

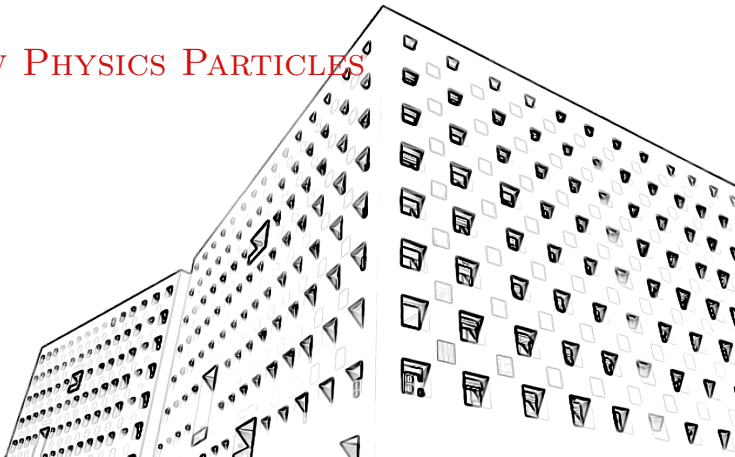


# CONSTRAINTS ON NEW PHYSICS PARTICLES

Zhijie Zhao

zhao@physik.uni-siegen.de

February 9, 2026





# Table of Contents

## 1 Vector-Like Lepton

► Vector-Like Lepton

► Long-Lived Charged Lepton

►  $W', Z'$

►  $H^\pm$

►  $H^{\pm\pm}$



# Vector-Like Lepton

## 1 Vector-Like Lepton

**Table:** Current experimental limits ( $E_{cm} = 13$  TeV,  $\mathcal{L} = 140 \text{ fb}^{-1}$ ) on VLL.

Process	Decay	Constraint (VLL)	Arxiv
$\tau'^+ \tau'^-$	$\tau' \rightarrow \tau a_\tau \rightarrow \tau \gamma \gamma$	0 – 700 GeV	2503.16699
$e'^+ e'^-, e' N, NN$	$e' \rightarrow Z(H)e, N \rightarrow W \ell$	0 – 1220 GeV	2411.07143
$\mu'^+ \mu'^-, \mu' N, NN$	$\mu' \rightarrow Z(H)\mu, N \rightarrow W \ell$	0 – 1270 GeV	2411.07143



# Vector-Like Lepton

## 1 Vector-Like Lepton

VLLs are non-chiral, which means that their left- and right-handed components have same gauge charges. The motivations of VLL:

- Hierarchy problem
- Muon  $g - 2$
- Dark matter
- Vacuum stability
- Flavor and mass hierarchy



# Why $\tau' \rightarrow \tau a_\tau$ ? (arXiv:2304.08509)

1 Vector-Like Lepton

- This model is renormalizable and includes only two new fields: a Dirac fermion  $\mathcal{E}$  and a complex scalar  $\phi$ .
- The  $a_\tau$  is long-lived particle, which leads to deposits in the muon systems.
- Violation of lepton universality from pion decays gives strong limits on the mixing of VLL with  $e^\pm$  and  $\mu^\pm$ .



# Why $\tau' \rightarrow \tau a_\tau$ ? (arXiv:2304.08509)

1 Vector-Like Lepton

The complex scalar can be written as

$$\phi = \left( v_\phi + \frac{1}{\sqrt{2}} \varphi \right) e^{ia_\tau/(\sqrt{2}v_\phi)}$$

$v_\phi$  is the vacuum expectation value, which can be much larger than the mass of  $a_\tau$ .  $\varphi_\tau$  is a CP-even scalar with mass of the order of  $v_\phi$ . The most general Yukawa couplings can be written as

$$- \begin{pmatrix} \bar{e}_L^3 & \bar{\mathcal{E}}_L \end{pmatrix} \begin{pmatrix} y_3 \left( v_H + \frac{h^0}{\sqrt{2}} \right) & 0 \\ m_o + \frac{y_o e^{i\beta_o}}{\sqrt{2}} (\varphi_\tau + ia_\tau) & m_{\mathcal{E}} + \frac{y_{\mathcal{E}} e^{i\beta_{\mathcal{E}}}}{\sqrt{2}} (\varphi_\tau + ia_\tau) \end{pmatrix} \begin{pmatrix} e_R^3 \\ \mathcal{E}_R \end{pmatrix} + \text{h.c.}$$



# Table of Contents

## 2 Long-Lived Charged Lepton

► Vector-Like Lepton

► Long-Lived Charged Lepton

►  $W', Z'$

►  $H^\pm$

►  $H^{\pm\pm}$



# Long-Lived Charged Lepton

## 2 Long-Lived Charged Lepton

**Table:** Current experimental limits ( $E_{cm} = 13$  TeV,  $\mathcal{L} = 140$  fb $^{-1}$ ) on Long-lived charged Lepton.

Process	Decay	Constraint (LLP)	Arxiv
$\tau'^+ \tau'^-$	$\tau' \rightarrow \tau \tilde{G}$	200 – 560 GeV	2502.06694





# Table of Contents

## 3 $W'$ , $Z'$

- ▶ Vector-Like Lepton
- ▶ Long-Lived Charged Lepton
- ▶  $W'$ ,  $Z'$
- ▶  $H^\pm$
- ▶  $H^{\pm\pm}$



$$W', Z'$$

$$3 W', Z'$$

**Table:** Current most stringent experimental limits ( $E_{cm} = 13$  TeV,  $\mathcal{L} = 139 \text{ fb}^{-1}$ )

Process	Decay	Constraint	ArXiv Number
$pp \rightarrow W'$	$W' \rightarrow \ell \nu$	$0.15 - 7 \text{ TeV}$	1906.05609, 2202.06075
$pp \rightarrow Z'$	$Z' \rightarrow \ell \ell$	$0 - 5 \text{ TeV}$	1903.06248, 2103.02708
$pp \rightarrow W'/Z'$	$V' \rightarrow WH/WZ/ff$	$0 - 5.5 \text{ TeV}$	2601.12583



# Table of Contents

4  $H^\pm$

- ▶ Vector-Like Lepton
- ▶ Long-Lived Charged Lepton
- ▶  $W', Z'$
- ▶  $H^\pm$
- ▶  $H^{\pm\pm}$



$H^\pm$   
4  $H^\pm$

**Table:** Current most stringent experimental limits ( $E_{cm} = 13$  TeV,  $\mathcal{L} = 139$  fb $^{-1}$ )

Process	Decay	Constraint	ArXiv Number
$pp \rightarrow H^\pm jj$	$H^\pm \rightarrow WZ$	0.2 – 1.5 TeV	2407.10798
$pp \rightarrow H^\pm$	$H^\pm \rightarrow W\gamma$	0.3 – 2.0 TeV	2406.05737
$t \rightarrow H^\pm b$	$H^\pm \rightarrow Wa, a \rightarrow \mu\mu$	120 – 160 GeV	2304.14247
$t \rightarrow H^\pm b$	$H^\pm \rightarrow cb$	60 – 160 GeV	2302.11739
$pp \rightarrow tbH^\pm$	$H^\pm \rightarrow tb$	200-2000 GeV	2102.10076
$pp \rightarrow tbH^\pm$	$H^\pm \rightarrow Wh$	230-3000 GeV	2411.03969
$pp \rightarrow WbH^\pm b$	$H^\pm \rightarrow \tau\nu_\tau$	80-3000 GeV	2412.17584



# Table of Contents

5  $H^{\pm\pm}$

- ▶ Vector-Like Lepton
- ▶ Long-Lived Charged Lepton
- ▶  $W', Z'$
- ▶  $H^\pm$
- ▶  $H^{\pm\pm}$



$H^{\pm\pm}$   
5  $H^{\pm\pm}$

**Table:** Current most stringent experimental limits ( $E_{cm} = 13$  TeV,  $\mathcal{L} = 139$  fb $^{-1}$ )

Process	Decay	Constraint	ArXiv Number
$pp \rightarrow H^{\pm\pm} jj$	$H^{\pm\pm} \rightarrow W^{\pm} W^{\pm}$	0.2 – 1.5 TeV	2407.10798
$pp \rightarrow H^{++} H^{--}$	$H^{\pm\pm} \rightarrow \ell\ell$	0 – 1.08 TeV	2211.07505



# Q&A

*Thank you for listening!*  
*Your feedback will be highly appreciated!*