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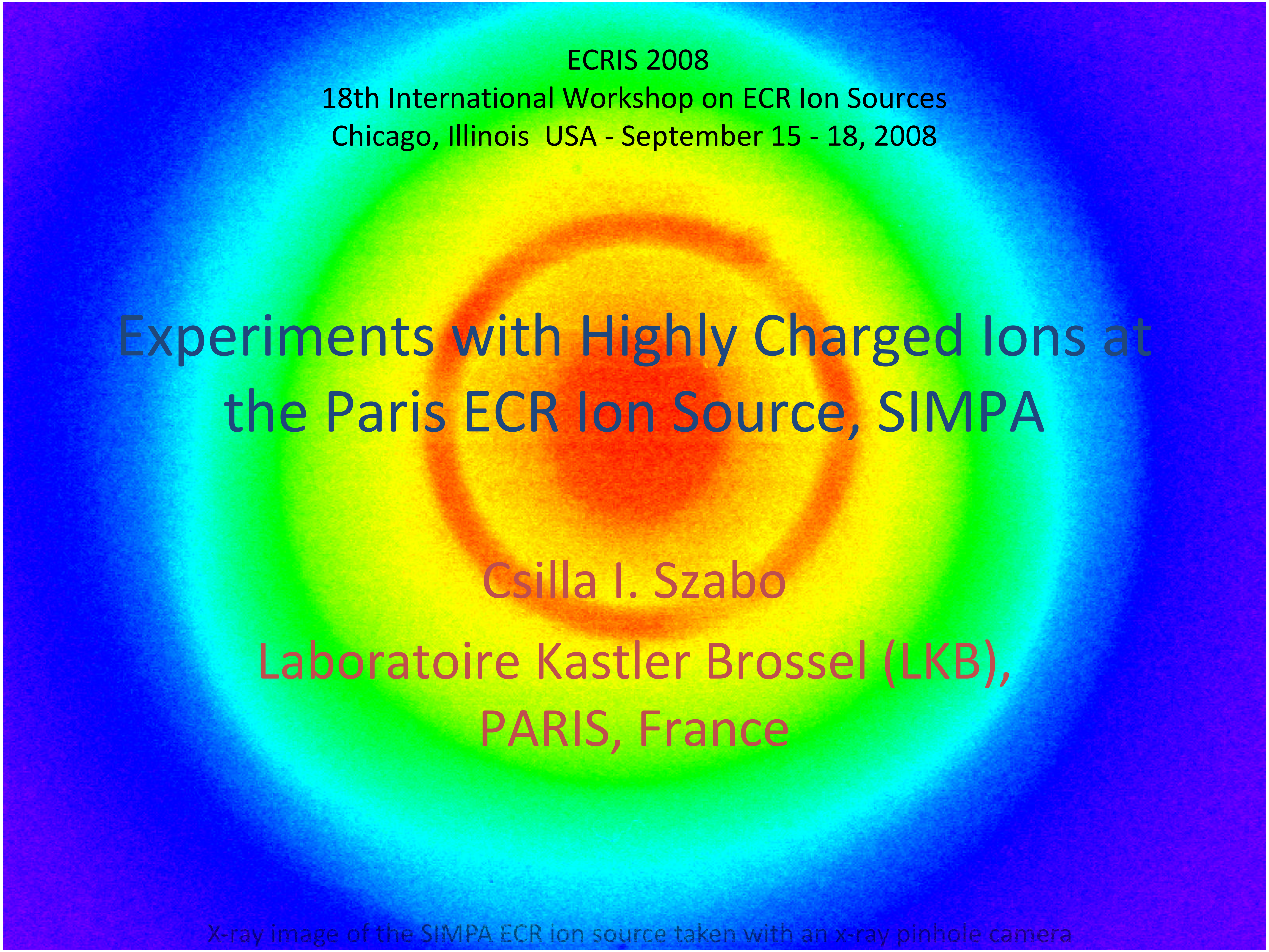
Experiments with Highly Charged Ions at the Paris ECR Ion Source, SIMPA

Csilla I. Szabo
Laboratoire Kastler Brossel (LKB), PARIS, France



X-ray image of the SIMPA ECR ion source taken with an x-ray pinhole camera

Collaboration

LKB

Laboratoire Kastler Brossel (LKB)
Paris, France

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Sergio Jose Coelho do Carmo

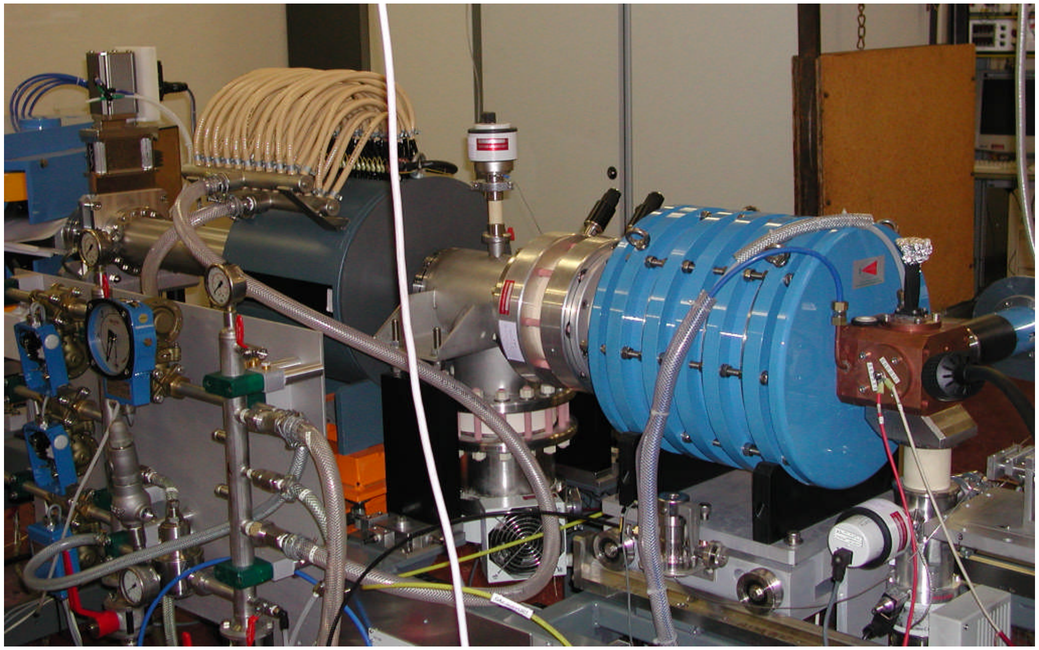
Experiments with Highly Charged Ions at the Paris ECR Ion Source, SIMPA

- outline -

- The SIMPA* Electron Cyclotron Resonance (ECR) ion source
- The Electrostatic Ion Beam Trap at SIMPA
- Electron temperature and density measurements of the plasma at the SIMPA ECR ion source
- Double crystal spectrometer for x-ray standards

* Source d’Ions Multichargés de Paris (Paris multiply-charged ion source).

The SIMPA ECR Ion Source Laboratory



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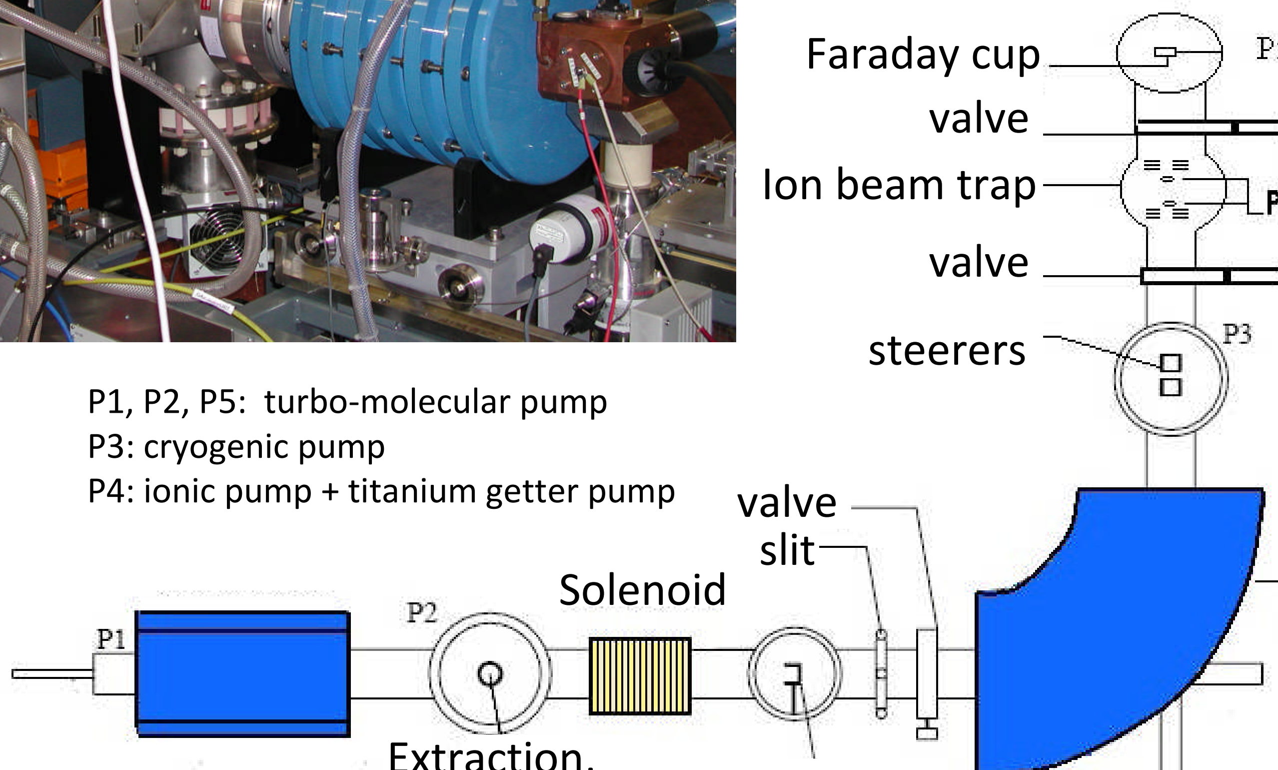
14.5 GHz microwave frequency
Extraction voltage: 0 V to 35 kV

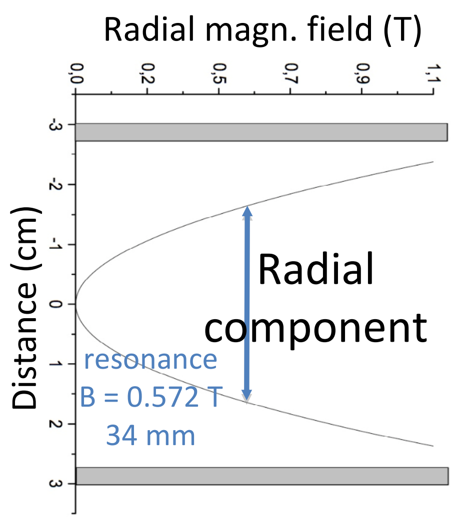


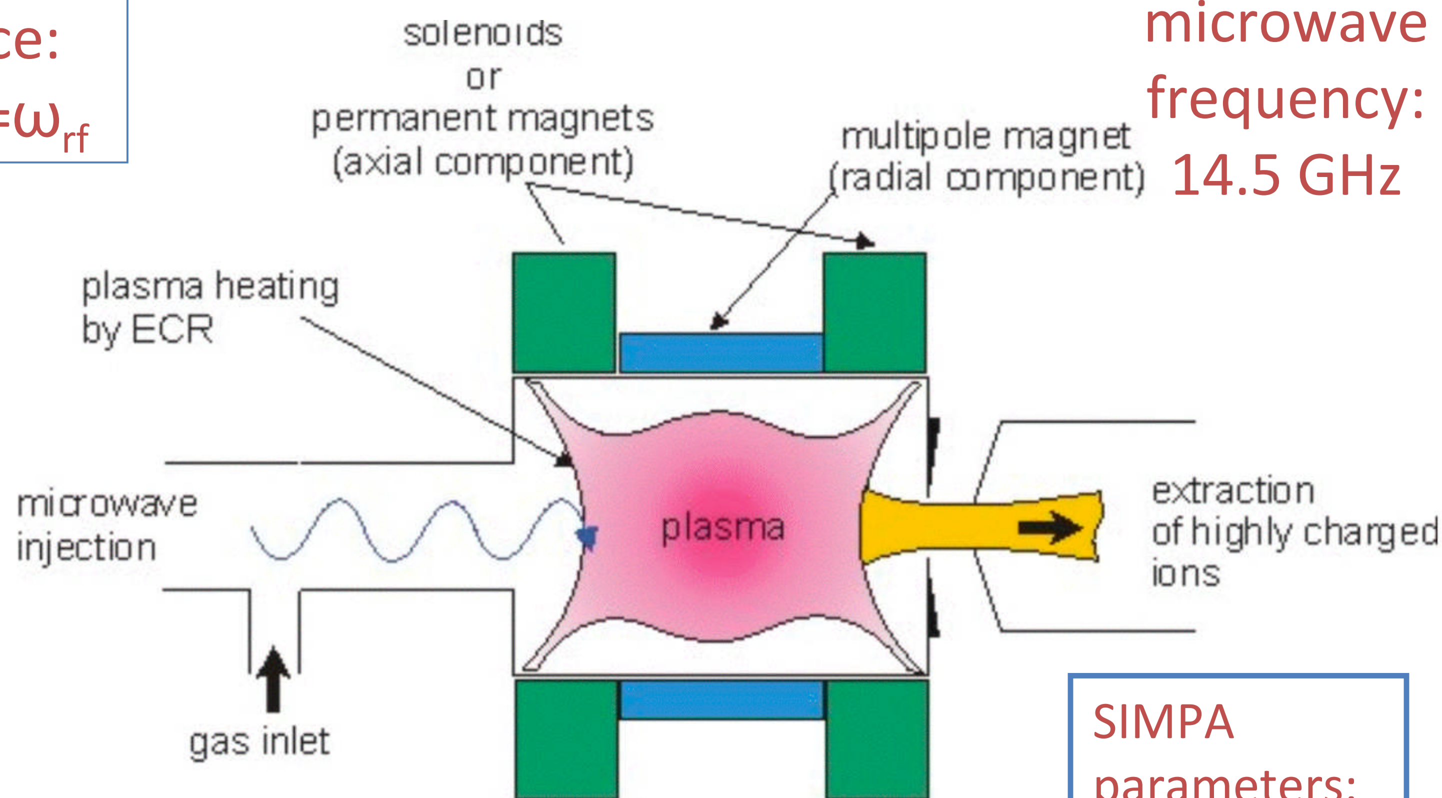
P1, P2, P5: turbo-molecular pump
P3: cryogenic pump
P4: ionic pump + titanium getter pump

Electron Cyclotron Resonance Ion Source

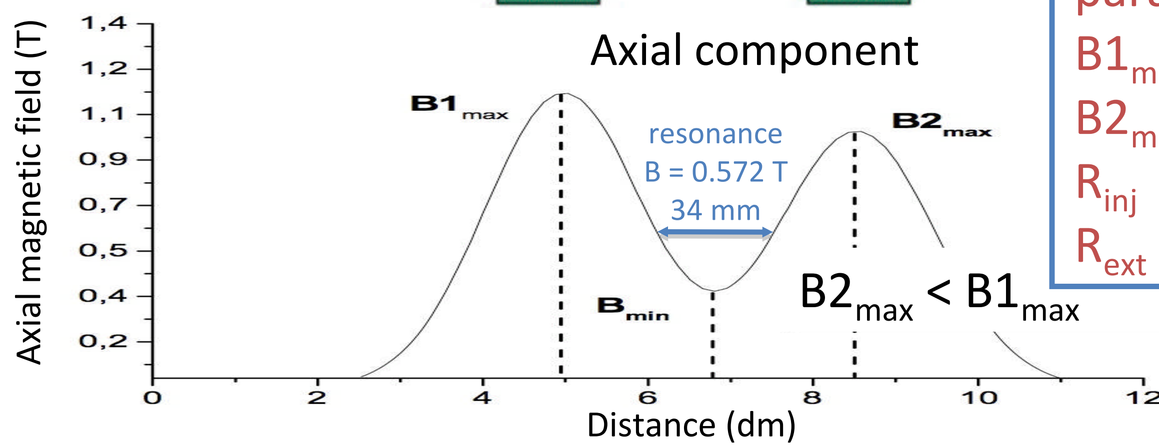
Resonance:
$\omega_e = B/qm = \omega_{rf}$

microwave frequency: 14.5 GHz



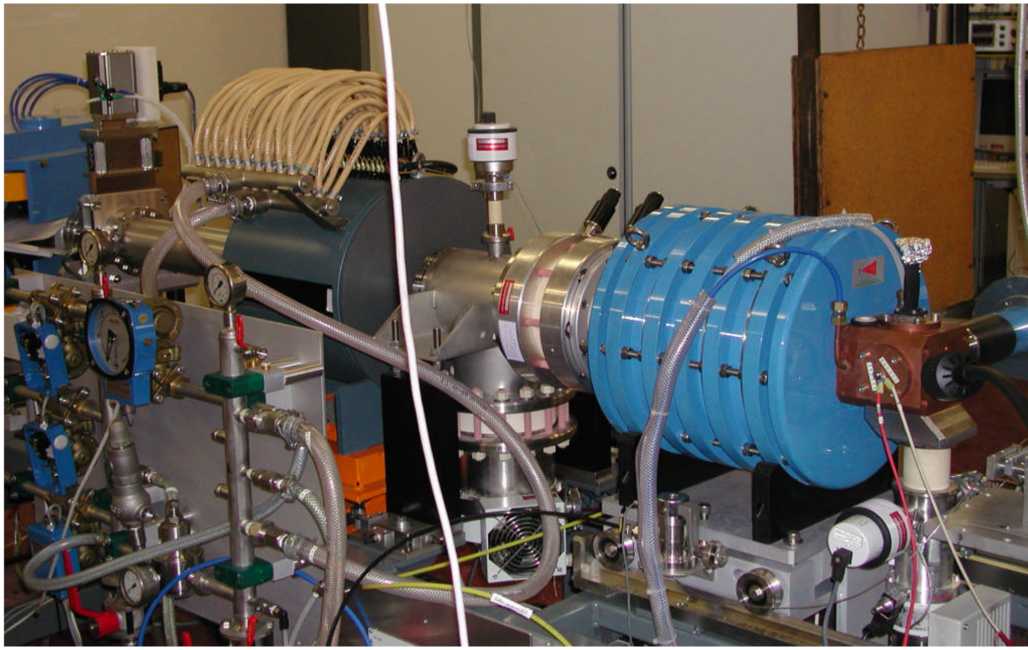


Minimum B field geometry



SIMPA parameters:
$B1_{max}$=1.18 T
$B2_{max}$=0.97 T
R_{inj} = 2.52
R_{ext} = 2.07

The SIMPA ECR Ion Source Laboratory



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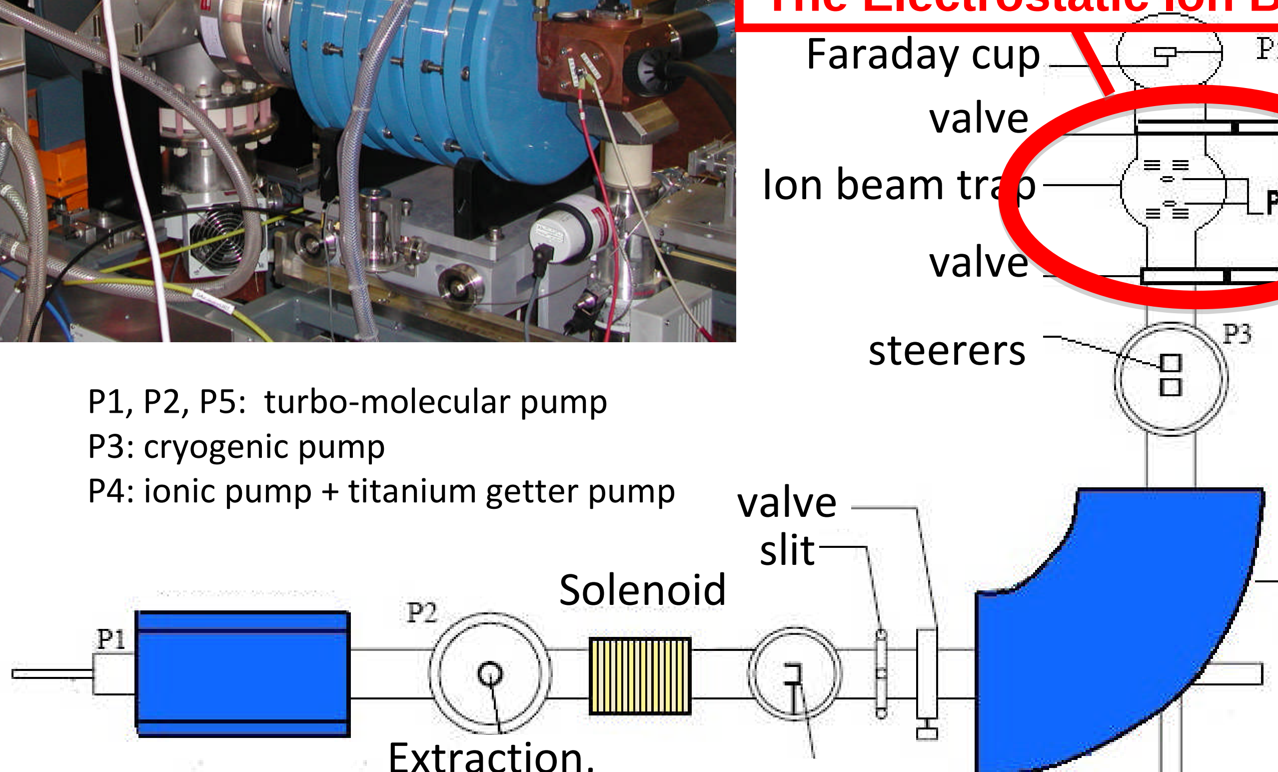
14.5 GHz microwave frequency
Extraxction voltage: 0 V to 35 kV

The Electrostatic Ion Beam Trap



P1, P2, P5: turbo-molecular pump
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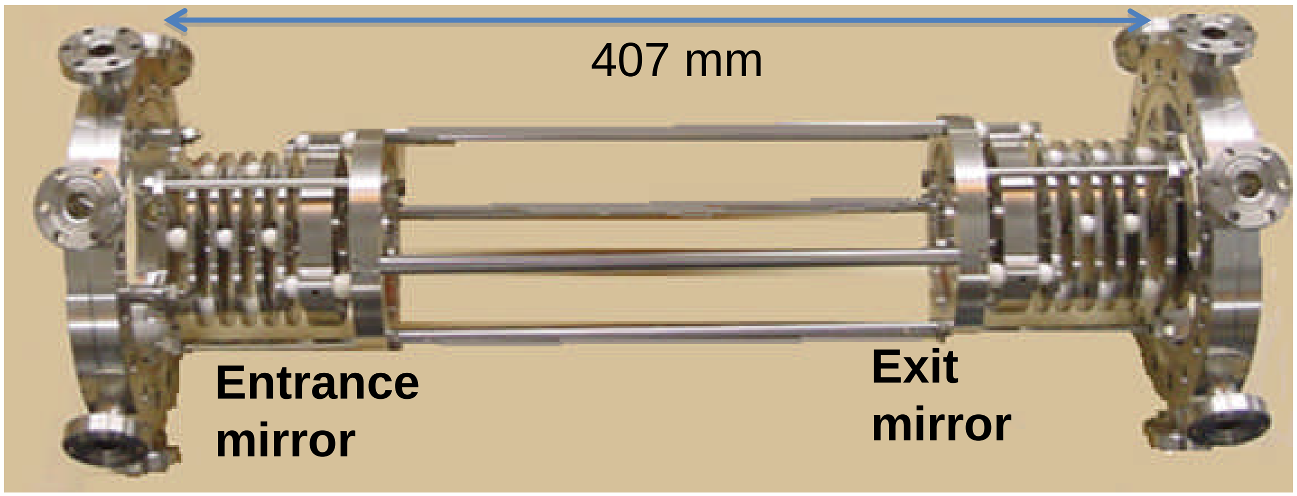
Trapping ion beams at keV energies

The Electrostatic Ion Beam Trap



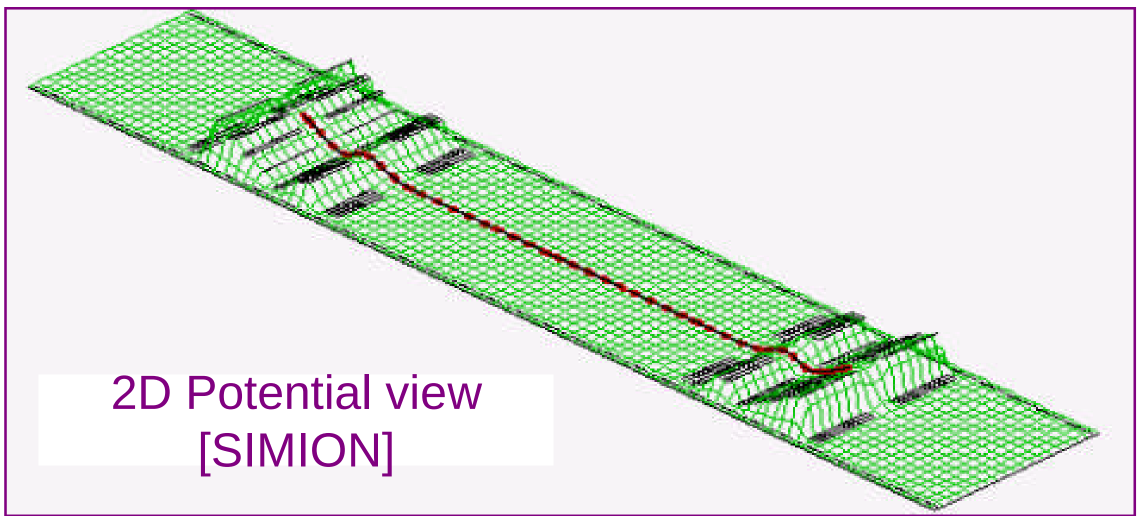
Based on a design from the Weizmann Institute

D. Zajfman et al. Phys. Rev. A pp. 1577-1580 55 (1997)

Beam energy:
4.2 keV / charge

Different from other traps:

- No magnetic fields
- No RF fields
- No mass limit
- Large field free region
- Simple to operate
- Directionality
- External ion source
- Easy beam detection

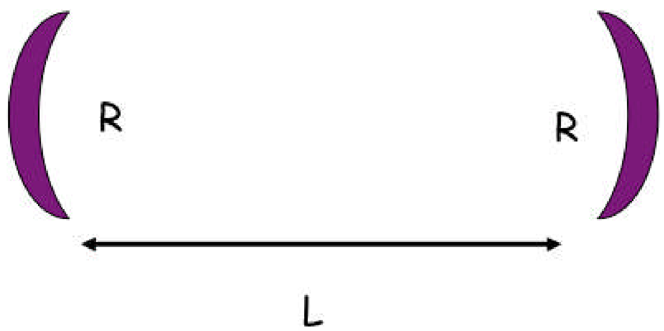


2D Potential view [SIMION]

Electrostatic Ion Beam Trap (EIBT)

An electrostatic bottle to trap highly charged ions

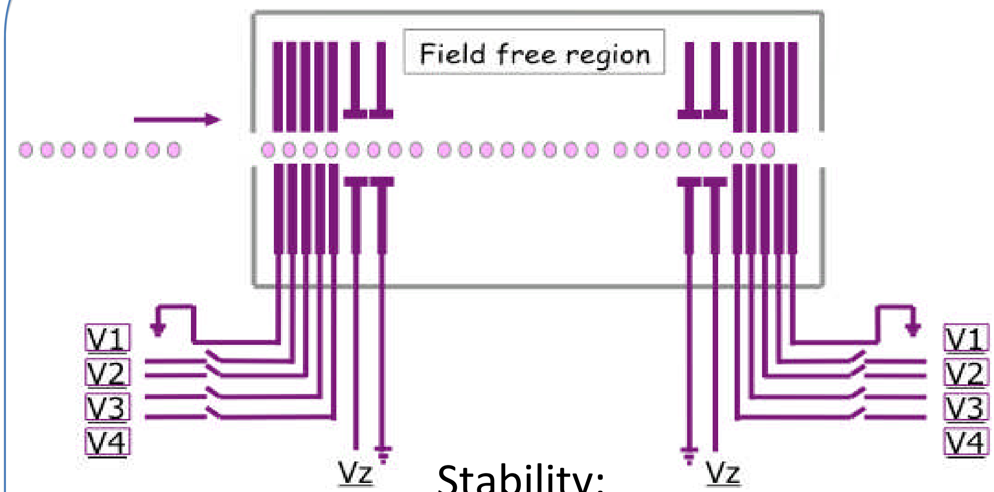
Optical Resonator



Stability:

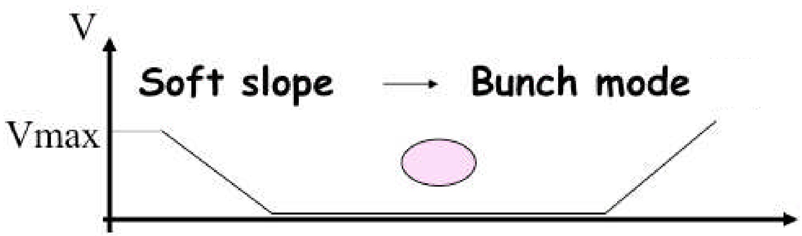
$$\frac{L}{4} \leq f \leq \infty$$

Electrostatic resonator



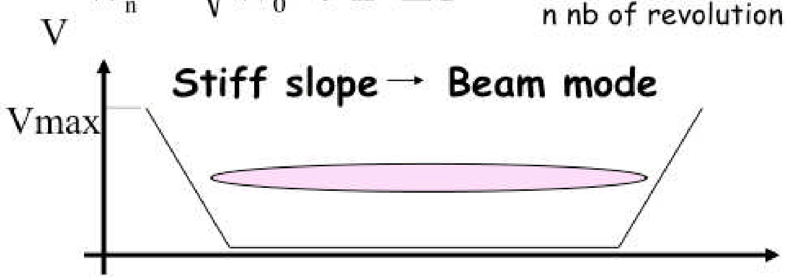
Stability:

$$\frac{L}{4} \leq f \leq \infty \qquad \frac{E_k}{q} < V_{max}$$



$$W_n = \sqrt{W_0^2 + n^2 \Delta T^2}$$

Wn bunch length
n nb of revolution



In the EIBT the focal length f is a function of the Einzel lens voltage Vz

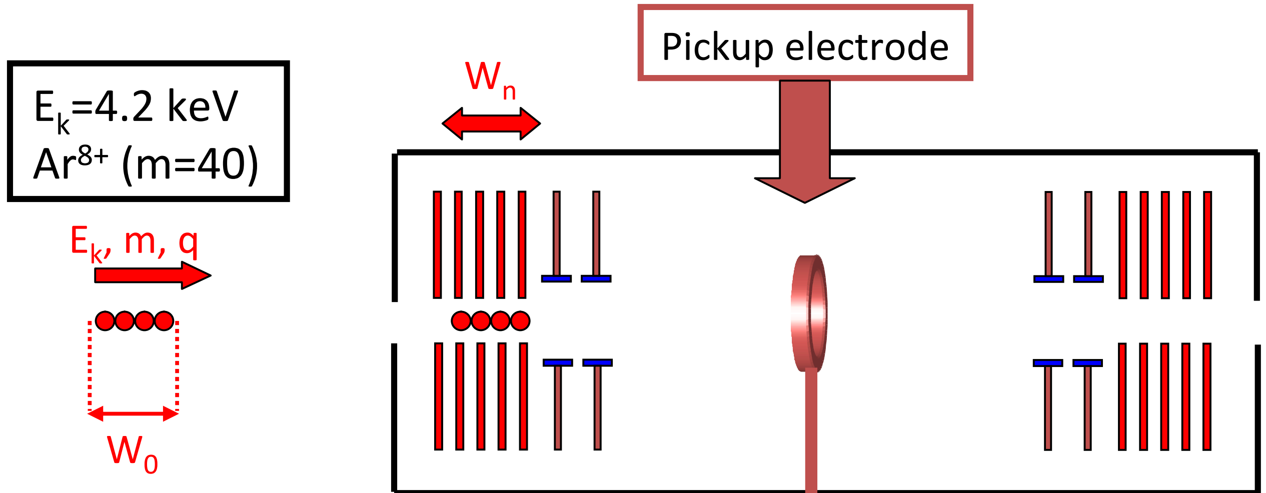
Longitudinal motion

- Oscillation: E.g. 875 kHz for Ar^{8+} at 4.2 keV

Tansverse motion

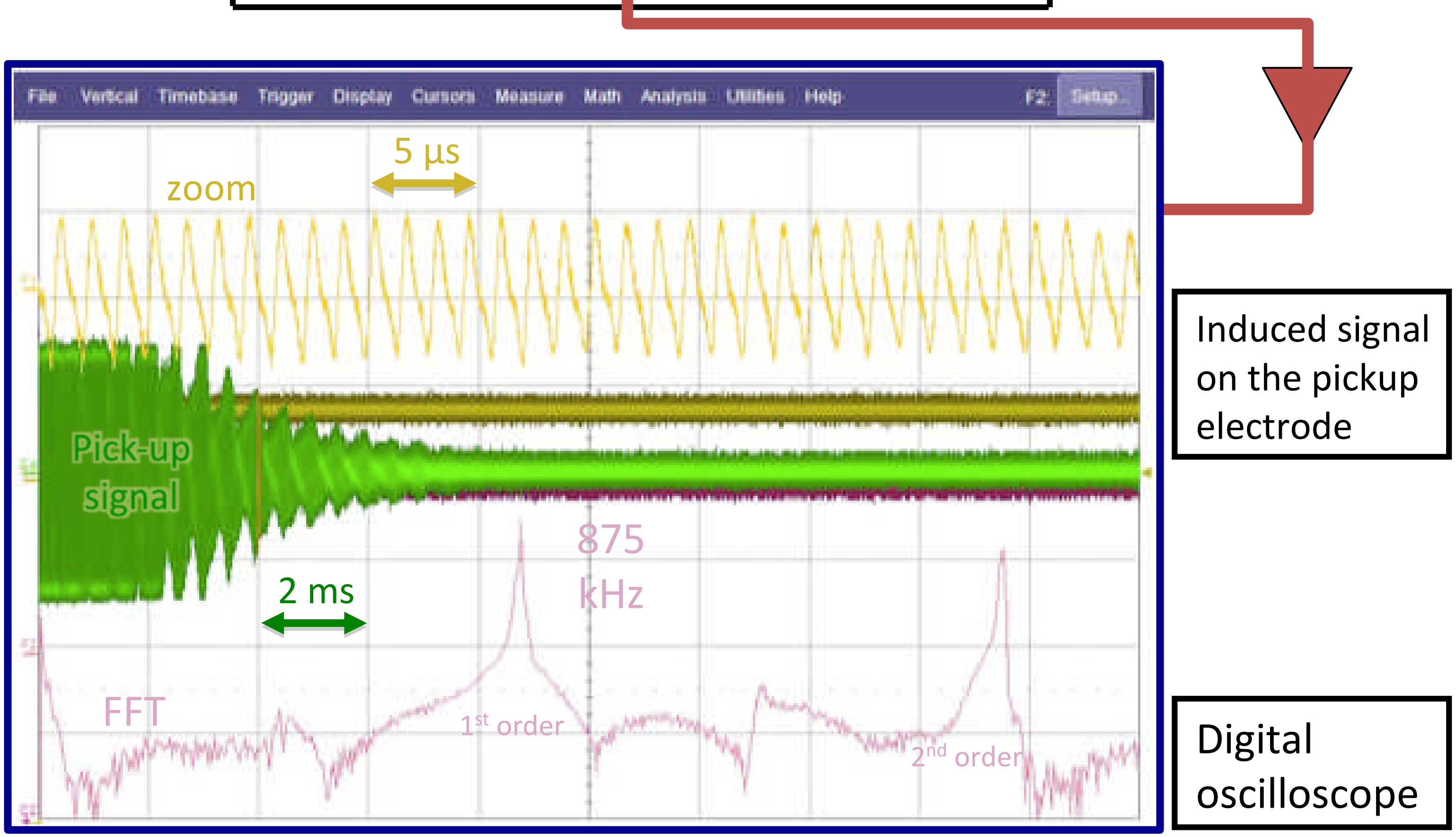
- Transverse velocity ≈1% longitudinal velocity
- All the stable phase space is full

Proof for trapping HCI

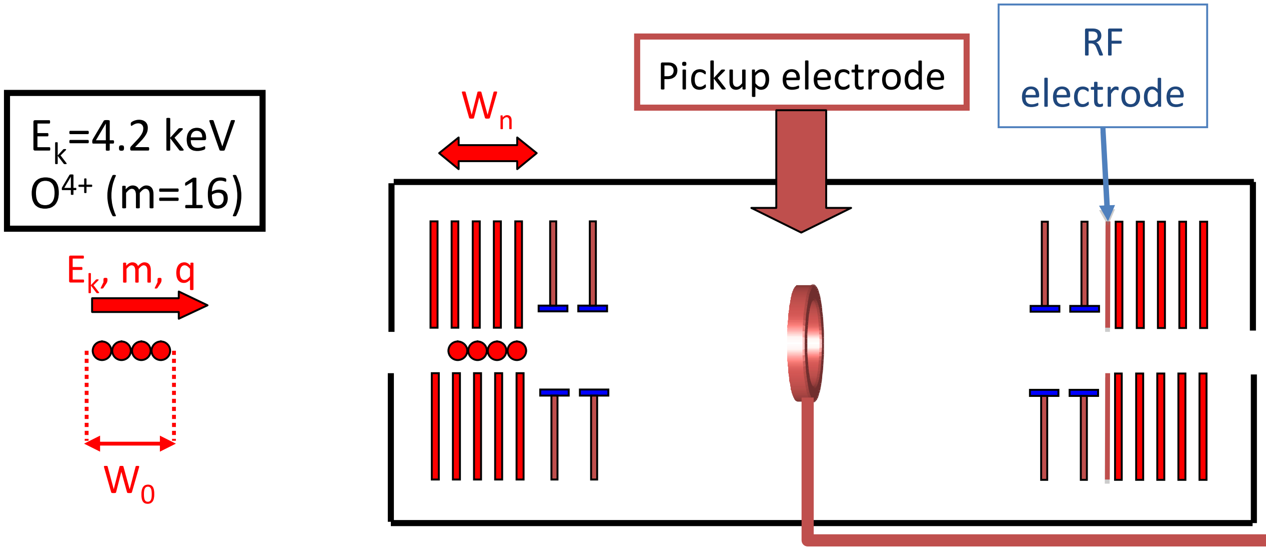


Trapping of HCI form O, Ar, Kr, Xe

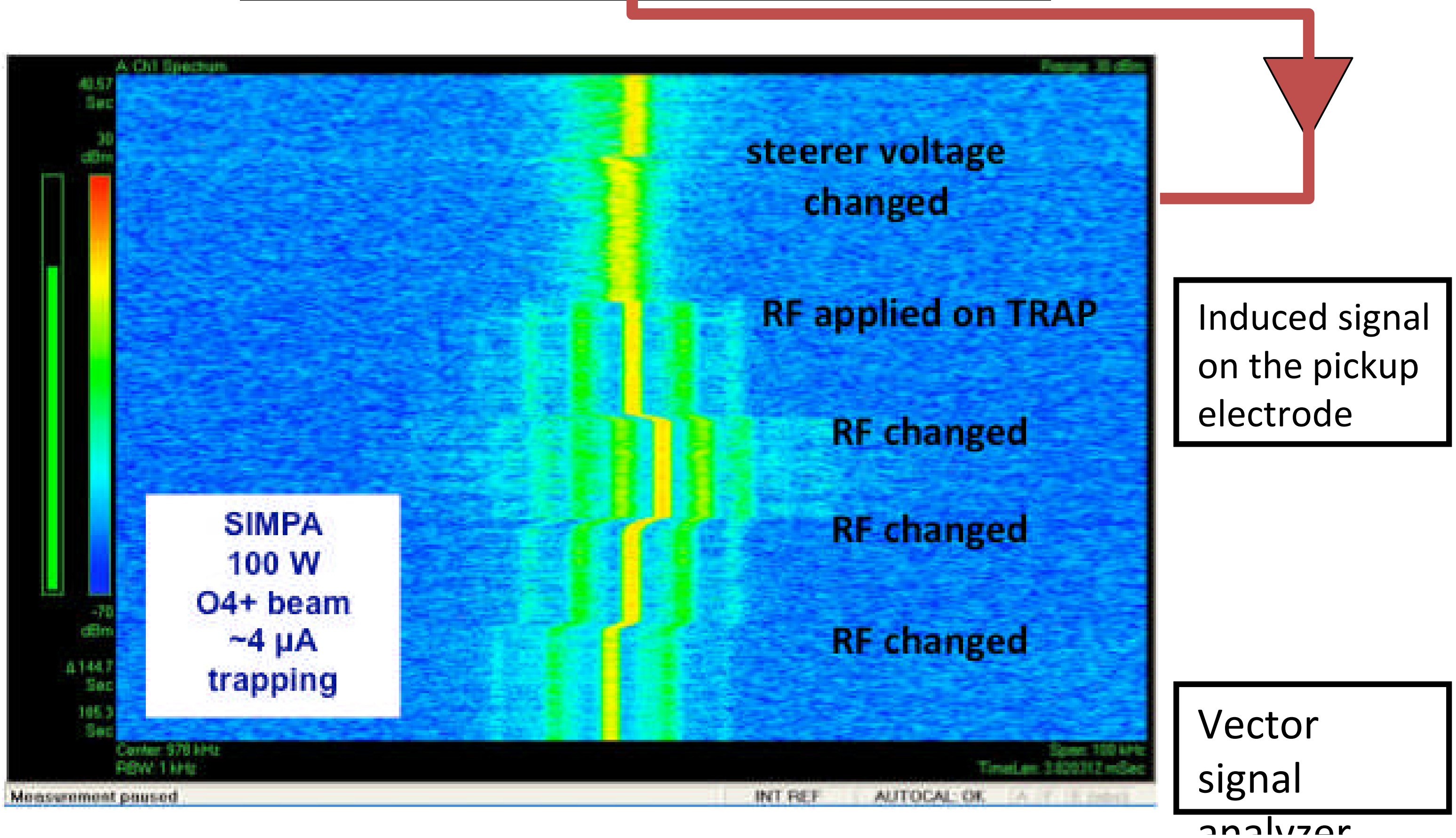
Up to charge states: O^{5+}, Ar^{13+}, Kr^{21+}, Xe^{20+}



Proof for trapping HCI



Up to 10 V Radio frequency added on one electrode

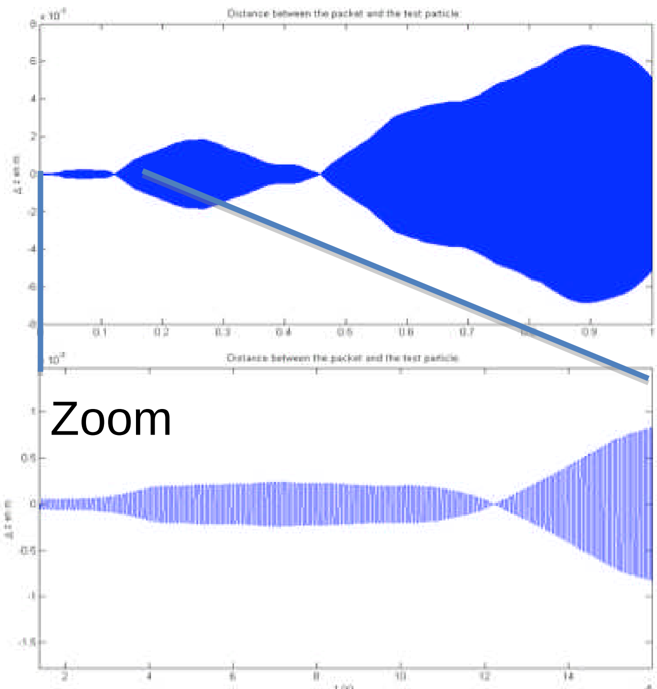


Simulations

Two Approaches

Bunching-debunching,

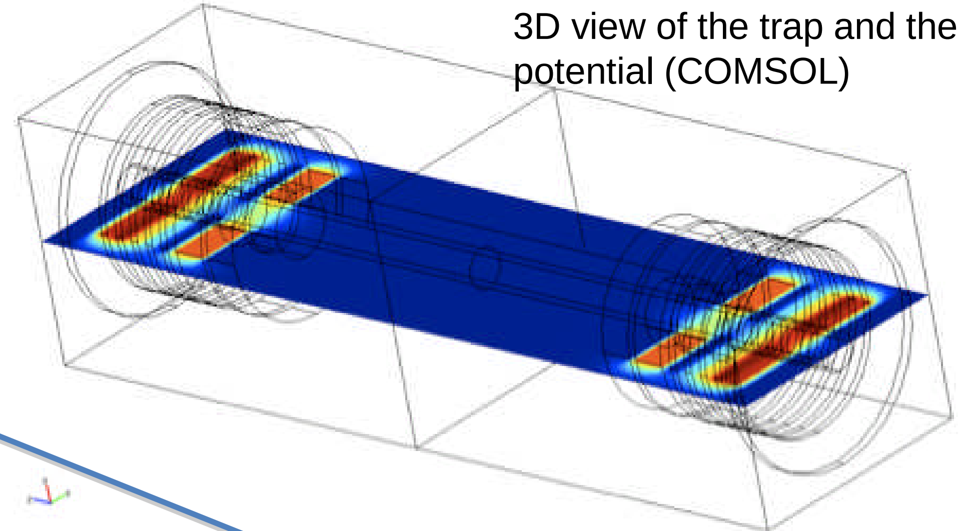
1D model by Pedersen et al implemented



behavior of a test ion close to a bunch of ions in the trap

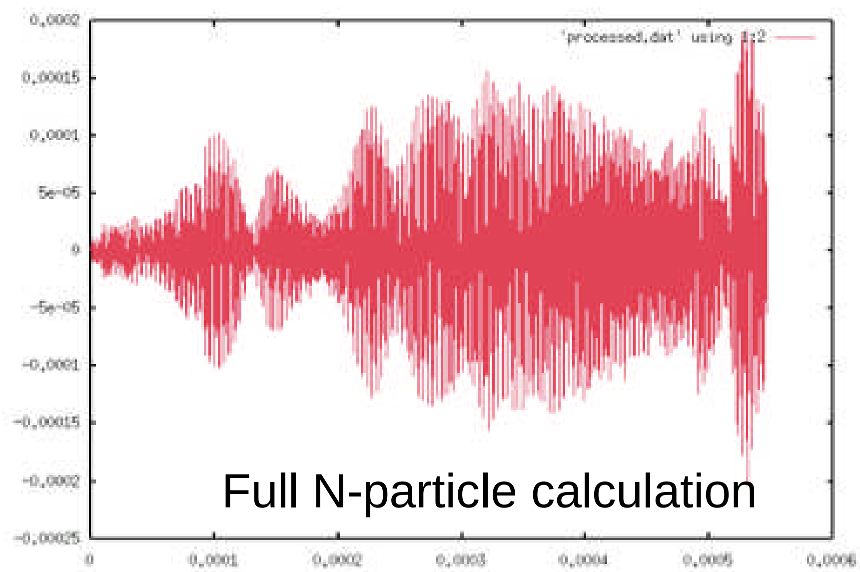
H.B. Pedersen et al. Phys. Rev. A pp 042703 65

3D view of the trap and the potential (COMSOL)



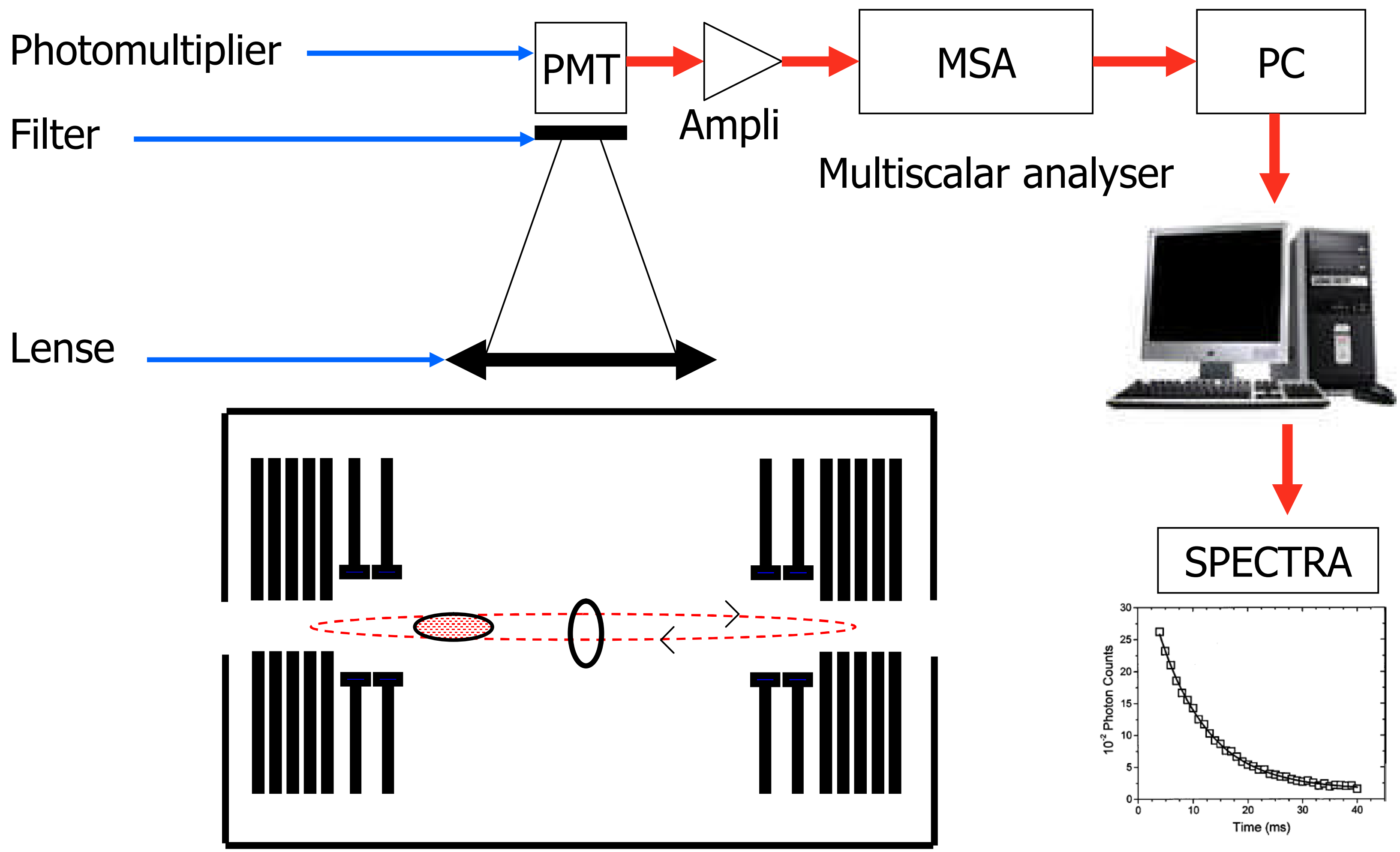
Transverse fluctuations

full N-particle calculation, in the potential generated by COMSOL according to configuration of our trap (A. Vallette)



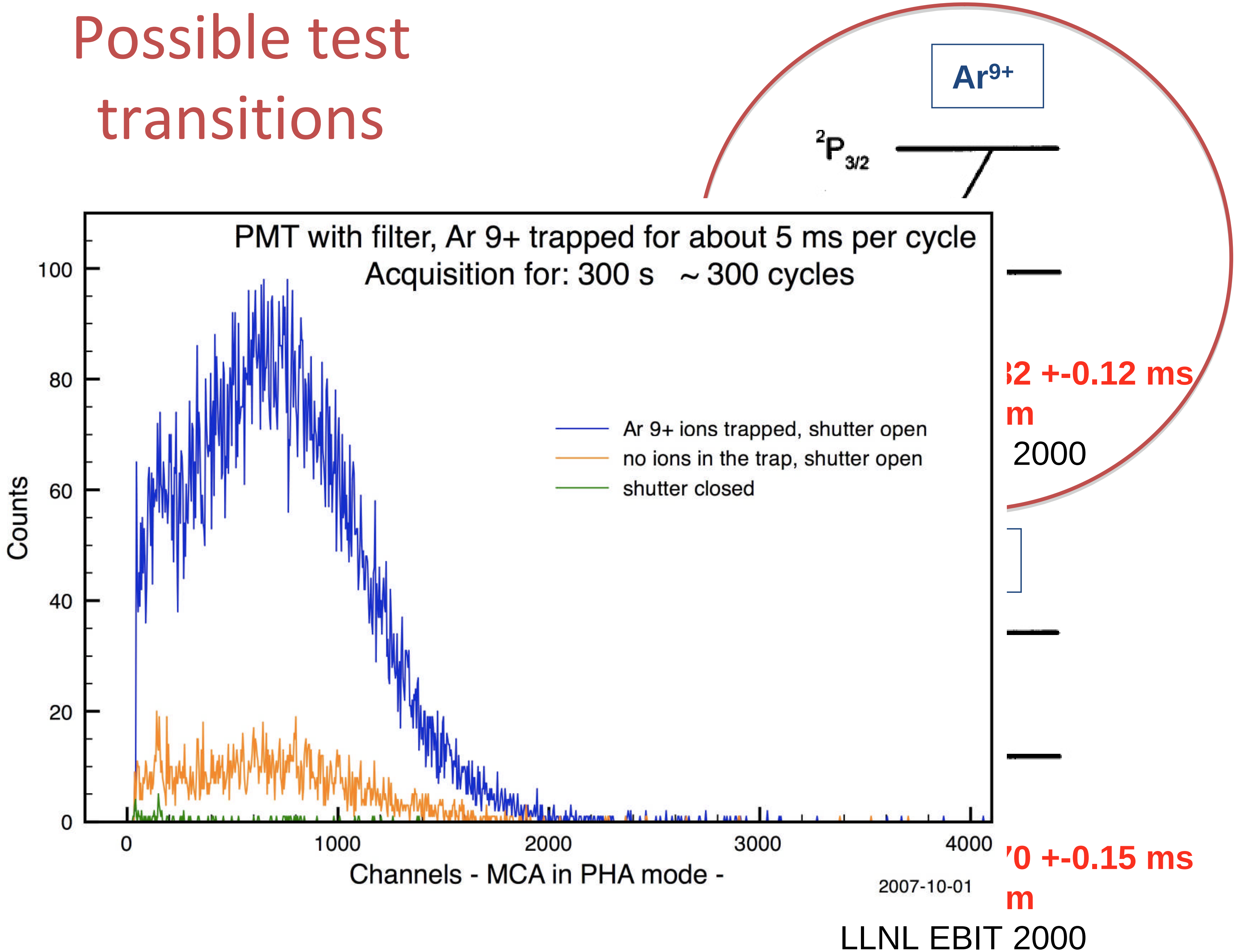
Metastable states lifetime measurements

Measurement of the life times of metastable states in highly charged ions in the millisecond time range

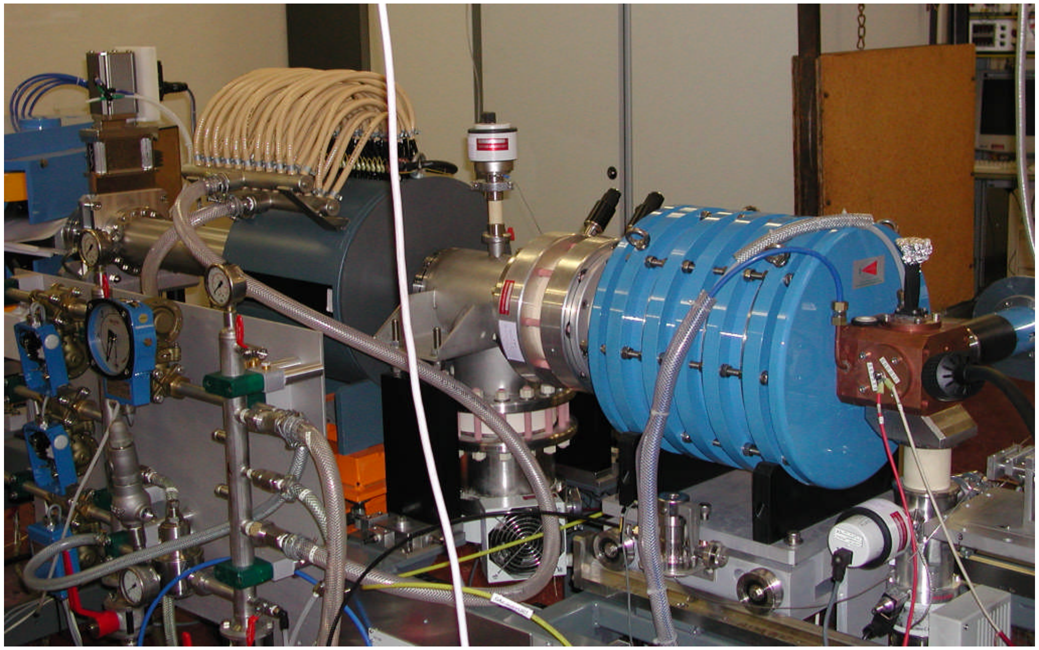


Are the extracted ions from the ECR Ion Source in excited states?

Possible test transitions



The SIMPA ECR Ion Source Laboratory



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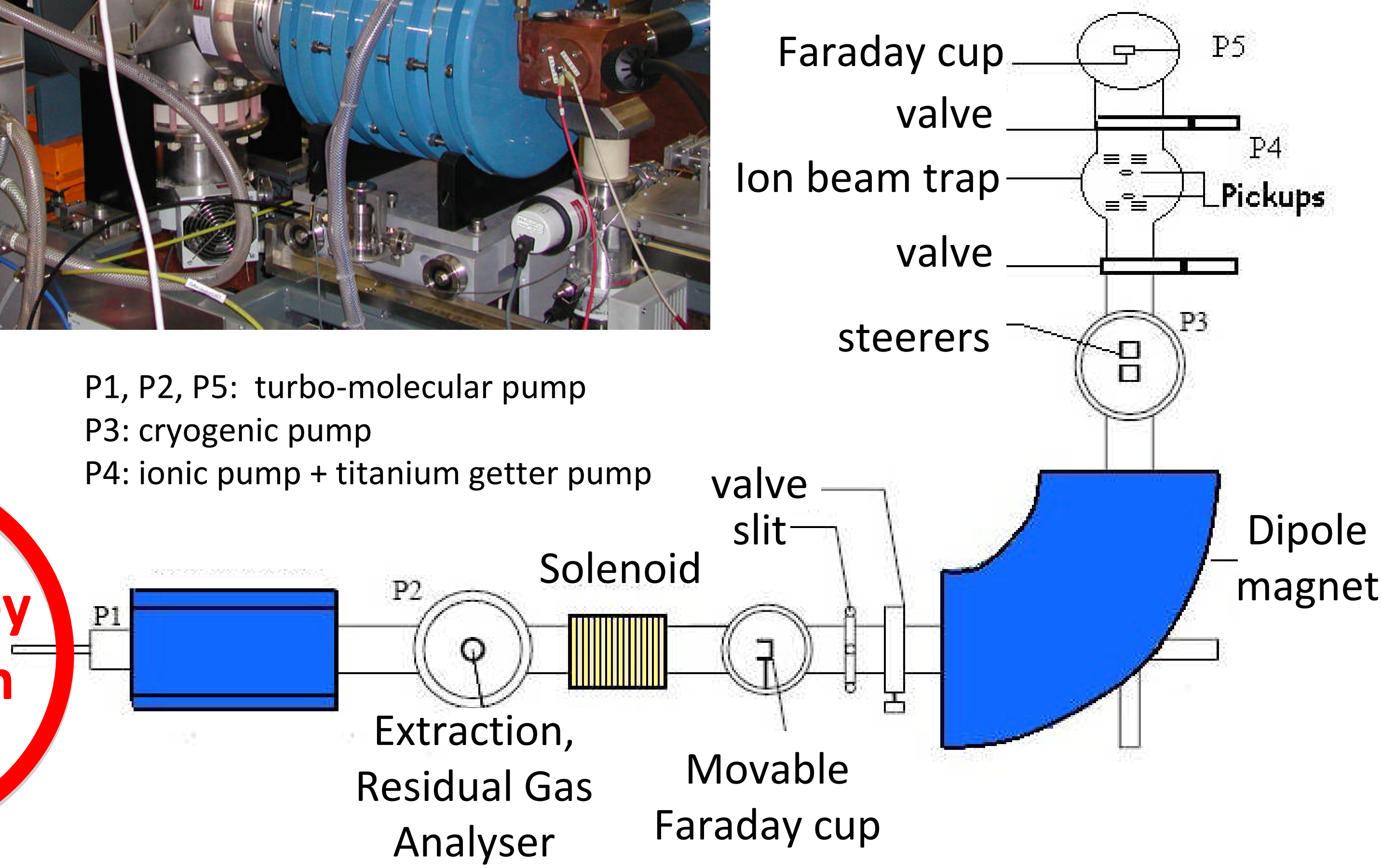
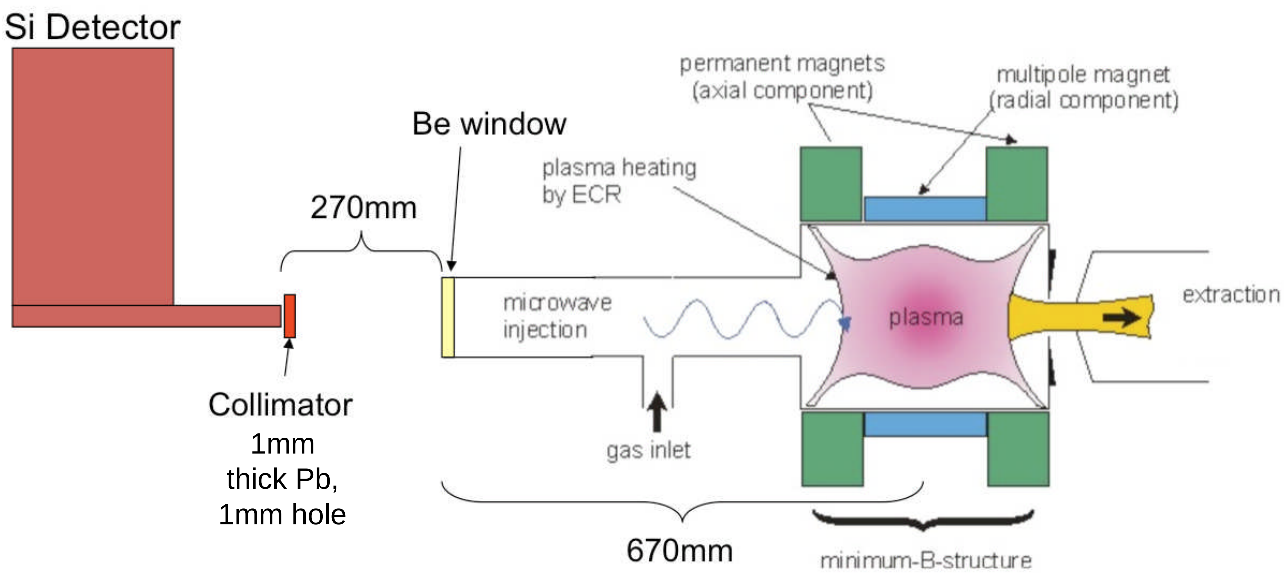
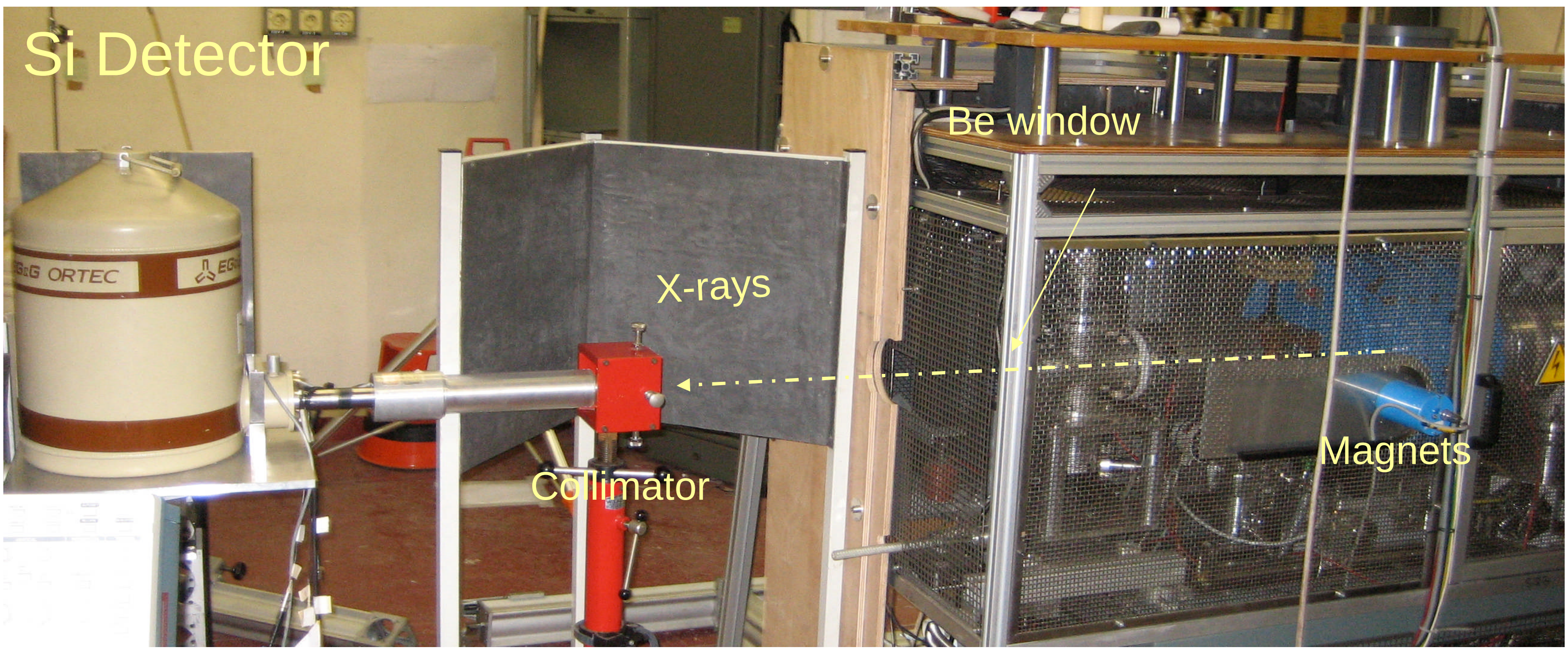


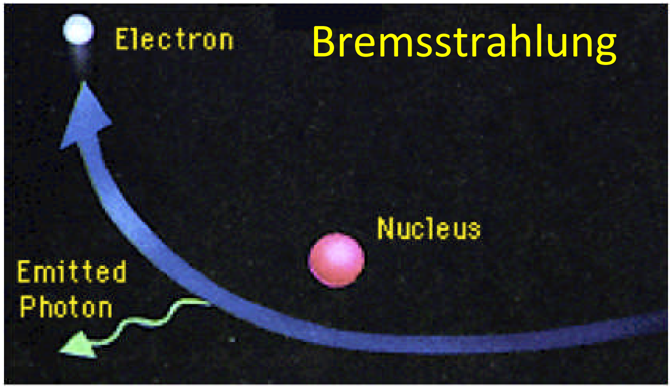
X-ray spectroscopy on injection side

Experimental setup for electron temperature measurements





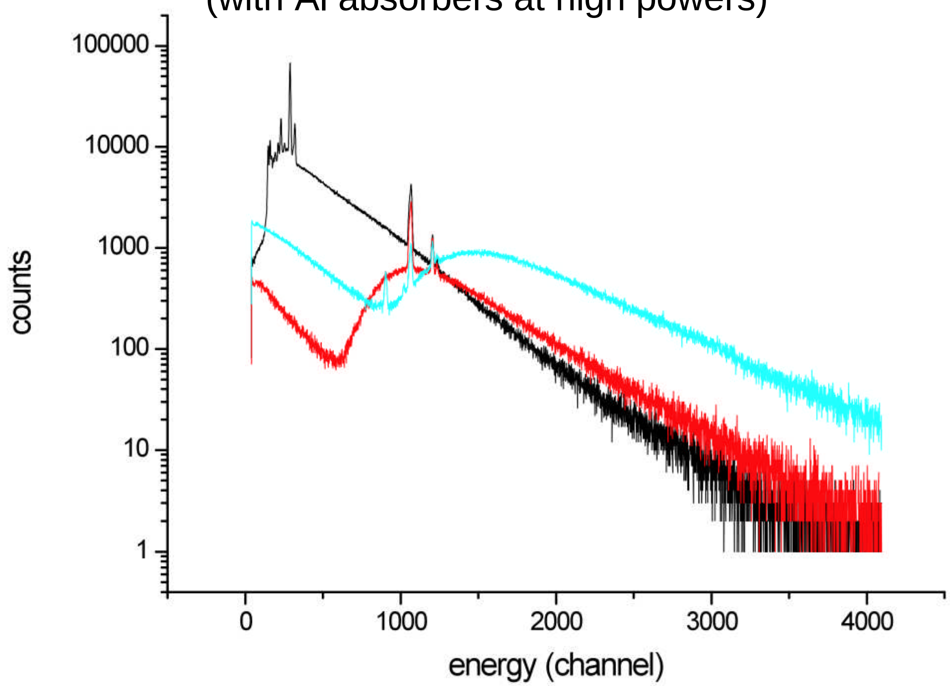
X-ray radiation detected by a silicon detector



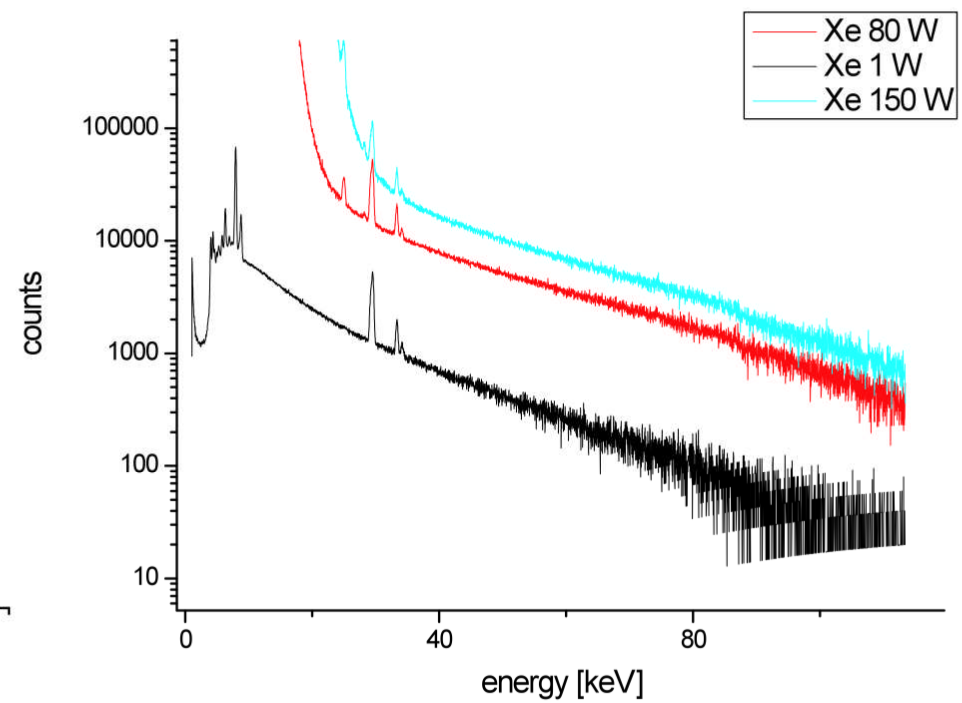
Resonant heating of electrons → Bremsstrahlung up to hundreds of keV x-ray energy

From the shape of the Bremsstrahlung spectrum → electron temperature in the plasma

Raw spectra
(with Al absorbers at high powers)

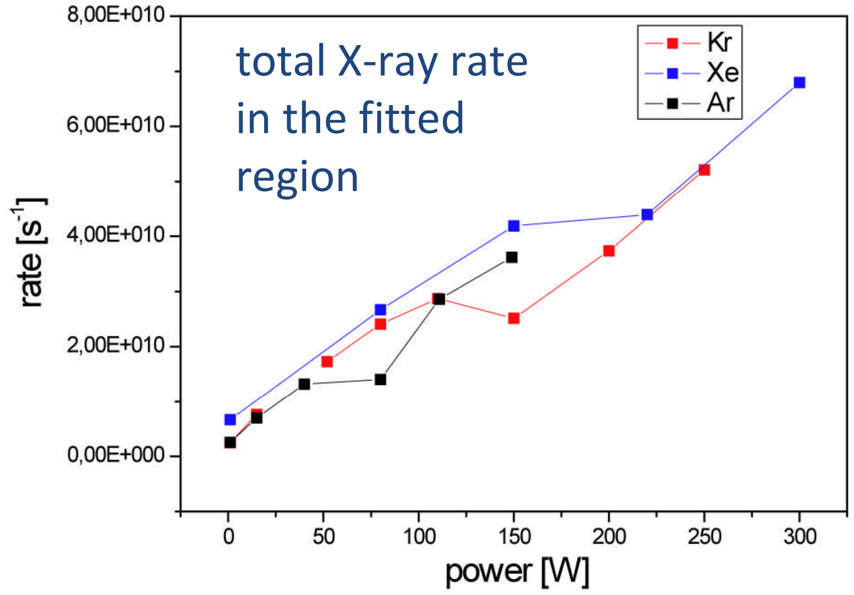


Corrected spectra

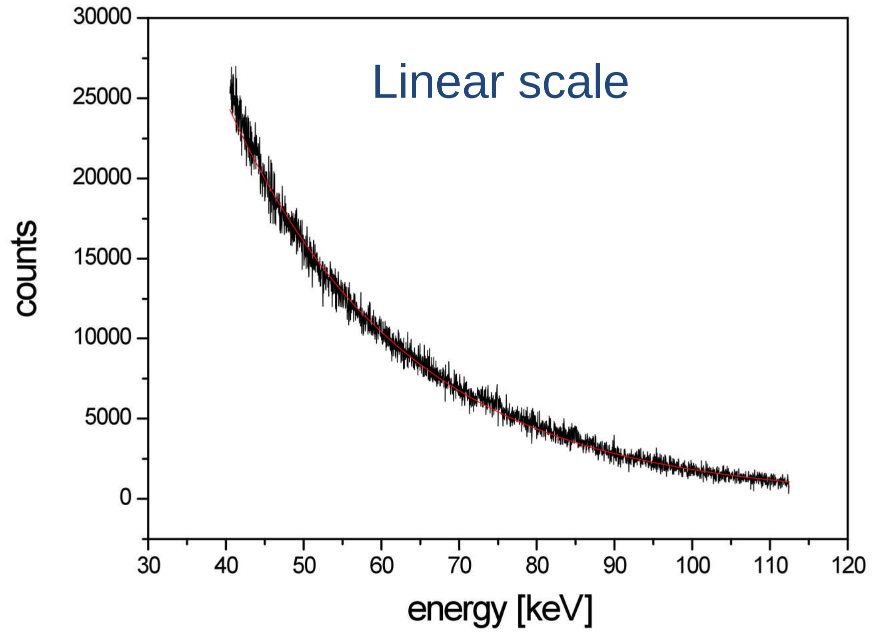


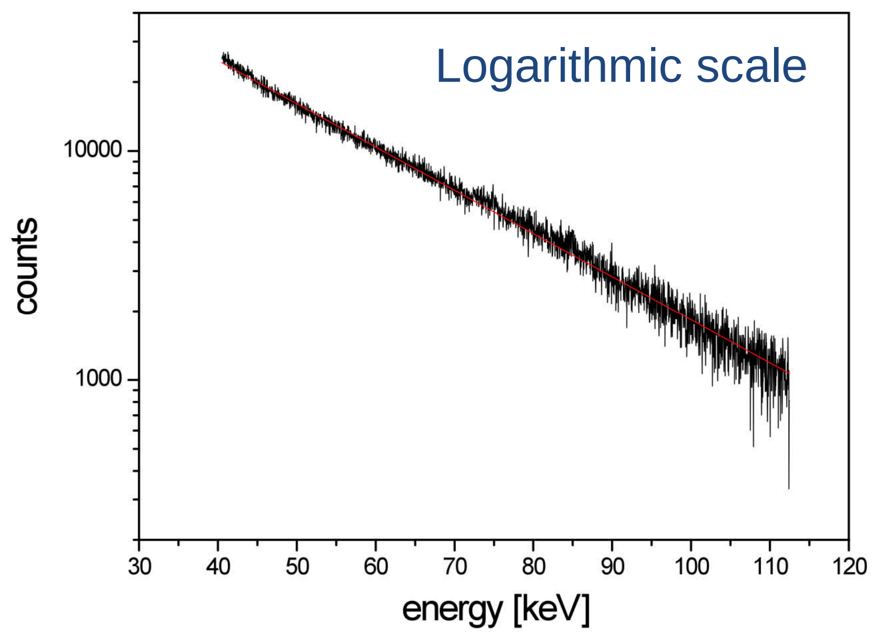
Exponential fit

After efficiency and absorption correction, the background can be fit to ~exp(-E/kT), where the fitting parameter kT will provide the Maxwellien electron temperature

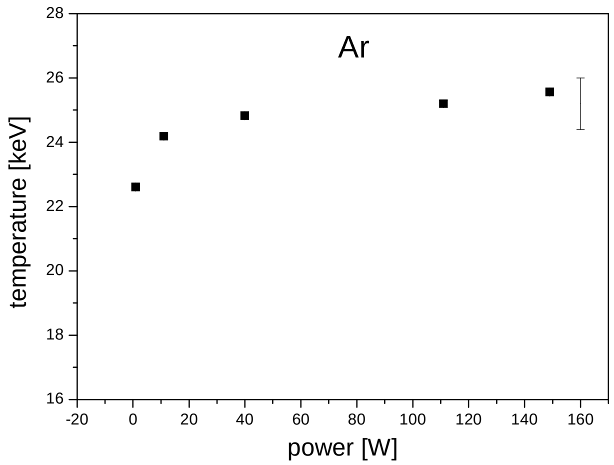


An example of the exponential fit
to the Bremsstrahlung spectrum from where the spectral temperature was obtained.



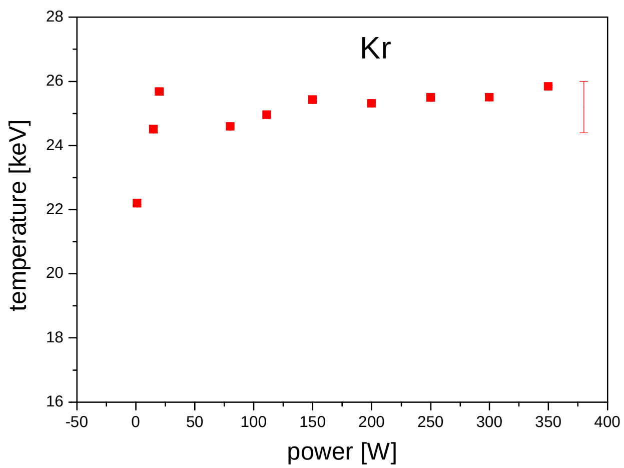


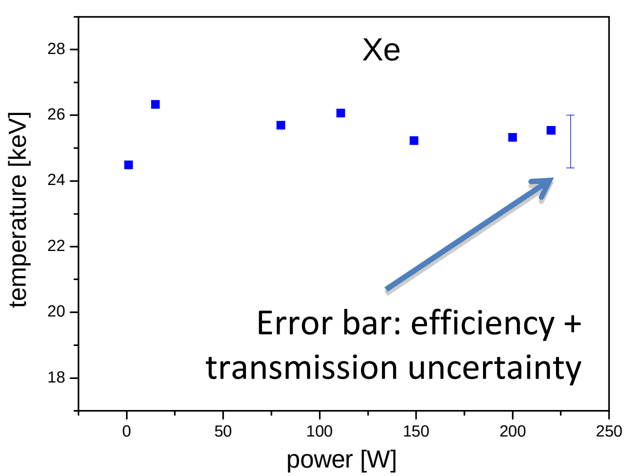
Results of the electron temperature measurements

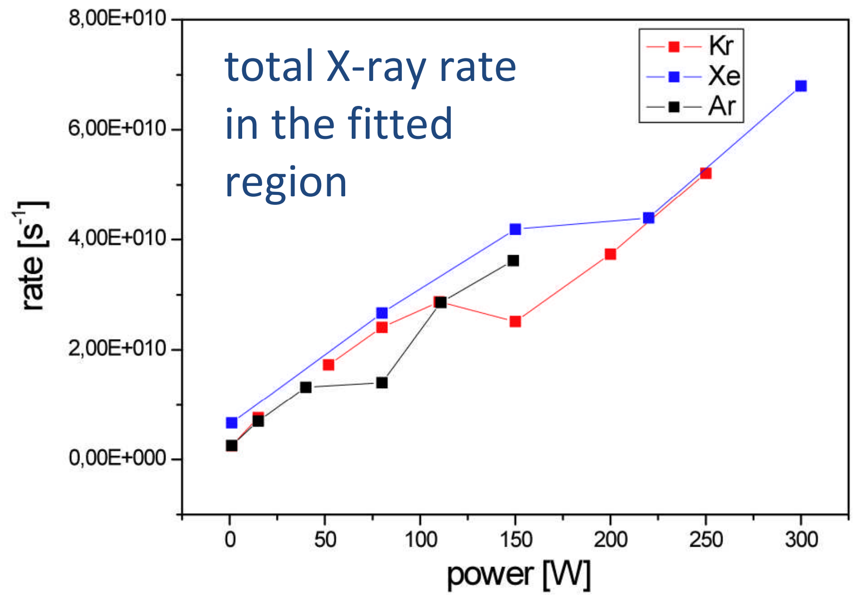


Slight increase initially at very low powers

Electron temperatures around 25±1 keV







The X-ray rate increases approximately proportionally with the microwave power.

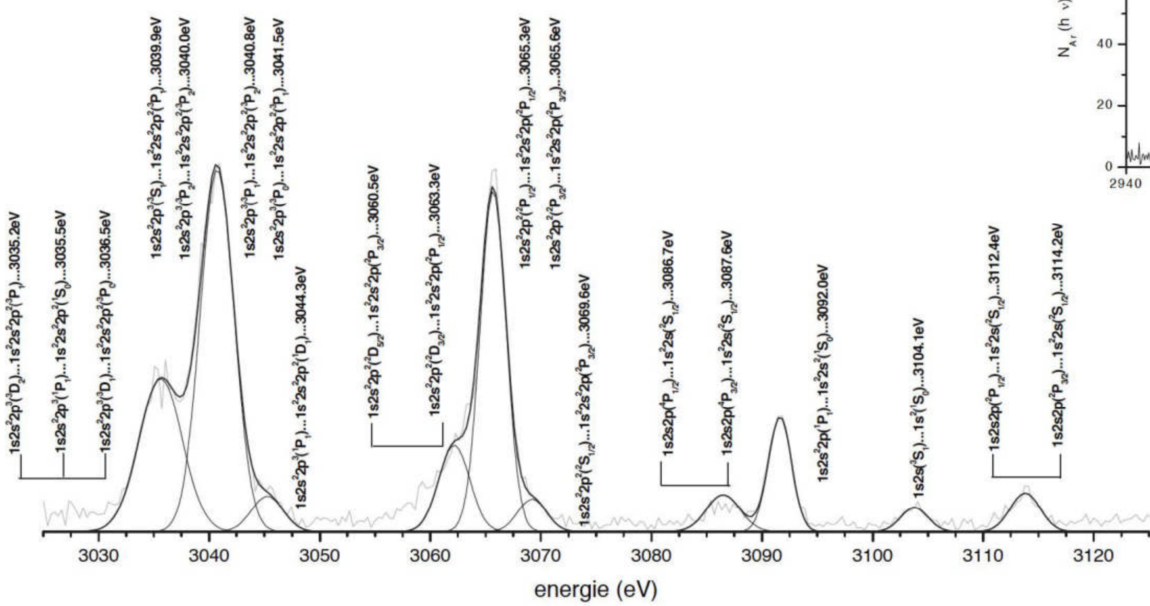
What about the ion component?

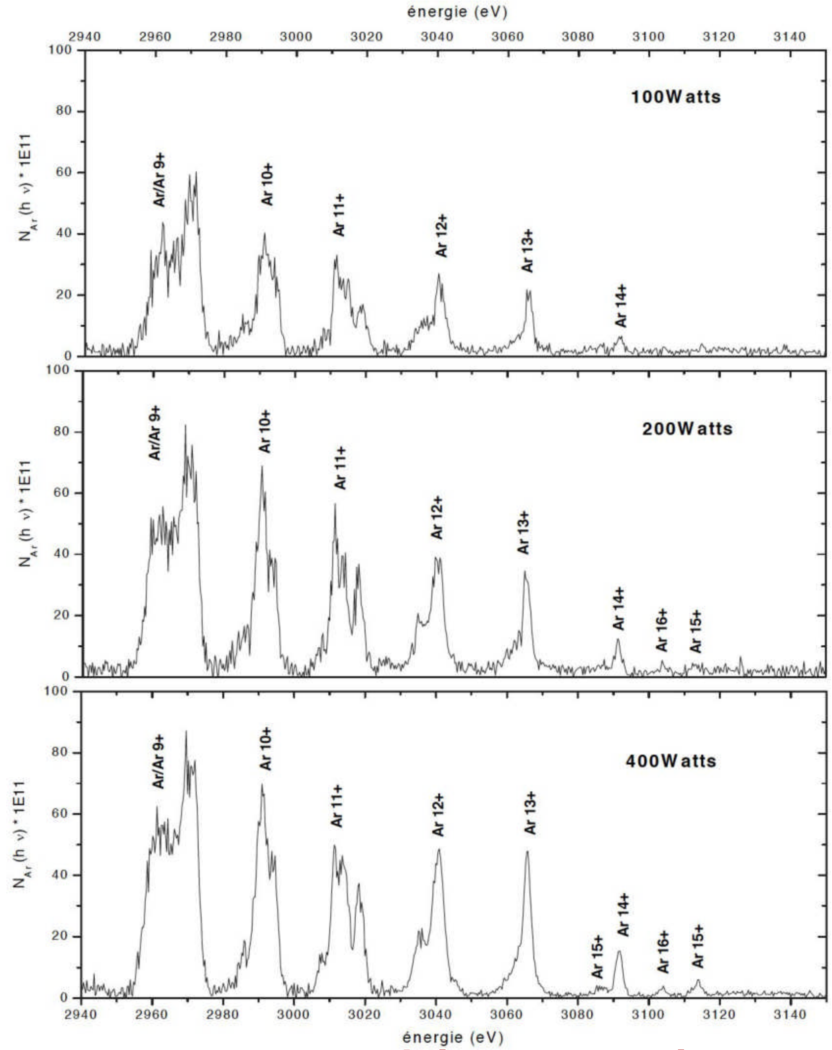
High resolution x-ray spectra with a mosaic crystal x-ray spectrometer

- first attempt -

Charge state distributions inside the ECR plasma can be deduced from the distribution of x-ray lines

Very accurate line identification is needed

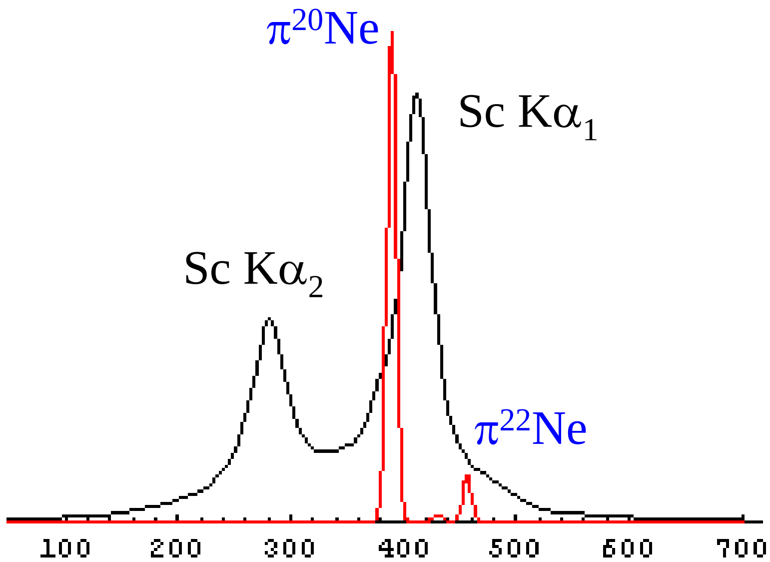




Double crystal instrument = Absolute wavelenghth measurement

X-ray energy standards?

- X-ray standards (solid state targets excited by electrons or photons) provides broad asymmetric lines (2 eV for Sc Kα_1, 0.4 eV spectrometer resolution)
- Exotic atoms and highly charged ions provide narrow lines



Low-energy X-ray standards from hydrogenlike pionic atoms,

D.F. Anagnostopoulos, D. Gotta, P. Indelicato, L. Simons, Phys. Rev. Lett. **91,** 240801 (2003).

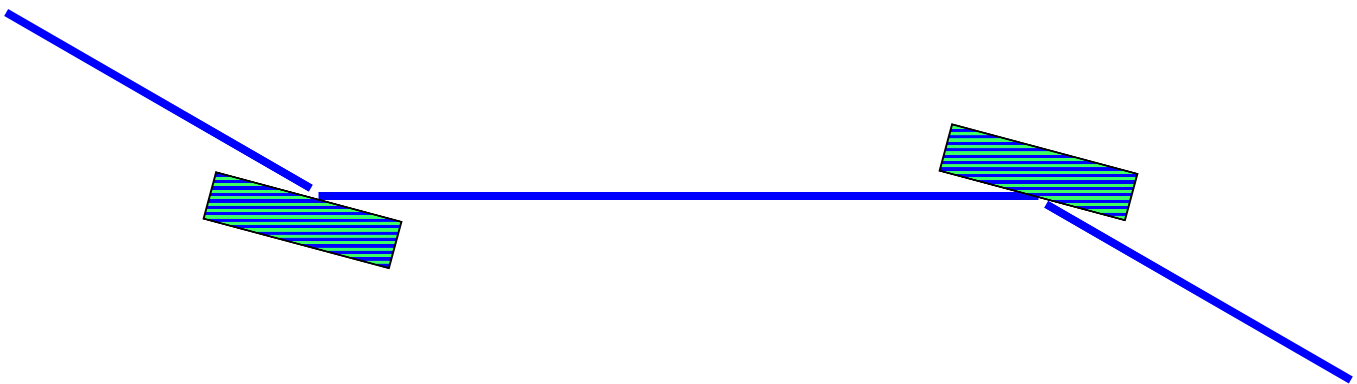
- Energy calibration
- Line shape

ECR ion source = bright, continous x-ray source

A double (flat) crystal x-ray spectrometer could be used

X-ray energy absolute measurement

- We are building a new absolute X-ray spectrometer i.e., with no need for reference line (contract BNM-National Bureau of Metrology)



$$2d\sin(\theta_{\mathrm{Bragg}}) = k\lambda$$

Non-dispersive (Ref. Angle)

If *d* is known there is only an index of refraction correction (n~a few 10^{-5}) to the Bragg law

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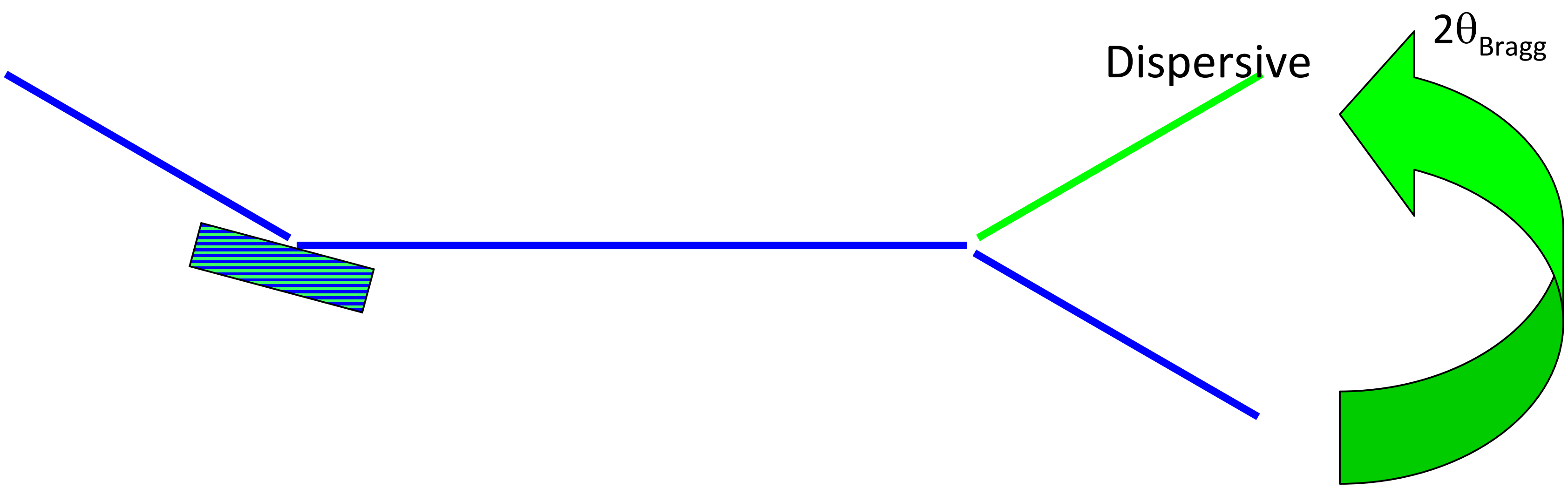

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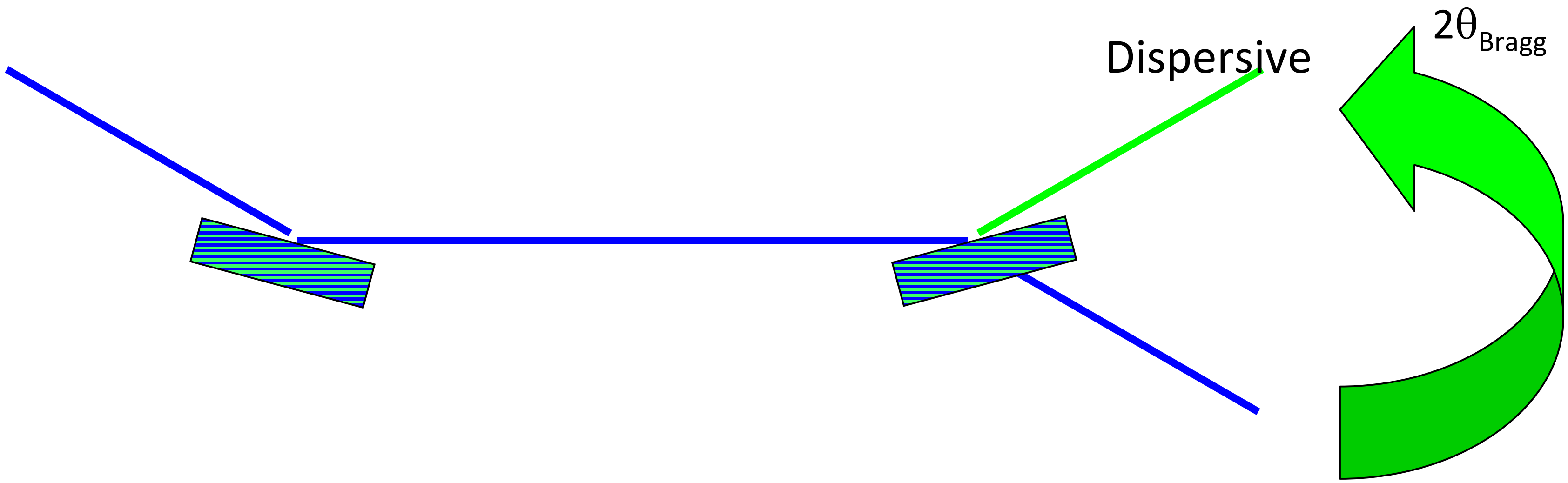

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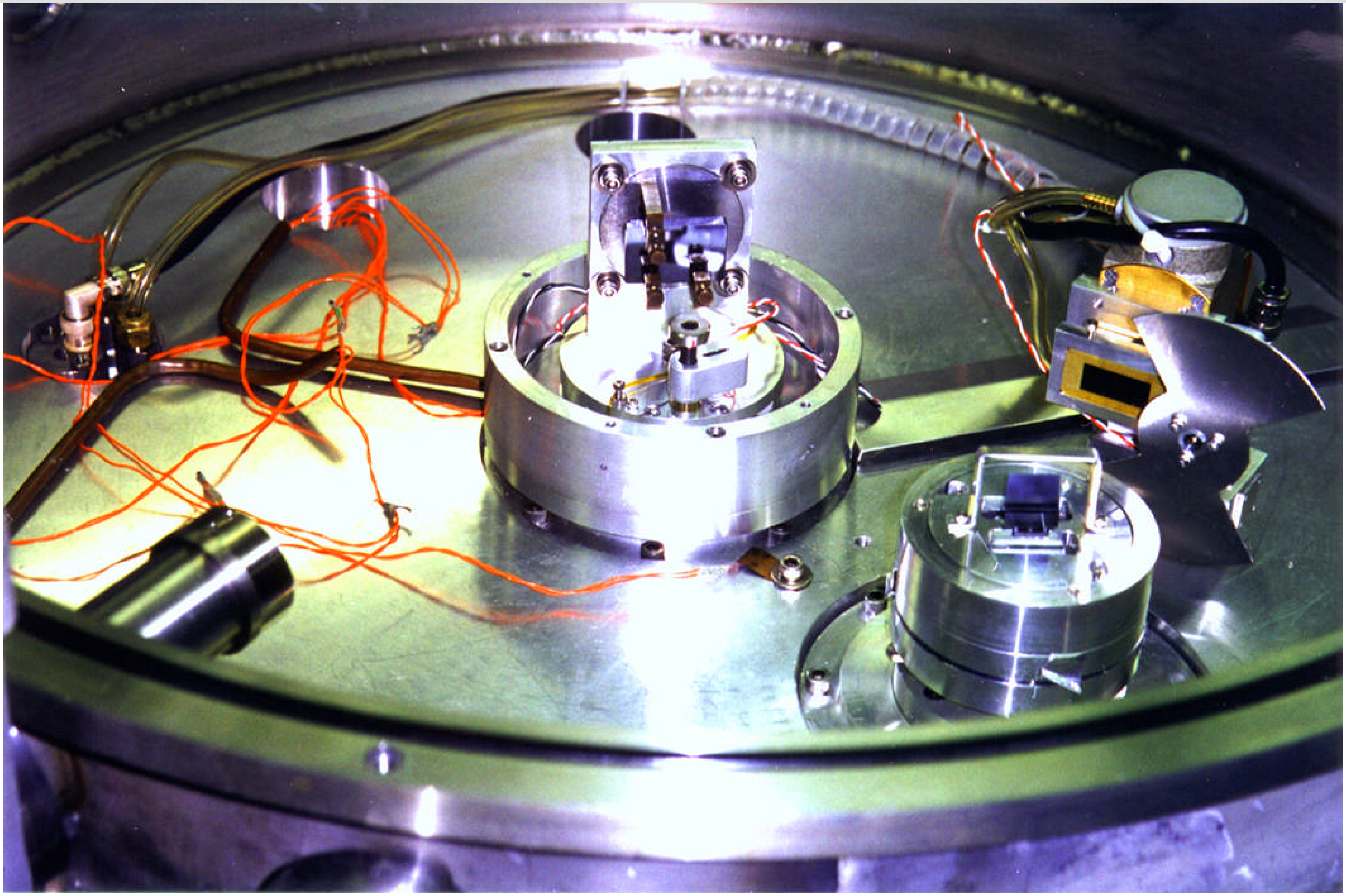
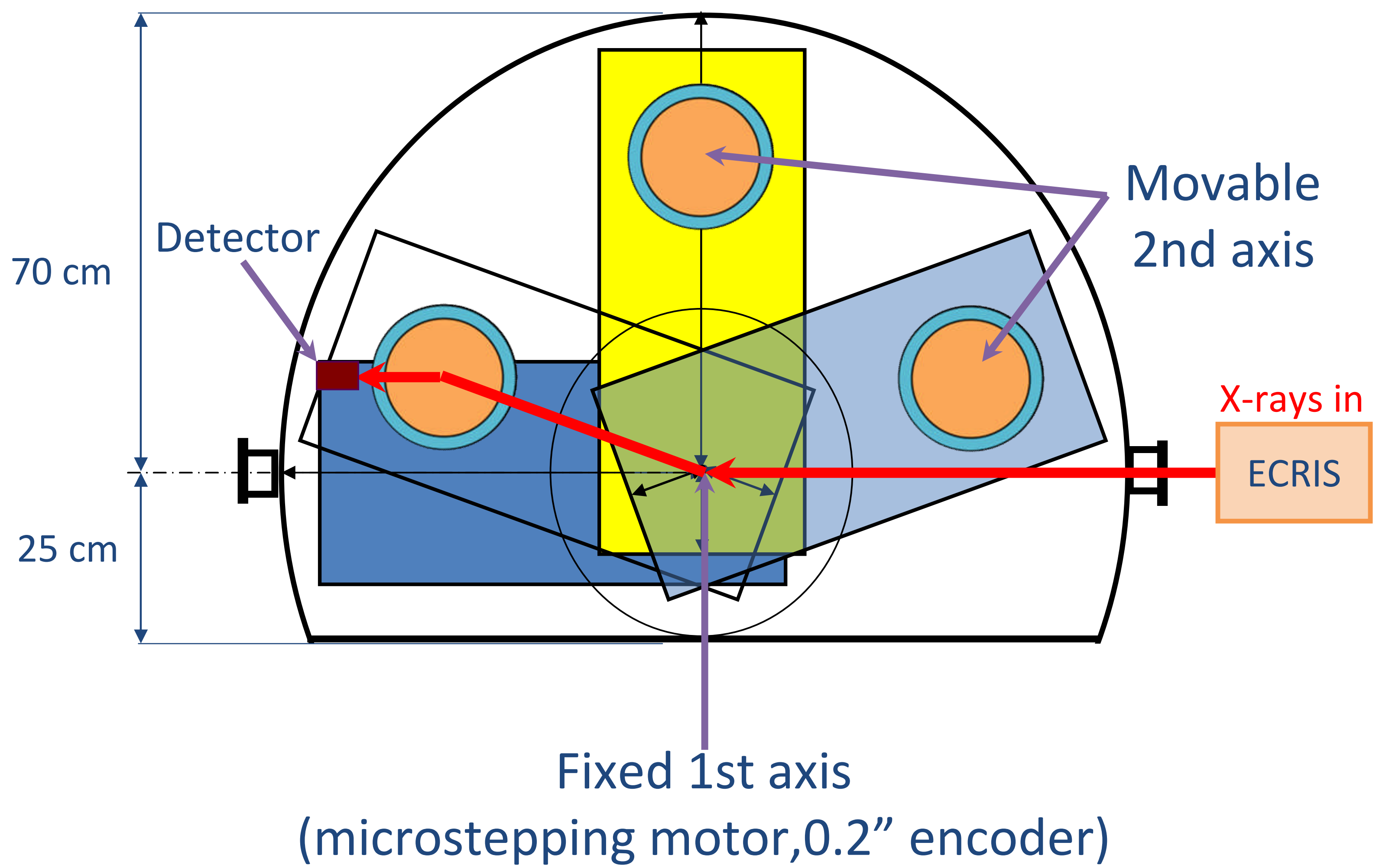
NIST Vacuum Double Crystal Spectrometer



1 keV to 12 keV absolute λ determination

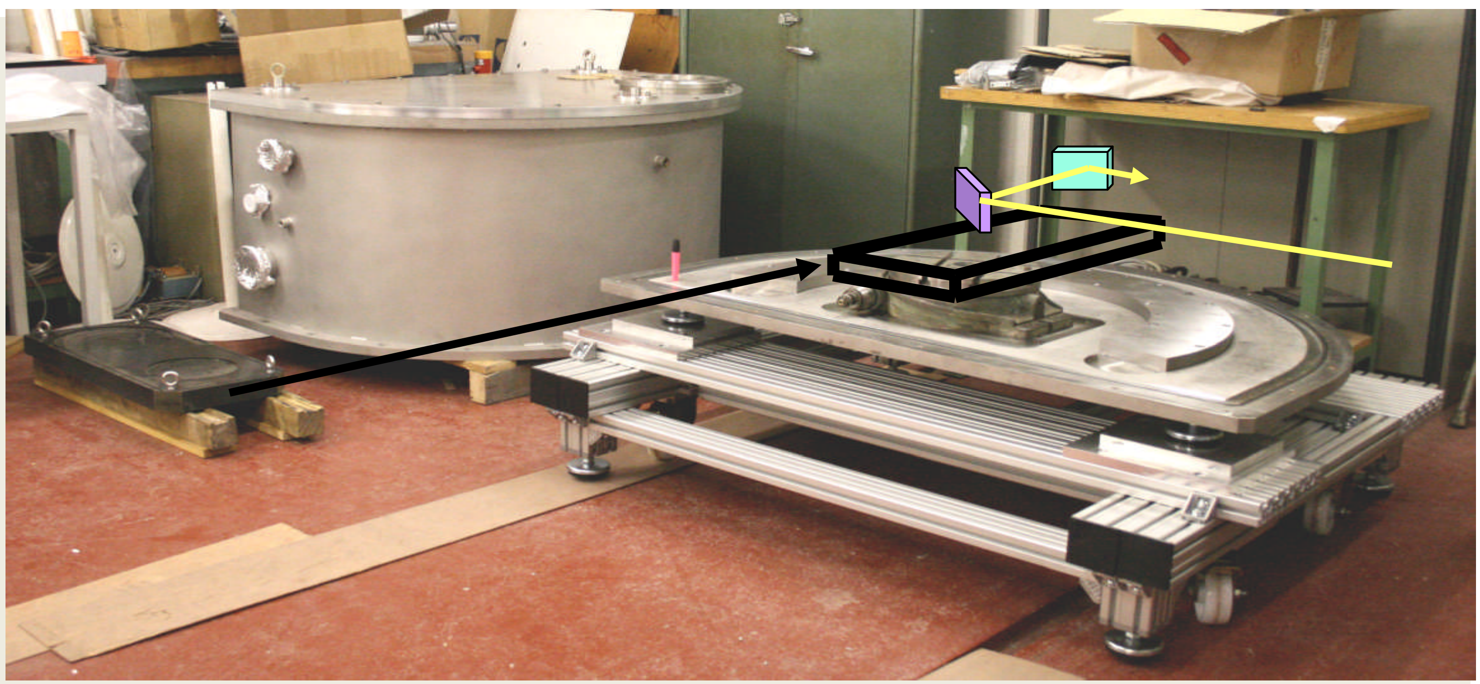
Two crystal spectrometer for a fixed source



Vacuum chamber, 900 kg+ spectrometer 300 kg

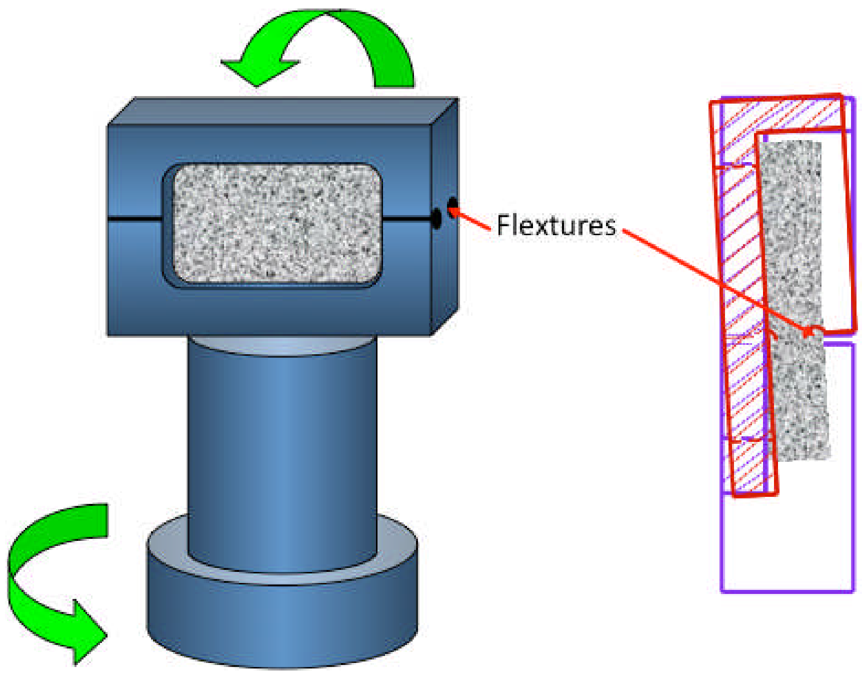
High stability design

Hunting for stability:
200 kg, LK3, alloy base plate, stabilized at 900 °C for 48 hours
Machined, stabilized at 700 °C for 24 hours, then ground to 2µm accuracy

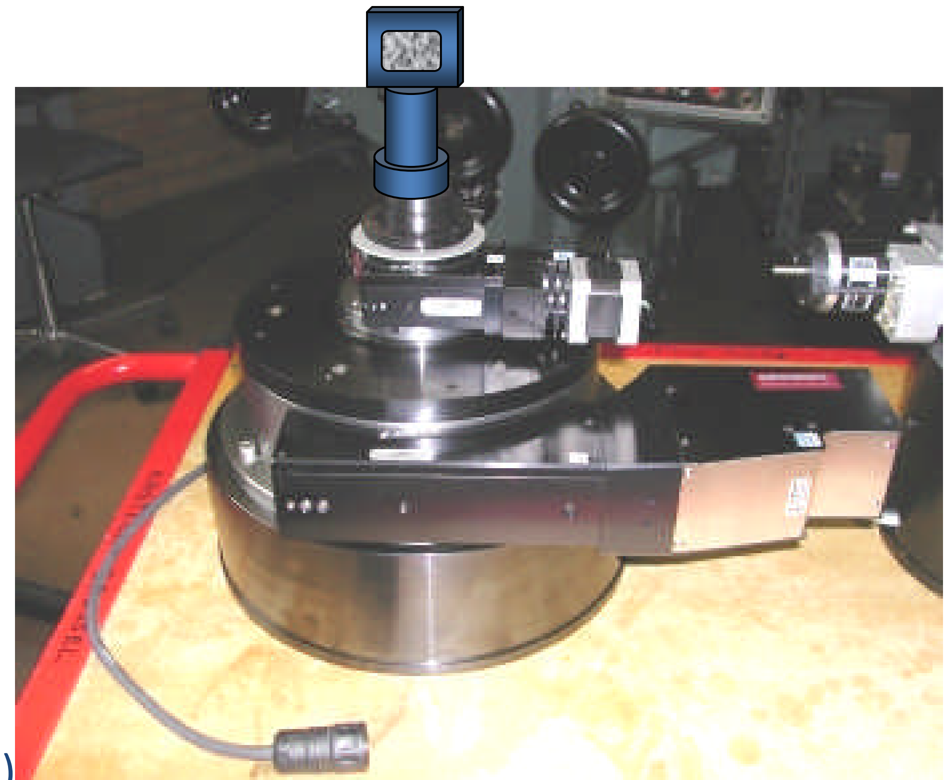


Crystal positioning, rotation

Crystal holder design



0.2” Heidenhain encoder (ROD 900+AWE 1024)



- Angular encoder accuracy 0.2”
- Angle range 15° to 65°
- Vacuum instrument

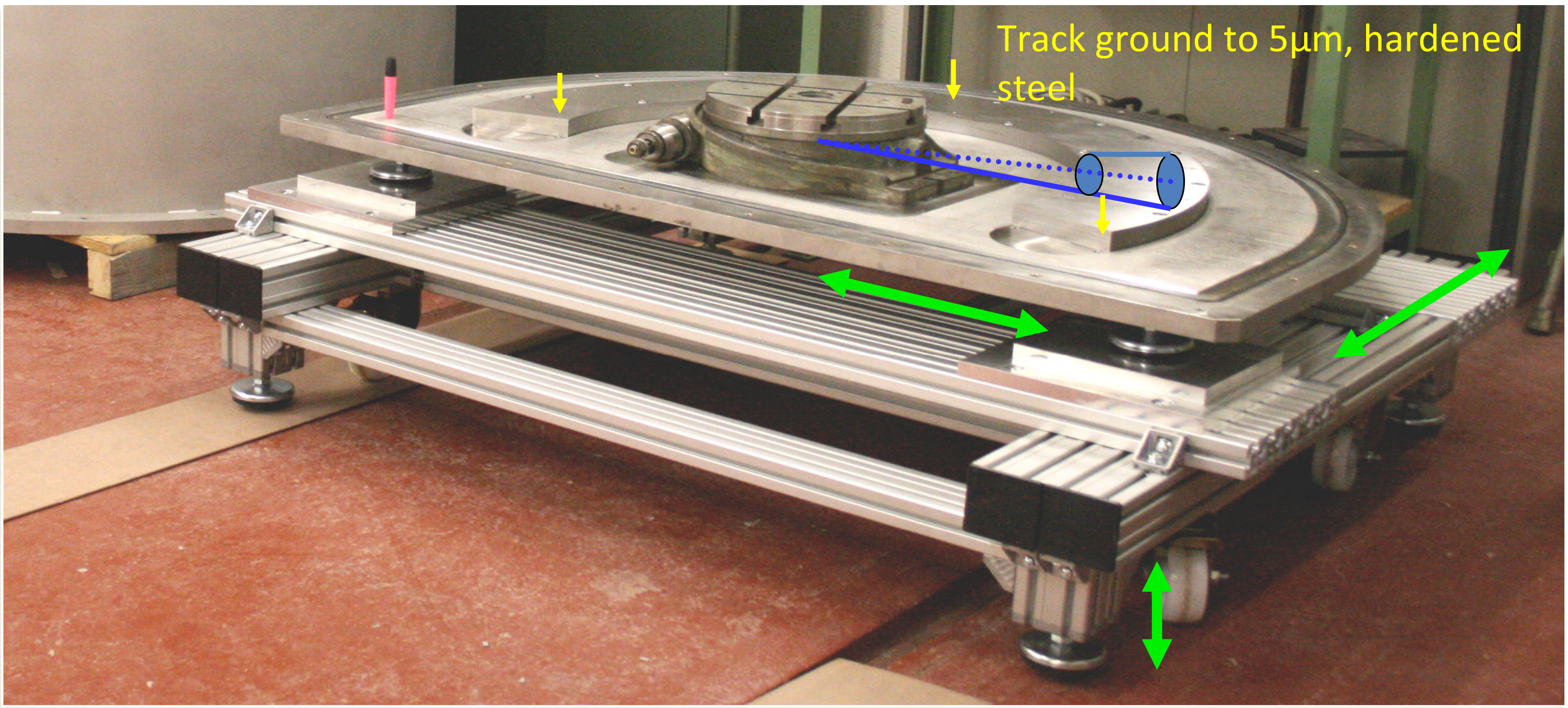
Si 220 and Si 111 crystal pairs made and measured at NIST (< 0.1 ppm)

•Si 220: 3.6 (0.45 ppm) to 12 (3.6 ppm) keV

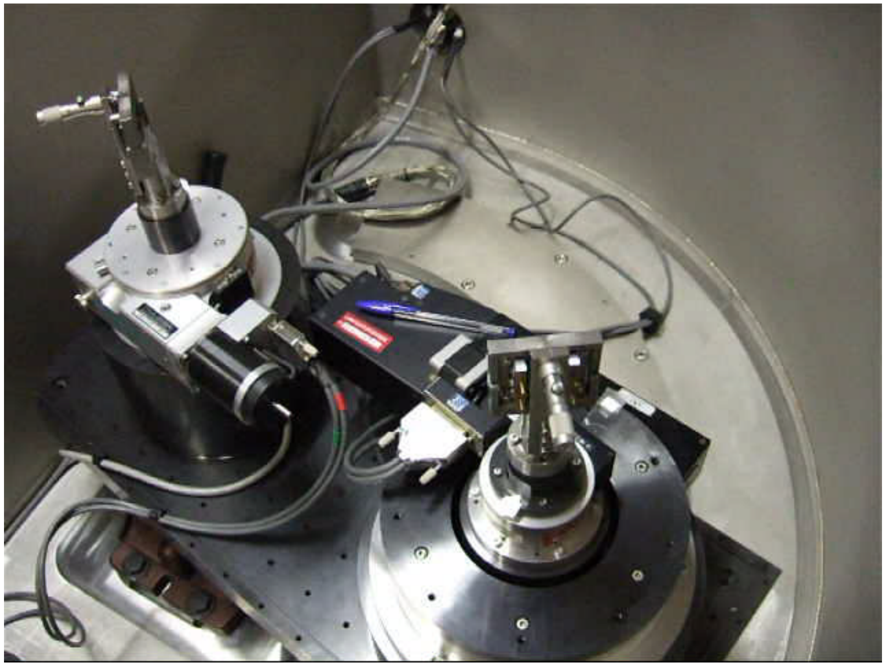
•Si 111: 2.2 (0.45 ppm) to 7.5 (3.6 ppm) keV

Positioning and alignment

Rotation of a 300 kg plate with good stability
Positioning of the 1.3 t spectrometer



The new double crystal spectrometer is ready for x rays at SIMPA



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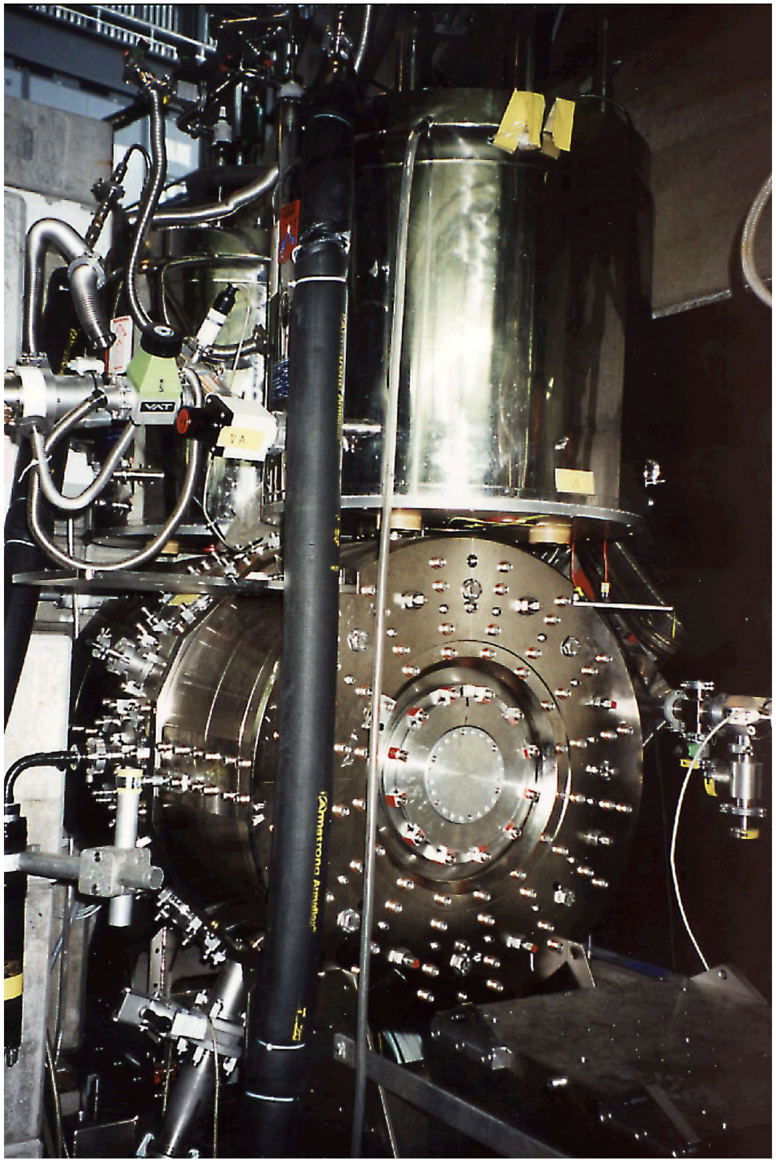
Summary

- Trapping of highly charged ions from an ECR ion source the first time with the new electrostatic ion beam trap
- Goal: Measurement of life times of meta-stable states
- Measured average electron temperature from the bremsstrahlung x-ray spectra: 25±1 keV
- The new double crystal spectrometer is ready for absolute measurement of strong transitions of HCI in the ECR ion source plasma.

X-ray image of the SIMPA ECR ion source taken with an x-ray pinhole camera

… in the future at SUPER-SIMPA



ECRIT used at PSI (Switzerland) at the pionic Hydrogen experiment

Frequencies ECRIT: 6.4 GHz disassembeled

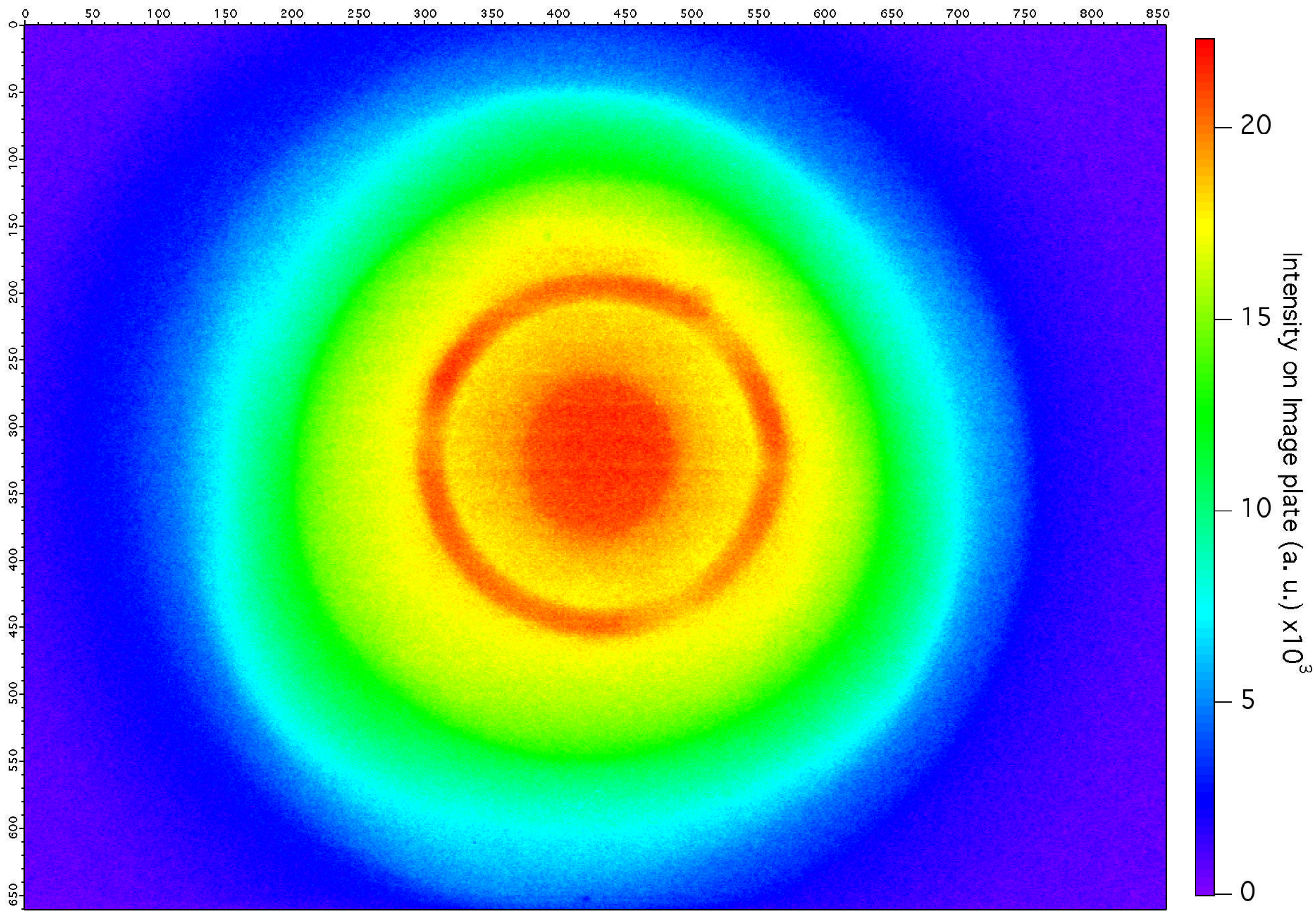
To be reassembled in Paris as Super-SIMPA:
18 GHz (broadband)
14.5 GHz
6.4 GHz

Extraction:
ECRIT: none
Super-SIMPA: 20 kV

LHe:
Continuous refilling

X-ray image of the SIMPA ECR ion source

X-ray image registered on phosphore storage image plate with the help of a Ta pinhole in approx 20 cm distance from the edge of the plasma

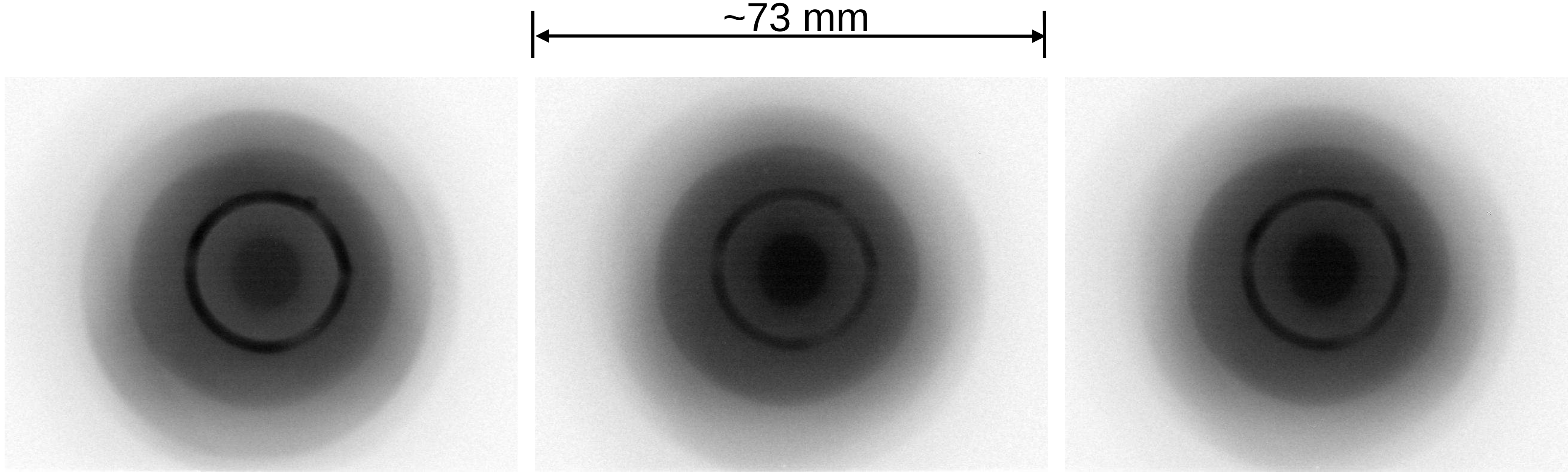


X-ray images on MS Image Plate at SIMPA

08-11-2007

Source settings: Kr gas, 50 W

5 min exposure time



no filter

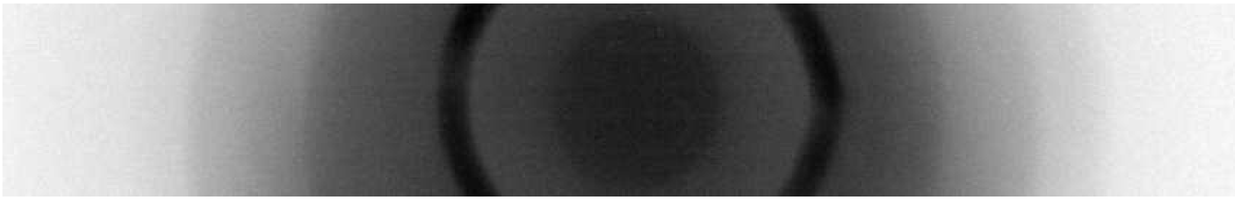
FeCr filter
110 um

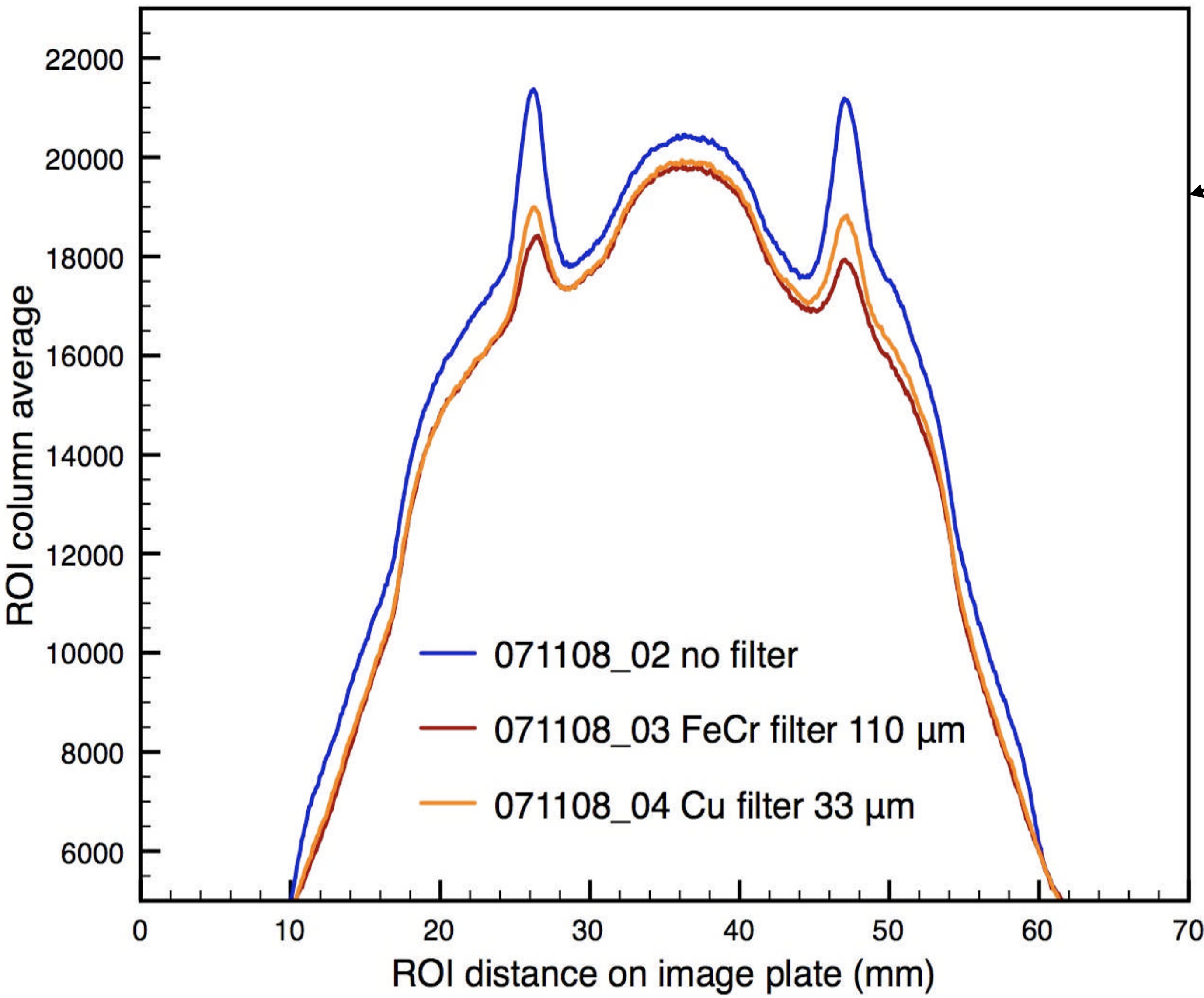
Cu filter
33 um

Plasma pinhole distance: min 210 mm

Pinhole-IP distance: ~1 m

Magnification: ~4.7





Column averages of ROIs with and without filters

The ring area gets filtered more with the FeCr filter