How can an ECRIS meet the requirements of next generation heavy ion accelerator facilities

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Outline

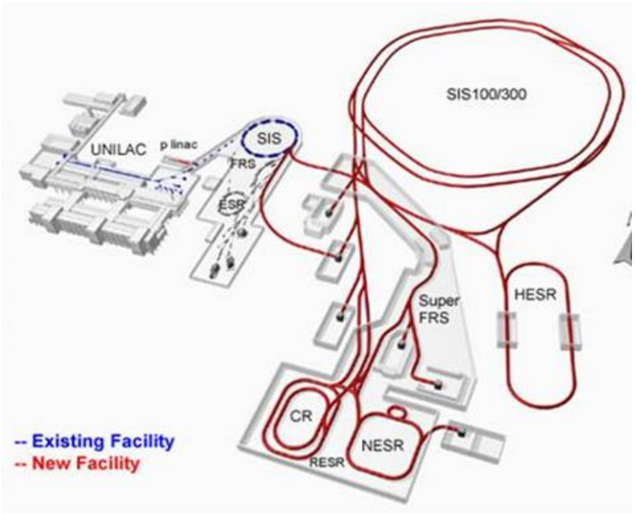
- Next generation heavy ion accelerator facilities

- Impact of highly charged ion source on the next generation heavy ion accelerator such as HIAF

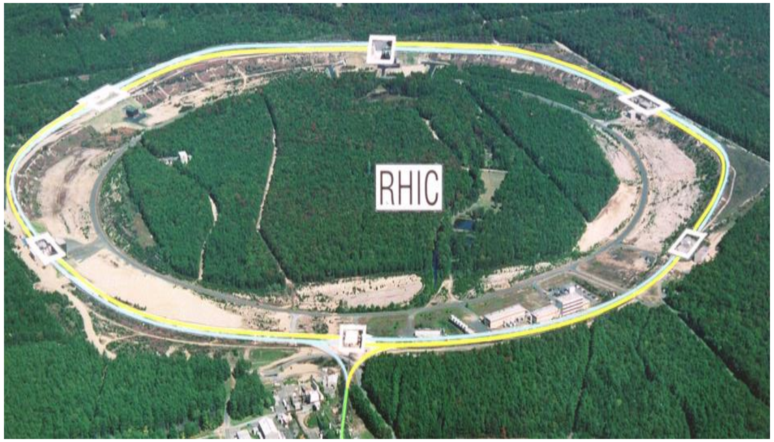
- ECRIS Challenges to meet the next generation heavy ion accelerator such as HIAF

- Summary

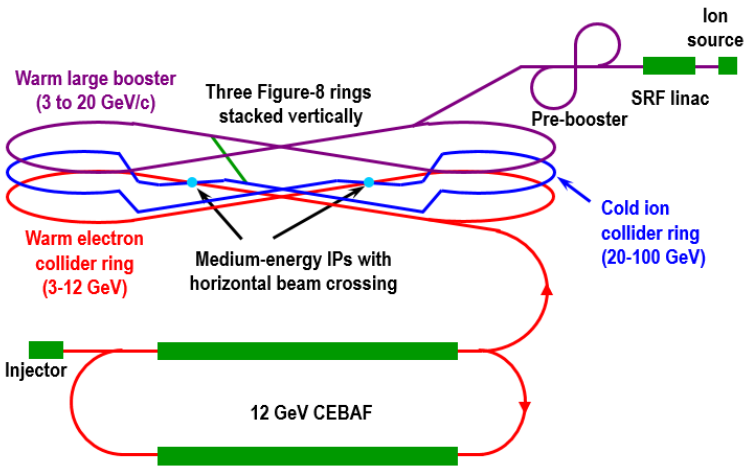
Intense highly charged pulsed-heavy-ion beams from ion source requested by accelerators



GSI FAIR U^{28+} 15emA/100µs



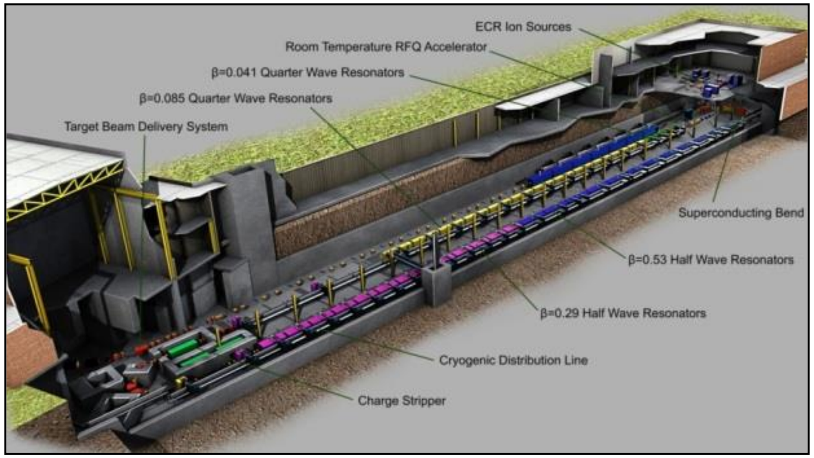
BNL RHIC Au^{32+} 2 emA/10µs



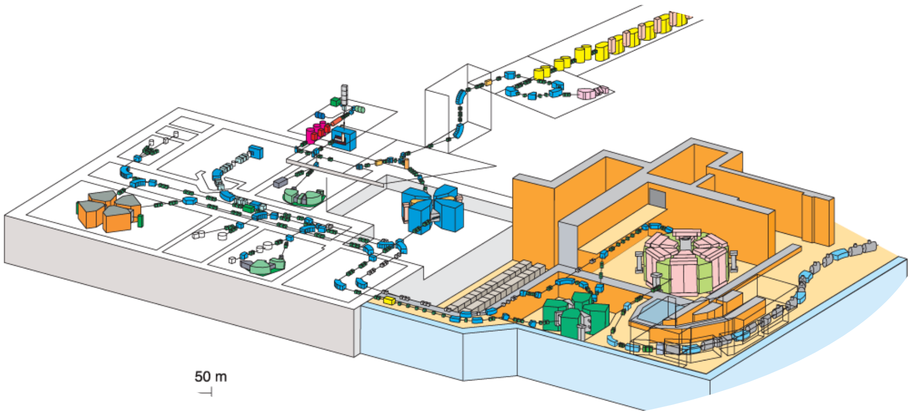
JLAB MEIC Pb^{30+}/ Au^{32+} 0.5 emA/500µs

IMP HIAF U^{34+} 1.7 emA/400µs

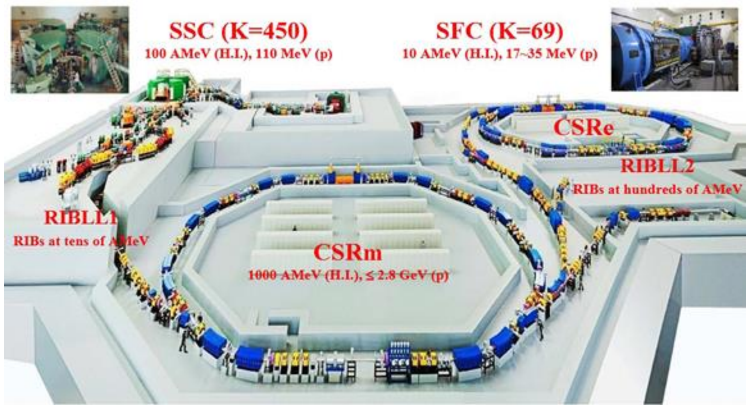
Intense highly charged CW-heavy-ion beams from ion source requested by accelerators



MSU FRIB U^{34+} 13pμA/CW



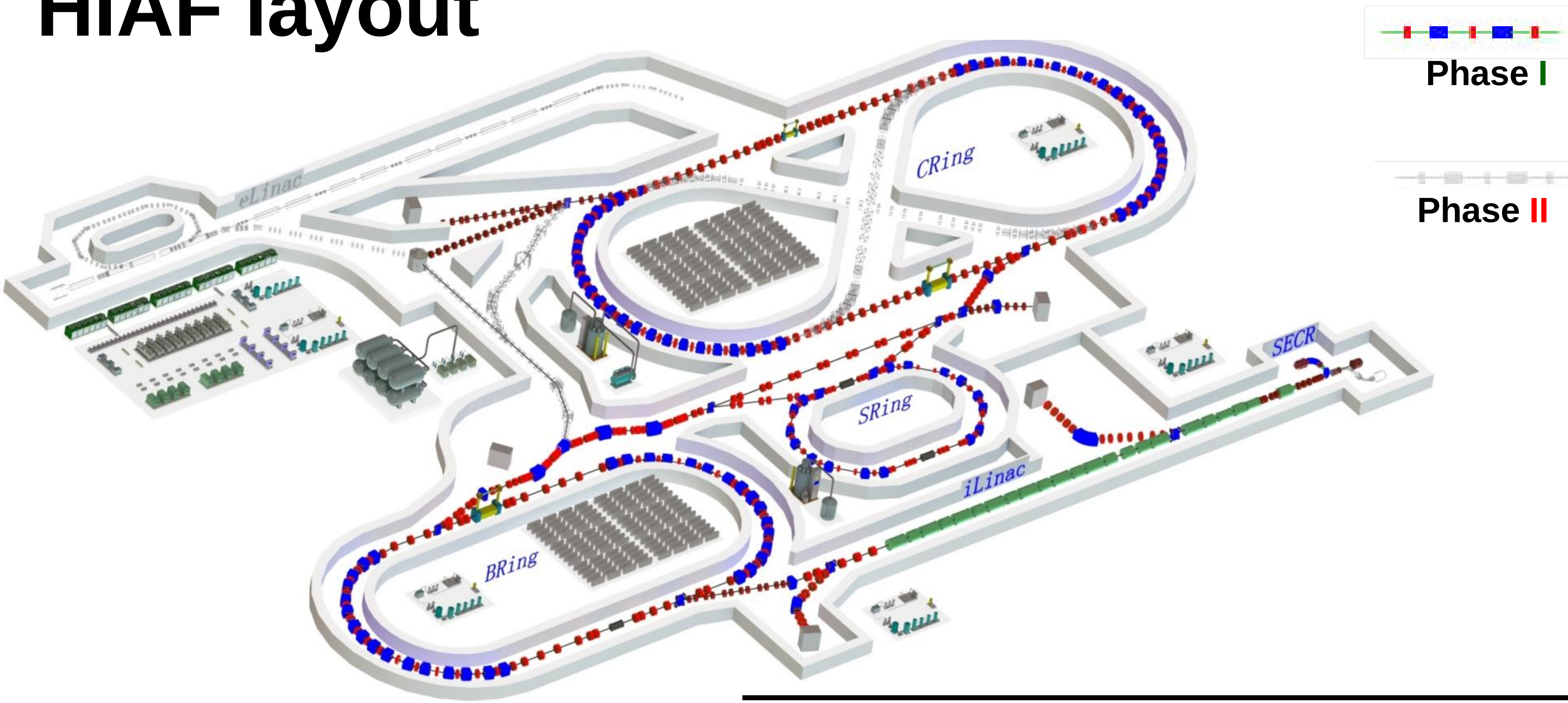
RIKEN RIBF U^{35+} 525eμA/CW



IMP HIRFL U^{41+} 100eμA/CW

SPIRAL2 Ar^{12+} 1emA/CW

HIAF layout



SECR: ECR ion source

iLinac: Superconducting ion linac

BRing: Booster ring

CRing: Compression ring

eLinac: Electron linac

SRing: High precision spectrometer

Accelerator		Ions	Energy	Intensity
Ion source	ECR	U^{34+}	14 keV/u	0.05 pmA
	H_2^+	H_2^+	14 keV/u	2.0 pmA
iLinac		U^{34+}	25 MeV/u	0.028 pmA
		H_2^+	54 MeV/u	1.0 pmA
BRing		U^{34+}	0.8 GeV/u	~3.3×10^{11} ppp
		p	9.5 GeV/u	~2.3×10^{12} ppp
CRing		U^{34+}	1.1 GeV/u	**~1.0×10^{12} ppp**
		U^{92+}	4.1 GeV/u	~2.0×10^{11} ppp
		p	12.0 GeV/u	~4.5×10^{12} ppp

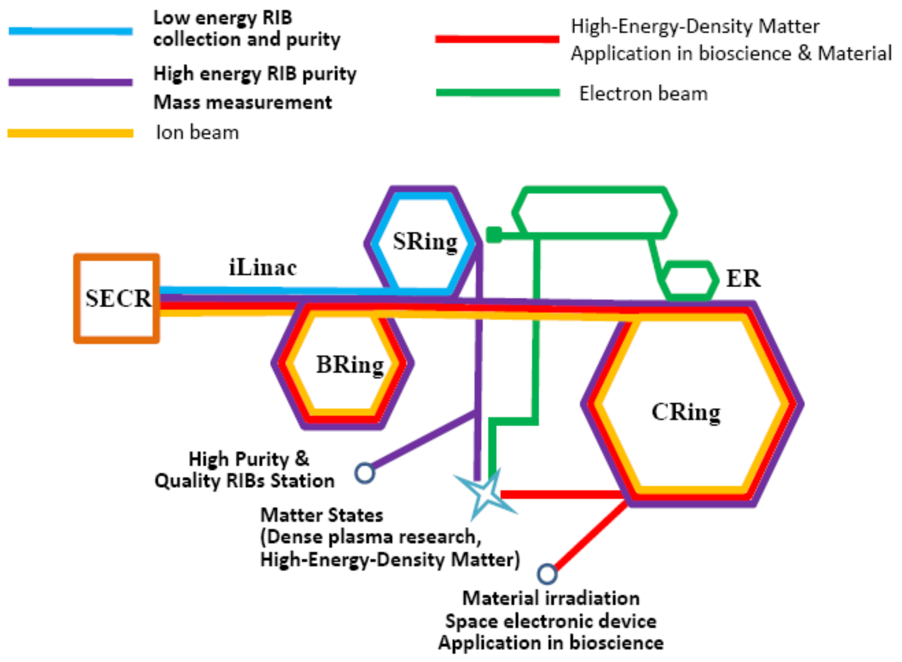
Main features of HIAF Phase I

- High intensity /Short pulse
  (1.0×10^{12} ppp / 50-100ns)
- High current & high charge state SC ion Linac
  (28 pμA/ U $^{34+}$/Superconducting)

Ion source related

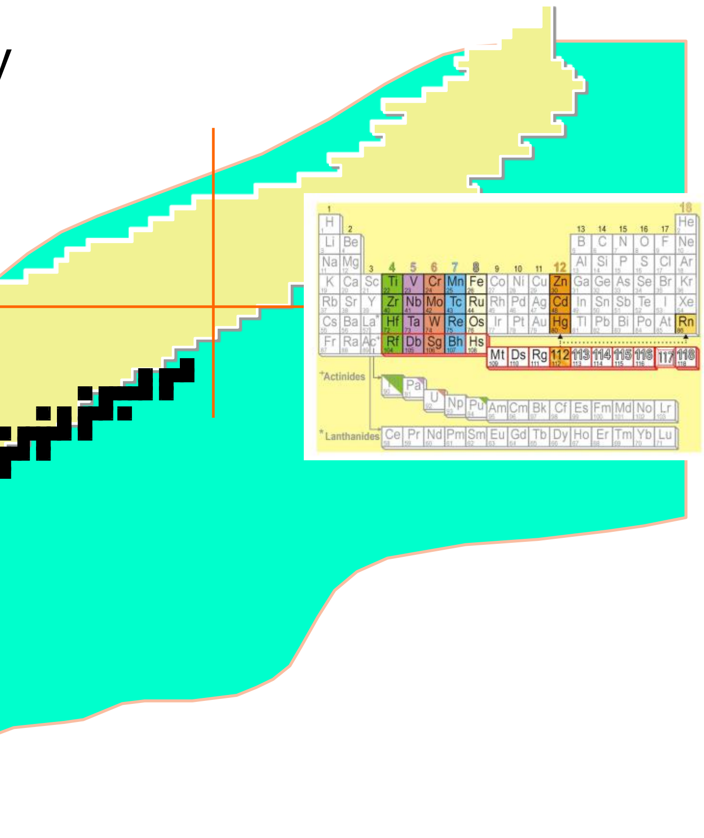
- Two planes painting injection supported by electron cooling
  Nearly 150 turns one injection, 5 times of conventional multiturn injection

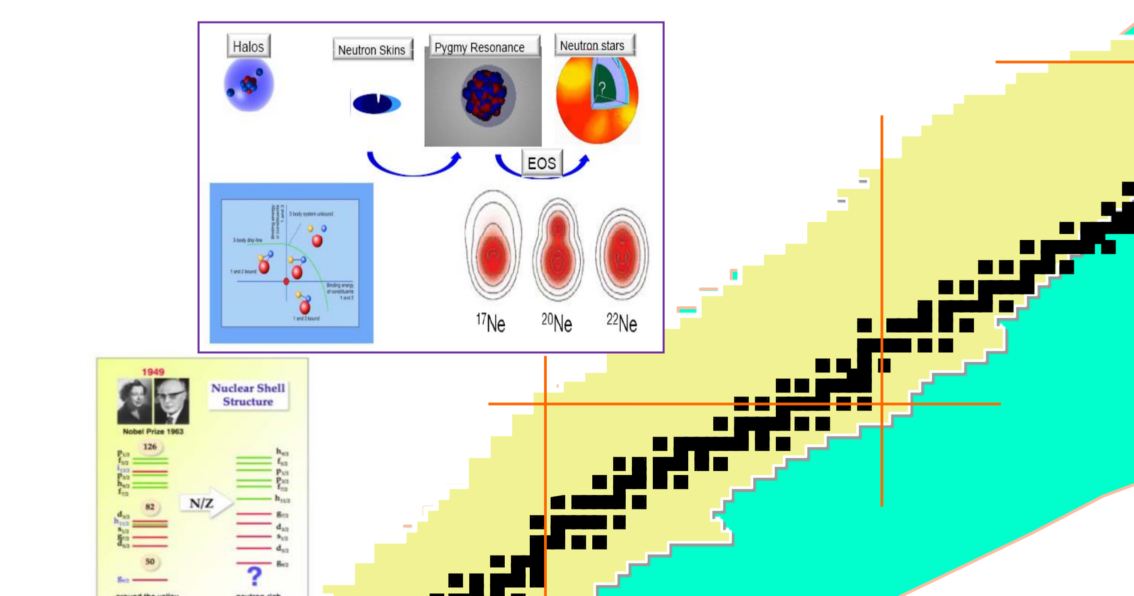
- Beam cooling
  (Electron, Stochastic)
- Super long period slow extraction
  (Quasi-continuous high energy beam,
- Multi-operation modes
  (parallel operation, beam splitting anc
  switching to different terminals)

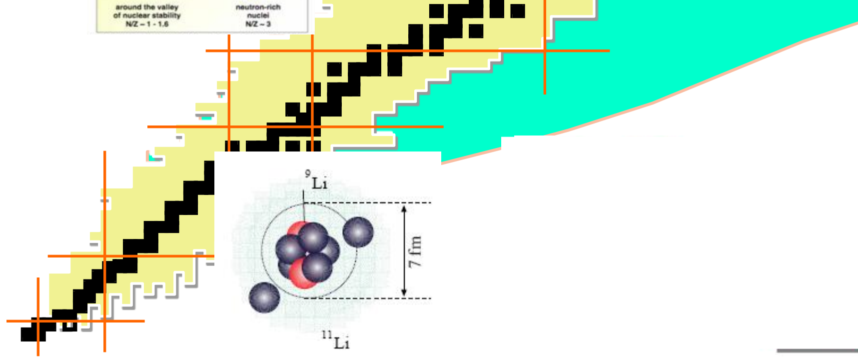


Nuclear Physics

- Exploring the limits of nuclear stability
- New phenomena far from stability
- Shell structure far from stability





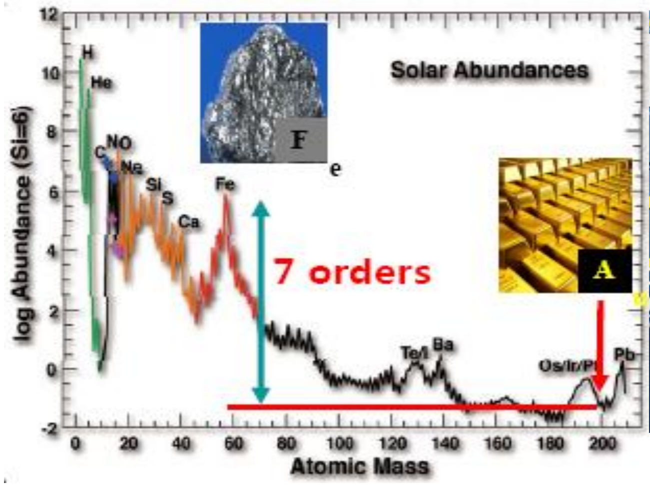


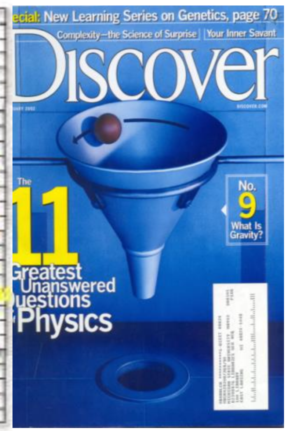
- Precise mass measurements for short-lived nuclei
- Synthesis of new isotopes near the proton-drip line
- Structure and reaction mechanism with exotic beams
- Properties of asym. nuclear matter at high density
- Decay and chemical properties of super-heavy nuclei
- Evolution of collective motion in complex nuclei

Nuclear Astrophysics

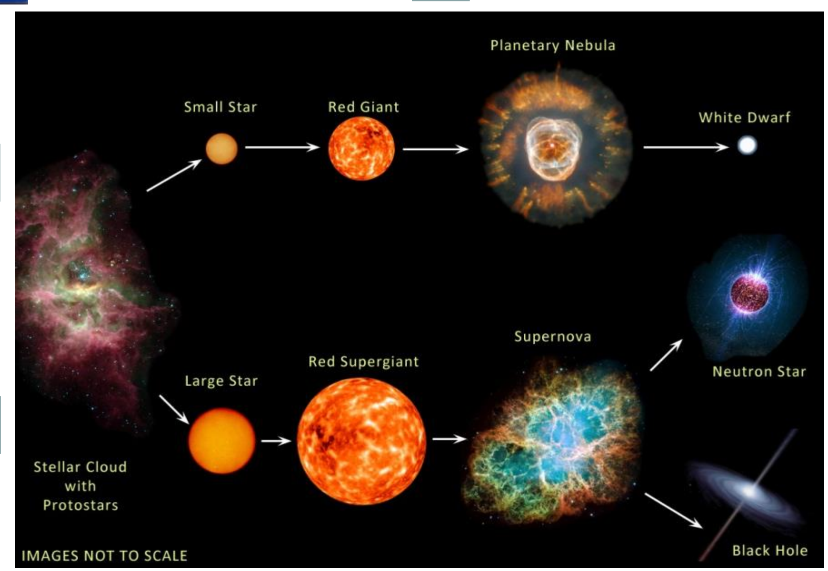
How were the heavy elements from iron to uranium made?

Top 11 Greatest Unanswered Questions of Physics





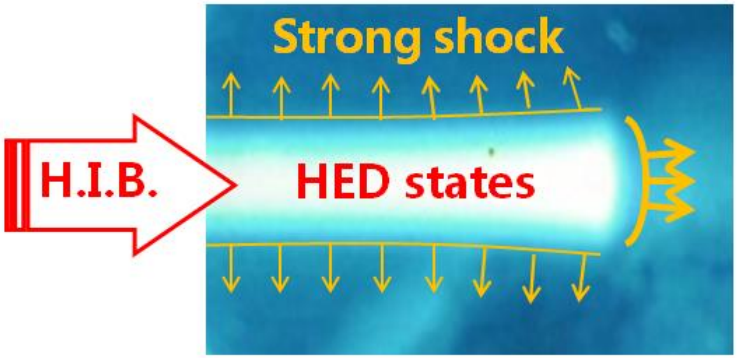
What are the nuclear reactions that drive stars and stellar explosions?



Evolution of stars and energy generation

Origin of chemical elements in Cosmos

High Energy Density Physics (HEDP)

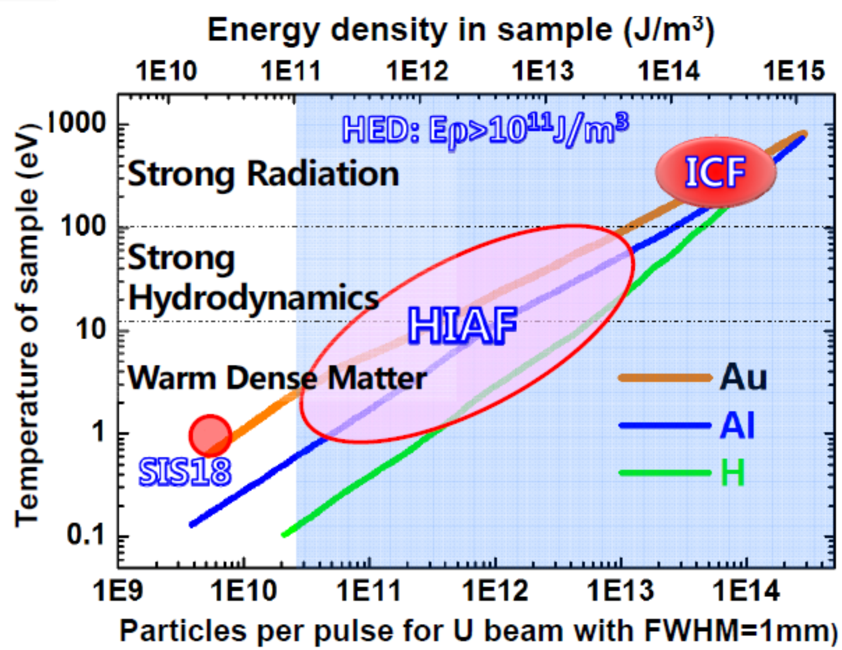


Advantages

- Fairly uniform physical conditions
- Large heated volume (mm^3-cm^3)
- High repetition rate
- Good reproducibility
- Any target material @high density

Key parameters of HEDP at HIAF

	SIS-18	FAIR	HIAF (Ph-1)
E_0	0.4 GeV/u	1 GeV/u	1.1 GeV/u
N	4×10^{9}	4×10^{11}	1×10^{12}
E_{total}	0.06 kJ	15 kJ	40 kJ
S_f	~1 mm	~1 mm	1mm - 0.5 mm
τ	130 ns	50 ns	130ns - 33 ns
E_s	~1 kJ/g	120 kJ/g	300 kJ/g- 1.2MJ/g
E_ρ	2×10^{10} J/m³	2.4×10^{12} J/m³	6×10^{12} J/m³ - 2.4×10^{13} J/m³



HIAF will offer new opportunity for HEDP !

Impact of highly charged ion source on the next generation heavy ion accelerator such as HIAF

Requirements of ion source from those high energy (GeV/u) high current heavy ion accelerators

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Performance + Cost

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$^{238}U^{34+}$ 、

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Performance + Cost

How to choose the basic beam from the ion source of HIAF ?

$^{238}U^{34+}$、 $^{238}U^{46+}$、 $^{238}U^{55+}$?

Will any ion source be able to produce 1-2 emA for pulsed beam 5 Hz/0.3-0.5 ms in the next 10 years?

Ion sources possibly utilized for the next generation heavy ion accelerator facility

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- **CW and pulsed beam**

  Only one choice: ECRIS

- **Pulsed beam**
  - **ECRIS** (3^{rd} &4^{th} Gen., challenging)
  - **EBIS** (too short pulse, less current)
  - **LIS** (too short pulse, R&D)
  - **MEVVA+ stripper** (≤3Hz, cathode lifetime)
  - **Gasdynamic ECR+ stripper** (R&D)
  - **New concept ion source** ?

  ……

Pulsed-beams from ion source for those high energy (GeV/u) high current heavy ion accelerators

Pulsed-beams from ion source for those high energy (GeV/u) high current heavy ion accelerators

Ion Source	ECRIS	EBIS	LIS	MEVVA
Ion beam	U^{34+}	Au^{32+}	Pb^{25+}	$U^{4+ \rightarrow 28+}$
Requested beam current	50 pμA 400 us	1.7 emA 10us	10 emA 6us	(U^{4+} 20 emA) U^{28+} 15emA 100us
Requested (ppp)	1.2×10^{11}	3.2×10^{9}	1.5×10^{10}	3.3×10^{11}
Facility	**HIAF/IMP**	**RHIC/BNL**	**LHC/CERN**	**FAIR/GSI**
Note	afterglow	pulsed	pulsed	Stripping
Achieved	10-15 pμA	1.7 emA	10 emA	5.7 emA
Data from	Design report	E. Beebe ICIS11	John Tambini's paper	Design report O.Kester talk

What is the potential capability for the ion sources to produce the beam similar to $^{209}Bi^{30+}$/ $^{238}U^{34+}$ in the next 5-10 years

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Estimated beam current	4.0 emA 400 us	30 emA 10us	100 emA 6us	(U^{4+} 100 emA) U^{28+} 75emA 100us
Ions per pulse	**2.8×10^{11}**	**6×10^{10}**	**1.5×10^{11}**	**1.6×10^{12}**
Note	afterglow	Pulsed	pulsed	stripping
Data from	Estimated	Private communication with E. Beebe	Estimated	Estimated

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- **Only talk about the beam current, not take into other issues.**

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There is a challenge for an ECRIS in pulsed beam production.
ECRIS community must take up the challenge!

- **Only talk about the beam current, not take into other issues.**

How much budget can a highly charged ion source save for a 100 MeV/u SC heavy ion linac

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	$^{238}U^{34+}$	$^{238}U^{46+}$	$^{238}U^{55+}$
Injection E （MeV/u）	1.3	1.3	1.3
Output E （MeV/u）	100	100	100
Design I_{max} （emA）	1.0	1.0	1.0
SC cavity	HWR009+HWR015+ Spoke021	HWR009+HWR015+ Spoke021	HWR009+HWR015+ Spoke021
SC cavities	44+100+248=392	40+92+176=308	32+80+152=264
Solenoids	78	65	55
CRM Reduced		11	16
Total length （m）	288	225	197
Budget reduced		**>70 M$** (MP not included)	**>100 M$** (MP not included)

How much budget can a highly charged ion source save for a 100 MeV/u SC heavy ion linac

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SC cavity	**HWR009+HWR015+**	**HWR009+HWR015+**	**HWR009+HWR015+**
Solenoids	**78**	**65**	**55**
CRM Reduced		**11**	**16**
Total length（m）	**288**	**225**	**197**
Budget reduced		**>70 M$ (MP not included)**	**>100 M$ (MP not included)**

It is very much worthy of developing highly charged ion source aiming at very high Charge state!

ECRIS Challenges to meet the next generation heavy ion accelerator such as HIAF

Evolution of ECRIS Generations

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1st G. ECRIS

- Prototyping
- Demonstration

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Evolution of ECRIS Generations

2nd G. ECRIS

- Critical techniques
- Effective tricks

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Evolution of ECRIS Generations

3rd G. ECRIS
- Superconducting techniques
- Performance boosting

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Evolution of ECRIS Generations

4th G. ECRIS
- Technology breakthrough or budget race?
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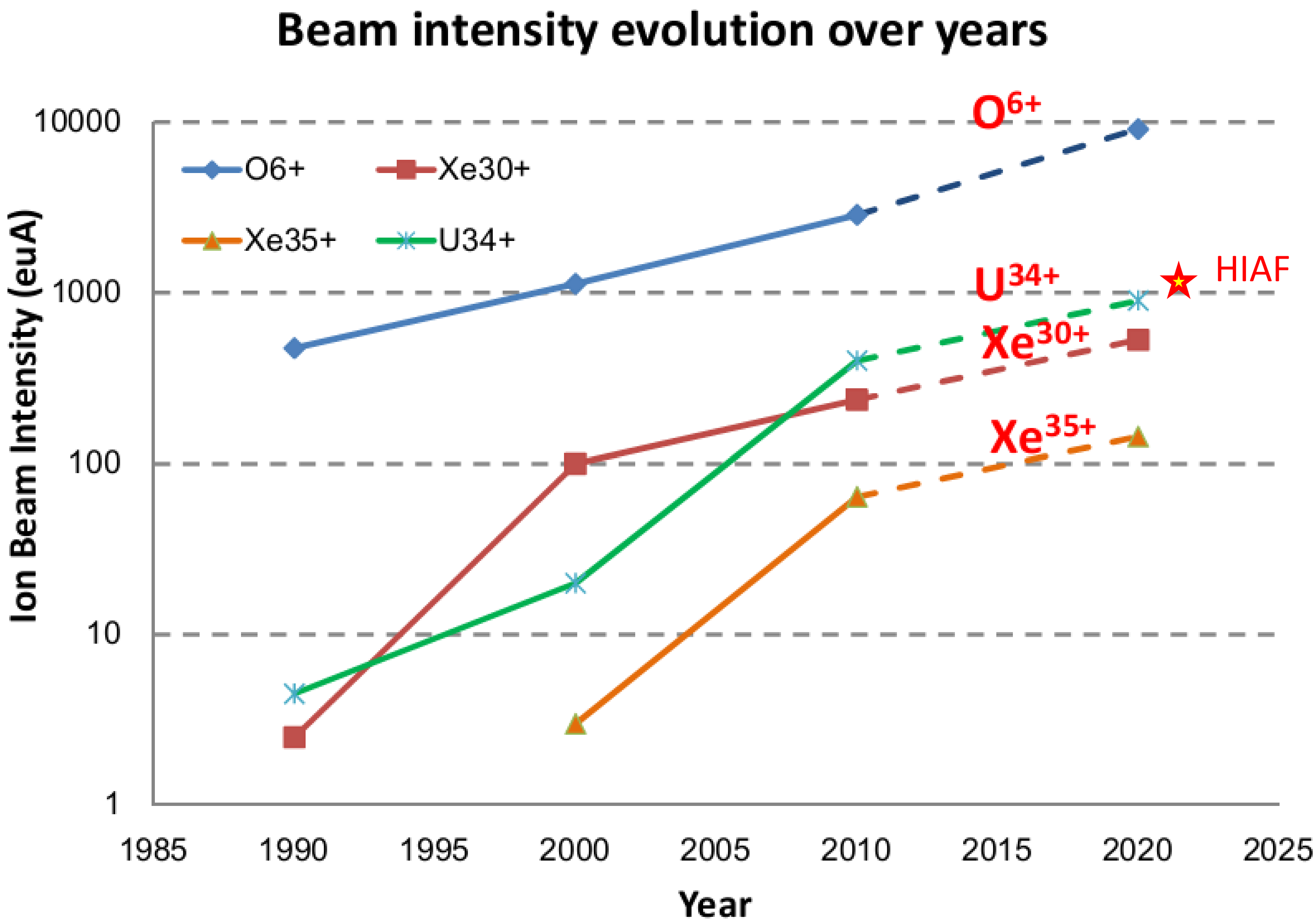
ECRIS Advancement



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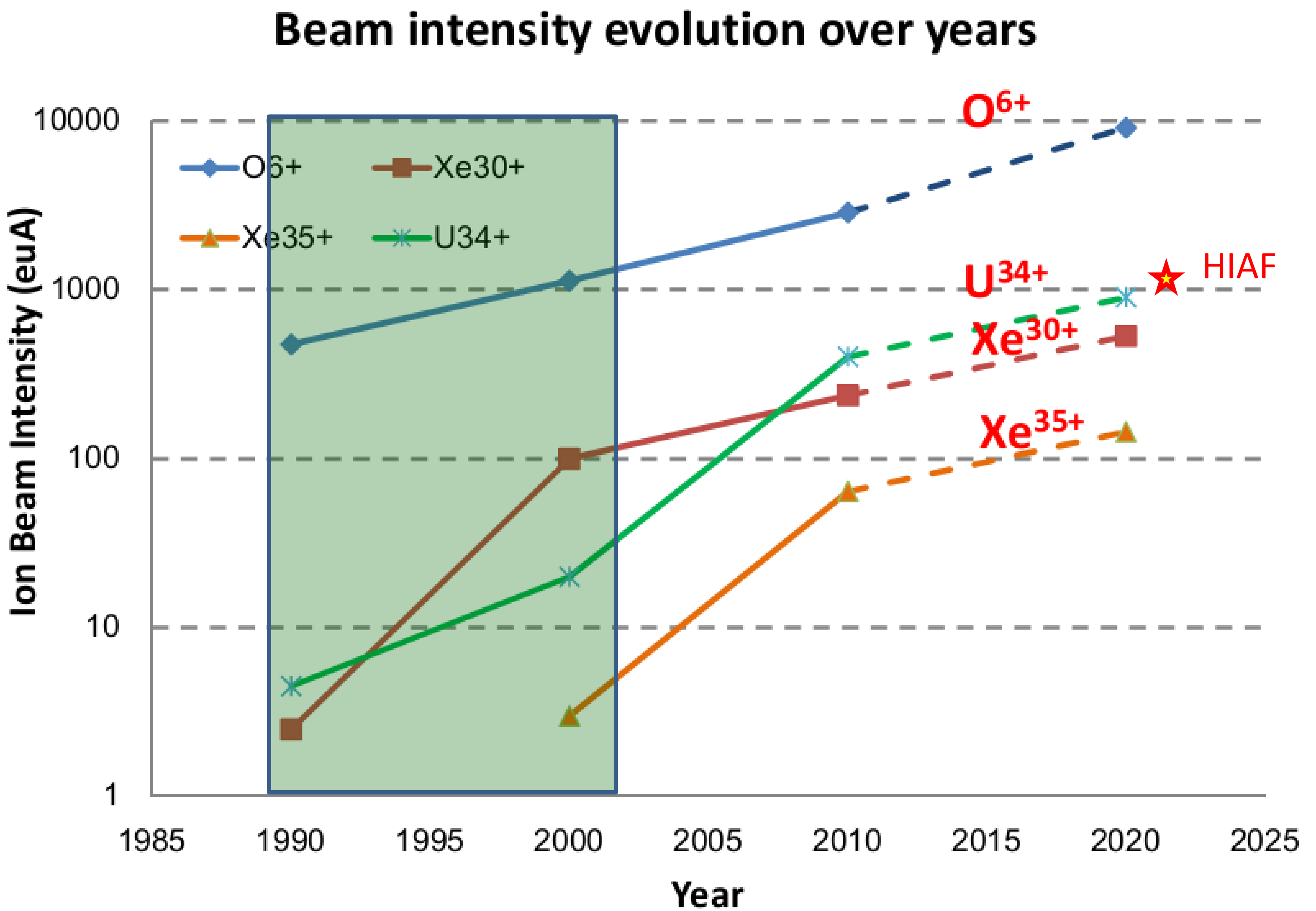

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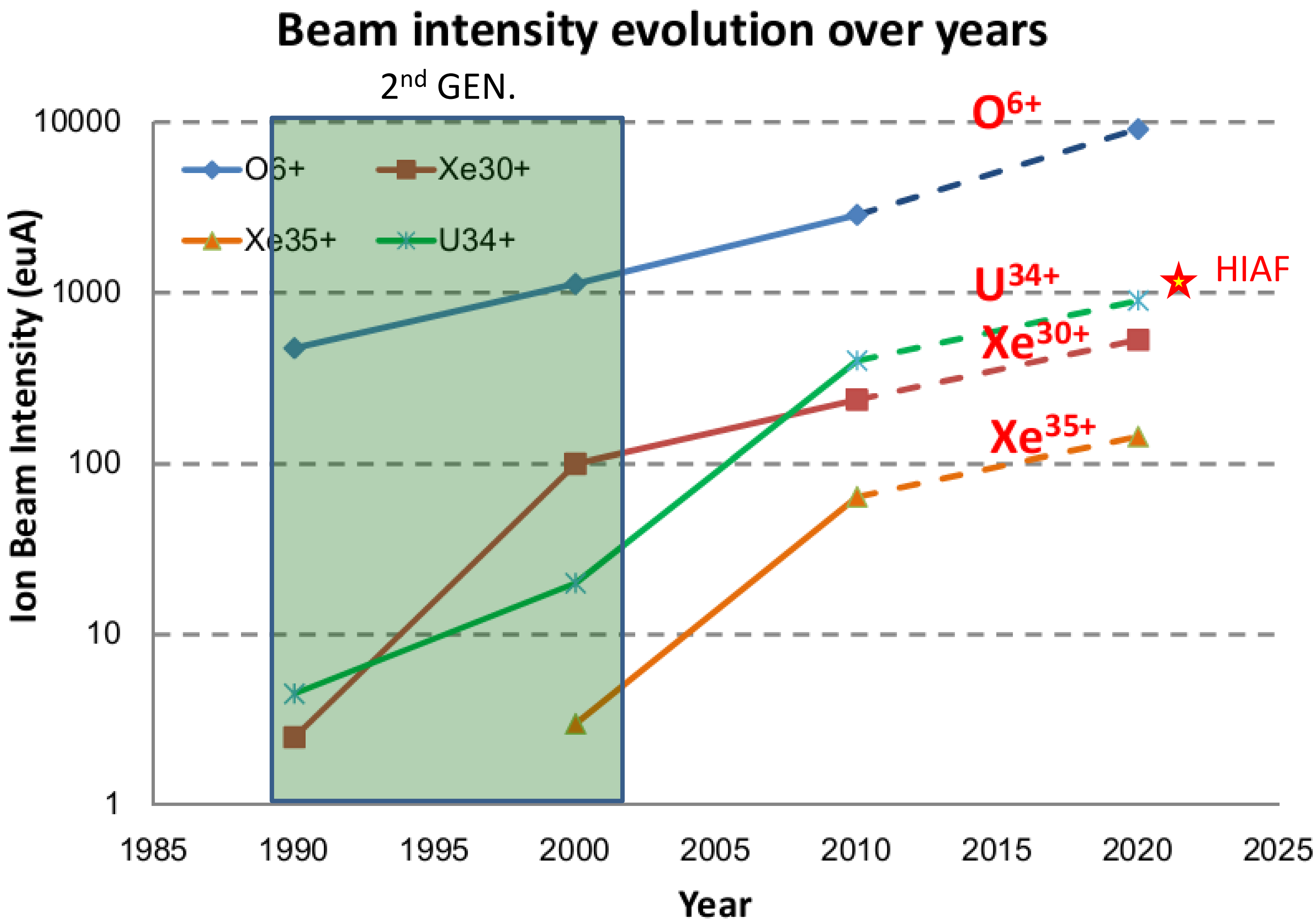

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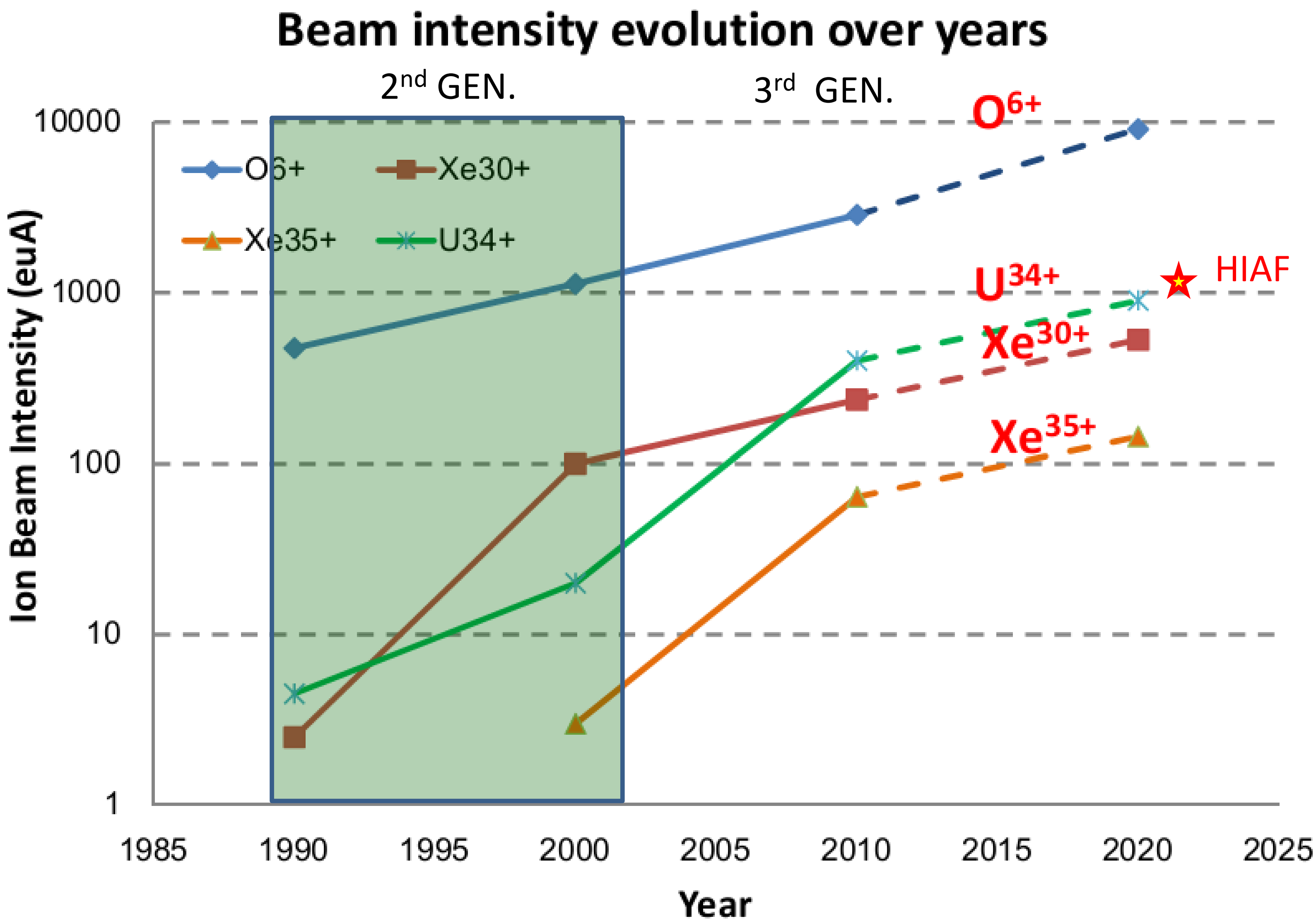

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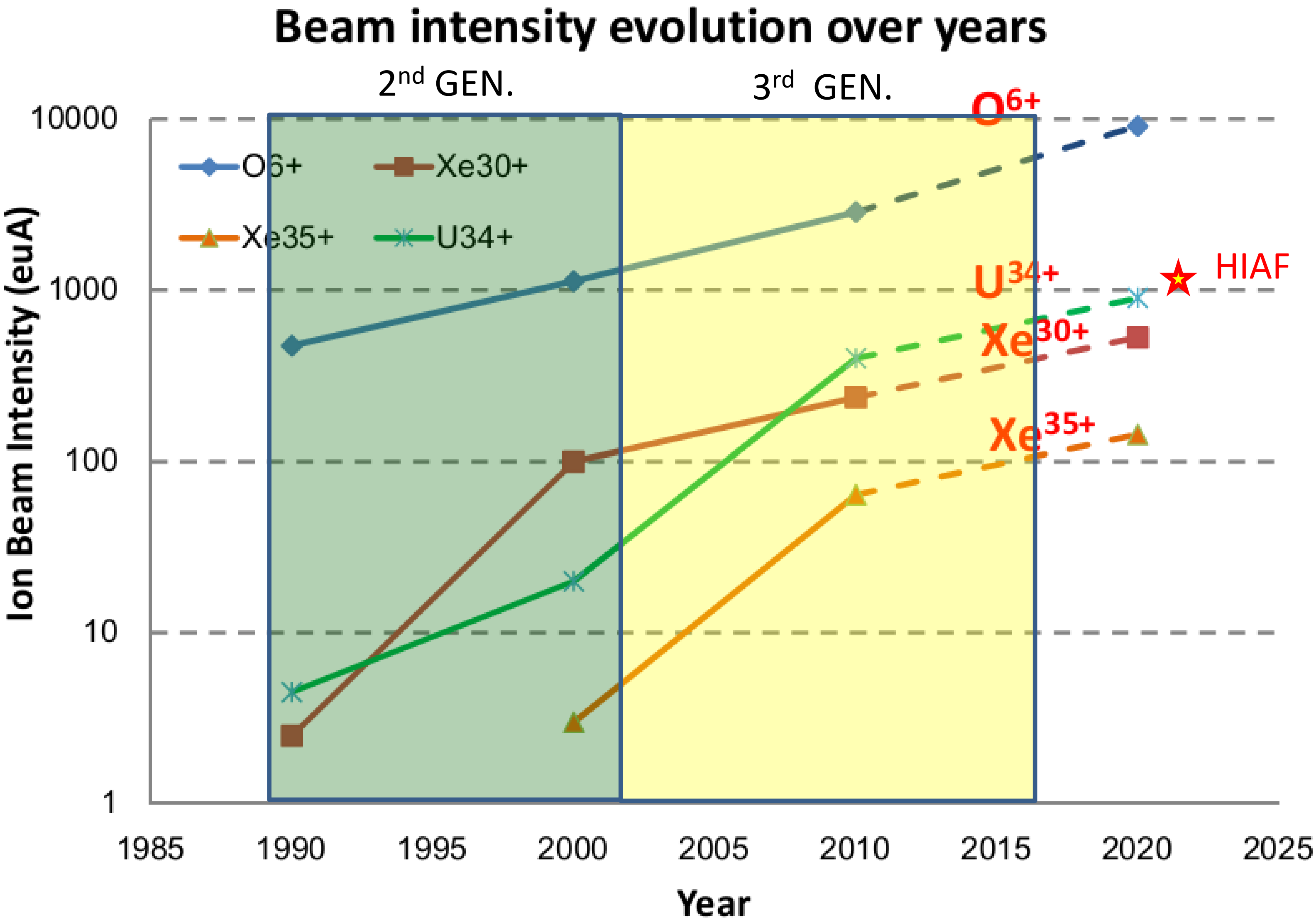

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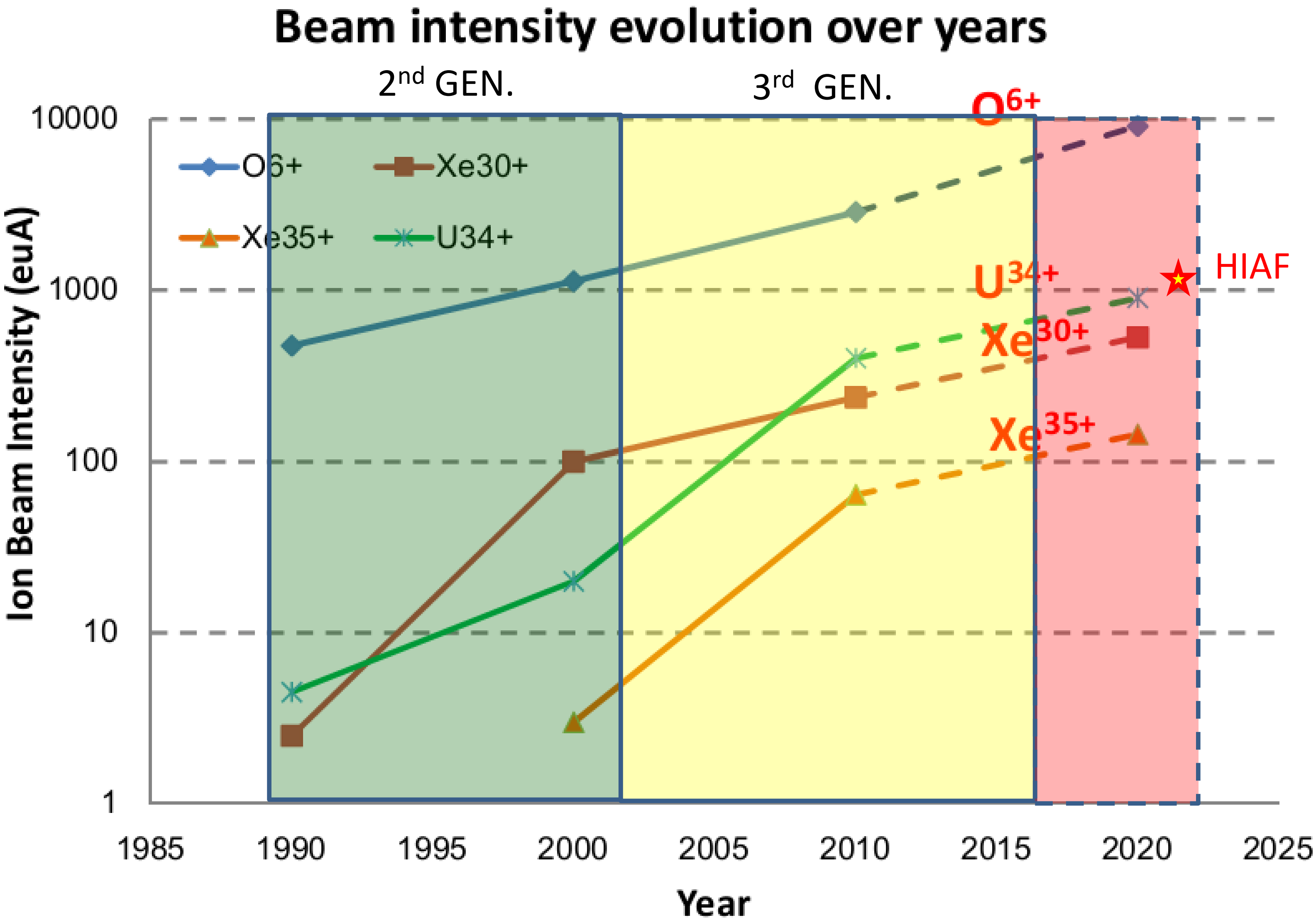

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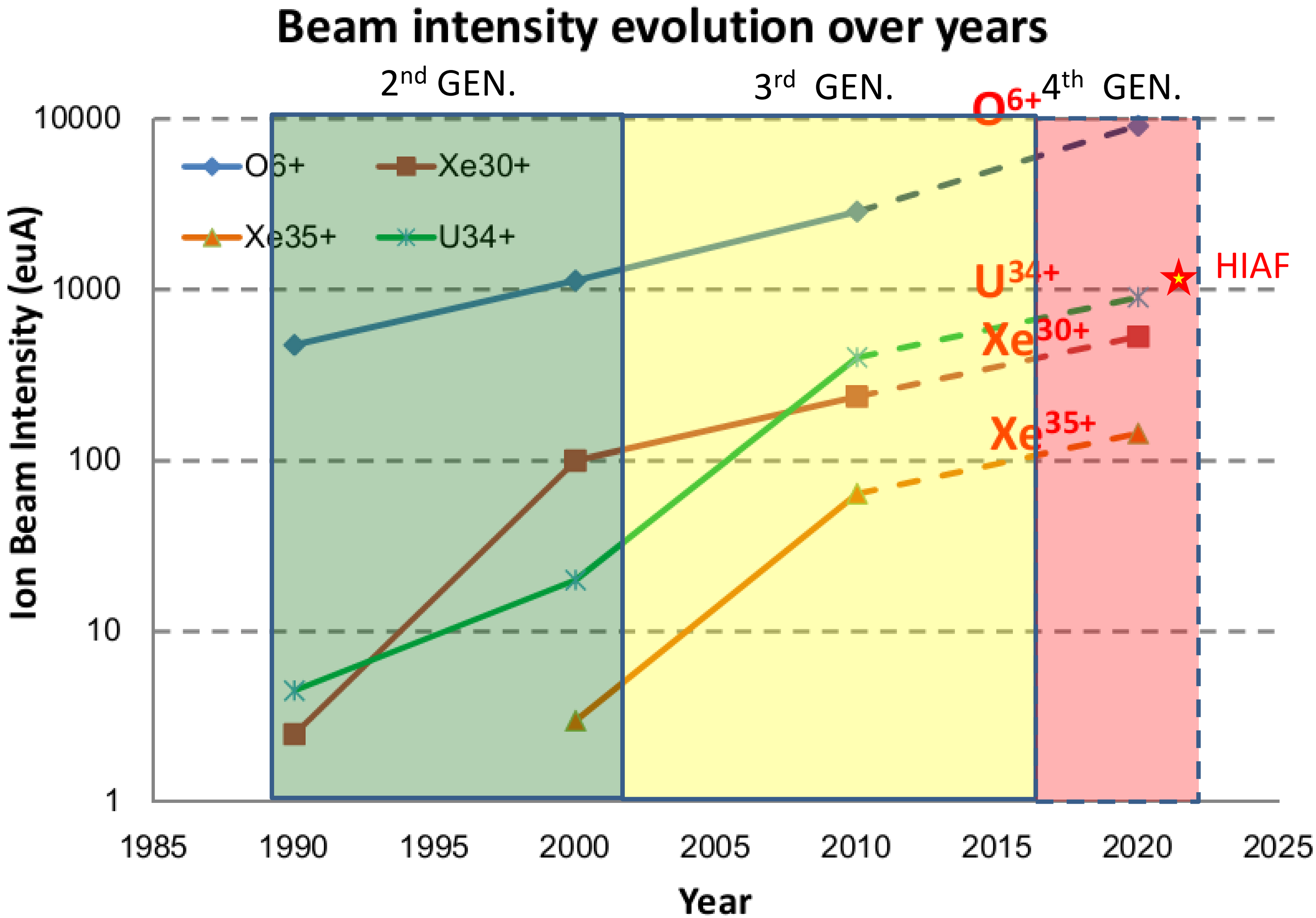


Expected performance of a 4th generation ECRIS

	$^{209}Bi^{30+}$/ $^{238}U^{34+}$ (CW beam)	$^{209}Bi^{42+}$/$^{238}U^{46+}$ (CW beam)	$^{209}Bi^{51+}$/$^{238}U^{55+}$ (CW beam)
2nd GEN ECRIS (14-18 GHz)	20 eμA	1.8 eμA	
3rd GEN ECRIS (24-28 GHz)	1000 eμA ?	50 eμA	5 eμA
4th GEN ECRIS (40-60 GHz)	2000 eμA ?	300 eμA ?	50 eμA ?

SECRAL source already produced $^{209}Bi^{30+}$ CW 700 eμA*. A new record!

- **Heavy ion intensity frontier is the main issue for HIAF.**
- **That is why HIAF chooses the 4th generation ECRIS.**

  Also keep CW option

- **Potential capability of the 4th generation ECRIS.**

* See L. Sun's talk on Tuesday, TUOMMH03

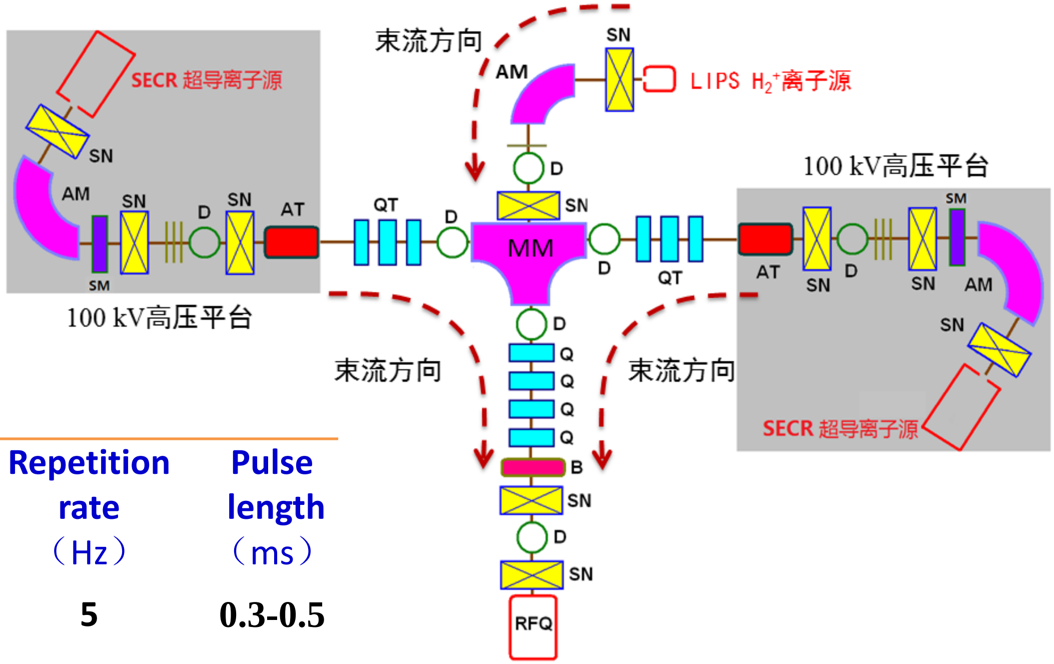
HIAF requirements to ion source

Basic beam and intensity

Bring: $^{238}U^{34+}$ 0.8GeV/u 0.33x10^{12} ppp

Cring: $^{238}U^{34+}$ 1.1GeV/u 1.0 x10^{12} ppp

Ion source: $^{238}U^{34+}$ 1.7 emA



Ion	Energy （keV/u）	Particle current （pmA）	Ion Current （mA）	mode	Repetition rate （Hz）	Pulse length （ms）
$^{18}O^{6+}$	14	0.30	1.80	pulse	5	0.3-0.5
$^{78}Kr^{19+}$	14	0.08	1.52	pulse	5	0.3-0.5
$^{238}U^{34+}$	14	0.05	1.70	pulse	5	0.3-0.5
H_2^+	14	2.0	2.00	pulse	5	0.3-0.5

If HIAF would request the ion source to deliver $^{238}U^{34+}$ 1.7 emA stable beam, the ion source would have to produce the maximum intensity around 2.5-3.0 emA.

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Are we ready to build the 4th generation ECRIS?
How long time it may take? Much more challenge!

However, a lot of challenges to build a 4th Gen. ECRIS

- 40-60 GHz/10-20 kW rf coupling.
- 40-60 GHz ECR superconducting magnet.
- High flux x-ray heating and plasma chamber heating.
- Beam quality (emittance) and long-term stability.
- 30-50 mA mixed highly charged ion beam extraction and transmission.
- Refractory metal ion beam production
- Risky and high cost.

Summary

Summary

- ECRIS with very high charge state and high current may play a significant role and contribute a lot in the next generation heavy ion accelerator such as HIAF in terms of beam intensity and cost-effective design.

- It is much worthy of developing the 4th generation ECRIS to explore the potential capability of the highly charged heavy ion beam production.

- Many technical challenges for the 4th generation ECRIS, strong R&D and prototyping are necessary.

Thank you for your attention!