Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Reconstruction of Boosted di-jets from di-Higgs Boson Decay into Four Bottom Quarks

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Hehe get it.. Higgs bison

Overview

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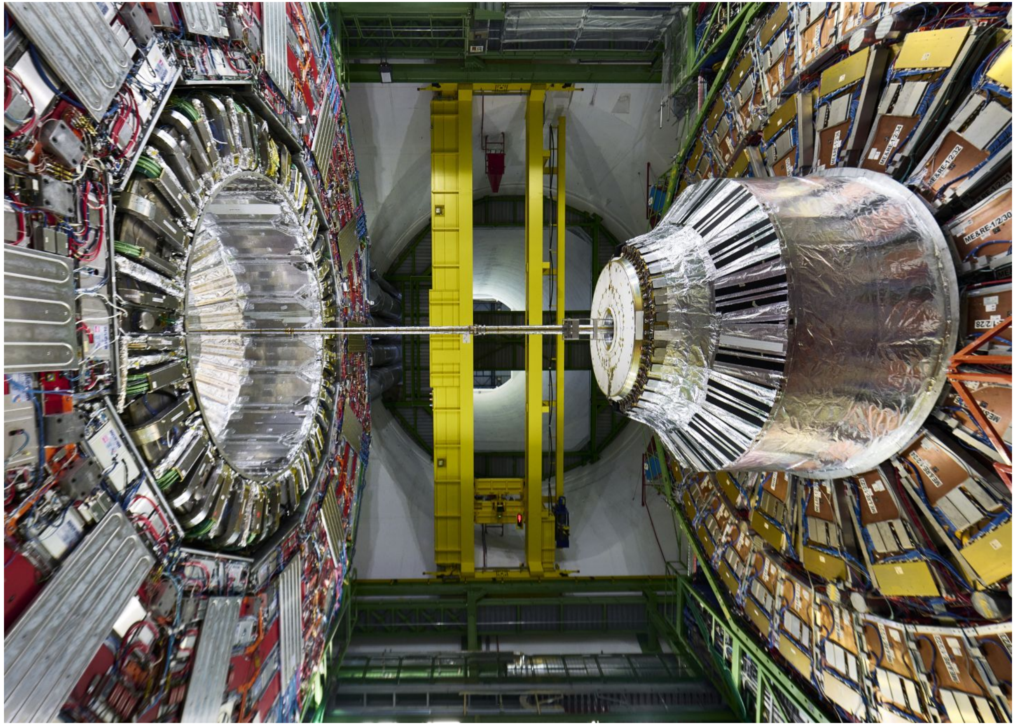
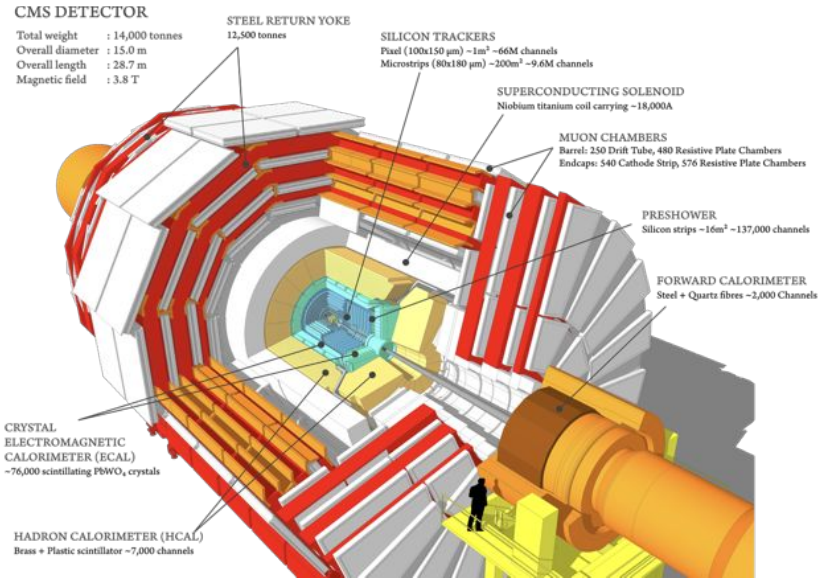


The Compact Muon Solenoid (CMS) at the Large Hadron Collider (LHC)

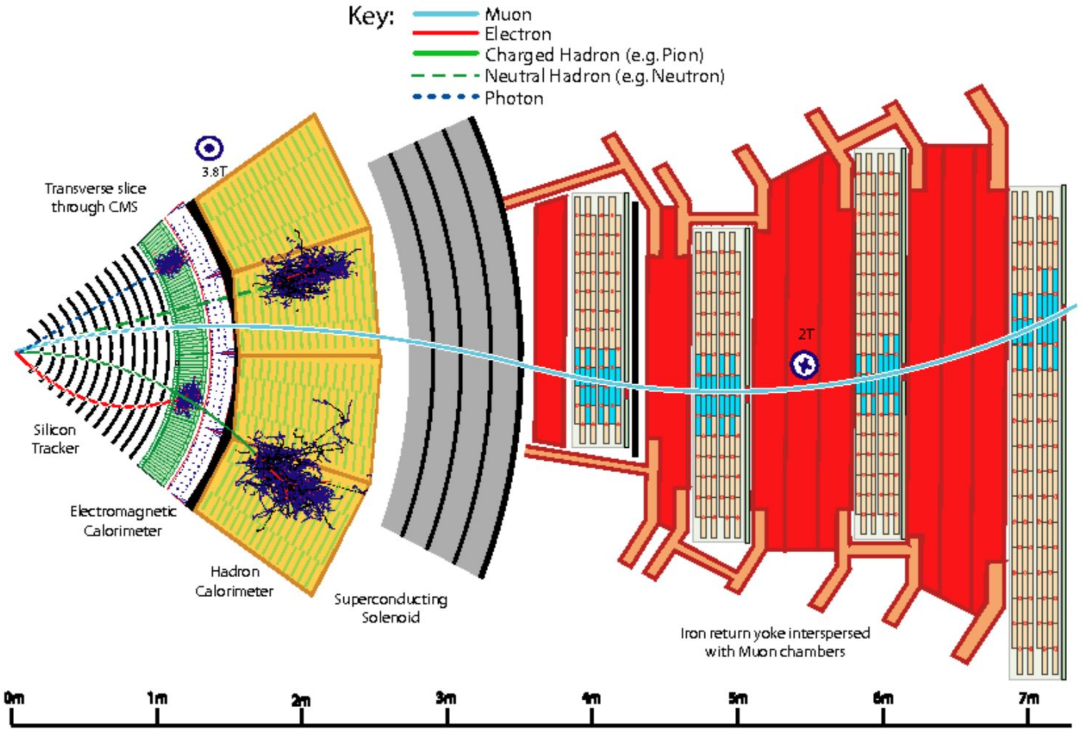
Introduction

- The CMS detector is one of four detectors at LHC
  - High energy beams shoot through the LHC perimeter, protons will collide close to the speed of light, and some energy is converted into mass, as new particles
    - ➢ **Superconducting Solenoid**: creates a uniform magnetic field to bend the paths of ejected particles
    - ➢ **Silicon Trackers:** records various positions of particles ejected, to calculate their momentums, & reconstruct their paths
    - ➢ **Crystal Electromagnetic Calorimeter (ECAL):** measures the energy of electrons and photons by stopping them completely
    - ➢ **Hadron Calorimeter (HCAL):** measures the energies of hadrons (particles made of gluons and quarks) by stopping them completely
    - ➢ **Muon Chambers:** detects muons after filtering through other particles, reconstructs its particle path to find momentum



A cutaway view of the CMS, and its components

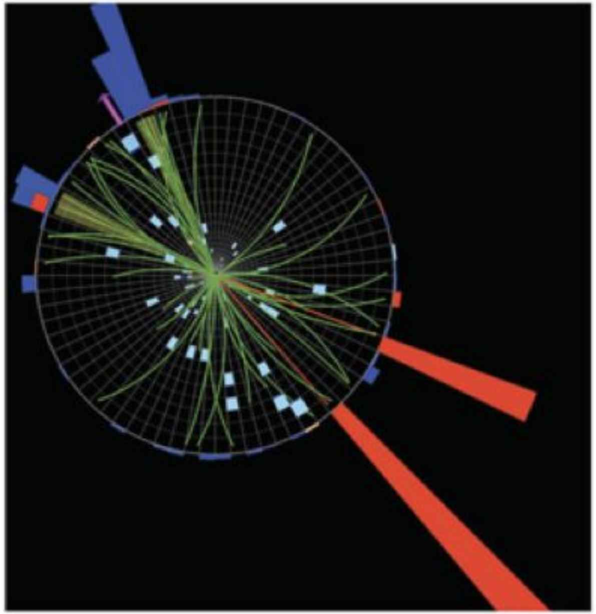
Introduction



A cross-sectional view of the CMS, and how it interacts with different particles

The Higgs Boson

- The Higgs boson is an elementary particle that was discovered in 2012 through the work at the LHC.
- What do we know?
  - It's a fundamental particle predicted by the Standard Model, theorized to explain how fundamental particles acquire mass
  - The Higgs field gives mass to everything in the universe.
    - The Higgs boson has self-coupling properties related to its mass, can lead to the infrequent production of two Higgs bosons, or di-Higgs boson particles.
    - Higgs boson have a short lifetime, and almost immediately decay in many different ways.
      - One of the most probable decays for a Higgs boson, with ~58% probability, results in the production of two bottom quarks.



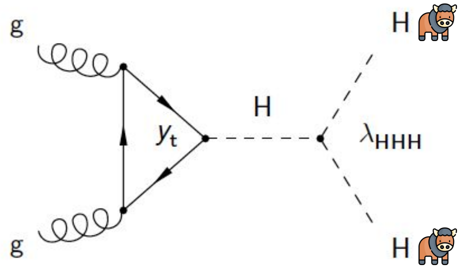
CMS candidate event for Higgs boson decaying into two bottom quarks

The Higgs Boson

- What don’t we know?
  - The Higgs boson has a very small mass, where does it come from?
    - Is it due to interaction with the higgs field? Is there relation to self-coupling?
  - Is the universe stable?
    - So far observations line up with our understanding of the SM Higgs boson and a stable universe, but for potentially massive Higgs boson particles we still need to collect more data to make an educated conclusion
  - The full story
    - The CMS is a general purpose experiment and can present indirect effects and phenomena that may illuminate new physics scenarios beyond the Standard Model

Purpose

Pair production of the Higgs boson in the standard model provides unique opportunities to look further into the structure of the Higgs potential. By measuring the production cross section, we are able to access the Higgs self-coupling to probe its effects on physics beyond the standard model.



Higgs pair production through gluon fusion, regulated by the trilinear Higgs self-coupling (λ), a fundamental parameter of the SM theory

Data Reconstruction

- Used proton-proton collision data from Run 2 (2016-2018) at 13 TeV, with simulated samples of di-Higgs signal hypothesis and SM background processes.
  - simulated processes that were modeled through a variety of Monte Carlo (MC) event generators to compare theory with collected data.
- We use a novel graph neural network (GNN) algorithm, Particle-Net, to identify jets that pass a boosted double b Higgs tagger requirement to select signal events.

Data Reconstruction

- Manual selections are made upon the data and background/signal processes to break down, and analyze the composition of the background that makes up our data.
  - Selections:

Selected Variable	Background/Signal	Data
Transverse Momentum	$p_T \geq 310$	$p_T \geq 310$
ParticleNet Xbb Tagger	$X_{bb} \geq 0.95$	$X_{bb} \geq 0.95$

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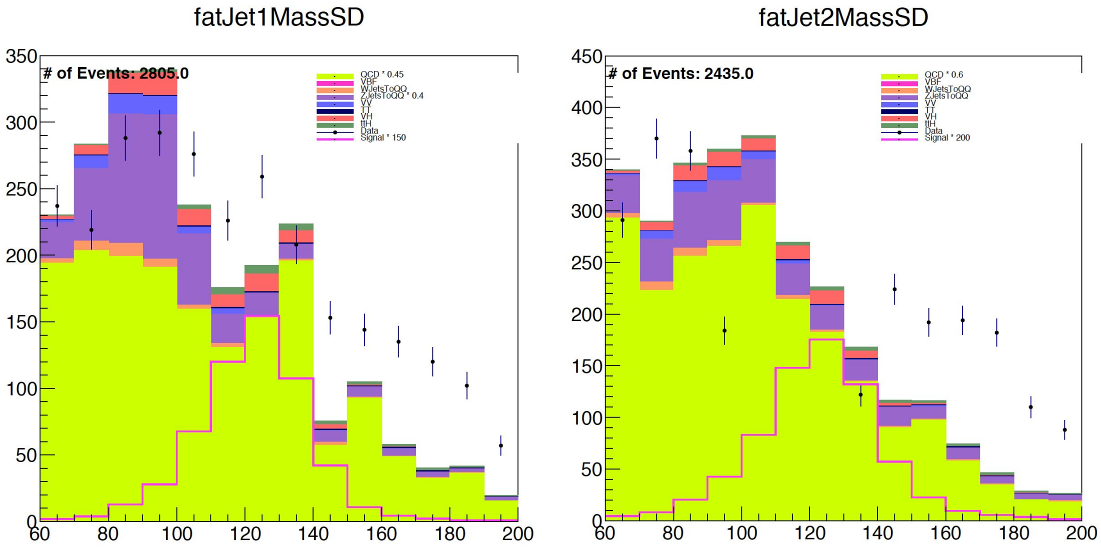
Plotting

- Histograms are constructed using the Python interface to ROOT C++.
  - **Goal**: validate existing analysis, to improve machine learning methods for jet tagging efficiency.
- Created histograms for desired variables
  - Contain events from all three years of collection, sorts the background process files into their categories to stack them, and draws the signal and data on top
  - Non-data histograms were filled with specific weighting per file, and normalized
- The plot had some extraneous background processes, mostly occupied by the QCD, with limited view of the signal.
  - Simulations then scaled depending on the number of events, to fit within our data curve.

Plots

Soft Drop Mass

- The soft drop algorithm is applied to Higgs boson jet candidates to remove soft and wide-angle radiation.
- These plots have different number of events due to the disparity in selections taken among variables.

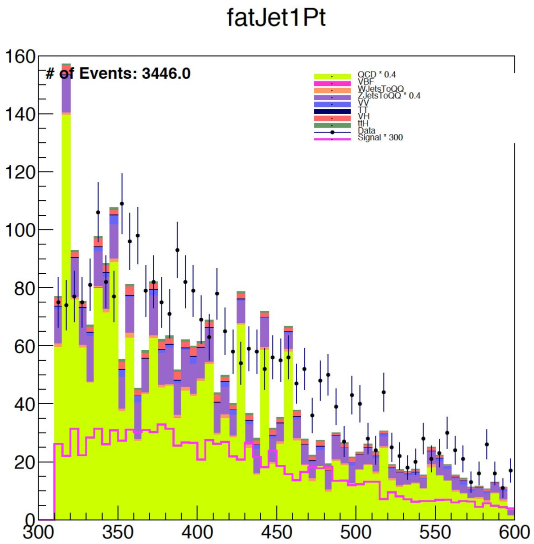


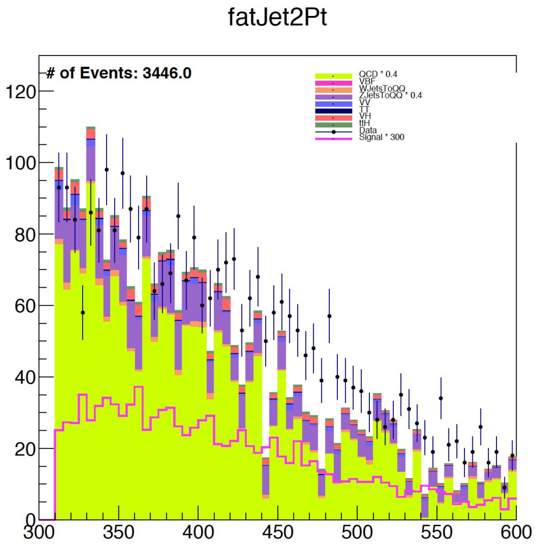
Soft Drop mass of Jet 1 (Left) and Jet 2 (Right)

Plots

Transverse Momentum of Jets

- We selected events with sufficiently large transverse momentum for the decay products of each Higgs boson to become merged into a single large-radius jet
- As you can see, there are clear disparities between the data, and the background processes that are meant to occupy the space within the data plot



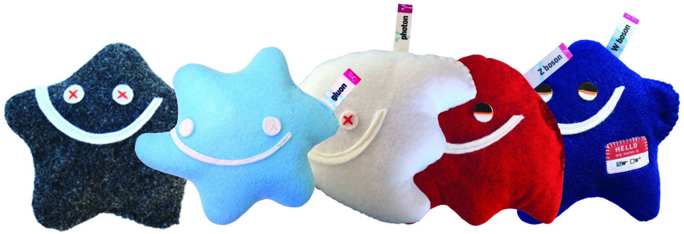


Transverse Momentum of Jet 1 (Left) and Jet 2 (Right)

Conclusion

Our histograms provided a good understanding of the composition of the background processes that make up our data. We saw that QCD and ZJetsToQQ make up a majority of the composition.

Moving forward due to our Monte Carlo statistical limitations, we would isolate the samples enriched with these dominant background sample processes individually to extract the shapes from these instead of using MC simulations.



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Especially the Higgs to my Higgs, Sherry, and my URA girlies :0)

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