Overview of underground and ion accelerator facilities for nuclear (& particle) physics in Asia

Byungsik Hong (Korea University)
Chair of Asian Nuclear Physics Association (ANPhA)
https://asiannuclearphysic.wixsite.com/anpha

52nd International Symposium on Multiparticle Dynamics (ISMD2023)
Károly Róbert Campus of MATE, Gyöngyös, Hungary, August 21-26, 2023
Introduction of ANPhA

- Short history
  - Three preparatory meetings in Tokyo (2008), Seoul (2009) and Beijing (2009)
  - Establishment of ANPhA in Beijing, July 18, 2009
  - Original member countries/region (8)
    - Australia, China, India, Japan, Korea, Mongolia, Taiwan, and Vietnam
- Objectives
  - To strengthen the collaboration among Asian nuclear research scientists through the promotion of nuclear physics and its transdisciplinary and applications
  - To promote the education in Asian nuclear science through mutual exchange and coordination
  - To coordinate among Asian nuclear scientists by actively utilizing existing research facilities
  - To discuss future planning of nuclear science facilities and instrumentation in Asia
Introduction of ANPhA

- Regular activities
  - Annual board meeting together with either ANPhA Symposium or Conference
  - During the pandemic period ANPhA continued the online meetings and ANPhA Symposia
- Return to the offline face-to-face meeting in 2023
  - Date: Nov. 10-11, 2023
  - Venue: Institute for Basic Science (IBS), Daejeon City, South Korea

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<th>Location</th>
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<th>Comments</th>
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<tr>
<td>17th Nov. 17, 2022</td>
<td>Beijing, China</td>
<td>13th ANPhA Symposium</td>
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<td>16th Dec. 03, 2021</td>
<td>Beijing, China</td>
<td>12th ANPhA Symposium</td>
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<td>12th Sep. 24, 2017</td>
<td>Halong City, Vietnam</td>
<td>ISPUN2017</td>
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<td>11th Nov 24, 2016</td>
<td>Sendai, Japan</td>
<td>8th ANPhA Symposium</td>
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<td>10th Oct. 24, 2015</td>
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<td>9th Nov. 07, 2014</td>
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<td>8th Feb. 19, 2014</td>
<td>Kolkata, India</td>
<td>6th ANPhA Symposium</td>
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<td>7th Apr. 27, 2013</td>
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<td>5th ANPhA Symposium</td>
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<td>6th Aug. 04, 2012</td>
<td>Adelaide, Australia</td>
<td>4th ANPhA Symposium</td>
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<td>5th Nov. 27, 2011</td>
<td>Hanoi, Vietnam</td>
<td>ISPUN2011</td>
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<td>4th Apr. 30, 2011</td>
<td>Lanzhou, China</td>
<td>3rd ANPhA Symposium</td>
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<td>3rd Oct. 02, 2010</td>
<td>Seoul, Korea</td>
<td>2nd ANPhA Symposium</td>
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<td>2nd Jan. 17, 2010</td>
<td>Tokai, Japan</td>
<td>1st ANPhA Symposium</td>
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<td>1st Jul. 18, 2009</td>
<td>Beijing, China</td>
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</table>
Introduction of ANPhA

 Establishment of the Division of Nuclear Physics (DNP) in Association of Asia-Pacific Physical Societies (AAPPS) in the 33rd Council meeting in Brisbane, Australia on Dec. 4, 2016

 Past Chairs
↓ Hideyuki Sakai, Japan (2009-2011)
↓ Yanlin Ye, China (2012-2014)
↓ Dong-Pil Min, Korea (2014-2016)
↓ Kazuhiro Tanaka, Japan (2017-2019)
↓ Weiping Liu, China (2020-2022)
Introduction of ANPhA

■ Current management (2023-2025)
  • Chair: Byungsik Hong (Korea)
  • Vice Chairs: Anthony Thomas (Australia), Guoqing Xiao (China), Tomohiro Uesaka (Japan)
  • Secretary to Chair: Yongsun Kim (Korea)

■ Board members (12 member countries/region)
  • Australia: Anthony Thomas (Univ. of Adelaide)
  • China: Furong Xu (Peking Univ.), Guoqing Xiao (IMP), Yugang Ma (Fudan Univ.), Bing Guo (CIAE)
  • India: Avinash C. Pandey (IUAC), Sumit Som (VECC), Vandana Nanal (TIFR)
  • Japan: Kazuhiro Tanaka (KEK), Atsushi Hosaka (RCNP), Hirokazu Tamura (Tohoku Univ.), Tomohiro Uesaka (RIKEN)
  • Korea: Byungsik Hong (Korea Univ.), Jin-Hee Yoon (Inha Univ.), Eun-Joo Kim (Jeonbuk Nat. Univ.)
  • Taiwan: Wen-Chen Chang (Academia Sinica)
  • Vietnam: Phan Viet Cuong (VINAGAMMA)
  • Myanmar: Nyein Wink Lwin (Univ. of Mandalay)
  • Kazakhstan: Kairat A. Kuterbekov (Eurasian Nat. Univ.)
  • Hong Kong (China): Jenny Hui Ching Lee
  • Mongolia: To be determined
  • The Philippines: Denny Lane Sombillo (Univ. of the Philippines)
Introduction of ANPhA

- White paper of ANPhA
  - Catalog of existing and planned accelerator facilities for nuclear physics in Asia-Pacific region
  - [https://kds.kek.jp/indico/category/1706/](https://kds.kek.jp/indico/category/1706/)

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**Ten Years of the Asian Nuclear Physics Association (ANPhA) and Major Accelerator Facilities for Nuclear Physics in the Asia Pacific Region**


1. ANPhA, Australia
2. ANPhA, China
3. ANPhA, India
4. ANPhA, Japan
5. ANPhA, Korea
6. University of Adelaide, ANPhA Vice Chair, Australia
7. Australian National University, Australia
8. CAIE, ANPhA Chair, China
9. IMP-CAS, ANPhA Board Member, China
10. Jadran University, ANPhA Board Member, China
11. HIEP, China
12. IUAC, ANPhA Board Member, India
13. TRAP, ANPhA Board Member, India
14. VECC, ANPhA Board Member, India
15. KEK, ANPhA Board Member, Japan
16. RIKEN, ANPhA Vice Chair, Japan
17. Tohoku University/JAEA, ANPhA Board Member, Japan
18. Osaka University/JAEA, ANPhA Board Member, Japan
19. Korea University, ANPhA Vice Chair, Korea

1. **Introduction**

   **Establishment of ANPhA**

   On 18 July 2009, the Asian Nuclear Physics Association (ANPhA) [1] was officially launched in Beijing by representatives from China, Korea, Japan, and Vietnam.

   The main objectives of ANPhA are clearly indicated in its bylaws:

   1. to strengthen collaboration among the Asian communities in nuclear research through the promotion of basic nuclear physics and its applications,
   2. to promote education in the Asian nuclear science communities through mutual exchange and coordination of resources,
   3. to encourage coordination among the Asian nuclear scientists for active utilization of existing research facilities, and
   4. to discuss future planning of the nuclear science facilities and instrumentation among member countries.

   According to the brief summary report prepared by Prof. Hideyuki Sakai, which appeared in *Nuclear Physics News* [2], entitled “Establishment of the Asian Nuclear Physics Association (ANPhA),” the story of the first days of ANPhA was as follows:

   ... Initially, the need of an organization like ANPhA was raised from time to time at the meetings of the Commission on Nuclear Physics (C12) of the International Union of Pure and Applied Physics (IUPAP) as well as at its...
Underground Laboratory

- Stawell Underground Physics Laboratory (SUPL)
  - Completed construction in 2022
  - Located in 240 km northwest of Melbourne (1,025 m deep)

Cavern walls:
- Pinned with steel
- Sprayed w. low radioactivity “shotcrete”
- Coated with Tekflex

Materials from Anthony Thomas
Underground Laboratory

**SABRE South Collaboration**
- A new dark matter searching group (46 members across 5 institutions)
- To measure the model independent modulation signal for dark matter caused by relative motion of the Earth through galactic halo
- Expect to reach $5\sigma$ discovery sensitivity to a DAMA-like signal within two years

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**ToF muon system**
- 9.6 m$^2 \times 5$ cm EJ200
- R13089 PMT $\times 16$ @ 3.2 GS/s

**Veto system**
- 12k litres Linear Alkyl Benzene + PPO & Bias-MSB
- Stainless steel, non-thoriated welds, lumirror coating
- Oil-proof base R5912 PMT $\times 18$ @ 500 MS/s

**DM target detector**
- Low-activity NaI(Tl) crystals
- R11065 low radioactivity PMT $\times \sim 14$ @ 500 MS/s

**Key requirement to understand modulation in background contributions:**
- Particle ID, e.g., $\mu/\gamma/\pi$

---

An engineering cutaway of the detector in its shield

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August 21-26, 2023

ISMD2023
Underground Laboratory

- Yemilab: a new underground laboratory
  - Y2L (700 m deep) constructed in 2003 to house KIMS dark matter search experiment
  - Yemilab (1,000 m deep) constructed in 2022

- Experimental area of Yemilab
  - Run by Center for Underground Physics (CUP) of IBS
  - Lab. space > 3,000 m² with 2.5 MW electricity
Dark matter search

- **COSINE-100 experiment @ Y2L**
  - Collaboration: Yale, CUP, Sheffield, San Paulo
  - DAMA/LIBRA annual modulation of standard halo model is rejected.

- **COSINE-200 experiment @ Yemilab**
  - Ultra-low background NaI crystals developed
  - Aims a world best limit for low-mass WIMP-proton spin-dependent interaction
  - Expect to begin the data taking run in 2025
Underground Laboratory

Neutrinoless double beta decay

- AMORE-II experiment @ Yemilab
  - 100 kg of $^{100}$Mo for 5 years to reach $T_{1/2}^{0\nu} > 4.5 \times 10^{26}$ years
  - Both phonons and photons measured by MMC+SQUID sensors
  - 90-crystal run from 2023: Full scale (100 kg of $^{100}$Mo) run from early 2025

- Li$_2^{100}$MoO$_4$ crystals in 5 and 6 cm cylinder (~400 crystals)
- DR inside shielding of 25cm Pb + 70cm of PE and water

- Recent progress in detector R&D
  - JINST 17, p07034(2022)

Cf.) CUPID @ LNGS with 240 kg of $^{100}$Mo

- August 21-26, 2023
- ISMD2023
China Jinping Underground Laboratory (CJPL)-II

Operation started in Dec. 2010

JUNA

Neutrinoless double beta decay

Neutrinoless double beta Decay

HPGe CDEX+

Dark matter

LXe PANDAX+

Neutrino experiments

Materials from Weiping Liu

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Underground Laboratory

China Dark Matter Experiment (CDEX)
Ge to search for light-WIMP: PRL 123, 221301 (2019)
Dark photon: PRL 124, 111301 (2020)

- CDEX-10 (2016): 10-kg Point Contact Ge detectors immersed into liquid nitrogen
  → CDEX-300 (2027)
  → CDEX-1T (????)

Cf.) LEGEND-200

LEGEND-1000

Particle and Astrophysical Xenon Experiment (PandaX)

- Panda-II (2014): Dual-phase Time Projection Chamber (TPC) with half-ton of ultra-high purity liquid Xe
  → PandaX-4T (2021): 5.75 tons of Xe
  → Panda-III (????): 200 kg to one ton of 90% enriched high-pressure gaseous $^{136}$Xe in TPC

Cf.) nEXO

SD WIMP-nucleon elastic cross section
PRL 127, 261802 (2021)

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Underground Laboratory

Jinping Neutrino Experiment (JNE)
Solar, geo-, and supernova neutrinos


Comparison of total muon flux

JUNA for nuclear astrophysics

$^{19}\text{F}(p,\gamma)^{20}\text{Ne}$: Nature 610, 656 (2022)
Explain Ca in the oldest star!

13C($\alpha$,n)$^{16}$O: PRL 129, 132701 (2022)

19F(p,$\alpha\gamma$)$^{16}$O: PRL 127, 152702 (2021)

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ISMD2023
RIB Accelerator Facility
Radioactive Ion Beam Factory (RIBF)
RIB Accelerator Facility

Beam Intensity of SRC as a function of year

159 new isotopes created since 2007

SRC:
Superconductive Ring Cyclotron
World’s First and Strongest
K2600MeV

primary beams
at 350 MeV/u

target

New facility (2006-)

RI beams
at ~250 MeV/u

BigRIPS:
Superconductive RI beam Separator
In-flight separator
World’s Largest Acceptance
High magnetic rigidity 9 Tm
RIB Accelerator Facility

EURICA (2011-2016): EUroball-RIKEN Cluster Array


HiCARI (2019-2020): Tracking Ge detectors for in-beam gamma spectroscopy

IDATEN (2021-): 84 LaBr₃ (Ce) + 2 Cover Ge detectors to measure lifetime of excited states

BRIKEN (2017-2021): He-3 detector array for beta-delayed neutron

SpiRIT TPC (2015-): heavy-ion collision program for EOS

SAMURAI (2012-): neutron detectors + CsI+... for neutron correlation

MoU with 41 institutions and universities in 19 countries

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RIB Accelerator Facility

Shell-evolution: magicity loss and new magicity

$^{78}$Ni revealed as a doubly magic stronghold against nuclear deformation


r-process path: nucleo-synthesis up to U

T1/2

Wu, PRL 118, 072701 (2018)

Mass

Li, PRL 128, 152701 (2022)

Phong, PRL 129, 172701 (2022)

Neutron-neutron correlation in the vicinity of the dripline

Tetra-neutron system

Kisamori, Shimoura, PRL 116, 052501 (2016)

Duer, Aumann, Nature 605, 678 (2022)

Equation-of-State in asymmetric nuclear matter

SN explosion, neutron-star, gravitational wave

Estee, PRL 126, 162701 (2021)

Discovery of $^{39}$Na

Ahn et al., PRL 129, 212502 (2022)
RIB Accelerator Facility

Present Acceleration Scheme

11 MeV/u
28GHz
SC-ECRIS
RILAC2
RRC
fRC
IRC
SRC

51 MeV/u
He stripper
35+\Rightarrow64+ (~20%)
Rot. C stripper
64+\Rightarrow86+ (~30%)
to BigRIPS

100 \text{ pA}

Large loss at the strippers: transmission efficiency is about 6% x20

2000 \text{ pA}

RIBF upgrade plan for more intense U beams

Upgrade plan

28GHz
SC-ECRIS
RILAC2
RRC
fRC
IRC
SRC

CSR1
CSR2

Ion-source upgrade X2
Charge Stripper Rings: beam recycling technology to increase transmission efficiency by a factor of 10

Requesting the construction budget now

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RIB Accelerator Facility

Rare isotope Accelerator complex for ON-line experiments (RAON)

- **Construction plan**
  - **Phase I [2011~2022]:**
    - Injector + ISOL + SCL3 + IF + Expt. Systems
  - **R&D [2023~2025]:**
    - SCL2 cavities & modules
  - **Phase II [Period to be determined ~2030 (?)]:**
    - Construction of SCL2
RIB Accelerator Facility

- Accelerator systems
- RI production systems
- Conventional utilities
- Experimental systems

Total campus area: ~ 1M m²

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RIB Accelerator Facility

The 1st SCL3 beam commissioning (Oct. 7, 2022)

Ar⁹⁺ beams accelerated by QWR #1~#5
Ar\textsuperscript{9+} beams accelerated by entire SCL3(QWR/HWR) on May 23

Ar\textsuperscript{9+} beams delivered to the KoBRA target on May 31
→ First RI production in F3 of KoBRA by Ar+C

SCL3 warm up and maintenance started from June.

The beams plan to be delivered to KoBRA for experiments in early 2024.
RIB Accelerator Facility

- ISOL beam lines including sub-systems commissioned with a Cs ion source in Dec. 2021
- RI beam commissioning using SiC target in Mar. 2023

- Driver beam: 35~70 MeV proton beams up to 70 kW
- Target: SiC, BN, MgO, LaC₂, UCₓ, CaO, BeO, etc.
- Ion Source: Surface, RILIS, Plasma
- RIB: 6 < A < 160, 10 < K < 80 keV, 10⁸ pps (Sn), > 90% purity for experiments
  - Incident on RFQ of the post accelerator with 10 keV/u
  - Full remote maintenance system with TIS modularization

ISOL beam commissioning with ISOL

- ²¹,²²,²⁴,²⁵Na on March 3
- ²⁶ᵐAl and ²⁰Na on May 23
  - Proton beam: 70 MeV, 1.2 μA
  - SiC target temperature: ~1,400°C (Ta heater ohmic heating 1.8 kW)
Beijing Radioactive Ion beam Facility (BRI F) @ CIAE

Proton cyclotron
(100 MeV, 200 μA)

Tandem (13 MV)

Superconducting Linac (13 MeV/q)

ISOL
(mass resolution: 20,000)

Q3D

Experimental terminals

Approved 2004
Commissioning 2016
Day-1 Expt. 2018

Materials from Bing Guo
RIB Accelerator Facility

Beijing Radioactive Ion beam Facility (BRIEF) @ CIAE

- Production of fission fragment RIBs (Rb, Sr, etc.)
- Number of produced RIB types: 24 → 55
- The shortest half-life of RIB with ISOL: 0.45 sec → 0.17 sec
- Beam intensity: $10^3 \sim 10^{10}$ pps

- First RIB Expt.: 3 $\beta - \gamma - \alpha$ exotic decays in $^{20}$Na [PRC103, L011301 (2021)]
- First Expt. with the post-accelerated Na beams on $^{40}$Ca target [NST32, 53 (2021)]
- First CLS Expt. [NIMA1032, 166622 (2022)]
RIB Accelerator Facility

Heavy Ion Accelerator Facility (HIAF): 1st Phase

BRing1: Booster Ring 1
- Circumference: 600 m
- Rigidity: $34 \rightarrow 40 \text{Tm}$
- Large acceptance (200/100)
- Two planes painting injection
- Fast ramping rate ($3-10 \text{ Hz}$)

$E_{B1}$: $0.8 \text{ AGeV, } 3 \times 10^{10} \text{ ppp }^{238}\text{U}^{35+}$
$1.75 \text{ AGeV, } 7.5 \times 10^{10} \text{ ppp }^{78}\text{Kr}^{19+}$
$2.6 \sim 3.0 \text{ AGeV, } 1.0 \times 10^{11} \text{ ppp }^{16}\text{O}^{6+}$

After optimization, beam intensity $X \sim 10$
beam energy $X > 30$

External target station
High Energy Density Physics (HEDP)
- Nuclear matter study - CEE
- Hypernuclear physics
- High energy irradiation

HIAF-I: 2018-2025
Budget: 1.6+1.2B CNY

SRing: Spectrometer Ring
- Circumference: 273 m
- Rigidity: $15 \rightarrow 20 \text{ Tm}$
- Electron/Stochastic cooling
- Precise measurement by two TOF detectors, four operation modes

SECRAL and FECR
- 28-45GHz, 1.0emA ($^{35+}$)

iLinac: Superconducting linac
- Length: 100 m
- Energy: $17 \sim 22 \text{ MeV/u (U}^{35+\sim46+}$

Low energy nuclear structure terminal

Huizhou City of Guangdong Province

Materials from Wenlong Zhan

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RIB Accelerator Facility

Heavy Ion Accelerator Facility (HIAF)

- Beam physics study
  - Highest pulse beam
- ECR ion source
  - 45 GHz 12 T Nb$_3$Sn SECRIS under assembling
- Key technology development for HI synchrotron
  - 0.3 mm chamber for high vacuum
  - High-gradient magnetic alloy RF for fast injection, etc.
  - Active power source for high repetition rate
  - Results
    - Beam Intensity $\rightarrow$ X100
    - Repetition rate $\rightarrow$ $\sim$10 Hz
    - Assembly time: years $\rightarrow$ months
    - Tuning time: months $\rightarrow$ days
- HFRS for in-flight fragmentation of projectiles
- High Accuracy Spectrometer at SRing
- CEE R&D and fabrications

<table>
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<tr>
<th>Laboratory</th>
<th>Facility</th>
<th>Design Intensity</th>
<th>Heavy Ion</th>
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<tr>
<td>BNL</td>
<td>AGS Booster</td>
<td></td>
<td>Au$^{32+}$</td>
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<tr>
<td>JINR</td>
<td>NICA Booster</td>
<td>$4 \times 10^9$</td>
<td>Au$^{32+}$</td>
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<td>GSI</td>
<td>SIS18</td>
<td>$1.0 \times 10^{11}$</td>
<td>U$^{28+}$</td>
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<td>FAIR</td>
<td>SIS100</td>
<td>$4.0 \times 10^{11}$</td>
<td>U$^{28+}$</td>
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<td>IMP</td>
<td>HIAF-SRing</td>
<td>$5/20 \times 10^{11}$</td>
<td>U/Bi ($^{35-45}$+)</td>
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<tr>
<td>IMP</td>
<td>HIAF-BRing-SRing</td>
<td>$1/5 \times 10^{12}$, $2/12 \times 10^{12}$</td>
<td>U/Bi ($^{35-45}$+)</td>
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</tbody>
</table>
Recent Image of the HIAF+CiADS site
Hadron Accelerator Facility

*Materials from Kazuhiro Tanaka*

- Upgrade of J-PARC for heavy-ion beams
  - New heavy-ion injector (LINAC and BOOSTER)
  - New experimental area and spectrometers

- Staging plan
  - On-going
    - pA collisions using existing beamline and spectrometer (Vector meson production in $e^+e^-$ decay modes)
    - Upgrade of the spectrometer for hadron measurements
  - Phase I
    - New LINAC and **reuse of KEK-PS 500 MeV booster**
    - Upgrades of the existing spectrometer
    - Beam Intensity: $10^8$ Hz for Au
  - Phase II
    - New booster and new spectrometer
    - Final configuration

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Summary

- Nuclear physics facilities in Asia in the construction, commissioning, upgrade, or operational stage:
  - Underground facilities: SUPL (Australia), CJPL-II (China), Yemi Lab. (Korea)
  - RIB accelerators: BRIF, JUNA, HIRFL, HIAF (China), RIBF, RCNP (Japan), RAON (Korea)
  - Hadron accelerators: HIAF (China), J-PARC (Japan)
  - Photon & electron accelerators: Spring-8, ELPH (Japan)

- The facilities in Asia, Europe, and U.S.A. are overlapped or complimentary. For example,
  - INFN Gran Sasso National Laboratory (LNGS) in Europe
  - The Isotope mass Separator On-Line facility (ISOLDE) at CERN in Europe
  - Facility for Rare Isotope Beams (FRIB) in Michigan State University in U.S.A.
  - Electron-Ion Collider (EIC) at BNL in U.S.A.

- The collaboration among different continents must be greatly beneficial to all of us!