Introduction to Phenomenology and Experiment of Particle Physics (PEPP)

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Abstract

Introductory chapter to the course PEPP 15 ECTS credits

1 Introduction

This course is the largest one in the present doctorate program. The more theoretical backgrounds you have learned in the courses Quantum Field Theory (QFT) and Standard Model and Extensions (SME). The more experimental aspects have been covered in the Experimental Methods (EXP) and Statistics and Error and Data Analysis for Particle and Nuclear Physics (SED) courses.

In this course the emphasis will be in how the parts you have learned in the other courses are applied together to understand the basic phenomena in particle physics. The PBL cycles in this course will thus require you to put together the knowledge from your other courses in a coherent fashion and extend it. Unfortunately, as you will discover the road from the underlying theory and the actual measurements can be a long one.

We will not follow any historical route or any of the more traditional ways of teaching particle physics. Instead the course consists out of a series of different but interdependent topics within the Standard Model.

2 Course Overview

2.1 The cycles

The course consists of 10 one week PBL cycles. The first eight are phenomenologically oriented and consists of both the theoretical methods and more importantly approximations that go into the description of the physical processes as well as of the experimental methods used to identify them. Since for all observables the strong interaction (QCD) plays a crucial role in actually determining the experimental characteristics of an underlying process, the course in effect introduces many of the techniques used in analyzing the purely strong interaction as well. The last two PBL cycles can be thought of as the culmination of the course part in total. It consists of putting together all the tools used in earlier parts of this course as well as the others to study neutral pion production and Higgs detection.

- Matrix element description of hard processes
- QCD cascades
- Multi-particle production
- Hadronic collisions
- Minimum bias

- Event properties
- Basics of Heavy Ion physics
- Flavour Physics at the LHC
- An experiment from start to end
- Higgs detection from beginning to end

2.2 Why this order

The order of the cycles is in increasing QCD complexity of the processes discussed. We start with the underlying fundamental process. This can be calculated directly in terms of standard Feynman perturbation theory from the underlying theory. The next cycle introduces the subject of QCD cascades. A strongly interaction particle can radiate gluons and quarks at high rates. This means that processes with a complicated final state and a large number of quarks and gluons are what really should be calculated. The method of QCD cascades is the main tool in handling this. The third cycle introduces what is really observed in the experiments, the hadrons and how the final states are produced from the QCD cascades discussed in the previous cycle. At this level we can in principle describe electron-positron collisions.

The next two cycles add again another level of complexity. We now also introduce hadrons in the initial state. This means that the radiation of quarks and gluons before the main hard interaction also needs to be treated in detail. The first cycle introduces the main aspects of this type of collisions while the second introduces the consequences of the fact that hadrons in general contain more strongly interacting particles than those contributing to the main hard process, as well as the fact collisions can happen without a hard collision present as well.

The next two cycles use all the ideas learned in describing the final state and how these ideas are put in practice with event generators. Heavy ion physics at high energies then is pushing the strong interaction complexity to an extreme such that it becomes simpler again and a new class of collective phenomena can appear.

The cycle on flavour physics is included both because it will play a role in LHC physics and because of the fact that strong interaction effects are once again important if one wants to go from the underlying standard model processes to what is actually observed.

The last two cycles, as mentioned above, are in a sense the culmination of the course part. They show how to put all the methods and tools introduced earlier together to analyze two experiments.

2.3 Matrix element description of hard processes

This cycle introduces the basic processes that underly the events and which can be calculated using Feynman diagrams in the standard Quantum Field Theory perturbation expansion. This cycle will treat three classes of processes, the basic QCD processes of scattering of quarks and gluons, the basic Electro-Weak processes like production of W and Z bosons and more complicated conventional processes that are important as backgrounds to 'new physics' processes.

2.4 QCD cascades

The strongly interacting quarks and gluons in the final states can easily radiate other quarks and gluons. This has as a consequence that one really should calculate an infinite number of processes to get realistic predictions. This cycle introduces the methods needed to handle this infinite sum of processes with so-called QCD cascades. The intermediate (infrared) divergences have as an underlying consequence the so-called Sudakov logarithms and the standard method to handle these using splitting functions is also introduced.

2.5 Multi-particle production

The radiated quarks and gluons of the previous cycles are in fact not observed directly because of the confinement of QCD. The process how these turn into hadrons is called hadronization and is the main subject of this cycle. In addition after the formation of hadrons the higher mass states decay into the lower mass stable ones before detection. This cycle describes how these aspect are modeled and introduce the concept of jets, the way high momentum quarks and gluons are more or less directly visible.

2.6 Hadronic Collisions

Hadrons themselves can also appear in the initial state. For hard collision there is a separation possible between the hard process and the intrinsic properties of the hadron. The latter are described by the so-called parton distributions. They are introduced in this cycle as well as how they are used to calculate actual cross-sections. The QCD cascades studied earlier in the final states happen also in the initial state and their main treatment by the use of evolution equations for distributions will be studied.

2.7 Minimum bias

The emphasis in the earlier cycles was on the hard processes and aspects directly related to it. In this cycle we study the other strong interactions that can happen, both soft and semihard. The former are the main part of the total cross-section but the latter play a main role in cross-sections and other properties via multiple interactions.

2.8 Event properties

It is not always necessary to study the full exact final state. This cycle is concerned with some more general properties of the events as seen in the detectors, the so-called event shapes. The major tool in implementing the ideas of the previous cycles, event generators, is also introduced and used in some simple exercises.

2.9 Basics of Heavy Ion physics

When nuclei are interacting instead of protons the situation is more complex. This cycle deals with high energy nuclear collisions, resulting in systems with extreme conditions regarding densities and temperatures. Recent experimental results indicate that the matter produced in these collisions consists of quarks and gluons rather than of normal nuclear matter. This state of matter does, however, not look like the Quark-Gluon Plasma predicted by theories. Instead it seems to have properties resembling a perfect liquid.

2.10 Flavour Physics at the LHC

This cycle treats another aspect of the physics that will be done at the LHC, in particular Flavour Physics with a strong emphasis on the possible physics of hadrons containing b-quarks. The cycle will give an overview of the underlying theoretical methods and in particular how the large QCD effects are treated using effective Hamiltonians. The question of the unique identification of relevant events as well as the observables, both CP-conserving and CP-violating, and the different types of observable CP violations will be studied.

2.11 An experiment from start to end

This is the first of two cycles where we will go through the entire process from the underlying theory to the experimental detections. In this cycle we construct a simple, semirealistic particle generator based on an expected P_T spectrum of neutral pions. The next step is to write a GEANT simulation based on an electromagnetic calorimeter with simple geometry. The generated particles should then be run through this simulation and the results treated as real experimental events. For these one should then identify the elecromagnetic showers and identify the neutral pions by reconstruction of the invariant mass. The P_T distribution is then determined, corrected for acceptance and efficiency by comparing the measured distribution with the input distribution.

2.12 Higgs detection from beginning to end

This cycle will take a different type of experiment than the previous one and one which will play an important role in the ATLAS physics program. Here the idea is to write a simple event generator for Higgs production from gluon-gluon collisions. Then the Higgs will be assumed to always decay to bottom quarks. With the tools learned in the earlier cycles one should build a simple event generator including the production of the jets. The main goal in this cycle is then to study how well ATLAS can determine the mass of the Higgs via this chain. An important part at the end is the discussion of backgrounds for this process.

3 Literature and Examination

This will be distributed with the different cycles separately.