Overview of Nuclear Physics Experiments at RIBF

H. Sakurai
RIKEN Nishina Center
RIKEN RI Beam Factory (RIBF)

Old facility

RIPS

GARIS

AVF

RRC

fRC

CRIB (CNS)

SHE (eg. Z=113)

60~100 MeV/nucleon

~5 MeV/nucleon

New facility

Experiment facility

Accelerator

To be funded
In phase II

Morita

RILAC

SRC

RRC

IRC

ZeroDegree

SLOWRI

SAMURAI

SCIT

SHARAQ

RI-ring

Otsuka

BigRIPS

Sakai

350-400 MeV/nucleon

Intense (80 kW max.) H.I. beams (up to U) of 345A MeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007
Present Status
BigRIPS/ZD
RIPS

Future Plan
Collaboration Framework
Proposed Experiments at RIPS, BigRIPS/ZD
RIB Intensity Comparison with that of MSU, GSI
Year 2009 Plan
Construction of Experimental Installations

Summary
**BigRIPS /ZeroDegree**

Exploration into “Isospin Frontier” toward the drip-lines
Reaction study fit for high energy domain 200-300A MeV

Coordinated by Kubo for BigRIPS
Coordinated by Aoi for ZeroDegree

**BigRIPS**
- Fragment Separator
- high acceptance for fission fragments
- pid for RI beams at the second section

**ZeroDegree**
- Multi-function BT line
- pid for ejectiles in inclusive- and semi-exclusive measurement
- medium resolution (p/dp ~ 2000 – 4000)

**RI-beam delivery line in 2007**

![Diagram of the RI-beam delivery line in 2007](image_url)
Delivery of identified RI-beam at BigRIPS
Based on two-stage separator scheme

T. Kubo et al.

Identify RI-beam species Z, A/Q by measuring ΔE, Bρ, TOF very accurately in an event-by-event mode using beam-line detectors on the 2nd stage. Aim at identification rate up to 1 x 10^6 pps.

total reaction cross section measurement with 2nd stage 2ndary target placed at F5
Identification of new isotopes $^{125,126}$Pd

T. Onishi et al, JPSJ 77 (08)083201.

Cf. $^{124}$Pd 19 counts, $^{125}$Pd(cand.) 1 count at GSI, 1997
PLB 415, 111 (97); total dose $\sim 1 \times 10^{12}$

Total dose $3.6 \times 10^{12}$ for 25 hrs
$\text{I} \sim 0.01 \text{ pnA on average}$

$A/Q$ resolution (r.m.s.): 0.041% at $Z=46$

$B\rho$ resolution (r.m.s.): 0.02%

$\Delta T$ resolution (r.m.s.): 40 psec
Identification of New Isotopes $^{125}\text{Pd}$ and $^{126}\text{Pd}$ Produced by In-Flight Fission of 345 MeV/nucleon $^{238}\text{U}$: First Results from the RIKEN RI Beam Factory


RIKEN, U. Tokyo, Osaka ECU, Rikkyo U., Saitama U, Tsukuba U., TITech GSI, ANL, NSCL, JINR, GANIL

JPSJ Award: Papers of Editors’ Choice
Commissioning and Experiments in 2008

Half a year delayed due to the problem of carry-over oil contamination in the refrigerators for the SRC and BigRIPS cryogenic system

November, $^{238}$U beam at 345 MeV/u and $\sim$0.4 pnA (max.) (10 times higher than in last year)

$7^{th}-25^{th}$ ZeroDegree Commissioning: detectors, optics, PID
Search for New Isotopes

December, $^{48}$Ca beam at 345 MeV/u and $>100$ pnA
$5^{th}-21^{st}$ Search for Halo Nuclei
In-beam gamma spectroscopy for island of inversion and beyond

Four proposed-experiments are combined
to form “one” collaboration
Programs are managed Not proposal-by-proposal
but RIB-by-RIB based
to save RIB tuning time and man-powers
to have the best programs according to the beam intensity
U86+ 345A MeV+ Pb 1.5mm, \( B\rho_01 = 7.395 \) Tm, No degrader

BigRIPS standard + ZDS Large Acceptance
RIPS (RIKEN Projectile-fragment Separator)

Intense RI beams for light mass region
Programs fit for intermediate energy domain ~100A MeV

Scientifically coordinated by Ueno

Light Exotic Nuclei such as \(^{8}\text{He}\), \(^{11}\text{Li}\): 

Polarized/Aligned RI beams:

Slow RI beams:

Nuclear Reactions at Low/Intermediate Energy
RIPS experiments, FY2008  (except for Wada’s MT)

- R403n(5B): Togano et al.
  - $^{31}\text{Cl}$ Coulomb dissociation
  - $^{30}\text{S}(p,\gamma)^{31}\text{Cl}$ reaction rate
  - Explosive hydrogen burning in X-ray bursts

- R407n(5B): Iwasa et al.
  - $^{28}\text{S}$ & $^{36}\text{Ca}$ Coulomb excitation
  - $B(E2), M_n/M_p$

- NP0709-RRC-038: Y.G. Ma et al.
  - 2 proton correlation of $^{23}\text{Al}$
    - Momentum correlation of 2 proton in $^{23}\text{Al}$
    - Proton radius of $^{23}\text{Al}$

- ML0707-RRC-012: Mihara et al.
  - $\mu(^{58}\text{Cu})$ by means of $\beta$-NMR
    - Cu impurity in Si semiconductor
HFS Spectroscopy of Laser Cooled $^7$Be$^+$ Ions @ Prototype SLOWRI - 1

$10^{-15}$ -fold reduction of kinetic energy!

cooling $10^9$ eV to $10^{-6}$ eV in kinetic energy

Laser Cooled $^7$Be$^+$

$T_{\text{ion}} < 10$ mK

Okada et al, PRL 101, 212502, published tomorrow

HFS of $^{11}$Be$^+$ was also measured (to be submitted). Charge radii of Be are in progress
International network and collaboration

Establishment of International Collaboration Framework
   LIA (France), China, EMMI (Germany), JUSTIPEN (USA)
   In near future, TRIUMF, JUSEIPEN(USA)

The State-of-Art Collaboration between Facility and Detector
   RIBF + MUST-2 (one proposal approved at PAC,
     more for a MUST-2 campaign)
   + GRAPE(CNS)+GRETA, AGATA (under discussion)
   + a Ge ball for decay spectroscopy ? (under discussion)
     Ge detectors from several institutes
   + ....

A few workshops will be organized in 2009
Proposed Experiments

**BigRIPS/ZD**
67 J.M. Daugas, moments of isomeric states in N~28 nuclei   LIA
68 R.M. Clark, Decay spectroscopy on n-rich nuclei with N~40   DOE
69 G. Simpson, Isomers in the n-rich Sn isotopes   LIA
70 P. Doornenbal, B(E2) for p-rich Sn isotopes   DALI
71 E. Ideguchi, Lifetime of excited states with GRAPE   GRAPE

**RIPS**
66 D. Beaumel/H. Otsu  He-10 spectroscopy   LIA, MUST2
65 G. Georgiev  Q-moment of isomeric state   LIA
### RIB Intensity Comparison with that of MSU, GSI

<table>
<thead>
<tr>
<th>RIB</th>
<th>Primary beams</th>
<th>RIB intensity [pnA]</th>
<th>RIB intensity [pps]</th>
<th>BigRIPS/ A1900</th>
<th>BigRIPS/ FRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>42–Si</td>
<td>48–Ca</td>
<td>200</td>
<td>300</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>48–Ni</td>
<td>58–Ni</td>
<td>(30)</td>
<td>6.0E-04</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>78–Kr</td>
<td>30</td>
<td>6.0E-05</td>
<td>0.5(58–Ni)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>64–Zn</td>
<td>(30)</td>
<td>2.0E-04</td>
<td>1.4(58–Ni)</td>
<td></td>
</tr>
<tr>
<td>54–Ca</td>
<td>86–Kr</td>
<td>30</td>
<td>5</td>
<td>2(76–Ge)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>76–Ge</td>
<td>(30)</td>
<td>20</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70–Zn</td>
<td>(30)</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>78–Ni</td>
<td>86–Kr</td>
<td>30</td>
<td>7.0E-02</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>238–U</td>
<td>5</td>
<td>6</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>100–Sn</td>
<td>124–Xe</td>
<td>10</td>
<td>4.0E-02</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td>128–Pd</td>
<td>238–U</td>
<td>5</td>
<td>3.0E-03</td>
<td>1300</td>
<td>1000</td>
</tr>
</tbody>
</table>

Xsections Epax2, ABLABRA

By Aoi
48-Ca, 124-Xe, 238-U beams compete on the world-wide market.
The Xe beam commissioning is needed

The Kr beams are not so powerful for flag-ship regions; 48-Ni, 54-Ca.
Other beams should be developed.
The 70-Zn beam is better choice for 54-Ca than Kr,
since RIKEN has great experiences of Zn at ECRIS.
To obtain the best performances, we need acceleration
test of Ni/Ge beams.
Year 2009 Plan

A/Q~2 beams with Z<=8 before summer
  Bypass beam line to skip IRC for AVF-RRC-SRC mode

SHARAQ Commissioning in March
  Experimental programs with polarized deuteron beams and light ion beams: 3NF, (d,3He), (p,2p)

Toward more intense beams
  A new 18GHz ECRIS for RILAC will be installed in March, 2009
    increase of the U beam by a factor of 10
  Zn, Xe beam commissioning
  R&D efforts for charge strippers

Experimental programs with Ca, Kr, Xe and U
Phase-II construction 2007-2012

To maximize the potentials of intense RI beams available at RIBF

http://rarfaxp.riken.go.jp/RIBF-TAC05/

SAMURAI - large acceptance
Kobayashi et al. in 2011

SHARAQ - high resolution
Shimoura et al. in 2009

SLOWRI - slow beams
Wada et al.

SCRIT - e-RI collision
Wakasugi, Suda et al.

Rare RI Ring – mass
Ozawa et al.

RI Spin Lab. at RIPS – pol. RI beam
Ueno et al.
**SCRIT  Wakasugi et al.**

Self-confining Radioactive Ion Target system realized in an electron-ring for e-RI scattering

Charge form factor measurement

\[ L > 10^{26} \text{ cm}^{-2} \text{s}^{-1} \text{ for 1 week} \]

\[ \rightarrow 10^5 \text{ pps injection} \]

Feasibility test at KSR, Kyoto-Univ.

Wakasugi et al., PRL 100, 164801(2008)

Luminosity achieved at KSR, Kyoto Univ.

\[ L = 2.4 \times 10^{25} \text{ cm}^{-2} \text{s}^{-1} \]

7x10^6 trapped ions during 85ms at 80mA current

SCRIT project in RIKEN

\[ L > 10^{27} \text{ cm}^{-2} \text{s}^{-1} \text{ 80mA(KSR) \rightarrow 300mA (Aurora)} \]

Photo-fission based ISOL for RI production
Budget Status and Construction Plan

**Approved in FY08**
- Facility Construction
  - SAMURAI (15M$ for FY08-11 magnet, detectors)
  - SHARAQ (high resolution)
  - BT line (2M$ for FY08)

**Requested for FY09**
- Operation budget
  - More than 6 months
- Construction budget for
  - SCRIT (e-RI)
  - a new injector linac

**FY10 and later**
- RI-ring, SLOWRI, IRC-RIPS BT
Summary

BigRIPS/ZD:
Two new n-rich isotopes at BigRIPS.
ZD commissioning was successful.
Experimental programs with a 48-Ca beam are scheduled in this Dec.
Spring in 2009, light-mass beams will be used for
  SHARAQ, 3NF, (d,3He), (p,2p)
Xe beam commissioning is necessary.
Beam development for Ni, Zn and Ge are next.

Construction:
SHARQ-BT and SAMURAI have been funded.
SCRIT as well as the new linac-injector are going to be funded

RIPS:
RIPS is in good shape to accept specific programs at
  intermediate energy as well as in a light mass region

Collaborations:
World-wide collaborations are being established.
SAMURAI Spectrometer   Kobayashi et al  2011-

versatile spectrometer with a large superconducting magnet

a large acceptance
exclusive measurements
neutron measurements
80cm gap, BL~ 7Tm, Bmax=3T
PID limited to A~100

Invariant/missing mass spectroscopy
  giant resonances
  single particle states via (p,2p) etc
EOS in asymmetric nuclear matter : SAMURAI-TPC
Particle correlations in a few-body system 3NF
Coulomb breakup for radiative capture c.s. (p,γ), (n,γ)