UNIVERSITY OF CAMBRIDGE

Focus topic needs: BSM

ECFA Higgs Factories: 2nd Topical Meeting on Generators

Sarah Williams (University of Cambridge), with input from many

Higgs factory physics goals

Schematic taken from slides by Michele Selvaggi at FCC week 2023 in London!

Higgs
factory

m_H, σ, Γ_H
self-coupling
H→ bb, cc, ss, gg
H→inv
ee→H
H→bs, ..

Top

m_{top}, Γ_{top}, ttZ, FCNCs

Flavor
"boosted" B/D/τ factory:

CKM matrix
CPV measurements
Charged LFV
Lepton Universality
τ properties (lifetime, BRs..)

$B_c \rightarrow \tau\, \nu$
$B_s \rightarrow D_s$ K/π
$B_s \rightarrow K^* \tau\, \tau$
B→ K* ν ν
$B_s \rightarrow \varphi\, \nu\, \nu$ …

QCD - EWK
most precise SM test

m_Z , Γ_Z , Γ_{inv}

$\sin^2\theta_W$, $R^Z{}_{\ell}$, R_b, R_c

$A_{FB}^{b,c}$, τ pol.

α_S ,

m_W, Γ_W

BSM
feebly interacting particles

Heavy Neutral Leptons (HNL)

Dark Photons Z_D

Axion Like Particles (ALPs)

Exotic Higgs decays

Unique sensitivity (complementary to hadron colliders) to (~low-mass) feebly interacting BSM forms a key pillar of physics goals at Higgs factories- I will (try to) summarise some needs/ wishes from MC generators!

Setting the scene

In preparing this talk, I found lots of interesting/useful material in the slides from the 1st generators workshop and last years e+e- workshop in Hamburg

Example schematic for dark matter candidates

Image credit: https://www.nature.com/articles/s41586-018-0542-z

"BSM" is a very broad umbrella in particle physics. For future Higgs factories must consider:

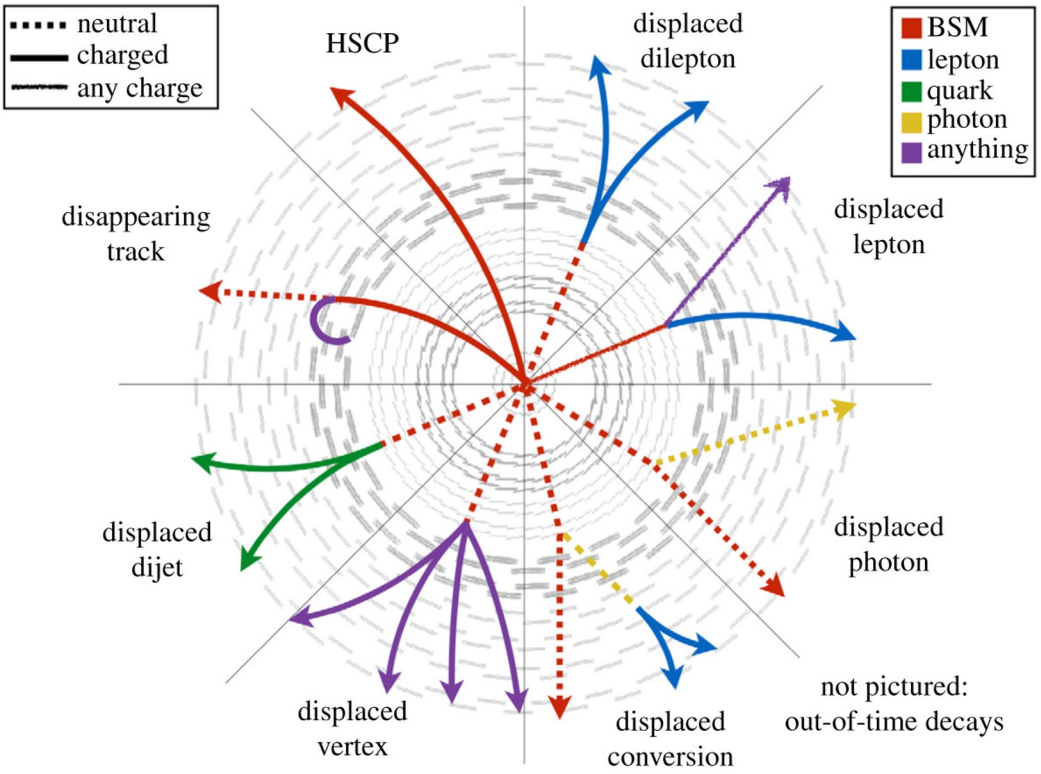
- Prompt vs long-lived?
- Typical backgrounds (both SM and detector/beam-induced).

This talk will include:

- Discussion on LLP treatment in Whizard
- Input from exotic scalars expert team.
- Experiences from FCCee LLP group.

i.e. quite LLP-focused!

LLPs



LLPs that are semi-stable or decay in the sub-detectors are predicted in a variety of BSM models:

- Heavy Neutral Leptons (HNLs)
- RPV SUSY
- Dark photons
- ALPs
- Dark sector models

The range of unconventional signatures and rich phenomenology to explore. Projections usually assume background-free searches

General BSM needs

Note- I "interpreted" this table from the snowmass report here: https://arxiv.org/abs/2203.12557 - apologies for mistakes! The (?) indicate where I wasn't sure…

- ISR modelling
- Full treatment of beam spectra (including beam-beam correlations) + polarization.

Generator/ requirement	Pythia	Sherpa	Herwig	Whizard	MadGraph
ISR modelling	Multiple PS options available- e.g. "simple" neglects interference between ISR/FSR	2 approaches for QED radiation: (1) electron structure function (2) Soft photon resummation (YSF)	Available in "angular ordered shower"	Resummation for colinear factorisation available at LL (NLL coming)	ISR @ LL (NLL coming?)
Beam spectra treatment	(?)	Allow "two-step" definition of particles entering hard interaction (different beam/bunch) CIRCE interface	Not included	CIRCE interface	Included through suitable PDFs
Beam polarization treatment	(?)	(?)	(?)	Supports polarisation fractions being provided.	(?)

Wish list: LLP decays in Whizard

… proper displaced vertex simulation for LLP decays in Whizard so that angular dependancies and correlations can be properly taken into account for arbitrary UFO models without needing additional patches/workarounds…

Wish list: LLP decays in Whizard

LLP decays currently not implemented in Whizard- two workarounds to generate displaced vertex:

1. (CLIC method) define proper LLP lifetime in GEANT particle table and let GEANT (run via ddsim) move the default decay vertex (0,0,0) to displaced position.
   - Pro(s): takes into account possible interactions of LLP in matter.
   - Con(s): need to ensure proper transfer of information from Whizard to GEANT (time consuming for scans). Plus not available in fast-sim.
2. (used in some ILC studies) allow Pythia to decay LLP for Whizard by modifying Pythia particle tables to inclue the dexy and set the decay time.
   - Pro(s): can be done semi-automatically from Whizard steering file and the secondary vertex is transferred to the output file.
   - Con(s): only correct for scalar particles (angular information not propagated).

Wish list: UFO functionality

Input from exotic scalar focus topic expert team…

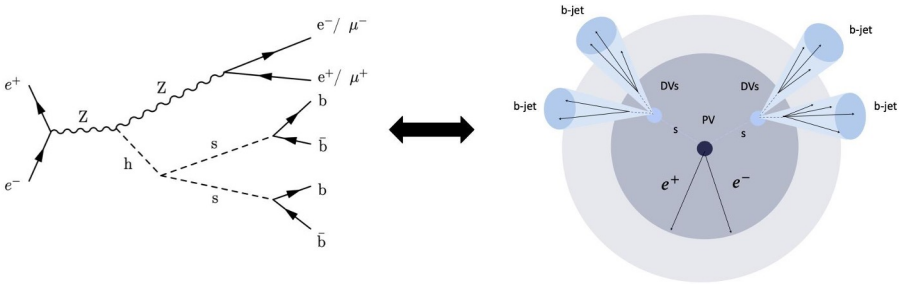
- Models in each generator should be available in UFO format to allow comparisons between generators
  - E.g. not all models in MadGraph library (https://cp3.irmp.ucl.ac.be/projects/madgraph/wiki/Models) are available in UFO format.
- Each generator should include a fully functional UFO interface.

Experiences in FCC-ee LLP working group

- As input to Snowmass, a white paper (published in Front. Phys. 10:967881 (2022)) studied three benchmark BSM scenarios and motivated further optimization studies (for more details see talk by J. Alimena in the October ECFA workshop)
  - HNLs
  - ALPs
  - Exotic higgs decays.
- Signals were generated using MadGraph5_aMC@NLO v3.2.0 for LO ***unpolarized*** parton level e+e- processes.
- I'll briefly summarise the progress since then that is relevant to generators (further details from a detector perspective in the recent FCC week talk)

Exotic Higgs decays at FCC-ee

First simulation and sensitivity studies for Higgs decays to long-lived scalars



- Extend SM with additional scalar (arXiv:1312.4992 , arXiv:1412.0018)
- Physical Higgs and scalar mix with angle $\sin\theta$ and scalar inherits couplings from Higgs

$$\Gamma\left(s \to X_{\mathrm{SM}} X_{\mathrm{SM}}\right) = \sin^2\theta\, \Gamma\left(h(m_s) \to X_{\mathrm{SM}} X_{\mathrm{SM}}\right)$$

Simulation details:

- Privately produced samples with Madgraph v3.4.1 + pythia8 + delphes using the Madgraph5 HAHM model with width of scalar set to get LLP.
- Simulation validated and first sensitivity study performed (assuming background-free search). For more details see presentation by Magda at topical ECFA WG1-SRCH meeting.

Open points for discussion

- Are there fundamental differences between generators when it comes to assumptions/frameworks used for calculating BSM processes? Can we expect ~ 100% agreement up to numerical precision when the same process is calculated?
- Can we include a BSM scenario in the benchmarks used for generator comparisons. Possible candidates could be:
  - "scalar-strahlung" ($e^+e^- \to ZS$) for various scalar masses with decays to $bb, \tau\tau$. Free parameters are ZZS coupling, width of S and branching fractions.
  - $h_{125} \to SS$ with sunsequent decays ($bb, \tau\tau$)

Conclusions/outlook

- I have tried to briefly present some arising considerations/requests from BSM (mainly LLPs) related to generators.
- Note: as Higgs factories also have (huge) indirect sensitivity to BSM through the precision measurement programme – a lot of the considerations discussed in the coming talks are also important for BSM.
- Thanks for listening- I am happy to take questions ☺