



# ECFA Study Focus Topics: **EXscalar - New exotic scalars**

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Second ECFA Workshop on  $e^+e^-$  Higgs/EW/Top Factories

WG1-SRCH - Physics Potential:  
Feebly interacting particles, direct low mass searches

October 11, 2023

## Outline:

- 1 Motivation
- 2 Previous studies
- 3 Focus topic
- 4 Status and plans

Many thanks to all who contributed to the presented results!

New results presented are “work in progress” ...

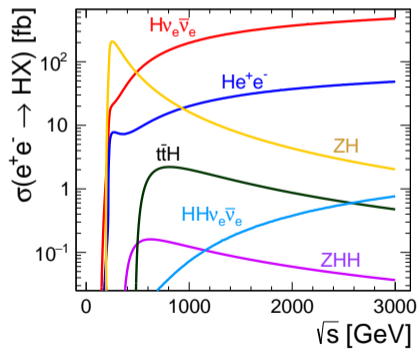
All mistakes are mine...

The background of the slide is a photograph of ancient Greek ruins. It shows a long, narrow colonnade of tall, weathered stone columns. The columns are arranged in two rows, creating a path that leads towards a larger, more complex structure in the distance. The sky is a clear, bright blue. The overall scene is well-lit, suggesting a sunny day. The ruins are made of light-colored stone, possibly limestone or marble, and show signs of significant age and wear.

# Motivation

## $e^+e^-$ Higgs factory

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



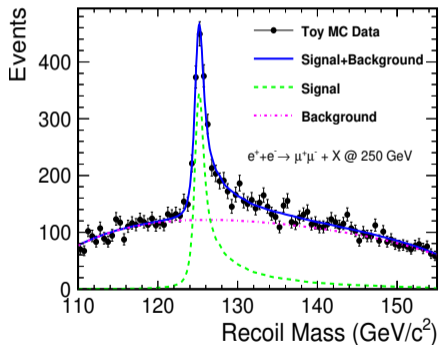
In the **ZH production** channel (dominant below 450 GeV) we can use “Z-tagging” for **unbiased selection** of events.

New channels open at higher energies allowing for direct access to **top Yukawa coupling** and **Higgs self-coupling**.

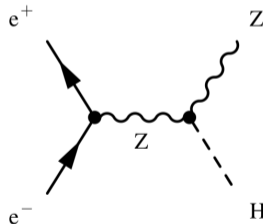
Precision **Higgs boson, top quark and electroweak measurements** will result in indirect **constraints on BSM** or **possible hints...**

## $e^+e^-$ Higgs factory

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

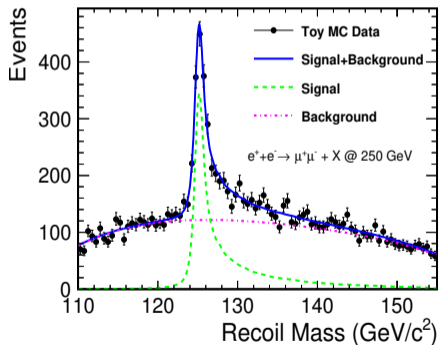


At 250 GeV we will focus on  $H_{125}$  production

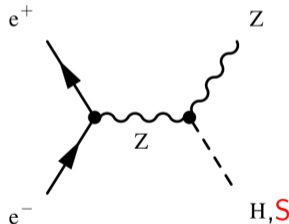


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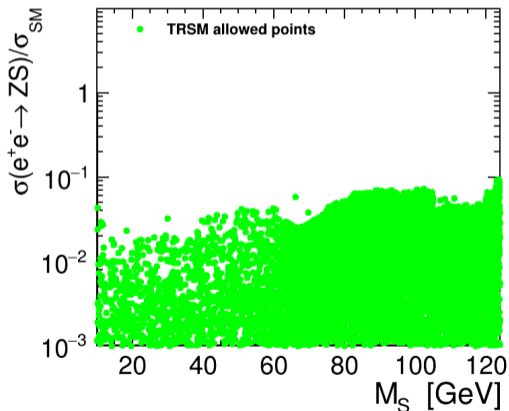
At 250 GeV we will focus on  $H_{125}$  production



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

## Possible scenarios

Benchmark points consistent with current experimental and theoretical bounds



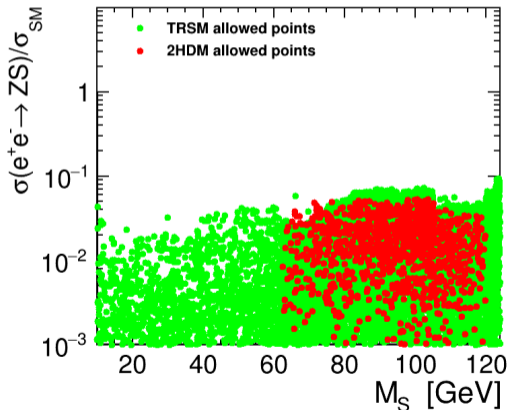
Two-Real-Singlet Model

thanks to Tania Robens

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

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### Two Higgs-Doublet Model

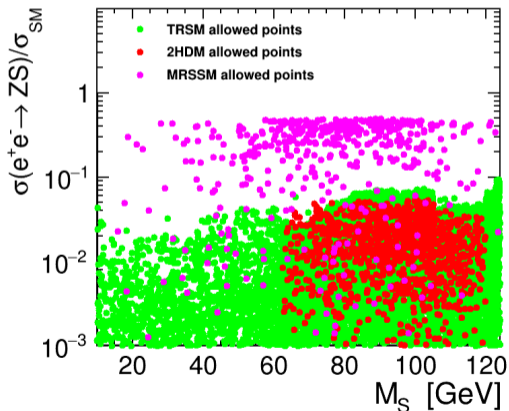
thanks to Kateryna Radchenko

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



## Possible scenarios

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### Two Higgs-Doublet Model

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### Minimal R-symmetric Supersymmetric SM

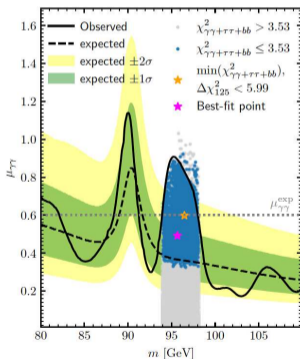
thanks to Wojciech Kotlarski [arXiv:1511.09334](https://arxiv.org/abs/1511.09334)

## Experimental hints...

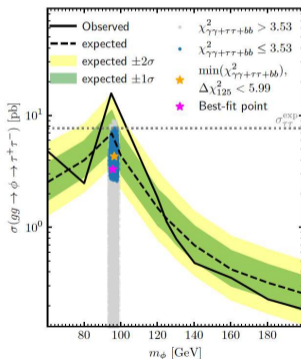
T. Biekötter, S. Heinemeyer, G. Weiglein arXiv:2203.13180

Some discrepancies point to new scalar with mass of  $\sim 95$  GeV and dominant decay to  $\tau\tau$ ...

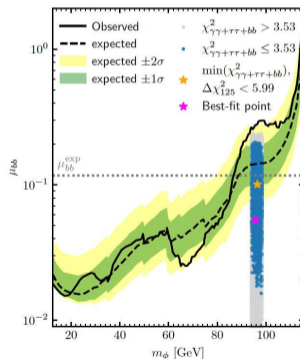
$$pp \rightarrow h_{95} \rightarrow \gamma\gamma$$



$$gg \rightarrow h_{95} \rightarrow \tau^+\tau^-$$



$$e^+e^- \rightarrow Zh_{95} \rightarrow Zb\bar{b}$$



Sven Heinemeyer @ First ECFA WS on  $e^+e^-$  Higgs/EW/top factories, October 2022



# Previous studies

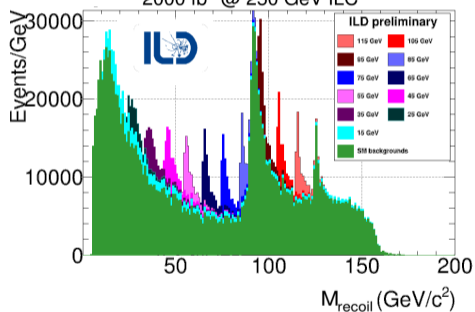
## Light scalar production

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

ILD study

[arXiv:1903.01629](https://arxiv.org/abs/1903.01629) [arXiv:2005.06265](https://arxiv.org/abs/2005.06265)

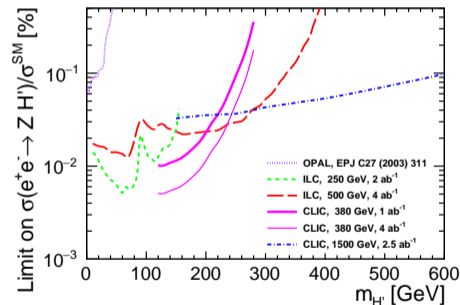
2000 fb<sup>-1</sup> @ 250 GeV ILC



Search independent on the scalar decay:

$$e^+e^- \rightarrow Z S^0 \rightarrow \mu^+\mu^- + X$$

Expected sensitivities of ILC and CLIC

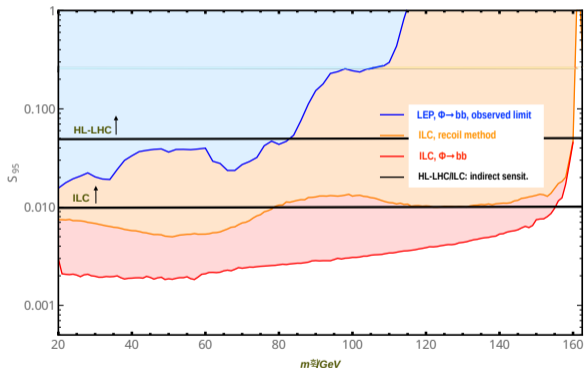


CLIC search assuming invisible decays

[arXiv:2002.06034](https://arxiv.org/abs/2002.06034) [arXiv:2107.13903](https://arxiv.org/abs/2107.13903)

## Light scalar production

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

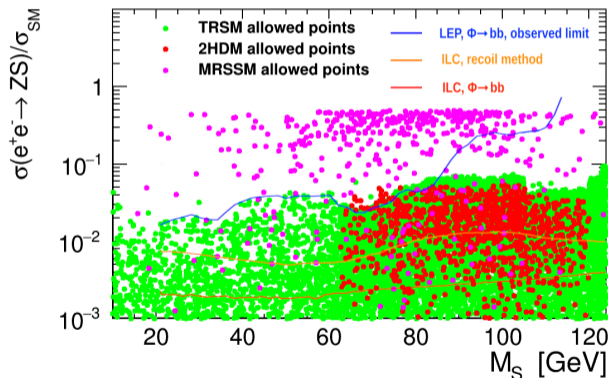


Expected 95% C.L. limits on the scalar production cross section  $\sigma/\sigma_{SM}$  assuming standard BRs

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

## Light scalar production

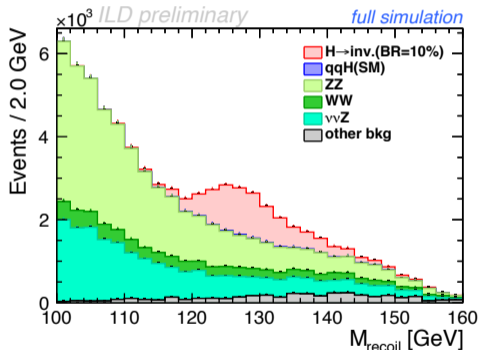
Estimated prospects for new scalar discovery in  $S \rightarrow b\bar{b}$  decay channel (LEP projection)



compared with presented benchmark point selections...

## Light scalar production

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

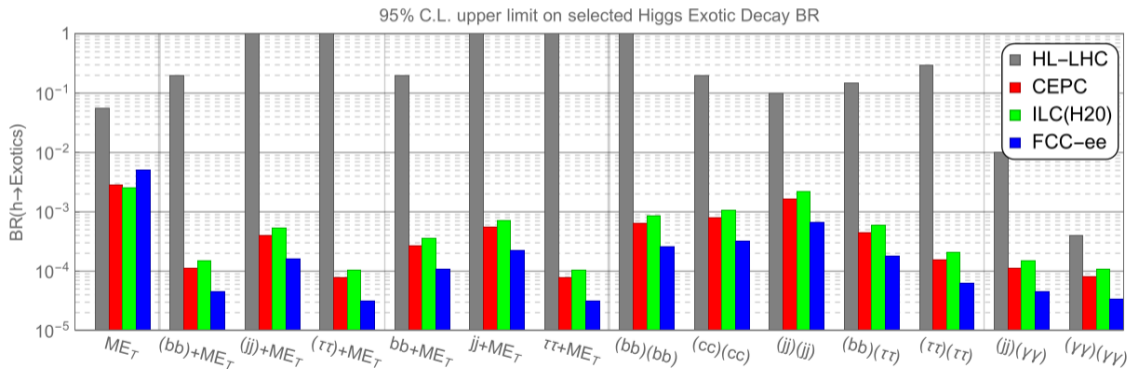


Expected 95% C.L. limit for  $2 \text{ ab}^{-1}$  collected at 250 GeV ILC: **0.23%**

arXiv:2002.12048

## Light scalar production

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



arXiv:1612.09284





# Focus topic

## 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, C<sup>3</sup>)

## Theoretical and phenomenological targets

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.

## 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).



# Status and plans

## Ready to go!

- Possible analysis targets defined
- Example model scenarios available
- Different channels to be considered - **many volunteers needed!**

## Ready to go!

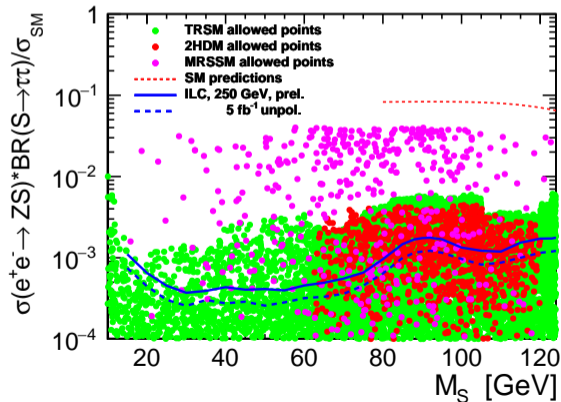
- Possible analysis targets defined
- Example model scenarios available
- Different channels to be considered - **many volunteers needed!**

## Planned activities

- First estimates of sensitivity in  $\phi \rightarrow \tau\tau$  channel (student available to continue)
- + Potential candidates identified to look at  $e^+e^- \rightarrow Z\phi$  with
- $\phi \rightarrow W^{(*)}W^{(*)}$  (S.S.Abdussalam)
  - $\phi \rightarrow b\bar{b}$  (A.F.Zarnecki)

## First result

Cross section limits for  $\sigma(e^+e^- \rightarrow ZS) \cdot BR(S \rightarrow \tau\tau)$  compared with allowed scenarios in different models



See dedicated talk on light scalar searches in the next session





**Waiting for you!**

A photograph of ancient Greek temple ruins, featuring several tall, weathered stone columns and arches. The scene is set against a clear blue sky, with some greenery visible in the background. The ruins are made of light-colored stone, showing signs of age and wear.

**Let us discuss...**