SiD Analyses for Snowmass Physics LoIs: Status and Plans

Chris Potter / University of Oregon

For Tim Barklow, Jim Brau, Lucas Braun, Masako Iwasaki, Laura Jeanty, Masakazu Kurata, Laura Nosler, Peter Onyisi, Austin Pryor, Amanda Steinhebel, Andy White

Snowmass 2021

LCWS2021
INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

SnowMass2021

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Welcome to Snowmass

Because of the COVID-19 pandemic, the Snowmass Report and the Community Summer Study (CSS) meeting will be delayed by one year and the overall schedule for the Snowmass process will be adjusted accordingly. See more information and update here.

The Particle Physics Community Planning Exercise (a.k.a. "Snowmass") is organized by the Division of Particles and Fields (DPF) of the American Physical Society. Snowmass is a scientific study. It provides an opportunity for the entire particle physics community to come together to identify and document a scientific vision for the future of particle physics in the U.S. and its international partners. Snowmass will define the most important questions for the field of particle physics and identify promising opportunities to address them. (Learn more about the history and spirit of Snowmass here "How to Snowmass" written by Chris Quigg). The P5, Particle Physics Project Prioritization Panel, will take the scientific input from Snowmass and develop a strategic plan for U.S. particle physics that can be executed over a 10 year timescale, in the context of a 20-year global vision for the field.

We aim for everyone's voice to be heard. Your contributions and participation are critical for the success of Snowmass and they will naturally occur as part of one or more working groups directed by the conveners. There will be various Town Hall meetings for us to communicate with you and to receive your feedback. You are also welcome to provide input and suggestions on the Slack channel (https://snowmass2021.slack.com/). This Snowmass wiki provides news and announcements and has pages dedicated to each frontier. Agendas and presentations of all Snowmass-related meetings are available via this Snowmass Indico link.

Sincerely,

Young-Kee Kim (DPF Chair), Tao Han (DPF Chair-Elect), Joel Butler (DPF Vice-Chair), Priscilla Cushman (DPF Past Chair)

Glennys Farrar (DAP Rep), Gabriela Gonzales (DGRAV Rep), Yury Kolomensky (DNP Rep), Sergei Nagaitsev (DPB Rep)

April, 2020

Snowmass 2021 [Clickable Link]

Snowmass Extension to 2022

Monthly Snowmass Newsletter

January 2021

Because of the COVID-19 pandemic, the Snowmass Report and the Community Summer Study meeting (CSS) will be delayed by one year until 2022. The overall schedule for the Snowmass process will be adjusted accordingly. After extensive consultation with our community and the frontier conveners/advisors, the Snowmass Steering Group recommends the following general guidelines for the implementation of the Snowmass delay:

- High-level activities will be on hold until the end of June, 2021. These activities include Frontier-level and Topical Group-level workshops, All-conveners meetings, Advisory Group meetings and Newsletters.
- Other Topical Group and cross-frontier activities should be either paused or reduced to a significantly lower level, proceeding only as necessary to ensure scientific continuity, meet essential programmatic needs, or maintain collaborative work with other units and communities.
  - No critical decisions will be made during the hiatus.
  - No individuals should feel obligated to participate in these activities.
- Individual, collaborative and self-organized work can continue at the discretion of the individuals involved.

All paused individual or group activities will continue to receive full consideration once the Snowmass process formally resumes.

ILC Simulation: Snowmass Resources

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ILC Simulation Resources for Snowmass 2021

This page gives links to the various resources that the ILC physics and simulation working groups are making available for projects on e+e- collider physics for the US community study Snowmass 2021. This page is being actively updated and documentation is being improved, so please check regularly for additional resources and documentation.

- **"ILC Study Questions for Snowmass 2021"**, arXiv:2007.03650 [hep-ph]
  This document presents a collection of open questions for possible Snowmass projects, describes our software framework, and provides contact information. It is a good place to start to learn about physics at ILC, and to get inspired to roll up your sleeves and get studying!

If you have additional questions, either post to the #ilc-snowmass channel on the snowmass2021 slack workspace, or send an email to ilcsnowmass@slac.stanford.edu.

Tutorials

A number of hands-on tutorials were developed for the benefit of Snowmass participants who wish to study ILC-related physics questions. The various tools and samples listed below were introduced, using simple step-by-step examples.

If you are new to ILC physics analysis, this is the place to start learning.

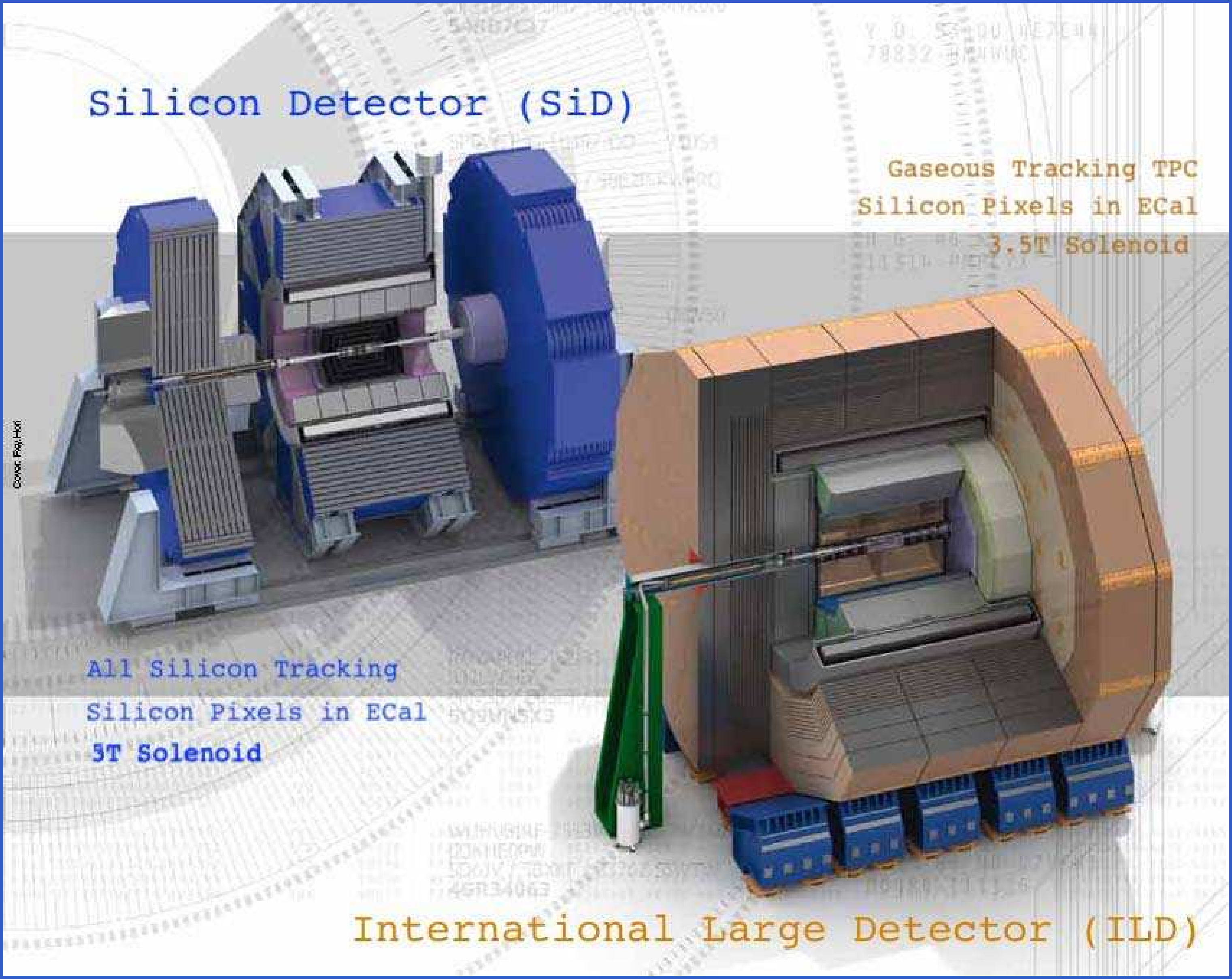
Recordings of the tutorials and the materials used can be found at the following links.

- MC/Simulation Framework Tutorial: ILC [General overview and introduction; held on Aug 28, 2020]
- MC/Simulation Framework Tutorial: Whizard for e+e- [MC event generation; Sept 28, 2020]
- MC/Simulation Framework Tutorial: ILC Analysis Walkthrough [Fast ILC detector simulation, example analysis; Oct 14, 2020]

Tools

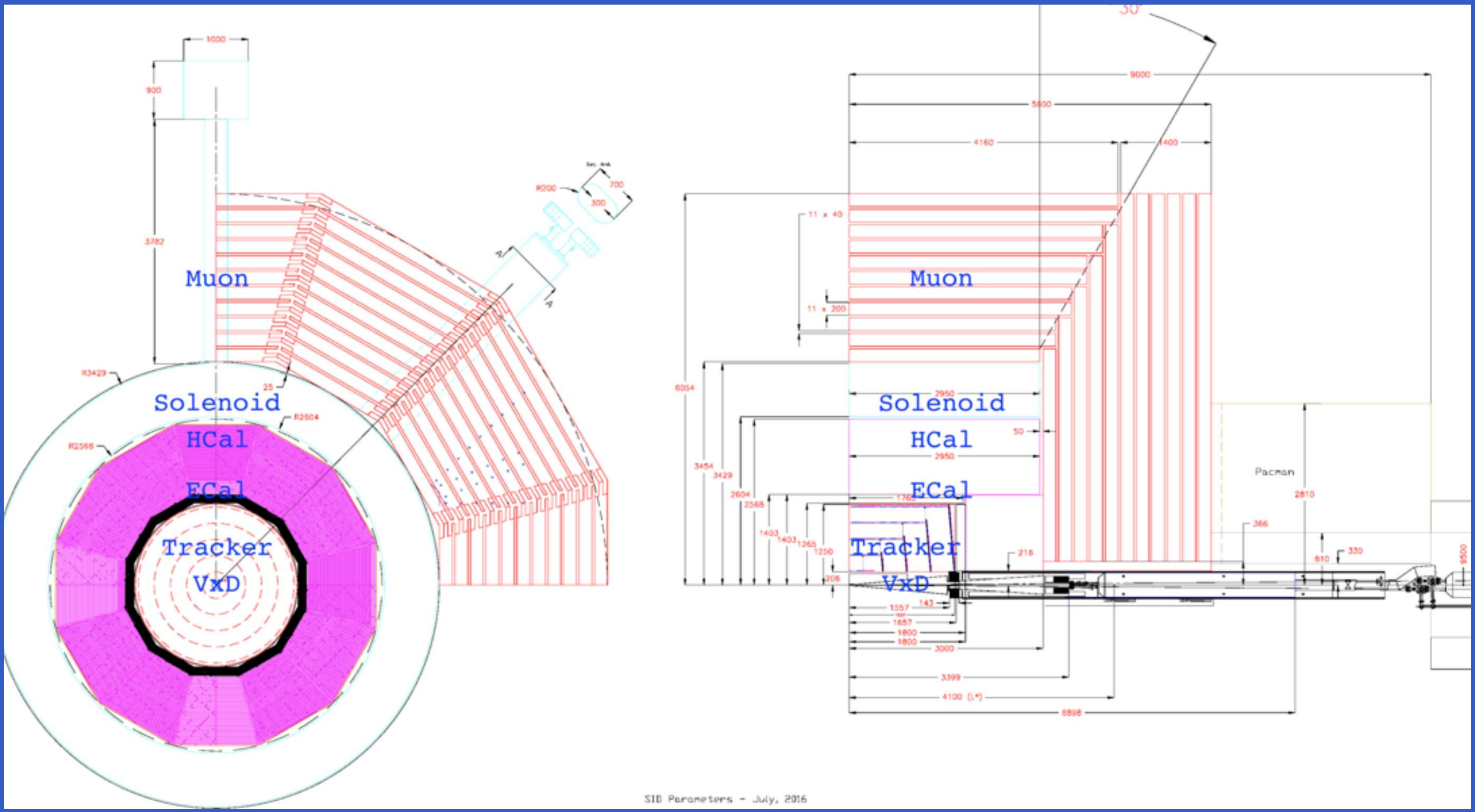
http://ilcsnowmass.org [Clickable Link]

SiD and ILD: ILC TDR Volume 4



Plenary session with Talks on SiD and ILD [Clickable Link]

SiD: ILC TDR Volume 4 (arXiv:1306.6329)



- The vertex detector (blue) has five layers instrumented with Silicon pixels while the tracker has five layers (orange dashed) instrumented with Silicon strips.
- The ECal (black) alternates Tungsten absorbing layers with Silicon pixels, the HCal (magenta) alternates Steel with scintillator sensitive layers.

SiD Monte Carlo Exercise 2020/21

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SiD Monte Carlo Exercise 2020/21

Documentation & Tools

- Primer on ILC Physics and SiD Software Tools (2002.02399)
- Whizard Event Generation on Hepforge (Whizard)
- Delphes Fast Detector Simulation (Delphes)
- Delphes SiD Documentation on Hepforge (DSiD)
- Jetset, Jade and Durham Tools for e+e- in Root (Finders)
- Example Root Macros for Analysis (macro1.cc, macro2.cc)

SiD DBD Signal & Background

- 250GeV CME, L=250fb-1, P=80/30 [WS DR DRi GL]
- 350GeV CME, L=350fb-1, P=80/30 [WS DR DRi GL]
- 500GeV CME, L=500fb-1, P=80/30 [WS DR DRi GL]
- 1000GeV CME, L=1000fb-1, P=80/20 [WS DR DRi GL]

SiD MC20 Signal

- 250 GeV CME, L=2x100ab-1, P=80/30
  - SM Single Higgs, Inclusive H [WS DR DRi GL]
  - SM Single Higgs, H to Tau Pairs, Inclusive Tau [MH DR DRi GL]
  - BSM Higgs, H to Invisible [WS DR DRi GL]
- 350 GeV CME, L=2x100ab-1, P=80/30
  - SM Single Higgs, Inclusive H [WS DR DRi GL]
  - SM Top Pair, Inclusive Top [WS DR DRi GL]
- 500 GeV CME, L=2x100ab-1, P=80/30
  - SM Single Higgs, Inclusive H [WS DR DRi GL]
  - SM Double Higgs, Inclusive H [WS DR DRi GL]
- 1000 GeV CME, L=2x10^5 ab-1, P=80/30
  - SM Double Higgs, Inclusive H [WS DR DRi GL]

SiD MC21 Signal & Background

- 250 GeV CME, L=2x1ab-1, P=80/30
  - Signal Higgs
    - BSM Higgs, H to Dark Photons [MH DR DRi GL]
  - Two Fermion Backgrounds
    - 2f e-e+->qq,l+l- [WS DR DRi GL]
  - Three Fermion Backgrounds
    - 3f e-A->Ze-,vW- [2x10ab-1] [WS DR DRi GL]
    - 3f Ae+->Ze+,vW+ [2x10ab-1] [WS DR DRi GL]
  - Four Fermion Backgrounds
    - 4f e-e+->WW [WS DR DRi GL]
    - 4f e-e+->Wev [WS DR DRi GL]
    - 4f e-e+->ZZ [2x10ab-1] [WS DR DRi GL]
    - 4f e-e+->Zee [WS DR DRi GL]
    - 4f e-e+->Zvv [2x10ab-1] [WS DR DRi GL]
- 350 GeV CME, L=2x1ab-1, P=80/30
- 500 GeV CME, L=2x1ab-1, P=80/30
- 1000 GeV CME, L=2x1ab-1, P=80/20

SiD Monte Carlo 2020/21 Page [Clickable Link]

Higgs to Invisible at $\sqrt{s} = 250$ GeV with SiD

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International Workshop on Future Linear Colliders

LOI - ILC/SiD Higgs to Invisible

Andrew White, Austin Prior, University of Texas at Arlington,
James Brau, Christopher Potter, Amanda Steinhebel, Makayla Massar, University of Oregon

August 2020

1 Introduction

The Higgs Boson, being the only true scalar particle yet discovered, is a fundamentally new entity in the world of high energy physics. As such, it imperative to explore every aspect of the Higgs properties. While, so far, experimental results are in line with the Higgs having the properties expected in the Standard Model, there is significant room for connections to new physics beyond the Standard Model. This LOI describes a study of possible decays of the Higgs into invisible particles, such as might comprise the Dark Matter.

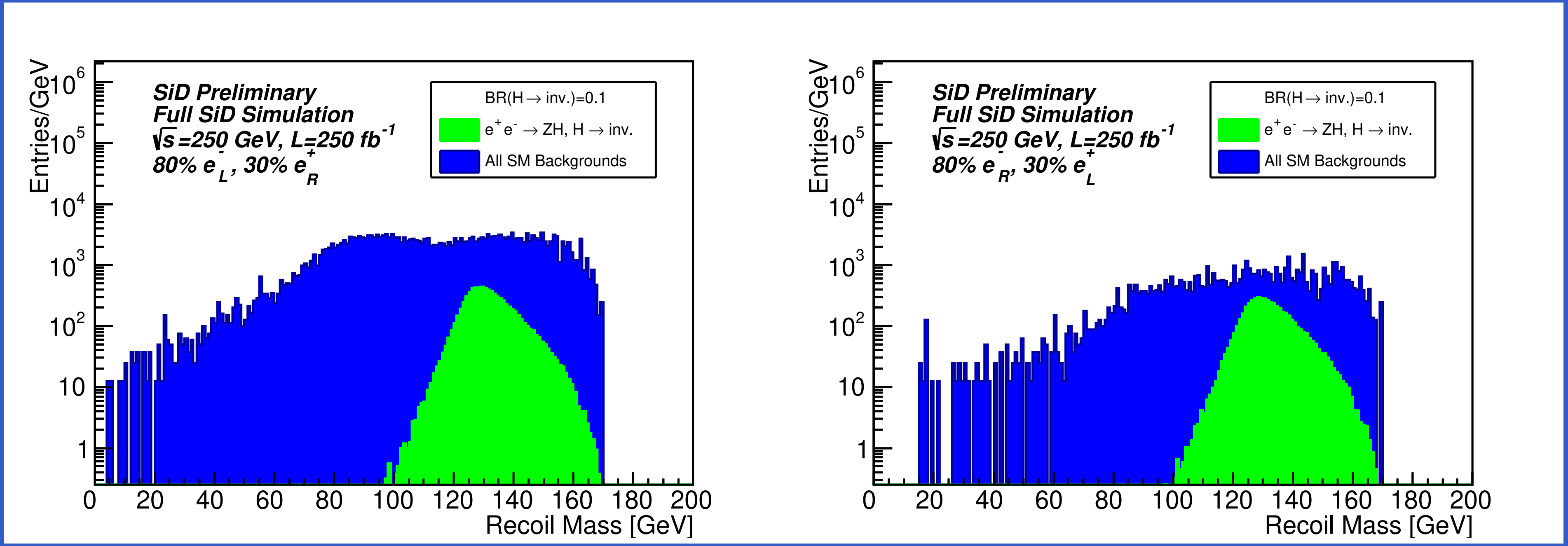
2 The search for invisible decays of the Higgs

The ATLAS and CMS experiments at the LHC have searched for invisible decays of the Higgs in a variety of channels. The current best limit, from a single search, is from ATLAS in the vector boson fusion process [2]. The limit set is 13% at 95% c.l. This limit has, in turn, been used to set a limit as a function of mass on the dark matter-nucleon scattering cross-section, as seen in Figure 1.

SNOWMASS21-EF2_EF1_Andy_White_Jim_Brau-185 [Clickable Link]

Full SiD Simulation Recoil Mass and Yields

Signal is green with BR($H \to$ inv.)=0.10, the Barklow DBD `all_SM_background` is blue.



Above, recoil mass after full signal selection. Below, cutflow yields and significances.

Requirement (Full)	S(LR)	B(LR)	S(RL)	B(RL)
$20 \leq p_T^{vis} \leq 70$ GeV	1.25e+04	7.71e+06	8.84e+03	1.07e+06
$75 \leq m_{vis} \leq 105$ GeV	1.16e+04	1.79e+06	8.21e+03	3.14e+05
$N_{jet} = 2$	1.16e+04	1.79e+06	8.21e+03	3.14e+05
$-0.9 \leq \cos\theta_{jj} \leq -0.2$	1.08e+04	8.68e+05	7.65e+03	1.78e+05
$110 \leq m_{recoil} \leq 150$	1.03e+04	3.6e+05	7.33e+03	8.39e+04

Full simulation (ILCSoft v02-00-02, SID o2_v3) scaled from 250fb^{-1} to 900fb^{-1}.

Amanda Steinhebel: Higgs to Invisible

Higgs-to-invisible Prospects with SiD

PD3: Physics Analys... | PD1/PD3: Theoretical ...

16 Mar 2021, 22:20
20m
Online Conference (Zoom)

CET: 22:20 16 March
PDT: 14:20 16 March
JST: 06:20 17 March

Speaker

Amanda Steinhebel (University of Oregon...

Description

While the Standard Model (SM) predicts a branching ratio of the Higgs boson decaying to invisible particles of O(0.001), the current measurement of the Higgs boson coupling to other SM particles allows for up to 20% of the Higgs boson width to originate from decays beyond the SM (BSM). The small SM-allowed rate of Higgs boson decays to invisible particles can be enhanced if the Higgs boson decays into new particles such as dark matter. Upper limits have been placed on BR(Hinv) by ATLAS and CMS at O(0.1), but the hadron environment limits precision. The ILC `Higgs factory' will provide unprecedented precision of this electroweak measurement. Studies of the search for Higgs-to-invisible processes in simulation are presented with SiD, a detector concept designed for the ILC. Preliminary results for expected sensitivity are provided, as well as studies considering potential systematics limitations.

Joint PD1/PD3 Parallel Session in Indico [Clickable Link]

Measuring the CP properties of the Higgs sector at electron-positron colliders

D. Jeans (KEK) [daniel.jeans@kek.jp]
I. Bozovic-Jelisavcic, G. Milutinovic-Dumbelovic
(Vinca Institute of Nuclear Sciences, Belgrade)
J. Brau, L. Braun, C. Potter (University of Oregon)

August 31, 2020

Letter of Interest for SnowMass2021: Energy Frontier

The violation of the CP symmetry is one of Sakharov's conditions for the matter–anti-matter asymmetry of our universe. Currently known sources of CP violation in the quark and neutrino sectors are too small to account for this. Is CP also violated in the Higgs sector? Is the 125 GeV mass eigenstate a mixture of even and odd CP states of an extended Higgs sector, or is CP explicitly violated in Higgs interactions. With what precision could such effects be measured at future electron-positron colliders?

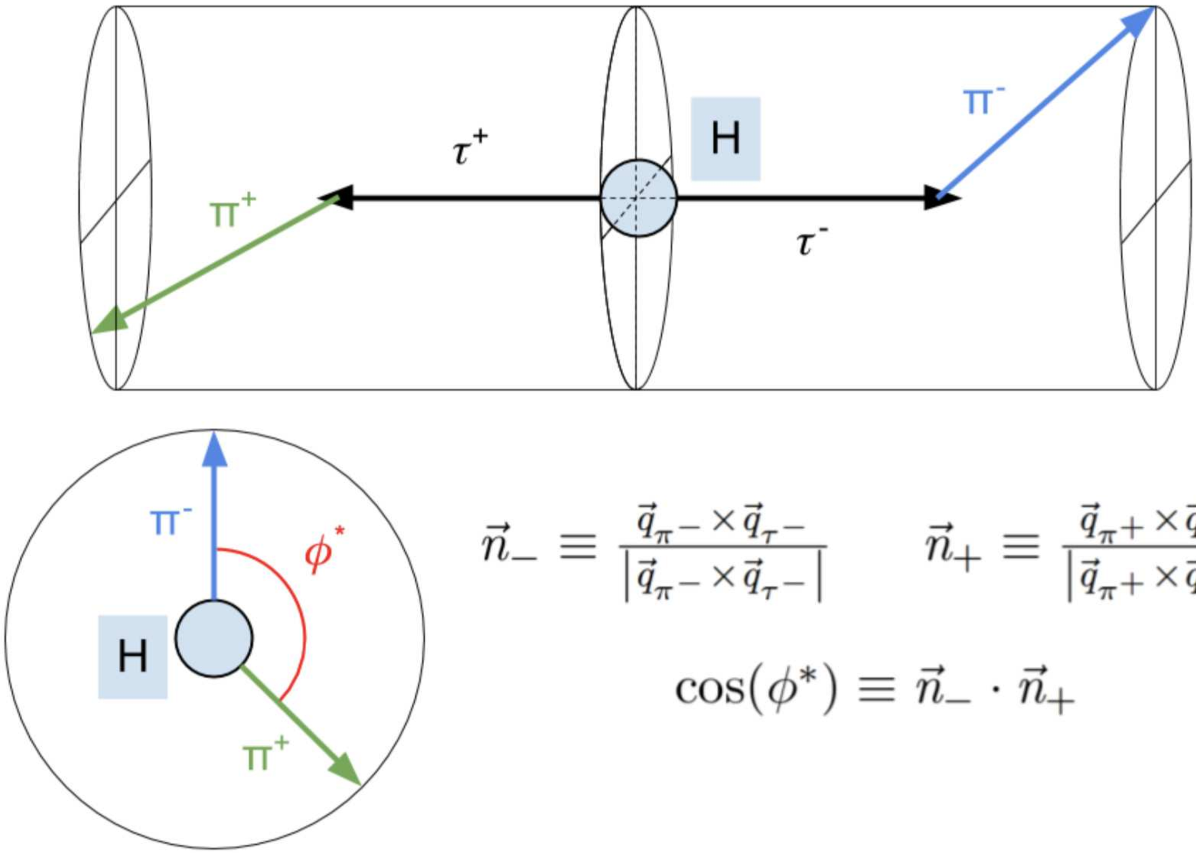
Several processes at e^-e^+ colliders are sensitive to the CP nature of the Higgs sector. Some are sensitive to fermionic, others to bosonic couplings; they also require different centre of mass energies, as summarised below.

SNOWMASS21-EF1_EF2_DanielJeans-113 [CLickable Link]

Higgs Mixing Angle

Tau-Based Analysis of Higgs CP Violation

- General methodology: extract **polarimeter vector** from analyzing tau decay; find **azimuthal angle** between τ^+ and τ^- polarimeter vectors
- Polarimeter vectors vary with tau decay; $\tau^\pm \to \pi^\pm \nu_\tau$ (below) and $\tau^\pm \to \pi^\pm \pi^0 \nu_\tau$ are the simplest to analyze, but using **higher-multiplicity decays** would allow for **more events** to be used



$$\vec{n}_- \equiv \frac{\vec{q}_{\pi^-} \times \vec{q}_{\tau^-}}{|\vec{q}_{\pi^-} \times \vec{q}_{\tau^-}|} \qquad \vec{n}_+ \equiv \frac{\vec{q}_{\pi^+} \times \vec{q}_{\tau^-}}{|\vec{q}_{\pi^+} \times \vec{q}_{\tau^-}|}$$

$$\cos(\phi^*) \equiv \vec{n}_- \cdot \vec{n}_+$$

Lucas Braun: Higgs to Tau Pairs

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H --> tau+,tau- CP Violation Analysis for SiD

16 Mar 2021, 22:40
20m
Online Conference (Zoom)

PD3: Physics Analys... | PD1/PD3: Theoretical ...

Speaker

Lucas Braun

CET: 22:40 16 March
PDT: 14:40 16 March
JST: 06:40 17 March

Description

The matter-antimatter asymmetry of the universe may result at least partially from CP violation. CP violation in mesons and neutrinos is too small to account for matter-antimatter asymmetry, motivating a search for CP violation in the Higgs sector. We present a study of the potential measurement of CP symmetry of the Higgs boson at the International Linear Collider (ILC) by the SiD experiment. We study the H --> tau+,tau- channel, which is particularly useful for CP analysis of leptonic Higgs decays because of its high branching ratio and the ease of extracting CP-sensitive statistics from tau decay products. Our method uses a double neural network system which takes energy and multiplicity statistics as inputs to tag tau events and their decay paths. We use CP-sensitivity-based event weighting methods to avoid strict cuts and make use of tau+- --> pi+-, pi+-pi0, l+-, pi+-2pi0, pi-+2pi+- decay modes. We focus on ZH, Z --> e+e-, mu+mu- events for simplicity. Our workflow performs very well against the dominant four-fermion background and yields strong preliminary mixing angle precision estimates. These results could help improve the precision of Higgs CP violation measurements at the ILC.

Joint PD1/PD3 Parallel Session in Indico [Clickable Link]

Higgs to LLP at $\sqrt{s} = 250$ GeV with SiD

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Sensitivity to decays of long-lived dark photons at the ILC

Laura Jeanty, Laura Nosler, and Chris Potter
*University of Oregon**
(Dated: August 28, 2020)

I. INTRODUCTION

Searches for light, weakly coupled particles are an important component of the physics program at present and future colliders. New hidden or dark sectors around the electroweak scale which are weakly coupled to the Standard Model (SM) through mediators are well motivated by numerous theoretical and observational considerations, including naturalness, dark matter, and electroweak baryogenesis. A classic benchmark for a potential vector-boson mediator between the SM and dark sector is the hypothetical dark photon, γ_D, which interacts with the SM through kinematic mixing with the weak hypercharge field B with coupling strength ϵ. The dark sector could also have a dark Higgs boson, h_D, which in the general case will mix with the SM Higgs Boson [1]. This opens up a Higgs portal production mode for dark photons. of long-lived γ_D as a benchmark to study the detector performance for detection of displaced decays.

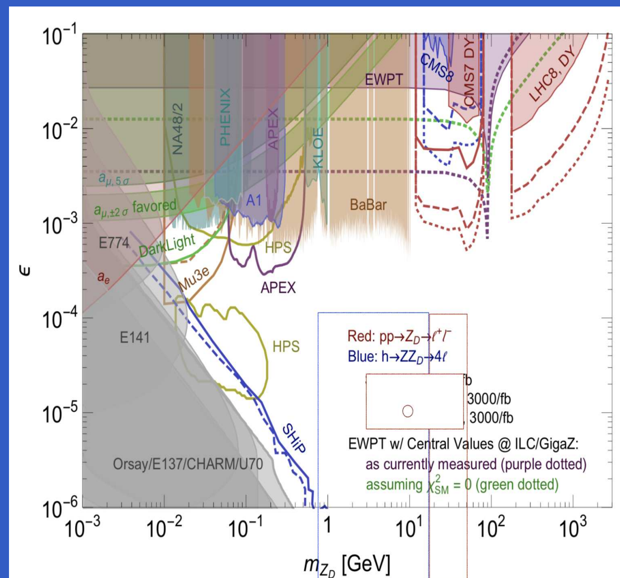
II. QUESTIONS TO STUDY

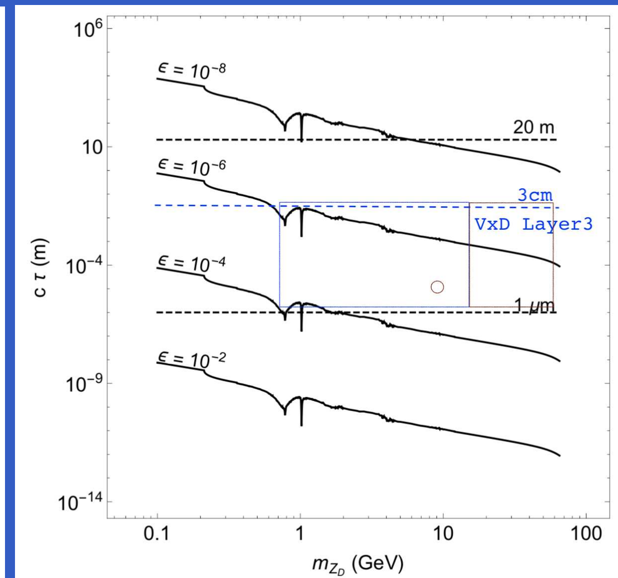
We plan to focus on the proposed ILC dataset of 2 ab^{-1} at $\sqrt{s} = 250$ GeV. We are interested to use truth-level signal simulation samples to explore the full acceptance available to the ILC detectors. To explore the expected detector performance, we aim to use a benchmark signal sample reconstructed with full simulation of the SiD detector. The nominal SiD vertex detector [5] comprises five barrels closed by four disks one each side, together with three more forward disks further along the beamline on each side. Barrels and disks are instrumented with Silicon pixels with 5 μm or better hit resolution [5]. Comparisons of truth-level acceptance and full simulation with the standard recon-

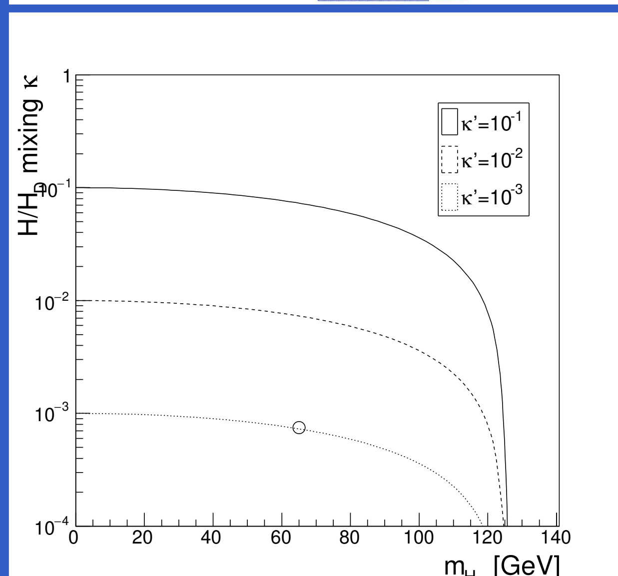
SNOWMASS21-EF9_EF8-081 [Clickable Link]

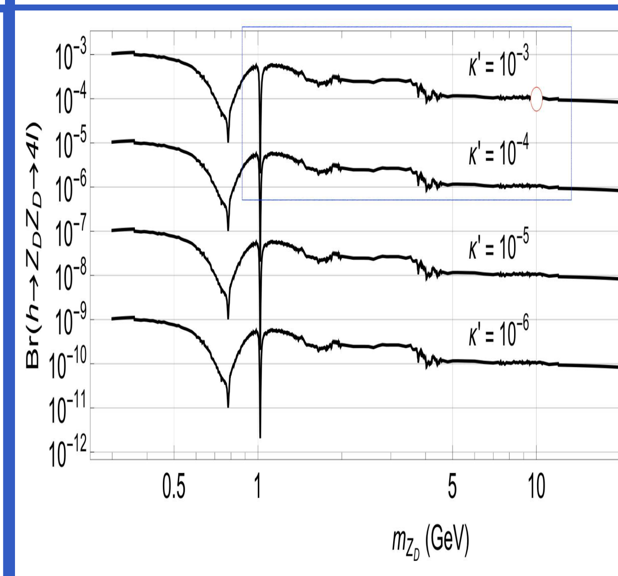
Dark Photon Benchmark: Displaced Vertices

$m_{Z_d} = 10$ GeV, $m_{H_d} = 65$ GeV, $\epsilon = 10^{-5}$, $\kappa = 7.5 \times 10^{-4}$









Curtin, Essig, Gori and Shelton (1412.0018)) [Clickable Link]

Laura Jeanty: Higgs to Long-lived Particles

LCWS2021
International Workshop on Future Linear Colliders

Long-lived dark photons at the ILC

18 Mar 2021, 06:00
19m
Online Conference (Zoom)

PD3: Physics Analys...
PD3/PD4: Physics Anal...

CET: 06:00 18 March
PDT: 22:00 17 March
JST: 14:00 18 March

Speaker

Laura Jeanty (University of Oregon...

Description

Searches for light, weakly coupled particles are an important component of the physics program at present and future colliders. A classic benchmark for a potential vector-boson mediator between the standard model and the dark sector is the hypothetical dark photon, which could be produced either directly or through a dark Higgs boson. As part of the US Snowmass process, we are studying the sensitivity for detection of long-lived dark photons at the ILC, using the Higgs portal production mode and displaced decays of long-lived dark photons as a benchmark to study the SiD detector performance for detection of displaced decays. In this talk, we will outline our plans for the study, and discuss progress so far, including first looks at both fast and full SiD simulation of long-lived dark photons produced via Higgs-strahlung at sqrt(s) = 250 GeV.

Joint PD3/PD4 Parallel Session [Clickable Link]

Higgs Self-Coupling at $\sqrt{s} = 500, 1000$ GeV

LCWS2021 INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

Higgs Self-Coupling at the ILC with the SiD Detector
(A Snowmass 2021 Leter of Interest)

Tim Barklow[1], James Brau[2,3], Masako Iwasaki[4,5,6,7], Masakazu Kurata[8], Peter Onyisi[9], and Chris Potter*[2,3]

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[2]Department of Physics, University of Oregon, Eugene, Oregon 97403-1274, USA
[3]Institute for Fundamental Science, University of Oregon, Eugene, Oregon 97403-1274, USA
[4]Department of Mathematics and Physics, Graduate School of Science, Osaka City University, Osaka, Japan
[5]Nambu Yoichiro Institute of Theoretical and Experimental Physics (NITEP), Osaka City University, Osaka, Japan
[6]Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, Japan
[7]Osaka University Institute for Datability Science (IDS), Osaka, Japan
[8]Graduate School of Science, University of Tokyo, Tokyo, Japan
[9]Department of Physics, University of Texas at Austin, Austin, Texas 78712, USA

August 31, 2020

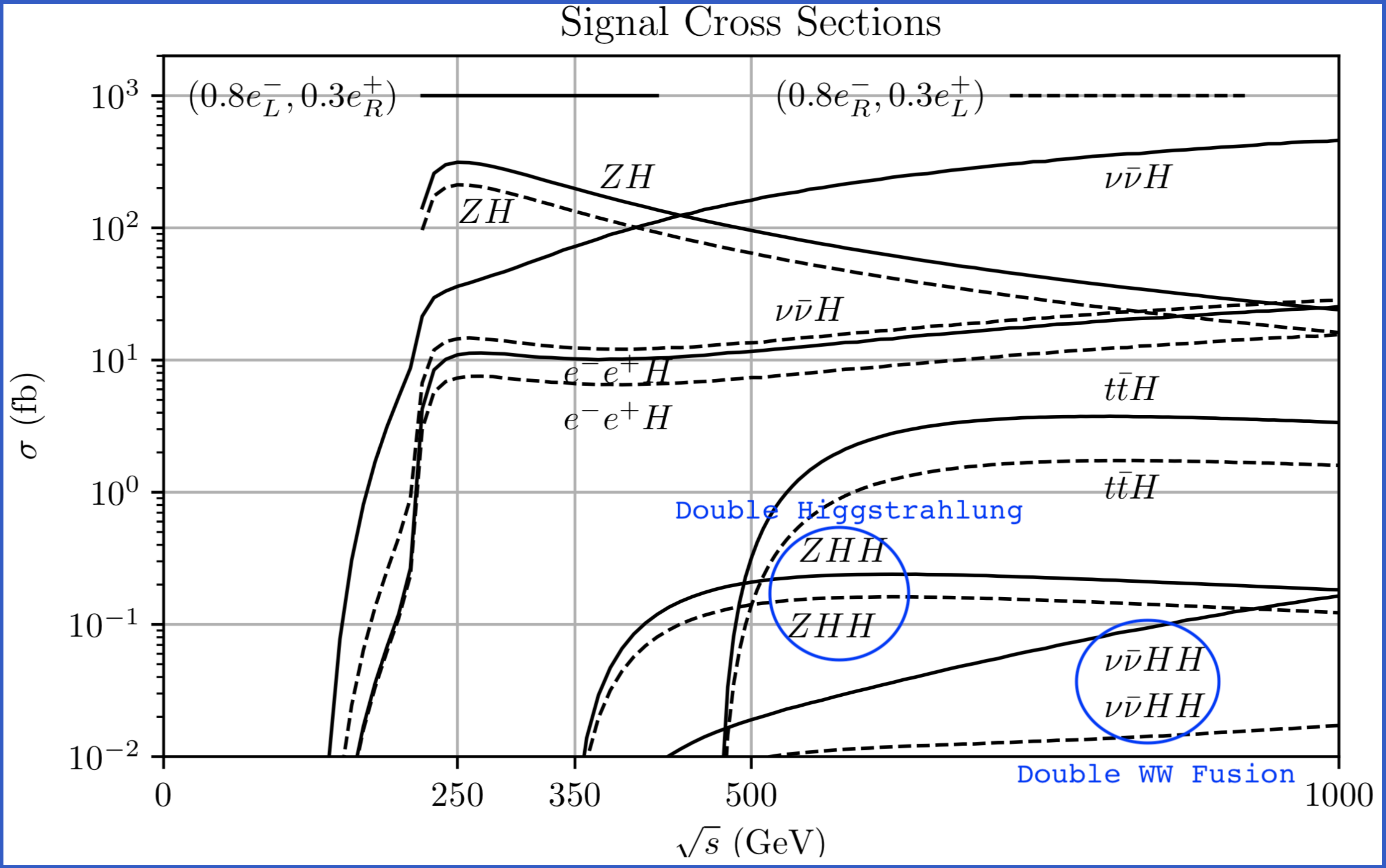
Abstract

Measuring the Higgs boson self-coupling λ_{hhh} with high precision is an important part of the program for particle physics in the coming decades. In the Standard Model (SM), $\lambda_{hhh}^{SM} = m_h^2/2v^2$ is determined by two parameters, $v = (\sqrt{2}G_F)^{1/2} \approx 246$ GeV and $m_h \approx 125$ GeV. In Beyond the SM (BSM) scenarios, new particles can enhance or diminish the self-coupling through mixing or in loops. In e^+e^- colliders λ_{hhh} is measured by measuring the cross section for double Higgs production $e^+e^- \to ZHH$ or $e^+e^- \to \nu\bar{\nu}HH$. In this study we investigate the expected sensitivity to λ_{hhh} at the ILC with the SiD detector.

SNOWMASS21-EF1_EF_Potter-155 [Clickable Link]

Double Higgs Cross Section vs CME

LCWS2021 INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS



"Primer on ILC Physics and SiD Software Tools", EPJP (2020) 135: 525 [Clickable Link]

Peter Onyisi: Di-Higgs and Self-Coupling

LCWS2021 INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

Di-Higgs production in e+e- Collisions and Measurement of the Higgs Self-Coupling

16 Mar 2021, 06:20

20m

Online Conference (Zoom)

PD3: Physics Analyses

CET: 06:20 16 March

PDT: 22:20 15 March

JST: 14:20 16 March

Speaker

Peter Onyisi (University of Texas ...

Description

Determination of the Higgs boson self-coupling is crucial for understanding the structure of the electroweak symmetry breaking vacuum. I will review the theoretical extraction of the self-coupling from observed cross sections of e+e- -> Zhh and e+e- -> vvhh at high energy, current projections of experimental sensitivity, and the limiting factors for this measurement.

PD3 Parallel Session in Indico [Clickable Link]

SiD Physics LoIs: Resuming Snowmass

- Higgs to Invisible at $\sqrt{s} = 250$ GeV (see Amanda Steinhebel's talk)
  - Preliminary results with full SiD simulation presented to the SiD Optimization meeting.
  - Preliminary Boosted Decision Tree analysis yields greater sensitivity.

SiD Physics LoIs: Resuming Snowmass

LCWS2021 International Workshop on Future Linear Colliders

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  - Preliminary Boosted Decision Tree analysis yields greater sensitivity.
- Higgs CP in Tau Pairs at $\sqrt{s} = 250$ GeV (see Lucas Braun's talk)
  - Preliminary results with fast simulation, preparing to study full SiD simulation.
  - Progress presented to the biweekly SiD Optimization meeting convened by the University of Glasgow (Dan Protopopescu and Aidan Robson).

SiD Physics LoIs: Resuming Snowmass

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  - Collaboration with Snowmass colleagues at Brookhaven National Lab is ongoing.

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  - Preliminary results with fast simulation, preparing to study full SiD simulation.
  - Collaboration with Snowmass colleagues at Brookhaven National Lab is ongoing.
- Higgs Self-coupling at $\sqrt{s} = 500, 1000$ GeV (see Peter Onyisi's talk)
  - Fast/full SiD simulation at $\sqrt{s} = 500, 1000$ GeV for double Higgs is ready.
  - Analysts will begin meeting regularly on the Snowmass resumption timetable.

SiD Physics LoIs: Resuming Snowmass

LCWS2021 INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

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  - Collaboration with Snowmass colleagues at Brookhaven National Lab is ongoing.
- Higgs Self-coupling at $\sqrt{s} = 500, 1000$ GeV (see Peter Onyisi's talk)
  - Fast/full SiD simulation at $\sqrt{s} = 500, 1000$ GeV for double Higgs is ready.
  - Analysts will begin meeting regularly on the Snowmass resumption timetable.
- Your participation in these studies would be welcomed! Contact the SiD Co-spokes Andy White (awhite@uta.edu) and Marcel Stanitzki (marcel.stanitzki@desy.de).