Summary of exotic scalar searches

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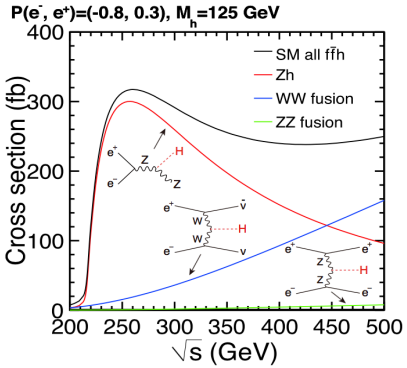
A detector for the next CERN flagship project: ILD
CERN, September 14 - 16, 2026

Outline:

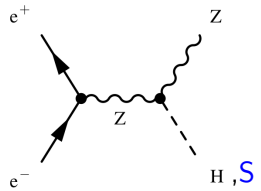
1. Introduction
2. Decay independent search
3. Search for $S \to b\bar{b}$
4. Search for $S \to \tau^+\tau^-$
5. Conclusions

Light scalar production at e^+e^-

Precision Higgs measurements should clearly be the primary target for a future Higgs factory.



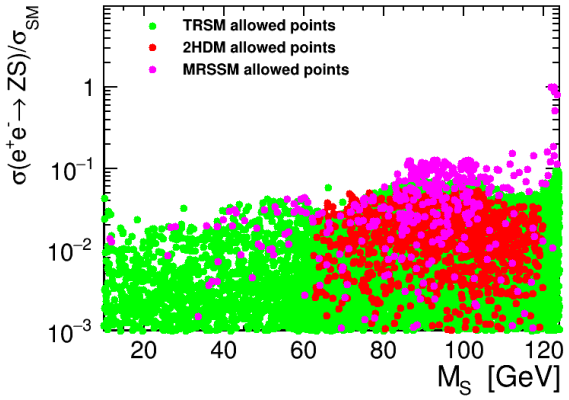
At 240-250 GeV we focus on H_{125} production in the ZH production channel (dominant below 450 GeV)



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

Light exotic scalar scenarios

Benchmark points consistent with 2023 experimental and theoretical bounds
Production cross sections up to few % of $\sigma_{SM}(M_S)$ allowed!



Two-Real-Singlet Model
thanks to Tania Robens
see arXiv:2209.10996 arXiv:2305.08595

Two Higgs-Doublet Model
thanks to Kateryna Radchenko
thdmTool package, see arXiv:2309.17431

Minimal R-symmetric Supersymmetric SM
thanks to Wojciech Kotlarski arXiv:1511.09334

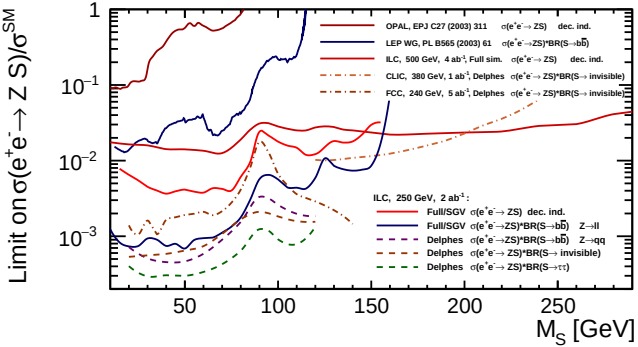
There are also some 'hints' from LEP and LHC, see eg. arXiv:2203.13180

ECFA Higgs/Top/EW factory study 2022-2024

Light scalar searches were selected as one of the ECFA study focus topics with scalar-strahlung process $e^+e^- \to Z\,S$ as one for the primary targets.

arXiv:2401.07564

Many new studies initiated within ILD, first results already included in the ECFA report

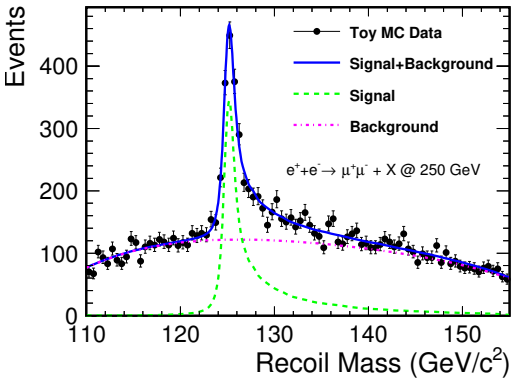


CYRM-2025-005

arXiv:2506.15390

Event reconstruction

Follow the approach used in the SM-like Higgs boson analysis in the ZH production channel: use "Z-tagging" with $Z \to e^+e^-/\mu^+\mu^-$ for unbiased selection of scalar production events



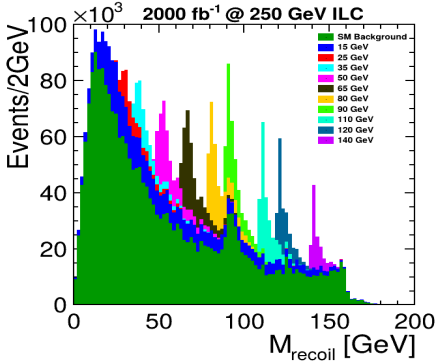
We avoid any possible dependence on the scalar decay channels (could be exotic or invisible)!

Additional MVA based selection looking at Z decay kinematics was used to suppress SM background from 2-fermion and 4-fermion processes

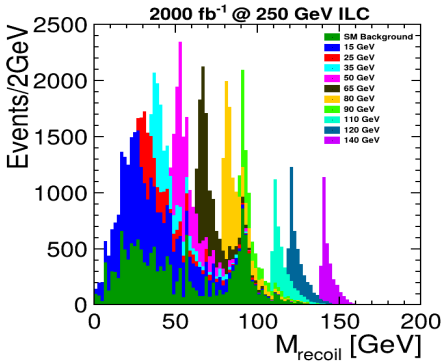
Decay mode independent analysis at 250 Gev

Recoil mass spectrum from signal and SM background simulation $Z \to \mu^+\mu^-$

before MVA cuts



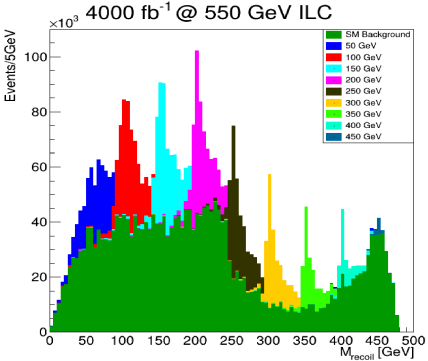
after MVA cuts



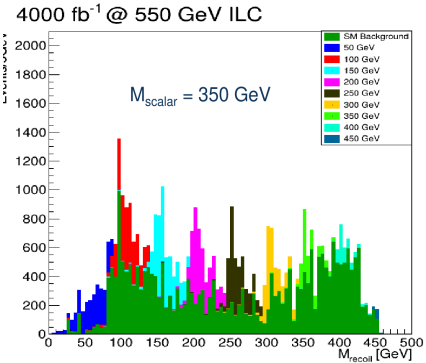
Decay mode independent analysis at 550 Gev

Recoil mass spectrum from signal and SM background simulation $Z \to e^+e^-$

before MVA cuts

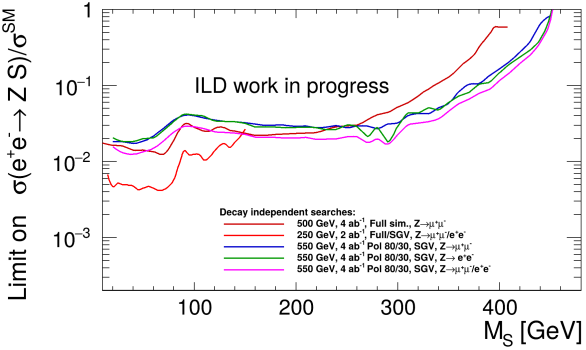


after MVA cuts



Cross section limits

Limits computed based on the recoil mass distribution of the Z against the new scalar using fractional event counting. Cross section limits from 250 GeV and 550 GeV center-of-mass energies.

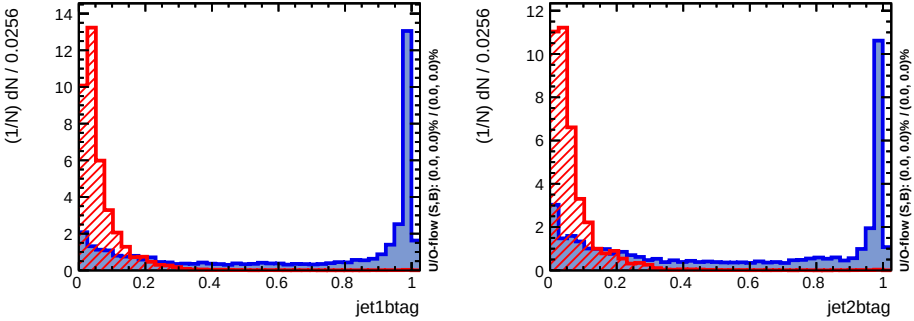


New 550 GeV results consistent with the old 500 GeV analysis.

Final state reconstruction

We can significantly improve our limits when looking for specific decay channel.
Decays to $b\bar{b}$ dominant in most models $\Rightarrow$ b tagging can be used for background suppression.

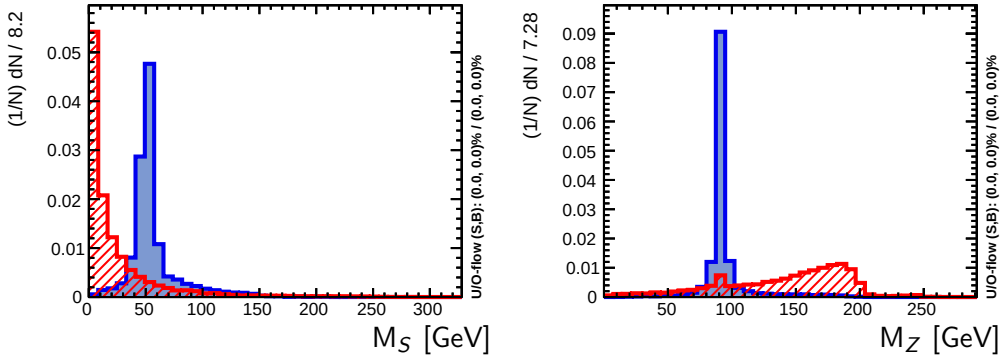
New study based on full simulation $\Rightarrow$ reliable estimate of selection efficiency.
Clear separation of signal events from (mostly light flavour) SM backgrounds



Final state reconstruction

Reconstructed invariant mass distributions for the scalar candidate (pair of tagged b jets) and Z boson candidate (pair of leptons) for the 250 GeV scenario.

Clear peaks visible for 50 GeV signal events ⇒ efficient discrimination from SM backgrounds.



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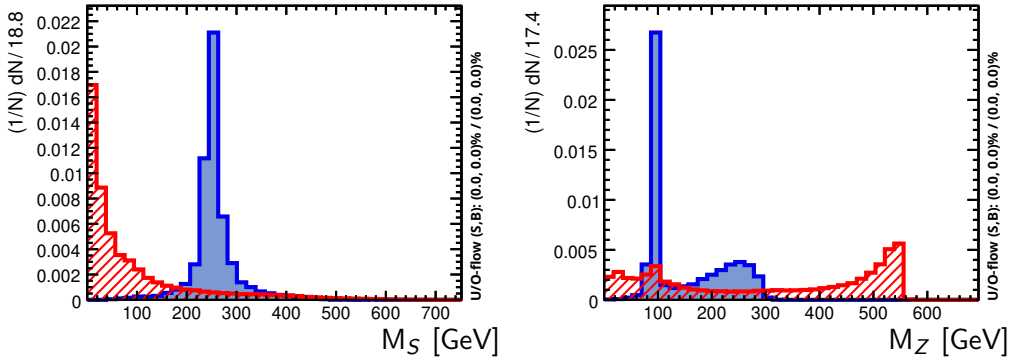
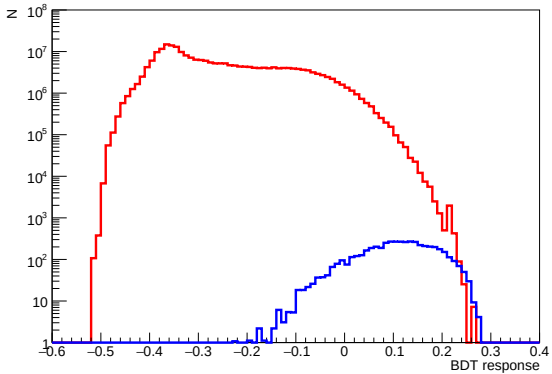


Event classification

250 GeV running scenario
BDT classifier for the hadronic Z decays
applied after very loose event preselection
(four hadronic jets, two with b-tag)

Example for $e_L^- e_R^+$ polarization,
signal for scalar mass of $M_S = 50\,\text{GeV}$

signal normalized to 1% of the $\sigma_{SM}(M_S)$



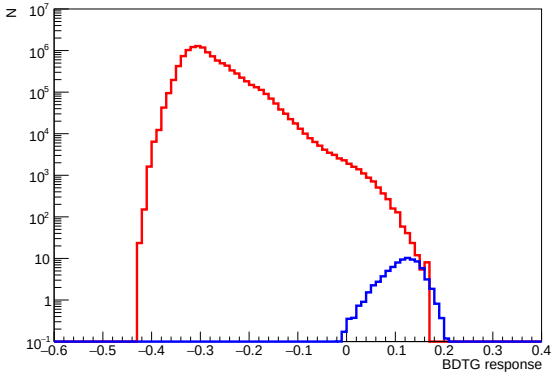
Huge background can be efficiently suppressed...

Event classification

550 GeV running scenario
BDTG classifier for the leptonic Z decays
applied after very loose event preselection
(two electrons or muons, two hadronic jets)

Example for $e_L^- e_R^+$ polarization,
signal for scalar mass of $M_S = 250\,\text{GeV}$

signal normalized to 1% of the $\sigma_{SM}(M_S)$



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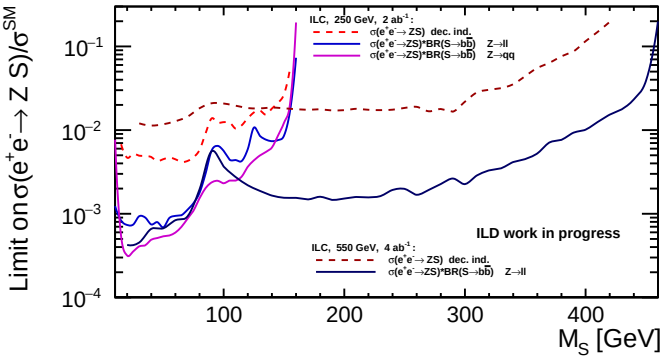
Results

Expected limits on the scalar production cross section (times $b\bar{b}$ branching ratio) extracted from the shape of the BDT response distribution:

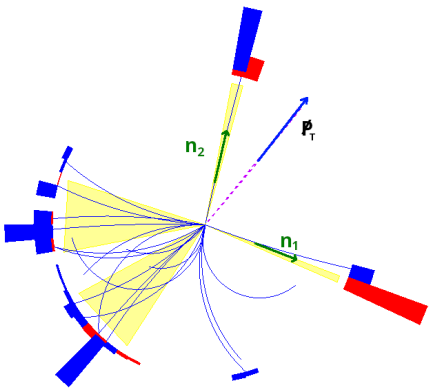


For 550 GeV leptonic Z decays only. Full simulation analysis of hadronic Z decays still to be concluded...

Scalar mass correction

arXiv:1509.01885

Example signal event with hadronic tau decays



Tau leptons are very boosted $\Rightarrow$ collinear approximation

Assume tau neutrinos are emitted in the tau jet direction.

Their energies can be found from transverse momentum balance:

$$\vec{p}_T \;=\; E_{\nu_1} \cdot \vec{n_1} + E_{\nu_2} \cdot \vec{n_2}$$

where $\vec{n_1}$ and $\vec{n_2}$ are directions of the two tau jets.

Unique solution !

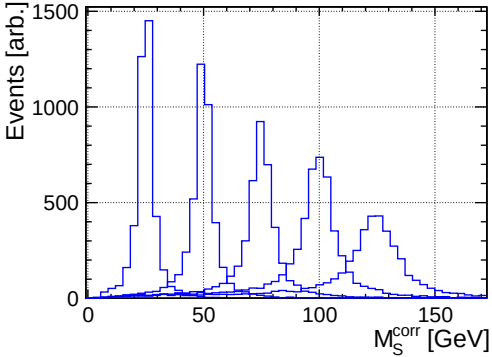
Works also for semi-leptonic and leptonic events!

Because of small tau mass $\Rightarrow$ small invariant mass of neutrino pair

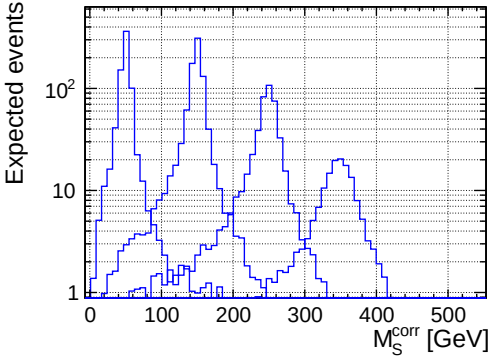
Mass correction

Example distributions of corrected mass:

Scalar masses of 25 to 125 GeV at 250 GeV



Scalar masses of 50 to 350 GeV at 550 GeV

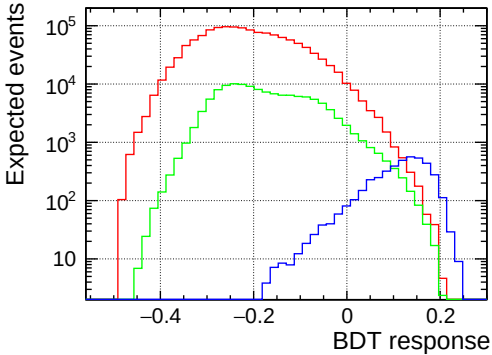


All tau decay channels combined

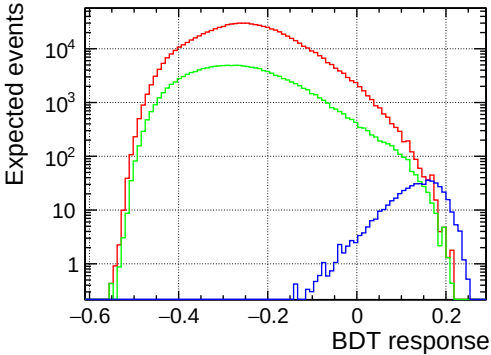
BDT response distribution

Example of BST response distribution: total SM bg., semi-leptonic ZZ, signal.

50 GeV scalar at 250 GeV



250 GeV scalar at 550 GeV

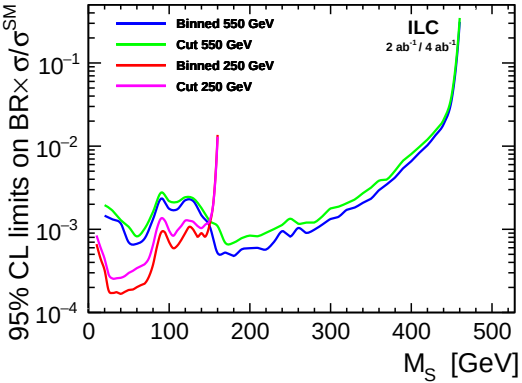


Signal of normalized to 1% of SM cross section for given mass

Cross section limits

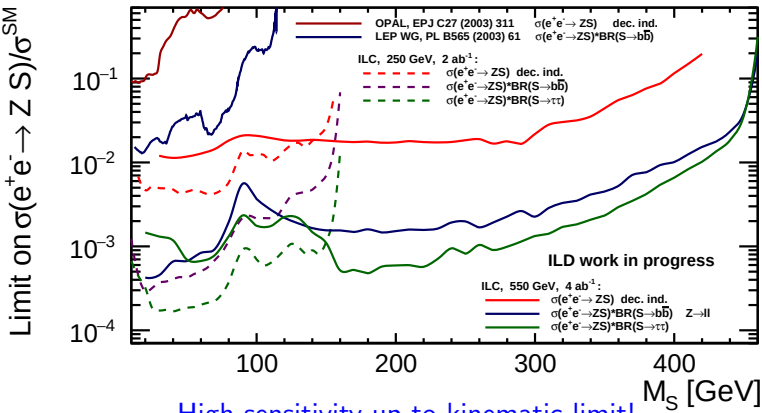
Final limits calculated from the BDT response histogram for signal and background

Limits improve by 20–40% compared to BDT cut method.



Comparison of results

Comparison of all recent ILD results for 250 GeV (dashed) and 550 GeV (solid line)



High sensitivity up to kinematic limit!

Conclusions

Many BSM scenarios include new scalars, still not excluded by existing data, they can be light!
Sizable production cross sections for new scalars can coincide with non-standard decay...

Different search strategies possible at future e^+e^- Higgs factories.
Many searches complementary to what can be addressed at LHC...

New results obtained recently within ILD for 250 GeV and 550 GeV ILC.
Already presented at ICHEP'2026, Corfu'2026, Higgs Days'2026...

Studies being finalized and publication draft is being prepared...


Thank you!

Event simulation

Studies based on existing ILD Monte Carlo samples for SM processes at 250 GeV and 550 GeV:

- generated with Whizard v.2.8.5/v.3.1,
- using default (SetA) ILC beam-spectrum,
- simulated and reconstructed using
  a full (GEANT 4) ILD detector simulation/SGV Fast simulation
  with ILD_l5_o2_v02 model and ILCSoft v02-02-01,
- processed using MARLIN modular framework
  for jet clustering with Durham algorithm and flavour tagging based on LCFIplus.

Signal samples, for scalar particle mass from 10 GeV up to 160 GeV for the 250 GeV scenario and from 20 GeV up to 460 GeV for the 550 GeV energy, were generated and processed with the same tools, but the detector simulation was done with SGV.

Total luminosity of $2\,\mathrm{ab}^{-1}/4\,\mathrm{ab}^{-1}$, with $\pm 80\%/\pm 30\%$ polarisation for e^-/e^+ (H-20 scenario).

S$\rightarrow \tau\tau$ event pre-selection for 250 GeV (550 GeV)

Multiple event categories have to be considered, depending on the assumed Z boson decay (hadronic or leptonic) and tau pair decay (hadronic, semi-leptonic, leptonic).

Events are required to have four high-level objects reconstructed: isolated leptons, tau jets or hadronic jets. Events with additional isolated photon (from ISR) are also accepted.

Z decay channel is identified first:

- events with two massive jets ($M_{j_1} > 5(8)$ GeV, $M_{j_2} > 3$ GeV) $\Rightarrow$ hadronic Z decays
- otherwise pair of leptons matching M_Z (60–140 GeV) required for leptonic Z decay

For scalar reconstruction two tau candidates need to be identified:

- isolated leptons ($e^{\pm}$ or $\mu^{\pm}$) or
- tau-tagged hadronic jets

Events with no or only one tau candidate are not considered