From: "Borg, Johan E" <j.borg@imperial.ac.uk>
Subject: Re: Notes on our meeting ...
Date: 3 July 2019 at 20:41:35 BST
To: "Kurup, Ajit" <a.kurup@imperial.ac.uk>, "Long, Kenneth R" <k.long@imperial.ac.uk>, Liam Cooper <liam.cooper@stfc.ac.uk>, "Lau, Hin" <h.lau17@imperial.ac.uk>

Hi all,

please find an update on the optical system below:

Assuming we use a Chameleon3 camera with an imx265 (like the one Ajit has), and each 250um fiber will (assuming 1:1 projection or direct coupling) illuminate 4116 pixels, with a maximum frame rate of 55fps (however, even shorter shutter times are possible).

Based on the photon rate the brightest fiber as calculated by HT (3.3GHz for protons, 15GHz for carbon ions), and assuming an exposure time of 1/60 (from what I understand this is the maximum at the full 55fps frame rate)), each pixel should receive 13.3k and 60.8k photons/frame for protons and carbon ions respectively.

This should be compared to the full-well capacity of 9777 e-, which corresponds to 13770 photons at peak QE (we're pretty close to the peak wavelength based on the fiber specification), so in principle we could (just about) use every photon from a proton beam, but would need to turn the exposure time down to about 1/260 for the carbon beam (should be perfectly fine).

However, 100% coupling is in any case not realistic, in particular if we image the end of the fiber bundle onto the sensor (which I think is preferable for the first tests).
For example, one attractive imaging solution would be a 45mm "relay lens" assembly from edmond optics , with a F4 aperture (#45-760, £285). Depending on how the light from the end of the fiber is distributed we'd end up with an efficiency of 1.6-6.2% (the lower number assuming a lamberitan distribution, the latter a top-hat with NA=0.5). This solution offers excellent imaging resolution

over the whole sensor at the cost of a slightly small aperture.

For a larger aperture while achieving decent (but far from great) resolution over the sensor, the best I've been able to come up with quickly is to use a pair of off-the-shelf triplet lenses form Thorlabs with an F2.5 aperture (e.g. TRH254-040, 2x£78, plus something like £35 for an optional adjustable iris, and £40 for some lens tube hardware). At F2.5 this option retains 4-16% of the light, at the cost of lower resolution (even at smaller apertures it's never nearly as sharp as the relay lens assembly), but since the fibers are quite large, and relying on calibration and off-line correction for light defocused onto the area used for adjacent fibers, the performance may be perfectly acceptable (but at the cost of more complex post-processing).

A (worst-case) transfer efficiency of 1.6% may seem terrible, but the signal to noise ratio will actually still be pretty good due to the large number of pixels per fiber: 4116*13300*0.016=876k, compared to a noise of 3*sqrt(4116)=192 yields an SNR=4550.
This is for a single frame, averaging over the whole spill (it's quite possible that better performance is achieved by extending the exposure time) this would ofcourse improve even further (for the proton beam by a factor of sqrt(55*5)=16.5, for the carbon 14.8).

For simplicity I'd go with the relay lens option, but please let me know what you think.

Best Regards,
Johan Borg

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All cost estimates exclude VAT