ICABU2024, 11.13.~15, Pohang, Korea

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Operation Status of KOMAC Linac

KAERI, KOMAC
Hyeok-Jung Kwon
on behalf of KOMAC

한국원자력연구원
Korea Atomic Energy Research Institute

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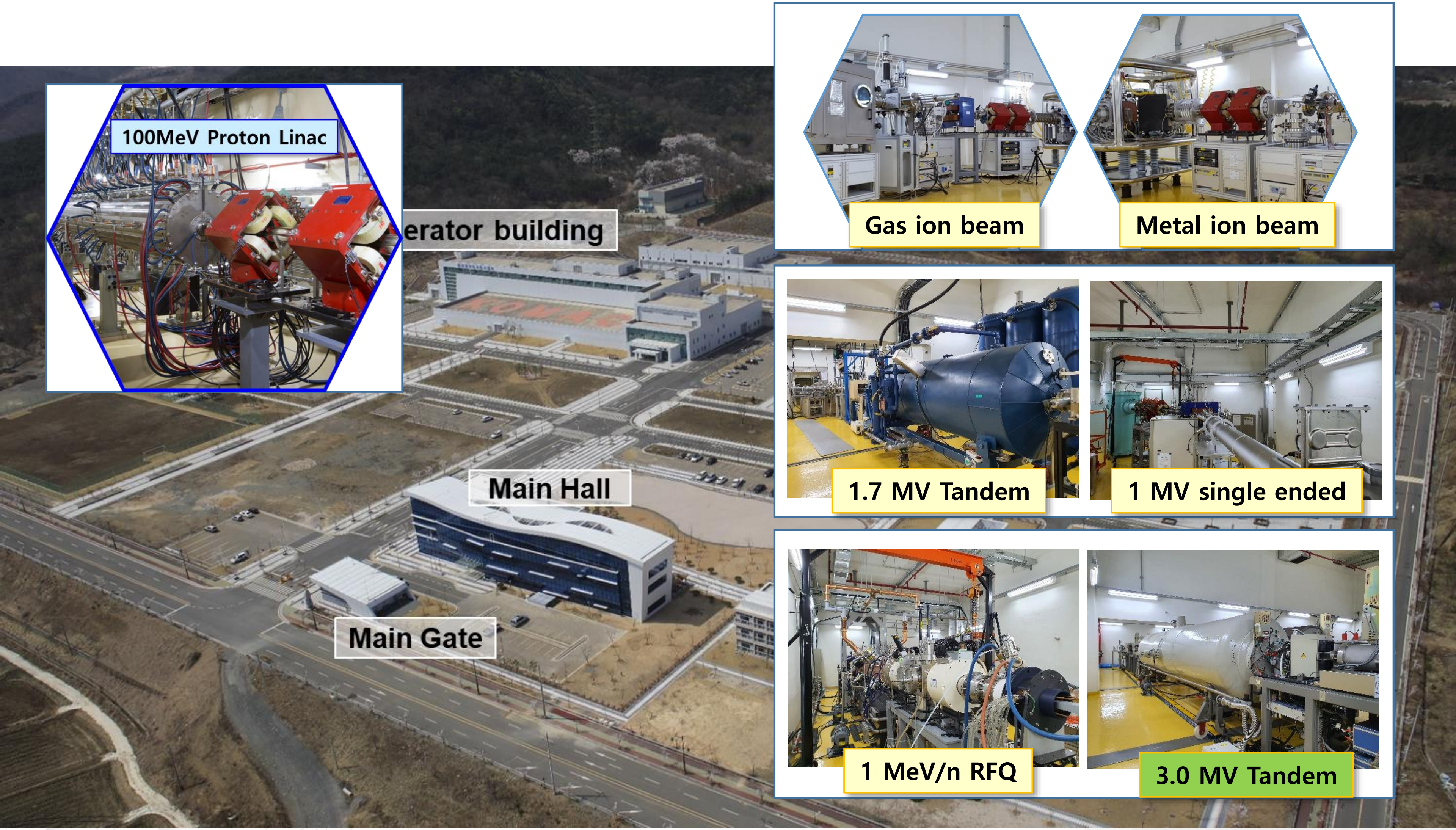
01 KOMAC Overview

Korea Multi-purpose Accelerator Complex

- One of branches of Korea Atomic Energy Research Institute (Gyeongju)
- Operation since 2013

KOMAC Site

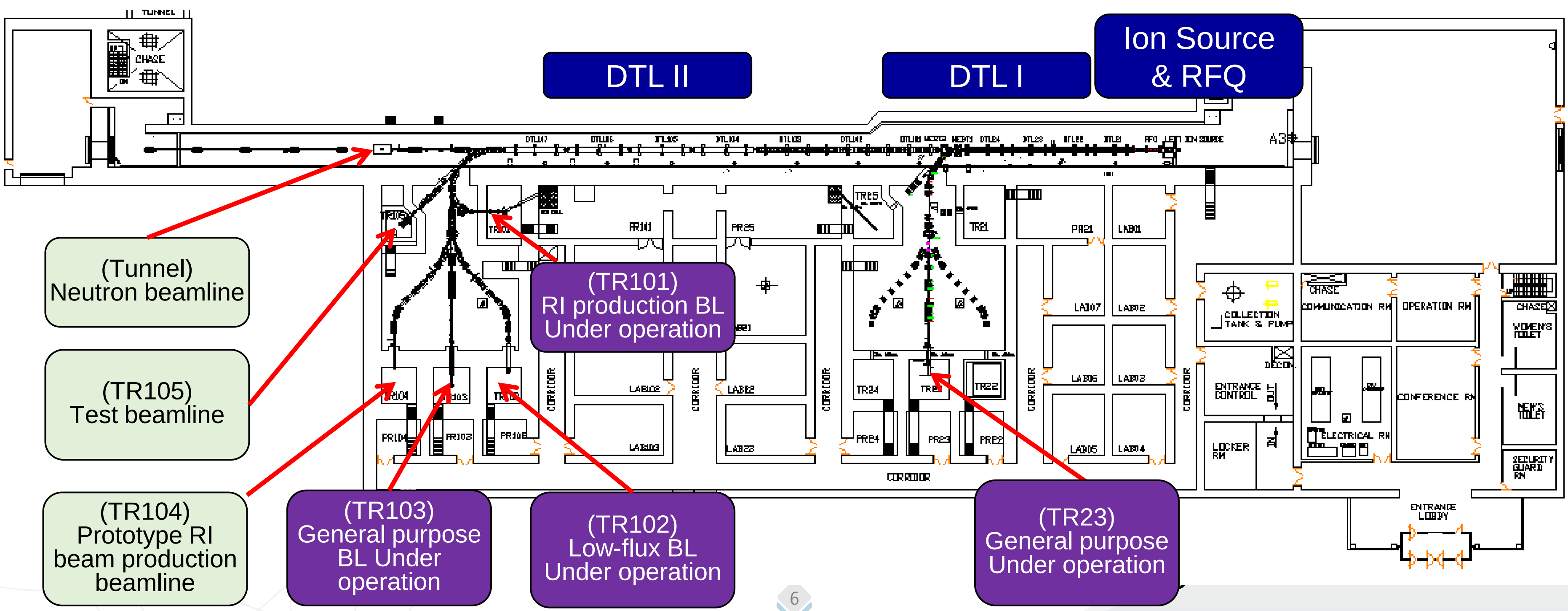

100MeV Proton Linac
erator building
Main Hall
Main Gate
Gas ion beam
Metal ion beam
1.7 MV Tandem
1 MV single ended
1 MeV/n RFQ
3.0 MV Tandem

100 MeV Linac

Features of KOMAC 100MeV 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
- 6 Beamlines for 20 MeV & 100 MeV

Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160



Achievements during Last Few Years

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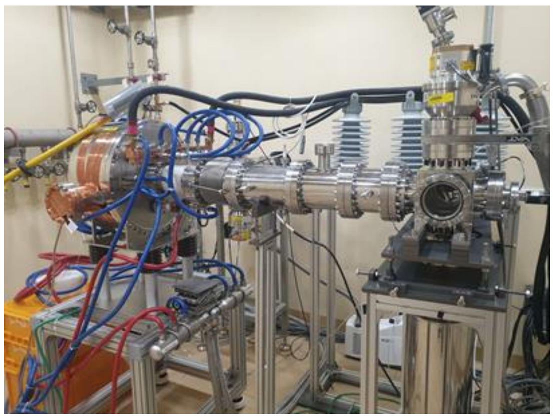
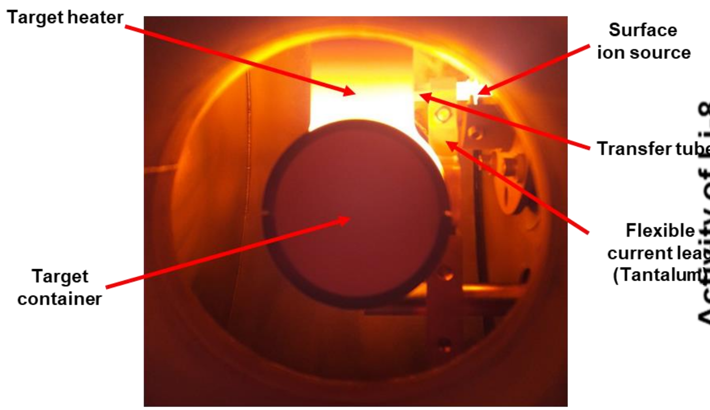
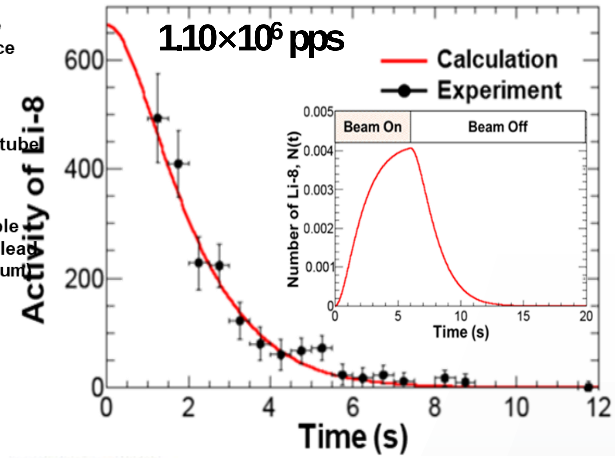
- **Radioisotope beam production (Li8), (2020)**
- **Terrestrial radiation (neutron) Test on Semiconductor devices**
- **Space radiation (proton) test on space parts**
- **Included in the facility list of JEDEC, JESD89B, (2021)**

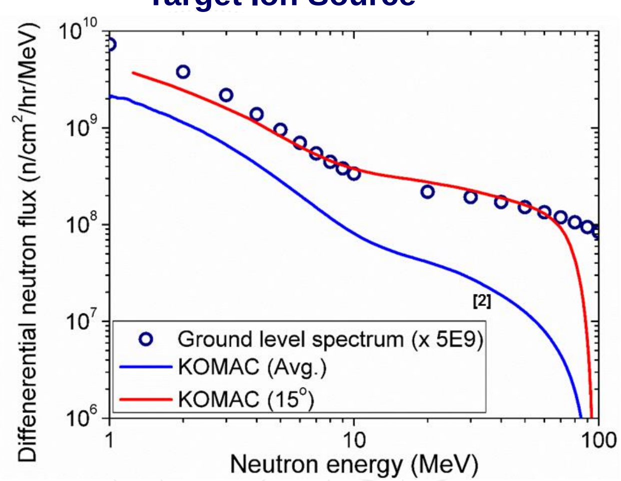


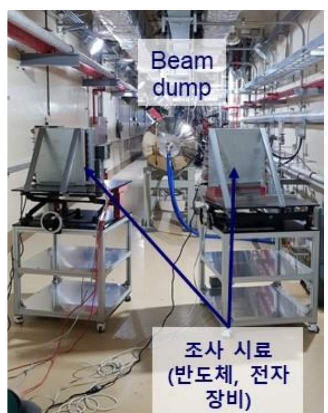
Target Ion Source

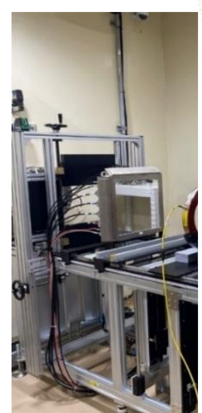


Target & ion source heating









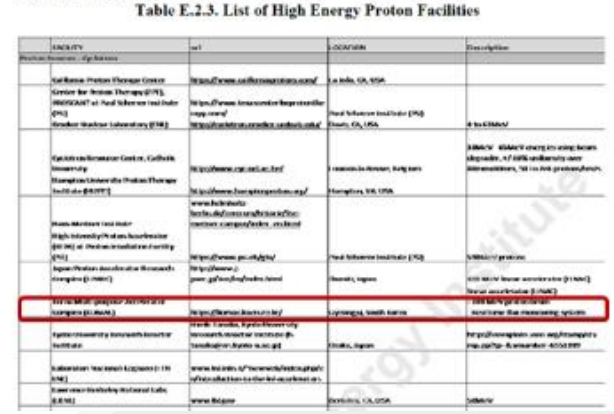
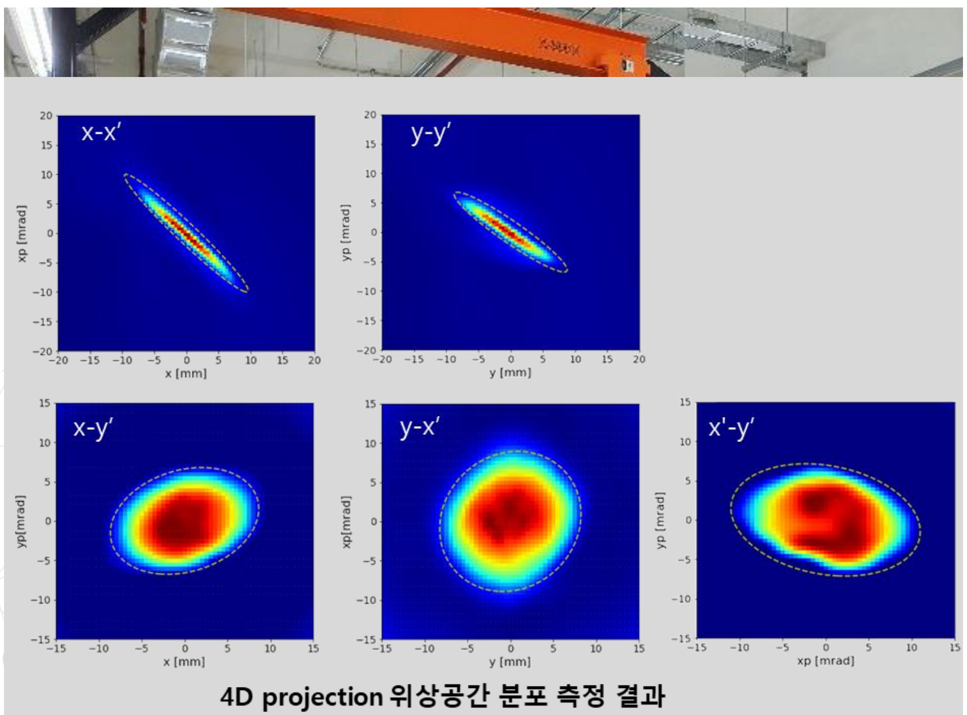

E.2 Facilities list (cont'd)

Table E.2.3. List of High Energy Proton Facilities

JESD89B facility list

Achievements during Last Few Years

- Beam Test Stand (BTS, injector + RFQ + beam line) operation, (2022)
- Operation time exceeds 30,000 hours (2022)
- Medical RI production (^{82}Sr) (2023)
- Space environment chamber installation (2023)
- 4D beam distribution in phase space (2024)
- 24 hour user beam service starts (2024)
- Energy upgrade preparation



BTS

30,000 hrs Ceremony (22.12.29)

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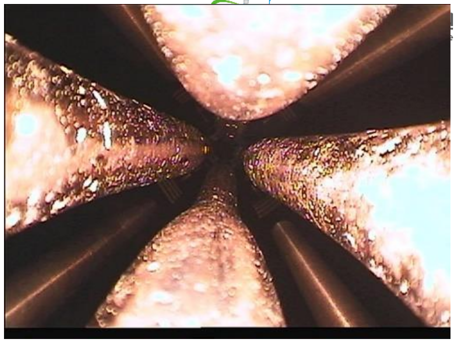
02

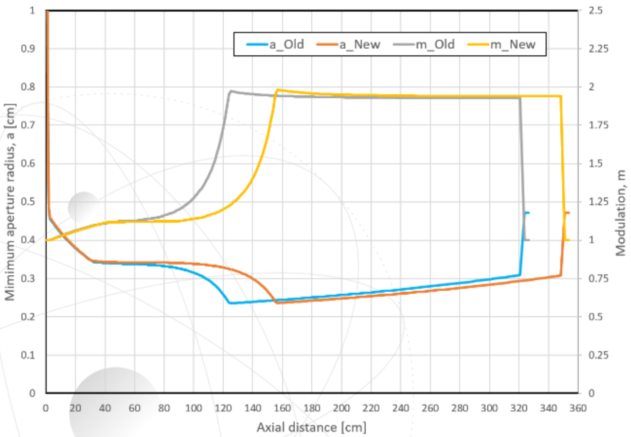
100 MeV Linac Issues

3 MeV RFQ - Aging

- Operation since 2005 (First developed RFQ in Korea)
    - Low transmission rate
    - Field flatness check – dipole field tilting – retuning
    - Vane erosion check
- Spare RFQ is necessary (SNS, J-PARC, LINAC4 RFQ case)
- Spare RFQ development
    - New design, 86.5 keV / 550 keV -> 54.0 keV / 580 keV (RFQ length : 3.2 m -> 3.5 m)
    - Field stabilization by dipole stabilization rods only (remove the coupling plate)
    - 4 sections -> 3 sections (in house brazing furnace)
    - New brazing technique (with modified filler groove)
- Spare RFQ is under construction, completed at 2025



Vane erosion observed using endoscope at April 30, 2021



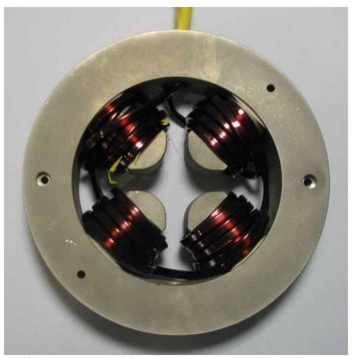
Focusing strength profile and vane radius (original and new one)

In-house brazing furnace

Spare RFQ under coarse machining

20 MeV DTQ - Aging

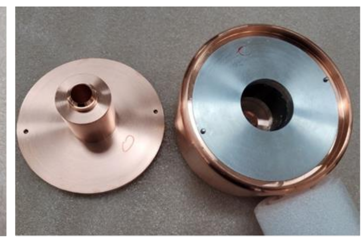
- Operation since 2005 (First developed DTL in Korea)
  - Used pool type electromagnet inside drift tube
  - Damaged insulation and corrosion of the yoke: electromagnet fault
  - Changed the fault electromagnet
- Considering the PMQ for 20 MeV DTQ: Prototyping completed
  - 16 segments trapezoidal Halbach geometry with Sm_2Co_{17} (n-induced degradation, temperature effect)



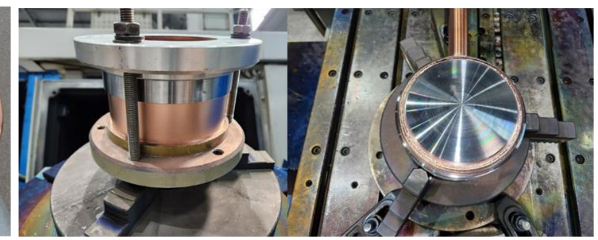
Pool type electromagnet (20 MeV DTL)

Cutting view of the drift tube
Poor insulation between windings and yoke

Array assembly



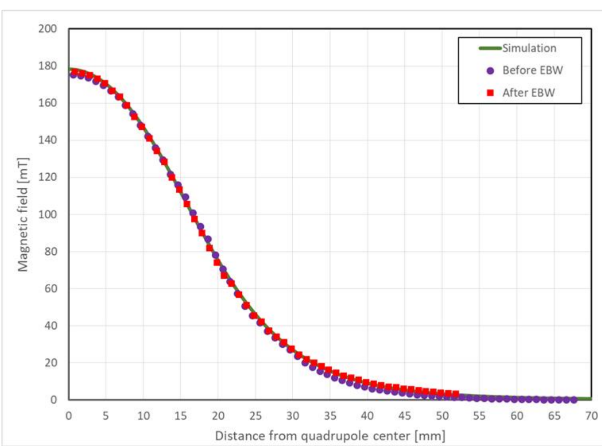
Installation



Magnetic shield

E beam welding

Vacuum test

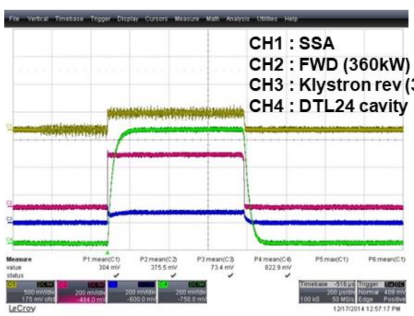


Magnet measurement (Before and after the welding)

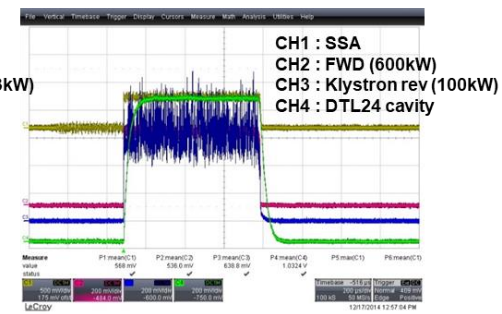
Fabrication process of the prototype PMQ

Klystron

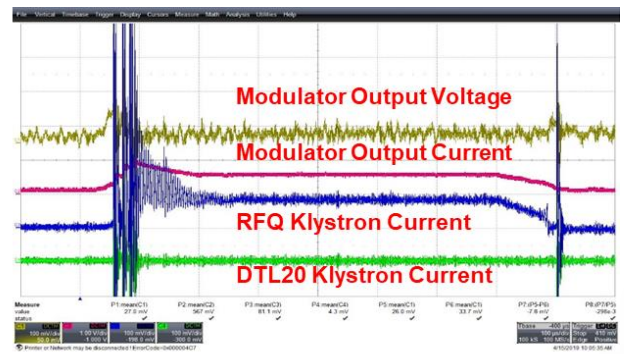
- 350 MHz, 1.6 MW RF peak power, 9% duty factor
  - 9 klystrons are used, modified from existing klystron (CERN, J-PARC)
- Klystron instability at specified power level (old klystron)
  - Instability and side band, gun perveance > 2 uperv. (?), change the klystron
- Breakdown at high voltage connector to oil tank (new klystron)
  - Replace with CERN type connector
- Weak points of the klystron are overcome



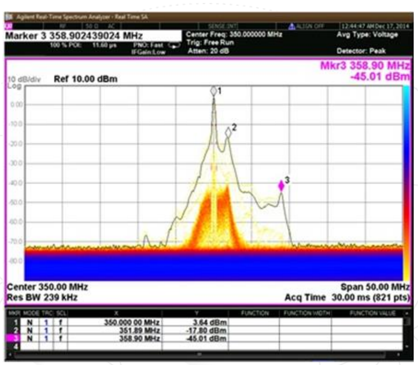
RF Waveform in normal condition



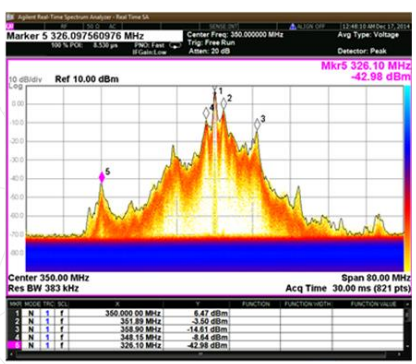
RF Waveform in abnormal condition



Breakdown in the cable connector in the oil tank



Spectrum in normal condition



Spectrum in abnormal condition

Spectrum in normal and abnormal condition

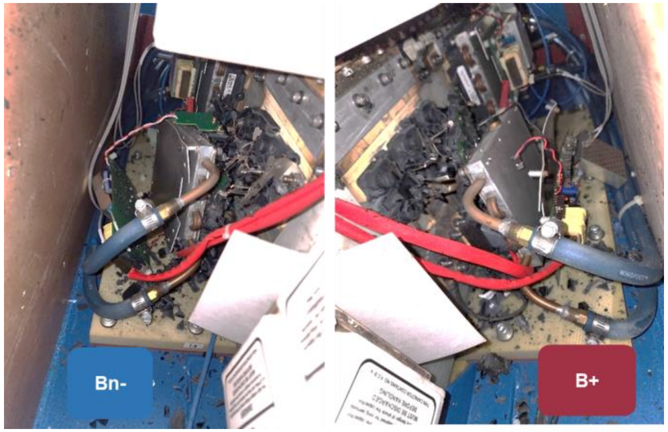
Previous connector

New connector

Change the connector

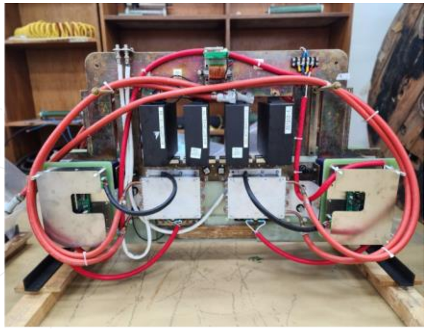
Modulator

- -110 kV, 50 A, 5.5 MW peak, 10 % duty (purchased from foreign company)
  - 4 modulators are used: One modulator drives 2 ea. or 3 ea. klystrons
  - High voltage converter modulator type (full bridge converter topology)
  - High frequency switching and transformers, without crowbar
  - Modulator itself is no longer available from the vendor
- IGBT blasting issue
  - Shoot through of the full bridge converter
  - Design and develop new switching plate protected against the external EMI (EMI shielding and high voltage insulation)
  - Design and develop new controller with the latest FPGA and additional IGBT shoot-through protection circuit
- Many parts could be delivered with domestic technology



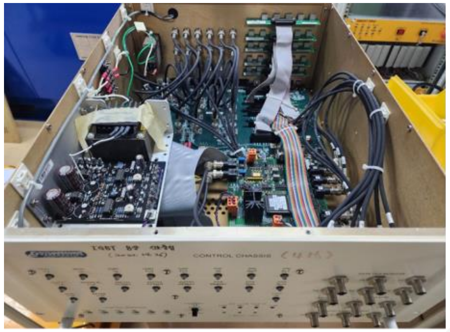
Catastrophic IGBT blasting

Original switching plate



Improved switching plate

Switching plate improvement



Original controller

Improved controller

Controller improvement

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03 Energy Upgrade Plan

Long-Term Roadmap

	2020 ~ 2024		2025~2029		2030~2040
100 MeV	User demand analysis	Beamline development (5 ea. → 10 ea.)		User service for research and industrial purpose	
200 MeV	Preliminary feasibility study (2021~)	Development			User service for research and industrial purpose
1000 MeV Grade			User demand analysis (~2029)		Preliminary feasibility study (2030~)

* National Advisory Council on Science & Technology, Roadmap of large scale accelerators and their operation strategies, March 2020

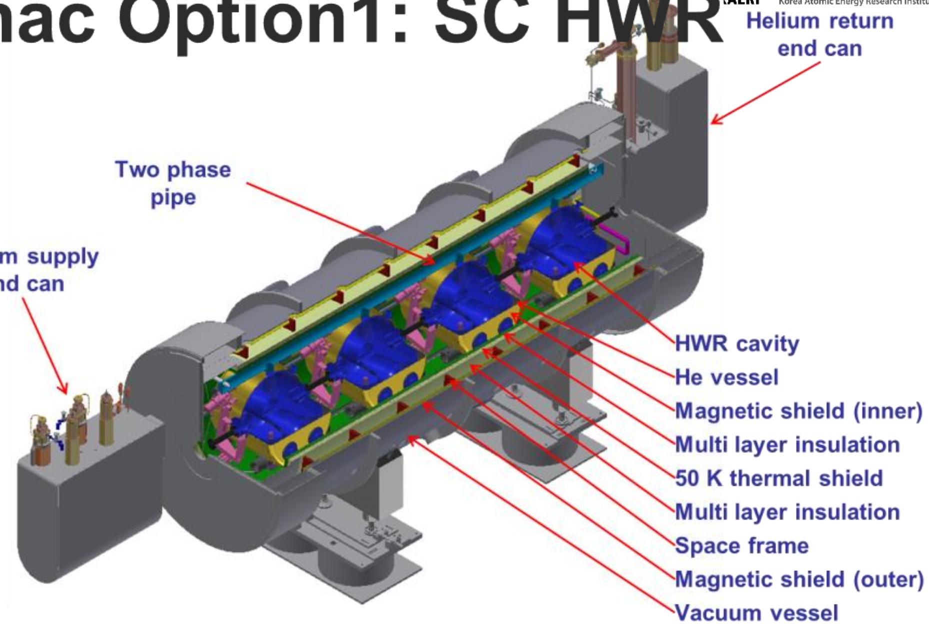
Short Term Plan (KOMAC 2^{nd} Phase) - 200 MeV Linac

- Why 200 MeV
  - Increasing demand
    - Terrestrial radiation test of semiconductor
    - Space radiation test of space parts
  - Common to Short / long pulse neutron source
    - RCS injector: > 200 kW @ 1 GeV
    - Linac injector: accelerating structure transition
  - 100 MeV -> 200 MeV
    - Single accelerator structure
    - Possible within existing site (without further site preparation)
  - Required modifications for RCS option
    - H- source
    - MEBT (chopper)
    - Increasing beam current up to 40 mA

200 MeV Proton Linac Option1: SC HWR

- Type: Superconducting HWR
- Use proven technology
- Cylindrical cryomodule
- 9 CMs, 36 HWRs from 100 to 200 MeV

Parameter	Unit	KOMAC HWR(0603)	FRIB (2013)
Frequency	MHz	**350**	322
Optimum beta	-	**0.56**	0.53
Stored energy	J	**23.1**	29.48
V_{acc} (@β_{opt})	MV	**3.61**	3.7
V_0	MV	**4.14**	-
E_{acc} (@β_{opt})	MV/m	**7.53**	7.5
E0	MV/m	**8.63**	-
Ep	MV/m	**29.08**	26.5
Bp	mT	**61.66**	63.2
Ep/Eacc	-	**3.86**	3.53
Bp/Eacc	mT/(MV/m)	**8.19**	8.43
R/Q (@β_{opt})	ohm	**256.6**	229.5
G	ohm	**116.1**	107.4
Q_0 (@Rs=20 nΩ)	-	**5.81E+9**	-
Cavity loss (@R_S=20 nΩ)	W	**8.75**	7.9
Aperture	mm	**40**	40
L_{eff} ($\beta_{opt}\lambda$)	m	**0.480**	0.493
Cavity inner diameter	m	**0.45**	0.46



- CM length: 3,600 mm (5,430 mm including end cans)
- CM diameter: 1,200 mm
- Heat load per CM

	2 K	50K
Static	11.0 W	144 W
Dynamic	8.1 W	-
U-tube and line*	10 W	24 W
Total	29.1 W	168 W

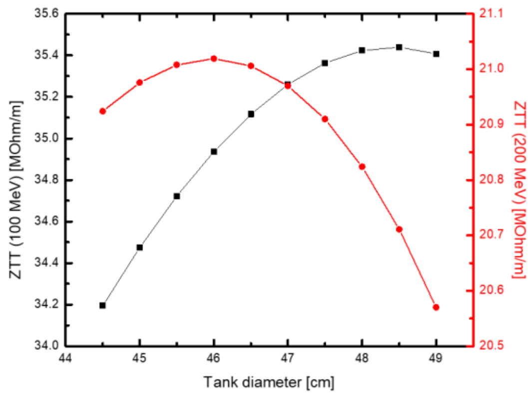
130 W** (4.5 K equivalent) / cryomodule

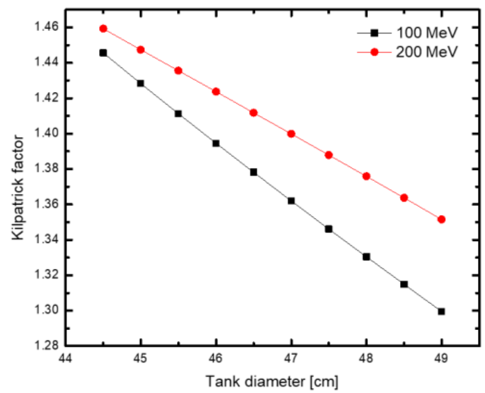
* Ref. SNS cryomodule parameter
** Including 25% margin

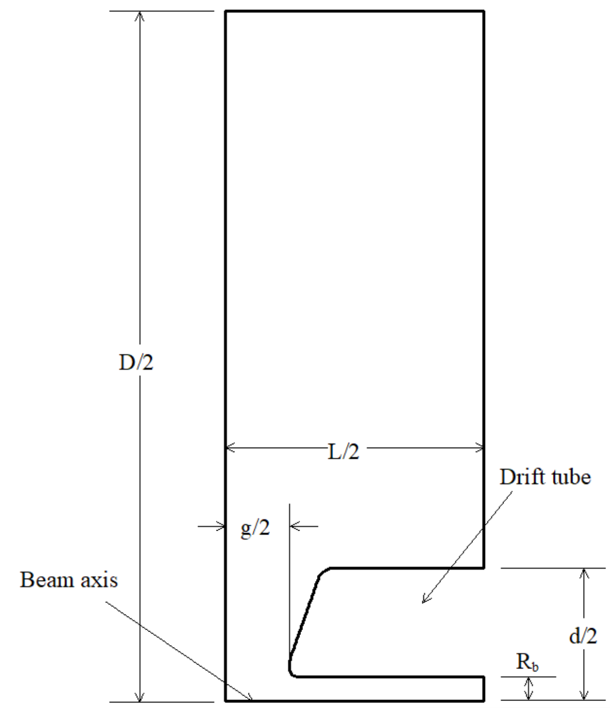
200 MeV Proton Linac Option2: NC SDTL

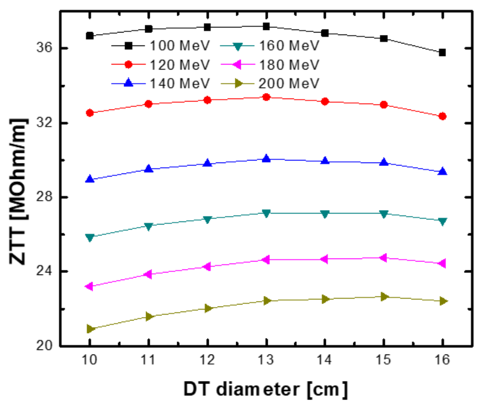
- **Design Consideration**
  - **- Separated type Drift Tube Linac**
  - **- Use proven technology**
  - **- (Doublet) focusing structure external to cavity**
  - **- Gap between SDTL tanks: 2 $\beta\lambda$**
  - **- Existing klystrons and modulators can be used**
- **Cell and tank Design**
  - **- Bore diameter: 30 mm**
  - **- Maximum ZTT**
  - **- Kilpatrick < 1.5**
  - **- RF power per tank < 1.2 MW @ 40 mA (1.6 MW klystron)**

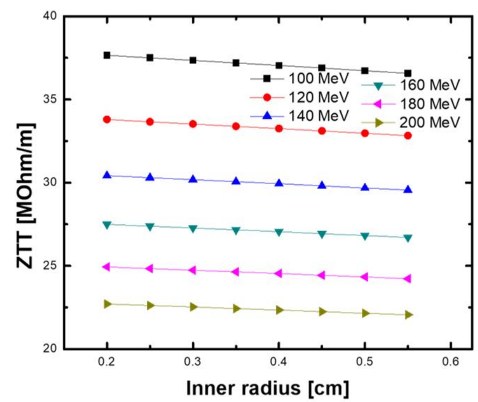
200 MeV Proton Linac Option2: Cell design







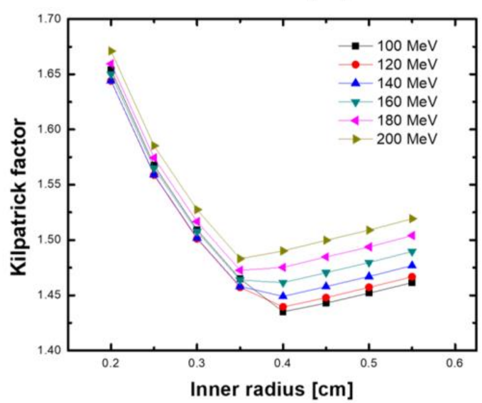


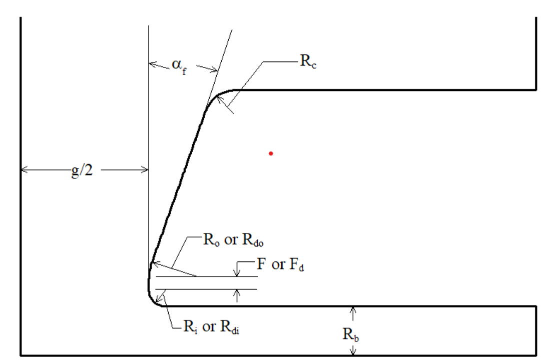


- **Cell optimization**

- 8 parameters with given frequency and energy

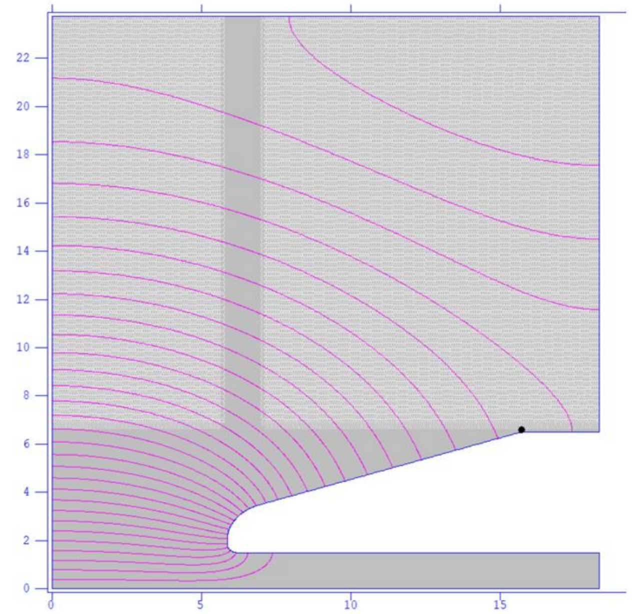
- ZTT vs. Kilpatrick

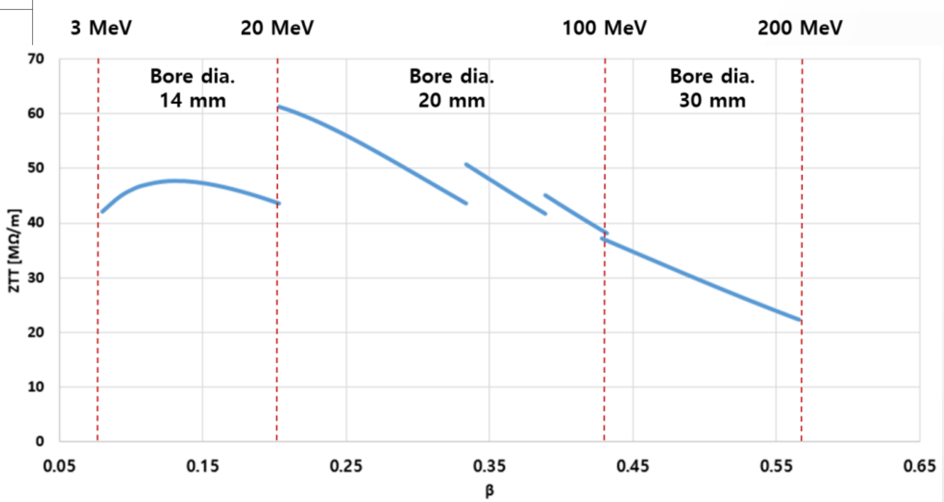




200 MeV Proton Linac Option2: Cell design

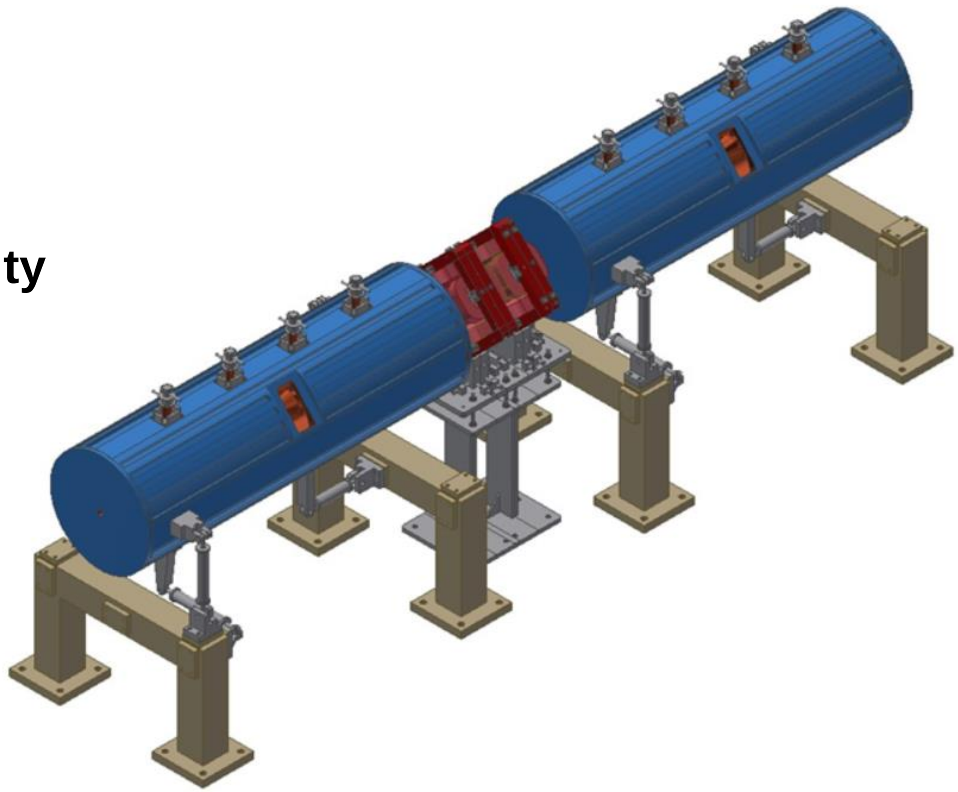
Parameter	Value
RF frequency	350 MHz, <1.2MW
Reference temperature	27 ^{o}C
Energy	100 MeV ~ 200 MeV
Tank diameter	491.6 mm
Drift-tube diameter	140 mm
Bore radius	15 mm
Drift-tube face angle	70 degrees
Drift-tube flat length	1 mm
Corner radius	0.5 cm
Inner nose radius	4 mm
Outer nose radius	18.5 mm
Stem diameter	36 mm
Max. Kilpatrick	1.4
E0	3.8 MV/m





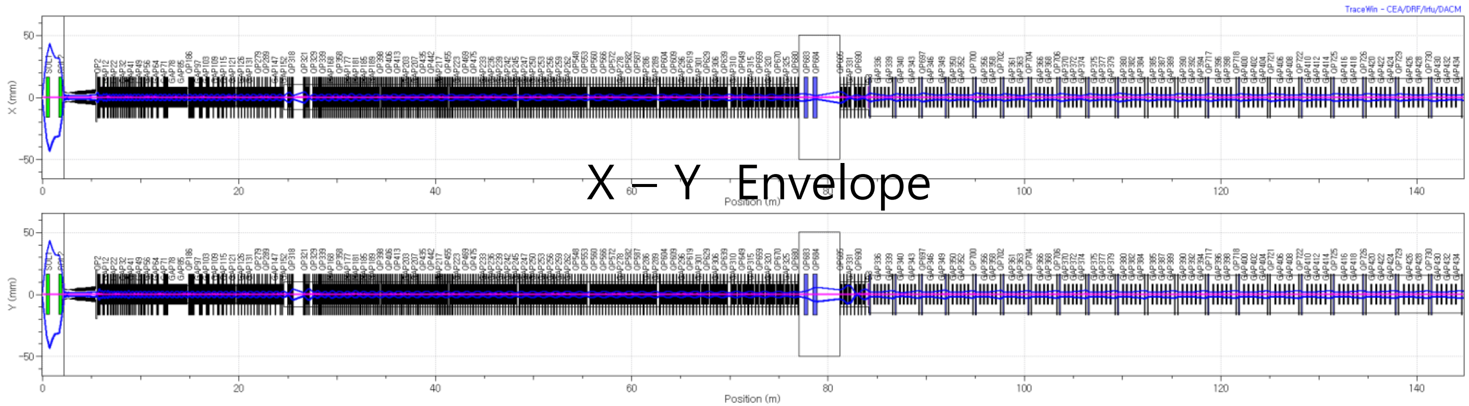
200 MeV Proton Linac Option2: SDTL design

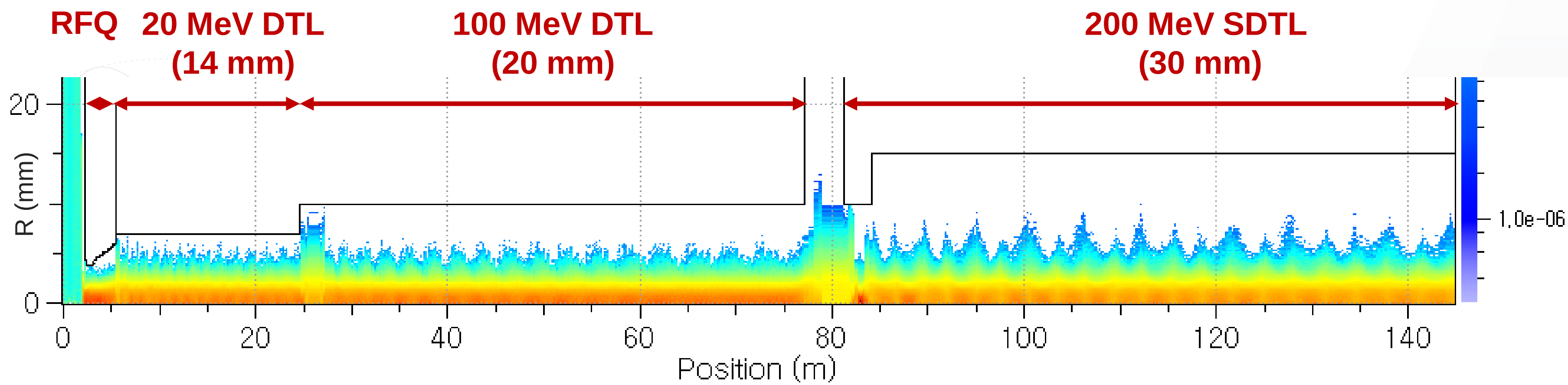
- Frequency: 350 MHz
- Energy range: 102.6 MeV ~ 200 MeV
- E0: 3.8 MV/m (Max. Kilpatrick < 1.4)
- RF power per tanks: < 1.2 MW (@ 40mA)
- Number of drift tubes per tank: 4
- Number of cells per tank: 5
- Tank inner diameter: 491.6 mm
- Doublet focusing external to cavity
- Gap between SDTL tanks: 2 $\beta\lambda$
- Total number of SDTL tanks: 20
- Real estate length: 60 m



200 MeV Proton Linac Option2: Beam

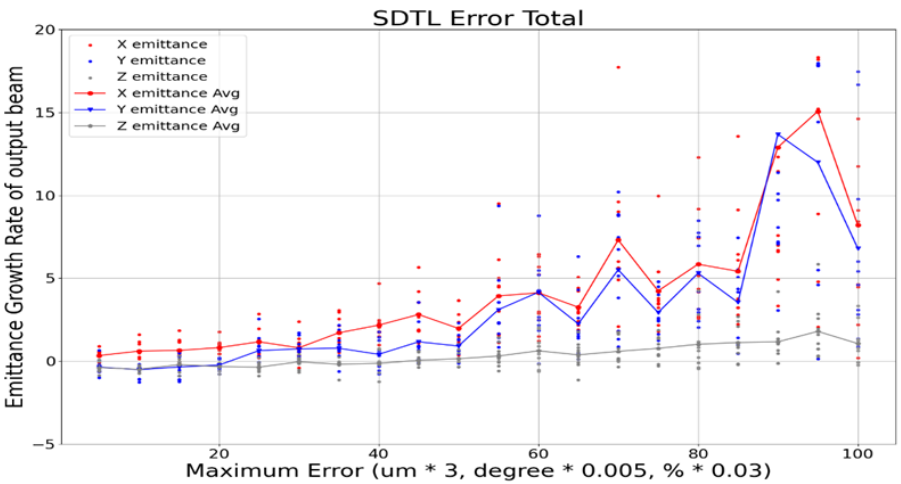
- Doublet between SDTL tanks
- Bore diameter 30 mm
- Matching section between 100 MeV DTL and 200 MeV SDTL
- Optimization is on going



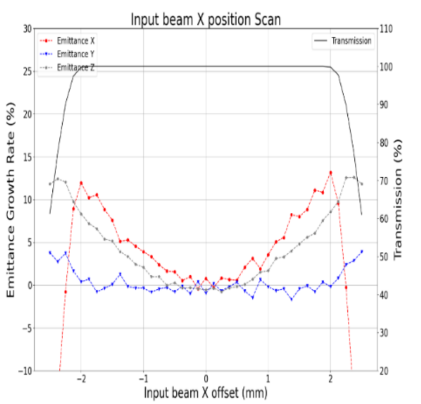


Radial beam density profile

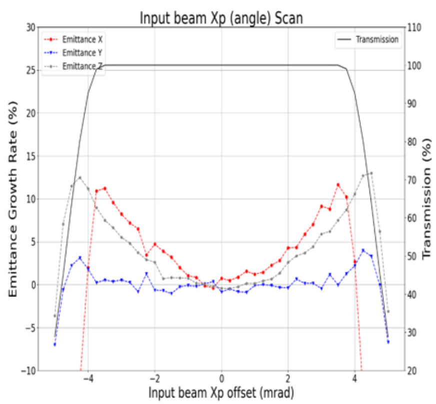
200 MeV Proton Linac Option2: Error study



Cavity and quadrupole error



Input beam position



Input beam angle

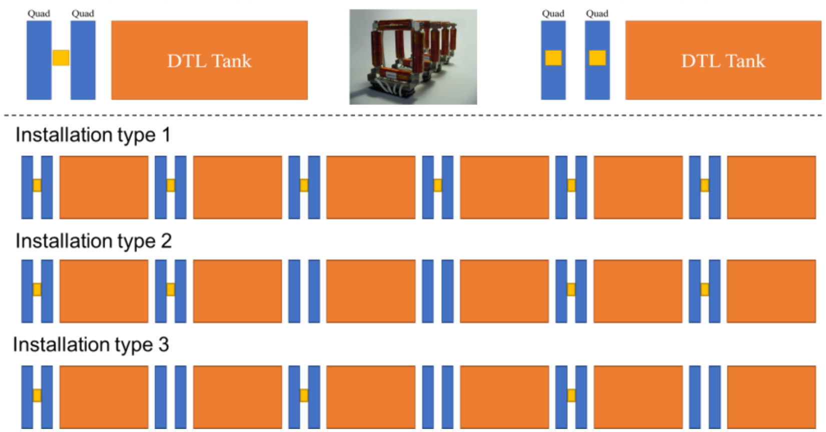
- **Beamline (Quad, cavity) error and input beam error**
- **Error distribution type: uniform distribution**
- **# of error lattice: 200 (10 lattice × 20 steps)**
- **Error statistical set up: 10 lattice per step**
- **# of macro particles: 10,000**
- **Criteria: emittance growth < 5%**

Error criteria for SDTL lattice

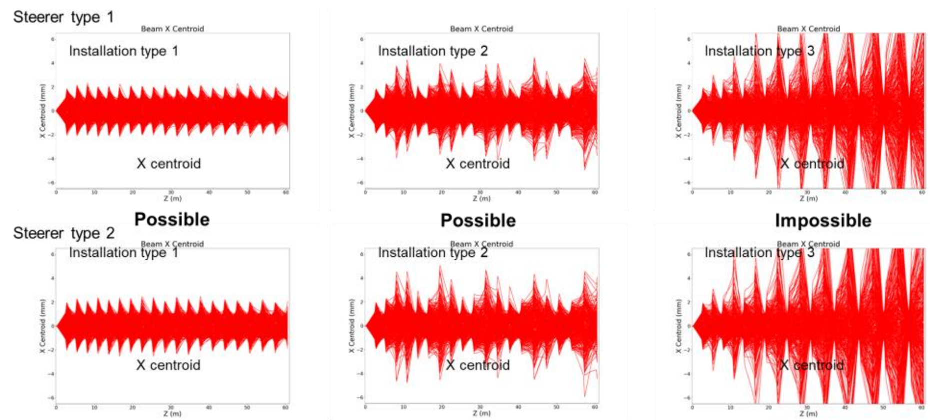
Error Type	Value
Quad magnet displacement (dx, dy)	$\pm 150\ um$
Quad magnet rotation (ϕ_x, ϕ_y, ϕ_z)	$\pm 0.25°$
Quad magnet gradient	$\pm 1.5\%$
Cavity displacement (dx, dy)	$\pm 150\ um$
Cavity rotation (ϕ_x, ϕ_y)	$\pm 0.25°$
Cavity Acc. Voltage	$\pm 1.5\%$
Cavity Phase (ϕ_{sync})	$\pm 1.5°$
Input beam Position (x, y)	$\pm 1\ mm$
Input beam angle (x, y)	$\pm 2\ mrad$

200 MeV Proton Linac Option2: Orbit correction

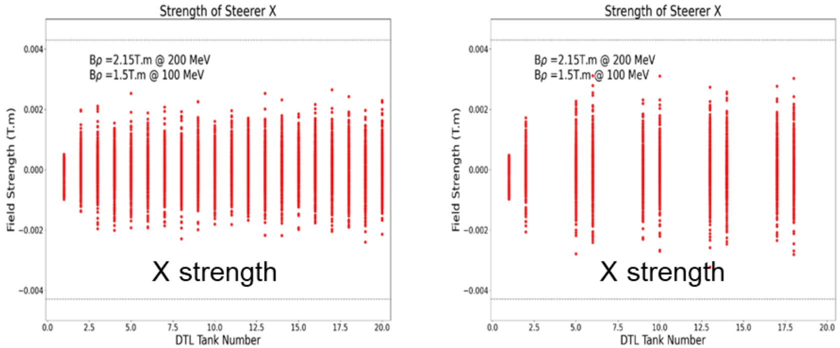
- 2 steerer types and 3 installation types
- Error type: Quad and cavity errors
- Less dependent on steerer type, 2 installation types are reasonable
- Required maximum field of steerer: 4.3×10^{-3} T m (2 mrad @ 200 MeV)



Steerer type and installation type

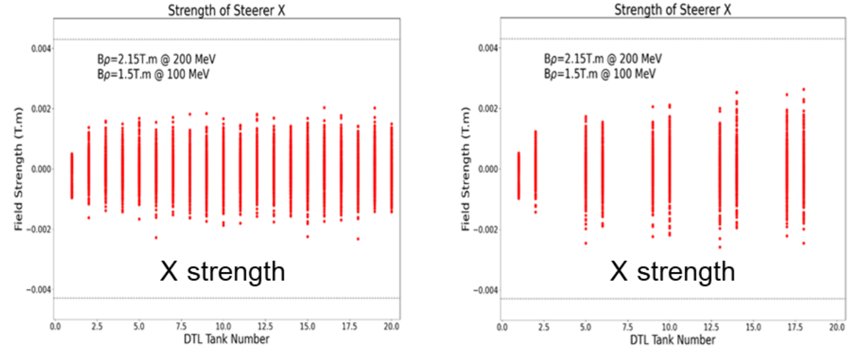


Beam centroid depending on steerer and installation type



Installation type 1 Installation type 2

Required field strength in steerer type1



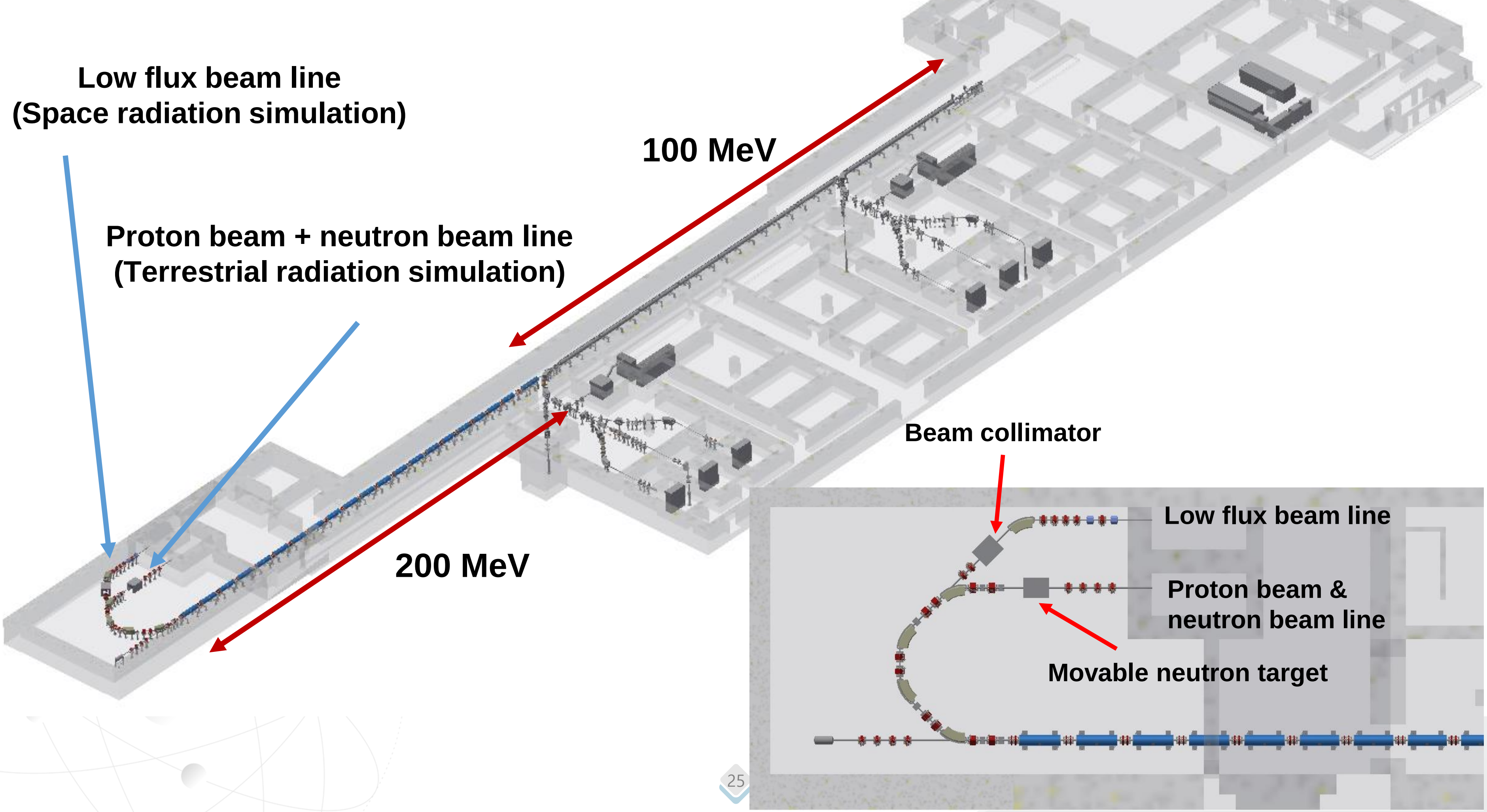
Installation type 1 Installation type 2

Required field strength in steerer type2

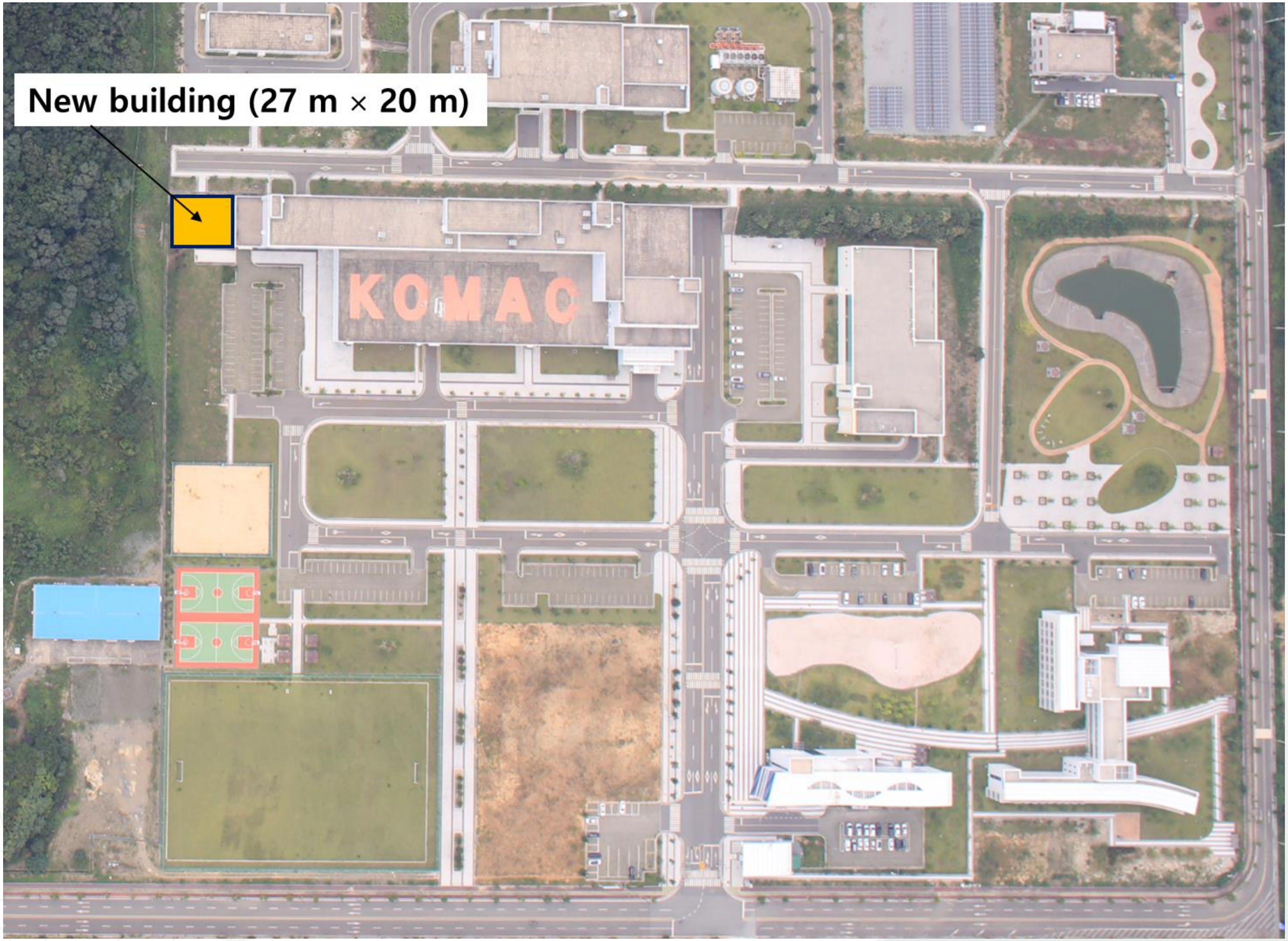
200 MeV Layout

Based on user demand, we are planning to install two beamlines

- **Low flux proton beamline (beam collimator and octupole magnets)**
- **Proton and neutron beamline (movable neutron generation target)**



200 MeV building extension



Summary

- **KOMAC overview**
  - **- 4 beamlines are under user service**
  - **- Achievement of application field development as well as machine itself**

- **100 MeV linac technical issues**
  - **- RFQ aging**
  - **- DTL aging (DTQ)**
  - **- Klystron**
  - **- Modulator**

- **Future plans**
  - **- 200 MeV linac (KOMAC phase 2)**
    - *** Considering 1 GeV machine (KOMAC phase 3) options**

더 나은 세상을 위한 **원자력기술**
국민과 세계가 지지하는 한국원자력연구원

Thank you
for your attention

한국원자력연구원
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