Large Acceptance Multi-Purpose Spectrometer (LAMPS) at RISP

Young Jin Kim
RISP/IBS

Behalf of the LAMPS Collaboration
RISP and RAON

RISP = Rare Isotope Science Project
Plan & build Rare Isotope accelerator and experimental facilities in Korea
RAON = Name of Rare Isotope accelerator complex (라온)
Pure Korean word: meaning “delight”, “joyful”, “happy”

Brief History
- International Science-Business Belt (ISBB) plan (Jan. 2009)
- International Advisory Committee (Jul. 2011)
- Institute for Basic Science (IBS) established (Nov. 2011)
- Rare Isotope Science Project (RISP) launched (Dec. 2011)

✓ Rare Isotope accelerator complex is the representative facility of IBS
- Technical Advisory Committee (May 2012)
- Baseline Design Summary (Jun. 2012)
- International Advisory Committee (Jul. 2012)
- Technical Design Report (Present)

More details
Talk by S. K. Kim tomorrow
Location

ATHIC 2012, Pusan Korea

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High-Energy Experiments
(E_{beam} > 18.5 MeV/u)
Nuclear Structure
Symmetry Energy

Low-Energy Experiments
(E_{beam} < 18.5 MeV/u)
Nuclear Structure
Nuclear Astrophysics
Material Science
β-NMR

### RAON Layout

- **Driver Linac**
  - Charge Stripper
  - SCL1 (18.5 MeV/u, 9.5 pμA)
  - RFQ (300 keV/u, 9.5 pμA)
  - ECR-IS (10 keV/u, 12 pμA)

- **Post Accelerator**
  - MEBT
  - SCL2 (200 MeV/u, 8.3 pμA for U^{78})
    - (600 MeV, 660 μA for p)
  - SCL3 (18.5 MeV/u)
  - RFQ
  - CB
  - HRMS
  - ECR-IS
  - Atom/Ion Trap
  - RF Cooler

- **Accelarator**
  - Driver Linac
  - Post Acc.
  - Cyclotron

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<td>RI beam</td>
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<td>Beam energy</td>
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<td>200 MeV/u</td>
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<td>Power on target</td>
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**More details**
Talk by S. K. Kim tomorrow

**ISOL (Isotope Separation On-Line) system**

**IF (In-flight Fragmentation) system**

- ISOL
- ECR-IS
- RFQ
- MEBT
- CB
- HRMS
- Atom/Ion Trap
- RF Cooler
- Cyclotron (p, 70 MeV, 1 mA)
- ISOL Target
- μSR
- Medical Research
- Fragmnet Separator
- IF Target
Why Rare Isotope Beam?

Based on the nuclear chart from RIA white paper

Stable nuclei (black)

Known nuclei (yellow)

Symmetry studies with Fr

Origin of heavy elements

Super heavy element

Fission limits

rapid n-capture process (r-process)

Large neutron excess

Terra incognita

In periodic table
- ~100 elements
- ~300 stable isotopes
- ~3,000 unstable isotopes

About 3,000 ~ 6,000 unknown isotopes yet to be discovered

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Double Magic $^{132}$Sn

Limit of nuclear stability?

Modification of shell structure

Based on the nuclear chart from RIA white paper

Number of protons $Z$

Number of neutrons $N$
Experiments at RAON

RISP.3 Experimental Systems

RISP.3.3 Nuclear Science Facilities
- RISP.3.3.1 High Resolution and ZeroDegree Spectrometers
- RISP.3.3.2 Large Acceptance Spectrometer
- RISP.3.3.3 Recoil Spectrometer

RISP.3.4 Applied Science Facilities
- RISP.3.4.1 β-NMR System
- RISP.3.4.2 μSR System
- RISP.3.4.3 High Precision Mass Measurement System
- RISP.3.4.4 High Precision Laser Spectrometer
- RISP.3.4.5 Bio-medical Research Facilities
- RISP.3.4.6 Neutron Science Facilities

More details
Talk by S. K. Kim tomorrow
Study of Nuclear Matter

1. Exploring the phase diagram of strongly interacting matter
   – Phase transitions (liquid ↔ gas, hadron ↔ QGP)
Study of Nuclear Matter

1. Exploring the phase diagram of strongly interacting matter
   - Phase transitions (liquid ↔ gas, hadron ↔ QGP)
2. Determining Equation of State (EOS) of the strongly interacting medium below and above the saturation density
   - Isospin dependence
Heavy Ion Experiment

Study of Nuclear Matter
1. Exploring the phase diagram of strongly interacting matter
   – Phase transitions (liquid ↔ gas, hadron ↔ QGP)
2. Determining Equation of State (EOS) of the strongly interacting medium below and above the saturation density
   – Isospin dependence
3. Modification of hadronic properties in dense medium
4. Importance for astrophysics
   – Supernovae and neutron stars
   – QGP at colliders (not for RISP)
Nuclear Equation of State

Bethe-Weizsäcker formula

\[ B(A,Z) / A = a_V - a_s A^{-1/3} - a_c Z(Z-1) A^{-4/3} - a_s \frac{(N-Z)^2}{A^2} + \delta_{\text{pair}} \]

(Ref.) C. F. von Weizsäcker, Z. Physik 96, 431 (1935)
N. Bohr, Nature 137, 344 (1936)

Energy of nuclear matter
(density and isospin asymmetry dependence)

\[ E(\rho, \delta) / A = E(\rho, \delta = 0) + E_{\text{sym}}(\rho) \delta^2 + O(\delta^4) + \ldots \]

where \( \rho = \rho_n + \rho_p, \delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}, a_s \approx E_{\text{sym}}(0.6 \rho_0) \)

Symmetry energy
Difference between neutron and symmetric matter (rather unknown)

C. Xu and B. A. Li, PRC 81, 044603(2010)
Physics Observables

Important to measure system size (Ca, Ni, Ru, Zr, Sn, Xe, Au, U), energy (lowest to top energies), centrality, rapidity & transverse momentum dependence

1. Pygmy and Giant dipole resonances
   • Energy spectra of gammas
   • Related to the radius of n-skin for unstable nuclei

2. Particle spectrum, yield, and ratio
   • n/p, ³H/³He, ⁷Li/⁷Be, π⁻/π⁺, etc.

3. Collective flow
   • v₁ & v₂ of n, p, and heavier clusters
   • Azimuthal angle dependence of n/p ratio w.r.t the reaction plane

4. Various isospin dependent phenomena
   • Isospin fractionation and isoscaling in nuclear multi fragmentation
   • Isospin diffusion (transport)
We need to accommodate
- Large acceptance
- Precise measurement of momentum (or energy) for variety of particle species, including $\pi^{\pm}$ and neutrons, with high efficiency
- Gamma detection for Pygmy and Giant dipole resonances
- Keep flexibility for other physics topic

Two setups
- Low-energy ($E < 18.5$ MeV/u) setup for the day-1 experiment
- High-energy ($E > 18.5$ MeV/u) setup

Beam
- State beam: $^{238}\text{U}$ up to 200 MeV/u
- Unstable beam: $^{132}\text{Sn}$ up to 250 MeV/u
Heavy Ion Experiment at RAON

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- **Driver Linac**
  - LEBT
  - RFQ (300keV/u, 9.5 pµA)
  - MEBT
  - SCL1 (18.5MeV/u, 9.5 pµA)

- **Post Accelerator**
  - MEBT
  - RFQ
  - CB
  - HRMS
  - RF Cooler
  - ISOL
  - Target
  - Cyclotron
  - IF Target

- **ISOL (Isotope Separation On-Line) system**

- **IF (In-flight Fragmentation) system**
  - μSR Medical Research

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**Intermediate design of LAMPS**

**Conceptual design of LAMPS**

**Gamma Detectors**

**Si-CsI Crystals Detectors**

**Neutron Detector Array**

**γ Detectors**

**Intermediate design of LAMPS**

3D schematic plot

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Low Energy LAMPS Experimental Setup

Gamma detector
(NaI or CsI)

Cluster detector
(Si+CsI)

Vacuum

Neutron Detector
(Scintillator array)

Geant4 simulation framework is under development

• Feasibility study
• Need to get all detector parameters for TDR
Low Energy LAMPS Experimental Setup

Geant4 based low energy LAMPS design

• Design of ΔE-E (Si+CsI) is completed
• Gamma array will be modified as spherical shape
• Forward Neutron Wall will be placed

Distance between target and detector = 20 cm

Forward neutron detector location ~ 5m from target position

ΔE-E (Si+CsI) array 8 segments and 8 layers

Gamma array

Target

Si layer

NaI crystal

CsI crystal

5 inch thick, 5 inch diameter

60 cm diameter

40 cm diameter

66 cm height

59 cm height

5 inch diameter

will be removed for beam pipe

2012-11-16

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Geant4 simulation is ongoing
- Each detector parts (to get detector parameters)
- Full simulation for feasibility study

Prototype testing is in progress

More details
Next talk by G. Jhang
Solenoid Spectrometer

**Time Projection Chamber (TPC)**
- GEM based & pad readout in end-caps (~100 k readout channels)
- 1 x 1.2 m² cylindrical shape
- Large acceptance (~3π Sr)

**Si+CsI**
- Si layers for ΔE & CsI for E
- 14° – 19° & 19° – 24° (350 mSr each)

**Solenoid magnet**
- More detailed optics and field mapping calculations are on going

More details
Next talk by G. Jhang
Dipole Spectrometer

For $B = 1.5$ T, $p/Z \sim 0.35$ GeV/c at $110^\circ$

For $B = 1.5$ T, $p/Z \sim 1.5$ GeV/c at $30^\circ$

Dipole acceptance $\geq 50$ mSr
Dipole length = 1 m
Rotatable+high resolution mode

- Multi particle tracking capability of isotopes for $p$, He, and heavier fragments
- Focal Plane detector for low momentum particles
- More than 3 tracking chamber stations (MWDC) for each arm
- Plastic scintillator ToF
  $\sigma_t < 100$ ps (essential for $\Delta p/p < 10^{-3}$ @ $\beta = 0.5$)

$B_Q = 0.5$T/m (x-focusing)

Energy range of proton: 10 - 400 MeV

For $B = 1.5$ T,
$p/Z \sim 0.35$ GeV/c at $110^\circ$
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Forward Neutron Detector Array

Large charged particle veto detector + neutron detector (composed of scintillator bars)
- Scintillator = 10 (W) x 10 (H) x 200 (L) cm$^3$
- 10 layers (20 scintillators/layer)
- Covering wide neutron energy range is important
- Capable for neutron tracking
- Geant simulation and detail R&D with prototype is in progress

More details
Next talk by G. Jhang
Schedule & Milestone

- **Superconducting solenoid magnet**
- **1st prototype + beam test**
- **1st prototype + beam test**
- **1st FEE delivered**

High energy system commissioning with stable beam

Low energy system commissioning with stable beam
Summary

• **RAON is RI beam accelerator in Korea**
  - RAON will provide high purity, high intensity various RI beams (e.g. $10^8$ pps $^{132}$Sn at 250 Mev/u)

• **RISP is on going for establishment of RAON accelerator and experimental facilities**
  ➡ For more details, talk by S. K. Kim tomorrow

• **Large Acceptance Multi-Purpose Spectrometer (LAMPS) at RAON**
  - Study of nuclear symmetry energy with RI and stable beam
  - Two detector setup for low and high energy
    - **Low energy:** gamma detector + Si+CsI detector + neutron detector
    - **High energy:** TPC + Si+CsI detector + neutron detector + MWDC + ToF + Solenoid magnet + Dipole magnet
    - ✓ To cover entire energy range of RAON with complete event reconstruction within large acceptance
  - Detail detector simulation and prototyping are in progress for TDR
    ➡ For more details, following talk by G. Jhang
  - Schedule, plan, and budget are established
  - Getting more collaborators from both domestic and oversea
    ➤ Forming International collaboration