LAYCAST : a proposed detector for long-lived particle searches at the CEPC

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based on [**Ye Lu, Ying-nan Mao, Kechen Wang, Zeren Simon Wang, hep-ph/2406.05770**]

OUTLINE

Theory Motivation

LLP: Relatively long lifetime or equivalently decay length

New particles become long-lived because of:
→ feeble couplings to SM particles
→ phase space suppression
→ approximate symmetry, …

The discovery of LLPs could explain some fundamental problems: neutrino mass, dark matter, ...

LLP searches are important ways to BSM physics.

Idea of LLP searches @ colliders

When a LLP produced at 0 (usually the IP),

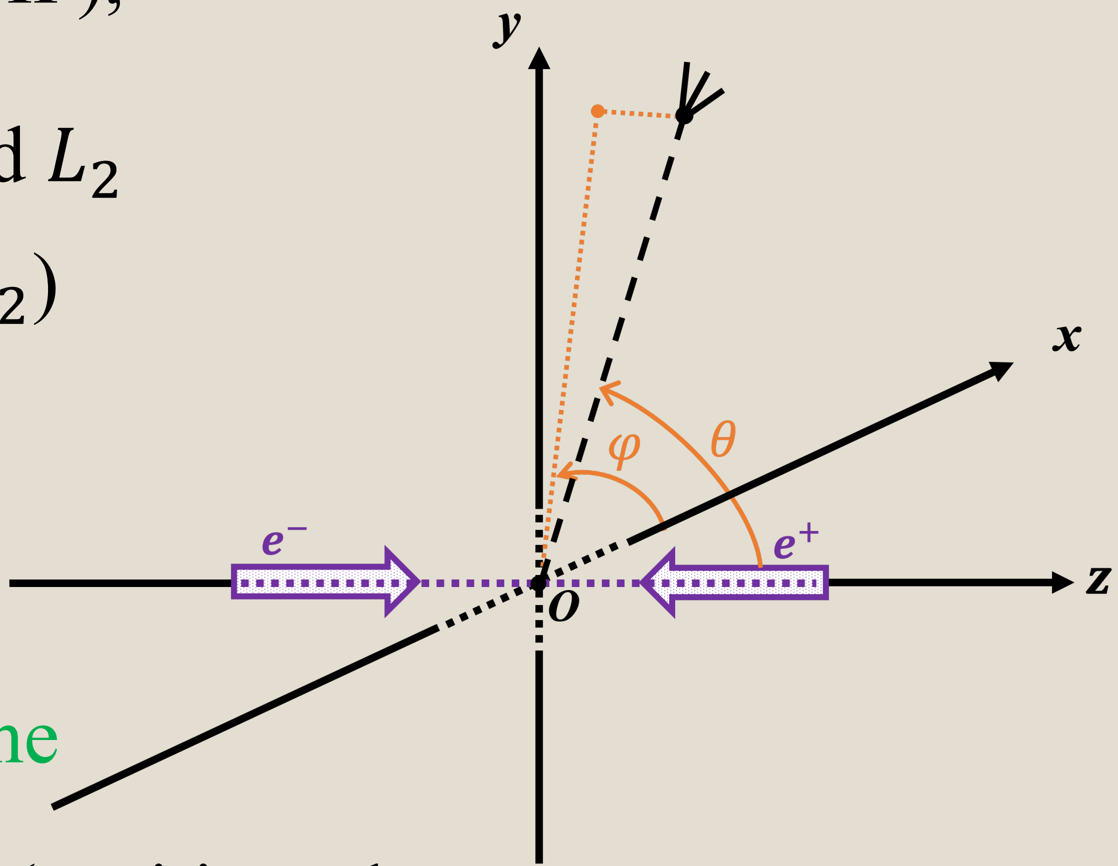
Probability of decaying between L_1 and L_2

$$P(\Delta L) = e^{-L_1/\lambda} - e^{-L_2/\lambda} \quad (L_1 < L_2)$$

where **decay length** in the lab. frame

$$\lambda = \beta\gamma\, c\tau = \left(\frac{p}{m}\right)\ (c\tau)$$

Kinematics lifetime in the rest frame



L_1 and **L_2** : determined by the detector (position, shape, volume, ...) & LLP's moving direction

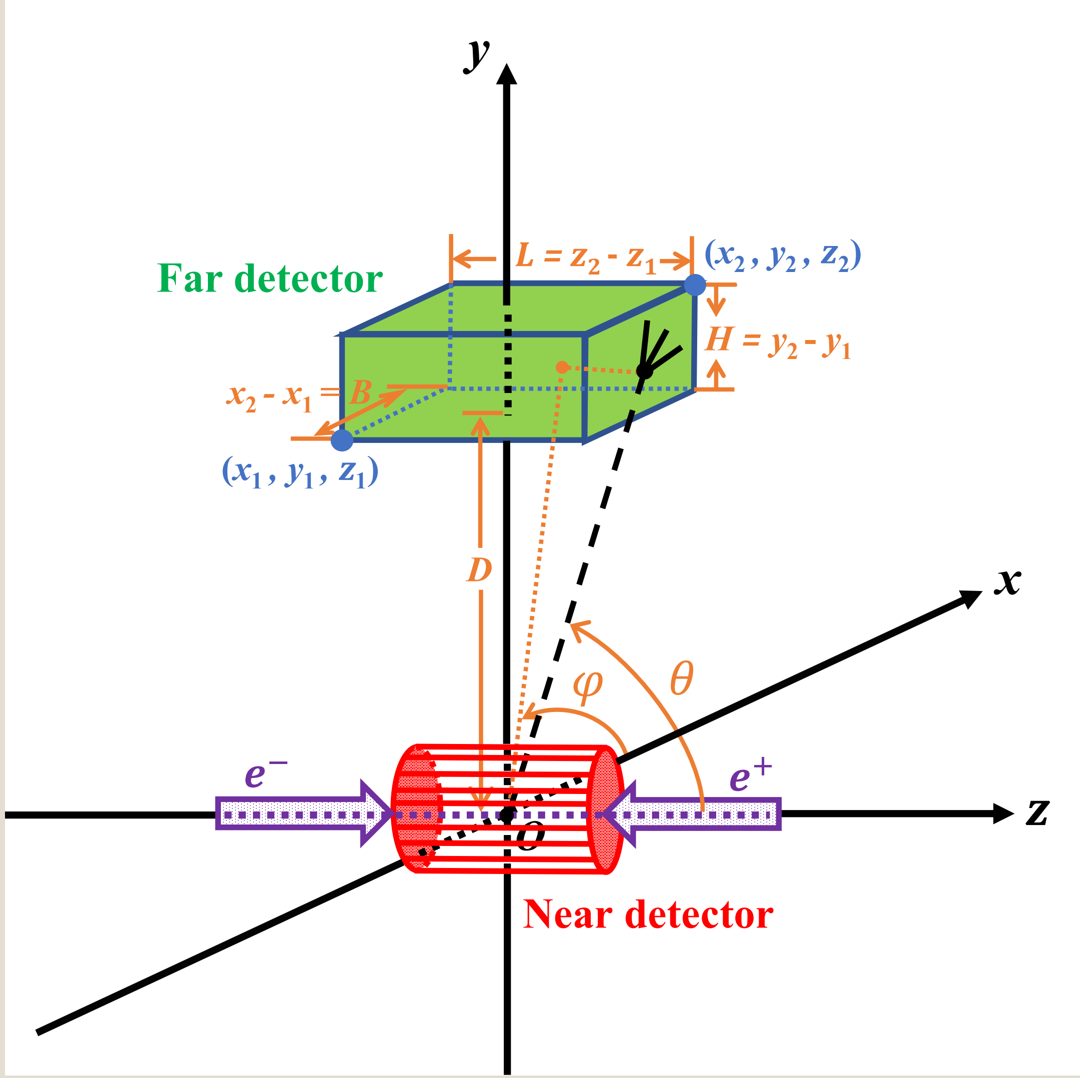
Signatures of LLPs in FD

When $\lambda \sim \mathcal{O}(100)$ m,

Mainly travel through and acts as missing energy in the near detector.

Far detector is more likely to observe the decay process, and reconstruct the time, position, direction, momentum, mass, etc.

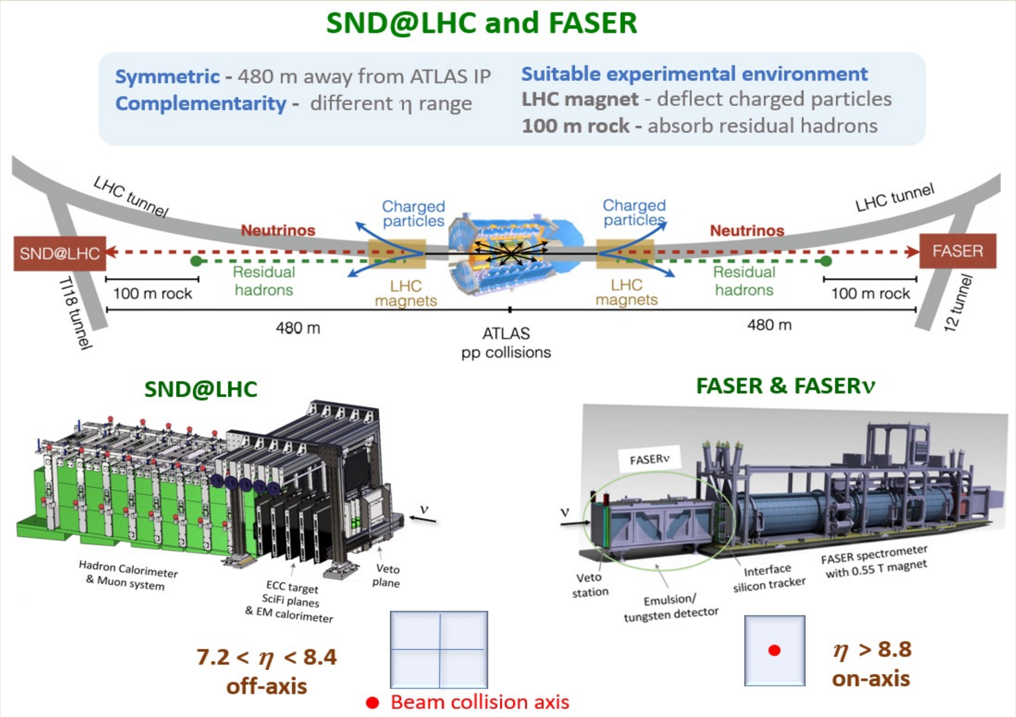
Far detector can enhance the discovery potential for LLPs with very long decay length.



[**1911.06576, Zeren Simon Wang and Kechen Wang**, Physics with far detectors at future lepton colliders]

FD experiments @ LHC

Current running



Proposed

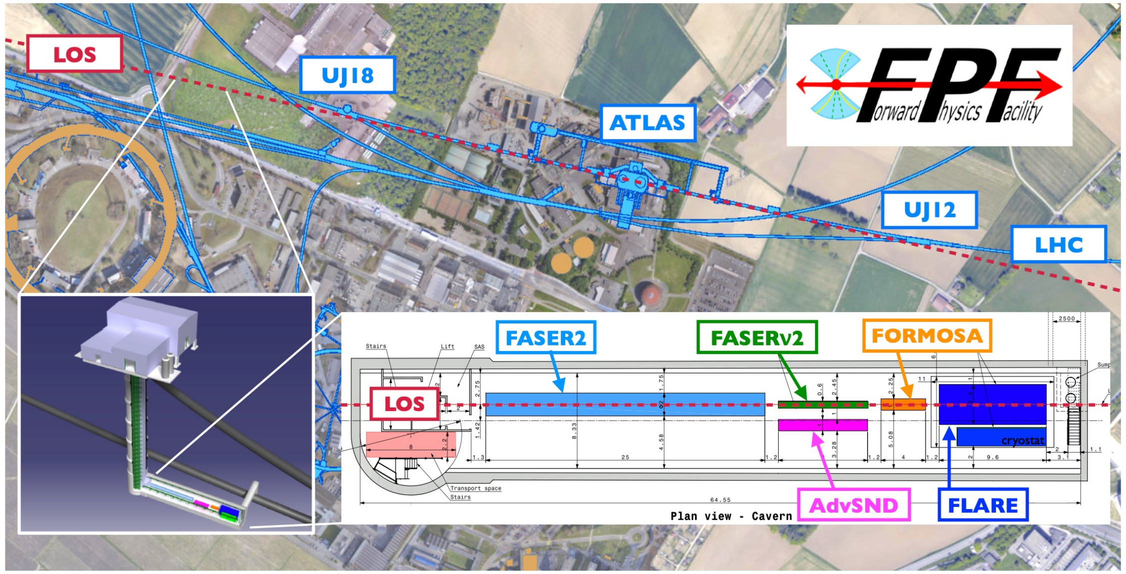


Figure 1: The preferred location for the Forward Physics Facility, a proposed new cavern for the High-Luminosity era. The FPF will be 65 m-long and 8.5 m-wide and will house a diverse set of experiments to explore the many physics opportunities in the far-forward region.

[https://snd-lhc.web.cern.ch/]

[https://faser.web.cern.ch/index.php/]

[http://www.ship-korea.com/SND.html]

[2210.02784, SND@LHC: The Scattering and Neutrino Detector at the LHC]

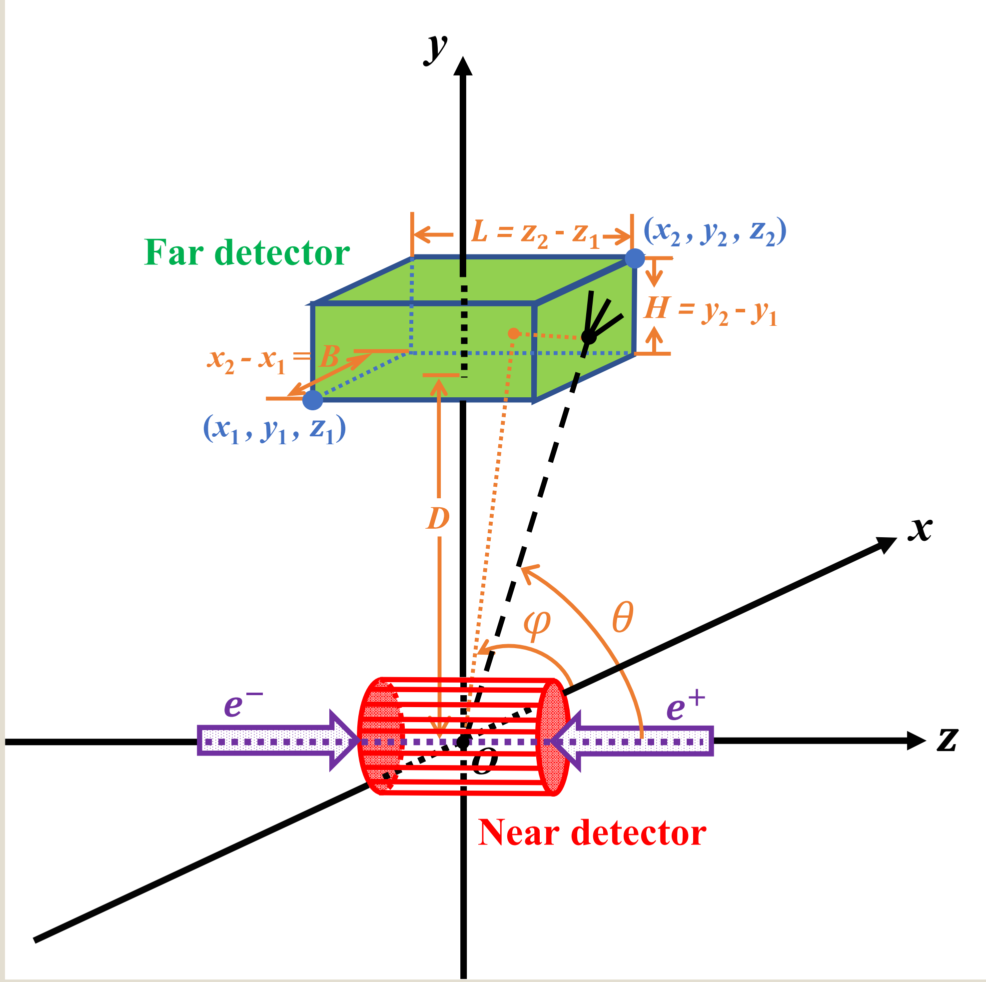
Proposed FD experiments：MATHUSLA, FASER2, FASERv2, AdvSND, FLArE, FORMOSA, CODEX-b, AL3X, ...

[2203.05090, The Forward Physics Facility at the High-Luminosity LHC]

FAr Detectors at the Electron Positron Collider (**FADEPC**)

[**1911.06576, Zeren Simon Wang and Kechen Wang**, Physics with far detectors at future lepton colliders]

	V [m^3]	B [m]	H [m]	L [m]	(x_1, y_1, z_1) [m]	(x_2, y_2, z_2) [m]	D [m]
FD1	5.0×10^3	10	10	50	(5, -5, -25)	(15, 5, 25)	5
					(10, -5, -25)	(20, 5, 25)	10
FD2	8.0×10^5	200	20	200	(-100, 50, 50)	(100, 70, 250)	50
					(-100, 100, 100)	(100, 120, 300)	100
FD3	8.0×10^5	200	20	200	(-100, 50, -100)	(100, 70, 100)	50
					(-100, 100, -100)	(100, 120, 100)	100
FD4	8.0×10^5	100	80	100	(-50, 50, -50)	(50, 130, 50)	50
					(-50, 100, -50)	(50, 180, 50)	100
FD5	3.2×10^6	200	80	200	(-100, 50, -100)	(100, 130, 100)	50
					(-100, 100, -100)	(100, 180, 100)	100
FD6	8.0×10^7	1000	80	1000	(-500, 50, -500)	(500, 130, 500)	50
					(-500, 100, -500)	(500, 180, 500)	100
FD7	8.0×10^5	2000	20	20	(-1000, 50, -10)	(1000, 70, 10)	50
					(-1000, 100, -10)	(1000, 120, 10)	100
FD8	8.0×10^5	20	20	2000	(-10, 50, -1000)	(10, 70, 1000)	50
					(-10, 100, -1000)	(10, 120, 1000)	100

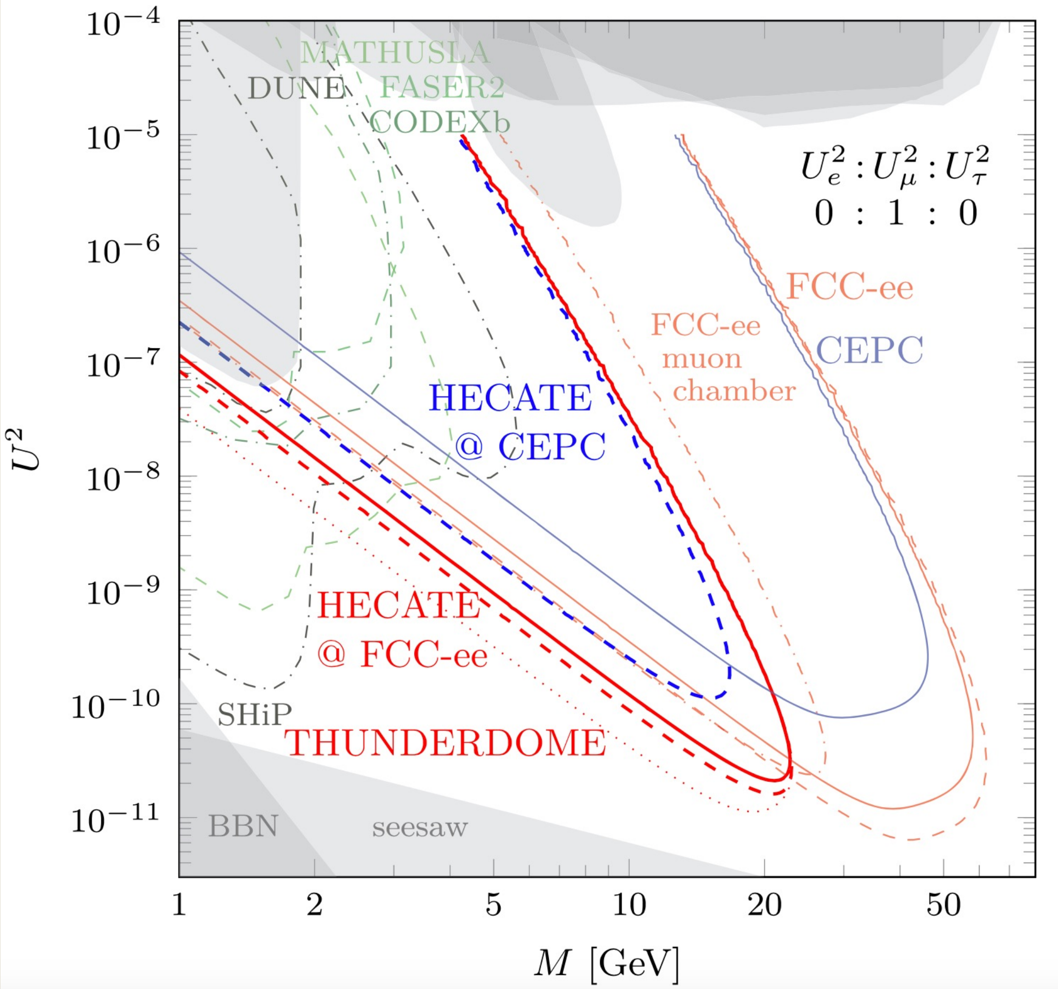


Simple shape: cuboid, similar to MATHUSLA
Varying: position & geometry size

HErmetic CAvern TrackEr (**HECATE**)

HNL: $Z \rightarrow N\nu$ @ $\sqrt{s} = 91.2$ GeV

[**2011.01005, Marcin Chrzaszcz, Marco Drewes, and Jan Hajer**, HECATE: A long-lived particle detector concept for the FCC-ee or CEPC]



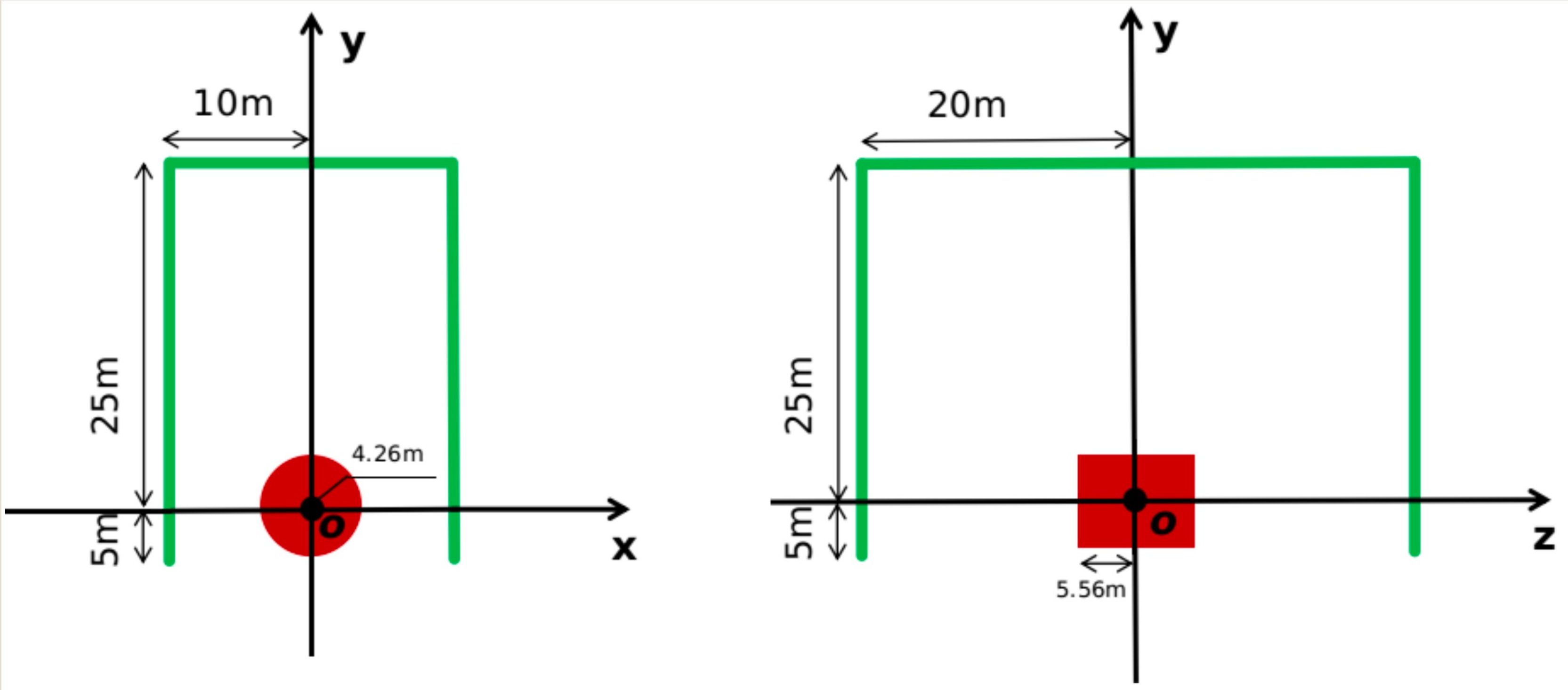
the HECATE detector would consist of resistive plate chambers (RPCs) or scintillator plates, constructed from extruded scintillating bars, located around the cavern walls and forming a 4π detector.

the HECATE detector should have at least two layers of detector material separated by a sizable distance. For reliable tracking, at least four layers, along with a smaller size and/or optimised geometry of the detector plates, would be required.

Fig. 1 Comparison of the sensitivities for nine signal events that can be achieved at the FCC-ee with 2.5×10^{12} Z-bosons (red) or CEPC with 3.5×10^{11} Z-bosons (blue). The faint solid curves show the main detector sensitivity ($l_0 = 5\,\text{mm}, l_1 = 1.22\,\text{m}$). The faint dash-dotted curve indicates the additional gain if the muon chambers are used at the FCC-ee ($l_0 = 1.22\,\text{m}, l_1 = 4\,\text{m}$). The thick curves show the sensitivity of HECATE with $l_0 = 4\,\text{m}, l_1 = 15\,\text{m}$ (solid) and $l_0 = 4\,\text{m}, l_1 = 25\,\text{m}$ (dashed), respectively. Finally, the faint dashed red line shows the FCC-ee main detector sensitivity with 5×10^{12} Z-bosons, corresponding to the luminosity at two IPs. For comparison we indicate the expected

LAYered CAvern Surface Tracker (**LAYCAST**)

[**2406.05770, Ye Lu, Ying-nan Mao, Kechen Wang, Zeren Simon Wang**, LAYCAST : LAYered CAvern Surface Tracker at future electron-positron colliders]



Red – ND

Green – FD

→ scintillating planes hanging from the roof and four vertical walls of the experimental hall

→ Detect LLP decaying in the space region between the outer edge of the ND and the FD.

Number of Signal Events

$$N_{\text{exp}} = N_{\text{pro}} \cdot P \cdot \text{Br} \cdot \epsilon$$

Number of LLPs produced

Probability of decaying inside the detector's fiducial volume

Branching ratio of LLP decaying into visible final state

Detector efficiency

Expected number of signal events:
depends on **theory model parameters** (mass, lifetime, kinematics) & **geometry** and **performance of detector** (position, shape, volume, efficiency)

Theoretical model

[**1911.06576, Zeren Simon Wang and Kechen Wang**, Physics with far detectors at future lepton colliders]

scenario		$h \to XX$ (Exotic Higgs Decays)	$Z \to N\nu$ (Heavy Neutral Leptons)	$Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ (Light Neutralinos in RPV SUSY)
LLP		X light scalar	N	$\tilde{\chi}_1^0$ light fermion
production $e^- e^+ \to$		Zh (main) $\nu\bar{\nu}h, e^- e^+ h$ (VBF)	Z	
$\sqrt{s}$ [GeV]		240	91.2	
N_h	CEPC FCC-ee	1.14×10^6 [16] 5.6 ab^{-1}, 7 years, 2 IPs	-	
N_Z	CEPC	-	7.0×10^{11} [16] (has been updated to 1.5×10^{12}) — **16 ab^{-1}**, 2 years, 2 IPs	
	FCC-ee		5.0×10^{12} [20] — **150 ab^{-1}**, 4 years, 2 IPs	

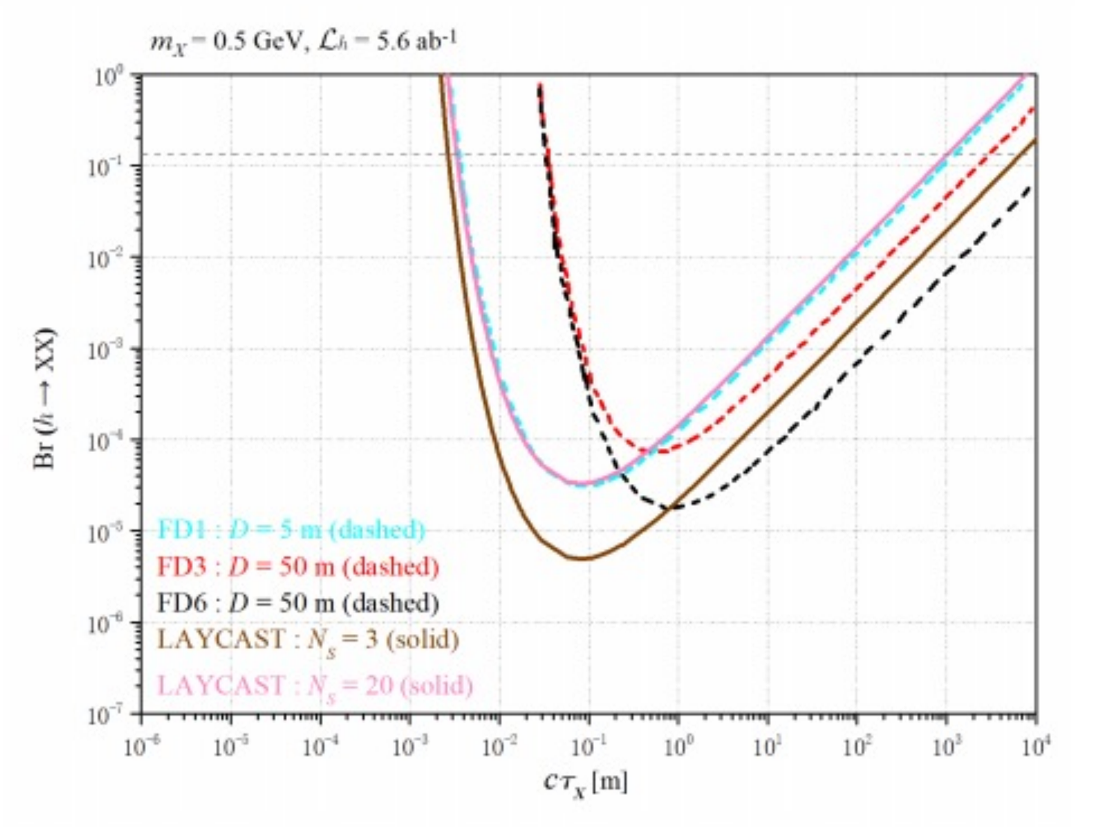
Axion like particles: $e^-e^+ \to \gamma\, a,\ a \to \gamma\gamma$ @ $\sqrt{s} = 91.2$ GeV

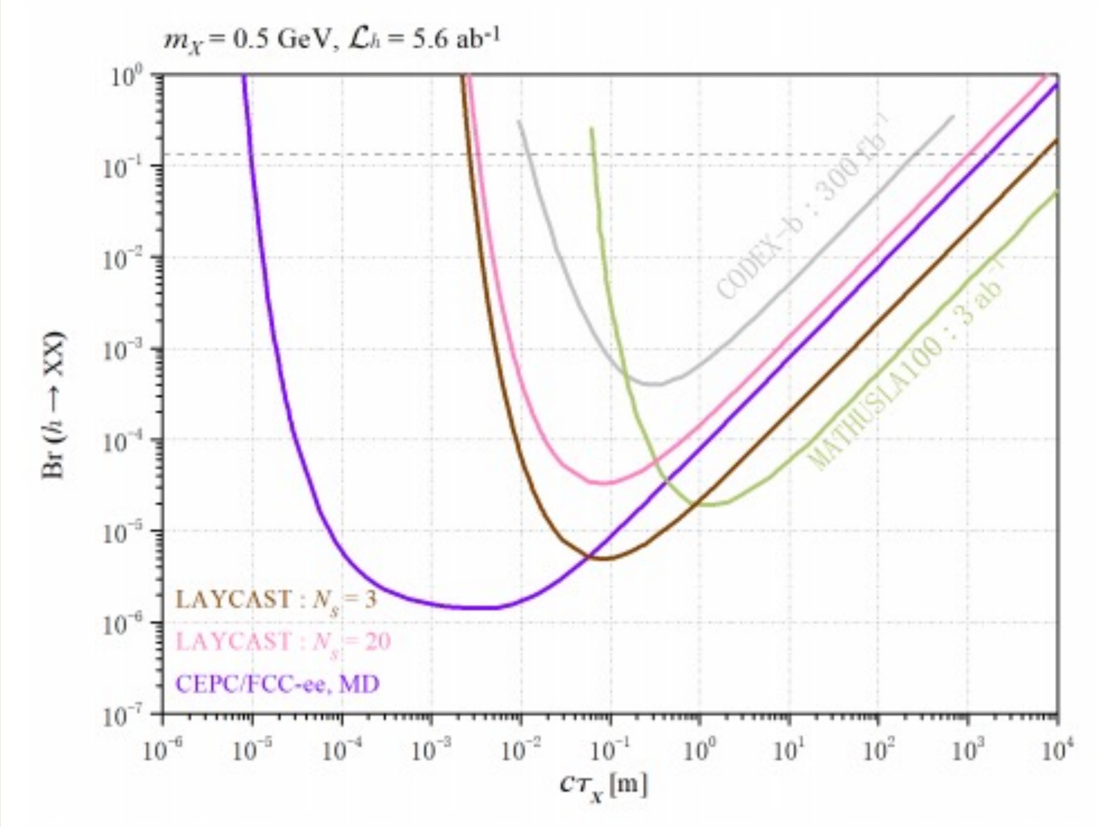
[**2201.0896, Minglun Tian, Zeren Simon Wang and Kechen Wang**, Search for long-lived axions with far detectors at future lepton colliders]

Results

Higgs decays: $h \to XX$ @ $\sqrt{s} = 240$ GeV

[**2406.05770, Ye Lu, Ying-nan Mao, Kechen Wang, Zeren Simon Wang**, LAYCAST : LAYered CAvern Surface Tracker at future electron-positron colliders]





→ 3-signal-event sensitivity of LAYCAST is better than that of FD1
→ 20-signal-event sensitivity of LAYCAST is similar to that of FD1

→ 3-signal-event sensitivity of LAYCAST can probe additional parameter space compared with the ND.

Results

HNL: $Z \rightarrow N\nu$ @ $\sqrt{s} = 91.2$ GeV

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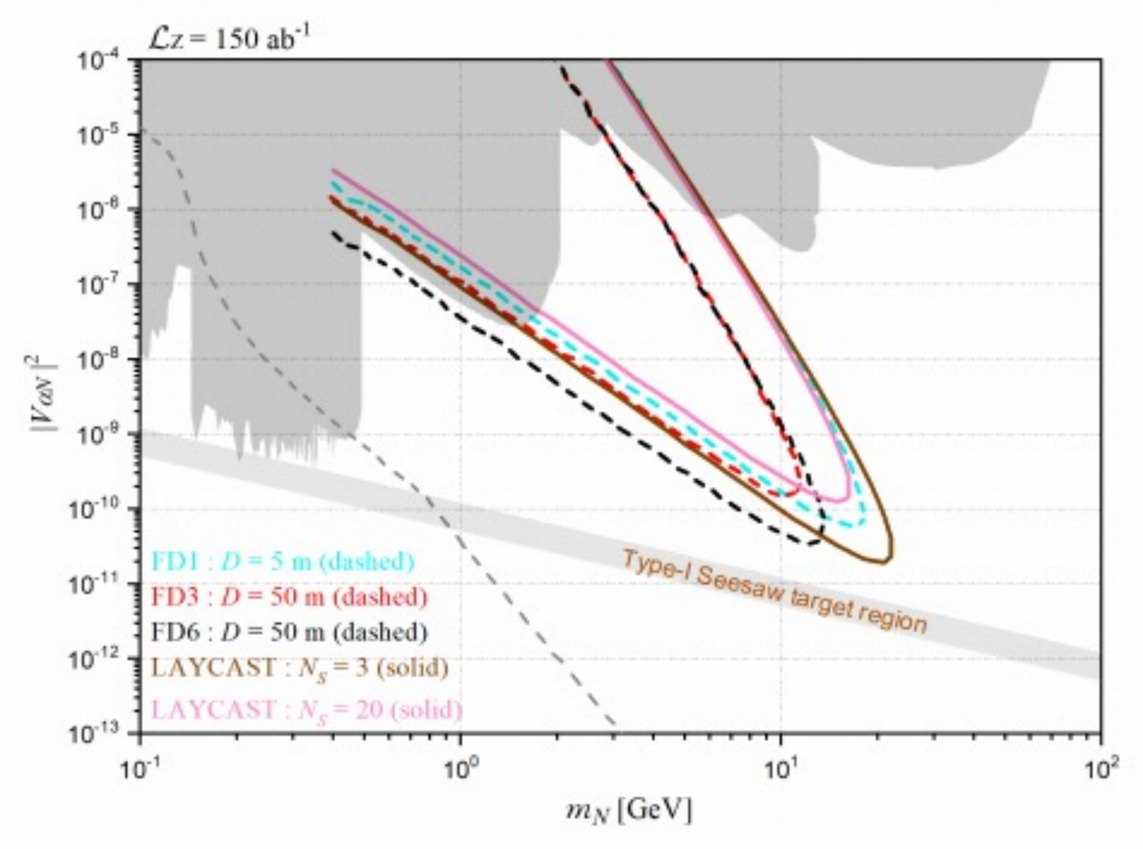

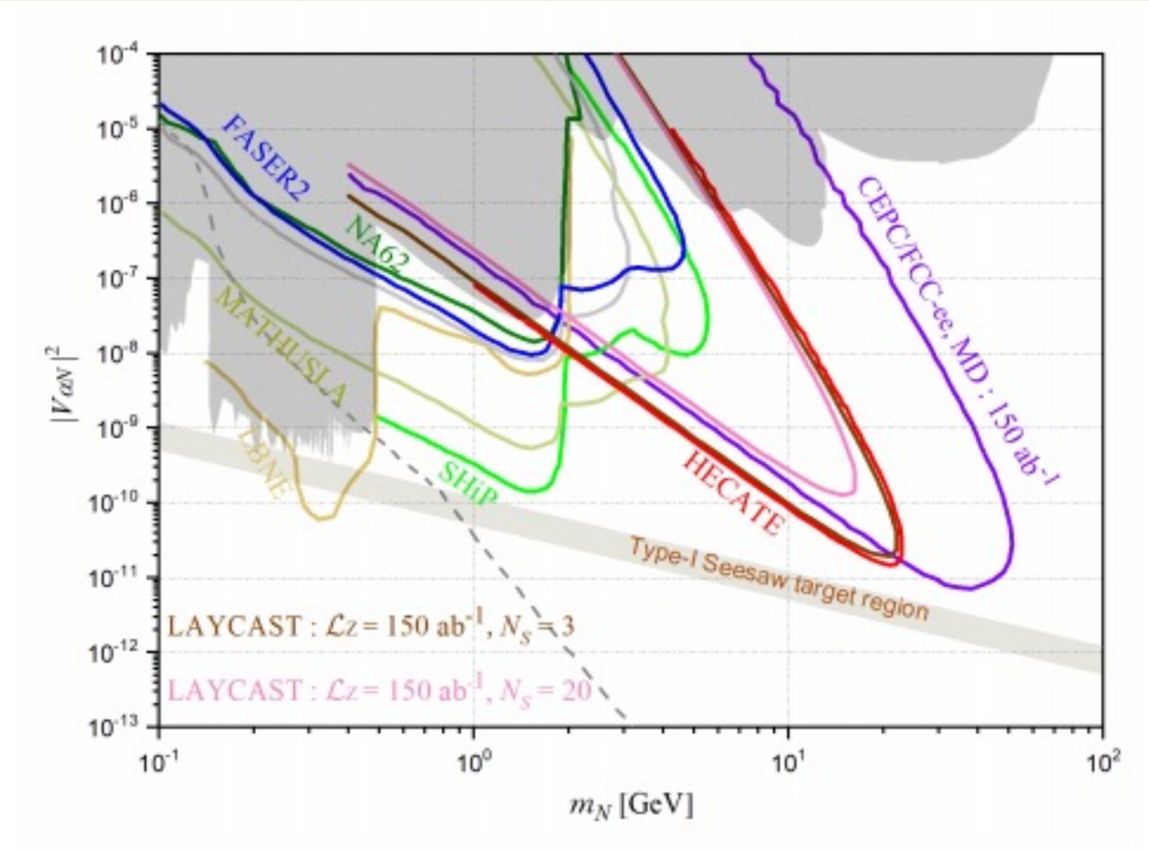

Results

RPV-SUSY neutralinos: $Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ @ $\sqrt{s} = 91.2$ GeV

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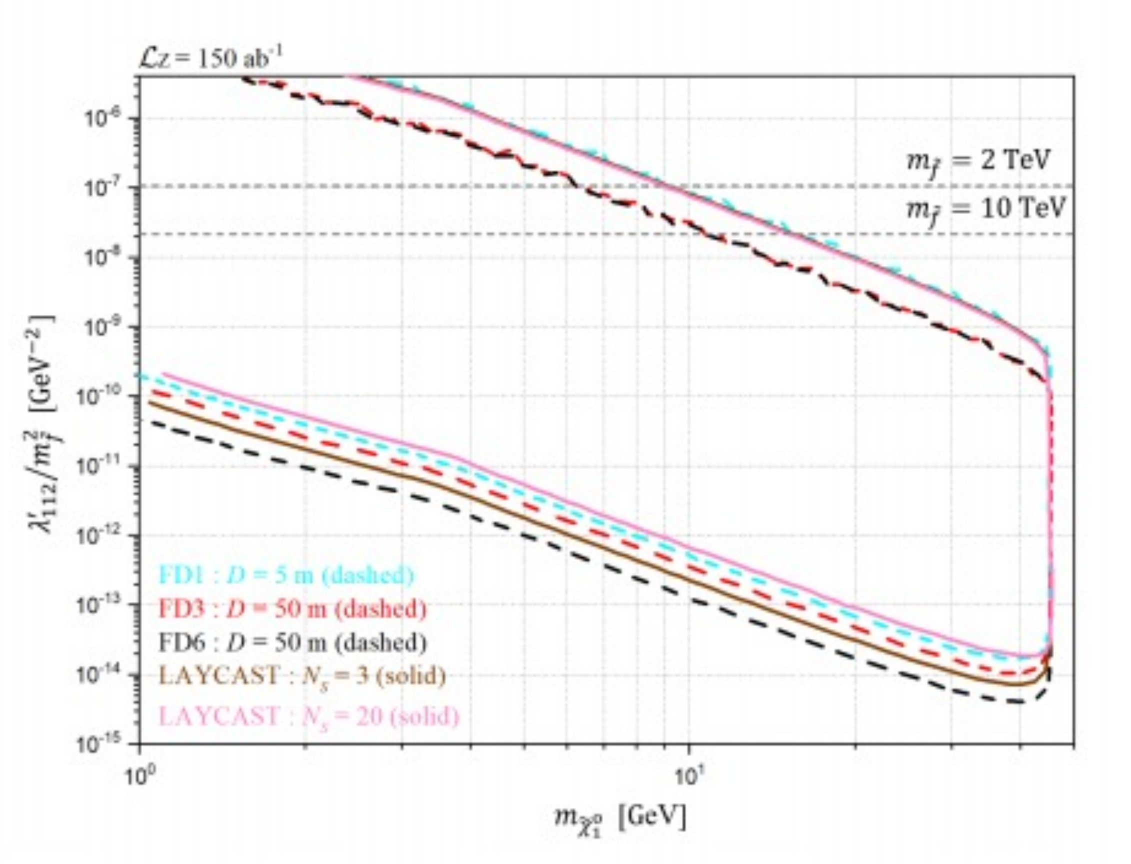

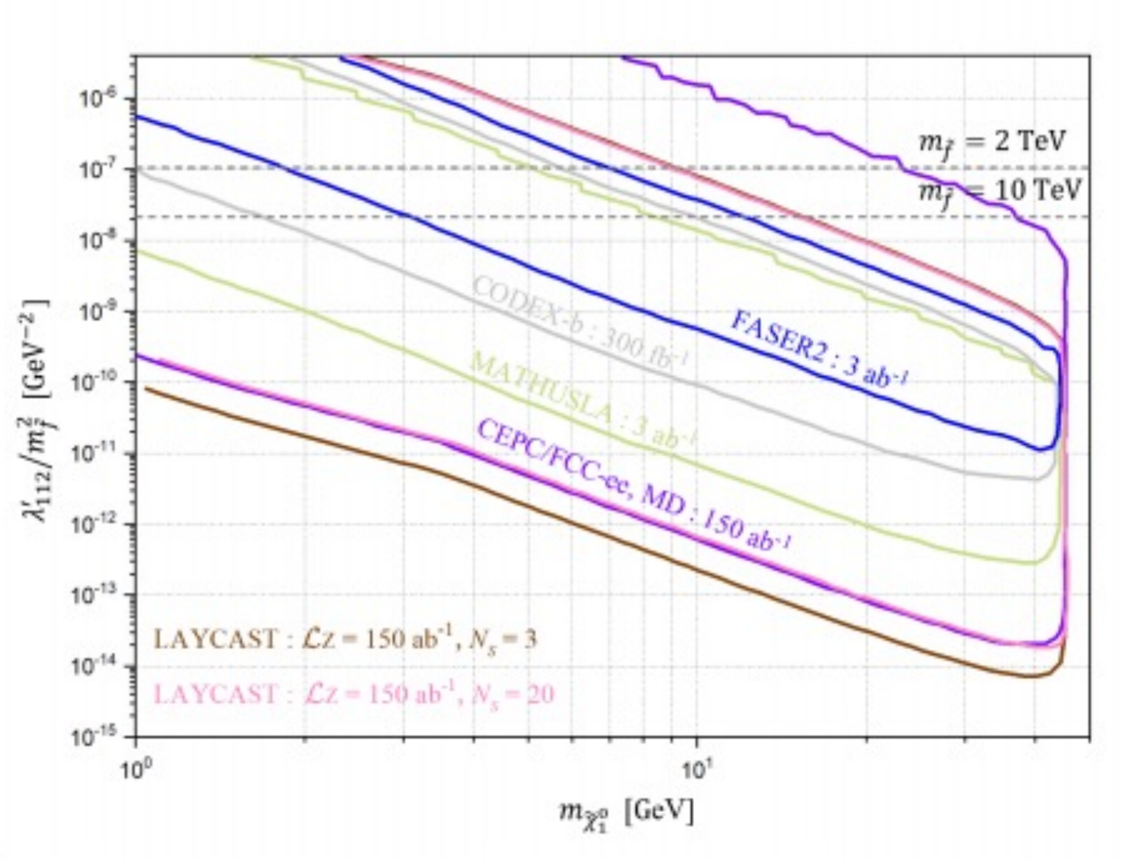

Results

Axion like particles: $e^-e^+ \to \gamma\, a,\ a \to \gamma\gamma$ @ $\sqrt{s} = 91.2$ GeV

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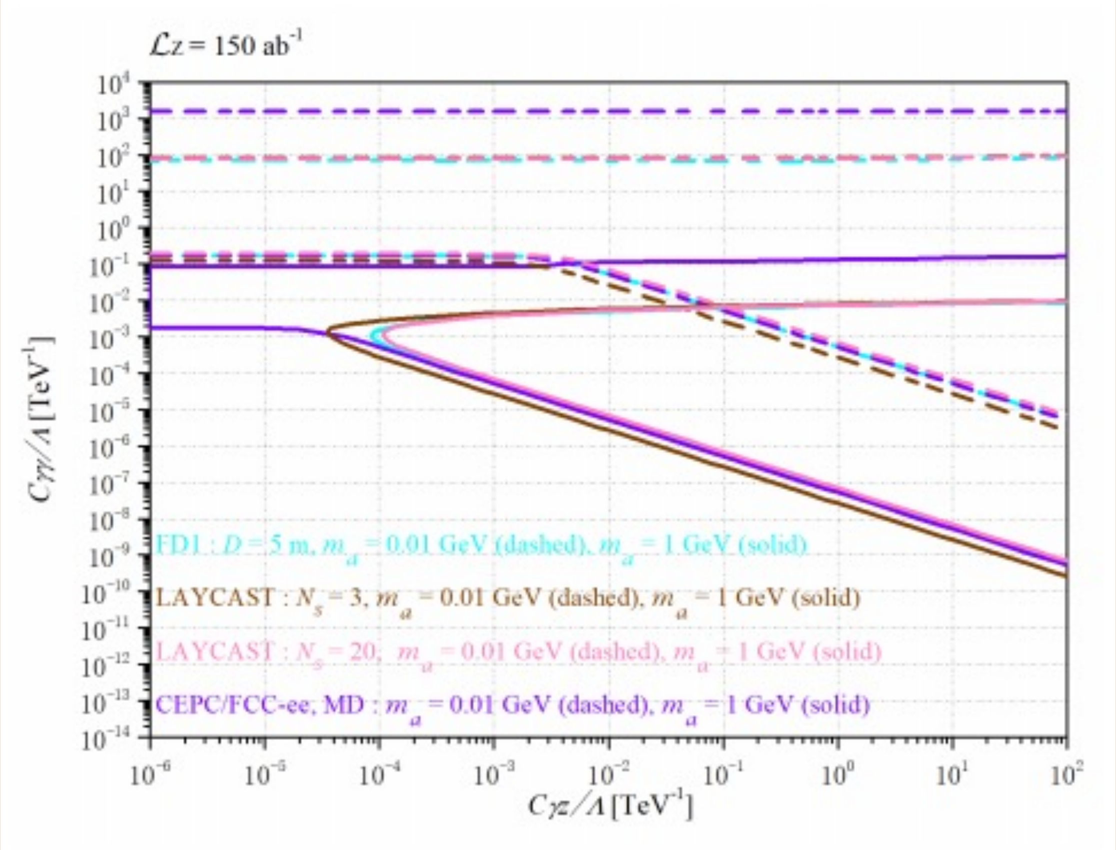

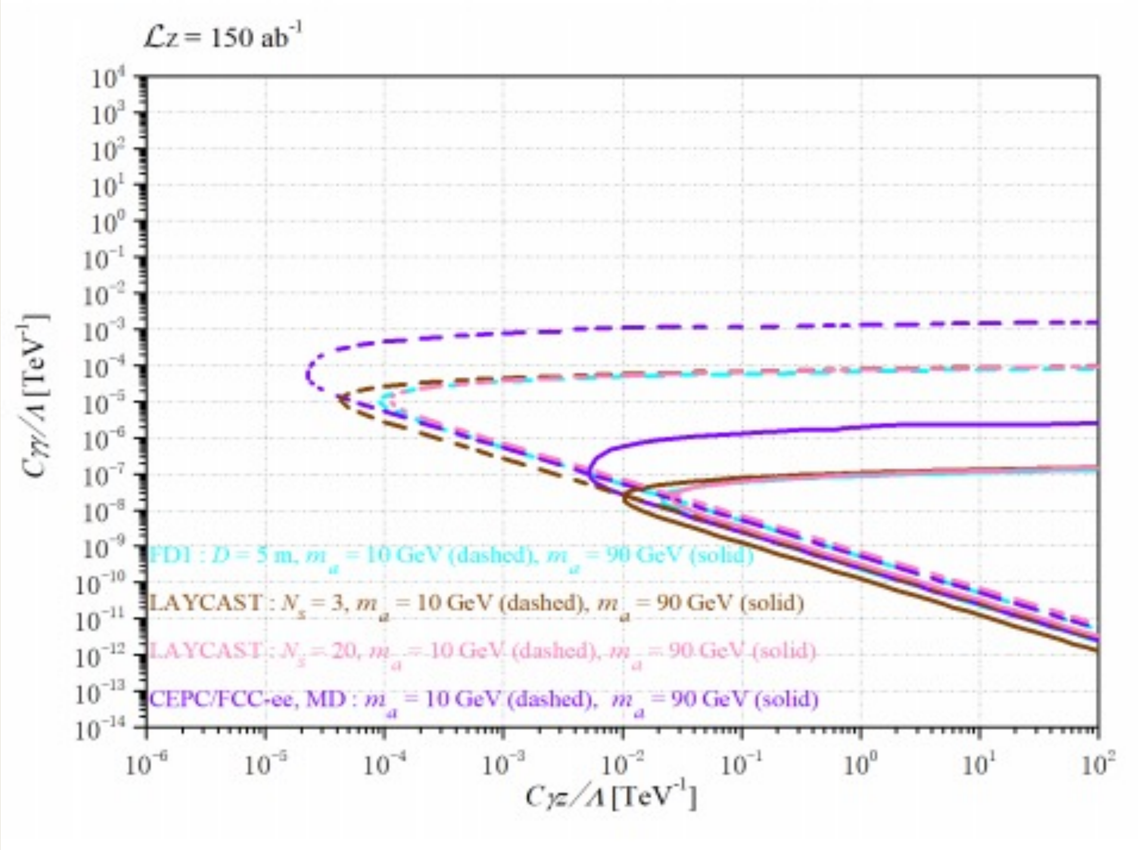

Effects of varying the cavern geometries

Higgs decays: $h \to XX$ @ $\sqrt{s} = 240$ GeV

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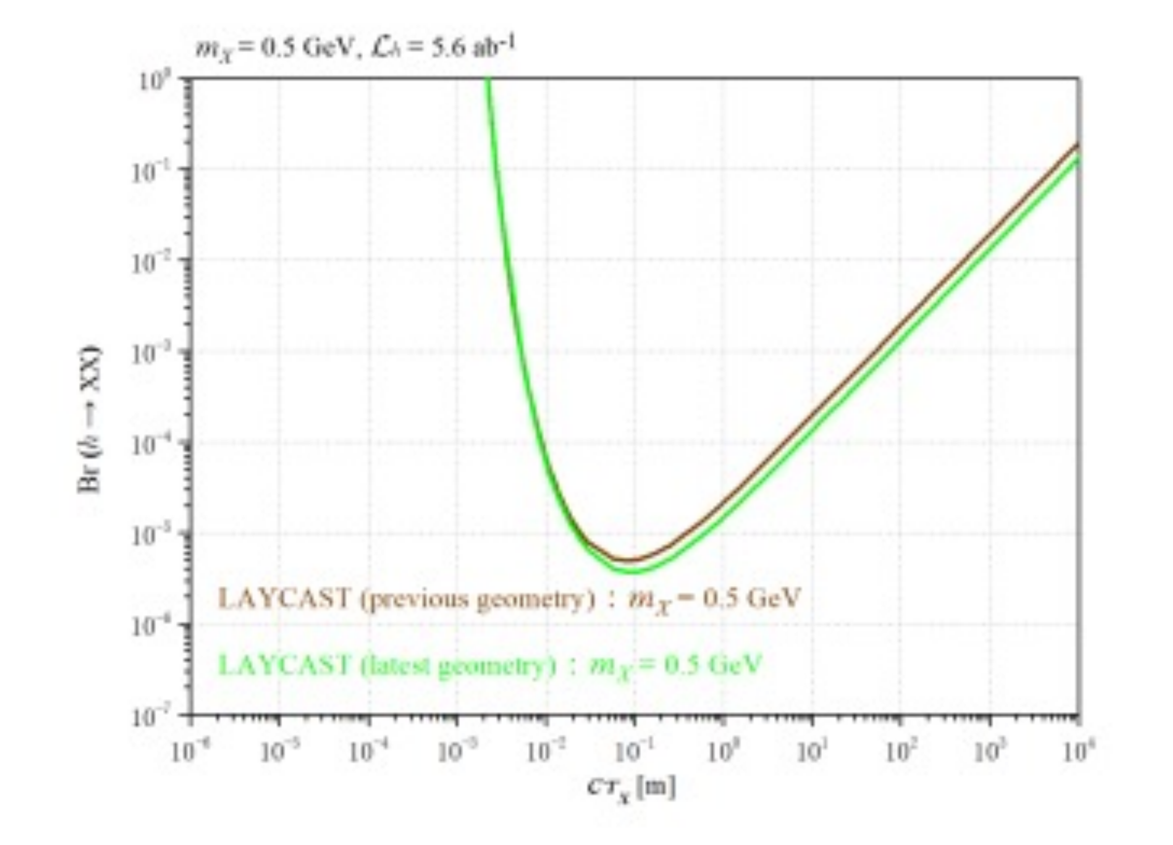


Previous geometry (L×W×H) :

$40\text{ m} \times 20\text{ m} \times 30\text{ m} = 2.4 \times 10^4\text{ m}^3$

Latest geometry (L×W×H) :

$50\text{ m} \times 30\text{ m} \times 30\text{ m} = 4.5 \times 10^4\text{ m}^3$

[J. Gao, CEPC Accelerator Overall Status: https://indico.cern.ch/event/820586/contributions/3511478/attachments/1908468/3152728/CEPC_ Accelerator_Overall_Status-V2.pdf , 2019.]

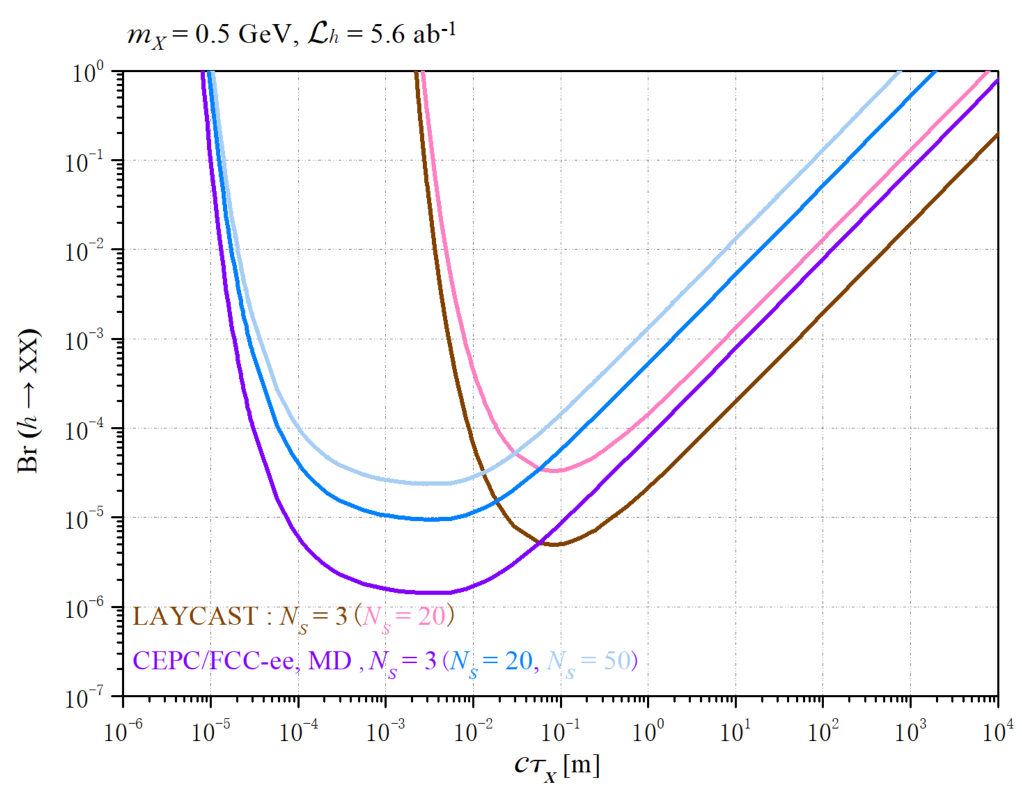
[CEPC Study Group, W. Abdallah et al., CEPC Technical Design Report – Accelerator (v2), (2023), arXiv:2312.14363, IHEP-CEPC-DR-2023-01, IHEP-AC-2023-01]

Discussion on the number of signal events

[**2406.05770, Ye Lu, Ying-nan Mao, Kechen Wang, Zeren Simon Wang**, LAYCAST : LAYered CAvern Surface Tracker at future electron-positron colliders]

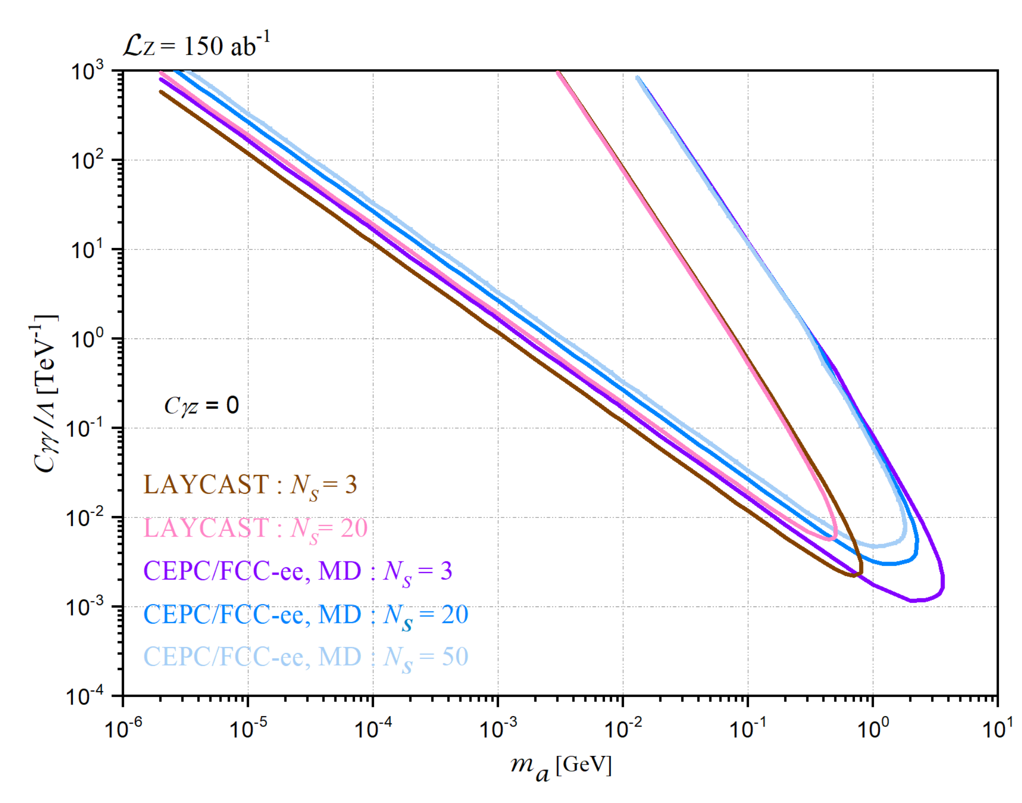
Higgs decays:

$h \to XX$ @ $\sqrt{s} = 240$ GeV



Axion like particles:

$e^- e^+ \to \gamma\, a,\ a \to \gamma\gamma$ @ $\sqrt{s} = 91.2$ GeV



effects of the background events: 95% C.L. : N_s = 3, 20, 50 ←→ N_b ~ 0, 100, 625

Effects of adding the cavern floor

Axion like particles: $e^- e^+ \to \gamma\, a,\;\; a \to \gamma\gamma$ @ $\sqrt{s} = 91.2$ GeV

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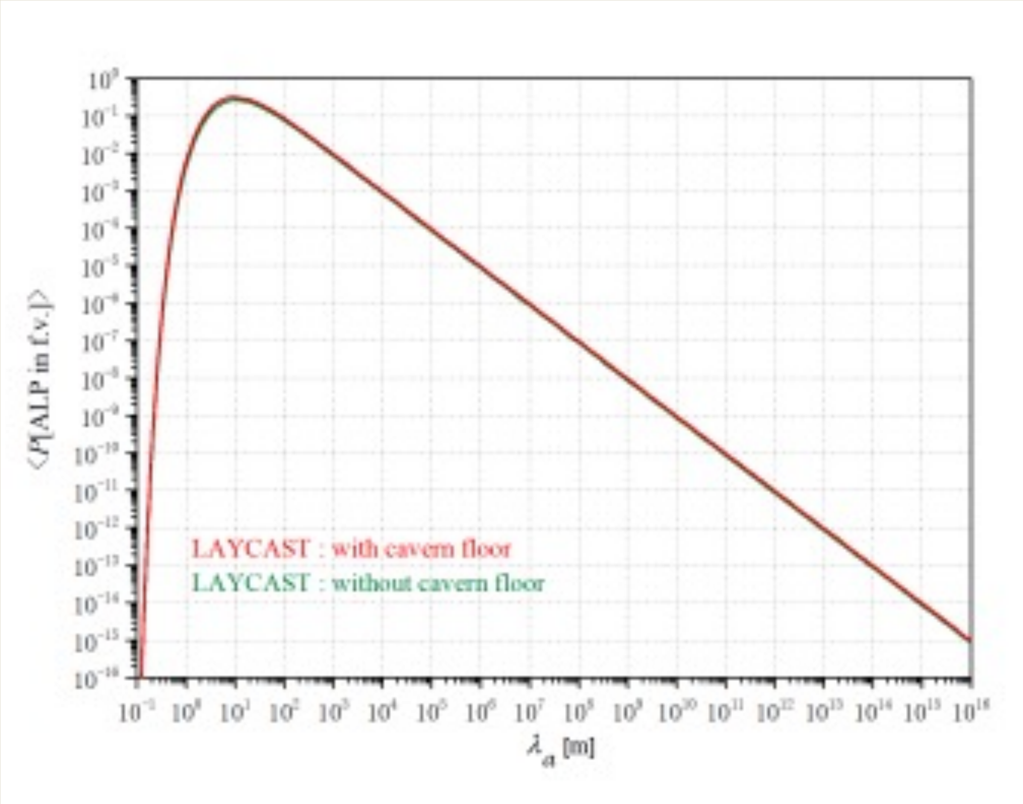

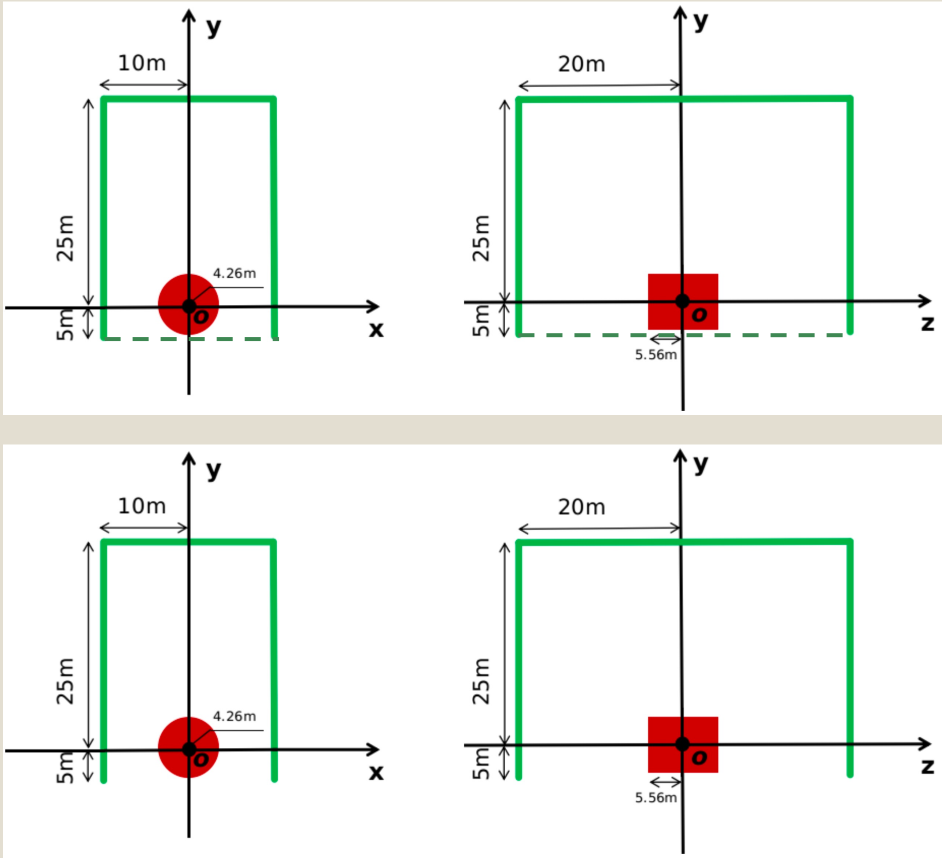

Summary & Discussion

LLPs searches @ ee colliders have **unique characteristics** (high lum., clean environment, transverse direction, recoil strategy) and are important ways to BSM physics.

The search for long-lived particles can be aided by the design of suitable detectors, such as Far Detectors.

Studies with proposed detector - LAYCAST
→ Different designs
→ Higgs decays, HNL, SUSY, ALP, ...

More issues
→ optimization: detector material & design with low cost ?
→ more LLP theory models ...

Thank you for your listening!