RIB Facilities in Japan

Tohru Motobayashi
RIKEN Nishina Center

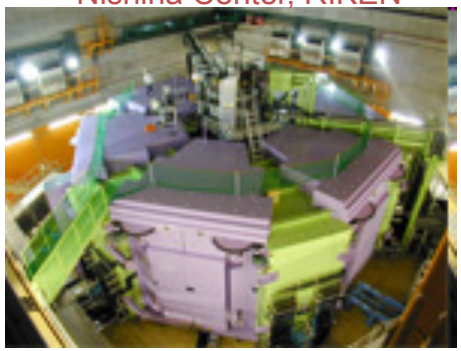
KEK – TRIAC and technology transfers
KISS – new project with multi-nucleon transfers
CNS, U. Tokyo – CRIB and a new low energy beam line (OEDO)
RCNP, Osaka Univ. – RI beams by fragmentation, direct reactions
RIKEN RIBF – current status and its upgrade programs under discussion
HIMAC – its use for intermediate-energy RI beams

RIKEN NiSHiNA CENTER

Large

Accelerator facilities for nuclear physics

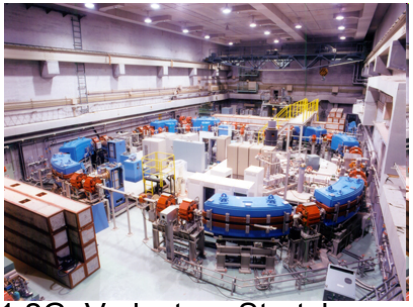
Nishina Center, RIKEN



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 (theray)

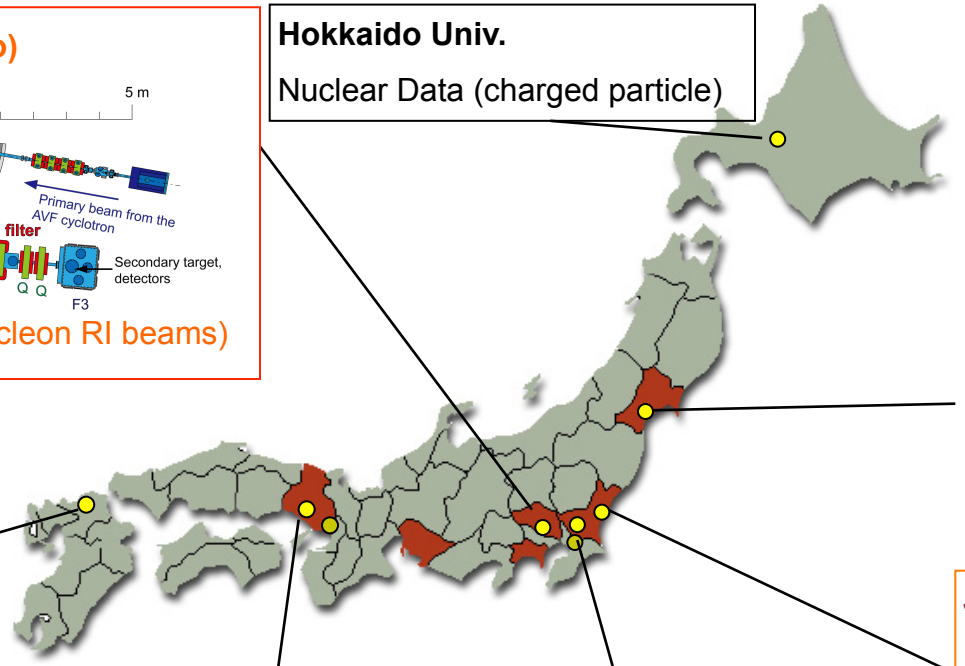
J-PARC, KEK/JAEA)

30GeV Proton Synchrotron

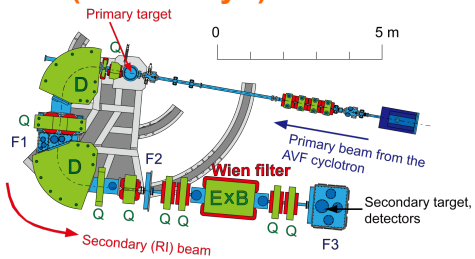
π, K, μ, n, (ν)

Small

Accelerator facilities for nuclear physics



CNS (Univ. Tokyo)



CRIB (~5 MeV/nucleon RI beams)

RI beam

Hokkaido Univ.

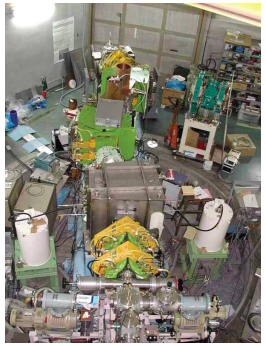
Nuclear Data (charged particle)

CYRIC (Tohoku Univ.)

Cyclotron (p 90 MeV)

light ion

Kyushu Univ.

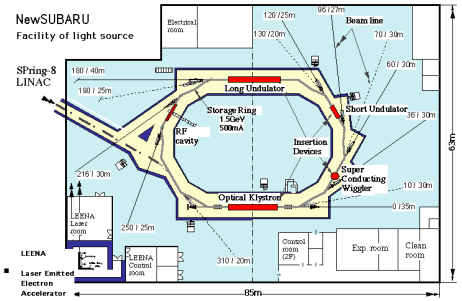


Tandem (~9 MV)

p, d, C, O, ..

- Jan. 2015

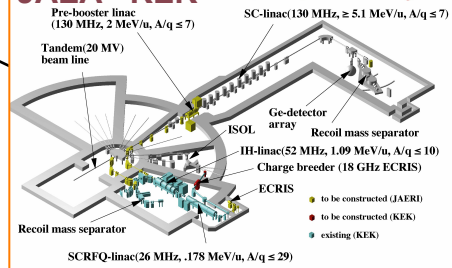
NEW SUBARU



SOR (2-10 MeV photons)

photon (inverse Compton)

JAEA - KEK



TRIAC (RI beams) → Tandem

heavy ion

- 201x

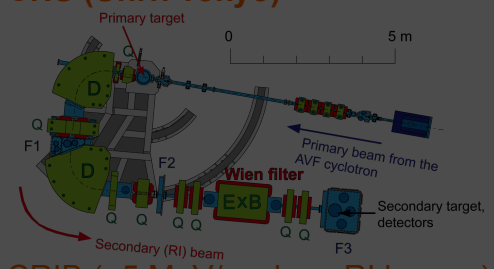
Tsukuba Univ.

Tandem → Vdg. (earthquake)

KEK – TRIAC and technology transfers

KISS – new project with multi-nucleon transfers

CNS (Univ. Tokyo)



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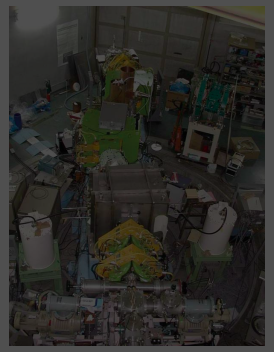
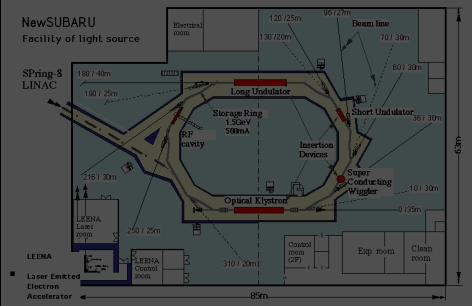


Tandem (~9 MV)

p, d, C, O, ..

- Jan. 2015

NEW SUBARU



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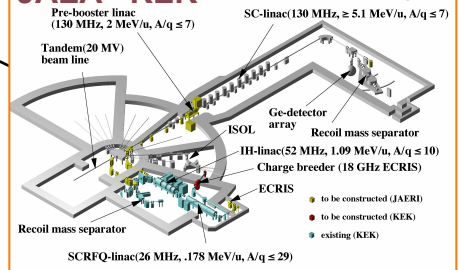


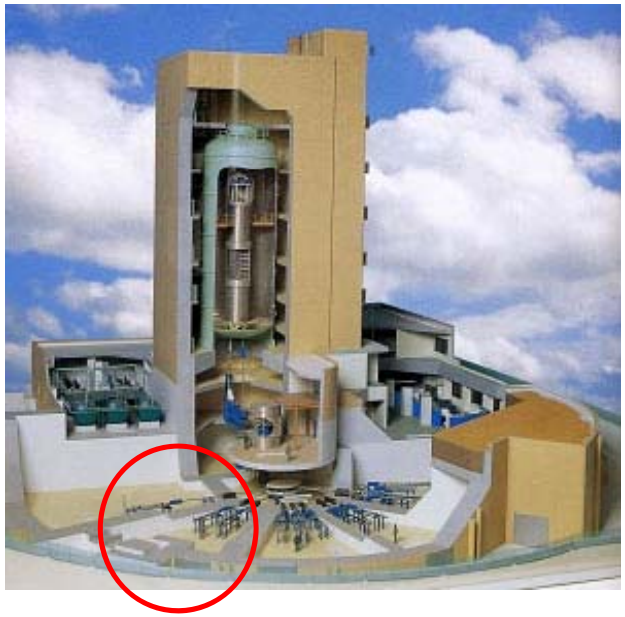
TRIAC (RI beams) - 2011

heavy ions

Tsukuba Univ.

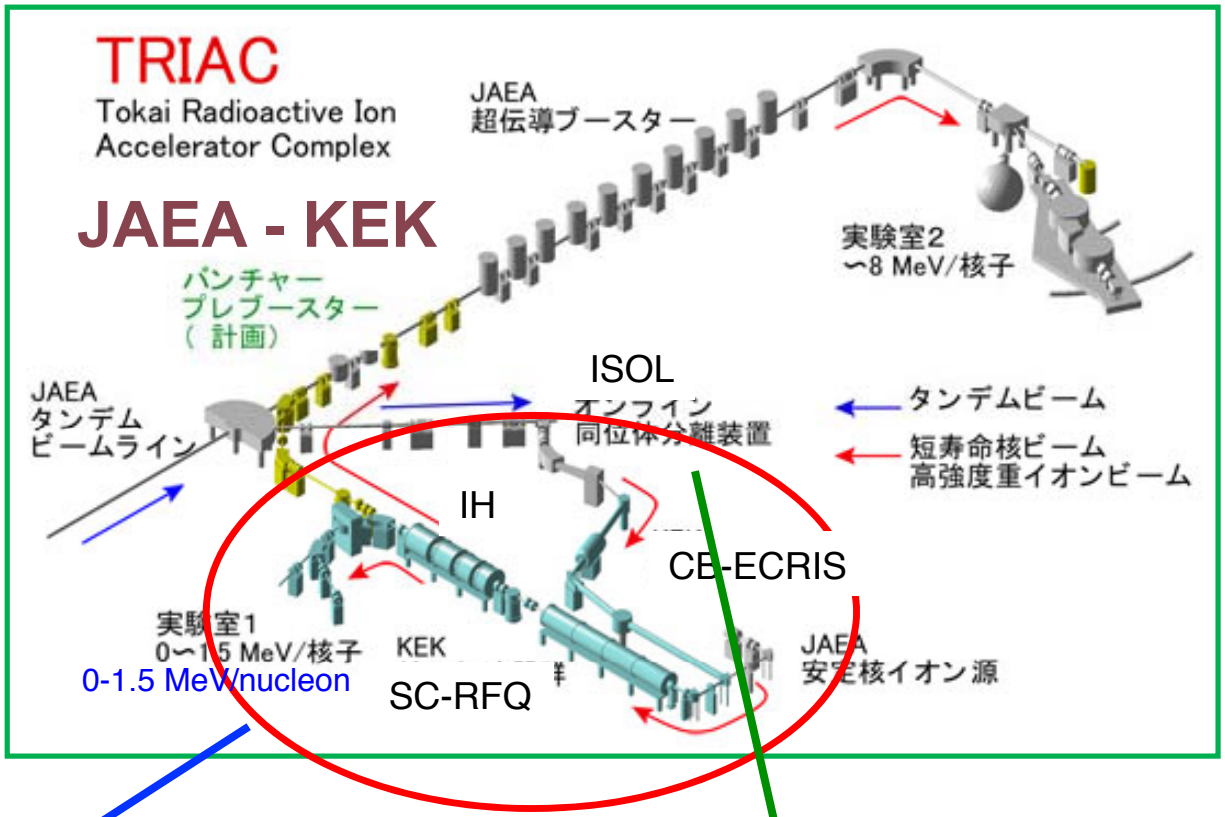
Tandem → Vdg. (earthquake)

photon (inverse Compton)



TRIAC (Tokai R.I. Acc. Complex)

Tandem beam → **ISOL** → CB-ECRIS → 2 linacs



JAEA 20 MV Tandem

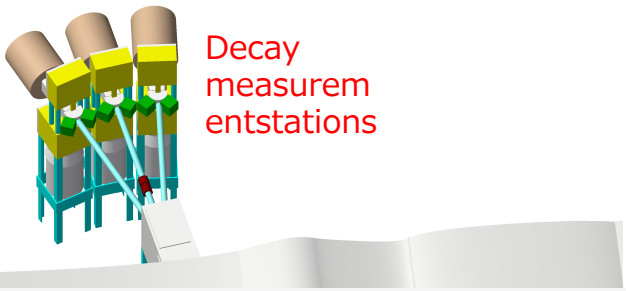
0-1.5 MeV/nucleon

2011

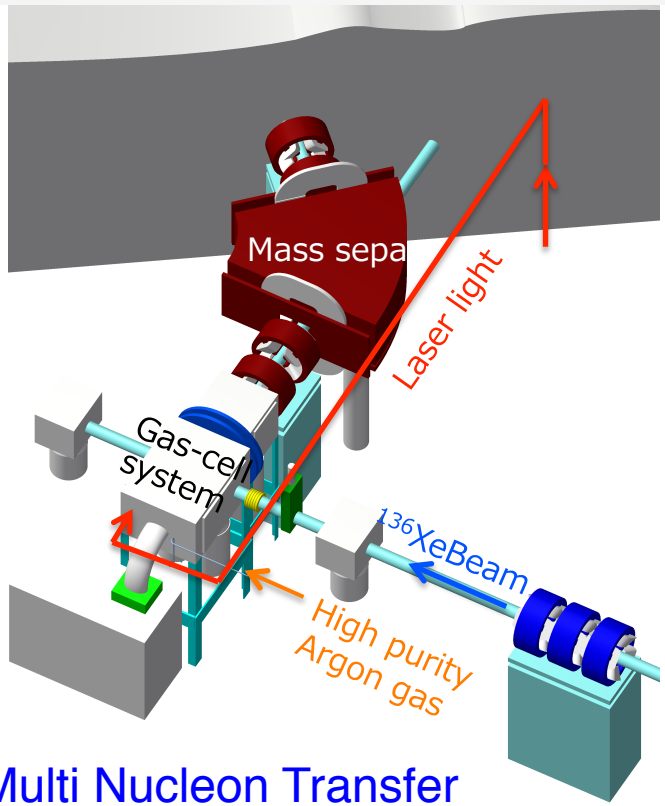
DIAC*, **Korea**
*Daejon Ion Accelerator Complex

e^- fission ion source
In SCRIT at RIKEN RIBF

KEK started KISS at RIKEN RIBF.

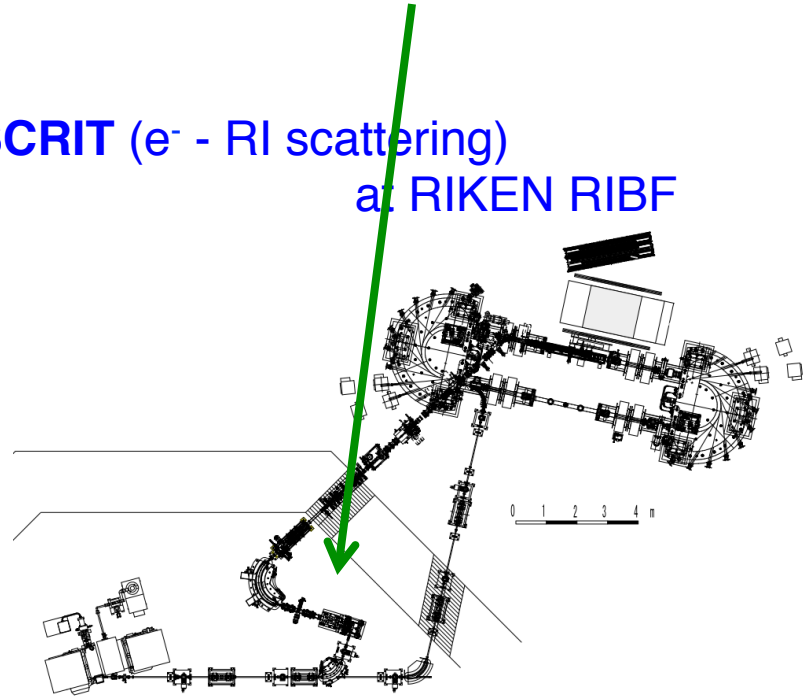


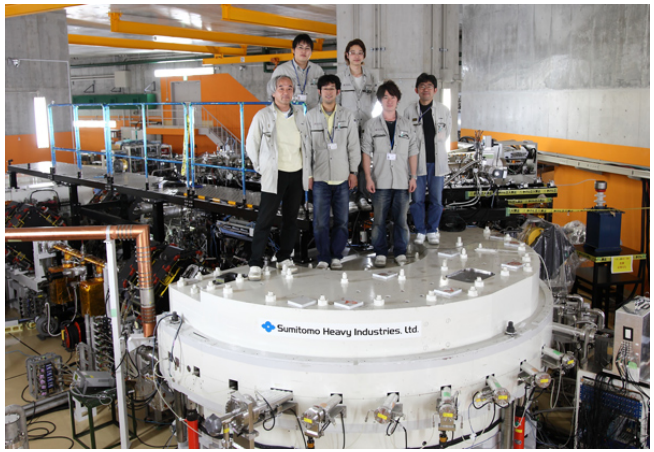
(selective) laser ionization of MNT* products



* Multi Nucleon Transfer
by RI beams (in future)

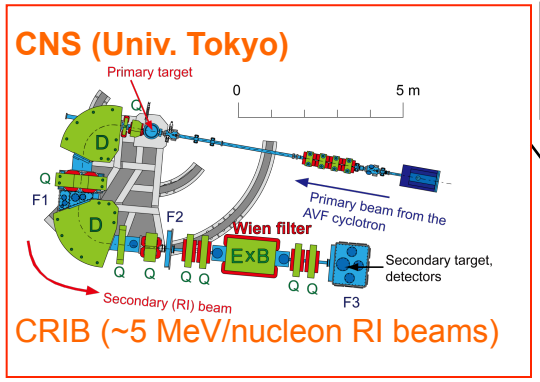
SCRIT (e^- - RI scattering)
at RIKEN RIBF





M. Wakasugi *et al.*, NIMB 317 (2013) 668

CNS, U. Tokyo – CRIB and a new low energy beam line (OEDO*)
+ recent highlights



RI beam

Hokkaido Univ.

Nuclear Data (charged particle)

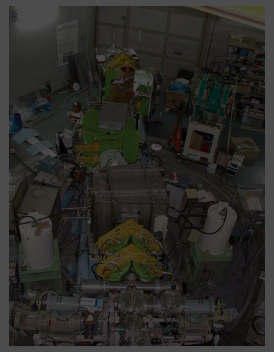
CYRIC (Tohoku Univ.)

Cyclotron (p 90 MeV)

light ions

* Optimized Energy Degrading Optics for RI beam

Kyushu Univ.

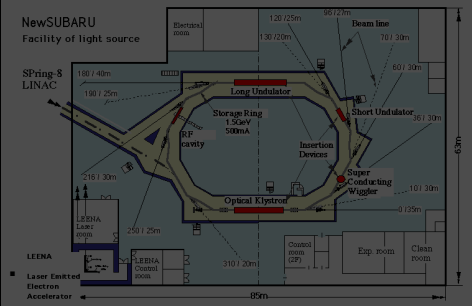


Tandem (~9 MV)

p, d, C, O, ..

- Jan. 2015

NEW SUBARU



SOR (2-10 MeV photons)

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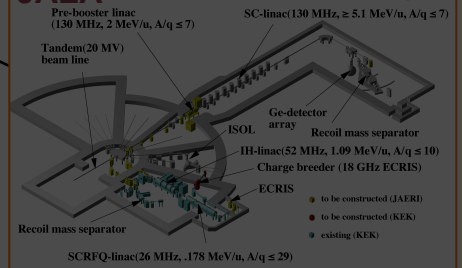
Tandem → Vdg. (earthquake)

JAEA



TRIAC (RI beams) → Tandem

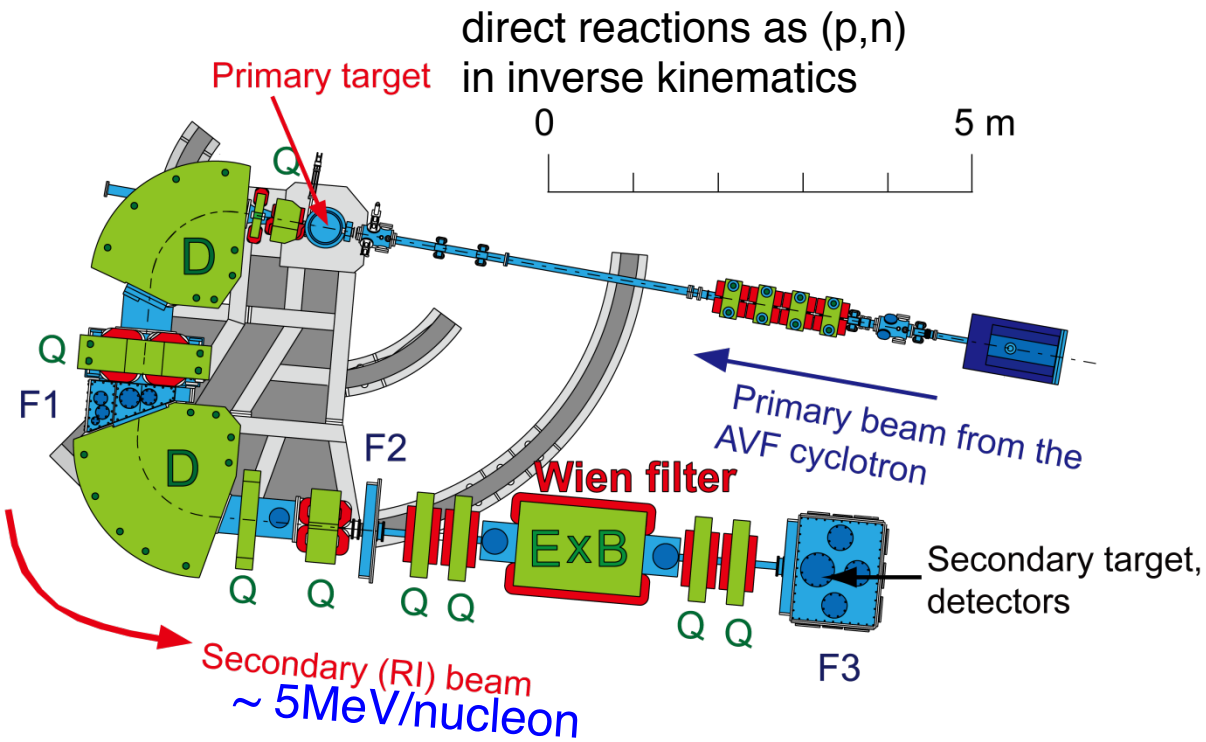
heavy ions

- 201x

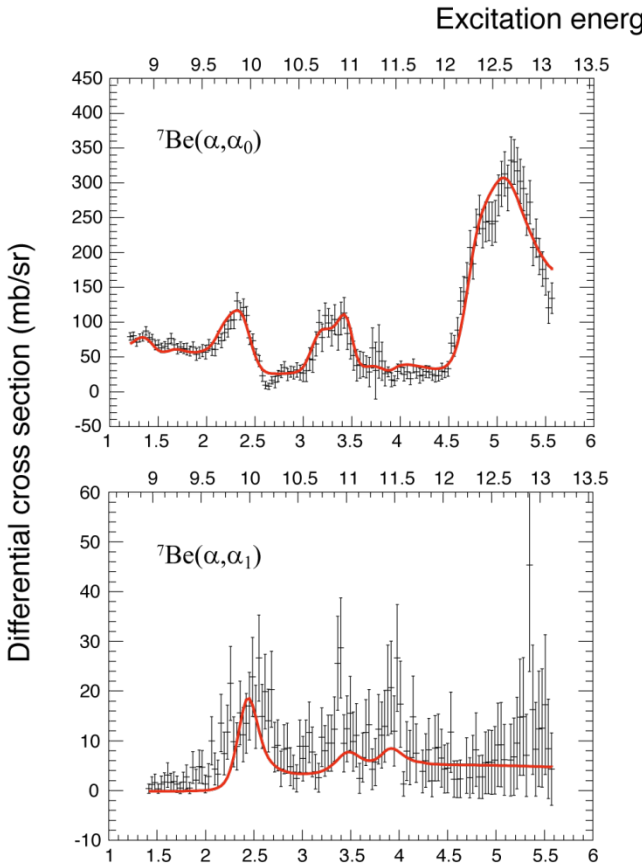
CRIB* uses ~10 MeV/nucleon beams from the AVF injector of RIKEN RIBF.

* CNS Radio-Isotope Beam separator

operated by **CNS (Univ. of Tokyo)**, located at RIBF (RIKEN Nishina Center).



^{7}Be(α,γ) of astrophysical interest

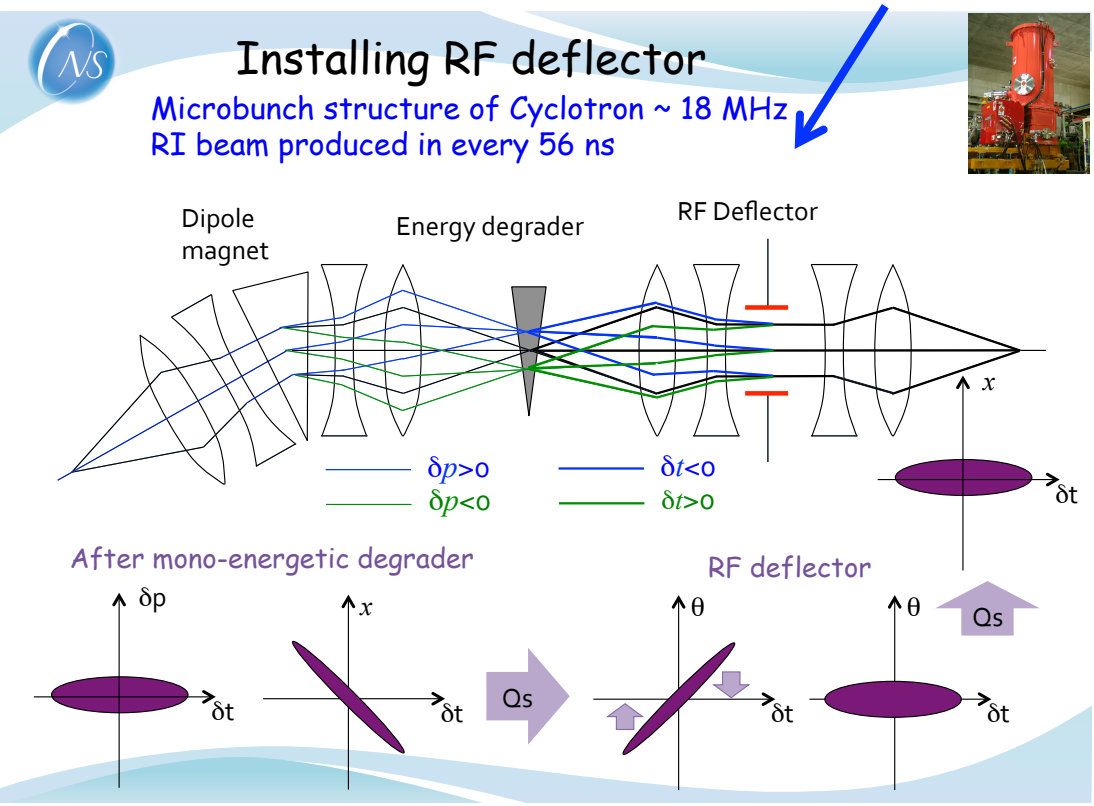


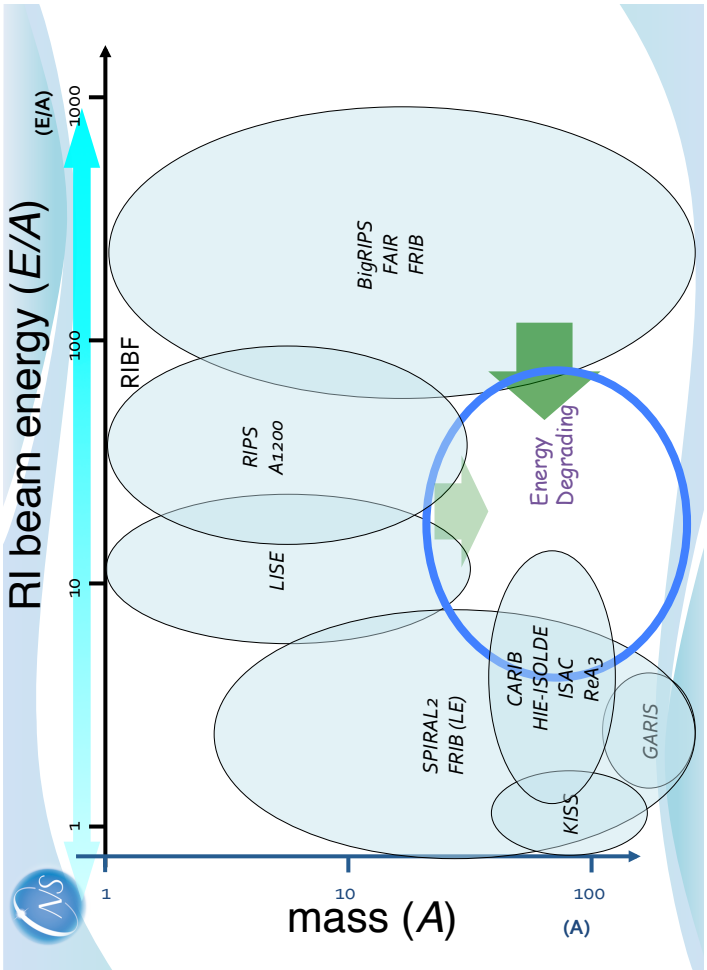
H. Yamaguchi *et al.*, PRC (2013)

Courtesy of Hidetoshi Yamaguchi

OEDO reduces the beam-spot size using the arrival-time difference
by an RF deflector (synchronized with the cyclotron RF)
even with a large energy-loss in the degrader (*e.g.* 200 → 20 MeV/nucleon)
to realize (versatile) fragmentation-based degraded beams of tens MeV/nucleon

bunched beam from cyclotron



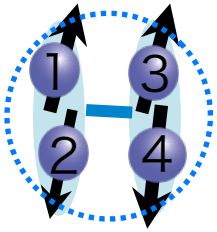


Courtesy of Susumu Shimoura

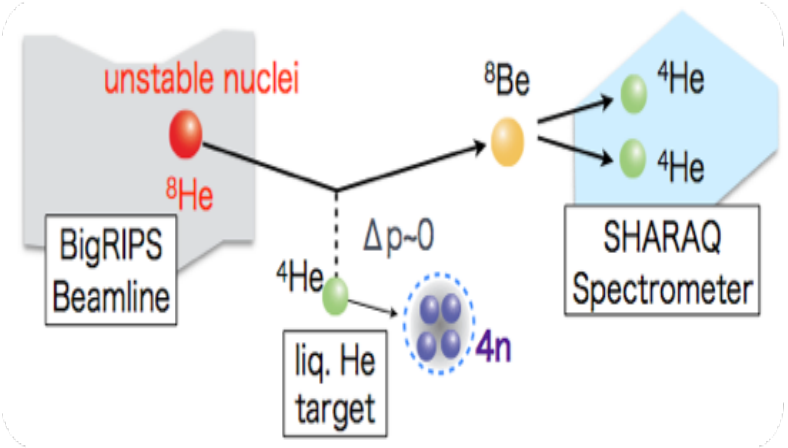
CNS built SHARAQ spectrometer at RIKEN RIBF.

(^{8}He,^{8}Be) – double charge-exchange -- on ^{4}He to study 4-neutron unbound states

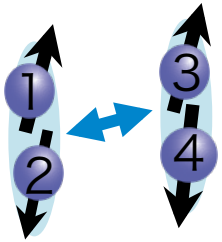
Search for Tetra-neutron resonance
In normal kinematics (missing mass measurement by detecting ^{8}Be)



4n resonance (g.s.)



4n scattering state



RCNP, Osaka Univ. – RI beams by fragmentation, direct reactions

K2600 **RIBF**

RI beam

Research Center for Electron Photon Science, Tohoku University (**ELPH**)

1.2GeV electron Stretcher

e^-

SPring-8 (RIKEN/JASRI)

8GeV e - Synchrotron

photon

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K400 Cyclotron

light ion / light heavy ion

HIMAC at National Institute of Radiological Sciences

800MeV/A Synchrotron

heavy ion

J-PARC, KEK/JAEA)

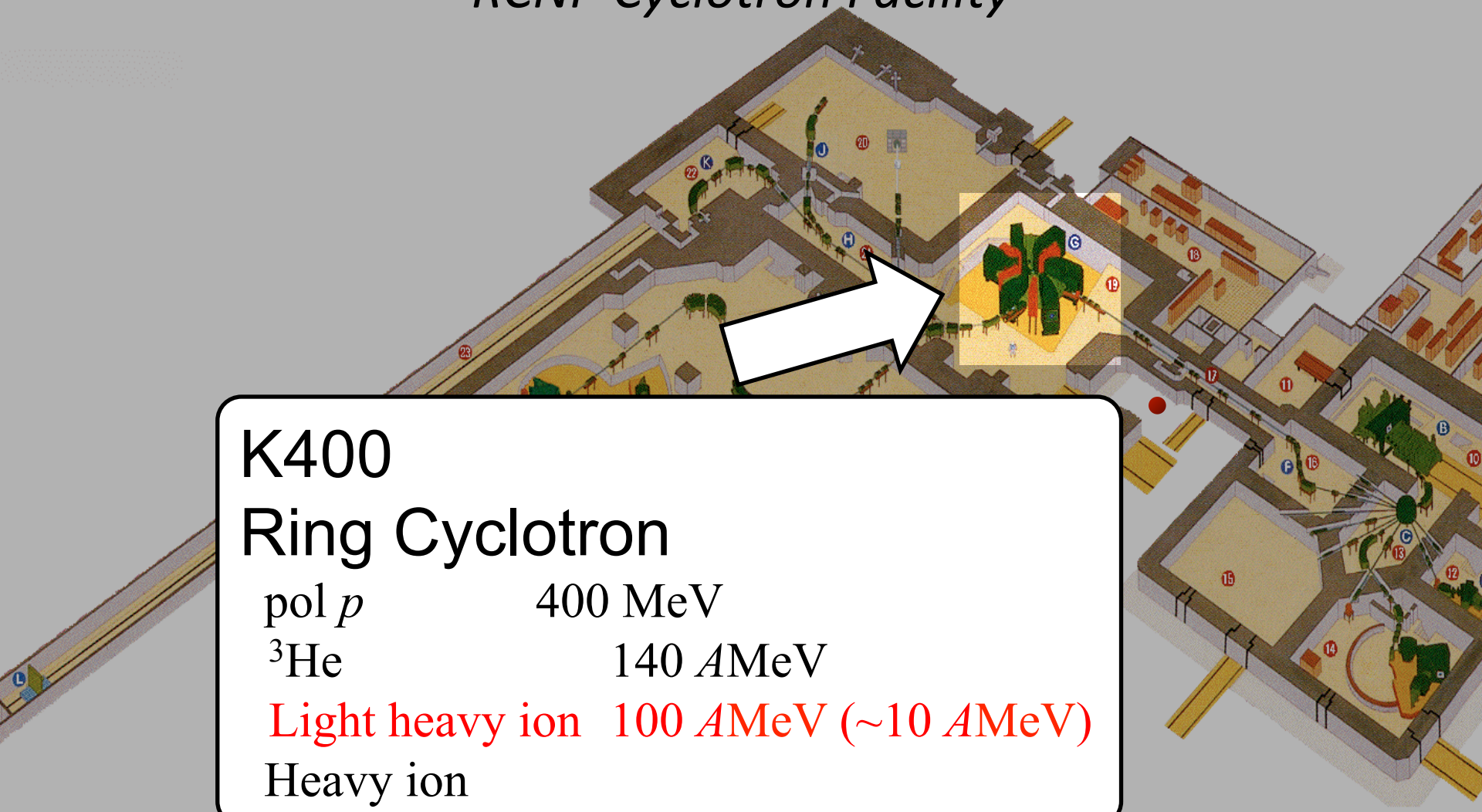
30GeV Proton Synchrotron

π, K, μ, n, (ν)

RCNP Cyclotron Facility

Courtesy of Nori Aoi

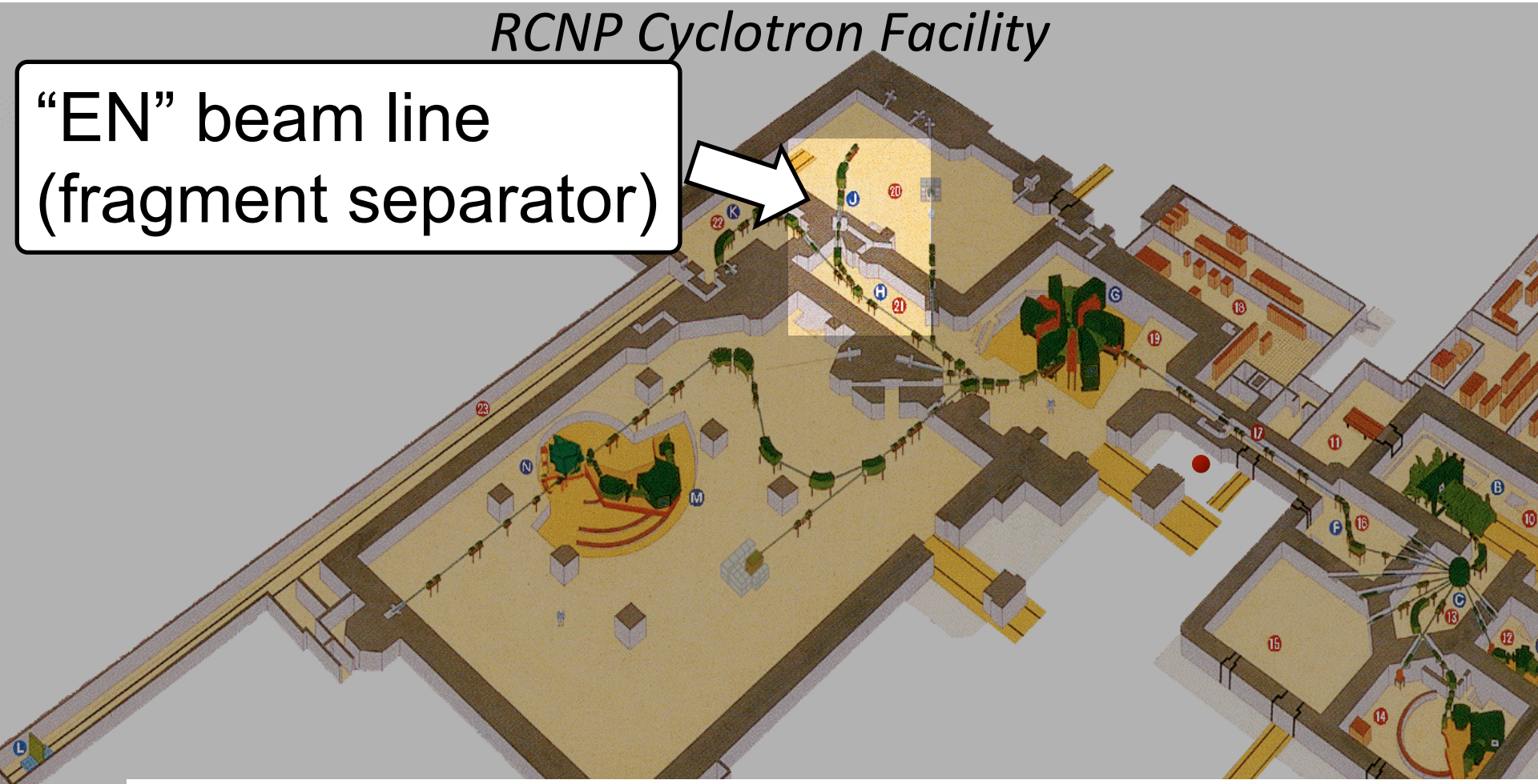
RCNP Cyclotron Facility



K400
Ring Cyclotron

pol *p*	400 MeV
^{3}He	140 *A*MeV
Light heavy ion	100 *A*MeV (~10 *A*MeV)
Heavy ion	

RCNP Cyclotron Facility



e.g.

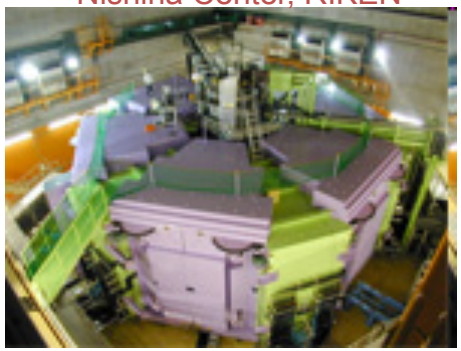
5.5 MeV/nucleon ^{17}N beam by ^{9}Be(^{18}O,^{17}N) at 9.3 MeV/nucleon ← bypass of AVF

high-spin (23/2^{+})isomer in ^{135}La ← ^{17}N+^{124}Sn fusion

A. Odahara, reported in ARIS2014

RIKEN RIBF – current status and its upgrade programs under discussion

Nishina Center, RIKEN



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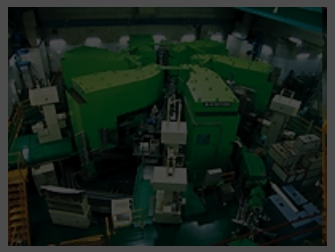

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J-PARC, KEK/JAEA)

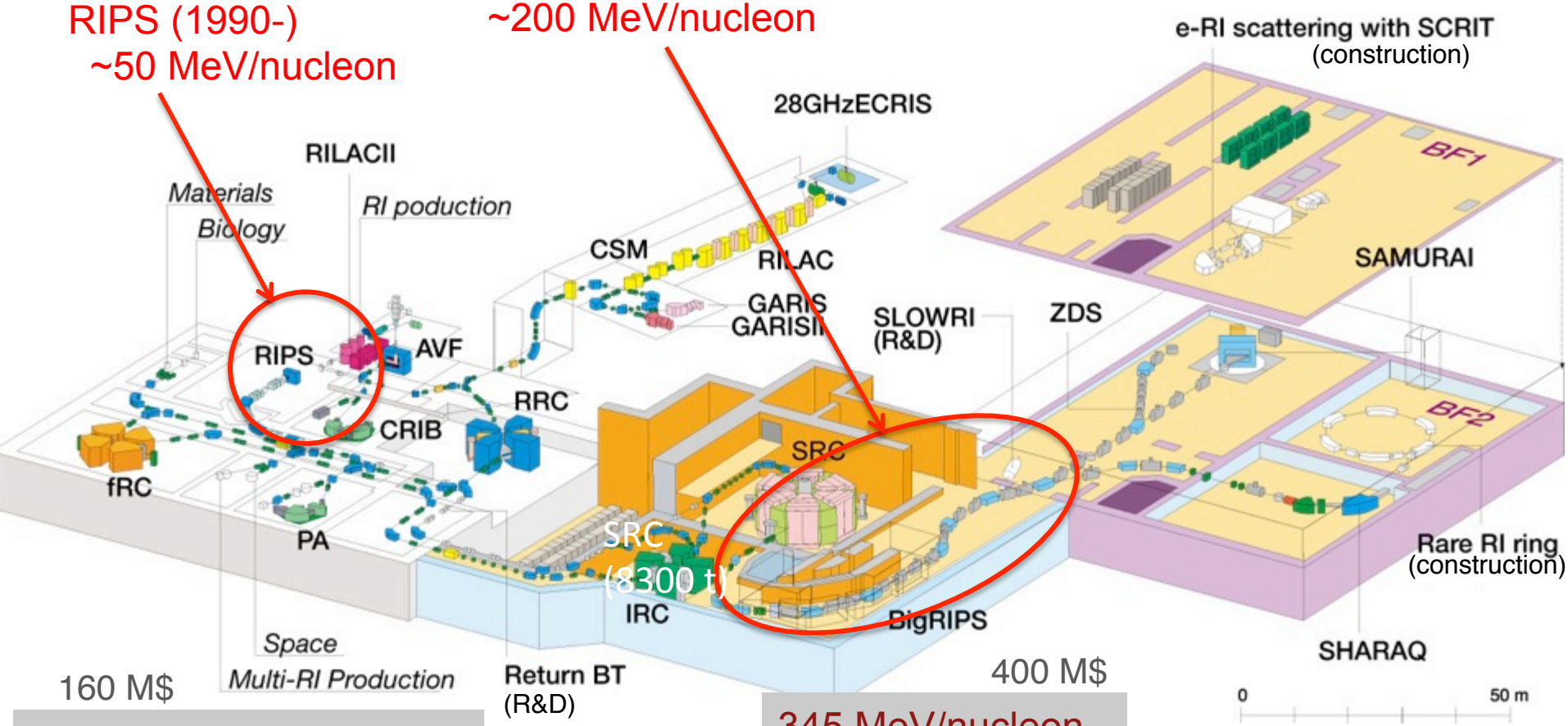
30GeV Proton Synchrotron

π, K, μ, n, (ν)

RIBF – a new generation RIB facility in operation
with world highest capability of **providing RI beams** in coming years!

RIPS (1990-)
~50 MeV/nucleon

BigRIPS (2007-)
~200 MeV/nucleon



160 M$

135 MeV/nucleon
for light nuclei (1986-)

400 M$

345 MeV/nucleon
up to U (2006-)

experimental
equipment

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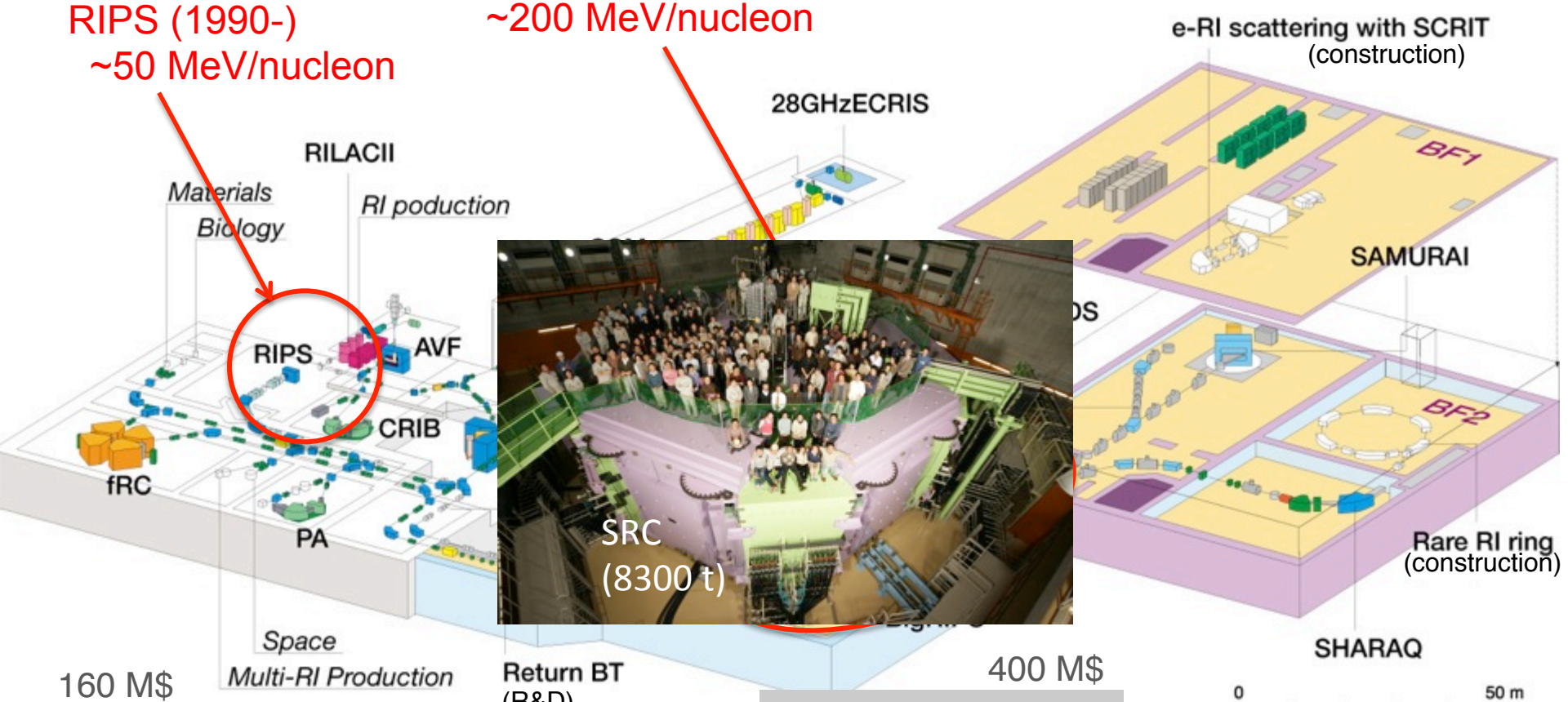

160 M$

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for light nuclei (1986-)

400 M$

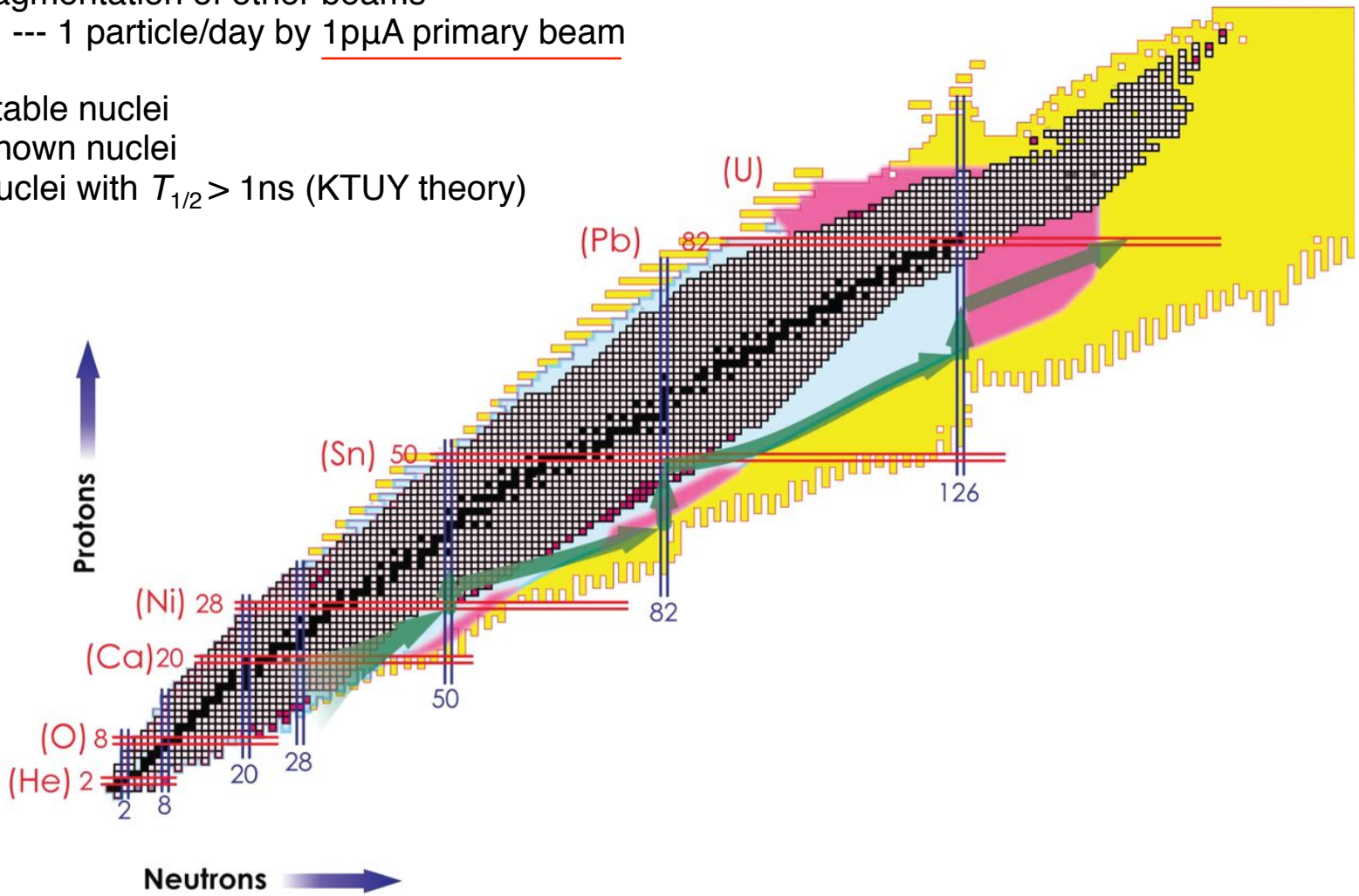
345 MeV/nucleon
up to U (2006-)

experimental
equipment

Nuclear chart potentially covered by RIBF

- fission + fragmentation of ^{238}U beams
- fragmentation of other beams
  --- 1 particle/day by 1pμA primary beam

- Stable nuclei
- Known nuclei
- Nuclei with $T_{1/2}$ > 1ns (KTUY theory)

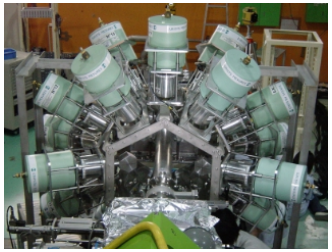


Motobayashi T , and Sakurai H Prog. Theor. Exp. Phys. 2012;2012:03C001

PTEP
Progress of Theoretical and Experimental Physics

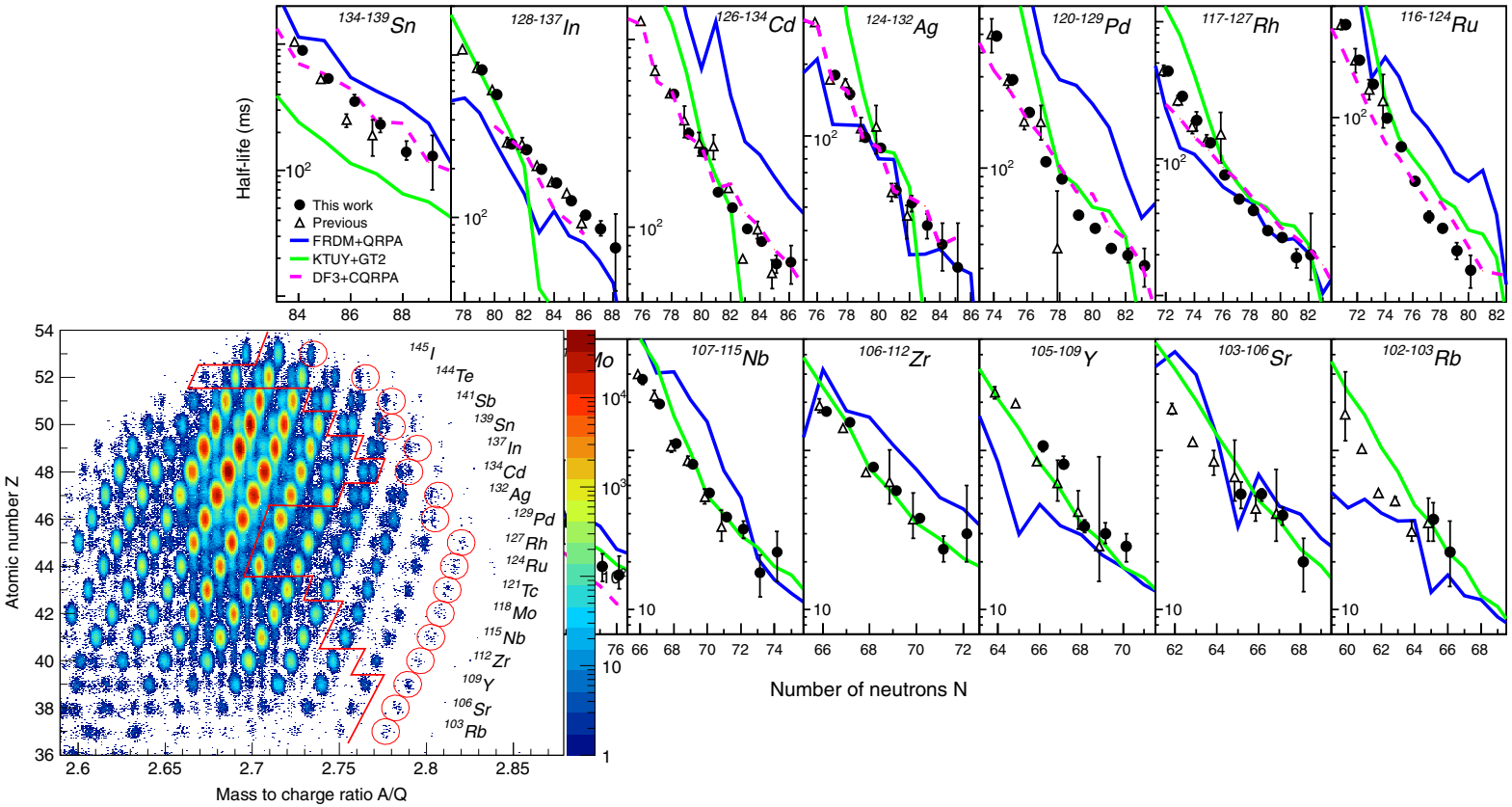
110 (40 new) half lives measured

EURICA + WASABI



12 EUROBALL clusters at RIKEN

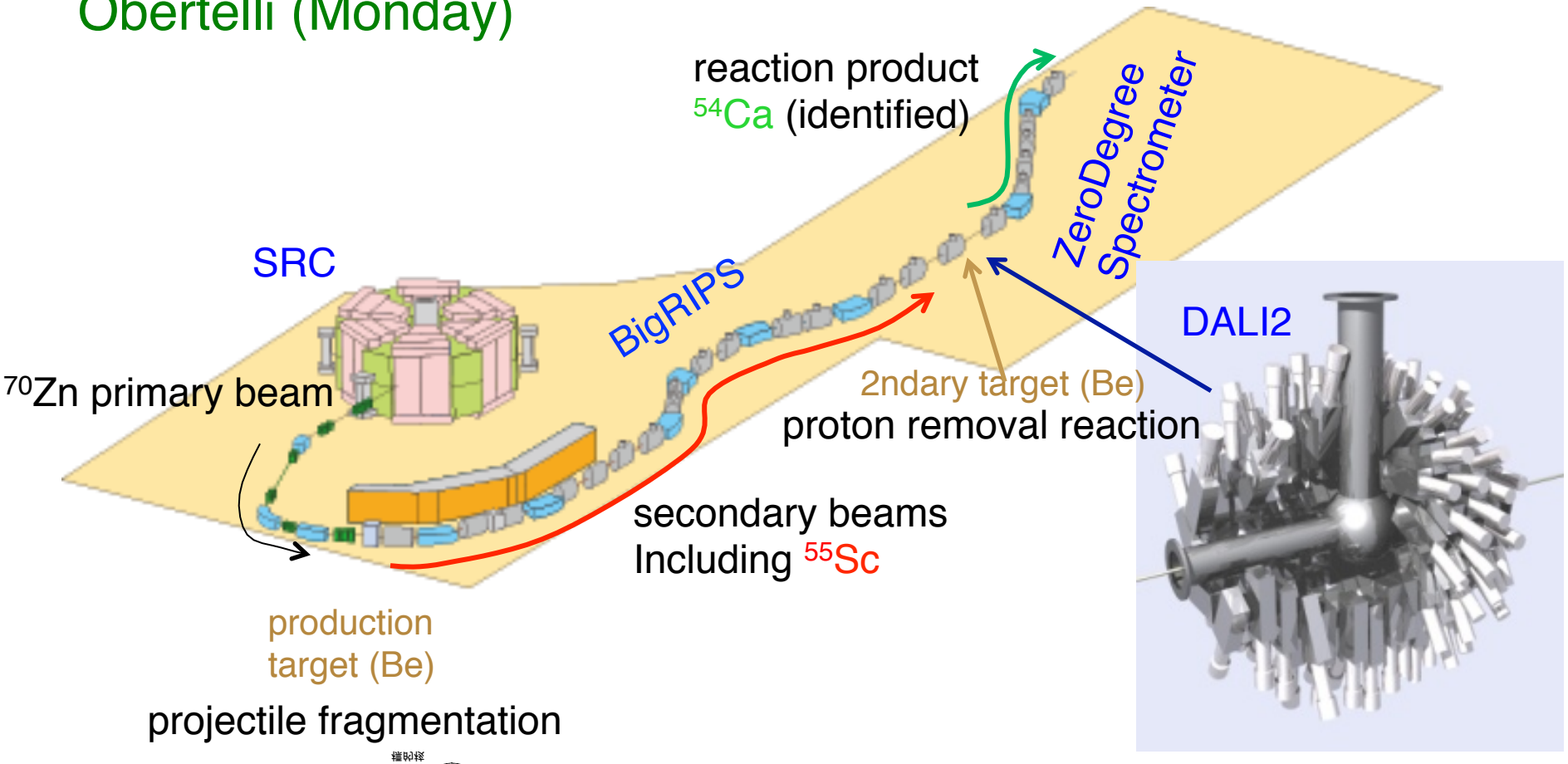
many r-process nuclei



Lorusso, Nishimura, *et al.*, PRL 114, 192501 (2015)

Low-lying states measured by deexcitation γ-rays with DALI2
direct reactions (inelastic, nucleon removal, …)

Obertelli (Monday)



γ-ray measurement
186 NaI(Tl) schintillators
with Doppler-shift correction

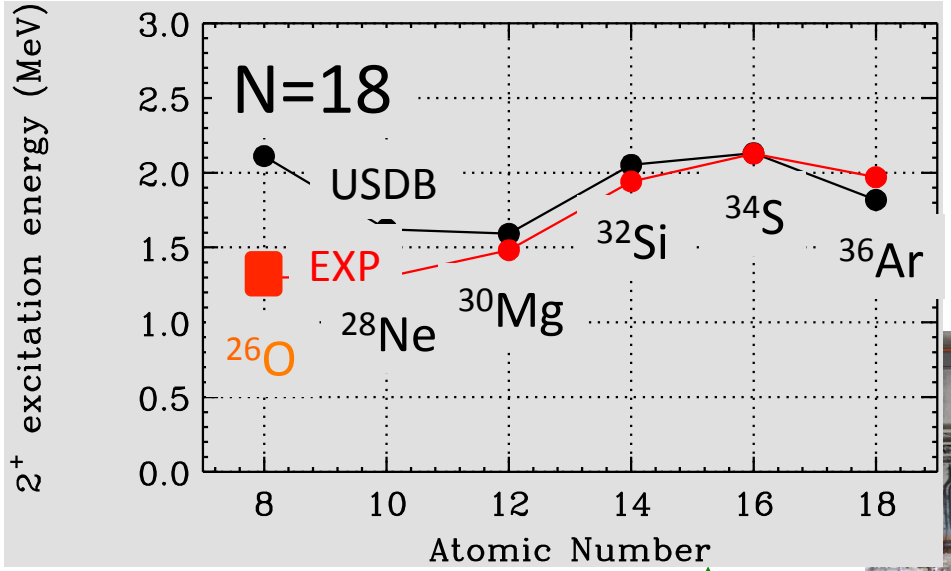
$^{27}F+C \rightarrow {}^{26}O^{*} \rightarrow {}^{24}O+2n$ ----- one neutron removal (knockout)

Being analyzed.

$E_r(^{26}O_{gs}) \lesssim 50$keV (preliminary)

A lower limit will also be obtained.

(unbound) states in ^{26}O



Ground state

5 times higher statistics

→better determination of energy

Excited state at ~1.3MeV

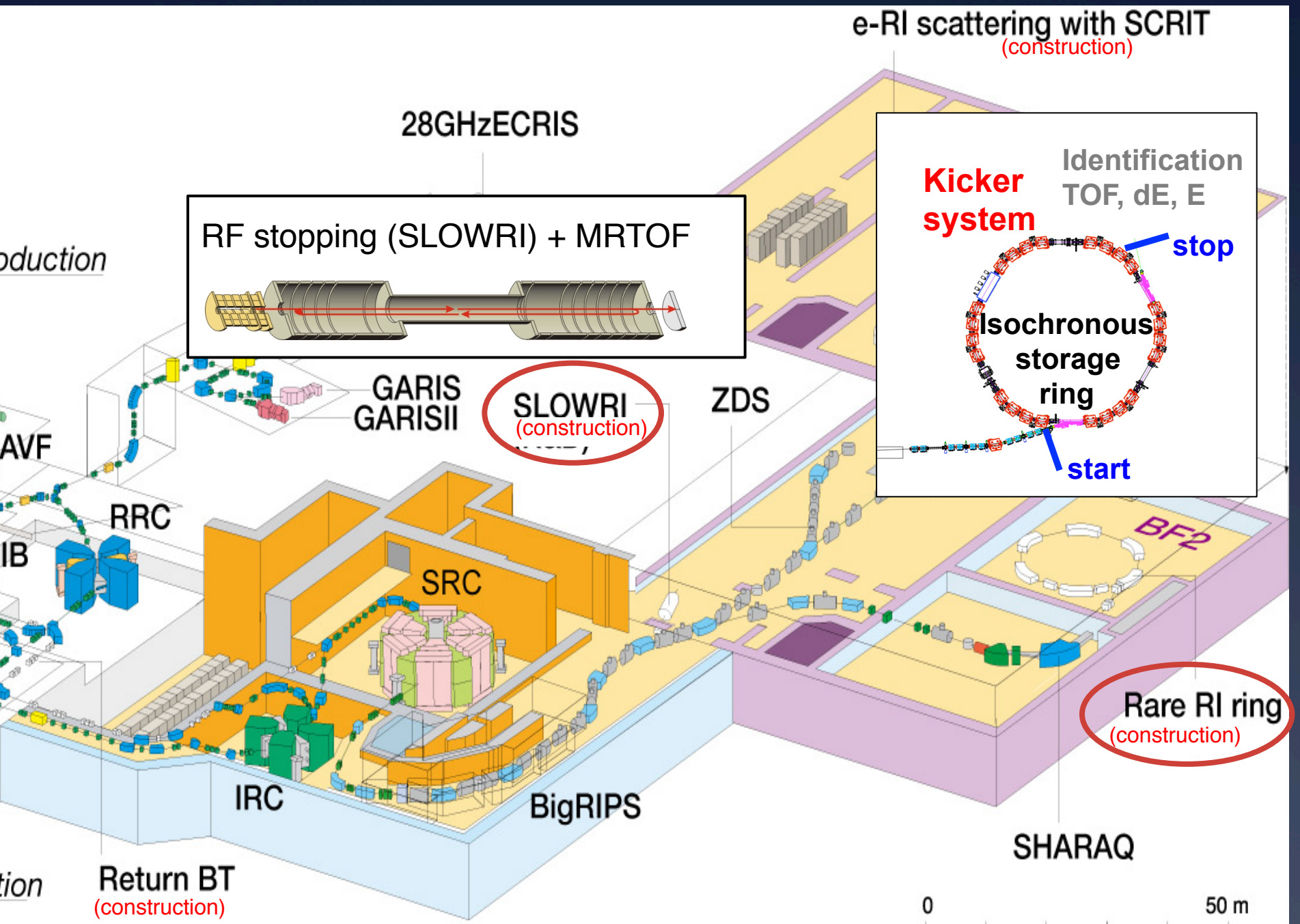
First observation

Most probably 2^+

No peak at ~4.2MeV

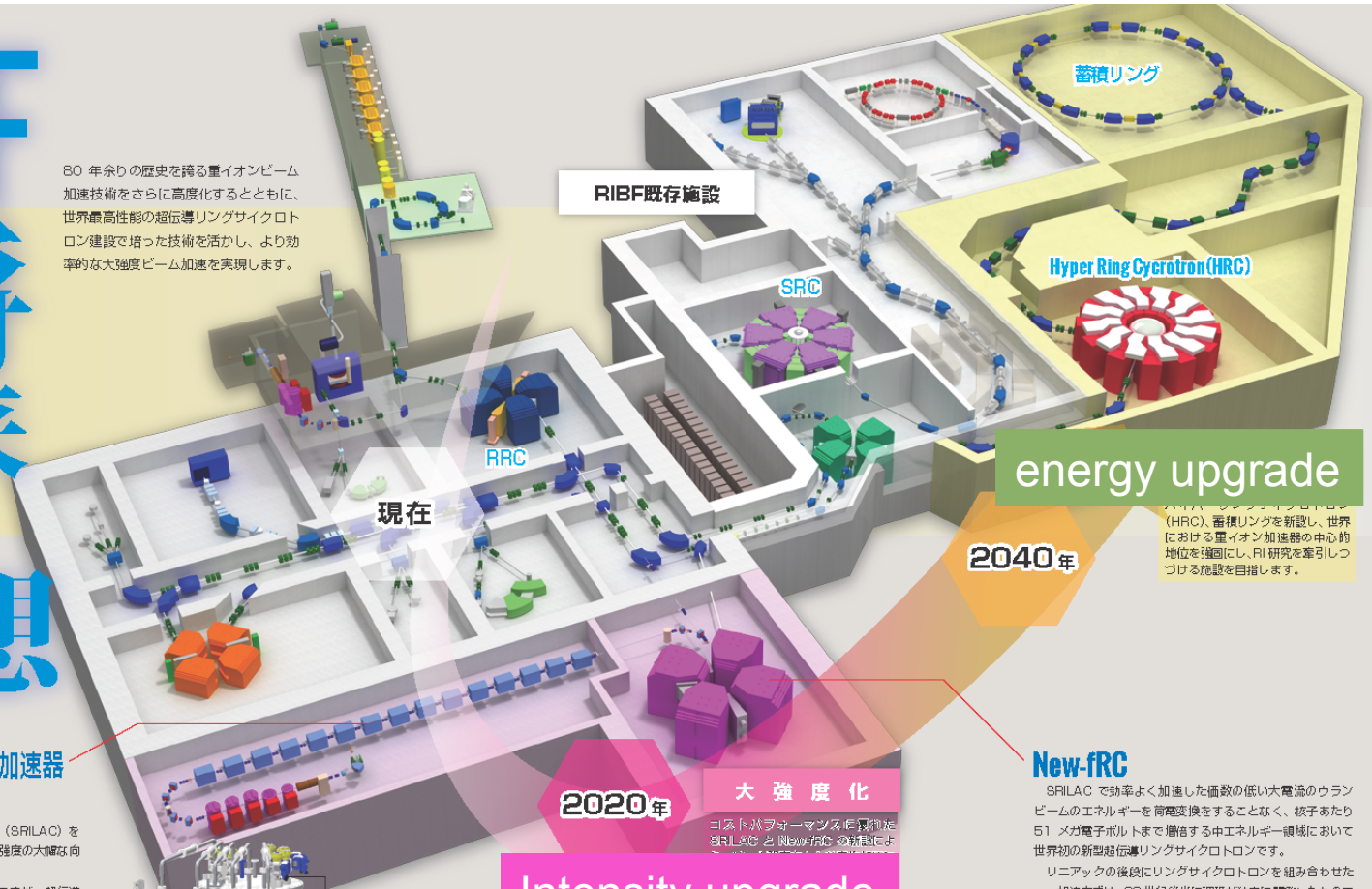
Kondo

Equipment and detectors under construction – mass measurements



RIBF 将来構想

80 年余りの歴史を誇る重イオンビーム加速技術をさらに高度化するとともに、世界最高性能の超伝導リングサイクロトロン建設で培った技術を活かし、より効率的な大強度ビーム加速を実現します。



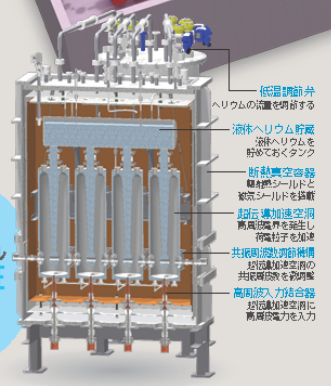
(HRC)、蓄積リングを新設し、世界における重イオン加速器の中心的地位を強固にし、RI研究を牽引しつづける施設を目指します。

理研超伝導重イオン線形加速器（SRILAC）

本計画では、理研超伝導重イオン線形加速器（SRILAC）を新設することにより、あらゆる重イオンビーム強度の大幅な向上を実現します。

SRILACはわずか43メートルの直線加速器ですが、超伝導空洞技術を用いることで、軌道長3 kmの理研リングサイクロトロン（RRC）と同等の加速性能と約1／2の電力消費を目指します。これにより、10倍の大電流イオンビームの効率的な加速を実現します。

これまでに培ってきた高周波、真空技術に加え、超伝導リングサイクロトロン（SRC）の超伝導技術を駆使し、新たにニオブ材の加工・形成技術、接合、表面処理、計測技術を確立することにより、安定的運転を可能とする低速度域用の超伝導重イオン線形加速器を新たに開発します。

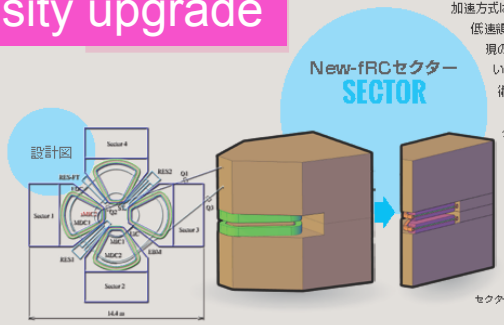


New-fRC

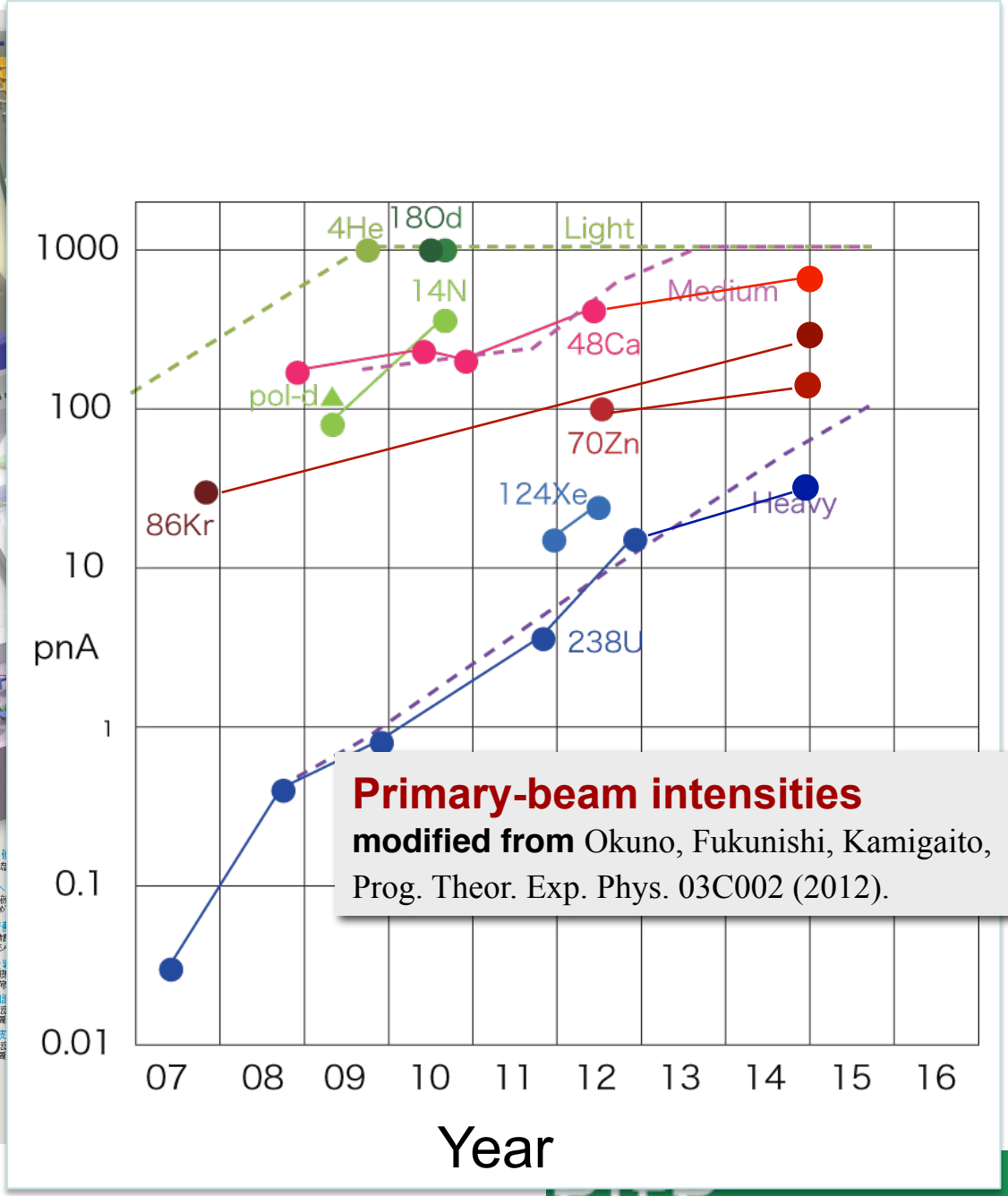
SRILAC で効率よく加速した価数の低い大電流のウランビームのエネルギーを荷電変換をすることなく、核子あたり51 メガ電子ボルトまで増倍する中エネルギー領域において世界初の新型超伝導リングサイクロトロンです。

リニアックの後段にリングサイクロトロンを組み合わせた加速方式は、20 世紀後半に理研が独自に開発したもので、低速領域でのリングサイクロトロンの等時性磁場実現の困難と、高速領域でのリニアックのコスト高という2つの問題を一気に解決する革新的な基幹技術です。

世界最高の加速性能を誇る超伝導リングサイクロトロン（SRC）建設で獲得した超伝導セクター電磁石の技術を駆使し、大電流に対応した入射・取り出しチャンネル、高加速電圧加速空洞、非破壊型ビーム診断機器の開発も合わせて行うことで、世界最大強度のウランビーム加速を実現します。



※図は計画中のため、変更される可能性があります。



Primary-beam intensities
modified from Okuno, Fukunishi, Kamigaito, Prog. Theor. Exp. Phys. 03C002 (2012).

June 2015

RIB Facilities in Japan*

* mostly in-flight

KEK – TRIAC and technology transfers
KISS – new project with multi-nucleon transfers
CNS, U. Tokyo – CRIB and a new low energy beam line (OEDO)
RCNP, Osaka Univ. – RI beams by fragmentation, direct reactions
RIKEN RIBF – current status and its upgrade programs under discussion
HIMAC – its use for intermediate-energy RI beams

Announcements

RIPS-25 Dec. 6-7, 2015, Hayama (near Tokyo)

Small symposium celebrating 25th anniversary of the RIKEN Projectile Fragment Separator (RIPS)

"Physics with Fragment Separators"

http://indico2.riken.jp/indico/conferenceDisplay.py?confId=1907

(search by "RIPS25 Anniversary")

NIC XIV (Nuclei In the Cosmos) - June 19-24, 2016, Niigata (Japan)

Symposium on nuclear astrophysics

http://nic2016.jp/