Major Accelerator Facilities for Nuclear Physics in Asia Pacific

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Abstract. Asian Nuclear Physics Association (ANPhA) is the central organization representing nuclear physics in Asia Pacific. ANPhA is now preparing a list of accelerators applicable for nuclear physics experiments in Asia Pacific. Among the listed facilities, world-class “major” accelerator facilities are mainly located in China (Heavy Ion Research Facility in Lanzhou (HIRFL), and its future extension in Huizhou, i.e. HIAF/CiADS, Beijing Tandem Accelerator National Laboratory (BTANL), which is now upgraded to Beijing RI beam Facility (BRIF), in India (Variable Energy Cyclotron Centre (VECC) in Kolkata), in Korea (RISP/RAON), and in Japan (RIBF at Riken, J-PARC, RCNP, and ELPH/LEPS). World class facilities based on the tandem accelerator are located at Mumbai and New Delhi in India, at Tokai-mura in Japan, and at Canberra in Australia. Characteristics of these “major” facilities including their facility developments will briefly be reviewed in comparing with similar facilities in Europe and North America.

1. Introduction to ANPhA
The Asian Nuclear Physics Association (ANPhA) [1] is the central organization representing nuclear physics in Asia Pacific, which was established in 2009, and now consists of eleven membership 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.
From 2016, ANPhA plays a role of the Division of Nuclear Physics (DNP) of Association of Asia Pacific Physics Societies (AAPPS). Therefore, practically, ANPhA (=AAPPS-DNP) is only organization to discuss and pursue issues in Asian nuclear physics community at present.

One of the most important and practical activities 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 the Asia Pacific region.

Another important activity of ANPhA is to prepare “ANPhA White paper [3]”. Even in the Asia Pacific region, many advanced accelerator facilities have been constructed. Some of them are really world class facilities. ANPhA is now preparing a catalog of accelerator facilities applicable for nuclear physics experiments as user facilities existing in Asia Pacific. This catalog, the ANPhA White Paper, is the most basic material for Asian nuclear physicists to consider present international collaboration in Asia Pacific, and to establish a future long-range plan for the construction of accelerator facilities for nuclear physics.

Now 28 accelerator facilities are listed in the ANPhA White Paper. Data will be updated yearly and the latest update was done in August 2018. Critical analysis of the present data has continuously been done for future facility planning and for possible future international collaboration. Data are now temporarily open on the KEK Indico system [3] and will be published soon in AAPPS-Bulletin.

2. Major Accelerator Facilities in Asia Pacific

![Fig. 1. Location of some “major” accelerator facilities for nuclear physics in Asia Pacific.](image_url)

Major accelerator facilities in the Asia Pacific region are mainly locating in China (Heavy Ion Research Facility in Lanzhou (HIRFL), Beijing RI beam Facility (BRIF), Korea (RISP/RAON), and Japan (RIBF at RIKEN, J-PARC) as shown in Figure 1. Most of them (HIRFL, BRIF, 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 current forefront of research in this field of nuclear physics. In this meaning, 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 facility.

However, 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 word, we have concentrated our research resources to medium energy heavy-ion physics and chosen to promote high energy heavy-ion physics abroad, i.e. outside Asia. This strategy seems successful at present. However, should we keep this strategy for coming ten years? Concentration of medium energy heavy-ion accelerator facilities in Asia Pacific may be too much now, I wonder. Should we be much more careful on our investment for our future activities in nuclear physics, which should have much wider spectrum?

Anyway, let me introduce the present status and future plans of some of our “Major Accelerator Facilities” briefly in the following Sections.

3. Chinese Facilities

![Fig.2. Chinese major accelerator facilities for nuclear physics.](image)

Construction of accelerator facilities in China is in very much strategic and clever way as shown in Figure 2. They constructed ordinal experimental facility based on the tandem electrostatic accelerator in 1986 in Beijing, and construction of the experimental facility based on Separated Sector Cyclotron (SSC) followed it in 1988 in Lanzhou.

After the successful operation of both facilities for approximately 20 years, an accumulator ring was added in SSC facility in 2008 and unstable nuclear beams produced through projectile fragmentation from stable nuclear beams obtained from SSC were accumulated in the ring, and many precise measurements of nuclear mass etc. 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. Unstable nuclei produced in the ISOL-target through nuclear reactions were collected for the re-acceleration by the tandem electrostatic accelerator. Then the
tandem facility and SSC facility were well converted to the most modern “unstable” nuclear beam facilities.

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 near Hong Kong. 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 (see Figure 3). 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.

4. Korean Facility
The major accelerator facility under construction in Korea is RAON (Rare isotope Accelerator complex for ON-line experiments) in RISP (Rare Isotope Science Project) hosted by IBS (Institute of Basic Science). This is the first big nuclear-physics construction in Korea. Location of RAON is in Daejeon city, and is almost the central part of South Korea. The ground breaking for accelerators and experimental buildings was done on Feb. 13th in 2017. RAON accelerator consists of three superconducting linear accelerators as shown in Figure 4. Combining three linacs, acceleration of both normal heavy-ion beams and unstable nuclear beams extracted from ISOL type ion source to sufficiently high energies for projectile fragmentation will be possible. As results RAON can provide much higher intensity unstable nuclear beams for experiments than any other facilities in the world. For the ISOL type ion sources, high intensity proton cyclotrons will be introduced as drivers. Now RAON people are concentrating to complete SLC3, low energy linac for unstable beams from ISOL type ion source and KOBRA low energy isotope separator. Construction of SLC2 (high energy driver) will follow the SLC3 construction. The first experiment using SLC3 and COBRA is scheduled in the late 2022.
5. Japanese Facilities

There are several large-scale accelerators in Japan as shown in Figure 5. Among them 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,
which should be realized in Japan for coming ~5 years. These are;

1. J-PARC (KEK) for hadron/nuclear physics with hadron beams, and some of 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 10 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. However, some of them will be implemented at US and European facilities, which are;

3. High energy heavy-ion collision (LHC, RHIC, J-PARC-HI) to study QGP properties, QCD phase diagram, and High density nuclear matter (Rank A). This field has its future projects of ALICE upgrade, STAR upgrade, and s-PHENIX construction. J-PARC-HI is an addition of a heavy-ion injector to J-PARC.
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).

Schematic layout of RIKEN-RIBF upgrade plan is shown in Figure 6. RIKEN-RIBF consists of several types of ring cyclotrons connected in cascade and one big Superconducting Ring Cyclotron, SRC. Upgrade of RF systems of SRC and “charge stripper rings” are the main part of the upgrade program. After the completion of the upgrade program, beam intensity of the cyclotron complex of
RIBF will be competitive to FRIB in US. High intensity beams accelerated by upgraded heavy-ion LINAC will be used for the search for new superheavy elements such as Z=119, 120 and beyond.

Fig.7. J-PARC at Tokai-mura, which is located near the beautiful seashore.

J-PARC (Japan Proton Accelerator Research Complex) 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 7. 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 its intense proton beam to neutron spallation source and pulsed muon source prepared 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.

There are two beam extractions from MR. One is the fast extraction for Neutrino Beam Facility (ν) for long baseline neutrino oscillation experiment, T2K, and the other is the slow extraction for counter experiments in Hadron Experimental Facility (Hd). Major future project of J-PARC for nuclear physics is the extension of the Hadron Hall three times as shown in Figure 8.

6. Future Perspective
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. Then we were forced to recognize that physics of hypernuclei and physics at RIB facilities should be unified for the understanding of the most spectacular events in our Universe. In other word, there is no border between Hypernuclear physics, Hadron physics, and traditional Heavy-ion physics. Nuclear physics is now stepping into the new horizon of the unification. We should think seriously this fact when we establish our future construction projects of
nuclear physics.

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References
[1] ANPhA: http://ribf.riken.jp/ANPhA/
[2] Kazuhiro Tanaka, “The First Year of the ANPhA (AAPPD-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. 8. Drawing of the present (existing) Hadron Experimental hall and its extension at J-PARC.