Experimental landscape

WG1-SRCH- Brainstorming session - Feb 25, 2022

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Signature based approach

As the underlying BSM scenario is unknown and we will never be able to consider all possible model benchmarks, we should also consider signature base approaches.

The goal is to be as model independent as possible. And look for all possible signatures which could be related to direct production of BSM states.

When taking into account new particle mass range, possible production and decay channels, expected signatures, there are tens of possible search options.

One of the possible goals of our WG could be to **classify existing studies according to the considered search strategy and make sure that all relevant scenarios are covered**.

Signature based approach

New particles can be:

- light, of the order of GeV or lighter (FIPs)
- heavy, of the order of or above EW scale (but below $\sqrt{s}$ to be directly produced; WIMPs)

As for production of new particles we can consider:

- single production in e^+e^- collisions
  - production in fusion processes ($\gamma\gamma$, γZ, ZZ, WW)
- pair production in e^+e^- collisions
- production in (rare) decays of SM states
- associated production (eg. together with Z boson)
- production with single beam (?)

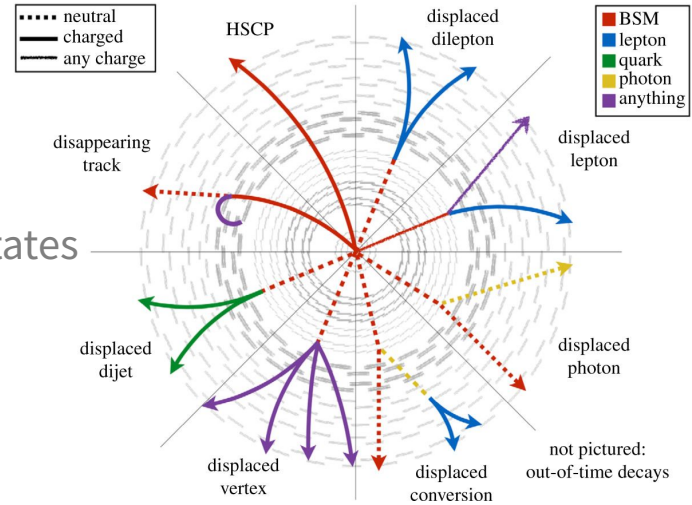
Signature based approach

New particles can be:

- short-lived, decay promptly, no measurable displacement
- long-lived:
  - stable (DM candidates) or quasi-stable (decay outside detector)
  - giving measurable decay length, vertex displacement or other non-standard signature
  - Stopped, slowed down, out-of-time

The final state of their decay can be:

- invisible
- partly visible (cascade decays), including very soft final states
- visible, decays into SM final state possible



Experimental challenges

We need to make sure that all possible signatures are properly measured:

- does detector design takes into account possible non-standard signatures
- is reconstruction software flexible enough to identify also “unexpected” signals
- what additional/new detector features could be used to enhance search sensitivity eg. higher timing resolution, better dE/dx ?

We should also be opened for other, non-standard search approaches to maximize physics output and search coverage

Thinking about additional experiments already before construction of the main collider (MATHUSLA-like)

Disclaimer

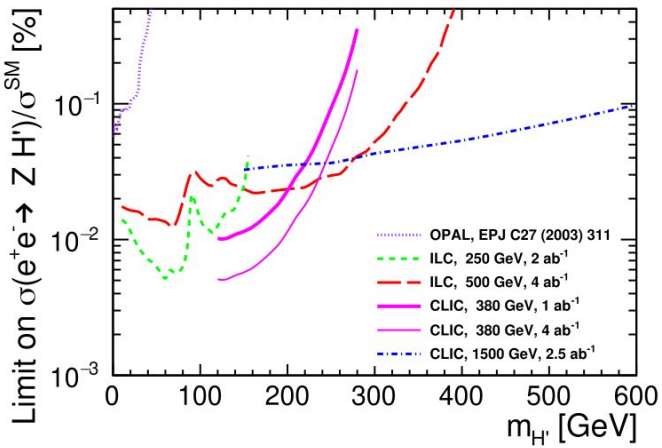
We collected some results here, showing the experimental landscape of direct BSM search studies for future Higgs/Top/EW factories.

Selection is arbitrary and biased.

Please let us know if something is missing.

Direct BSM searches: light or heavy

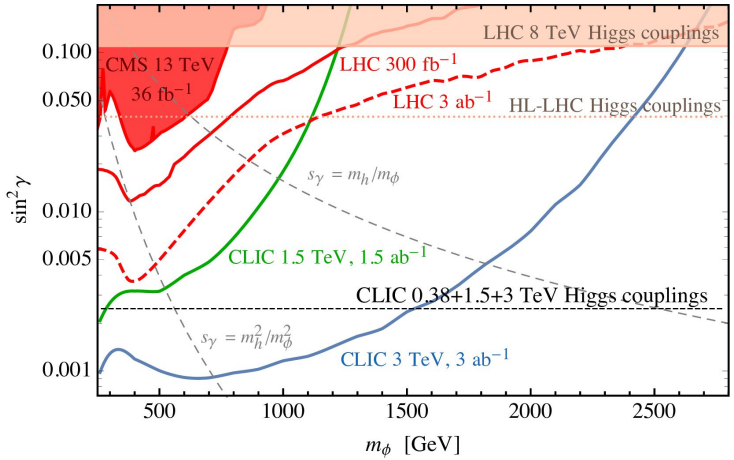
While a large range of models and parameter space has been excluded at the LHC many "light new physics" scenarios are still possible and should be searched for at e^+e^-



Search for associated production of new scalar: $e^+e^- \to Z\,S$: arXiv:1903.01629 arXiv:2005.06265 arXiv:2002.06034

Higgs sector extended by a new heavy singlet state Φ, decay channel

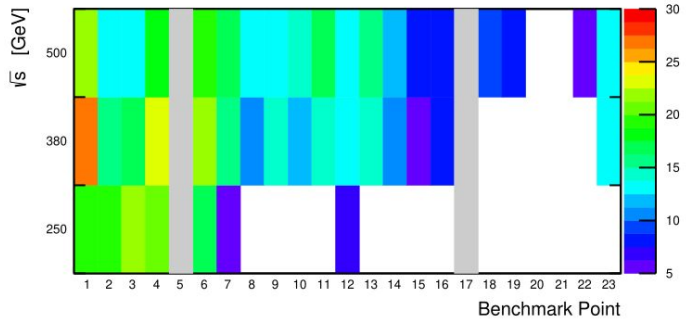
$\phi \to H\,H \to 4\,b$



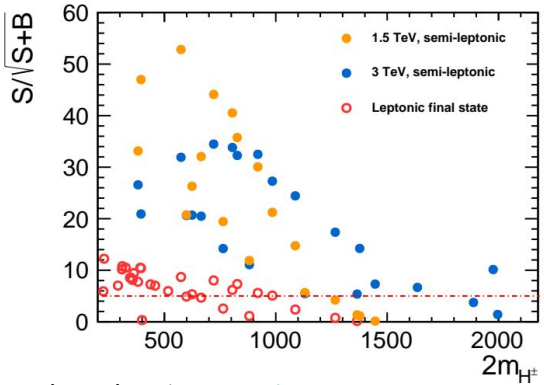
arXiv:1812.02093

Pair-production of Inert Doublet Model (IDM) scalars

Neutral scalars: $e^+e^- \to A\,H$ arXiv:2002.11716



Charged scalars: $e^+e^- \to H^+H^-$ arXiv:1811.06952 arXiv:2201.07146

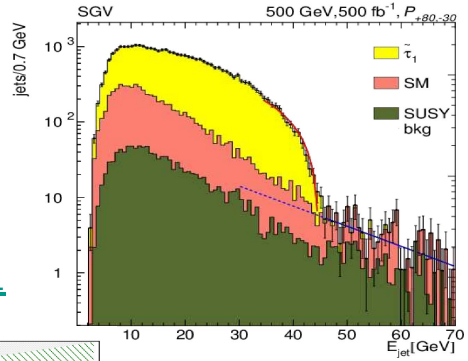


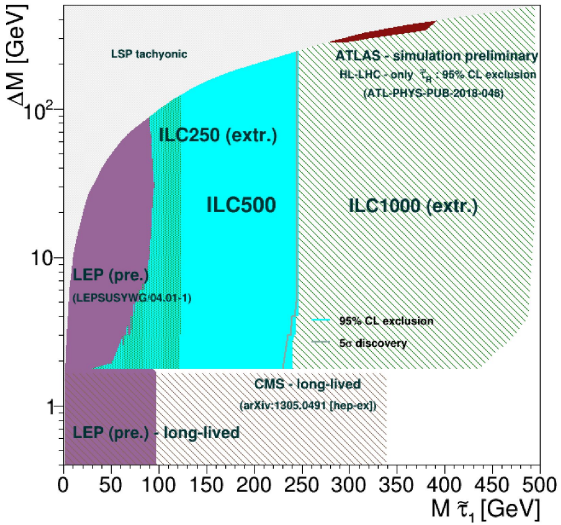
IDM benchmark points: arxiv:1809.07712

Search for stau pair-production

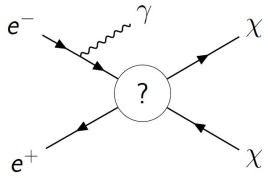
arXiv:1912.06643

Teresa Núñez @ ILCX2021



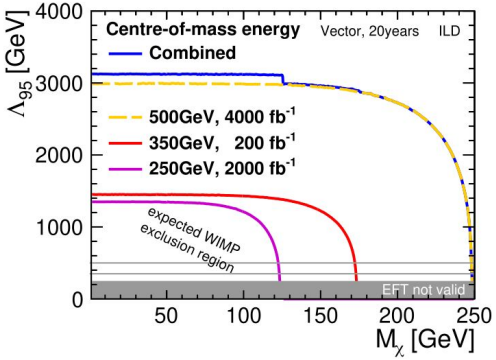


Mono-photon



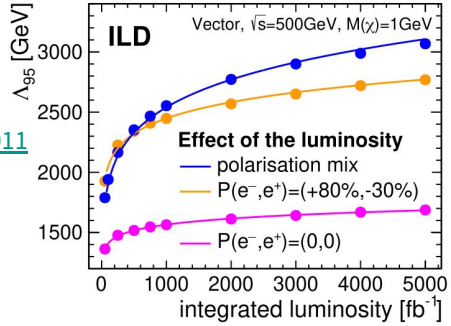
High sensitivity to light DM pair-production

ILC 250+350+500 GeV



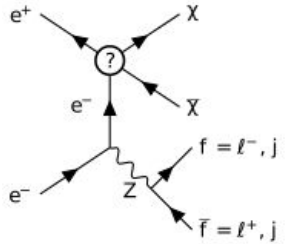
arXiv:2001.03011

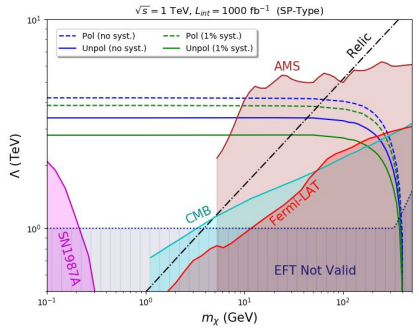
Beam polarisation crucial for significant reduction of systematic uncertainties



Mono-Z

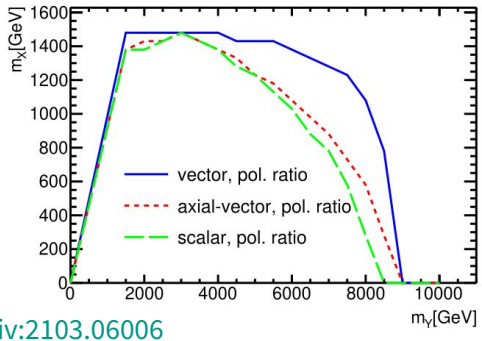
arXiv:2110.06903



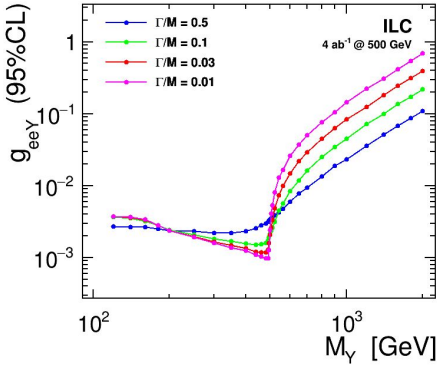


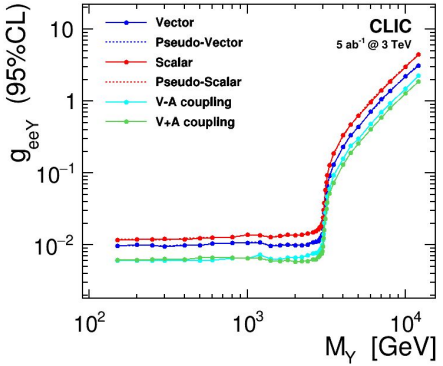
Constraints on light mediator exchange and very small couplings

CLIC 3 TeV, geY = 1



arXiv:2103.06006

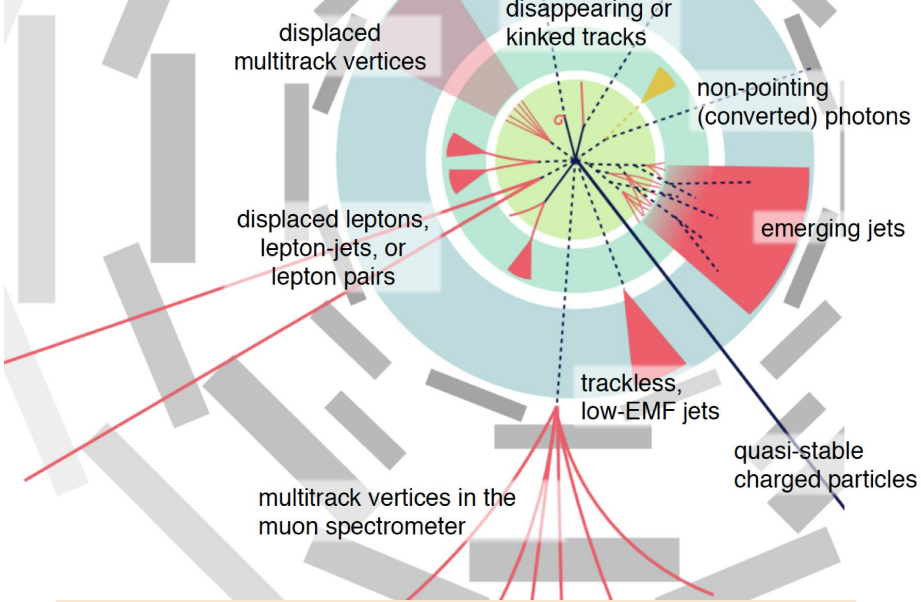




arXiv:2107.11194

Long-lived particles

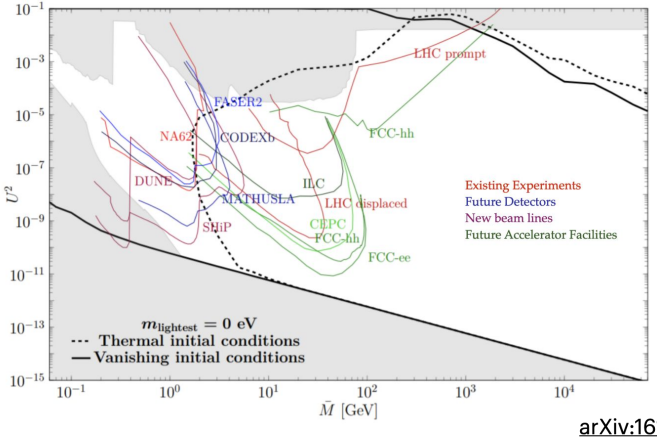
- Signature-driven analyses
- Connected to central questions
  - Neutrino masses, dark or hidden sectors, exotic Higgs boson decays, SUSY…
- FCC-ee (Eur. Phys. J. Plus 136, 1056 (2021), arxiv:2106.15459)
  - Dedicated case study (https://indico.cern.ch/category/5664/
  - LoI for snowmass and white paper under preparation
  - Latest presentation by Juliette Alimena:
    - https://indico.cern.ch/event/1066234/timetable/?view=standard#118-long-lived-particles



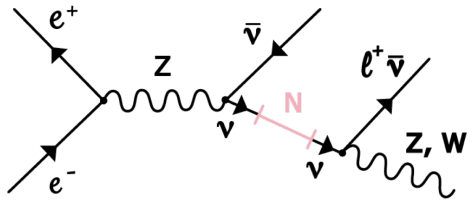
Finished masters/projects

- Simulation of long-lived Heavy Neutral Leptons and Axion-Like Particles at the FCC-ee - Lovisa Ryagaard and Nils Eriksson, Uppsala University, January 2022
- Towards Vertexing Studies of Heavy Neutral Leptons with the Future Circular Collider at CERN - Rohini Sengupta, Uppsala University, June 2021.
- Long-Lived Particles at the FCC-ee - Rohini Sengupta, Uppsala University, January 2021.
- Prospects of Sterile Neutrino Search with the FCC-ee - Sissel Bay Nielsen, University of Copenhagen, December 2017.

Heavy Neutral Leptons

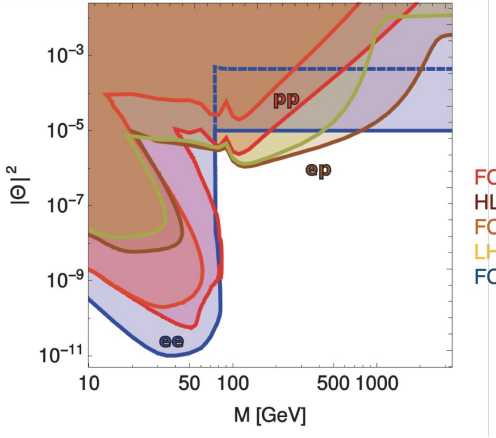


arXiv:2102.12143



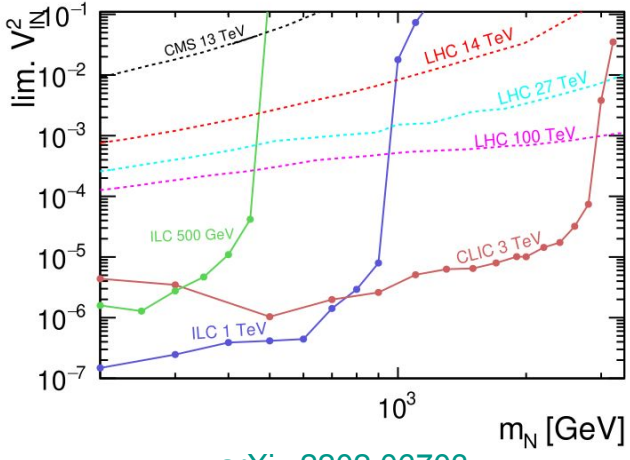
Displaced vertex signature for low couplings or low mass: Tracker

arXiv:1612.02728



Also prompt!

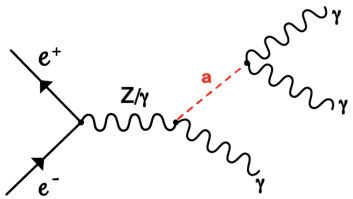
Direct reconstruction for high masses (N→qqℓ)

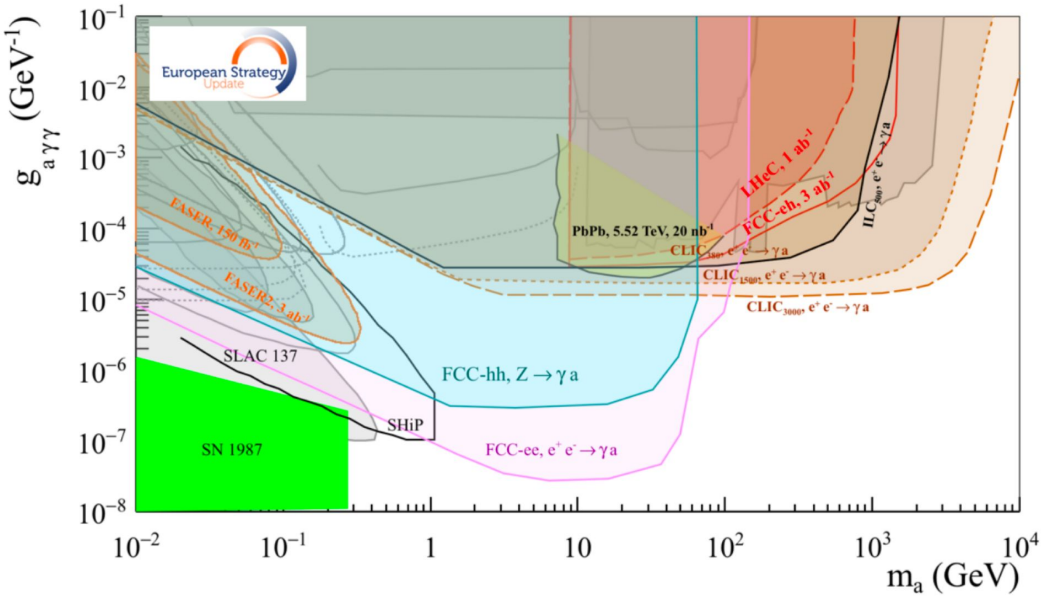


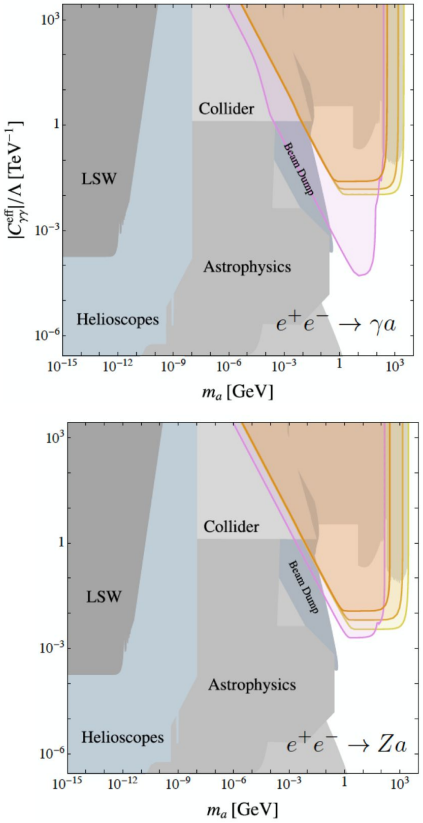
arXiv:2202.06703

ALPs

Displaced photon decay: calorimeters, timing







Exclusion limits for ALPs coupled to photons. All curves correspond to 90% CLexclusion limits, except for LHeC/FCC-eh (95% CL exclusion limits), FCC-ee (observation offour signal events) and FCC-hh (observation of 100 signal events). From the Briefing Book

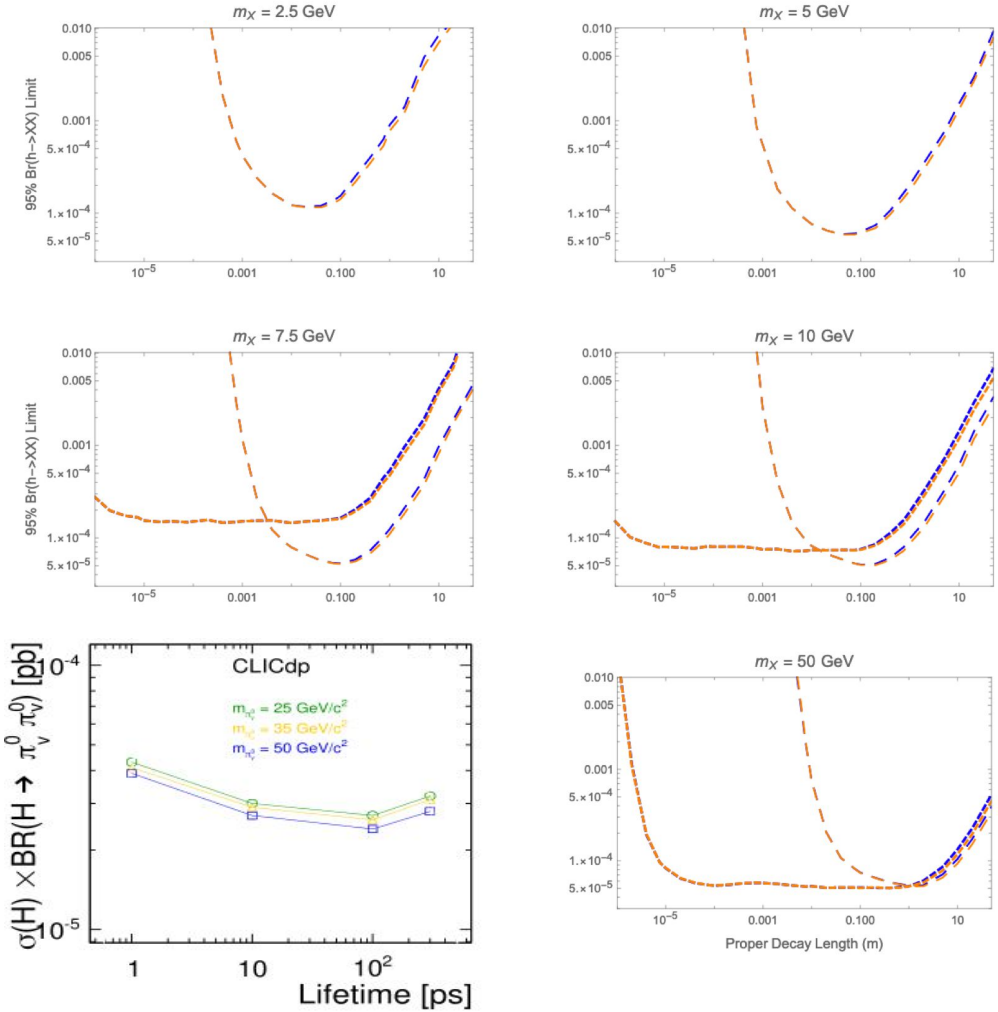
arXiv:1808.10323

Higgs boson decays

H -> XX decays

Projected 95% h→XX branching ratio limits as a function of decay length for a variety of X masses. Blue lines are for CEPC and orange lines are for FCC-ee, and where only one is visible they overlap. [arXiv:1812.05588]

CLIC: Hidden Valley searches ⇒ https://cds.cern.ch/record/2625054



Disappearing track signature

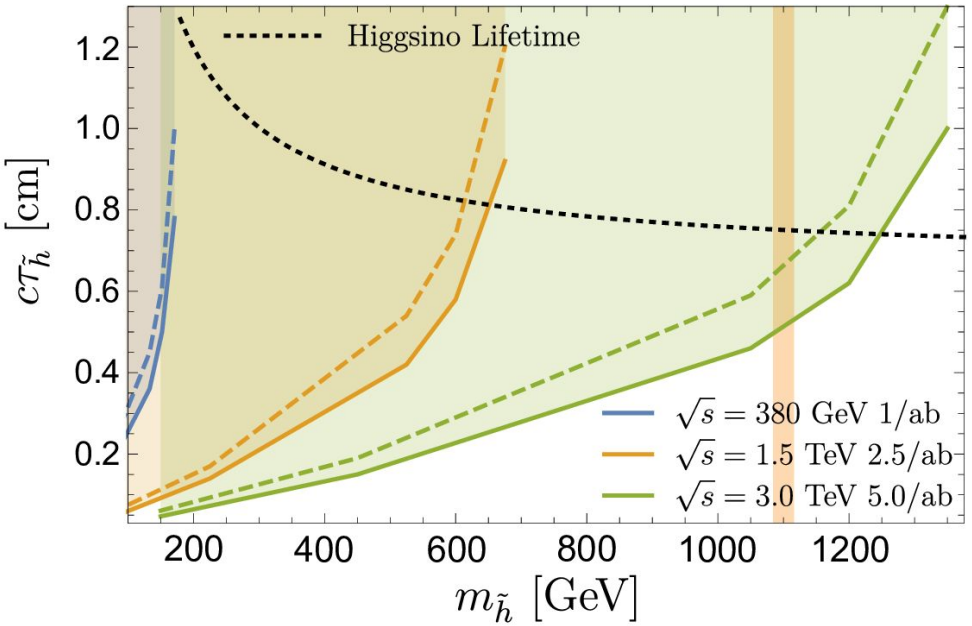
Degenerate Higgsino Dark Matter scenario

If mass difference between chargino and higgsino is very small, chargino can be long-lived. Pions from its decay

$$X^{\pm} \rightarrow \pi^{\pm} X^{0}$$

are too soft to be reconstructed

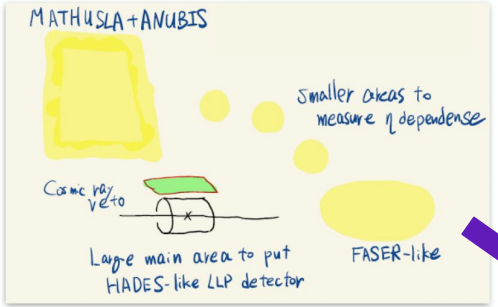
⇒ disappearing tracks

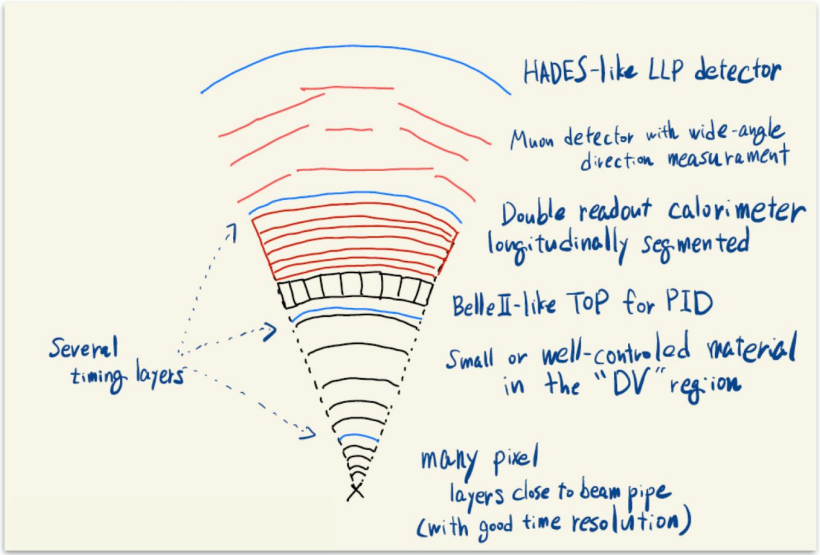


arXiv:1812.02093 arXiv:1812.06018

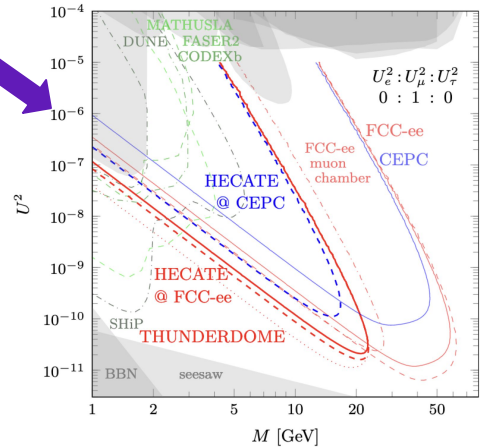
Ryu Sawada

A dream LLP detector?





Can we incorporate LLP to the design of the future collider Experiments?



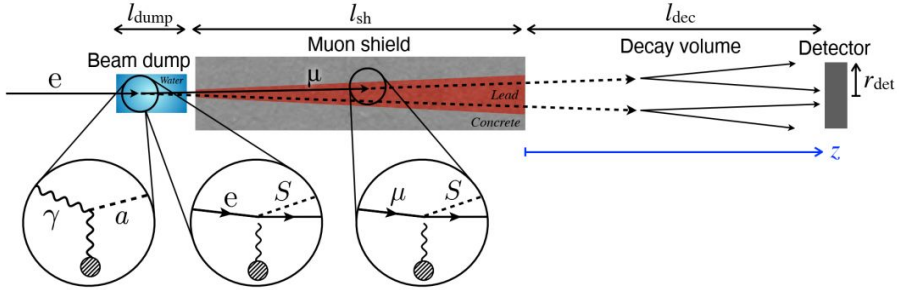
e.g. FCC-ee/CepC Mathusla-like concept HECATE: arXiv:2011.01005

FAr Detectors
https://arxiv.org/abs/1911.06576
for ALPs at FCC-ee, CepC
https://arxiv.org/abs/2201.08960

Beam dump experiment?

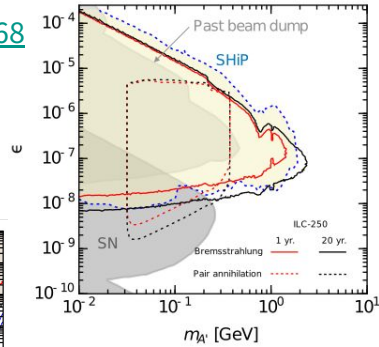
At linear colliders extreme intensities expected at electron and positron beam dumps opening unique options for fixed-target experiments focused on rare processes.

General scheme of an experiment searching for axion-like particles, new scalars or dark photons



One can look for visible products of LLPs decays (like a →γγ, S→$\ell^+\ell^-$) or for secondary interactions of invisible decay products in dedicated far detector (like in direct DM detection experiments; approach used in SLAC Beam Dump Experiment E137: arXiv:1406.2698)

arxiv:2105.13768



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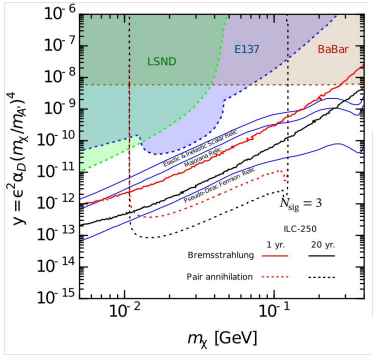
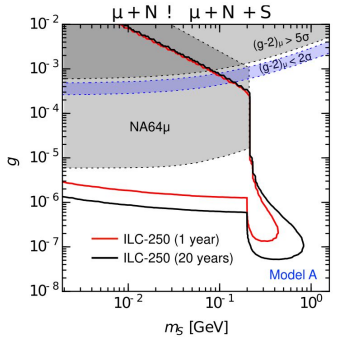
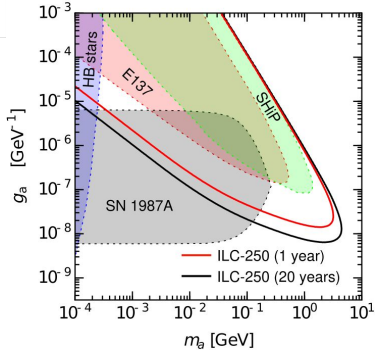


Dark Photon decays:
← invisible and visible ↑

ALP production





New scalars

arxiv:2009.13790