Particle hunting with data from the Large Hadron Collider

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Abstract

About the ***Project Overview***:
Our project focuses on scanning high-energy particle collision data from the Large Hadron Collider (LHC) available through the CERN Open Data portal. The goal is to identify specific particle species by reconstructing their properties using methods of particle hunting applied to different data-objects, such as electron-based vs. muon-based measurements."
About the ***Data collection***:
The data used in this project come primarily from the Compact Muon Coil (CMS) experiment, CMS is the main experimental sites on the Large Hadron Collider (LHC), this study focuses on the CMS detection data for analyzing the results of high-energy particle collisions and identifying specific particle species.

Key Concepts

- ***Particle Physics:***
  Particle physics studies the smallest building blocks of matter-subatomic particles, such as protons, electrons, and quarks, governed by fundamental forces. This field centers on the Standard Model, which describes all known particles and forces except gravity.
- ***Large Hadron Collider (LHC):***
  The Large Hadron Collider (LHC) at CERN is the world's largest particle accelerator, colliding protons or heavy ions at high energies to study fundamental forces. Its key achievements include discovering the Higgs boson in 2012.
- ***Standard Model***
  The **Standard Model** is a comprehensive theory in particle physics describing fundamental particles and their interactions (excluding gravity). It's often compared to a periodic table for subatomic particles.
- ***Invariant mass***
  Invariant mass is a key concept in particle physics representing the combined energy and momentum of particles. It is used to identify particles in high-energy collisions, such as detecting the Higgs boson at the LHC.
- ***PDG(Particle data group)***
  For more detailed information on particle physics concepts, please refer to the Particle Data Group's 2022 Particle Physics Booklet.

Calculate the invariant mass

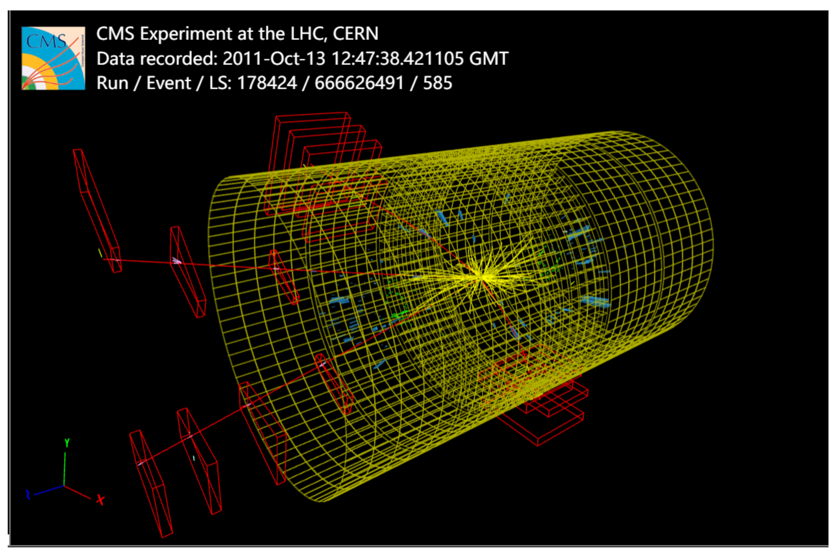
To calculate the invariant mass of two muon leptons, we use the following formula:

$$M = \sqrt{(E_1 + E_2)^2 - (p_{tot1} + p_{tot2})^2}$$

Here, E_1 and E_2 are the energies, and p_{tot1} and p_{tot2} are the momenta of the two muons. The data can be accessed using specific functions in the dataset (e.g., data.E1, data.px1). We used Python's NumPy library for the calculation, ensuring that functions like sqrt are correctly defined.

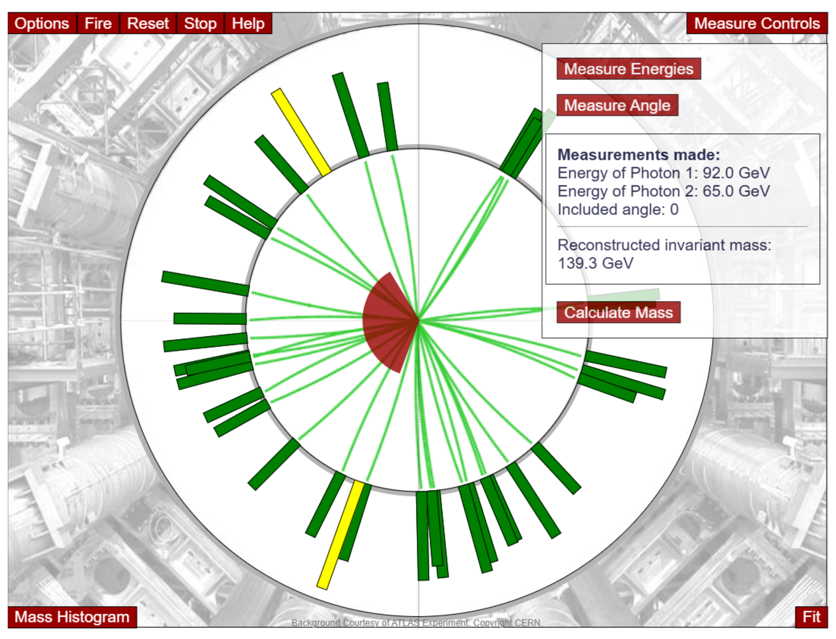
Visualizing Collisions

This was our first experience with data analysis from particle collisions. We used the CMS event display tool to visualize some collisions and familiarize ourselves with the data. This tool allows you to visualize actual collision events that contributed to the discovery of the Higgs boson in 2012. By following a few simple steps, you can explore events where the Higgs boson transforms into photons or leptons, providing a hands-on way to understand the data analysis processes used in particle physics research.



Identification and reconstruction of particles using LHC experimental data

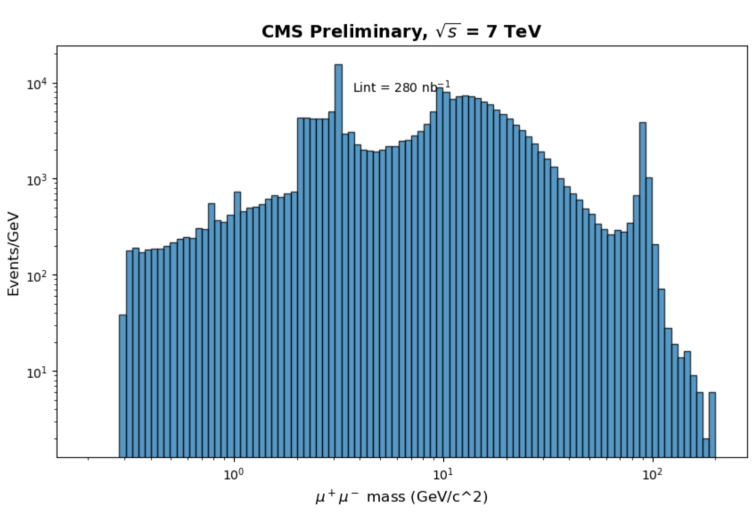
This section simulates the LHC's working principles, allowing users to adjust parameters and reconstruct the Higgs boson's mass. The simulation demonstrates how to identify potential Higgs boson events by measuring photon energy and direction, mirroring the methods used in our project.
With a simulation tool developed by the HEP group from Lancaster University.



This figure shows a simulation of how the Large Hadron Collider (LHC) identifies and reconstructs the mass of the Higgs boson. Users can adjust parameters like magnetic field strength and energy thresholds to observe their effects on detecting photon energy. By measuring photon energies and angles from collisions, the simulation calculates the invariant mass, helping to identify potential Higgs boson events.

Plots for di-muon mass

This graph shows a histogram of the invariant mass distribution of muon pairs (μ^+, μ^-) measured in the CMS experiment. This histogram is commonly used to analyze events in high-energy particle collisions

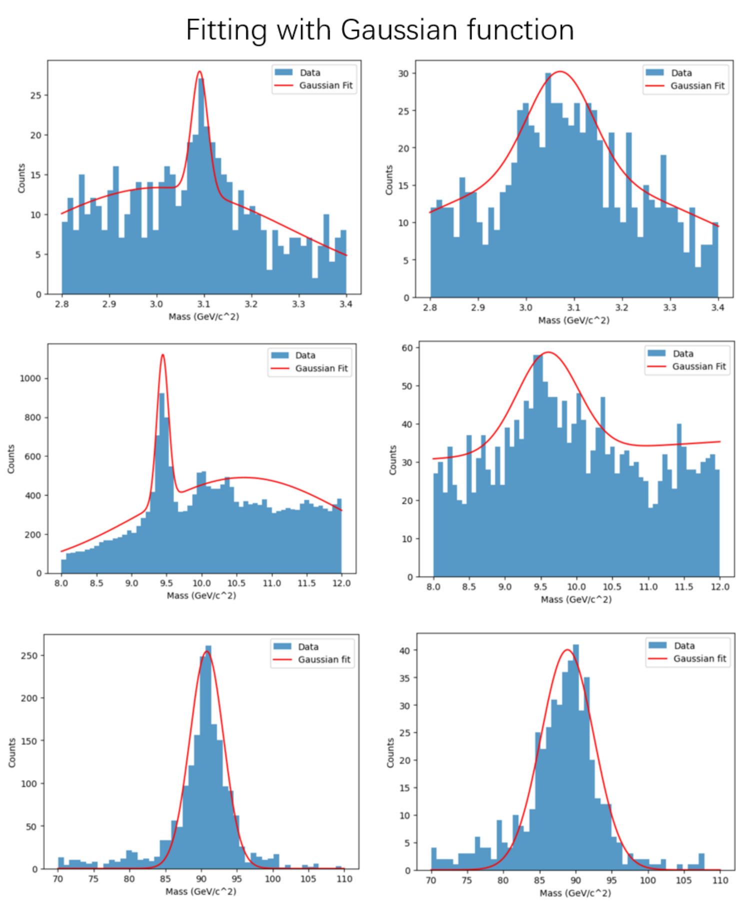


Fit the mass peaks at 3GeV, 9GeV and 90GeV

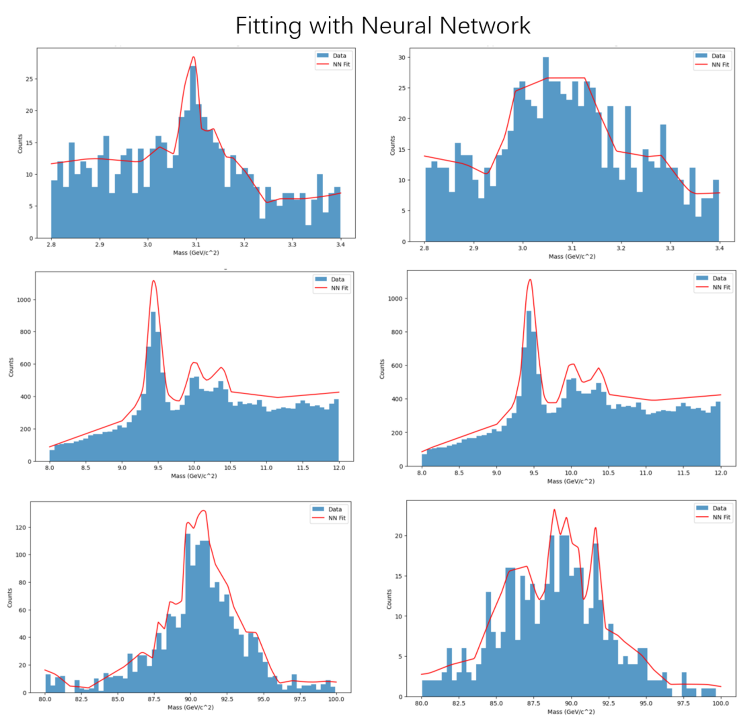
In this section, we focus on fitting the peaks observed at 3 GeV, 9 GeV, and 90 GeV in both di-muon and di-electron plots. The 3 GeV peak corresponds to the J/ψ meson, the 9 GeV to the Υ (Upsilon) meson, and the 90 GeV to the Z boson. To model these peaks accurately, we employed two methods for comparison.

- The left column shows fits for di-muon events, while the right column shows fits for di-electron events.
- The first, second, and third rows correspond to the fits at 3 GeV, 9 GeV, and 90 GeV, respectively.
- x-axis: reconstructed mass (GeV).
- y-axis: number of entries per mass bin.

Fitting with a multi-Gaussian peak function:



Fitting with neural network:



From the figure, the neural network fitting method seems more suitable than the Gaussian function.

Conclusions

This work provides a foundation for deeper exploration, including analyzing larger data samples and comparing results with other experiments like ATLAS, potentially leading to new discoveries in high-energy physics.

References

- CERN Open Data Portal, http://opendata.cern.ch, accessed on August 21, 2024.
- Large Hadron Collider, CERN. Available at: https://home.cern/science/accelerators/large-hadron-collider, accessed on August 21, 2024.
- Review of Particle Physics by R.L. Workman et al. (Particle Data Group), published in Progress of Theoretical and Experimental Physics (2022, 083C01).