$Z' + E_T^{miss}$ searches and their interpretations

Even S. Haaland

University of Oslo

LHC DM WG Meeting
November 30, 2023

Introduction

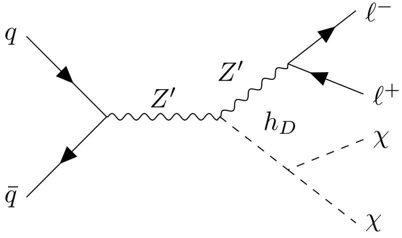
- Following the previous (inclusive) dilepton resonance search(es) in ATLAS we are now looking at *exclusive* $\ell\ell + X$ final states.
- In the analysis described here we are we are looking for dilepton resonances in events with $e^+e^-/\mu^+\mu^-$ and some level of $\mathrm{E}_\mathrm{T}^\mathrm{miss}$.
- A CONF note (ATLAS-CONF-2023-045) was published for EPS this summer, using the $Z' + \mathrm{E}_\mathrm{T}^\mathrm{miss}$ benchmark models described here.
- Interested in learning which models and benchmarks that would be most interesting to consider for future iterations of the analysis, for dark states in general an in particular from a DM perspective.

Outline

1. Overview of models and benchmarks/parameters.
2. Summary of search strategy and results.
3. Dark matter interpretation.
4. Discussion of future plans/ideas.

The dark-Higgs model

- New heavy scalar, h_D, with couplings to Z' and a dark scalar, χ (possible DM candidate).
- The Z' acts as the portal between the SM and the dark sector.
- Assume minimal mixing between h_D and SM Higgs.

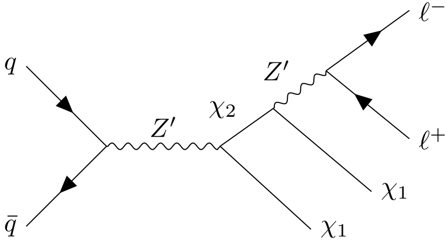


Free parameters

Masses: $m_{Z'}$, m_{h_D}, m_χ
Couplings: g_D, g_q, g_ℓ

The light-vector model

- Relatively light Z' with off-diagonal couplings to two dark fermion states, χ_1 (possible DM candidate) and χ_2.
- The Z' acts as the portal between the SM and the dark sector.
- Requires large mass splitting between χ_1 and χ_2.



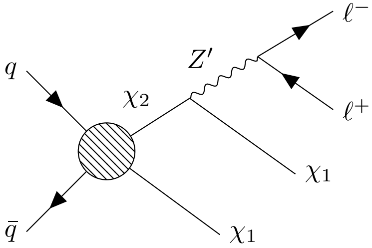
Free parameters

Masses: $m_{Z'}$, m_{χ_1}, m_{χ_2}
Couplings: g_D, g_q, g_ℓ

The light-vector model w/ EFT coupling

Not considered in the CONF note!

- Similar to the light-vector model, but with the first Z' mediator replace by a contact interaction.
- Scale of the EFT coupling given by the parameter Λ.
- Does not rely on Z' coupling to quarks.



Free parameters

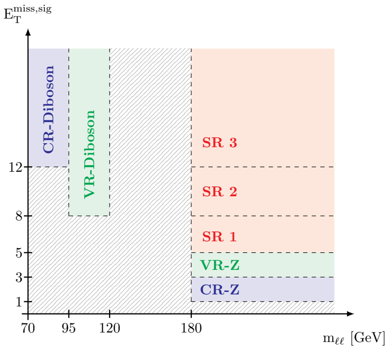
Masses: $m_{Z'}$, m_{χ_1}, m_{χ_2}
Couplings: g_D, g_ℓ
EFT scale: Λ

Parameters and benchmark scenarios

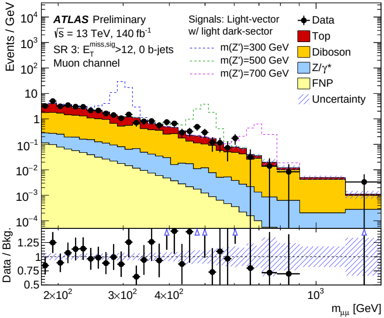
- **Couplings:** $g_D = 1$, $g_q = 0.1$, $g_\ell = 0.01$ (Inspired by V2 scenario from LHC DM WG recommendations.)
- **Z' masses:** 200-1000 GeV
- **Dark sector benchmarks:**

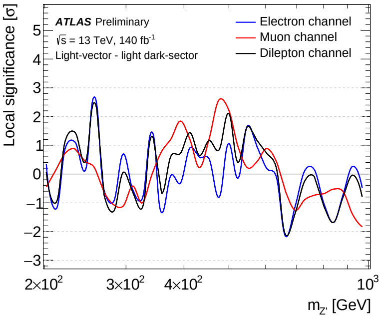
	Dark-Higgs	Light-vector
Light dark-sector	$m_\chi = 5$ GeV $m_{h_D} = 125$ GeV	$m_{\chi_1} = 5$ GeV $m_{\chi_2} = m_{\chi_1} + m_{Z'} + 25$ GeV
Heavy dark-sector	$m_\chi = 5$ GeV $m_{h_D} = m_{Z'}$	$m_{\chi_1} = m_{Z'}/2$ $m_{\chi_2} = 2m_{Z'}$

Search strategy and results

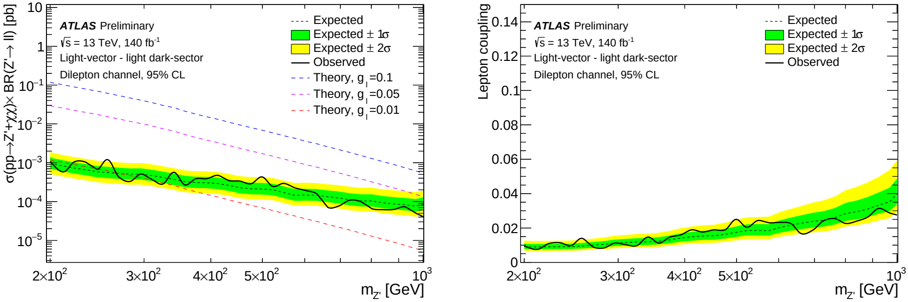


- **SR strategy:**
  - $m_{\ell\ell} > 180$ GeV
  - Three bins in $E_T^{miss,sig}$
  - *b*-jet veto
- No significant excess observed.



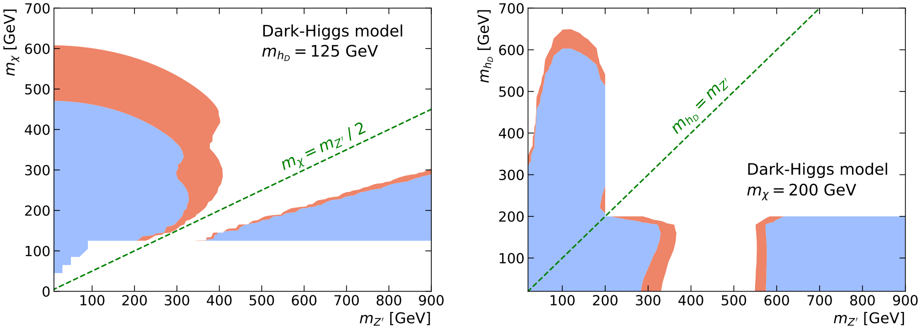


Exclusion limits



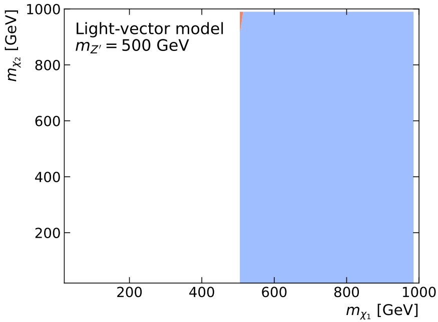
- **Example:** light-vector model w/ light dark-sector benchmark.
- Upper limits on the cross section and the $Z'\ell\ell$ coupling as a function of Z' mass.
- Lepton coupling limits calculated assuming that $\sigma \propto g_\ell^2$.

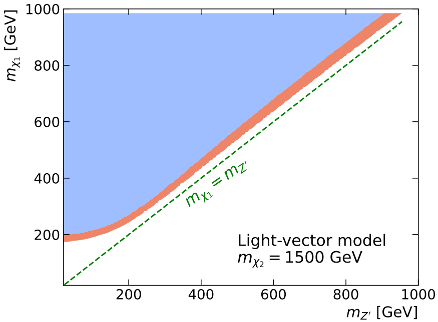
Relic density predictions: **dark-Higgs model**



- Our benchmarks:
  - **Light dark-sector:** $m_\chi = 5$ GeV, $m_{h_D} = 125$ GeV
  - **Heavy dark-sector:** $m_\chi = 5$ GeV, $m_{h_D} = m_{Z'}$
- In plots: white=overproduced; blue=underproduced; red=approximately correct RD.
- For $m_\chi = 5$ GeV: DM ***always*** overproduced!
- Can get ∼correct RD by increasing m_χ.

Relic density predictions: **light-vector model**





- Our benchmarks:
  - **Light dark-sector:** $m_\chi = 5$ GeV, $m_{\chi 2} = m_{Z'} + 30$ GeV
  - **Heavy dark-sector:** $m_\chi = m_{Z'}/2$ GeV, $m_{\chi 2} = 2m_{Z'}$
- In plots: white=overproduced; blue=underproduced; red=approximately correct RD.
- DM overproduced in our benchmarks, but ∼correct RD can be reproduced by increasing the masses of the dark-sector particles.

Future plans and ideas

Some plans and ideas for future iterations of the search include:

- Calculating fiducial cross-section limits. (For Run2 paper.)
- Including the light-vector EFT model. (For Run2 paper.)
- Applying ML methods, e.g. pNNs, to optimise search sensitivity. (Run2+3 analysis and PhD thesis of Oda Langrekken.)
- Considering low Z' masses, i.e. $m_{Z'} < m_Z$. (Run2+3 analysis?)

...but consider DM interpretations by ideally using models that better accommodate the RD constraints.

Summary & Discussion

- Have performed a search for dilepton resonances in the $\ell\ell + E_T^{miss}$ final state using the full ATLAS Run II data.
- Focused on the novelty of the final state, and considered a set of dark-sector benchmark models that are found to not reproduce the observed RD.
- For future iterations, can we improve the models and provide more interesting interpretations of the search?
    - Tuning the mass parameters of the models we have to better fit the observed RD?
    - Should the couplings be adjusted?
    - Are there other models that can produce this final state?
    - Interested in short-term "quick-fixes" as well as things to study on a larger timescale are!

Ideas and recommendations are warmly welcome!