International Nuclear Physics Conference
June 3 – 8, 2007
Tokyo International Forum

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INPC 2007
TOKYO, JAPAN

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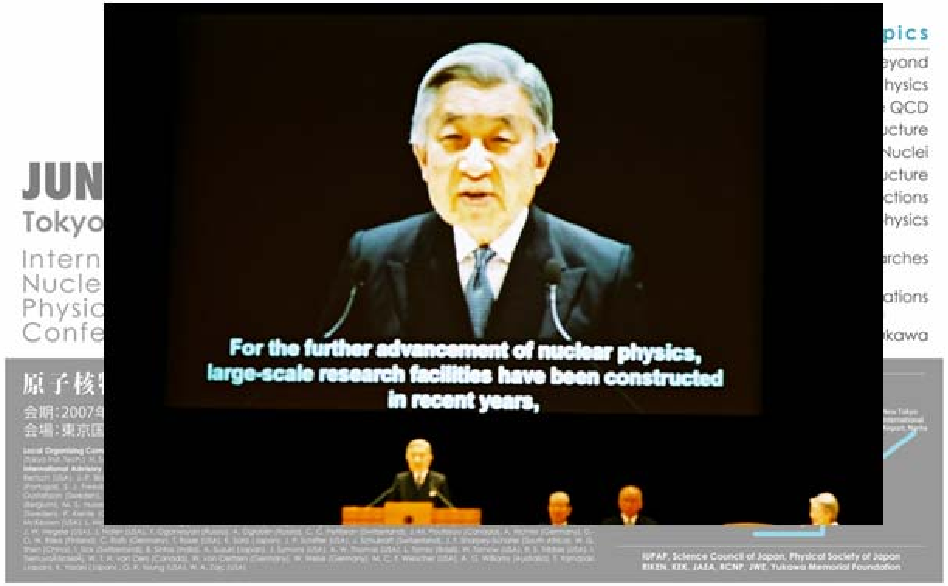


Flash Report on the first outcome from RIKEN RI beam factory commissioned on March 27, 2007

Y. Yano
RIKEN Nishina Center

June 6, 2007

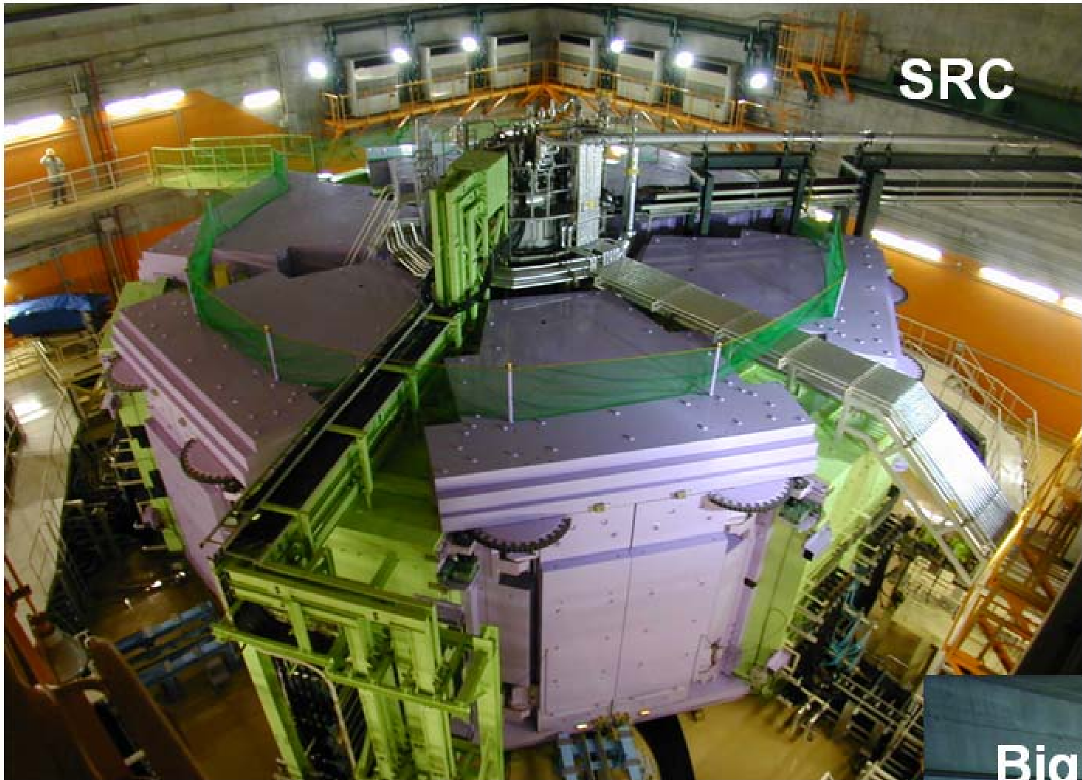
Flash Report
on the first outcome from RIKEN RI beam factory
commissioned on March 27, 2007

Discovery of a very neutron-rich
new isotope Pd 125 (N=79, Z=46)

The first test experiment of RIBF, Last week

Y. Yano
RIKEN Nishina Center
June 6, 2007

World's First and Strongest K2600MeV (8,300tons) Superconducting Ring Cyclotron



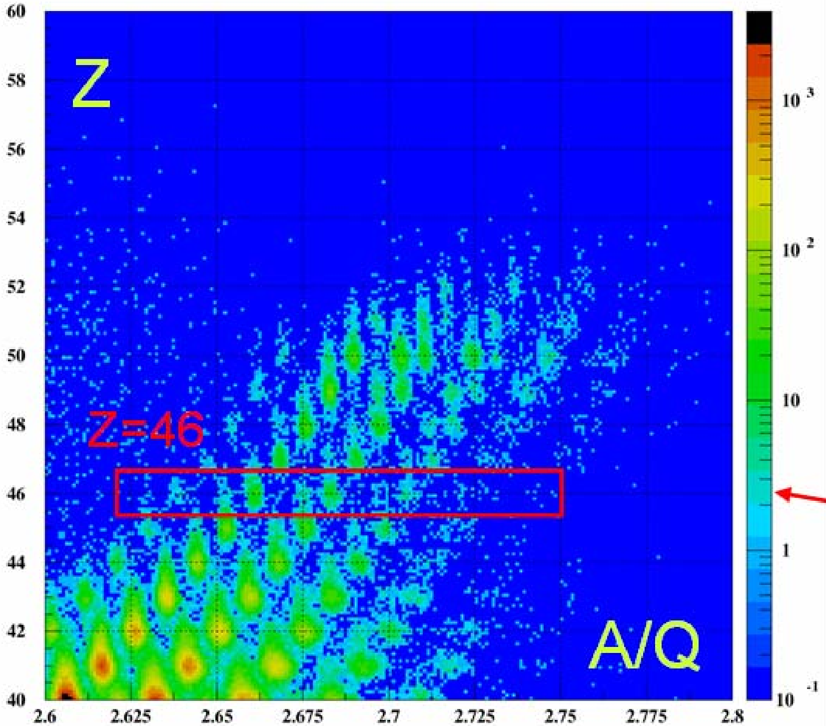
345 MeV/u Uranium ($^{238}U^{86+}$) beam

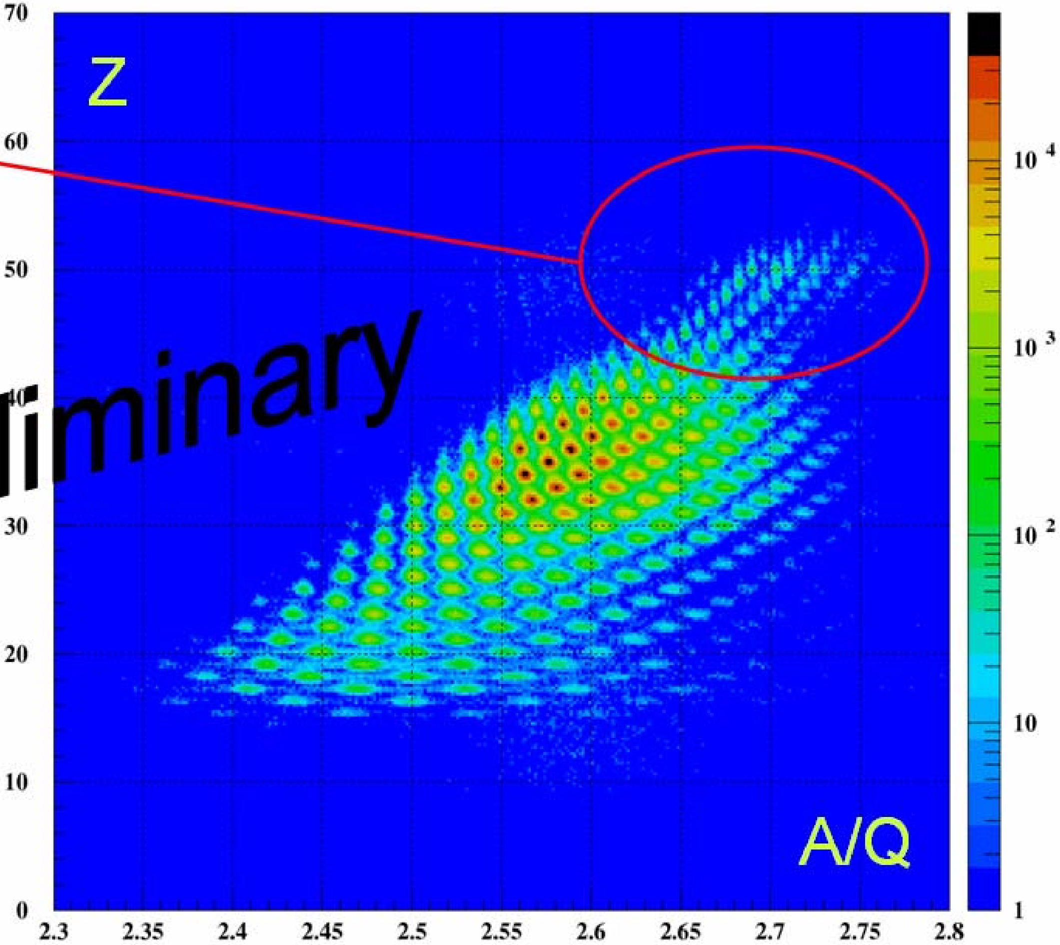
10^8 particles/s (5 orders of magnitude smaller than the goal intensity)

World's Largest Acceptance 9 Tm (77 m) Superconducting RI beam Separator

Fission fragments produced in 7 mm thick Be target

Z vs. A/Q Plot

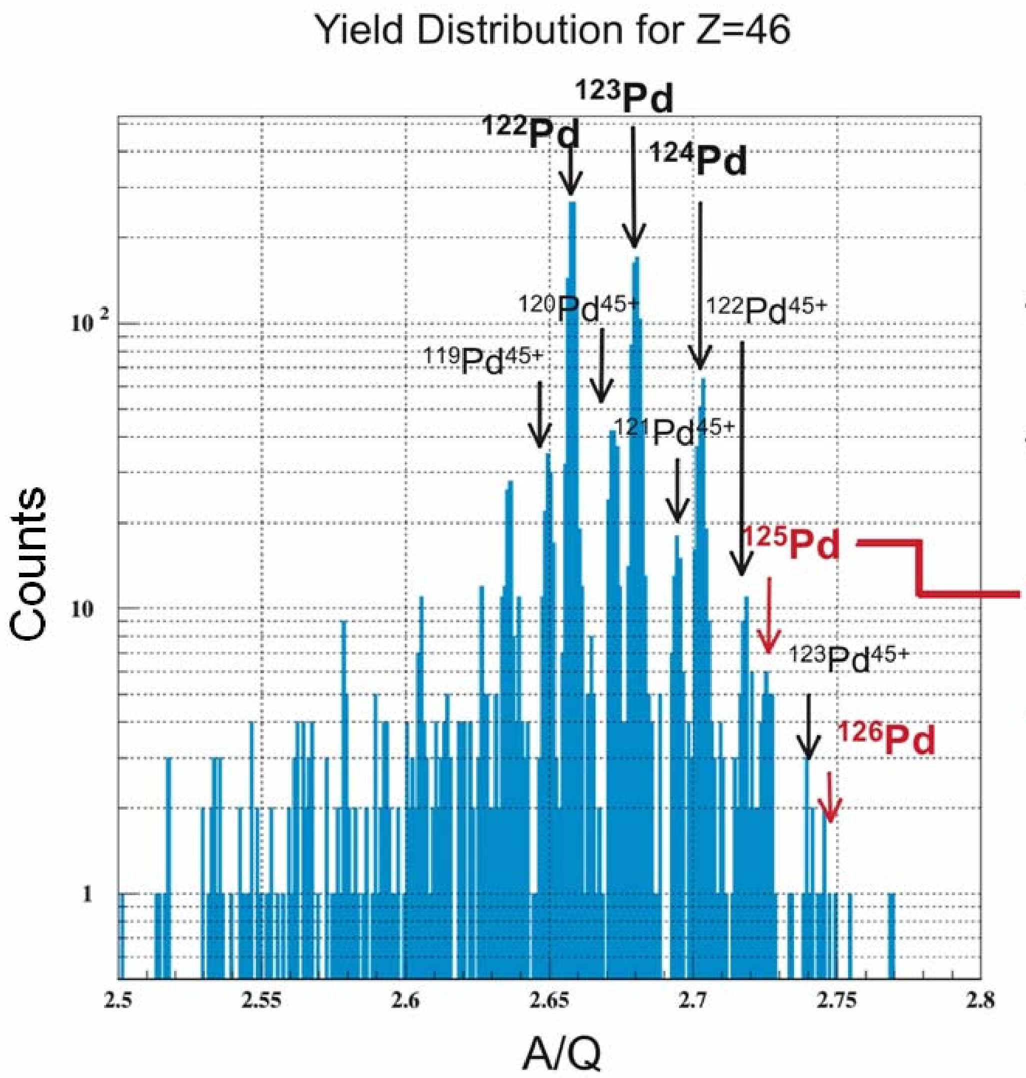




Preliminary

B ρ : 7.438 Tm

Total dose: 1.08×10^{13}
Total time: 25.4 hour



$^{119}Pd^{45+}$ 2.6444(2.6495) 118counts

^{122}Pd 2.6521(2.6577) 850 counts

$^{120}Pd^{45+}$ 2.6666(2.6722) 157 counts

^{123}Pd 2.6739(2.6800) 580 counts

$^{121}Pd^{45+}$ 2.6888(2.6943) 59 counts

^{124}Pd 2.6956(2.7026) 187 counts

$^{122}Pd^{45+}$ 2.7111(2.7177) 33 counts

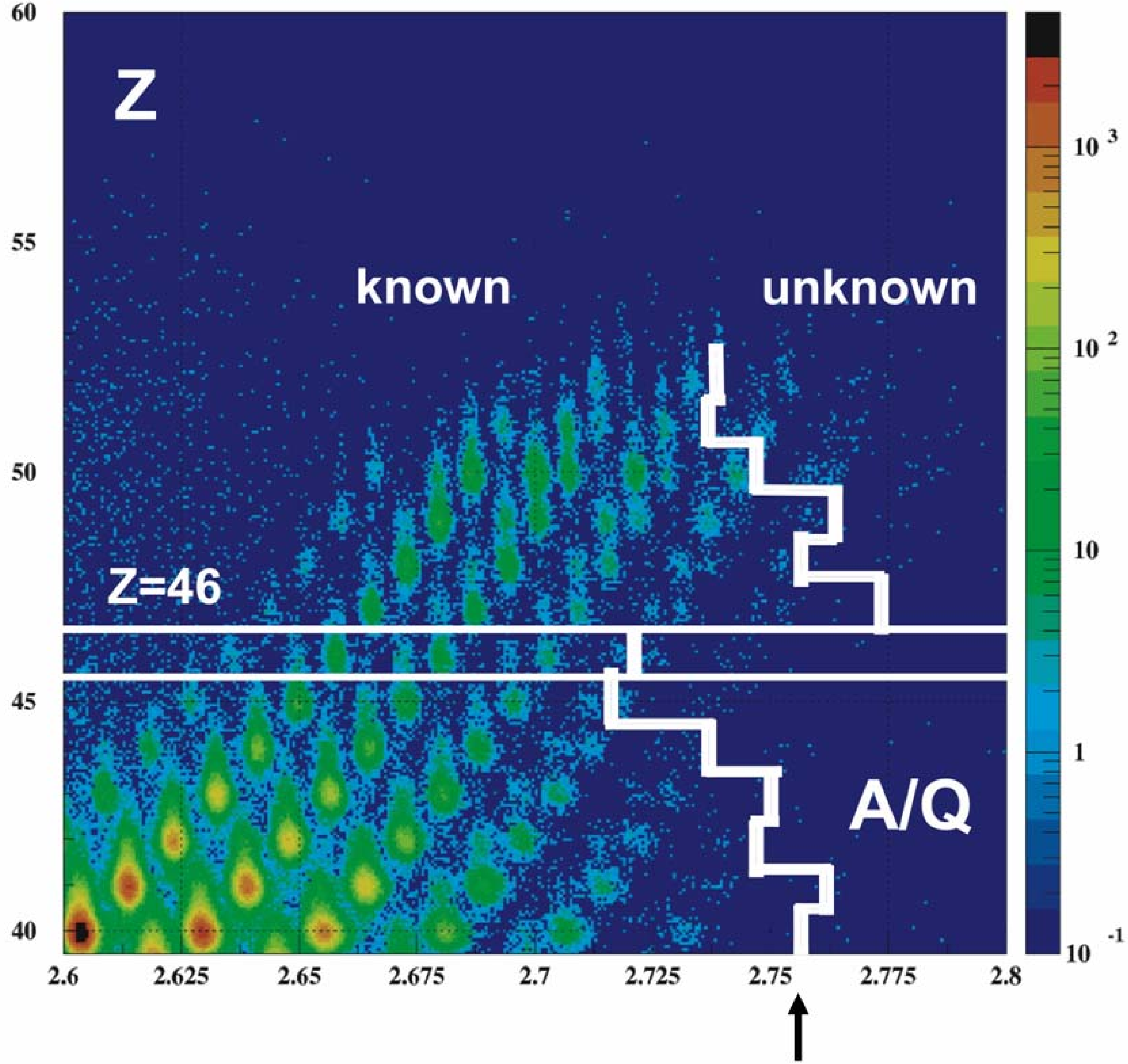
^{125}Pd 2.7174(2.7255) 26 counts

$^{123}Pd^{45+}$ 2.7333(2.7392) 7 counts

^{126}Pd 2.739()

Preliminary

A/Q resolution(r.m.s): 0.07%



M.Bernas et a. PLB 331(94)19; PLB 415(97) 111 (GSI)

The great launch
to explore nuclear world
so far inaccessible !

Experiment Team

T. Kubo (Spokesman), T. Ohnishi, K. Yoshida, A. Yoshida, K. Kusaka,
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K. Yoneda, H. Otsu, S. Takeuchi, D. Kameda, T. Sugimoto, Y. Kondo,
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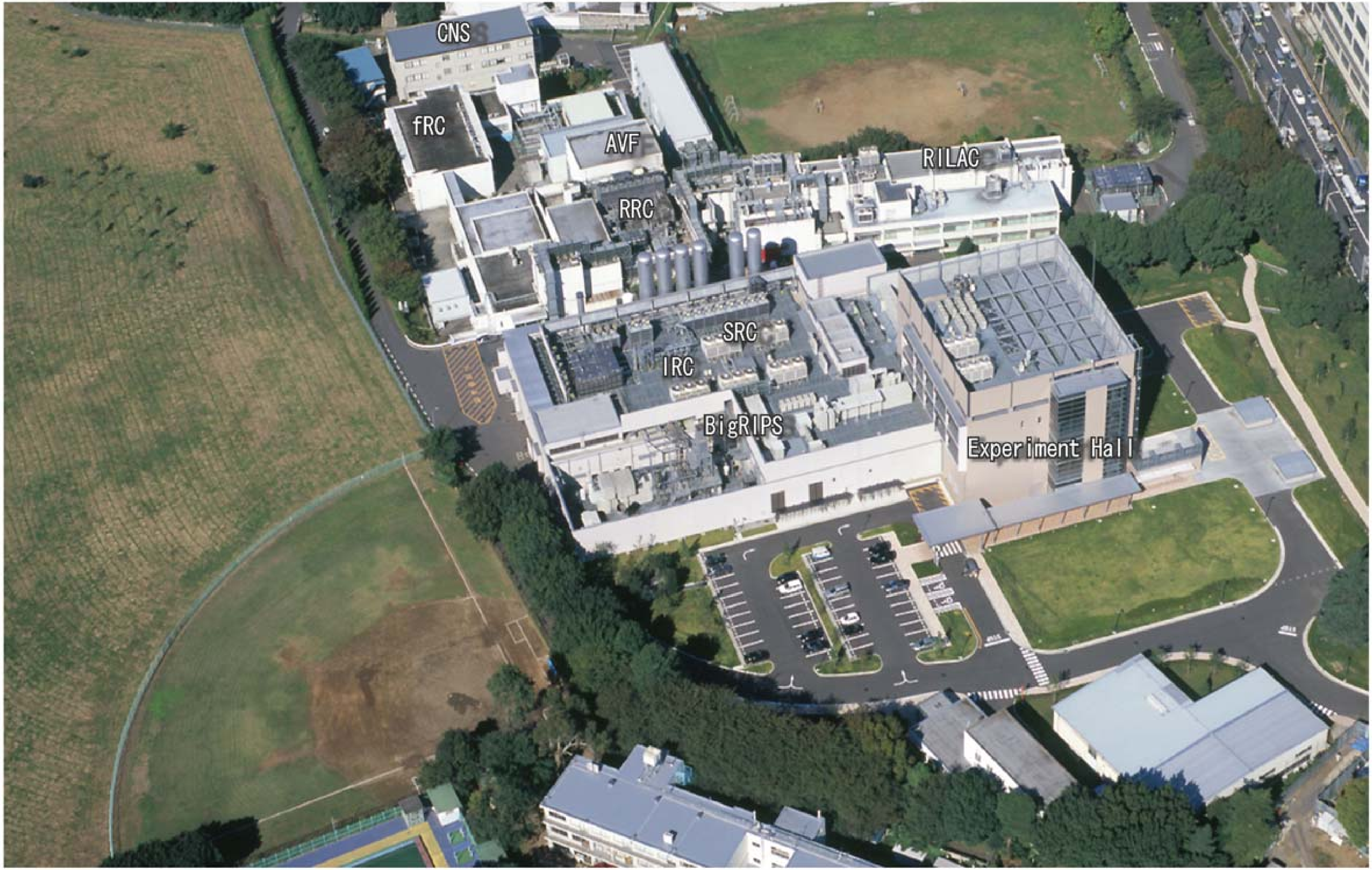
Y. Mizoi (OECU/Osaka, Japan)
M. Matsushita (Rikkyo U., Japan)
H. Suzuki, T. Nakao, H. Kimura, (U. Tokyo, Japan)
T. Kuboki, T. Yamaguchi, K. Suzuki (Saitama U., Japan)
A. Ozawa, T. Moriguchi, Y. Yasuda (U. Tsukuba, Japan)
T. Nakamura, T. Nannichi, T. Shimamura, Y. Nakayama (Tokyo Tech., Japan)

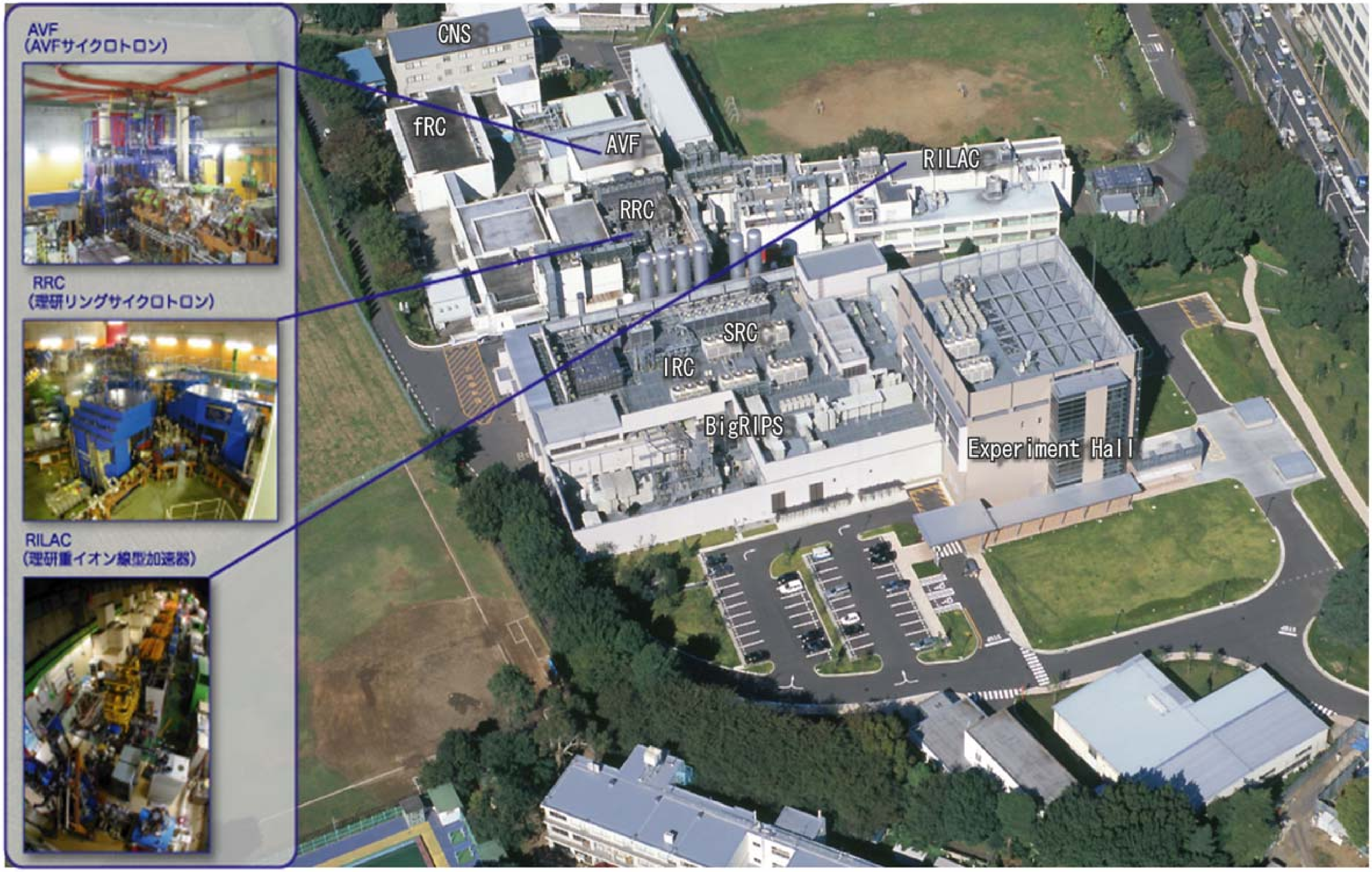
H. Geissel, H. Weick (GSI, Germany)
J. Nolen (ANL, USA)
O. Tarasov, T. Nettleton, D. Bazin, B. Sherrill, D. Morrissey (NSCL/MSU, USA)
W.Mittig (GANIL, France)

Overview

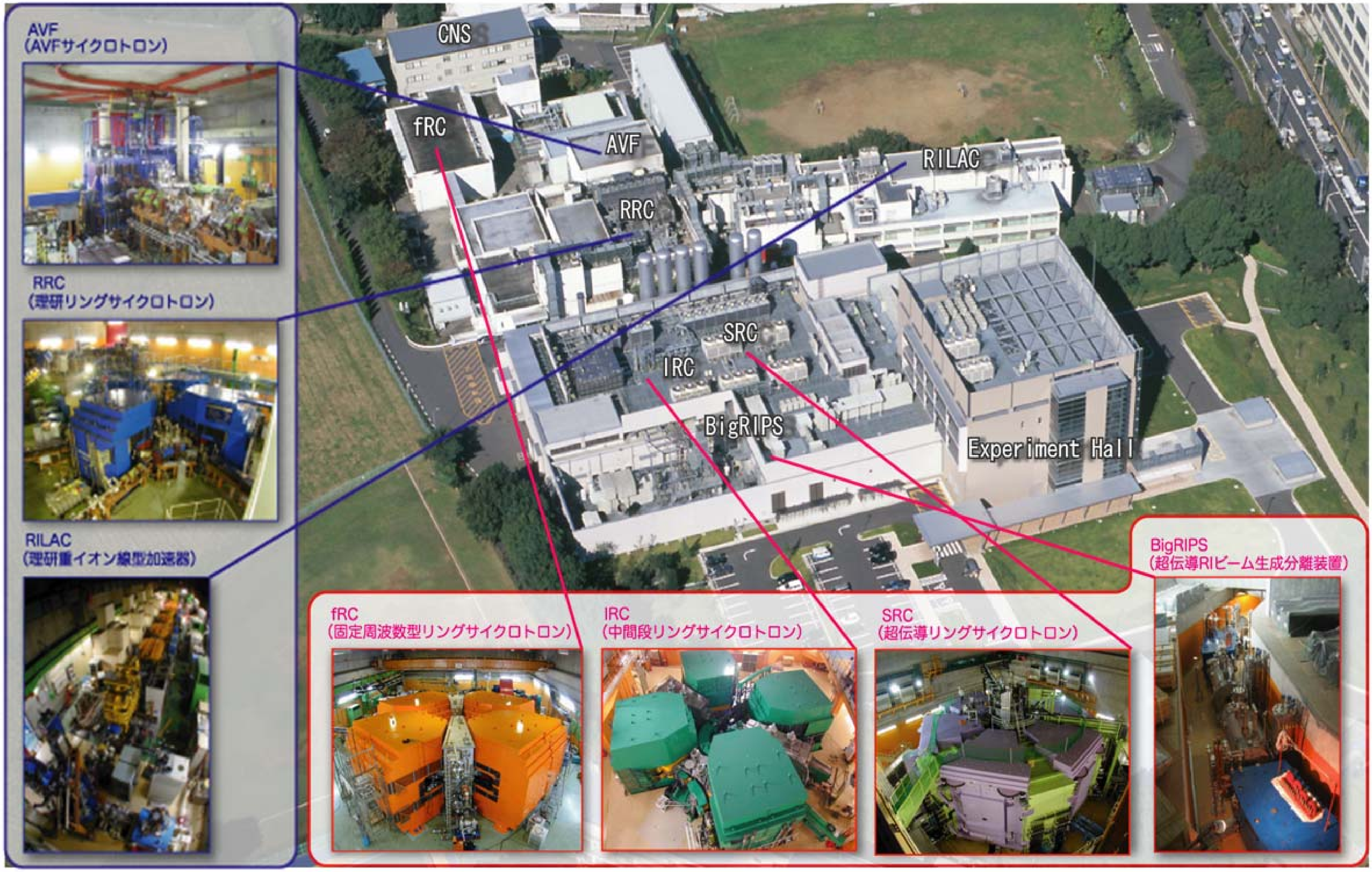
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city



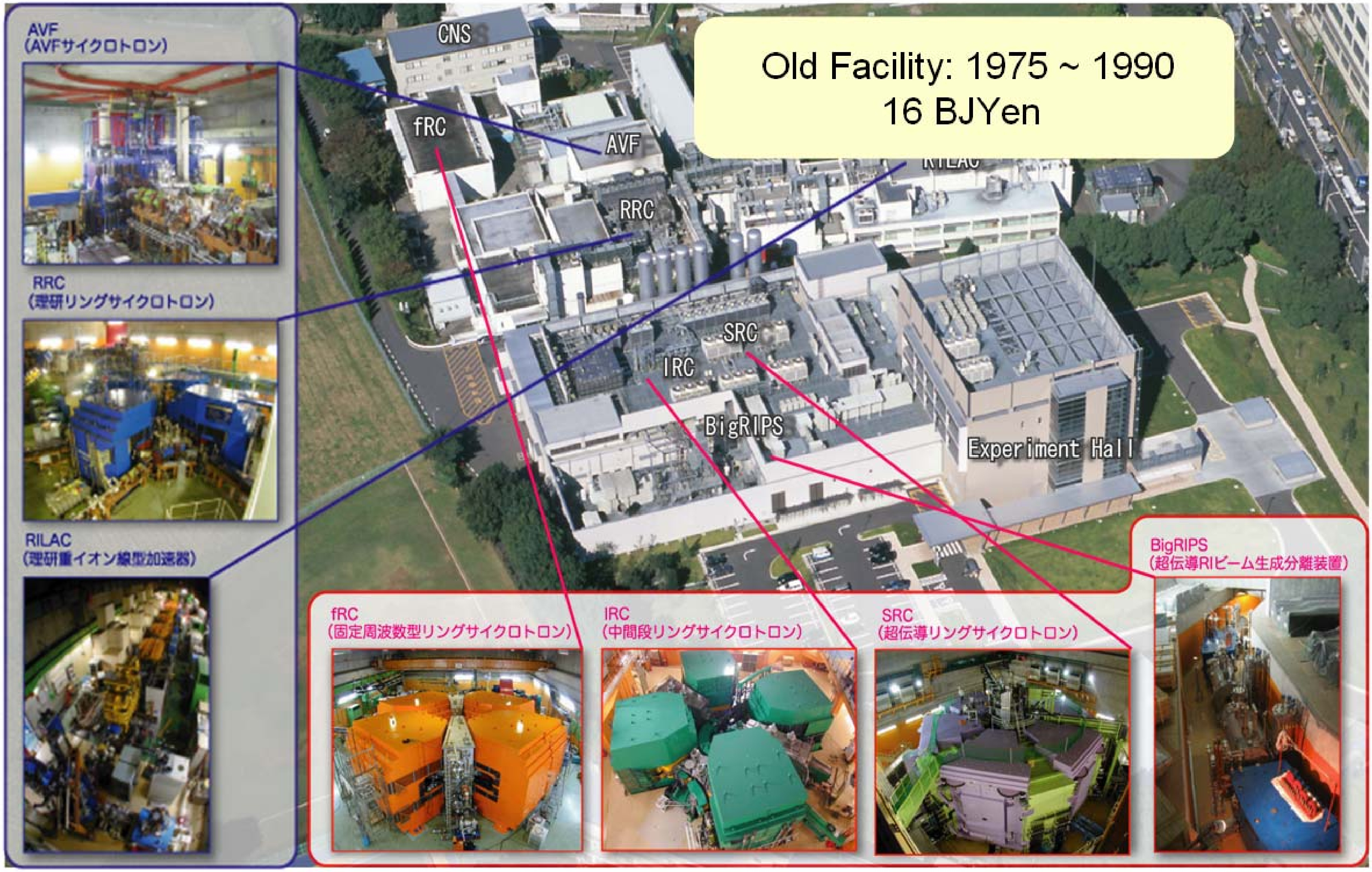
RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city



RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city

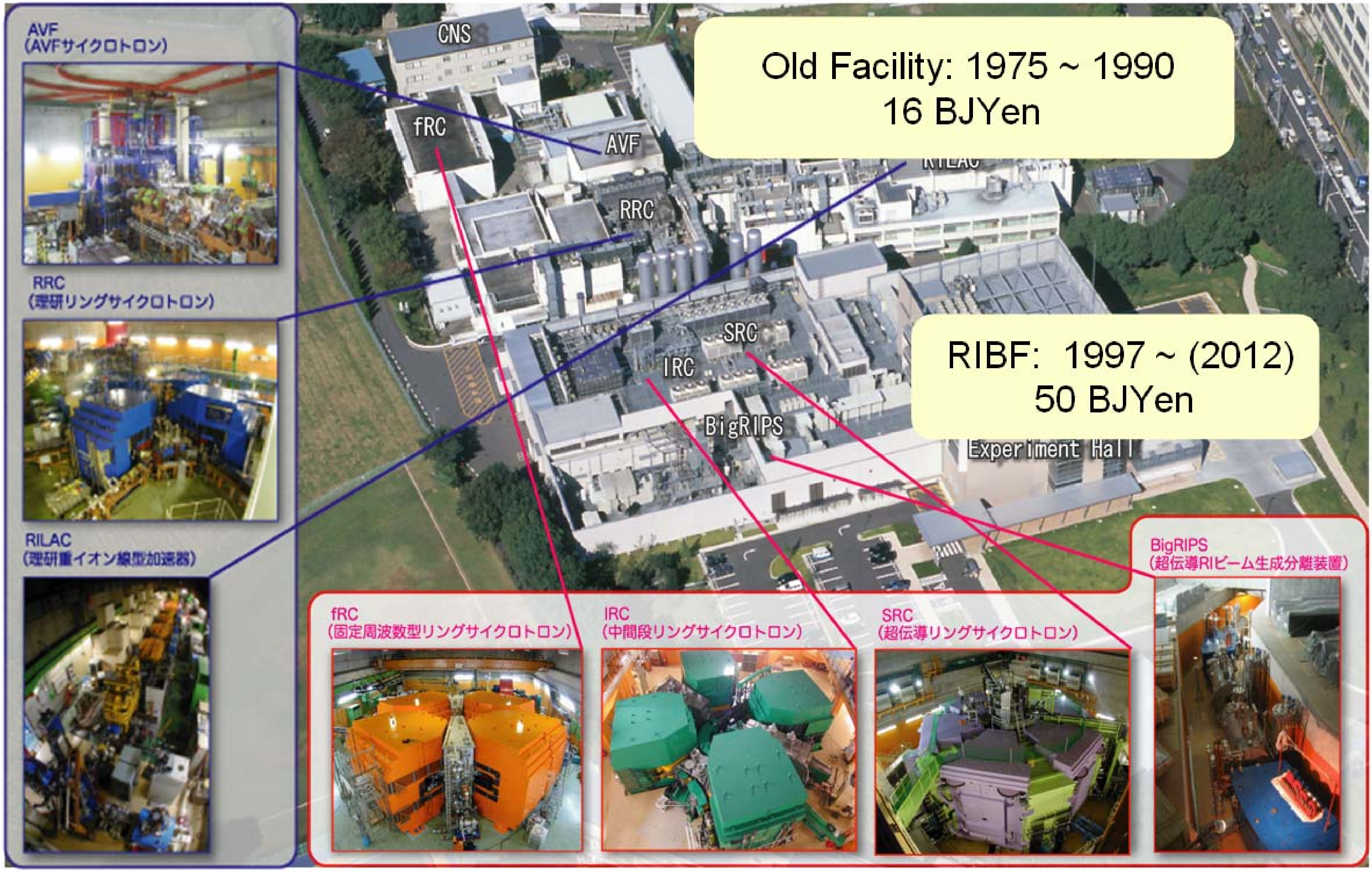


RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city



RIKEN NiSHiNA CENTER

RI Beam Factory (RIBF), RIKEN Nishina Center, Wako-city



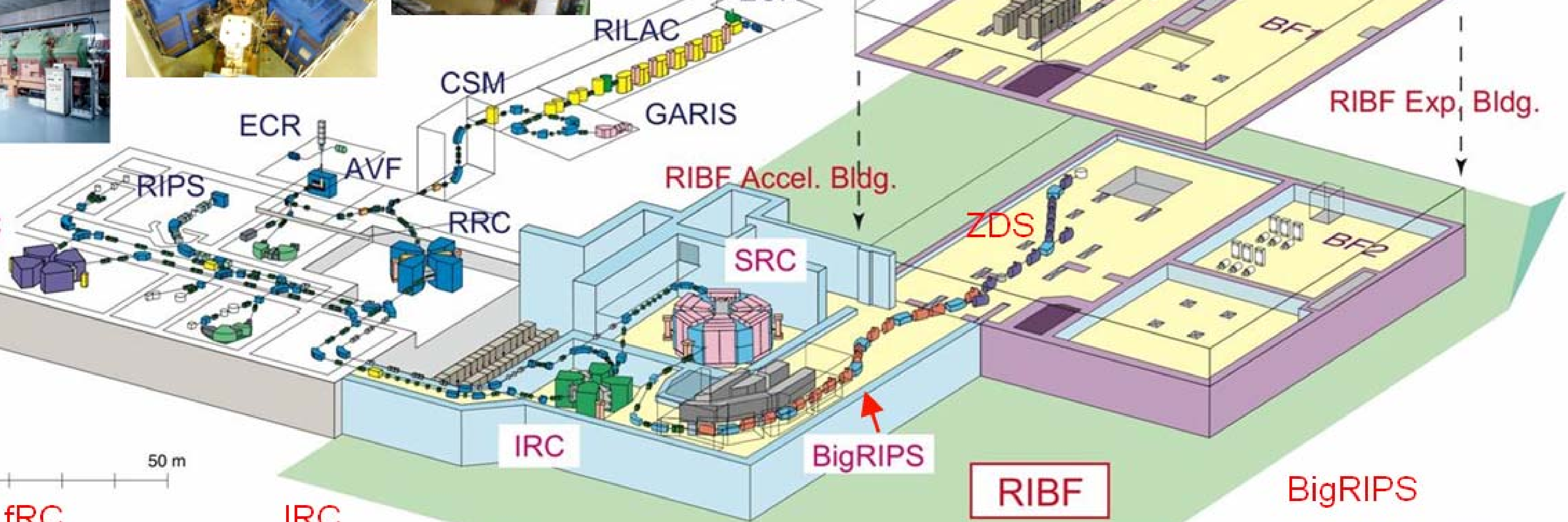
Layout of RIBF (in 2007)

RIPS

RRC

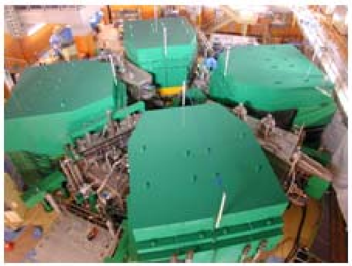
RILAC

ZDS



fRC

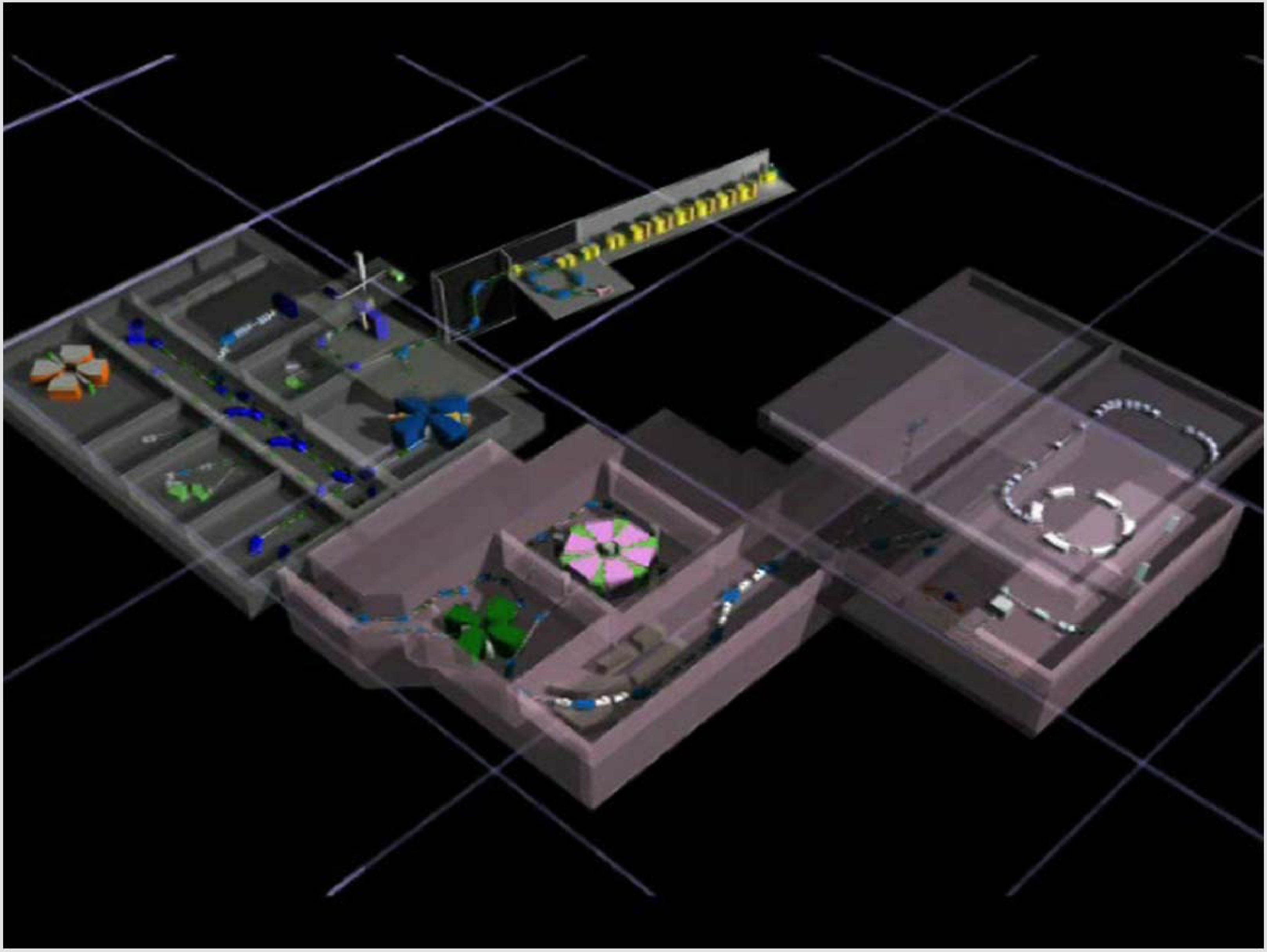
IRC



SRC

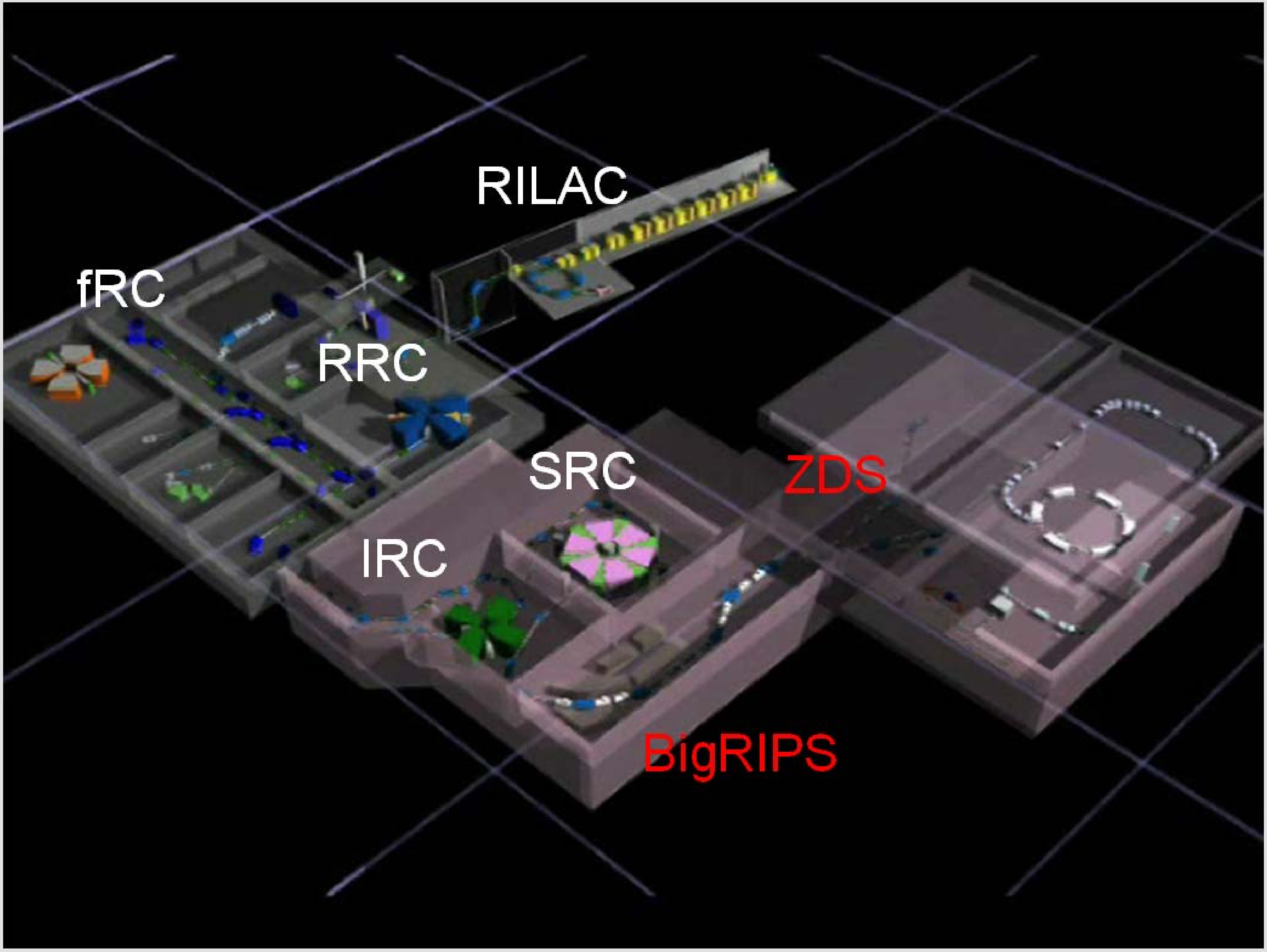
BigRIPS

Acceleration Flow in RI Beam Production



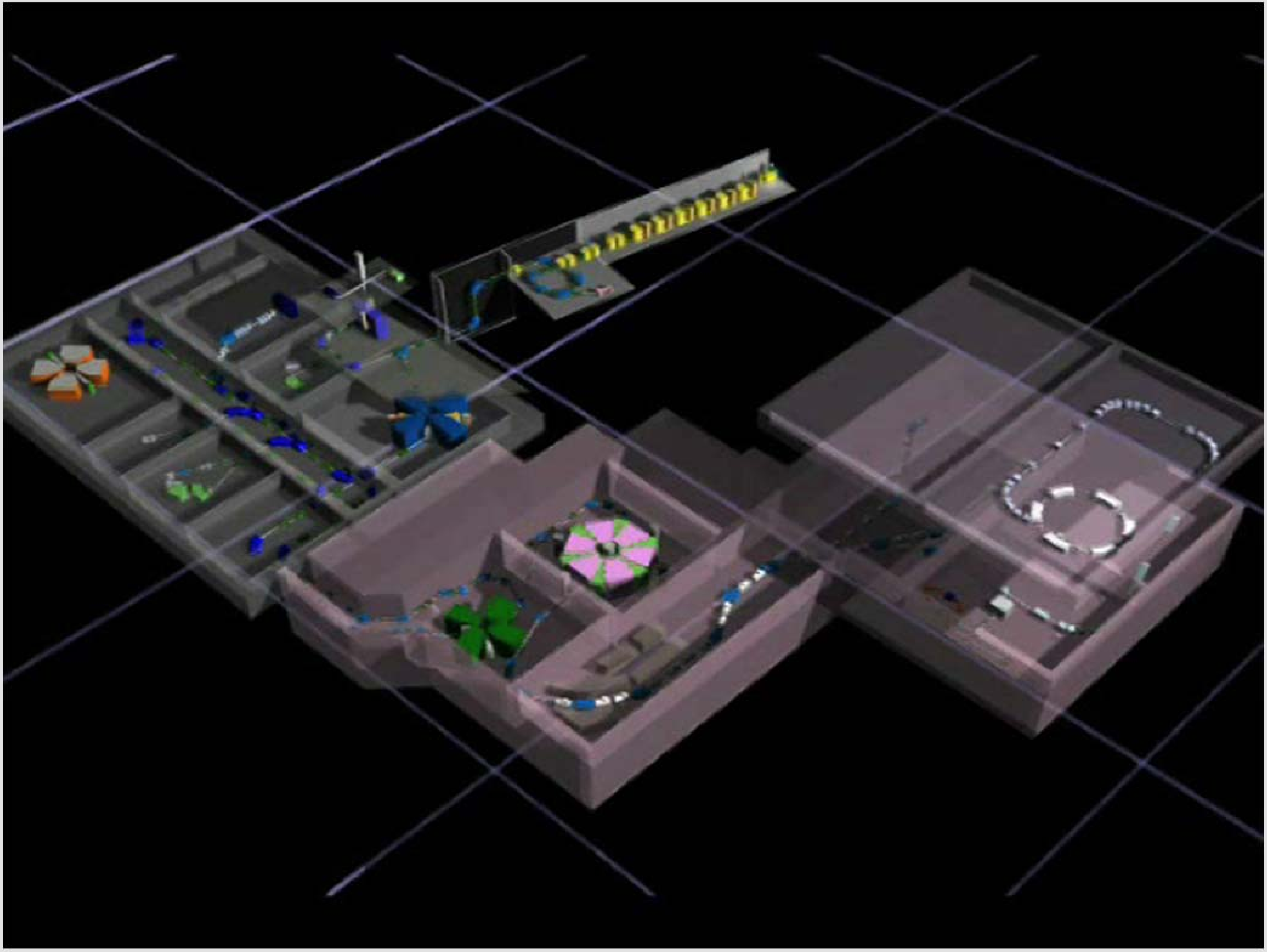
by N. Miyauchi

Acceleration Flow in RI Beam Production



by N. Miyauchi

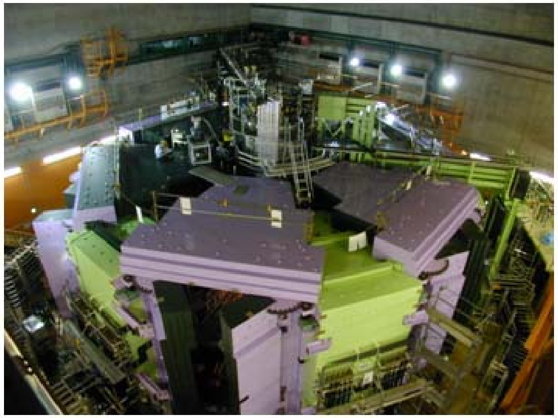
Acceleration Flow in RI Beam Production

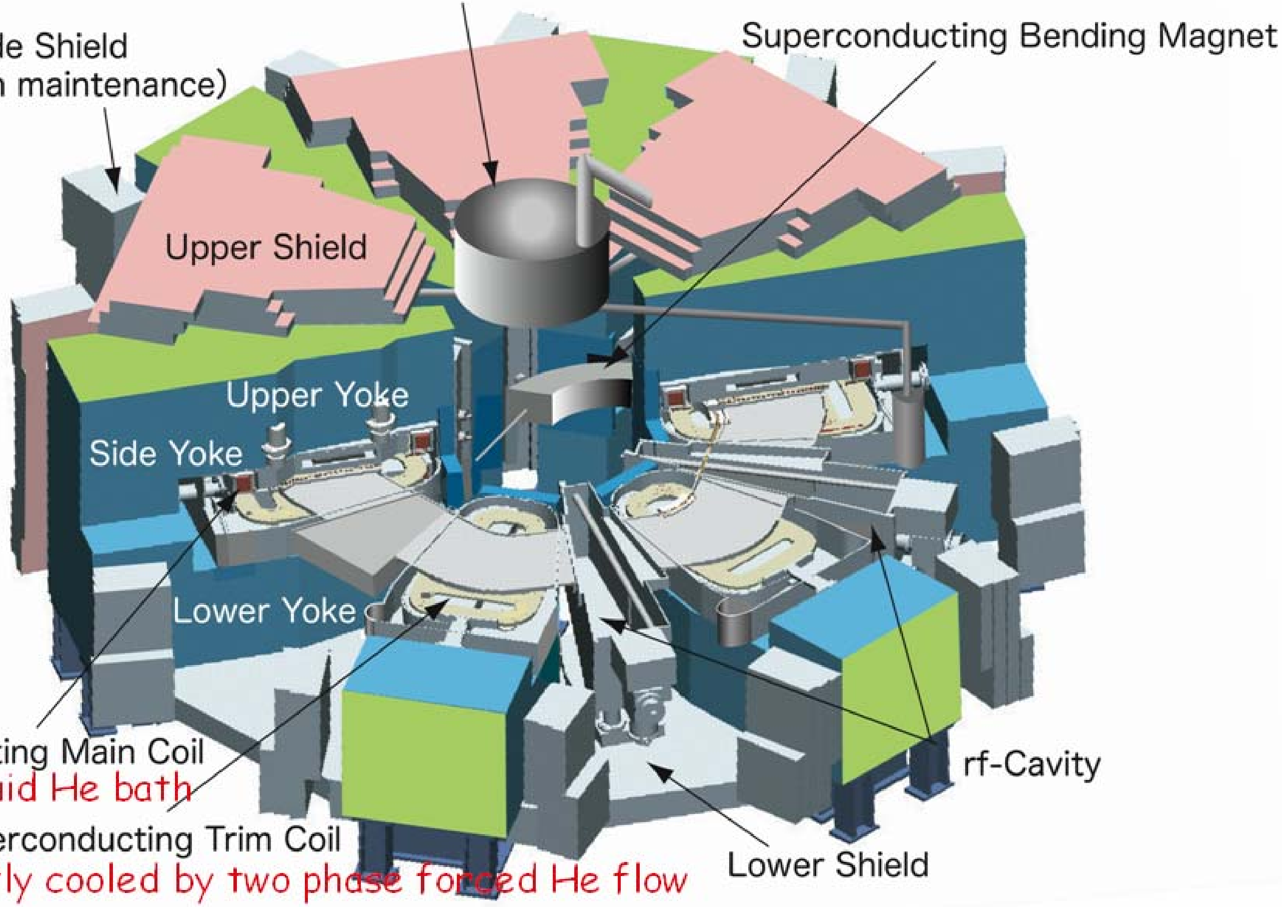


by N. Miyauchi

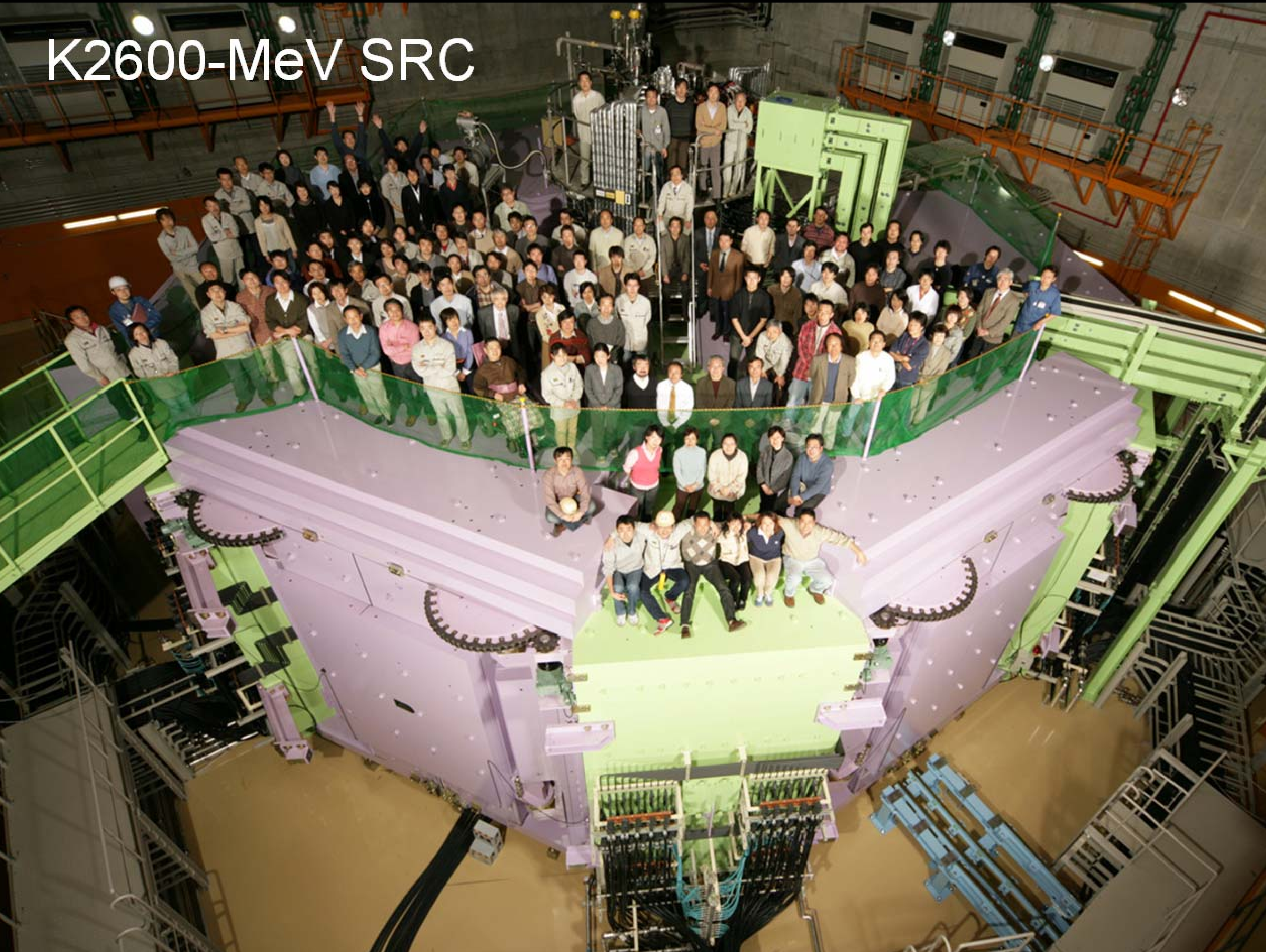
Superconducting Ring Cyclotron (SRC) (world's first)

K = 2,600 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons

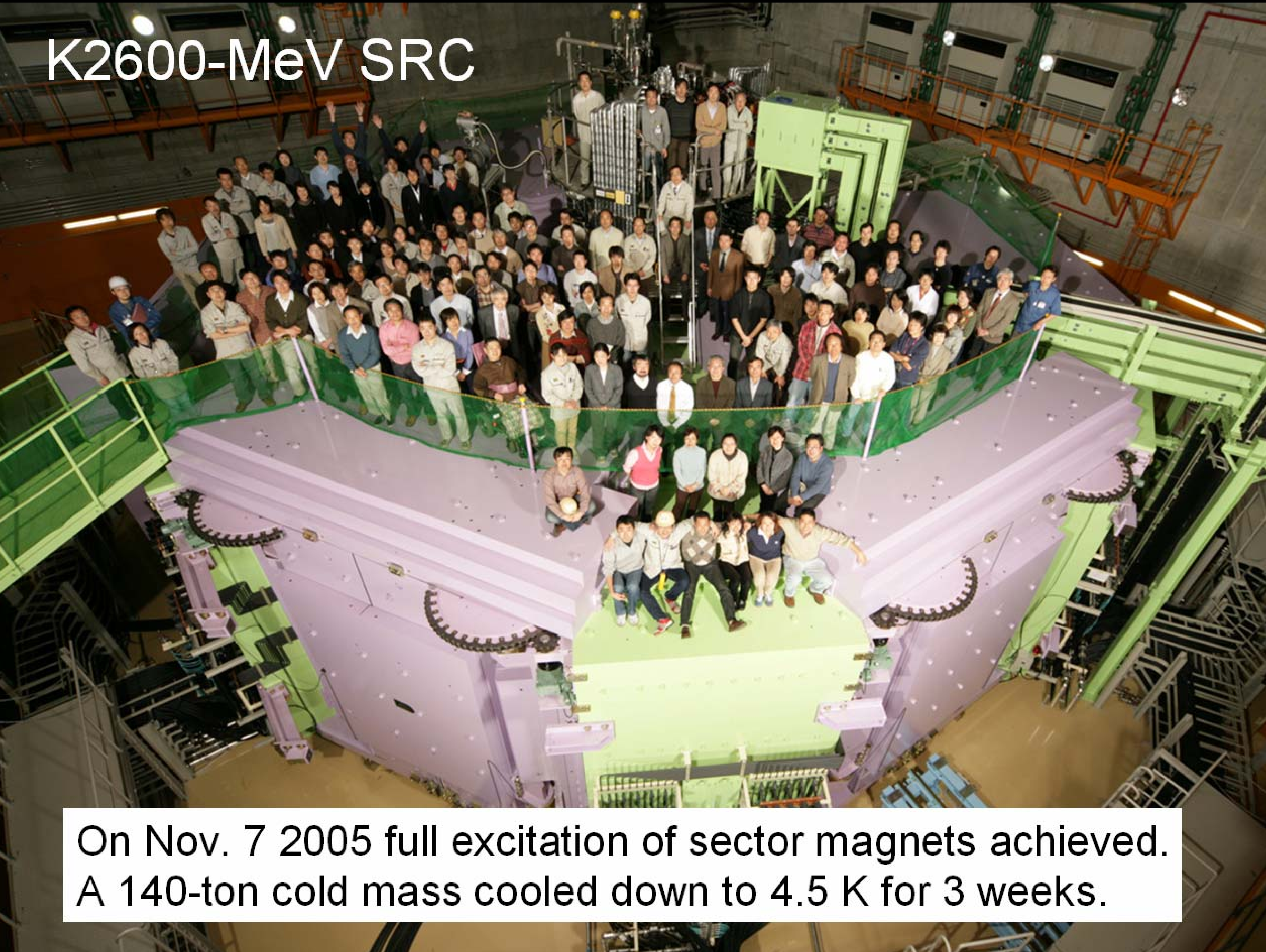




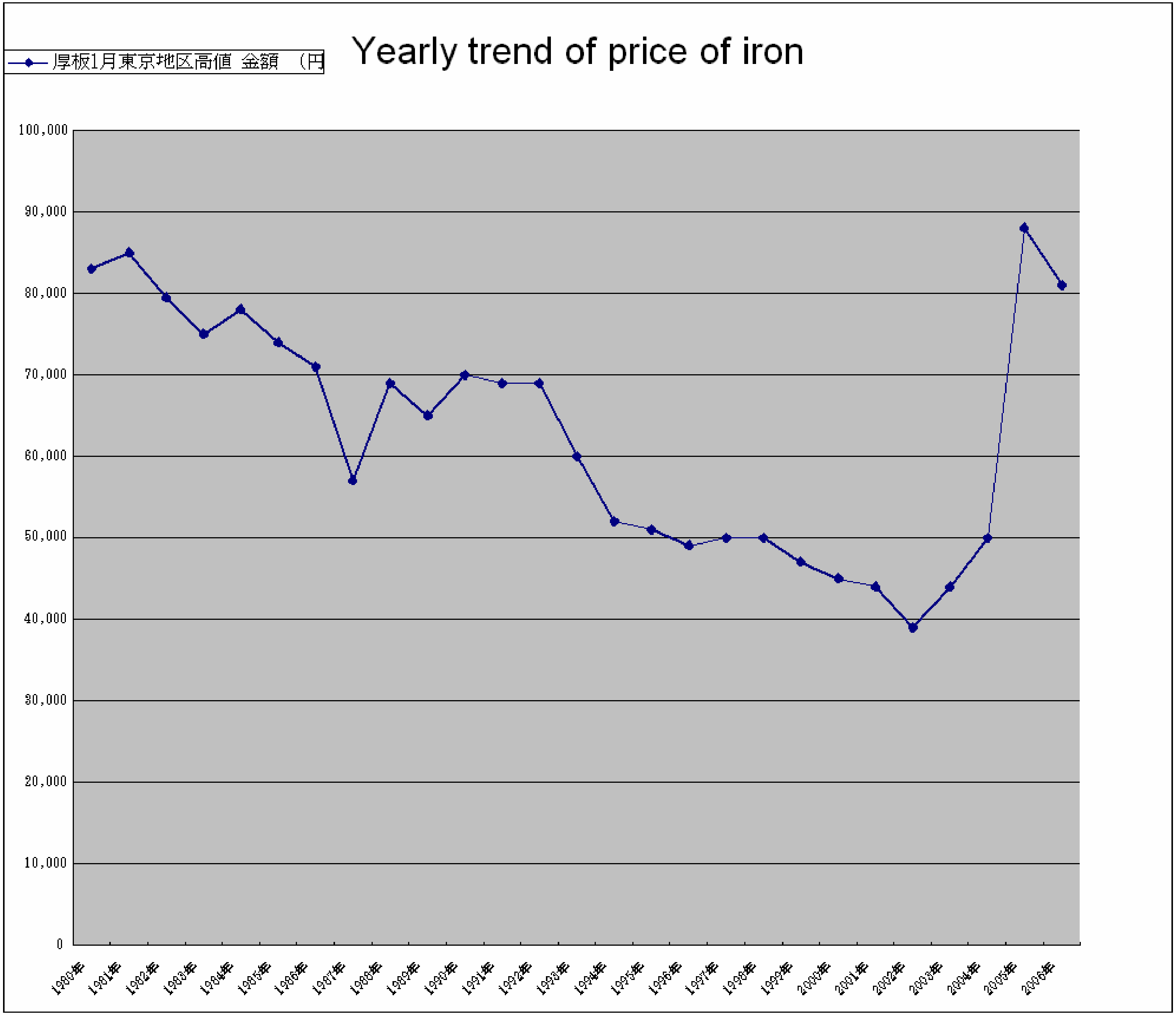
K2600-MeV SRC



K2600-MeV SRC



On Nov. 7 2005 full excitation of sector magnets achieved.
A 140-ton cold mass cooled down to 4.5 K for 3 weeks.


Yearly trend of price of iron
厚板1月東京地区高値 金額 （円
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980年
1981年
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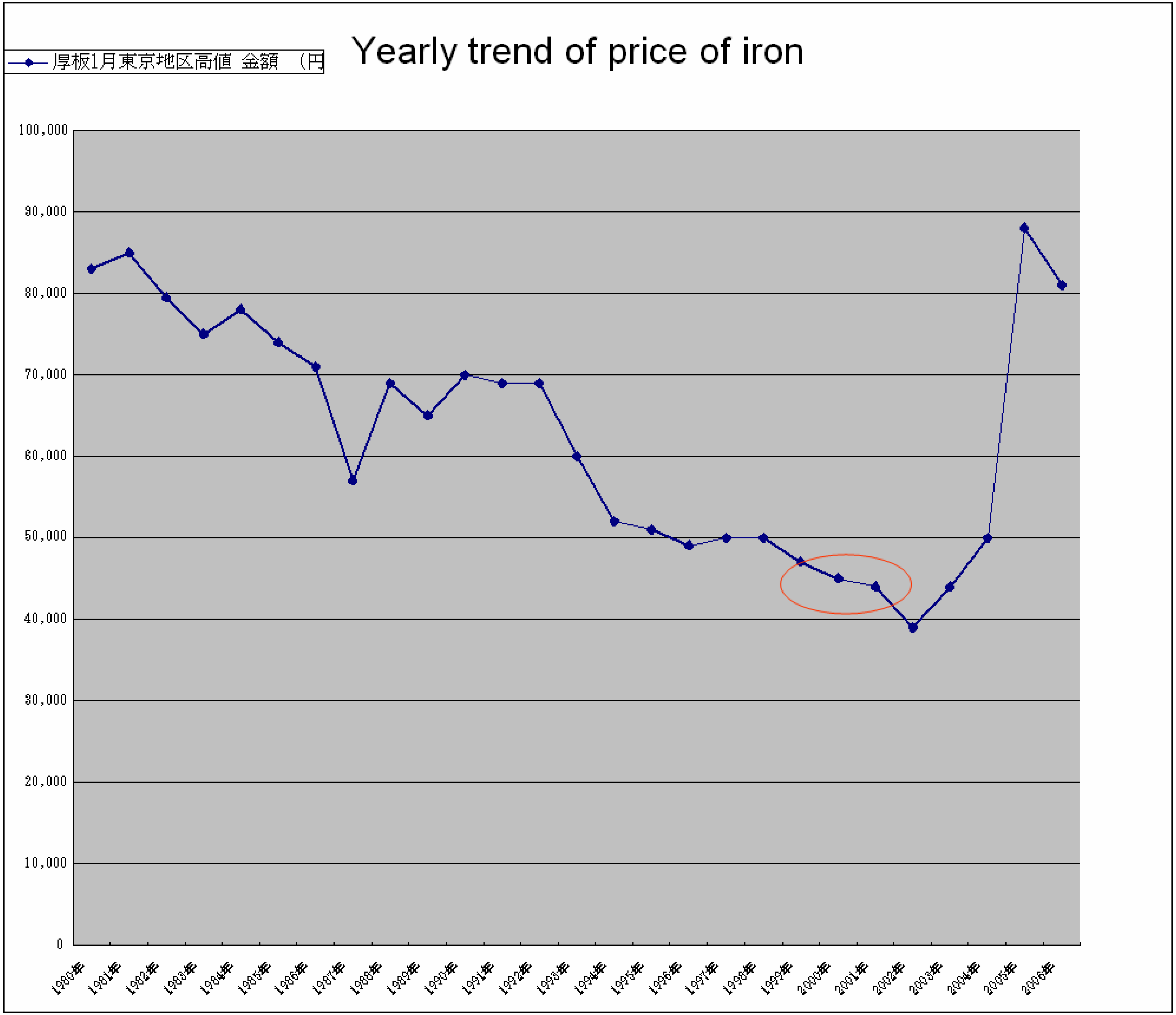
2006年



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100,000
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60,000
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40,000
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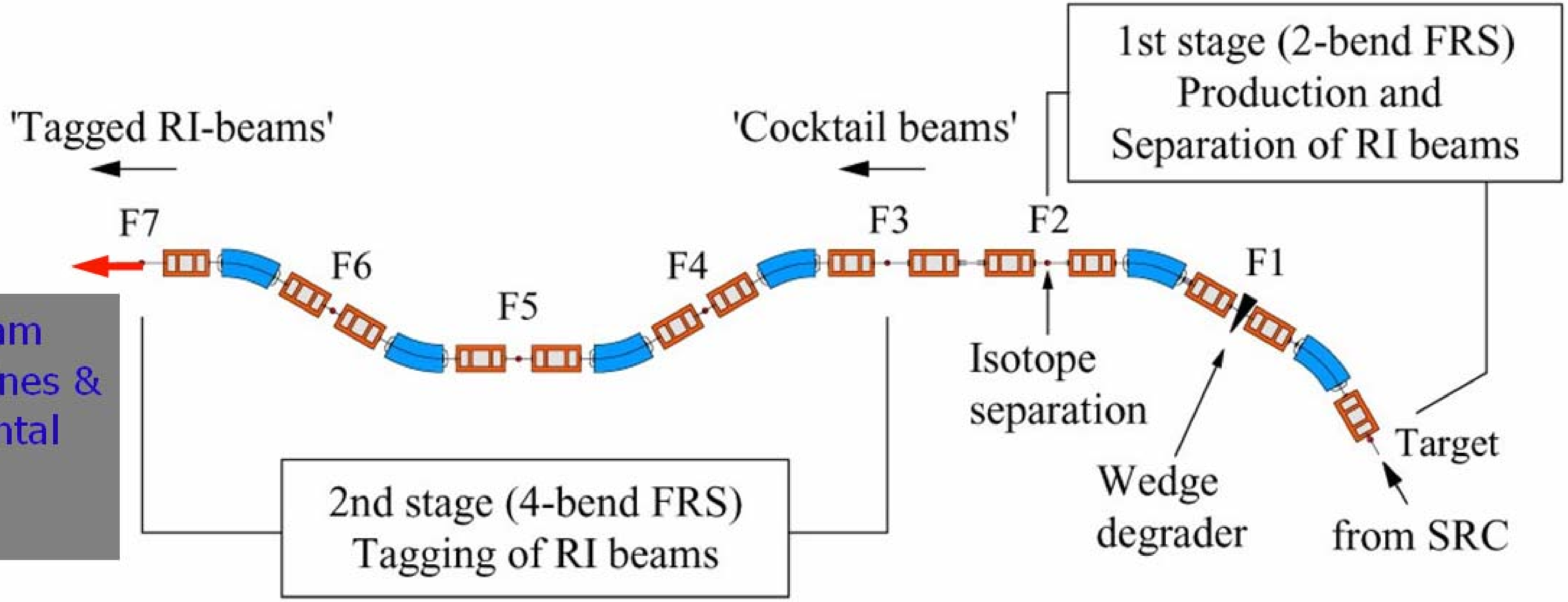
2006年

BigRIPS, Tandem (two-stage) Separator to deliver tagged RI beams



To RI-beam delivery lines & experimental setups

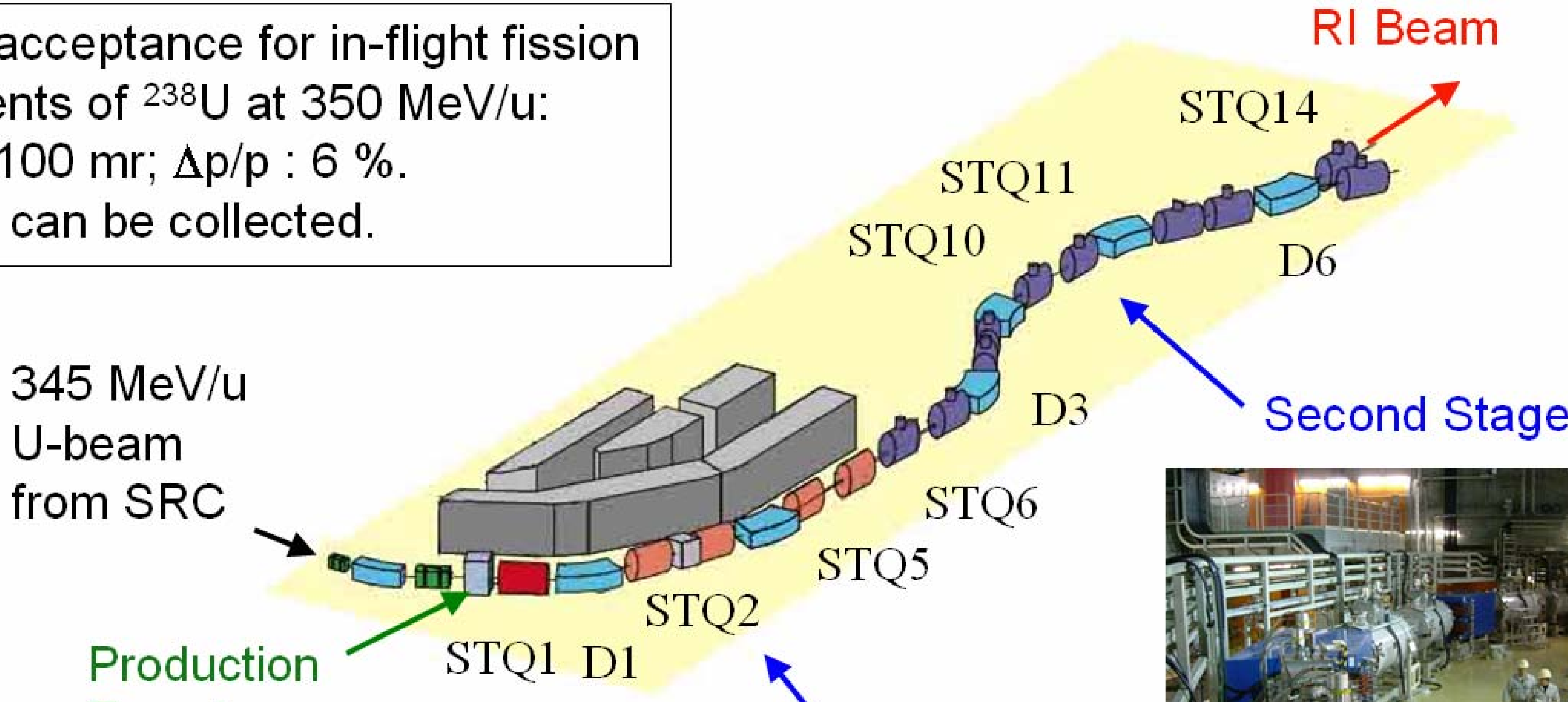
TOF, Bρ, ΔE $\rightarrow$ Z, A/Q (A, Q), P

Identify RI-beam species in an event-by-event mode

T. Kubo, RIKEN

BigRIPS (bird's eye view)

Large acceptance for in-flight fission fragments of ^{238}U at 350 MeV/u:
$\Delta\phi$: ~ 100 mr; $\Delta p/p$: 6 %.
~ 50% can be collected.

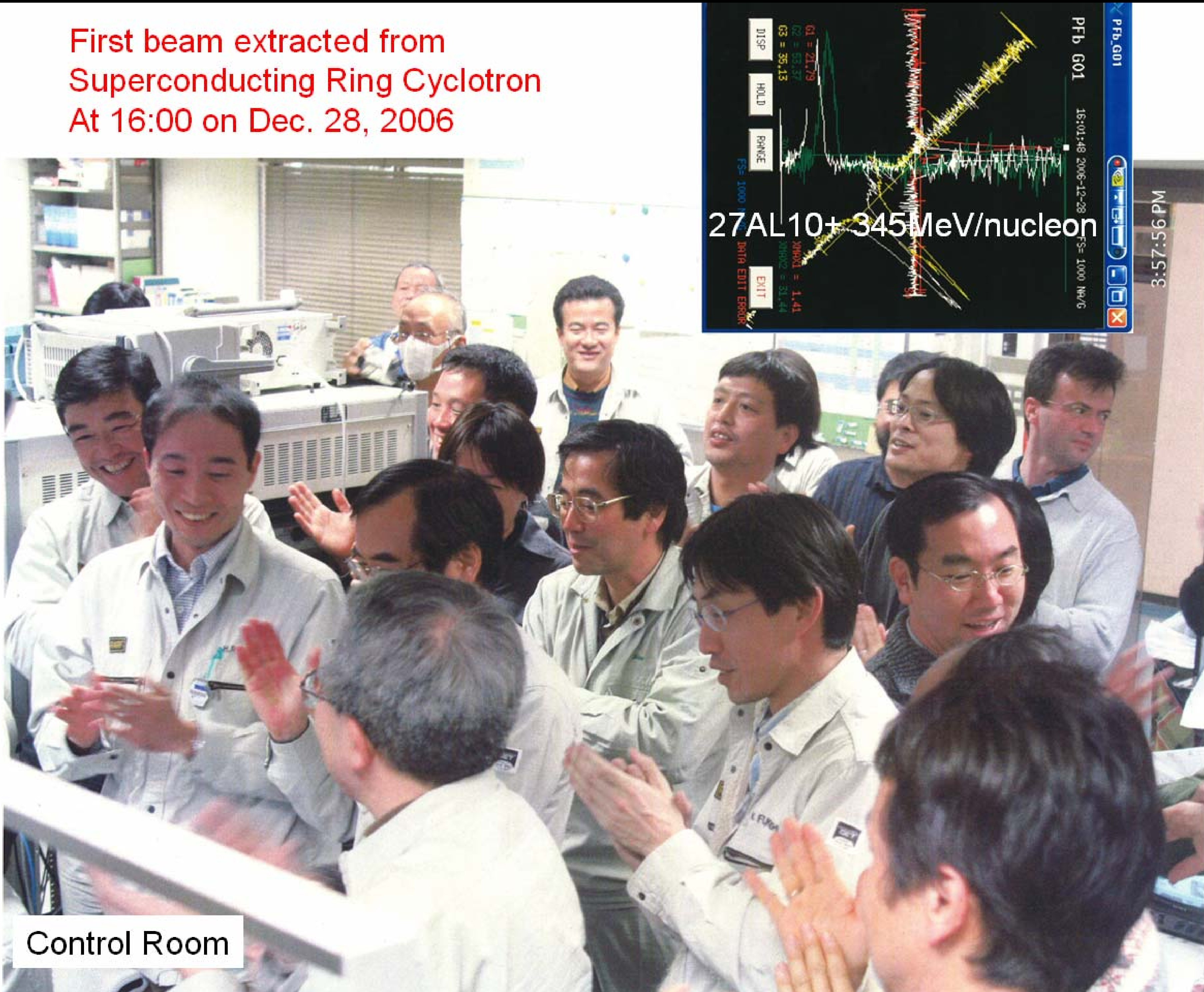


STQ:
14.1 T/m
24 cm ϕ warm-bore

5000 tons concrete shielding

Commissioning

First beam extracted from
Superconducting Ring Cyclotron
At 16:00 on Dec. 28, 2006



"Science" : Dec. 2006

"Nature" : Dec. 2006

Japan speeds up nuclear physics

No particle accelerator in the world is strong enough to create a usable beam of uranium ions. But that will change next month, when Japan switches on a huge facility of connected accelerators, to produce the world's most powerful beams of heavy radioactive isotopes.

Radioisotopes are forms of elements that are unstable because they contain either more or fewer neutrons than usual, and so undergo radioactive decay. Nuclear physicists are studying rare short-lived isotopes to understand their properties and how they are formed. The RIKEN research institute in Saitama, Japan, already has accelerators that can create the world's strongest radioisotope beams, but even these are only powerful enough to produce usable beams for the lighter elements.

But next month, RIKEN will switch on a major upgrade. The ¥44-billion (US$378 million) Radioactive Isotope Beam Factory will add two more ring cyclotrons and the world's first superconducting ring cyclotron to the existing linear accelerator and ring cyclotron. It will then be able to accelerate beams of any element up to uranium at 70% of the speed of light. The accelerated beams are smashed into a target such as beryllium to knock out neutrons and protons and create the desired radioisotopes.

The facility should open a new realm of astrophysics. "With this new facility, scientists at RIKEN have the opportunity to study nuclear isotopes that exist only in the hottest stars of the Universe," says John Schiffer, a senior scientist at the Argonne National Laboratory in Chicago, Illinois.

"Scientists will be able to study nuclear isotopes that exist only in the hottest stars."

As well as exploring the formation of uranium, RIKEN plans to measure the properties of various very short-lived nuclei, as well as looking for 'magic numbers' of neutrons and protons that allow heavy nuclei to be surprisingly stable. These experiments will start from next year, with full operation scheduled for 2011. The facility makes Japan the world leader in the field, says Ysushige Yano, director of the RIKEN Nishina centre for accelerator-based science, adding that Japan's other big physics facilities have just been upgrades of US and European versions. "But this time it is different," he boasts. "This time, Japanese scientists are leading the way."

Rivals aim not to let Japan savour its victory for long. A US plan for a superconducting linear accelerator called the Rare Isotope Accelerator has stalled, at a proposed cost of $1 billion. But France is expected to complete construction of its new radioisotope facilities, including experiments, by around 2012 and Germany by 2014. "In five or six years, Japan may lose the number one position," says Sydney Gales, director of the French heavy-ion accelerator GANIL in Caen. ■

Ichiko Fuyuno

Often he is asked what he has done with the roughly $350,000 in Nobel Prize money, an enormous sum in a country where experienced researchers are being promised 30,000 rubles ($1150) a month by 2008. He says that he has put the money away for the college educations of his two great-grandchildren, a twin boy and girl living in Princeton, New Jersey.

He sold his country house to help pay for medical treatment and likens his fate to that of two great Soviet physicists, Igor Y. Tamm and Lev D. Landau, both Nobel laureates with whom he worked. (Like Tamm, Ginzburg was recruited to help design the first Soviet nuclear bombs, but by a stroke of luck, he says in his Nobel autobiography, his low security rating kept him in Moscow, away from the Arzamas-16 military site.) Although he is proud to have followed in the footsteps of Tamm and Landau as a physicist, he says he is ...h [to the ... an essay ...hich he is ...Physics, ...18. ...otrophic disease, ...a respira- ...nen case. ...ears after accident. ...rance for ...an essay ...the very ...dreamed ...s death,"

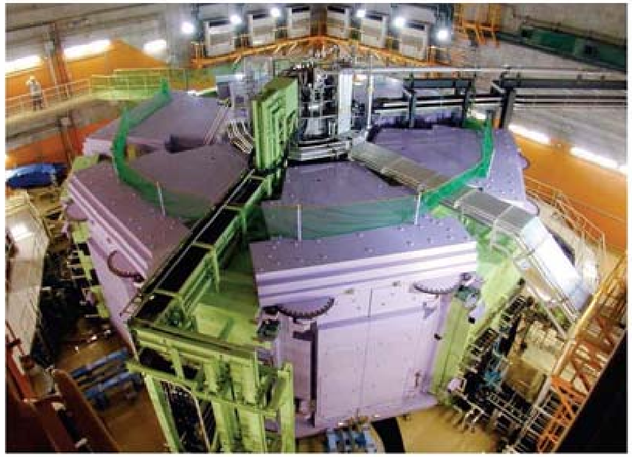
...in a rela- ...to avoid ...anasia, a ...hat I can. ..."success- ...e written, ...f articles ...uch long ...l the joke ...e?' The

...fficiently ...ht-to-die ...to write ...has con-

...ing inter- ...Zdravy ...g that he ...rse in his ...ays. "For

–**BRYON MacWILLIAMS**

Bryon MacWilliams is a writer in Moscow.



NUCLEAR PHYSICS

Japan Gets Head Start in Race to Build Exotic Isotope Accelerators

A new facility begins to explore the structure of the nucleus as Europe awaits two machines and the United States revises its plans

WAKO, JAPAN, AND ROSEMONT, ILLINOIS— Sometime this month, a warning siren will clear personnel out of the bowels of a massive concrete building in Wako, a city just east of Tokyo. Then, the world's most powerful cyclotron will propel a stream of uranium ions at a carbon target. The resulting smashup will produce radioactive nuclei that have never existed outside a supernova. Such fleeting exotic bits of matter should help unify a fragmented theory of the nucleus, reveal the origins of the heavier elements, and provide clues to why the universe contains so much more matter than antimatter.

Data from the $380 million Radioactive Isotope Beam Factory (RIBF) at the Institute of Physical and Chemical Research (RIKEN) in Wako "will allow us to form a new framework for nuclear physics," says Hiroyoshi Sakurai, chief nuclear physicist at RIKEN's Nishina Center for Accelerator-Based Science, which built and will operate the machine. Richard Casten, a nuclear physicist at Yale University, agrees that knowledge sifted from the atomic shards "will be transformational in our understanding of nuclei."

But Japanese physicists aren't the only ones staking a claim to this fertile turf. RIBF is the first in a new generation of exotic isotope accelerators. Researchers in Germany and France hope to have machines ready to power up in 2010 and 2011, respectively. Meanwhile, a U.S. National Research Council (NRC) report released last week makes the case for building the most powerful machine of all. U.S. researchers hope the report will jump-start a project, once known as the Rare Isotope Accelerator (RIA), that stalled last year after the U.S. Department of Energy (DOE) ordered researchers to cut in half the projected $1 billion cost. "This report helps get the project unstuck by more clearly defining the science that can be done with it and the international situation," says Michael Turner, a cosmologist at the University of Chicago and chief scientist at DOE's Argonne National Laboratory in Illinois, one of two institutions vying for the machine.

Accounting for more than 99.9% of an atom's mass and less than a billionth of its volume, the nucleus is a knot of protons and neutrons. Nature provides 260 stable nuclei, and researchers have glimpsed 10 times that number of unstable ones. But machines that produce even more would provide new insights into the structure of the nucleus.

For example, since the 1940s, physicists have known that nuclei with certain "magic" numbers of protons or neutrons appear to be more stable than might otherwise be expected. However, recent findings suggest that the known magic numbers—2, 8, 20, 28, 50, 82, and 126—may not apply to nuclei with an extreme excess or deficiency of

Milestones of Commissioning

At 16:00 on December 28 2006, the first beam extracted from the SRC: a 345 MeV/nucleon 27Al10+ beam was extracted. Its mass to charge ratio is the same as that of a 238U88+ beam. In this acceleration trial we skipped the fRC, because the vacuum leaking took place in this cyclotron. We could, however, confirm the acceleration performance of the SRC.

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At 3:00 on March 15 2007, the first RI beams were generated and identified by the BigRIPS. A 345 MeV/nucleon 86Kr31+ beam, mass to charge ratio of which is the same as that of a 238U86+ beam, was projectile-fragmented. In this test run, we succeeded in operating the full cyclotron cascade including the fRC for the first time. After the first beam run, we accelerated a uranium beam with the fRC, and we observed that the most probable charge state after the stripping at 51 MeV/nucleon is 86+ in stead of 88+ originally expected.

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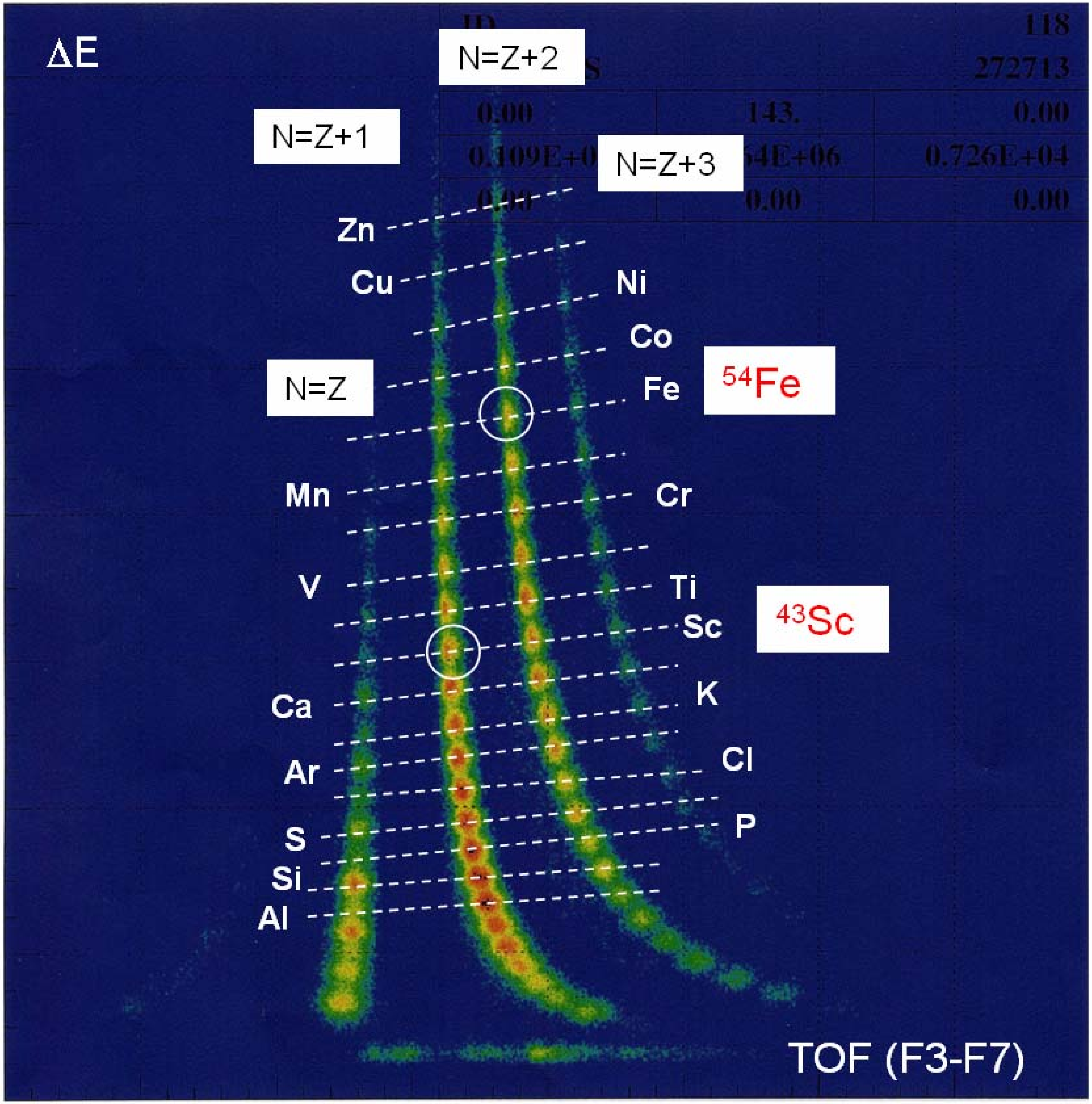
At 21:00 on March 23 2007, we succeeded in accelerating a 238U86+ beam up to 345 MeV/ nucleon.

And eventually, at 6:40 on March 27, we successfully identified a large variety of RI beams produced via the in-flight fission of the 345 MeV/nucleon uranium beam.

First RIB Prod.
15th Mar. 2007

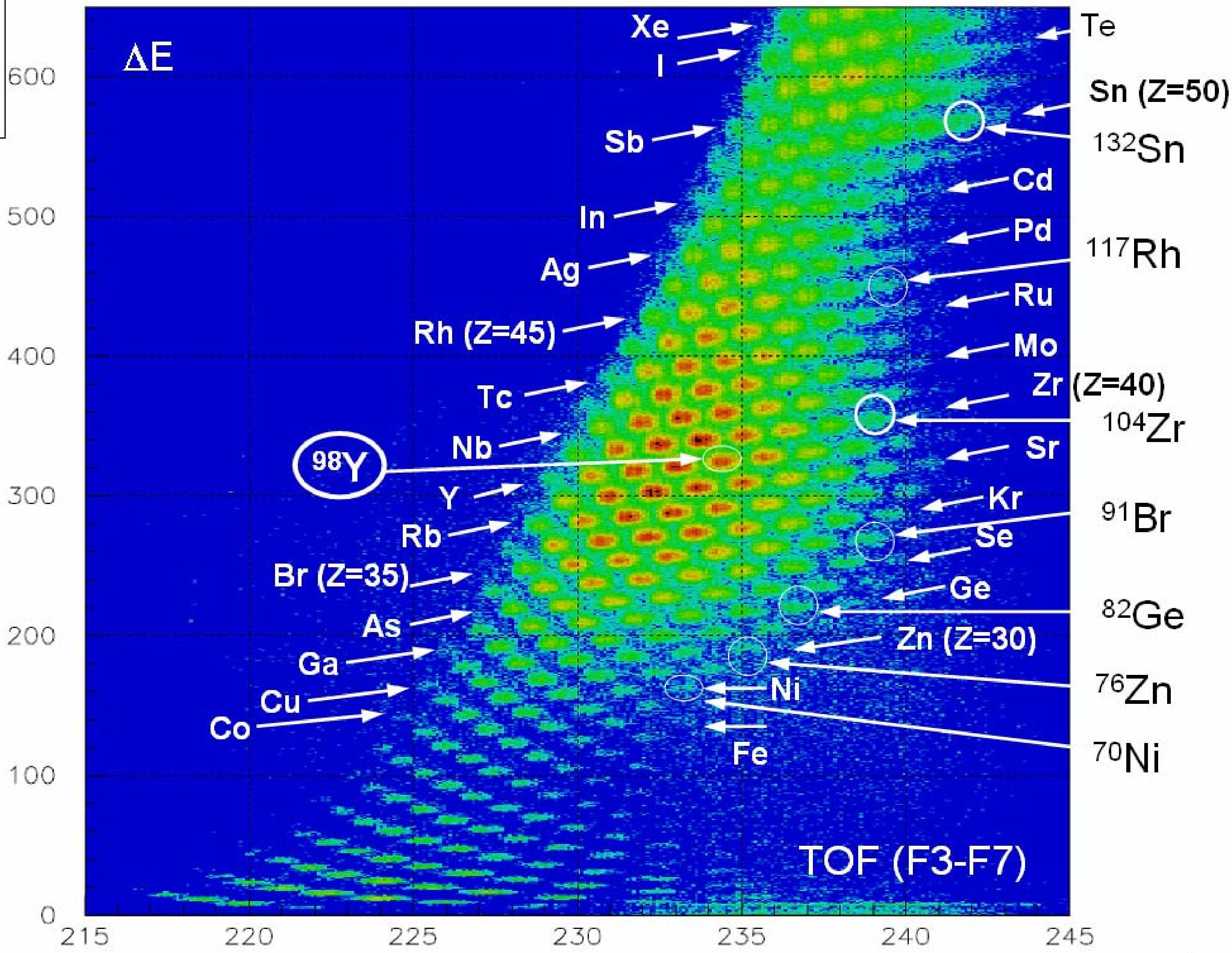
^{86}Kr + Be(2mm) at 345 MeV/u



T. Kubo et al.

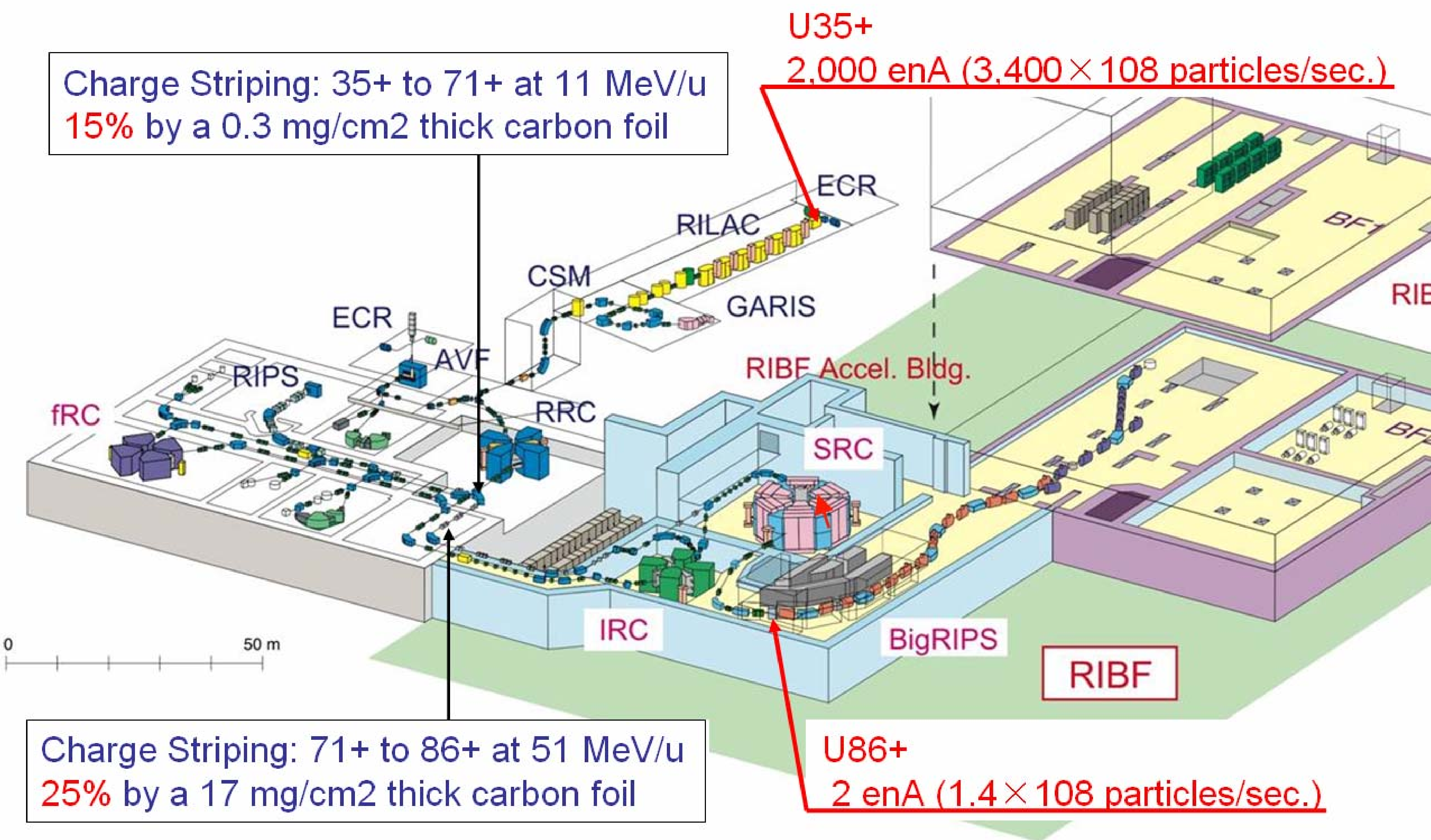
First Fission Fragment Prod.
27th Mar. 2007

^{238}U + Be(7mm)
at 345 MeV/u



T. Kubo et al.

Beam Transmission efficiency in the first test run



Miserable efficiency: 1%

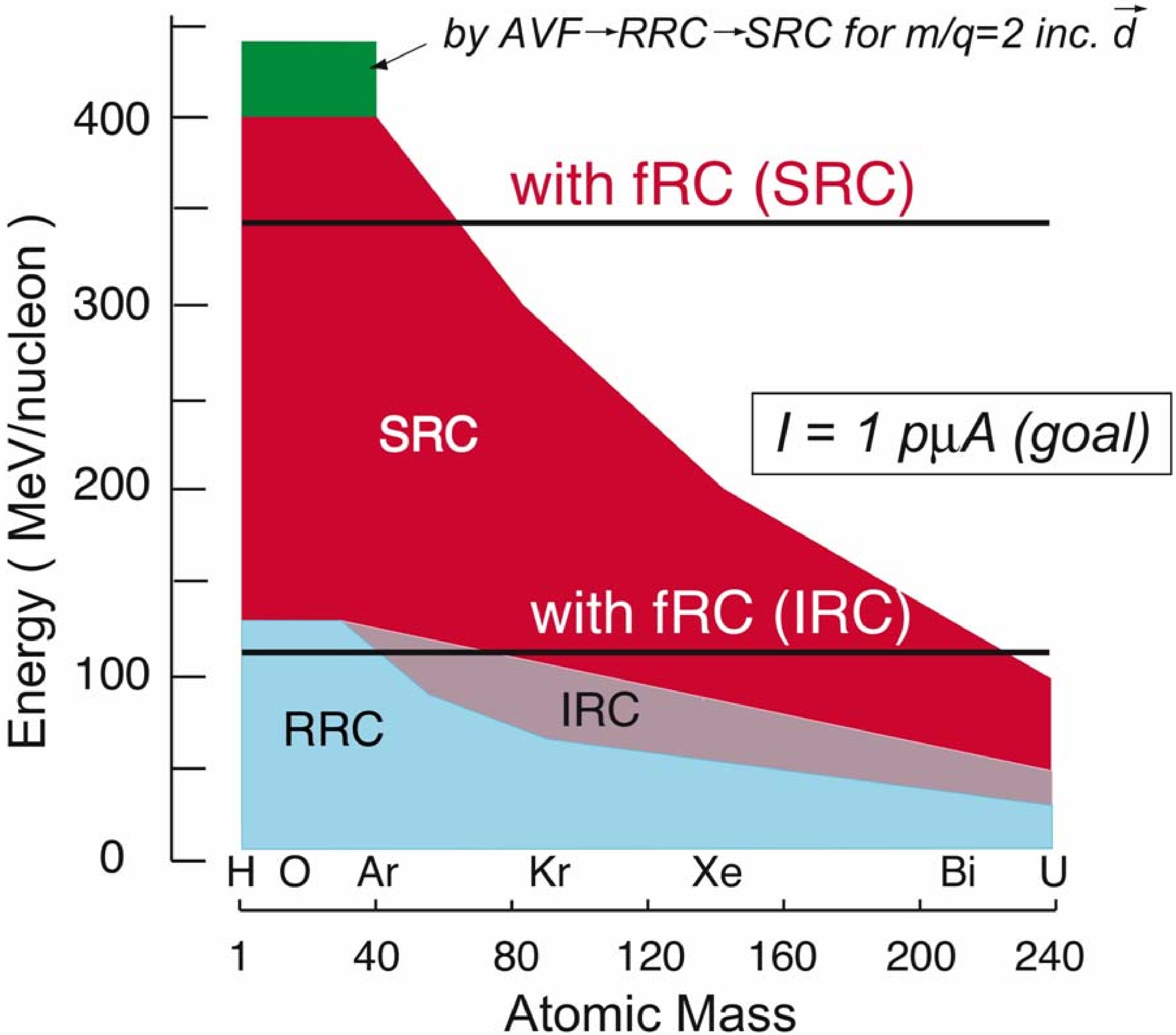
We were confronted with a variety of machine troubles in this first long run. The troubles were as follows:

A flat-top cavity of the IRC could not be excited because its high-power leakage rf electromagnetic wave damaged discharge damper resistors of electrostatic inflector and deflector placed nearby this cavity; the deflector channel for the beam extraction with a curvature of 90 m was incorrectly manufactured to have inverse curvature against the beam trajectories;

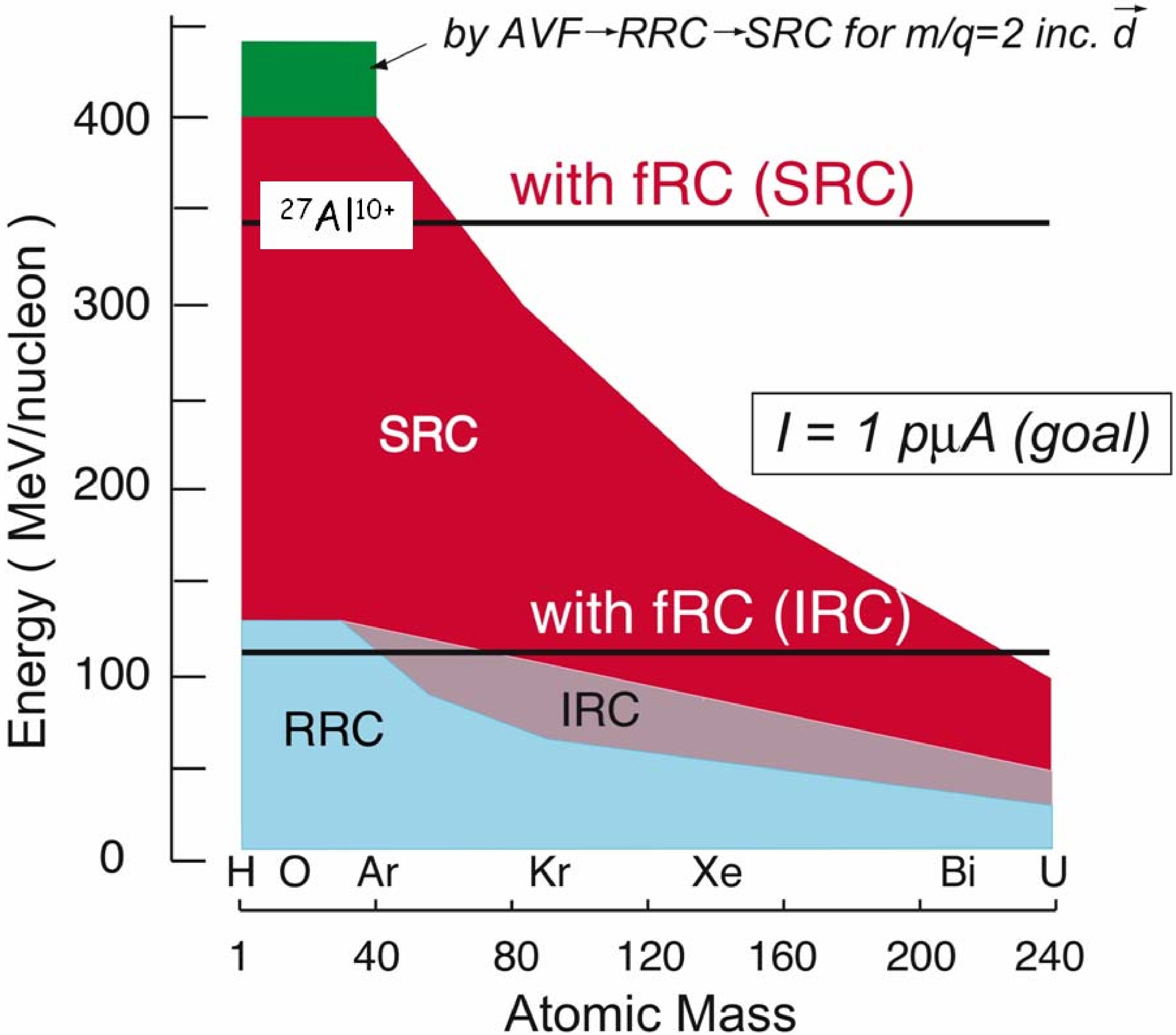
In the SRC, 1 rf cavity among 4 rf cavities and a flat-top cavity could not be excited due to burn out of the contact fingers and the oscillator trouble; even in the operational three rf cavities, enough acceleration voltages could not be generated due to the lack of enough conditioning time.

These troubles brought about miserable beam transmission efficiency and experimental duty factor. This test experiment run was carried out for machine debugging and conditioning, and operator training, as well.

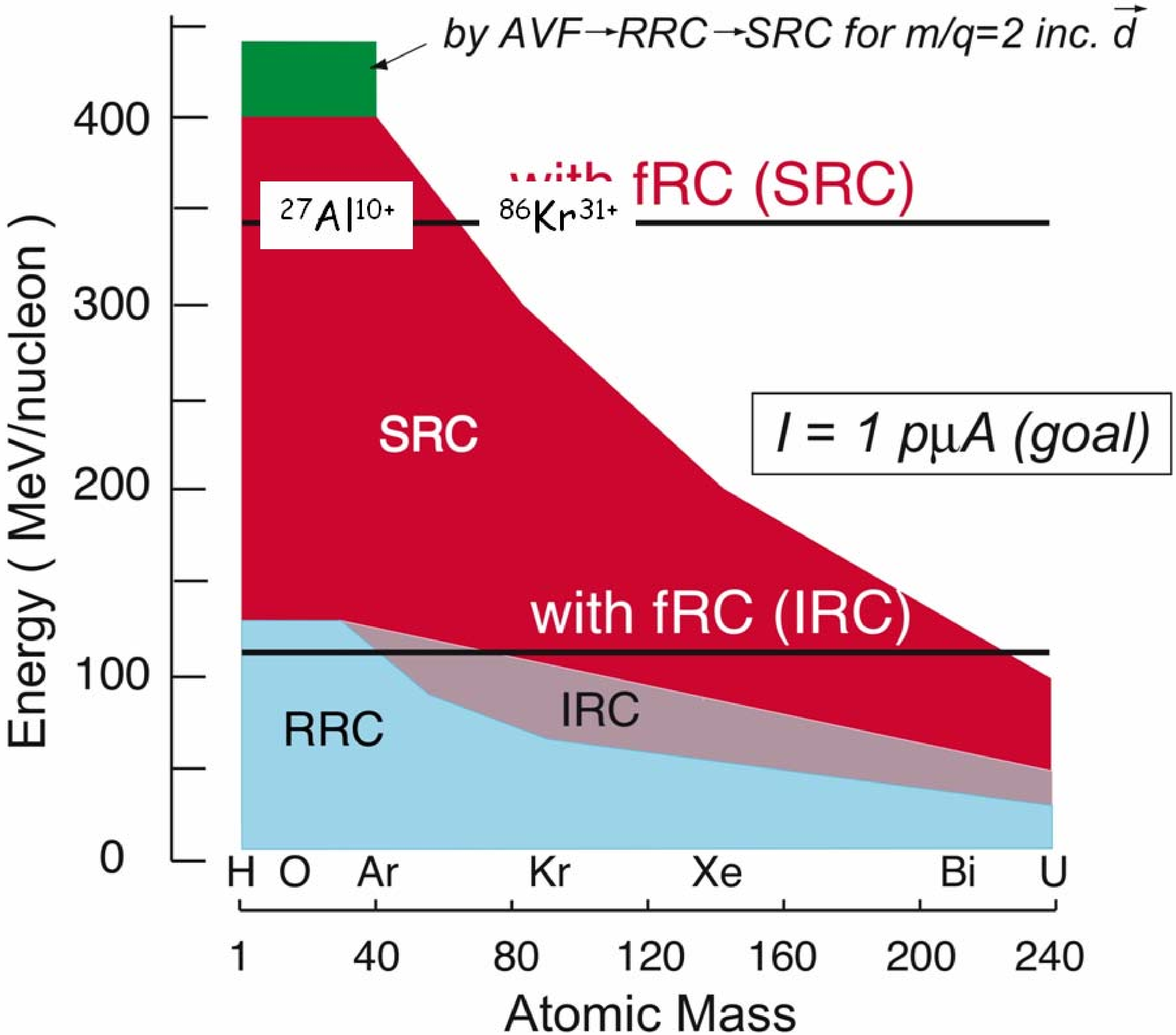
Acceleration performance of RIBF



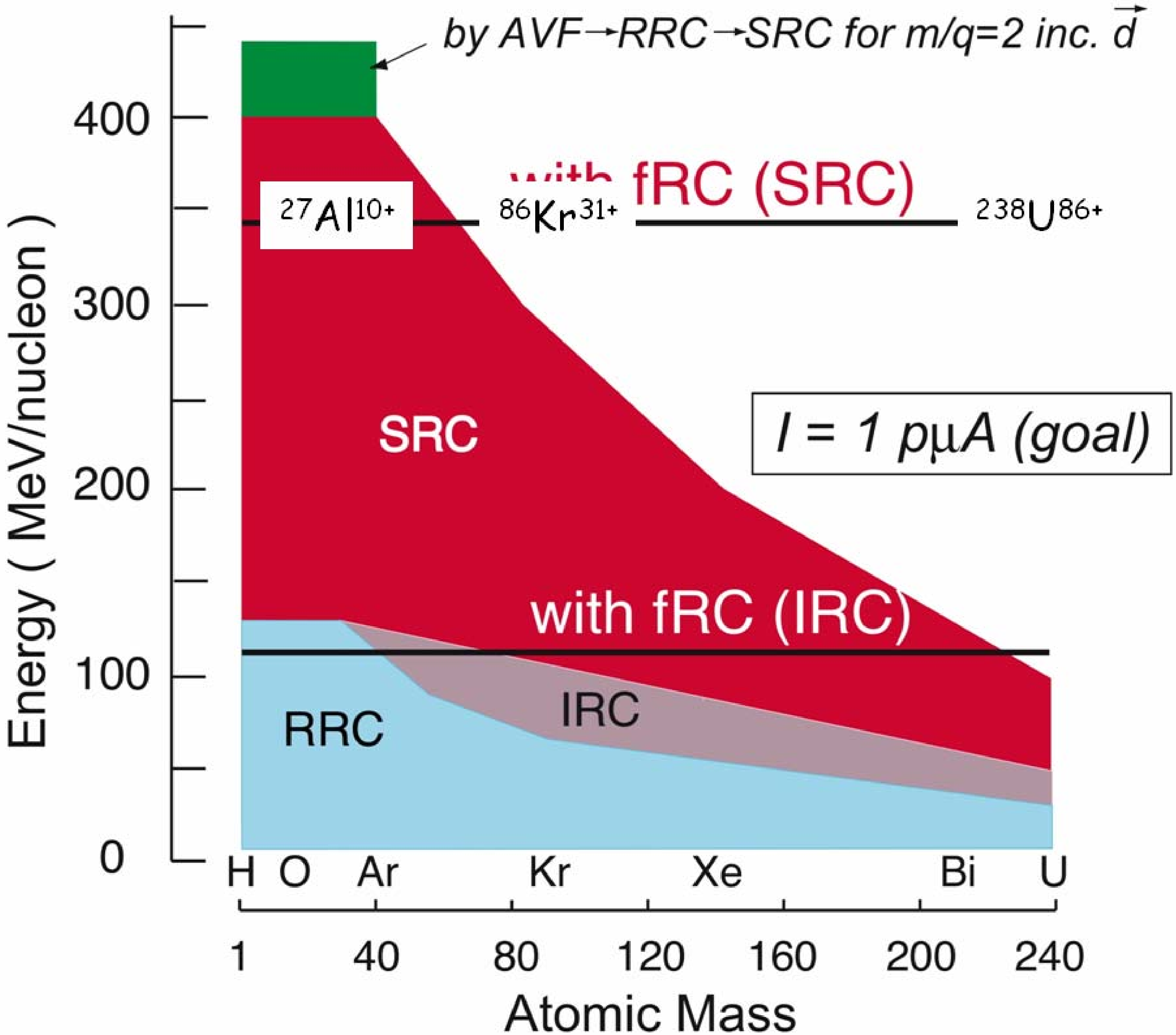
Acceleration performance of RIBF



Acceleration performance of RIBF



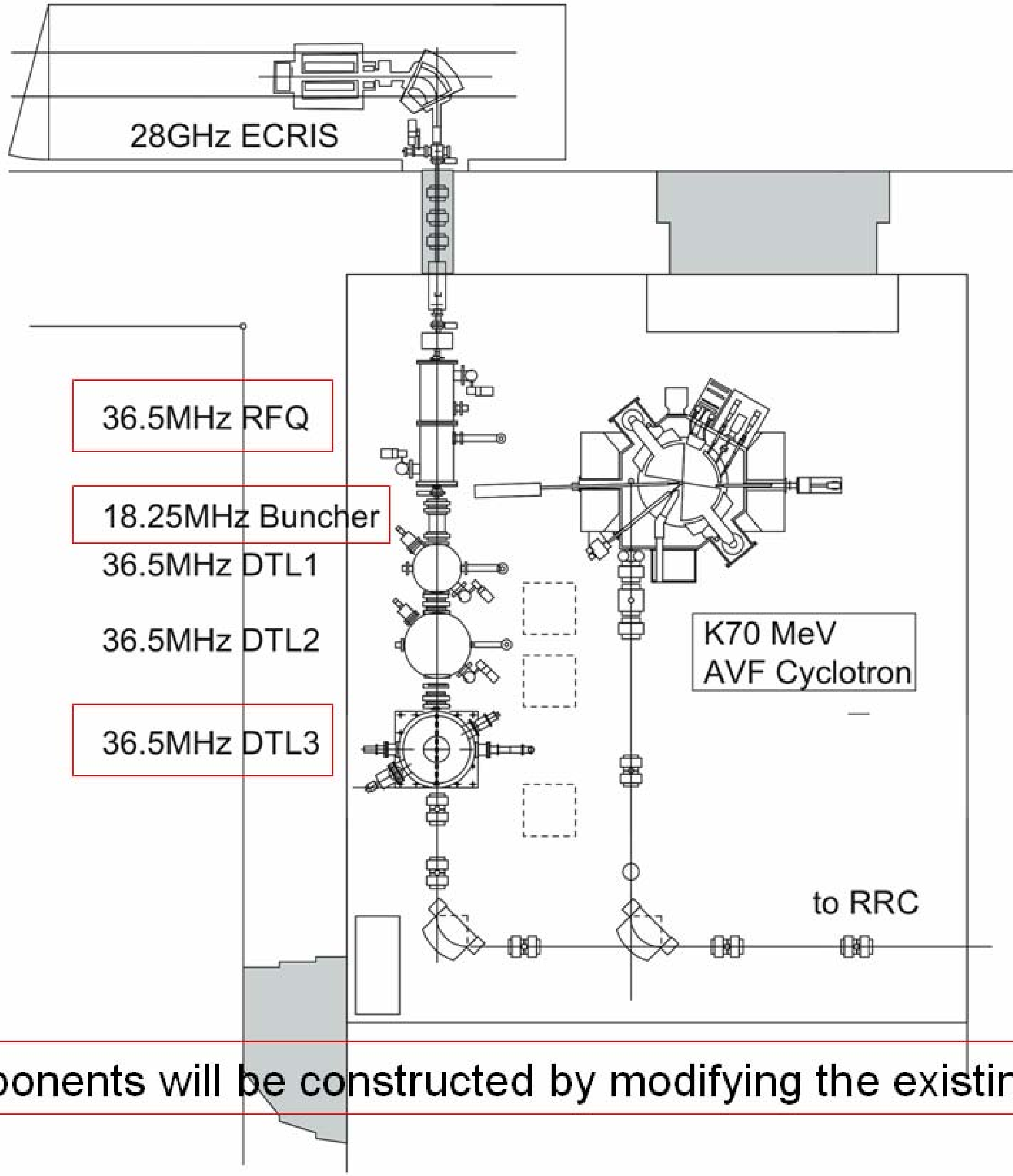
Acceleration performance of RIBF



Future Upgrades

- Repair, Conditioning
- New Injector to RRC, with 28 GHz SC-ECRIS
- Liquid Li Charge Stripper
- Construction of Major Experimental Installations

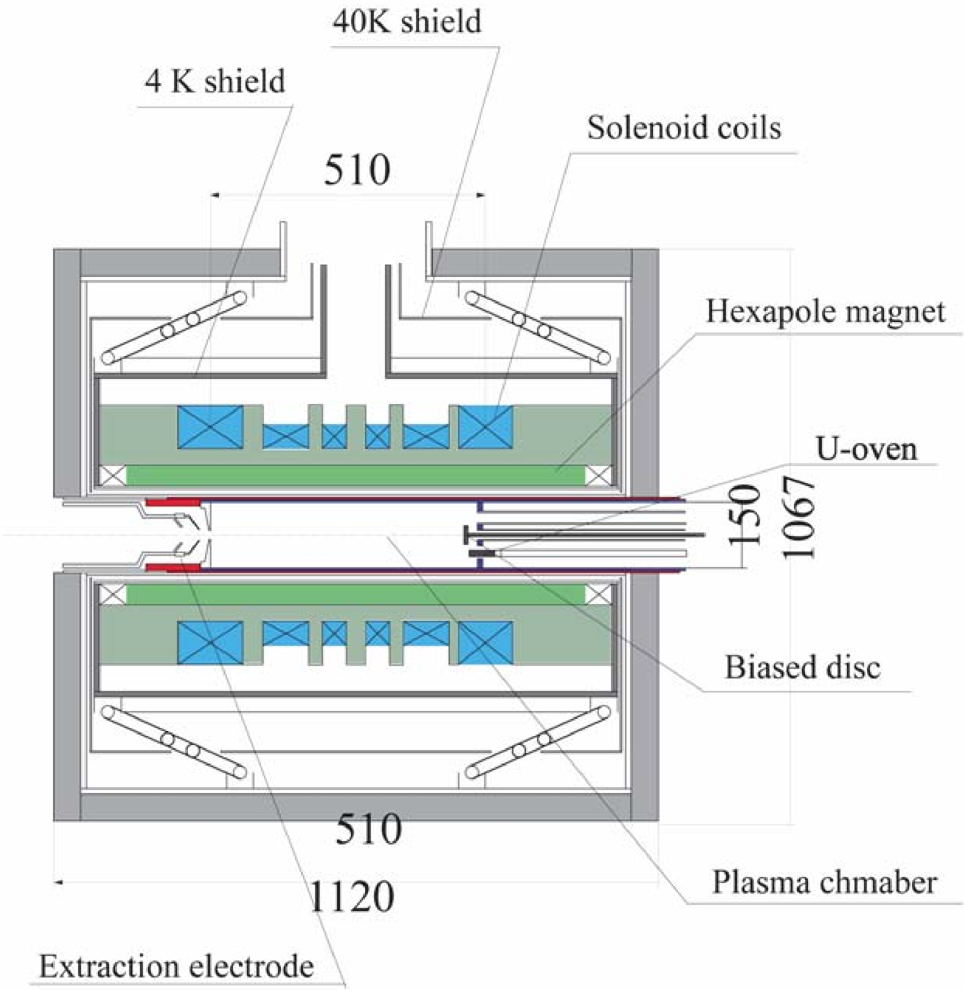
New injector to RRC will be operational late in 2008



These components will be constructed by modifying the existing ones

Conceptual design of new SC-ECRIS(28GHz)

Operation test will be started in summer 2008



$(B_{axial})_{max}$	4T
$(B_{rad})_{max}$	2T
B_{min}	0~1T
Chamber length	51cm
Mirror-mirror space	51cm
Chamber diameter	15cm

Final goal

U^{35+} >15pμA

Comparison of other operational ECR sources

	AECR-U	RIKEN	VENUS
Freq. (GHz)	14GHz	18GHz	28GHz
B_{inj}/B_{min}	4	2.8	4
B_{rad}/B_{min}	2.1	2.2	2.2
plasma volume (cm^3)	~125	~100	~500
DB/DR (kG/cm)	~2.7	2.7	~2.6
RF power (kW/L)	~1.0	0.3	~0.5
Method	UO_2+Oven	UF_6	Bi+Oven
U^{35+}	16μA (0.45pμA)	2μA (0.06pμA)	180μA (5.pμA)

$$I_q = \frac{n_q\, q\, V}{\tau_c}$$

n_q : ion density

q : charge state

V : plasma volume

τ_c : ion confinement time

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	SC-ECRIS
Freq. (GHz)	28
B_{inj}/B_{min}	>4
B_{rad}/B_{min}	>2.2
plasma volume (cm^3)	~1100
DB/DR(kG/cm)	2.7
PF power(kW/L)	1.0
Method	UO_2+IH oven
U^{35+}	

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PF power(kW/L)	1.0
Method	UO_2+IH oven
U^{35+}	> 530μA (16pμA)

$$I_q = \frac{n_q \, q \, V}{\tau_c}$$

n_q : ion density

q : charge state

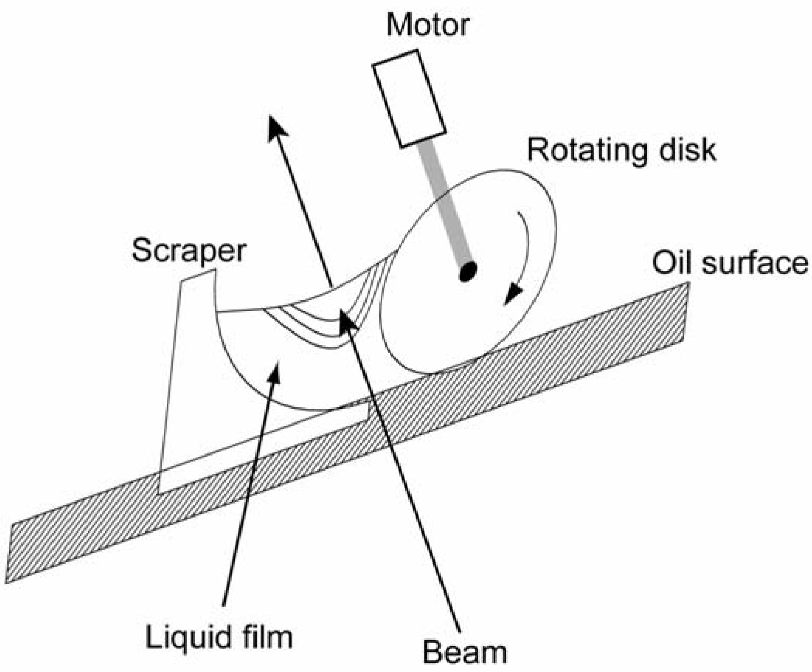
V : plasma volume

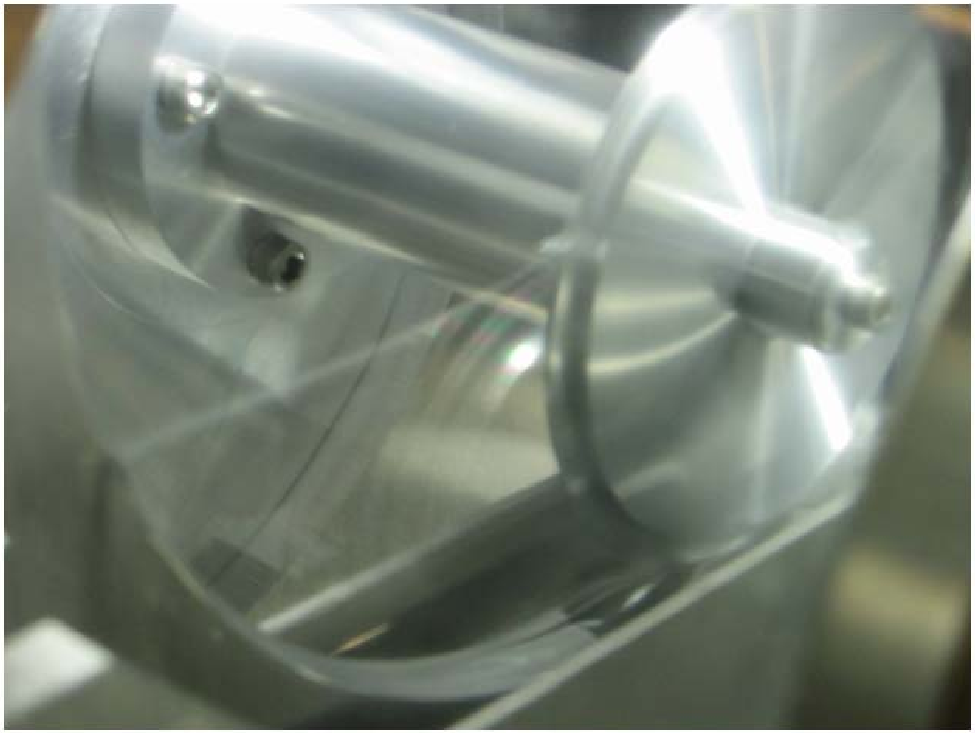
τ_c : ion confinement time

Conceptual design of Liquid Li Stripper

Operation test will be started in autumn of 2007

SH200 silicone oil of 50 cst kinematic viscosity is used. An about 0.1-mg/cm^2-thick film (of silicone oil withstood approximately 8 W/cm^2 heat deposit at maximum. (10 kW/cm^2 for 1pμA 350 MeV U beam)





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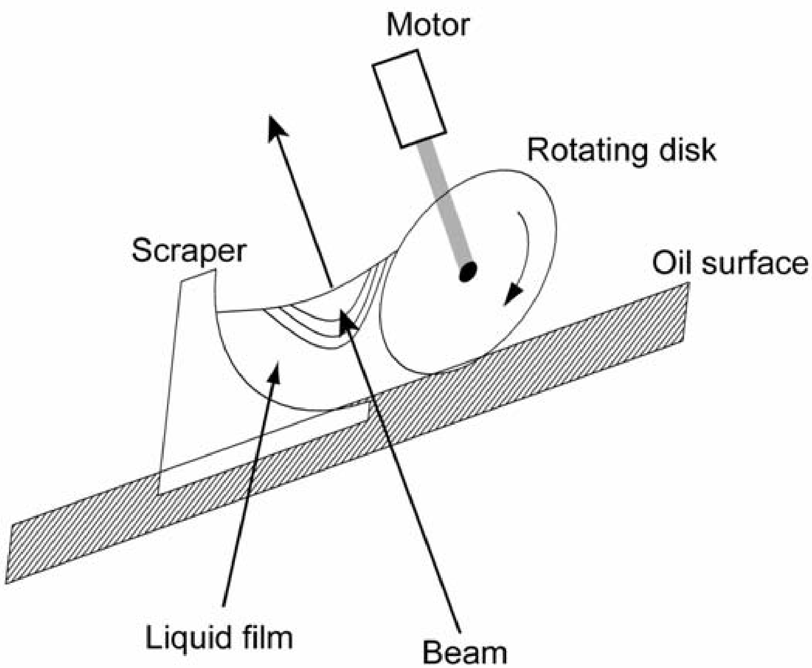

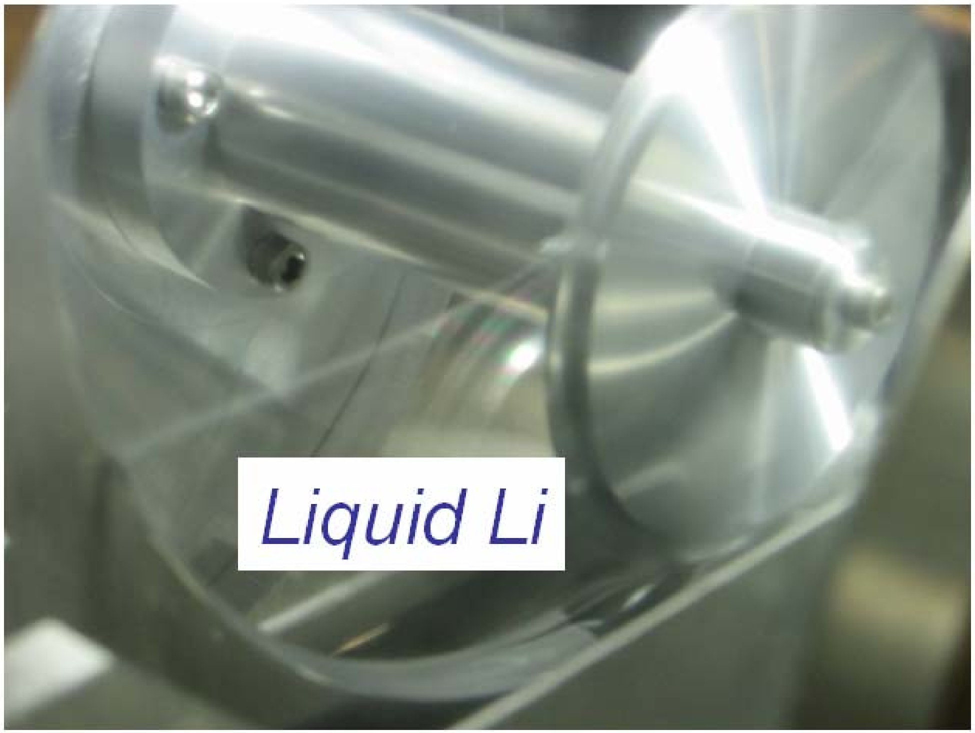

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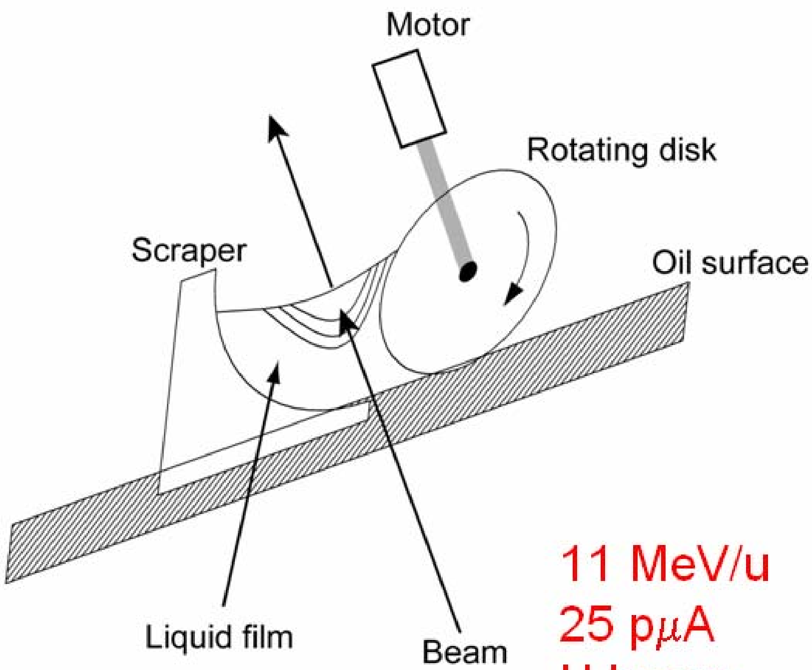
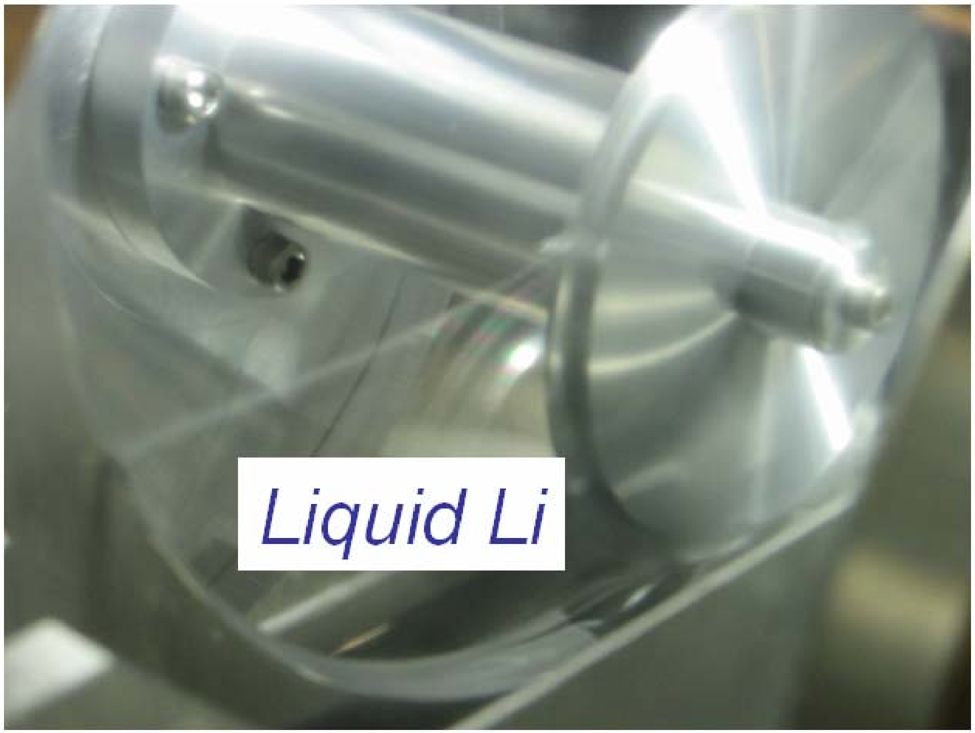
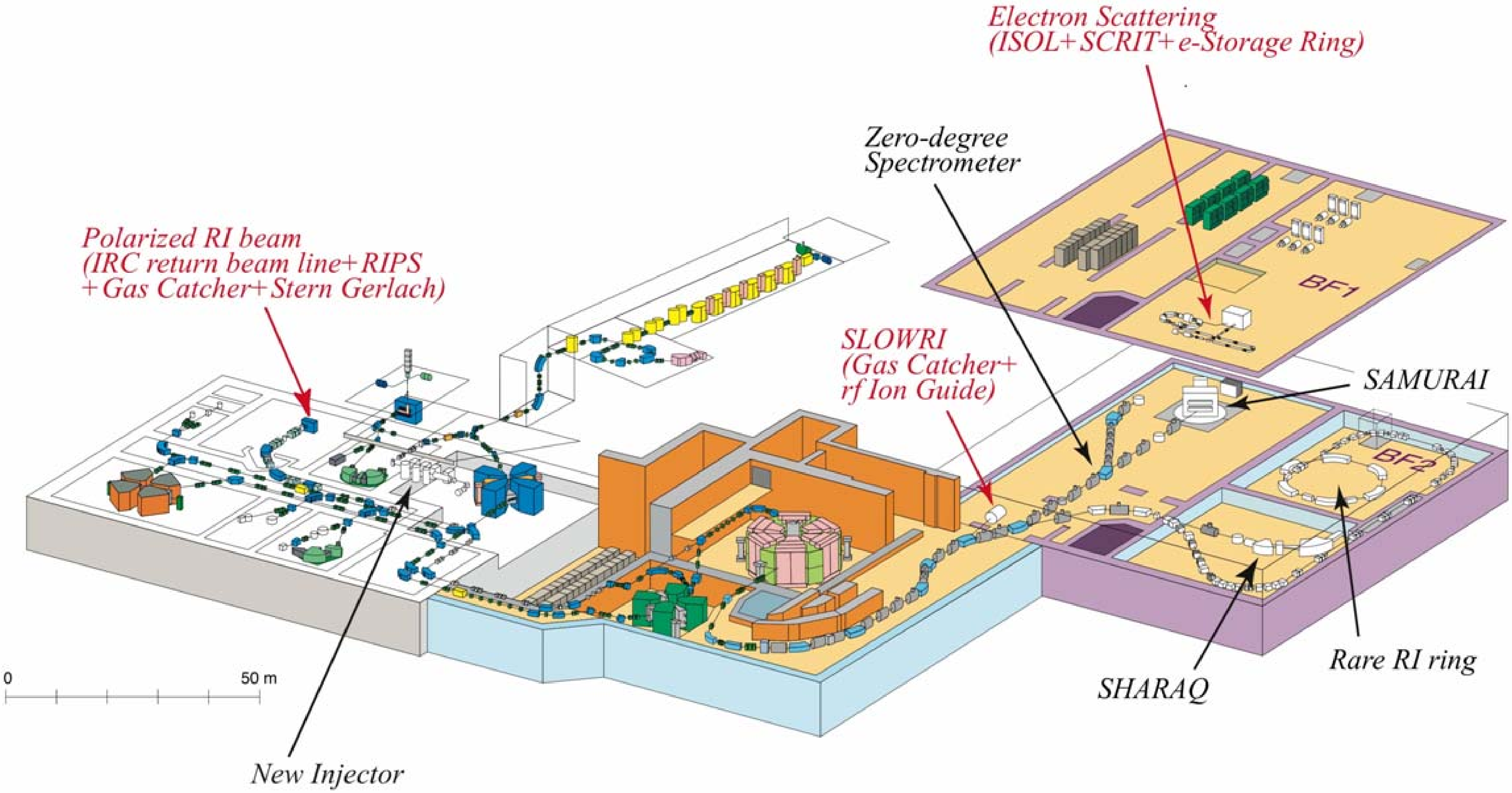


11 MeV/u
25 pμA
U beam



Major Experimental installations planned



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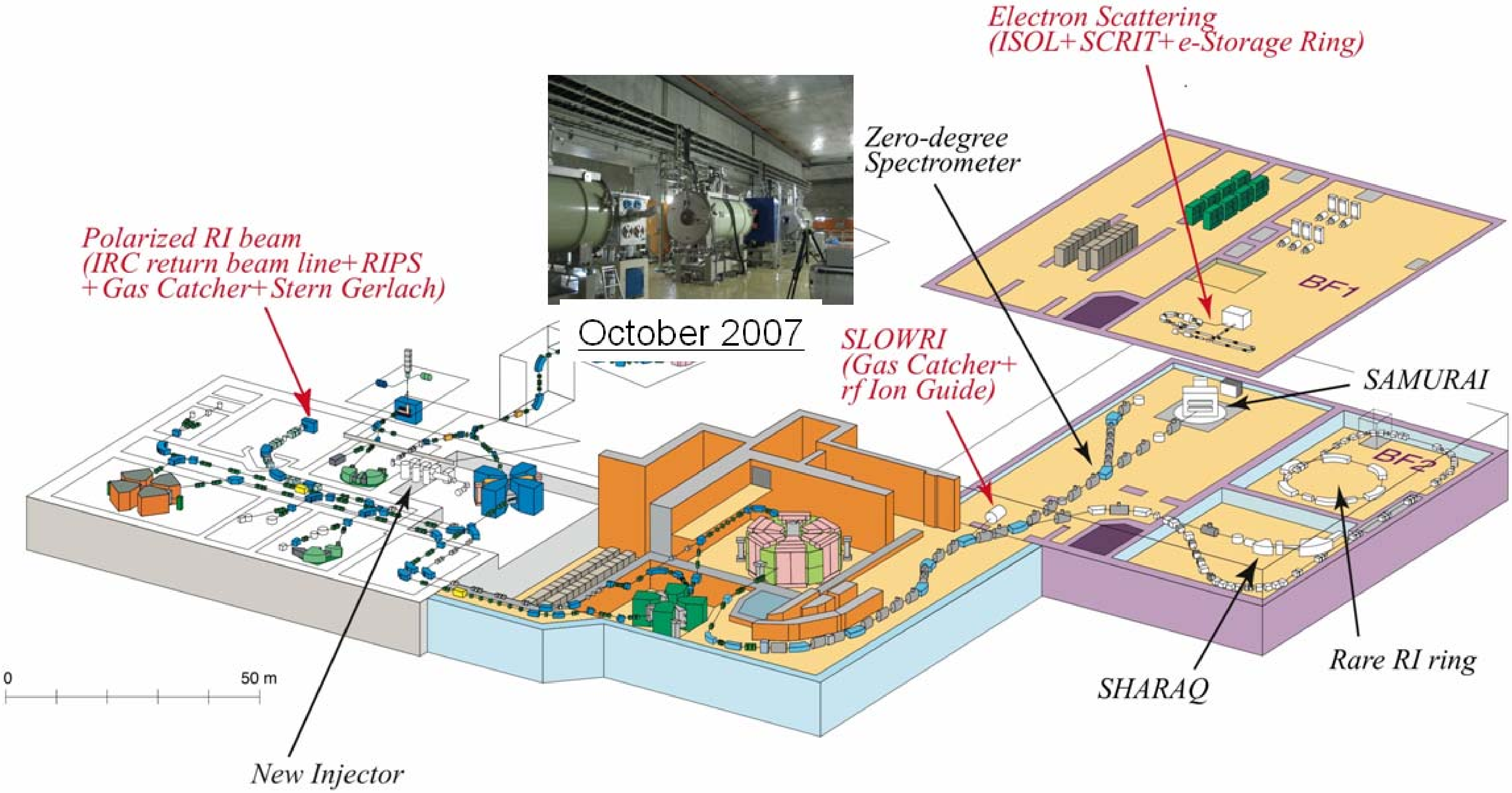

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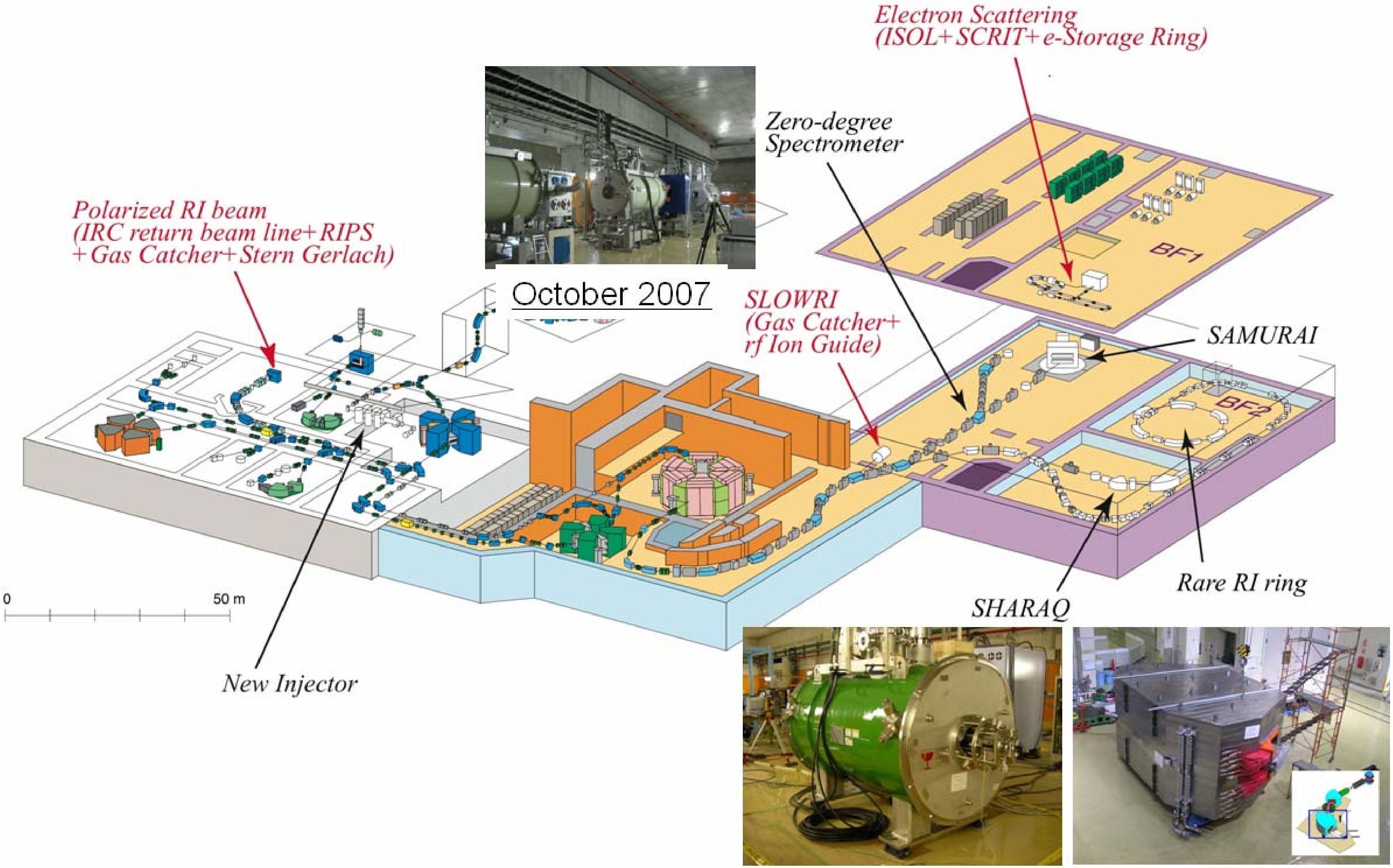
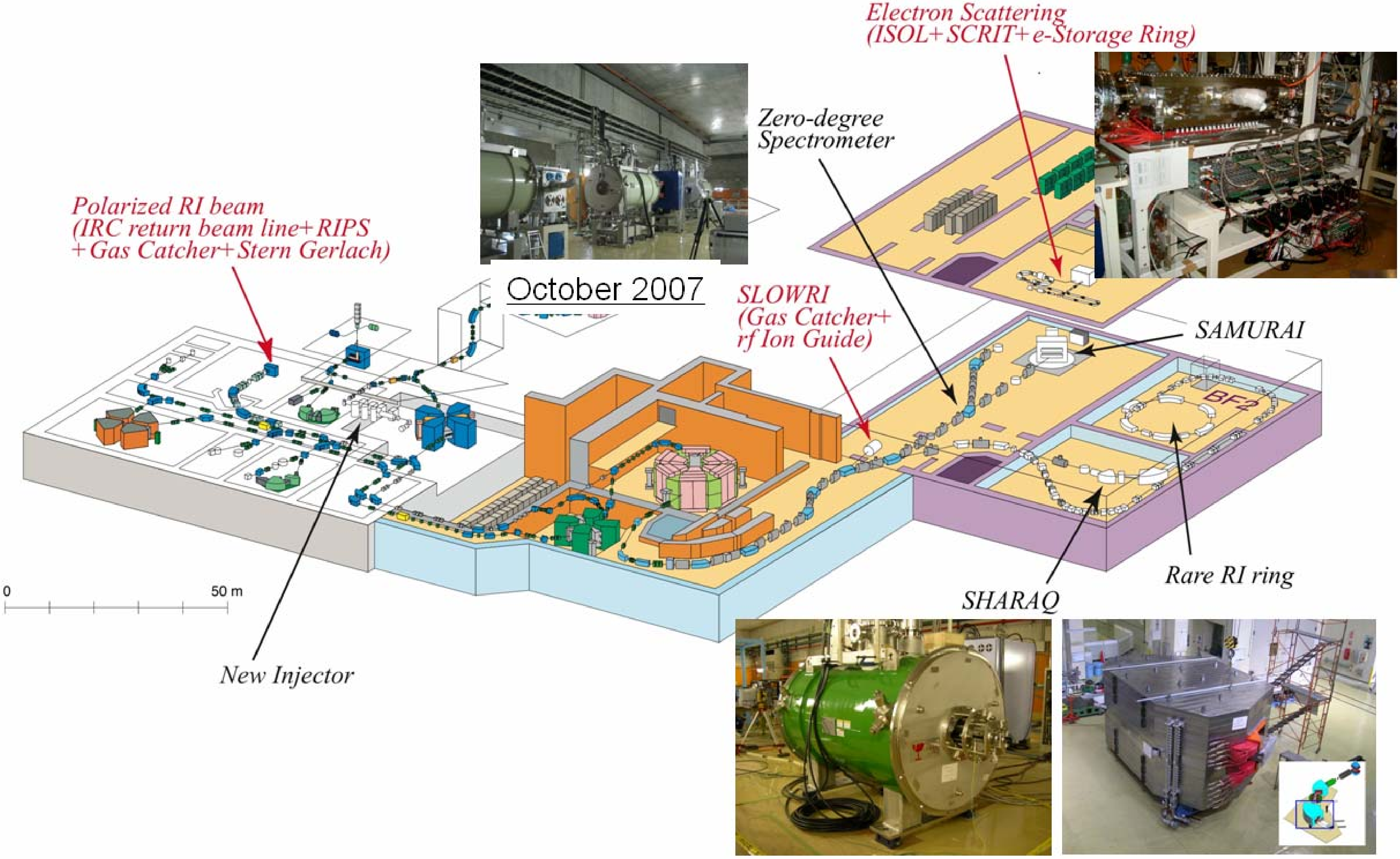


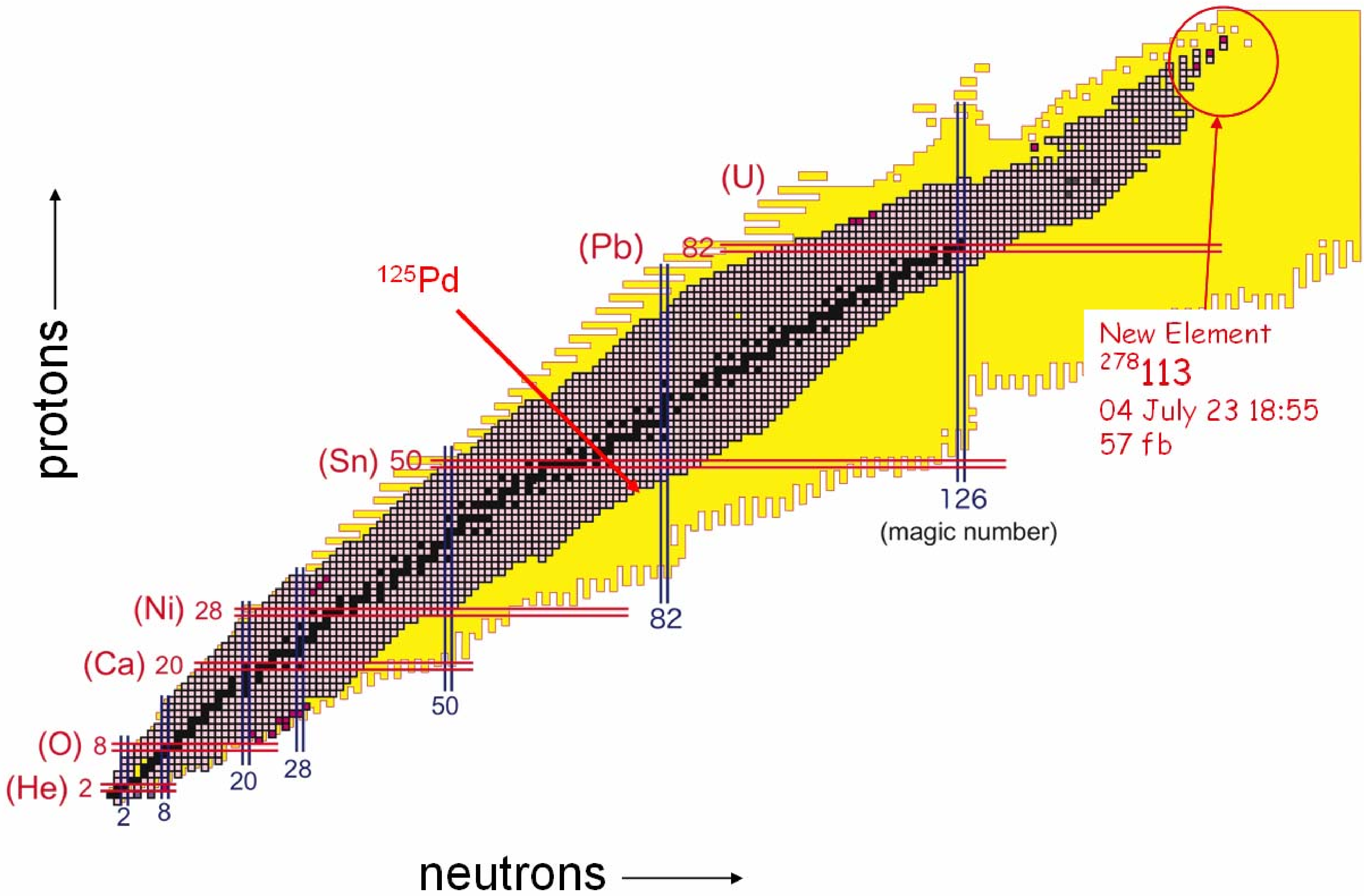
October 2008

Major Experimental installations planned

Observed elastically scattered electrons off self-confined Cs ions on Apr. 28 2007



October 2008

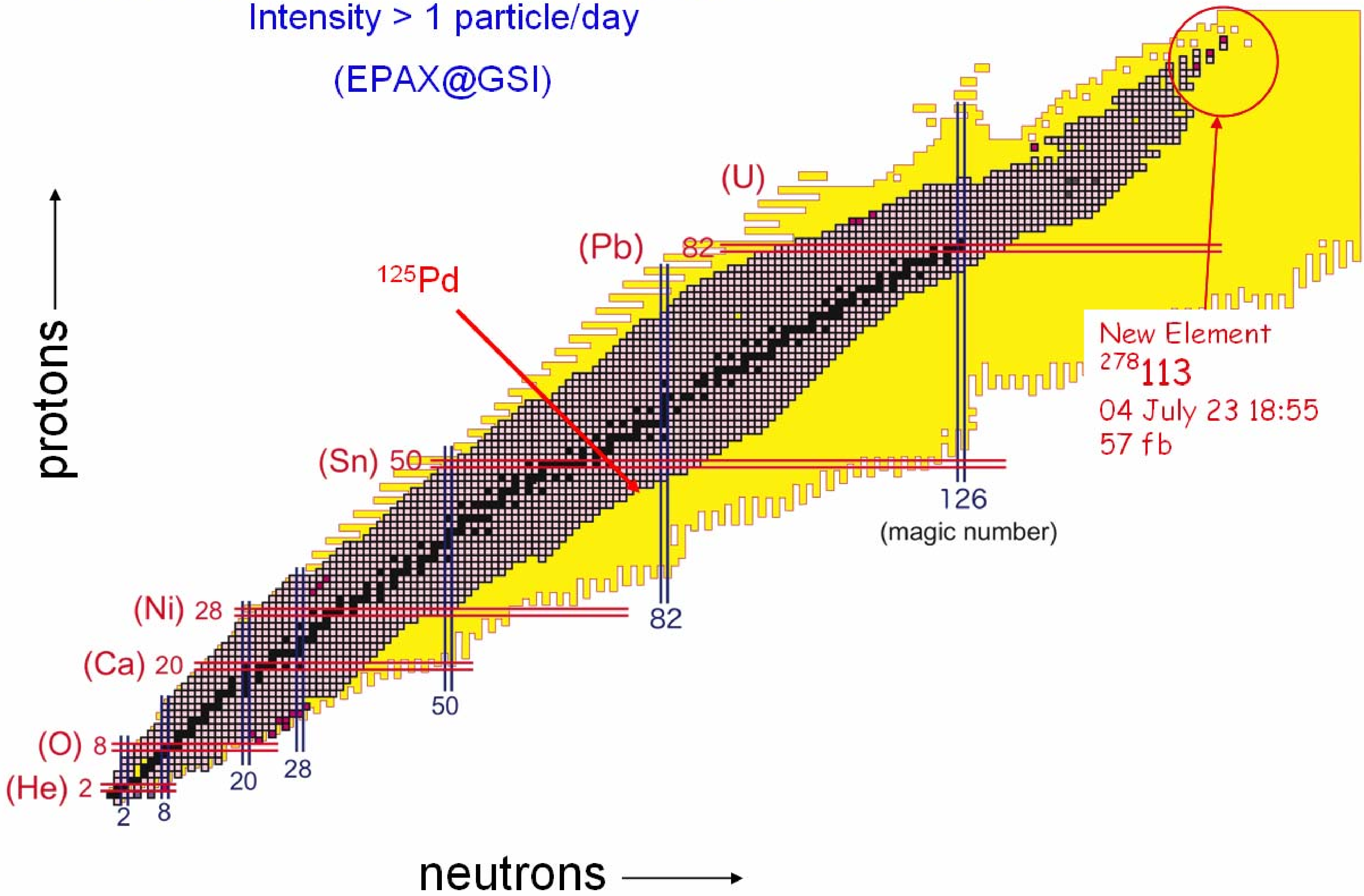


protons
neutrons
(U)
(Pb)
82
^{125}Pd
(Sn) 50
(Ni) 28
(Ca) 20
(O) 8
(He) 2
2
8
20
28
50
82
126
(magic number)
New Element
^{278}113
04 July 23 18:55
57 fb

Great expansion of nuclear world by RIBF

Intensity > 1 particle/day

(EPAX@GSI)



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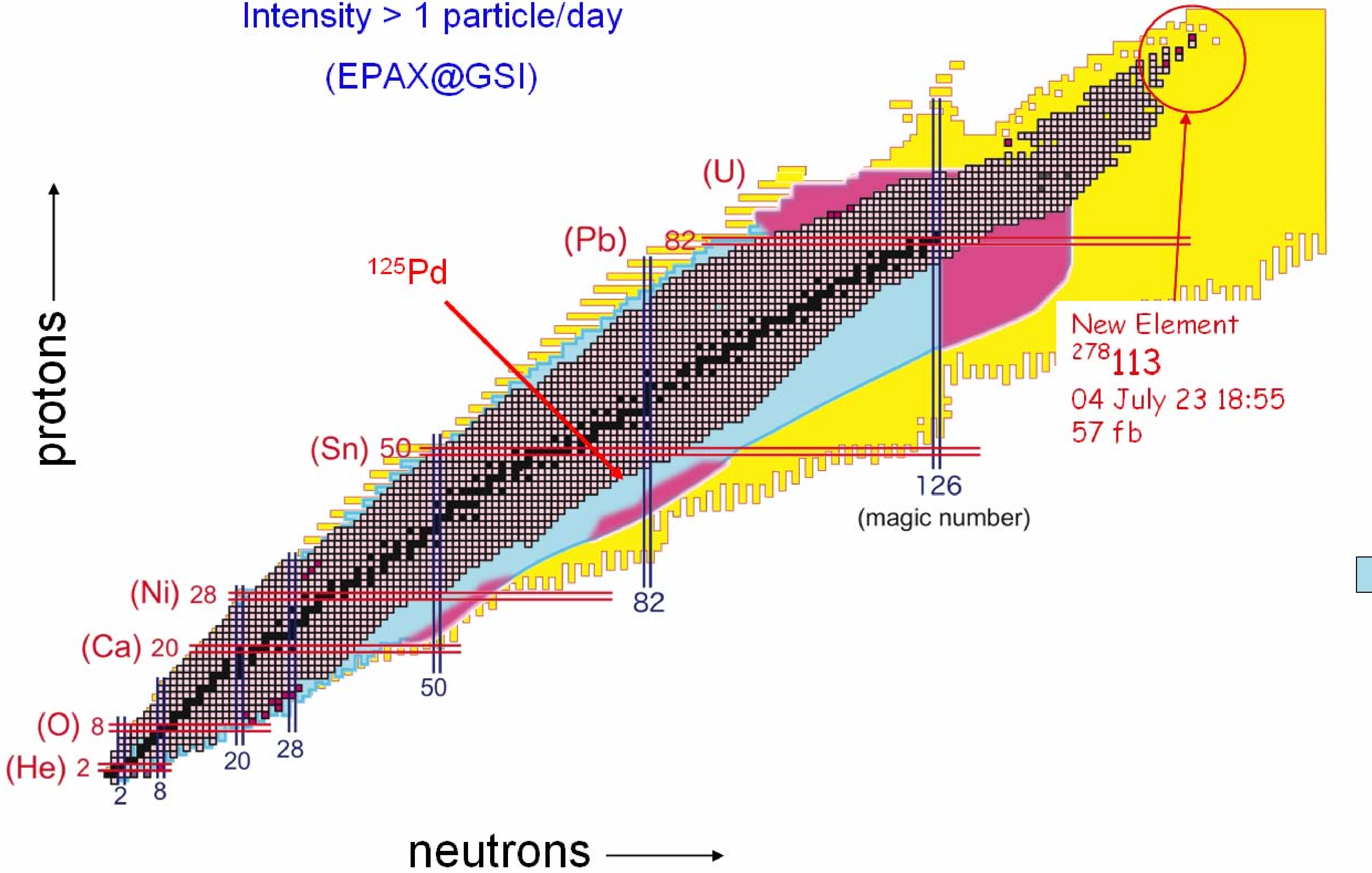

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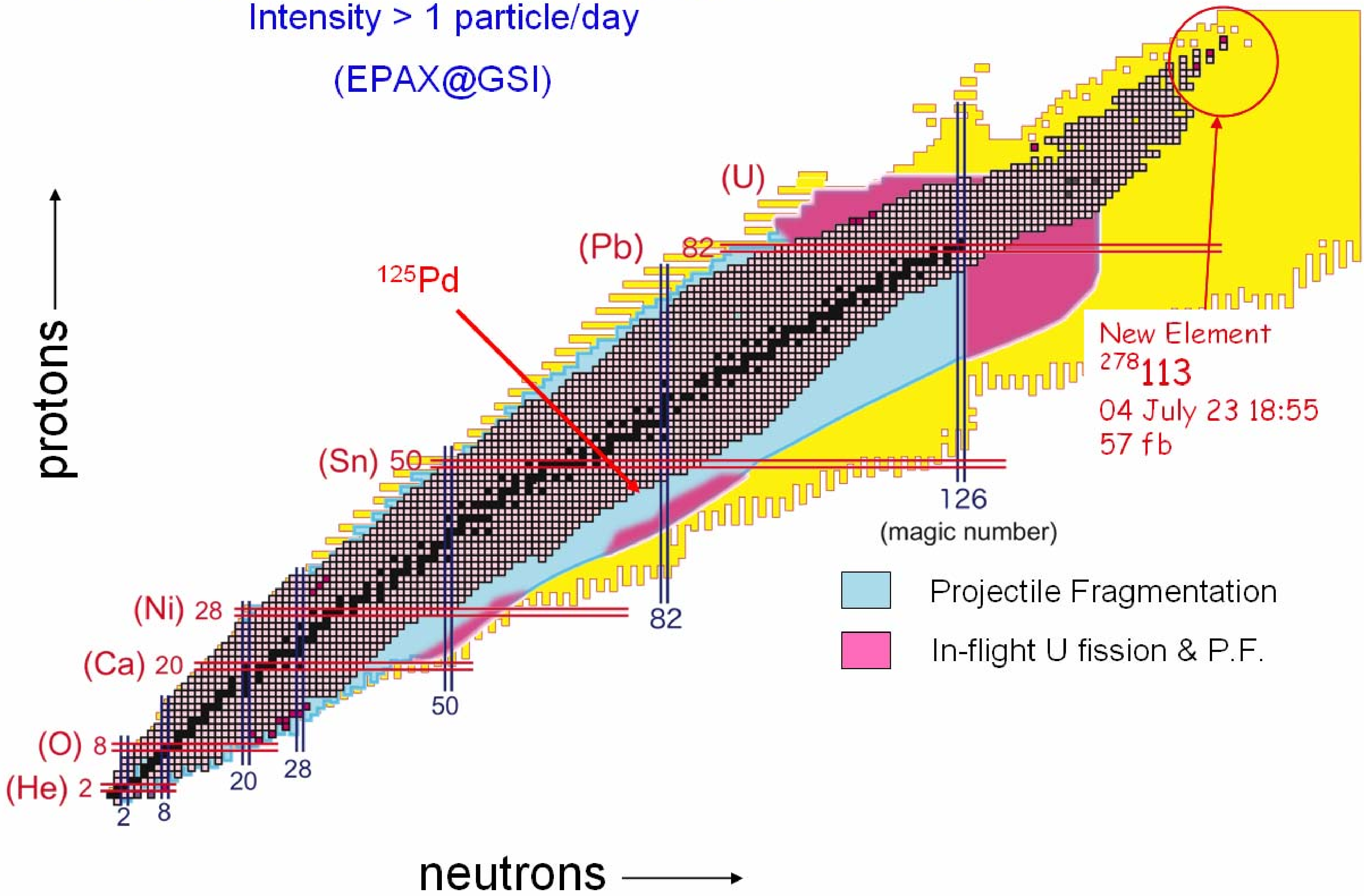

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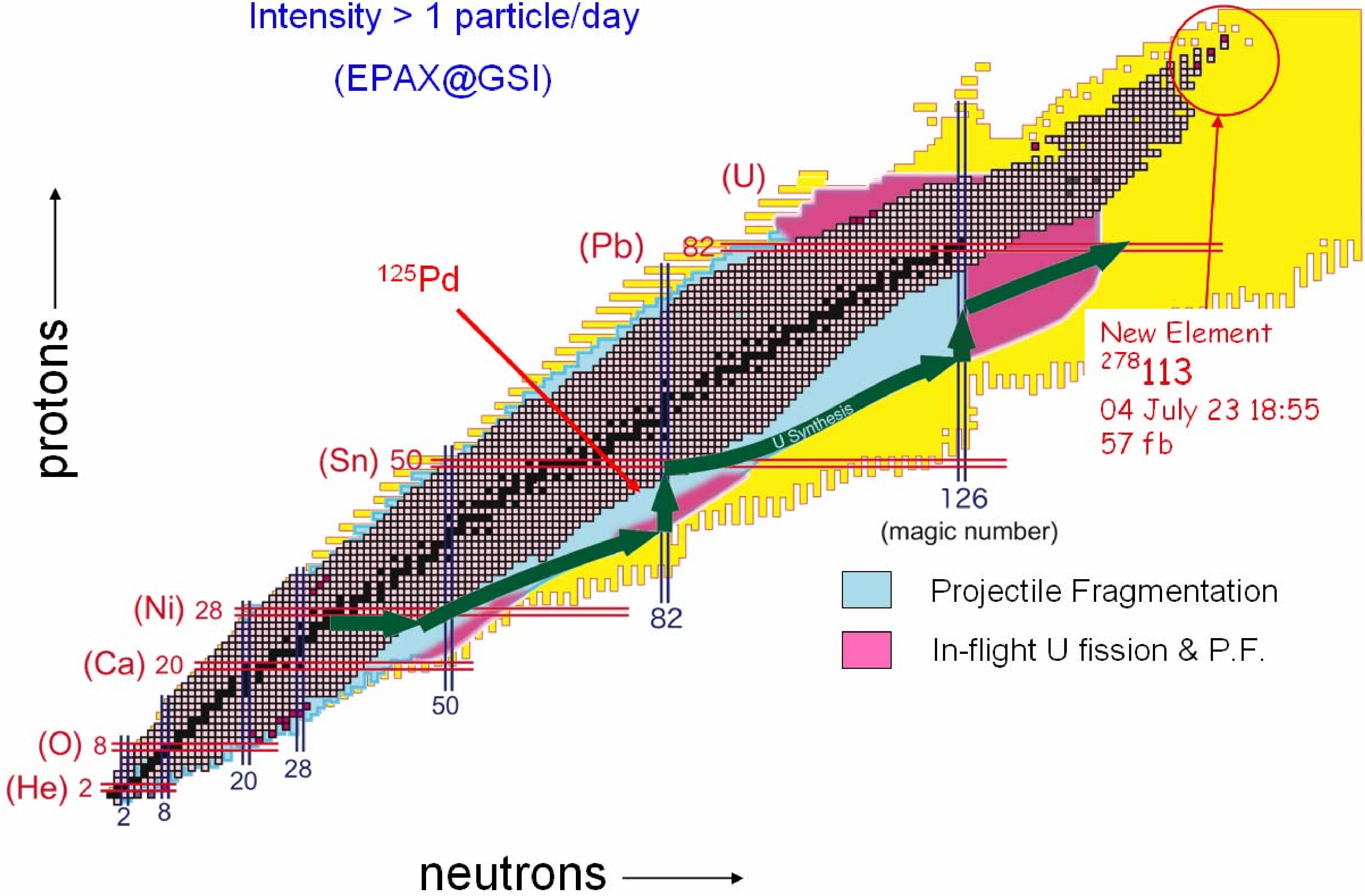

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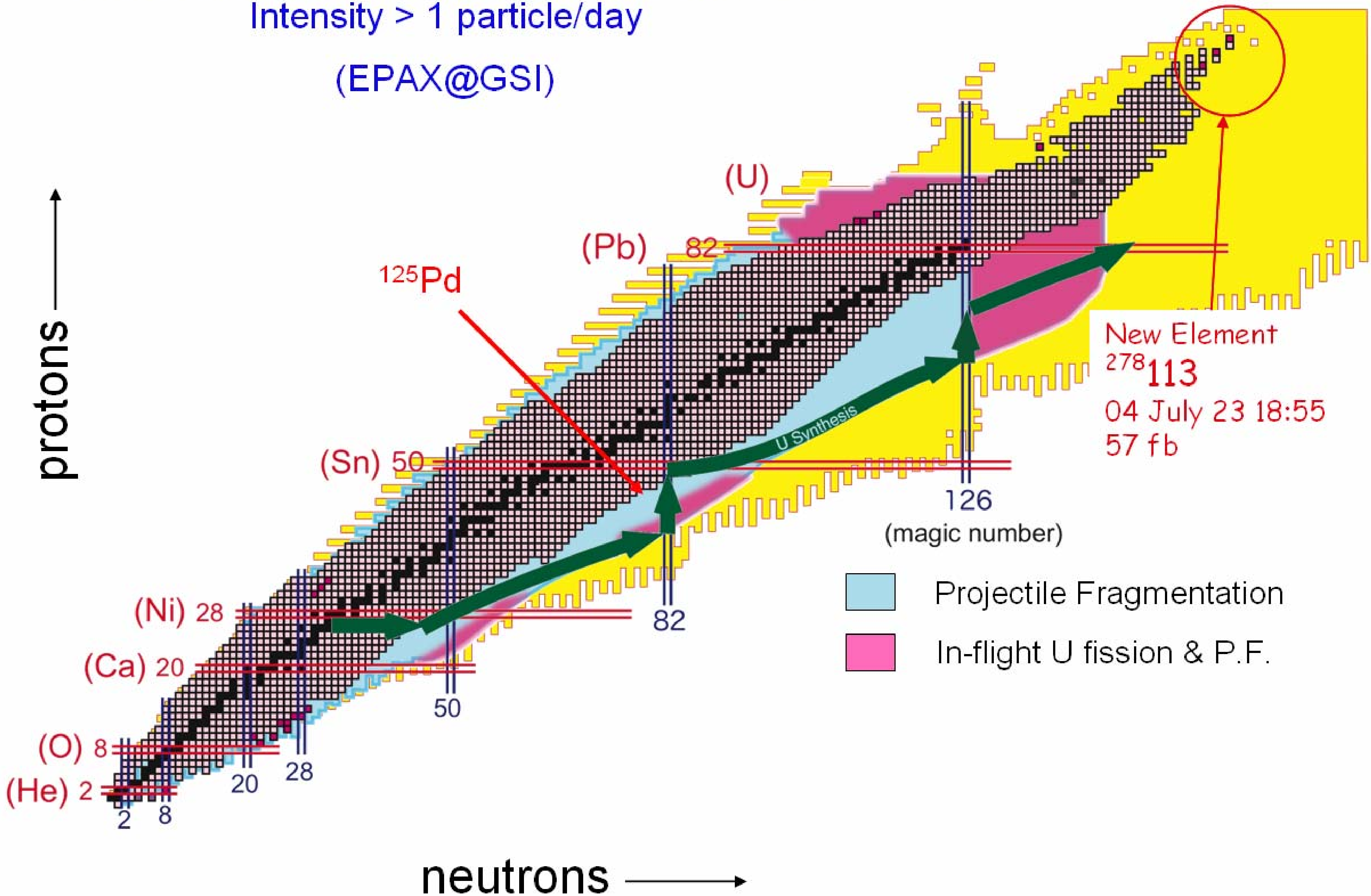

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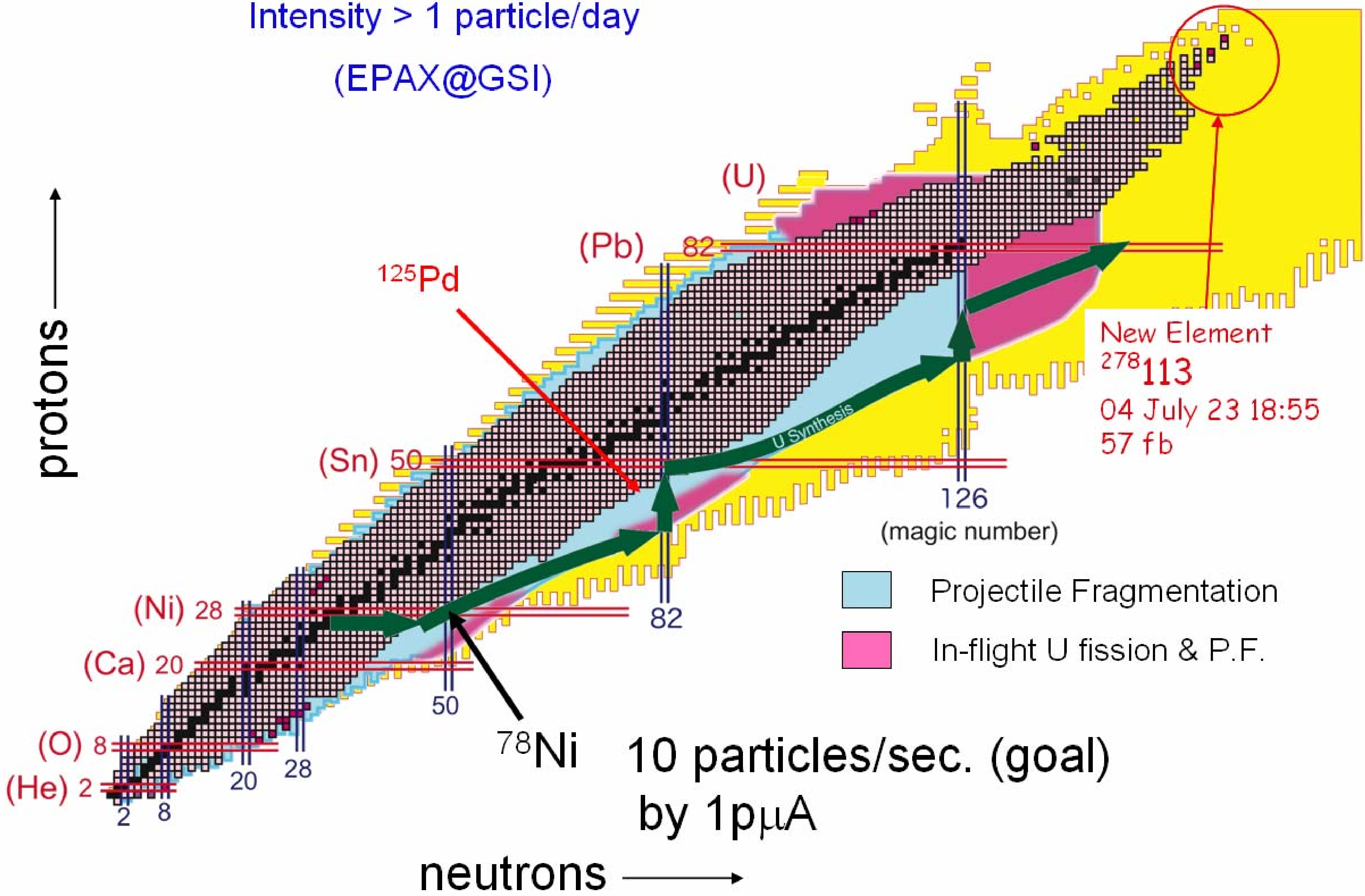
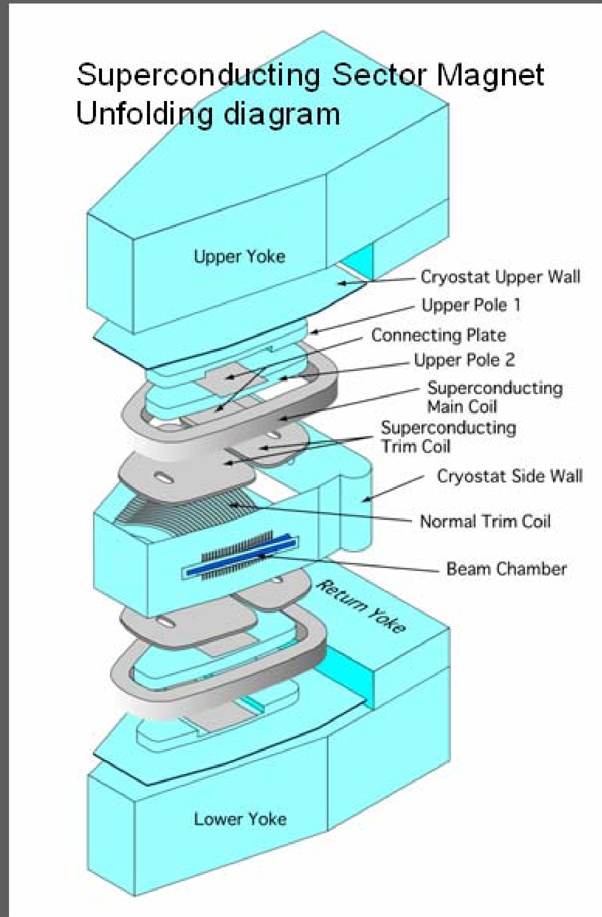
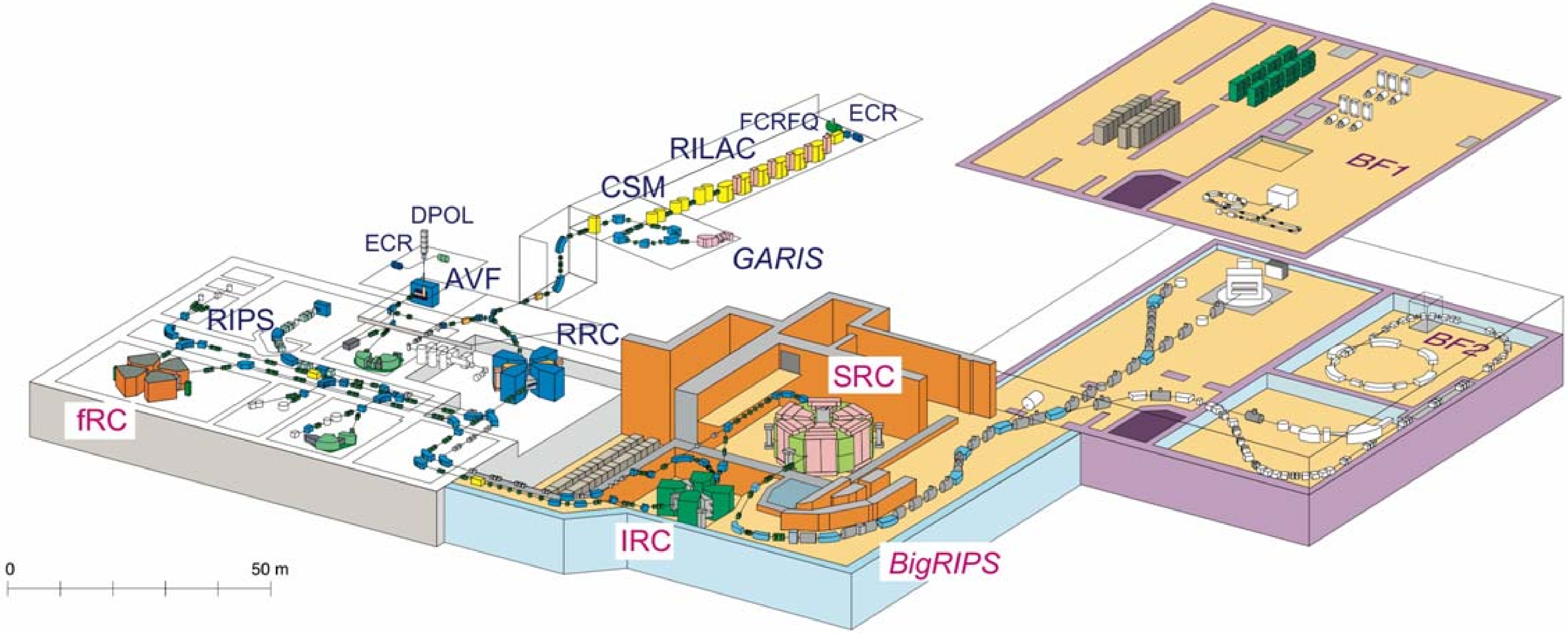
(EPAX@GSI)



Back Up

K2600-MeV SRC: April 200-July 2005





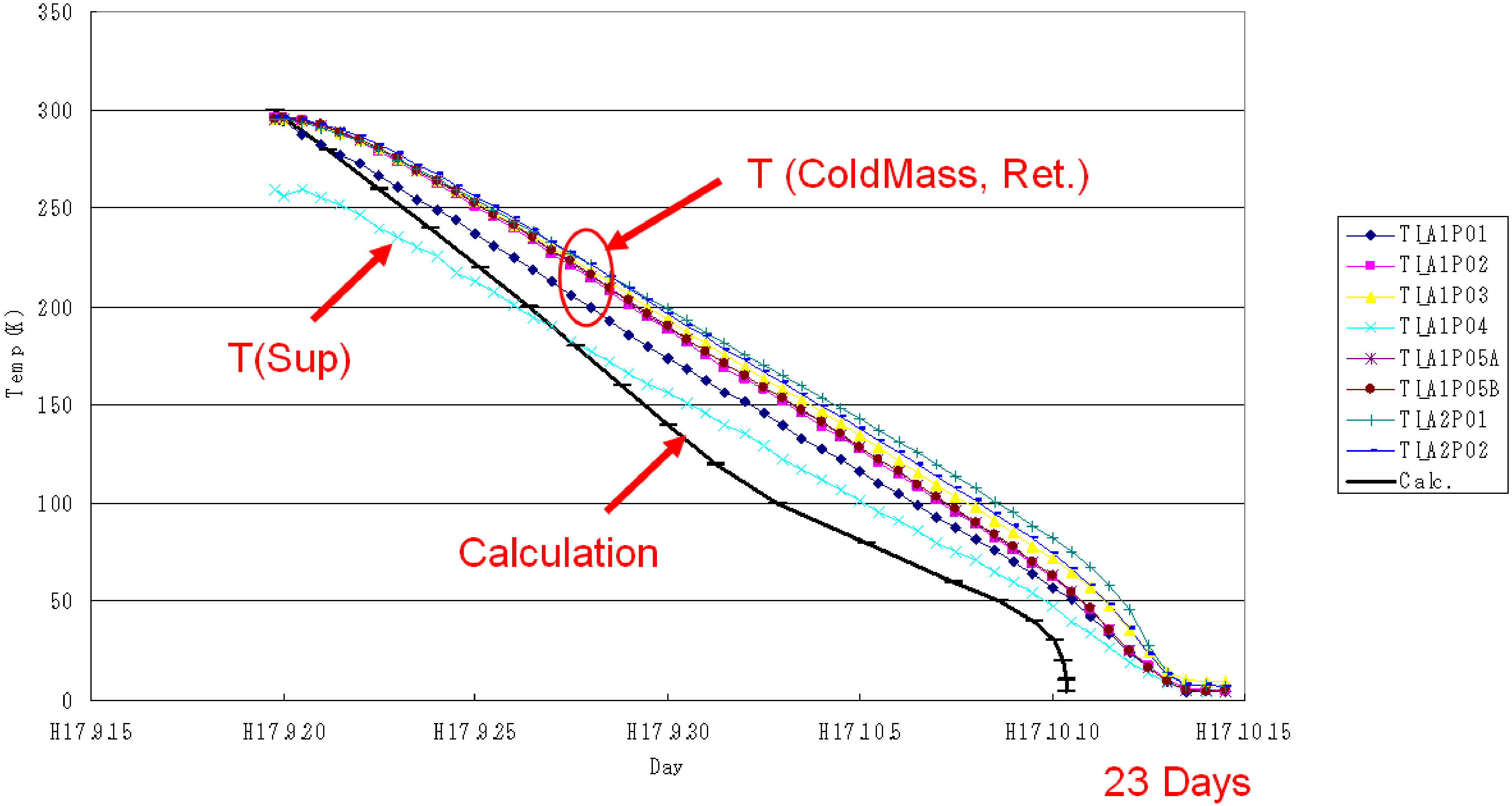
FCRFQ
ECR
RILAC
CSM
DPOL
ECR
AVF
GARIS
RIPS
RRC
SRC
fRC
IRC
BigRIPS
BF1
BF2
0
50 m

Cool-down of the SRC

Cold Mass

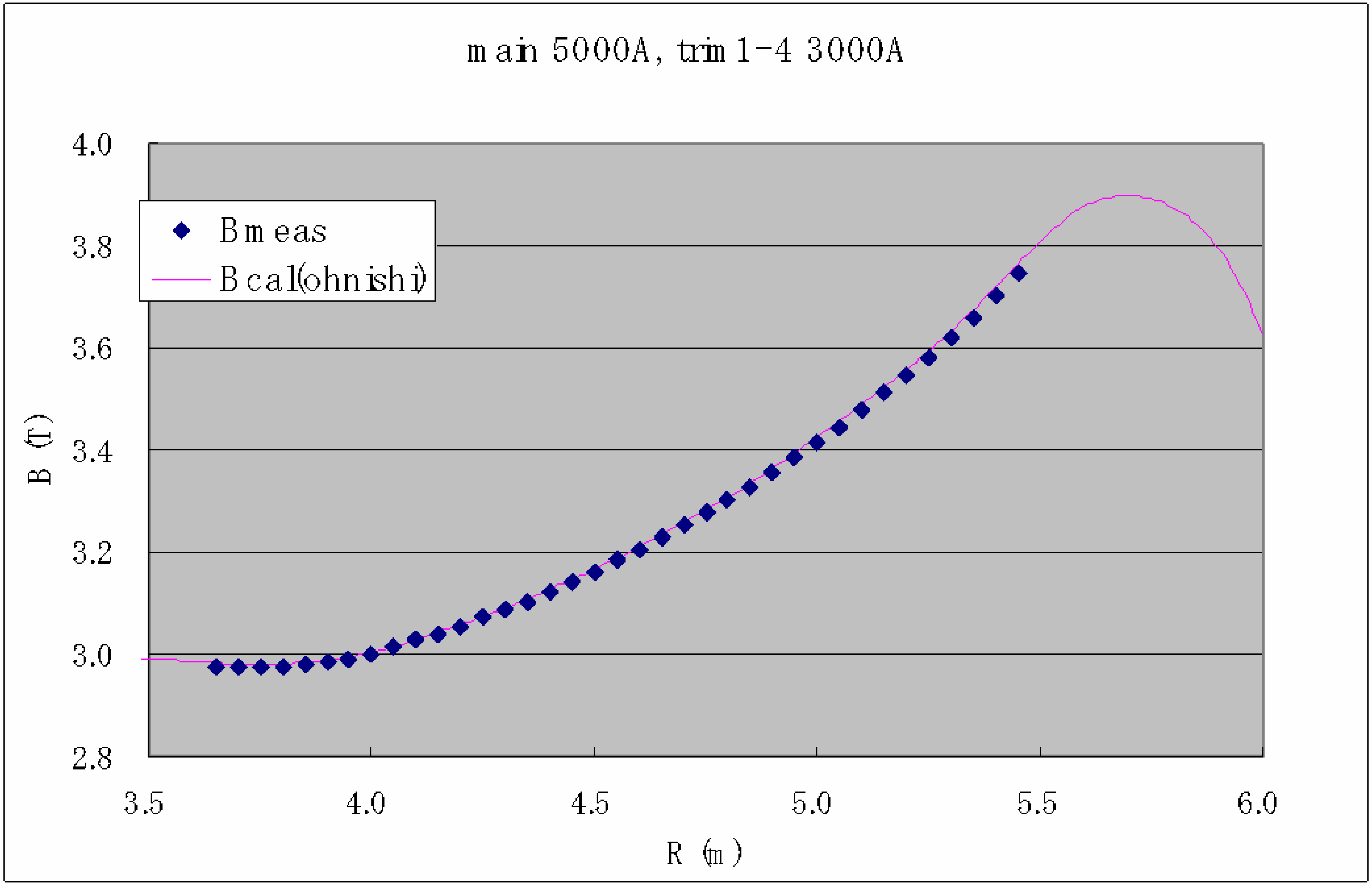
Stainless Steel: 101 ton

Aluminum: 41 ton



Example of field mapping of SRC

Along the center line of the sector magnet

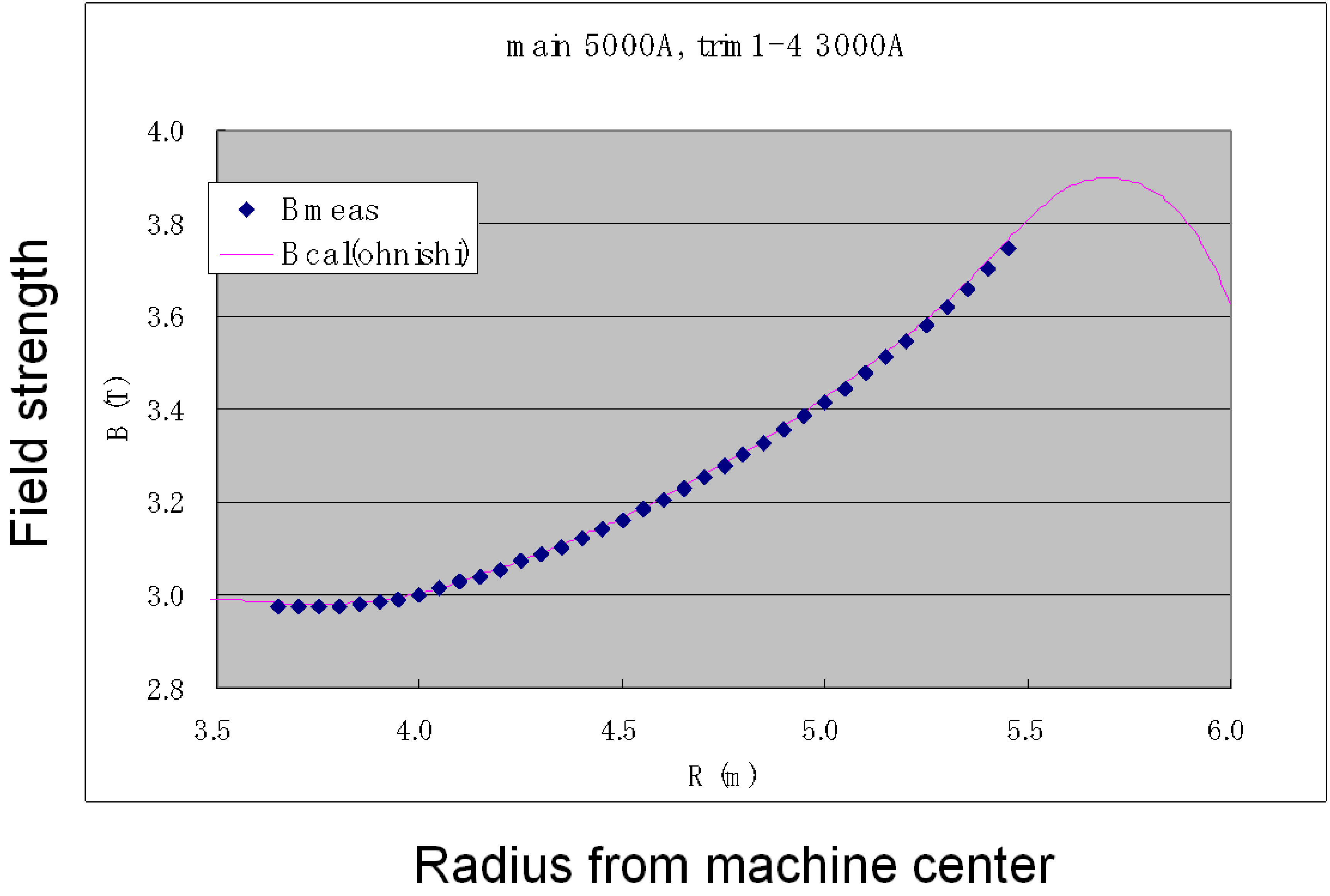


Field strength

Radius from machine center

Example of field mapping of SRC

Along the center line of the sector magnet



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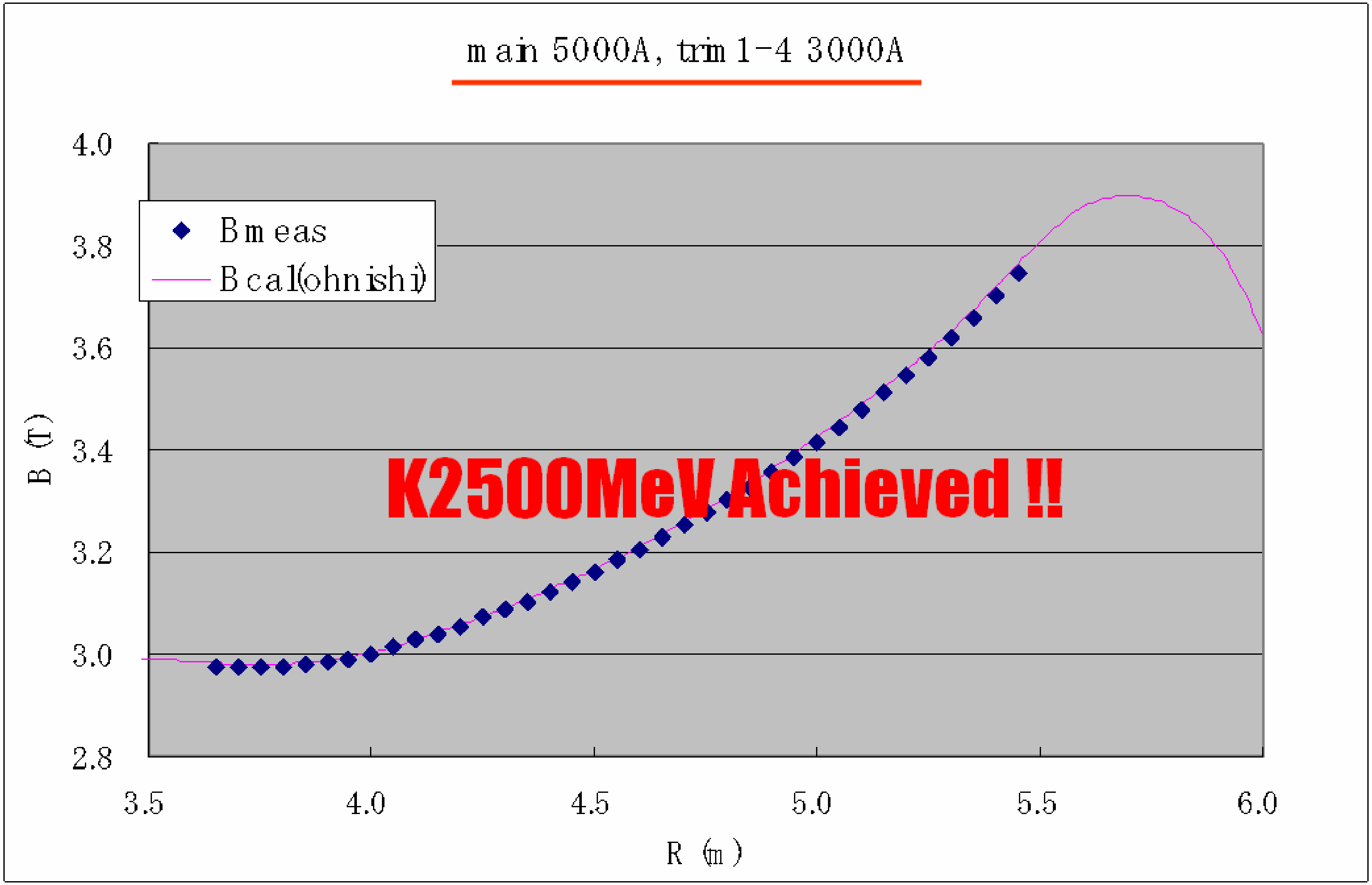


Radius from machine center

Merits of the present iron-covered structure. (Y. Yano, 2000)

(Self magnetic-flux and radiation leakage-shield structure)

(1) We do not need any extra non-magnetic (!) local radiation shielding of the concrete blocks as big as 3 m cubes.

(2) The stray field in the valley (whose flux direction is opposite to that of the sector field) is reduced from 0.5 T to 0.04 T (at maximum).

(2-1) The maximum sector field needed is reduced. (3.8 T realized!)

(2-2) The maximum magnetomotive force required is also reduced. (4MAT realized! Without coil quenching)

(2-3) The maximum stored energy and the electromagnetic forces exerted onto the main coil are significantly reduced. (Confirmed!)

(2-4) We need not use the superconducting magnetic channels .

(2-5) The shift of the injection and extraction trajectory depending on the negative stray field strength is greatly reduced (almost no shift.) .

(2-6) We use the rf cavities and valley chambers having the structures with small modifications to those of the IRC because of the low stray field.

(3) The stray field outside the SRC is reduced to a few gauss. We need neither the active magnetic shielding difficult to fabricate nor the thick iron plates enclosing the huge SRC vault.

(~10gauss except the near air gaps between the shields)

(3-1) We place the rf oscillators near the SRC like the RRC and the IRC. (<40gauss)

(3-2) The SRC vault is now very safe for working people even inside the SRC.

(4) Reducing the cold mass by placing the pole at the room temperature significantly shortens the cooling time. (~24 days)

Basic parameters of BigRIPS

Configuration	Two-stage separator
First stage	Two bends
Second stage	Four bends
Energy degrader	Achromatic wedge
Quadrupoles	Superconducting
Angular acceptance	
Horizontal	80 mr
Vertical	100 mr
Momentum acceptance	6 %
Max. magnetic rigidity	9 Tm
Total length	77 m
Momentum dispersion*	
First stage	-2.31 m
Second stage	3.3 m
Momentum resolution**(1st order)	
First stage	1290
Second stage***	3300

In-flight fission of ^{238}U at 350 MeV/u
~ 100 mr
~ 10 %

* At the mid-focus of the stage.
** Those in the case when a 1 mm beam spot is assumed.

T. Kubo et al.

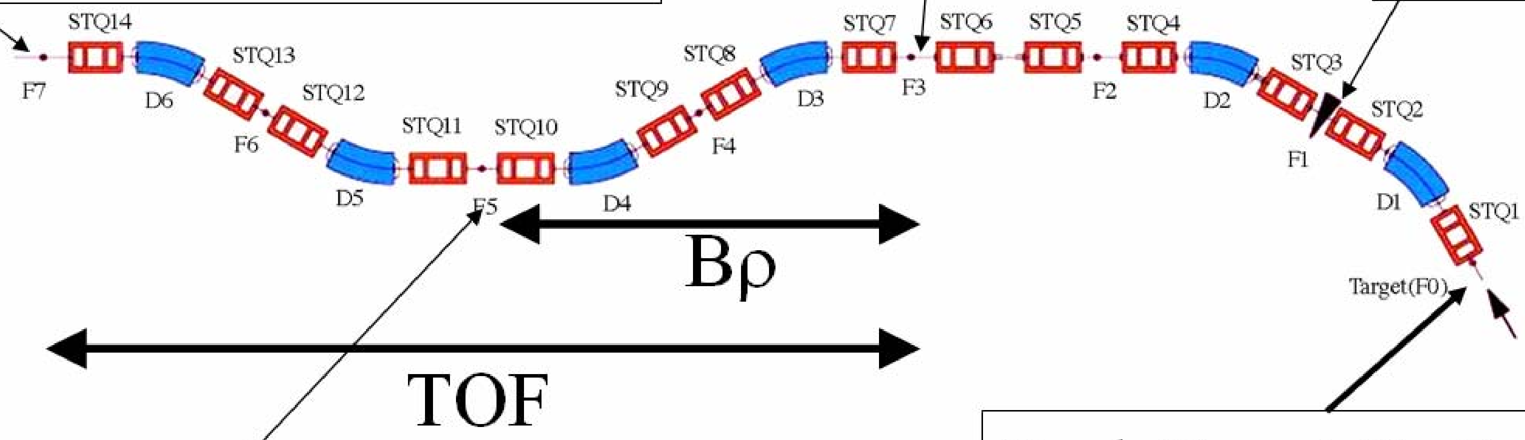
Setup for May-2007 Commissioning

Setup to search for new isotopes

Double Achromatic
PL 0.2mmt
PPAC(x,y) x2
Silicon 0.33 mmt x2 for ΔE
NaI for E
Clover for isomeric states

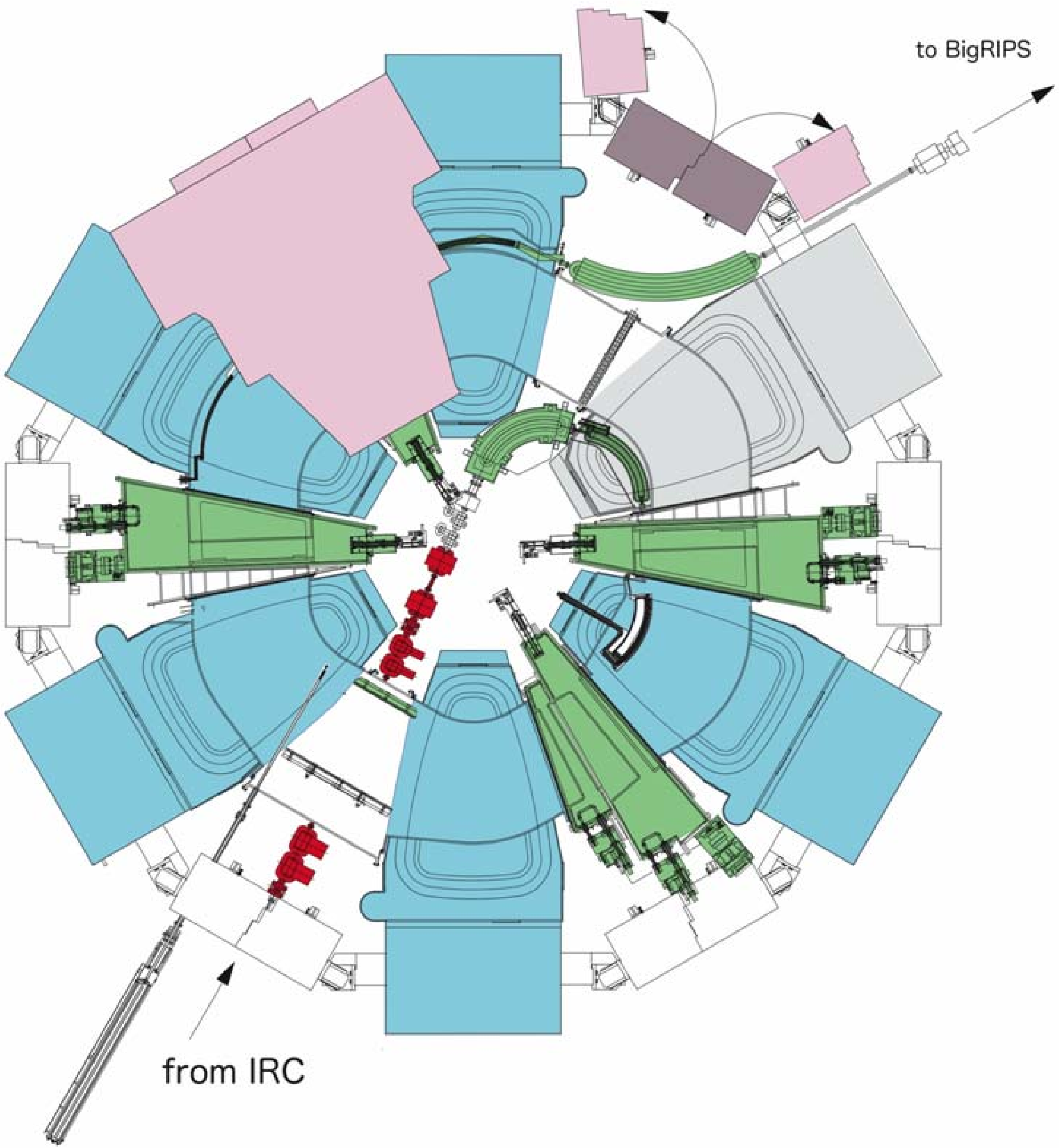
Double Achromatic
PL 0.2mmt
PPAC(x,y) x2

Mom. Slit
Dp/p=2%
(Max 6%)
W/o Wedge

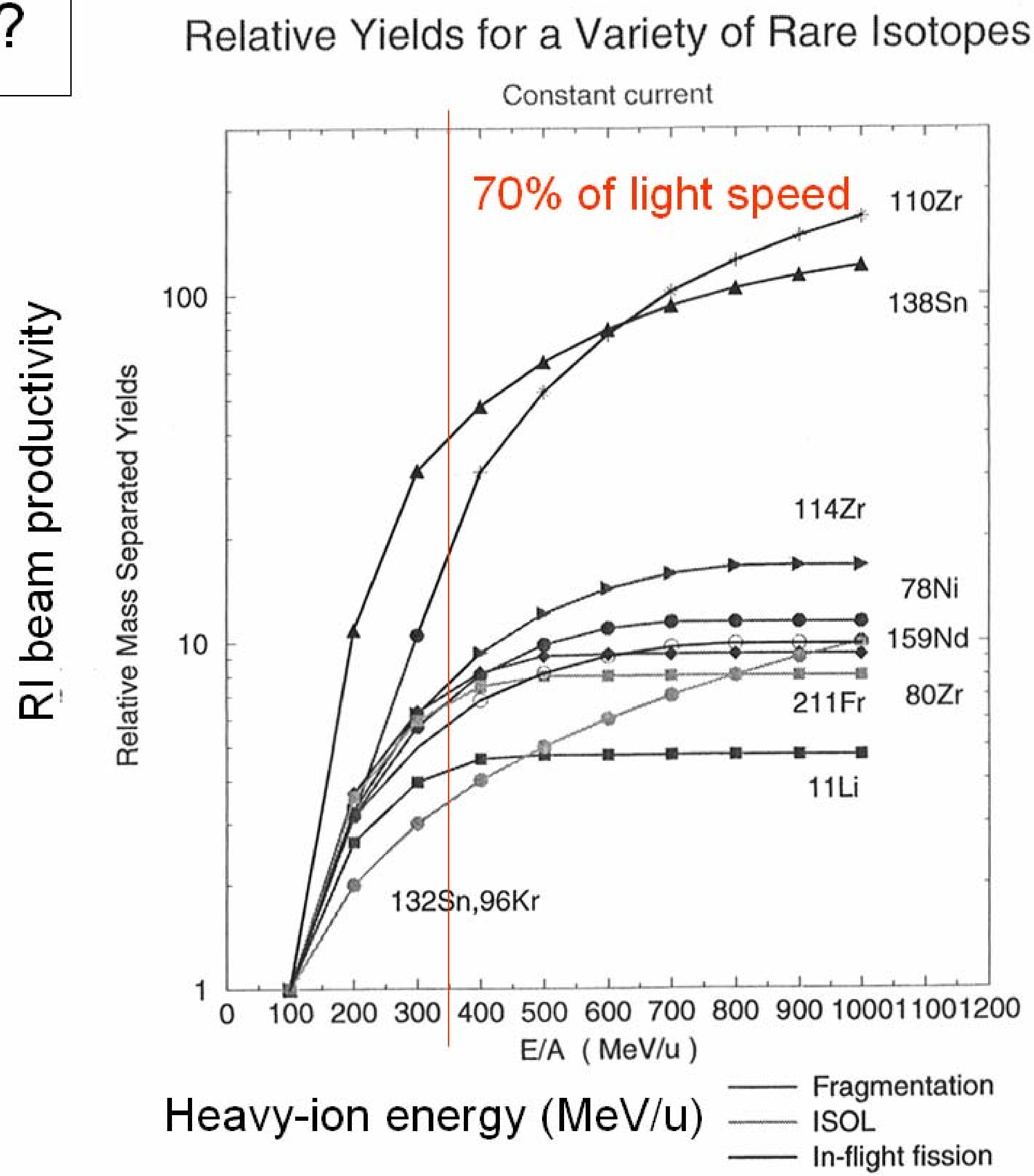


Momentum Dispersive
PPAC(x,y) x2

Prod. Target Be 7mmt
Beam-intensity monitor
PL 1mmt x 3


to BigRIPS
from IRC

Why 350 MeV/u ?


Relative Yields for a Variety of Rare Isotopes
Constant current
70% of light speed
RI beam productivity
Relative Mass Separated Yields
110Zr
138Sn
114Zr
78Ni
159Nd
211Fr
80Zr
11Li
132Sn,96Kr
100
10
1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
E/A (MeV/u)
Heavy-ion energy (MeV/u)
Fragmentation
ISOL
In-flight fission