# Search for Parte es

**Daniel Guerrero (Fermilab) on behalf of the CMS Collaboration XIII** International Conference on New Frontiers in Physics August 27, 2024







## Long-lived Particles: A gateway to BSM

• **SM** is an example of fundamental laws giving rise to long-lived particles (LLPs)



#### Search for Long-lived Particles in CMS

#### Daniel Guerrero (Fermilab)





# Long-lived Particles: A gateway to BSM

- **SM** is an example of fundamental laws giving rise to long-lived particles (LLPs)
- **BSM scenarios** predict new particles with sizable lifetimes  $\tau$  (small decay width I)

#### **Suppressed couplings**

e.g. Higgs portals to hidden/dark sectors



Search for Long-lived Particles in CMS

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Scale suppression (heavy virtual mediator) e.g. split-SUSY

![](_page_2_Picture_13.jpeg)

# Long-lived Particles: A gateway to BSM

- **SM** is an example of fundamental laws giving rise to long-lived particles (LLPs)
- BSM scenarios predict new particles with sizable lifetimes  $\tau$  (small decay width  $\Gamma$ )

![](_page_3_Figure_4.jpeg)

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Search for Long-lived Particles in CMS

Most BSM searches probe short-lived or stable signatures, LLP frontier is yet to be fully exploited at the LHC!

![](_page_3_Picture_12.jpeg)

![](_page_3_Picture_13.jpeg)

# **Search for LLPs in CMS**

## Program is enriched with "unconventional" searches

- Broad signatures (lifetime, charge, decays, interaction w/ detectors)
- Designed for signatures and interpreted for various benchmarks

#### Common challenges:

- Standard triggers and object reconstruction are not fully efficient
- Unconventional backgrounds (e.g. cosmic rays and rare SM processes)

#### Tailored strategies:

- Novel triggers and object reconstructions
- Innovative machine learning applications
- Today's talk focuses on recent Run-2 and Run-3 results

Other LLP searches can be found here: <u>preliminary results</u> and <u>publications</u>

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Search for Long-lived Particles in CMS

![](_page_4_Picture_14.jpeg)

![](_page_4_Picture_21.jpeg)

![](_page_4_Picture_22.jpeg)

# **Search for LLPs in CMS**

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Search for Long-lived Particles in CMS

![](_page_5_Picture_14.jpeg)

![](_page_5_Figure_15.jpeg)

![](_page_5_Figure_17.jpeg)

![](_page_5_Picture_18.jpeg)

![](_page_5_Picture_19.jpeg)

![](_page_5_Picture_20.jpeg)

# **Search for HSCPs: Overview**

#### Model independent search with broad interpretations

- Strongly interacting (e.g. gluino R-hadrons) and lepton-like (e.g.  $\tau'$ ) HSCP
- ATLAS 3.3 global excess at  $m_{\tilde{g}} =$  1.4 TeV (JHEP06(2023)158)
- Signature: Isolated high- $p_T$  track with large ionization energy losses (dE/dx) in silicon tracker
  - Backgrounds: Fake tracks, bad ionization measurement, overlapping tracks (pileup, boosted mesons)

#### Run-2 strategy

• Single muon trigger, track in silicon tracker / bin • Data-driven background model:  $10^{\circ}$ Events Ionization method 10 • Ionization discriminants:  $G_i^{Strips}$  and  $F_i^{Pixels}$ •  $G_i^{\text{Strips}}$  shape from control region ( $F_i^{\text{Pixels}} < 0.9$ ) 10 10 • Fit it to signal region data ( $F_i^{\text{Pixels}}$ >0.9) 10 (g)/α Mass method: (Data-Bh Exploits mass relation with dE/dx and momentum -7 Derive shape and normalization from control regions.

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#### Search for Long-lived Particles in CMS

![](_page_6_Figure_14.jpeg)

![](_page_6_Figure_16.jpeg)

## **Search for HSCPs: Results**

## No significant excess over background expectation

Two methods lead to similar sensitivities

#### Interpretations:

- 95% CL limits on production cross sections ( $\sigma$ )
- Total of 10 different benchmarks:
  - split SUSY:  $\tilde{g}$  and  $\tilde{t}$  R-hadrons
    - ATLAS excess corresponds to  $\sigma_{\tilde{g}\tilde{g}}=0.59$  fb
    - CMS limit:  $\sigma_{\tilde{g}\tilde{g}} < 0.32$  fb
  - GMSB  $\tilde{\tau}$ , pair-produced  $\tilde{\tau}$  ( $\tilde{\tau}_R \tilde{\tau}_R$ ,  $\tilde{\tau}_L \tilde{\tau}_L$  and  $\tilde{\tau}_L \tilde{\tau}_R$ )
  - $Z/\gamma \rightarrow \tau'^{(1e)}\tau'^{(1e)}$  and  $Z/\gamma \rightarrow \tau'^{(2e)}\tau'^{(2e)}$
  - $Z'_w \rightarrow \tau'^{(2e)} \tau'^{(2e)}$  and  $Z'_{SSM} \rightarrow \tau'^{(2e)} \tau'^{(2e)}$ 
    - Excess motivated model (2205.04473)
    - CMS limit ( $m_{ au'^{(2e)}}$  = 5 TeV,  $m_{ au'^{(2e)}}$  = 600 GeV):  $\sigma_{Z'} < 0.03$  fb

#### Search for Long-lived Particles in CMS

#### **CMS-PAS-EXO-18-002**

![](_page_7_Figure_17.jpeg)

![](_page_7_Figure_20.jpeg)

![](_page_7_Figure_21.jpeg)

![](_page_7_Picture_22.jpeg)

# Search for VLLs w/ MDS showers: Overview

### Search for vector-like leptons (VLLs) with LLP decays

- VLL singlet decays into a long-lived pseudoscalar ( $a_{\tau}$ ) and prompt  $\tau$  (JHEP06(2023)158)
- $a_{\tau}$  is very light and decays to photons
- Signature: Displaced diphoton decays + prompt  $\tau$  decays
- LLP decays in the muon system:
  - $a_{\tau}$  decays  $\rightarrow$  EM shower (like a sampling calorimeter)
  - Muon detector shower (MDS)  $\rightarrow$  large cluster of muon hits
  - Sensitive signature:
    - High cluster reconstruction efficiency (DBSCAN clustering)
    - Small background due to large shielding material
      - jet punch-through, muon brems, cosmic muons, pile-up, SM ( $K_I^0$ )
    - Used previously in CMS analyses:
      - (<u>CMS-EXO-21-008</u>, <u>CMS-EXO-22-017</u>)

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#### Search for Long-lived Particles in CMS

![](_page_8_Picture_16.jpeg)

![](_page_8_Figure_18.jpeg)

![](_page_8_Figure_27.jpeg)

- 0.9 0.8

![](_page_8_Figure_32.jpeg)

![](_page_8_Picture_33.jpeg)

# Search for VLLs w/ MDS showers: Results

### Run-2 Strategy:

- MET triggers
- At least 1 hadronic tau ( $\tau_h$ ) and 1 MDS cluster
- Categories: Barrel (DT) or Endcap (CSC) cluster
- Discriminant variable: # of hits in the cluster ( $N_{hits}$ )
- Background estimate from data
  - $N_{hits}$  shape from control region (reverting  $\tau_h$  ID cuts)
  - Normalization from fit to signal region data
- No significant excess is observed
- Interpretations:
  - Very light pseudoscalar,  $m_a = 2 \text{ GeV}$
  - 95% CL production cross section vs pseudoscalar lifetime ( $c\tau_a$ ) and VLL mass
  - VLL masses are excluded up to ~690 GeV, depending on pseudoscalar  $c\tau_a$

![](_page_9_Figure_16.jpeg)

# Search for displaced di-muons: Overview

### Inclusive search for neutral LLPs decaying to muons

- Hidden Abelian Higgs model (H  $\rightarrow Z_D Z_D, Z_D \rightarrow \mu\mu$ )
- RPV SUSY model ( $\tilde{q} \rightarrow q \tilde{\chi}_1^0, \ \tilde{\chi}_1^0 \rightarrow \mu \mu \nu$ )

#### • Signature:

- Displaced opposite-charged dimuons
- Backgrounds due to instrumentation and reconstruction mistakes

#### Run-3 strategy (2022 data)

- New dimuon trigger:
  - Lower trigger  $p_T$  and  $d_0$  thresholds  $\rightarrow$  2-4 x signal w.r.t. 2018 (Run-2)
- Muon types: STA (muon system only) and TMS (Tracker+ Muon system)
- Categories: STA-STA and TMS-TMS

#### Search for Long-lived Particles in CMS

![](_page_10_Figure_14.jpeg)

# Search for displaced di-muons: Results

![](_page_11_Figure_5.jpeg)

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#### CMS-EXO-23-014/JHEP05(2024)047)

Search for Long-lived Particles in CMS

![](_page_11_Picture_10.jpeg)

# Search for displaced dijets: Overview

![](_page_12_Picture_1.jpeg)

- **Signature:** Displaced dijets
- Run-3 strategy (2022 data)
  - Tracker-only based analysis

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efficien

Trigger

Challenging due to large QCD background

#### New Run-3 key ingredients

- Displaced dijet trigger: 5-10 x signal gain
- Improved displaced vertex (DV) reconstruction
- LLP taggers using Graph Neural Networks (GNNs)
  - $g_{displaced}$  combines displaced tracks + DVs info
  - $g_{prompt}$  combines prompt tracks info

![](_page_12_Figure_13.jpeg)

#### Search for Long-lived Particles in CMS

#### **CMS-PAS-EXO-23-013**

## Search for exotic Higgs decay to long-lived scalars (S) in hadronic final states

Η

b, d,  $\tau = f$ 

![](_page_12_Figure_19.jpeg)

![](_page_12_Picture_21.jpeg)

![](_page_12_Figure_22.jpeg)

![](_page_12_Picture_23.jpeg)

![](_page_12_Picture_24.jpeg)

# **Search for displaced dijets: Results**

## Background estimate: ABCD method

- Cuts on  $g_{displaced}$  and  $g_{prompt}$  scores
- Expected background:  $3.34 \pm 1.28$  events
- Observation: 3 data events

#### Interpretations:

- 95% CL limits on BR(H $\rightarrow$ SS), S  $\rightarrow$  bb, dd,  $\tau\tau$
- LLP mass range: 15-55 GeV
- 10 x sensitivity improvement w.r.t Run-2 results
- First-ever displaced S  $\rightarrow \tau \tau$  sensitivity for  $c\tau < 1$  m

![](_page_13_Figure_10.jpeg)

![](_page_13_Figure_12.jpeg)

#### **CMS-PAS-EXO-23-013**

![](_page_13_Figure_16.jpeg)

![](_page_13_Picture_17.jpeg)

# **Outlook to Run 3: New MDS trigger**

- Run-2 MDS analyses relied on available MET and lepton triggers
- New Run-3 L1 CSC High-Multiplicity Trigger (HMT) seed using number of hits
- New Run-3 HLT paths targeting single and double MDS clusters
- Actively collecting and analyzing Run-3 data!

![](_page_14_Figure_5.jpeg)

Trigger efficiency as function of the largest CSC cluster size ( $N_{hits}$ )

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Search for Long-lived Particles in CMS

![](_page_14_Figure_10.jpeg)

**New LLP** 

triggers

![](_page_14_Figure_11.jpeg)

Event triggered by the CSC HMT trigger in 2022

![](_page_14_Picture_15.jpeg)

## Summary

• Innovative use of the detectors is crucial to advancing LLP frontier at the LHC and the HL-LHC

## LLP Searches: Great example of a fully integrated effort

Theory, triggers, data management, algorithms, and analysis

## Recent CMS searches were presented today:

- Run-2: HSCPs and VLLs with LLP decays in the muon system
- Run-3: Displaced dimuons and displaced dijets
- Run-3 brings LLP-tailored strategies that could enable future discoveries

## **STAY TUNED!**

#### **Daniel Guerrero (Fermilab)**

Search for Long-lived Particles in CMS

![](_page_15_Picture_12.jpeg)

![](_page_15_Picture_14.jpeg)

## Run-3 HMT triggered event

![](_page_15_Picture_16.jpeg)

![](_page_15_Picture_17.jpeg)

# Additional Material

![](_page_16_Picture_1.jpeg)

![](_page_17_Figure_0.jpeg)

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#### Search for Long-lived Particles in CMS

**ICNFP 2024** 

![](_page_17_Figure_6.jpeg)

# Cross

![](_page_17_Picture_8.jpeg)

#### Search for VLLs w/ MDS showers: Extended **CMS** Preliminary 138 fb<sup>-1</sup> (13 TeV) **CMS-PAS-EXO-23-015** 10 Data (OOT)

![](_page_18_Picture_1.jpeg)

![](_page_18_Figure_2.jpeg)

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Search for Long-lived Particles in CMS

![](_page_18_Figure_7.jpeg)

**CSC** category observable

![](_page_18_Picture_10.jpeg)

![](_page_18_Picture_11.jpeg)

![](_page_19_Figure_0.jpeg)

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Search for Long-lived Particles in CMS

![](_page_19_Figure_4.jpeg)

#### **ICNFP 2024**

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# Search for displaced di-muons: Extended

![](_page_20_Figure_1.jpeg)

## **STA-STA** and **TMS-TMS** mass distributions (Dark photon model)

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Search for Long-lived Particles in CMS

![](_page_20_Figure_6.jpeg)

![](_page_20_Picture_7.jpeg)

2

# Unlocking the CMS Muon System to catch LLPs

![](_page_21_Figure_1.jpeg)

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Search for Long-lived Particles in CMS

- Muon system acts as a sampling calorimeter:
  - 4 detector layers (active material) and steel (absorber)
  - LLP decays induce a particle shower
- Large background suppression from steel shielding
- Extra LLP coverage:
  - Sensitivity to large lifetimes (> a few meters)
  - Sensitive to LLP energy  $\rightarrow$  very light LLPs,  $\mathcal{O}(1 \text{ GeV})$
  - Broad range of LLP decays: qq,  $\pi^+\pi^-$ , KK,  $\tau^-\tau^+$ , ee,  $\gamma\gamma$

## Muon System provides us with a unique opportunity to extend our LLP discovery reach!

![](_page_21_Picture_15.jpeg)

![](_page_21_Picture_16.jpeg)

# **CMS LLP Summary**

#### **Overview of CMS long-lived particle searches**

		CI	MS Preliminary	March 2024	
	UDD, <i>q̃→tbs, m<sub>ä</sub></i> = 2500 GeV	ã	2104,13474 ( <b>Jets with displaced vertices</b> ) 0,0006–0,09 m		140 fb <sup>-1</sup>
SUSY RPV	UDD, $\tilde{g} \rightarrow tbs$ , $m_{\tilde{g}} = 2500 \text{ GeV}$	a a	2012.01581 ( <b>Displaced jets</b> ) 0.003–1 m		132 fb <sup>-1</sup>
	UDD. $\tilde{t} \rightarrow \overline{dd}$ . $m_{\tilde{t}} = 1600 \text{ GeV}$	τ τ	2104.13474 (Jets with displaced vertices) 0.00035–0.08 m		140 fb <sup>-1</sup>
	UDD. $\tilde{t} \rightarrow \overline{dd}$ . $m_{\tilde{t}} = 1600 \text{ GeV}$	ĩ	2012.01581 ( <b>Displaced jets</b> ) 0.002–1.32 m	:	132 fb <sup>-1</sup>
	LQD, $\tilde{t} \rightarrow bl$ , $m_{\tilde{t}} = 600 \text{ GeV}$	ĩ 1	808.05082 ( <b>2μ + 2 jets</b> ) <0.031 m		36 fb <sup>-1</sup>
	LQD, $\tilde{t} \rightarrow bl$ , $m_{\tilde{t}} = 460 \text{ GeV}$	ĩ	2110.04809 ( <b>Displaced leptons</b> ) 0.0001–10 m	-	118 fb <sup>-1</sup>
	LQD, $\tilde{t} \rightarrow bl$ , $m_{\tilde{t}} = 1600 \text{ GeV}$	ĩ	2012.01581 ( <b>Displaced jets</b> ) 0.005–0.24 m	:	132 fb <sup>-1</sup>
SUSY RPC	GMSB, <i>g̃→gĜ</i> , m <sub>g̃</sub> = 2450 GeV	ĝ	2012.01581 ( <b>Displaced jets</b> ) 0.006–0.55 m	:	132 fb <sup>-1</sup>
	GMSB, $\tilde{g} \rightarrow g\tilde{G}$ , $m_{\tilde{g}} = 2100 \text{ GeV}$	ĝ	1906.06441 ( <b>Delayed jet + MET</b> ) 0.32–34 m		137 fb <sup>-1</sup>
	Split SUSY, $\tilde{g} \rightarrow q \bar{q} \chi_1^0$ , $m_{\tilde{g}} = 2500$ GeV	ĝ	2012.01581 ( <b>Displaced jets</b> ) 0.007–0.36 m	:	132 fb <sup>-1</sup>
	Split SUSY, $ ilde{g} ightarrow qar{q}\chi_1^0,m_{ ilde{g}}=1300~{ m GeV}$	<i>ĝ</i> 1	802.02110 ( <b>Jets + MET</b> ) <1 m		36 fb <sup>-1</sup>
	Split SUSY (HSCP), $f_{\tilde{g}g}$ = 0.1, $m_{\tilde{g}}$ = 1600 GeV	ĝ	CMS-PAS-EXO-16-036 ( <b>dE/dx</b> )	>0.7 m	13 fb <sup>-1</sup>
	mGMSB (HSCP) $ aneta=10,\mu>0$ , $m_{ ilde{ au}}=247$ GeV	τ	CMS-PAS-EXO-16-036 (dE/dx + TOF)	>7.5 m	13 fb <sup>-1</sup>
	Stopped $\tilde{t}$ , $\tilde{t} \rightarrow t \chi_1^0$ , $m_{\tilde{t}} = 700 \text{ GeV}$	ĩ	1801.00359 ( <b>Delayed jet</b> )	60-1.5e+13 m	39 fb <sup>-1</sup>
	Stopped $\tilde{g}$ , $\tilde{g} \rightarrow q \bar{q} \chi_1^0$ , $f_{\tilde{g}g} = 0.1$ , $m_{\tilde{g}} = 1300$ GeV	ĝ	1801.00359 (Delayed jet)	50–3e+13 m	39 fb <sup>-1</sup>
	Stopped $\tilde{g},  \tilde{g}  ightarrow q \bar{q} \chi_2^0 (\mu \mu \chi_1^0),  f_{\tilde{g}g} = 0.1,  m_{\tilde{g}} = 940 \; { m GeV}$	ĝ	1801.00359 ( <b>Delayed μμ</b> )	600–3.3e+12 m	39 fb <sup>-1</sup>
	AMSB, $\chi^{\pm} \rightarrow \chi_1^0 \pi^{\pm}$ , $m_{\chi^{\pm}} = 700 \text{ GeV}$	χ <sup>±</sup>	2004.05153 ( <b>Disappearing track</b> ) 0.7–30 m		140 fb <sup>-1</sup>
	$\tilde{g}  ightarrow q \bar{q} \chi_1^0$ or $q_{_{u/d}} \bar{q}_{_{d/u}} \chi_1^{\pm}, \chi_1^{\pm}  ightarrow \chi_1^0 \pi^{\pm}$ , $m_{\tilde{g}} = 1600 \text{GeV}, m_{\chi_1^0} = 1575 \text{GeV}$	$\vee \chi_1^{\pm}$	1909.03460 ( <b>Disappearing tracks + jets with M<sub>T2</sub></b> )	:	137 fb <sup>-1</sup>
	$\tilde{q} \rightarrow q \chi_1^0$ or $q' \chi_1^{\pm}$ , $\chi_1^{\pm} \rightarrow \chi_1^0 \pi^{\pm}$ , $m_{\tilde{q}} = 2000$ GeV, $m_{\chi_1^0} = 1000$ GeV	$\chi_1^{\pm}$	1909.03460 ( <b>Disappearing tracks + jets with M<sub>T2</sub></b> ) 0.26–2 m		137 fb <sup>-1</sup>
	$\tilde{t} \rightarrow t \chi_1^0$ or $b \chi_1^\pm$ , $\chi_1^\pm \rightarrow \chi_1^0 \pi^\pm$ , $m_{\tilde{t}} = 1100$ GeV, $m_{\chi_1^0} = 1000$ GeV	$\chi_1^{\pm}$	1909.03460 ( <b>Disappearing tracks + jets with M<sub>T2</sub></b> ) 0.25–9 m	:	137 fb <sup>-1</sup>
	GMSB, $\chi_1^0 \rightarrow H\tilde{G}(50\%)/Z\tilde{G}(50\%)$ , $m_{\chi_1^0} = 600 \text{ GeV}$	$\chi_1^0$	2212.06695 ( <b>Trackless jets + MET</b> ) 0.04–12 m	:	138 fb <sup>-1</sup>
	GMSB, $\chi_1^0 \rightarrow H\tilde{G}(50\%)/Z\tilde{G}(50\%)$ , $m_{\chi_1^0} = 300 \text{ GeV}$	$\chi_1^0$	2212.06695 ( <b>Trackless jets + MET</b> ) 0.05–24 m	:	138 fb <sup>-1</sup>
	GMSB SPS8, $\chi_1^0 \rightarrow \gamma \tilde{G}$ , $m_{\chi_1^0} = 400$ GeV	$\chi_1^0$	1909.06166 ( <b>Delayed γ(γ)</b> ) 0.2–6 m		77 fb <sup>-1</sup>
	GMSB, co-NLSP, Ĩ→IĜ, mĩ = 270 GeV	Ĩ	2110.04809 ( <b>Displaced leptons</b> ) 5e-05–2.65 m	:	118 fb <sup>-1</sup>
Higgs+Other	$H \rightarrow Z_D Z_D(0.1\%), Z_D \rightarrow \mu \mu, m_H = 125 \text{ GeV}, m_X = 20 \text{ GeV}$	X	2205.08582 ( <b>Displaced dimuon</b> ) 5e-05–5 m	9	98 fb <sup>-1</sup>
	$H \rightarrow Z_D Z_D(0.1\%), Z_D \rightarrow \mu \mu(15.7\%), m_H = 125 \text{ GeV}, m_X = 5 \text{ GeV}$	X	2112.13769 ( <b>Displaced dimuon scouting</b> ) 0.0001–0.25 m	:	101 fb <sup>-1</sup>
	$H \rightarrow XX(10\%), X \rightarrow ee, m_H = 125 \text{ GeV}, m_X = 20 \text{ GeV}$	x	1411.6977 ( <b>Displaced dielectron</b> ) 0.00012+25 m	-	20 fb <sup>–1</sup> (8 TeV)
	$H \rightarrow XX(0.03\%), X \rightarrow II, m_H = 125 \text{ GeV}, m_X = 30 \text{ GeV}$	x	2110.04809 ( <b>Displaced leptons</b> ) 0.001–0.12 m	:	118 fb <sup>-1</sup>
	$H \rightarrow XX(10\%), X \rightarrow b\bar{b}, m_H = 125 \text{ GeV}, m_X = 40 \text{ GeV}$	x	2012.01581 ( <b>Displaced jets</b> ) 0.001–0.53 m		132 fb <sup>-1</sup>
	$H \rightarrow XX(10\%), X \rightarrow b\bar{b}, m_H = 125 \text{ GeV}, m_X = 40 \text{ GeV}$	X	2110.13218 ( <b>Displaced jets + Z</b> ) 0.004–0.248 m	:	117 fb <sup>-1</sup>
	$H \rightarrow XX(10\%), X \rightarrow b\bar{b}, m_H = 125 \text{ GeV}, m_X = 40 \text{ GeV}$	X	2107.04838 ( <b>Hadronic decays in CSCs</b> ) 0.12–450 m	:	137 fb <sup>-1</sup>
	$H \rightarrow XX(10\%), X \rightarrow \tau\tau, m_H = 125 \text{ GeV}, m_X = 7 \text{ GeV}$	X	2107.04838 ( <b>LLP decays in CSCs</b> ) 0.02–23 m	:	137 fb <sup>-1</sup>
	dark QCD, $m_{X_{dark}} = 1500$ GeV, $m_{\pi_{dark}} = 10$ GeV, agonstic	X <sub>dark</sub>	2403.01556 ( <b>Emerging jet + jet</b> ) 0.003–0.3 m	:	138 fb <sup>-1</sup>
	dark QCD, $m_{X_{dark}} = 1500 \text{ GeV}$ , $m_{\pi_{dark}} = 10 \text{ GeV}$ , GNN	X <sub>dar</sub> 2	403.01556 ( <b>Emerging jet + jet</b> ) < <0.4 m	-	138 fb <sup>-1</sup>
	$H \to XX(10\%), X \to bb, m_H = 125 \text{ GeV}, m_X = 40 \text{ GeV}$	<i>x</i>	CMS-PAS-EXO-23-013 ( <b>Displaced Jets Run3</b> ) 0.0005–2.5 m		35 fb <sup>-1</sup> (13.6 TeV)
	$H \rightarrow XX(10\%), X \rightarrow dd, m_H = 125 \text{ GeV}, m_X = 40 \text{ GeV}$	x	CMS-PAS-EXO-23-013 ( <b>Displaced Jets Run3</b> ) 0.0005–2.5 m	:	35 fb <sup>-1</sup> (13.6 TeV)
	$H \rightarrow XX(10\%), X \rightarrow \tau \bar{\tau}, m_H = 125 \text{ GeV}, m_X = 40 \text{ GeV}$	X	CMS-PAS-EXO-23-013 ( <b>Displaced Jets Run3</b> ) 0.001–0.5 m		35 fb <sup>-1</sup> (13.6 TeV)
		$10^{-7}$	$10^{-5}$ $10^{-3}$ $10^{-1}$ $10^{1}$ $10^{3}$		
			ст [m]		

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

#### Search for Long-lived Particles in CMS

#### Daniel Guerrero (Fermilab)

## <u>CMS LLP Summary Plots</u>

![](_page_22_Picture_10.jpeg)

![](_page_22_Picture_11.jpeg)

# **CMS Higgs to LLPs Summaries**

![](_page_23_Figure_1.jpeg)

Daniel Guerrero (Fermilab)

Search for Long-lived Particles in CMS

## **CMS LLP Summary Plots**

**ICNFP 2024** 

**Displaced** leptons X→ee/µµ, m =30 GeV 2110.04809

 Dimuon scouting *B*(X→μμ)=0.14, m<sub>y</sub>=20 GeV 2112.13769

- Displaced dimuon *B*(X→μμ)=0.14, m<sub>y</sub>=20 GeV EXO-23-014

Z + displaced jets X→bb, m<sub>v</sub>=15 GeV 2110.13218

 Displaced jets X→dd, m<sub>v</sub>=15 GeV 2012.01581

-MS Clusters X→ττ, m, =15 GeV EXO-21-008

![](_page_23_Picture_14.jpeg)

# **CMS HNL Summary**

#### **Overview of CMS HNL results**

![](_page_24_Figure_2.jpeg)

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included)

#### **Daniel Guerrero (Fermilab)**

#### Search for Long-lived Particles in CMS

## **CMS LLP Summary Plots**

		March 2024
	0.04-1.24 TeV 1806.10905 (≥ 1j + 2µ)	
	100−980 GeV 2202.08676 ( $3l$ , ≥ $4l$ , $1\tau$ + $3l$ , $2\tau$ + $2l$ , $3\tau$ + $1l$ , $1\tau$ + $2l$ , $2\tau$ + $1l$ )	137
	100−990 GeV 2202.08676 ( $3l$ , ≥ $4l$ , $1\tau$ + $3l$ , $2\tau$ + $2l$ , $3\tau$ + $1l$ , $1\tau$ + $2l$ , $2\tau$ + $1l$ )	137
	0.1−1.065 TeV 2202.08676 ( $3l$ , ≥ $4l$ , $1\tau$ + $3l$ , $2\tau$ + $2l$ , $3\tau$ + $1l$ , $1\tau$ + $2l$ , $2\tau$ + $1l$ )	137
	$100-890 \text{ GeV}  2202.08676 \ (3l, \ge 4l, 1\tau + 3l, 2\tau + 2l, 3\tau + 1l, 1\tau + 2l, 2\tau + 1l)$	137
	0.01–1.24 TeV 2403.00100 ( <b>3e</b> )	138
	0.1-4.7 TeV 2112.03949 ( <b>2e + 2i</b> )	137
	0.1-4.8 TeV 2112.03949 ( <b>2e + 2i</b> )	137
	0.1-5  TeV 2112.03949 ( <b>2µ + 2i</b> )	137
	0.1 - 5.4 TeV 2112.03949 ( <b>2u + 2i</b> )	137
	0.1-2.79 TeV 2307 06959 ( <b>2e.</b> > <b>4i</b> )	137
	0.1 - 3.59  TeV 2307 06959 ( <b>2e. &gt; 4i</b> )	137
	0.1 - 4.38  TeV = 2307.06959 (20) - 24j	137
	$0.1 - 4.1 \text{ TeV}$ 2307.06050 (2µ, $\geq 4j$ )	127
	$0.1 - 4.1 \text{ (eV} = 2507.00959 (2\mu, 2 + j))$	127
	$0.5-6.1 \text{ TeV} \qquad 2210.03082 (2\mu + 2j)$	137
	$1-3.52 \text{ TeV}$ 1811.00806 ( $2\tau + 2j$ )	36 fl
	1-3.75 TeV 1811.00806 ( <b>2τ + 2j</b> )	36 ft
		137
		137
		137
)		137
1j)		137
, ≥ 1j)		137
≥ <b>1</b> j)		137
$1, \geq 1\mathbf{j}$		137
· •		137
		137
		137
		137
		137
		127
e 1i)		120
⊂, ⊥j/  1 (2µ 1i)		100
(2ο 1i)		
(2e, 1j)		
-υ±± ( <b>ζμ, ±j</b> )		138   42 ft
	0.05–23 TeV 22	06.08956 ( <b>2μ + 2j</b> ) 137
10-1		
Ma	ass Scale [TeV]	

![](_page_24_Picture_8.jpeg)

![](_page_24_Picture_10.jpeg)

![](_page_24_Picture_11.jpeg)