Exotics searches at ATLAS

The most recent results at the ATLAS detector

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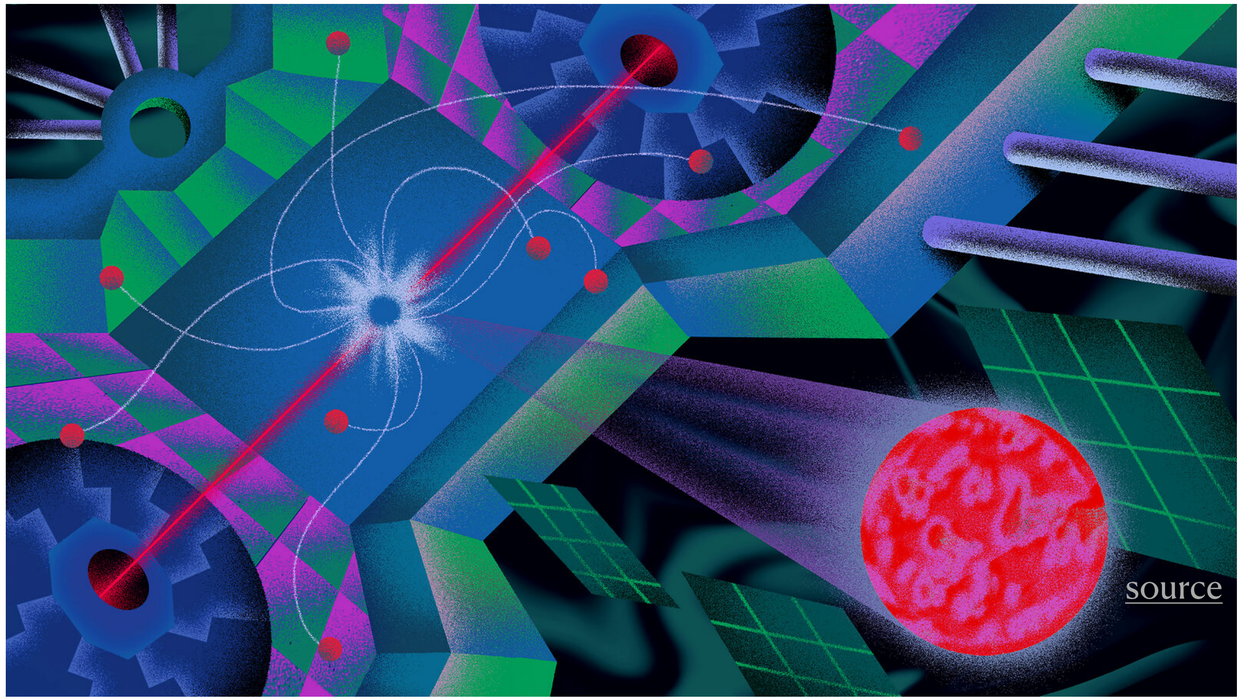
Searches for Beyond Standard Model physics

- Standard Model is an extremely accurate theory which is able to precisely describe the majority of fundamental interaction and elementary-particle phenomena seen so far
- But... There are questions, and among many of them:
  Why is there baryon asymmetry in visible Universe?
  What is behind the $(g-2)_\mu$ anomaly?
  What are suitable Dark Matter candidates?
- $\Rightarrow$ A collective effort from theorists, phenomenologists and experimentalists to find answers



- Experiments, including LHC, work on finding signatures of Exotics physics
- ATLAS experiment Exotics Working Group is searching for physics beyond the Standard Model with a signature-based program

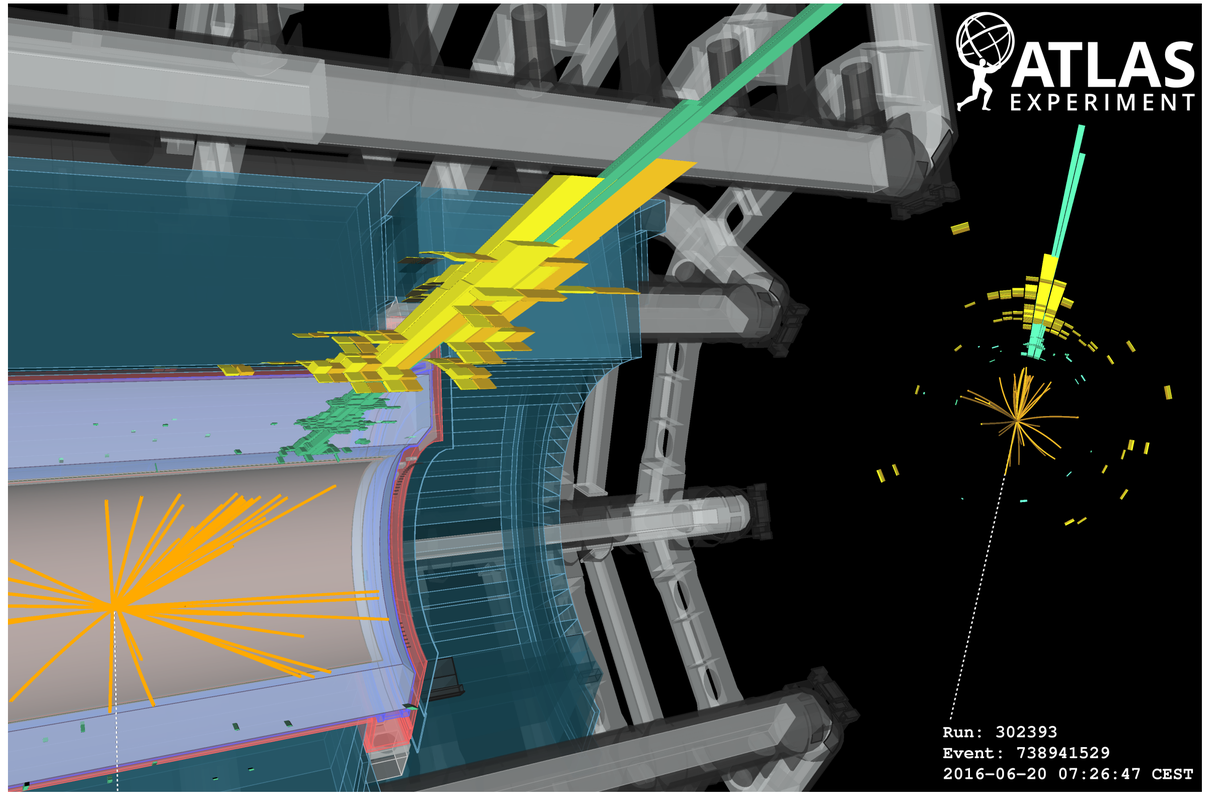
Recent results from ATLAS Exotics program

- The presented searches for Exotics physics are based on the analysis of *pp* collisions at $\sqrt{s} = 13$ TeV at ATLAS during Run 2 (2015-2018) → reduced statistic uncertainty

  We believe in its high discovery potential

- Improved object reconstruction, better reconstruction techniques
- Optimised event selection and choice of discriminative variables
- Continuous rectification of SM description
  - reduced systematic uncertainty
  - better signal sensitivity

Extending the phase space for BSM signal hunting



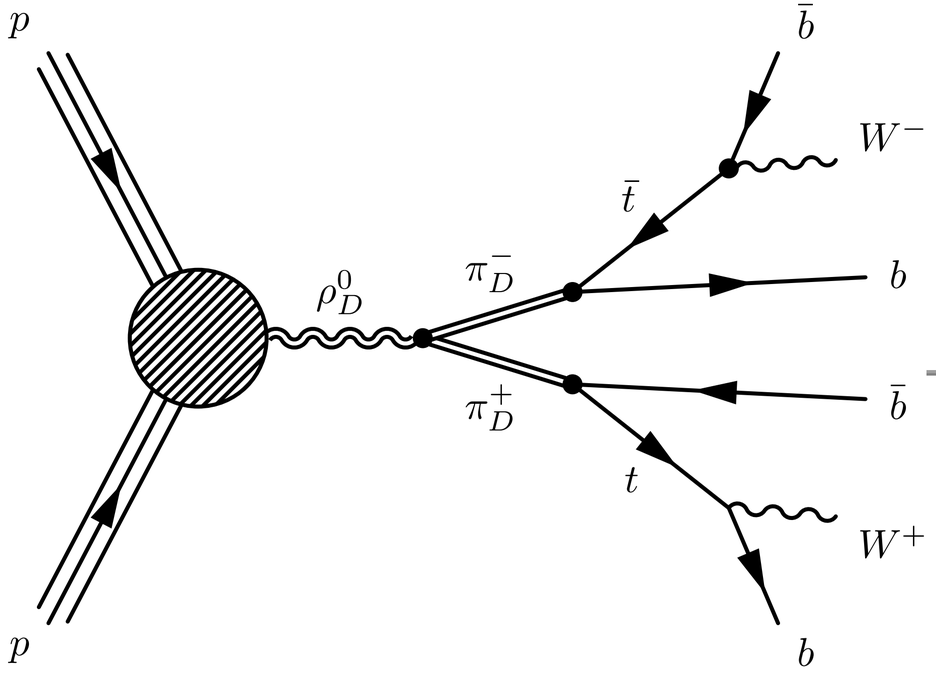
The second highest $E_{\mathrm{T}}^{\mathrm{miss}}$ monojet event in the 2016 ATLAS data
source

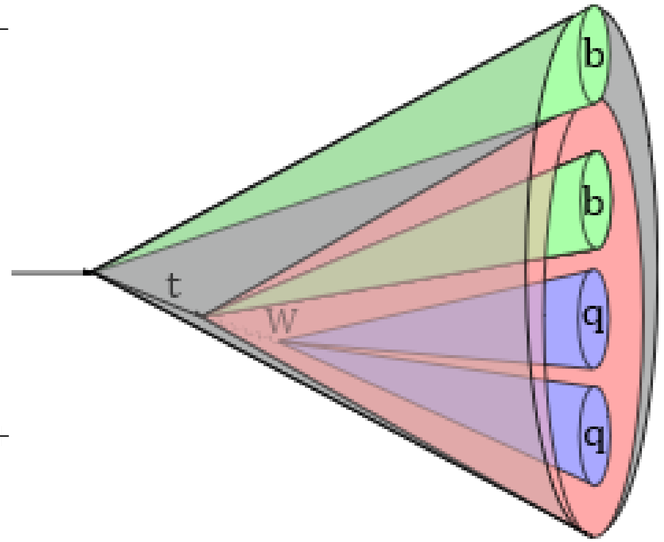
Topics on the agenda

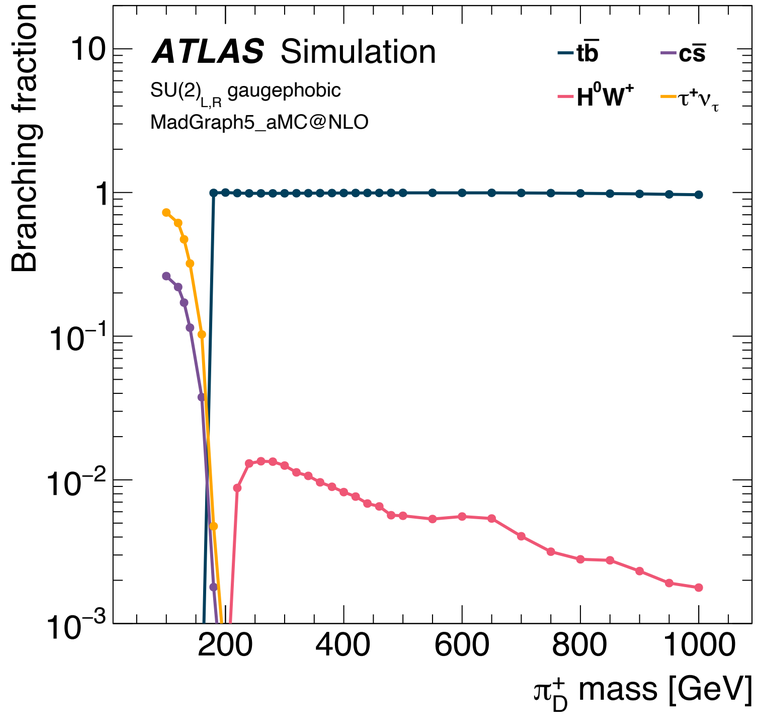
- Search for dark mesons decaying to top and bottom quarks
  - arXiv:2405.20061, submitted to JHEP
- Combined search for the massless dark photon
  - arXiv:2406.01656 , submitted to JHEP
- Search for new particles in events with a hadronically decaying W or Z boson and large missing transverse momentum
  - arXiv:2406.01272, submitted to JHEP

Search for dark mesons decaying to *t* and *b* quarks (1)

- Strongly coupled dark sector as extension to the SM
- Dark π and ρ mesons can be produced via coupling with SM EW bosons
- Dark pion promptly decaying to SM: predominantly, charged dark pions → *ttbb*, neutral dark pions → *tttb*
- This analysis: *ttbb* and *tttb* final states in all-hadronic and 1-light-lepton channels



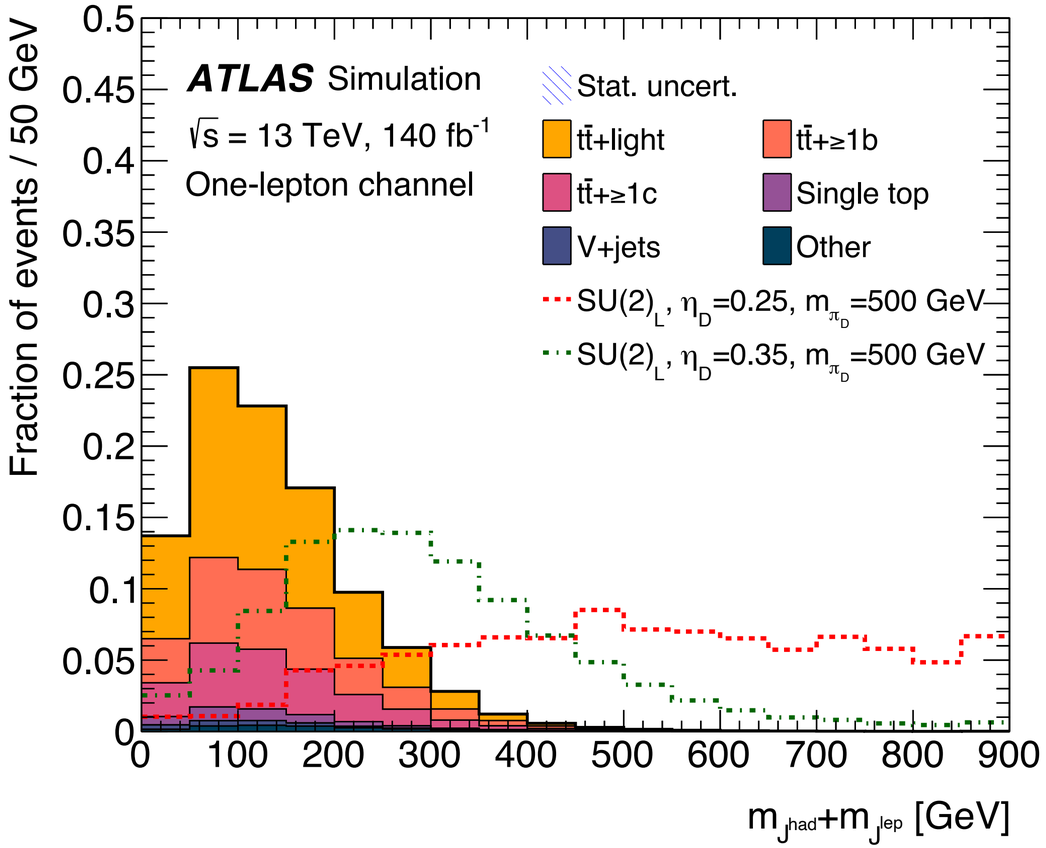




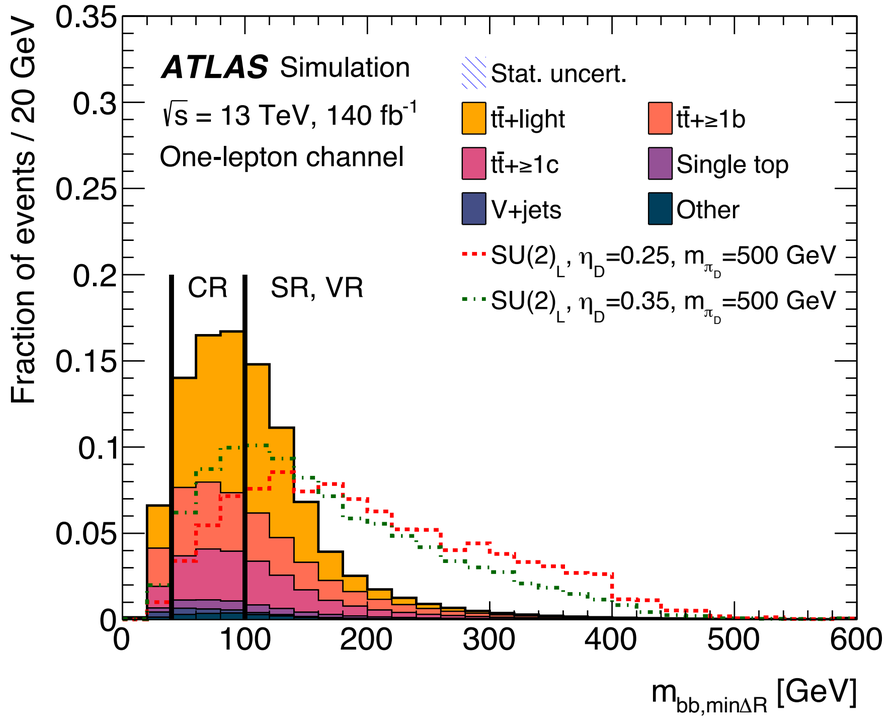
arXiv:2405.20061

Search for dark mesons decaying to t and b quarks (2)

- Events of interest have multiple jets, at least 3 b-jets
- Dark pions identified as large-radius (large-R) jets
- Selection based on the kinematic variables, e.g. $m_{bb}/p_{\mathrm{T},bb}$, $m_{bb,min\Delta R}$



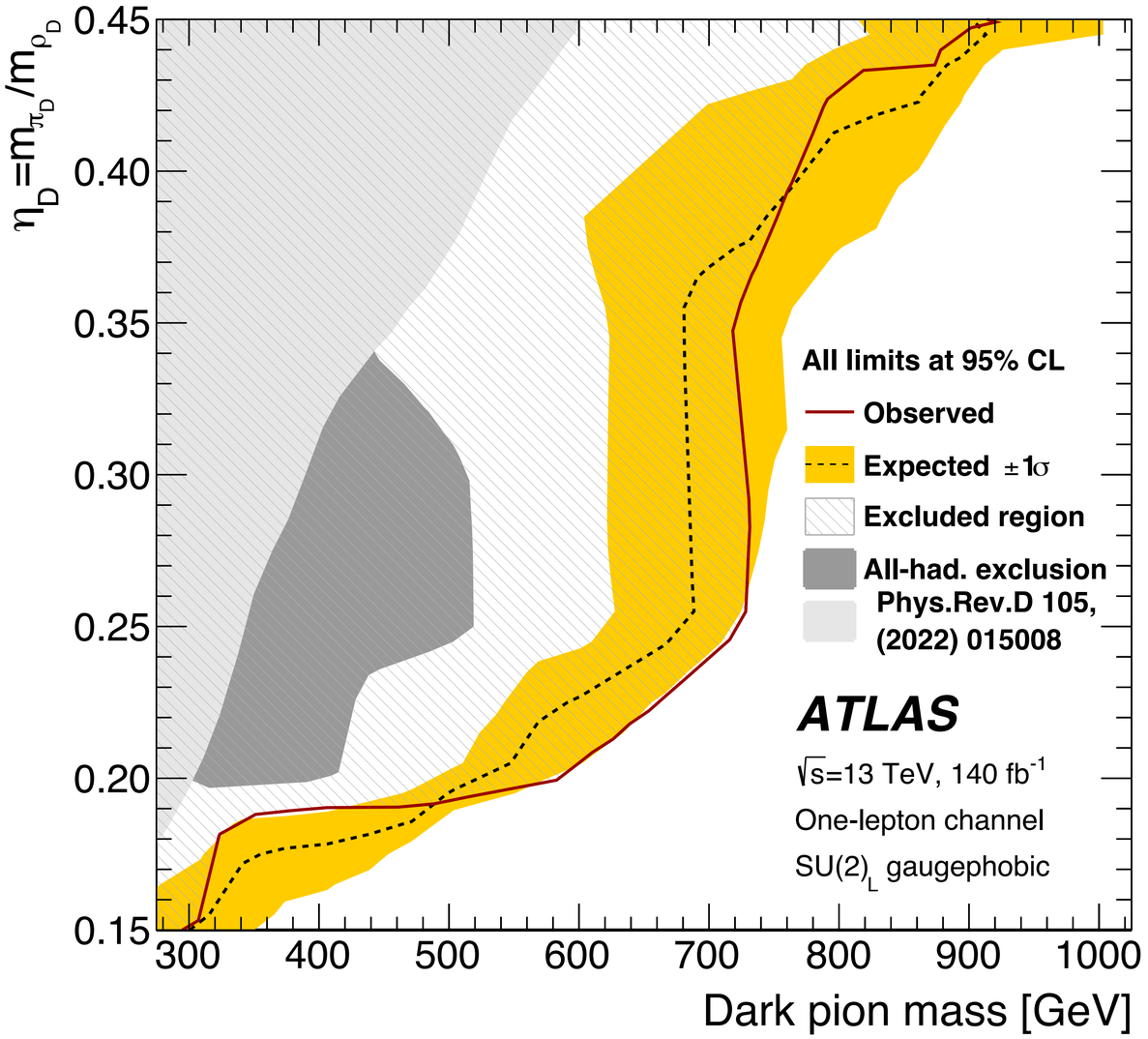
$$m_{\rho/\pi}^{\mathrm{DM}} = \sqrt{\sum_{j=1}^{N_j} \mathscr{P}^2_{\text{large}-R\text{ jet}}}$$



- Multi-jet background in the all-had channel is data-driven estimated
- $t\bar{t} + \geq b$ events contribution MC modelled with floating normalisation in the fit in the 1-l channel

arXiv:2405.20061

Search for dark mesons decaying to *t* and *b* quarks (3)

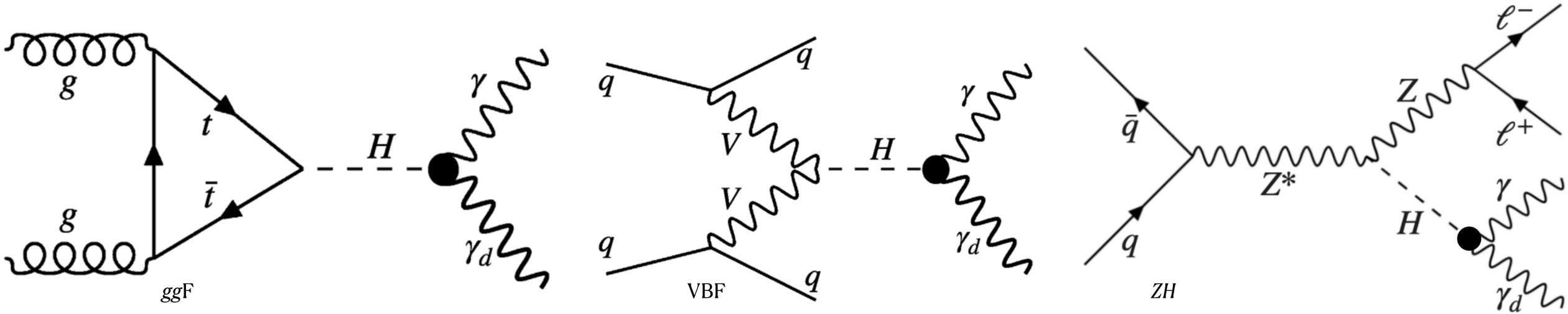


- Good agreement between data and the SM background expectation
- ⇒First direct constraints on the flavour-conserving QCD-like dark matter model
- The one-lepton contour fully contains the all-hadronic result
- The best exclusion limits on the dark rho-meson and dark pion masses for the moment:
- For $m_\pi^{\mathrm{DM}}/m_\rho^{\mathrm{DM}} = 0.45\ (0.25)$, dark pion with $m_\pi^{\mathrm{DM}} < 943\ (738)$ GeV are excluded

arXiv:2405.20061

Combination of searches for dark photon (1)

- Dark photon can be produced in decays $H_{125}/H_{\mathrm{BSM}} \to \gamma\gamma_d$
- The $H \to \gamma\gamma_d$ combination is well motivated by the competitive ATLAS results in the individual decay modes
- This combination considers 3 Higgs production modes:
  - $ggF \to H \to \gamma + E_{\mathrm{T}}^{\mathrm{miss}}$
  - VBF $\to Hqq \to \gamma + qq + E_{\mathrm{T}}^{\mathrm{miss}}$
  - ZH production leading to $\gamma + E_{\mathrm{T}}^{\mathrm{miss}} + Z$ where $Z \to ll$

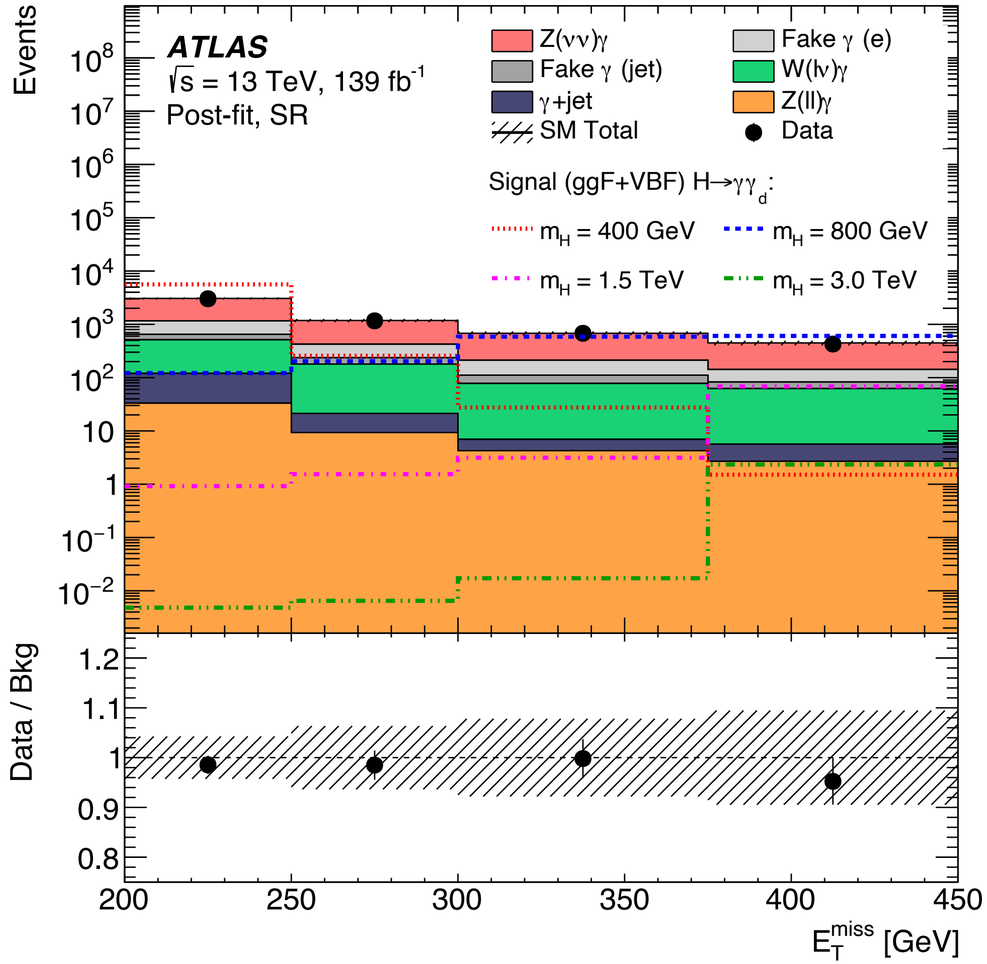


arXiv:2406.01656

Combination of searches for dark photon (2)

- In combination, the resulting likelihood function accommodates the correlation of the nuisance parameters
- γ_d presence is characterised by the missing transverse energy $E_{\mathrm{T}}^{\mathrm{miss}}$
- Two scenarios:
  - SM Higgs boson $m_H = 125$ GeV: ZH and VBF channels
  - Heavy Higgs $m_H = 400 - 3000$ GeV: VBF and *gg*F channels

Channels	VBF	ZH	mono photon recast(ggF)
Trigger by	$E_{\mathrm{T}}^{\mathrm{miss}}$	Lepton(s)	Photon
Photons	1	1	≥ 1
E_{T}^{γ} [GeV]	$\in (15, \max(110, 0.733 \times m_{\mathrm{T}}))$	> 25	> 150
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 60	> 200
Jets	2 or 3, $m_{j_1 j_2} > 250$ GeV $\lvert\Delta\eta_{j_1 j_2}\rvert > 3$, $\lvert\Delta\phi_{j_1 j_2}\rvert < 2$	≤ 2	≤ 1
Leptons	0 (e, μ)	2, $m_{\ell\ell} \in (76, 116)$GeV	0 (e, μ, τ)
Discriminant	m_{jj} and m_{T} in SR and 4 CRs	BDT score and 1 CR	$E_{\mathrm{T}}^{\mathrm{miss}}$
Considered processes	VBF (and ggF added for this combination)	ZH	VBF, ggF
Combination scenario	SM, BSM	SM	BSM
m_H (GeV)	60 - 2000	125	400 - 3000
Reference	Eur. Phys. J. C 82 (2022) 105 arXiv:2109.00925	JHEP07(2023)133 arXiv:2212.09649	ATL-PHYS-PUB-2023-003 arXiv:2011.05259

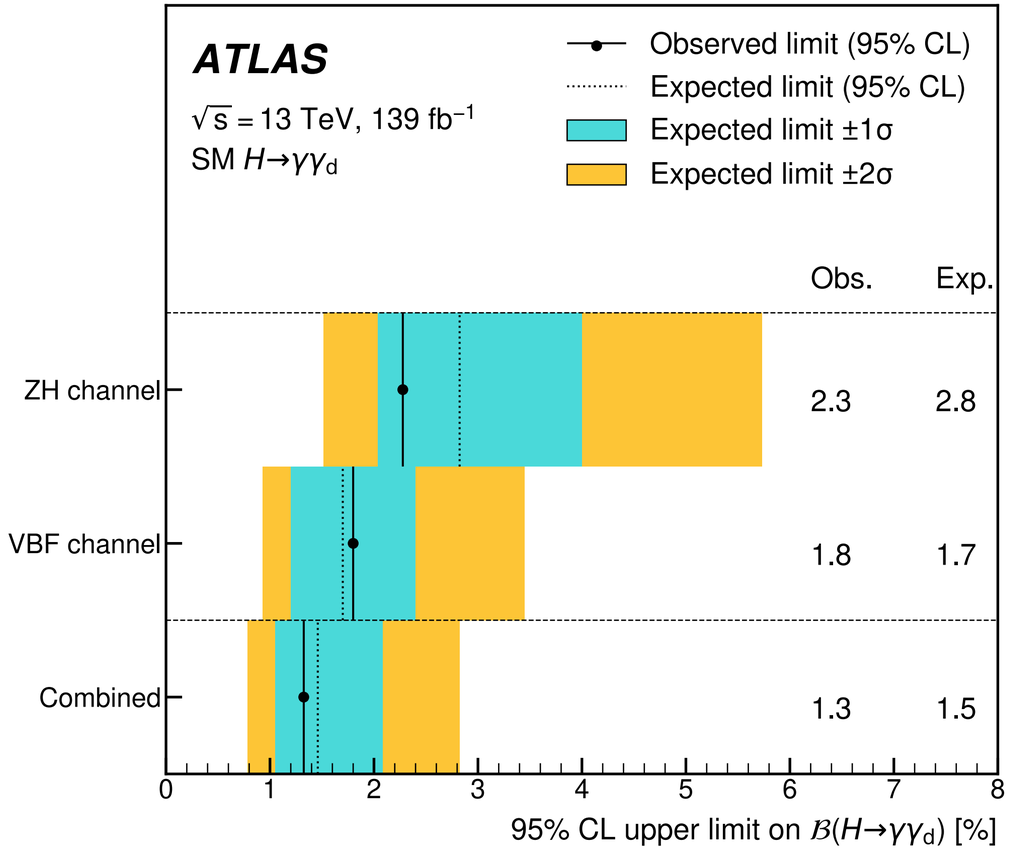


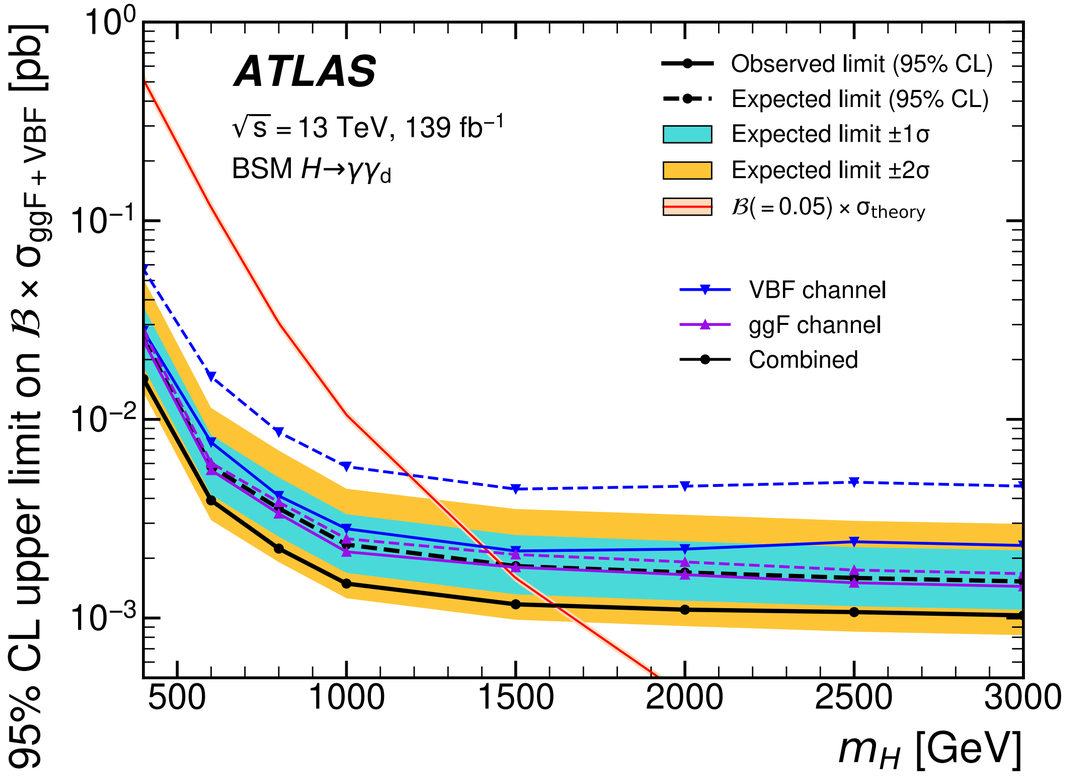
arXiv:2406.01656

←Property: Hassnae El Jarrari (CERN)

Combination of searches for dark photon (3)

- The upper limit of the $\mathcal{B}(H_{125} \to \gamma\gamma_d)$ is 1.3% — the most stringent constraint on the SM Higgs at the LHC
- The upper limit on $\sigma_{pp \to H_{\mathrm{BSM}}} \times \mathcal{B}(H_{\mathrm{BSM}} \to \gamma\gamma_d)$ in $H \to \gamma\gamma_d$ decays is set to 1 fb for $m_H = 3$ TeV
- By assuming theoretically predicted H_{BSM} production rate and the 5% decay $\mathcal{B}(H_{\mathrm{BSM}} \to \gamma\gamma_d)$, $H_{\mathrm{BSM}} \to \gamma\gamma_d$ decay was excluded for H_{BSM} mass below around 1.6 TeV excluded

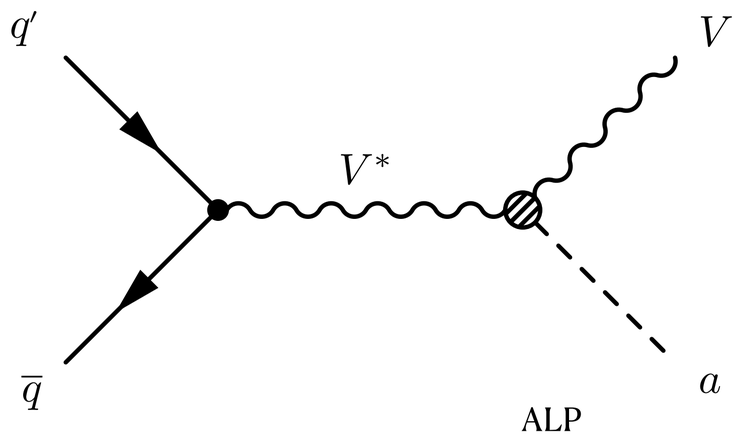




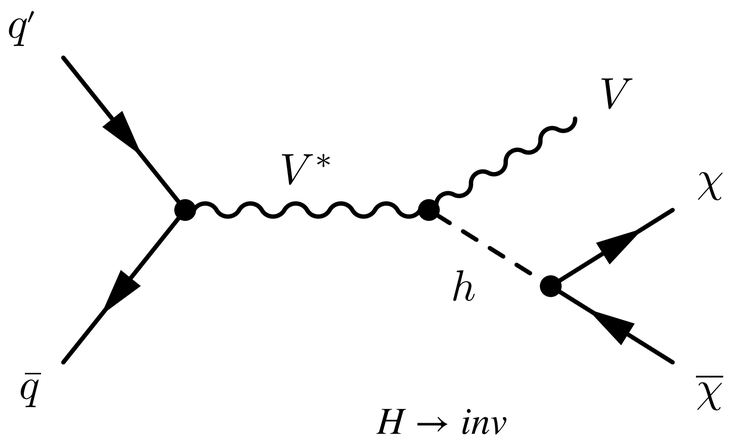
arXiv:2406.01656

Search for new particles in hadronic decays of W or Z with missing E_{T}(1)

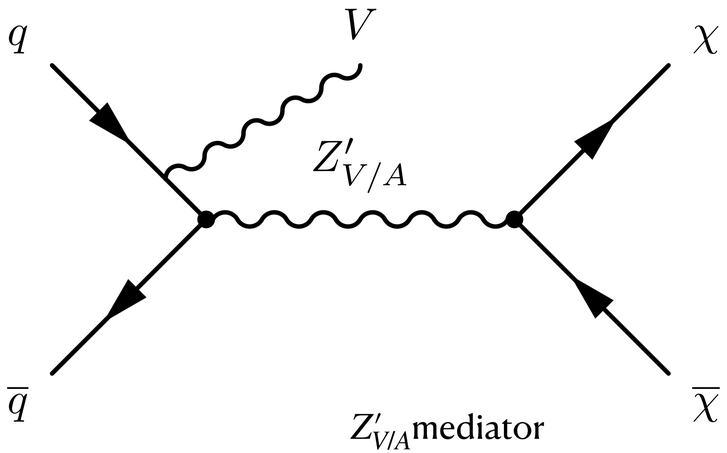
- Dark Matter produced in association with hadronically decaying vector boson (W/Z)
- BSM signal interpretation models: invisible Higgs decay, ALPs, WIMPs models with an axial/vector mediator, etc.
- Non-interacting $DM \rightarrow E_{\mathrm{T}}^{\mathrm{miss}}$, events with no leptons and the tag on the associated boson production $V \rightarrow qq$
- This is the search with increased sensitivity w.r.t. to the previous one with the partial Run 2 data set



ALP



$H \rightarrow inv$

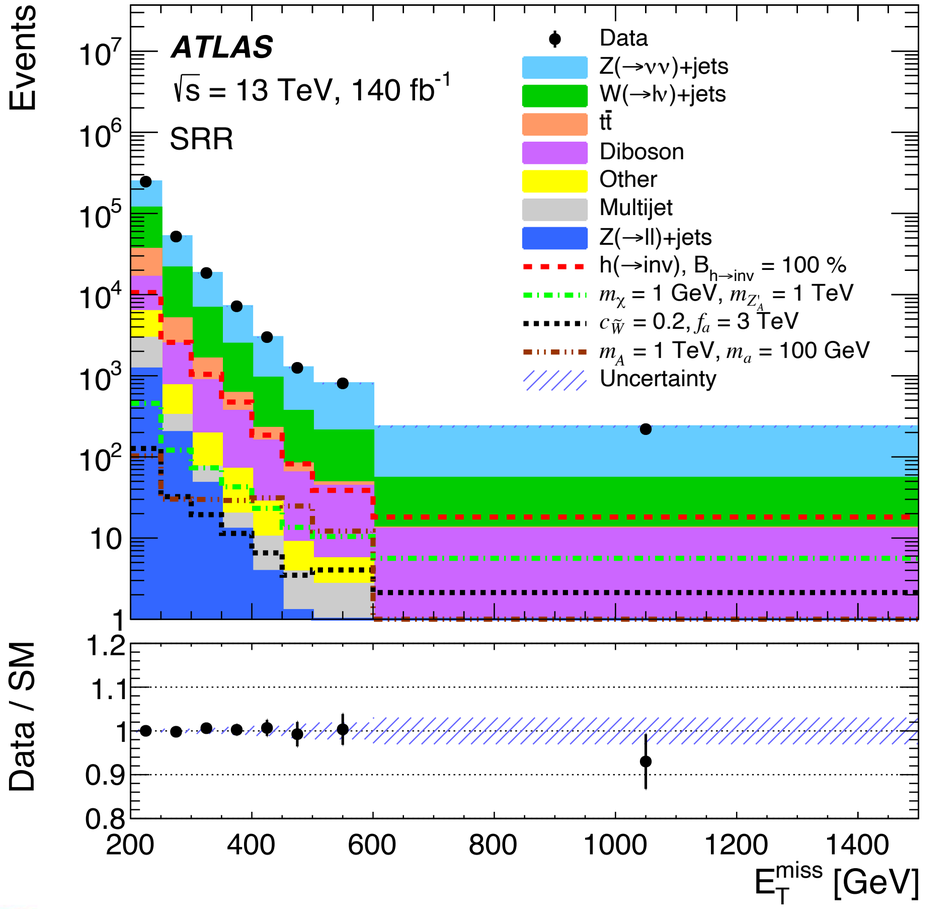


$Z'_{V/A}$mediator

https://arxiv.org/pdf/2406.01272

Search for new particles in hadronic decays of W or Z with missing E_{T}(2)

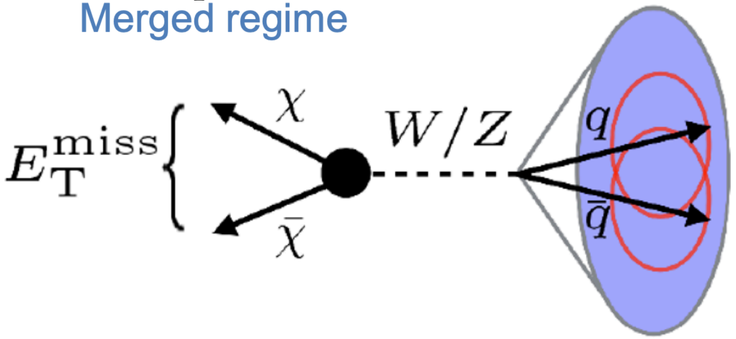
- Depending on the Lorentz boost of the vector boson V:
  - Merged regime: large-R jet $p_{\mathrm{T}} > 250$ GeV
  - Resolved regime: reconstructed V ($m_{j_1,j_2} \in [65,105]$ GeV, $\Delta R_{j_1,j_2} < 1.4$, $\Delta\phi_{j_1,j_2} < 140°$)
- $Z(\rightarrow \nu\nu)$+jets background estimated in di-leptonic phase space
- W+jets and $t\bar{t}$ contribution defined in events with muon and b-jets
- Maximum likelihood fit to the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution



1 large R-jet (R=1.0)

$E_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV

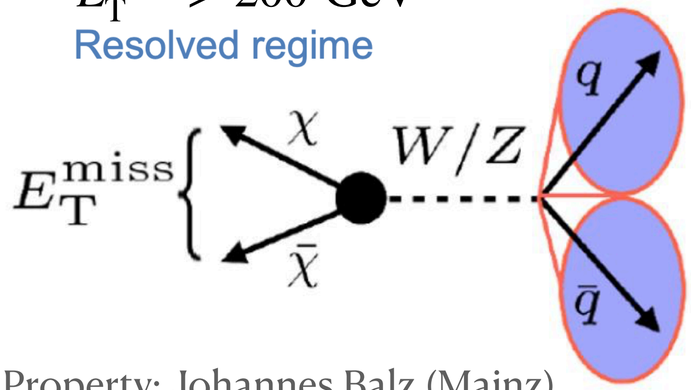
Merged regime



2 small R-jets (R=0.4)

$E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV

Resolved regime

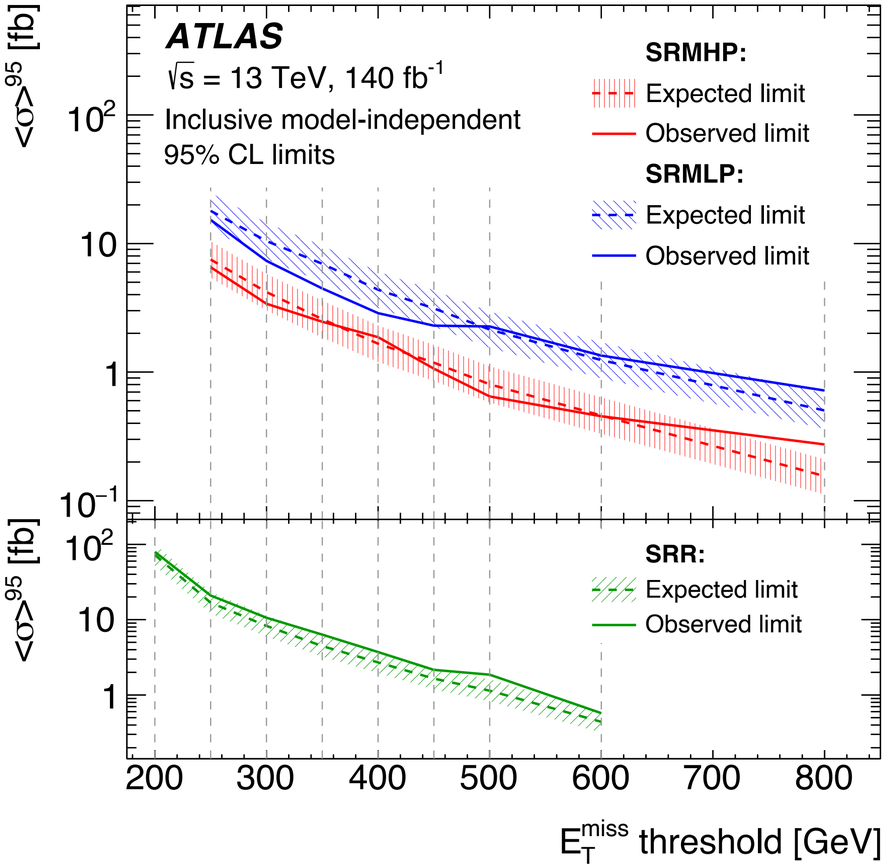


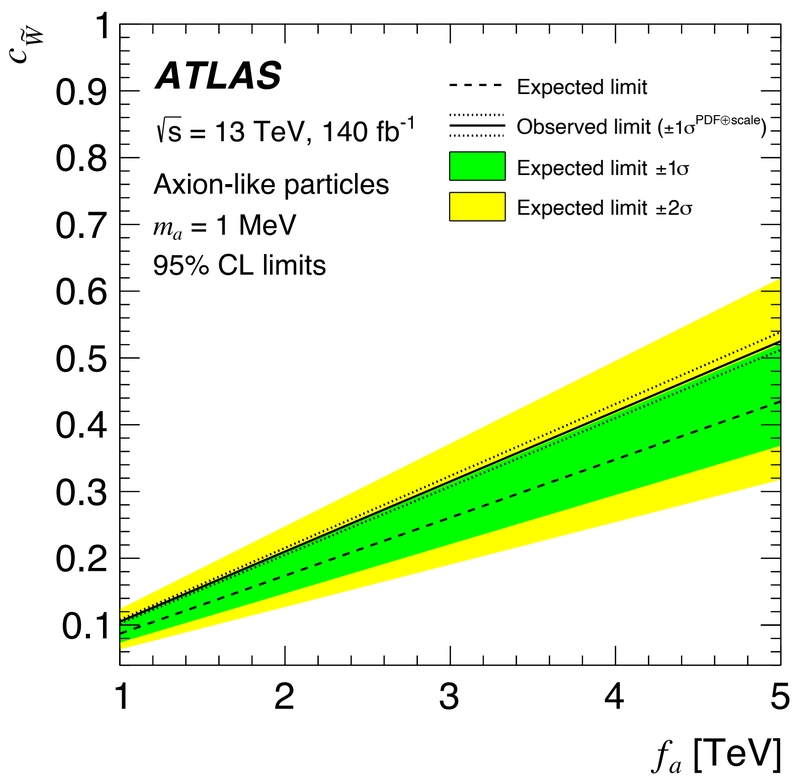
https://arxiv.org/pdf/2406.01272

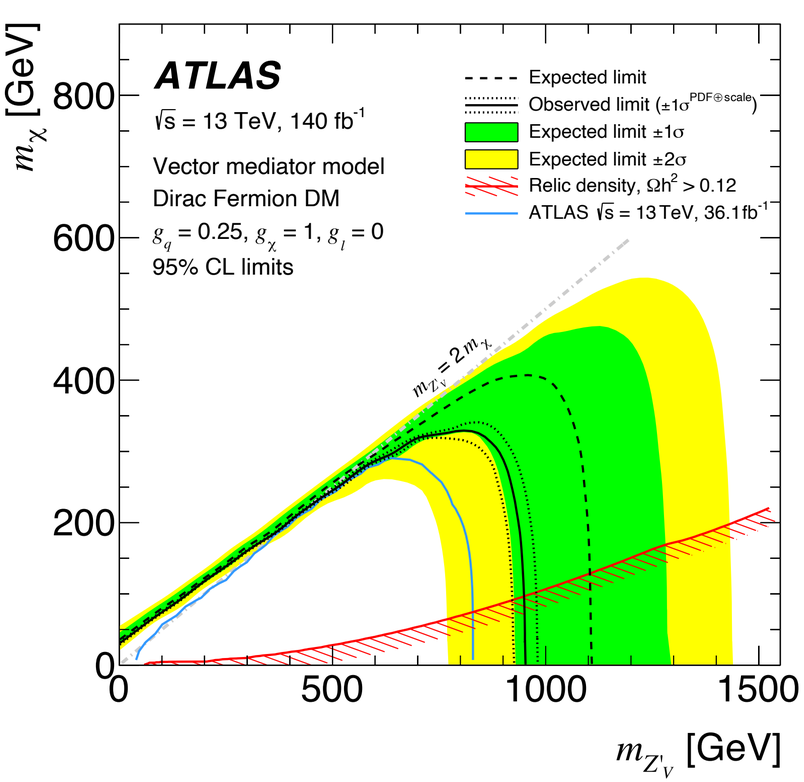
←↑Property: Johannes Balz (Mainz)

Search for new particles in hadronic decays of W or Z with missing E_{T}(3)

- The observed (expected) limit on the branching ratio $\mathcal{B}(H \to inv)$: 0.34 (0.31)
- Model-independent upper exclusion limit on the visible cross section of BSM processes: 0.3 to 79.5 fb — 1.9 x improvement
- Vector mediator masses up to 955 GeV are excluded, for a DM mass of 1 GeV and a fixed choice of couplings
- The ALP couplings $c_{\tilde{W}}$ above 0.1 are excluded for the effective scale f_a = 1 TeV







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Conclusions

- ATLAS Exotics program aims to test multiple BSM models
- In the presented searches for Exotics particles, no significant excess is observed above the Standard Model prediction
- The new analyses demonstrate consistent improvement in the results.
- More data (the LHC Run 3 is ongoing), continuous improvement of reconstruction and selection techniques, analysis combination and re-interpretation are still the major efforts at the ATLAS experiment in pursuit for finding BSM physics. Stay tuned!

Thank you for your attention!