HADES

[2011.01005]

A long lived particle detector concept for the FCC-ee or CEPC

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Long-lived particles (LLPs)

Portals to hidden sectors

- Many extension to the SM feature hidden sectors
- A key signature of such models are LLPs
- Right handed neutrinos are a prime example

Minimal SM extension with heavy neutral leptons (HNLs)

$$\mathcal{L}_{\nu_R} = -y_{ai}\bar{\ell}_a \varepsilon \phi \nu_{Ri} - \frac{1}{2}\overline{\nu^c_{Ri}} M_{ij} \nu_{Rj} + \text{h.c.}$$

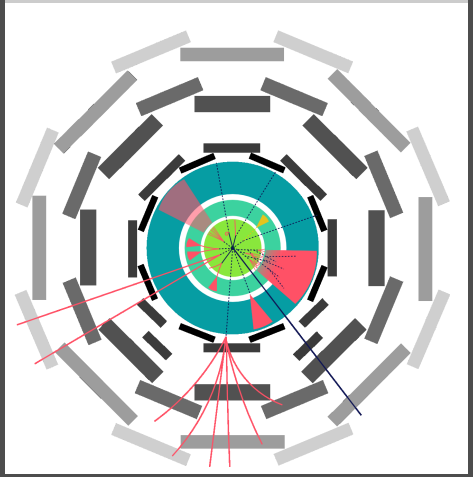
Interaction with heavy bosons of the SM

$$\mathcal{L} \supset -\frac{m_W}{v}\overline{N}\theta^*_a \gamma^\mu e_{La} W^+_\mu - \frac{m_Z}{\sqrt{2}v}\overline{N}\theta^*_a \gamma^\mu \nu_{La} Z_\mu - \frac{M}{v}\theta_a h \overline{\nu_{L\alpha}} N + \text{h.c.}$$

Search strategy

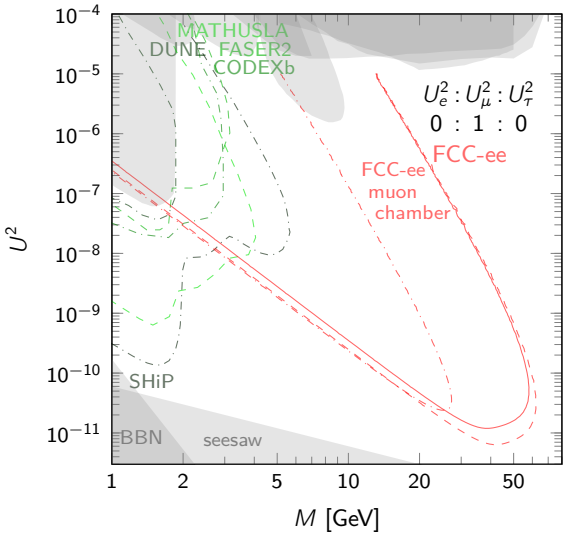
Based on appearing tracks and displaced vertices

LLP signatures [1903.04497]



Sensitivity for HNLs at future electron colliders (9 events)

FCC-ee



$2.5 \cdot 10^{12}$ Z-bosons

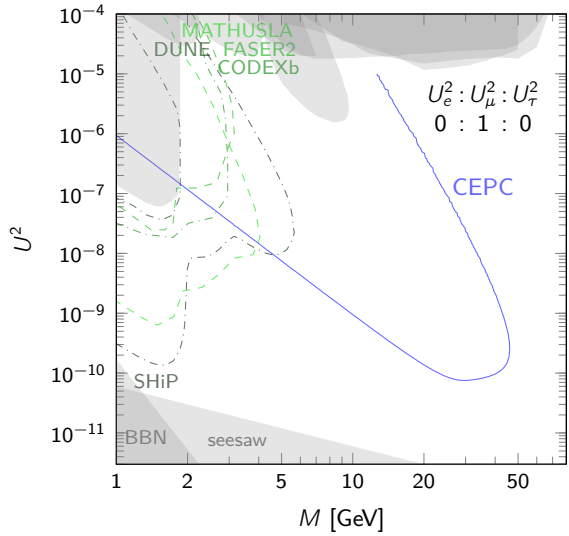
— main detector ($l_0 = 5\,\text{mm}$, $l_1 = 1.22\,\text{m}$)

-·- muon chambers ($l_0 = 1.22\,\text{m}$, $l_1 = 4\,\text{m}$)

$5 \cdot 10^{12}$ Z-bosons

- - - main detector

CEPC



$3.5 \cdot 10^{11}$ Z-bosons

— main detector ($l_0 = 5\,\text{mm}$, $l_1 = 1.22\,\text{m}$)

Sensitivity scaling for HNL in displaced detectors

1 dim estimate for number of observed events

$$N_{\text{obs}} \simeq L\sigma_N \left[\exp\left(-\frac{l_0}{\lambda_N}\right) - \exp\left(-\frac{l_1}{\lambda_N}\right)\right]$$

- $\lambda_N = \dfrac{\beta\gamma}{\Gamma_N}$ $\qquad \Gamma_N \simeq 12\dfrac{U^2 M^5 G_F^2}{96\pi^3}$
- $\beta\gamma \simeq \dfrac{m_Z^2 - M^2}{2 m_Z M}$ $\qquad$ (Z-boson at rest)

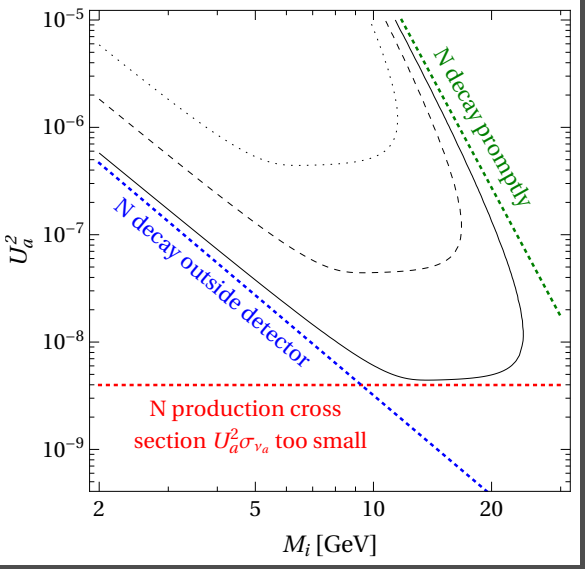
For $\lambda \gg l_1 \gg l_0$

$$N_{\text{obs}} \propto L U^4 \frac{M^5 l_1}{\beta\gamma}$$

For fixed mass and number of observed events

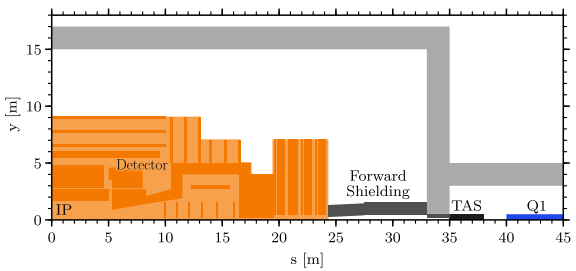
$$U^2 \propto \frac{1}{\sqrt{l_1}} \propto \frac{1}{\sqrt{L}}$$

HNL sensitivity contours [1903.06100]

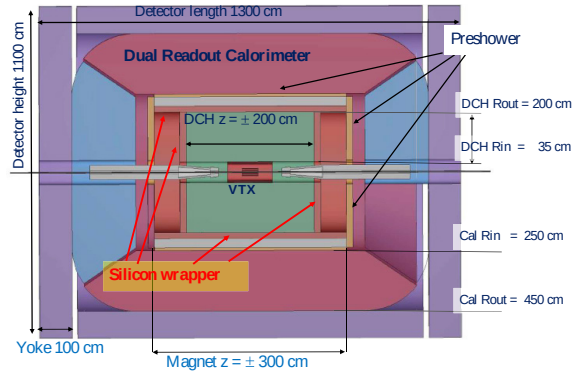


FCC cavern and detector layout

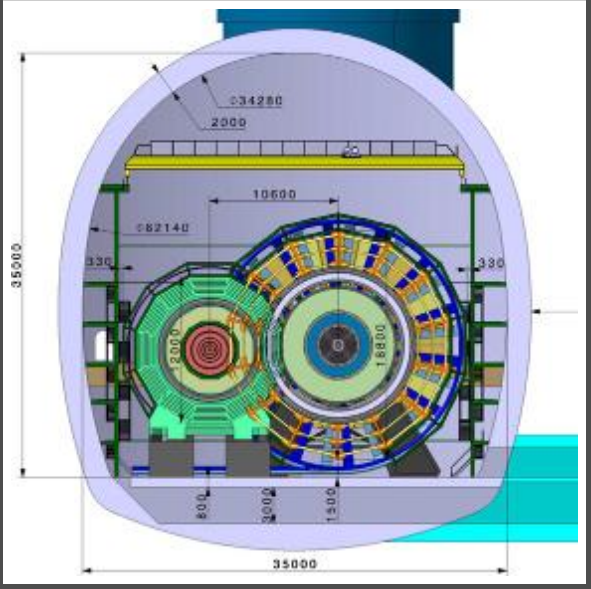
FCC caverns [FCC-hh 2019]



FCC-ee IDEA detector [FCC-ee 2019]



FCC-ee CLD *vs.* FCC-hh detector [FCC-ee 2019]



Comparison

- Cavern size: $r = 15\,\text{m}$, $z \simeq 50\,\text{m}$
- Detector size: $\mathcal{O}(10\,\text{m})$

Proposal: *HAdron-collider-cavern DEtector System (HADES)*

Idea

- Exploit the additional space surrounding the FCC-ee detectors in the FCC-hh caverns
- Build a 4π LLP detector

Layout

- ***Cover the cavern surface with $1\,\mathrm{m}^2$ scintilator plates***
- Assuming cylindrical caverns with $r = 15\,\mathrm{m}$ and $z \simeq 50\,\mathrm{m}$
- Results in $\sim$6000 readout channels
- Minimum of two layers allows for timing
- Main detector serves as veto

Sensitivity calculation for spherical detector

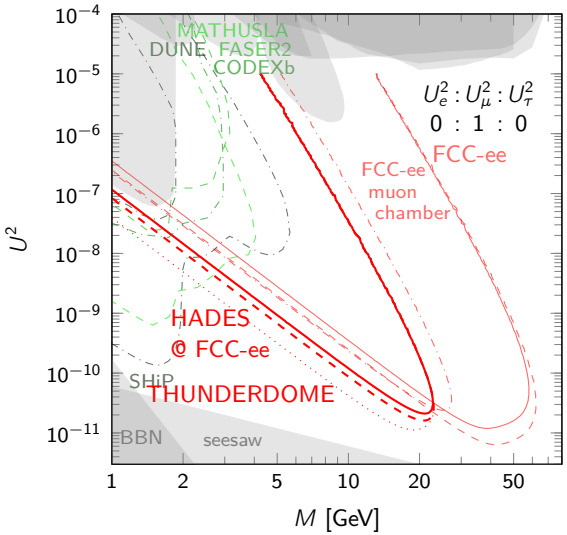
U^2 sensitivity gain $\propto \sqrt{\frac{l_1}{1.22\,\mathrm{m}}}$ where $l_1 = 15$–$25\,\mathrm{m}$

Totally Hyper-UNrealistic DEtectoR in a huge DOME (THUNDERDOME)

Extremely expensive huge cavern with $l_1 = 100\,\mathrm{m}$ for comparison

Sensitivity of HADES to HNLs

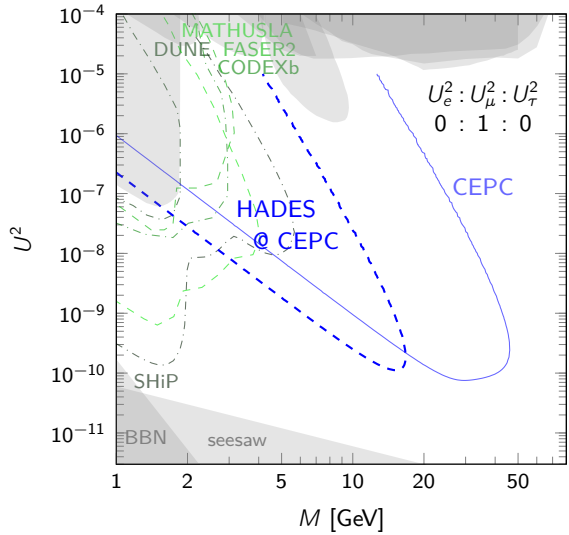
HADES @ FCC



HADES
- $l_0 = 4\,\text{m},\ l_1 = 15\,\text{m}$
- $l_0 = 4\,\text{m},\ l_1 = 25\,\text{m}$

THUNDERDOME (very unrealistic)
- $l_0 = 4\,\text{m},\ l_1 = 100\,\text{m}$

HADES @ CEPC



HADES
- $l_0 = 4\,\text{m},\ l_1 = 25\,\text{m}$

All efficiencies assumed to be 100 %

Half a magnitude sensitivity gain in U^2

Costs

Scintillator

- EJ-200 scintillator (long optical attenuation length, fast timing)
- Single panel with thickness of 1 cm cost around 500 CHF
- Total cost of 3–5 MCHF
- Cheaper alternatives would reduced cost significantly

Readout electronics together with the clear and wave-shifting fibers

- Estimated based on Sci-Fi detector from LHCb [LHCb 2014]
- Cost per channel around 30 CHF
- Total cost around 200 kCHF

Total

- Cost is dominated by scintillators
- ***Cost for two layers lies below 10 MCHF***
- At FCC-ee construction time cheaper and better technology should be available

Conclusion

- Long-lived particles provide promising signatures for hidden sector extension to the SM
- HADES could fill a gap between the FCC main detectors and other dedicated experiments
- The costs would be of order of ten million Swiss franc

References

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