

SEARCHES FOR FEEBLY INTERACTING PARTICLES AT



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for the LLP FCC-ee working group

ICHEP 2022
BOLOGNA



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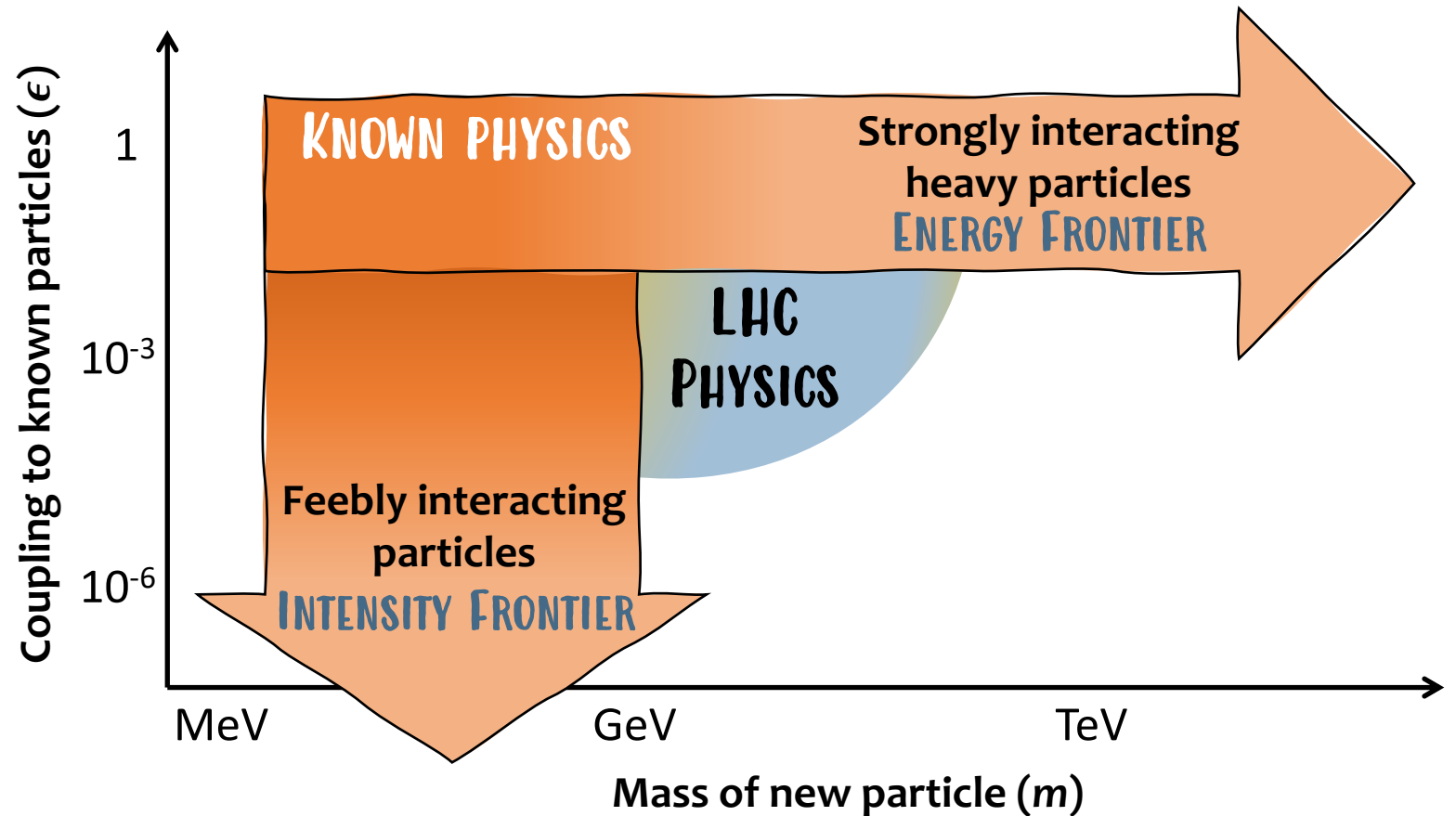
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THE LANDSCAPE OF NEW PARTICLES @ COLLIDERS

- Collider physics: a plethora of measurements and searches
- The Standard Model is complete and confirmed. Burning questions remain!

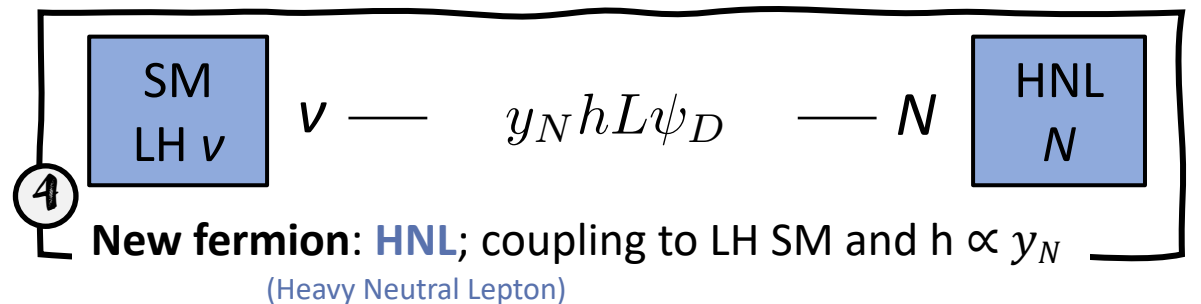
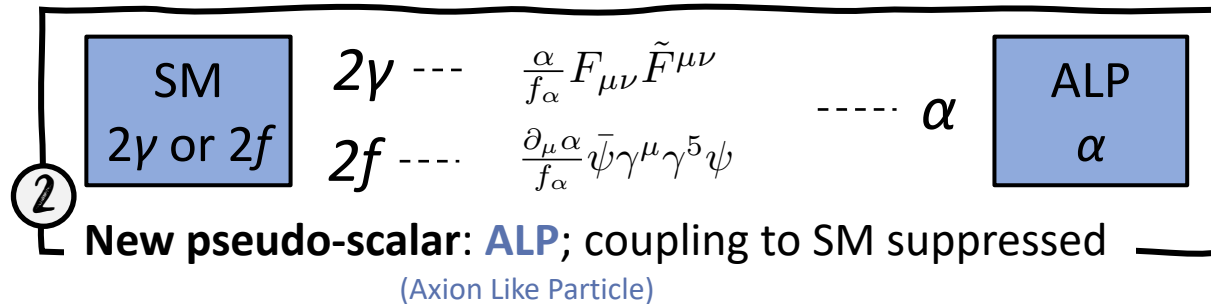
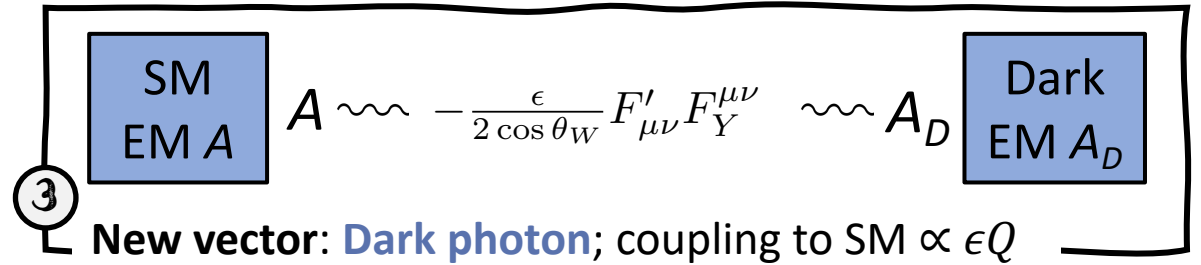
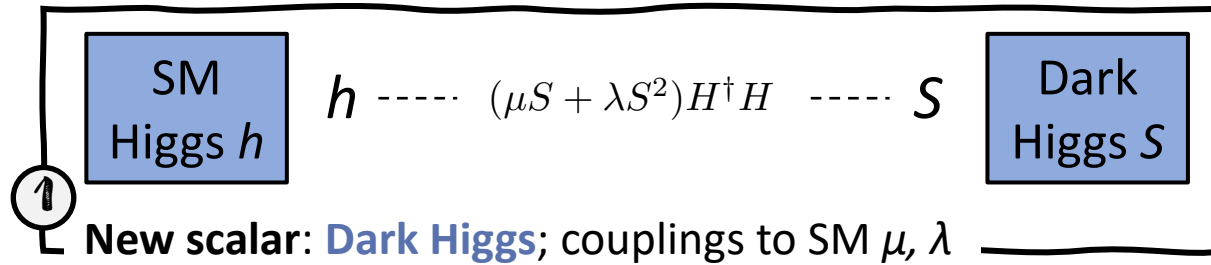
2.4 MeV	1.3 GeV	170 GeV	0
u	c	t	γ
4.8 MeV	104 MeV	4.2 GeV	0
d	s	b	g
<2 eV	<2 eV	<2 eV	91 GeV
ν_L	ν_M	ν_H	Z
0.5 MeV	16 MeV	1.8 GeV	80 GeV
e	μ	τ	W
			126 GeV
			H



FEEBLY INTERACTING PARTICLES (FIPs)



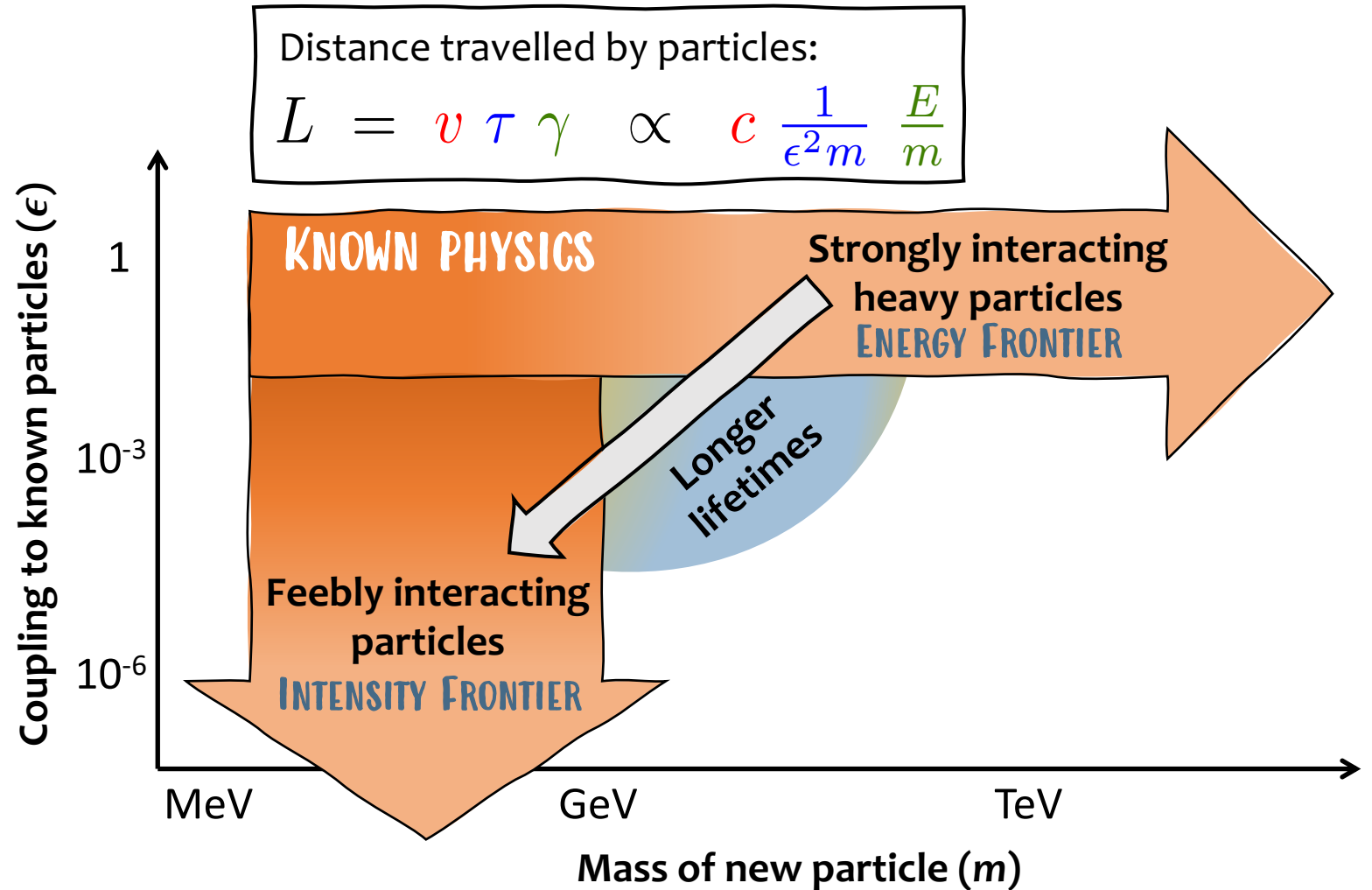
- Due to interacting feebly, they are linked to a “hidden sector”
- Couplings between SM and hidden sector result from “portal” operators
- Large number of specific models; can be simplified to the following:



- The masses of the new particles can span several orders of magnitude

THE LANDSCAPE OF NEW PARTICLES @ COLLIDERS

- **Lifetime:**
a characteristic of weakly interacting (light) particles
- Distinct signatures
- **Opportunity for exploration!**
 - in current and **future colliders** and dedicated experiments



THE FCC PROJECT

2020 EUROPEAN STRATEGY UPDATE



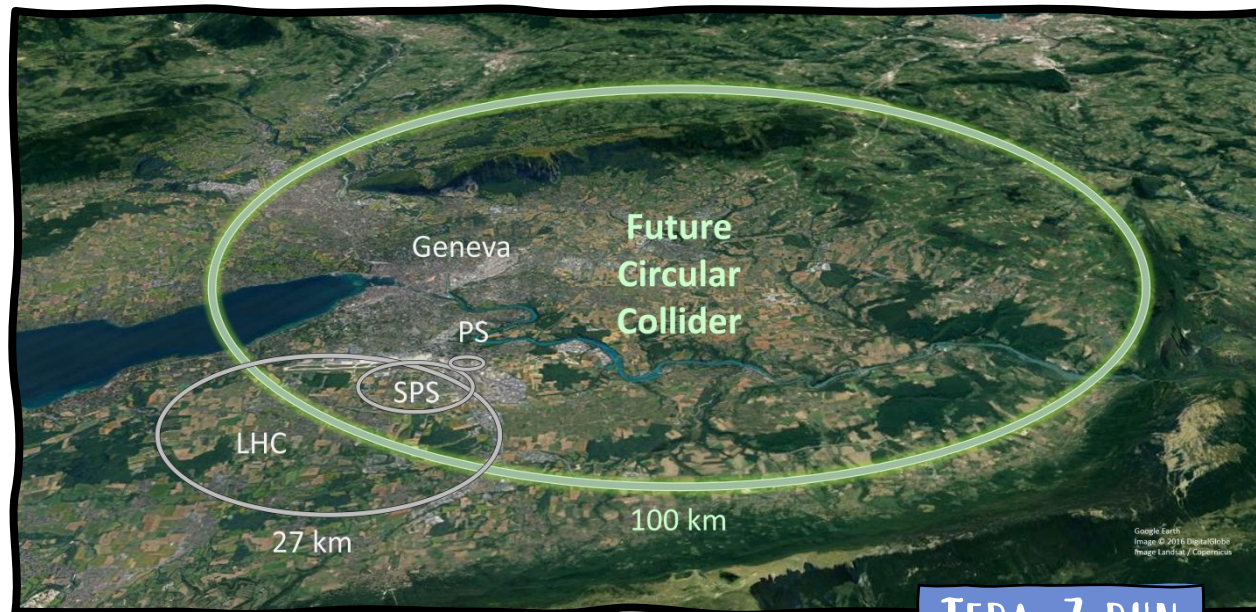
An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy.

<https://europeanstrategy.cern/european-strategy-for-particle-physics>



Aims at pushing both **energy** and **intensity frontiers** of particle colliders

- Conceptual design report (2020)
- Technical and financial feasibility study due for next EU strategy update (2027)



TERA-Z RUN

Stage	Collisions	CME	L (ab ⁻¹)	N events
FCC-ee	e ⁺ e ⁻	90 GeV (Z-pole)	150	5x10¹² Z
		160 GeV (WW)	10	10 ⁸ WW
		240 GeV (HZ)	5	10 ⁶ HZ
		365 GeV (tt)	1.5	10 ⁶ tt
FCC-hh	pp	100 TeV	30	2x10 ¹⁰ H 3x10 ⁷ HH
FCC-eh	ep	3.5 TeV		

Runs with heavy ions not included

TOWARDS ASSESSING SENSITIVITY TO FIPs

Opportunities for detailed studies

European strategy update
(2018-2020)



Snowmass community planning
(2020-2022)



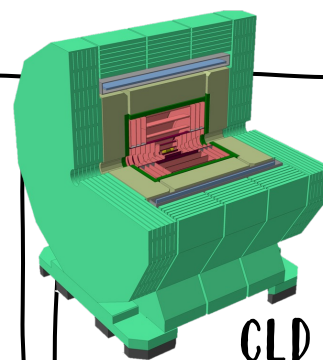
FCC feasibility study
(input to next strategy update)



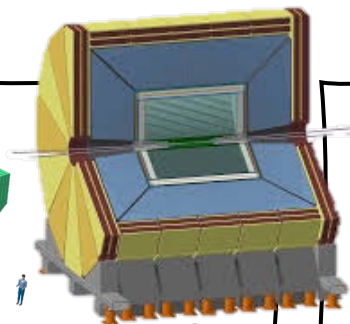
Typical workflow



Sample generation of various models, e.g.
MadGraph5_aMC@NLO for parton-level e^+e^-
PYTHIA for parton shower and hadronisation



CLD



IDEA

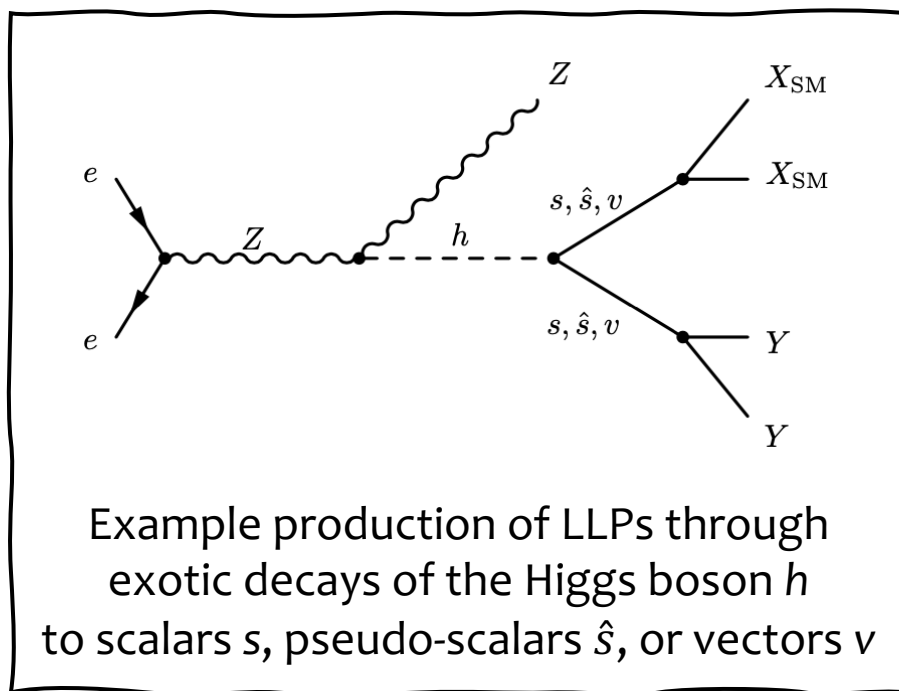
Parameterised detector simulation
e.g. IDEA DELPHES card



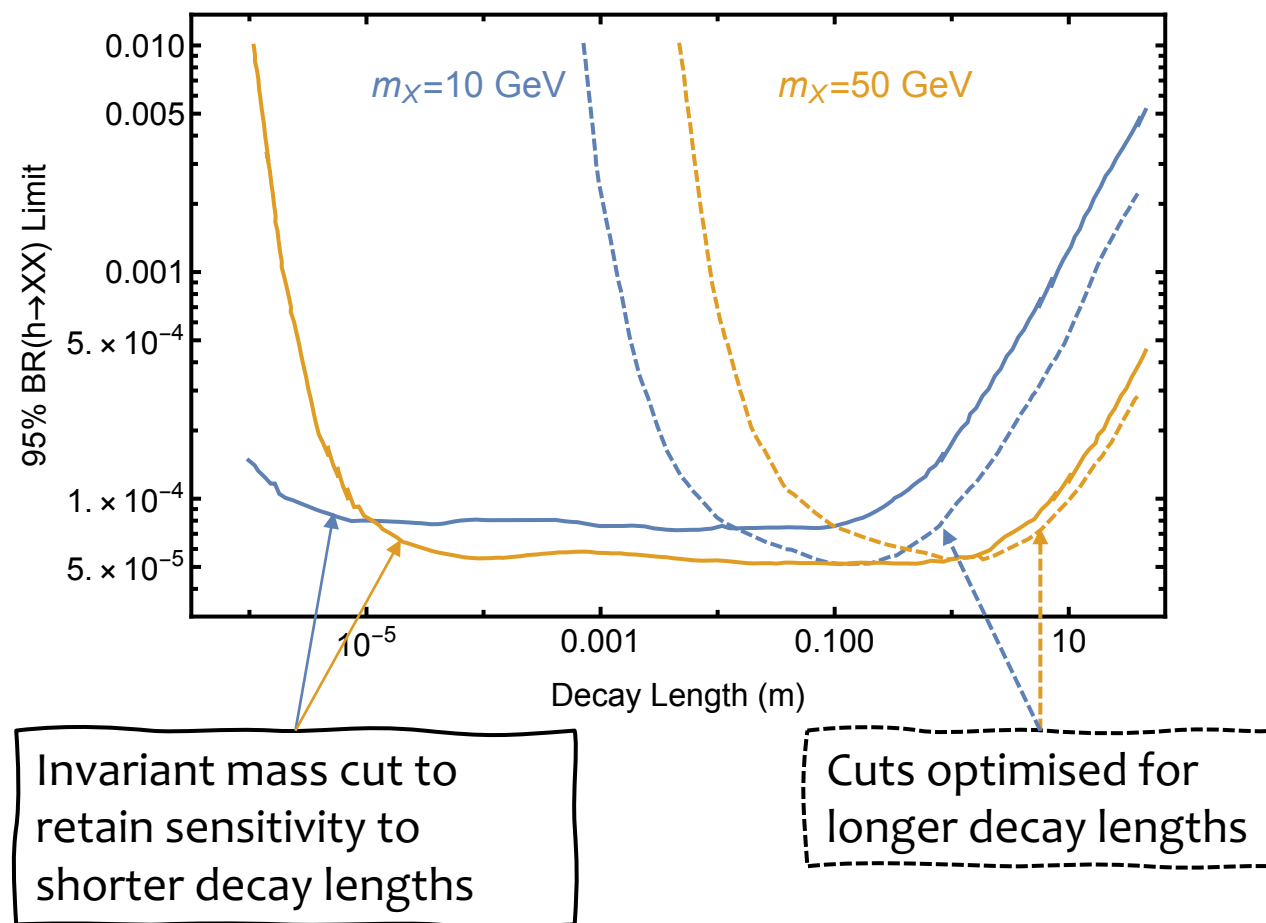
Analysis code
e.g. FCCAnalysis

EXOTIC DECAYS OF THE HIGGS BOSON

- The only elementary scalar particle that has been discovered!
 - Can have sizeable coupling to undiscovered particles

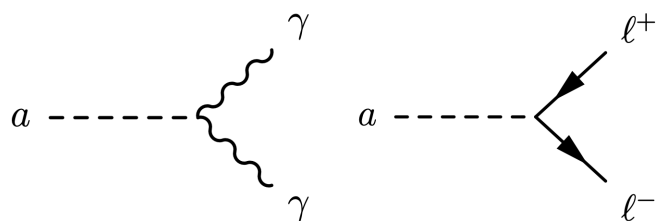


Sensitivity of FCC-ee to exotic Higgs boson decays to LLPs (X)

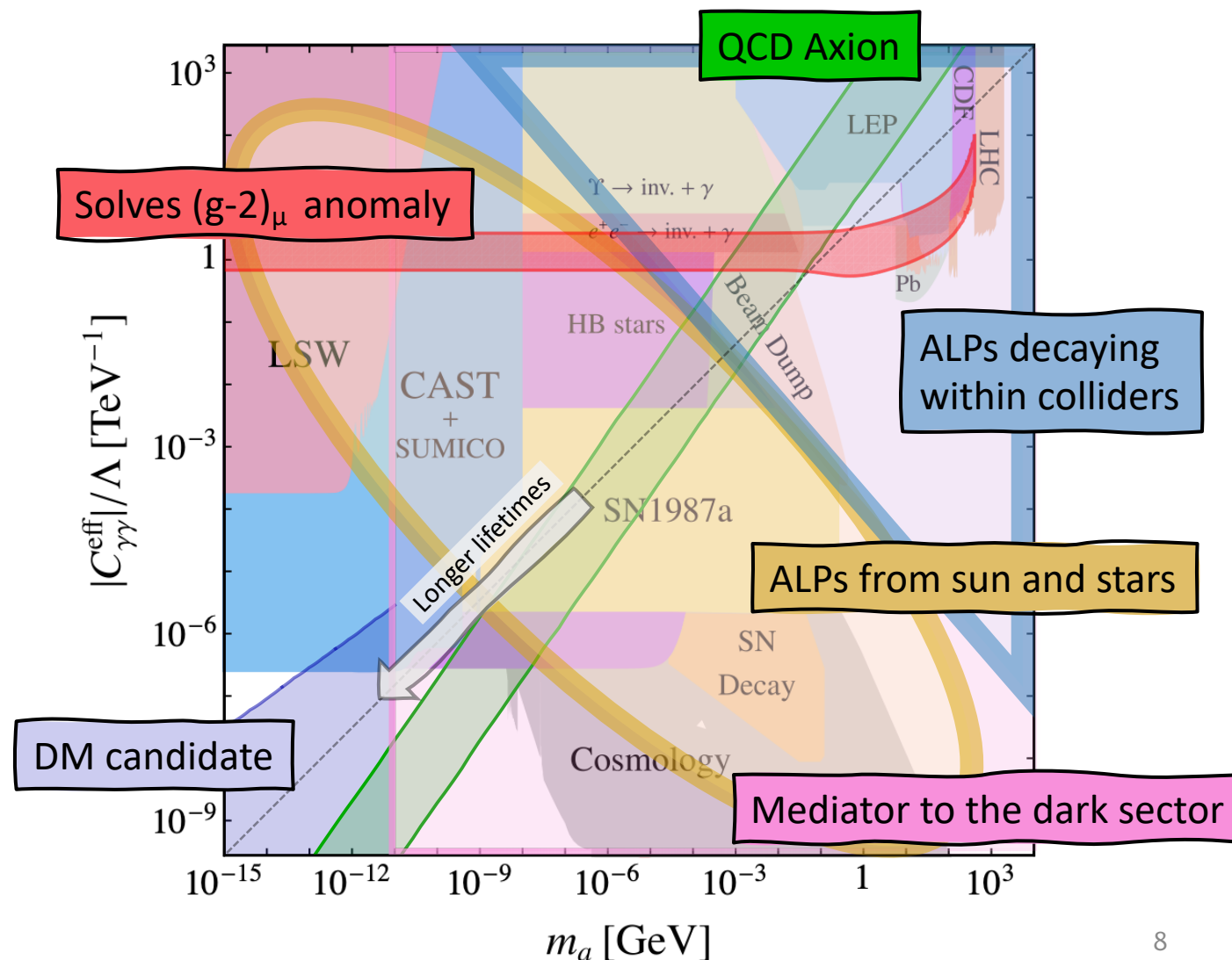


PSEUDOSCALAR PORTAL – ALPs

- Pseudoscalar SM-singlets; can appear in theories with broken global symmetries
- “Low” mass particles with suppressed couplings to SM
- BR to SM particles depends on their mass

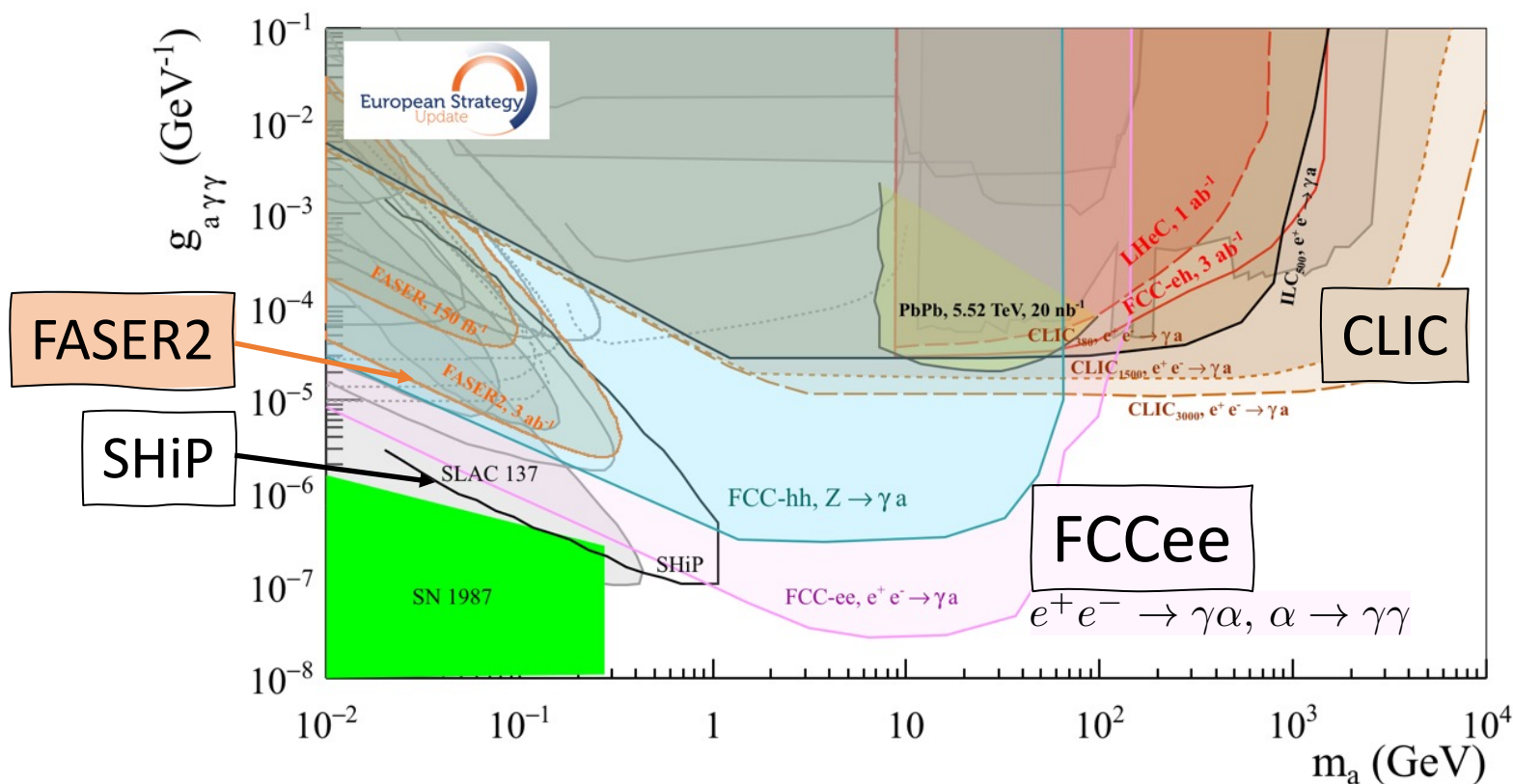


Dominant decays at the FCC



Thanks to Andrea Thamam for the figure!

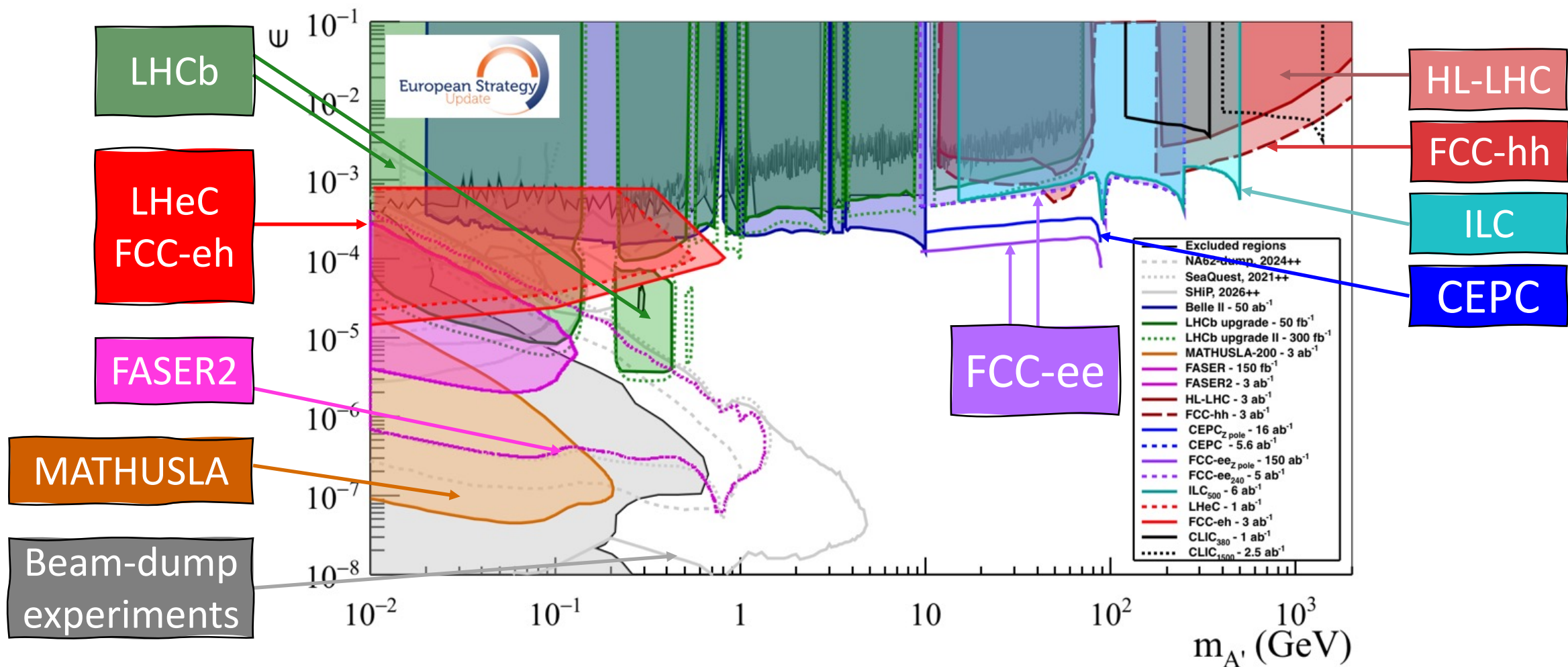
REACH FOR ALPS IN FUTURE EXPERIMENTS



- Couplings to H accessible via $e^+e^- \rightarrow H\alpha$, $\alpha \rightarrow b\bar{b}$
 - similar for couplings to Z
- Decays to SM particles other than photons are less constrained
 - additional opportunity for ALP discovery at the FCC-ee.

The sensitivity provided by FCC-ee uniquely extends other limits by up to four orders of magnitude in the 1-100 GeV mass range

VECTOR PORTAL – REACH FOR DARK PHOTONS



Complementarity of collider and other accelerator experiments

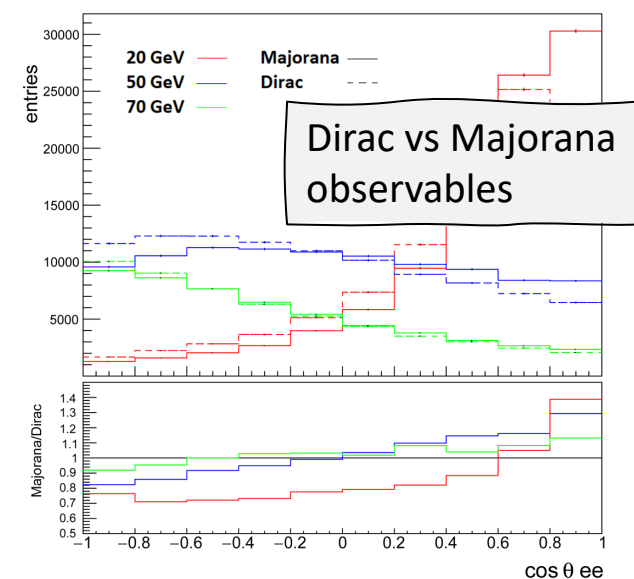
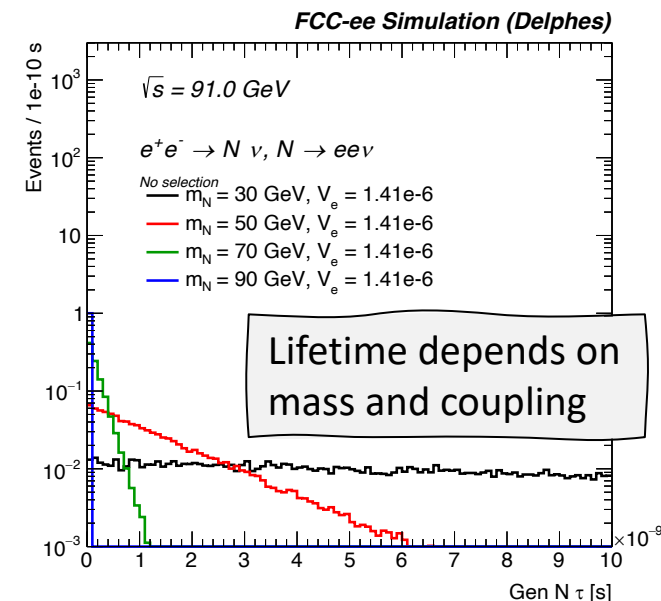
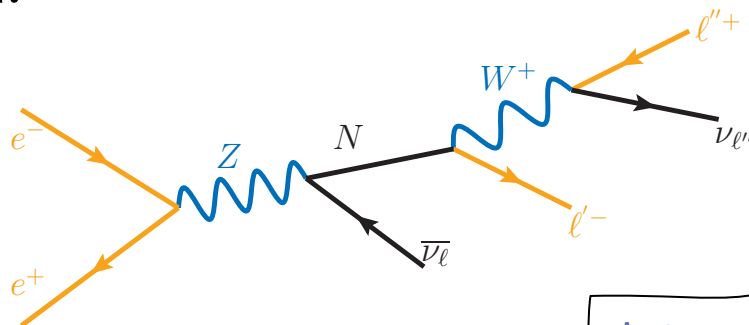
NEUTRINO PORTAL – HNLS

Many puzzles associated with neutrinos

- Oscillations, masses, further properties
 - e.g. Dirac or Majorana?

See-saw mechanism

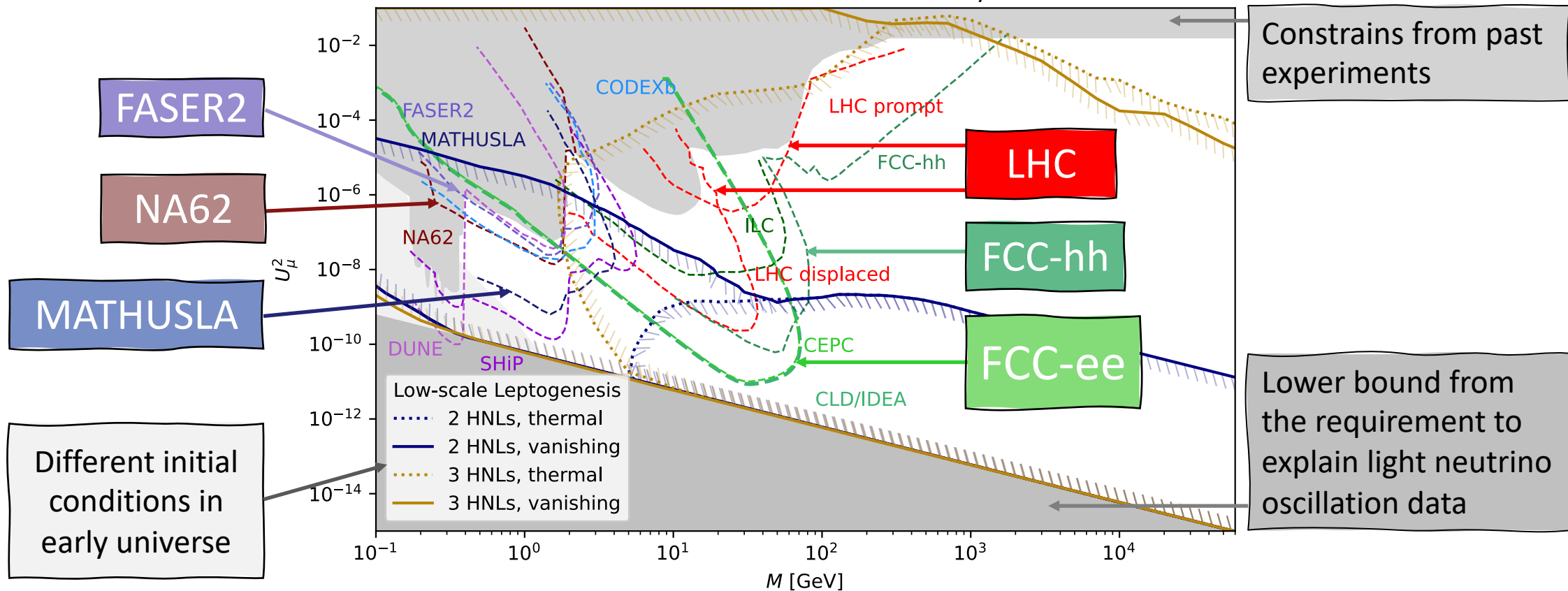
- Generic model used to understand the relative sizes of observed neutrino masses to other fermions
- Two or more right-handed fields
- Results in new particles: Heavy Neutral Leptons (HNLS)
- Do these particles exist? What are their masses?
- Are they Dirac or Majorana?
- $\mathcal{L}^{int} = \mathcal{L}^W + \mathcal{L}^Z + \mathcal{L}^H$



Interesting experimental explorations ahead

REACH FOR HNLS IN FUTURE EXPERIMENTS

See also talk from M. Drewes on ICHEP2022 Neutrino Physics session

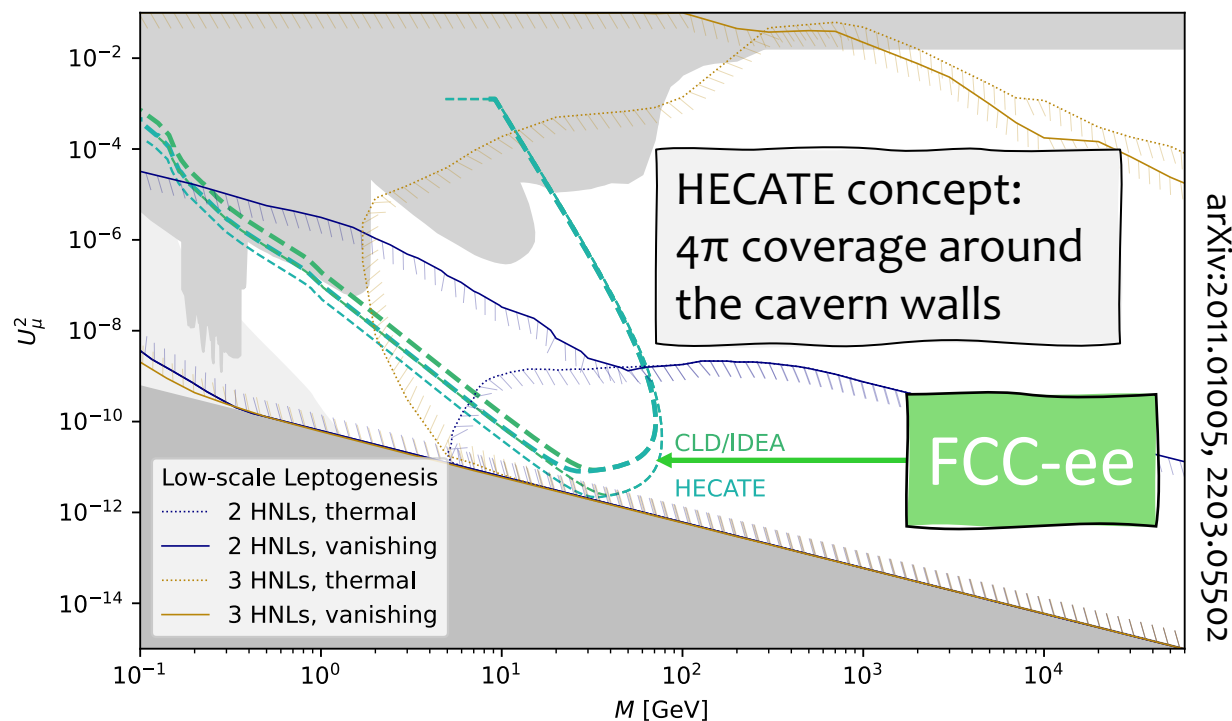


FCC-ee running at the Z-pole has the potential to exclude the region of masses and couplings down to the see-saw limit

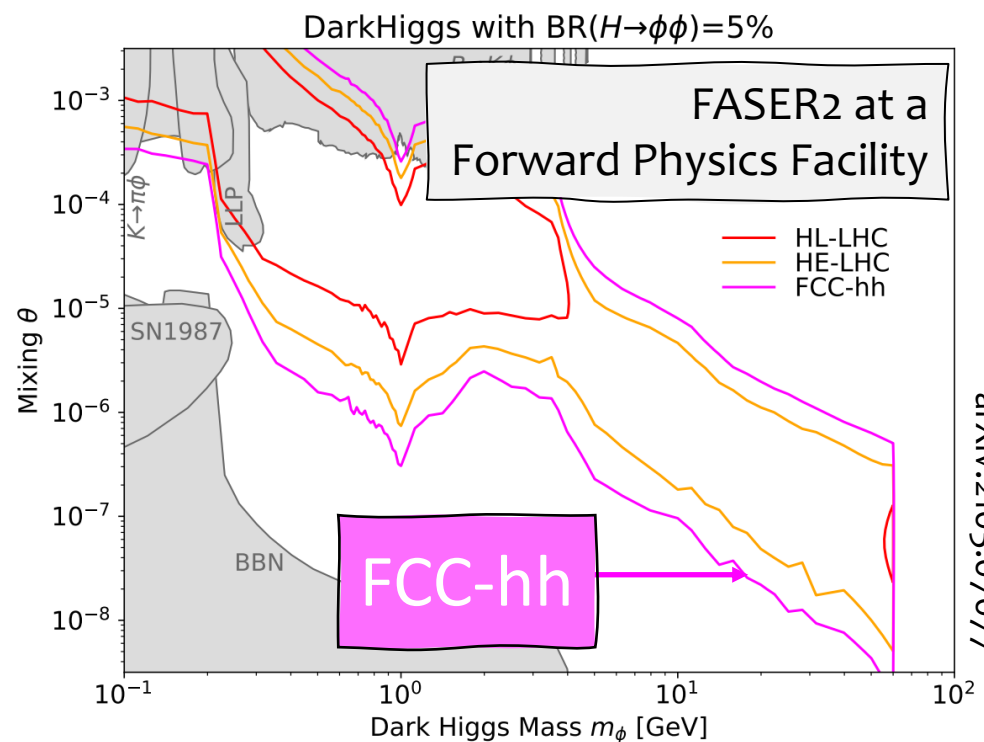
FURTHER OPPORTUNITIES FOR FIPs AT FCC

Two examples. More proposals on arXiv.

At FCCee



At FCChh



**Significant opportunities open up, beyond what can be done with conventional collider detectors!
Essential to account for them since the beginning, to minimize overheads later on.**

IN BRIEF

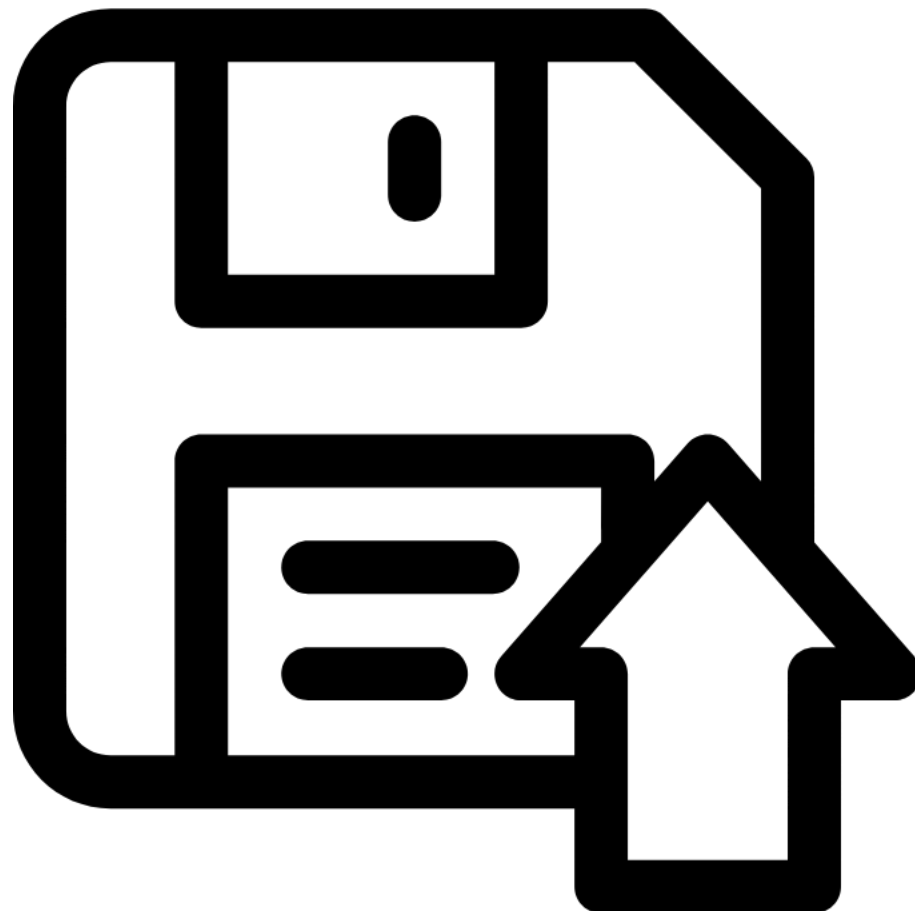
- FCC-ee will push the intensity frontier of particle physics
 - 5×10^{12} Z bosons expected to be produced
- It has the potential to discover **feebly interacting new particles**, in a phase space where no other experiment will ever have sensitivity
 - dark Higgses, ALPs, dark photons, HNLs
- **Unique opportunity to help answer some of the pressing questions of our Universe**
- We need to study FIPs@FCC now, to account for them in the design of the detectors and facilities
- Lots of room for newcomers – please join the pursuit!



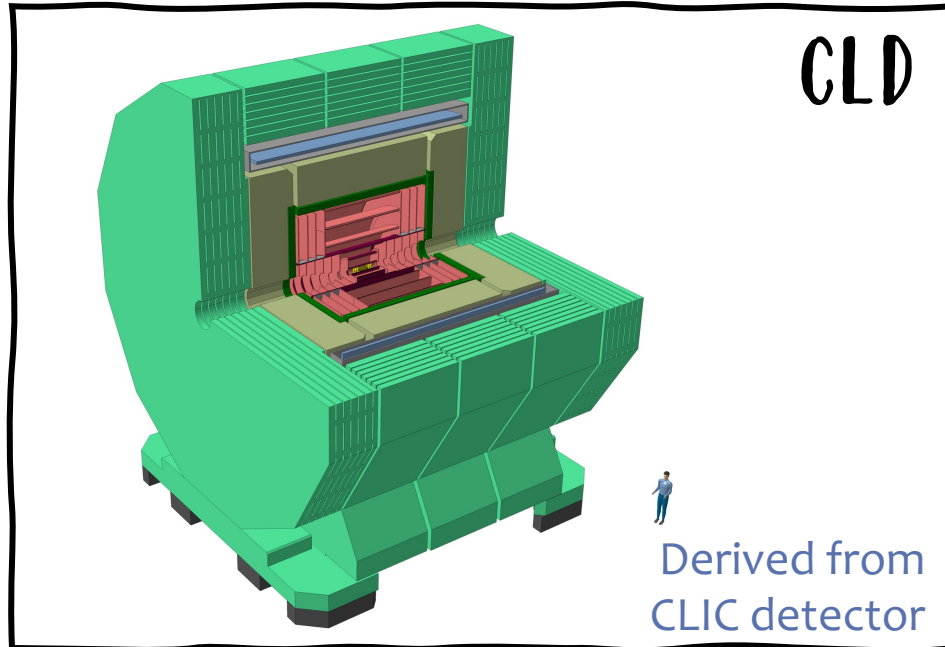
LLP-FCCee-informal@cern.ch



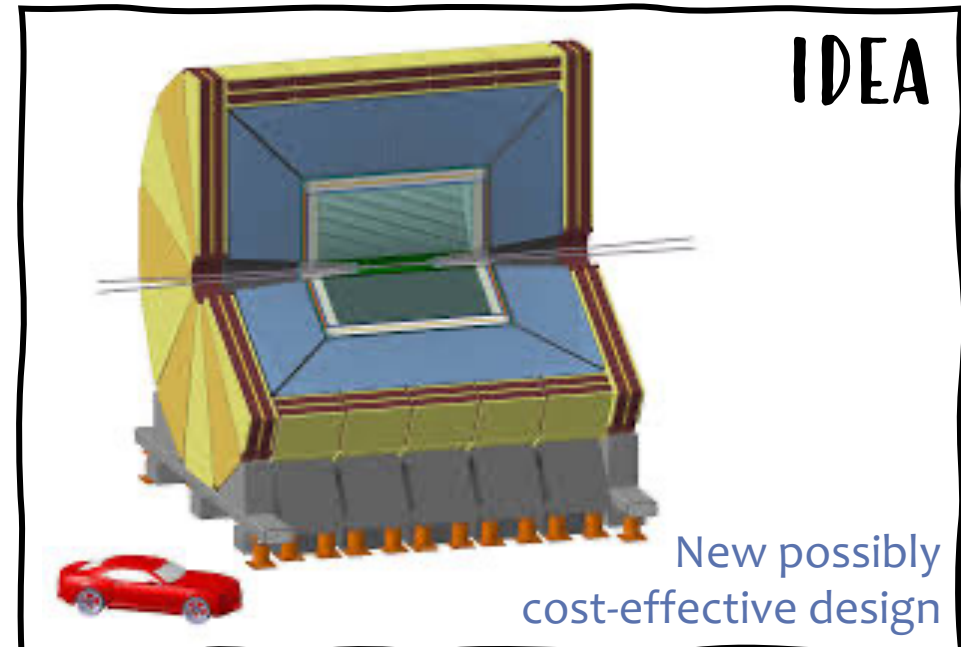
<https://indico.cern.ch/category/5664/>



FCCee BASELINE DETECTOR CONCEPTS



Full silicon tracker
3D high granularity calorimeter
Solenoid outside calorimeter



Ultra-light drift chamber
Dual read-out calorimeter
Solenoid inside calorimeter

Still being evaluated and optimised.
Will have to cover well all physics cases, **incl. the most challenging ones**

REACH FOR DARK HIGGS

