Physics and Technology of ion sources

Lecture with exercises

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1) Introduction

The physics of ion sources comprises:

- Production of charged particles (Electrons, Ions) → Production of plasma
- Ionisation of atoms (Electron impact ionisation, photoionisation)
- Plasma extraction
- Beam shaping and charged particle transport
- Beam diagnostics
- Applications in basic science and industry

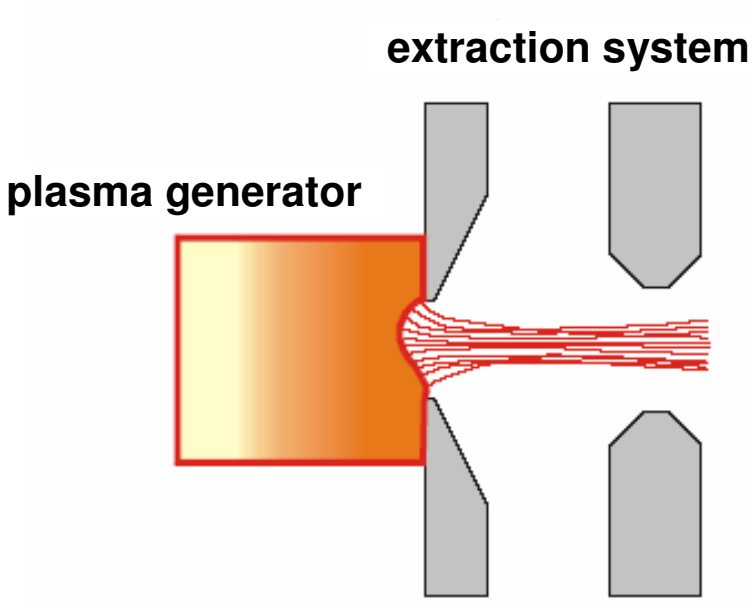
Production of charges particles:

Electrons → electron guns

Ions (positive or negative) → ion sources

Principle of a plasma ion source:

- plasma generation
- extraction
- beam transport



Production of ions:

- positive ions can be produced by electron impact, photons or on hot surfaces

  $e^- + X = X^+ + 2e^-$ (successive ionisation)

- negative ions
  An electron has to be attached or charge exchange of a positive ion on a hot surface or in metal vapour (alkaline, mainly Cs)
  → exothermal process due to electron affinity

electron affinity > 0
→ negative ion is stable
(Table)

Electron affinities and ionization energies of elements

Ionization potential (eV)
− Electron affinity (eV)

Group I A	II A	III A	IV A	V A	VI A	VII A	VIII A
1 H 13.59 0.75							2 He 24.58 0.078
3 Li 3.39 0.62	4 Be 9.32 < 0	5 B 8.30 0.28	6 C 11.26 1.26	7 N 14.54 ≤ 0	8 O 13.61 1.46	9 F 17.42 3.39	10 Ne 21.56 < 0
11 Na 5.14 0.54	12 Mg 7.64 < 0	13 Al 5.98 0.46	14 Si 8.15 1.38	15 P 10.55 0.74	16 S 10.36 2.07	17 Cl 13.01 3.61	18 Ar 15.76 < 0
19 K 4.34 0.50	20 Ca 6.11 ≈ 0	31 Ga 6.00 0.3	32 Ge 7.88 1.2	33 As 9.81 0.80	34 Se 9.75 2.02	35 Br 11.84 3.36	36 Kr 14.00 < 0
37 Rb 4.18 0.48	38 Sr 5.69 < 0	49 In 5.78 0.3	50 Sn 7.34 1.25	51 Sb 8.64 1.05	52 Te 9.01 1.97	53 I 10.45 3.06	54 Xe 12.13 < 0
55 Cs 3.89 0.47	56 Ba 5.21 < 0	81 Tl 6.11 0.3	82 Pb 7.41 1.1	83 Bi 7.29 1.1	84 Po 8.43 1.9	85 Ar 9.5 2.8	86 Rn 10.74 < 0

Additional mechanism: dissociation of molecules $e^- + XY = X^- + Y$

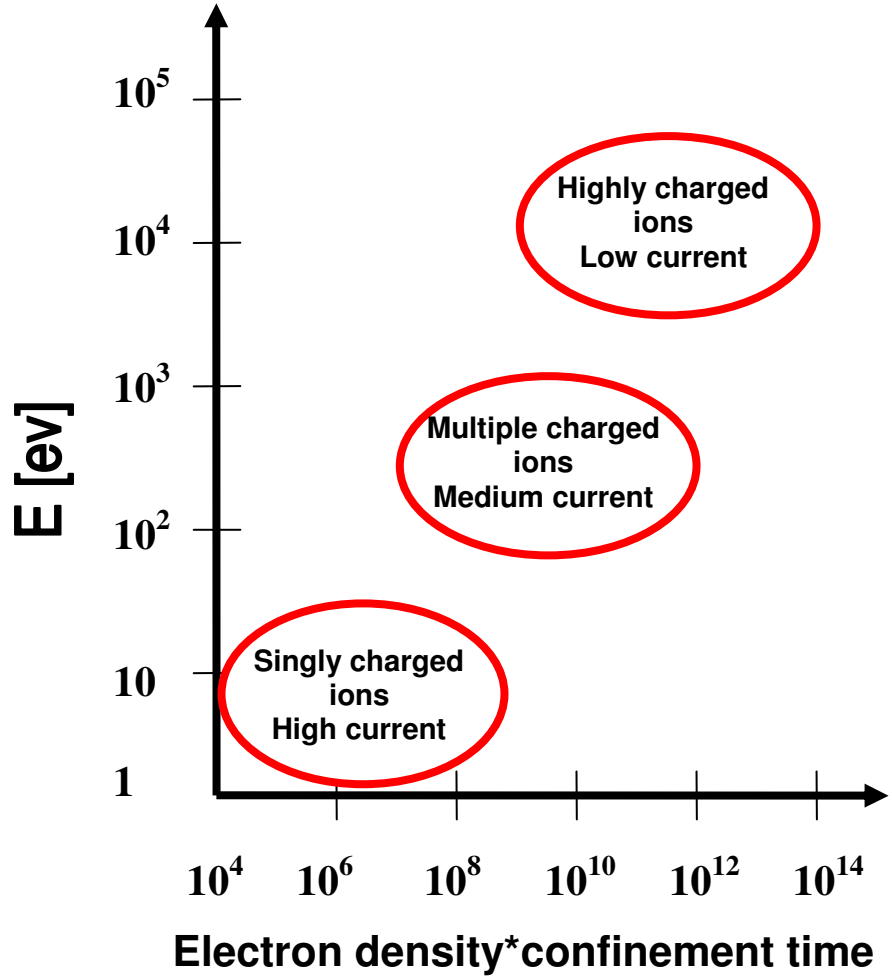
excitation $e^- + XY = X^+ + Y^- + e^-$

Classification of ion sources:

The classification of the ion sources can be done via the kinetic energy of the electrons in [eV] in the plasma and the plasms density + confinement time in the plasma.

The electron energy determines the maximum charge state that can be reached in the plasma by electron impact ionisation.

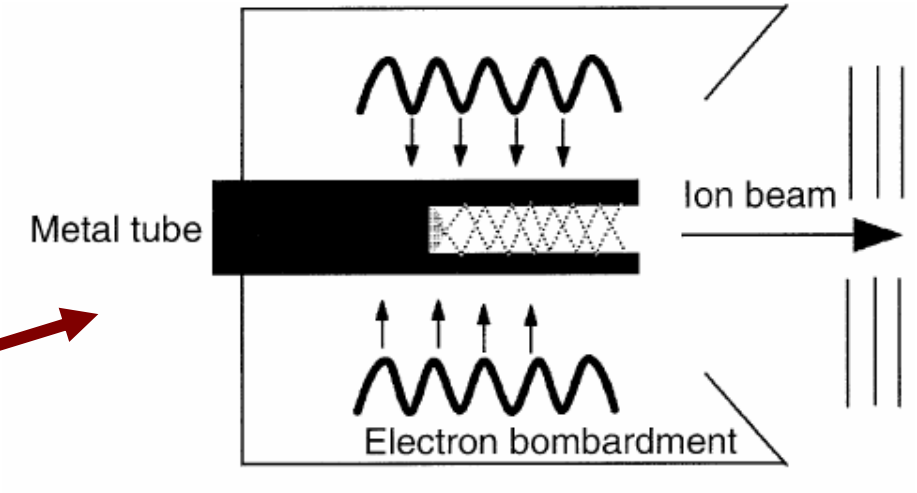
The product of density and confinement time determines the time required to reach a certain charge state.



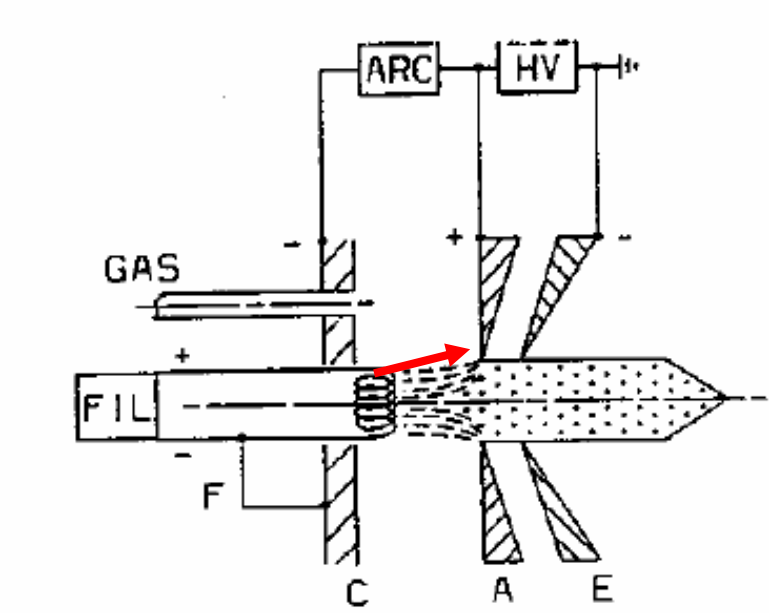
Type of ion sources:

- Ion sources that deliver high beam currents up to several amperes, but low ion charge states.
- Ion sources that deliver highly charged ions (up to U^{92+}), but low intensities.

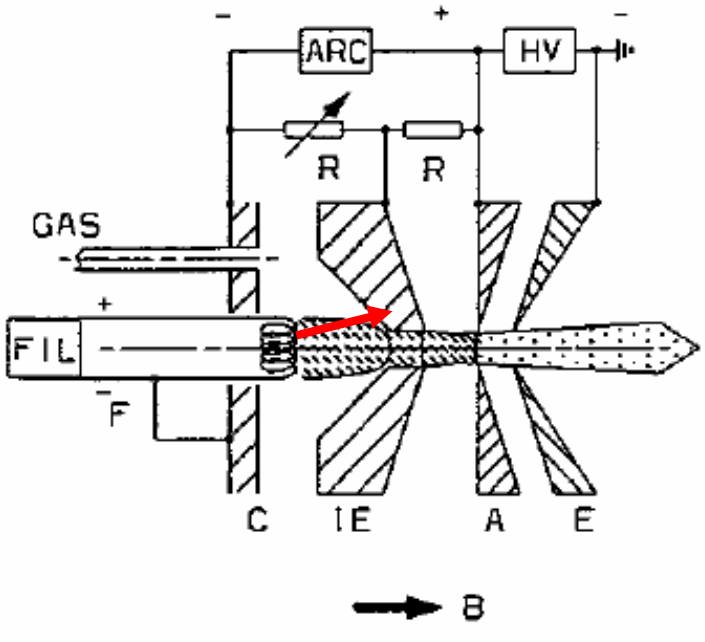
simple ion source → surface ion source



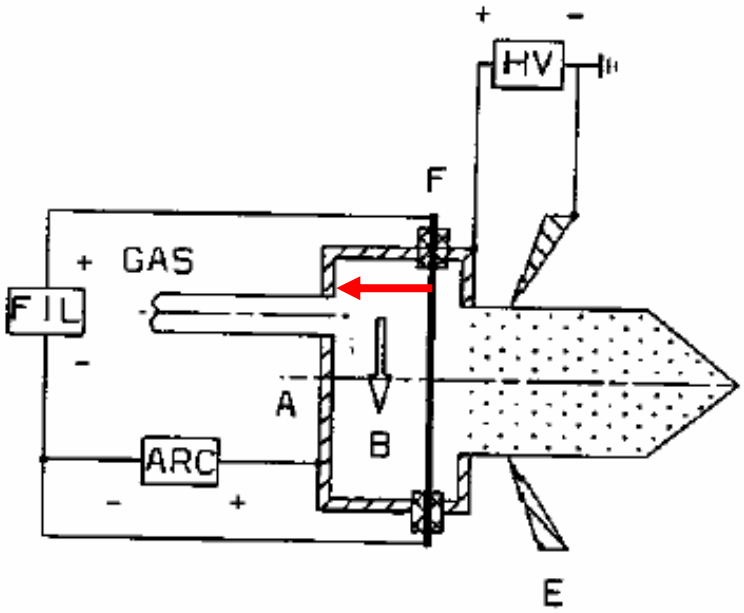
Electron impact ion source



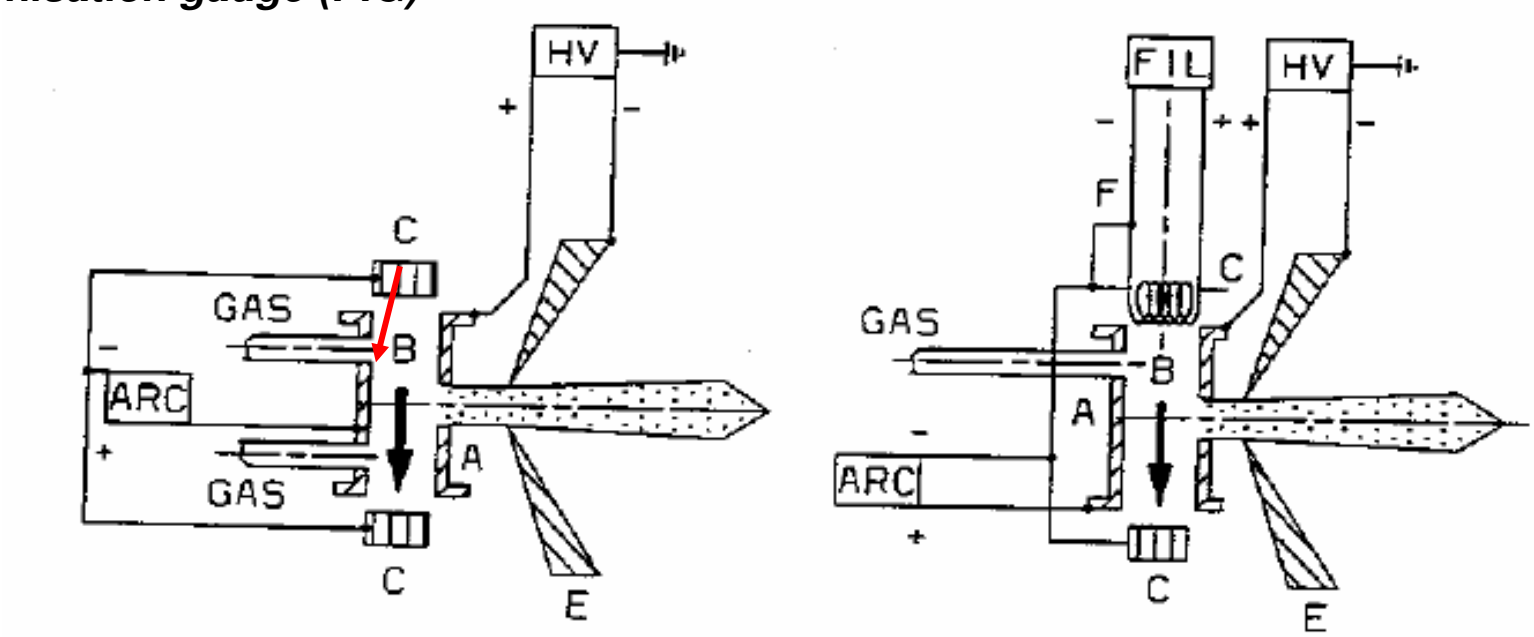
Plasmatron ion source



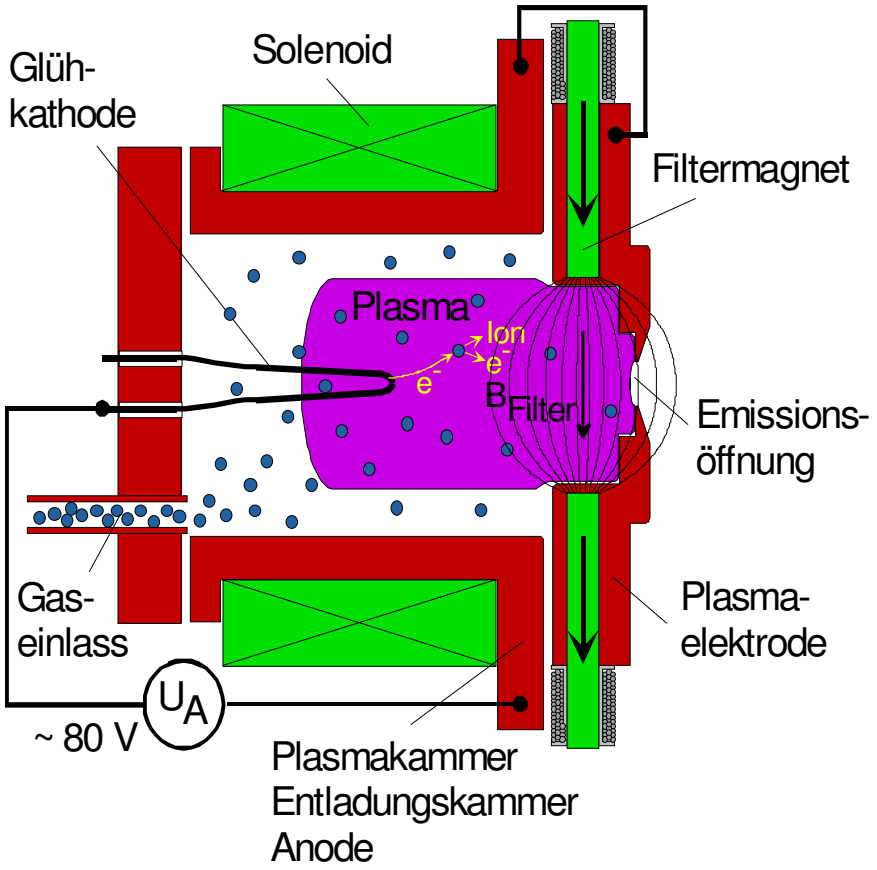
Magnetron ion source



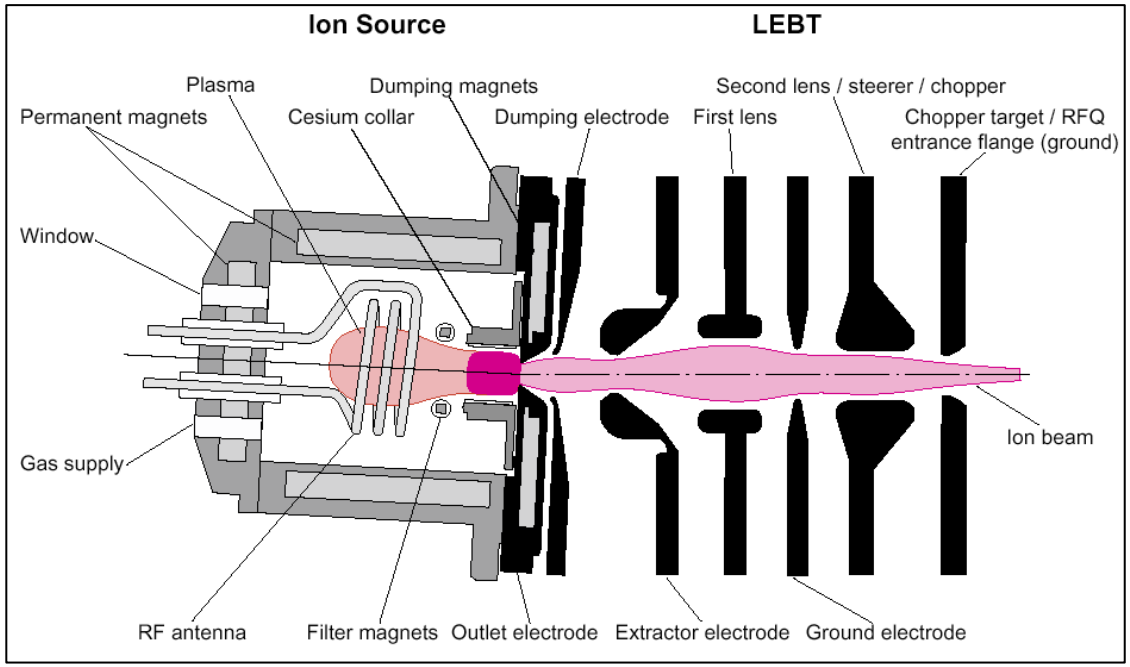
Penning ionisation gauge (PIG)



Volume ion source



rf-ion source

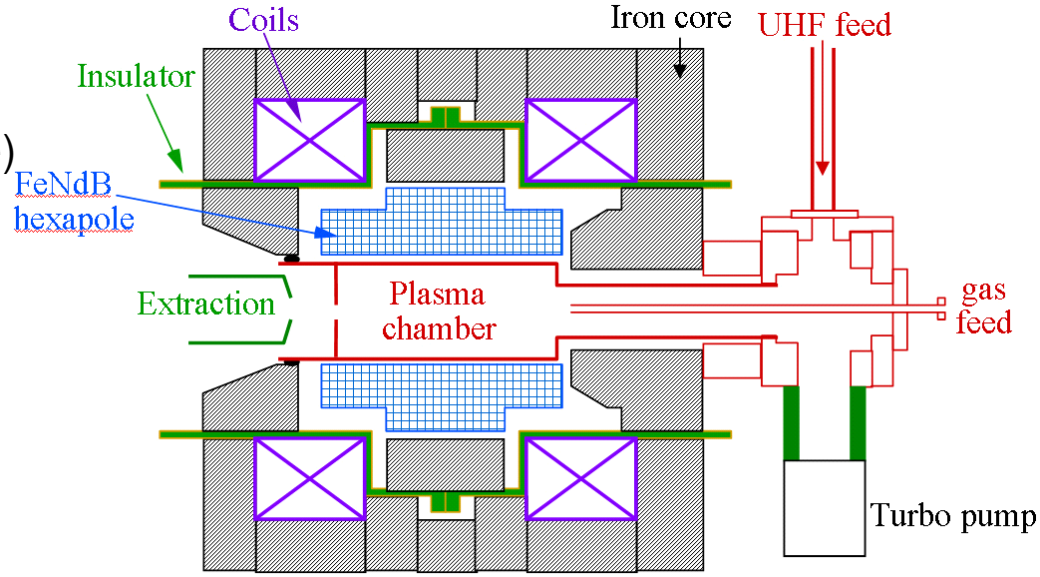


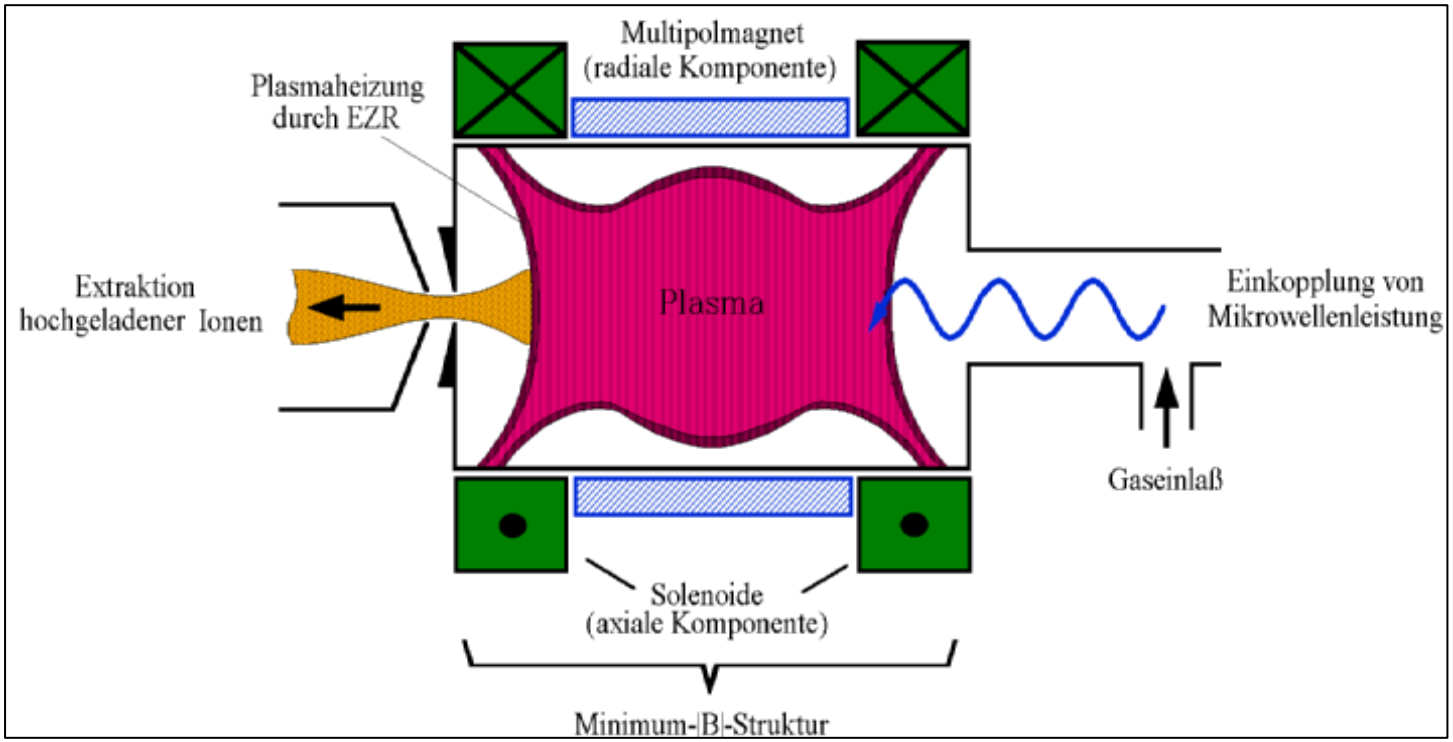
High charge state ion sources:

ECRIS (Electron Cyclotron Resonance Ion Source)

Microwave heated plasma

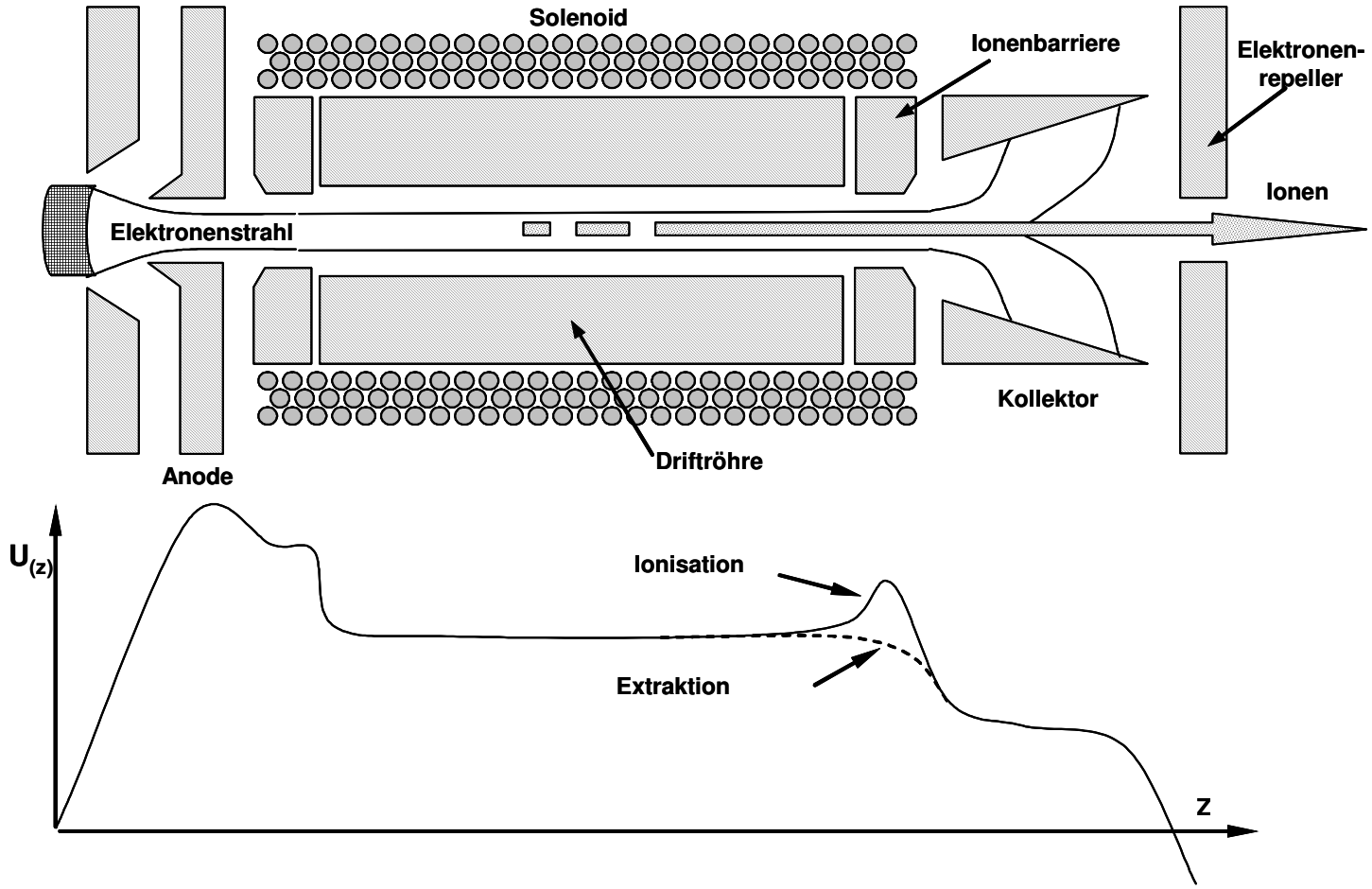
→ magnetic confinement of the ions
via a solenoid and a multipolar field





The electron beam ion source (EBIS)

The ions are confined in an electron beam. The electron beam is focused by a strong magnetic field from a solenoid.



Application of ion beams:

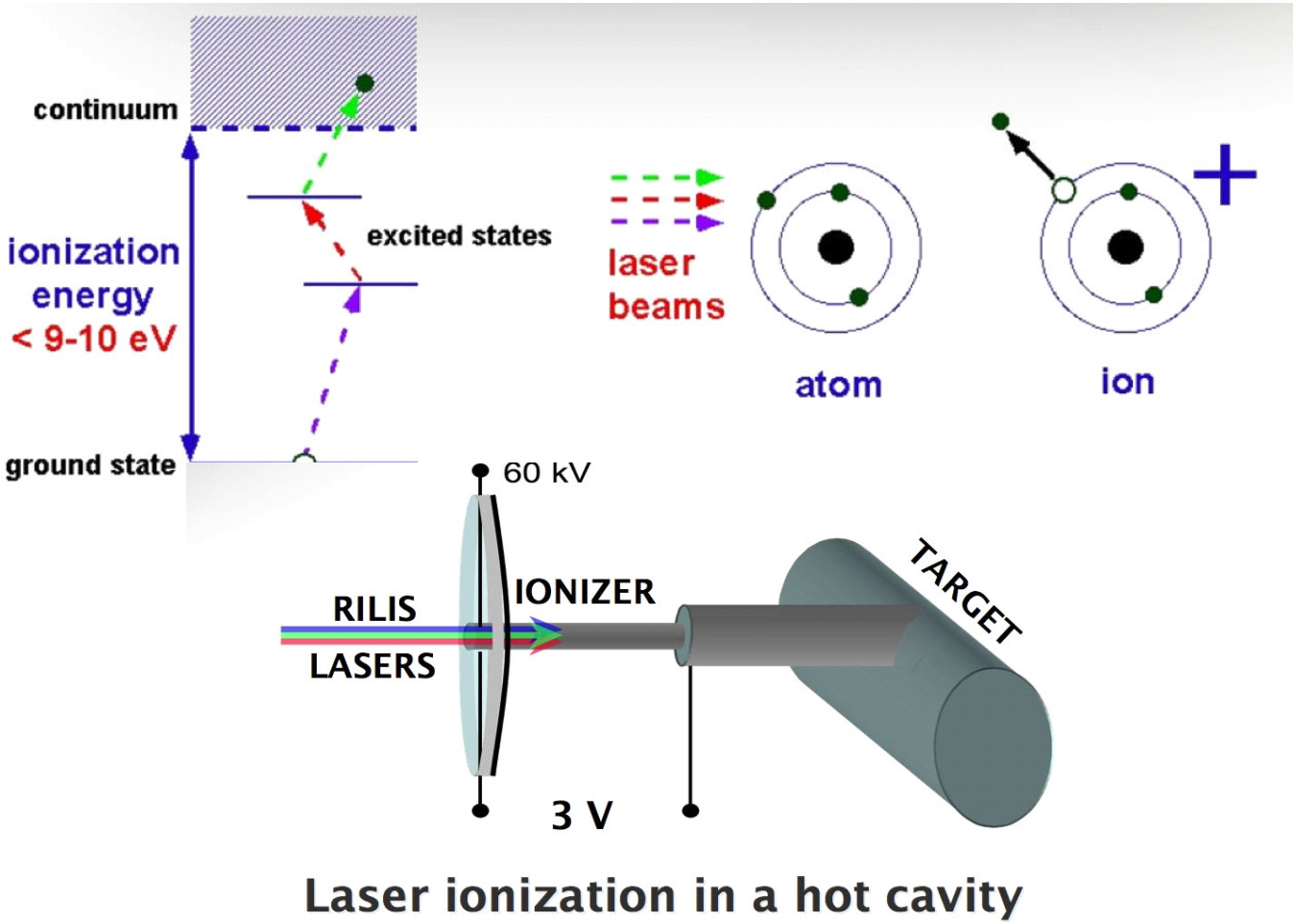
Sputtering, plasma etching, ion thrusters, Atomic physics, implantation, mass spectrometry, ion accelerators

Aside plasma ion source
Ions can be delivered by resonance laser ionisation.

(RILIS resonant laser ionisation ion source)

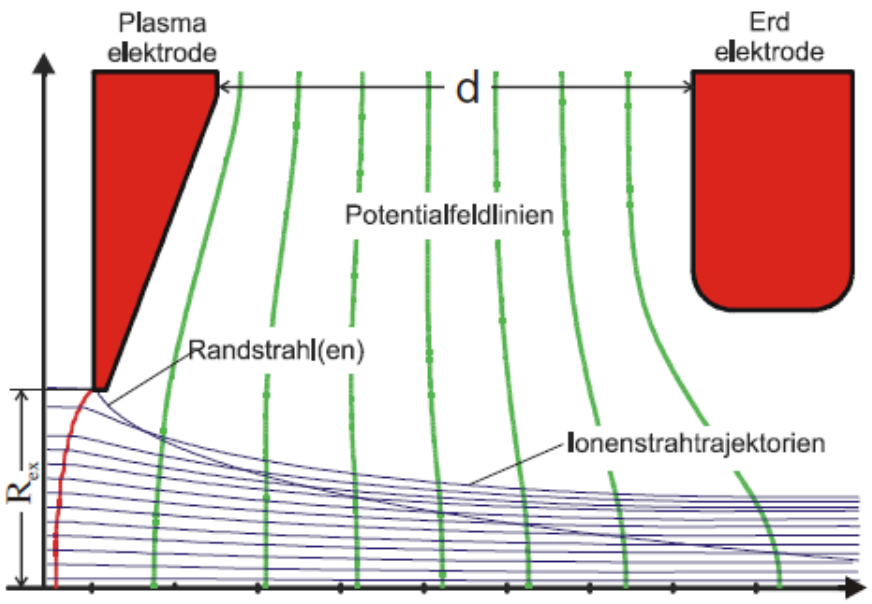
Ionisation via multi step resonance laser excitation:

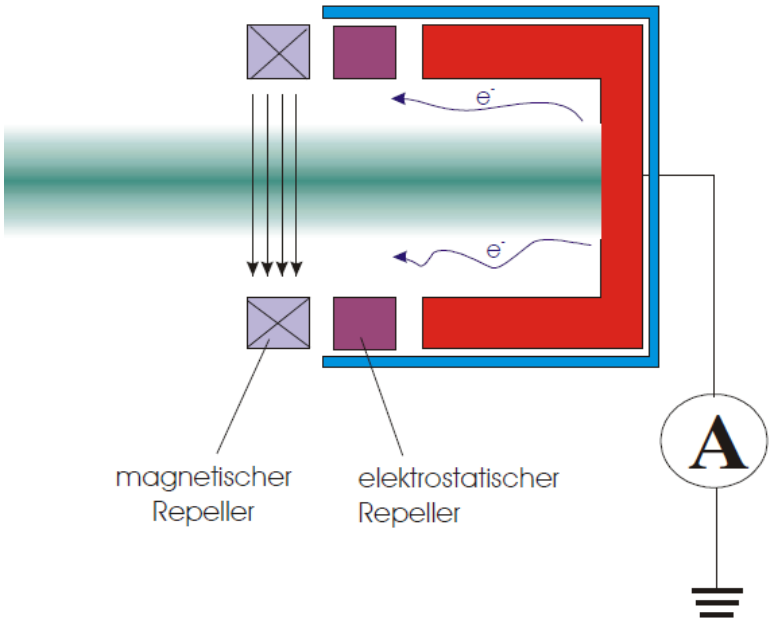
Example: ISOLDE RILIS

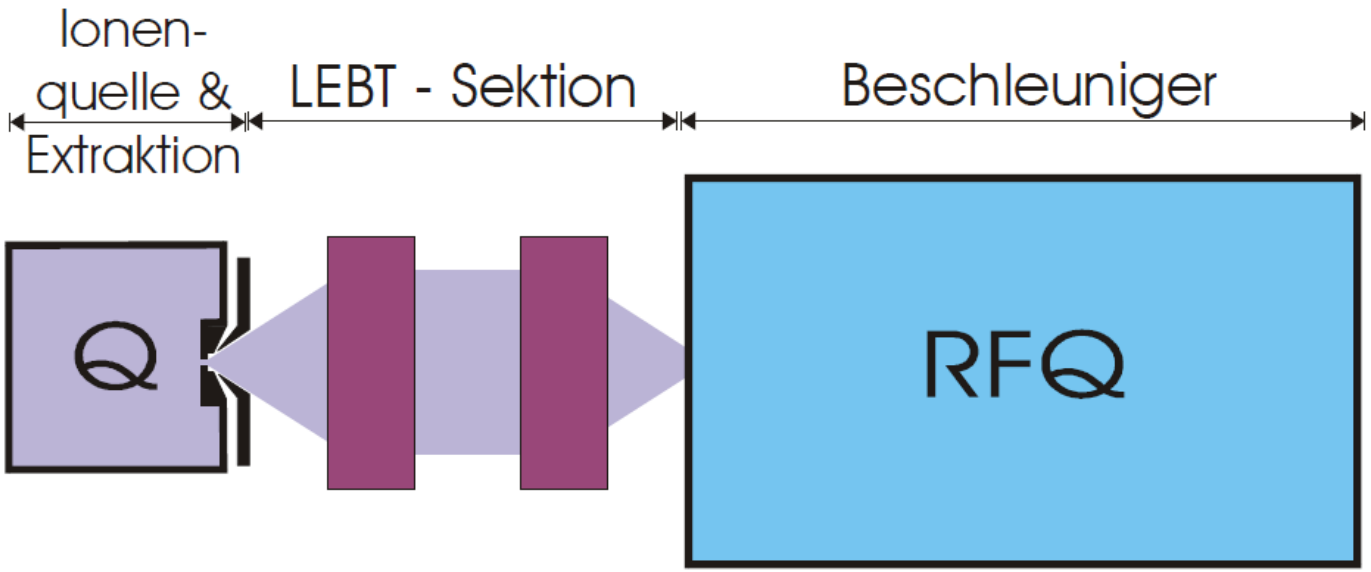


Laser ionization in a hot cavity

Beam formation, -transport und -diagnostics:







Important physical quantities used in the lecture:

The kinetic energy of charged particles is measured in *electron volts* (eV).
1 eV is the energy a singly charged particle acquires when it moves through a potential of 1 Volt.

1 eV = e * (1 Volt) = $1.6022*10^{-19}$ J

The mass of an electron is $m_e = 9.109*10^{-31}$ kg
The mass of the proton is $m_p = 1.672*10^{-27}$ kg
The atomic mass unit is 1 u = $1.6606*10^{-27}$ kg
The elementary charge of a particle is e = $1.6022*10^{-19}$ As

An electron with 1 eV kinetic energy is moving with a velocity of about 594 km/s.

Top-ten reasons why it's great to be an ion source physicist

10. Spouses never need to worry about what their ion source physicist husband or wife is up to when they still aren't home by midnight...they know with great confidence that they're just at the lab changing a source!
9. Between
   - the International Conference on Ion Sources,
   - the Workshop on Ion Source Issues Relevant to a Pulsed Spallation Neutron Source,
   - the ECR Ion Source Workshop,
   - The International Conference on Negative Ions, Beams and Sources,
   - the International Symposium on the Production and Neutralization of Negative Ions and Beams,
   - the Workshop on Negative Ion Formation and Beam Handling,
   - the International Conference on Sources of Highly Charged Ions,

   the ion source community has the greatest number of conferences and workshops of any scientific discipline measured per linear inch of subject matter
8. Endless hours can be devoted to the important philosophical meaning of "pi" as in "the output emittance is 0.2 pi-mm-mrad"
7. Believe it or not, sometimes the SNS ion source antenna picks up free Satellite Television!
6. High-voltage, hydrogen gas, antennas and power supplies: it's every little kids dream!
5. In what other field can you acquire a Ph.D., and then spend your professional life practicing the occult?
4. When the phone rings during dinner time, you always know who it is: no its not a tele-marketer, it just the lab...the ion source went down!
3. In what other field could you advertise a workshop on "RF-driven, multicusp, Cesium-enhanced H-sources for the SNS", and have 50 people actually show up?
2. Job security...when was the last time you heard a manager say, "the ion source is running so well, we're going to let the entire group go."
1. It's a subject in which anyone can make a contribution, and everyone has an opinion!

Courtesy of Stuart Henderson/ORNL