



Update on the HINA project



Michele Sguazzin

16/03/2026



Interest of Highly Charged Ions

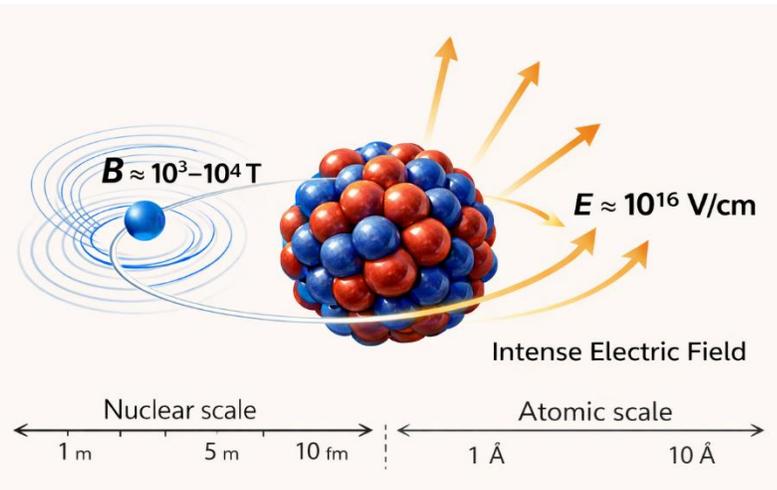
HINA



Highly-charged **I**ons for **N**uclear physics and **A**strophysics

Why HCIs?

One of the most striking examples of the **interplay** between **atomic physics** and **nuclear physics!!**



Main properties

1. Size few pm
2. Few strongly bound electrons (keV)
3. Extreme electric and magnetic field
4. Strong electron-nucleus wave functions overlap

Polynesian
Goodness of
the moon



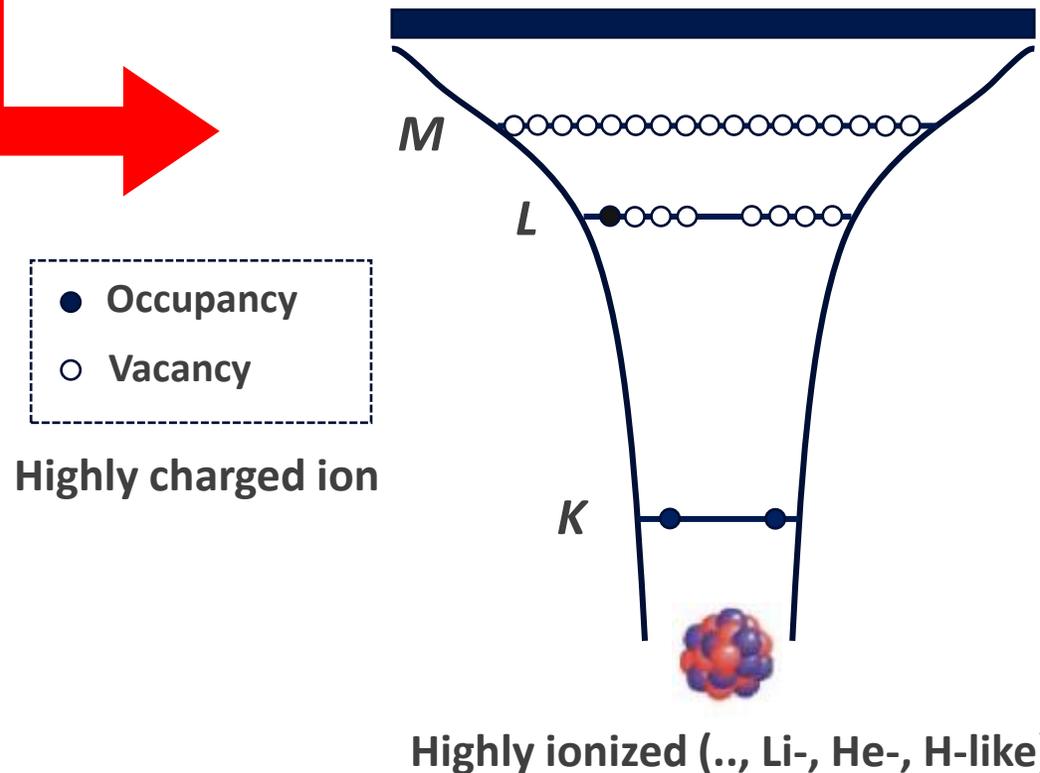
HINA project objective

Project goal:

Study nuclear decay in highly charged ions (HCIs)

Project goal:

Study nuclear decay in highly charged ions (HCIs)



The number of bound electrons influences weak decays channel such as



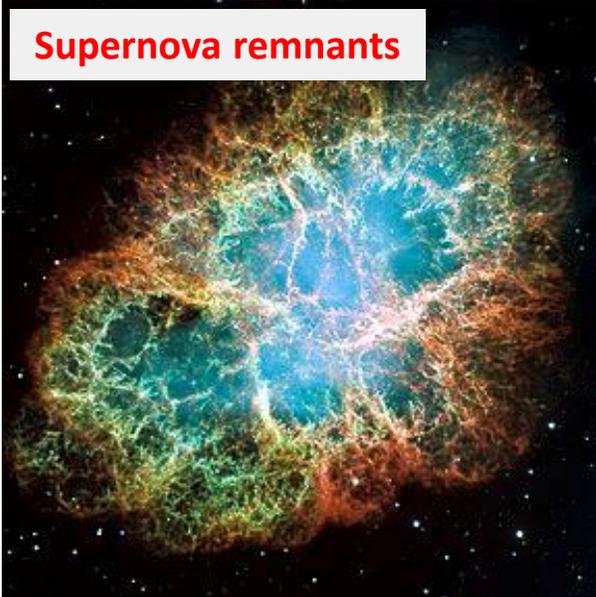
Electron Capture (EC)
Beta decay (β^\pm)



Huge change in the decay rate λ and lifetime!

HICs: an exotic matter?

Supernova remnants



Where do we find them?

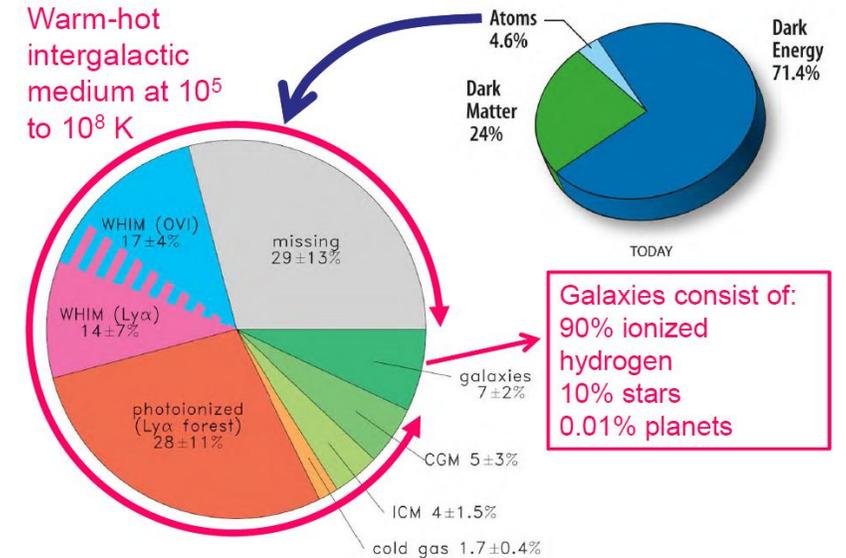
Active galactic nuclei



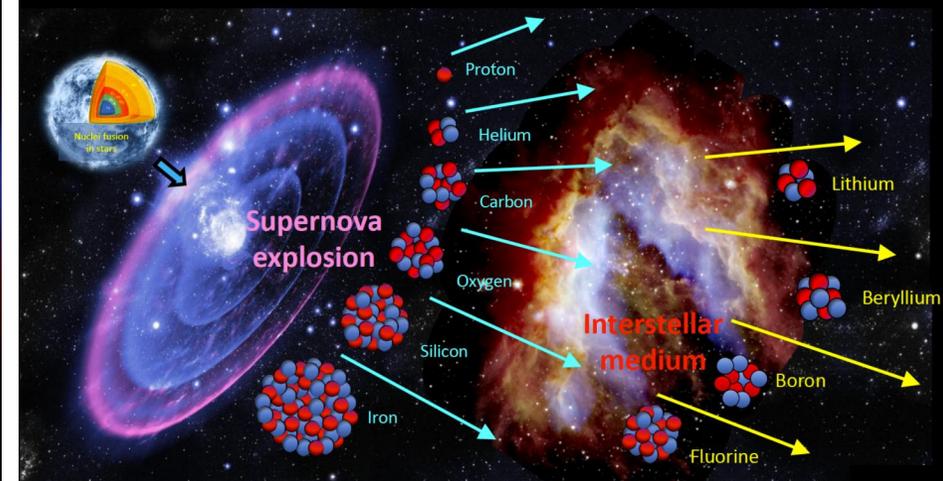
Stellar corona



NS merger

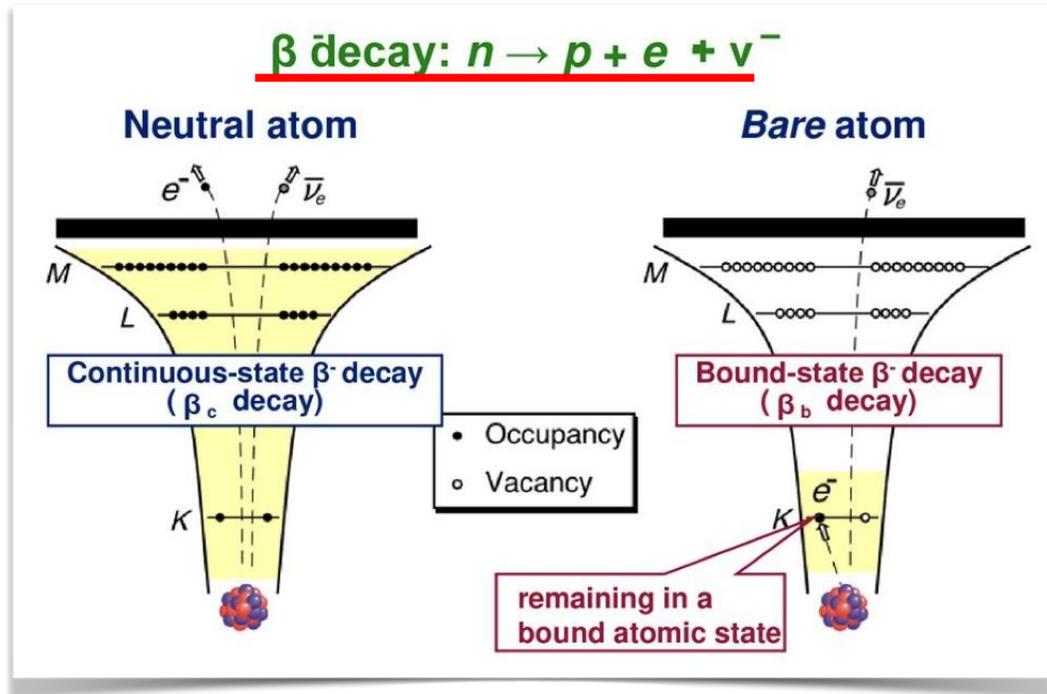
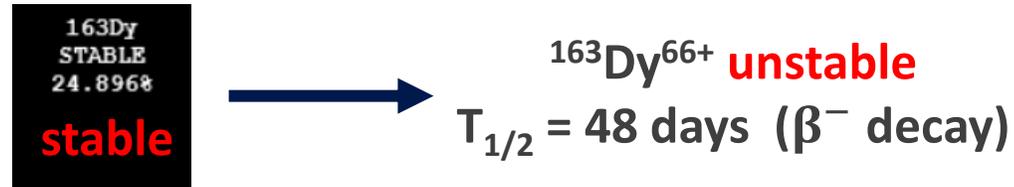


Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays, C, O, Ne, Mg, Si, ..., Fe, with the interstellar medium.



Measurements of the secondary cosmic ray nuclei fluxes and the secondary to primary flux ratios are important in understanding the propagation of cosmic rays in the Galaxy.

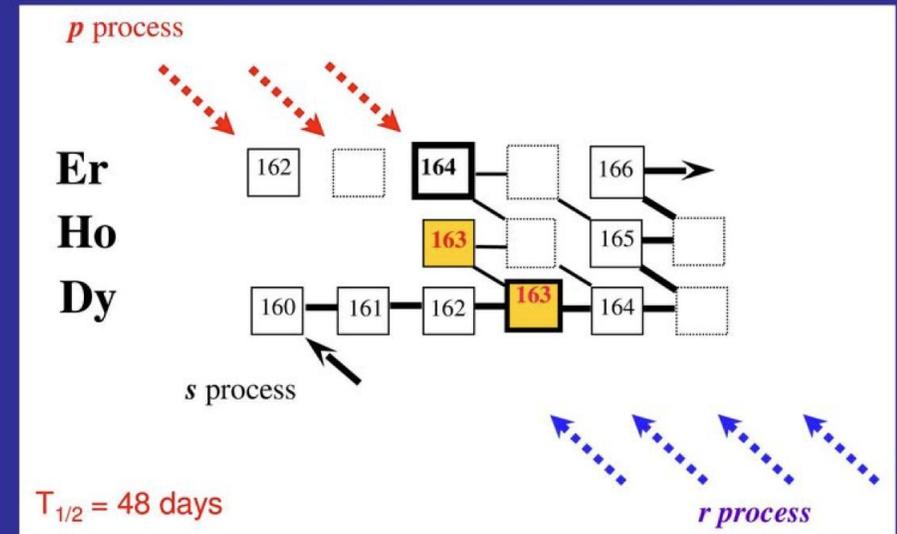
First observation of nuclear decay of HClIs



$$Q_{\beta_b}(K, L, \dots) = Q_{\beta_c^-} - |\Delta B_{e^-}| + |B_{e^-}^{K, L, \dots}|$$

Bound-State β^- decay of ^{163}Dy

s process: slow neutron capture and β^- decay near valley of β stability at $kT = 30 \text{ keV}$; \rightarrow high atomic charge state \rightarrow bound-state β decay

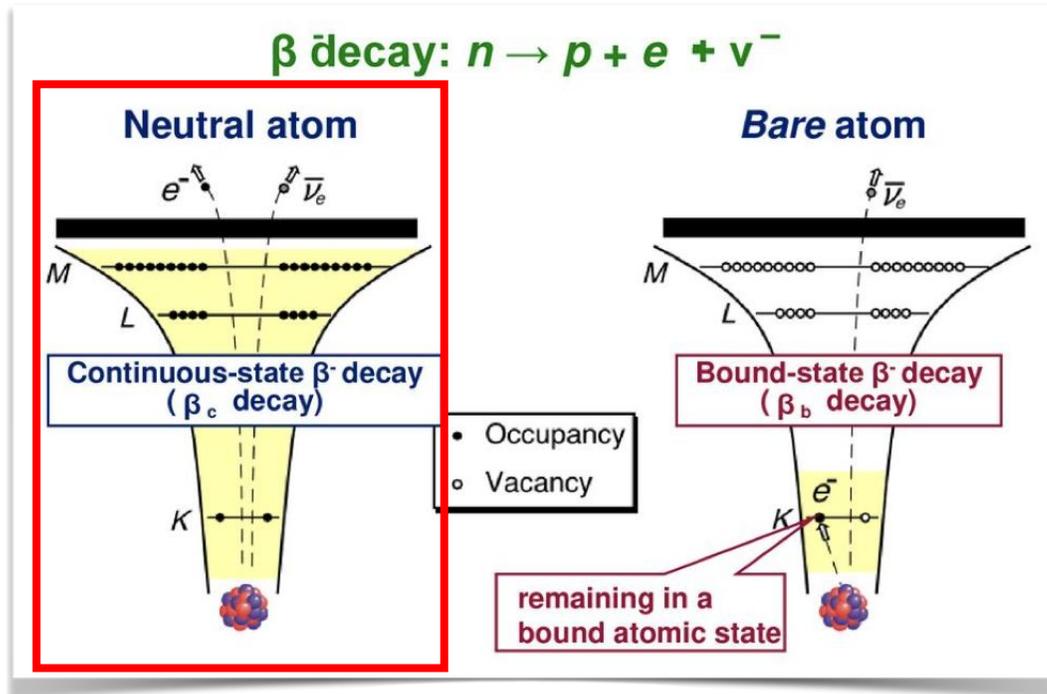
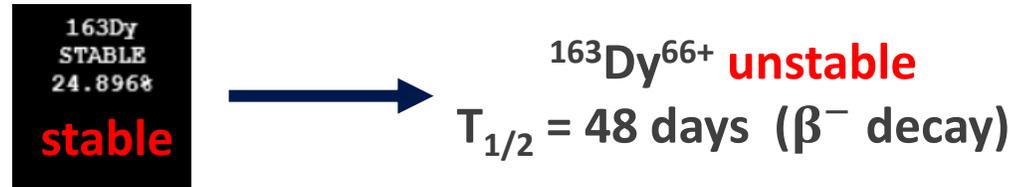


branchings caused by bound-state β decay

M. Jung et al., Phys. Rev. Lett. 69 (1992) 2164

Nuclear decay is NOT constant!

First observation of nuclear decay of HCIs

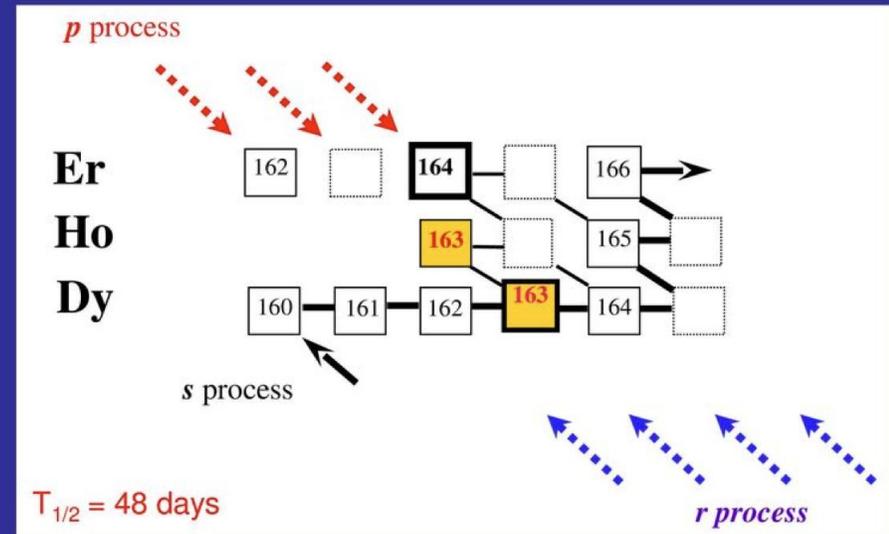


$$Q_{\beta_b}(K, L, \dots) = Q_{\beta_c^-} - |\Delta B_{e^-}| + |B_{e^-}^{K, L, \dots}|$$

-2,8keV

Bound-State β -decay of ^{163}Dy

s process: slow neutron capture and β -decay near valley of β stability at $kT = 30 \text{ keV}$; \rightarrow high atomic charge state \rightarrow bound-state β decay

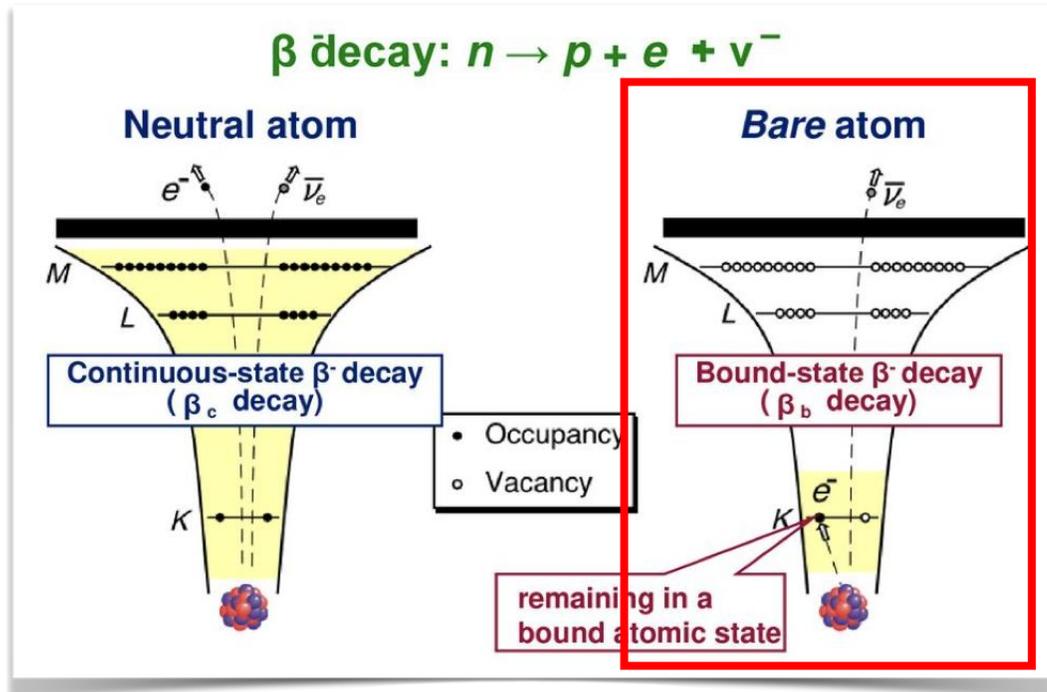
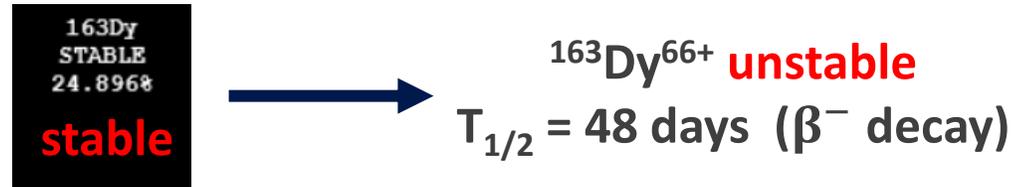


branchings caused by bound-state β decay

M. Jung et al., Phys. Rev. Lett. 69 (1992) 2164

Nuclear decay is NOT constant!

First observation of nuclear decay of HClIs

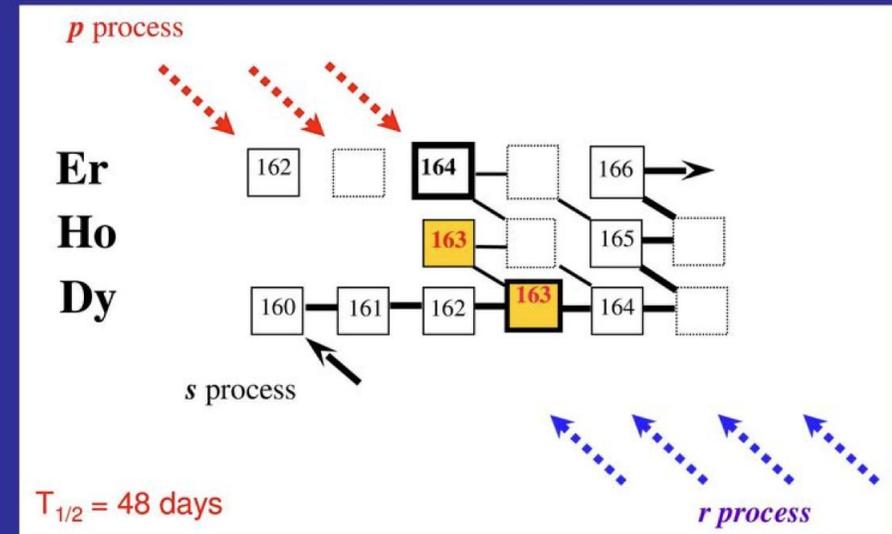


$$Q_{\beta_b}(K, L, \dots) = Q_{\beta_c} - |\Delta B_{e^-}| + |B_{e^-}^{K, L, \dots}|$$

49keV -2,8keV 13keV 65keV

Bound-State β -decay of ^{163}Dy

s process: slow neutron capture and β -decay near valley of β stability at $kT = 30 \text{ keV}$; \rightarrow high atomic charge state \rightarrow bound-state β decay

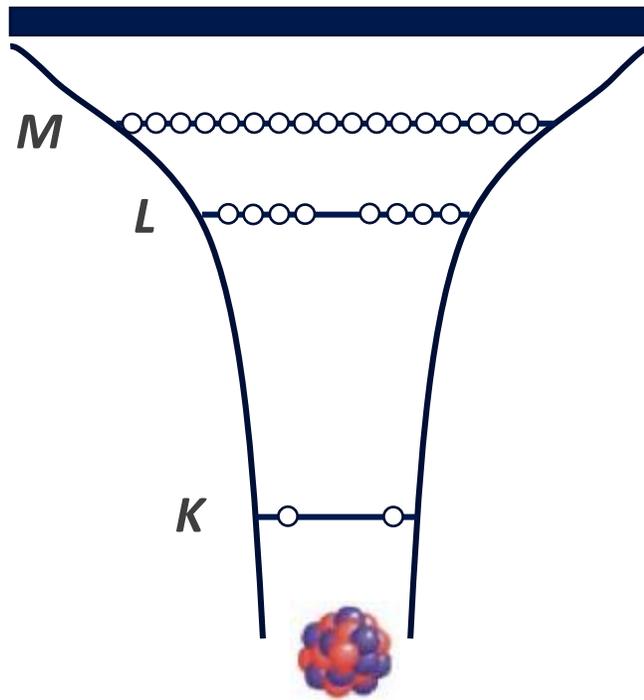


branchings caused by bound-state β decay

M. Jung et al., Phys. Rev. Lett. 69 (1992) 2164

Nuclear decay is NOT constant!

Orbital Electron Capture on HCIs



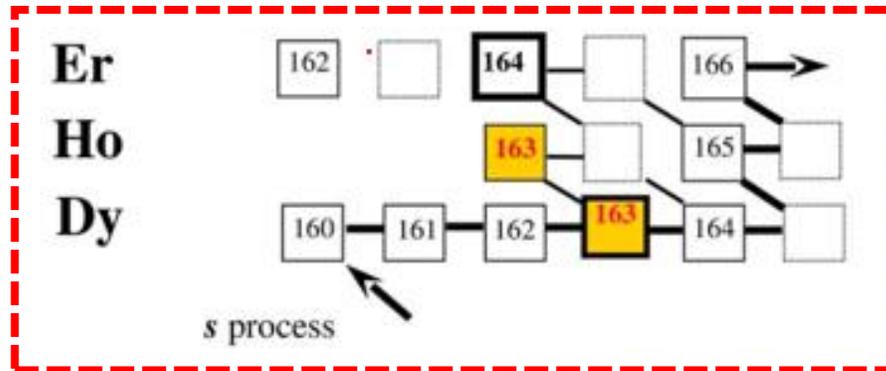
- Occupancy
- Vacancy

Highly charged ion

Fully ionized ions

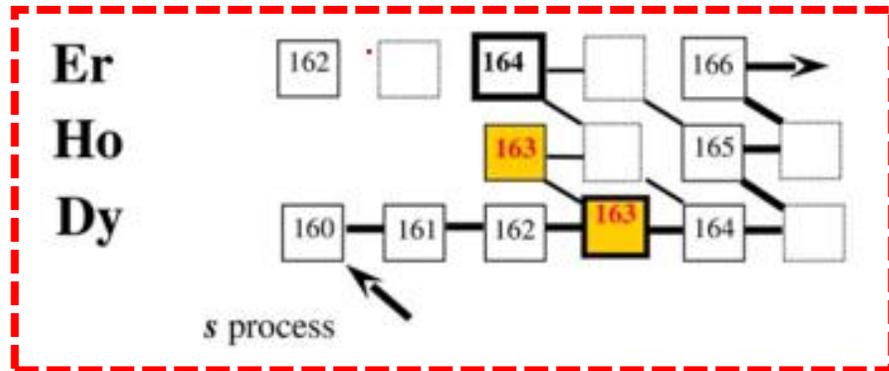
Orbital electron capture is blocked!

Orbital Electron Capture on HCl's



Orbital electron capture is
blocked!

Orbital Electron Capture on HCIs



^{163}Ho
4570 y
100%

unstable

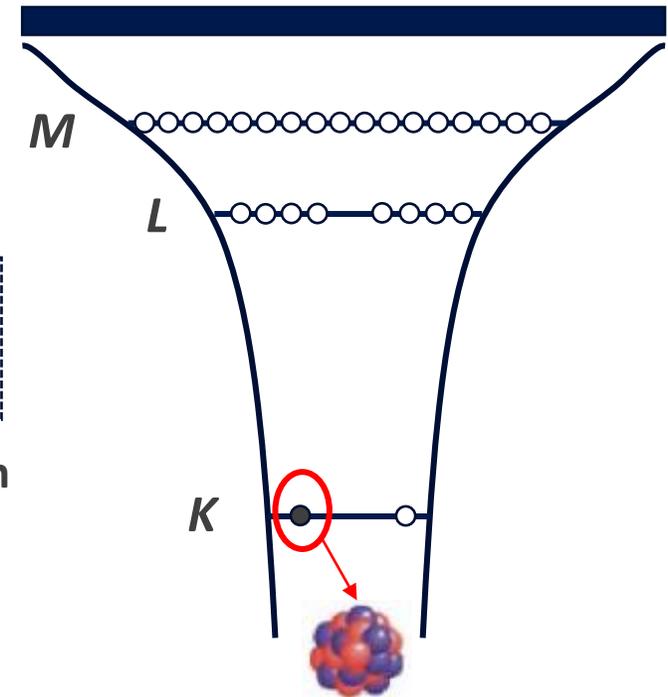
$T_{1/2} = 4570$ days
(EC decay)



$^{163}\text{Ho}^{67+}$ stable

● Occupancy
○ Vacancy

Highly charged ion



Orbital electron capture is blocked!

Electron-nucleus coupling can be responsible for the change in decay rates!

Measurement decay rate on H- & He-like ^{140}Pr 

GSI Helmholtzzentrum für
Schwerionenforschung



^{140}Pr 3.39 min $\epsilon+\beta^+=100\%$	^{141}Pr STABLE 100%
^{139}Ce 137.64 d $\epsilon=100\%$	^{140}Ce STABLE 88.449%

EC

$$W = \frac{2\pi}{\hbar} |\langle f | \hat{O} | i \rangle|^2 \rho_f$$

$\propto |\psi(0)|^2$

Density of v_e
final states per
energy

*Litvinov et al., PRL, 2007

Measurement decay rate on H- & He-like ^{140}Pr 

^{140}Pr 3.39 min $\varepsilon + \beta^+ = 100\%$	^{141}Pr STABLE 100%
^{139}Ce 137.64 d $\varepsilon = 100\%$	^{140}Ce STABLE 88.449%

EC

Theoretical expectation



$$\frac{\lambda_{EC}(H\text{-like})}{\lambda_{EC}(He\text{-like})} \sim 0.5$$

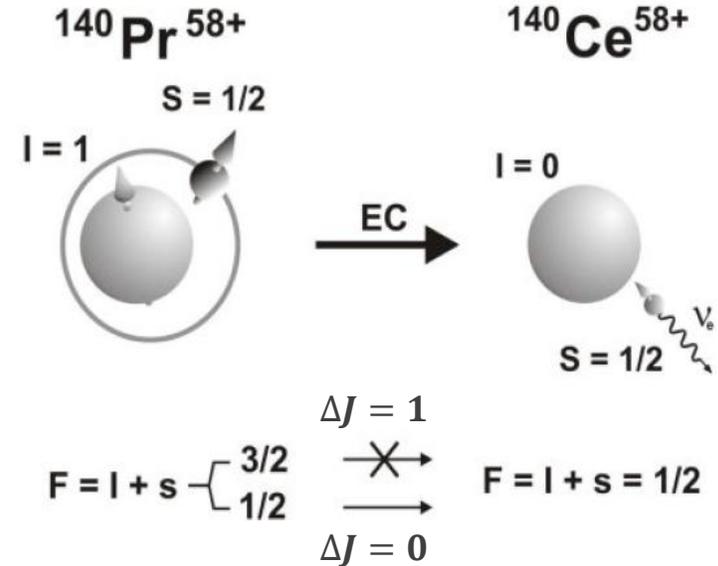
Experimental measurement



$$\frac{\lambda_{EC}(H\text{-like})}{\lambda_{EC}(He\text{-like})} \sim 1.49(8)$$

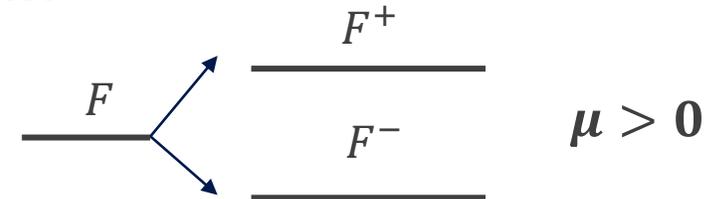
*Litvinov et al., PRL, 2007

Why such mismatch?



1. Hyperfine states

$$F^{\pm} = I \pm \frac{1}{2}$$



Measurement decay rate on H- & He-like ^{140}Pr



^{140}Pr 3.39 min $\varepsilon+\beta^+=100\%$	^{141}Pr STABLE 100%
^{139}Ce 137.64 d $\varepsilon=100\%$	^{140}Ce STABLE 88.449%

EC

Theoretical expectation



$$\frac{\lambda_{EC}(H\text{-like})}{\lambda_{EC}(He\text{-like})} \sim 0.5$$

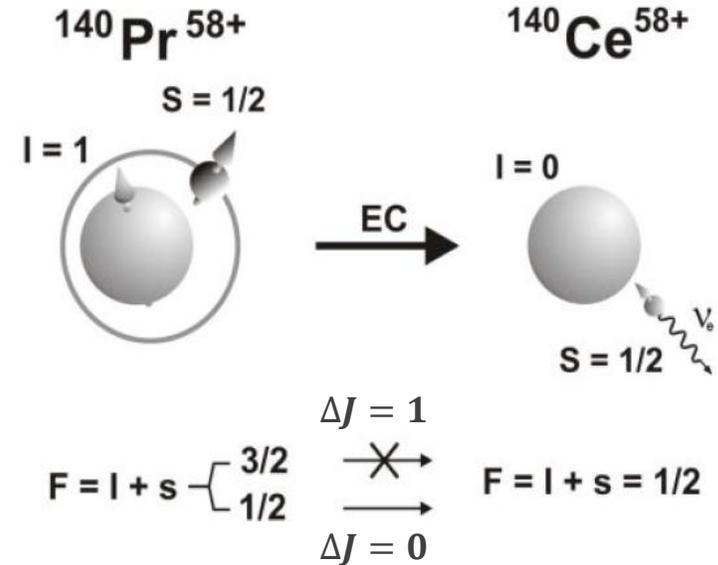
Experimental measurement



$$\frac{\lambda_{EC}(H\text{-like})}{\lambda_{EC}(He\text{-like})} \sim 1.49(8)$$

*Litvinov et al., PRL, 2007

Why such mismatch?



1. Hyperfine states
2. Angular momentum conservation
3. Sensitivity to population of this state

Several cases of interest in HCIs

PHYSICAL REVIEW C 77, 014306 (2008)

Orbital electron capture decay of hydrogen- and helium-like ions

Zygmunt Patyk,¹ Jan Kurcewicz,² Fritz Bosch,³ Hans Geissel,³ Yuri A. Litvinov,³ and Marek Pfützner²

¹Soltan Institute for Nuclear Studies, Hoża 69, PL-00-681 Warsaw, Poland

²Institute of Experimental Physics, Warsaw University, Hoża 69, PL-00-681 Warsaw, Poland

³Gesellschaft für Schwerionenforschung (GSI), Planckstrasse 1, D-64291 Darmstadt, Germany

(Received 3 August 2007; published 10 January 2008)



Due to the hyperfine interaction and the conservation of the total angular momentum some transitions become forbidden, which may drastically change the EC decay rate.

- a) EC decay with transition, $I_f = I_i$
- b) EC decay with transition, $I_f = I_i \pm 1$

GOOD AGREEMENT WITH ¹⁴⁰Pr EXPERIMENTAL MEASUREMENT!

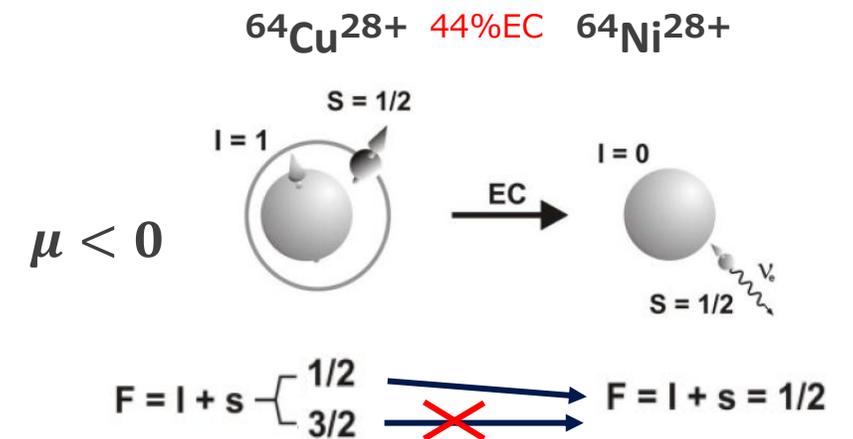
HINA



Cosmic Ray

Suggested nuclei to be studied experimentally

H-like ion	$I_i^{\pi_i} \rightarrow I_f^{\pi_f}$	μ/μ_N	δE (eV)	$\tau_{1/2}$	$T_{1/2}$
¹⁹ Ne	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^+$	-1.89	0.004	3 d	17.3 s
³⁷ Ar	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	+1.15	0.01	10 h	35 d
⁶⁴ Cu	$1^+ \rightarrow 0^+$	-0.22	0.009	7 h	12.7 h
⁶⁸ Ga	$1^+ \rightarrow 0^+$	+0.01	0.001	5 yr	67.7 min
⁷¹ Ge	$\frac{1}{2}^- \rightarrow \frac{3}{2}^-$	+0.55	0.041	12 min	11.2 d
¹⁰⁸ Ag	$1^+ \rightarrow 0^+$	+2.69	0.53	0.24 s	2.37 min
¹³¹ Cs	$\frac{5}{2}^+ \rightarrow \frac{3}{2}^+$	+3.54	0.98	31 ms	9.69 d
¹⁴¹ Nd	$\frac{3}{2}^+ \rightarrow \frac{5}{2}^+$	+1.01	0.43	0.4 s	2.5 h
¹⁷⁸ Ta	$1^+ \rightarrow 0^+$	+2.74	2.87	1.6 ms	9.31 min



ANNUAL REVIEW OF NUCLEAR AND PARTICLE SCIENCE Volume 57, 2007

Review Article

Cosmic-Ray Propagation and Interactions in the Galaxy

Andrew W. Strong¹, Igor V. Moskalenko², and Vladimir S. Ptuskin³

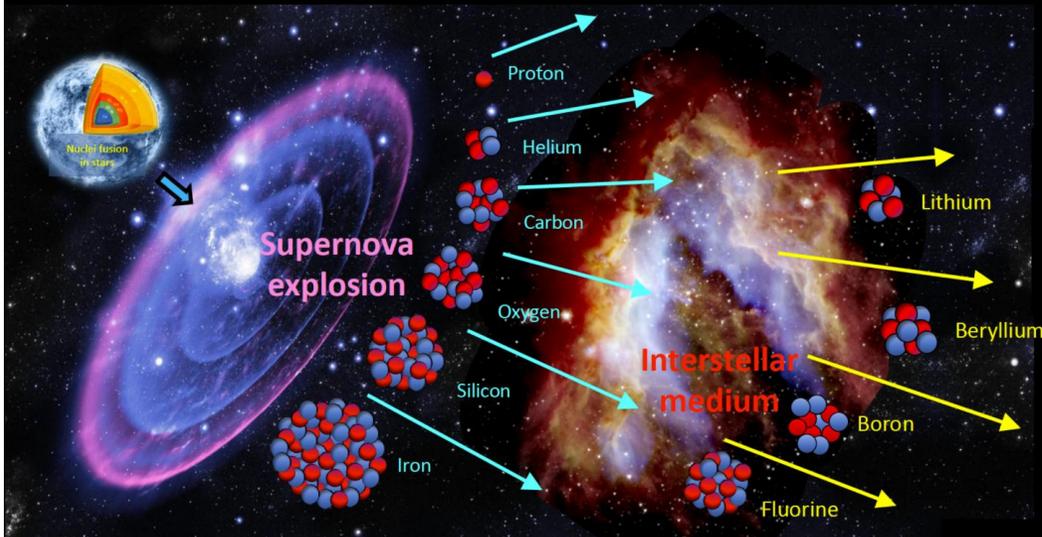
Hide Affiliations

Affiliations:

¹Max-Planck-Institut für extraterrestrische Physik, 85741 Garching, Germany; email: aws@mpe.mpg.de

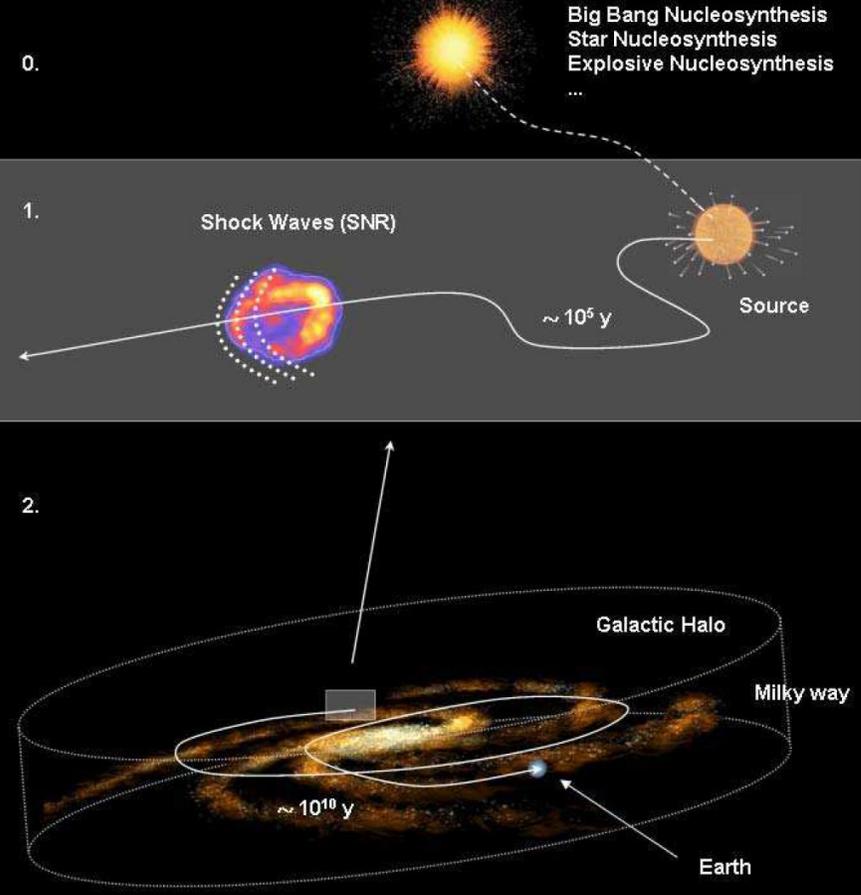
²Hansen Experimental Physics Laboratory and Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, California 94305; email:

Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays, C, O, Ne, Mg, Si, ..., Fe, with the interstellar medium.



Measurements of the secondary cosmic ray nuclei fluxes and the secondary to primary flux ratios are important in understanding the propagation of cosmic rays in the Galaxy.

Galactic Cosmic Rays Life



NEED FOR ACCURATE MEASUREMENTS TO IMPROVE MODELS ACCURACY!

Where can we study HCI?

Where can we study HCI?

The prerequisite for decay studies of heavy HCIs is their **production** in a (high) atomic charge state of interest

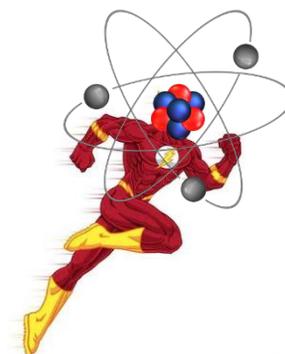


Not naturally available!
This is a challenging task!!

Large nuclear physics facilities



GSI
GSI Helmholtzzentrum für
Schwerionenforschung



C, Cu foil



Charge
state
selection!

Beam Energy

U : 50-1000 MeV/u

Ne: 50-2000 MeV/u

p : 4,5 GeV

Production:

- *In-flight* production and separation of exotic nuclei
- Stripping foils used to remove bound electrons

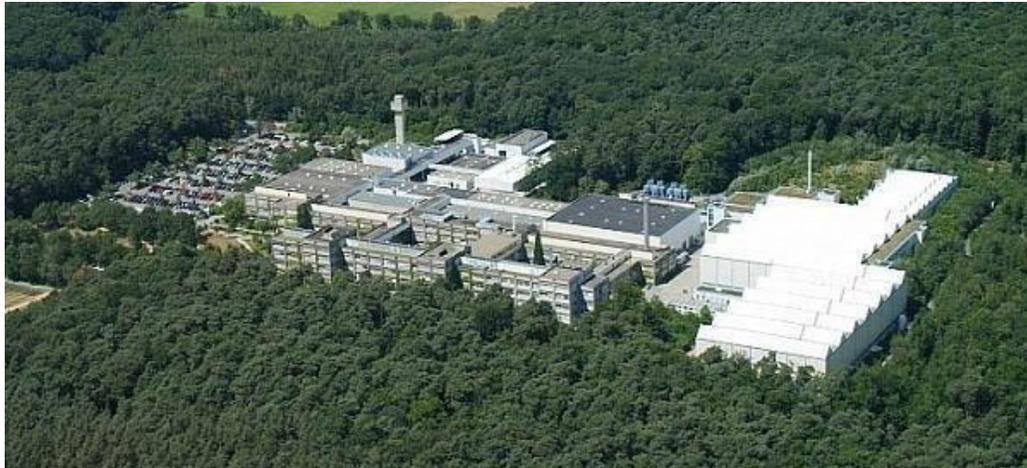
Where can we study HCI?

The prerequisite for decay studies of heavy HCIs is their **production** in a (high) atomic charge state of interest

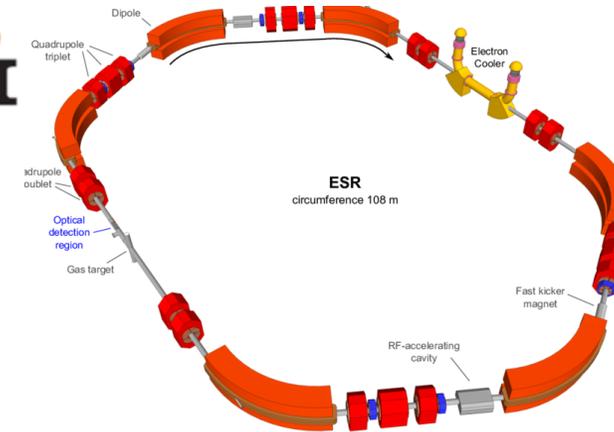


Not naturally available!
This is a challenging task!!

Large nuclear physics facilities



GSI
GSI Helmholtzzentrum für
Schwerionenforschung



Studies carried
out in
Heavy-ion
storage rings!

Beam Energy

U : 50-1000 MeV/u
Ne: 50-2000 MeV/u
p : 4,5 GeV

HCI studies timeline

1992

M. Jung et al.,
PRL 69 (1992), 2164

2024

Leckenby et al.,
Nature 635, 2024

Where can we study HCI?

Disadvantages

1. High operation cost
2. Limited efficiency for radiation detection
3. Limited beam time (only few rings world-wide)

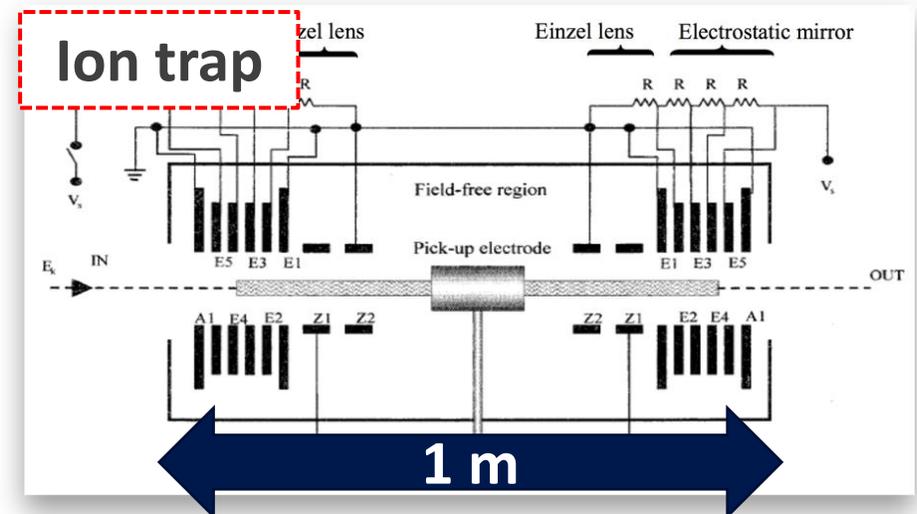
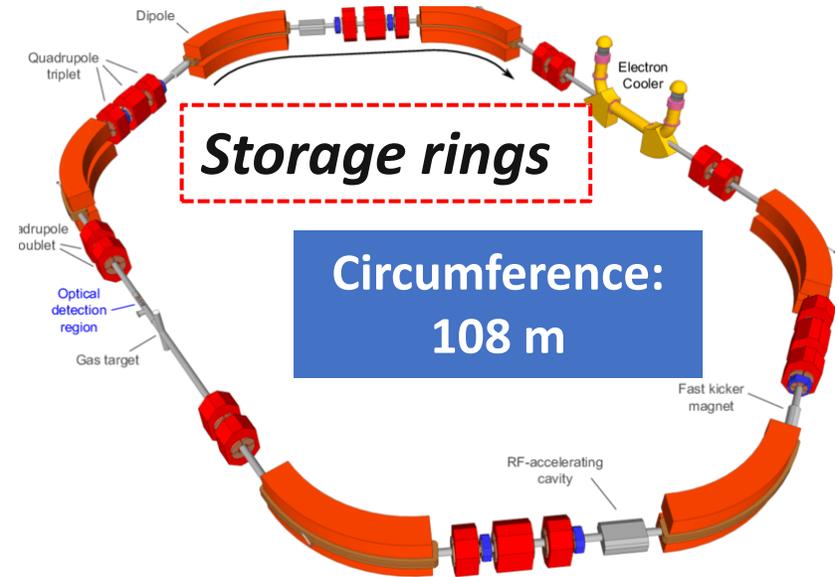
ISOL facilities



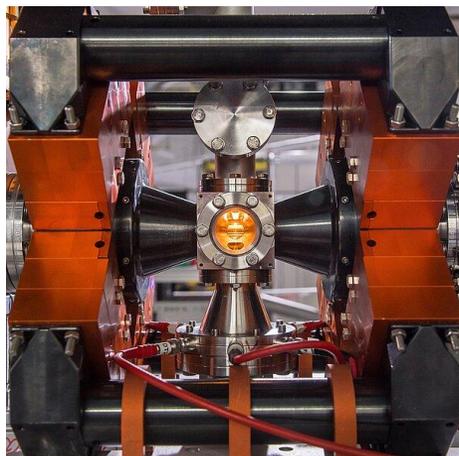
WELL SUITED
FOR IN-TRAP
SPECTROSCOPY
STUDIES!

Can we investigate HCIs in ion traps?

Traps are an alternative to storage rings since they are smaller, cheaper, eco & “outperform”



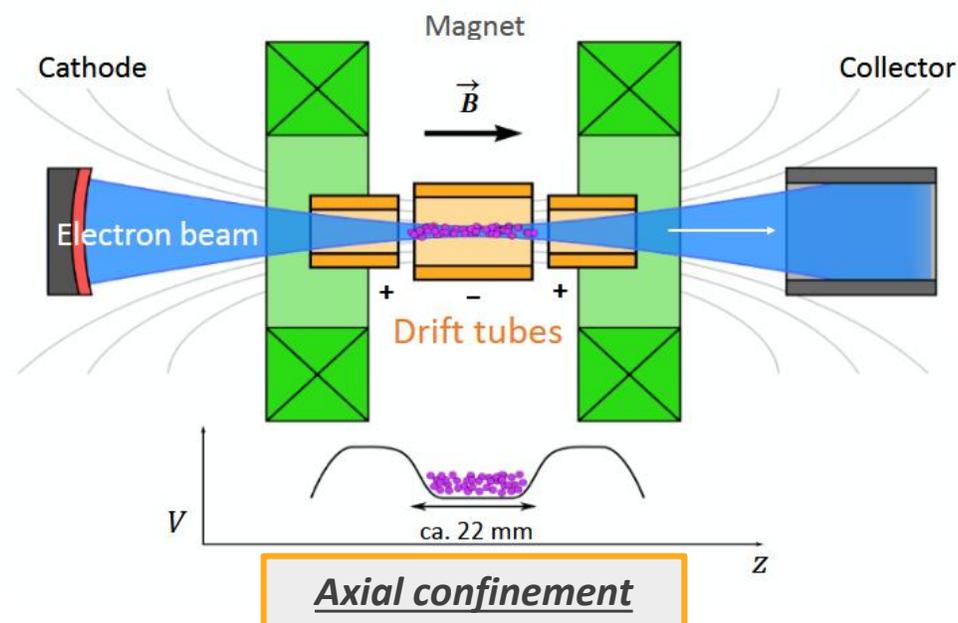
Can HCs be produced at low energies?



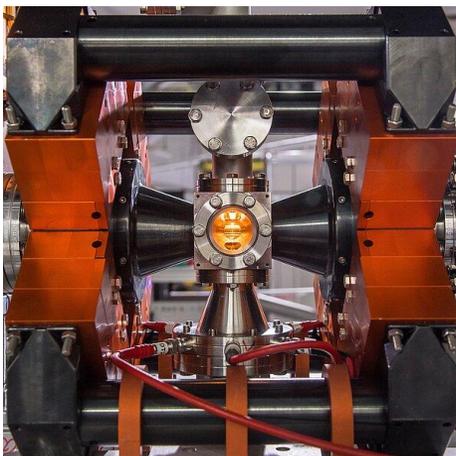
SPECIAL TYPE OF ION TRAPS

EBIT

(Electron Beam Ion Trap)



Can HCl be produced at low energies?



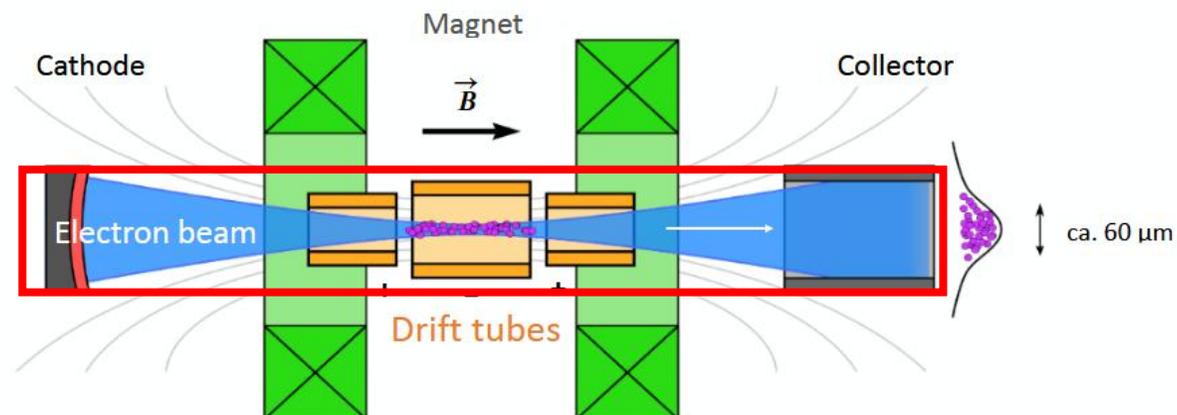
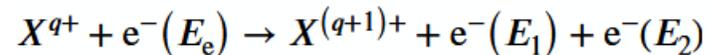
SPECIAL TYPE OF ION TRAPS

EBIT
(Electron Beam Ion Trap)

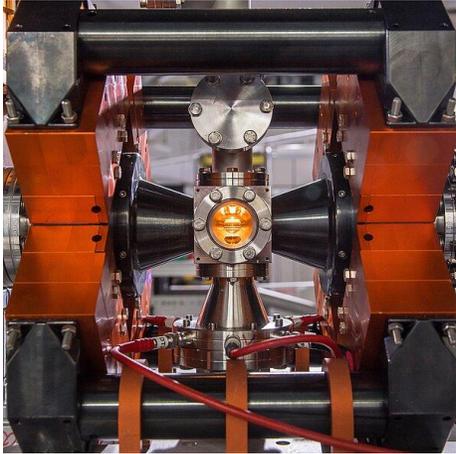


Electron beam (up to tens keV)

- Ionization of injected ions
- Radial confinement



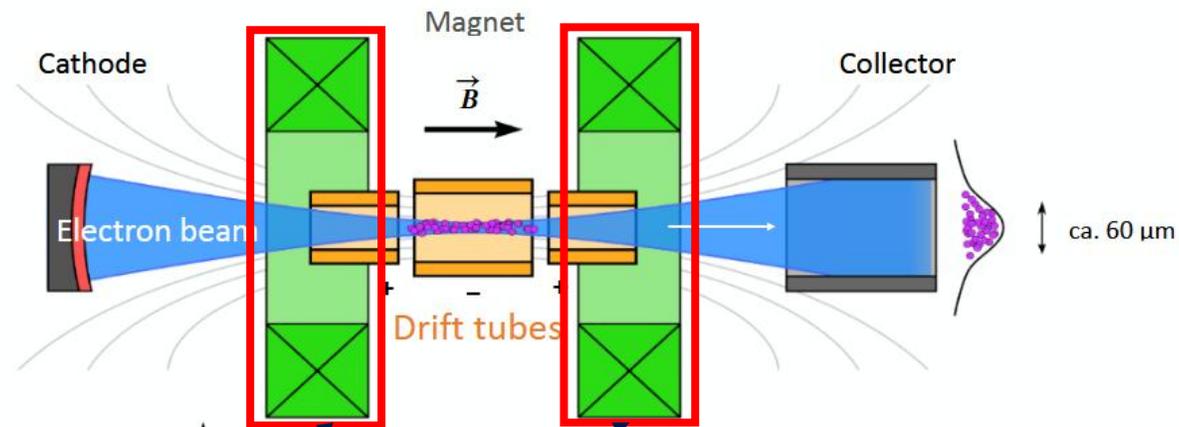
Can HCl be produced at low energies?



SPECIAL TYPE OF ION TRAPS

EBIT

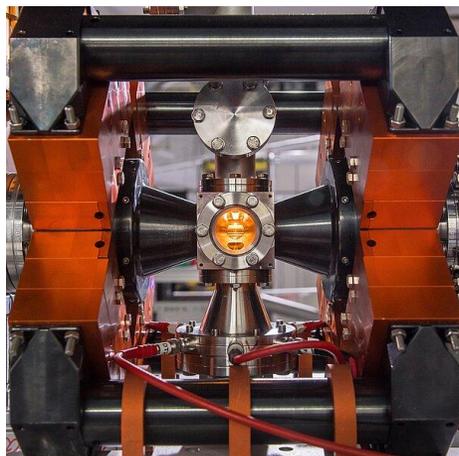
(Electron Beam Ion Trap)



Magnetic field (up to few Tesla)

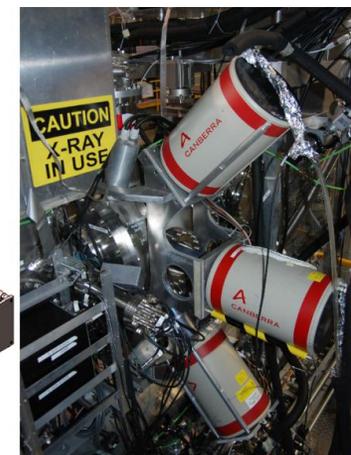
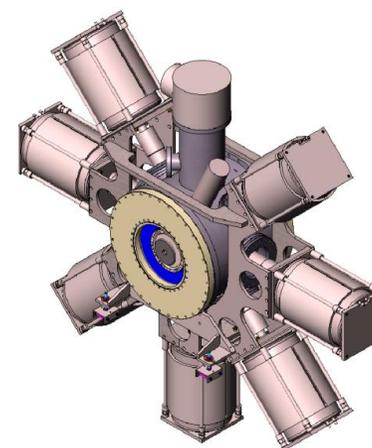
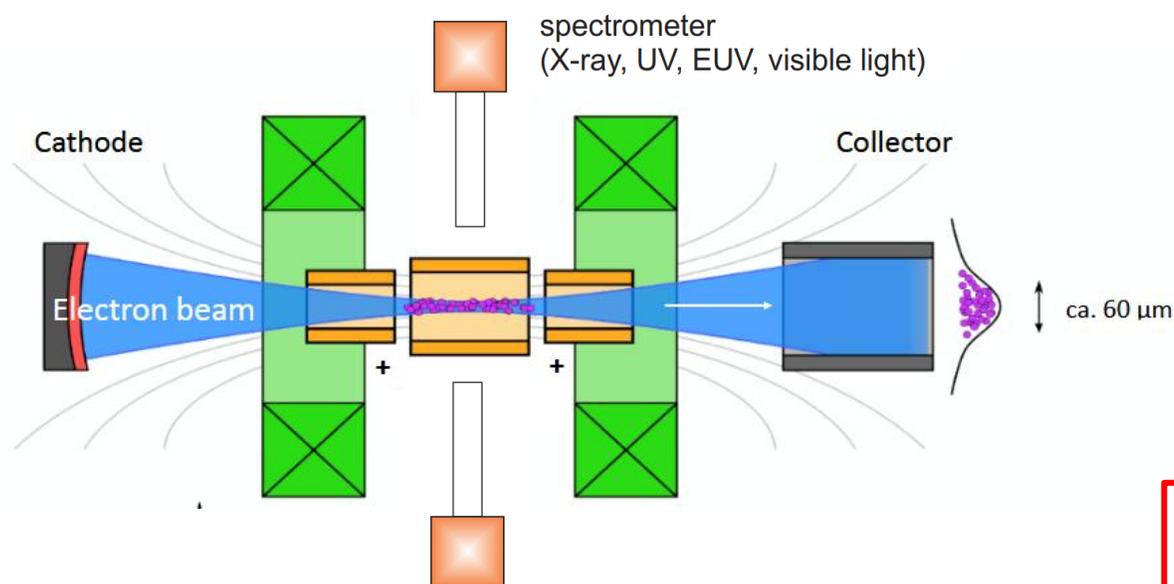
- Compression of the electron beam

Can HClIs be produced at low energies?



SPECIAL TYPE OF ION TRAPS

EBIT
(Electron Beam Ion Trap)



In-trap spectroscopy of charge-bred radioactive ions
*A. Lennarz et al., *PRL* 113, 082502 (2014)

HINA project



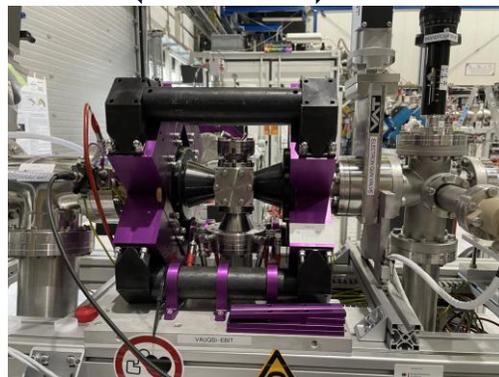


Develop of Compact EBIT (HC-EBIT)



Room temperature EBIT reduce construction & maintenance cost

32 cm



Compact EBIT properties

Electron beam energy (E_e)
around ten keV

Electron beam current (I_e)
up to 80 mA

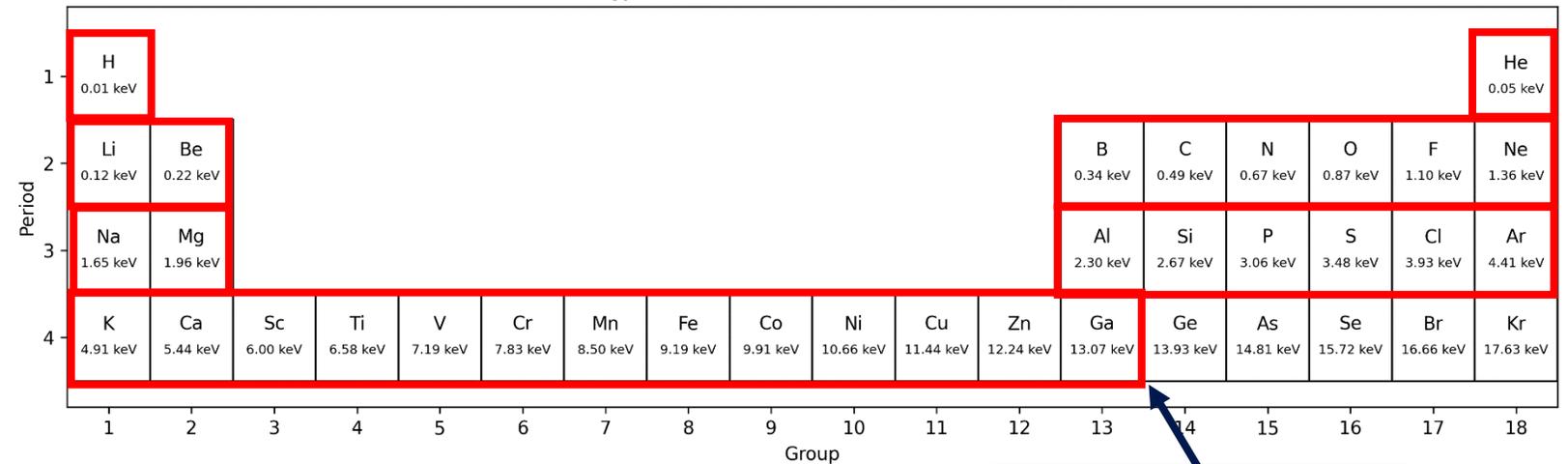


Develop of Compact EBIT (HC-EBIT)



Room temperature EBIT reduce construction & maintenance cost

Energy to Produce H-like Ions ($E = 13.6 Z^2 \text{ eV}$)



Max H-like system

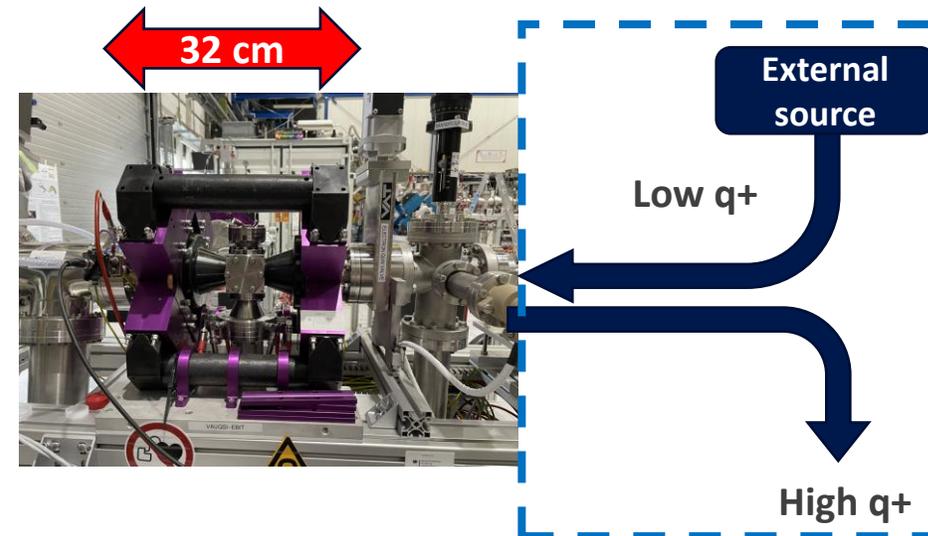


Develop of Compact EBIT (HC-EBIT)



Room temperature EBIT reduce construction & maintenance cost

1. Design and development
2. Injection & Extraction ion optics
 - Acceptance & Capture efficiency

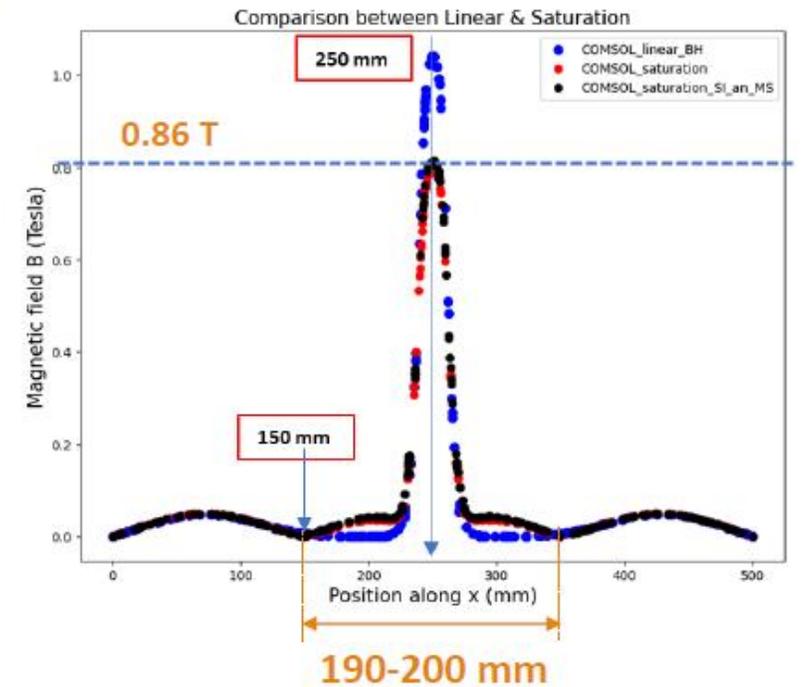
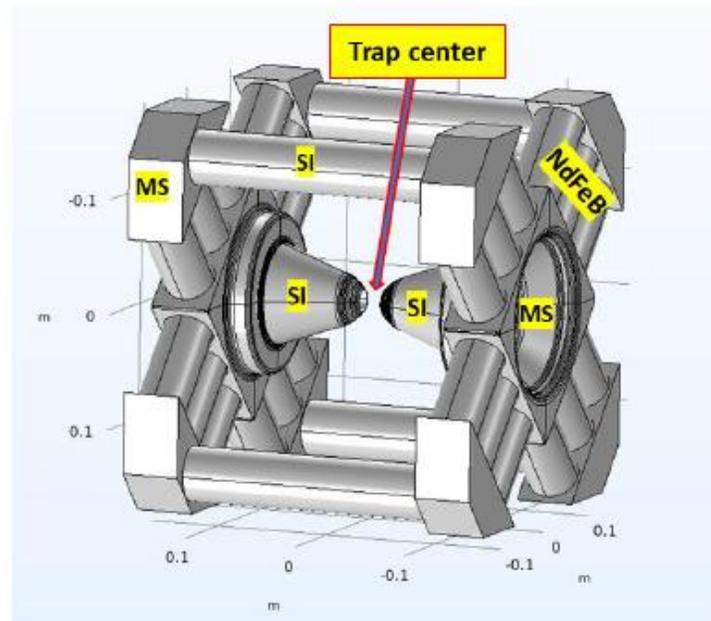
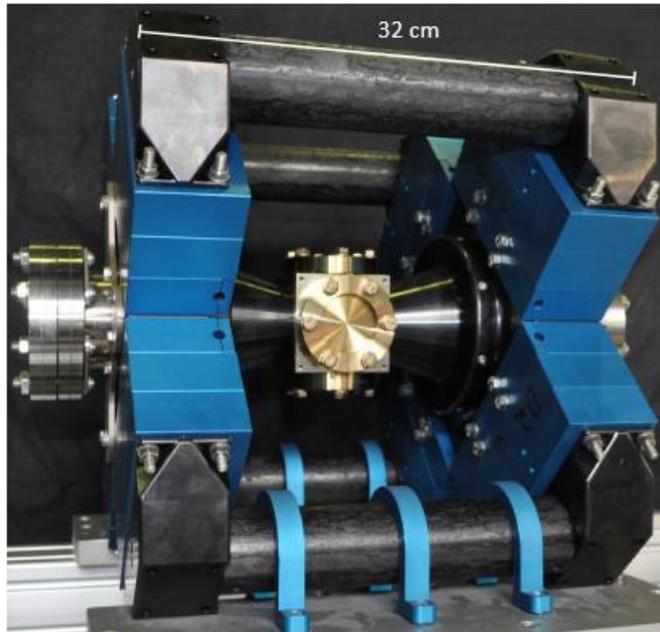


- For example:*
- Ion traps
 - Mass Experiments
 - Laser experiments

EBIT dynamics

Definition parameters (vacuum, electron-ions overlap, acceptance) crucial to optimize HCIs production and confinement.

Magnetic field investigation



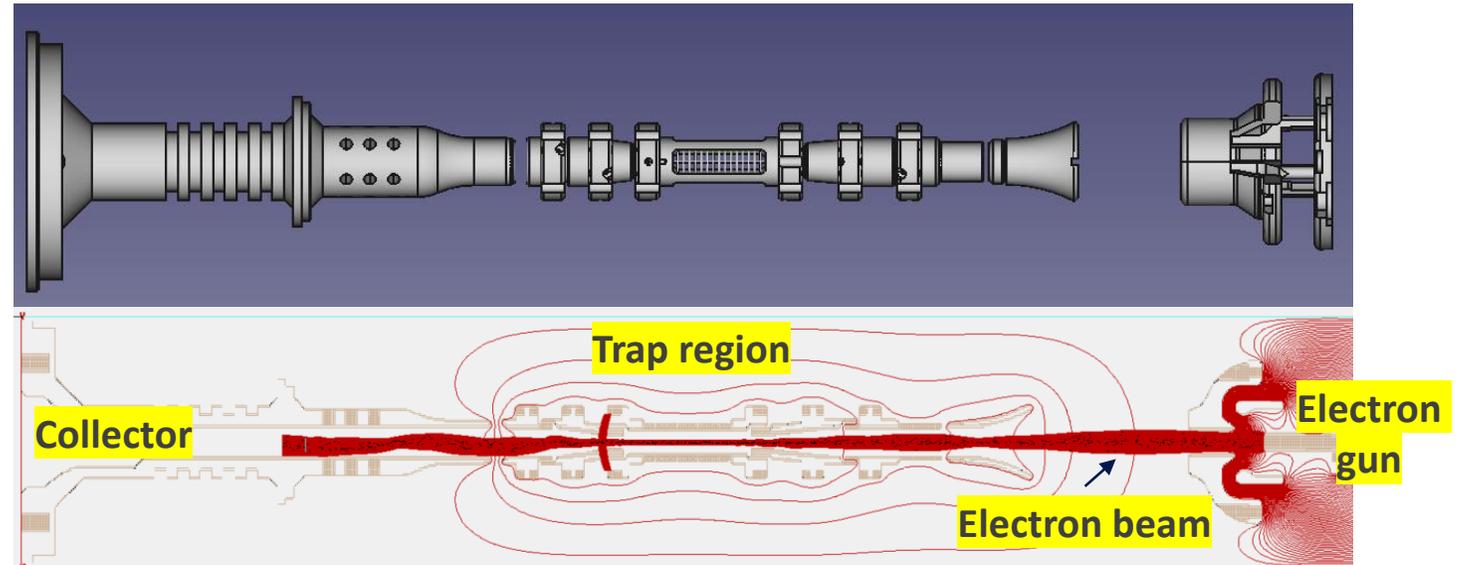
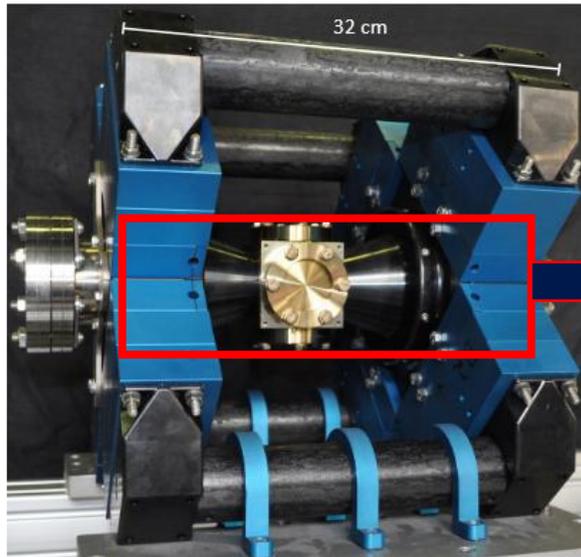
EBIT dynamics

Definition parameters (vacuum, electron-ions overlap, acceptance) crucial to optimize HCIs production and confinement.

Magnetic field investigation



Electron beam evolution



HC-EBIT simulations campaign (2023-2025)

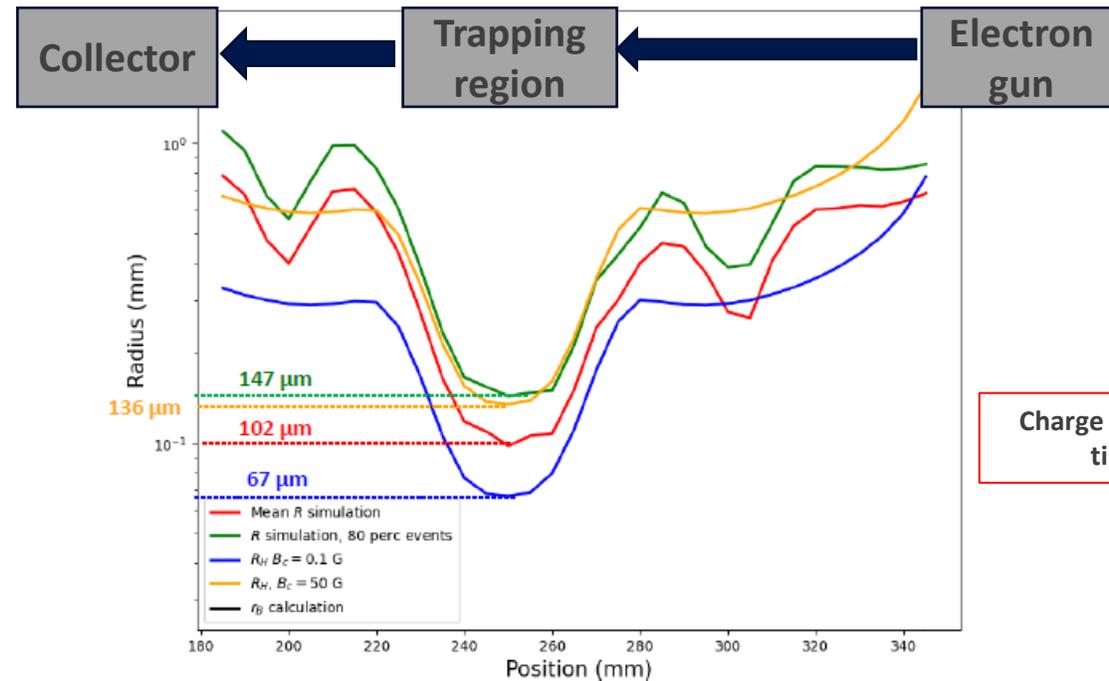
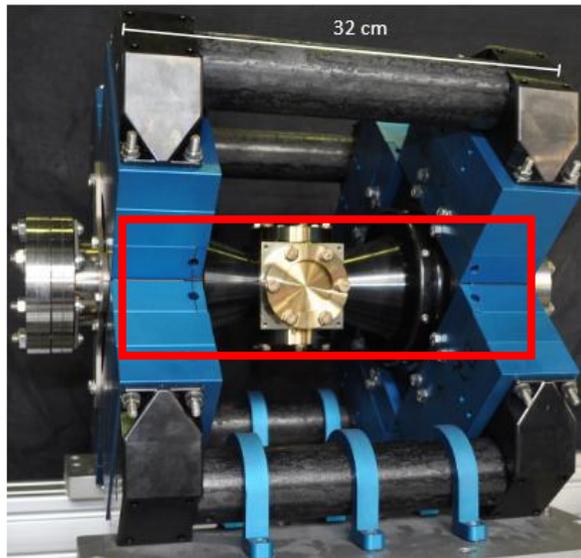
EBIT dynamics

Definition parameters (vacuum, electron-ions overlap, acceptance) crucial to optimize HCIs production and confinement.

Magnetic field investigation



Electron beam evolution



e^- density and speed

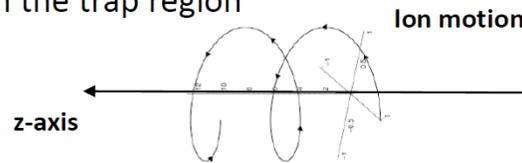
$$\tau \propto \frac{1}{n_e \cdot v_e}$$

Charge breeding time

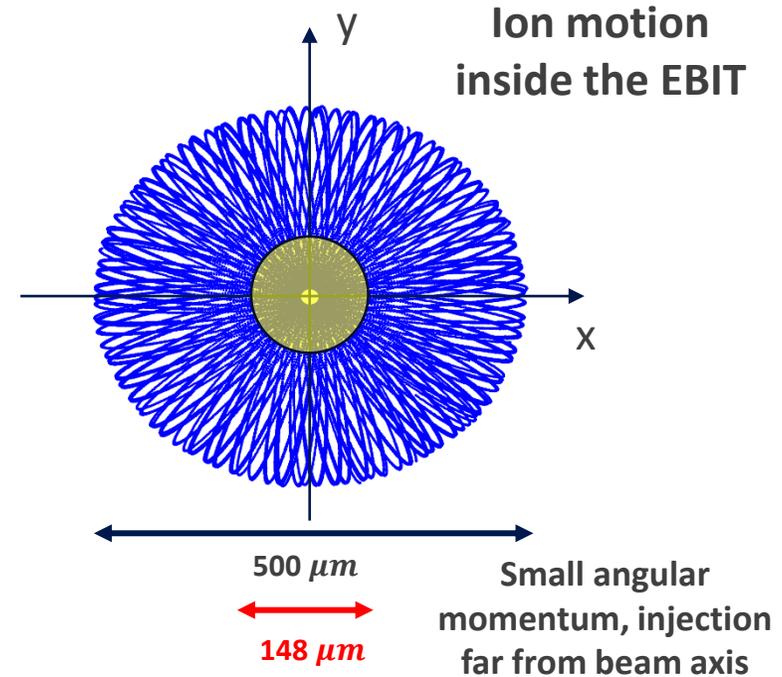
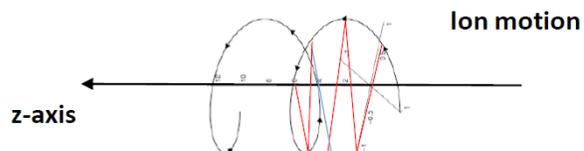
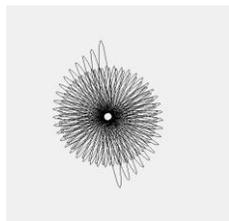
EBIT dynamics

Definition parameters (**vacuum**, **electron-ions overlap**, **acceptance**) crucial to **optimize HCIs production and confinement**.

- Magnetic field \vec{B} along z-axis, responsible for the sychron motion of the ions around the z-axis in the trap region



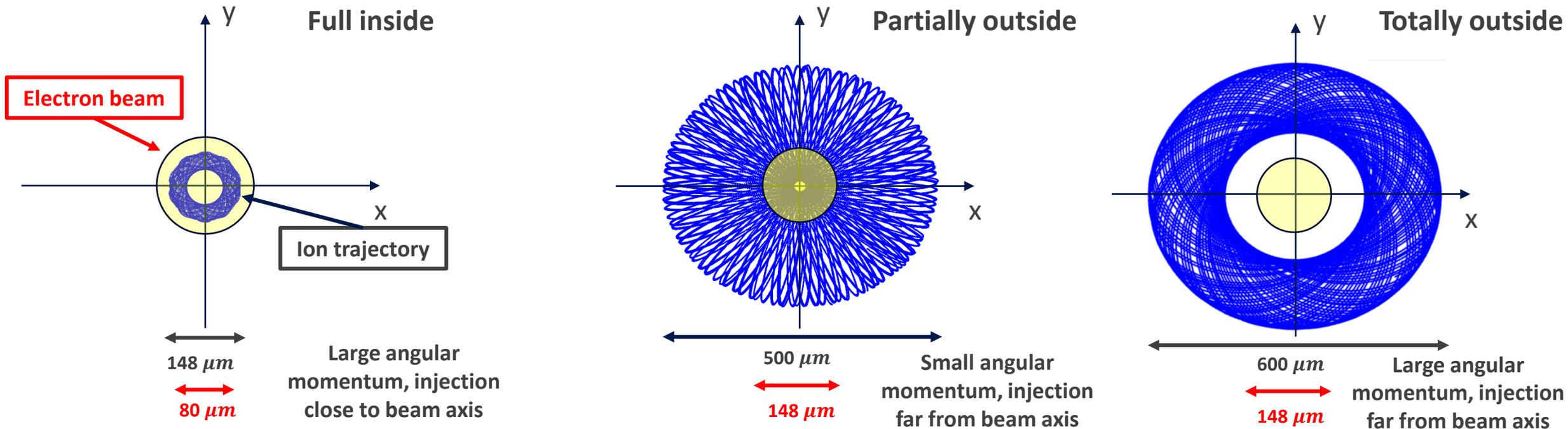
- Electric field \vec{E} produced by the electron beam. The intensity of this field depends on:
 - Linear density of the electron beam (current intensity, beam energy and beam radius)



EBIT dynamics

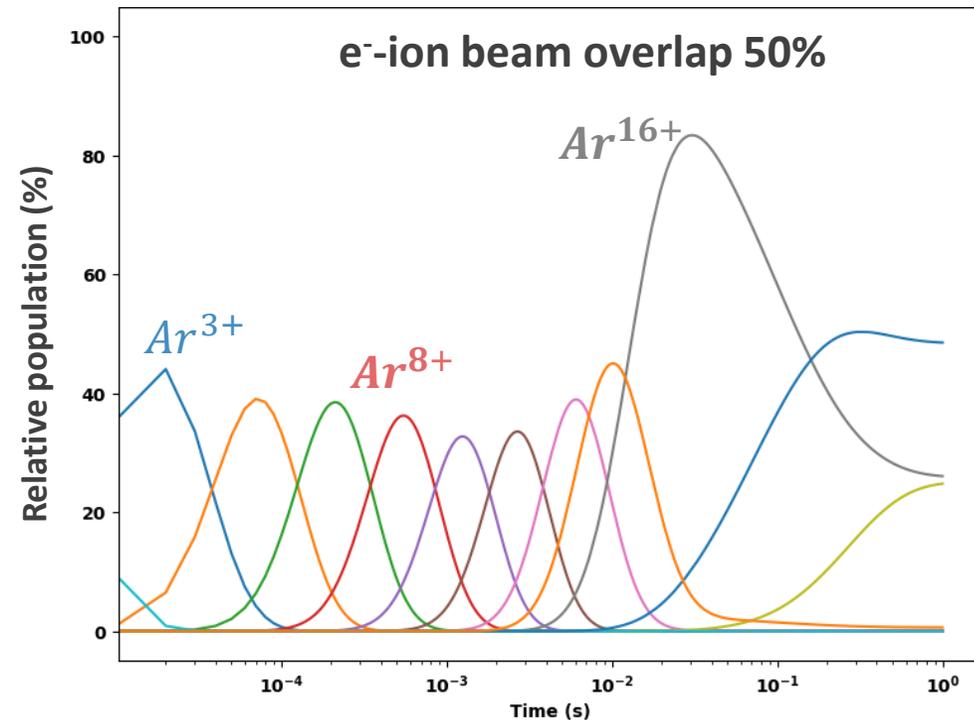
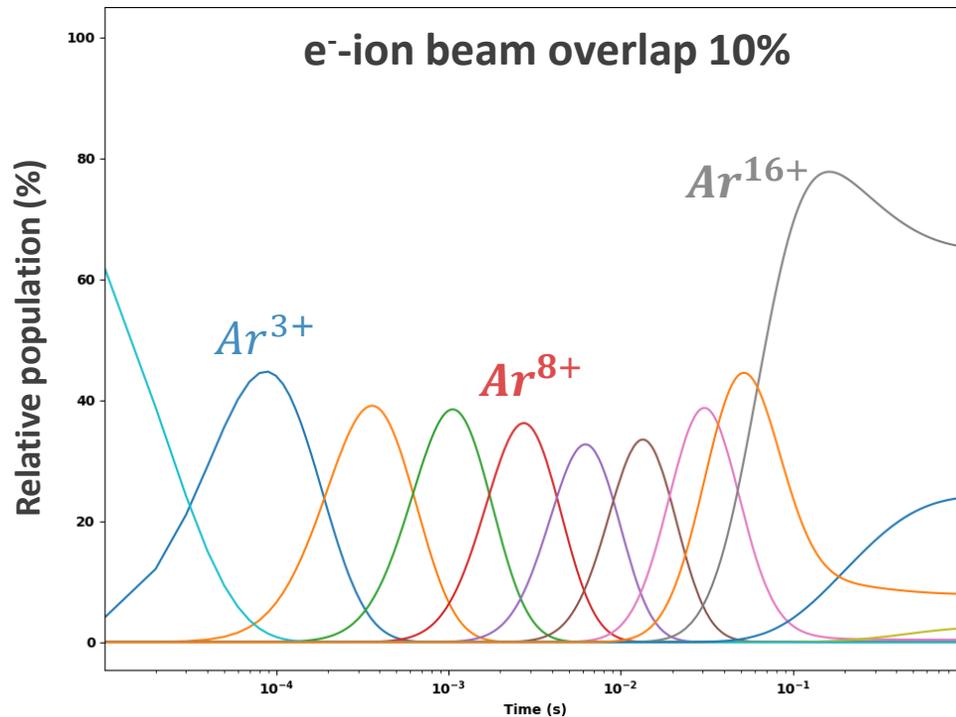
Definition parameters (**vacuum, electron-ions overlap, acceptance**) crucial to **optimize HCIs production and confinement**.

Depending on the way the ions are injected into the EBIT (**transverse velocity and position**), they can follow different trajectories which bring them to spend more or less time inside the electron beam.



EBIT dynamics

Definition parameters (**vacuum**, **electron-ions overlap**, **acceptance**) crucial to **optimize HCIs production and confinement**.



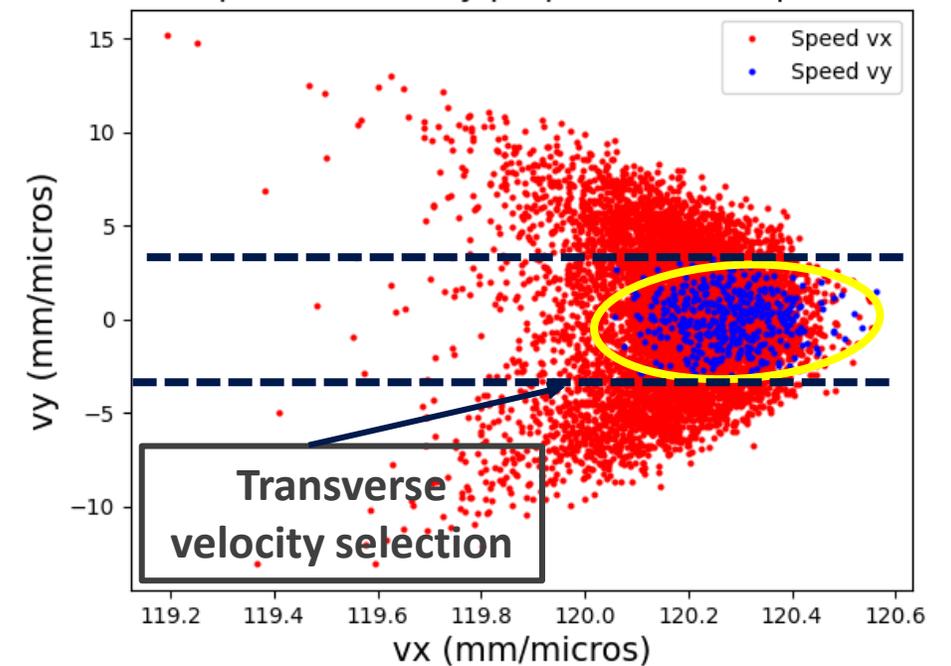
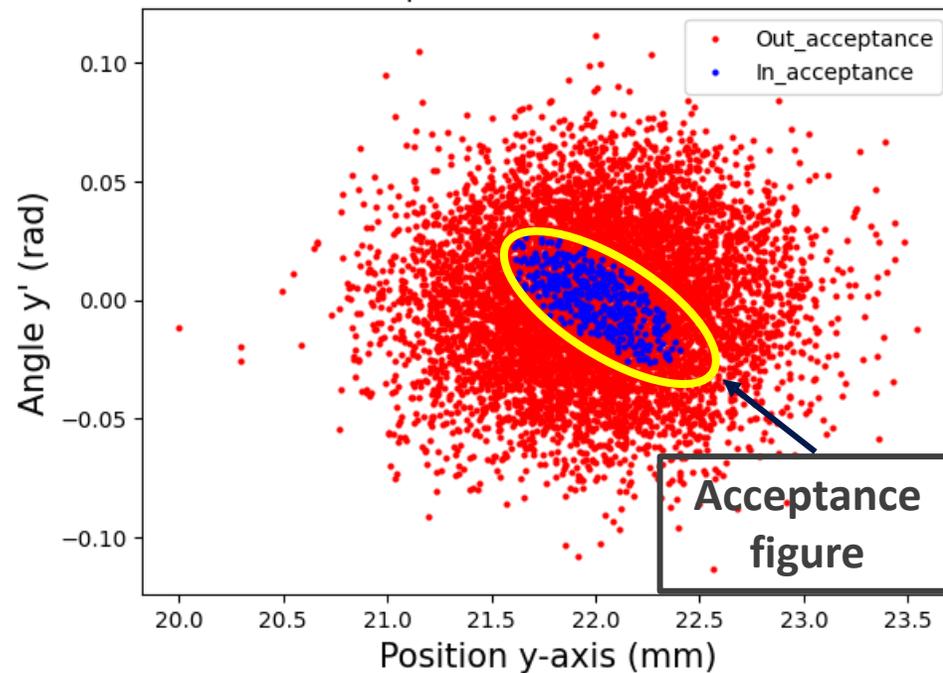
Improved Electron-beam overlap enhance high charge states achievable!

EBIT dynamics

Definition parameters (**vacuum, electron-ions overlap, acceptance**) crucial to **optimize HCIs production and confinement**.

Trap parameters:

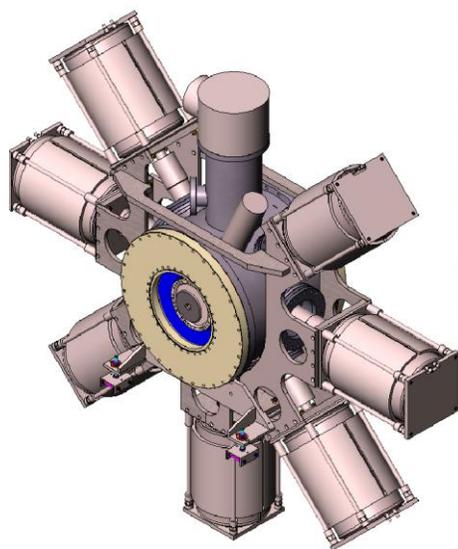
- $E_{e\text{-beam}} = 3.5 \text{ keV}$
- $I_{e\text{-beam}} = 17.91 \text{ mA}$



RMS Emittance (ϵ_{RMS}) for injected ion beam in x & y about 8 mm·mrad

EBIT

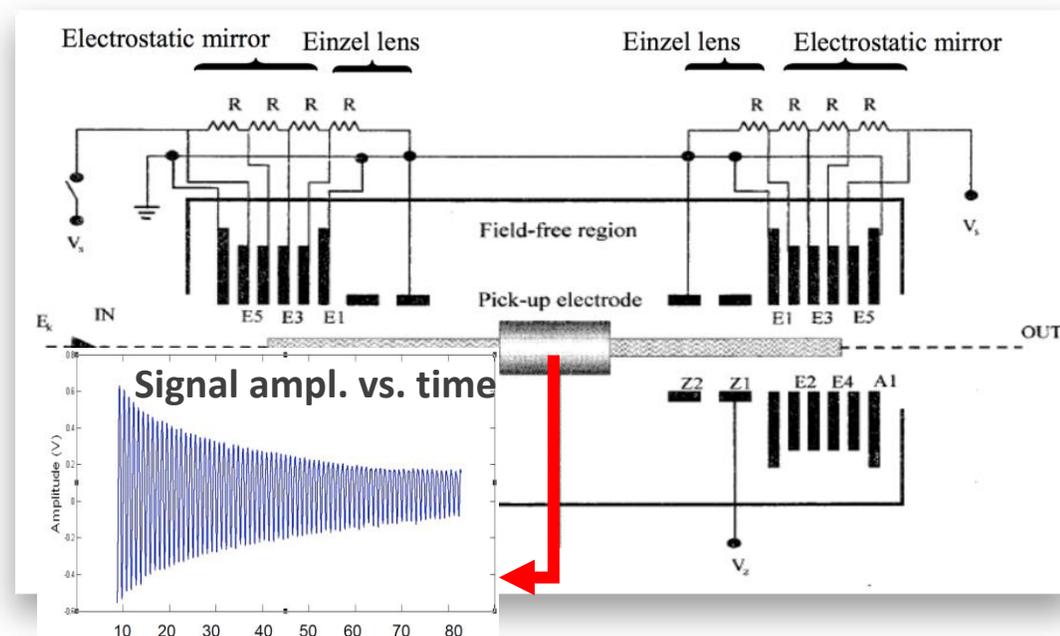
(Electron Beam Ion Trap)



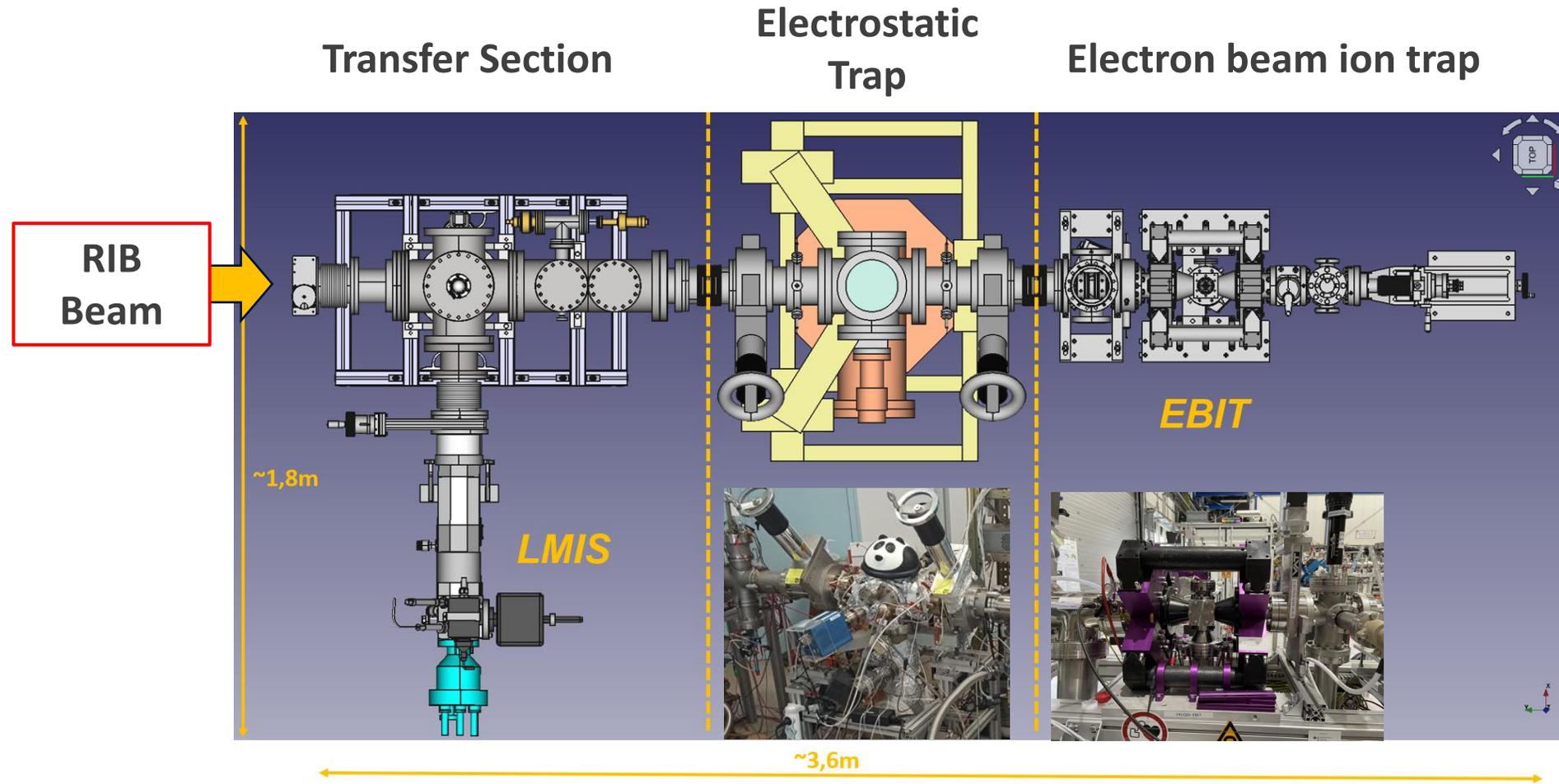
* K.G. Leach et al., EPJ Web of Conferences

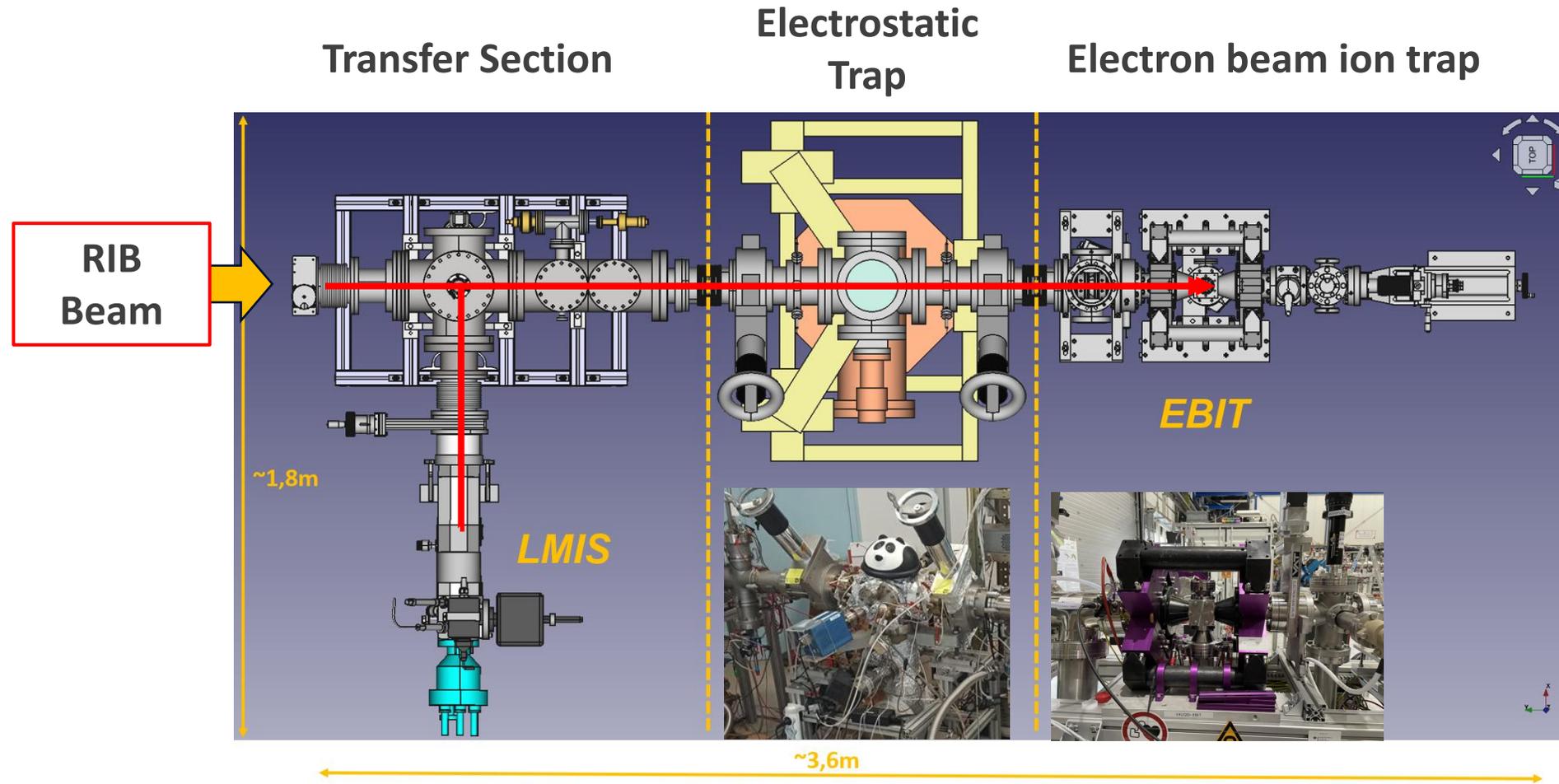
In-situ X-ray spectroscopy

External Electrostatic ion trap

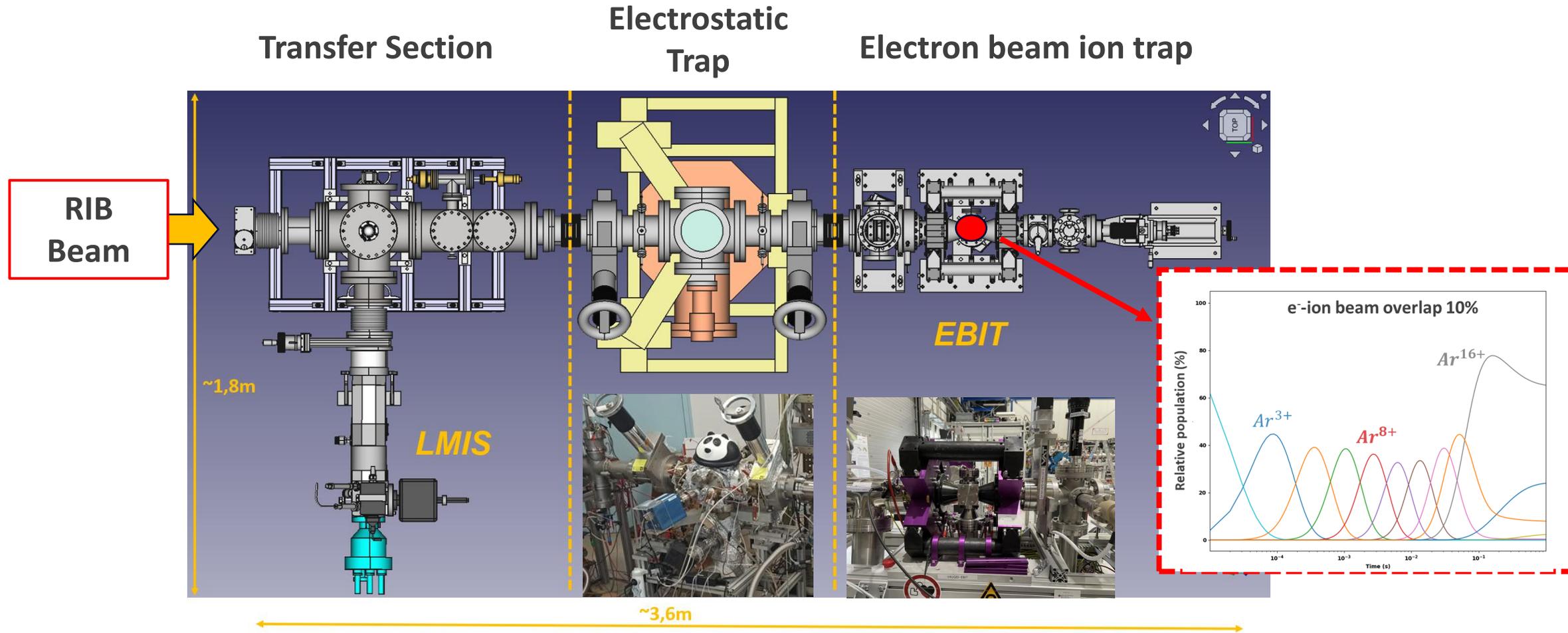


Decay signal on the pickup electrode

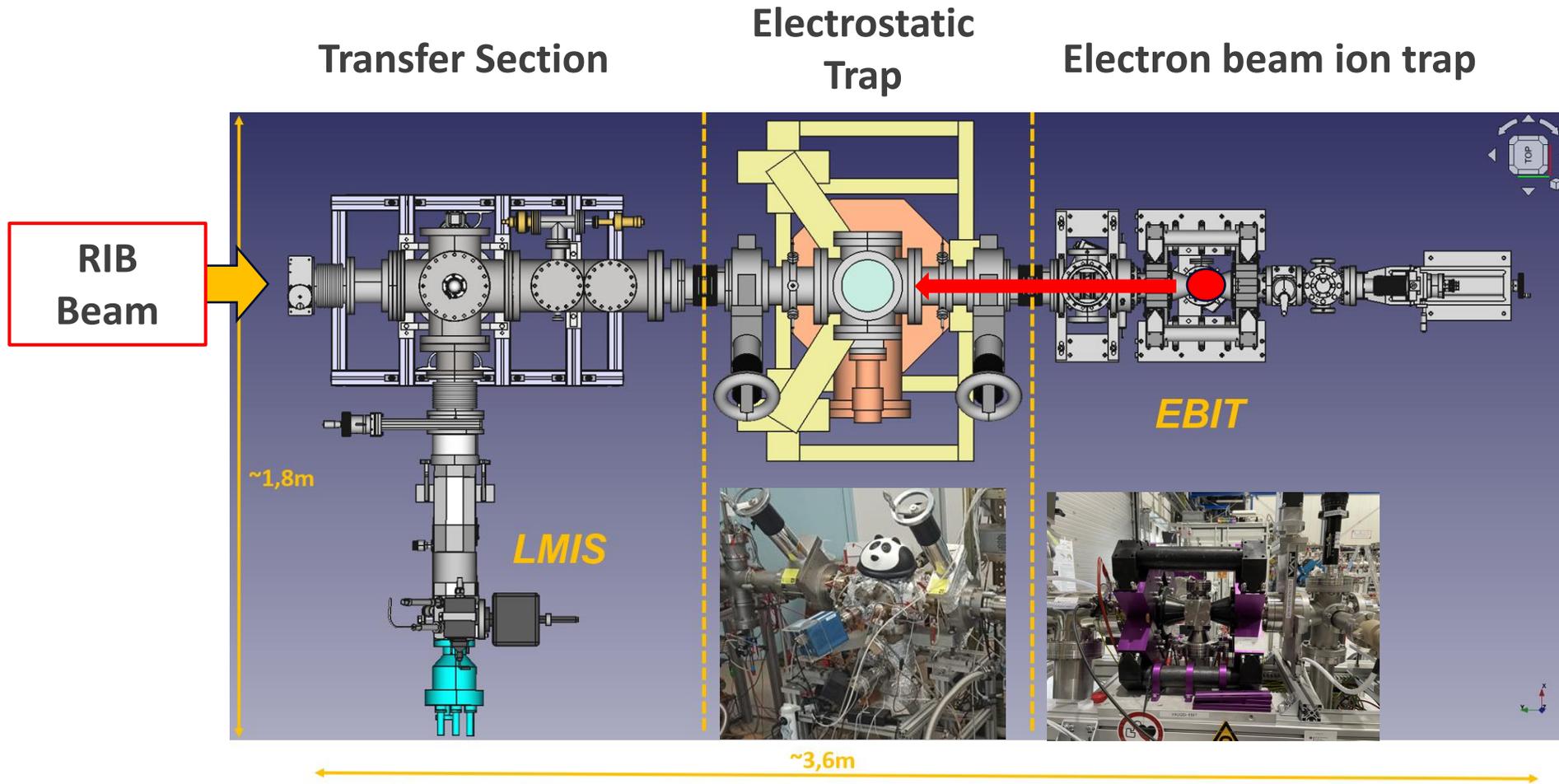


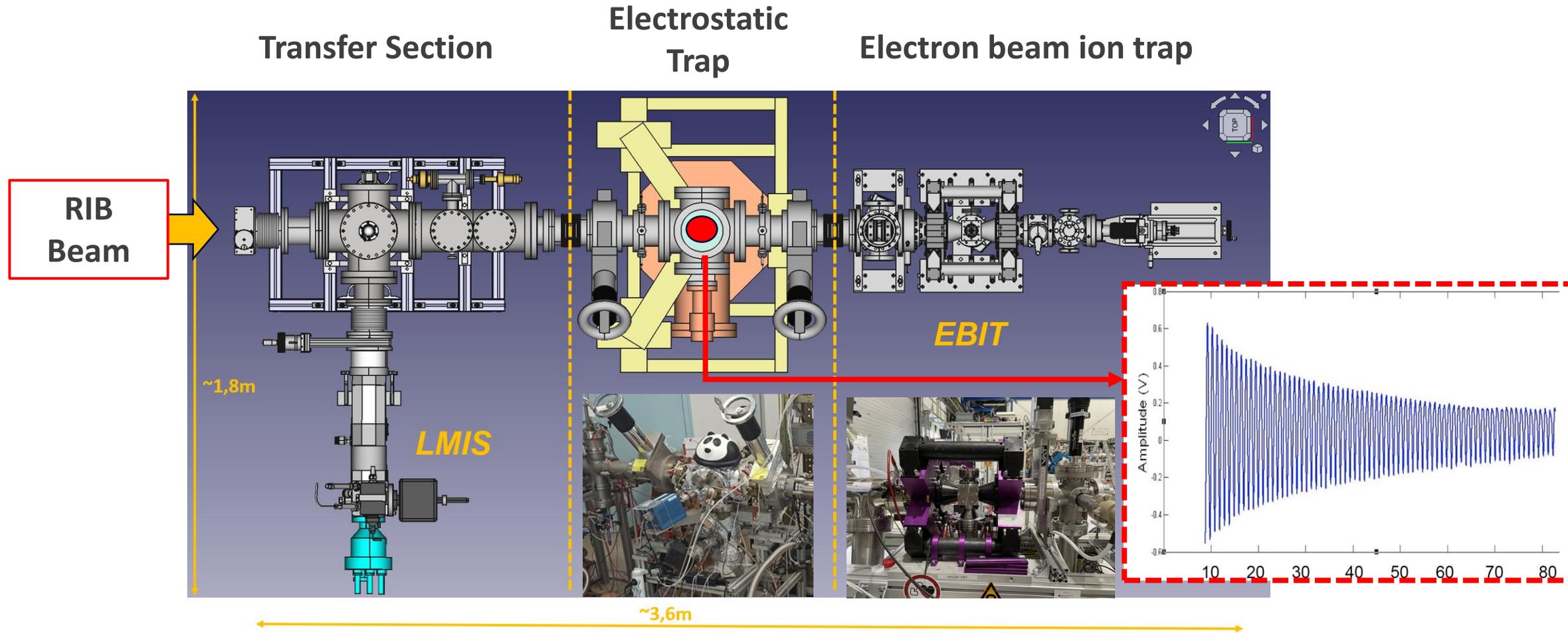


Conceptual design HINA experimental line



Conceptual design HINA experimental line







2ND
PHASE

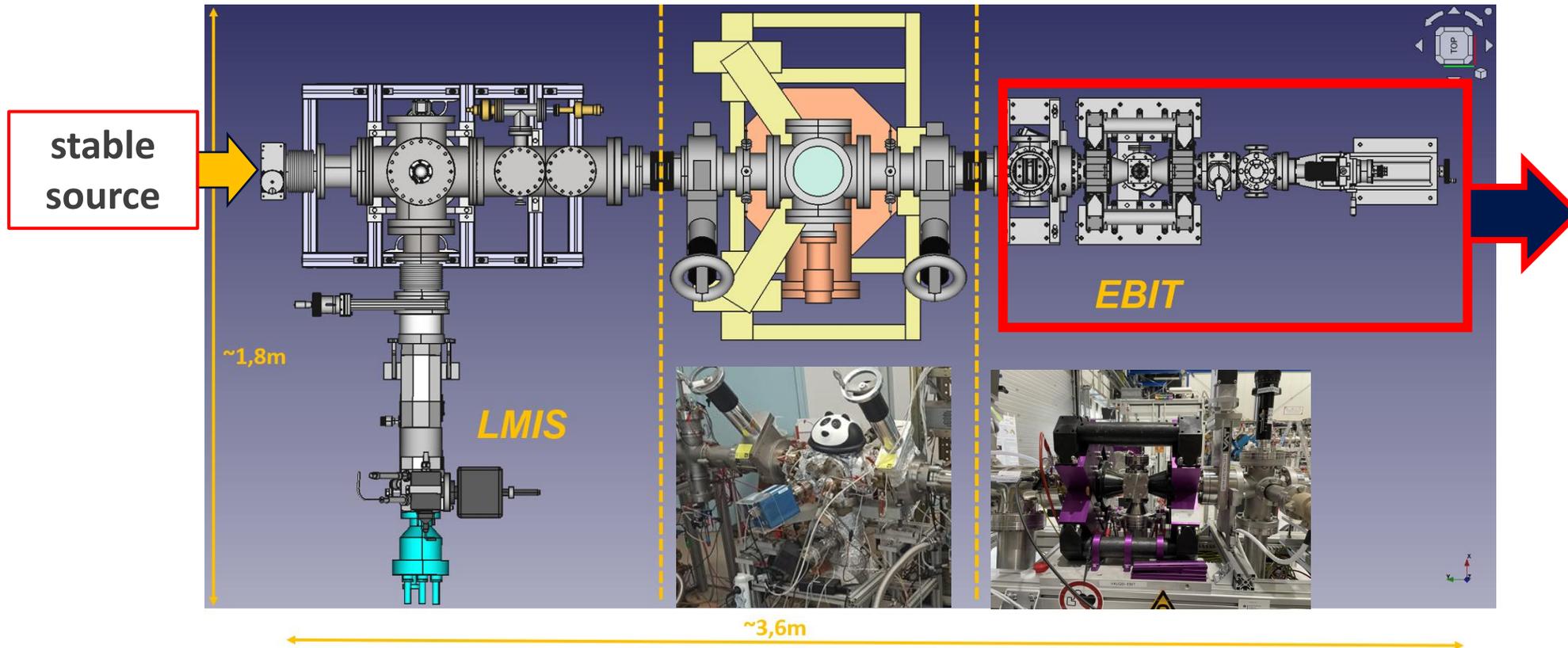
EBIT construction (MPIK) and
commissioning with stable beams (IJCLab)

ijc Lab
Irène Joliot-Curie
Laboratoire de Physique
des 2 Infinis

Transfer Section

Electrostatic
Trap

Electron beam ion trap



MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK
HEIDELBERG



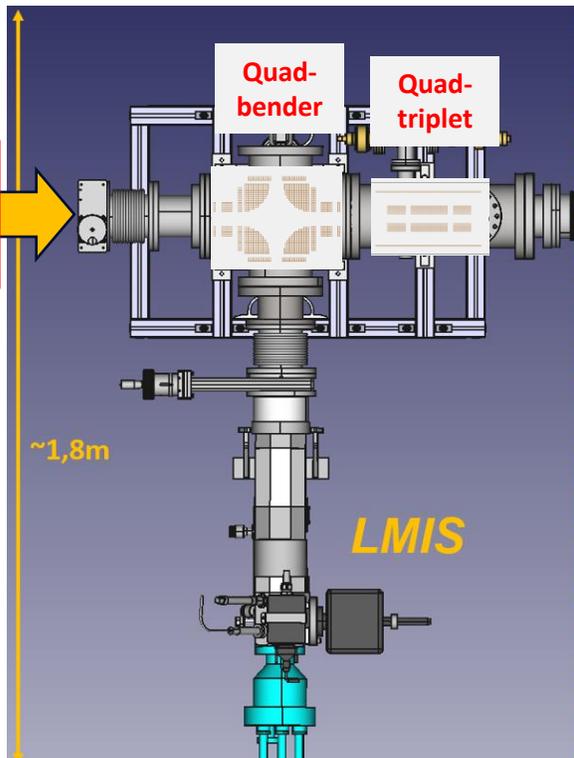
2ND
PHASE

EBIT construction (MPIK) and
commissioning with stable beams (IJCLab)

ijcLab
Irène Joliot-Curie

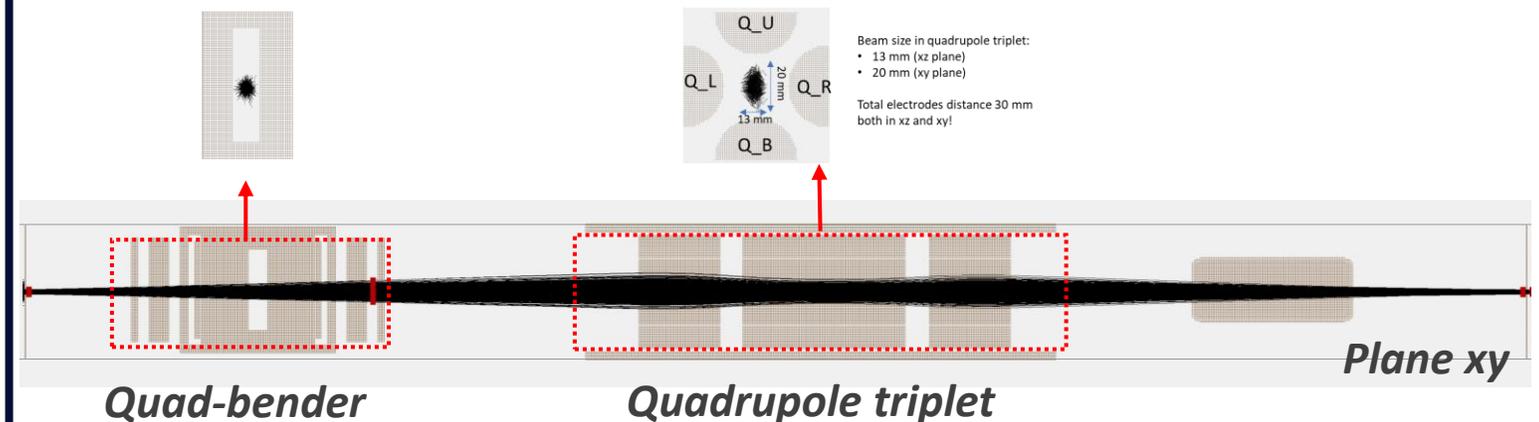
Laboratoire de Physique
des 2 Infinis

Transfer Section



Transfer Section

- Off-line characterization completed (June 2025)
- Transferred to new installations (July 2025)
- Optics simulations & Alignment/installation (May 2026)
- Commissioning - Summer 2026





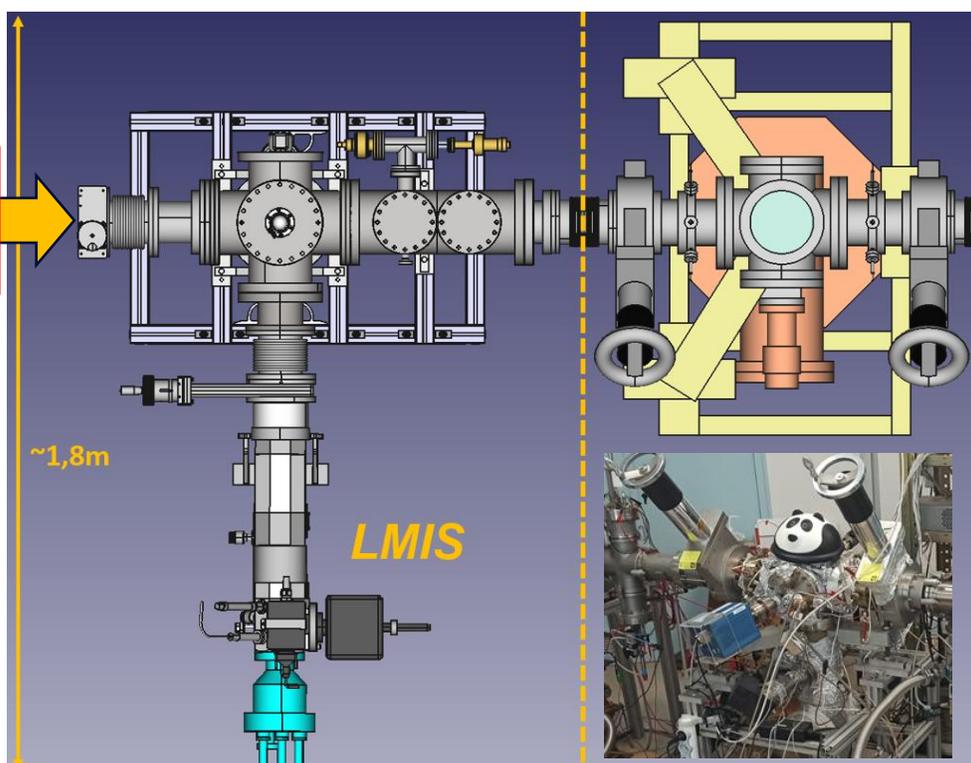
2ND
PHASE

EBIT construction (MPIK) and
commissioning with stable beams (IJCLab)

ijcLab
Irène Joliot-Curie

Laboratoire de Physique
des 2 Infinis

Transfer Section



Electrostatic ion trap

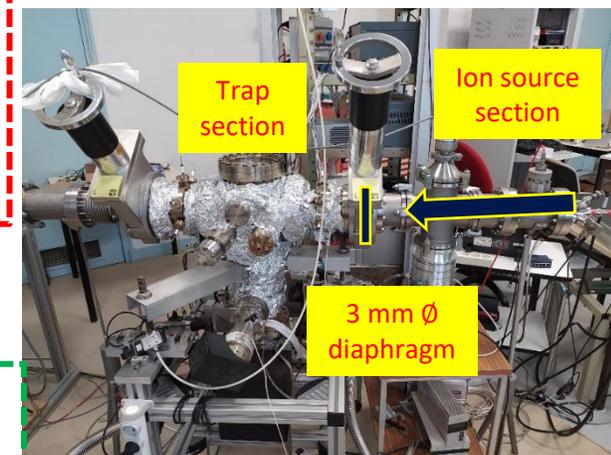
Situation October 2023

Trap Vacuum: $3 \cdot 10^{-7}$ mbar
Pickup electrode: no signal
Max trapping time : few μ s



Situation December 2025

Trap Vacuum: $4 \cdot 10^{-10}$ mbar
Pickup electrode: 50 mV signal
Max trapping time: >100 ms



HINA project & IJCLab

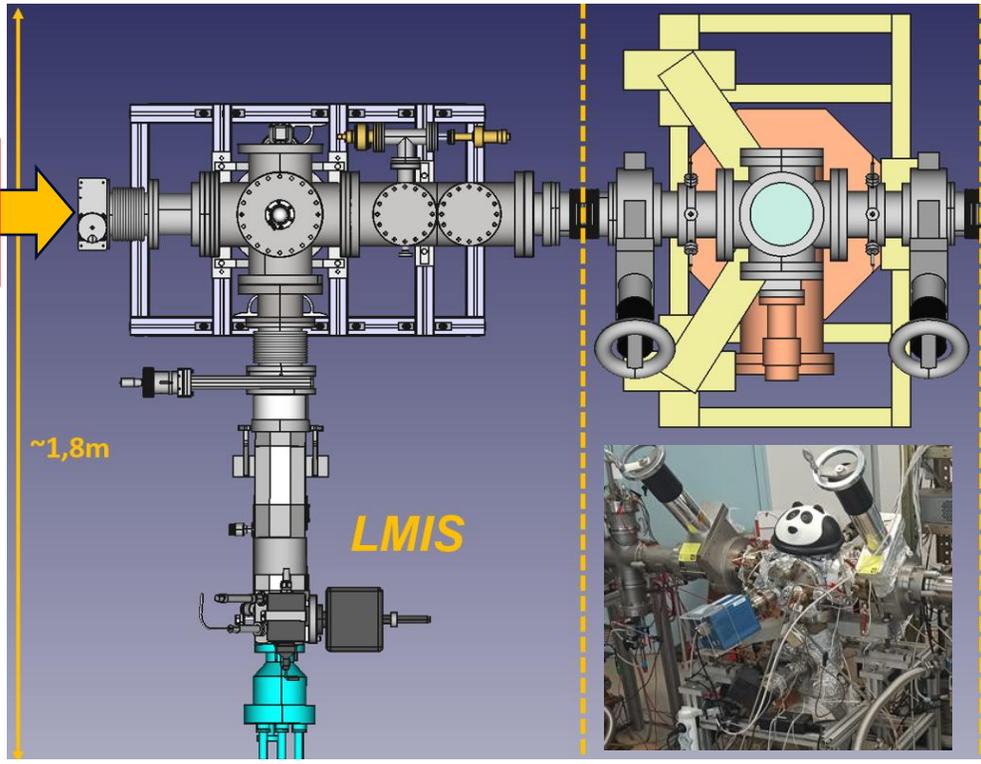


2ND PHASE

EBIT construction (MPIK) and commissioning with stable beams (IJCLab)



Transfer Section



- Electrostatic ion trap**
- Final test, between May-July 2026
 - Transferred to new installations (September 2026)
 - Alignment/installation (December 2026)

Test-bench ready for HC-EBIT commissioning

Shipping to IJCLab by end of 2027

Future of HINA project at DESIR

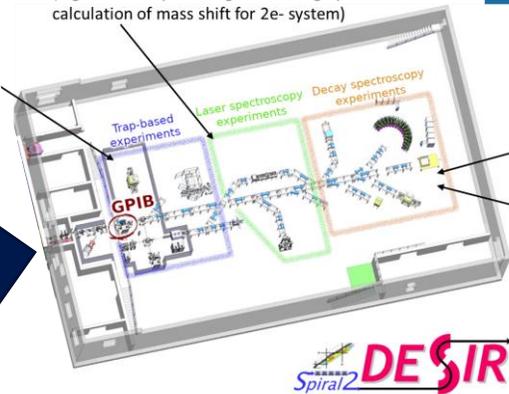
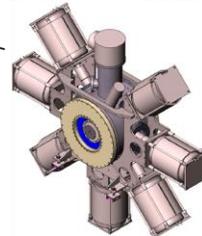
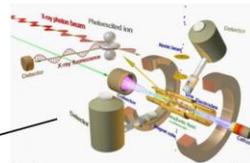


GANIL



High precision collinear laser spectroscopy e.g. Be^{2+} , B^{3+} and C^{4+}
Transition $1s2s\ ^3S_1 \rightarrow 1s2p\ ^3P_1$ laser accessible UV
(high sensitivity to charge radii & high precision calculation of mass shift for $2e^-$ system)

HINA Spectroscopy of HCIs:
Nuclear physics
Astrophysics
Atomic physics, ...



Spiral2 DESIR

Letter of intent HINA (Wednesday):

- HINA commissioning - LoI 22
- Electron capture on H-, He and Li-like ^{37}Ar , ^{64}Cu and ^{68}Ga - LoI 26

Future perspectives in the use of HCIs for other experiments (Wednesday):

- Highly Charged Ions Collinear Laser Spectroscopy - LoI 27

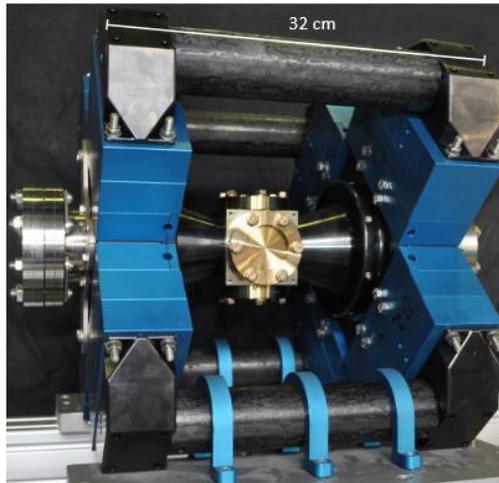
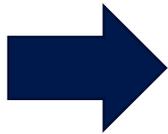
Second phase of the project



EBIT construction will take place in parallel with the installation of the project at Tancrede!



In the frame of the HINA project we are working on the development of an EBIT for the study of HCl decay!



HC-EBIT
developed in collaboration with



Several challenges must be overcome to reach high charge states!

We are working on the optimization of the injection and extraction system to maximize the ionization efficiency and make possible in-trap decay studies!

.....Thank you for your attention.....