

Priorities for the future analyses in ILD

Report from ILD Physics Working Group

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on behalf of the Physics WG conveners



A detector for a Higgs factory and beyond

ILD meeting at CERN

January 17, 2024

Priorities for the future analyses in ILD have not been defined/discussed as such, yet.

Presented in this talk is my personal view, based on very fruitful discussions we had in the last two days and also many discussions we had in the past.

It is rather meant to be an input for the discussion...



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Can be divided into three main areas:

- Physics potential studies based on ILD detector design
- Detector performance studies, for detector design optimization and development
- Software performance studies, for development of new analysis tools and procedures

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The three areas of activities overlap in many cases, no sharp division.

Most studies include both physics and detector concept aspects, and depend crucially on the software tools used.

Even when focusing on the physics case, we need to put balanced effort into software development and detector performance studies...

There is significant overlap with the Software Working group.



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convince decision makers that ILC is worth the investment
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- present ILD as a compelling option for other colliders
defined last year as one of our priorities
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make full use of recent ML and AI developments



Final report

Expected by the end 2025 (all inputs probably need to be finalized mid 2025).

To be submitted as an input to the next European Strategy Update.

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Focus topics see talk by Jenny yesterday

Topics, that have not been covered in detail yet, interesting for all considered projects.

The goal is to encourage communication and collaboration between different groups, exchange expertise, attract new people...

Most of the proposed topics have already been considered for ILD.

It should be our priority to contribute to the Focus Topics whenever possible.

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This will be focus of this presentation...

ILD contact persons members of the topical expert teams

#	topic	lead group	ILD group	ILD contact person
1	HtoSS	HTE	Higgs/EW	Taikan Suehara
2	ZHAng	HTE (GLOB)	Higgs/EW	Ivanka Bozovic, Natasa Vukasinovic
3	Hself	GLOB	Higgs/EW	Junping Tian
4	Wmass	PREC	Higgs/EW	Graham Wilson
5	WWdiff	GLOB	Higgs/EW	Jenny List
6	TTthres	GLOB (HTE)	Top/HF/QCD	Marcel Vos
7	LUMI	PREC	Higgs/EW	Ivanka Bozovic
8	EXscalar	SRCH	BSM	Mikael Berggren
9	LLPs	SRCH	BSM	Filip Zarnecki
10	EXtt	SRCH	BSM	Teresa Nunez
11	CKMWW	FLAV	Top/HF/QCD	Uli Einhaus
12	BKtautau	FLAV	Top/HF/QCD	—
13	TwoF	HTE	Top/HF/QCD	Adrian Irles and Roman Pöschl
14	BCfrag and Gsplit	PREC (FLAV)	Top/HF/QCD	Adrian Irles

List of active works (ongoing and planned)

- ILD: Comprehensive $H \rightarrow ss$ paper exists, including discussion on additional RICH on detector [arxiv:2203.07535](https://arxiv.org/abs/2203.07535)
(maybe good to replace with latest strange tagging)
- ILD: Ongoing work with DNN (ParticleNet/Par. Transformer)
 - For us: first result targeted at March (JPS) or July (LCWS)
- IDEA: strange tagging with ParticleNet etc. gives good results, real $H \rightarrow ss$ analysis to be done? [arxiv:2202.03285](https://arxiv.org/abs/2202.03285)
- CEPC: work ongoing based on ParticleNet [arxiv:2310.03440](https://arxiv.org/abs/2310.03440)
- Others?

What to do in ILD?

- Establish strange tagging algorithm: by ~ middle 2024
 - Probably DNN-based, PID input important (CPID?)
 - Should also include charge ID
 - Consideration of systematic effects
- Dependence on detector performance
 - dE/dx (pixel TPC? Difference with drift chamber in FCC?)
 - Timing (some model needed for physics analysis)
 - Cherenkov? (ambitious for ECFA timescale?)
- Physics analysis based on the algorithm (250 GeV and higher)
 - Separation of b/c/s/ud/g (gluon tag is also important)
- Other BSM contributions?
 - $H \rightarrow bs$?

Zhang – previous(ongoing) ILC/ILD work

(68% CL, pure scalar)

[Snowmass White Paper: CPV,
arXiv:2205.07715v3]

Collider	pp	pp	pp	e^+e^-	e^+e^-	e^+e^-	e^+e^-	e^-p	$\gamma\gamma$	$\mu^+\mu^-$	$\mu^+\mu^-$	target
E (GeV)	14,000	14,000	10 times more \mathcal{L}	250	350	500	1 TeV VBF 8 ab ⁻¹	1,300	125	125	3,000	(theory)
\mathcal{L} (fb ⁻¹)	300	3,000		250	350	500		1,000	250	20	1,000	
HZZ/HWW	$4.0 \cdot 10^{-5}$	$2.5 \cdot 10^{-6}$	✓	$3.9 \cdot 10^{-5}$	$2.9 \cdot 10^{-5}$	$1.3 \cdot 10^{-5}$	$1.6 \cdot 10^{-5}$	✓	✓	✓	✓	$< 10^{-5}$
$H\gamma\gamma$	-	0.50	✓	-	-	-	-	-	0.06	-	-	$< 10^{-2}$
$HZ\gamma$	-	~ 1	✓	-	-	-	~ 1	-	-	-	-	$< 10^{-2}$
Hgg	0.12	0.011	✓	-	-	-	-	-	-	-	-	$< 10^{-2}$
$H\bar{t}\bar{t}$	0.24	0.05	✓	-	-	0.29	0.08	✓	-	-	✓	$< 10^{-2}$
$H\tau\tau$	0.07	0.008	✓	0.01	0.01	0.02	0.06	-	✓	✓	✓	$< 10^{-2}$
$H\mu\mu$	-	-	-	-	-	-	-	-	-	✓	-	$< 10^{-2}$

1. I. Bozovic, N. Vukasinovic, G. Kacarevic, Probing CPV mixing in the Higgs sector in VBF at 1 TeV ILC, PoS(EPS-HEP2023)404, *to be submitted to Phys. Rev. D*
2. D. Jeans and G. W. Wilson, Measuring the CP state of tau lepton pairs from Higgs decay at the ILC, Phys. Rev. 302 D 98 013007 (2018), [arXiv:1804.01241](https://arxiv.org/abs/1804.01241)
3. Working Group Report: Higgs Boson", in Community Summer Study 2013: Snowmass on the Mississippi. 10, 2013, [arXiv:1310.8361](https://arxiv.org/abs/1310.8361)

Zhang – potential ILC/ILD studies

Further studies can determine whether there is scope to improve the sensitivity, or to extend it to additional interactions.

PHYSICS ANALYSES

- Other channels in HZ: (inclusive Z decays), H to WW to hadrons (decay)
- Other energies: H to $\tau\tau$ at higher ILC energies
- Analyses refinement: use optimal observable(s) to enhance sensitivity to the Higgs CP structure

THEORY

- Expand interpretation framework connecting SMEFT/angular observables/specific BSM models (to understand the baryon asymmetry)

ALGORITHMS

- Tracking and ID: τ and jet reconstruction
- Jet charge measurement (quark-antiquark separation in H to VV hadronic decays)

λ_{HHH} : How ILD can contribute?

(some random midnights thoughts...)

- **Analysis of $e^+e^- \rightarrow ZH$ with a scan of $\sqrt{s} \sim 250$ GeV**
 - effect from λ sensitive to $\sqrt{s} \sim 250$: multiple σ_{ZH} help lift degeneracy
 - anomalous HZZ couplings also highly correlated to SM coupling ~ 250 , multiple $d\sigma$ help
 - also an opportunity to find out the optimal initial \sqrt{s} of ILC
- **Analysis of $e^+e^- \rightarrow ZHH$ with $\lambda_{HHH}/\lambda_{SM}=2$**
 - demonstrate the (discovery) potential by full sim.
 - \sqrt{s} can be chosen at ~ 550 GeV, in light of other benefit of y_t
 - incorporate all available improved analysis algorithms

LUMI – potential ILC/ILD studies

LABS is preferred for the point-to-point lumi control, novel (central) processes to be investigated. Detailed designs for LumiCal detectors are needed for different collider setups and different detector concepts.

SIMULATION STUDIES

- ILC needs detailed metrology study for LABS at all ILC energies
- Di-photon production - A detailed study of the luminosity calibration using this process is still lacking and would be very important; Feasibility of angular acceptance precision ($50 \mu\text{m}$) for centrally reconstructed photons
- Other processes (i.e. di-muon production); Angular acceptance and position resolution of the central tracker

THEORY

- Implementation of radiative fermion pair production in LABS (di-photon) generators
- Implementation of NNLO EW corrections for di-photon production

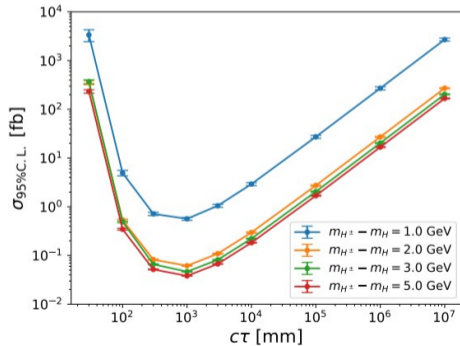
Status and plans

- **Decay-mode independent search** [arXiv:1902.06118](#) [arXiv:2005.06265](#)
Plan to resume full simulation study, using the most up-to-date samples and tools (Mikael, Teresa)
- **Light scalar search in $\tau^+\tau^-$ decay channel** [preliminary results presented at EPS'2023, Higgs'2023](#)
First results based on DELPHES quite promising (with simplified analysis).
Working on final limits from DELPHES study ([Kamil Zembaczynski @ Warsaw](#)).
Full simulation sample request to be submitted soon.
- **Light scalar search in $b\bar{b}$ decay channel**
Initial study with DELPHES samples started ([Bartek Brudnowski @ Warsaw](#)).
Full simulation sample request to be submitted soon.
- **Search for invisible Higgs decays**
Study to be repeated with new analysis tools / key4hep ([Carsten](#))

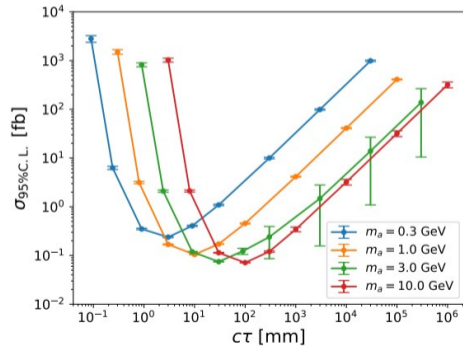
Status and plans

Expected cross section limits for processes with single displaced vertex (work in progress)

Heavy scalars (IDM)



Light pseudoscalar (ALP)



J.Klamka, S&A meeting, Dec 6, 2023

- One analysis being set up by UE
 - use new CPID for particle identification
 - use new neural network tagger (M. Meyer) for flavour tagging
 - use 250 GeV ILD MC production from 2020
 - target: statistical uncertainty on $|V_{ij}|$ including reconstruction efficiencies and backgrounds
 - focus on V_{cs} (impact of PID on s-tagging)
- FCC-ee (IDEA) analysis desired!
- Given huge statistics, study of systematics are vital and can inform detector design decisions!

▷ $e^+e^- \rightarrow \tau\tau$

- D. Jeans et al (IDR, 500GeV, 250GeV in the pipeline)

▷ $ee \rightarrow qq\bar{q}$ at 250 GeV (and above). Focus on AFB measurements

- T. Suehara et al
<https://agenda.infn.it/event/34841/contributions/208275/attachments/111331/158807/231011-2f-ecfa-naga-e-suehara.pdf>
- R. Poeschl, F. Richard, A.I. J. Márquez (see Jesus talk tomorrow, ILD paper on its way), Okugawa et al
- Full simulations studies ($\mu/b/c/s$) Focus on flavour tagging, PID, jet-charge measurement
- Precision physics for indirect BSM searches
- Assume a revisited precision on Z-couplings to fermions (via GigaZ or RadReturn measurements).
- Exploiting the ILC/ILD characteristic features: beam polarization, high energy reach, PID, etc

▷ PID, flavour tagging

- See yesterday session <https://agenda.linearcollider.org/event/10211/contributions/53835/>
- And U. Einhaus talk <https://agenda.linearcollider.org/event/10211/contributions/53839/>

▷ No current efforts on Full Simulation at **GigaZ**.



Table of observables proposed:

- a) crosscheck model performance
- b) revisit models/tuning using LEP/SLC data
- **c) study full simulation and detector performance**

▷ Open (detector) points

- Tracker acceptance impact.
- Kaon ID.
- Jet charge measurements → hadronization is a source of uncertainty if not double tagging is used

▷ ILD recent progresses on adapting the generation chain

- to use **Pythia8** (facilitating playing with tuning parameters)
- To use **QCD NLO** ee→qq calculations in Whizard (with PS matching).
- Zhijie Zhao, J. List, M. Berggren

<https://agenda.infn.it/event/34841/contributions/208079/attachments/111374/158899/ECFA2023-zzi.pdf>

Activities so far

is there more?

WWdiff

- last ILD qqInu analysis: https://github.com/ILDAnaSoft/ILDbench_WWqqInu
=> Graham Wilson...
- recent MC samples in ILD available at 250 GeV
- available MC samples from other detector concepts?
- work in the context of PhD thesis Leonhard Reichenbach (U Bonn / CERN, mainly CLD)
 - improve tracking for electrons, especially in the forward region (GSFs, use info from reconstructed Brems photons...?), understand role of material budget
- work in the context of Master thesis Andre Silva (U Coimbra / DESY, ILD)
 - semileptonic event selection at 250 GeV
- fully hadronic channel: some synergies with U Einhaus' work for CKMWW topic

differential WW cross-section needed as input for next generation SMEFT fit of Higgs & EW sector - we should not leave this to theorists!

Summary

TTthres

The next large-scale e+e- facility in HEP can (should) do a lot of top physics!

An energy scan through the pair production threshold yields the ultimate top quark mass measurement + width, strong coupling, top quark Yukawa

A broad precision programme of top measurements unfolds above threshold including many processes (tt, tt γ , ttg, single top, ttZ, ttH, VBF tt production) and many measurements (σ , A_{FB} , polarization, CP-odd observables...).

Expert team is in place, with representatives from experiment and theory.
Long-term goals are clear and several smaller (but very nice) projects are defined.

Looking forward to more ideas and your contributions.

ILD Status and Plans

EXtt

- FCC-ee studies currently going on using DELPHES and planning to move to more realistic detector simulation in Key4hep
- Previous CLIC studies focused on $\phi = h$ ([arXiv:1801.04585](https://arxiv.org/abs/1801.04585))
- Nothing specifically done at the ILD/ILC in this direction

We aim to find people willing to do some work with the ILD on this topic

**Interesting to figure out the possible profit of ECM > 350 GeV and polarisation
in both beams**

- 1 **HtoSS** – $e^+e^- \rightarrow Zh: h \rightarrow ss$ ($\sqrt{s} = 240/250$ GeV)
- 2 **ZHang** – Zh angular distributions and CP studies
- 3 **Hself** – Determination of the Higgs self-coupling
- 4 **Wmass** – Mass and width of the W boson ...
- 5 **WWdiff** – Full studies of WW and $e\nu W$
- 6 **TTthres** – Top threshold: Detector-level simulation study of $e^+e^- \rightarrow t\bar{t}$...
- 7 **LUMI** – Precision of the luminosity measurement
- 8 **EXscalar** – New exotic scalars
- 9 **LLPs** – Long-lived particles
- 10 **EXtt** – Exotic top decays
- 11 **CKMWW** – CKM matrix elements from W decays
- 12 **BKtautau** – $B^0 \rightarrow K^{0*}\tau^+\tau^-$
- 13 **TwoF** – EW precision: 2-fermion final states ($\sqrt{s} = M_Z$ and beyond)
- 14 **BCfrag** and **Gsplit** – Heavy quark fragmentation and hadronisation, gluon splitting...



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In particular those pointing significant role of polarisation or high energy stages.



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We need to continue working on the convincing physics case
and compelling detector concept for future Higgs Factory

If you want to get involved, please contact us:

ild-physics-conveners@desy.de