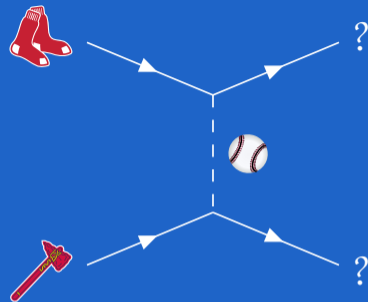


12th Edition of the Large Hadron Collider Physics Conference (LHCP2024)

June 3–7, 2024

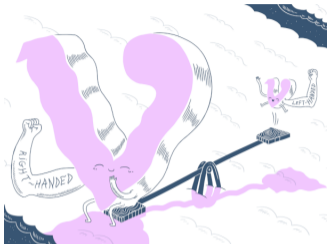


Prompt searches for feebly interacting particles

Joscha Knolle on behalf of the ATLAS & CMS Collaborations

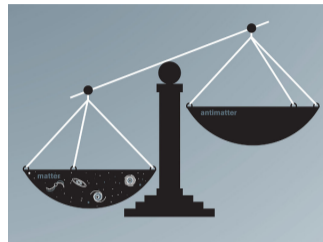
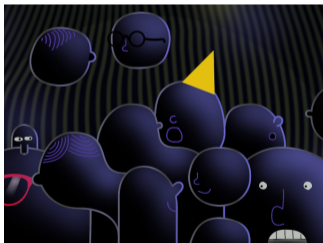


Why search for new physics?



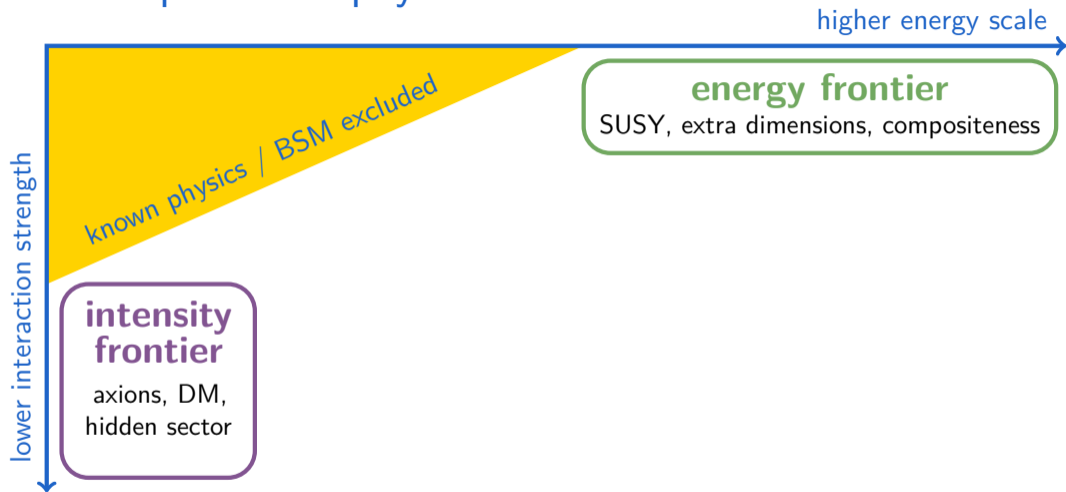
nonzero neutrino mass
⇒ see-saw mechanism?

dark matter
⇒ particle nature?

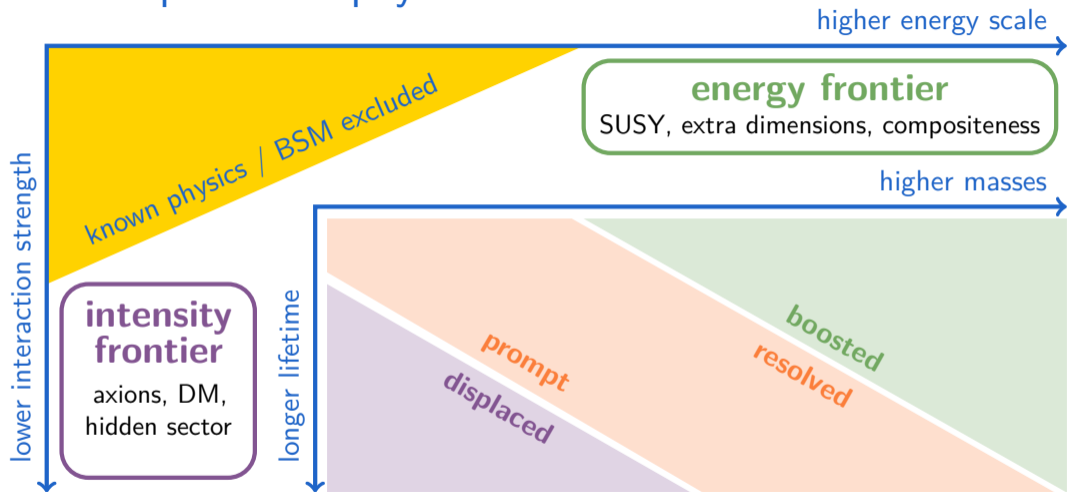


matter-antimatter
asymmetry ⇒ mechanism
for leptogenesis?

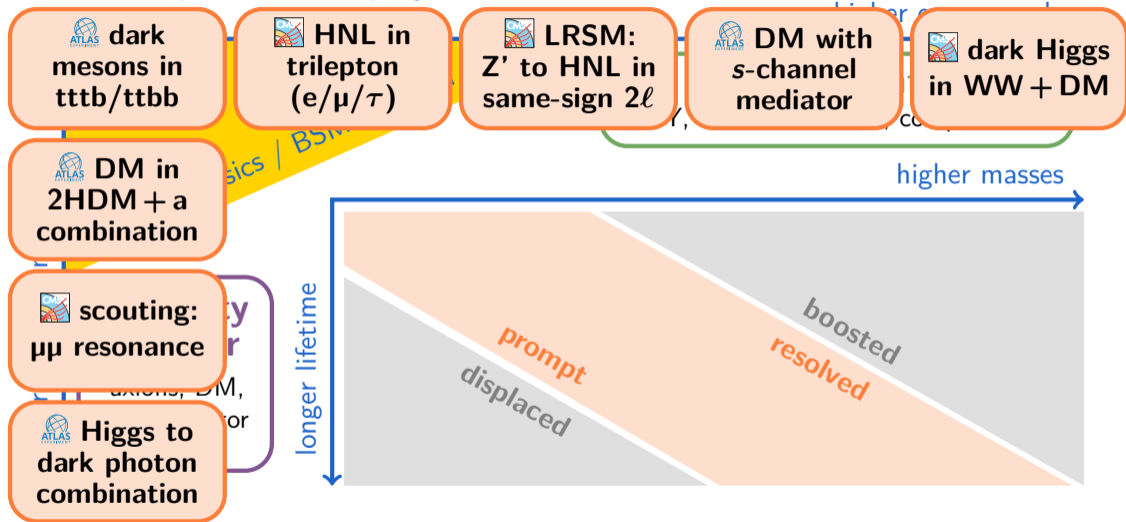
Landscape of new-physics searches



Landscape of new-physics searches



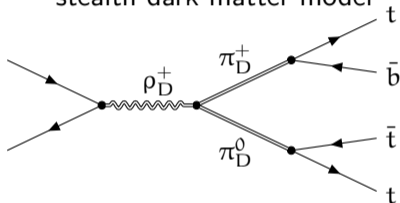
Landscape of new-physics searches



Dark mesons decaying to top and bottom quarks

arXiv:2405.20061, submitted to JHEP 

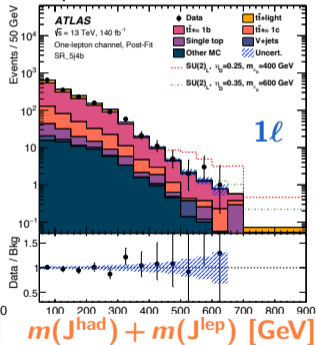
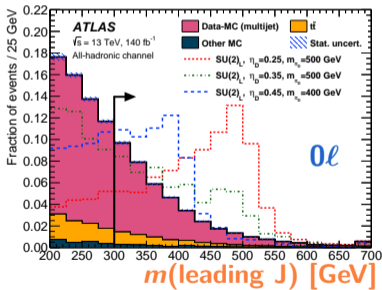
- dark pseudoscalar π_D and vector ρ_D mesons in stealth dark matter model



- search for (mostly resonant) π_D pair production in $t\bar{t}t\bar{t}b$ and $t\bar{t}b\bar{b}$ final states

- $300 < m(\pi_D) < 1200$ GeV,
 $0.15 < m(\pi_D) / m(\rho_D) < 0.45$

- $0l$: ≥ 6 jets, of which ≥ 3 b-tagged
 \Rightarrow reclustered to ≥ 2 large-radius jets J
- $1l$: ≥ 5 jets, ≥ 3 b-tagged, =1 lepton
 \Rightarrow reclustered to $J^{\text{had}} + J^{\text{lep}}$

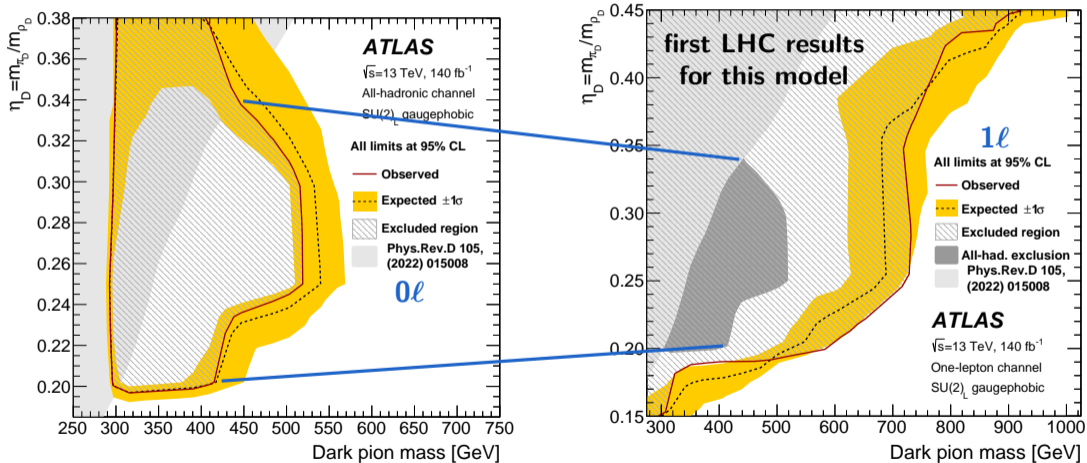


- main backgrounds: multijet ($0l$), $t\bar{t}$ +HF ($1l$)

Dark mesons decaying to top and bottom quarks

arXiv:2405.20061, submitted to JHEP 

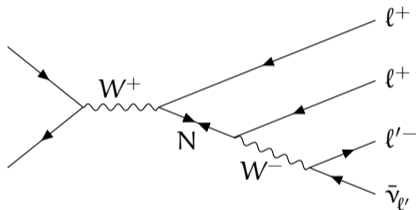
- simultaneous fit to signal and control regions, separately for 0ℓ and 1ℓ channels



Heavy neutral leptons in prompt trilepton events

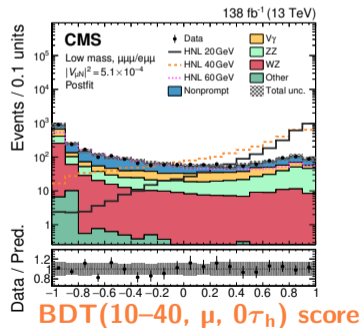
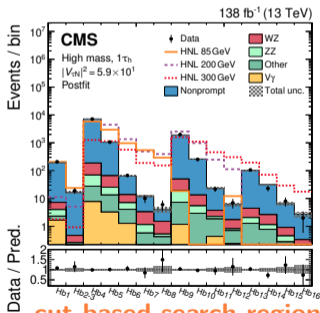
arXiv:2403.00100, accepted by JHEP [↗](#)

- Majorana or Dirac heavy neutral lepton mixed with SM neutrinos



- search for prompt decays with masses from 10 GeV to 1.5 TeV

- trilepton events with up to one τ_h (first time!), categorized by lepton flavors
- “low mass” $m_N < m_W$: W from decay off-shell
- “high mass” $m_N > m_W$: W from production off-shell

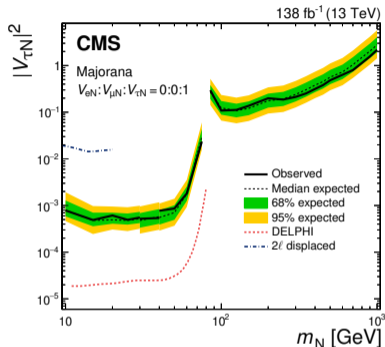
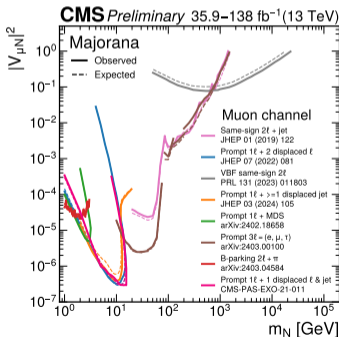
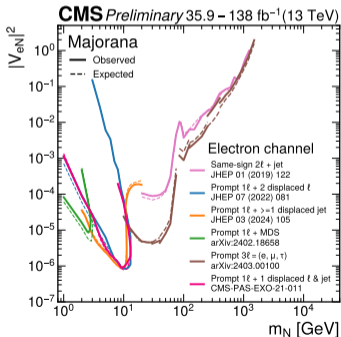




Heavy neutral leptons in prompt trilepton events

arXiv:2403.00100, accepted by JHEP

- exclusion limits for three scenarios:
 - exclusive electron, muon, or tau neutrino coupling
- **prompt trilepton** from 10 GeV to 1.5 TeV, complements displaced **trilepton** & **dilepton** below 20 GeV



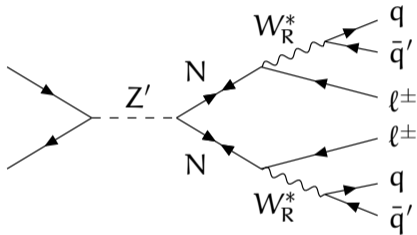
- first high-mass tau limits

more HNL searches:
 arXiv:2405.17605, sub-
 mitted to Phys. Rept.

Z' boson decaying to pair of heavy Majorana neutrinos

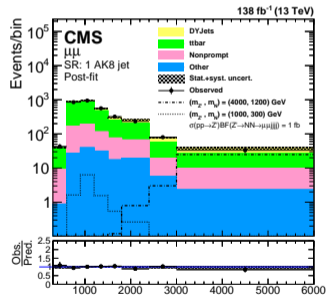
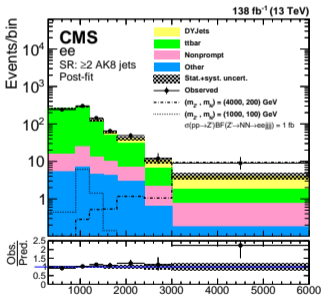
JHEP 11 (2023) 181 [↗](#)

- left-right symmetry model:
 $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$



- search for high-mass Z' with mass gap to N
 \Rightarrow boosted N decay

- same-sign dilepton events, categorized by lepton flavor and number of large-radius jets
- N's from $\ell + 2$ jets or 1 large-radius jet
 \Rightarrow two N's to reconstruct Z' mass



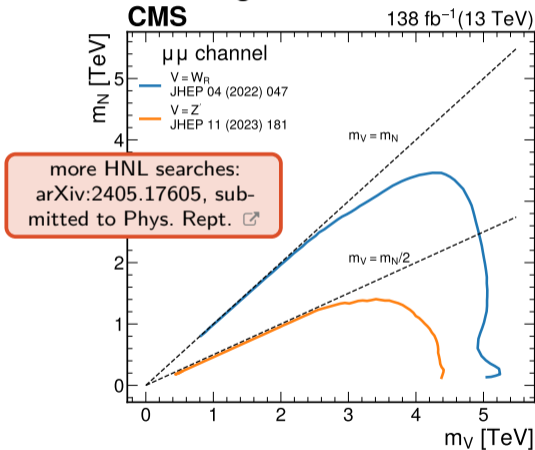
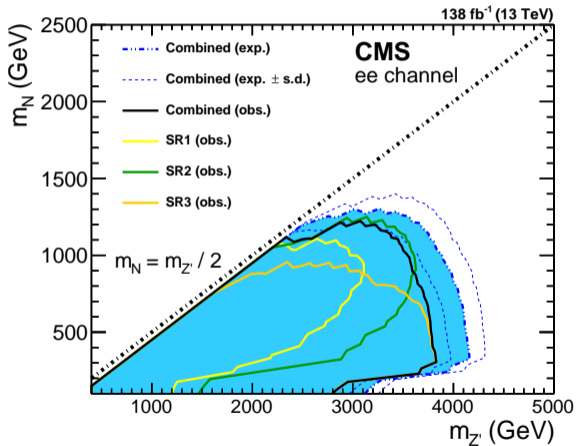
reconstructed Z' mass [GeV]



Z' boson decaying to pair of heavy Majorana neutrinos

JHEP 11 (2023) 181 [↗](#)

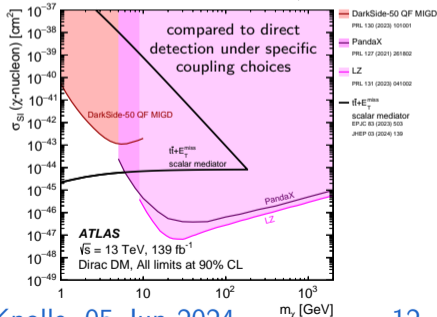
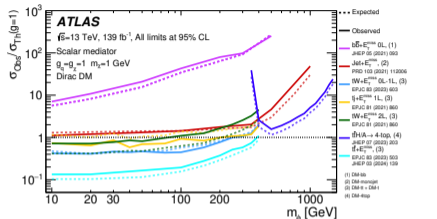
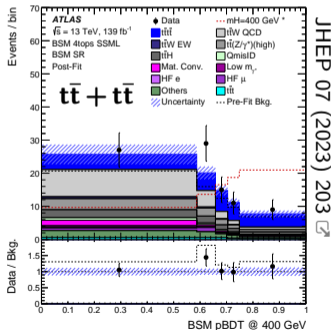
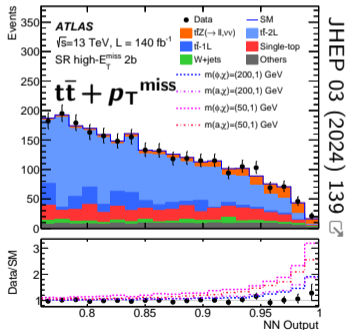
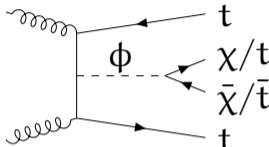
- simultaneous fit to signal and control regions, $t\bar{t}$ and DY background constrained



Dark matter with s -channel scalar mediator

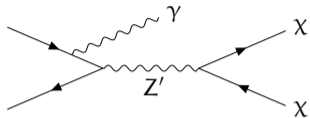
arXiv:2404.15930, submitted to Eur. Phys. J. C [↗](#)

- interpretation of $X + p_T^{\text{miss}}$ and visible searches
- Dirac DM χ with s -channel scalar mediator ϕ

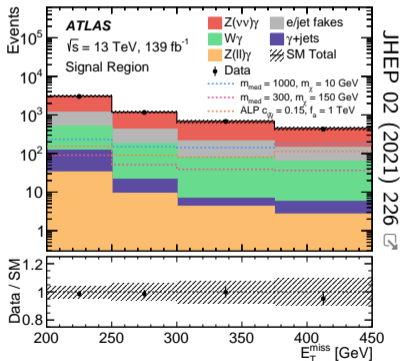


Dark matter with s -channel vector mediator

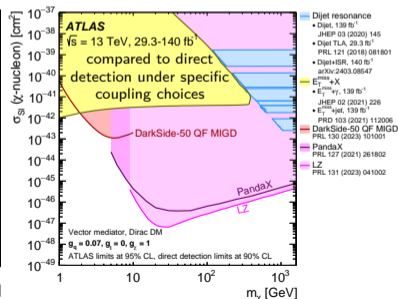
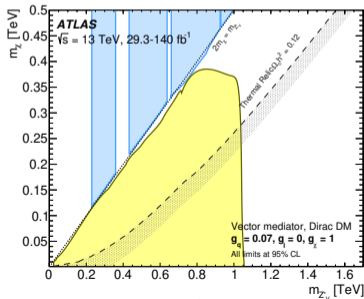
arXiv:2404.15930, submitted to Eur. Phys. J. C [↗](#)



- interpretation of $X + p_T^{\text{miss}}$ and resonance searches
- Dirac DM χ with s -channel vector mediator Z' , different coupling scenarios considered
- complementarity between different searches, and with direct detection experiments (but model dependent)



JHEP 02 (2021) 226 [↗](#)

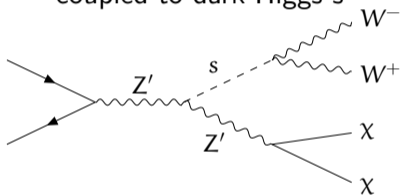




Dark matter in $W^+W^- + p_T^{\text{miss}}$ events

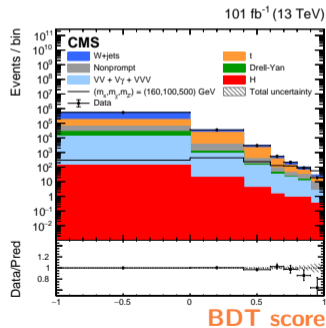
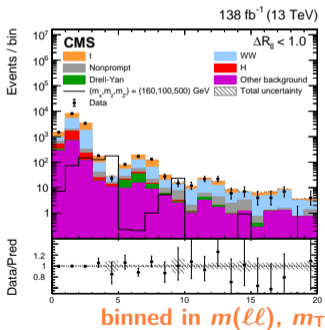
JHEP 03 (2024) 134 [↗](#)

- DM particle χ with U(1) symmetry yielding Z' , coupled to dark Higgs s



- $W^+W^- + p_T^{\text{miss}}$ search
- considered mass ranges:
 $160 < m_s < 400$ GeV,
 $200 < m_{Z'} < 2500$ GeV,
 $100 < m_\chi < 300$ GeV

- $2\ell 2\nu$ channel: categorize by dilepton mass and ΔR , and transverse mass of subleading ℓ and p_T^{miss}
- $\ell\nu qq$ channel: BDT to discriminate against W +jets background





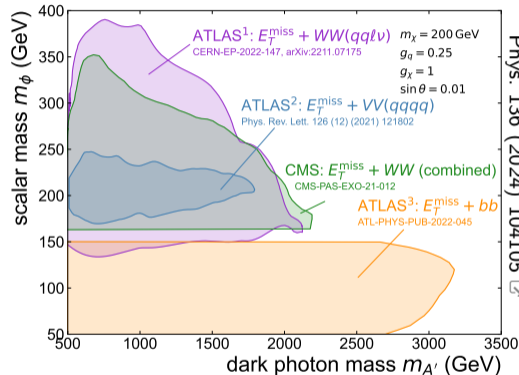
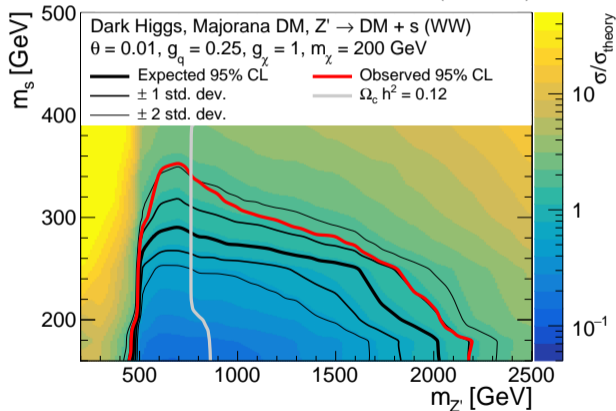
Dark matter in $W^+W^- + p_T^{\text{miss}}$ events

JHEP 03 (2024) 134 [↗](#)

- simultaneous fit to signal and control regions: top, WW, DY, W+jets constrained

CMS

138 fb⁻¹ (13 TeV)



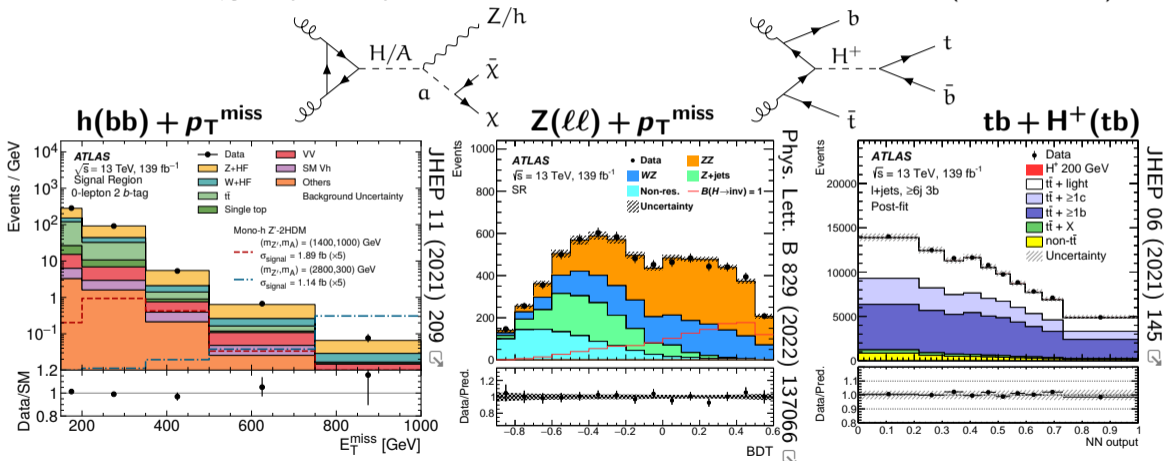
Ferber et al., Prog. Part. Nucl. Phys. 136 (2024) 104105 [↗](#)

more DM searches in
 arXiv:2405.13778, sub-
 mitted to Phys. Rept. [↗](#)

Dark matter in 2HDM with pseudoscalar mediator

arXiv:2306.00641, submitted to Sci. Bull.

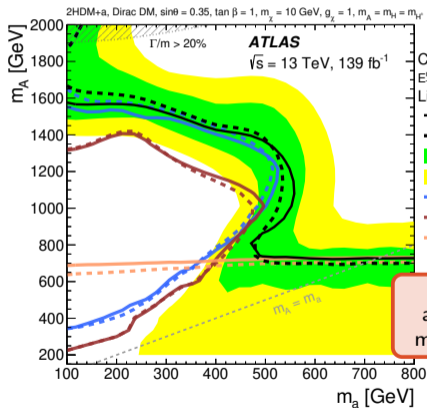
- DM fermion χ coupled to pseudoscalar mediator a in extension of 2HDM (h, H, A, H^\pm)




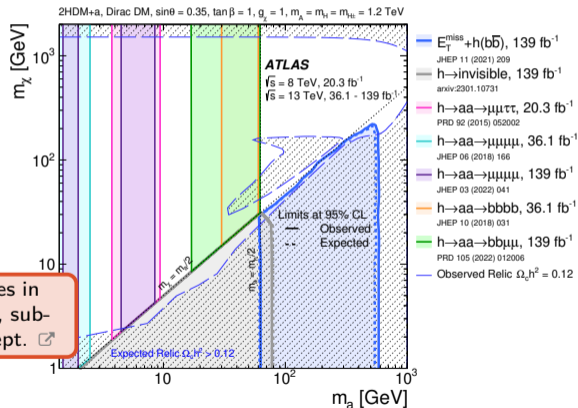
Dark matter in 2HDM with pseudoscalar mediator

arXiv:2306.00641, submitted to Sci. Bull. 

- consistent interpretation of searches and combination of three most sensitive channels
- significant complementarity between $X + p_T^{\text{miss}}$ and resonance searches



more DM searches in
arXiv:2403.09292, sub-
mitted to Phys. Rept. 

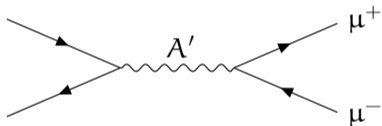




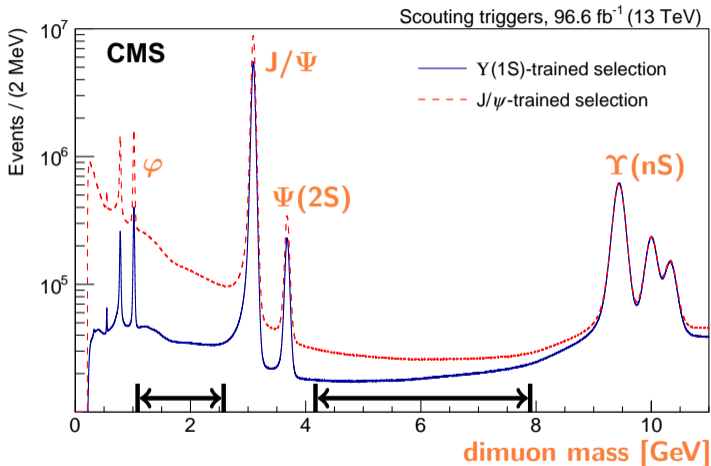
GeV-scale dimuon resonances with scouting

JHEP 12 (2023) 070 [↗](#)

- search for low-mass narrow resonance promptly decaying to dimuon
- e.g. dark photon, 2HDM + a



- “scouting”: high rate by storing dimuon events at high-level trigger
- 2 muons with $p_T > 4$ GeV from common vertex

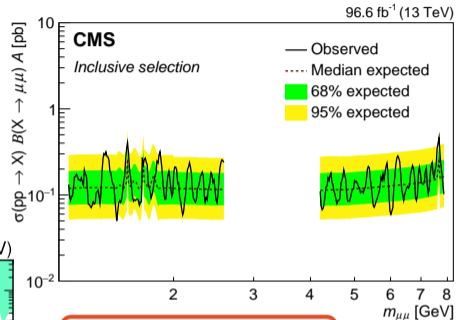
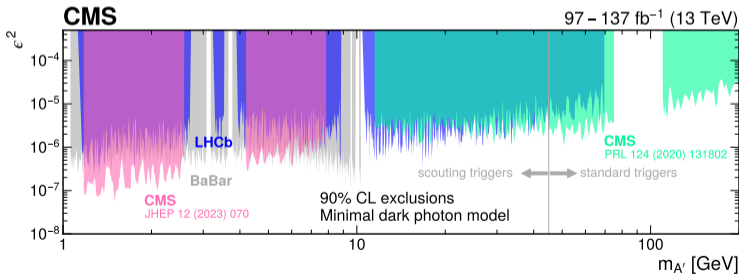




GeV-scale dimuon resonances with scouting

JHEP 12 (2023) 070 [↗](#)

- fit sliding mass window with signal+bkgd function
- signal modeled analytically; mass resolution 1.3%
- background modeled empirically to accommodate resonances, different trigger acceptances
- model-independent limits, and **interpretations**



more scouting searches:
 arXiv:2403.16134, submitted to Phys. Rept. [↗](#)

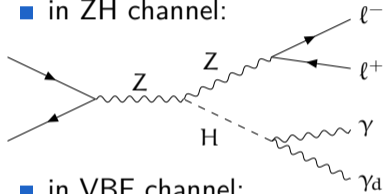
more dark sector:
 arXiv:2405.13778, submitted to Phys. Rept. [↗](#)

Higgs boson decays to photon and massless dark photon

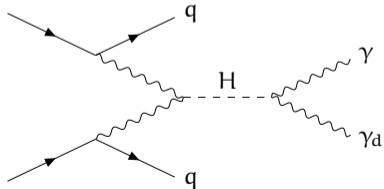
arXiv:2406.01656, submitted to JHEP

- extra dark sector $U(1)_d$:
massless dark photon γ_d

- in ZH channel:

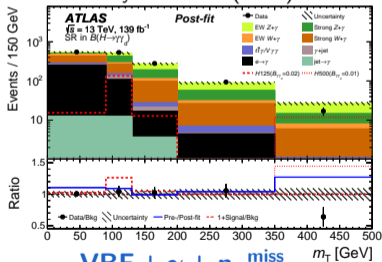


- in VBF channel:

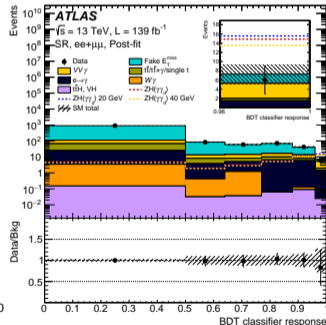


- combination of searches for Higgs decays $H \rightarrow \gamma + \gamma_d$
- ggF channel: $\gamma + p_T^{\text{miss}}$ search [JHEP 02 (2021) 226]
- consider SM Higgs and new scalars above 400 GeV

Eur. Phys. J. C 82 (2022) 105



VBF + $\gamma + p_T^{\text{miss}}$

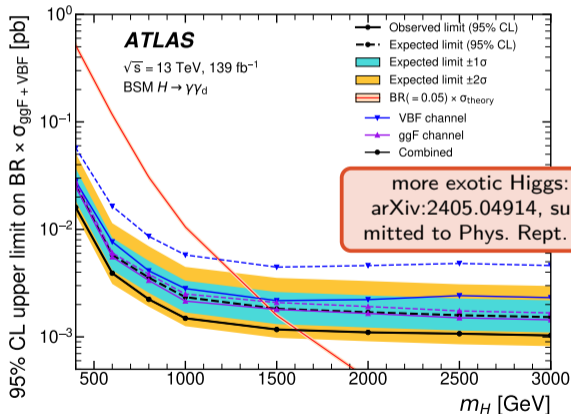
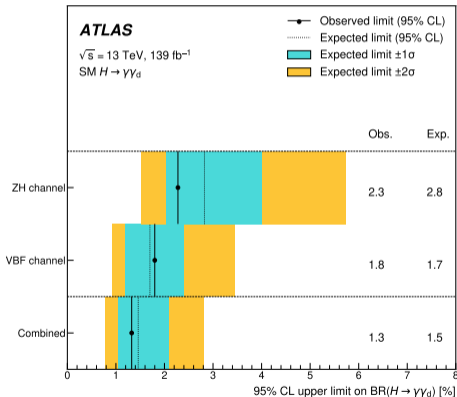













$Z(\ell\ell) + \gamma + p_T^{\text{miss}}$











Higgs boson decays to photon and massless dark photon

arXiv:2406.01656, submitted to JHEP [↗](#)

- SM Higgs scenario: $\mathcal{B} > 1.3\%$ is excluded, from ZH and VBF combination
- BSM Higgs scenario: limits cover 400 GeV to 3 TeV, from VBF and ggF combination



-  ATLAS Collaboration, Search for dark mesons decaying to top and bottom quarks in proton-proton collisions at $\sqrt{s}=13$ TeV with the ATLAS detector, arXiv:2405.20061, submitted to JHEP [↗](#)
-  CMS Collaboration, Search for heavy neutral leptons in final states with electrons, muons, and hadronically decaying tau leptons in proton-proton collisions at $\sqrt{s}=13$ TeV, arXiv:2403.00100, accepted by JHEP [↗](#)
-  CMS Collaboration, Review of searches for vector-like quarks, vector-like leptons, and heavy neutral leptons in proton-proton collisions at $\sqrt{s}=13$ TeV at the CMS experiment, arXiv:2405.17605, submitted to Phys. Rept. [↗](#)
-  CMS Collaboration, Search for Z' bosons decaying to pairs of heavy Majorana neutrinos in proton-proton collisions at $\sqrt{s}=13$ TeV, JHEP 11 (2023) 181 [↗](#)
-  ATLAS Collaboration, Constraints on dark matter models involving an s -channel mediator with the ATLAS detector in pp collisions at $\sqrt{s}=13$ TeV, arXiv:2404.15930, submitted to Eur. Phys. J. C [↗](#)
-  ATLAS Collaboration, Search for new phenomena with top-quark pairs and large missing transverse momentum using 140 fb^{-1} of pp collision data at $\sqrt{s}=13$ TeV with the ATLAS detector, JHEP 03 (2024) 139 [↗](#)
-  ATLAS Collaboration, Search for $t\bar{t}H/A \rightarrow t\bar{t}\bar{t}\bar{t}$ production in the multilepton final state in proton-proton collisions at $\sqrt{s}=13$ TeV with the ATLAS detector, JHEP 07 (2023) 203 [↗](#)
-  ATLAS Collaboration, Search for dark matter in association with an energetic photon in pp collisions at $\sqrt{s}=13$ TeV with the ATLAS detector, JHEP 02 (2021) 226 [↗](#)
-  CMS Collaboration, Search for dark matter particles in W^+W^- events with transverse momentum imbalance in proton-proton collisions at $\sqrt{s}=13$ TeV, JHEP 03 (2024) 134 [↗](#)
-  ATLAS Collaboration, Combination and summary of ATLAS dark matter searches interpreted in a 2HDM with a pseudo-scalar mediator using 139 fb^{-1} of $\sqrt{s}=13$ TeV pp collision data, arXiv:2306.00641, submitted to Sci. Bull. [↗](#)
-  CMS Collaboration, Dark sector searches with the CMS experiment, arXiv:2405.13778, submitted to Phys. Rept. [↗](#)

-  ATLAS Collaboration, Exploration at the high-energy frontier: ATLAS Run 2 searches investigating the exotic jungle beyond the standard model, arXiv:2403.09292, submitted to Phys. Rept. [↗](#)
-  ATLAS Collaboration, Search for dark matter produced in association with a standard model Higgs boson decaying into b-quarks using the full Run 2 dataset from the ATLAS detector, JHEP 11 (2021) 209 [↗](#)
-  ATLAS Collaboration, Search for associated production of a Z boson with an invisibly decaying Higgs boson or dark matter candidates at $\sqrt{s}=13$ TeV with the ATLAS detector, Phys. Lett. B 829 (2022) 137066 [↗](#)
-  ATLAS Collaboration, Search for charged Higgs bosons decaying into a top quark and a bottom quark at $\sqrt{s}=13$ TeV with the ATLAS detector, JHEP 06 (2021) 145 [↗](#)
-  CMS Collaboration, Search for direct production of GeV-scale resonances decaying to a pair of muons in proton-proton collisions at $\sqrt{s}=13$ TeV, JHEP 12 (2023) 070 [↗](#)
-  CMS Collaboration, Enriching the physics program of the CMS experiment via data scouting and data parking, arXiv:2403.16134, submitted to Phys. Rept. [↗](#)
-  ATLAS Collaboration, Combination of searches for the Higgs boson decays into a photon and a massless dark photon using pp collisions at $\sqrt{s}=13$ TeV with the ATLAS detector, arXiv:2406.01656, submitted to JHEP [↗](#)
-  ATLAS Collaboration, Observation of electroweak production of two jets in association with an isolated photon and missing transverse momentum, and search for a Higgs boson decaying into invisible particles at 13 TeV with the ATLAS detector, Eur. Phys. J. C 82 (2022) 105 [↗](#)
-  ATLAS Collaboration, Search for dark photons from Higgs boson decays via ZH production with a photon plus missing transverse momentum signature from pp collisions at $\sqrt{s}=13$ TeV with the ATLAS detector, JHEP 07 (2023) 133 [↗](#)
-  ATLAS Collaboration, ATLAS searches for additional scalars and exotic Higgs boson decays with the LHC Run 2 dataset, arXiv:2405.04914, submitted to Phys. Rept. [↗](#)