# FIRST MEASUREMENTS WITH THE PSI ECRIT

L. Simons[1*], S. Biri[2], V. Boisdourdain[3], M. Demeter[2], D. Gotta[4], A. Gruber[5], P. Indelicato[3], B. Leoni[1], H. Fuhrmann[5], L. Stingelin[1], A. Wasser[1], J. Zmeskal[5]

[1]Paul Scherrer Institut, Villigen PSI, CH5232 Villigen, Switzerland
[2]Institute of Nuclear Research (ATOMKI), Debrecen, P.O. Box 51, H-4001, Hungary
[3]Université Pierre et Marie Curie, Laboratoire Kastler-Brossel, F-75252 Paris, France
[4]Institut für Kernphysik, Forschungszentrum Jülich, Germany
[5]Institut für Mittelenergiephysik, Austrian Acad. of Sci., Vienna

At the Paul Scherrer Institute (Switzerland) an ECR Ion Trap (ECRIT) has been set up with the goal to produce narrow X-ray lines for a high statistics diagnosis of the resolution function of a high resolution Bragg crystal spectrometer. The ECRIT itself has a hybrid structure magnetic trap (consists of a superconducting split coil magnet with special iron inserts and a permanent magnet hexapole) and a 6.4 GHz microwave emitter. Without extracting and analyzing the ion beams argon plasmas were generated with different ionisation degree. The magnetic dipole $^3S_1$-$^1S_0$ transition of helium-like argon (lifetime 0.21μs) with a peak/background ratio of 8:1 with an intrinsic width of about 40 meV was used to successfully characterise two different spherically bent Bragg crystals.

## 1. INTRODUCTION

The effort described here aims at the production of X-rays at energies of 3 keV with small intrinsic line widths as a tool to determine properties of Bragg crystals [1]. It makes use of the fact that E1 X-rays from hydrogen-like atoms as well as M1 X-rays from helium-like atoms have natural line widths negligibly small compared to the expected resolution of the Bragg crystals. Electron cyclotron resonance (ECR) devices profit from an additional feature as compared to other sources of X-rays from highly charged ions as the kinetic energy of the ions is on the level of eV only, which for 3 keV X-rays results in a Doppler broadening of only 40 meV [2].

The investigations described here are different from earlier experiments using crystal spectrometers in combination with ECR sources. These mostly aimed at a determination of plasma properties leading to a deeper understanding of the processes governing the physics of such sources [3,4].

The work described here plays a decisive role in the course of an ongoing experiment at PSI [1,5], which heavily relies on a well determined response function of the crystal spectrometer.

## 2. EXPERIMENTAL SET-UP

The experiment as depicted in figure 1 can be subdivided into three parts:

1. The ECR ion trap (ECRIT) device itself (figure 2) consists out of a superconducting split coil magnet which together with special iron inserts provides the mirror field configuration, an AECR-U [6] style hexapole and a 6.4 Ghz power regulated microwave emitter. The mirror field parameters provide one of the highest mirror ratios for ECR sources with values of 4.3 of over the length of the plasma chamber. The hexapole is cooled at the front pieces and on the inner radius by a forced flow of demineralised water. The plasma chamber is formed by a 0.4 mm thick stainless steel tube of inner diameter of 85 mm and a length of 265 mm axially limited by copper insertions. At the position of the hexapole gap the stainless steel tube is perforated by a series of diameter 2.5 mm holes allowing for radial pumping in addition to axial pumping. An extraction voltage of 2 kV had been routinely applied with the current measured serving as a parameter for a stable operation. A reference pressure (without plasma) of 1.7 $10^{-7}$ mbar was achieved. Gas filling was supplied radially through the gaps in open structure hexapole. The gas composition was routinely surveyed with a quadrupole mass spectrometer. With the exception of the hexapole all pieces had been built at PSI or were available there.

* E-mail: leopold.simons@psi.ch

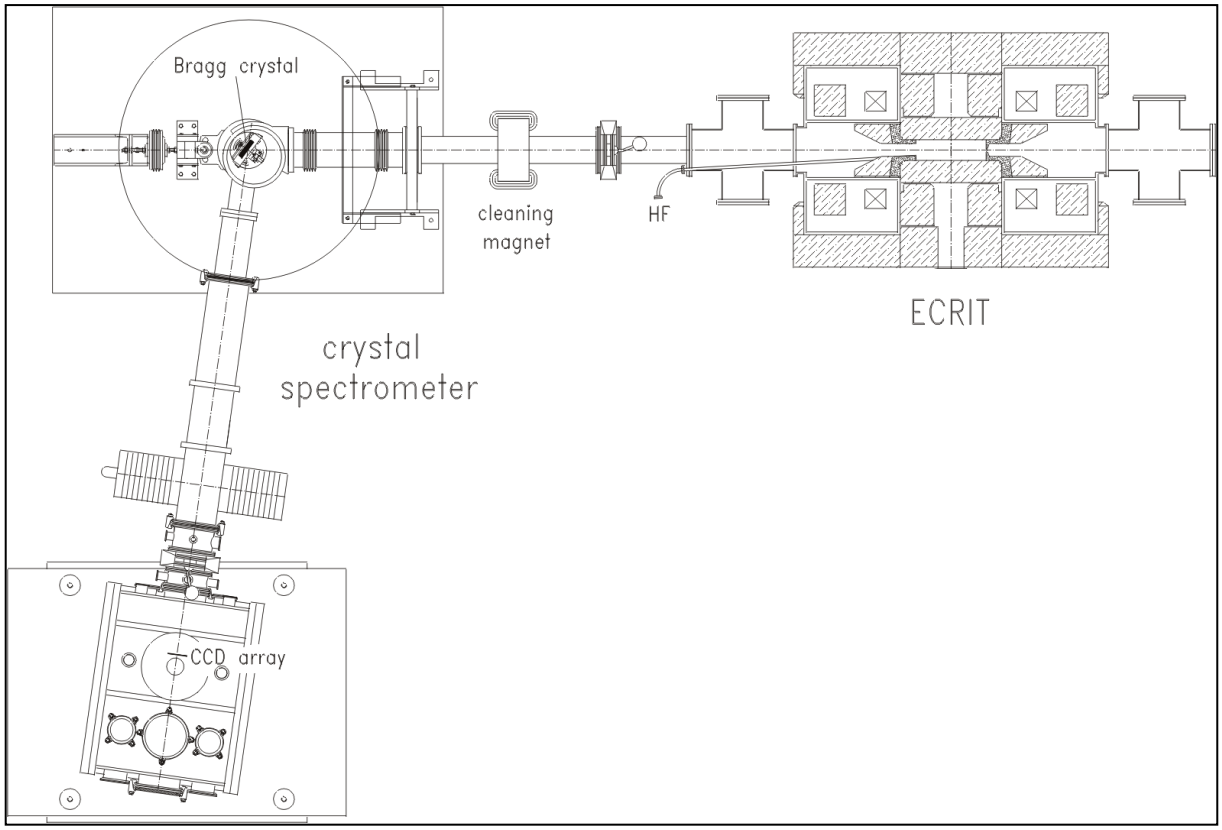


Figure 1. Set-up of the experiment.

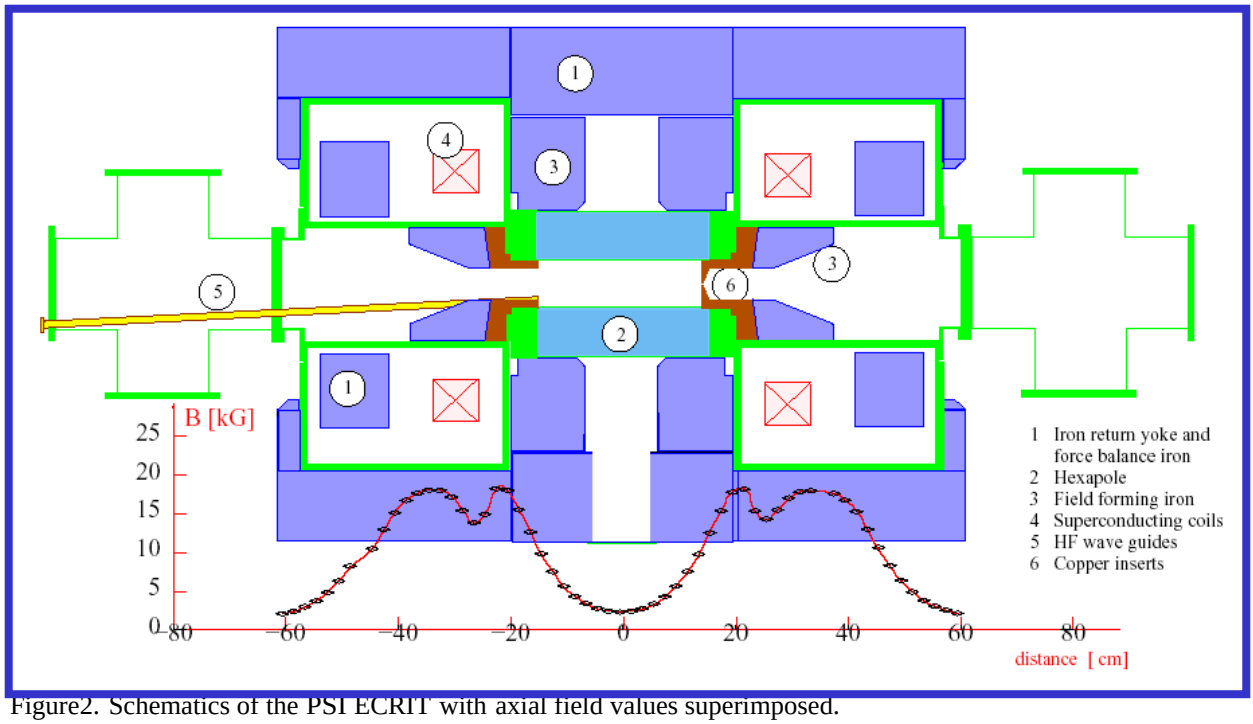


Figure2. Schematics of the PSI ECRIT with axial field values superimposed.

2. A Bragg crystal spectrometer of reflection type (Johann configuration) was installed at a distance of 2330 mm from the center of the ECRIT [1]. A silicon [111] and a quartz [10-1] crystal were subject of the investigation The crystals are circular plates with a diameter of 100mm and a thickness of 0.3 or 0.2mm,

respectively. They were spherically bent with a curvature radius of 2985.4 mm. It was the goal to use the M1 transition of helium-like argon with an energy of 3104 eV and a lifetime of 0.21µs. The corresponding Bragg angles had values of 36.7 degree for the quartz and 39.6 degree for the silicon crystal, respectively. The expected resolutions as calculated with the XOP code [7] are 22'' and 23'' which corresponds to an energy resolution of about 444 meV (quartz) or 418 meV (silicon). The calculated focal distance of the plasma source from the crystal is 1784mm (quartz) and 1903mm (silicon) indicating a not optimal set-up with the plasma being placed outside the Rowland circle. The focal position of the CCD detector could be changed over a distance of 86 mm only implying the X-rays of the lower ionization degrees below 12+ not being properly localized. The angular range covered allowed the different ionization levels up to 16+ to be observed.

3. A CCD pixel detector with a pixel size 40 µm x 40 µm and an energy resolution of 140 eV at 3 keV was used to detect the Bragg reflected X-rays [8]. The detector consisted out of six chips with a total height of 72 mm and a width of 48 mm. The granularity of the detector was decisive in discriminating charged particle events against X-rays possessing different topologies. For an optimized plasma source a drastic increase of energetic electrons was discovered which required the use of a cleaning magnet installed at a distance of one meter in front of the crystal into the direction of the plasma. The CCD chips and the following electronics had to protected against light as well as HF stray power by a 30 µm thick Beryllium window installed in the vacuum tube in front of the CCD.

## 3. PERFORMED EXPERIMENTS

In a first step with low HF power and minimum field values around 1.4 kG the proper working of the whole set-up was checked with X-rays of low ionization degree. In consequence the HF power was gradually increased and with the Bragg angles set to the proper values for a simultaneous observation of the well separable X-rays from both $Ar^{10+}$ and $Ar^{11+}$ ( Figure 3) an optimum for the HF power was found at about 450W. The turn-around time from introducing a change of parameters to the evaluation of a measurement was about one minute. Going to Bragg angles valid for higher ionization degrees the strength of the mirror field as well as the argon pressure were optimized for a maximum intensity of X-rays from highly ionized atoms. In addition a gas mixture $Ar/O_2$ with a mixing ratio of 1:9 was found to be necessary to achieve this goal. The working pressure was 1.4 $10^{-6}$ mbar. In a total tuning time of 10 hours the M1 transition $^3S_1$-$^1S_0$ at 3104 eV as well as the E1 transition $^1P_1$-$^1S_0$ at 3140 eV of $Ar^{16+}$ could be observed (Figure 4). The typical illumination time of the CCD chips of 1 min before readout resulted in a high probability of double hits per pixel even in the M1 peak. As a consequence the highest peaks in the spectra for medium charge states show saturation effects. In order to reduce the intensity and especially in order to improve the peak/background ratio an aluminum collimator was inserted at a distance of 185 mm from the center of the plasma. It left a free hole with the dimensions 16mm(h) x 10mm(v). The optimum value for the HF power was re-established as well as the values of the field strength.

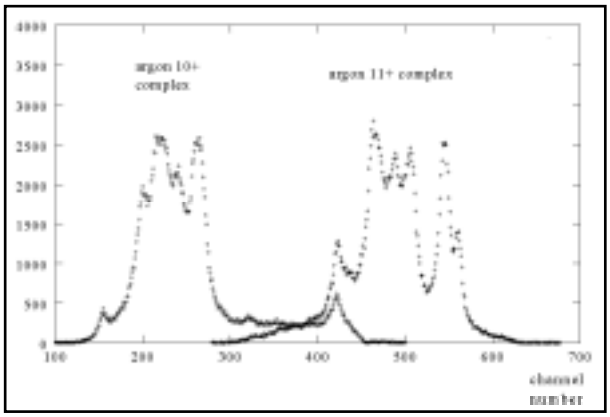


Figure 3: The $Ar^{10+}$ and $Ar^{11+}$ complexes as obtained after optimization. Two spectra for two different settings of the crystal spectrometer are superimposed. The most prominent peaks show saturation effects.

In the subsequent investigations of the Bragg crystals the response function was determined for different openings of the crystal surface. Also the sharpness of the focus was measured as a function of the distance of the CCD detector from the crystal. For a centered circular opening with a diameter of 40mm the theoretical resolution was found for both crystals. The nominal configuration during experiments with exotic excludes the crystal surface at a horizontal distance of ±30mm from the center. For this configuration a worsening by about 20% was obtained for both crystals.

## 4. RESULTS

Concerning the operation of the ECRIT it can be stated that a 6.4 Ghz emitter is obviously sufficient to provide a highly intensive source of M1 X-rays from Ar16+ ions in the special hybrid magnetic structure with radial pumping and using the gas mixing technique. After turning the system on it worked in a stable and reproducible way after about one hours warming up time. The observation of the X-rays alone is sufficient for a successful tuning in a short time thus making the M/q analysis of extracted ions superfluous. An extraction voltage was applied, however and the current drawn was measured as an additional indication for a properly working apparatus. No influence of the high voltage on the intensity of the X-rays could be observed for voltages between 0 and 6 kV.

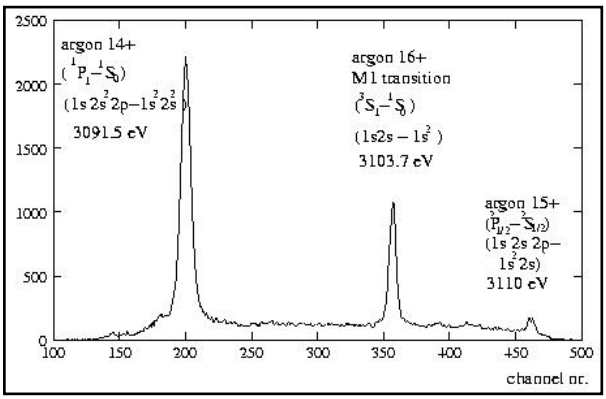


Figure 4: The spectral region of $Ar^{14+}$, $Ar^{16+}$ (M1 transition) and $Ar^{15+}$ after optimisation.

## 5. CONCLUSION AND OUTLOOK

The characterization of two crystals could be performed in about ten hours each. This is in contrast to a time of about two weeks of continuous measurement needed for a characterization with exotic atoms. The use of an ECR device as a source for X-rays is also preferable compared to a synchrotron light source as the whole crystal is illuminated fully thus establishing similar conditions as in an experiment with exotic atoms X-rays.

In future it is planned to improve on the peak/background ratio by insertion of a proper slit of tapered material with a hole of 1mm(v) x 50mm(h). A two frequency heating (6.4+10.2) Ghz is foreseen as well as an insertion of an $Al_2O_3$ coated plasma chamber and a small-size, disk-shape biased electrode. In addition the achievable pressure will be optimized in reducing the surface of the iron insertion pieces drastically. As a first goal it is planned to observe hydrogen-like argon and to extent the production of X-rays to chlorine (in the form of $ClH_4$) and sulphur ($H_2S$). Additionally also a thorough investigation of X-ray intensities as a function of its radial origin inside the plasma is easily possible with the special crystal spectrometer set-up.

As an extension of the present investigation it is planned to measure the Lamb shift in hydrogen-like krypton with a double-flat crystal spectrometer.

## ACKNOWLEDGEMENTS

The suggestions and the help of D. Hitz and K. Stiebing in the preparatory phase of the experiment are warmly acknowledged. We also thank H. Reist for giving us the 6.4 GHz emitter as a free gift.

## REFERENCES

[1] S. Biri, L. Simons, D. Hitz, Rev. Sci. Instr. **71** (2000) 1116.

[2] C. Bernard, PhD thesis, Université Claude Bernard, Lyon, 1996.

[3] G. Douysset et al., Phys. Rev. **E61** (2000) 3015.

[4] P. Grübling et al., Rev. Sci. Instr. **69** (1998) 1367.

[5] http://pihydrogen.web.psi.ch

[6] Z. Q. Xie and C. M. Lyneis, Proc. 13th Int. Workshop on ECRIS, College Station, TX, USA, 1997. Pp. 16-21.

[7] M Sanchez det Rio and R.J. Dejus. "XOP: Recent developments" SPIE proceedings (1998) 3448.

[8] N. Nelms et al., Nucl. Instr. Methods **A484,** (2002) 419.