Particle Physics with the Large Hadron Collider

Reagan O'Neil CAS '27, Chris Tyburski CAS '27
Elliot Lipeles, CAS Dept. of Physics and Astronomy

PennCURF
CENTER for UNDERGRADUATE RESEARCH & FELLOWSHIPS

Introduction

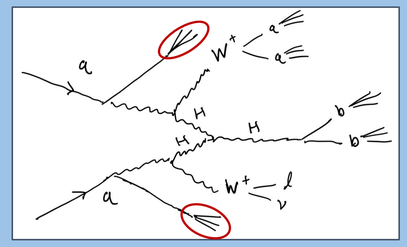
- High-Energy Physics studies elementary particles and their interactions
- The Standard Model of Particle Physics describes three fundamental forces and all fundamental particles, excluding gravity
  - Matter particles (fermions) such as quarks make up matter, such as protons and neutrons
  - Force particles (bosons) such as photons carry electromagnetic, strong, and weak forces
- The Large Hadron Collider, located at CERN in Geneva, Switzerland is the world's largest particle collider
  - ATLAS is one of nine LHC detector experiments
- ATLAS collaborators measure known properties of the Standard Model at greater and greater accuracies
- ATLAS experiment also searches for physics that contradicts or extends the Standard Model (Beyond SM Physics)

Methods

- Postdoctoral Researcher Prachi Atmasiddha generated particle collisions in MadGraph, with additional simulations in Delphes and Pythia8
  - Simulated events mimic the detector, but more data is obtained by the computer
  - Analysis on simulated data allows studies of methods to be applied on real detector data
- Analysis and visualization of data in C++ and Python using ROOT software
- When reconstructed correctly, reco particle and truth particle have same properties
  - 2D histograms should be linear
  - 1D histograms should have same shape

VBS Quark Reconstruction in VBS-VVh

Process



- Semileptonic VBS-VVh channel
- Same-sign W^+W^+
- Quarks (q or b in diagram) produce jets (cones of subatomic particles)
- Eventually measure coupling constant of central triple-Higgs (H) vertex
- Analysis to reduce "background" so the intended signal is more visible

Analysis

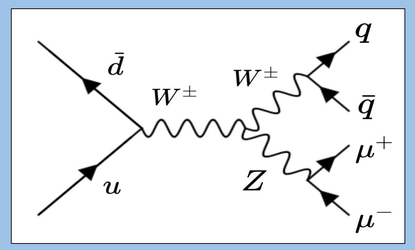
- Assign correct jets to proper VBS quarks (red)
- Choose closest jet to quark as "truth" or correct
- Tested four methods for selecting jets without truth data about quark (realistic to detector)
  - Compared selections to "truth" jets
  - Calculated efficiencies for each method:

$$Eff = \frac{(\#\ correctly\ assigned\ events)}{(\#\ events\ with\ two\ quarks)}$$

- Selection methods included sorting jet pairs by rest mass (M_{jj}), highest Δη, transverse momentum (P_T) and total momentum (P_i)
- Additional background processes such as ISR made jet assignment difficult
- Best method – Pair of jets with the highest $\sqrt{P_i P_j}$:
  - 62.3% efficiency
  - Only 64.7% of events with two VBS quarks have two "elgible" jets (close to the quark)
    - Efficiency shouldn't go above 64.7%

W and Z Reconstruction in Wqq-Zll

Process

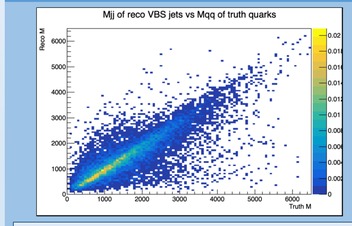


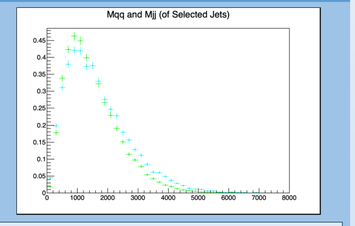
- One of three processes examined
  - W->quarks, Z->leptons
  - Z->quarks, Z->leptons
  - Z->bottom quarks. Z->leptons
- Quarks (q or b in diagram) and all products grouped into 'fat jet'
- Leptons observed either muons or electrons

Analysis

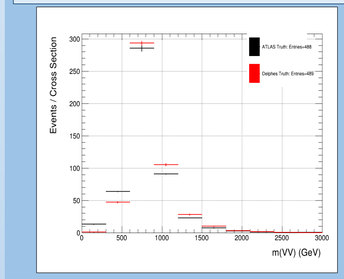
- W boson reconstructed from highest P_T jet
- Z boson reconstructed from highest two P_T leptons
- Cuts placed on invariant mass, P_T j, η, and ΔR
- Utilized event-level and detector-level reconstruction and compared with ATLAS simulation results
- Using m(VV) histogram comparison, found Delphes simulation optimized to ATLAS when including next to leading order events
- Fit Delphes ATLAS simulation and Delphes EFT simulation to ATLAS simulation results:
  - Parameter of old physics contribution ≈ 1
  - Likely no contribution from new physics (expected at energy level)

Results





Above Left: 2D histogram comparing invariant mass of reconstructed VBS jets with inv. mass of truth VBS quarks.
Above Right: 1D histogram showing the overlay of invariant mass of reconstructed VBS jets and inv. mass of truth VBS quarks.
The 2D histogram shows a proportional, linear trend and the shapes of the 1D histogram are similar. This reconstruction with the best method of highest $\sqrt{P_i P_j}$, has correctly reconstructed a high percentage of VBS quarks.



Left: Comparison of m(VV) distribution of ATLAS Simulation with Delphes Simulation

Found similar distribution of m(VV) up to 3000 GeV and similar number of qualifying events (488 and. 489, respectively)

Future Research

- Once particles are properly reconstructed, background distributions can be obtained
- Hope to separate background from the signal via different distributions
- Reconstruction methods tested on simulated data are used on ATLAS detector data

Acknowledgements & References

The authors thank Elliot Lipeles and Prachi Atmasiddha for their mentorship and guidance working on physics with the LHC this summer.

Rene Brun and Fons Rademakers, ROOT - An Object Oriented Data Analysis Framework, Proceedings AIHENP'96 Workshop, Lausanne, Sep. 1996, Nucl. Inst. & Meth. in Phys. Res. A 389 (1997) 81-86.
See also "ROOT" [software], Release v6.30/06, 03/04/2024