Recent ATLAS Dark Matter Search Results

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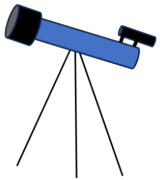
Introduction

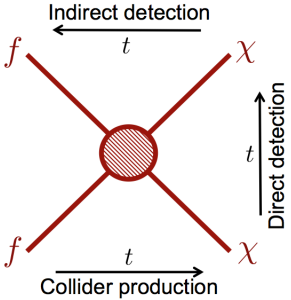
- A range of cosmological observations suggest that we don't understand a lot about the Universe.
- We call the gravitationally interactive part of that lack of knowledge Dark Matter (DM).
- Plenty of viable models predict the DM to be particle-based, at least partially.
- We don't have good DM candidates in the Standard Model unfortunately.
- BSM models with DM – motivation to search for new physics.

- Rotation curves of galaxies;
- Cosmic microvawe background;
- Gravitation lensing maps of bullet cluster;
- Large-scale structure of Universe.



DM searches at LHC (and ATLAS!)

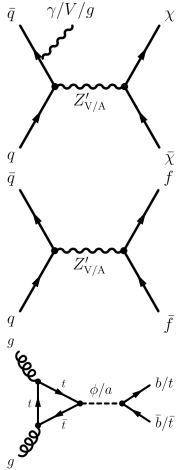
- Why search for DM at LHC? Well, why not?
- Complementary to direct/inderect detection experiments.
- Kinematic differences mean that different physics are being probed.



- Simplified models are usually considered, typically 4-5 DoF.
- More complete models (e.g. 2HDM+a, pMSSM) are also an option.
- Obviously, simplified models are motivated by complete models and the two don't exist independently from each other.

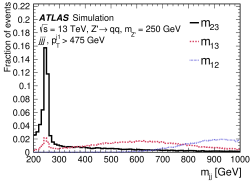
Part I – Simplified Models – s-channel

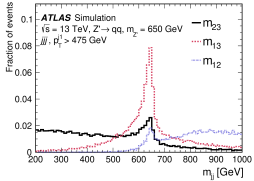
- The common choice of DM simplified models for Run-2 is V/AV s-channel exchange.
- Only a few parameters – DM mass, mediator mass and coupling to DM/SM, simple kinematics.
- Several complementary key signatures:
  - $E_T^{\text{miss}} + X$ (usually jet/γ/V)
  - Dijet resonances.
  - Dilepton resonances.
- Scalars (or PS) as mediators is another possibility, often in association with heavy flavour.
- t-channel – just as viable as models, but less popular so far.



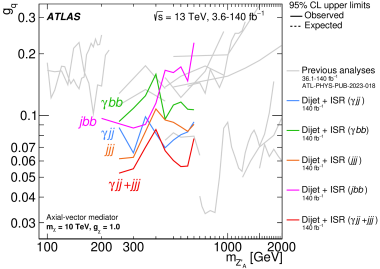
Low Mass Resolved Dijet Resonances

- Dijet resonance searches are limited by trigger bandwidth at $m_{jj} \approx 1$ TeV.
- ISR jet or photon recoiling against mediator gives access to lower masses.
- j/γ + jj/bb signatures, four channels.
- Data-driven background, non-trivial combinatorics in trijet event selection.



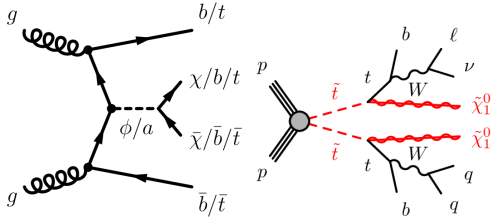


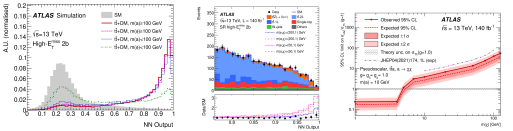
- Trijet and γjj channels combined, improving sensitivity.
- jbb extends to 200 GeV, bridging the gap.



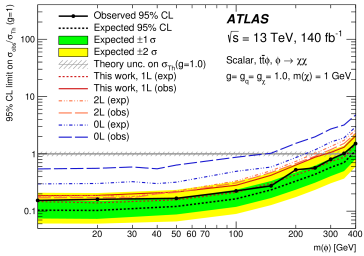
top-pair and E_T^{miss} with 1ℓ

- S/PS mediator production in association with two top quarks.
- SUSY and s-channel DM search, with two NNs optimized for different signal models.
- Additional NN for resolved top-quarks tagging.



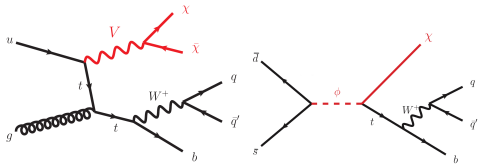


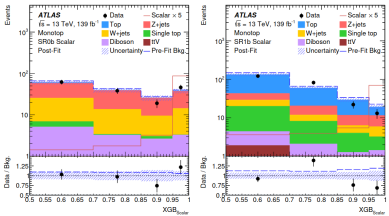
- Limits on m_χ and $m_{a/\phi}$.
- Combination with $0/2\ell$ $tt + E_T^{\text{miss}}$.



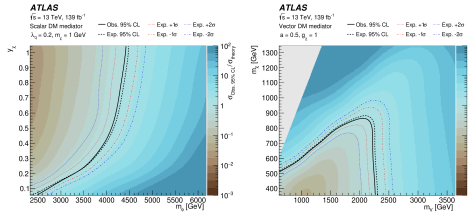
Monotop + E_T^{miss}

- Scalar (vector) mediators for (non-)resonant production modes.
- Signal MC reweighting techniques.
- High-granularity 4D signal models parameter space.
- DNN-based top tagger, XGboost for bkg/signal discrimination.
- Target 0/1 *b*-jets selections.



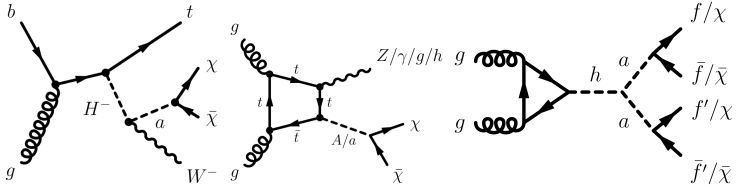


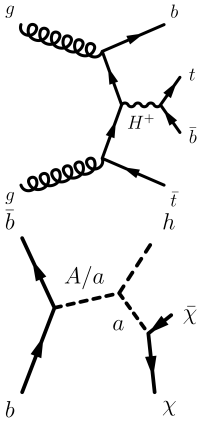
Scalar (vector) limits improved by 800 (300) GeV.



Part II – 2HDM(+a)

- 2HDM model with an additional pseudoscalar SM-DM mediator a, 14 parameters.
- Wide range of "mono-X" signatures, with sensitivity to different regions of the parameter space.
- $Z + E_T^{\text{miss}}$ and $h + E_T^{\text{miss}}$ production boosted as $Z/h + a$ can be produced resonantly.
- Four top and $tbH^{\pm}(\rightarrow tb)$ for visible mediator decays.

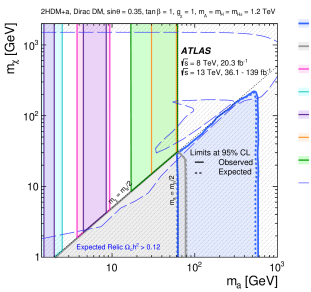




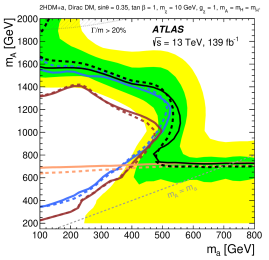
2HDM+a Combination

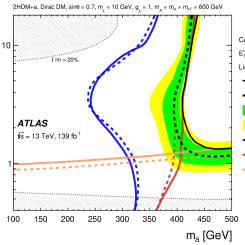
- A large effort from ATLAS collaboration to cover the possible 2HDM+a signatures with the Run-2 dataset.
- Combination of most complementary channels, scans of parameter space.
- Reinterpretation of other large-scale programmes such as $h \to$ inv and $h \to aa$ searches.

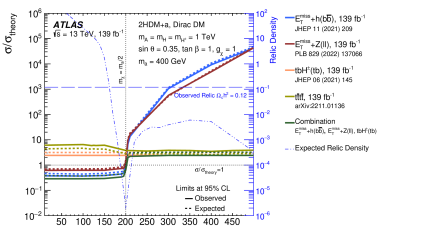
Analysis/Scenario	1a	1b	2a	2b	3a	3b	4a	4b	5	6
$E_{\mathrm{T}}^{\mathrm{miss}} + Z(\ell\ell)$ [74]	x	x	x	x	x	x	x	x	x	
$E_{\mathrm{T}}^{\mathrm{miss}} + h(b\bar{b})$ [75]	x	x	x	x	x	x	x	x	x	x
$E_{\mathrm{T}}^{\mathrm{miss}} + h(\gamma\gamma)$ [84]	x	x			x	x	x	x		
$E_{\mathrm{T}}^{\mathrm{miss}} + h(\tau\tau)$ [78]	x			x						
$E_{\mathrm{T}}^{\mathrm{miss}} + tW$ [77]	x	x	x	x	x	x	x	x		
$E_{\mathrm{T}}^{\mathrm{miss}} + j$ [45]	x	x			x	x	x	x		
$h \to$ invisible [86]	x	x			x					x
$E_{\mathrm{T}}^{\mathrm{miss}} + Z(q\bar{q})$ [127]	x						x	x		
$E_{\mathrm{T}}^{\mathrm{miss}} + b\bar{b}$ [128]							x	x		
$E_{\mathrm{T}}^{\mathrm{miss}} + t\bar{t}$ [128,129]							x	x		
$t\bar{t}t\bar{t}$ [85]	x	x	x	x	x	x	x	x	x	
$tbH^{\pm}(tb)$ [76]	x	x	x	x	x	x	x	x	x	
$h \to aa \to f\bar{f}f'\bar{f}'$ [79,80,81,82,83]										x

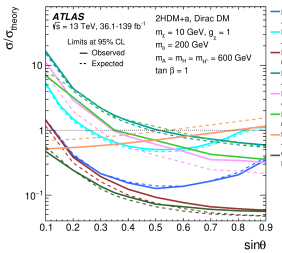


2HDM+a Combination



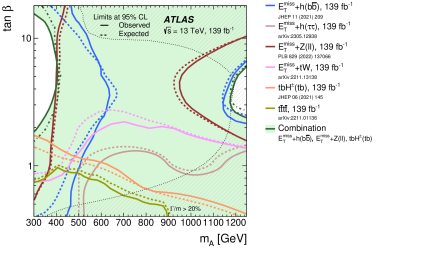






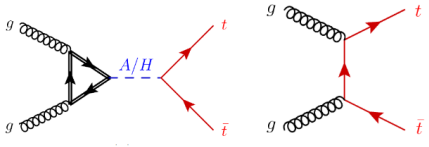
Combination:

- $h(bb) + E_T^{\text{miss}}$
- $Z(\ell\ell) + E_T^{\text{miss}}$
- $tb + H(tb)$

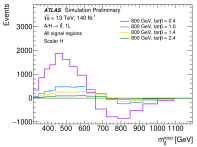


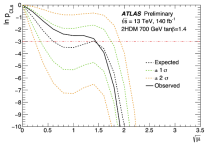
Neutral Higgs to $t\bar{t}$ Search

- Type-II 2HDM/2HDM+a models predict heavy (pseudo-)scalar.
- Decay into top-quarks pair search.
- Strong interference with SM $t\bar{t}$.

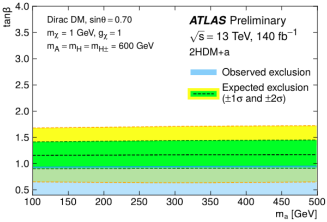


- $1-2$ leptons and b-jets associated to top-quark decays as signatures.
- In 1ℓ case merged/resolved topologies considered.





- Fit procedure taking the SM interference into account.
- Non-monotonic CL_s behaviour, limits interpolated from CL_s ($\sqrt{u}=1$) scan.

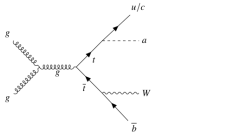


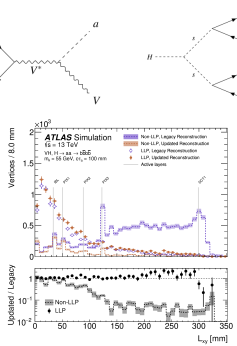
Part III – Dark Sector

- Main idea of hidden (or dark) sector theories is existence of particles not charged under strong, weak, or EM forces.
- But may interect (weakly) with SM through portal/mediator interactions.
- Phenomenologically attractive, as such models can address a lot of current gaps in the SM.
- Can search for the mediators at LHC!
- Experimentally, signatures can be very unique and interesting.

Light LLPs to Displaced Vertices

- Dark sector and ALP models can give rise to long lived particles (LLPs).
- Displaced jets + leptonically decaying vector boson as signature.
  - First limits on $t \to aq$ production.
- Additionally VBF Higgs production considered.
  - Dedicated VBF trigger, 37.5fb^{-1}.
- Improved track reconstruction in Inner Detector, suppressing false positives and improving sensitivity.
- First ATLAS search to directly utilize these improvements.

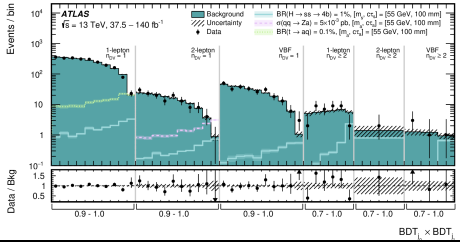


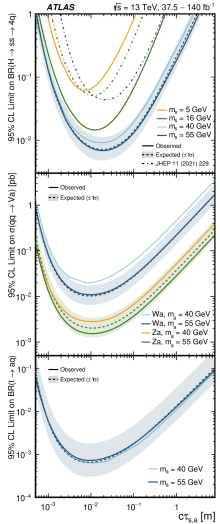


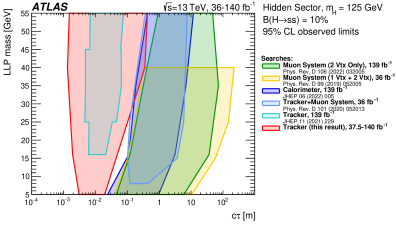
ATLAS Track Reco

Light LLPs to Displaced Vertices

- Per-jet BDTs to select displaced jets, $\text{BDT}_{j0} \times \text{BDT}_{j1}$ as main discriminant.
- Displaced vertex reconstruction, search regions based on n_{DV}.
- No excess over SM observed.



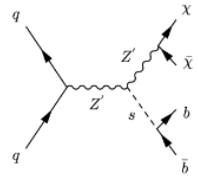


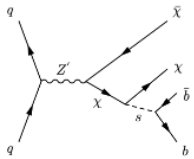


- Limits improved by an order of magnitude.
- First limits set on photophobic ALPs.

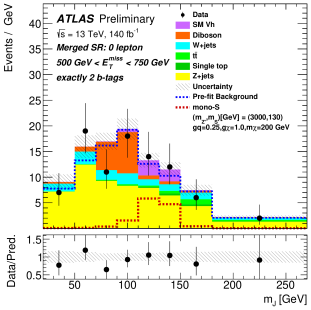
Mono-S(bb)

- Dark sector model with scalar s (dark Higgs).
- Higgs mechanism for DM mass, s lighter than DM candidate χ, mixing with SM Higgs.
  - Low mass $b\bar{b}$ resonance + E_T^{miss} search, largely unexplored at colliders.
- Mediator Z' coupling to DM g_χ floating for benchmark models.

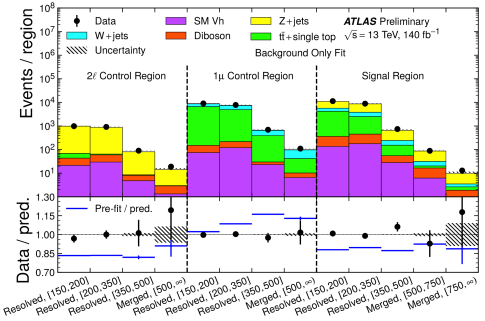




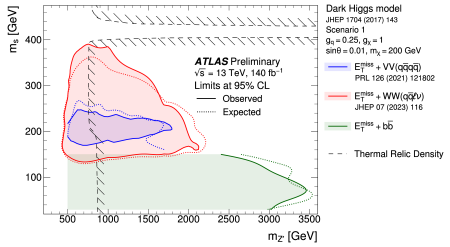
- Resolved and merged b-jet-pairs topologies.
- $X \to bb$ mass-agnostic tagger developed for merged topologies.



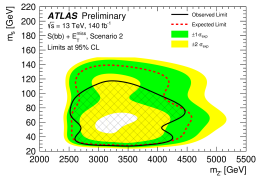
Mono-S(bb)

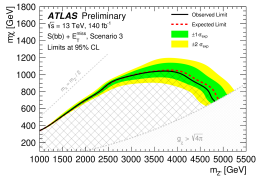


- Complementary sensitivity to high-mass dark Higgs searches.
- First limits on cosmological relic-density-compatible models.



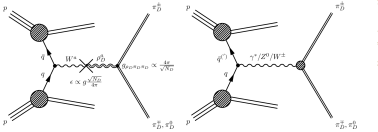
- Dedicated search improves sensitivity.

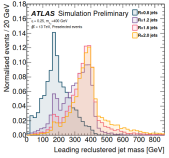


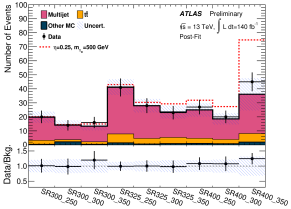


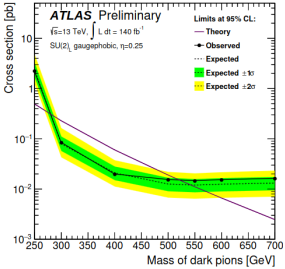
Dark Mesons

- Strongly-coupled dark sector, gaugephobic $SU(2)_L$.
  - Pair-production of pseudoscalar dark pions decaying into SM.
- tt, bb, tb dominant decay modes, $3t1b$ and $2t2b$ signatures.
- H_T triggers due to high jet multiplicity.
- Large R jets with width optimized for dark pion masses.







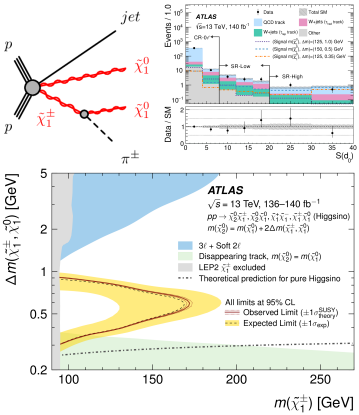


Part IV – SUSY

- Sorry, I am not even going to try to give a summary of SUSY on one slide.
- LSPs can be good DM candidates.

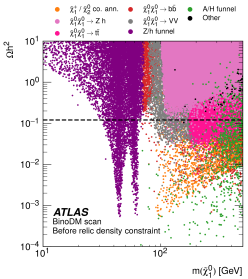
Low Mass Splitting Higgsinos

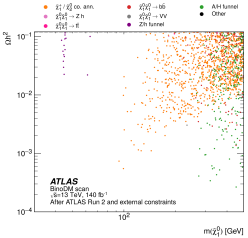
- Almost mass-degenerate higgsinos can provide viable DM candidates.
- Prompt and LLP higgsino searches leave a gap $\Delta m(\chi_1^{\pm}, \chi_0) = 0.3 - 1$ GeV.
- Not an easy region for DD experiments either.
- Signatures with soft, mildly displaced pions (or leptons) allow access to this regime.
- "Mildly" meaning most decay charged particles are passing through innermost tracking layer.
- ISR topologies increase sensitivity to lower mass-splitting and reduce the background.

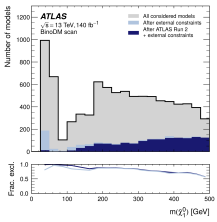


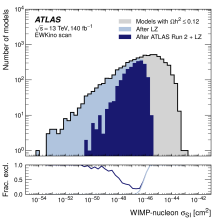
pMSSM Electroweak Scan

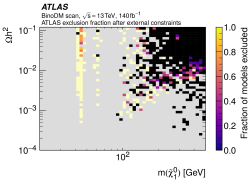
- ATLAS has a large programme for SUSY searches and reinterpretations.
- Results of the eight searches are interpreted in the pMSSM model (19 DoF).
- BinoDM scan over bino-like neutralinos satisfying relic density constraints.











Conclusions

- Presented recent ATLAS results in searches for DM.
- Unfortunately no Dark Matter has been discovered.
- New techniques, both experimental and statistical, have been developed and tested.
- Combinations of searches performed, enhancing sensitivity.
- Run-2 summary papers are out for EXOT and SUSY.

Thank You For Your Attention!