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Course description: Experimental techniques in particle physics

Introduction:

PhD students joining a large collider experiment have normally not participated in the design of the experimental apparatus. Yet it is very important to understand why a particular experiment is designed as it is and what limitations and possibilities this imposes upon the physics questions one can address by the experiment.

Another aspect is to understand how to correct measured data for instrumental shortcomings so that the correct result of the collision can be reconstructed. Also for these corrections, the PhD student is likely to use tools (computer simulations) which others have constructed, at least partly.

The main objective of the course is therefore that the student learns the basic principles of making collisions and detecting the emitted particles. Stimulated by this, the student analyzes how this has influenced how a particular experiment has implemented these principles.

The approach can be as technical as the student prefers. The theoretical student can view individual detector cells as black boxes which provide an output proportional to the energy deposit, while the technically interested student can also include the mechanisms for extracting a signal, amplify and digitize it. Thus the topic is very suitable for PBL-pedagogy within a mixed group with wide spread interests and learning needs.

The course focuses on the experimental techniques used in high energy physics and examples are chosen from high energy physics. However, the general principles, are applicable also to nuclear physics and astro-particle physics experiments and even for medical imaging by ionizing radiation.

The PBL cycles:

The course divides in five one week cycles each representing a PBL cycle.

PBL1. *Interaction by particles in matter creates detector signal*
PBL2. *Tracking for momentum and particle identification*
PBL3. *Calorimetry and lepton identification*
PBL4. *Analog and digital processing of detector signals*
PBL5. *Accelerator techniques*

It is preferable PBL 1-4 are given in the sequence indicated but PBL2 and PBL3 can be interchanged without problem. PBL5 can be given at any time in the sequence.

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Learning goals:

PBL1. *Interaction by particles in matter creates detector signal*
This cycle covers the different ways by which particles interact with matter by electromagnetic and strong interactions. Electromagnetic interactions result in ionization, and excitation of atoms in the material. The formalism for a charged particle energy loss in matter as described by the Bethe Bloch formula is worked through and its consequences for particle detection are analysed in particular in the relativistic limit. Properties of materials suitable as detectors are discussed. The concepts of energy loss by Cherenkov and transition radiation are studied. Low energy particle identification by ΔE-E measurements is described. Practical limitations for stopping particles are identified.

PBL2. *Tracking for momentum and particle identification*
High momentum particles can not be stopped by ionization energy loss only. High resolution energy measurement thus have to be made by determining the momentum from the curvature of particle tracks in a magnetic field. Different gas filled ionization detectors for charged particle tracking are discussed. Secondary vertex detection by silicon detectors is also studied. Particle identification by flight-time, Cherenkov and transition radiation detectors is introduced.

PBL3. *Calorimetry and lepton identification*
For neutral particles and if the particle momentum is too high to obtain sufficient momentum resolution, calorimetry has o be used. Electromagnetic as well as hadronic calorimetry is studied. Calorimetric response for particles interacting by electromagnetic, weak and strong interaction and how the fundamental interactions are used to identify photons, electrons and muons are studied. Materials and readout of sampling and crystal calorimeters are discussed.

PBL4. *Analog and digital processing of detector signals*
The information from a detector is the amount of charge (normally femto coulombs) which is proportional to the deposited energy. The electronic chain how to convert charge to voltage, amplify the voltage signal, digitize pulse amplitude and time, suppress zero data and build an event and to save the event to mass storage is followed. The parallel chain of extracting fast triggering information from the amplified signal through different levels of physics based electronic and computational selection mechanisms by which the data sample is enriched up to a million times in real time, is paid special attention. Examples are taken from ATLAS and ALICE.

PBL5. *Accelerator techniques*
The accelerators used in high energy physics are discussed. The principles of injection, acceleration and storing beams of protons and ions in a synchrotron-storage ring is worked through. Special emphasis is paid to the parameters that the experimenter has to understand and by which the experimental search is optimized. Concepts as emittance, storage time and luminosity are discussed. In particular methods, to measure the luminosity and to make an absolute normalization of the experimental result are worked through.