



EXscalar - New exotic scalars

Focus topic introduction and status report

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EXscalar - focus topic planning meeting
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Main deliverable

exact timescale still unclear

Final study report

Physics Potential of a Higgs / Top /EW Factory

All WG1 Coordinators and Subgroup Conveners
Many...

Abstract

This documents summarizes the work of the Physics Potential Working Group of the ECFA Study on Future Higgs / Top / Electroweak Factories.....

Keywords

Higgs Boson, Top Quark, Electroweak Physics

1 Introduction

Focus topics

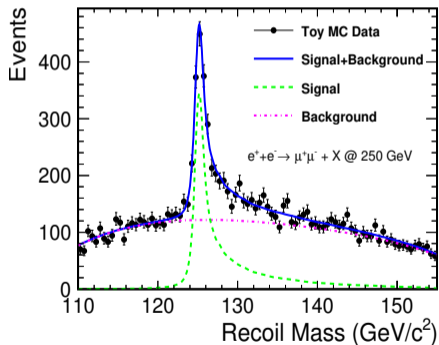
Selected in order to stimulate new engagement and trigger additional activities in areas where further work would be still be beneficial...

arXiv:2401.07564

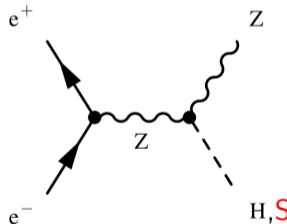
Topic	Lead group	Relevant \sqrt{s} [GeV]				
		91	161	240–250	350–380	≥ 500
1 HtoSS	HTE			✓	✓	✓
2 ZHang	HTE (GLOB)			✓	✓	✓
3 Hself	GLOB			✓	✓	✓
4 Wmass	PREC		✓	✓	✓	✓
5 WWdiff	GLOB			✓	✓	✓
6 TTthres	GLOB (HTE)				✓	✓
7 LUMI	PREC	✓	✓	✓	✓	✓
8 EXscalar	SRCH			✓	✓	✓
9 LLPs	SRCH	✓	✓	✓	✓	✓
10 EXtt	SRCH				✓	✓
11 CKMWW	FLAV		✓	✓	✓	✓
12 BKtautau	FLAV	✓				
13 TwoF	HTE (PREC)	✓	✓	✓	✓	✓
14 BCfrag and Gsplit	PREC (FLAV)	✓	✓	✓	✓	✓

Motivation

Precision Higgs measurements are clearly the primary target for future Higgs factory.



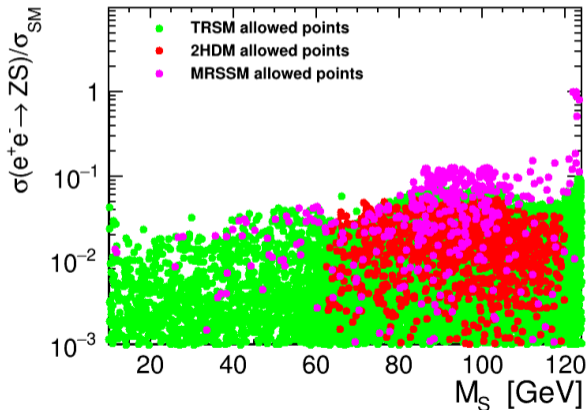
At 250 GeV we will focus on H_{125} production



But production of additional, light exotic scalar states is still not excluded by the existing data!

Motivation

Benchmark points consistent with current experimental and theoretical bounds



Two-Real-Singlet Model

thanks to Tania Robens

see [arXiv:2209.10996](https://arxiv.org/abs/2209.10996) [arXiv:2305.08595](https://arxiv.org/abs/2305.08595)

Two Higgs-Doublet Model

thanks to Kateryna Radchenko

thdmTool package, see [arXiv:2309.17431](https://arxiv.org/abs/2309.17431)

Minimal R-symmetric Supersymmetric SM

thanks to Wojciech Kotlarski [arXiv:1511.09334](https://arxiv.org/abs/1511.09334)

There are also some 'hints' from LEP and LHC, see eg. [arXiv:2203.13180](https://arxiv.org/abs/2203.13180)

as defined in the focus topic report [arXiv:2401.07564](https://arxiv.org/abs/2401.07564)

Theoretical and phenomenological targets (1)

Higgs factories are best suited to search for light exotic scalars in the process:

$$e^+ e^- \rightarrow Z \phi$$

Production of new scalars can be tagged, independent of their decay, based on the recoil mass.

We should look for different scalar decay channels e.g. $b\bar{b}$, $W^{+(*)}W^{-(*)}$, $\tau^+\tau^-$ or invisible

Non-standard decays channels of the new scalar should also be looked for.

For maximum sensitivity, feasibility of including hadronic Z decays should be explored.

as defined in the focus topic report [arXiv:2401.07564](https://arxiv.org/abs/2401.07564)

Theoretical and phenomenological targets (2)

As a second benchmark scenario for the EXscalar focus topic, light scalar pair-production in 125 GeV Higgs boson decays is proposed:

$$e^+ e^- \rightarrow Z H \rightarrow Z \phi \phi$$

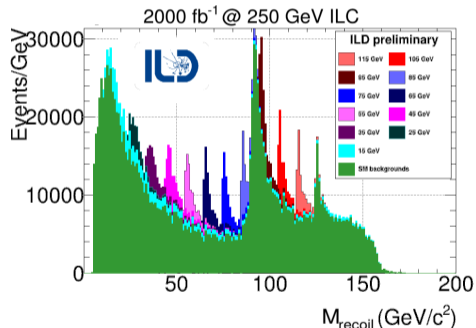
Here again, different decay channels should be considered, both SM-like and exotic.

While new scalar states could in general be long-lived, only scenarios with prompt decays are included in this focus topic (while a dedicated topic focuses on LLPs, see next presentation).

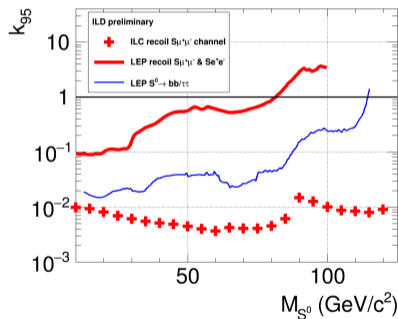
Prospects for new scalar observation in scalar-strahlung process...

Decay mode independent search

ILD full simulation study [arXiv:1903.01629](https://arxiv.org/abs/1903.01629) [arXiv:2005.06265](https://arxiv.org/abs/2005.06265)



Reconstructed recoil mass spectra for
 $e^+e^- \rightarrow Z S^0 \rightarrow \mu^+\mu^- + X$

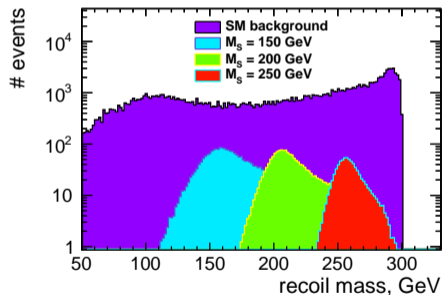


Expected sensitivity
 (relative to SM-like Higgs boson production rate)

Decay mode dependent search

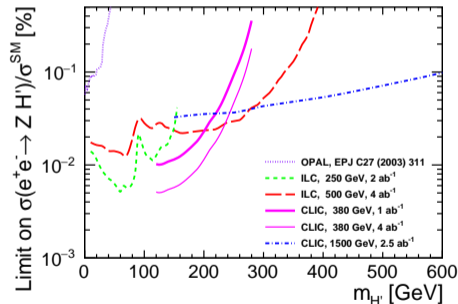
CLIC fast simulation study assuming invisible scalar decays [arXiv:2002.06034](#) [arXiv:2107.13903](#)

Reconstructed recoil mass spectra



for hadronic Z decays

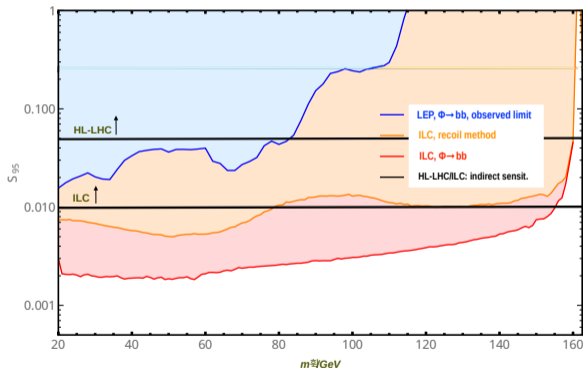
Expected sensitivities of CLIC



compared with decay independent limits from LEP and ILC

Decay mode dependent search

Estimated prospects for new scalar discovery in $S \rightarrow b\bar{b}$ decay channel (LEP projection)

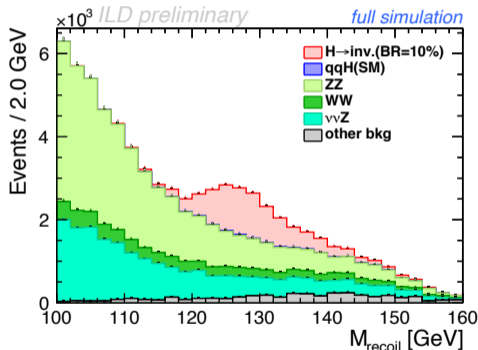


Expected 95% C.L. limits on the scalar production cross section σ/σ_{SM} assuming standard BRs

[arXiv:1801.09662](https://arxiv.org/abs/1801.09662)

Light scalar search in H_{125} decays

New scalar production in 125 GeV Higgs decays \Rightarrow sensitivity via invisible decays (?)

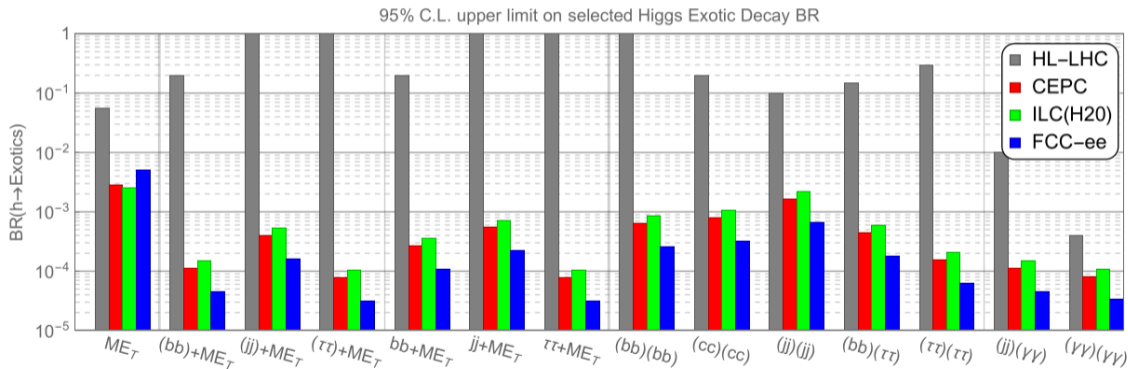


Expected 95% C.L. limit for 2 ab^{-1} collected at 250 GeV ILC: **0.23%**

arXiv:2002.12048

Light scalar search in H_{125} decays

New scalar production via exotic 125 GeV Higgs decays - generator level only

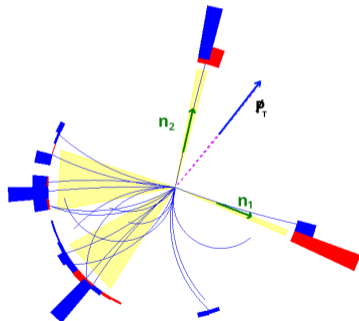


arXiv:1612.09284

Decay dependent search

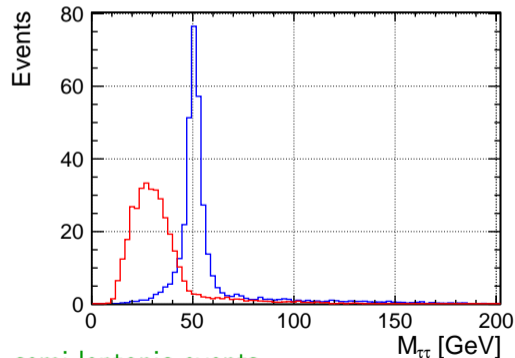
Search for exotic scalar decays to tau pair, $S \rightarrow \tau\tau$ (fast simulation study)

Tau reconstruction [arXiv:1509.01885](https://arxiv.org/abs/1509.01885)



Both neutrino energies can be reconstructed!

Scalar mass reconstruction

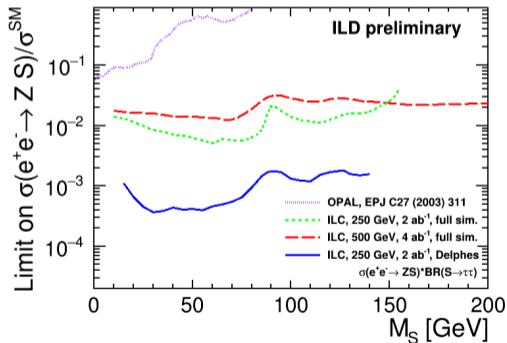


semi-leptonic events

Decay dependent search

Cross section limits for $\sigma(e^+e^- \rightarrow Z S) \cdot BR(S \rightarrow \tau\tau)$

compared with decay independent limits on σ/σ_{SM} from earlier studies



Targeted analysis results
in order of magnitude
increase in sensitivity...

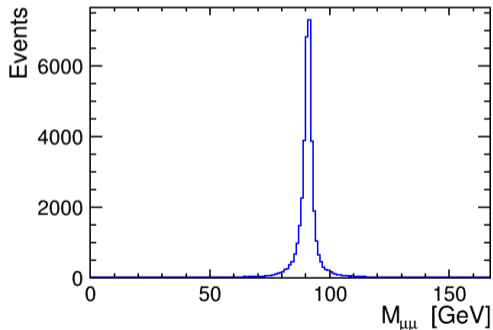
Possible gain in discovery
reach depends on the BR!

Preliminary results presented at EPS-HEP'2023, work in progress...

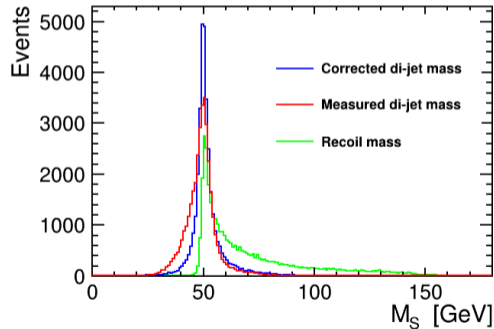
Decay dependent search

Search for exotic scalar decays to b-quark pair, $S \rightarrow b\bar{b}$ (fast simulation study)

Z mass from leptonic decays



Scalar mass reconstruction



First results, work in progress...

What is still not (fully) covered

Decay mode independent search

- current results based on $Z \rightarrow \mu\mu$ channel. Could be improved by using hadronic decays?
ILD plans to resume full simulation study, using the most up-to-date samples and tools

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ILD plans to resume full simulation study, using the most up-to-date samples and tools

Decay mode dependent search

- scenarios with invisible scalar decays, $\text{BR}(S \rightarrow \text{inv}) \approx 100\%$
could be a simple extension of the decay mode independent study ?
- other SM-like scalar decays like $S \rightarrow \gamma\gamma$ or $S \rightarrow W^{(*)}W^*$

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Other production channels:

- scalar production in SM-like 125 GeV Higgs boson decays
example model exists, signal samples could be easily produced

What is still not (fully) covered

Other production channels:

- scalar production in SM-like 125 GeV Higgs boson decays
example model exists, signal samples could be easily produced

Not exactly in the focus topic description:

- light scalar production in Z boson decays (?!)
 $e^+e^- \rightarrow Z \rightarrow S Z^*/\gamma^*(\rightarrow f\bar{f})$ or $e^+e^- \rightarrow Z \rightarrow S \gamma$
small contribution of “radiative return” events visible in 250 GeV Whizard simulation

Other relevant issues

When collecting results for the final report we should also try to address the following:

- what are the main experimental challenges
- what is the impact of the key detector performance parameters
- role of polarisation
- systematic uncertainties from SM/BSM theory predictions (SM parameters)
- systematic uncertainties from experiment



Let us discuss...

Expert team

Responsible WG1-SRCH convener: A. Filip Żarnecki

WG1 coordination contact: Jenny List

- FCCee contact: Sven Heinemeyer
 - ILD contact: Mikael Berggren
 - CLIC contact: A. Filip Żarnecki
 - Theory contact: Tania Robens
- LHC contacts:
- Nikolaos Rompotis (ATLAS)
 - Abdollah Mohammadi (CMS, C³)