Performance of the New Nuclear Microprobe SNAKE

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The nuclear microprobe SNAKE [1] (**S**uperconducting **N**anoscope for **A**pplied (**K**ern-) nuclear physics **E**xperiments) is a new dedicated instrument at the Munich tandem accelerator and has gone into routine operation in 2001. SNAKE is capable of focussing protons as well as heavy ions to spot sizes of 1 micron diameter and below. It is an unique tool for applied interdisciplinary research, by materials analysis and by micro- and nanoscale modifications of samples. One highlight of this system is a three dimensional hydrogen analysis with micron resolution and a sensitivity in the ppm range [2]. Another interesting application is the investigation of the dynamics of repair processes in living cells.Therefore double strang breaks are introduced by microscopically aimed single ion irradiation of cells.

SNAKE is set up at the 0° beamline of the 15 MV tandem accelerator (fig. 1). It consists of a two stage ionoptical demagnification, starting behind the analysing magnet. A precision slit system has been developed for providing the object and defining the divergence of the ion beam [3]. The first stage of the imaging system is performed by an standard magnetic quadrupole doublet lens, whereas the second and main part is carried out by a superconducting multipole lens [4,5]. The focussed ion beam is scanned laterally over the sample in the target chamber via an electric or a magnetic deflector. The reaction products - induced by the projectile in the target - can be measured with several different detectors simultaneously. By correlating the events with the actual position of the beam, a two dimensional image containing a special information of the sample can be generated.

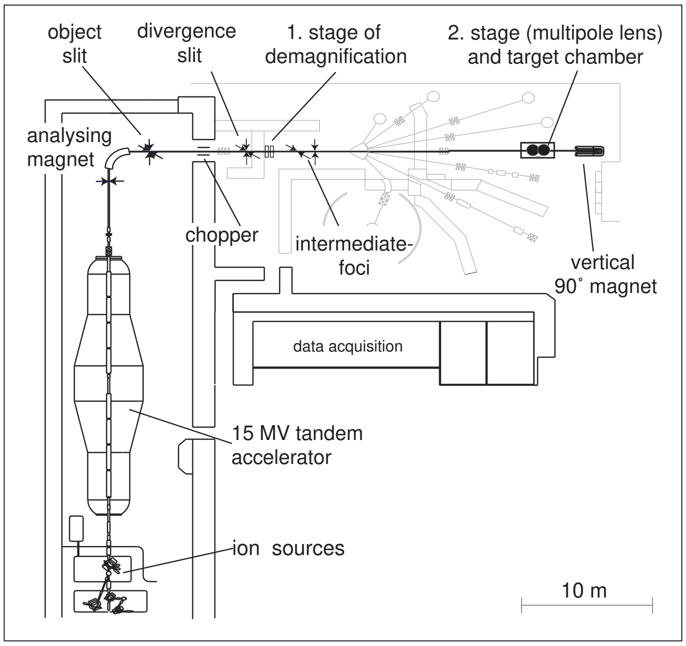

Fig. 1: Setup of the nuclear microprobe at the Munich tandem accelerator. The precision microslits are indicated with arrows. The experiments take place in the target chamber situated in the 0° beam line of hall 1

The first beamline experiments for the characterisation of the microprobe have been carried out with a 90 MeV sulfur beam (mass energy product 45 MeV·u). During the focussing procedure the scintillation of an CsI-crystal induced by the ion beam is viewed via an optical microscope [6]. This enables to correct the imaging system from parasitic aberrations. Fig. 2 a shows a series of profiles from a slightly underfocussed beam. The first order aberration is a sextupole error, showing up in the tilted vertical sidewalls of the beam. This aberration can be influenced by applying an external current to the superconducting correction loops of the focussing lens. It is possible to correct the vertical and horizontal beam shape separately (fig. 2 b,c). The best result is achieved with and current of 200 mA in loop 1 and 70 mA in loop 2 (fig. 2 d). The remaining curved shape represents the spherical aberration. Due to an intrinsic multipole correction field of the lens, this aberration is successfully kept at a low level. If all correction are applied and the beam is focussed a tiny spot - the visible size is limited by the optical investigation - can be seen (fig. 2 e).

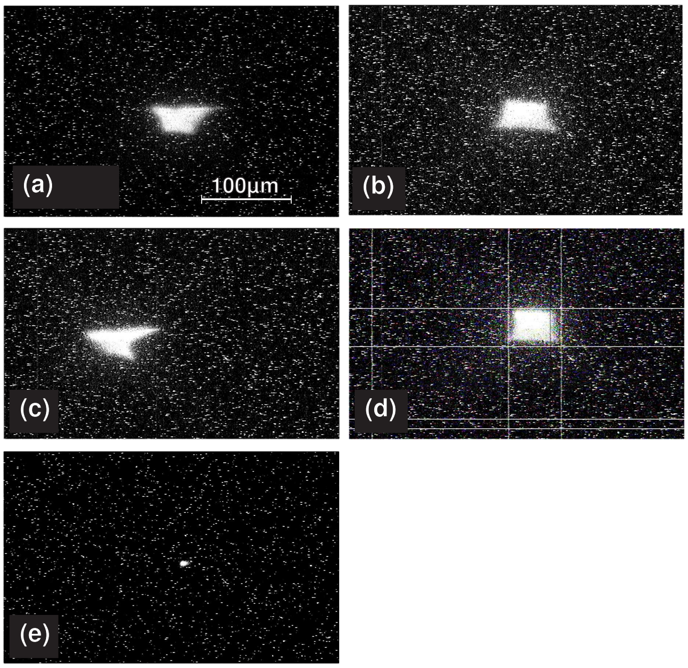

Fig. 2: Scintillation light of the ion beam induced in a CsI-crystal. The scale is equal in all pictures. (a) slightly underfocused ion beam with no corrections, (b) external current in loop 1, (c) external current in loop 2, (d) corrected with currents in both loops, (e) focussed down

The lateral resolution of the whole system can be tested by scanning the beam over a horizontal and vertical grid structure. There are two different modes in which nuclear microprobes are operated. They are characterised by the ion beam current at the target. The high current mode (I = 10 pA to 1 nA) is mostly used for elemental analysis of specimen via methods like Particle Induced X-ray or Gamma-ray Emission (PIXE, PIGE), Rutherford BackScattering (RBS) and Nuclear Reaction Analysis (NRA). In the "pencil beam" mode only a few 1000 atoms per second and less are delivered to the sample. This mode is mainly applied in irradiation and modification experiments as well as in Scanning Transmission Ion Microscopy (STIM).

The resolution of SNAKE was determined in both modi separately. The achieved lateral resolution in the elemental analysis mode at the maximum acceptance of the final focussing lens is 1.63 ± 0.10 μm in x-direction and 1.19 ± 0.06 μm in y-direction (fig. 3). It was measured by counting the projectiles in an annular silicon detector, after elastic scattering with the Au-nuclei under large angles ($30 - 60°$). In the pencil-beam mode a resolution of 1.27 ± 0.05 μm in x- and 0.320 ± 0.038 μm in y-direction is achieved (fig. 4). This measurement was performed by counting the transmitted ions in a pin-diode situated in the focal plane of the 90° analysing magnet [7].

These values demonstrate clearly, that SNAKE is capable of performing standard analyses with micron resolution. Further time resolved measurements showed that parasitic effects, originating not from the superconducting multipole lens, have a strong influence on the lateral resolution [8]. It has been proven that a 50 Hz oszillation of the ion beam deteriorates the resolution significantly, especially in x-direction. The source is not identified up to now. Additional a slow mechanical movement of the focussing lens relative to the investigated sample was observed. This effect limits the resolution in longer lasting measurements to about 1 μm. If all parasitic effects are eliminated or corrected, calculations show that submicron resolutions are possible at almost full acceptance.

References

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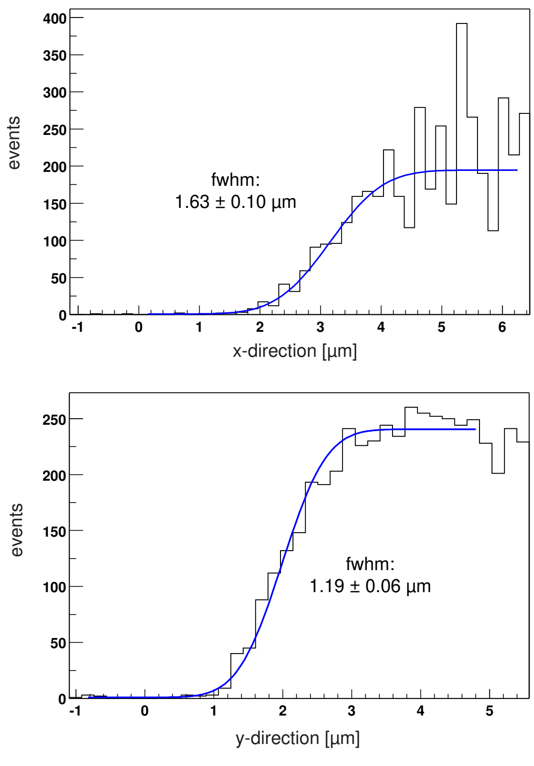

Fig. 3: Horizontal and vertical line scan of the 90 MeV sulfur beam at full angular acceptance over the edge of a gold grid. The fwhm of the fitted errorfunction represents the achieved lateral resoulution in x- and y-direction

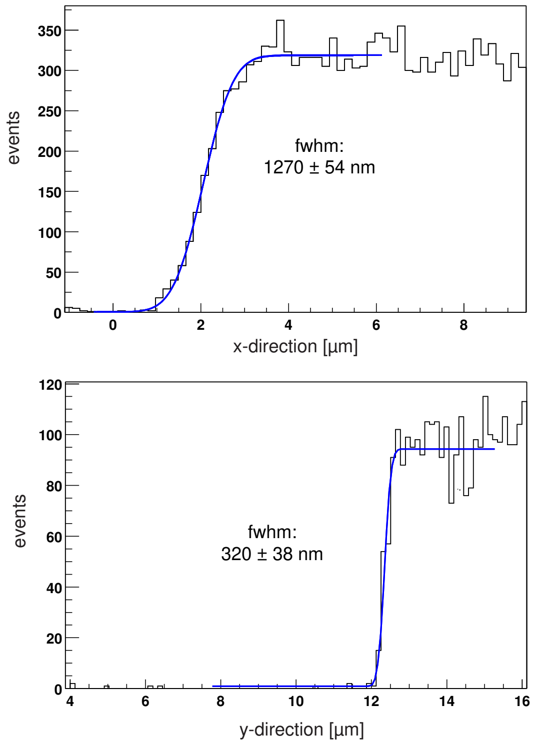

Fig. 4: Horizontal and vertical line scan of the 90 MeV sulfur beam in the pencil beam mode. The fwhm of the fitted errorfunction represents the achieved lateral resoulution in x- and y-direction