The Korean Proton Engineering Frontier Project

42nd ICFA Advanced Beam Dynamics Workshop on High-Intenstity, High-Brightness Hadron Beams

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Nashville, USA

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Proton Engineering Frontier Project

양 성 자 기 반 공 학 기 술 개 발 사 업 단

(http://www.komac.re.kr)

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PEFP Proton Engineering Frontier Project

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- Status of the Accelerator Development
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Overview of PEFP

PEFP Proton Engineering Frontier Project

- Project : Proton Engineering Frontier Project (PEFP)

  21C Frontier Project, Ministry of Education, Science & Technology

- Project Objectives :

  1st : Developing & constructing a proton linear accelerator (100MeV, 20mA)

  2nd : Developing technologies for the proton beam utilizations & accelerator applications

  3rd : Promoting industrial applications with the developed technologies

- Project Period : 2002.7 – 2012.3 (10 years)

- Project Cost : 128.6 B Won (Gov. 115.7 B, Private 12.9 B)
  (Gyoungju City provides the land, buildings & supporting facilities)

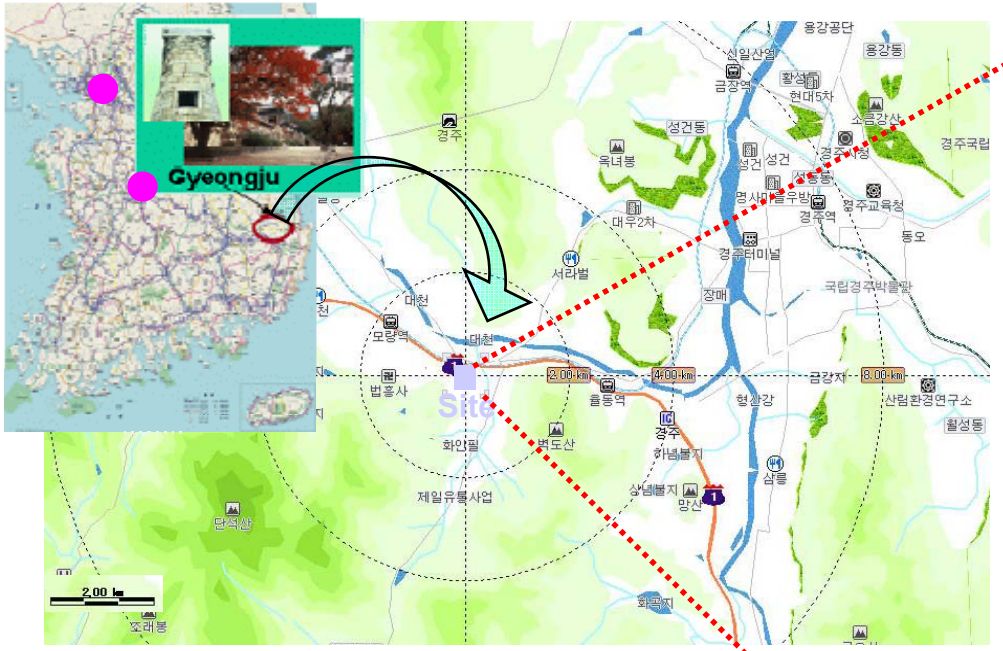
Project History – Project Site Selection

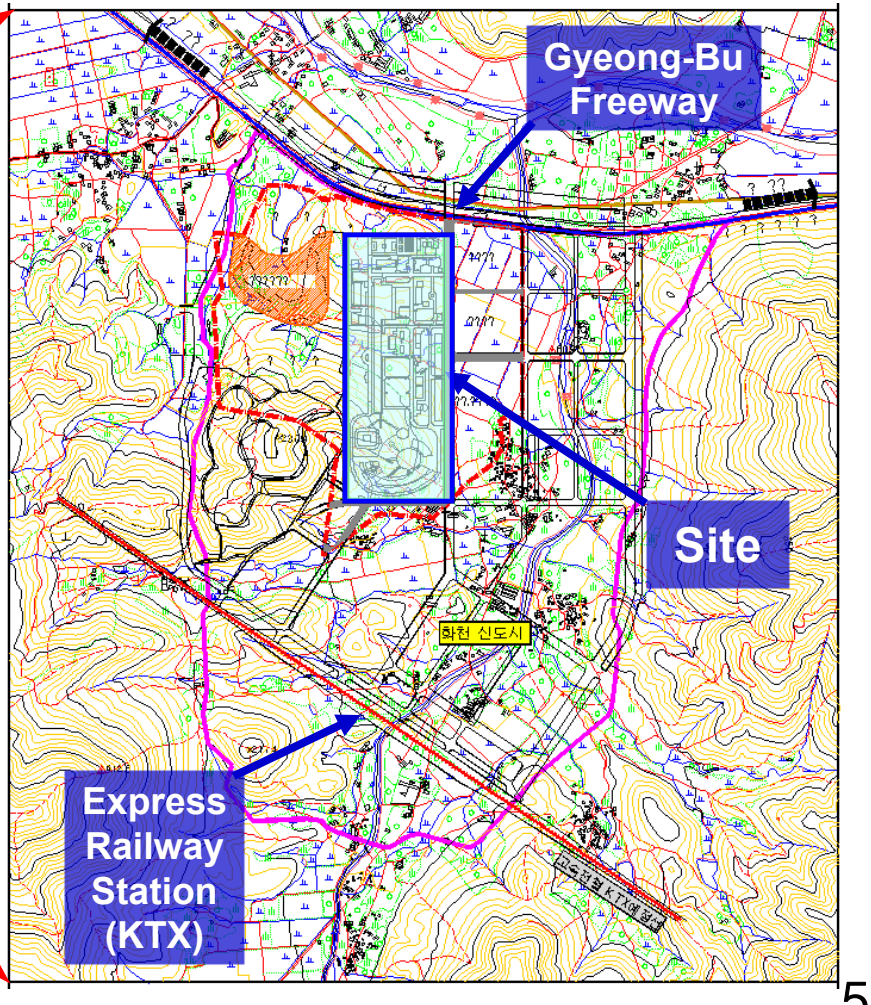
PEFP Proton Engineering Frontier Project

Step	Year order	Calendar		What's done
		Year	Month	
I	1	'02	7	Approved and Lunched the Project
			9	Lunched 17 sub-projects for the 1st year of Step-1
			12	Opened 1st Public subscription for Site - 5 local governments applied : Daegu, Iksan, Yoenggwang, Choerwon, Chuncheon
		'03	4	Cabinet Council suspended the Site Selection process and bound it to Nuclear Waste Storage Site
			5	Opened 2nd Public subscription for Site in conjunction with Nuclear Waste Storage Site - Buan local government applied
	2	'03	7	Started 2nd year with 21 sub-projects
		'04	2	Opened 3rd Public subscription for Site in conjunction with Nuclear Waste Storage Site
	3	'04	7	Started 3rd year with 23 sub-projects
		'05	2	Project assessment for the 1st step
			4	Completed project plan for the 2nd step
			6	Opened 4th Public subscription for Site in conjunction with Nuclear Waste Storage Site - Gyeongju, Kunsan, Yeongdeok, Pohang applied
			6	Signed Project Contract for the 2nd step (between KAERI & MOST)
II	1	'05	7	Started 1st year of the 2nd step with 18 sub-projects
			11	Gyeongju hosted the Project with 89% favorable residential vote
		'06	2	Selected Geoncheon as the project site in Gyeongju city
			3	Signed Cooperation contract Gyeongju city
	2	'06	4	Started 2nd year of the 2nd step with 19 sub-projects
	3	'07	4	Started 3rd year with 19 sub-projects
		'08	2	Completed project plan for the 3rd step
III	1	'08	4	Project assessment for the 2nd step
			5	Signed Project Contract for the 3rd step (between KAERI & MEST)
			4	Started 1st year of the 3rd step with 8 sub-projects

The “Site” Selected

Geoncheon, Gyeongju (Area; 440,000 m^2)

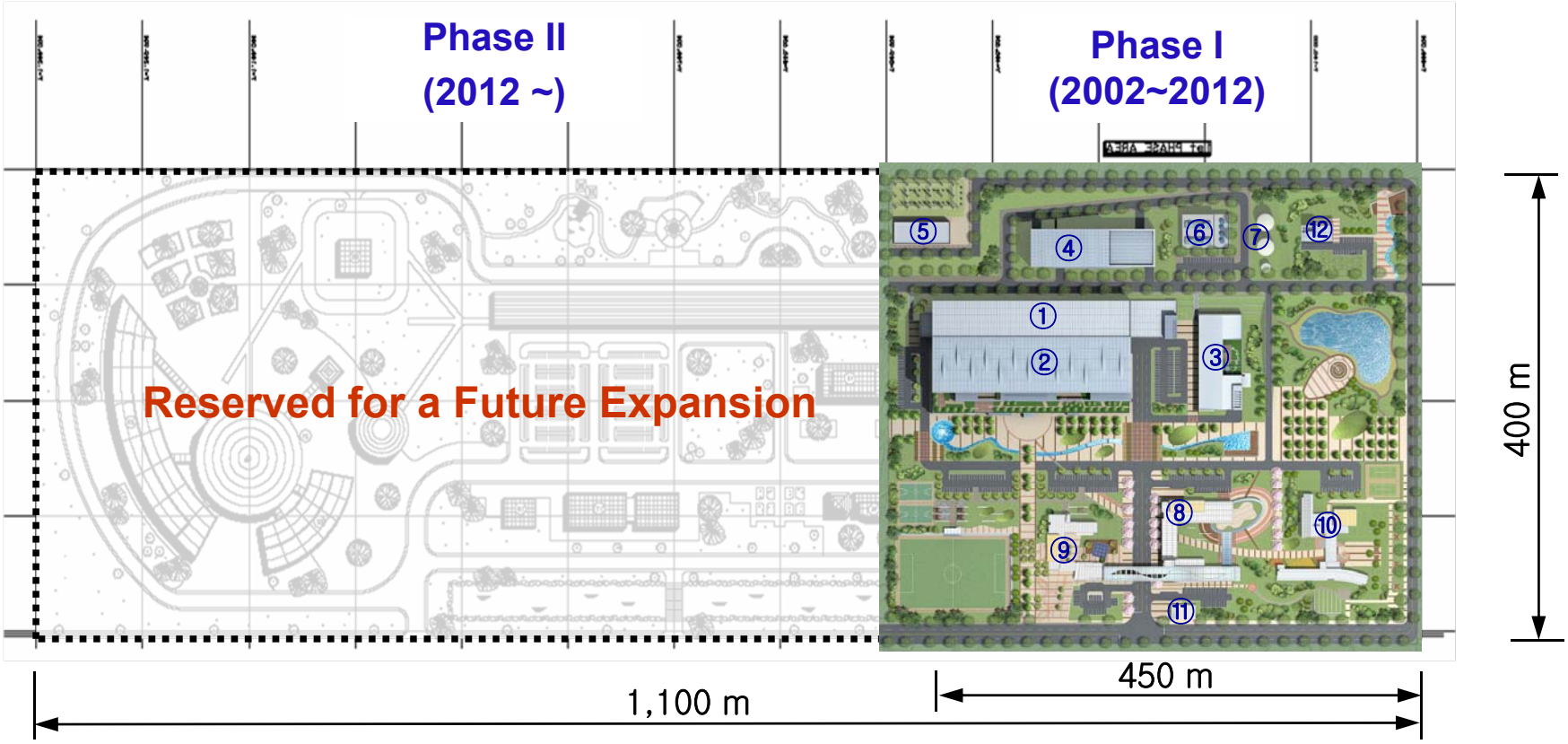




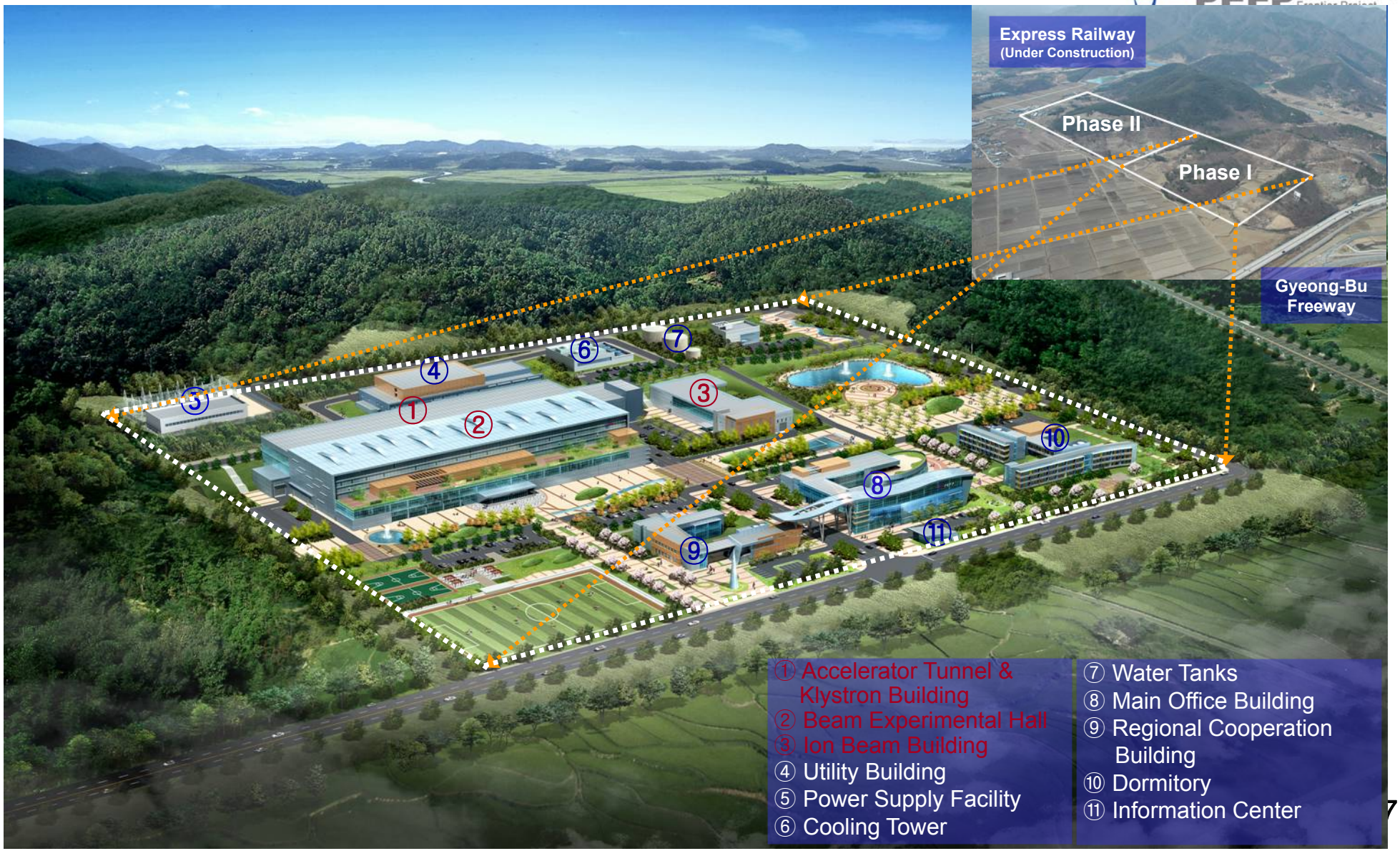
Easy access for users (2.5h from Seoul by KTX)

Transportation	*Start Point*	*Dist.*
Gyeong-bu Freeway	*Gyeongju IC*	*4.3 km*
Express Railway (KTX) (under construction)	*New Gyeongju Sta.*	*1.5 km*

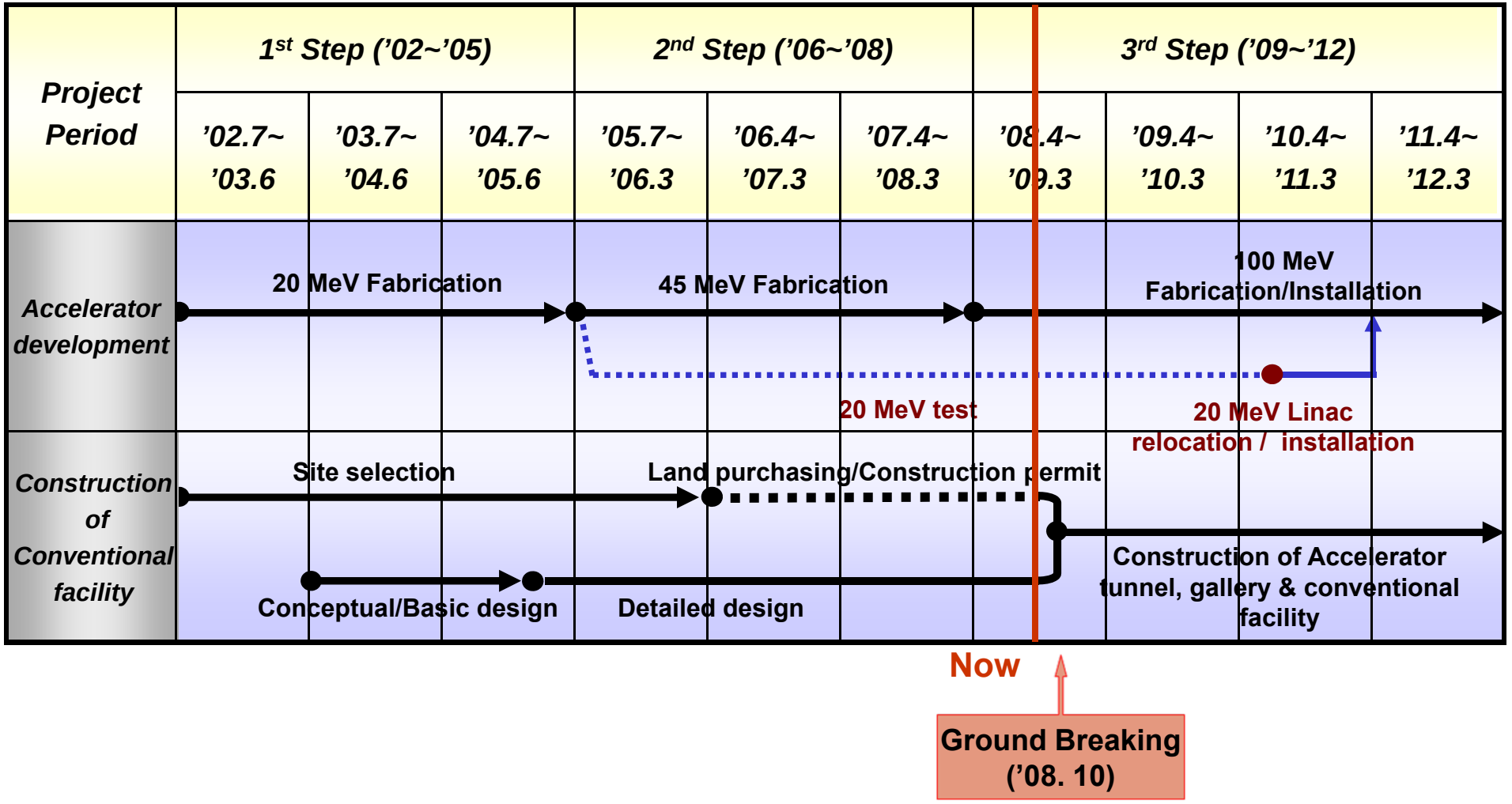
Layout of the Site



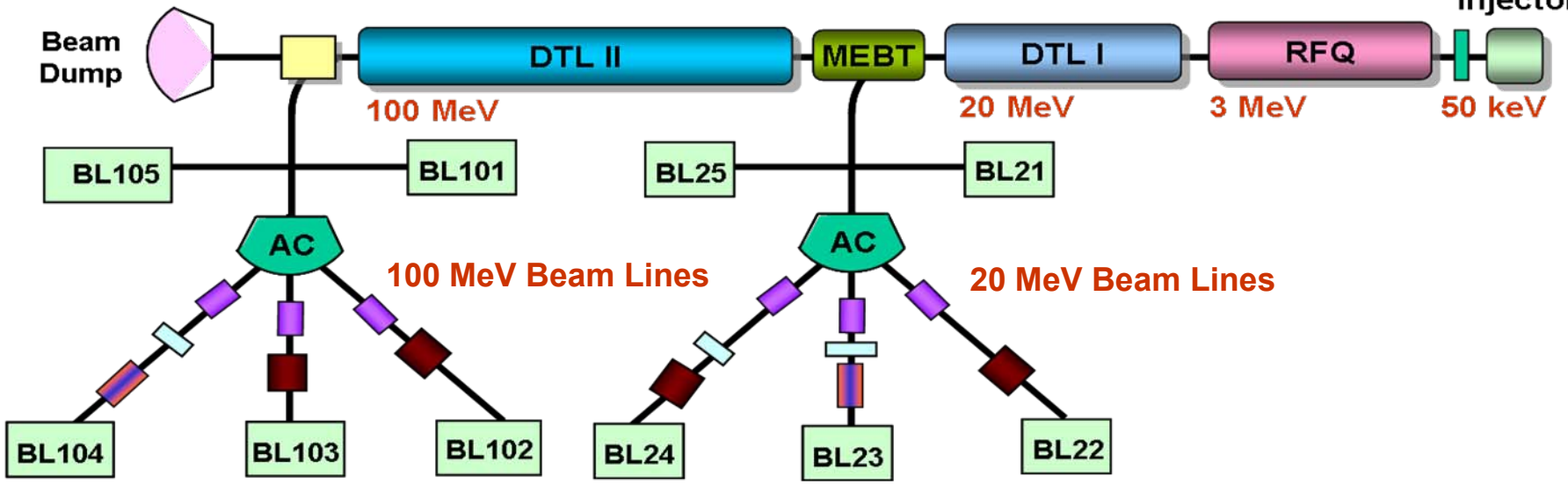
Site Plan for the PEFP



Project Schedule



Schematics of the PEFP Linac & Beamlines



■ Accelerator Parameters

▪ Particle	Proton
▪ Max Beam Energy	100 MeV
▪ Operational Mode	Pulse
▪ Max. Peak Current	20 mA
▪ RF Frequency	350 MHz
▪ Max Repetition Rate	120 Hz / 60 Hz
▪ Max Pulse Length	2 ms / 1.33 ms
▪ Max Beam Duty	24% / 8%

■ Specific Features of the PEFP Accelerator

- A 50 keV Injector, 3 MeV RFQ and 20 & 100 MeV DTL's.
- To extract the beam at 20 and 100 MeV
- To distribute the beam to 3 beam lines at 20 MeV and 3 beam lines at 100 MeV sequentially by programmable AC magnets
- Each beam line has specific beam parameters

Status of the PEFP 20 MeV Linac

PEFP Proton Engineering Frontier Project

Klystron for RFQ
350 MHz 1 MW CW



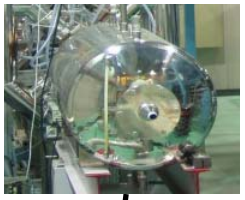
Waveguide
WR2300



Klystron for DTL
350 MHz 1 MW CW



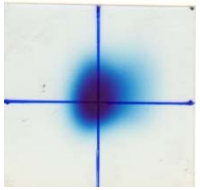
Beam Dump
100 kW

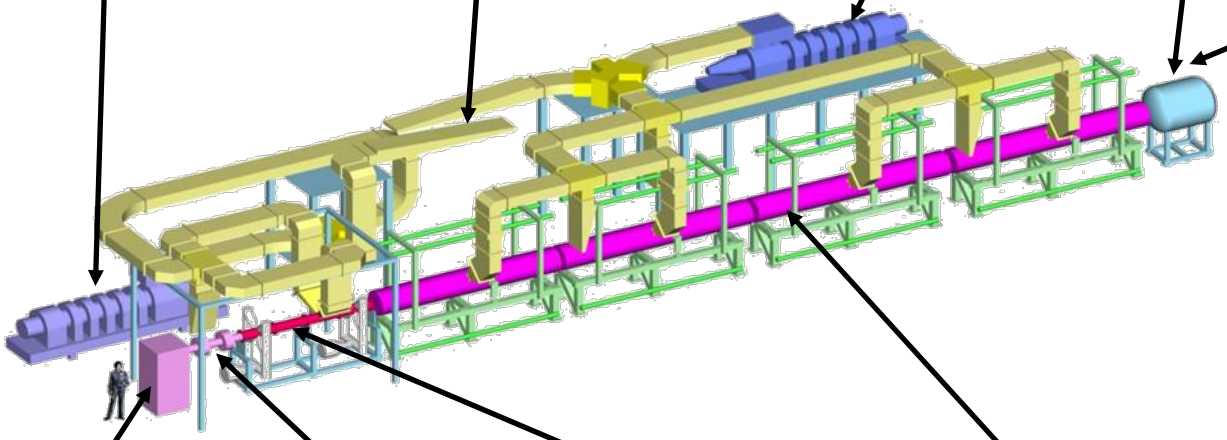


Target station for user

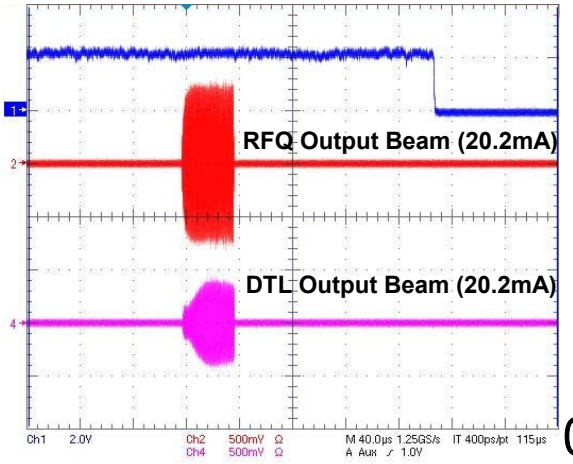


Beam Profile





- **RFQ & DTL : fabricated and tuned**
- **Full Power RF test: completed**
- **Beam test results**
  (20 MeV, 20 mA peak at 50 us, 1.0 Hz)
- **Beam test is underway to tune the operation parameters**





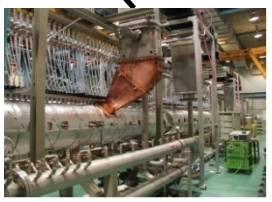
Injector
50 keV 40 mA



LEBT



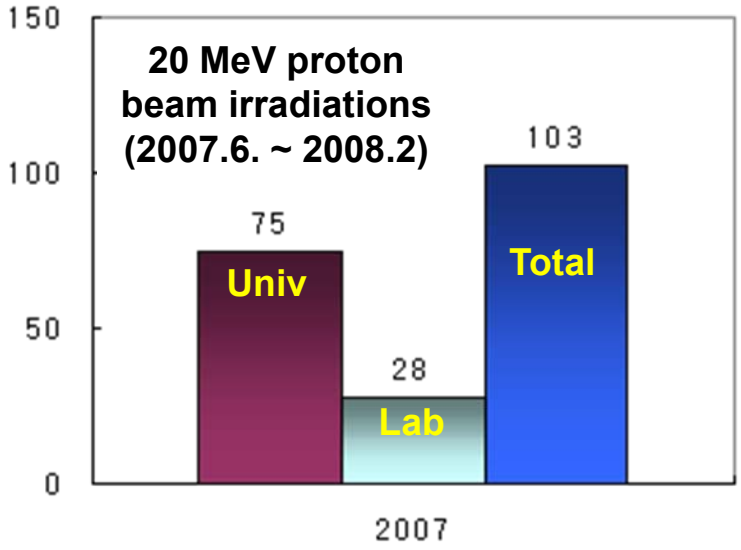
3 MeV RFQ
350 MHz 4-Vane

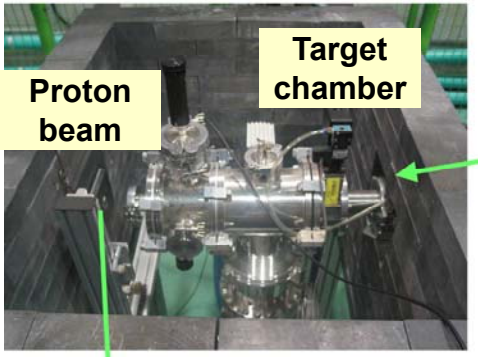


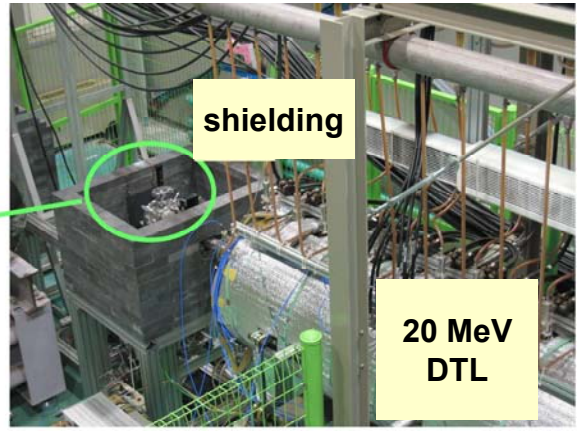
20 MeV DTL
4 -Tank 150-DT

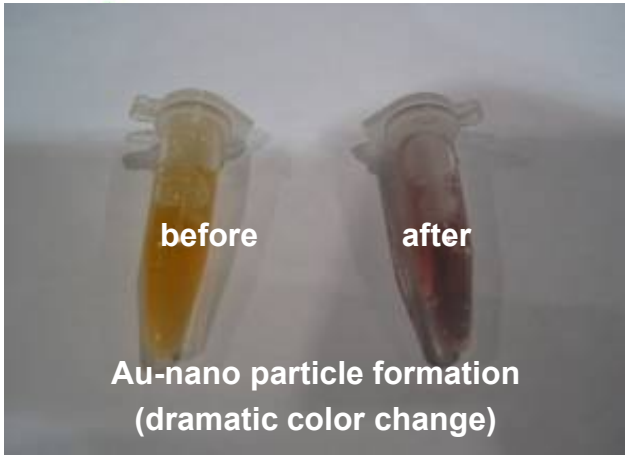
20 MeV Proton Linac Operation

- Began to supply the proton beam to meet part of user's demand
- Obtained MOST/KINS permit on June 2007
- Beam condition: Avg. current : 0.1 μA, Rep. rate : 0.1 Hz, Pulse length : 50 μs
- Operated only on weekend





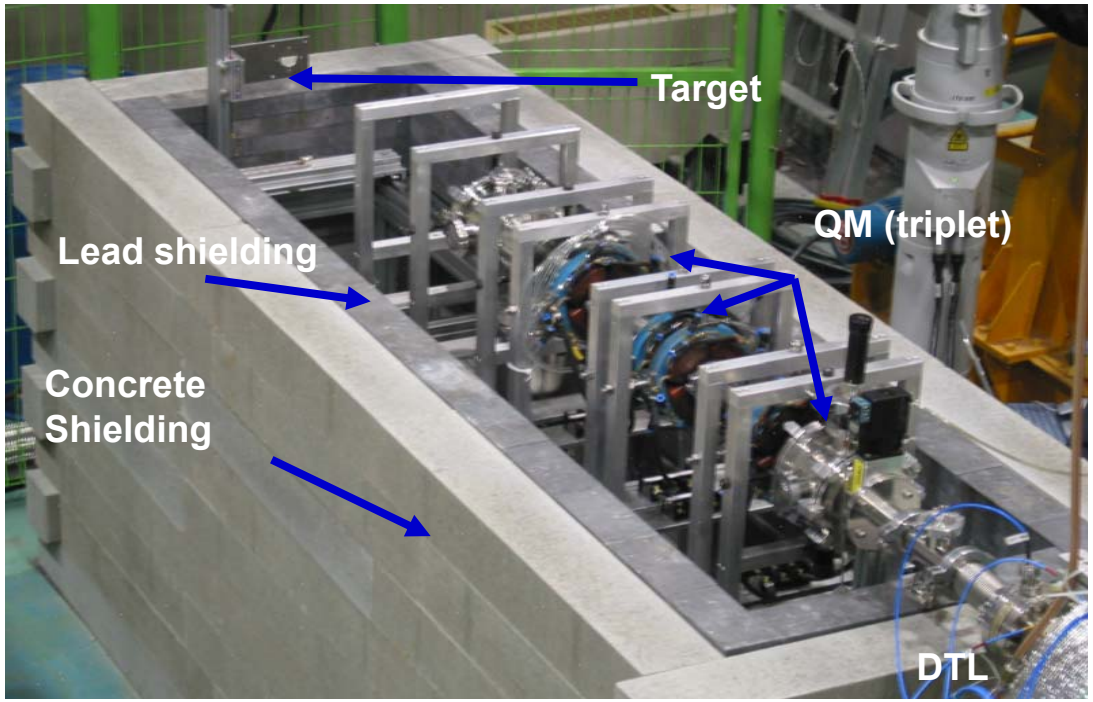


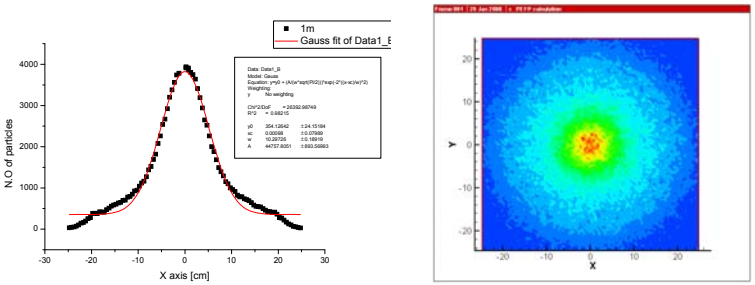


Upgraded 20 MeV Irradiation Station

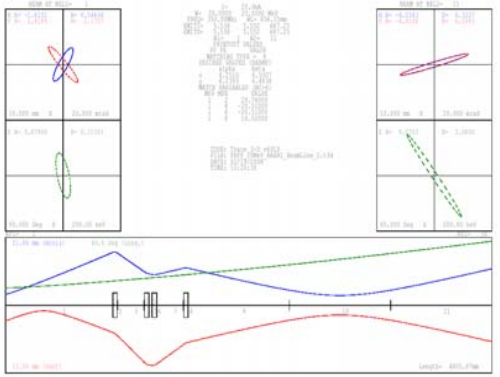
PEFP Proton Engineering Frontier Project

- To meet increasing demand for 20 MeV proton beam
- Revised the operation permit by adding tighter shielding (Apr. 08)
- Beam conditin: Avg. current : 1.0 μA, Rep. rate : 1 Hz, Pulse length : 50 μs (10-fold increase)
- Expected users: 150/year (weekend operation only)





External beam
Able to modulate the beam size at target



Beam optics with a QM triplet

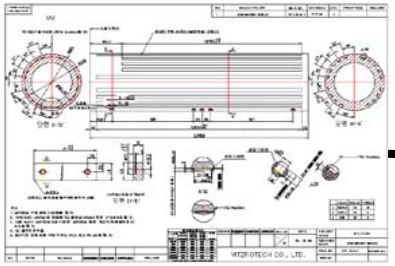
PEFP DTL for 20~100MeV

PEFP Proton Engineering Frontier Project

	DTL101	DTL102	DTL103	DTL104	DTL105	DTL106	DTL107
Cell number	34	28	25	23	21	20	19
Energy [MeV]	33.1	45.3	57.1	69.1	80.4	91.7	102.6
Length [mm]	6737.97	6707.26	6791.74	6877.06	6777.65	6869.92	6880.20
E0 [MV/m]	2.58	2.58	2.58	2.58	2.58	2.58	2.58
H at wall [A/m]	3402.9	3429.2	3442.3	3393.3	3403.0	3370.5	3377.7
Stored Energy [J]	15.8	15.9	16.2	16.1	16.0	16.0	16.1
Beam Power [kW]	257.4	241.3	231.2	235.5	222.2	222.5	214.2
Copper Power [kW]	807.3	798.0	808.9	791.3	785.9	782.2	789.4

Fabricated & Tested 45 MeV DTL

- Energy : 20~45 MeV, RF frequency : 350 MHz, Length : 13.7m (two tanks)



Design of DTL tank



Machining
Accuracy <100 μm

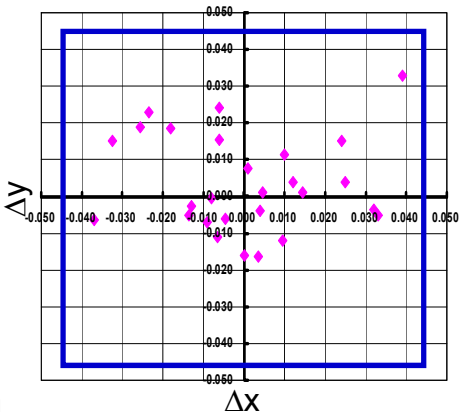


Plating
Thickness < 100 μm



Assembling
accuracy < 100 μm

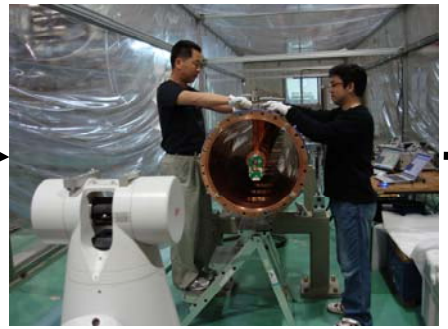
Allowed error:
50 μm



DT alignment < 40 μm



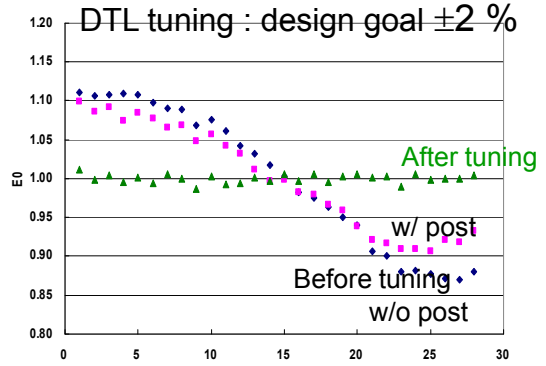
DT QM
(B = 1.75 T±1%)



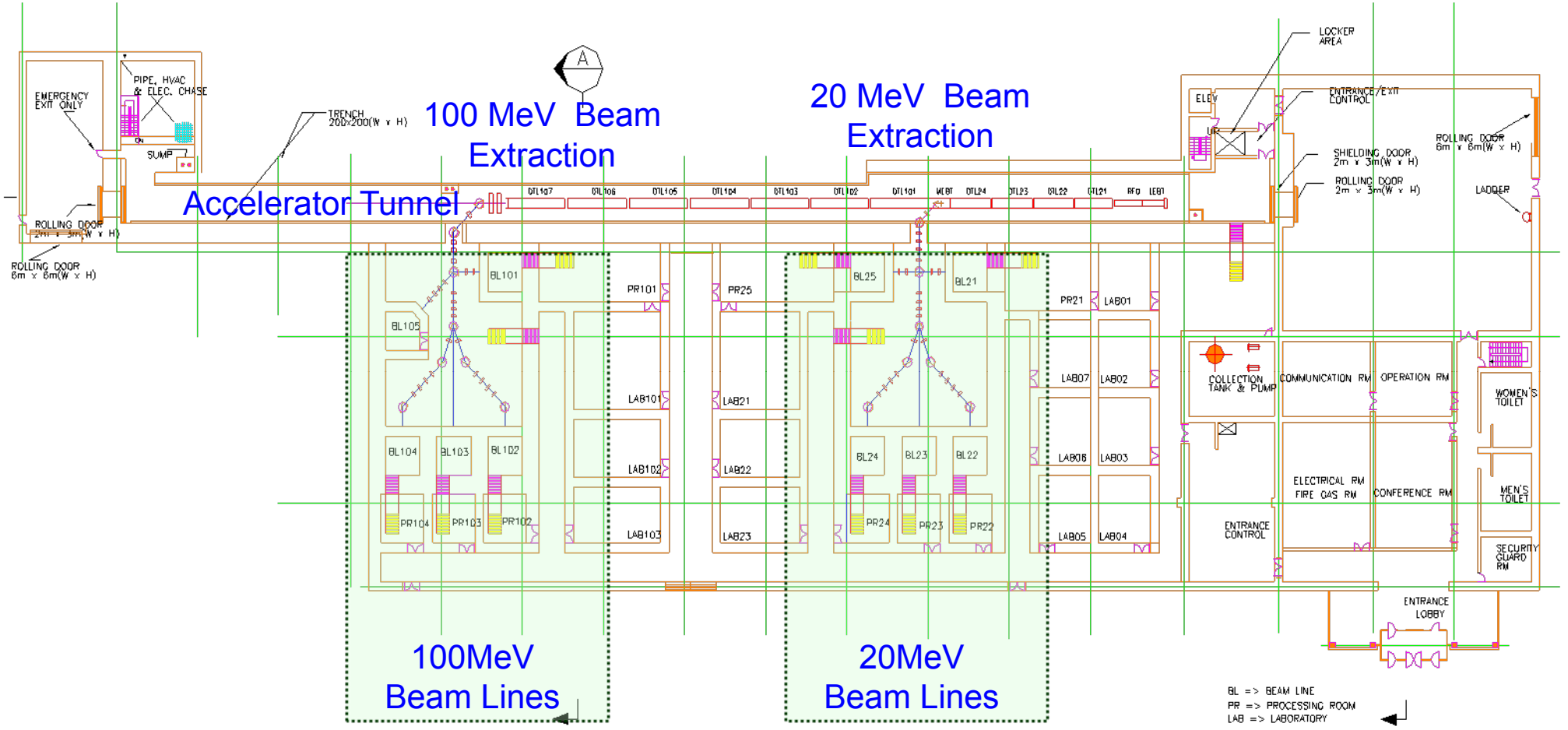
DT mounting
(alignment error < 50 μm)



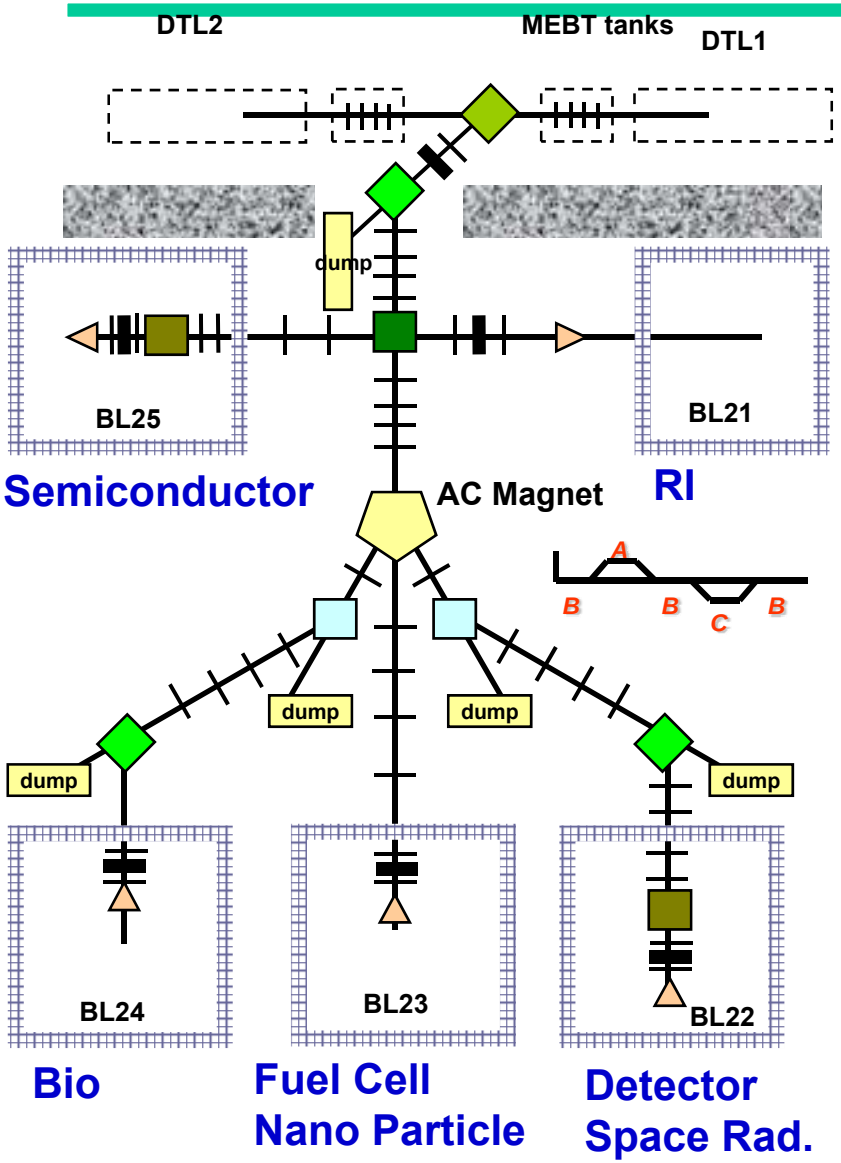
Fabricated DTL tank



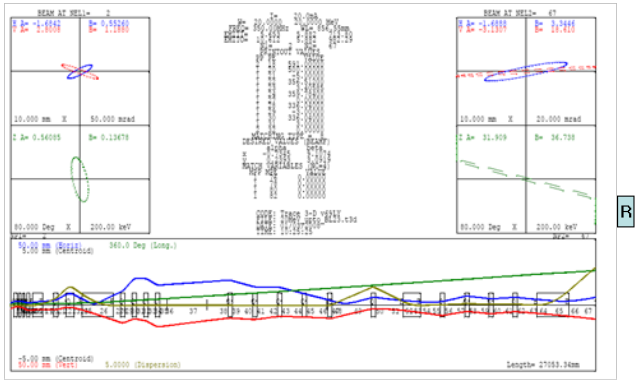
Layout of the PEFP Linac & Beamlines

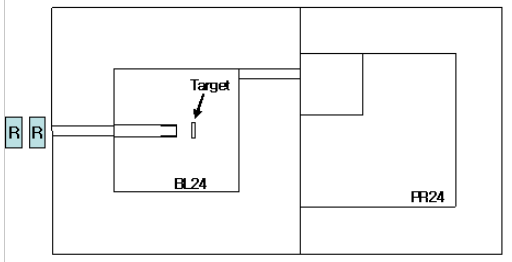


20 MeV Beamlines



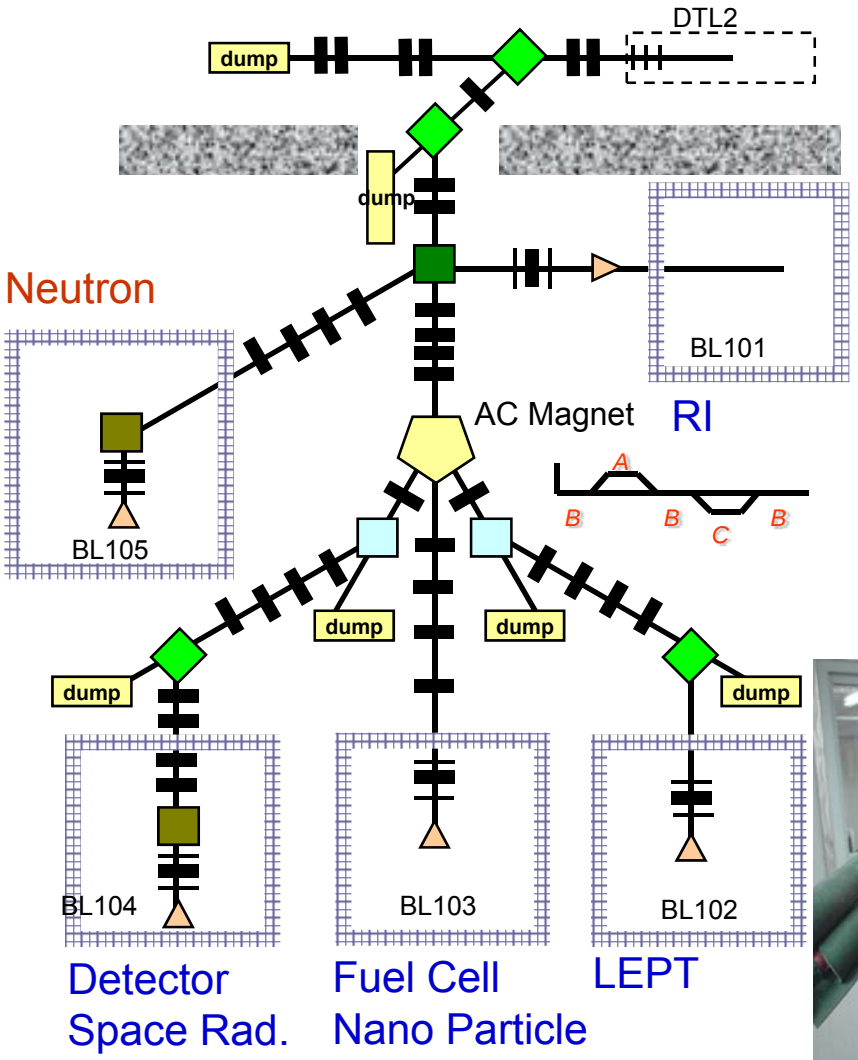
Beam Line	Application Field	Rep. Rate	Max. Avg. Current	Irradi. Cond.	Max. Area (Dia.)	Ref. Target
BL21	RI Prod. (PET)	60Hz	2.4mA	Hor. Vac.	100mm	H_2O
BL22	Detector Space Rad.	15Hz	60μA	Vert. Atm.	300mm	Si
BL23	Fuel Cell, Nano Particle	30Hz	1.2mA	Hor. Vac.	300mm	Si
BL24	Bio. Sample (Cell, Plant)	15Hz	0.6mA	Hor. Atm.	300mm	H_2O
BL25	Semi-conductor	60Hz	0.6mA	Vert. Atm.	300mm	Si





Beam Optics Calculation and Target Room Design (BL24)

100 MeV Beamlines

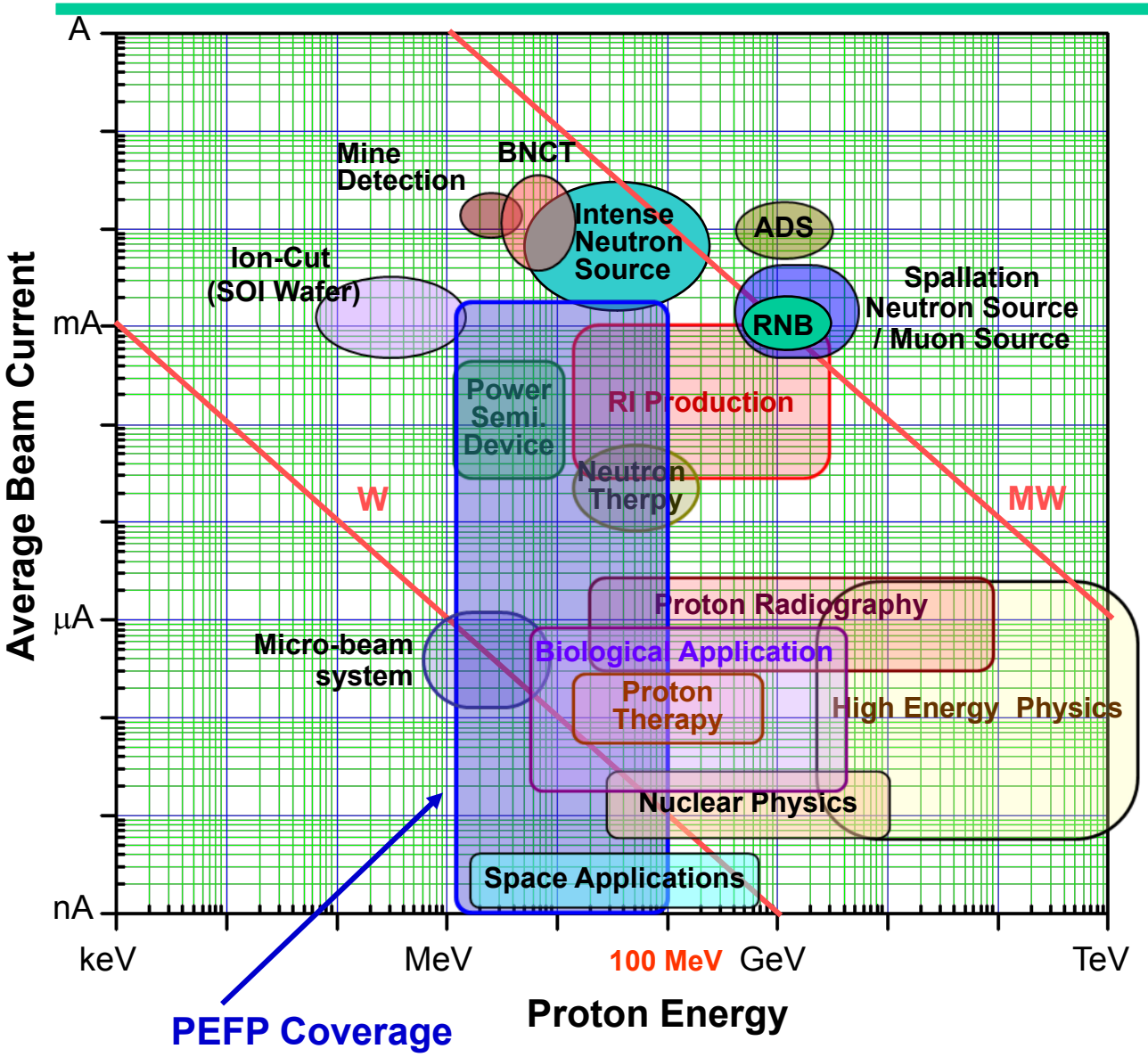


Beam Line	Application Field	Rep. Rate	Max. Avg. Current	Irradi. Cond.	Max. Area (Dia.)	Ref. Target
BL101	RI	60Hz	1.6mA	Hor. Vac.	100mm	W
BL102	LEPT (Animal, Cell)	7.5Hz	10μA	Hor. Atm.	300mm	H_2O
BL103	Fuel Cell Nano Particle	15Hz	300μA	Hor. Atm.	300mm	Si
BL104	Detector, Space Rad.	7.5Hz	10μA	Vert. Atm.	300mm	Si
BL105	Neutron	60Hz	1.6mA	Vert. Vac.	300mm	W



- **Quadrupole, Dipole, and AC magnets are fabricated in IHEP, China**

Utilization & Application Fields of the Proton Beam



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

Development of the User Facilities & Programs

PEFP Proton Engineering Frontier Project

❑ Activities for development of users & user facilities

- **Demand survey :** through the PEFP's homepage **(http://www.komac.re.kr)**
- **Construction and operation of a test beam line :** with PEFP 20-MeV linac and 50-MeV cyclotron at KIRAMS
- **Beam line studies** : on the beam energy control, beam distribution, flux control, dose measurement, etc.

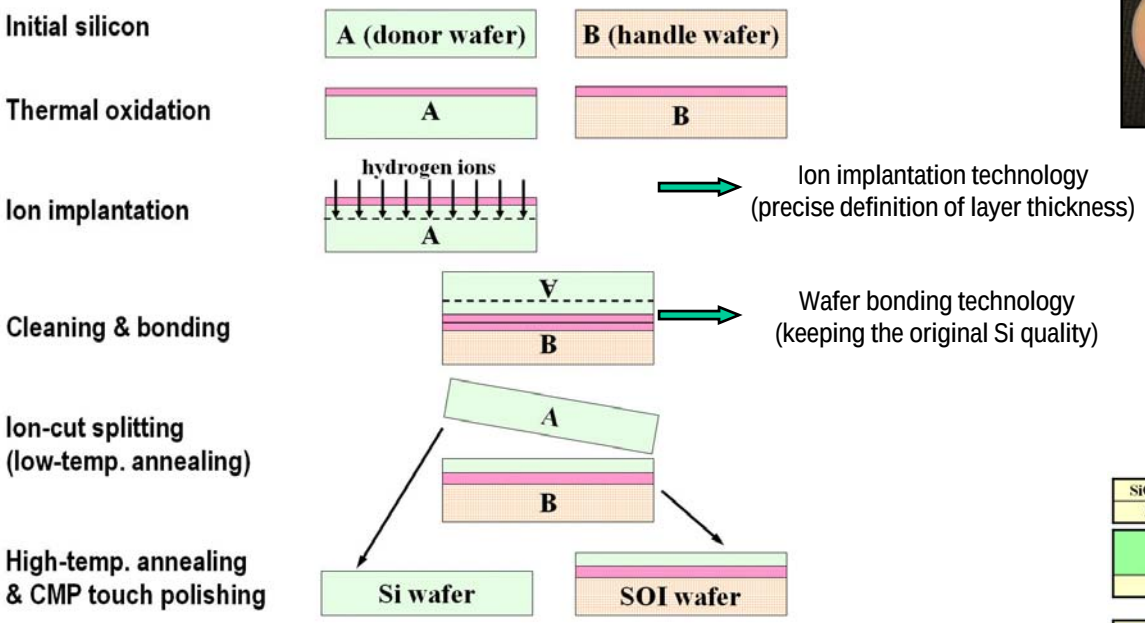
❑ User Program Development (2003~2008)

Research Fields	*Sub-categories*
Nano technology	*Ion-cutting, Nano-particle shaping & fabrication, Carbon nano-tube, Nano-machining*
Information technology	*High power semiconductor, Semiconductor manufacturing R&D, Proton beam lithography*
Space technology	*Radiation hard electronic device, Radiation effect on materials*
Bio-technology	*Mutations of plants & micro-organisms*
Medical research	*Low energy proton therapy study, Biocompatible material, Biological radiation effects, New RI production R&D*
Material science	*Proton irradiation effects with various materials Gemstone coloration*
Environment & Energy	*Bio-ethanol production study, New micro-organism development for bio fuel, New material for fuel cell ; electrolyte, nano catalyst, organic solar cell*
Nuclear & particle physics	*Detector R&D, Nuclear data, TLA (Thin Layer Activation)*

Ion-cut technology and SOI/GOI wafer (KIGAM)

PEFP Proton Engineering Frontier Project

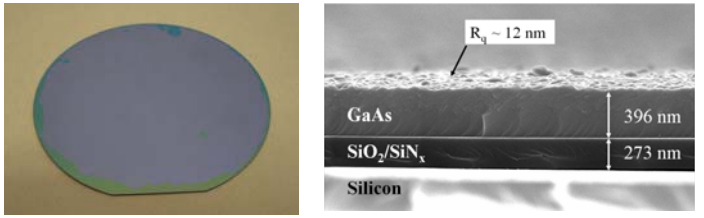
- Si-on-insulator (SOI) wafer & GaAs-on-insulator (GOI) wafer fabrication
- GaN layer transfer by ion-cut process
- Industrialization of Ion-cu techanology



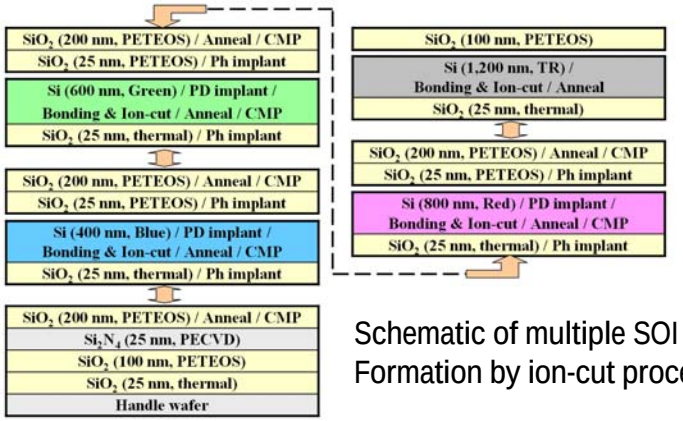
Schematic of the ion-cut process for thick-SOI wafers fabrication



SOI wafer



GOI wafer and FE-SEM image

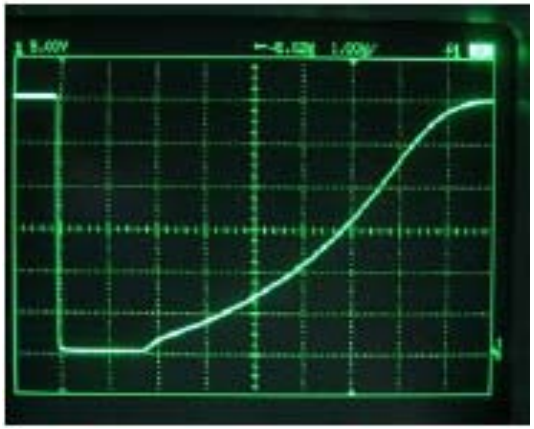


Schematic of multiple SOI layers Formation by ion-cut process

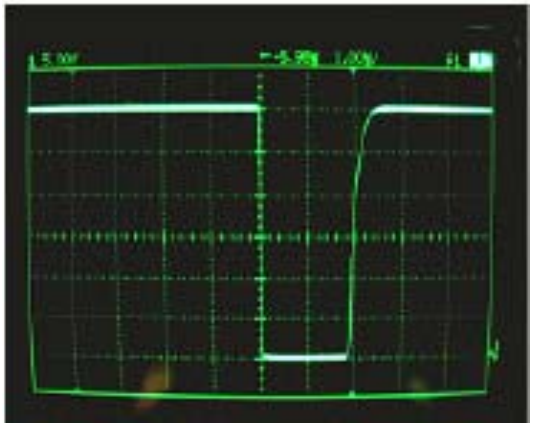
Proton beam and Semiconductor (Uiduk University)

PEFP Proton Engineering Frontier Project

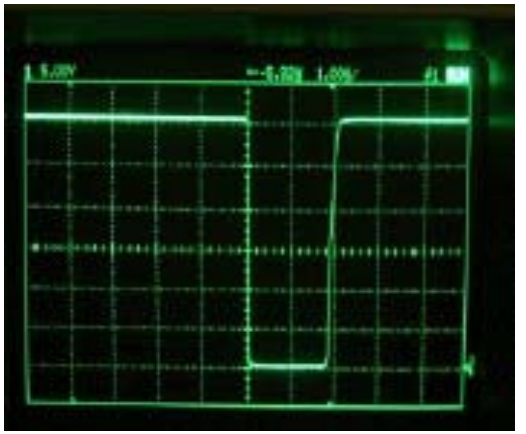
- One of useful industrial applications of low energy proton beam is to produce power semiconductors with fast switching characteristics through charge carrier lifetime control.
- After proton beam irradiation, switching speed of FRD(fast recovery diode) and IGBT were improved more than about 5 times.



No irradiation



electron beam irradiation



proton beam irradiation

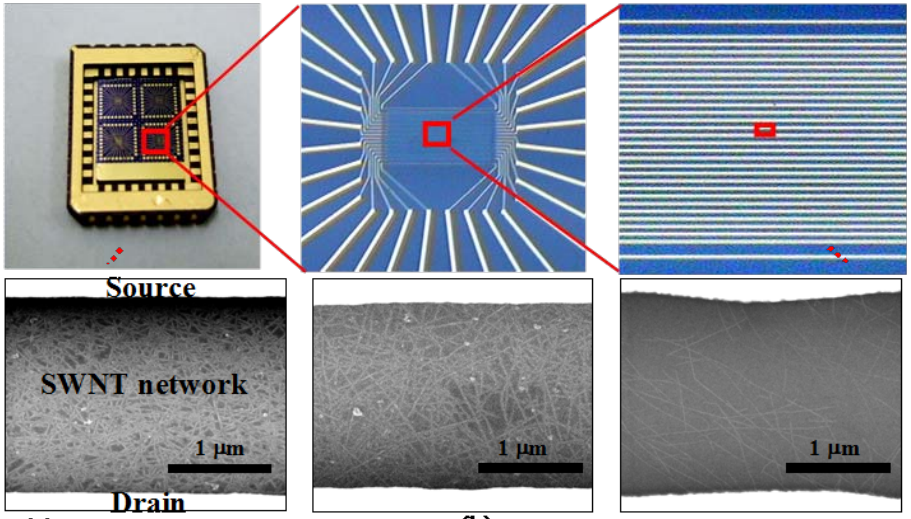


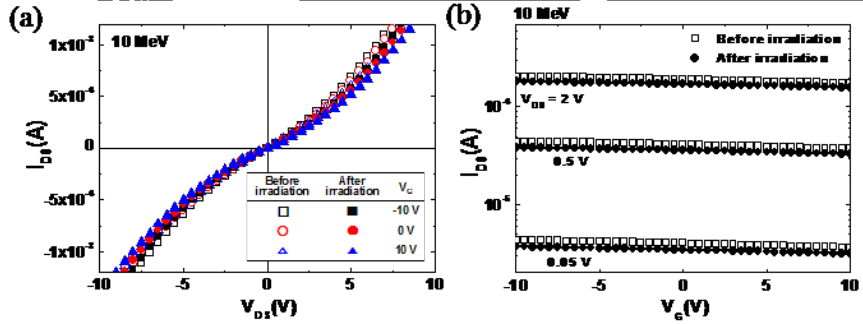
660V, 10A IGBT

Proton beam & Nano-Technology (GIST/Korea Univ./Samsung SDI)

PEFP Proton Engineering Frontier Project

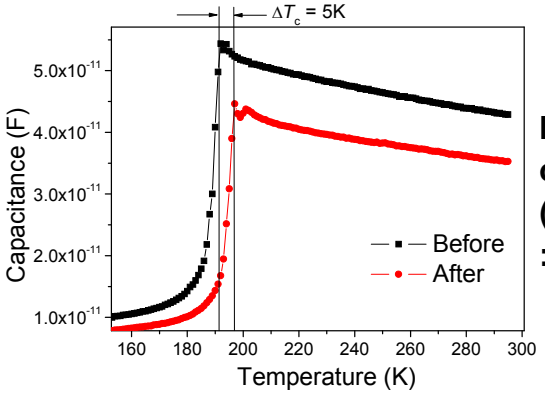
- Nano-particle production : Nano-particle in a fuel cell, Au nano-particle production
- Study of proton irradiation effects on various materials and their application





CNT-FET semi-conductor and

Proton irradiation effects



Proton irradiation effects on KD_2PO_4 (after replacing H_2 with D_2) : Study on the phase transition temperature



Au nano-particle formation By 20-MeV proton irradiation

Proton Beam and Bio-Technology (Hyundai Biotech Research Institute)

PEFP Proton Engineering Frontier Project

- R&D on the mutation of plants, vegetables, flowers (rose, lily, iris, etc) has been carried out.
- Participating company: New Seoul Seed Company (1st step) and Hyundai Seed Company (2nd step)
- Collaboration university: Chunbook university, Suncheon univertiy
- Two kinds of new seed were proposed for the registration at the end of 2007.







New varieties of
radish and red pepper













Various size of Chinese cabbage mutants



Orchid mutant selection

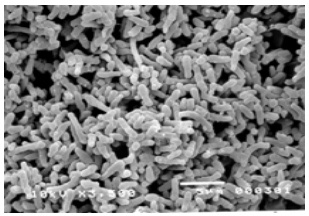
Proton Beam and Environment-Technology (KAERI)

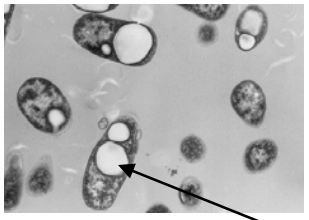
PEFP Proton Engineering Frontier Project

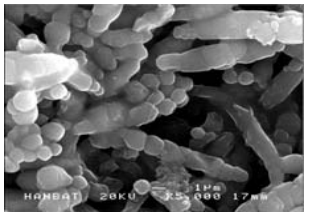
- New genetic resources were made by mutation process using proton beam irradiation.
- Mutation of mircoorganisms: E-coli to produce biodegradable plastics
  PHB(1st step) and PHBV(2nd step) plastics
- A knife sample was made using PHV plastics.

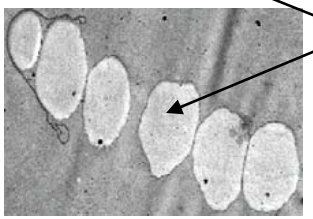
Conventional

KAERI









PHB granule

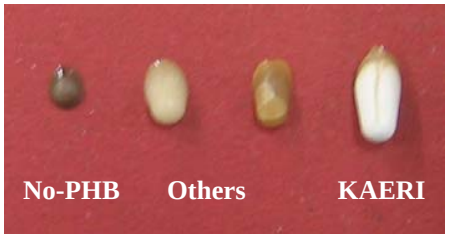


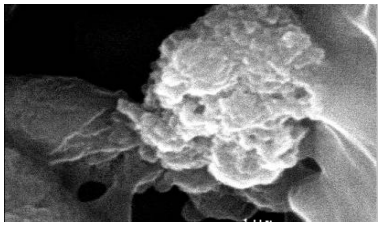
Fermentation



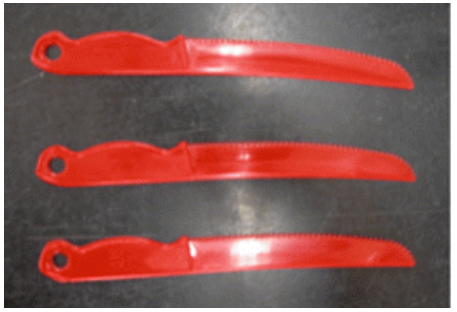


Yield : 60-70g/L PHB





99% PHB
80% Autolysis



Non-biodegradable Plastic knife (Polyethylene)

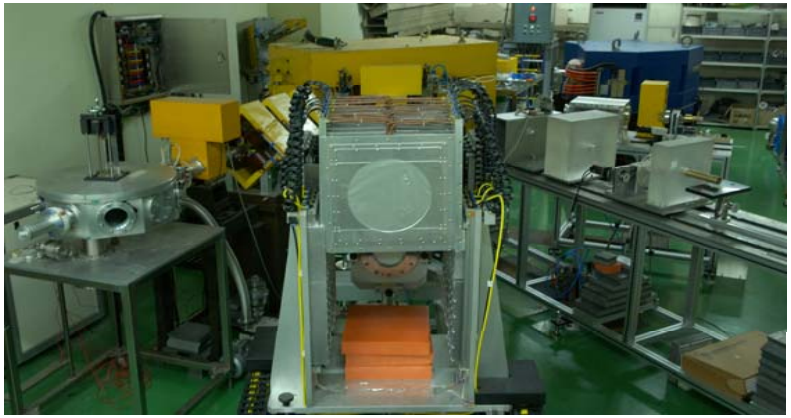


Biodegradable Plastic knife (Polyhydroxyalkanoate)

Proton Beam and Medical Application (KIRAMS)

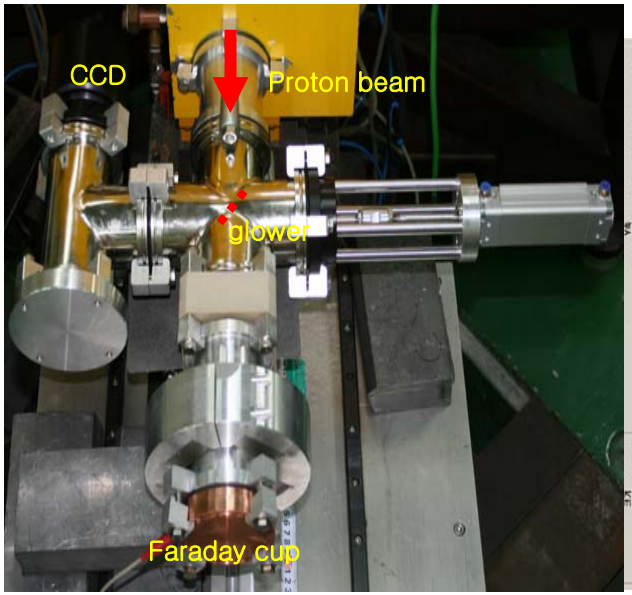
PEFP Proton Engineering Frontier Project

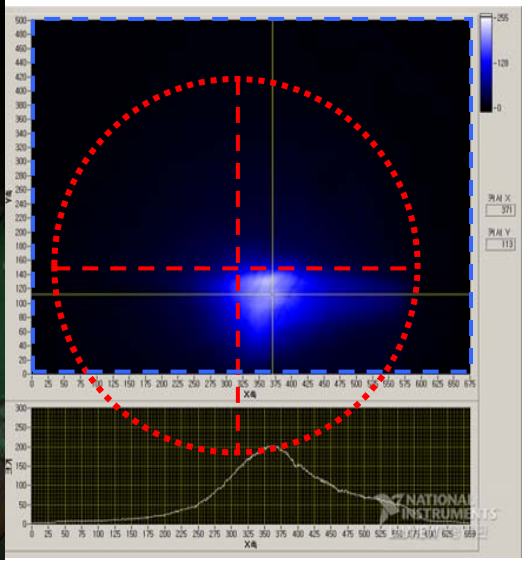
- Low energy proton therapy system is very useful for treatment of eye melanoma and age-related macular degeneration and basic research of proton therapy technology development.
- LEPT system using 70~100 MeV proton beam will be developed in this project.
- Prototype beam line was developed and installed a the MC-50 cyclotron at KIRAM.





Low energy proton therapy system



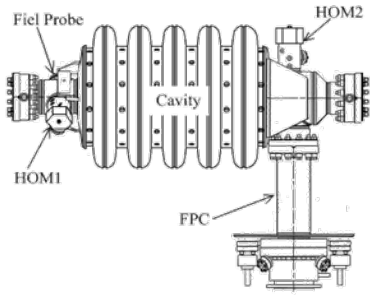


Beam Profile monitoring system

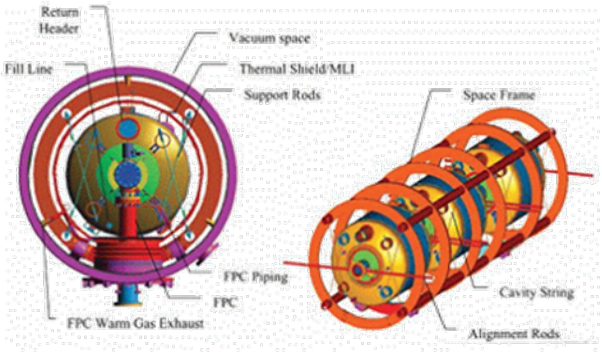
Superconducting RF Linac R&D Activities for the Future (I)

PEFP Proton Engineering Frontier Project

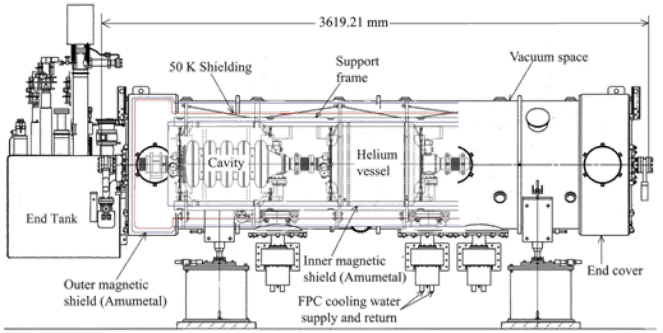
- β=0.42, RF: 700 MHz SC Cavity, RF coupler, Tuner, Vacuum Vessel, Helium
- Fabricated & tested a Copper Cavity (warm module)



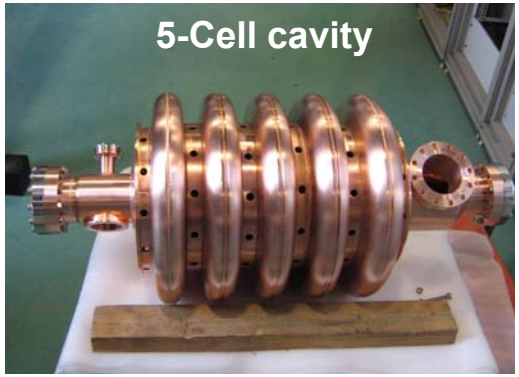
5-cell cavity with fundamental coupler

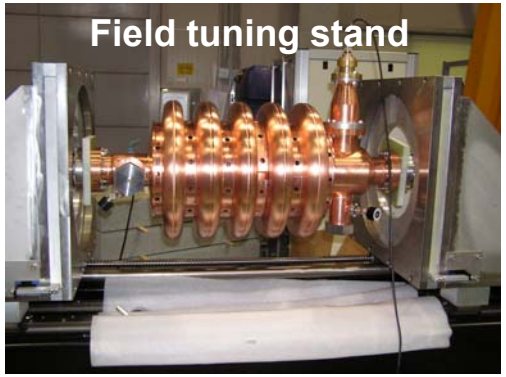


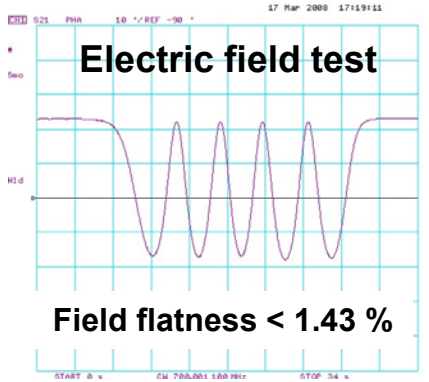
Thermal insulator



Designed SRF module







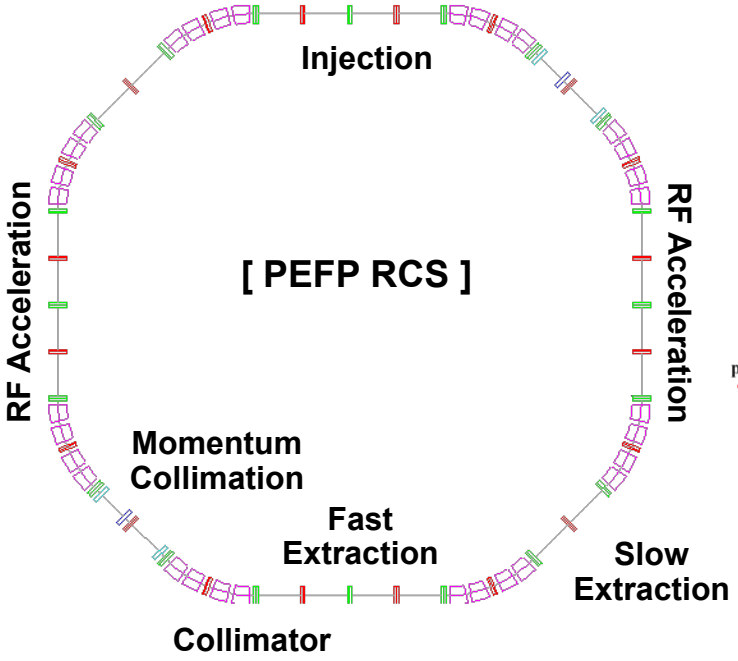
Rapid Cycling Synchrotron R&D Activities for the Future (II)

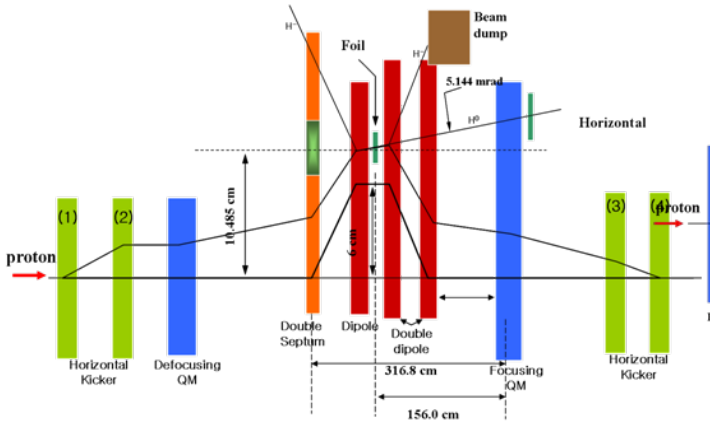
PEFP Proton Engineering Frontier Project

- **Injector: 100/200 MeV Linac**
- **Injection type: charge exchange**
- **Extraction type: fast & slow**
- **Energy: 1 / 2 GeV**
- **Super-period: 4 (20 cells)**
- **Circumference: 224 m**
- **Power supply type: resonant**

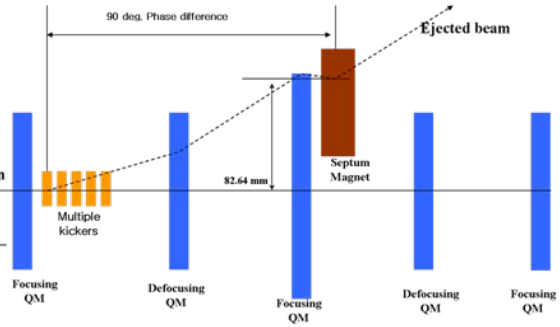
Upgrade Path

Stage	*Injection [GeV]*	*Extraction [GeV]*	*Repetition Rate [Hz]*	*RF voltage [KV]*	*Beam 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*





[Injection system]



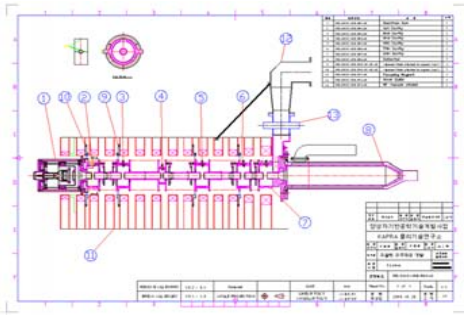
[Extraction system]

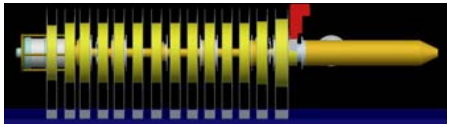
High Power RF Source – MW Klystron R&D Activities for the Future (III) KAPRA

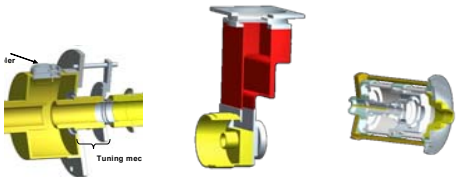
PEFP Proton Engineering Frontier Project

- **Successfully Developed a 700 MHz, 1 MW (CW) Klystron (prototype)**
- **Established full scale process from design to test, and infrastructures such as test stand, Baking Furnace, etc.**
- **A company (EM-TECH) was established in July, 2008 for klystron production.**

Design & Fabrication



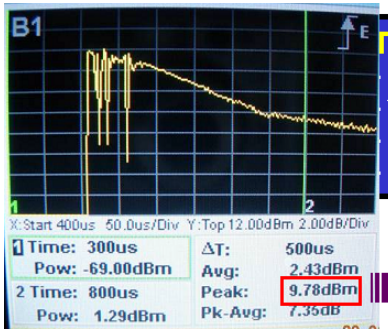




Test Stand



Performance Test Result



Test Condition
- Input Voltage : -95 kV
- Vacuum Pressure : 2.5E-8 Torr
- Input Frequency : 700 MHz
- Input RF Power : 30 W

Measured Output Power : 89.78dBm (950kW)

Established Infrastructures (@ KAPRA)





Summary

PEFP Proton Engineering Frontier Project

- 20 MeV Proton Linac : completed & achieved designed beam energy & current
- Gyeongju city was selected as the project site.
- Civil construction is scheduled to the end of this year.
- To complete 100 MeV Linac & Beamlines in March 2012.
- Beam utilization program before completing linac construction is a main characteristic of PEFP. It should be an essential element for the linac development project to be successful.
- R&D for future extension: SRF, RCS, and Klystron.