Development of a beam monitor for ion therapy in HVCMOS technology

Introduction

Radiotherapy is, beside the chemotherapy, the main method in treatment of tumors. The most commonly used radiotherapy is x-ray and gamma radiation. More recently, irradiation with heavy ionized particles—such as protons and carbon ions—have been introduced clinically. The source of these particles is a particle accelerator. In contrast to x-ray and gamma radiation, ions depose most of the energy is a small tissue volume. This is the result of the effect, that deposed energy is inversely proportional to the particle velocity, so particles lose most of the energy near the end of their path when they get slow (Bragg peak).

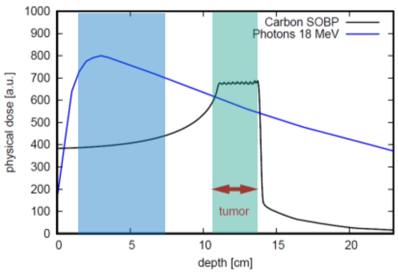

Figure 1: Radiation dose vs particle depth for photons and ions

By adjusting the beam direction and particle energy it can be achieved that greatest energy is delivered to the tumour, and the healthy tissue in front and behind the tumour is less affected. Under realistic conditions, the minimum spot size is determined not by the capability of the beam than by the accuracy of the tumour localization during treatment.

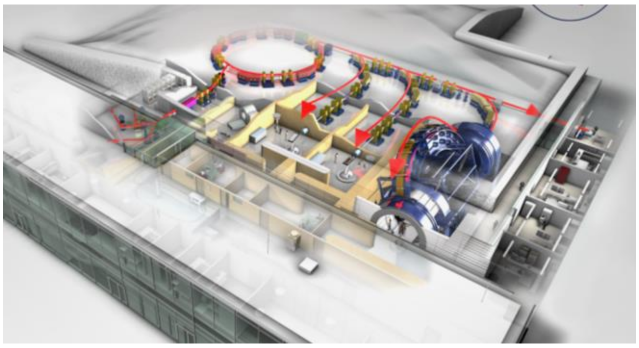

Figure 2: Floorplan of Heidelberg ion beam therapy center

We are developing the device – beam monitor – that precisely measures the position of the beam. The beam monitor could be applied at the Heidelberg Ion-Beam Therapy Center (HIT).

Motivation for our development

The present beam monitor is made of gas-filled ionization and multiwire chambers (MWC) that provide dose, position, and spot size information.

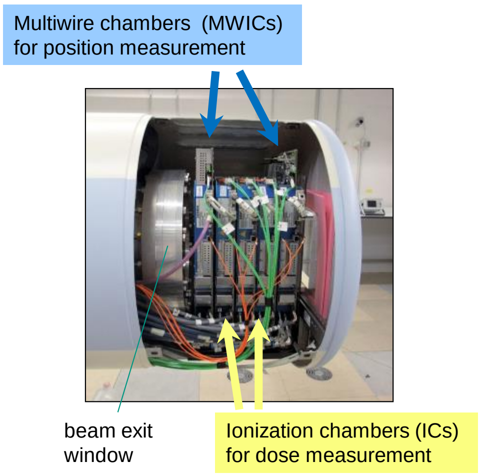

Figure 3: Existing beam monitor

The gas-detectors have one drawback, they cannot be operated in the magnetic field of MRI. An MRI compatible beam monitor (MR guided radiotherapy) would significantly improve the precision of the irradiation since the position of the tumour could be tracked in real time and the beam could permanently be adjusted. By knowing exact position of the tumour, smaller spot size could be used. The result would be a tumour treatment that would have little effect on healthy tissue.

Our beam monitor would be based on HV-CMOS pixel sensors. These sensors are invented in our group. The key advantage of HV-CMOS sensors over MWC is that HV-CMOS sensors are not magnetic and can be operated in the field of MRI.

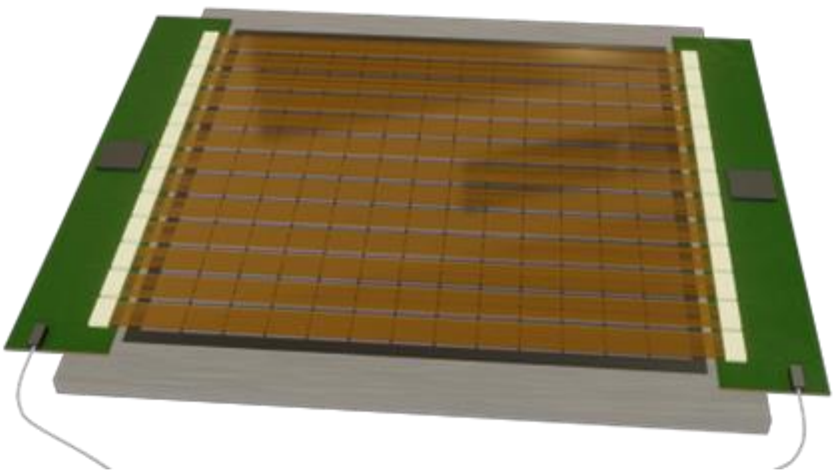

Figure 4: Drawing of the planned HVCMOS beam monitor. The sensor plane could consist of 169 sensor chips, bonded to interconnect foils

HVCMOS technology

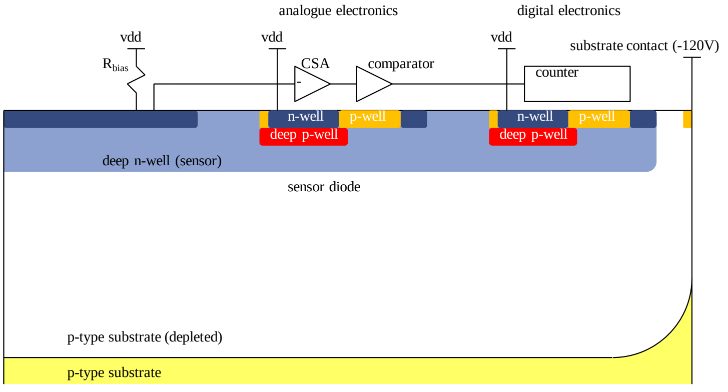

Figure 5: Cross section through HVCMOS pixel

HV-CMOS sensors combine signal generation in the sensor diode (n-well in p-substrate) with readout electronics (placed in the n-well of the pixel) on the same die. The high depletion voltage increases the depletion zone and assures fast charge collection and improves radiation tolerance. HVCMOS technology is more radiation tolerant than other CMOS technologies because they use large and depleted sensor diodes, which minimizes the charge collection time for signal charge.

We have already designed and tested several senor prototypes with counting and integrating readout electronics. The latest prototype (HITCNT2) has a size of 1cm x 1cm. The sensors have been tested in the beam at HIT with promising results. Capability to measure beam position and required radiation tolerance have been shown.

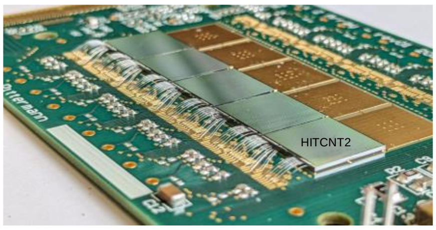

Figure 6: Five HITCNT2 chips bonded to multichip PCB

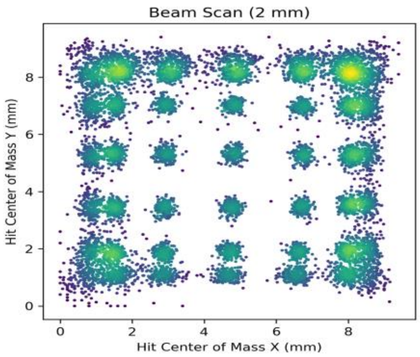

Figure 7: Beam position measured with HITCNT2

Possible themes

For the development of HVCMOS beam monitor for ion therapy we need support, and we offer master and bachelor theses and internships with several themes that can be combined within one master/bachelor work or followed individually. You would learn to design and to test ASICs by working on development of one of most advanced tumour treatment method.

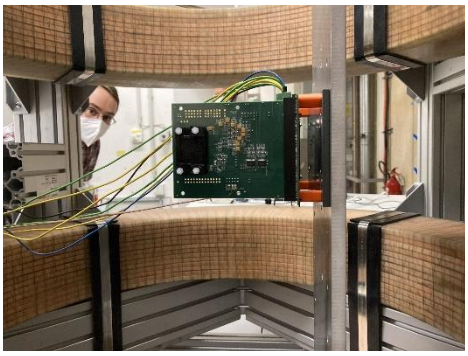

Figure 8: Sensor test in magnetic field

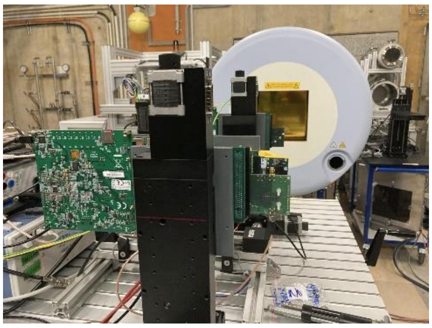

Figure 9: Measurement in the test beam

If you chouse to focus on experimental work (tests and detector assembly), you would learn FPGA-, software- and PCB-design, chip packaging technology, have possibility to build detector-systems (with a sensor chip that is bonded to PCB, with FPGA as interface, USB controller chip, self-made software) and test them in our lab or at particle accelerators (test beams).

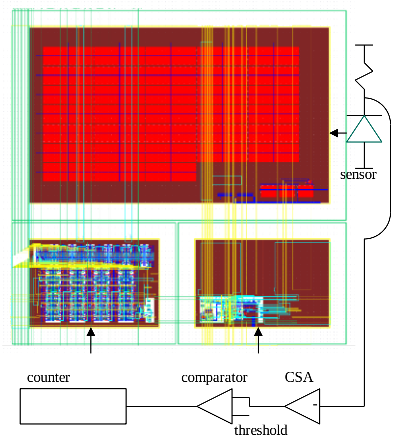

Figure 10: Pixel layout (HITCNT1)

Theme 1: One theme would be the design of the next sensor prototype. The new sensor chip would be based on the existing one with several improvements would be implemented. The counting frequency should be increased by improving amplifier design. Digital part should be modified to allow calculation of 2D beam projections and threshold tuning. Data transmission rate should be optimized.

Theme 2: Another theme could be automated characterization of our radiation hard standard cell library (using tool Cadence Liberate) and synthesis and place and route using tools Innovus and Genus.

Theme 3: A new prototype with integrating electronics could be also designed.

Theme 4: The thesis could also include measurements and design of a large multichip detector. (The final beam monitor should be 25cm x 25cm and should contain very little material, ideally only the 100µm chips free standing or glued to foils). Novel interconnection technology using Al-redistribution layers is needed. This next prototype would bring us closer to the final demonstrator that would have the required sensitive area.

Required skills:

Basic knowledge of ASIC design (e.g. obtained within courses DAS, DDS or PSCOC) is beneficial.

For some themes, knowledge of HDL and C++.

Duration: 6 months

Language: English or German

Location: Building 242 (IPE), Campus North

Contact: Ivan Peric (ivan.peric@kit edu)