary

- Accelerator operation
  - Commissioned the 100-MeV linac with 1 kW in 2013
  - Increased beam power to 10 kW in 2014 (30 kW in 2016)
  - Availability > 90% in 2015

  : Stable so far

- Beam service
  - Many Users with complicated requirements
  - New beam lines for RI production in 2016 and for low-flux in 2017

  : Preparing beam lines one by one according to user demand

- Lessons learned
  - Multi-tanks driven by a klystron: good
  - No MEBT between RFQ & DTL: good
  - High-duty ion source: BN coating problem
  - Ion pump: not suitable for DTL

More study is required.

Thank you

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