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Use of Accelerators for Research & Training in The University Environment

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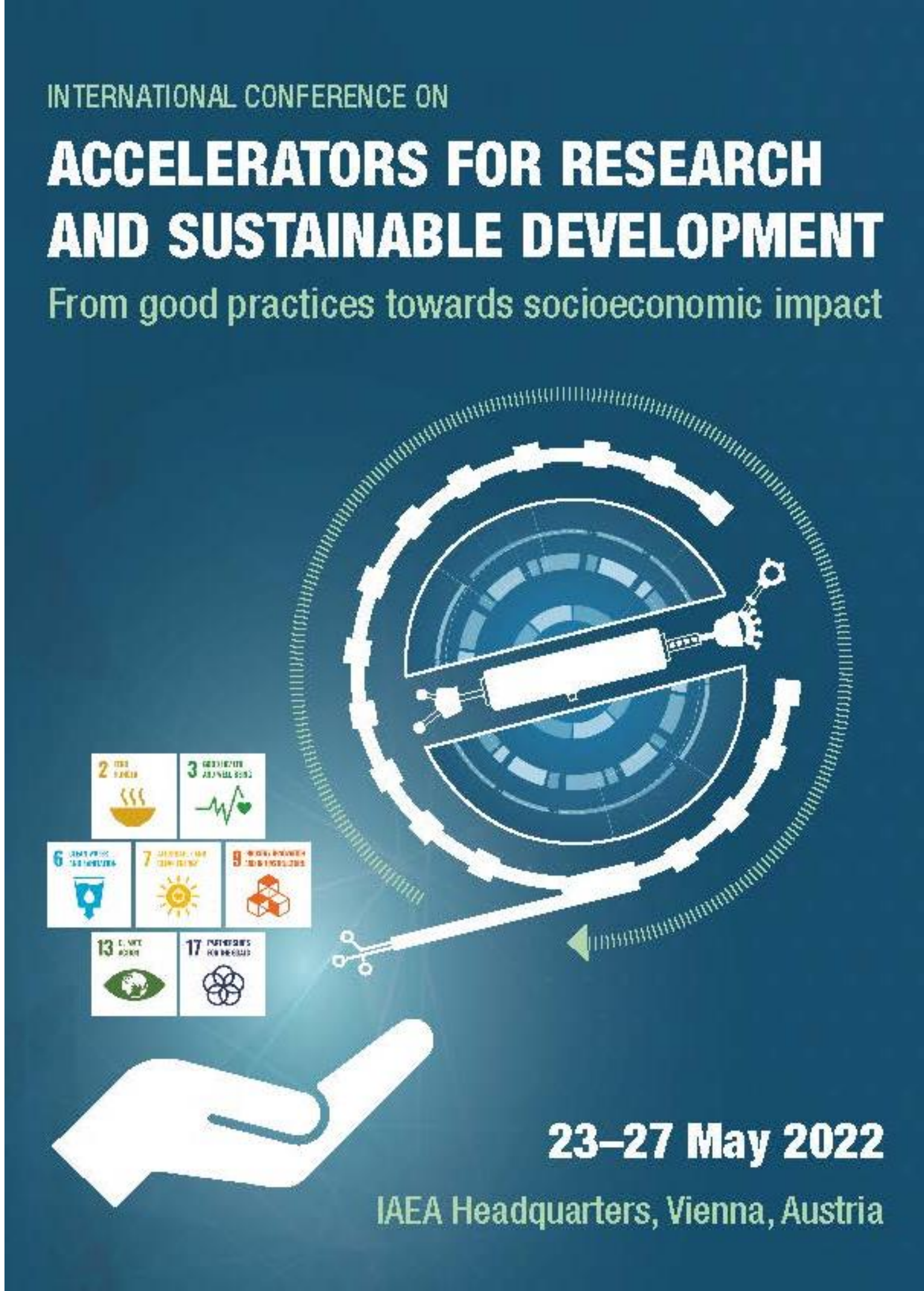

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- ■ Research and Training project

Introduction of Dept. of Accelerator Science

- **2014.03 :** Foundation of Dept. of Accelerator Science in Graduate School
  - **"KU-IBS Science Park"** MOU (2013.03) ignited to establish Dept. of Accelerator Science to educate & train graduate students in association with "RISP Project" (Development & Construction of Heavy-ion accelerator)
- **2017.05 :** Completion of Building for Accelerator Experiments
  - R&Ds of accelerator technologies & science in collaboration with Institutes (RISP, KAERI, KIRAMS, PAL, KBSI, KEK, etc.) and industries.
  - Started to install small-sized accelerators donated from Institutes :
    - Electrostatic accelerator : light ions, 150 keV, 5 mA
    - Microtron-based THz Free Electron Laser system : 7 MeV, 40 mA/5 μsec
    - 14.5 GHz ECR ion source : 10 keV, 5 mA
    - sub-ps Electron Linac : ~60 MeV, 0.2~0.5 nC/0.2~2 ps
  - Diagnostics, Magnetic measurements, RF system/coupler test, etc.
- **2019.03 :** Establish "**Accelerator Research Center**"

Introduction of Dept. of Accelerator Science

■ **Globalization of Research Infrastructures & Education Programs in Accelerator Science**

GOAL

Cultivation of Experts in Accelerator Science & Development and Operation of innovative research infrastructures

Researches & Trainings

Research & Training in collaboration with National Projects

R&Ds for Novel Accelerator Technology and Science

Outreach Program for Beginners or Non-experts in Accelerator Science

Training & Supporting program for industries in regional area

Infrastructures for Accelerator Research & Developments

Developments of Test Benches for R&Ds and Trainings

- Electrostatic Ion Accelerator
- ECR Ion Source & Mass Spectroscopy
- Microtron-based THz Free Electron Laser & Applications
- ps, 50 MeV e^- Linac (To be installed)
- RF test system (cold test / 325MHz)
- Magnet measurement system

Utilization & Spin-off in Accelerator Science

Experimental Nuclear Physics and Applications using Ion Beams

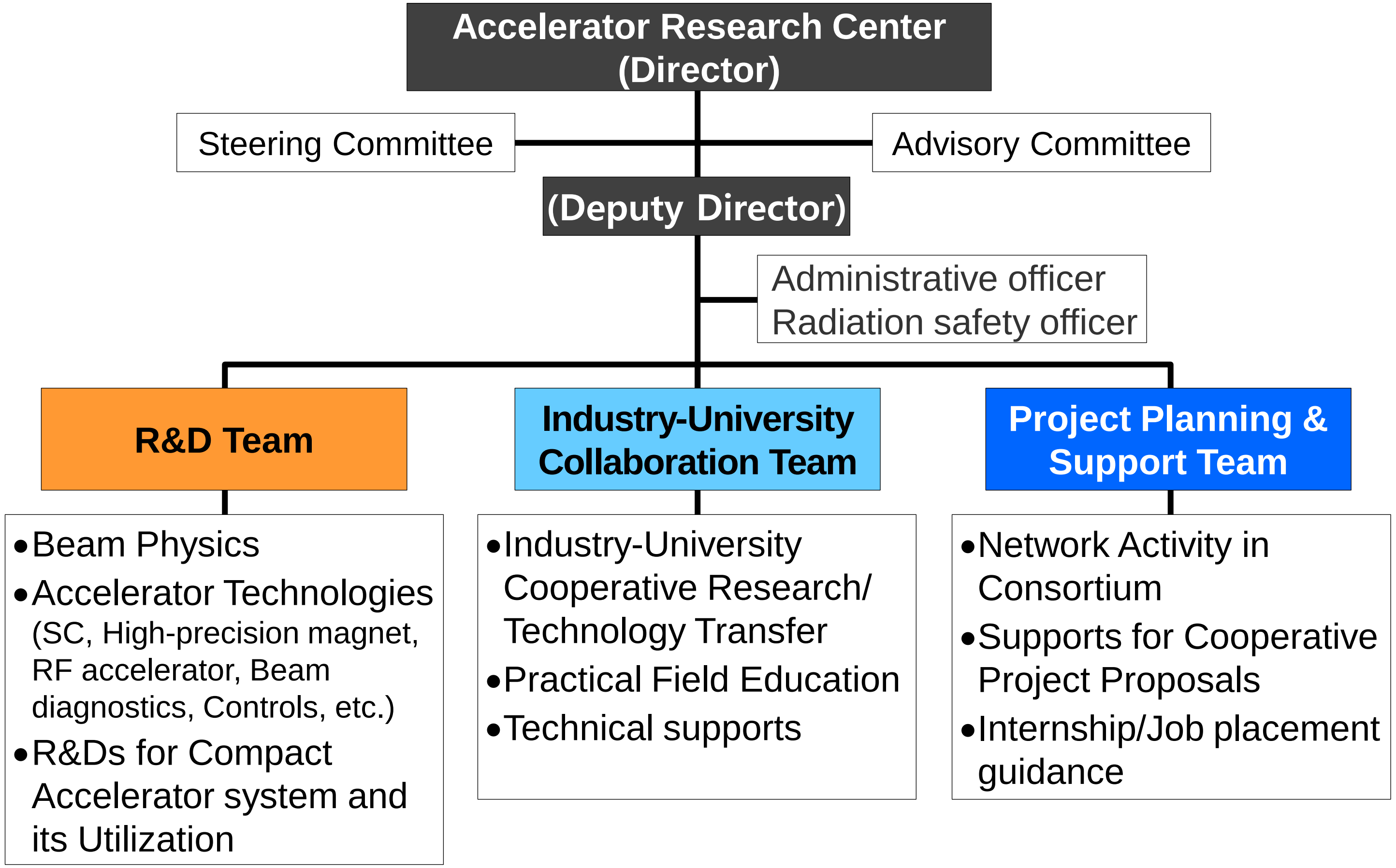
R&Ds on Compact Accelerators for Cancer Therapy and Detection technology

R&Ds on Applications and Utilization of Accelerator-based Radiation sources

Introduction of Accelerator Research Center

■ Accelerator Research Center / Department of Accelerator Science

- **4 Professors, 10 Research Scientists, 1 Radiation safety/1 administrative officers**
- **25 Graduate students**

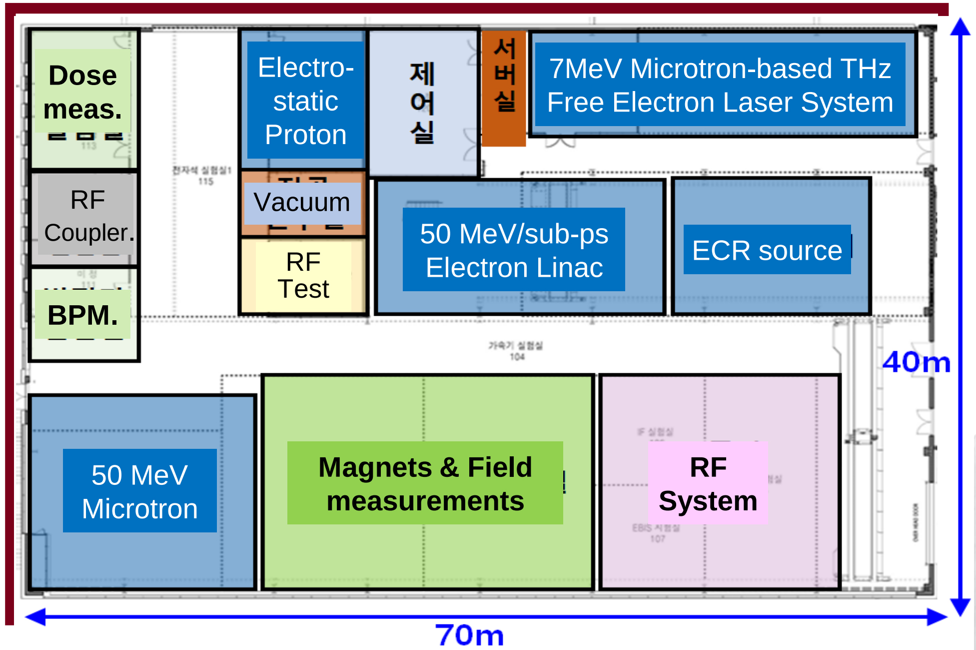


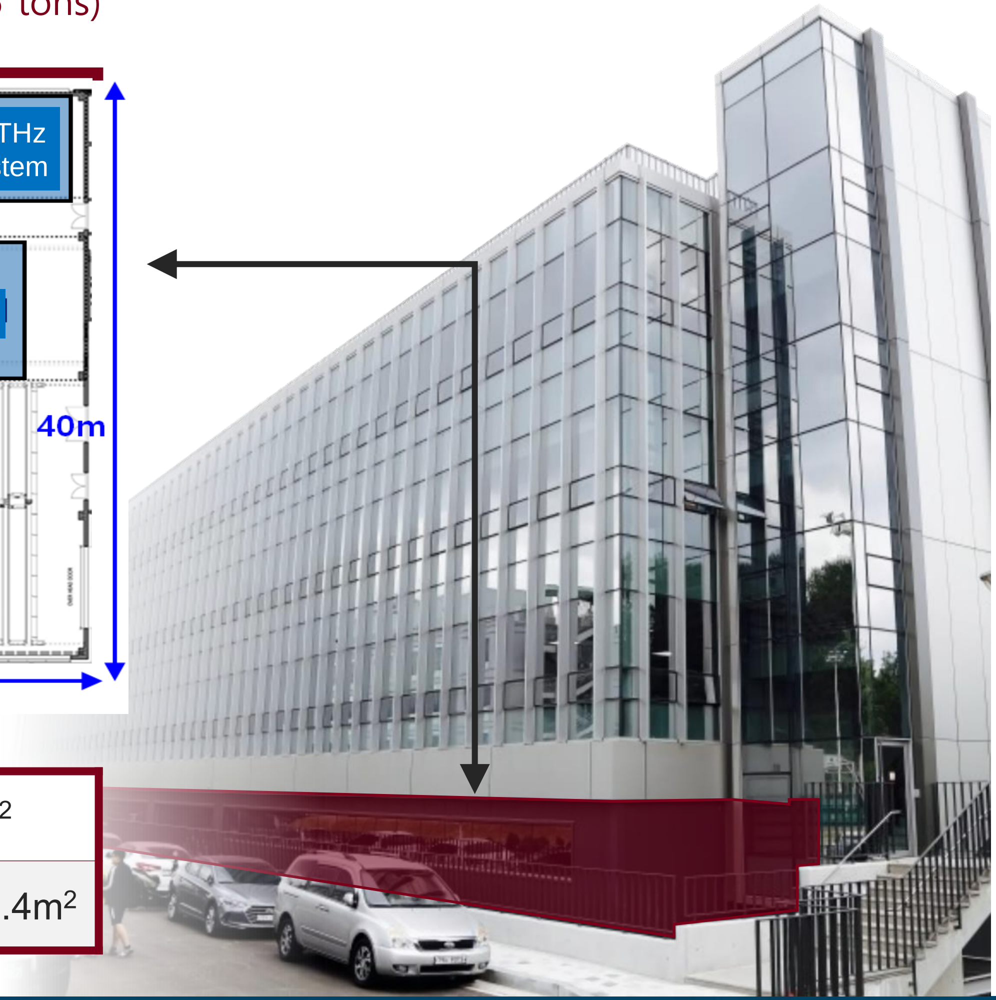
Facility of Accelerator Research Center

Accelerator-ICT Building

First Floor : Experimental Area

※ 70 m x 40 m x 8 m with 2 Cranes (10 tons, 5 tons)





Experimental Area	**1^{st} floor**	70 x 40 m^2
Office	**2^{nd} / 3^{rd} floor**	585.3m^2 / 309.4m^2

Facility of Accelerator Research Center

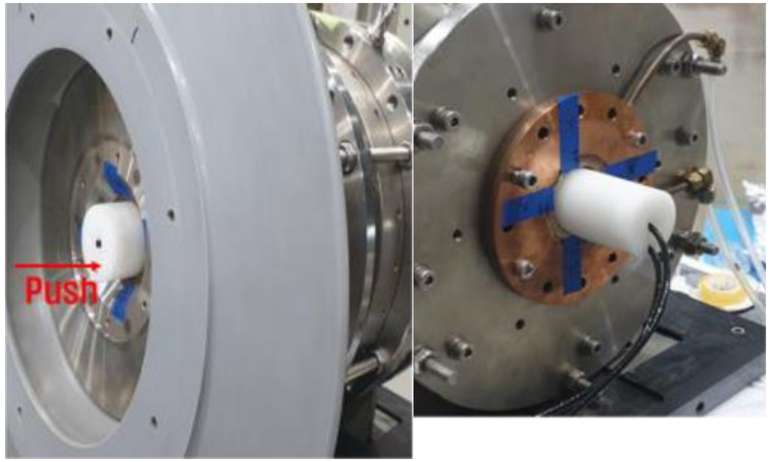
Accelerator-ICT Building

First Floor : Experimental Area

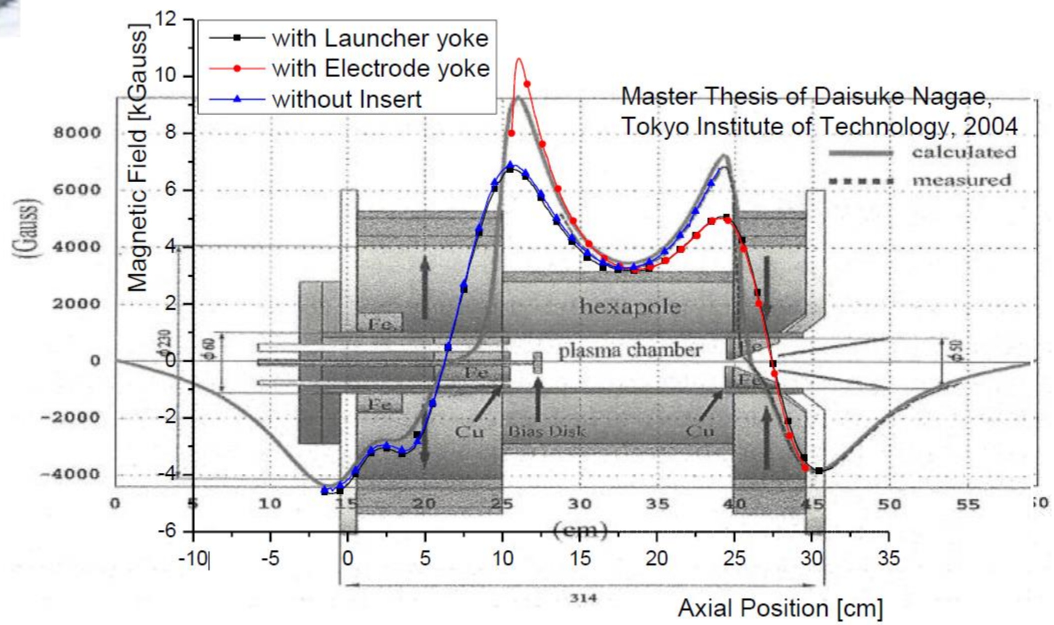
※ 70 m x 40 m x 8 m with 2 Cranes (10 tons, 5 tons)

Facility of Accelerator Research Center

ECR Ion Source :
Magnetic Field Measurement & Modification of Electrode and Launcher

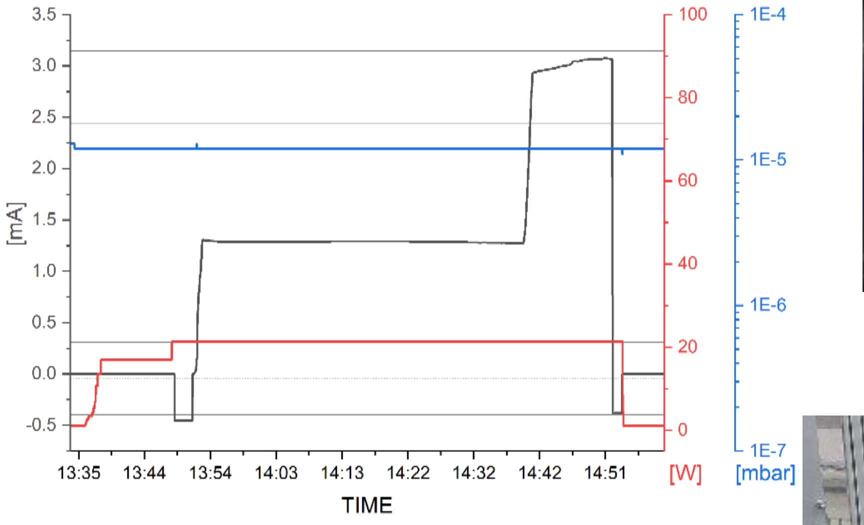


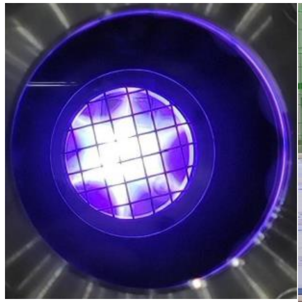
Electrode Yoke **Launcher Yoke**

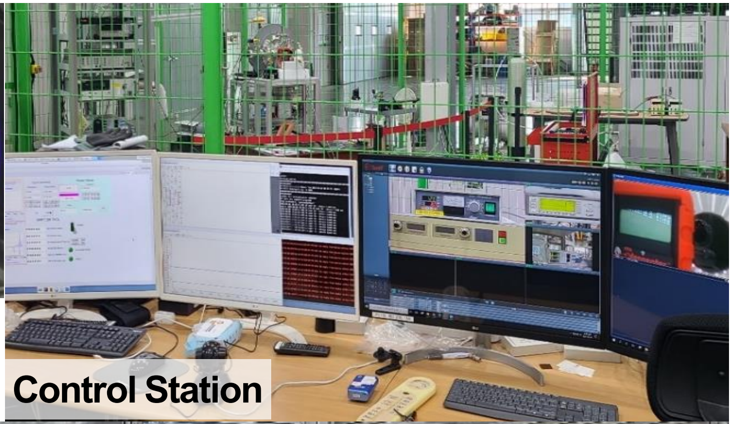


Facility of Accelerator Research Center

ECR Ion Source : Refurbishment and Performance Test

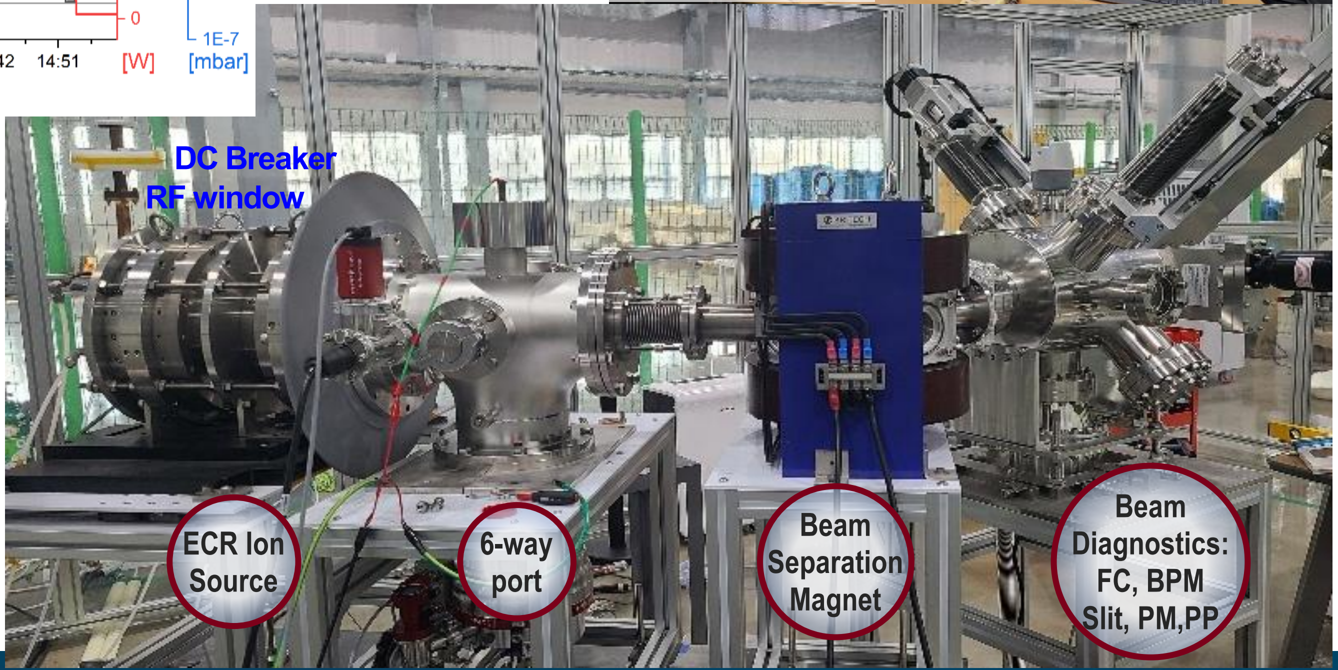






- RF freq. : 14.252 GHz
- V_{ext} : 10 kV ~ 15 kV
- Room Temp. : 19°C
- Humidity : 32%

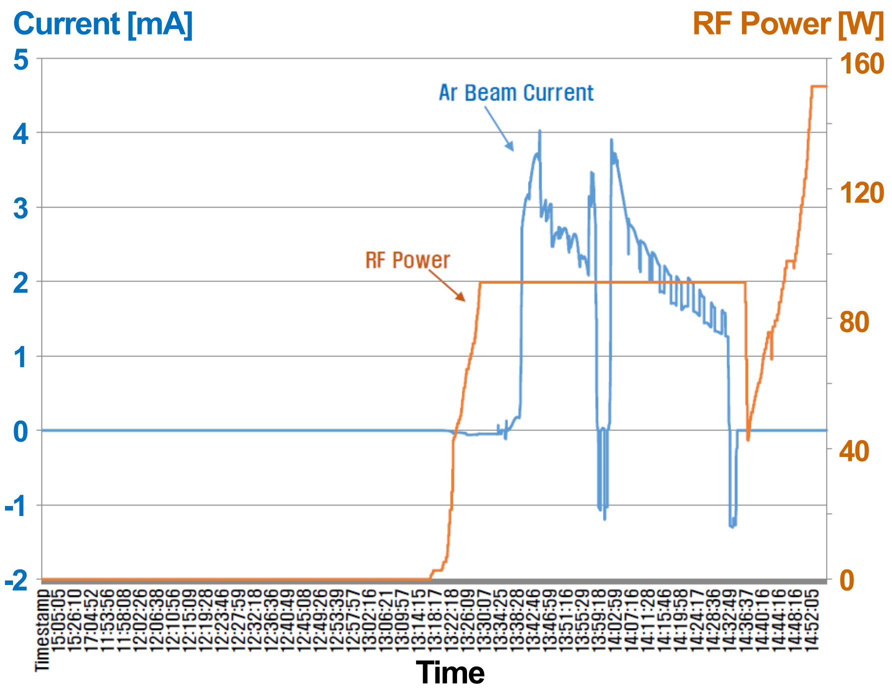
- **Beam Stability ~0.1% for 1 hr with ~1.3 mA of Ar and ~21 kW RF power**



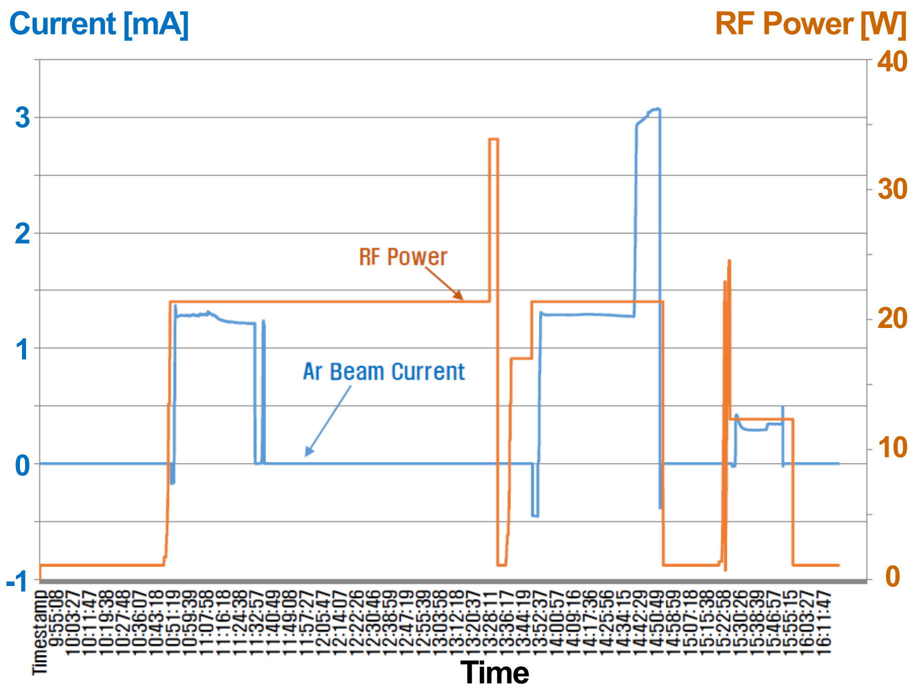
Facility of Accelerator Research Center

ECR Ion Source : Extracted Ar Beam Current vs. RF Power

1st Beam up to 4 mA



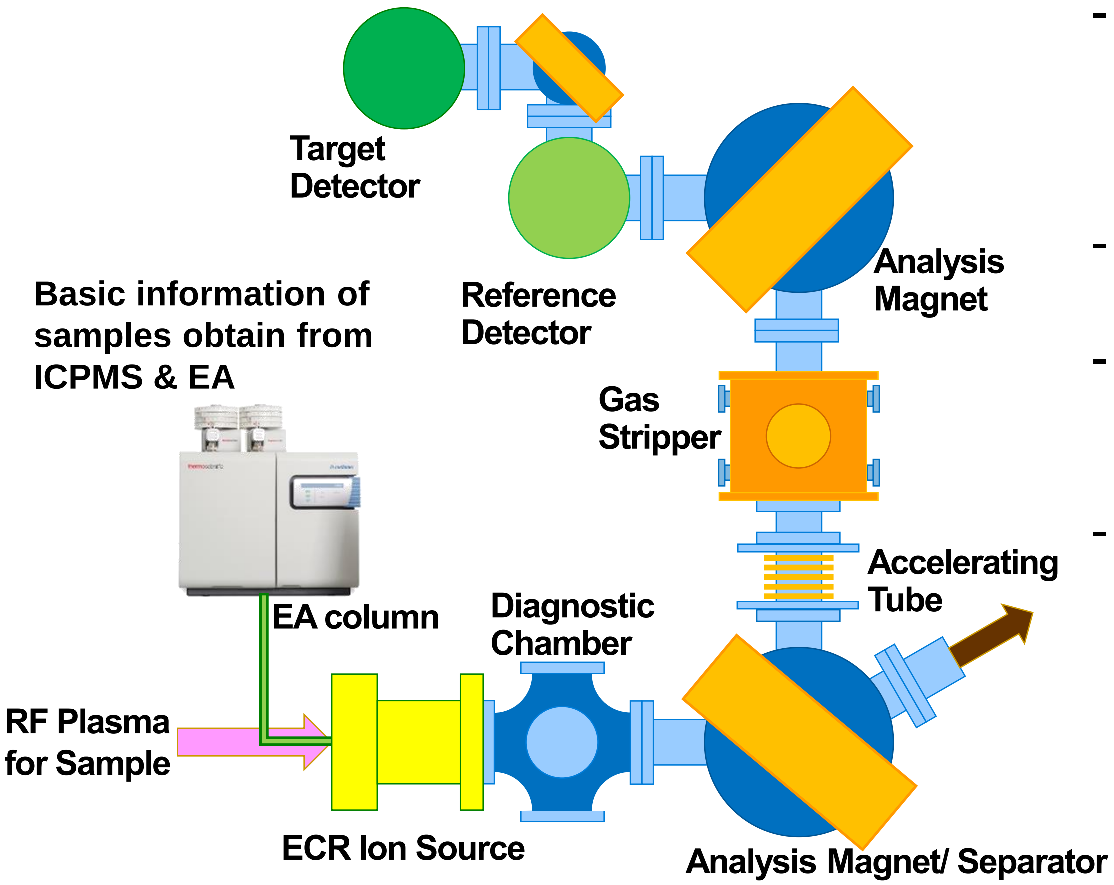
Journey to stabilize Beam current



R&Ds on Ion Sources for Scientific Tools

Collaboration with KBSI : Positive Ion Mass Spectroscopy

- Base information of samples obtain from ICPMS & EA
- Nuclides available for Target detecting – C, B isotopes



- Positive ions generated from ECR ion source on high voltage platform (basically 150 keV or 300 keV) are accelerated to Gas stripper and separated by Analysis magnet (2nd)
- After reference detecting using Faraday cup, C or B isotope will be counted using MCP or GEM.
- The reference composition of sample is analyzed using ICPMS (Inductively coupled plasma mass spectrometry) and EA (Elemental analyzer)
- The 1st Analysis magnet will be used either deflecting ion beams into different beamline or low energy mass spectroscopy.

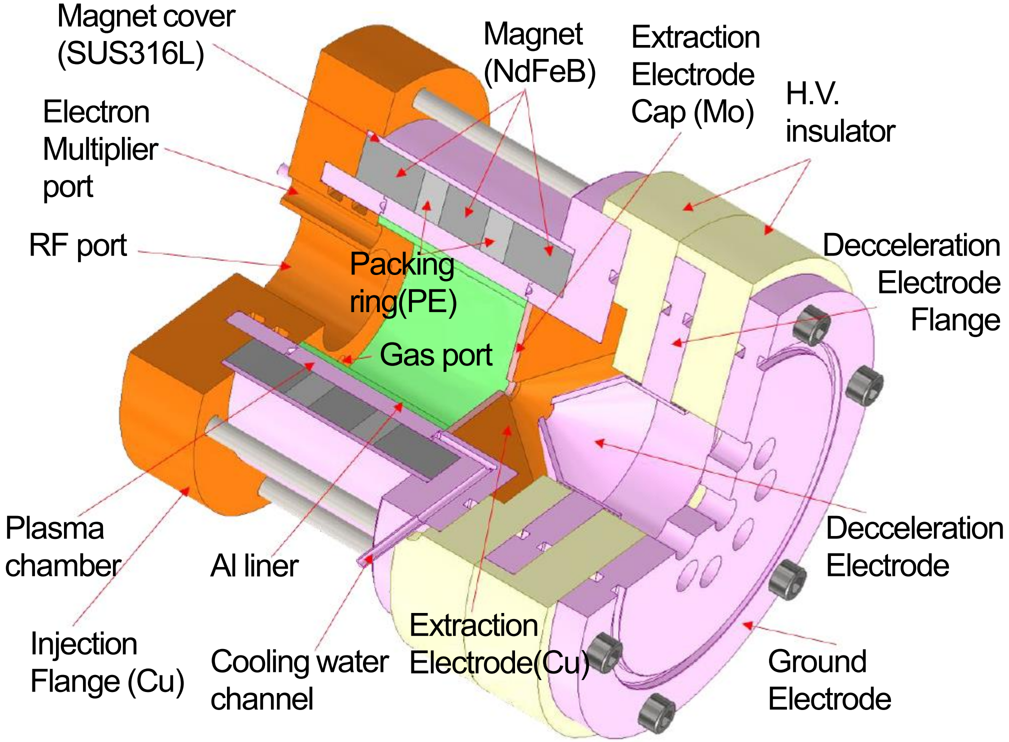
(Courtesy of Byeong-Seob Lee, KBSI)

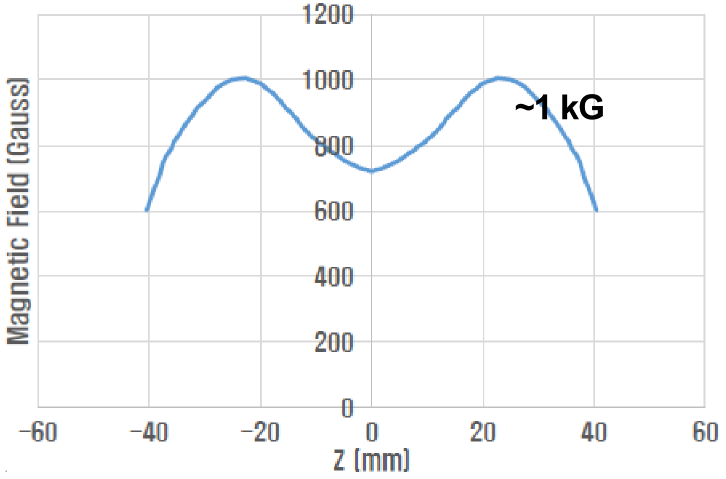
R&Ds on ECR Ion Sources for BNCT

Collaboration with KBSI : High current ECR Ion source for Proton & Deuteron

-

RF frequency & Power	**2.45 GHz, 200 W**
Magnet material	**NdFeB**
ECR ion source size	**Φ140 × L110 mm**
Liner/Electrode cap material	**Aluminum**





- It will employ an external electron ion source to generate high intensity of proton and/or deuteron ion beam by increasing electron density in plasma chamber
- Peking Univ. achieved high intensity of proton & deuteron beam, 20 mA & 15 mA in CW, respectively.

Ref. Rev. Sci. Instrum. 85, 02A943 (2014), Chin. Phys. B Vol.27, No. 5 055204 (2018)

R&Ds on Compact Linac for BNCT

Extension to RFQ for several MeV ions

RFQ design parameters :

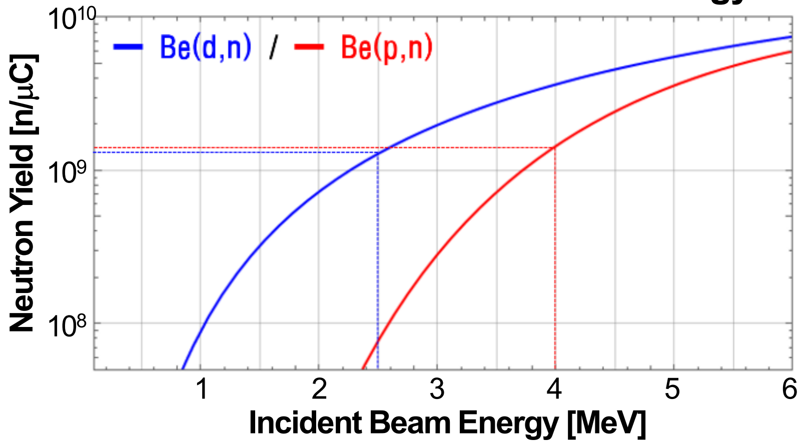
- $^{9}Be(p,n)^{9}B$
- $^{9}Be(d,n)^{10}B$

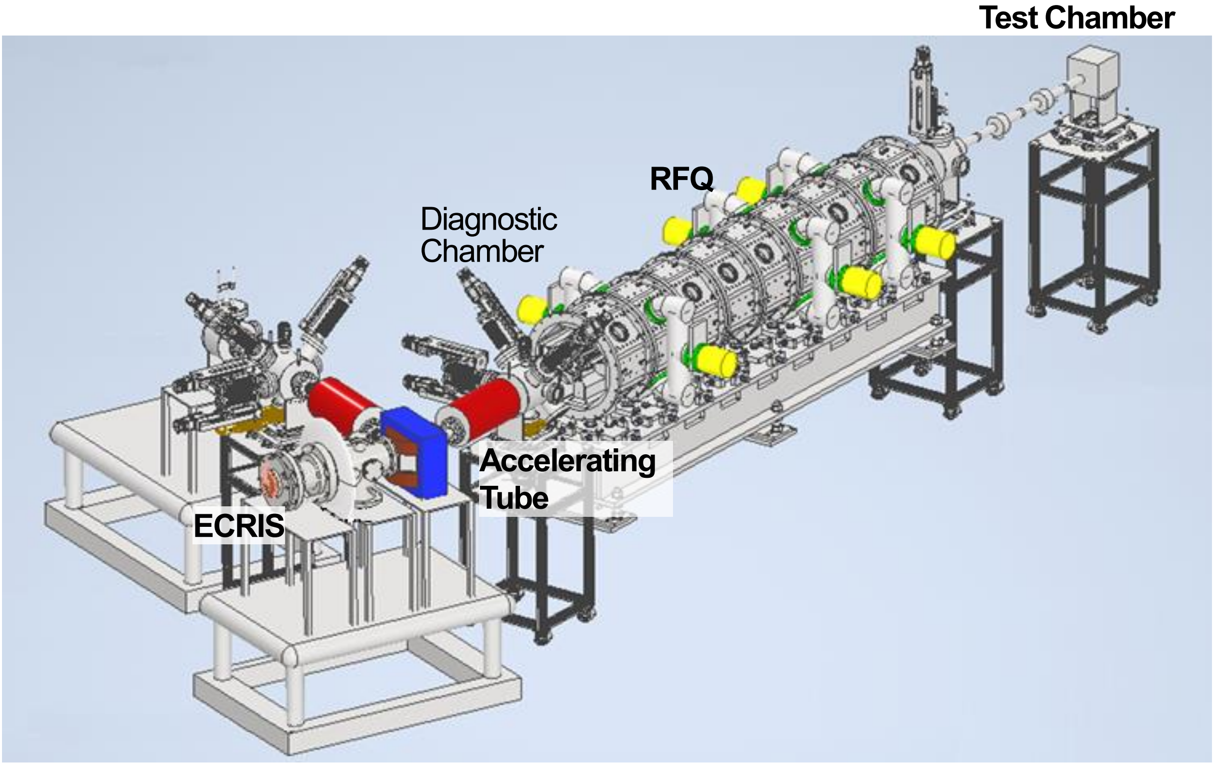
Particle	Frequency	Input E	Output E	Current	Length	Vane V
Proton	**352 MHz**	**40 keV**	**4.0 MeV**	**10 mA**	**4.34 m**	**72 kV**
Deuteron	**200 MHz**	**30 keV**	**2.5 MeV**	**15 mA**	**3.13 m**	**70 kV**

Experimental Chambers :

- Neutron Target/Moderator Test
- Low Energy Nuclear Physics Experiments

Total Neutron Yield vs. incident energy



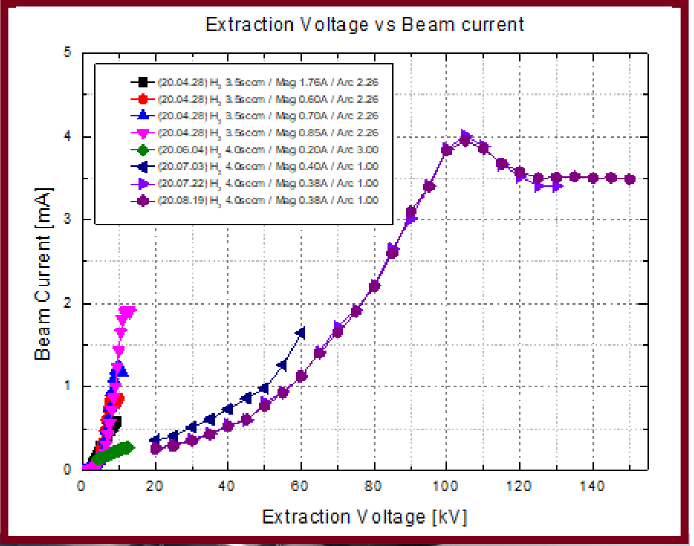


Ref. J. Bahng, Rev. Sci. Instrum. **91**, 023323 (2020); doi: 10.1063/1.5128619

Facility of Accelerator Research Center

Electrostatic Proton Accelerator for Implantation

- Accelerating Tube : up to 170 kV, suppression of electron back streaming
- Beam shaping magnets should be designed.

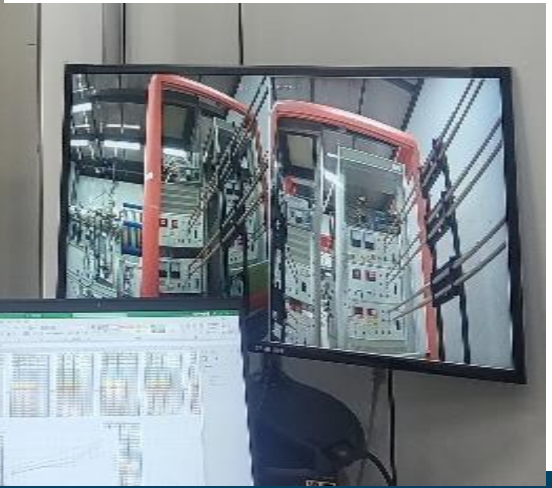


Ion sources

PIGatron : 20 kV/ 3.5 mA

DuoPlasmatron : 30 kV/ 20 mA

- Filament : 15V/100A
- Arc : 150V/15A
- Electro-Magnet : 20V/10A
- Extractor : +30kV/20mA
- Extraction Bias : -10kV/10mA
- Accelerating Bias : -30kV/2mA

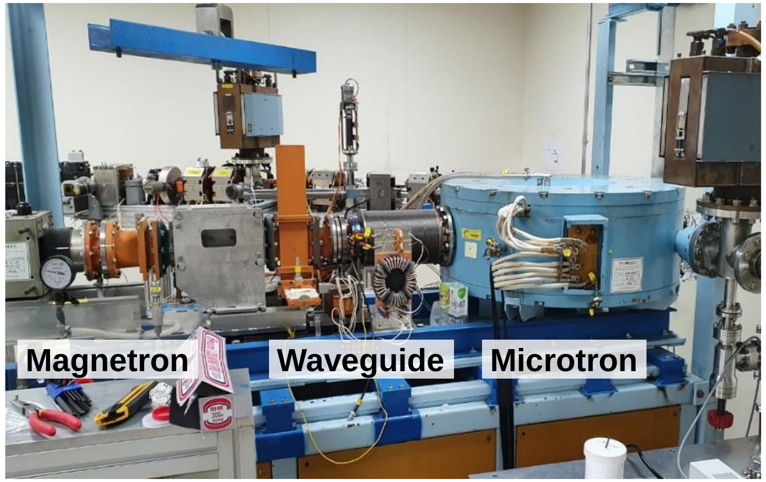


Facility of Accelerator Research Center

Microtron-based THz Free Electron Laser system

Specifications:

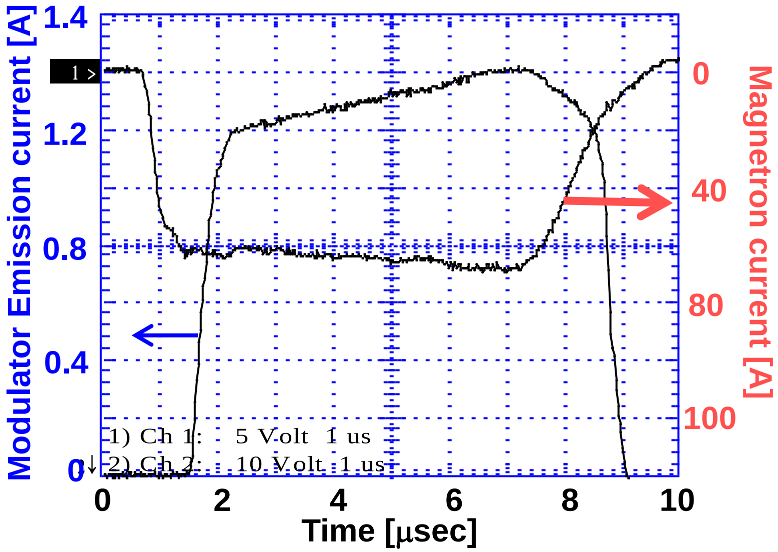
- 7 MeV, 40 mA/pulse
- Magnetron: 2.806 GHz
- Modulator: 6 μs, <10Hz rep. rate
- 3 Dipoles, 6 QMs, Undulator(2m/25mm)
- Optical Resonator: Waveguide type (2mm), Transmissive OC

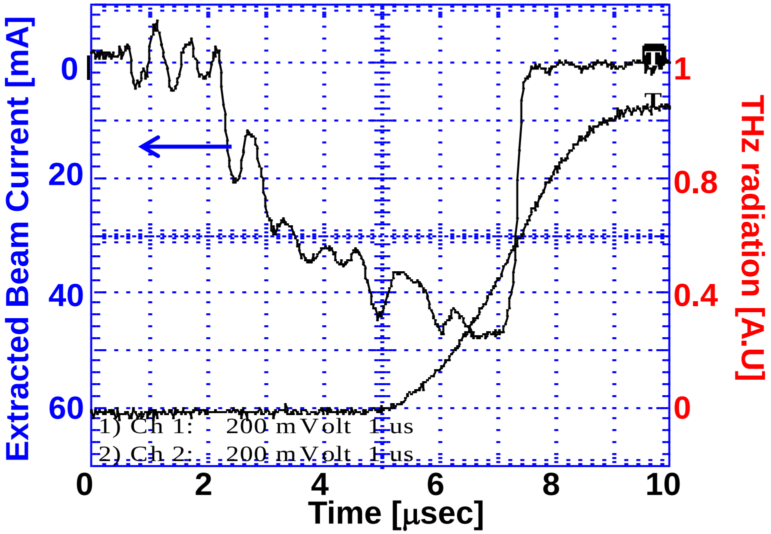


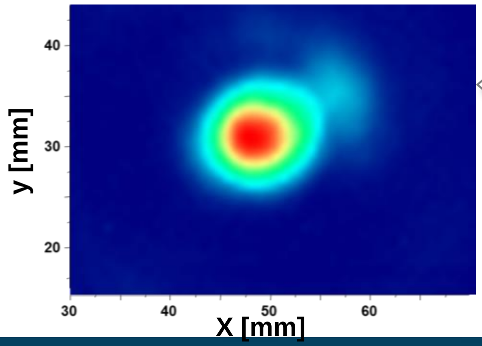
Facility of Accelerator Research Center

Microtron-based THz Free Electron Laser system (Old data)

- Electron Beam : 7 MeV, Average 40 mA/5 μsec macropulse, 3 Hz rep. rate
- THz FEL : ~25.6 W per macropulse

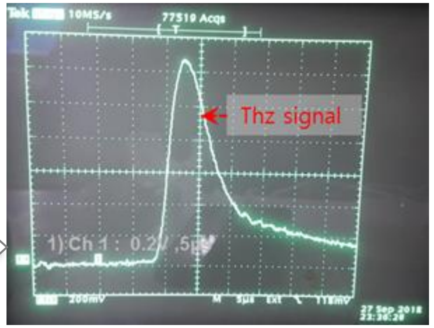






Transverse shape of THz Beam collimated

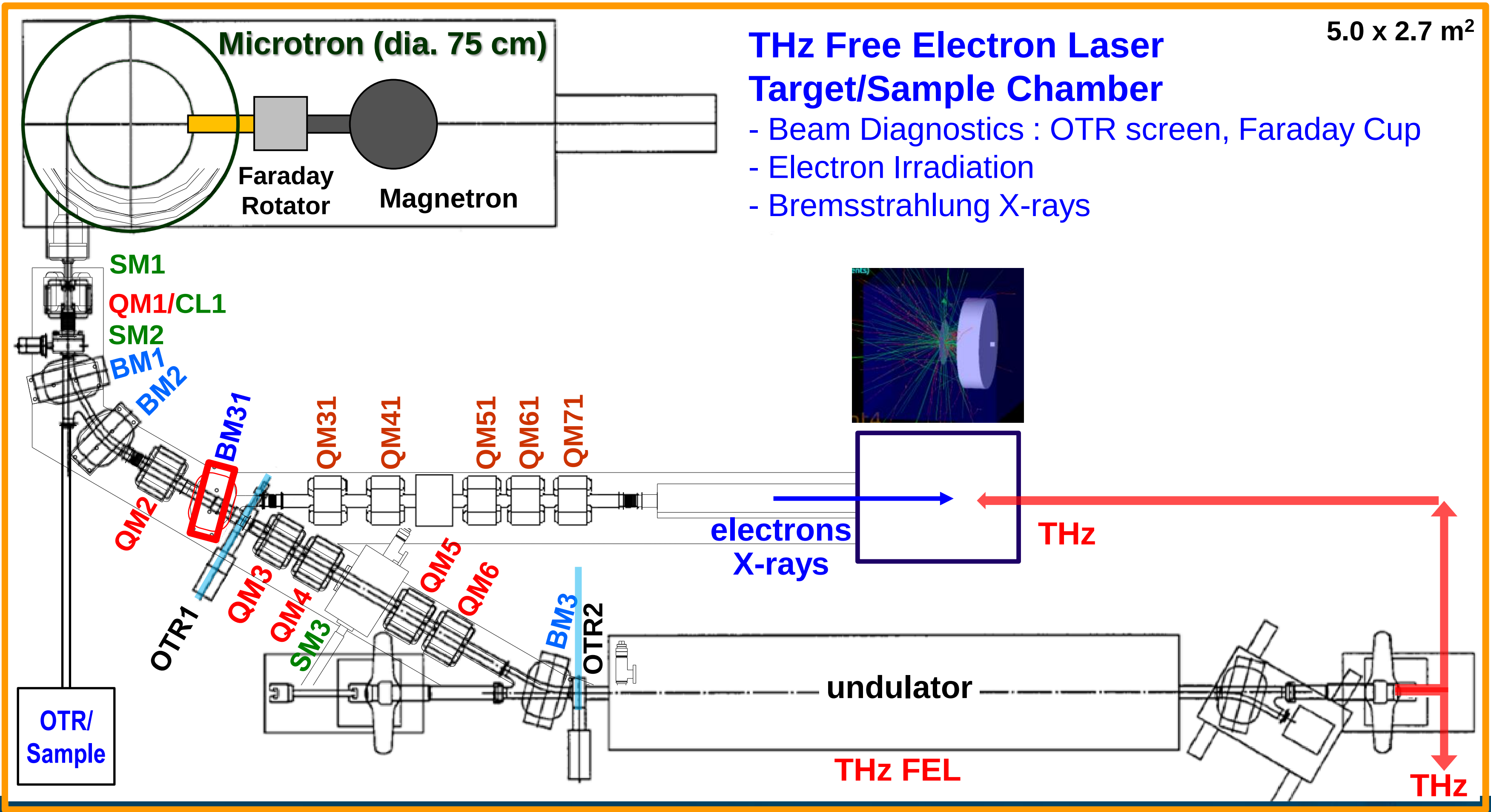
THz Signal measured by LHe Si Detector



R&Ds on Microtron-based system

Microtron-based THz FEL beamline and X-ray/Electron Irradiation Beamline :

- Beamline 2 for e-beam irradiation and OTR screen (BM1 OFF)
- Beamline 3 for Radiation effects or pump-probe experiments (BM31 ON)



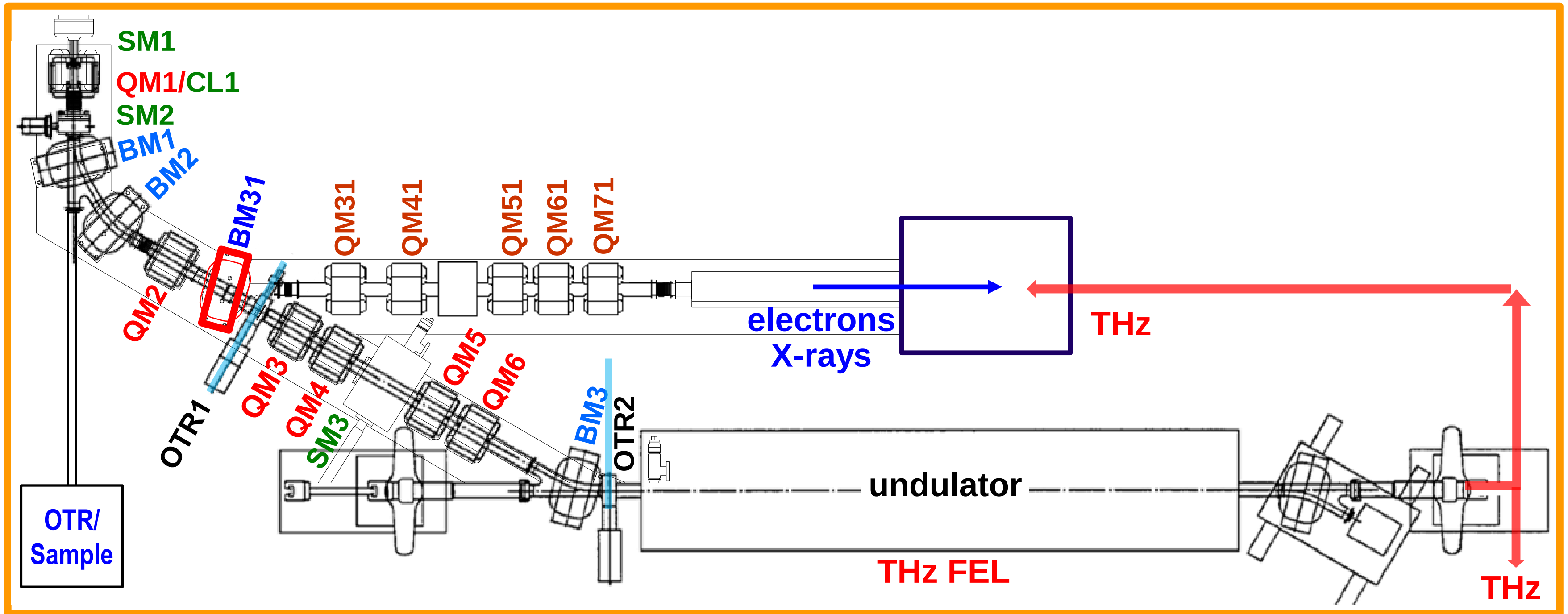
R&Ds on Microtron-based system

Microtron-based THz FEL beamline and X-ray/Electron Irradiation Beamline :

- Beamline 2 : Beam diagnostics, E-beam irradiation
- Beamline 3 : Radiation Effects on materials, bio-samples, etc.
  - Electron and/or X-ray Irradiation, Pump-probe experiments (THz spectrum)

Needs R&Ds for switching techniques for Pump-probe experiments

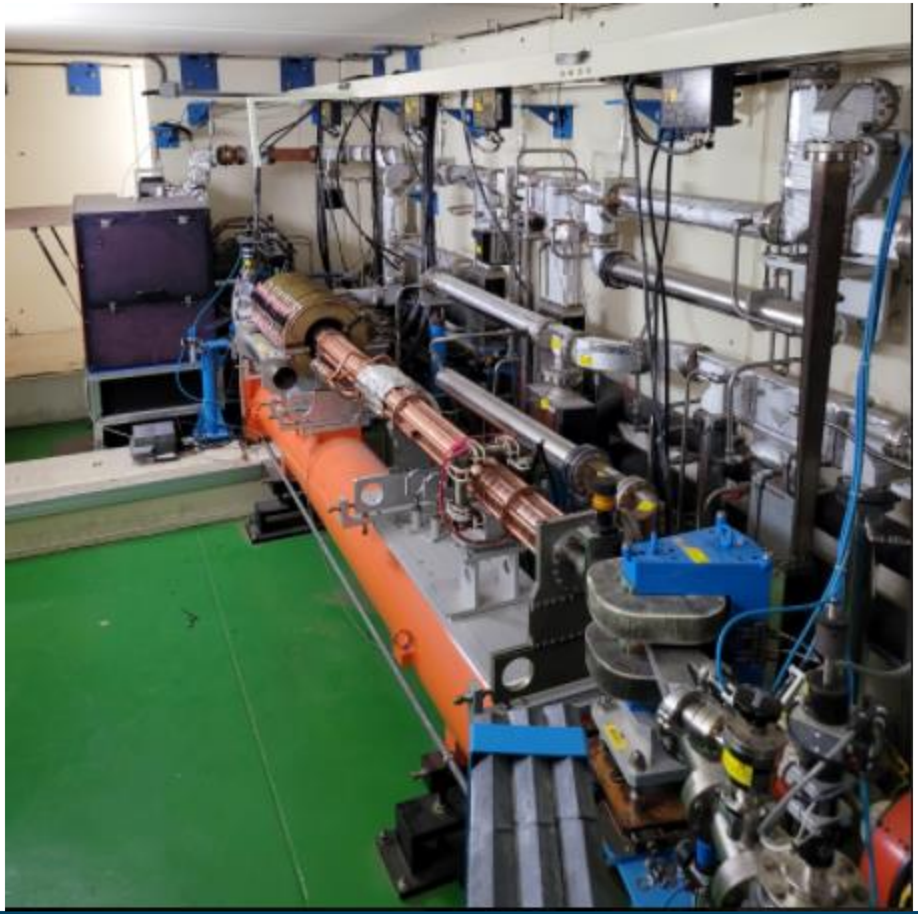
1. Switching "ON – OFF – Re-normalizing cycle scanning" of 30° Dipole (BM31)
2. RF trigger + Scanning magnet : zero field – FEL, +30° - BL 3, -30° - Null signal



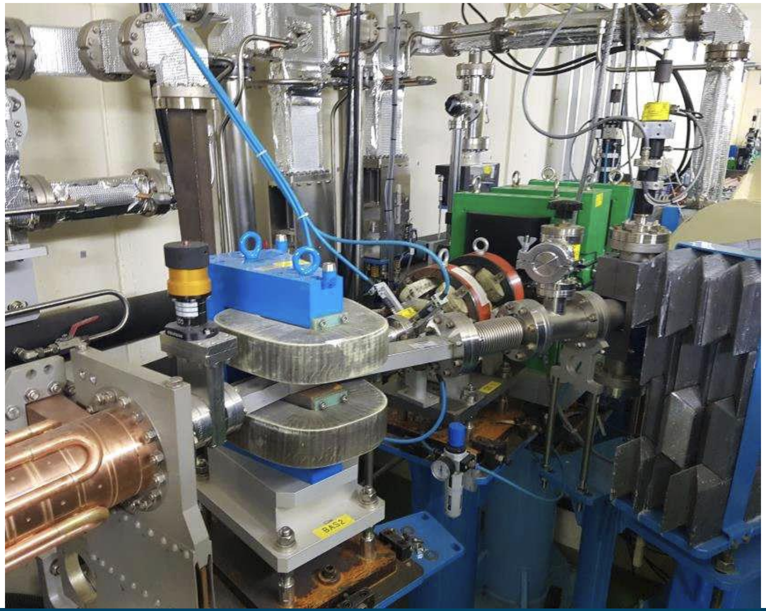
Facility of Accelerator Research Center

Electron Linear Accelerator (to be transferred and installed in KU):

- Photocathode gun, S-band RF cavities, Bending magnet, Chicane, Klystron, Pulsed Modulator (150 MW)



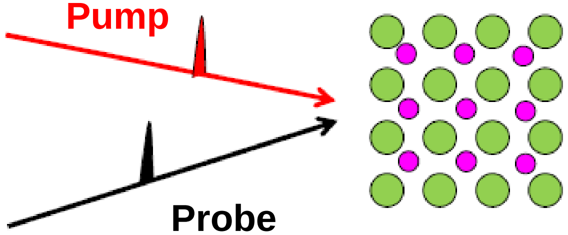
- 60 MeV, 30 Hz rep. rate
- (0.2 ~ 0.5) nC per (0.5 ~ 2) psec
- Chicane for bunch compression : 75 ~ 150 fsec
- Coherent Transition Radiation for fs THz (broadband 0.1~10 THz)



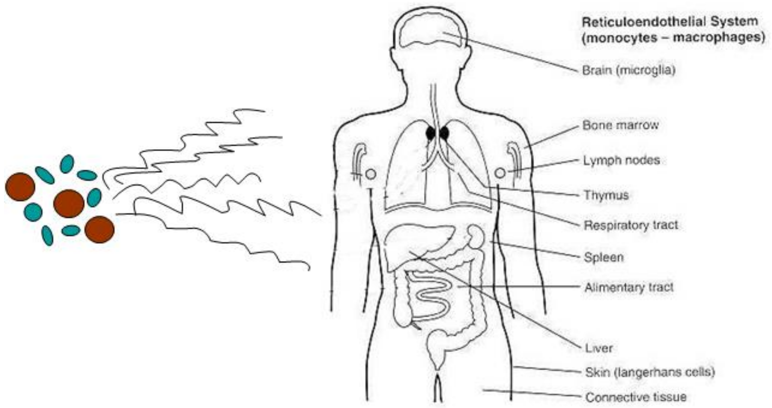
R&Ds using 60 MeV, sub-ps Electron Linear Accelerator

THz generation and THz pulse and/or fs electron applications :

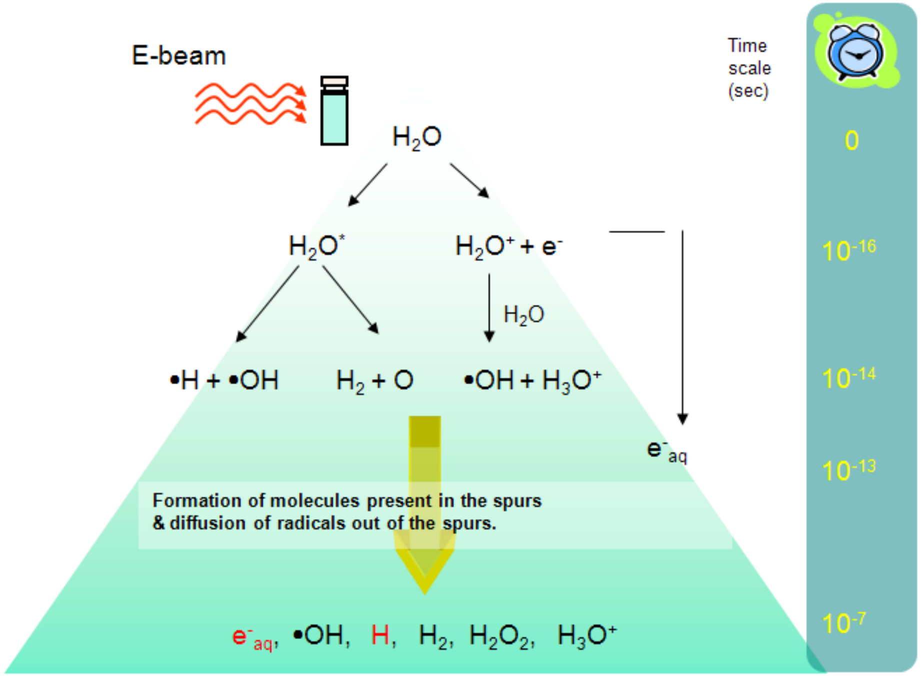
- CTR broadband/fast THz radiation : THz spectroscopy, pump-probe experiment
- Radiotherapy : ultrashort pulse, high peak dose rate
- Material structure and reaction by radiation, ionizing radiation, etc.



· THz pump – Vis/IR Probe
· Vis/IR pump – THz Probe



Radiotherapy



Radiation effects

International Conference on Accelerators for Research and Sustainable Development #Accelerators2022 23–27 May 2022 IAEA, Vienna, Austria

Facility of Accelerator Research Center

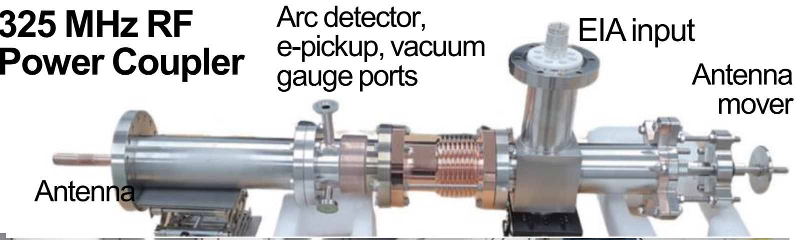
RF system and 325 MHz RF coupler test bench :

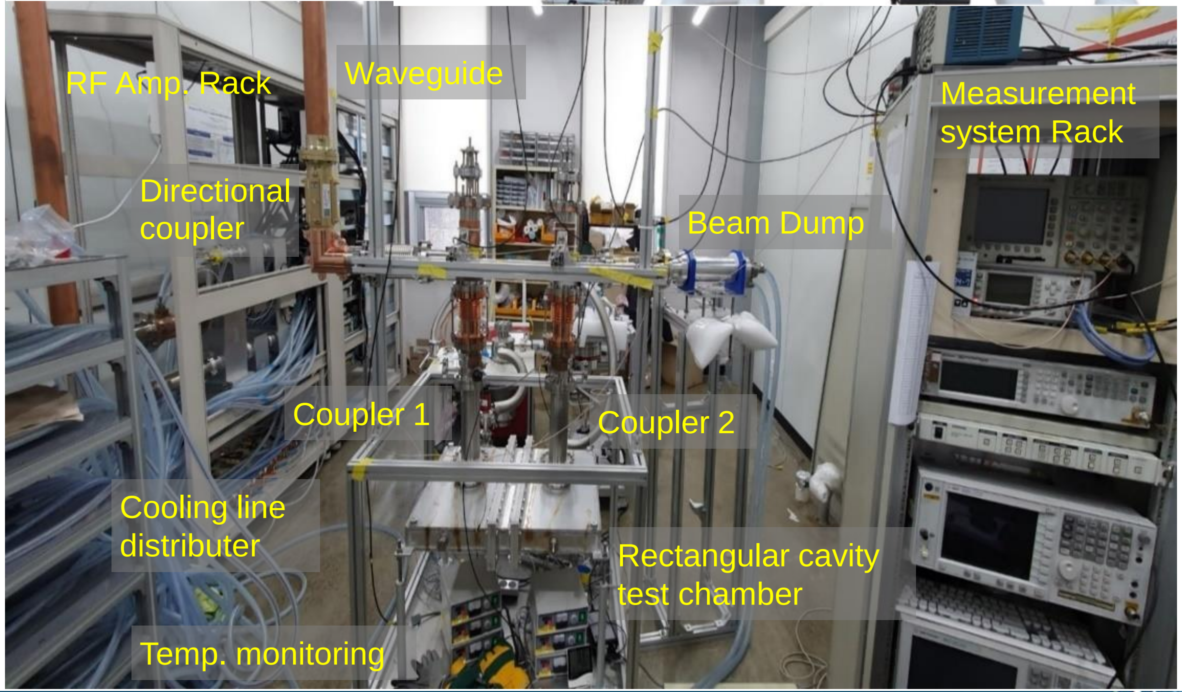
- RF measurement system (cold test) : Network analyzer, Spectrum analyzer, Signal generator, Oscilloscope, components
- 325 MHz RF coupler test bench

· Spectrum analyzer, Signal generator, Oscilloscope
· Test cavity with tuner/spacer
· RF power source, Cooler
· Circulator, Waveguide, Directional coupler, Beam dump, Attenuator/Divider,
· Pick-up detectors, Arc detector, Vacuum gauge

RF performance test (cold test)

325 MHz RF coupler test bench





Facility of Accelerator Research Center

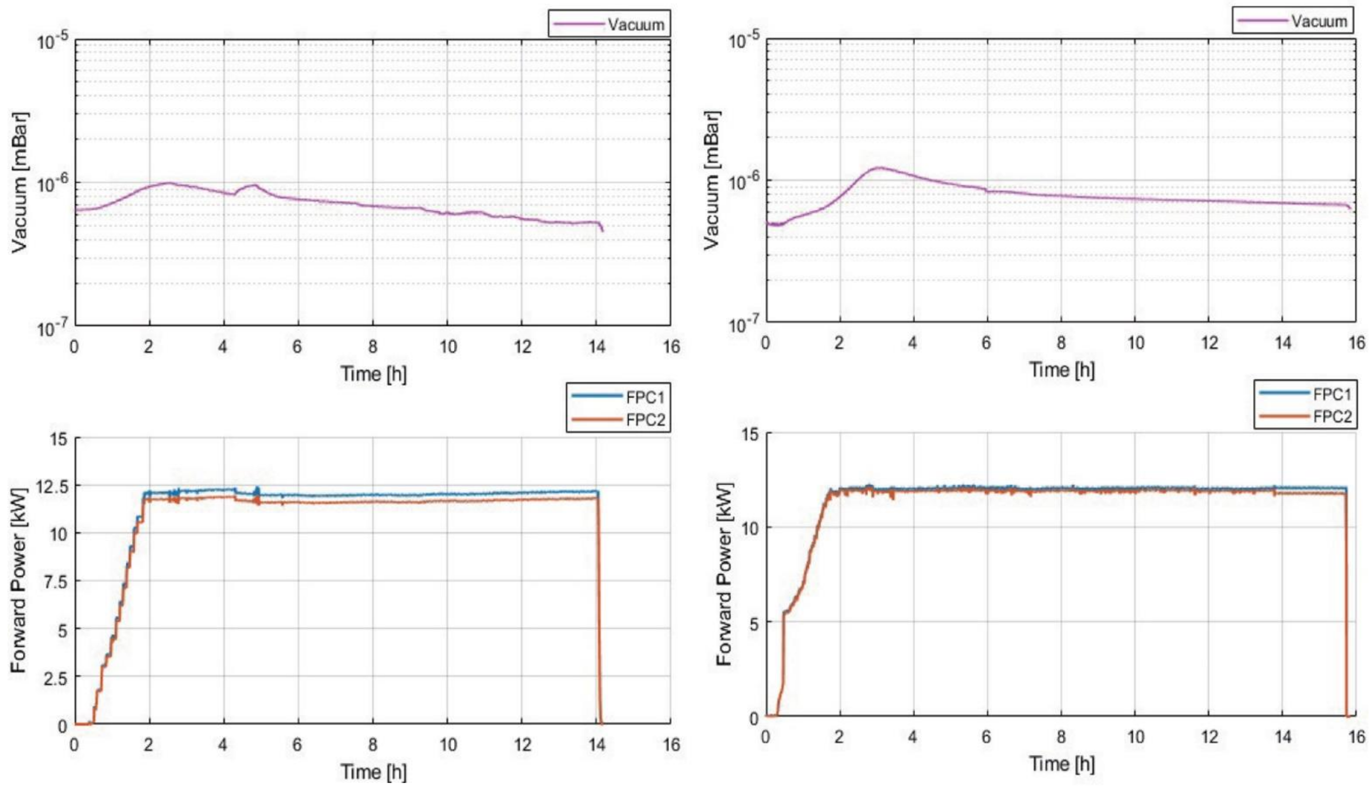
325 MHz RF Coupler Test :

- Cleaning and high vacuum
- Conditioning: started from pulsed to CW keeping low power and increase RF power gradually.

CW high-power test

Vacuum pressure (top)

Forward power at the directional coupler (bottom)



(a) for 12 h

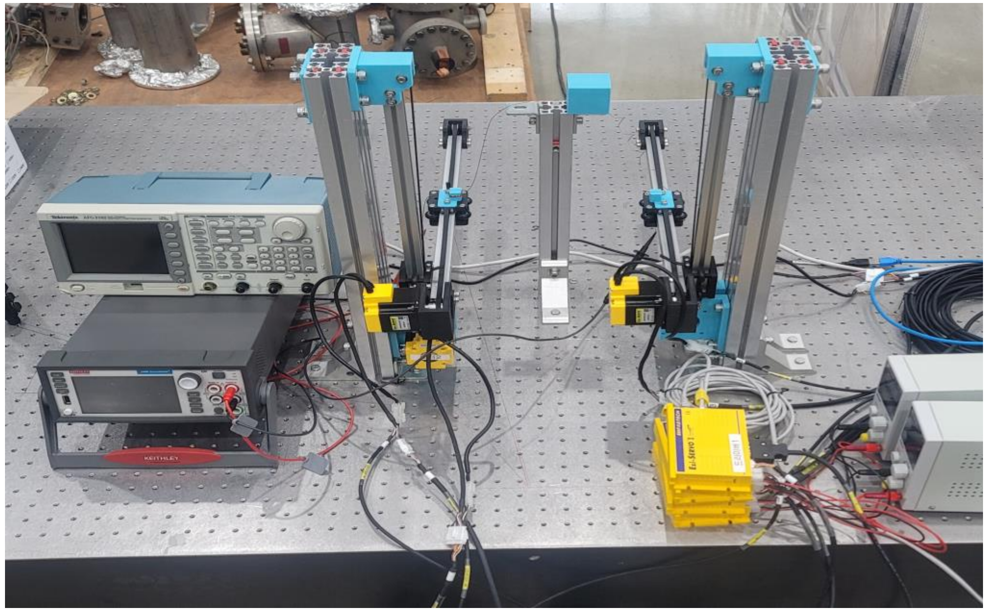
(b) for 14 h

Facility of Accelerator Research Center

Magnetic Field Test System (under development) : Stretched wire method

- Cu or Ti wire connected to two x-y stages
- Low noise voltmeter
- Measurements and data analysis for harmonics
- Determine how to measure : circular motion, scanning method and speed, stretching tension

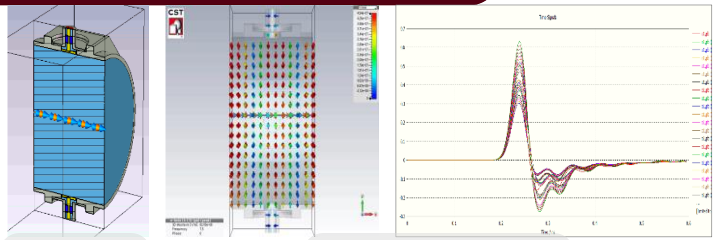
Test of Trajectory dependance on harmonics measurements



Bench for Magnetic Harmonics Measurements

Experiment program for Training in KU

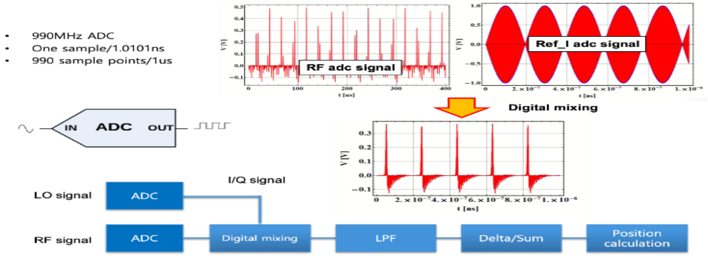
BPM Design and analysis



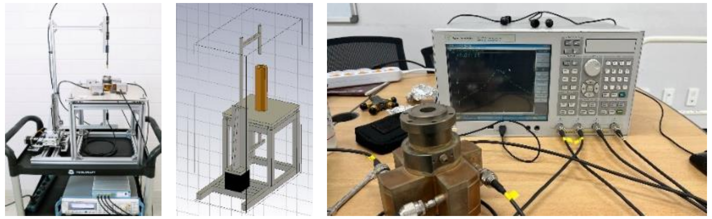
BPM Design

3D simulation/analysis

Circuit Design for BPM



RF Test of BPM



BPM test bench

BPM RF test

Beam Diagnostics

Scope

Understanding of Beam diagnostic system required for design, fabrication, performance test and Experimental Practice

Contents

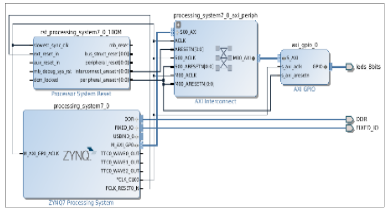
- Basics of BPM design and related electronics
- Understanding of Beam Orbit Stabilization
- 3D Simulation, RF test, Data Analysis
- Design of Analog and Digital Circuit electronics
- Trial test of Beam Orbit Stabilization

Instruments

- CST code
- Network Analyzer, Spectrum Analyzer, Signal Generator, Oscilloscope
- Test bench, mini circuit RF components, Beam simulation code
- Button & cavity BPM for Test

Experiment program for Training in KU

Electronics (SoC) Practice

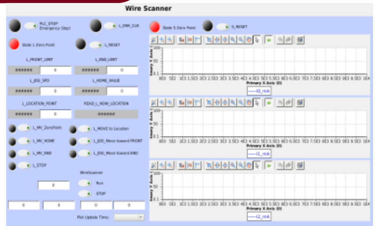


Programmable Logic

Processing System

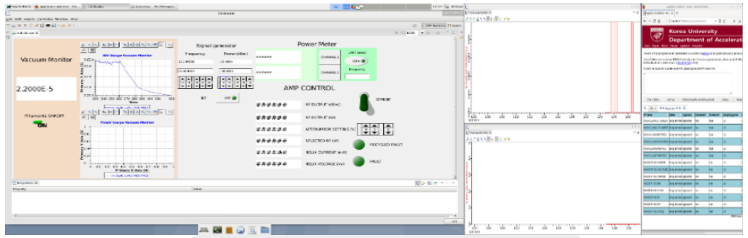
Control based on EPICS

Actuator



Wire Scanner monitor

EPICS-based Instrument Control



Control & Monitor of Accelerator

Control System based on EPICs

Scope

Understanding of Design Skill of Accelerator control system required for operation and performance test

Contents

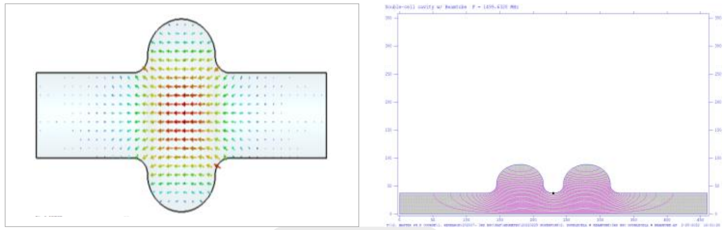
- Basic theory of Control : Programming language, Operating system, Network, Data communication, Embedded system, etc.
- EPICS : Distributed Control system, Archiver Appliance, Control System Studio, etc.
- Instrument or motor control using EPICS
- Organizing DB/Storage for Accelerator
- Practice of Electronics (SoC)

Instruments

- Instrument for test
- Computer, Electronics education board
- Motor and Driver

Experiment program for Training in KU

Design of RF cavity (CST)

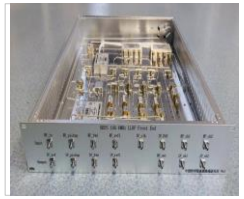


Cavity

Practical test of RF circuit

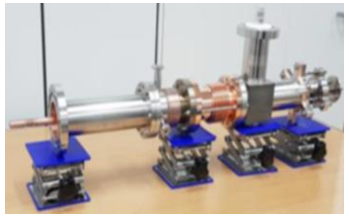
Low Pass filter

Band Pass filter



RF circuit

RF Test of cavity or coupler



325 MHz RF Power Coupler

1.5GHz cavity

RF system and Test

Scope

Understanding of RF system and Accelerating cavity, RF measurements

Contents

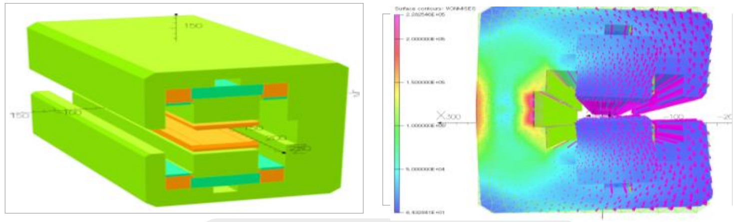
- Basic theory of Control : Programming language, Operating system, Network, Data communication, Embedded system, etc.
- EPICS : Distributed Control system, Archiver Appliance, Control System Studio, etc.
- Instrument or motor control using EPICS
- Organizing DB/Storage for Accelerator
- Practice of Electronics (SoC)

Instruments

- CST code
- Network Analyzer, Spectrum Analyzer, Signal Generator, Oscilloscope
- RF power meter, Crystal detector
- Power coupler, mini circuit, Amplifier

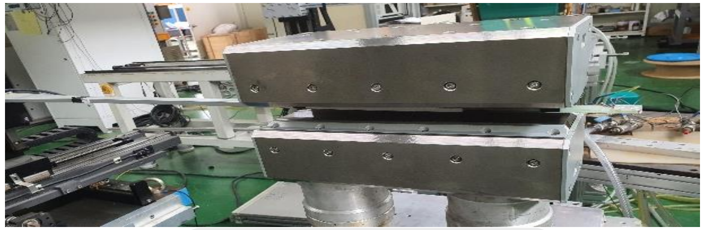
Experiment program for Training in KU

Simulation Design (CST)



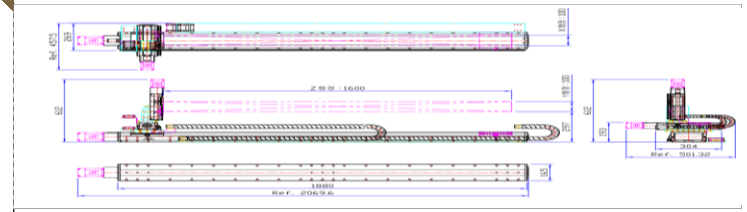
3D Design of Electro-magnet

Fabrication & Engineering Design



LGBM (Electro-magnet type)

Magnetic field measurement



Measurement system : Hall probe mapper

Magnet design and field test

Scope

Simulation design and magnetic field measurement of Electro-magnets

Contents

- Basic theory of Electro-magnet : Magnetic field, Field strength, Uniformity, Harmonics.
- Design of Electro-magnet : Magnet pole, yoke, Coil parameter, Shimming, etc.
- Utilities: Cooling, Supporter, Alignment, PS., etc.
- Performance Test : Required parameter measurements, High order error.

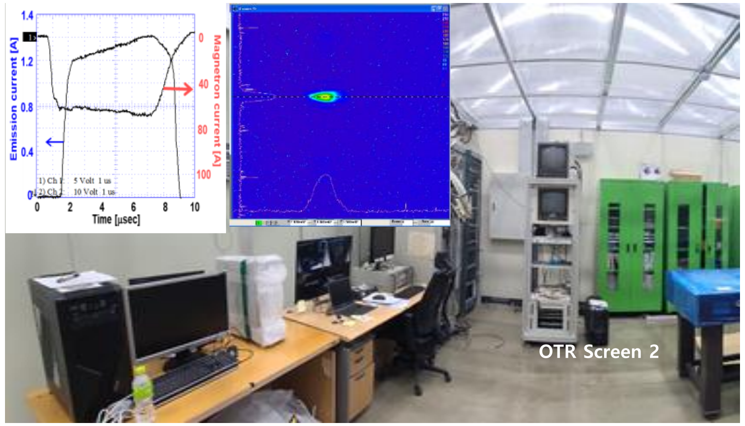
Instruments

- OPERA, CST, Permeant Dipoles, Gauss meter
- Hall prove mapper (X,Y,Z 방향 Mapping)
- Stretch wire (Single Stretch Wire , Vibrating)
- Reference magnet (Solenoid, Dipole, Quadrupole, Sextupole)
- P/S (System 8000 or 9700), Chiller

Experiment program for Training in KU

Microtron & THz FEL

Operation & Experiments



Operation of compact accelerator

Scope

Operating Compact accelerator system to understand the role and function of each components and understanding the beam dynamics

Contents

- Introduction of Accelerator and FEL
- Vacuum and Cooling system
- Operation of microtron
- Beam parameter measurements, current, profile, emittance
- Beam optics: variation of beam shape due to field strength
- Pre-alignment for FEL and lasing of FEL

Instruments

- Microtron-based THz FEL system
- THz detector
- Beamline

Research & Training project

■ Research and Training Project in Accelerators and Beamlines

- **Project-based Support from Government (‘22~’27, ~1.3 M$/yr)**
- 55 mater degree and 90 Doctorial degree in 6 years (from two consortiums)
- Korea University Sejong organized a Consortium with 10 universities to cultivate graduate students in Accelerator science, as Accelerator scientists or engineers, Beamline scientists or engineers, etc.
- **Participants**: 69 professors and 100 graduate students
- Mostly personnel expenses of student and cost for training and activities
- Credit exchange, Experimental Practice,
- **Summer and winter schools (two-week intensive program)**
- **Workshop (yearly)**

Thank you

Acknowledgements

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