

Status & future SHE study at RIKEN (Development of GARIS-II)

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**Gas-filled recoil ion separator GARIS-II
D. Kaji, K.Morimoto, N.Sato et al., RIKEN Accel. Prog. Rep. 42, (2009).**

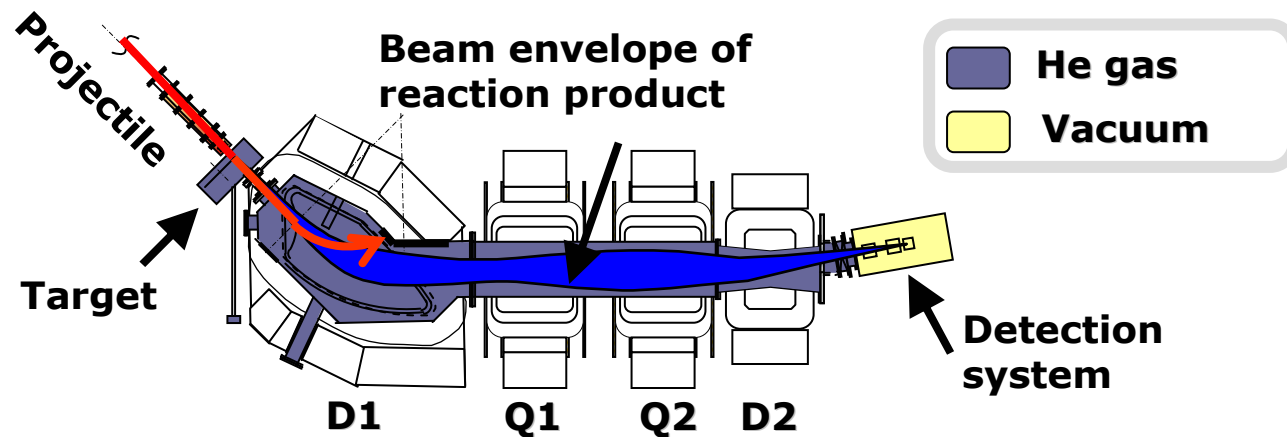
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1 Status of SHE study at RIKEN (Lesson from GARIS)

GARIS

One of the world active gas-filled recoil separator for SHE study



Powerful tool

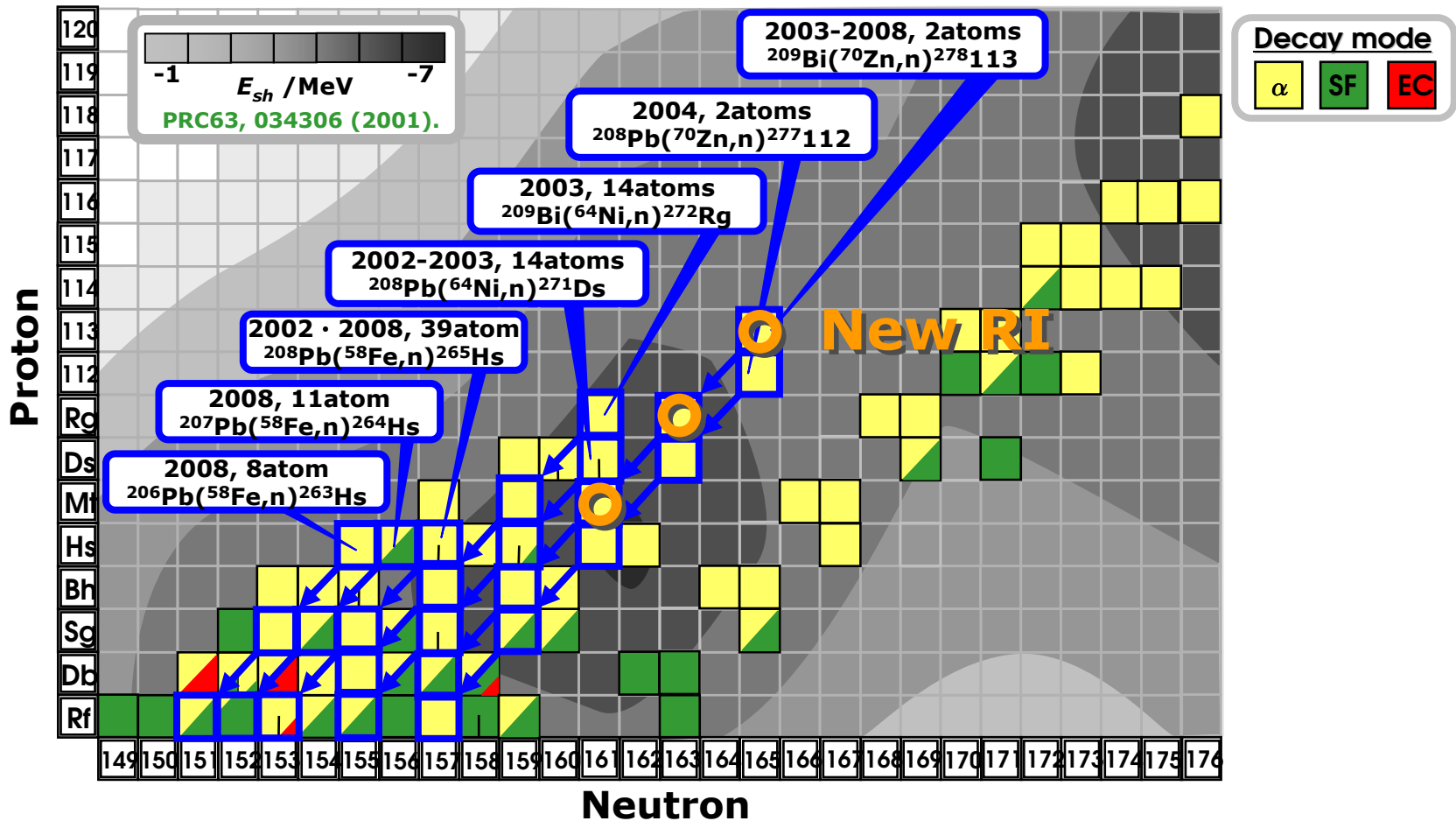
For Pb/Bi-based fusion study

- New element search
- Decay spectroscopy
- Reaction study

For actinide-based fusion study

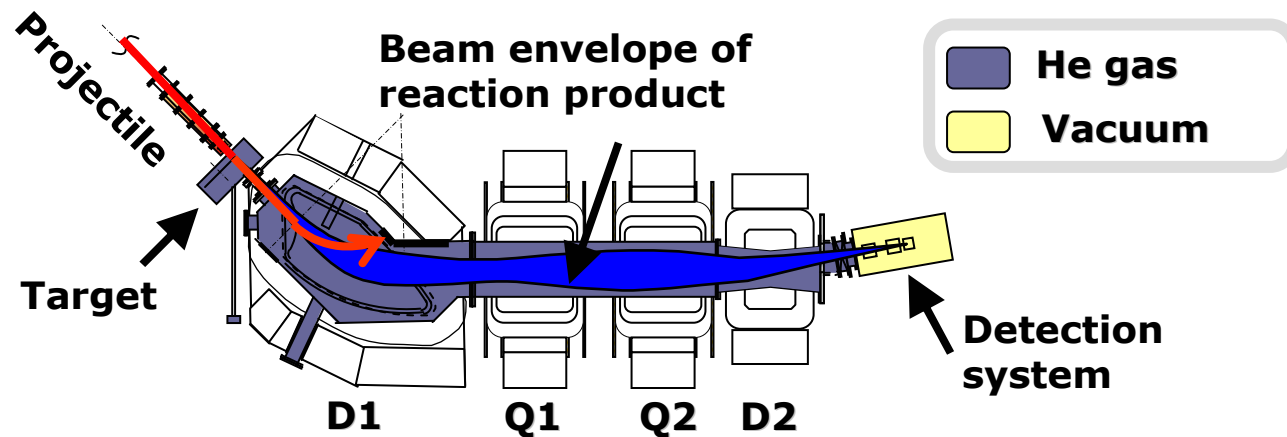
- Decay spectroscopy
- Pre-separator for SHE chemistry

Cold fusion study by GARIS



GARIS

One of the world active gas-filled recoil separator for SHE study



Powerful tool

For Pb/Bi-based fusion study

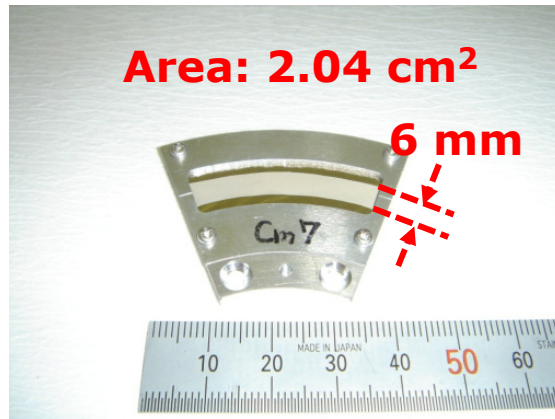
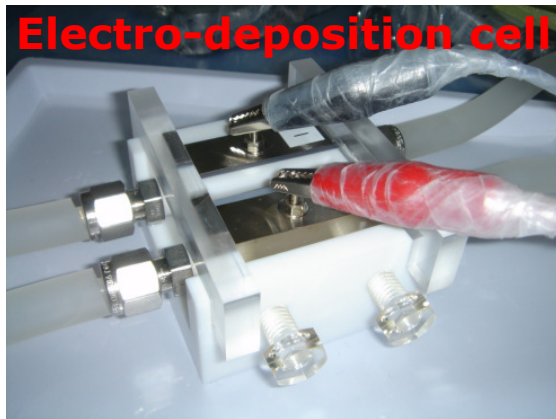
- New element search
- Decay spectroscopy
- Reaction study

For actinide-based fusion study

- Decay spectroscopy
- Pre-separator for SHE chemistry

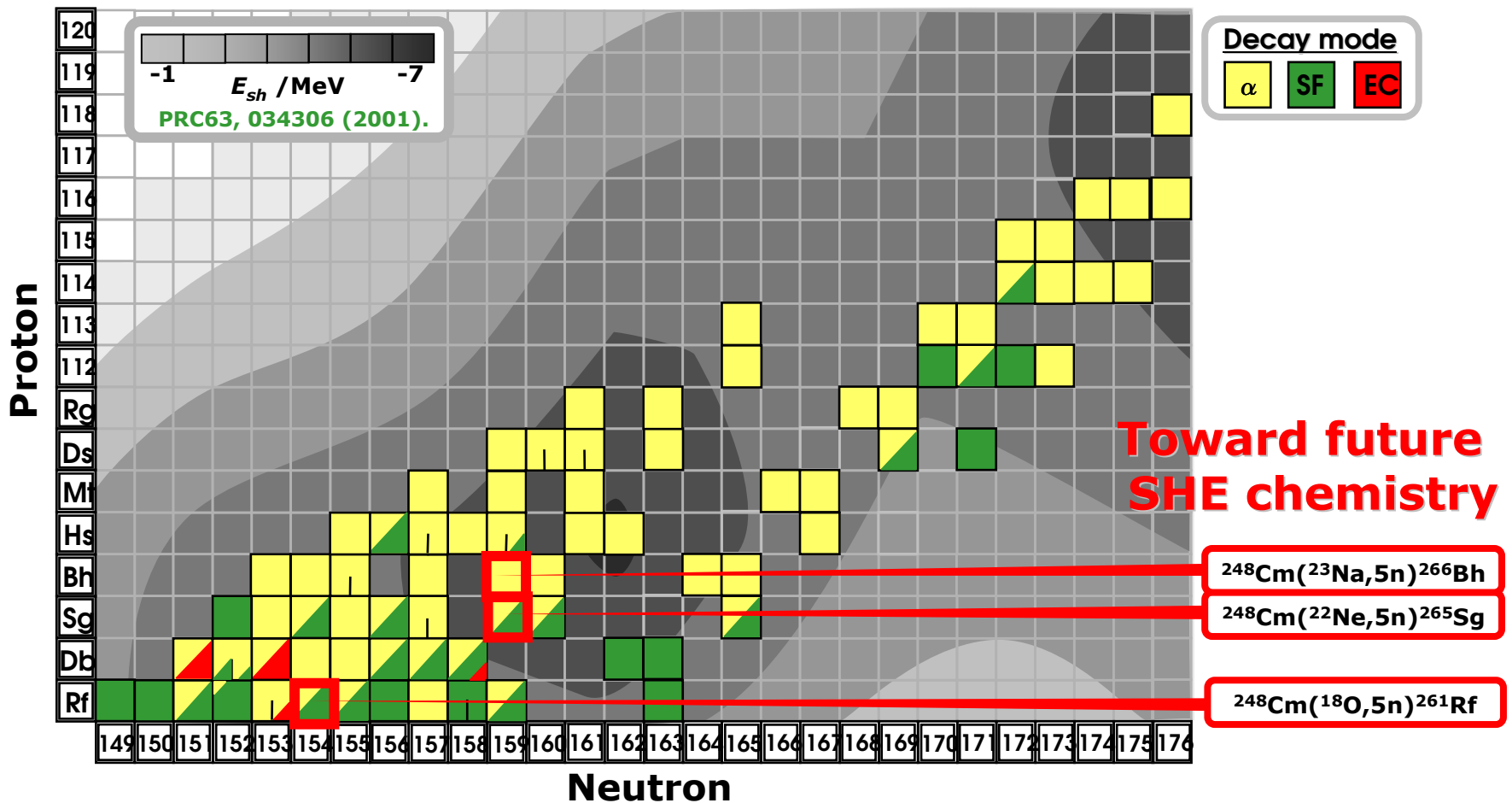
^{248}Cm target

**350 $\mu\text{g}/\text{cm}^2$ $^{248}\text{Cm}_2\text{O}_3$ on 2.0 μm Ti backing foil
(Preparation by electro-deposition after purification with ion exchange)**



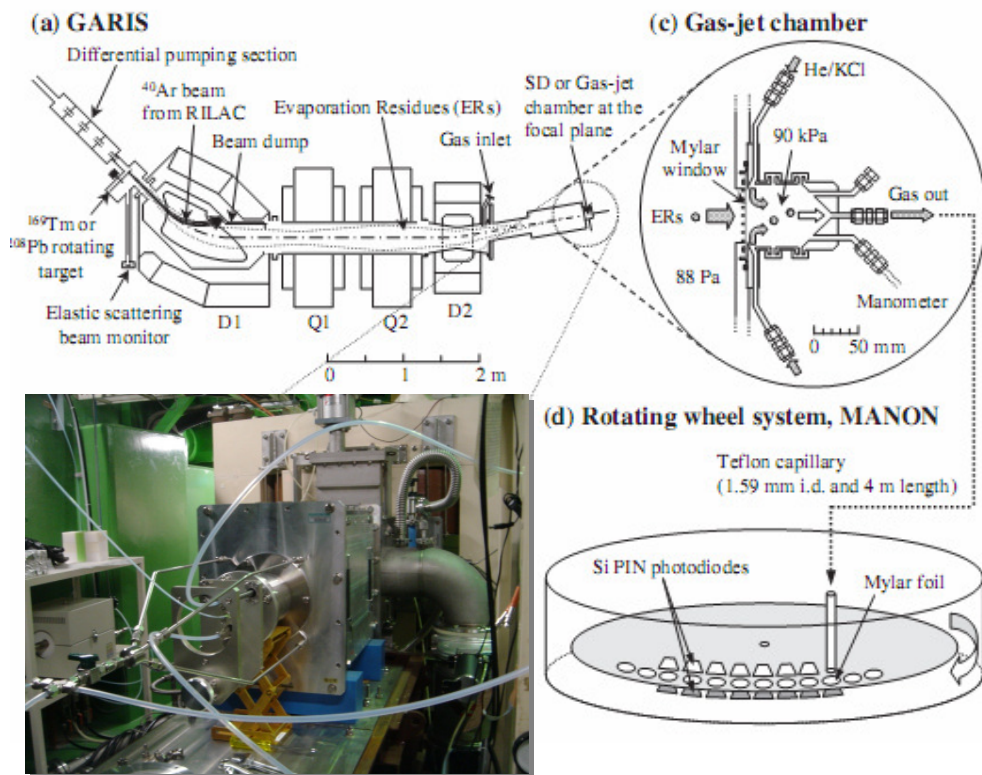
- **Effective to stand against high intensity beam**
- **Enables SHE production in neutron rich-side**

Hot fusion study by GARIS

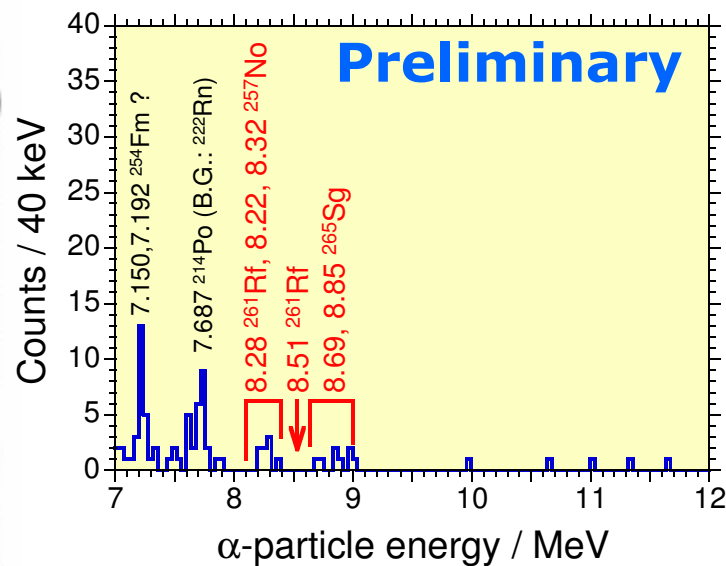


GARIS + gas-jet system

Gas-jet coupled to GARIS as a pre-separator
 (Promising tool for next-generation SHE chemistry)



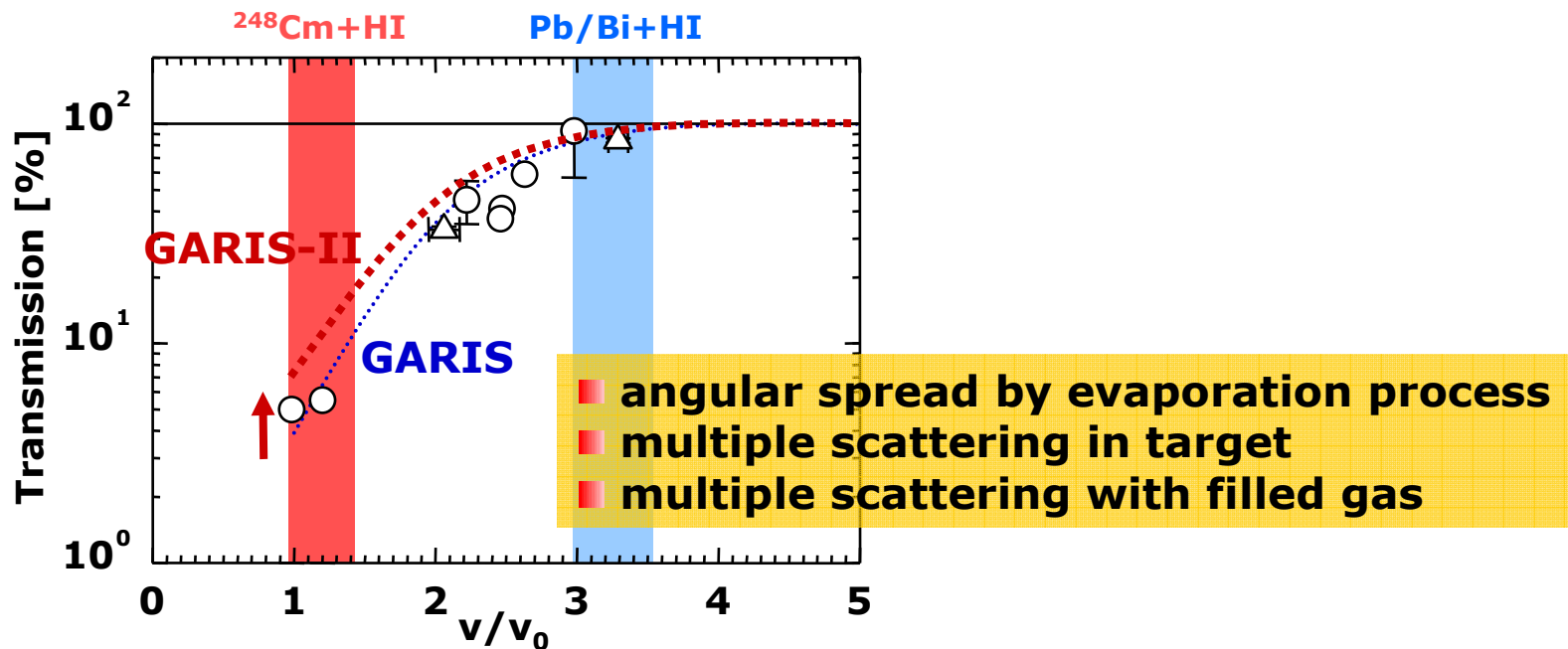
$^{248}\text{Cm}(^{22}\text{Ne}, 5n)^{265}\text{Sg}$



H. Haba, H. Kikunaga, D. Kaji et al., J. Nucl. Radiochem. Sci., 9 27(2008).

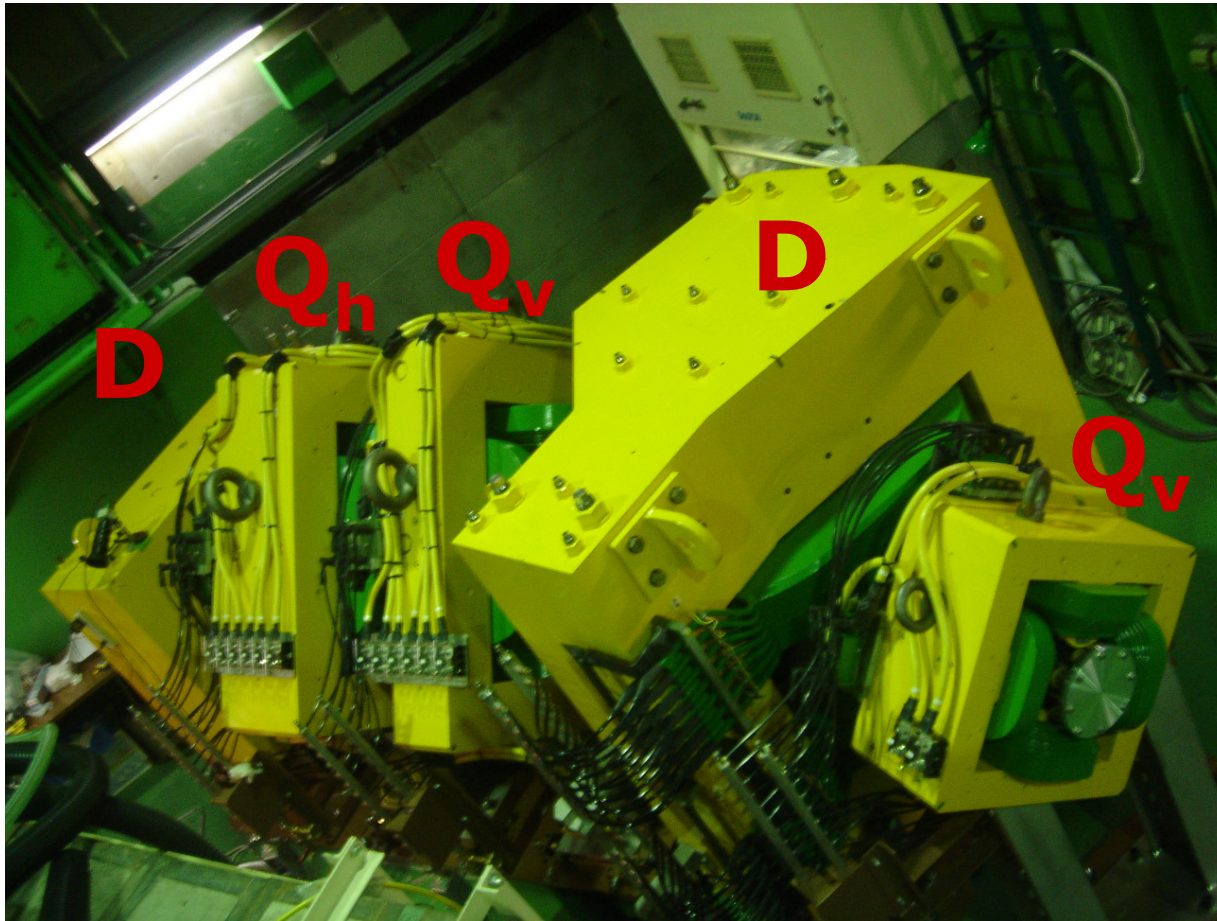
Difficulties in hot fusion study

	Pb/Bi-based fusion	Cm-based fusion
Transmission	High (80%)	Low (Under 10%)
Background level	Low (Under 10 cps)	High (Over 10 kcps)
Z_{\max} search ($B\rho$ Limit)	$Z_{\max} \leq 118$	$Z_{\max} \leq 110$



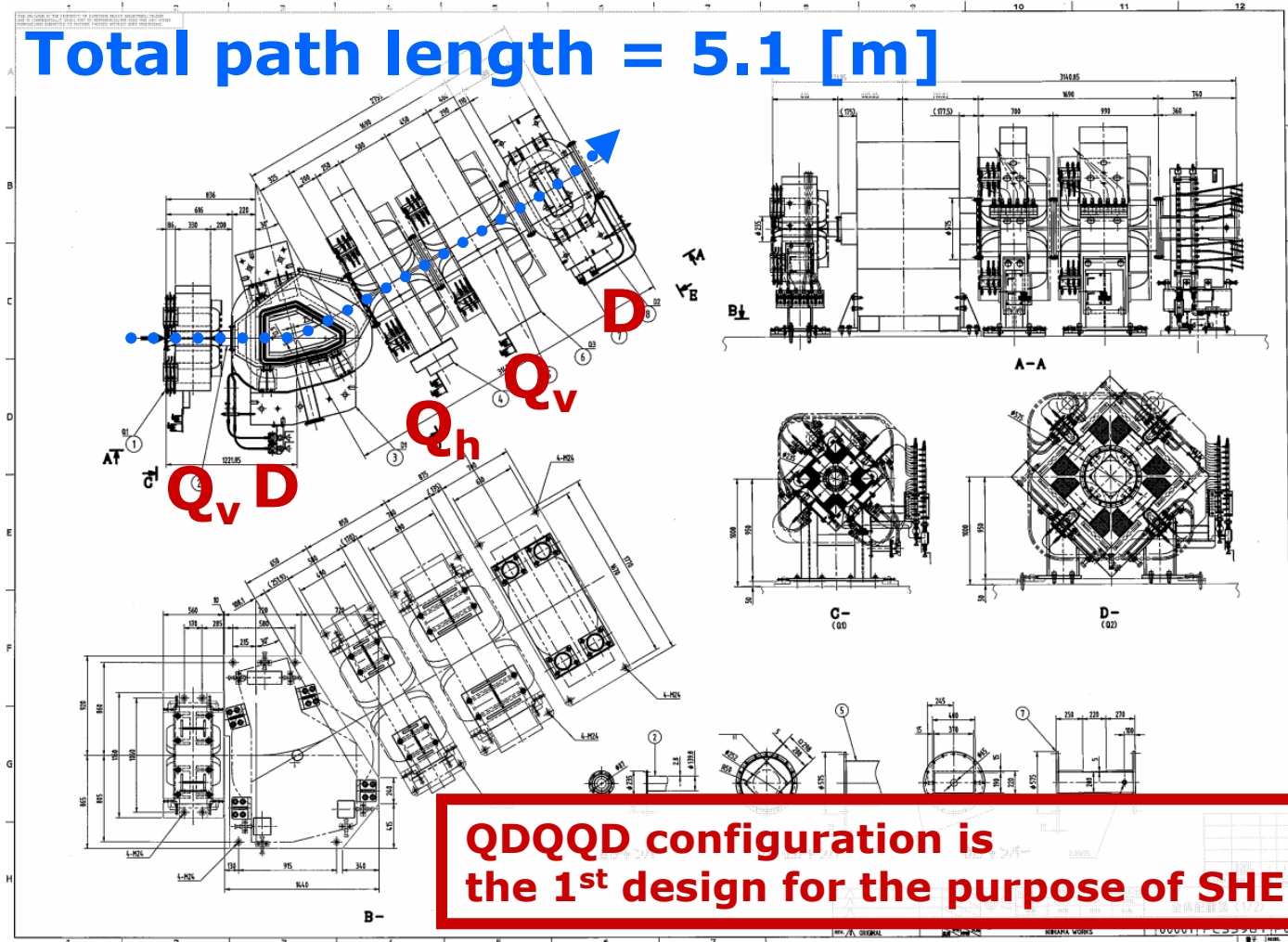
2 Development of GARIS-II (Big project since the birth of GARIS)

GARIS-II (Photograph)



Schematic view

Total path length = 5.1 [m]



Parameters for all magnets

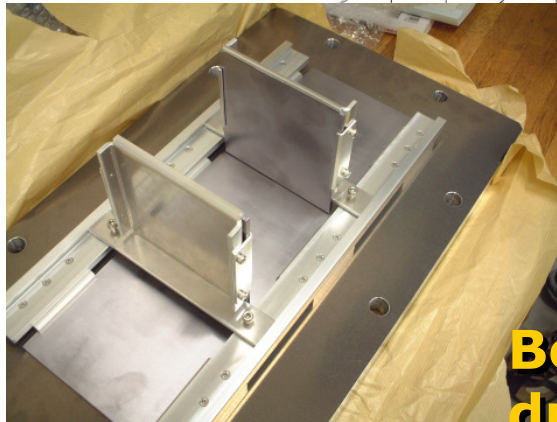
Q1	Max field grad.	12.2 T/m
	Bore radius	150 mm
	Pole length	330 mm
D1	Pole gap	150 mm
	Max field	1.69 T
	Deflecting angle	30 deg
	Radius of central ray	1440 mm
	Entrance angle	0 deg
Q2	Max field grad.	4.70 T/m
	Bore radius	300 mm
	Pole length	250 mm
Q3	Max field grad	5.27 T/m
	Bore radius	300 mm
	Pole length	450 mm
D2	Pole gap	200 mm
	Max field	0.86 T
	Deflecting angle	7 deg
	Radius of central ray	2850 mm
	Entrance angle	0 deg
	Exit angle	-7 deg

■ **Y focus**
(X defocus)

■ **better matching to D1 acceptance**

■ **Primary beam is separated**

D1 chamber



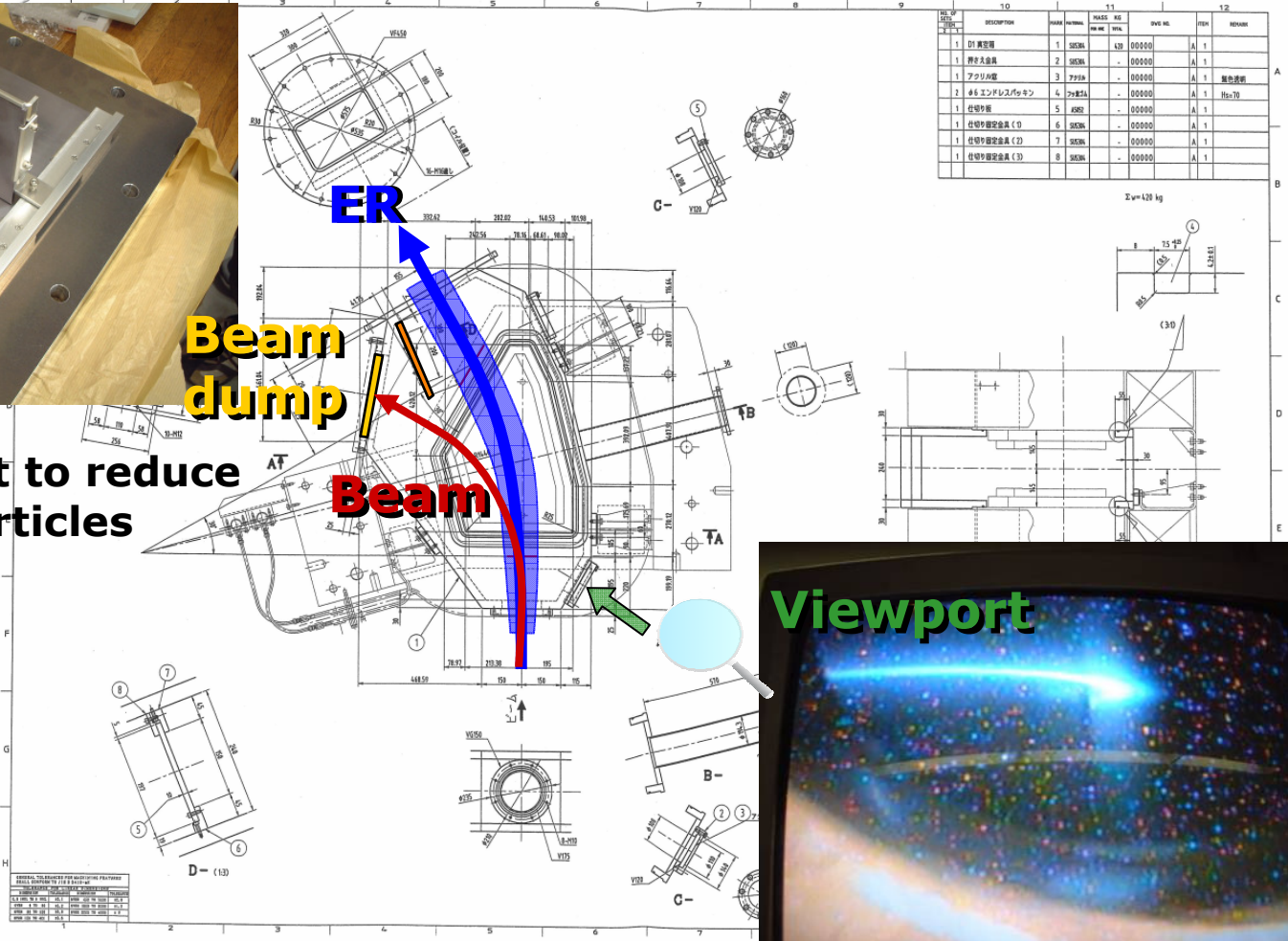
Beam dump

Movable slit to reduce beam-like particles

Beam

ER

Viewport



Parameters for all magnets

Q1	Max field grad. Bore radius Pole length	12.2 T/m 150 mm 330 mm
D1	Pole gap Max field Deflecting angle Radius of central ray Entrance angle Exit angle	150 mm 1.69 T 30 deg 1440 mm 0 deg 30 deg
Q2	Max field grad. Bore radius Pole length	4.70 T/m 300 mm 250 mm
Q3	Max field grad Bore radius Pole length	5.27 T/m 300 mm 450 mm
D2	Pole gap Max field Deflecting angle Radius of central ray Entrance angle Exit angle	200 mm 0.86 T 7 deg 2850 mm 0 deg -7 deg

- **Y focus**
(X defocus)
- **better matching to D1 acceptance**

- **Separation of ER**
from primary beam

- **X focus**
(Y defocus)

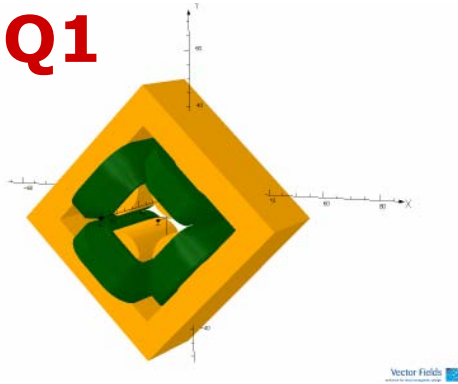
- **Y focus**
(X defocus)

- **Separation of ER**
from transfer product & LCP

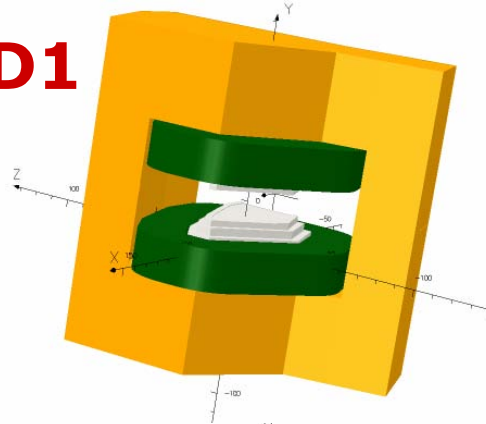
Light Charged
Particles

Mechanical design & 3D magnetic field calculation by OPERA

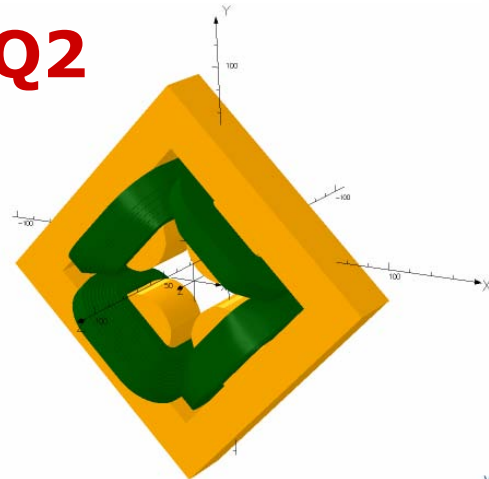
Q1



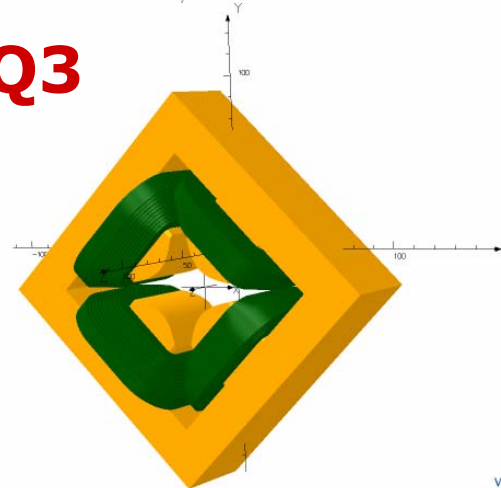
D1



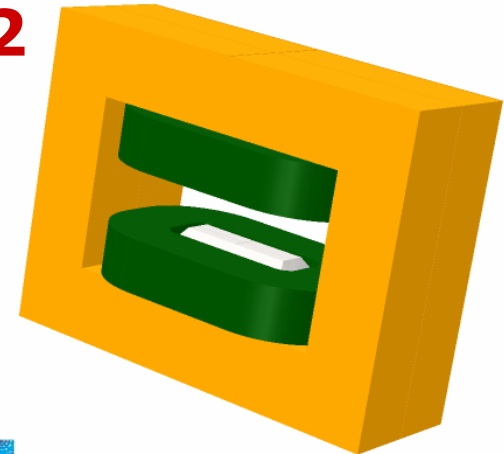
Q2



Q3

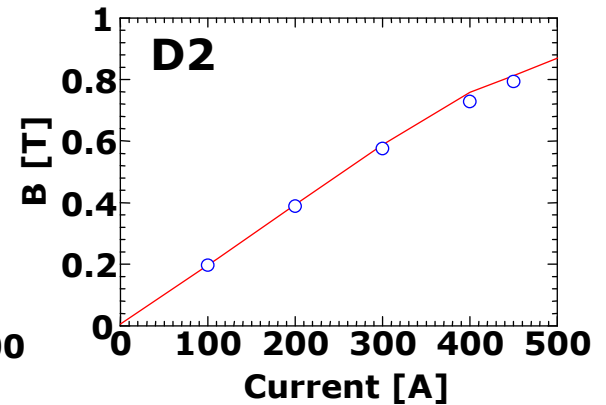
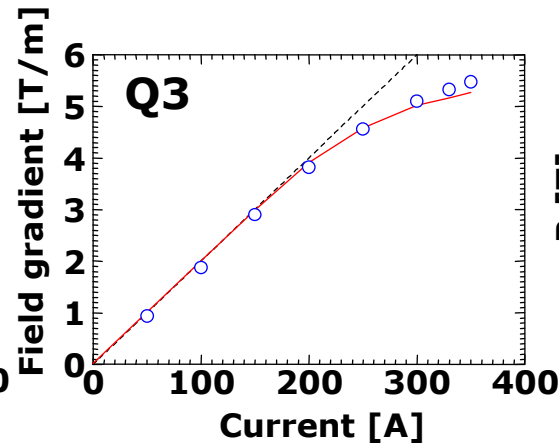
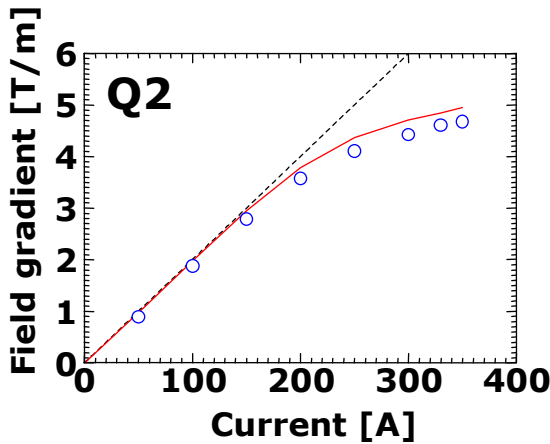
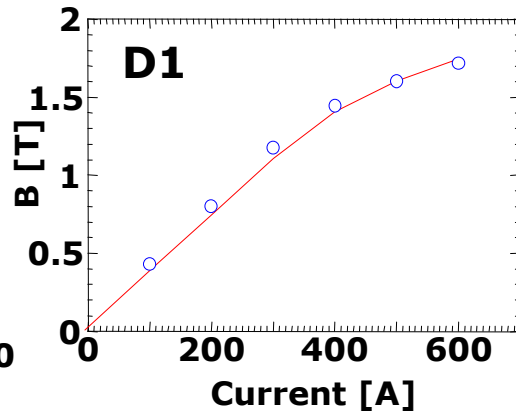
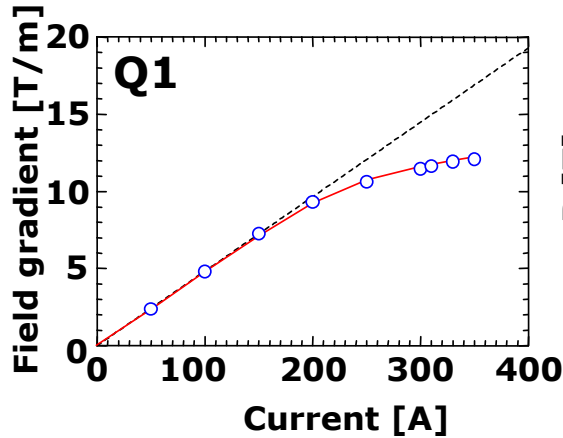


D2



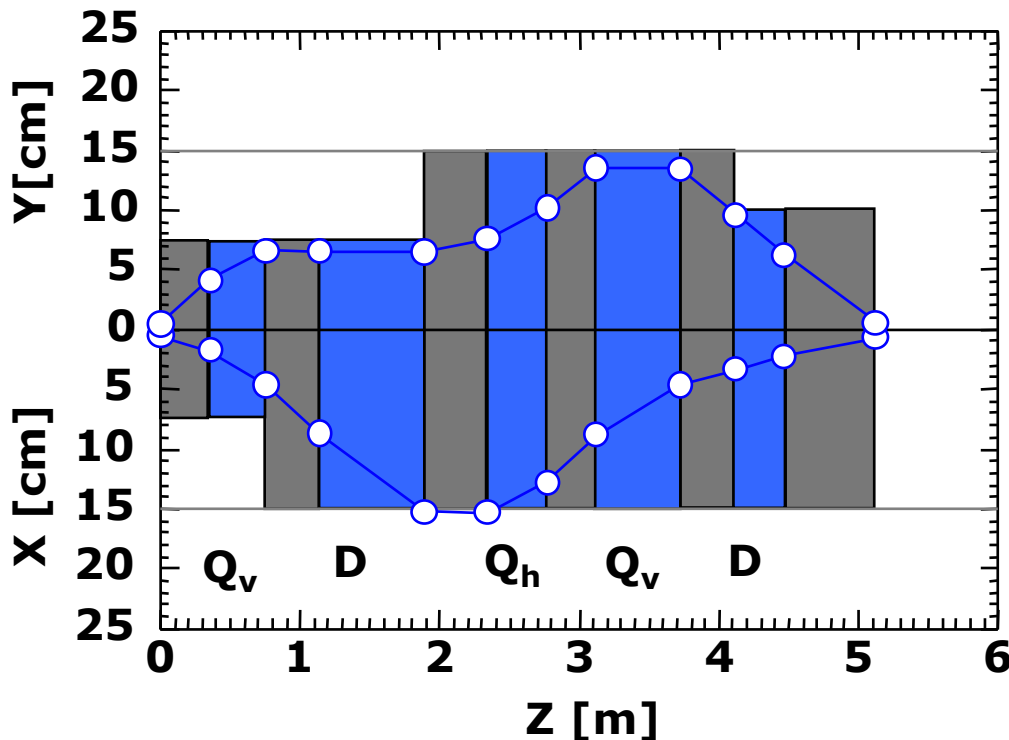
<http://www.ces-kbk.com/sdi-sp/vf/index.htm>

Magnetic field measurement



Ion optical characteristics

Beam envelope calculated by TRANSPOT



GARIS-II

$L = 5.12$ [m]

$B\rho$ (max) = 2.43 [Tm]

Acceptance (X) = 48 [mrad]

Acceptance (Y) = 118 [mrad]

Solid angle = 20.2 [msr]

K. L. Brown et al.: SLAC Report 91 Rev. 1, 1974.

Characteristics of GARIS-II

	GARIS	GARIS-II
Configuration	$DQ_h Q_v D$	$Q_v D Q_h Q_v D$
Bending angle [deg]	45 + 10	30 + 7
Total path length [m]	5.76	5.12
Acceptance (X) [mrad]	± 61	± 48
Acceptance (Y) [mrad]	± 57	± 118
Solid angle [msr]	12.2	20.2
Max Brho [Tm]	2.16	2.43
Filled gas	He	He or (He/H ₂ mix)

-0.64 m

×1.7 up

13% up

Comparison

(GARIS-II vs. World working gas-filled RS)

	DGFRS	BGS	RITU	GARIS	TASCA (HTM)	TASCA (SIM)	GARIS-II
Configuration	$DQ_h Q_v$	$Q_h D_h D$	$Q_v D Q_h Q_v$	$D Q_h Q_v D$	$D Q_h Q_v$	$D Q_v Q_h$	$Q_v D Q_h Q_v D$
Length [m]	4.0	4.7	4.7	5.8	3.5	3.5	5.1
Bend. Angle [deg]	23	25+45	25	45+10	30	30	30+7
Solid angle [msr]	8.8	45.0	10.0	12.2	13.1	4.3	20.2
B_ρ (max) [Tm]	3.10	2.50	2.20	2.16	2.40	2.40	2.43
Dispersion [mm/%]	7.5	20.0	10.0	9.7	9.0	1.0	17.7
Transmission [%]	41*	49-59*	?	40*	60*	36*	75

$^{238}\text{U}(^{48}\text{Ca}, 3n)^{283}\text{112}$

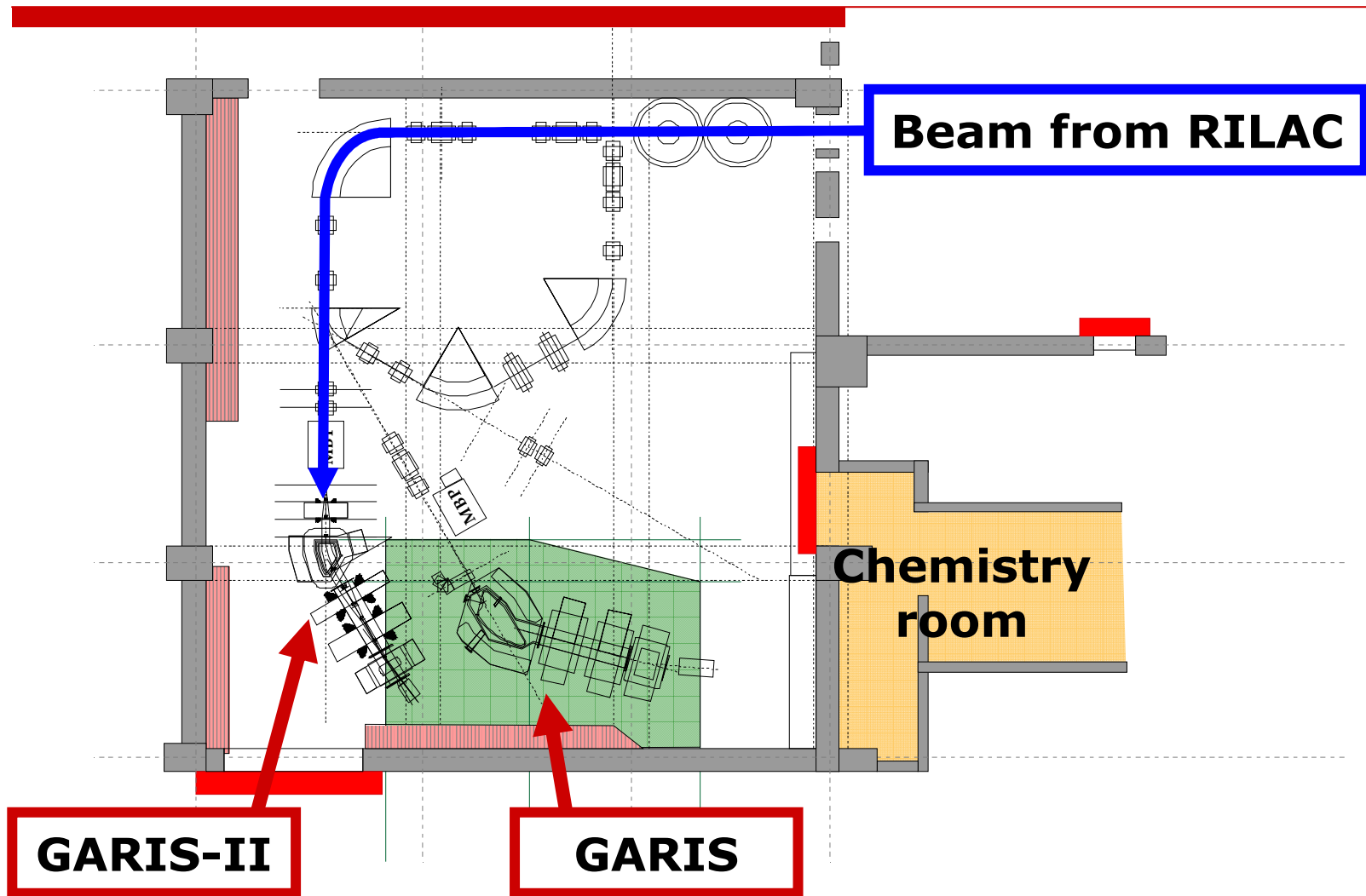
Cross section : 3 pb **
 Intensity : 2 pA
 Target thickness : 500 $\mu\text{g}/\text{cm}^2$
 Transmission : 75%

3 atoms/day

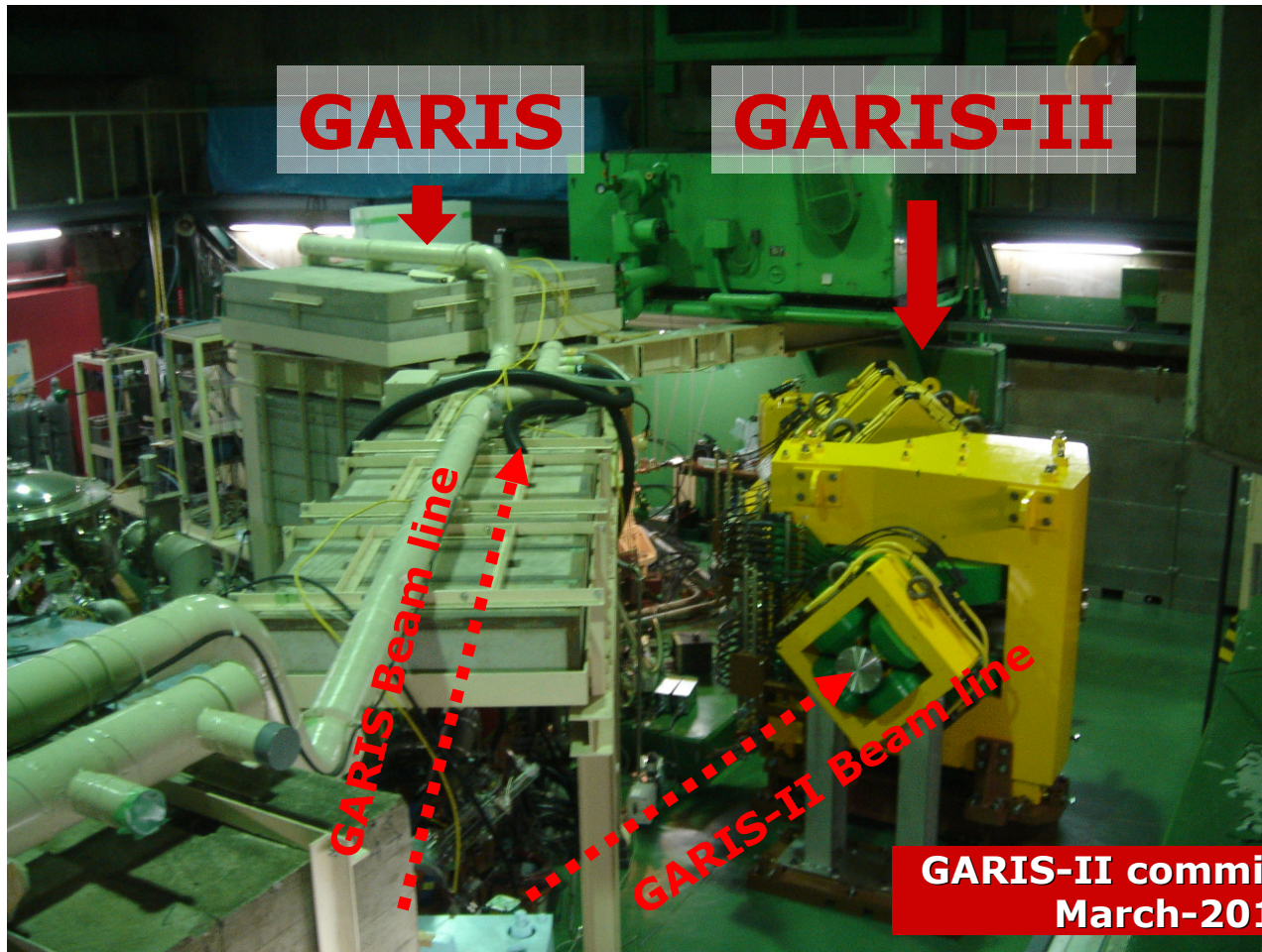
* M. Shaedel, TASCA workshop 2006 (2006).

** Yu. Ts. Oganessian et al., Nucl. Phys. A 734, 195 (2004).

Installation into RILAC facility

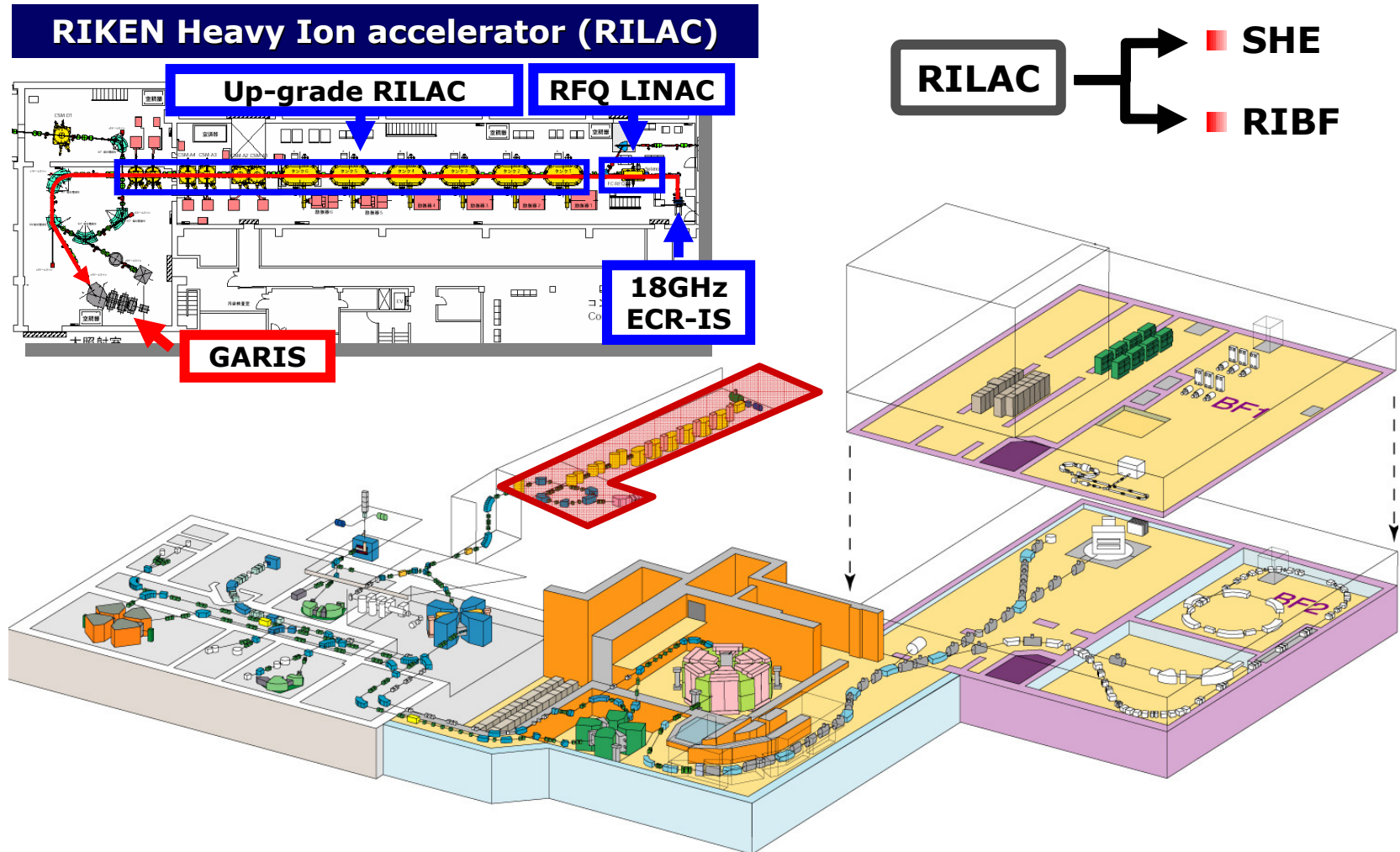


Status of GARIS-II

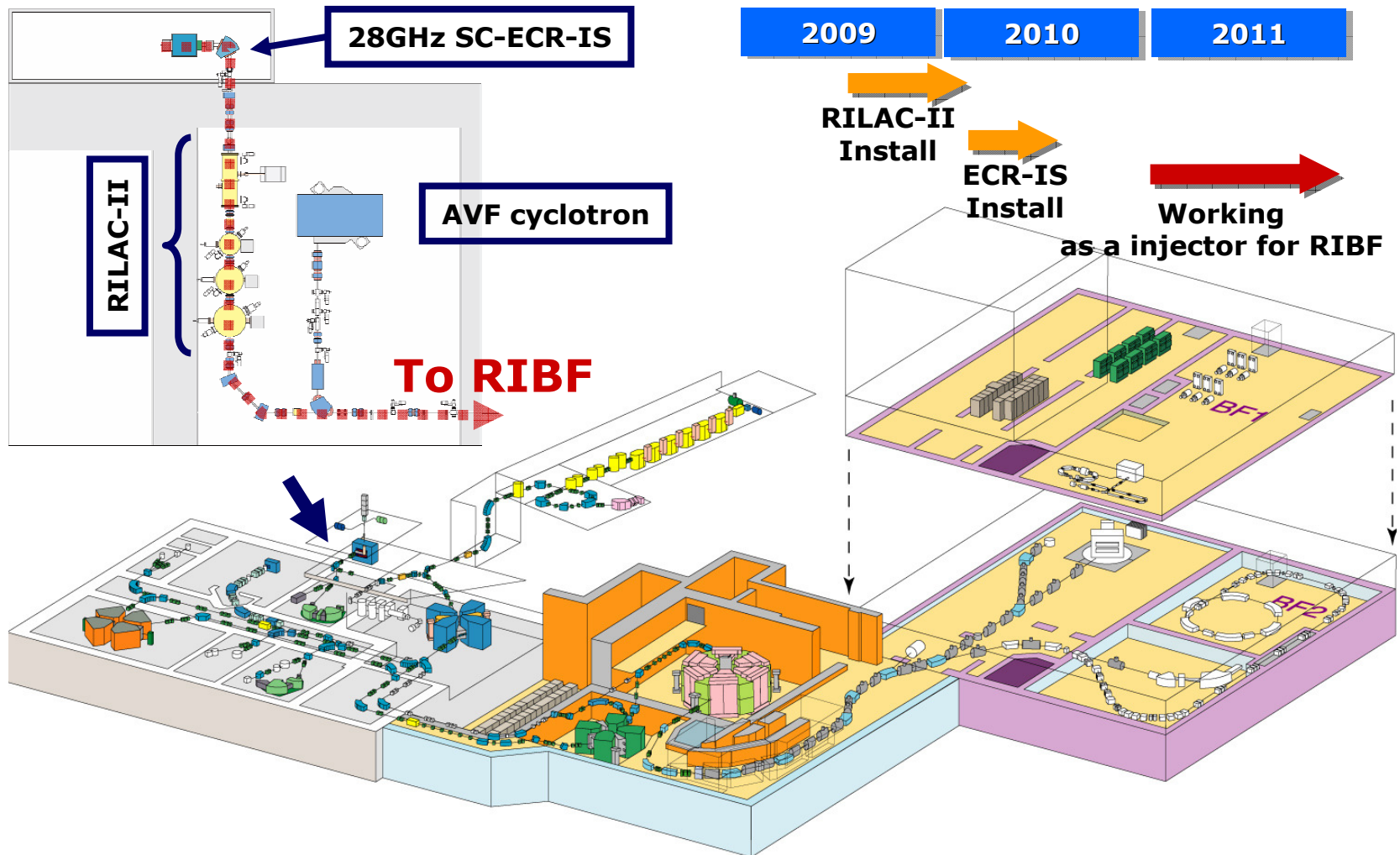


3 Accelerator development in RIBF

SHE study in RIBF (Present)

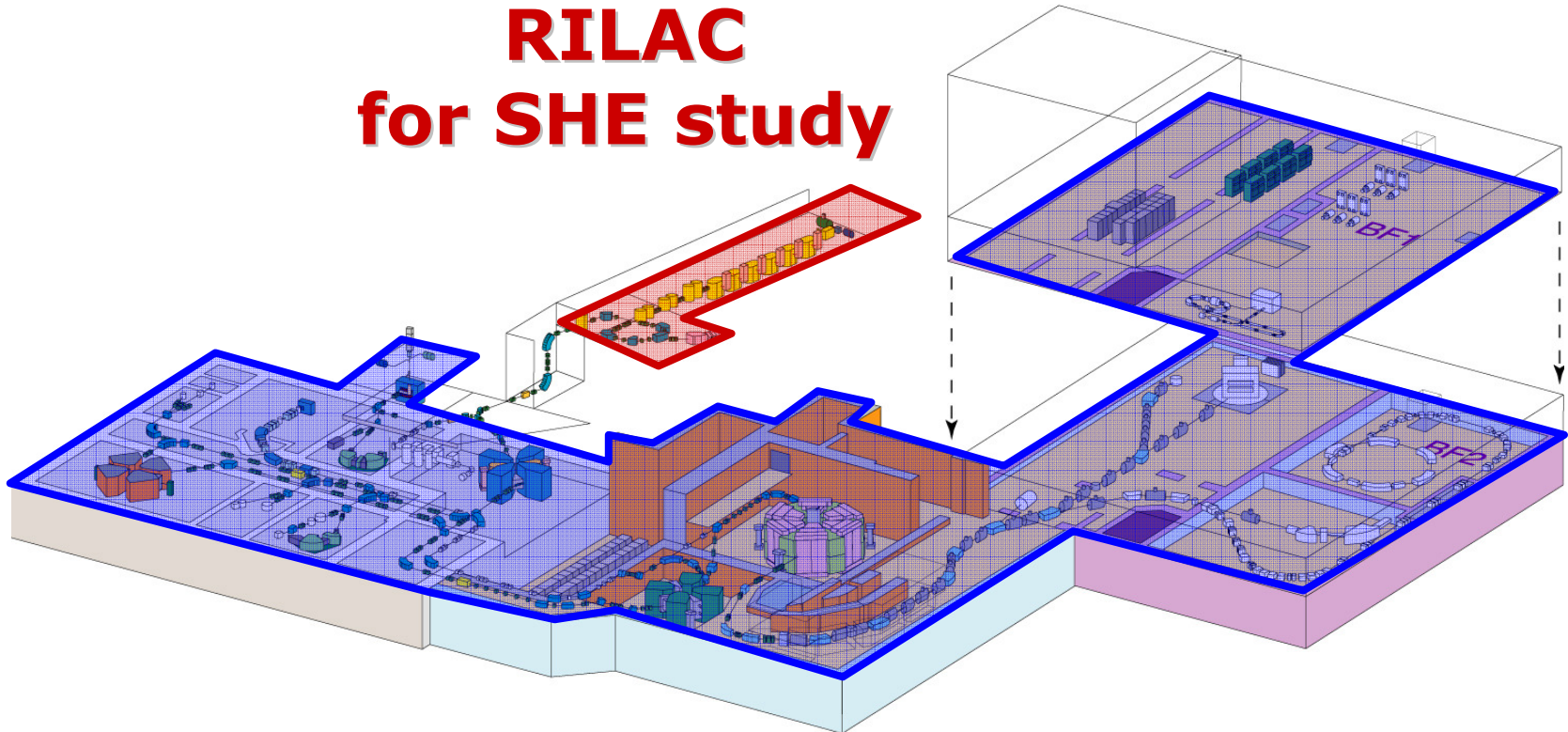


New injector development



SHE study in RIBF (After 2011)

**RILAC
for SHE study**



**RILAC-II
for RI beam study**

Summary

GARIS-II is developing for hot fusion study.

Design → Construction → Installation → Commissioning
(March-2010)

Finished ! **Finished !** **Finished !**

GARIS-II

- Configuration = $Q_v D Q_h Q_v D$
- Total flight path length = **5.12 [m]**
- Bending angle = **30 + 7 [deg]**
- Solid angle = **20.2 [msr]**
- Installation = **RILAC facility**



GARIS-II developers

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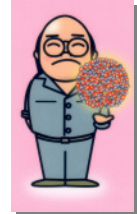
- We would like to thank Y. Yano, Kubo, O. Kamigaito, H. Okuno, M. Kase, N. Fukunishi, M. Fujinawa, E. Ikezawa, Y. Watanabe, Y. Uwamino, and H. Sakamoto for design, construction, and installation of GARIS-II.



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- We would like to thank our family for continuous encouragement and hearty support.