Proton Engineering Frontier Project

OECD Nuclear Energy Agency

Fifth International Workshop on the Utilisation and Reliability of High Power Proton Accelerators (HPPA5)

(6-9 May 2007, Mol, Belgium)

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Proton Engineering Frontier Project
양 성 자 기 반 공 학 기 술 개 발 사 업 단

Project Goals of PEFP

PEFP Proton Engineering Frontier Project

- Project Name : Proton Engineering Frontier Project (PEFP)
  21C Frontier Project, Ministry of Science and Technology

- Project Goals :

  1st : Developing & constructing an 100MeV proton linear accelerator with high duty

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

  3rd : Promoting industrial applications with developed technologies

- Project Period : 2002.7 – 2012.3 (10 years)

- Project Cost : 128.6 B Won (130M$)
  (Gyoungju City provides **the land & the supporting facilities)**

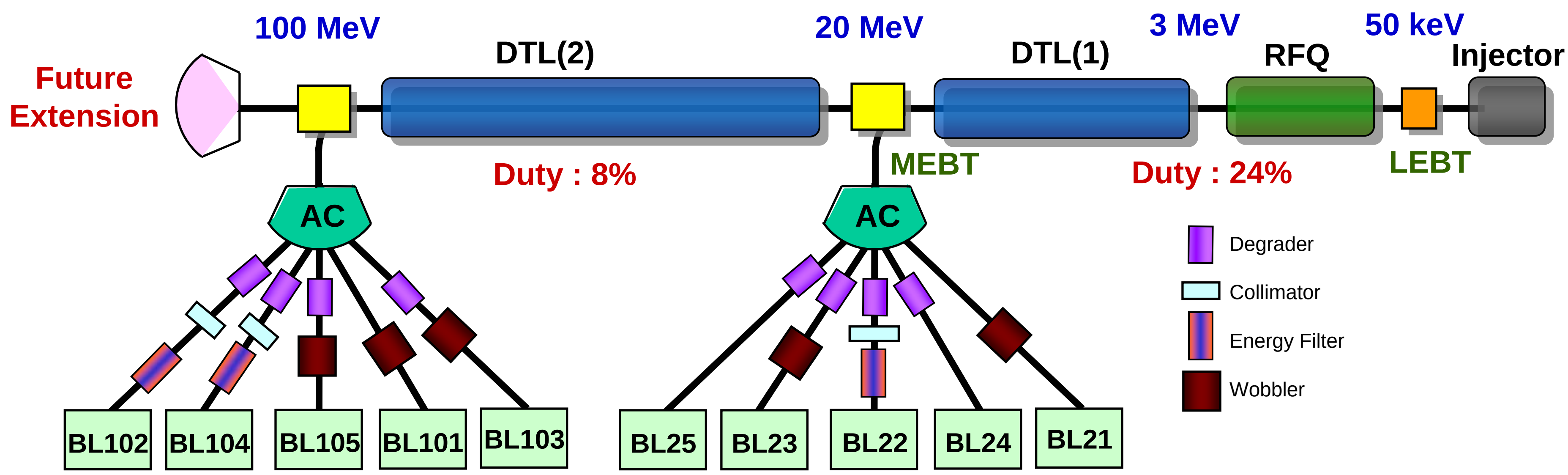
Basic Accelerator Parameters

PEFP Proton Engineering Frontier Project

▪ Particle	:	Proton
▪ Beam Energy	:	20 MeV / 100MeV
▪ Operational Mode	:	Pulsed
▪ Max. Peak Current	:	20 mA
▪ RF Frequency	:	350 MHz
▪ Repetition Rate	:	Max. 120Hz(20MeV) / 60Hz(100MeV)
▪ Pulse Width	:	Max. 2.0ms(20MeV) / 1.33ms(100MeV)
▪ Max. Beam Duty	:	Max. 24%(20MeV) / 8%(100MeV)

* High Duty Factor is a key issue.

PEFP Accelerator Layout



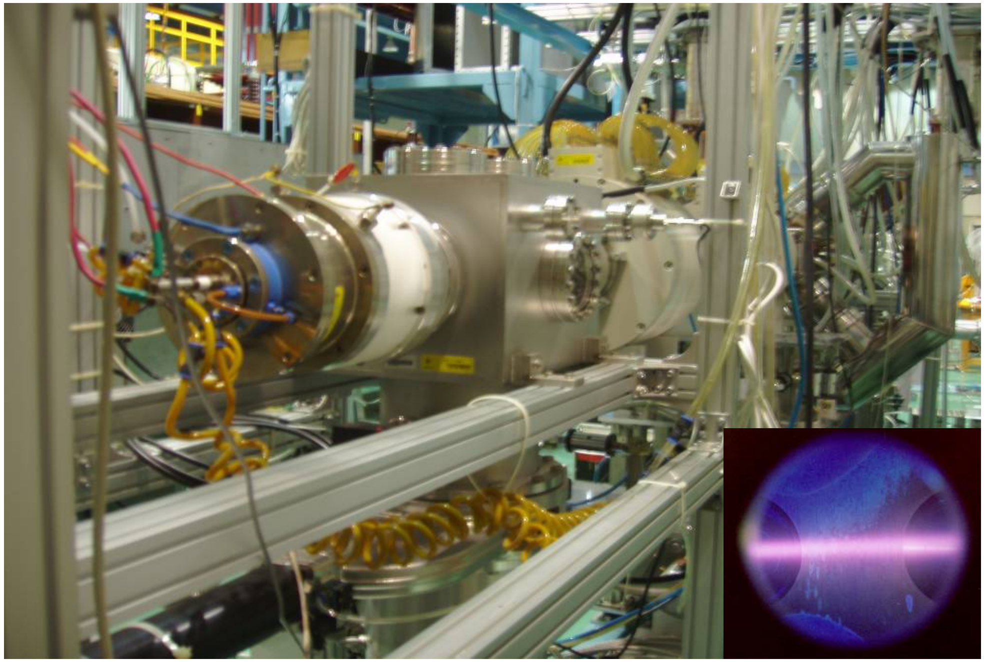
- 102 : ST, BT
- 104 : LEPT, Medical Application
- 105 : Neutron Science
- 101 : RI
- 103 : Material Science

- 25 : Material Science, Industrial Application
- 23 : IT, Semiconductor
- 22 : BT/ST, Medical Application
- 24 : Neutron Science
- 21 : RI

- The PEFP Accelerator composes of 50keV Proton Injector, 3MeV RFQ and 100MeV DTL.
- It can extract protons at 20MeV and 100MeV.
- AC magnets to distribute beams for each beam line simultaneously.

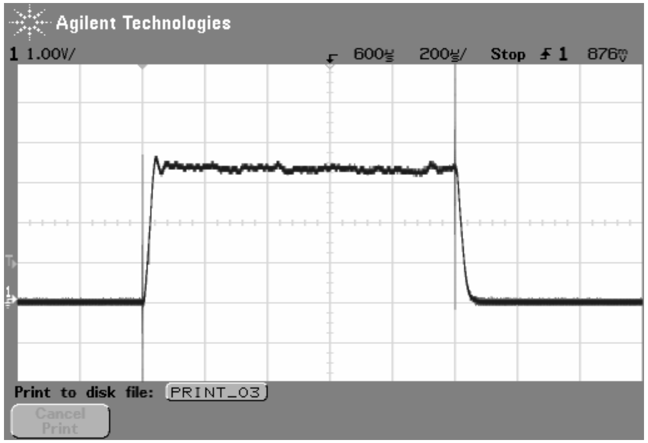
Proton Injector

PEFP Proton Engineering Frontier Project

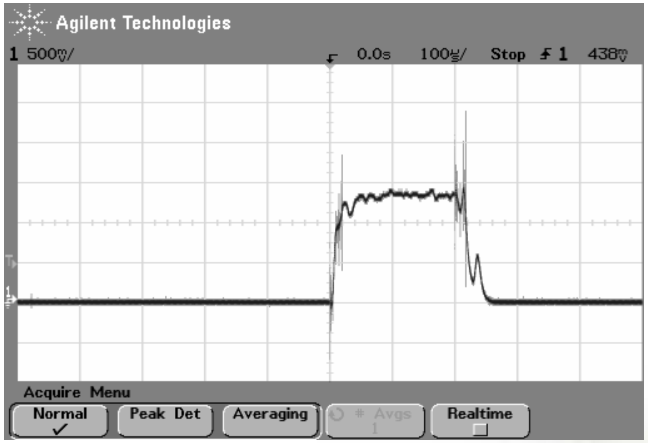


- Duoplasmatron ion source
- Max. Beam current : DC 40 mA H^+ at 50kV
- Normalized emittance : 0.2 π mm mrad (90%)
- Proton fraction : >80%
- Operation Mode : DC & Pulse (50us ~ 2ms)
- Filament Lifetime (40mA) : 40hrs
- No trip during the filament lifetime : Reliable

1ms Beam



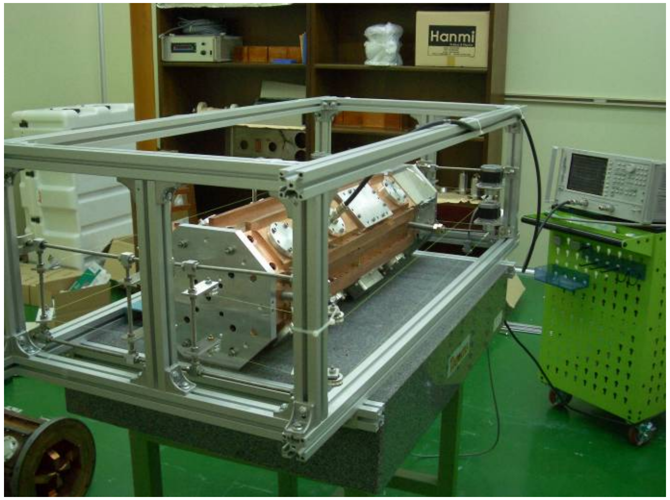
200us Beam



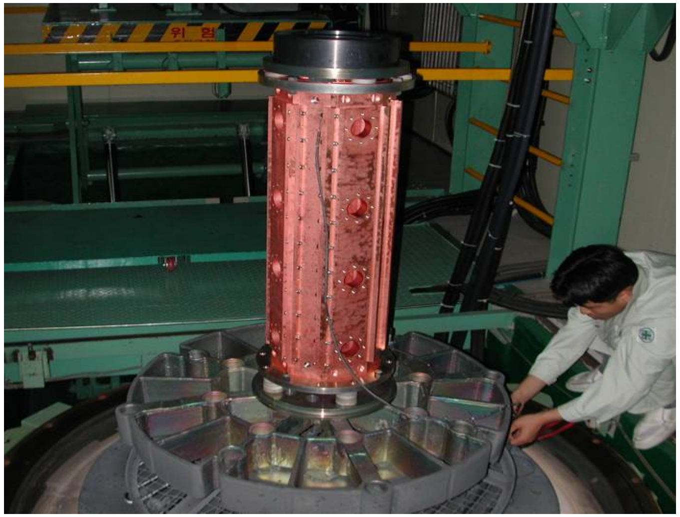
Pulse Beam Extraction With HV switch

RFQ Fabrication Technology

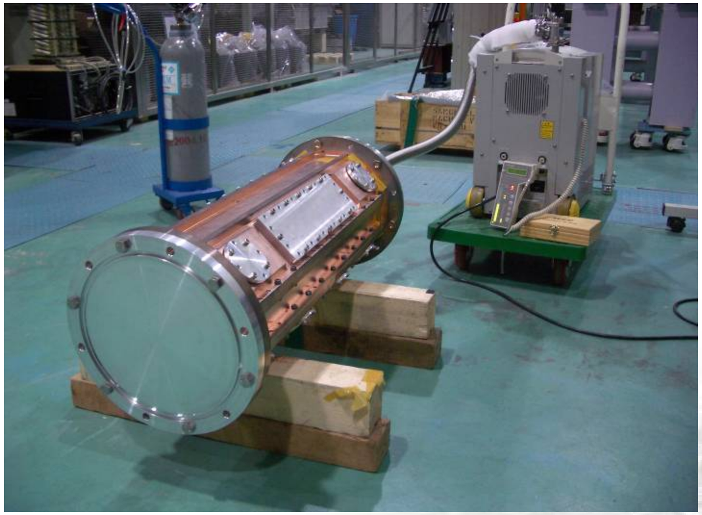
Vane machining



Vane adjustment before Brazing



Brazing

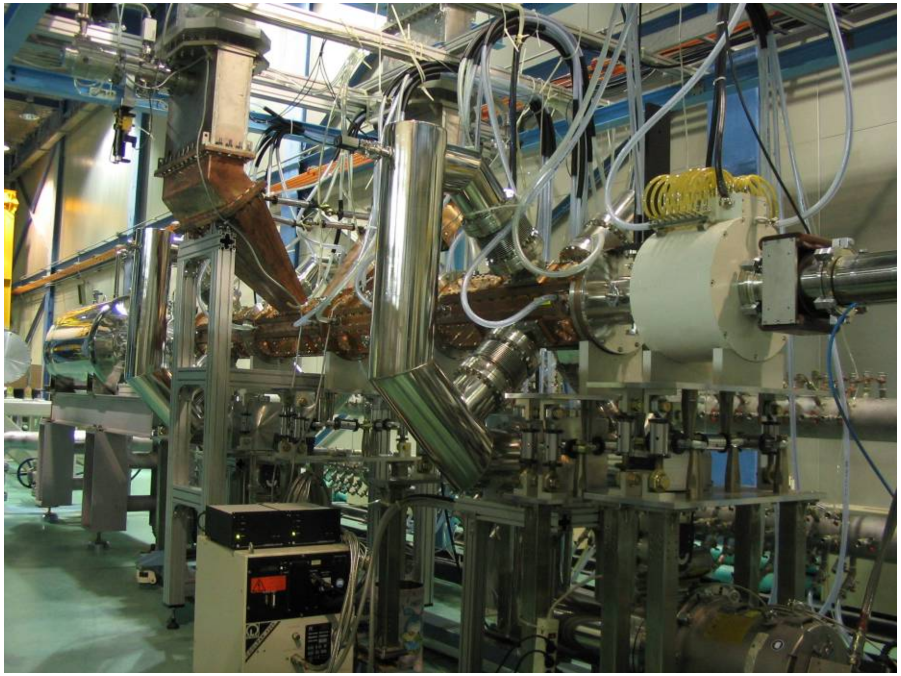


Leak test (< 1e-9torr.l/s)

3 MeV RFQ

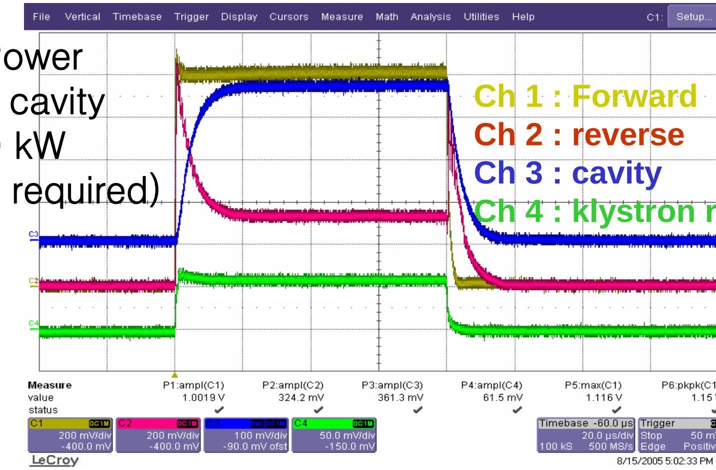
PEFP Proton Engineering Frontier Project

❑ Set up for Test of RFQ

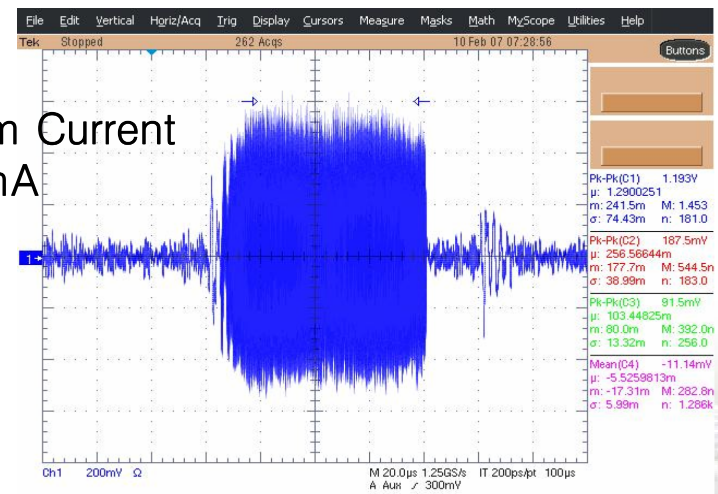


❑ Results of the RF & Beam test

RF Power
inside cavity
440 kW
(110% of required)



Peak Beam Current
5 mA

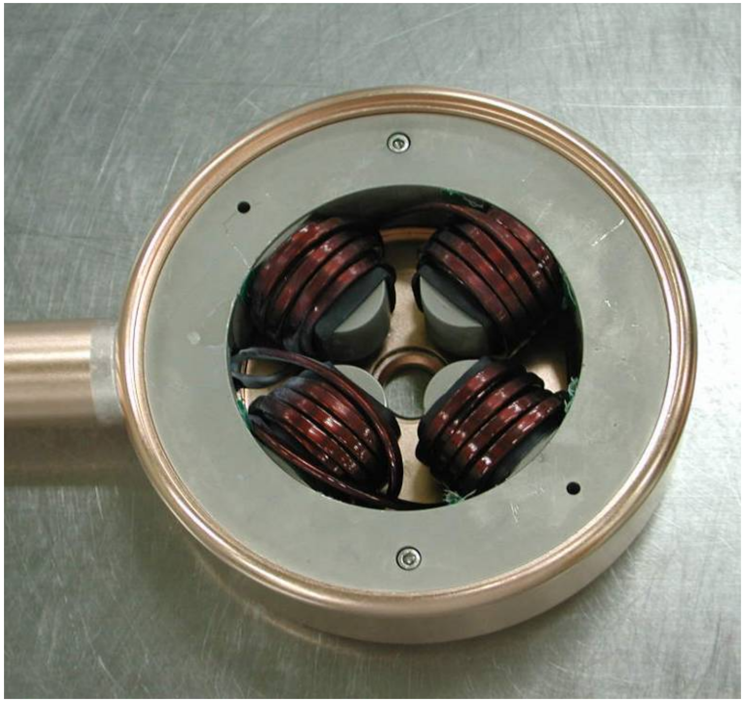


Cavity field and Beam current signal

- RFQ have been fabricated and tuned.
- Peak Power RF test has been done.
- Beam test with limited current has been done to check basic design parameters.

EQM of the Drift Tube

EQM for 20MeV DTL



- Transformer wire
- Pool type cooling
- Compact
- Need assessment of long term reliability

EQM for 20~100MeV DTL

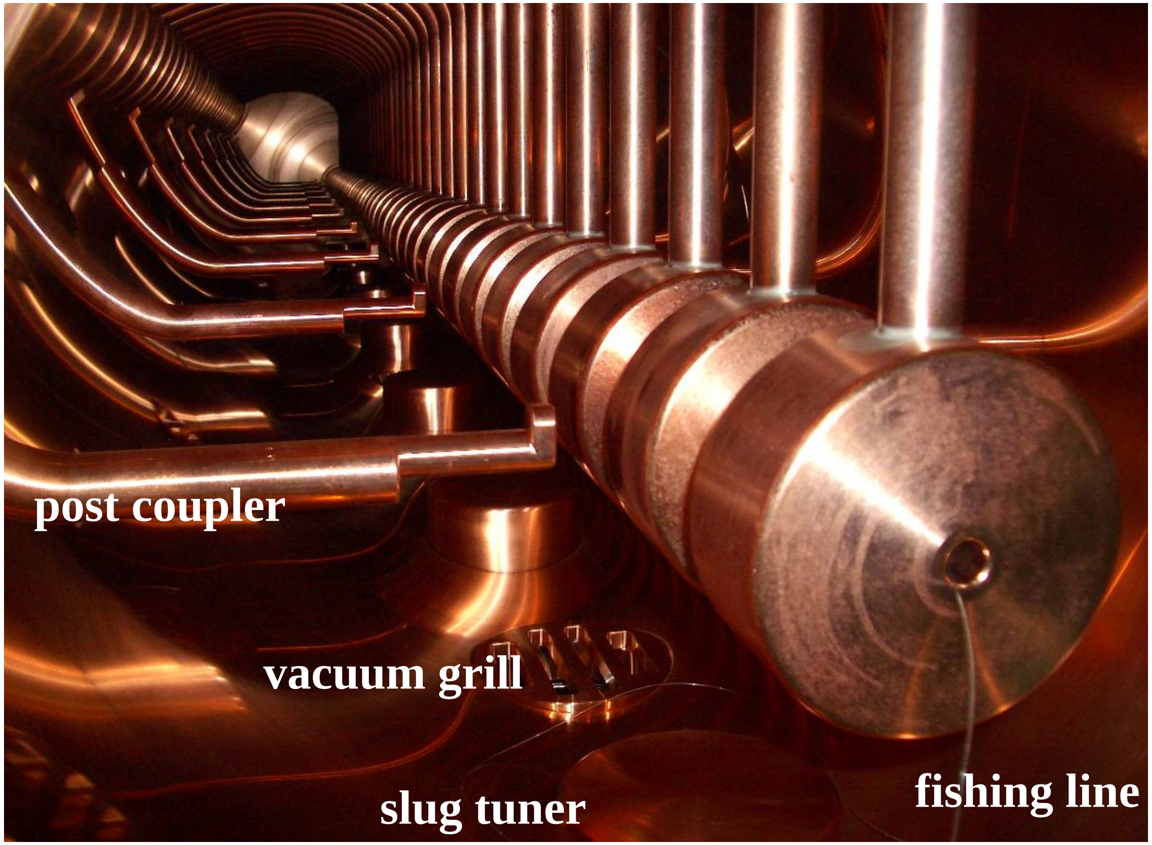
- Hollow Conductor
- Larger volume than pool type
- Well proven technology

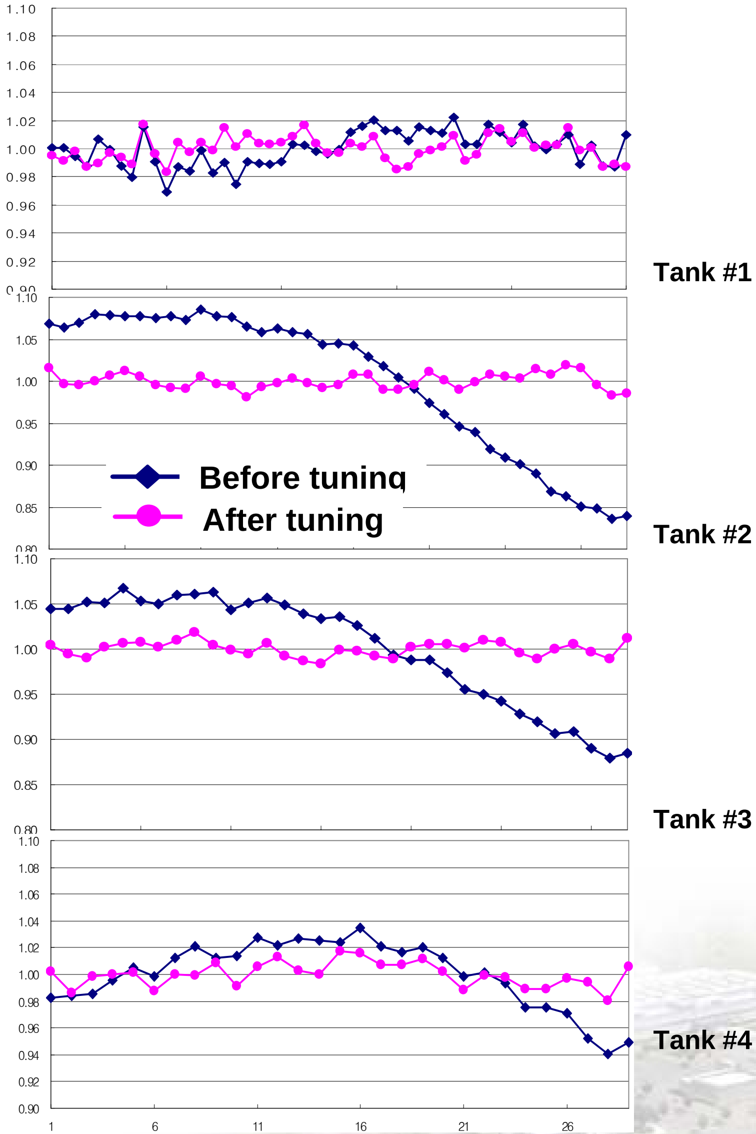
20MeV DTL Tuning

- **Frequency : 350MHz ±5kHz ,**
- **Field : design value ± < 2 %**

-Tilt sensitivity : < 100%/MHz

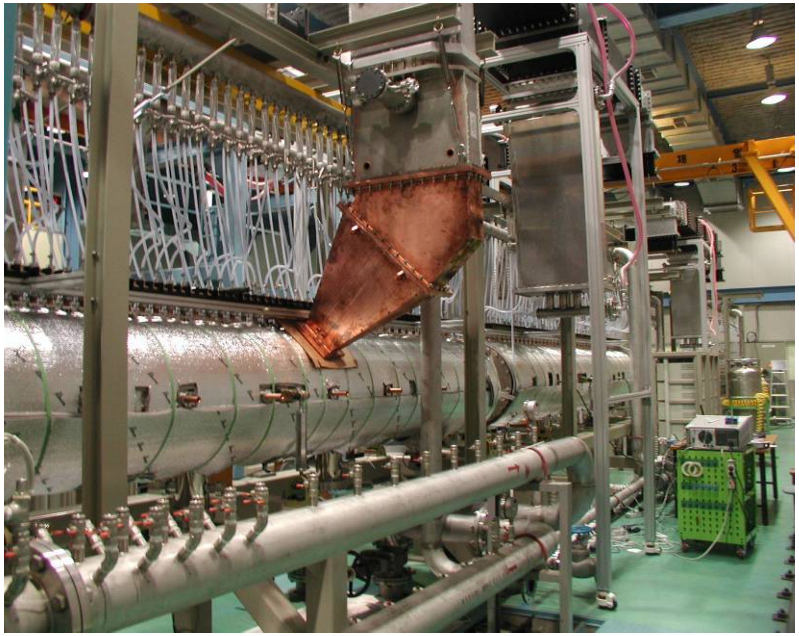
: Bead Pull Measurement





20 MeV DTL

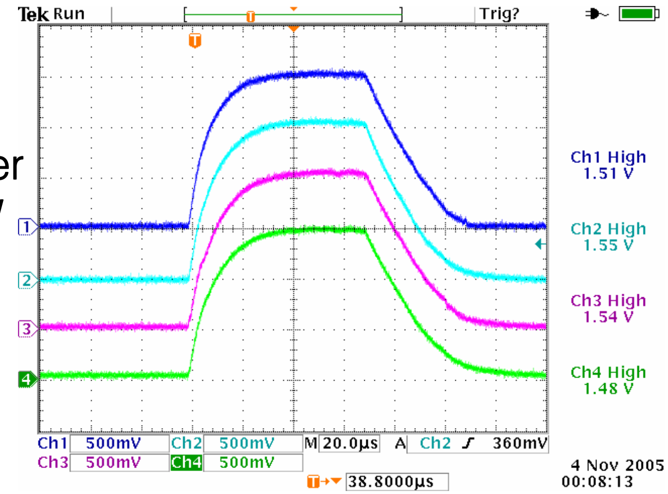
❑ Set up for Test of DTL



- DTL has been fabricated and tuned.
- Peak Power RF test has been done successfully.
- Beam test with limited current has been done (20MeV, 2mA peak at 50us, 0.1Hz)
- Beam Transmission is ~100%.

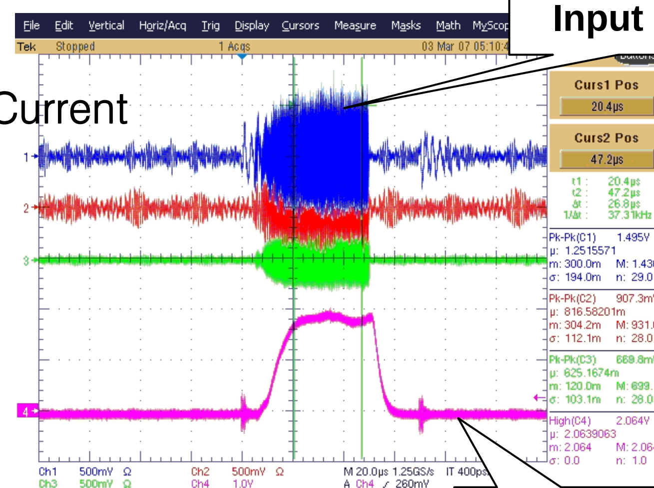
❑ Results of the RF & Beam test

RF Power 600 kW



Peak Beam Current 2 mA

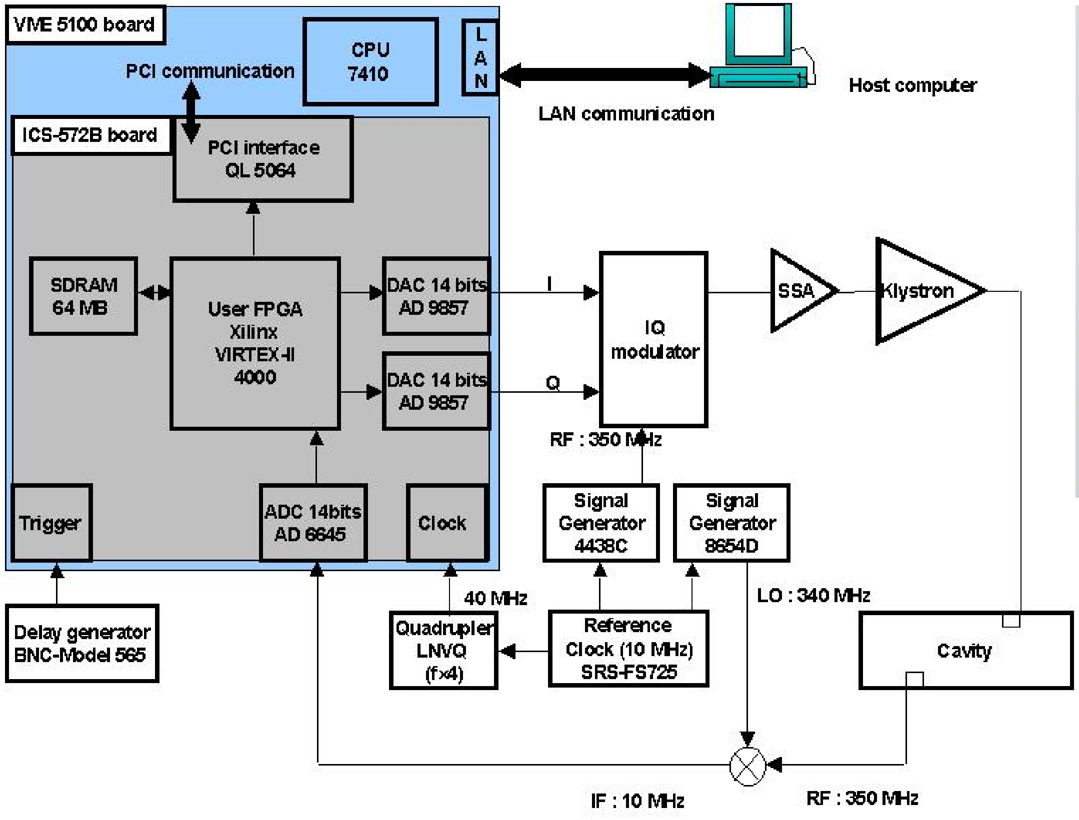
Input (CT)



Output (Faraday)

Digital LLRF Development

- LLRF requirement : RF amplitude < 1%, RF phase < 1 degree
- Control system : Digital - FPGA PMC board hosted in VME PowerPC board
- Control algorithm : Feedback (Proportional+Integral) + Feedforward (Implemented in VHDL)



MVME5100 Carrier Board

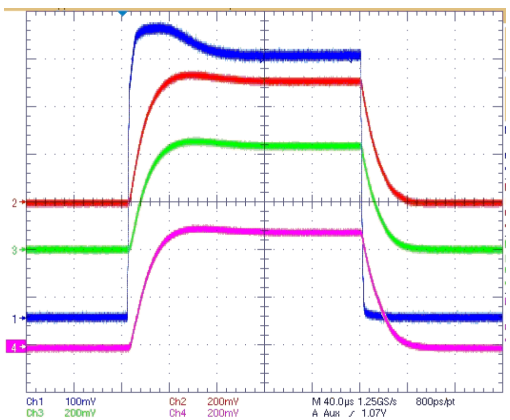
<u>ICS572B Commercial FPGA Board</u>

- Six SMA IO port
  - 2 ADC, 2 DAC, 1 Clock and 1 Trigger
- On board storage
  - 64 Mbytes of SDRAM
  - 8 Mbytes of QDR-II SRAM
- On board FPGA
  - Xilinx Virtex-II model
  - XC2V4000, 4million system gates

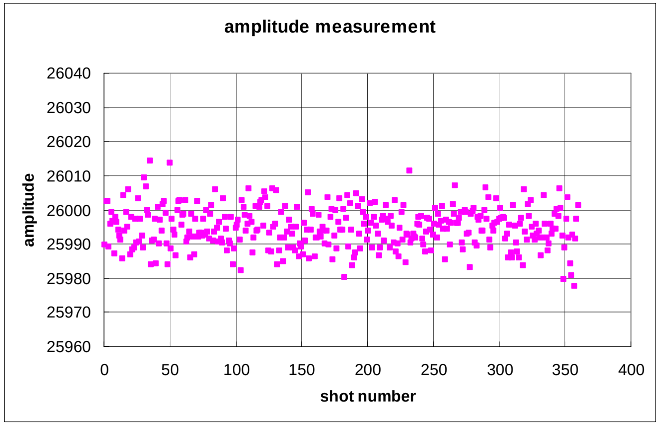
LLRF Test Results

PEFP Proton Engineering Frontier Project

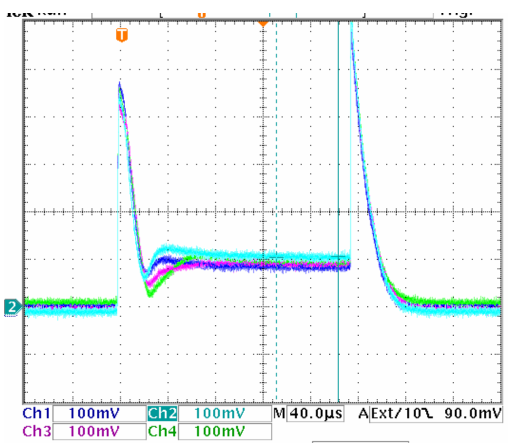
- RF pulse width / repetition rate / peak power : 200μs / 0.1 Hz / ~ 150 kW per tank
- Control gain value (I set / Q set / Pgain / I gain) : 26,000 / 0 / 1.0 / 70,000
- RF stability (error in amplitude / error in phase) : < 0.08% / 0.12 degree



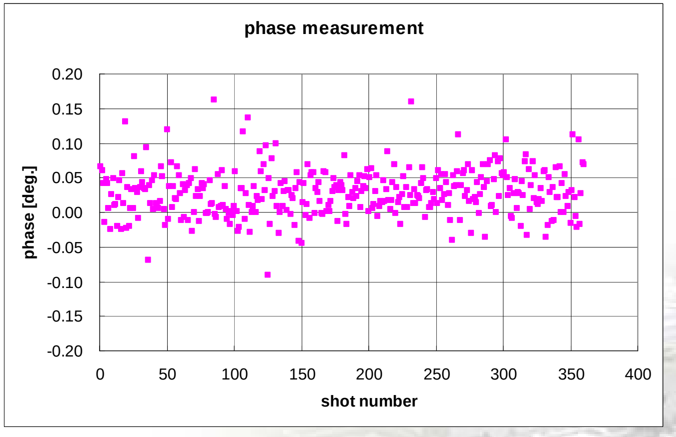
RF power profile
150 kW / tank
ch1 : klystron forward,
ch2 : tank1,
ch3 : tank2,
ch4 : tank3



Pulse to pulse RF amplitude variation



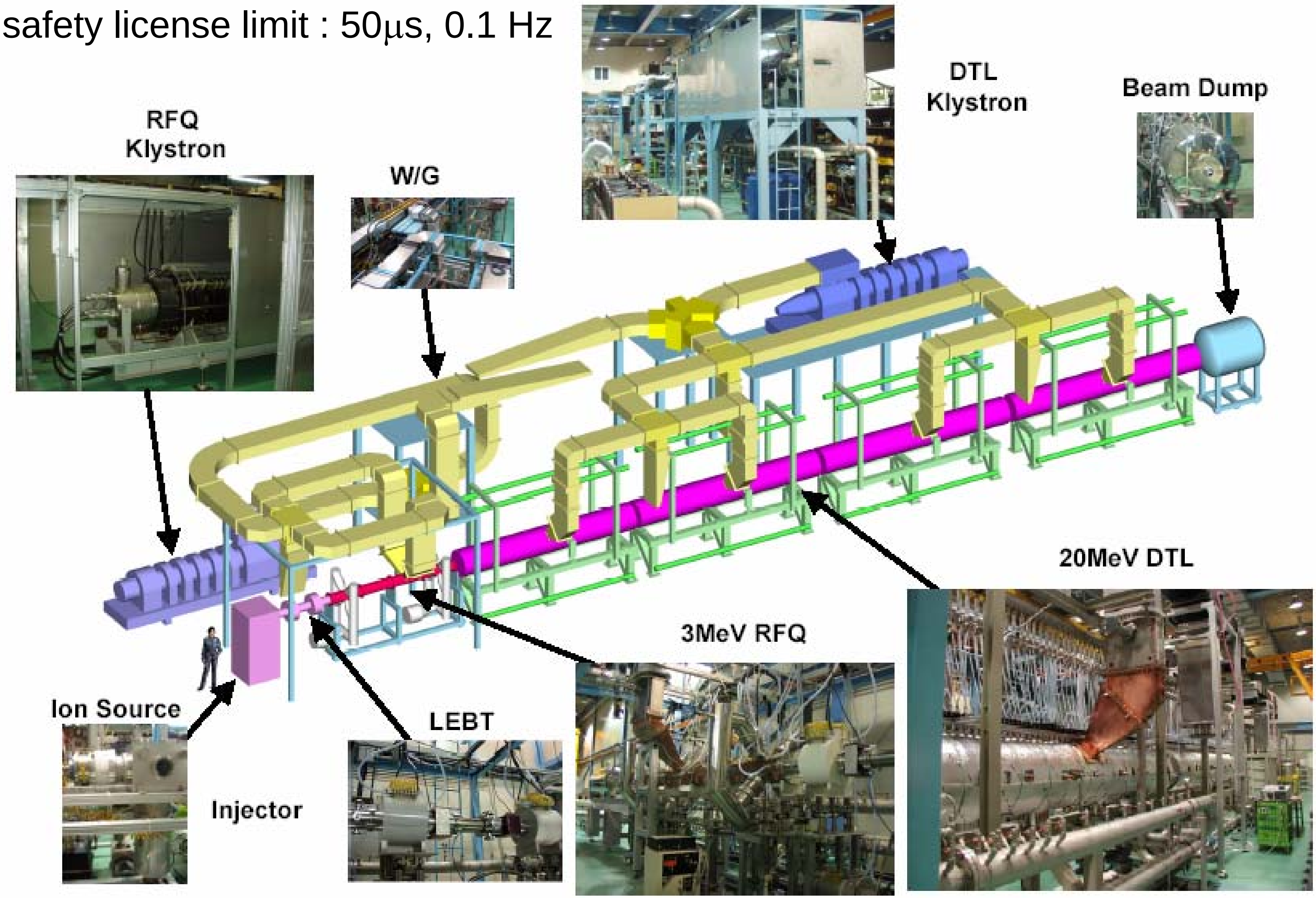
Reflected RF power profile
150 kW / tank
ch1 : tank1,
ch2 : tank2,
ch3 : tank3,
ch4 : tank4)
Over-coupling due to
beam loading (coupling beta : 1.6)



Pulse to pulse RF phase variation

PEFP 20 MeV Proton Linac in Daejeon

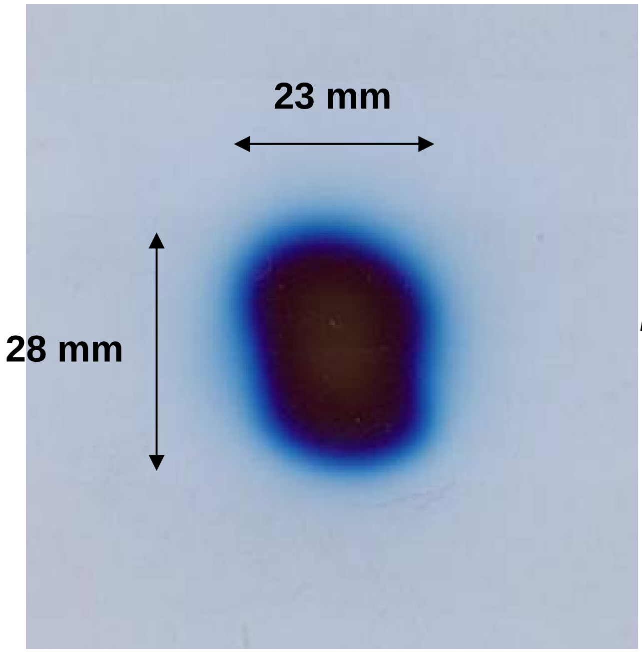
Radiation safety license limit : 50μs, 0.1 Hz



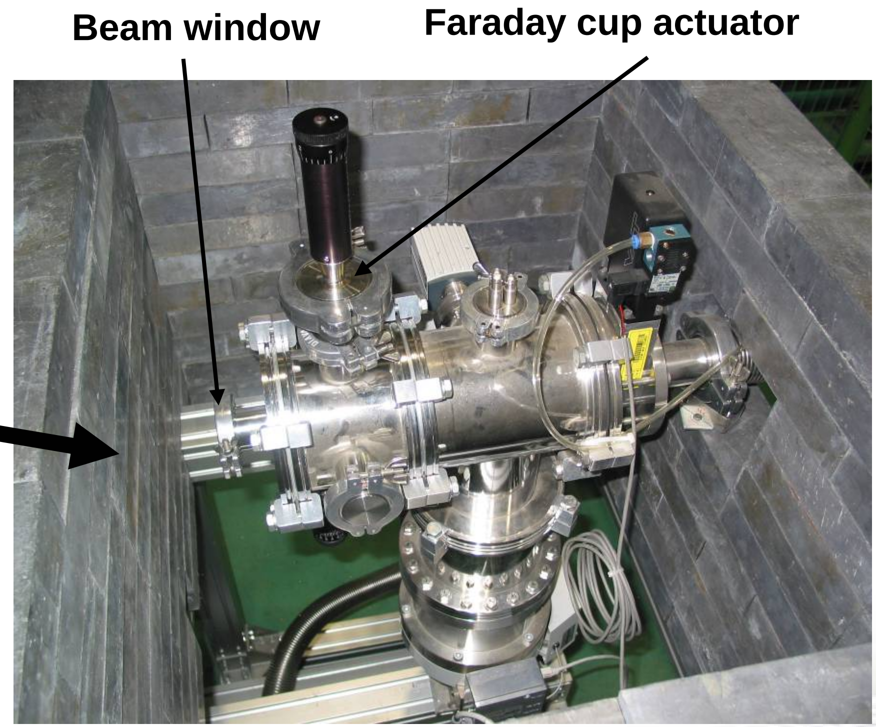
20 MeV beam extraction into air for users

- Beam window : 0.5 mm aluminum
- Beam energy / average current : 20 MeV / 15 nA (3mA peak, 50μs, 0.1 Hz) (radiation safety license limit)
- Dose per beam pulse measured by using ion chamber : 62.24 Gy / pulse

: The beam will be supplied to users for their beam applications.



Beam profile at 85 mm apart from the beam window (MD55- Gafchromic film)

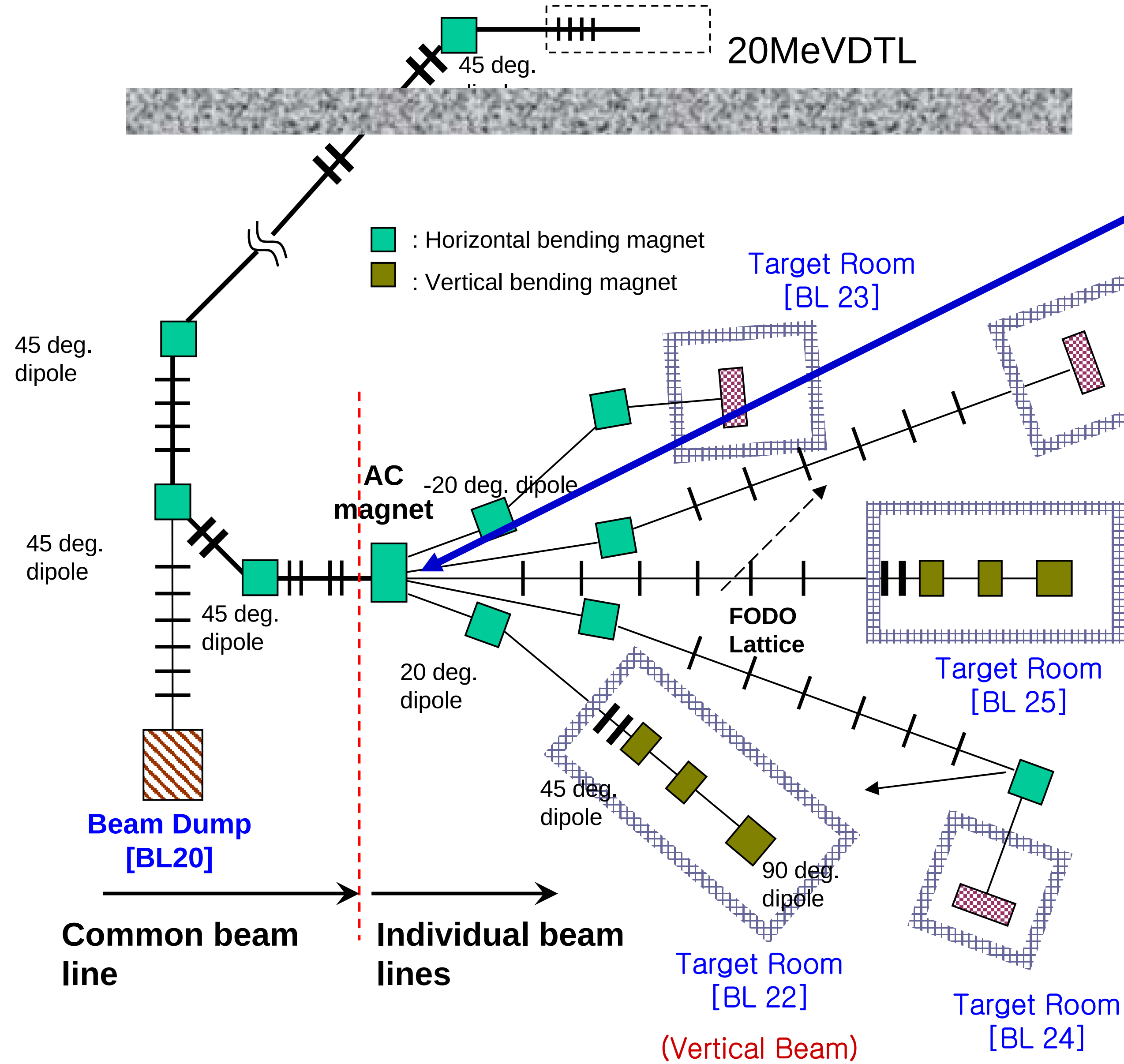


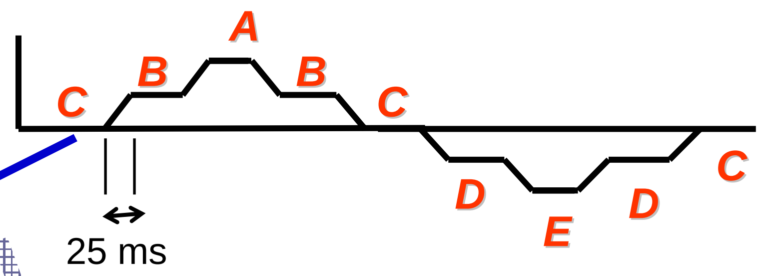
Beam dump with beam extraction window located at the end of the DTL

20 MeV Beam Lines for User Facilities

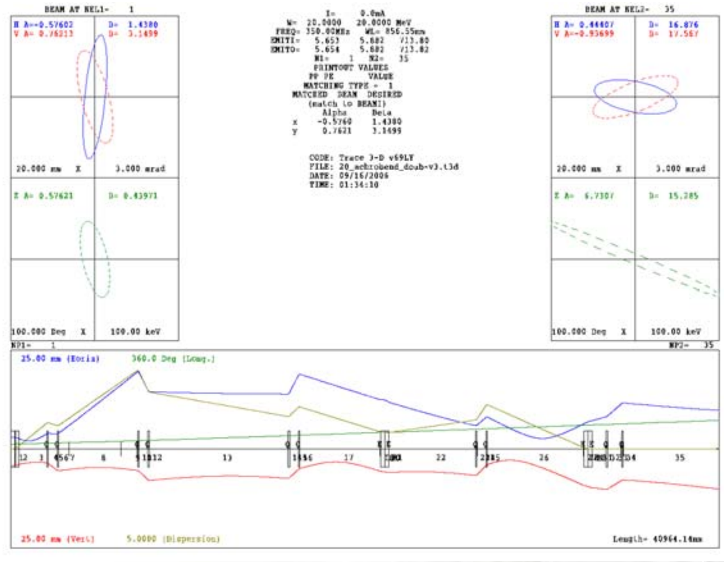
Beam Line	Energy	Avg. Current	Irrad. Condition	Max. Irrad. Dia.	Application Field
BL20	20 MeV	~4.8 mA	Horizontal Vacuum	–	– Beam Dump – Material Test – with High Current Beam
BL21	20 MeV	120 μA ~1.2 mA	Horizontal Vacuum	100mm	– RI Production
BL22	3~20 MeV	10 nA ~60 μA	Vertical External	300mm	– BT, ST – Detector Test – Space Radiation Effect – Liquid, Powder Sample Available
BL23	3~20 MeV	60 μA ~1.2 mA	Horizontal External	300mm	– Power Semi. Device Development – Semiconductor Application
BL24	20 MeV	120 μA ~1.2 mA	Horizontal Vacuum	100mm	– BNCT – Low Energy Neutron Source
BL25	20 MeV	120 μA ~1.2 mA	Horizontal Vacuum	300mm	– Industrial Application for Mass Production

Layout of the 20 MeV Beam Lines





◈ *Programmable Power Supply*



Beam Optics of TR 25

100 MeV Beam Lines for User Facilities

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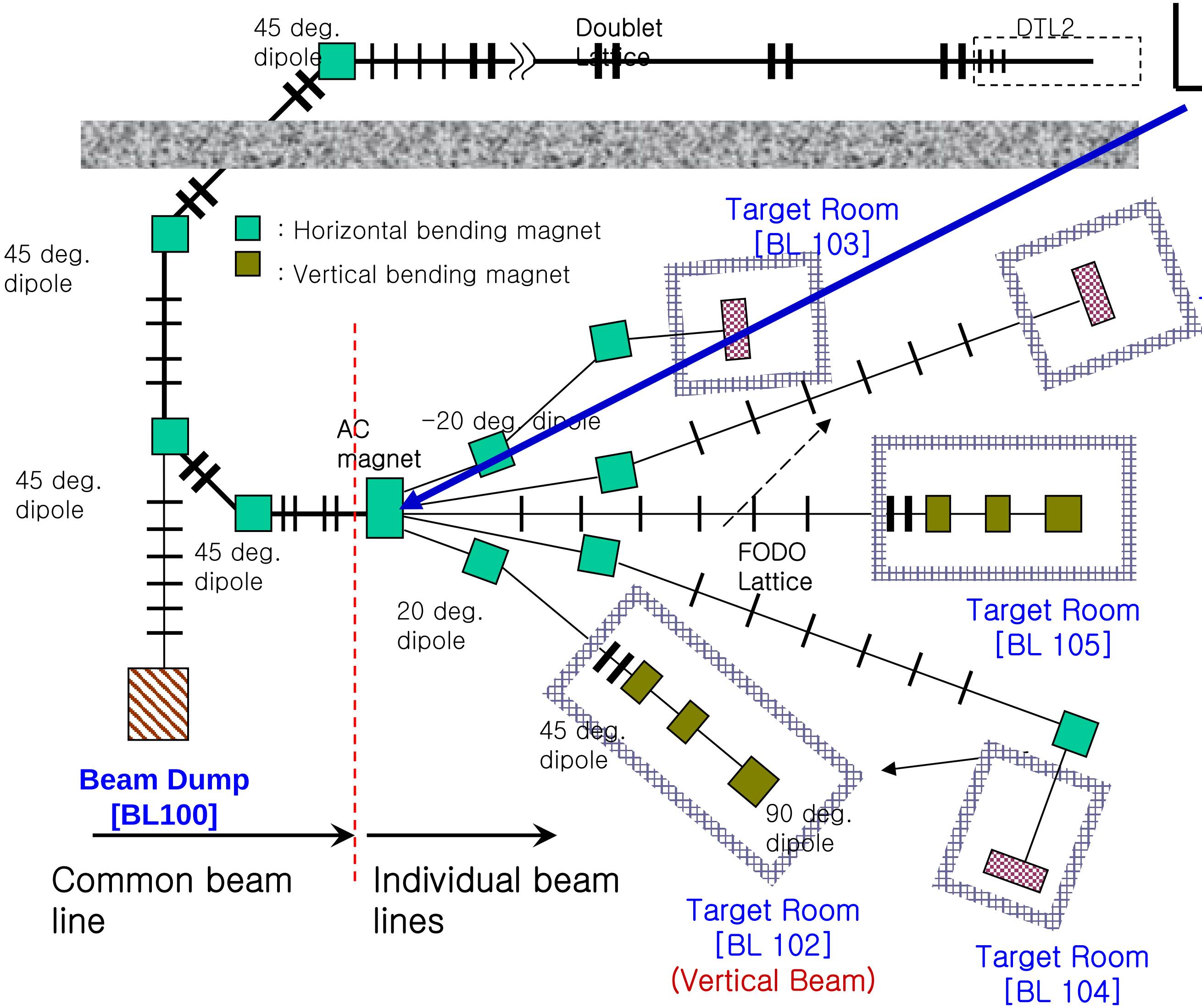
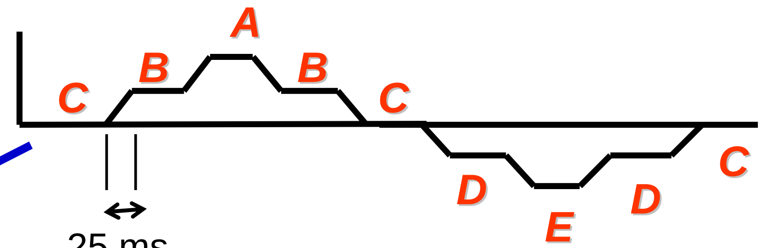
Beam Line	Energy	Avg. Current	Irrad. Condition	Max. Irrad. Dia.	Application Field
BL100	100 MeV	~1.8 mA	Horizontal Vacuum	-	- Beam Dump - Material Test with High Current Beam
BL101	33,45,57, 69,80,92, 103 MeV	30~ 300 μA	Horizontal Vacuum	100mm	- RI Production
BL102	20~ 103 MeV	~10 μA (10 nA)	Vertical External	300mm	- BT, ST, Medical Application - Detector Test - Space Radiation Effect - Liquid, Powder Sample Available
BL103	20~ 103 MeV	30~ 300 μA	Horizontal External	300mm	- Industrial Application for Mass Production
BL104	20~ 103 MeV	10 nA ~10 μA	Horizontal External	300mm	- Low Energy Proton Therapy - Medical Applications - Pencil Beam Available
BL105	103 MeV	30~ 300 μA	Horizontal Vacuum	100mm	- Neutron Source - Nuclear Material Test - Nuclear Data Measurement

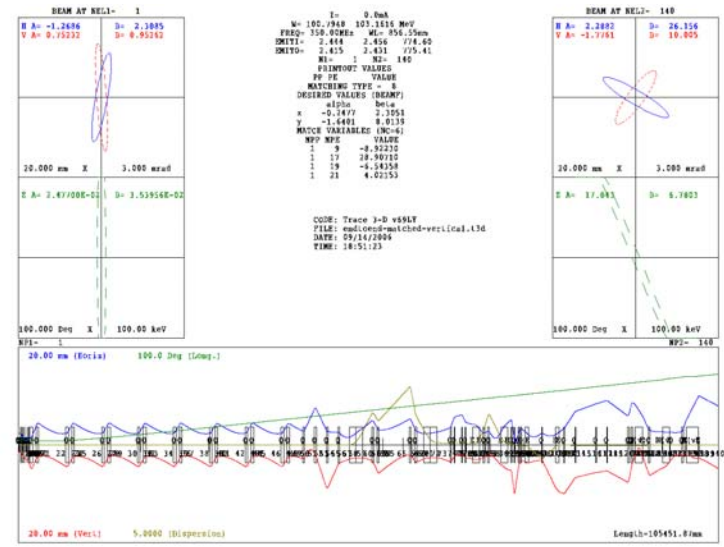
Layout of the 100 MeV Beam Lines

PEFP Proton Engineering Frontier Project





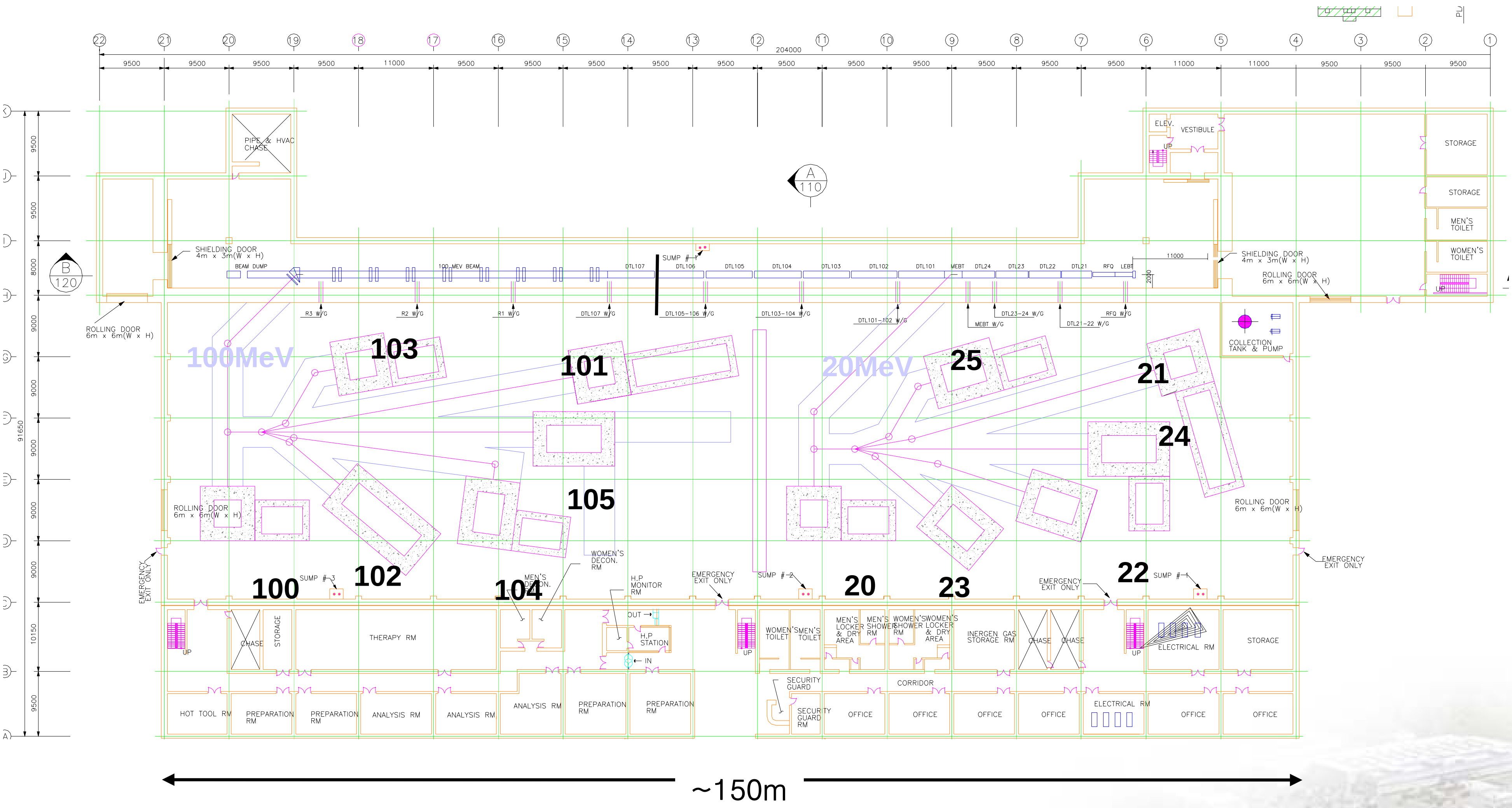
- Programmable Power Supply:



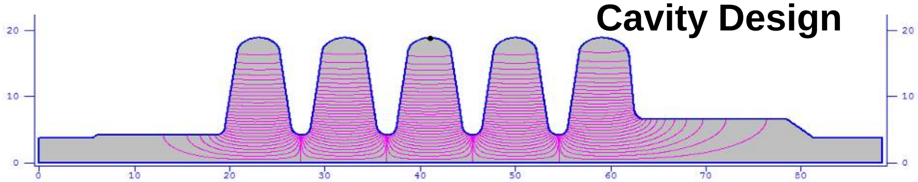
Beam Optics for BL102

Experimental Hall Layout

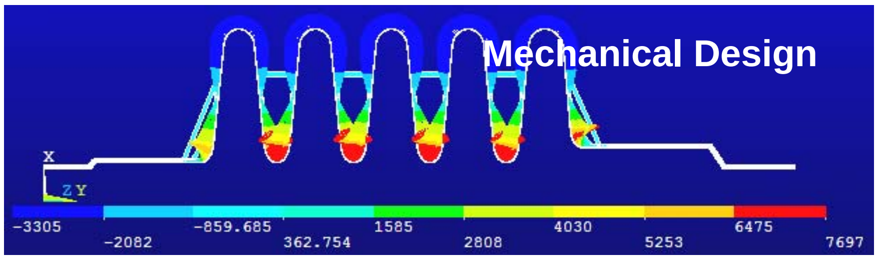
PEFP Proton Engineering Frontier Project

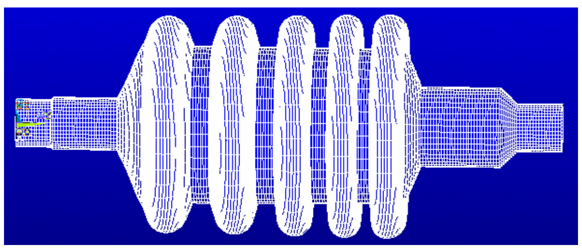


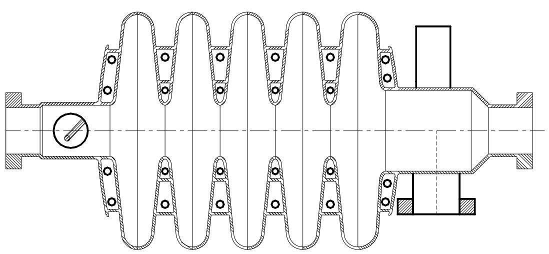
SL R&D for Future Extension



Cavity Design




Vibration Calculation

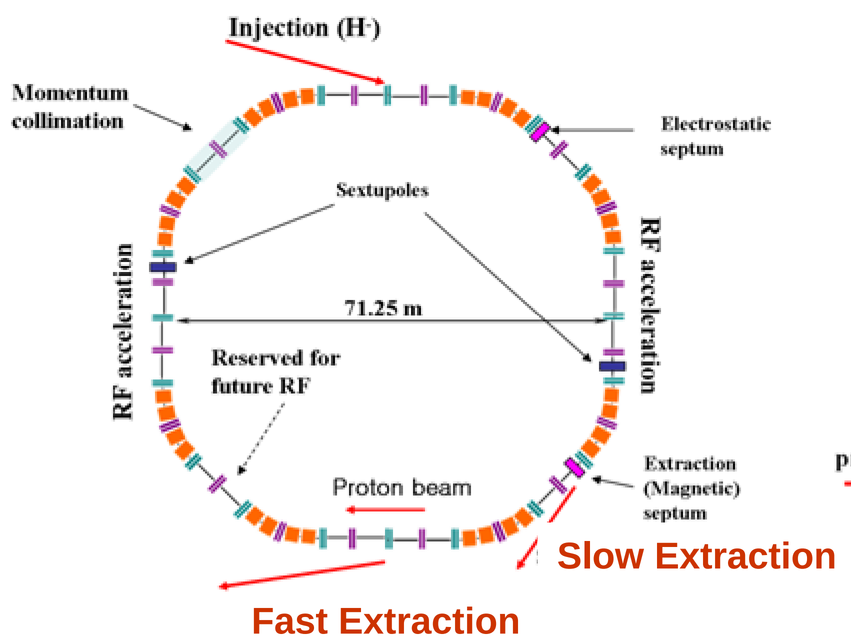

Cavity Design

- **Strategy**
  - **To do feasibility study for a low beta cavity**
  - **To develop basic technologies for SC linac for the future extension.**

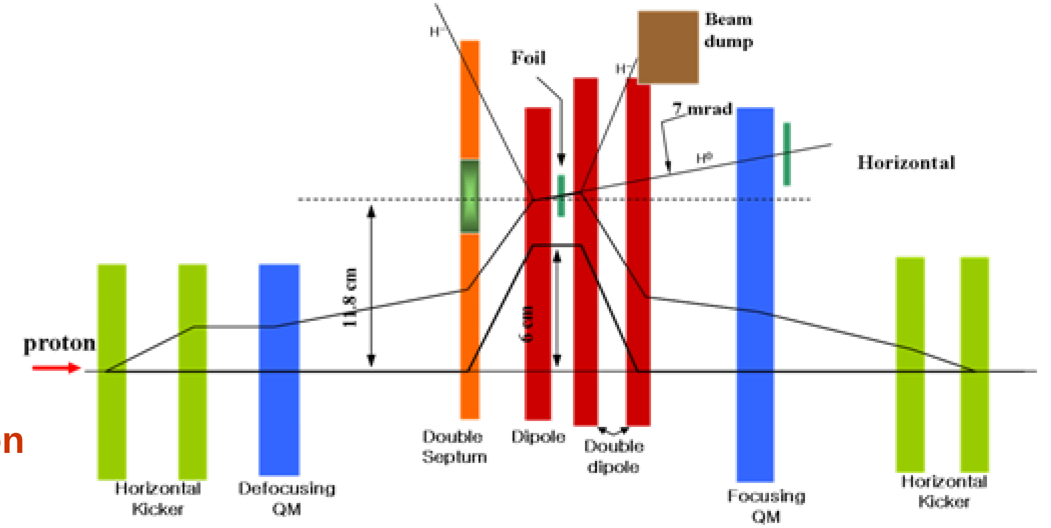
Ion type	Proton
Operation mode	Pulse
Injector frequency	350 MHz
Operation frequency	700 MHz
Beam current	20 mA *
Pulse length	1.3 ms *
Pulse repetition rate	60 Hz *
Energy range	80 MeV~140 MeV
Duty factor	8.0% *
SRF cavity geometrical beta	0.42

RCS R&D for Future Extension

- **Schematic layout of PEFP RCS**



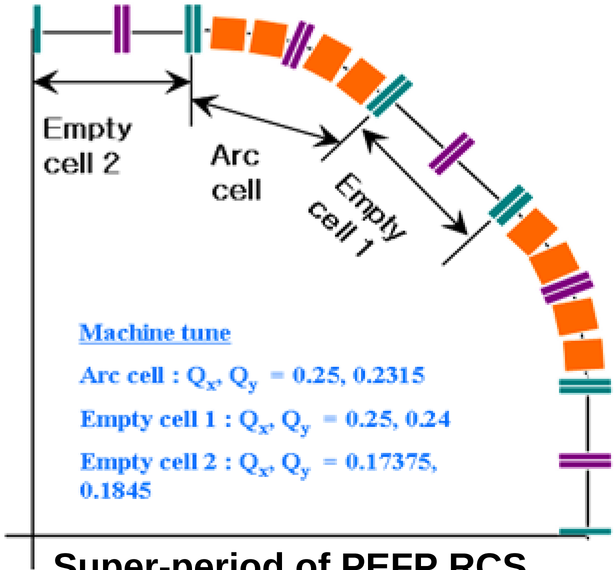
- **Strategy**
  - **Extension of the 100 (200) MeV linac**
  - **58 kW spallation neutron source in the first stage**
  - **Expand up to 900 kW through 5 stages**



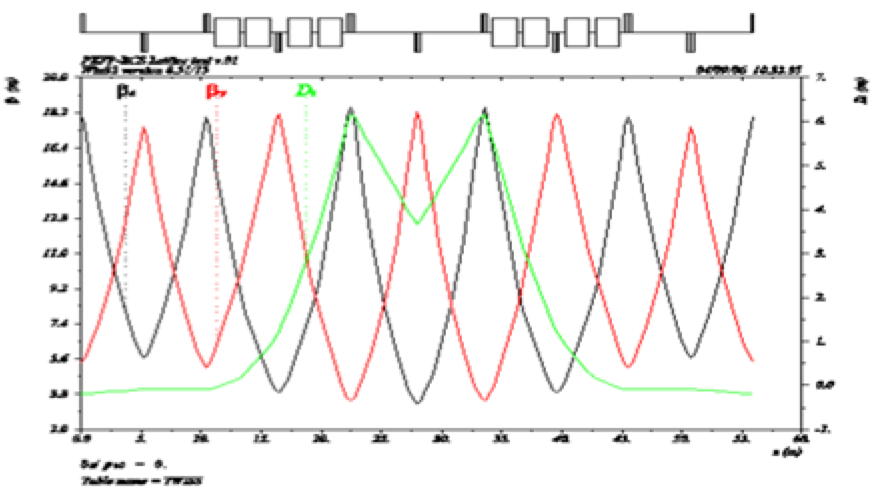
Conceptual design for Injection

Stage	*Injection [MeV]*	*Extraction [GeV]*	*Repetition Rate [Hz]*	*RF voltage [KV]*	*Beam Power [KW]*
Initial	*100*	*1*	*15*	*45*	*58*
Upgrade #1	*100*	*1*	*30*	*90*	*116*
Upgrade #2	*100*	*2*	*30*	*130*	*232*
Upgrade #3	*100*	*2*	*60*	*260*	*466*
Upgrade #4	*200*	*2*	*60*	*260*	*900*

RCS Lattice Study



Super-period of PEFP RCS

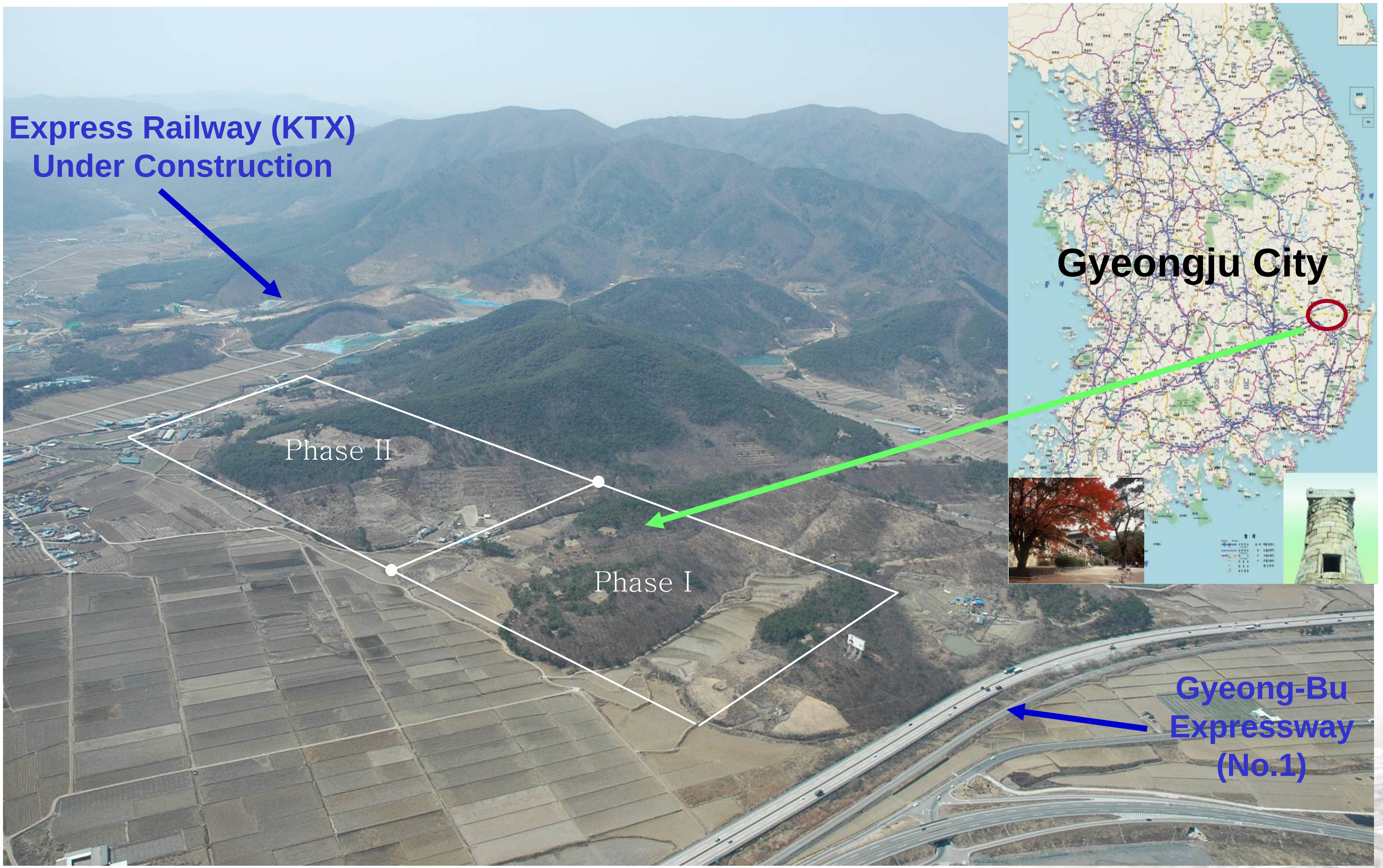


Lattice Function of Super-period

- **Basic parameters of PEFP RCS**

Beam power (kW)	*58 ~ 900*
Injection energy (GeV)	*0.1 ~ 0.2*
Injection type	*Charge Exchange*
Extraction type	*Fast & Slow*
Extraction energy (GeV)	*1 ~ 2*
Repetition rate [fast/slow] (Hz)	*15~30 ~ 60 / 1*
Circumference (m)	*223.824*
Number of cells	*20*
Lattice structure	*FODO*
Super-period	*4*
Tunes of Q_X / Q_Y	*4.39/4.29*
Transition gamma	*4.4*
Number of dipole	*32*
Dipole field at 1 GeV (T)	*0.56*
Power supply type	*Resonant*
RF harmonic number	*2*
Required RF voltage at 30 Hz	*90 kV*

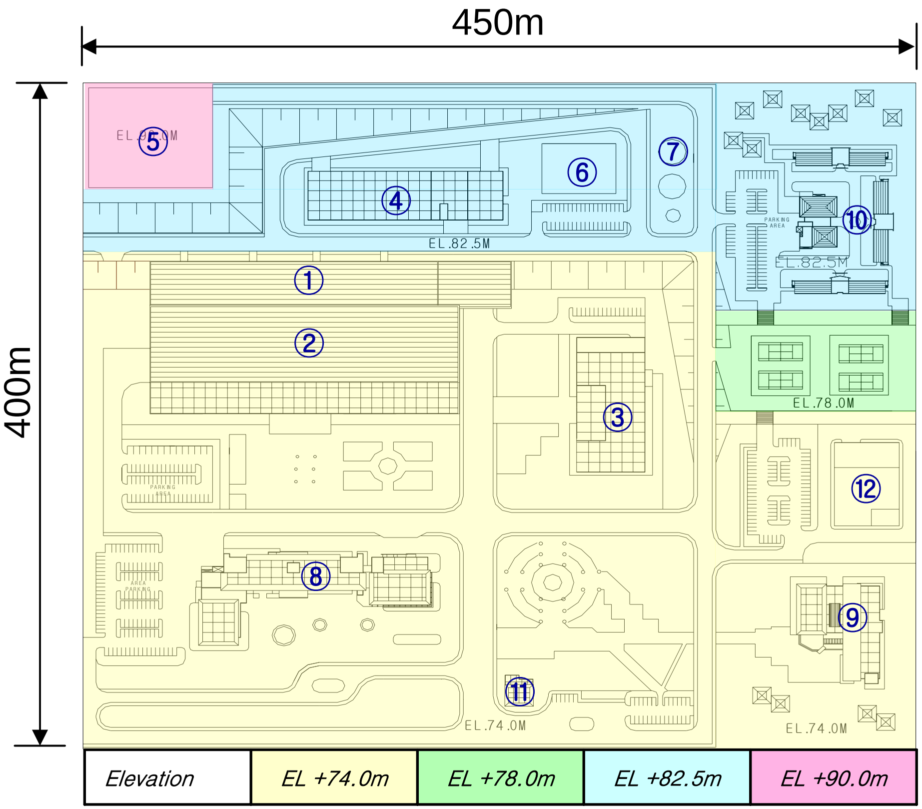
Bird's Eye View of the Site



Site Preparation Plan for the 100MeV Facility

PEFP Proton Engineering Frontier Project

❑ Site Arrangement for Phase I



Area : 400m(W)×450(L) = 180,000㎡

Construction Milestone for the100MeV Accelerator

PEFP Proton Engineering Frontier Project

Milestone	Major Activities
2006. 4	*Project contract between Gyeongju and PEFP/KAERI* *Site work started*
2007. 6	*Purchasing the land and attaining the construction License*
2007. 10	*Construction will start* *- Ground Breaking, excavation, utility & building etc.*
2008. 7	*Start of the 20MeV Accelerator Installation*
2009. 12	*Extraction of a 20MeV Proton Beam*
2011. 12	*100MeV Accelerator Installation and Commissioning*
2012. 3	*Completion of the PEFP project*

Summary

- At KAERI Daejeon site,
  - Many technologies for a proton linac with high duty factor have been developed.
  - Technical issues, especially reliability, have been solved step by step.
  - 20 MeV machine has been installed and is being tested.
  - 100 MeV machine has been designed and being fabricated.
  - 20/100MeV proton beam lines is being developed.

- In Gyeongju,
  - Gyeongju city is the site for PEFP.
  - We will move the machine to the site in 2008.
  - Beams to users will be supplied from 2012.
  - Full duty (24%, 8%) operation will be performed.

- We are considering the future plan of this facility.
  - Superconducting Linac, RCS design study
  - Spallation Neutron, Isotope Production, and ADS Study