11th International Conference on HEAVY ION
ACCELERATOR TECHNOLOGY

RCNP cyclotron facility

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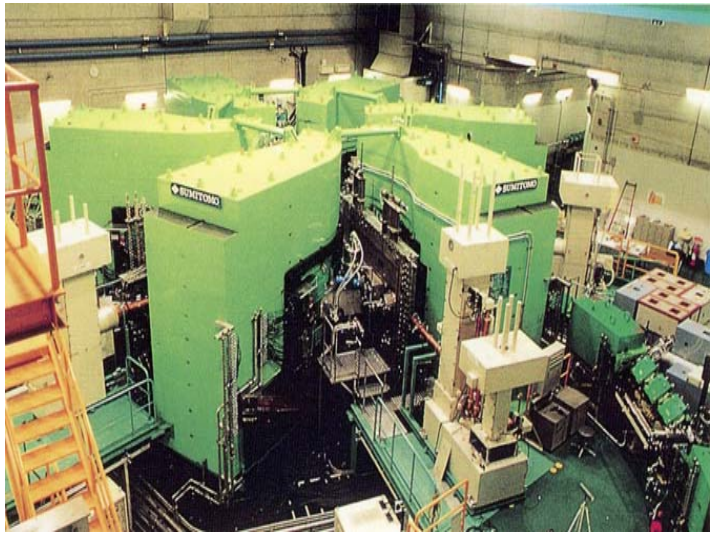
Outline

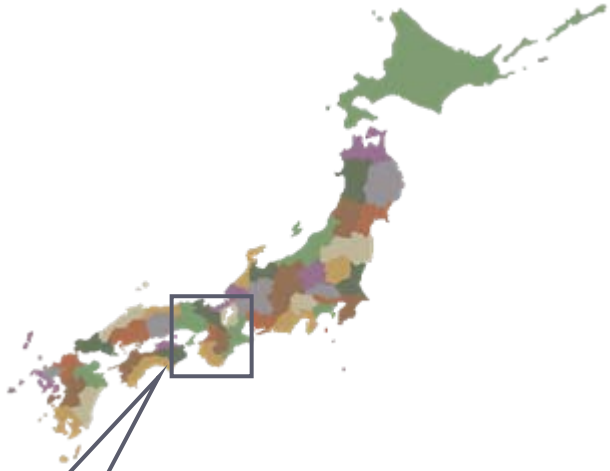
1. Overview of the RCNP facility
2. FLAT-TOP acceleration by the AVF cyclotron
3. 18-GHz ECR ion source
4. Some results with heavy ion beams
   - γ-decay of high-spin isomers
   - Production of ^{210}Fr for electron EDM search
5. Summary

Research Center for Nuclear Physics, Osaka University

Cyclotron Laboratory : Nucleon, Meson, Hadron Physics

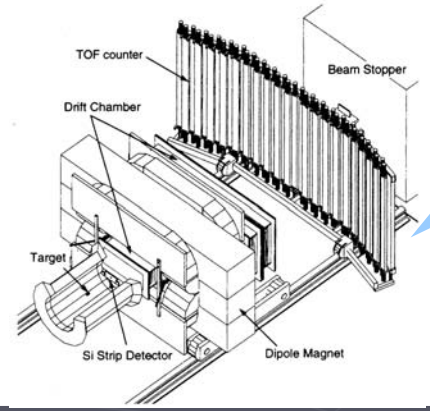
AVF cyclotron with K=0.14 GeV and Ring cyclotron with K=0.4 GeV
Polarized p,d & light heavy ion with Ep=0.01 ~ 0.4 GeV , E/A=0.01 ~ 0.1 GeV

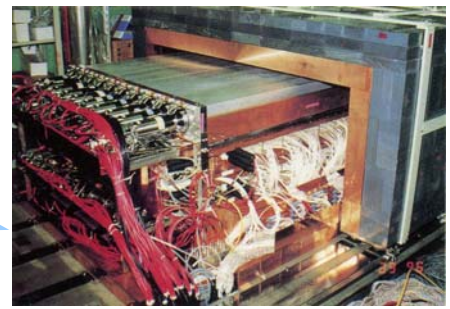




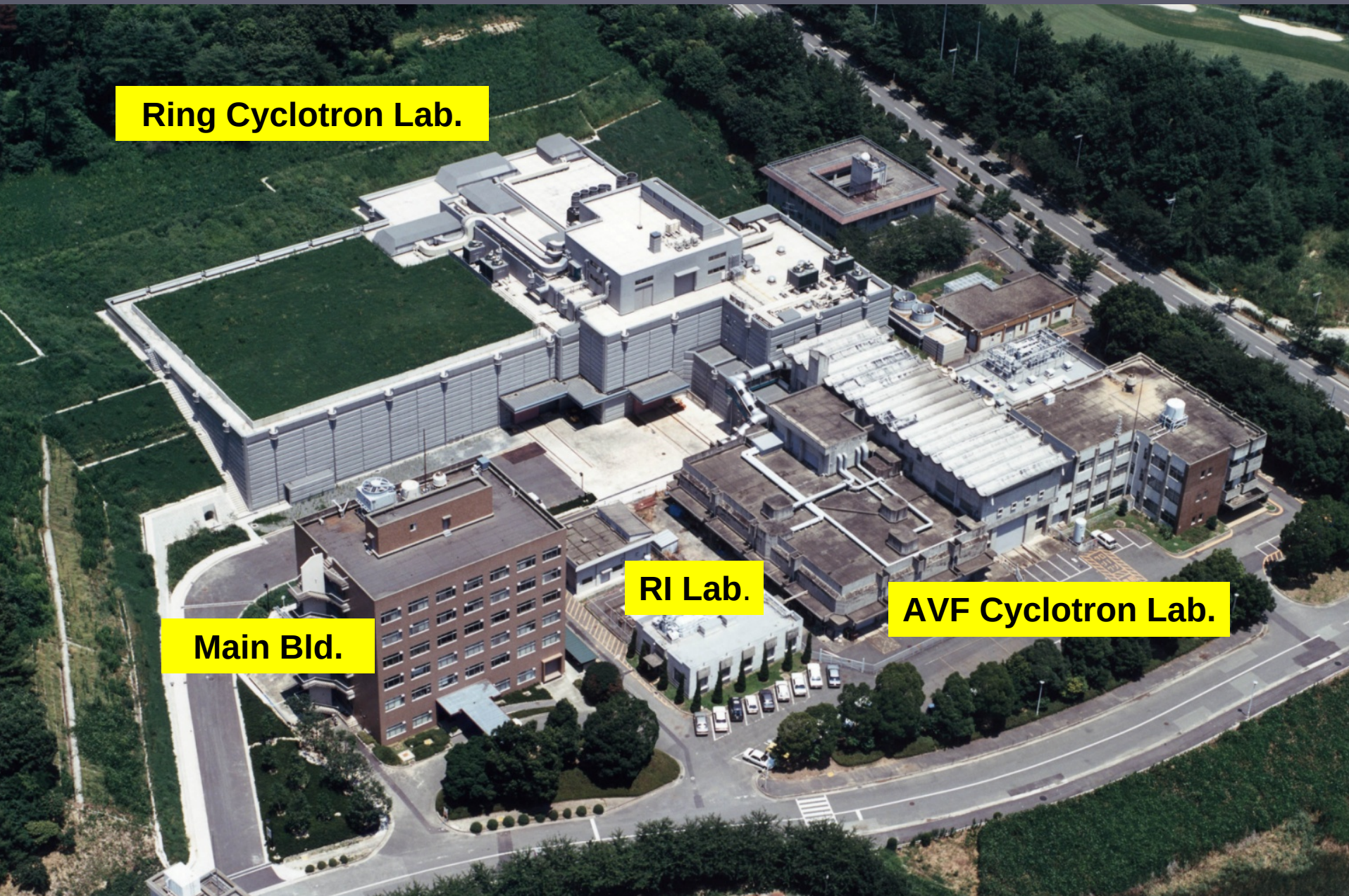
Ohto Cosmo Observatory : Lepton Nuclear Physics
Underground laboratory with low background
(500 m depth, 10 Bq/m^3 Rn & 4*10^{-3}/m^2/s cosmic μ
Double b-decay, Dark matter search, etc.

Laser Electron Photon Laboratory : Quark Nuclear Physics
1 ~ 3.5 GeV Polarized Photon Beams by Back Scattering of
Laser Photons (2 ~ 6 eV) from 8 GeV electrons at Spring-8



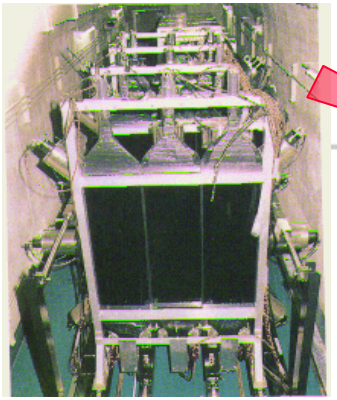


RCNP Cyclotron Facility



RCNP Cyclotron Facility

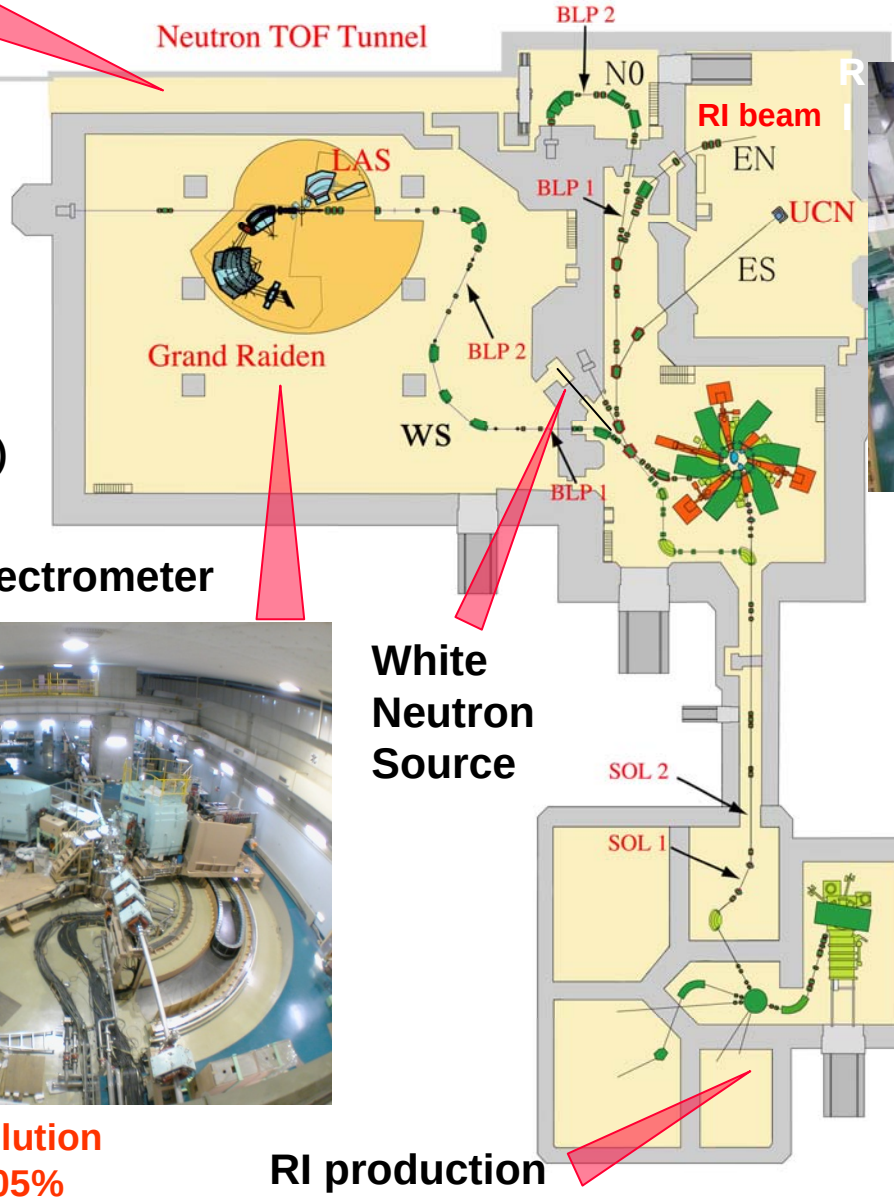
Neutron polarimeter



10ucn/cc at 90neV
(with 400W proton)

Ring Cyclotron

K=400 MeV
since 1992
ΔE/E ~ 0.01%



Double Arm Spectrometer

Energy Resolution
ΔE/E ~ 0.005%

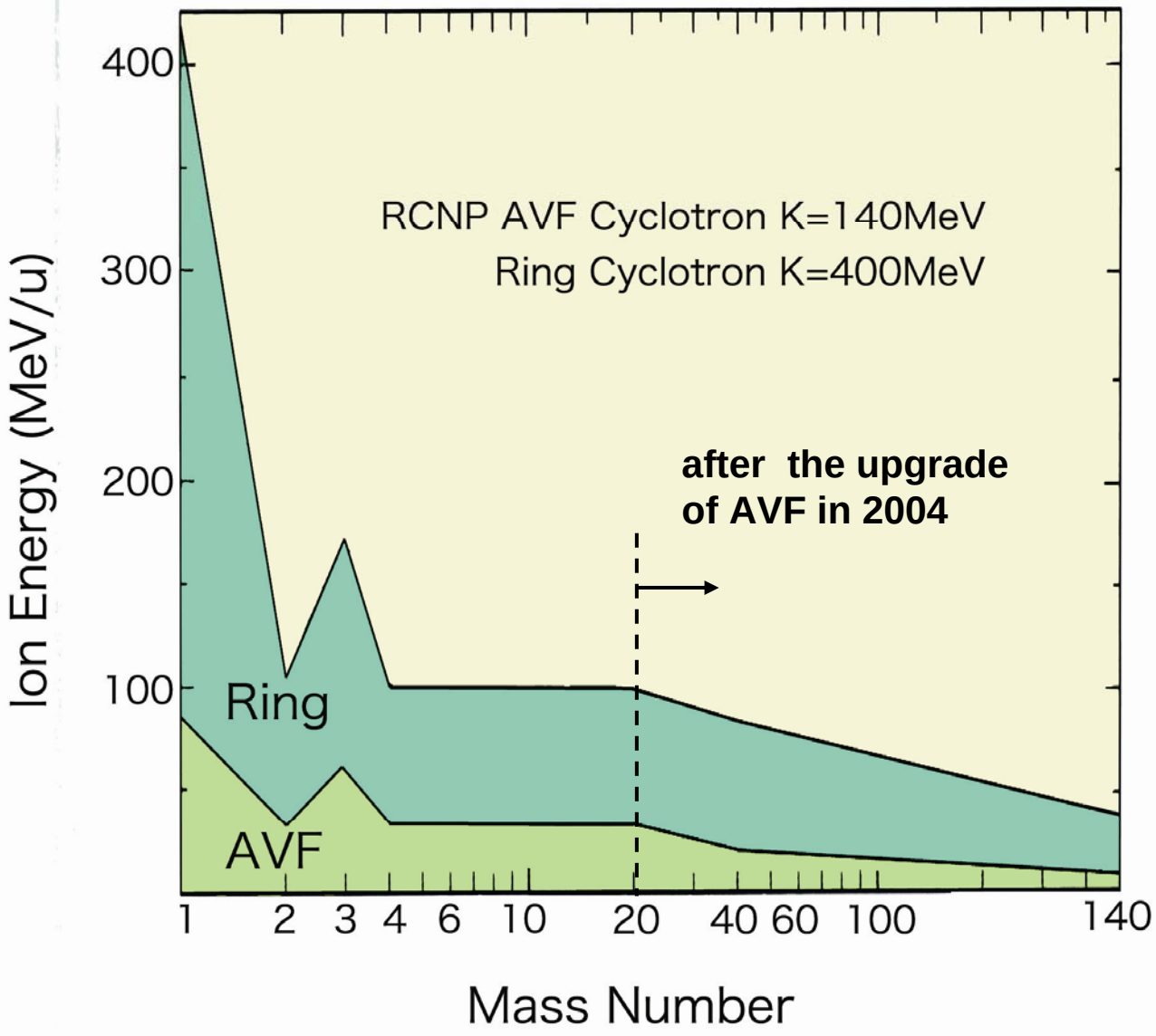
White
Neutron
Source

RI production

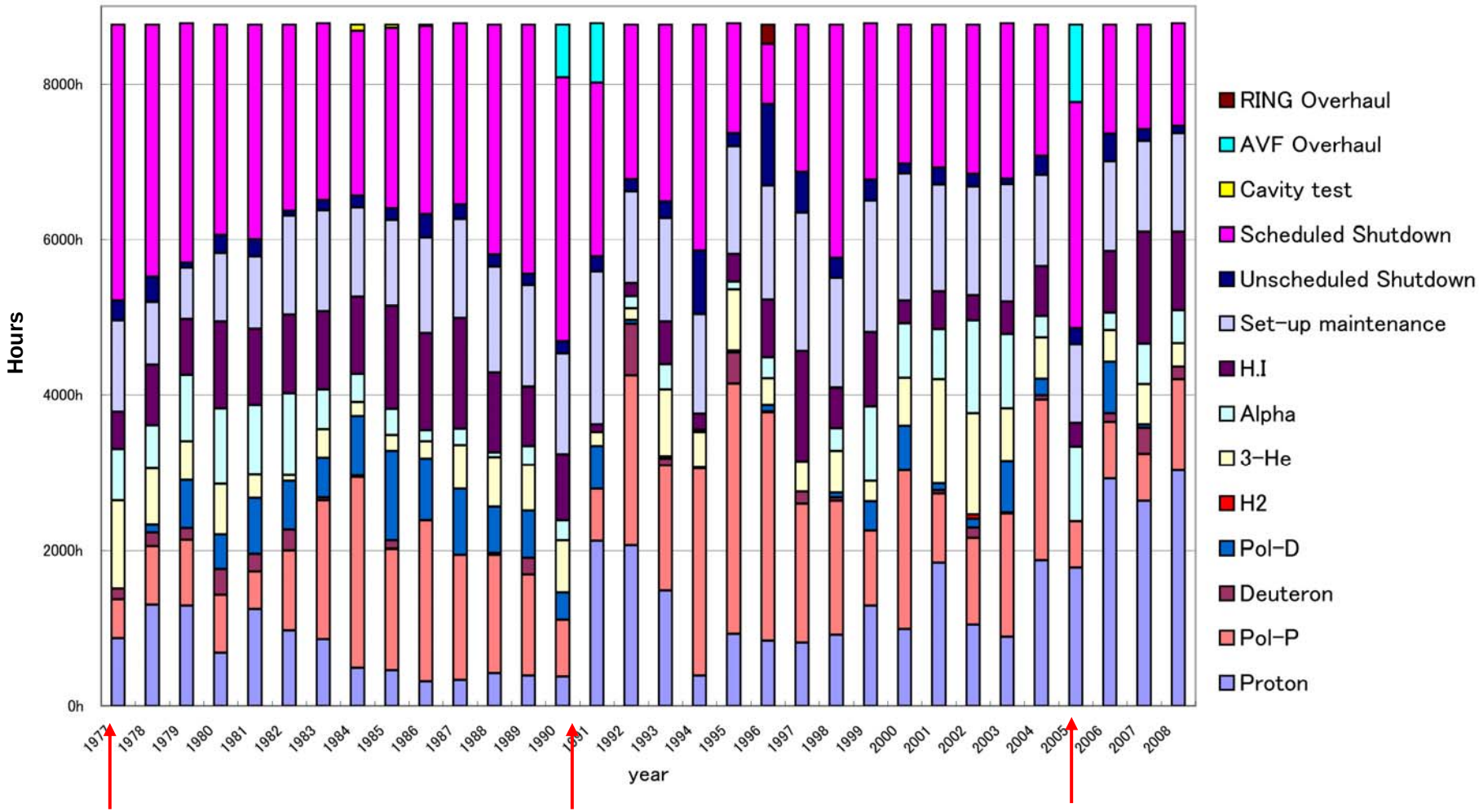
AVF Cyclotron

K=140 MeV
since 1973
ΔE/E < 0.1%

Upgraded recently


RCNP AVF Cyclotron K=140MeV
Ring Cyclotron K=400MeV
after the upgrade
of AVF in 2004
Ring
AVF
Ion Energy (MeV/u)
400
300
200
100
1
2
3
4
6
10
20
40
60
100
140
Mass Number

Operating statistics

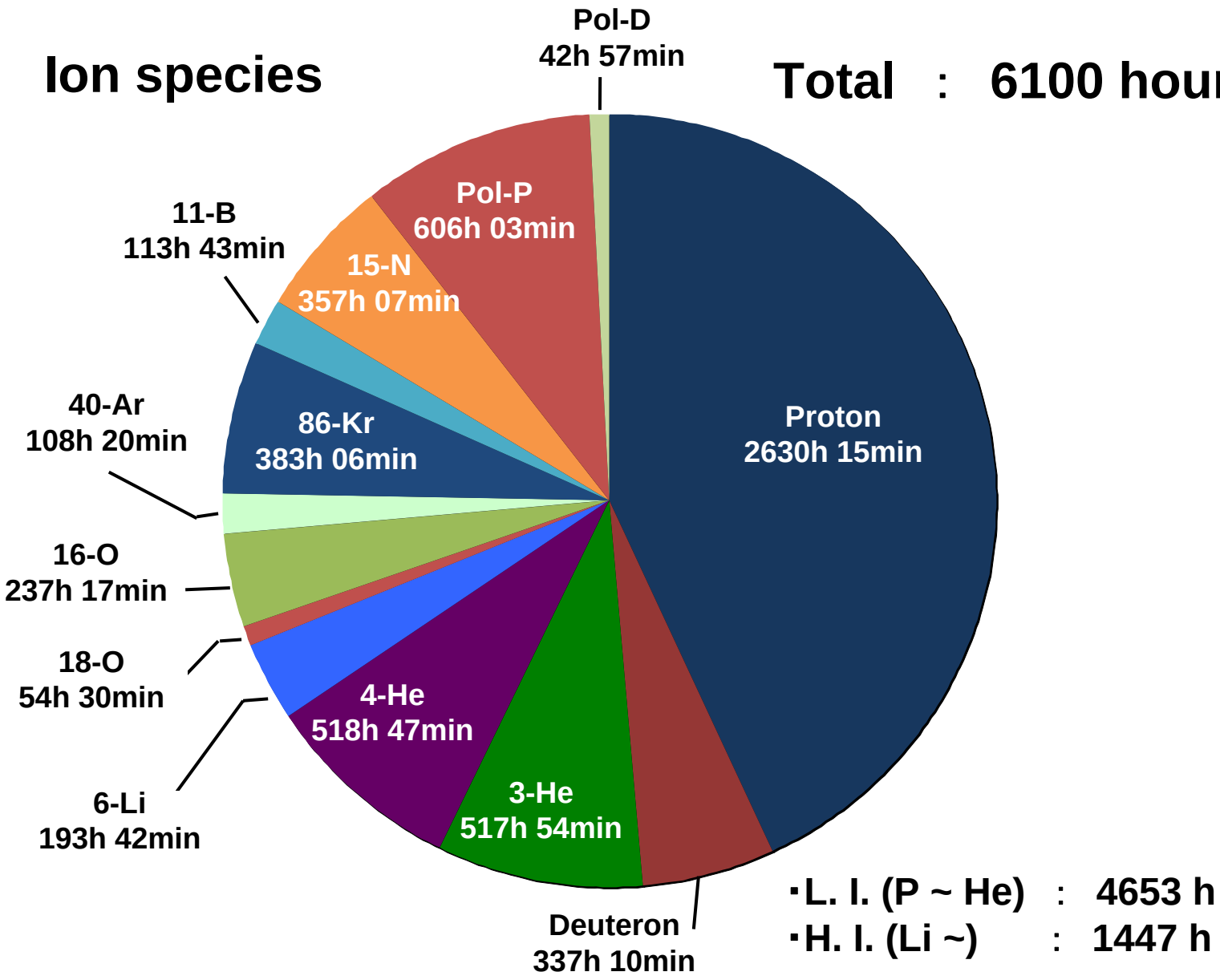


AVF cyclotron was commissioned

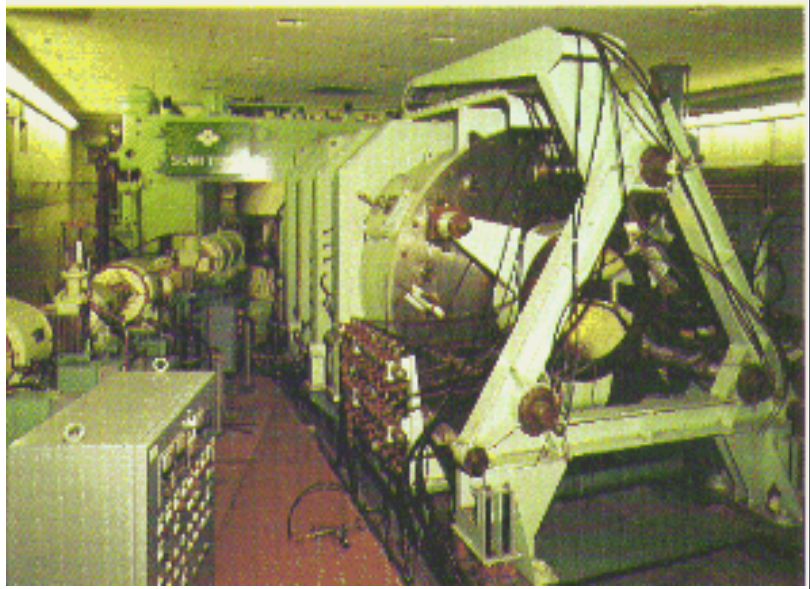
Ring cyclotron was commissioned

Developments were started to increase the intensity of HI beams

Operating statistics in 2007



RCNP K140 AVF Cyclotron

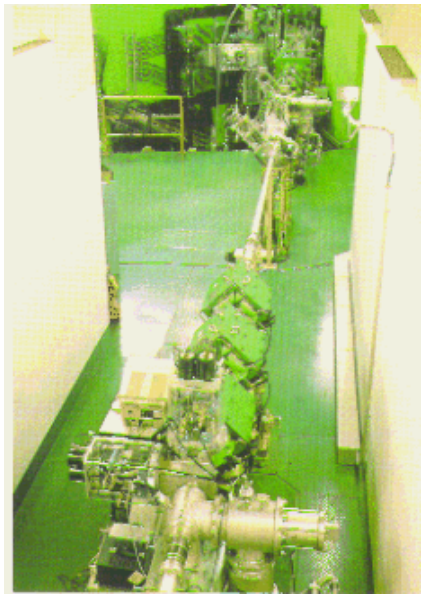


Magnet

- •Pole diameter : 3.3 m
- •Pole gap : 20.6 cm ~ 34.7 cm
- •Averaged field : 1.6 T
- •Trim coils : 16 sets
- •Valley coils : 3 ~ 5 sets
- •Weight : 400 tons

Acceleration system

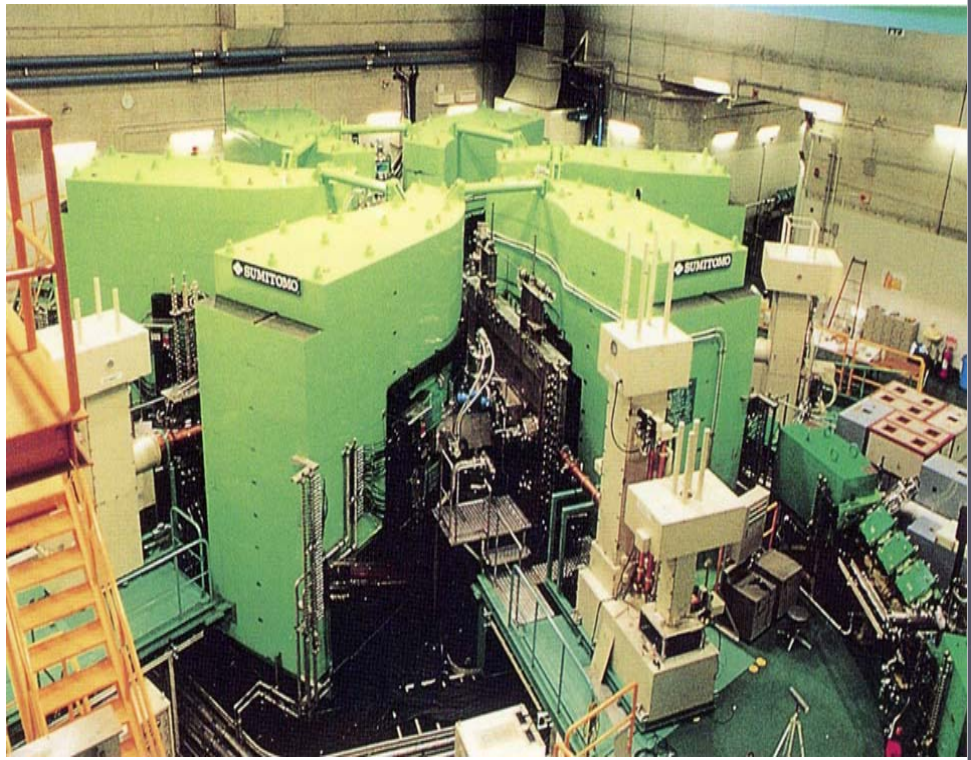
- •Dee : Single 180 degrees type
- •Resonator : Moving short
- •Frequency : 6 ~ 18 MHz
- •Max. acceleration voltage : 80 kV
- •Extraction system: Electrostatic deflector
- •FT system (k=5,7,9)



Ion Sources

- •External ion source : Atomic beam type polarized ion source, ECR ion source
  18 GHz SCECR ion source

RCNP K=400 Ring Cyclotron



Magnet

- Sector magnets : 6 sets
- Pole gap : 6 cm
- Maximum magnetic field : 1.75 T
- Trim coils : 36 sets
- Injection radius : 2 m
- Extraction radius : 4 m
- Weight : 2200 tons

Acceleration system

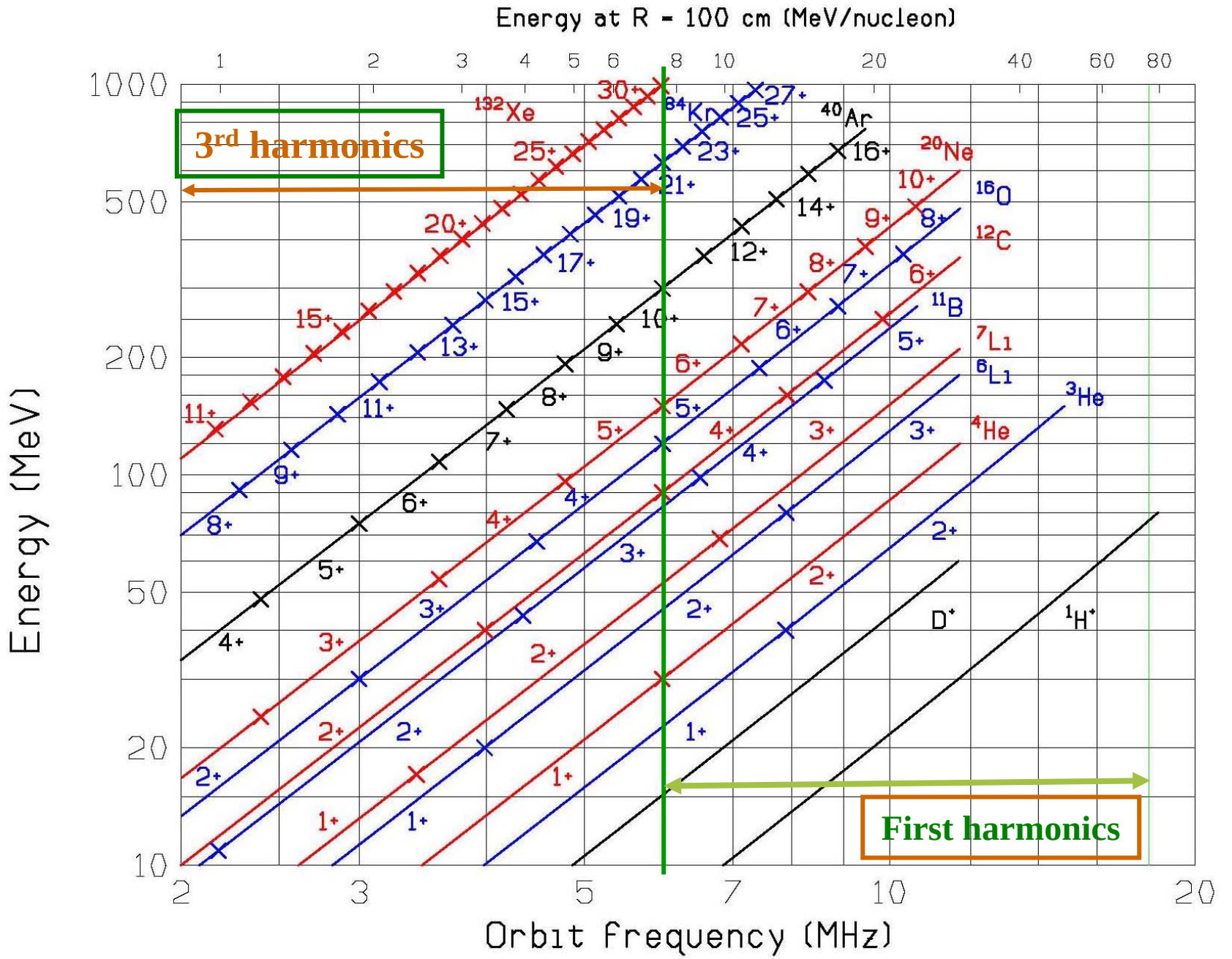
- Single gap type : 3 sets
- Frequency : 30 ~ 52 MHz
- Max. acceleration voltage : 500 kV
- RF power : 250 kW/cavity

Flat-top cavity

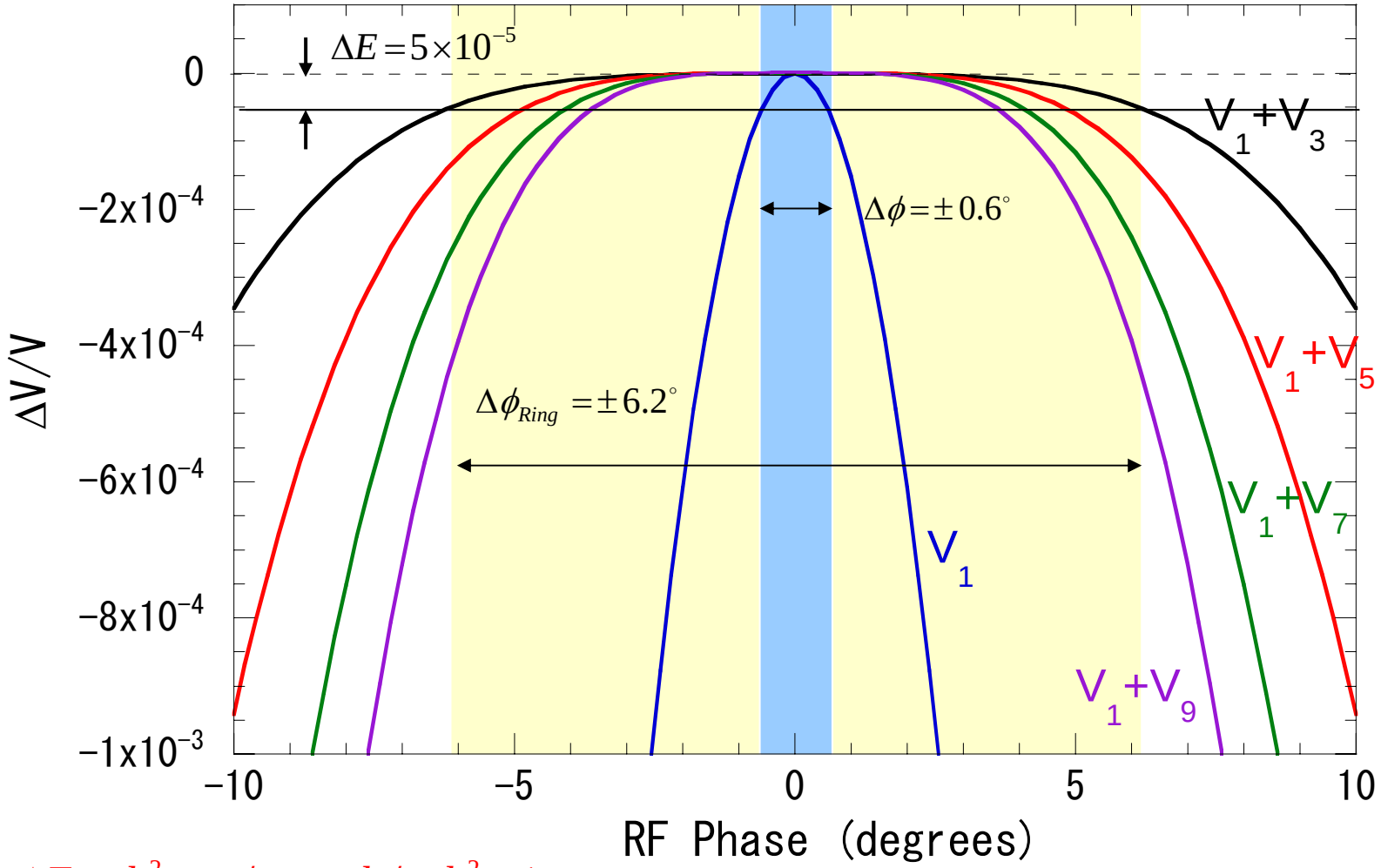
- Single gap type : 1 set
- Frequency : 90 ~ 156 MHz

⇨ **Key element for high quality beam**

World first FT system operating at variable frequencies


Energy at R = 100 cm (MeV/nucleon)
1
2
3
4
5
6
8
10
20
40
60
80
1000
500
200
100
50
20
10
Energy (MeV)
2
3
5
7
10
20
Orbit Frequency (MHz)
3rd harmonics
First harmonics
132Xe
84Kr
40Ar
20Ne
16O
12C
11B
7Li
6Li
3He
4He
D+
1H+
30+
27+
25+
23+
21+
19+
17+
15+
13+
11+
9+
8+
7+
6+
5+
4+
3+
2+
1+
16+
14+
12+
10+
9+
8+
7+
6+
5+
4+
3+
2+
1+
10+
9+
8+
7+
6+
5+
4+
3+
2+
1+
RCNP AVF

Voltage Waveform of Fundamental and FT acceleration Using 3rd, 5th, 7th and 9th Harmonic Frequencies



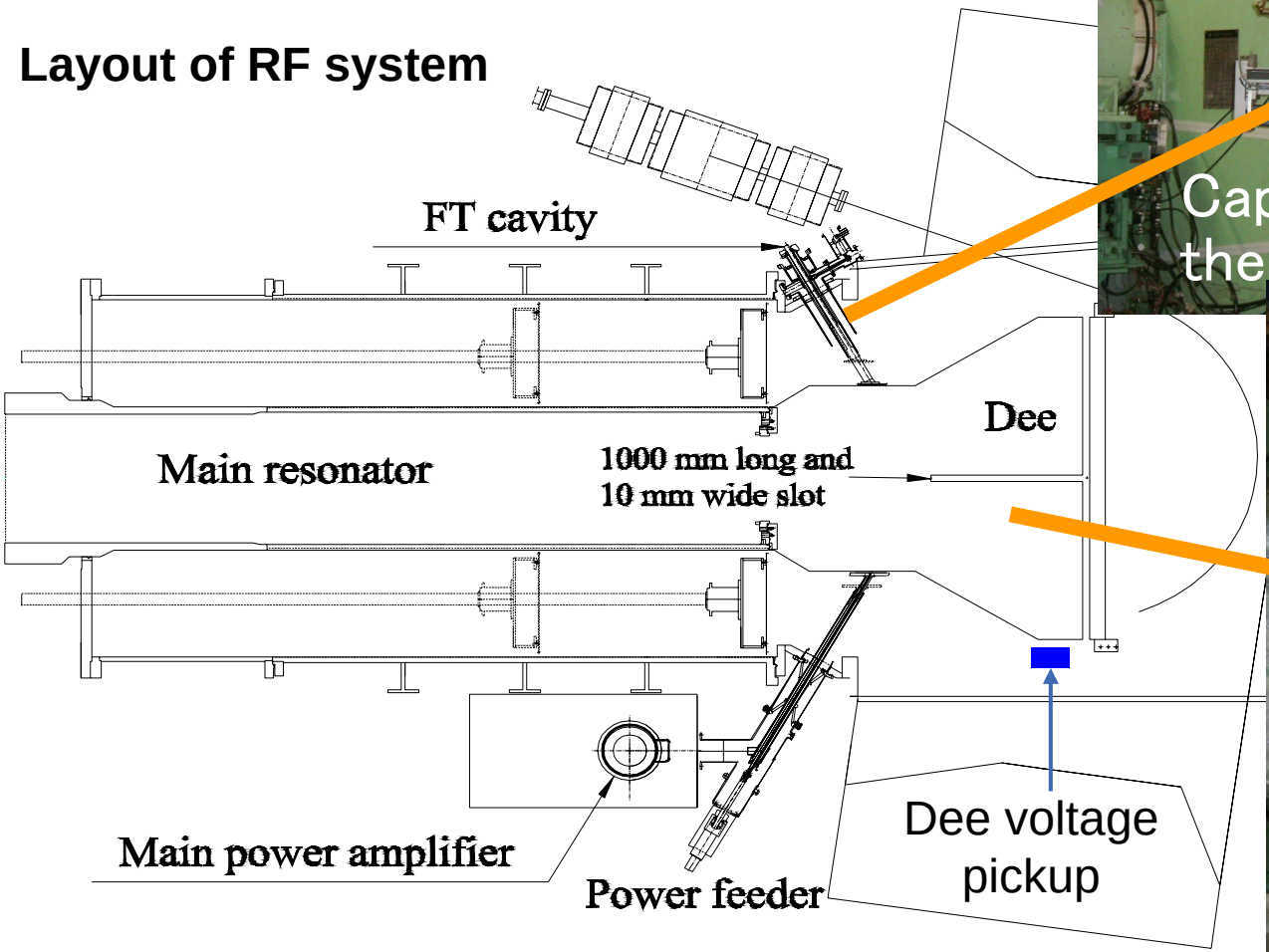
$$\frac{\Delta E}{E} = \frac{k^2\cos\phi - \cos k\phi - k^2 + 1}{k^2 - 1}$$

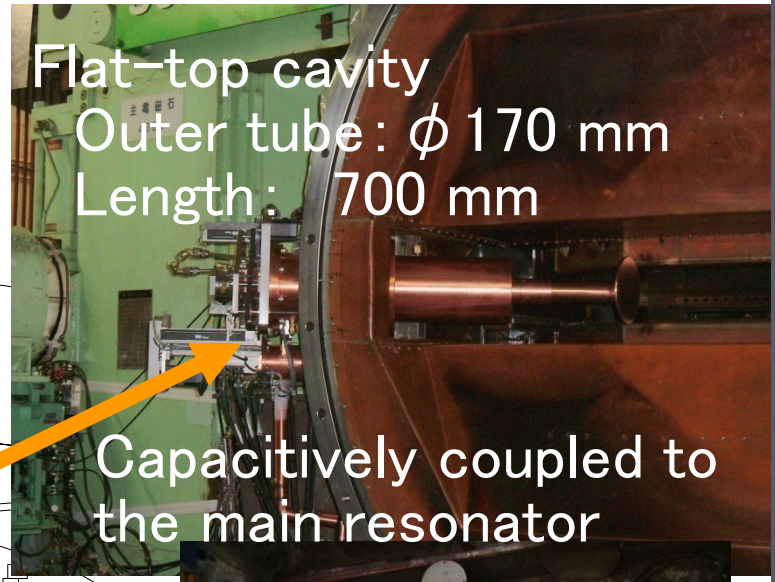
FT system for the AVF cyclotron

Characteristics

- Harmonic frequency : 50 ～ 80 MHz
- Harmonics : k = 5, 7, 9

Layout of RF system

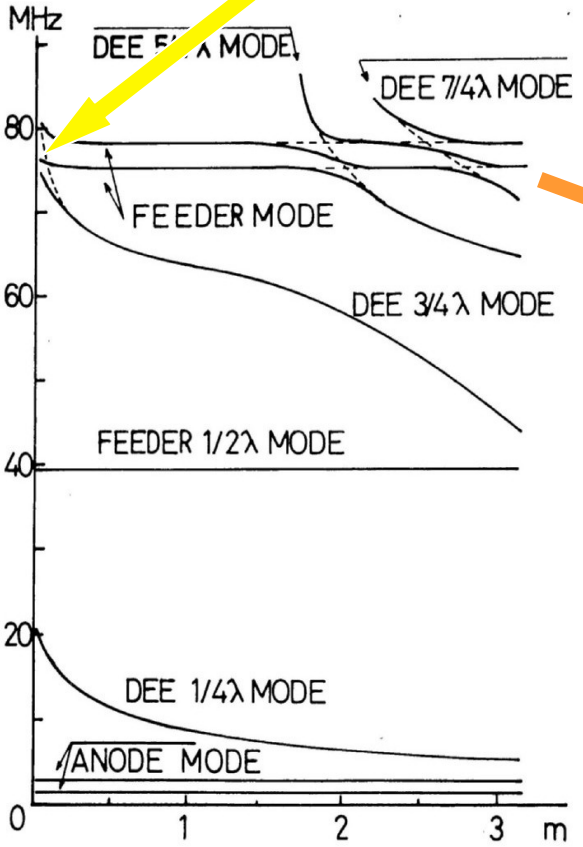


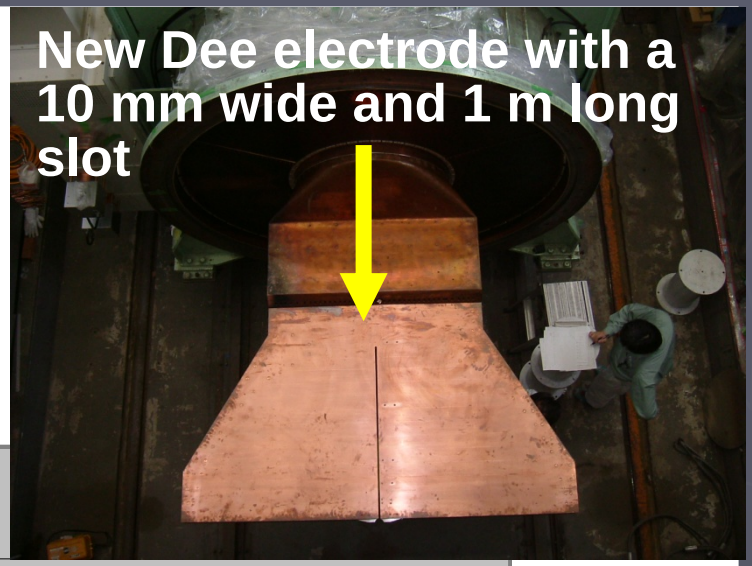


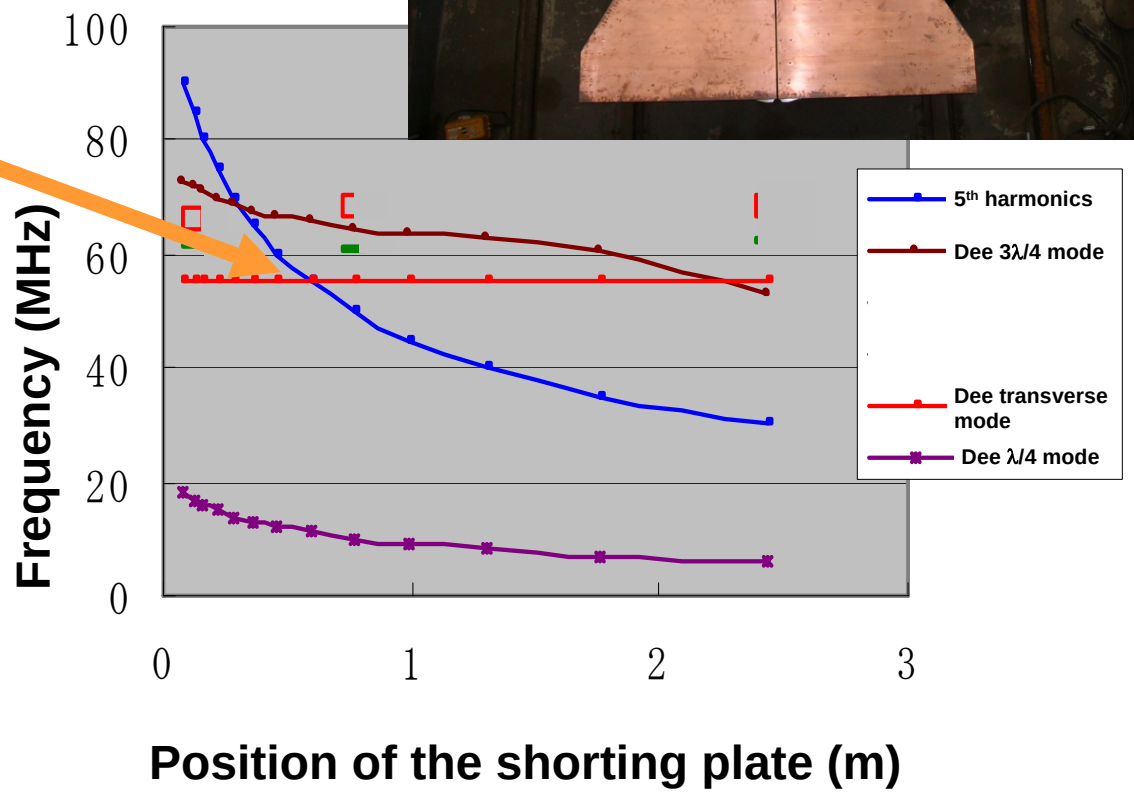
Modification of the Dee Electrode

to avoid the interference by the parasitic resonance mode near 80 MHz generated in the transversal direction of the dee electrode

E_p = 300 MeV

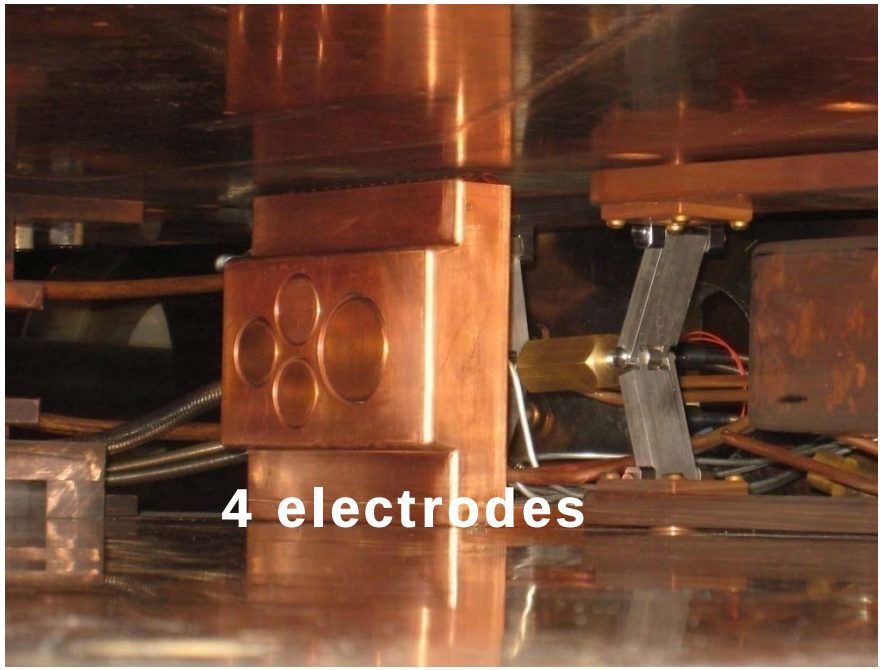






Dee Voltage Pickup

Dee-voltage pickup electrode



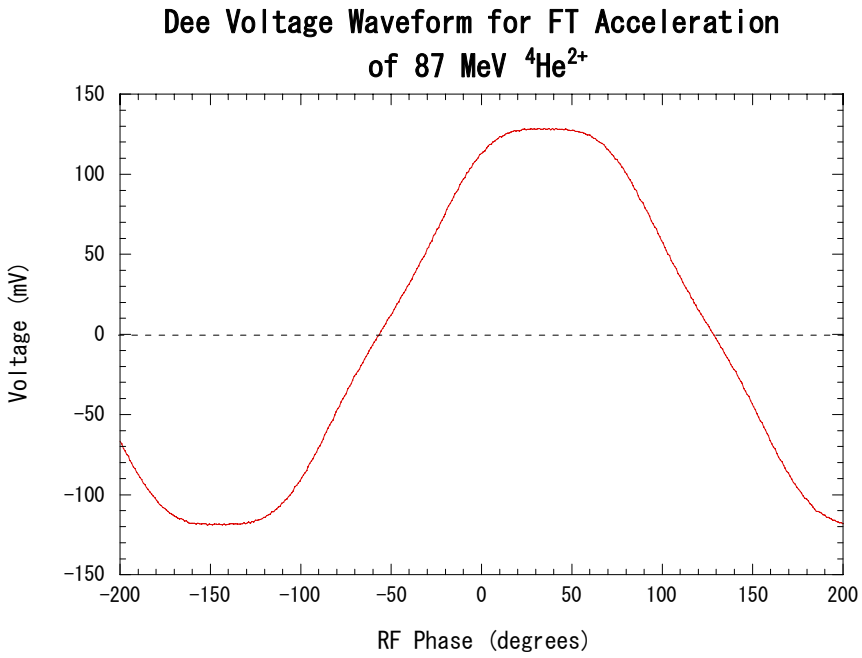
facing the Dee electorode, placed near the acceleration gap, used for regulation of RF system.

Example of the pickup voltage waveform

87MeV 4He2+ (400MeV @Ring)

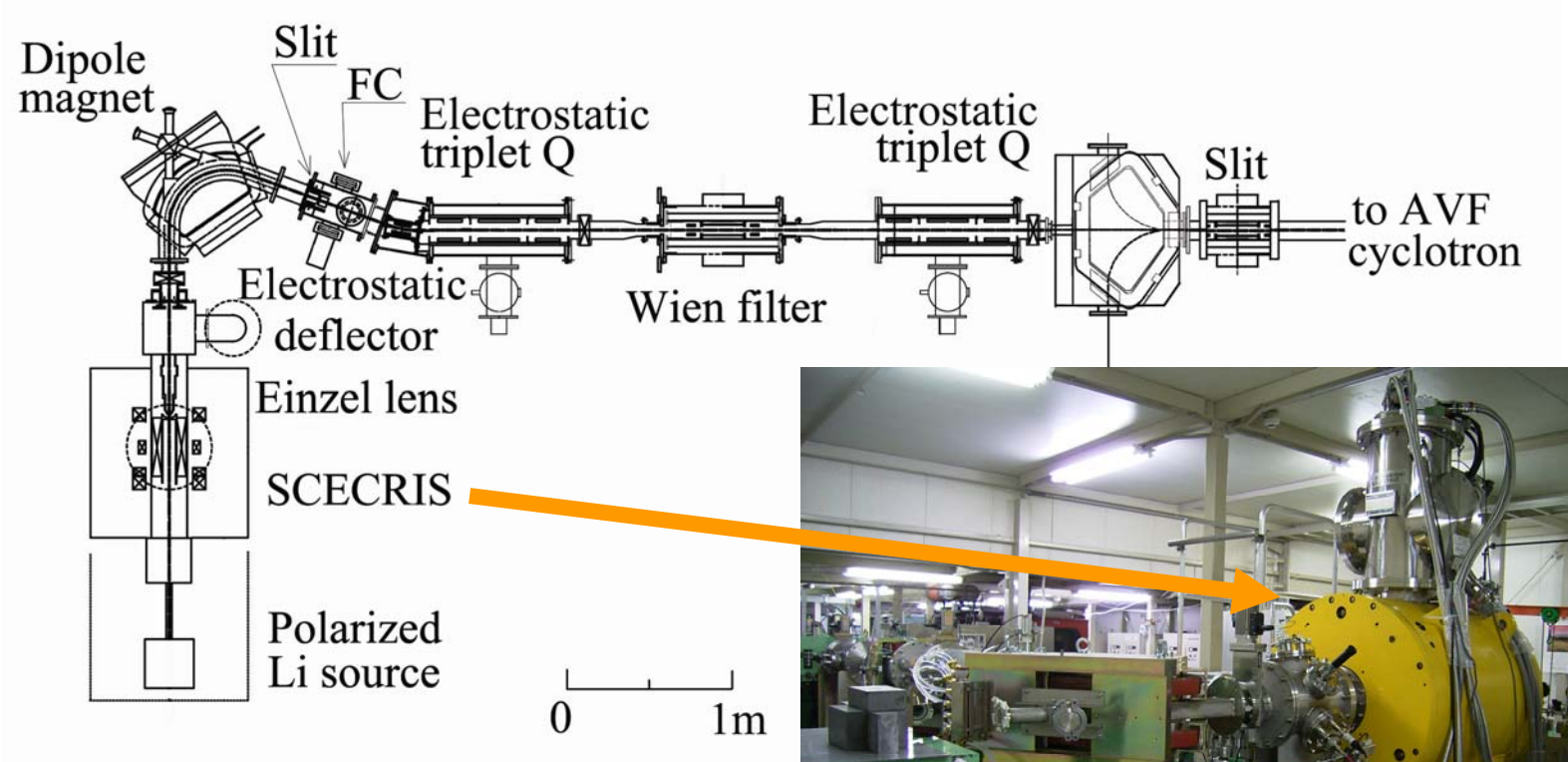
f_1 = 10.144 MHz

f_5 = 50.720 MHz



18 GHz Superconducting ECR Ion Source

- **Highly charged heavy ions**
- **A variety of heavy ions at high intensity**

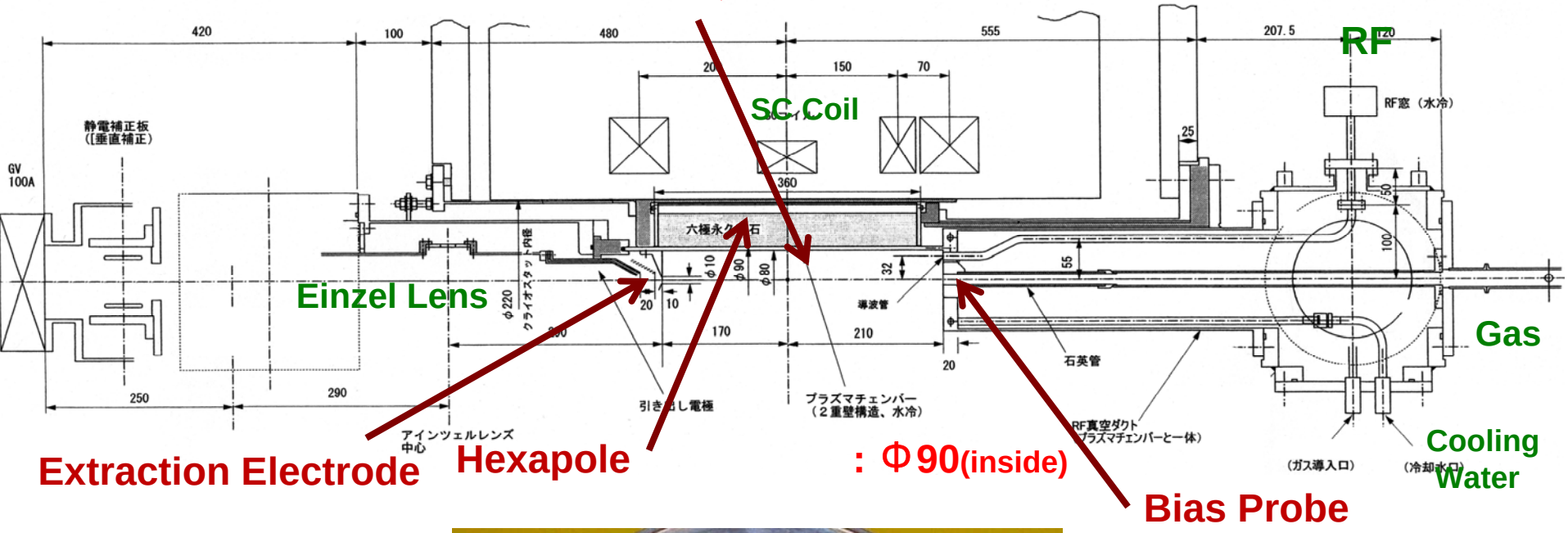


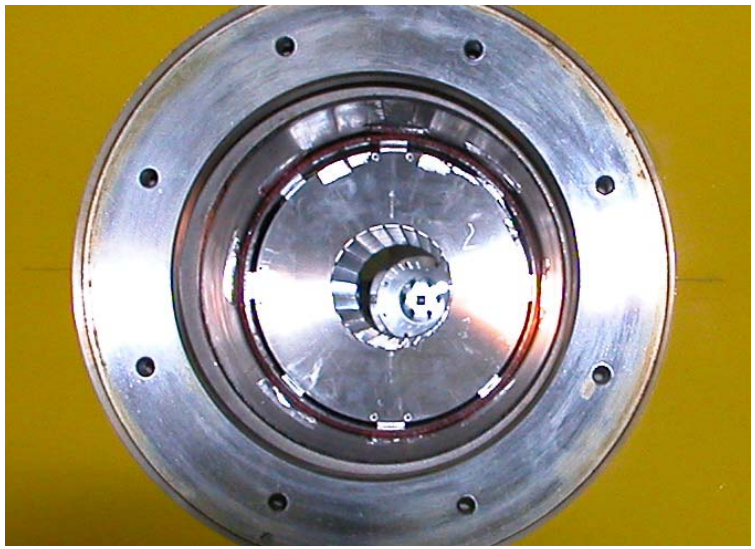
800 eμA $^{18}O^{6+}$ beam with RF power of 600 W

Plasma Chamber

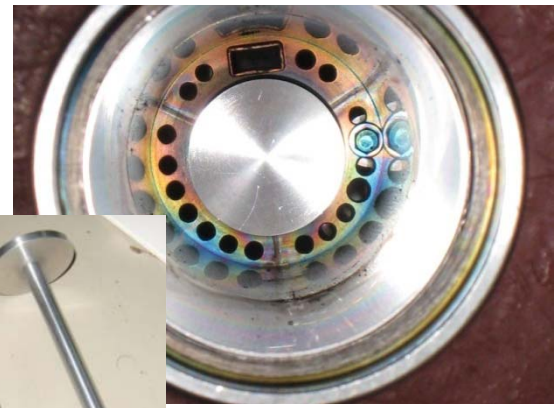
Plasma Chamber:
Φ80x380L、1800cm^3

Al liner of 1 mm in thickness
inside of plasma chamber





~1T on the chamber wall



Ion Currents (eμA)

＊→Optimized for these ions

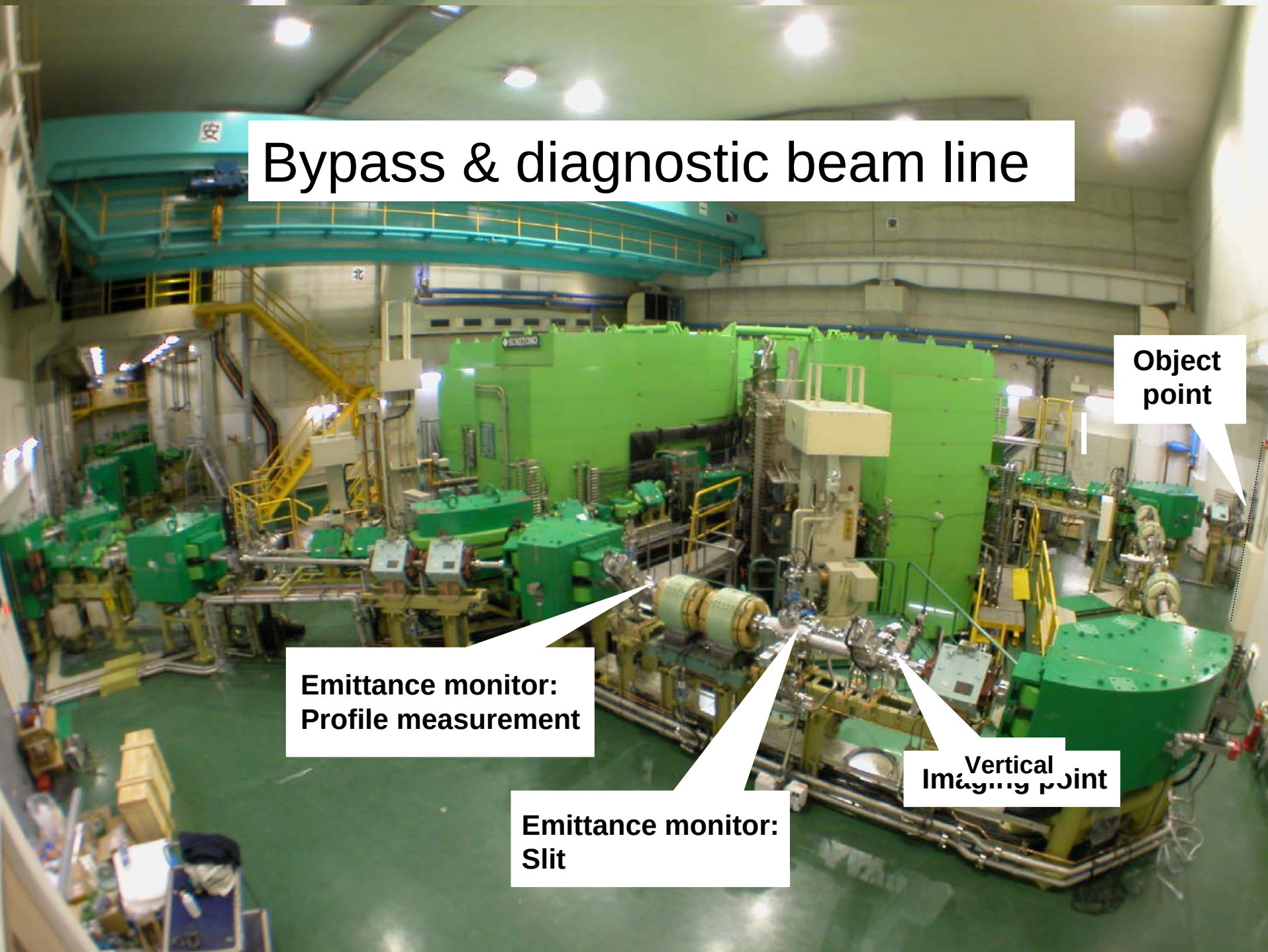
	2+	3+	4+	5+	6+	7+	RF
^{11}B (^{4}He) ※1	1.3	4.1	9.3	＊8.2			400W
^{12}C (CH4) (^{4}He)		---	410	＊115	---		500W
^{15}N (^{4}He)		167	477	＊725	117		500W
^{16}O (^{4}He)	10	178	---	＊779	517	27	500W
^{18}O (^{4}He)		88	235	475	＊673	39	500W
	11+	12+	13+	14+			
^{40}Ar (^{16}O)	＊188	70	17	3			500W
	20+	21+	22+	23+	24+	25+	
^{86}Kr (^{16}O)	32	26	21	＊13	8.1	4.5	600W
	28+	29+	30+	31+	32+	33+	
^{136}Xe (^{16}O)	11.3	10.6	8.8	6.2	＊4.2	2.3	770W

comparable ion beams from NEOMAFIOS

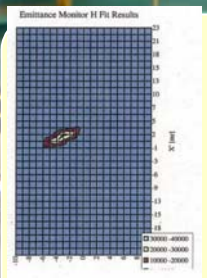
	4+	5+	6+	7+
^{14}N	110	65	6	
^{16}O	80	30	10	0.2

※1 MIVOC Method with o-carborane ($C_2B_{10}H_{12}$)

- **Bean intensity is increased by one order of magnitude compared to the existing NEOMAFIOS.**
- **Highly charged ions become available for heavier elements.**


Bypass & diagnostic beam line
Object point
Emittance monitor: Profile measurement
Emittance monitor: Slit
Vertical

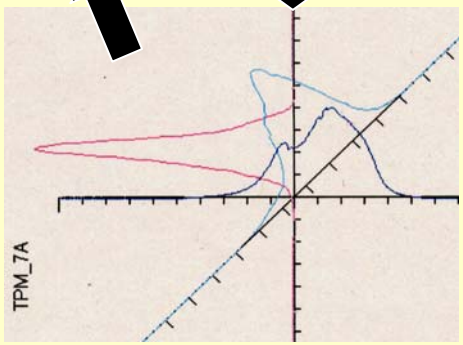
Bypass & diagnostic beam line



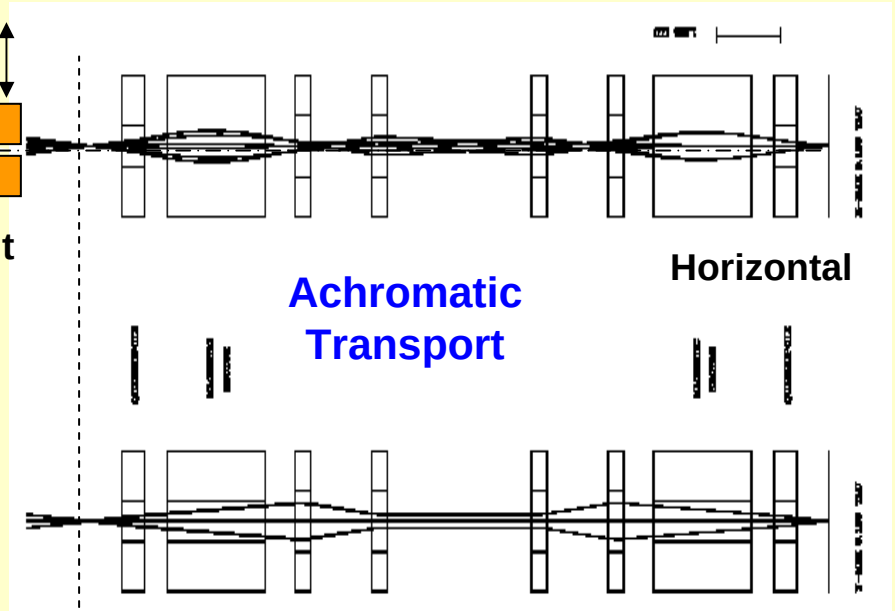
Emittance

Profile monitor

Slit



Profile measurement



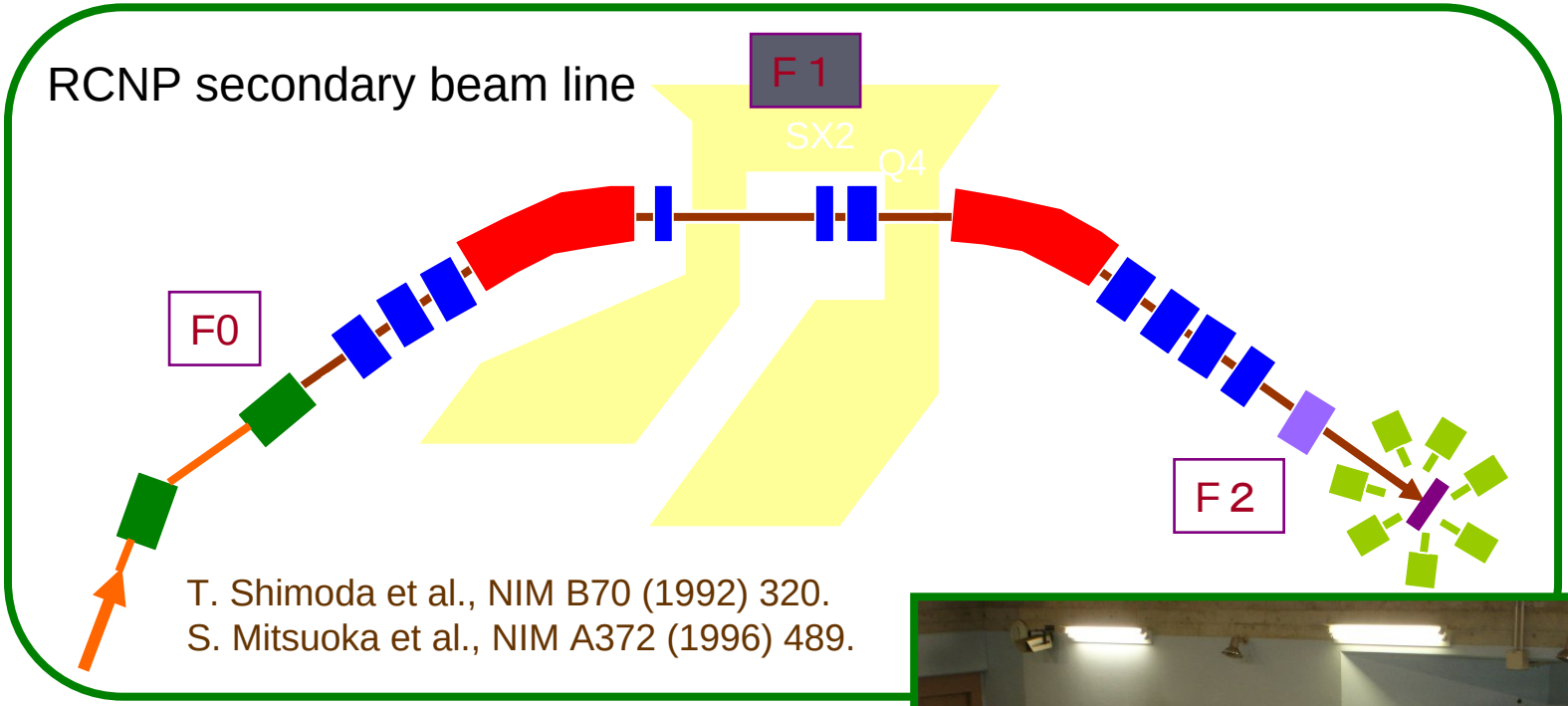
Object point

Vertical

Imaging point

Emittance monitor:
Slit

EN (Exotic Nucleus) beam line

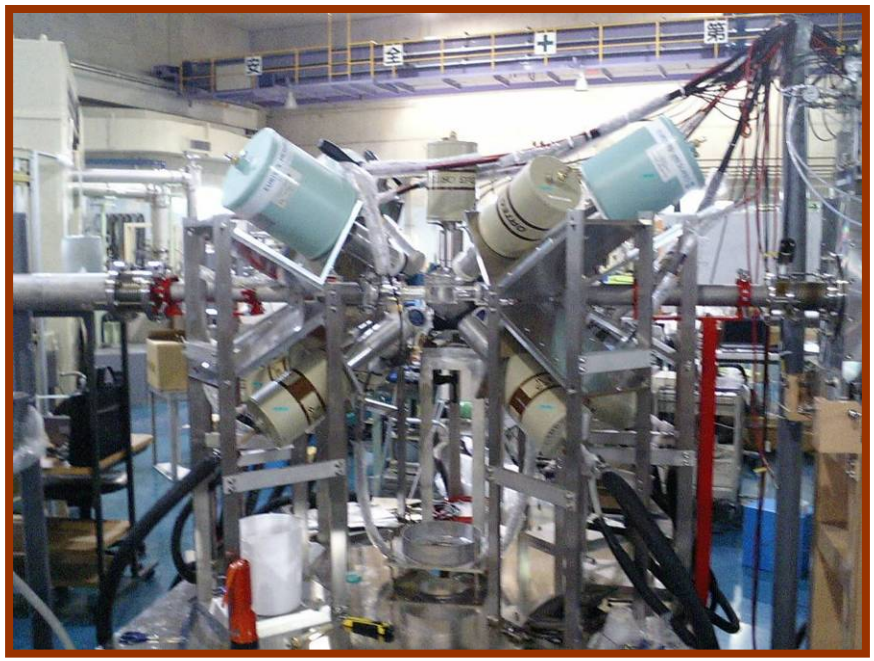


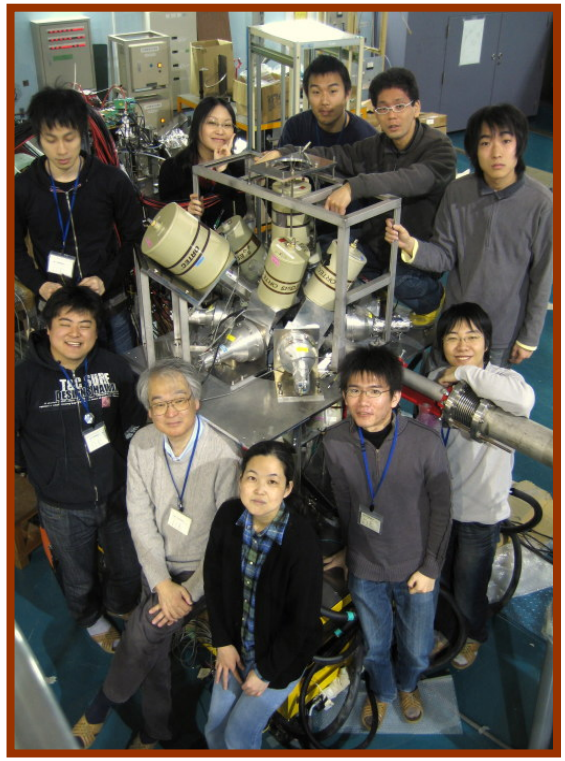
Maximum rigidity	3.2 Tm
Energy acceptance	$\Delta E/E$ = 16 %
Angular Acceptance	$\Delta\theta$ = 40 mrad
	$\Delta\phi$ = 28 mrad
Path length	16.8 m

RCNP Ge array

14 Ge det.
total efficiency
1.9 % at 1.3 MeV

14 Ge + 6 BGOACS
total efficiency
1.0 % at 1.3 MeV





Ge det. :
Dep. of Phys. & RCNP Osaka Univ.,
Dep. of Phys. Tohoku Univ., SUNY

search for high-spin shape isomers in *N*=83 isotones
^{17}N **RI beam fusion reaction**

primary reaction : ^{9}Be(^{18}O,^{17}N)^{10}B 9.2 MeV/u, 0.8 pμA

secondary reaction : ^{130}Te + ^{17}N 5.0 MeV/u, ~10^5 pps

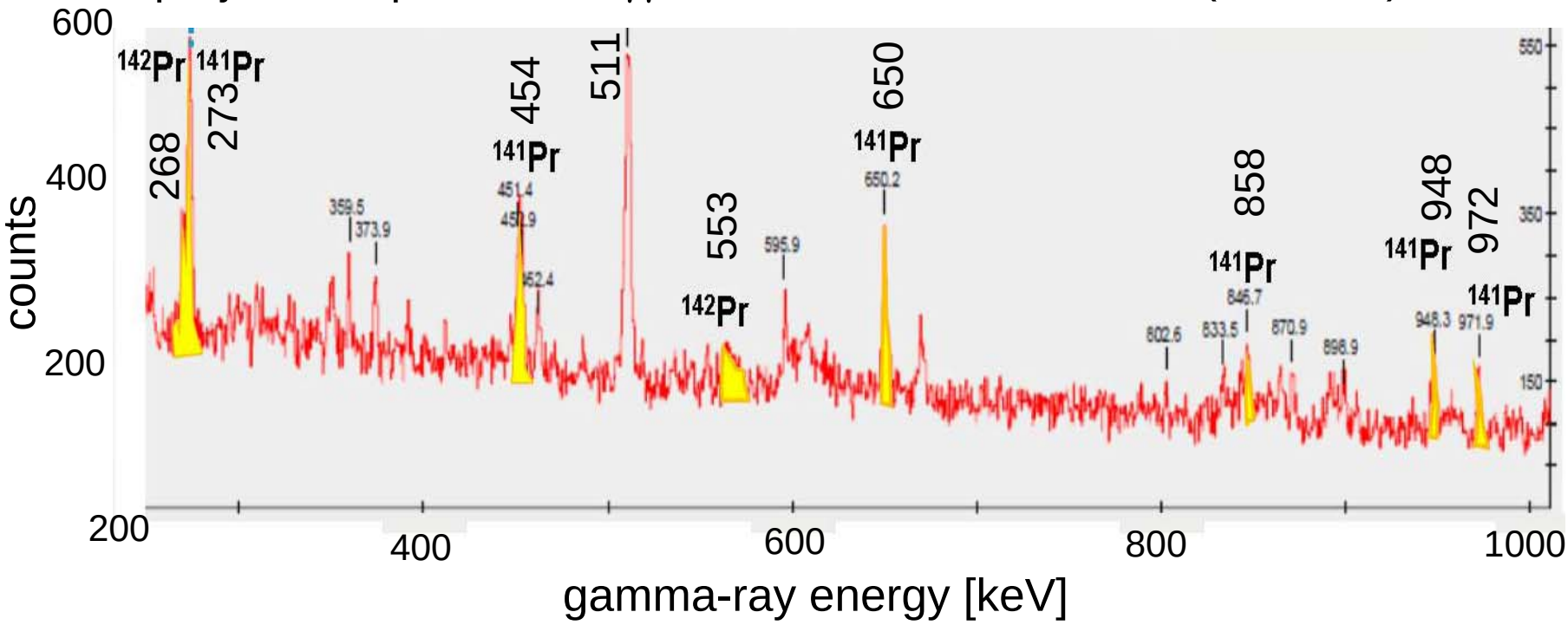
Gamma-rays by secondary fusion reaction were observed.

preliminary result

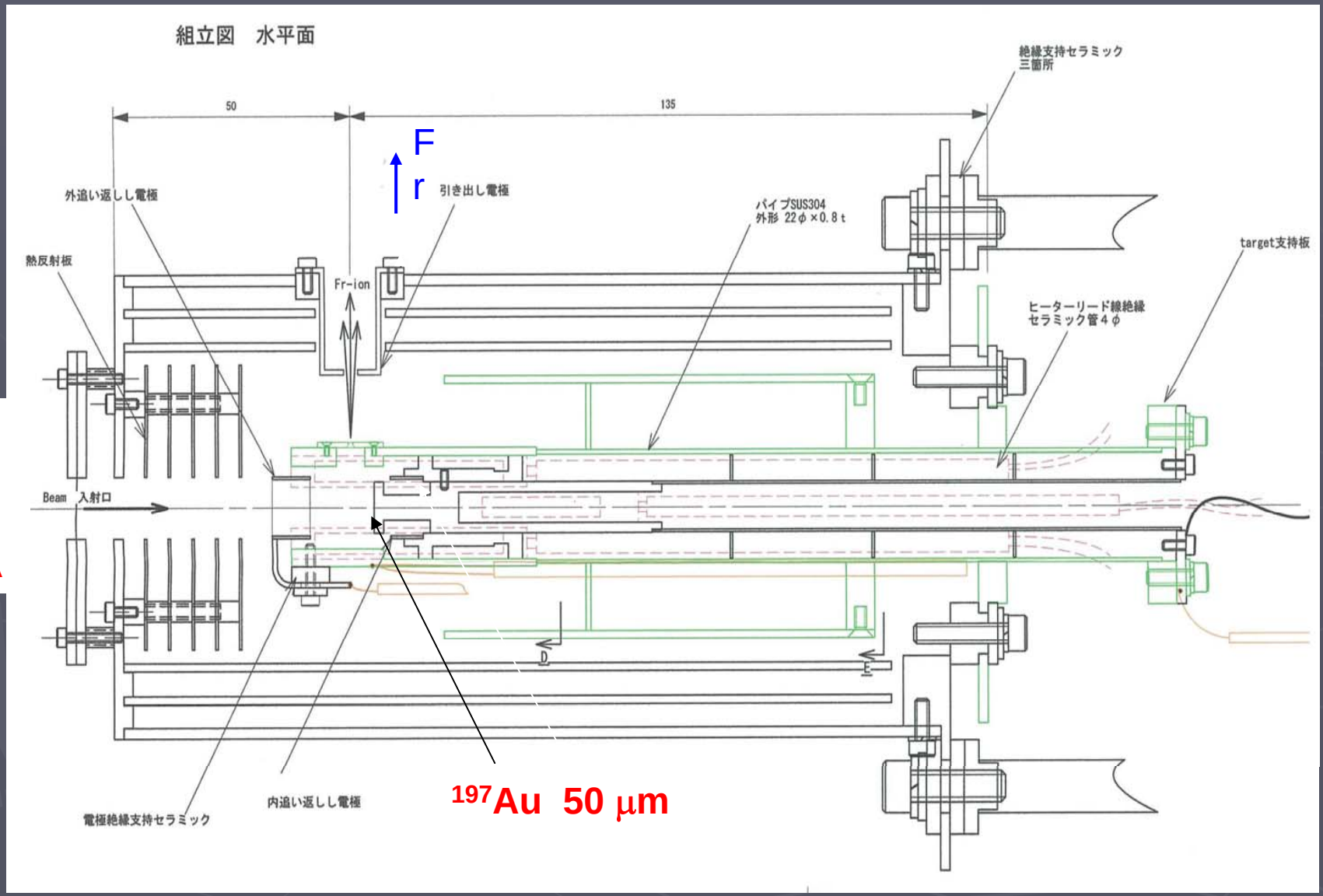
^{130}Te (^{17}N, 4n) ^{141}Pr

^{130}Te (^{17}N, 5n) ^{142}Pr

projection spectrum of γγ coincidence



Oven target and surface ionizer to produce ^{210}Fr for e-EDM measurement

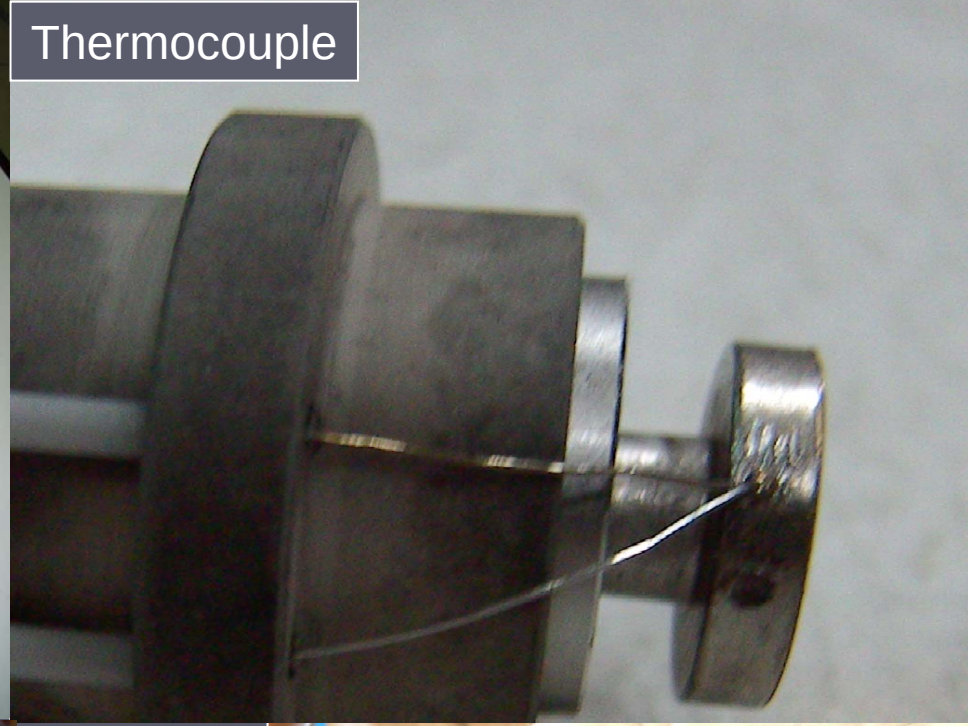


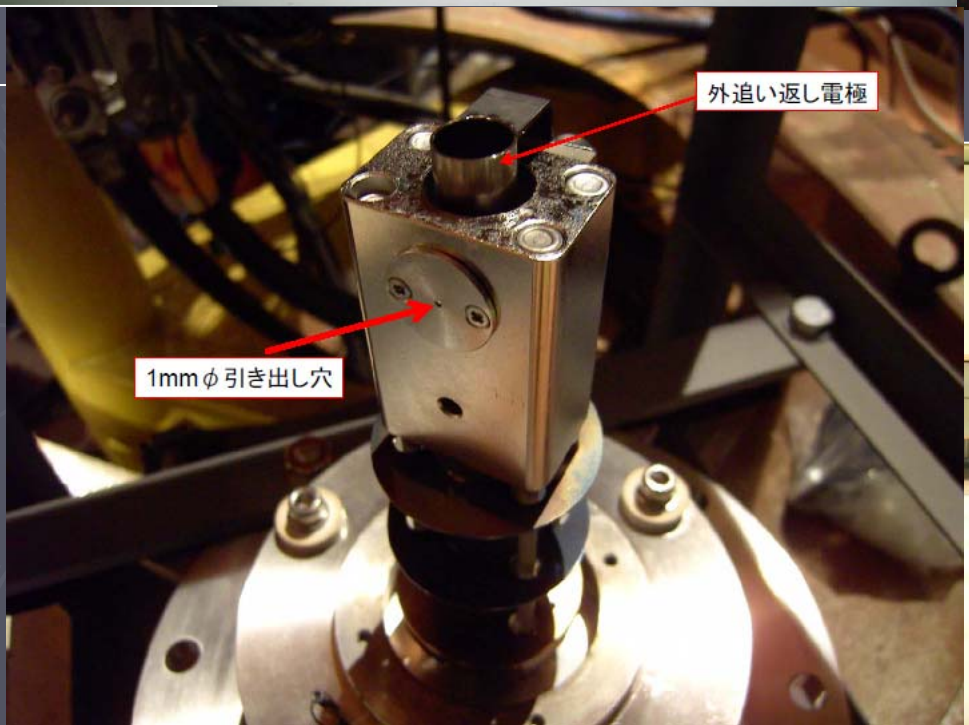
$^{18}O^{5+}$
100
MeV
1 pμA

Target rod

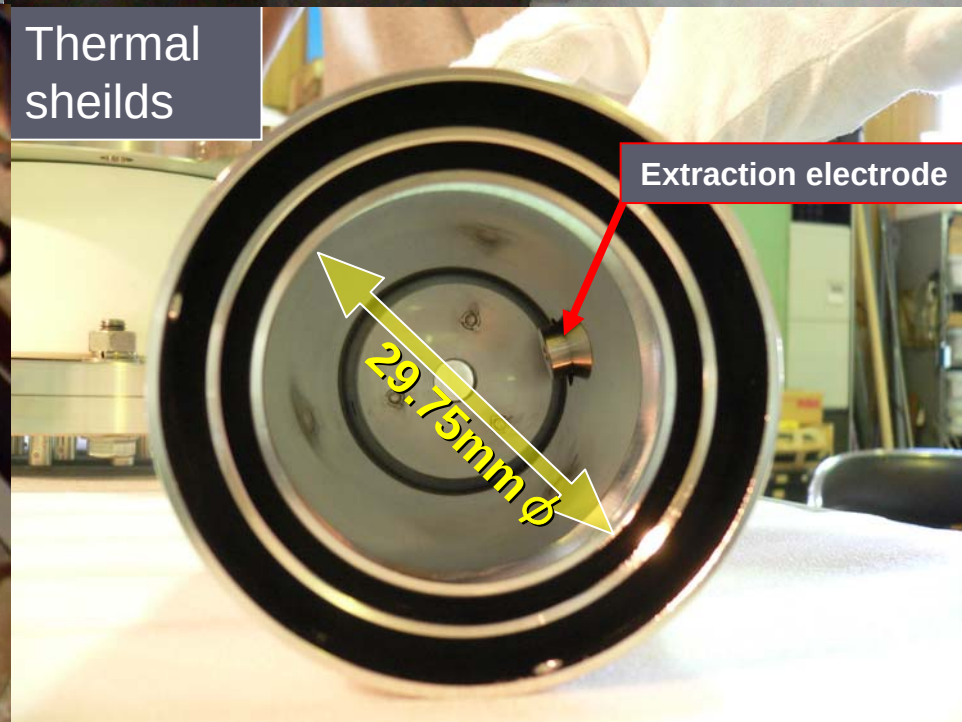
10ϕ 50μm Au

Thermocouple



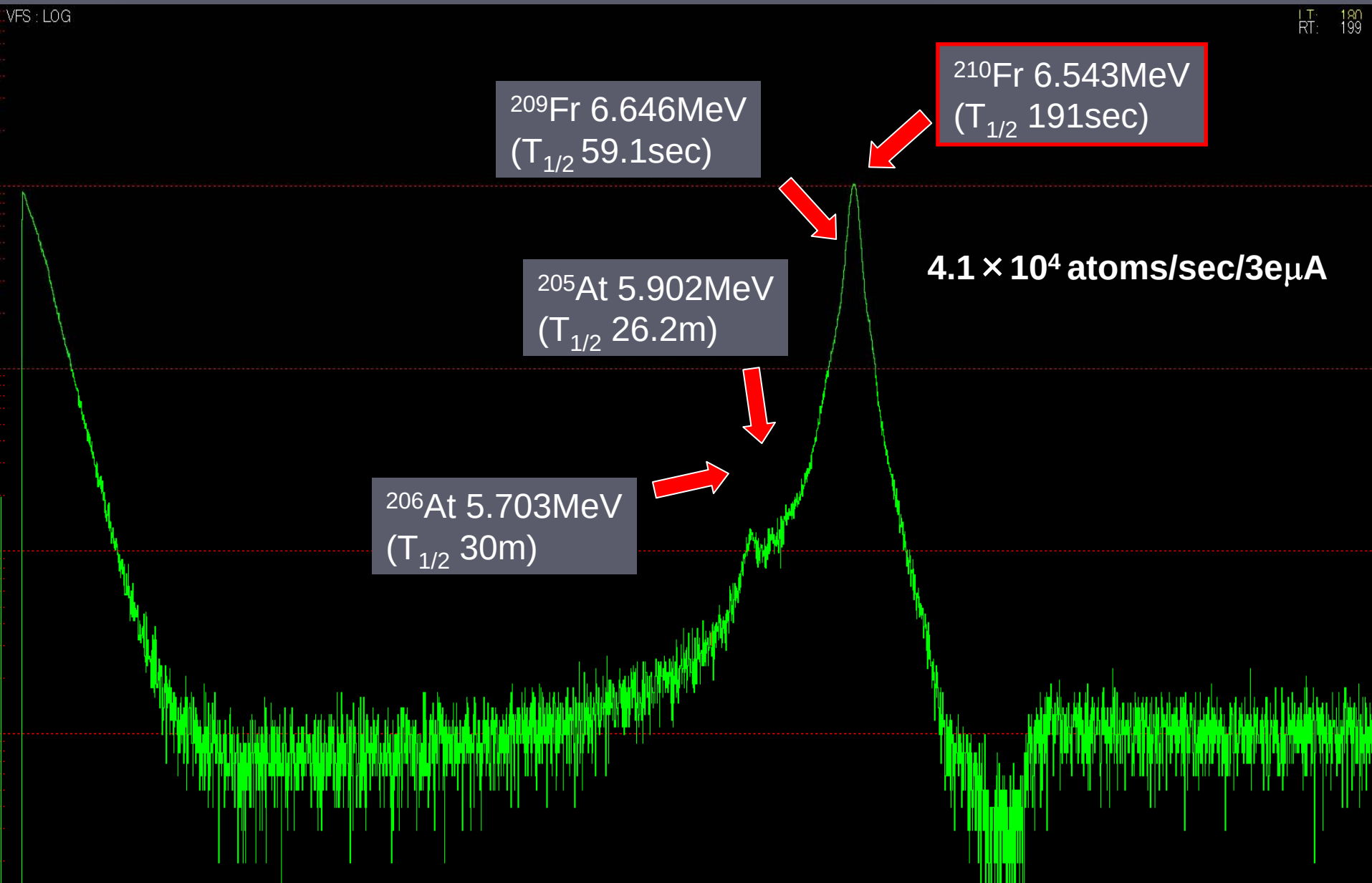


Thermal sheilds



Surface ionizer

Spectrum of α-particles (log scale)



Summary

- **The RCNP cyclotron facility provides a variety of ion beams in a wide energy region.**
- **Developments are in progress to increase research opportunities.**
  - **FT system**
  - **SCECR ion source**
  - **Optimization of the central region to improve the transmission through the AVF cyclotron.**

Thank you for your attention