Keynote talk: Major Accelerator Facilities in Asia Pacific

Kazuhiro Tanaka
Chair of ANPhA (=AAPPS-DNP)
and
Institute of Particle and Nuclear Studies, and
Particle and Nuclear Division of J-PARC,
KEK: High Energy Accelerator Research Organization
• **Asian Nuclear Physics Association**
  – Launched in **2009**
  – Central organization representing Nuclear Physics in Asia Pacific.

• **Eleven membership countries and regions**
  – Australia, China, Hong Kong, India, Japan, Kazakhstan, Korea, Mongolia, Myanmar, Taiwan, and Vietnam.

• **Objectives (defined in bylaws for ANPhA)**
  – To strengthen “Collaboration” among Asian nuclear research scientists through the promotion of nuclear physics and its transdisciplinary and applications
  – To promote “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

• **ANPhA plays the role of Division of Nuclear Physics of Association of Asia Pacific Physics Societies (AAPPS-DNP).**
Our Main Accel. Facilities in AP

- HIRFL
- RAON/RISP
- J-PARC
- RIBF
- MRTOF
- KISS & MRTOF
- HIAF/CiADS (Huizhou)
- BRIF-II
- VECC RIB
- VEC-RIB
- Cambera Soleroo

Hadron
In-flight RIB
ISOL RIB
Major Accelerator Facilities in Asia Pacific
for RIB experiments and/or Hadron experiments

• China
  – HIRFL (Heavy Ion Research Facility in Lanzhou)
    -> HIAF (High Intensity Heavy Ion Accelerator Facility)
  – BTANL (Beijing Tandem Accelerator National Laboratory)
    -> BRIF (Beijing Rare Ion Facility)
  – Beijing ISOL

• Korea
  – RAON (Rare isotope Accelerator complex for ON-line experiments) in RISP (Rare Isotope Science Project)

• Japan
  – RIBF (Radioactive Ion Beam Facility) -> 30 times intensity upgrade
  – J-PARC (Japan proton Accelerator Research Complex)
    -> Hd-EX (Hadron Hall Extension)
Strategy for Large Scale Facilities in China

1986 Beijing String Accelerator HI-13
1988 Lanzhou Synchrotron Accelerator SSC
2008 Lanzhou Storage Ring CSR

2014-2018 Beijing String Upgrade Project
2018-2024? Heavy Ion Application Facility HIAF
2028? Beijing ISOL Device

HIRFL (Beijing Rare Ion Facility) + CiADS
Heavy Ion Research Facility in Lanzhou (HIRFL)

**SSC (K=450)**
- 100 AMeV (H.I.), 110 MeV (p)
- Operated in 1988

**SFC (K=69)**
- 10 AMeV (H.I.), 17~35 MeV (p)
- Operated in 1963

**CSR (Cooling Storage Ring)**
- RIBLL1
  - RIBs at tens of AMeV
  - Operated in 1997

**CSRe**
- RIBLL2
  - RIBs at hundreds of AMeV

Clinical trial for Skin-tumor therapy started in 2006

Clinical trial for deep-seated tumor therapy started in 2009
HIAF (CDR1 Approved by Gov.)

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

HIAF-I: 2018-2024
Budget: 1.5~1.6+1.2 B CNY

External target station
- High Energy Density Physics
- Nuclear Matter study-CEE
- Hypernuclear
- High energy irradiation

L: 180m, Bp: 25 Tm
HFRS

SRing: Spectrometer ring
- Circumference: 273m
- Rigidity: 13-15 Tm
- Electron/Stochastic cooling
- Precise Measurement by Two TOF detectors, Four operation modes

BRing1: Booster ring 1
- Circumference: 600 m
- Rigidity: 34 Tm
- Large acceptance (200/100)
- Two planes painting injection
- Fast ramping rate (5-10Hz)

iLinac: Superconducting linac
- Length: 100 m
- Energy: 17~22 MeV/u($U^{35+}$~$46^+$)

Low energy nuclear structure terminal

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

Listen Dr. Xiao Hong Zhou’s talk at Plenary 2!
China Initiative Accelerator Driven System (CIADS)

- 2015年12月建议书获国家发改委批准
- 经费: ~（18+12）亿元 (中央财政+地方政府)
- 建设地点: 广东省惠州市
- 建设及合作单位: 广州分院、近物所、高能所、合肥物质院、401、中广核等

CIADS layout

Proton LINAC:
- 250~600 MeV
- 10 mA with CW mode

Sub-critical core:
- LBE coolant
- <10 MWt

Spallation Target:
- granular flow > 2.5 MW
HIAF and CiADS constructed in Huizhou

- Heavy ion facility HIAF granted with feasibility permit by national commission.

- ADS transmutation facility CiADS granted with feasibility permit by national commission.

- HIAF and CiADS facility feasibility reports were approved by Ministry of national development on Jan. 29, 2018, which means the funding of two projects is settled. Both will have ground breaking at the end of 2018.

CiADS and HIAF can be connected, with former as a driver.
Realization of a new large research infrastructure in Belgium: MYRRHA
Beijing Rare Ion Facility BRIF finished its first experiment with Tandem accelerated ISOL separated $^{20}$Na on 31 Jan, 2018.

100 MeV proton cyclotron achieve 200 $\mu$A current and simultaneous two direction extraction.
Beijing ISOL Facility
500M$  2018-2028, CIAE & PKU
Rare Isotope Science Project (RISP) in Korea

- **Low Energy Experiments**
  - Nuclear Astrophysics

- **Post Accelerator**
  - ISOL system
  - IF system
  - CB: Charge Breeder
  - HRMS: High Resolution Mass Separator

- **Driver LINAC**
  - ECR-IS (10keV/u, 12 μA)
  - LEBT
  - RFQ (500keV/u, 9.5 μA)
  - MEBT
  - SCL (18.5 MeV/u, 9.5 μA)
  - Charge Stripper

- **SCL (200 MeV/u, 8.3 μA for U+79)**
  - (600MeV, 660 μA for p)

- **RFQ**

- **RF Cooler**

- **IF Target**

- **μSR, Bio-medical**

- **High Energy Experiments**
  - Nuclear Structure/Symmetry Energy

- **ISOL**
  - ISOL: direct fission of $^{238}$U by 70MeV-proton Cycl.
  - IF: 200MeV/u, 8.3pμA of $^{238}$U (400kW SCL)

- **High intensity RI beams by ISOL & IF**

- **More exotic RI beams combining by ISOL+IF**

- **High quality neutron-rich RI beams**
  - $^{132}$Sn with up to ~250MeV/u, up to ~10$^8$pps

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Bird-eye view on construction site (~’17.12.)
Major Accelerator Facilities for Nuclear Physics in Japan

Nishina Center, RIKEN
K2600 RIBF
Heavy ion (RIB)

Research Center for Electron Photon Science, Tohoku University (ELPH)
1.2GeV electron Stretcher
e⁻

SPRING-8 (RIKEN/JASRI)
8GeV e⁻ Synchrotron
photon

RCNP, Research Center for Nuclear Physics, Osaka University
K400 Cyclotron
light ion / light heavy ion

HIMAC at National Institute of Radiological Sciences
800MeV/A Synchrotron
heavy ion (therapy)

J-PARC, KEK/JAEA
30GeV Proton Synchrotron
π, K, μ, n, (ν)
Future Plans (~5 years) of Nuclear Physics in Japan

**Endorsed by Japanese Nuclear Physics Executive Committee, 2016**

- **J-PARC (KEK)**
  - Hadron/nuclear physics w/hadron beams -> **Hadron Hall extension**
  - Fundamental Physics/Particle physics with muons
    -> **mu-e conversion (COMET), g-2**

- **RIBF (RIKEN)**
  - Expand neutron-rich heavy element productions to transuranium
  - Production of superheavy Z=119 and beyond
    -> **RIBF upgrade for intensity x30**

- **ELPH (Tohoku) and LEPS@SPring-8 (RCNP Osaka)**
  - Hadron Physics with electron beams -> **Detector/Beam upgrades**

- **High Energy Heavy Ion Collision (LHC, RHIC, J-PARC)**
  - QGP properties, QCD phase diagram, High density matter
    -> **ALICE upgrade, s-PHENIX/STAR upgrade, J-PARC-HI R&D**

- **Nuclear Theory**
  - Hadrons via Lattice QCD, Nuclear structure via Monte Carlo Shell Model, etc.
    -> **9 projects with K computer and beyond**

Science Council of Japan selected Major Project
RIKEN RIBF (RI Beam Factory) -- cyclotron cascade for heavy ion beam acceleration

RIKEN RIBF

483 MeV/nucleon

fRC
IRC

345 MeV/nucleon up to U (2006-)

135 MeV/nucleon for light nuclei (1986-)

experimental equipment

RIKEN RIBF
a new generation RIB facility in operation with world highest capability of providing beams of unstable nuclei

RIKEN RIBF (RI Beam Factory) -- radioactive isotope beams

RIKEN RIBF (RI Beam Factory)  

RIPS (1990-)  
~50 MeV/nucleon

BigRIPS (2007-)  
~200 MeV/nucleon

135 MeV/nucleon for light nuclei (1986-)

345 MeV/nucleon up to U (2006-)

Experimental equipment
element $Z=113$ Nihonium (Nh)  
-- produced by $^{70}\text{Zn}+^{209}\text{Bi}$ fusion at $\sim5\text{MeV/nucleon}$
Second Stage of BigRIPS for Particle Identification

EURORIB 2018, Giens, France
Naoki FUKUDA, RIKEN, Nishina Center
High-Resolution Particle Identification at BigRIPS

$^{238}\text{U} (345 \text{ MeV/u}) + \text{Be (2.9 mm)}, B\rho = 7.990 \text{ Tm}$


r.m.s. $A/Q$ resolution: 0.034%
6.1 $\sigma$ separation
Discovery of $^{72}$Rb: A Nuclear Sandbank beyond the Proton Drip Line


$^{124}$Xe(345 MeV/u, 30–35 pnA) + Be 4 mm

Known

$^{72}$Rb

$^{73}$Rb

$^{77}$Zr

$^{72}$Rb: $T_{1/2} = 103(22)$ ns

$^{73}$Rb: $T_{1/2} \leq 81$ ns
Hadron Hall for Counter Experiments with \( \sim 150 \text{kW} \) SX
Nuclear, Hadron, & Particle Physics at Hadron Hall
NS: Neutron Star
Biggest Nucleus in COSMOS
Remnant of Supernova
Mass: 1~2 SM, Radius: ~10 km,
→ Highest density matter in space
Internal Structure is still unknown

Present COSMOS
Matter consists of u,d-quarks and electron

Can stable Strange matter exist?

New COSMOS
New matter consists of u,d,s-quarks and electron

We studied $\Lambda$ hypernuclei (No. of s-quark=1)
at KEK-PS and J-PARC and lead the world!
For Strange matter study, two strange particles must be implanted in a nucleus
→ 100 times higher intense beam is necessary!
Only possible at J-PARC!

Strangeness Nuclear Physics in J-PARC
Structure of NS ➔ New Era of Material Understanding

Matter including s-quark

$\Lambda$ hypernuclei
$\Xi$ hypernuclei

Micro Neutron Star in our Laboratory

Nuclei with 2 s-quarks
New Horizon of Nuclear Physics
Neutron star mergers: gravitational waves and production of heavy elements

Gravitational wave emission seen together with electromagnetic signals

The messengers from neutron star mergers:

- Gravitational waves
- Electromagnetic signals characterizing the nuclei in the ejecta
- Neutrinos

Neutron star mass

This depends on the Equation of State (EOS) of Nuclear Matter including strangeness (Hyper Nuclear Matter!).

Time evolution determined by the radioactive decay of r-process nuclei (science drive of facilities with RIB)

Angela Bracco
Simulation Results on GW170817

http://www.cfca.nao.ac.jp/pr/20171016
SUBARU telescope at Mauna Kea (4208m)
EOS of High-Density Matter

- Hyperon appearance → Softening of EOS
- “Hyperon Puzzle”: cannot sustain $2M_\odot$!
- Need extra repulsions from $\Lambda\Lambda n\bar{n}$ three-body force; $\Xi p-\Lambda\Lambda$ coupling.

NS–NS merger


Viewgraph by Prof. Nagae, Kyoto U.
Astronomical Observation challenges the Standard Nuclear Physics.

Core of Neutron Star (NS)

Test ground of High Density Matter

M\textsubscript{max} > 2M\odot

M\textsubscript{max} < 1.5M\odot

Hyperons should appear!

Nuclear Many-Body Theory

Hypernuclear Data

\(\Delta E = 1 \text{ MeV}\)

YN Scattering Data

Limited statistics

Observation of 2M\odot NS

Viewgraph by Prof. Nagae, Kyoto U.
<table>
<thead>
<tr>
<th>Accelerators for Nuclear Physics in the World</th>
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<td><strong>Beams</strong></td>
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| **Hot QCD** | A+ A | — | LHC(ALICE) | RHIC | Missing Asian?  
J-PARC-HI for dense matter? |
| **Cold QCD** | hadron | J-PARC+ Hdx  
HIRFL+ HIAF | FAIR(SIS100) | — | Missing American? |
| | γ, e^- | Spring8 (LEPS)  
ELPH | MAMI | JLAB-12GeV | 1+ many |
| | collider | BES-III  
Belle-II | NICA  
LHCb | eRHIC  
eIC | 1 in the world? |
| **Many body Problem (RI Beam)** | PF | RIBF+ upgrade  
HIRFL  
HIAF | GSI/FAIR | FRIB | Good competitions!! |
| | Both | RISP(RAON) | | | |
| **ISOL** | BRIF-II  
RIB-ANURIB  
HIAF+ CIADS | SPIRAL2  
SPES  
HIE-ISOLDE  
MYRRHA | ARIEL-II | | |
| **Super ISOL** | Beijing-ISOL | EURISOL | — | FRIB upgrade for US? |
| **Pol proton** | (High Resolution) | RCNP RC | KVI | Texas A&M  
iThemba (South Africa) |
Summary

• Present status and future projects of major Accelerator facilities for Nuclear Physics in AP are briefly summarized.

• **Now Asian accelerator facilities are the world class facilities.**

• At present RIBF and HIRFL are world leading facilities of RIB.

• In near Future, upgraded RIBF and new HIAF will be world leading facilities.

• Now RI beam facility is changing/expanding from projectile fragmentation (PF) facility to the target ion source (ISOL) facility.

• RAON in Korea will be the first RIB facility with ISOL and PF.

• Combining HIAF + CiADS will be new type of RIB, i.e. combination of Sub-critical reactor + ISOL and PF facility. Is MYRRHA also?

• Beijing ISOL will be a combination of the real reactor and ISOL.

• **Completion of facility does not mean the success of physics. Then collaborative works of world wide nuclear physicists at world wide facilities are a key for the future fruitful outputs of good physics.**

• In this meaning, I hope Beijing ISOL can be ASIANISOL like EURISOL.
Summary II

- It becomes clear that our knowledge of Nuclear Physics is insufficient to explain the most spectacular event in our Universe, i.e. Neutron Star Mergers.
- We need more precise knowledge of beta decays (mass of nuclei!) around neutron drip line. MR-TOF by Wada-san may help us?
- We have to find a new mechanism of Nuclear Force which makes EOS stiffer. This should be the real understanding of three body force in nuclear center, i.e. repulsion core.
- EOS must be the EOS of hypernuclear matter, since $3\rho_0$ world naturally contains strangeness.
- In this meaning, understanding of three body force with generalized nuclear force including strangeness is essential, such as $\Lambda nn$.
- Fortunately we have sufficient amount of good tools to solve these problems in the world, i.e. good accelerators.
- Nuclear Physics is now stepping into the new horizon of the unification. There is no border between Hypernuclear physics, Hadron physics, and traditional Heavy-ion physics, each other.

- 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.
Super Computers

We have very good computers, too!
Thank you very much for your attention.

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