SAND2011-2779C

The new Sandia Light Ion Microbeam†

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Abstract

The Ion Beam Laboratory of Sandia National Laboratories (SNL) was recently relocated into a brand new building. The 6 MV High Voltage Engineering (HVE) tandem accelerator (hosting the heavy ion microbeam and several analytical beam lines) and the 350 kV HVE implanter with a nanobeam were moved to the new building. There were several new pieces of equipment acquired associated with the move, among them a new high brightness 3 MV Pelletron accelerator, a high resolution light ion microbeam, a nanoimplanter, and a Transmission Electron Microscope (TEM) connected to the tandem accelerator. In this paper this new facility will be described, and initial results of the new microbeam will be presented.

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†Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Introduction

Sandia National Laboratories' (SNL) Ion Beam Laboratory (IBL) had been housed in a temporary building for the past 34 years. The laboratory included a 350 kV ion implanter, a 2.5 MV single-ended van de Graaff accelerator, and a 6 MV tandem van de Graaff accelerator with a heavy ion microprobe and a Radiofrequency Quadrupole (RFQ) booster. The IBL had been engaged in a variety of ion beam analysis (IBA) projects and SNL's radiation effects program depended on the heavy ion microprobe. As the IBL developed new projects, a need arose for more space for new beam lines, which was not possible in the available space. In addition, the building was not up to the current building codes (asbestos, etc.) and we experienced repeated utility failures. In 2001 a study of the IBL by independent experts recognized that a renovation would not solve the problems and their report recommended that we move the IBL into a new building. In December 2008 the budget was approved and the construction work started. In December 2009 the building was partially finished to be ready to start moving equipment. The new building has 1850 m^2 laboratory space plus 650 m^2 office space, shown in Figure 1, compared to the total space of 1300 m^2 of the old building. One of the target rooms has 76 cm thick shield walls that allow to perform high radiation experiments. All three accelerators have beam lines going into this room. The 350 kV implanter and the 6 MV tandem van de Graaff were moved to the new building by the end of March 2010. The first ion beam from the implanter was produced in February 2010, and the first ion beam from the tandem van de Graaff was delivered in July 2010. The project will be completed by July 2011 and at that time the IBL will become fully operational.

In the frame of the new IBL project we were able to replace the really old 2.5 MV single-ended van de Graaff accelerator with a new National Electrostatic Corporation (NEC) high-brightness 3 MV Pelletron machine. In addition, we acquired an Oxford Microbeams Ltd. microprobe specifically designed for this machine, which will be designated as the SNL light ion microprobe. There were two other additions to the IBL: a 100 kV "nanoimplanter" by A&D, which is a special Focused Ion Beam (FIB) system and a Transmission Electron Microscope (TEM) connected to the

6 MV tandem van de Graaff. In this paper we will review the specification of the new microbeam and present some very initial results.

The Pelletron accelerator and the light ion microprobe

The aging 2.5 MeV van de Graaff of the IBL was replaced by a 3UH-2 Pelletron machine made by NEC. This machine is a high brightness, fully computer controlled accelerator, ideal for a light ion nuclear microprobe. During the installation of the system, the accelerator met and even exceeded of all requirements. The specified and actual parameters are shown in Table 1.

Parameter	Unit	Specification	Actual
Terminal voltage	MV	0.3-3.0	0.29-3.3
TV stability (1 hour)	V	<± 100	± 25
TV Ripple	V	<± 100	± 50
H current at 3 MV	µA	80	85
He current at 3 MV	µA	40	53
H current at 0.3 MV	µA	40	50
He current at 0.3 MV	µA	20	38
Brightness	$A/(m^2rad^2eV)$	10	15

Table 1

The new light ion microprobe is an OM-150 triplet from Oxford Microbeams Ltd. This system is a triplet lens configuration, which when operated in the coupled CDC configuration (converging, diverging, converging, with the first two lenses having the same excitation) exhibits high demagnifications in both the X and Y planes. This system is capable of sub-micron focusing with large acceptances. With the working distance being 95 mm the magnifications are M_x=120 and M_y=30. The lens system is driven by two OM-52e power supplies that are low-voltage high current power supplies with high short- and long- term current stability specifically designed to power the OM series quadrupole lenses. The output voltage is 0-3 V with 0-100 A constant current. The maximum current ripple is 5 mA and it has a current stability of less than 5 ppm. The power supplies can be controlled either manually or by a computer through the digital control interface. The microbeam uses Fisher slits instead of the usual Oxford Microbeam Ltd.

slits, this is the first time these slits are used in this configuration. The object slits are 3.2 RC V-slits with a maximum opening of 150 µm and can be completely closed with 0.1 µm steps. The aperture slit is a 1.4 RCI slit system, which consist of 4 independently movable, insulated jaws. Each can be moved over about 22 mm with 3 µm steps. Insulated tantalum electrodes make it possible to measure the current on each jaw independently. Since the V-slits can have less than 5 W thermal load another air-cooled model 1.4 RCI slit system was placed upstream from the V-slits to protect them. During the initial operation we found it necessary to put a water-cooled aperture (rated at 1 kW) upstream from the protection slits. All slits can be remotely controlled from NIM modules. The beam scanning is provided by two sets of OM-25 coils (1 for main scanning and 1 for dog-leg scanning) with an OM1015e scan controller. The power for the scanning coils is provided by two Kepco BOP 100-4LD bipolar current amplifiers. These are specially tuned for inductive loads and have high linearity, low crossover distortion, and low noise. This is the first time Oxford Microbeams Ltd. used these current amplifiers for their system. During the test of the system we found that the eddy currents induced in the lid of the scanning coil housing affected detrimentally the quality of the focused beams. These lids are being replaced with new, aluminum lids.

The vacuum chamber was custom designed and made by Raith Gmbh. They worked together with Oxford Microbeams Ltd. on the design of the whole vacuum system, which is fully automatic and interlocked. The chamber has a high precision xyz stage with a travel range in the x-and y directions (perpendicular to the ion beam) of ± 50 mm. The laser interferometer system of the stage provides a resolution of 5 nm. Parallel to the beam, the z direction has a travel range of -17 to +3 mm, which allows moving the sample surface in focus for a wide range of target thicknesses. In this direction the motion is controlled by rotary encoders with a precision of better than 1 µm. The stage is fully computer controlled by Raith's Escosy software, which allows navigation using GDS II layout maps. The chamber is equipped with a large number of electrical connections since one of the main applications will be testing integrated circuits. The design drawing of the chamber is shown in Figure 3. An OM-40 (JEOL) optical microscope is inserted in the chamber in the path of the ion beam. This microscope has a prism with a whole in it that allows the ion beam pass through it. It makes it possible to optically see the area the ion beam is scanning which makes sample positioning very easy. Unfortunately, it limits the scan size to about 2 mm.

Initial test results

During the installation a test was performed using 2.5 MeV protons. To determine the performance of the microbeam system we used Scanning Transmission Ion Microscopy (STIM) on a grid fabricated by the National University of Singapore in 2 μm nickel. This grid has a sidewall angle of > 89^o, which makes it an ideal calibration and test standard. The dimensions of the grid are shown in Figure 4. The width of the bars in the grid is certified to be 4±0.1 μm. The STIM signal was recoded by a Hamamatsu S1223-01 PIN diode positioned ~10-20^o off axis of the ion beam. The beam current was monitored in a suppressed Faraday cup mounted on a different location on the stage (the stage was moved back and forth between the cup and target from time to time). The microbeam was scanned along a line crossing one of the bars of the calibration grid and a STIM signal was recorded using the Oxford Microbeam Ltd. data acquisition system. The beam's full width at half maximum was extracted by fitting a theoretical profile, which assumed a perfectly rectangular grid, and a Gaussian beam profile.

The microbeam was tested in both low (single ion experiments) and high current (IBA) modes. During the initial part of the test the V-slits were badly damaged from the beam and the test had to be completed using the four-jaw slits that were originally intended as protection slits for the V-slits. This made it difficult to precisely determine the performance of the microbeam in the y direction but did not cause any problem in the x directions. The slits have been repaired since and they are being reinstalled. In high current mode we achieved 900 pA current on the target with a 0.6x1.1 μm^2 beam spot size. A STIM image of the cross of the bars of the calibration target is shown in Figure 5 with the locations of the x and y line scans. The line scans and the theoretical fits are shown in Figure 6. In the low current mode we achieved 9 pA with 250 nm beam diameter in the x direction. The x line scan and the theoretical fit is shown in Figure 7.

Future plans

In the near future a Rontec SSD-12 Si drift detector will be installed in the chamber. This detector has 12-segments with a hole in the center to allow the ion beam to go through, actively cooled and has a 0.54 str solid angle at 6 mm from the sample or 1.09 str at 4 mm. The Raith chamber is designed that the OM-40 microscope can be extracted and the SDD12 can be inserted from the bottom. The detector was used in the past on the Sandia heavy ion microbeam line (with protons) and its design and performance was published in [3]. The data acquisition/beam control system (which is on loan from Oxford Ltd. currently) will be replaced with an in house developed system based on the FastCom MPA3 mutiparameter system. The new system will be able to perform 6-channel IBIC, TRIBIC, Single Event Upset mapping, and PIXE experiments. The new microbeam will be used among other projects for high spatial resolution IBIC/TRIBIC on modern electronic devices, luminescence studies of Metal-Organic-Framework scintillators, erosion/redepositon studies of wall materials on tokamak tiles, and μPIXE on biological samples.

Acknowledgement

The authors would like to thank Stuart van Deusen (Sandia) and Mark Sundquist (NEC) for the operation of the Pelletron accelerator well after working hours.

References

[1] Scanning 2.0 Pre-Lens Magnetic Scanning System, User Manual, Oxford Microbeams Ltd., Revision 2.0, January, 2011

[2] Raith µBEAM Chamber and Stage System Manual, Raith Gmbh, Dortmund, Germany, November 11, 2010

[3] B.L. Doyle, D.S. Walsh, P.G. Kotula, P. Rossi, T. Schulein, and M. Rhode, in Proc. of 10th international Conference of Particle Induced X-ray Emission and its Analytical Applications PIXE 2004, Portoroz, Slovenia, June 4-8, 2004

Figure captions

Figure 1

The layout of the new Ion Beam Laboratory

Figure 2

Configuration of the OM-150 lens and OM-25 scanning system [1]

Figure 3

CAD drawing of the Raith end chamber (a) from the back and (b) from the beam side [2]

Figure 4

SEM picture of the grid used as calibration and test target. It was manufactured by the National University of Singapore in 2 µm nickel with side wall angles >89^{o}. Phoe is curtesy of Geoff Grime, Oxford Microbeams Ltd.

Figure 5

STIM image of a cross of the 4 µm wide bars of the calibration target. The red lines mark the place of the x and y line scans performed to determine the beam diameter.

Figure 6

Line scans in high current mode (900 pA) in the (a) x and (b) y directions and the theoretical fits to them.

Figure 7

Line scan in low current (9 pA) in the x direction and its theoretical fit.

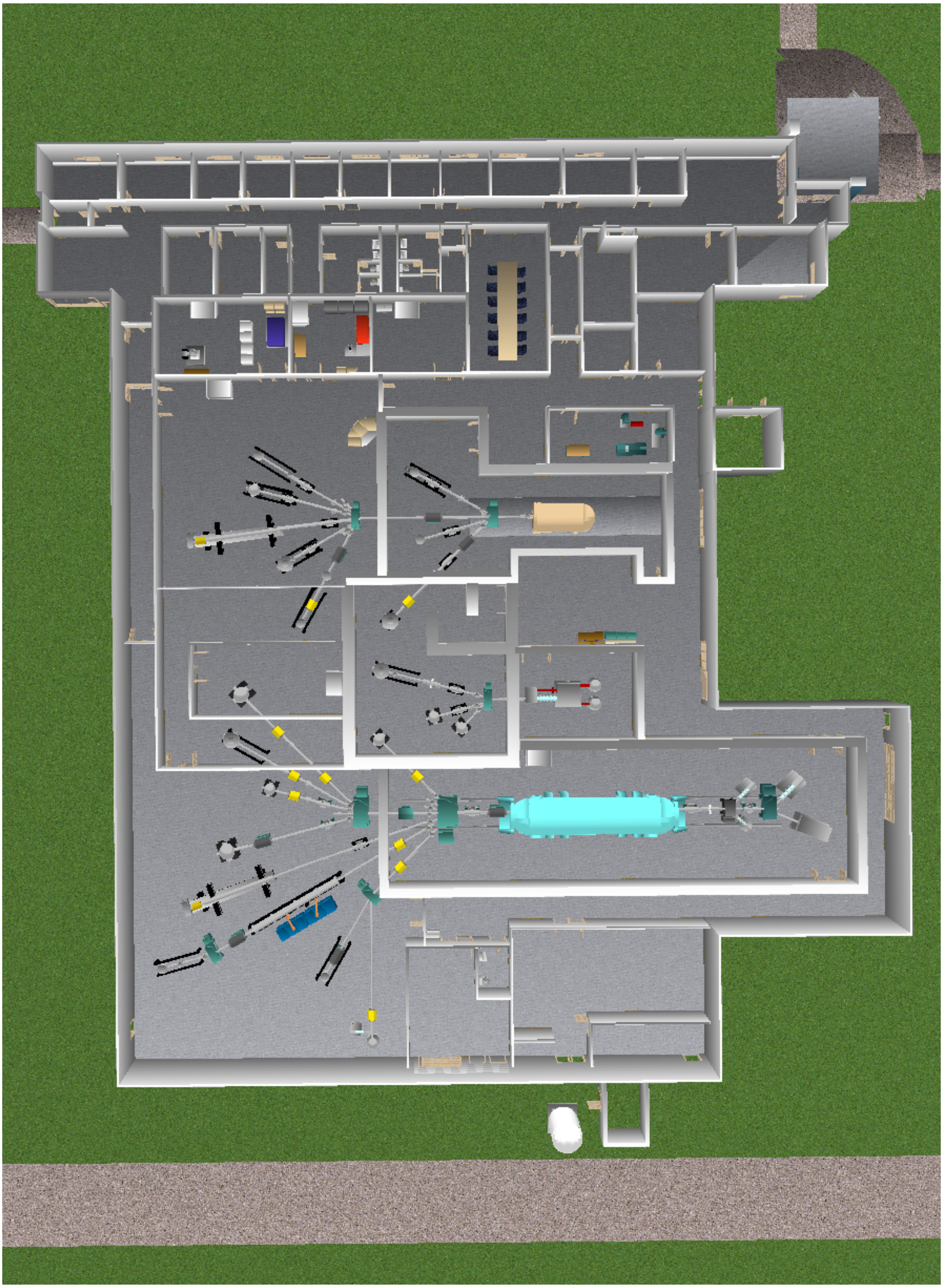


Figure 1

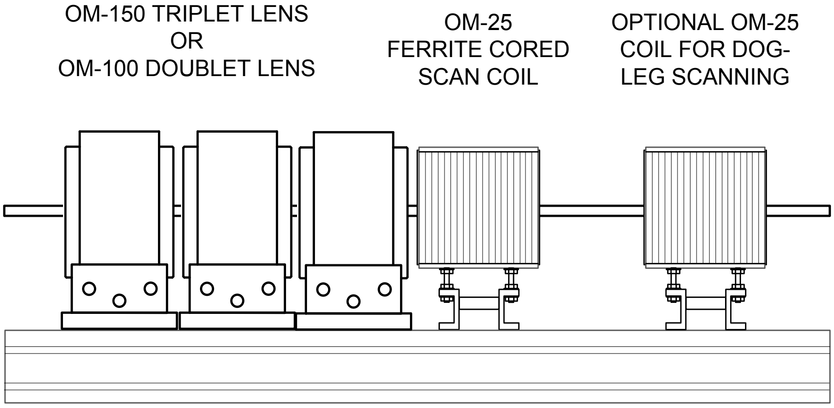

OM-150 TRIPLET LENS
OR
OM-100 DOUBLET LENS
OM-25
FERRITE CORED
SCAN COIL
OPTIONAL OM-25
COIL FOR DOG-
LEG SCANNING

Figure 2

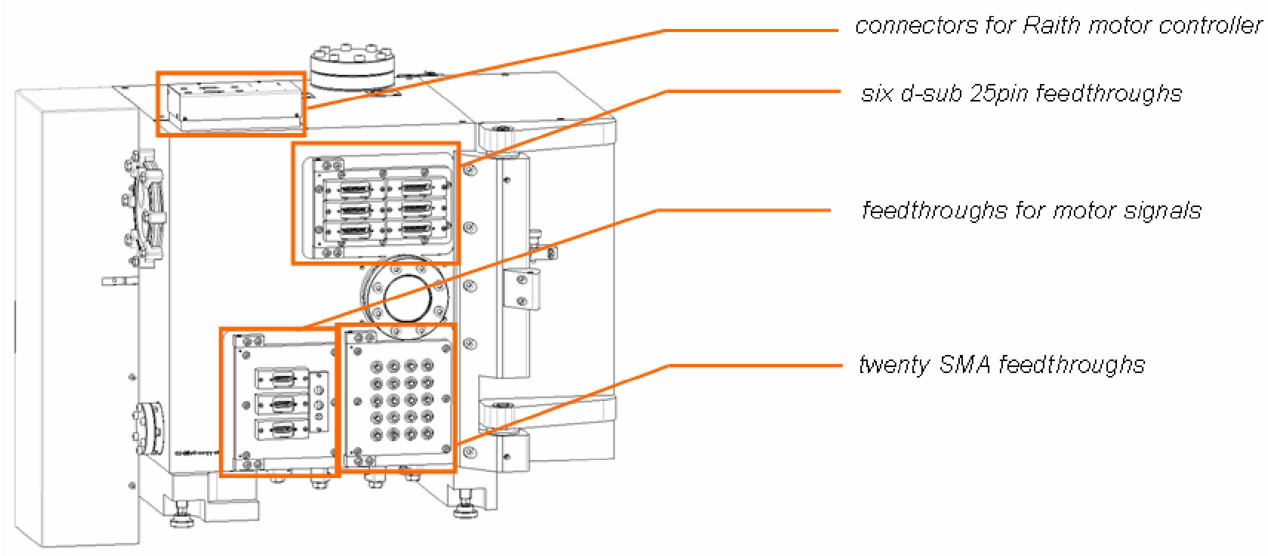


Figure 3a

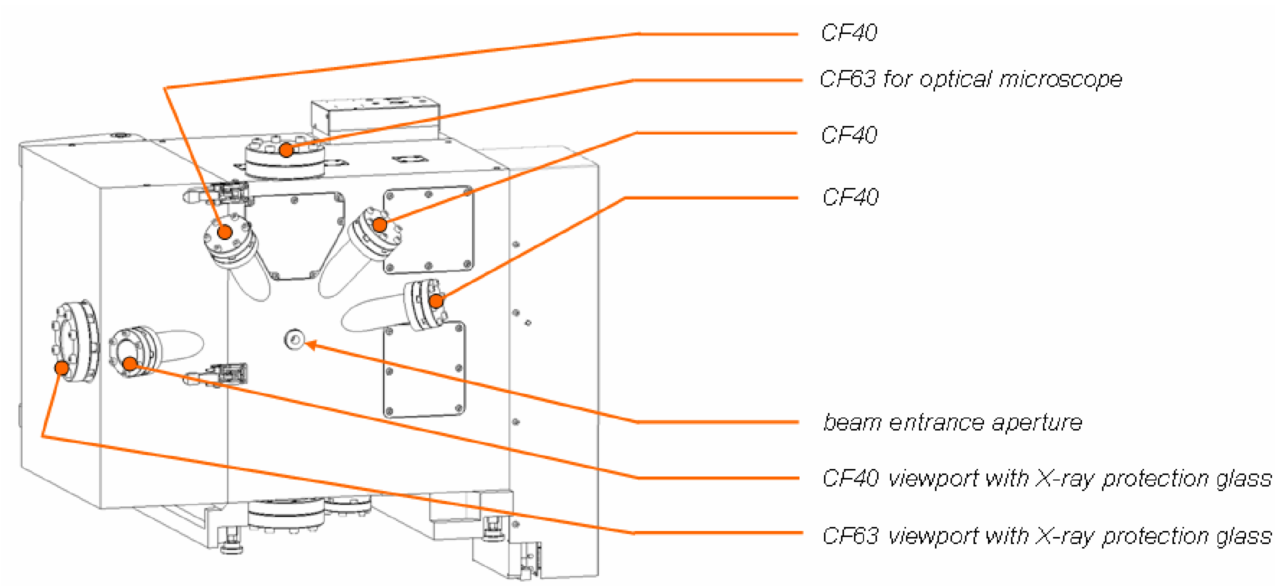


Figure 3b

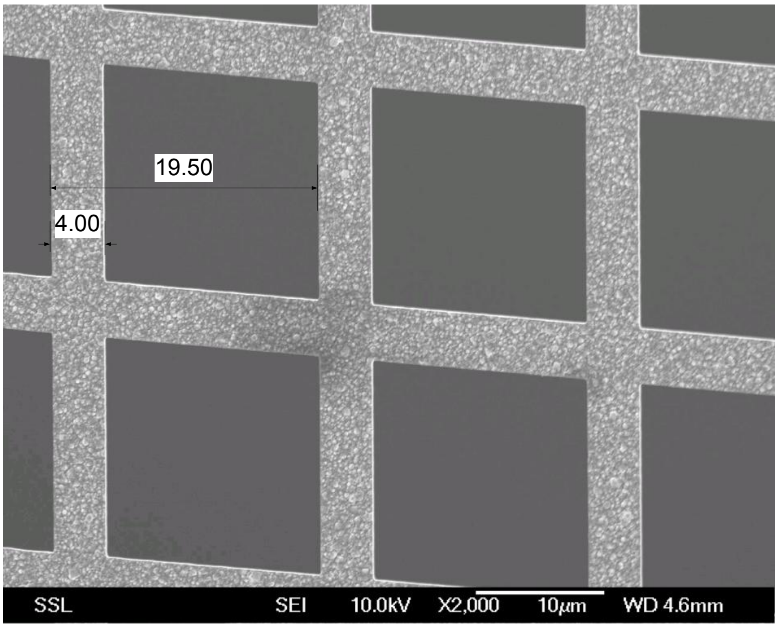


Figure 4

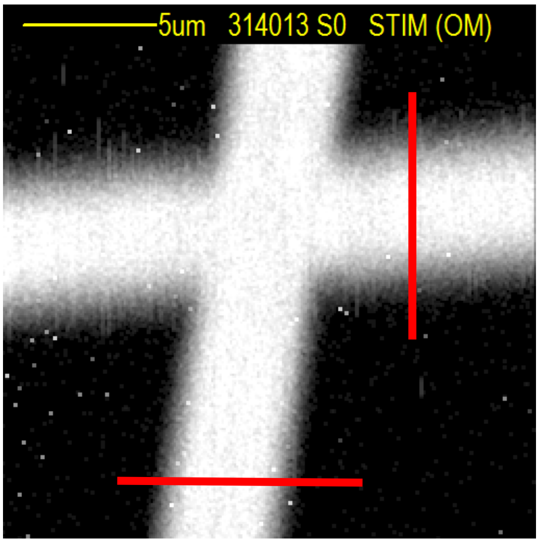


Figure 5

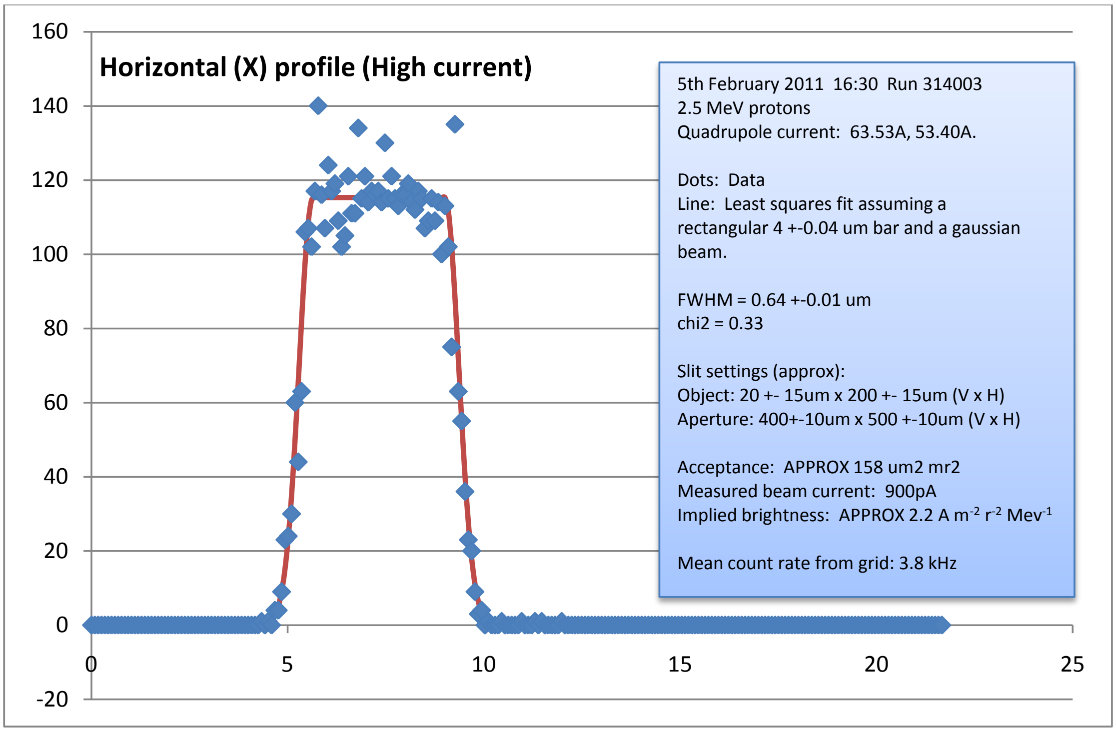


Figure 6a

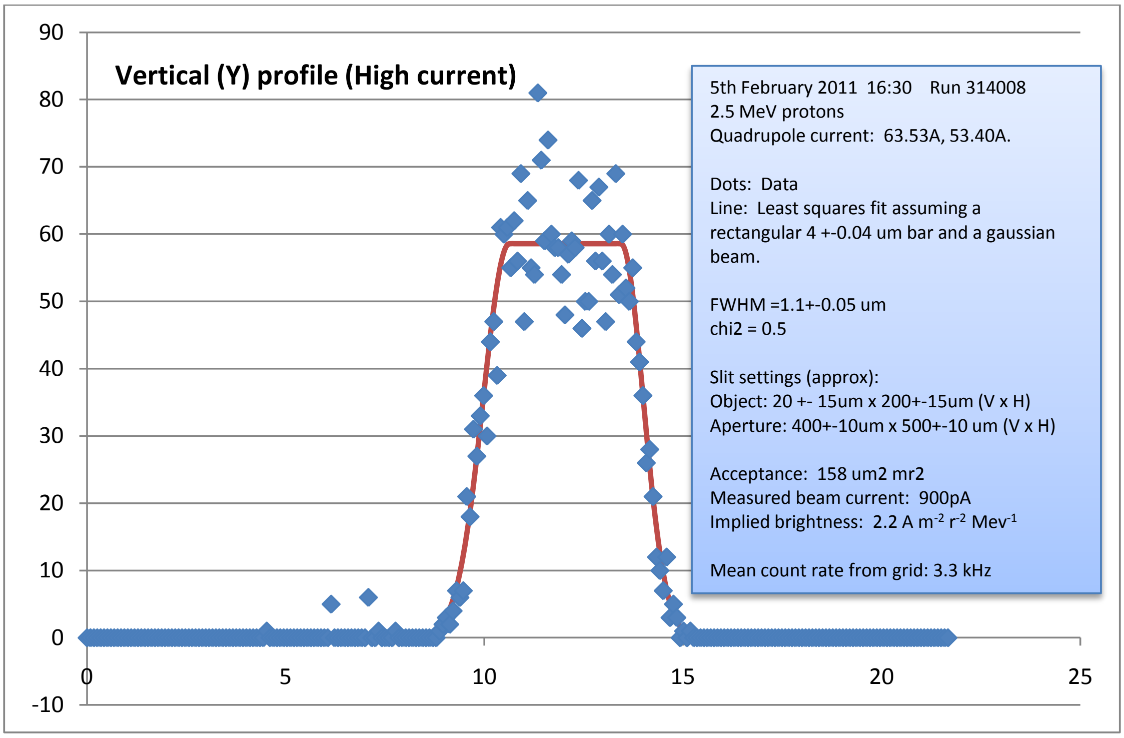
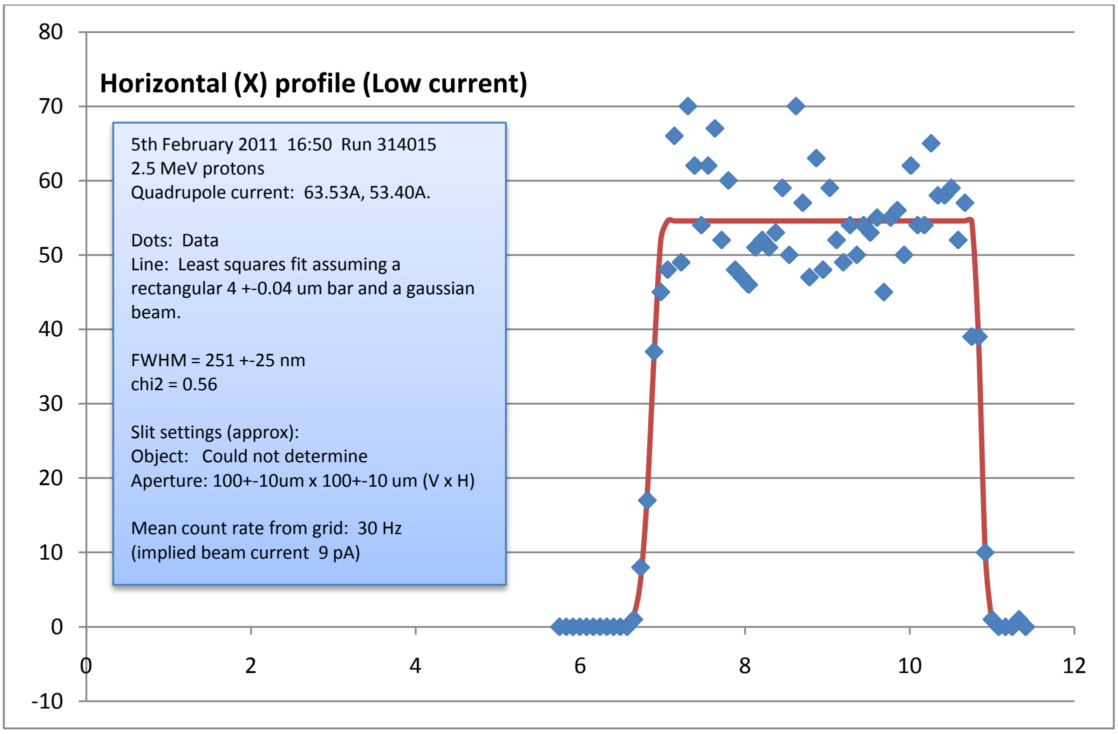


Figure 6b



Horizontal (X) profile (Low current)
5th February 2011 16:50 Run 314015
2.5 MeV protons
Quadrupole current: 63.53A, 53.40A.
Dots: Data
Line: Least squares fit assuming a rectangular 4 +-0.04 um bar and a gaussian beam.
FWHM = 251 +-25 nm
chi2 = 0.56
Slit settings (approx):
Object: Could not determine
Aperture: 100+-10um x 100+-10 um (V x H)
Mean count rate from grid: 30 Hz
(implied beam current 9 pA)
80
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12

Figure 7