Higgs Invisible Decays at the FCC

Higgs Production via Vector Boson Fusion

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Outline

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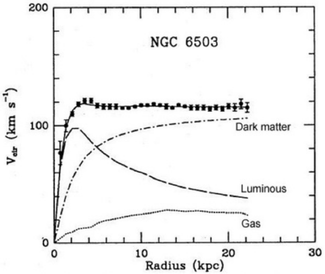
A Brief Review of Dark Matter

Searching for Dark Matter

Evidence

- Galaxy rotation curves
- Rough 85 percent of all matter is dark matter (by mass)



K.G. Begeman, A.H. Broels, R.H. Sanders. 1991. Mon.Not.RAS 249, 523.

A Brief Review of Dark Matter

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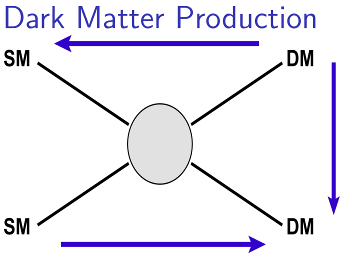

- We focus on dark matter production: can we see deviations from standard model invisible decays?
- Thus far, we've been able to put strong constraints on the masses of dark matter particles, but we have not yet observed dark matter production

Outline

Future Circular Collider

Motivation for Dark Matter Exploration

- Why haven't we observed dark matter production?

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Motivation for Dark Matter Exploration

- Why haven't we observed dark matter production?
- One possibility: the cross sections for Higgs production are too low at our current energy scales
- The Future Circular Collider would reach order of magnitude higher energy scales, which would dramatically increase the Higgs production cross section

Outline

Higgs Invisible Decays

What is a Higgs Invisible Decay?

A decay from the Higgs boson to undetected final products

- Example of interest: dark matter
- Standard Model example: Higgs to neutrinos
- The current exclusion on branching ratio for Higgs to Dark Matter is 15%. At less than 1%, we can test some of the predominant dark matter theories

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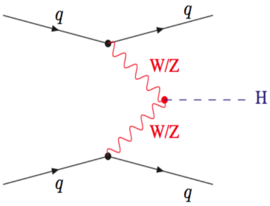
Vector Boson Fusion



Outline

What decays look invisible?

In order to detect dark matter production, we must have high enough sensitivity to the standard model Higgs invisible decay to detect extremely small deviations from it.

Signal versus Background

- Though we are interested in dark matter, we cannot simulate dark matter production. Here, our signal is the Higgs decay to neutrinos.
- Key problem: many decays look like a Higgs to neutrinos decay. These decays are our background.

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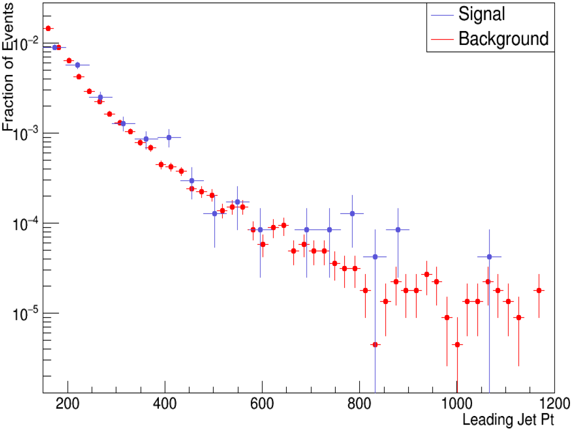
Primary Background Events

- Z to neutrinos or low pt leptons
- W to a low pt lepton and a neutrino
- TTbar decays with a low pt lepton

Distinguishing between Signal and Background

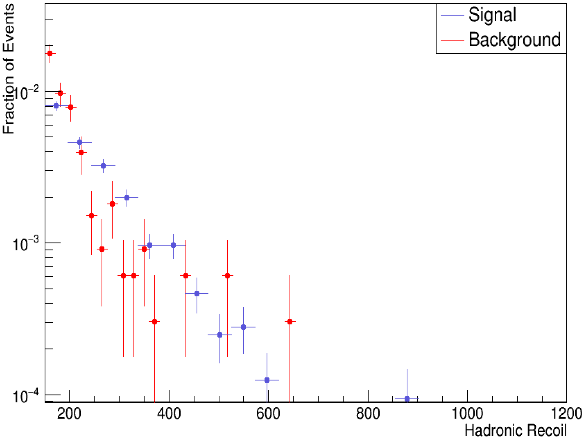
Leading Jet Transverse Momentum



The background shown is the sum of the three backgrounds discussed in the previous slide (Z, W, and ttbar). Histograms are normalized to one.

Distinguishing between Signal and Background

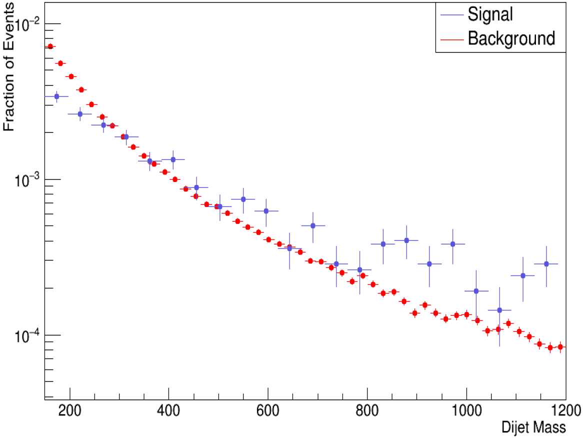
Hadronic Recoil



- Hadronic recoil (u_T) is the recoil against the hadron in transverse plane - equal to the transverse of the vector boson
- $u_T + MET + q_T = 0$, q_T is the pt of the vector boson

Distinguishing between Signal and Background

Dijet Mass

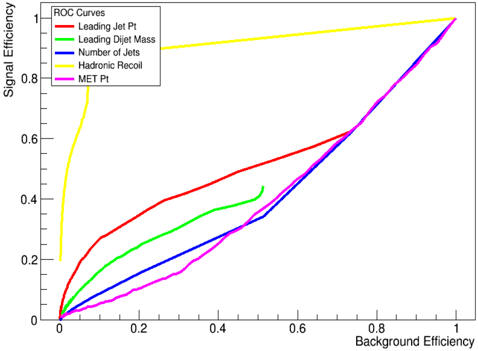


Dijet mass is the mass of the two leading jets

Distinguishing between Signal and Background

Receiver Operating Characteristic Curves

Which variables provide the best means of distinguishing signal from background?



- Gini index

Eliminating Background Events

First Round Veto

Vetoing events with one or two isolated, high pt leptons eliminates the majority of the Z and W background

Matching

- Assume decays from Z or W to invisible products have similar properties to Z or W decays to visible products

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- Match simulations of Z or W to visible leptons against the invisible outputs to determine what portion of invisible events were Z or W events
- Uses a fitting algorithm developed several years. We developed a simple Heppy tree-builder to interface easily with the algorithm, which makes results more easily replicable.

Summary

- The Future Circular Collider could be of great use for detecting dark matter.
- Detecting dark matter production will require high sensitivity to other invisible decay modes.
- We have developed an easy-to-use method of determining sensitivity, particularly for the case of Higgs invisible decays via the vector boson fusion production mode.

- Outlook
  - Apply our method to large enough vector boson fusion data sets to precisely determine the sensitivity of the FCC to Higgs invisible decays via VBF
  - Apply this method to other decay modes

Acknowledgments

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QUESTIONS?

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Analysis Methodology

How does the fitting framework work?

Basic Idea

- Inject a trial signal at every point along the histogram
- Float the fit until the ratio of likelihood of there being a signal to the likelihood of there being no signal is maximized (log likelihood)

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What's special about this fit?

- We are examining a situation in which there are 6 control regions
- Each bin for a given control region is tied to the corresponding signal bin, so that all seven regions vary together
- Input uncertainties allow there to be small changes in how the 7 event types vary