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Injector Characteristics of 100-MeV Proton Linac at KOMAC

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On behalf of the KOMAC Accelerator team

30 Aug., 2016
KOMAC, KAERI

KAERI

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Korea Multi-Purpose Accelerator Complex
양성자가속기연구센터

Outline

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KOrea Multi-purpose Accelerator Complex

- Introduction to KOMAC facility
- Injector Characteristics and Issues
- Ion source related R&D
- Summary

❖ Introduction to KOMAC facility

KOMAC Site : Gyeong-ju, Korea

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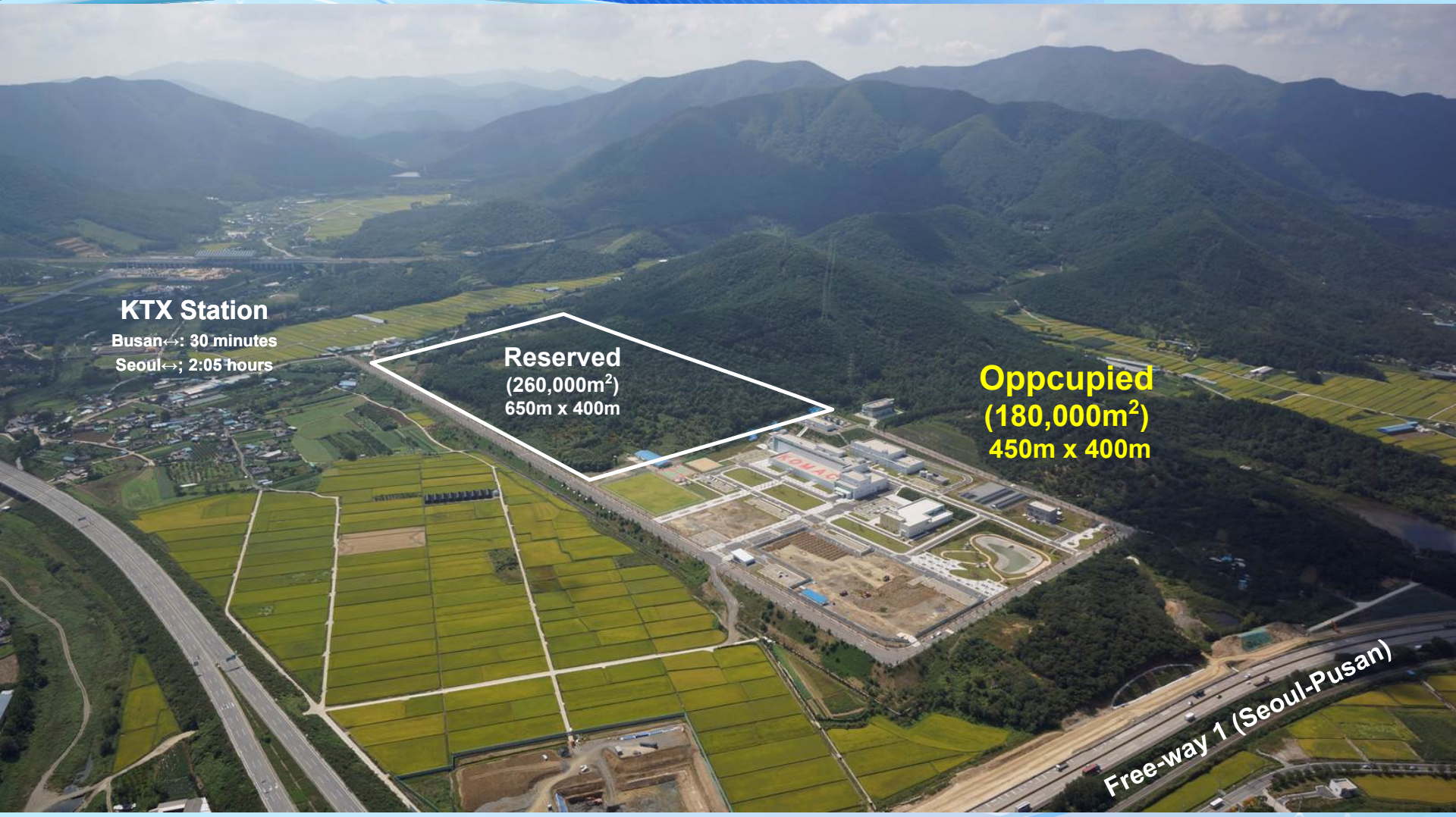

Main Facility of KOMAC

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Overview of Linac and Beam Lines

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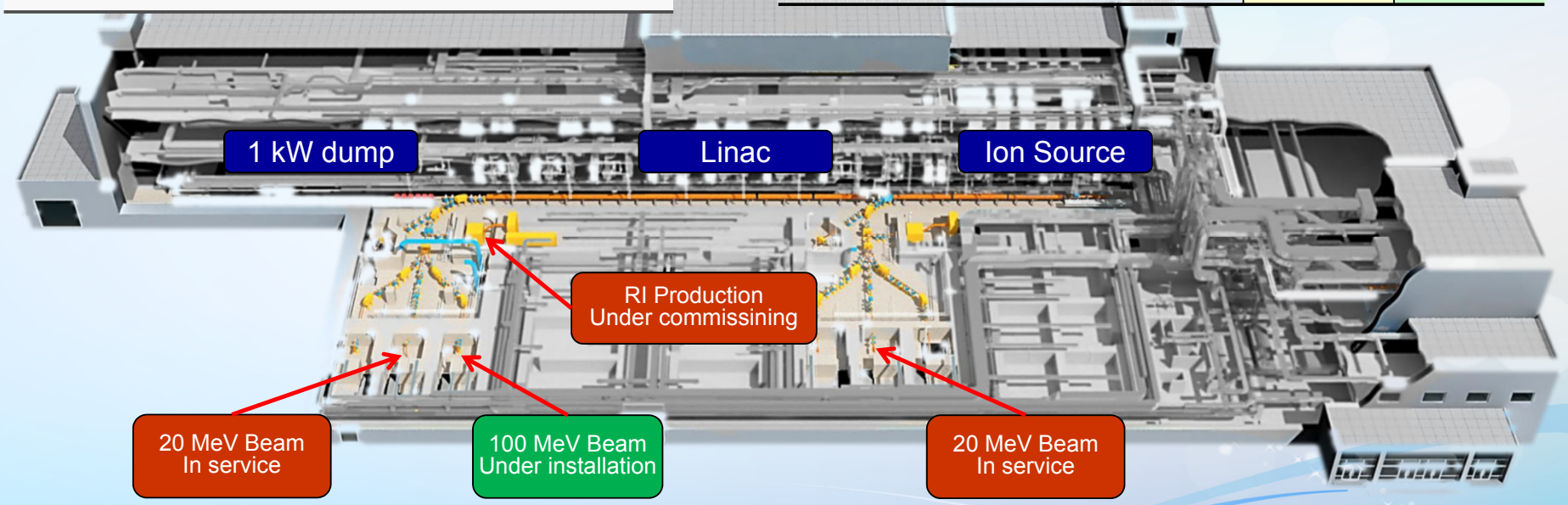
Features of KOMAC 100MeV linac

- 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



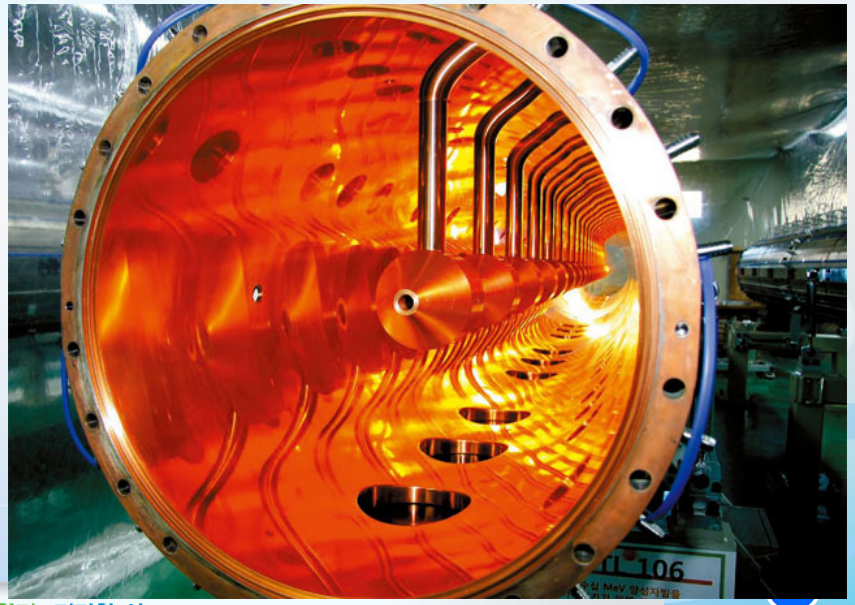
Accelerator Development

- Developed proton linac technologies
  - 2.45 GHz Microwave ion source
  - 350 MHz 4-vane RFQ
  - 350 MHz DTL
  - 700 MHz Elliptical SC cavity for future extension
  - Digital LLRF and EPICS control system

5-cell SCC prototyping

- Built KOMAC 100-MeV proton linac with the domestic companies

KOMAC DTL

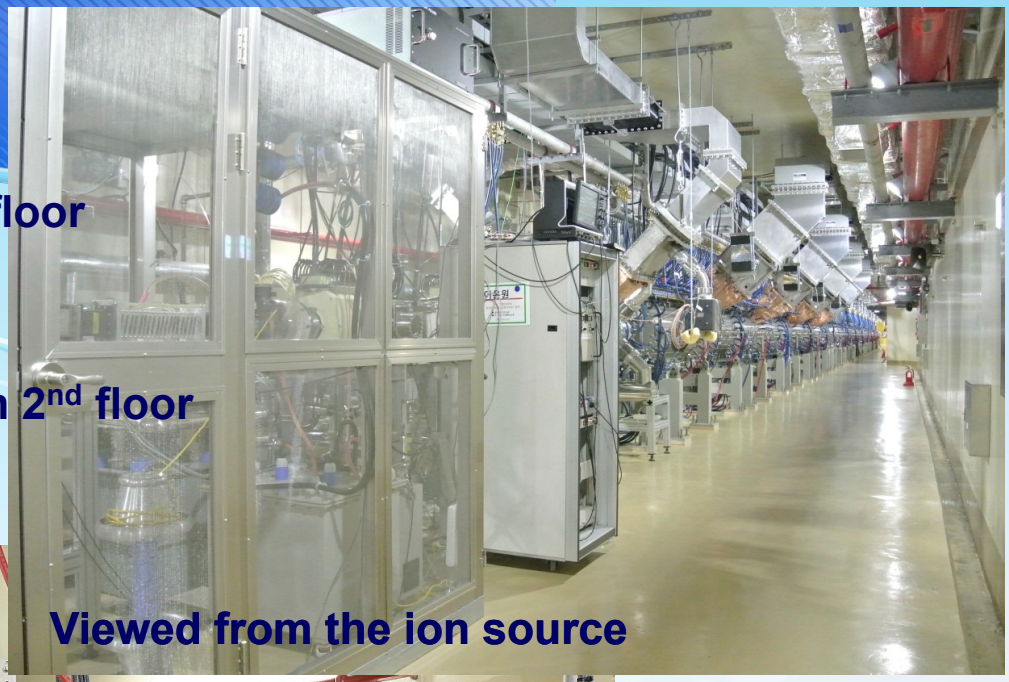


KOMAC Injector

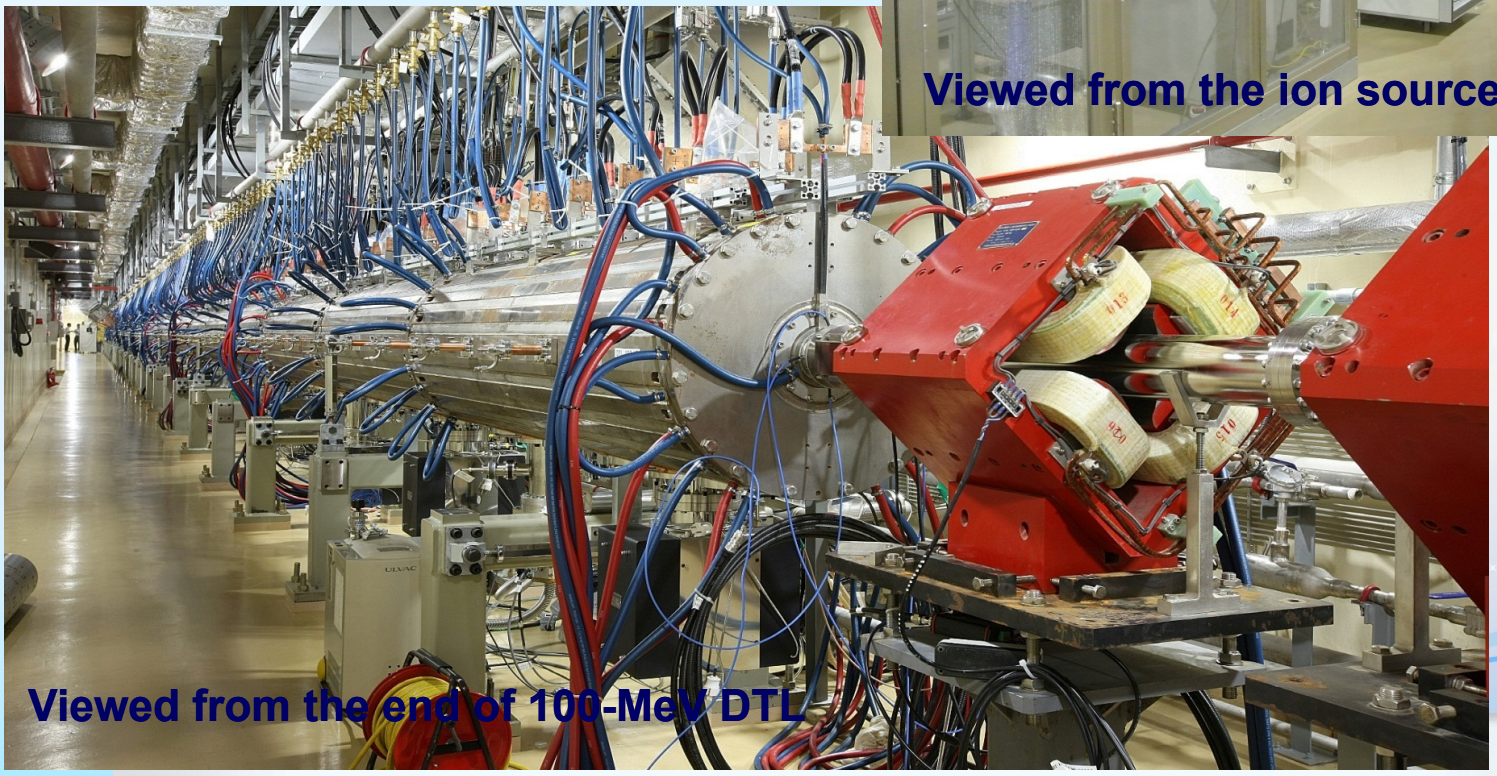
KOMAC RFQ

100-MeV Linac

- Linac and beam lines : installed in 1st floor
- Tunnel : 100 m
- 100-MeV linac : 75 m
- HPRF and cooling system : installed in 2nd floor



Viewed from the ion source



Viewed from the end of 100-MeV DTL

Target Room

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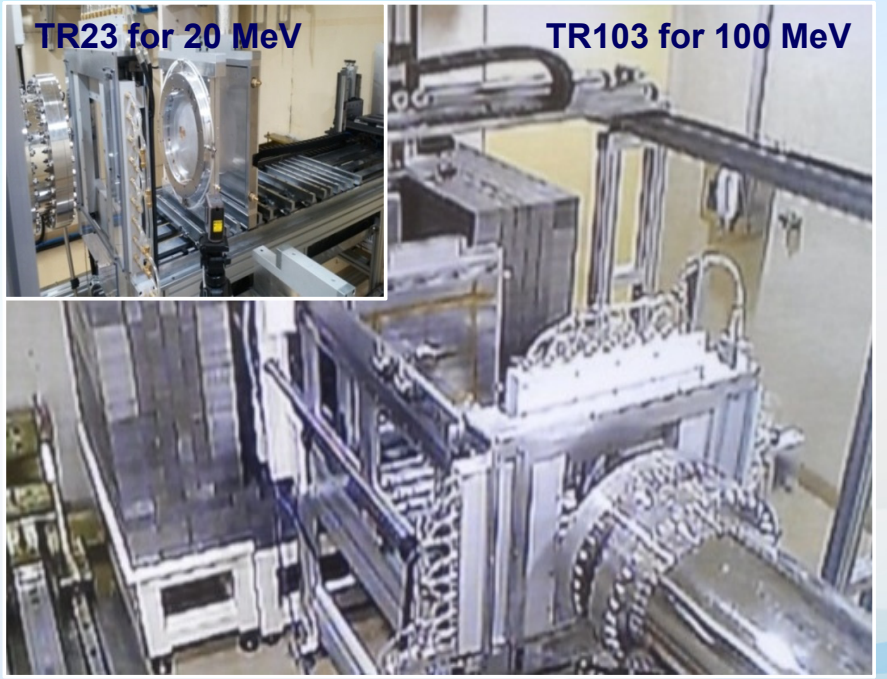
- 2 beam lines and 2 target rooms are installed and in services
  - 1 for 20 MeV, 1 for 100 MeV
- Irradiation: in air through 0.5-mm Al-Be alloy window

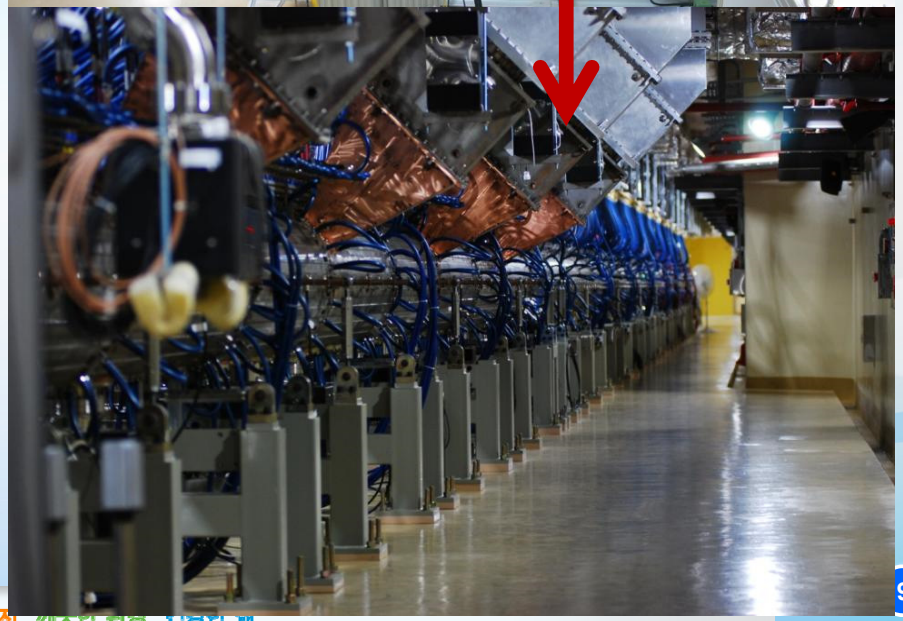
Beam line



Target room

High Power RF System

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

Beam Commissioning

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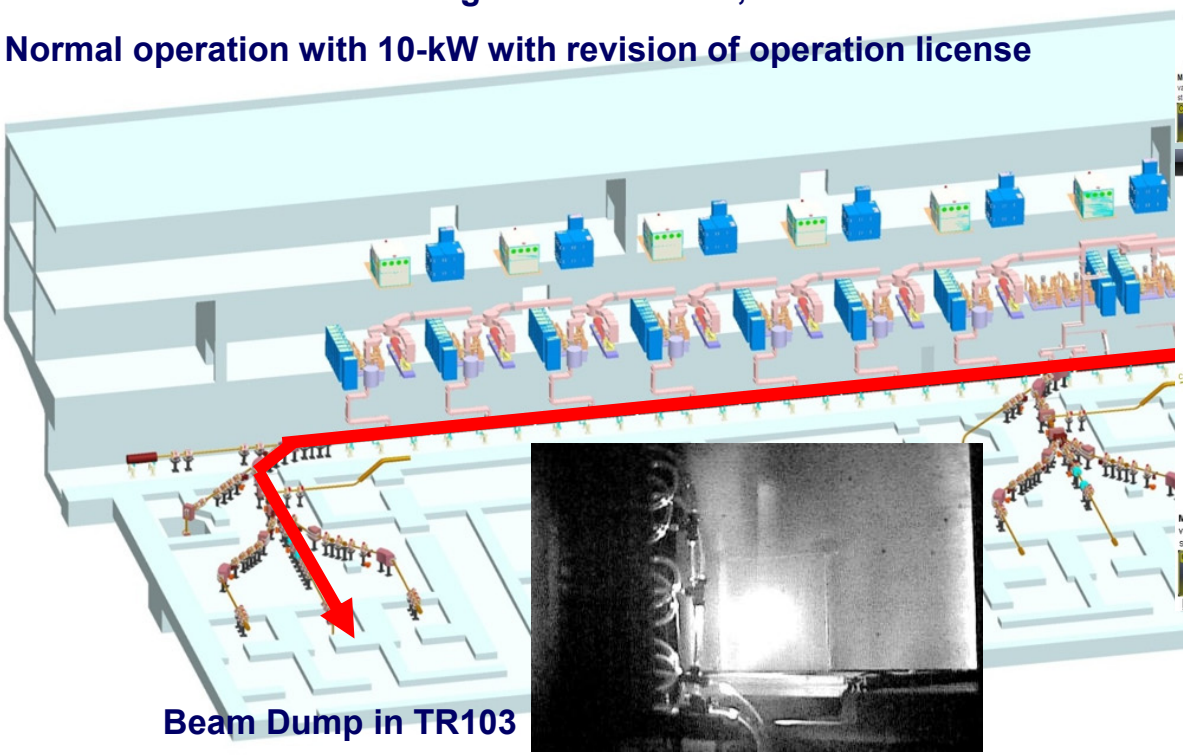
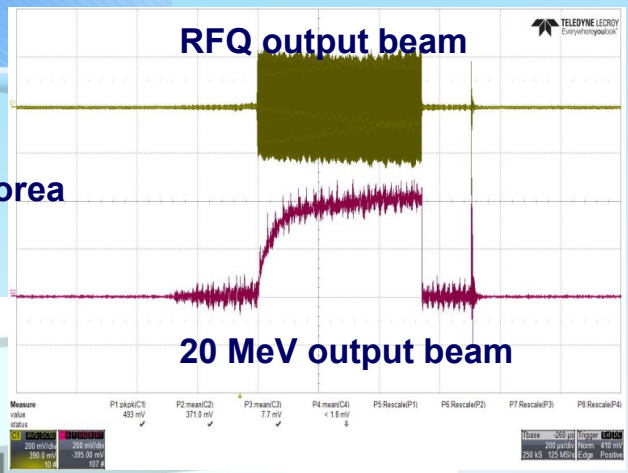
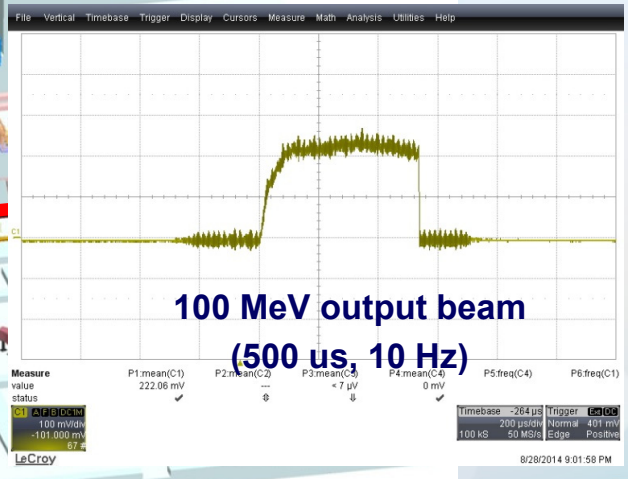
- Delivered 1-kW beam into TR103 in July, 2013
- Checked beam energy change by turning off 7 DTL tanks one-by-one
- Operation license by the Nuclear Safety and Security Commission of Korea
- Started user beam services for 1-kW beam from July 22, 2013
- Achieved 10-kW beam in August 2014: 550us, 10Hz
- Normal operation with 10-kW with revision of operation license



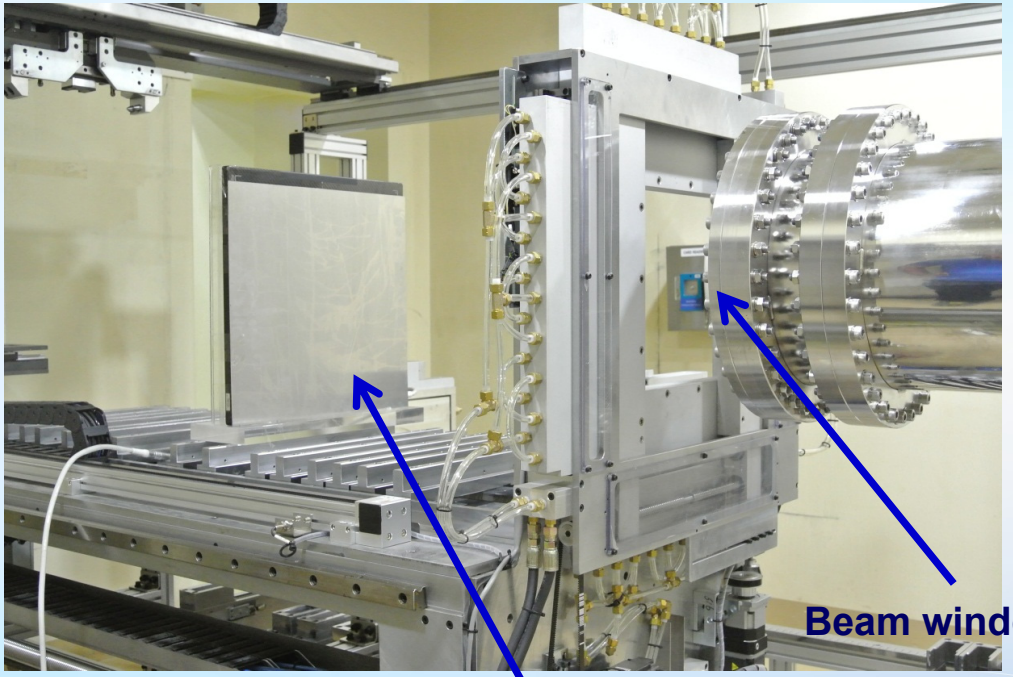
Beam Dump in TR103

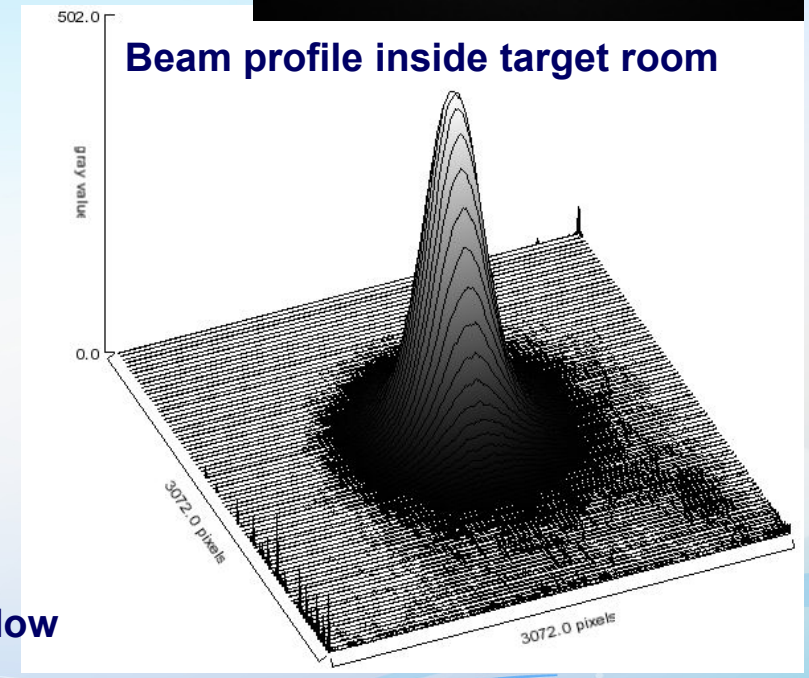




Beam Profile at Target Room

- 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 um





Beam rms radius : 25 mm

Summary of Operation History

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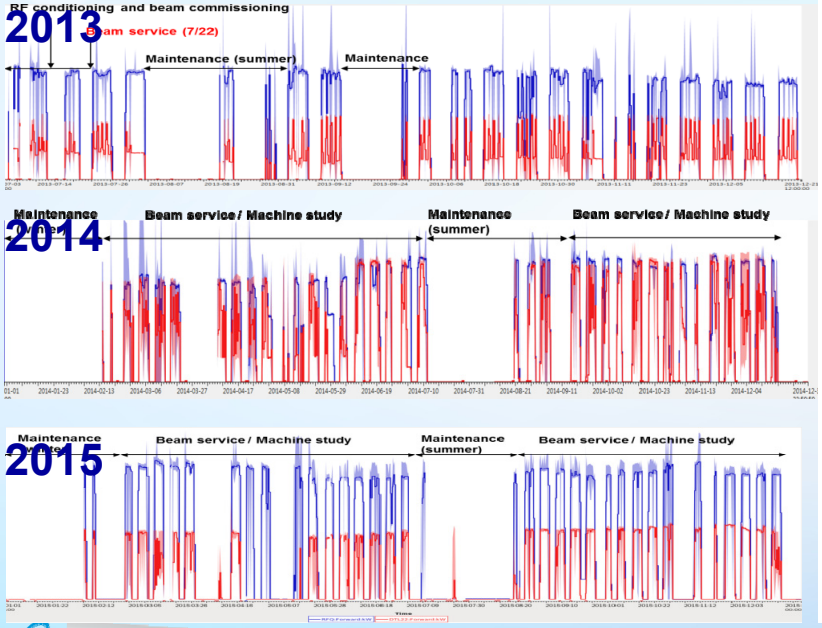
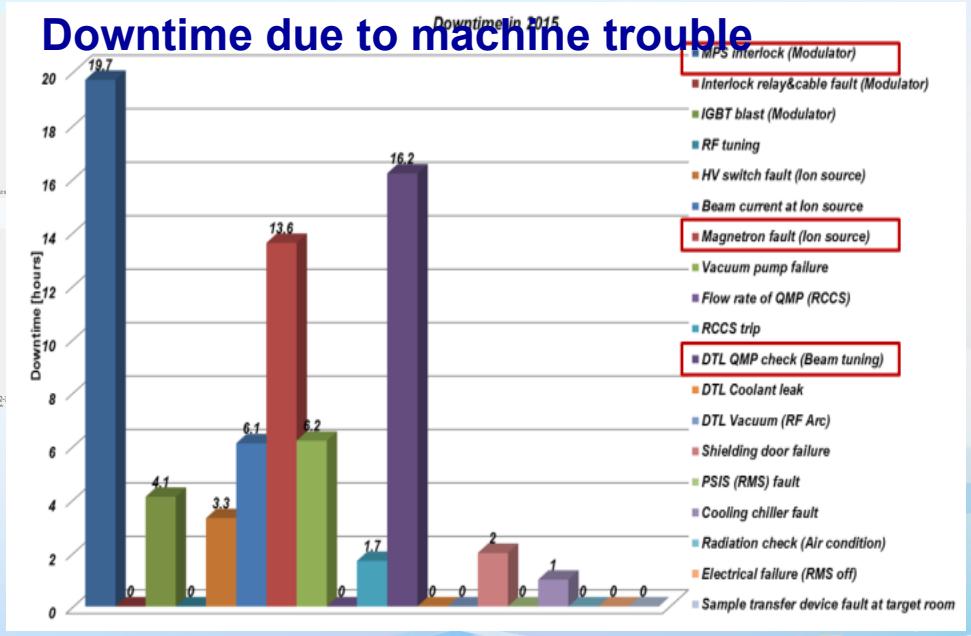
- ❖ Operated in weekly-based schedule through a yearly plan
  - ▪ Beam service: Monday 13:00 ~ Friday 12:00
- ❖ Operation statistics

	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%





Beam Line Development (1)

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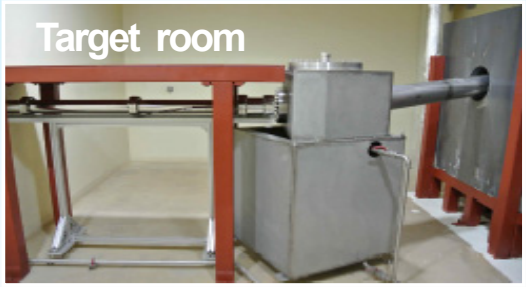
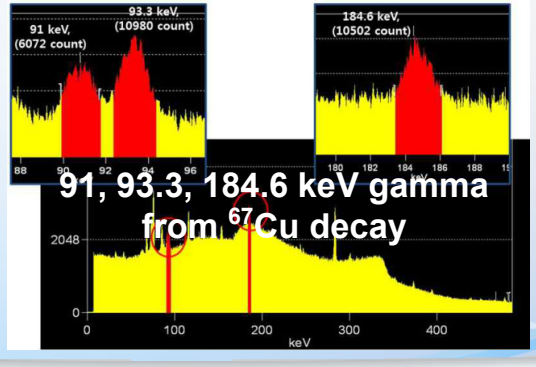
❖ RI Beamline: 100-MeV Proton

- **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

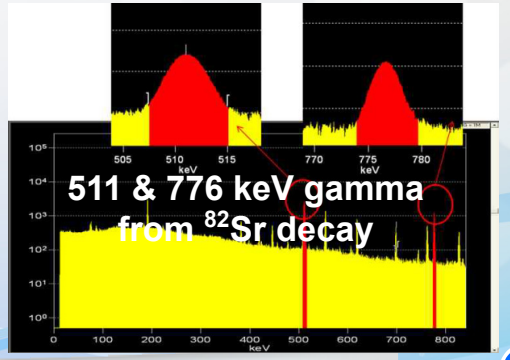


Target Preparation

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



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



Beam Line Development (2)

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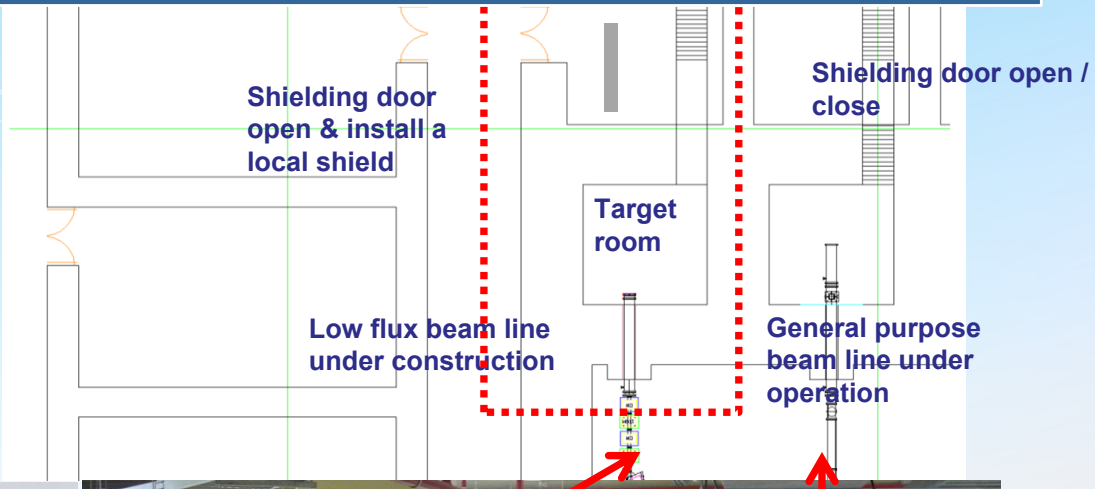
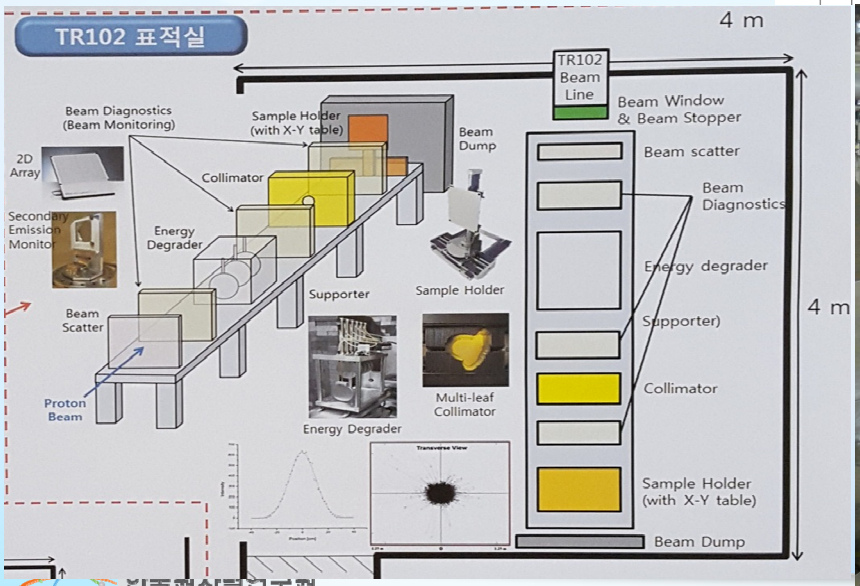
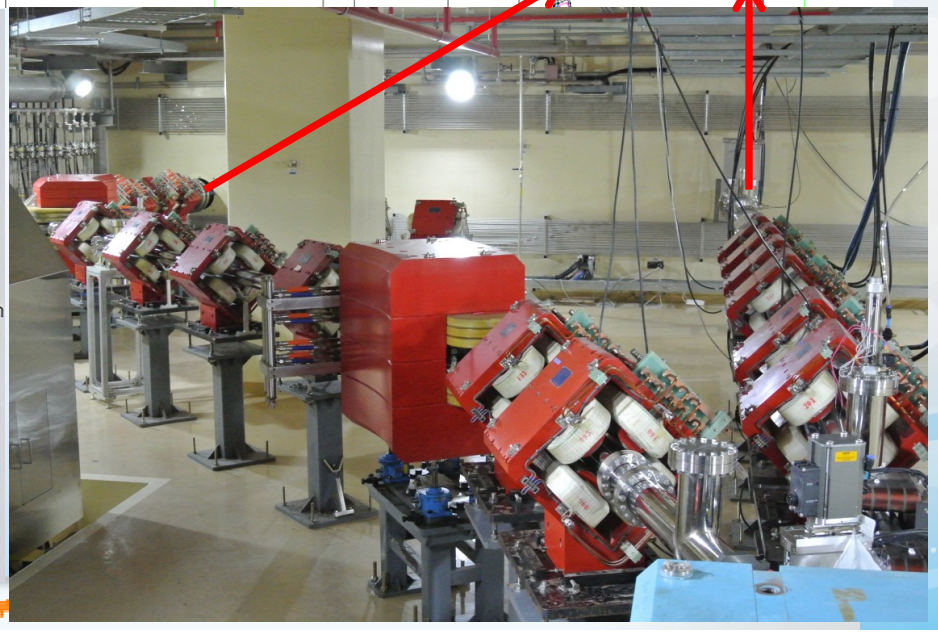
❖ Beamline for Low Flux Users: 100-MeV Proton

- **Specification of the low flux beam line**
  - **Beam energy: max. 100 MeV**
  - **Flux: 10^8 p/cm^2 s**
  - **Target size : 10 cm X 10 cm**
- **Shielding door: always open**
- **Add Local shield**
- **Increase the accessibility**







❖ Injector Characteristics and Issues

Proton Injector

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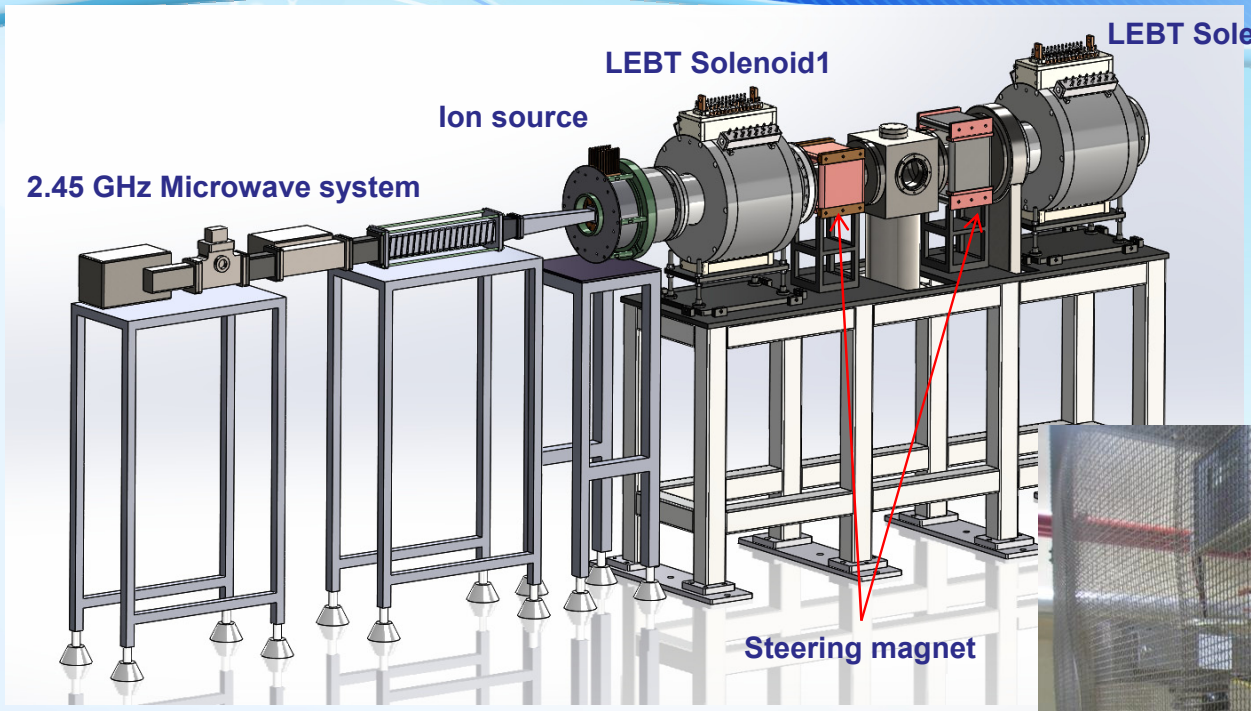

- Single EM solenoid for IS
- HV insulation with WG DC break
- IGBT HV switch for extraction
- Pulsed beam with CW plasma

Proton injector for 100-MeV KOMAC Linac

- 2.45 GHZ microwave ion source
- Two electromagnet solenoids
- Two steering magnets
- Vacuum box for diagnostics and pumping
- RFQ entrance collimator and electron trap

Microwave Ion Source Development

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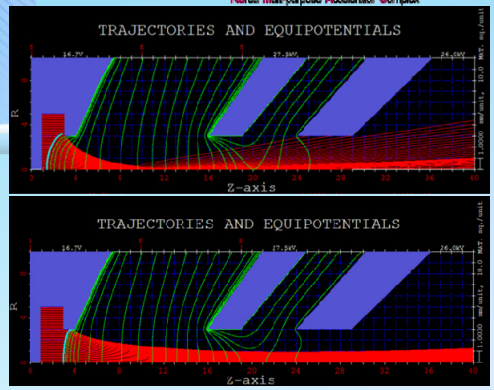
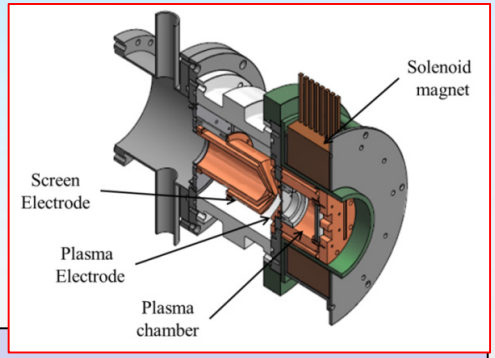
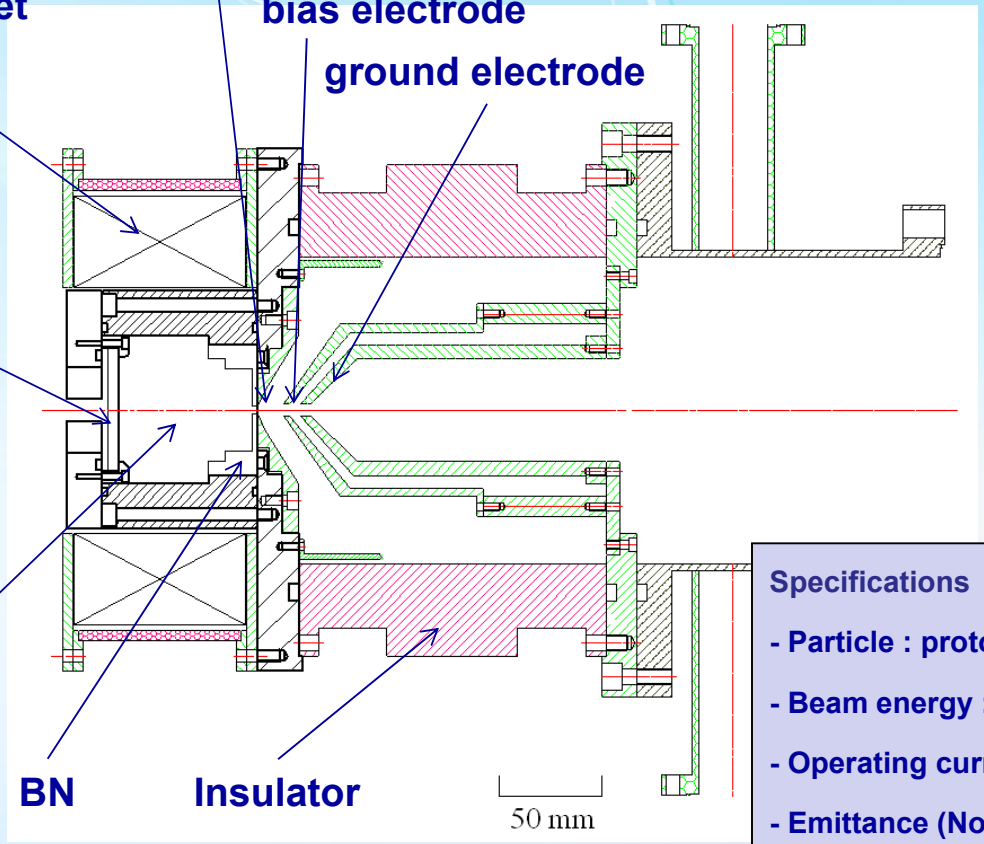




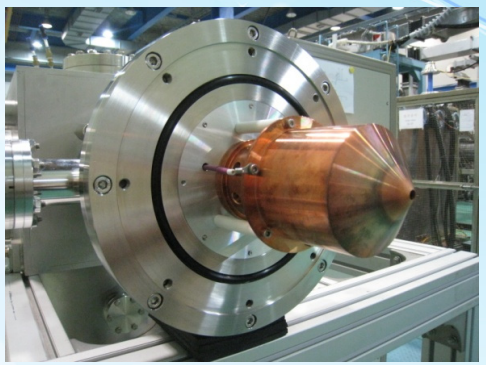


Specifications

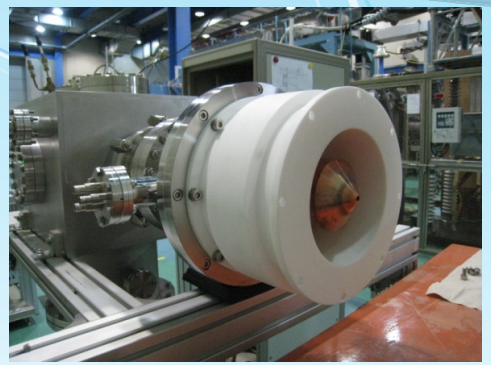
- Particle : proton
- Beam energy : 50 keV
- Operating current : 20 mA
- Emittance (Normalized rms) : 0.2 π mm mrad
- Proton fraction : > 80%
- Operation time without maintenance : > 500 hrs
- Microwave frequency : 2.45GHz

Long life time without maintenance for weekly based operation

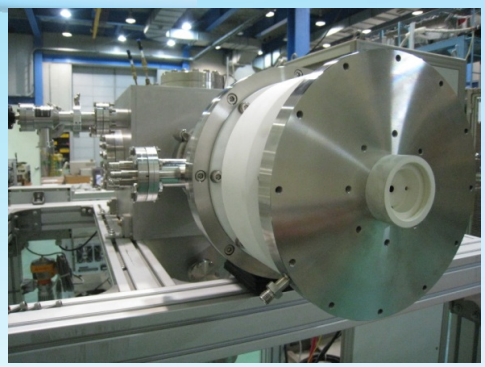
Ion Source Assembly



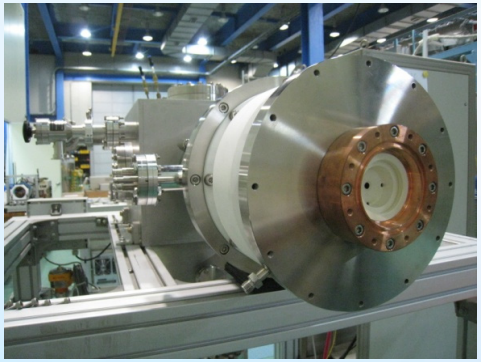
1. Install a bias electrode after linked a bias feed-through



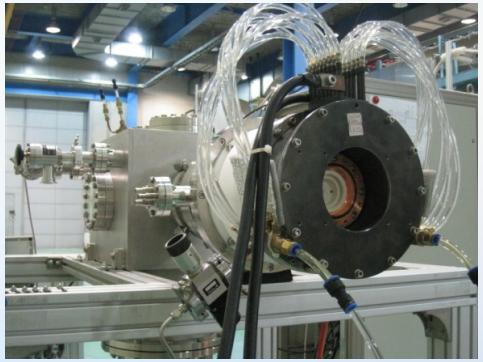
2. Install high voltage insulator



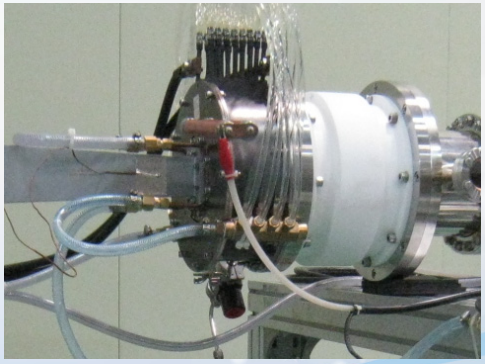
3. Install a flange with a plasma electrode, a gas injection port and a boron nitride lining



4. Install an plasma chamber

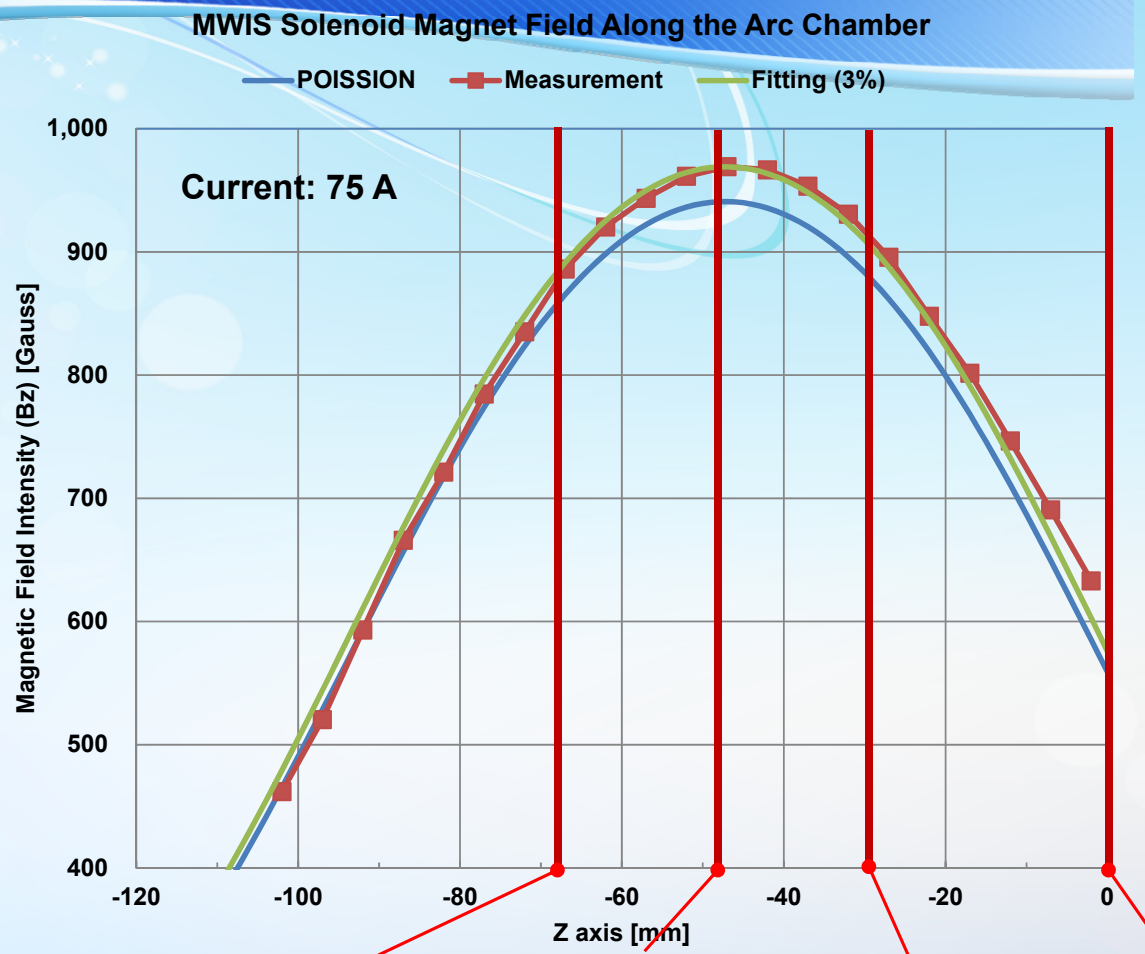


5. Install a solenoid magnet and cooling lines and a needle valve



6. Install ridged waveguide to plasma chamber

Magnetic Field along the Plasma Chamber



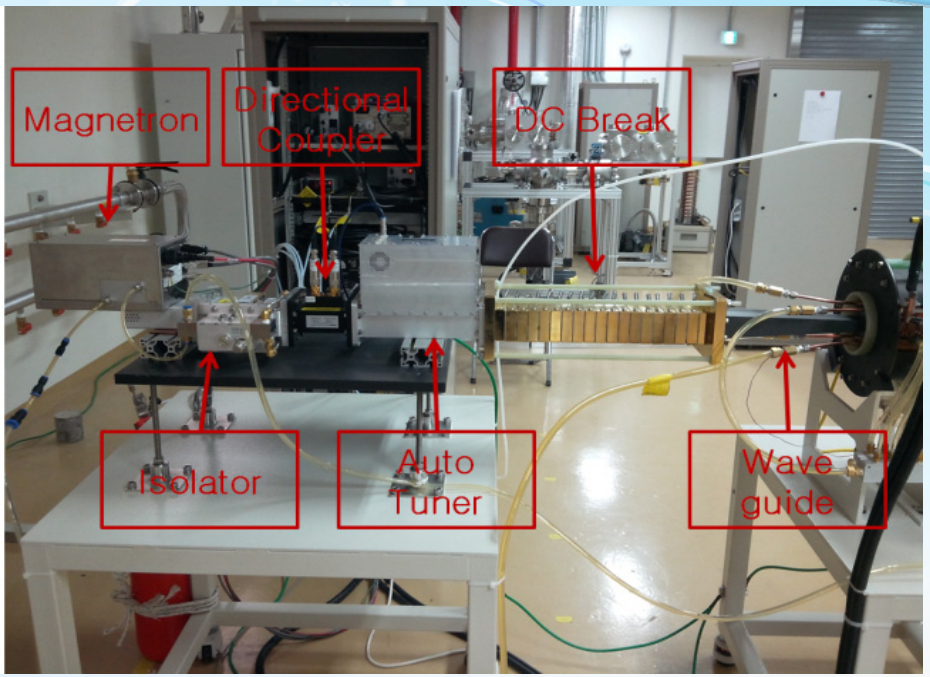
Magnet center (-47.5mm)

Plasma electrode (0mm)

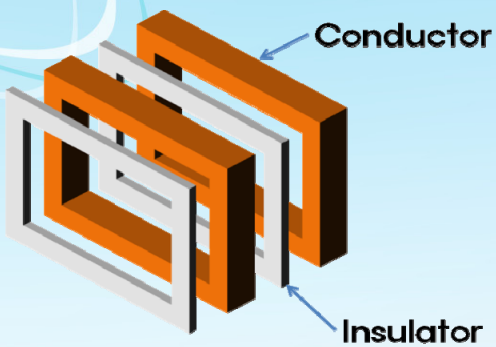
Window position of -67.4mm chamber (-67.4mm)

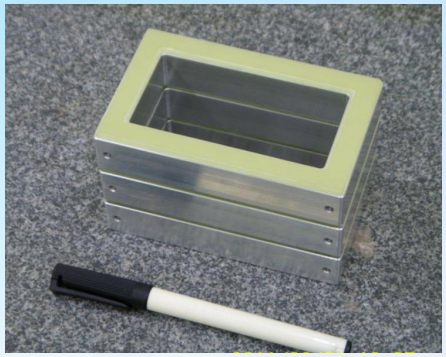
Window position of -29.1mm chamber (-29.1mm)

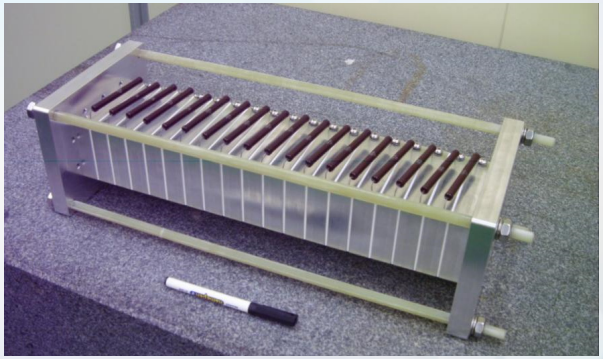
Microwave System



- Multi-layer waveguide DC Break







Microwave system specifications

- Frequency: 2.45 GHz
- Power: 1 kW CW
- Tuning: 3-stub with auto-matcher
- Protection: circulator with dummy load
- Ridged waveguide coupling system
- Multi-layer waveguide DC break

- Insulator : G-10 (2mm of thickness)
- Conductor : Al(20mm of thickness, WR340)
- Number of Layers : 19
- Divider resisters : 160MΩ x 19

Plasma Discharge and Beam Extraction

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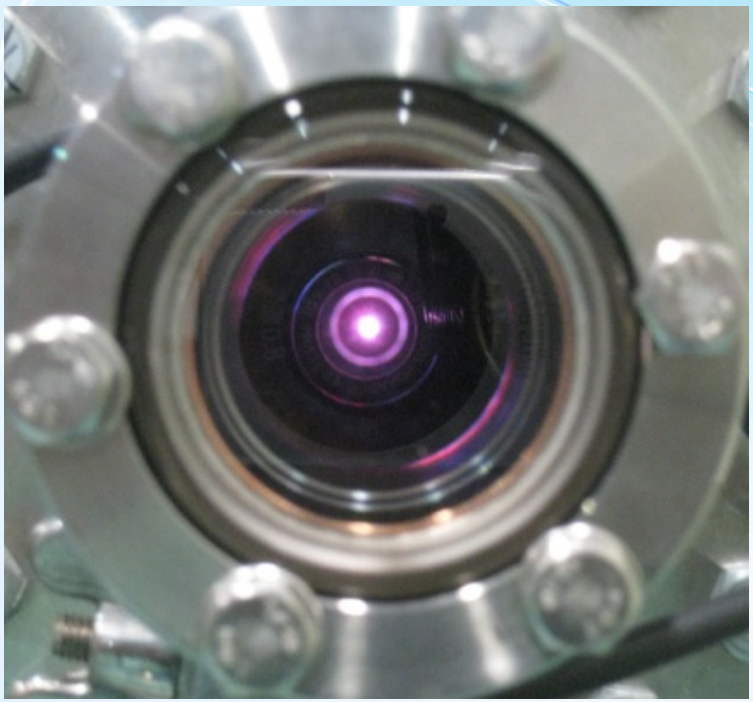
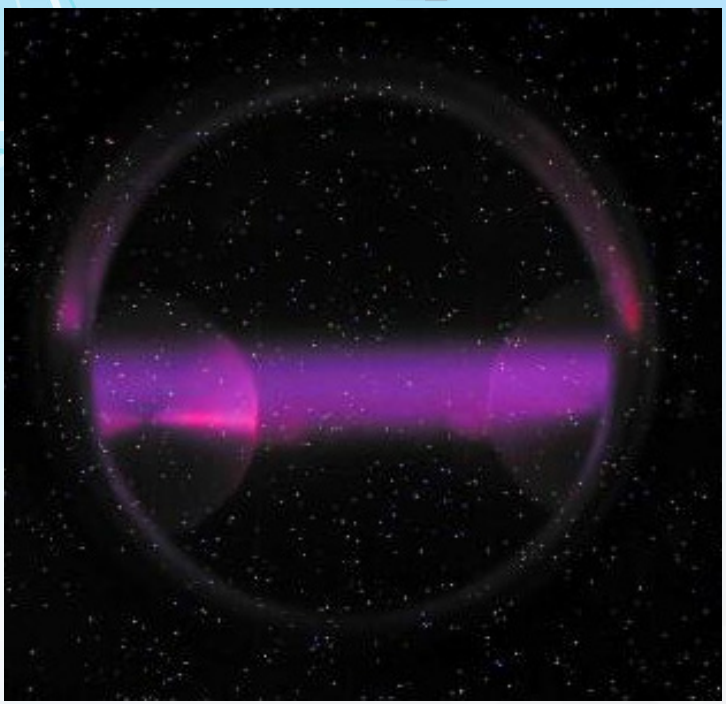


Gas : H2
H2 pressure (Indicated value) : 1.0 × 10^-5 torr
Microwave power : 400 W
Solenoid magnet current : 75 A



Gas : H2
H2 pressure (Indicated value) : 2.0 × 10-5 torr
RF power : 600 W
Solenoid magnet current : 82 A
Bias voltage : -1 kV
Extraction voltage : 35 kV
Extraction current : 16 mA DC @ Faraday cup
Beam current was limited due to the beam dump heating

LEBT Solenoid Scan

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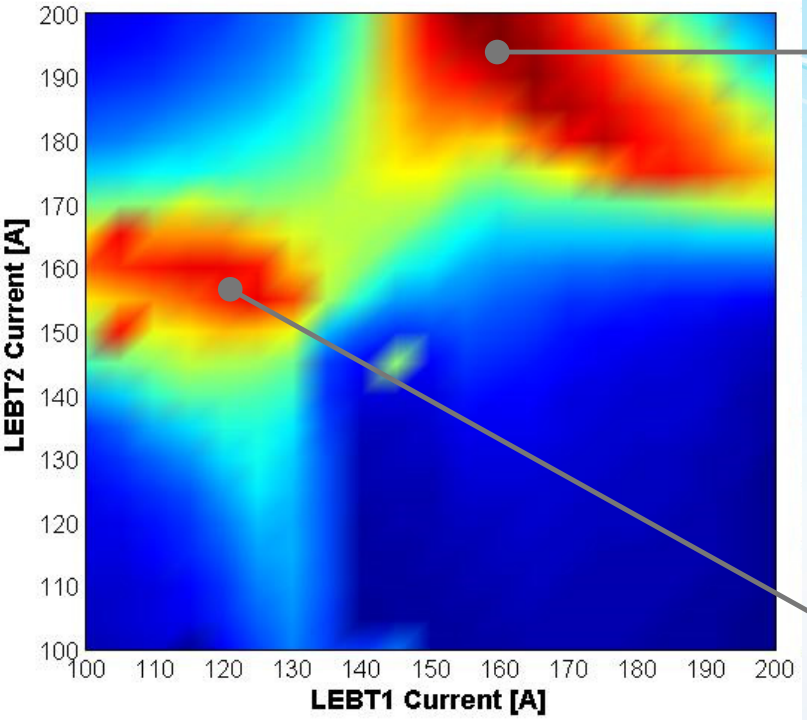
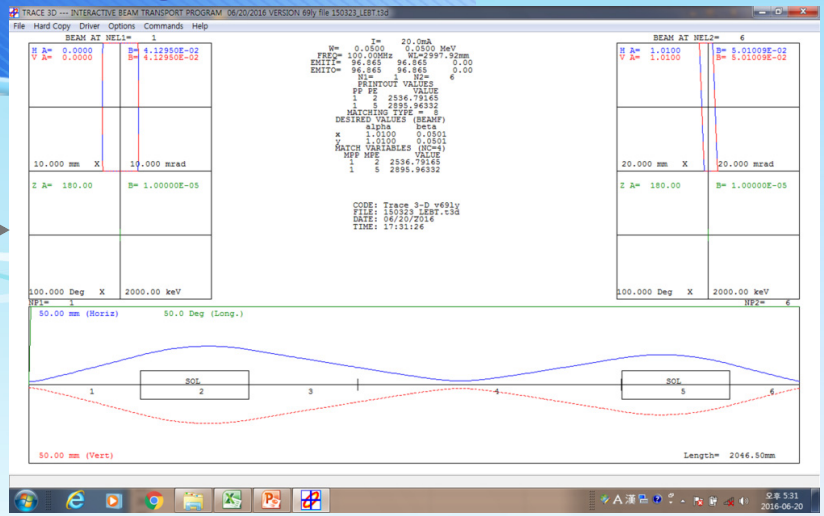
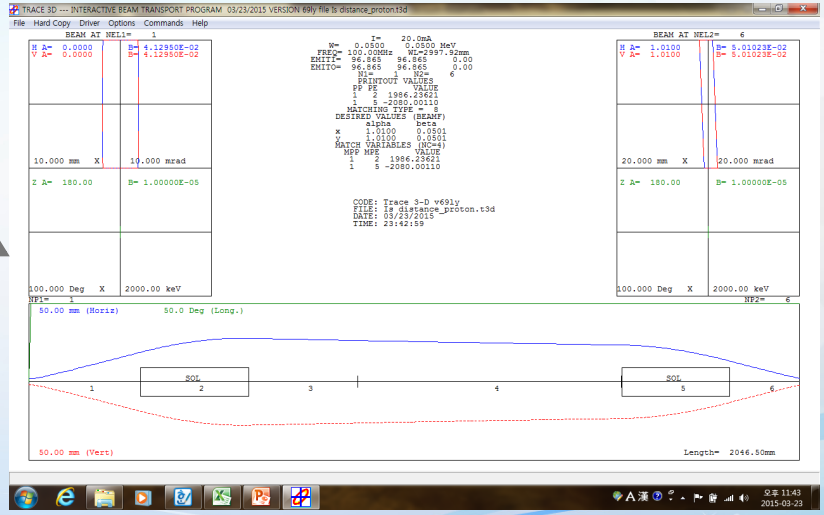


Crossing beam optics in LEBT



Parallel beam optics in LEBT



Normally operated in parallel beam optics because H2 plus ion can be focused in crossing beam optics

Emittance Measurement

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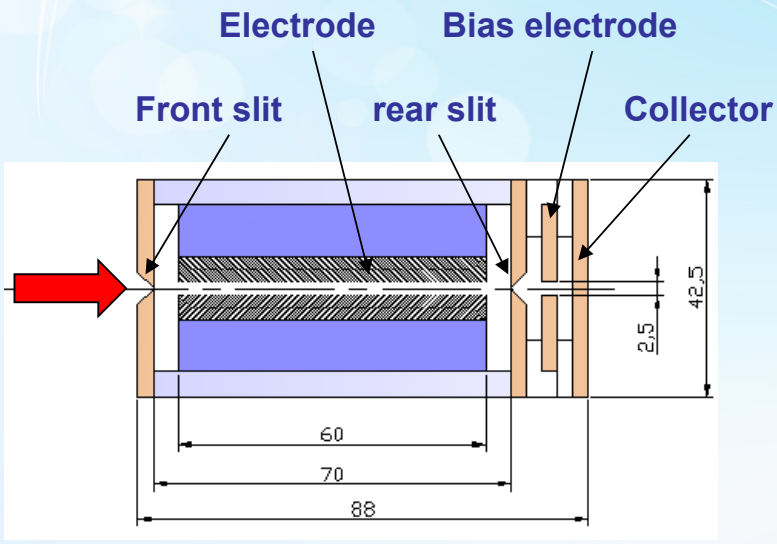
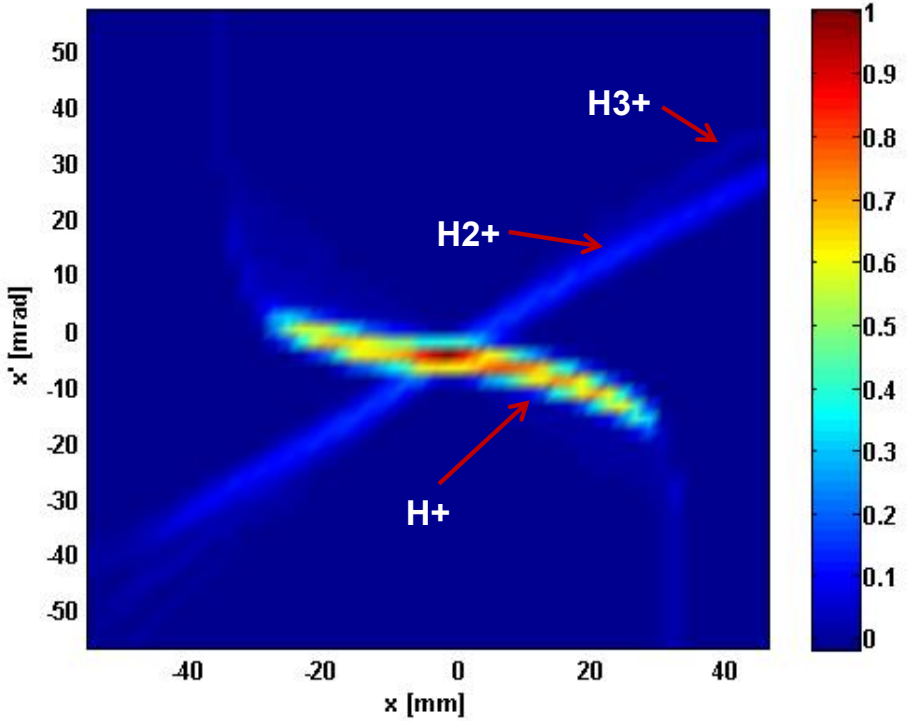
Allison type emittance scanner



Side view



Phase space distribution measured in the middle of two LEBT solenoids

- Pressure : 1.7×10^-5 torr (3.0 sccm)
- IS solenoid : 80.5A, Microwave power : 500W
- Extraction voltage : 50kV, bias voltage : -2kV
- Beam current: 12.2mA
- X step : 2mm , X' resolution : 2.3mrad (20V)
- Normalized RMS emittance : 0.35 π mm mrad (0.2 π mm mrad design value)

Proton Fraction

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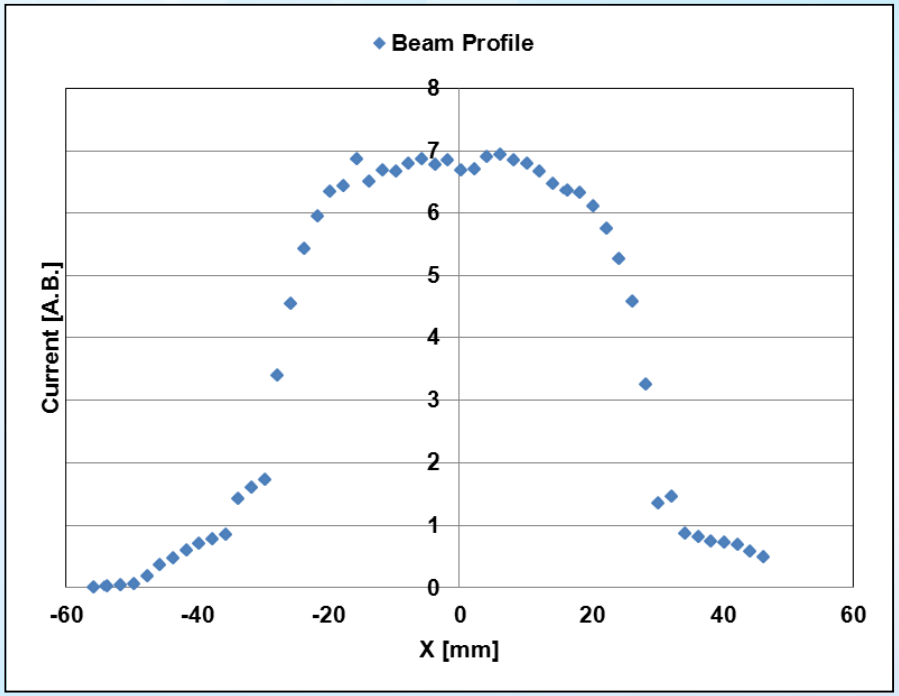
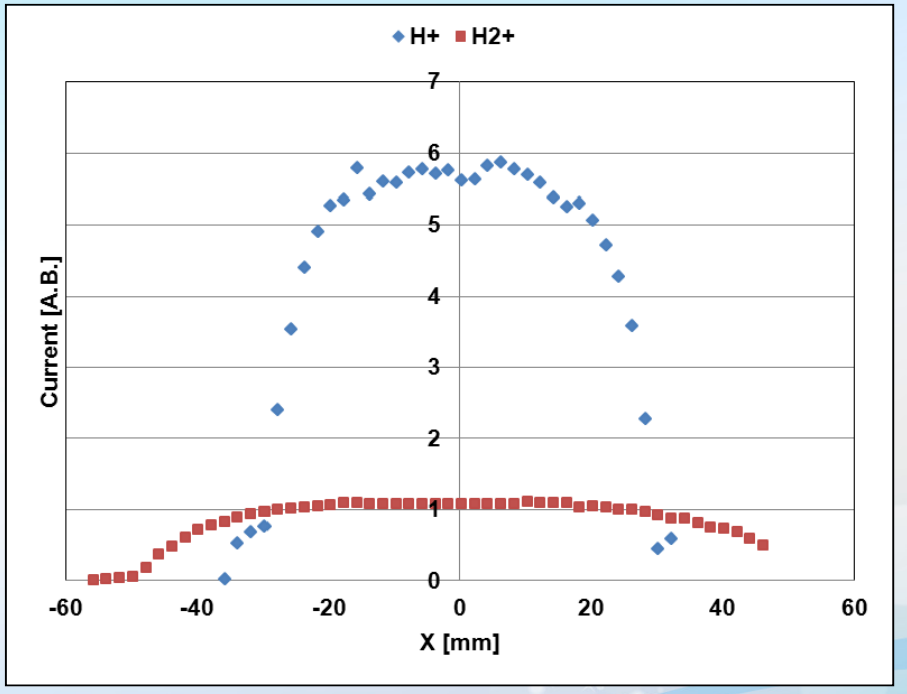
- H2+ profile was assumed to be uniform
- Ignore H3+ data
- Proton fraction (H+ : H2+) 77% : 23%



Beam profile of the total beam



Resolved Beam profile

Electron Trap Effect

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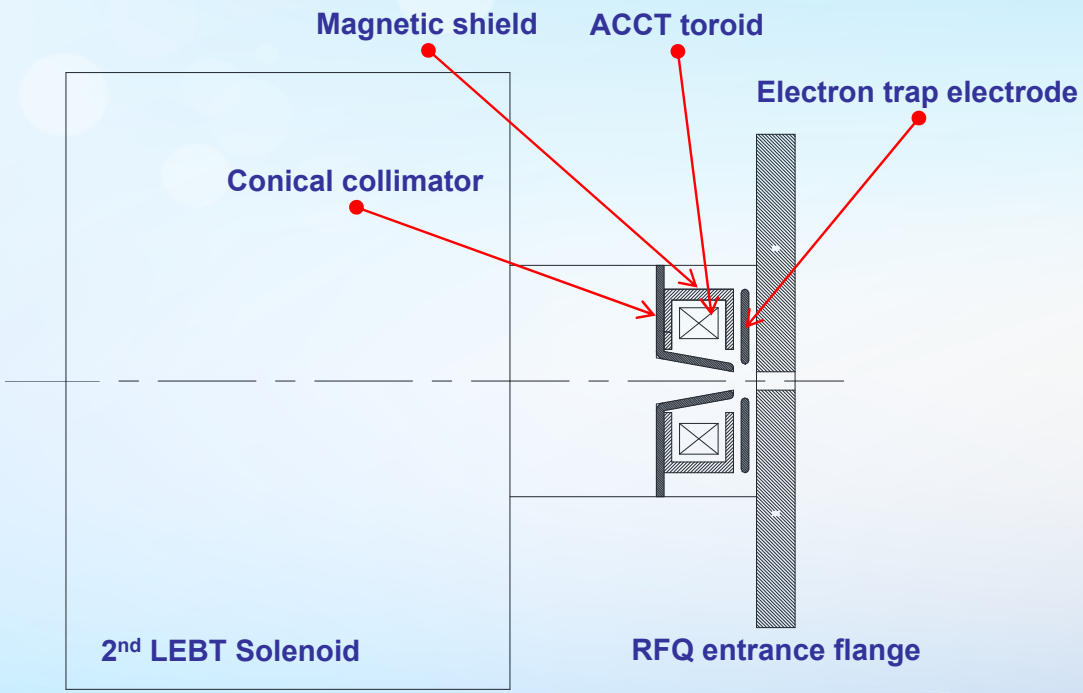
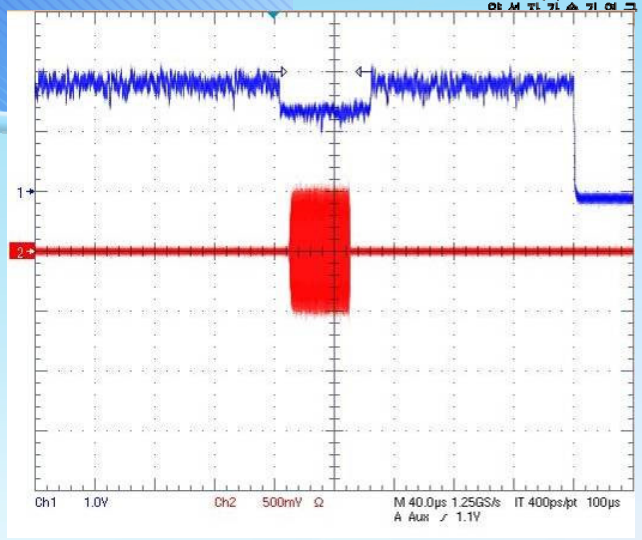
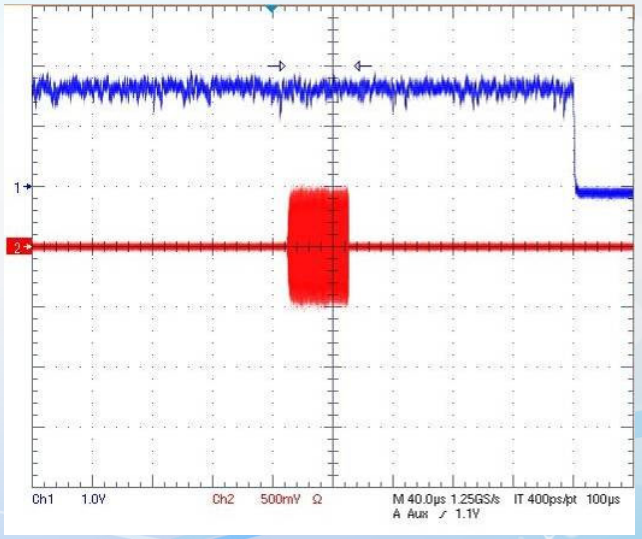
Korea Multi-purpose Accelerator Complex

- Operating voltage of the trap : 1.2kV
- Dip of the ACCT current for low trap voltage during RFQ beam acceleration period
- The current maintains constant above ~ -1kV





Trap voltage : 0kV

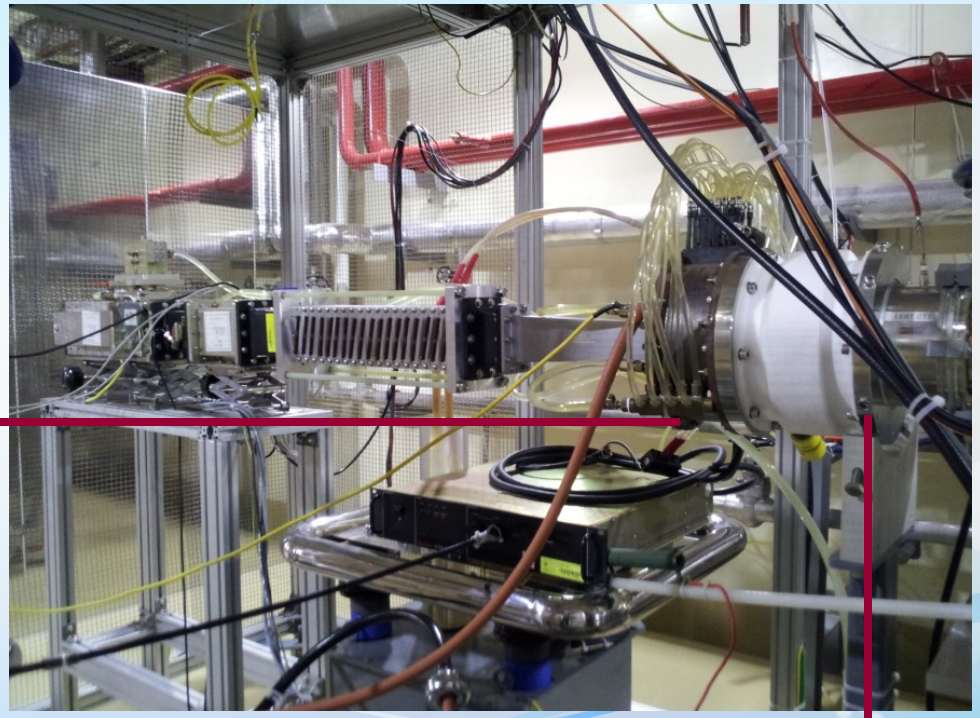


Trap voltage : -1.4kV

Ion Source Issues 1 – HV Switch

- KOMAC ion source Requirement: 50 keV, 20 mA peak, 2.5 ms, 120 Hz (30 % duty)
- Operation mode: CW plasma, pulsed beam extraction
- Failure of the switch was a problem. Now fixed by adjusting gate drive timing and current limiting resistors.

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



Ion Source Issues 2 – BN coating

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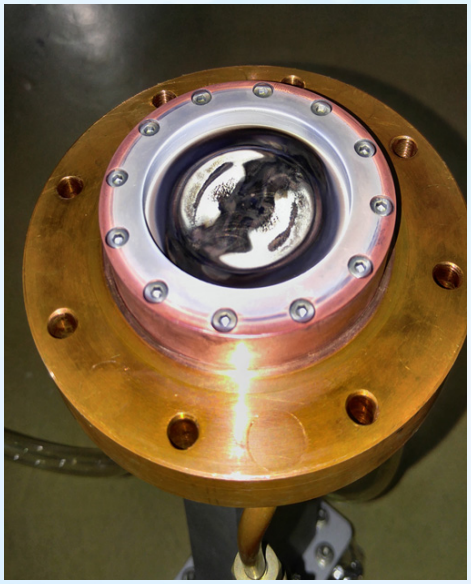
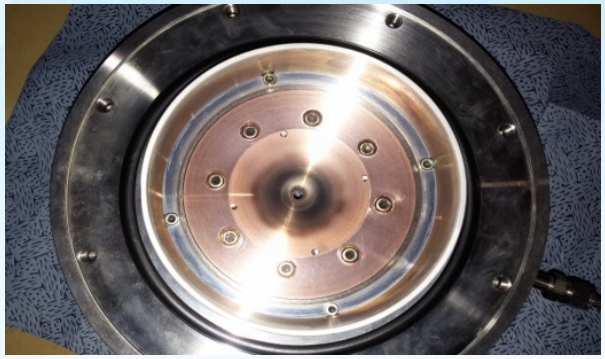
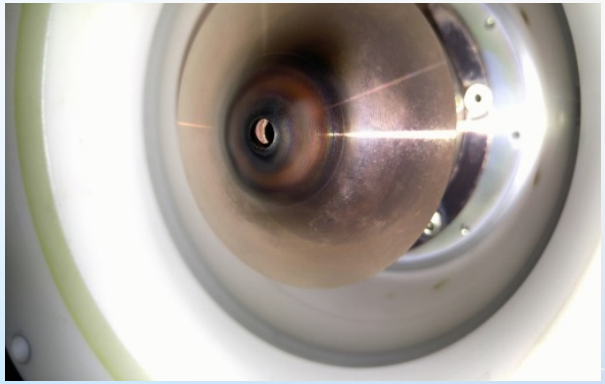
- CW plasma operation: electrode being coated with BN
  - BN from the microwave window
  - Frequent arcs between electrodes: Switch failure
- Preventive maintenance: overhaul after 500-hr operation

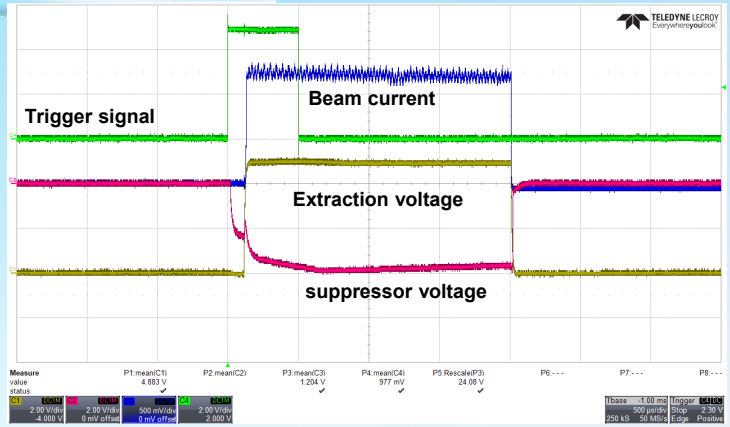


BN after 1,000 hour operation

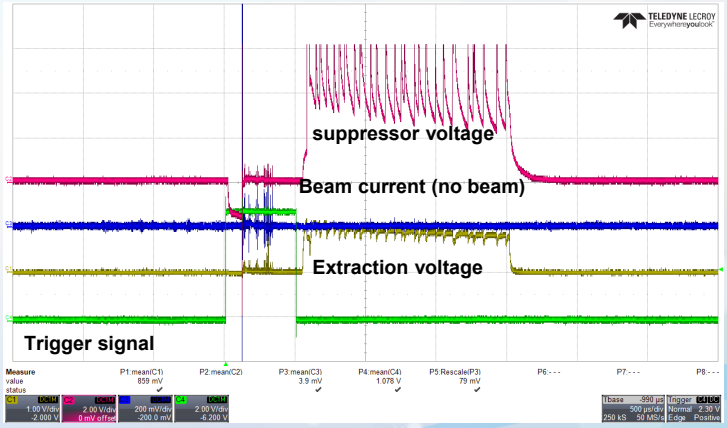




BN(insulator) coating on plasma electrode (upper) and extraction electrode (lower)

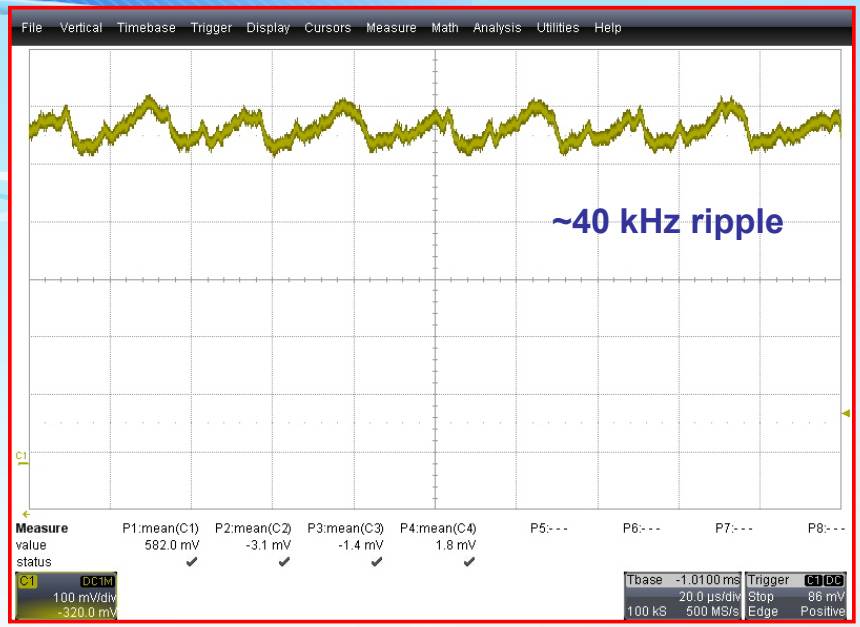


Normal operation waveform

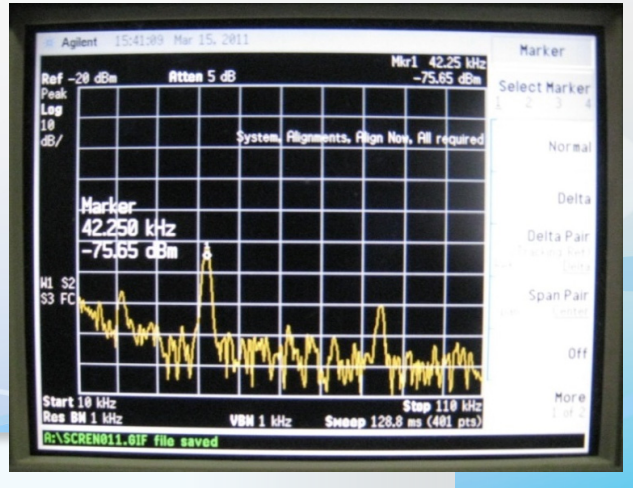


Abnormal waveform due to coating

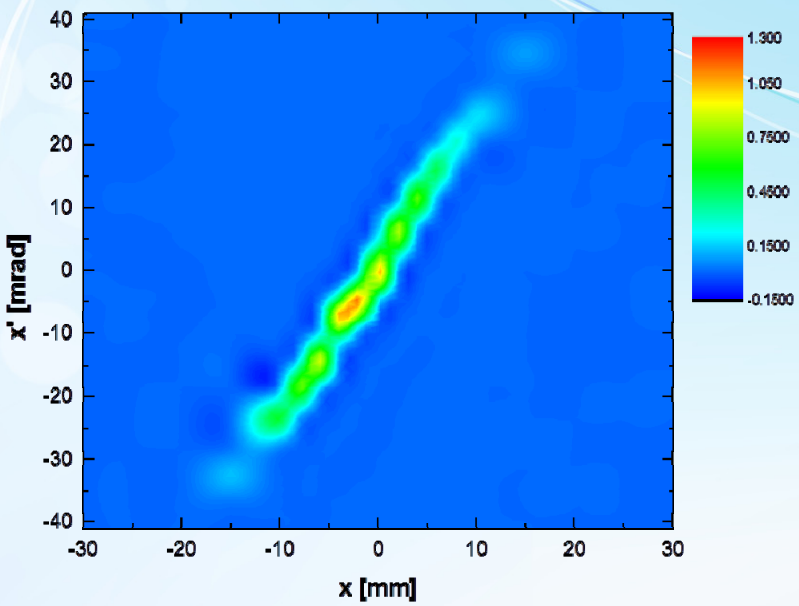
Ion Source Issues 3 – Beam Current Ripple



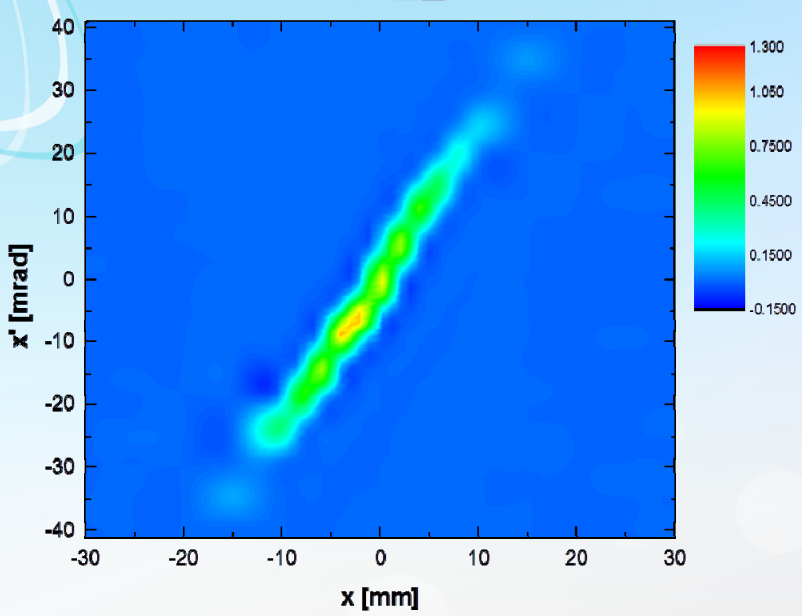
- Spectrum measurement at forward and reflected signal
  - 42.25kHz peak, regardless of magnet power supply status
- Microwave frequency depending on Power
  - 400W setting : 2.464250GHz
  - 310W setting : 2.462575GHz
- Magnetron power supply switching frequency : 20~22kHz



Ion Source Issues 4 – Neutralization



Base pressure: 1E-7 torr
Measurement condition: 1.1E-5 torr hydrogen
Extraction voltage: 50 kV
Bias voltage: -2 kV
Normalized rms emittance: 0.318 π mm mrad

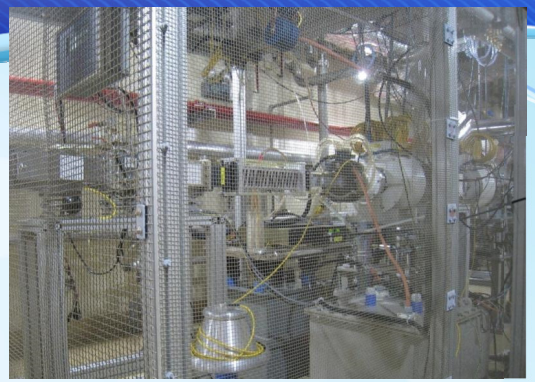


Base pressure: 1E-7 torr
Measurement condition
1.1E-5 torr hydrogen + 2.1E-5 torr krypton (1sccm)
Extraction voltage: 50 kV
Bias voltage: -2 kV
Normalized rms emittance: 0.249 π mm mrad

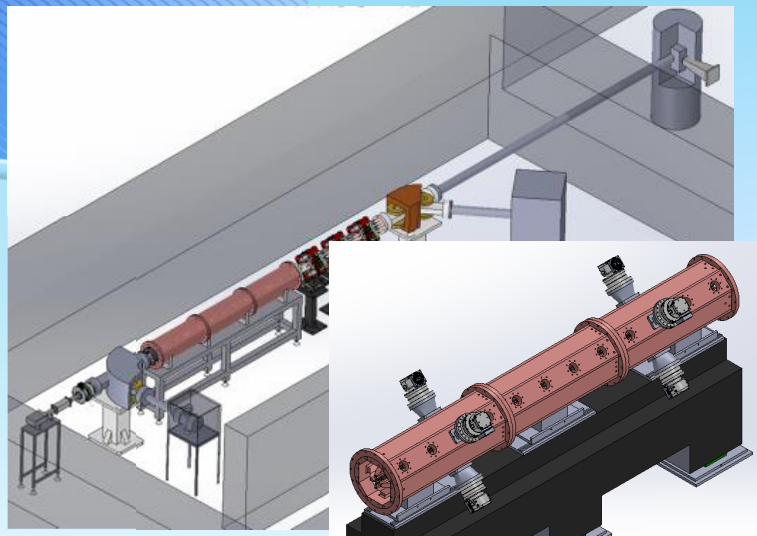
Measured at Test bench with beam focusing solenoid
Normalized rms emiitance reduced by ~20% with Kr adding

❖ Ion Source related R&D

Ion Source Test Bench (1)

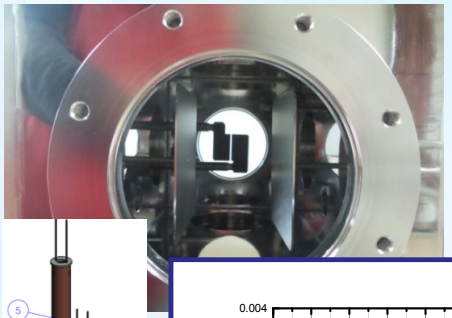


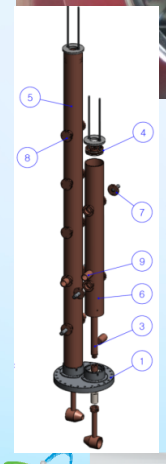
- Improvement of injector for 100-MeV linac

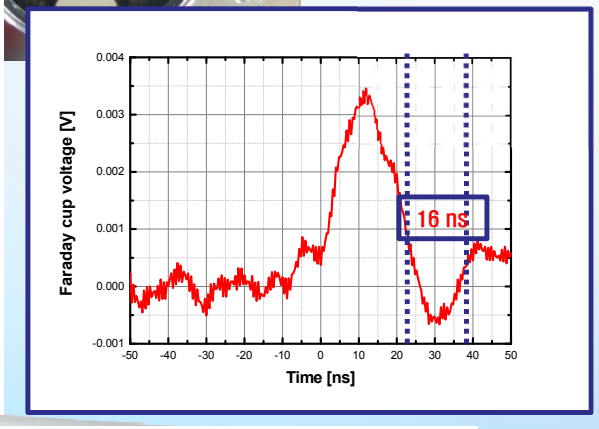


- He2+ ion source test for new RFQ

Ion Source Test Bench







- 10ns grade short pulse beam generation

- Alternative to Duopigatron for Ion implanter

Ion Source Test Bench (2)

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IS control rack
- HV PS
- Bias PS
- Magnet PS
- Gas flow control

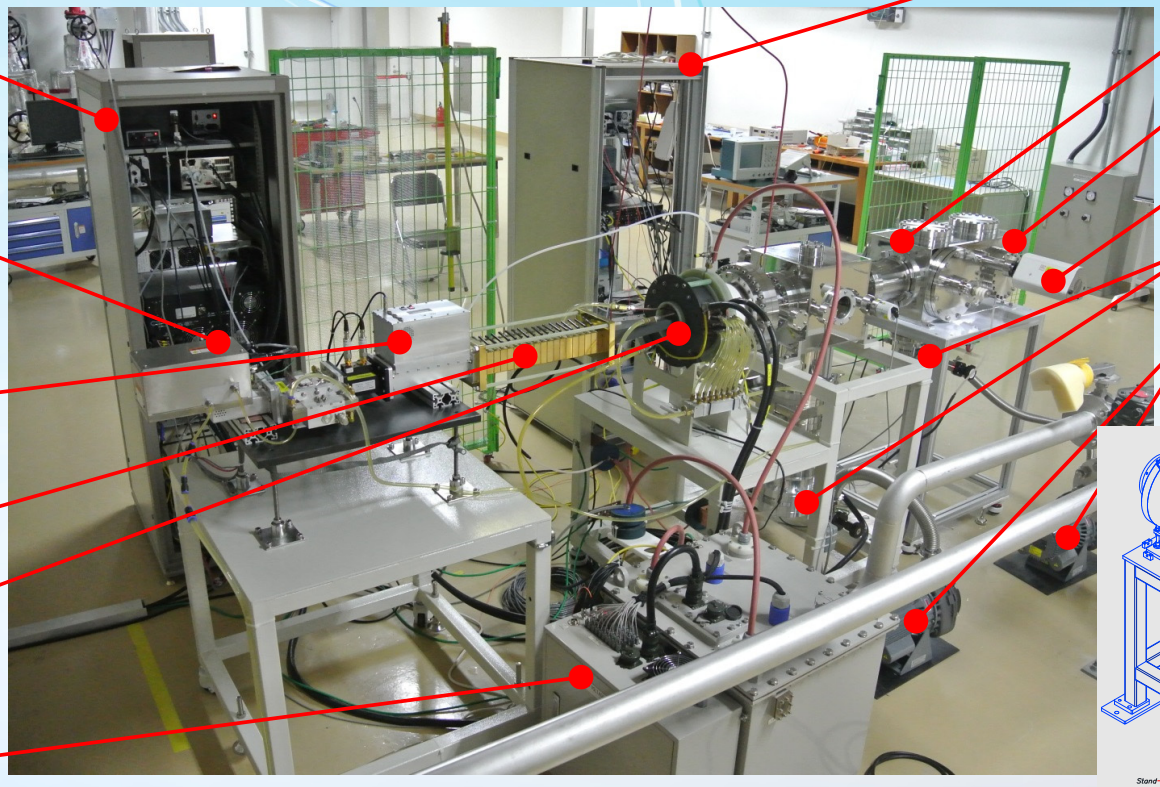
Magnetron

3-stub tuner

WG DC break

Ion source

HV switch
For extraction



Control rack
- Timing system
- Vacuum control
- Diagnostics

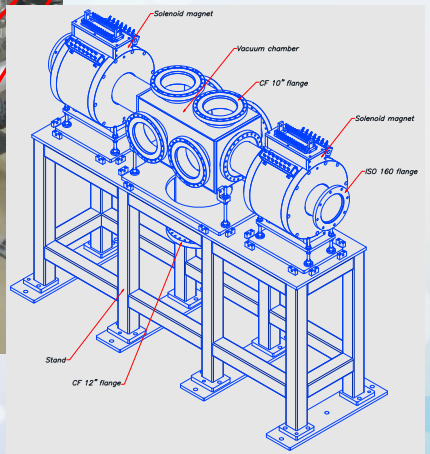
Diagnostic chamber

Faradycup

RGA

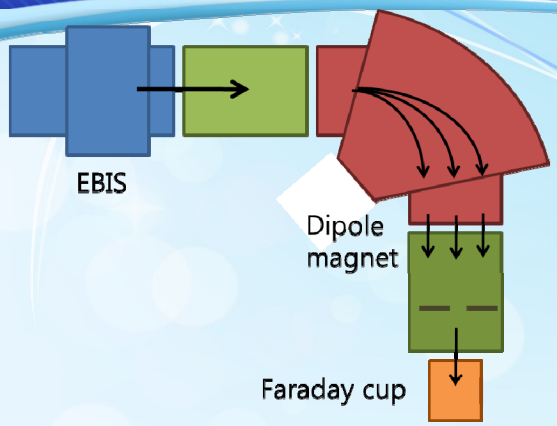
TMP

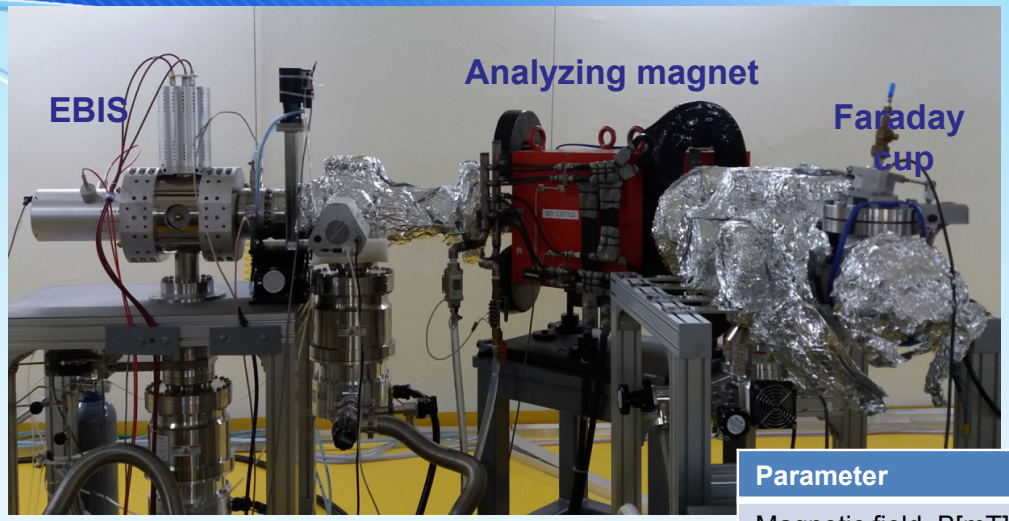
Scroll pump



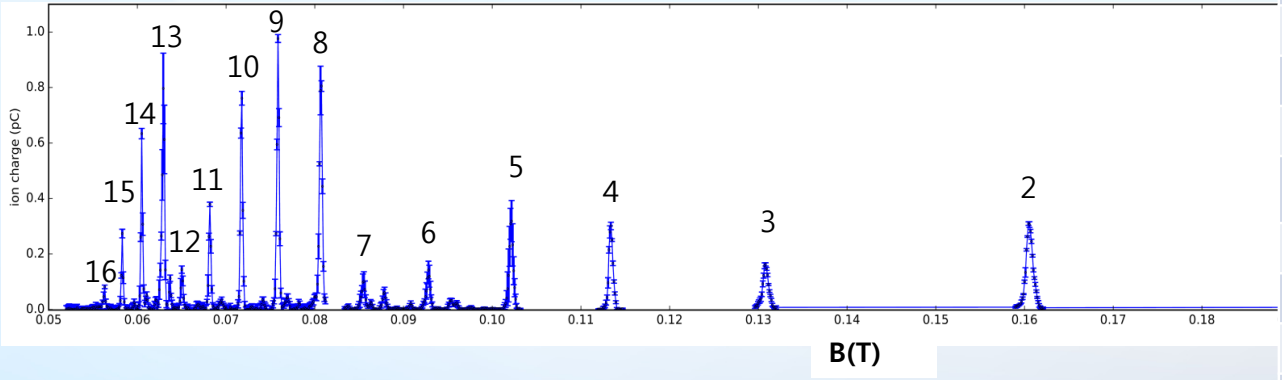
Almost same as the one used for LINAC operation (source of spare parts for reliable LINAC injector operation)
Test bench for various operating condition, components tests and new design to improve the ion source
LEBT with two solenoid with a diagnostic chamber is under fabrication

EBIS for New RFQ





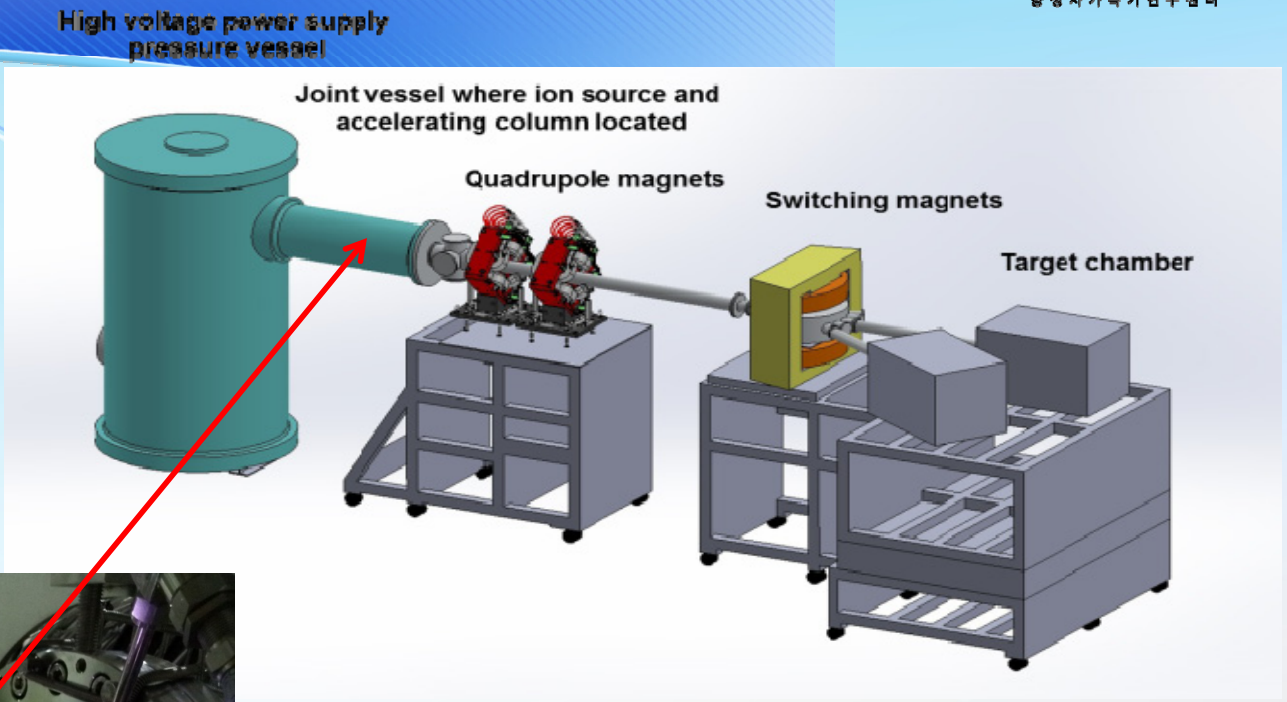
Ar^{+n} spectrum

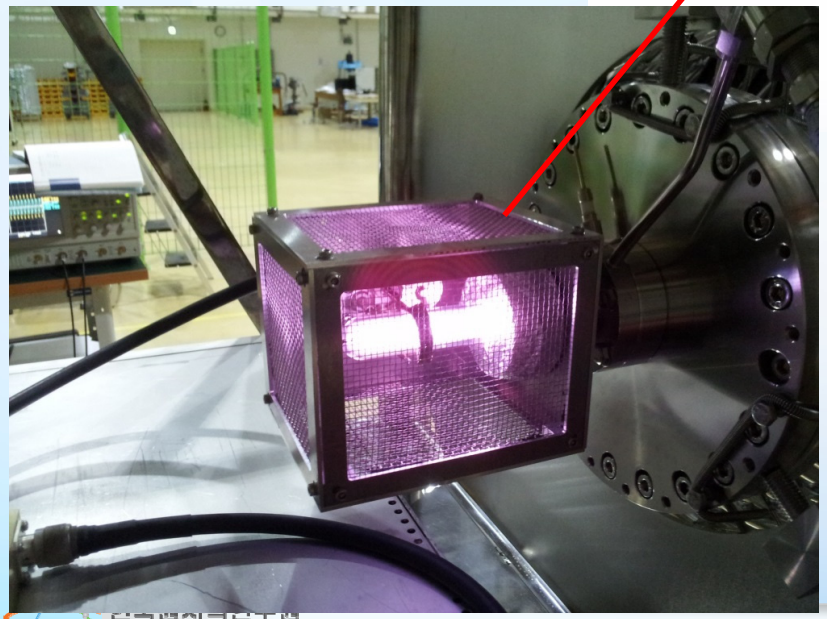


Parameter	EBIS-A
Magnetic field, B[mT]	600
Magnet	NdFeB
Electron energy, E_e[keV]	≤30
Max. electron current, I_e[mA]	≤200
Max. current density, j_e[A/cm^2]	≤600
Drift tube length, L[cm]	6
Cathode diameter [mm]	1.0
Trap capacity, C_{el}[pC]	91
Drift tube number	3

To generate multiply-charge ion beam for new heavy ion RFQ, electron beam ion source is under development
Test stand with a permanent magnet based commercial EBIS (Dreebit) prepared and under test
Large scale EBIS based on SC solenoid is under development

Compact RF Ion Source for 1 MV Accelerator





Compact 200 MHz RF Ion Source

- Ion species: gaseous (proton, O, N, etc)
- Frequency: 200 MHz
- 1-turn antenna coil with variable capacitor matching
- Permanent magnet to assist plasma generation
- RF power by using VCO and SSA

Summary

- 100-MeV Linac & Beamlines
  - Successfully commissioned 100-MeV linac with 1 kW in 2013
  - Increased beam power to 10 kW in 2014
  - Commissioning of the RI production beam line in 2016
  - Construction of the low flux beam line in 2016

- Issues on Proton Injector for 100-MeV Linac
  - 2.45 GHz microwave ion source with single solenoid
  - Frequent HV switch failure - fixed
  - BN coating - preventive maintenance
  - Beam current ripple
  - Neutralization - effective

- Ion source related R&D
  - Test bench prepared
  - EBIS for new RFQ
  - Compact RF ion source for 1-MV electrostatic accelerator


Thank you
안내동
www.komac.re.kr