# Charge breeding with EBIS/T within I3-EURONS

1) Motivation and objectives

2) EBIS/T basics relevant for breeding

3) Participants and available set-ups

4) Advanced charge breeding (tasks)

# Integrated Infrastructure Initiative
# EURONS (European Nuclear Structure Research)

* 9 networking activities, 11 access activities (large scale facilities) and 13 joint research activities (JRA)

* Networking: further integration and coordination of nuclear structure activities within Europe

* Access: implementation and coordination of the access to various European research infrastructures (GSI, GANIL, ISOLDE…) for most efficient use

* JRAs: Ion source technology, detection systems, instrumentation for reaction studies in storage rings, instruments for precision experiments

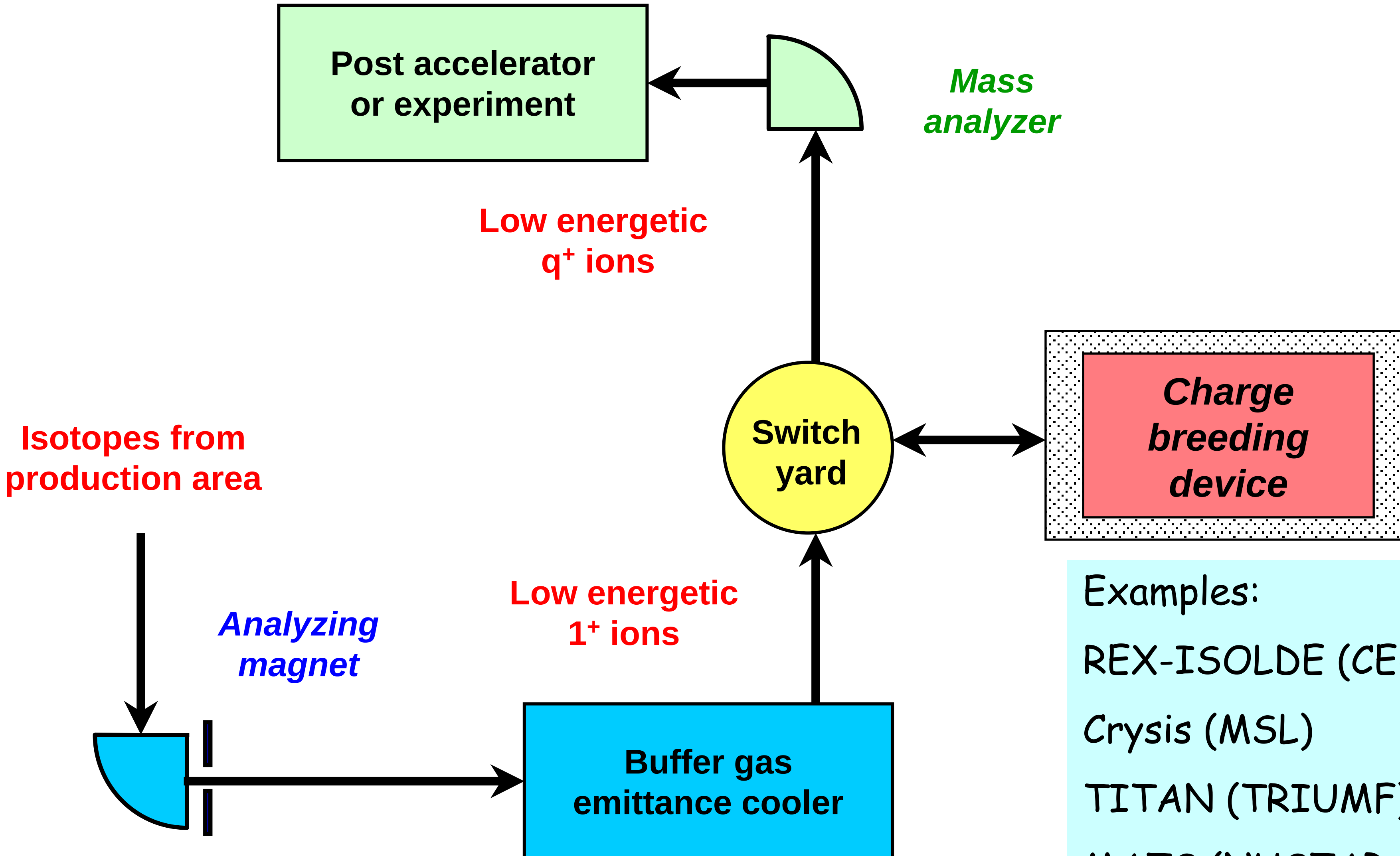
* Support from the EU 14,055 M€

* Contribution from EU for JRA3 (charge breeding) 420 k€

# Motivation for breeding ions

- Highly charged ions of isotopes from different regions of the nuclear chart become available for post acceleration
- Post accelerator becomes more efficient (pulsed structures at higher resonance frequencies)
- Highly charged ions for low energy experiments (mass measurements, Penning trap assisted spectroscopy, X-ray spectroscopy, reaction spectroscopy etc.)
- Determination of ionisation cross sections (well defined current density)

# Charge state breeder set-up




Examples:

REX-ISOLDE (CERN)

Crysis (MSL)

TITAN (TRIUMF)

MATS (NUSTAR, GSI)

# Objectives advanced charge breeding

To optimize the charge breeding process:

* Increasing the breeding efficiency
* Improving the beam quality
* Improving the beam purification

Three relevant processes determine efficiency, beam quality and beam purity, which can be improved:

* Injection into the high charge state ion source
* Breeding and cooling of highly charges ions
* Extraction and separation of the exotic nuclei.

# Limits from the ion source

| | |
|---|---|
| intensity | → confinement capacity, breeding time (rep. rate) |
| short lifetime | → electron current density |
| efficiency | → beam cooling & injection, confinement capacity, charge state distribution, extraction emittance |
| beam purity | → rest gas pressure, small emittance, beam optics |

# Participants of the JRA3 “charge breeding

1) Ludwig Maximilians Universität München, Germany (activity coordinator, O. Kester) in collaboration with GSI and Frankfurt university (R. Becker)

2) LPSC Grenoble, France (T. Lamy, P. Sortais)

3) CLRC Daresbury, UK (K. Connell, D. Warner) in collaboration with C. Barton (York)

4) ISOLDE (CERN), Switzerland (P. Delahaye, T. Fritioff, F. Wenander, M. Lindroos, C. Hill)

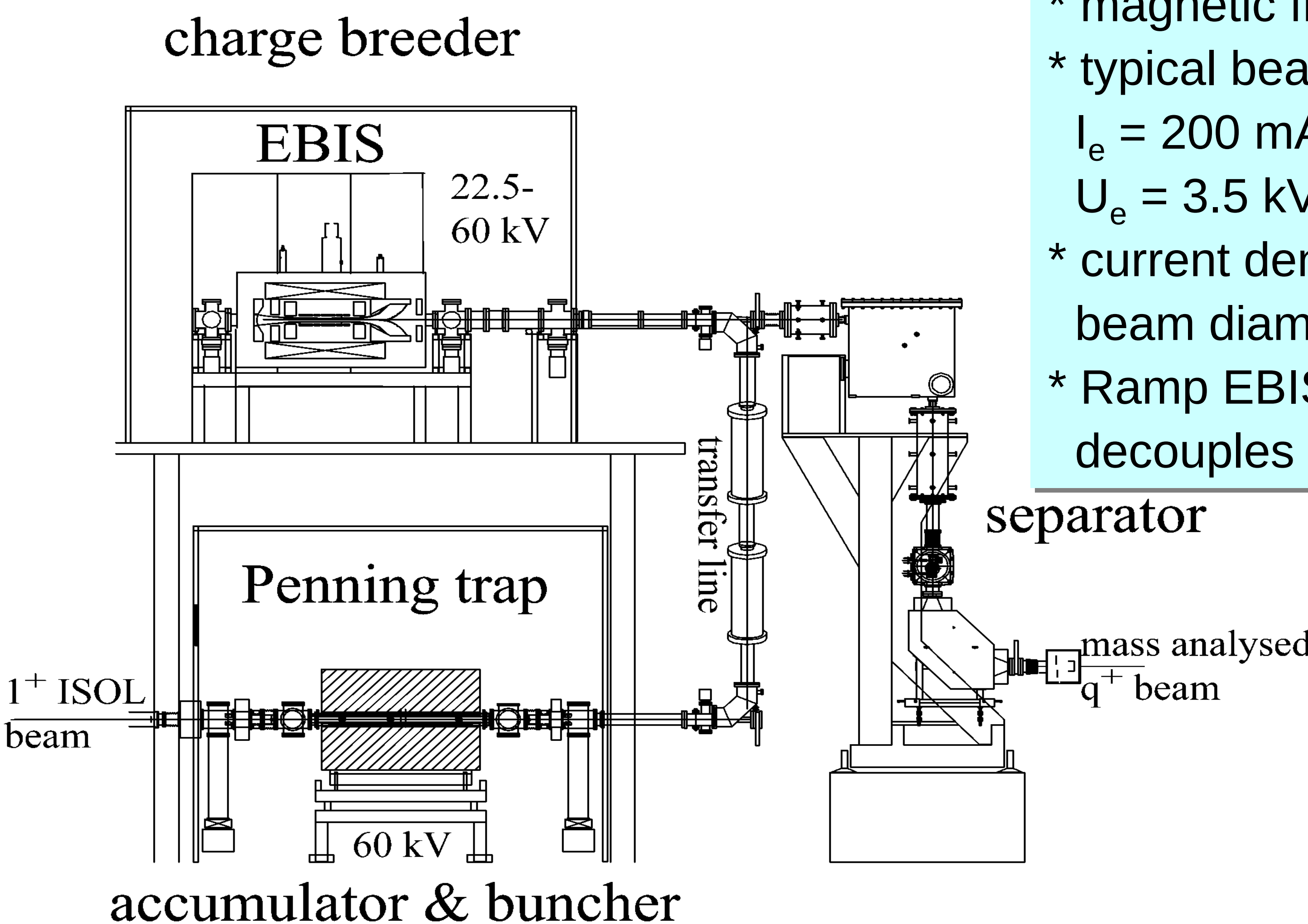
5) MPI-K Heidelberg, Germany (J. R. Crespo, J. Ullrich)

**Guests and observers: GANIL, INFN-LNL, TRIUMF, RIKEN**

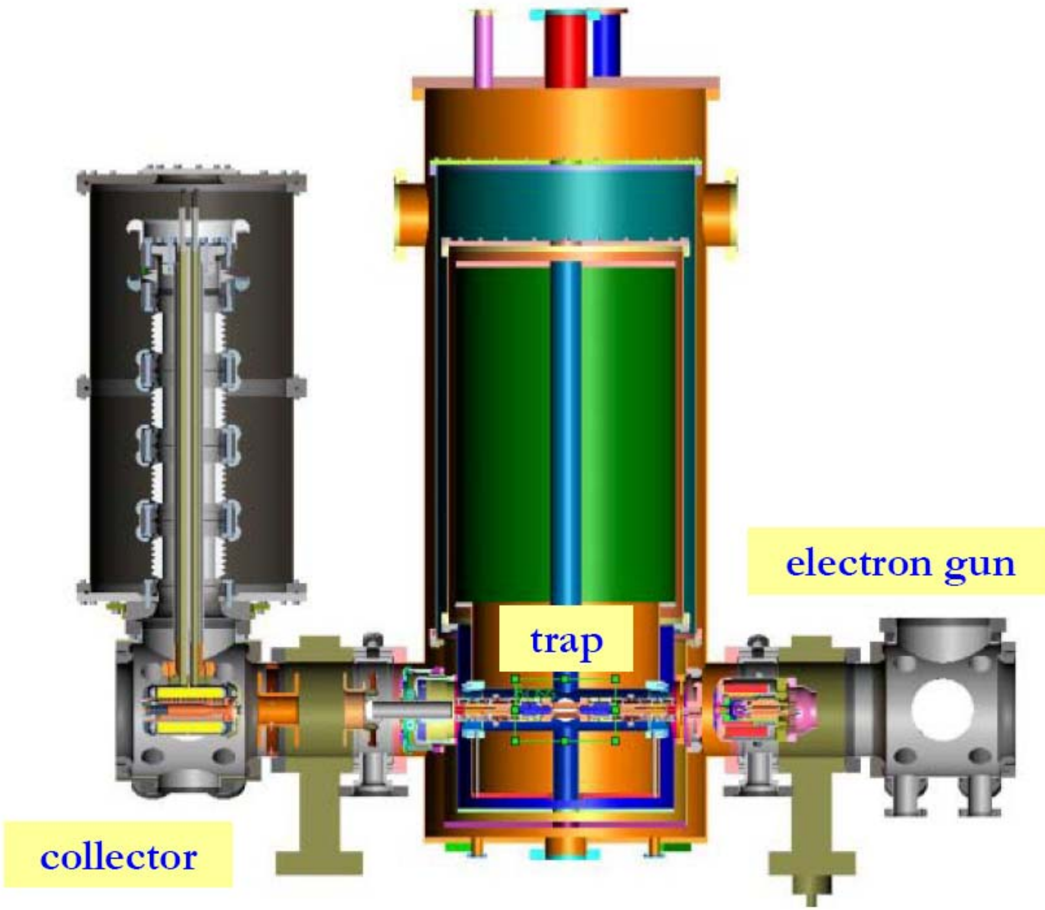
# ISOLDE: REXEBIS

REXEBIS

* magnetic field 2 T
* typical beam parameter:
  $I_e$ = 200 mA,
  $U_e$ = 3.5 kV, $L_e$ = 0.8 m
* current density: ~160 A/cm$^2$
  beam diameter ~0.4-0.5 mm
* Ramp EBIS platform voltage → decouples ISOL part and LINAC



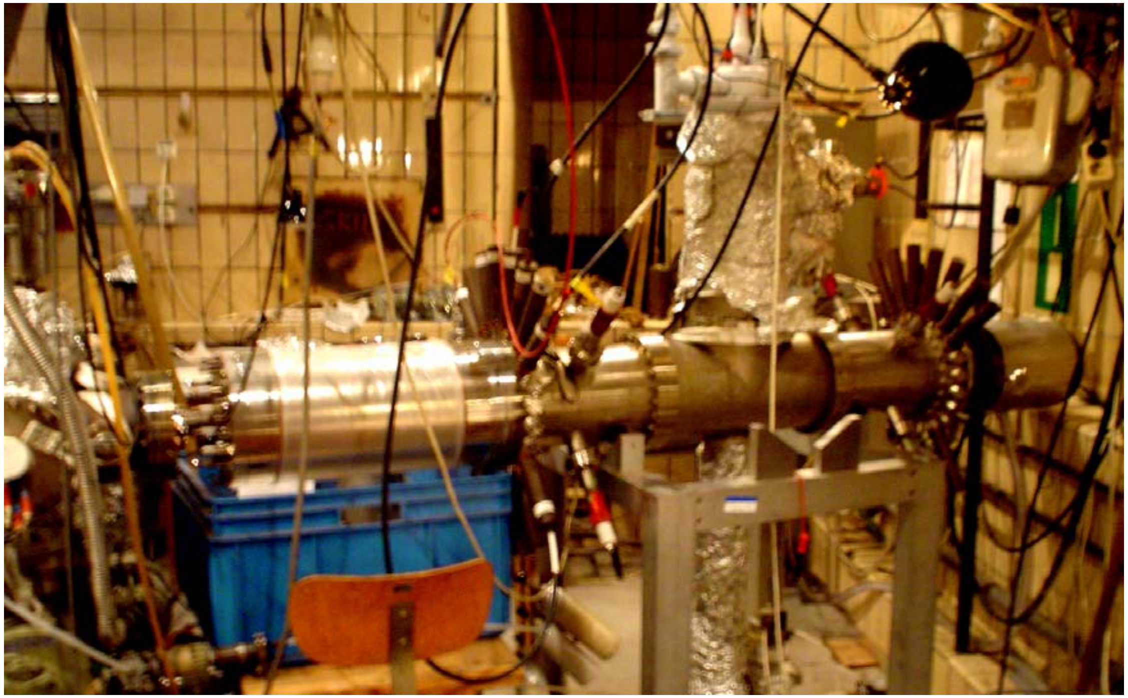
# MPI-K Heidelberg: EBIT




EBIT

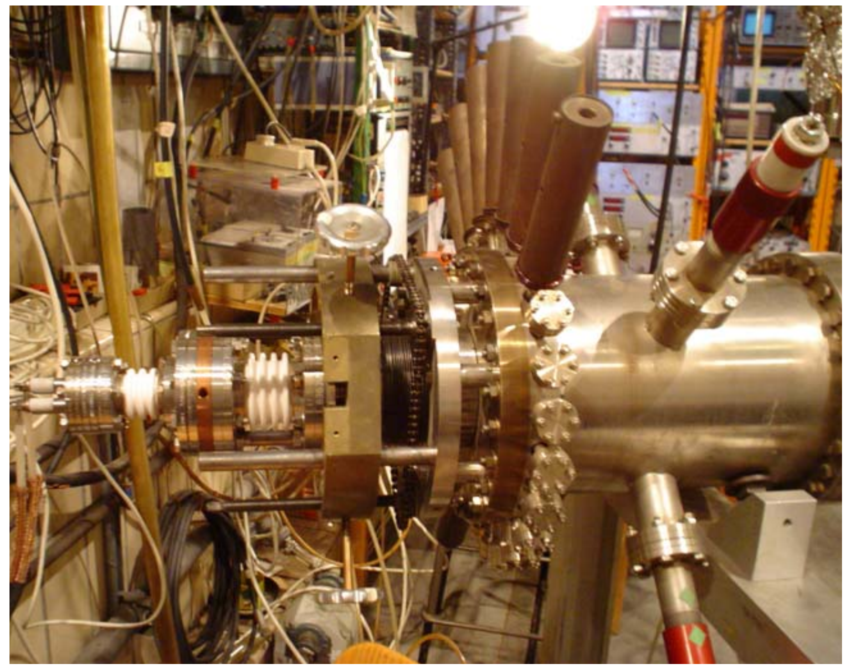
* Magnetic field 7 T
* Typical beam parameter:
  $I_e$ = 360 mA,
  $U_e$ = 150 kV, $L_e$ = 0.04 m
* Current density: ~6000 A/cm$^2$
  beam diameter ~ 45 μm
* Scanning of electron beam energy
* X-ray spectrometer
* External ion injection from MEVVA possible

# Frankfurt MAXEBIS @ GSI

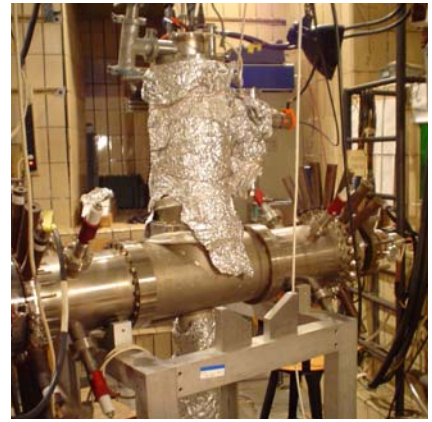


* New gun, new structure, new collector → new EBIS!
* Non suppressed collector → 30 kW can be dissipated

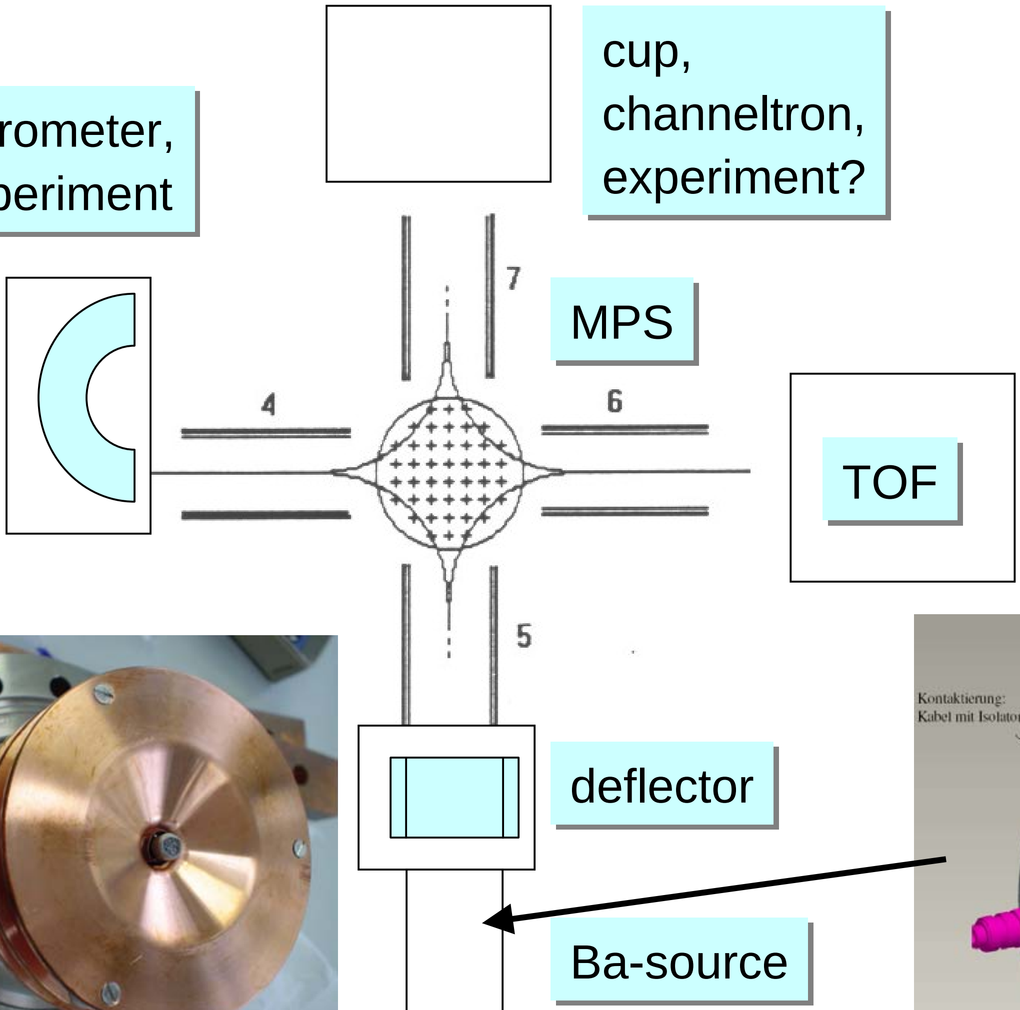
* Maximum magnetic field 5 T
* $I_e$ = 3 A, $U_e$ = 25 kV, $L_e$ = 0.8 m
* Current density adjustable: ~100-1000 $A/cm^2$



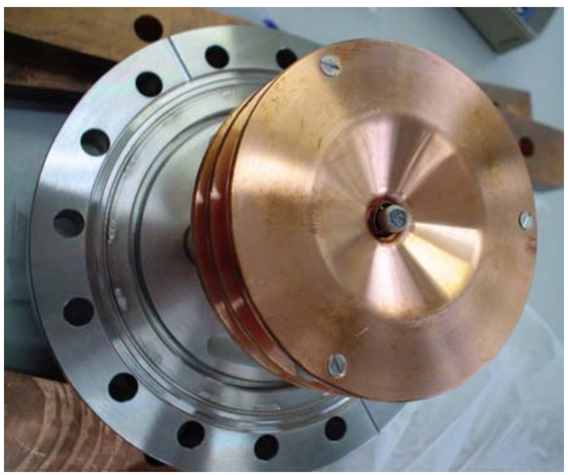
# MAXEBIS setup @ GSI

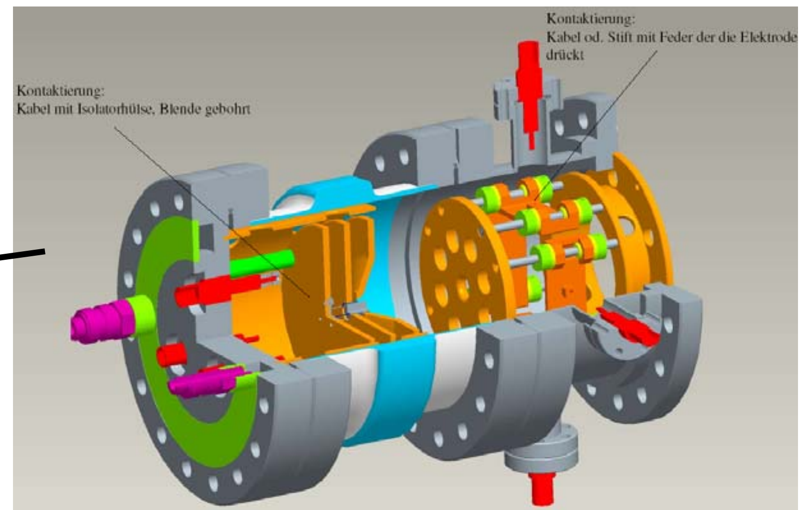


spectrometer,
2. experiment




MAXEBIS





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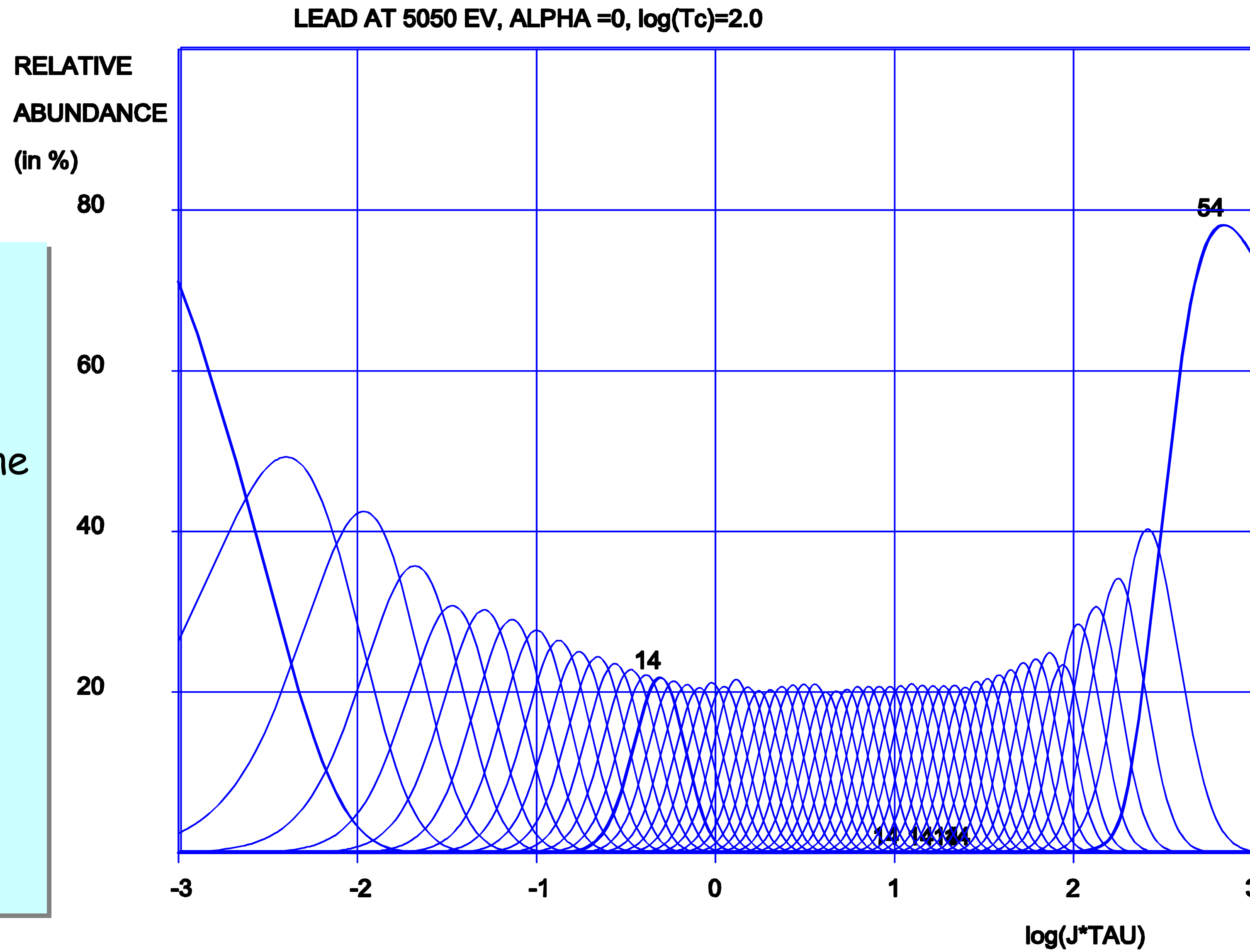
# Tasks1: Manipulation of charge state distribution




Breeding at shell closures (LMU/GSI, ISOLDE, MPI-K)

goal: efficiency in one charge state >50%

Example:

$Pb^{54+}$ at 5050 eV beam energy

Radiative recombination?

# Tasks2: Exploration of DR

DR resonant processes for manipulation of the charge state distribution and isobaric purification (ISOLDE, MPI-K)

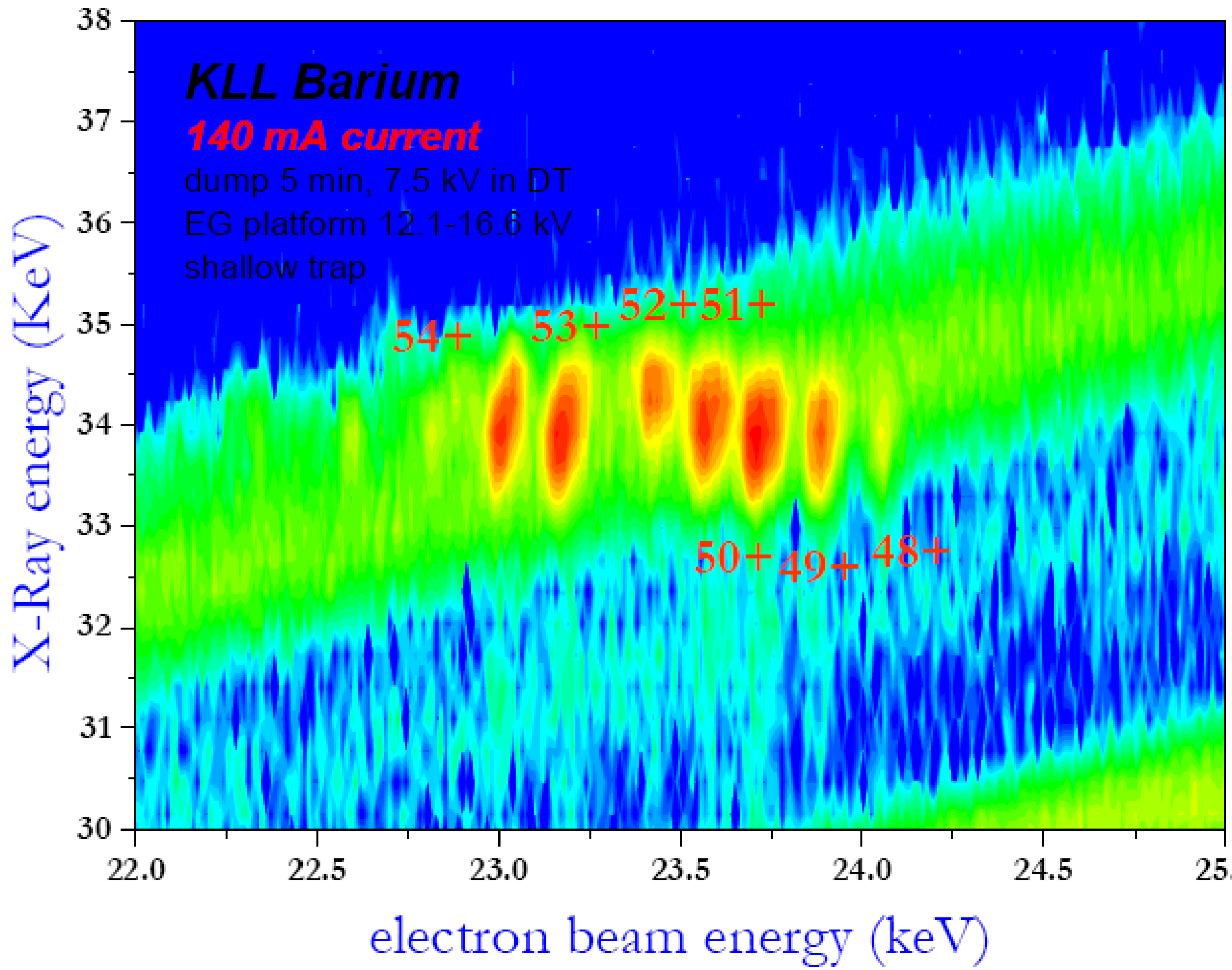
Exploration → MPI-K

test with radioactive ions

→ ISOLDE

Manipulation of e-beam energy (space charge!)

## DR resonances of O-like to He-like Ba

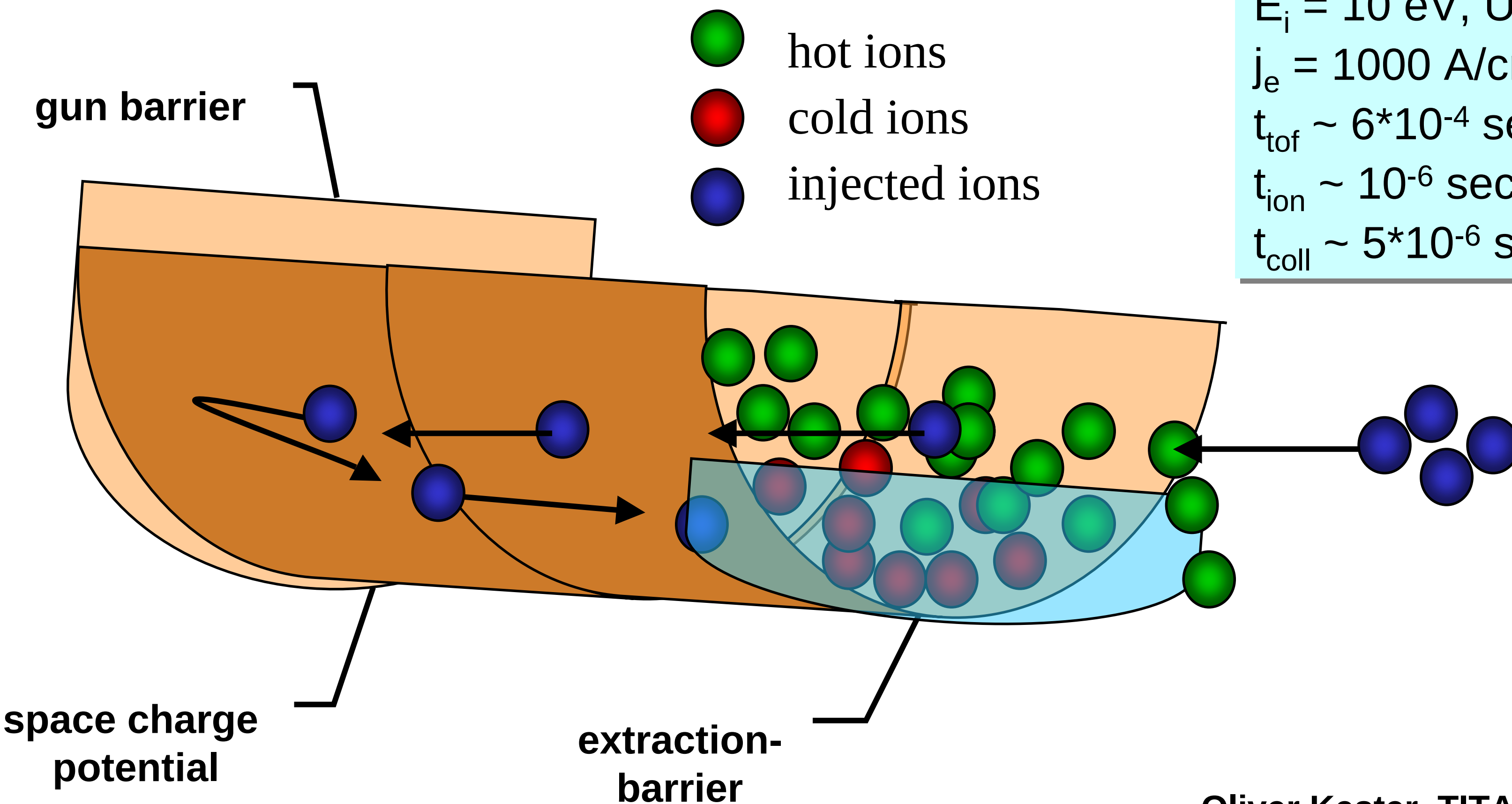


# Tasks 3: Coulomb target

Beam injection into a partially neutralized electron beam (LMU/GSI, ISOLDE)

**typical time constants:**

$m_i$ = 200 u (injected), $q_i$ = 1
$m_j$ = 20 u (target), $q_j$ = 6
$E_i$ = 10 eV, $U_e$ = 10000 eV
$j_e$ = 1000 A/cm$^2$
$t_{tof} \sim 6 \cdot 10^{-4}$ sec (1m EBIS/T)
$t_{ion} \sim 10^{-6}$ sec (1+→2+)
$t_{coll} \sim 5 \cdot 10^{-6}$ sec



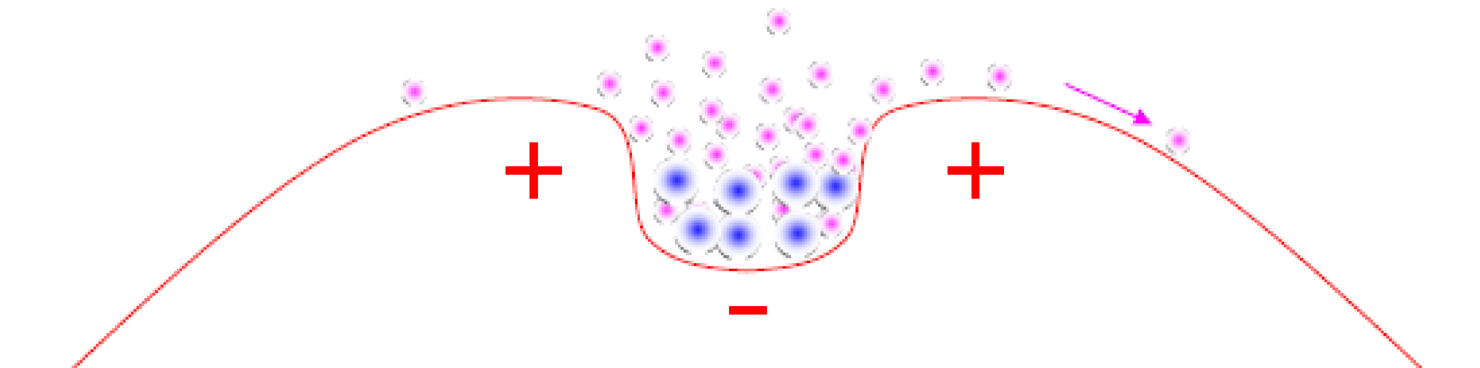
# Tasks 4: Cooling of highly charged ions

Cooling of highly charged ions (evaporative cooling)

→ Improvement of the beam emittance

→ Improvement of beam purification of radioactive ions from contamination (all participants)

- collisions with beam electrons heat up ion ensemble
- light, less tightly trapped ions (e.g. $Ne^{10+}$ ) evaporate removing thermal energy




- heavy, highly charged ions (e.g. $Ba^{53+}$ ) remain trapped

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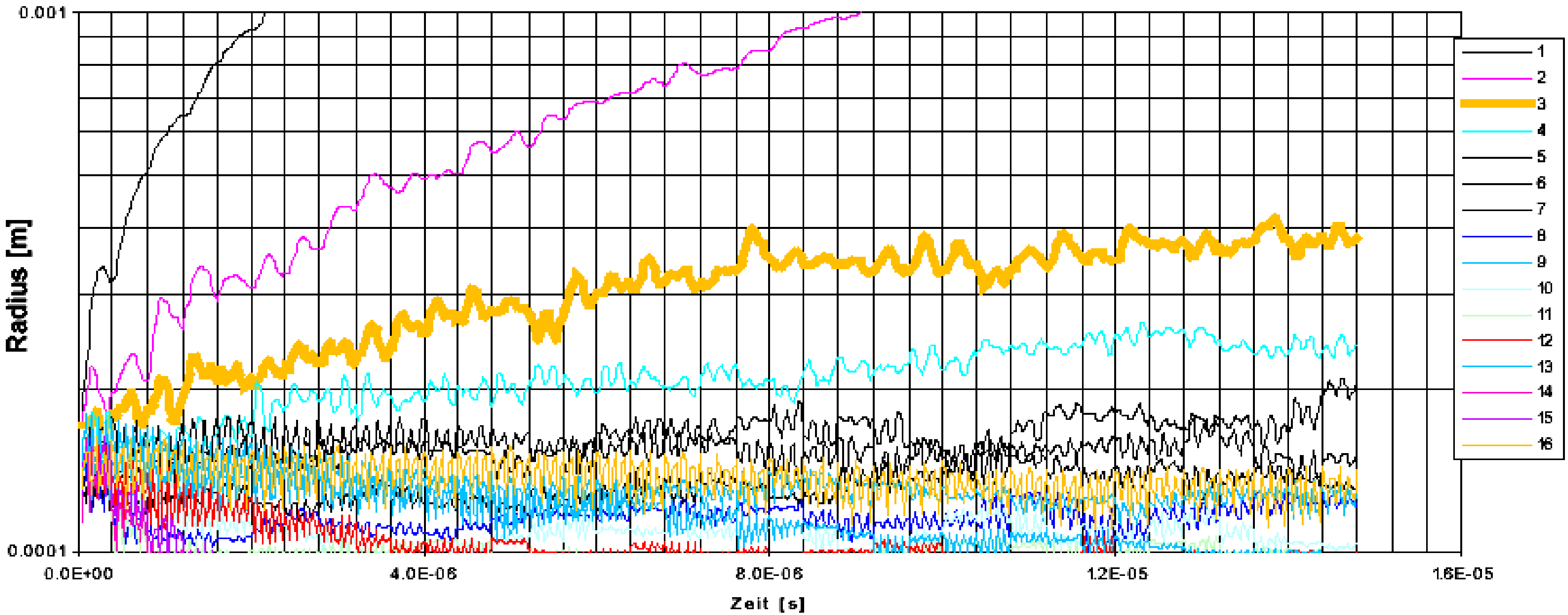
# Positions of the ions within the potential well



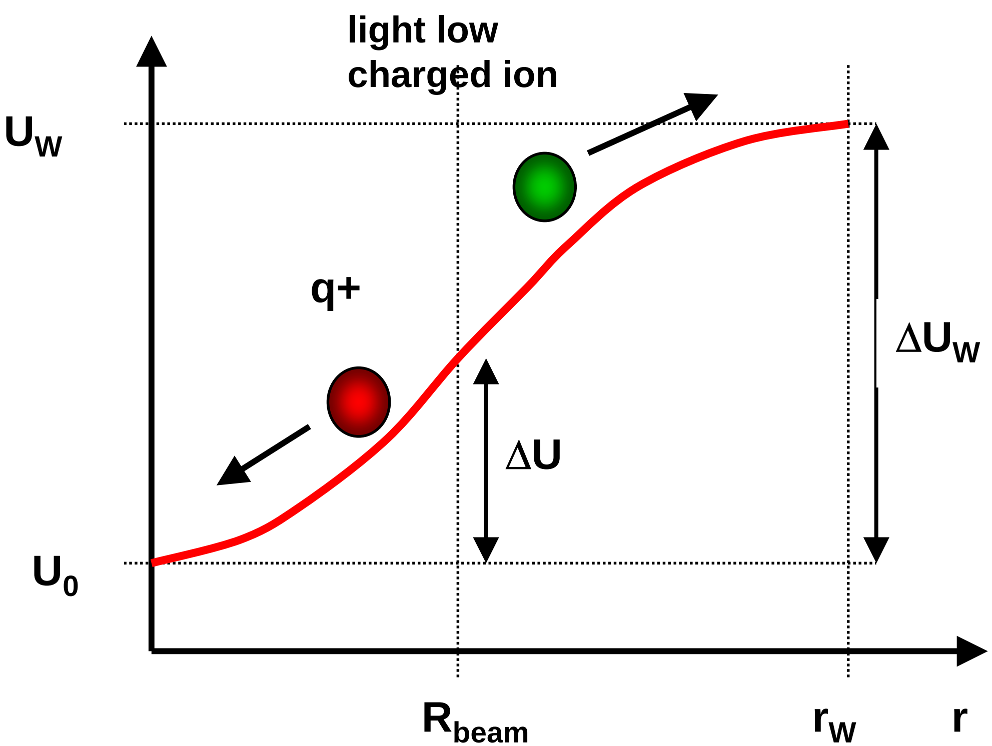

Energy exchange via elastic collision

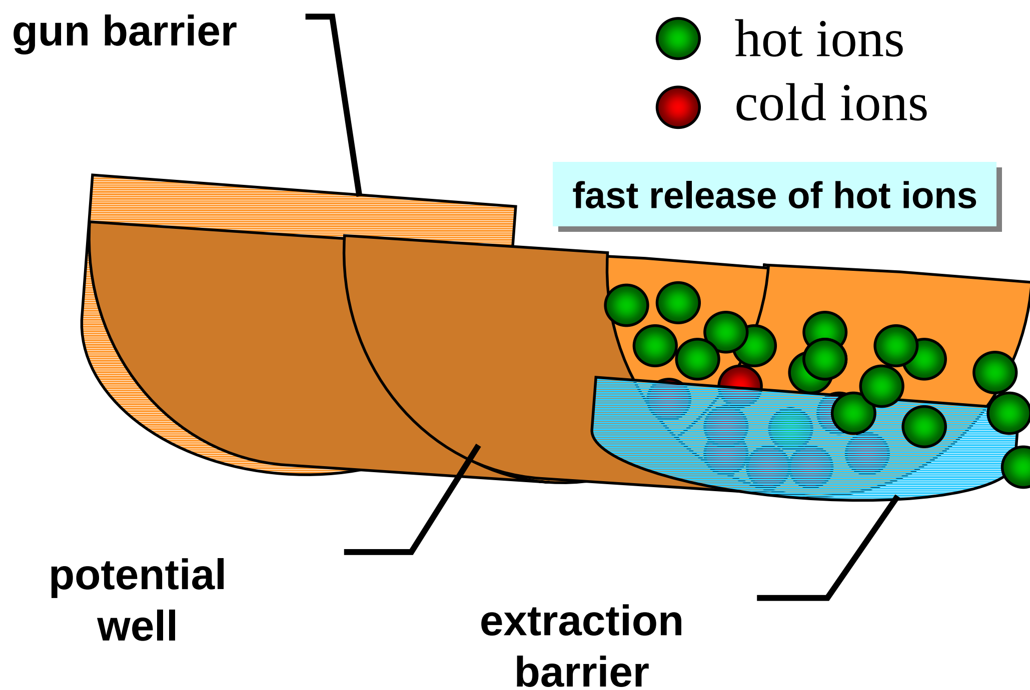
→ concentration of highly charged ions towards beam axis

→ smaller emittance for highly charge ions

$$\varepsilon_{r,r'} = 2 r_{ion} \cdot \sqrt{\frac{\Delta U_{dep}}{U_{acc}} + \frac{r_{ion}^2 B^2 q}{2 m U_{acc}}}$$

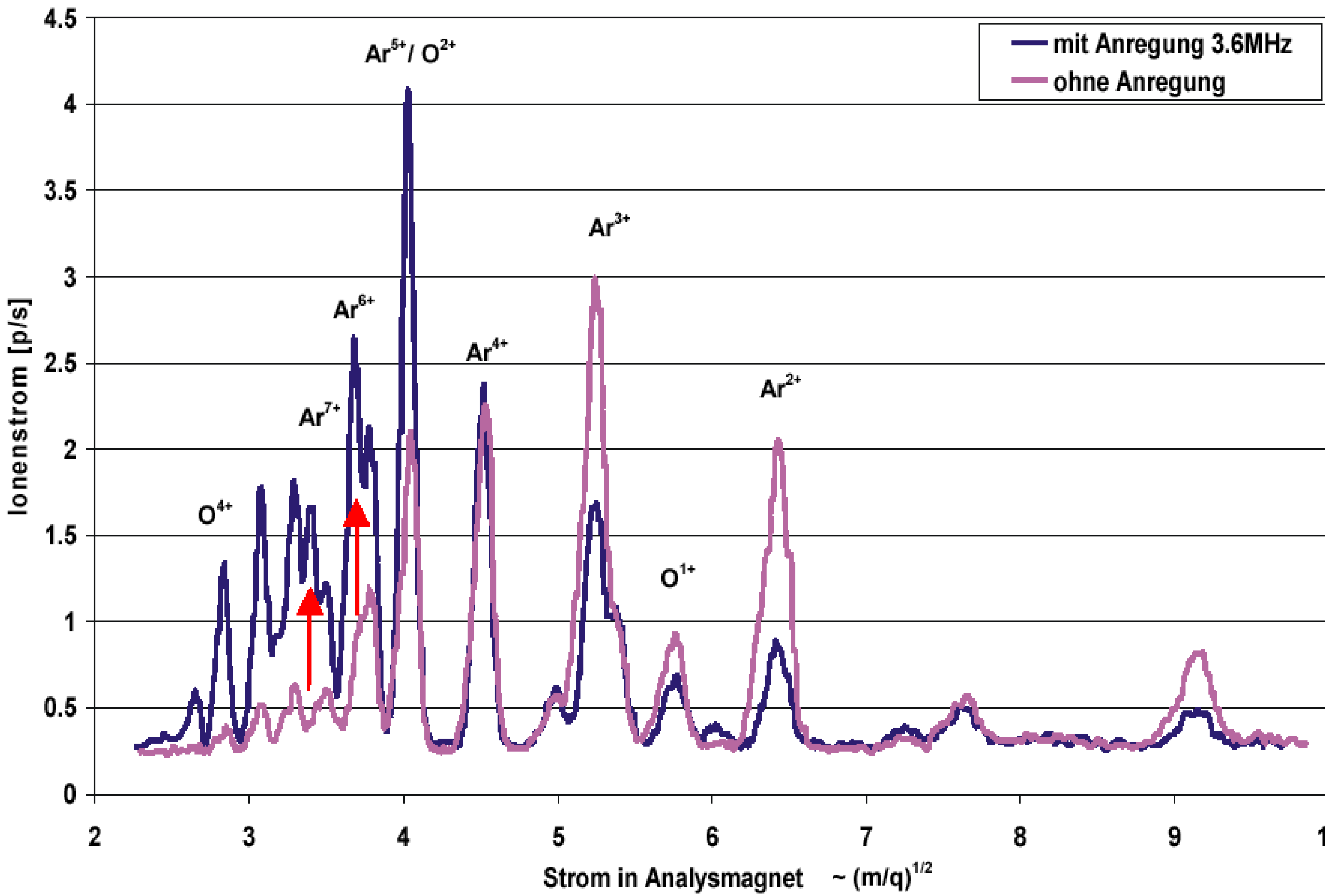
# Cooling of highly charged ions




**Dynamic barrier or rf-excitation!**

# Cooling of highly charged ions by removing low charged ions



# Summary

- Charge breeding is beneficial for post acceleration and experiments with highly charged ions

Development towards:

- Short breeding times, good beam quality, high efficiency, high purity

Advanced charge breeding:

- Charge state manipulation
- Improved injection (Coulomb target)
- HCI cooling and improvement of beam emittance and purification

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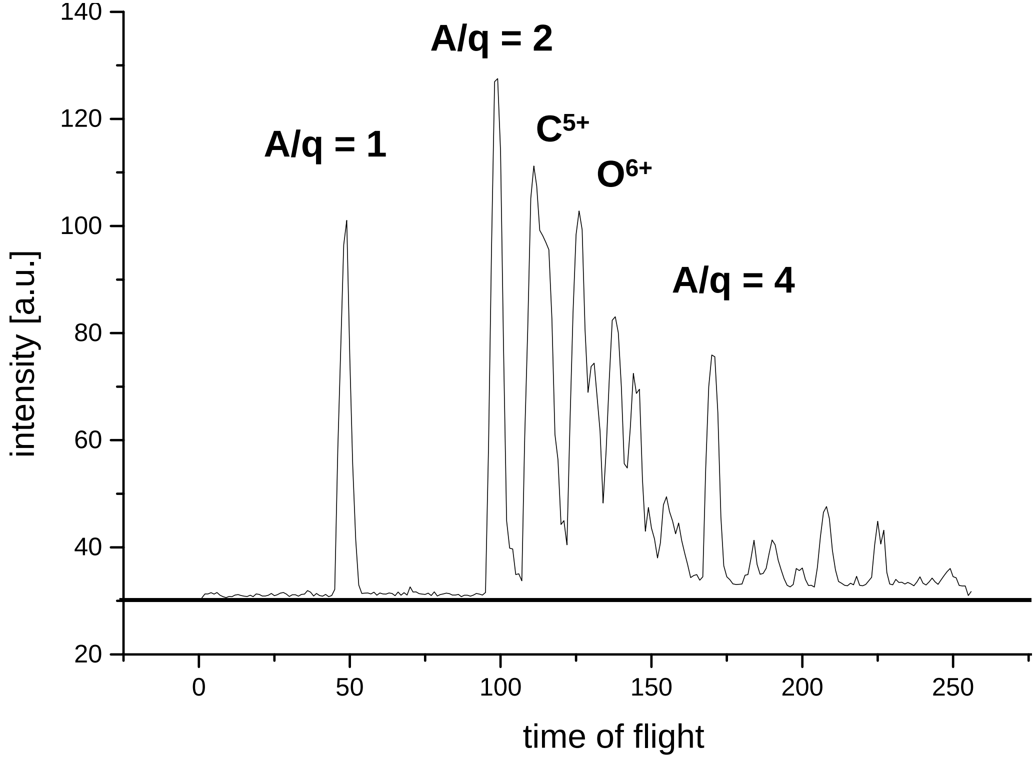
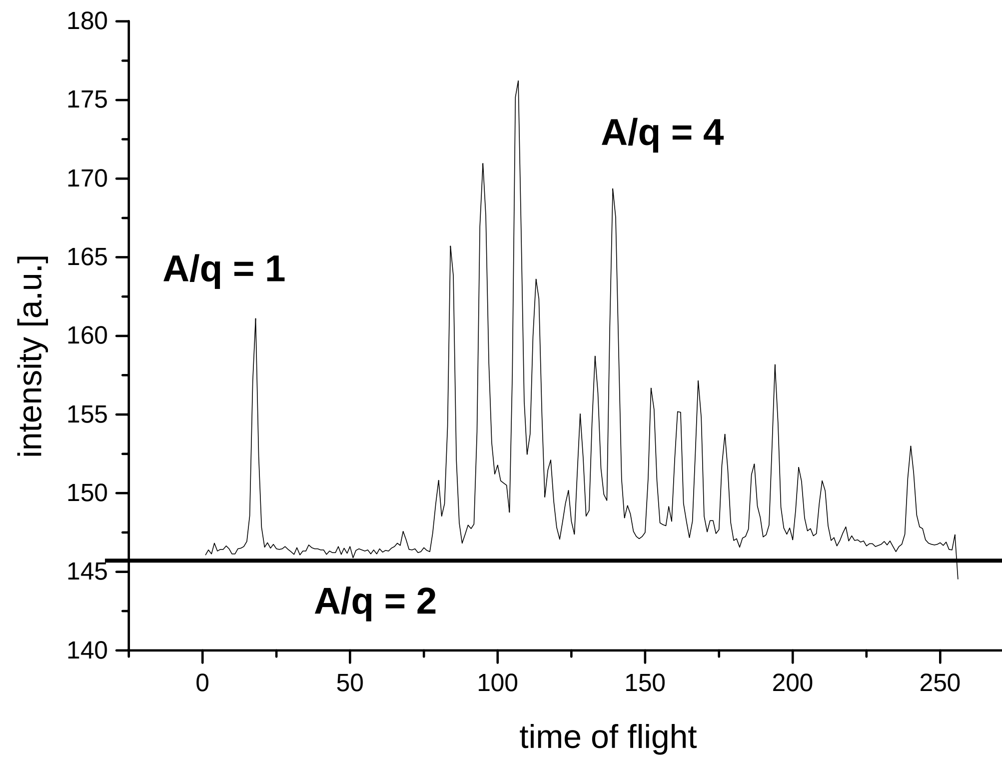
# First TOF spectra with 200 mA




Ar spectrum + rest gas
t = 10 ms
Small energy spread

Rest gas spectrum (A/q = 2 in maximum)
t = 500 ms
Large energy spread




Oliver Kester, TITAN workshop, 10.06.2005