CYCLOTRONS 2007
The 18th International
Conference on Cyclotrons
and Their Applications

Developments of the RCNP cyclotron cascade

K. Hatanaka, M. Fukuda, T. Saito,
T. Yorita, H. Tamura, M. Kibayashi,
H. Okamura, A. Tamii, Y. Sakemi,
K. Nagayama, M. Uraki, S. Morinobu

Research Center for Nuclear Physics
Osaka University

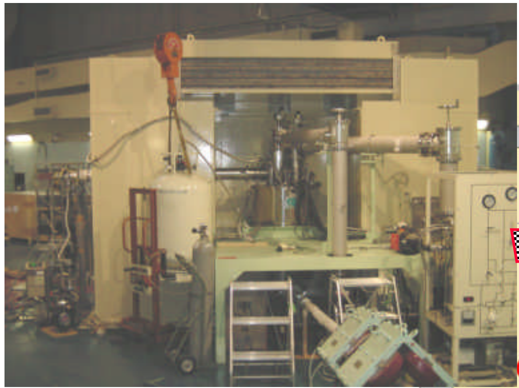
October 3, 2007 Giardini Naxos, Messina, Italy

Outline

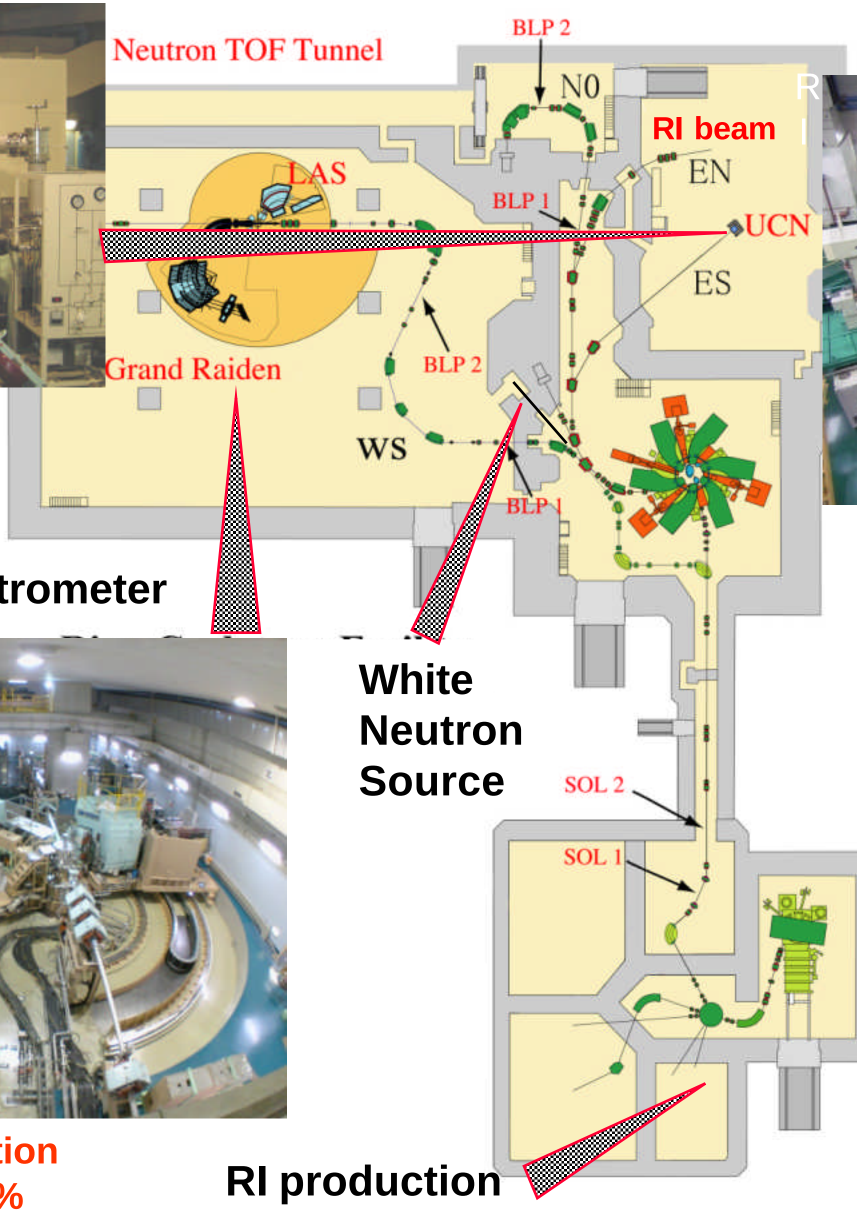
1. RCNP Cyclotron Facility
2. Flat-top Acceleration System (TUPPRA27)
3. 18 GHz Superconducting ECR Ion Source
4. New Beam Line
5. New Control System
6. New Power Supplies
7. Summary

RCNP Cyclotron Facility

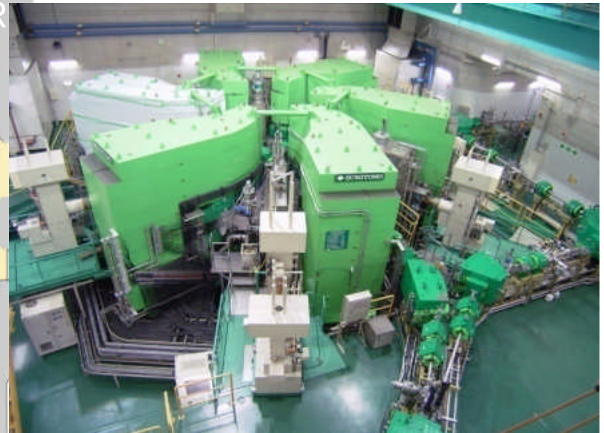
Cryogenic UCN Source



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



Ring Cyclotron
K=400 MeV
since 1992
DE/E ~ 0.01%



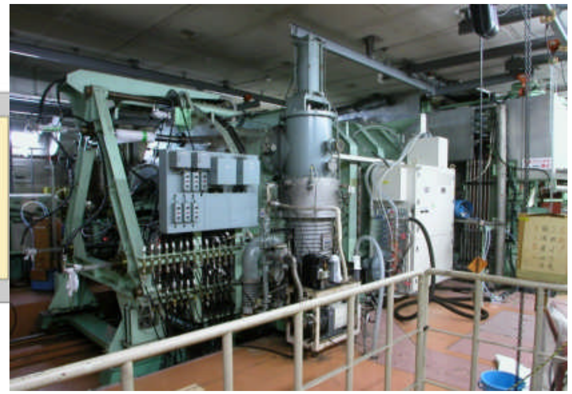
Double Arm Spectrometer

Energy Resolution
DE/E ~ 0.005%

White Neutron Source

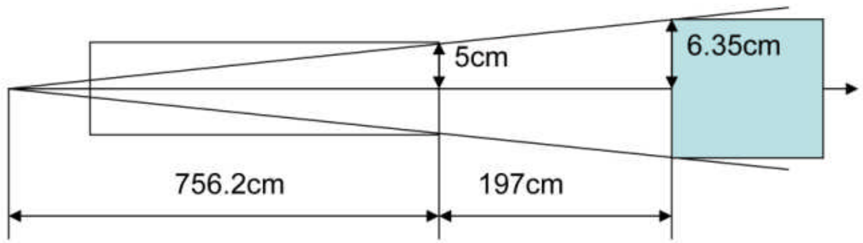
RI production

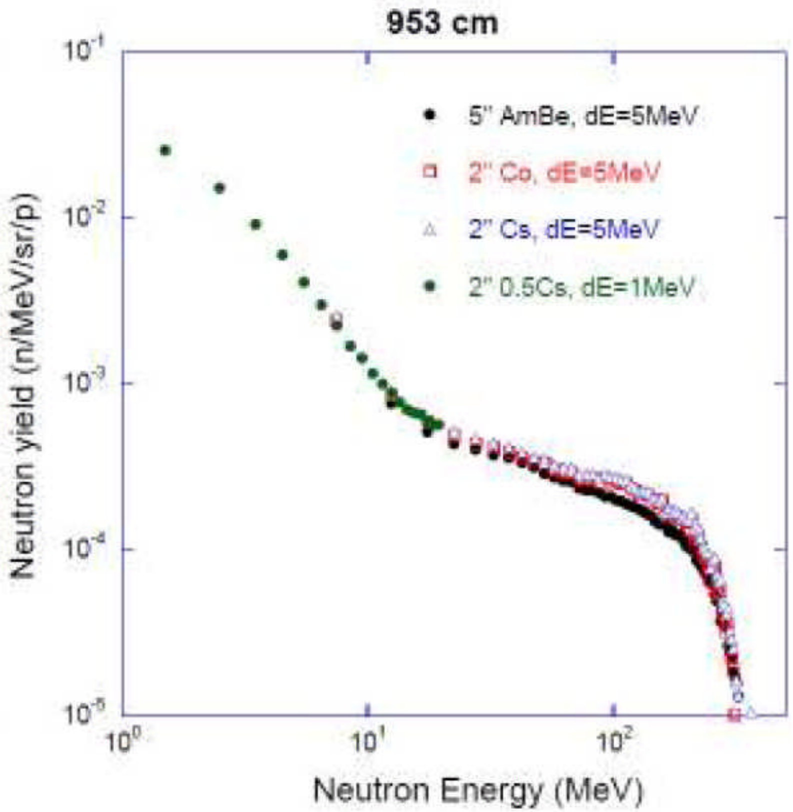
AVF Cyclotron
K=140 MeV
since 1973
DE/E < 0.1%

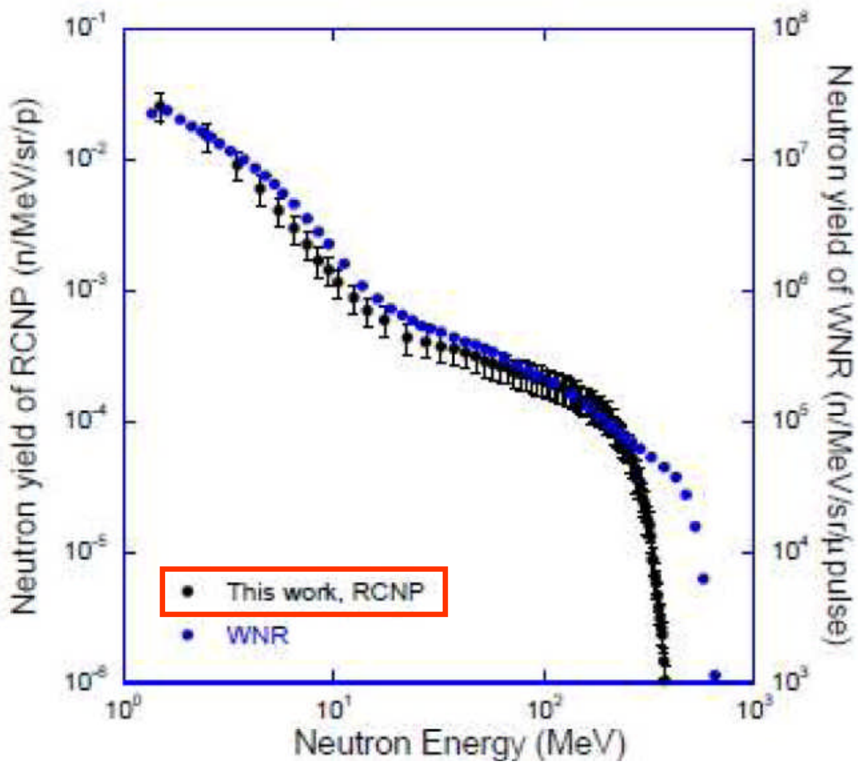


Upgraded recently

Neutron energy spectrum







Research programs at the RCNP cyclotron facility

- **Nuclear Physics**

  Few nucleon system
  Medium modification of the interaction
  Spin isospin excitations
  Giant resonance
  Heavy ion physics with radioactive isotopes

  . . .
- **Fundamental Symmetry**

  Ultra Cold Neutron
  ^{210}Fr EDM
- **Interdisciplinary Researches**

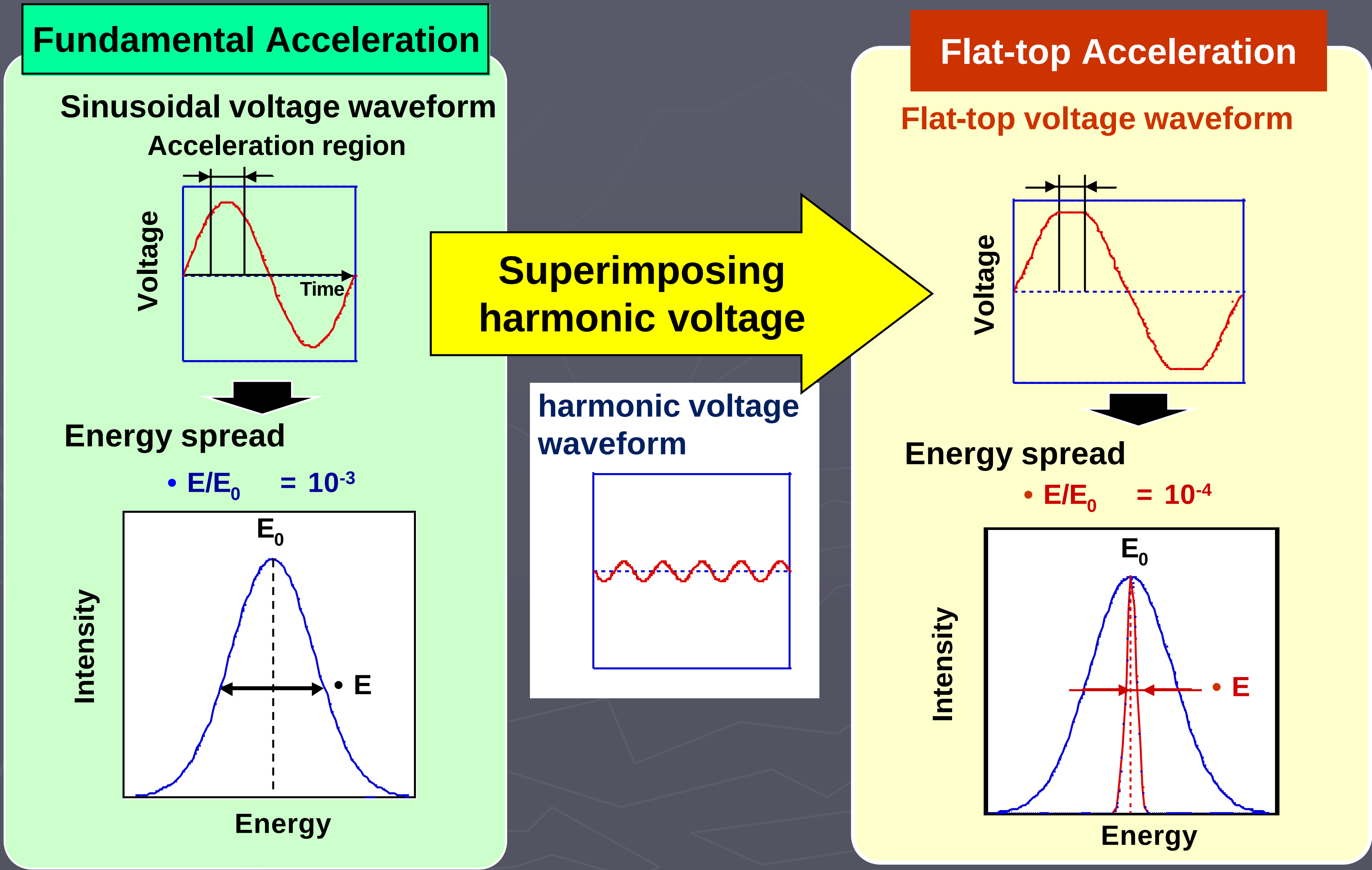
  Nuclear chemistry
  Biological science
  Material science
  Radiation damage of semiconductor devices

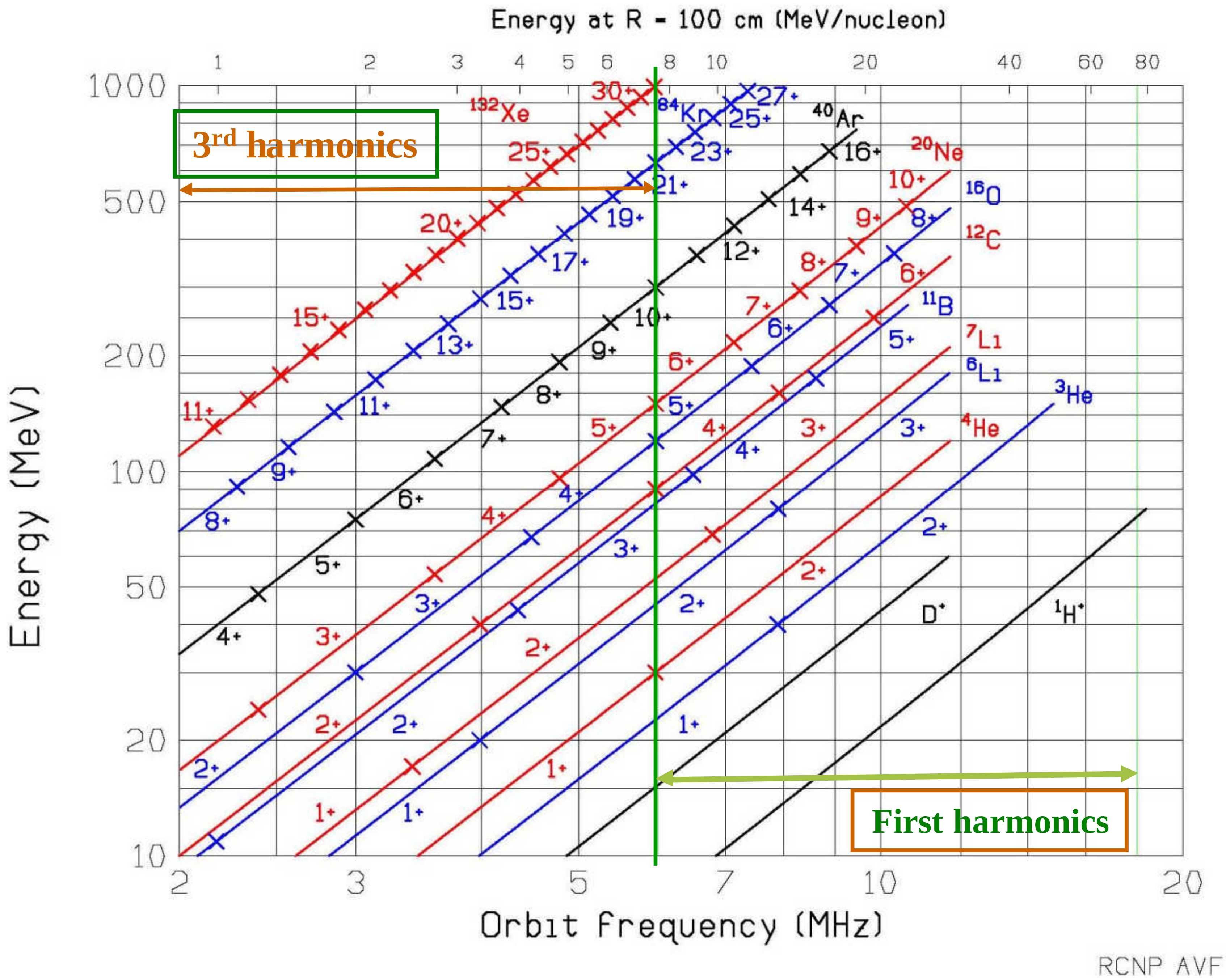
Requirements for Beam Conditions of AVF Cyclotron

Conditions	High Intensity Mode	High Resolution Mode	Flat-top Acceleration
Intensity	a few mA	hundreds nA	Increasing
Energy spread	$1 \sim 5*10^{-3}$	$0.5 \sim 1*10^{-3}$	$\sim 1*10^{-4}$
Emittance	10p mm mr	~ 5p mm mr	< 5p mm mr
Extraction	Multi-turn	Quasi-single-turn	Pure single-turn
Transmission efficiency	Low	High	Very high
Beam halo	Small	Small	Halo-free

2. Flat-top Acceleration System

- **Principle**




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

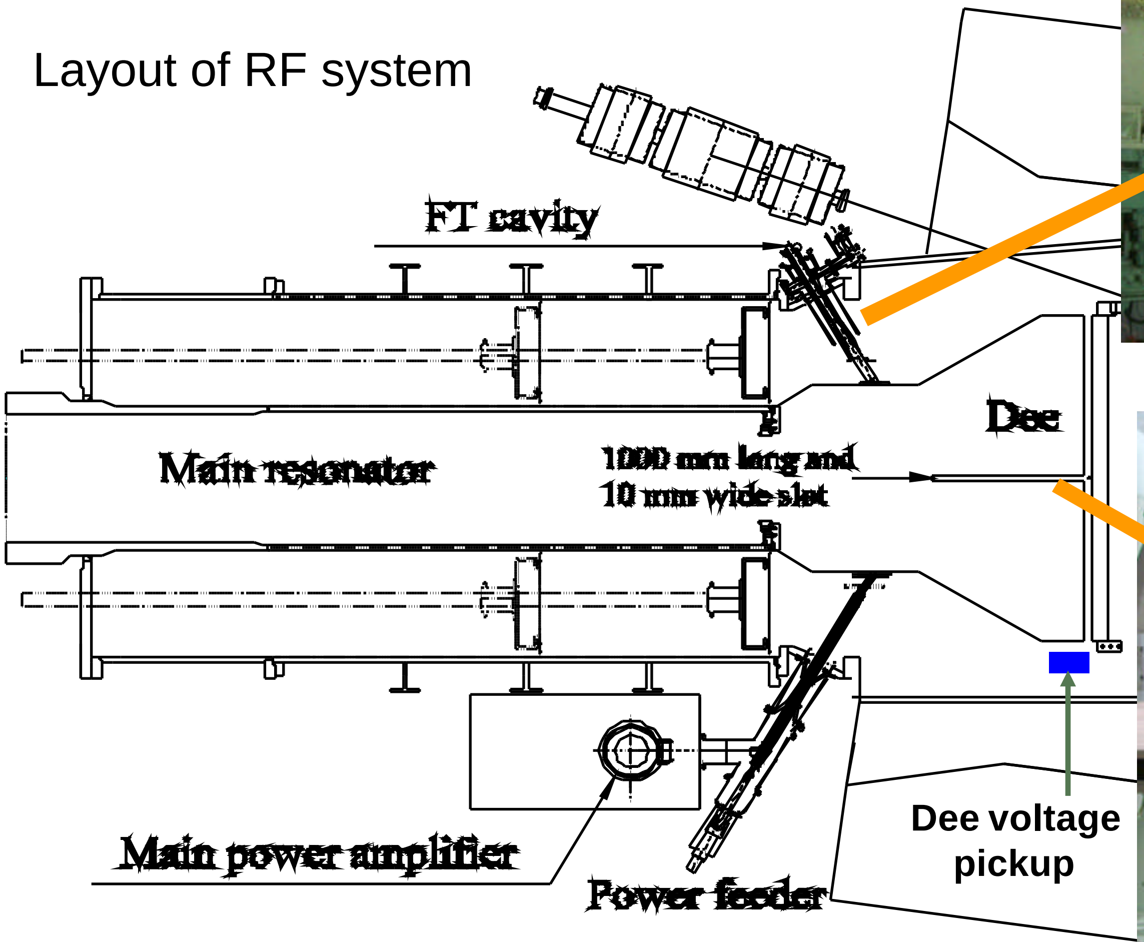
Flat-top Cavity

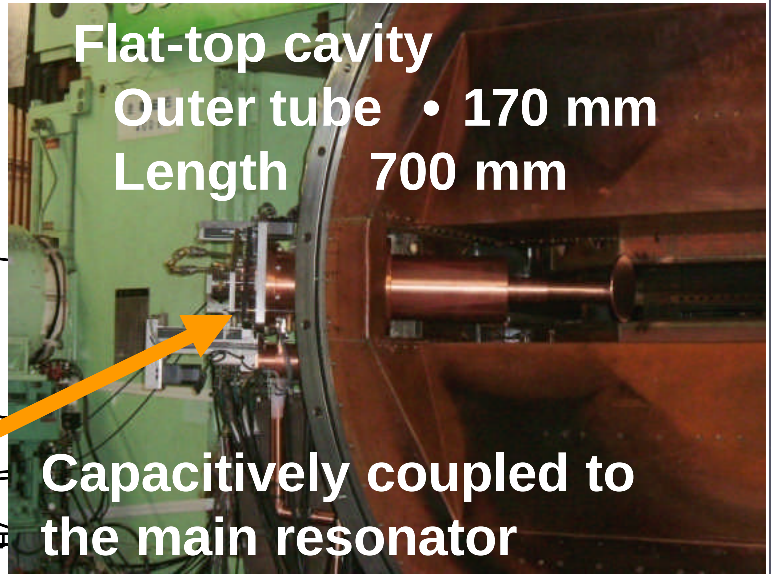
- **Characteristics**

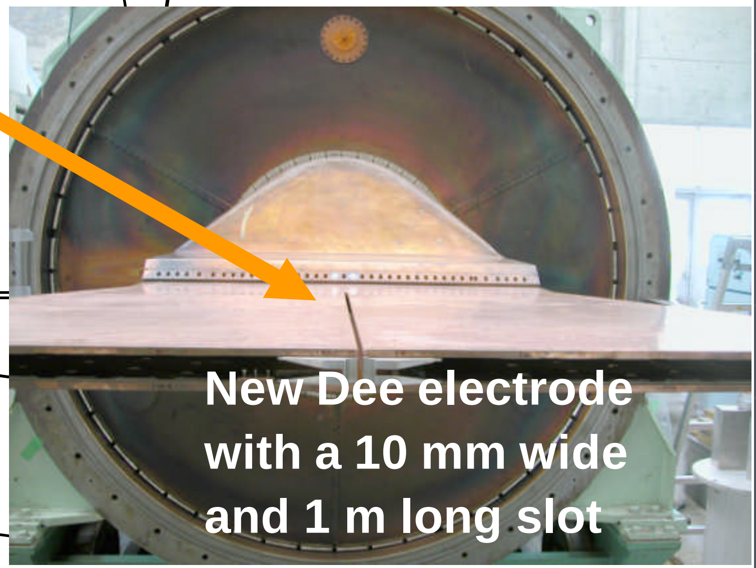
  Harmonic frequency : 50   80 MHz

  Harmonics : k = 5, 7, 9

Layout of RF system

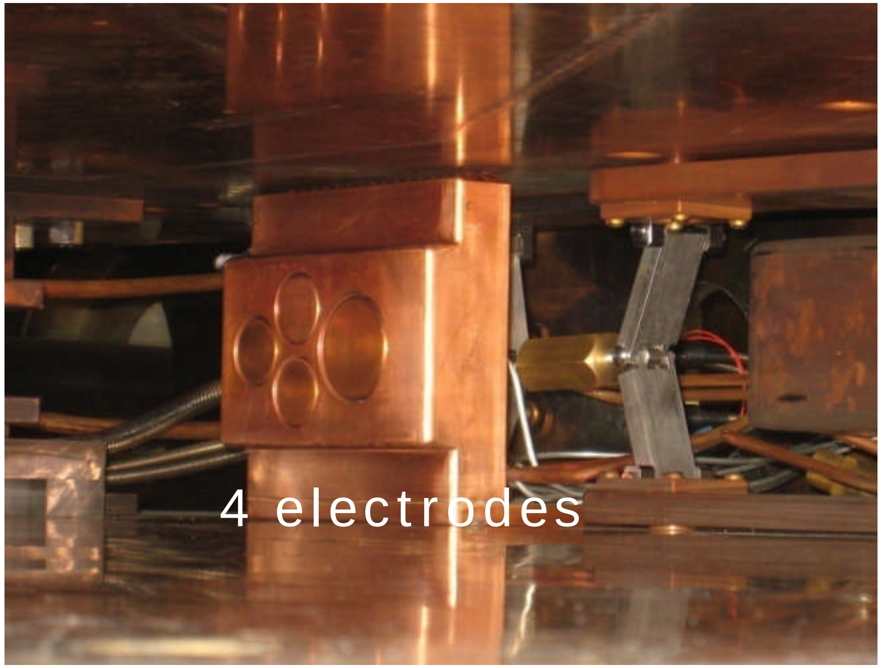






Flat-top Voltage Waveform

Dee-voltage pickup electrode



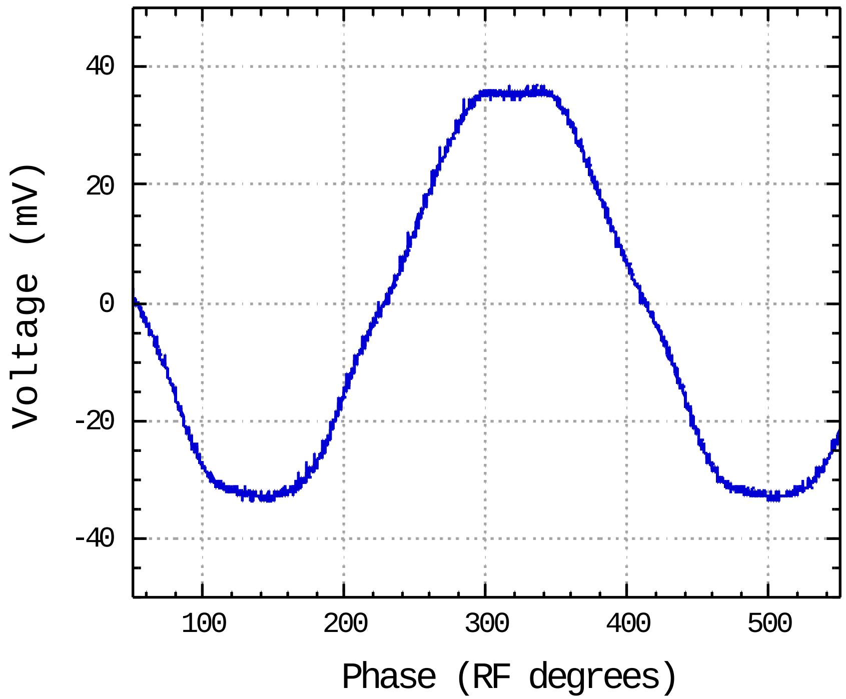
facing the Dee electorode, placed near the acceleration gap, used for regulation of RF system.

Example of the pickup voltage waveform

53MeV proton (300MeV @Ring)

f_1 = 15.417 MHz

f_5 = 77.084 MHz



Improvement of 300 MeV Proton Beam

Energy spread and intensity of 300 MeV proton beam

- transferred to Grand-RAIDEN in achromatic mode
- elastically scattered off a gold target : 197Au(p, p) at 8 deg., 1.68 mg/cm^2 thick

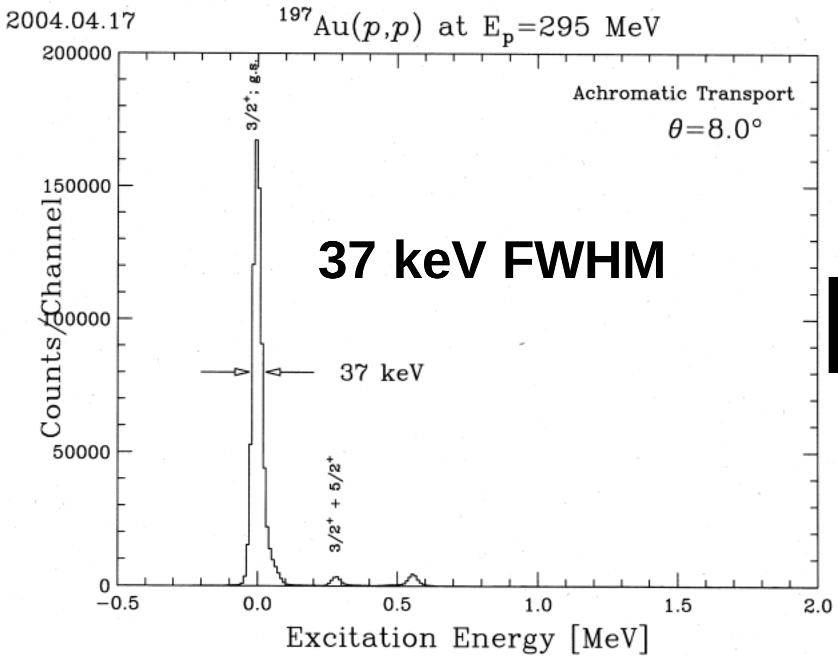
So far April in 2004

AVF : Fundamental acceleration

Ring : Flat-top acceleration

5 nA

(20 nA for • E=70 keV)



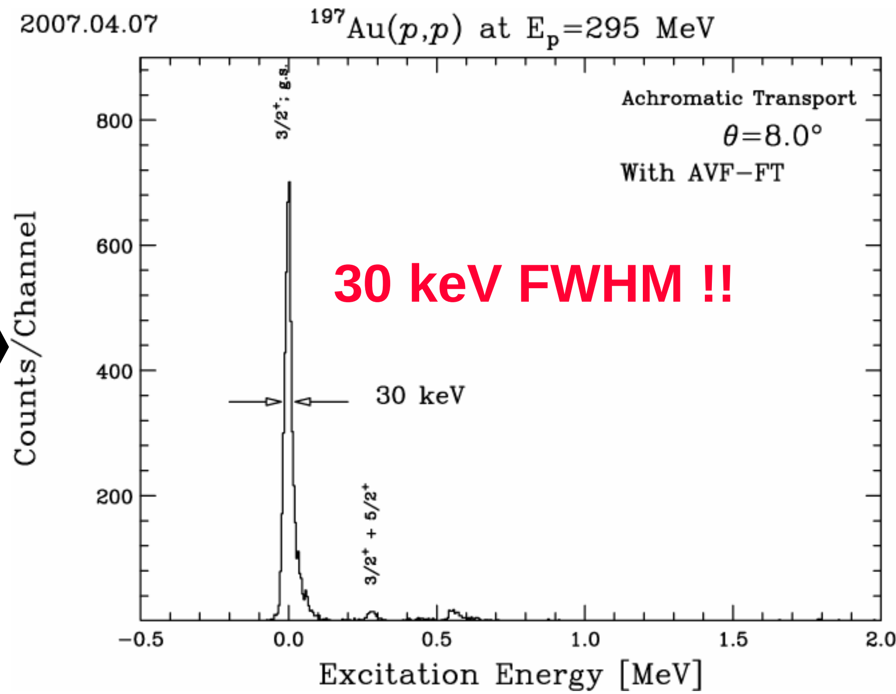
Recent result April in 2007

AVF : Flat-top acceleration

Ring : Flat-top acceleration

20 nA

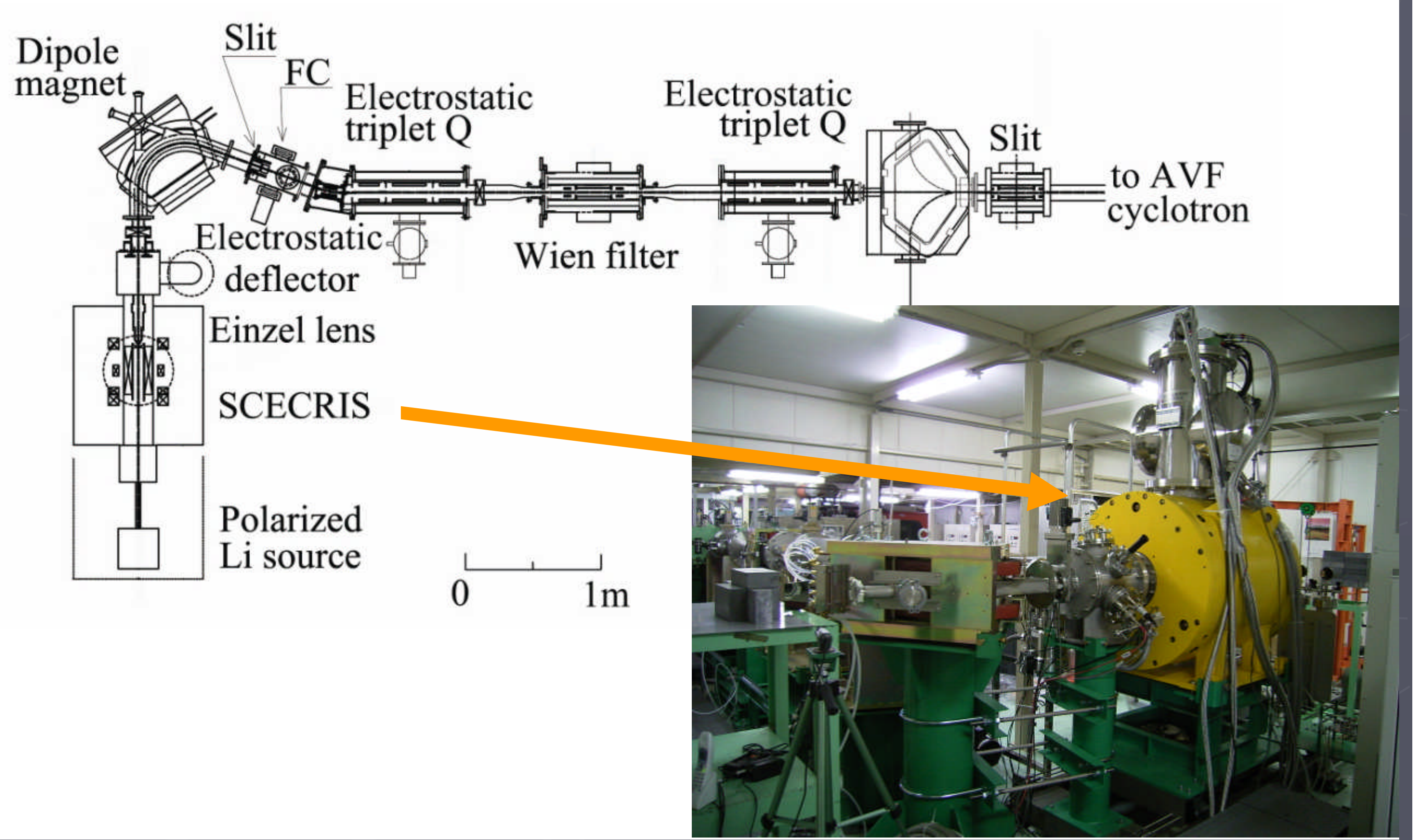
(60 nA for • E=70 keV)



3. 18 GHz Superconducting ECR Ion Source

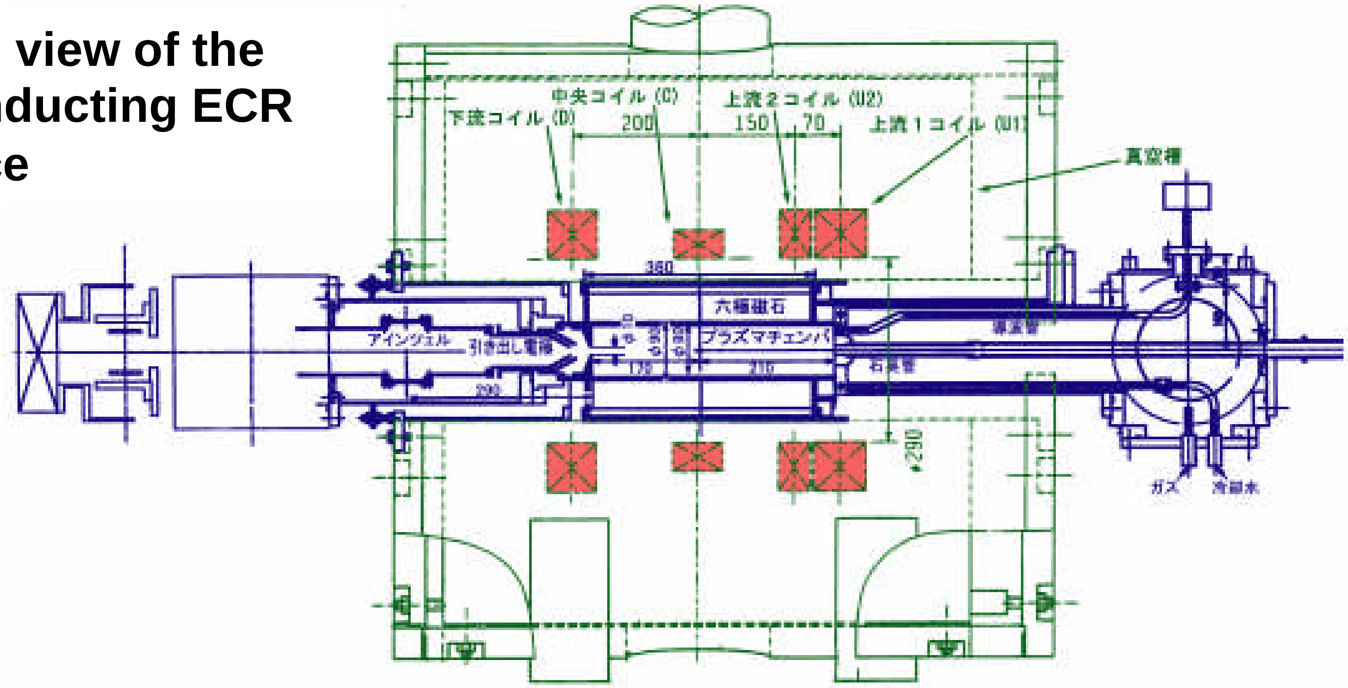
Highly charged heavy ions

A variety of heavy ions at high intensity

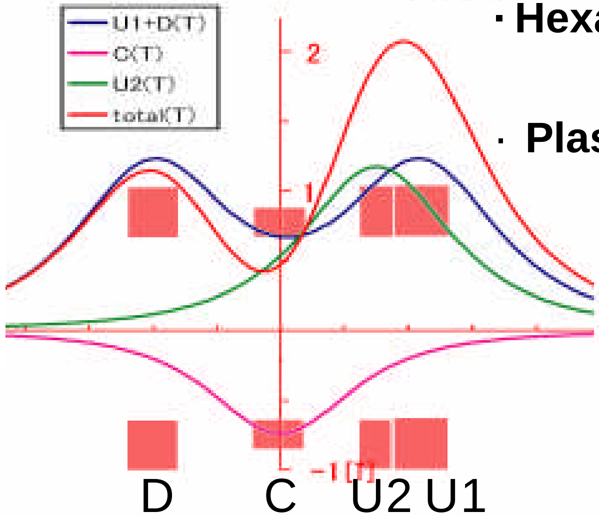


Superconducting Coils

Sectional view of the superconducting ECR ion source



Axial magnetic field distribution produced by the superconducting mirror coils



- Hexapole permanent magnet
  Aperture : 90mm
- Plasma chamber
  Inner diameter : 80mm

Production of Heavy Ions

Gaseous ions such as $^{16,\,18}O$, ^{40}Ar, ^{86}Kr

^{11}B ion by MIVOC method using o-carborane($C_2B_{10}H_{12}$)

	2+	3+	4+	5+	6+	7+	
^{11}B	1.3	4.1	9.3	* 8.2			15kV
^{15}N	71	85	114	158	* 75	7	15kV
^{16}O	136	190	---	264	*400	53	15kV
^{18}O		76	140	142	*238	37	18kV

^{4}He support gas

	4+	5+	6+	7+	8+	9+
^{40}Ar	9.4	---	15	20	50	57
12kV		10+	11+	12+	13+	14+
		---	* 46	* 27	* 12	3.9

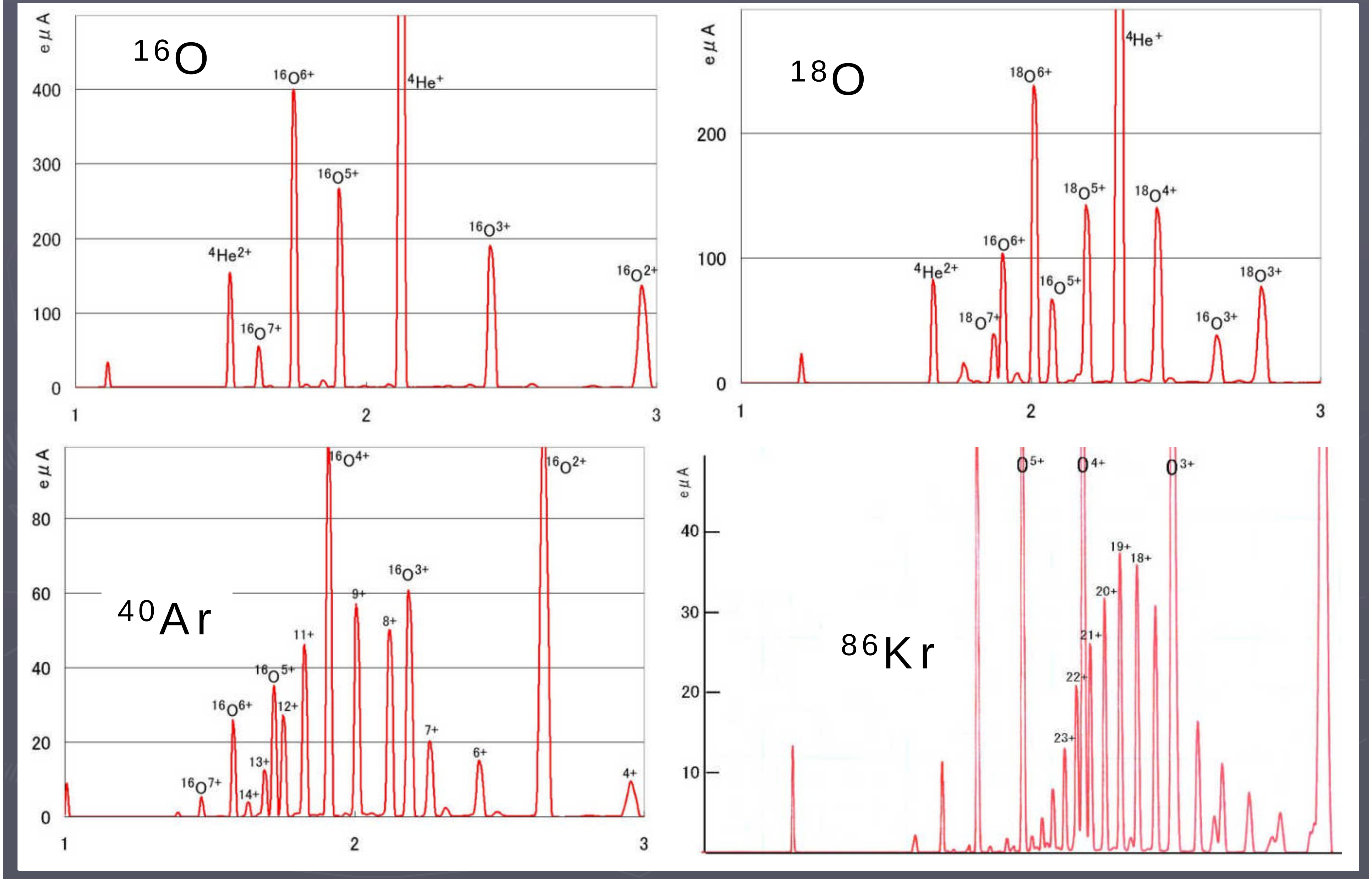
	12+	13+	14+	15+	16+	17+	18+	19+
^{86}Kr	5.1	7.8	11	16	---	31	36	38
15kV		20+	21+	22+	23+	24+	25+	26+
		32	* 26	* 21	* 13	8.1	4.5	2.1

*optimization

^{16}O support gas

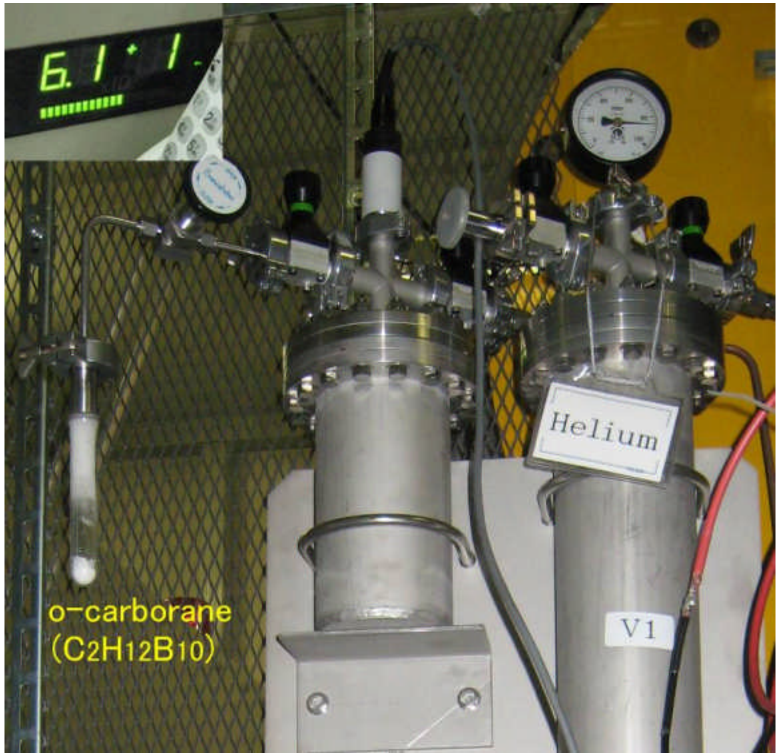
Provided for users

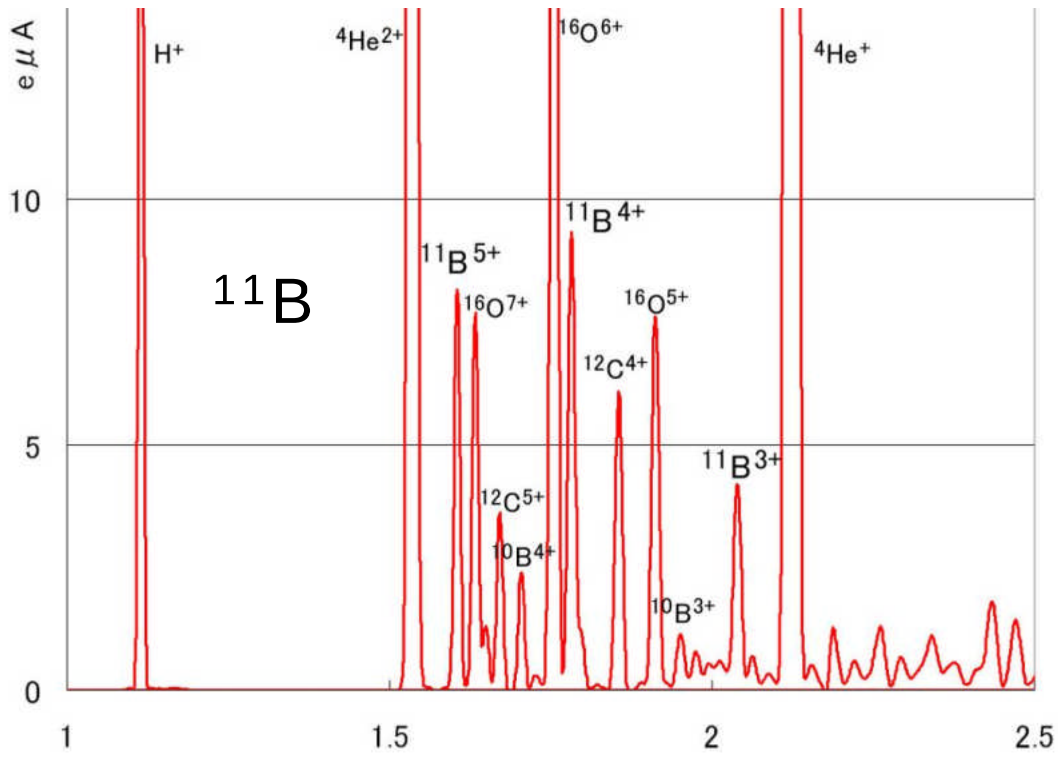
Charge State Distributions (I)

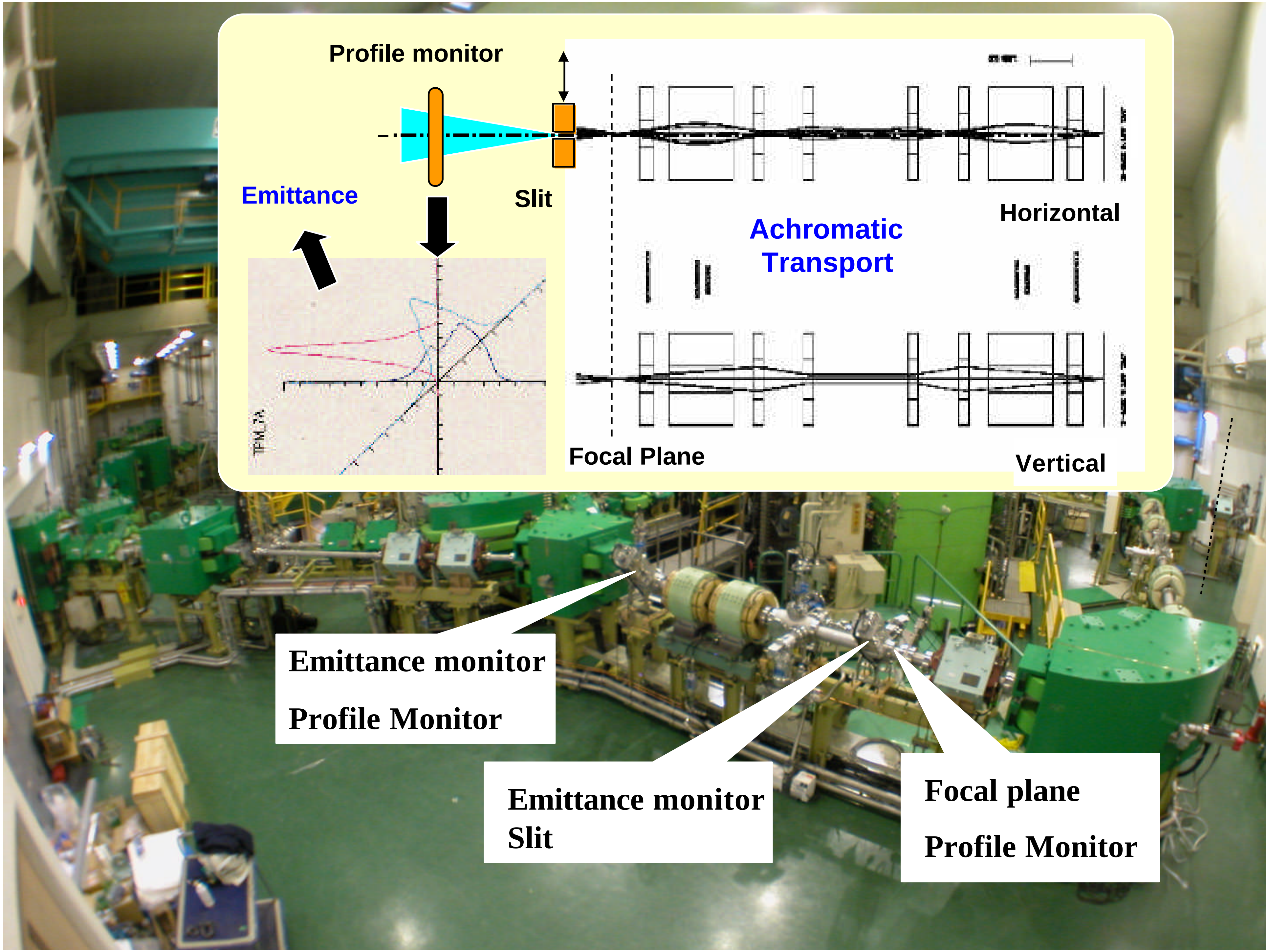


Charge State Distribution (II)

- **Production of ^{11}B ion**
  - **- MIVOC (Metal Ion from VOlatile Compounds)**
  - **- o-carborane ($C_2B_{10}H_{12}$)**
  - **- vapor pressure of 1-2 Torr.**







Profile monitor
Emittance
Slit
Achromatic
Transport
Horizontal
Focal Plane
Vertical
Emittance monitor
Profile Monitor
Emittance monitor
Slit
Focal plane
Profile Monitor

Emittance Measurement

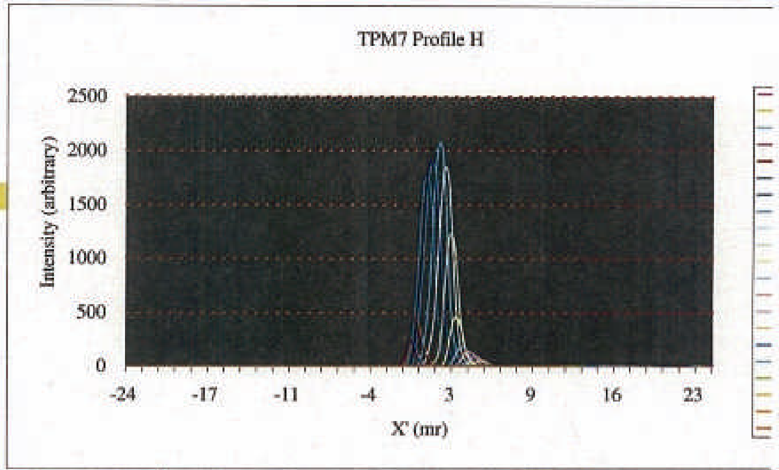
emh	年	月	日	時	分	秒
測定時刻	2007	~~1~~ 2	16	22	1	48

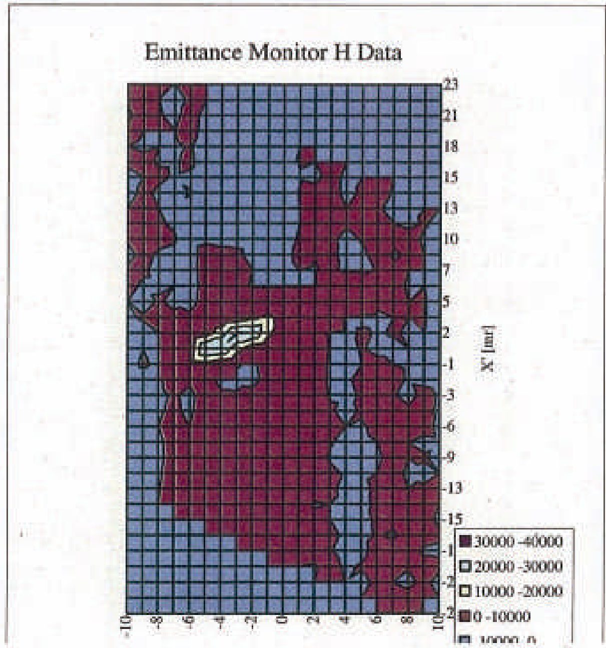
	フィット値	統計推定値	
height	2275.05	1119.77	
X_0	-3.23	-3.02	mm
X_sigma	1.82	1.83	mm
X'_0	1.45	1.28	mr
X'_sigma	1.14	1.42	mr
correlation (rho)	0.85	0.55	
constant	0.01		

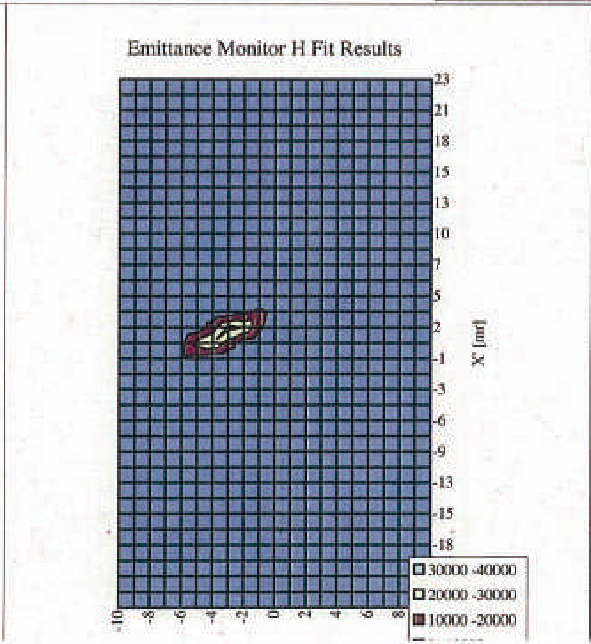
ファイル名:
emh_070216220148.csv

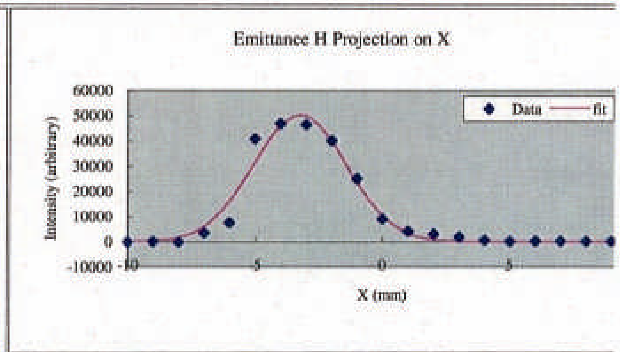
1-rho^2	0.27	
r.m.s. deviation	25.95	
	エミッタンス	
emittance (sigma)	1.07	π mm mr
Emittance (50%)	1.49	π mm mr
Emittance (90%)	4.94	π mm mr

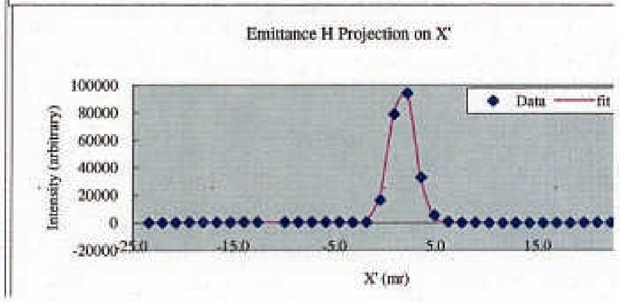
- =5p mm mrad



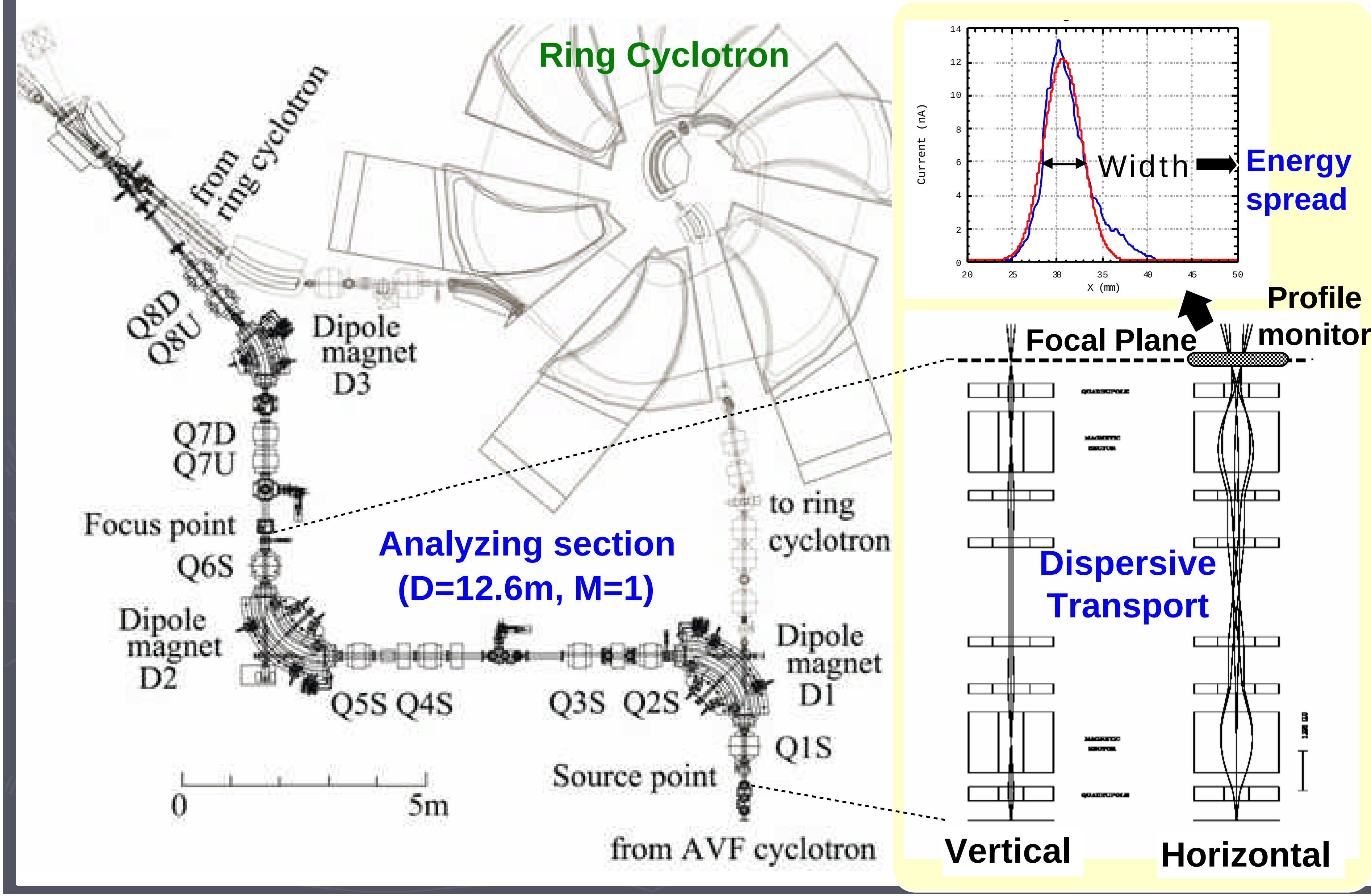








Energy Spread Measurement

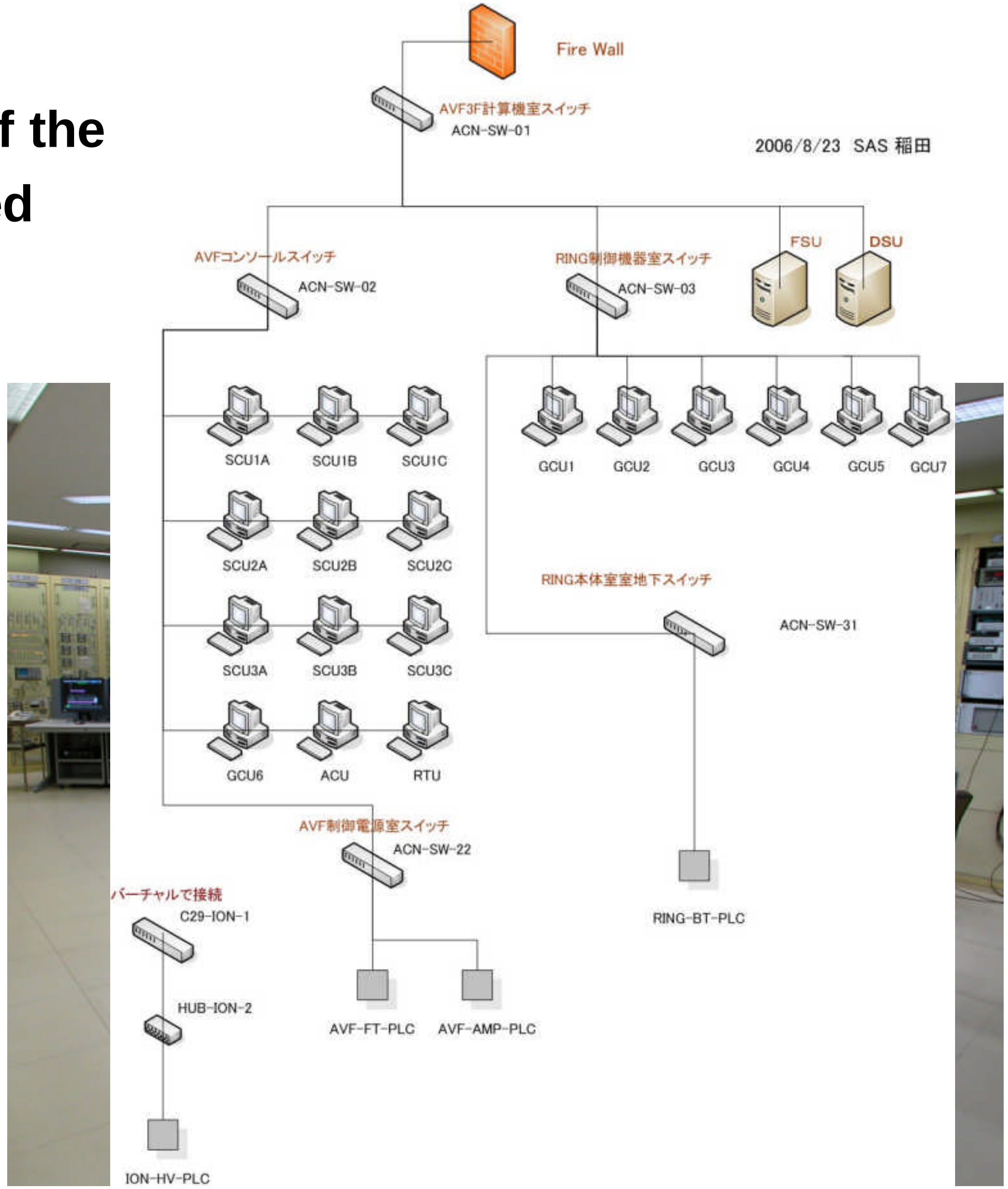


5. New Control System

- Background of the renewal
  - Difficulty in maintenance of the
  - Very slow processing speed

- PC-base control system
  - Maintaining hierarchical control system
  - Distributed control system using network
  - 3 sets of main console
  - “InTouch” software for human machine interface

- New local controller
  - PLC(Programmable Logic Controller)



6. New Power Supplies

• Background of the renewal

- More than 35 years have passed since the fabrication of the AVF cyclotron.
- Most of electric parts are not available now.

• Trim coil power supplies
  - 16 power supplies
  - modification of max. coil currents

• RF power supplies for a final amplifier tube
  - Screen-grid
  - Control-grid
  - Filament

New power supplies
for 13 pairs of trim coils

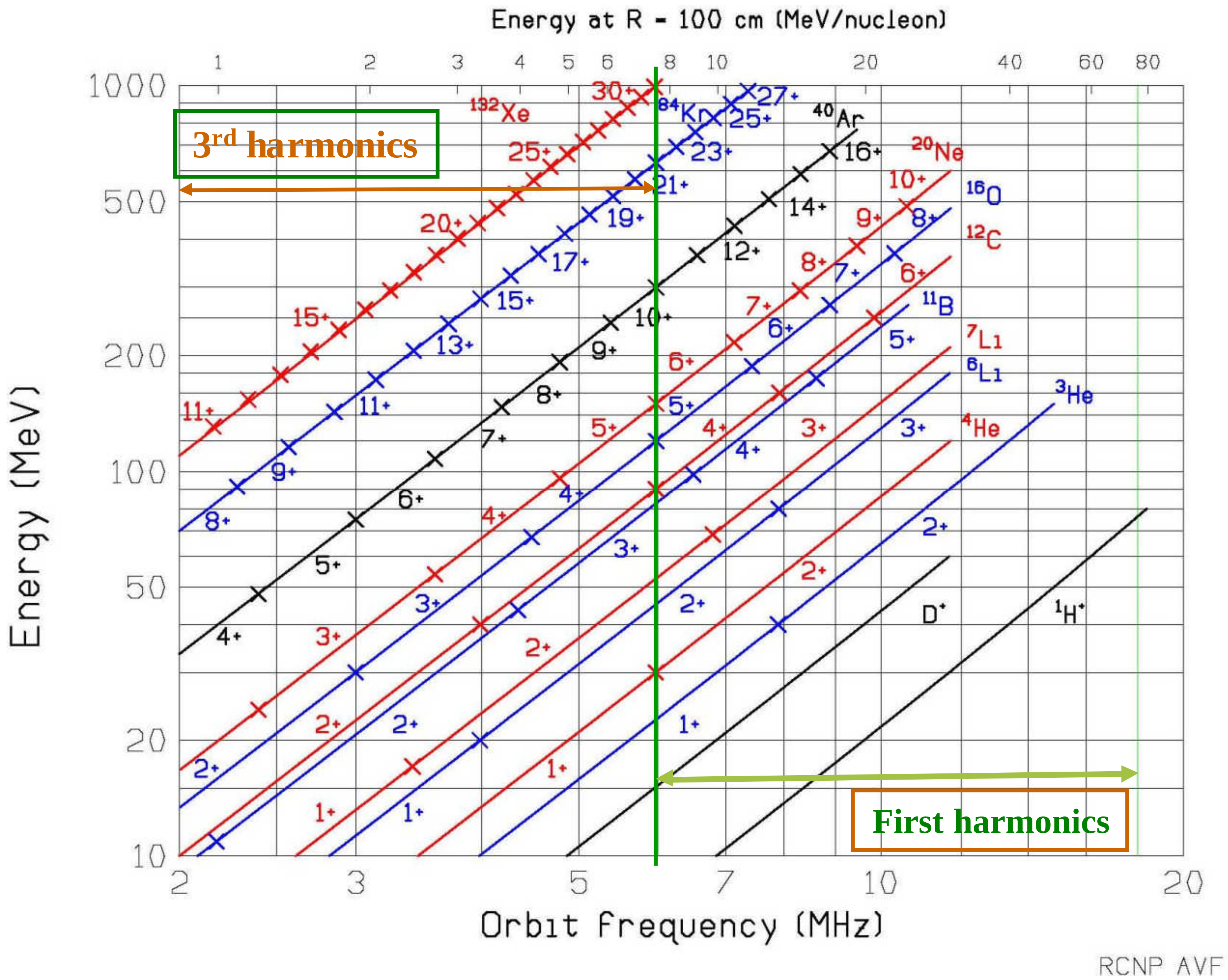
7. Summary

- The upgrade of the RCNP AVF cyclotron has been successfully started and is continued.
- The beam quality and intensity of 300 MeV proton has been improved by the flat-top acceleration in the AVF cyclotron. Developments are being performed to apply the system to other beams.
- An 18 GHz superconducting ECR ion source has been commissioned to increase the beam intensity of highly-charged heavy ions; 7.5 MeV /u $^{86}Kr^{23+}$ was delivered for experiments.
- A new beam line has been installed to diagnose the quality of the beam from the AVF cyclotron and helps to make it match to the acceptance of the ring cyclotron. It also makes 10-400 MeV protons and 1-100 MeV/u heavy ions available for a variety of researches in nuclear physics and fundamental physics as well as interdisciplinary studies.

Development of Flat-top Accelerated Beam

Particle	Energy (MeV)		AVF fundamental frequency (MHz)	Harmonics	
	Ring	AVF		Order	Freq. (MHz)
^{4}He	400	87.14	10.144018	5	50.72009
				7	71.008126
^{3}He	420	87.81	11.65007	5	58.25035
$^{86}Kr^{21+}$		640	6.0129	9	54.1161
d	80	18.73	6.75	9	60.75
pol.D	200	43.6	10.11632	5	50.5816
p	200	39.32	13.375664	5	66.87832
p	250	46.7	14.496449	5	72.482245
p	300	53.3	15.416773	5	77.083865

Under development



Energy at R - 100 cm (MeV/nucleon)
3rd harmonics
First harmonics
Energy (MeV)
Orbit frequency (MHz)
132Xe
84Kr
40Ar
20Ne
16O
12C
11B
7Li
6Li
3He
4He
D+
1H+
RCNP AVF