Examining Decay Mechanisms of the Higgs Boson

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Summary of research questions and results

1. How are the quantities p_t, ΔR between a tau and a neutrino, and ΔR between a muon and a tau, different between decay mechanisms?
   P_t for a flavor violating decay is much higher than the p_t for a regular standard model decay. Both delta_R's for the standard model decays are less than the delta_R's for the flavor violating decays.
2. How do we select the above variables and decays so that we know whether the decay has flavor violation? Otherwise known as "making cuts".
   Choose the average between the maximum bins of the two curves. We chose the average because it was the most likely to throw away the most garbage events while keeping the most significant events.
3. How well does examining the quantities from (1) predict events with a Higgs decay into a τμ final state?
   The p_t is really good because in the standard model decay the p_t is split with neutrinos which take up to 2/3 of the energy away. The neutrinos also cause the angle between the muon and the tau to change. Even though the change is not as drastic as p_t, this still provides a good benchmark for discerning between two decay types.

Motivation and background

In particle physics, certain quantities must be conserved for an event to occur in nature. These quantities, quantum numbers, could represent several properties of a particle. This proposal directly relates to the quantum number known as *flavor*. Flavor refers to a way of classifying a family of particles that we call leptons. In the Standard Model of particle physics, the recently discovered Higgs boson should decay into groups of particles and antiparticles while preserving flavor. The Higgs is flavorless, meaning the particles it decays into should have flavors which cancel each other out. This means flavor is conserved – if the beginning and ending number is equal. But this might not be true for the Higgs boson because it is a new particle which has not been studied in as much detail as other particles.

If we can better understand how to tell if a decay is a flavor violating decay, then we can distinguish said decay from a Standard Model decay. The Standard Model of particle physics does not allow for quantities like flavor to NOT be conserved. So, if we could find some of these particle decays that violate flavor then these decays would be a brand new area of physics. This is a very exciting frontier for all physicists around the world, especially those at the Large Hadron Collider in Switzerland, where these decays are studied.

We want to find where the Higgs boson decays violate flavors. Using the analysis of questions 1 and 2, the relevant decays can be chosen from a very large dataset with many different types of decays. Once question 3 is answered, it can then be decided if flavor violating decays happen often enough to promote a new branch of particle physics.

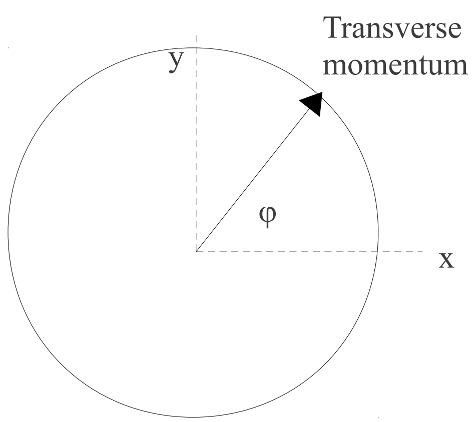
Dataset

The dataset is a collection of particle information and each particle's kinematics and decay information. This dataset was generated by a series of three programs: MadGraph5, Pythia 8, and DELPHUS. MadGraph5 and Pythia 8 are Monte Carlo generators and DELPHUS is a fast detector simulator. This dataset is currently being used in an actual study at the University of Washington Physics department.

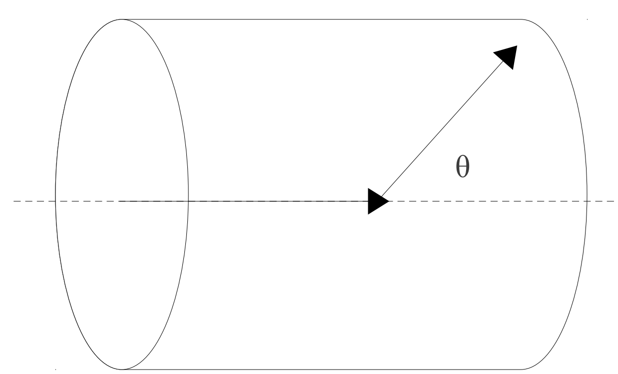
The program will check for a download of the necessary files. Some of the files are full of only flavor violating decays, some have flavor conserved decays, and some files have both.

Each file, regardless of what type of decays it contains, has the following format. The first column gives the number for each particle in a given decay event. The second column gives the Particle Data Group's identification of the given particle, represented by a number (for more information see http://pdg.lbl.gov/2002/montecarlorpp.pdf). Next, the status is listed for each particle. Status 1 means the particle is stable and status 2 means the particle is unstable. In columns four and five, the daughters can be found. This refers to what the particle is decaying to. If this column contains a -1, then there will be no daughters because -1 indicates stability (no decay).

The next three columns contain the kinematic variables p_t, η, and φ. The transverse momentum, p_t, is orthogonal to the beam direction. η is a quantity called pseudorapidity which is a measure of how fast the particle is moving along the beam pipe axis. The angle φ is measured upwards from the x-axis, toward the y-axis. The figures below illustrate these quantities. The last three columns represent energy, mass, and charge.



Looking into the beam pipe



Side view of the beam pipe

Pseudorapidity, $\eta = -\ln(\tan(\theta/2))$
Transverse momentum, $p_t = \sqrt{((p_x)^2 + (p_y)^2)}$
ΔR = sqrt((delta_eta)^2 + (delta_phi)^2)

Methodology

There is no need to perform any data cleaning as the files are all in a usable format already. A few different algorithms will be used to choose decays and then plot the information accordingly. From these plots, the binning will be fiddled with to provide analyzable curves. From the intersection of the curves in each case, the location of the "cuts" from research question (2) can be determined. The curves will represent the Standard Model decays and the Flavor Violating decays. From this comparison, the ratio of the number of flavor violating decays to the number of total given decays can be found. This number will show how probable it is that the Higgs decays violate flavor, thus violating the Standard Model. This violation of the Standard Model would be the reason for a brand new study of particle physics.

Decay Class Algorithm:

1) Check the status column for the Higgs boson which is represented by the number 2. Also check the PDG column - it will be represented by the number 25.
2) Find the decay products of Higgs bosons by means of the daughter columns:
   1. Find status 1 mu in one branch of the decay (one daughter column)
   2. Find status 2 tau and follow its decay to see if anything later down the chain is a hadron (PDG ID>100) in the other branch
3) Add kinematic variables to a list:
   1. (mu, pt), (mu, eta), (delta phi (mu,tau))
   2. Make a histogram of the list by means of the histogram binning algorithm

Hist binning algorithm:

1) Make a plot with the x-axis ranging from zero to the maximum of the list. (This plot will not look very useful for the problem at hand)
2) Check the first bin's frequency. If the first bin frequency is less than ten percent of the maximum bin's frequency then delete that first bin, and widen the remaining bins. Repeat this process for the last bin, too. This process will widen the curve while keeping the curve just as accurate, essentially like zooming in.
3) The result will be a curve whose edges are ten percent of the maximum value.

Locating cut algorithm

1) Examine each of the histograms of the cut variables. These histograms will each have a SM curve and a FV curve.
2) Locate the spot where the curves intersect. This is the criteria for each cut for each relevant variable listed in the first research question.

Results

Unfortunately, I think the datasets are corrupted because there math domain errors in calculating kinematics because this is standard physics. So I could not get actual results.

Reproducing your results

To obtain the data necessary to perform this analysis, follow this link: https://www.dropbox.com/sh/bq42r64j9hjdngu/UabdWXMu4H. To perform the analysis, simply run the source code by typing in the command line:

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python flavor_violation.py
```

Collaboration

I did not collaborate with anyone on the code but I obtained datasets from William Johnson.

Reflection

I wish I had known more about classes before starting this assignment. I learned how to manipulate datasets very well.