Intense Beam Ion Sources Development at IMP

L Sun

Institute of Modern Physics, CAS

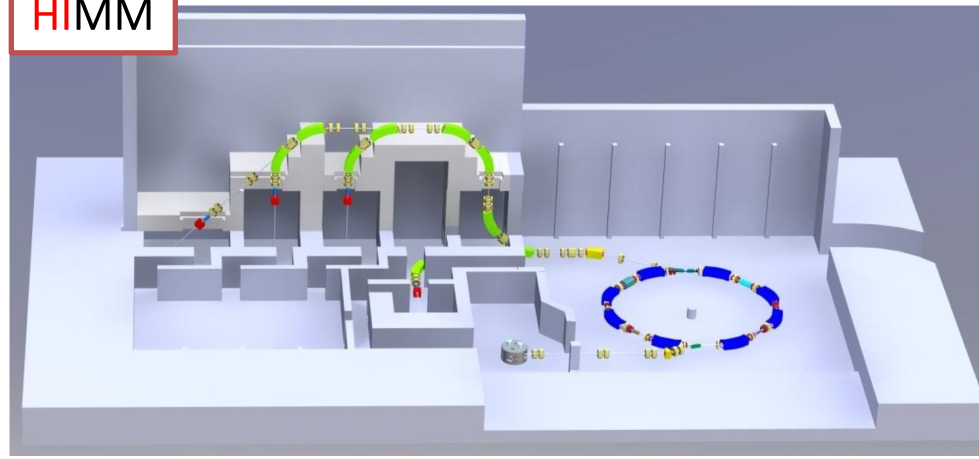
Outline

- Needs for high intensity ion beams at IMP
- Heavy ion ECR sources
    - Room temperature ECRISs
    - Permanent magnet ECRISs
    - SC-ECRIS
- Intense proton beam sources
- Ion sources for next generation heavy ion accelerator
    - Next generation ECRIS
    - Laser ion source

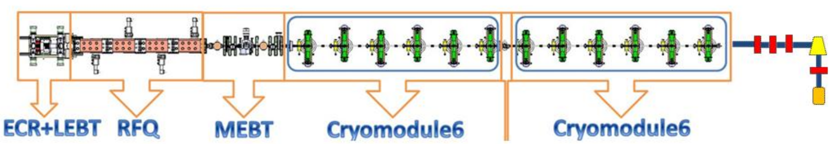
Needs of intense ion beams

HIRFL

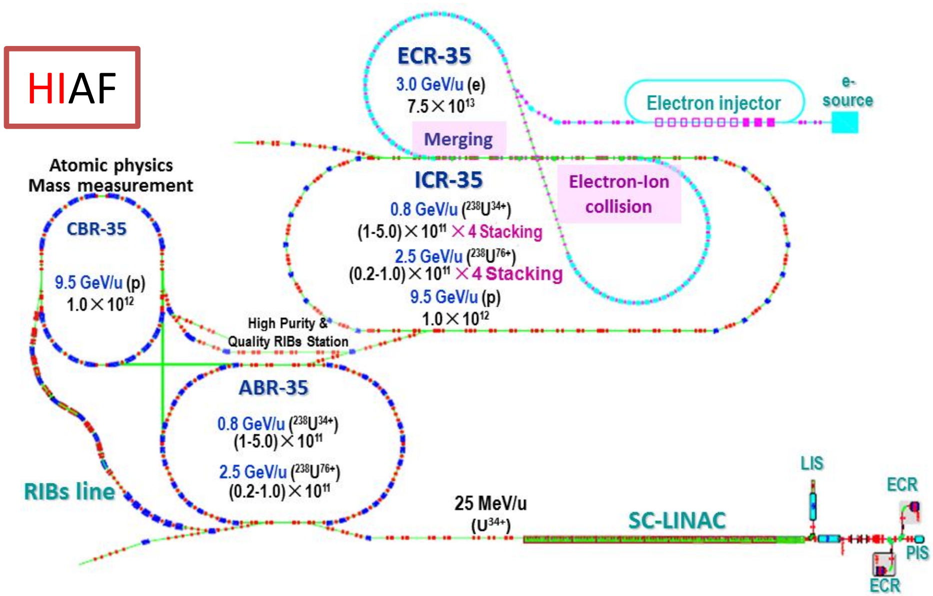
HIMM



CIADS



HIAF

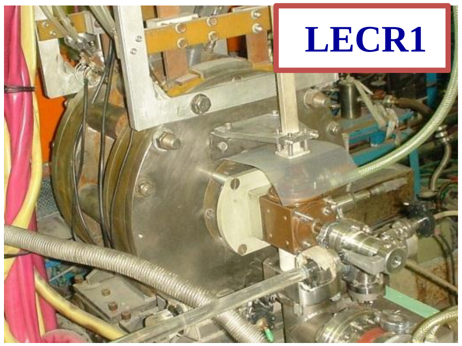


Outline

- Needs for high intensity ion beams at IMP
- Heavy ion ECR sources
  - Room temperature ECRISs
  - Permanent magnet ECRISs
  - SC-ECRIS
- Intense proton beam sources
- Ion sources for next generation heavy ion accelerator
  - Next generation ECRIS
  - Laser ion source

RT-ECRIS

Ar^{9+} 320μA, Ar^{11+}80μA
Kr^{15+}100μA, Kr^{17+}70 μA



IMP 10 GHz LECR1
Bz 1.0T, Br 0.7T
1990-1995-1996

O^{7+} 140μA, Ar^{11+} 185μA
Kr^{19+}50μA, Xe^{26+}50 μA
Ca^{11+}130 μA, Fe^{13+}65 μA
Zn^{13+}50 μA, Pb^{30+} 8 μA

IMP 14 GHz
LECR2
Bz 1.5T, Br 1.0T
1997-1999

O^{7+} 240μA, Ar^{11+} 325μA
Ar^{8+} 1.0 mA, Xe^{26+} 95 μA
Fe^{13+} 141 μA, Ar^{17+} 0.4 uA
Ar^{18+} .. Pb^{40+} 0.2 μA,

IMP 14-18 GHz
LECR3
Bz 1.7T, Br 1.0T
1999-2003

Updated to LECR2M

Preliminarily:
1.3emA O^{6+}, 210eμA
Other beams:
F, Ne, S, Ar, Xe,
Ca, Fe, Ni, Pb etc.

2005-2006

PM-ECRIS

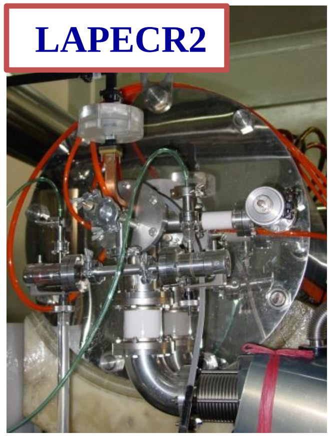
LAPECR1

>30keV/q

For HIRFL low charge state ion beam injection

Ar^{1+-8+} , Xe^{1+-10+} and other low charge state ion beams

LAPECR2

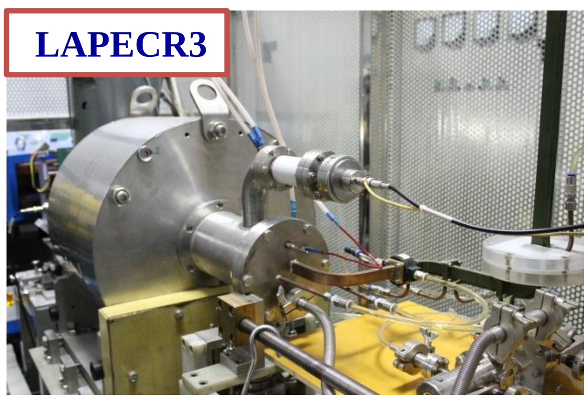


320kV HV platform

For multiple research activities

Ar^{4+-16+} , Xe^{10-30+} and metallic ion beams

LAPECR3



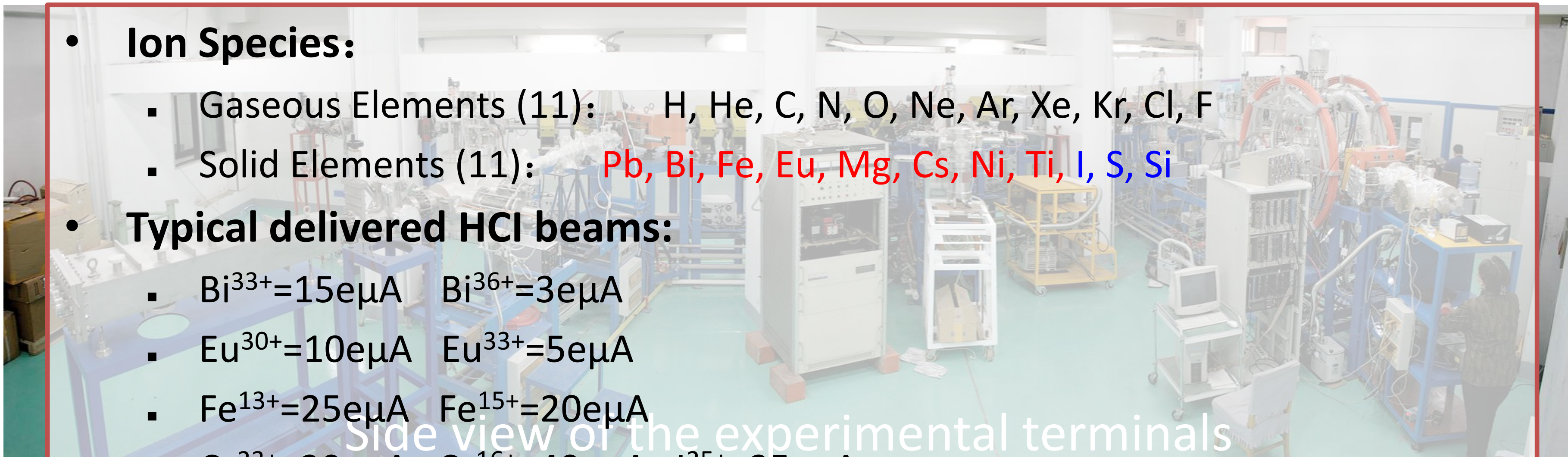
22 keV/q C^{5+} for Hadron Cancer Therapy (HIMM)

> 100 euA C^{5+} beam for the facility

LAPECR2 with 320 kV HV Platform

Side view of the experimental terminals

LAPECR2 with 320 kV HV Platform


Side view of the experimental terminals

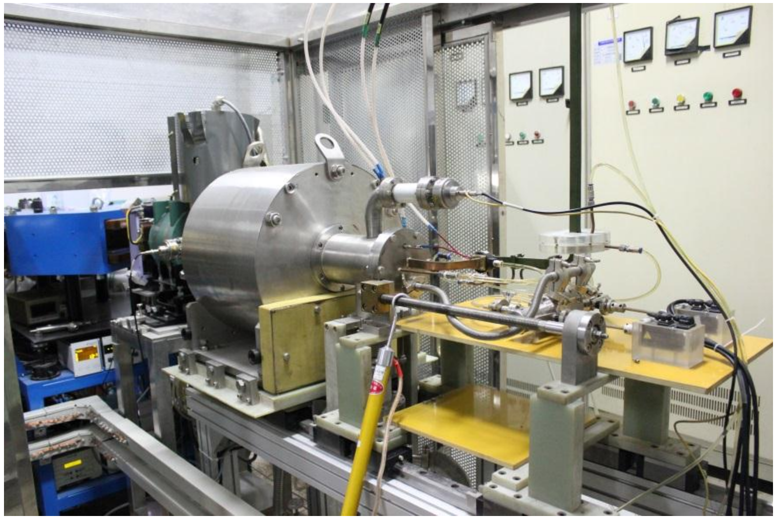
- **Ion Species:**
  - Gaseous Elements (11): H, He, C, N, O, Ne, Ar, Xe, Kr, Cl, F
  - Solid Elements (11): Pb, Bi, Fe, Eu, Mg, Cs, Ni, Ti, I, S, Si
- **Typical delivered HCI beams:**
  - Bi^{33+}=15eμA Bi^{36+}=3eμA
  - Eu^{30+}=10eμA Eu^{33+}=5eμA
  - Fe^{13+}=25eμA Fe^{15+}=20eμA
  - Cs^{23+}=20eμA Cs^{16+}=40eμA I^{25+}=35eμA
  - Ar^{16+}=2eμA Xe^{30+} =11eμA Kr^{23+}=15eμA
  - Mg^{7+}=35eμA Ni^{17+}=12eμA Ti^{11+}=20eμA Si^{9+}=12eμA
- **Total operation time (2007—now):**
  - Experiment beam time: **31,300** hours
  - Service time: 3,000 hour
  - New beam study: 3,000 hours

> 37,000 hours' operation time till now

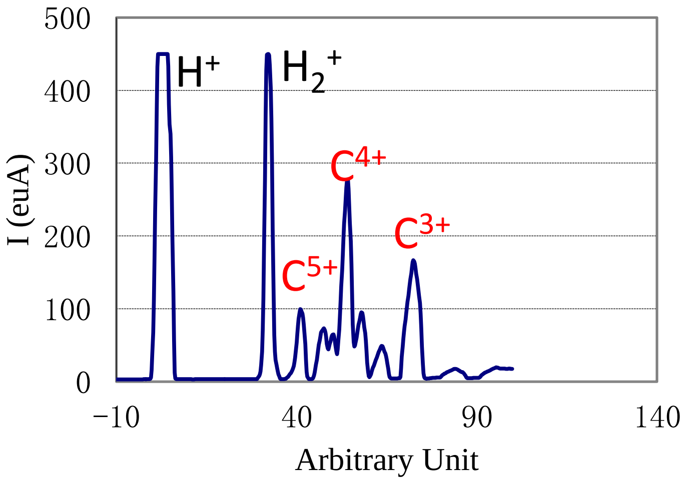
LAPECR3

Ion Source Parameters

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

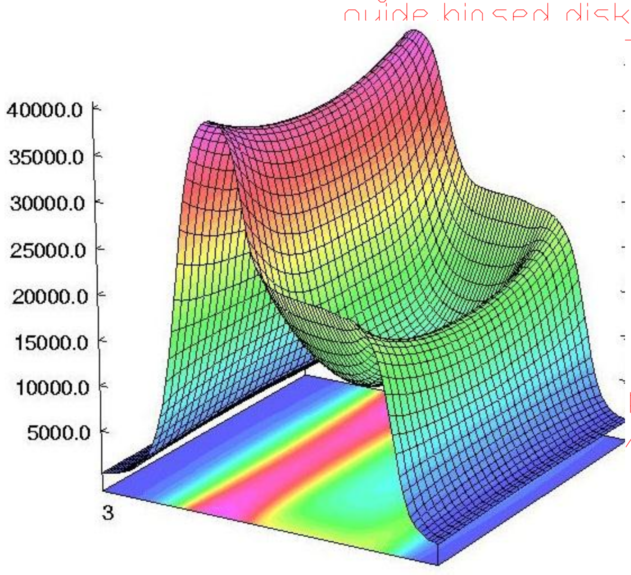


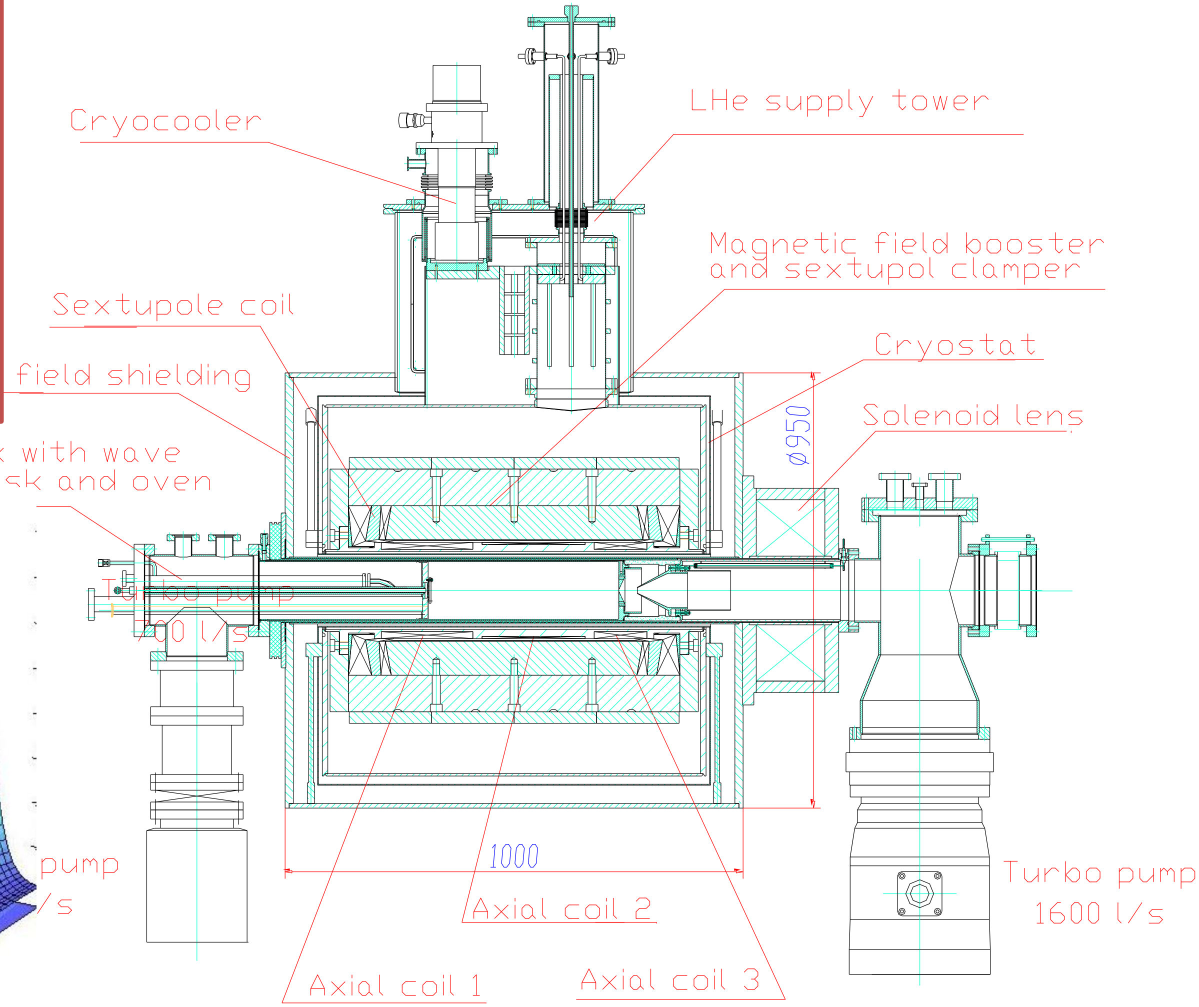
100 euA C^{5+} production



SECRAL

Fully superconducting magnet
Axial field: 3.6, 2.2T
Sextupole at the wall: 2.0 T
RF frequency: 18-28 GHz
Plasma chamber: Ø126 mm
Warm bore: Ø140 mm
Extraction voltage: 25 kV
Fabrication: 2002-2005

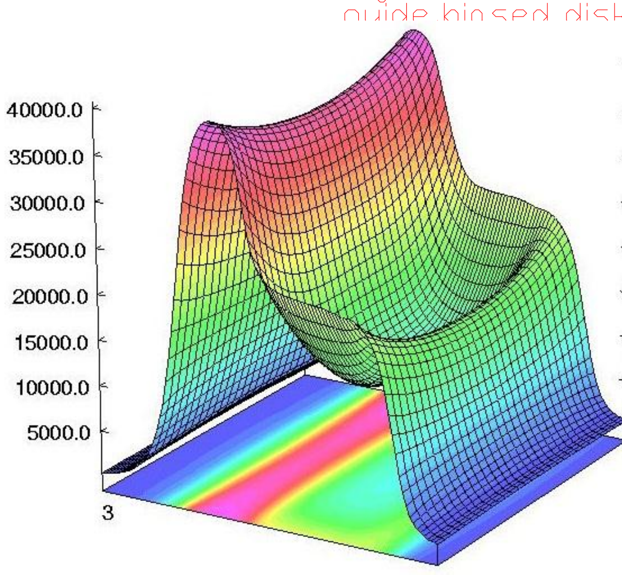


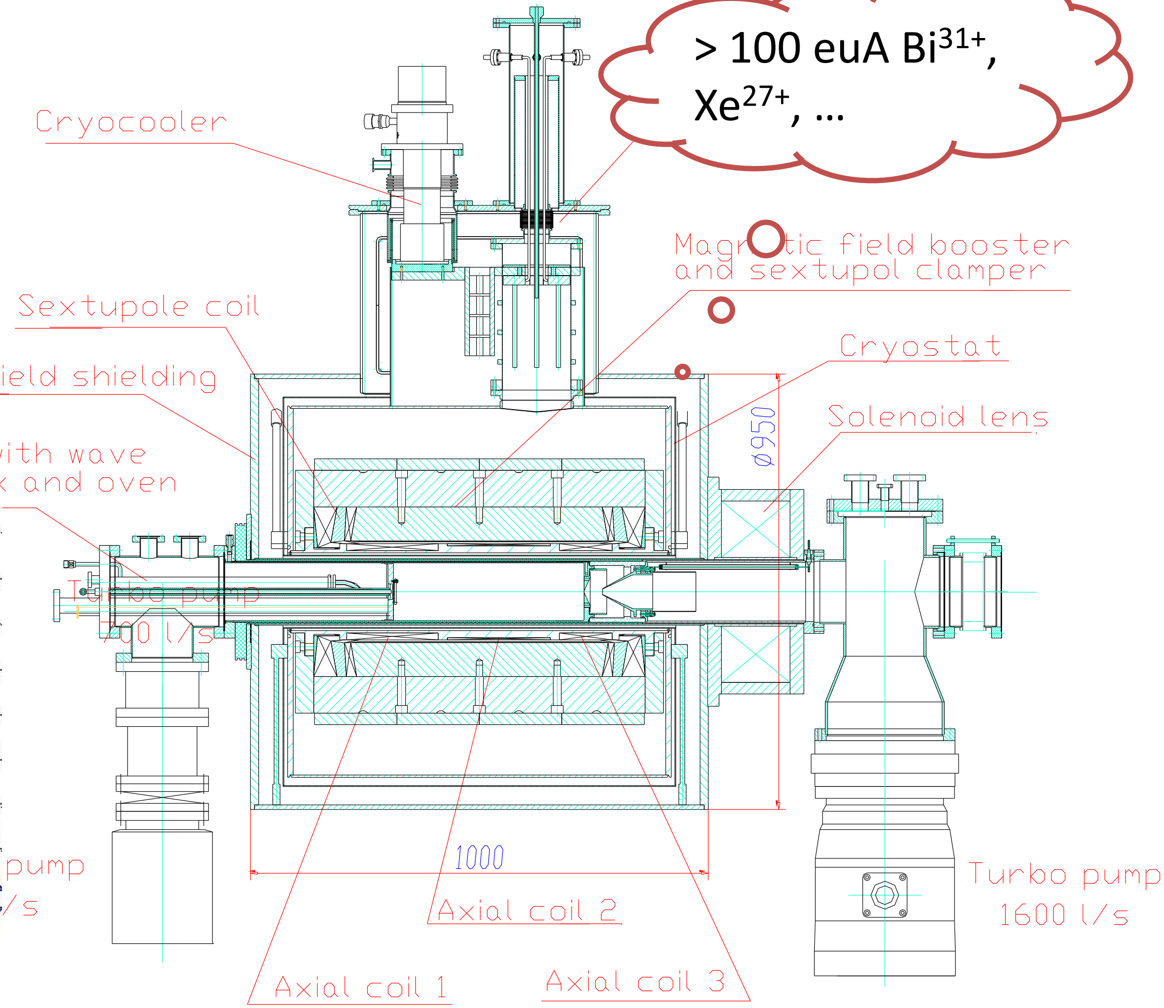


SECRAL

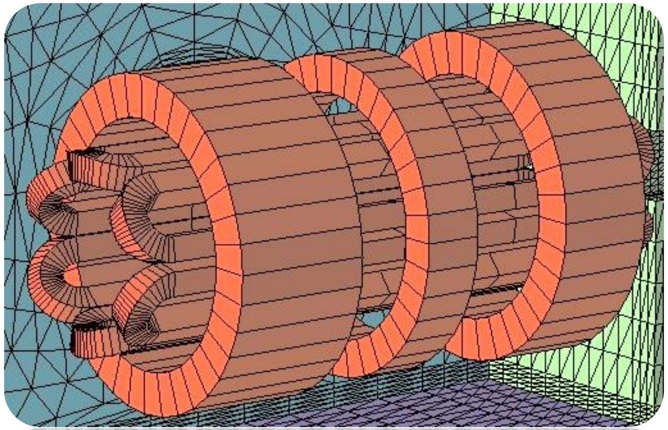
Fully superconducting magnet
Axial field: 3.6, 2.2T
Sextupole at the wall: 2.0 T
RF frequency: 18-28 GHz
Plasma chamber: Ø126 mm
Warm bore: Ø140 mm
Extraction voltage: 25 kV
Fabrication: 2002-2005

> 100 euA Bi^{31+}, Xe^{27+}, …

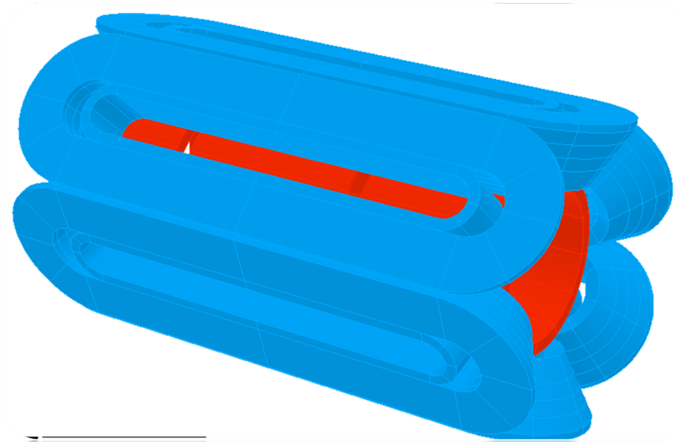




Unique Design of SECRAL

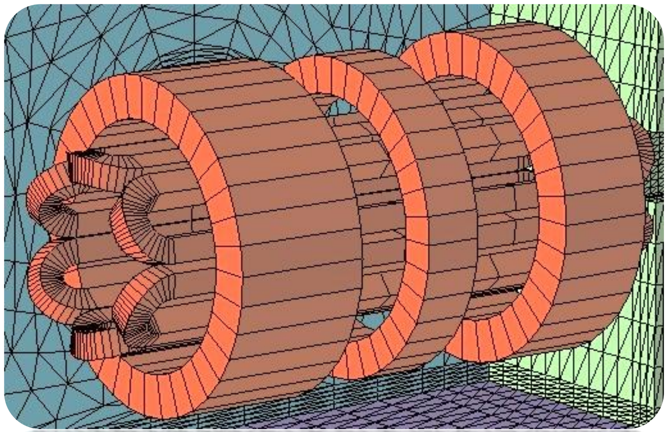


Examples:
SERSE (INFN/Catania)
VENUS (LBNL)
SuSI (MSU)
SC-ECRIS (RIKEN)



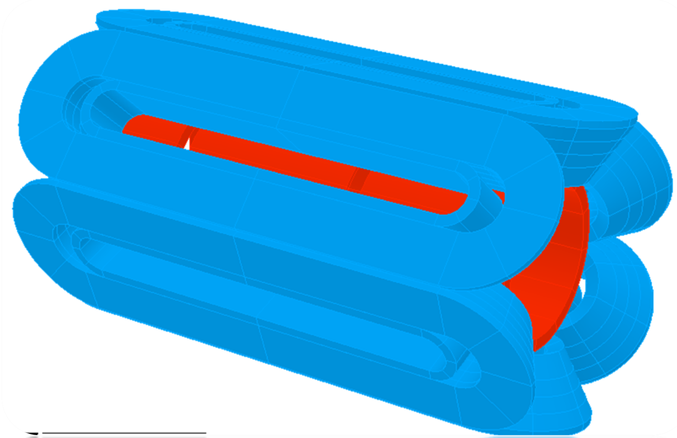
Examples:
SECRAL (IMP/Lanzhou)
SECRAL II (IMP/Lanzhou)

Unique Design of SECRAL



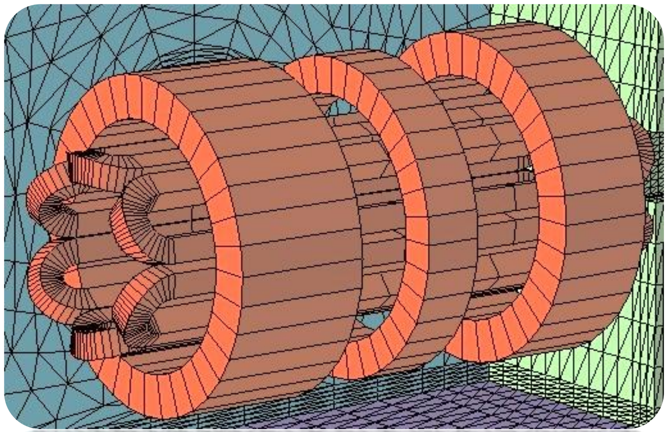
Examples:
SERSE (INFN/Catania)
VENUS (LBNL)
SuSI (MSU)
SC-ECRIS (RIKEN)

Pros:
- Higher Sextupole Field
- Larger plasma chamber



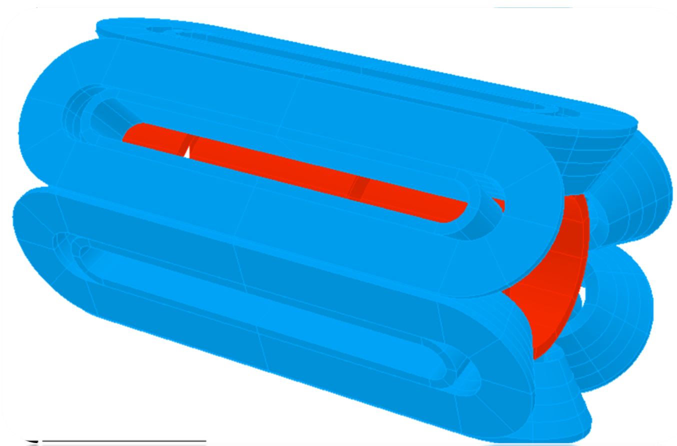
Examples:
SECRAL (IMP/Lanzhou)
SECRAL II (IMP/Lanzhou)

Unique Design of SECRAL



Examples:
SERSE (INFN/Catania)
VENUS (LBNL)
SuSI (MSU)
SC-ECRIS (RIKEN)

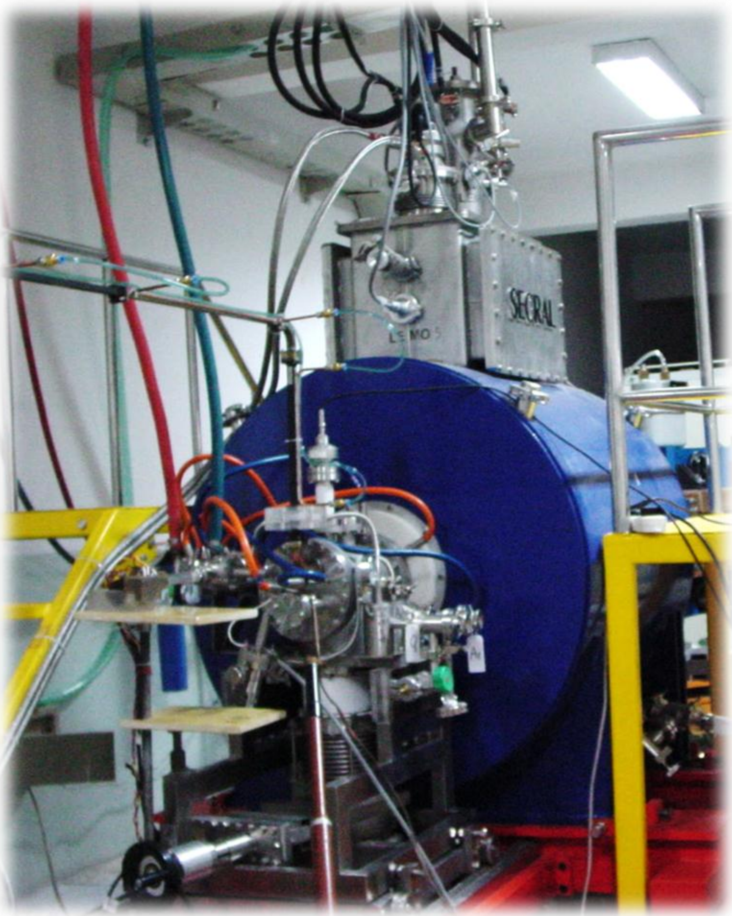
Pros:
- Higher Sextupole Field
- Larger plasma chamber



Examples:
SECRAL (IMP/Lanzhou)
SECRAL II (IMP/Lanzhou)

Pros:
- More compact magnet body
- Easier handling of magnet clamping
- Lower source cost

SECRAL Performance



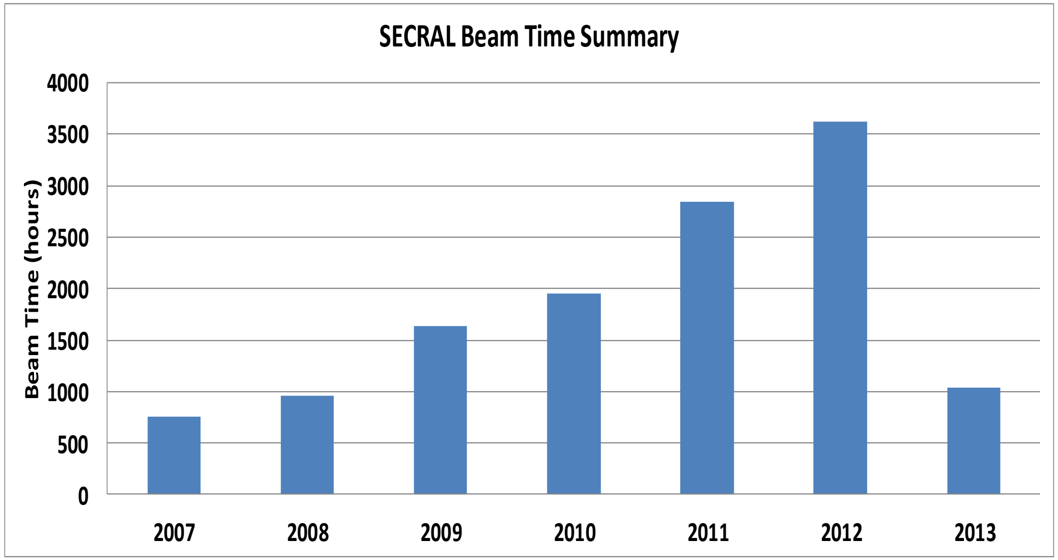
Typical specifications for source test

Frequency	**18 GHz/24 GHz**
Max. RF Power	3.2 kW/5.0 kW
Plasma Chamber	SS/Al
Max. HV	26 kV

Typical performance from source test

	SECRAL	**VENUS**
Xe^{27+}	455	411
Xe^{30+}	236	211
Xe^{35+}	64	38
Xe^{42+}	2	1
Bi^{31+}	395	310
Bi^{50+}	4.3	5.3
U^{33+}	202/SP	450/HiTO

SECRAL Operation Status



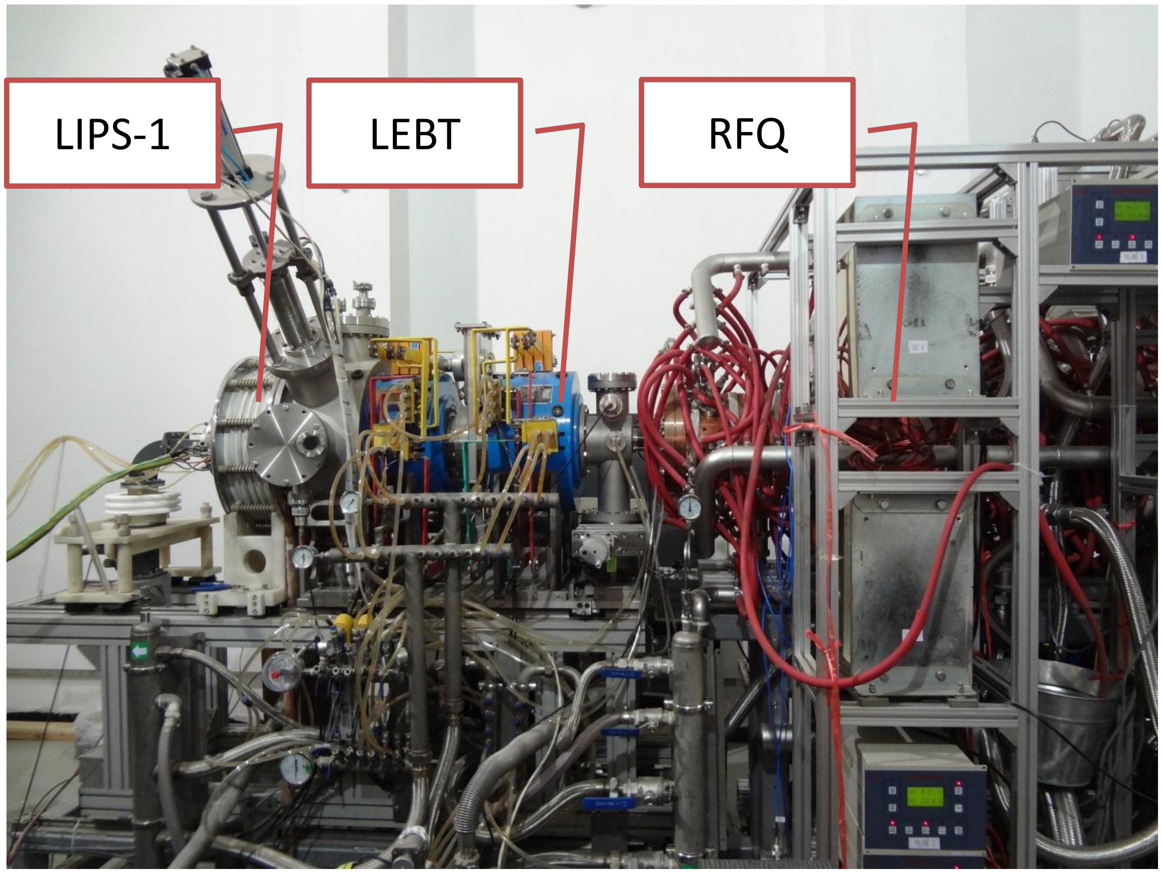
Up to 30th April, 2013

- **Operation frequency 24 GHz/18 GHz**
- **Up to now the total beam time from SECRAL since May 2007: >13,000 hours**
- **Mostly for high charge state, very heavy ion beams, such as Xe^{27+}, Sn^{27+}, Bi^{36+}, U^{32+}**

Outline

- Needs for high intensity ion beams at IMP
- Heavy ion ECR sources
  - Room temperature ECRISs
  - Permanent magnet ECRISs
  - SC-ECRIS
- Intense proton beam sources
- Ion sources for next generation heavy ion accelerator
  - Next generation ECRIS
  - Laser ion source

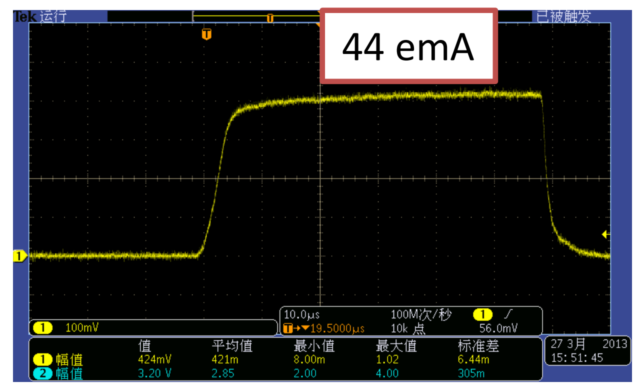
LIPS-1 for CHPS



Courtesy of X. L. Guan, et al from Tsinghua University

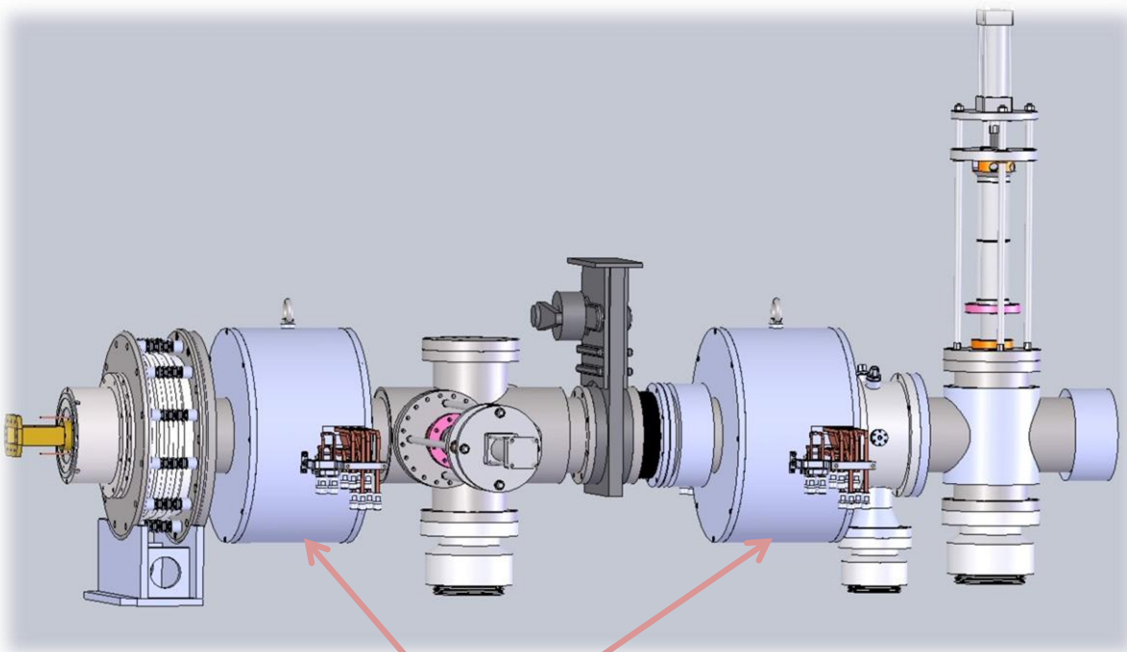
Required Parameters

E	**50 keV**
Current	≥ 60 emA
Repetition rate	50 Hz
Pulse width	500 μs
Rise time	80 μs
Fall time	40 μs
Reliability	> 120 hrs

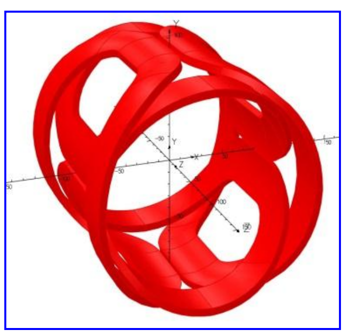


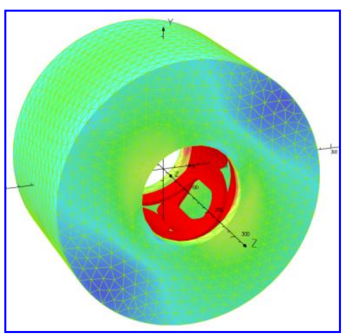
RFQ output beam bunch (from ACCT)

LIPS-1 for C-ADS

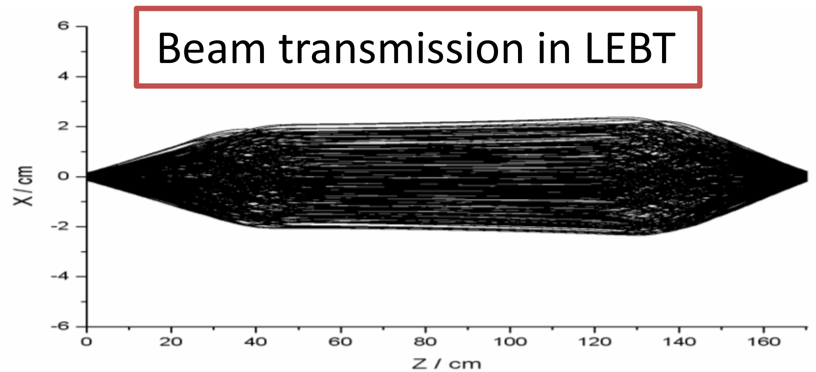


Ion type	proton
Energy	35 keV
Beam current	10 mA
Operation mode	CW
ΔE/E	<0.1%
Beam stability	<±1%
α	2.41
β	7.72 (cm/rad)
ε (n.rms)	<0.2 (π.mm.mrad)

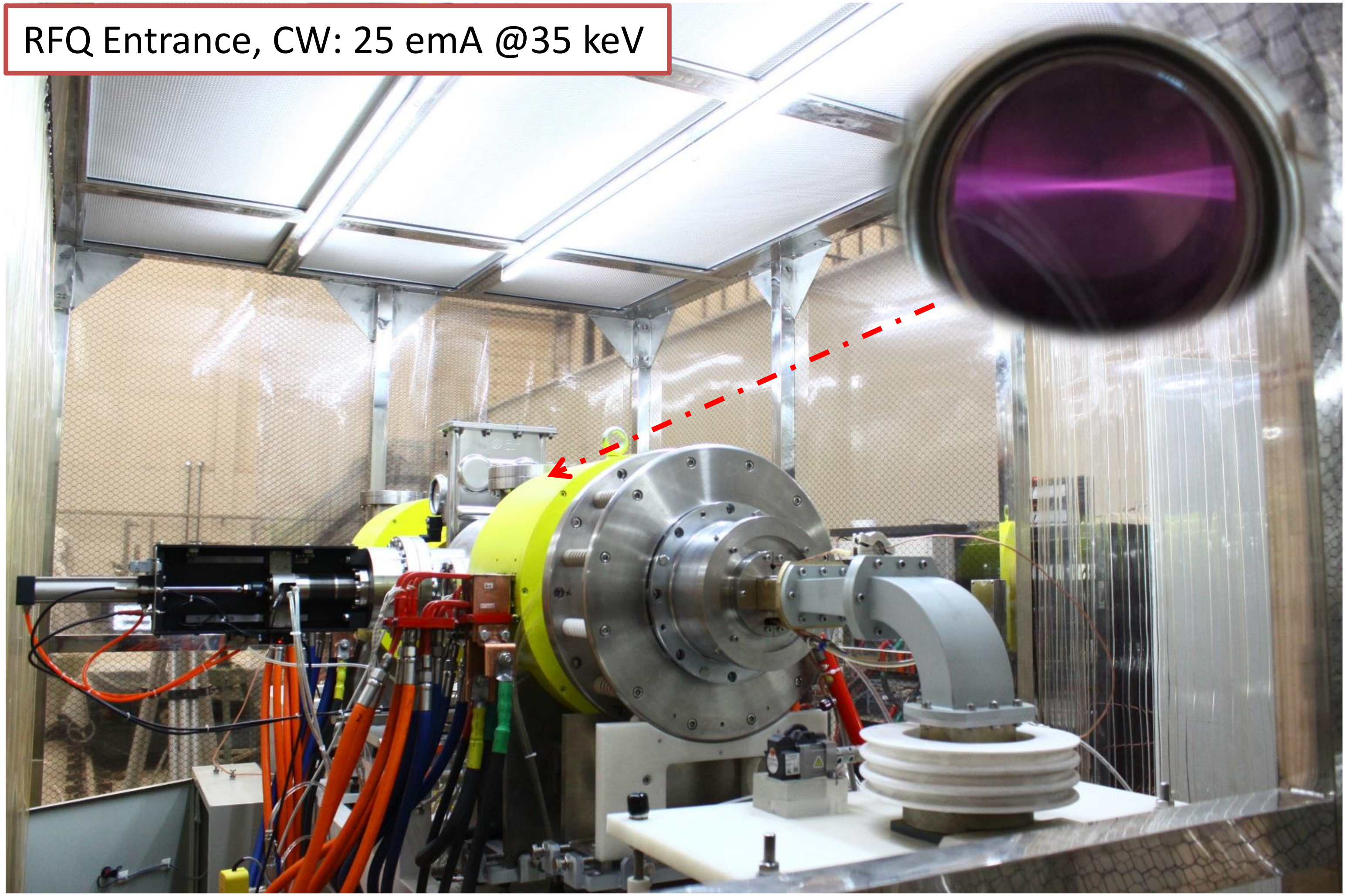




Beam transmission in LEBT



LIPS-1 on Test Bench

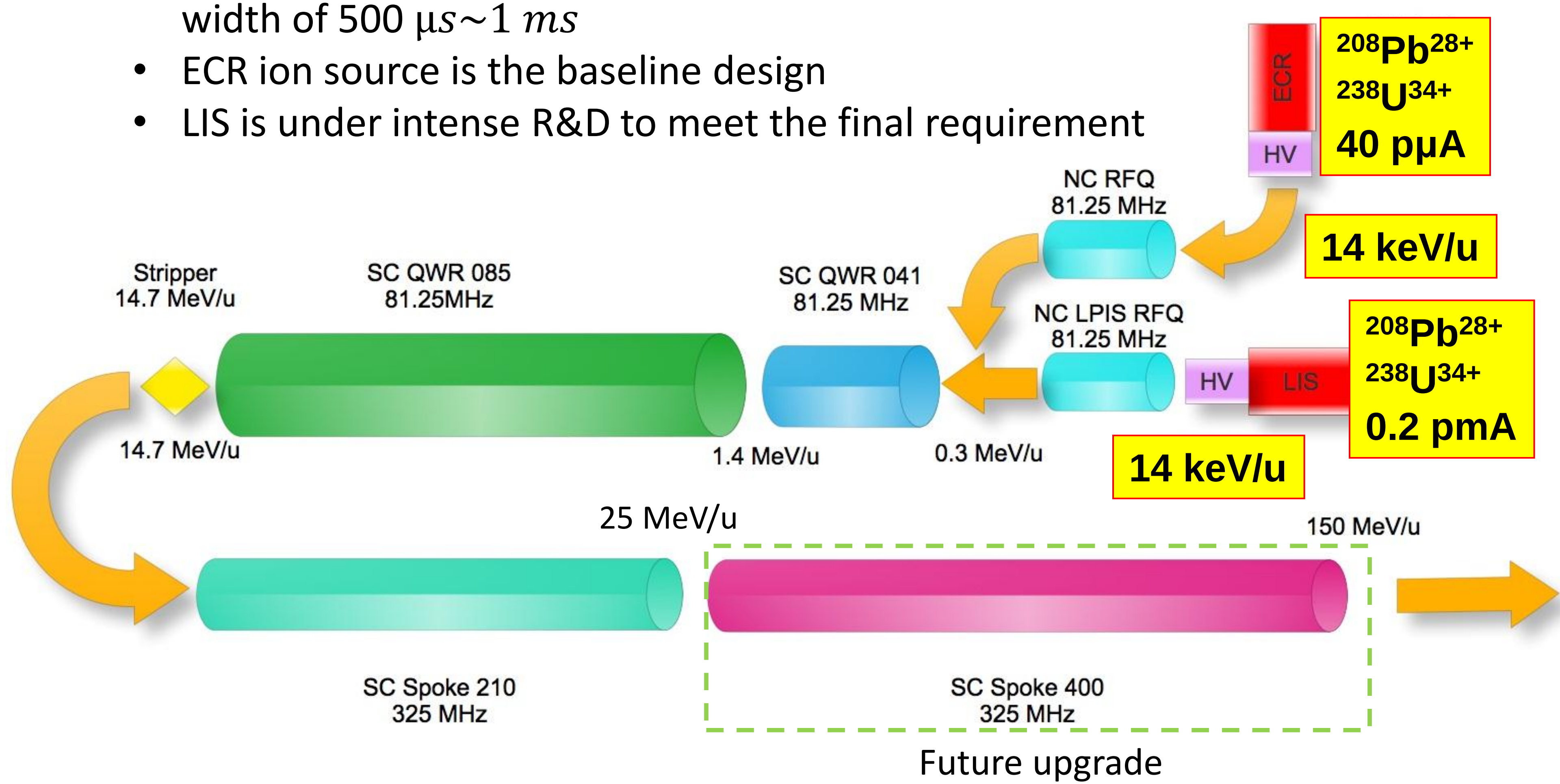


Outline

- Needs for high intensity ion beams at IMP
- Heavy ion ECR sources
  - Room temperature ECRISs
  - Permanent magnet ECRISs
  - SC-ECRIS
- Intense proton beam sources
- Ion sources for next generation heavy ion accelerator
  - Next generation ECRIS
  - Laser ion source

HIAF Linac Injector

- Pulsed beam with repetition rate of 2 Hz and pulse width of 500 $\mu s \sim 1\ ms$
- ECR ion source is the baseline design
- LIS is under intense R&D to meet the final requirement



Next G. ECRIS

$$\omega_{rf} = eB/m_e \quad n_e \sim \omega_{rf}^2$$

$$\sum n_q = n_e$$

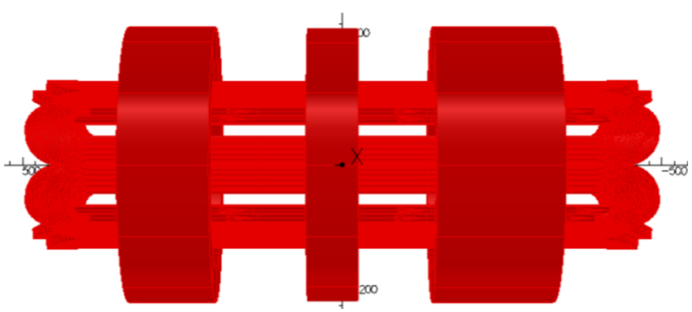
$$I_q \propto n_q \cdot V_{plasma}$$

> 1 emA U^{34+}

	18GHz	24 GHz	28 GHz	42 GHz	56GHz
B_{inj} (T)	2.6	3.4	4	6	8
B_{ext} (T)	1.4	1.8	2.2	3.3	4.4
B_{min} (T)	0.5	0.7	0.8	1.2	1.6
B_{rad} (T)	1.3	1.7	2	3	4

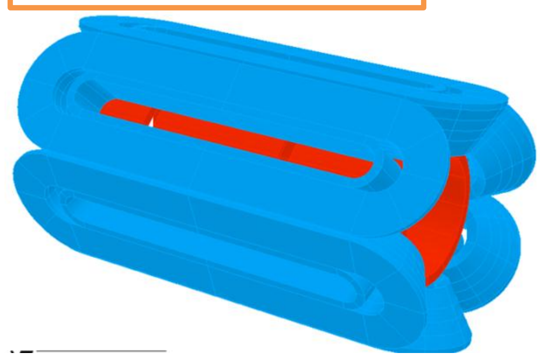
High magnetic field with reasonably sized plasma chamber

Conventional Structure



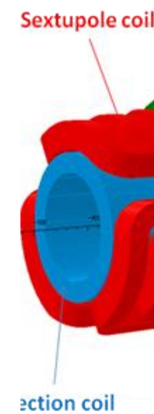
Fully Nb_3Sn

Reversed Structure



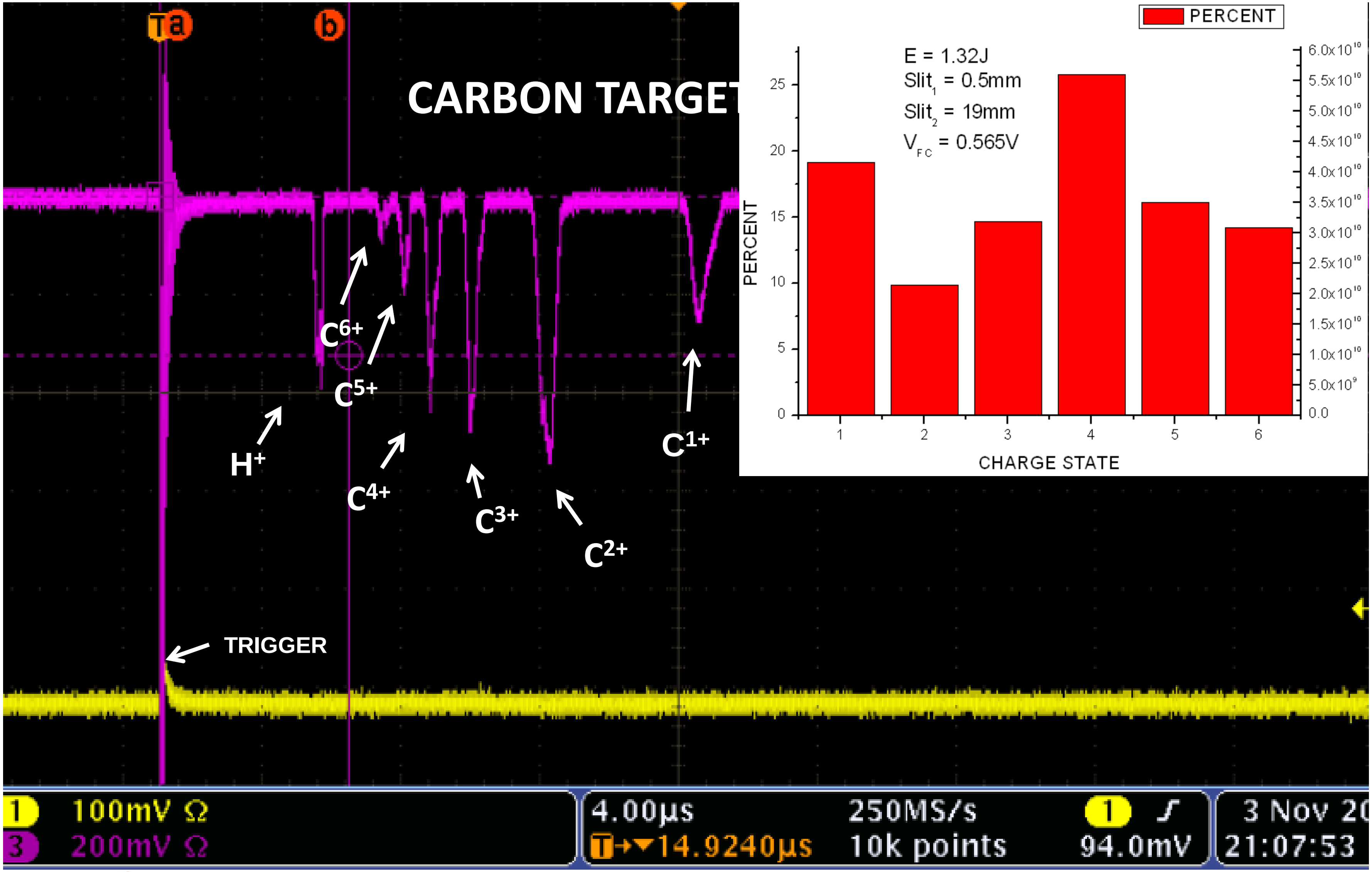
Fully Nb_3Sn

Mixed structure

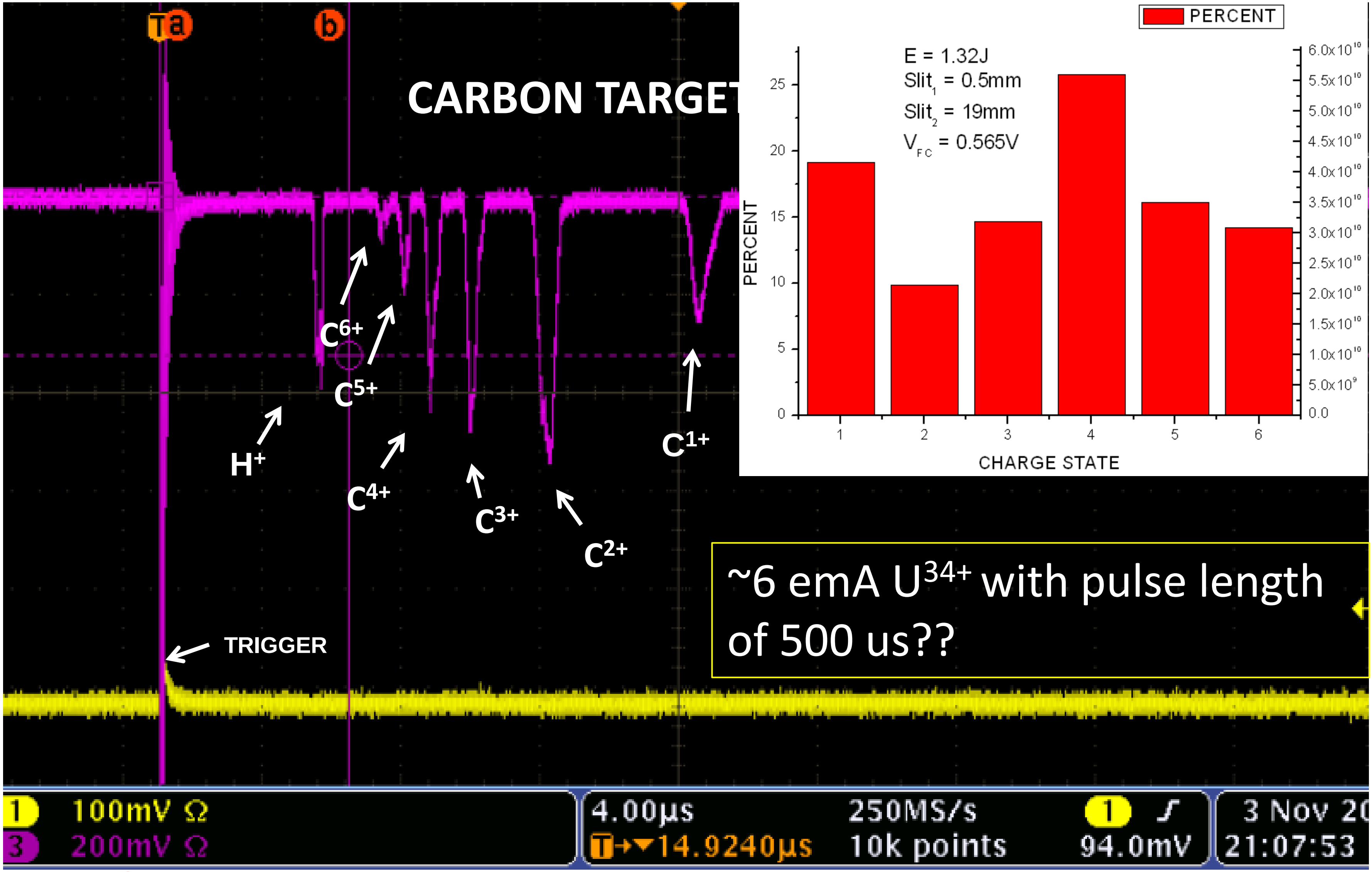


NbTi + Nb_3Sn

Powerful LIS



Powerful LIS



~6 emA U^{34+} with pulse length of 500 us??

Challenges

- Choice of high pulsed energy Laser machine for the ion source
  - CO_2
  - Nd: glass
  - Nd: YAG
  - …
- Production of highly charged ion beams from very heavy metal materials
- Matching the extracted beam to downstream RFQ
  - DPIS
  - LEBT
- Beam quality control
  - Beam emittance
  - Stable operation time
  - Reliability and stability
  - Energy spread

Summary

- Series of reliable intense beam high charge state ion sources have been successfully built and put into application at IMP.
- Proton beam sources are under development to meet the needs of C-ADS project.
- To have the beam intensities for future advanced heavy ion accelerators, Mission impossible? →very challengeable!!

Thanks !!