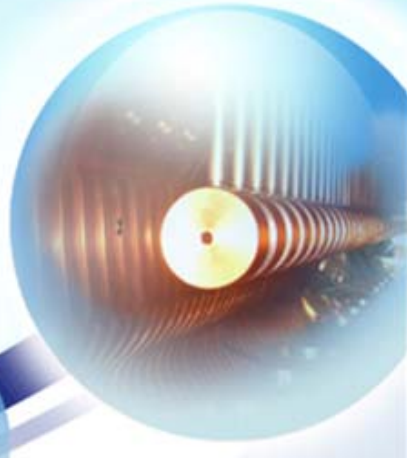
IPAC 2010
Kyoto Japan, May 24-28, 2010

Status of the PEFP :

A High Duty Proton Linac and Its Application

Byung-Ho Choi
on behalf of the Proton Engineering Frontier Project



양성자기반공학기술개발사업단
Proton Engineering Frontier Project
http://www.komac.re.kr

❑ Contents

PEFP Proton Engineering Frontier Project

❑ Overview

PEFP Proton Engineering Frontier Project

■ **Project: Proton Engineering Frontier Project (PEFP)**

21C Frontier R&D Program, MEST, Republic of Korea

■ **Objectives:**

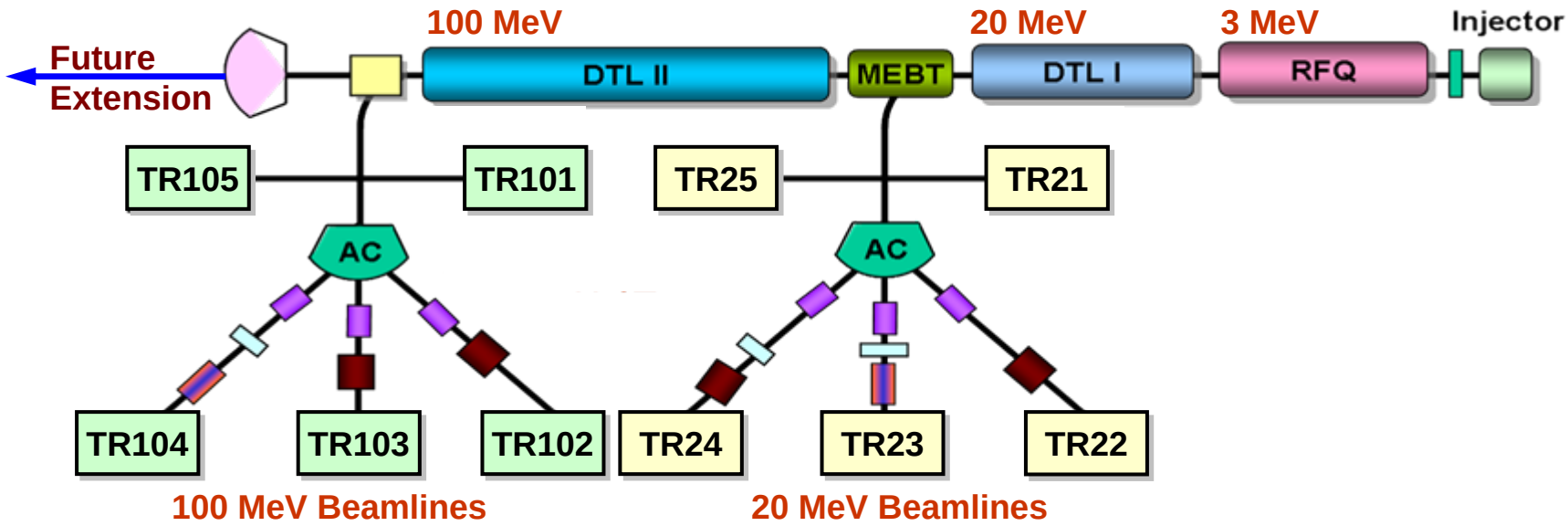
- To develop a High Power Proton Linac (100MeV, 20mA)
- To develop Proton Beam Utilization & Accelerator Application Technologies
- To support R&D Programs and industrialize Developed Technologies

■ **Period: July 2002 – March 2012 (10 years)**

■ **Budget: 128.6 B KRW (Gov. 115.7 B, Private 12.9 B)**

(Gyeongju City: Land, Buildings & Supporting Facilities)

❑ Schematics of PEFP Accelerator & Beamlines

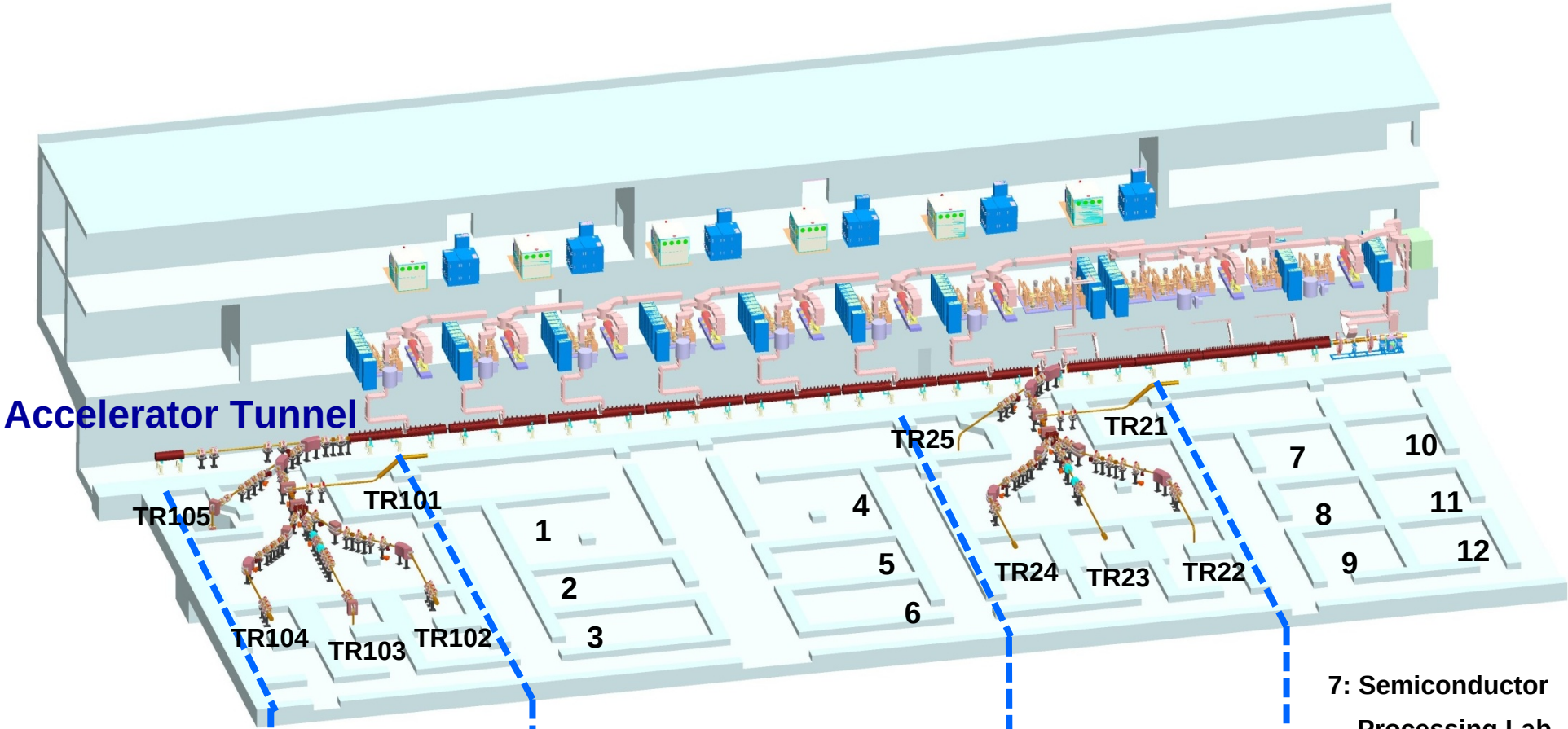


Features of the PEFP linac

- 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
  - Beam to be distributed to 3 BL via AC

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

❑ Layout of Accelerator Tunnel & Experimental Hall

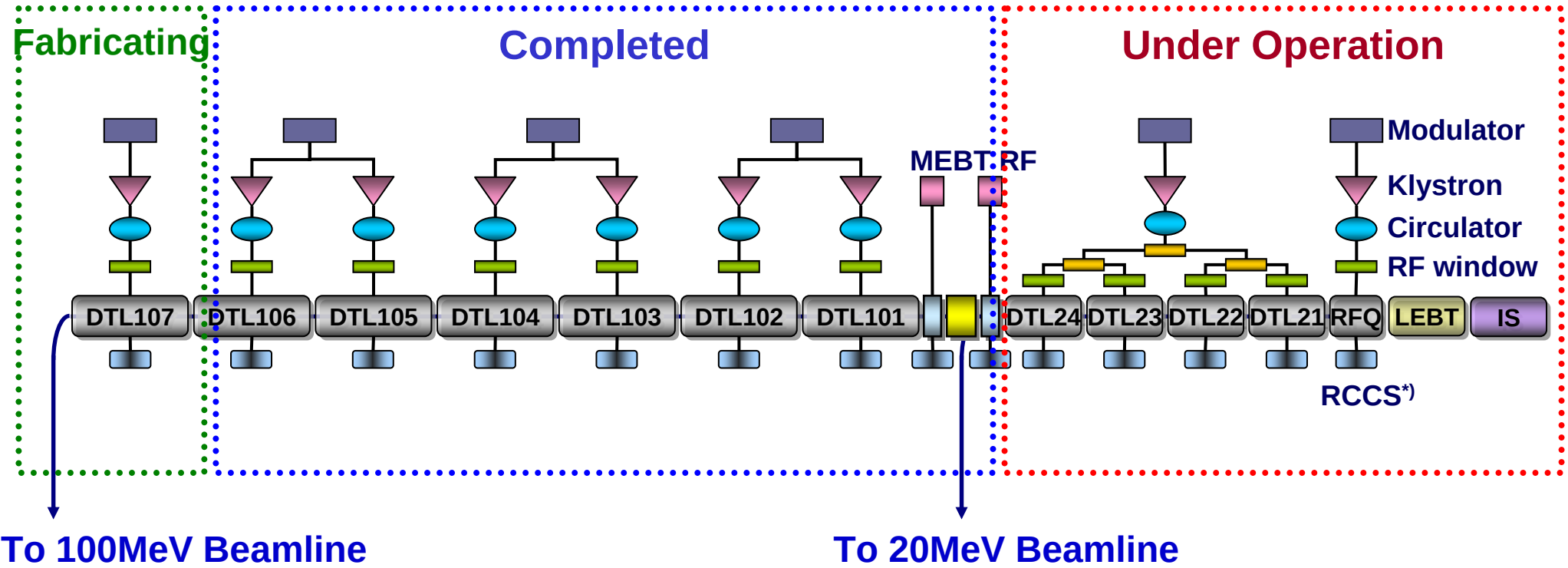


1: RI Processing Lab
2: Bioengineering Lab
3: Biocell Analysis Lab
4: Activation Analysis Lab
5: Basic Science Lab
6: Radio-Medical Lab

7: Semiconductor Processing Lab
8: Material Analysis Lab
9: Nano-processing Lab
10: Detector R&D Lab
11: SRF Lab
12: RCS Lab

❑ Status of Accelerator Development

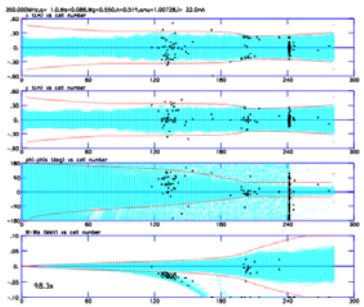
- 20MeV: fully developed & installed and under routine operation
- 6 tanks up to 91 MeV: fabricated, partly tested & prepared
- 1 tank (91~102 MeV): under fabrication



*) RCCS (Resonance Control Cooling System)

❑ RFQ Design & Fabrication

- 350 MHz, 4 vane structure, 85kV constant voltage (1.8 Kilpatrick)
- 3.25 m long with resonant coupling and dipole stabilizer rods
- Established a full fabrication process with domestic companies

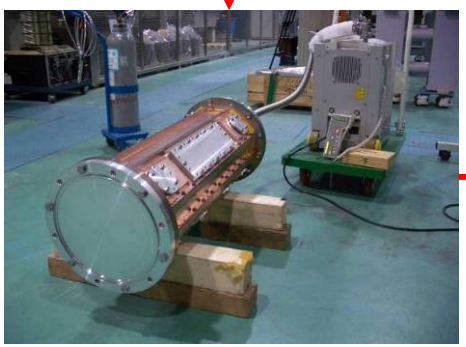


Design

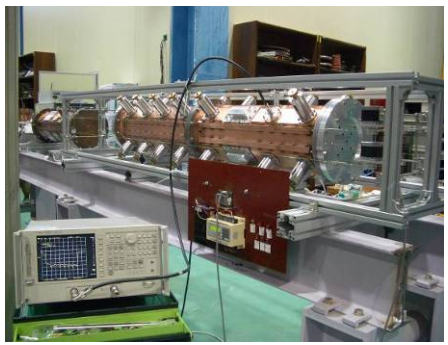
Vane machining

Tuning before Brazing

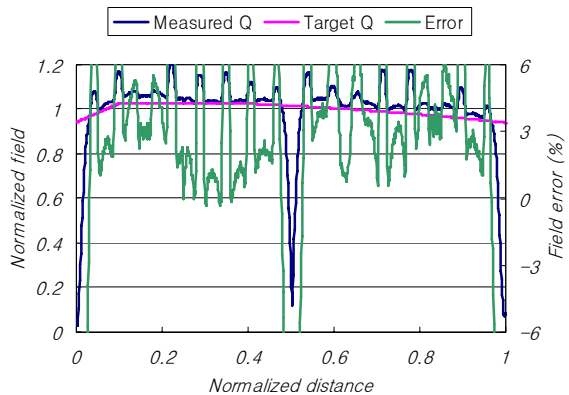
Brazing



Leak test (< 1e-9torr.l/s)



Tuning



Frequency : 349.931 MHz
Q field : < ± 2%
D field : < ± 5% of Q

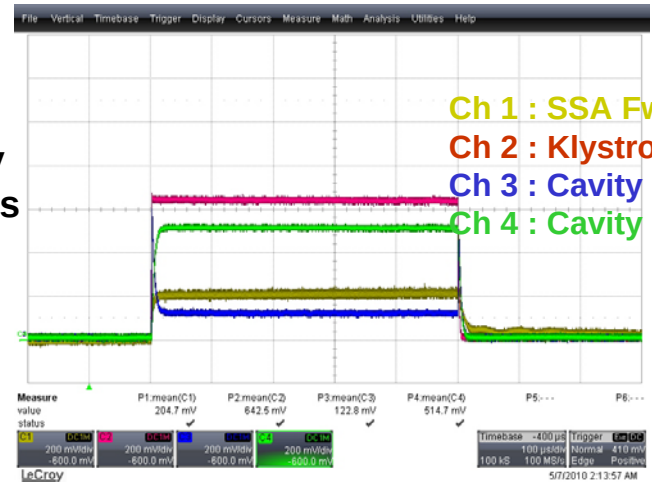
❑ 3MeV RFQ Test

PEFP Proton Engineering Frontier Project

❑ Set up for Test of RFQ

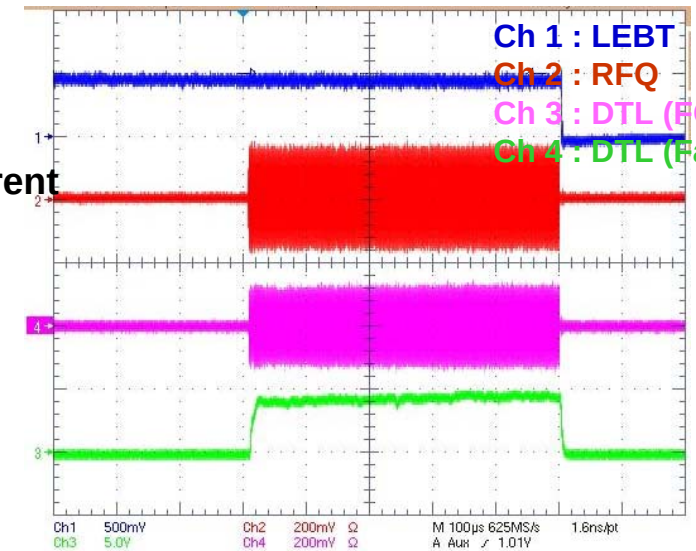
❑ Results of the RF & Beam test

RF Power
inside cavity
440 kW, 500us



< Cavity field signal >

Beam Current
500us



< Beam current signal >

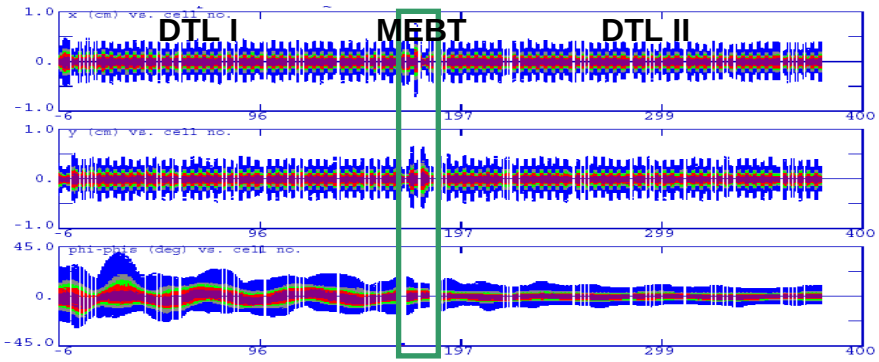
❑ Remarks of RFQ test

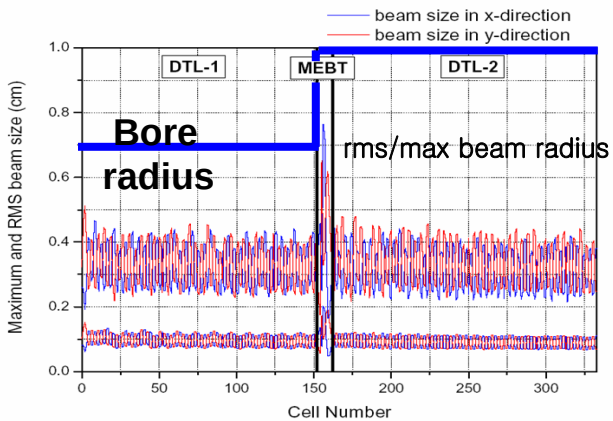
- RFQ have been fabricated and tuned. (Aug., 2005)
- Full Peak Power RF test has been done. (Oct., 2005)
- Beam test up to 20mA has been done. (Mar., 2008)
- Routinely used for the beam acceleration. (Now)

❑ DTL Design

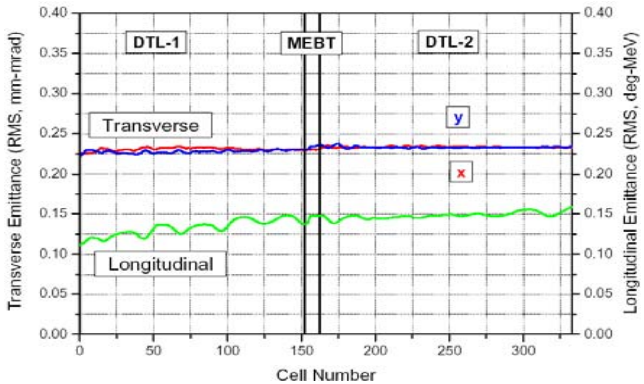
	DTL I	DTL II
Beam Energy (MeV)	3 → 20	20 → 100
Max. Beam Duty (%)	24	8
Max. Repetition Rate (Hz)	120	60
RF Frequency (MHz)	350	

Beam Dynamics (PARMILA)

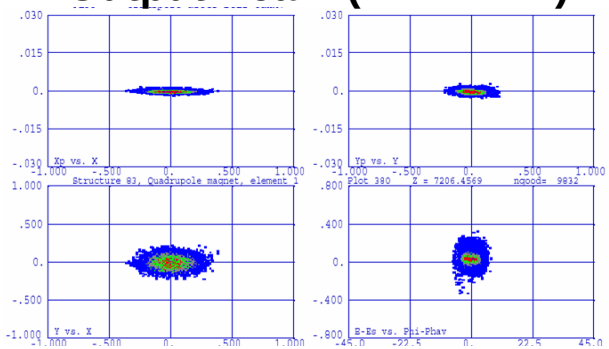




Emittance



Output Beam (PARMILA)



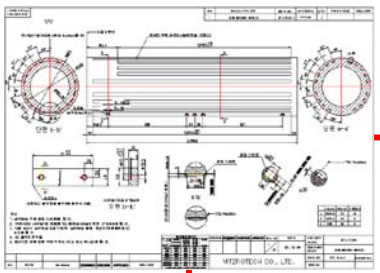
Tank	DTL I				DTL II						
	21	22	23	24	101	102	103	104	105	106	107
E [MeV]	7.18	11.50	15.80	20.00	33.1	45.3	57.1	69.1	80.4	91.7	102.6
Cells	51	39	33	29	34	28	25	23	21	20	19
Length [m]	4.431	4.649	4.755	4.776	6.737	6.707	6.791	6.777	6.777	6.869	6.880
E0 [MV/m]	1.3				2.58						
RF [kW]	225.0	225.0	224.0	221.0	1064.7	1039.3	1040.1	1026.8	1008.1	1004.7	1003.6

❑ DTL Fabrication

PEFP Proton Engineering Frontier Project

- **Established a full fabrication process;**
  from design to field tuning, and RF test

Design of DTL

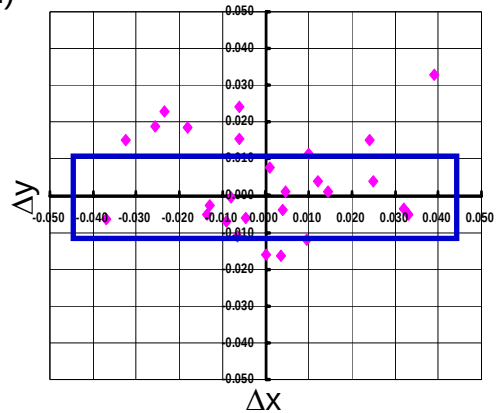


Machining
(Acc <100 μm)

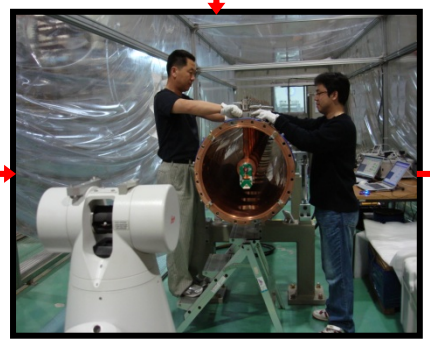
Copper Plating
(Thickness < 100 μm)

Tank Assembling
(Tolerance < ±100 μm)

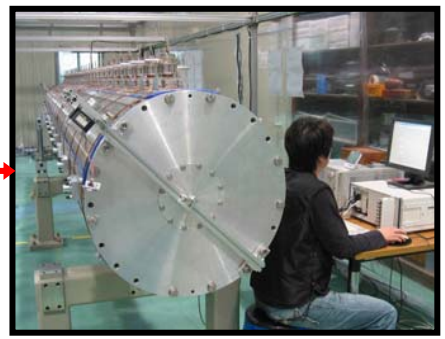
DT alignment < 40 μm



DT+ EQM Fabrication
(B = 1.75 T±1%)

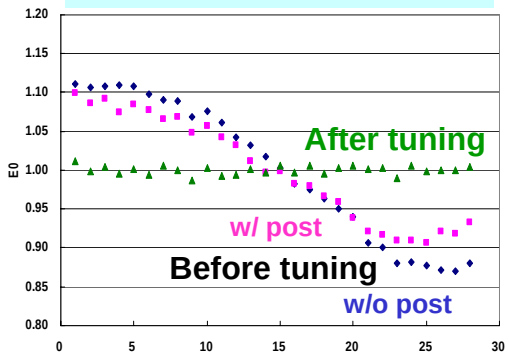


DT Mounting & Alignment
(Tolerance < ±50 μm)



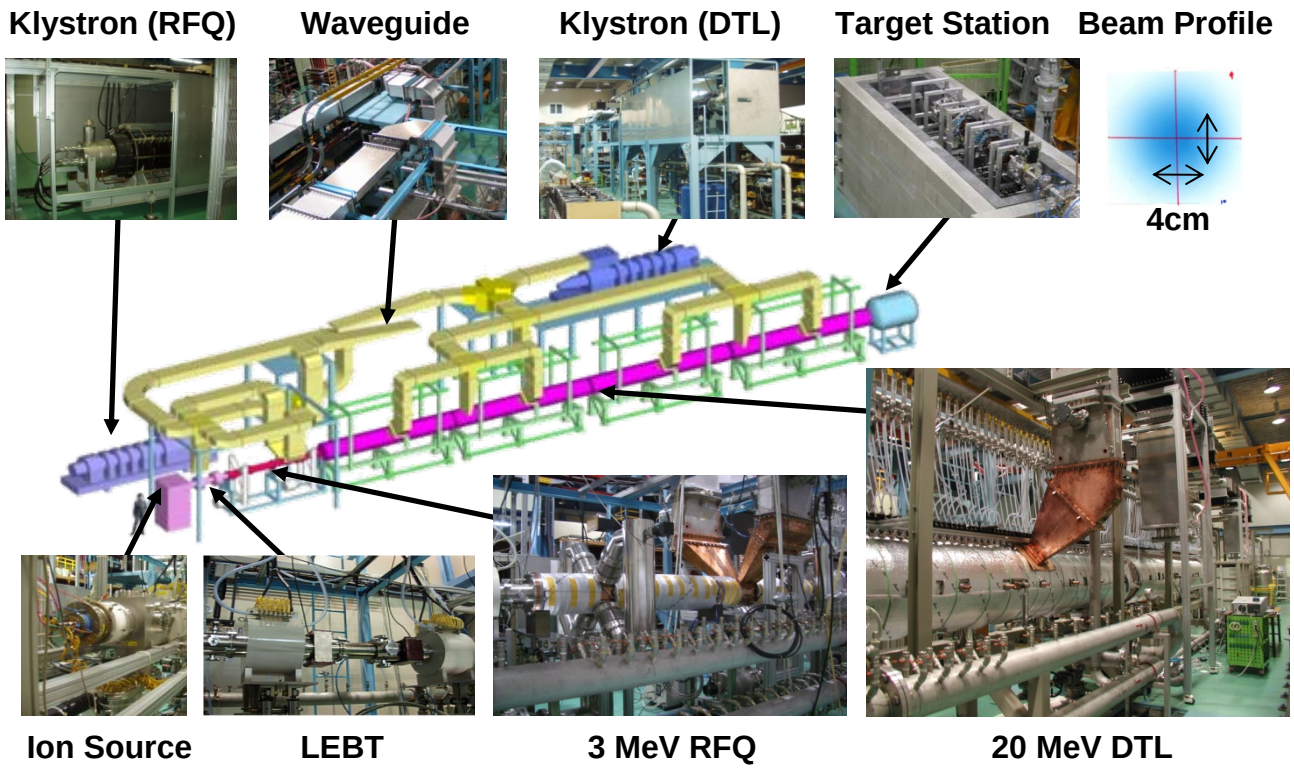
Tuning Test

Field Tuning < ±1.5 %



❑ PEFP 20 MeV Linac Performance

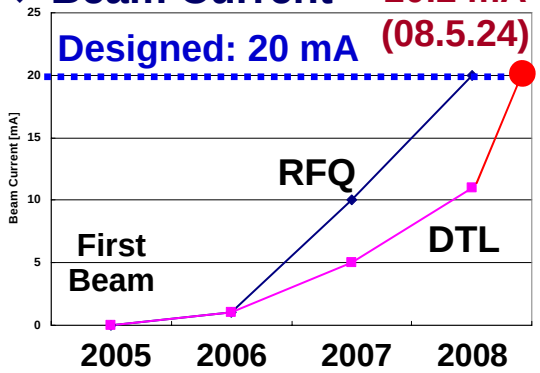
- 20 MeV of front-end of 100 MeV was completed in 2005
- Extracted first beam (July 2005)
- Obtained operation license (June 2007)
- Started beam service (July 2007)
- Temporary service for users before moving to Gyeongju



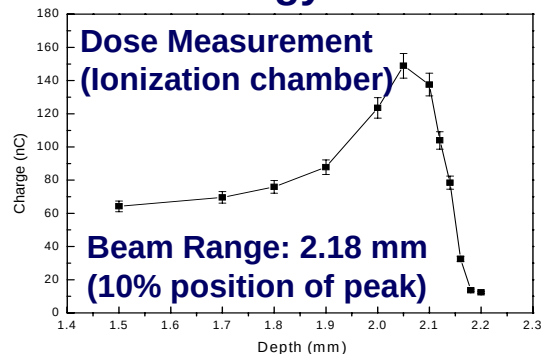
Refer to MOPD 050 & MOPE 036

❖ Beam Current

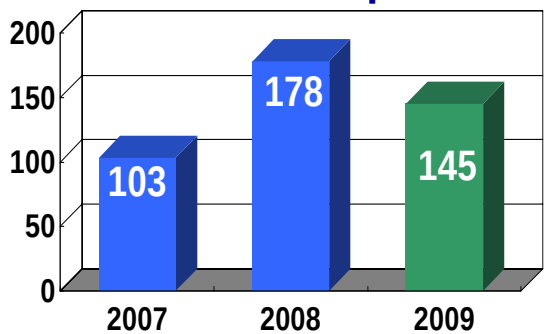
20.2 mA (08.5.24)



❖ Beam Energy: 20.33 MeV



❖ Irradiated Samples

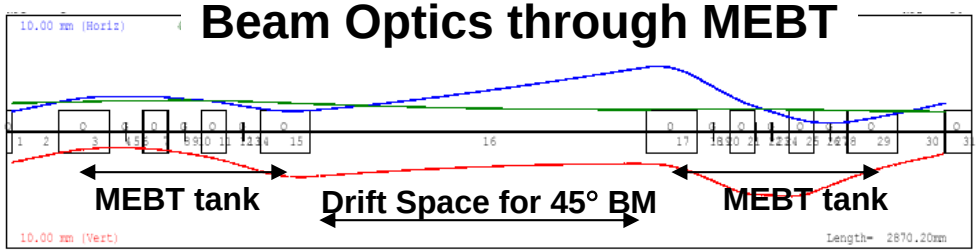


❑ MEBT (Medium Energy Beam Transport)

PEFP Proton Engineering Frontier Project

- **For 20 MeV Beam Extraction,**
  - ⇒ A Long Drift Space between DTL-1 and DTL-2 to place a bending magnet
  - ⇒ Beam phase matching issue
- **Solution:** 2 buncher cavities of 3 cells with 4 QMs
  - ⇒ QM for transverse matching, and RF for longitudinal matching

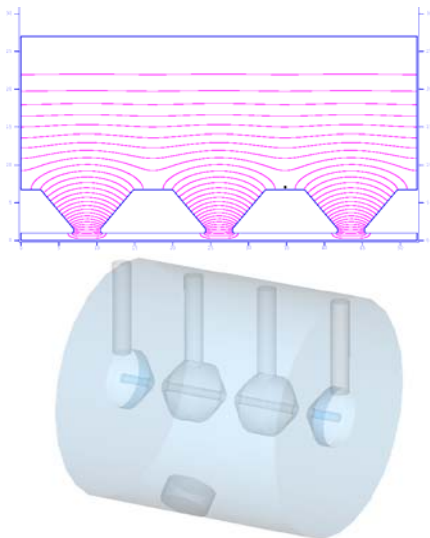
Beam Optics through MEBT



MEBT tank parameters

Parameters	Values
Cell number	3
Cell Length	174.0 mm
Gap Length	35.5 mm
Tank Length	522.1 mm
Synchronous Phase	-90 deg.
Power for tank1	33 kW
Power for tank2	14 kW

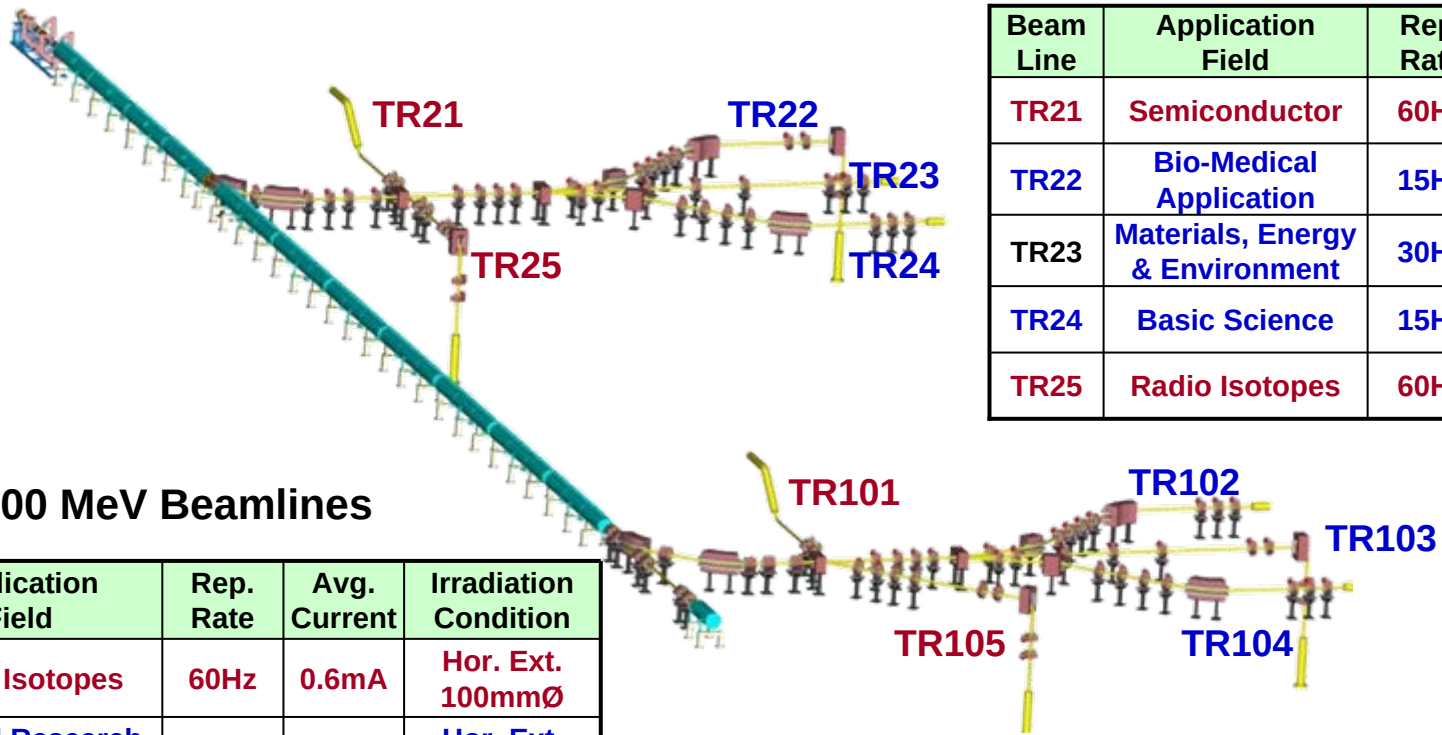
MEBT Tank Design



MEBT tank & DT

❑ Beamline Development

- Completed design of beamlines by reflecting user's requirement
- Different conditions; beam current, size, vacuum/external, hor./ver.
- Developed components (BM, QM, ACM & beam instruments)



20 MeV Beamlines

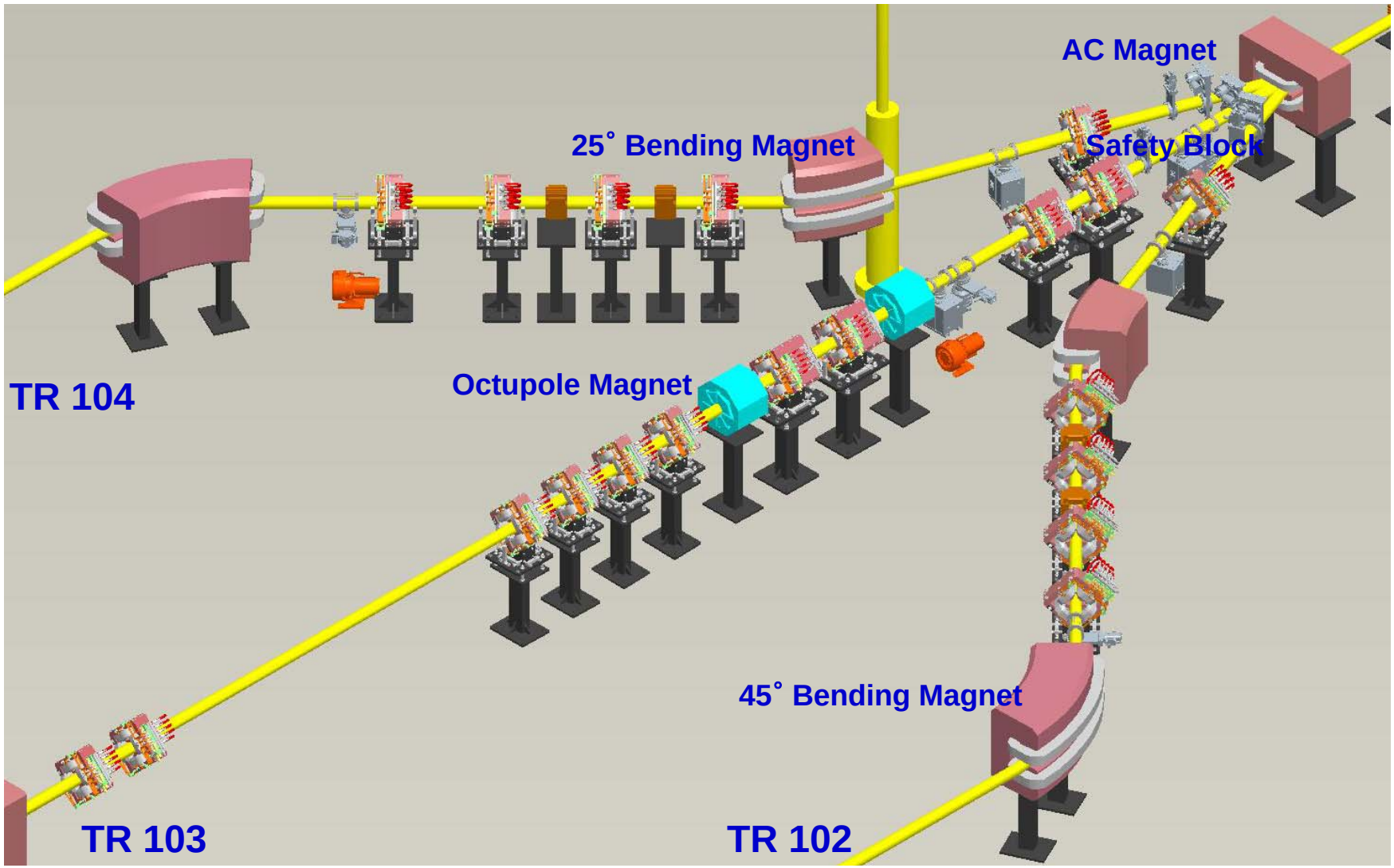
Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR21	Semiconductor	60Hz	0.6mA	Hor. Ext. 300mmØ
TR22	Bio-Medical Application	15Hz	60μA	Hor. Ext. 300mmØ
TR23	Materials, Energy & Environment	30Hz	0.6mA	Hor. Ext. 300mmØ
TR24	Basic Science	15Hz	60μA	Hor. Ext. 100mmØ
TR25	Radio Isotopes	60Hz	1.2mA	Hor. Vac. 100mmØ

100 MeV Beamlines

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR101	Radio Isotopes	60Hz	0.6mA	Hor. Ext. 100mmØ
TR102	Medical Research (Proton therapy)	7.5Hz	10μA	Hor. Ext. 300mmØ
TR103	Materials, Energy & Environment	15Hz	0.3mA	Hor. Ext. 300mmØ
TR104	Basic Science Aero-Space tech.	7.5Hz	10μA	Hor. Ext. 100mmØ
TR105	Neutron Source	60Hz	1.6mA	Ver. Vac. 100mmØ

❑ Details of Beam Lines

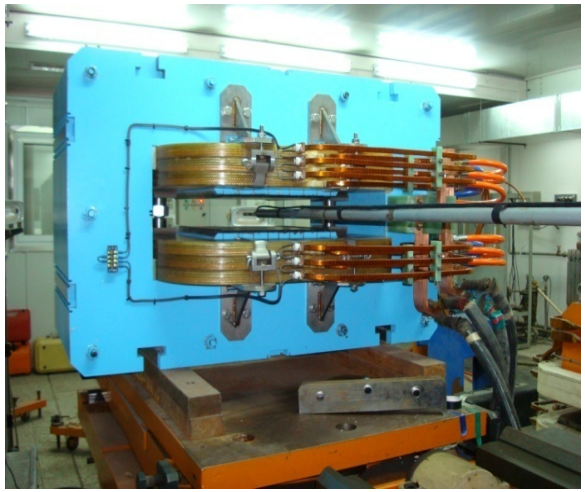
- AC magnet with 7.5 Hz can distribute beam pulses to 3 beamlins successively
- 3 targets can provide beam simultaneously



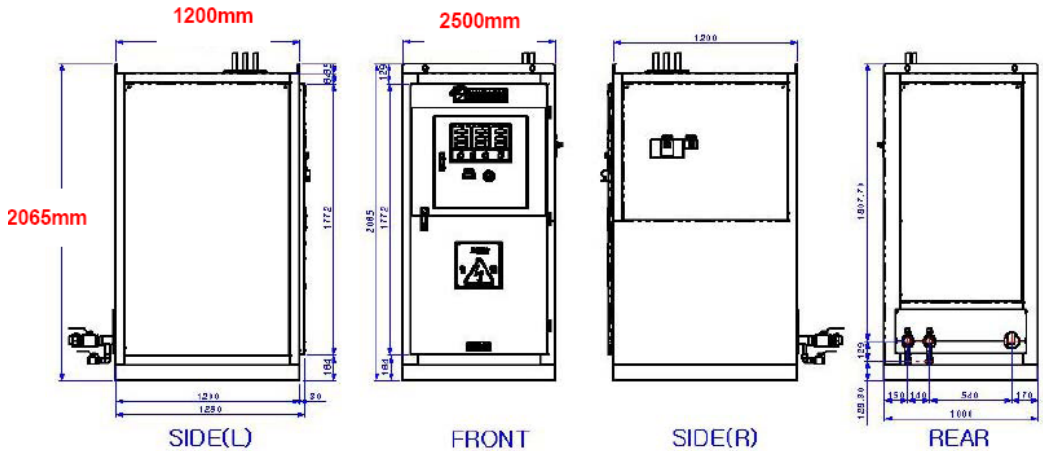
❑ Beamline Key Components: AC Magnet & Programmable PS

PEFP Proton Engineering Frontier Project

❖ AC Magnet for Beam Distribution



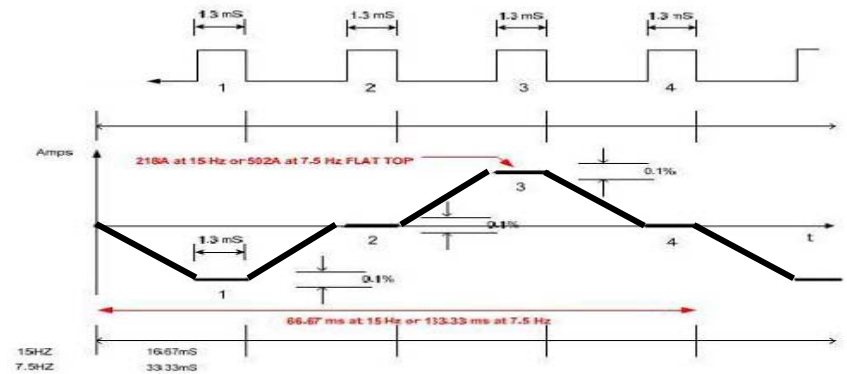
❖ Programmable Power Supply



❖ Specifications

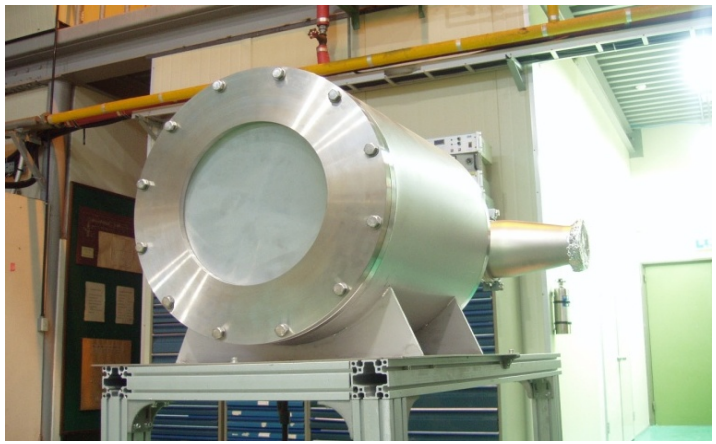
Bending angle	±20°	
Pole gap (mm)	75	
Max. B filed (T)	0.436	1
Eff. length (mm)	507	
Max. Current (A)	217.7	501.8
Op. freq (Hz)	15	7.5
	for 20 MeV	for 100 MeV

❖ Waveform of Power Supply

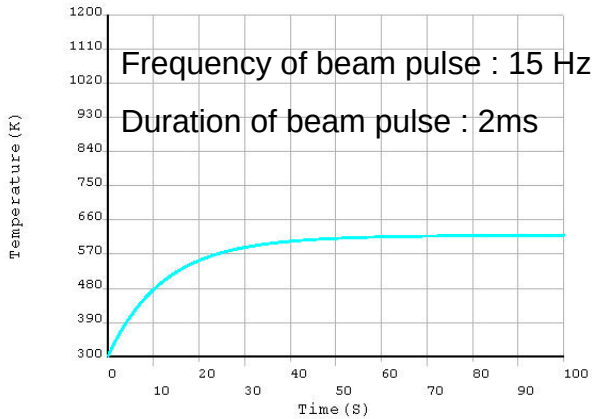


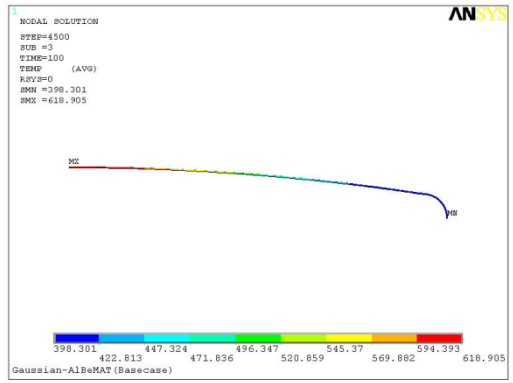
❑ Beamline Key Components: Large Beam Window

❖ Beam Window



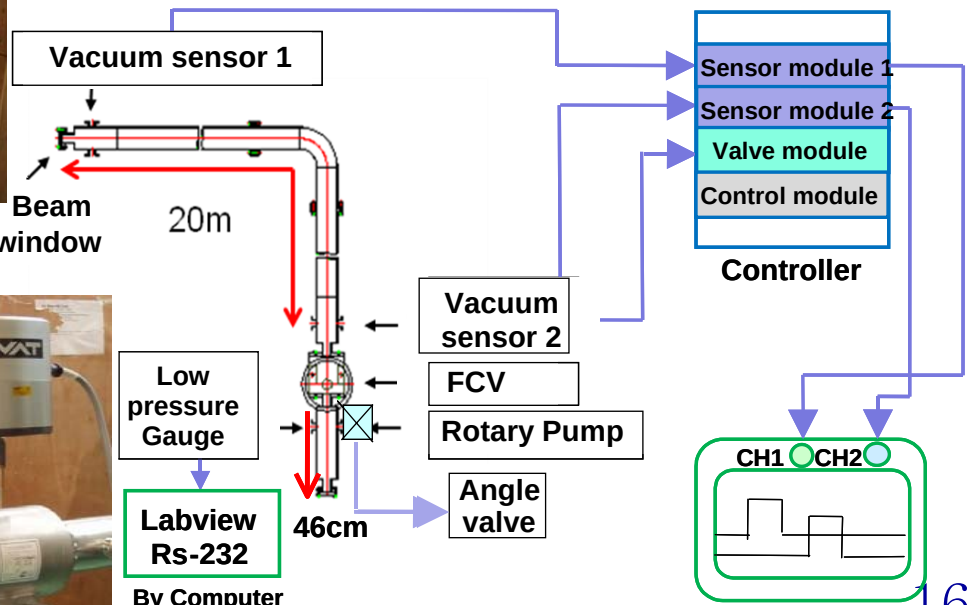
❖ Thermal Analysis





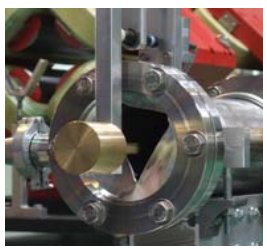
- **Specification**
  - Concave type
  - AlBeMet (38% Al, 62% Be)
  - Diameter: 300 mm
  - Thickness: 0.5 mm

Window breaking tool (1kg)



❖ Vacuum Protection from window breaking

- Fast closing valve
- Closing time : 15ms
- Max. pressure rising
  : 3.8E-1torr@ 20m length
  : 4.2E-2torr@ before accelerator
- Shock wave velocity : ^{2}~1km/s

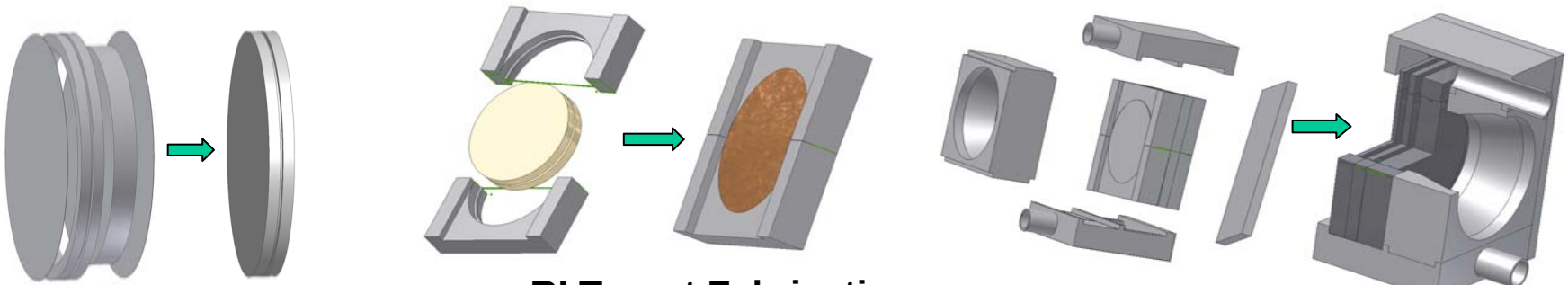


0.1mmt : 35cm

❑ Target System Development

❖ **Target system for radioisotope production for high current & power beam**

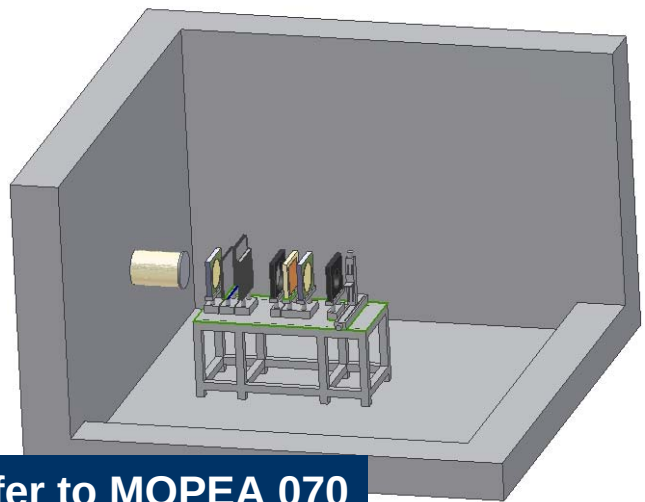
- Targeted RI: Sr-82, Cu-67, Ge-68 (target material: RbCl, ZnO, Ga)

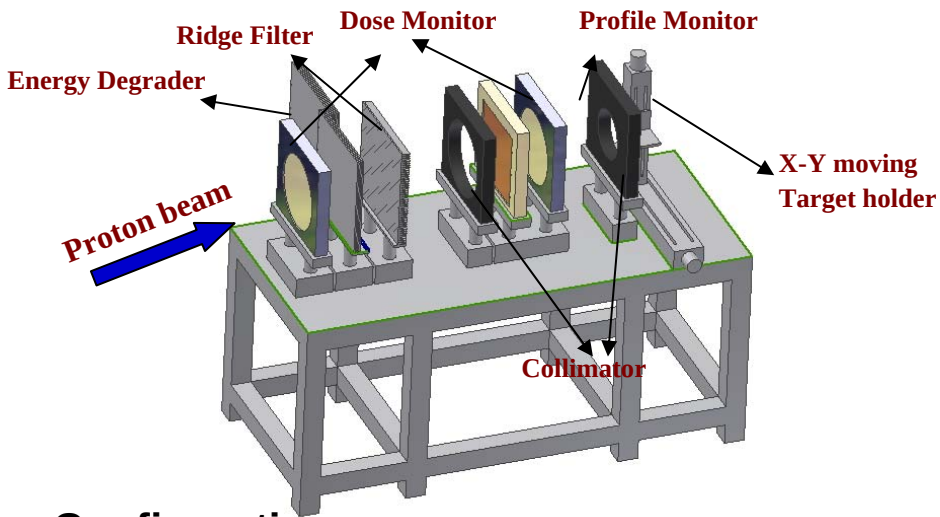


RI Target Fabrication

❖ **Proton beam irradiation system with very large area**

- Large & uniform beam (300mm dia.), In-situ beam monitoring, remote operation





Irradiation system Configuration

Refer to MOPEA 070

❑ Site Plan and Preparation for the PEFP

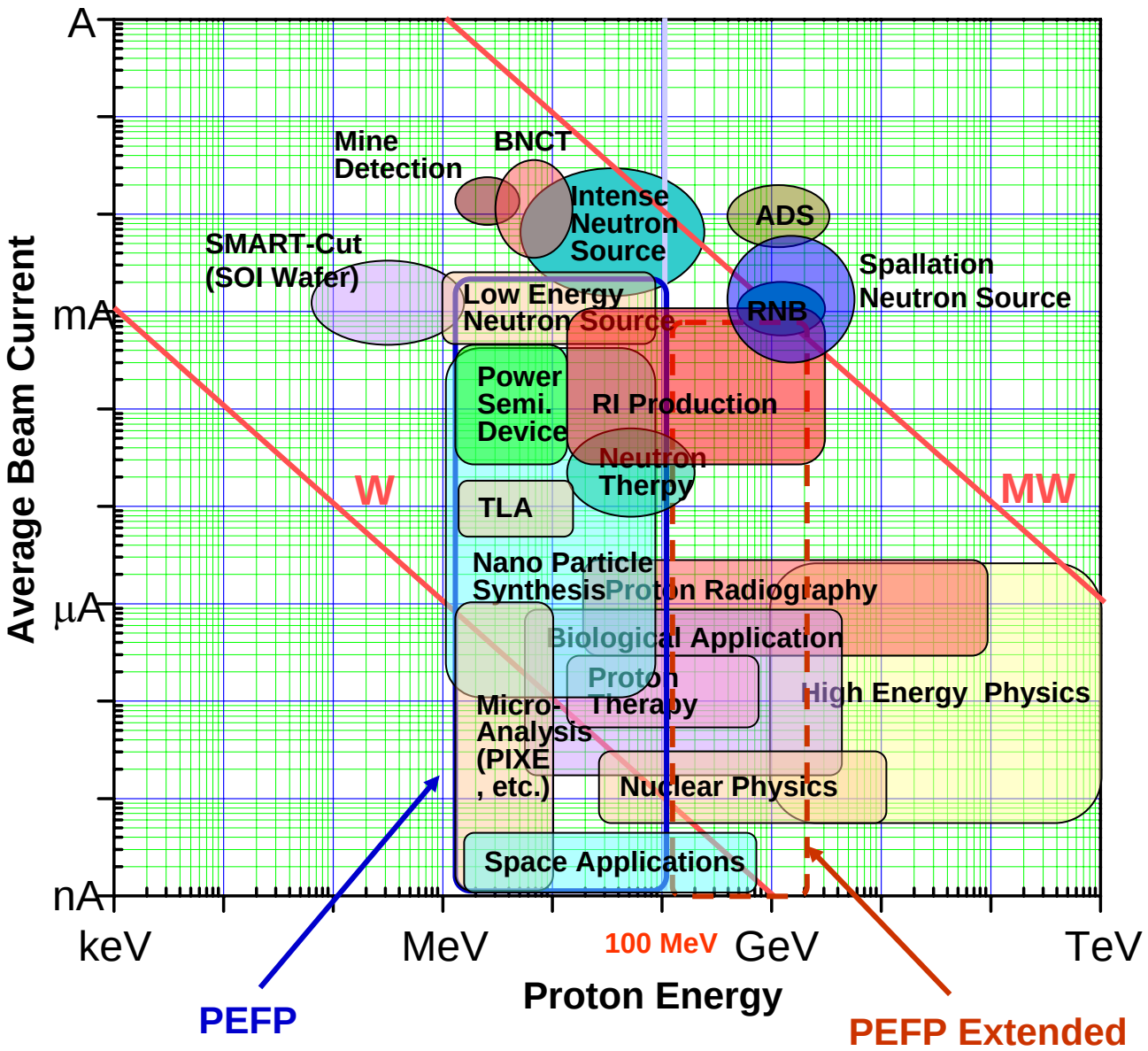
PEFP Proton Engineering Frontier Project

Proton Accelerator Research Center

Location: Gyeongju **Area: 44,000m²**
Ground Breaking('09.5) **Completion('12.3)**

① Accelerator Building
② Experimental Hall
③ Ion Beam Facility
④ Utility Building
⑤ Substation
⑥ Cooling Tower
⑦ Water Storages
⑧ Main Office Building
⑨ Regional Cooperation Center
⑩ Dormitory
⑪ Information Center
⑫ Sewage Plant

❑ Application Fields with Proton Beams



- **Industrial applications**
  ion-cut, power semiconductor devices
- **Medical applications**
  BNCT, RI production, proton therapy
- **Biological applications**
  mutation of plants and micro-organisms, micro-beam system, etc.
- **Space applications**
  radiation tests of space components and radiation effects, etc.
- **Defense applications**
  mine detection, proton & neutron radiography
- **Intense neutron source**
  radiation damage study, nuclear materials, target & modulator development, etc.
- **MW beam utilization areas**
  - Spallation Neutron Sources
  - Muon Source
  - Radioactive Nuclei Beams
  - High Energy Physics (mesons, neutrinos)

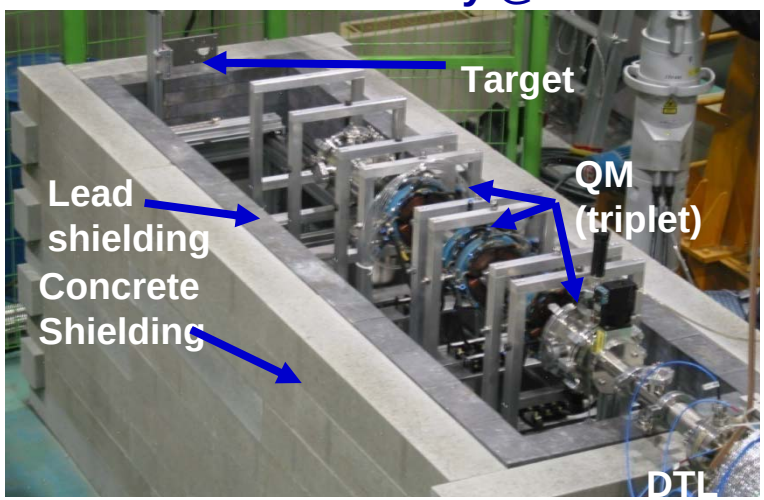
❑ R&D Program using Proton Beam

PEFP Proton Engineering Frontier Project

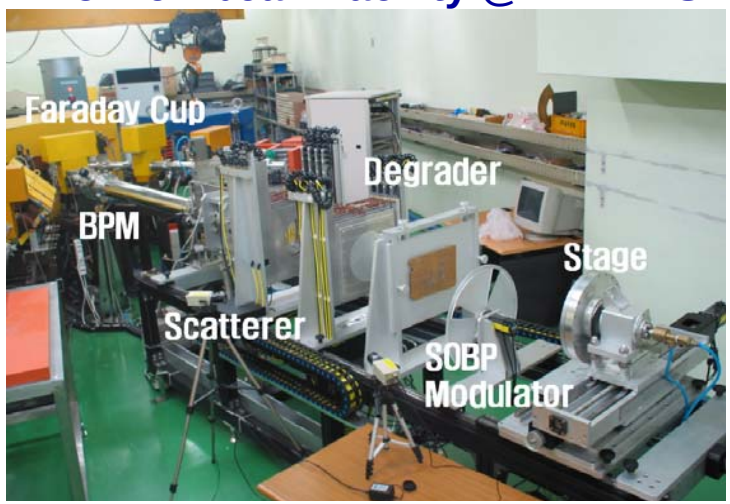
❑ User Program Development (2003 ~)

Research Fields	Sub-categories
Nano Technology	Ion-cutting, Nano-particle fabrication, Carbon nano-tube, Nano-machining
Information Technology	High power semiconductor, Semiconductor manufacturing R&D, etc.
Space Technology	Radiation hard electronic device, Radiation effect on materials
Bio-Technology	Mutations of plants and micro-organisms
Medical research	RI production, Low energy proton therapy study, Biological radiation effects, etc.
Materials Science	Proton irradiation effects with various materials, Gemstone colouring
Energy & Environment	New materials for fuel cell, nano catalyst, organic solar cell, New μ-organism (bio fuel)
Nuclear & Particle Physics	Detector R&D, Nuclear data, TLA (Thin Layer Activation)

❖ 20 MeV Beam Facility @ KAERI



❖ 45 MeV beam facility @ KIRAMS*

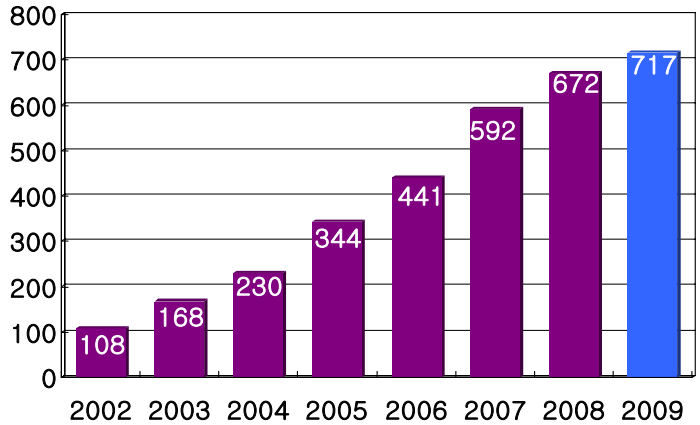


❑ Status of PEFP User Program

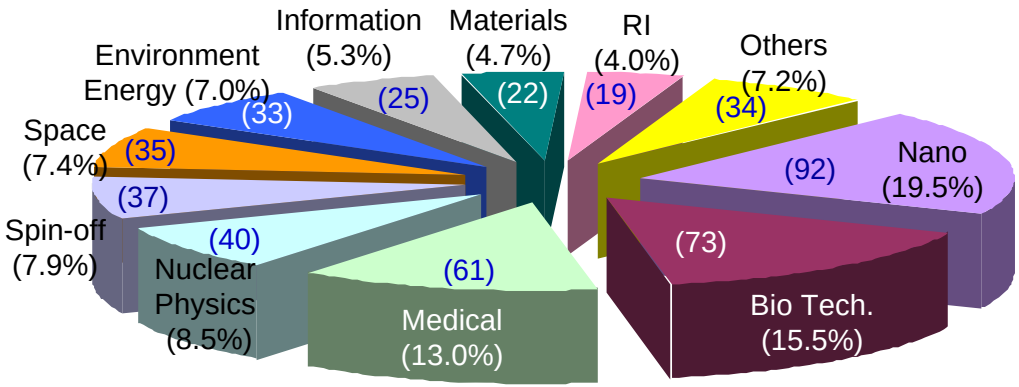
PEFP Proton Engineering Frontier Project

❖ **Goals for the user program;**
- Build up a strong community of proton beam users
- Diversify R&D fields by using proton beams

❖ No. of Proton Beam Users

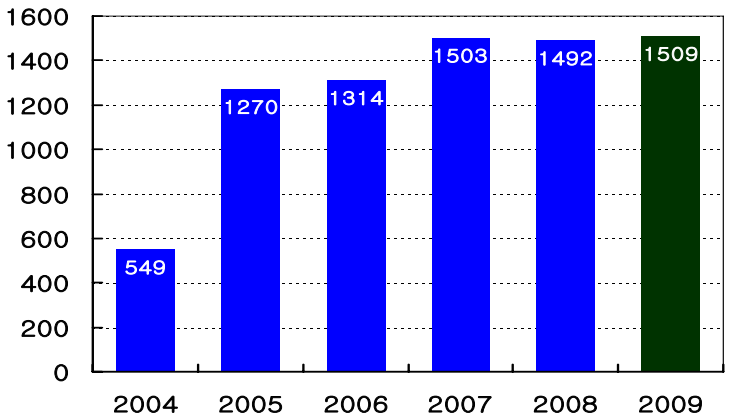


❖ User Distribution (R&D Fields)

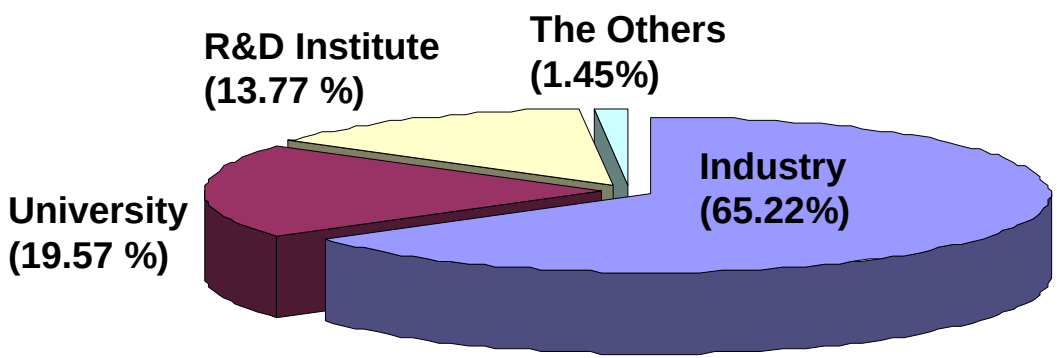


❖ Irradiated Samples

(20 MeV Linac, MC-50 @ KIRAMS))



❖ User Distribution (138 Institutions)

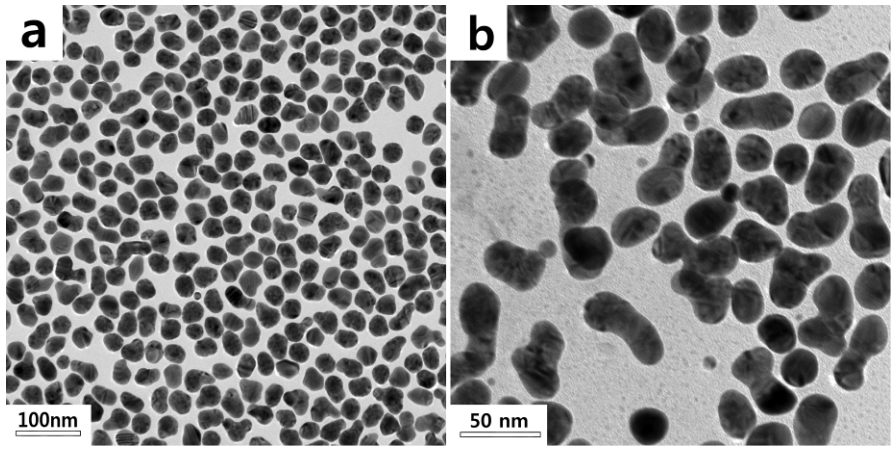


❑ R&D Activities (I) – Nano

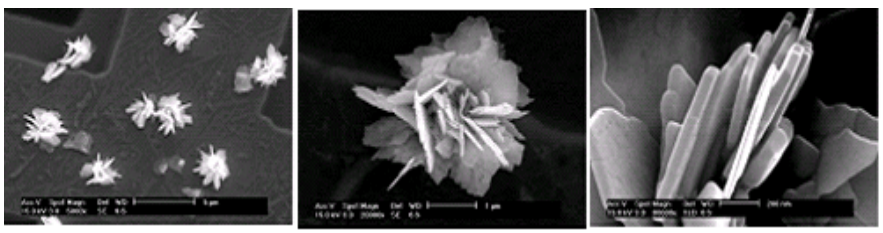
PEFP Proton Engineering Frontier Project

❖ **Fabrication of metallic nano-particles; Gold, Platinum, Silver etc**

❖ **Silver nano particle (SEM Images)**

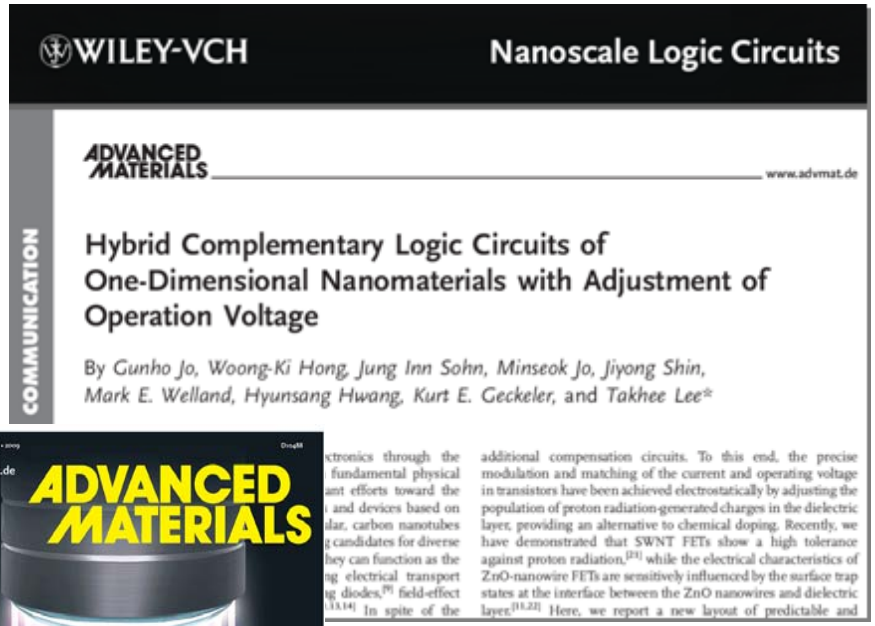


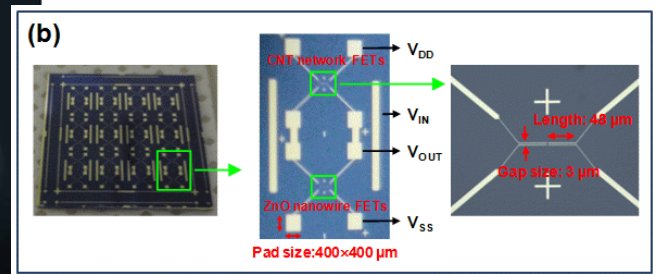
❖ **Silver nano crystal (Flower) formation**



Refer to MOPEA 069

❖ **Fabrication of Hybrid Nano-Logic Device - n-type nanowire + p-type nanotube**





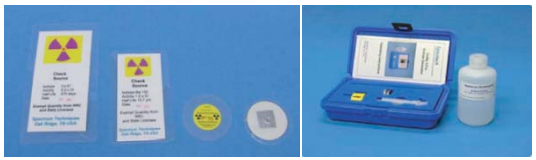
❑ R&D Activities (II) - Medical

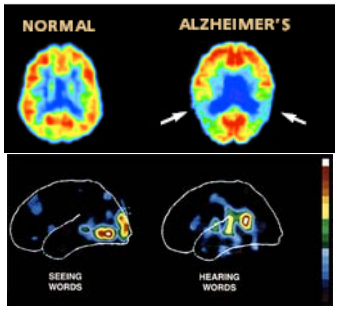
PEFP Proton Engineering Frontier Project

❖ Medical RI Production

- Medical RI production using high energy (100MeV) and high current proton beam
- Mass production of many kinds of RI
- Substitution for imported RI

❖ RI products and their applications





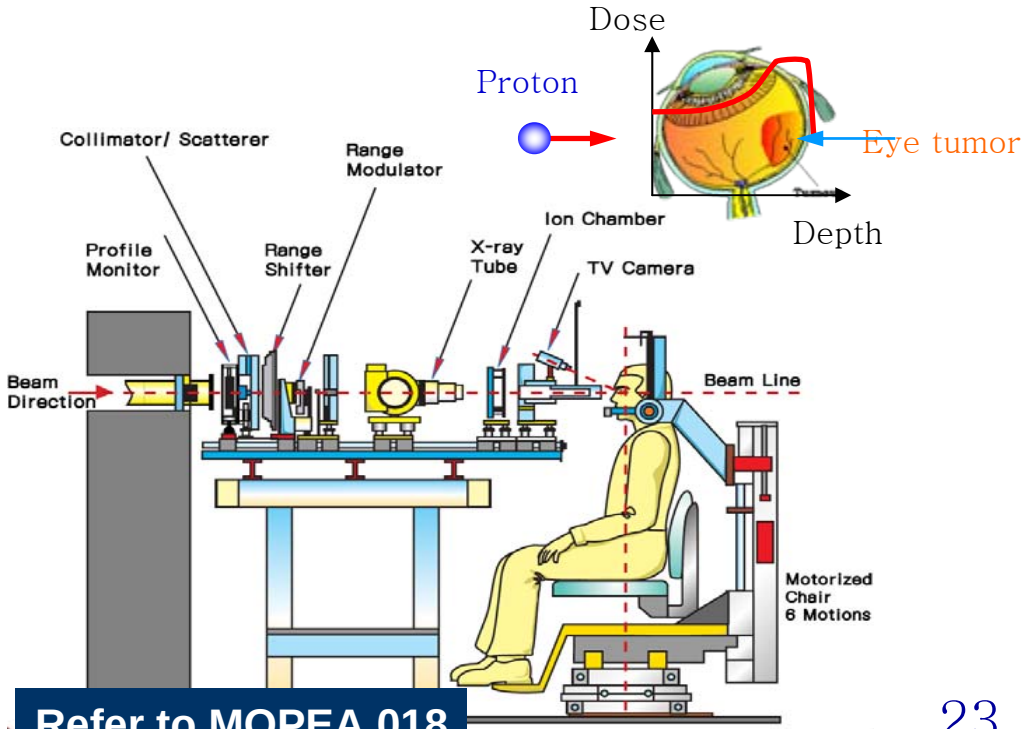
❖ Medical RI available

Proton Energy	R I
Low energy (<20MeV)	F-18, C-11, O-15, N-13, Pd-103
Medium Energy (30~100MeV)	Tl-201, Ga-67, I-123, I-124, In-111, Co-57
High Energy (>100MeV)	Al-26, Mg-28, Si-32, Be-7, Na-22, Ge-68, Sr-82, Tc-95, Cu-67

❖ Low Energy Proton Therapy

- Proton therapy machine & technology
- Basic study of proton therapy
- Facility for radiation biological R&D
- Study of proton therapy for eye tumors

❖ Principle of Eye therapy



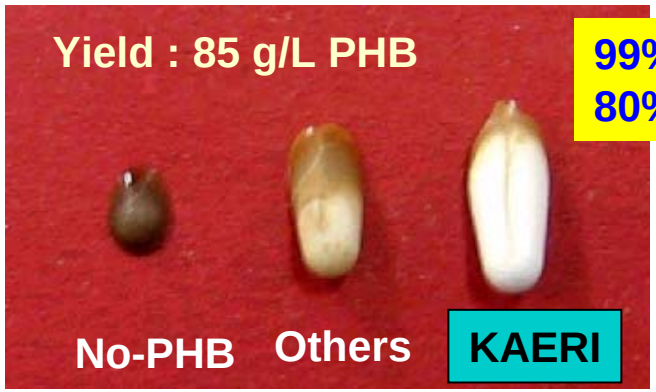
Refer to MOPEA 018

❑ R&D Activities (III) – Bio

PEFP Proton Engineering Frontier Project

❖ Biodegradable Plastic

- Mutant breeding of microorganism
- PHB production using E-coli



99% PHB content
80% autolysis

Yield : 60-70g/L PHB

Biodegradable Plastic Knife

❖ Mutation Studies

- Mutant Breeding of Vegetables
- Plant breeding of Flowering Tree

Technology transfer was performed at 2008

Chinese cabbage transferred to company

Mutants of radish (M3)

Lagerstroemia indica

❑ R&D Activities (IV) – Semiconductor

PEFP Proton Engineering Frontier Project

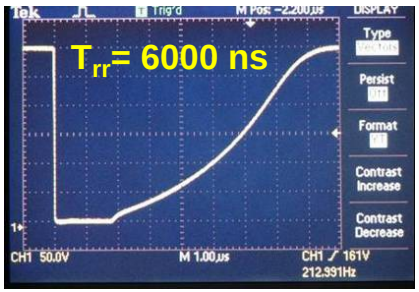
❖ Power Semiconductor

- Control of minority carrier lifetime
- High power & speed power semiconductor
- FRD, IGBT, BJT etc.

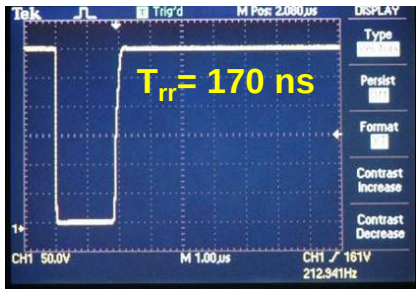
❖ Ion-cut Technology

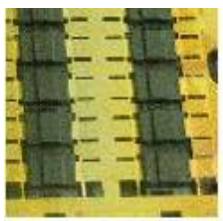
- Development of Ion-cut technology
- Manufacture SOI and GOI wafers
- Thin layer of compound semiconductor

❖ Minority Carrier Lifetime (1/35)



Proton Irradiation

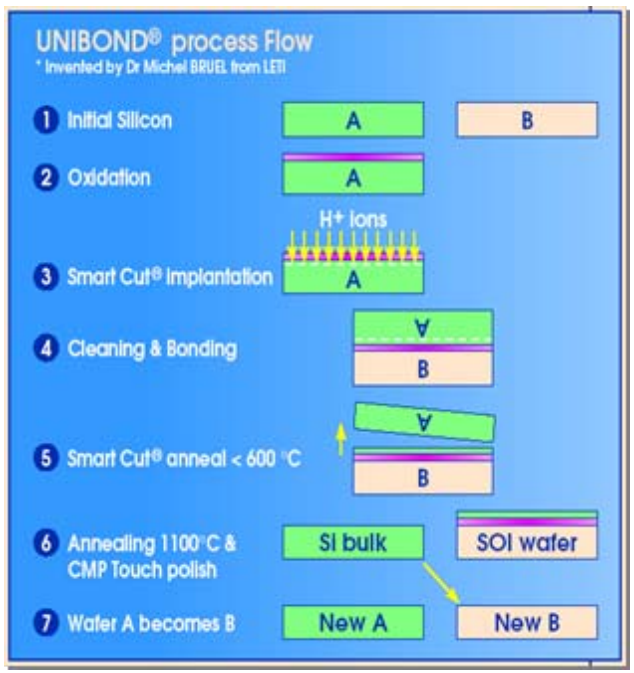


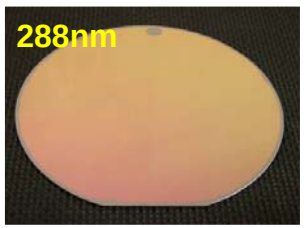


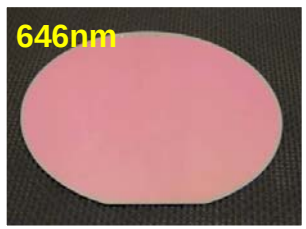
FRD
(Fast Recovery Diode)

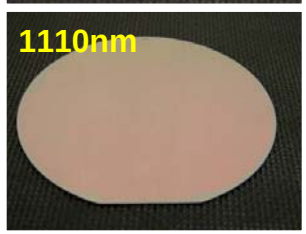
IGBT
(600V, 5A)
And Power IGBT

❖ Ion-cut Technology







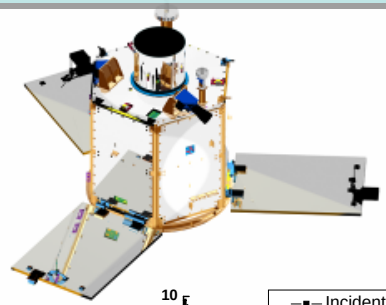


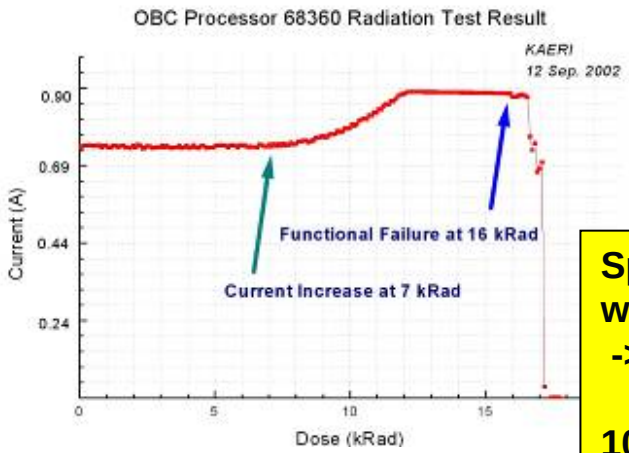
❑ R&D Activities (V) – Space & Others

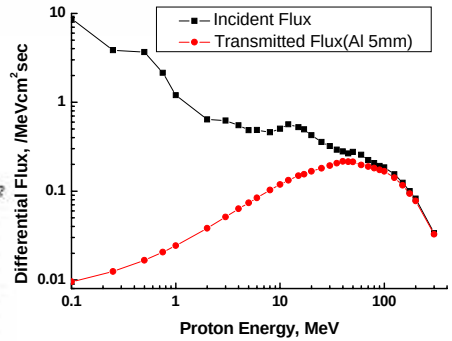
PEFP Proton Engineering Frontier Project

❖ Space Radiation Test

- Radiation hardness test of semiconductor devices for space crafts
- Total Dose Effect, Single Event Effect, etc.



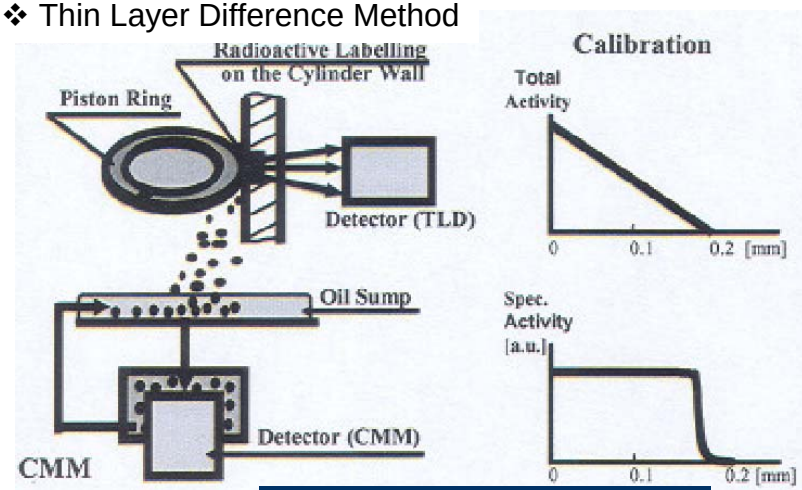




Space environment of MACSAT with 5mm Al shielding
-> total radiation dose 400 rad for 3 years
1000% margin -> 4 krad

❖ TLA (Thin Layer Activation)

❖ Thin Layer Difference Method

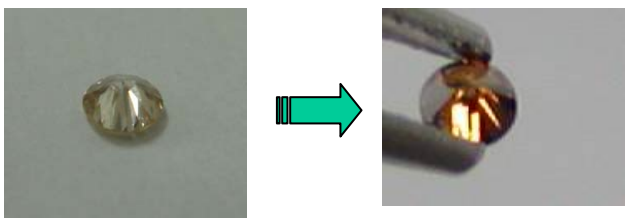


❖ Concentration

Refer to MOPEA 037

❖ Gemstones Coloration

- Optical property modifications of gemstones by irradiation & heat treatment



❑ Activities for the Future

❑ Two Extension Options of the PEFP

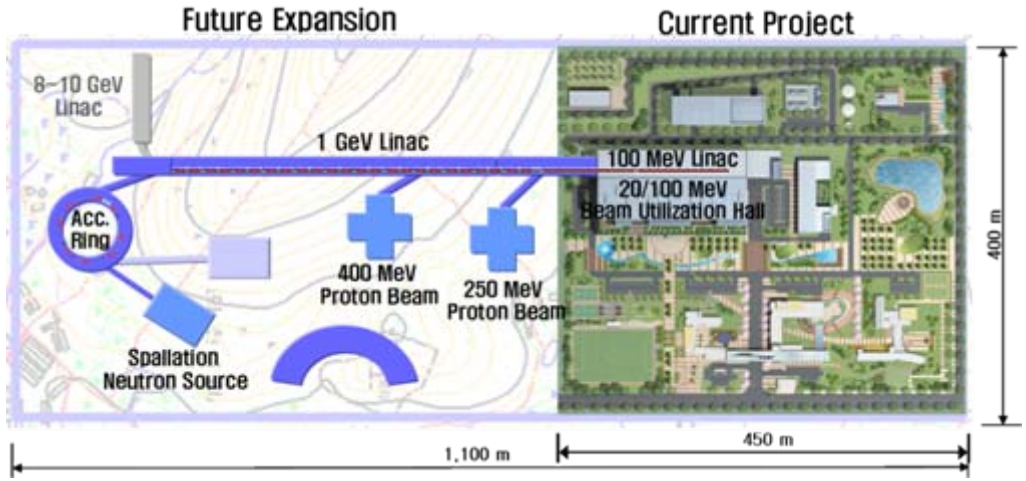
Proposed by Science & TEchnology Policy Institute (Feb, 2009)

: in a research report on "*Long-term Planning for Proton Engineering Frontier Project*"

Primary Proton Beam ➡ Secondary Neutron Beam

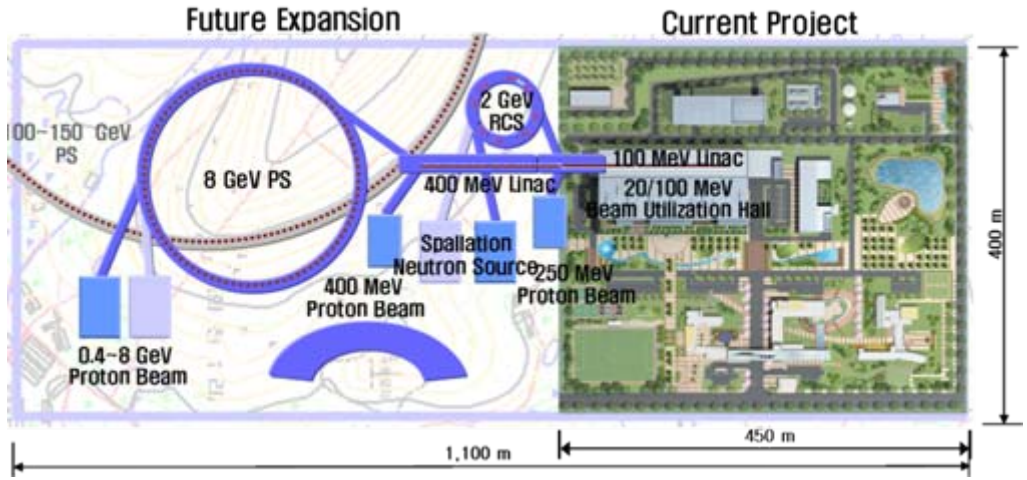
❖ Option 1

- **1 GeV SC Linac + Accumulation Ring**
  - ⇒ 2 MW Spallation Neutron Source
  - ⇒ 250, 400 Proton Beam



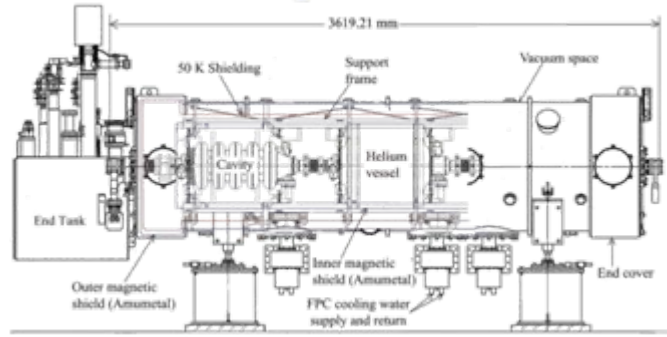
❖ Option 2

- **200 MeV SC Linac + 2 GeV RCS**
  - ⇒ 0.5 MW Spallation Neutron Source
  - ⇒ 250 MeV Proton Beam
- **400 MeV SC Linac + 8 GeV PS**
  - ⇒ 8 GeV Proton Beam

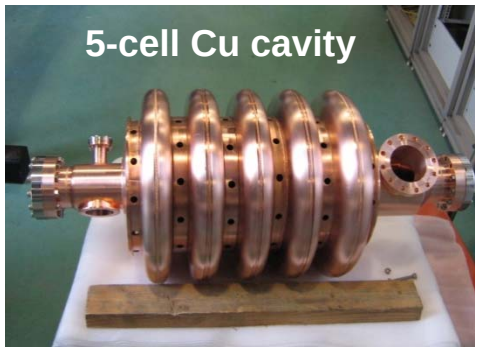


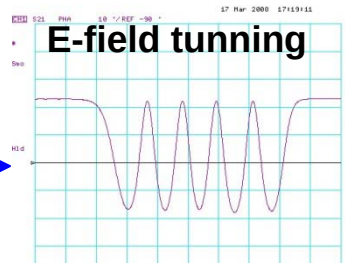
❑ Superconducting Linac Development

- β=0.42, RF: 700 MHz
- SC Cavity, RF coupler, Tuner, Vacuum Vessel, etc.
- Fabricated & tested a warm module (Cu Cavity)
- Fabricated and tested a 2-cell cold module (Nb Cavity)

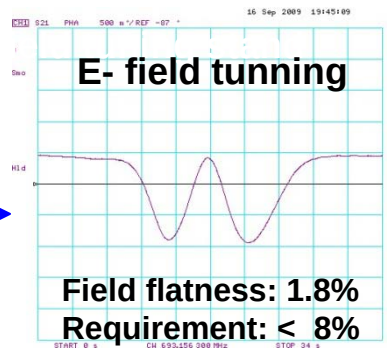


< Designed SRF module >



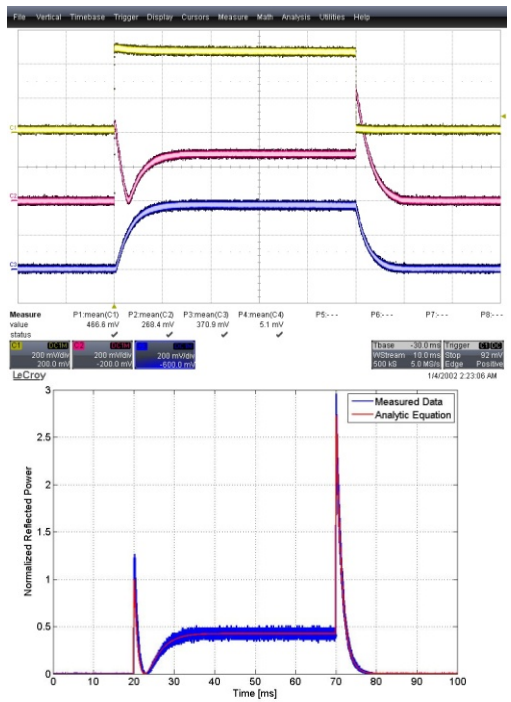


Field flatness < 1.43 %



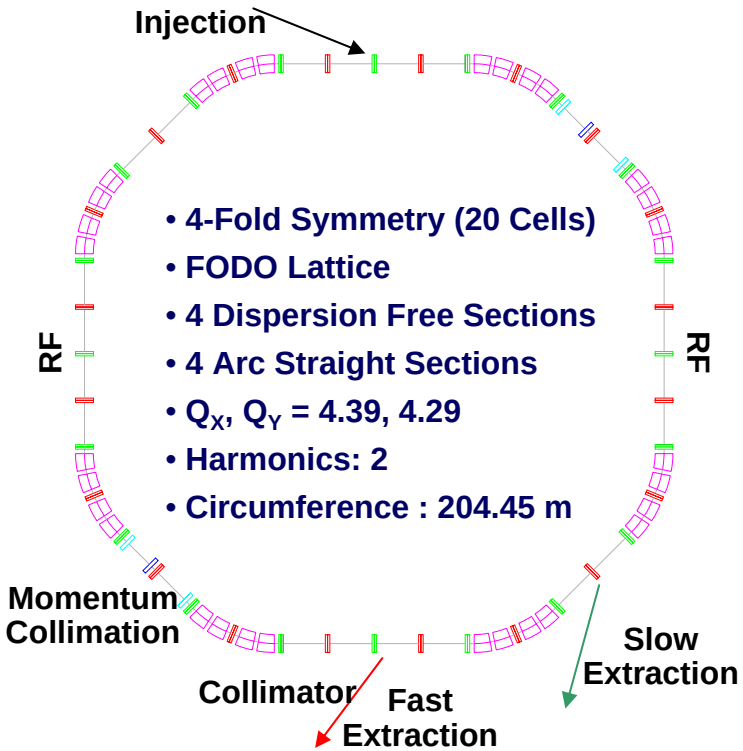
Field flatness: 1.8%
Requirement: < 8%

Refer to WEPEC 044



Eacc ~ 1.8 MV/m
(Available RF power limit)
Q0 ~ 3.7E7

❑ Rapid Cycling Synchrotron

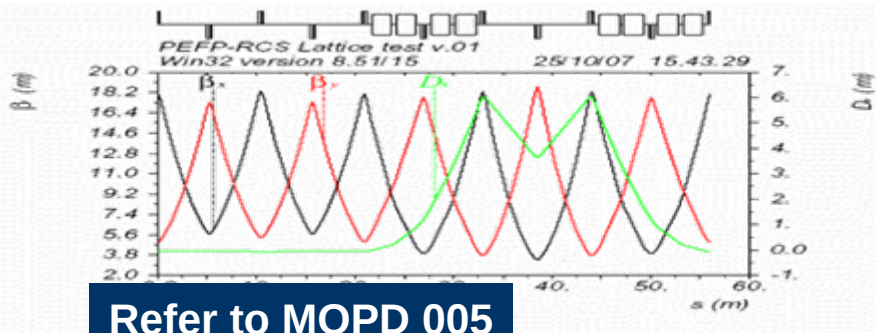


- Injection Energy: 100 (200) MeV
- Extraction Energy: 1 (2) GeV
- Injection : Charge Exchange
- Fast Extraction : Spallation neutron source
- Slow Extraction (~450 MeV): Medical application

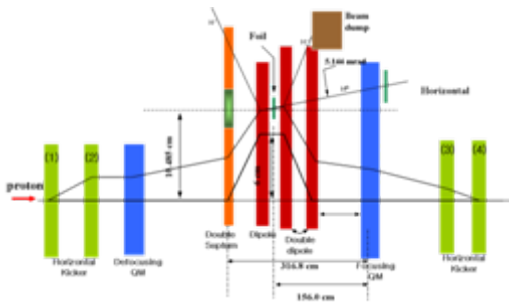
❖ Upgrade Path

	Injection [GeV]	Extraction [GeV]	Repetition [Hz]	RF [KV]	Power [KW]
Initial	0.1	1.0	15	80	60
Upgrade #1	0.1	1.0	30	140	120
Upgrade #2	0.1	2.0	30	260	250
Upgrade #3	0.2	2.0	30	250	500

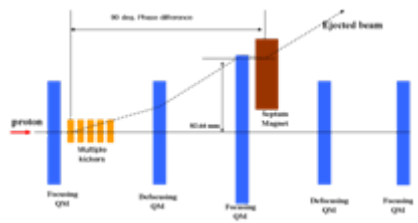
❖ Lattice Design



Refer to MOPD 005



[Injection system]



[Extraction system]

❑ Summary

PEFP Proton Engineering Frontier Project

➢ 100 MeV, 20 mA Proton Linac & Beamlines

- 20 MeV Linac :
  - Completed & in beam service
  - Achieved designed beam energy & current
- Higher energy part:
  - 20~91 MeV DTL : fabricated and tested
  - 91-100 MeV DTL : under fabrication
- To relocate the 20 MeV linac to the site from April 2011
- To complete the 100 MeV linac & beamlines by March 2012

➢ Construction Work

- Under site preparation; leveling along with excavation
- To start construction work in July 2010, accelerator buildings to be completed by June 2011

➢ Beam Utilization & Applications

- Cultivated and fostered user programs in the wide range of research fields
- Produced promising outcomes including some industrialized

➢ Activities for the Future (a Spallation Neutron Source)

- R&D in SCL, RCS, RF Power Source, Spallation Neutron Target, and Beam Sharing


Thank you very much
for your attention