WAO10
April 12 – 16, 2010
INTEC, KAERI, Korea

Operation Status of the PEFP Proton Accelerator

Hyeok-Jung Kwon (hjkwon@kaeri.re.kr)
on behalf of the Proton Engineering Frontier Project

Contents

Overview

PEFP Proton Engineering Frontier Project

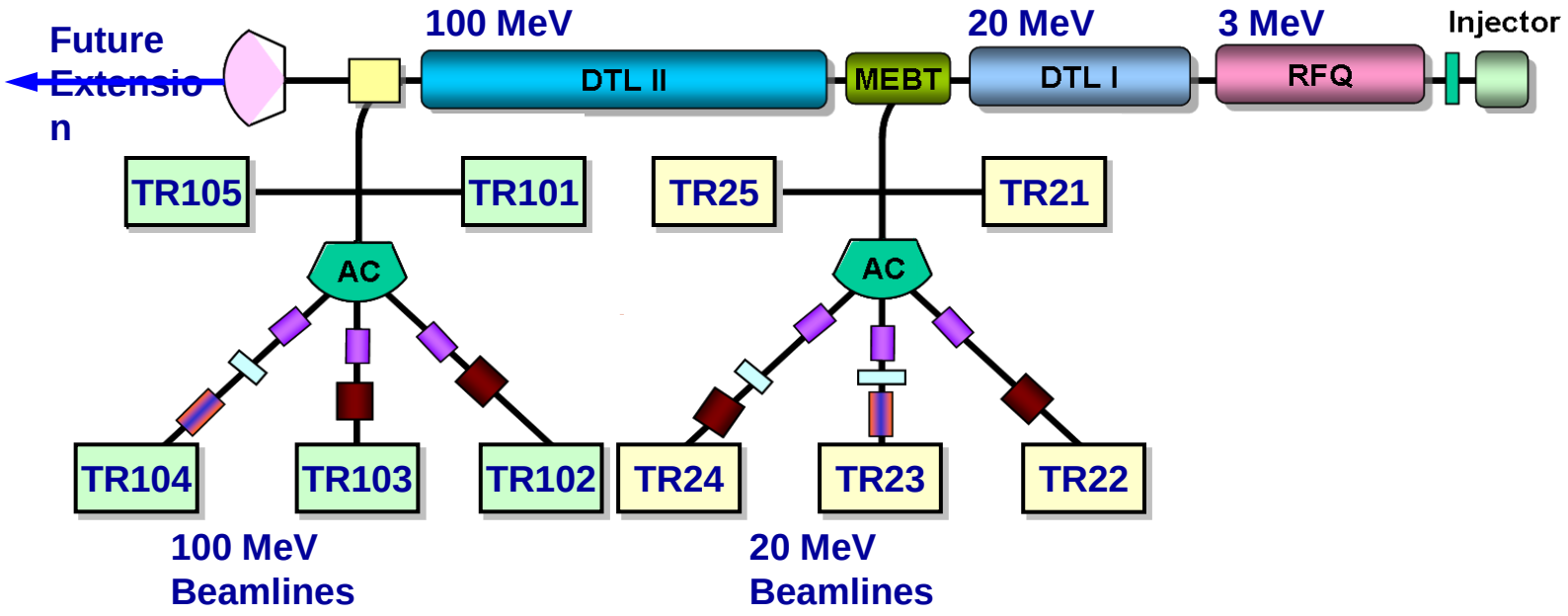
- **Project : Proton Engineering Frontier Project (PEFP)**
  21C Frontier R&D Program, MEST, Republic of Korea

- **Objectives :**
  - To develop a High Power Proton Linac (100MeV, 20mA)
  - To develop Beam Utilization & Accelerator Application Technologies
  - To 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 : Site, Buildings & Supporting Facilities)

Schematics of PEFP Linac & Beamlines



Features of the PEFP linac

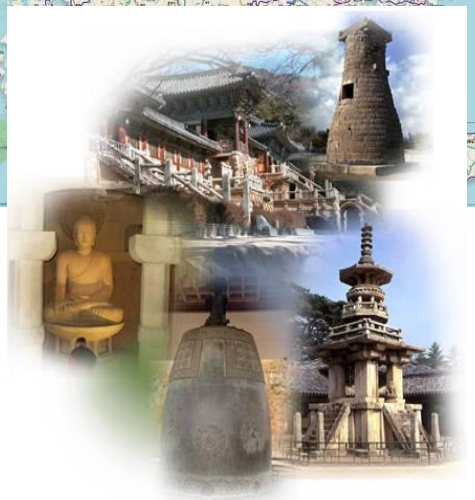
- 50 keV Injector (Ion Source + LEBT)
- 3 MeV RFQ (4-vane type)
- 20 & 100 MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV
  - Beam to be distributed to 3 BL via AC

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

Project Site

PEFP Proton Engineering Frontier Project

❖ Gyeongju provided the site (Area: 440,000 m^2), building and support facilities (The capital of Shilla dynasty for 992 years, from BC 57 to AD 935.)



Construction Schedule

PEFP Proton Engineering Frontier Project

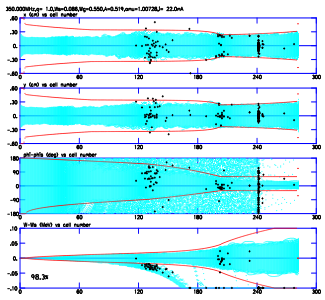
Date	Major Activities
Sep. 2008	Obtained the construction permit
May 2009	Started construction (ground breaking)
Jul. 2010	To start foundation work (accelerator & beam utilization building)
Jun. 2011	To complete accelerator, ion beam & utility facility building
June 2011	To supply 154 kV power & water
Dec. 2011	To complete mechanical, electrical, I&C system
Mar. 2012	To complete of buildings & yard facilities
Mar. 2012	To complete the project

Contents

RFQ Fabrication

PEFP Proton Engineering Frontier Project

❖ **Established a full fabrication process with domestic companies**

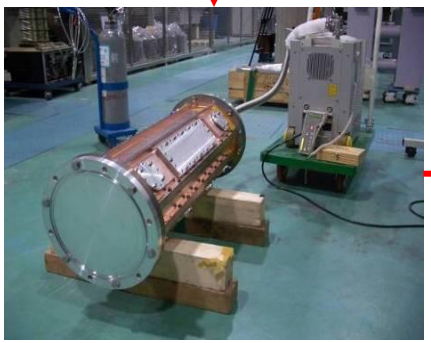


Design

Vane machining

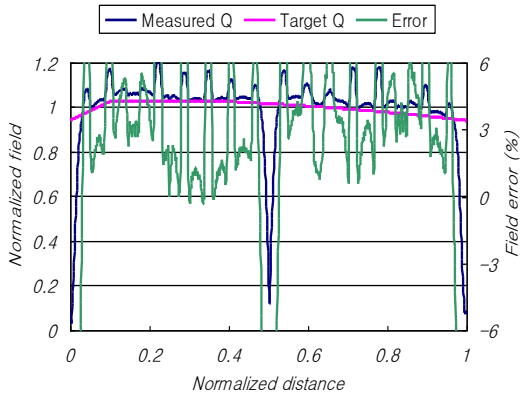
Tuning before Brazing

Brazing



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

Tuning

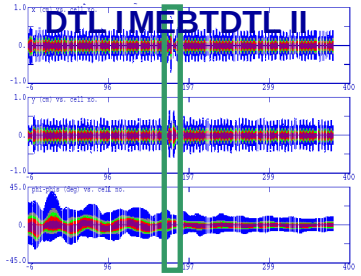


Frequency : 349.931 MHz
Q field : < ± 2%
D field : < ± 5% of Q

DTL Fabrication

❖ **Established a full fabrication process with domestic companies**

Design

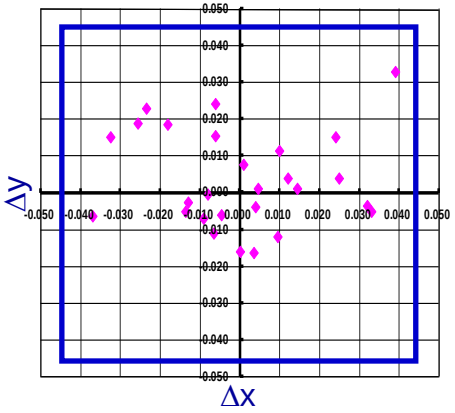


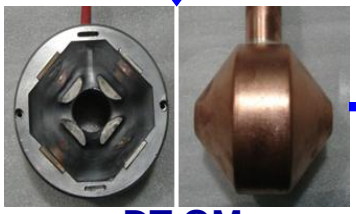
Machining (Acc <100 μm)

Copper plating

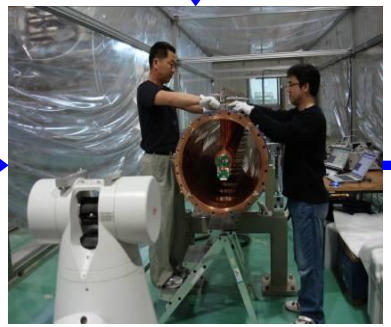
Assembly

DT alignment < 40 μm

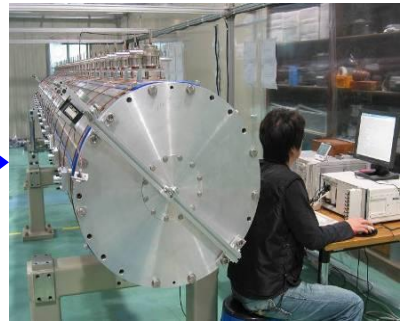




DT QM Fabrication (B = 1.75 T±1%)

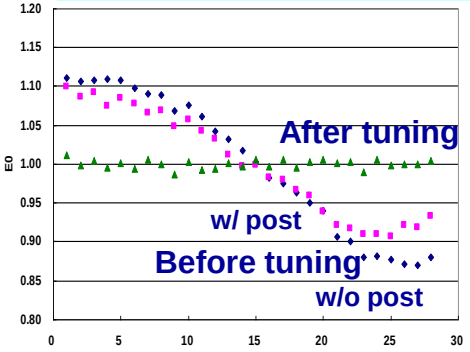


DT alignment



Tuning

Field Tuning < ±1.5 %



PEFP 20 MeV Linac at Daejeon KAERI site

PEFP Proton Engineering Frontier Project

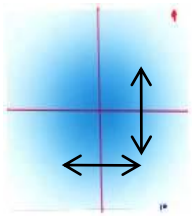
- Operation since June 2007

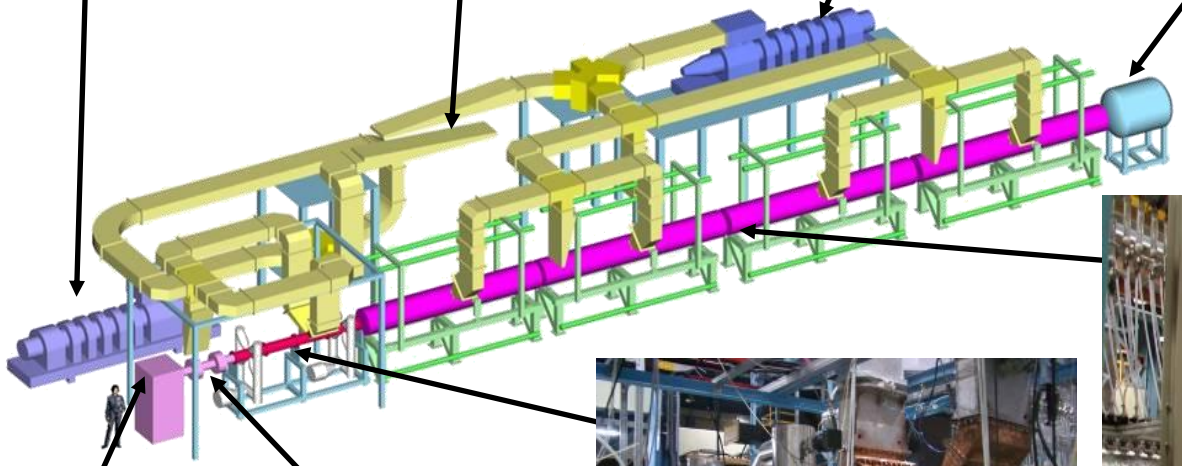
Wednesday Facility Tour (15:00~)

Klystron (RFQ) | Waveguide | Klystron (DTL) | Target Station | Beam Profile











Ion Source | LEBT | 3 MeV RFQ | 20 MeV DTL

20-MeV Accelerator Operation at KAERI Site

PEFP Proton Engineering Frontier Project

- Operation objectives
  - To supply beam to users
  - To study the characteristics of the proton machine
  - To use as a test stand of the 100-MeV machine components
- Building & Utilities
  - General test hall which contains accelerator, RF system, power supplies
  - Electrical power station, cooling station
- Operation since June 2007 (operation license re-issued at May ’08 with more shielding)
- Beam condition: Avg. current: 1.0 μA, Rep. rate: 1 Hz, Pulse length: 50 μs
  - Beam condition mainly limited by the radiation shielding

Cooling utilities

Electrical power system utilities

Control System

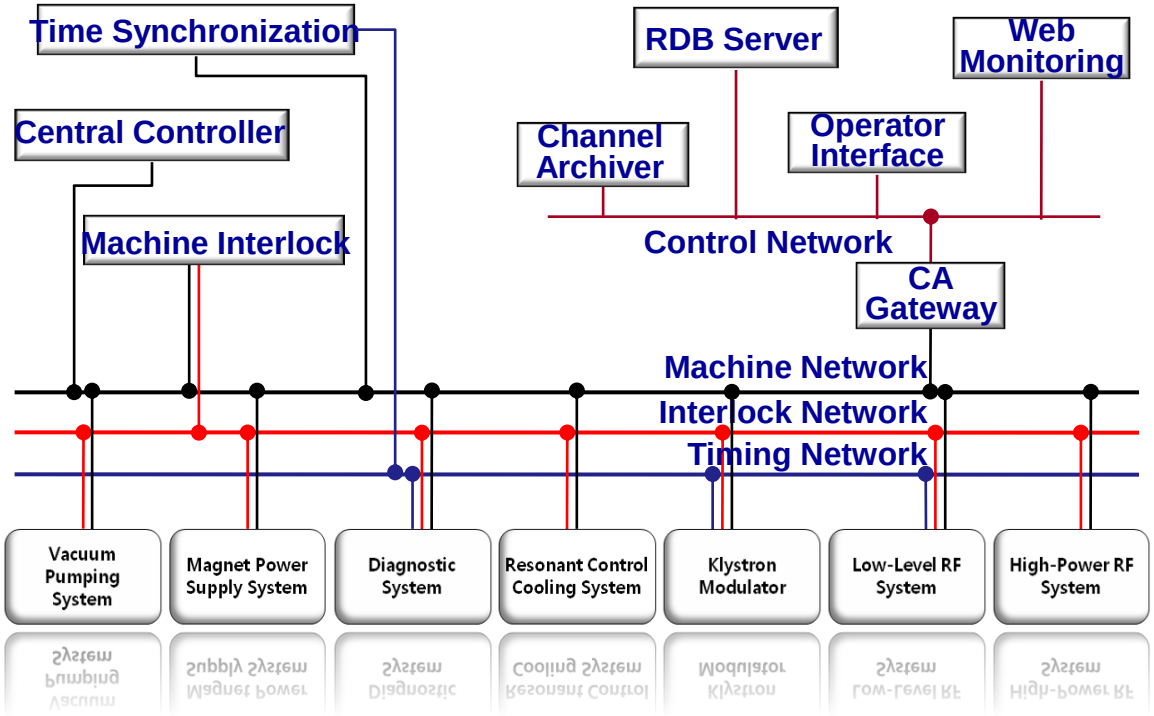
PEFP Proton Engineering Frontier Project

❖ EPICS and Digital based

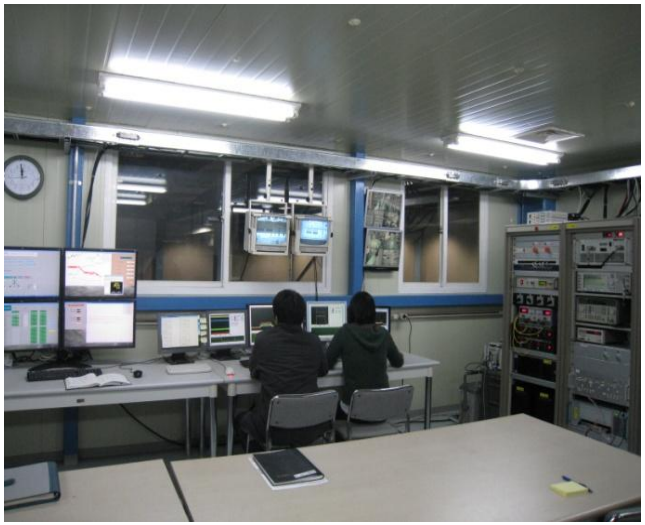
O-35, P-13

Time & Central Controller

Data Management & Visualization



20 MeV Control Room (Monitoring and test bench oriented)



Operator Interface

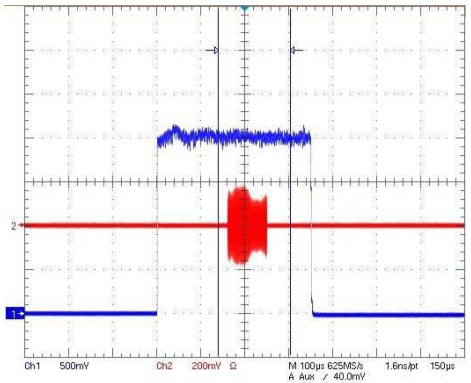
RF & Beam Monitor

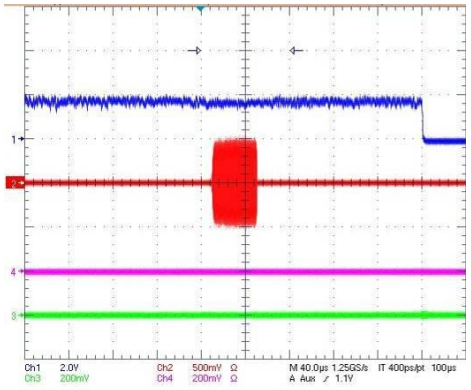
LLRF Control

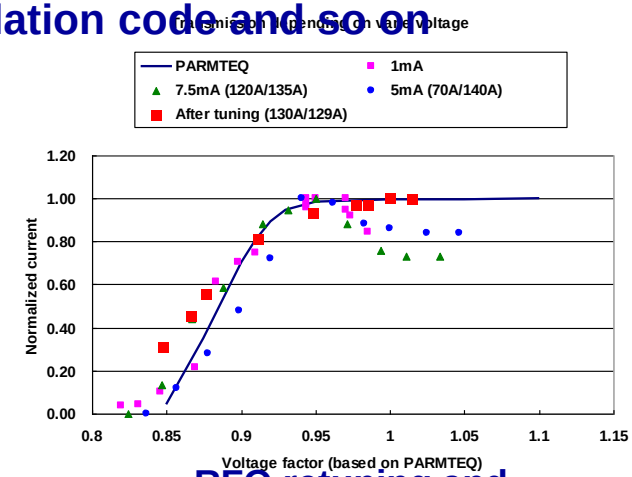
RF & Beam EPICS OPI Server

20-MeV Accelerator Commissioning

- **We learned many things about the proton accelerator**
  - **Neutralization, RFQ set point determination, DTL RF set point determination, methods to tune the accelerator using simulation code and so on**

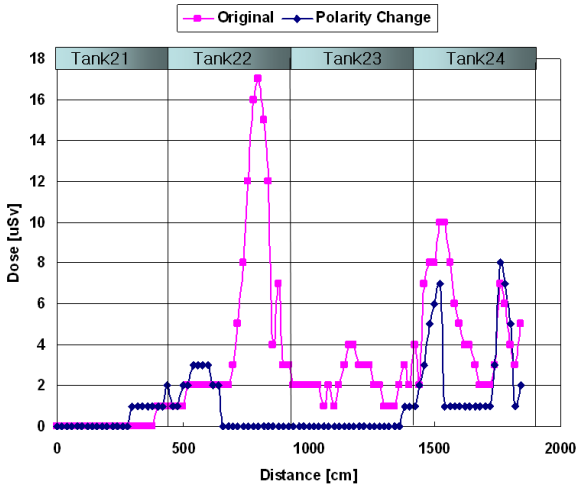


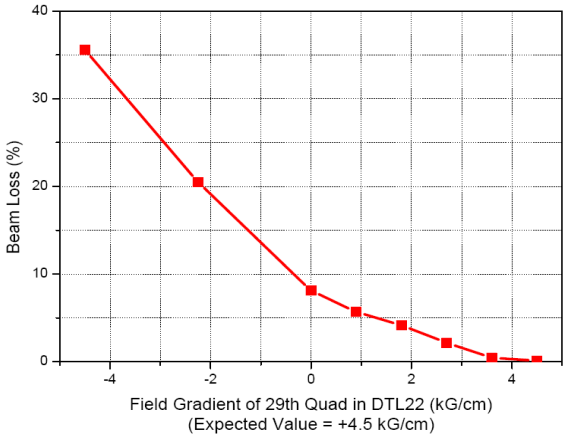


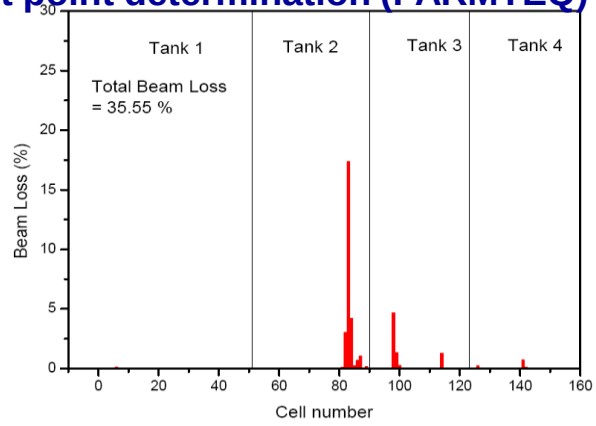


Fixing the beam oscillation by timing adjustment

RFQ retuning and RF set point determination (PARMTEQ)



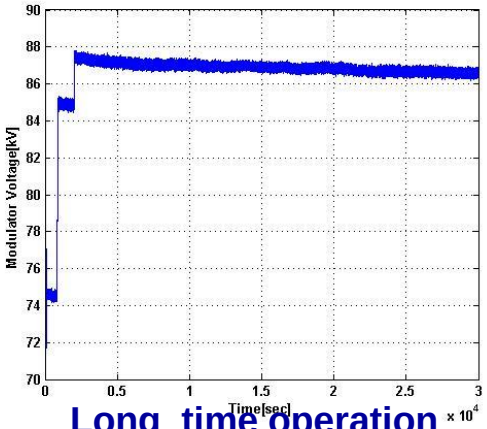




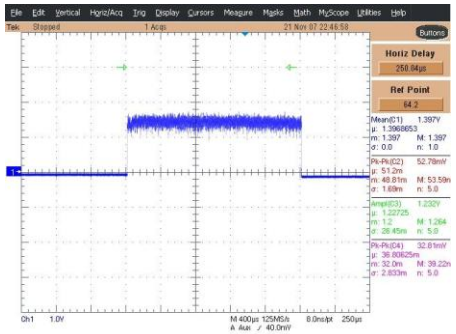
DTL beam transmission (~50%) -> beam loss distribution measurement -> predict the polarity mistake of QM by using PARMILA -> QM polarity reversal ->beam transmission (100%)

20-MeV Accelerator Performance Study

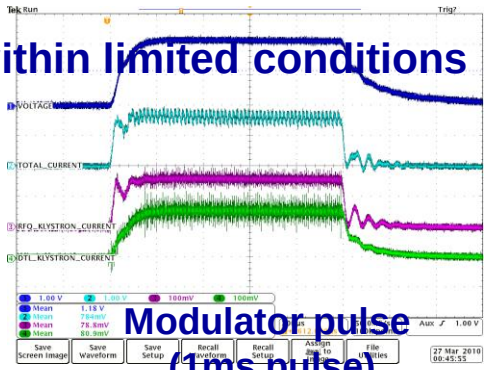
- Machine performance check within limited conditions
  - Long pulse operation
  - Long time operation
- Beam study



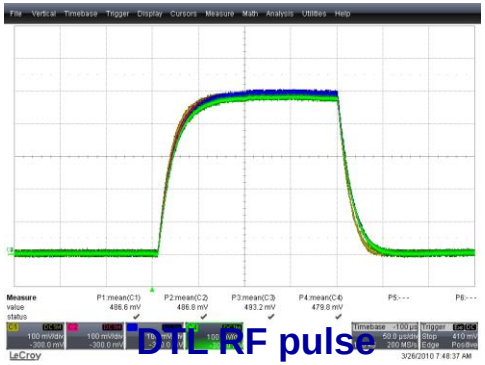
Long time operation
(modulator voltage)



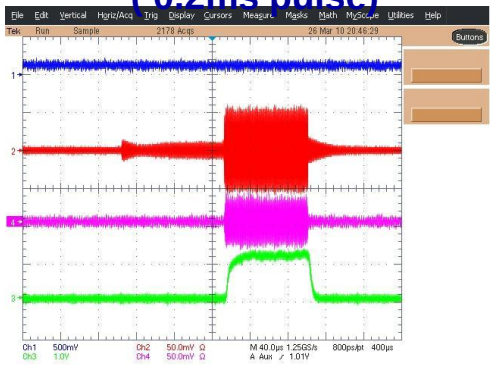
Long pulse operation
(LEBT beam, 2ms pulse)



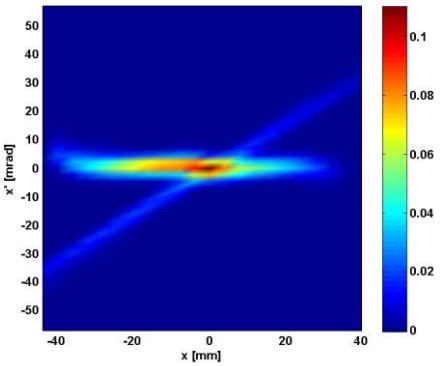
Modulator pulse
(1ms pulse)



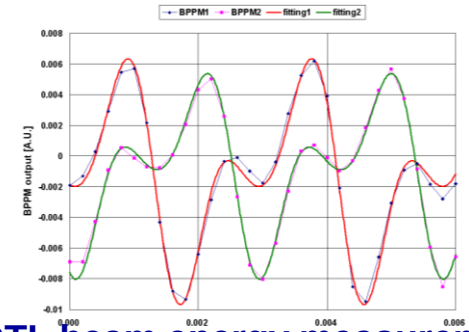
DTL RF pulse
(0.2ms pulse)



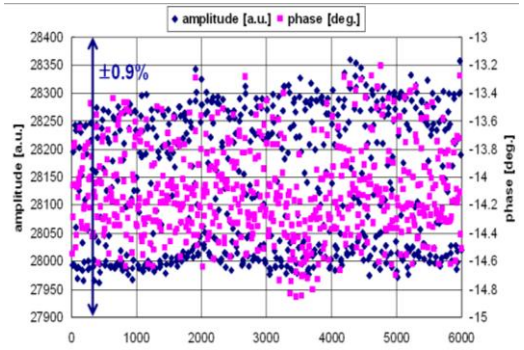
Beam pulse
(DTL beam, 0.1ms pulse)



LEBT beam emittance



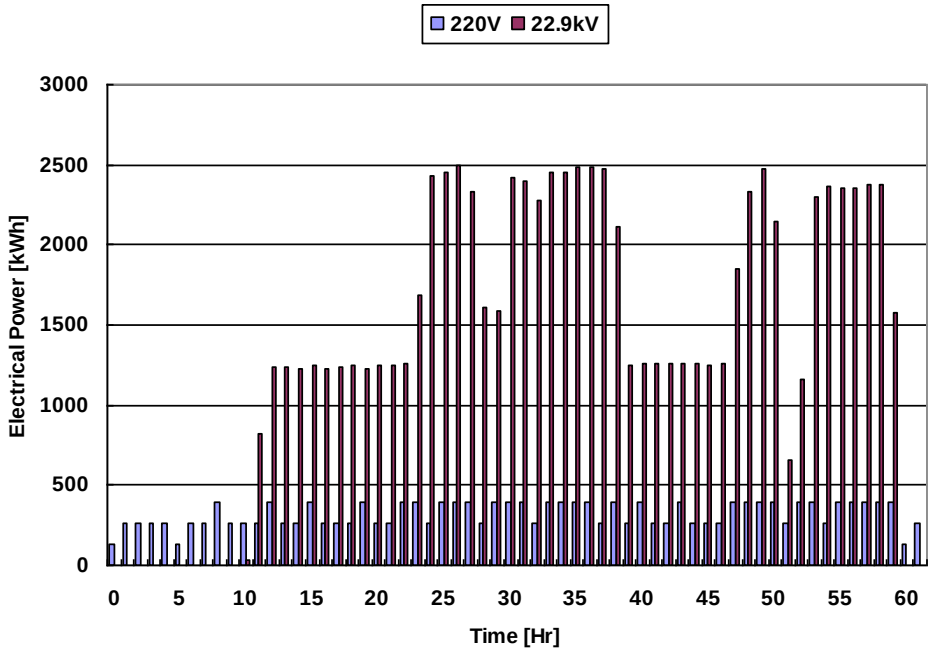
DTL beam energy measurement

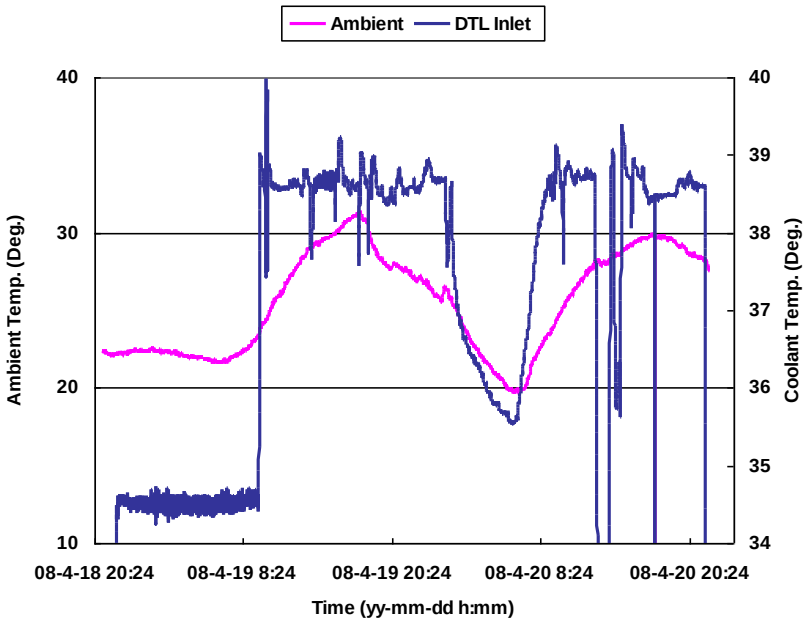


DTL LLRF control

High Power Operation of the Klystron

- Two sets of high power klystron for 20-MeV accelerator
  - : 350MHz, 1.6MW average electron beam power, 1.1MW average RF power
  - : Two sets of 2MW DC high voltage power supply, 2MW cooling system
- Long time operation of the klystron beam
  - : Day time (full power operation), Night time (half power operation)
  - : Heat at the collector serves as a big heat reservoir for the cooling system
  - : The cooling temperature stabilized within tolerance in spite of the large change of the ambient conditions
- Two 2MW DC power supplies were replaced with one modulator at the end of 2009



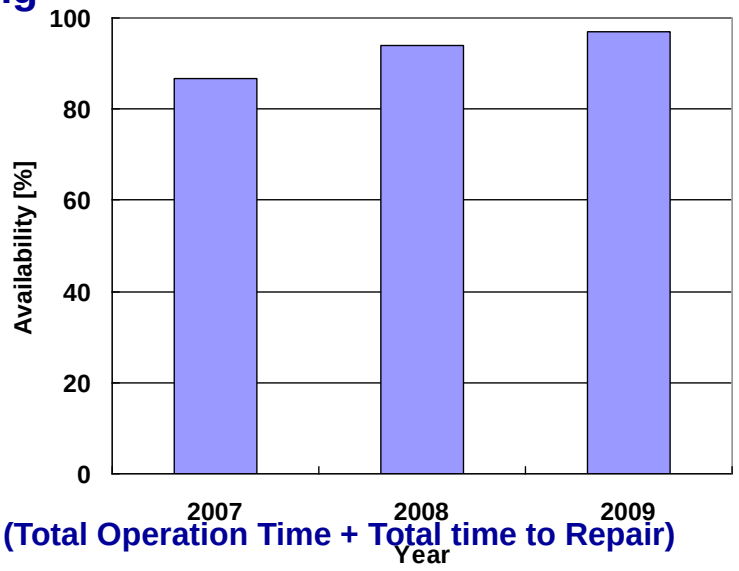


20-MeV Machine Operation Statistics

PEFP Proton Engineering Frontier Project

O-40

- Scheduled maintenance period
  - Vacuum system, power supplies, cooling system and so on
  - Installation of the 100-MeV component for performance test
    (ex: modulator, LLRF system upgrade, beam diagnostics)
- Unscheduled maintenance
  - Directly affect to the machine normal operation schedule
  - No severe accidents of the machine due to low duty operation
  - Sources mainly divided into two categories : HVPS trip, coolant leakage
  - Statistics may be meaningless because of short operation time,
    but the time to repair is decreasing
    as time goes on



Machine availability = Total Time to Repair / (Total Operation Time + Total time to Repair)

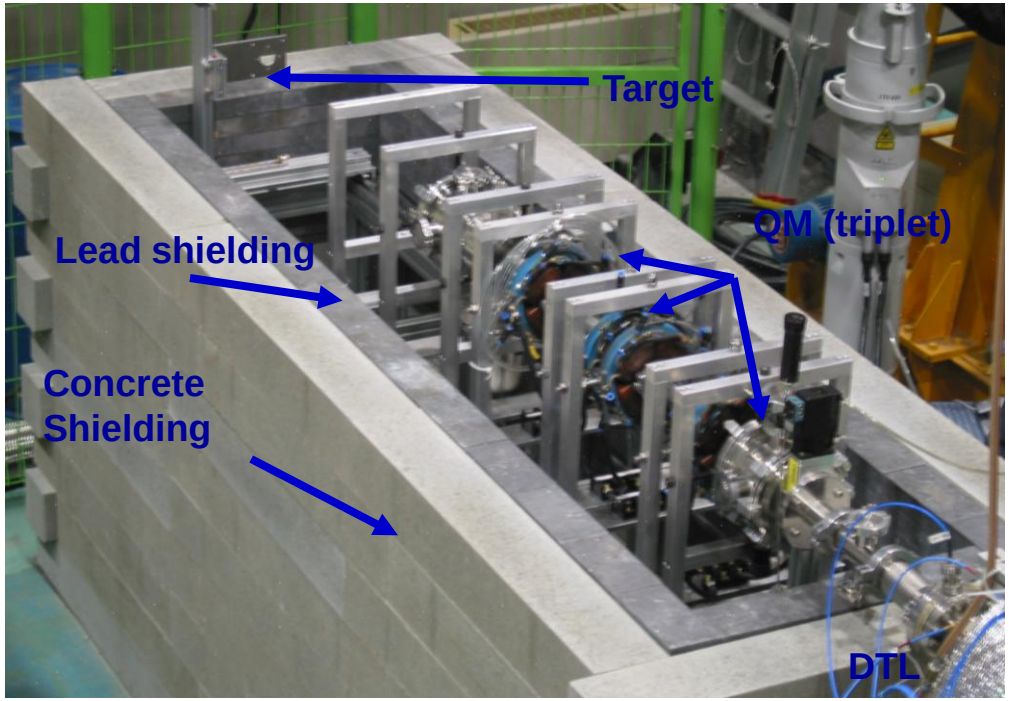
20-MeV Beam Irradiation Station & its operation

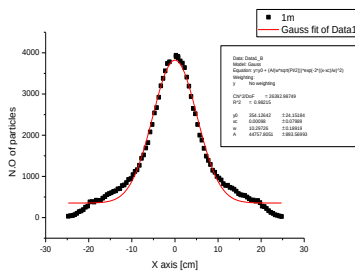
- To meet demands for 20 MeV proton beam users
- Beam condition: Avg. current: 1.0 μA, Rep. rate: 1 Hz, Pulse length: 50 μs
- Installed a QM triplet to control the beam size at the target
- Operation

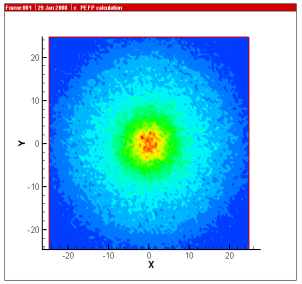
  : Minimum - Supervisor 1, accelerator operator 3, beam line operator 2

  : Beam shutter closes for the accelerator only operation

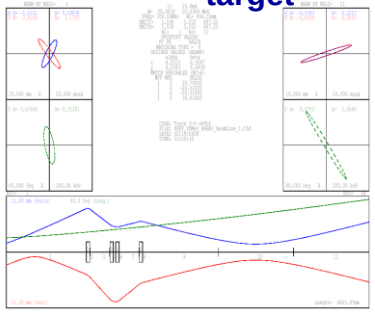
  : Services for users: 150/year (weekend operation only)







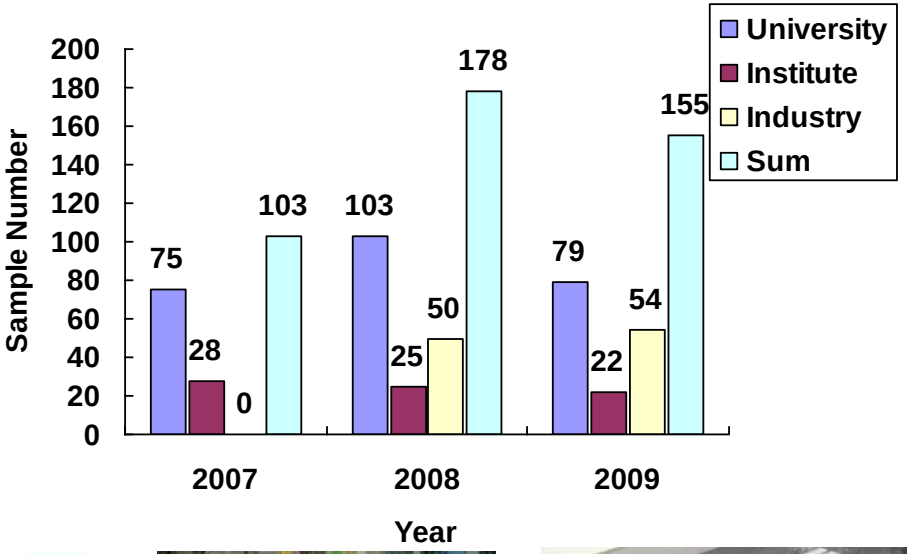
External beam
Able to modulate the beam size at target

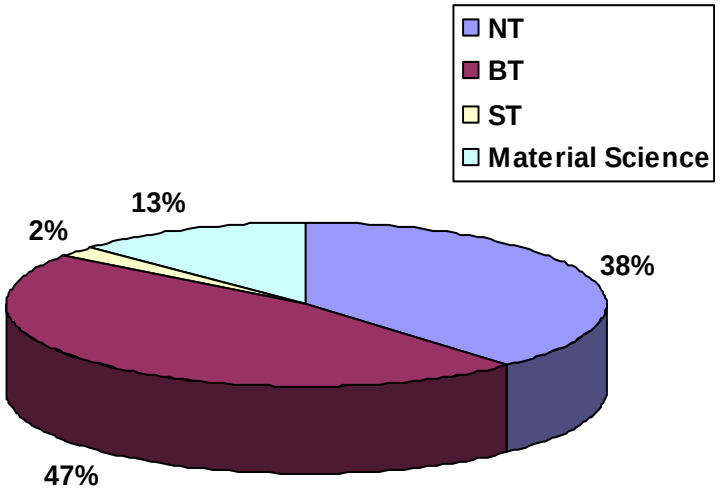


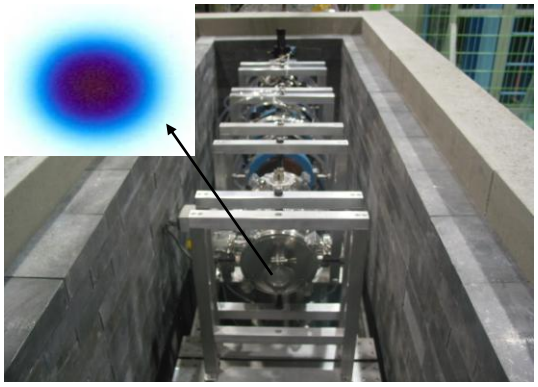
Beam optics with a QM triplet

20-MeV Beam Irradiation Statistics

- Users submit the application form through homepage (www.komac.re.kr)
- Users contact the beam line operator and decide the irradiation conditions
- Beam line operator performs the irradiation test
- Total 436 samples were irradiated since 2007

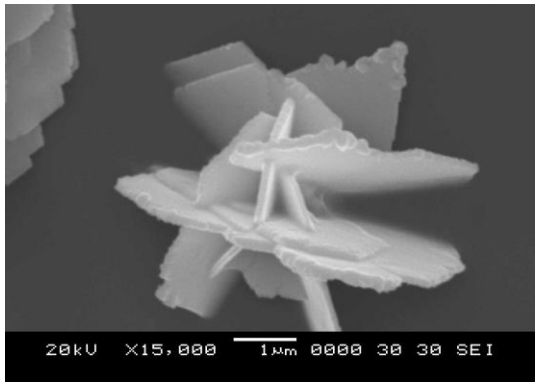






20MeV proton beam line

Mutation of bacillus induced by proton beam



Ag Nano particles generated by proton beam

I. Overview

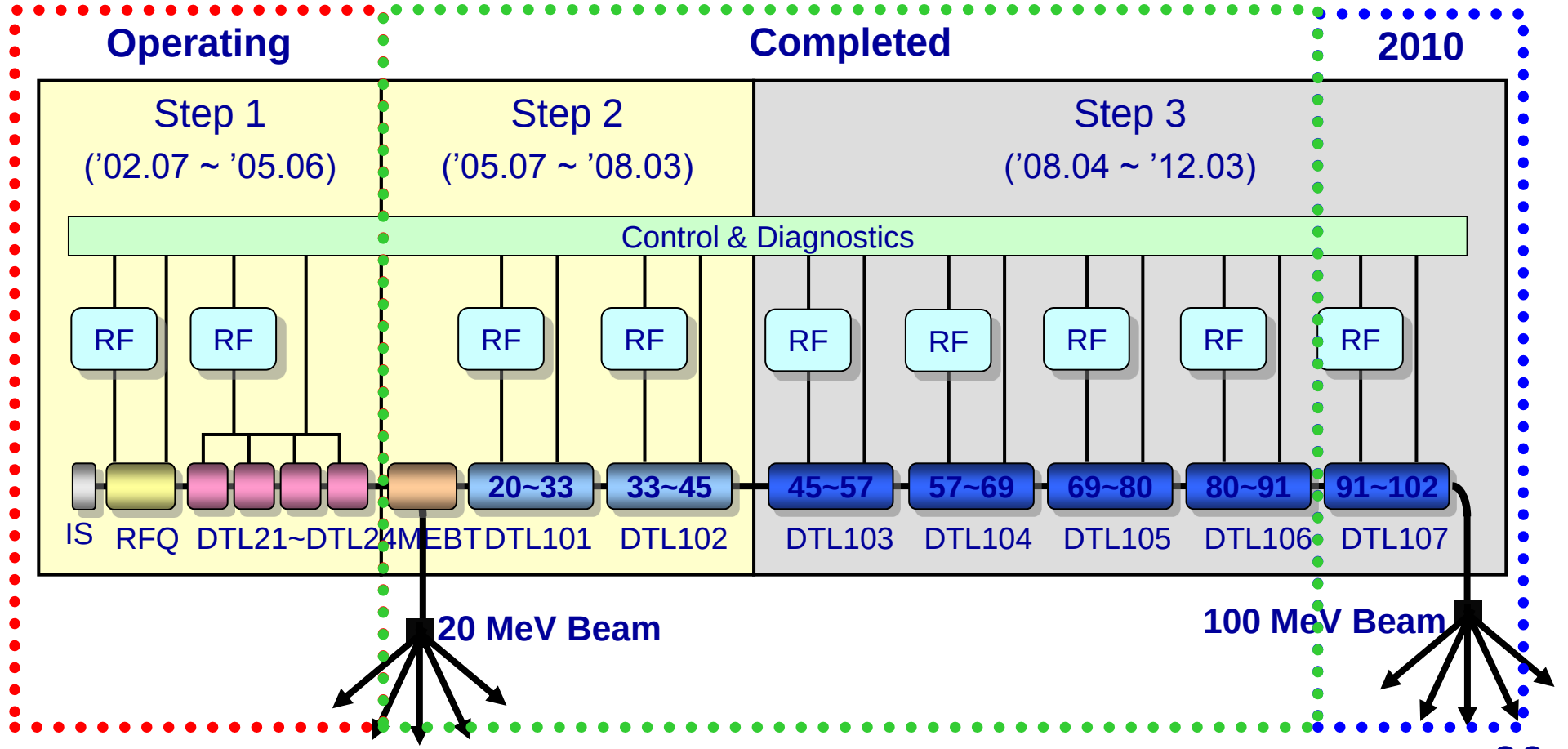
II. 20-MeV Accelerator Operation (Status)

III. 100-MeV Accelerator Operation (Plan)

IV. Summary

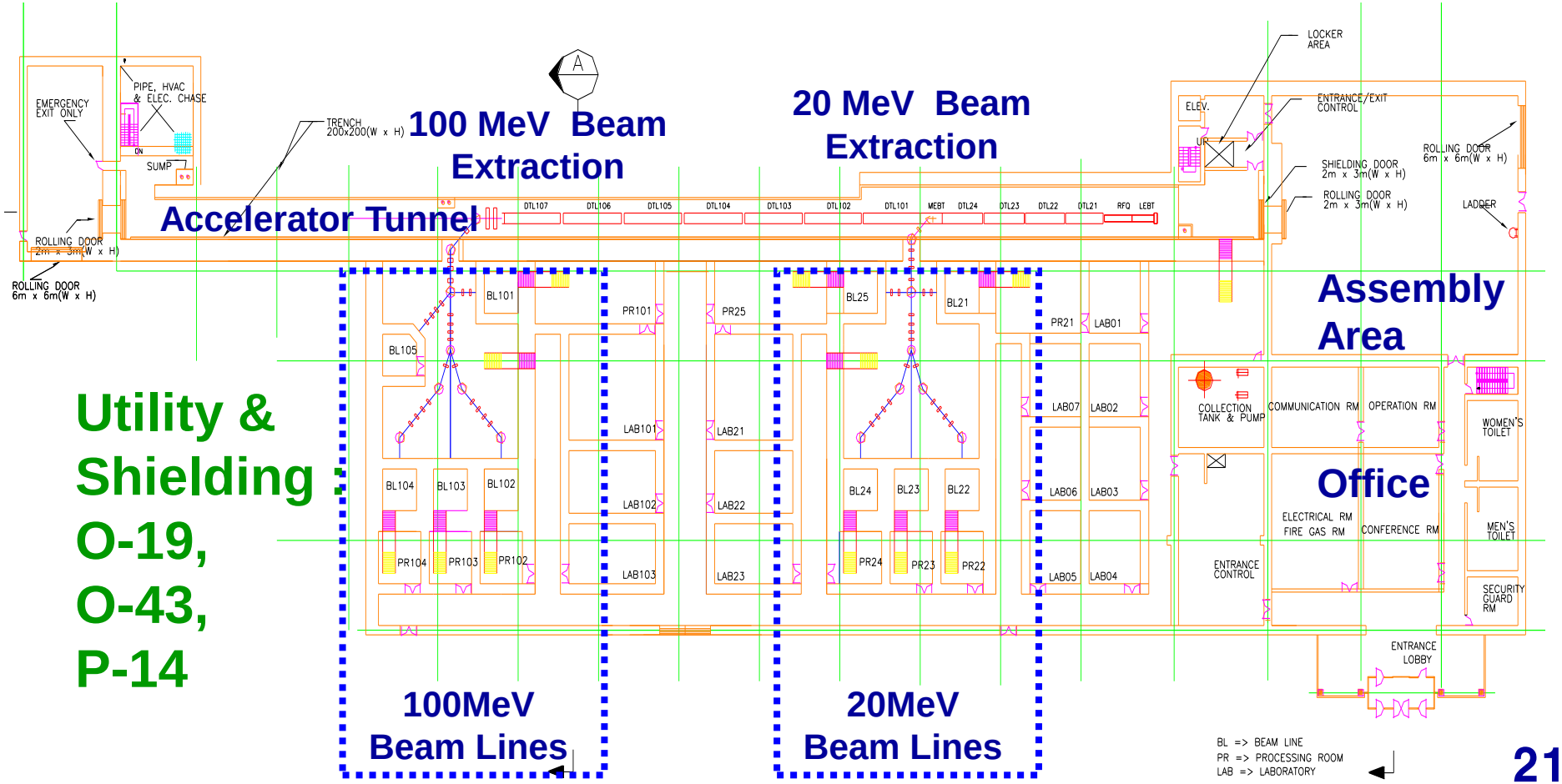
Status of Accelerator Development

- Fully developed & integrated up to 20 MeV in Daejeon site
- The fabrication of tanks up to 91MeV has been finished.
- Last tank will be fabricated in this fiscal year.



Accelerator tunnel & Experimental hall

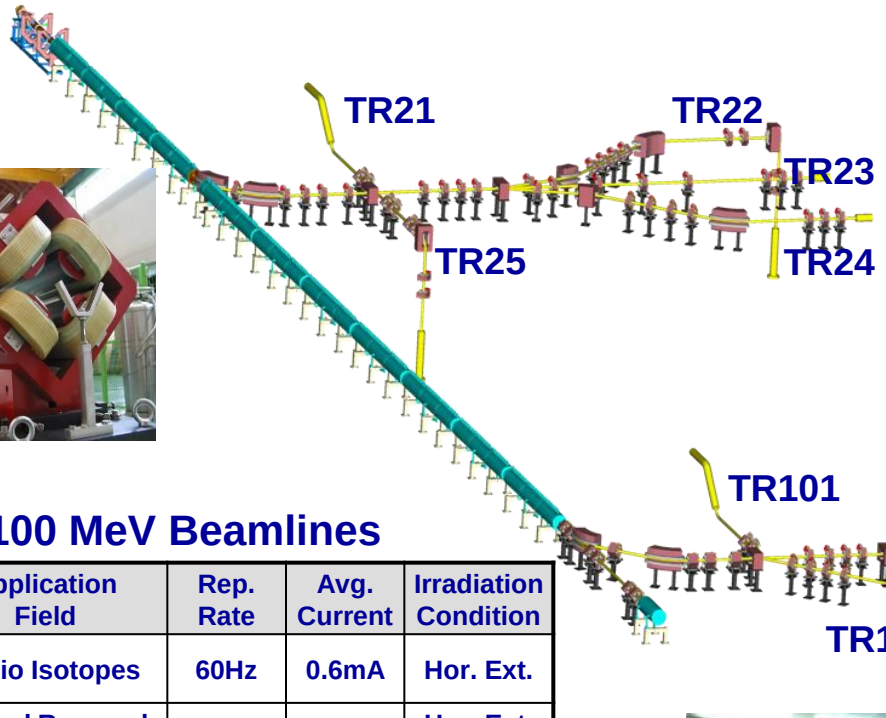
- Beam extraction from the accelerator : 20-MeV, 100-MeV
- Target rooms : Total 10 target rooms (5 rooms / beam line)
- 3 target rooms at 20-MeV beam lines (TR22, 23, 24) or 100- MeV beam lines (TR102, 103, 104) can be operated simultaneously by using AC magnet



Beam Line and Target Room Specifications

PEFP Proton Engineering Frontier Project

- ❖ Completed design by reflecting user's requirement
- ❖ Developed components (QM, ACM, DM & beam instruments)



20 MeV Beamlines

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

100 MeV Beamlines

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

300mmΦ beam window

Accelerator Commissioning Plan

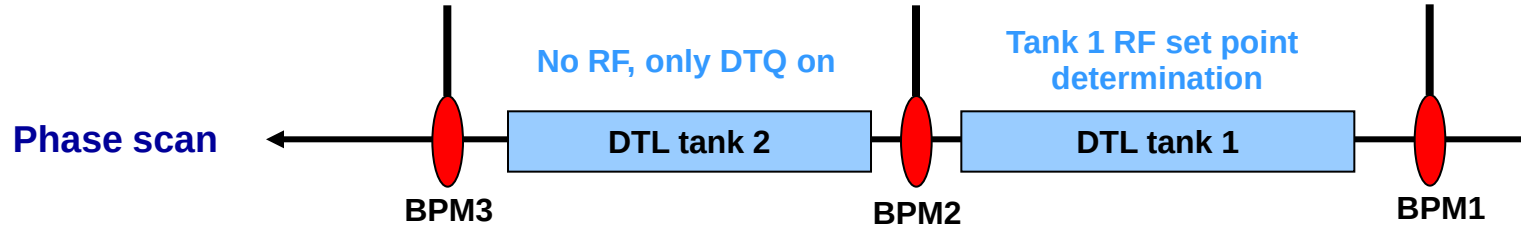
- Conditions : No empty DT, measurement device and steerer should be located outside
- Initial beam parameter : 100MeV, 20mA, 50us, 1Hz (100W)
- 1kW beam dump inside the tunnel : will be used for the accelerator commissioning
- Scheme for the RF and beam position set point

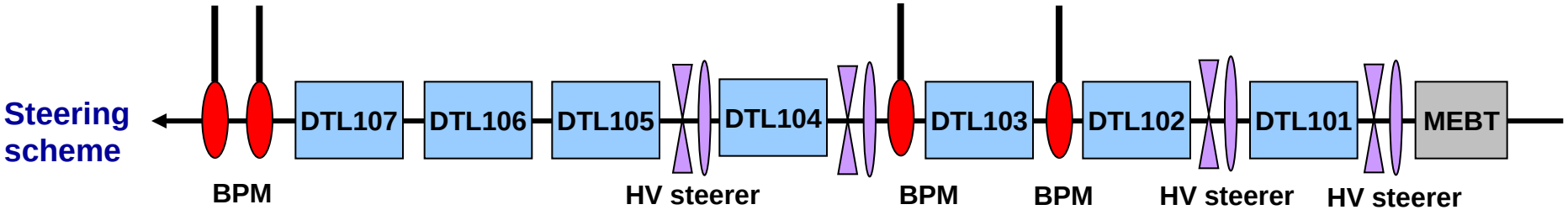
: RF set point - phase scan method by beam phase measurement

Comparison between measured beam phase and PARMILA results

: Beam position – steering magnet + BPM sets

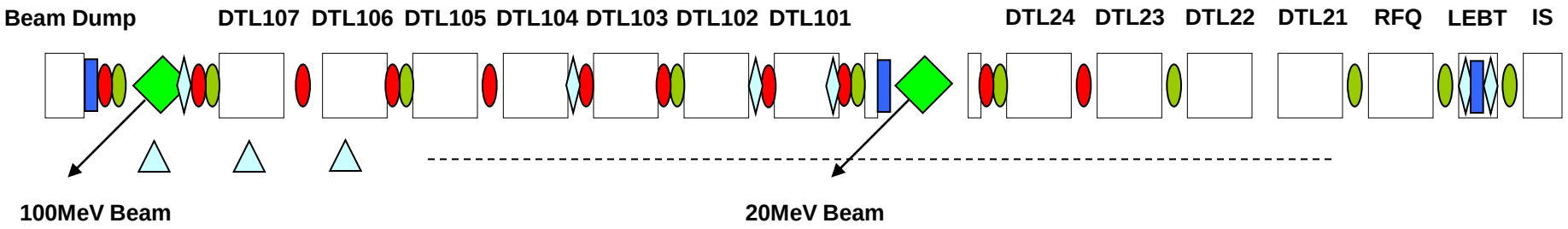
Algorithm based on the transfer matrix conversion of Twiss parameters





Accelerator Commissioning Plan – Beam diagnostics layout

- Beam diagnostics layout based on the RF and beam position set point plan
- Layout will be confirmed by PARMILA code



Steerer (H. V. pair) : 6 sets

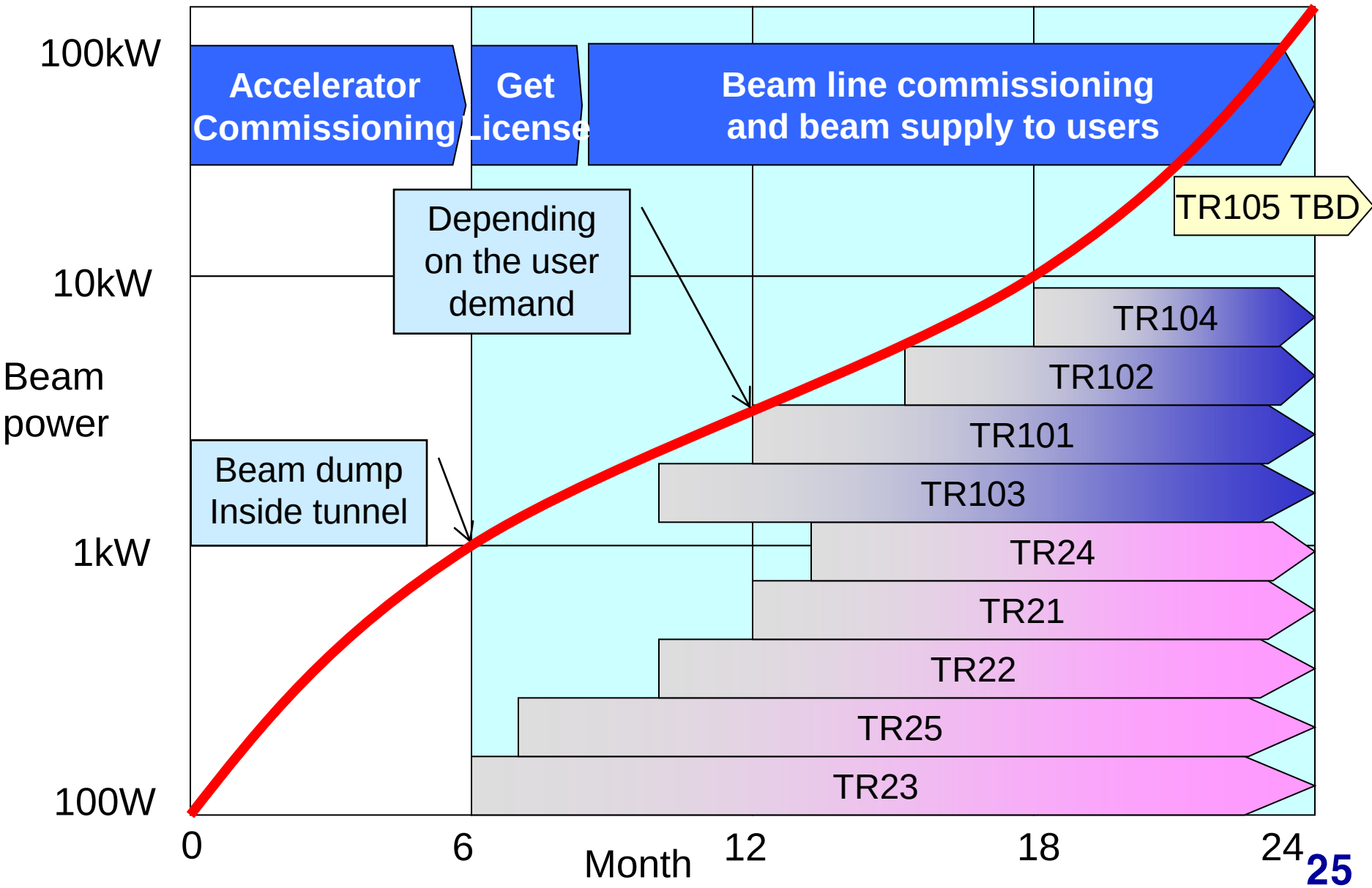
BPM : 11 sets

BCM : 10 sets

Beam profile monitor
& emittance scanner : 3 sets

Beam loss monitor

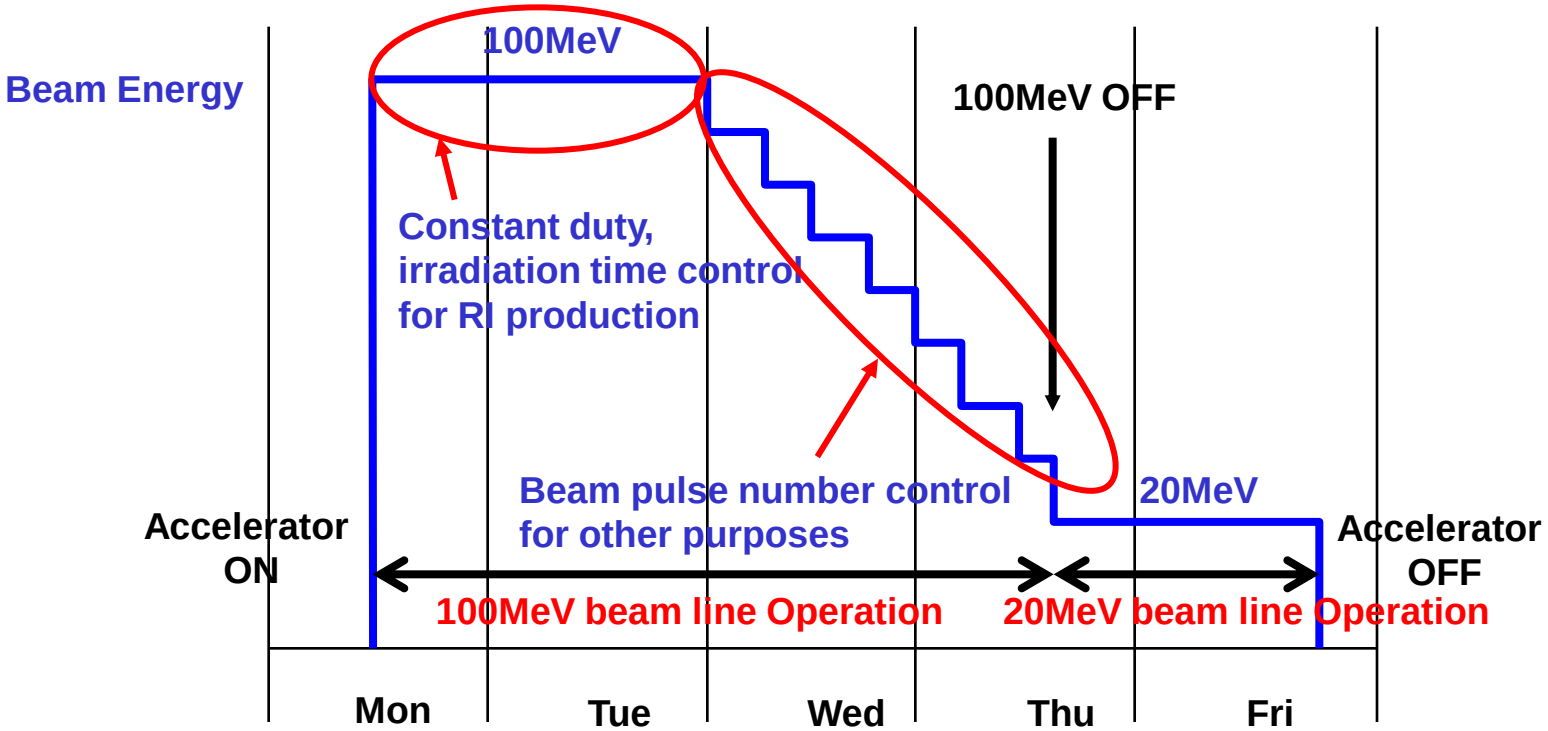
Beam Line Commissioning Plan



Operation Plan

- Operation plan is based on the weekly schedule
- 5 days / week (turn on : Monday, turn off : Friday)
- Beam time between 100MeV and 20MeV depends on the user demand
- Planned beam ON time : 2,000 hrs/year (based on the user's demand survey)
- Operator : Total 12 operators, 4 / shift (supervisor: 1, RF: 2, beam: 1), 3 shifts / day
- Operation plan based on year

  - Machine operation period : 9 months (2~7, 9~11) - Maintenance : 3 months

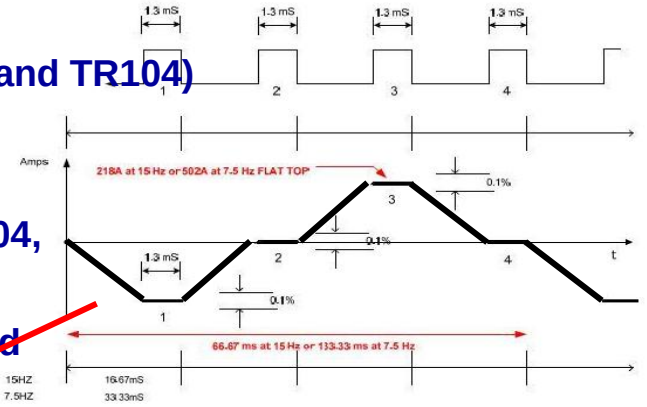


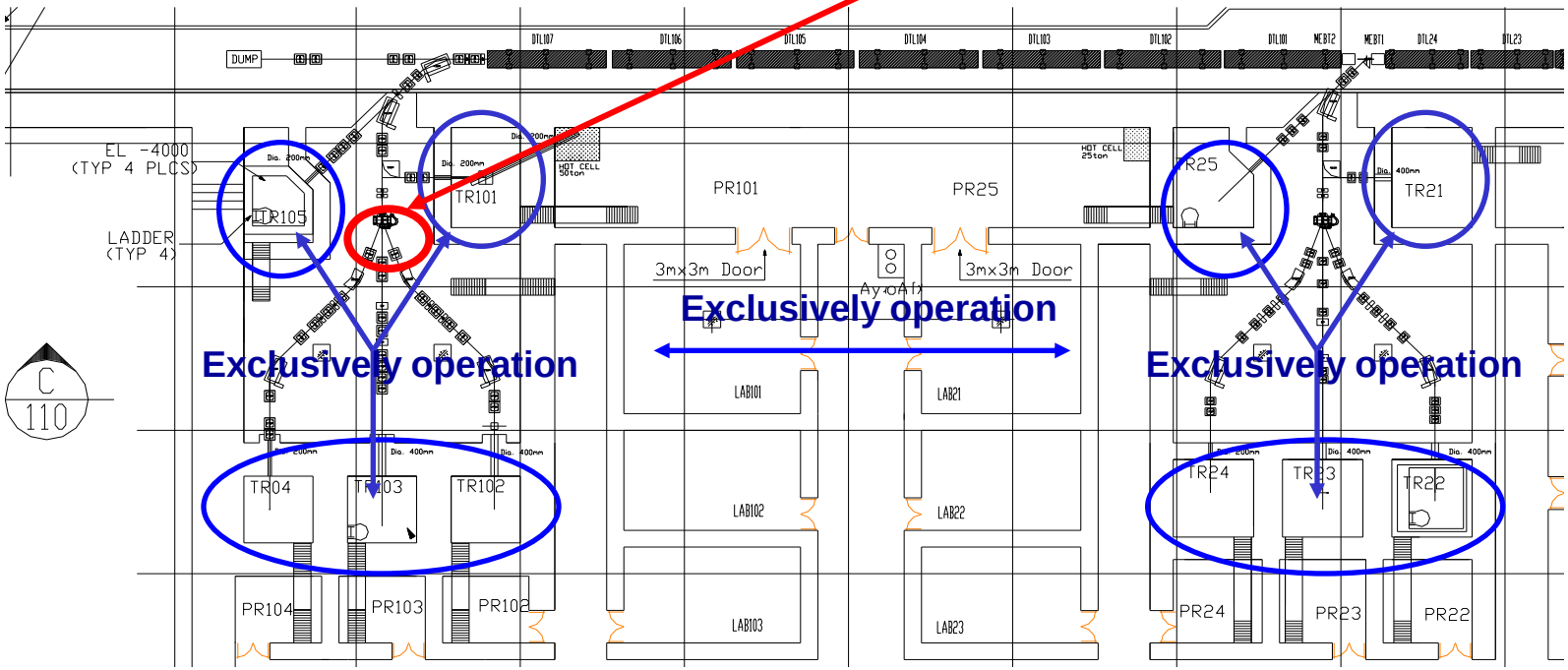
Target Room Operation Scenario (Accessibility Issue)

PEFP Proton Engineering Frontier Project

P-07, P-08

- Exclusive Beam Extraction Operation
  1) 20MeV and 100 MeV beam utility are not operated together.
  2) Group 1(TR101), Group2(TR105) and Group3(TR102, TR103 and TR104) are also operated exclusively to each other groups.
- Accessibility
  1) At any case, access is permitted to one of TR102, 103 and 104, when the beam is not supplied to that target room.
  2) Access to TR101, TR105 and BTL enclosure is only permitted after beam turns off.





Target Room Operation Scenario (Safety Issue)

PEFP Proton Engineering Frontier Project

- RF operation
  - : Set the optimum duty for the entire weekly operation condition
  - : Maintain constant duty regardless of the beam pulse width
  - : Emergency RF off – control room, klystron gallery, modulator room
- Beam operation
  - : Based on the weekly schedule (irradiation time control, pulse number control)
  - : Emergency beam off – control room, target room, processing room
  - : Beam shutter close confirmation – target room, processing room
- Strategy
  - : Beam shutter open / close – processing room
  - : Beam on permission condition

    (Multiple permission : all following 5 conditions should be confirmed)

    plan, shielding door closed, beam shutter open,

    processing room operator OK, control room operator OK
  - : Monitoring - Motion detection CCTV, wired / wireless communication
  - : Target room shielding door

    from inside – can open the door without any permission

    from outside – need multiple permission

    (control room, processing room, beam shutter)

Target Room Operation – Virtual Request From Users

PEFP Proton Engineering Frontier Project

- Target room operation was simulated with virtual proton beam request
- Decide the weekly operation schedule (irradiation conditions, target room and time)

Request form from virtual users

Determine irradiation condition, required time, target room -> decide weekly operation schedule

The Virtual Request for Proton beam

Gyeong-ju Proton Accelerator Research Center

2013. 3

No	Client	Date	Sample	Quantity	Objective	Due Date	Irradiation Condition	Beam line	Operation date
1	A Lab	D-15	Bacillus (6 condition)	6 batch	Mutation of Bacillus	D+5			
2	[illegible]	[illegible]	[illegible]des	10 liter	Pt nanopartcle oroduction	D+10			
3	C Hospital	D-14	RI Production(Ge-68)	1Ci	PET Calibration	D+6			
4	D University	D-13	Radiation detection	2 batch	Study on new radiation detector	D+6			
5	E Company	D-12	Electric semiconductor	100 ea	IGBT(1000V)	D+6			

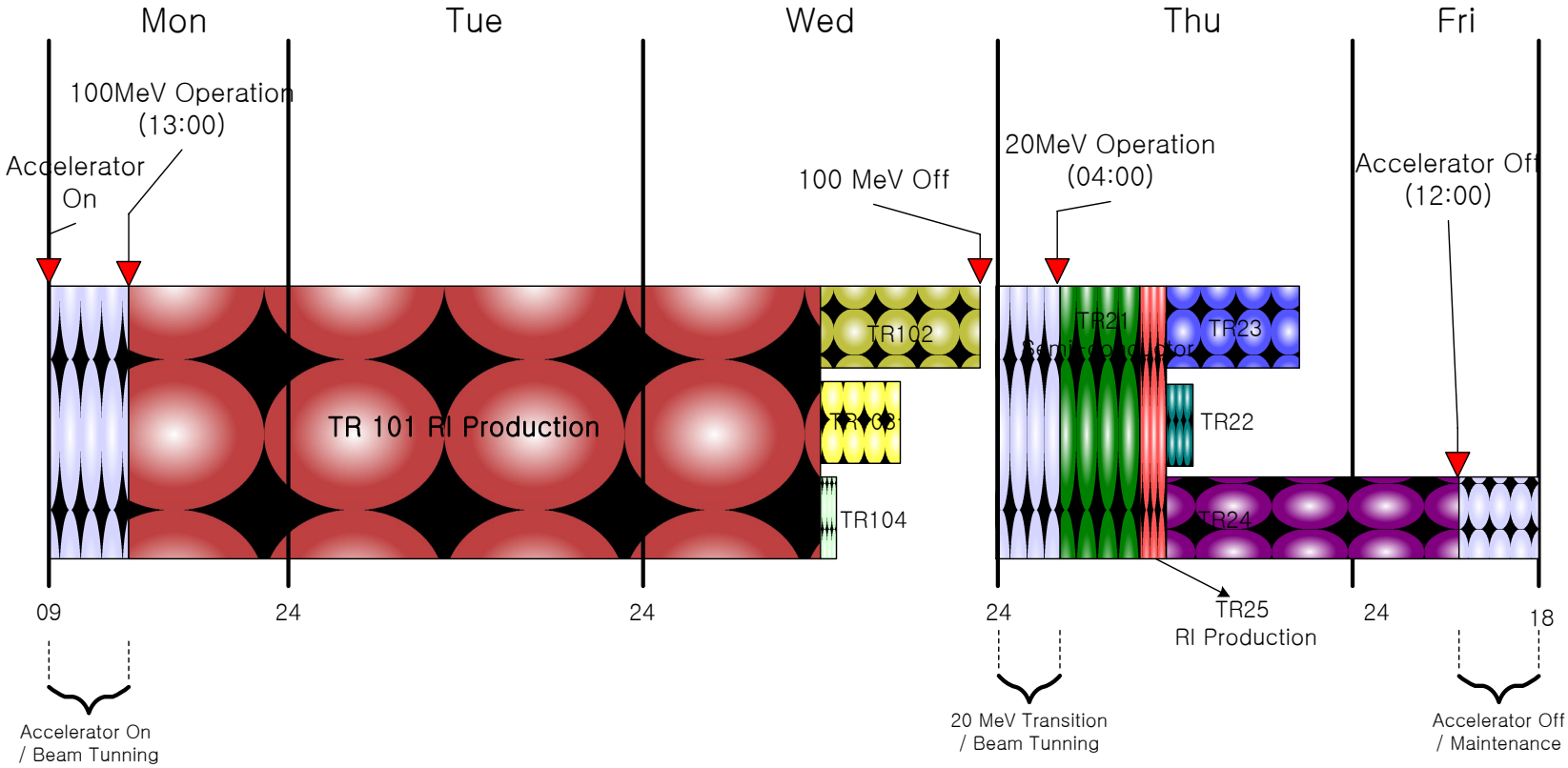
Target RM	Client	Date	Sample	Quantity	Objective	Condition	Irradiatin time	Beam Time
TR101	C Hospital	D-14	RI Ge-68	1Ci	PET calibration	Beam E: 30~10MeV current: 400uA	yield:32uCi/uAh irradiation time: 3.25day	78h
TR101	R Company	D-5	RI Production (Na-22)	3Ci	Long-life positron source	Beam E: 90~70MeV current: 400uA	yield:27uCi/uAh irradiation time: 11.57day	278h
TR102	G University	D-11	Bean (3 batch)	90g	Mutation of bean	Dose: 500, 1000, 1500Gy Dose rate: 1Gy/sec	1 batch = 30g 500+1000+1500=3000 sec	2h
TR102	H Company	D-11	Woody material processing	1kg	Fermentation of Alcohol	Dose: 50kGy Dose rate: 50Gy/sec	1 batch = 100g 1000 x 10 = 10000sec=166min	4h
TR102	I Hospital	D-10	Small animal (mouse)	5 ea	In-vivo test for tumor cell	Dose: 0.1,0.2,0.5,1,2Gy Dose rate: 0.05Gy/sec	2+4+10+20=36sec	2h
TR102	Q University	D-6	Collid Mixture	1 liter	Investigation of Ineration with oil	Dose: 10kGy Dose rate: 10Gy/sec	1 batch = 1 liter 1000 sec	2h
TR103	K Lab	D-9	Nuclear Material (5x5cm, 5mmt)	5 ea	H embritteleness for SUS	Fluence: 1e16 #/cm2 Flux density: 1e13 #/cm2-sec	1000 x 5 =5000sec=83min	3h
TR104	F Lab	D-12	Cosmic ray effect	3 ea	TID effect for CPU	Dose: 50krad Dose rate: 100rad/sec	500 x 3=1500sec=25min	2h
TR21	E Company	D-12	Electric semiconductor	100 ea	1GBT(1000V)	Fluence: 1e13#/cm2 Flux density: 1e11 #/sec	100sec x 100 = 10000sec=166min	4h
TR22	A Lab	D-15	Bacillus badge	6 batch	Mutation of Bacillus	Total Dose: 10,20,50,100,200,500Gy	10+20+50+100+200+500=880sec	2h
TR23	B company	D-14	Pt Solution	10 liter	Pt nano particle production	Beam E: 17MeV Current: 5uA	1 batch =1 liter, 20 min 20 x 10 = 200 min	5h
TR23	J Company	D-10	Au Solution	5 liter	Au nano particle production	Beam E: 17MeV Current: 5uA	1 batch =1 liter, 20 min 20 x 5 = 100 min	3h
TR24	O University	D-13	Radiation Detector	2 batch	Indurance test for high-radiation	Beam E: 20MeV Current: 0.1nA	not defined	all day
TR25	N Hospital	D-7	RIProduction(F-18)	1Ci	PET Therapy	Beam E: 13MeV Current: 50uA	yield:90mCi/uAh irradiation time: 0.25 hour	2h

Target Room Operation - Simulation

PEFP Proton Engineering Frontier Project

P-07

- **Based on the weekly operation schedule (Accelerator side)**
  - **: Determine the RF duty**
  - **: Determine the time when beam line transition should be performed**
    - **TR101 vs. common beam line (TR102, TR103, TR104)**
    - **100-MeV vs. 20-MeV**
    - **TR21 vs. TR25 vs. common beam line (TR22, TR23, TR24)**



Contents

Summary

PEFP Proton Engineering Frontier Project

20-MeV accelerator operation status

- **Beam service to users at KAERI site in Daejeon.**
- **Study on the proton accelerator**
- **Test of the 100-MeV accelerator components**

: It will be valuable experiences to set up the 100-MeV machine operation and maintenance plan

100-MeV accelerator operation plans

- **Accelerator and beam line commissioning plan**
- **Beam line and target room operation scenario**