Optimization of Neutrino Measurement in a Search for a Charged Higgs Boson with ATLAS

Josephine Brewster, Supervised by Michel Lefebvre

Department of Physics and Astronomy, University of Victoria

Standard Model of Particle Physics (SM)

Best understanding of the fundamental particles that make up the universe and how they interact.

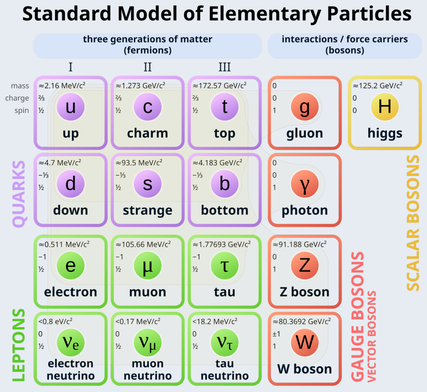


Figure 1:Particles that make up the SM.

The ATLAS Detector

A detector on the Large Hadron Collider (LHC) where protons are collided at high energies, sometimes creating interesting, unstable particles.

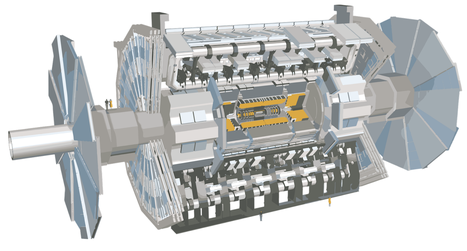


Figure 2:ATLAS Detector. Source: [1]

Why a Charged Higgs Boson?

A more complex Higgs sector appears in many beyond SM models.

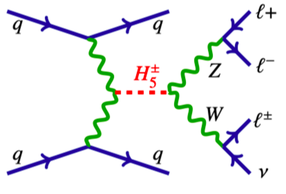
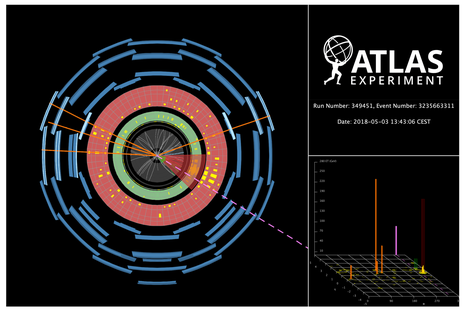


Figure 3:A Signal Feynman Diagram [2]

Missing Transverse Momentum

Some particles are invisible to the ATLAS detector and are only seen via conservation of momentum.



Search for a Charged Higgs Boson

- This analysis searches for a singly-charged Higgs boson ($H^{\pm}$) decaying to a Z and a W boson.
- Looking at Z boson decaying to two leptons and W boson decaying to a lepton and a neutrino.
- The decay products of W and Z are summed up to see a $H^{\pm}$ resonance at $M_{H^{\pm}}$.

Project Goals

Neutrinos do not interact with the detector. **Longitudinal momentum of the neutrino ($p_{\nu \mathrm{L}}$) is not measurable.**

Goals of this project are to use simulated data and truth information to:

- create a procedure for evaluating performance of methods for determining $p_{\nu \mathrm{L}}$.
- evaluate how well current method is performing.
- investigate if other methods can improve performance.

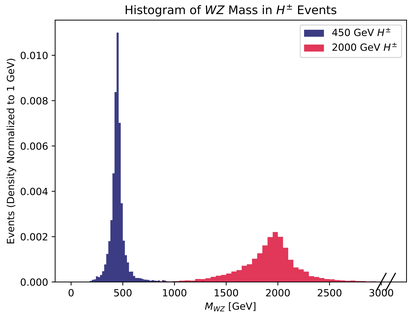


Figure 4:$H^{\pm}$ Signal

Finding $p_{\nu \mathrm{L}}$ and Procedure for Evaluating and Comparing Methods

Using the well-measured mass of the W boson, we can fix that its decay products (lepton ℓ and neutrino ν) add to give the W mass. This determines $p_{\nu \mathrm{L}}$ up to a quadratic:

$$p_{\nu \mathrm{L}} = \frac{\mu\, p_{\ell \mathrm{L}}}{p_{\ell \mathrm{T}}^2} \pm \frac{E_\ell}{p_{\ell \mathrm{T}}^2}\sqrt{\mu^2 - p_{\ell \mathrm{T}}^2 p_{\nu \mathrm{T}}^2} \qquad (1)$$

$$\mu \equiv \frac{M_W^2}{2} + \mathbf{p}_{\ell \mathrm{T}} \cdot \mathbf{p}_{\nu \mathrm{T}}$$

where $\mathbf{p}_{\nu \mathrm{T}}$ is known from missing momentum.

What solution do we choose?

Reliability Metric

Choose a width δ. Let $p_{\nu \mathrm{L},1}$ be the "chosen" solution and let $p_{\nu \mathrm{L},2}$ be the other solution.

- If $|p_{\nu \mathrm{L},1} - p_{\nu \mathrm{L}}^{\mathrm{truth}}| < \delta$, the "correct" solution was chosen;
- Else if $|p_{\nu \mathrm{L},2} - p_{\nu \mathrm{L}}^{\mathrm{truth}}| < \delta$, the "incorrect" solution was chosen;
- Else, neither solution was close enough to the truth to be considered correct.

Note: Solutions are complex about 30% of the time. Here we focus on the real case.

Methods for Finding $p_{\nu \mathrm{L}}$

- **Original:** Choose the $p_{\nu \mathrm{L}}$ solution with the smallest absolute value (used in previous paper [2]).
- **Close to jj:** Choose solution closest to the p_{L} of the VBS jets.
- **Close to Zjj:** Choose solution closest to the p_{L} of the sum of the VBS jets and the Z leptons.
- **Close to ℓ:** Choose solution closest to the p_{L} of the lepton decaying from the W boson.

Results

All results shown are for a simulated $H^{\pm}$ with mass 450 GeV and $\delta = 70$ GeV.

Method	Correct Choice	Incorrect Choice	Far From Both
Original	59 %	25%	16%
Close to ℓ	55 %	30%	16%
Close to jj	50 %	34%	16%
Close to Zjj	50 %	34%	16%

Table 1:Evaluation of methods using reliability metric.

Conclusion and Next Steps

- A reliability metric was created to evaluate methods for determining $p_{\nu \mathrm{L}}$.
- Using this metric, it was shown that the method used in the previous paper was only choosing the "correct" solution in 59% of events.
- No simple methods using p_{L} of other event objects were found to lead to better results. This may mean that there is no better handle in the event other than the one being used currently.

The next step is to evaluate complex solutions.

Acknowledgements

We acknowledge and respect the Lək̓ʷəŋən (Songhees and Xʷsepsəm/Esquimalt) Peoples on whose territory the university stands, and the Lək̓ʷəŋən and W̱SÁNEĆ Peoples whose historical relationships with the land continue to this day.
I would like to thank Michel Lefebvre for supervising me and the UVic ATLAS group for their support. This research was supported by the Jamie Cassels Undergraduate Research Awards, University of Victoria.

References

[1] "Atlas detector and technology." https://atlas.cern/Discover/Detector.

[2] ATLAS Collaboration, "Search for resonant WZ production in the fully leptonic final state in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector," *The European Physical Journal C*, vol. 83, July 2023.

March 19, 2025