# Accelerator Activities in Korea

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**October 26, 2022**

# Accelerator facilities in Korea

**O'Chang (KBSI, PAL)**
- 4GSR (synchrotron)

**Dajeon (RISP - IBS)**
- RAON (Rare isotope accelerator)


**Pohang (PAL - POSTECH)**
- PLS-II (synchrotron)
- PAL-XFEL
- PAL-EUV (synchrotron)

**Kyungju (KAERI)**
- **KOMAC** (Proton linac)

**Busan (DIRAMS, KIRAMS)**
- 6 MeV C-band LINAC (radiotherapy-electron)
- 50MeV e-FLASH Radiotherapy

# Pohang Accelerator laboratory (PAL),
# Pohang University of Science & Technology (POSTECH)

# PAL Accelerators

I. PLS (synchrotron, 2.5 GeV, 200 mA): 1988 - 2011
- First large-scale accelerator

II. Major upgrade of the PLS (3GeV 400 mA)
- 3.0 GeV **PLS-II** upgrade 2009 - 2011
- User service 2012 -
- With 3-500 MHz SRF cryomodules

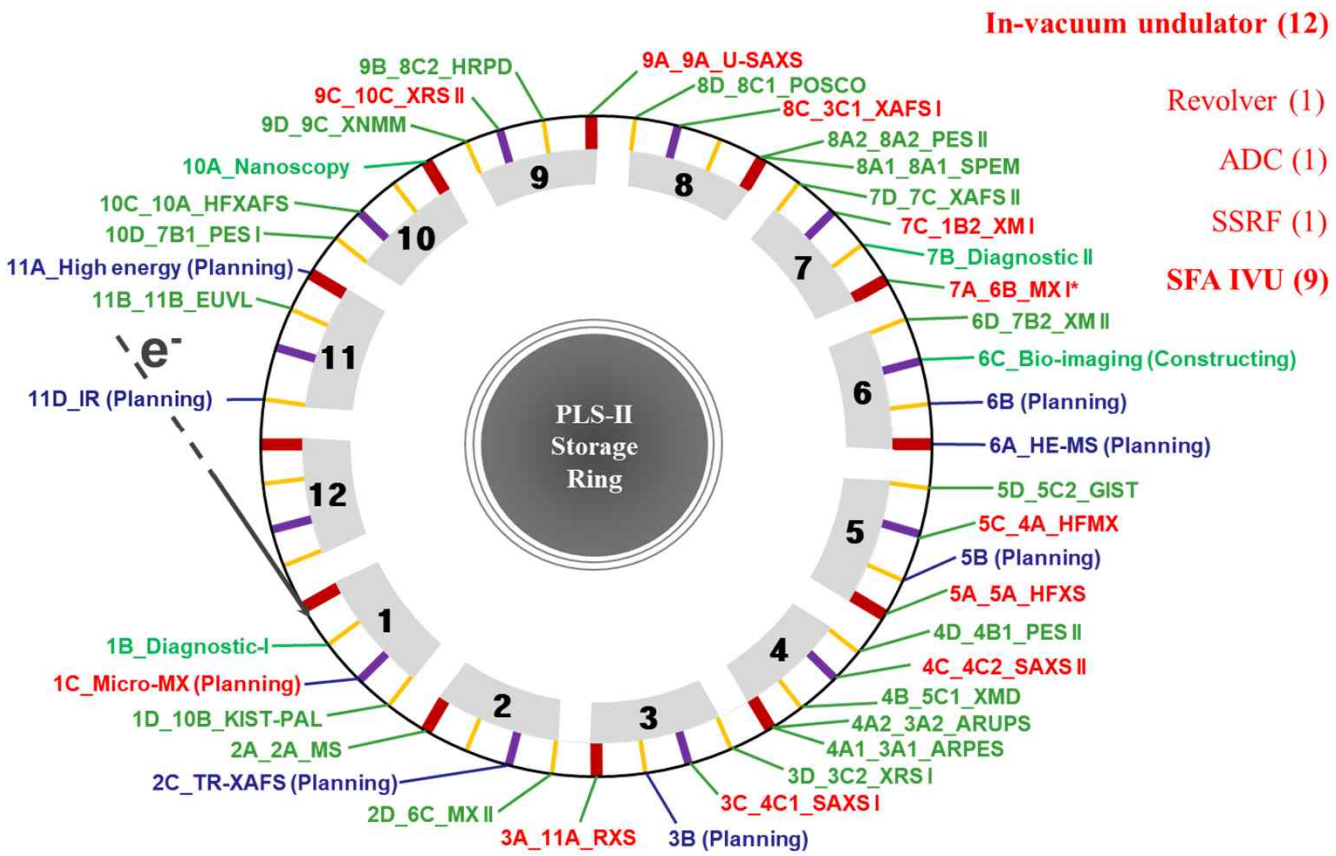
III. PAL-XFEL (11 GeV)
- Construction including commissioning 2010 - 2016
- Saturation of 0.1 nm FEL 2017
  (Demo experiment of coherent X-ray imaging)
- User service 2017 -

IV. PAL-EUV (400 MeV, Synchrotron)
- Construction including commissioning 2020 - 2023
- User service 2023 -
- For semi-conductor R&D

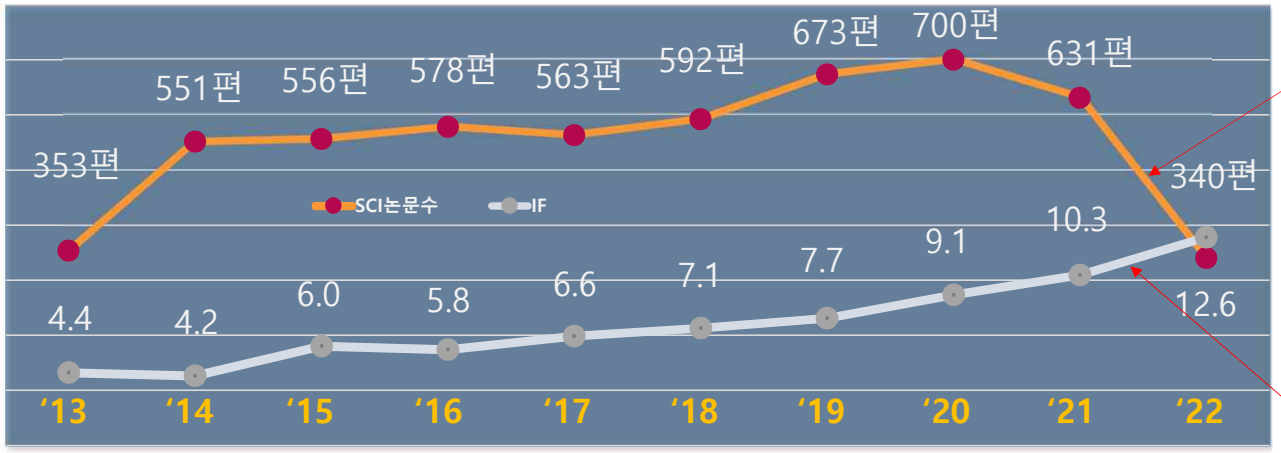

PAL POHANG ACCELERATOR LABORATORY

# Beam Line Map and Accelerator Tunnel of PLS-II

Total 32 beamlines with24 IDs and 8 BMs



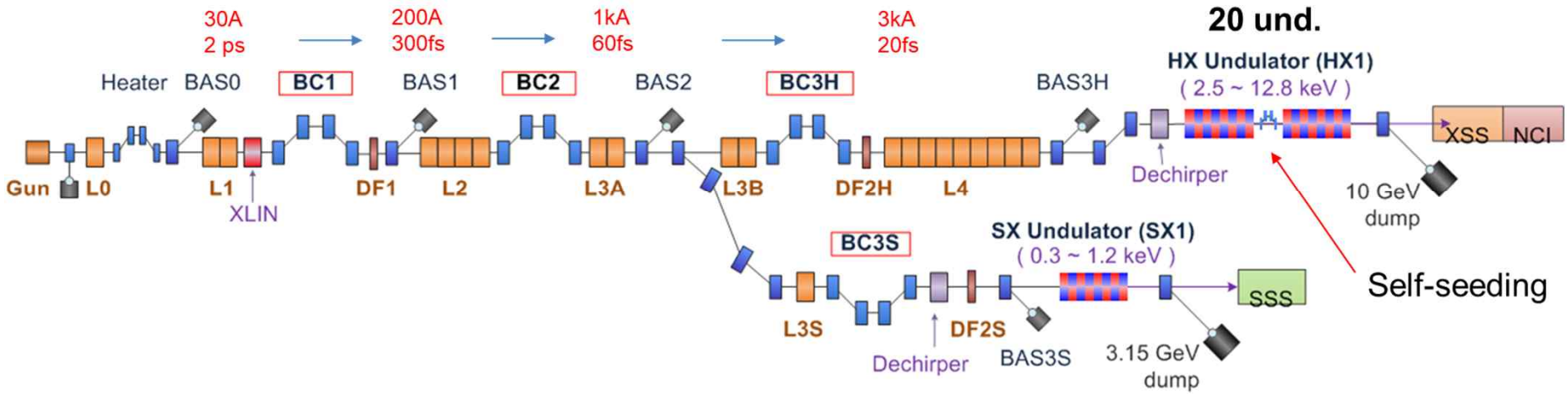

# User Achievements with PLS-II and PAL-XFEL (September, 2022)




Number of SCI publications

Average IF each paper

# PAL-XFEL Overview



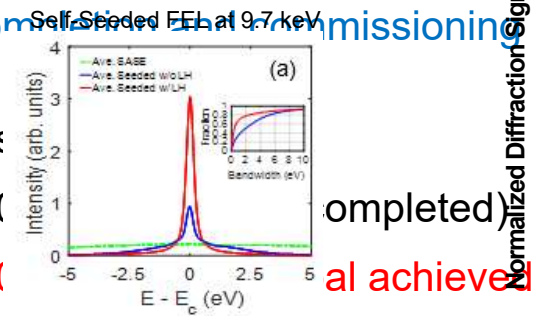

**Main parameters**

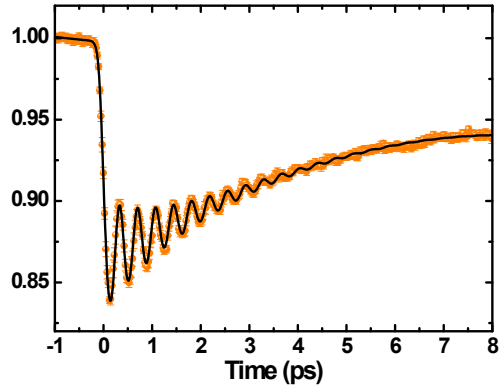
| | |
|---|---|
| e⁻ Energy | 11 GeV |
| e⁻ Bunch charge | 20-200 pC |
| Slice emittance | < 0.4 mm mrad |
| Repetition rate | 60 Hz |
| Pulse duration | 5 fs – 50 fs |
| Peak current | 3 kA |
| SX line switching | DC magnet |
| | (to be changed to Kicker by 2020) |

| Undulator Line | HX1 | SX1 |
|---|---|---|
| Photon energy [keV] | 2.0 ~ 14.5 | 0.25 ~ 1.25 |
| Beam Energy [GeV] | 4 ~ 11 | 3.0 |
| Wavelength Tuning | energy | gap |
| Undulator Type | Planar, out-vac. | Planar |
| Undulator Period / Gap [mm] | 26 / 8.3 | 35 / 9.0 |

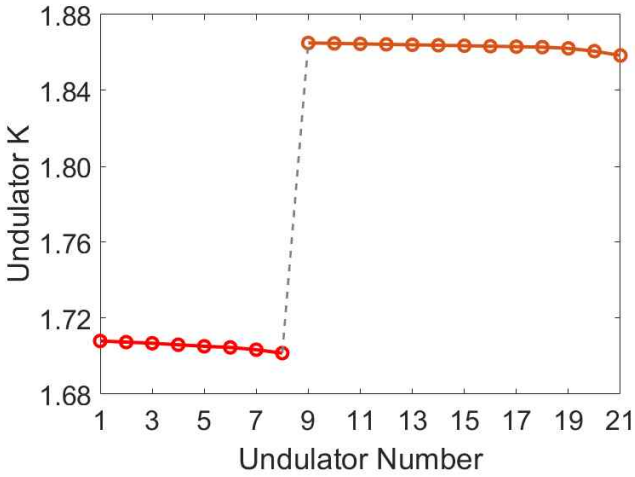
# Achievements from PAL-XFEL

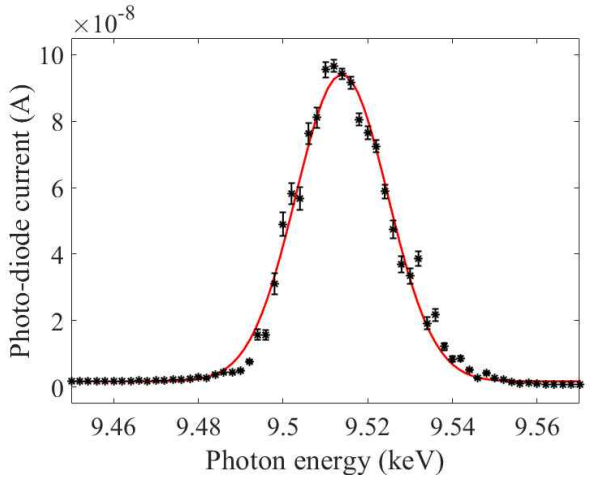
- April 2011 — PAL-XFEL project started
- Dec. 2015 — Installation co[illegible] commissioning started
- June 14, 2016 — First SASE las[illegible]
- Nov. 27, 2016 — Saturation of ([illegible]ompleted)
- March 16, 2017 — Saturation of ([illegible]al achieved)
- June 7, 2017 — First User Service
- Nov. 2018 — Permission granted to operate up to 11 GeV
- Mar. 2019 — 60 Hz operation started
- May 2020 — Self-Seeding operation
- Dec. 2021 — HX & SX parallel operation



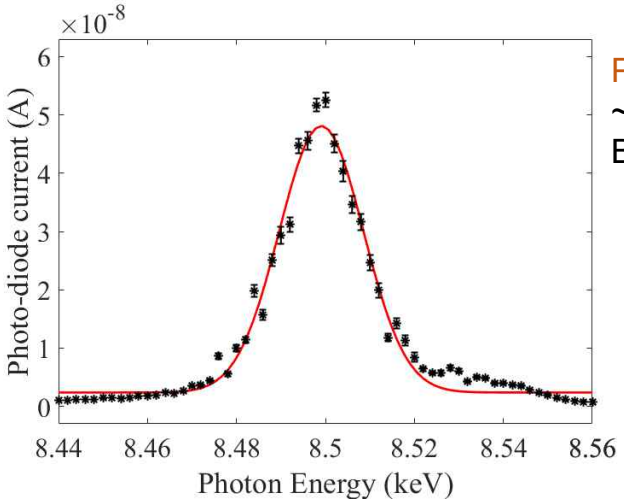



# Operation with Two-Color FEL in 2022



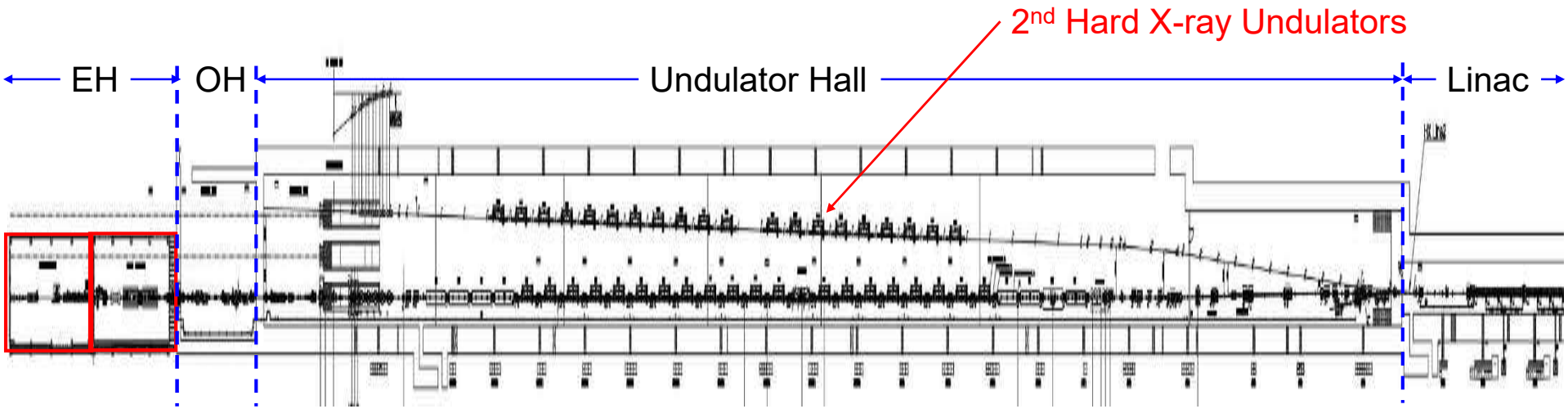

Pump (9.5 keV)
~224 μJ
BW ~10.9 eV (rms)




Probe (8.5 keV)
~257 μJ
BW ~9.5 eV (rms)

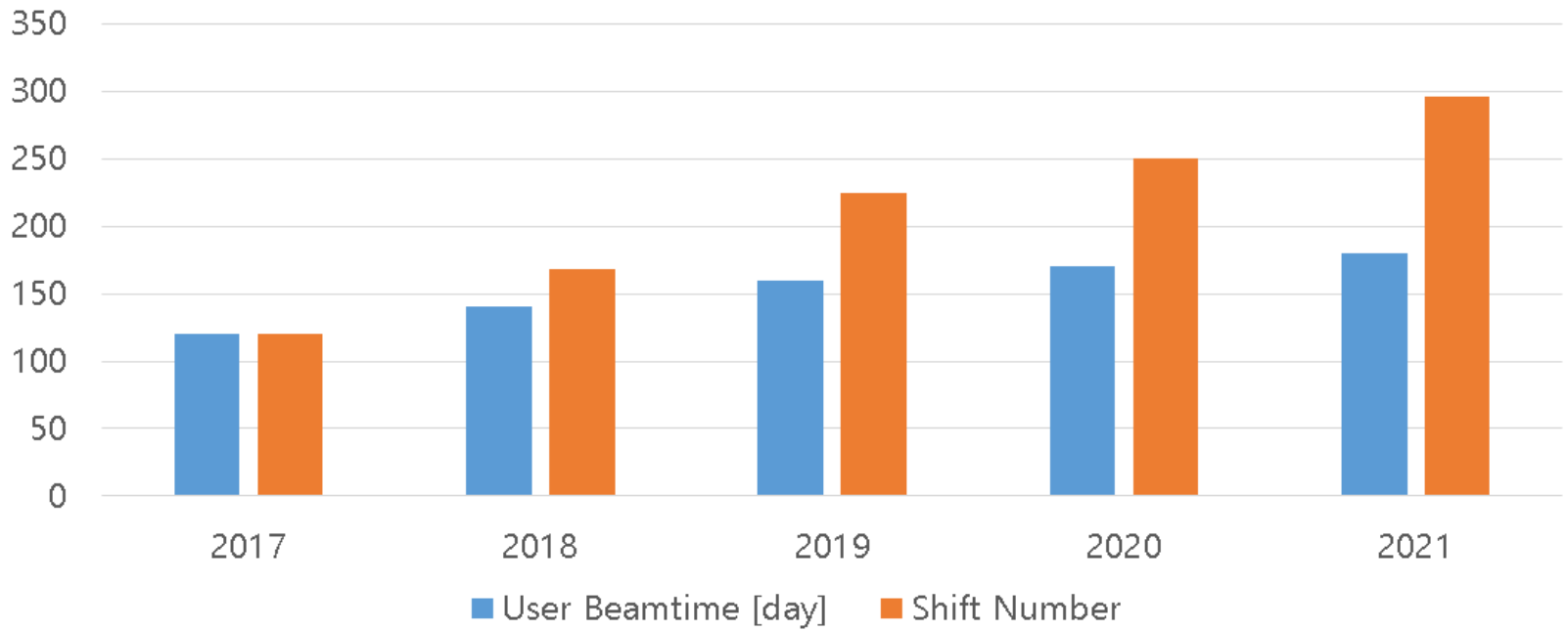
- 9.5 keV pump + 8.5 keV probe
- $E$_beam: 7.997 GeV
- Norm. emittance at HU1: 0.53 mm (hor.) / 0.38 mm (ver.)
- Peak current:  2.8 kA
- Delay between two pulses: 60 fs

# Plan for Second Hard X-ray Beamline




- Funding in 2025.
- Because of the limited space, the 2nd hard X-ray beamline will be installed in a tilted way.
- As an alternative, we proposed vertical polarization undulators for the 2nd hard X-ray beamline.
- In that case, 2nd hard X-ray undulators will be parallel to 1st hard X-ray undulators and FEL will be reflected to horizontal direction in the optical hutch.
- A prototype of the vertical polarization undulator will be developed until the end of 2024.

# Beam-time & Shift Number




※ In 2022, 190 days user beamtime will be delivered

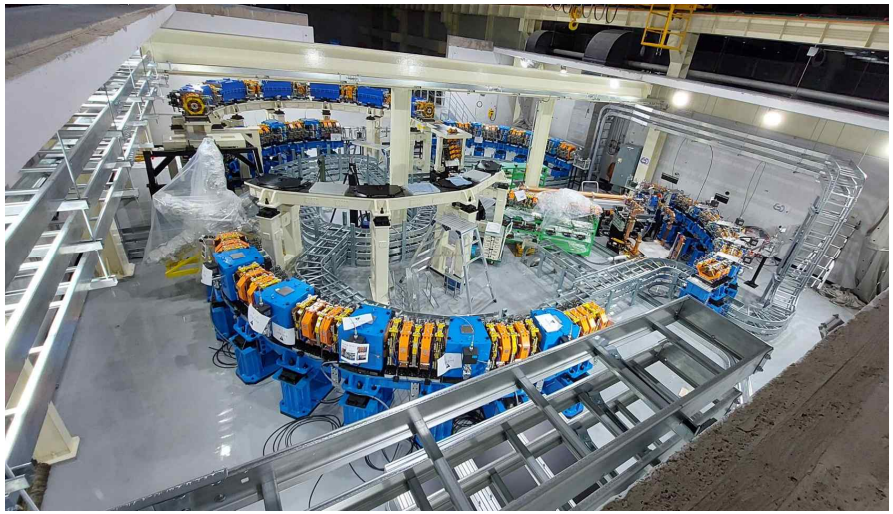
# PAL-EUV Accelerator

PAL-EUV is a new Low Energy Synchrotron Light Source, fully funded from Korean Government
To provide diffraction-limited radiation at EUV range
Application mainly for semiconductor R&D

- Injector Linac (to 20 MeV)
  - Photocathode gun + 3 m accelerator column
  - 10 MW S-band klystron + solid state modulator
- Booster Ring (400 MeV)
  - 2 straights for injection/extraction
  - 500 MHz PLS cavity (reuse)
  - Storage Ring (400 MeV)
- 4 straights for injection and three IDs
  - 140 mA beam with 500 MHz NC cavity
  - 1500 MHz harmonic cavity

# PAL-EUV Accelerator

- Tunnel will be closed and beam commissioning will start in late November, 2022.
- Beam commissioning until summer 2023
- Beamline research with high-harmonic generation EUV source
- EUV beam service from 3rd Quator 2023
- Second ID beamline will start in 2023.
- For second ID, permanent magnet undulator with cryogenic temperature



5th October, 2022

# Rare Isotope Project (RISP), Institute of Basic Science (IBS)

# Rare Isotope Science Project (RISP)

- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science** research in Korea.

  * RAON - Rare isotope Accelerator complex for ON-line experiments

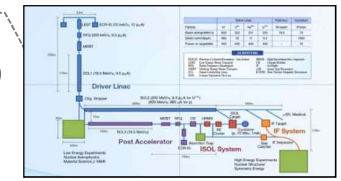
- **Budget: KRW 522.8 billion (US$ 420 million)**

  for accelerators and experimental apparatus

- **Period: 2011.12 ~ 2022.12 (1st Phase)**

## System Installation Project

Development, installation, and commissioning of the accelerator systems that provides high-energy (200MeV/u) and high-power (400kW) heavy-ion beam




## Facility Construction Project

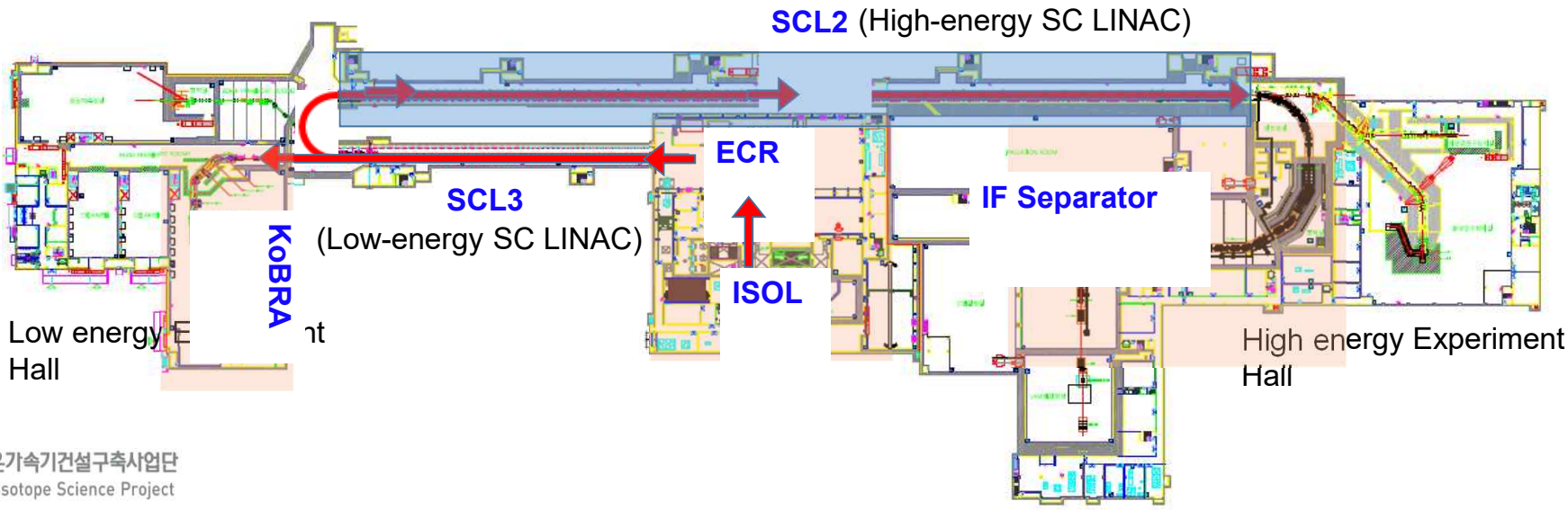
Construction of research and support facility to ensure the stable operation of the heavy-ion accelerator, experiment systems, and to establish a comfortable research environment

※ Accelerator and experiment buildings, support facility, administrative buildings, and guest house, etc.

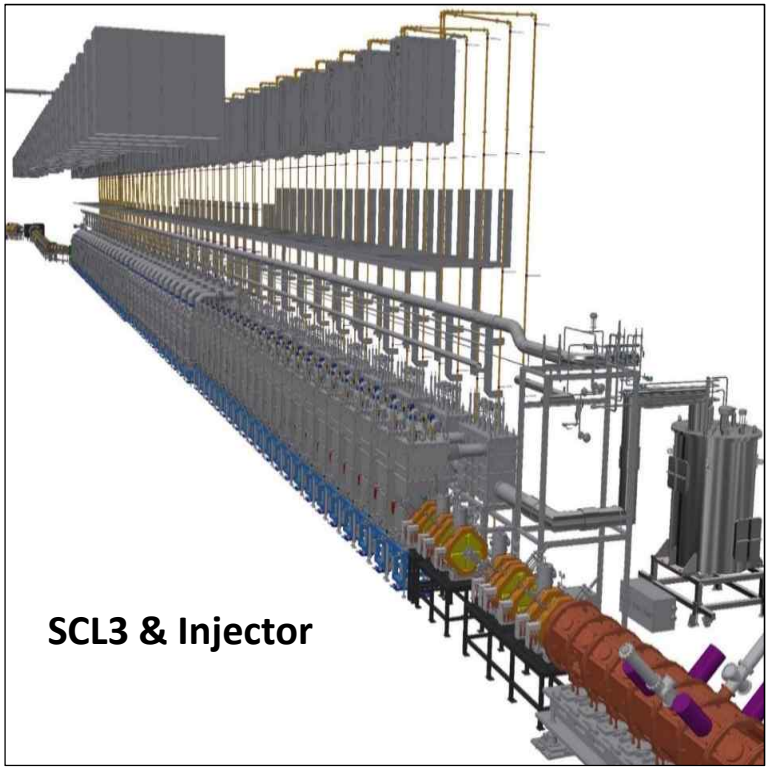
- **Providing high intensity RI beams by ISOL and IF**
  ISOL: direct fission of $^{238}$U by 70 MeV proton
  IF: 200 MeV/u $^{238}$U (intensity: 8.3 pμA)
- **Providing high quality neutron-rich beams**
  e.g., $^{132}$Sn with up to 250 MeV/u,
  up to $10^9$ particles per second
- **Providing More exotic RI beam**
  **production by combination of ISOL and IF**

# RIB production at RAON

| | KoBRA | ISOL | IF Separator |
|---|---|---|---|
| Driver | SCL3(ECR/ISOL) | Cyclotron | SCL3(ECR/ISOL)->SCL2 |
| (Post) Acceleration | | SCL3 or SCL3->SCL2 | |
| Production Mechanism | Direct reactions Multi Nucleon Transfer | P induced U fission | PF, U fission |
| RIB Energy | < a few tens of MeV/u | > a few of keV/u | < a hundreds of MeV/u |



# Phased Installation




❖ **Phase 1 (~2022)**

- Injector, SCL3, ISOL beam commissioning
- All experimental systems including IF separator system to be installed and machine commissioned

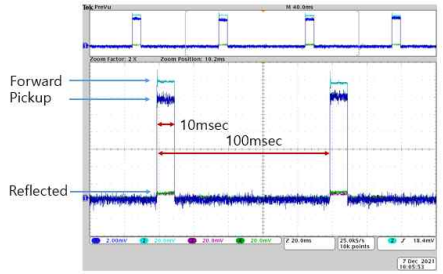
❖ **Phase 2 (~2029)**

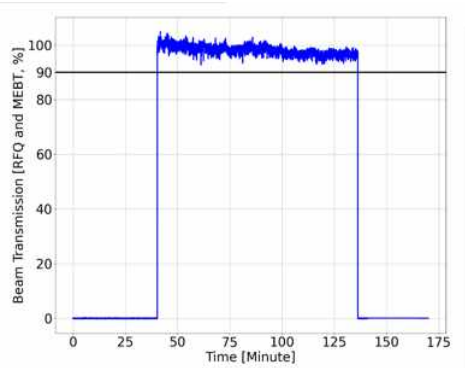
- High energy Linac, SCL2
- Prototyping R&D until 2025

SCL3 → installation done on 2021
& atarting commissioning on Oct 2022

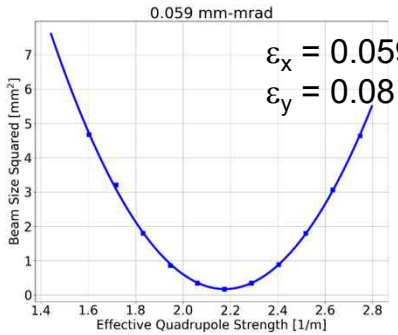
# Commissioning Injector Beam, done

- 10% beam duty operation: 96 minutes, 10Hz, 10msec (2021.12.07.)
  * Injector transmission > 94%
- MEBT beam emittance measurement based on quad scan

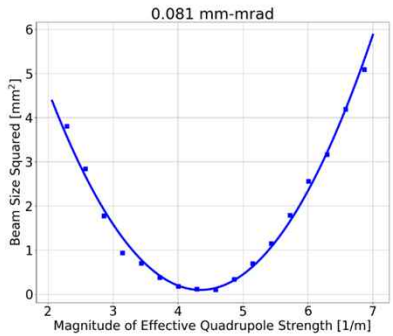


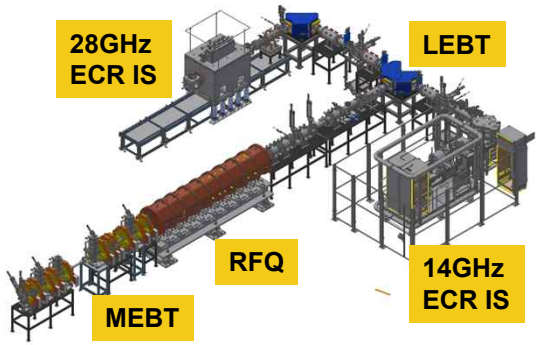

Injector beam transmission

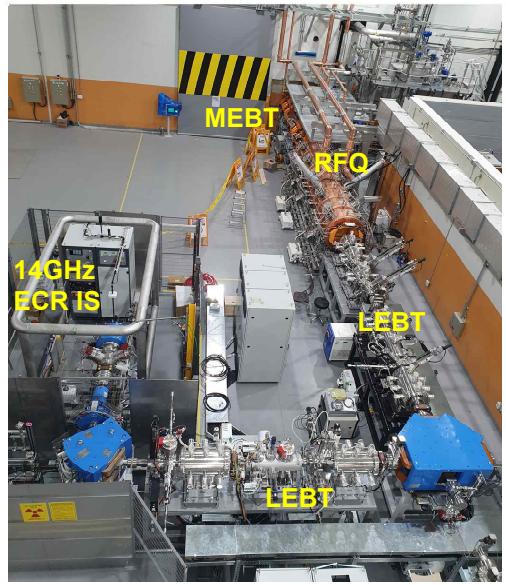



$\varepsilon_x$ = 0.059 mm-mrad
$\varepsilon_y$ = 0.081 mm-mrad




MEBT quad scan
(emittance measurement)



# Commissioning Low-energy LINAC (SCL3), on-going

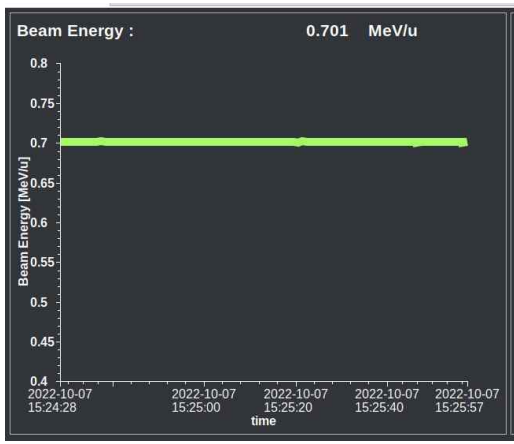
- Cryogenic plant for SCL3, ready and working
- He distribution, in cold ready
- All SCL3 SRF cryomodules (22 QWRs, 15 HWR-As and 18 HWR-Bs are in cold temperature
- All interlock system for cryoplant and cryomodules, ready

**The first cool-down : started @ 7th of Sep. 15:30**

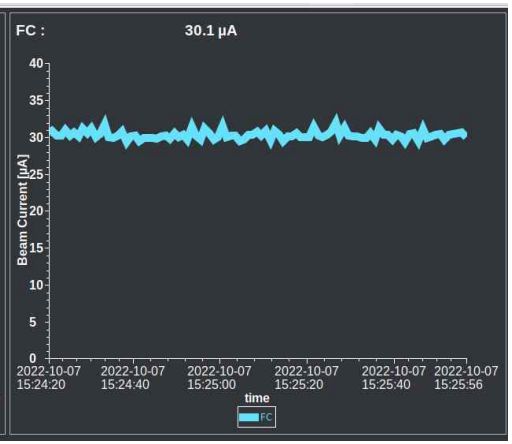
- **First acceleration was observed on Oct. 7 !!**

(with first five QWR modules only)

Further commissioning is going on until 2023
Experiments will start Feb. 2024




Measured beam energy




Measured beam energy

# Further Commissioning & Optimization of Beam until 2023

- October : Cool-down of HWR/RF conditioning
- November : 2K pumping for HWR section/RF conditioning
- December : 2K stabilization for HWR section/RF conditioning Second beam commissioning toward HWR A5.
- January-March, 2023 : Beam commissioning for whole SCL3

# Multipurpose Synchrotron Radiation Construction Project (4GSR), Korean Basic Science Institute (KBSI) & PAL

# Project Outline

❖ **Multipurpose Synchrotron Radiation Construction Project**

- Period: 2021 July to 2027 June (6yrs)
- Budget: 1.0454 Trillion KRW (≈ USD 750M)
- Land: 540,000 ㎡ / Building: 69,400 ㎡
- Location: Ochang, Chungcheongbuk-do

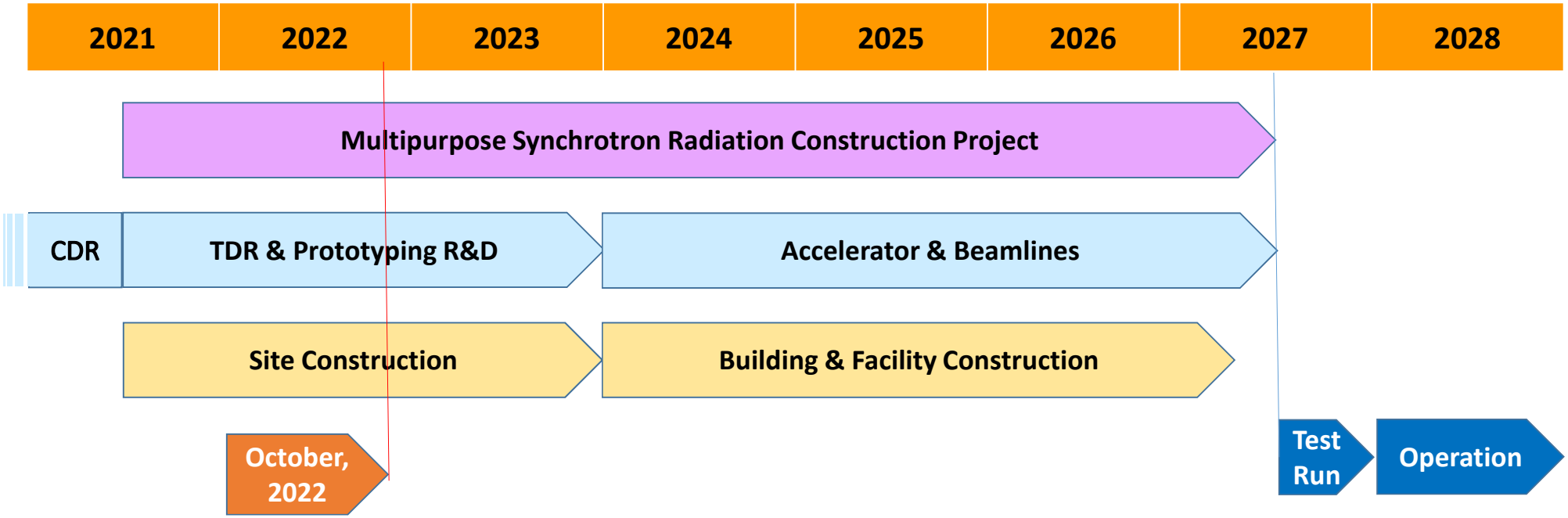
❖ **2 Institutions working together**

- KBSI: Hosting institution in charge of Building and Facility
- PAL: Partner institution in charge of Accelerator and Beamlines

## ❖ Specifications

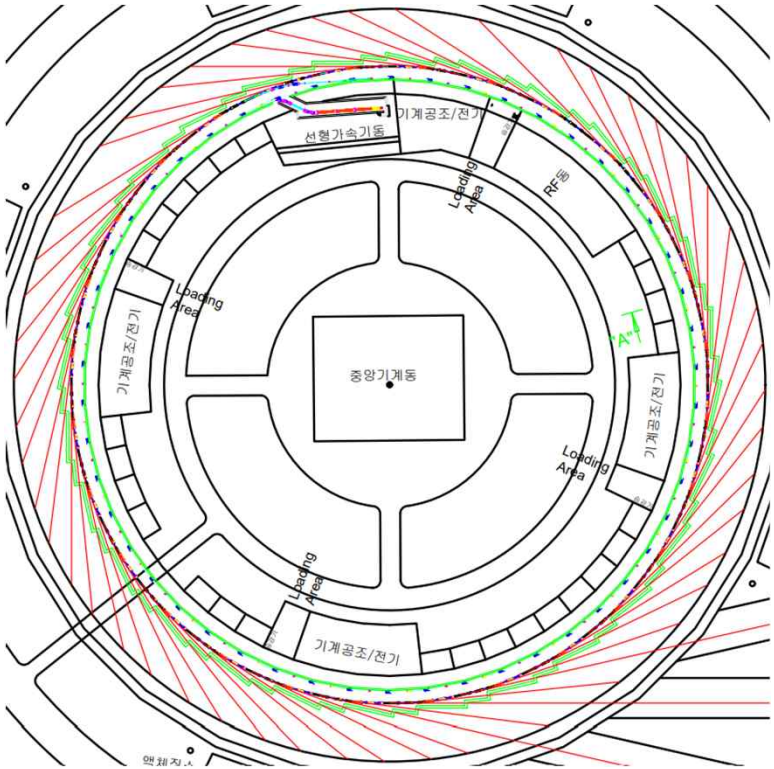
- Beam Energy: 4 GeV
- Beam Emittance: less than 100 pm·rad (CDR: 58 pm·rad)
- Circumference: 800m
- Beamlines : more than 40
- Accelerator: Gun, Injector LINAC, 4 GeV Booster
- Lattice: MBA-7 Bend Achromat

# Project Timeline



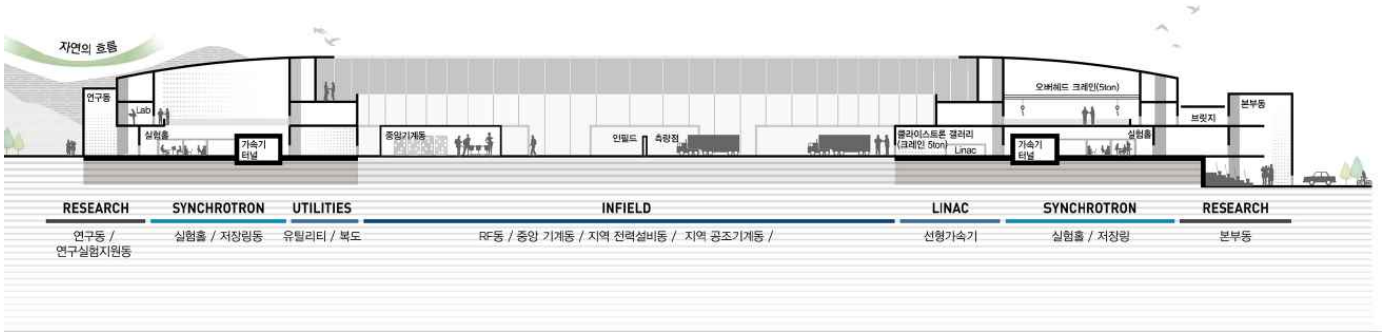
# Primary Parameters

Gun → LINAC → Booster Ring → Storage Ring



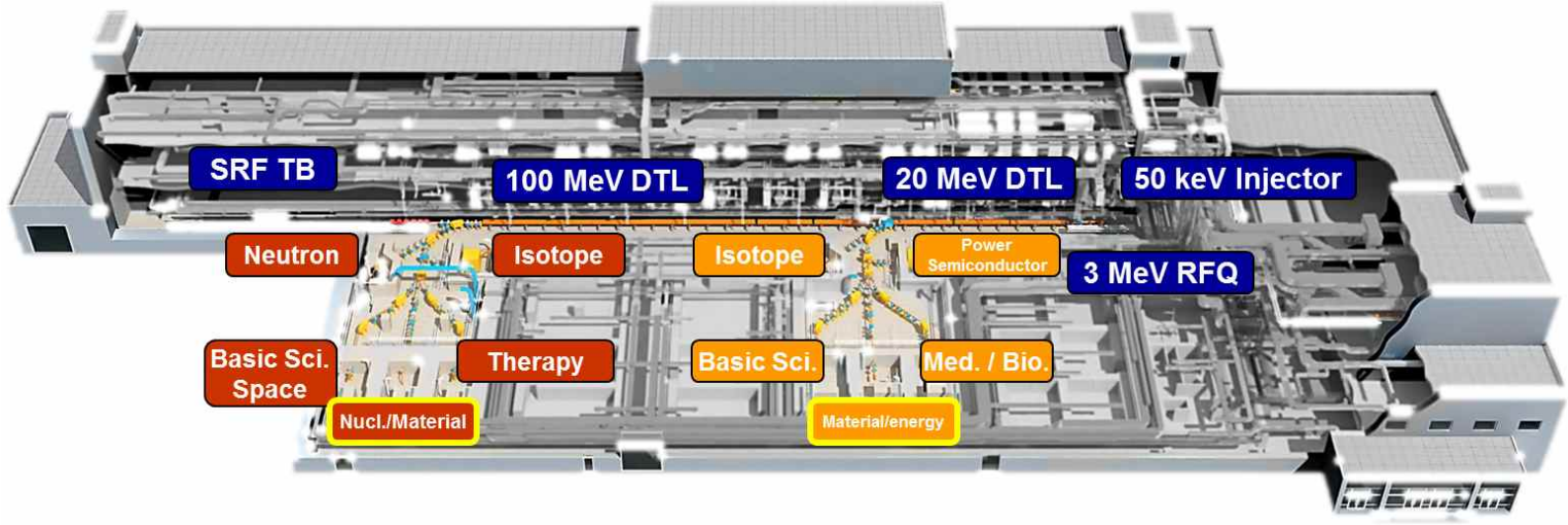

| General Parameter | |
|---|---|
| Energy / GeV | 4.0 |
| Symmetry / Sub-Symmetry | 28 |
| Straight Sections: No & Length / m | 28 / 6.5 |
| Ring Circumference / m | 798.8 |
| # Dipole Magnets | 28 * 7 = 196 |
| Nat. Emittance / prad m | 58 |
| regular hor/ver @ coupling | 55 / 6 @ 10 % |
| Diffraction limited source for | l > 1.7 / 0.365 nm |
| Energy spread | 1.20E-3 |
| Bunch Length $s_t$ / ps | 10.68 (without HC) / 53.40 (with HC) |
| **RF Parameter & Others** | |
| RF frequency / MHz | 499.877 |
| # cavities / total Voltage | 3 x nc / 3.5 MV (1.8 MV max) |
| # buckets: total / gap | 1332 / 267 |
| Harmonic RF system | 3rd, passive,sc, 800 kV |
| Average current / mA | 400 |
| Lifetime / h | 4.54 (flat) / 8.81 (round) |
| Top up operation | yes |
| Injection scheme | 4 Kicker bump |
| Beam pipe (in achrom.) / $mm^2$ | D: 24(H)*20(V) @ Straight Section |
| Magnets: | |
| max. bending magnet field / T | 1.7 |
| max. quadrupole grad. T/m | 56 |
| max. sextupole strength $T/m^2$ | 1844 |

# 4GSR Design – Building Cross-session

# Korea Multi-Purpose Accelerator Complex – KOMAC (KAERI)

KAERI KOMAC
Korea Multi-purpose Accelerator Complex



# Outline of KOMAC

Construction - 2002.7~2012.12 Proton Engineering Frontier Project (PEFP)

Budget - ~$300M ( Government: $180M, Gyeongju: $110M, Industry: $10M )

Specification - **High Current (20 mA) Proton Linear Accelerator**

Applications - Atmospheric/Space Radiation Effects, RI Production, Bio, Basic sciences, Secondary Particle Productions

- In last 5 years, supported 489 projects of 1,967 users from 188 institutions


KAERI KOMAC Korea Multi-purpose Accelerator Complex

# Characteristics – 100 MeV Proton LINAC

- 2.45 GHz Microwave ion source
- 350 MHz 4-vane RFQ (Radio Frequency Quadrupole)
- 350 MHz Drift Tube Linacs
- Digital LLRF and EPICS control system

| | |
|---|---|
| Extraction Energy | 100 MeV |
| Max. Peak Beam Current | 20 mA |
| Max. Beam Duty | 8% |
| Avg. Beam Current | (max) 1.6 mA |
| Pulse Length | 0.1 - 1.33 ms |
| Max. Repetition Rate | 60 Hz |
| Max. Average Beam Power | 160 kW |

**KOMAC Injector**

**KOMAC RFQ**

**KOMAC DTL**

# Proposing: Korea Spallation Neutron Source (KSNS)

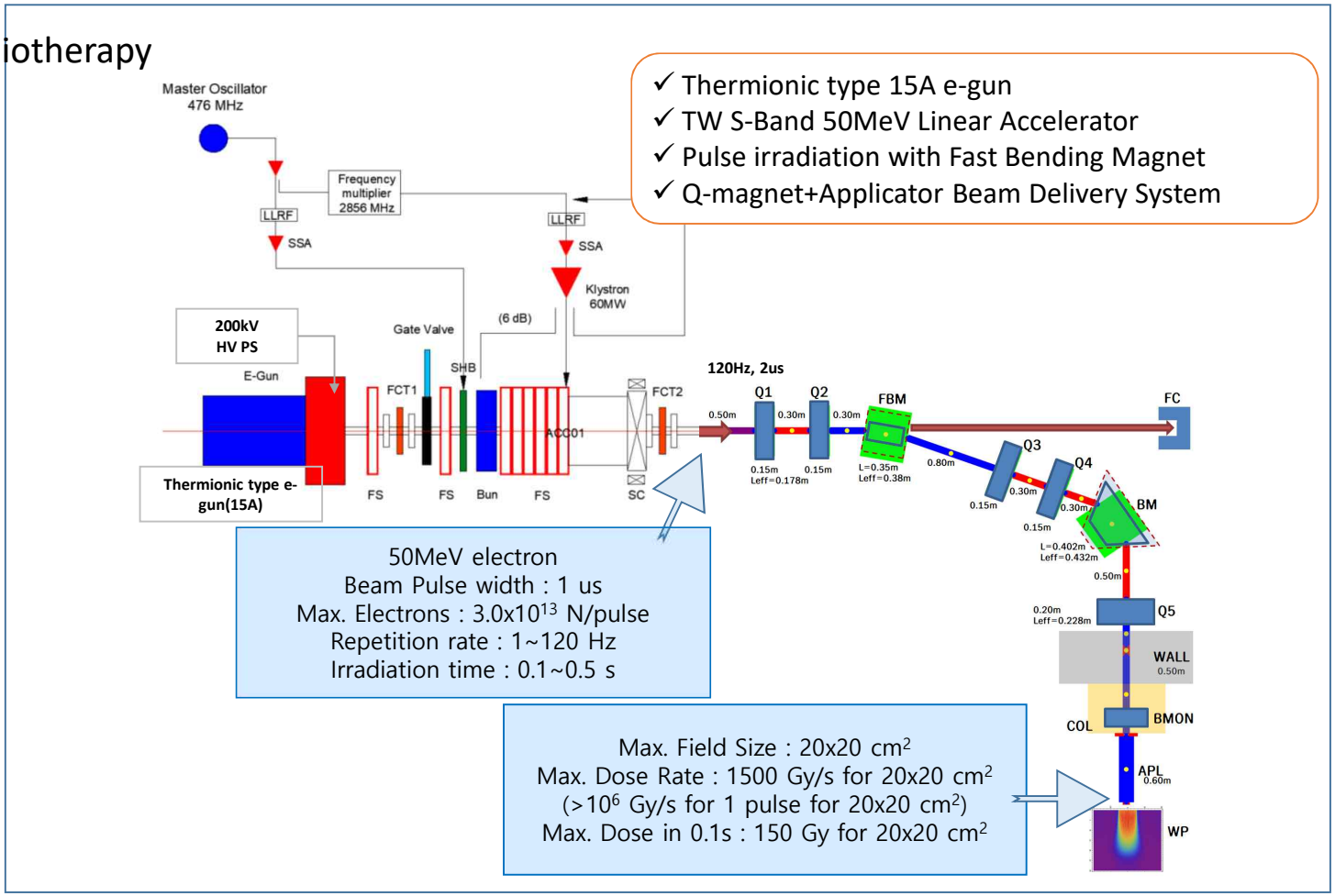
- 2-GeV Rapid Cycling Synchrotron
- MW-class Spallation Target Station
- Proton beamline for deep-space radiation tests
- Neutron beamlines for neutron science

# Medical Application of Acelerators

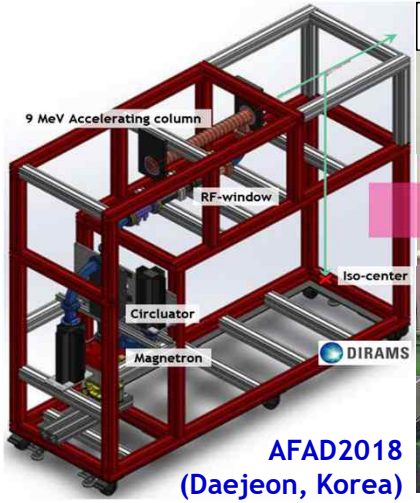
- 50MeV e-FLASH  Radiotherapy System of KIRAMS
- 9 MeV C-band LINAC @ DIRAMS

# 50MeV e-FLASH Radiotherapy System of KIRAMS

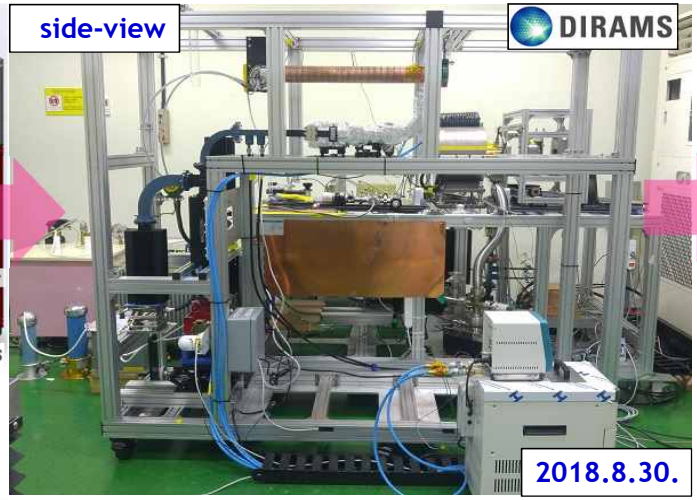
50MeV electron Flash Radiotherapy System
- 1 step : 2021 – 2023
- 2 step : 2024 - 2025

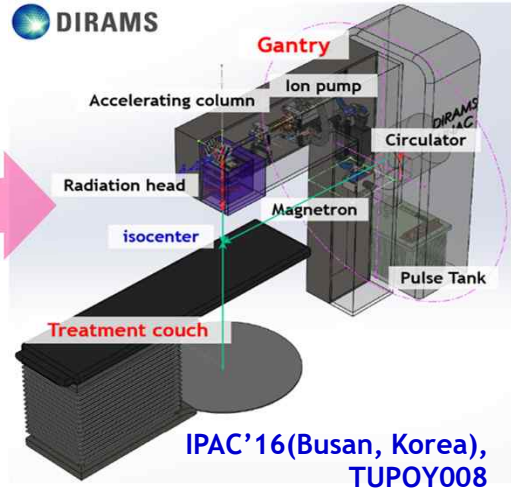


# 9 MeV C-band LINAC @ DIRAMS




AFAD2018
(Daejeon, Korea)

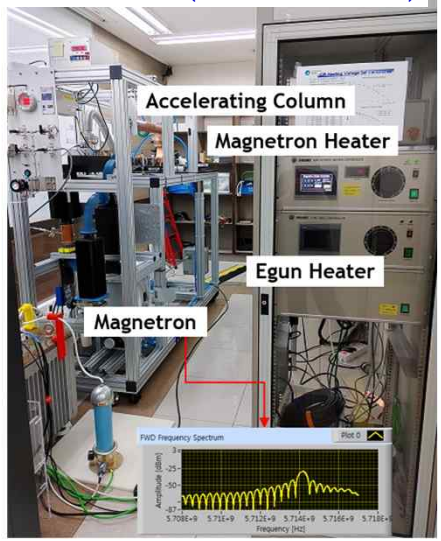



IPAC'16(Busan, Korea),
TUPOY008

- We are developing a radiotherapy machine consisting of a gantry, a support stand, a treatment couch, a control console, etc.
- The 9 MeV Accelerating column was manufactured and bonded using vacuum-brazing with our DIRAMS machines.
- The 9 MeV LINAC located in the gantry-like frame was constructed and operates with the solid-state pulse modulator.
- After getting the radiation license (2022), we will study the beam from LINAC and provide the FLASH irradiation.

2020.11.23 @ HDR (treatment room)

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