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Übungen zu Teilchenphysik I

Wintersemester 2024/25

Exercise 6 To be worked on until January 16, 2024

$H \to ZZ$: Higgs boson discovery

The discovery of the previously predicted Higgs boson was made at the LHC (CERN) in 2012 and thus an important piece of the Standard Model of particle physics was confirmed. One of the decay channels that led to the discovery was the decay into four leptons. Compared to the other decay channels, this decay channel is ideally suited for analysis inside a Jupyter Notebook, which you will carry out in this assignment.

The focus of this exercise will be to rediscover the decay of the Higgs boson into two Z bosons, which in turn decay into four charged leptons, $H \to ZZ \to 4\ell$. From all charged leptons, only electrons and muons are used in the analysis, since decays of the Z boson into two τ leptons, $Z \to \tau\tau$, are much more difficult to handle, and it will be more difficult to distinguish the $H \to ZZ$ signal from backgrounds[1].

The aim is to increase the sensitivity of the unfiltered data set and to achieve a high ratio between the background and the signal by requiring certain thresholds on specific quantities. At the end of the exercise, the significance of the carried out measurement will be estimated. Based on the resulting significance, a first statement about the detection of a Higgs-like boson in this decay channel can be made. A detailed statistical treatment of the significance or the combination of measurements to increase the significance might be presented in one of the further TP2 courses.

The inspiration for this exercise is the following example analysis.

[1] The τ leptons decays before they reach the first tracker layer but it is possible to reconstruct them from the visible final states. The difficulty arises with the additional neutrinos in the available τ lepton decays.

Event visualization

To get familiar with the signatures of proton-proton collision events recorded by the CMS experiment, have a look at the visualization of the CMS detector with the iSpy WebGL. To investigate some events, download a small fraction of the data set from this exercise to your local machine, click on the folder icon on the `iSpy WebGL` website and use the *Open local file(s)* option to select your file. The various components of the CMS detector, which are used to detect different particles, are illustrated in Fig. 1.

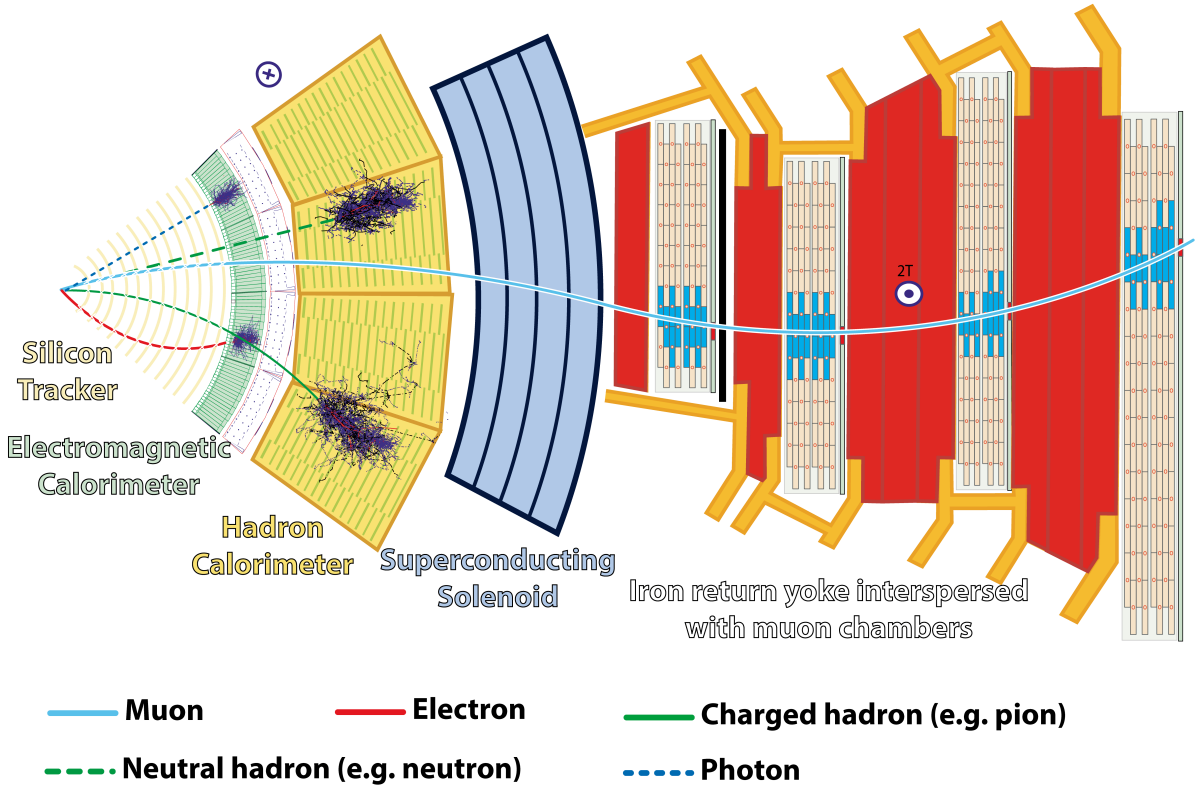

Figure 1: Slice showing CMS sub-detectors and how particles interact with them[2].

By using `iSpy WebGL`, try to understand the functionality of each component by enabling them in the 'Detector' menu, and select events with interesting signatures from the event collections. Try also to enable and disable 'Physics' objects in the corresponding menu. The main task in this section is the exemplary manual classification of the results according to their decay channels. The classification is later automated using software designed for this purpose.

[2] https://cds.cern.ch/record/2120661

The data set contains events with different Higgs boson decays. Try to identify an event for each of the following decay modes based on the signatures in the event display:

- $\mathrm{H} \to \mathrm{ZZ} \to 4\ell$
- $\mathrm{H} \to \gamma\gamma$
- $\mathrm{H} \to \mathrm{W}^+\mathrm{W}^- \to 2\ell 2\nu$

How would the typical signature of these individual decays appear in the detector? You can save an image of the current view by using *Print Image to File* (camera icon).

For the rest of the exercise, i.e., the data analysis part, we will again use a Jupyter Notebook on the jupytermachine (Datenanalyse). The notebook can be found in the tp1_forstudents repository.