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10th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators, DIPAC2011, Hamburg, Germany, May 16th—18th, 2011

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

DIPAC2011, Hamburg, Germany, May 16th - 18th, 2011

First Measurements with the Test Stand for Optical Beam Tomography

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Abstract

A test stand for optical beam tomography was developed. As a new non destructive beam-diagnostic system for high current ion beams, the test stand will be installed behind the chopping system in the Frankfurt Neutron Source (FRANZ) low energy beam transport section. This test stand consists of a rotatable vacuum chamber with a mounted CCD camera. The maximum rotation angle amounts to 270°. In a first phase the optical beam profile measurement and 3D density reconstruction is tested at a time independent 10 keV He beam. The measurements and performance of data processing algorithms are compared with the beam transport simulations. In a later phase the performance with time dependent beams has to be evaluated. In compression mode FRANZ will deliver a 200 mA proton beam at 120 keV with a repetition rate of 250 kHz and a duty cycle of 2.5%. An overview of the first phase results are shown.

Beam induced fluorescence

For low energy ion beams the geometric cross section can be used to estimate photon production.

$$N_{photon} = \frac{\sigma}{4ek_BT} \cdot \frac{r_{lens}^2 \cdot c_{corr}}{r_{dist}^2} \cdot x \cdot p \cdot I \cdot t$$

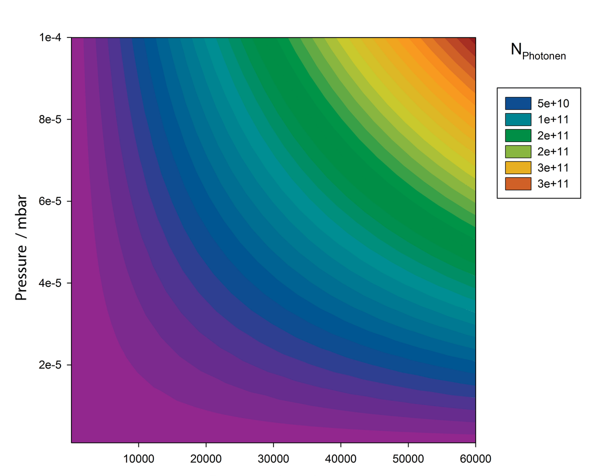


Fig. 1: Theoretical plot of photon production dependent on pressure and time.

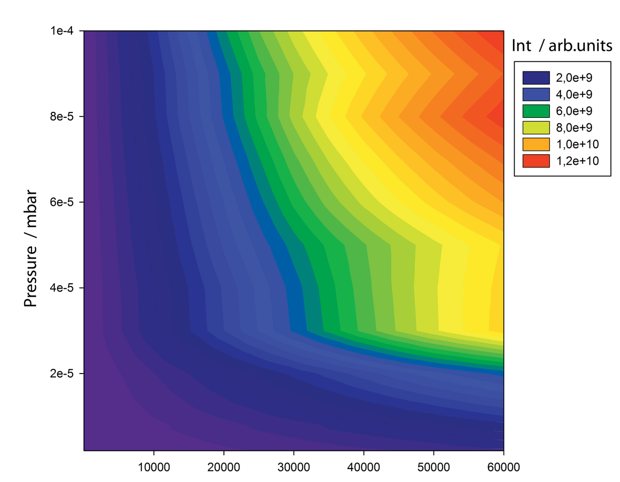


Fig. 2: Measured intensity distribution for N_2 as residual gas.

Image corrections

For proper reconstruction the images need to be preprocessed.

- **Background subtraction**
  For each position and background light situation a background image is needed.
- **Vignetting**
  A correction for nonlinear deformations like natural illumination falloff is needed because photon densities are interpreted as particle densities.
- **Rotational shift**
  Rotational shift can occur due to camera mounting. In order to reconstruct the 2D particle density all positions need to have the same image section angle.
- **Static shift**
  Static shift can occur due to camera mounting. For 2D particle density reconstruction all images need the same centre of rotation.

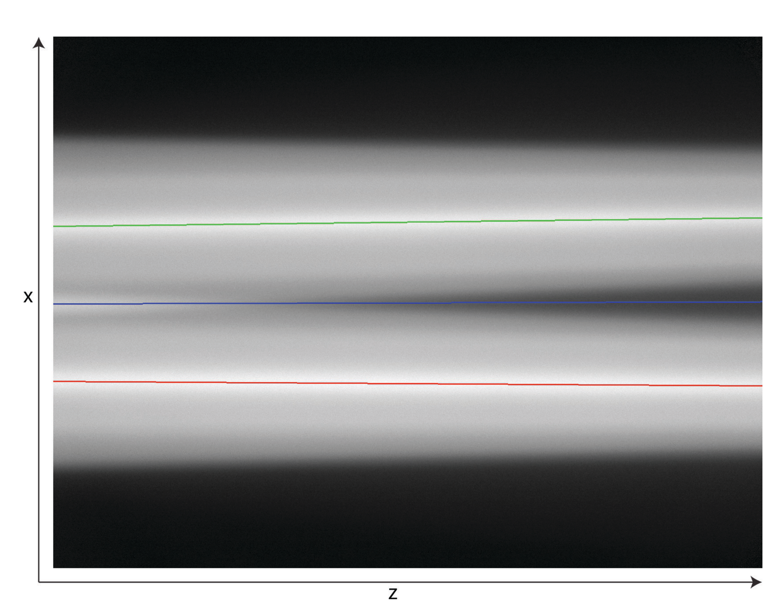


Fig. 3: Plot of beam imaged at 0° (upper) and 180° (lower) beam axes (green, red) and corresponding correction axis (blue) are displayed as an overlay.

Methods for shift correction

- **Centre of mass**
  The reconstruction can be done in the centre of mass system. As a major disadvantage the beam position cannot be reconstructed
- **Basic linear regression**
  The images taken at 0° and 180° contain the same information but from different positions. With linear regression the beam axes at 0° and 180° can be estimated and rotational as well as shift parameters be extracted as shown in Fig. 3.

Outlook

To test system and algorithm performance we plan to use apertures to generate a well-defined beam envelope. In addition we want to use potential barriers to examine the impact of electrons on photon generation and their influence when reconstructing beam luminosity densities. Therefore a residual gas ion spectrometer can be mounted with 90° offset to the camera and map the beam potential.

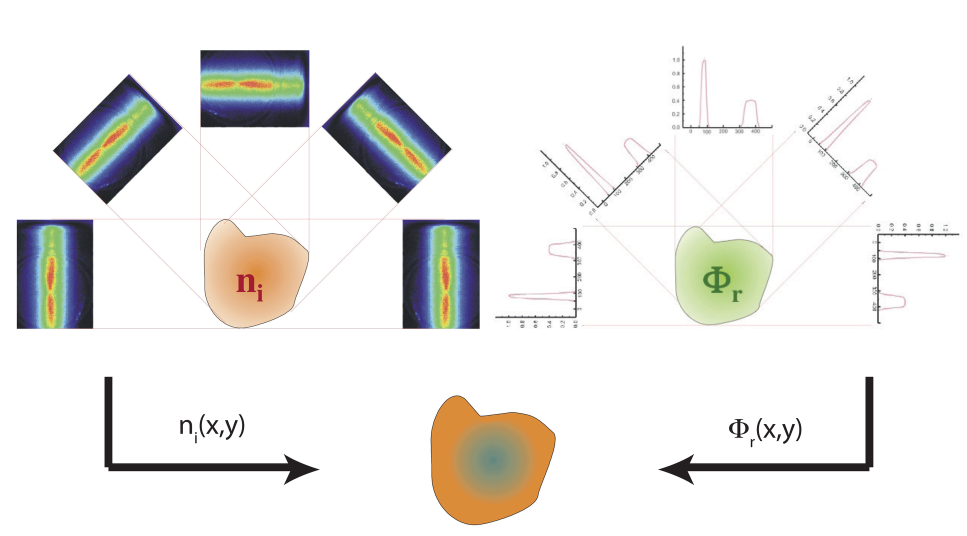
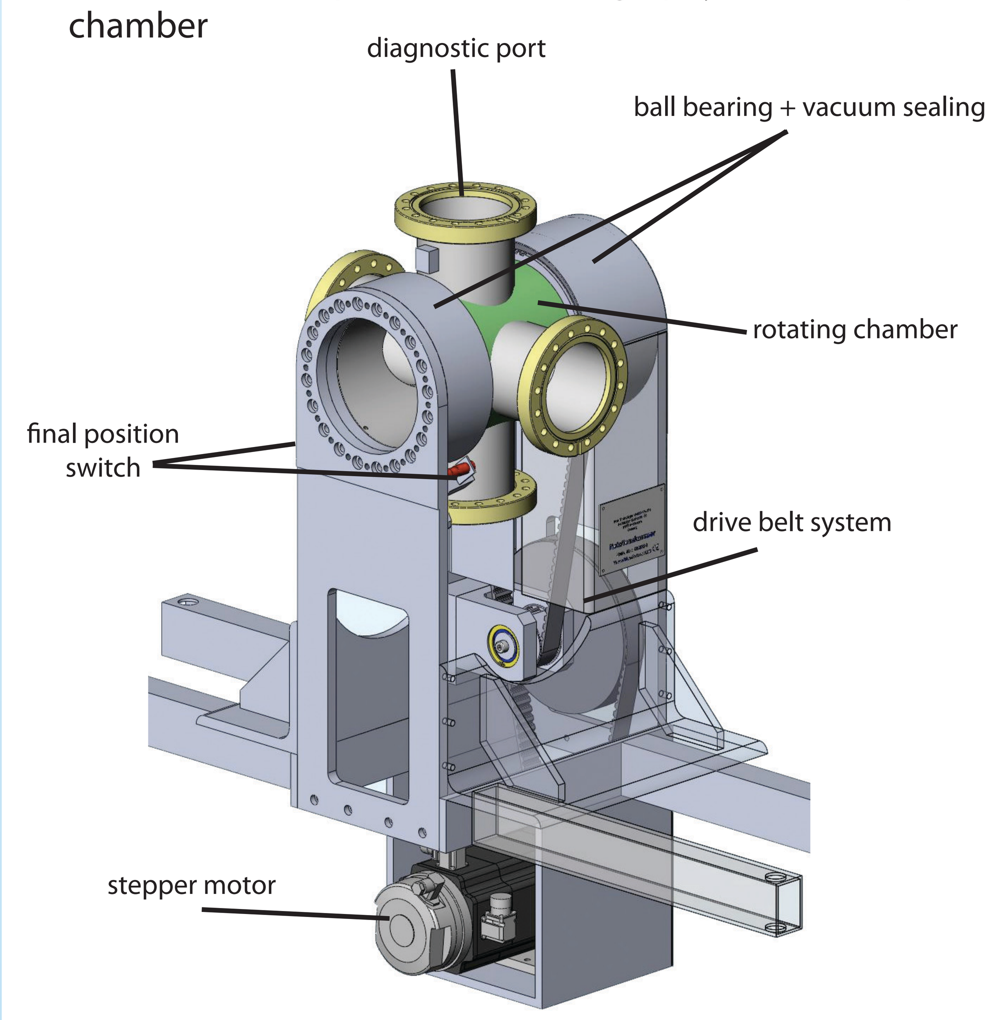


Fig. 4: Particle distribution and beam potential can be reconstructed.

Test stand

A test stand for optical beam tomography was developed. The test stand consists of a rotational vacuum chamber



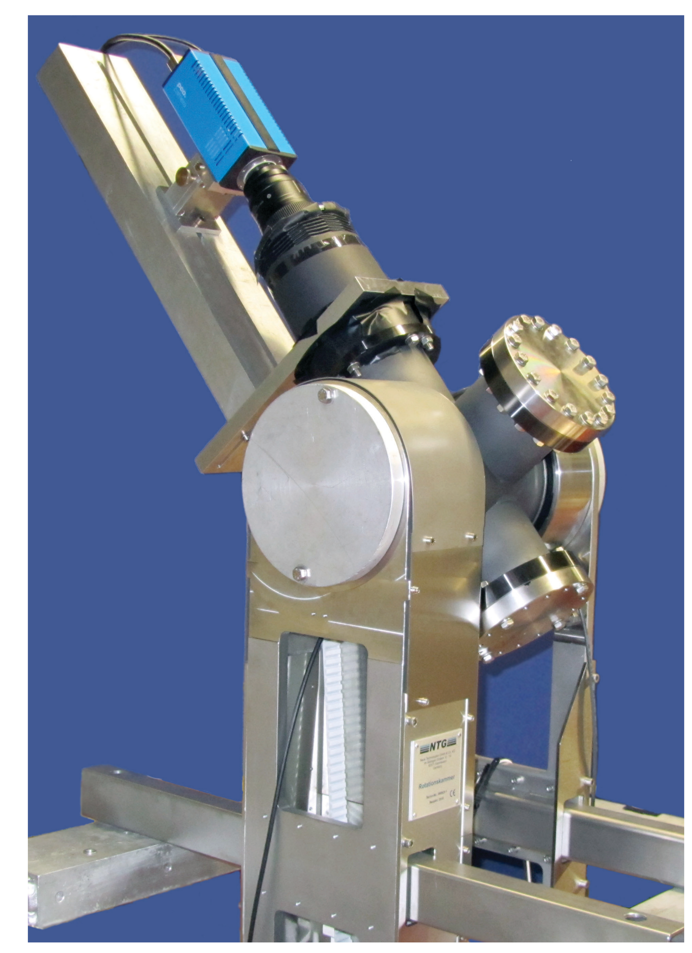


Fig. 5: Actual test stand with mounted camera.

Data

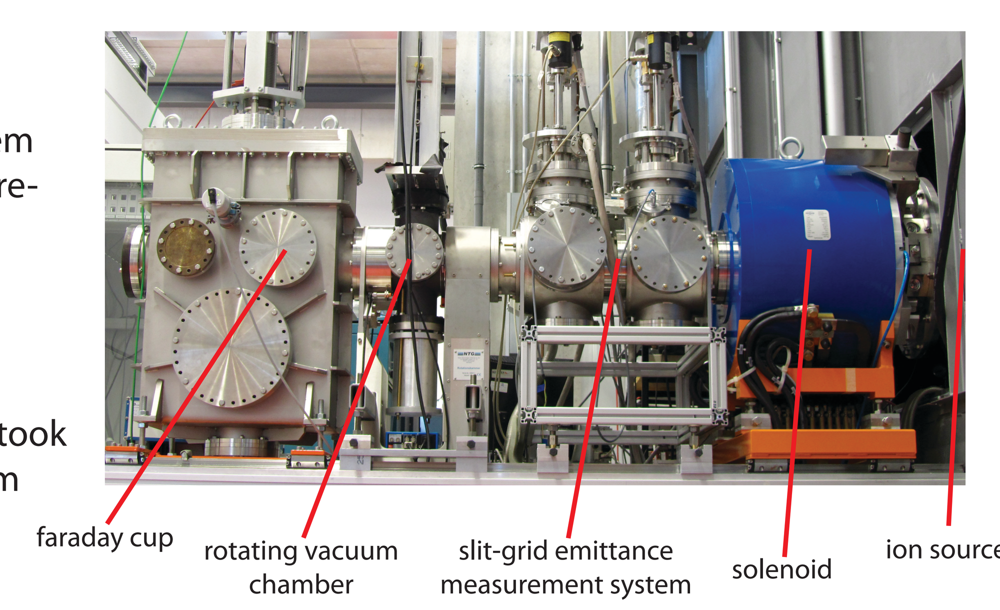
- Magnetic angular sensor with 3600 impulses / turn
- Vacuum tested to $3 \cdot 10^{-8}$ mbar
- Blackened surfaces
- 4 diagnostic ports with DN100CF flanges
- Camera with 1600x1200 pixel @14bit/pixel

Experiment

For a first experiment we set up an elementary test environment.

- 10 keV He ion source
- Solenoid up to 0.66 T
- Slit-grid emittance measurement system for x plane particle distribution measurement
- Rotating vacuum chamber with 270°
- Faraday cup

In a first tomographic measurement we took 181 images from 0° to 180°. The ion beam was focused with 0.21 T resulting in 13 mm beam diameter at the rotating vacuum chamber.



Measurement

For the first measurement 181 profiles from 0° to 180° as in Fig. 6 were taken. The images were post-processed with background subtraction and vignetting correction. The asymmetry in the beam profile is shown in Fig. 7. The rotational and static shift was estimated using the basic linear regression method described before (Fig. 3). A tomographic reconstruction from these images was successfully done and is shown in Fig. 8. For a first comparison we measured the x plane particle distribution with the slit-grid emittance measurement system. This distribution was forward calculated and optical profiles at camera position were generated using LINTRA[1]. In Fig. 7 LINTRA generated profile and measured profile integrated over z are displayed.

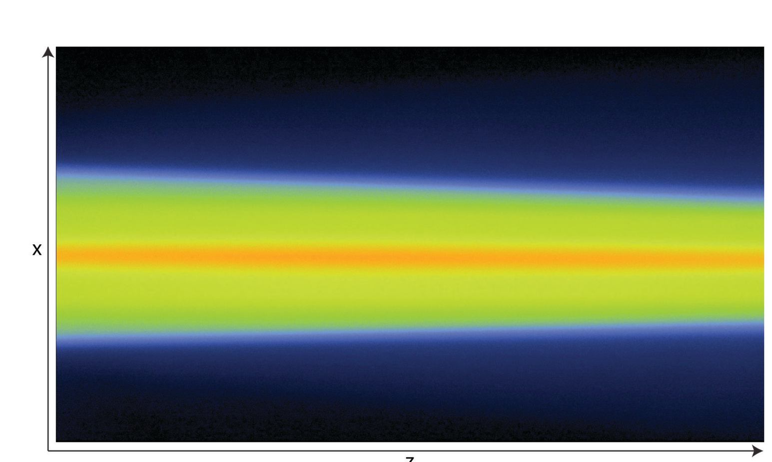


Fig. 6: Beam profiles taken at 0° in the rotating vacuum chamber. Image post processed with background subtraction and vignetting correction.

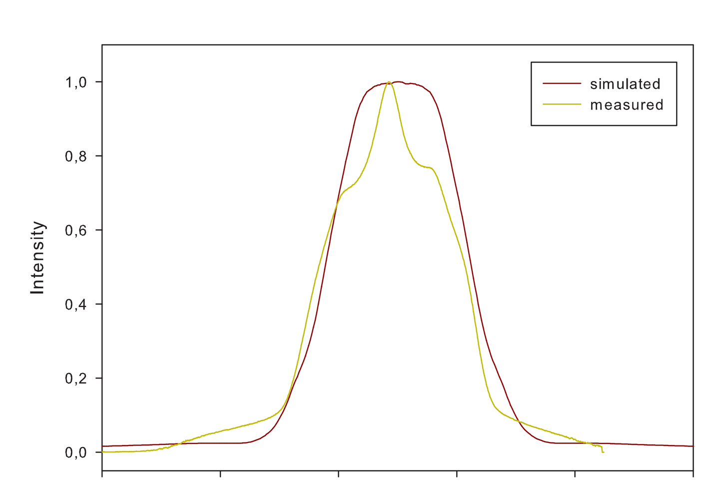


Fig. 7: Beam profile taken at 0° in the rotating vacuum chamber and simulated profile integrated over z. Asymmetric drop-off from maximum to beam boundaries in measured profile.

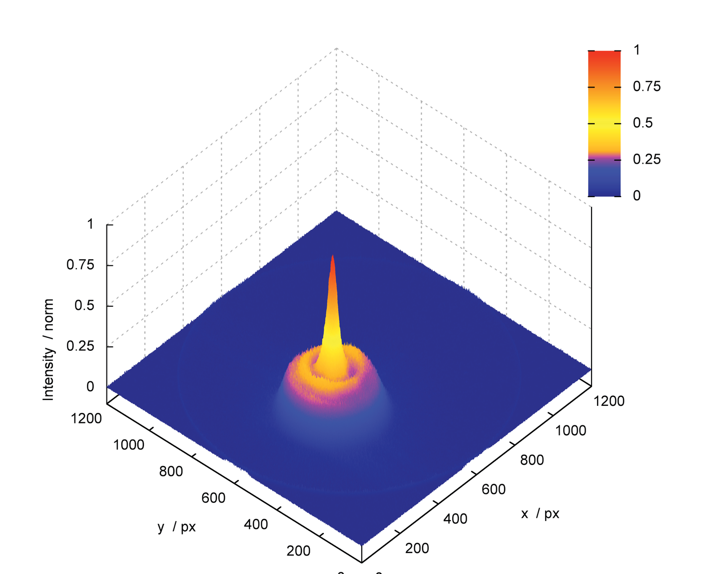


Fig. 8: Beam luminosity density reconstruction slice. Ring structures become visible.

[1] O. Meusel J. Pozimski, LINTRA ein Computerprogramm zur Berechnung des Strahltransportes teilkompensierter, hochperveanter Ionenstrahlen., GrakoNews, 1/1999