The joint research activity ULISINT – presented to the public

Introduction

My name is Johann Heuser, I am physicist at the GSI Helmholtz Center for Heavy-Ion Research in Darmstadt, Germany and spokesperson of the HadronPhysics3 joint research activity "ULISINT". The acronym stands for "Integration of ultra-light silicon tracking and vertex detection systems for frontier precision experiments". It brings together participants from three silicon detector project groups of the CBM and PANDA experiment at FAIR, the new international accelerator facility under construction next to the GSI grounds, to address technological challenges we have in common with the integration of the detector systems into nuclear physics experiments.

Silicon tracking detectors are very sophisticated devices. They are essentially specialized digital camera systems with very high spatial and time resolution that can image the many charged particles that are produced in nuclear collisions. Examples of such detectors are shown in Fig. 1. When traversing the detector, the particles release electrical charge in the silicon sensors that is then read out by dedicated electronics. Several detection layers are arranged along the particles' direction of flight. The detector systems are installed in a strong magnetic field that bends the tracks. With the help of specialized software, the particle trajectories are reconstructed from the track points in the detector layers and the charge and momentum of the particles are thus determined. The accuracy of the reconstruction must be high enough to allow for the identification of certain track topologies, e.g. particles decaying in or just before the detector into two or more daughter particles. This is known as "vertex detection".

Which are the scientifically exciting aspects of the "ULISINT" research?

Silicon tracking and vertex detectors were pioneered in the 1980s years, became available to large experiments in the 1990s, and are now the backbones of any modern high-energy and nuclear physics experiment. They have been at the forefront of new discoveries, for instance they are mandatory for the identification of particles which contain or decay into heavy quarks, in particular charm, bottom, and top, as well as the Higgs boson.
The detectors can only be built with high-tech materials and procedures. We develop and use most modern semiconductor sensors, innovative electronics chips, high-performance materials, high-density interconnections, and advanced computing software and hardware. Every detector system is a very specific construction, uniquely adapted to its role in a given experiment. The developments take years of work. No detector is like the other. They have in common that they are required to be of very low mass, ultra-thin. This is because unlike a normal camera that we use to take photos of our surrounding world, we have no optical lenses attached to our devices. The camera itself stands on the trajectory of the particles and is traversed by them. All what is left in the camera is a small amount of electrical charge in a small spot of the silicon sensor. In order to reconstruct the trajectories, several

detection layers have to be installed. Since the trajectories are disturbed by the material of the detection layers, we try to construct the detectors with the minimum thickness possible.
This is not trivial, though. For instance, we need to have fast detectors. Fast electronics significantly dissipates power and must be actively cooled. Pipes with a cooling agent, however, introduce more material. There are also further passive materials like cables and mechanical support structures that cannot be avoided but must be designed to be as lightweight as possible, from suitable materials that create lowest scattering of the particles.

The assembly and the handling of such delicate components pose numerous practical problems at the limit or beyond commercial availability. The research teams are charged with finding solutions and new approaches. This many-dimensional task is very exciting and challenging, as it brings together a scientific goal (achieving the measurement of certain nuclear physics observables) with possible solutions through various modern technologies. Physicists, engineers and technicians work together, coming from research institutes, universities and industry worldwide. Students are an important part of the teams.

Who is participating in ULISINT?

Our research team comprises participants from Germany (GSI Darmstadt, Goethe University Frankfurt), Italy (INFN Torino) and Ukraine (State enterprise SE SRTIIE Kharkov, Kiev Institute for Nuclear Research).

What do we want to achieve with this activity?

I explained already that we want to achieve very low-mass silicon detector systems, with focus on developing demonstrators for applications in the forthcoming CBM and PANDA experiments to be built at the international research center FAIR in Darmstadt. We are though not alone with this aim. Several other groups worldwide, in particular from the high-energy physics community, are highly experienced in developing such detectors for their purpose. Some of our developments are therefore done in close cooperation with institutes also active in high-energy physics. Two examples shall be given: (1) the development of an ultra-thin monolithic pixel detector, where the application in the heavy-ion physics experiment CBM even sets the highest performance standards, and (2) the active cooling of the front-end electronics with carbon dioxide as agent, employing a system with sophisticated controls for efficient, stable operation.

In ULISINT we follow-up this task in three complementary sub-projects, each being worked on by an own team of the participants introduced earlier. The sub-projects are:

a) Integration of an innovative thin micro-strip tracking detector system for large-area coverage;
b) Integration of a thin fast hybrid pixel detector system for tracking in high particle densities;
c) Integration of an ultra-thin monolithic pixel detector system for decay vertex identification.

A few of the developments and prototype components produced by the ULISINT research team are illustrated in Fig. 2. Naturally, the activities are closely integrated into the experimental collaboration's work. Topical workshops, as the one illustrated in Fig. 3, help focusing the view.

In which way will ULISINT eventually benefit society?

It is almost guaranteed that when working with high-technologies also ideas appear for spin-off products that were not originally in the focus of the primary scientific question but address wider aspects of applications or society. This includes medical applications, e.g. X-ray imaging with superior capabilities at lower radiation dose as compared to traditional nuclear films, or even new ways of measuring dose in real-time during a therapy. The ULISINT goals do not target such applications directly, but e.g. the ultra-thin monolithic pixel detector system has sister-projects for dosimetry applications ongoing that comprise the same thin CMOS imager chips mounted on ultra-thin flexible printed circuit boards. The high performance of further electronic chips developed in the project makes them also interesting for fields like material research with synchrotron radiation, crystallography and space science.

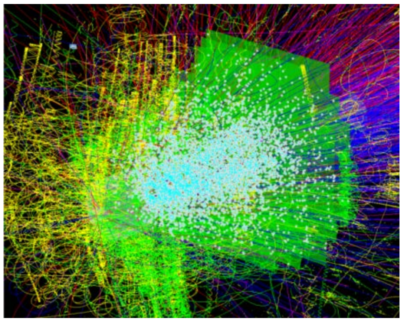
Why should a young person choose to study science, and why in Europe?

Science is a key discipline to the understanding of our world, from the fundamental questions of how the universe is composed to the advancement of our lives with high-tech products. There are many fields one could become engaged in. Some allow combining both the fundamental and practical aspects, as in experimental high-energy physics and nuclear physics applications.
Universities in Europe do certainly offer high quality education and play major roles in scientific research. Modern research projects tend to be internationally arranged, so that the doors are open to both European and non-European students to be broadly trained, meet fellow researchers from all over the world, and to even develop job opportunities in Europe and abroad.

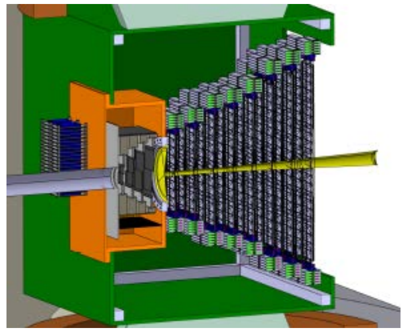
Further information:

- ULISINT research activity: http://ulisi-wiki.gsi.de
  Contact: J.Heuser@gsi.de
- HadronPhysics3: http://hadronphysics3.eu
- CBM experiment: http://www.fair-center.eu/for-users/experiments/cbm.html
- PANDA experiment: http://www-panda.gsi.de
- FAIR research center: http://www.gsi.de/fair/index_e.html
- GSI Helmholtz Center for Heavy Ion Research: http://www.gsi.de/portrait/index_e.html

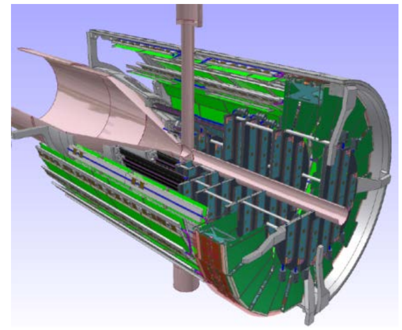
Figure 1: Silicon tracking and vertex detector systems



(a) Computer simulation of a single central heavy-ion collision in the CBM experiment at FAIR: About 1000 charged particles (most of them protons, pions and kaons) are created when a gold ion, accelerated to a typical energy of 25 GeV per nucleon, collides with a stationary gold target. The curved lines represent their trajectories in the magnetic field. Most of the particles fly through the layers of the silicon detector system (shown in green color). Up to 10 million of such collisions will take place per second.

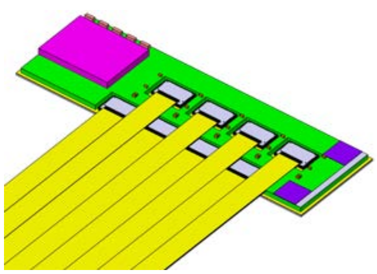


(b) Engineering model of CBM's silicon tracking detector system, showing eight planar "camera" layers. The detector system will be 1 m long and will comprise about 1000 silicon sensors on 4 m^2 active area. The additional vertex detector is in the target's vacuum vessel shown on the left. The detector is crossed by the beam pipe and surrounded by a thermal enclosure to operate at -5° C.

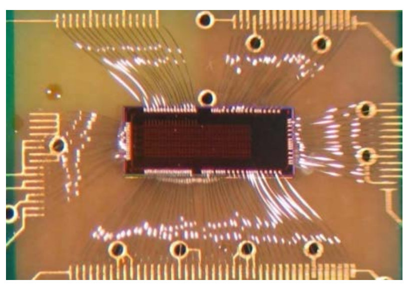


(c) Engineering model of the silicon vertex detection system of the PANDA experiment, showing four barrel detection layers and four forward disks. The inner two barrel and disk layers are made from thin hybrid pixel detectors. The detection system is about 1 m long. The detector is crossed by the beam pipe.

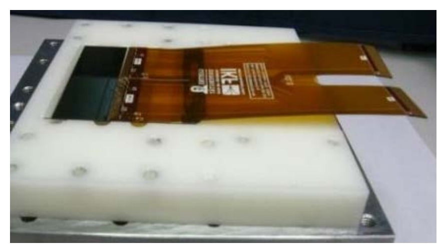
Figure 2: Prototype components under development in ULISINT



(a) Concept of the read-out side for a detector module of the CBM silicon tracking system. The micro-strip detectors are read out through several individual ultra-thin flat cables attached to the silicon sensor at one end and to read-out ASICs at the other end. The ASICs are installed on a front-end board, shown in this figure. The arrangement of cables, ASICs and the implications for the realization of the thousands of electrical interconnections ("bonding") are under study in particular with respect to quality assurance.



(b) Prototype of a self-triggering pixel readout chip developed for the PANDA vertex detector. It features low power consumption, high readout rate and a very high dynamic range. On this photo the chip is shown on a test circuit board. Current activities focus on the addition of low-mass components like cap-less low-noise power regulators important for the mass-minimization of the detector system.



(c) Prototype of an ultra-thin module under development for the CBM micro-vertex detector. Two CMOS pixel sensors thinned down to 50 micro meters are attached to a flexible bus system. Two of those objects will be mounted on both sides of a 200 micro meter thick diamond support, enabling heat removal from the electronics despite of the detector operating in the vacuum of the target chamber.

Figure 3: Work meeting of members of the ULISINT research activity

ULISINT Workshop on "Module assembly for the CBM Silicon Tracking System", 3-7 December 2012 at GSI Darmstadt: Hands-on work on bonding machines in the clean room area of GSI's detector laboratory.