Superconductivity in High Energy Particle Accelerators

Peter Schmüser
DESY and Institut für Experimentalphysik, Universität Hamburg

The basics of superconductivity are outlined with special emphasis on the features which are relevant for the application in magnets and radio-frequency cavities for high energy particle accelerators. The special properties of superconducting accelerator magnets are described: design principles, magnetic forces, quench performance, persistent magnetization currents and eddy currents. Practical examples are given from HERA and LHC. The design principles and basic properties of superconducting cavities are explained as well as the observed performance limitations and the countermeasures. The ongoing research efforts towards maximum accelerating fields are addressed.

Hans Weise (DESY)

Electron Accelerators Based on Superconducting RF Technology

Abstract:

The acceleration of electrons in superconducting RF structures has a long and successful history. First structures were developed almost 50 years ago and used at HEPL, Stanford. In the mid 80ies a superconducting electron accelerator was built at Darmstadt University (S-DALINAC) which to some extend could be seen as a prototype for the first large scale installation based on superconducting technology at Jefferson Laboratory (CEBAF): two superconducting accelerators with together 338 cavities. Today the so-called TESLA technology is the basis of several on-going or proposed projects. The technology is sufficiently mature to make e.g. the FLASH free-electron laser at DESY a successfully operated and worldwide acknowledged user facility. The European XFEL is going to use 800 accelerating structures, future projects aim for continuous wave operation of TESLA like cavities, or for real large scale facilities (ILC Linear Collider).

Andreas Peters (Univ. Heidelberg)

Medical applications of accelerators and linked detector technologies

Outline of the talk:

- An introduction about the historical developments of accelerators and their use for medical applications: tumour treatment from X-rays to particle therapy
- Description of the underlying physics and biology of particle therapy; implications on the requirements for the needed beam parameters (energy, intensity, focus, beam structure)
- Accelerator technology used for particle therapy so far: cyclotrons and Synchrotrons
- Particle therapy facilities worldwide: an overview and some examples in detail: PSI/Switzerland, HIMAC/Japan, LomaLinda/USA, HIT/Heidelberg
- A short excursion: use of common detector systems for accelerator beam diagnostics and dose monitoring for the treatment: high-precision ionization chambers (IC) and multi-wire proportional chambers (MWPC); examples from PSI and HIT
- Outlook to new accelerator concepts proposed for particle therapy: FFAGs, laser plasma accelerators, dielectric wall accelerators and others

Medical and industrial applications of linear electron accelerators

Roland Schmidt, Siemens Healthcare

The first industrial applications of linear electron accelerators showed up in the Fifties of the last century. We will give a short overview about the history of this technology, especially about their rise in medical industry for cancer treatment.

In the second chapter, we will talk about the basic physics, the functionality, the main components and limitations of this technology. This will be explained at the model of a typical S-band accelerator, as it is used at Siemens and other competitors for medical applications.
In a side view, we will look at the necessary assemblies, which are used to operate this type of accelerators appropriately, like modulators, injectors or dose chambers. An example of a complete system in a clinical environment will be shown.

The third part of this talk will open a window in the industrial fields like security business (e.g. cargo screening) or NDT (non destructive testing) and point out how worldwide linear electron accelerators might become more and more important.

A brief look at our facility in Rudolstadt, Thuringia, will close this talk.

Production of accelerators and accelerator components in industry

Michael Pekeler, ACCEL Instruments GmbH

The production of superconducting magnets, normalconducting and superconducting RF cavities and accelerator modules and complete linacs used in high energy particle accelerators or synchrotron light sources will be described. The development of a superconducting cyclotron including beam lines and gantries for medical proton therapy will be briefly presented. An overview of other usage of accelerators in industry will be given.

Review of new technologies in semiconductor detectors

Abstract

Planar Silicon detectors have transformed the way we look at ionising particles and x-rays. They are nowadays important players in high energy physics with several hundreds of square meters only in the LHC experiments, and are getting more and more used in medicine and biology. However the future challenges posed by the need to cope with high radiation levels, tiny radiation lengths, fast response and rates, high detection efficiencies and large area coverage are pushing the high energy physics and bio-medical communities to search for new ideas in semiconductor detectors.

This talk will explore the near, medium and far future in new technologies in semiconductor sensors. Strategies on tracking in the upgraded LHC luminosity and Linear Colliders environments will be discussed together with proposed ideas on semiconductor detectors perspectives in x-ray imaging.

Semiconductors as Particle Detectors

Dr. Ingrid-Maria Gregor, DESY

In this presentation an overview on the use of semiconductors as particle detectors in the fields of high energy physics and astrophysics will be given. After an introduction to semiconductor detectors, existing semiconductor detectors will be described. The focus will be on challenges in future high energy physics experiments. Different concepts depending on the physics demands and running conditions will be introduced. Examples for detectors at the sLHC and a Linear Collider will be shown.

Accelerators and Detectors at the Technology Frontier

Hans-Günther Moser,

Max-Planck-Institut für Physik, 80807 München, Germany

In particle physics photon detectors are mainly used for detection of scintillation light in calorimeters, but also used for the detection of Cerenkov light in RICH detectors or air-shower telescopes. Semiconductor detectors (Silicon PIN-diodes) have been used successfully for the readout of crystal calorimeters with high light yield. In other applications, especially if ligh levels are low or if accurate timing is required, photomultiplier tubes are still dominant.

However, new devices, like avalanche photodiodes (APD) or silicon multipliers (SiPM: Geiger APD arrays) have the potential to replace photomultiplier tubes in those fields. Their advantages are superior quantum efficiency, low cost and insensitivity to magnetic fields.

In this seminar the basic principles of photon detection with silicon detectors (and other semiconductor materials) will be discussed. Special emphasis will be given to APDs and SiPMs.

Guillaume Potdevin

The X-ray Free Electron Lasers: a great opportunity for science, a challenge for detectors!

X-ray Free Electron Lasers are in the process of revolutionizing photon science ; not only will they improve by several orders of magnitude the available peak brilliance and pulse intensities, but they will also provide pulses of much shorter period than existing light sources (shorter than 100fs), and the light produced will also be almost completely coherent. This opens the road to a whole range of new experiments, such as ultra fast coherent diffraction imaging, high energy density matter experiments, or femto-second time resolved experiments.

These new experiments will also set the detectors requirements at an unprecedented level: the position sensitive detectors will have to register at very high speed (up to 5MHz for the European XFEL) up to 10^4 photons per pixel (up to 12keV) while maintaining single photon sensitivity. In addition they may have to face integrated doses of the order of 1GGy, within a few years of operation. Those requirements have triggered the development of innovative technical solutions such as *dynamically gain switching* or *non linear-response DEPFET* based amplifiers, *in-pixel digital or analogue storage pipelines,* and large and flexible DAQ systems.

During this talk some examples of scientific applications of XFEL facilities and their attached requirements for detectors will be presented. Then emphasis will be put on the specific difficulties attached to detectors development for XFEL applications, and finally a presentation of the innovative technical solutions adopted for the three European-XFEL large pixel detectors projects, will be given.

N. Otte

Photo-detectors in Astroparticle Physics

Astroparticle physics is a relatively new field that intersects particle physics, astronomy and cosmology. The field uses, for example, neutrinos, charged cosmic rays and gamma-rays as messengers to study fundamental questions such as the origin of cosmic rays, the evolution of the Universe or the nature of dark matter.
A common problem in astroparticle physics are low event rates, which require large detector volumes, for example, the atmosphere or ice. One possibility to cover large volumes is by "watching" it with photon detectors and detect photons that are emitted in secondary processes after an interaction of the primary particle in the detector volume. Three examples of existing ground-based astroparticle detectors that use photo-detectors are the neutrino detectors ICE cube and ANTARES, the cosmic ray experiment AUGER, and gamma-ray experiments such as Cherenkov telescopes.
I discuss the requirements of photo-detectors in these experiments and suitable photodetector
candidates.

“Advances in Position Sensitive Photodetectors for PET applications”

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Abstract

Positron Emission Tomography (PET) is a nuclear medicine imaging technique which produces a three-dimensional image of the spatial distribution of a positron-emitting radioisotope (radiotracer). This gives information about the functional processes in a living subject.

The PET principle is based on the simultaneous detection (within a time window of the order of 5-10 ns) of the pair of back-to-back gamma rays emitted by the annihilation of the positron with an electron. A key part of a PET system is the gamma ray detector system that surrounds the patient. Each pair of two detectors involved in a coincidence event provides the position of the interaction of the gamma within the detector itself and the measure of the energy released in the interaction. This is usually accomplished by the use of inorganic scintillators coupled to some sort of position sensitive photodetectors (PSPD). The well established solution for the clinical PET cameras is the so-called “block detector”.

The position sensitive photo detectors so far applied in dedicated fields such as small animal imaging never made the big leap forward into the world of clinical PET. The recent advances in front-end electronics and computing technology and the increasing need for multi modality instrumentation such as PET/MR has now opened new opportunities for the advent of novel kinds of detectors. After more than 20 years from its introduction now is time for a change of the clinical PET detector module.

This presentation is a brief review of the use of position sensitive detectors in PET together with an overview of the near-future perspectives. A special attention is given to the development of a new class of magnetic field compatible solid state photodetectors: the so-called Silicon Photo-Multipliers (SiPM).

Abstract for the 430th Heraeus-Seminar "*Accelerators and Detectors at the Technology Frontier*", April 2009, Bad Honnef, Germany

Positron-emission-tomography (PET) applications in neuroscience

Professor Dr. med. Peter H. Weiss-Blankenhorn

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Positron-emission-tomography (PET) is a widely used imaging technique in basic and clinical neuroscience research. In fact, functional imaging of brain activity in healthy subjects and patients started with PET. In the recent years, PET has been complemented by other imaging methods, like functional magnetic resonance imaging (fMRI), magnet-encephalography (MEG), transcranial magnetic stimulation (TMS) etc. In this overview, the application of the PET technique in three areas of current neuroscience research will be highlighted.

In the area of motor cognition, PET is indispensable when active motor processes are examined. Complex motor deficits after stroke, like the apraxias, involve disorders of imitation and object use. Studies using PET helped to disentangle the neural substrate underlying the imitation of meaningful and meaningless movements and the object-trigger system. Furthermore, the differential neural mechanisms supporting action in near and far space based on clinical observations in neurological patients with neglect were characterized with the help of PET.

Deep brain stimulation (DBS) has proven to be an effective treatment of movement disorders, like Parkinson's disease. However, the patho-physiology underlying the beneficial effects of DBS is not well understood. In a series of PET studies, the neural consequences of motor and cognitive DBS effects were determined. Moreover, the less known effects of DBS on autonomous functions in Parkinson's disease (e.g., sensory gating) were investigated by PET.

In recent years, PET has gained importance in the field of pharmacological and receptor imaging. The clinical diagnosis of Parkinson's disease is aided by imaging the dopaminergic system with PET. While imaging of the serotonergic transmission is an essential part of investigations dealing with psychiatric disorders, like schizophrenia, measuring the neurotransmitter adenosine with PET allows insights into the (patho-)physiology of sleep.

Rüdiger Schmidt (CERN)

ABSTRACT: “The LHC accelerator: Technology and First Commissioning”

For the LHC to provide particle physics with proton-proton collisions at the centre of mass energy of 14 TeV with a luminosity of 10^{34} $cm^{-2}s^{-1}$, the machine operates with high-field dipole magnets using NbTi superconductors cooled to below the lambda point of helium. The LHC requires both, the use of existing technologies pushed to the limits as well as the application of novel technologies. After commissioning of the highly complex hardware systems, beam operation started in September 2008. In only a few days the beam was captured and stored, with a lifetime of several hours. A large number of measurements were performed. The performance with beams was very promising, indicating that first collision could be achieved within a few weeks. On 19 September 2008, during powering tests of the main dipole circuit in one of the LHC sectors, a serious electrical fault produced an electrical arc resulting in mechanical and electrical damage. Helium was released from the magnet cold mass contaminating the insulation and beam vacuum enclosures. The lecture will introduce the LHC, discuss initial beam commissioning and will conclude by describing the ongoing activities and an giving outlook to the future.

Rasmus Ischebeck (PSI)

Advanced Accelerator Concepts

Present particle accelerators are based on radiofrequency cavities. Accelerating fields of up to about 100 MV/m are routinely achieved, and the technology is mature enough for large research facilities and for medical applications. The accelerating fields are limited by breakdown on the cavity surface. Several possible concepts to overcome these limitations and to generate fields of several GV/m are being studied, ranging from higher frequency metallic cavities to dielectric structures and plasma wakes. Power sources include the wake fields of high-current drive beams, as well as pulsed lasers. I will present experimental results, including the demonstration of electron acceleration in vacuum by the electromagnetic field of a laser, and the energy doubling of 42 GeV electrons in a meter-long plasma wake and give an overview of this very active research area.

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Title: New Trends in Detector Development for Particle Physics

Abstract:

Great discoveries in particle physics are quite frequently connected to novel particle detection techniques. At present, we are witnesses of an era with exciting prospects for discoveries beyond the Standard Model, using a new generation of accelerators. We will discuss examples of the instrumentation for the particle detectors either installed or being planned for these accelerators, and indicate some new ideas emerging for even more powerful detector systems, to be considered for future accelerator projects.

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