Status of the cyclotron facility at Research Center for Nuclear Physics

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RCNP Accelerator Facility

Aiming at
Precision Nuclear Physics

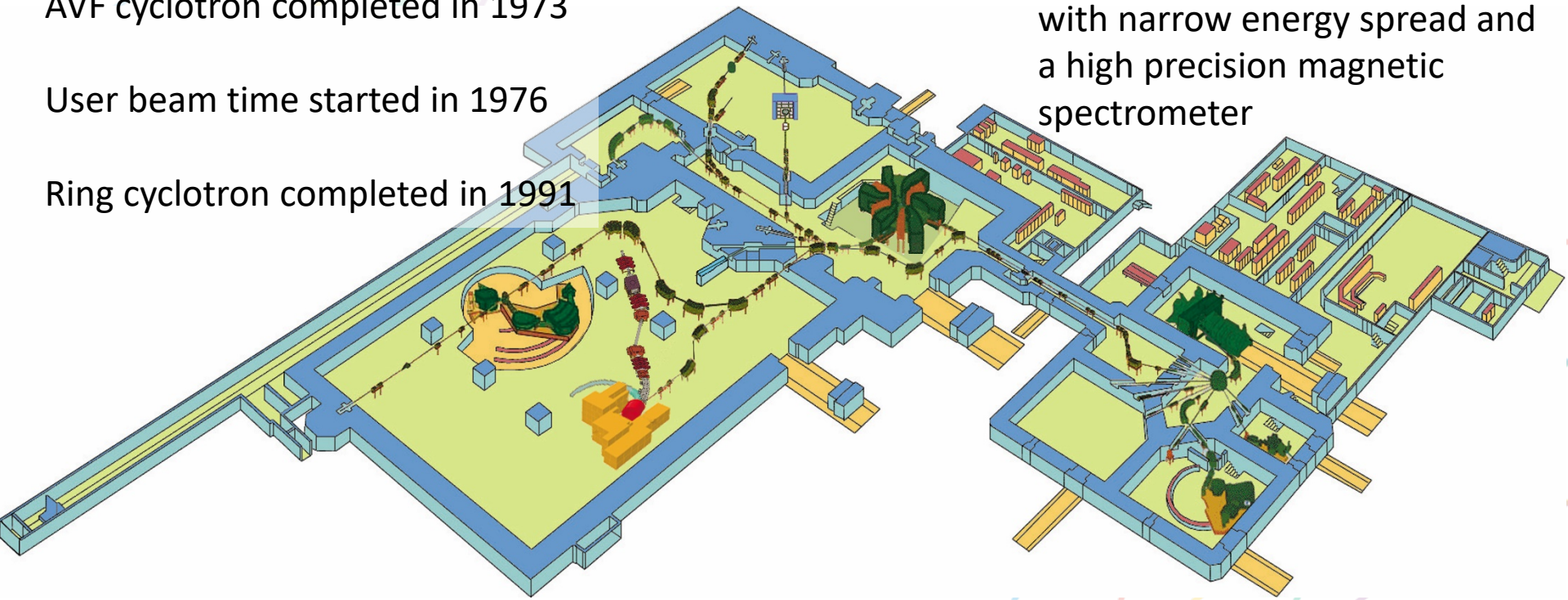
Equipped with proton beams with narrow energy spread and a high precision magnetic spectrometer

Founded in 1971

AVF cyclotron completed in 1973

User beam time started in 1976

Ring cyclotron completed in 1991



RCNP Accelerator Facility

Present K140 AVF Cyclotron

Present K140 AVF Cyclotron

1973 Completed

Proton 10～80MeV

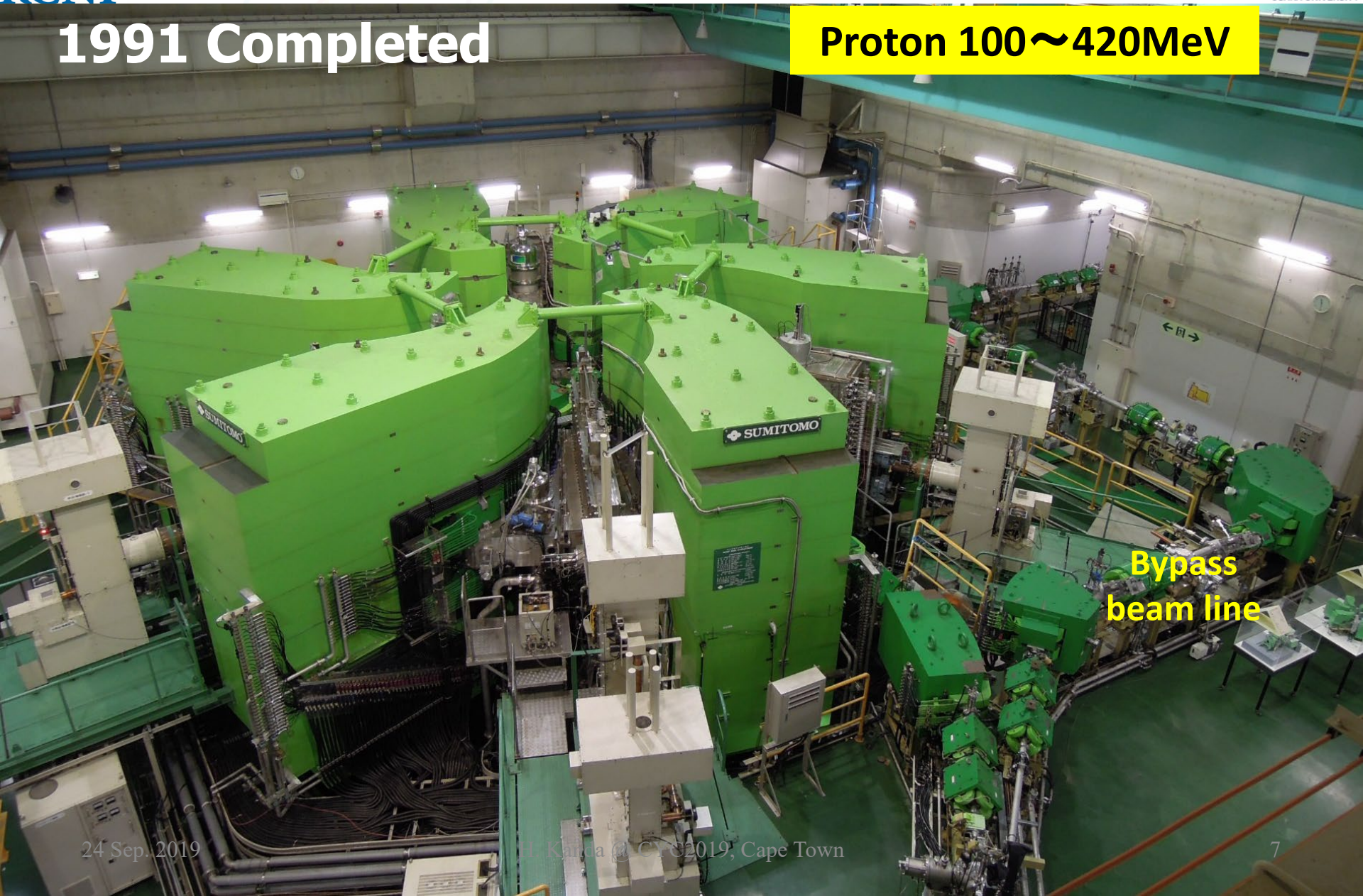
1991 Mainly used as an injector of the ring cyclotron

Magnet
- Pole diameter : 3300 mm
- Pole gap : 206 ~ 347 mm
- Averaged field : 1.6 T
- Extraction radius : 1000 mm
- Trim coils : 16 pairs
- Valley coils : 3 ~ 5 pairs
- Weight : 400 tons

Acceleration system
- Dee : Single type with 180 degree spanning angle
- Resonator : Coaxial type with a movable short
- Frequency : 6 ~ 19 MHz
- Max. acceleration voltage : 60 kV
- Acceleration harmonics : 1, 3
- Extraction system : Electrostatic deflector, weak-focusing magnetic channel

Ion Sources
- External ion source : Atomic beam type polarized ion source, Room-temperature and superconducting ECR ion sources

Present K400 Ring Cyclotron



Present K400 Ring Cyclotron

1991 Completed

Proton 100～420MeV

Magnet

- Sector magnets : 6
- Pole gap : 60 mm
- Maximum magnetic field : 1.75 T
- Trim coils : 36 pairs
- Injection radius : 2 m
- Extraction radius : 4 m
- Weight : 2200 tons

Acceleration system

- Single gap type cavity : 3
- Frequency : 30 ~ 52 MHz
- Acceleration harmonics : 6, 10
- Max. acceleration voltage : 500 kV
- RF power : 250 kW/cavity

Flat-topping cavity

- Single gap type : 1
- FT harmonics : 3
- Frequency : 90 ~ 156 MHz

Bypass beam line

Available ion beam

AVF	AVF+RING
$^{1}H^{1+}$, $^{2}H^{1+}$	$^{1}H^{1+}$, $^{1}H_{2}^{1+}$, $^{2}H^{1+}$
$^{3}He^{1+}$, $^{3}He^{2+}$, $^{4}He^{1+}$, $^{4}He^{2+}$	$^{3}He^{2+}$, $^{4}He^{2+}$
$^{6}Li^{2+}$, $^{7}Li^{3+}$	$^{6}Li^{3+}$, $^{7}Li^{3+}$
$^{11}B^{3+}$, $^{11}B^{5+}$	$^{11}B^{5+}$
$^{12}C^{4+}$, $^{12}C^{5+}$, $^{13}C^{5+}$	$^{12}C^{6+}$, $^{13}C^{6+}$
$^{15}N^{6+}$	$^{15}N^{7+}$
$^{16}O^{5+}$,$^{16}O^{6+}$,$^{18}O^{4+}$,$^{18}O^{5+}$, $^{18}O^{6+}$,$^{18}O^{7+}$	$^{16}O^{8+}$,$^{18}O^{8+}$
$^{19}F^{4+}$	
$^{20}Ne^{6+}$,$^{20}Ne^{7+}$,$^{20}Ne^{8+}$,$^{22}Ne^{6+}$,$^{22}Ne^{8+}$	$^{22}Ne^{10+}$
$^{24}Mg^{5+}$	
$^{36}Ar^{11+}$,$^{40}Ar^{8+}$,$^{40}Ar^{11+}$,$^{40}Ar^{12+}$	$^{36}Ar^{16+}$,$^{40}Ar^{17+}$
$^{86}Kr^{21+}$,$^{86}Kr^{23+}$	
$^{129}Xe^{29+}$,$^{132}Xe^{24+}$	

Energies (AVF cyclotron)

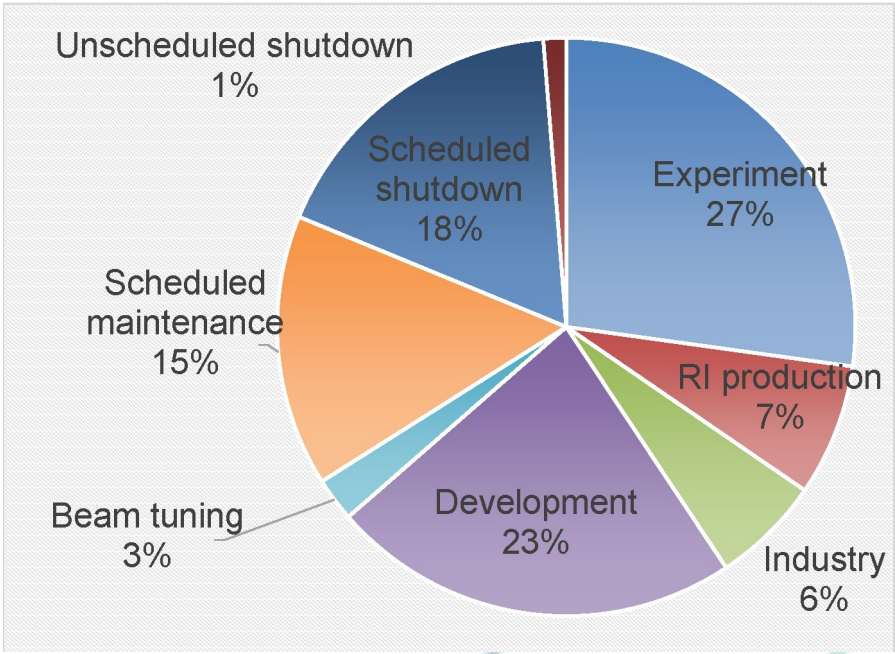
Max. Energy ($M/Q \leq 5$)	$^{1}H^{+}$	80 MeV
	$^{2}H^{+}$, $^{4}He^{2+}$	35 MeV/A
	$^{3}He^{2+}$	180 MeV
	Heavy Ions	140 $(Q/A)^2$ MeV

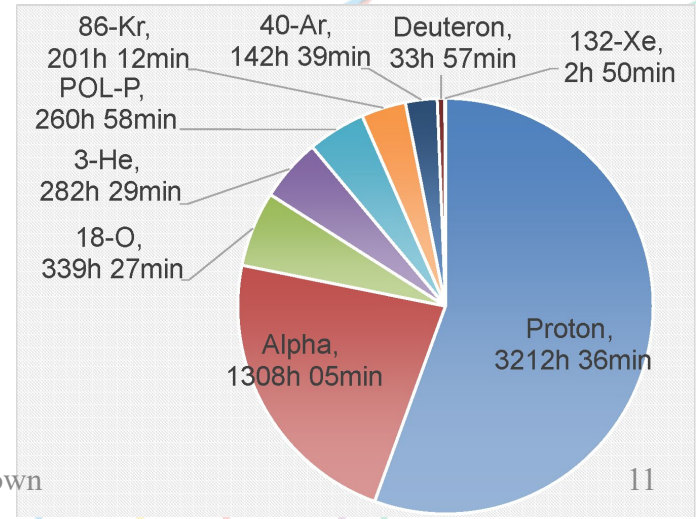
Energies (Ring cyclotron)

Max. Energy ($M/Q \leq 3$)	$^{1}H^{+}$	420 MeV
	$^{2}H^{+}$, $^{4}He^{2+}$	100 MeV/A
	$^{3}He^{2+}$	420 MeV
	Heavy Ions	400 $(Q/A)^2$ MeV

Operation Statistics

- 5784 hours working time in 2018 : 66% of 1 year
  - 2420 hours for Physics experiments
  - 646 hours for RI production
  - 535 hours for neutron irradiation (industrial use)
- 111 hours of unscheduled shutdown (due to troubles during the machine time)
- Proton and alpha beams dominate up 78% of the working time for Physics, RI production and secondary particle production





Recent activities

1. CAGRA+GRANDRAIDEN campaign
2. RI production for supply to researchers in many fields of science
3. Muon beam line: MuSIC
4. White neutron beam for study of the soft error of integrated circuits

2. Supported by KAKENHI (Grants-in-aid for scientific studies) by Japanese ministry of Education, Culture, Sports, Science and Technology (MEXT)

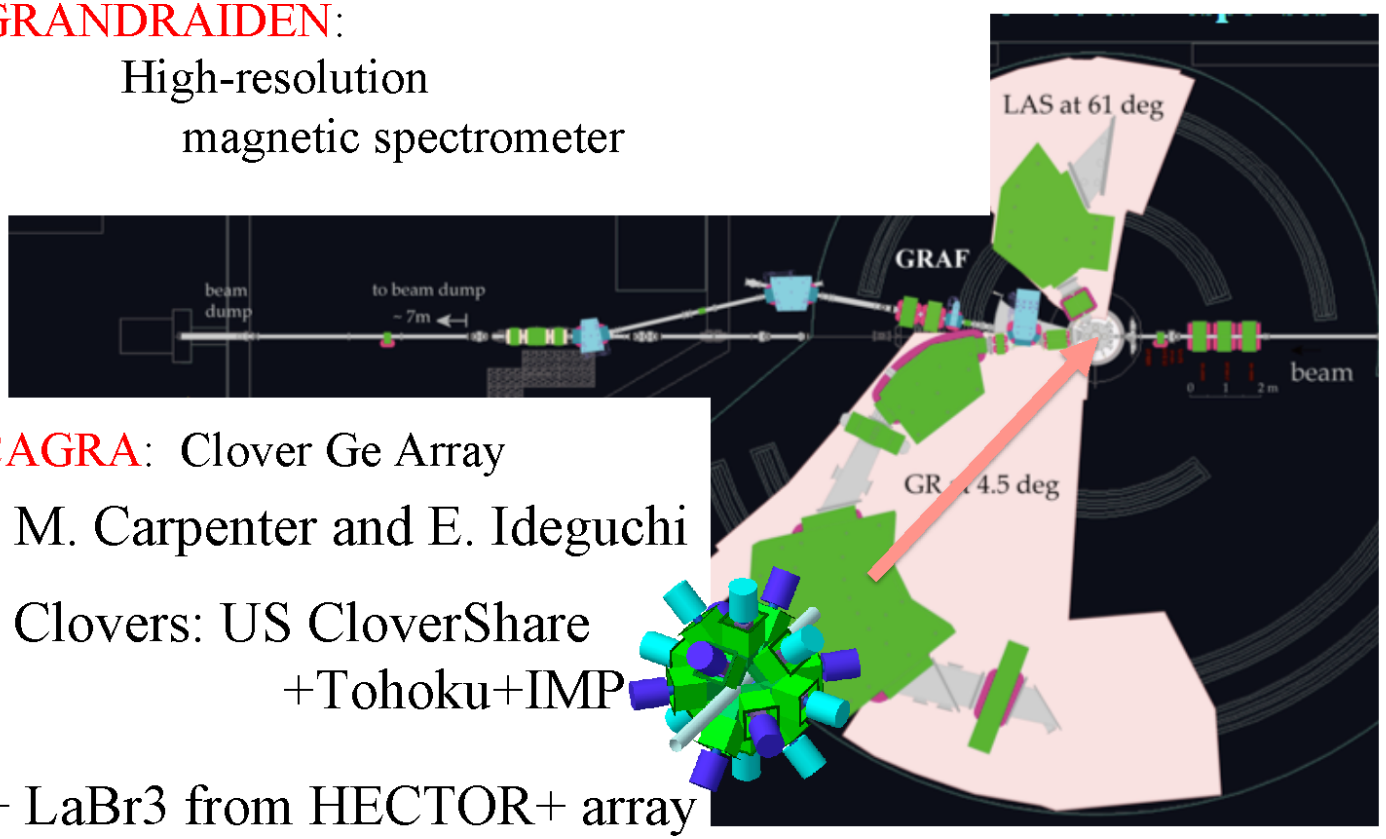
2. 3. 4. Key technologies in JST-OPERA program supported by Japan Science and Technology Agency

CAGRA+GRANDRAIDEN

CAGRA+GR Campaign Exp. From Oct. 2016

A. Tamii (RCNP)

GRANDRAIDEN:
High-resolution
magnetic spectrometer



CAGRA: Clover Ge Array
M. Carpenter and E. Ideguchi

Clovers: US CloverShare
+Tohoku+IMP

+ LaBr3 from HECTOR+ array
(Milano)

N. Aoi GRETINA-AGATA workshop 2016

Supply Platform of Short-lived Radioisotopes

MEXT KAKENHI
(Grant-in-Aid for Scientific Research on Innovative Areas)

Our AIM:

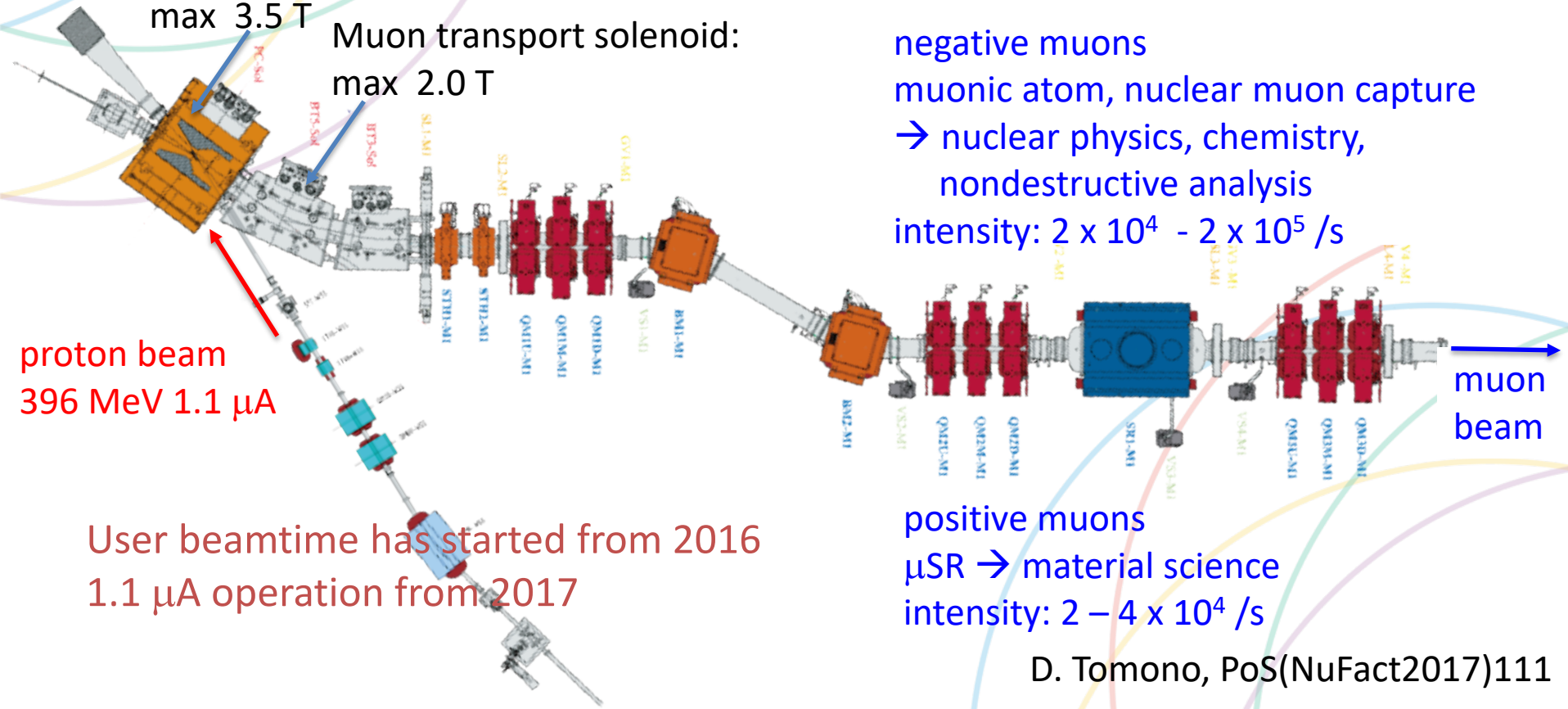
- Supply of short-lived RIs which cannot be purchased from JRIA.
- Immediate and stable supply of RIs by all-Japan accelerator consortium consisting of high performance facilities.
- Unification of contact desks at RCNP as a core of collaborative use and research to improve convenience and to increase users.
- Supporting basic research in a various field, based on the peer-review system on the scientific merit and impact

Muon beam line

- Muon Science Innovative Channel (MuSIC)

Pion capture solenoid:
max 3.5 T

Muon transport solenoid:
max 2.0 T



proton beam
396 MeV 1.1 μA

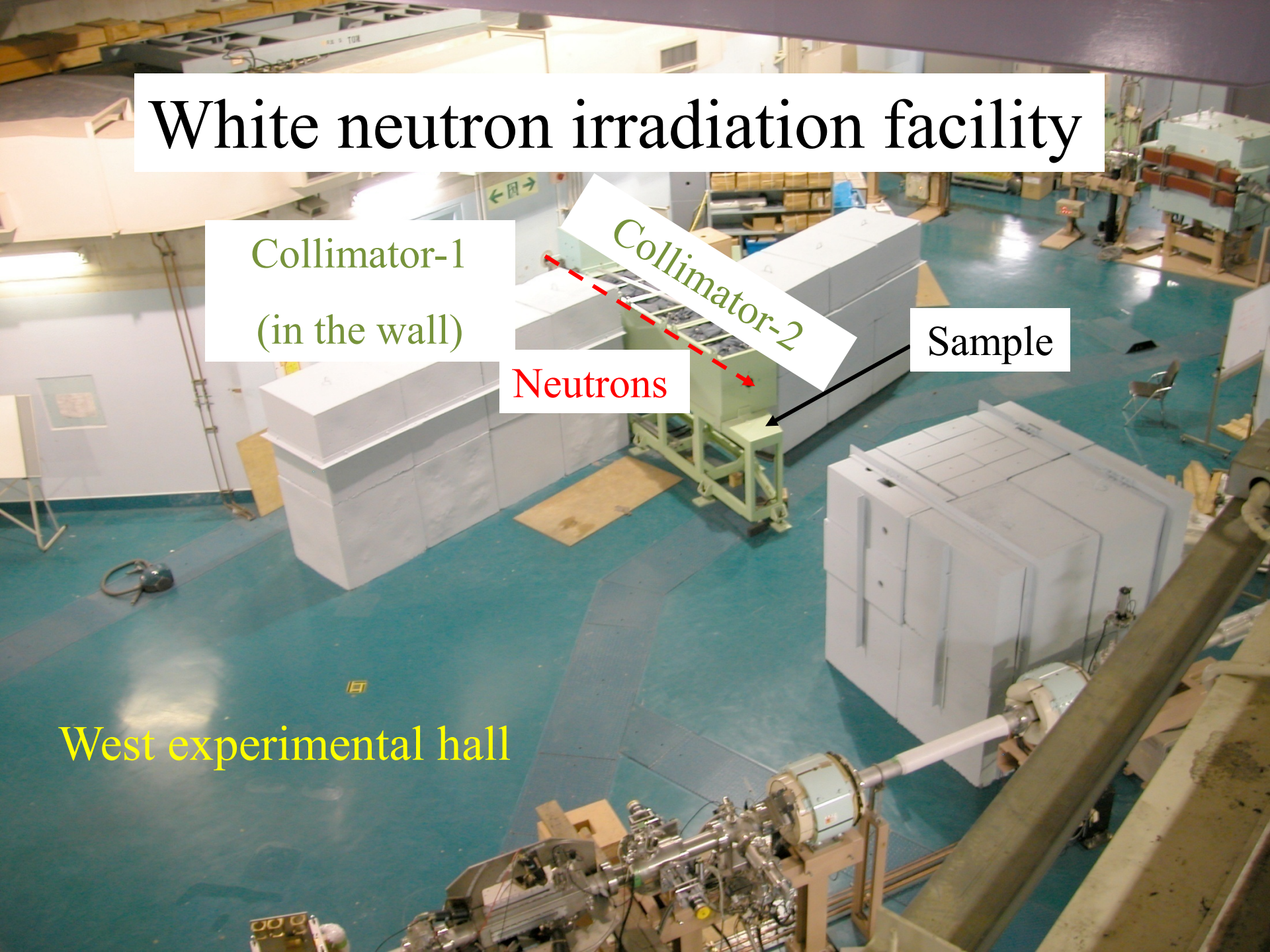
User beamtime has started from 2016
1.1 μA operation from 2017

negative muons
muonic atom, nuclear muon capture
→ nuclear physics, chemistry,
nondestructive analysis
intensity: 2 x 10^4 - 2 x 10^5 /s

muon beam

positive muons
μSR → material science
intensity: 2 – 4 x 10^4 /s

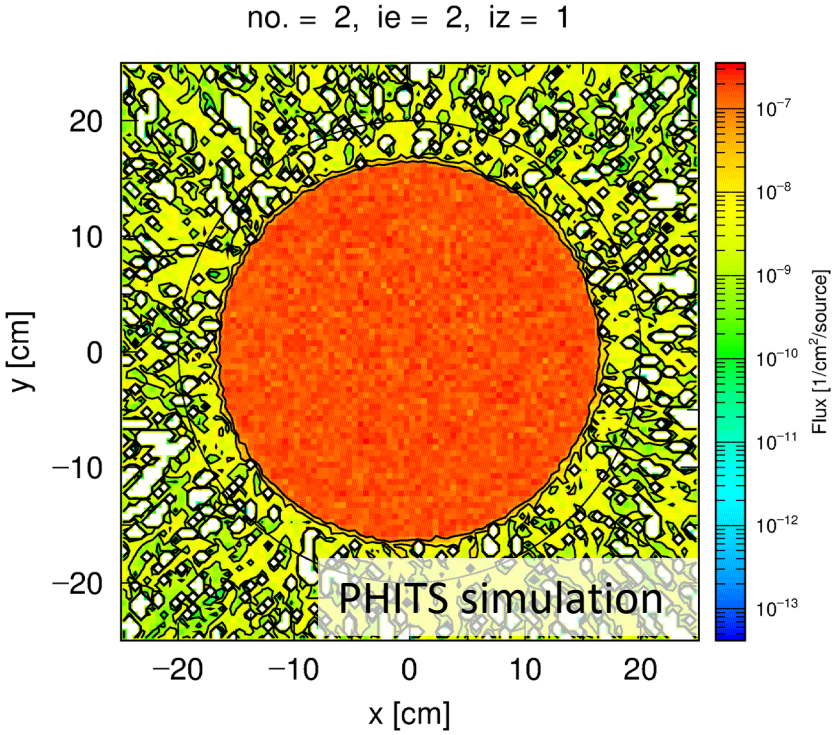
D. Tomono, PoS(NuFact2017)111

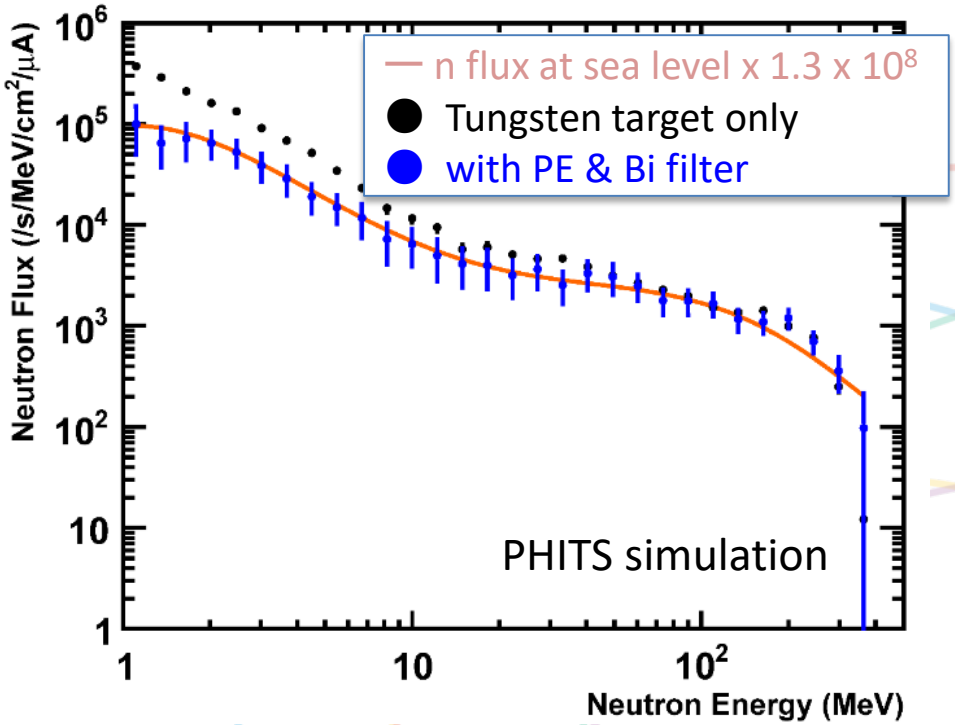

White neutron irradiation facility
Collimator-1
(in the wall)
Collimator-2
Sample
Neutrons
West experimental hall

Upgrade of white neutron beams

- Larger aperture collimator → 300 mm diameter beam
- Polyethylene and Bismuth filter → better reproduction of energy spectrum

One of the important matter in the upgrade





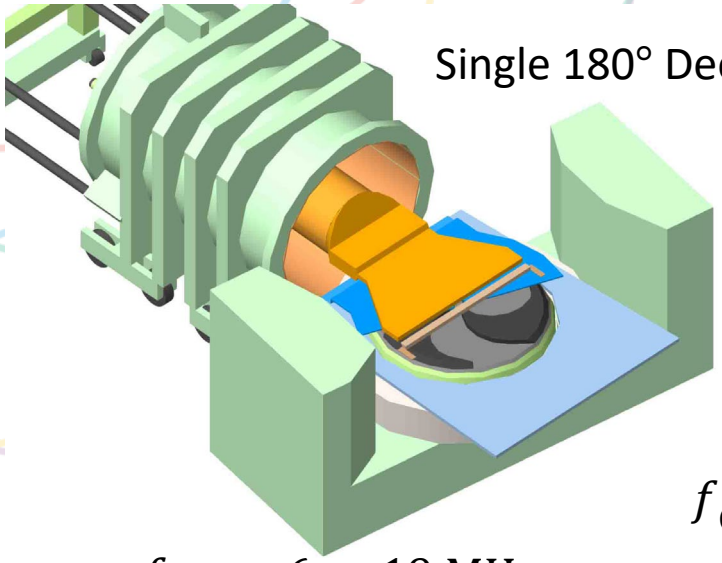
Upgrade of the AVF cyclotron

- Renewal of old (46 years old) cyclotron
  - For reduction of down time due to troubles in old parts
  - By replacing almost all the parts of cyclotron except for poles, yokes, and main coils

- Upgrade of beam intensity (> 10 times higher)
  - For
    - Mass production of radioisotopes
    - Efficient use of secondary beams (neutrons, muons)
    - Higher intensity and higher quality for experiments in nuclear physics
  - By
    - Reducing emittance of low energy beams for injection to match the acceptance of the AVF cyclotron
    - Changing single 180-degree dee to double 90-degree dees for higher acceleration per turn
    - Adopting subharmonic buncher (the same one before the upgrade)

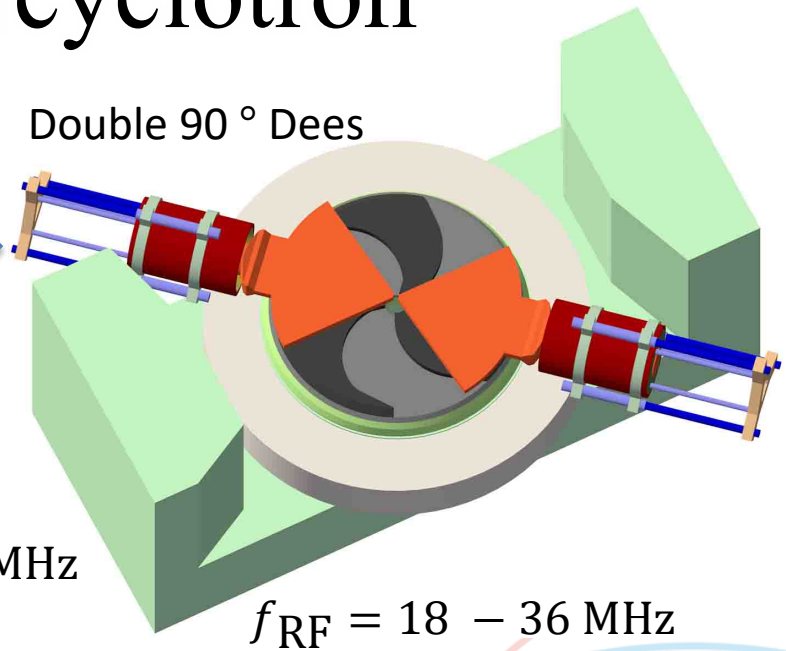
For detail: M. H. Fukuda WEA03 (tomorrow)

Upgrade of AVF cyclotron



$f_{\mathrm{RF}} = 6 - 19$ MHz

$f_{\mathrm{cycl}} = 6 - 19$ MHz



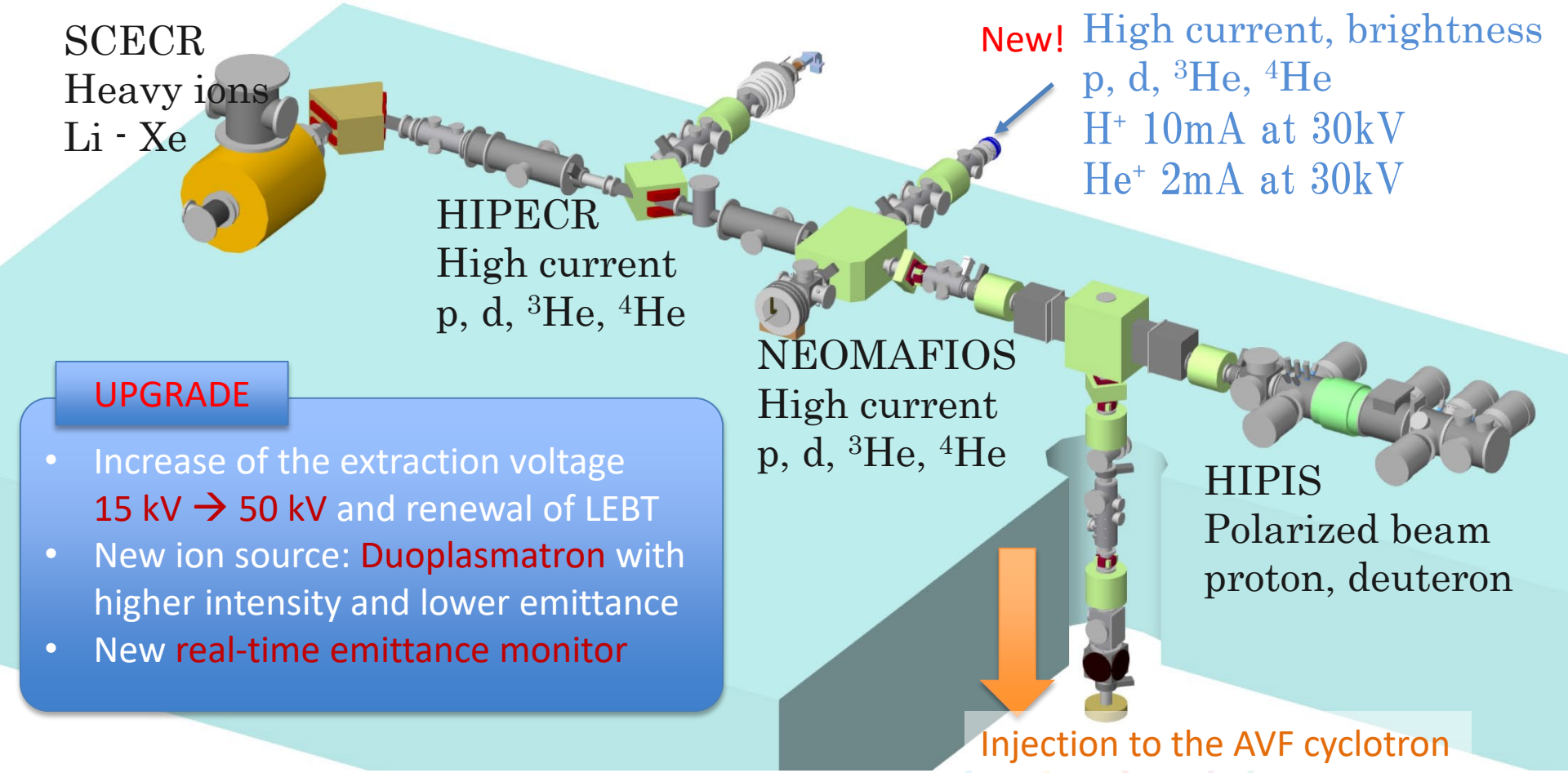
$f_{\mathrm{RF}} = 18 - 36$ MHz

Hamonics	1	2		3	6
Particle	Proton	Proton	Heavy ion	Heavy ion	Heavy ion
Energy range (MeV/n)	58 – 100	14 – 70	14 – 27	6 – 26	2 – 7
Energy gain per turn ($\Delta E/qV$)	2.8	4	4	2.8	4

※ Main proton beam: 65 MeV(AVF)+392 MeV(Ring) → f_{cycl} =16.8 MHz, f_{RF} = 33.6 MHz with $h = 2$

Ion sources and a low energy beam transport (LEBT)

- We have 4 active ion sources and 1 new ion source to be added at RCNP
- They are used for characteristic particle beams



UPGRADE

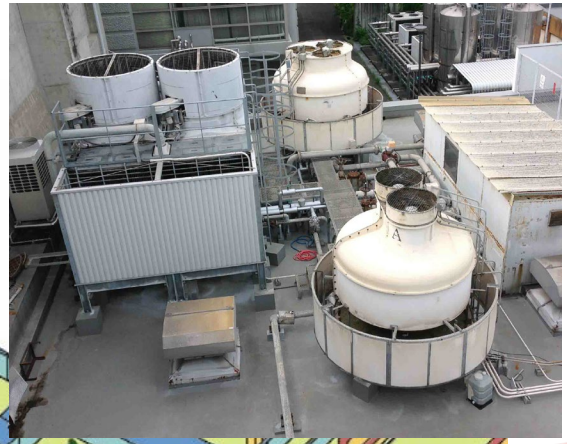
- Increase of the extraction voltage 15 kV → 50 kV and renewal of LEBT
- New ion source: Duoplasmatron with higher intensity and lower emittance
- New real-time emittance monitor

Upgrade of the facility

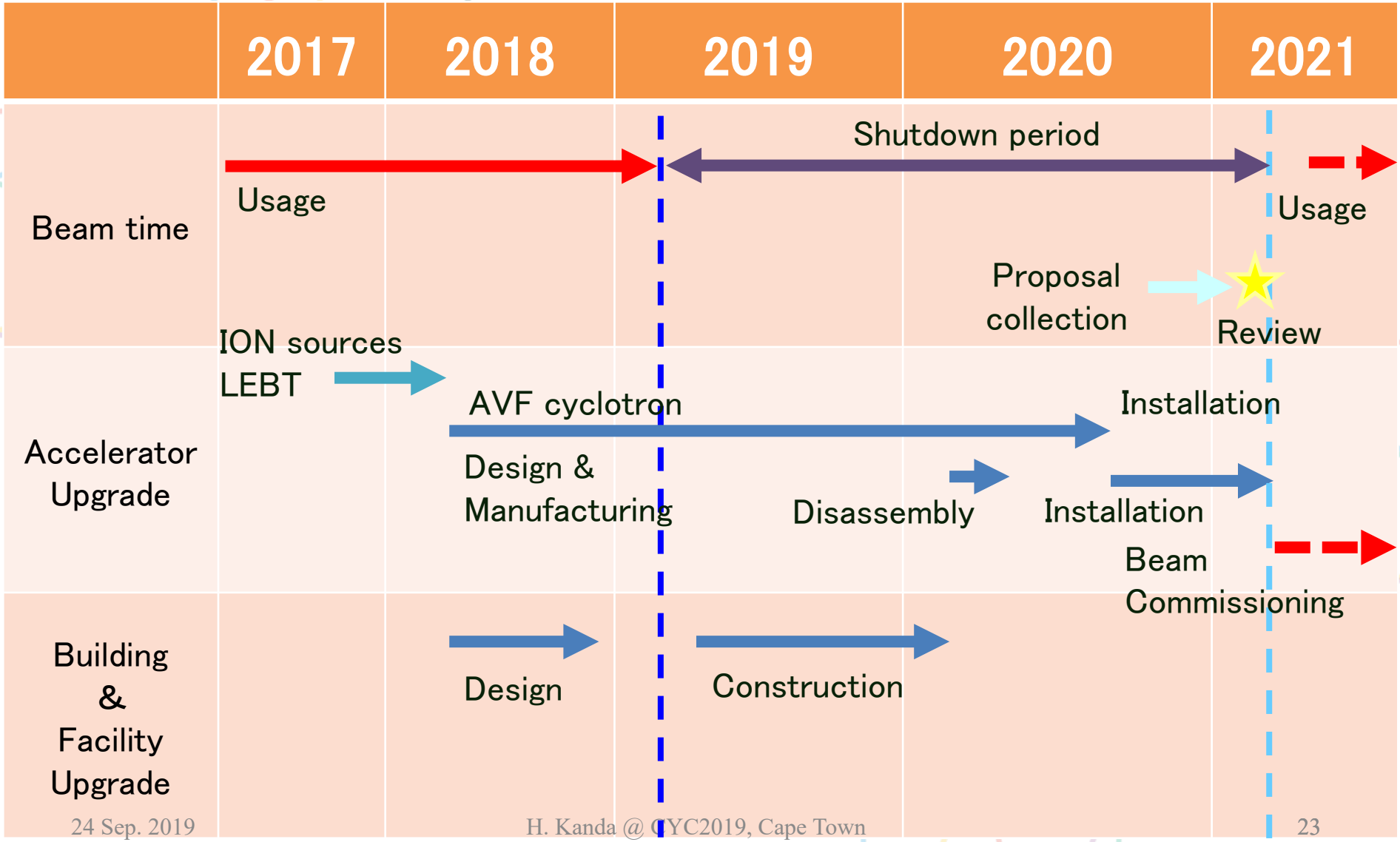
- Aim
  - Handling the higher intensity beams after the upgrade of the AVF cyclotron
  - Renewal of old facilities
- List of items
  - Renewal of the AVF cyclotron hall (cranes, ceilings)
  - Increase of the thickness of shielding walls
  - Renewal of shielding gates
  - Increase of the cooling capacity
  - Renewal of RI drainage system
  - Renewal of electric systems
  - Renovation of the white neutron beam line

→ For reinforcement of the function as the center of subatomic science

Under construction!



Schedule of the upgrade works



Summary

- RCNP, Osaka University working for 48 years is the one of the center of subatomic science in Japan
- Adding with the nuclear physics experiments, our recent activity includes radiation chemistry, biology, nuclear medicine, and computer science.
- We upgrade the AVF cyclotron for 10 times of beam intensity
- We also upgrade our facility for handling the more intense beam and also reinforcing the function as the center of subatomic science.
- The upgrade is planned to be completed by March 2021