Optimization of The Imaging System for Trapped $^{40}Ca+$ Ions

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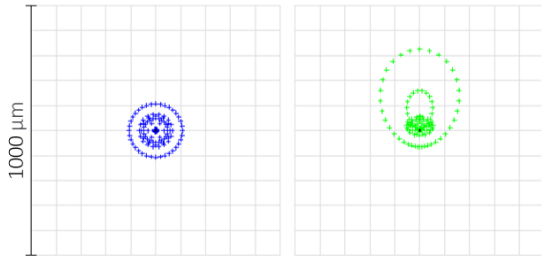
1. Introduction

Quantum computers based on trapped ions is one of the most promising platforms for quantum computation. One of the key parts for such a platform is the imaging system. It comprises of a set of lenses including the objective mounted on a vacuum chamber, which collects the photons emitted by the trapped ions and focuses them on the camera matrix. Such system must satisfy the main requirements: efficient collection of the ions radiation to maximize the signal to noise ratio and the ability to distinguish different ions in the chain.

2. Modeling

We examined two systems based on 2f- and 4f- lens configuration. Both of them were modeled in the Zemax package. Despite the fact that the lenses formed a 4f- system intended to reduce spherical aberrations, the beam size calculated in the approximation of geometric optics on the camera matrix had a radius of about 70 μm. This significantly exceeded the Airy disk radius of approximately 3 μm (see Fig. 1).



Optical system length 465 mm	Light source in the optical axis	Light source moved radially for 100 μm
Root mean square radius, μm	68	115
Airy dick radius, μm	3	

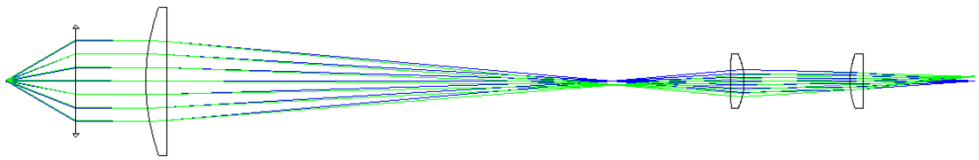


Fig.1: *4f lens configuration*

The second setup consisted of just two lenses: one with a 33 mm effective focal length mounted on a vacuum chamber (NA ≈ 0.5) and another with a 500 mm focal length. According to Zemax simulation, geometric optics approximation gives a spot size on the camera matrix of 1.1 μm, which is smaller than the Airy disk radius of approximately 6 μm (see Fig.2).

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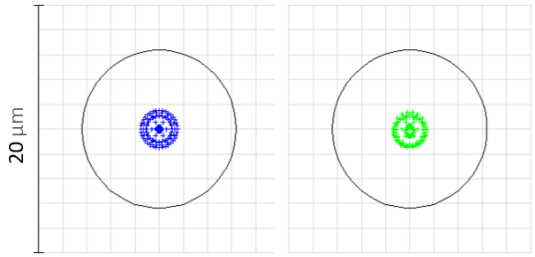


Optical system length 552 mm	Light source in the optical axis	Light source moved radially for 100 µm
Root mean square radius, µm	1.1	1.1
Airy dick radius, µm	6	

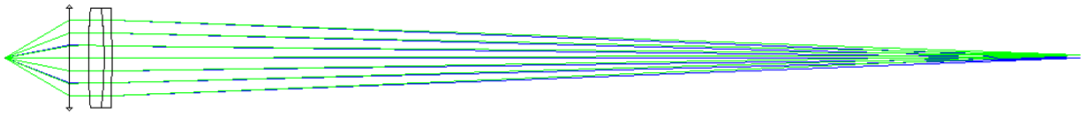
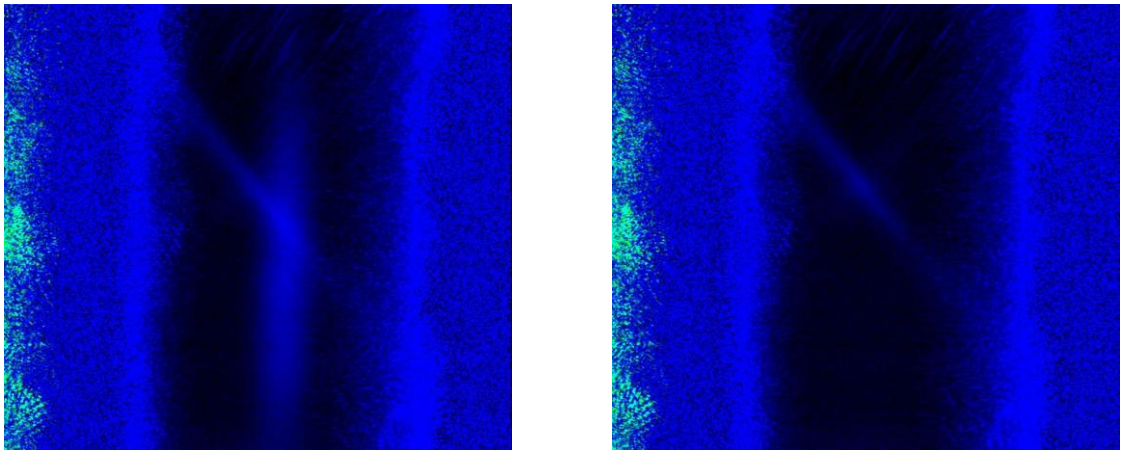


Fig. 2: *2f lens configuration*

3. Results

Based on the simulations we found suitable lenses and installed them in the experimental setup. Finally, the image of the ions in the trap was obtained. On the left in Fig. 3 is a vertical line of cold trapped ions, and on the right is nothing but radiation reflected from the electrodes and background noise.



Cloud of ions in the center of the picture

Reflected radiation and background noise

Fig. 3: *Trapped ions cloud*

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