

# Recent highlights in BSM searches from the LHC

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## ATLAS & CMS experiments at the LHC



Run-2 (2015–2018):

~140 fb<sup>-1</sup> recorded per experiment at 13 TeV

#### Run-3 (2022–2025):

Now running at 13.6 TeV, aiming for >250 fb<sup>-1</sup> Nearly doubling the Run-2 dataset

#### Combined total by end of Run-3:

~450 fb<sup>-1</sup> per experiment (Run 1+2+3)

Expands reach for rare processes, heavier particles, and sensitivity to new physics signatures

1 fb<sup>-1</sup> corresponds to around 100 million million (potential) collisions

#### Growing total luminosity



Complementary experiments, designed to independently explore wide range of physics phenomena

Together, provide cross-verification of results  $\rightarrow$  core strength of LHC physics

#### **Reconstructed signatures**

Layered sub-detector systems  $\rightarrow$  allow precise particle identification and energy/momentum measurement

#### Standard objects:

- *Electron*: inner tracks + EM calorimeter energy
- *Photon*: EM clusters without associated tracks
- *Muon*: tracks in tracker + muon system
- **Jet**: anti- $k_{T}$  algorithm to PF-like inputs
- *b-jet*: identified using secondary vertex tagging
- *Hadronic tau*: narrow jet with specific decay signature
- *MET*: negative vector sum of transverse momentum (*hallmark of invisible particles escaping detector*)





Beyond these, we go outside the box to look for *<u>nonstandard objects and unusual signatures</u>*. like displaced/trackless jets, secondary vertices, ...

## BSM program at the LHC

• We have measured SM with unprecedented precision

**ATLAS Public Results** 

CMS Public Results

- But many open questions Beyond the Standard Model (BSM)
- LHC's BSM search program targets broad phase space for new physics
- The high energy and growing dataset provides powerful environment to explore new physics
  - produce new heavy particles
  - probe rare or exotic signatures
- Increasingly, novel techniques, like machine learning are used to enhance signal sensitivity







CMS-PAS-SUS-23-017

CMS-PAS-SUS-23-017

Phys.Rev.Lett. 134 (2025) 12, 121801

#### Dark sector map



## Dark sector map

#### https://cms.cern/news/mapping-uncharted-territory-cms-reviews-searches-dark-matter



#### Search for DM+pencil jet





First search at LHC to use low-multiplicity jet signature and supervised machine learning to enhance signal sensitivity

Mass range considered DM candidate: 0.1 - 1 TeV Mediator: 2-5 TeV Z' particle: 0.3 - 3 GeV

800

600

(**GeV**) <sup>200</sup> <sup>400</sup>

300

200

100

2000

No significant excess observed.

Exclude mediator mass upto 4.25 TeV for DM mass 100 GeV at 95% CL

#### Expand sensitivity: 1.8 TeV $\rightarrow$ 4.2 TeV!





## Search for mono-Higgs(bb)





## DM with dark Higgs $\rightarrow$ bb



#### Resolved & Merged SR, sliced further in MET regions



## Dark Higgs scalar $s \rightarrow bb$ ,

Probe low ms region





#### Places stringent constraints Exclude $30 < m_s < 150$ GeV with Z' upto 4.8 TeV







## Heavy resonances $\gamma$ H and $\gamma$ Z with bb





Target spin-1 Z'  $\rightarrow \gamma H$  and spin-0 S  $\rightarrow \gamma Z$ 

Boosted H/Z $\rightarrow$ bb decay

Jet substructure algorithm (ParticleTransformer)

Jet mass regression (ParticleNet)



#### No significant excess observed



Most stringent limits to date

#### Exotic Higgs decay to 4 tau final state

 $H \rightarrow aa \rightarrow 4\pi$  final state Results presented: 4 GeV < ma < 15 GeV  $a \rightarrow 2\tau \rightarrow \mu \tau_{\rm b}$  boosted decay product

Exotic Higgs decays Summary from ATLAS

aa)

10





ATLAS Preliminary

July 2022

## Anomaly detection for dijet resonance search

Resonances Status ATLAS-HMBS-2024-34 arXiv:2502.09770

14

Weakly supervised ML to search for resonant signal, localized peak in m<sub>...</sub>

on Limit BC) [fb]

dd)r

ರ



Use 2 ML strategies to estimate backgrounds in different SRs. In each SR, search for local excess across various models

Optimized to be model-independent Aims for sensitivity to broad range of new physics 95% CL upper limits on  $\sigma(pp \rightarrow A \rightarrow BC)$  set by the 2 ML strategies for 20 signal models ATLAS  $\sqrt{s} = 13 \text{ TeV}$ , 139 fb<sup>-1</sup>  $\varepsilon = 0.02$ M, τ<sub>21</sub> 20 Exp. CURTAINs Obs. CURTAINs Exp. SALAD Obs. SALAD Exp.  $\pm 1\sigma$ Exp.  $\pm 2\sigma$ Obs. Dijet  $\left(\frac{2m}{Dr} < 0.4\right)$ Obs. Dijet  $\left(\frac{2m}{n} > 0.4\right)$ Obs Diboson V′2600 V′2800 V′3000 signal model

Similar performance, stronger limits for some models than existing di-jet searches

#### Summary of Diboson resonances

HVT model C:  $g_F = 0$ ,  $g_H = 1$ 

<sup>†</sup>with  $\ell = \mu, e$ 

\*small-radius (large-radius) jets are used in resolved (boosted) events





15





arXiv:2503.17186

CMS-PAS-SUS-24-003, CMS-PAS-SUS-24-012, CMS-PAS-EXO-23-017

CMS-PAS-SUS-23-014

## Search for direct slepton production



#### Supersymmetry ATLAS-HMBS-2024-64 arXiv:2503.17186



Uses cut-and-count & BDT methods, each optimized for different  $\Delta m$  splittings

For the first time, sensitivity across full

## Search for Electroweakinos production



CMS-PAS-SUS-24-003



CMS covers full  $\Delta m$  spectrum in compressed scenario!

#### Comprehensive search with boosted objects

Search for SUSY in final states with highly Lorentz-boosted top guarks, W, Z, H, or leptonic jets

- Razor kinematic variables: signal-like localized peak, falling background
- Deep neural network, ParticleNet tagger for boosted object reconstruction





Supersymmetry

CMS-PAS-SUS-23-014

#### Summary of ATLAS SUSY searches



	ATLAS S July 2024	TeV	<b>ATLAS</b> Preliminary $\sqrt{s} = 13$ TeV					
	Model	Si	ignature	∫£ dt [fb	<sup>1</sup> ] Mass limit		i i i	Reference
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0 e,µ mono-jet	2-6 jets $E_{\gamma}^{t}$ 1-3 jets $E_{\gamma}^{t}$	niss 140 niss 140	q         [1x, 8x Degen.]         1.0         q         [8x Degen.]         0.9         1.0 <th1.0< th=""> <th1.0< th="">         1.0</th1.0<></th1.0<>	1.85	m( $\tilde{\ell}_{1}^{0}$ )≤400 GeV m( $\tilde{q}$ )-m( $\tilde{\ell}_{1}^{0}$ )=5 GeV	2010.14293 2102.10874
	ğğ, ğ→qqXı	$0 e, \mu$	2-6 jets $E_{\gamma}^i$	140	ğ ğ Forbidden	1.15-1.95	2.3 m( $\tilde{\chi}_1^0$ )=0 GeV m( $\tilde{\chi}_1^0$ )=1000 GeV	2010.14293 2010.14293
gluino	$\tilde{S}$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}W\tilde{X}_{1}^{0}$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell)\tilde{\chi}_{1}^{0}$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_{1}^{0}$	1 e,μ ee,μμ 0 e,μ SS e,μ	2-6 jets 2 jets $E_{\gamma}^{\pi}$ 7-11 jets $E_{\gamma}^{\pi}$ 6 jets	niss 140 niss 140 140 140	8 Ř Ř Ř 1.15	1.97	2 m(k <sup>n</sup> <sub>1</sub> )<600 GeV 2 m(k <sup>n</sup> <sub>1</sub> )<700 GeV m(k <sup>n</sup> <sub>1</sub> )<700 GeV m(k <sup>n</sup> <sub>1</sub> )<600 GeV m(k <sup>n</sup> <sub>1</sub> )=200 GeV	2101.01629 2204.13072 2008.06032 2307.01094
	$\xi  \tilde{g}\tilde{g}, \tilde{g} \rightarrow t t \tilde{\chi}_1^0$	0-1 e,μ SS e,μ	3 b E <sup>r</sup> <sub>7</sub> 6 jets	niss 140 140	<sup>8</sup> / <sub>8</sub> 1.25		2.45 m( $\tilde{\chi}_1^0$ )<500 GeV m( $\tilde{g}$ )-m( $\tilde{\chi}_1^0$ )=300 GeV	2211.08028 1909.08457
	$\tilde{b}_1 \tilde{b}_1$	0 <i>e</i> , <i>µ</i>	2 b E <sub>7</sub>	niss 140	$\frac{\tilde{b}_1}{\tilde{b}_1}$ 0.68 1.255		$m(\tilde{\chi}_{1}^{0}) < 400 \text{ GeV}$ 10 GeV $< \Delta m(\tilde{b}_{1}, \tilde{\chi}_{1}^{0}) < 20 \text{ GeV}$	2101.12527 2101.12527
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 -$	$bh\tilde{\chi}_{1}^{0} = 0 e, \mu$ 2 $\tau$	6 b E	niss 140 niss 140	δ <sub>1</sub> Forbidden 0.23-1.35 δ <sub>1</sub> 0.13-0.85		$\Delta m(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, m(\tilde{\chi}_{1}^{0}) = 100 \text{ GeV}$ $\Delta m(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, m(\tilde{\chi}_{1}^{0}) = 0 \text{ GeV}$	1908.03122 2103.08189
sbottom	$\begin{array}{l} \tilde{I}_{1}\tilde{I}_{1}, \tilde{I}_{1} \rightarrow \tilde{\mathcal{U}}_{1}^{0} \\ \tilde{I}_{1}\tilde{I}_{1}, \tilde{I}_{1} \rightarrow \mathcal{W}b\tilde{\mathcal{V}}_{1}^{0} \\ \tilde{I}_{1}\tilde{I}_{1}, \tilde{I}_{1} \rightarrow \tilde{\mathcal{W}}b\tilde{\mathcal{V}}_{1}^{0} \\ \tilde{I}_{1}\tilde{I}_{1}, \tilde{I}_{1} \rightarrow \tilde{\tau}_{1}bv, \tilde{\tau} \\ \tilde{I}_{1}\tilde{I}_{1}, \tilde{I}_{1} \rightarrow c\tilde{\mathcal{X}}_{1}^{0}/\tilde{c}\tilde{c} \end{array}$	$0.1 \ e, \mu$ $1 \ e, \mu$ $\rightarrow \tau \tilde{G}$ $1.2 \ \tau$ $\tilde{c} \rightarrow c \tilde{k}_1^0$ $0 \ e, \mu$	$\geq 1$ jet $E_T^{t}$ 3 jets/1 $b$ $E_T^{t}$ 2 jets/1 $b$ $E_T^{t}$ 2 $c$ $E_T^{t}$	niss 140 niss 140 niss 140 niss 140 niss 36.1	Till         1.25           Till         Forbidden         1.05           Till         Forbidden         1.4           E         0.85         1.4		$m(\tilde{x}_{1}^{0})=1 \text{ GeV}$ $m(\tilde{x}_{1}^{0})=500 \text{ GeV}$ $m(\tilde{\tau}_{1})=800 \text{ GeV}$ $m(\tilde{x}_{0}^{0})=0 \text{ GeV}$	2004.14060, 2012.03799 2012.03799, 2401.13430 2108.07665 1805.01649
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_2^0, \tilde{\chi}_2^0$	$\delta e, \mu$ $\delta Z/h\tilde{\chi}_1^0$ 1-2 $e, \mu$	1-4 b E <sub>7</sub>	niss 140	<i>i</i> <sub>1</sub> 0.55 <i>i</i> <sub>1</sub> 0.067-1.18		$m(\ell_1, \hat{c}) \cdot m(X_1) = 5 \text{ GeV}$ $m(\hat{X}_2^0) = 500 \text{ GeV}$	2102.10874 2006.05880
	$\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$ $\tilde{t}_2^+ \tilde{t}_2^0$ via WZ	3 e,µ Multiple ℓ/iets	1 b E <sub>7</sub>	niss 140			$m(\tilde{\chi}_{1}^{0})=360 \text{ GeV}, m(\tilde{r}_{1})-m(\tilde{\chi}_{1}^{0})=40 \text{ GeV}$ $m(\tilde{k}_{1}^{0})=0 \text{ winc-binc}$	2006.05880
electroweak	$\begin{array}{c} \chi_{1/2} \text{ via } wz \\ \\ \bar{\chi}_{1}^{\pm} \bar{\chi}_{1}^{\mp} \text{ via } WW \\ \bar{\chi}_{1}^{\pm} \bar{\chi}_{2}^{0} \text{ via } Wh \\ \bar{\chi}_{1}^{\pm} \bar{\chi}_{1}^{0} \text{ via } \bar{\ell}_{L/F} \\ \\ \\ \hline \\ \begin{array}{c} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$	$e_{e,\mu}$ $e_{e,\mu}$ Multiple (/ jets $2 e, \mu$ $2 \tau$ $2 e, \mu$ $2 \tau$ $2 e, \mu$ $e_{e,\mu}$ $0 e, \mu$	$\geq 1$ jet $E_{T}^{T}$ $E_{T}^$	nias 140 r 140	\$		$\begin{split} m(\tilde{r}_{1}^{*}) - m(\tilde{r}_{1}^{*}) &= S \ GeV \ \text{wine-bing} \\ m(\tilde{r}_{1}^{*}) - m(\tilde{r}_{1}^{*}) &= S \ even \ \text{wine-bing} \\ m(\tilde{r}_{1}^{*}) &= S \ even$	1911.12606 1908.02215 2004.1098.2108.07566 1909.628215 2420.20000 1909.628215 1911.12606 2401.14222
		$\begin{array}{c} 4 \ e, \mu \\ 0 \ e, \mu \end{array} \ge 2 \ e, \mu \end{array}$	$\geq 2 \text{ large jets } E_1^2$ $\geq 2 \text{ jets } E_1^2$ $\geq 2 \text{ jets } E_1^2$	niss 140 niss 140 niss 140	H 0.45-0.93 Ĥ 0.45-0.93		$BR(\tilde{\ell}_1 \rightarrow ZG)=1$ $BR(\tilde{\ell}_1^0 \rightarrow ZG)=1$ $BR(\tilde{\ell}_1^0 \rightarrow KG)=0.5$	2108.07586 2204.13072
	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ pro	., long-lived $\tilde{\chi}_1^{\pm}$ Disapp. trk	1 jet $E_7^r$	niss 140	$\frac{\tilde{\chi}_{1}^{\pm}}{\tilde{\chi}_{1}^{\pm}}$ 0.21		Pure Wino Pure higgsino	2201.02472 2201.02472
long-lived	Stable ĝ R-hadr Metastable ĝ R- Di tr Di	$\begin{array}{lll} & & \mbox{pixel dE/dx} \\ \mbox{iadron}, \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$	$E_T^n$ $E_T^n$ $E_T^n$ $E_T^r$	niss 140 niss 140 miss 140 miss 140	ž [r(ž) =10 m] č,μ 0.36 τ 0.36	2.0	$ \begin{array}{c} \mathbf{k} \\ \mathbf$	2205.06013 2205.06013 ATLAS-CONF-2024-011 ATLAS-CONF-2024-011 2205.06013
RPV	$\begin{array}{c} \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{0}/\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{+}\rightarrow\\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}/\tilde{\chi}_{2}^{0}\rightarrow\\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}/\tilde{\chi}_{2}^{0}\rightarrow\\ \tilde{\pi}_{1}\tilde{\kappa}_{1}\tilde{\kappa}_{1}\tilde{\chi}_{1}^{0}\rightarrow\\ \tilde{\pi}_{1}\tilde{\kappa}_{1}\tilde{\kappa}_{1}\tilde{\kappa}_{1}^{0}\rightarrow\\ \tilde{\pi}_{1}\tilde{\kappa}_{1},\tilde{\kappa}_{1}^{-}\rho\delta\\ \tilde{\chi}_{1}^{+}/\tilde{\chi}_{2}^{0}/\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0}\rightarrow\\ \tilde{\chi}_{1}^{+}/\tilde{\chi}_{2}^{0}/\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0}\rightarrow\\ \end{array}$	$\begin{array}{ccc} \chi \rightarrow \ell \ell \ell & 3 \ e, \mu \\ \chi \ell \ell \ell \ell \nu & 4 \ e, \mu \\ \phi a q q \\ b s \\ b b s \\ & \\ \ell s \\ h s \\ & \\ \ell s \\ \mu \\ t h s, \tilde{\chi}^+_1 \rightarrow b h s \\ & 1 - 2 \ e, \mu \end{array}$	0 jets $E_1^t$ $\geq 8$ jets Multiple $\geq 4b$ 2 jets + 2 b 2 b DV $\geq 6$ jets	140 140 140 36.1 140 36.7 140 136 140		55 1.6 1.4-1.85 1.6	Pure Wino m(ℓ <sup>2</sup> )=200 GeV 2.34 Large ℓ <sup>2</sup> / <sub>1</sub> ; m(ℓ <sup>2</sup> )=200 GeV bino like m(ℓ <sup>2</sup> )=500 GeV BR(ℓ <sub>1</sub> →qµ)=100%, cos#=1 Pure higgsino	2011.0643 2103.11884 2401.1633 ATLAS.COM-2016.003 2010.01015 1710.07171 2406.18367 2003.11856 2106.06000
	*Only a selection of phenomena is show simplified models, o	he available mass limits on n n. Many of the limits are bas f. refs. for the assumptions i	new states o sed on made.	r <b>1</b>	0 <sup>-1</sup>		Mass scale [TeV]	

20

## 4. Exotic/Unconventional Signatures



arXiv:2505.01634



arXiv:2505.02429



CMS-PAS-EXO-24-012

## Semi-visible jets or anomalous signature

displaced

prompt



**Exotic Signatures** 

### Search for emerging jets

visible



arXiv:2505.02429

#### ATLAS' first Run-3 result!

#### 1. Cut and count based strategy

Prompt-Track-Fraction (PTF) measures

# tracks starting near collision point

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m<sub>n</sub> = 10 GeV, m<sub>n</sub> = 1.5 TeV

SR 🚛

ATLAS

10<sup>2</sup> = √s = 13.6 TeV, 51.8 fb<sup>-1</sup>

10 high-m preselection

ATLAS

0

√s = 13.6 TeV 51.8 fb<sup>-1</sup>

high-m preselection

m<sub>x</sub> = 10 GeV, m<sub>x</sub> = 1.5 TeV

 $10^{-3}$ 

10<sup>4</sup>

10<sup>3</sup>

10<sup>2</sup>

10-

10

10-4 10-5

10<sup>-6</sup> 10<sup>-7</sup> 10<sup>-8</sup>

- Uses high-level jet observables: displaced tracks and secondary vertex info; jet substructure - Re-interpretable and less model dependent

Data

Data

Leading jet N

- 2. *ML* based strategy
- Uses per-jet transformer-based ML algorithm
- to differentiate emerging jets from SM jets
- Maximizes sensitivity to specific models

Two categories: low and high dijet mass:

1.  $m_{\rm H}$  < 1 TeV  $\rightarrow$  novel emerging jet trigger, trigger matched jets p<sub>T</sub> > 250 GeV, PTF<0.04 2.  $\tilde{m_{ii}}$  > 1 TeV  $\rightarrow$  high pT trigger, jet pT > 520 (300) GeV



First direct constraint on emerging jet pair production via s-channel mediator.

First application of a transformer-based algorithm for emerging



23

## Resonance search using Scouting data



PARKING

NORMAL

ew 1000 events/second

HIGH LEVEL TRIGGER

LEVEL-1 TRIGGER

- Traditional triggers  $\rightarrow$  high p<sub>T</sub> thresholds, low efficiency for low mass resonance
- *Run-3 Scouting* dataset  $\rightarrow$  lower p<sub>T</sub> thresholds (records limited event info  $\rightarrow$  allows high event rate)
- Search for low mass resonance  $(\phi \rightarrow \tau \tau \rightarrow \mu \tau_{h})$



#### Summary of Exotic searches



0.0-3.5 1811.00806 (2T + 2j)

Mass Scale [TeV]

0.5-6.6 1911.03947 (2)

**Overview of CMS EXO results** CMS Preliminary August 2023 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> 0.5-7.9 1911.03947 (2) 0.35-4.0 1712.03143 (2u + 1y: 2e + 1y: 2i + 1y) Zy resonance Wy resonance 1.5-8.0 2106.10509 (1j + 1y) 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> other 0.72-3 25 1808.01257 (1i + 1y) Higgs y resonance Color Octect Scalar, k1 = 1/2 0.5-3.7 1911.03947 (2) 137 fb<sup>-</sup> 137 fb<sup>-</sup> Scalar Diquark 0.5.7.5 1911.03947 (24 pp + Z/y + X0.6-1.6 2303.04596 (pp + //, pp + y 37 fb<sup>-1</sup> 138 fb<sup>-</sup>  $t\bar{t} + \phi$ , pseudoscalar (scalar),  $g_{res}^2 \times BR(\phi \rightarrow ee/\mu\mu) > = 0.01(0.003)$ 0.015-0.075 CMS-PAS-EXO-21-018 (31, 2 4/)  $t\bar{t} + \phi$ , pseudoscalar (scalar),  $g_{1\mu\nu}^{c} \times BR(\phi + ee/\mu\mu) > = 0.03(0.04)$  $t\bar{t} + \phi$ , pseudoscalar,  $g_{2\mu\nu}^{2} \times BR(\phi + t\tau) > = 0.2$ 0.108-0.35 CMS-PAS-EX0-21-018 (3/, > 4/ 138 fb 0.045-0.35 CMS-PAS-EXO-21-018 (3/, a 4/) 138 fb $t\bar{t} + \phi$ , scalar,  $a\bar{t}_{--} \times \beta R(\phi \rightarrow \tau \tau) > = 0.2$ 0.02-0.1 CMS-PAS-EXO-21-018 (3/. = 4/ 138 fbquark compositeness (II),  $\eta_{11,00} = 1$ 0.0-24.0 2103.02708 (2/) 140 fbcontact-interactions quark compositeness (II).  $\eta_{LLNR} = -1$ 0.0-36.0 2103.02708 (2) 140 fb Excited Lepton Contact Interaction 0.2-5.6 2001.04521 (2e + 2i 77 fb<sup>-1</sup> 77 fb<sup>-1</sup> 0.2-5.7 2001.04521 (2µ+2j) vector mediator (qq),  $g_0 = 0.25$ ,  $g_{DH} = 1$ ,  $m_g = 1$  GeV 0.35-0.7 1911.03761 ( a 3) 18 fb<sup>-1</sup> vector mediator ( $l\bar{t}$ ),  $g_q = 0.1$ ,  $g_{2W} = 1$ ,  $g_l = 0.01$ ,  $m_y > 1$  TeV (axial-)vector mediator ( $q\bar{q}$ ),  $g_q = 0.25$ ,  $g_{2W} = 1$ ,  $m_g = 1$  GeV 0.2-1.92 2103.02708 (2e, 2u) 140 fb-0.5-2.8 1911.03947 (2) 137 fb (axial-)vector mediator ( $\chi\chi$ ),  $q_1 = 0.25$ ,  $q_{100} = 1$ ,  $m_2 = 1$  GeV 0.0-1.95 2107.13021 ( a 1i + p7" 101 fb-(axial)-vector mediator  $(t\bar{t}), g_{g} = 0.1, g_{cot} = 1, g_{f} = 0.1, m_{g} > m_{med}/2$ 0.2.4.64 2103.02708 (2e, 2) 140 fb<sup>-1</sup> 36 fb<sup>-1</sup> scalar mediator (+ $t/t\bar{t}$ ),  $g_{ij} = 1$ ,  $g_{LH} = 1$ ,  $m_{\chi} = 1$  GeV scalar mediator (+ $t\bar{t}$ ),  $g_{ij} = 1$ ,  $g_{DH} = 1$ ,  $m_{\chi} = 1$  GeV 0.0-0.29 1901.01553 (0.1/+ = 2i+p?\*\* 0.05-0.4 2107.10892 (0, 1f + ≥ 2j + p<sup>(11)</sup>) 137 fb<sup>-1</sup> 101 fb<sup>-1</sup> scalar mediator (fermion portal),  $A_i = 1, m_i = 1$  GeV oseudoscalar mediator (+)/V),  $g_{ij} = 1$ ,  $g_{DR} = 1$ ,  $m_g = 1$  GeV 0.0-0.47 2107.13021 (≥ 1j + p 101 fb<sup>-1</sup> 36 fb<sup>-1</sup> dark matter pseudoscalar mediator (+t/tf),  $q_n = 1$ ,  $q_{\text{DH}} = 1$ ,  $m_r = 1$  GeV 0.0-0.3 1901.01553 (0, 1/ + 2 2i + persi 137 fb<sup>-1</sup> 16 fb<sup>-1</sup> 36 fb<sup>-1</sup> 138 fb<sup>-1</sup> pseudoscalar mediator (+tř),  $g_0 = 1$ ,  $g_{0H} = 1$ ,  $m_f = 1$  GeV 0.05-0.42 2107.10892 (0. 1/ + 2 2j + p7" 27 / 00-156 1010.10069 (4) 0.0-1.6 1908.01713 (h + p<sup>mm</sup>) 1.5-5.1 2112.11125 (2) • p<sup>mm</sup> complex sc. med. (dark QCD), mhr = 5 GeV, cTX = 25 mm Baryonic Z', g<sub>1</sub> = 0.25, g<sub>0tt</sub> = 1, m<sub>g</sub> = 1 GeV Z' mediator (dark OCD), more = 20 GeV, rev = 0.3, grave = grave  $Z' = 2HDM, g_{Z'} = 0.8, g_{DW} = 1, tan\beta = 1, m_{\chi} = 100 \text{ GeV}$ Leptoquark mediator,  $\beta = 1, \beta = 0.1, A_{\chi, DW} = 0.1, 800 < M_{LO} < 1500 \text{ GeV}$ 36 fb<sup>-1</sup> 77 fb<sup>-1</sup> 0.3-0.6 1811.10151  $(1\mu + 1j + p_{i}^{\text{pres}})$ axion-like particle, f<sup>-1</sup> = 1.2 TeV<sup>-1</sup> 5-2.0 CMS-PAS-EX0-21-007 (pp + yy) 103 fb<sup>-1</sup> 138 fb<sup>-1</sup> inelastic dark matter model,  $y = 10^{-6}$ ,  $\sigma_D = 0.1$ 0.003-0.08 2305.11649 (2 displaced µ + p()\*\*\* 0.02-0.08 2305.11649 (2 displaced µ + p<sup>res</sup> 0.02-0.08 2305.11649 (2 displaced µ + p<sup>res</sup> inelastic dark matter model,  $y = 10^{-7}$ ,  $g_D = 0.1$ dark Higgs,  $g_4 = 0.25$ ,  $g_{100} = 1$ ,  $\theta = 0.01$ ,  $m_2 = 200$  GeV,  $m_2 = 700$  GeV 138 fb 0.16-0.352 CMS-PAS-EXO-21-012 (11+2j+p<sup>(r)ts</sup>, 21+p<sup>(r)ts</sup>) 137 fb-36 fb<sup>-1</sup> 38 fb<sup>-1</sup> 38 fb<sup>-1</sup> RPV stop to 4 quarks 0.08-0.52 1808.03124 (2): 4) **RPV** RPV squark to 4 quarks RPV gluino to 4 quarks 0.1-0.72 1806.01058 (2j) 0.1-1.41 1806.01058 (2) RPV stop scouting boosted 0.07-0.2 CMS-PAS-EXO-21-004 (scouting boosted dijet 128 fb-RPV mass degenerated higgsinos to trijet boosted scouting 0.07-0.075 & 0.095-0.105 CM5-PAS-EXO-21-004 (scouting boosted trijet 128 fb-36 fb-1 36 fb-1 ADD (jj) HLZ, nep = 3 0.0-12.0 1803.08030 (2) 0.0-9.1 1812.10443 (2y, 2f) ADD (yy, #) HLZ, np = 3 101 fb<sup>-1</sup> 36 fb<sup>-1</sup> 0.0-11-8 2107.13021 (= 1j + press ADD Gox emission, nup = 2 ADD 08H (ii) 0- = 6 0.0-8.2 1803.08030 (2j) 0.0-5.6 2205.06709 (ep) ADD QBH (ep), nED = 4 138 fb-1 ADD DBH (er) n= 4 0.0.5.2 2205.05709 (ex) 138 fb ADD QBH (µT), nED = 4 0.0-5.0 2205.06709 (µT) 138 fbextra dimensions ADD QBH (M), nto = 6 2 0.7 5 2305 7998 (V + 0 138 fb 140 fb<sup>-1</sup> 36 fb<sup>-1</sup> RS  $G_{KK}(U)$ ,  $k/\overline{M}_{Pl} = 0.1$ 0.0-4.78 2103.02708 (2/) RS  $G_{\text{EX}}(yy), k/\overline{M}_{\text{III}} = 0.1$ 0.0-4.1 1809.00327 (2y) 0.5-2.6 1911.03947 (2j) 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> RS G<sub>EC</sub>(q0, gg), k/M<sub>21</sub> = 0.1 0.059 1803 08030 (2) RS OBH (ii) . Dec = 1 138 fb<sup>-1</sup> 36 fb<sup>-1</sup> RS QBH (yj), nED = 1 2.0.5.2 2305.07998 (¥+J) non-rotating BH, Mo = 4 TeV, Dro = 6 0.0-9.7 1805.06013 (>71(/, y)) 3-brane WED  $g_{ex}(\phi + g \rightarrow ggg)$ ,  $g_{grav} = 6$ ,  $g_{det} = 3$ ,  $\varepsilon = 0.5$ ,  $m(\phi)/m(g_{ex}) = 0.1$ 2.0-4.3 2201.02140 (2) 138 fb<sup>-1</sup> 0.4-2.8 2202.06075 (f + pres) split-UED, u > 2 TeV 138 fb 137 fb<sup>-1</sup> excited light guark (gg), A = m." 0.5-6 3 1911.03947 (20) excited light quark (qq),  $K = M_q$ excited light quark (qq),  $f_3 = f = f = 1, K = m_q^*$ excited b quark,  $f_5 = f = f = 1, K = m_q^*$ 138 fb-138 fbexcited ferminos 1.0-6.0 2305.07998 (y+) 1.0-2.2 2305.07998 (y+i) excited electron,  $f_6 = f = f = 1$ ,  $A = m_0^2$ excited muon,  $f_5 = f = f = 1$ ,  $A = m_0^2$ 0.25-3.9 1811.03052 (y+2e) 36 fb<sup>-1</sup> 36 fb<sup>-1</sup> 0.25-3.8 1811.03052 (y + 2u) 36 fb<sup>-1</sup> vMSM,  $|V_{eW}|^2 = 1.0$ ,  $|V_{\mu W}|^2 = 1.0$ 0.001-1.24 1802.02965; 1806.10905 (3µ; a 1j + 2µ)  $\begin{array}{l} \text{VMSM}, \ |V_{eW}|^2 = 1.0, \ |V_{\mu M}|^2 = 1.0 \\ \text{VMSM}, \ |V_{eW}|^2 = 1.0, \ |V_{\mu M}|^2 = 1.0 \\ \text{VMSM}, \ |V_{eW}V_{\mu M}^*|^2 / (|V_{eW}|^2 + |V_{\mu M}|^2) = 1.0 \end{array}$ 0.001-1.43 1802.02965; 1806.10905 (3e; a 1j + 2e) 36 fb<sup>-1</sup> 36 fb<sup>-1</sup> 0.02-1.6 1806.10905 (≥ 1j + µ + e) heavy fermions Type-III seesaw heavy fermions, Flavor-democratic Vector like taus, Doublet 0.1-0.98 2202.08676 (3/, 2 4/, 1+ 3/, 2+ 2/, 3+ 1/, 1+ 2/, 2+ 1/ 138 fb 138 fb-0.1-1.045 2202.08676 (3t, ≥ 4t, 1x + 3t, 2x + 2t, 3x + 1t, 1x + 2t, 2x + 1t) Vector like taus. Singlet 0 125/0 15 2202 08676 (3/. > 4/. 1x + 3/. 2x + 2/. 3x + 1/. 1x + 2/. 2x + 1/) 138 fb-137 fb<sup>-1</sup>  $Z_{0}$ , narrow resonance,  $\epsilon^2 = 8 \times 10^{-6}$  (90% C.L.) 0.0115-0.075 1912.04776 (20  $Z_D$ , narrow resonance,  $\epsilon^2 = 6 \times 10^{-5}$  (90% C.L.)  $Z_D$ , narrow resonance,  $\epsilon^2 = 4 \times 10^{-5}$  (90% C.L.) 0.11-0.2 1912.04776 (2µ) 137 fb<sup>-1</sup> 97 fb<sup>-1</sup> 97 fb<sup>-1</sup>  $Z_D$ , narrow resonance,  $\epsilon^2 = 7 \times 10^{-7}$  (90% C.L.)  $Z_D$ , narrow resonance,  $\epsilon^2 = 3 \times 10^{-6}$  (90% C.L.) 0.0011-0.0026 CMS-PAS-EXO-21-005 (2µ) CMS-PAS-EXO-21-005 (2) 0.0042-0.0079 140 fb-SSM Z'UD 0.2-5.15 2103.02708 (2e. 2u) 140 fb<sup>-1</sup> 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> 140 fb<sup>-1</sup> 138 fb<sup>-1</sup> 138 fb<sup>-1</sup> 138 fb<sup>-1</sup> SSM Z'(qq) 0.5-2.9 1911.03947 (2) Z'(qq) Superstring Z', 01-0.125 1905.10331 (11.1) 0.2-4.6 2103.02708 (2e, 2) heavy gauge bosons LFV Z', BR(eu) = 10% 0.2-5.0 2205.06709 (eu) 0 TeVLFV Z', BR(et) = 10% 0.2-4.3 2205.06709 (er) LEV Z. BRIAN = 10% 0.2-4.1 2205.06709 (ur) SSM W(IV) 0.4-5.7 2202.06075 (f + p("") 138 fb<sup>-1</sup> 78 fb<sup>-1</sup> 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> Leptophobic Z' 5-0.45 1909.04114 [2] SSM W(qq) 0.5-3.6 1911.03947 (2j) LRSM Wa(Wa), Ma, = 0.5Mm 0.0-5.0 2112.03949 (20 + 21) SSM W(TV) 0.6-4.8 2212.12604 (T + ppin 138 fb<sup>-1</sup> 36 fb<sup>-1</sup> LRSM W<sub>8</sub>(eN<sub>8</sub>), M<sub>8</sub> = 0.5M<sub>W</sub> 0.0-4.7 2112.03949 (2e + 2)  $B_3 - L_2 Z^*$ ,  $|g_{Z'}| \times [1 \text{ TeV}/m_2^*] = 0.08$ ,  $B_{23} = 0$ LRSM  $W_R(\tau N_R)$ ,  $M_{3h} = 0.5M_{2h}$ . 35-2.2 2307.08708 (Z'→µµ + ≥ 1b) 138 fb<sup>-1</sup> 36 fb<sup>-1</sup> 137 fb<sup>-1</sup>

10-

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#### Summary of LLP searches

Common ATLAS and CMS summary plots for Higgs boson mediated hidden sectors involving long-lived particles





## Overview: selective list of recent BSM results at LHC



## Few more BSM results (not covered in this talk)





Vector-like T quark New scalar resonance Displaced dimuons  $H \rightarrow aa \rightarrow 4e$  CMS-PAS-B2G-23-009 CMS-PAS-B2G-24-001 CMS-PAS-EXO-24-008 CMS-PAS-EXO-24-031

Vector-like leptons	<u>2503</u>
Lepto-quarks	<u>2503</u>
Heavy neutral leptons	<u>2503</u>
Long-lived particles	<u>2503</u>
New scalar with ttbar	<u>2503</u>

2503.22581 2503.19836 2503.16213 2503.20445 2503.17254

More exciting BSM results this afternoon:

Exotics results from ATLAS by Michael Revering Vector-like quarks at LHC by Elias Bernreuther New pseudoscalar search with ATLAS by Sara Khaled

#### Summary & Outlook

- ★ Exciting and wide range of BSM landscape at the LHC.
- ★ Many results from 140 fb<sup>-1</sup> of Run-2 dataset.
   Searches with Run-3 are ramping up.
- ★ Increasing the sensitivity to new physics with novel reconstruction techniques, and probing unexplored regimes, both at higher and lowest masses.
- ★ Highlighted only a selective sample of recent BSM results.

2025 BREAKTHROUGH PRIZE IN FUNDAMENTAL PHYSICS



Stay tuned for many more results from the LHC!