



# Higgs/Electroweak Parallel Sessions Guided Tour

Graham W. Wilson

University of Kansas

July 11, 2024

## Higgs, Electroweak

Dirk Zerwas (DMLab and IJCLab)

Graham Wilson (Kansas U.)

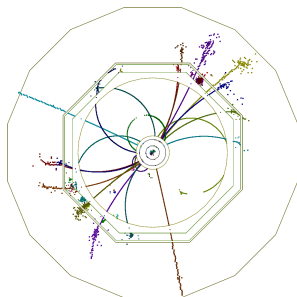
Tatsuya Masubuchi (Osaka U.)

Patrick Meade (Stony Brook)

Georg Weiglein (DESY)

Shinya Kanemura (Osaka U.)

Manqi Ruan (IHEP)



Apologies in advance to all 24 speakers. I had time to review/select only a few topics to highlight; they are from the session I chaired. I often was in other sessions or focused on other obligations.






Tue 09/07

09:00	<b>Higgs measurements at the LHC and HL-LHC (Invited)</b>	Dengfeng Zhang 
	<i>Ito Hall, Ito International Research Center</i>	09:00 - 09:30
	<b>Determination of CP-violating Higgs couplings with transversely-polarized beams at the ILC</b>	Dr Cheng Li 
	<i>Ito Hall, Ito International Research Center</i>	09:30 - 09:50
10:00	<b>Prospects of measuring quantum entanglement in <math>H \rightarrow \tau\tau</math> at a future <math>e^+e^-</math> Higgs factory</b>	Mr Cedric Breuning 
	<i>Ito Hall, Ito International Research Center</i>	09:50 - 10:10
	<b>Decoding Higgs Boson Branching Ratios from Event Shape Variables</b>	Daniel Reichelt 
	<i>Ito Hall, Ito International Research Center</i>	10:10 - 10:30
11:00	<b>Collider Tests of Nanohertz Gravitational Waves</b>	Dr Shaoping Li 
	<i>Ito Hall, Ito International Research Center</i>	11:00 - 11:15
	<b>Searching for heavy neutral leptons in electron positron colliders</b>	Arindam Das 
	<i>Ito Hall, Ito International Research Center</i>	11:15 - 11:30
	<b>Testing the gauged U(1)B-L model for loop induced neutrino mass with dark matter at future colliders</b>	GUOHAO YING 
	<i>Ito Hall, Ito International Research Center</i>	11:30 - 11:45
	<b>Higgs Production at <math>\mu^+\mu^-</math> Colliders</b>	Mr Lukas Treuer
	<i>Ito Hall, Ito International Research Center</i>	11:45 - 12:00
12:00	<b>Exploring new physics by loop-corrected decays of additional Higgs bosons</b>	Mariko KIKUCHI 
	<i>Ito Hall, Ito International Research Center</i>	12:00 - 12:15
	<b><math>S4b + X_S</math> via electroweak multi-Higgs production as smoking gun signal for the Type-I 2HDM at the LHC</b>	Dr Prasenjit Sanyal
	<i>Ito Hall, Ito International Research Center</i>	12:15 - 12:30

Latter block = joint session with BSM/Global Interpretations

09:00	<b>Electroweak measurements at the LHC and HL-LHC (Invited)</b> <i>Koshihisa Hall, Science building n.1</i>	Anne-Marie Magnan		09:00 - 09:30
	<b>Searching for new physics in WW and single-W events</b> <i>Koshihisa Hall, Science building n.1</i>	Jenny List		09:30 - 09:50
10:00	<b>Higher-order initial state radiation in e+e- annihilation</b> <i>Koshihisa Hall, Science building n.1</i>	Andrej Arbuzov		09:50 - 10:10
	<b>New renormalization scheme in extended Higgs sectors for Higgs precision measurements</b> <i>Koshihisa Hall, Science building n.1</i>	Kei Yagyu		10:10 - 10:30
11:00	<b>Searching for Charged Higgs Bosons via <math>Se^{+}e^{-} \rightarrow H^{+}H^{-} \rightarrow c\bar{b} b\bar{b} cb</math> at Linear Colliders</b> <i>Koshihisa Hall, Science building n.1</i>	George W.-S. Hou		11:00 - 11:20
	<b>Impact of quark flavor violating SUSY on <math>h(125)</math> decays at future lepton colliders</b> <i>Koshihisa Hall, Science building n.1</i>	Prof. Keisho Hidaka		11:20 - 11:40
	<b>Towards an update of the ILD ZHH analysis</b> <i>Koshihisa Hall, Science building n.1</i>	Bryan Bliewert		11:40 - 11:55
12:00	<b>Higher-order effects in the trilinear Higgs coupling for future collider experiments</b> <i>Koshihisa Hall, Science building n.1</i>	Shuhei Ohzawa		11:55 - 12:10
	<b>Loop induced <math>H\pm W\pm Z</math> vertex in CP violating two Higgs doublet model and its impact on collider phenomenology</b> <i>Yushi Mura</i>			

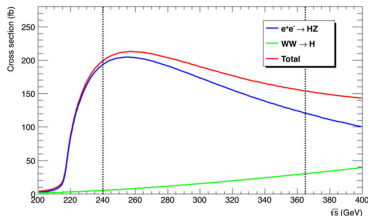
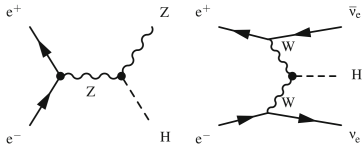
## 14h00 - 15h30. Joint session with BSM/Global Interpretations

16:00	<b>BSM Triple Higgs couplings at the ILC/CLIC</b> <i>Koshiba Hall, Science building n.1</i>	<i>Francisco Arco et al.</i> 	16:00 - 16:25
	<b>ECFA Study: Higgs Self-coupling</b> <i>Koshiba Hall, Science building n.1</i>	<i>Sven Heinemeyer</i> 	16:25 - 16:45
	<b>New collider implications on a strongly first order EWPT.</b> <i>Koshiba Hall, Science building n.1</i>	<i>Ricardo Florentino</i> 	16:45 - 17:00
17:00	<b>Double Higgs production in composite two Higgs doublet model</b> <i>Koshiba Hall, Science building n.1</i>	<i>Kodai Sakurai</i> 	17:00 - 17:15
	<b>Higgs self coupling: Theory status</b> <i>Koshiba Hall, Science building n.1</i>	<i>Matthew Mccullough</i> 	17:15 - 17:40

# Higgs: Raison d'être of a Higgs Factory

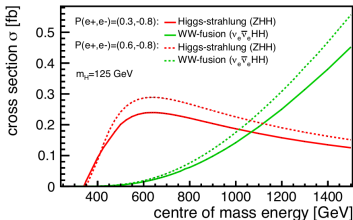
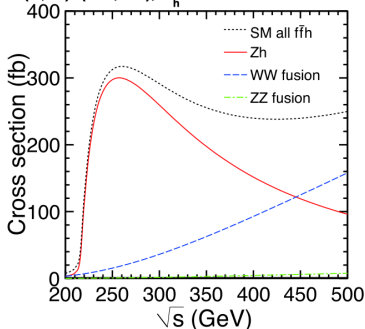
Key measurements:  $\sigma_{ZH}$ ,  $m_H$ ,  $\mathcal{B}_i$ .

Leads to  $g_{HZZ}$ ,  $g_{HWW}$ ,  $\Gamma_{\text{tot}}$ .



3 regimes. Threshold (Higgs-strahlung).  
Intermediate (WW-fusion). 400 GeV+  
needed to start to probe HHH directly.

$P(e^+, e^+) = (-0.8, 0.3)$ ,  $M_h = 125 \text{ GeV}$



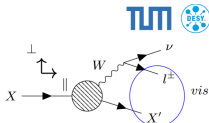
## Towards an update of the ILD ZHH analysis

International Workshop on Future Linear Colliders (LCWS2024) | 2024/07/10

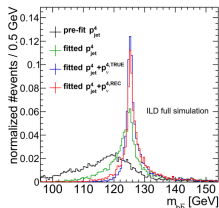
Bryan Bliewert<sup>1,2</sup>, Caterina Vernieri<sup>3</sup>, Dimitris Ntounis<sup>3</sup>, Jenny List<sup>1</sup>, Julie Munch Torndal<sup>1,4</sup>, Junping Tian<sup>5</sup>

### Neutrino correction with kinematic fitting

- for semileptonic decay (SLD) processes
  - already in  $ZH \rightarrow b\bar{b}/c\bar{c}$ , 66% of events include at least one SLD
- procedure:
  - identify/tag heavy quark jet
  - identify lepton in jet
  - calculate neutrino four momentum from kinematics with kinematic fitting, the best solution is selected
- status: in production (in MarlinReco)



Recovering the neutrino kinematics. Y. Radkhorrani [2022]



Improved di-jet mass reconstruction. Y. Radkhorrani [2022]

Towards an update of the ILD ZHH analysis | International Workshop on Future Linear Colliders (LCWS2024) | Bryan Bliewert | 2024/07/10

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Emphasis on tool development and demonstrating performance gains with realistic detector model in this challenging flagship process. Excellent prospects for  $\delta(\lambda)/\lambda$  of 20%. Would benefit too from energy/lumi upgrades.

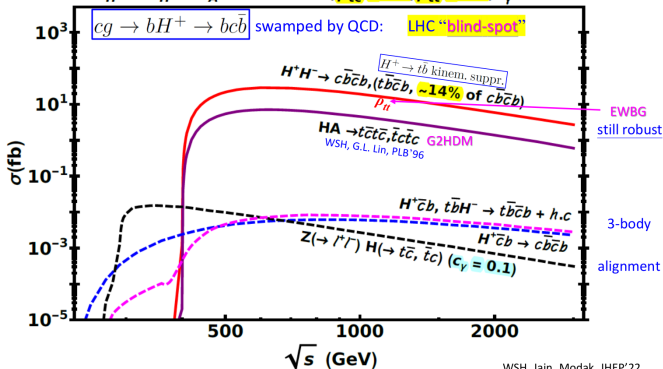


### IV. $e^+e^- \rightarrow H^+H^- \rightarrow c\bar{b}c\bar{b}$ @ ILC500

A "what if" situation at LHC.

$cg \rightarrow tH/A \rightarrow ttc(\text{bar})$   $ttc(\text{bar})$  cancel

$m_{H^+} = m_H = m_A = 200 \text{ GeV}$ ,  $\rho_{tc} = 0.1, \rho_{tt} = 0.1, c_\gamma = 0.0$



WSH, Jain, Modak, JHEP'22

# *Impact of quark flavor violating SUSY on $h(125)$ decays at future lepton colliders*

*K. Hidaka*

*Tokyo Gakugei University*

*Collaboration with*

*H. Eberl, E. Ginina (HEPHY Vienna)*

*References:*

*Phys. Rev. D 91 (2015) 015007 [arXiv:1411.2840 [hep-ph]]*

*JHEP 1606 (2016) 143 [arXiv:1604.02366 [hep-ph]]*

*IJMP A34 (2019) 1950120 [arXiv:1812.08010 [hep-ph]]*

*PoS(EPS-HEP2021) 594, 2021 [arXiv:2111.02713 [hep-ph]]*

*PoS(ICHEP2022) 536, 2022 [arXiv:2211.07243 [hep-ph]]*

*PoS(EPS-HEP2023) 487, 2023*

*LCWS2024, 8-11 July 2024, University of Tokyo, Japan*



## Loop induced $H^\pm W^\pm Z$ vertex in CP violating two Higgs doublet model and its impact on collider phenomenology

Yushi Mura (Osaka U. Ph.D student)  
Collaborator: Prof. Shinya Kanemura (Osaka U.)



arXiv:2407.xxxxx



International Workshop on Future Linear Colliders  
2024/07/10

S. Kanemura and Y.M., arXiv:2407.xxxxx

## Impacts on collider phenomenology

### • Benchmark points

	(in GeV)	$m_{H^\pm}$	$m_{H_2}$	$m_{H_3}$	$Z_7$	$\rho_{tt}$	$\alpha_1 = -\alpha_2$
large $\rho_{tt}$	BP1	200	500	210	$1.5e^{2.0i}$	0.1	0.1
small $\rho_{tt}$	BP2	200	500	210	$1.5e^{2.0i}$	0.001	0.1

### • Production of $H^\pm$ in $e^+e^-$ collider

Pair production process  $e^+e^- \rightarrow H^+H^-$  S. Komamiya, Phys. Rev. D (1988)

	BP1		BP2	
$\text{Br}(H^\pm \rightarrow W^\pm Z)$	$2.8 \times 10^{-3}$		$9.4 \times 10^{-1}$	
$\sqrt{s}$	500 GeV	1 TeV	500 GeV	1 TeV
$\sigma(H^-H^+)$	$3.0 \times 10$ fb	$2.0 \times 10$ fb	$3.0 \times 10$ fb	$2.0 \times 10$ fb
$\sigma(H^-H^+) \times \text{Br}$	$8.7 \times 10^{-2}$ fb	$5.6 \times 10^{-2}$ fb	$2.8 \times 10$ fb	$1.9 \times 10$ fb
Event #	261	168	$8.4 \times 10^4$	$5.7 \times 10^4$

$3 \text{ ab}^{-1}$  integrated luminosity  
is assumed

### • Testing $H^\pm W^\mp Z$ vertex in the general 2HDM motivates future colliders



## Higgs measurements at the LHC and HL-LHC

Dengfeng Zhang (University of Sheffield)  
on behalf of the ATLAS and CMS Collaborations

The 2024 International Workshop on Future Linear Colliders  
July 09, 2024

University of Tokyo, Japan

Determination of  $\mathcal{CP}$ -violating  $HZZ$  interaction with polarised  
beams at the ILC

[arXiv: 2405.08494]

Cheng Li<sup>1</sup>, Gudrid Moortgat-Pick<sup>2</sup>

<sup>1</sup>School of Science  
Sun Yat-sen University

<sup>2</sup>II. Institut für Theoretische Physik  
Universität Hamburg

LCWS 2024, Tokyo  
July 9, 2024



## Electroweak measurements at the LHC and HL-LHC with ATLAS and CMS

Anne-Marie Mignan, Imperial College London  
**IMPERIAL**

on behalf of the ATLAS and CMS Collaborations

8<sup>th</sup>-11<sup>th</sup> July 2024, LCWS 2024, Tokyo, Japan



Prospects of measuring  
quantum entanglement in  $\tau\tau$  final states  
at a future  $e^+e^-$  Higgs factory

Philip Bechtle, Cedric Breunig, Klaus Desch, Christian Greife  
LCWS 2024 – University of Tokyo

09.07.2024



# Decoding Higgs Boson Branching Ratios from Event Shape Variables

based on:

Knobbe, Krauss, DR, Schumann EPJC 84 (2024) 1, 83 [arXiv:2306.03682]

Gehrmann-de Ridder, Preuss, DR, Schumann [arXiv:2403.06929]

Daniel Reichelt, 9 July 2024

# Searching for heavy neutral leptons in electron positron colliders

LCWS2024 July 9, 2024  
The University of Tokyo



Arindam Das  
Hokkaido University



# Collider Tests of Nanohertz Gravity Waves

Shaoping Li

@ Hongo, The University of Tokyo

2024.07.09

Lisp & K.-P. Xie: 2307.01086  
S. Kanemura & Lisp: 2308.16390



# Testing the gauged $U(1)_{B-L}$ model for loop induced neutrino mass with dark matter at future colliders



大阪大学  
OSAKA UNIVERSITY

Guohao Ying

paper in preparation

Department of Physics, Graduate School of Science, Osaka University  
Collaborator: Prof. **Shinya Kanemura** (Osaka U.), **Yushi Mura** (Osaka U.)



LCWS2024@UTokyo, July 9th, 2024

Lukas Treuer (ltreuer@post.kek.jp)

1<sup>st</sup> year PhD student at KEK and The Graduate U. Adv. Studies (SOKENDAI)

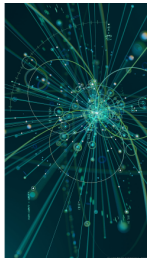
In collaboration with Prof. Fuyuhiko Kitano (KEK, SOKENDAI); Yu Hamada (DESY), Ryutarō Matsuda (KEK), Shohei Okawa (KEK), Ryoto Takai (KEK, SOKENDAI), Hiromasa Takaura (YITP)

## HIGGS PRODUCTION AT $\mu^+\mu^+$ COLLIDERS

AND A NEW CALCULATION SCHEME FOR TOTAL  
CROSS SECTIONS WITH INTERMEDIATE PHOTONS

Will appear on the arXiv very soon!

International Workshop on Future Linear Colliders (LCWS) 2024  
July 9<sup>th</sup> 2024



$4b + X$  via electroweak multi-Higgs production as smoking  
gun signals for the Type-I 2HDM at the LHC

Prasenjit Sanyal

Konkuk University, Korea

## Exploring new physics by loop-corrected decays of additional Higgs bosons

Mariko Kikuchi (Nihon U.)

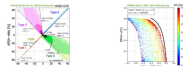
Masashi Aiko (NIT Miyakononojo College)

Shinya Kanemura (Osaka U.)

Kodai Sakurai (Tohoku U.)

Kei Yagyu (Osaka U.)

*Comput.Phys.Commun.* 301 (2024) 109231



<http://www.het.phys.sci.osaka-u.ac.jp/~hcoup/>

## Searching for New Physics in WW and singleW Events

LCWS 2024  
Tokyo University  
July 10, 2024

Ulrich Einhaus<sup>1</sup>, Andre Filipe Silva<sup>1,2</sup>, Leonhard Reichenbach<sup>3,4</sup>, **Jenny List**<sup>1</sup>

<sup>1</sup> Deutsches Elektronen-Synchrotron DESY

<sup>2</sup> University of Coimbra

<sup>3</sup> Bonn University

<sup>4</sup> CERN



CLUSTER OF EXCELLENCE  
QUANTUM UNIVERSE

## Higher-order initial state radiation in $e^+e^-$ annihilation

Andrej Arbuzov

Dubna

based on works with U. Voznaya:  
JPG'2023, PRD'2024  
(supported by RSF grant N 22-12-00021)

LCWS-2024, 8-11 July, Tokyo university, Japan

10th July 2024

Andrej Arbuzov

Higher-order ISR ...

10th July 2024

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## Higher-order effects in the trilinear Higgs coupling for future collider experiments

Work in progress

Shuhei Ohzawa (U. of Toyama)

Collaborators: Mitsuru Kakizaki<sup>A</sup>, Nagisa Hiroshima<sup>B, C</sup>

2024 International Workshop on Future Linear Colliders (LCWS2024), U. of Tokyo  
July 10, 2024

<sup>A</sup>U. of Toyama

<sup>B</sup>Yokohama National U.

<sup>C</sup>RIKEN iTHEMS



## New renormalization scheme in extended Higgs sectors for Higgs precise measurements

Kei Yagyu (Osaka U.)



In collaboration with

Shinya Kanemura (Osaka U.) and Mariko Kikuchi (Nihon U.)

*Paper in preparation*

LCWS2024

July 10<sup>th</sup>, The University of Tokyo



## BSM Triple Higgs couplings (at one-loop) at $e^+e^-$ Colliders

Francisco Arco (he/him)

International Workshop on Future Linear Colliders (LCWS2024)  
Higgs, Electroweak Parallel Session  
University of Tokyo, Japan – July 10, 2024

Ongoing work with S. Heinemeyer and M. Mühlleitner



Sven Heinemeyer, LCWS24 (Tokyo), 10.07.2024

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[JHEP 06 (2024) 063]

## Double Higgs production in composite two Higgs doublet model

Kodai Sakurai (Tohoku University)

Collaborators :

Stefania De Curtis<sup>A</sup>, Luigi Delle Rose<sup>B</sup>, Felix Egler<sup>C</sup>,  
Margarete Mühlleitner<sup>C</sup>, Stefano Moretti<sup>D,E</sup>

<sup>A</sup>: U. of Florence, <sup>B</sup>: Calabria U., <sup>C</sup>: KIT, <sup>D</sup>: U. of Southampton, <sup>E</sup>: Uppsala U

LCWS2024, July 10th

New collider implications  
on a strongly first order EWPT.

Ricardo R. Florentino

Particle Physics Theory Group  
Graduate School of Science  
Osaka University

Collaborators: Prof. Shinya Kanemura; Dr. Masanori Tanaka

LCWS July 2024

arXiv:2406.03957

Ricardo Florentino

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## Higgs Self-Coupling: Theory Status

LCWS2024  
July 10<sup>th</sup> 2024

Matthew McCullough  
CERN

First, I very much appreciate the hard work done to mount this great workshop. Personally, I was touched by the opportunity to share in the celebration of Sachio's life.

It has been wonderful with the LC Vision discussion.

But,

- 1 Tour guides need time to do the tour.
- 2 4 days is too short. It is too overly parallel (up to 9-fold!).
- 3 Having parallel accelerator / (physics & detector) summaries not helpful to informing both communities and encouraging synergies!
- 4 I thought summary talks after the banquet night had been eliminated...

Thanks!