Recent searches for new phenomena with the ATLAS detector

Presented by Mohamed Zaazoua

On behalf of the **ATLAS Collaboration**

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science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation

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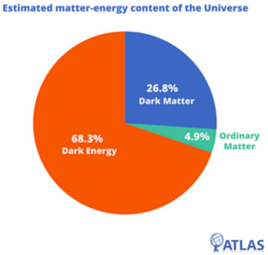
ATLAS EXPERIMENT

Introduction

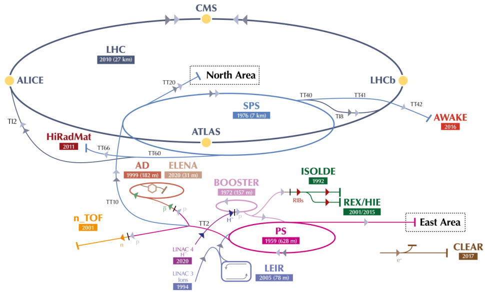
- The SM is successful, but not complete.
- Dark Matter existence is now firmly established.
  - Despite its abundance, its nature remains an open question for particle physics.
  - Favorite collider candidates can be produced at the LHC.
- B-anomalies are not addressed yet.
- The long-standing muon magnetic anomaly is not solved yet.
- Many BSM extensions that offer theoretical explanation to these questions are tested using ATLAS detector at the LHC.
- Only some of the ATLAS results using the full Run2 data are presented here.
- For more, check ATLAS public results page (link)



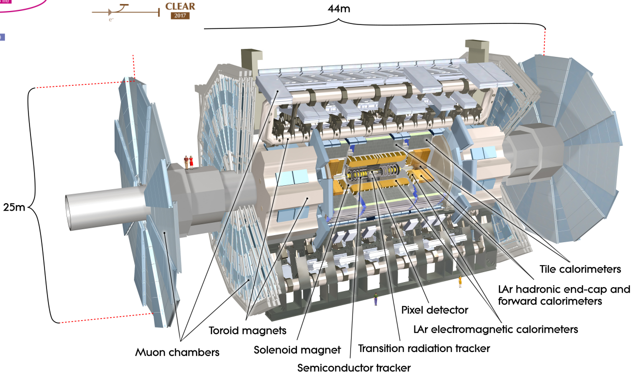
Overview

1. Searches for scalar and vector leptoquarks
2. Searches for new high mass resonances
3. Dark Matter searches in final states with large missing transverse momentum
4. Dark Sector searches using unconventional and long-lived particle signatures
5. SUSY searches targeting production of winos and higgsinos

LHC and ATLAS experiment



- Accelerate and collide beams of protons/ions.
- $\sqrt{s} = 7, 8, 13, 13.6$ TeV
- Recreate the condition of early universe.
- Record-holder in energy and size

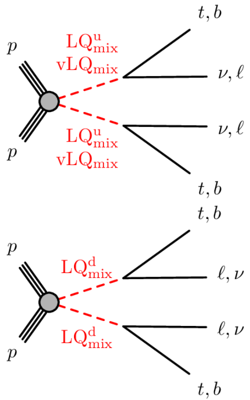


- General purpose, hermetic detector.
- Tracking + calorimeter technology: ID, ECAL, HCAL, MS
- Toroidal magnet system
- Two-level trigger system: record 1kHz from 40MHz

Search for pair-produced scalar and vector leptoquarks

arXiv:2210.04517

- LQs are color & electrical charged bosons predicted by BSM theories to connect quark and lepton sectors.
- LQs are promising candidates to address: LFU and anomalous magnetic moment of the muon.
- Investigating all possible LQs decays into: (t,b) (e,μ,ν)
- Detector signature: one ℓ, high MET, $\geq$ 4 jets from hadronically decaying t and b quarks.
- Interpreted as search for a pair-produced LQs of charges $\pm(2/3)$e (up-type) or $\pm(1/3)$e (down-type).



- Main backgrounds: $t\bar{t}$, W+jets, single-t-quark, tW
- Dedicated NNs used for signal and background separation.

Search for pair-produced scalar and vector leptoquarks

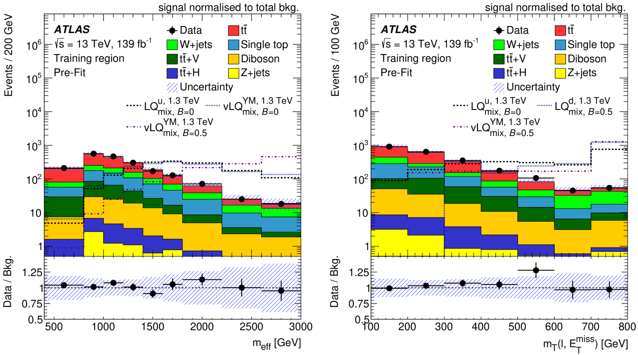
Event selection

Preselection			
$E_{\mathrm{T}}^{\mathrm{miss}}$ triggers			
exactly one signal lepton			
veto on additional baseline leptons			
$E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$			
≥ 4 small-R jets			
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) > 30\,\mathrm{GeV}$			
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, j_{1,2}) > 0.4$			
Top reweighting region	**W+jets CR**	**Single-top CR**	**Training region**
$n_b \geq 1$	$n_b = 1$	$n_b = 2$	$n_b \geq 1$
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) \geq 120\,\mathrm{GeV}$	$50\,\mathrm{GeV} \leq m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 120\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 120\,\mathrm{GeV}$	$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) \geq 120\,\mathrm{GeV}$
$am_{\mathrm{T2}} < 200\,\mathrm{GeV}$	$am_{\mathrm{T2}} > 200\,\mathrm{GeV}$	$am_{\mathrm{T2}} > 200\,\mathrm{GeV}$	$am_{\mathrm{T2}} > 200\,\mathrm{GeV}$
-	t_{had} candidate veto	large-R jet veto	-
-	lepton charge $= +1e$	-	-
-	-	$\Delta R(b_1, b_2) > 1.2$	-

- Top reweighting is appiled to single-top and $t\bar{t}$ events to improve the estimation of backgrounds (improved modelling of kinematic variables).

Search for pair-produced scalar and vector leptoquarks
Neural network training

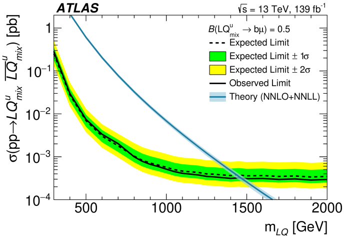
- MC events are used to train several NNs for various signal hypotheses.
- NeuroBayes package (link) is used:
  - One input node for each input variable, one bias node, user-defined number of hidden nodes (15), one output node giving NN output score
  - $t\bar{t}$, W+jets, single-t-quark and $t\bar{t}$+V are used as bckg in the training.
- Good modelling of the input variables in the training region i.e: m_{eff}, $m_T(\ell, E_T^{miss})$
  - No excess over SM predictions is observed

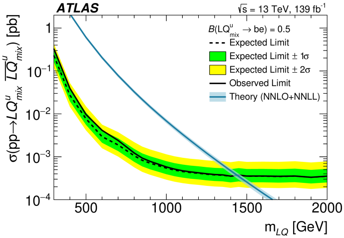


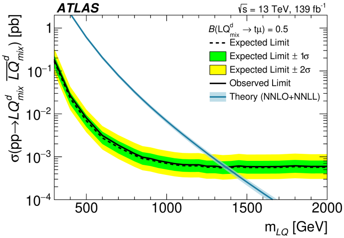
m_{eff}: scalar sum of the transverse momenta of leptons, jets, and E_T^{miss}.

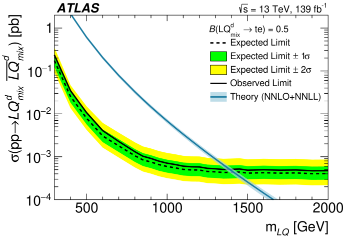
Search for pair-produced scalar and vector leptoquarks

Limits on the XS of pair-produced scalar LQ



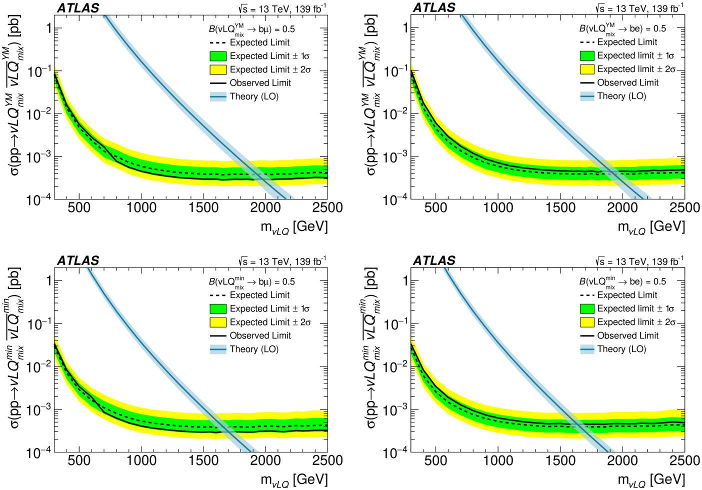






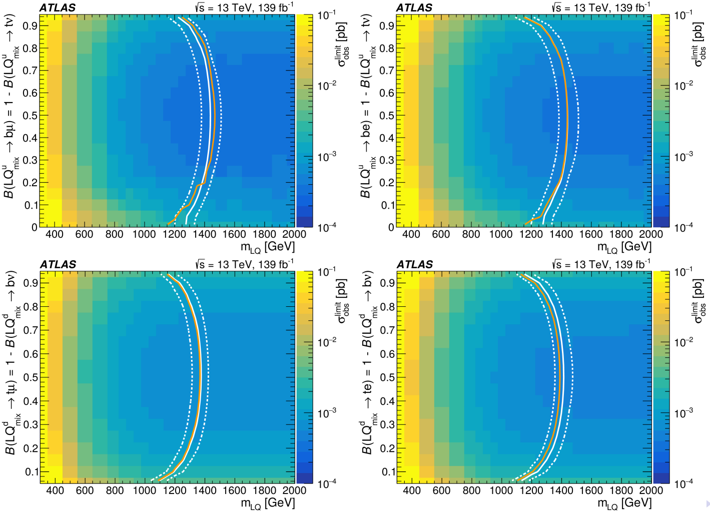
Search for pair-produced scalar and vector leptoquarks

Limits on the XS of pair-produced vLQ



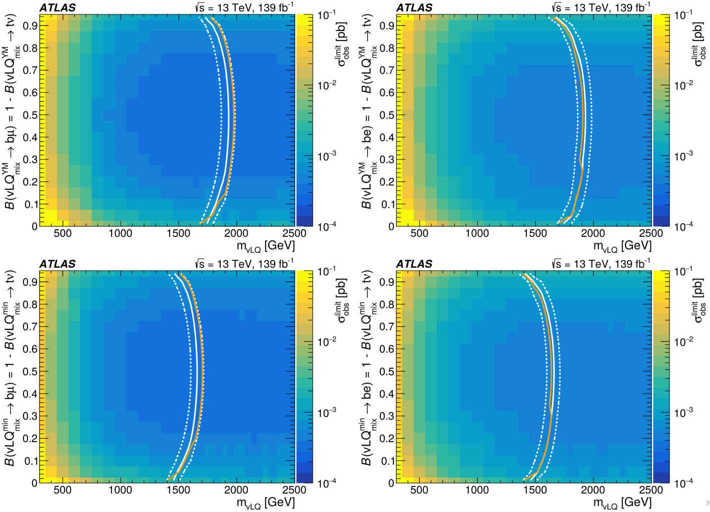
Search for pair-produced scalar and vector leptoquarks

Expected (solid white, $\pm 1\sigma$ ranges dashed) and observed (solid red) exclusion limits on the m_{LQ} as a function of the branching ratio into charged leptons at 95% CL.



Search for pair-produced scalar and vector leptoquarks

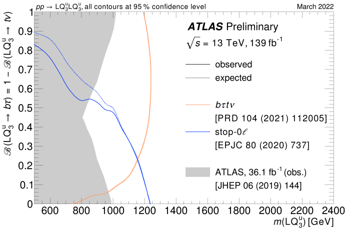
Expected (solid white, $\pm 1\sigma$ ranges dashed) and observed (solid red) exclusion limits on the m_{vLQ} as a function of the branching ratio into charged leptons at 95% CL.

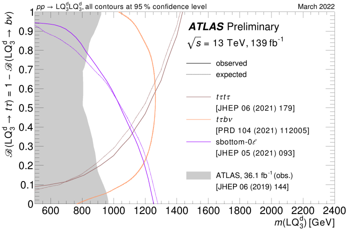


summary plots for the current ATLAS constraints on LQ

ATL-PHYS-PUB-2022-012

- Exclusion contours derived for four different pair-production scenarios of scalar LQs, decaying to (t,b) and also depending on the scenario to the 3rd or 1st/2nd lepton generations.
- Several dedicated searches and two reinterpretations of searches for supersymmetric particles target these signal models
  - contour for pair-produced scalar third-generation up-type (down-type) LQs with decays $LQ_3^u \to t\nu/b\tau$ ($\to b\nu/t\tau$), as a function of m_{LQ} and $B(LQ_3^U \to b\tau)$ ($B(LQ_3^d \to t\tau)$)
  - reinterpretation of the search for pair production of supersymmetric top squarks with no leptons in the final state (left: stop-0ℓ right: sbottom-0ℓ).





Search for new high mass resonances $\rightarrow \tau\nu$

ATLAS-CONF-2021-025

- Motivated by violation of lepton universality, additional SU(2) symmetry group.
- BSM theories predict additional charged or neutral heavy gauge bosons: W', Z':
  - Sequential SM (Flavor-universal benchmark model) assumes couplings of W' and Z' to fermions identically to W and Z in the SM.
  - Non-Universal Gauge Interaction Models (NUGIM): different couplings for the three ℓ generations.
  - Models with left-right symmetry: left-symmetry for weak interaction and right-symmetry must be broken at some energy scale (massive W' and Z')

- ATLAS previous searches:
  - W' $\rightarrow \ell\nu$ ($\ell = e, \mu$): exclude W' in the SSM with masses up to 6.0 TeV at 95% CL.
  - W' $\rightarrow \tau\nu$: exclude W' in the SSM with masses up to 3.7 TeV at 95% CL. (2015-16 data)
- This search: W' $\rightarrow \tau\nu$
- Experimental signature: high transverse momentum tau lepton decays and large MET:
  - Only hadronic reconstruction of tau (65% of all decays): a ν, one or three $\pi^{\pm}$ and up to two π^0.

Event selection & selected numbers of events

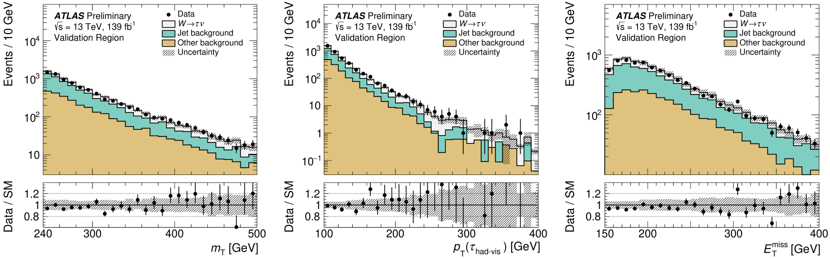
	Preselection
$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger	$70, 90, 110$ GeV
Event cleaning	applied
$\tau_{\text{had-vis}}$ tracks	1 or 3
$\tau_{\text{had-vis}}$ charge	± 1
$\tau_{\text{had-vis}}$ p_{T}	> 30 GeV
$\tau_{\text{had-vis}}$ $p_{\mathrm{T}}^{\mathrm{leadTrack}}$	> 10 GeV
Lepton veto	applied
$\Delta\phi(\tau_{\text{had-vis}}\ p_{\mathrm{T}}, E_{\mathrm{T}}^{\mathrm{miss}})$	> 2.4 rad

	Region requirements				
	SR	**CR1**	**CR2**	**CR3**	**VR**
Tau identification	L	VL $\setminus$ L	L	VL $\setminus$ L	L
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 150 GeV	< 100 GeV	< 100 GeV	> 150 GeV
$p_{\mathrm{T}}/E_{\mathrm{T}}^{\mathrm{miss}}$	$\in [0.7, 1.3]$	$\in [0.7, 1.3]$	–	–	< 0.7
m_{T}	–	–	–	–	> 240 GeV

Selection	Data	$W \to \tau\nu$	Jet background	Other background	W'_{SSM} (5 TeV)
Preselection	3640749	101810	–	89460	18.463
Tau identification	1189863	84370	–	62770	16.804
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	58528	13406	30760	12555	15.090
$0.7 < \frac{p_{\mathrm{T}}}{E_{\mathrm{T}}^{\mathrm{miss}}} < 1.3$	18528	9662	5761	3348	13.810
$m_{\mathrm{T}} > 1$ TeV	58	51.1	9.96	12.0	7.236

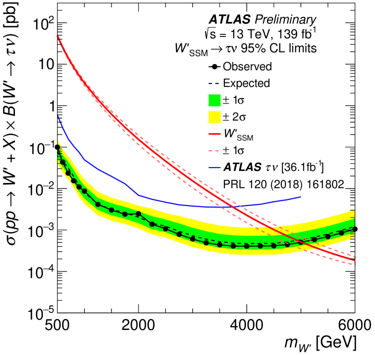
Search for new high mass resonances $\rightarrow \tau\nu$
Jet background estimation

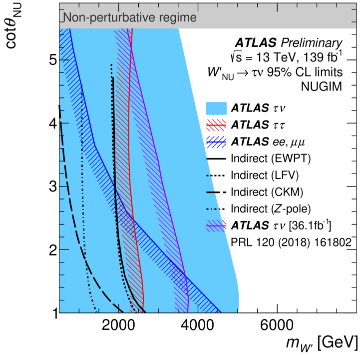
- Jet bckgd is estimated using a data-driven approach that uses 3 dedicated CRs.
- Validated in a dedicated VR: $p_T/E_T^{miss} < 0.7$ and $m_T > 240\,GeV$
- Non-jet bckgds are estimated using simulation.
- Good agreement between data and estimated bckgds: Distributions of the transverse mass, m_T, the momentum of the $\tau_{had-vis}$ candidate, p_T, and the missing transverse momentum in the event, E_T^{miss}, in the validation region.



Search for new high mass resonances $\to \tau\nu$
Interpretation

- Exclusion limits on BR*$\sigma(W' \to \tau\nu)$ in the SSM and NUGIM models.
- SSM W' excluded for masses up to 5.0 TeV at 95% CL.
- For NUGIM W', the exclusions are applied for $3.5 < m_{W'} < 5.0$ TeV as function of $1 \leq cot\theta_{NU} \leq 5.5$ (coupling to the third-generation fermions)
  - Indirect limits at 95% CL from fits to electroweak precision measurements (EWPT), lepton flavor violation (LFV), CKM unitarity and the original Z-pole data are also overlaid.





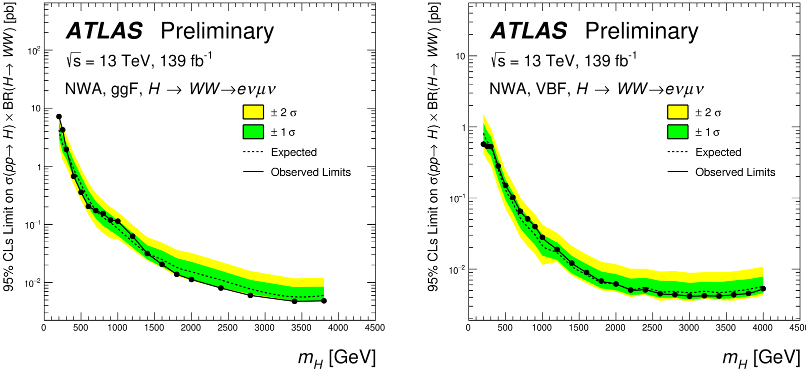
Search for heavy resonances in $W^+W^- \to e\nu\mu\nu$

ATLAS-CONF-2022-066

- Various hypotheses of physics BSM predict non-SM heavy resonances, including scalar, vector triplet, and tensor gravitons, that can all decay into the same final states as the SM Higgs boson.
- This is a search for neutral heavy resonances ($\mathcal{R} \to WW(\to e\nu\mu\nu)$)
- The analysis includes a jet inclusive signal category targeting resonances produced via ggF as well as two signal categories ($N_{jet} = 1$ and $N_{jet} \geq 2$) targeting VBF topologies.
- The normalizations of the dominant background contributions from $t\bar{t}/Wt$ and non-resonant WW production are constrained using dedicated control regions.
- 5 different modules: 3 scalar resonances and 2 non-scalar resonances.
- No excess above the SM backgrounds.

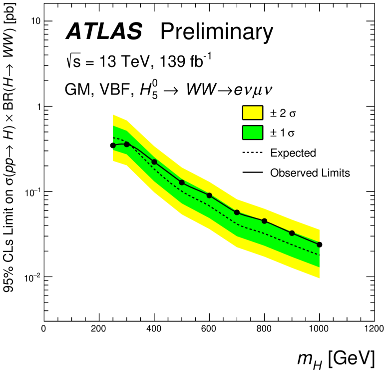
Search for heavy resonances in $W^+W^- \rightarrow e\nu\mu\nu$

- The 1st scalar have decay width much smaller than the resolution of the ATLAS detector, a narrow width approximation (NWA).
- Upper limits on the Higgs production $\sigma \times BR(H \rightarrow WW)$ for this signal for the ggF (left) and the VBF (right) production modes.



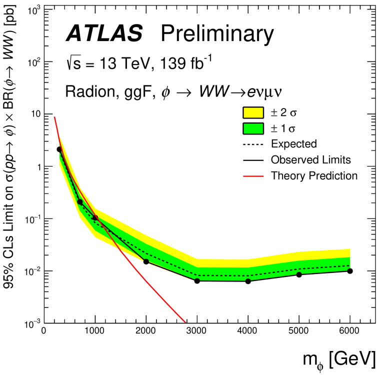
Search for heavy resonances in $W^+W^- \to e\nu\mu\nu$

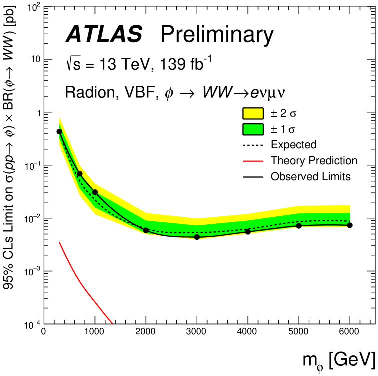
- The 2nd module is a neutral scalar predicted by the Georgi-Machacek (GM) Higgs fiveplet model (in which the particle does not couple to fermions leaving it with only a VBF production)
- Upper limits on the Higgs production $\sigma \times BR(G^*/H \to WW)$ for a heavy Higgs boson arising from the Georgi-Machacek model with VBF production mode.



Search for heavy resonances in $W^+W^- \to e\nu\mu\nu$

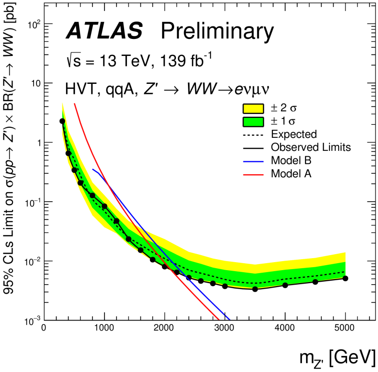
- The 3rd scalar is the Radion particle, which arises in the bulk Randall-Sundrum (RS) model.
- Upper limits on the Higgs production $\sigma \times BR(H \to WW)$ for this signal for the ggF (left) and the VBF (right) production modes.

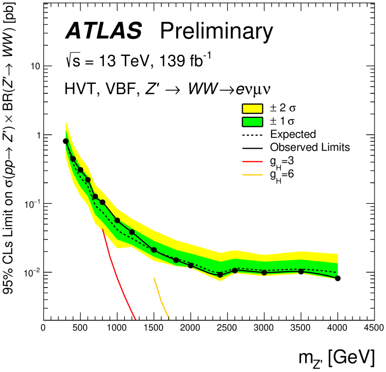




Search for heavy resonances in $W^+W^- \to e\nu\mu\nu$

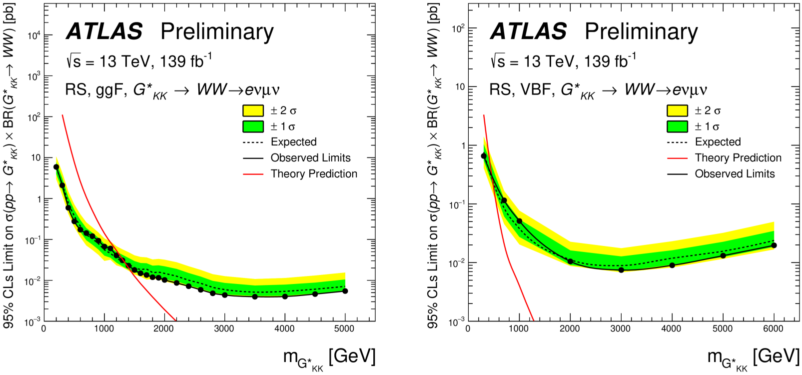
- The 1st non-scalar model consists of a heavy vector triplet (HVT) which incorporates new heavy vector bosons denoted as Z' and W'.
- Upper limits on the resonant boson production $\sigma \times BR(V'/H \to WW)$ for this signal for the qqA (left) and the VBF (right) production modes.





Search for heavy resonances in $W^+W^- \to e\nu\mu\nu$

- The 2nd non-scalar model is the bulk RS model having a spin-2 Kaluza-Klein graviton produced via both VBF and ggF and decaying to WW.
- Upper limits on the graviton production $\sigma \times BR(G^*KK/H \to WW)$ for a Kaluza-Klein graviton in the bulk RS model with ggF (left) and the VBF (right) production modes.



Dark Matter searches in final states with large missing transverse momentum

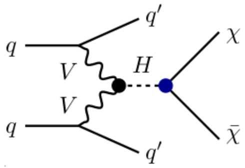
JHEP 08 (2022) 104

ATL-COM-PHYS-2022-457: submitted to PLB

ATLAS-CONF-2022-069

Invisible Higgs boson search using VBF signature

data sample: L=139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV



- powerful topology: VBF + MET
- signal: VBF, ggF
- main background: V+j, multijets

The experimental signature:

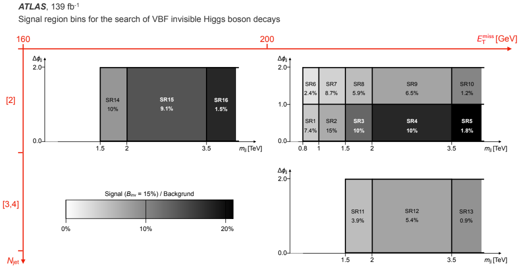
- pair of energetic jets
- wide gap in η_{jj}
- large invariant mass m_{jj}

Results corresponding partial run 2 dataset: (link)

- Limit on $B_{H\rightarrow inv}$: 0.37 at 95% CL.

Results corresponding full run 2 dataset: Changes and improvements

- Relaxed selection criteria on m_{jj}, $\Delta\eta_{jj} > 3.8$ and $\Delta\Phi_{jj}$
- E_T^{miss} requirement slightly increased
- Events with 3 or 4 jets are used as well (if compatible with FSR)
- MET and dPhijj binning is used



Improvements efficiency:

Better S/B ratio for large m_{jj} and smaller $\Delta\Phi_{jj}$

Signal and control region definitions

SR definitions:

Lepton/photon veto
$p_T(j_1) > 80$ GeV
$p_T(j_2) > 50$ GeV
$\eta_{j_1} * \eta_{j_2} < 0$

$\Delta\Phi_{jj} < 2.0$
$\Delta\eta_{jj} > 3.8$
$mjj > 0.8$ TeV
$N_{bjets} < 2$

$E_T^{miss} > 160$ GeV
$p_T^{\text{all jets}} > 140$ GeV
$E_{T,soft}^{miss} < 20$ GeV
$2 \leq N_{jets} \leq 4$

$p_T(j_{3,4}) > 20$ GeV
JVT or fJVT($j_{3,4}$)
$C_{j3,4} < 0.6$
$m_{j3,4}^{rel} < 0.05$

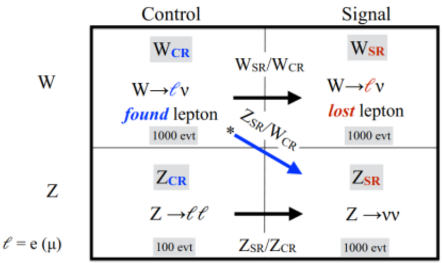
CR definitions:

$Z \rightarrow \ell\ell$

- $N_{lep} = 2$
- $p_T(\ell_1) > 30$ GeV
- $|m_{\ell\ell} - m_Z| < 25$ GeV
- $E_T^{miss} < 70$ GeV

$W \rightarrow \ell\nu$

- $N_\ell = 1$
- $p_T(\ell_1) > 30$ GeV
- S_{MET}(e)$> 4\sqrt{GeV}$
- $m_T(\mu) > 20 GeV$

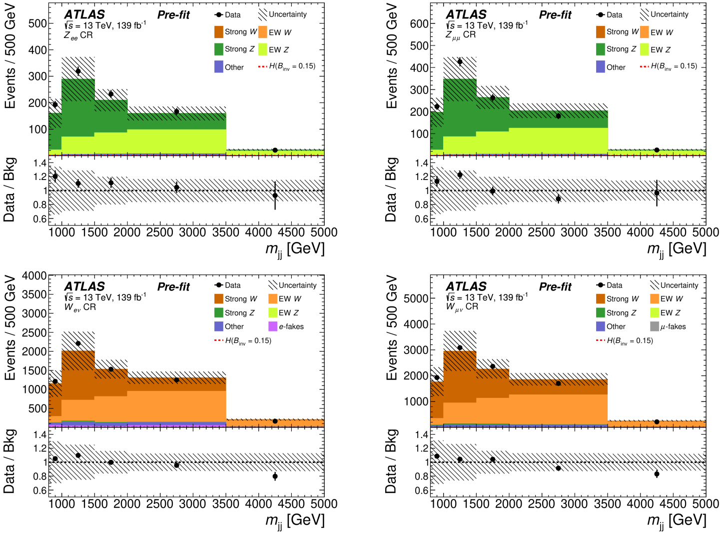


simplified picture for illustration

Background estimation

V+jets: about 95%

- data driven technique uses CRs (binned similarly to SR) to constrain this Background.
- Good agreement between observed yield and expectation from simulation.



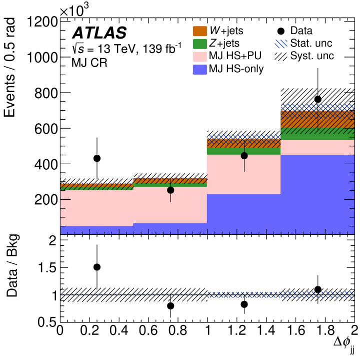
Background estimation

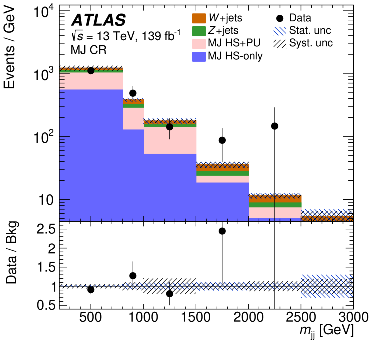
Other sources: Multijet, diboson, ttbar.

- ttbar, diboson: predicted directly from simulation.
- Two methods are used for the suppression of multijet background: 'Rebalance and Smear' technique and the 'pileup-CR' method.

  Yields in a MJ enriched CR with single jet triggered data (compared to MET triggered data)

Observed and predicted distributions





Systematic Uncertainties

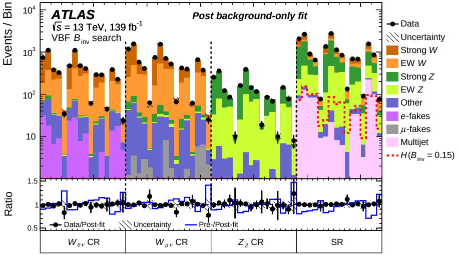
- Contributions to the 68% confidence interval of the fitted signal strength μ from different sources of systematic uncertainty.
- The 'Remaining' category contains E_T^{miss}, luminosity, and pile-up uncertainties, and a diboson uncertainty in the $Z_{\ell\ell}$ CR.

Source	Contribution to $\pm 1\sigma$ (= 0.052)
Data stats.	0.029
V+jets data stats.	0.022
MC stats.	0.014
Multijet	0.021
μ/e-fakes	0.019
Lepton	0.017
(Lepton – muon only)	0.0049
(Lepton – electron only)	0.016
JER	0.015
JES	0.011
Remaining	0.012
V+jets – theory	0.015
Signal – theory	0.0056

Results

- good agreement of expected background yields and observed data.
- Observed (expected) upper limit of 15% (0.103) on $B_{H\to inv}$ at 95% CL.

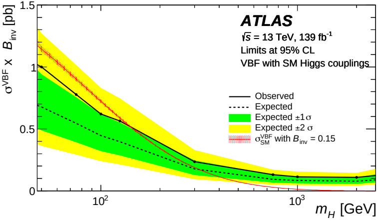
Postfit results of SR and CR bins.



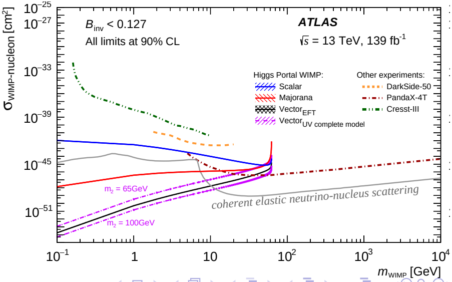
More details about the interpretation in:
Journal reference: LHEP-270, 2022

Interpretation:

invisible decays of heavy scalar particles (med to DM)



Upper limits on the SI $\sigma_{WIMP-nucleon}$ using Higgs portal interpretations.



$H \rightarrow$ invisible Search : Combination

Combined the five Run-2 search results, and then combined with Run-1 results:

Run 2 ($\sqrt{s} = 13$ TeV, L 139 fb^{-1})

- VBF + MET
- VBF + γ + MET
- Z($\ell\ell$) + MET
- $t\bar{t}$ + MET
- jets + MET

Run 1 ($\sqrt{s} = 7, 8$ TeV, L 25 fb^{-1})

- VBF + MET
- Z($\ell\ell$) + MET
- W/Z + MET (W/Z: had decay)

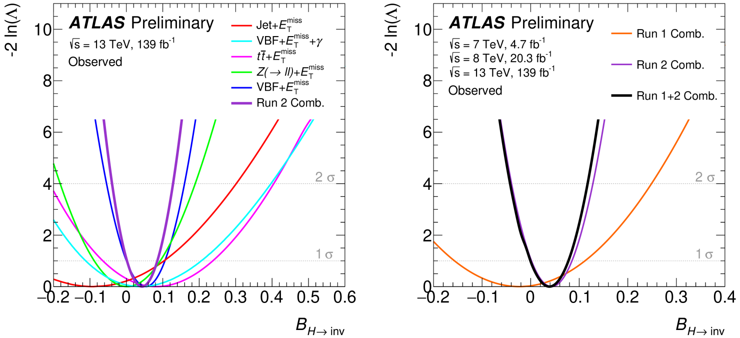
Run 2 Combination:

- Small overlap for VBF+MET & jets+MET ($\sim$ 0.2% data), negligible impact ($<$ 0.1%)
- Most experiment uncertainties, and some signal uncertainties are correlated.
- Background modelling unc uncorrelated (differences in leading background, kinematic phase space, and usage of data driven methods)

Run 1+ Run 2 Combination:

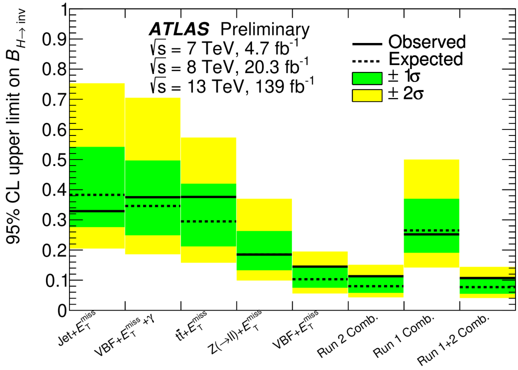
- Almost all uncertainties are uncorrelated
- modelling of calorimeter response and jet energy calibration as same methods are applied in both runs, hence they are correlated.

Combination results



- Run 2 combination brings a relative sensitivity improvement of 22% with respect to VBF Run 2 result (0.15 at 95% CL).
- Run 1+2 combination reaches a relative sensitivity improvement of 26% with respect to VBF Run 2 result.

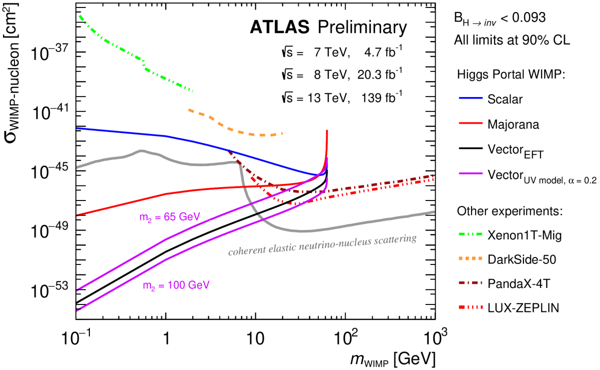
Combination results



- The most stringent observed (expected) limit 0.107 (0.077) at 95% CL.
- Run 2 sensitivity is dominated by VBF+MET
- Leading uncertainty : W/Z+jets modelling (driven by VBF+MET)
- Sub-leading uncertainties: data/MC statistics, leptons/jets measurements, other Bckg modelling.

Combination results

Interpretation



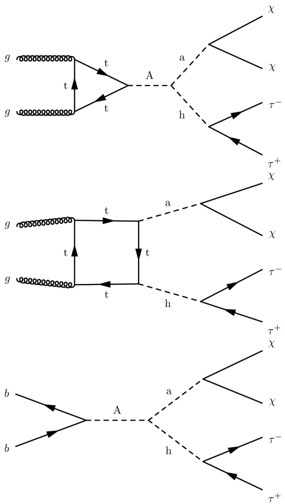
- The combination provide the most stringent limit on the $\sigma^{SI}_{nucleon-WIMPs}$.
- Very competitive results compared to direct detection experiment in low mass.
- Assume several WIMP hypotheses: Scalar, Majorana fermion, vector

Search for DM produced in association with SM h$\to \tau\tau$

ATLAS-CONF-2022-069

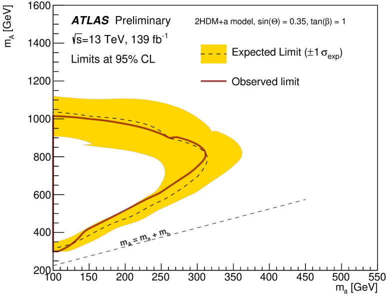
- One alternative strategy is to focus on the case of DM particles produced in association with SM particles: X+E_T^{miss} signatures, X=j,γ,V,t,h.
- mono-Higgs topologies are an important tool in the DM LHC searches: h($\to \tau\tau$)+E_T^{miss}
- SUSY extension of the Higgs sector with a second scalar doublet (2HDM).
- The 2HDM+a model extends the baseline 2HDM by adding a new pseudoscalar singlet a with Yukawa-like coupling to the DM candidate χ and the SM fermions.
- a acting as a mediator between the SM particles and the DM sector.

- 2HDM+a scenarios with H production modes: ggF and $b\bar{b}$ annihilation.

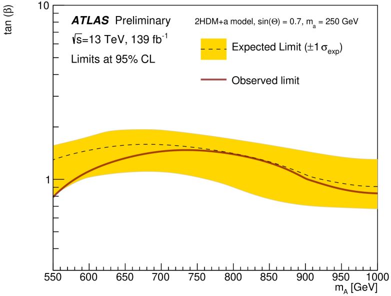


Search for DM produced in association with a $H \rightarrow \tau\tau$

- Backgrounds: main: SM h$\rightarrow \tau\tau$, Z($\ell\ell$)h. minor: Z, VV, $t\bar{t}$, Wh
- The analysis considers two two-dimensional scans in parameter values – the first in (m_A,m_a)and the second in (m_A,$tan\beta$)
- Observed and expected exclusion contours at 95% CL (a) as a function of m_a and m_A with $tan\beta = 1$ and $sin\theta = 0.35$, (b) as a function of m_A and $tan\beta$ with $m_a = 250$ GeV and $sin\theta = 0.7$.
- The excluded area is (a) to the left of the solid line, (b) below the solid line.



(a)



(b)

Motivation

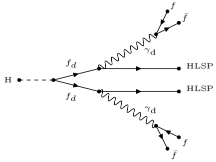
arxiv.2206.12181: Submitted to JHEP

- Huge and ambitious efforts have been spent on the search of viable WIMP candidates.
- Many fascinating new ideas and models for Dark Matter interpretation have been blooming.
- One hypothesis is that the DM constituents could be neutral under SM interactions, but they could interact through a new force under a "hidden" charge.
- This new hidden symmetry would be mediated by a massive gauge boson, called dark photon, and expected to couple to the SM via a kinetic mixing.

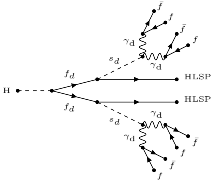
Light and neutral LLP $\rightarrow$ collimated pairs of ℓ or hadrons

- BSM theories predict the existence of unstable dark sector particle from SM Higgs boson decays.
- γ_d mix kinetically with SM γ and decay into leptons and quarks.
- Focus on kinetic mixing ($\epsilon < 10^{-6}$) responsible for the lifetime of γ_d, and mass ranges between $\mathcal{O}(MeV)$ and $\mathcal{O}(GeV)$: γ_d decays happen in macroscopic distance from the IP.
- γ_d small mass and large Lorentz boosts result in collimated fermions in dark photon jet structure (DPJs)
- Two Higgs production modes: ggF and WH, and two models for the interpretation: FRVZ and HAHM.

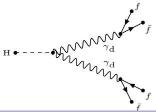
FRVZ: $2\gamma_d$ + 2HLSP(Hidden Light Stable Particle)



FRVZ: $4\gamma_d$ + 2HLSP



HAHM(Hidden Abelian Higgs Model): $2\gamma_d$



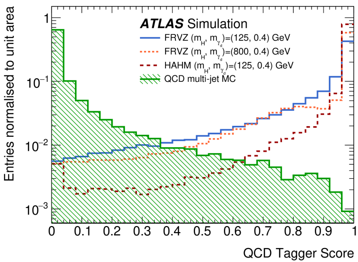
Event selection

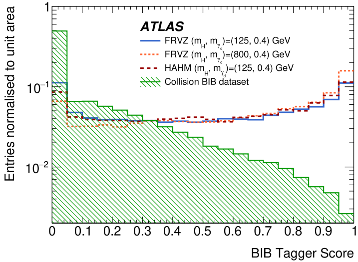
- This is a search for a displaced DPJs.
- Two dedicated triggers for the two exclusive search categories:
  - ggF: two MS-based triggers and one calorimeter-based trigger.
  - WH: single-electron or single muon triggers.
- Two mutually-exclusive types of DPJs are defined:
  - Muonic DPJs ($\mu\mathrm{DPJs}$): ≥ 2 tracks in MS, found in a narrow cone with no corresponding jets or tracks in the ID.
  - Calorimeter DPJs (cDPJs): narrow jets with $\frac{E_{jet}^{EMCal}}{E_{jet}^{tot}} \leq 40\%$, and do not match either muons or tracks from the ID.

Light and neutral LLP → collimated pairs of ℓ or hadrons

Backgrounds

- Main sources: multijet (hadronic jets resulting in mis-identified DPJs) and W+jets.
- Suppressed using dedicated discriminator: QCD tagger based on convolutional neural network (CNN), which uses as input a 3D representation of the jet's energy deposit.
- Beam-Induced-Background (BIB) from LHC beam interaction with accelerator components, suppressed using BIB tagger: trained to discriminate between signal and fake cDPJs from BIB.

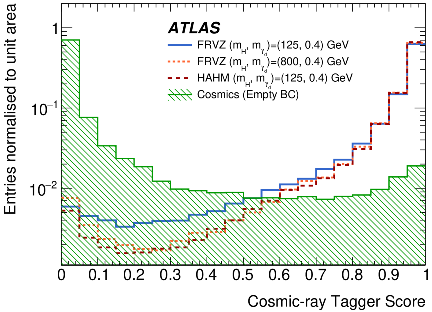




Light and neutral LLP $\rightarrow$ collimated pairs of ℓ or hadrons

Backgrounds

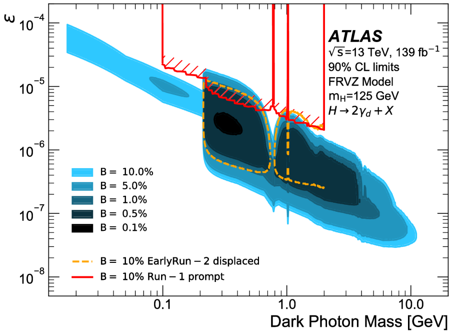
- Another source of background is the cosmic-ray muons
- mis-identified cDPJs suppressed through a jet timing selection.
- mis-identified μ-DPJs suppressed using a dense NN: trained on μ track parameters and on timing information of μ hits in the RPC.

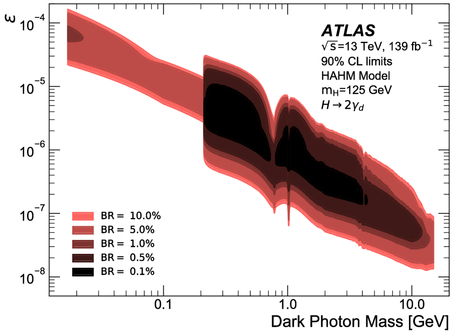


Light and neutral LLP $\rightarrow$ collimated pairs of ℓ or hadrons

Interpretation

- No significant disagreement is observed with respect to the SM backgrounds.
- Upper limits on the $BR * \sigma$ of the Higgs-mediated dark photon production.
- Exclusion limits are obtained for single choice of γ_d mass and mean proper lifetime, then extended to 2D exclusion contour.
- exclusion contours of the BR for $H \rightarrow 2\gamma_d$+X as a function of the m_{γ_d} and the kinetic mixing parameter ϵ for FRVZ and HAHM models.





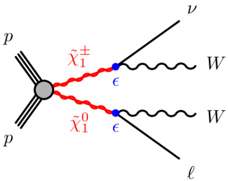
More interesting and recents results for LLP searches:

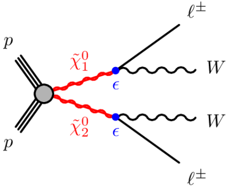
- Search targets for the first time in ATLAS, the production of a Higgs boson in association with a Z boson, with subsequent decay of the Higgs into a photon and a dark photon. (link)
- Search for a long-lived, heavy neutral lepton (HNLs) or ($\mathcal{N}$), which would provide right-handed partners to SM neutrinos and explain why neutrinos are so light. (link)

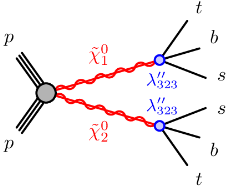
SUSY searches targeting production of winos and higgsinos

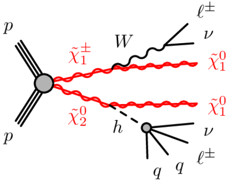
ATLAS-CONF-2022-057

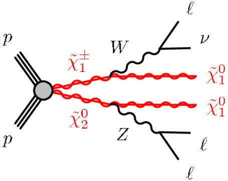
- Heavy BSM particles could decay into multiple massive SM bosons or t, which subsequently decay with considerable BR into same-sign ℓ and jets: SS t pairs, scalar gluons (sgluons), heavy scalar bosons of extended Higgs sectors, Majorana heavy neutrinos, and vector-like top quarks.
- Exp Signature: 2 SS ℓ or 3 ℓ, large E_T^{miss} and hadronic jets.
- 1st ATLAS result from a two-SS-lepton selection targeting direct chargino and neutralino production
- Scenarios considered: directly produced wino-like electroweakinos with bino-like LSP in RPC SUSY (down), and higgsino-like electroweakinos with RPV terms (right).





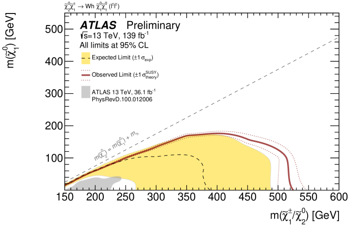


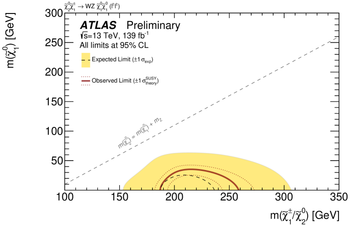


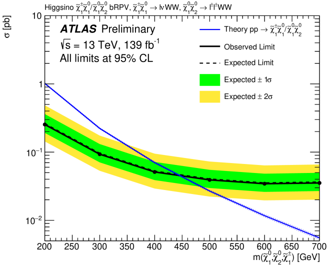


SUSY searches targeting production of winos and higgsinos

- Exclusion limits for the (right-top) Wh-mediated and the (right-dn) WZ-mediated simplified model of wino $\chi_1^\pm \chi_2^0$ production. Observed (solid) and expected (dashed) limits on $\chi_1^\pm/\chi_2^0$ and χ_1^0 masses.
- In topologies with intermediate states including either Wh or WZ pairs, wino masses up to 525 GeV and 260 GeV are excluded, respectively, for a bino of vanishing mass. Higgsino masses smaller than 440 GeV are excluded in a natural R-parity-violating model with bilinear terms







(down-left) Exclusion limits as a function of higgsino $\chi_1^0/\chi_2^0/\chi_1^\pm$ mass in the bilinear RPV model.

Conclusions

- Full Run2 datasets of 139 fb^{-1} and $\sqrt{s} = 13$ TeV are used for searches of new phenomena beyond the SM.
- No excess above the expected SM backgrounds.
- Exclusion limits are evaluated for different BSM scenarios:
  - Scalar and vector LQs cross-section and mass.
  - W' cross-section from SSM and NUGIM theories.
  - 5 different modules cross-section: narrow-width approximation NWA, Higgs fiveplet mode, Radion particle, heavy vector triple, bulk RS model.
  - WIMPs cross-section predicted by many BSM models.
  - The 2HDM+a model: extension of the baseline 2HDM
  - Dark photon cross-section
- Since no evidence for BSM particles, ATLAS will enhance its searches for new BSM signals using:
  - Combinations of results from different channels and analyses.
  - Benefit from the ATLAS Run3 datasets high luminosity after the latest upgrade of the detector.

Thanks for your attention!

Backup

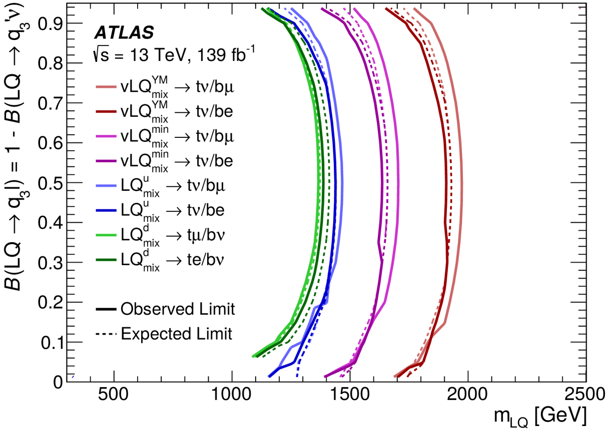
LQs

Expected and observed 95% CL lower limits on the LQ mass at B = 0.5 for the eight signal hypotheses considered in this analysis.

	Exp. limit [GeV]	Obs. limit [GeV]
$\mathrm{LQ}^{\mathrm{u}}_{\mathrm{mix}} \to t\nu/b\mu$	1440^{+60}_{-60}	1460
$\mathrm{LQ}^{\mathrm{u}}_{\mathrm{mix}} \to t\nu/be$	1440^{+60}_{-60}	1440
$\mathrm{LQ}^{\mathrm{d}}_{\mathrm{mix}} \to t\mu/b\nu$	1380^{+50}_{-60}	1370
$\mathrm{LQ}^{\mathrm{d}}_{\mathrm{mix}} \to te/b\nu$	1410^{+60}_{-60}	1390
$\mathrm{vLQ}^{\mathrm{YM}}_{\mathrm{mix}} \to t\nu/b\mu$	1930^{+50}_{-60}	1980
$\mathrm{vLQ}^{\mathrm{YM}}_{\mathrm{mix}} \to t\nu/be$	1930^{+50}_{-70}	1900
$\mathrm{vLQ}^{\mathrm{min}}_{\mathrm{mix}} \to t\nu/b\mu$	1660^{+50}_{-50}	1710
$\mathrm{vLQ}^{\mathrm{min}}_{\mathrm{mix}} \to t\nu/be$	1650^{+50}_{-60}	1620

LQs

Expected (dashed lines) and observed (solid lines) exclusion limits on the leptoquark mass as a function of the branching ratio into charged leptons at 95% CL. Up-type scalar LQs decaying into muons (electrons) are shown in light (dark) blue, down-type scalar LQs decaying into muons (electrons) in light (dark) green, vector LQs in the Yang–Mills coupling scenario in light (dark) red, and vector LQs in the minimal coupling scenario in light (dark) violet. For up-type scalar and vector LQs the range in B is 0–0.95, for down-type scalar LQs it is 0.05–0.95.



Signal and control region definitions

jet centrality:

$$C_i = exp(-\frac{4}{(\eta^{j1} - \eta^{j2})^2}(\eta^i - \frac{\eta^{j1} + \eta^{j2}}{2})^2), \qquad i = j_3, j_4$$

jet relative invariant mass:

$$m_i^{rel} = \frac{min(m_{j1,i}, m_{j2,i})}{m_{jj}}, \qquad i = j_3, j_4$$

MET significance (fake-e):

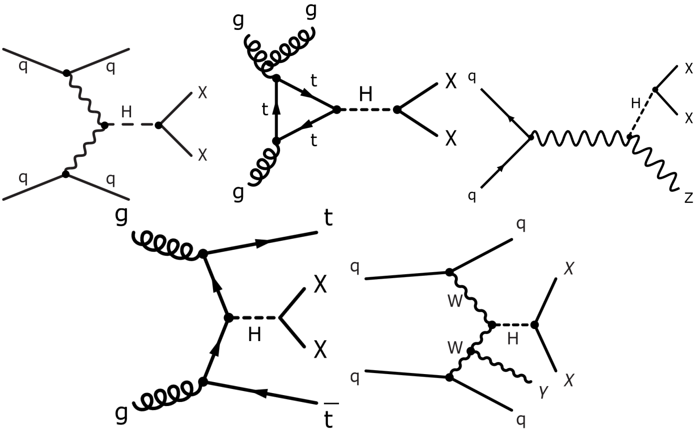
$$S_{MET} = \frac{E_T^{miss}}{\sqrt{p_T^{j1} + p_T^{j2} + p_T^e}}$$

transverse mass (fake-μ):

$$m_T = \sqrt{2E_T^\ell E_T^{miss}(1 - cos\phi(\ell, E_T^{miss}))}, \ell = \mu$$

Invisible Higgs combination

- This document presents a statistical combination of searches for H$\rightarrow$ invisible decays:



- 139 fb^{-1} of pp collisions at a centre-of-mass energy of $\sqrt{s} = 13$ TeV.
- Combination with the results of 4.7 fb^{-1} at $\sqrt{s} = 7$ and 20.3 fb^{-1} at 8 TeV.

The present analysis considers the 2HDM+a model as a benchmark and uses it to optimize the search and interpret the results. The model is described by 12 additional parameters not present in the SM:

- Masses of CP-odd Higgs boson A, CP-even Higgs boson H, and the charged Higgs bosons $H^{\pm}$ are set to be equal to each other.
- The mass of the fermionic DM particle χ is set to 10 GeV.
- The DM Yukawa coupling y_{χ} to pseudoscalar a is set to 1.
- Mixing angles α and β are constrained to satisfy $cos(\alpha - \beta) = 0$, where α is the mixing angle between CP-even Higgs bosons h and H, and $tan\beta$ is the ratio of the vacuum expectation values (VEV) of the two Higgs doublets.
- Quartic couplings of the pseudoscalar potentials and Higgs potential λ_1, λ_2 and λ_3 are all set to 3.
- The mixing angle between the two pseudoscalars, Θ, is required to satisfy $sin\Theta = 0.35$ or $sin\Theta = 0.75$.

Backgrounds

- Further multijet background is estimated using data-driven method (ABCD): relying on the assumption that 2 variables defining the signal region are uncorrelated for background events.

  The planes used in the estimation of the backgrounds for the three ggF SRs are formed by max(Σp_T) and either $\Delta\phi_{DPJ}$ in $SR^{ggF}_{2\mu}$, or Π QCD tagger in SR^{ggF}_{2c} and $SR^{ggF}_{c+\mu}$.

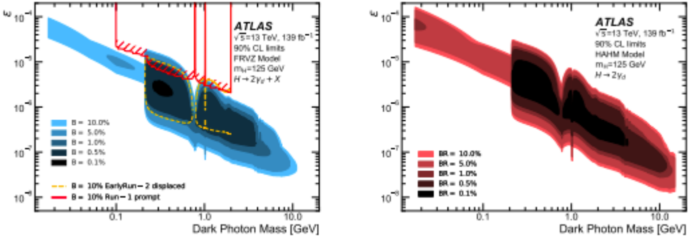
- Contribution from cosmic-ray muons are subtracted from observed yields.
- The presence of BIB is reduced to a negligible level.

Light and neutral LLP $\rightarrow$ collimated pairs of ℓ or hadrons

Two models are used for the optimisation of the event selections and the interpretation of the final results: the Falkowski–Ruderman–Volansky–Zupan (FRVZ) model and the Hidden Abelian Higgs Model (HAHM).

- In the FRVZ model, a pair of dark fermions f_d is produced via a Higgs boson decay and can lead to final states with either two or four dark photons.
- In the two dark photon case, f_d decays into a dark photon and a stable dark fermion, which is assumed to be the hidden lightest stable particle (HLSP). Whereas in the four dark photon case, f_d decays into an HLSP and a dark scalar s_d that in turn decays into a pair of γ_d.

Light and neutral LLP $\rightarrow$ collimated pairs of ℓ or hadrons



(a) FRVZ (b) HAHM

Figure 13: The 90% CL exclusion contours of the branching ratio (B) for the decay $H \rightarrow 2\gamma_d + X$ as a function of the γ_d mass and the kinetic mixing parameter ϵ for (a) the FRVZ model and (b) the HAHM model. These limits are obtained assuming branching fractions between 0.1% and 10% for Higgs boson decays resulting in dark photons. For γ_d mass below twice the muon mass, the combination of the caloDPJ signal regions is used. The figure also shows regions excluded by the previous ATLAS searches for jets from displaced [14] (orange line) and prompt [17] (red line) decays of dark photons.

SUSY

SUSY remains a compelling framework as it provides solutions to the gauge hierarchy problem without the need for large fine tuning of fundamental parameters, offers gauge coupling unification, and contains weakly interacting particles that can contribute to the dark matter.

Charginos, $\chi^{\pm}_{1,2}$, and neutralinos, $\chi^{0}_{1,2,3,4}$, collectively referred to as 'electroweakinos', are the ordered mass eigenstates formed from the linear superposition of the higgsinos, winos, and binos, which are the SUSY partners of the Higgs and electroweak gauge bosons, respectively.

A discrete multiplicative symmetry, RP-parity, is often introduced in SUSY models to avoid rapid proton decay. If RP-parity is conserved (RPC) the lightest supersymmetric particle (LSP) is stable and is required to be neutral and colourless to evade observation

In R-parity-violating (RPV) SUSY, a χ^0_1, LSP would decay to SM particles and, due to its Majorana nature, it may give rise to SS lepton final states.

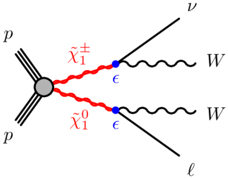
Three winos (symbol $W^{\pm}$ and W_3) are the superpartners of the W bosons of the SU(2)L gauge fields.

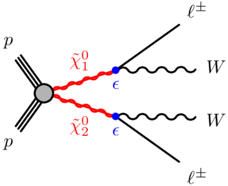
The bino is the superpartner of the U(1) gauge field corresponding to weak hypercharge

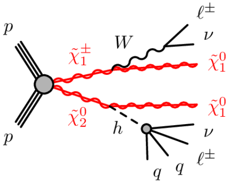
SUSY searches targeting production of winos and higgsinos

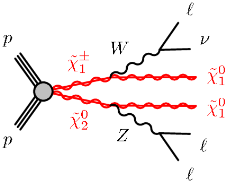
ATLAS-CONF-2022-057

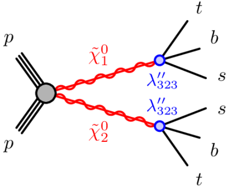
- Heavy BSM particles could decay into multiple massive SM bosons or t, which subsequently decay with considerable BR into same-sign ℓ and jets: SS t pairs, scalar gluons (sgluons), heavy scalar bosons of extended Higgs sectors, Majorana heavy neutrinos, and vector-like top quarks.
- Exp Signature: 2 SS ℓ or 3 ℓ, large E_T^{miss} and hadronic jets.
- 1st ATLAS result targets two-SS-lepton selection targeting direct chargino and neutralino production: Such production may be dominant at the LHC according to naturalness considerations, which suggest that the lightest electroweakinos have masses near the electroweak scale while the superpartners of the gluon and quarks can be heavier than a few TeV. This search covers so-far unconstrained kinematic regions, not yet excluded by previous three lepton analyses











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ATLAS-CONF-2022-057

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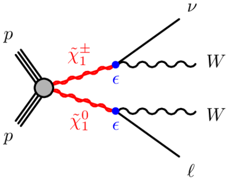
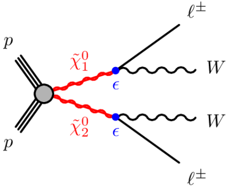
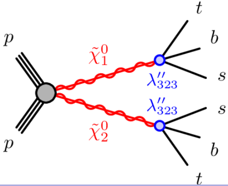
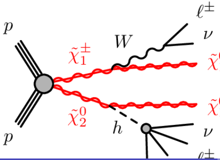
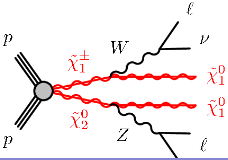
- Exp Signature: 2 SS ℓ or 3 ℓ, large E_T^{miss} and hadronic jets.
- 1st ATLAS result targets two-SS-lepton selection targeting direct chargino and neutralino production:
- The event selection provides optimal sensitivity to four target models: (i, ii) simplified models of winos and binos with on-shell WZ or Wh as intermediate states; (iii) higgsino production with bilinear R-parity-violating (bRPV) terms; and (iv) higgsino production with R-parity violating decays to top quarks via baryon-number violating UDD couplings











ABSTRACT-2022-387

Many theories beyond the Standard Model (BSM) have been proposed to address several of the Standard Model shortcomings, such as the origin of dark matter and neutrino masses, the fine-tuning of the Higgs Boson mass, or the observed pattern of masses and mixing angles in the quark and lepton sectors. Many of these BSM extensions predict new particles or interactions directly accessible at the LHC. This talk will present some highlights on recent searches based on the full Run 2 data collected by the ATLAS detector at the LHC with a centre-of-mass energy of 13 TeV. These include searches for leptoquarks and vector-like fermions, new high mass resonances and lepton flavour violating decays, dark matter searches in final states with large missing transverse momentum, as well as dark-sector searches using unconventional and long-lived particle signatures.