All Permanent Magnet ECR Ion Source Development and Operation Status at IMP

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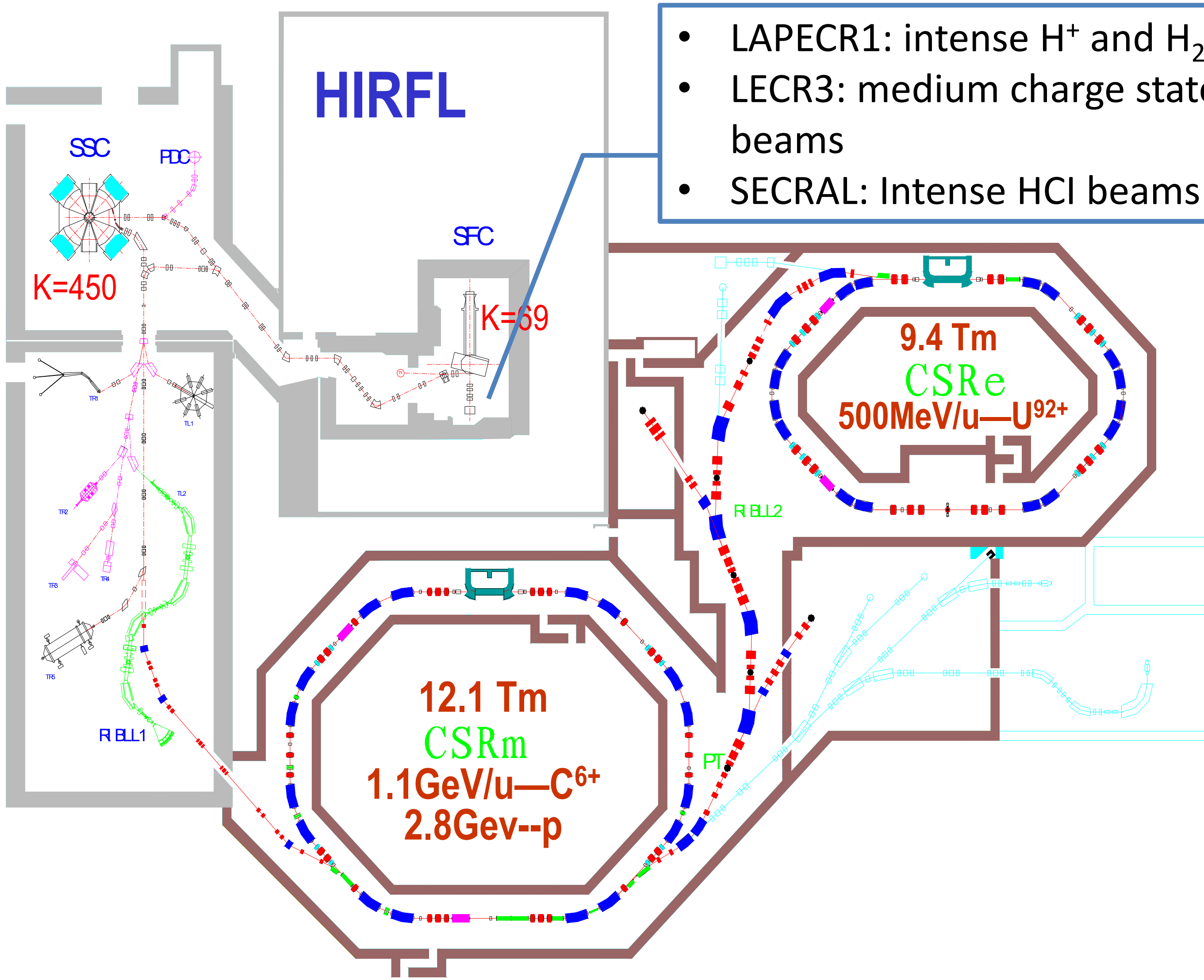
Outline

- Introduction to IMP facility
- Why all permanent magnet?
- All permanent magnet ECRISs at IMP
  - LAPECR1
  - LAPECR2
  - LAPECR3

HIRFL in Lanzhou

- LAPECR1: intense H^+ and H_2^+
- LECR3: medium charge state ion beams
- SECRAL: Intense HCI beams

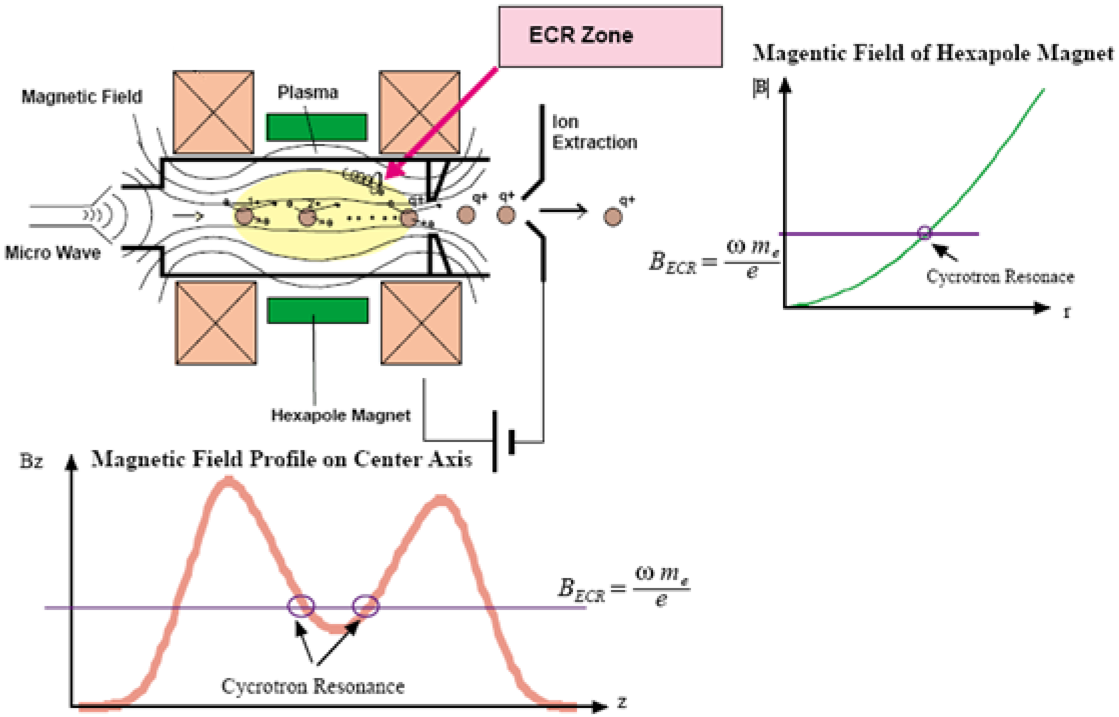


Research Activities at IMP

- New isotopes synthesis
- Spectroscopy on unstable nuclei
- Precise Mass measurement
- Irradiative Material, Biology experiments
- Cancer therapy
- RIB structure experiments
- Atomic Physics
- Material physics
- Astrophysics
- ……

Different purpose ECRISs are built at IMP for the various needs

ECR Ion Sources



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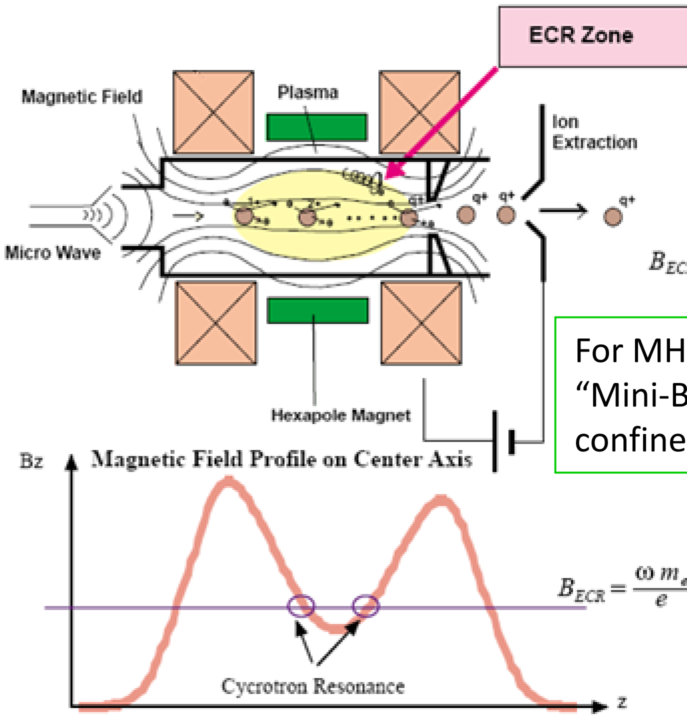
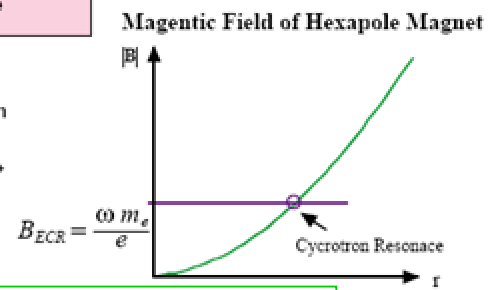
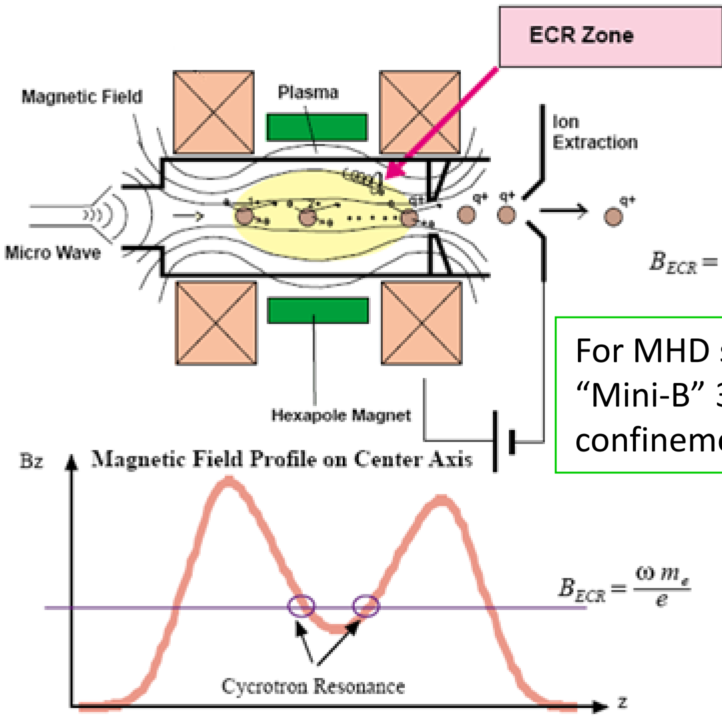
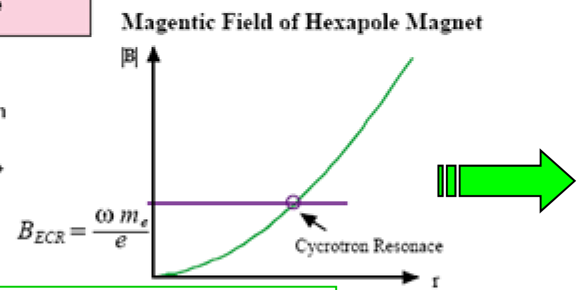




For MHD stability→
"Mini-B" 3D magnetic
confinement

ECR Ion Sources





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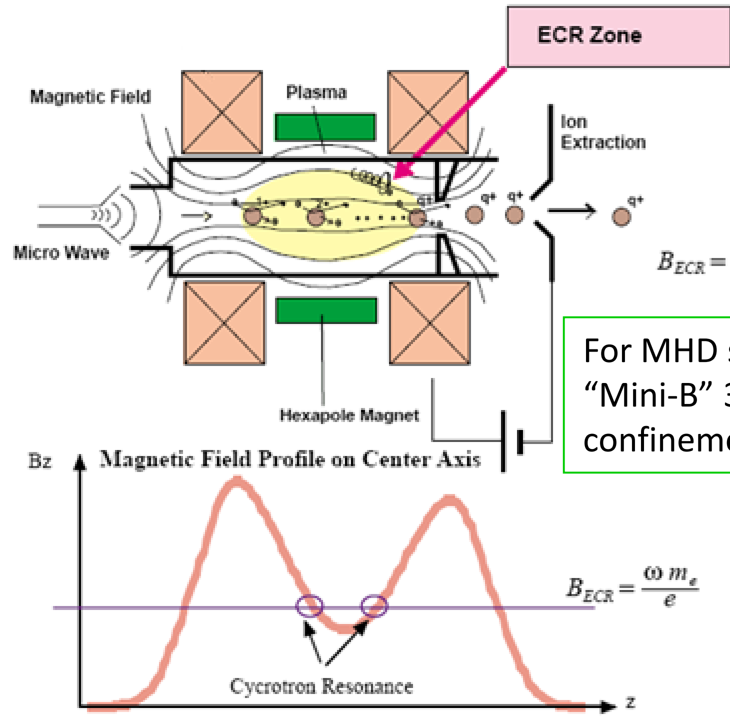

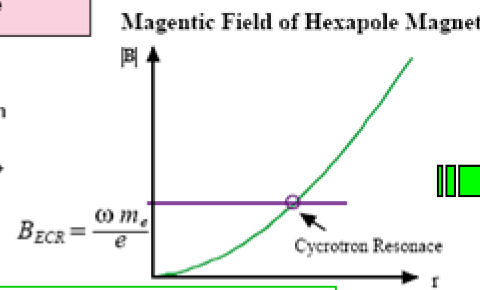

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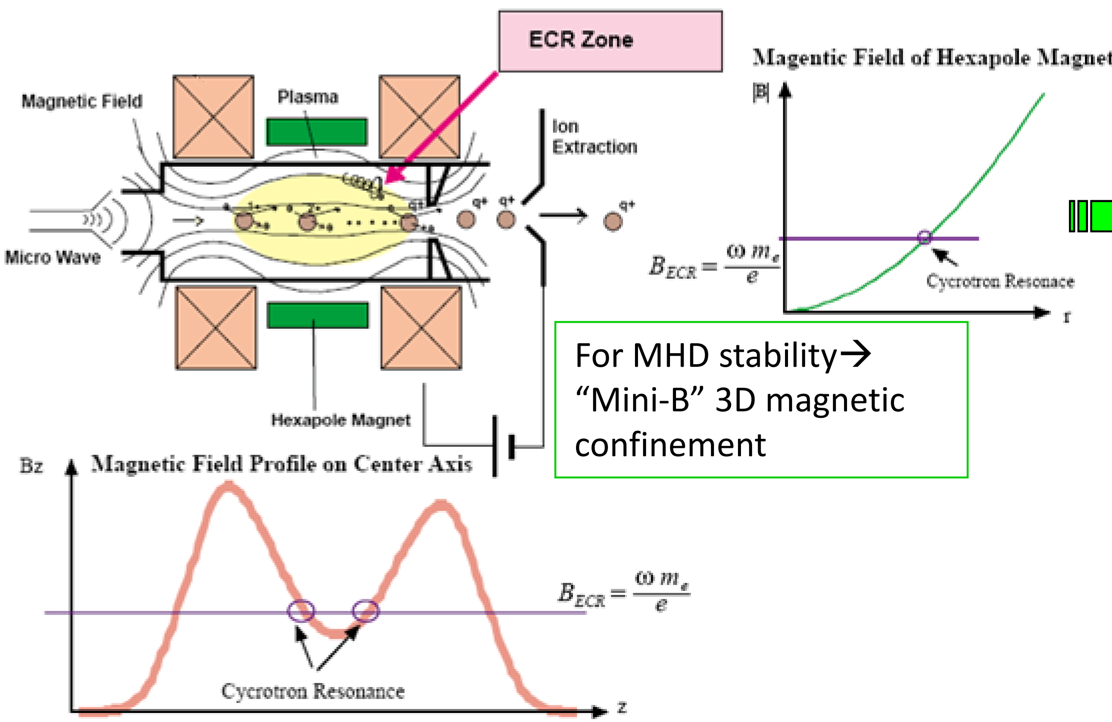
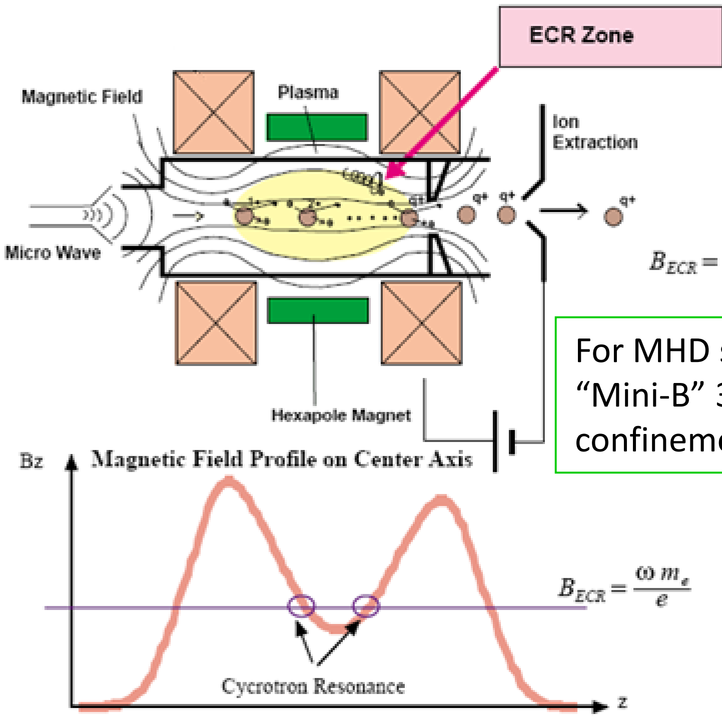
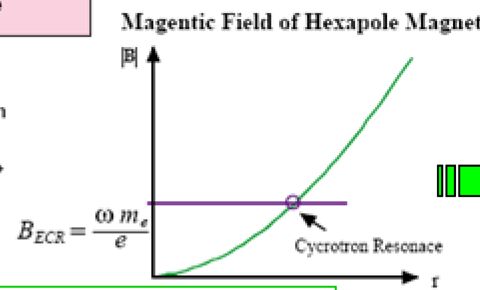


For MHD stability→ "Mini-B" 3D magnetic confinement

Permanent magnet

ECR Ion Sources

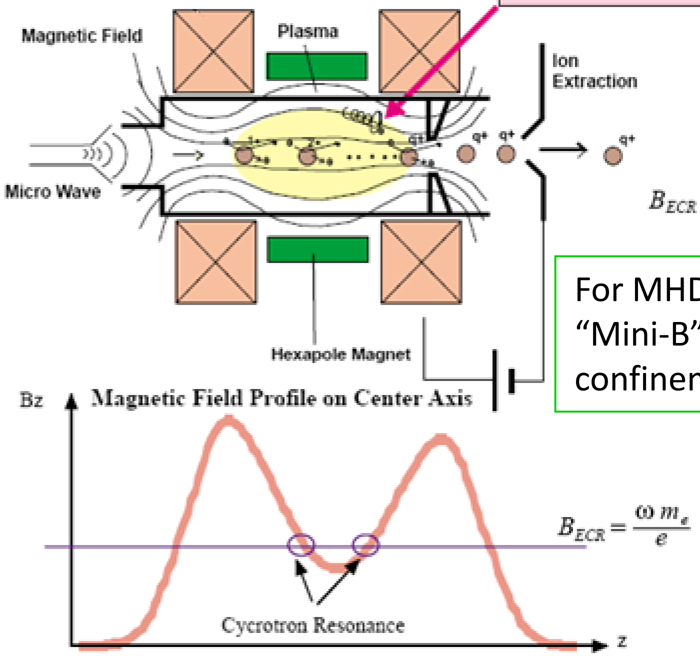


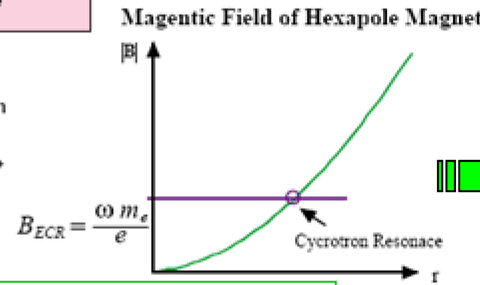


For MHD stability→ “Mini-B” 3D magnetic confinement

- Permanent magnet
- SC- magnet hexapole

ECR Ion Sources





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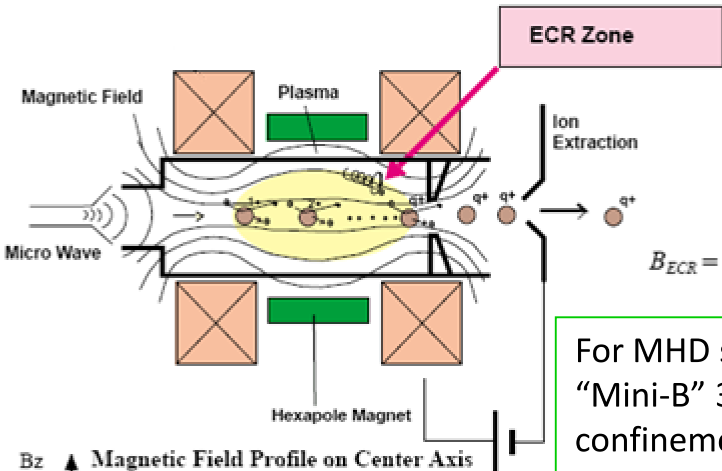

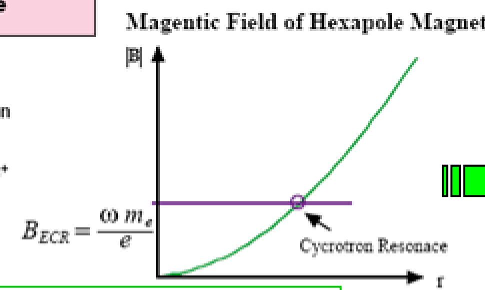

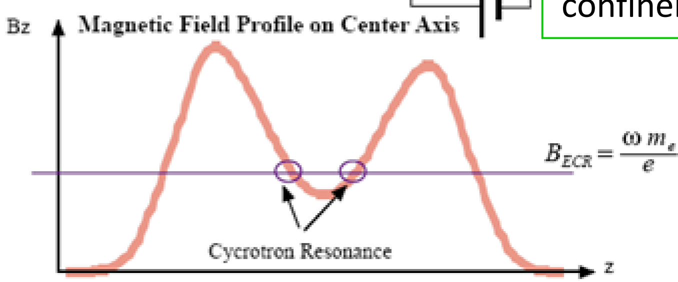

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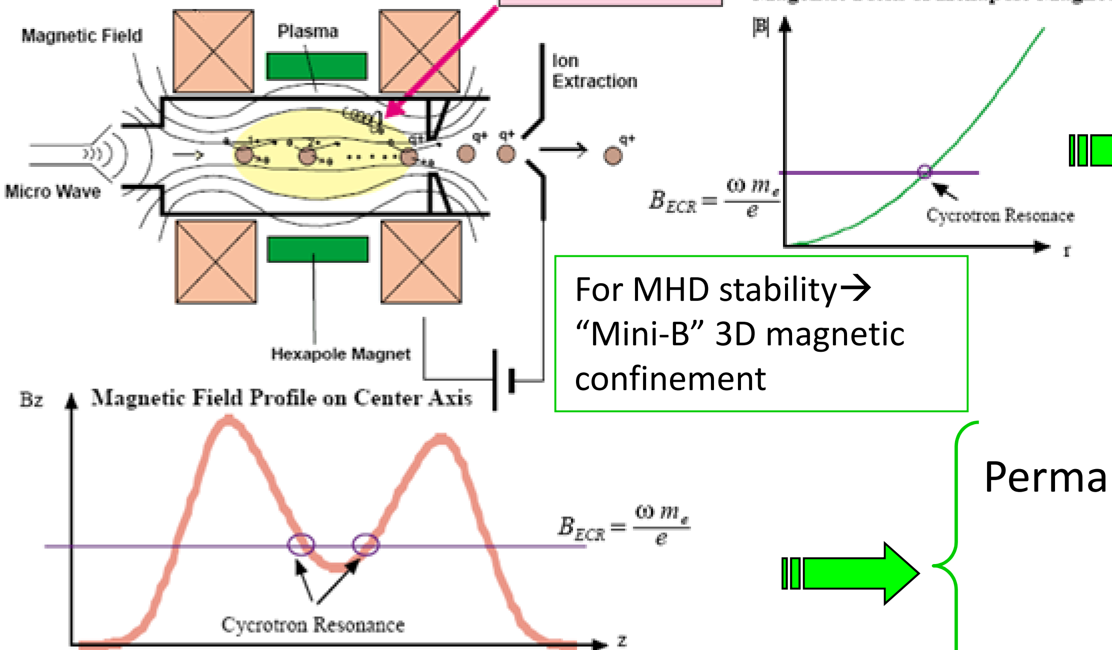

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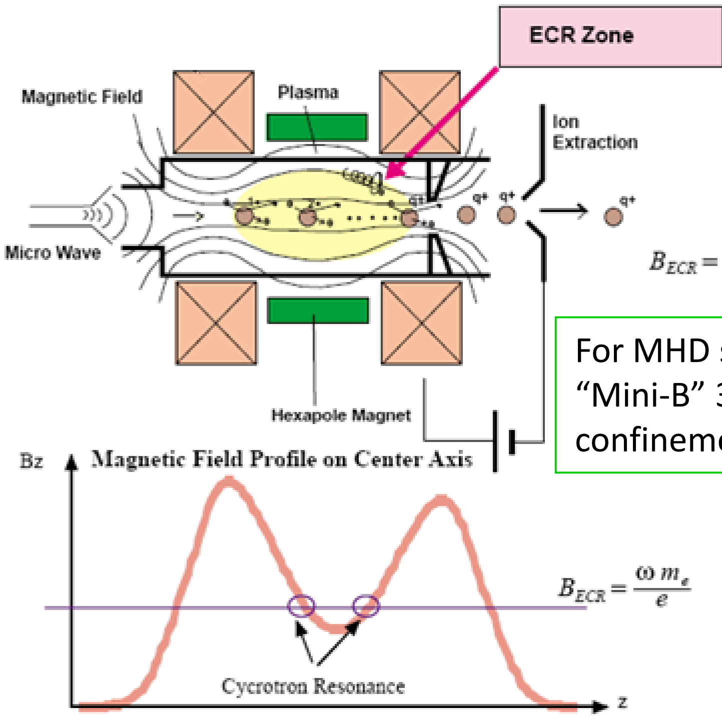

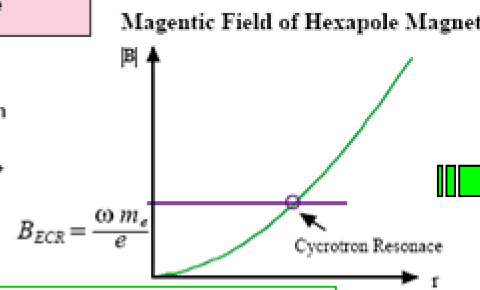

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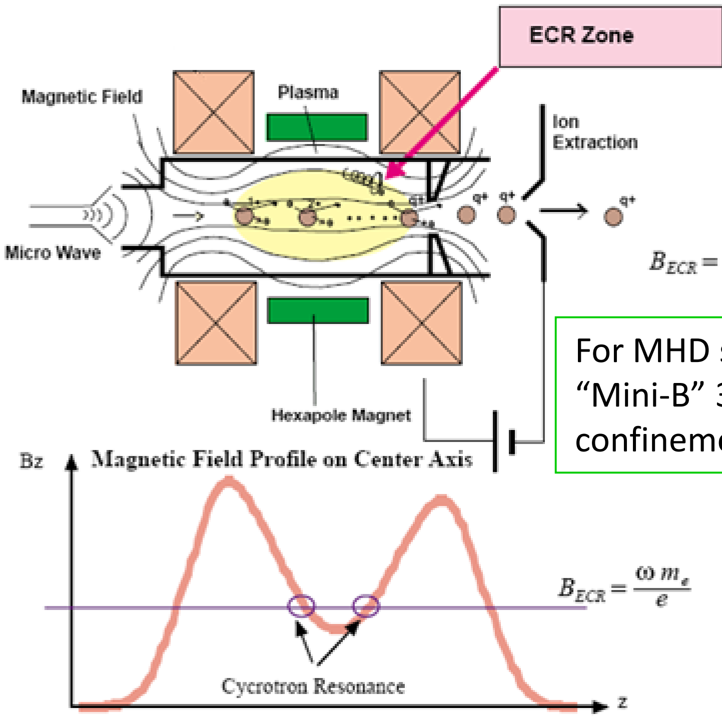

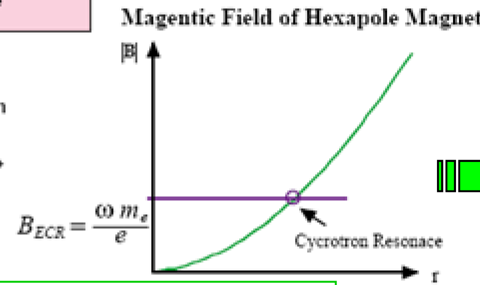

For MHD stability→ "Mini-B" 3D magnetic confinement

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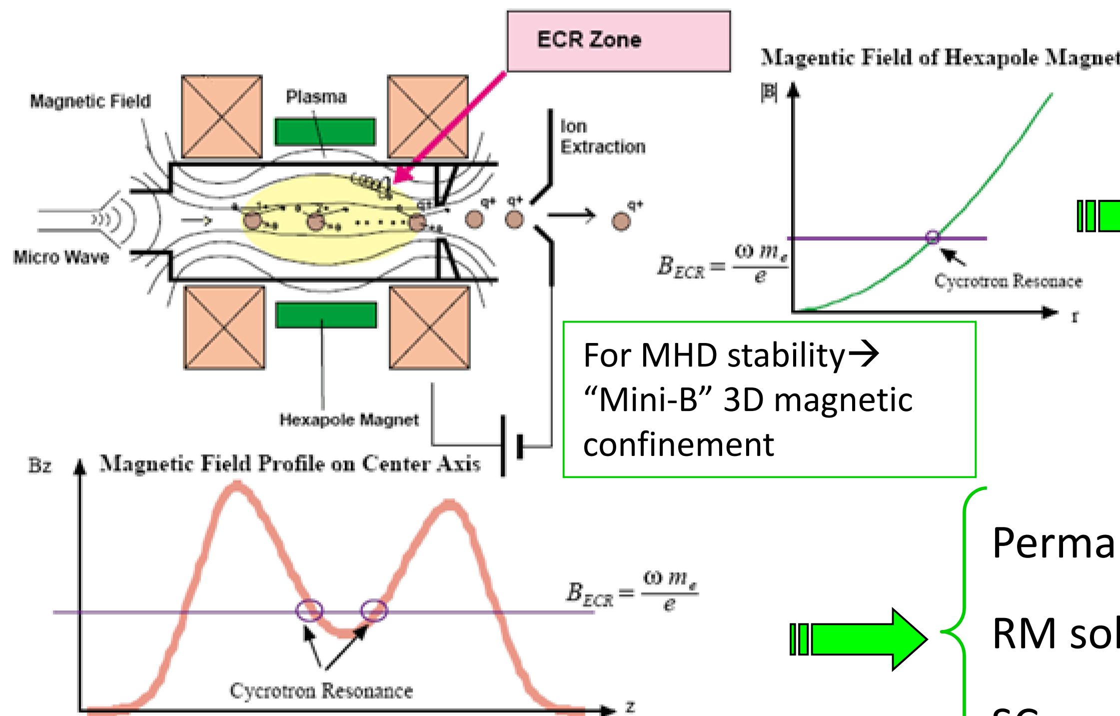
- SC- magnet solenoids (LTS, HTS)

ECR Ion Sources



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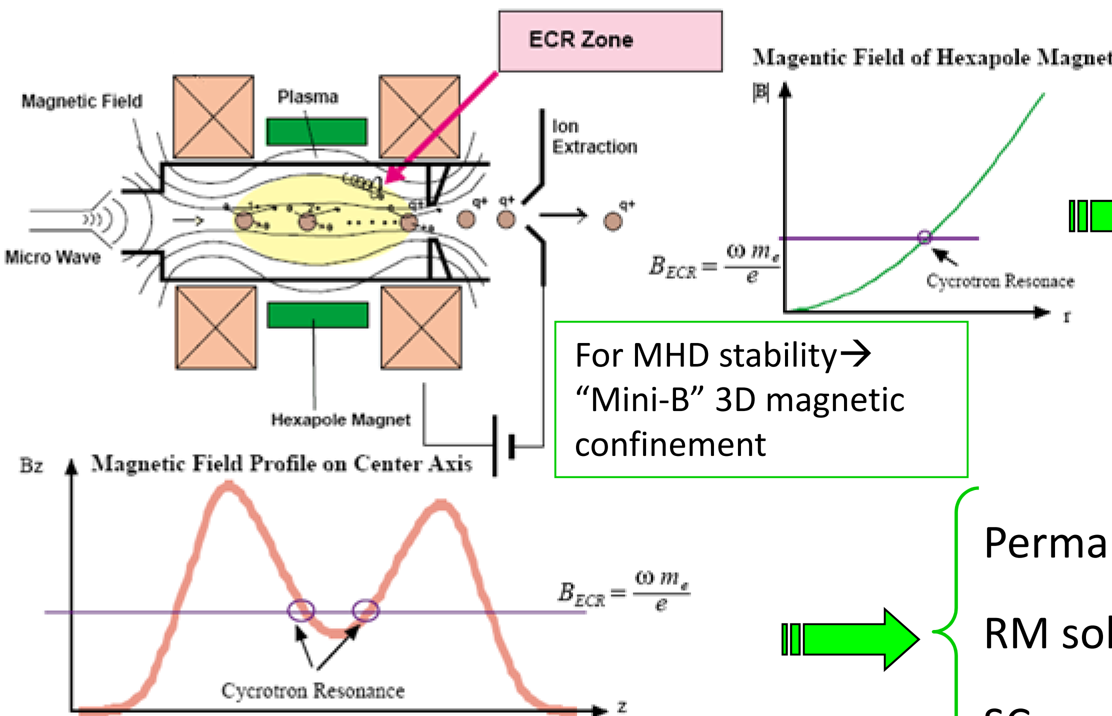

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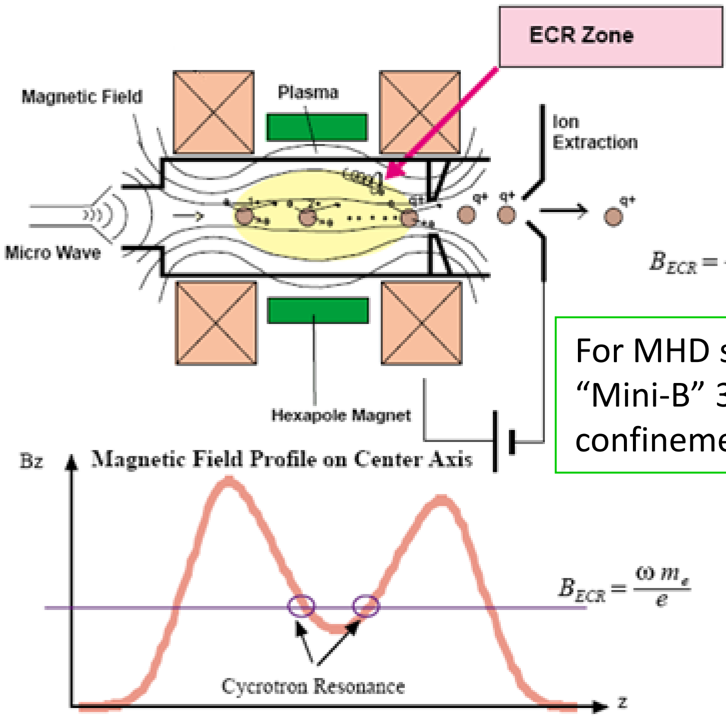
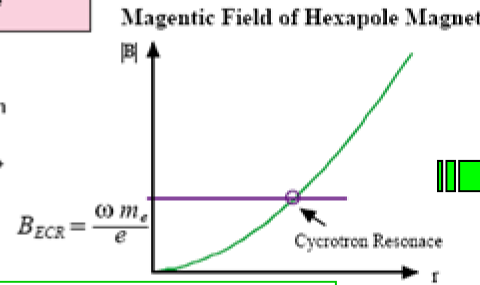
All permanent magnet ECRIS
Nanogan series ion sources
BIE series ion sources
LAPECR1, LAPECR2, LAPECR3
Kei1, Kei2
SOPHIE
Operated 2.45 ~ 14 GHz

ECR Ion Sources





For MHD stability→ "Mini-B" 3D magnetic confinement

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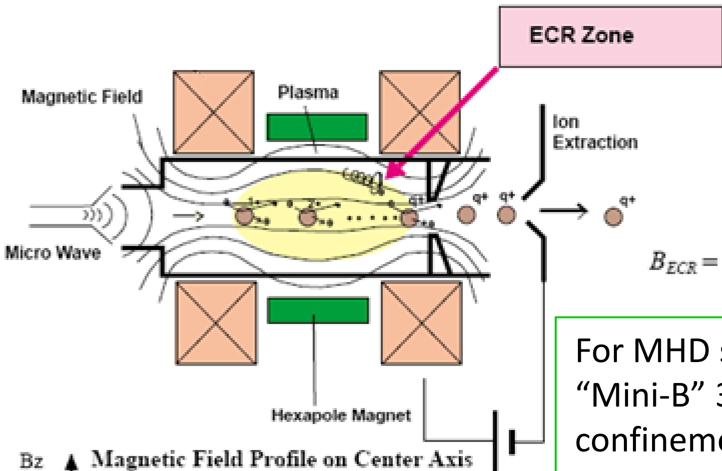
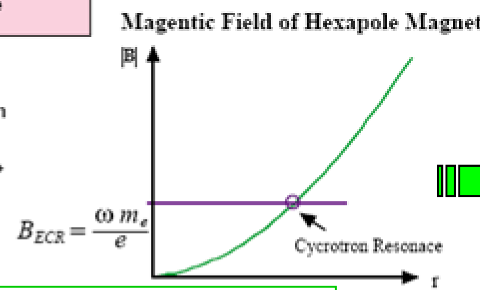
- SC- magnet solenoids (LTS, HTS)

All permanent magnet ECRIS	Classical RM ECRIS
Nanogan series ion sources	GTS source
BIE series ion sources	AECR-U
LAPECR1, LAPECR2, LAPECR3	LECR2, LECR3, LECR4
Kei1, Kei2	RIKEN 18 GHz
SOPHIE	ECR4, Caprice
Operated 2.45 ~ 14 GHz	Operated 10 ~ 18 GHz

ECR Ion Sources





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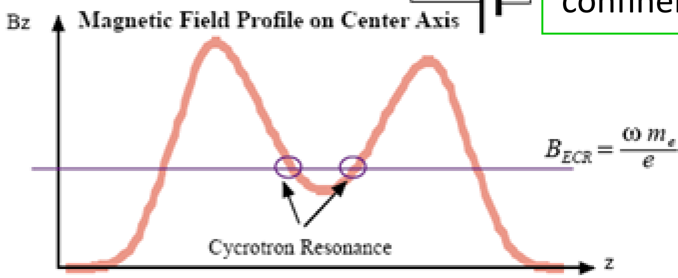
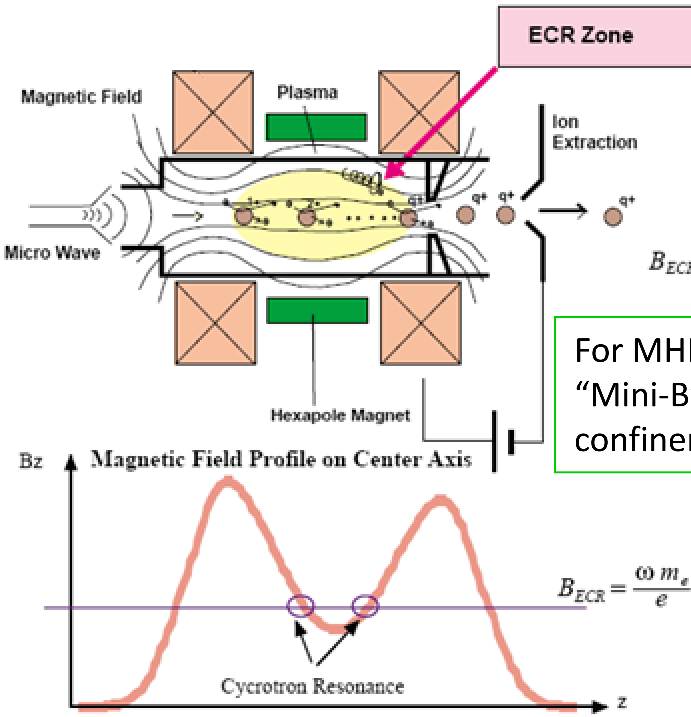


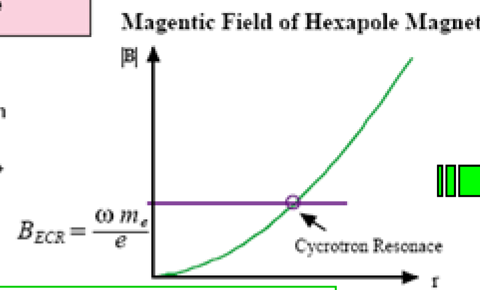
- Permanent magnet
- SC- magnet hexapole

- Permanent magnet
- RM solenoidal coils
- SC- magnet solenoids (LTS, HTS)

All permanent magnet ECRIS	Classical RM ECRIS	Hybrid SC-ECRIS
Nanogan series ion sources	GTS source	RAMSE, SHIVA
BIE series ion sources	AECR-U	A-PHOENIX
LAPECR1, LAPECR2, LAPECR3	LECR2, LECR3, LECR4	PKDELIS
Kei1, Kei2	RIKEN 18 GHz	Dubna 18 GHz
SOPHIE	ECR4, Caprice	
Operated 2.45 ~ 14 GHz	Operated 10 ~ 18 GHz	Operated 14 ~ 28 GHz

ECR Ion Sources





For MHD stability→ "Mini-B" 3D magnetic confinement

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- Permanent magnet
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All permanent magnet ECRIS	Classical RM ECRIS	Hybrid SC-ECRIS	Fully SC-ECRIS
Nanogan series ion sources	GTS source	RAMSE, SHIVA	SERSE 18 GHz
BIE series ion sources	AECR-U	A-PHOENIX	VENUS 28GHz
LAPECR1, LAPECR2, LAPECR3	LECR2, LECR3, LECR4	PKDELIS	SECRAL 18~24 GHz
Kei1, Kei2	RIKEN 18 GHz	Dubna 18 GHz	SUSI 18~24 GHz
SOPHIE	ECR4, Caprice		RIKEN SCECRIS 28 GHz
Operated 2.45 ~ 14 GHz	Operated 10 ~ 18 GHz	Operated 14 ~ 28 GHz	Operated 18 ~ 28 GHz

Features of All Permanent ECRISs

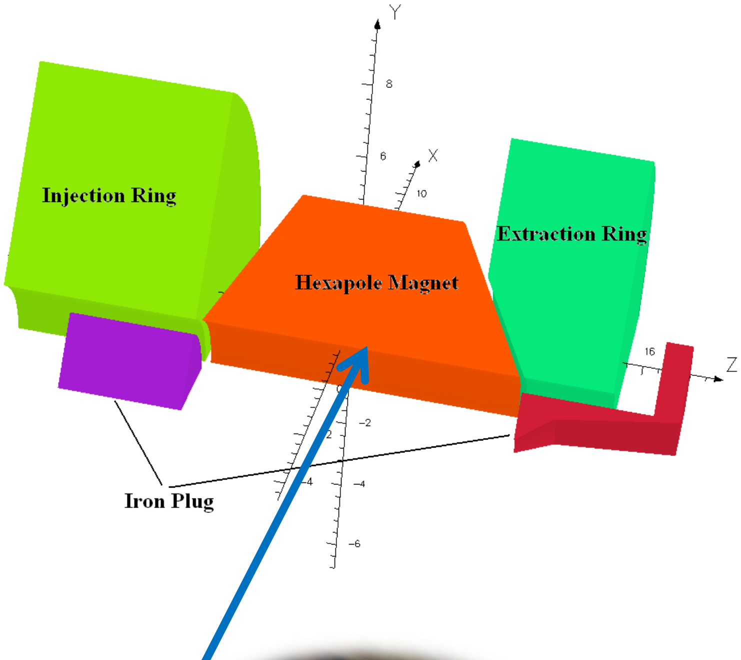
Pros:

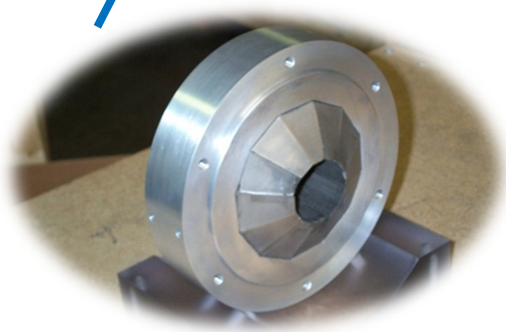
- Very compact device
- Easy maintenance
- Simple and easy to operate
- Low electricity consumption
- No need for large volume LCW
- Cost saving

Cons:

- No flexibility for magnetic field optimization
- Lower magnetic field and smaller chamber volume
- Moderate HCI beam intensity

LAPECR1





12-segment conical shaped sextupole

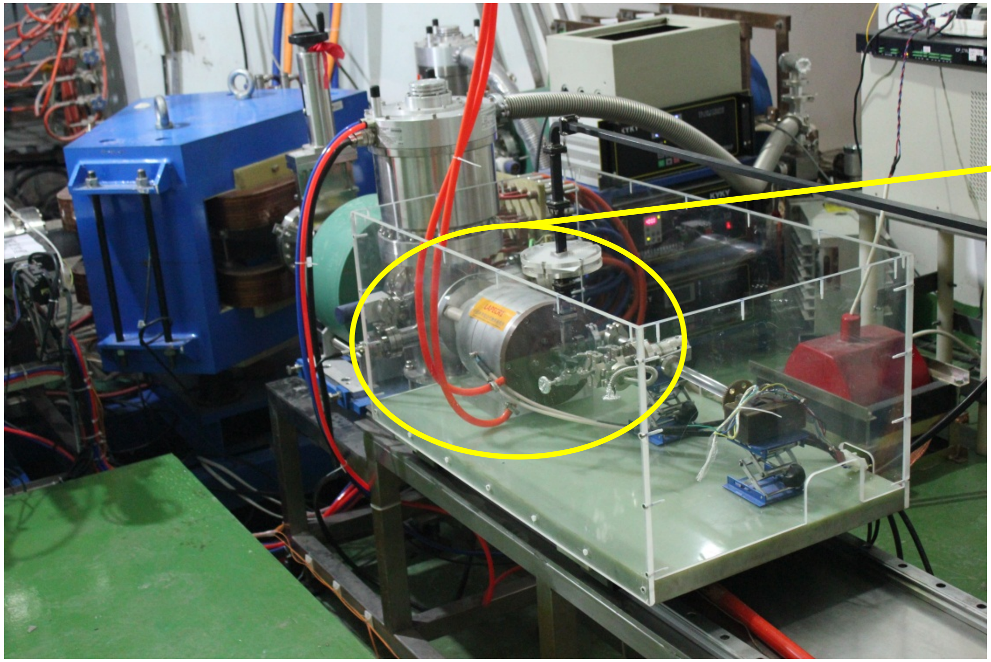
Typical Parameters of LAPECR1 source

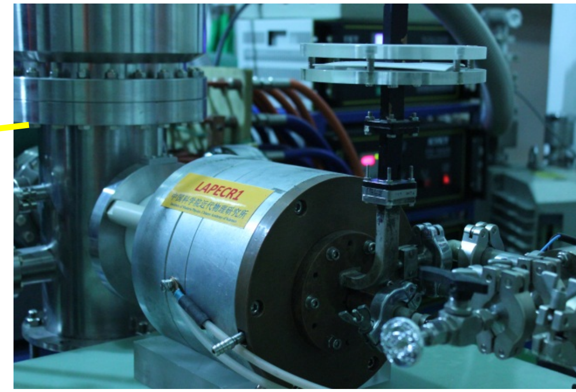
B_{inj}	1.0 T
B_{ext}	0.56 T
Hexapole pole surface	1.1 T
Plasma chamber ID	40 mm
f	14.5 GHz
RF power	1 kW
Dimension	Φ102 mm×296 mm
Weight	~25 kg
Permanent material	N45M NdFeB
L_{mirror}	74 mm
L_{ECR}	55 mm
HV	30~50kV

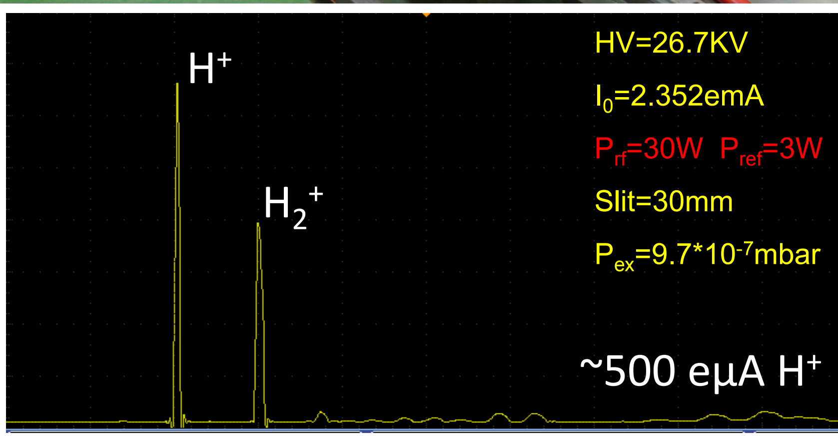
Purpose of LAPECR1

- **To produce low charge state ion beams with the currents varying from several emA to tens of euA**
  - **such as: He^{+},He^{2+}, B^{+}, C^{+}, C^{2+}, O^{+}, O^{2+}, N^{+}, N^{2+}, Ar^{+}…**
- **To produce medium charge state ion beams with the currents varying from several euA to several hundred euA,**
  - **Such as：B^{4+}, C^{4+}, N^{5+}, O^{6+}, Ne^{8+}, Ar^{8+}, Ar^{9+}…**
- **To produce low charge state ion beams of some metallic elements;**
- **Suitable to be put on a HV platform or some small laboratory.**

LAPECR1 for HIRFL Accelerator

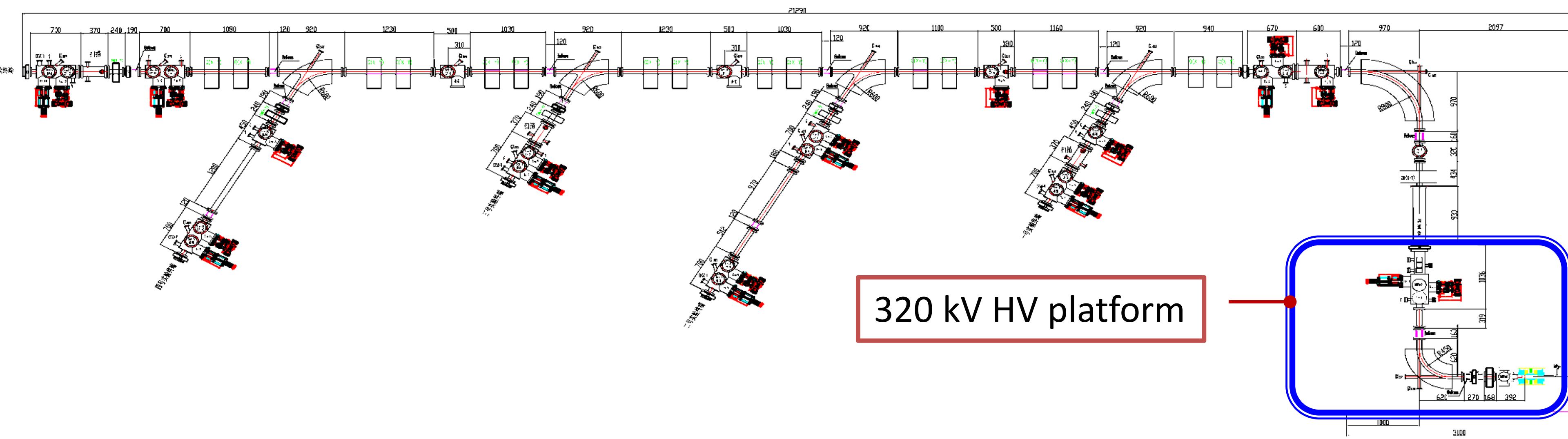






- Floated to HV max. 36 kV
- Long time stable
- Intense H^+ and H_2^+ beams
- Easy Operation and simple setup

Motivation for LAPECR2



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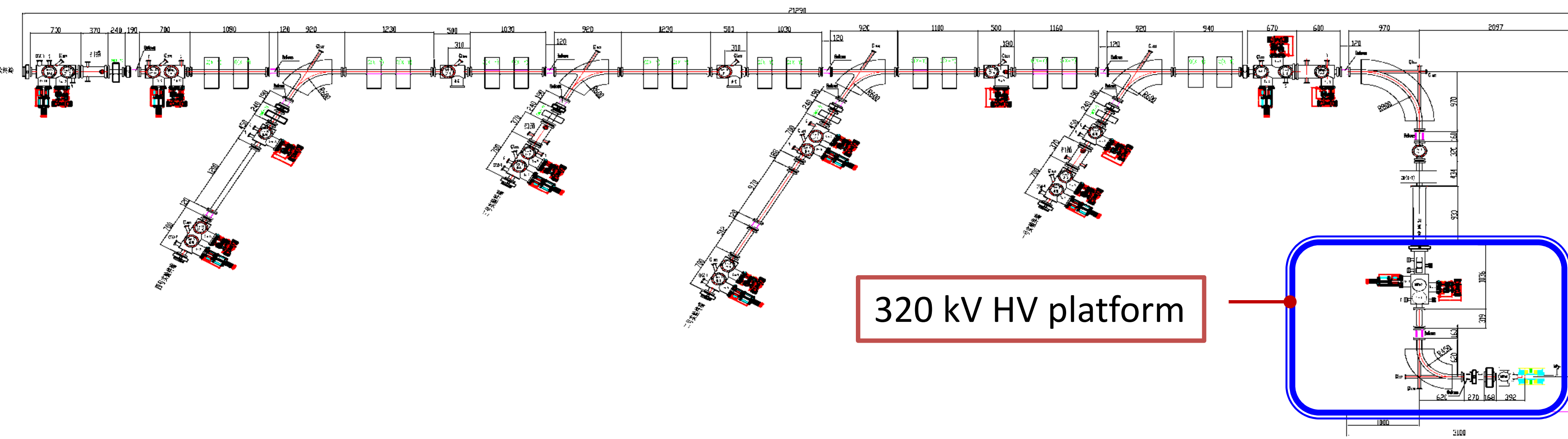
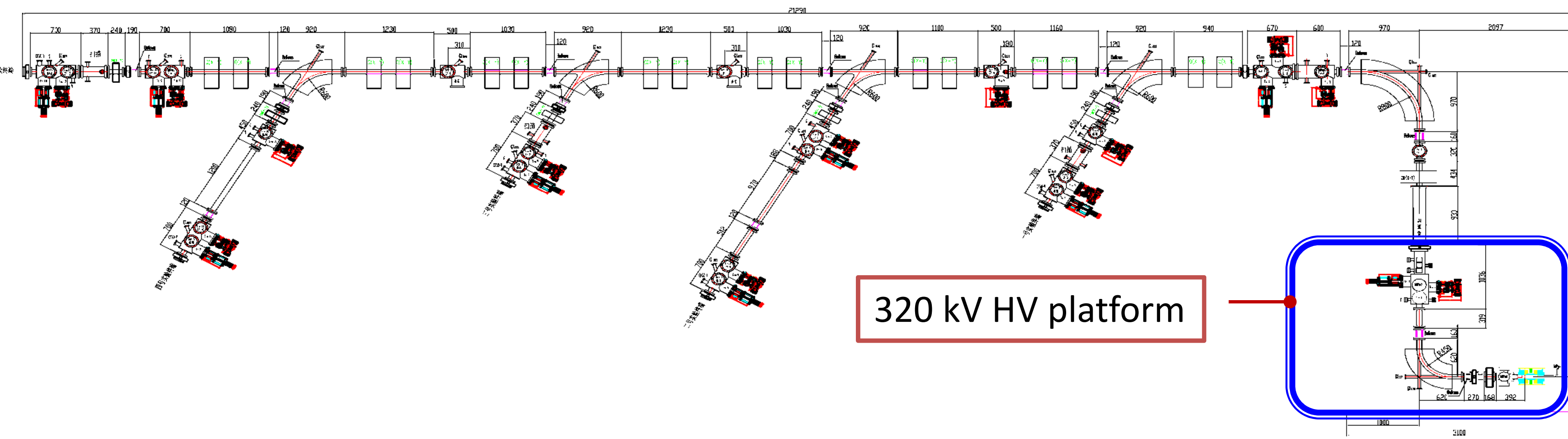


- highly charged ion physics
- material developing
- biophysics
- astrophysics
- atomic physics…

Motivation for LAPECR2



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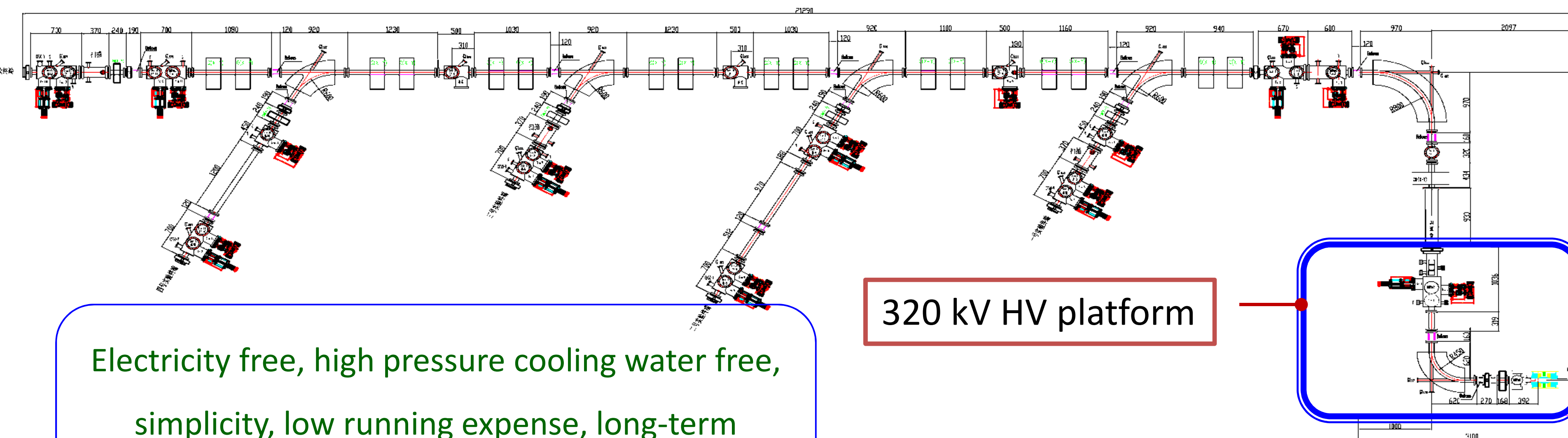

320 kV HV platform

Electricity free, high pressure cooling water free, simplicity, low running expense, long-term running stability.

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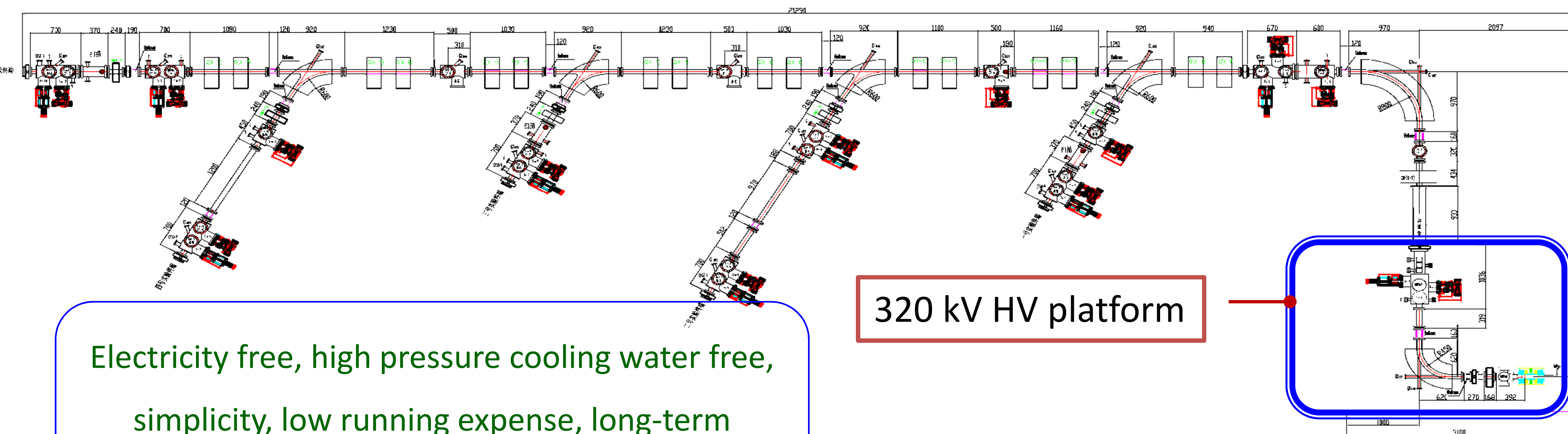

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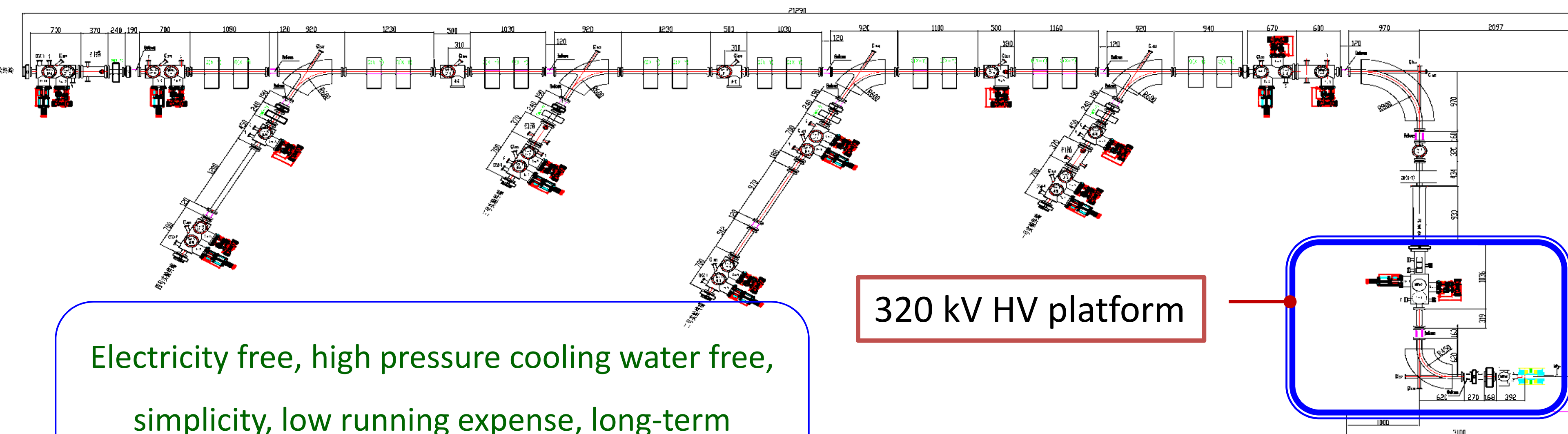


320 kV HV platform

Electricity free, high pressure cooling water free, simplicity, low running expense, long-term running stability.

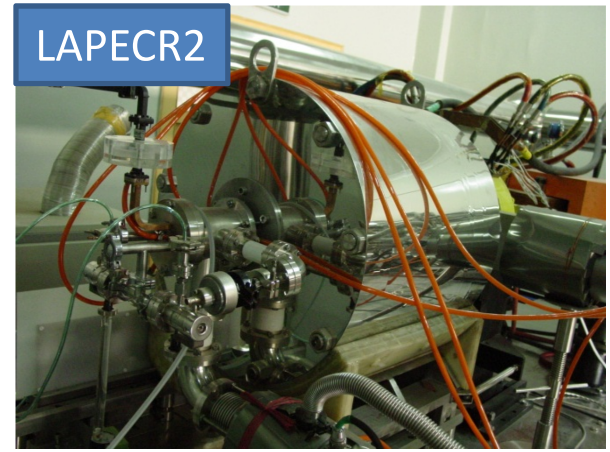
Used on IMP 320 kV HV platform to produce stable intense medium charge state ion beams such as: hundreds of *euA* Ar^{8+}, C^{4+}; high charge state ion beams, such as gaseous ion beams Ar^{14+}, Kr^{20+}, Xe^{27+} etc., and also metallic ion beams Ca^{14+}, Pb^{27+}…

- highly charged ion physics
- material developing
- biophysics
- astrophysics
- atomic physics…

LAPECR2 Parameters

Comparison of the parameters

Parameters	LAPECR2	LECR2
Axial Mirror Peaks (T)	1.28, 1.07	1.5, 1.1
B_{min} (T)	0.42	0.39
B_{rad} (T)	1.21	1.0
Hexapole Material (NdFeB)	36-segmented N45M	24-segmented N42
μW Frequency (GHz)	14.5	14.5
μW Power Coupling Mode	Off-axial Direct	Coaxial
L_{mirror} (mm)	255	265
L_{ecr} (mm)	100	86
Plasma Chamber ID (mm)	67	70
Chamber Material	316 L SS	316 SS



Commissioning Results

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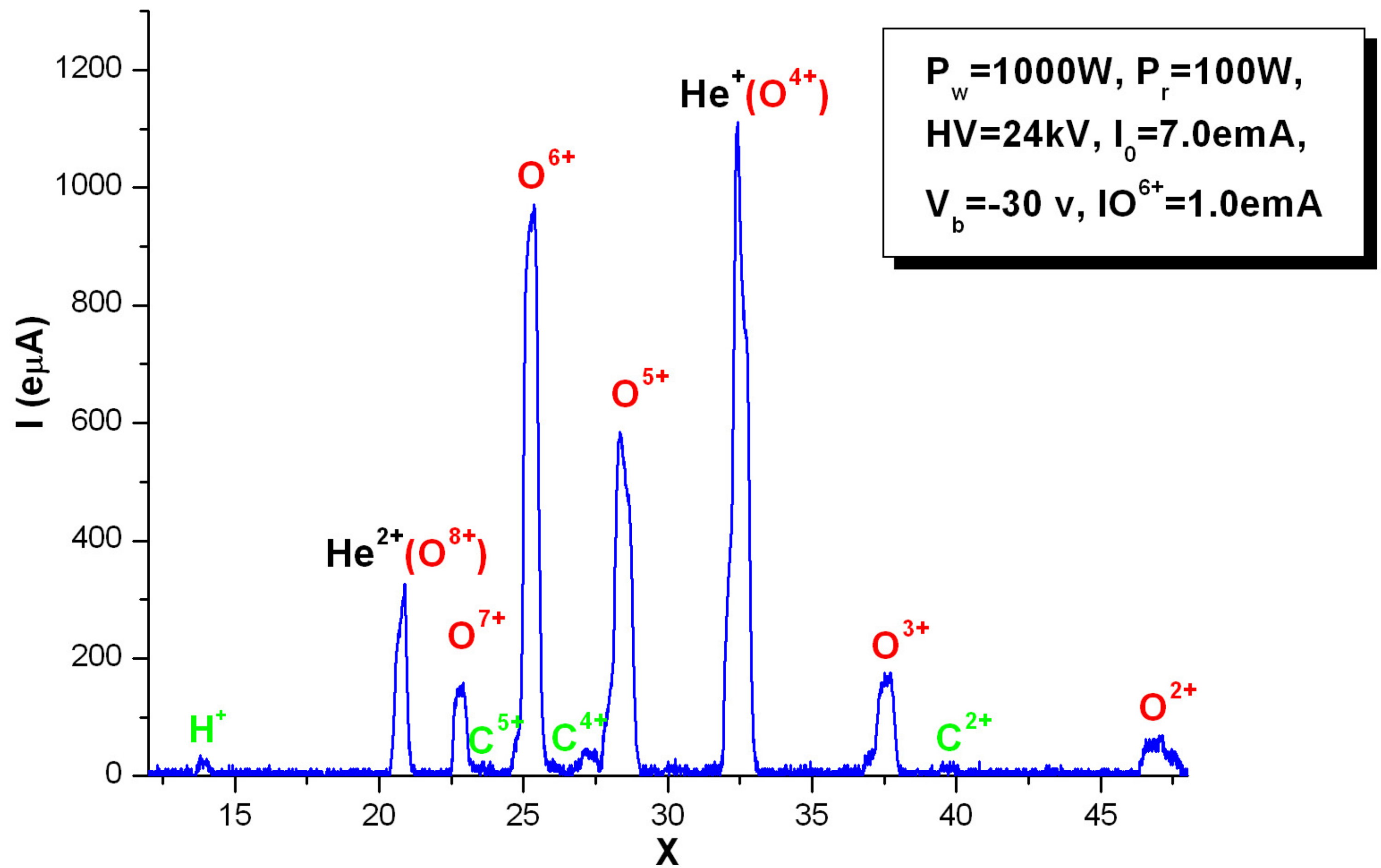

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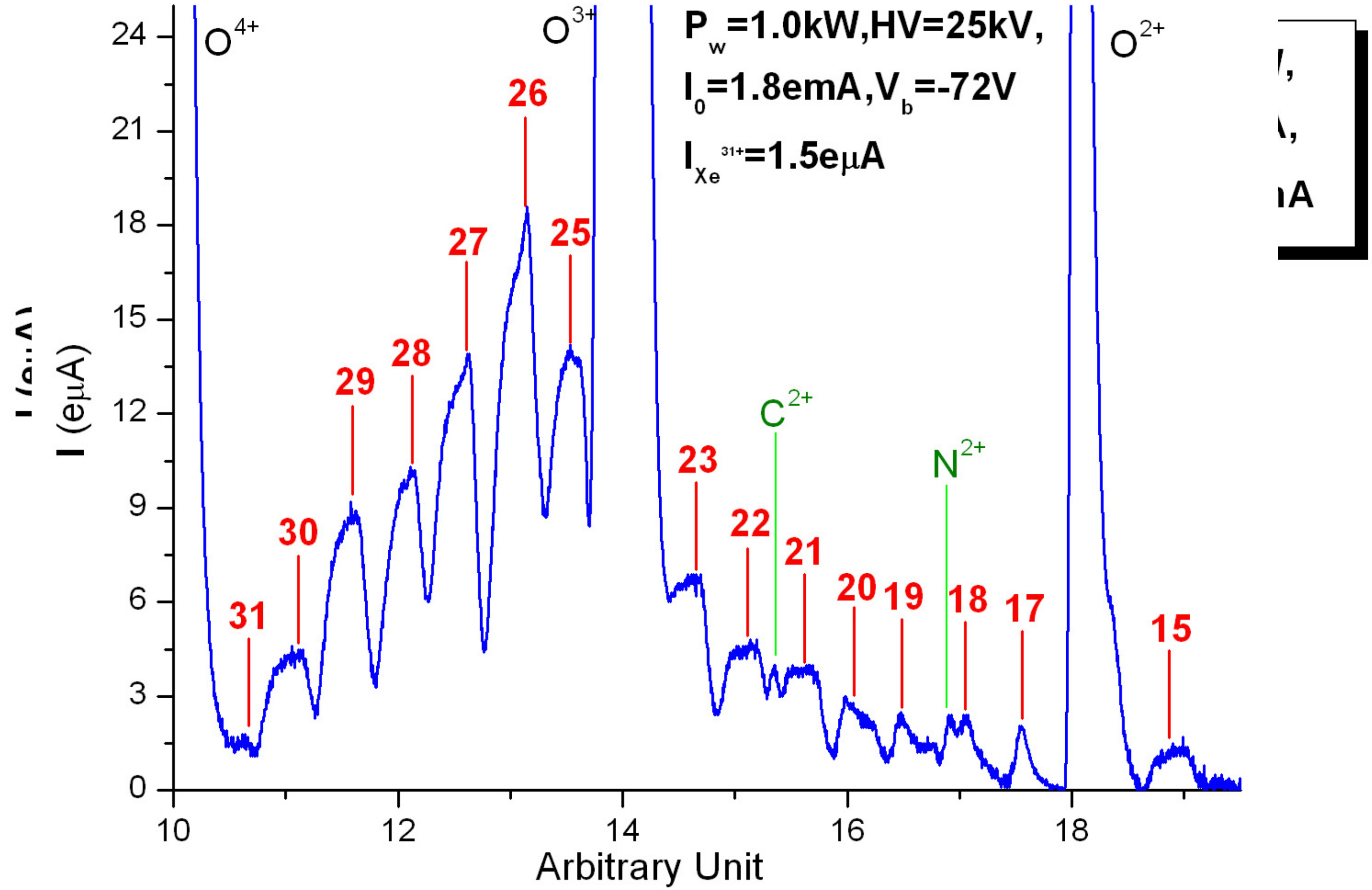

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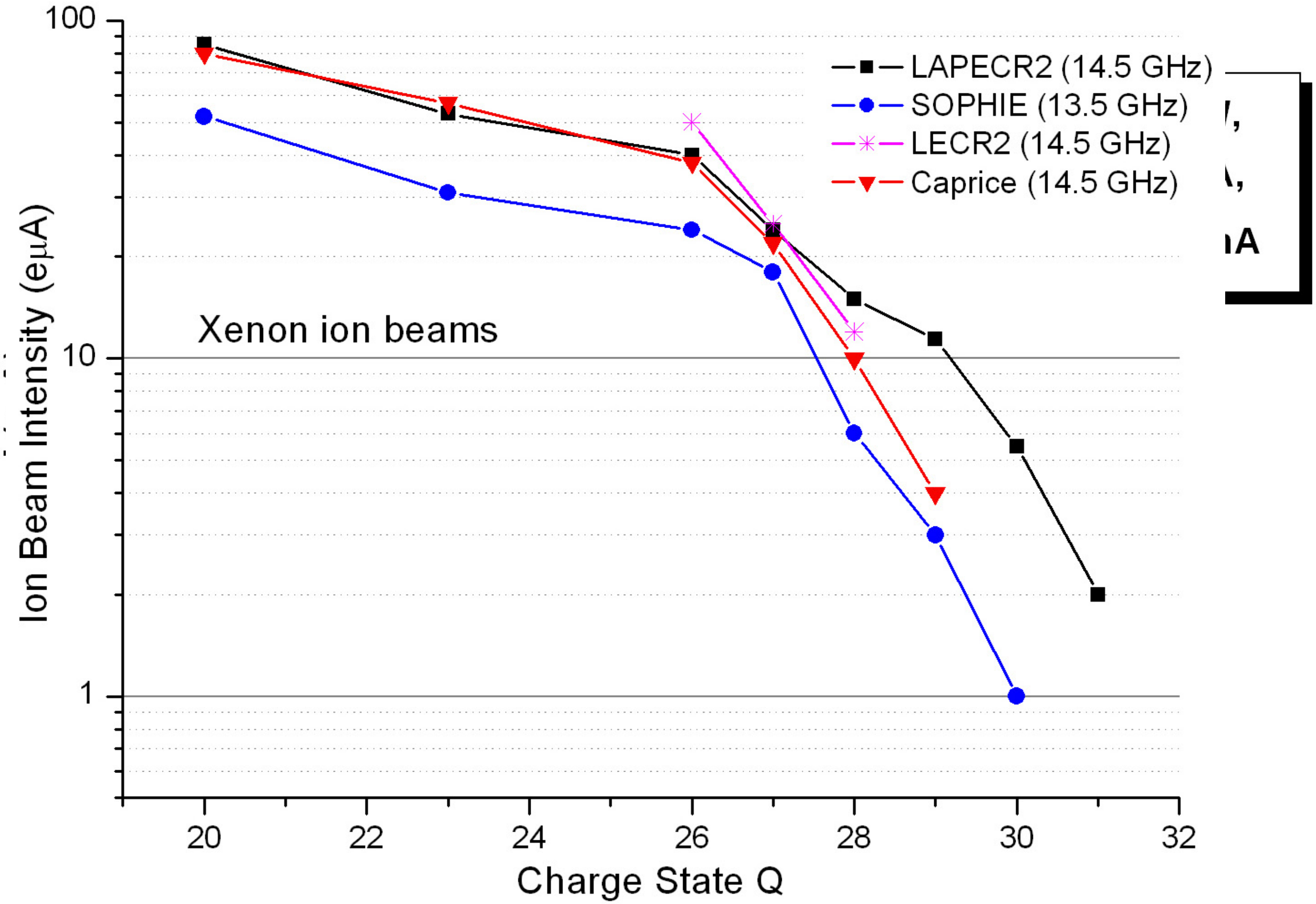
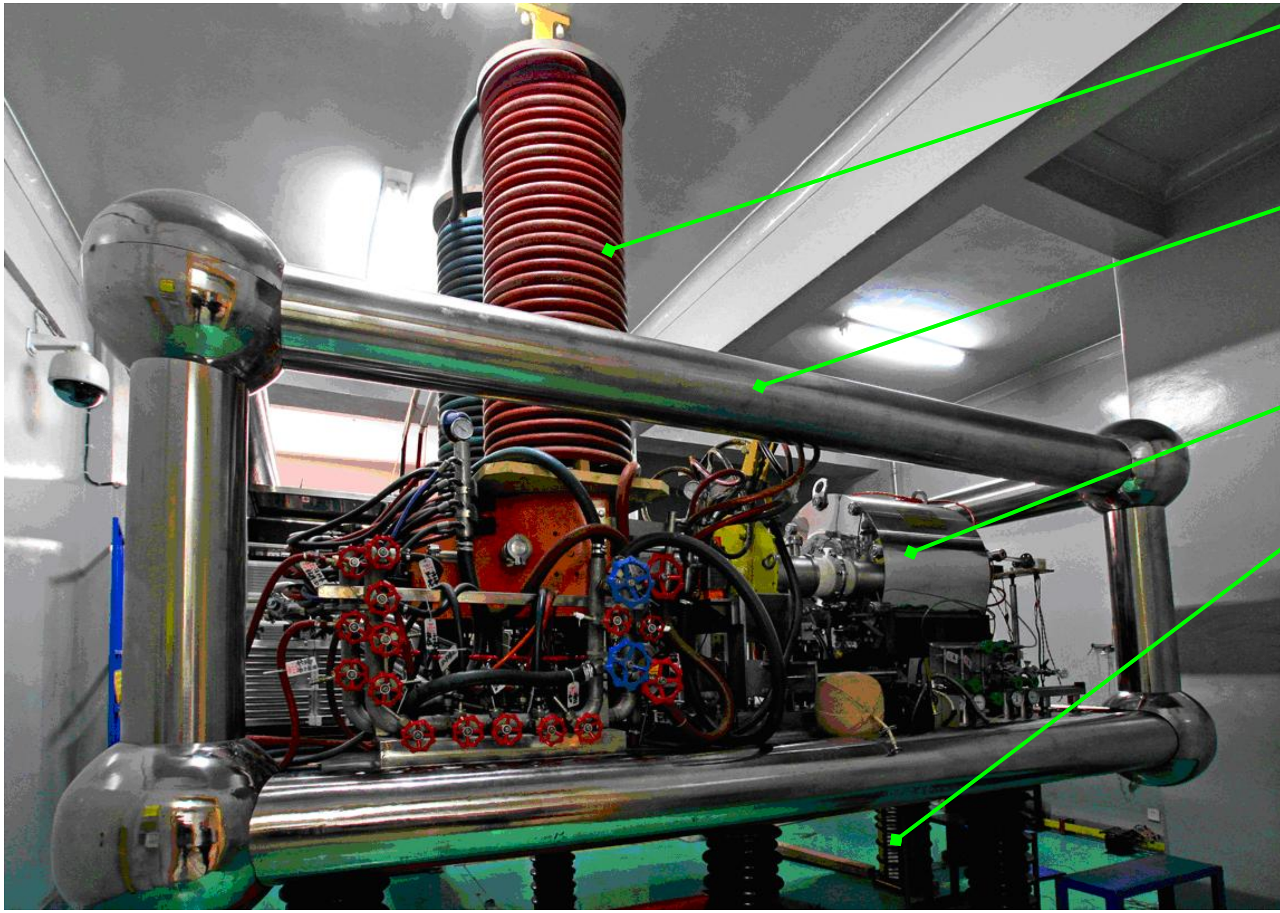


320 kV HV Platform



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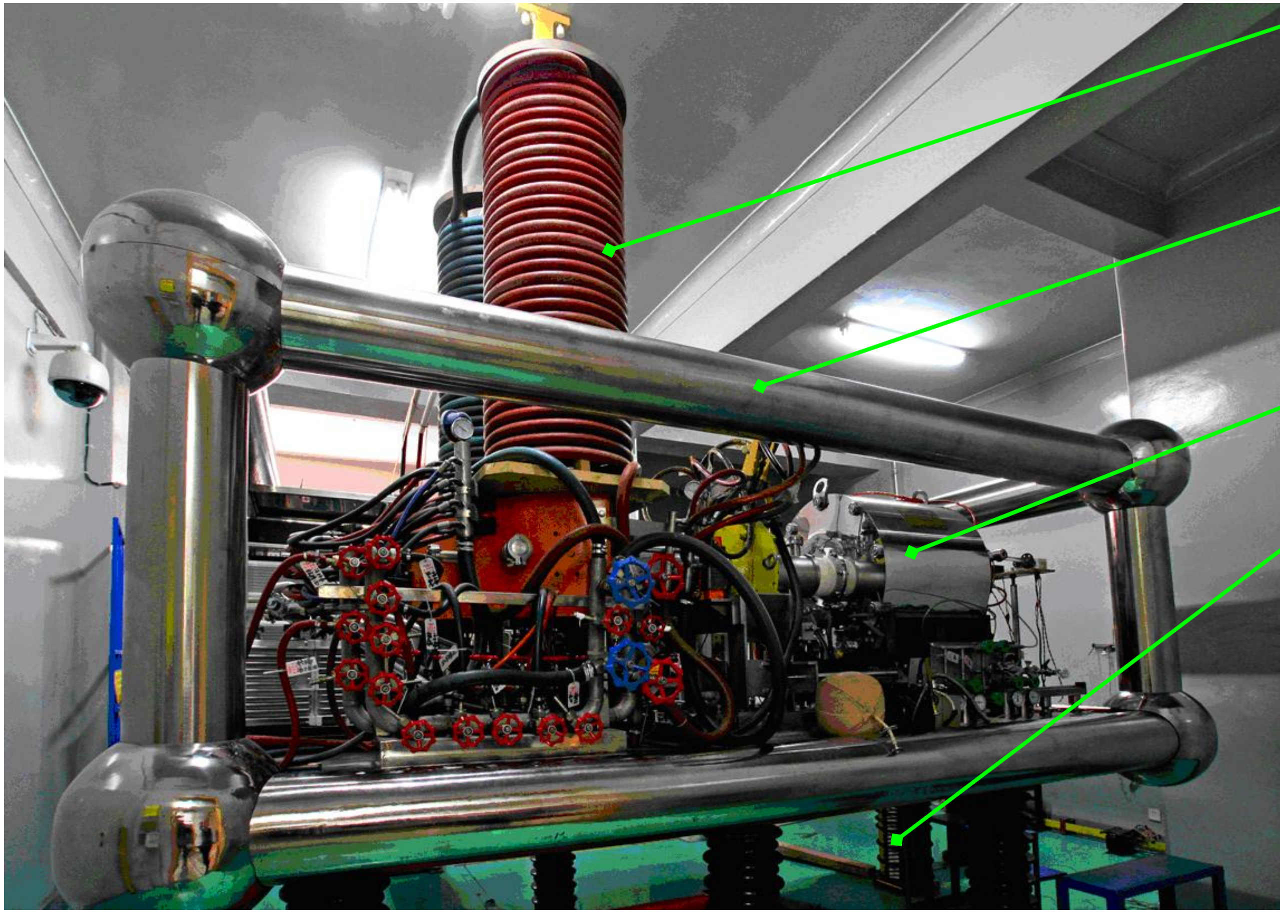


Water resistor columns

HV platform shielding electrode

LAPECR2

Insulator columns

Energy Range：

5 keV/q~340 keV/q

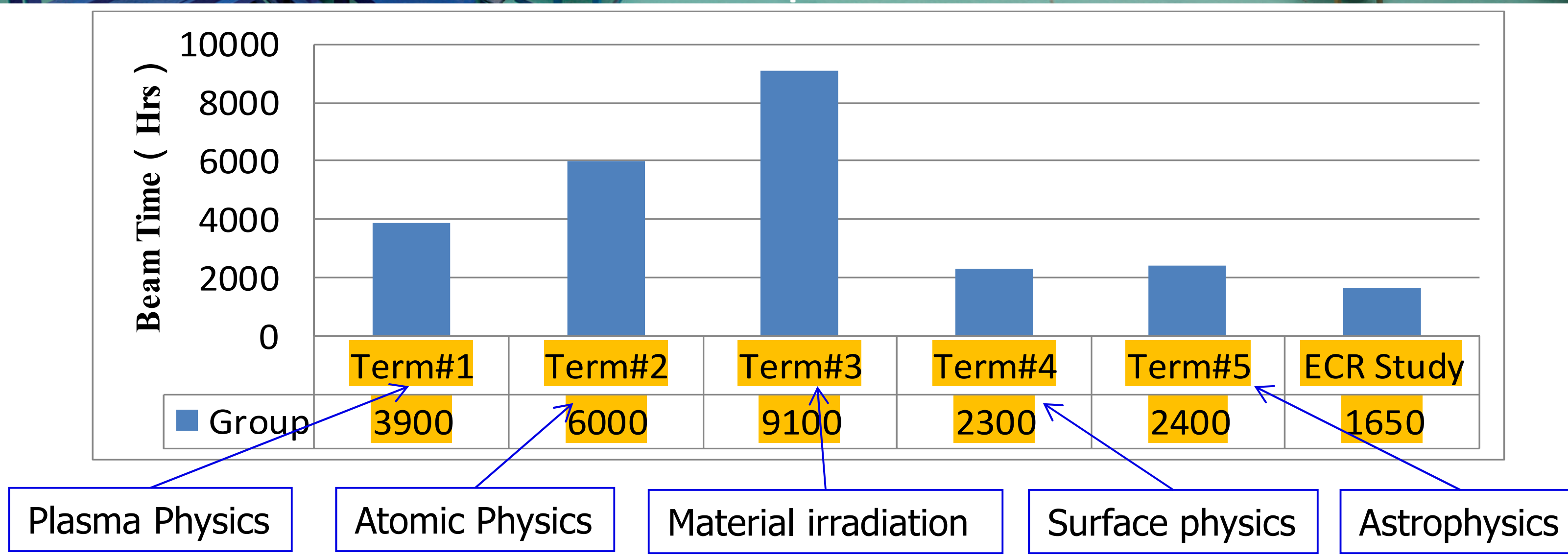
Operation Status of LAPECR2

- **Ion Species：**
  - Gaseous Elements (9)： H, He, C, N, O, Ne, Ar, Xe, Kr
  - Solid Elements (9)： Pb, Bi, Fe, Eu, Mg, Cs, I, F, S
- **Typical delivered HCI beams:**
  - Bi^{33+}=15eμA Bi^{36+}=3eμA
  - Eu^{30+}=10eμA Eu^{33+}=5eμA
  - Fe^{13+}=25eμA Fe^{15+}=20eμA
  - Cs^{23+}=20eμA Cs^{16+}=40eμA I^{25+}=35eμA
  - Ar^{16+}=2eμA Xe^{30+} =11eμA Kr^{23+}=15eμA
- **Total operation time (2007—2011):**
  - Experiment beam time: **25,300** hours
  - Service time: 2,050 hour
  - New beam study: 2,700 hours

Mostly with only 400 W microwave power

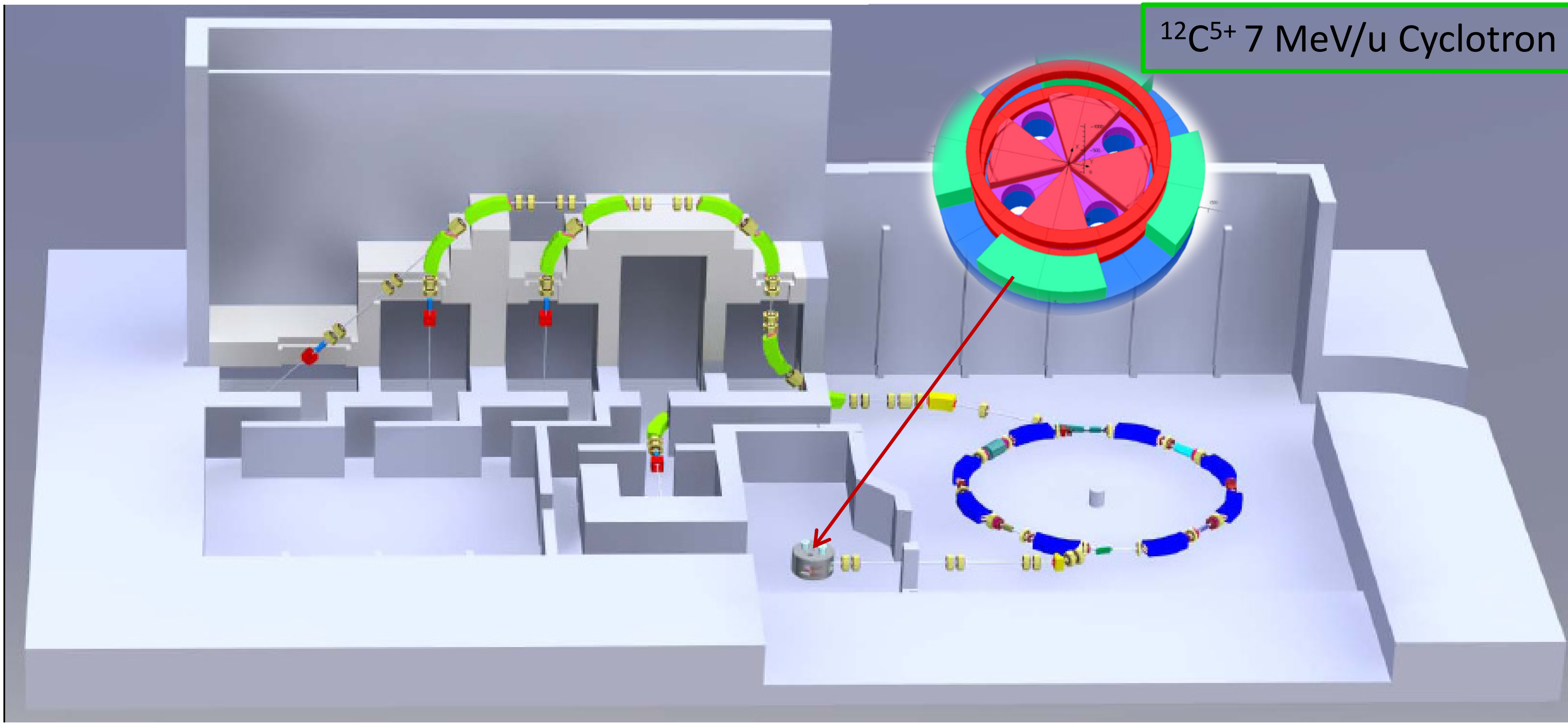
Almost 35,000 hours' operation time till July 2012

Multi-discipline Studies



Heavy Ion Treatment Facility in Lanzhou (HITFiL)

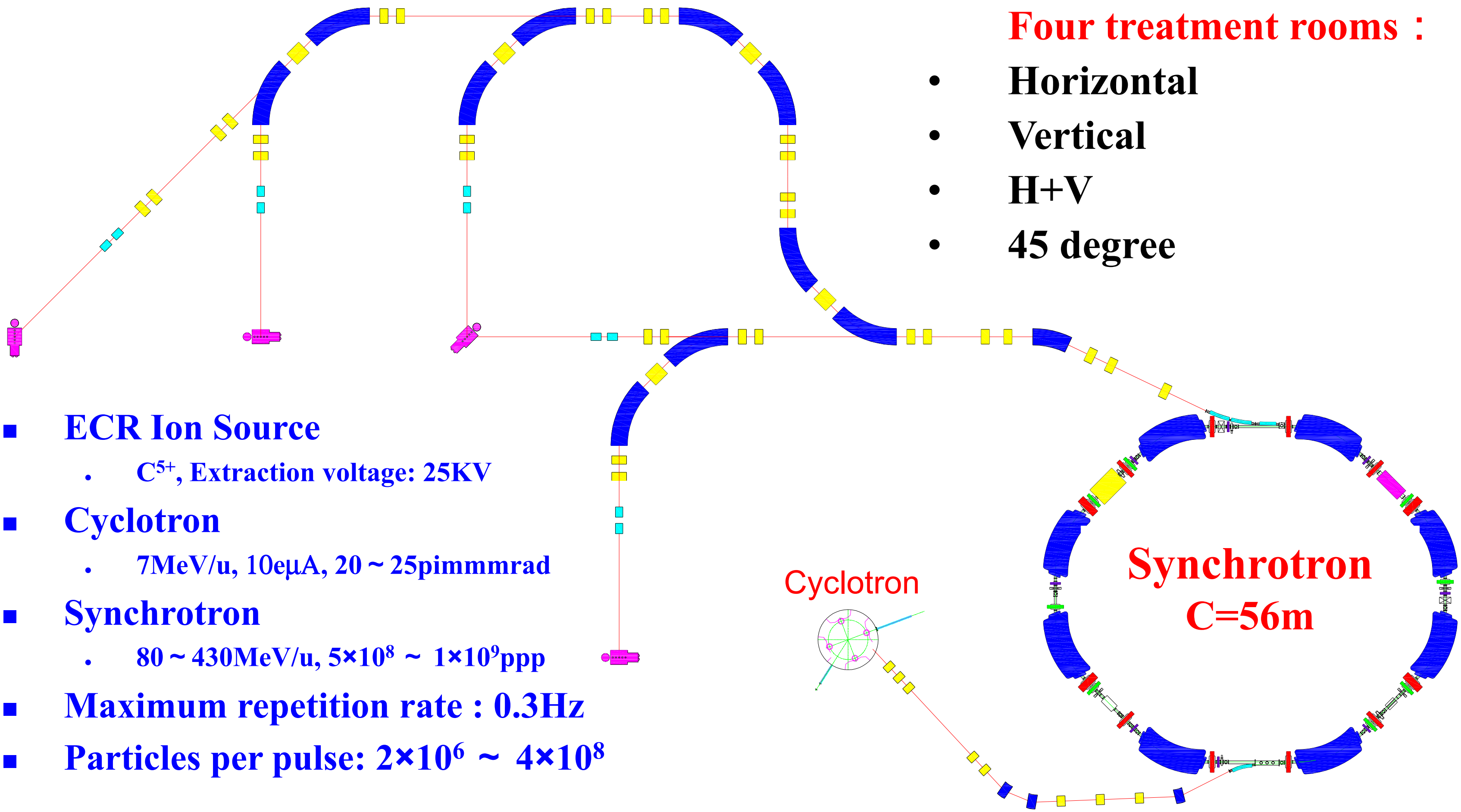
HITFiL Project



Combination: ECR + Cyclotron + Synchrotron Ring

430 MeV/u Carbon ions, 1×10^{9} particles/spill

Accelerators



Four treatment rooms：

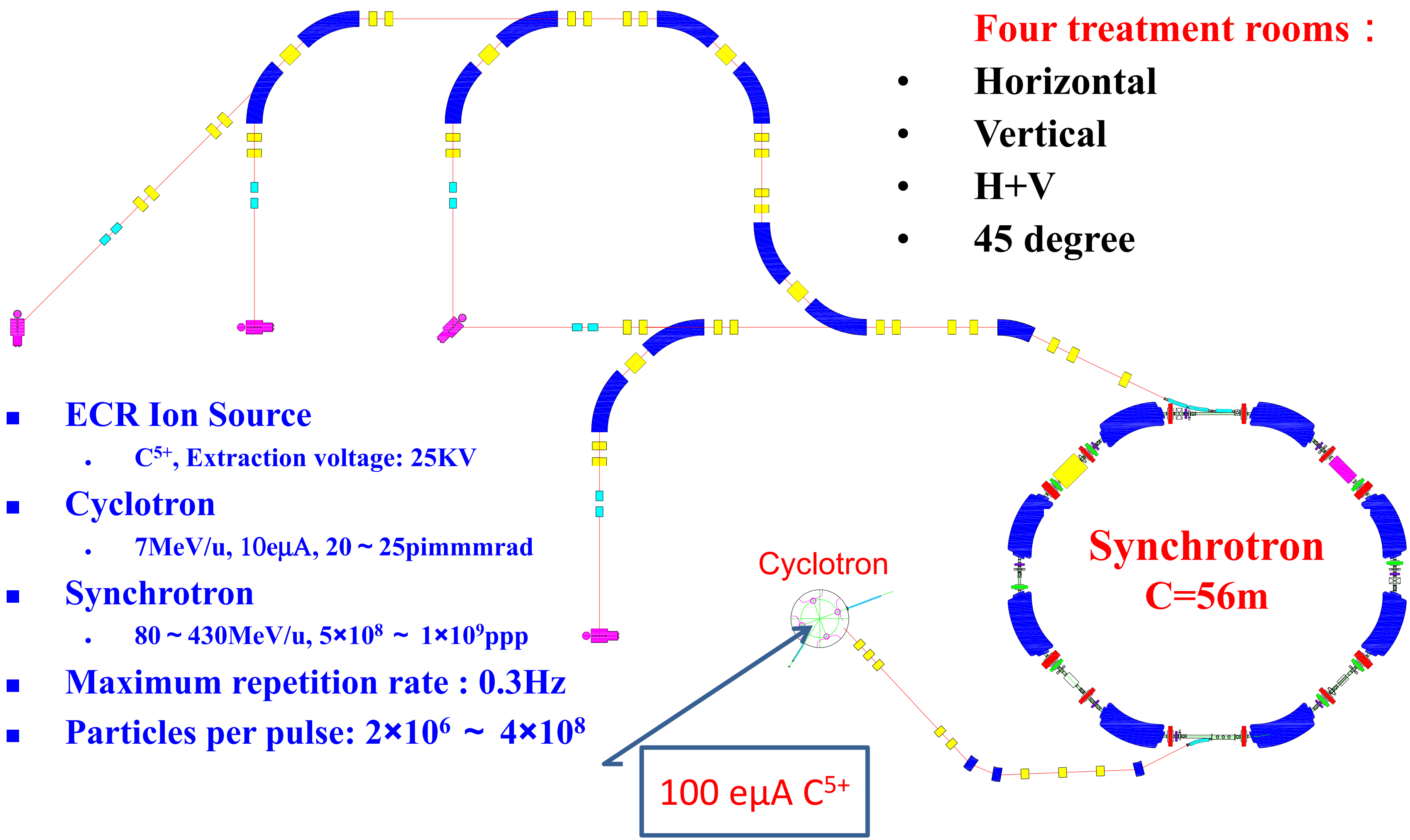
- Horizontal
- Vertical
- H+V
- 45 degree

- **ECR Ion Source**
  - C^{5+}, Extraction voltage: 25KV
- **Cyclotron**
  - 7MeV/u, 10eμA, 20 ~ 25pimmmrad
- **Synchrotron**
  - 80 ~ 430MeV/u, 5×10^8 ~ 1×10^9ppp
- **Maximum repetition rate : 0.3Hz**
- **Particles per pulse: 2×10^6 ~ 4×10^8**

Accelerators

Four treatment rooms：

- Horizontal
- Vertical
- H+V
- 45 degree



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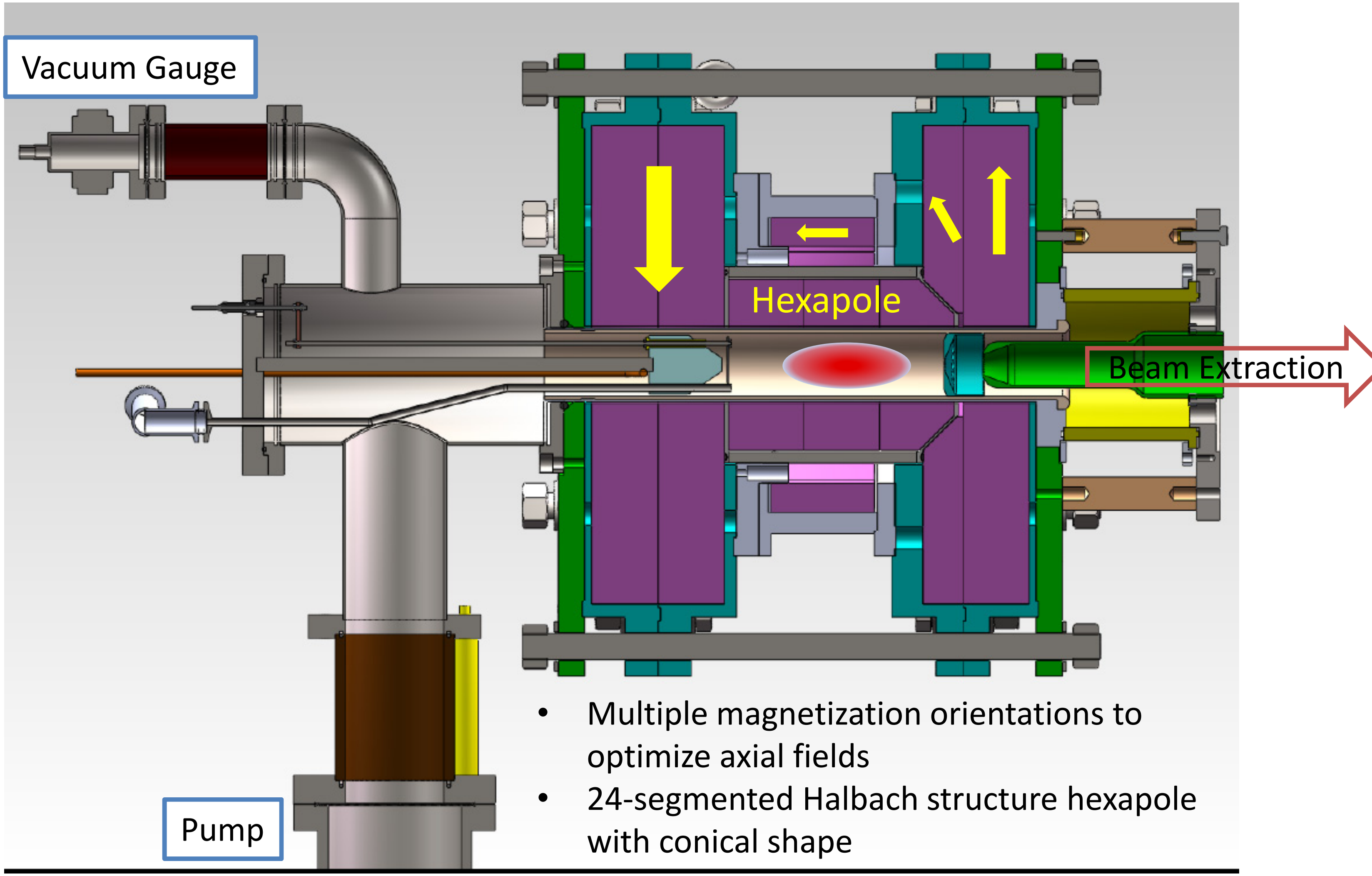
LAPECR3 Design Parameters

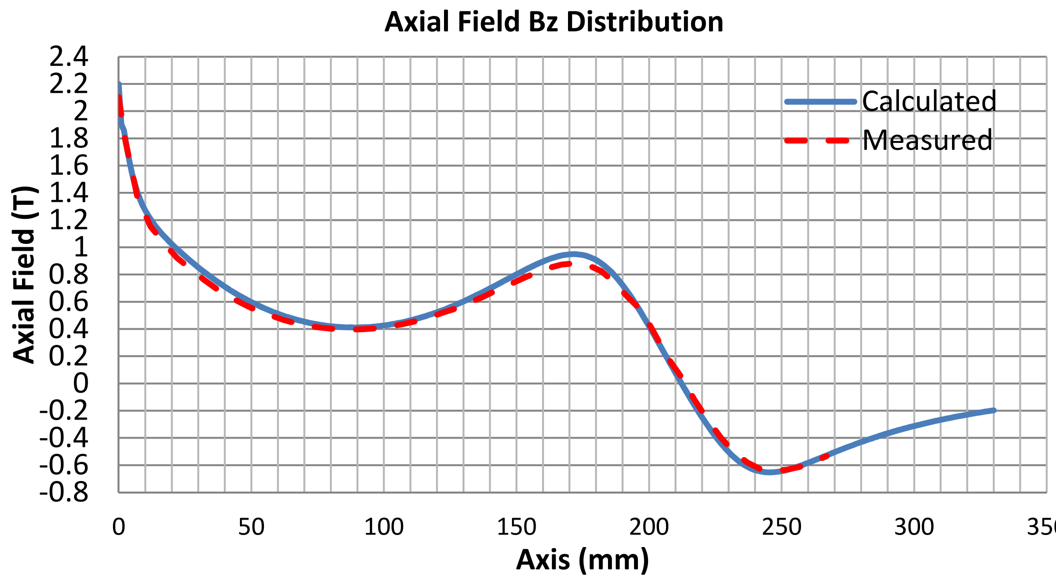
	LAPECR3	LAPECR2
Axial Field (T)	1.8-0.40-0.94	1.3-0.43-1.08
Field on Inner Chamber Wall -B_r (T)	1.14	1.21
Mirror Length (mm)	170	255
ECR Length (mm)	64	92
Operation Frequency (GHz)	13.75-14.5	14.5
Chamber ID (mm)	50	67
Effective Chamber Volume (L)	0.33	0.9
RF Feeding	WR62 Rectangular	WR62 Rectangular
Plasma chamber cooling	Water Cooled	Water Cooled
Max. Designed Operation HV (kV)	25	25
Max. Designed μW Power (kW)	0.70	1.1
External Dimension (mm)	Ø450×380	Ø650×560
NdFeB Weight (kg)	157	649
NdFeB Type	N50M & N42SH	N48M & N42SH

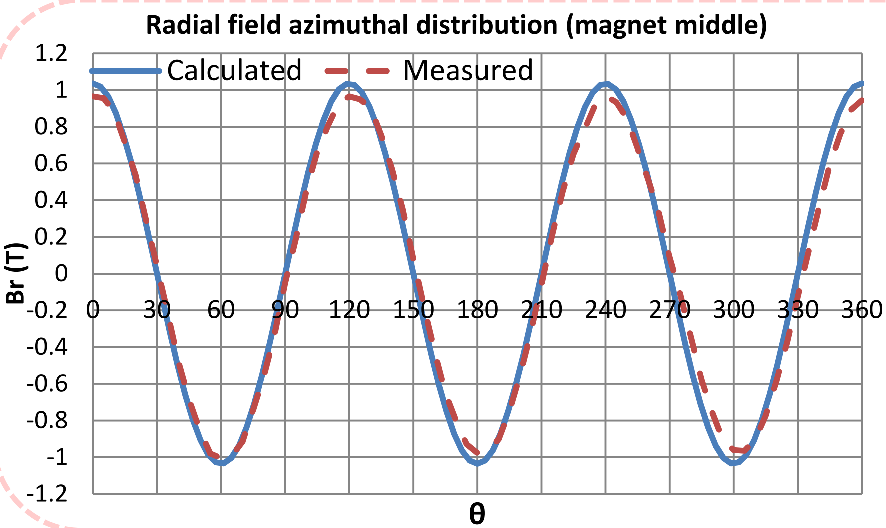
Magnetic Structure

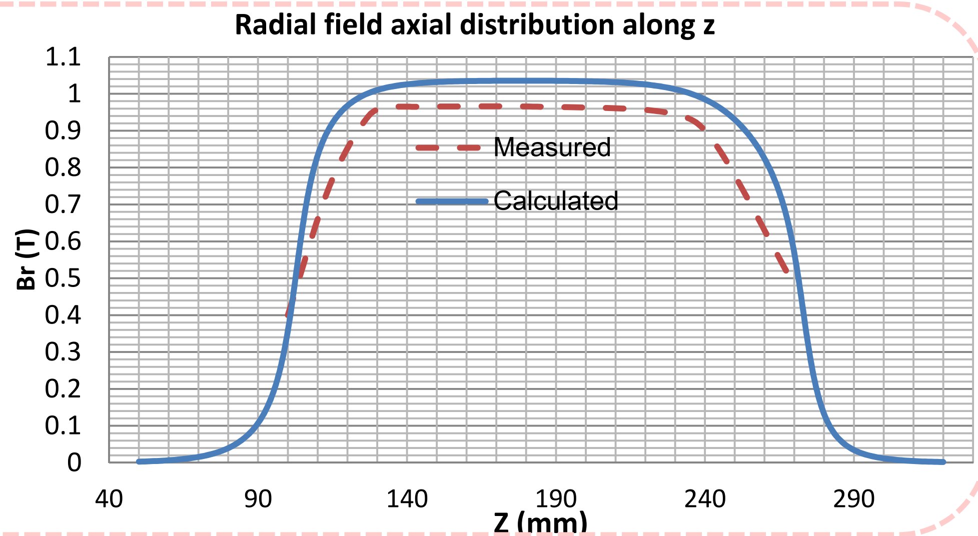


- Multiple magnetization orientations to optimize axial fields
- 24-segmented Halbach structure hexapole with conical shape

Magnetic Field Mapping





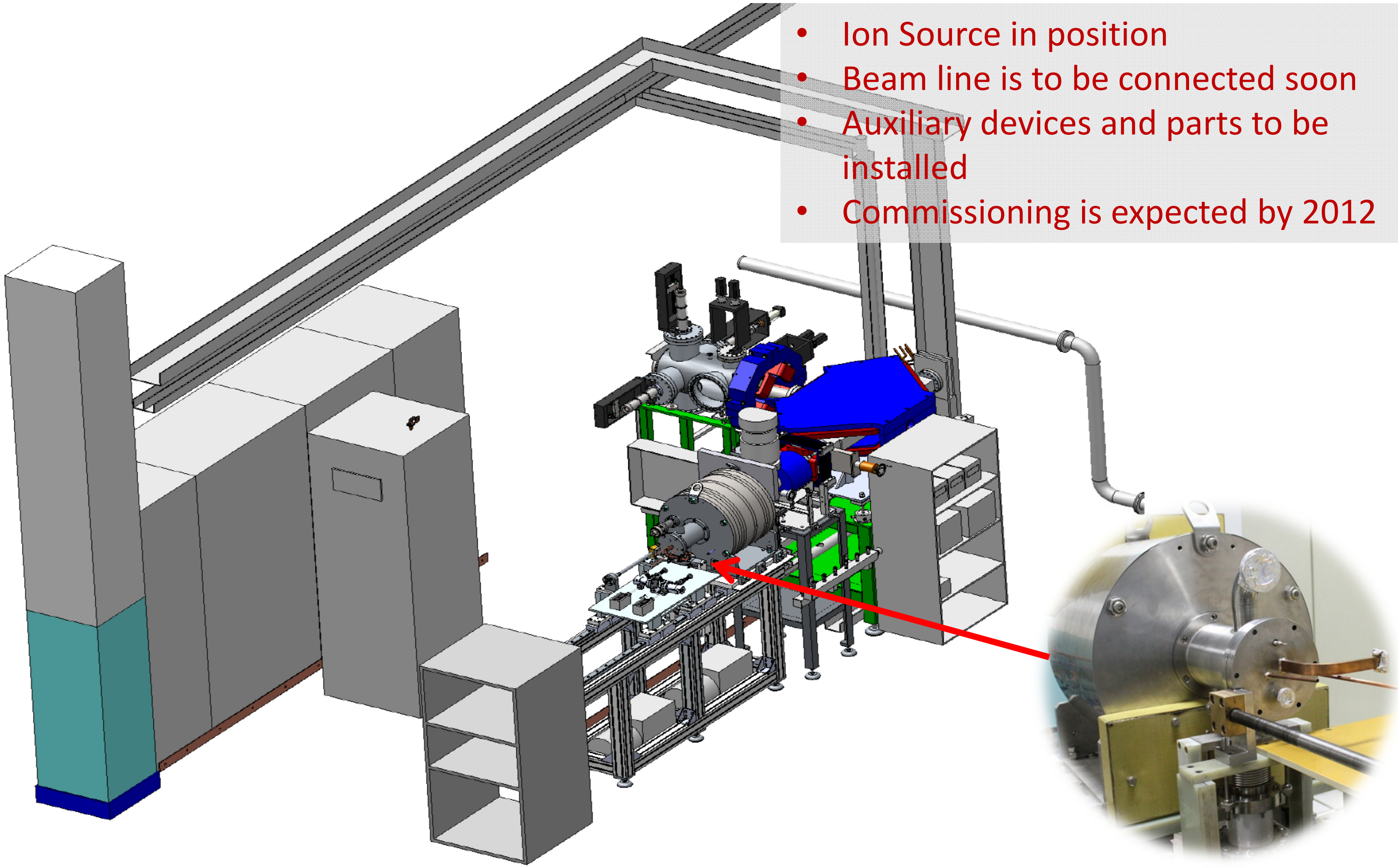


Final Parameters

	Designed	Final specs.
Axial Field (T)	1.8-0.40-0.94	1.8-0.40-0.85
Field on Inner Chamber Wall -B_r (T)	1.14	1.0
Mirror Length (mm)	170	172
ECR Length (mm)	64	~70
Operation Frequency (GHz)	13.75-14.5	13.75-14.5
Chamber ID (mm)	50	47.5
Effective Chamber Volume (L)	0.33	0.30
RF Feeding	WR62 Rectangular	WR62 Rectangular
Plasma chamber cooling	Water Cooled	Water Cooled
Max. Designed Operation HV (kV)	25	25
Max. Designed μW Power (kW)	0.70	0.70
External Dimension (mm)	Ø450×380	Ø455×382
NdFeB Weight (kg)	157	157
NdFeB Type	N50M & N42SH	N50M & N42SH

Test Bench

- Ion Source in position
- Beam line is to be connected soon
- Auxiliary devices and parts to be installed
- Commissioning is expected by 2012



But…

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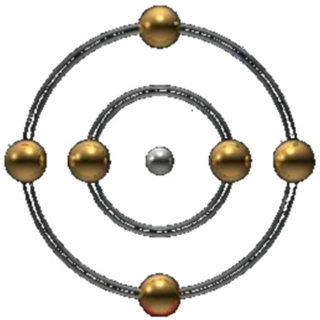

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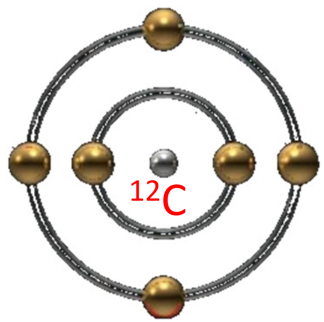
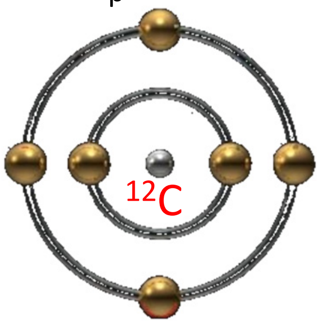


But…

C^{5+}: I_p = ~400 eV



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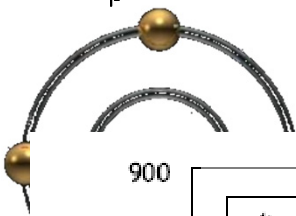

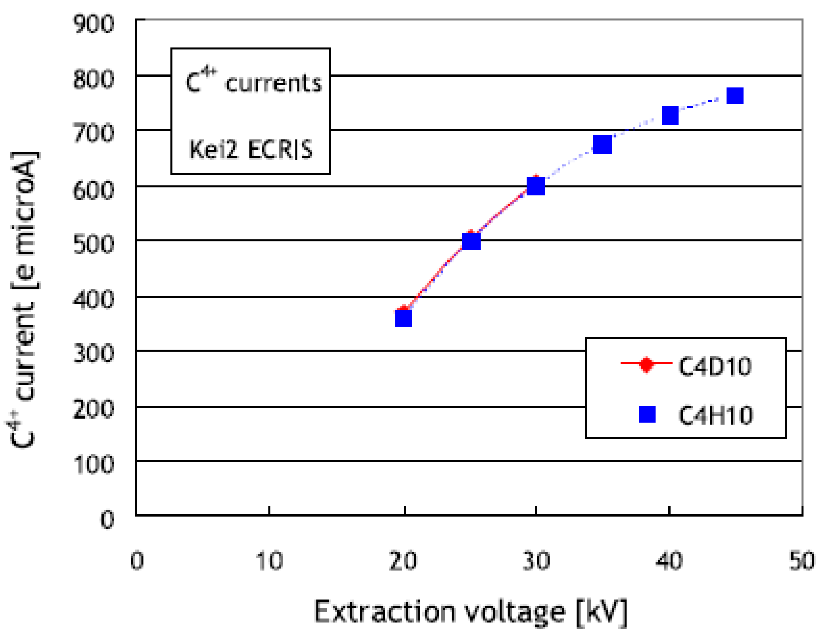

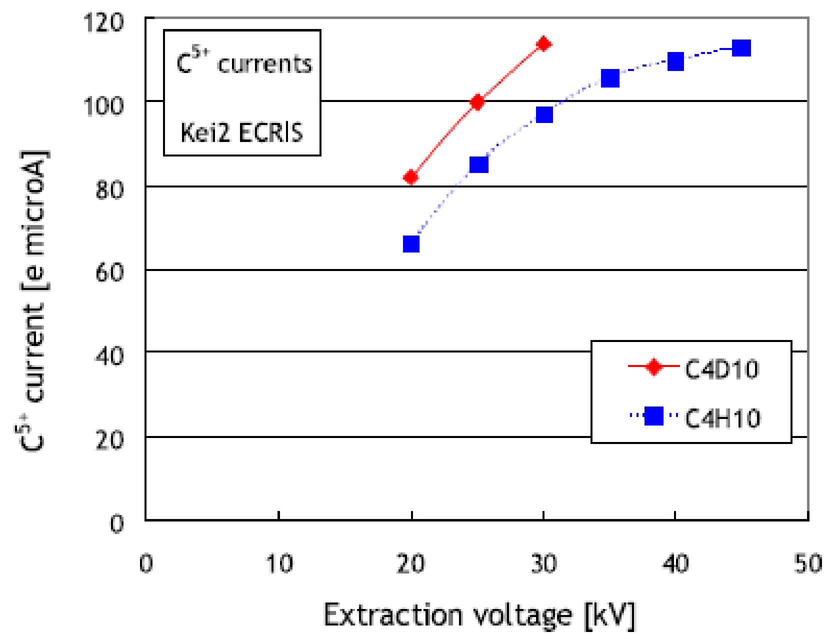

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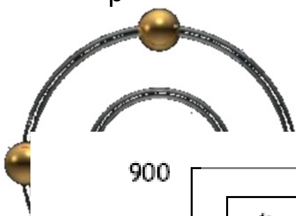

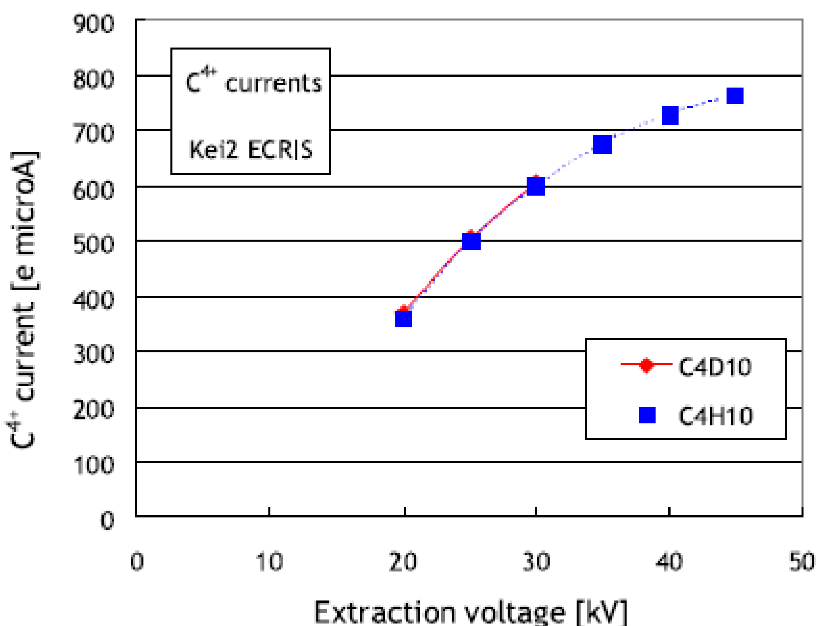

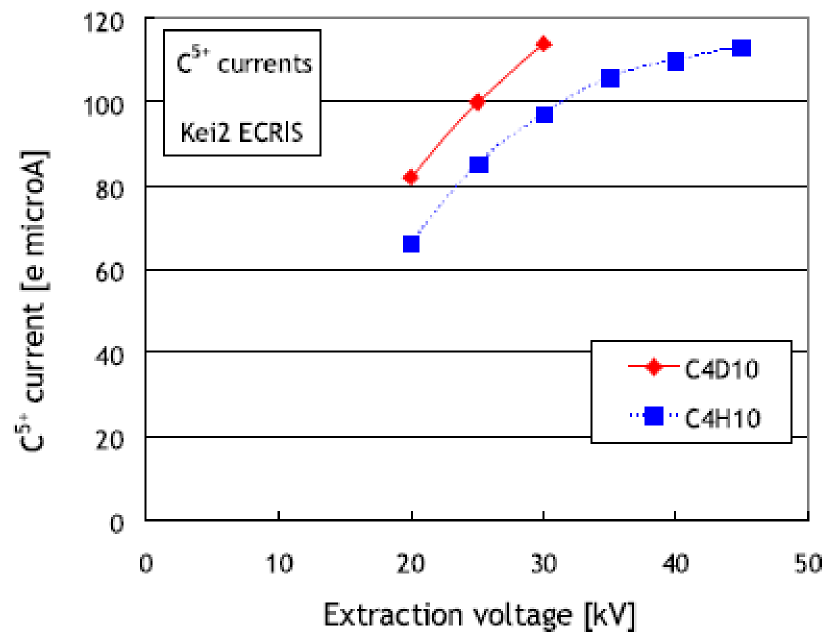

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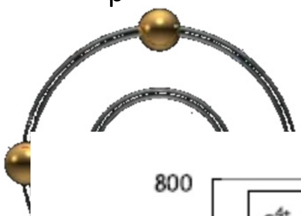

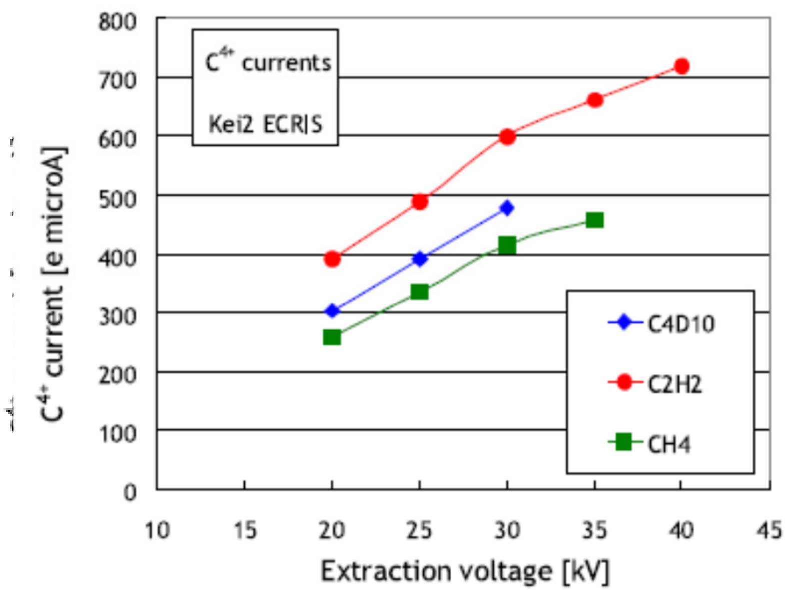

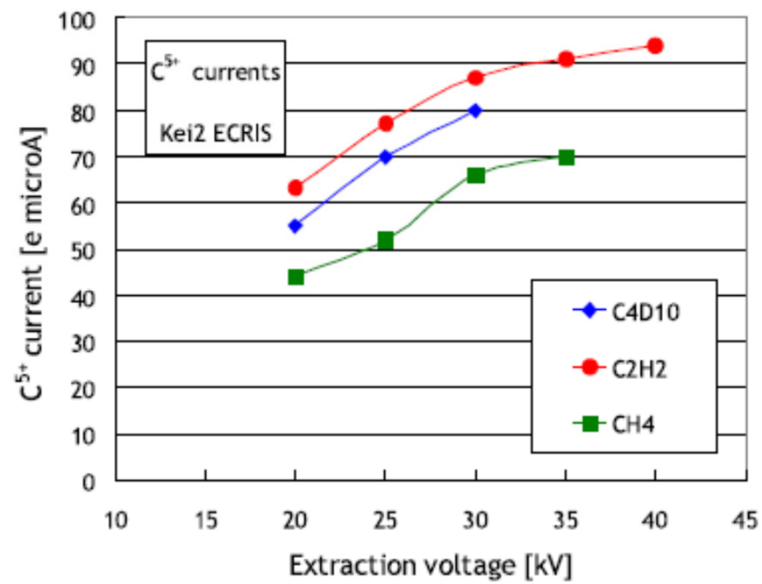

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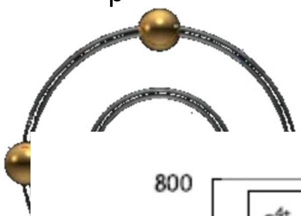
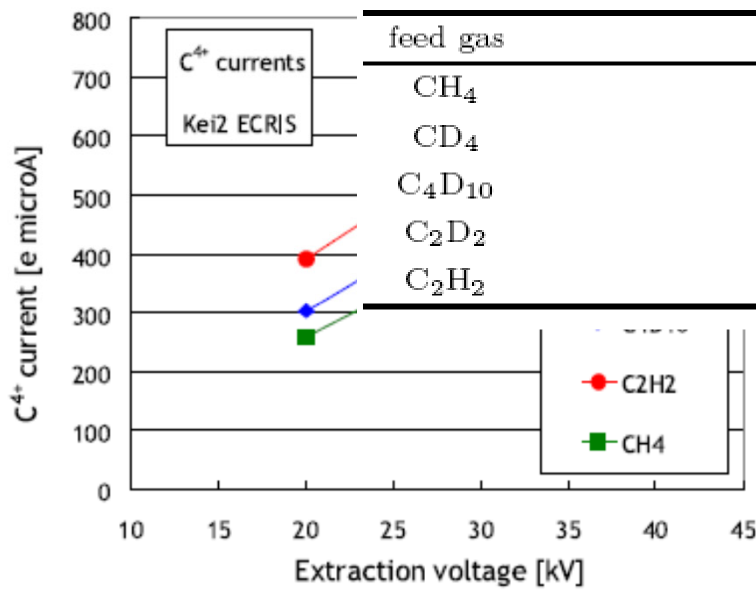
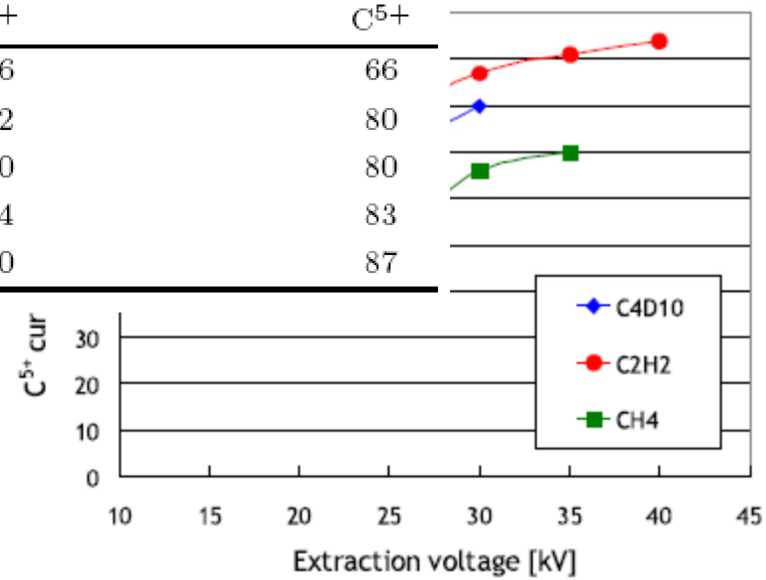


Table 1. Best C^{4+} and C^{5+} currents (eμA) @30kV (NB with not well operating biased disk).

feed gas	C^{4+}	C^{5+}
CH_4	416	66
CD_4	452	80
C_4D_{10}	480	80
C_2D_2	544	83
C_2H_2	600	87





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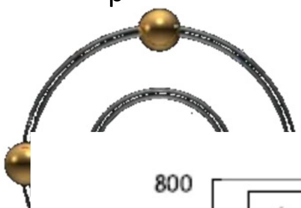

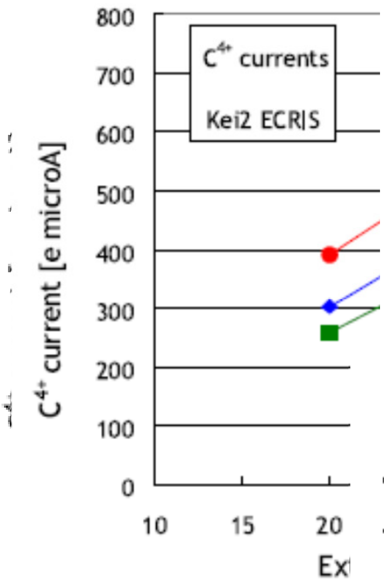

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feed gas	C^{4+}	C^{5+}
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C_4H_{10}	600	97
CD_4	555	110
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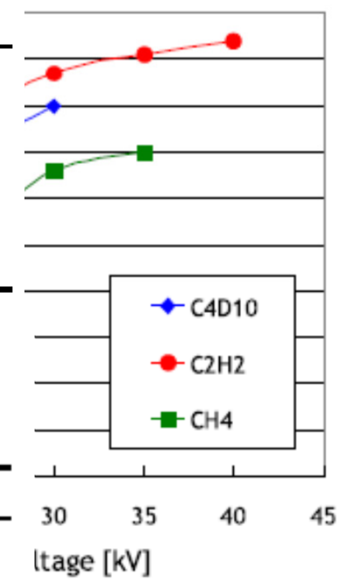

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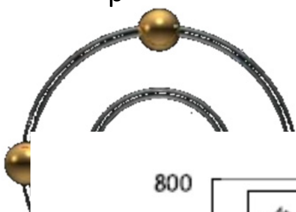

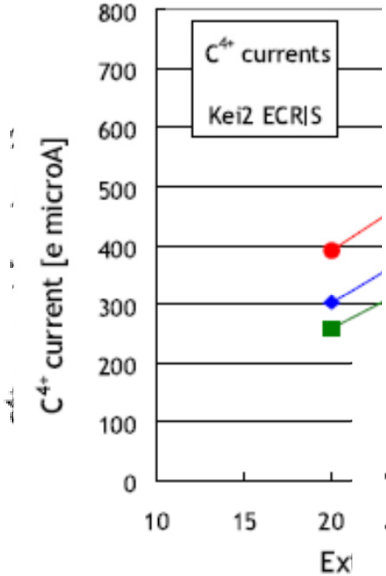

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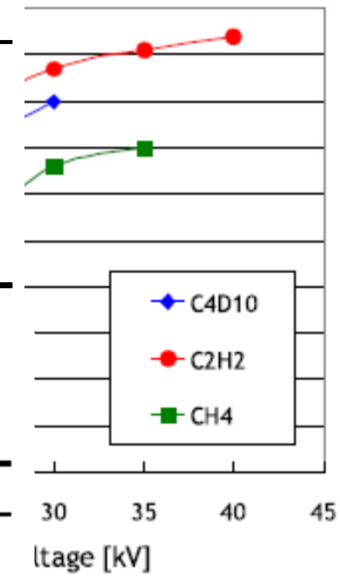

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Isotopic effects are obvious for higher charge state C^{5+} ion, but to produce intense C^{5+} beam >100 eμA is still challengeable (LAPECR2: 300W from TWT→190 euA C^{5+} with C_2H_2)

Thanks !!