ZH jet pairing methods for Higgs self-coupling sensitivity optimization at a future Higgs factory

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Abstract

In 2012, the ATLAS and CMS collaborations, based at the Large Hadron Collider (LHC) at CERN, experimentally confirmed the existence of a particle consistent with the Standard Model (SM) Higgs boson, the final missing piece of the SM. The next step in verifying the SM is to perform precise measurements of the Higgs boson's parameters, including the Higgs self-coupling, which has a direct impact on the shape of the Higgs potential. A proposed post-LHC particle collider, the Future Circular Collider (FCC), offers improved sensitivity to the Higgs self-coupling. This project focuses on the most common, but still unexplored, decay channel of the associated production of a Z and Higgs boson: both particles decay into quarks. This project will investigate multiple methods toward identifying Z boson candidates by analyzing simulated FCC data using Z decay product masses and jet identification scores as metrics. Then, the recoil mass will be calculated to be used as a metric for evaluating sensitivity toward the Higgs self-coupling.

Introduction

At the beginning of time, a spontaneous breaking of symmetry occurred in the **Higgs potential** (Figure 1)

Higgs self-coupling determines shape of Higgs potential, see if coupling strength differs from Standard Model (SM)

Currently no colliders sensitive enough for Higgs self-coupling.

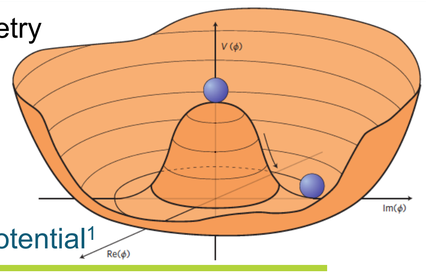


Figure 1 (right): Higgs potential[1]

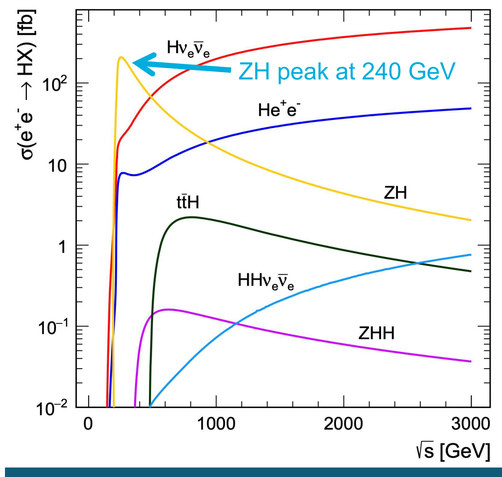


Figure 2 (left): Cross sections for Higgs production processes at an e⁺e⁻ collider[2]

Future Circular Collider (FCC): proposed next-generation particle accelerator.

"Higgs factory" phase: e^+e^- collider at $\sqrt{s} = 240$ GeV (Figure 2)

Max associated production of a Z and Higgs boson (ZH)

ZH is sensitive to variations in the Higgs self-coupling

Hadronization

When particles collide and decay at high energies, **they form jets**

Figure 3:

- ZH decays most commonly into groups of quarks.
- Confinement forbids quarks to be unpaired.
- Quarks are created from vacuum to pair with quarks produced from ZH and uphold confinement

The shower of particles produced is called a jet.

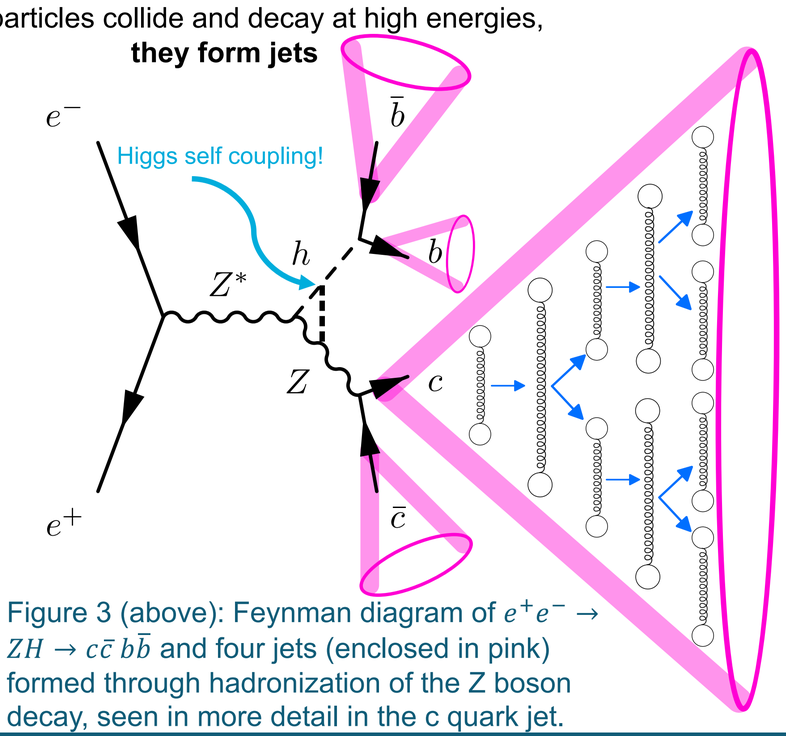


Figure 3 (above): Feynman diagram of $e^+e^- \rightarrow ZH \rightarrow c\bar{c}\,b\bar{b}$ and four jets (enclosed in pink) formed through hadronization of the Z boson decay, seen in more detail in the c quark jet.

Methods

Find Z boson candidates, then calculate **recoil mass** to find Higgs candidates

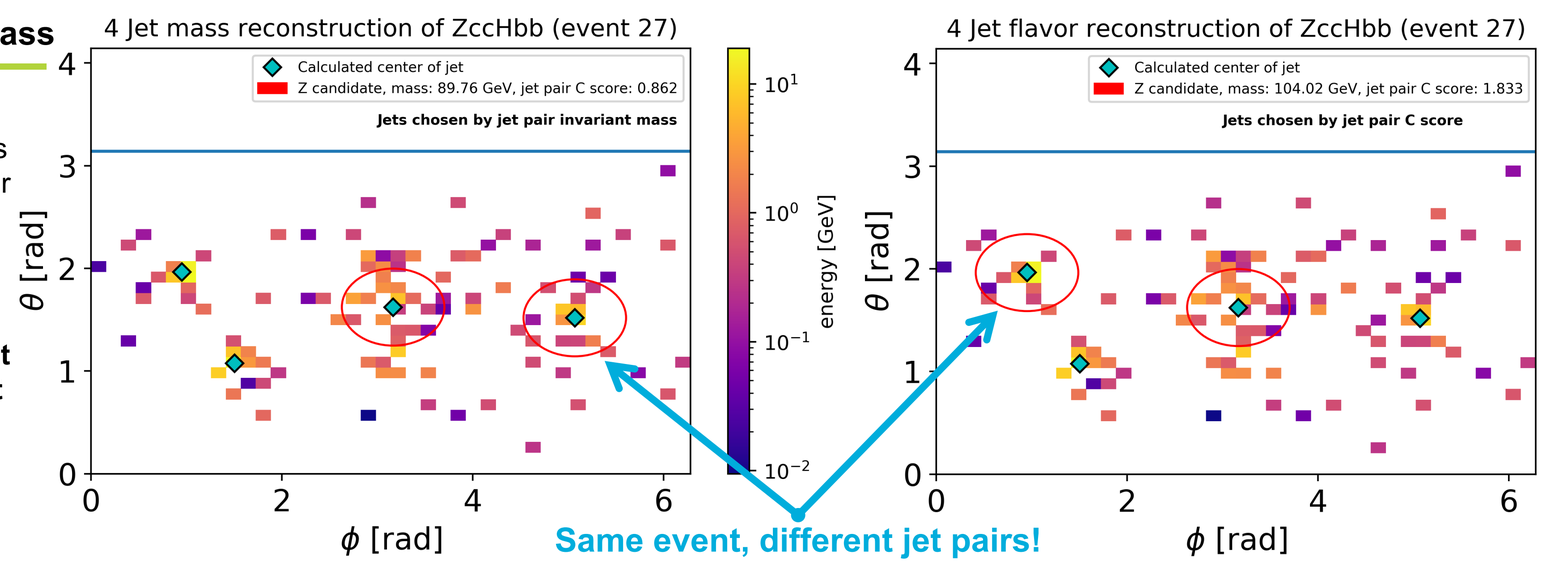
Durham algorithm:

- Exclusive jet reconstruction
- Four jets, one per quark

Invariant Mass

Calculate invariant mass of each jet pair using mass, energy, and momentum

Find invariant mass closest to Z boson mass (m_Z): ~91.188 GeV



Same event, different jet pairs!

Flavor Score

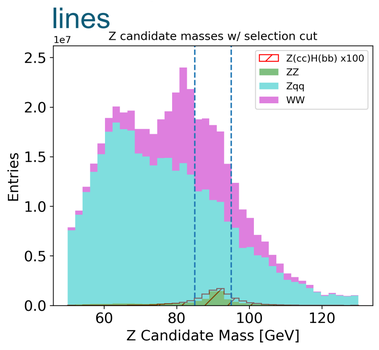
Calculate likelihood that a jet comes from hadronized charm quark (0 to 1).

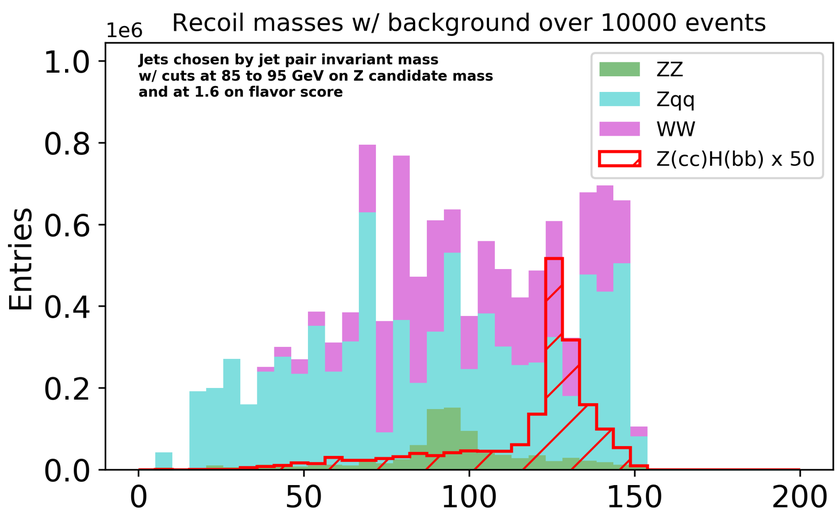
Find maximum possible charm flavor score

Figures 5a (left) and 5b (right): Simulated ZH decay with different jet candidate methods (candidates circled in red)

Results

Figure 6a (below): Z candidate masses with selection cut of 85 to 95 GeV depicted with dotted lines





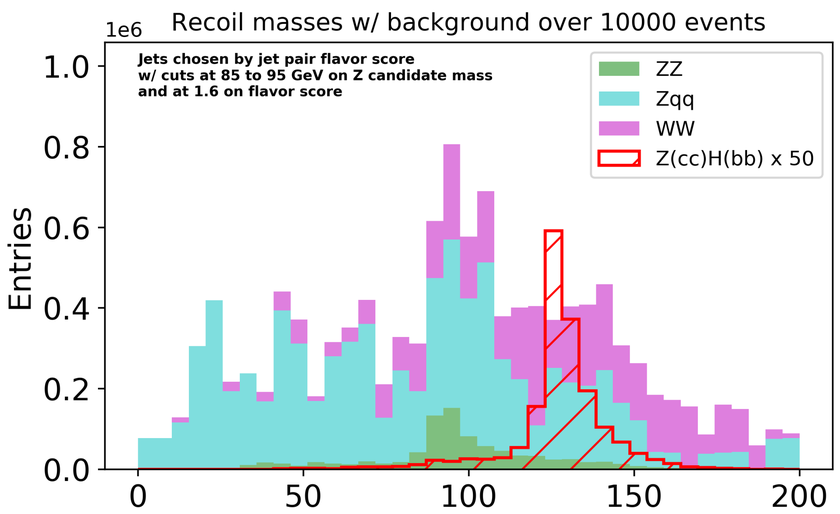
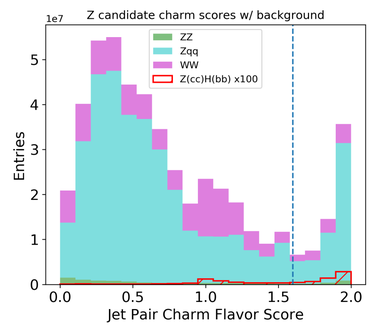


Figure 6b (below): Z candidate flavor scores with selection cut of 1.6 depicted with dotted line



Figures 7a (center left) and 7b (center right): Simulated ZH decay (signal in red) with different jet candidate methods, over background

Conclusions:

Two methods were identified for tagging jet pairs as Z boson candidates: choosing jet pair closest to m_Z and evaluating flavor scores.

Flavor score method has a greater $\frac{S}{\sqrt{B}}$ than invariant mass method by a factor of ~1.3.

Future steps: other jet reconstruction methods (inclusive algorithms), and include other Higgs final states in signal. Ultimately, a multivariate analysis would be implemented to maximize $\frac{S}{\sqrt{B}}$

Acknowledgements

First and foremost, I give special thanks to my mentor, Dr. Abraham Tishelman-Charny for his guidance and patience throughout the course of this project. I would also like to thank to Dr. Elizabeth Brost for her valuable insight and feedback. This project was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI). This project is not export controlled.

References:
1. Ellis, John, Mary K. Gaillard, and Dimitri V. Nanopoulos. "A historical profile of the Higgs boson." The standard theory of particle physics (2016): 255-274.
2. Abramowicz, H., Abusleme, A., Afanaciev, K. et al. Higgs physics at the CLIC electron–positron linear collider. Eur. Phys. J. C 77, 475 (2017). https://doi.org/10.1140/epjc/s10052-017-4968-5

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