Dark Matter and Dark Sectors at the LHC

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On behalf of the CMS and ATLAS collaborations



Unexplained phenomena

- Gravity
- Dark matter
- Dark energy
- Matter-antimatter asymmetry
- •••

Experimental tensions (?)

- $(g-2)_{\mu}$
- m_W
- $R(D^*)$
- *X*17
- •••

...

Fine-tuning problems

- $\theta_{CP} \approx 0$
- Hierarchy problem
- Neutrino masses
- Choice of parameters



Most consistent and precise theory in human history



For the first time, no clear indication about what the missing pieces are Dark sectors (DS) can address any of these problems

- New interactions with the standard model (SM) can provide dark matter (DM) candidates
- New symmetries can solve other theoretical and finetuning problems
- New particles can explain experimental tensions
- Dark sectors have their own **dark charges**, so are stable under their conservation laws, and can have rich structure
- Inherently weak interaction with the SM mediated via a new particle often called a **portal or mediator**



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- Inherently weak interaction with the SM mediated via a new particle often called a **portal or mediator**

No hints about any details of the DS!

- Masses, couplings, gauge structures, portals, are very unconstrainted
- Zoo of theories: ALPs, WIMPs, SUSY, Hidden Valleys, Extra Dimensions, Axions, Dark Photons, ...

So, how do we start looking for DSs?



To avoid breaking SM symmetries, four commonly studied ways to communicate with DS:

- Spin-1 Portal: new U(1) interaction mixes with SM hypercharge
- Spin-0 Portal: scalar (Higgs-like) or pseudoscalar (e.g. ALPs) that couple to DS
 - Fermion Portal: Yukawa couplings between DS and SM fermions
 - Neutrino Portal: HNLs mix with neutrinos



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Many portals within direct reach, others can show up at lower energies due to quantum mechanical mixing

How can we probe this at colliders?











Disclaimer:

Precision measurements are also powerful probes for DSs, but focus on well-predicted SM observables which are sensitive to corrections from DS effects

Since they are experimentally different from DS searches, they will not be covered in this talk



MET+X searches

- DS produced recoiling against SM system
- Missing transverse energy since DS is invisible

Portal resonances

- Known SM processes cross sections are affected by DS
- Search for bumps in mass distributions

Unconventional signatures

- More complicated DSs can produce signatures completely different from SM (disappearing tracks, emerging jets, displaced leptons, etc.)
- New reconstructed objects often necessary

MET+X



Strategy

- Invisible DS particles produced via mediator that couples to SM and DS
- DS particles recoil against SM (jet, photon, V, Higgs, t/b, tt/bb, etc.)
- Since (transverse) momentum is conserved, measure missing (transverse) momentum

Target

- Simplified DM models (e.g. WIMPs) with parameters: m_{med} , m_{DM} , g_q , g_χ
- Higgs portals
- Any model with invisible decays! Very model independent search

MET+X Results

[1] - JHEP 11 (2021) 153
[2] - JHEP 02 (2021) 226
[3] - arXiv:2402.16561



- A few representative examples of the many Run 2 MET+X results from ATLAS and CMS are shown
- Evolution of MET algorithms to improve sensitivity (pile-up mitigation, ML, etc.)
- "Control regions" in data to constrain and/or predict backgrounds
 - Often through simultaneous binned likelihood fits with signal regions

JHEP 11 (2021) 153

Limits from Mono-Jet



- As an example, the same mono-jet search can be re-interpreted for many DS/DM models
 - Simplified DM models: WIMPs with vector, axial, pseudoscalars, fermion portals
 - $B(H \rightarrow inv)$
 - Leptoquarks & other more complex models
- For WIMPs, can constrain directly m_{DM} and m_{med}
 - Can interpret these as limits on $\sigma_{DM-nucleon}$
 - Compare with direct-detection experiments!

Resonance Searches



Strategy

- New DS-SM mediator produced in pp collisions
- Mediator decays back to SM (instead of decaying to DS like in MET+X scenario)
- Look for Breit-Wigner resonances "bumps" in mass distributions

Target

- Model-independent limits on $\sigma(pp \to X)B(X \to SM SM)A$ as function of m_{med}
- Similar models to MET+X, since if it can be produced via SM, it can decay back to it

Resonance Searches

[1] - <u>JHEP 12 (2023) 070</u> [2] - <u>arXiv:2403.08547</u> [3] - <u>Phys. Lett. B 796 (2019) 68</u>



- Target high masses (~TeV) via traditional triggers
- Target low masses (~GeV) via production of another particle to trigger on (e.g. photon + 2 jets)
- Enhance sensitivity to low masses via high-rate ("scouting") triggers that select a larger fraction of signal-like events, but record less event information
- Parametrized background distributions determined from Monte Carlo, corrected in data
- "Bump-hunting": fit generic signal Breit-Wigner bumps convoluted with the detector resolution

Results from (some) Resonance Searches

JHEP 12 (2023) 070 arXiv:2403.08547 Phys. Lett. B 796 (2019) 68



- Place limits based on the mass of the resonance and the cross section
- Dark photon model commonly used for benchmarking with other experiments, relies on mixing parameter ϵ between the $U(1)_D$ and SM hypercharge
- Model independent limits can be placed on simple Gaussian bumps at different m values, with different widths Γ

Ground Covered



MET+X and resonance searches have excluded large phase space of simplified DM models like WIMPs throughout Run 1 and 2 of the LHC

Colliders and Direct Detection



- Important complementarity between colliders and direct detection experiments for simplified DM models
 - Spin dependence
 - Nature of mediator
 - Nature of dark matter particle(s)

Unconventional Signatures

- First-generation of searches at colliders found no convincing evidence for BSM
 - Excellent limits on simplified models have been placed
 - New ideas (scouting, ML, etc.) are still able to improve sensitivity, but we are reaching the limits of what can be done with current colliders
 - Will be re-iterated with Run 3 data (ongoing!)



Unconventional Signatures

- First-generation of searches at colliders found no convincing evidence for BSM
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 - New ideas (scouting, ML, etc.) are still able to improve sensitivity, but we are reaching the limits of what can be done with current colliders
 - Will be re-iterated with Run 3 data (ongoing!)
- More complex DS models and/or alternative DM mechanisms (non WIMP) being investigated
 - Freeze-in, inelastic DM, FIMPs, etc.
 - Complex DSs (e.g. dark QCD) could contain a stable (DM) particle as well as an unstable particles that could decay in our detectors (e.g. LLPs)
- Give rise to new types of signatures that we don't typically reconstruct at colliders
 - We would not have seen these objects at all
 - Would have evaded all previous constraints



Schema stolen from André Lessa

Unconventional Signatures

Some examples of unconventional signatures that would have evaded typical reconstruction and triggers



Unconventional Signatures: New Approaches

Need new approaches to reconstruct these signatures:

- New data streams:
 - **Scouting:** high-rate triggers, save quickly less info per event
 - **Parking**: low-rate triggers, save large amount of raw detector data to be reconstructed later
- New triggers:
 - Many dedicated new triggers to target unconventional topologies
- New offline reconstructions:
 - Looking at physics objects that may not conform to traditional, SM-like objects

Important part of Run 3 (2023-2025) is to leverage these new approaches

HLSP

HLSP

 $\gamma_{
m d}$

 $\gamma_{
m d}$

 f_{d}

 \overline{f}_{d}

Long Lived Dark Photons

- Displaced, collimated SM fermions reconstructed in the calorimeter or μ spectrometer (MS)
 - Hidden lightest stable particle contributes only to p_T^{miss}
- Two new triggers to target signal:
 - 3 μ 's using the MS only <u>JINST 15 (2020) P09015</u>
 - 1 μ in the MS + 1 μ within $\Delta R < 0.4$ of the first JINST 8 (2013) P07015







Emerging Jets

- X_{dark} produced, travel ~cm, decay to Q_{dark} and q
 - Two showers not associated to primary vertex
- Target jets with tracks with large displacement in the plane orthogonal to the beam d_{xy}
- Alternative approach with a Graph Neural Network (GNN)





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Merged Diphotons

- Two photons from ϕ decay too merged to look like distinct photons, but not so collimated that they would look like one photon
- Dedicated CNN developed to analyze ECAL deposits
 - Distinguish single γ , two γ 's, or hadronic activity
- Second CNN to reconstruct diphoton mass
- Validate with boosted π^0 , η decays





Conclusions

- The LHC has covered a lot of ground in DM and DS searches
- Complementary approach to indirect and direct detection experiments

• LHC Run 3

- New physics programmes are being developed for BSM searches
 - Several talks at this conference cover them in more detail than I had time for
 - E.g. collider BSM sessions Wednesday at 3pm and today at 5pm
- New data sources, triggers, and reconstructions
- New dark sectors are being explored

• HL-LHC

- Unprecedented luminosity will allow us to look at even rarer phenomena
- New detector technology will unlock new possibilities
 - e.g. trigger on tracks directly will massively improve many DS searches
- FCC-ee, Muon Collider?
 - Exciting new frontiers for our quest to explore BSM

Backup



Hidden Valleys



Improving MET+X and Resonance Searches



+ better methods: event selection, jet tagging, background estimations, etc.

Soft Unclustered Energy Patterns

- Strongly coupled dark sector connected via scalar portal
- Large 't Hooft coupling in quasi conformal dark sector
 - Long, efficient showering window, which produces spherical, high multiplicity jets
- Trigger on events with SUEP recoiling against ISR
- Background prediction using extended ABCD method







Unconventional Signatures: Displaced Jets in μ Spectrometer

- Dark particles *s* produced, travel ~m, decay to *ff*, which shower
 - Showers in the μ spectrometer
- Dedicated trigger to look for several tracks in the μ spectrometer within a jet's typical radius, $\Delta R = 1.5$
- Dedicated reconstruction for displaced decays in the spectrometer





- Set limits on $c\tau, \sigma$
- Assumptions on DS structure, BRs, masses, etc. for these limits

Unconventional Signatures: Semivisible Jets

- χ produced through a Z' mediator, which shower, some decaying back to SM quarks, some staying in DS, controlled by ratio r_{inv}
 - Collimated mixtures of visible and invisible particles
- Use p_T^{miss} , N-subjettiness, energy correlators, soft-drop mass in a BDT to discriminate between SVJ and SM jets







- Set limits on $m_{Z'}$, m_{dark} , r_{inv}
- Assumptions on dark sector, such as showering, gauge structure, etc.

EXO-CMS Summary Plots

Overview of CMS EXO results



| ATLAS Heavy | Particle Search | es* - 95 | % CL Upper Exclusion Limits | ATL | AS Preliminary | ATLAS Long- | ived Particl | le Searches* | - 95% CL Exclusion | | ATLA | S Preliminary |
|--|--|---|--|---|---|--|--|--|--|--|--|--|
| Status: March 2023 | | | | $\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$ | $\sqrt{s} = 13 \text{ TeV}$ | Status: March 2023 | | | | $\int \mathcal{L} dt = (32.8 -$ | 139) fb ⁻¹ | \sqrt{s} = 13 TeV |
| Model | ℓ, γ Jets† E_T^m | iss ∫£ dt[fb ⁻¹ |] Limit | | Reference | Model | Signature | ∫£ dt [fb ⁻¹] | Lifetime limit | - | | Reference |
| ADD $G_{KK} + g/q$ ADD non-resonant $\gamma\gamma$ ADD OBH ADD BH multijet RS1 $G_{KK} \rightarrow \gamma\gamma$ BS1 $G_{KK} \rightarrow \gamma\gamma$ | $0 e, \mu, \tau, \gamma$ $1 - 4 j$ Ye 2γ - - - 2 j - $- \ge 3 j$ - 2γ - - 2γ - - | es 139 - 36.7 - 139 - 3.6 - 139 - 139 | Mo Ms Ms Ma Ma Grav mass | 11.2 TeV n = 2 8.6 TeV n = 3 HLZ NLO 9.4 TeV n = 6 9.55 TeV n = 6, M _D = 3 TeV, rot BH 1.5 TeV k/M _{PT} = 0.1 | 2102.10874 1707.04147 1910.08447 1512.02586 2102.13405 | RPV $\tilde{t} \rightarrow \mu q$ RPV $\tilde{\chi}_1^0 \rightarrow eev/e\mu v/\mu\mu v$ RPV $\tilde{\chi}_1^0 \rightarrow qqq$ | displaced vtx + muon displaced lepton pair displaced vtx + jets | 136 \tilde{t} lifetime 32.8 $\tilde{\chi}_1^0$ lifetime 139 $\tilde{\chi}_1^0$ lifetime | | 0.003-6.0 m $m(\tilde{t}) =$ 0.003-1.0 m $m(\tilde{q}) =$ 0.00135-9.0 m $m(\tilde{\chi}_1^0) =$ | 1.4 TeV 1.6 TeV, $m(\tilde{\chi}_1^0) =$ 1.3 TeV 1.0 TeV | 2003.11956 1907.10037 2301.13866 |
| Bulk RS $g_{KK} \rightarrow tt$ Bulk RS $g_{KK} \rightarrow tt$ | t e, μ ≥1 b, ≥1J/2j γe | 36.1 s 36.1 s | GKK mass 2.3 TeV gKK mass 3.8 | TeV $\Gamma/M_{Pl} = 1.0$ $\Gamma/m = 15\%$ | 1808.02380 | $\operatorname{GGM} \tilde{\chi}^0_1 \to Z \tilde{G}$ | displaced dimuon | 32.9 $\tilde{\chi}_1^0$ lifetime | | 0.029-18.0 m m(ĝ)= | 1.1 TeV, $m(ilde{\chi}^0_1) {=}$ 1.0 TeV | 1808.03057 |
| SSM $Z' \rightarrow \ell\ell$ | 2 e, µ | · 139 7 | Z' mass | $\operatorname{Tier}(1,1), \mathcal{B}(\mathcal{A}^{(***)} \to tt) = 1$ | 1903.06248 | GMSB | non-pointing or delayed 3 | 139 $\tilde{\chi}_1^0$ lifetime | | 0.24-2.4 m m($\tilde{\chi}_1^0,$ |)= 60, 20 GeV, $\mathcal{B}_{\mathcal{H}}$ = 2% | 2209.01029 |
| $\begin{array}{c} \text{SSM } Z' \to \tau\tau \\ \text{Leptophobic } Z' \to bb \\ \text{Leptophobic } Z' \to tt \\ \text{SSM } W' \to tr \end{array}$ | 2τ – 2b – 0 e,μ ≥1b,≥2J Ye 1 e,μ – Ye | - 36.1 2 - 36.1 2 es 139 2 | Z' mass 2.42 TeV Z' mass 2.1 TeV Z' mass 4, W' mass | 1 TeV Γ/m = 1.2% | 1709.07242 1805.09299 2005.05138 1906.05609 | $\begin{array}{c} \text{GMSB} \ \tilde{\ell} \rightarrow \ell \tilde{G} \\ \text{GMSB} \ \tilde{\tau} \rightarrow \tau \tilde{G} \end{array}$ | displaced lepton displaced lepton | 139 <i>ℓ</i> lifetime 139 <i>τ</i> lifetime | 9-270 mm | $m(\tilde{\ell}) = m(\tilde{\ell}) = m($ | 600 GeV 200 GeV | 2011.07812 2011.07812 |
| SSM $W' \rightarrow \tau v$ SSM $W' \rightarrow tb$ HVT $W' \rightarrow WZ$ model B HVT $W' \rightarrow WZ \rightarrow \ell v \ell' \ell'$ | 1 τ - Υε - ≥1 b, ≥1 J - 0-2 e, μ 2 j / 1 J Υε model C 3 e, μ 2 j (VBF) Υε | es 139 V - 139 V es 139 V es 139 V | W' mass 2 W' mass 2 W' mass 340 GeV 2 | 5.0 TeV 4.4 TeV 3. TeV $g_V = 3$ $g_V c_H = 1, g_f = 0$ | ATLAS-CONF-2021-025 ATLAS-CONF-2021-043 2004.14636 2207.03925 | AMSB $pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^0, \tilde{\chi}_1^+ \tilde{\chi}_1^-$ AMSB $pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^0, \tilde{\chi}_1^+ \tilde{\chi}_1^-$ | disappearing track large pixel dE/dx | 136 $\tilde{\chi}_1^{\pm}$ lifetime 139 $\tilde{\chi}_1^{\pm}$ lifetime | | 0.06-3.06 m $m(\tilde{\chi}_1^+)$ 0.3-30.0 m $m(\tilde{\chi}_1^+)$ | : 650 GeV : 600 GeV | 2201.02472 2205.06013 |
| HVT $Z' \rightarrow WW$ model B LRSM $W_R \rightarrow \mu N_R$ | 1 <i>e</i> ,μ 2]/1J Ye 2μ 1J - | - 80 V | Z' mass 3.9 W _R mass | $g_V = 3$ 5.0 TeV $m(N_R) = 0.5 \text{ TeV}, g_L = g_R$ | 2004.14636 1904.12679 | Stealth SUSY | 2 MS vertices | 36.1 S lifetime | 0.1-5 | $\mathcal{B}(\tilde{g} \rightarrow \mathcal{B})$ | $Sg = 0.1, m(\tilde{g}) = 500 \text{ GeV}$ | 1811.07370 |
| Cl qqqq Cl ℓℓqq | – 2j – 2e,μ – – | 37.0 | Λ | 21.8 TeV η ₁₁ 35.8 TeV η ₁₁ | 1703.09127 2006.12946 | Split SUSY | displaced vtx + E ^{miss} | 139 g lifetime | | $> 0.45 \text{ m}$ $m(g) = 0.02-13.2 \text{ m}$ $m(\tilde{g}) = 0.02-13.2 \text{ m}$ | 1.8 TeV, $m(\chi_1^c) = 100 \text{ GeV}$ | 2205.06013 |
| Cl eebs Cl μμbs Cl tttt | 2 e 1 b - 2 μ 1 b - ≥1 e,μ ≥1 b,≥1 j γε | 139 / 139 / s 36.1 / | Λ 1.8 TeV Λ 2.0 TeV Λ 2.57 TeV | $egin{array}{llllllllllllllllllllllllllllllllllll$ | 2105.13847 2105.13847 1811.02305 | Split SUSY | $0 \ \ell, \ 2 - 6 \ \text{jets} + E_{\text{T}}^{\text{miss}}$ | 36.1 g lifetime | | $m(\tilde{g}) =$ | 1.8 TeV, $m(\tilde{\chi}_1) = 100 \text{ GeV}$ 1.8 TeV, $m(\tilde{\chi}_1^0) = 100 \text{ GeV}$ | ATLAS-CONF-2018-003 |
| Axial-vector med. (Dirac DI Pseudo-scalar med. (Dirac Vector med. Z'-2HDM (Dir Pseudo-scalar med. 2HDM | DM) - 2 j - c DM) 0 e, μ , τ , γ 1 - 4 j Ye irac DM) 0 e, μ 2 b Ye M+a multi-channel | - 139 r 9s 139 r 9s 139 r 139 r | mend 3.8 mend 376 GeV m ₂ / 3.0 TeV m _a 800 GeV | $\begin{array}{l} \textbf{TeV} & g_q{=}0.25, \ g_\chi{=}1, \ m(\chi){=}10 \ \text{TeV} \\ g_q{=}1, \ g_\chi{=}1, \ m(\chi){=}1 \ \text{GeV} \\ \text{tan} \beta{=}1, \ g_Z{=}0.8, \ m(\chi){=}100 \ \text{GeV} \\ \text{tan} \beta{=}1, \ g_Z{=}0.8, \ m(\chi){=}100 \ \text{GeV} \end{array}$ | ATL-PHYS-PUB-2022-036 2102.10874 2108.13391 ATLAS-CONF-2021-036 | $H \to ss$ $H \to ss$ | 2 MS vertices 2 low-EMF trackless jets | 139 s lifetime 139 s lifetime | | 0.31-72.4 m 0.19-6.94 m | m(s)= 35 GeV m(s)= 35 GeV | 2203.00587 2203.01009 |
| Scalar LQ 1 st gen Scalar LQ 2 nd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen Scalar LQ 3 rd gen Vector LQ mix gen Vector LQ 3 rd gen | $\begin{array}{cccc} 2e & \geq 2j & \forall e \\ 2\mu & \geq 2j & \forall e \\ 1\tau & \geq b & \forall e \\ 0e,\mu & \geq 2j, \geq 2b & \forall e \\ \geq 2e,\mu, \geq 1\tau \geq 1j, \geq 1b & - \\ 0e,\mu, \geq 1\tau \geq 0-2j, \geq b & \forall e \\ multi-channel \geq 1j, \geq 1b & \forall e \\ 2e,\mu,\tau & \geq 1b & \forall e \end{array}$ | 139 139 131 139 | LO mass 1.8 TeV LO mass 1.7 TeV LO mass 1.49 TeV LO ^m mass 1.49 TeV LO ^m mass 1.24 TeV LO ^m mass 1.24 TeV LO ^m mass 1.24 TeV LO ^m mass 1.26 TeV LO ^m mass 1.26 TeV LO ^m mass 1.26 TeV LO ^m mass 1.96 TeV | $\begin{array}{l} \beta = 1 \\ \beta = 1 \\ \mathcal{B}(\mathrm{LQ}^{\prime} \to br) = 1 \\ \mathcal{B}(\mathrm{LQ}^{\prime} \to br) = 1 \\ \mathcal{B}(\mathrm{LQ}^{\prime} \to tr) = 1 \\ \mathcal{B}(\mathrm{LQ}^{\prime} \to br) = 1, \text{YM coupl.} \end{array}$ | 2006.05872 2006.05872 2003.01294 2004.14060 2101.11582 2101.12527 ATLAS-CONF-2022-052 2303.01294 | VH with $H \rightarrow ss \rightarrow bbbb$ FRVZ $H \rightarrow 2\gamma_d + X$ FRVZ $H \rightarrow 4\gamma_d + X$ $H \rightarrow Z_d Z_d$ $H \rightarrow T Z_d Z_d$ | 2ℓ + 2 displ. vertices 2 μ-jets 2 μ-jets displaced dimuon | 139 s lifetime 139 γ_d lifetime 139 γ_d lifetime 32.9 Z_d lifetime ist 26.1 Z_c lifetime | 4-85 mm 0. 2.7-5 0.009-24.0 m | 554-939 mm m(y _d): 34 mm m(y _d): m(Z _d) | m(s)= 35 GeV = 400 MeV = 400 MeV = 40 GeV | 2107.06092 2206.12181 2206.12181 1808.03057 |
| $\begin{array}{c} \text{VLQ } TT \rightarrow Zt + X \\ \text{VLQ } BB \rightarrow Wt/Zb + X \\ \text{SOULD } T_{5/3}T_{5/3}T_{5/3}T_{5/3} \rightarrow Wt \\ \text{VLQ } T \rightarrow Ht/Zt \\ \text{VLQ } Y \rightarrow Wb \\ \text{VLQ } Y \rightarrow Wb \\ \text{VLL } t' \rightarrow Z\tau/H\tau \end{array}$ | $\begin{array}{c c} 2e/2\mu/23e,\mu\geq 1 \ b,\geq 1 \ j & -\\ multi-channel \\ t+X & 2(SS)/23e,\mu\geq 1 \ b,\geq 1 \ j & Ye \\ & 1e,\mu & \geq 1 \ b,\geq 3 \ j & Ye \\ & 1e,\mu & \geq 1 \ b,\geq 1 \ j & Ye \\ & 0e,\mu & \geq 2b,\geq 1 \ j & Ye \\ & multi-channel & \geq 1 \ j & Ye \end{array}$ | 139 36.1 95 36.1 95 139 195 139 195 36.1 195 36.1 195 139 105 139 | T mass 1.46 TeV B mass 1.34 TeV K ₂₇ mass 1.64 TeV T mass 1.64 TeV W mass 1.8 TeV B mass 1.85 TeV B mass 2.0 TeV | $\begin{array}{l} {\rm SU(2) \ doublet} \\ {\rm SU(2) \ doublet} \\ {\rm SU(2) \ doublet} \\ {\rm SU(2) \ singlet, s_{7}=0.5} \\ {\rm SU(2) \ singlet, s_{7}=0.5} \\ {\rm SU(2) \ singlet, s_{7}=0.5} \\ {\rm SU(2) \ doublet, s_{8}=0.3} \\ {\rm SU(2) \ doublet, s_{8}=0.3} \\ {\rm SU(2) \ doublet, s_{8}=0.3} \\ {\rm SU(2) \ doublet} \\ {\rm SU(2) \ doublet} \end{array}$ | 2210.15413 1808.02343 1807.11883 ATLAS-CONF-2021-040 1812.07343 ATLAS-CONF-2021-018 2303.05441 | $\begin{array}{c c} & \phi(200 \text{ GeV}) \rightarrow ss & kt \\ \hline \\ $ | w-EMF trk-less jets, MS v w-EMF trk-less jets, MS v w-EMF trk-less jets, MS v | vtx 36.1 s lifetime vtx 36.1 s lifetime vtx 36.1 s lifetime vtx 36.1 s lifetime | 0.04-21.5 m 0.06-52.4 | 0.41-51.5 m σ m σ | s = 1 pb, m(s) = 50 GeV s = 1 pb, m(s) = 50 GeV s = 1 pb, m(s) = 150 GeV | 1902.03094 1902.03094 1902.03094 |
| Excited quark $q^* \rightarrow qg$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $b^* \rightarrow bg$ Excited lepton τ^* | - 2j - 1γ 1j - - 1b,1j - 2τ ≥2j - | 139 36.7 139 139 | q" mass q" mass b" mass 3.2 Te r" mass | 6.7 TeV only u^* and $d^*, \Lambda = m(q^*)$ 5.3 TeV only u^* and $d^*, \Lambda = m(q^*)$ 4.6 TeV $\Lambda = 4.6$ TeV | 1910.08447 1709.10440 1910.08447 2303.09444 | $W \to N\ell, N \to \ell\ell\nu \qquad c$ $W \to N\ell, N \to \ell\ell\nu \qquad c$ | isplaced vtx ($\mu\mu$, μe , ee) + isplaced vtx ($\mu\mu$, μe , ee) + | μ 139 N lifetime | 0.74-42 mm 3.1-33 mm | m(N)= m(N)= | 6 GeV, Dirac 6 GeV, Majorana | 2204.11988 2204.11988 |
| $\begin{array}{c} \text{Type III Seesaw} \\ \text{LRSM Majorana } \nu \\ \text{Higgs triplet } H^{\pm\pm} \rightarrow W^{\pm}W \\ \text{Higgs triplet } H^{\pm\pm} \rightarrow \ell\ell \\ \text{Multi-charged particles} \\ \text{Magnetic monopoles} \end{array}$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | es 139 - 36.1 - 139 - 139 - 139 - 34.4 | Nº mass 910 GeV Nu mass 3.2 Te H** mass 350 GeV H** mass 1.08 TeV monopole mass 1.59 TeV | $\begin{split} m(W_R) = 4.1 \text{TeV}, g_L = g_R \\ \text{DY production} \\ \text{DY production} \\ \text{DY production}, [q] = 5e \\ \text{DY production}, [q] = 1g_D, \text{ spin } 1/2 \end{split}$ | 2202.02039 1809.11105 2101.11961 2211.07505 ATLAS-CONF-2022-034 2 1905.10130 | $\begin{array}{c} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | isplaced vtx ($\mu\mu$, μe , ee) + isplaced vtx ($\mu\mu$, μe , ee) + | e 139 N lifetime N lifetime 0.00 | 0.49-81 mm 0.39-51 mm 0.1 0.01 0.1 | m(N)= m(N)= 1 10 | 6 GeV, Dirac 6 GeV, Majorana ¹⁰⁰ cτ [m] | 2204.11988 2204.11988 |
| *Only a selection of the ava †Small-radius (large-radius, | partial data full data ailable mass limits on new sta s) jets are denoted by the lette | ites or phenoi er j (J). | 10 ⁻¹ 1 mena is shown. | ¹⁰ Mass scale [TeV |] | Y p *Only a selection of the av | ailable lifetime limits | atais shown. 0.001 | 0.01 0.1 | 1 10 100 | τ [ns] | |