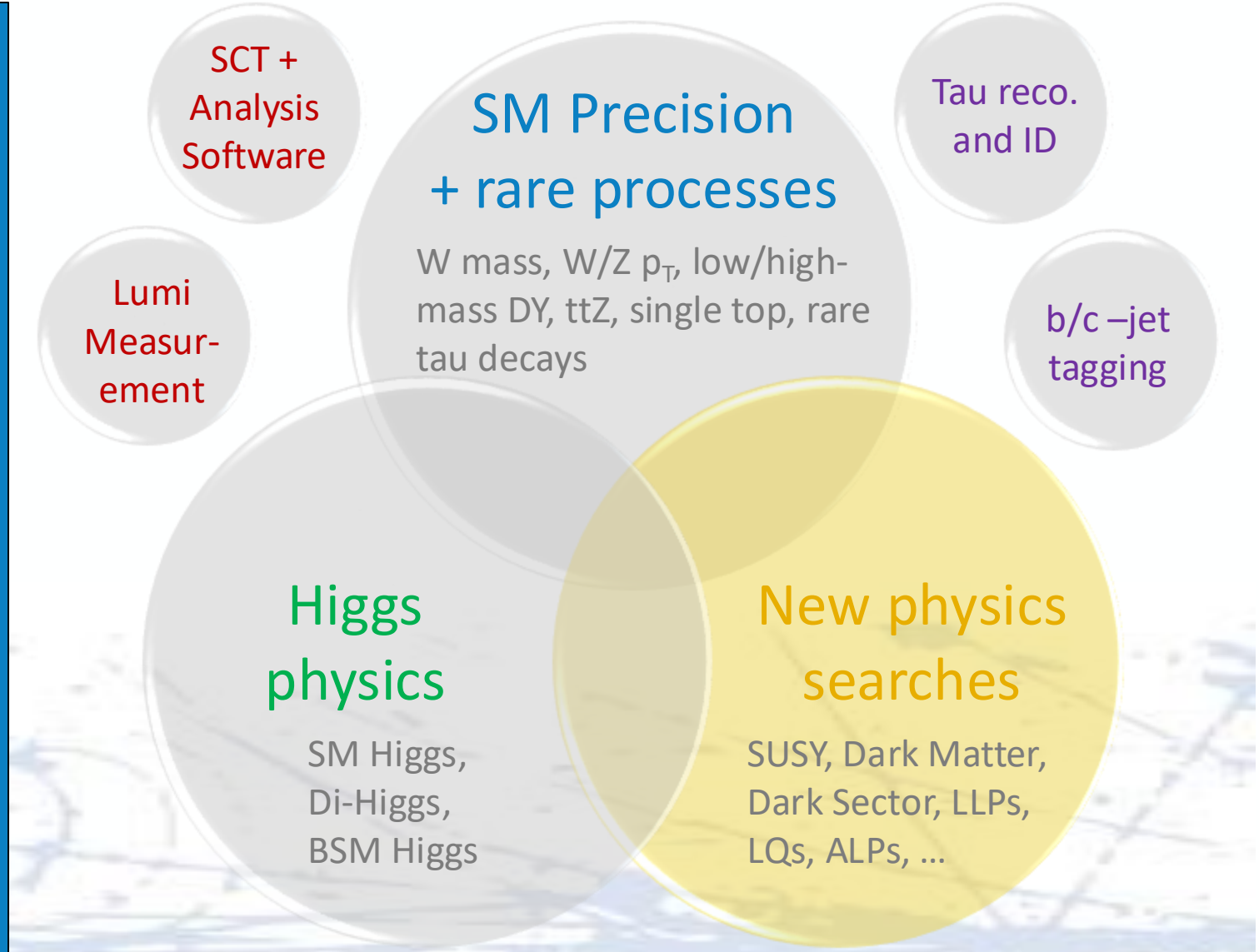
ATLAS BSM Physics Searches

John Anders

23rd May 2025
HEP Annual Meeting

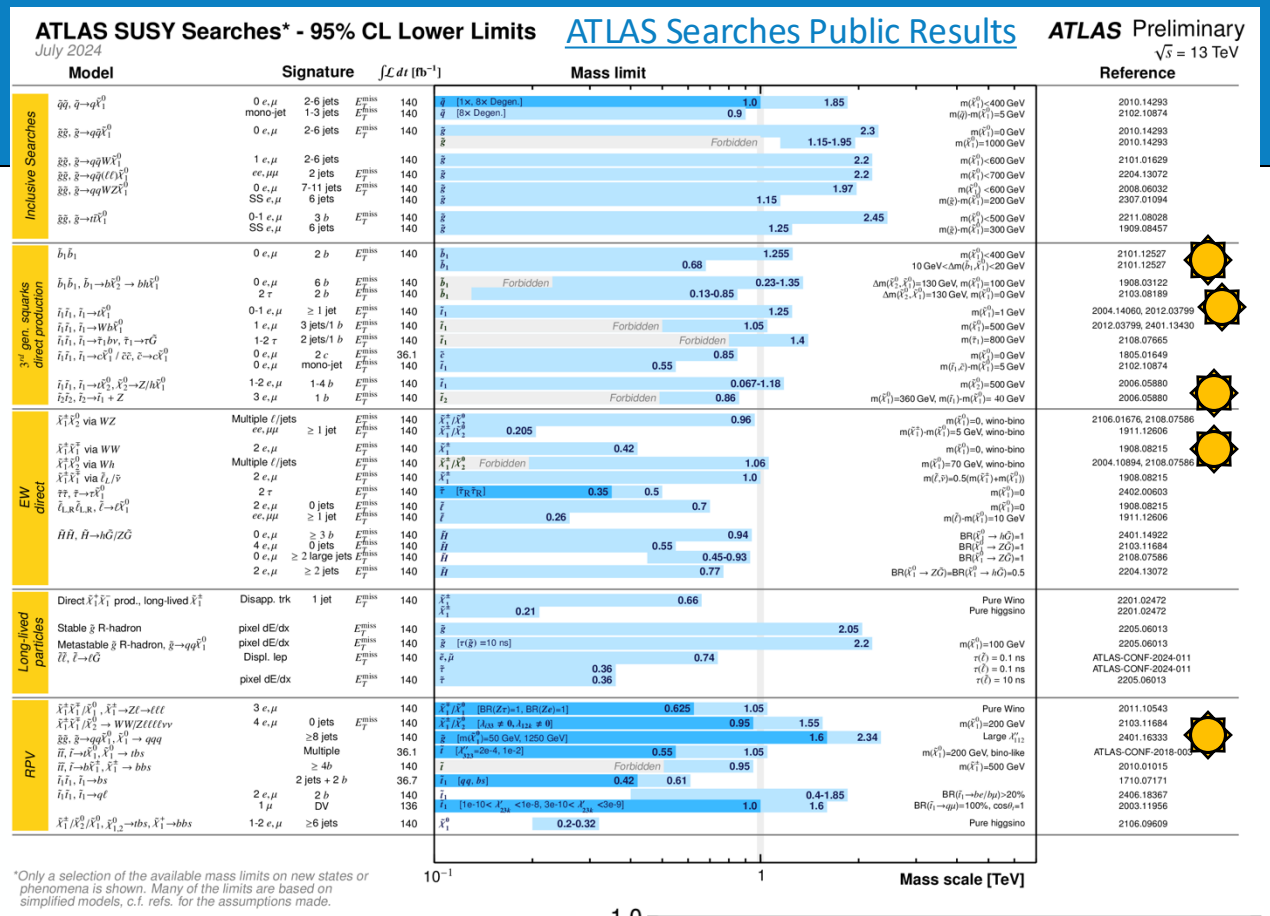


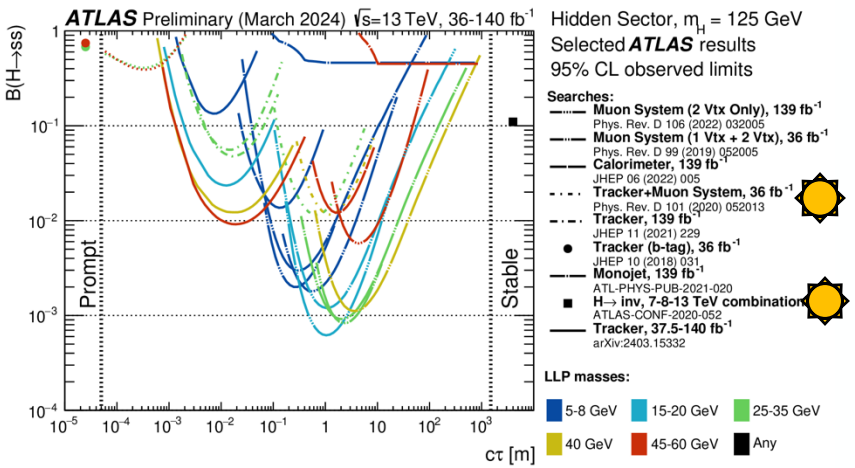
UNIVERSITY OF LIVERPOOL

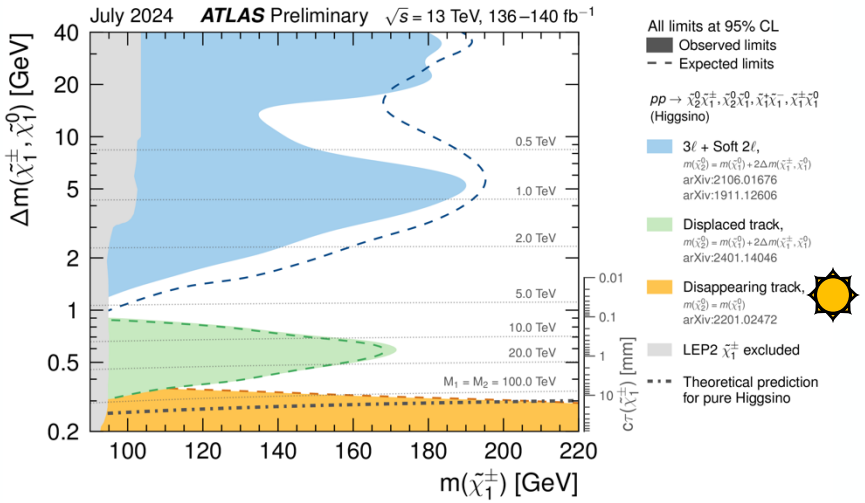
ATLAS EXPERIMENT

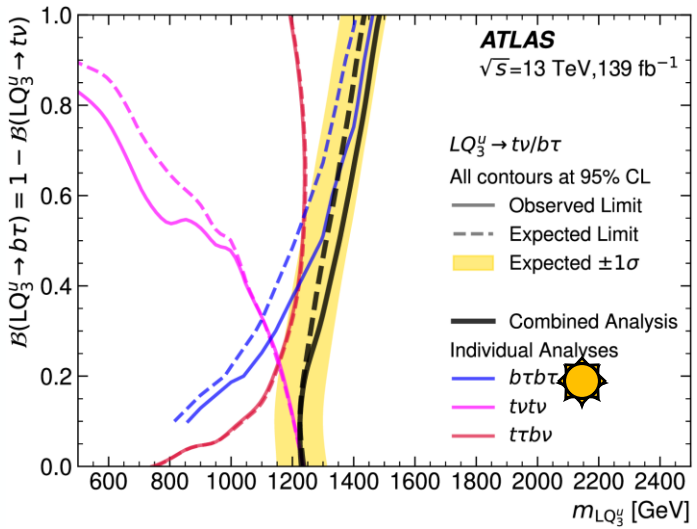
BSM Physics - Overview

- Tremendous effort in ATLAS to search for new physics, motivated by questions that remain unanswered by the Standard Model/Higgs
  - Higgs Hierarchy problem, Dark Matter, Lepton-flavour violation, matter anti-matter asymmetry, force unification….
- The group are at the forefront of exploiting new reconstruction methods, AI techniques for signal isolation and reinterpretation of existing results (☀ - Liverpool involvement)
- Our main focuses are split between a few highly-motivated scenarios
  - Supersymmetry (Monica, John)
  - Leptoquarks (Andy, Mehul, Jordy, John)
  - Dark Sector (Nikos, Monica, Rebecca, Shirsendu, John)
  - BSM Higgs (Nikos, Andy, Stephen)









BSM Physics – BSM Higgs

Nikos, Andy, Monica, Stephen

- Many BSM theories include an extended Higgs sector
  - Introducing a family of higgs particles, such as a heavy CP-neutral Higgs (A), charged Higgs ($H^{\pm}$) and a heavy Higgs (H)
  - Can provide insight into DM, force unification and CP violation
- Ongoing/recent searches for new heavy Higgs particles
  - A→ Zh: Significant effort in Run 2. Team now developing the analysis in Run 3 (Nikos)

    Expected Publication: Next Year
  - BSM Higgs Summary and HH resonant combination: Limits on resonant Higgs production up to 5 TeV (Nikos)

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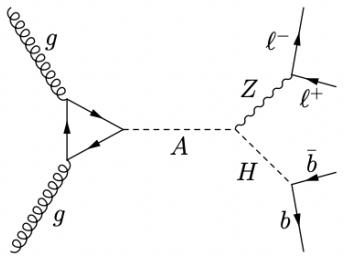
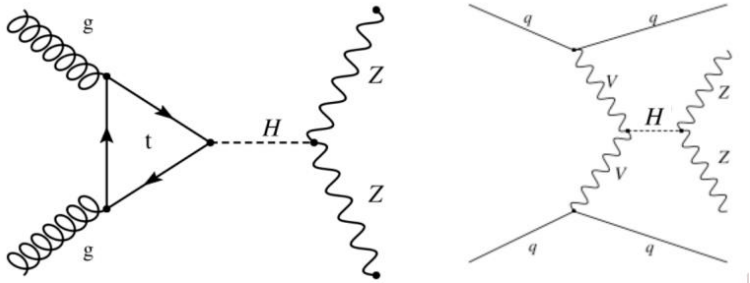
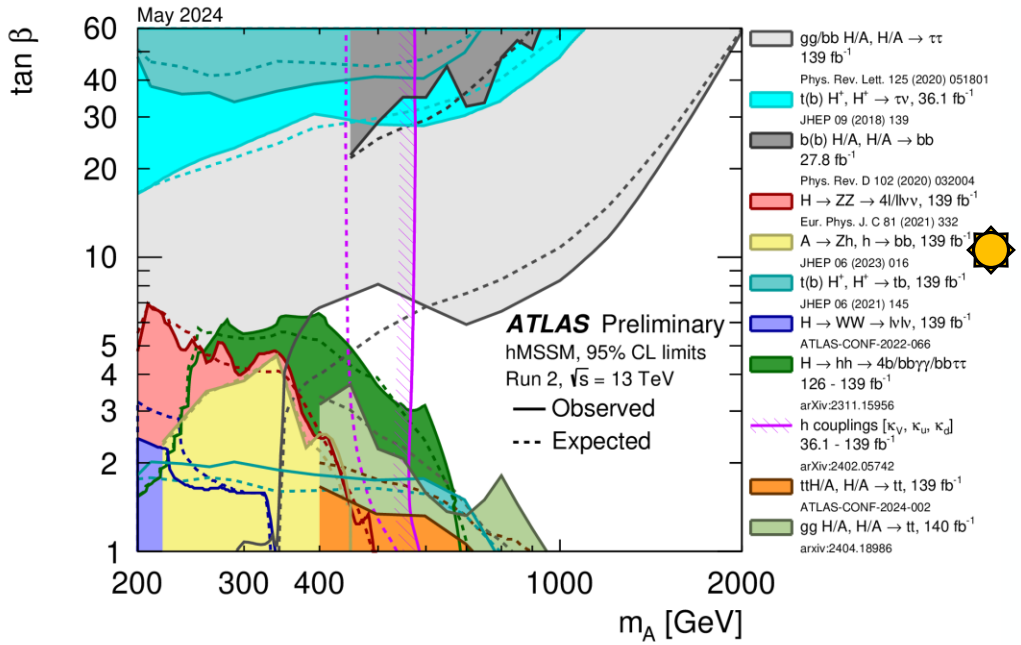
  - Run 3 Search for heavy Higgs production decaying to ZZ, and Zh → invisible (Andy, Monica, Stephen)-
    - See Stephen's slides

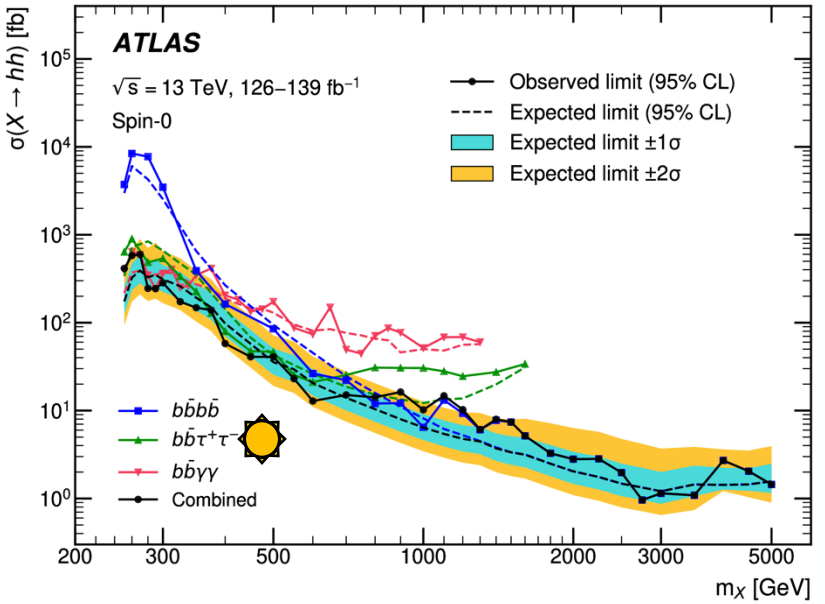
    Expected Publications:

    H→ZZ Autumn, Zh → inv, next year







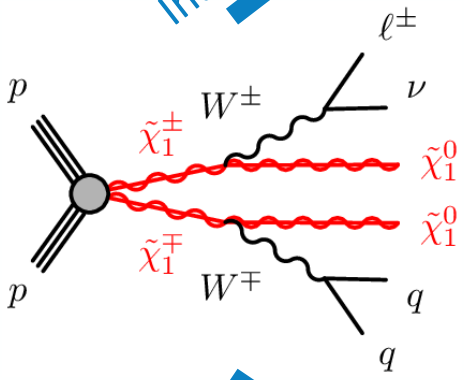


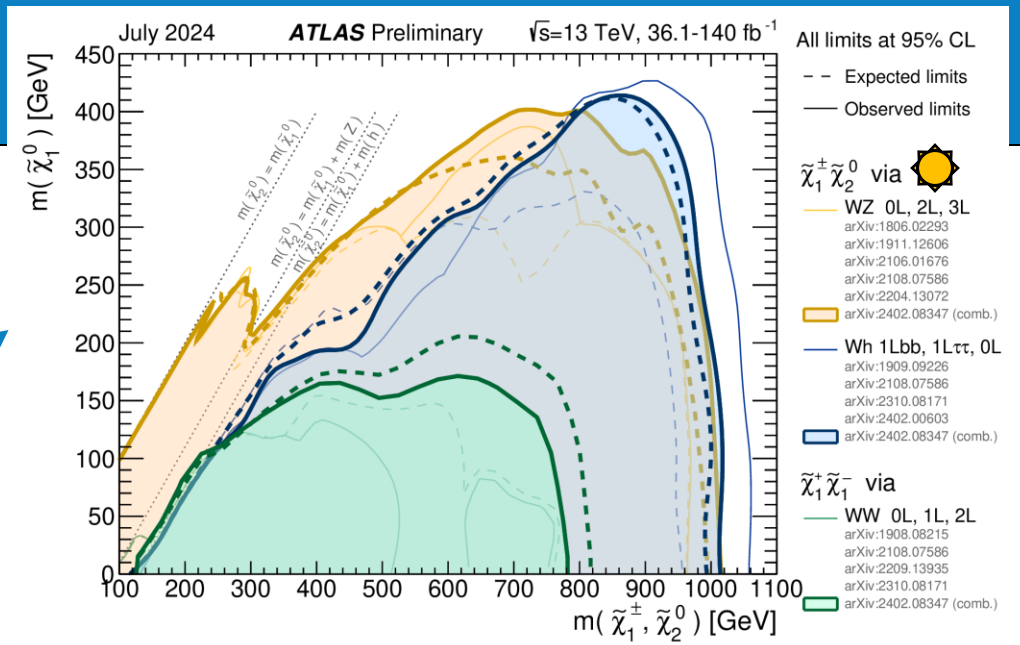
BSM Physics – Supersymmetry

Monica, John

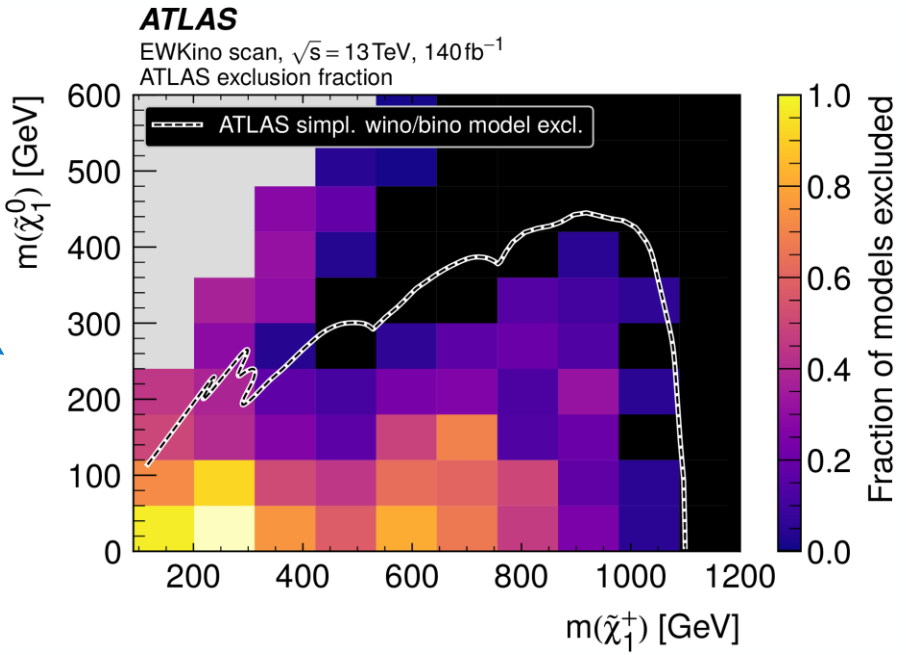
- Supersymmetry theories introduce a new gauge symmetry, resulting in a partner "sparticle" for each SM particle
  - Phenomenologically very rich
  - Huge phase space to cover
  - Can solve a plethora of unanswered questions with the SM
    - Higgs hierarchy, Flavour violation, Dark matter…
- In the past, ATLAS has searched for simplified models
  - Easy to optimise for but would not really be how SUSY would realise itself in nature
- Now considerable work investigating complex models
  - Guided by scans to identify "gaps" in coverage and theoretical motivations
  - More difficult to target!

Simplified Model Interpretation





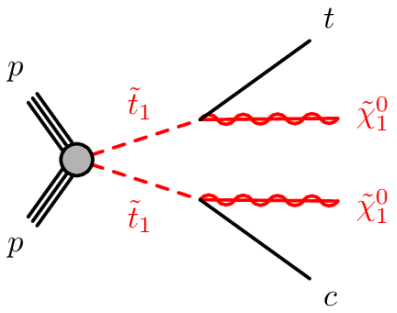
Complex model "Scan"

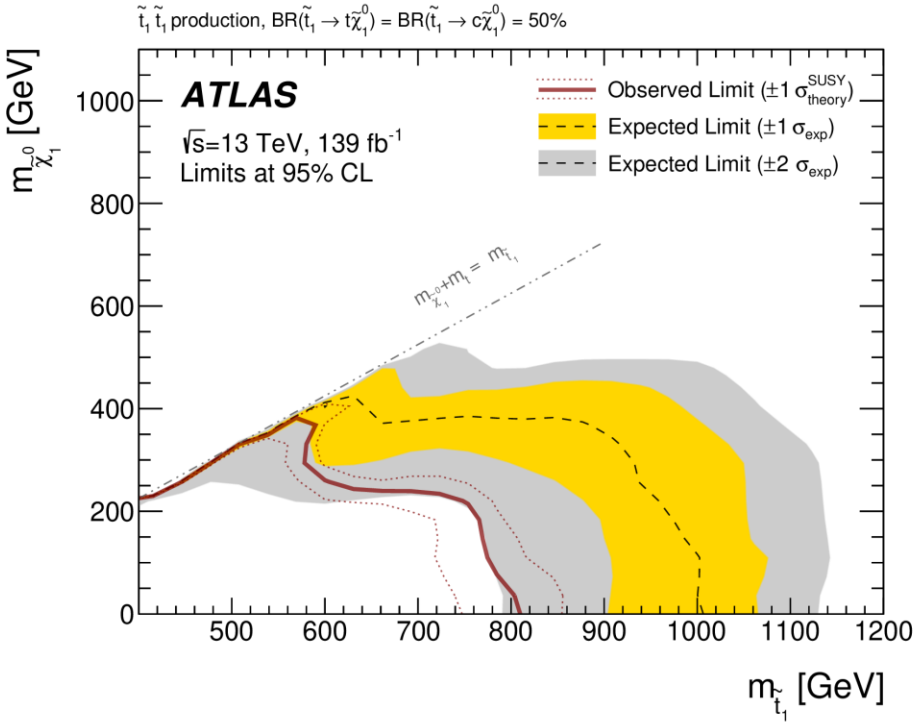


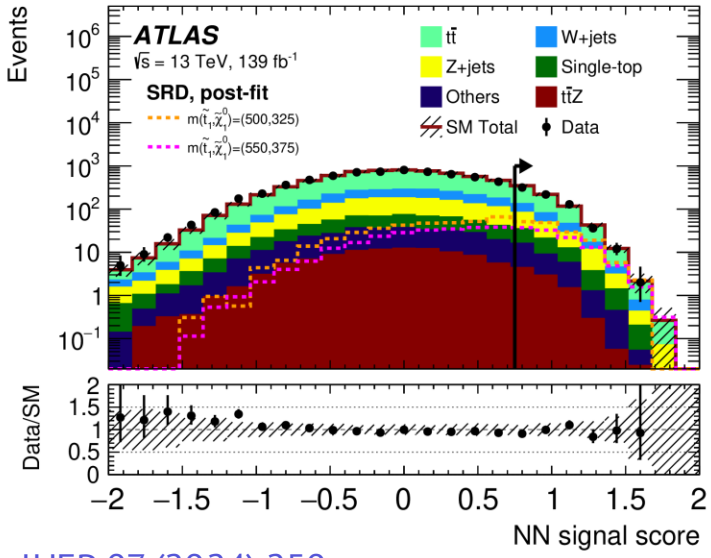
BSM Physics – Supersymmetry – Non-Minimal Models

John

- Focusing on complex models in the tcMET analysis (John)
  - Beyond the "simplified" case, as multiple BRs are available for the SUSY particles
  - Focuses on the difficult to target "asymmetric decay" mode
  - ML techniques (Neural networks) used to isolate signal and background







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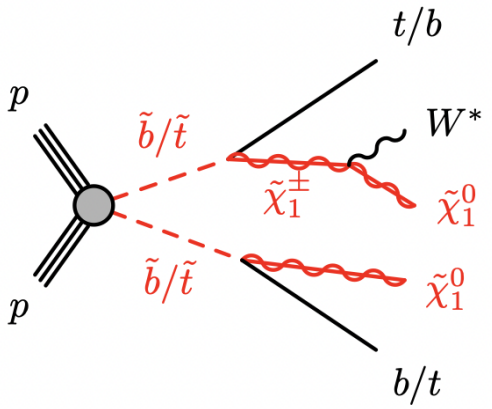
- Ongoing work performing a related analysis in the tbMET channel (John)
  - Presence of compressed electroweakinos suggested by loop corrections



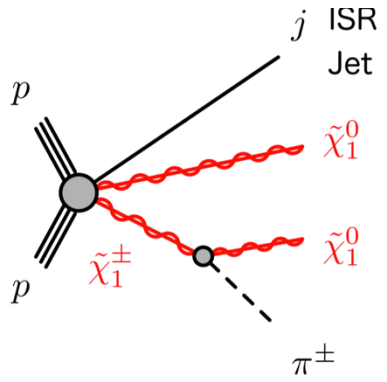
Expected Publication: Summer

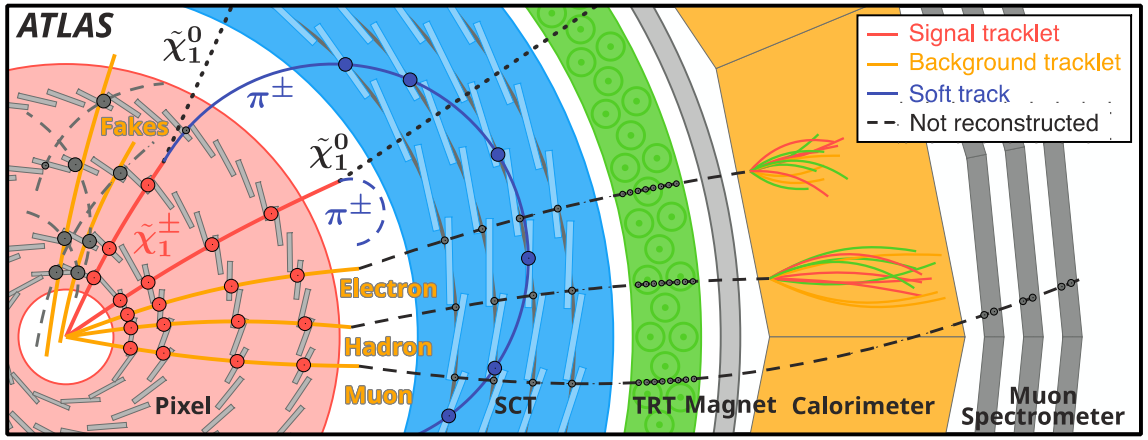
BSM Physics – Supersymmetry – Compressed States

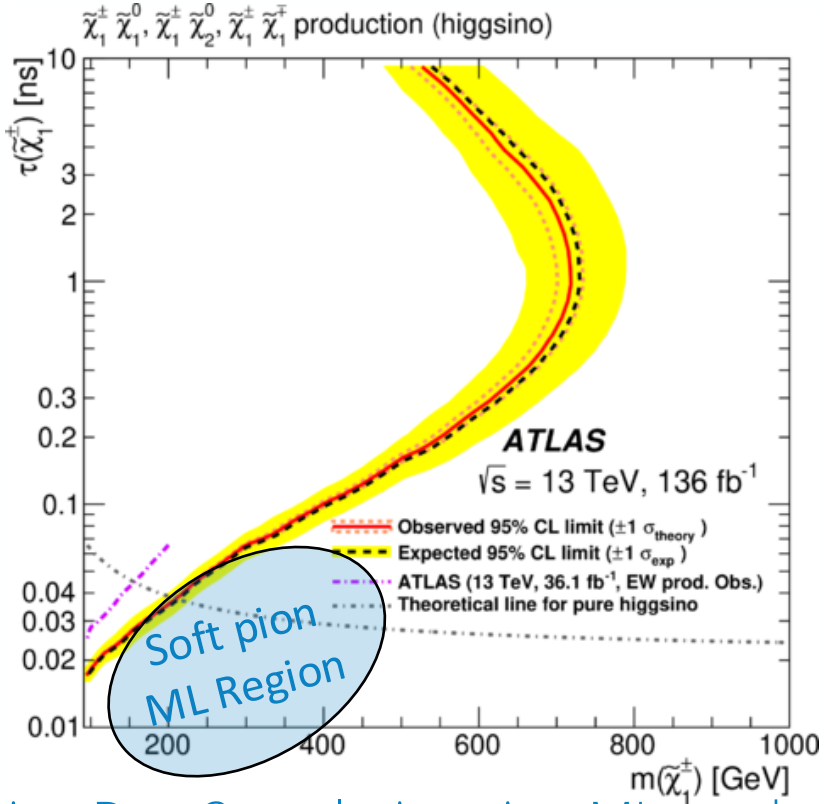
Monica, John

- Quasi-degenerate SUSY mass states (Δm~100MeV) are highly sought after and both prompt and long-lived signatures remain a key target for ATLAS searches

- "Disappearing Track" analysis (Monica, John)
  - A direct search for "compressed" Higgsinos
  - Very low energy decay products
  - Attempt to directly identify the chargino, using interactions within the innermost detector layers







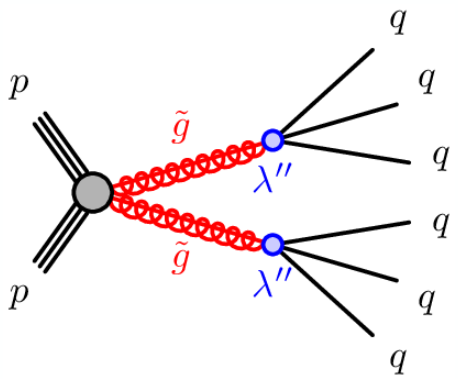
- Ongoing Run 2 analysis using ML methods to reconstruct the "soft" pion
  - Attempting to increase sensitivity in the short lifetime region

Expected Publication: Autumn

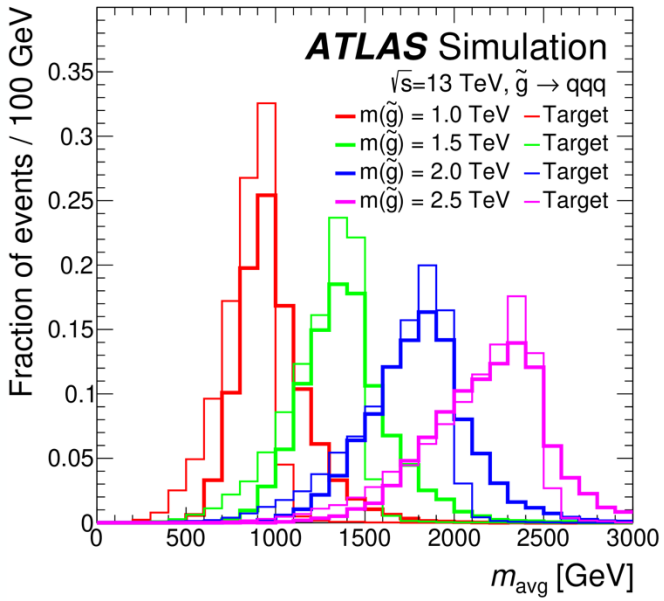
BSM Physics – Supersymmetry – R-Parity Violation

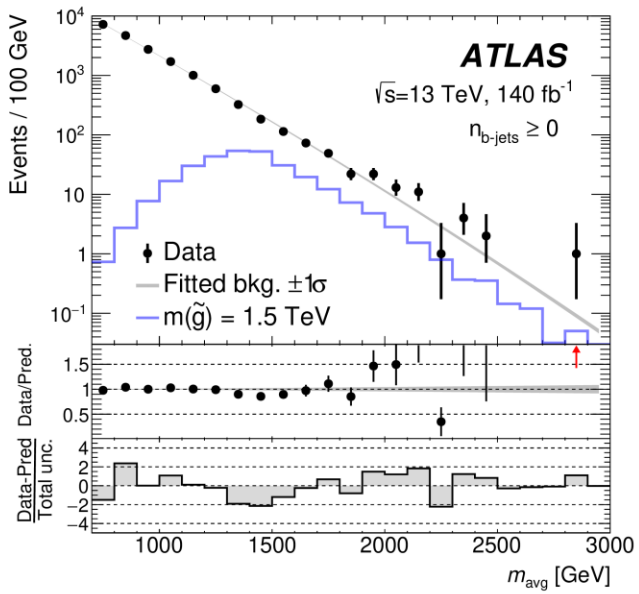
John

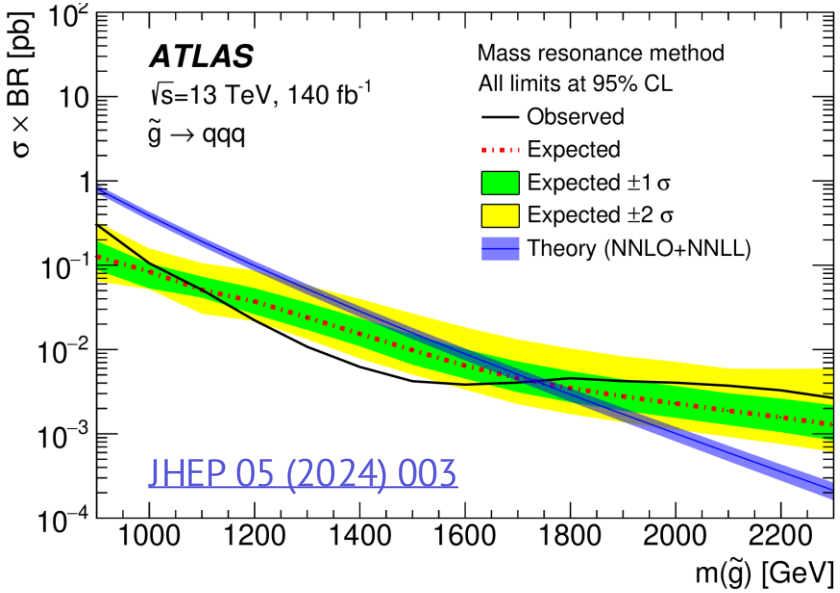
- We generally assume R-parity conservation (prevents proton decay & provides a dark matter candidate)
- But we may allow "certain" R-parity decays and remain consistent with existing measurements
  - Standard R-parity conserving analyses are no longer sensitive if this is the case
- RPV Multijet analysis (John)
  - Dedicated search for RPV gluino decays



  - Novel usage of neural networks to correctly identify which combination of jets belong to each gluino and to calculate the average gluino mass → Bump Hunt!







BSM Physics – Leptoquarks (LQs)

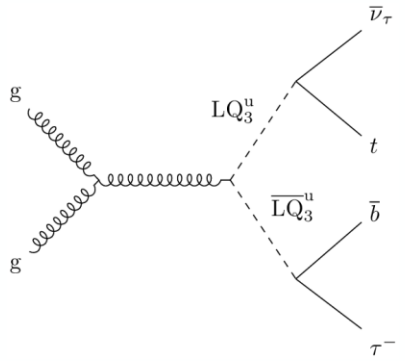
Andy, Carl, Monica, Mehul, John

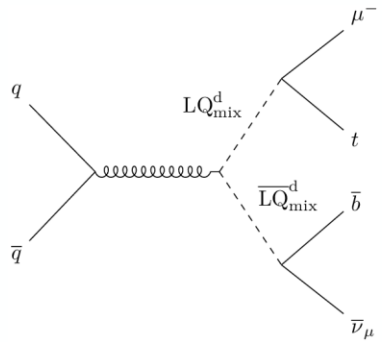
- Leptoquarks can be introduced to provide a coupling between quarks and leptons
  - Provides explanations for flavour anomalies and g-2
- The phenomenology can be similar to existing searches, enabling existing results to be reinterpreted
  - Reinterpretation of SUSY results (Monica, John)
- Dedicated searches are also required to fully explore the phase space (Andy, Jordy, Mehul)
  - Run 3 Search for LQ pair production events with the bb$\tau\tau$ final state – ongoing (see Mehul's slides)

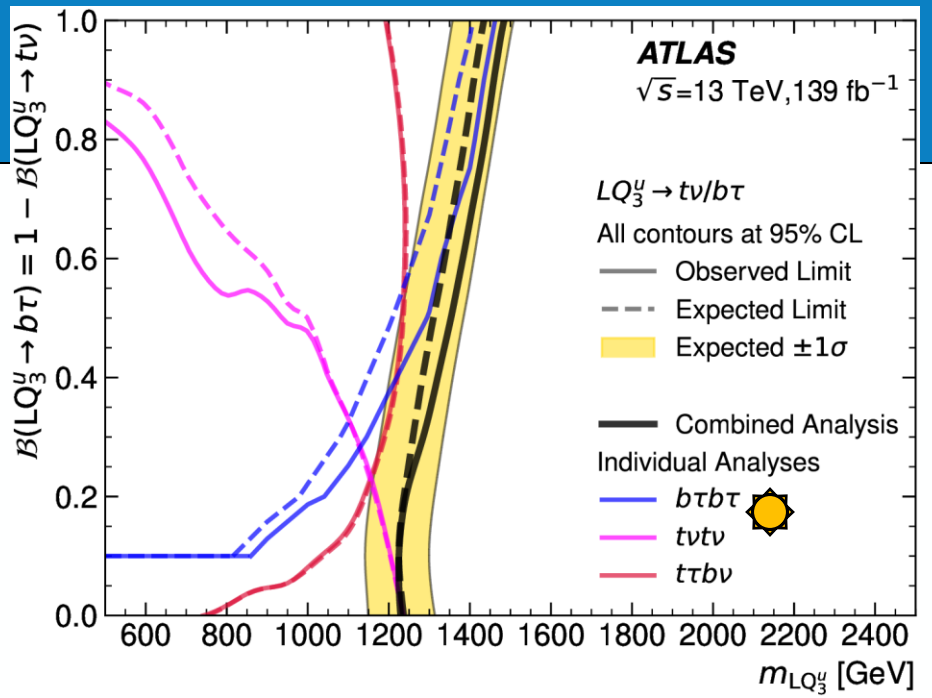
Expected Publication: Winter

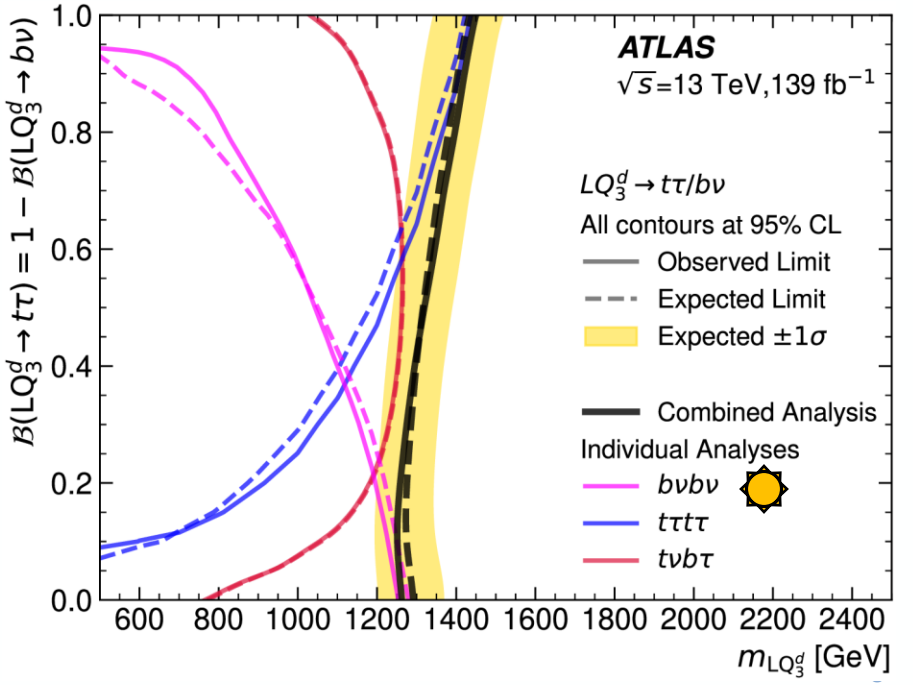
- Searches are designed such that they can be statistically combined (Andy, Monica, John)
  - Combination of existing results provides enhanced sensitivity to LQ production
  - Considering "mixed" scenarios with multiple open decay modes

Phys. Lett. B 854 (2024) 138736





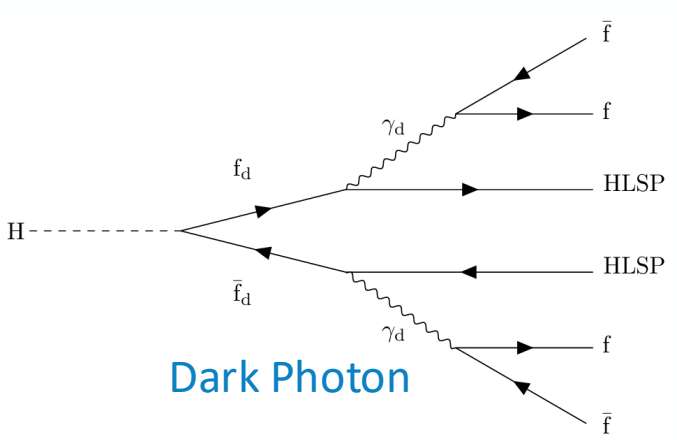




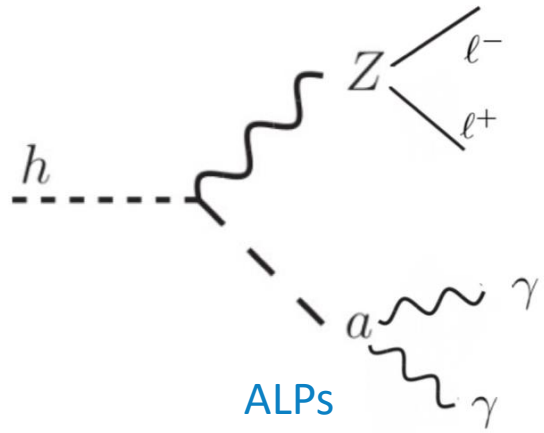
BSM Physics – Dark Sector– Unconventional Signatures

Monica, Nikos, Rebecca, Shirsendu

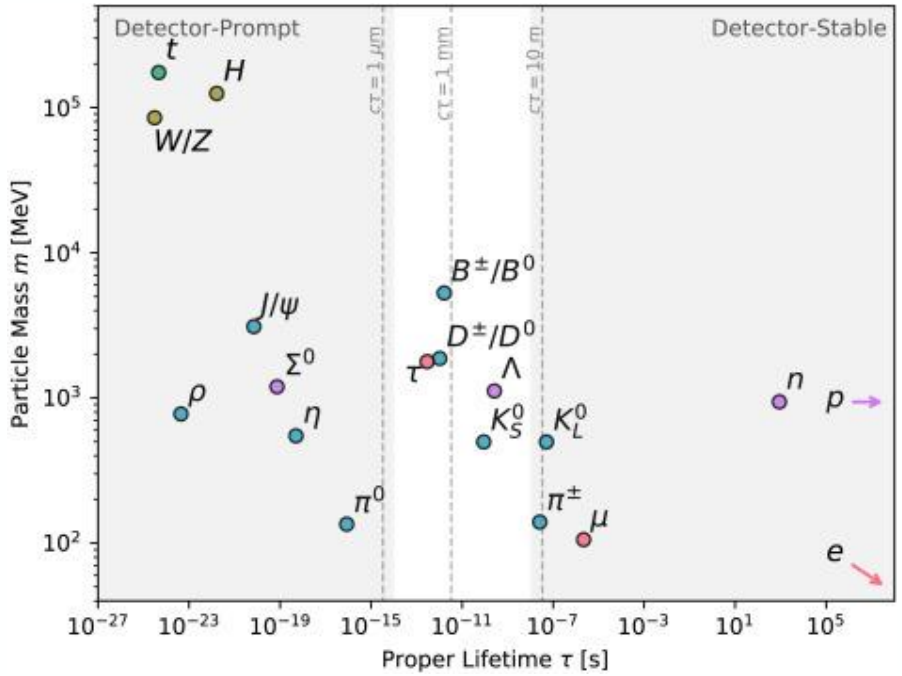
- Dark Sector theories predict a set of "dark" particles which interact very rarely with SM particles (including a DM candidate)
  - We can use Higgs production as a portal to the dark sector
  - The BR(Higgs → invisible) leaves room for dark sector particles to be produced in Higgs decays
- Typical benchmark models: Dark photons, Axion like particles
  - Might arise in Higgs decays either directly or in cascade
  - The dark sector particles can decay into SM particles
- Depending on the dark sector SM coupling, unconventional signatures are expected with long lived particles
  - This shouldn't be too unexpected as the SM contains many long-lived particles (LLPs)
  - As we usually consider "prompt" particles, final states with LLPs require dedicated reconstruction techniques!



Dark Photon



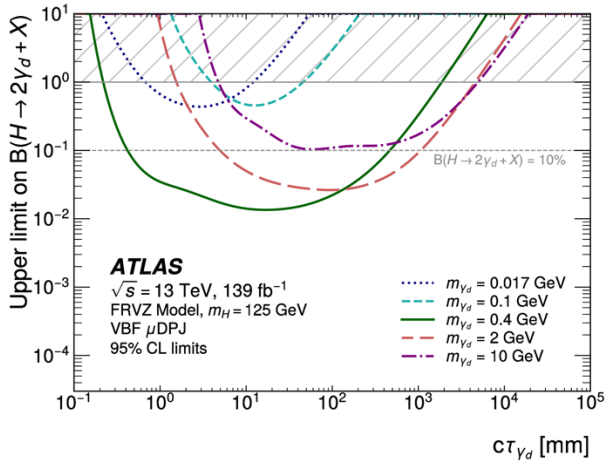
ALPs

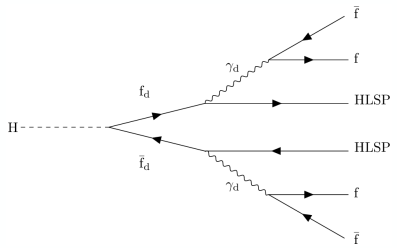


BSM Physics – Dark Sector– Unconventional Signatures

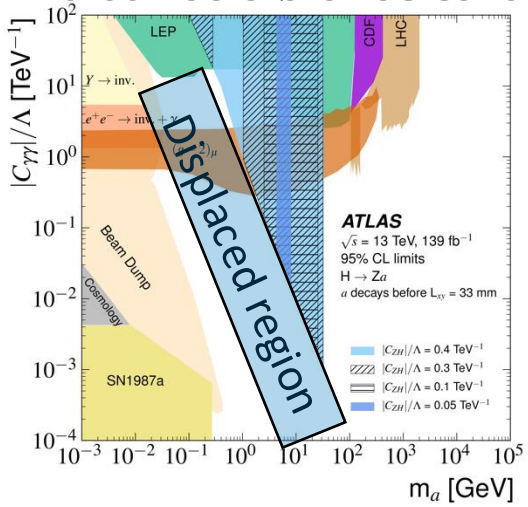
Monica, Nikos, Rebecca, Shirsendu

- Recent results using GNNs to identify Dark photon production with the Higgs as a portal (Monica, Cristiano) [Eur. Phys. J. C 84 (2024) 719]

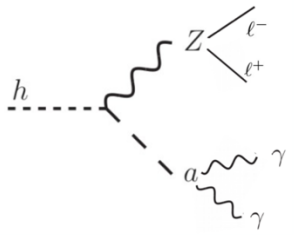




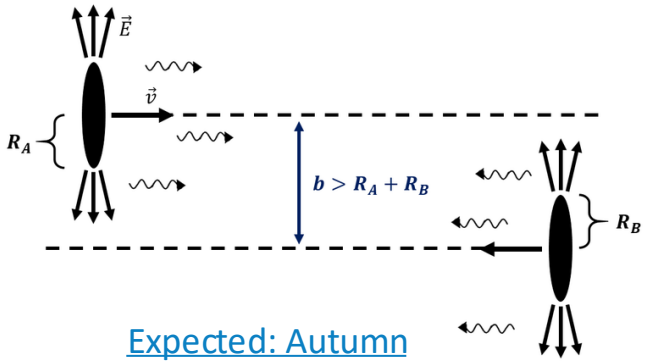
- Adapting the GNN techniques from the previous (displaced Dark photon) analysis to search for displaced ALPs (Monica, Nikos, Rebecca)
  - Using Run 3 data to target the (uncovered) region that would provide contributions to g-2



Expected: Autumn



- Developing a novel Run 3 ALPs analysis using Pb-Pb collisions (Monica, Nikos, Shirsendu)
  - Ultra peripheral collisions (UPC) used to investigate ALPs production
  - Production cross-section is dependent on Z^4
    - Significant increase in PbPb collisions when compared to pp collisions (despite the lower overall luminosity!)
  - See Shirsendu's slides



Expected: Autumn

Conclusion

- ATLAS has a plethora of BSM searches
  - Wide ranging BSM program investigating phenomenologically complete models (Extended Higgs, SUSY) and simpler extensions to the SM (LQs, Dark Photons, ALPs)
  - Another very important aspect is that these searches also have a “model” independent interpretation, providing even more impact and interpretability
- Run 2 analyses are being wrapped up, and Run 3 analyses are ongoing
  - The increased luminosity and CMS energy in Run 3 provide significant benefits here
  - Analyses are designed such that combinations with existing Run 2 analyses should be easy to perform
- Ongoing developments focusing on complex scenarios, and exploiting all available data
  - Searching for new models in complex final states
  - Developing complex search techniques (using AI etc)
  - Improving ATLAS particle reconstruction
- It’s an interesting time to search for BSM Physics!
  - I haven’t discussed the Lorentz invariance violation analysis (Uta) and SMEFT fits using high-mass DY data (Uta)
  - Also not included: EFT interpretations of SM measurements to further increase the impact of our work!