Status of RAON and its Beam Dynamics

HB2018
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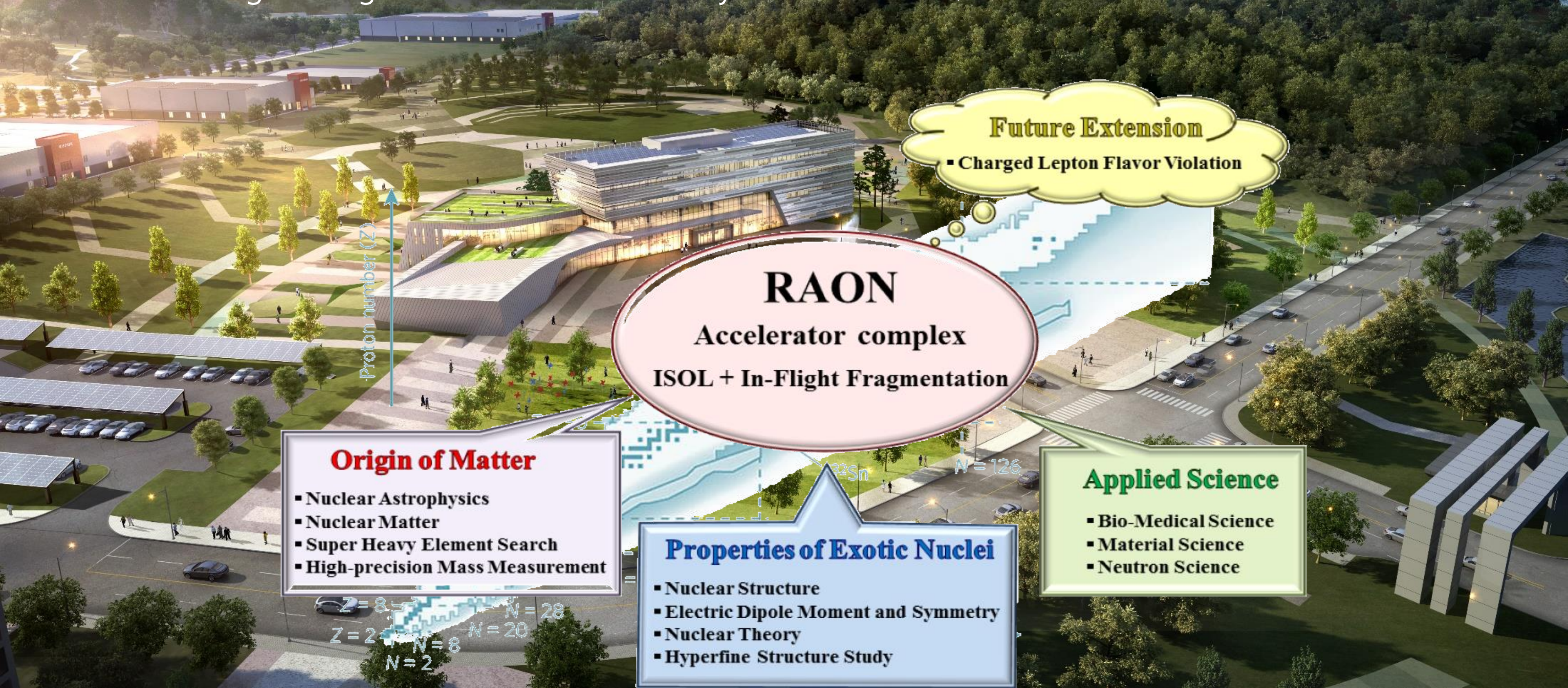
(On Behalf of Rare Isotope Science Project)
RISP / IBS

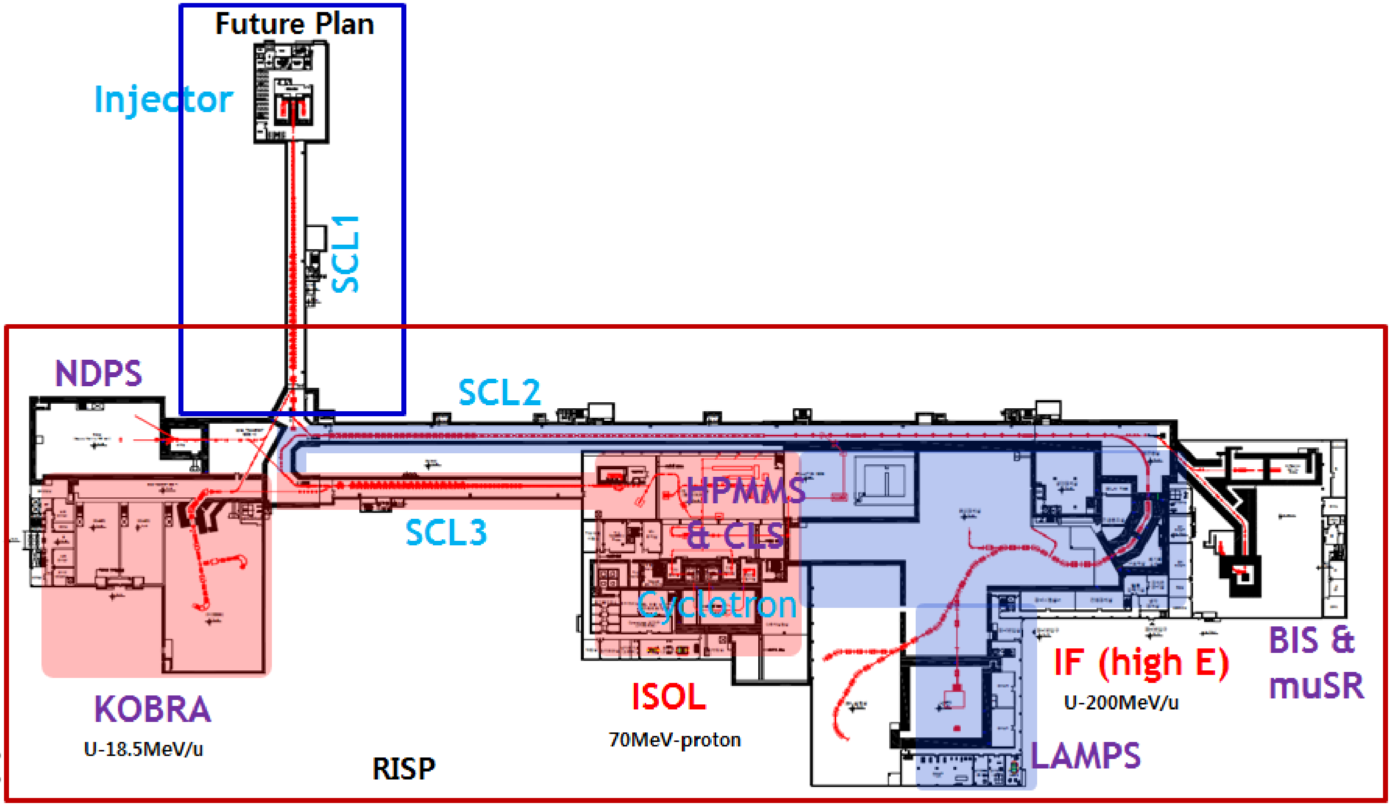
Rare Isotope Science Project (RISP)

- Goal: To build a heavy ion accelerator complex RAON for rare isotope science research in Korea.
  - ✓ RAON: <u>R</u>are isotope <u>A</u>ccelerator complex for <u>ON</u>-line experiments
- Period: 2011.12 ~ 2021.12
- Project cost: Total 1.44B US$
  - Accelerator and Experimental Systems: 460M US$
  - Civil Engineering and Conventional Facility: 980M US$



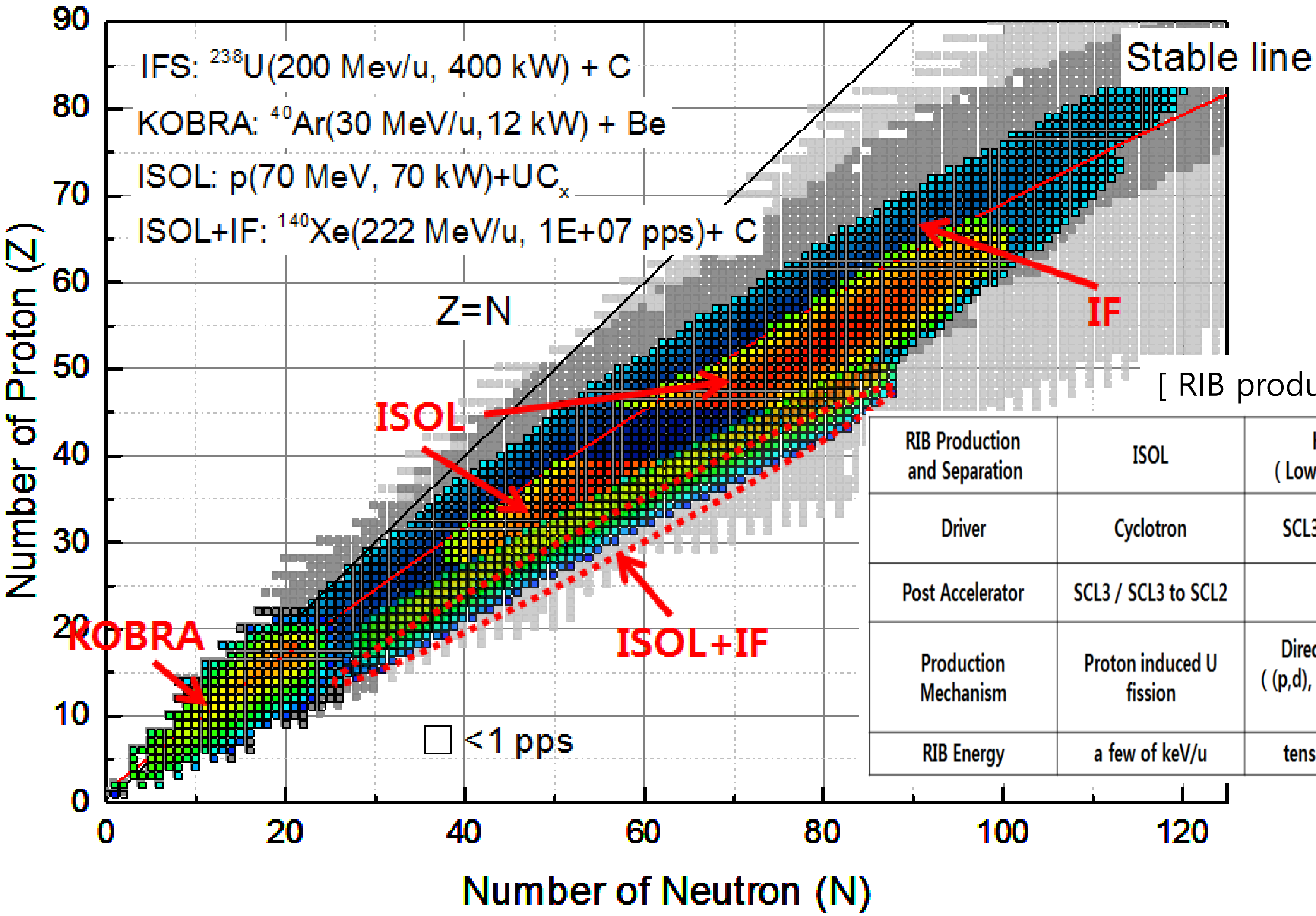
Characteristics of RAON

- High intensity RI beams by both ISOL and IF
  - ISOL: Direct fission of ^{238}U by 70MeV proton cyclotron (~10^{14} f/s)
  - IF: 200MeV/u, 400 kW ^{238}U by RAON superconducting Linac
- High quality neutron-rich RI beams
  - ~250MeV/u ^{132}Sn up to ~10^{8} pps
- More exotic RI beam by combining IF and ISOL



RIB from RAON

- RAON will provide access to unexplored regions of the nuclear chart.
  - More exotic, more intense and more various RIBs to global users



[RIB production @ RAON]

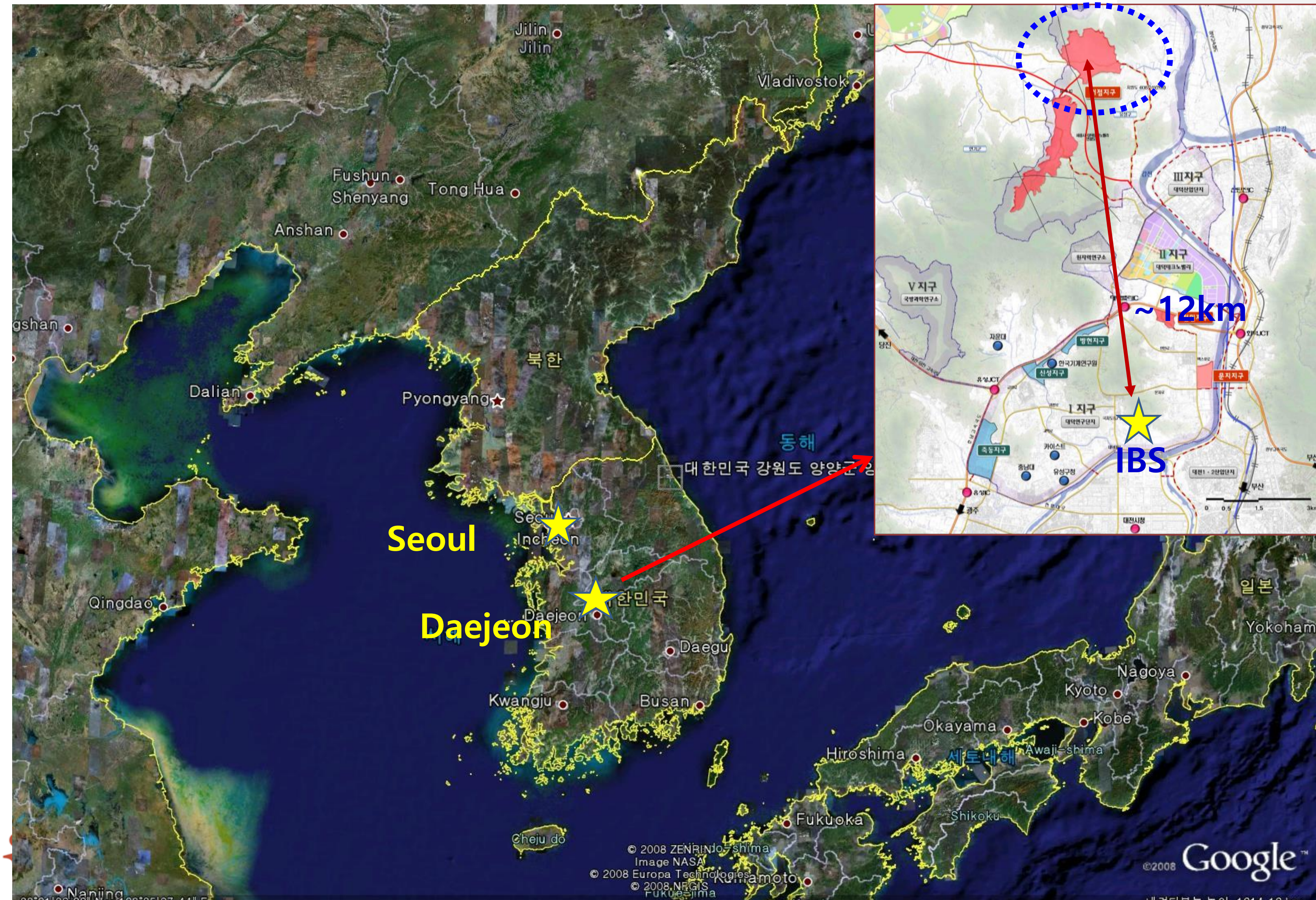
RIB Production and Separation	ISOL	KOBRA (Low Energy IF)	IF (High Energy)
Driver	Cyclotron	SCL3 (or SCL1)	SCL3 to SCL2 (or SCL1 to SCL2)
Post Accelerator	SCL3 / SCL3 to SCL2	-	-
Production Mechanism	Proton induced U fission	Direct Reaction ((p,d), (3He, n) etc) MNT	PF, U fission
RIB Energy	a few of keV/u	tens of MeV/u	hundreds of MeV/u

History and Milestone of RISP

- 2010.02: Preliminary Design Study
- 2011.02: Conceptual Design Study
- 2011.11: Rare Isotope Science Project (RISP) Launched
- 2012.06: Baseline Design Summary
- 2013.06: Technical Design Report
- 2014.06: Site & Budget Finalized
- 2014.12: Civil Engineering & Construction for RISP Started
- 2016.06: Starting SC Cavity Test in Off-site SRF Facility
- 2016.12: First Beam Test of RFQ
- 2017.10: SCL demo Beam Test (RFQ+1set of QWR)

- 2018.11: Starting mass production of QWR, HWR cavities
- 2019.04: Starting SCL3 Installation
- 2020.06: Starting Beam Commissioning of SCL3
- 2020.12: Civil Construction Finished
- 2021.10: Starting Beam Commissioning of SCL2
- 2021.12: RISP Construction Phase Finished

RAON Site



~12km
IBS
Ⅲ지구
Ⅱ지구
Ⅴ지구
Ⅰ지구
Jilin
Vladivostok
Fushun
Shenyang
Tong Hua
Anshan
Dalian
Pyongyang
북한
동해
대한민국 강원도 양양군
Seoul
Incheon
Daejeon
Qingdao
Daegu
Kwangju
Busan
Cheju do
일본
Yokohama
Nagoya
Kyoto
Kobe
Okayama
Hiroshima
세토내해
Awaji-shima
Shikoku
Fukuoka
© 2008 ZENRIN
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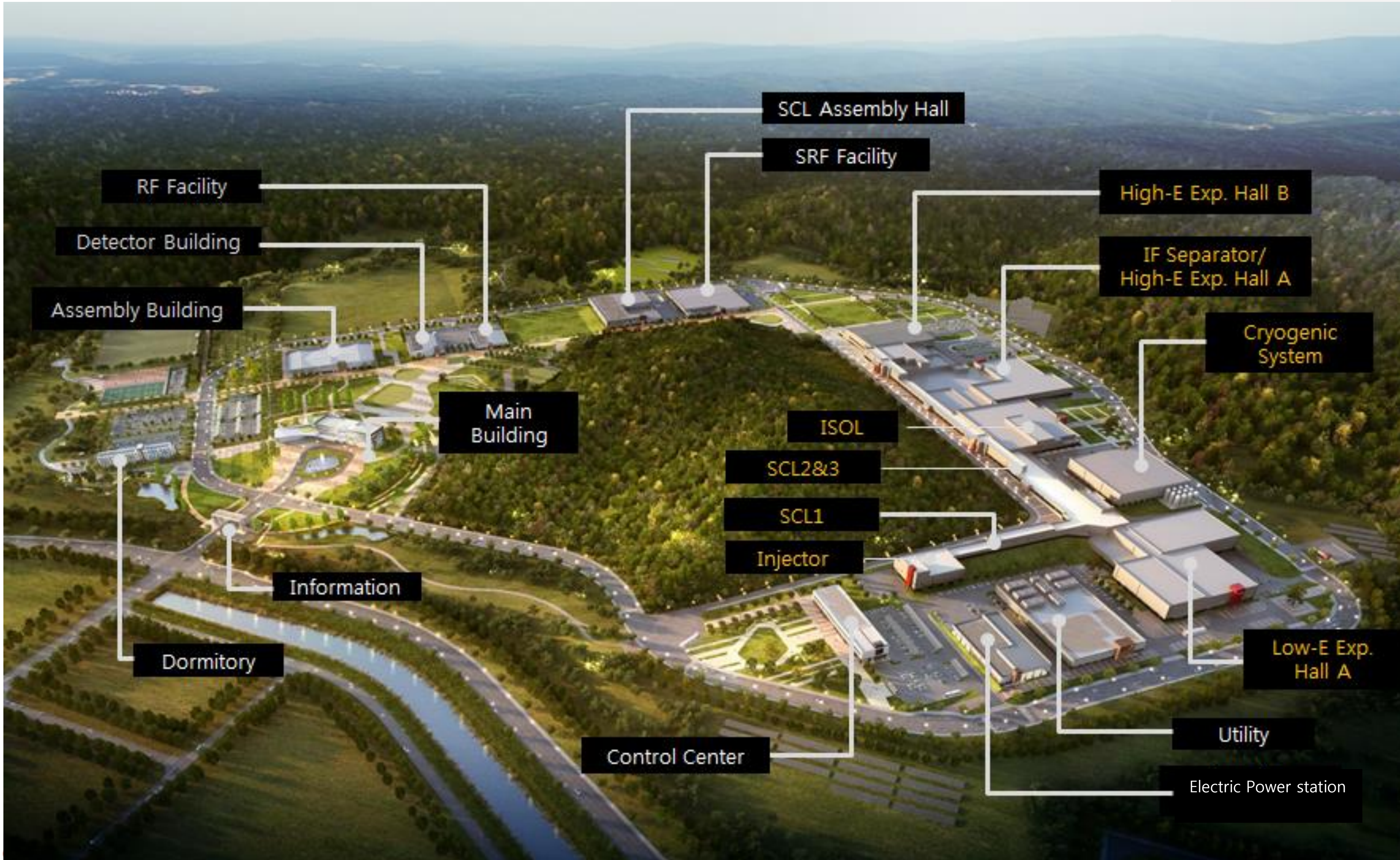
38°21'36.92" N 128°35'27.44" E
내려다보는 높이 1614.16 km

Bird's Eye View



Construction Status

- Civil Engineering & Construction for RISP Started from December 2014.
- Installation on SCL cavities will start in 2019.

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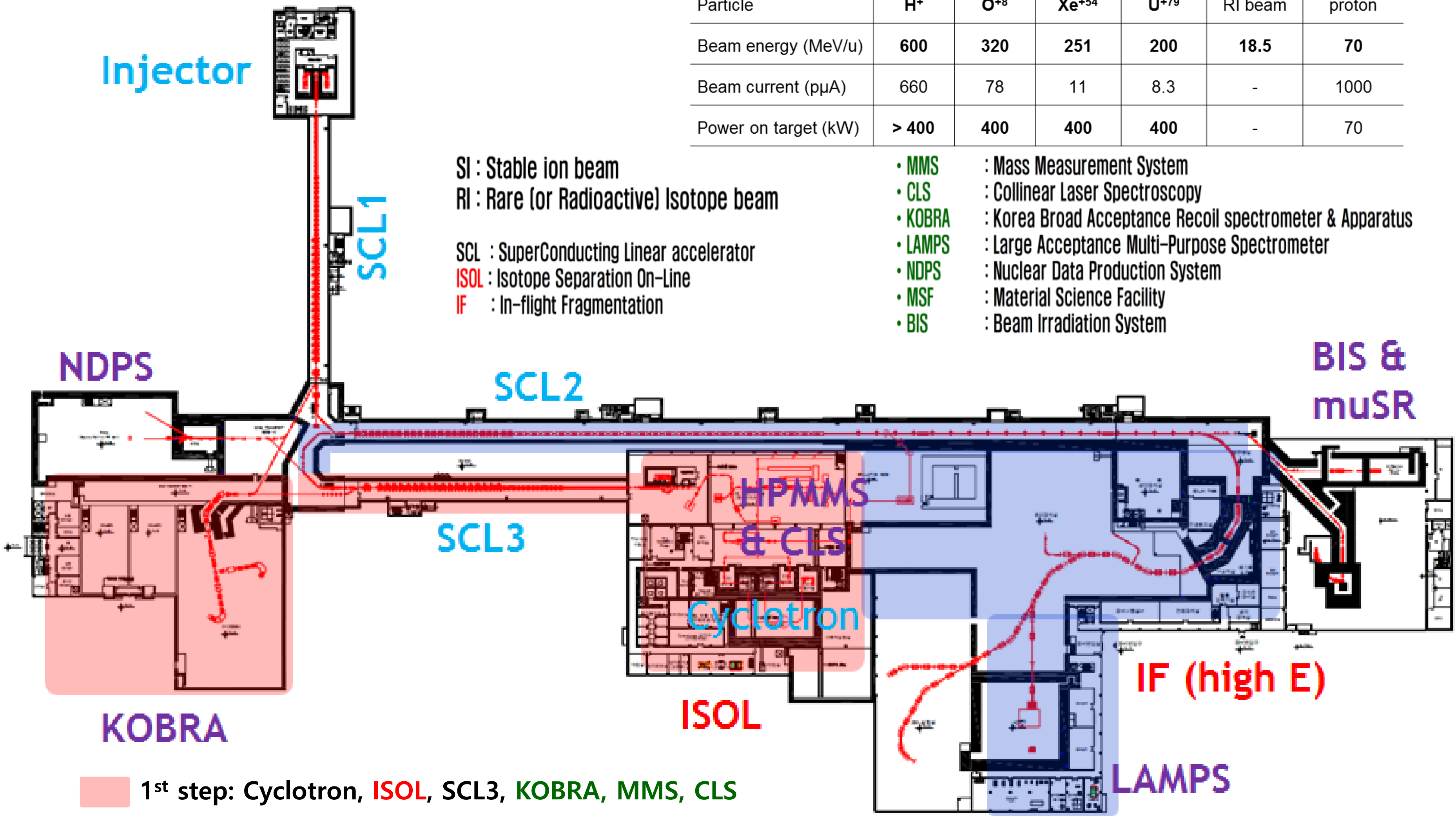
RAON Layout and Beam Specification

	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy (MeV/u)	**600**	**320**	**251**	**200**	**18.5**	**70**
Beam current (pμA)	660	78	11	8.3	-	1000
Power on target (kW)	**> 400**	**400**	**400**	**400**	-	70

SI : Stable ion beam
RI : Rare (or Radioactive) Isotope beam

SCL : SuperConducting Linear accelerator
ISOL : Isotope Separation On-Line
IF : In-flight Fragmentation

- MMS : Mass Measurement System
- CLS : Collinear Laser Spectroscopy
- KOBRA : Korea Broad Acceptance Recoil spectrometer & Apparatus
- LAMPS : Large Acceptance Multi-Purpose Spectrometer
- NDPS : Nuclear Data Production System
- MSF : Material Science Facility
- BIS : Beam Irradiation System



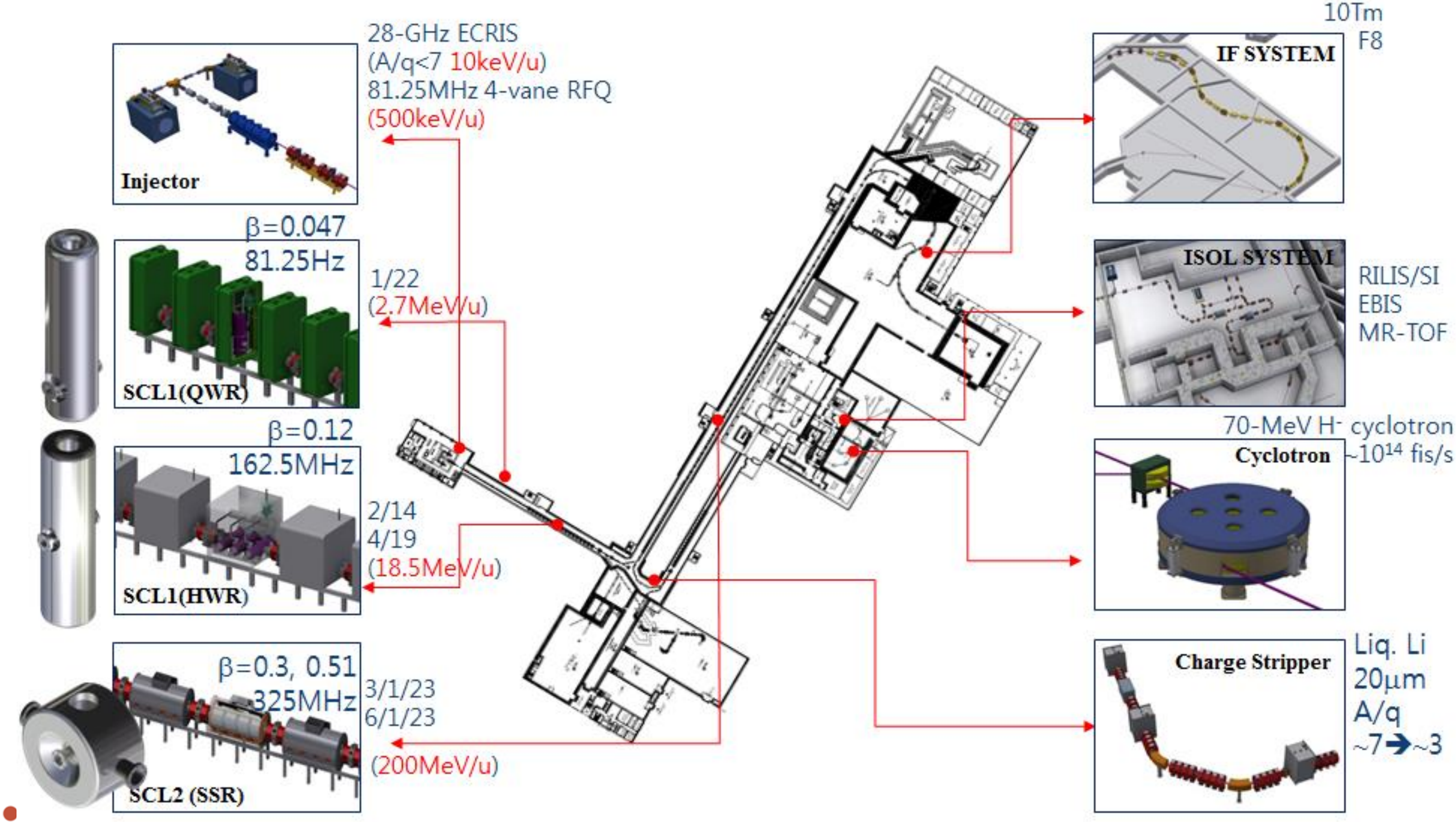
1st step: Cyclotron, ISOL, SCL3, KOBRA, MMS, CLS

2nd step: SCL2, IF, LAMPS

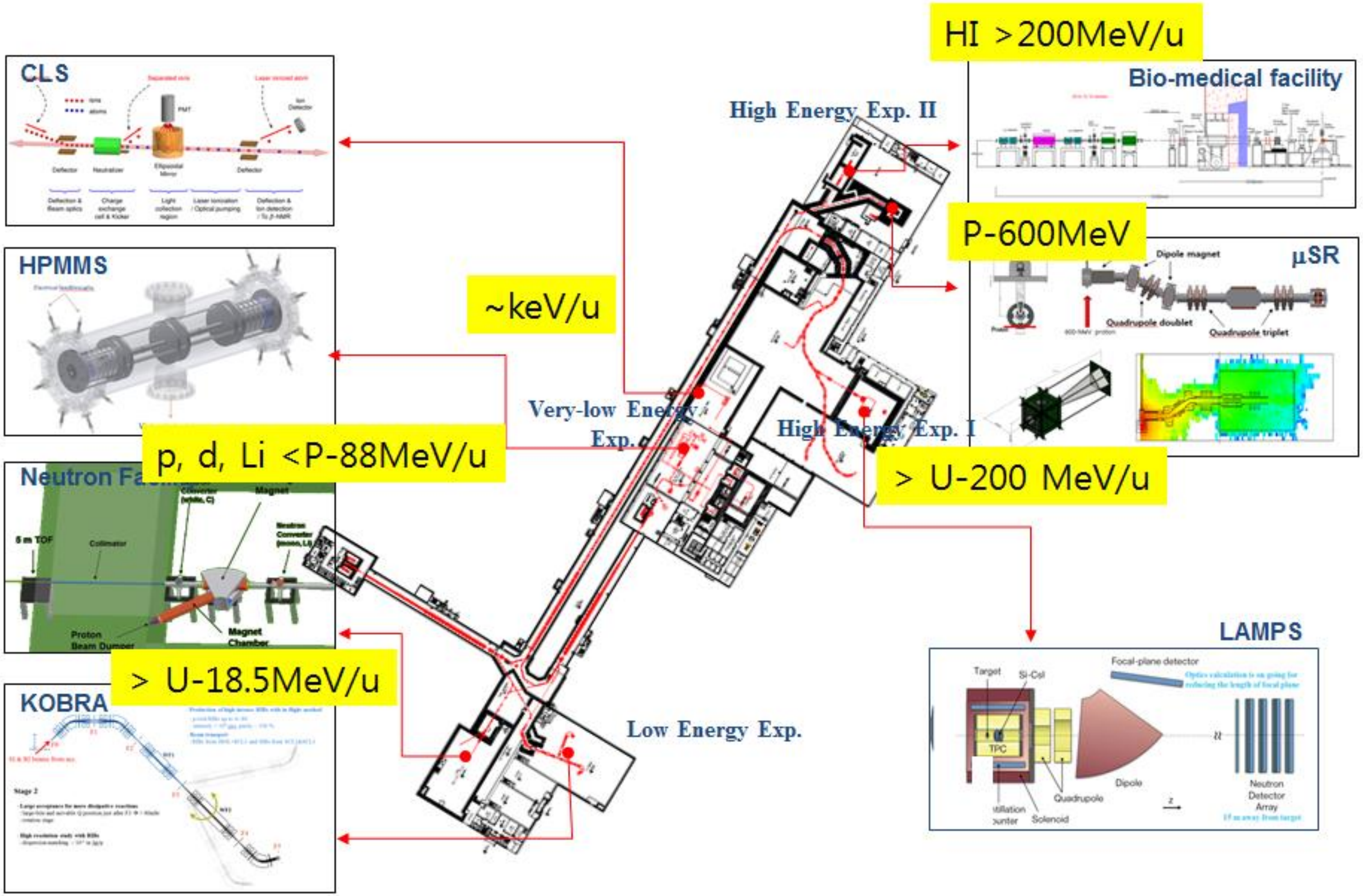
3rd step: SCL1, NDPS, MSF, BIS

Accelerator and RI production System

- SCL1 and SCL3 have the same accelerating structures.

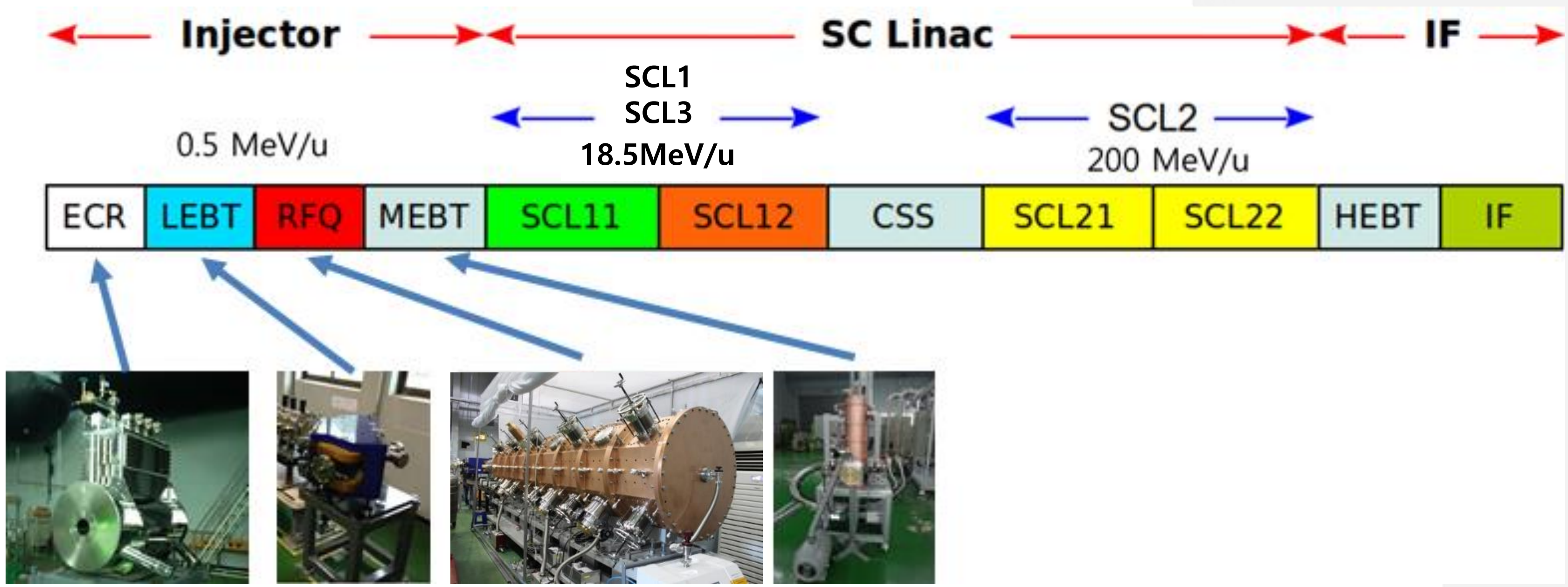


Experimental Systems



Injector System

- Injector consists of ECR, LEBT, RFQ and MEBT.
- For uranium acceleration, SCL3 injector was modified to be similar to SCL1 injector.
- The development of MHB and VE will be performed in future.
  - In the initial stage, we will operator the linac without MHB and VE.
  - They can be install in the reserved space in future.



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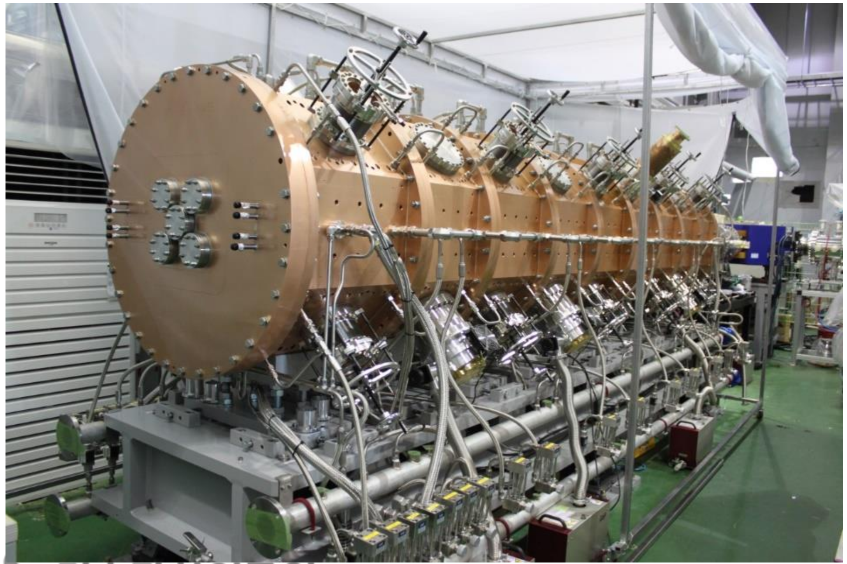
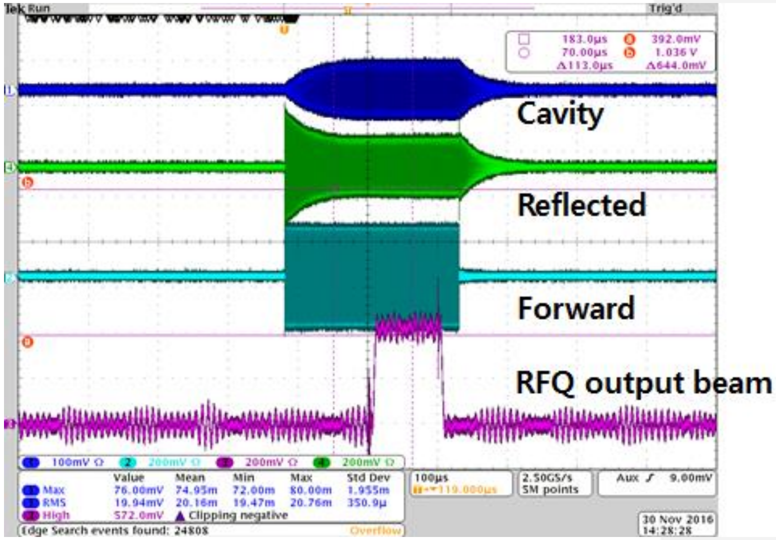
Status of RAON RFQ

- RFQ was designed by RI (Dr. L. Young)
- Voltage ramping for small length
- Conventional 4-vane type including bunching section
- Tuning and Beam Test were performed.
  - Qaud. Field < ±2% of Design
  - Dipole Field < ±5% of Q
- High power conditioning is in progress. (TUA2WC04, Bum-Sik Park)

Parameter	Value
Reference particle	$^{238}U^{33.5+}$ (33+, 34+)
Freq.	81.25 MHz
Input/output Energy	10/500 keV/u
Structure	4-vane type
Operation mode	CW
Peak Surface Field	1.7 Kilpatrick
Transmission (PARMTEQ)	98%
Length (m)	4.94



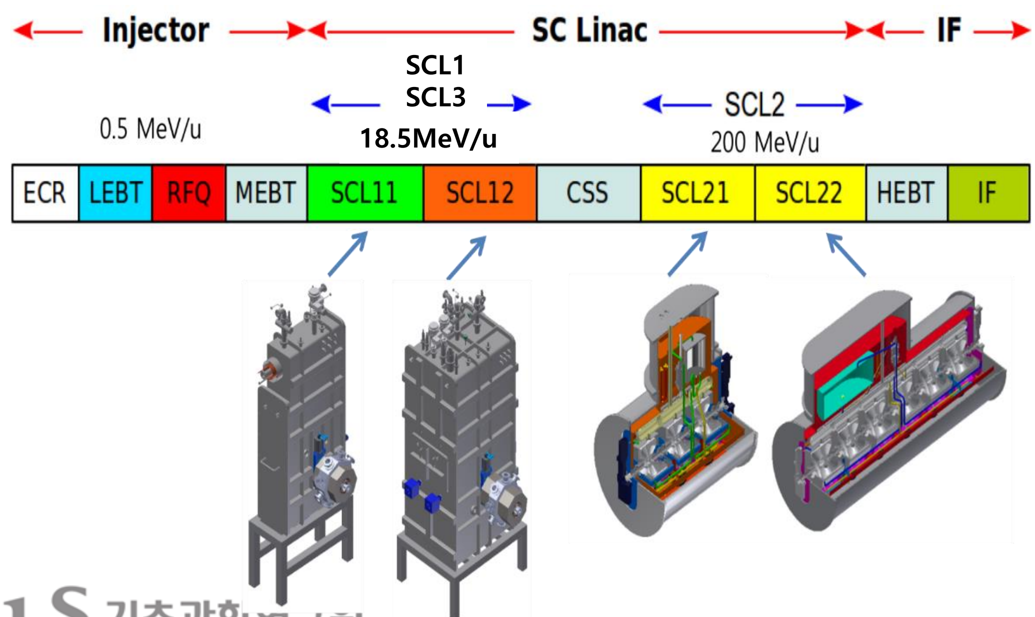
[Assembled RFQ (2016)]

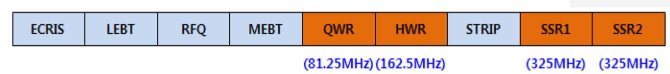


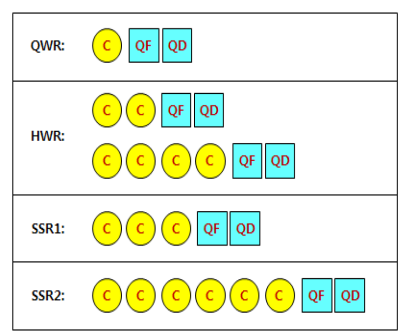
[RFQ beam Test (2016, Oxygen), ~3 μA]

RAON SCL

- 4-different SC cavities: QWR, HWR, SSR1, SSR2
  - Optimum set of β_g = 0.047 (QWR), 0.12 (HWR), 0.30 (SSR1), 0.51(SSR2)
- Reference particle: $^{238}U^{33.5+}$ (QWR, HWR), $^{238}U^{79+}$ (SSR1,SSR2)
- Focusing: normal conducting quadrupole magnets between cryomodules
- Relatively large aperture (40/50 mm diameters) to reduce beam loss
- Charge stripper between HWR and SSR1 for effective acceleration
- Charge selection in bending sections



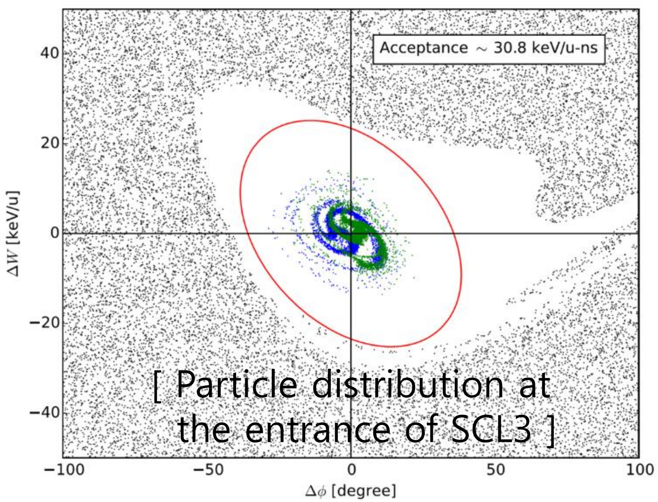




	QWR	HWR	SSR1	SSR2
β_g	0.047	0.12	0.30	0.61
CM #	22	13/19	23	23
Cavity # / CM	1	2/4	3	6
Cavity #	22	102	69	138
(SCL3+SCL2) (SCL1+SCL3+SCL2)	331 cavities, 100 CM 455 cavities, 154 CM			
Charge stripper	33, 34 → 77~81 (Uranium)			
HWR energy SSR2 energy	18.5 MeV/u (Uranium) 200 MeV/u (Uranium)			

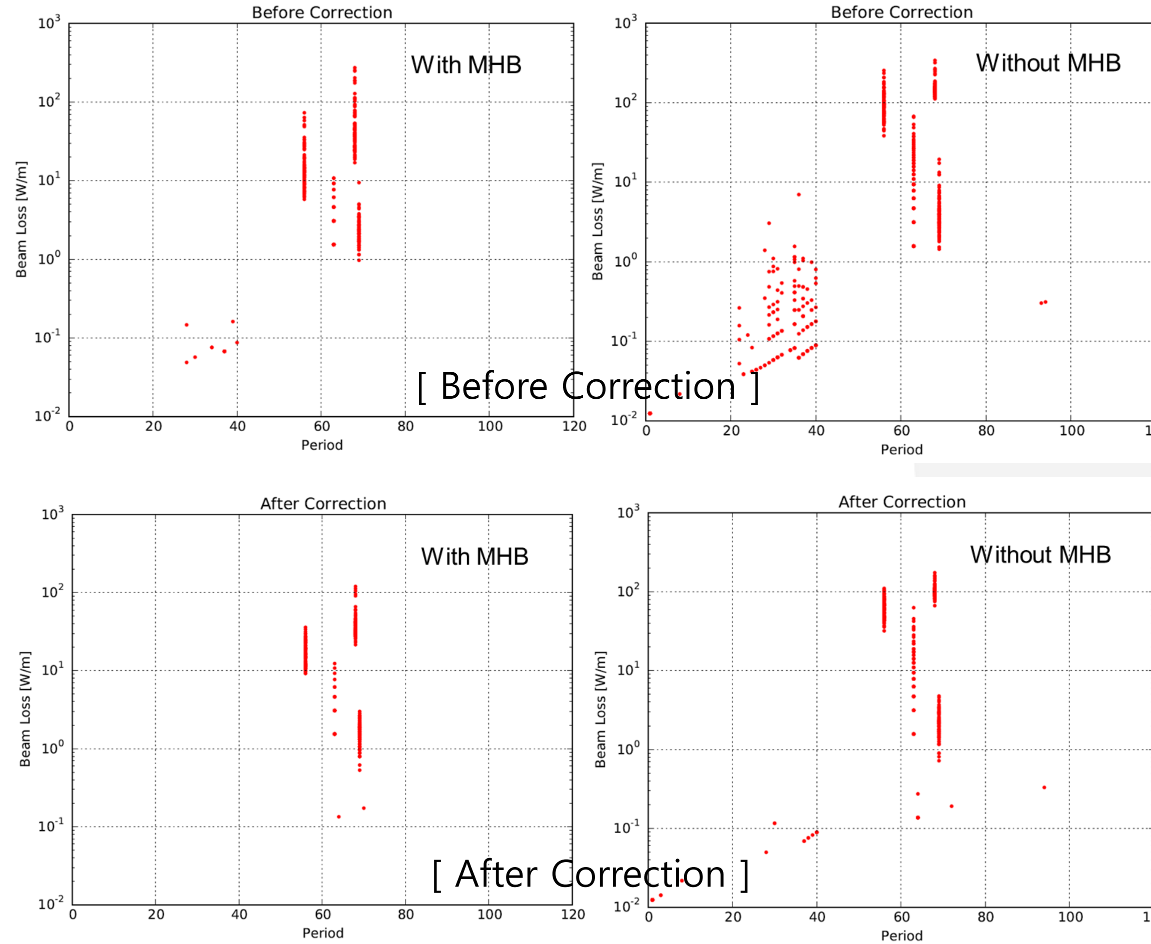
Error Analysis

- Start-to-End Error study with and without MHB and VE (TRACK code)
  - After orbit correction the beam loss expected less than 1 w/m even without MHB and VE.



[Particle distribution at the entrance of SCL3]

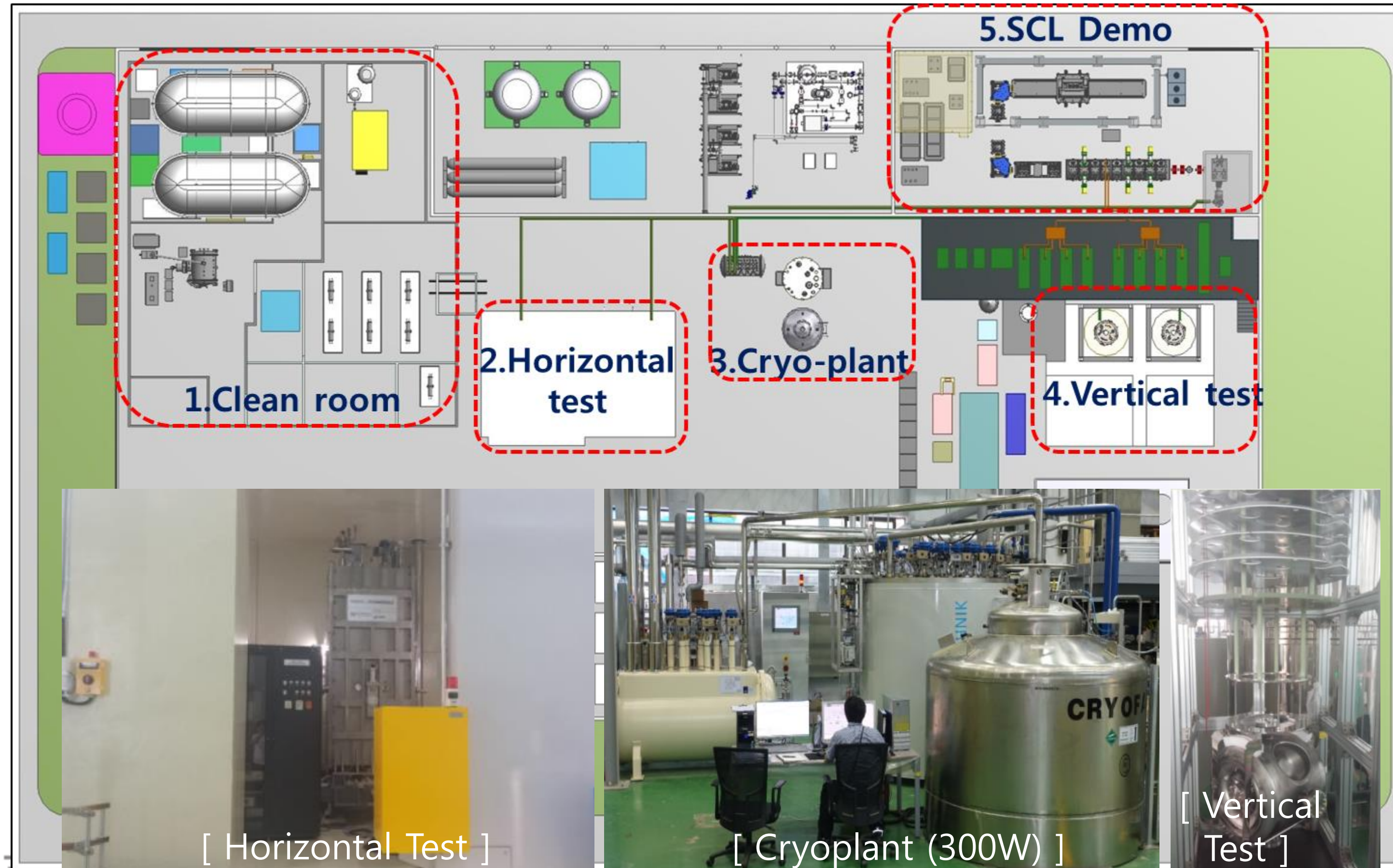
Error type	Value	Distribution
Quadrupole Displacement (Transverse, Longitudinal)	±150 μm	Uniform, max
Quadrupole Rotation (about z-axis)	±5 mrad	Uniform, max
Cavity Displacement (Transverse)	±1 mm	Uniform, max
Cavity Rotation (about z-axis)	±5 mrad	Uniform, max
Cavity Amplitude	±1% peak to peak ±0.34% (rms)	3σ truncated Gaussian, σ
Cavity Phase	±1° peak to peak ±0.34° (rms)	3σ truncated Gaussian, σ



[Beam Loss through SCL3 ~ SCL2]

Off-Site SRF Test Facility

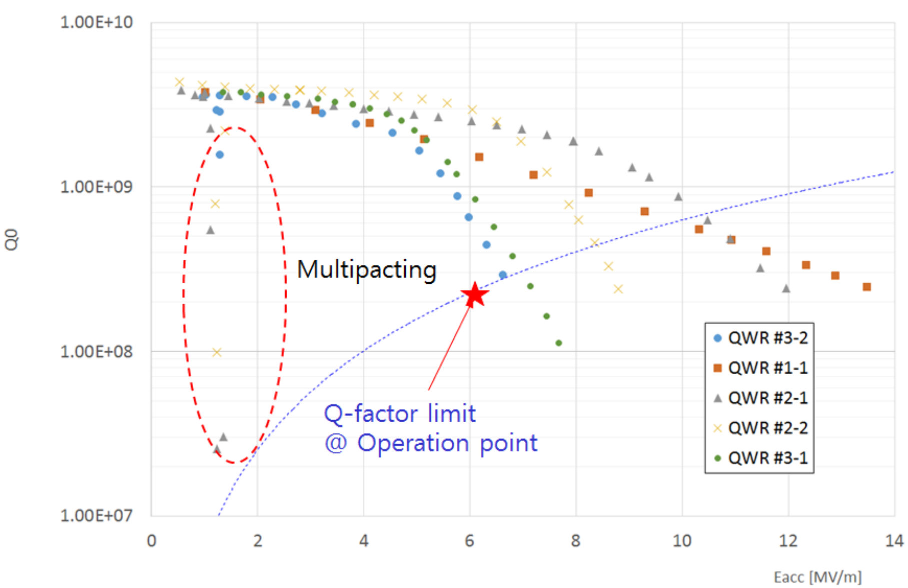
- Start operation from June, 2016 in the KAIST Munji campus.
- Performance test of SC cavities and cryomodules
- Quality control of SC cavities and CMs delivered by venders in mass production.



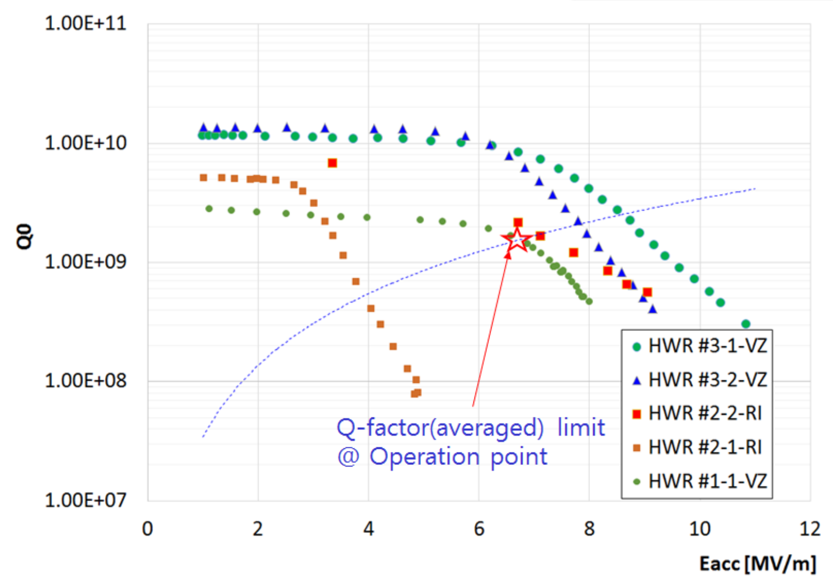
[Horizontal Test] [Cryoplant (300W)] [Vertical Test]

Status of SC Cavities

- Test of 5 QWR, 7 HWR, 1 SSR1 cavities were performed.
  - Off-site test Facility: 3 QWR, 4 HWR cavities
  - TRIUMF/Cornell: 2 QWR(TRIUMF), 3 HWR (TRIUMF/Cornell)
    1 SSR1(TRIUMF)
- Development of SSR cavities are in progress
- The mass production of QWR and HWR cavities will start in Nov. 2018.
- Temperature measurement of cryomodules (WEP2PO016, Heetae Kim)



[Performance Test of QWR Cavities]



[Performance Test of HWR Cavities]

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SCL demo Beam Commissioning

- Purposes of SCL demo TFT (2017):
  - Beam commissioning of RFQ and 1 set of QWR cryomodule
  - Testing Linac system including RF, diagnostics, control system, cryogenic system and so on
  - Experience on RFQ and superconducting linac operation

- Reference particle: $^{16}O^{7+}$ (10 keV/u from ECR ion Source, pulsed beam)
- Operation condition: 50% of maximum RF amplitude in QWR cavities (from radiation shielding issues)

- Brief history of SCL demo
  - November 30, 2016: First beam from RISP RFQ
  - August 2017: QWR installation finished and RFQ beam test
  - September 2017: 1st QWR beam test
  - October 2017: 2nd QWR beam test, RFQ beam test

Acknowledgements

- A lot of members in RISP (even outside TFT) were involved in the SCL demo commissioning.

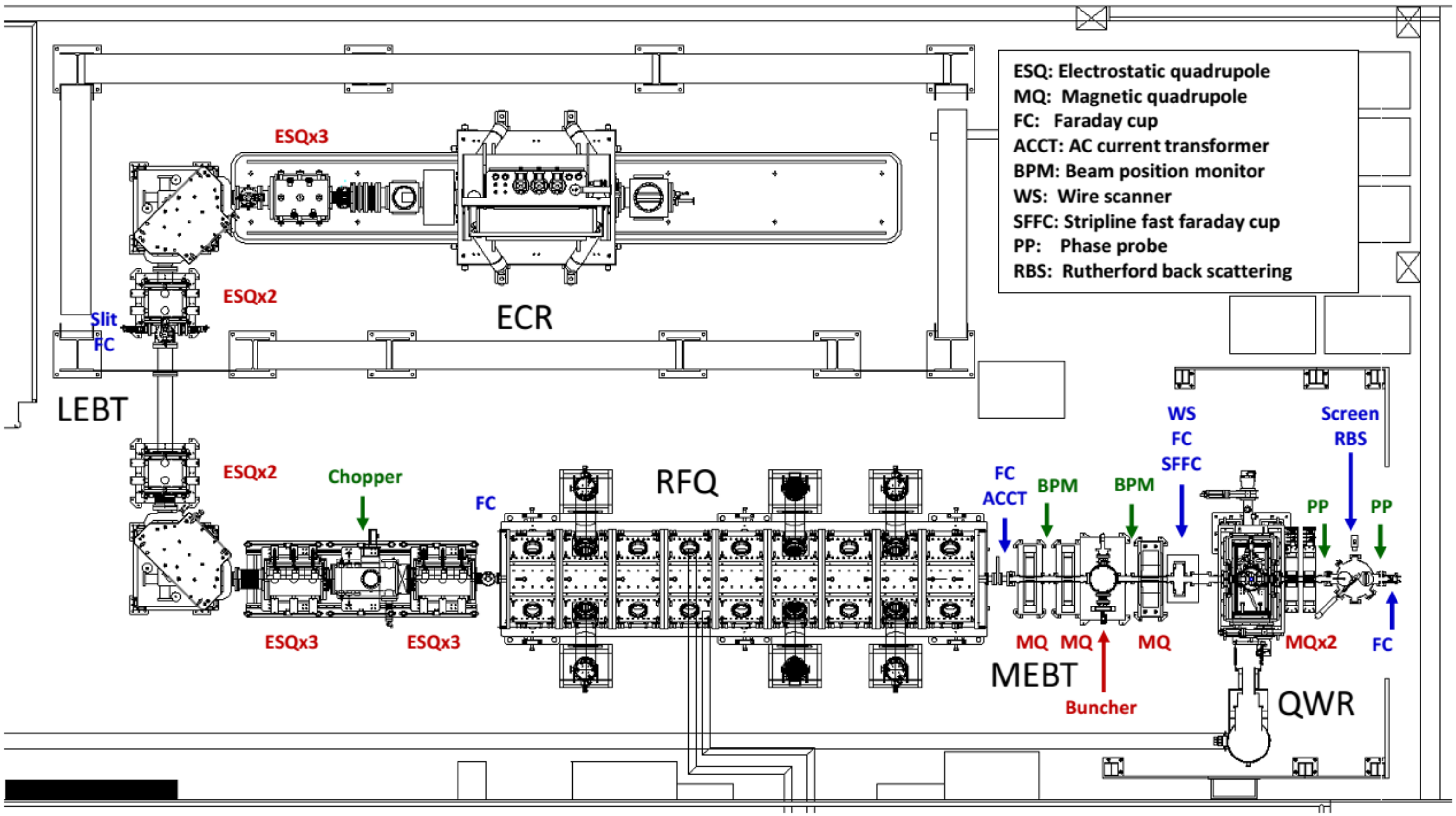
- I thank to Dr. Lagniel and his colleagues at GANIL for their hospitality and helps during our visit there for us to obtain some experience from the SPIRAL2 injector beam commissioning.

[SCL demo TFT member (Feb. 2017)]

Leader	J. H. Jang
ECR ion source	Y. H. Kim
LEBT / RFQ / MEBT	B. S. Park
QWR cavity	I. K. Shin
QWR cryomodule	Y. K. Kim
Beam diagnostics	G. D. Kim
RF	H. J. Jang
Central Control	S. I. Lee
Local Control	S. Choi
Vacuum	J. H. Kim
Magnet	S. J. Choi
Cryogenic system	J. H. Shin
Beam commissioning plan	D. Jeon
Utility	D. G. Lee
Radiation protection	S. J. Lee
Radiation safety	B. J. Kim
Drawing	J. H. Cho

SCL-demo Facility Layout

- To install beam diagnostics and QWR, radiation shielding structure was modified (KAIST Munji campus, Daejeon)
- Status of beam diagnostics: TUP1WE01 (Yeonsei Chung)
- Development of fast protection system: WEP2PO12 (Hyunchang Jin)



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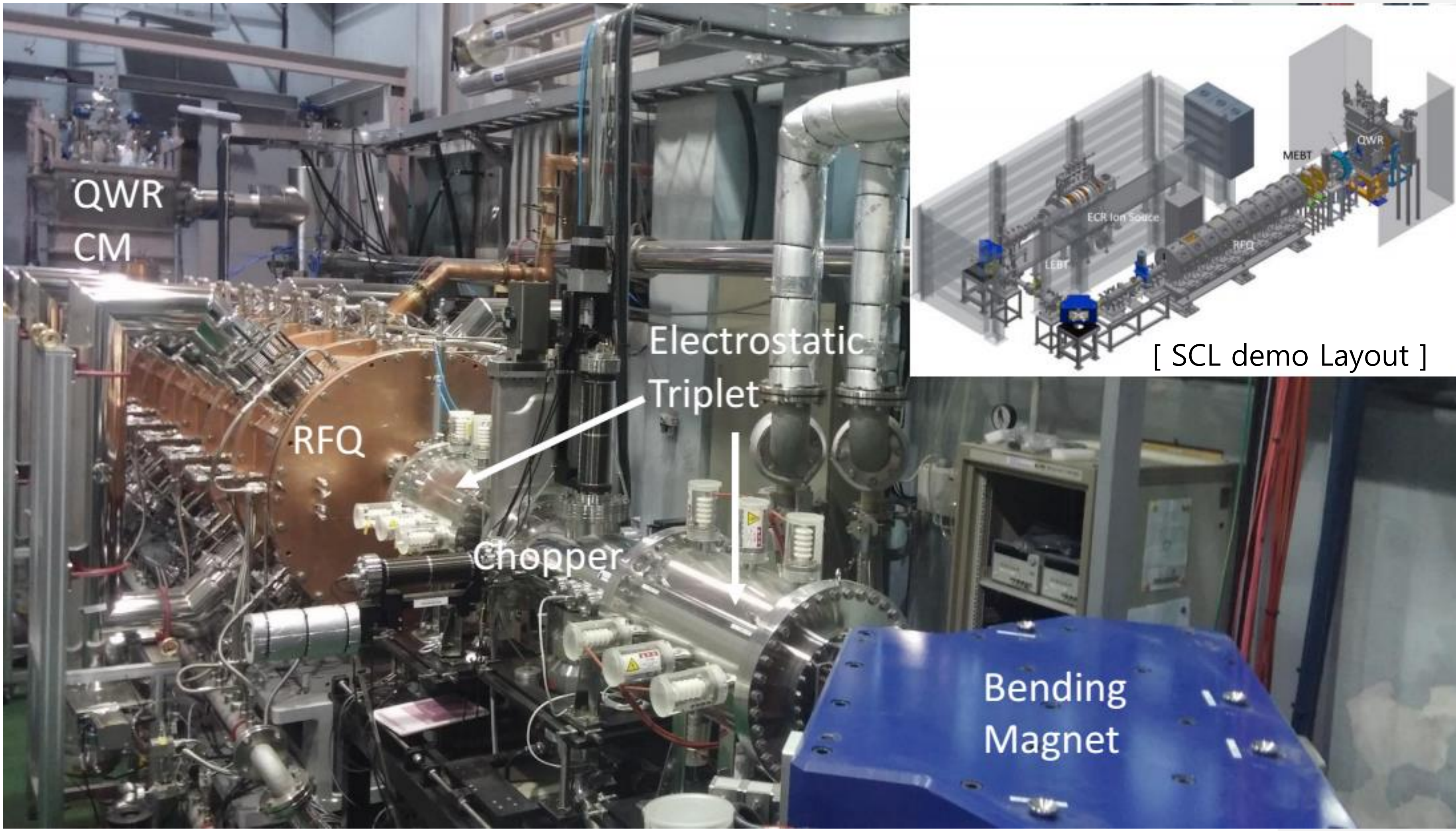
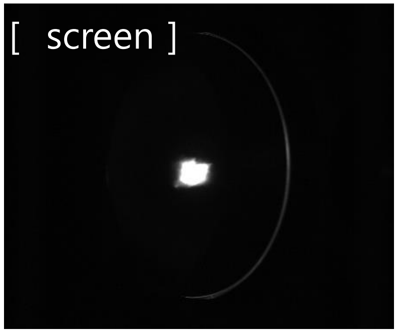
Installed SCL demo Facility

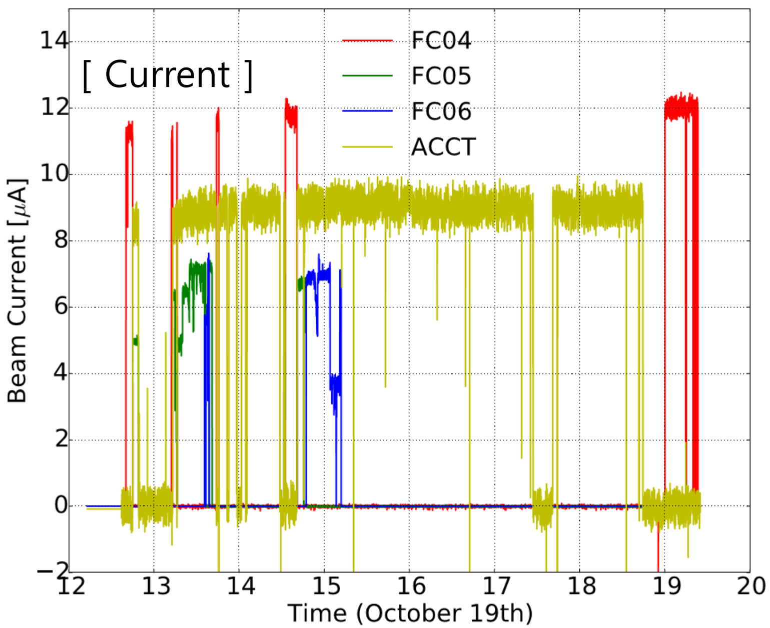


Beam Current

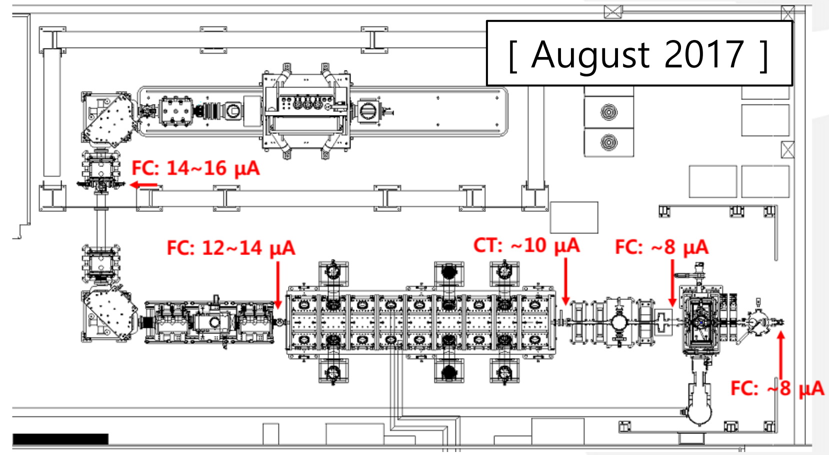
- Beam currents were measured by ACCT and FCs



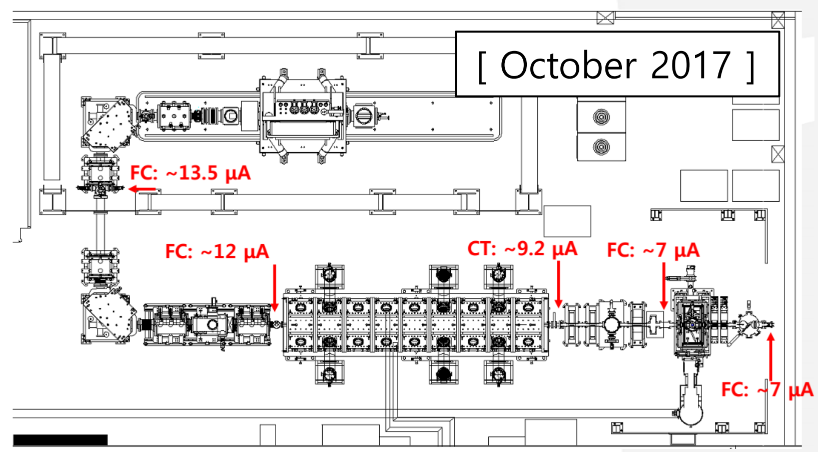
[Beam on screen]



[Beam current on FC and ACCT (October 19th, 2017)]



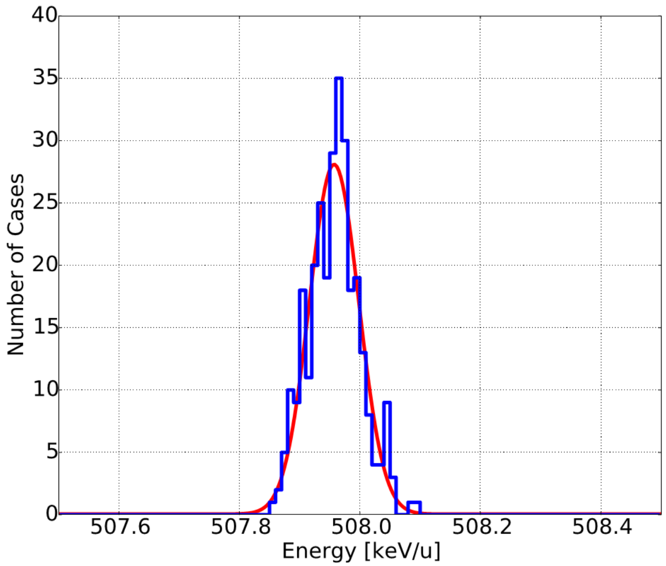
[August 2017]



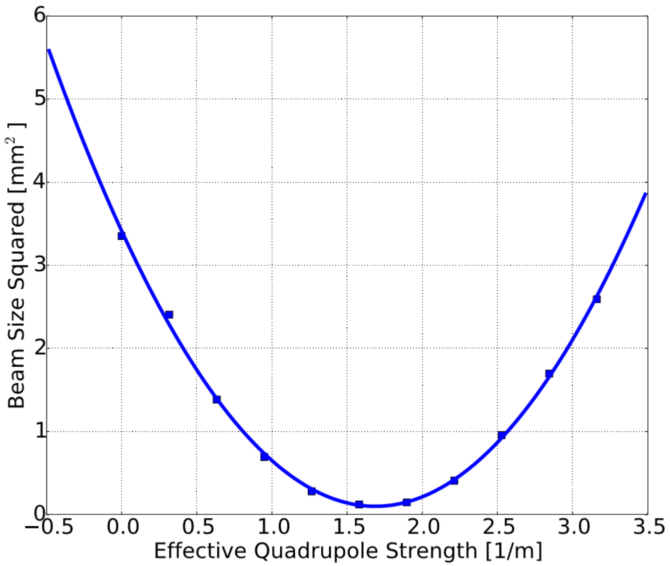
[October 2017]

RFQ Beam Energy and Emittance

- Beam energy was measured by TOF method between two BPMs.
  - PARMTEQ simulation 508.5 ± 4.0 keV/u
  - Measured energy 507.96 ± 0.12 (3σ) keV/u
- Transverse emittance was measured by quad scan method.
  - Horizontal normalized rms emittance ~ 0.14 mm-mrad
  - Vertical normalized rms emittance ~ 0.19 mm-mrad



[RFQ output energy (TOF using BPMs)]

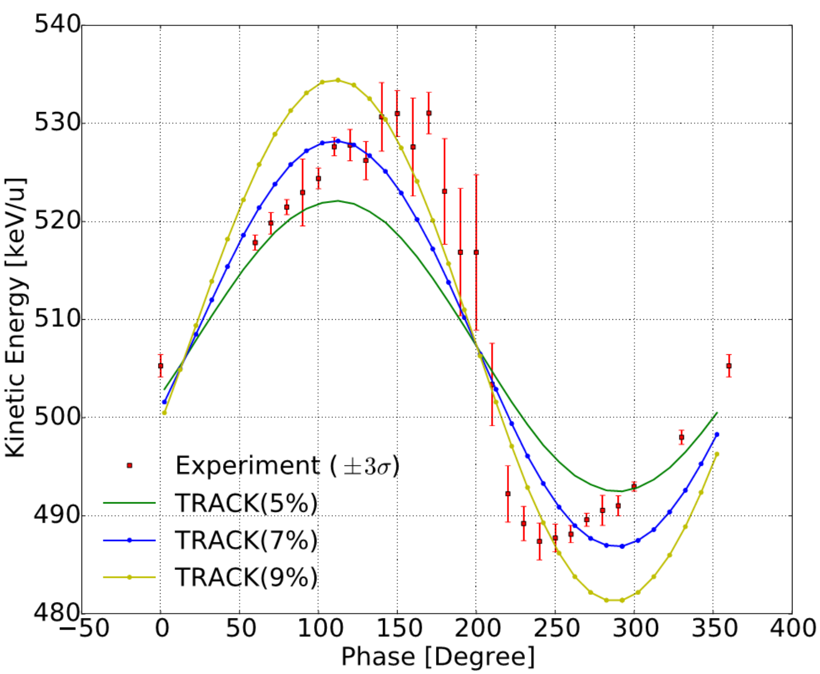


[Beam size measurement (Horizontal case)]

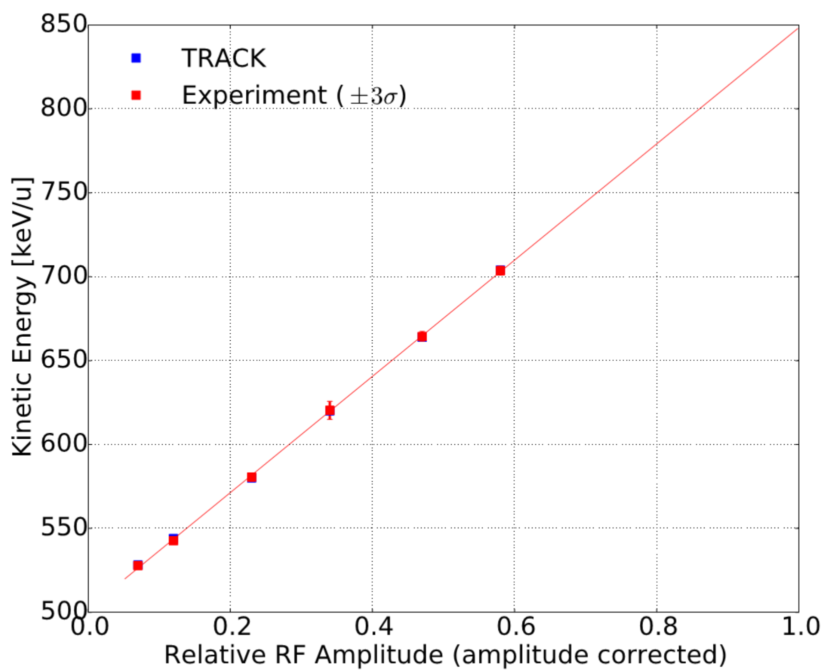
QWR Energy

- Phase scan with 5% RF amplitude (LLRF)
- Comparing TRACK simulation with varying RF amplitudes in 4~10%
- QWR energy:
  - 703.6 ± 2.8 (3 σ) keV/u for 50%(LLRF) of maximum RF amplitude
  - Expected ~ 848 keV/u for 100% RF amplitude case

Amplitude	7.1 %
Phase	117 degree



[TRACK simulation and Exp. with 5% of RF amplitude]



[QWR energy depending of RF amplitude]

Conclusions

- Prototyping and Testing QWR and HWR cavities are finished.
  - Their mass production will start from November 2018.
  - Development of SSR cavities are in progress.

- The beam commissioning of SCL demo for RAON was performed in 2017.
  - Experience on beam commissioning of RFQ and a QWR cavity
  - Testing RF system, diagnostics, control system, cryogenic system and so on for linac operation

- Installation of QWR cavities in SCL3 will start from April 2019.

- The beam commissioning of SCL3 will start from June 2020.

- The beam commissioning of SCL2 will start from October 2021.

Thank you very much for your attention!