Dresden Electron Beam Ion Sources: Latest Developments

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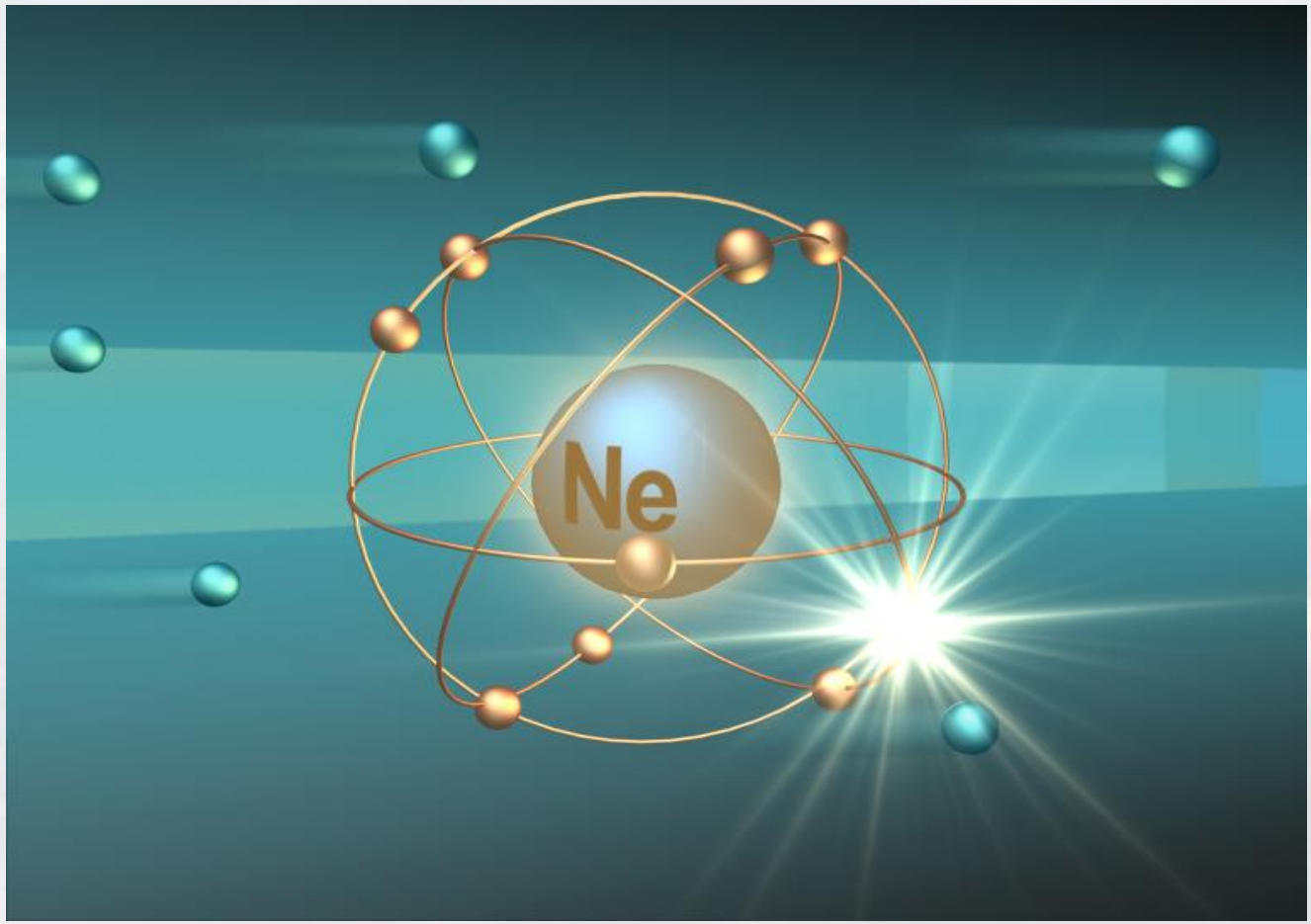
DREEBIT GmbH Dresden

TECHNISCHE UNIVERSITÄT DRESDEN

DREEBIT Electron & Ion Beam Technologies

Exciting Properties of Highly Charged Ions

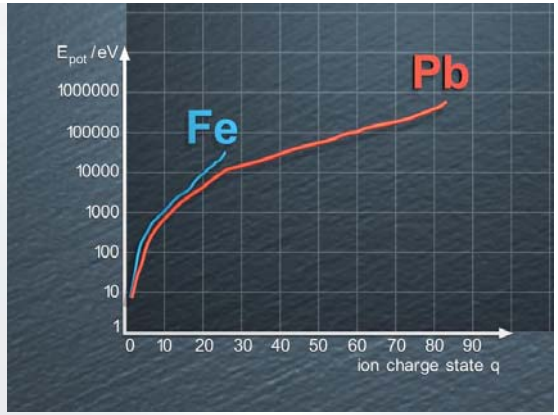


Exciting Properties of Highly Charged Ions

Potential energy

The potential energy of an ion increases with the degree of ionization

Example: Xe^{44+} has a potential energy that is 4600 times higher than that of Xe^{1+}



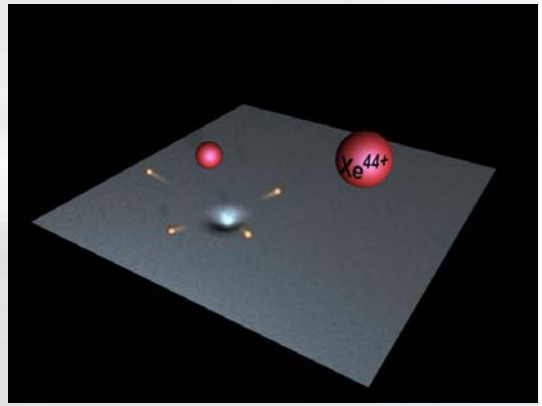
High power deposition into the surface

The deposition of potential energy leads to ultrafast intense electronic excitations

Power deposition: 10^{12} … 10^{14} W/cm²

High yield of secondary particles

Irradiation with highly charged ions results in up to 300 times higher secondary particle yields



High specific energy gain for ion acceleration

linear accelerator: ~ q

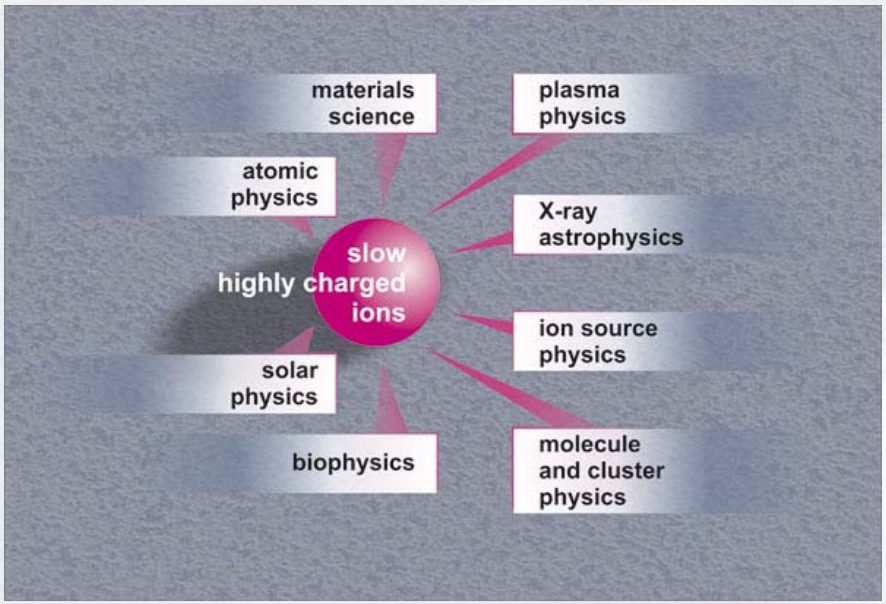
cyclical accelerator: ~ q^2

→ **effective ion acceleration**

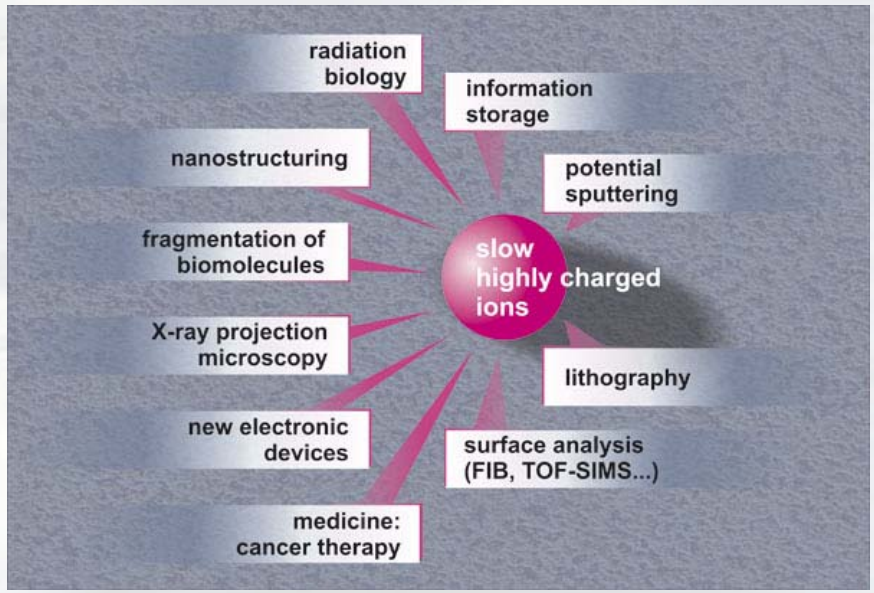
Applications of Highly Charged Ions

The interest of using highly charged ions in both basic and applied research increases continuously

Basic Research



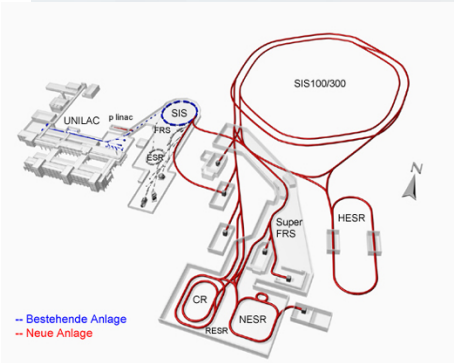
Applied Technology



How to produce highly charged ions

Ion Accelerators
(GSI, TSR HD)

Stripping
→ up to bare nuclei at high projectile energies



(© GSI Darmstadt)

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

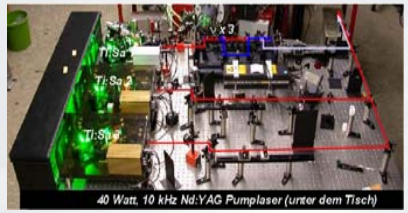
Ionization in high-dense electron beams

electron beam compression in strong magnetic fields

up to small amounts of U^{92+}

Laser Ion Sources

Pulsed laser irradiation of selected targets



(© Uni Mainz)

Pb^{27+} etc.

EBIT / EBIS


Greenland
U. S.
CANADA
UNITED STATES
RUSSIA
KAZAKHSTAN
MONGOLIA
CHINA
JAPAN
NORTH ATLANTIC OCEAN
MOROCCO
ALGERIA
LIBYA
EGYPT
IRAN
SAUDI ARABIA
INDIA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
NIGERIA
ETHIOPIA
SOMALIA
MEXICO
VENEZUELA
COLOMBIA
BRAZIL
PERU
BOLIVIA
PARAGUAY
CHILE
ARGENTINA
DEMOCRATIC REPUBLIC OF THE CONGO
TANZANIA
ANGOLA
ZAMBIA
MOZAMBIQUE
ZIMBABWE
NAMIBIA
BOTSWANA
SOUTH AFRICA
MADAGASCAR
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
INDONESIA
AUSTRALIA
PAPUA NEW GUINEA
THAILAND
PHILIPPINES
MALDIVES
SEYCHELLES
St. Helena
French Southern and Antarctic Lands

EBIT / EBIS

Germany is the land with the highest EBIT/EBIS density!

Cryogenic EBIT/EBIS:

MPIK Heidelberg
TU Dresden
MPIP Berlin
DESY Hamburg
GSI Darmstadt

Warm EBIT/EBIS:

TU Dresden
FZ Dresden-Rossendorf
FSU Jena
University Duisburg-Essen
GSI Darmstadt

EBIT Design

„classical“ cryogenic EBIT

- superconducting coils
  → (3… 8) T magnetic field

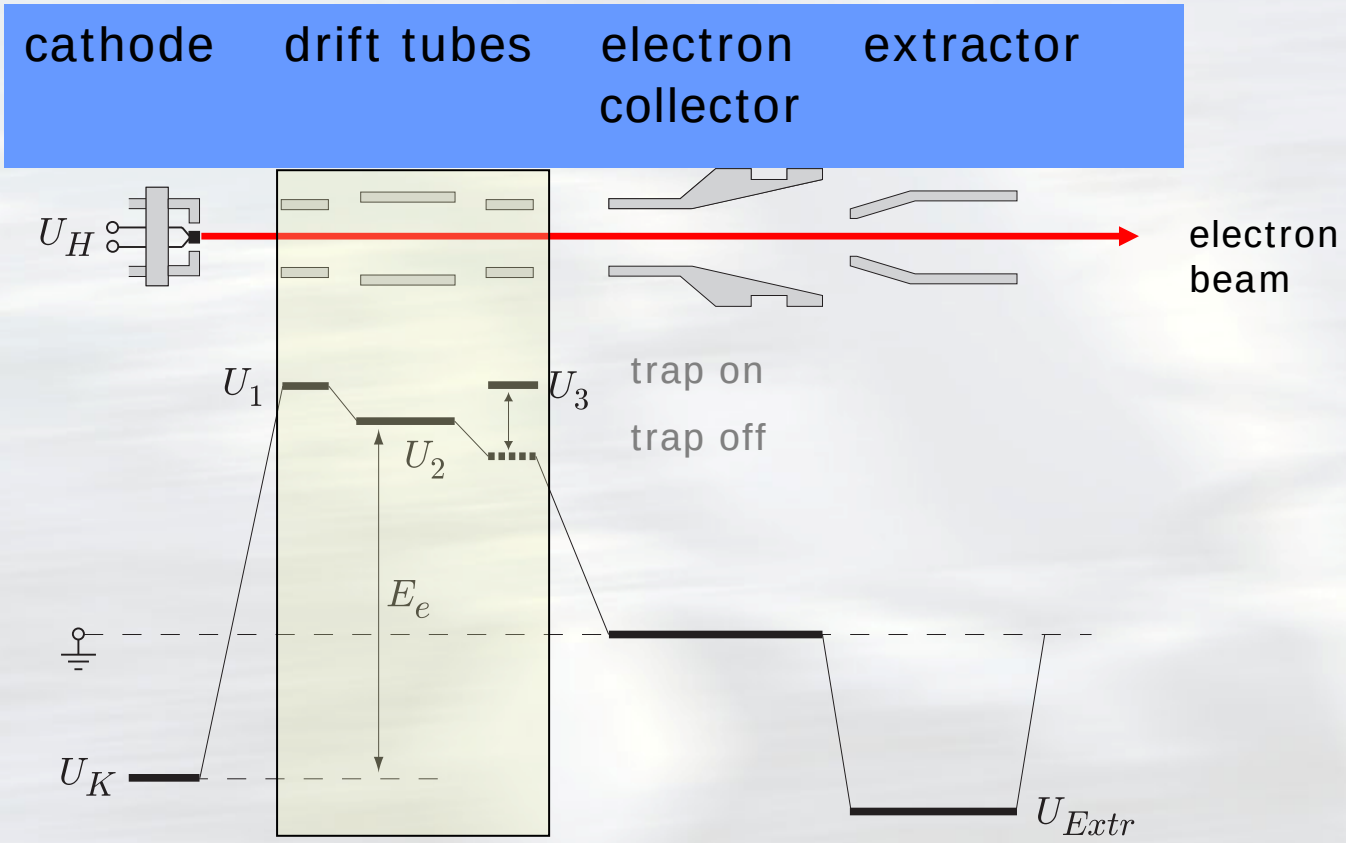
  ⇒ j_e > 1000 A/cm^2
- highest charge states
  $Xe^{(52...54)+}$, up to U $^{(90...92)+}$
- large devices,
  liquid helium cooling
- latest developments:
  Refrigerator cooling

room-temperature EBIT

- permanent magnets (SmCo, NdFeB)
  (250…620) mT at the axis

  ⇒ j_e = (200… 600) A/cm^2
- bare ions up to Z=28,
  Kr^{34+}, $Xe^{(44...48)+}$, Ir^{67+}
- compact, transportable,
  low initial and maintenance costs,
  short setup times

Dresden EBIT/EBIS: principle of operation



Room-Temperature Sources of Highly Charged Ions

Electron & Ion Beam Technologies

Dresden EBIT Dresden EBIS Dresden EBIS-A

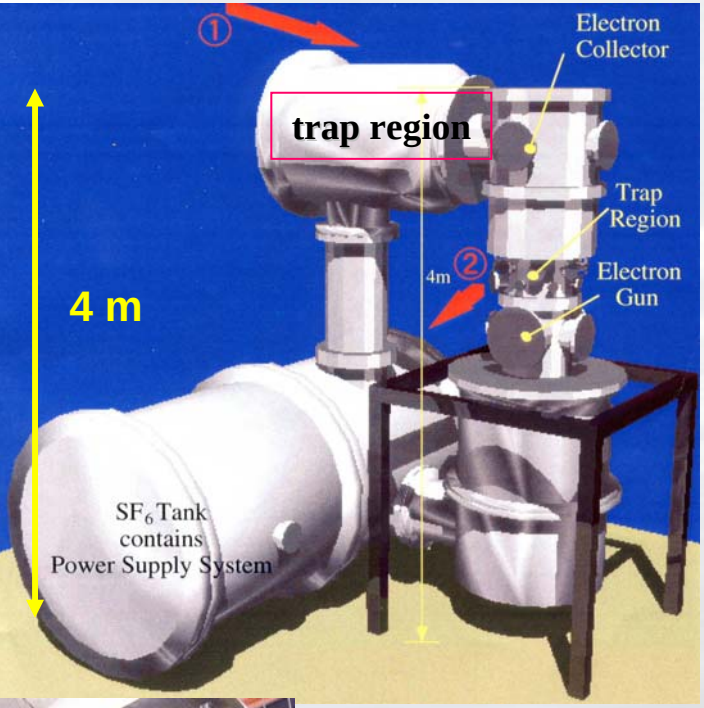
- Low initial and maintenance costs
- Low specific price per ion
- Compact device, simple to operate
- Long-term stable, reliable
- Photon spectroscopy inside the trap
- Ion extraction with small beam emittance

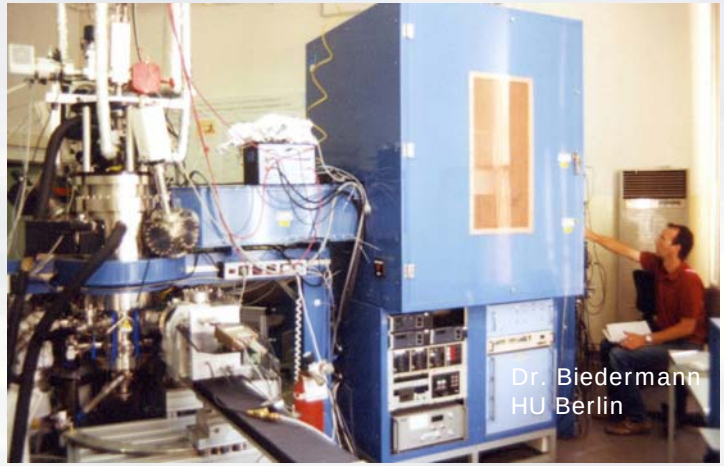
www.dreebit.com

Room-Temperature Sources of Highly Charged Ions – Technical Parameters

parameter	Dresden EBIT	Dresden EBIS	Dresden EBIS-A
B / mT	250	400	600
max. E_e / keV	15	25	30
max. I_e / mA	50	100	200
j_e / A cm^{-2}	< 300	< 300	< 600
L / cm	2	6	6
N	3	3	3
magnet	SmCo	NdFeB	NdFeB

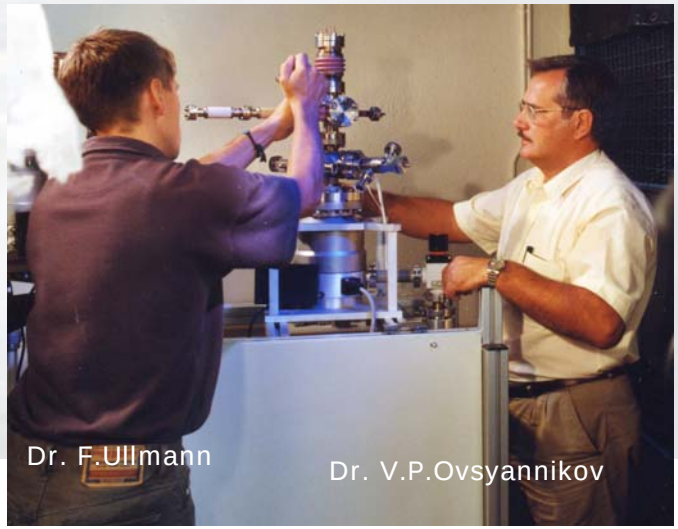
Comparison of Sizes



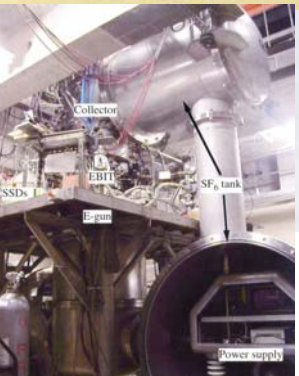


LLNL EBIT

(photo MPI für Plasmaphysik Berlin)

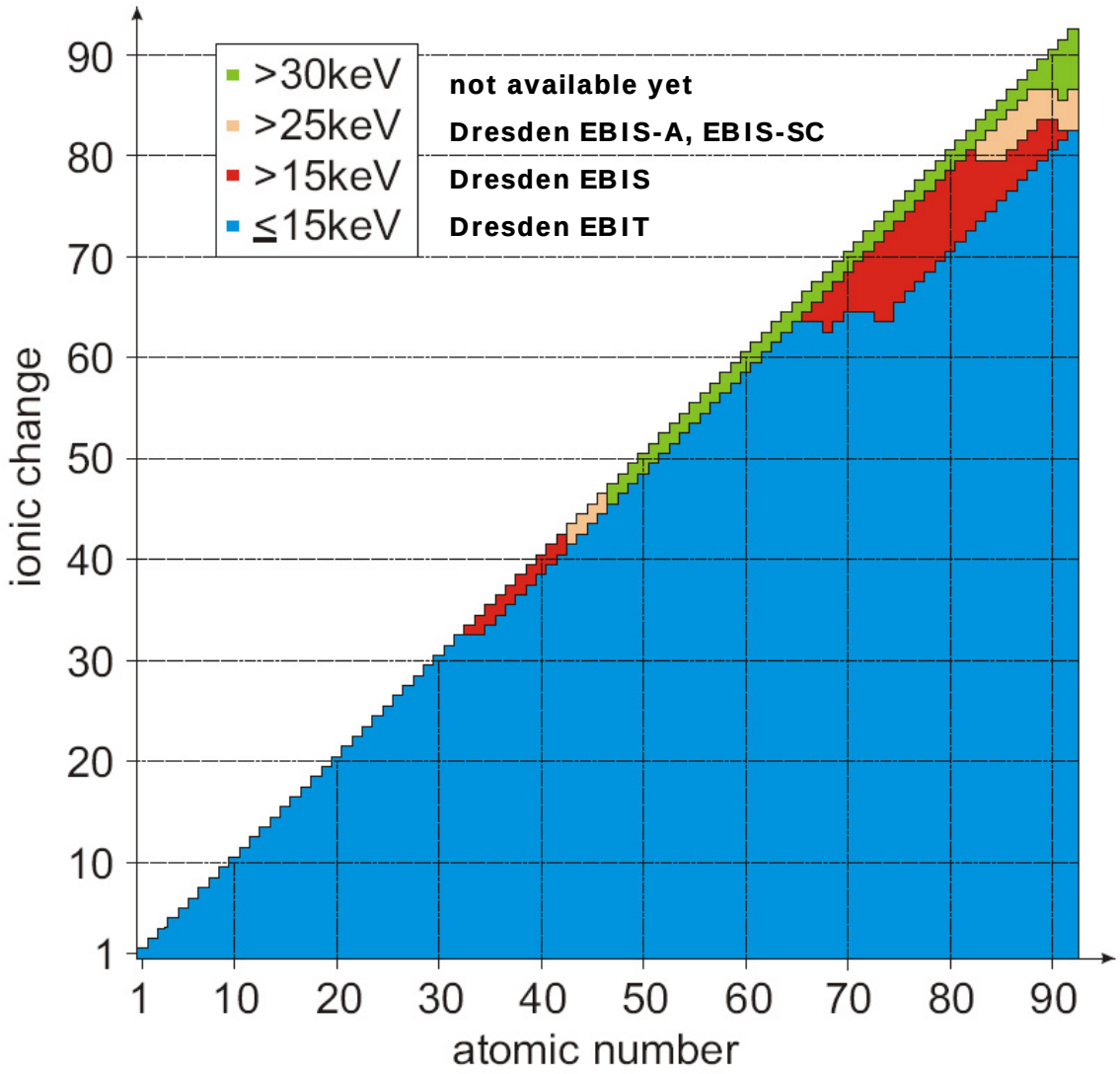


Dresden EBIT



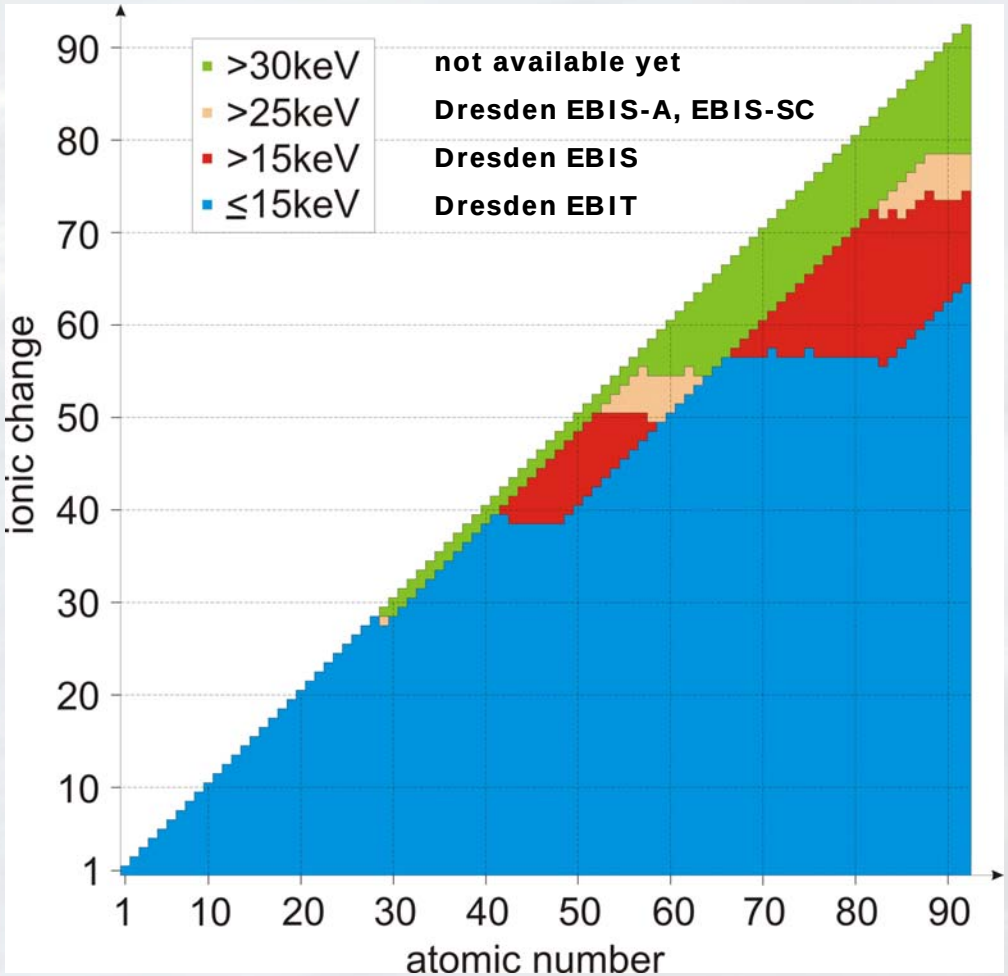
Tokyo EBIT

Ultimative Limits of Ion Production – Selection of Electron Energy



Even the Dresden EBIT is able to produce most of the possible ion charge states of all stable elements!

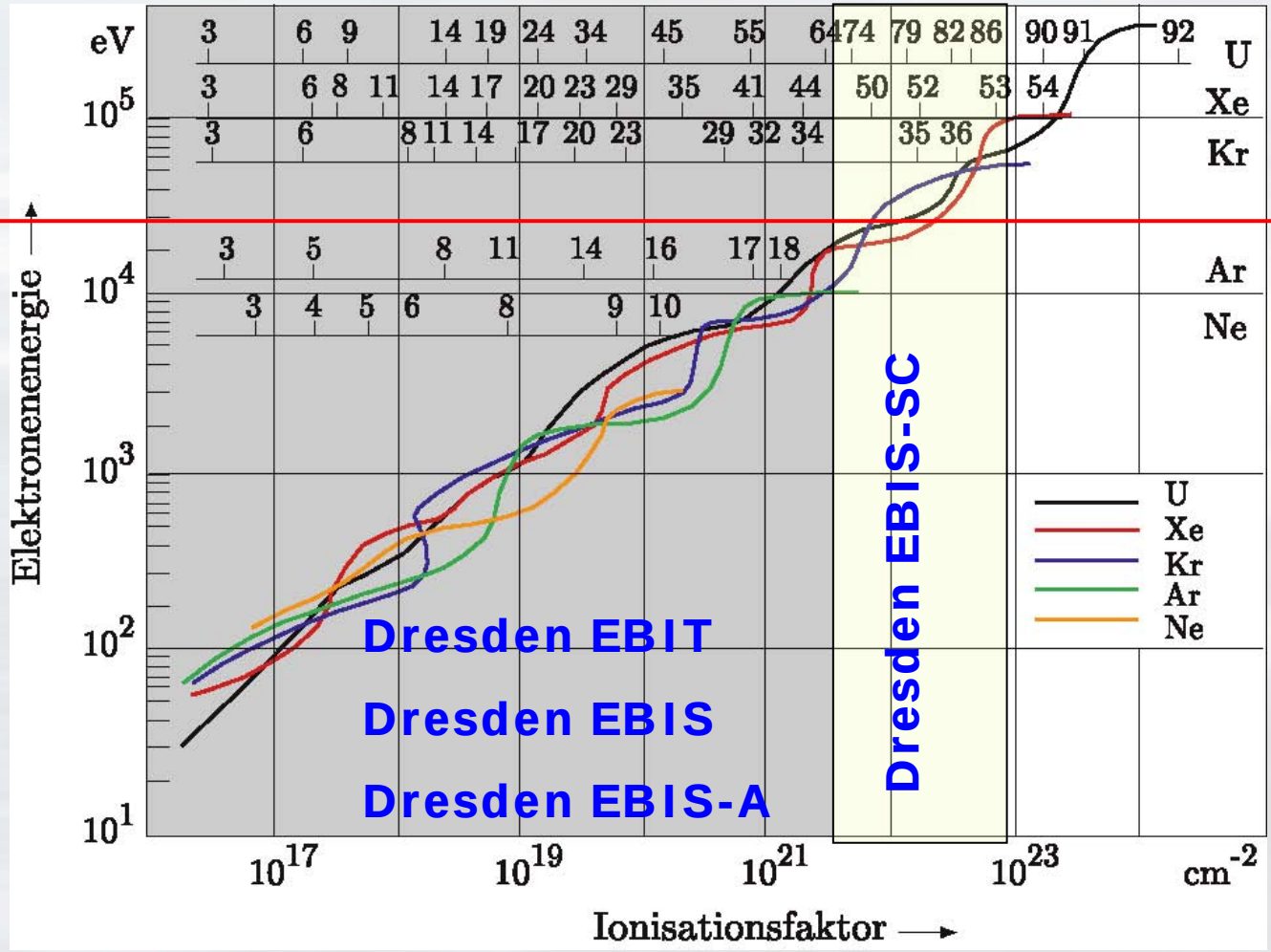
Ion Production at Optimal Electron-Impact Ionization Cross-Sections



The optimal ionization cross-section occurs at

$2.7 \times E_B$

Limits of Ion Production – Ionization Factor



electron energy limit for the Dresden EBIT/EBIS ion source family

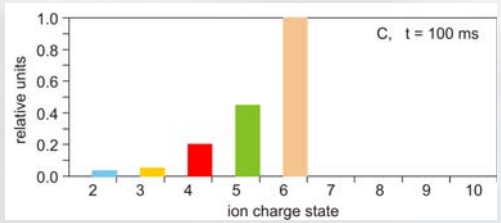
Upper Limit of the Electrical Trap Capacity

$$C = 1*10^{13} * L[m] * I_e [A] * \mathbf{a} * \mathbf{f} / (E_e [eV])^{1/2} \quad \text{elementary charges}$$

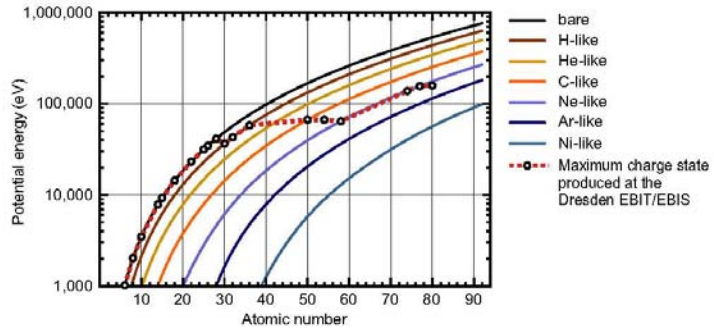
L – trap length
I_e – electron beam current
E_e – electron energy
α - ratio of useable ions in the ion charge state distribution
f - compensation of the electron beam

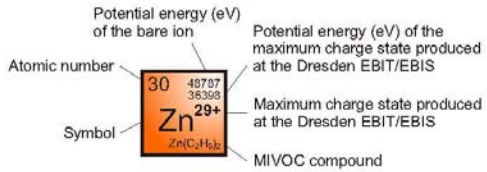
Ion source	max. trap capacity
Dresden EBIT	3 x 10^8 e
Dresden EBIS	2 x 10^9 e
Dresden EBIS-A	4 x 10^9 e
Dresden EBIS-SC	6 x 10^{10} e

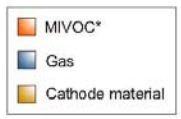
role of α



Examples of Produced Ions







* Metal Ions from Volatile Compounds

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Dresden, Germany
Tel: +49 (0351) 2159 184
www.dreebit.com

DREEBIT Electron & Ion Beam Technologies

EBIS(W):
An Innovative New Generation of Ion Sources

+

= new product

EBIS + Wien filter → ion beams with individual ion charge states

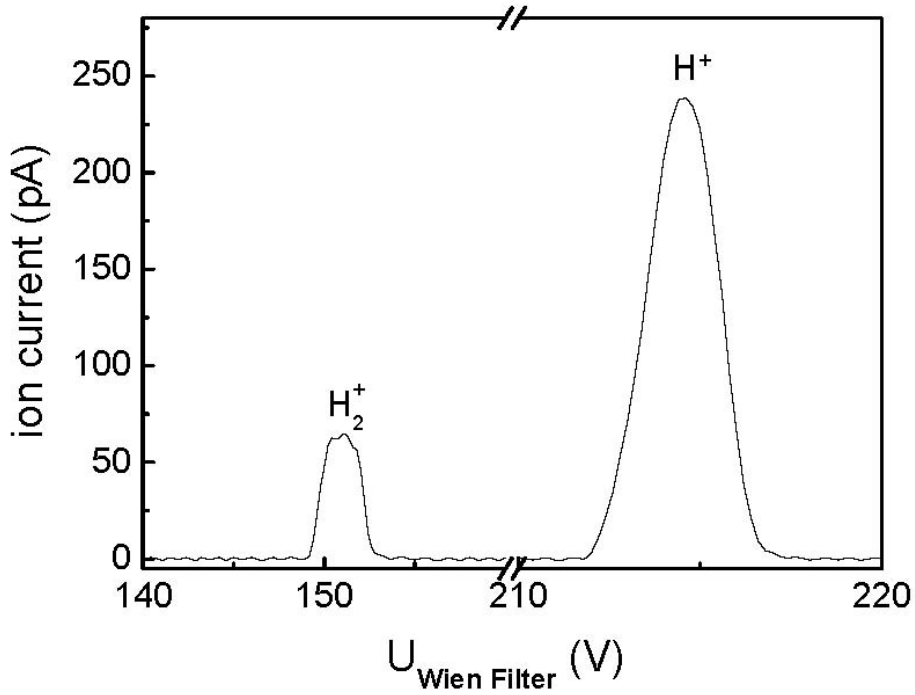
„W“ – Family :
A new Generation of Ion Sources

Dresden EBIT-W **Dresden EBIS-W** **Dresden EBIS-AW**

New product family:

EBIS/T with integrated Einzel lense and Wien filter

„W“ – Family : Some Ion Extraction Spectra

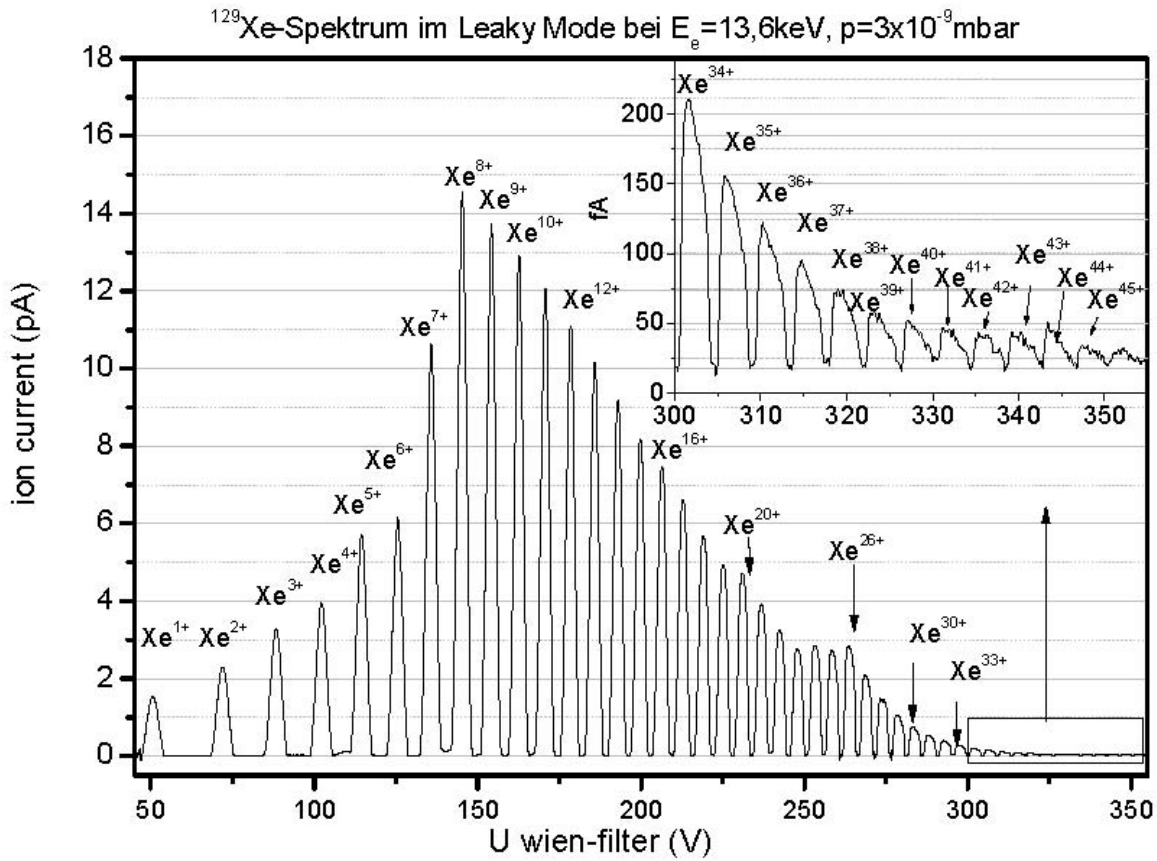


Dresden EBIS

Leaky mode

H_2

„W“ – Family : Some Ion Extraction Spectra

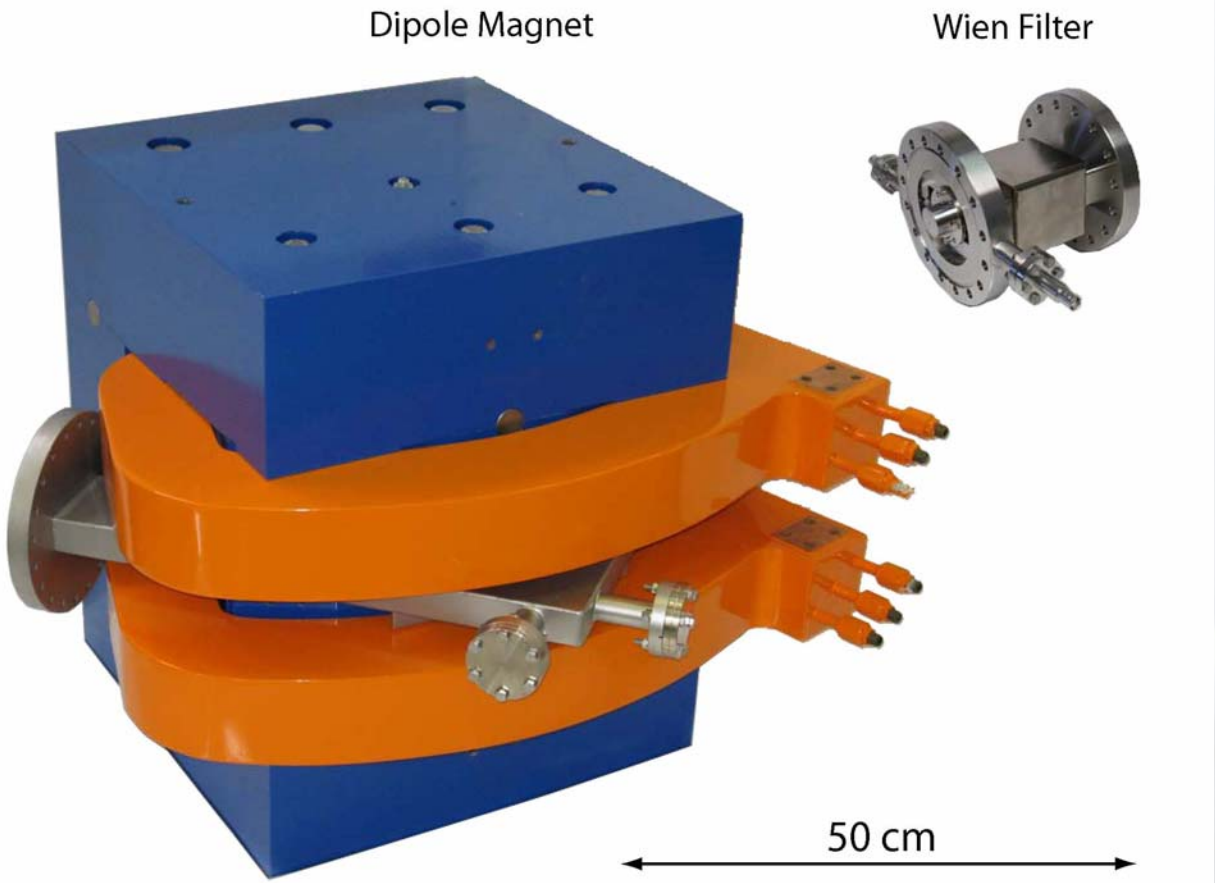


Dresden EBIS

leaky mode

Xe-129

Comparison of Sizes – Dipole Magnet and Wien Filter



resolution > 80

Wien filter
DREEBIT GmbH
product number 21007
http://www.dreebit.com

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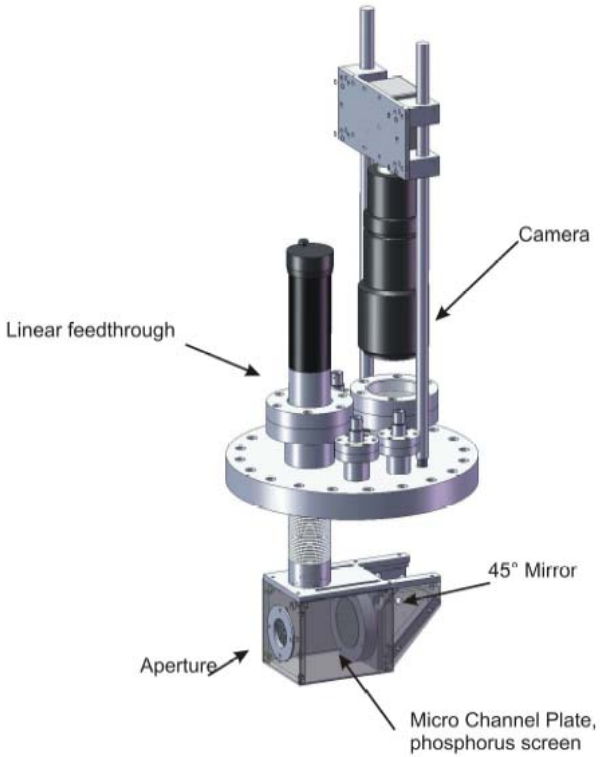
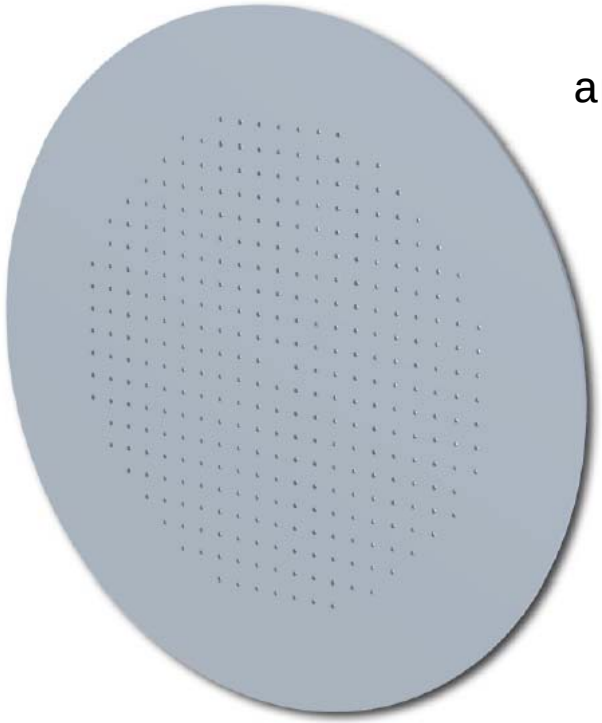
Electron & Ion Beam Technologies

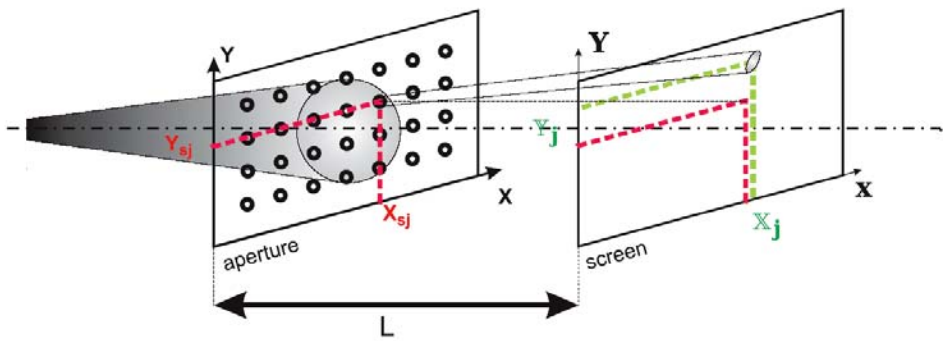
Dresden EBIS-A: Beam Emittance



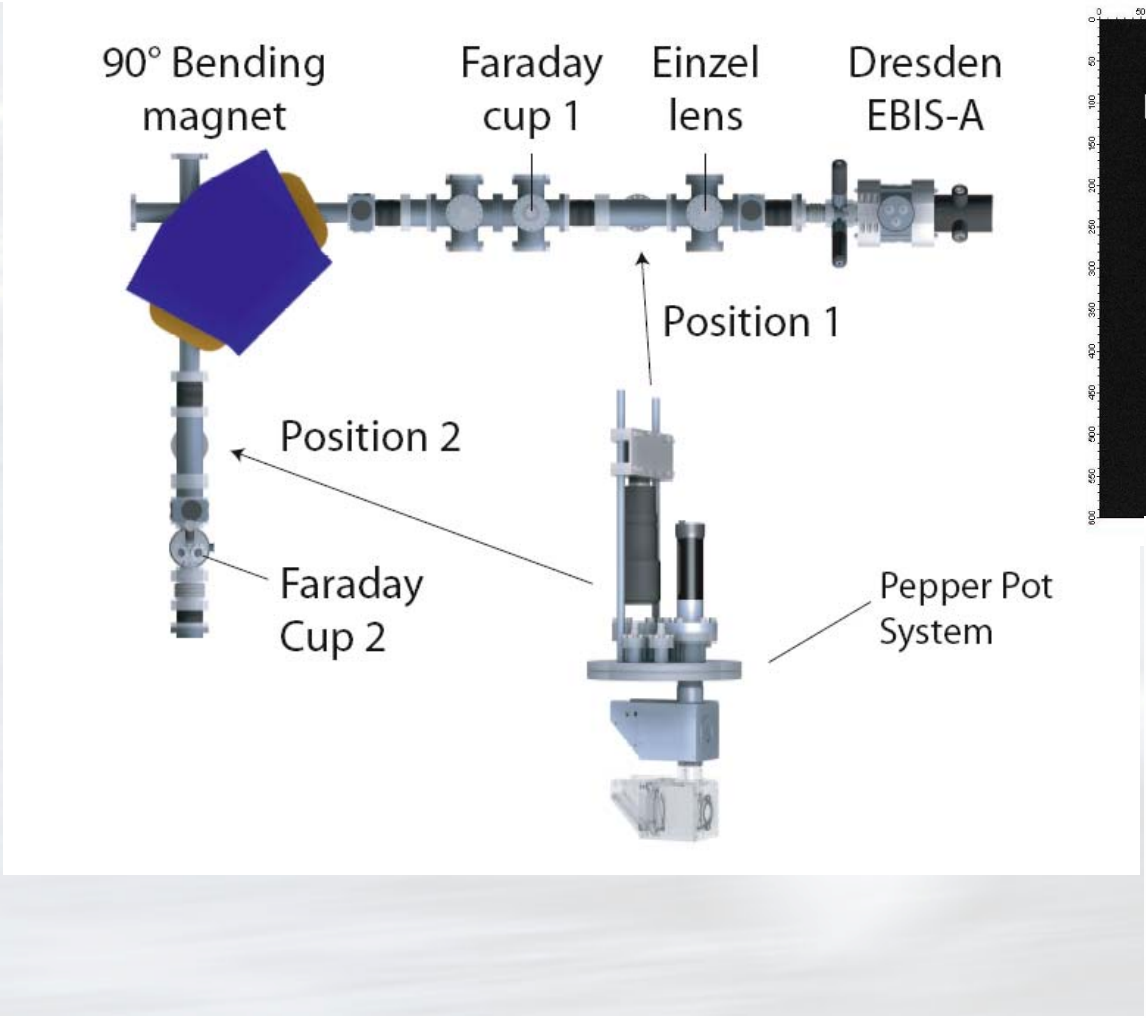
(a) Pepper Pot System

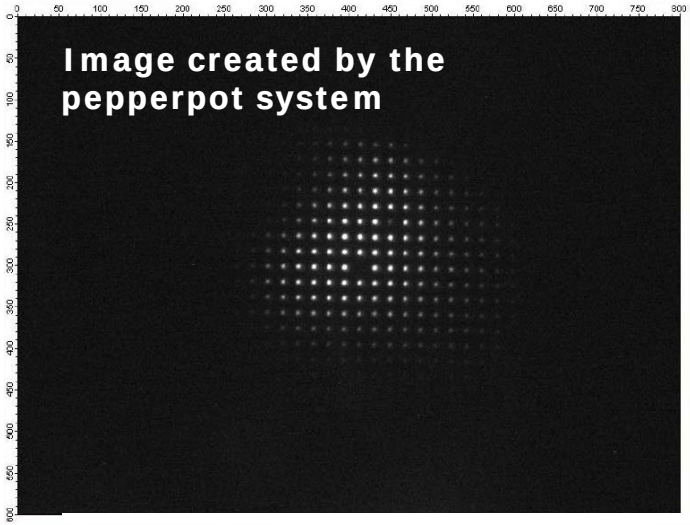


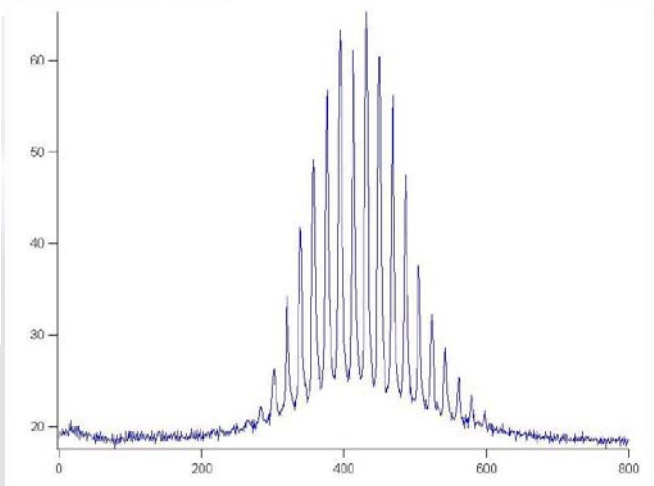
aperture



Dresden EBIS-A: Beam Emittance







RMS Emittance of a C^{6+} Ion Beam

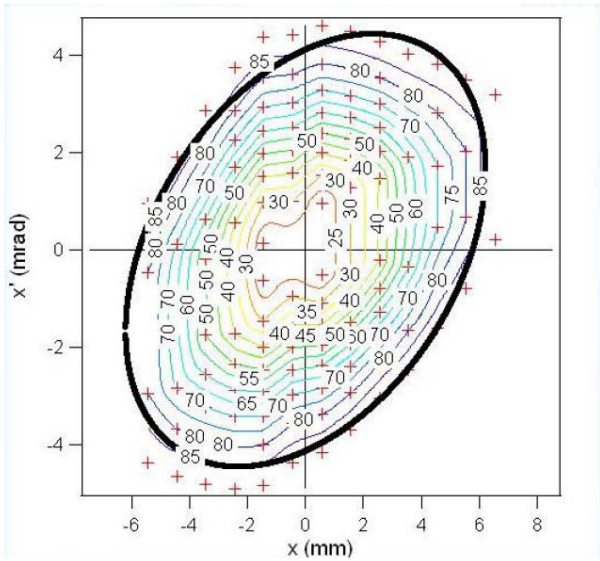
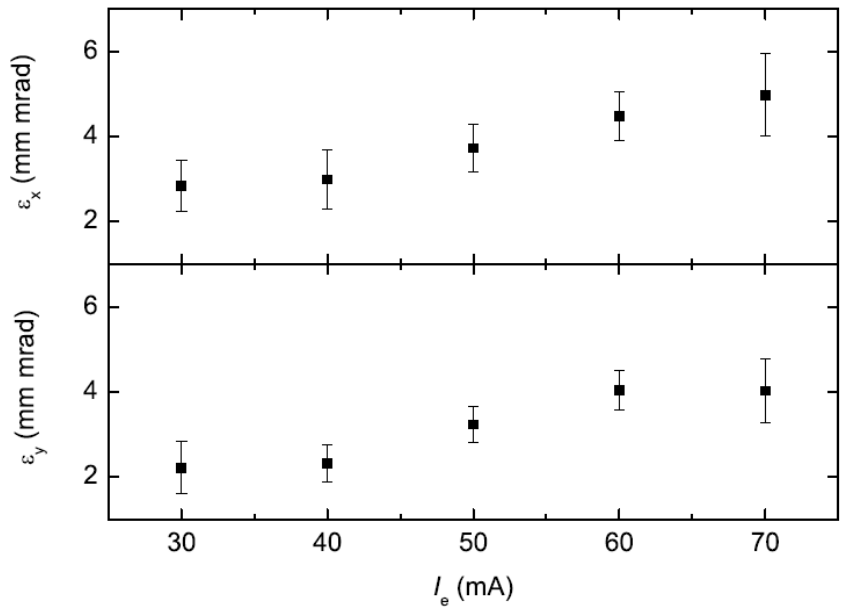


Figure: Trace space plot of the example image (with ellipse)



RMS emittance of a 30 keV C^{6+} ion beam

The Next Generation: Dresden EBIS-SC

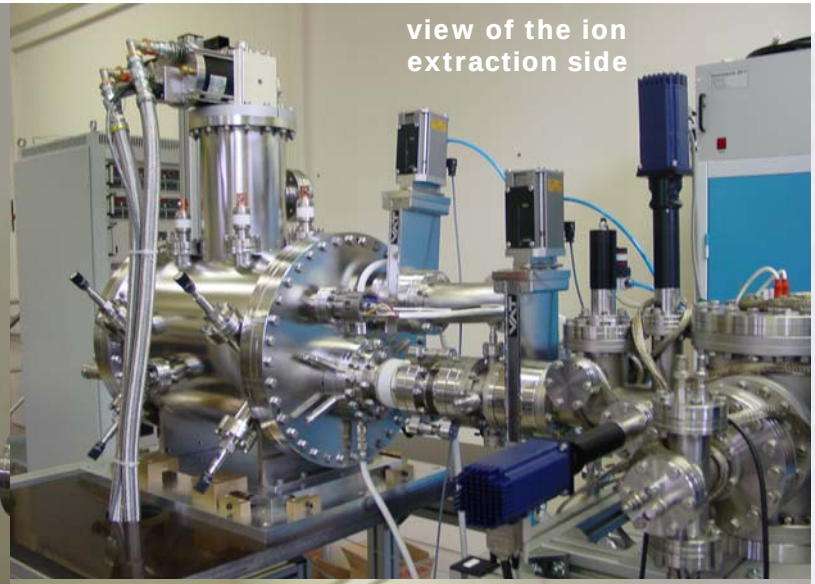
A new generation of EBIS sources, the Dresden EBIS-SC, is being designed for new fields of applications.

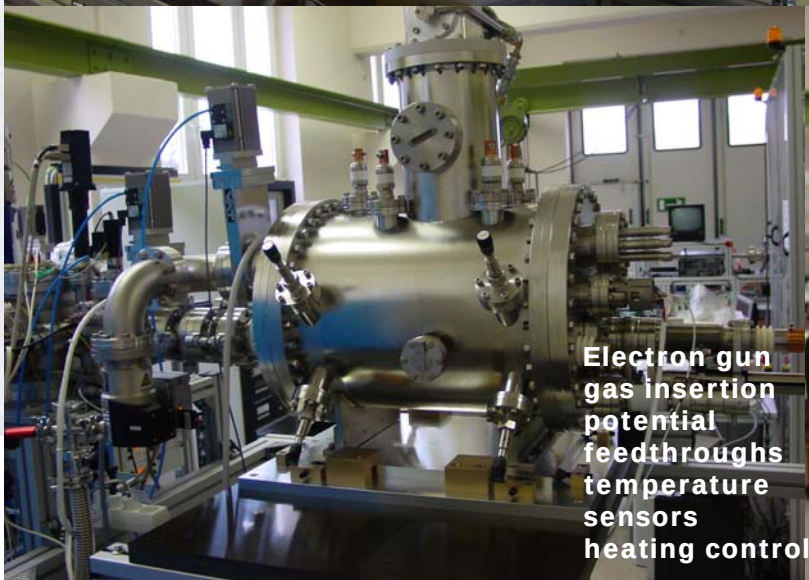
The Dresden EBIS-SC is a superconducting compact ion source which is based on the most modern principles of refrigeration technologies as well as electron-beam technologies.

The next generation: Dresden EBIS-SC

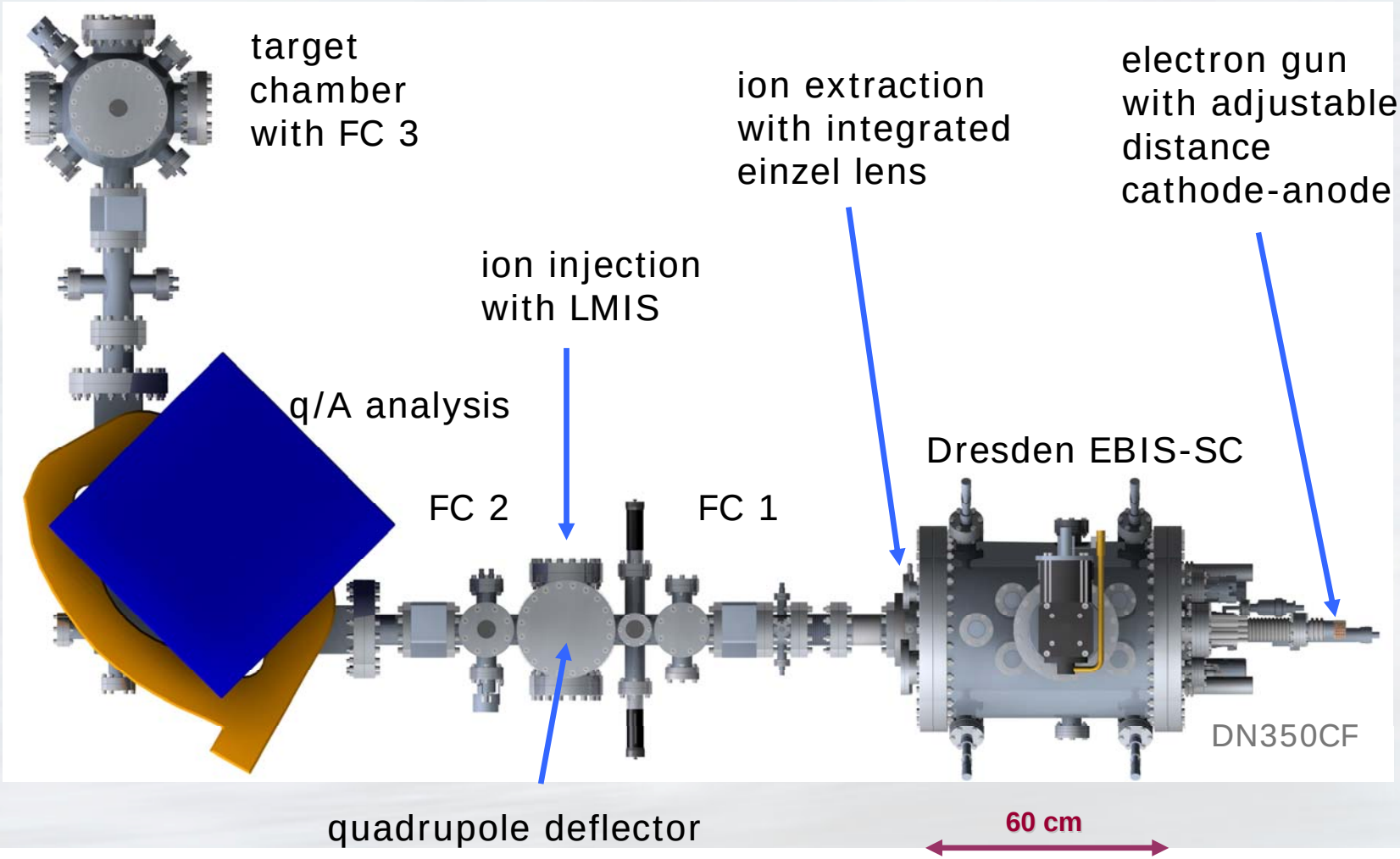
Parameter	Value
Total length	approx. 60 cm; DN350CF
Magnetic field (on axis)	up to 6 T
Electron energy	up to 30 keV
Electron current	1 A
→ eff. electron current density	> 1000 A/cm^2
Trap length	20 cm, 8 drift tube segments individual controllable
→ Trap capacity	up to 6·10^{10} elementary charges

The Dresden EBIS-SC Test Bench





The Dresden EBIS-SC Test Bench



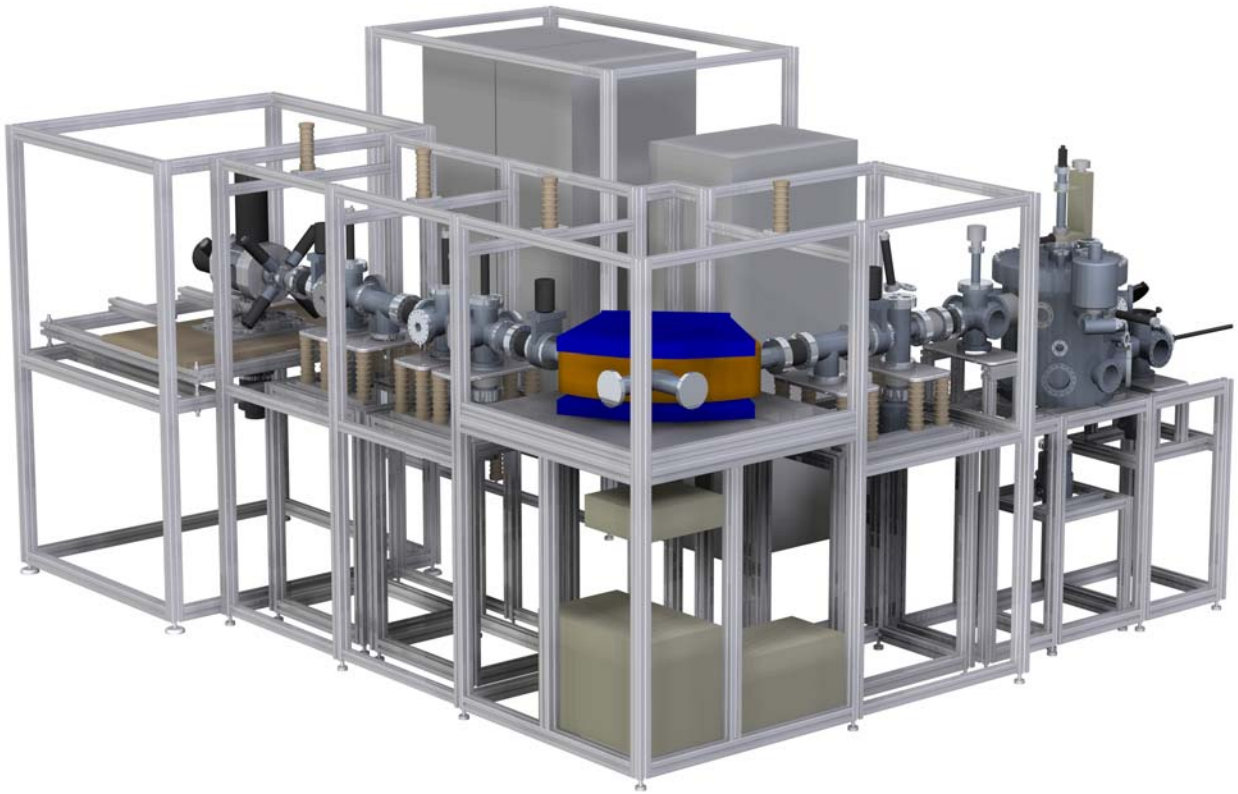
Dresden EBIS-SC: First (preliminary) Results

parameter	value
electron beam current	750 mA
electron energy	10.5 keV
electron beam transmission	0.9984
ion pulse widths	(6…10) μs

Applications in Accelerator Technology

Low Energy Ion Irradiation Facility

Applications: Low Energy Ion Irradiation Facility



- ion deceleration down to 10 eV*q
- ion acceleration up to 1.5 MeV
- ion pulses from ns to 100 μs width
- DC ion beams
- beam diameters from 500 μm up to cm

Charge Breeding

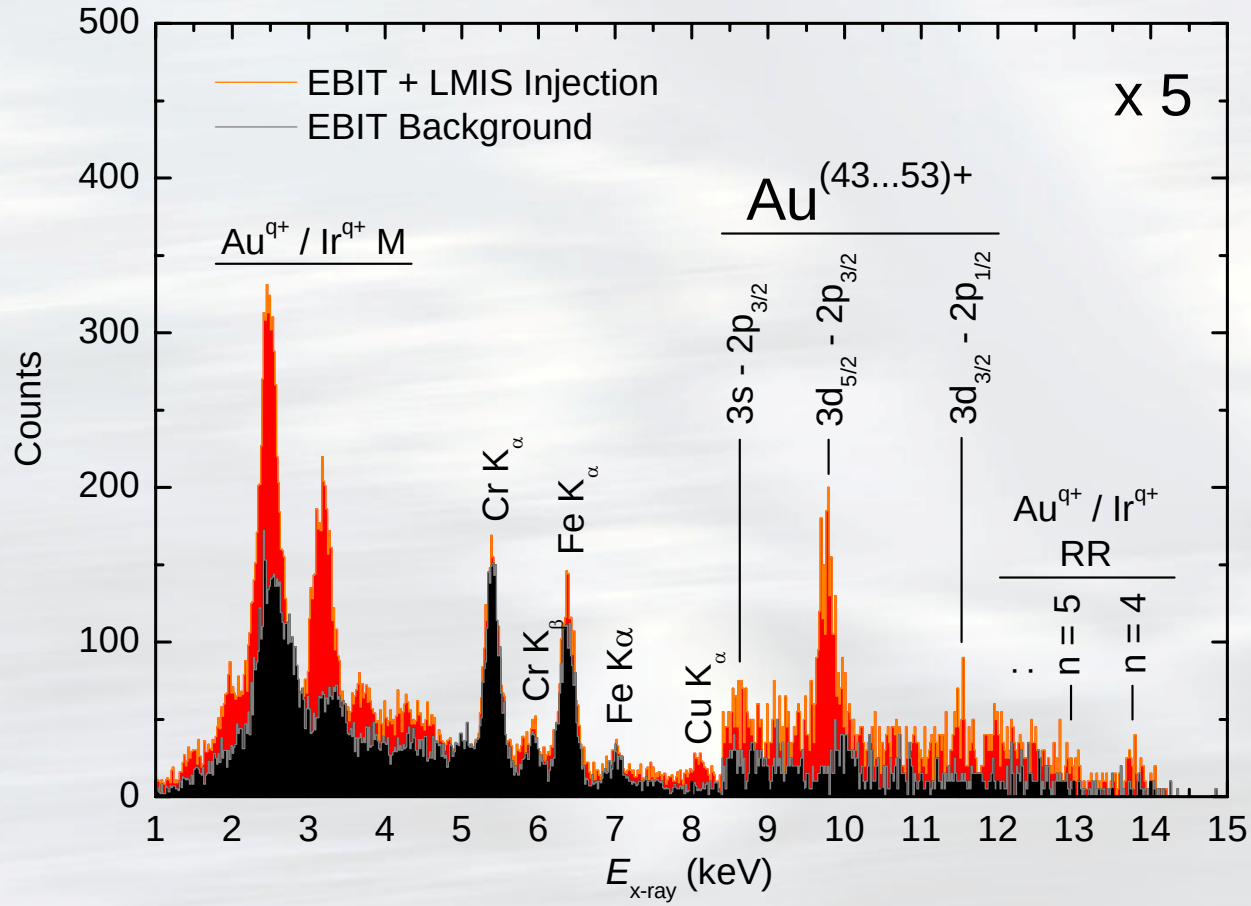
Applications: Charge Breeding

Concept:
Primary ion source
→ Beam of low charged ions
→ Injection into a charge breeding apparatus – ECRIS or EBIT
→ Reextraction of highly charged ions

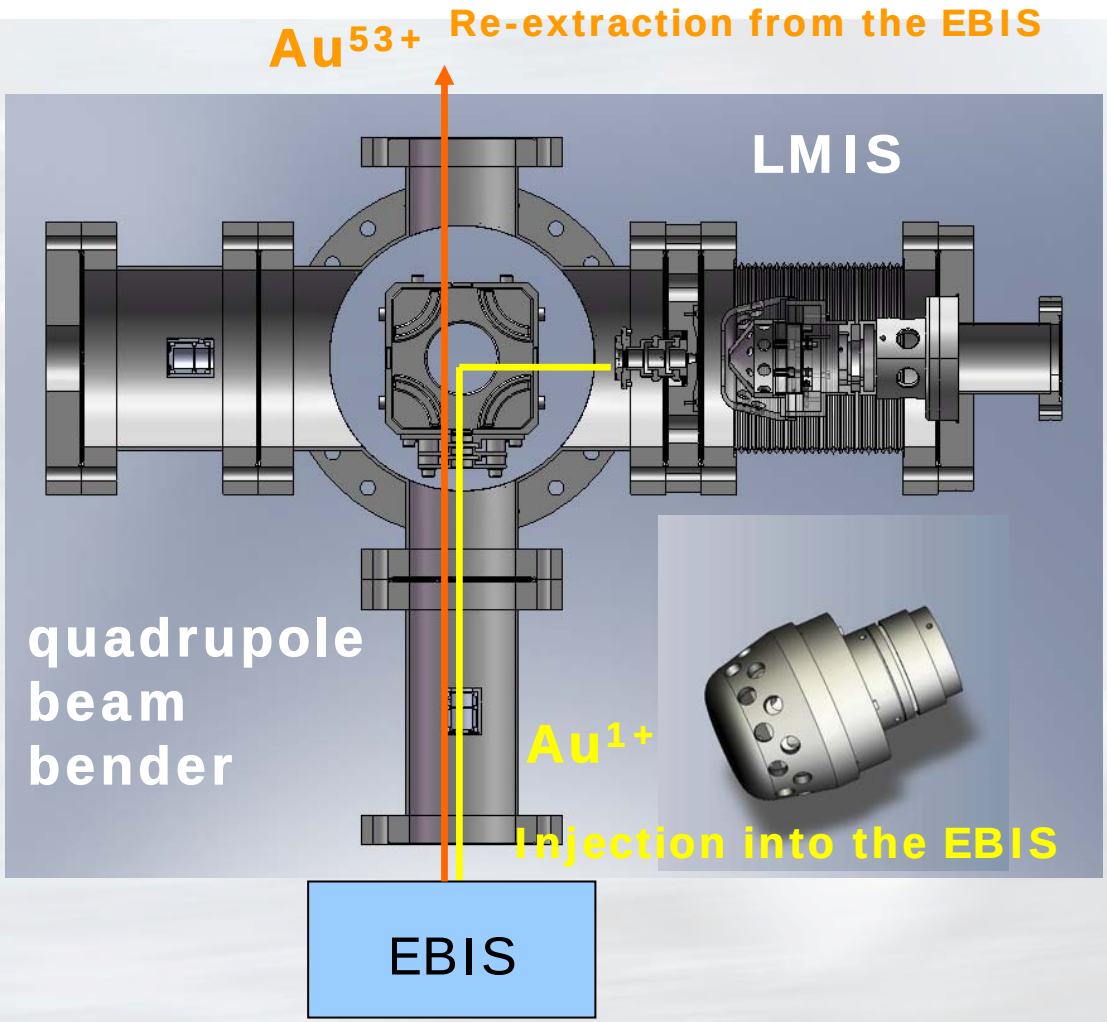
Important properties of a charge breeder:

efficiency, **rapidity**, and **properties of the extracted ion beam**

Charge Breeding: Gold



Charge Breeding:
Liquid Metal Ion Source with Quadrupole Beam Bender



New ion injection techniques for

Bismuth

Germanium

Erbium

Indium

Gold

Ceasium

Antimony

Platinum

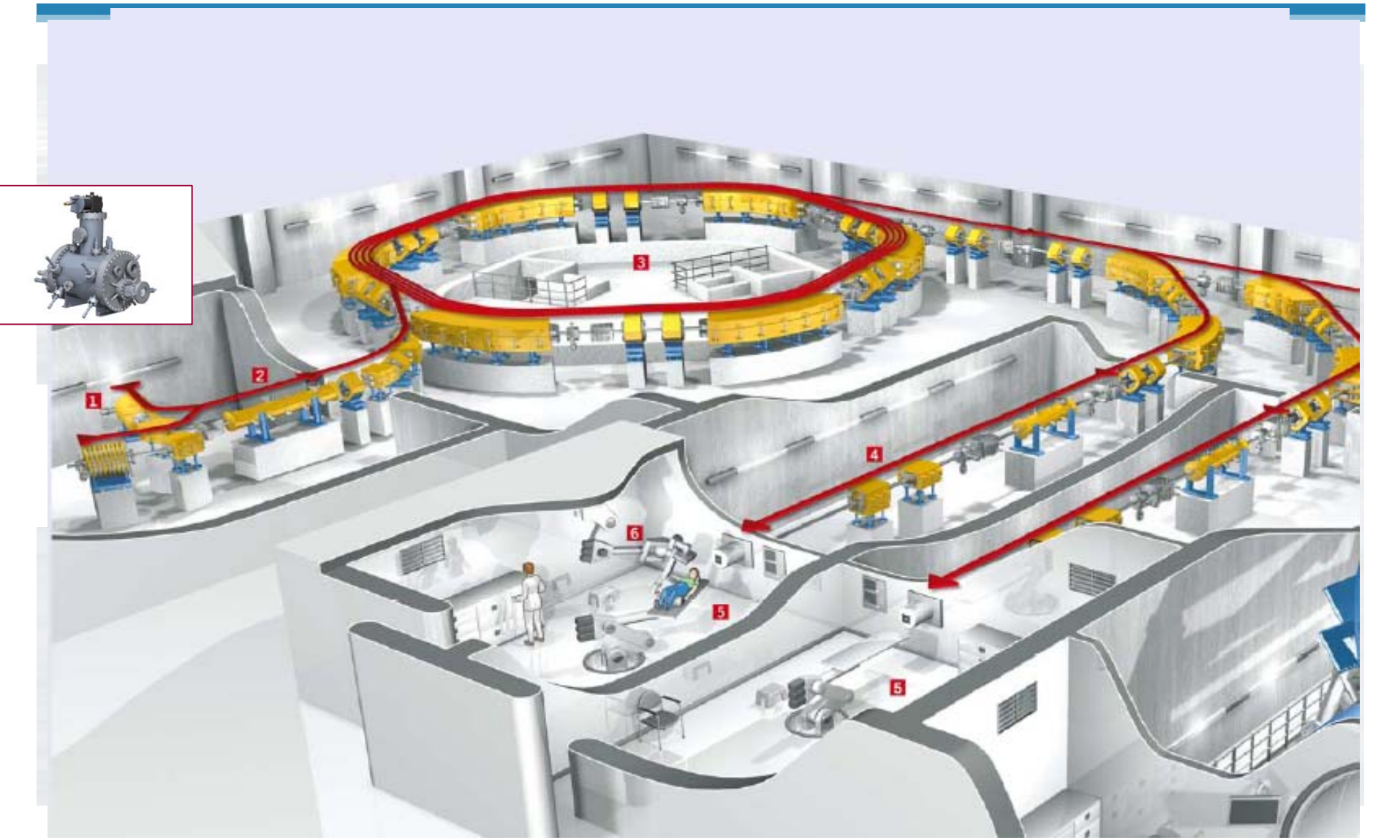
Praseodymium

and others

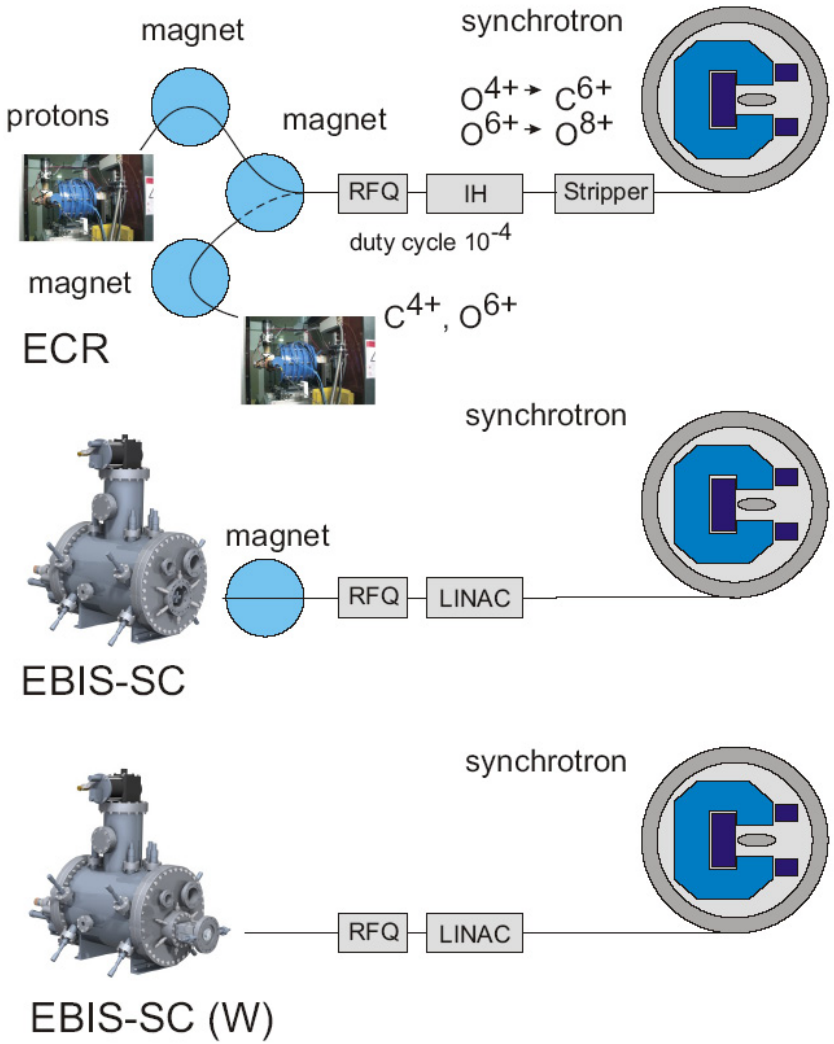
Applications in Medical Therapy Accelerators

Synchrotrons

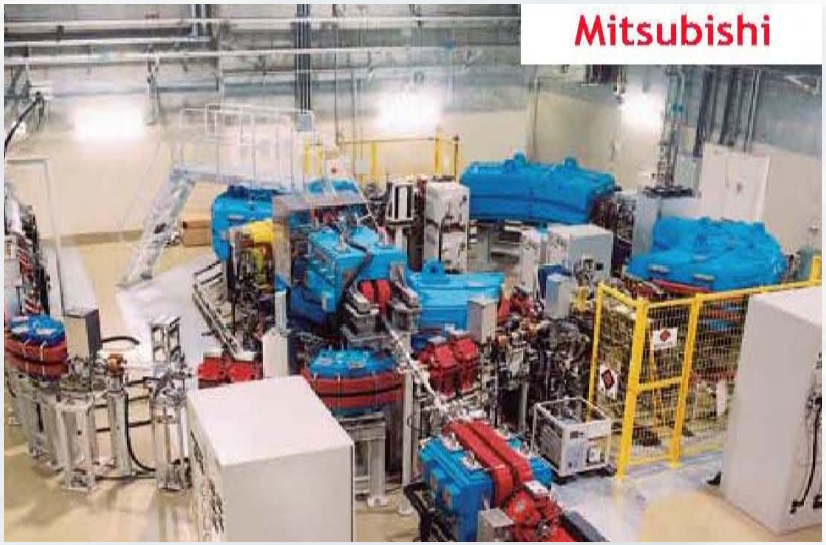
Medical Cancer Therapy – Synchrotrons I

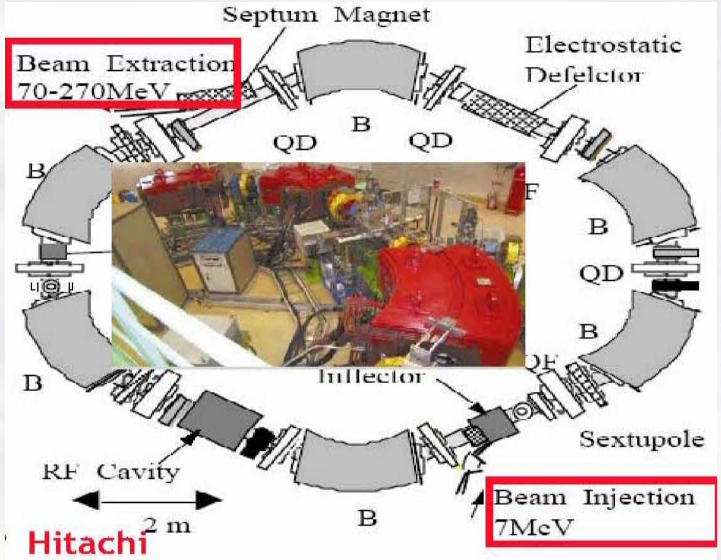


Medical Cancer Therapy – Synchrotrons II



Medical Cancer Therapy – Other Solutions ?

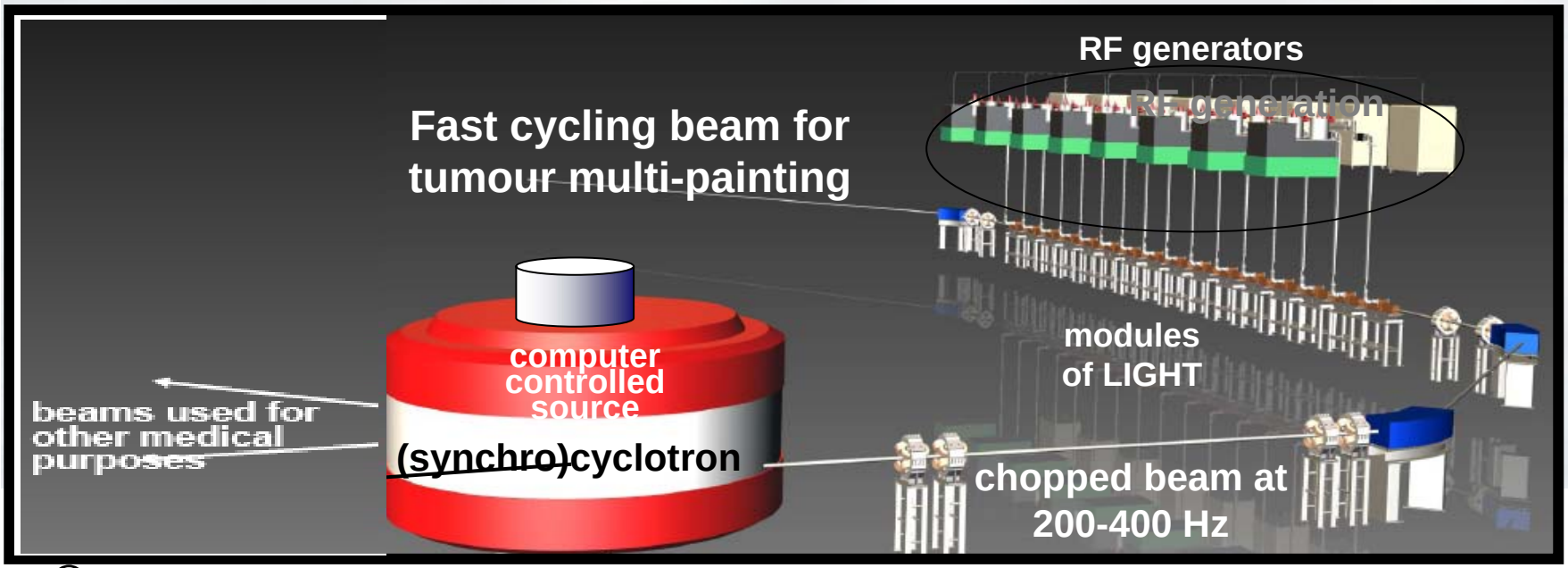




CYCLINAC

Medical Cancer Therapy – CYCLINAC I

TERA approach to treat moving organs and solve other problems:
high-current cyclotron + novel fast-cycling linac
=
“CYCLINAC”



Medical Cancer Therapy – CYCLINAC II

CABOTO at 12 Ghz would be shorter and would consume less power (CNAO consumes 3-4 MW)

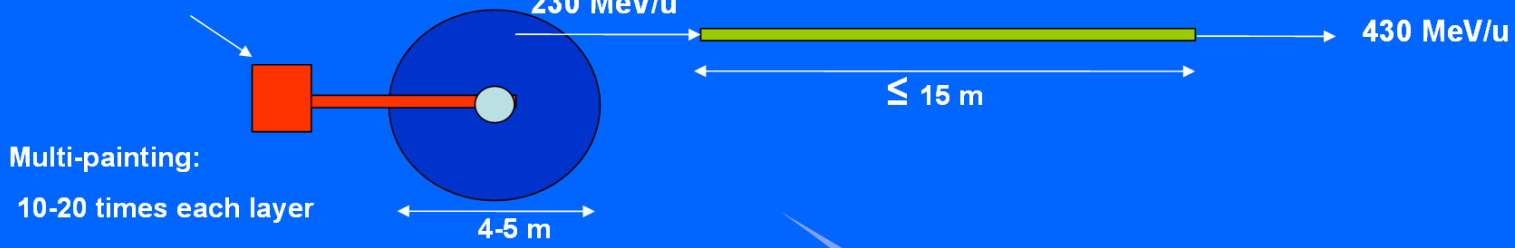
SC EBIS source by

DREEBIT – Dresden

300-400 Hz – 10^8 C/pulse

400 MV – 12 GHz linac

≤ 1 μs pulses



Superconducting Synchrocyclotron

230 MeV/u

H_2^+ and C^{+6}

@ 300-400 Hz

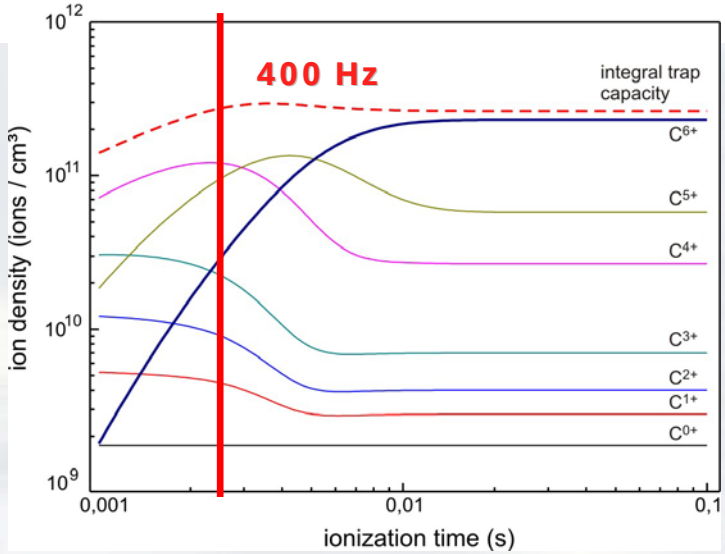
(TERA + EPFL+ A. Laisné)

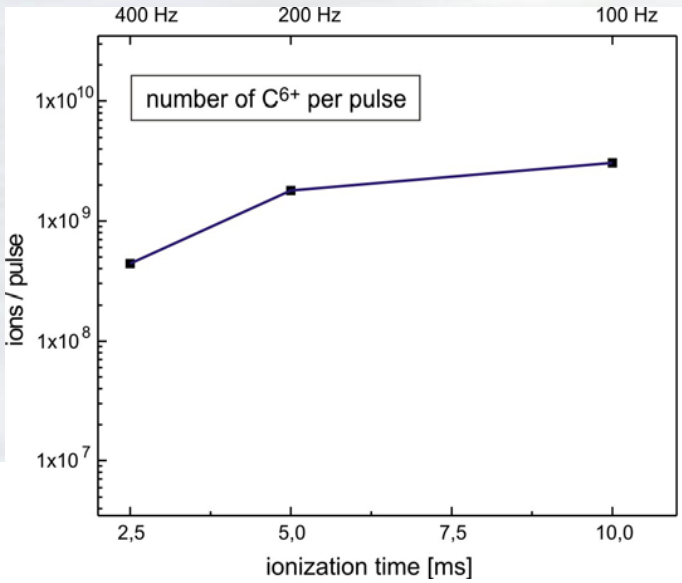
This is the

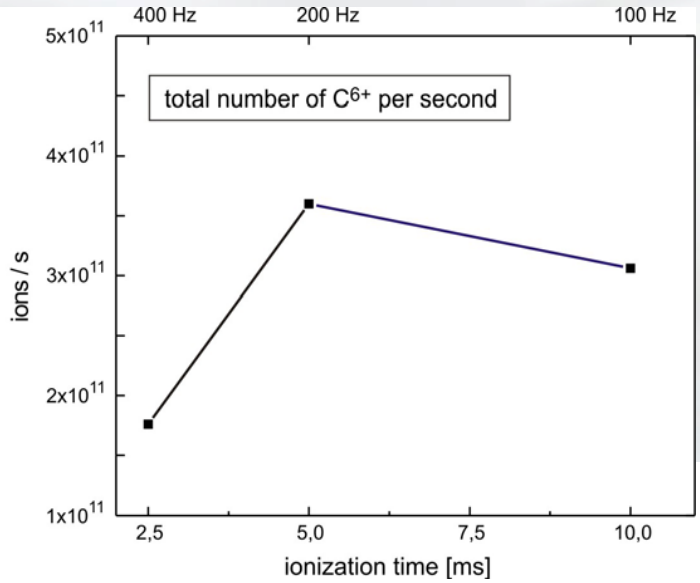
« CABOTO 12 GHz » design project proposed for a collaboration with CLIC, EPFL

Medical Cancer Therapy – CYCLINAC III

Requirement: 1∗10⁸ ions / puls







The Dresden EBIS/EBIT ion source family consists of four generations of ion sources:

Dresden EBIT

Dresden EBIS

Dresden EBIS-A

small-size room-temperature sources of highly charged ions

Dresden EBIS-SC

high-performance superconducting EBIS

Broad fields of applications:

- accelerator technology (medicine, surface science, AMS, ...)
- ion implantation
- nanotechnology
- surface analysis
- .....

Thank you !

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A.Silze

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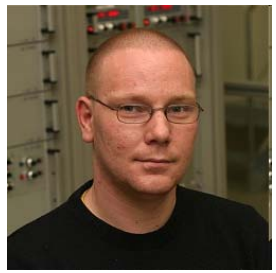
Dr. Ovsyannikov

Dr. Grossmann



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DREEBIT

Electron & Ion Beam Technologies

http://www.dreebit.com