Proc. 13th Int. Conf. on Nucleus-Nucleus Collisions
JPS Conf. Proc. **32**, 010001 (2020)
https://doi.org/10.7566/JPSCP.32.010001

Major Accelerator Facilities for Nuclear Physics in Asia Pacific

Kazuhiro Tanaka

Chair of Asian Nuclear Physics Association (ANPhA)
Institute of Particle and Nuclear Studies (IPNS) and
Particle and Nuclear Physics Division, J-PARC Centre,
High Energy Accelerator Research Organization (KEK),
Oho 1-1, Tsukuba-shi, Ibaraki-ken, 305-0801 Japan.

**E-mail: kazuhiro.tanaka@kek.jp*

(Received July 17, 2019)

Asian Nuclear Physics Association (ANPhA) is the central organization representing nuclear physics in Asia-Pacific. ANPhA is now preparing a list of Asia-Pacific accelerator facilities for nuclear physics experiments. Among them, characteristics of the world class "Major" accelerator facilities are briefly summarized in comparison with similar facilities in Europe and North America.

KEYWORDS: Asian Nuclear Physics Association (ANPhA), Major Accelerator Facility, RI beam, Hadron beam, Electron and photon beams

1. Introduction

The Asian Nuclear Physics Association (ANPhA) [1] was established in 2009 in Beijing, where representatives of the first four member countries of ANPhA gathered together. ANPhA is the central organization representing nuclear physics in Asia Pacific and currently consists of eleven member countries and regions, i.e. Australia, China, Hong Kong, India, Japan, Kazakhstan, Korea, Mongolia, Myanmar, Taiwan, and Vietnam.

The basic objectives of ANPhA are;

1. To strengthen "Collaboration" among Asian nuclear research scientists through the promotion of nuclear physics and its transdisciplinary and applications,
2. To promote "Education" in Asian nuclear science through mutual exchange and coordination,
3. To "coordinate" among Asian nuclear scientists by actively utilizing existing research facilities,
4. To "discuss future planning" of nuclear science facilities and instrumentation in Asia.

In 2015, ANPhA decided to play a role as the Division of Nuclear Physics (DNP) of Association of Asia Pacific Physics Societies (AAPPS). By the approval of AAPPS, AAPPS-DNP was established in 2016. Thus ANPhA chair is also the chair of AAPPS-DNP, and supposed to attend activities of AAPPS as the its extended Council meeting member. Therefore, ANPhA (=AAPPS-DNP) is, in practice, a major organization to discuss and pursuit issues in Asian nuclear physics community.

Another important activity of ANPhA is to organizing ANPhA (=AAPPS-DNP) awards for young Scientists [2] for ANPhA supported scientific meetings, which were selected appropriate times per year (6 times in 2019) in Asia Pacific region.

2. ANPhA White Paper

In Asia Pacific region, many advanced accelerator facilities have been constructed. Some of them are world top class. ANPhA is now preparing a list of Asia-Pacific accelerator facilities available for nuclear physics experiments, This list is called ANPhA White Paper [3], which provides a kind of catalog of current user facilities, expected to be useful for planning international collaborations and establishing a long-range plan of accelerator construction for our future activities of nuclear physics in Asia Pacific. Since international collaborations is by its nature world-wide, the White Paper would be useful also for our European and American colleagues of nuclear physics.

Data for 28 accelerator facilities are collected in the White Paper at present, and will be updated yearly. The latest update was made in August 2018. Critical analysis of the listed data have continuously been made. The ANPhA White Paper is now temporarily linked to the KEK Indico system [3] and will be published elsewhere.

3. Major Accelerator Facilities in Asia Pacific

Large-scale accelerator facilities in Asia Pacific region are mainly located in China (Heavy Ion Research Facility in Lanzhou (HIRFL), Beijing Tandem Accelerator National Laboratory (BTANL)), Korea (RISP/RAON), and Japan (RIBF at RIKEN, J-PARC). Many of them (HIRFL, BTANL, RISP/RAON and RIBF) are medium energy heavy-ion accelerator facilities and are competing with European facilities such as SPIRAL2, HIE-ISOLDE, SPES, MYRRHA and North American facilities such as ARIEL-II and FRIB. In addition, future extension plans of these Asian facilities are really aiming far beyond the wave front of the research in nuclear physics. Thus these Asian research facilities are keeping world best positions in medium-energy heavy-ion physics. Hadron physics facility in Asia Pacific (J-PARC) is also world leading.

In contrast, there are no high energy heavy-ion accelerators and colliders (such as ALICE in LHC in CERN, RHIC in BNL in USA, and NICA in DUBNA in Russia) in Asia Pacific. In other words, we have concentrated our research resources to medium energy heavy-ion physics and promoted high energy heavy-ion physics research in facilities abroad or outside Asia. This strategy seems successful at present. However we have to check it for our future research activities in Asia Pacific for, at least, coming ten years. For example, I am afraid that the concentration on medium energy heavy-ion accelerators is too strong in Asia-Pacific. A similar tendency may exist in Europe. A question that should be carefully considered is if our investment for future activities should be in a wider scope.

In the following Chapters, the present status and future plans of some of our “Major Accelerator Facilities” are briefly introduced.

4. Chinese Facilities

Construction of accelerator facilities in China is in very much strategic and clever way as shown in Figure 1. They constructed ordinary experimental facility based on the tandem electrostatic accelerator in 1986 in Beijing and construction of the experimental facility based on Split Sector Cyclotron (SSC) followed it in 1988 in Lanzhou.

After the successful operation of both facilities for approximately 20 years as “normal” nuclear (heavy-ion) beam facilities, an accumulator ring was added in SSC facility in Lanzhou in 2008 and SSC was used as the injector to the ring. “Unstable” nuclear beams produced through projectile fragmentation from “normal” (stable) nuclear beams obtained from SSC were accumulated in the ring and many precise measurements of nuclear mass and other properties of unstable nuclei were carried out. For Beijing facility they added small but very high intensity cyclotron to produce “unstable” nuclear (heavy-ion) beams by using the ISOL-type target ion source. High intensity proton beam obtained from the small cyclotron irradiated the ISOL-target which was heated up by beam power as well as electrical heater. Unstable nuclei produced in the ISOL-target through nuclear reactions were thus evaporated from the surface of the target and collected for the re-acceleration by the tandem electrostatic accelerator. Conversion of unstable nuclear beams thus obtained to negative ions was made through a Rb vapor cell. Then the tandem facility and SSC facility were well converted to the most modern “unstable” nuclear beam facilities.

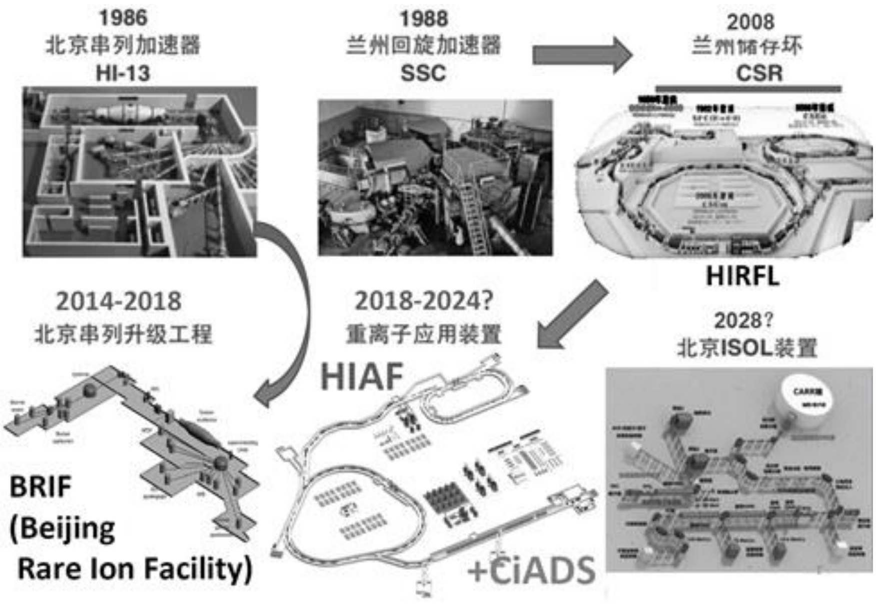

Fig.1. Chinese major accelerator facilities for nuclear physics.

Their next steps are the construction of very High Intensity Accelerator Facility (HIAF) for the production of unstable nuclear beams based on the projectile fragmentation, which is the natural extension from Lanzhou’s SSC facility but constructed in the other place, i.e. Huizhou city. By combining very strong proton driver prepared for Chinese initiative Accelerator Driven System (CiADS), unstable nuclear beams separated from ISOL target as well as the subcritical ADS reactor will be used as the starting beams instead of “stable” nuclear beams in future. They have another dream of very high intensity unstable nuclear beams, i.e. the SUPER ISOL facility based on the combination of nuclear reactor and linear accelerator in Beijing, i.e. Beijing ISOL.

5. Korean Facility

The major accelerator facility under construction in Korea is RAON (Rare isotope Accelerator complex for ON-line experiments) of RISP (Rare Isotope Science Project) hosted by IBS (Institute of Basic Science). This is the first big nuclear-physics project in Korea involving construction of a world class accelerator complex. Location of RAON is Sindong area in Daejeon city, which is almost the center of South Korea and 2-3 hours travel by KTX fast train from both Seoul and Pusan. The ground breaking for the accelerators and experimental buildings was done on Feb. 13th in 2017.

RAON accelerator consists of three superconducting linear accelerators (linacs) as shown in Figure 2. Combining three linacs, acceleration of normal heavy-ion beams and unstable nuclear beams extracted from an ISOL type ion source to sufficiently high energies to projectile fragmentation is realized. As results RAON can provide much higher intensity unstable nuclear beams than any other facilities in the world. For the ISOL type ion sources, high intensity proton cyclotrons are introduced as drivers.

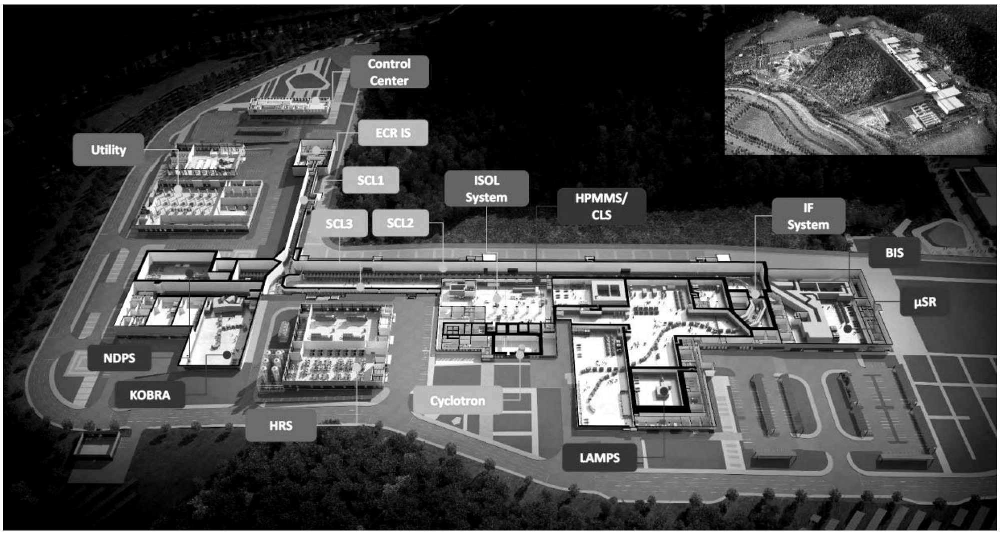

Fig.2. RAON accelerator complex of RISP of IBS in Korea

R&D of superconducting accelerator devices have already started and test cryo-module of acceleration cavity showed sufficiently high field gradient with less heat load than expected, i.e. ready for mass production. Operation test of ISOL type ion sources has started at hot-cell mock-up. Remote maintenance scheme of the ISOL type ion source will be tested there.

Now RAON people are concentrating on completing SLC3, low energy linac for unstable beams from the ISOL type ion source and KOBRA low energy isotope separator. Construction of SLC2 will be followed by the SLC3 construction, but construction priority of SLC1 is the lowest at present. It means that SLC3 will be used for the acceleration of both stable heavy-ion beams and unstable nuclear beams from ISOL type ion source. The first experiment using SLC3 and COBRA will be performed by the end of 2022.

6. Japanese Facilities

There are several large-scale accelerators in Japan as shown in Figure 3.

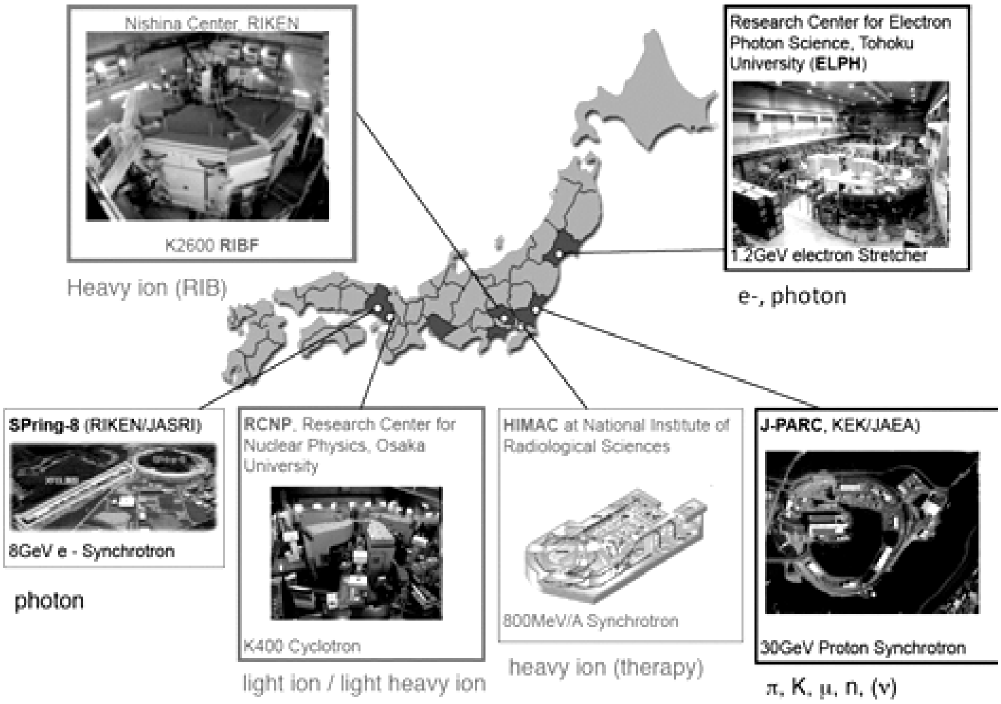

Fig.3. Large scale accelerator complexes located in Japan.

Among them the following 2 research complexes and their future plans were endorsed by Japanese Nuclear Physics Executive Committee in 2018 as the most important (Rank S) facilities and future plans of nuclear physics in Japan for coming ~5 years. They are;

1. J-PARC (KEK) for hadron/nuclear physics with hadron beams, and some of fundamental/particle physics with muons, which has its future project of Hadron Hall Extension.
2. RIBF (RIKEN) for nuclear structure and nuclear reaction studies using world highest intensity RI beams, which has its future project to increase RI beam intensity of 30 times higher for expanding neutron-rich heavy element production to trans-uranium and superheavy z=119-120 elements and beyond.

In addition to them, three research fields were selected as important subjects (Rank A or B) for Japanese nuclear physics;

3. High energy heavy-ion collision (LHC, RHIC, J-PARC-HI) to study QGP properties,

QCD phase diagram, and High density nuclear matter, which has its future projects of ALICE upgrade, STAR upgrade, s-PHENIX, and J-PARC-HI addition to J-PARC (Rank A).
4. High energy heavy-ion and electron collisions at EIC at JLAB or BNL (Rank B).
5. Nuclear physics part of Nuclear Transmutation system for long lived fission fragments produced in the nuclear fuel (Rank A).

Thus you can understand that J-PARC in KEK and RIBF in RIKEN are the two-top facilities of Japanese nuclear physics community. Then extension of Hadron Experimental Hall and 30 times intensity upgrade of RIBF are the two-big future plans in Japan.

Schematic layout of RIKEN-RIBF in operation is shown in Figure 4. It consists of several types of ring cyclotrons connected in cascade including one big superconducting ring cyclotron, SRC.

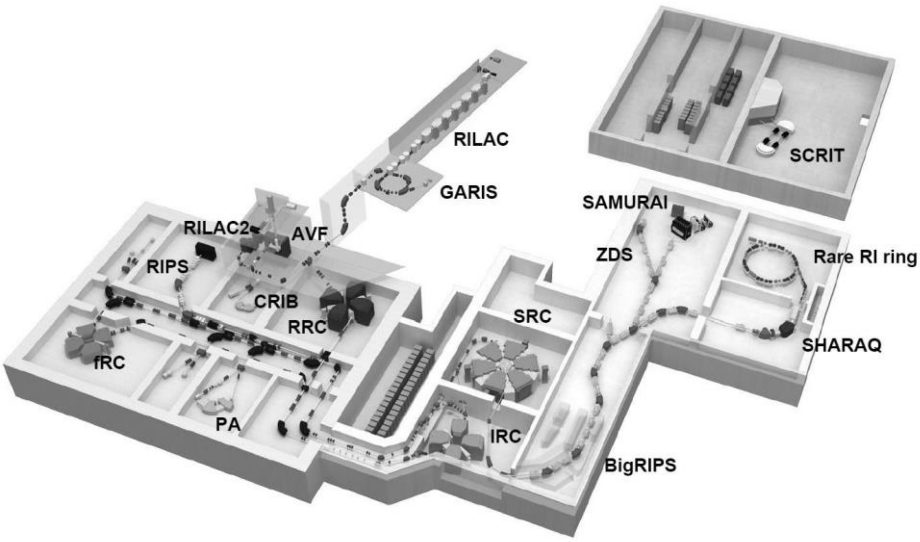

Fig.4. Schematic layout of RIBF-RIKEN accelerator complex.

Unstable nuclear beams are produced by projectile fragmentation (PF) with a large solid angle PF separator, the BigRIPS. Upgrade for 30 times higher intensity is mainly performed by upgrading injector LINAC and by the modification of charge stripping system between cyclotrons. Performances of SRC and BigRIPS will be upgraded in order to accept higher intensity primary nuclear beams. High intensity beams accelerated by upgraded LINAC will also be used for the search of new superheavy elements such as Z=119, 120 and beyond. The upgraded BigRIPS will expand the possible research area in the nuclear chart drastically. This upgrade project is named as “Landing to Stable Island”.

J-PARC (Japan Proton Accelerator Research Complex) is the most advanced accelerator facility in Japan. J-PARC consists of three accelerators, i.e. 400 MeV Linac, 3 GeV Rapid Cycle Synchrotron (RCS) and 30 GeV-Main Ring (MR). The bird eye view of J-PARC is shown in Figure 5.

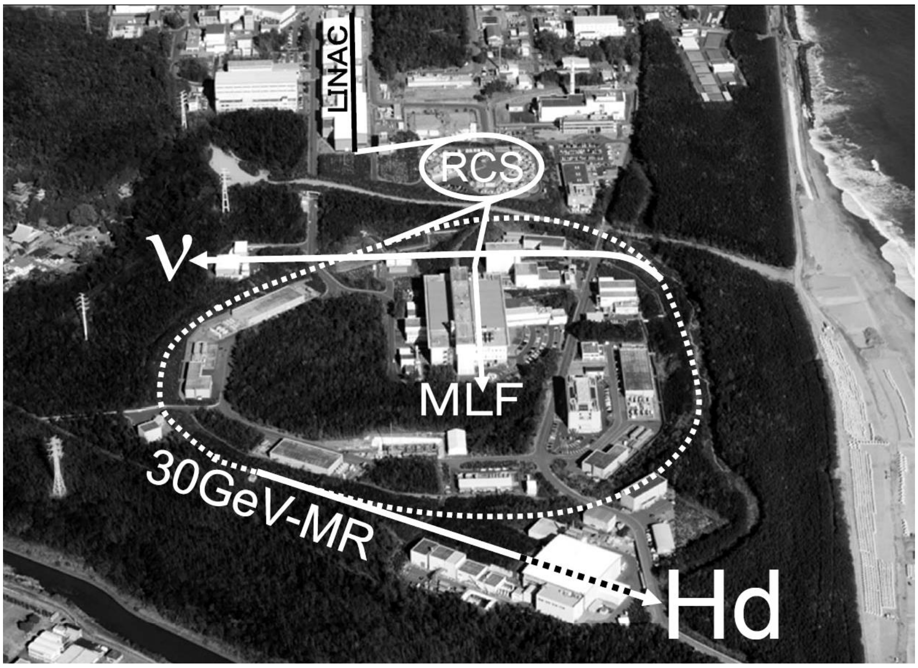

Fig.5. J-PARC at Tokai-mura locates near beautiful seashore.

The most important characteristic of J-PARC is its high design beam power, which is 1MW for RCS and 0.75MW for MR. RCS provides intense proton beams to a neutron spallation source (n) and a pulsed muon source (μ) installed in Materials and Life Science Facility (MLF). Some fraction of the beam extracted from RCS is injected to MR and accelerated up to 30 GeV.

Two ports for extracting the beams from MR were constructed. One makes the fast extraction for Neutrino Beam Facility (ν) for long baseline neutrino oscillation experiment, T2K, and the other provides the slow extraction for counter experiments in Hadron Experimental Facility (Hd). Four experimental facilities (n, μ, ν and Hd) provide their characteristic intense secondary beams for users. The highest proton beam energy of MR is now 30 GeV instead of its design energy of 50 GeV. It is mainly because of insufficient budget for fully preparing power supplies of MR magnets.

Major future project of J-PARC for nuclear physics is the extension of the Hadron Hall three times as shown in Figure 6.

7. Future Perspectives

In 2017, the first neutron star mergers (NSM) were observed by gravitational wave and electromagnetic signals at the same time. From the gravitational wave signals, we could deduce the equation of state (EOS) of nuclear matter including strangeness, i.e. hypernuclear matter. From the time evolution of electromagnetic signals, we could learn the characteristics of radioactive nuclei, i.e. r-process nuclei, in the ejecta. This forces us to recognize that physics of hypernuclei and physics at RIB facilities should be integrated for the understanding of the most spectacular events in our Universe. In other words, there is no border between Hypernuclear physics, Hadron physics, and traditional Heavy-ion physics, each other. Nuclear physics is now stepping into the new horizon of the unification.

I hope this NN2018 conference is the start point of this NEW UNIFICATION, and home works from NSM will be solved within 3 years, i.e. until the next NN conference. Fortunately, we have sufficient amounts of good tools to solve these problems in the world, i.e. very good accelerator facilities. In addition, we know we have very powerful "super" computers, too!

OK, let's start working harder!

Acknowledgment

The author would like to express his sincere thanks to Board members of Asian Nuclear Physics Association (ANPhA), who prepared the data for ANPhA White Paper.

References

[1] ANPhA: http://ribf.riken.jp/ANPhA/
[2] Kazuhiro Tanaka, "The First Year of the ANPhA (AAPPS-DNP) Awards for Young Scientists", AAPPS Bulletin, Vol. 28, No. 1, pp. 43-45.
[3] ANPhA White Paper: https://kds.kek.jp/indico/category/1706/
Notes for KEK Indico users, please find the username and password at the first page you opened (Most users) or "click for the password" on the page which you can find after closing the popup window to login (Google Chrome users).

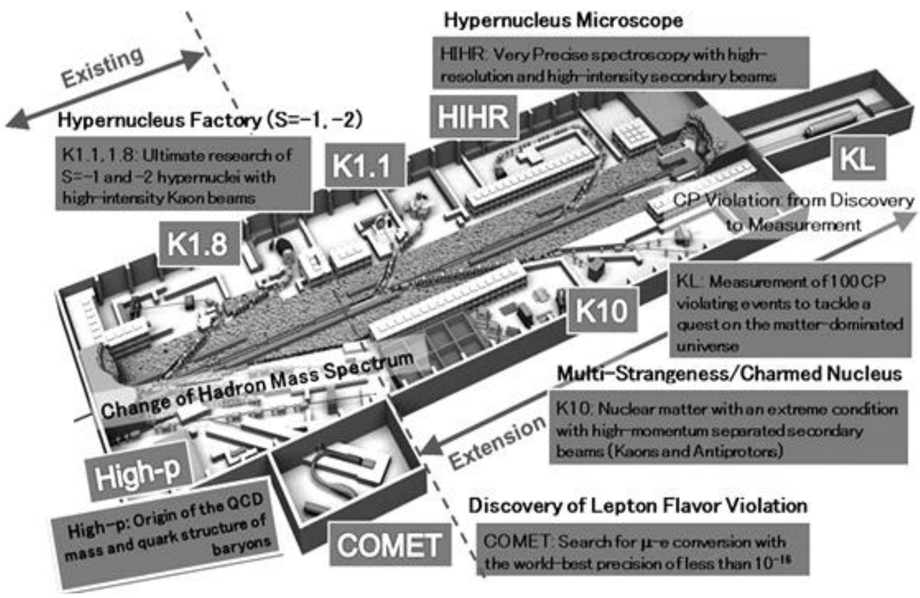

Fig.6. Drawing of the present (existing) Hadron Experimental hall and its extension.