Searches for BSM Physics in ATLAS

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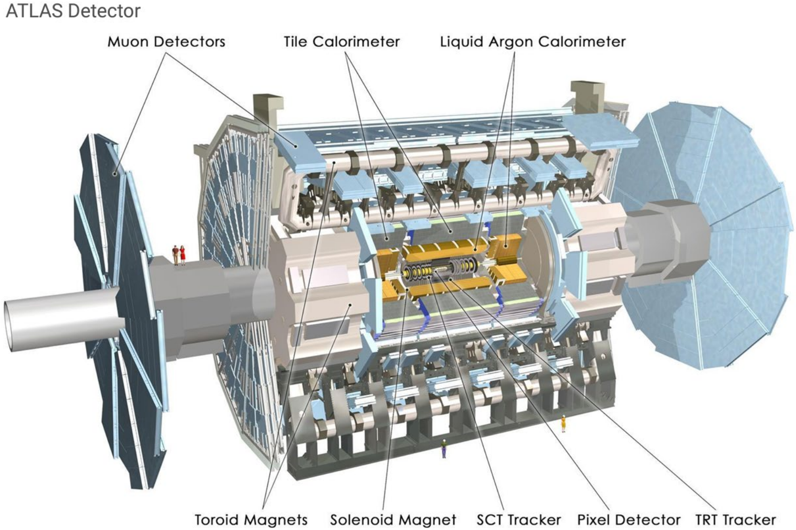
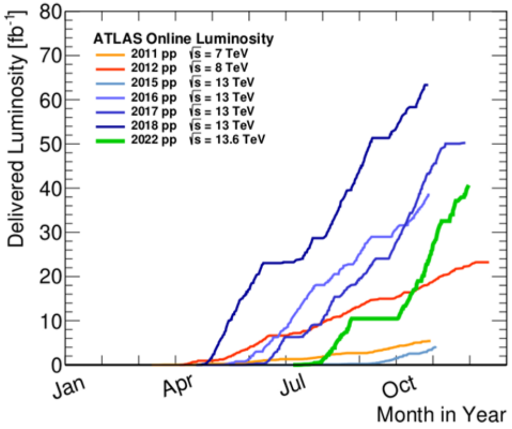
Introduction

- The ATLAS experiment has collected over 200 fb^{-1} of integrated luminosity at 7, 8, 13, and 13.6 TeV. Over 1,100 papers published to date, most of them searching for BSM physics.
- A 15-minutes is **necessarily** a selection of results. I will try to focus in well-motivated areas of BSM physics and recent results.



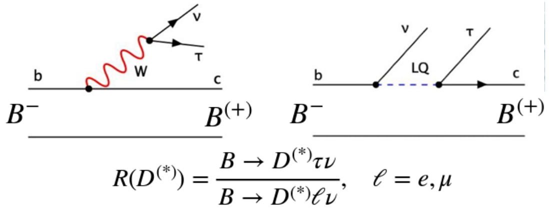


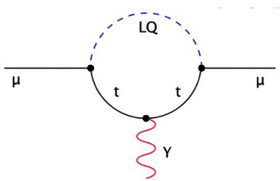
Walkthrough

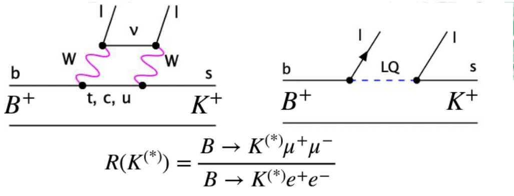
- We will review three different types of searches performed with the full Run 2 dataset.
- They cover a wide range of different phenomena and showcase the capabilities of the ATLAS detector and creative novel methods used to analyze the Run 2 data.
  - **Leptoquark searches:** traditional topic with a recent burst of interest because of B-physics anomalies
  - **Long-lived particles:** huge BSM area with some very non-traditional analysis methods
  - **Exotic Higgs decays:** powerful way to access very weakly-coupled new physics that would be otherwise inaccessible
- Each of these topics have, themselves, many more exciting results. The full set of ATLAS public results can be found here: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications

Leptoquark searches

- **Leptoquarks** are good simple models to explain recent anomalies in data
  - Mediator of flavor-changing neutral current
  - Can violate Lepton Flavor Universality
- **Predicted** in many Grand Unification Theories: SU(5), Pati-Salam SU(4), R-parity violating SUSY
- **Connect** the quark and lepton sectors







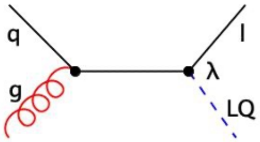
Pair Production

flavour-diagonal | cross-generational

cross-section depends on m_{LQ}

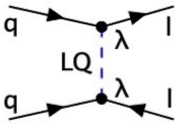
Single Production

cross-section $\propto \lambda^2$
sensitive to higher m_{LQ} for high λ



Non-resonant Production

cross-section $\propto \lambda^4$
sensitive to very high masses
interference with SM



Summary of leptoquark searches

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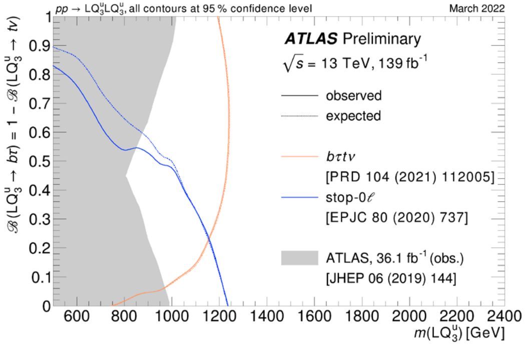
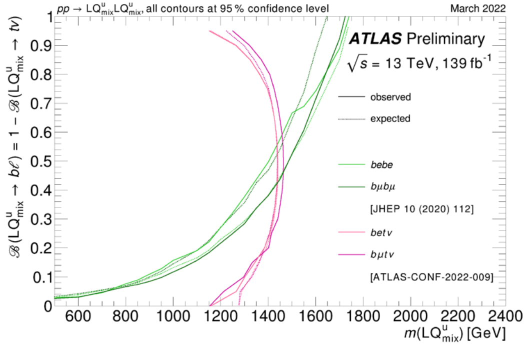
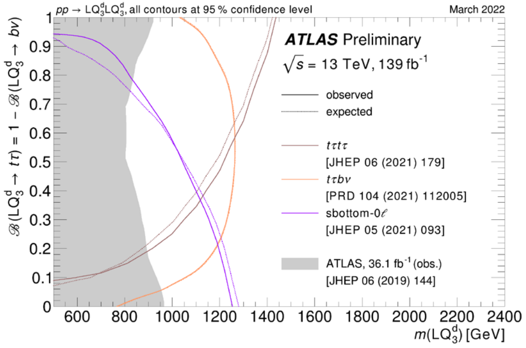
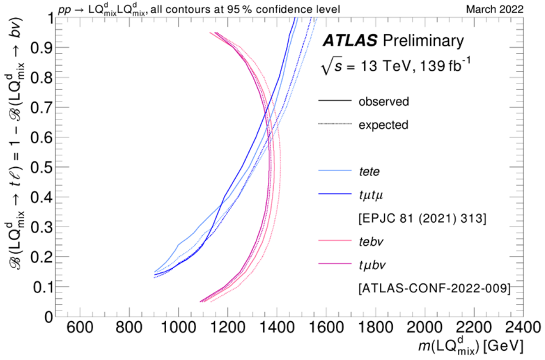






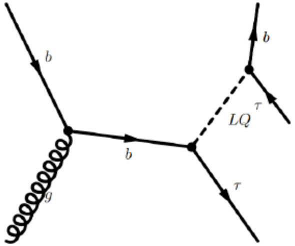


- **Scalar** and **vector** leptoquarks
- Parameters:
  - Mass and charge
  - (λ) Yukawa coupling
  - (β) BF into charged leptons or neutrinos
    - $\beta = 1$ couple only to charged leptons
    - $\beta = 0$ couple only to neutrinos
  - (κ) coupling to color:
    - Gauge origin, YM ($\kappa = 0$)
    - Minimal ($\kappa = 1$)

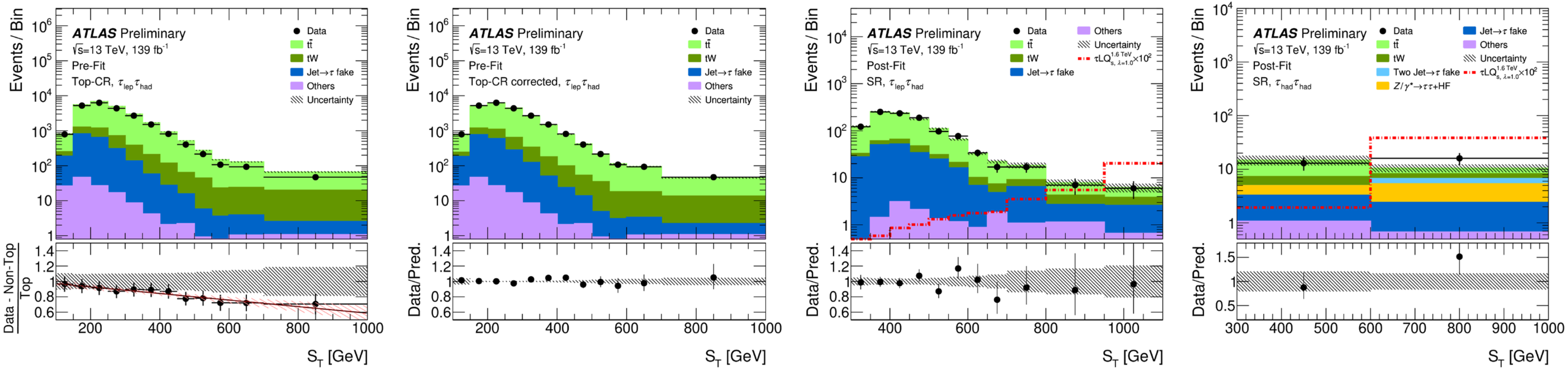
Scalar leptoquark $LQ^{\tilde{S}_1} \to b\tau$

ATL-CONF-2022-037

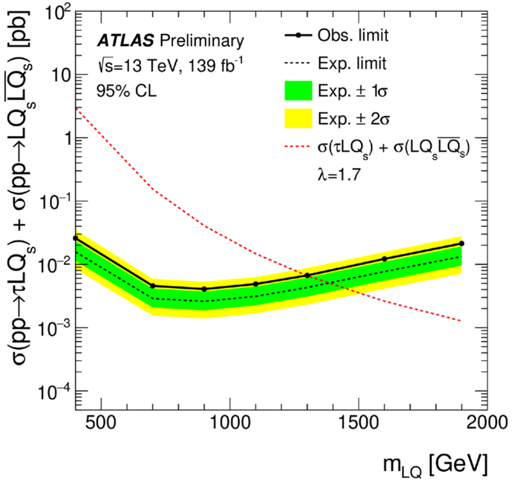
- Searches for singly and pair-produced scalar $LQ \to \tau + b$
- Selection: $\geq$ 1 b-jet, 2 OS τ
  - Signal/background discrimination at high S_T
  - had-had and had-lep decay modes of the τ pair
  - Dominant top quark background corrected as a function of S_T
- Limited by statistics and top background modeling

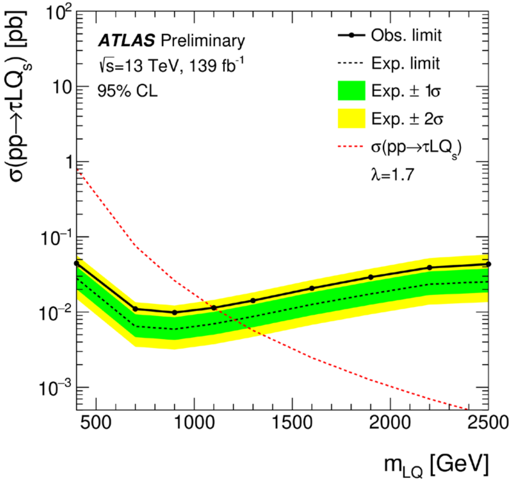


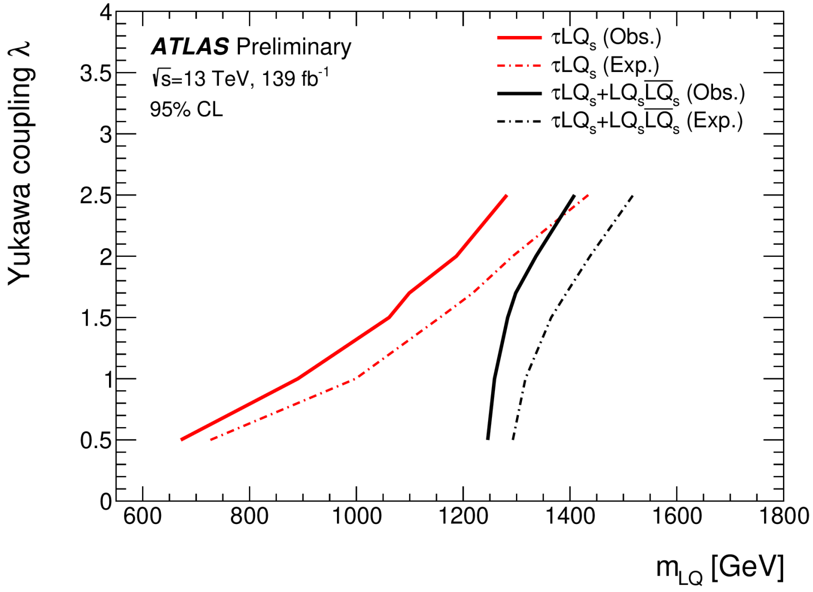
$$S_T = \sum_{b-\text{jet},\ell,\tau} p_T$$



Scalar leptoquark $LQ^{\tilde{S}_1} \to b\tau$







$m(LQ)$ excluded up to 0.89 (1.28) TeV for $\lambda = 1.0$ (2.5) for singly produced LQ

Pair-produced $LQ_3^{d(u)} LQ_3^{d(u)} \rightarrow b\tau b\tau$

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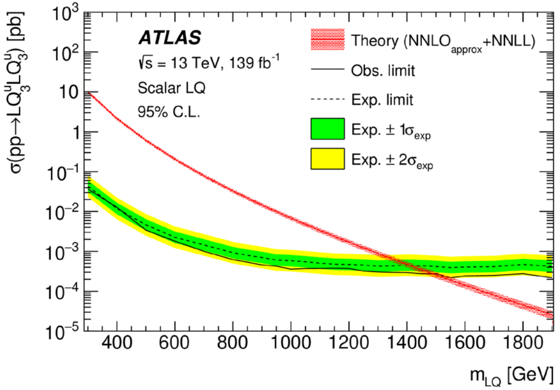
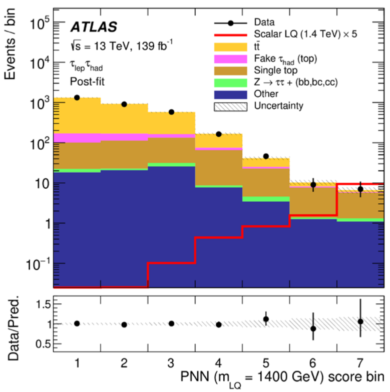
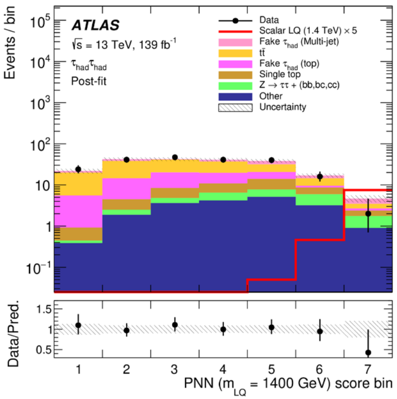
ATL-EXOT-2021-15

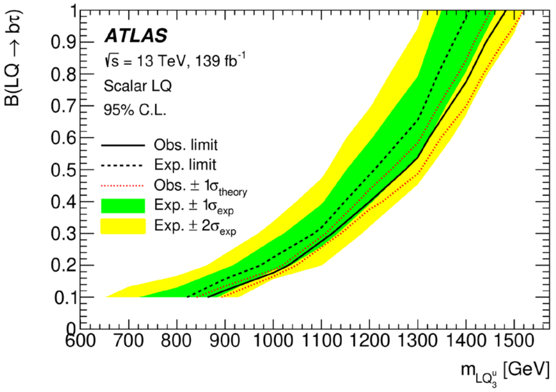
- Pair-produced scalar or vector $LQ \rightarrow \tau + b$
  - Family-diagonal Yukawa coupling
- Selection: $\geq$ 2 jets ($\geq$1 b-jet), 2 OS τ
  - had-had and had-lep decay modes of the τ pair
  - Dominant top quark background corrected as a function of S_T



Parametrized NN, as a function of m_{LQ} hypothesis trained to discriminated signal and background

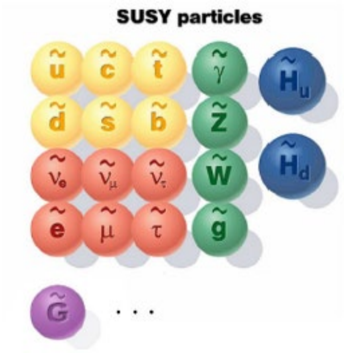


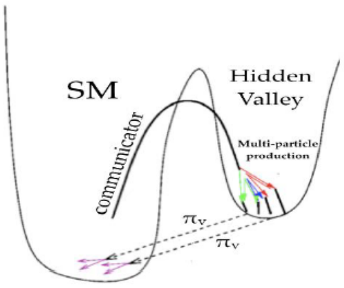


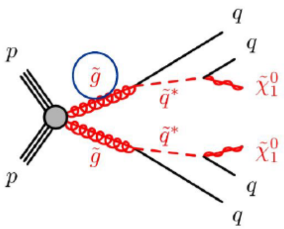


Long-lived particles

- Many BSM theories include particles with macroscopic lifetimes.
- Strong interplay between theory and experiments
  - Specific theories can suggest new signatures to explore
  - Results are presented in benchmarks but can be re-interpreted with different models

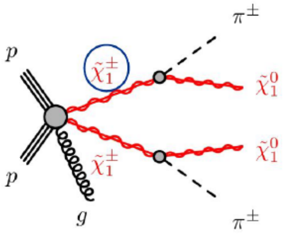






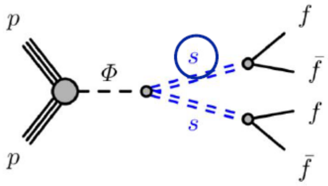
off-shell decays

e.g. split-SUSY with squarks mass > 10 TeV



phase-space

Small mass splitting e.g. AMSB

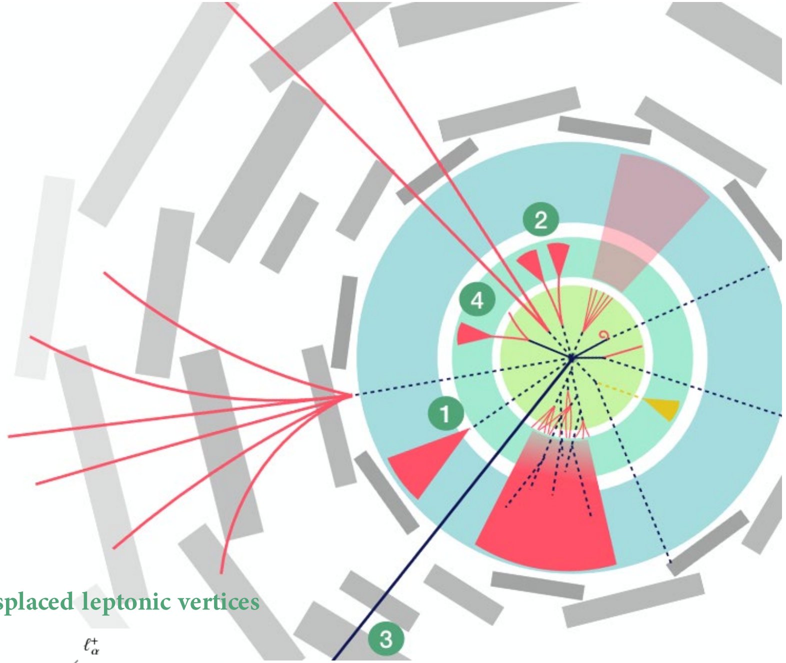


small couplings

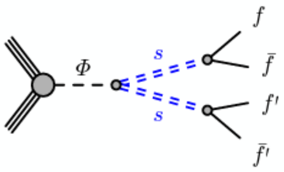
e.g. weakly-coupled dark sector, small R-parity violation, …

Signature-based searches

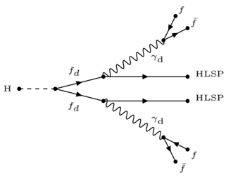
- **Long-Lived Particles**: non-SM particles that travel macroscopic distances
- **Challenging Signatures**: Does not use *standard* objects/data-flow/… and/or defy in some sense our theoretical prejudice of how new physics would appear
- **Best experimental strategy** depends on the properties of the particle



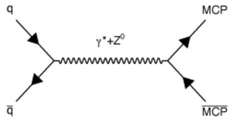
(1) Displaced hadronic jets



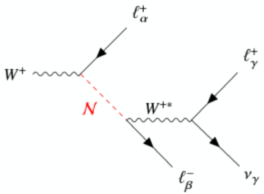
(2) Displaced leptonic jets



(3) Highly ionizing particles

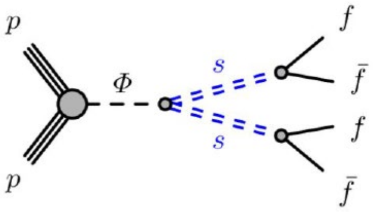


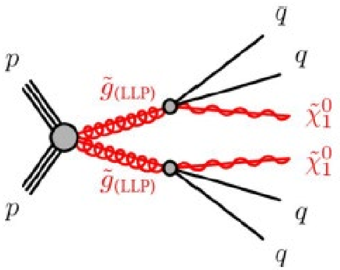
(4) Displaced leptonic vertices

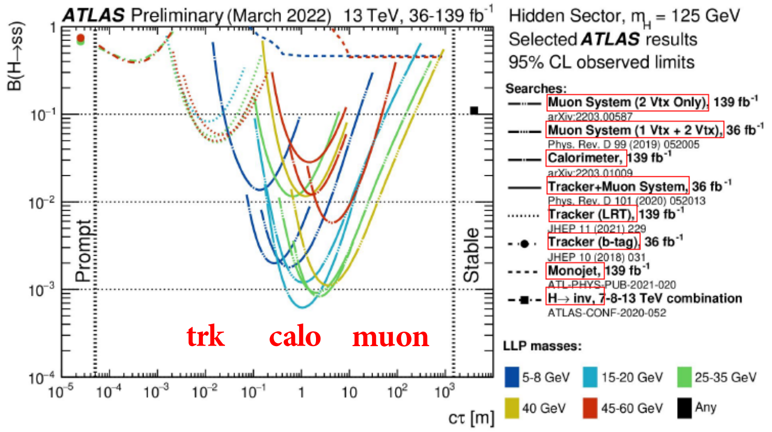


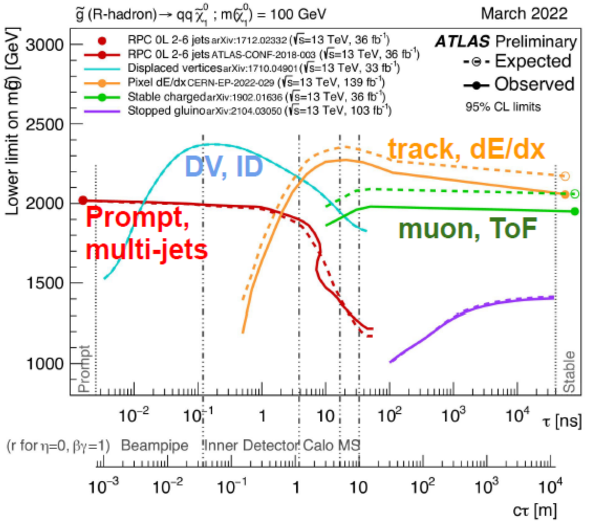
Summary of long-lived results

Standardized benchmarks help ensuring coverage across signatures









Inner tracker charged particles

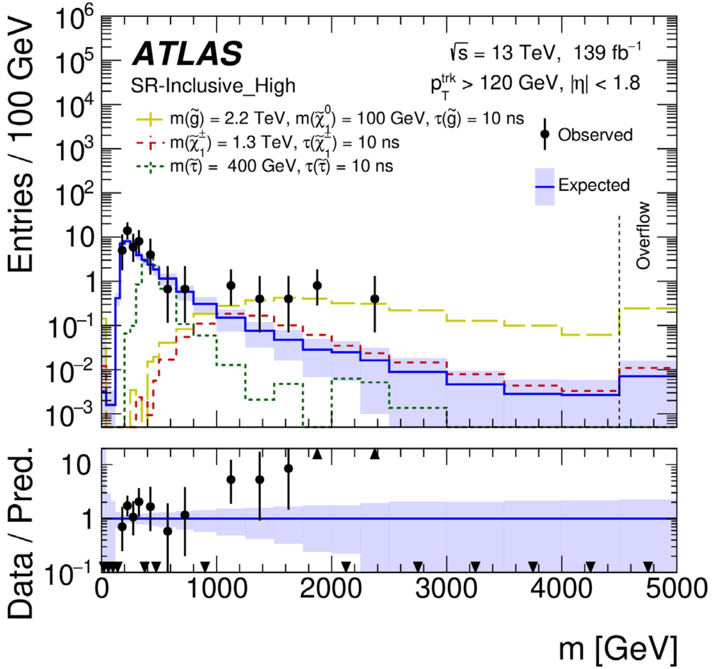
ATL-SUSY-2018-042

- High-p_T, high-quality reconstructed track with large ionization energy loss (dE/dx, calibrated in low-μ runs)
- Triggering on missing transverse-momentum
- Entirely data-driven background estimation

$$m = p/(\beta\gamma)$$

from inner detector — from pixel detector

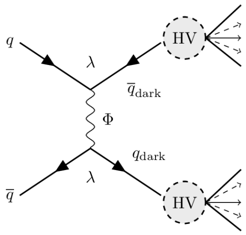
- Excess observed: 3.6σ local (3.3σ global)
- Many cross-checks performed. Timing information indicates $\beta \approx 1$.
- No obvious instrumental/analysis problem found.

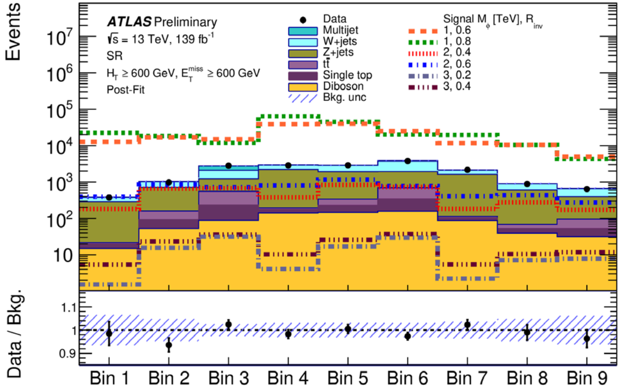


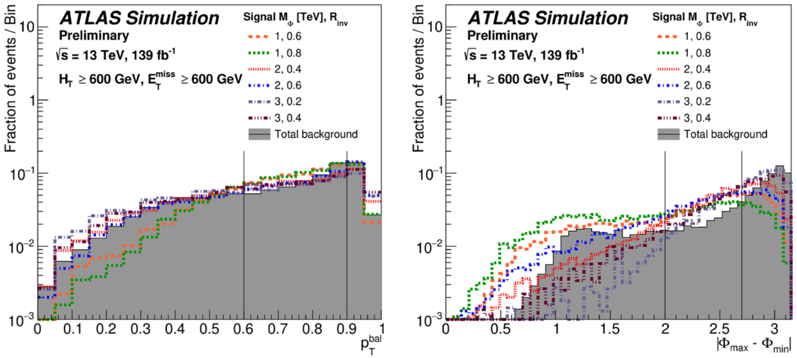
Semi-visible jets

ATL-CONF-2022-038

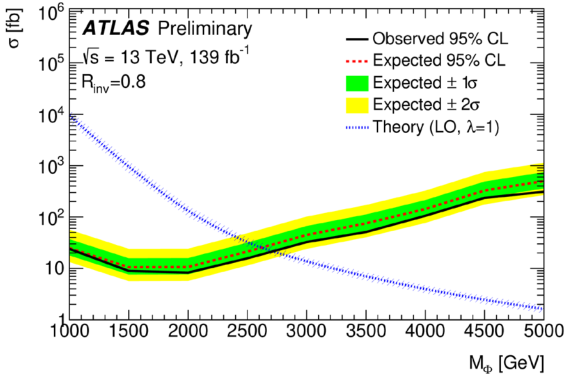
- Semi-visible jets from partial decays back to SM
- When additional jets boost the system, E_T^{miss} is present
- Two main observables:
  - Back-to-back jets balance
  - Missing momentum aligned with high-p_T jet

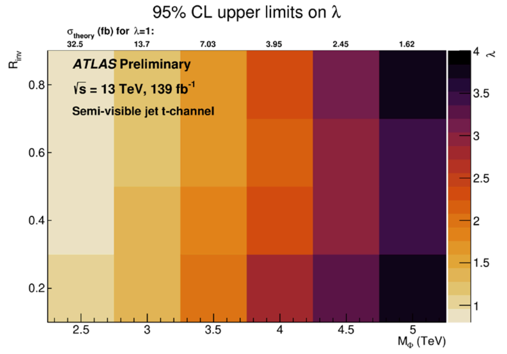






Signal parametrized by ratio of invisible to visible hadrons (R_{inv})

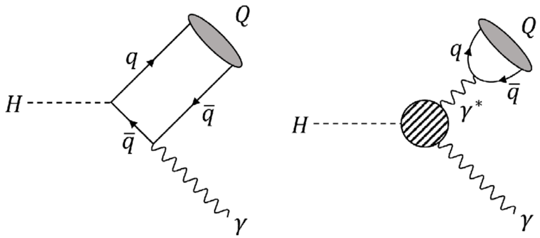


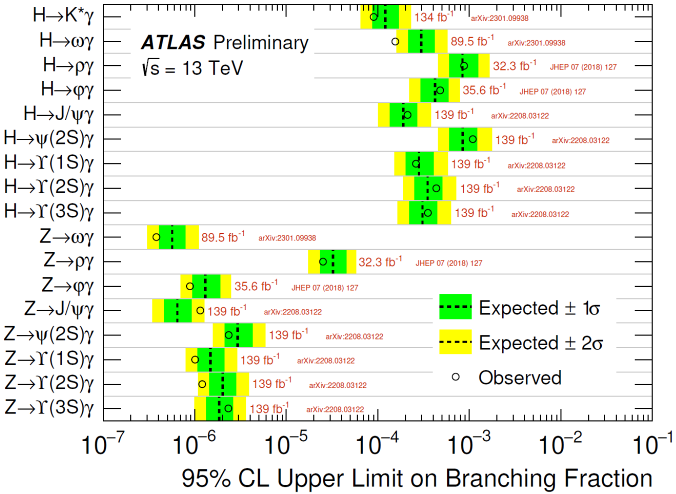


Searches for $H(Z) \to \gamma + \text{meson}$

ATL-PHYS-PUB-2023-004

- Search for $H(Z) \to \gamma + Q$
  - Two contributions to the decay amplitude, direct and indirect, which interfere destructively.
  - Distinct signature avoids large QCD background seen in inclusive searches
- Higgs boson decays probe b and c Yukawa couplings
  - Sensitive to both magnitude and sign.
- Z boson decays provide a test of QCD factorization
  - Small power corrections in terms of the ratio of the QCD energy scale over Z mass
  - Clean probe of meson light cone distribution amplitudes from a theory perspective





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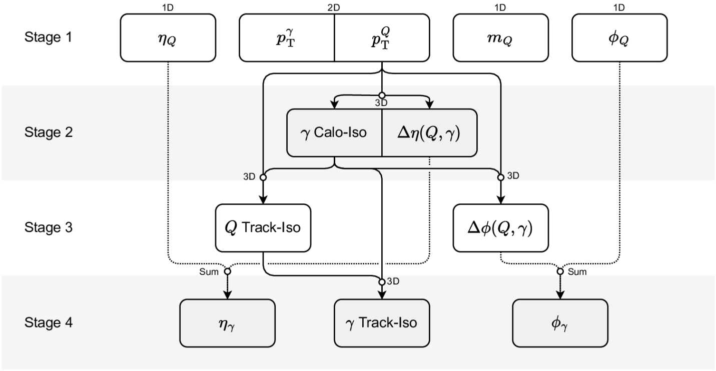
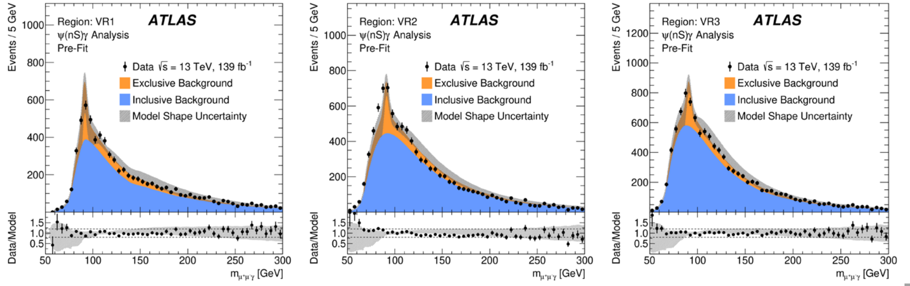
Search for $H(Z) \rightarrow \psi/\Upsilon + \gamma$

ATL-HDBS-2018-053

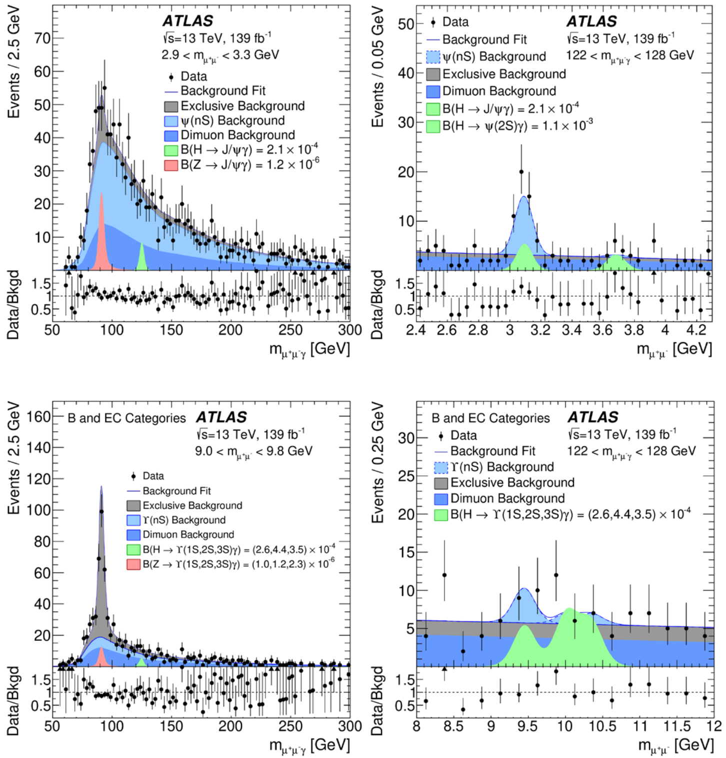


Data-driven parameterized simulation of inclusive background

Region		$p_T^{\mu\mu}$	Photon Isolation	Q Isolation
Generation Region	(GR)	> 30 GeV	Relaxed	Relaxed
Validation Region 1	(VR1)	Full	Relaxed	Relaxed
Validation Region 2	(VR2)	> 30 GeV	Relaxed	Full
Validation Region 3	(VR3)	> 30 GeV	Full	Relaxed
Signal Region	(SR)	Full	Full	Full



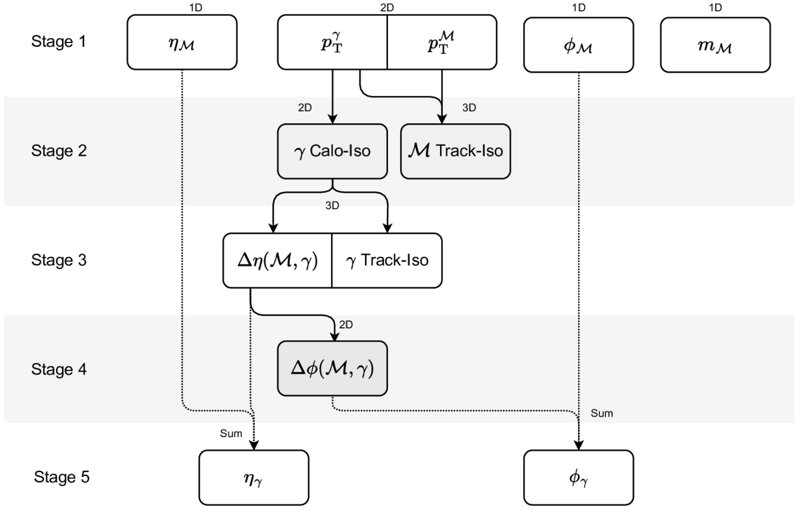
2D templates in $m_{\mu\mu\gamma} \times m_{\mu\mu}$



Search for $H(Z) \rightarrow \omega/K^* + \gamma$

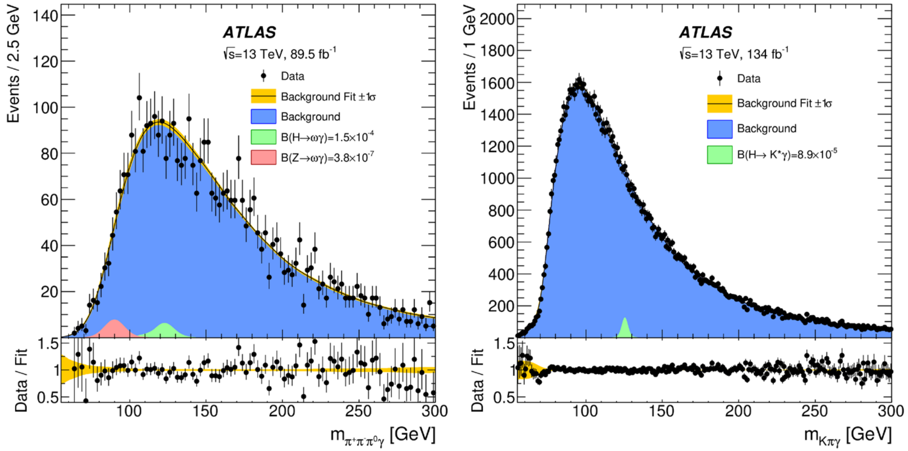
ATL-HDBS-2019-033

- Use adapted τ reconstruction to identify $\omega \rightarrow \pi^-\pi^+\pi^0$ decays
- Strategy used both online (trigger) and offline
- Keeps high trigger efficiency



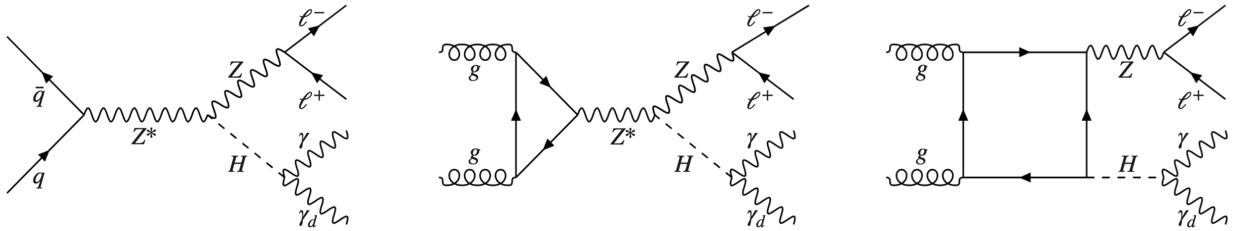
- Exotic Higgs decays also sought for in the $H \rightarrow K^*\gamma$ channels (flavor-violating decay)
- Explore $K^* \rightarrow K\pi$ decay for offline reconstruction
- Trigger based on photon only

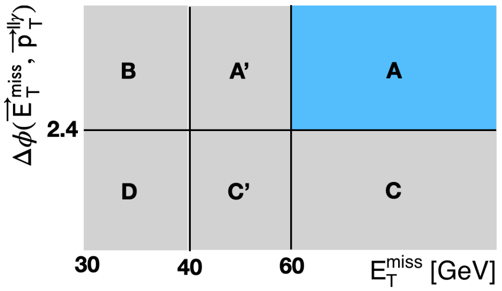
1D templates in $m_{Q\gamma}$

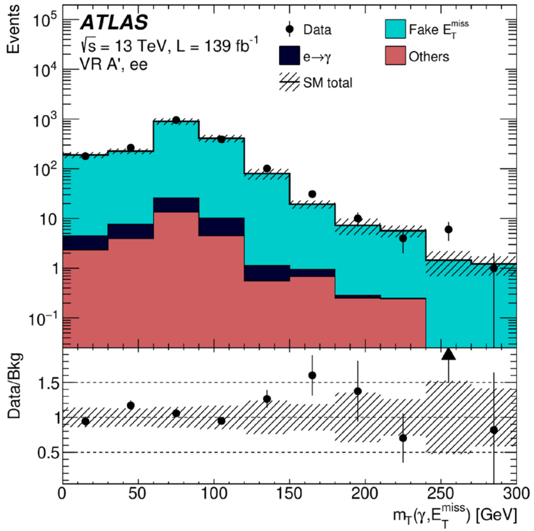


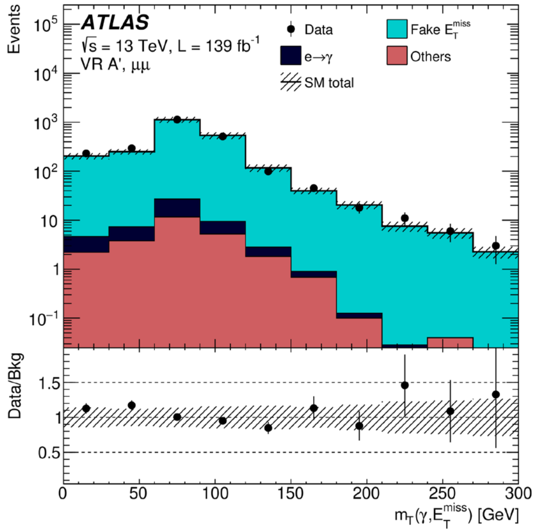
Search for $ZH \rightarrow \gamma + \gamma_D$

ATL-HDBS-2019-013



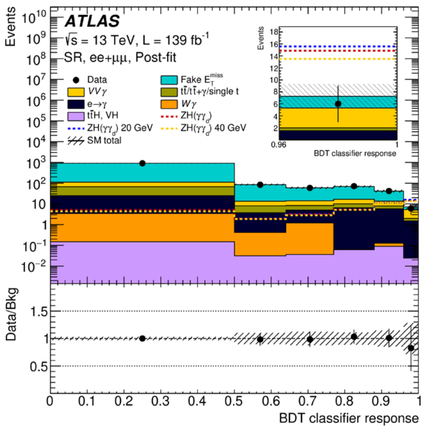




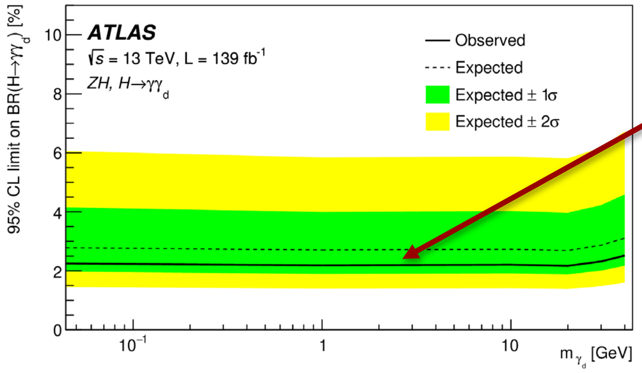


Leading source of background are $Z\gamma$ events with instrumental E_T^{miss}. Estimated with ABCD method.

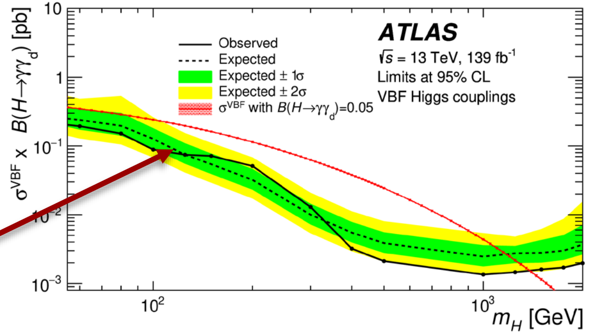
Search for $ZH \rightarrow \gamma + \gamma_D$



Dedicated BDT trained to improve signal discrimination with respect to dominant background sources.



ZH results have an observed limit of $BR(H \rightarrow \gamma\gamma_D) = 2.2\%$



Previous VBF results have an observed limit of $BR(H \rightarrow \gamma\gamma_D) = 1.8\%$

Conclusions

- ATLAS has a healthy BSM search program
- In this talk, we presented three active areas of research with recent results using the full Run 2 dataset
- Many more results with Run 2 dataset are still being studied
- In the meantime, exciting new Run 3 data is being collected since 2022. And we are starting again this year!
- Run 3 comes with new developments that will enable new BSM searches
  - New detectors (NSW, …)
  - New triggers (compressed scenarios, long-lived particles …)
  - New reconstruction algorithms (improved vertexing, large-radius tracking, …)
- Stay tuned!