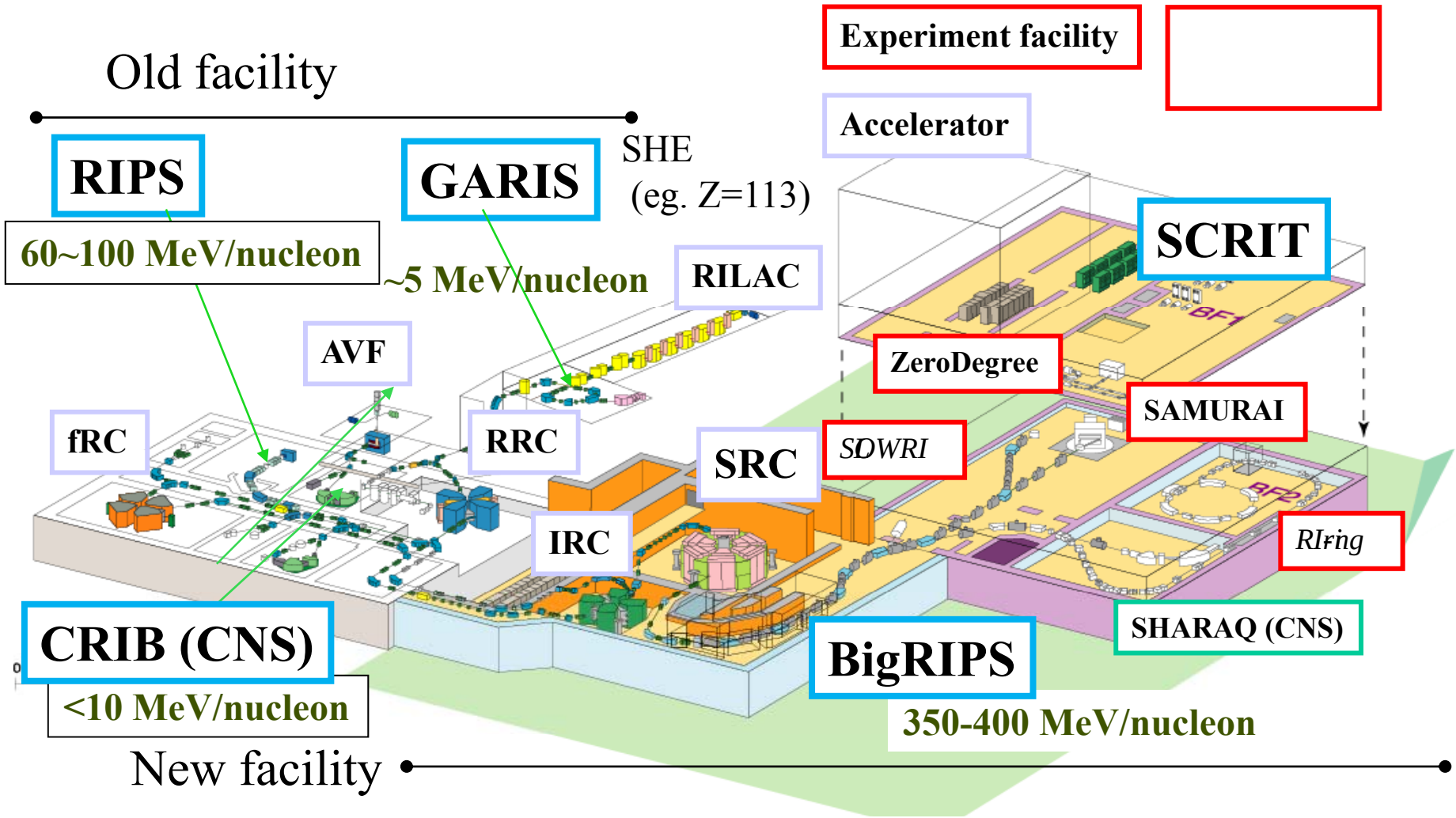
RIKEN RI Beam Factory

H. Sakurai
RIKEN Nishina Center

RIKEN RI Beam Factory (RIBF)



Intense (80 kW max.) H.I. beams (up to U) of 345AMeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007

In-flight RIB programs

BigRIPS 350-400A MeV

ZeroDegree, SHARAQ

Devices under construction and to be funded

SAMURAI, SLOWRI, Rare RI-Ring

RIPS 60-100A MeV

CRIB <10A MeV

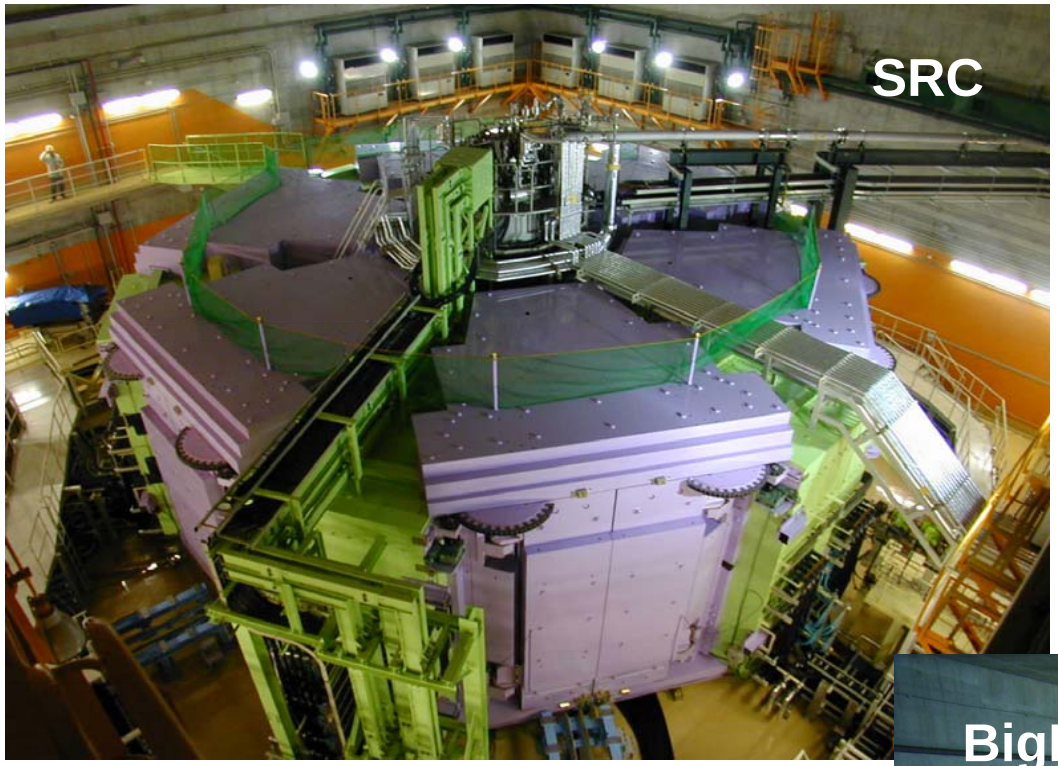
ISOL programs

SCRIT

Low energy programs ~5A MeV

SHE at GARIS

International Collaboration



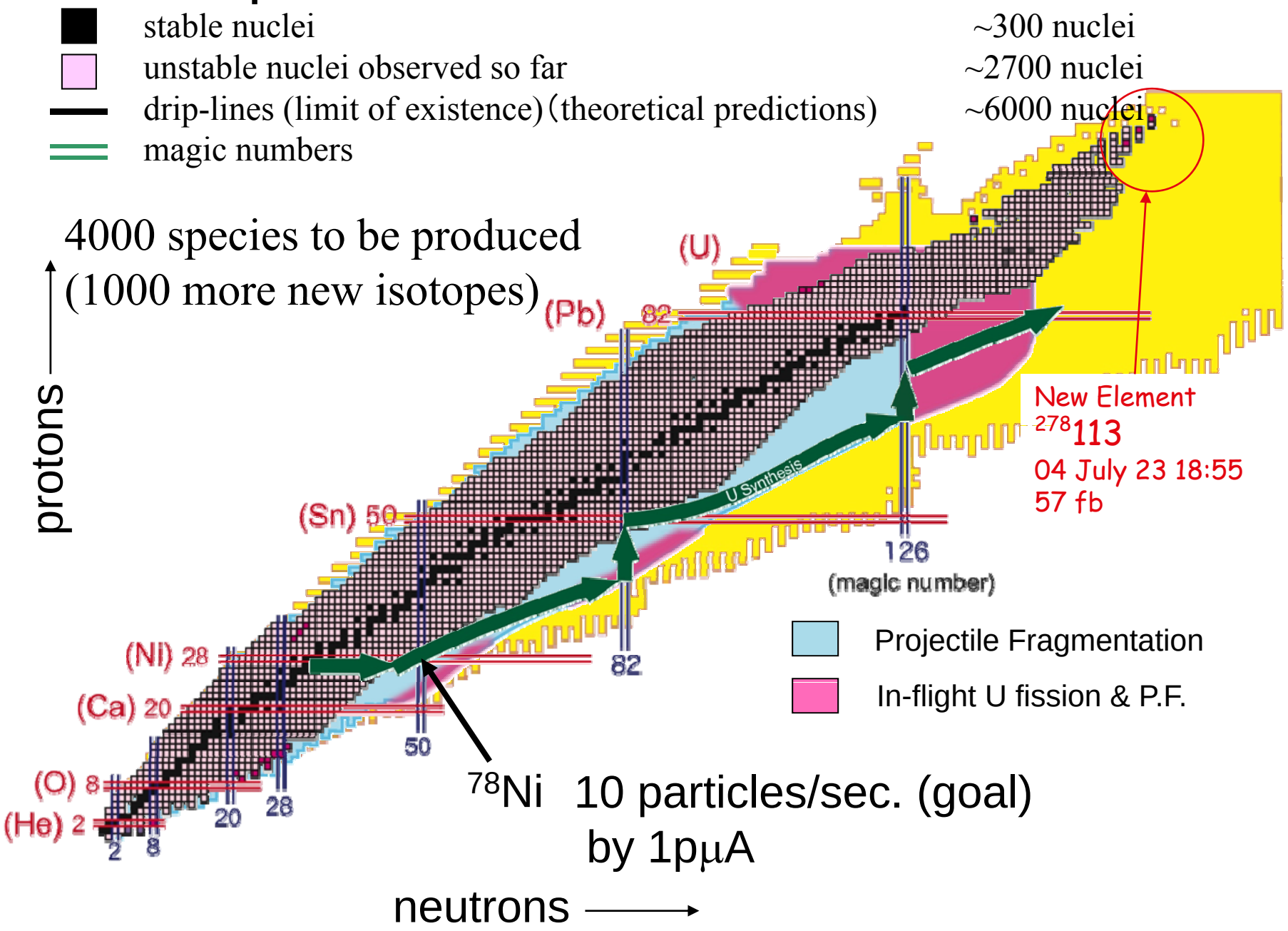
World's First and Strongest
K2600MeV
Superconducting Ring Cyclotron

400 MeV/u Light-ion beam
345 MeV/u Uranium beam

World's Largest Acceptance
9 Tm
Superconducting RI beam Separator

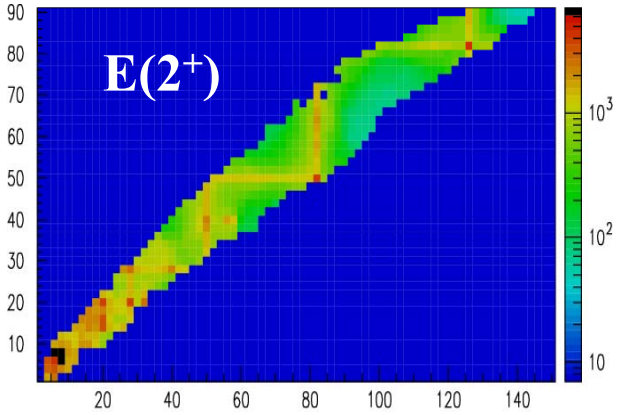
~250-300 MeV/nucleon RIB

Exploration of the Limit of Existence

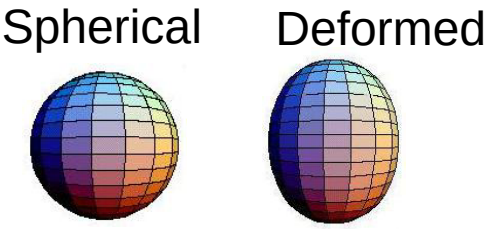


Liberation from Stable Region and Exotic Nuclei

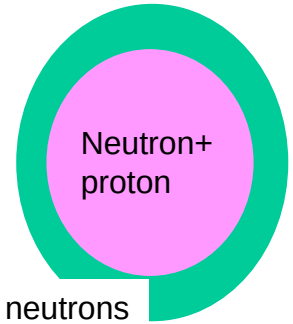
Shell Evolution : magicity loss and new magicity

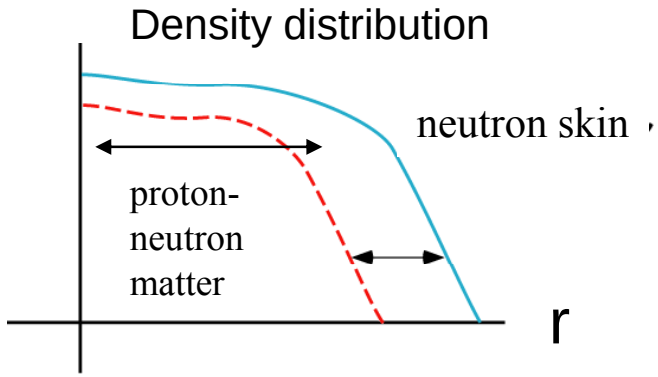


Shape ?
Shell gap ?
Single particle level ?
Cluster formation?
Role of 3NF ?
Magicity loss ?
50、82、126、184



Dynamics of new “material” : Neutron-skin（halo）





Skin thickness ? Density distribution ?
Role of skin in reactions ?
Pairing in skin ? di-neutrons?
Exotic modes of skin ?

RIBF provides data for nuclei far from the stability line

Challenges in establishing new frame work of nuclear physics

Challenge for r-process path and explosion in supernovae

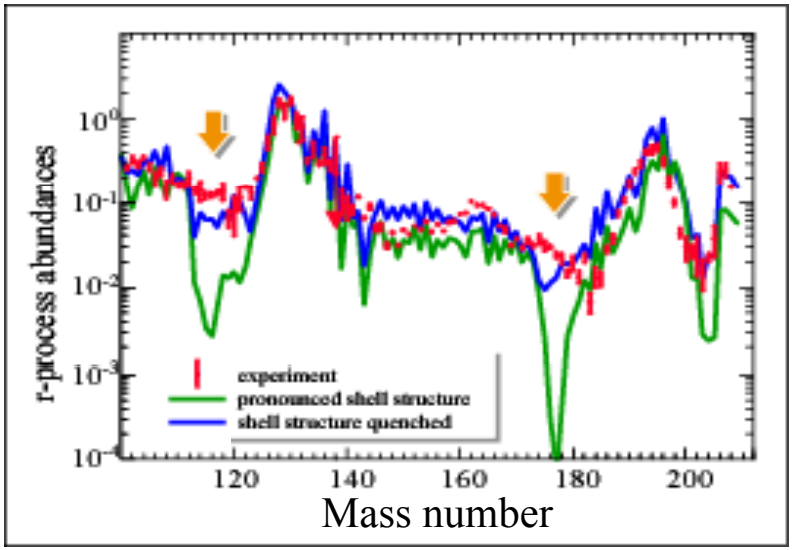
Synthesis up to U （r-process）

unknown neutron-rich nuclei

theoretical predictions only

Necessary of experimental investigation for nuclear properties of heavy and neutron-rich nuclei

Mass, life-time, decay mode

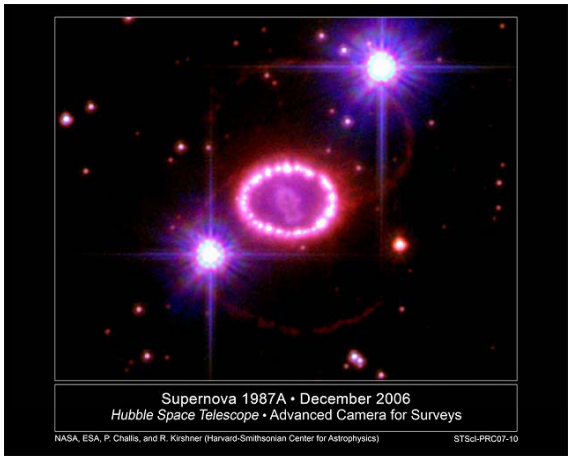


Explosion mechanism of supernova

No explosion in theoretical works

Outer crust of neutron star

Necessary of experimental study for Equation-of-State for nuclear matter



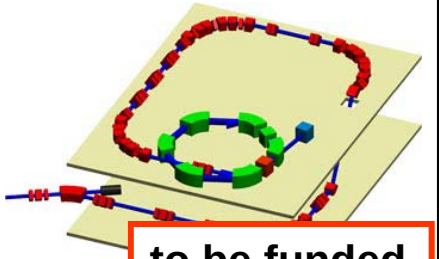
1987A

New Devices of RIBF

To maximize the potentials of intense RI beams available at RIBF

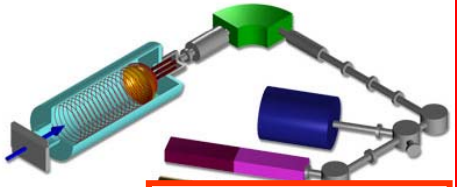
for several 100 – 1000 species

Rare RI ring



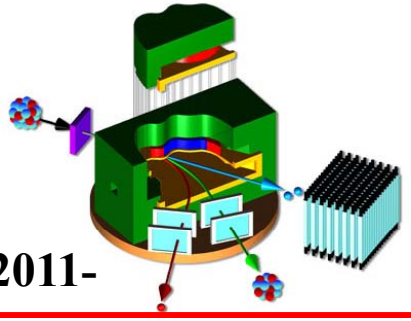
to be funded

SLOWRI



to be funded

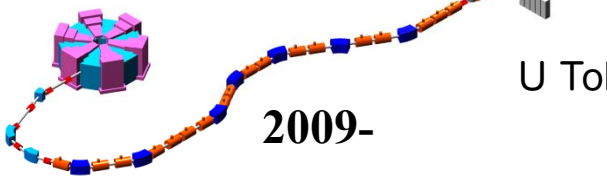
SAMURAI



2011-

- mass
- half-life
- excited states
- deformation
- charge radii
- matter radii
- charge distribution
- matter distribution
- EM moments
- single particle states
- astrophysical reactions
- giant resonances
- exotic modes
- HI collisions (EOS)

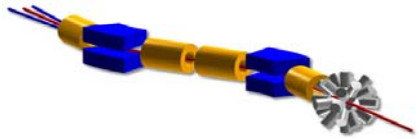
SHARAQ spectrometer



U Tokyo

2009-

ZeroDegree

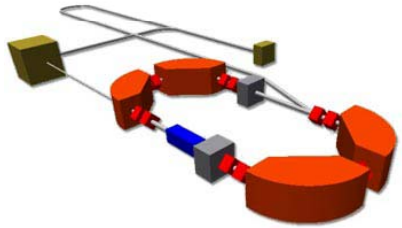


2008-

IRC-to-RIPS BT

to be funded

SCRIT

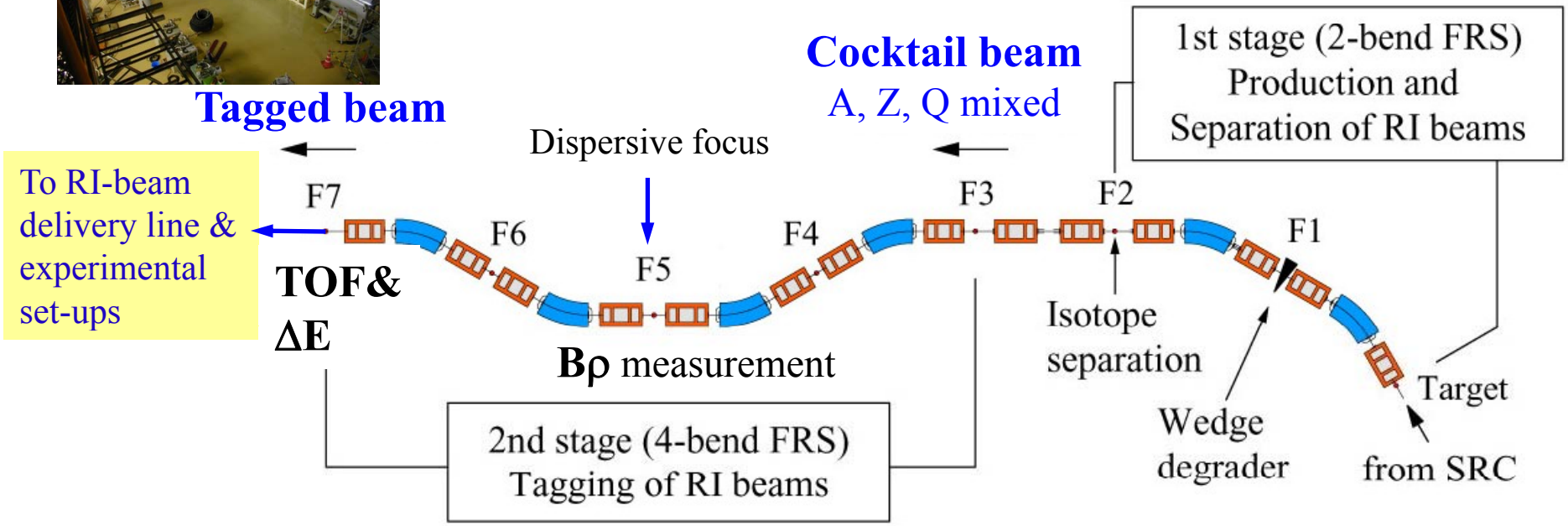


2010-

Delivery of tagged RI-beam

Based on two-stage separator scheme

T. Kubo et al.

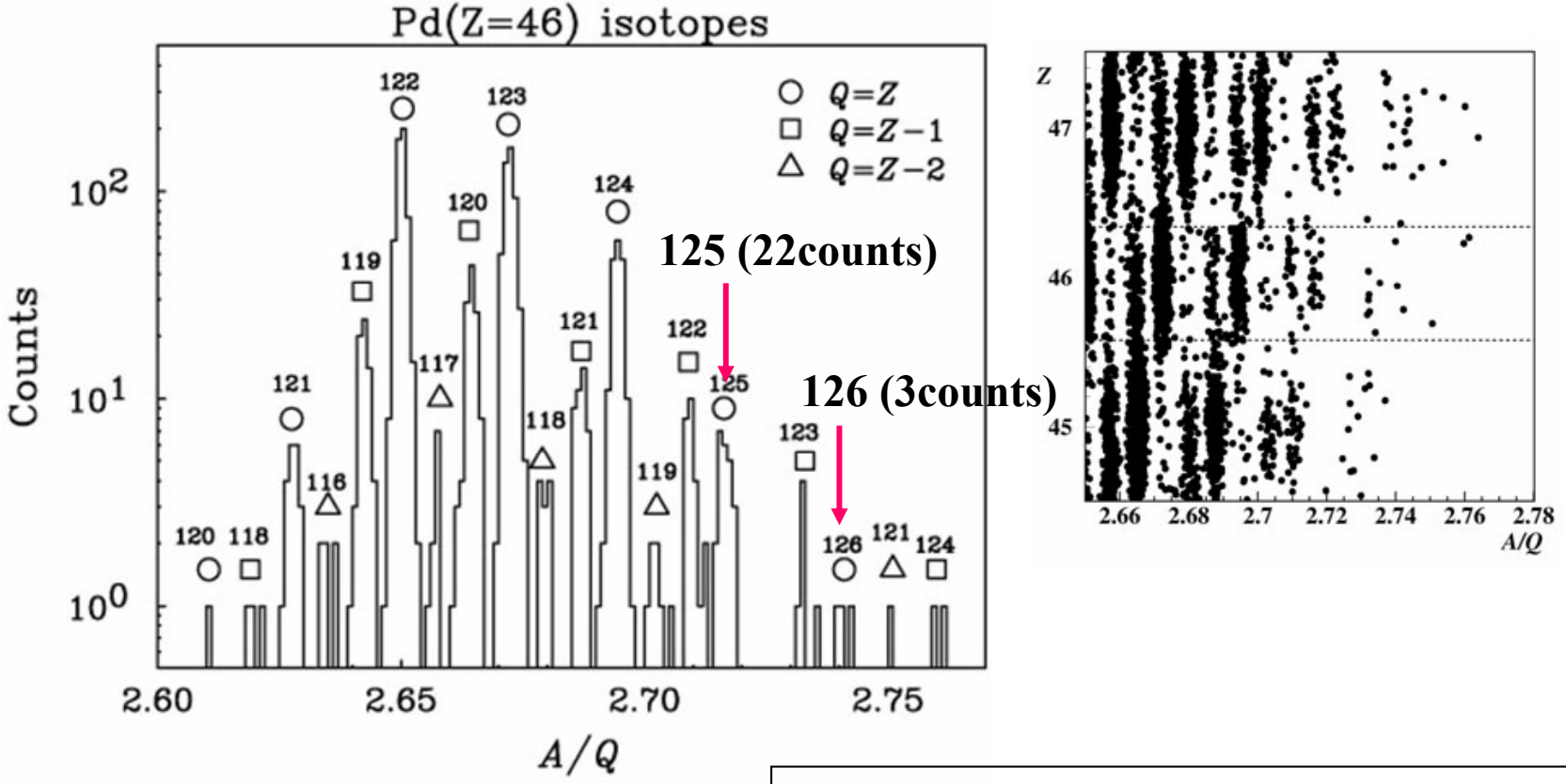


Identify RI-beam species Z, A/Q by measuring ΔE, Bρ, TOF in an event-by-event mode using beam-line detectors on the 2nd stage. Aim at tagging rate up to 1 x 10^6 pps.

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.



Total dose 3.6x10^{12} for 25 hrs
I ~0.01 pnA on average

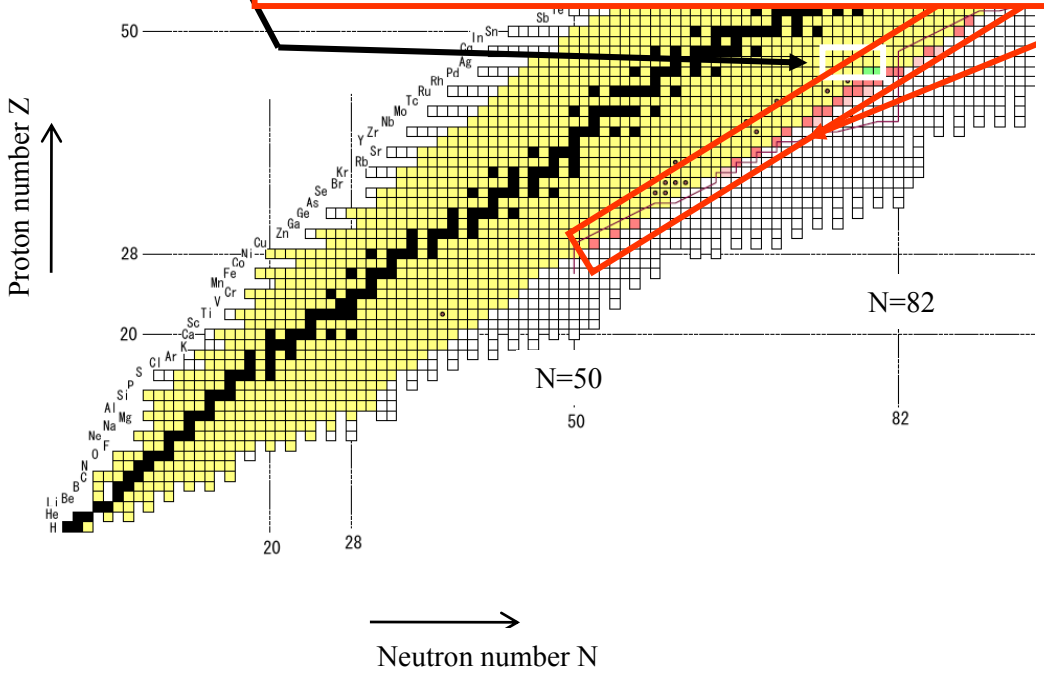
A/Q resolution(r.m.s): 0.041% at Z=46
Bρ resolution (r.m.s): 0.02%
ΔT resolution (r.m.s.): 40 psec

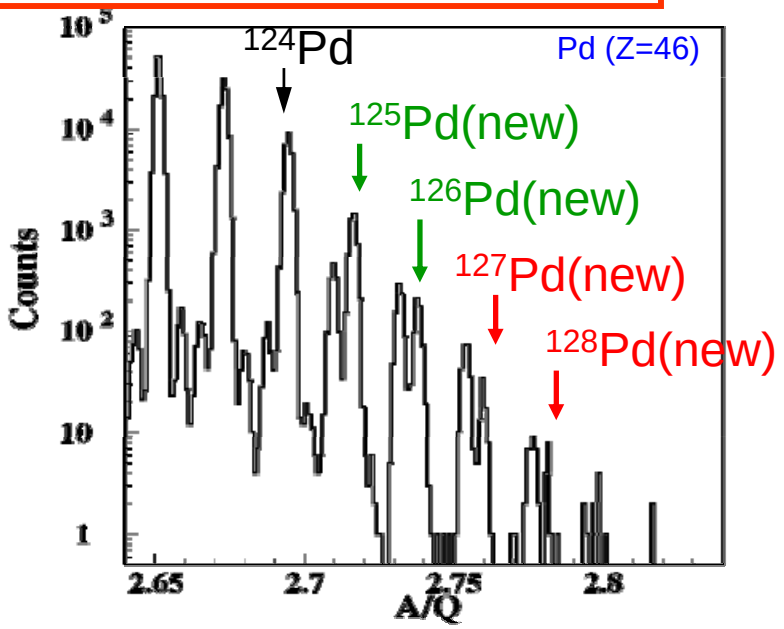
Cf. ^{124}Pd 19 counts, ^{125}Pd(cand.) 1count at GSI, 1997
PLB 415, 111 (97); total dose ~1x10^{12}

New isotopes observed at BigRIPS in 2007-2008

May 2007 345A MeV ^{238}U beam 0.02 pnA (max)
Two new isotopes, ^{125,126}Pd (Z=46), Onishi et al. JPSJ 77 (08) 083201

Nov. 2008 345A MeV ^{238}U beam 0.4 pnA(max)
More than 30 new isotopes in Mn(Z=25) to I(Z=53)
to be submitted to JPSJ soon.



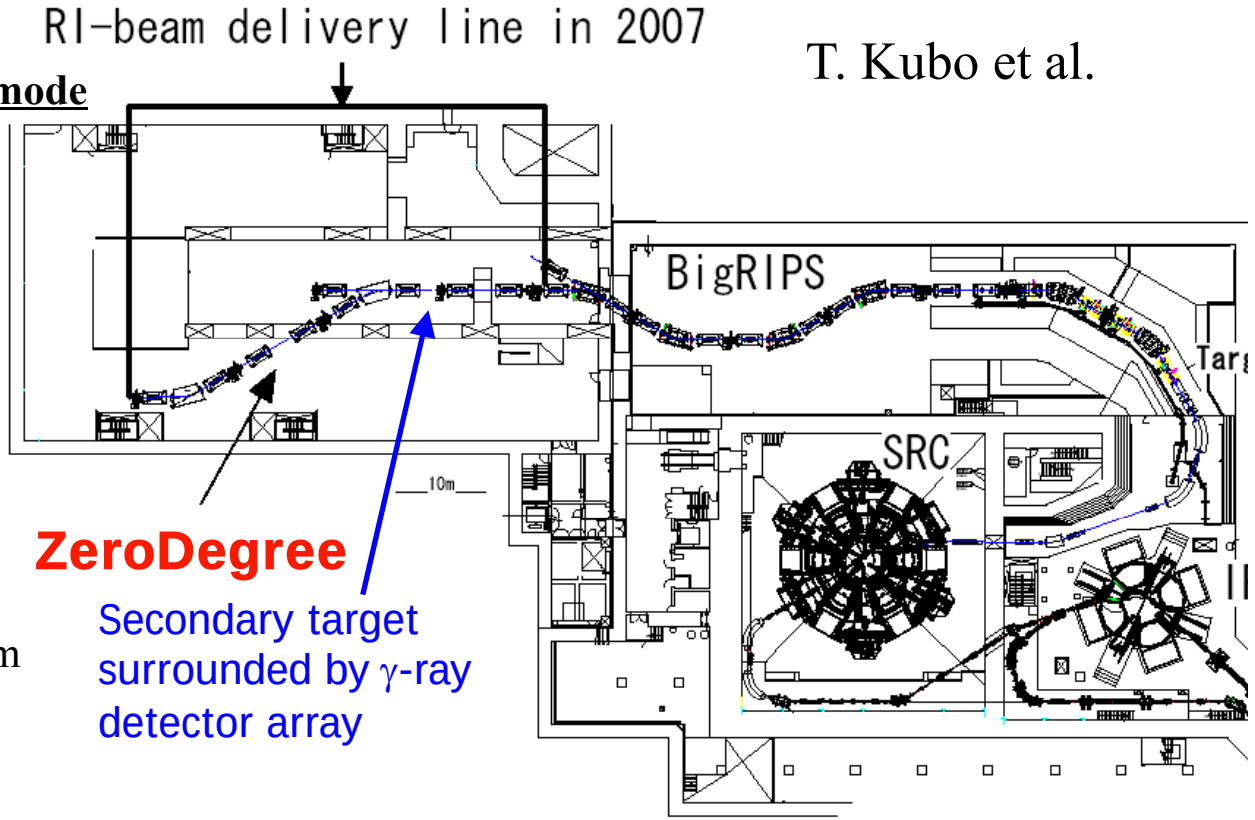


ZeroDegree spectrometer : multi-function beam-line

- RI-beam delivery line has been designed to work as spectrometer, in order to be used for studies of secondary reactions of exotic nuclei via inclusive/semi-exclusive measurements, such as in-beam gamma spectroscopy.
- The same quadrupoles and dipoles as those of BigRIPS.
- Two-bend anti-mirror symmetric system

T. Kubo et al.

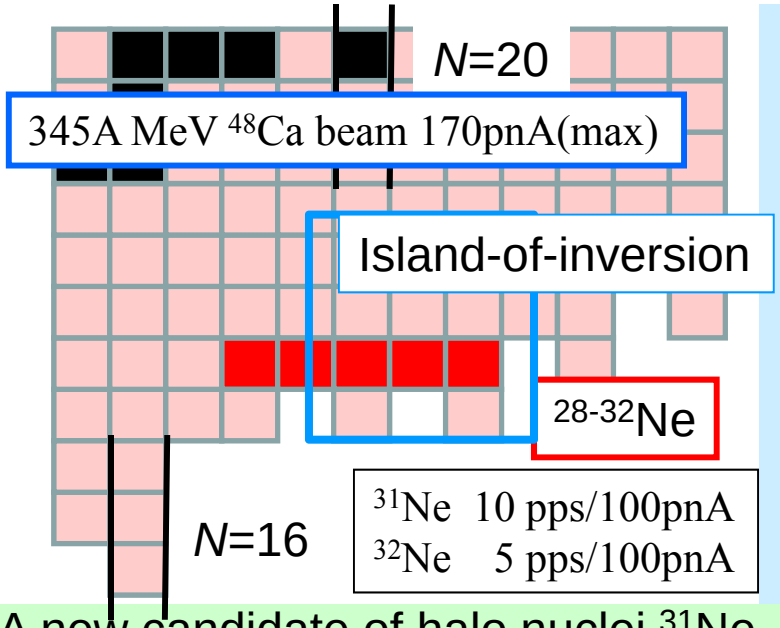
(1)Achromatic large acceptance mode
total flight path length ~ 36m
angular acceptance
Δθ =+/- 45mrad, Δϕ=+/- 30mrad
cf. 250A MeV neutron-rich beams
grazing angle
~ 20 mrad for Pb targets
momentum acceptance
Δp/p =+/- 3%
momentum resolution
(x,p)/(x,x) = 1240
maximum magnetic rigidity 7.3 Tm
5 sigma separation in A at A=200

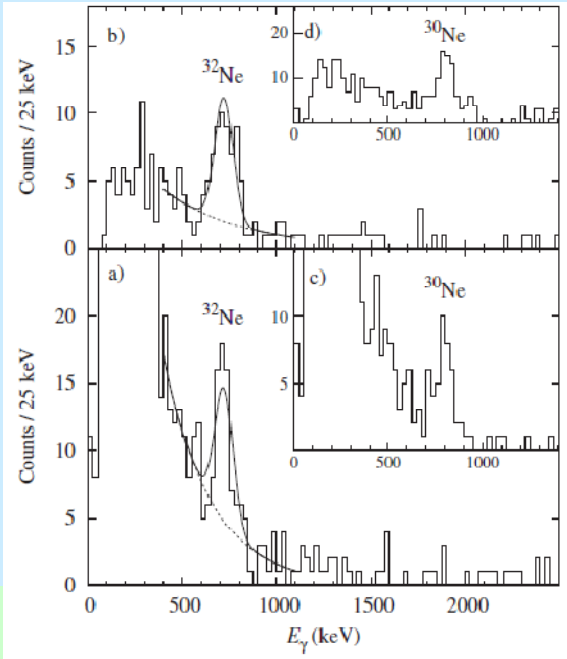


DayOne Experiments in Dec., 2008
-The first data in the "island-of-inversion" -

RIKEN NISHINA CENTER

Coordinated by Aoi



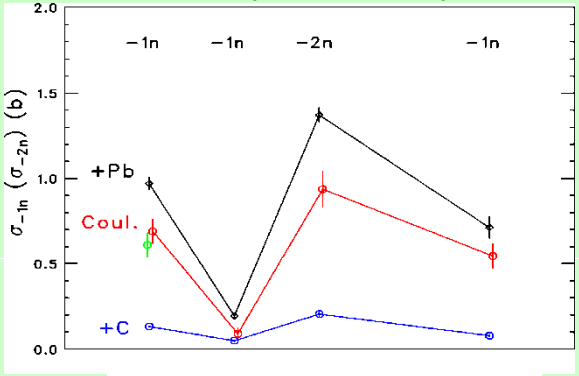


Spectroscopy of ^{32}Ne and the "island-of-inversion"

Doornenbal, Scheit et al.
PRL 103, 032501 (2009)

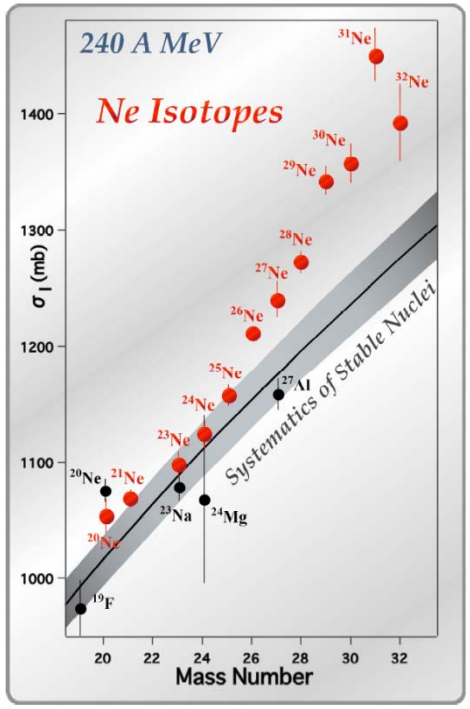
A new candidate of halo nuclei ^{31}Ne via Coulomb breakup

Nakamura et al., PRL 103, 262501(2009)



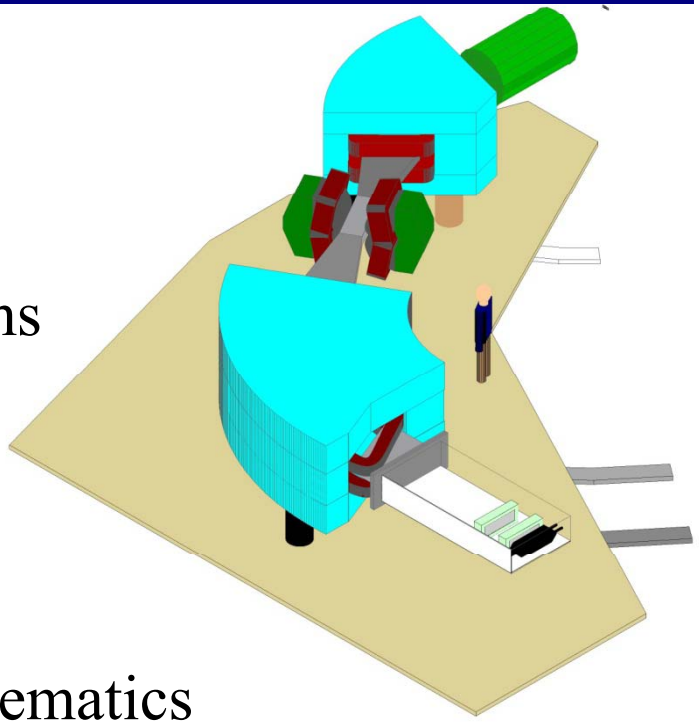
Total interaction cross sections for the neutron-rich Ne isotopes

Takechi, Otsubo et al., NN Collision, 2009



SHARAQ Spectrometer Sakai et al 2009-

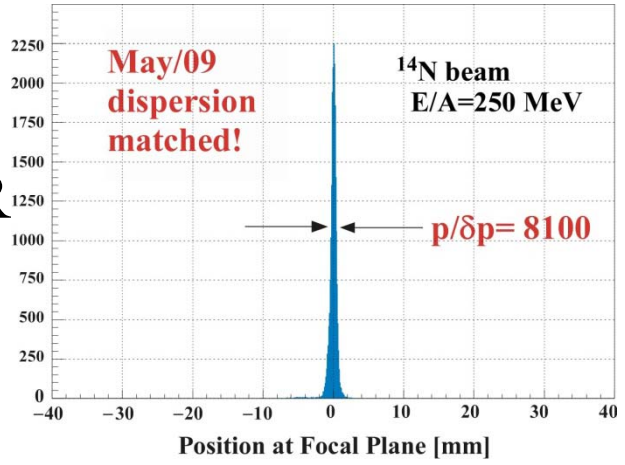
External investment by CNS, Univ. of Tokyo
Focal plane detector made in GANIL, France



High resolution spectrometer for fast RI beams
$p/\Delta p \sim 15{,}000$, $\Delta\theta<1$mrad, $B\rho=6.8$Tm
Dispersion matching technique

RI beam as new probe to control Δq, ΔS, ΔT
Missing mass spectroscopy with standard kinematics
Spin-isospin response probed by fast RI beams :
transparent at 300*A* MeV
Double charge exchange : double GTR, IVSMR
Multi-neutron system, etc.

Commissioning in March, May 2009
First experiment in Oct.-Nov. 2009 (t,^{3}He)



Programs at SRC-BigRIPS in 2009

250A MeV Polarized deuteron beam — AVF-RRC-SRC

d+p elastic scattering for 3NF at BigDpol (Sekiguchi)

250A MeV ^{14}N beam — AVF-RRC-SRC

SHARAQ Commissioning (Sakai)
Dispersion Matching Mode in BigRIPS for (d,^{3}He) (Itahashi)
Kappa-Spectrometer Commissioning (Kobayashi)

320A MeV ^{4}He — RILAC-RRC-IRC-SRC

(t. ^{3}He) reaction at SHARAQ (Miki)

345A MeV ^{238}U 0.8pnA(max) — RILAC-RRC-fRC-IRC-SRC

In-beam gamma (Aoi) / Decay spectroscopy(Sumikama) at ZDS

345A MeV ^{48}Ca — RILAC-RRC-IRC-SRC

Total interaction cross sections(Otsubo)/
In-beam gamma spectroscopy(Scheit/Takeuchi) at ZDS

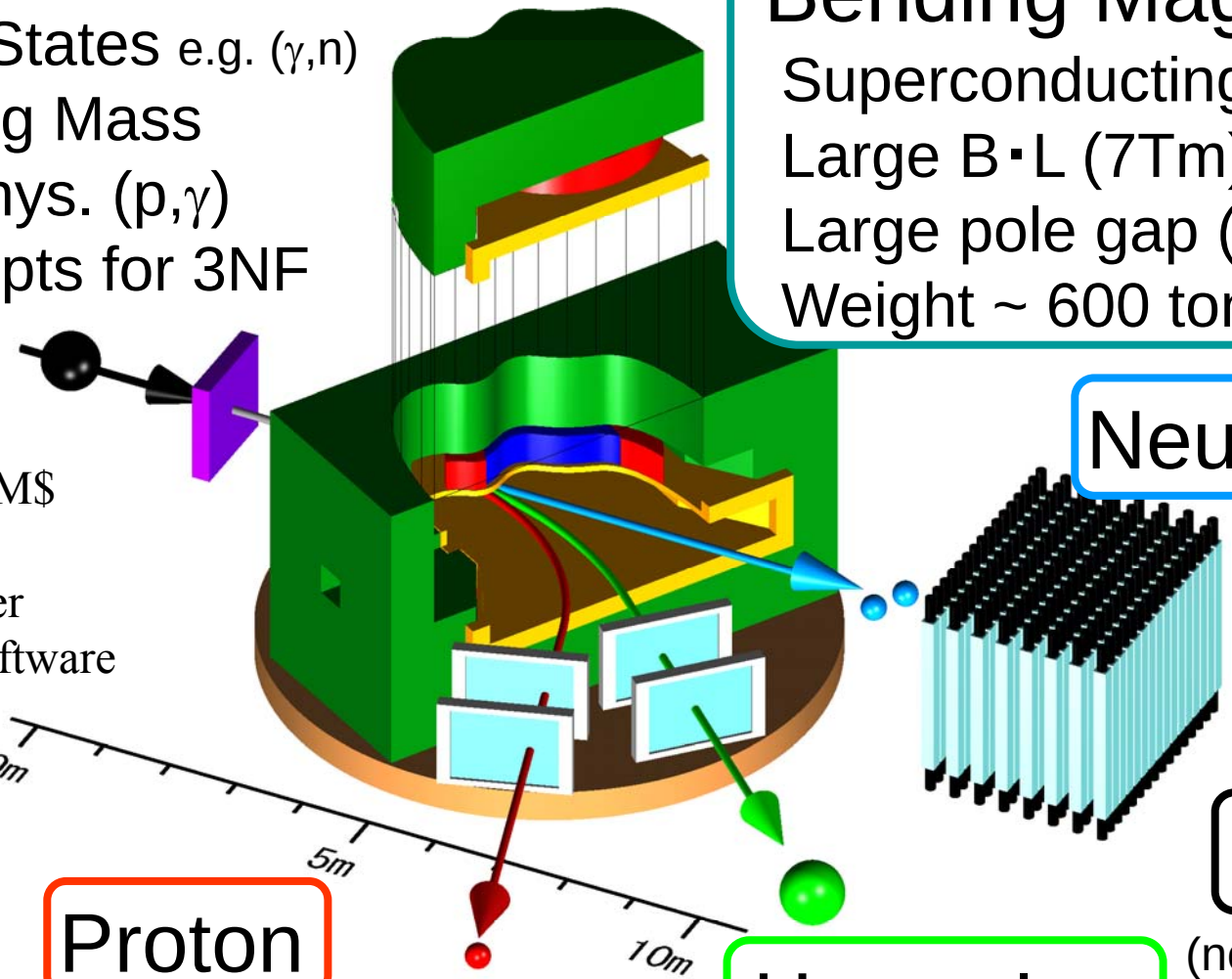
SAMURAI Spectrometer Kobayashi et al 2011-

versatile spectrometer with a large superconducting magnet

Spectroscopy of
Unbound States e.g. (γ,n)
(p,2p) Missing Mass
Nucl. Astrophys. (p,γ)
Deuteron expts for 3NF
Nucl. Matter

15M$ covers
SC-Magnet 9M$
Detectors
neutron counter
electronics, software
STQ for BT

$\vec{d}$ setup
(not shown in picture)



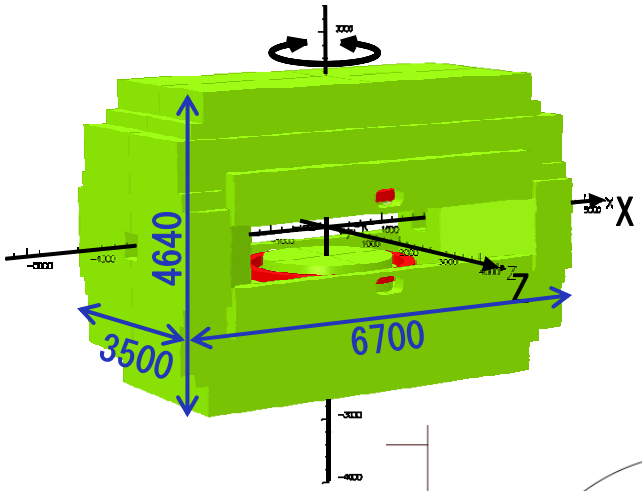
Bending Magnet
Superconducting
Large B·L (7Tm)
Large pole gap (80cm)
Weight ~ 600 ton

Neutron

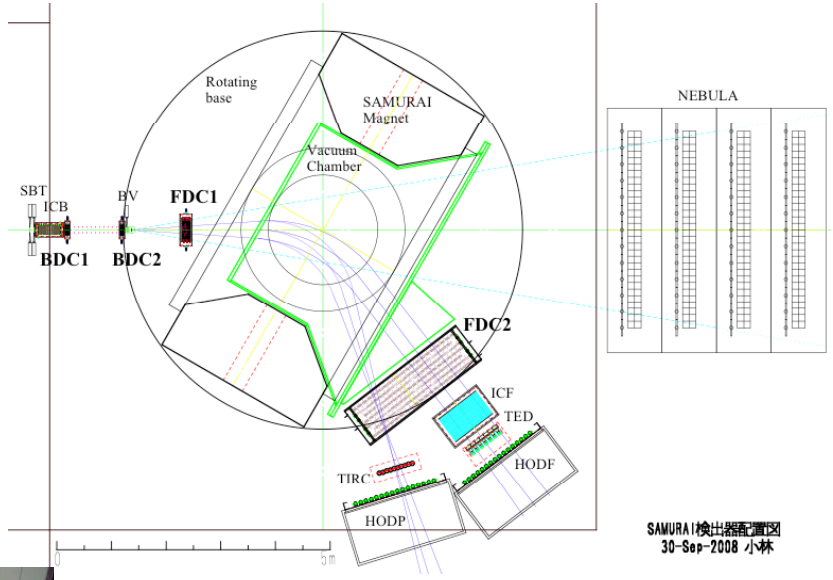
TPC
(not shown in picture)

Proton

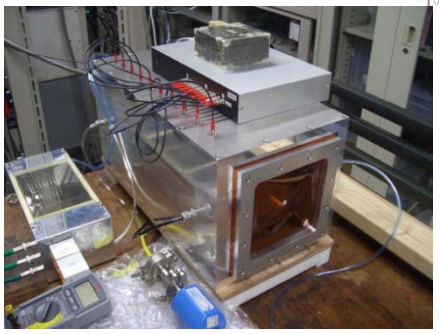
Heavy Ion



Magnet designing in progress
~ Oct 2010 Factory fabrication
~ March 2011 Construction in RIBF
~ May 2011 Ready to run



Neutron detector … 1/4 Done
Ready in March 2010



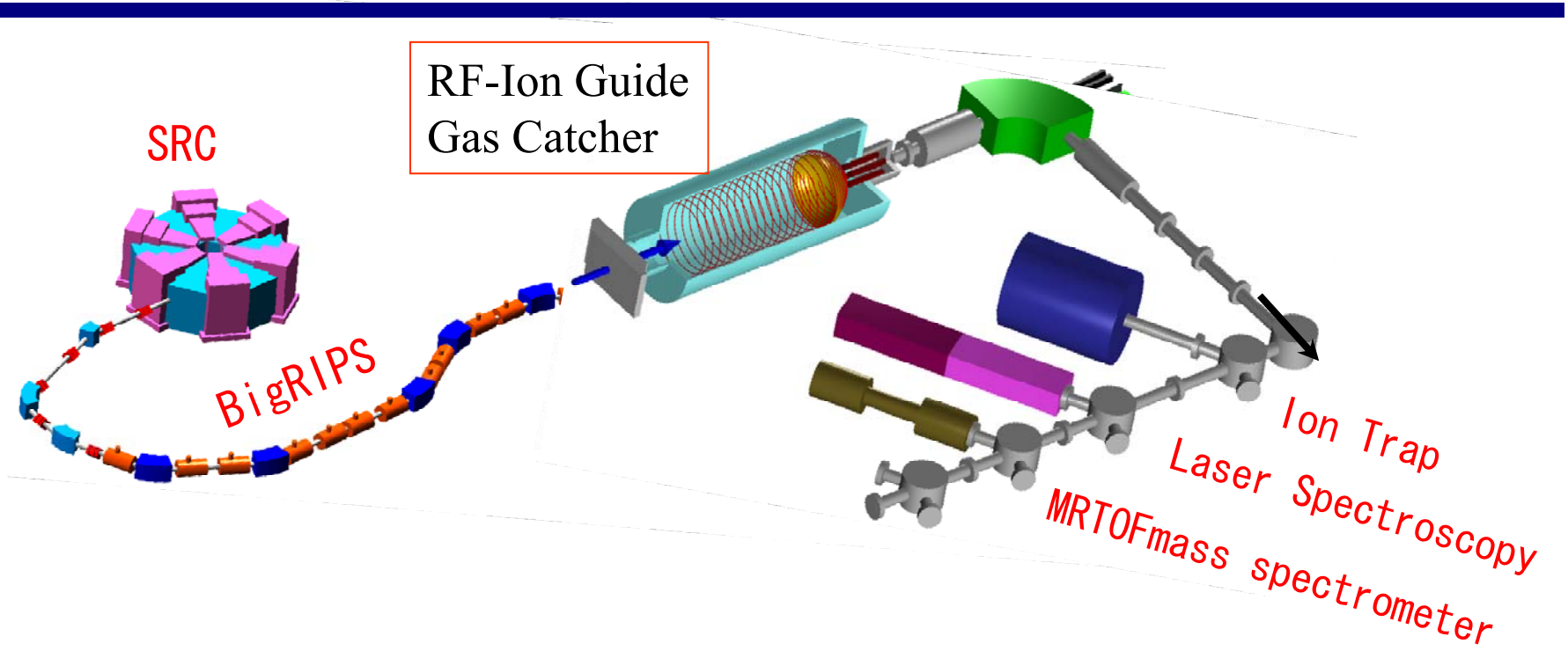
ICB

Heavy Ion detectors … in progress
~ March 2010 ICB, ICF, HODF, HODP, BDC1,2, FDC1
~ March 2011 FDC2,…

To be ready for commissioning in Summer 2011

SLOWRI

M. Wada et al.



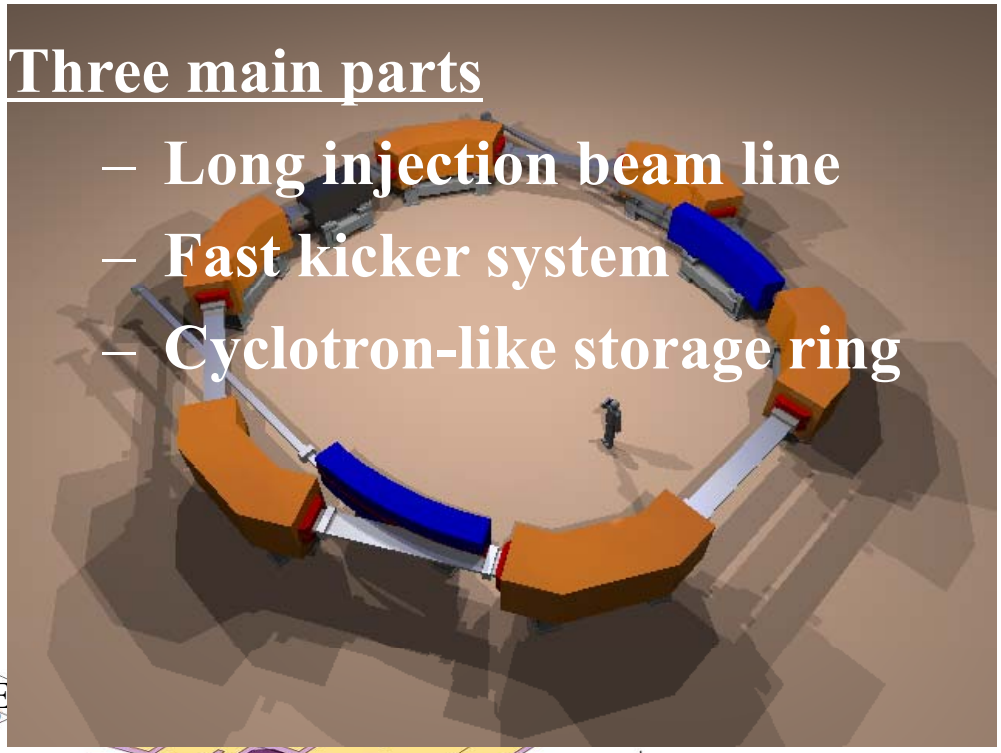
Slow RI beams of 3000 nuclear species for all of elements

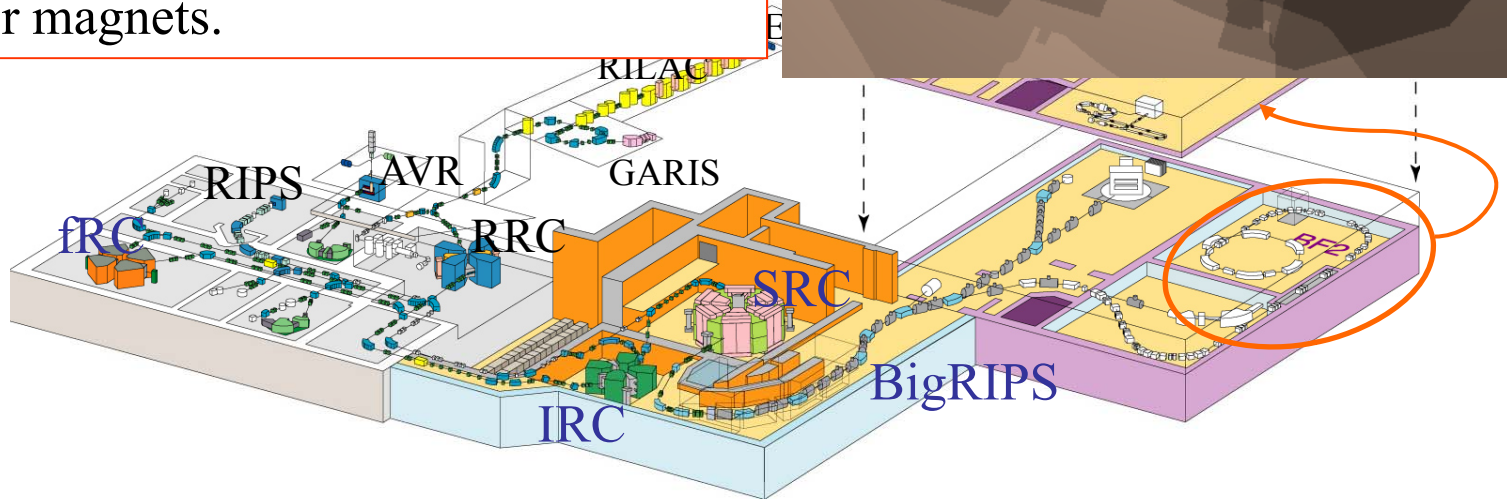
Mass spectroscopy ; Penning Trap, MR-TOF for 1000 species
Laser spectroscopy : spin, moment, radii for 600 species
pilot experiments at RIPS for the Be isotopes
Decay spectroscopy : beta-delayed charged-particle emission

Rare-RI ring project in RIKEN RIBF

- **Precise mass measurement**
- **High accuracy**
  $\Delta m/m \sim 10^{-6}$
- **High efficiency**
  - **Individual Injection**
- **Measurement time < 1ms**
  - **For short-lived RI**

Designing storage ring with companies: sector magnets, trim coils, septum and kicker magnets.

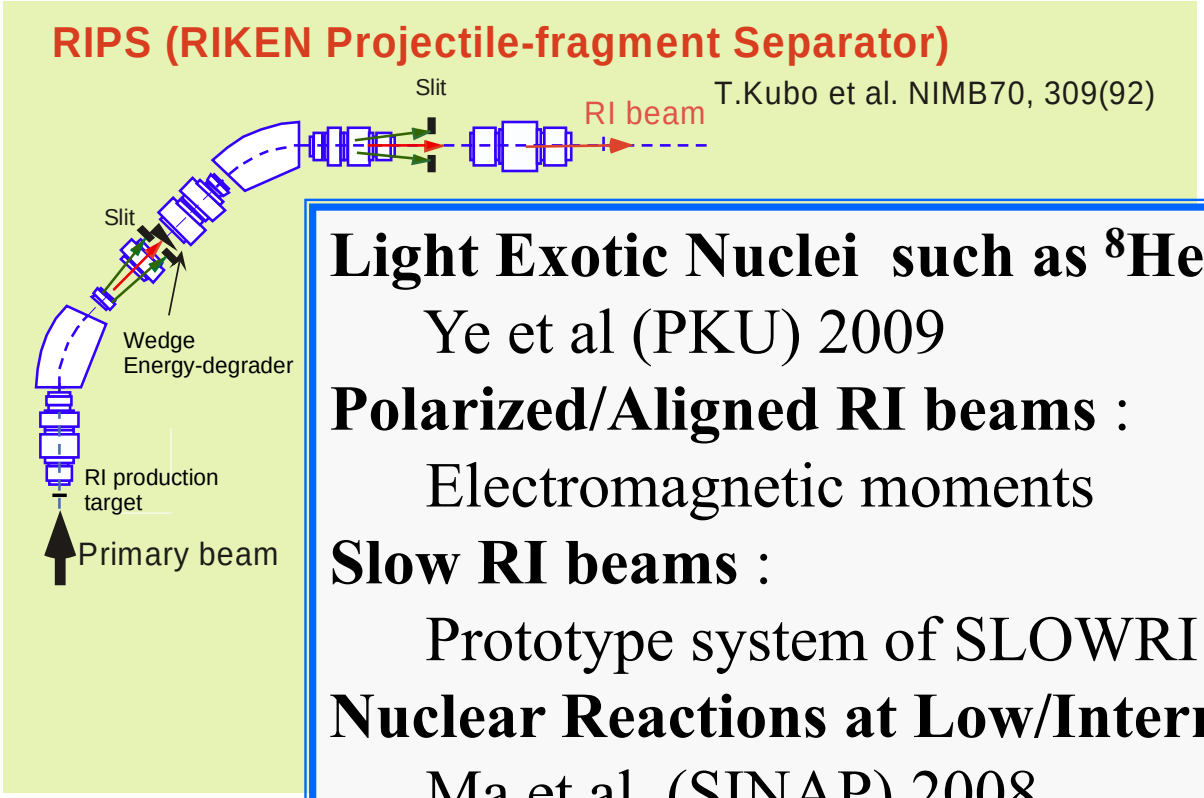




Intermediate/Low energy RIB
RIPS
CRIB

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}He, ^{11}Li :
Ye et al (PKU) 2009

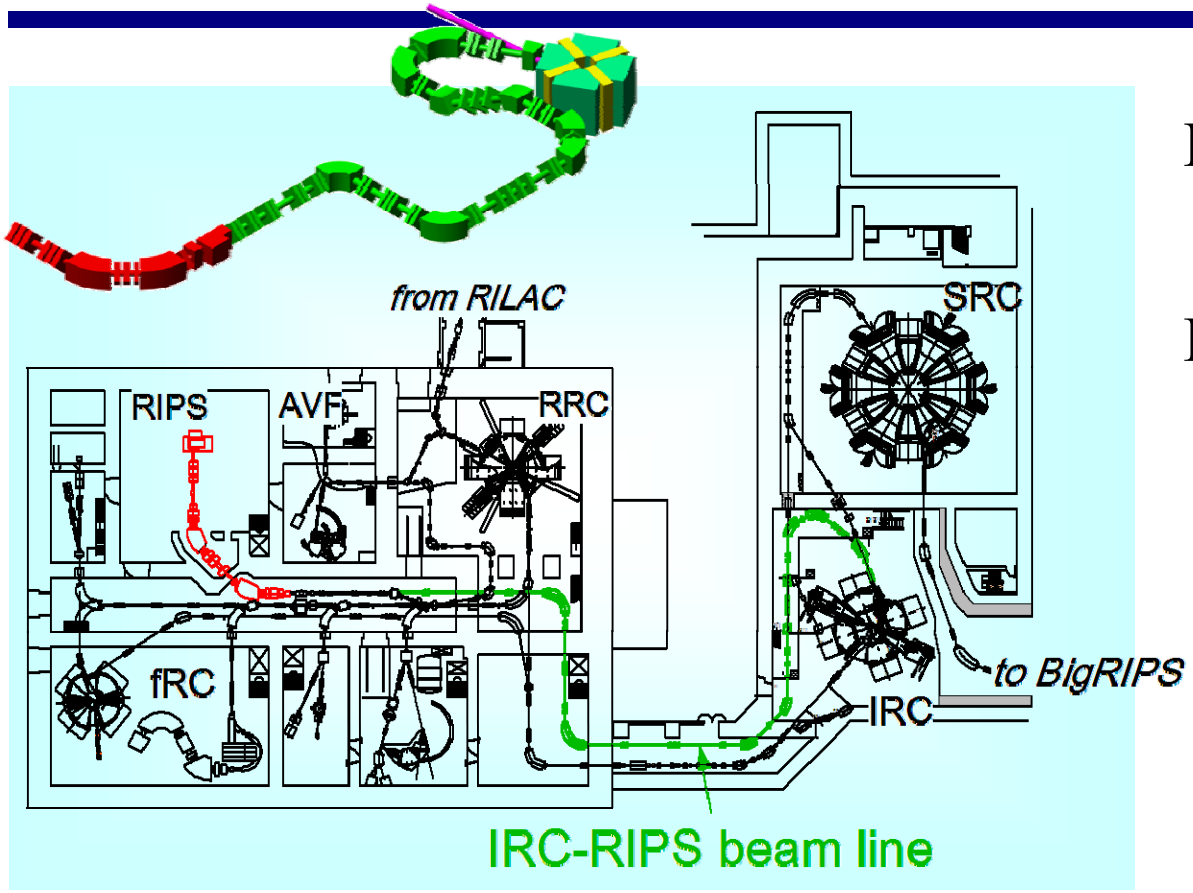
Polarized/Aligned RI beams :
Electromagnetic moments

Slow RI beams :
Prototype system of SLOWRI

Nuclear Reactions at Low/Intermediate Energy
Ma et al. (SINAP) 2008
Banerjee et al. (VECC) hot GDR with BaF_2

IRC-to-RIPS BT Line

Ueno et al.



MultiUse of IRC beams

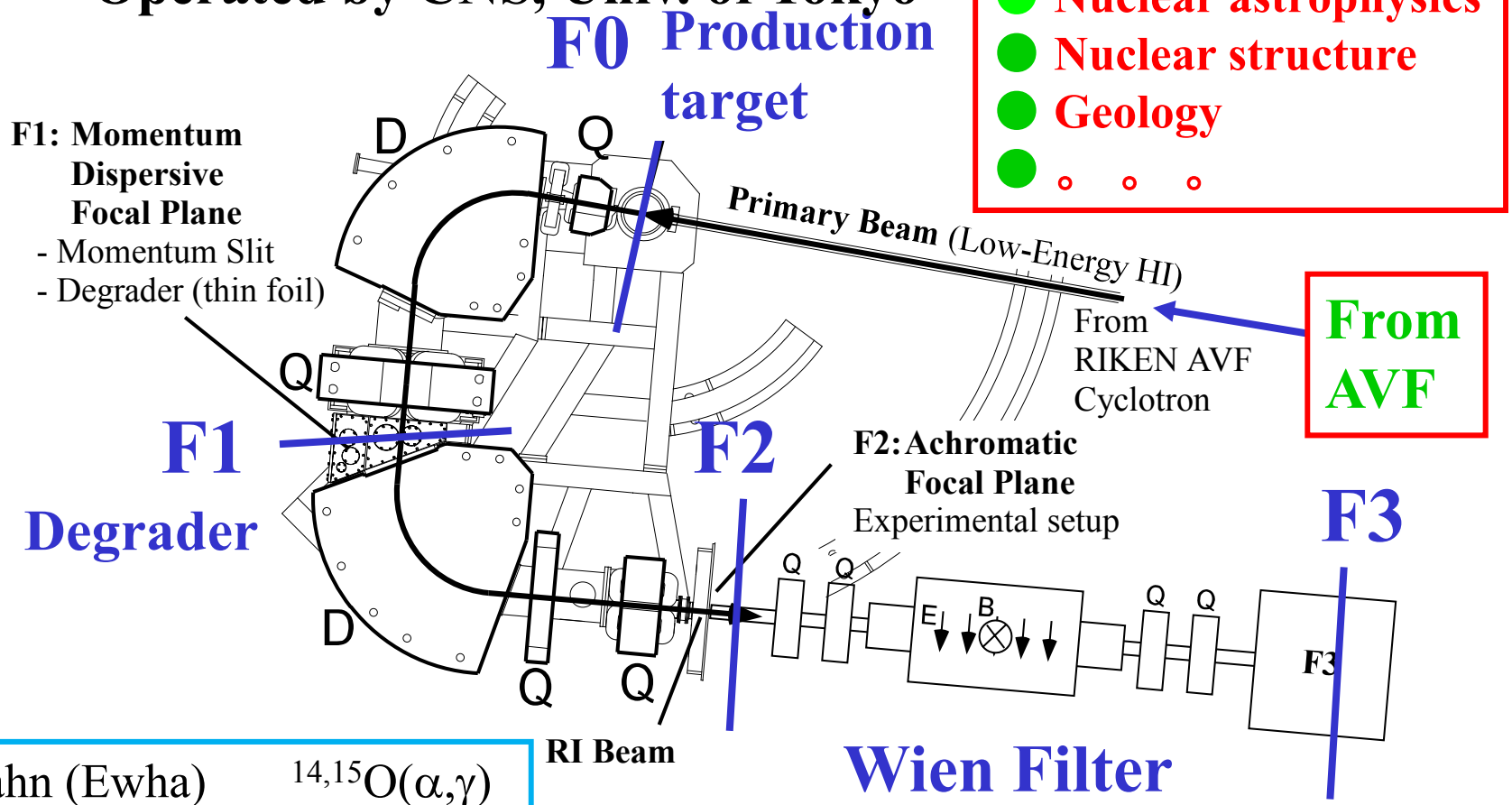
Beam sharing between
RIPS user and
BigRIPS user

Low-energy in-flight RI beam separator CRIB

http://www.cns.s.u-tokyo.ac.jp/crib/crib-intro.html

Operated by CNS, Univ. of Tokyo

- Nuclear astrophysics
- Nuclear structure
- Geology
- ...



Hahn (Ewha)	$^{14,15}O(\alpha,\gamma)$
Liu/Guo (CIAE)	$^{12}N(p,\gamma)$
He(IMP)	$^{18}Ne(\alpha,p)$
Lee(Chung-Ang)	$^{26}Si(p,\gamma)$

5 m

Yanagisawa, Kubono, et al: NIM A 539 74 (2005)

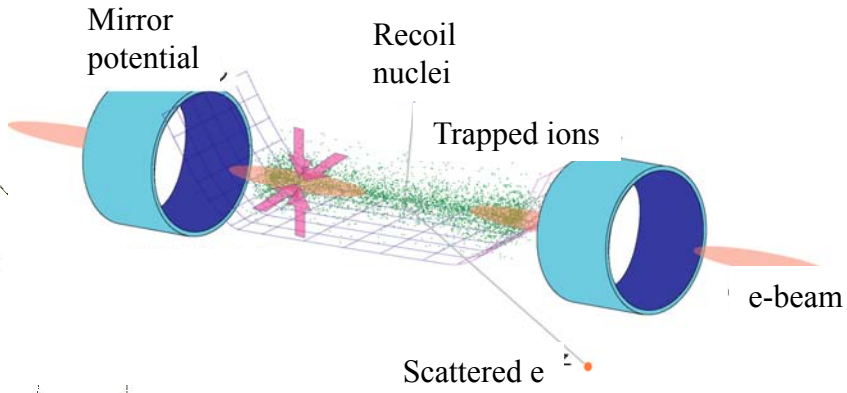
Collaborators;
Italy, Canada,Korea, Brazil, China, Vietnam, Hungary

ISOL

SCRIT-system for e+RI scattering

Wakasugi et al.

Microtron
- 150MeV, ~1kW
- Two functions
  - Injector for e-storage ring
  - driver for RI production



Wakasugi et al., PRL 100 (2008) 164801
Suda, et al., PRL 102 (2009) 102501

RI Ion Source + ISOL
- Photo-induced fission (UC_2)

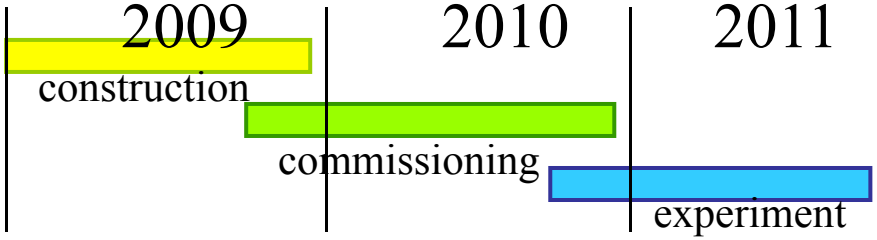
Ion transport line

e-storage ring
- 300MeV (up to 700MeV), 300mA

SCRIT

Scattered-e detectors
- DC + Calorimeter

Schedule



RTM was commissioned at the end of 2009

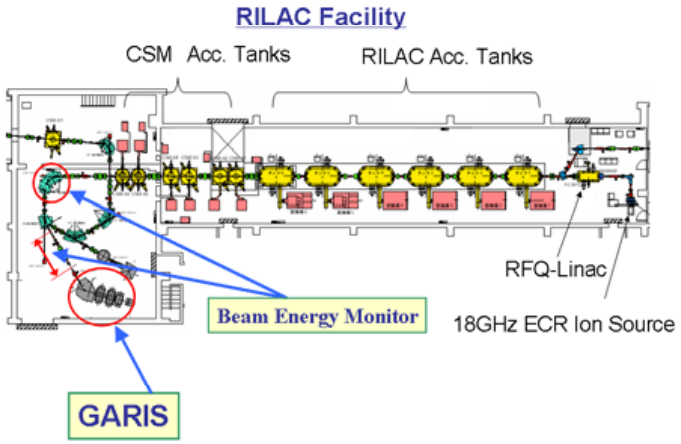
Beam accumulation in the SR2 will be started at the end of Feb. 2010

SCRIT device will be installed in 2010

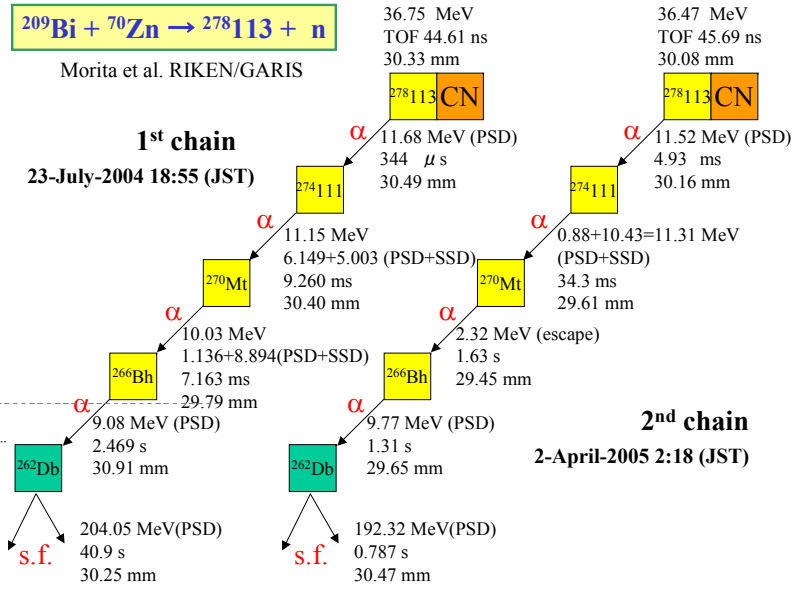
SHE

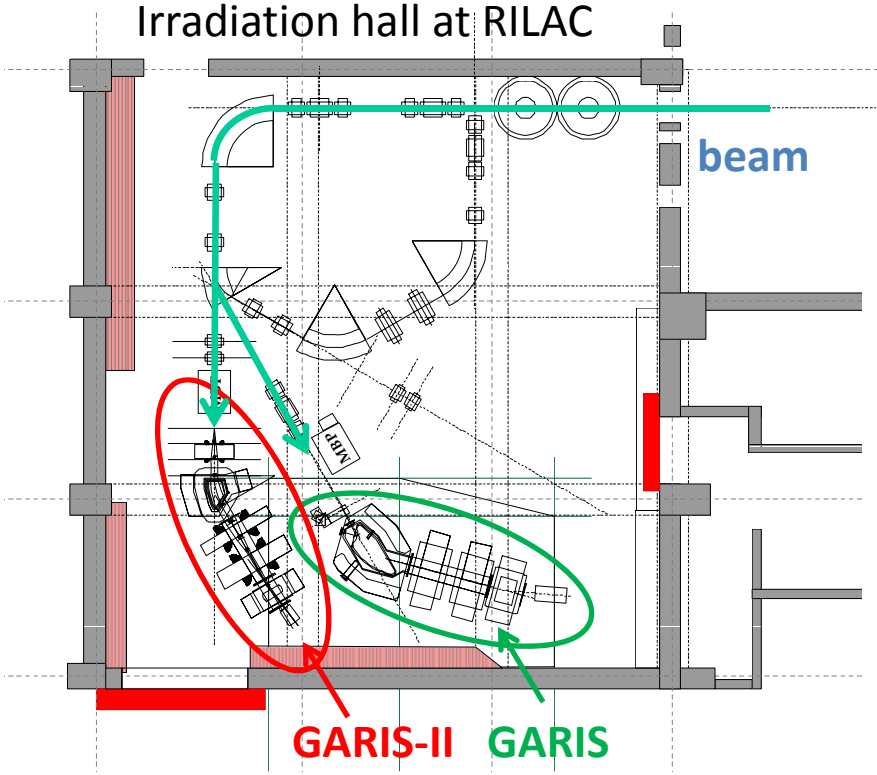
GARIS (gas-filled recoil ion separator)

Morita



113th elements





Grant-in-Aid

Cm-248 target (7mg 1M$)

new spectrometer GARIS-II

under construction

More MT in 2010 and later

new RILAC-II dedicated for RIBF

Experiments planned with use of GARIS, GARIS-II

Search for the heaviest nuclei (GARIS)

^{205}Tl(^{70}Zn, *n*)^{274}Rg(111)→ confirmation of ^{278}113 production
^{208}Pb(^{76}Ge, *n*)^{283}114 → highest Z with cold-fusion reaction
^{248}Cm(^{54}Cr, 3*n*)^{299}120 → highest Z never reported so far

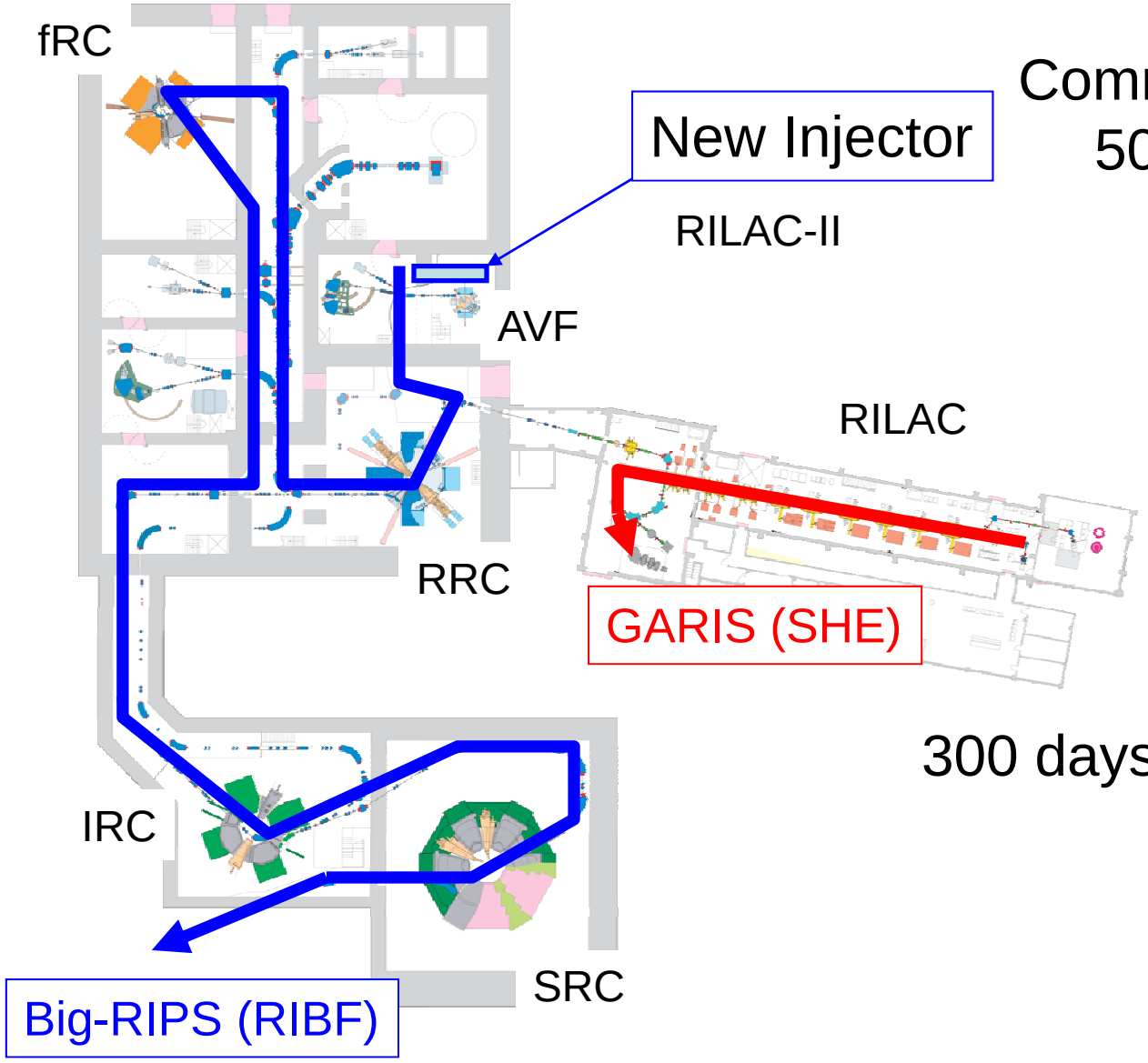
Spectroscopy of the heaviest nuclei (GARIS, GARIS-II)

^{208}Pb(^{50}Ti, *n*)^{257}Rf
^{209}Bi(^{48}Ca, 2*n*)^{255g,m}Lr

Chemistry of the heaviest elements (GARIS, GARIS-II).

							Atomic Number
^{248}Cm	+	^{18}O	→	^{261}Rf	+	5*n*	104
^{248}Cm	+	^{19}F	→	^{262}Db	+	5*n*	105
^{248}Cm	+	^{22}Ne	→	^{265}Sg	+	5*n*	106
^{248}Cm	+	^{23}Na	→	^{266}Bh	+	5*n*	107
^{248}Cm	+	^{26}Mg	→	^{270}Hs	+	4*n*	108
^{248}Cm	+	^{27}Al	→	^{271}Mt	+	4*n*	109
^{238}U	+	^{48}Ca	→	^{283}112	+	3*n*	112

Independent operation of RIBF and SHE research

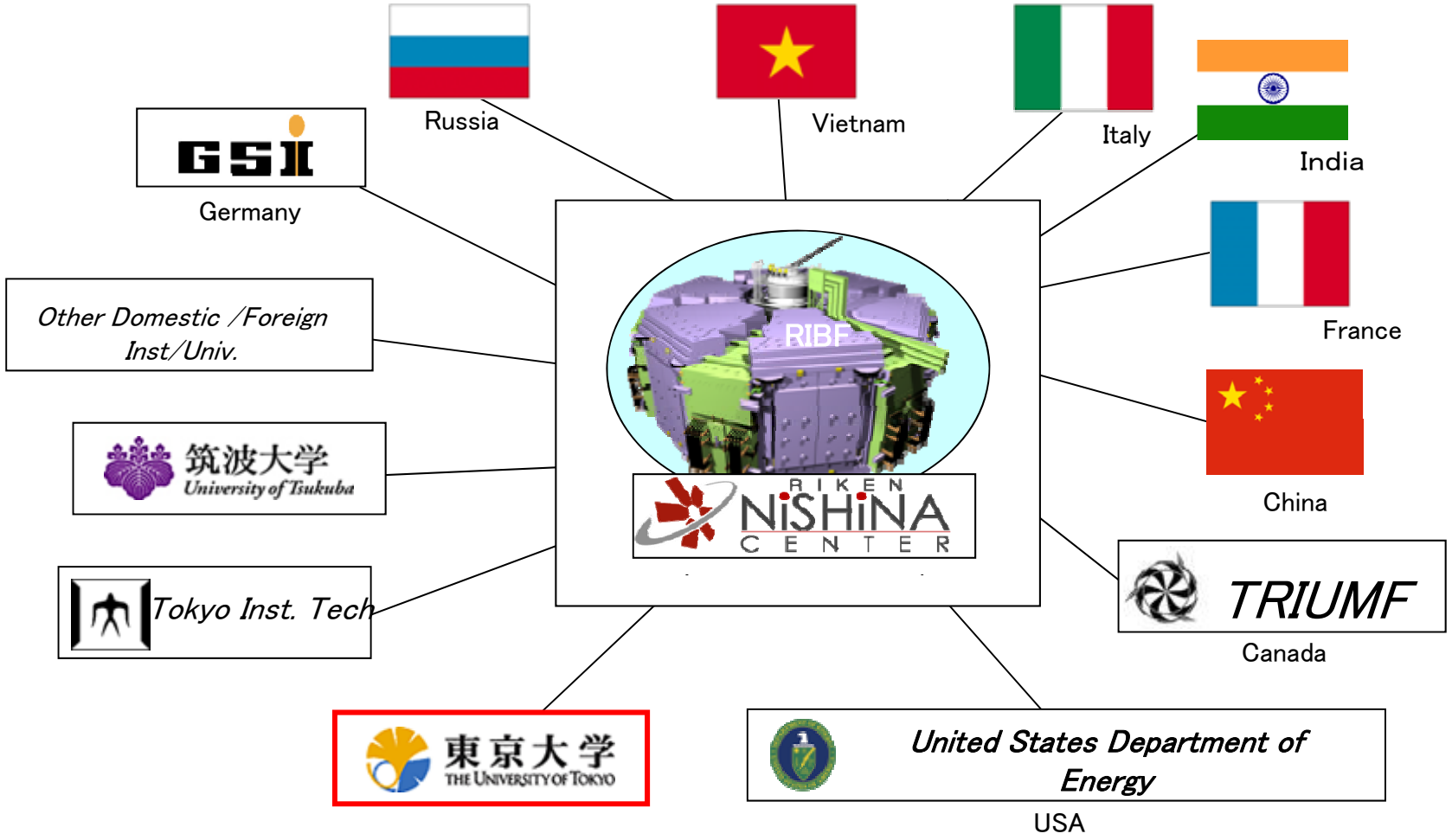


Commissioning in 2010
50 - 100 pnA of U
for RIBF

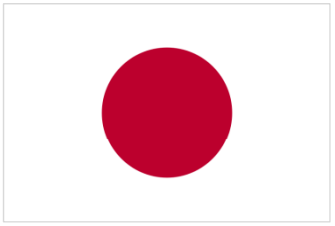
300 days per year for SHE

International Collaboration

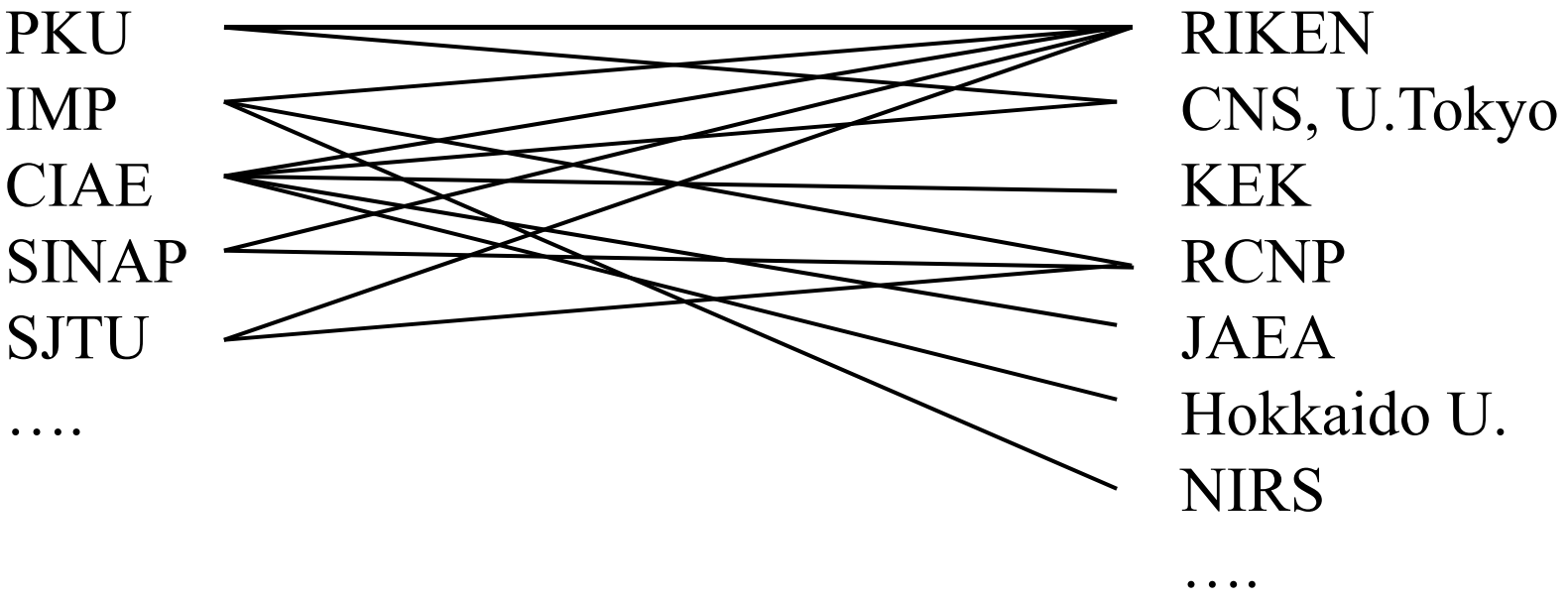
Promotion of Nuclear Physics Programs Under Domestic/International Collaborations



Co-organization of PAC with CNS, Univ. of Tokyo
External investment by CNS: SHARAQ, CRIB



Institute/University Based



Council for China-Japan Research Collaboration on Nuclear Physics

Established since 2006
signed by Chinese Nuclear Physics Society and RIKEN Nishina Center
To promote and expand collaborative relations in the field of nuclear physics
Council meeting has been organized every year since 2007.

Peking University

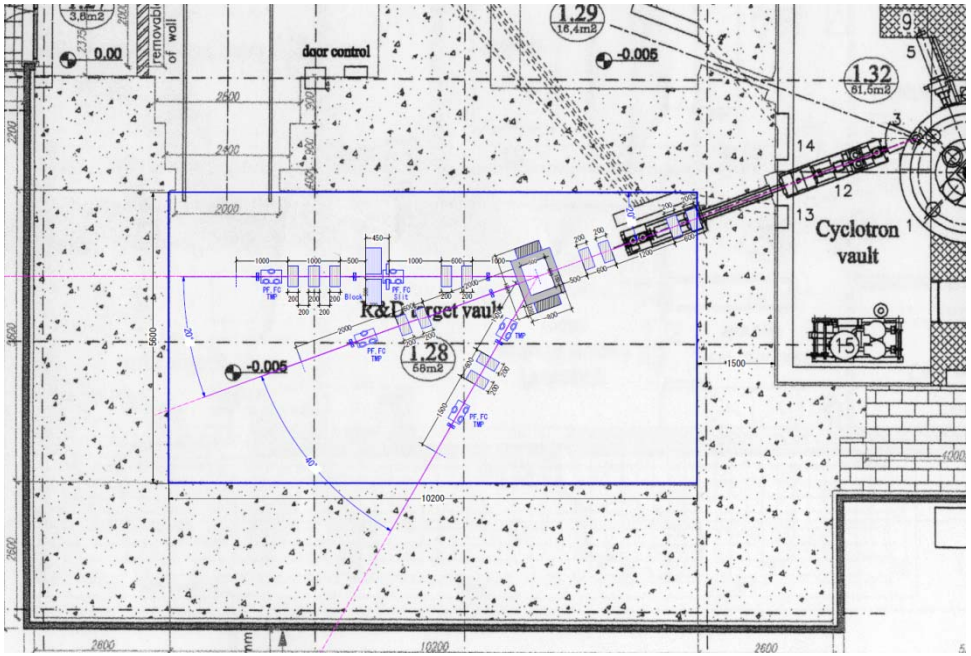
International Summer School on Subatomic Physics
for graduate students in China, other Asian countries
initiated by PKU and RIKEN since 1999
distinguished lecturers in China, EU, US, Japan

Nishina School
Education programs since 2007
(1) undergraduate students
Training for instrumentations
(2) graduate students
Long term stay for thesis projects
as International Program Associate Fellow

Opening Ceremony, Oct.-7, 2008


Opening Ceremony, Sep.-29, 2009

Vietnam Atomic Energy Commission
Institute of Physics, Vietnam Academy of Science and Technology



Hospital 108 project
VAEC, U. Hanoi
Hanoi U of Tech
IOP

Experiment area was designed under collaboration of RIKEN, CNS

Summary

BigRIPS: The new spectrometers ZDS/SHARAQ are going on.
SAMURAI is now under construction
SLOWRI, Rare RI-ring are to be funded
SCRIT: will start to have e-RI scattering in 2011
RIPS /CRIB: give unique opportunities of low/intermediate energy and light RIBs for structure and astrophysics
IRC-to-RIPS BT line is to be funded
SHE: GARIS-II and new linac RILAC-II will give more opportunities.

International/Domestic Collaboration; for examples,
to have a joint operation of RIBF with CNS, U. Tokyo
to have country-based cooperation with China
to have a joint education program with PKU, China
to have research cooperation with IOP, Vietnam