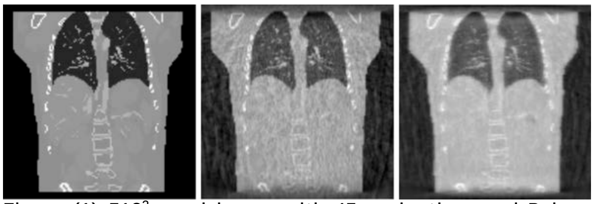

Figure (1) 512^3 voxel image with 45 projections and Poisson noise, (a) original (b) reconstruction using FDK, (c) reconstruction using SART.

In terms of speedup, a CPU projection takes 24s on average in an Intel Core i7-4930K with 32Gb of RAM while a GPU projection takes 137ms in high accuracy settings and 17ms with the same accuracy in a NVIDIA Tesla k40c, resulting on a speedup of 175% and 1400% respectively.
Figure 2 shows speed results for a single forward projection of a single angle in both low and high accuracy settings for different detector and image sizes, in logarithmic scale. It is easy to see in the figure that the algorithm is $O(n^3)$ for the image size and $O(n^2)$ for the detector size. Note that in the biggest image sizes memory bandwidth is a relevant factor in the time, as the image size in memory gets over 8Gb. Times for backprojection are always around 10% of the times for forward projection.

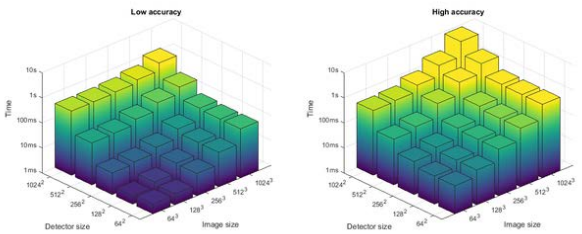

Figure (2) Time for a single projection in the GPU, compared against the number of voxels and the number of detector pixels, for different accuracy levels, (a) 1 sample per voxel (as in matrix based methods), (b) 10 samples per voxel.
Conclusions: The GPU based code speeds up the image reconstruction to over 3 orders of magnitude than CPU based algorithms, allowing the use of iterative reconstruction methods in clinically reasonable time scales. The future work involves modifying the algorithm for motion correction using the concepts from phase space tomography at CERN[3]. Additionally, an EIT based real-time motion detection will be used to better estimate patient motion, which can then be fed into CBCT reconstruction algorithm allowing for a dual modality based 4D CBCT.

Keywords: Cone Beam Computed Tomography, motion corrected imaging, electrical impedance tomography, lung radiation therapy, GPU

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Current and future strategies developed at Paul Scherrer Institute

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The Center for Proton Therapy at PSI has been the worldwide pioneer of pencil beam scanned (PBS) proton therapy. Clinical operation started in 1996 on Gantry1, with Intensity Modulated Proton Therapy already being delivered clinically in 1999. Currently the facility is composed of two gantries and one horizontal beam line for ocular therapy. Gantry2, clinically operational since 2013, is a new generation proton PBS gantry, developed in-house at PSI, whilst Gantry3, currently in the technical commissioning phase, will be a ProBeam Gantry from Varian Medical System. First patient treatments on this facility will be at the end of 2016.
Our future strategies are in a number of directions. First, we are working on significantly increasing the delivery speed of PBS treatments using continuous line scanning rather than discrete spots. This has already been demonstrated as a proof-of-principle on Gantry2, and the major work currently is on the development of fast beam monitoring, together with strategies for analyzing the resulting measured profiles.
Second, the treatment of moving targets (4D) will be clinically implemented based on different motion mitigation techniques, including advanced rescanning, gating and continuous scanning. For the optimization of the 4D treatment delivery, different scanning techniques (i.e. volumetric and layered rescanning) have been evaluated and both will be implemented clinically. In order to calculate the dosimetric effect of the interplay between motion and scanning, our in house developed TPS system has been upgraded to include a fast and comprehensive 4D dose calculation option based on a deformable dose calculation grid, where the timing of the delivery parameters and the patient breathing (including variable breathing patterns) can be accurately taken into account.
Our third aim is the clinical implementation of daily adaptive proton therapy, in order to more accurately take into account daily anatomical and positioning variations. As a CT-on-rails scanner is installed in the Gantry2 bunker, 3D planning images can be acquired on a daily basis and used for a daily optimization of the plan before the daily delivery. In addition, on the ProBeam system, Cone-Beam CT acquisitions will be possible, allowing us to also investigate the usefulness of CBCT for daily adaptive approaches. In the daily optimization process, the cumulative dose delivered to the patient will be estimated using log-file based dose calculations as a type of 'entrance-dosimetry' which can reconstruct the actual delivered dose in the patient geometry of the day. This is based on machine log files, which are saved for each delivery, and which include all the machine parameters for the specific delivery (i.e. exact spot position, spot weight, MU per spot[1]). Finally, we are also investigating advanced uses of MRI imaging in proton therapy, for instance to monitor anatomical changes, organ motion and in-vivo range verification.

Keywords: spot scanning, 4D treatment, adaptive proton therapy

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Imaging for online control of particle therapy

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