DREEBIT-Electron Beam Ion Sources and Traps

for Applications in Accelerator Physics

Speaker:

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DREEBIT GmbH
and
Dresden University of Technology

Agenda

Why Highly Charged Ions

Properties, Production, Sources of HCI

EBIS/T Short History

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DREEBIT Ion Sources

Room Temperature and Superconducting Ion Sources

Product Portfolio

Ion Beam Optics and Diagnostics

Applications

Charge Breeding and Medical Particle Therapy

References

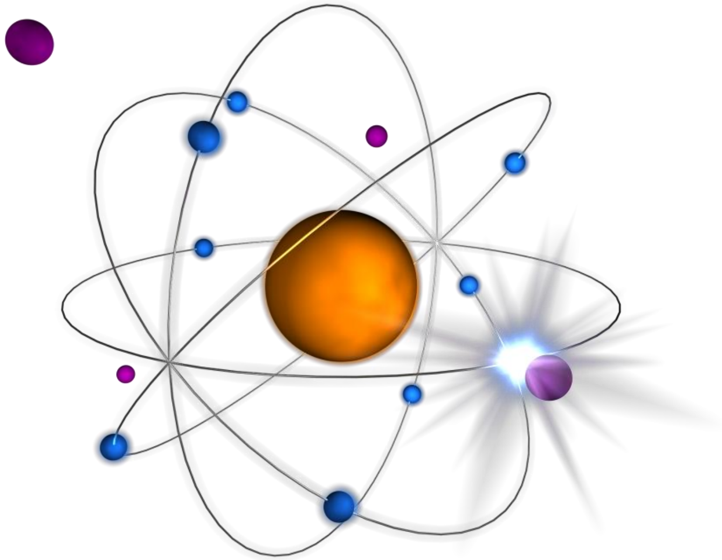
National and International Customer-specific Irradiation Facilities

Resumé

Why Highly Charged Ions ?

Properties of

highly charged ions



Properties of Highly Charged Ions

Extremely Compact Accelerator Structures are possible

Due to their high charge q ions can be accelerated very effectively

~ q for electrostatic accelerators

~ q^2 for circular accelerators

Example:

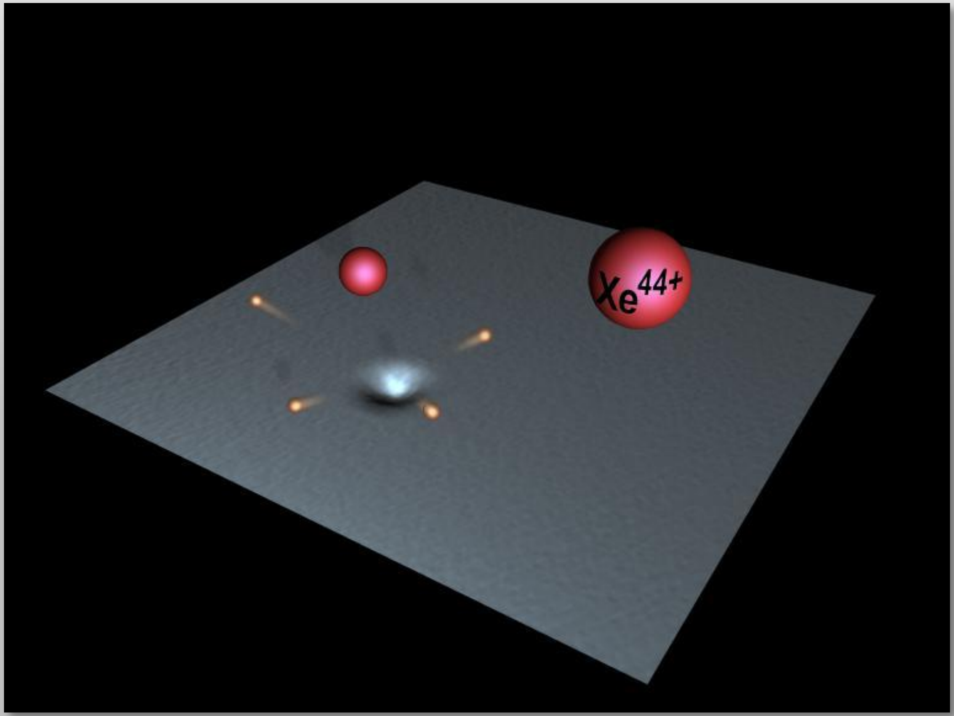
Xe^{1+} and Xe^{44+} acceleration at ΔU = 20 kV

ΔU = 20 kV	**electrostatic accelerator**	**circular accelerator**
Xe^{1+}	20 keV	20 keV
Xe^{44+}	880 keV	38720 keV = 38,72 MeV
		(energy gain about factor 2000!)

Properties of Highly Charged Ions

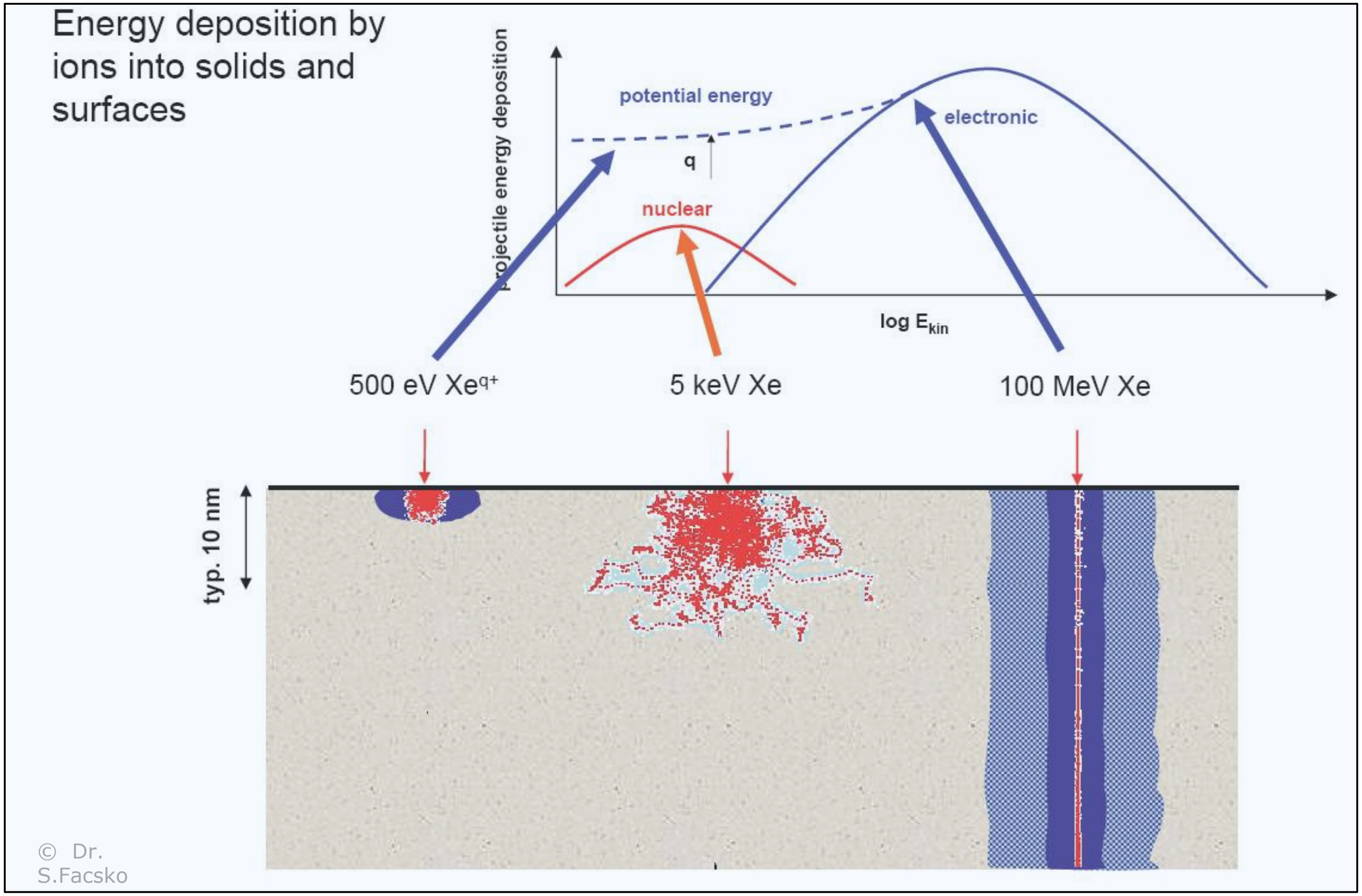
High power Deposition into Surfaces

The deposition of potential energy leads to ultrafast intense electronic excitations. Energy density: **10^{12} … 10^{14} W/cm²**



Properties of Highly Charged Ions

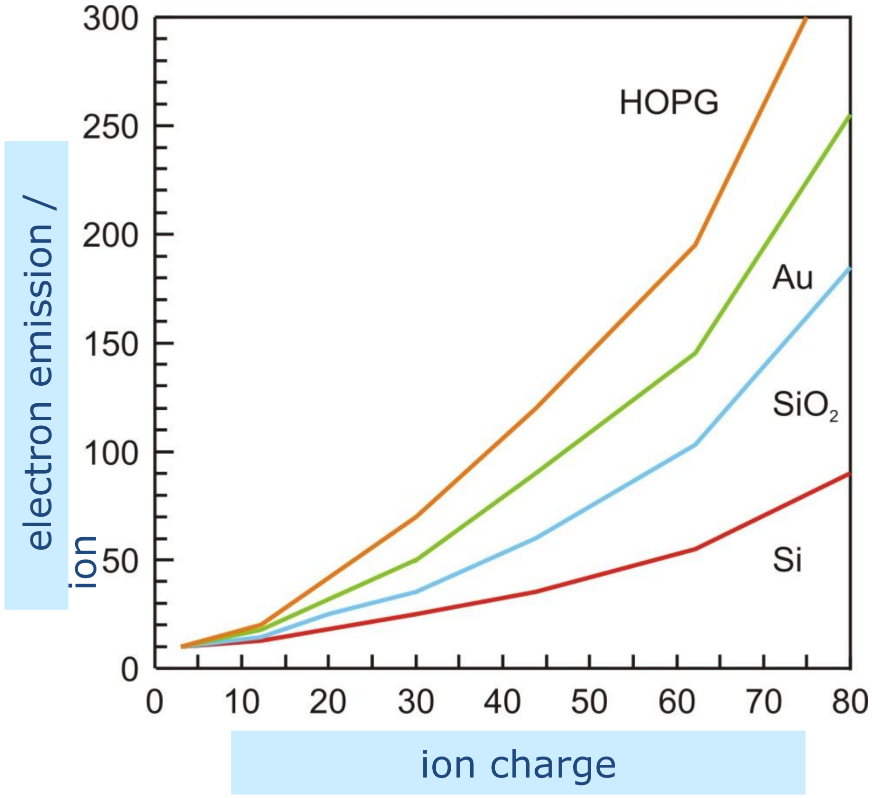
Energy Deposition into Surfaces



Properties of Highly Charged Ions

HCI give higher Yields of Secondary Ions and Electrons

J.W.McDonald et al: NIM B 240, 829 (2005)



Total electron yields

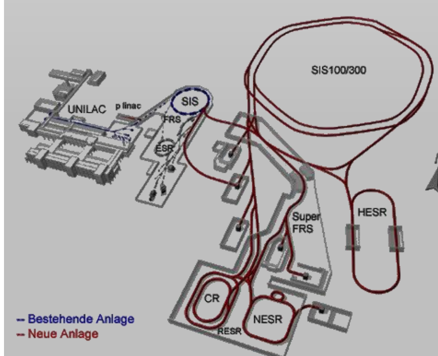
vs ion charge state q

How to Produce Highly Charged Ions?

Ion Accelerators (GSI, TSR HD)

Stripping

→ Up to bare nuclei at high projectile energies



up to U^{92+}

ECR Ion Sources

Electron Cyclotron Resonance (ECR)

→ Heating of a magnetically confined plasma

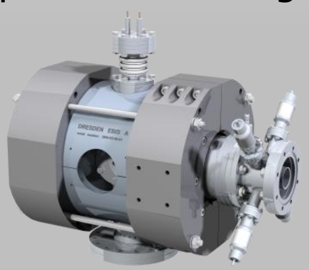
Ar^{16+}, Ta^{38+}, Au^{41+}

Electron Beam Ion Sources/Traps

→ Ionization in high-dense electron beams

→ Electron beam compression in strong magnetic fields

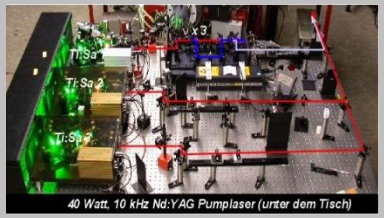
→ Superconducting or permanent magnets



up to small amounts of U^{92+}

Laser Ion Sources

→ Pulsed laser irradiation of selected targets



Pb^{27+} etc.

EBIS/T – Short History

Selected Milestones

Year	Place/ Name	Device	Ions	Source type (B, trap length)
1968	Dubna (USSR) Donets	IEL I, IEL II	Au^{19+}	warm EBIS 0.4 T, 16 cm
1971	Dubna (USSR) Donets/Pikin	KRION I	C^{6+}, N^{7+}, O^{8+}, Ne^{10+}	SC 1.2 T, 1.2 m
1974	Dubna (USSR) Ovsyannikov/Donets	KRION 2	Ar^{18+}, Kr^{36+}, Xe^{54+}	SC 2.2 T, 1.2 m
1981 1986	Orsay (France) Arianer	CRYEBIS 1 CRYEBIS 2	C^{6+}, N^{7+}, Ne^{10+}, Ar^{18+}	SC, 3 T, 1.66 m SC, 5 T, 1.66 m
1984	Saclay (France) Faure	DIONE	Ar^{16+}, Kr^{30+}, I^{41+}	SC, 6 T, 1.2 m

EBIS/T – Short History

Selected Milestones

Year	Place/Name	Device	Ions	Source type (B, trap length)
1988 1990	LLNL (USA) Levine Marrs/Knapp	EBIT-I EBIT-II **(birth of EBIT!)**	Xe^{54+}, U^{88+}	SC, 3 T, 2 cm ($E_{(e,max)}$ = 29 keV)
1990	LLNL (USA) Marrs/ Schneider	S-EBIT	U^{92+}, Cf^{96+}	SC, 3 T, 2 cm ($E_{(e,max)}$ = 215 keV)
1999	Freiburg (Germany) Crespo	F/HD-EBIT	Xe^{54+}	SC, 9 T, 4-30 cm
2009	Brookhaven (USA) Beebe/Pikin	RHIC-EBIS	Xe^{36+} high current EBIS	SC 6 T, 1.5 m

EBIS/T – Short History

Selected Milestones

Year	Place/ Name	Device	Ions	Source type (B, trap length)
1999	TU Dresden (Germany) Ovsyannikov/ Zschornack	Dresden EBIT	Ar^{18+}, Xe^{44+}, Ir^{67+}	warm EBIT 0.25 T, 2 cm ($E_{(e,max)}$ = 15 keV)
2005 2008	Dreebit GmbH (Germany) Ovsyannikov/ Zschornack	Dresden EBIS Dresden EBIS-A	Ar^{18+}, Xe^{48+}, Ir^{67+}	warm EBIS, 0.4/0.6 T, 6 cm ($E_{(e,max)}$ = 25 keV)
2009	Dreebit GmbH (Germany) Ovsyannikov/ Zschornack	Dresden EBIS-SC (medical applications and R&D)	C^{6+}, Ar^{18+}, Xe^{48+}	SC, 6 T, 4-30 cm ($E_{(e,max)}$ = 20 keV)

EBIS/T – Short History

Selected Milestones

There are actually about 60 EBIS/EBIT around the world.
(For a list see R.Becker, O.Kester; RSI 81(2010) 02A513)

Most of them are special laboratory constructions.

Two commercial supplier worldwide:

1. Physics and Technology Livermore (USA)

REBIT (Refrigerated Electron Beam Ion Trap)

2. DREEBIT GmbH Dresden (Germany)

Dresden EBIT
Dresden EBIS
Dresden EBIS-A

} Room-Temperature EBIS/T

Dresden EBIS-SC
(Refrigerated Electron Beam Ion Trap)

Room Temperature EBIS/T

DREEBIT Ion Sources

- Dresden EBIT
- Dresden EBIS
- Dresden EBIS-A

Dresden EBIS-SC (superconducting)

DREEBIT Ion Sources

20cm

Measured ion pulses

Ion	Max. Ions/pulse	Max. pulse rate/Hz
H^+	$3 \cdot 10^9$	500
H_2^+	$3 \cdot 10^9$	1000
C^{4+}	$8 \cdot 10^8$	10
C^{6+}	$4 \cdot 10^8$	10
Ar^{16+}	$2 \cdot 10^7$	2
I^{43+}	$1 \cdot 10^6$	1

- L-He free at 4.2K
- electron beam energy up to 30 keV
- electron beam current up to 700 mA
- magnetic field on-axis 6T

Ion Source Output

DREEBIT Ion Sources

Pulsed mode (ions/pulse)

Ion	EBIT	EBIS-A	EBIS-SC	EBIT:EBIS-A:EBIS-SC
C^{4+}	24.000.000	80.000.000	900.000.000	1 : 3 : **38**
C^{6+}	10.000.000	30.000.000	400.000.000	1 : 3 : **40**
Ar^{16+}	900.000	7.800.000	250.000.000	1 : 9 : **278**
Ar^{17+}	45.000	1.400.000	22.000.000	1 : 31 : **489**
Ar^{18+}	6.000	90.000	1.500.000	1 : 15 : **250**
Xe^{44+}	10.000	700.000	10.000.000	1 : 70 : **1000**

Ion Optics and Diagnostics

DREEBIT Product Portfolio

Electron & Ion Beam Technologies

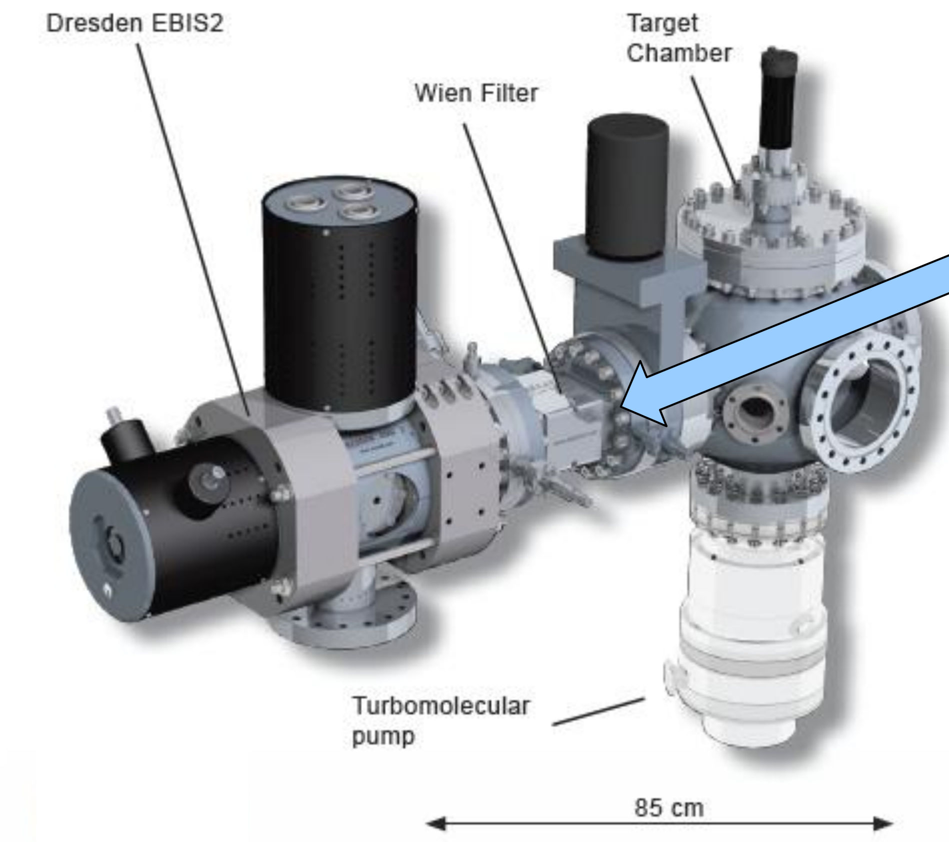
- Einzel lense
- Deflector
- Ion beam deceleration/acceleration system
- ExB Particle separator (Wien Filter)
- Faraday Cup
- Quadrupole Beam Bender
- Retarding Field Analyzer
- Pepperpot Emittance Meter…

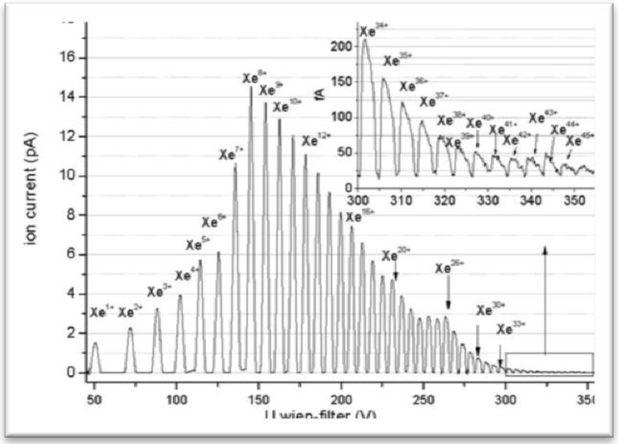






q/A Analysis with a Wien filter





Ion Irradiation Facilities

DREEBIT Product Portfolio

Ion Irradiation Facility S

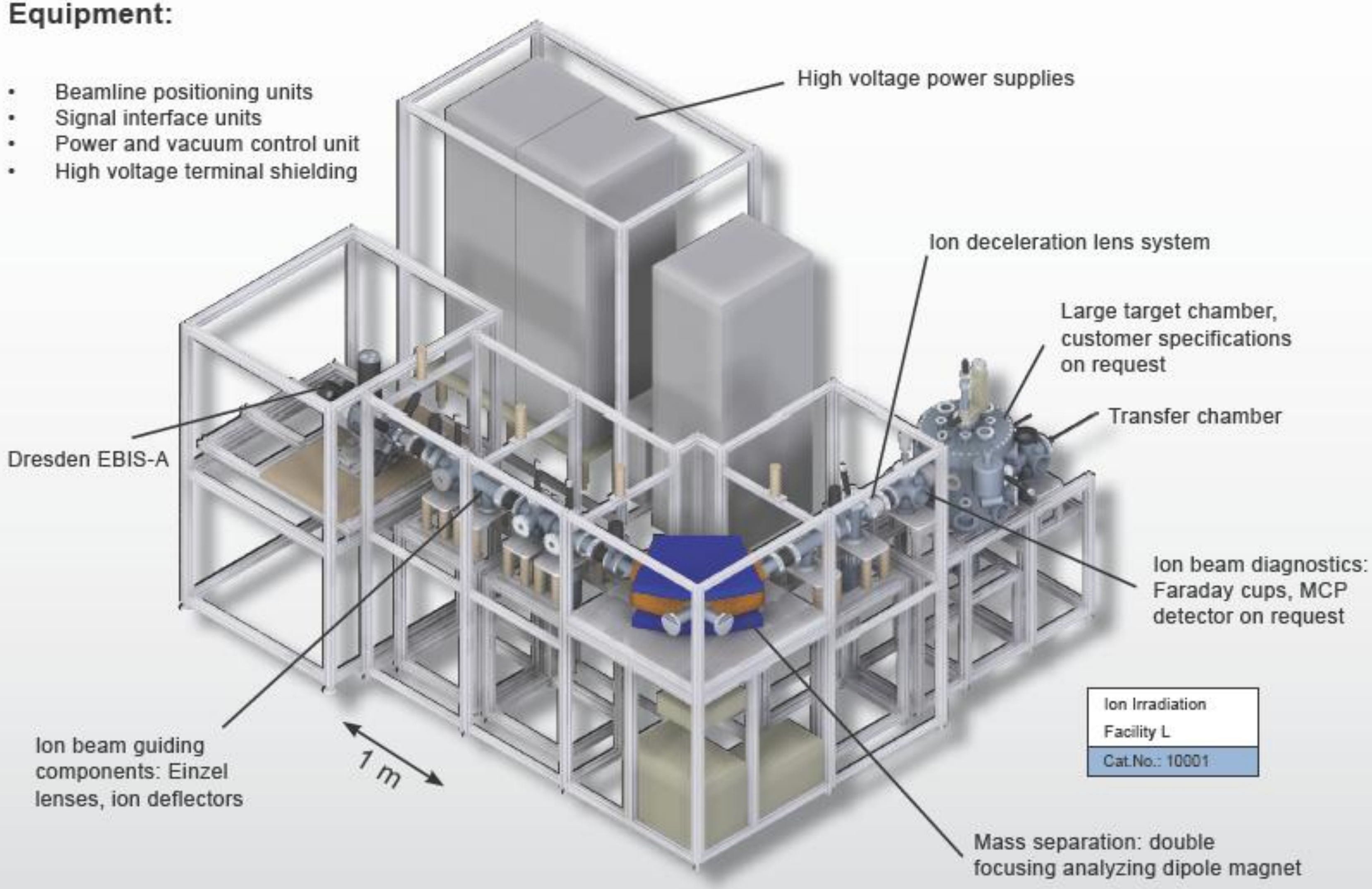
Ion Irradiation Facility L

Ion Irradiation Facilities

DREEBIT Product Portfolio

Equipment:

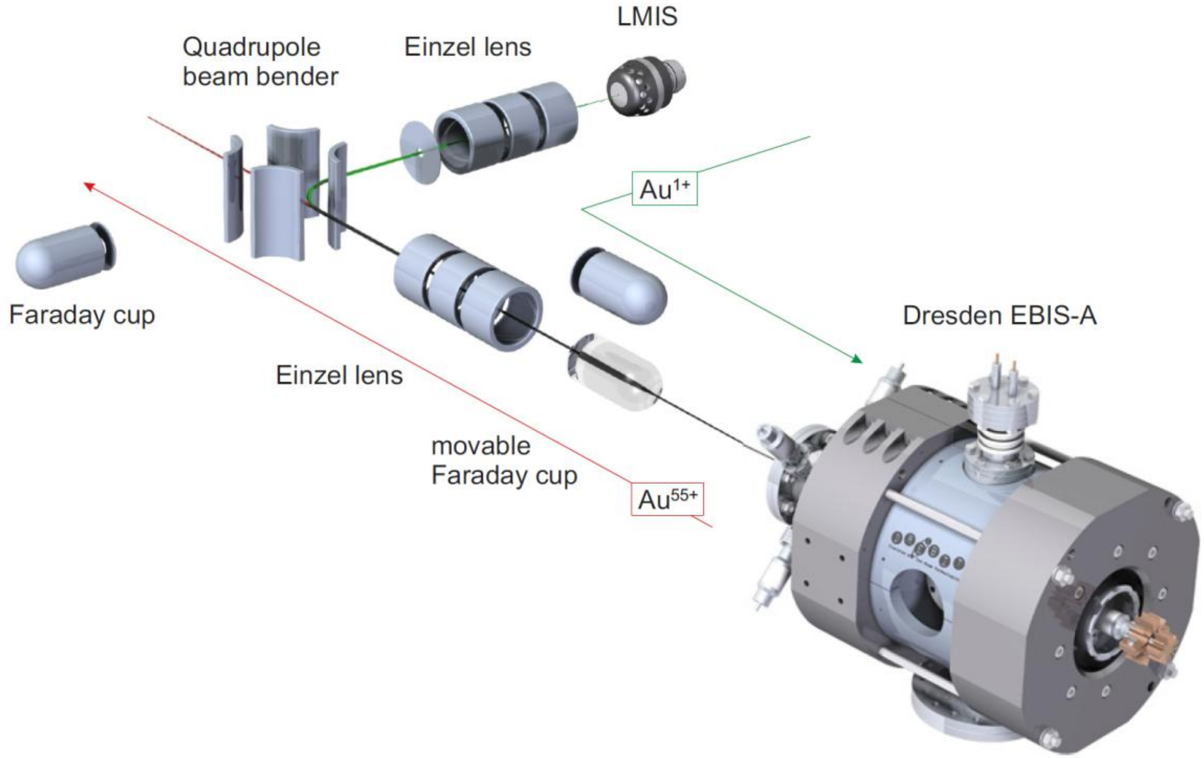
- Beamline positioning units
- Signal interface units
- Power and vacuum control unit
- High voltage terminal shielding

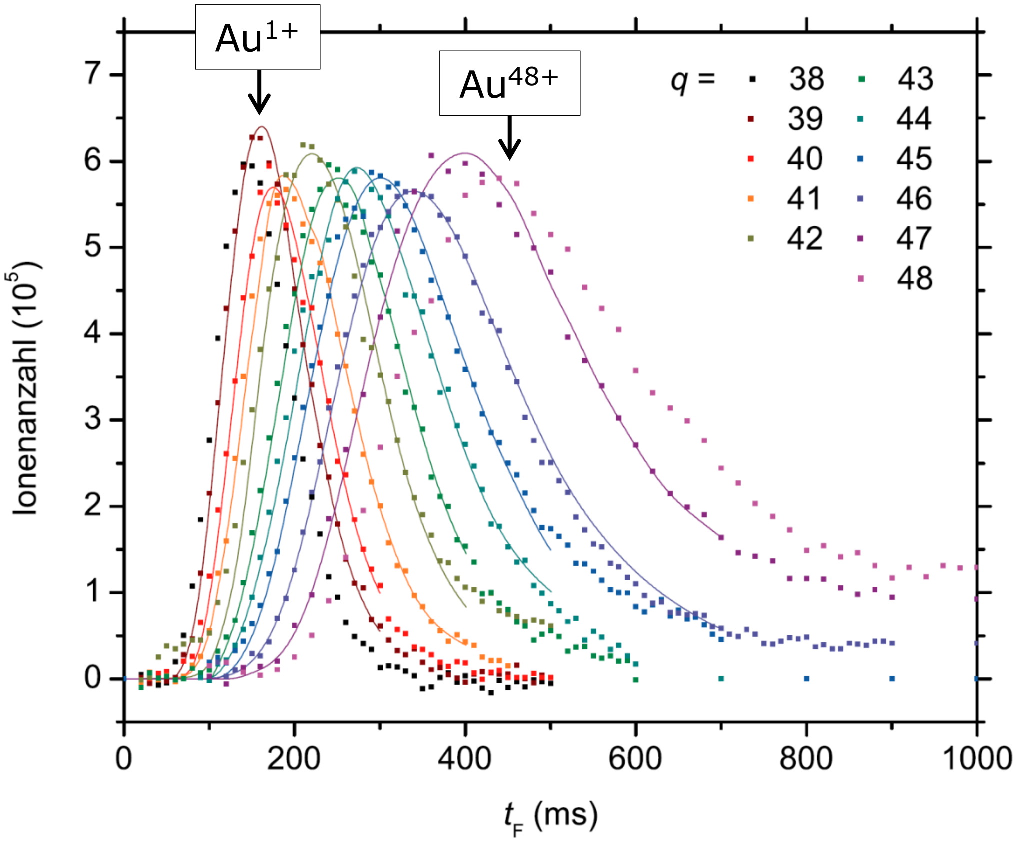


Applications

Charge Breeding

Charge Breeding





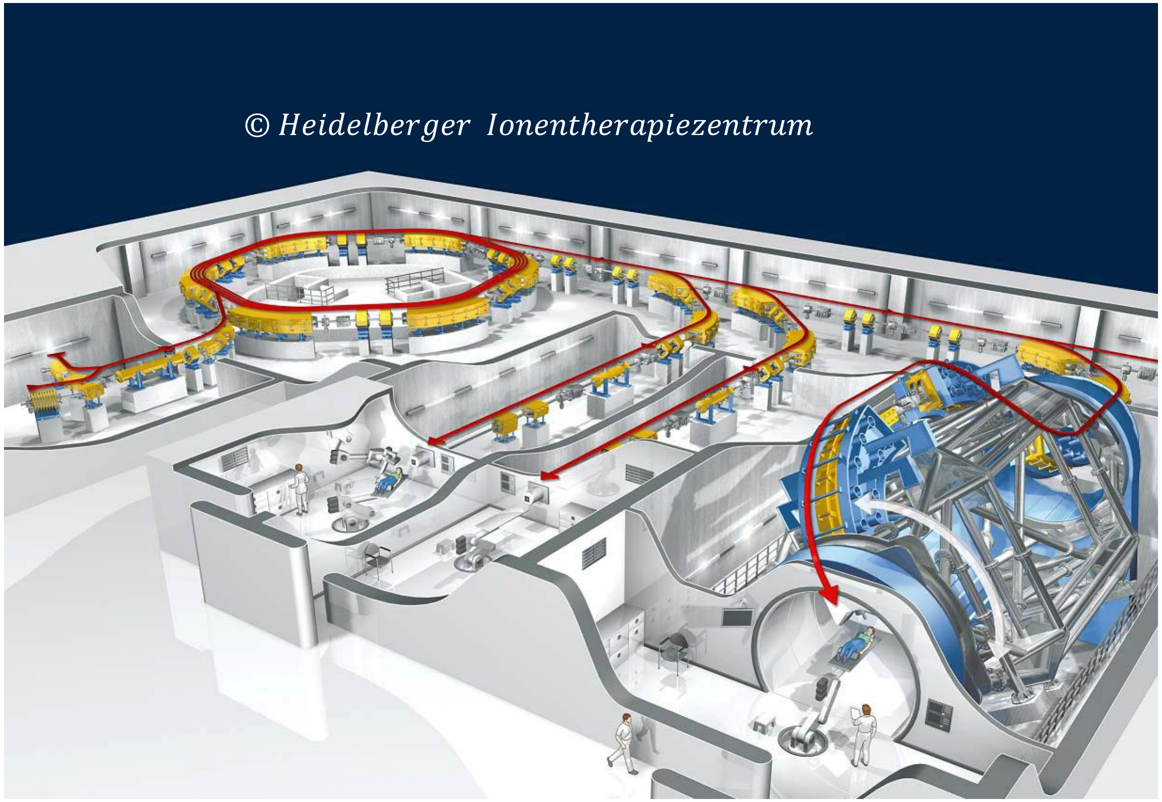
q/A analysis

→ Evolution of the ion charge states Au^{38+} to Au^{48+}

Description:

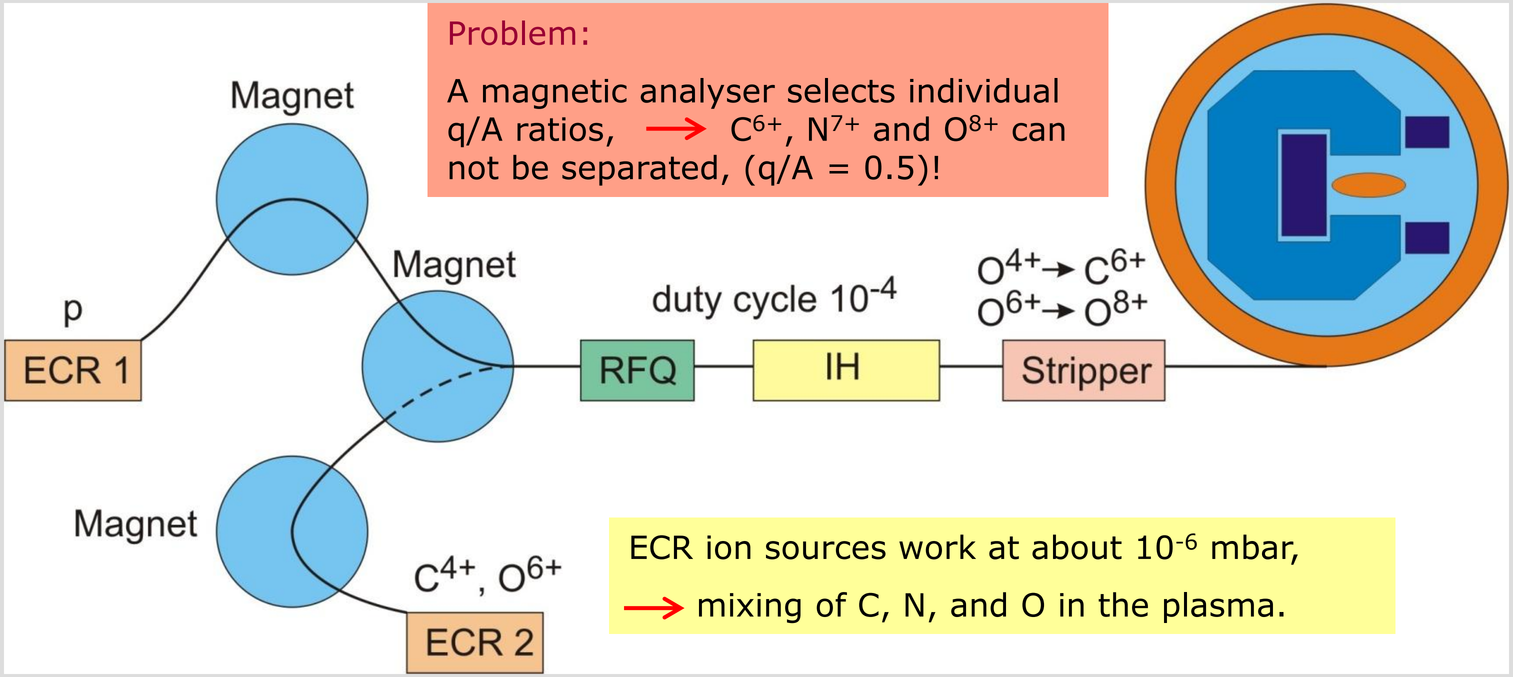
$$dN_{q+}/dt = \lambda_{q-1} \cdot N_{q-1} - \lambda_q \cdot N_q + \lambda_{q+1} \cdot N_{q+1}$$

Hadron Therapy



Basic Structure of a Synchrotron-based Irradiation Facility

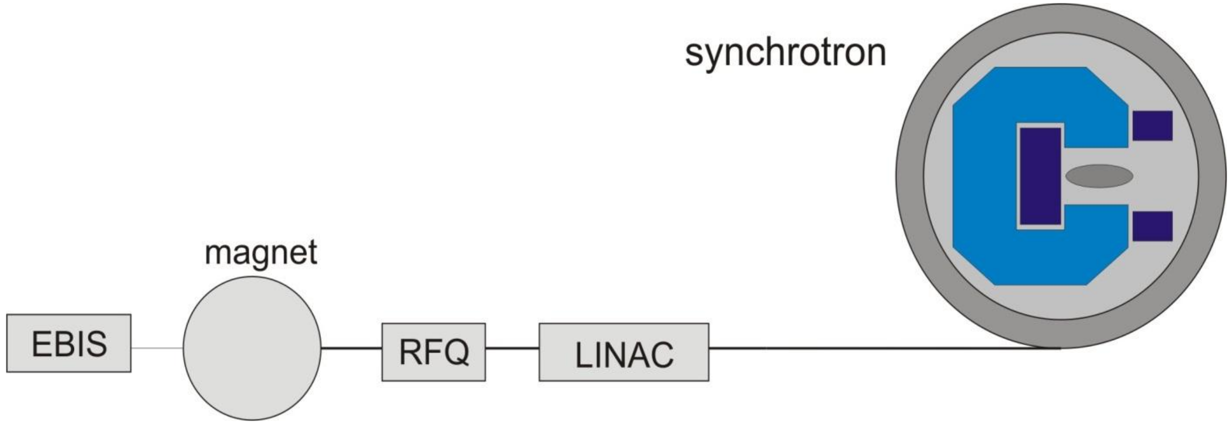
Heidelberg Hadron Therapy Facility HIT:



R.Becker, ICIS-05 PA9/RSI MS # C05005

Simplification of Therapy Facilities by using an EBIS

Electron & Ion Beam Technologies



Advantages:

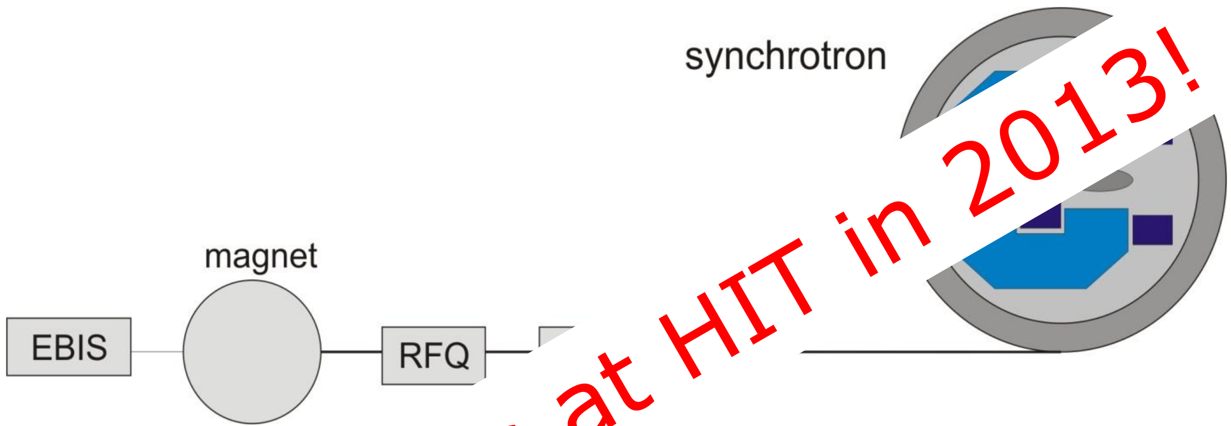
- only one ion source
- only one separation magnet
- shorter LINAC
- no stripper
- lower injection energy
- single-turn injection (at 4 MeV/u)
- smaller synchrotron magnets
- lower power consumption

the complexity of the irradition facility decreases,

the beam quality is improved,

costs can be reduced

Simplification of Therapy Facilities by using an EBIS



First Experiments at HIT in 2013!

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DREEBIT Reference Facilities

Customer-specific Irradiation Facilities

SIEMENS

TECHNISCHE UNIVERSITÄT DRESDEN

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Friedrich Schiller

University of Jena

Uniwersytet Jagielloński

Krakow

GSI

UNIVERSITÄT DUISBURG ESSEN

CLEMSON UNIVERSITY

The Jan Kochanowski University of Humanities and Sciences

Resumé

Application Potential of DREEBIT EBIS/T Systems

Dresden EBIS/T systems have been succesfully commissioned and operated at Low Energy Beamlines,

but can also be used as ion sources for:

1. Cyclotrons
2. Synchrotrons
3. Synchro-Cyclotrons
4. Cyclotron Driven Linac
5. Dielectric Wall Accelerator
6. Direct Driven Accelerator
7. Fixed Field Alternating Gradient Accelerator

Thank you

http://www.dreebit.com