Report of the biophysics department

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The Scientific Activity of the Biophysics activity in 2013 led to tremendous breakthroughs in the field of medical physics and space radiation protection. The achievements are essential for the future FAIR activities, where the high-energy beams will open new possibilities for both medical and space research. It has been a very successful year also for the technological transfer, patents, and awards received by group members.

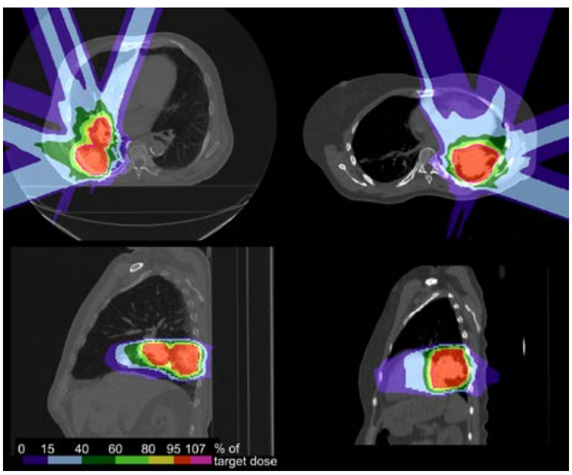

Figure 1: 4D-treatment plans of two lung cancer patients treated with C-ions. The distorted entry channel dose is a result of the differential motion between the target and other organs, such as the chest wall, during the breathing cycle. The sagittal cuts (bottom) illustrate the high conformity also in the SI main motion direction. From ref. [2]

Medical Physics

The Local Effect Model (LEM), developed by Dr. Michael Scholz, already used in treatment planning with heavy ions at HIT (Heidelberg) and CNAO (Italy), has been now extended to protons with a surprising result [3]. In fact, the relative biological effectiveness of protons is assumed to be 1.1, but our simulations show that it is much bigger than 1 at the end of the range, and this lead to a shift in the effective range of the protons (Figure 2). Taking into account the range shift is likely to lead to great improvements in proton therapy, where the market is much broader than in C-ion therapy (44 proton therapy centers are currently in operation worldwide).

In preparation for the PRIOR facility, to be installed in FAIR, we produced the first-ever high-energy proton image of an animal target with high-energy protons (800 MeV) at ITEP in Moscow, Russia and then at the Los Alamos National Laboratory in USA (Figure 3). The PANTERA experiment is an APPA project developed in strong collaboration between the Plasma Physics and Biophysics Department at GSI.

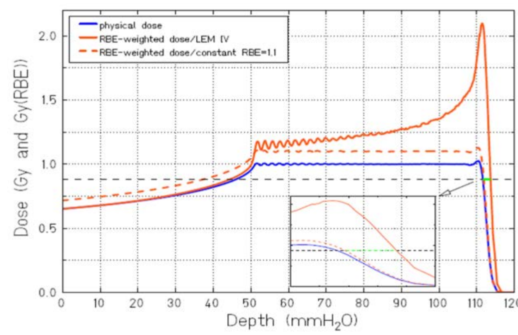

Figure 2: Predictions of the LEM model on the biologically effective dose (solid orange line) along a proton SOBP used for therapy. The increased effectiveness of the slow protons results in a range shift of 2-3 mm, which could hit an organ at risk below the tumor.

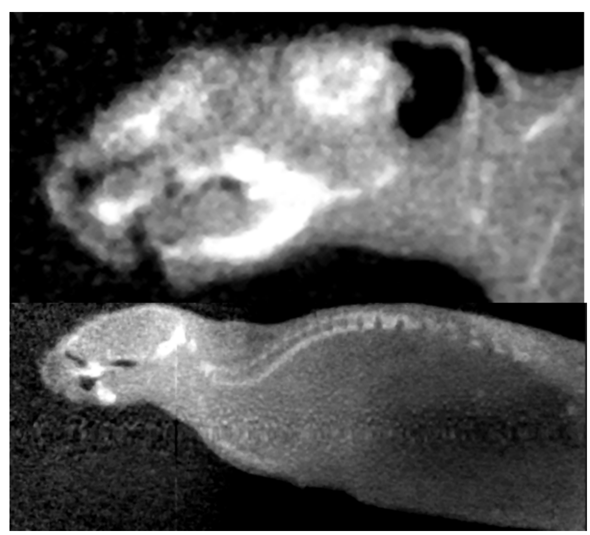

Figure 3: Proton radiography of a mouse obtained in 2013 at the Los Alamos National Laboratory using 800 MeV proton and a setup similar to that under construction at FAIR (PRIOR facility). The upper image is a zoom of the skull. The theoretical resolution at FAIR with 4.5 GeV protons will be 10 μm. From ref. [4].

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Space Radiation

GSI is the European facility selected by ESA for ground-based cosmic ray simulations. During 2013, we ran the ESA-sponsored IBER (radiobiology) and ROSSINI (shielding) projects. Within IBER, we tested the possibility of using human tissue slices as an alternative to animal studies [9]. Shielding experiments using Mars and Moon soil are ongoing, within the project supported by ESA and led by the space company Thales-Alenia Space (Figure 4). Results are important to estimate the depth of the caves/tunnels to be selected by future Moon/Mars explorers to build underground planetary bases without breaking ground for excavation.

Figure 4: Martian soil under preparation for a shielding experiment in Cave A at GSI. The test is performed using 1 GeV/n 56Fe-ions, whose attenuation properties have been shown to simulate reasonably well the attenuation of cosmic rays. A better simulation will be possible at FAIR using 10 GeV/n ions. The research is supported by ESA (ROSSINI contract).

A recent research report at GSI [6] addressed an old question in space travel – the origin of light flashes, observed by astronauts during spaceflight (first reported by the crew of the Apollo 11 lunar mission). Heavy charged particles in the cosmic rays are responsible of the light flash (phosphene) experienced by the astronauts, but the target area in the head remained unclear: some authors proposed the eye, while others contended that the target could be the optical nerve or specific areas in the brain. A careful analysis of the treatment plans used at GSI to treat patients with head-and-neck tumors show a clear correlation between the dose in the retina and the perception of light flashes, as measured by the patient using a pushbutton (Figure 6). We conclude that the phosphenes are caused by direct heavy ion traversals through the retina.

Technological transfer

RaySearch Laboratories AB (a leading Swedish company in treatment planning software) has entered into a license agreement with GSI regarding techniques for calculating radiobiological effective dose in ion beam treatments. RaySearch acquired the rights to integrate algorithms and know-how from GSI related to the LEM in RaySearch's RayStation® treatment planning system. The LEM and RaySearch's algorithms for dose calculation will be built into the system's module for carbon treatment plan optimization. The first application of the system will be at the MedAustron facility under construction in Wiener Neustadt (Austria).

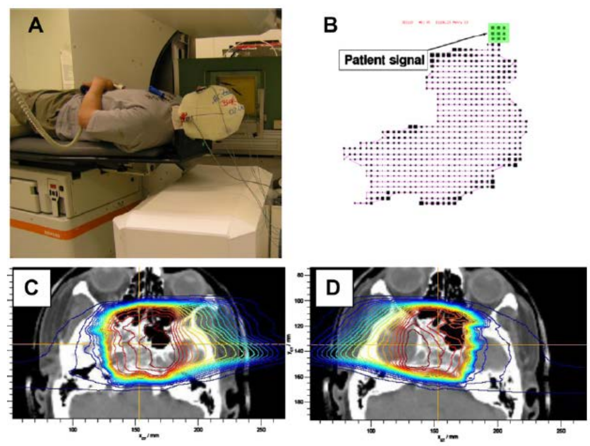

Figure 5: Example of the correlation between carbon beam-spot position in the head and phosphene reception in a patient. (A) Patient during the treatment with the fixation mask and holding the pushbutton. In this figure the beam is hitting the right side of the patients' head. (B) Beam scanning path (beam's eye view) for one slice of carbon ion irradiation. The area marked in green is correlated with phosphene stimulation, based on pushbutton time analysis. (C) Planned physical dose distributions for a two-field treatment in the same patient. The beam enters from the right side. The color scale indicates the fraction of the dose to the tumor. The patient reported phoisphenes when the field was in the eye (green area in B).(D) Same as in C, but beam from the left side. No dose deposition in the eye, and no light flashes reported by the patient. Note that the optical nerves are in the field in both right and left irradiation. Figures from ref. [6].

The 4D treatment plan concept has been patented by C. Graeff and C. Bert: Erstellung eines Bestrahlungsplans bei bewegtem Zielvolumen ohne Bewegungskompensation", Nr. 10 2011 056 339. The PANTERA idea for theranostics using high-energy protons was patented by H. Stöcker and M. Durante: COMBINED ION IRRADIATION AND RADIOGRAPHY DEVICE - PCT/EP2012/071567

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Awards

Marco Durante received the 2013 IBA Prize for Applied Nuclear Science and Nuclear Methods in Medicine from the European Physical Society (EPS) and the 2013 Bacq & Alexander award from the European Radiation Research Society (ERRS)

Daniela Kraft received the 2013 LH Gray Young Investigator award for the European Radiation Research Annual Meeting and the 2013 Christoph Schmelzer Award of the Verein zur Förderung der Tumortherapie mit schweren Ionen.

Lisa Herr won the Philipp Siedler Award 2013 of the Physikalischer Verein Frankfurt.

Thomas Friedrich got the GBS Award for Young Scientists 2013, awarded by the German Society for Biological Radiation Research.

Matthias Prall got the award for the best poster presented at the Workshop on "Particle Radiosurgery: A new Frontier in Physics in Medicine" in Obergurgl, Austria

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