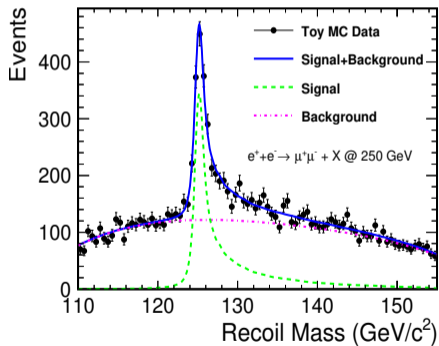# Report on ECFA Study Focus Topics:
EXscalar - New exotic scalars
LLPs - Long Lived Particles

Aleksander Filip Żarnecki
Faculty of Physics, University of Warsaw
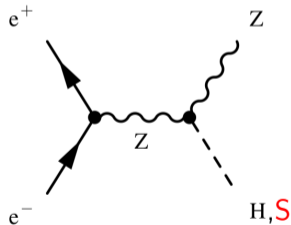
A detector for a Higgs factory and beyond
ILD meeting
CERN, January 15-17, 2024

Motivation

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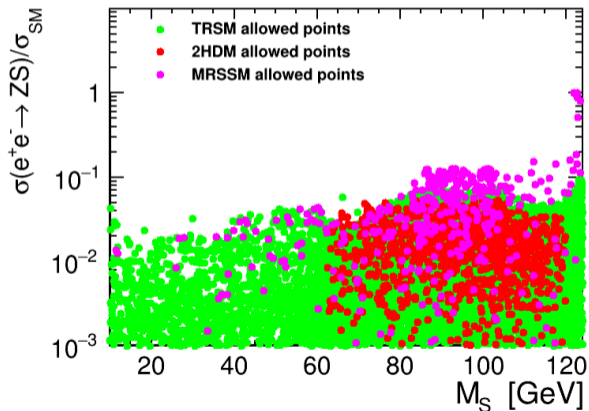

At 250 GeV we will focus on H_{125} production

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

Possible scenarios

Benchmark points consistent with current experimental and theoretical bounds

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

Theoretical and phenomenological targets

1. Light exotic scalar production in the process:

$$e^+ e^- \to Z \, \phi$$

Different scalar decay channels possible 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.

2. Light scalar pair-production in 125 GeV Higgs boson decays is proposed:

$$e^+ e^- \to Z \, H \to Z \, \phi \, \phi$$

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).

Existing results

New scalar search in scalar-strahlung process
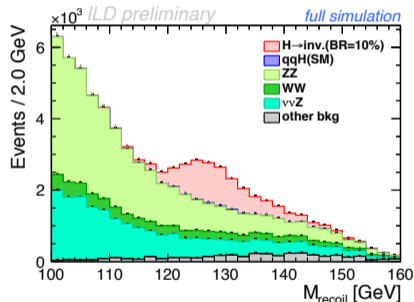
arXiv:1902.06118 arXiv:2005.06265

New scalar production in 125 GeV Higgs decays
⇒ sensitivity via invisible decays
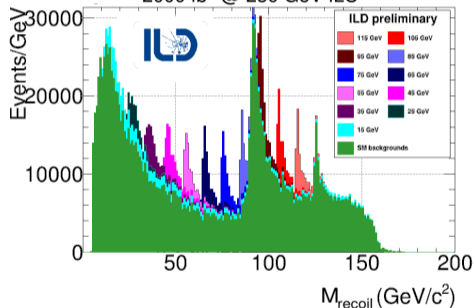
Search independent on the scalar decay:
$$e^+ e^- \rightarrow Z\, S^0 \rightarrow \mu^+ \mu^- + X$$

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

arXiv:2002.12048

Status and plans

- Decay-mode independent search
  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
  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).
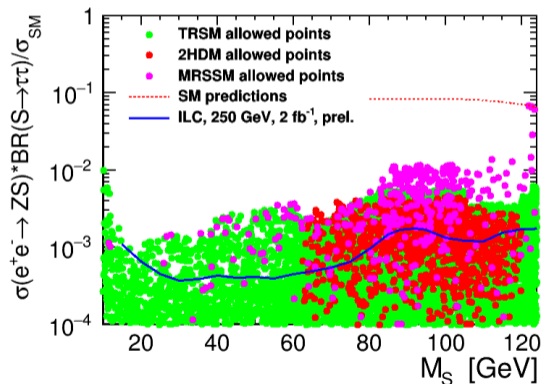 Full simulation sample request to be submitted soon.

Status and plans

First results on $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to \tau\tau)$ sensitivity   (DELPHES)
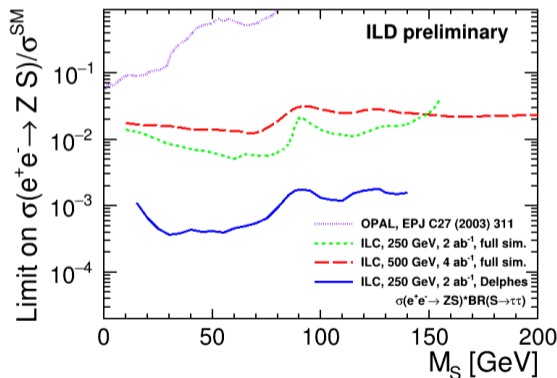
Status and plans

First results on $\sigma(e^+e^- \rightarrow Z\,S) \cdot BR(S \rightarrow \tau\tau)$ sensitivity   (DELPHES)

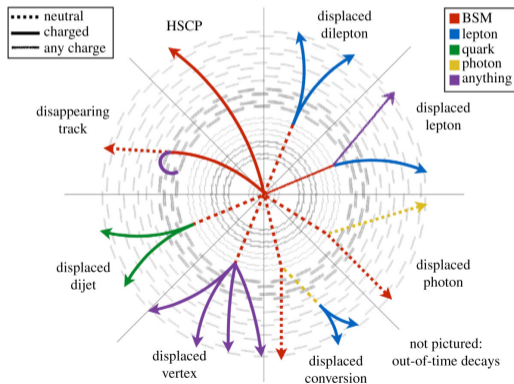compared with presented benchmark point selections...

LLPs - Long Lived Particles

Motivation

New long-lived particles (LLPs) could provide answers to many open questions of the SM.

Possible scenarios:

- Heavy Neutral Leptons (HNLs)
- Axion-Like Particles (ALPs)
- exotic decays of the Higgs boson
- ...

Possible signatures:

Phil. Trans. R. Soc. A.377: 20190047

Targets

- Signatures
  A large variety of "standard-like" and non-standard signatures can be considered.

- Analysis tools
  New analysis methods need to be developed for these signatures. Not only for reconstruction of displaced tracks and vertices, but also making full use of all capabilities of the detectors (eg. timing, dE/dx etc.)

- Theory and phenomenology
  Experimental sensitivities will be derived based on signatures. These signature-based sensitivities need to be interpreted and combined in actual BSM models.

Status and plans

Ongoing full simulation study by Jan Klamka:

- Track reconstruction settings modified for better LLP acceptance.
- Vertex finding efficiency tested on different event topologies (two extreme cases)
- Background from overlay events estimated.
- First limits on mono-LLP production extracted.
- Performance compared for TPC with pad readout and all-silicon tracking design.

Status and plans

Ongoing full simulation study by Jan Klamka:

- Track reconstruction settings modified for better LLP acceptance.
- Vertex finding efficiency tested on different event topologies (two extreme cases)
- Background from overlay events estimated.
- First limits on mono-LLP production extracted.
- Performance compared for TPC with pad readout and all-silicon tracking design.

Still on the "To Do" list:

- Background estimates from hard processes (expected to be negligible)
- Casting signature limits to different BSM models.
- Study expected performance of pixel-TPC (see talk by Jan in previous session)
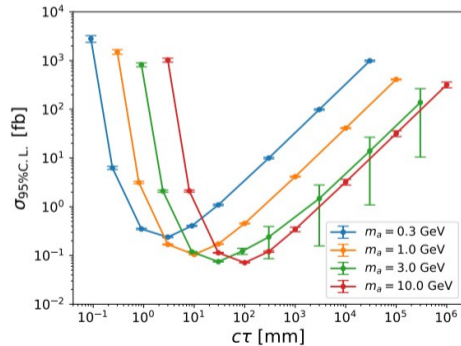
Status and plans

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

Heavy scalars (IDM)
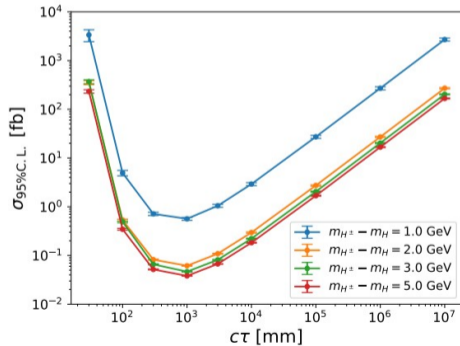
Light pseudoscalar (ALP)

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