Searches for BSM physics using challenging and long-lived signatures with the ATLAS detector

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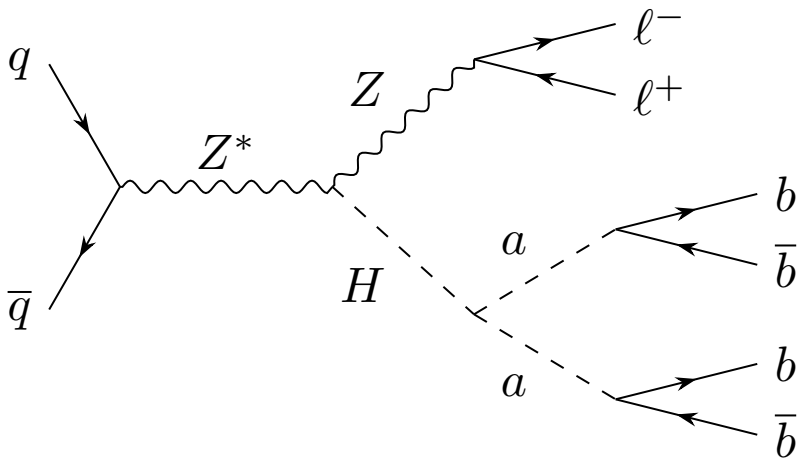
Introduction

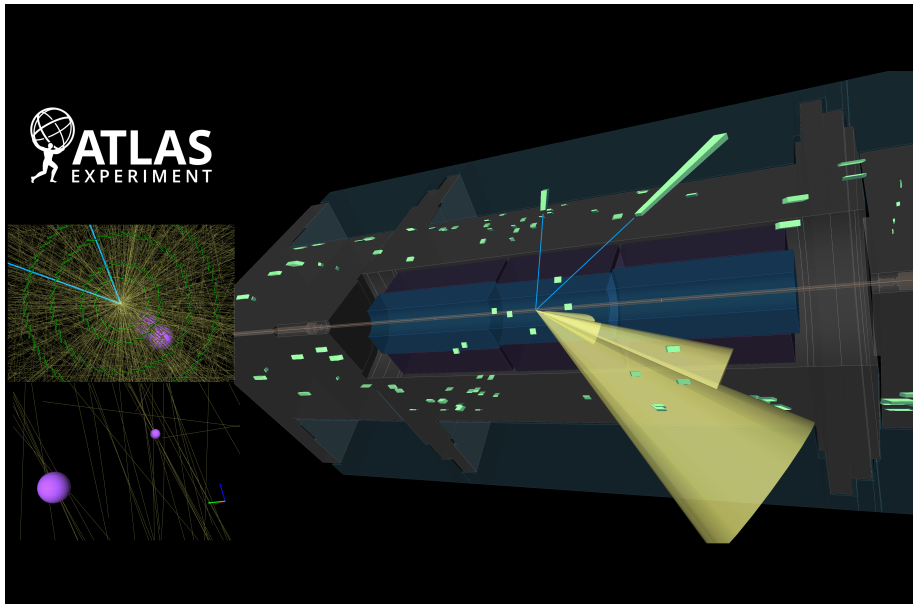
- To address dark matter, neutrino mass, hierarchy problem, ... Searching Heavy Neutral Leptons (HNL), Long-living particles (LLP)
- Predicted by several SM extensions (BSM, including SUSY models, universal extra dimension, ...) Decaying far from interaction point

- Large Radius Tracking (LRT) to recover displaced tracks
- Additional techniques to handle unconventional signatures

- Exploit *pp* collisions at Center of Mass Energy: $\sqrt{s} = 13$ TeV
- ATLAS data Luminosity analyzed: 139 fb^{-1} (unless specified)

Higgs to LLP w/ ≥ 2 displaced ID vtx - arXiv:2107.06092

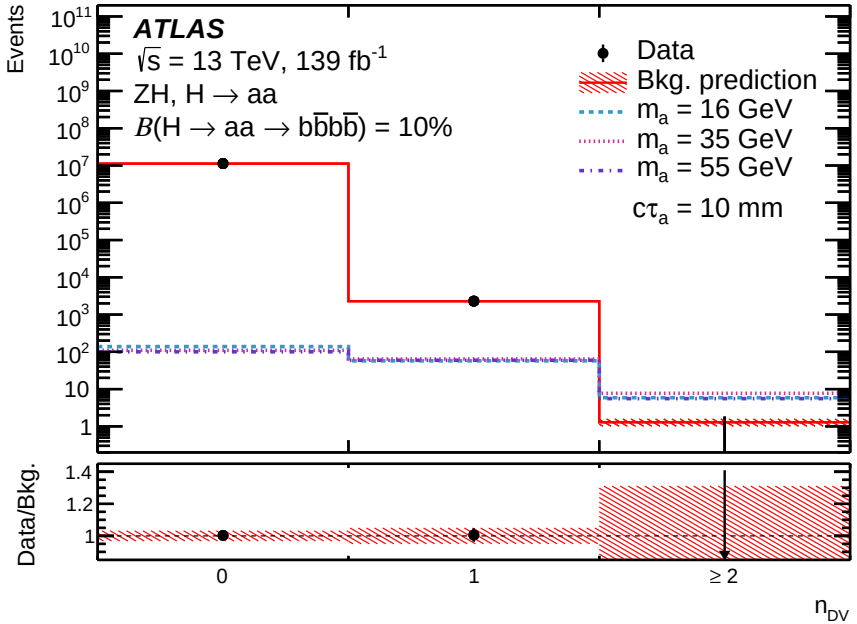


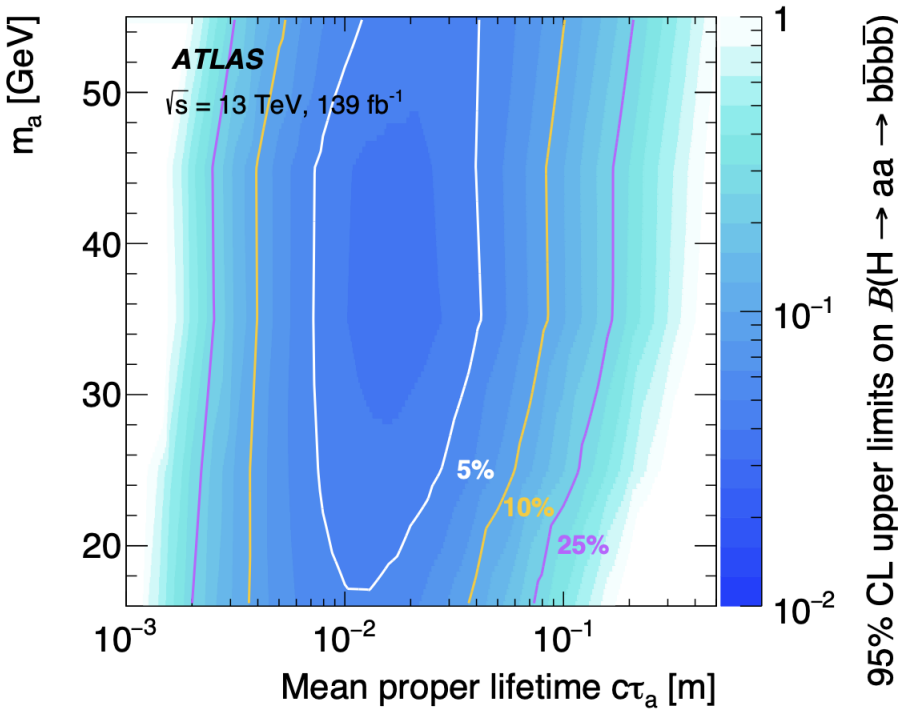


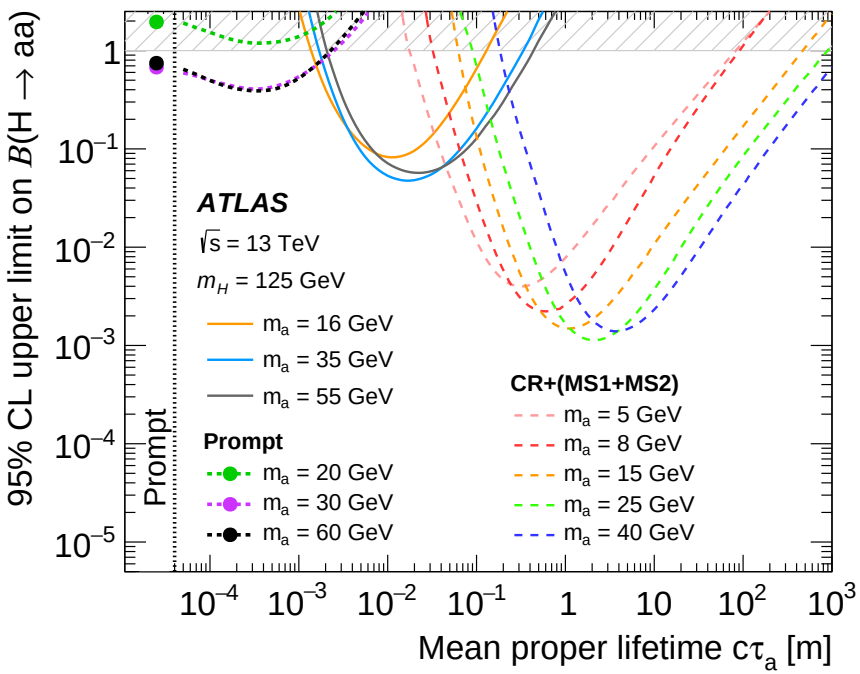
- Trigger on Z leptons ($\ell = e, \mu$)
- Select jets exploiting vtx and charged hadron fractions
- Use uncalibrated displaced jets to prefilter events
  $\rightarrow$ Run LRT on this subset
- Combine > 2 tracks into ≥ 2 displaced vtx w/ high mass

- Bkgd estimated reverting n_{vtx} requirement
- Expected events:
  $1.30 \pm 0.08(\mathrm{stat}) \pm 0.27(\mathrm{syst})$
- Validated in high-p_{T} photon triggered events

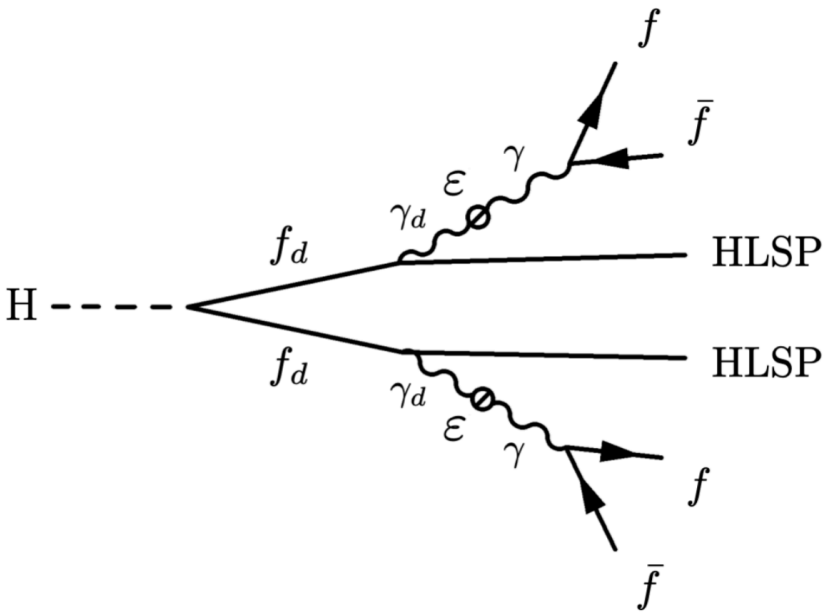
- Statistically dominated
- Systematics from non-std reco methods (depending on m_a):
  - displaced vtx performance (up to 12%, depends on $c\tau_a$)
  - event filter ($< 3.8\%$)
- Probe $3.7 < c\tau_a < 37$ mm gap





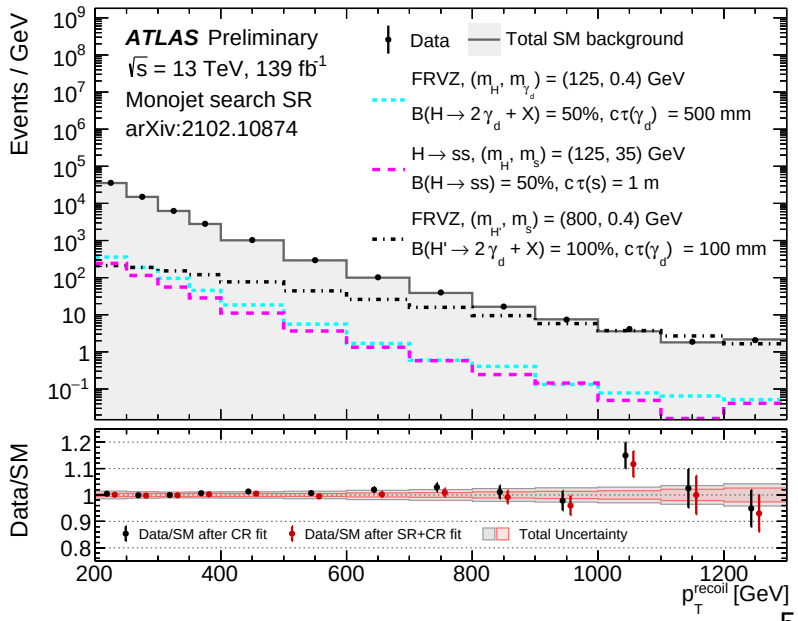


Dark sector with the monojet - ATL-PHYS-PUB-2021-020

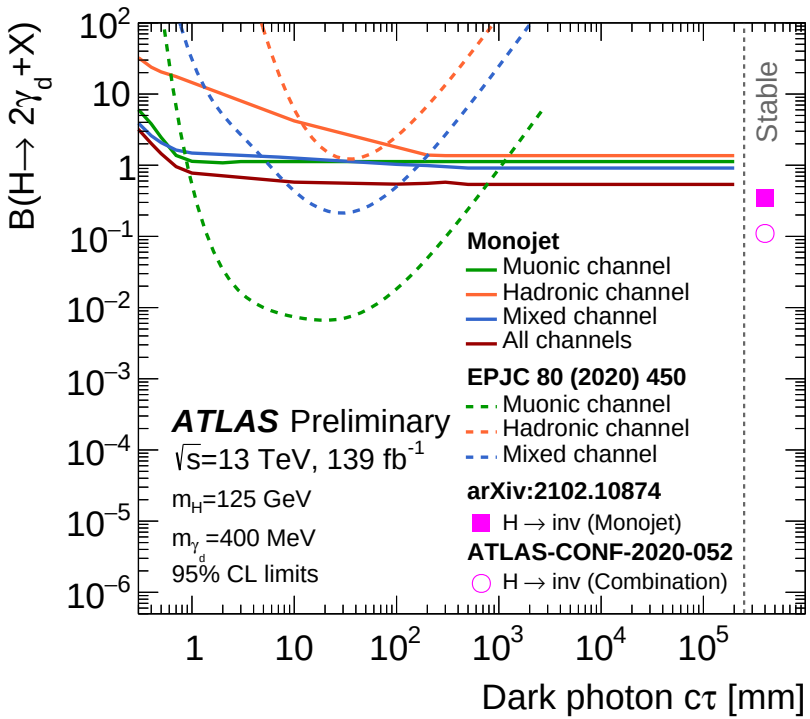


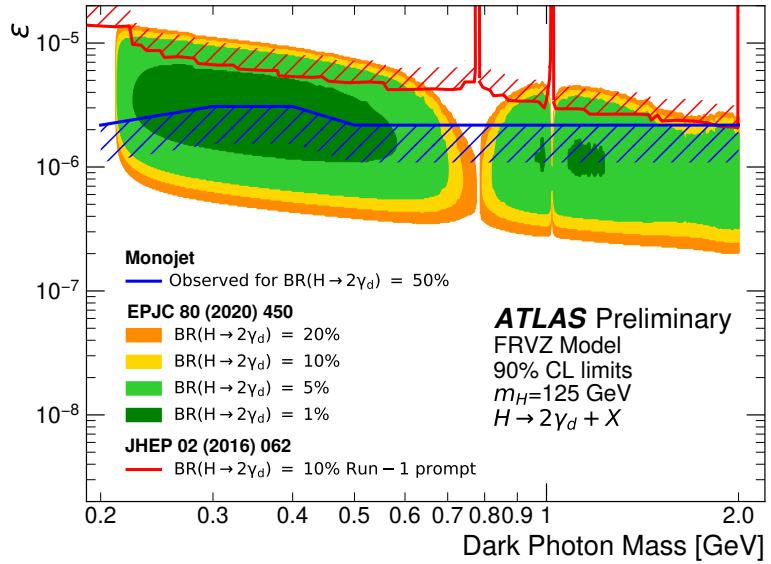
- Higgs portal to new physics: long-lived scalar/dark photon
- $\epsilon < 10^{-5} \Rightarrow$ large γ_d lifetime
- ISR monojet final state $+E_T^{\text{miss}}$
- Bkgd dominated by $Z \to \nu\nu$+jets, W+jets

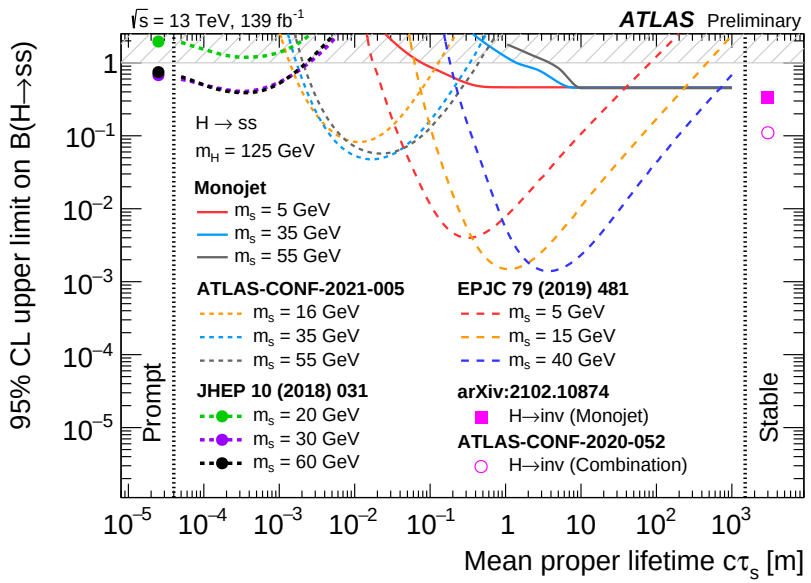
- Cuts to suppress pile-up, QCD and NCB
- $\min|\Delta\phi(E_T^{\text{miss}}, \text{jet})| > 0.4$
- Data-driven estimates: e/μ in CR as invisible to compute recoil against hadronic jets



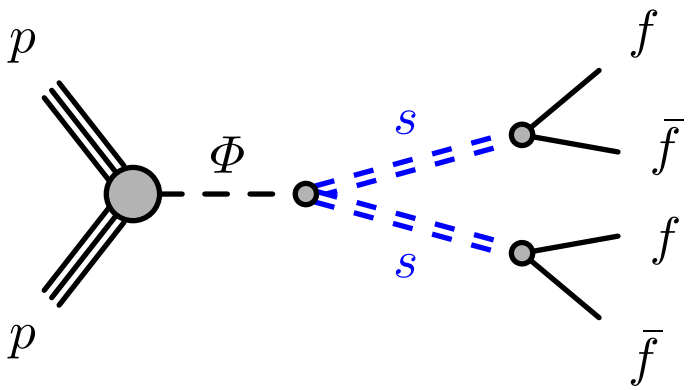
- No excess of data over SM predictions
- Largest systematics w/ jets and E_T^{miss}
- RECAST framework to test new models





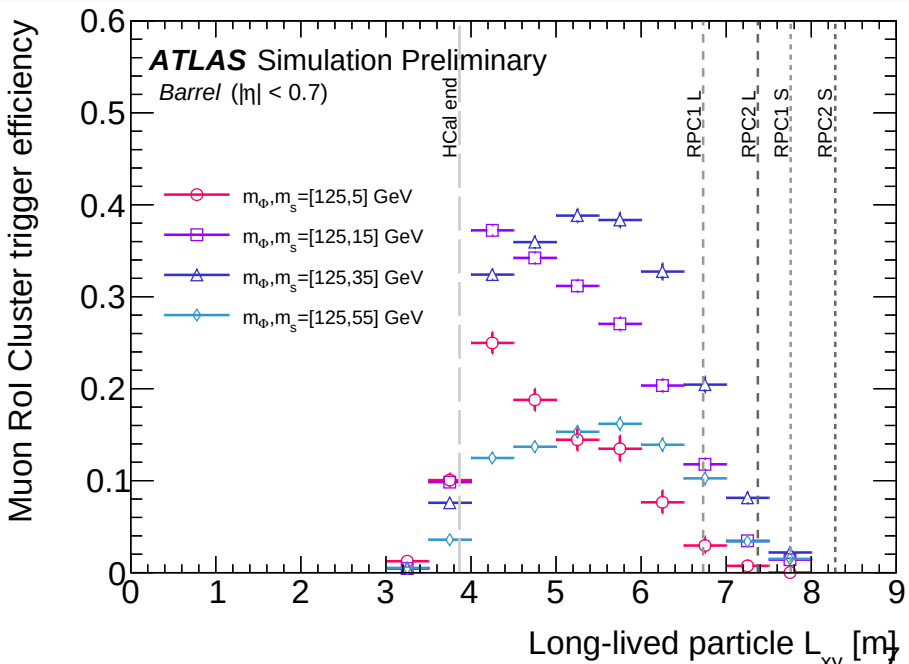


Displaced hadronic jets in MS - ATLAS-CONF-2021-032



- Jets displaced 3-14 m from primary vtx, consider also $t\bar{t}$
- ≥ 2 displaced MS vertices, separated by $\Delta R \geq 1.0$, trigger matched
- Main background: punch-through jets, and from non-collision

- Dedicated RoI Cluster trigger and MS displaced vertex algos
- 2 muon L1 RoIs $p_{\mathrm{T}} > 10$ GeV
- 3 (4) HLT RoIs in barrel (endcap) in $\Delta R < 0.4$ cone
- Back-extrapolate track segments exploiting multilayer distance in MDT chambers



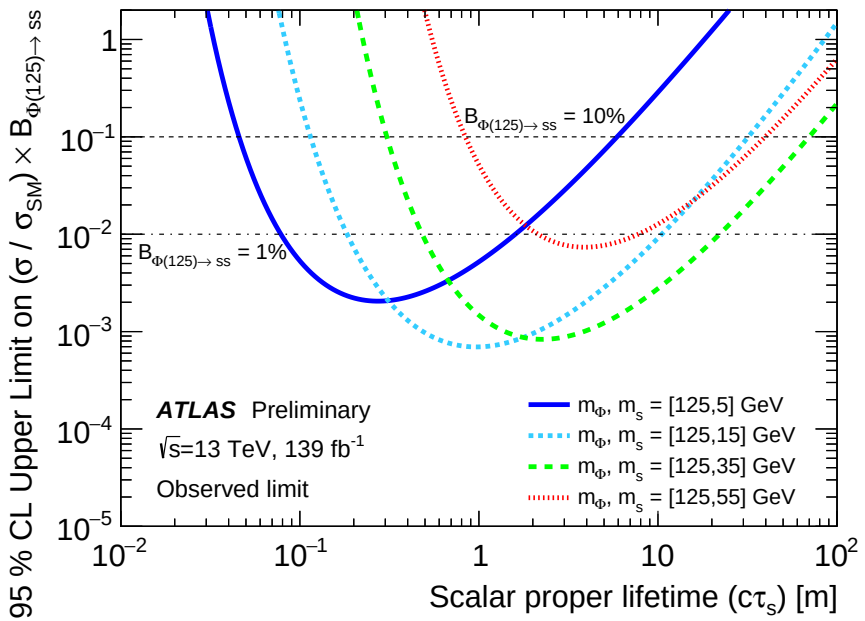
- To remove punch-through $\rightarrow$ vtx isolation from ID tracks and calo jets
- MS efficiency to reconstruct vertices improves at higher signal mass
- Best after outer calo edge $\approx$ 4 m and before middle stations $\approx$ 7 m
- Endcap $\mathscr{O}(70\%)$ higher than barrel $\mathscr{O}(5-25\%)$, worse bkgd rejection

- Main systematic uncertainties in barrel (endcap):
  - mismodeling of L1 μ trigger efficiency: 20% (24%)
  - vertex reconstruction efficiency: 11% (13%)
  - efficiency extrapolation method: 1.9% to 30% depending on signal sample

- Expected background: $0.32 \pm 0.05(\mathrm{stat})$ events

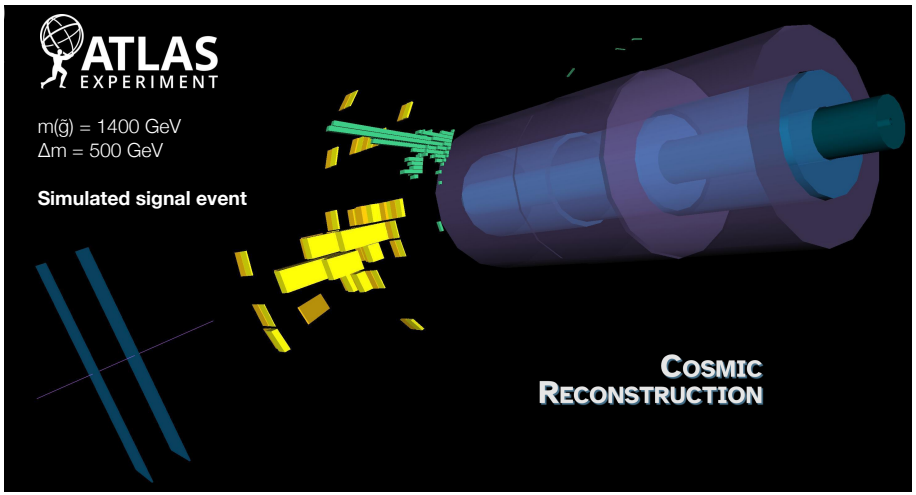
No events observed in signal region

95%CL excluded BR($H \rightarrow ss$)>10% for 4 cm $< c\tau_s <$ 71.3 m



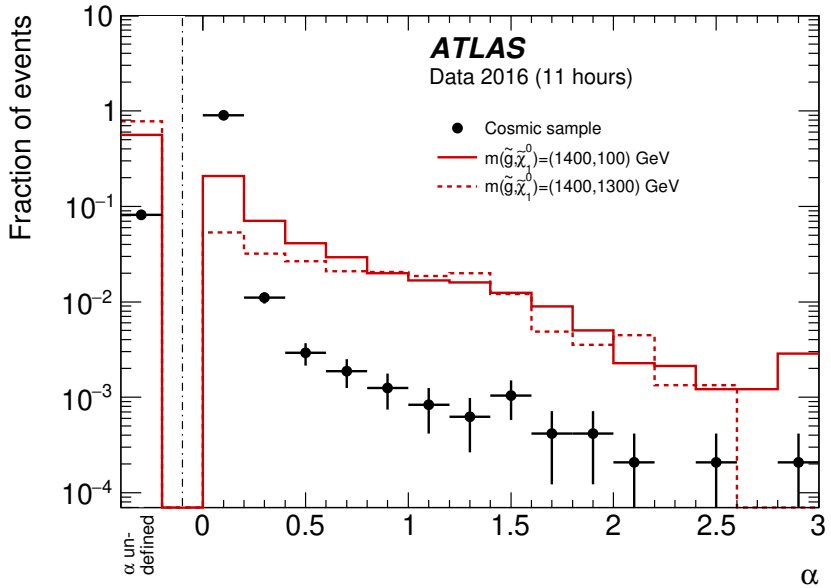
Stopped long-lived particles - JHEP 07 (2021) 173

- Long-lived gluinos coming at rest in detector, produced in one BX and decay in another w/ out-of-time energy deposit release in calo
- Use empty bunches. Integrated live time (579 h)
- Non-collision background dominant (cosmic rays, beam-gas/halo)



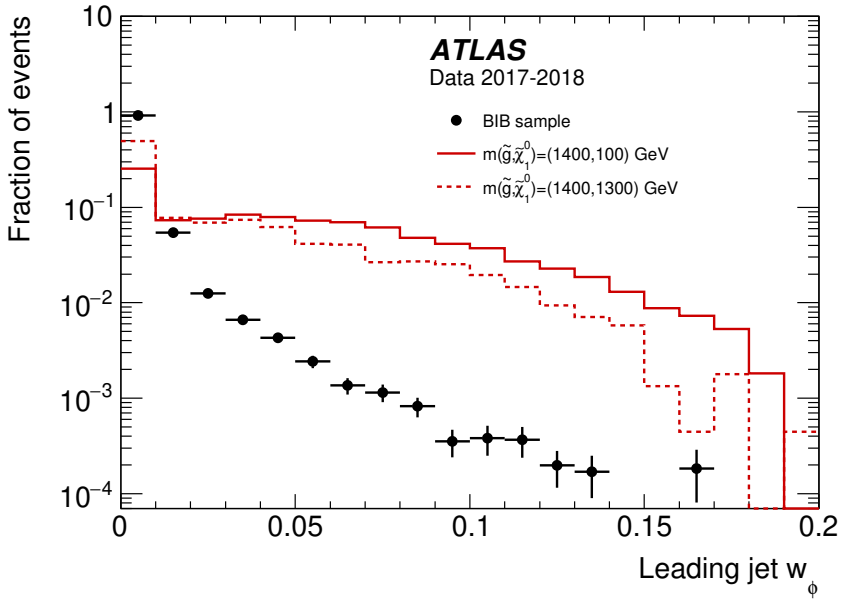
- Veto events w/ muon segments overlapping leading jet (α)
- No pile-up correction applied

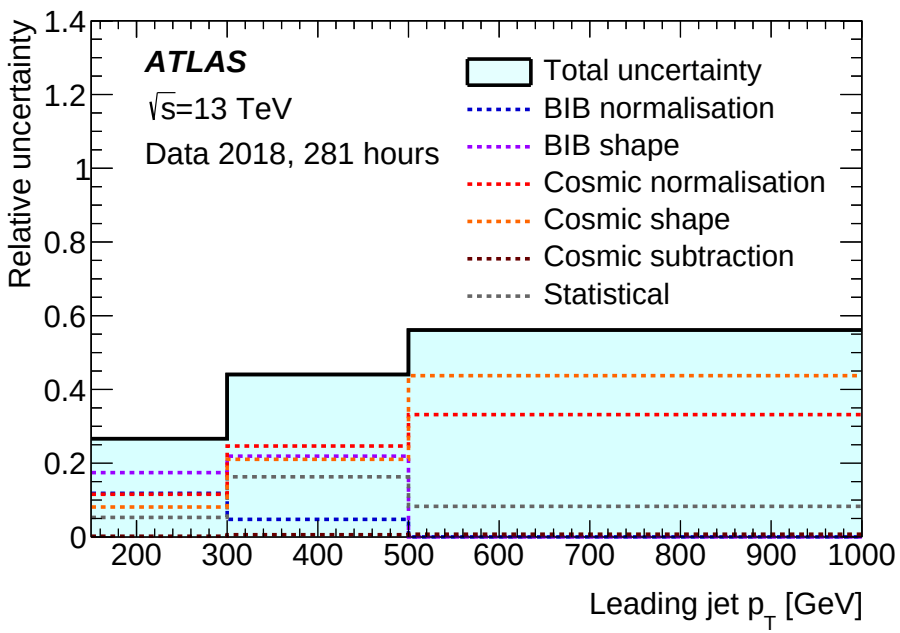
- Trigger on $E_T^{\text{miss}} > 50$ GeV, jet $p_T > 55$ GeV
- Events w/ jet $p_T > 90$ GeV, no primary vtx

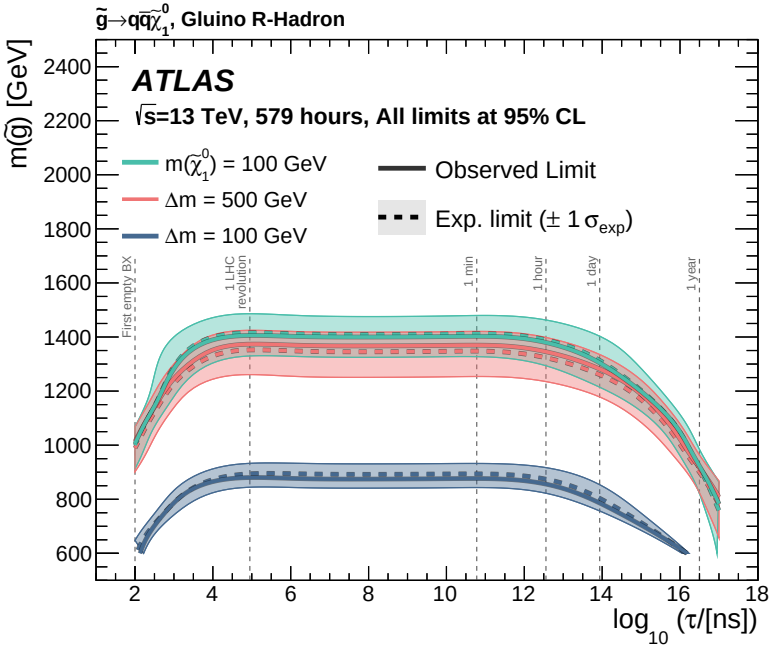


- Displaced isotropic vertex non-pointing to IP (w_Φ)
- Reject BIB jets (narrow showers, parallel to beam)

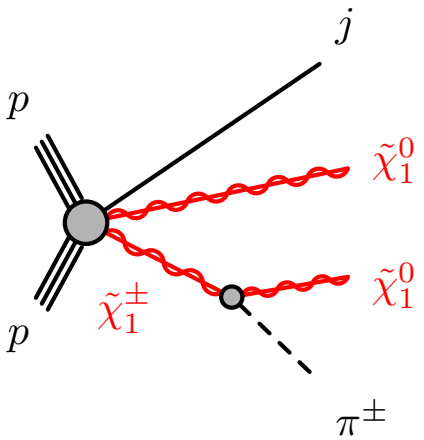
- Main systematics: Cosmic and BIB leading-jet p_T modeling
- No excess observed in data



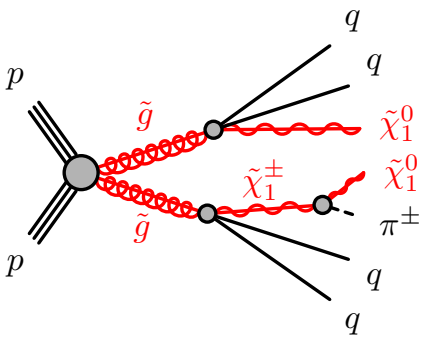




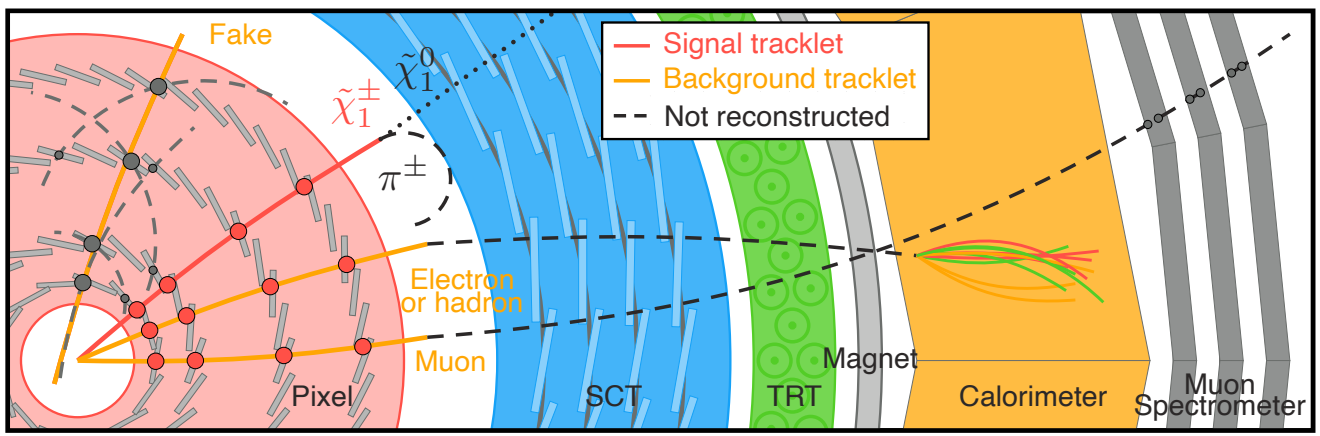
Disappearing-track charginos - ATLAS-CONF-2021-015



- EW (w/ ISR) and strong chargino production
- Boosted, deposit energy in Pixel before decay
- Pure wino or light higgsino LSP
- Escape detection, trigger on high-p_T jet and E_T^{miss}

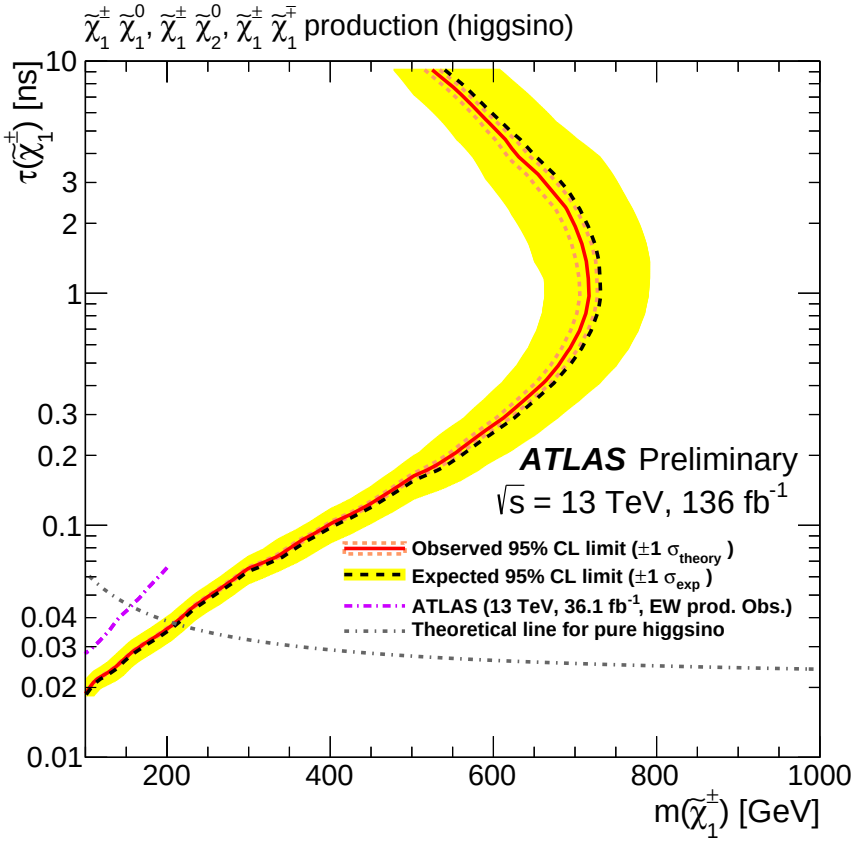


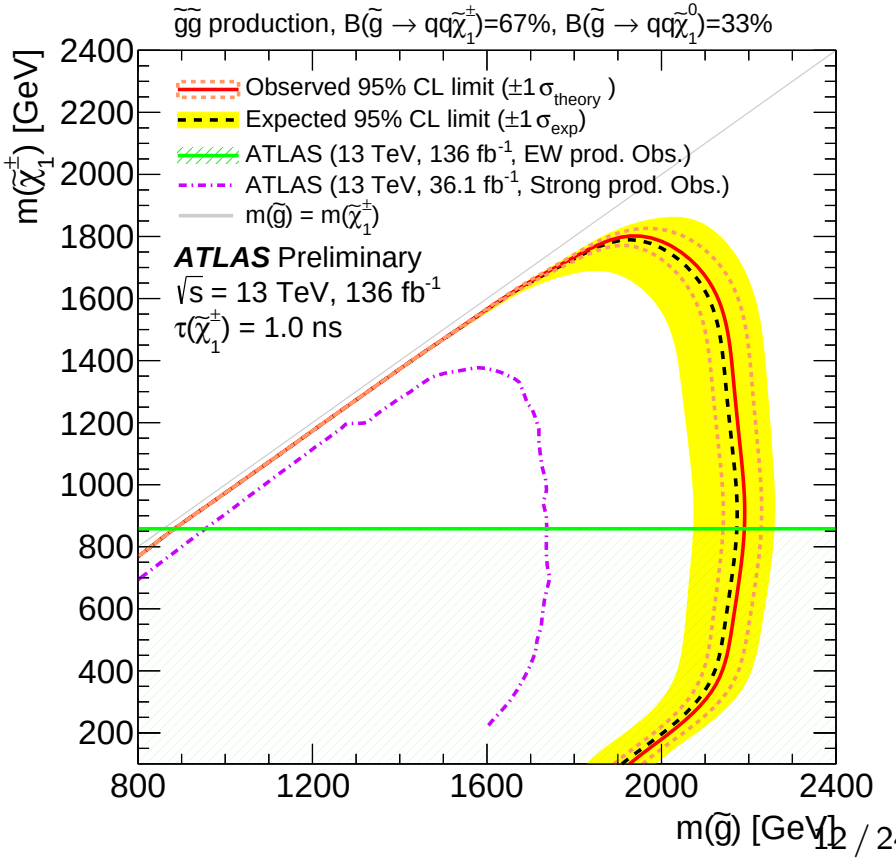
- Tracklet selection: $n_{\text{Pix}}^{\text{hits}} \geq 4$, no SCT
- Disappearing tracks: veto calo (e), MS tracks (μ)
- Data-driven background estimates



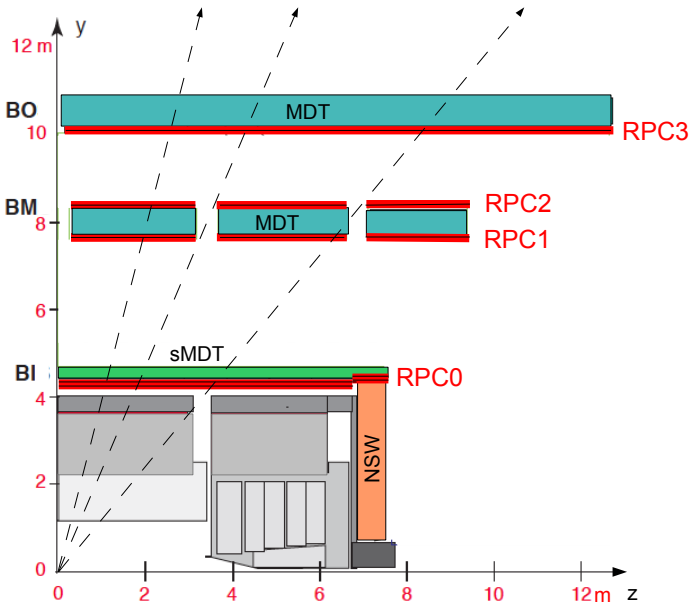
- Systematics: ISR/FSR
- Fake tracklets bkgd fraction and modelling
- Tracklet reconstruction efficiency

- Results: good agreement between data and background predictions
- 95%CL Excluded $m_{\tilde{\chi}_1^\pm} < 660(210)$ GeV for pure wino (higgsino)
- For $m_{\tilde{\chi}_1^\pm} = 300$ GeV, $\tau_{\tilde{\chi}_1^\pm} = 0.2$ ns in pair-prod $\tilde{g}$: $m_{\tilde{g}} < 2.1$ TeV



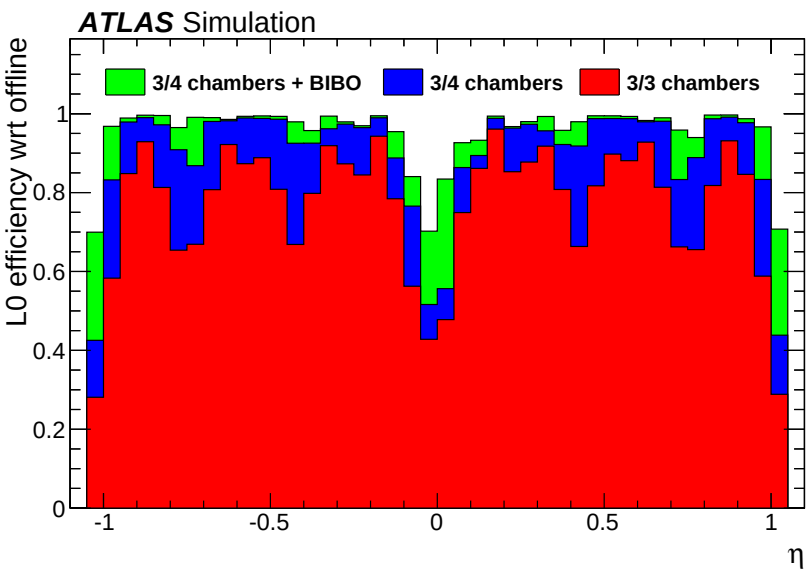


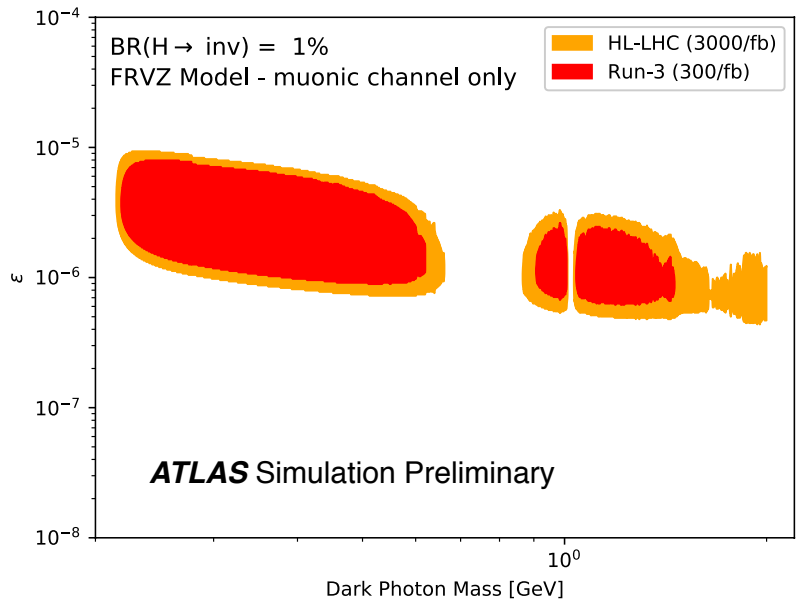
HL-LHC: Dark-photons into displaced collimated muons



ATL-PHYS-PUB-2019-002

- New L0-multimuon and L0-sagitta muon triggers
- 7% and 20% efficiency improvement w.r.t. Run-2
- Increased acceptance in the barrel (75% → 95%)





Conclusions

- More dataset lumi improved sensitivity to BSM physics searches
- New analysis techniques developed to cope with exotic signatures
- No excess observed, more stringent limits are set on several models

- Looking forward to Run-3 to increase statistic
- Continue to improve detector knowledge and combined performances
- Many more results expected in the near future, stay tuned!

References

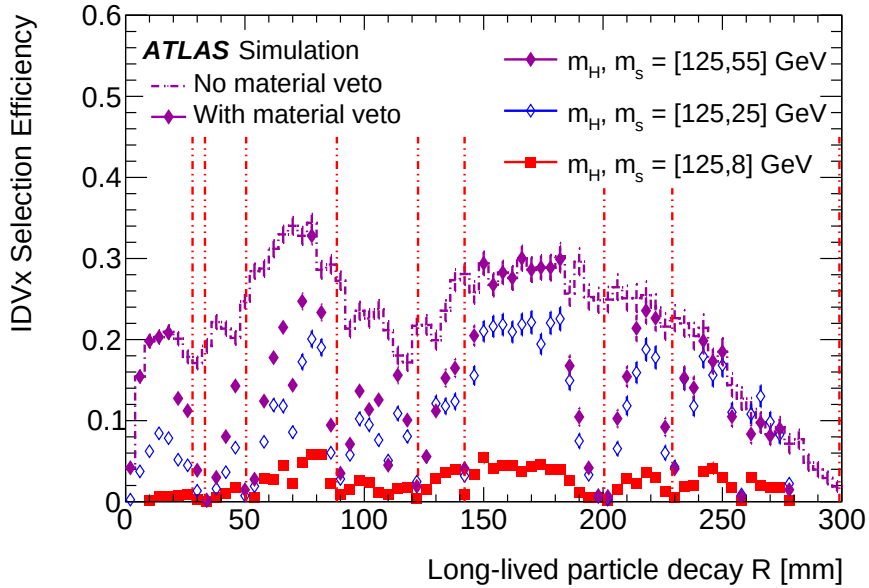
- "Search for exotic decays of the Higgs boson into long-lived particles in *pp* collisions at $\sqrt{s} = 13$ TeV using displaced vertices in the ATLAS inner detector", arXiv:2107.06092
- "Constraining the dark sector with the monojet signature in the ATLAS experiment", ATL-PHYS-PUB-2021-020
- "Search for events with a pair of displaced vertices from long-lived neutral particles decaying into hadronic jets in the ATLAS muon spectrometer in *pp* collisions at $\sqrt{s} = 13$ TeV", ATLAS-CONF-2021-032
- "A search for the decays of stopped long-lived particles at $\sqrt{s} = 13$ TeV with the ATLAS detector", JHEP 07 (2021) 173
- "Search for long-lived charginos based on a disappearing-track signature using 136 fb-1 of pp collisions at √s = 13 TeV with the ATLAS detector", ATLAS-CONF-2021-015
- "Search prospects for dark-photons decaying to displaced collimated jets of muons at HL-LHC", ATL-PHYS-PUB-2019-002

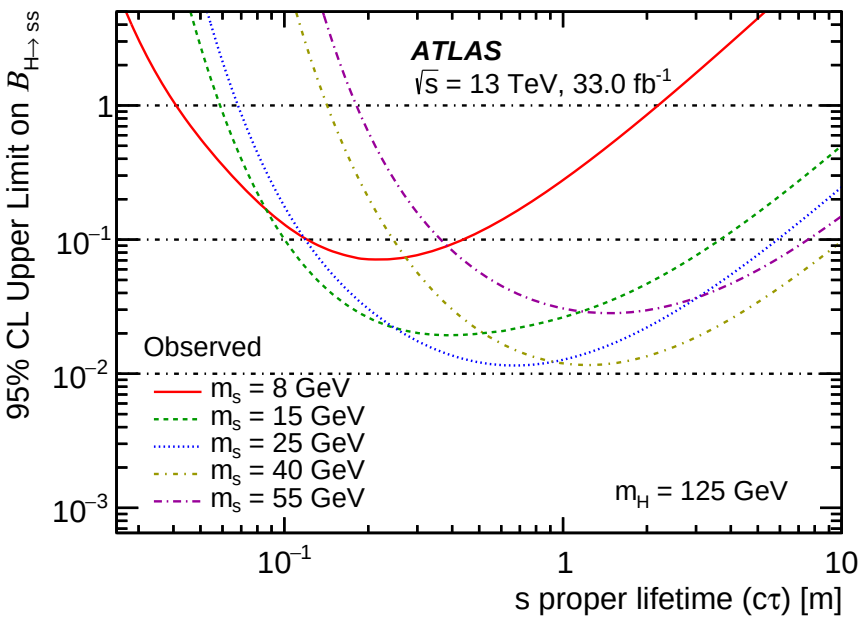
Additional References

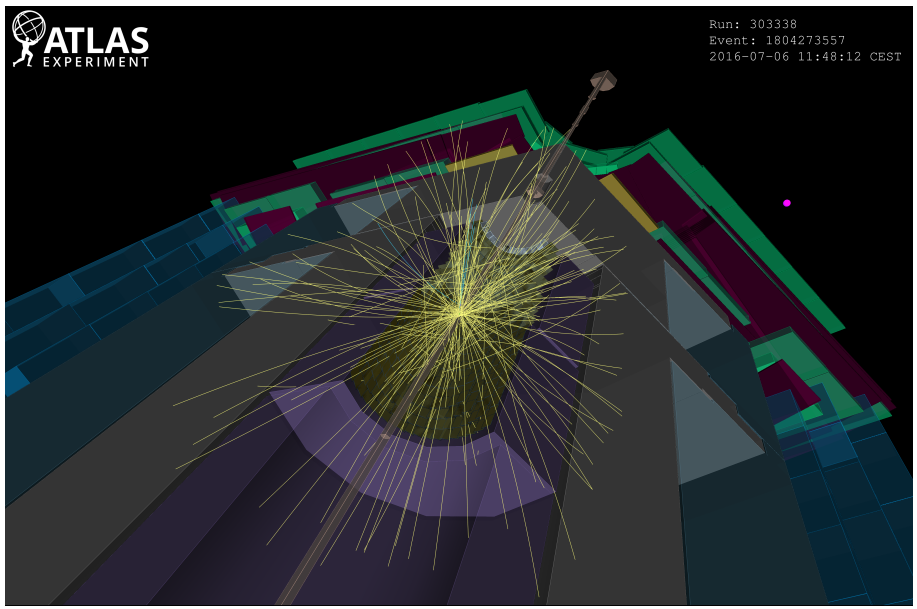
- "Search for long-lived neutral particles produced in *pp* collisions at at $\sqrt{s} = 13$ TeV decaying into displaced hadronic jets in the ATLAS inner detector and muon spectrometer", Phys. Rev. D 101 (2020) 052013
- "Search for light long-lived neutral particles produced in *pp* collisions at $\sqrt{s} = 13$ TeV and decaying into collimated leptons or light hadrons with the ATLAS detector", Eur. Phys. J. C 80 (2020) 450
- "Search for heavy neutral leptons in decays of W bosons produced in 13TeV*pp* collisions using prompt and displaced signatures with the ATLAS detector", JHEP 10 (2019) 265
- "Search for heavy long-lived multi-charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector" , Phys. Rev. D 99 (2019) 052003
- "Search for magnetic monopoles and stable high-electric-charge objects in 13TeVproton-proton collisions with the ATLAS detector", Phys. Rev. Lett. 124 (2020) 031802
- "Search for displaced leptons in $\sqrt{s} = 13$ TeV *pp* collisions with the ATLAS detector", Phys. Rev. Lett. 127 (2021) 051802
- "Search for long-lived, massive particles in events with a displaced vertex and a muon with large impact parameter in *pp* collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", Phys. Rev. D 102 (2020) 032006
- "Reinterpretation of the ATLAS Search for Displaced Hadronic Jets with the RECAST Framework", ATL-PHYS-PUB-2020-007

Backup

Displaced hadronic jets in Inner Detector and MS



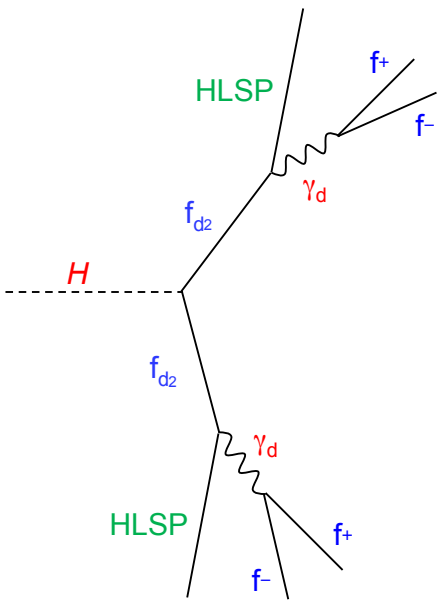


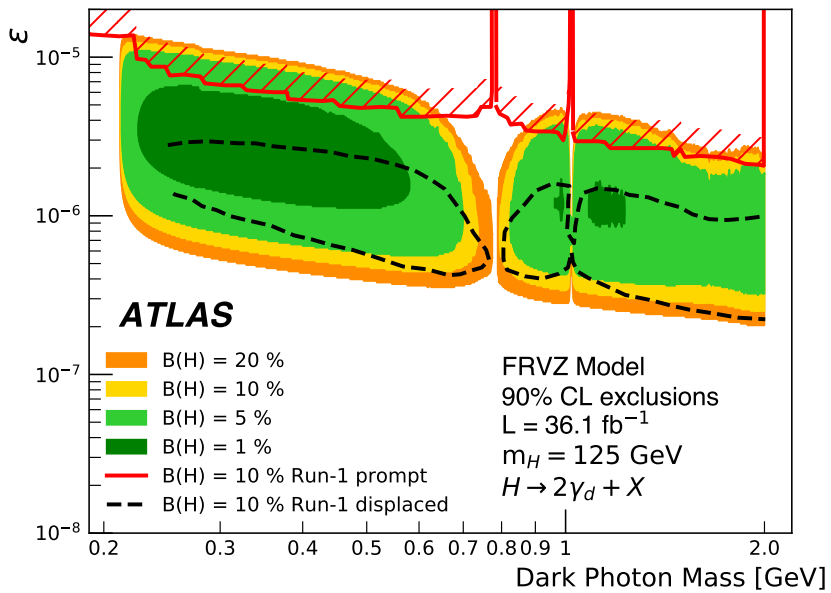


Phys. Rev. D 101 (2020) 052013

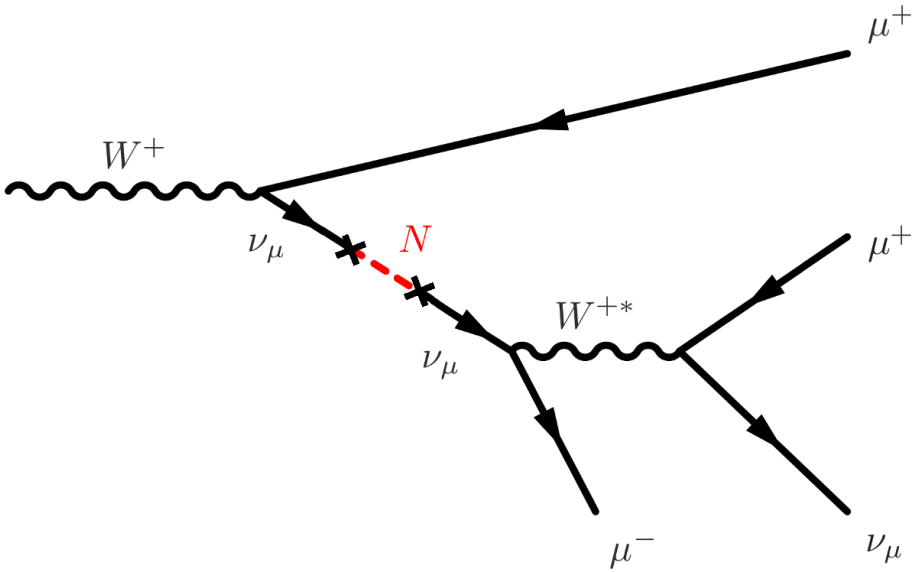
Dark photons in collimated leptons or light hadrons

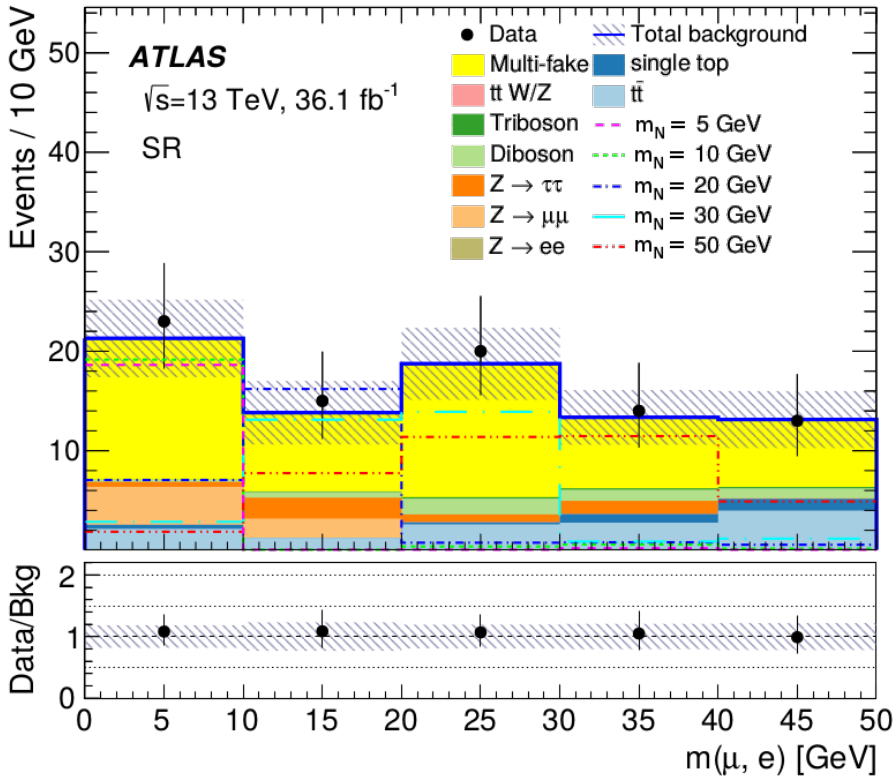
Eur. Phys. J. C 80 (2020) 450

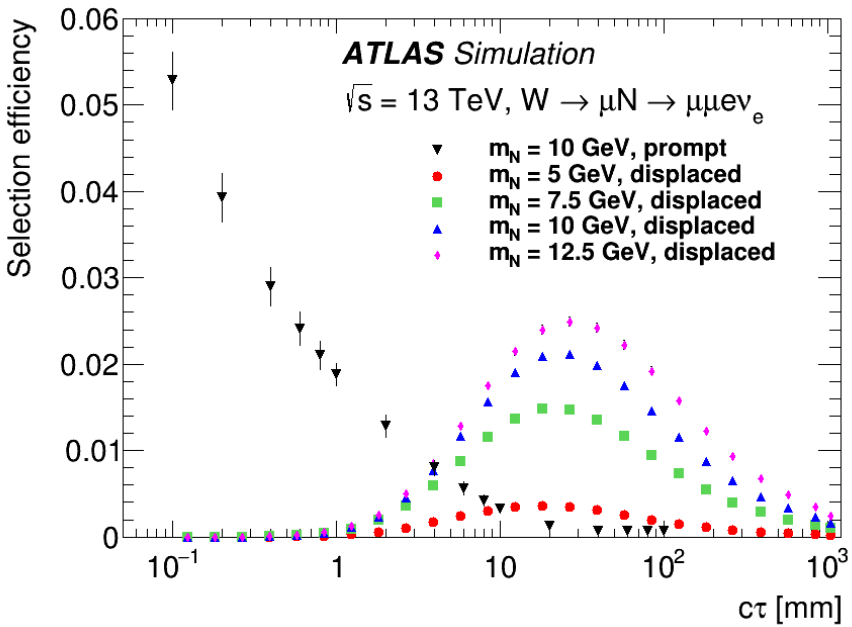


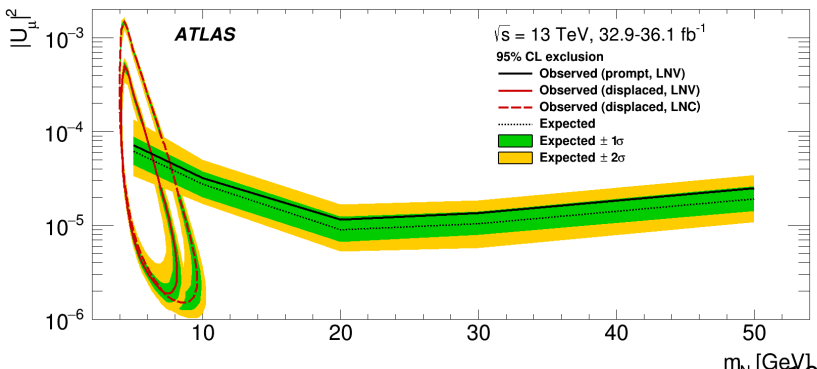


HNL w/ prompt and displaced leptons - JHEP10(2019)265

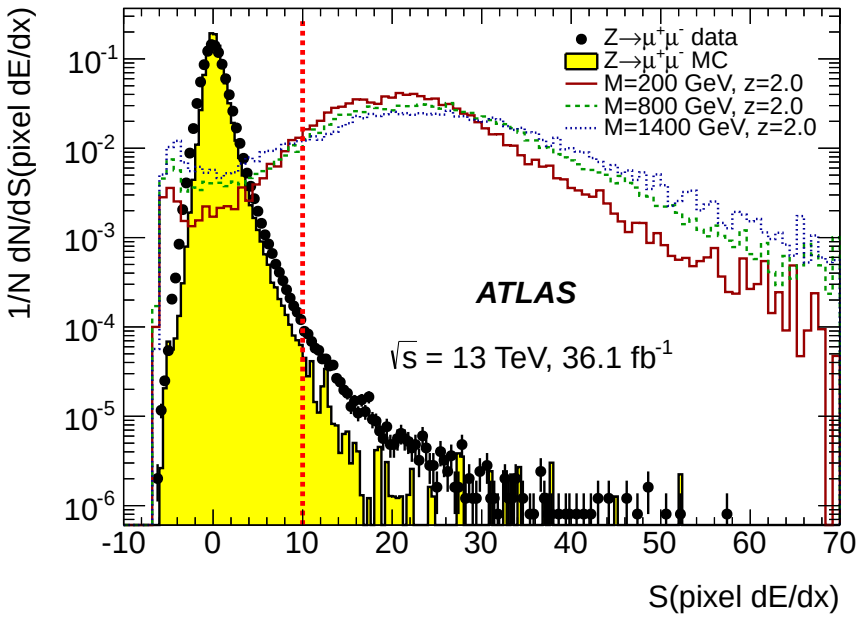


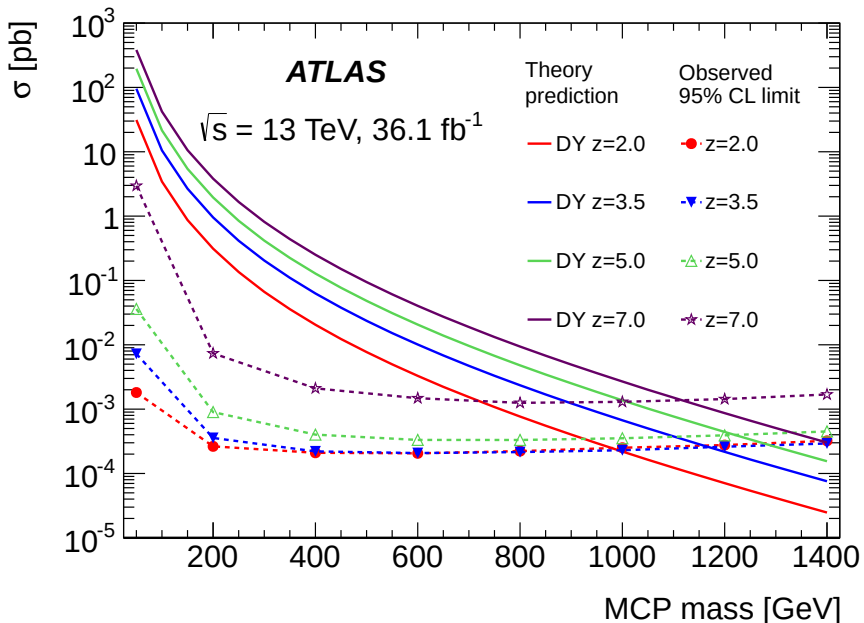




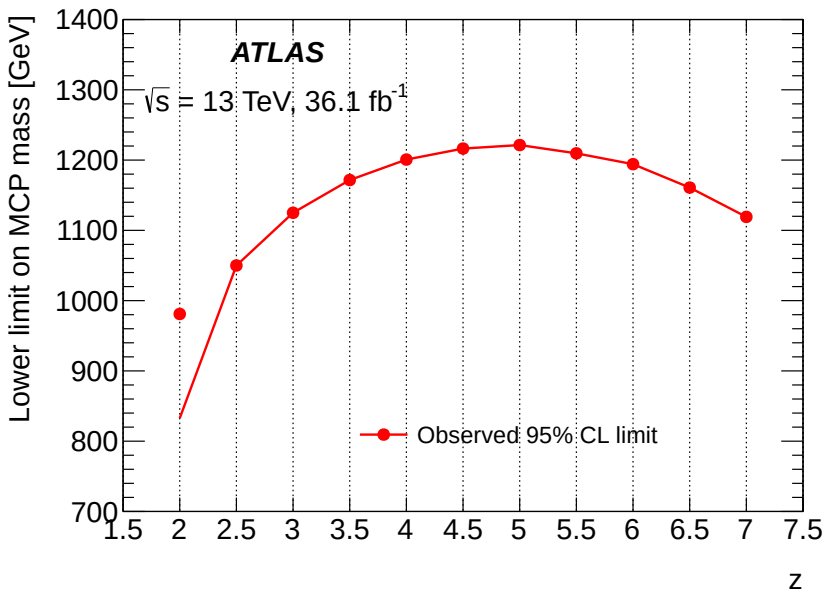


Heavy long-lived multi-charged particles ($2 \leq |q| \leq 7e$)



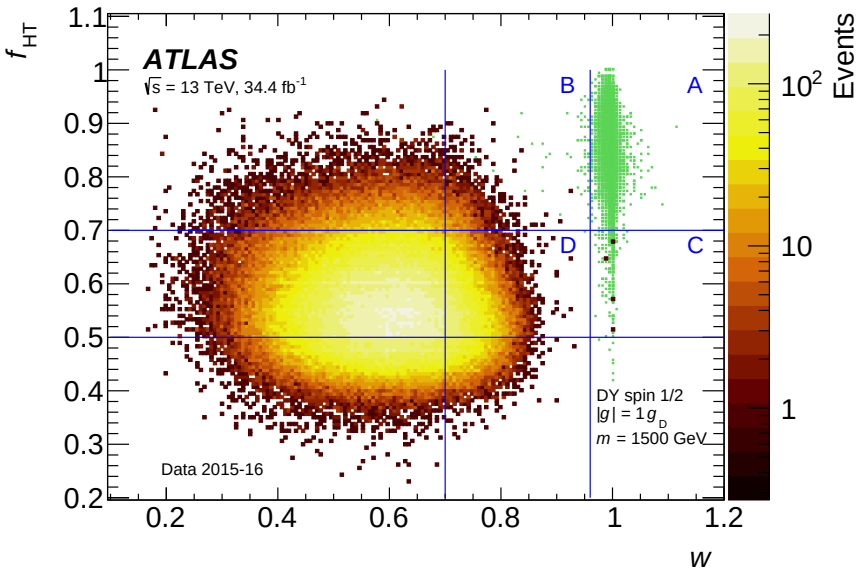


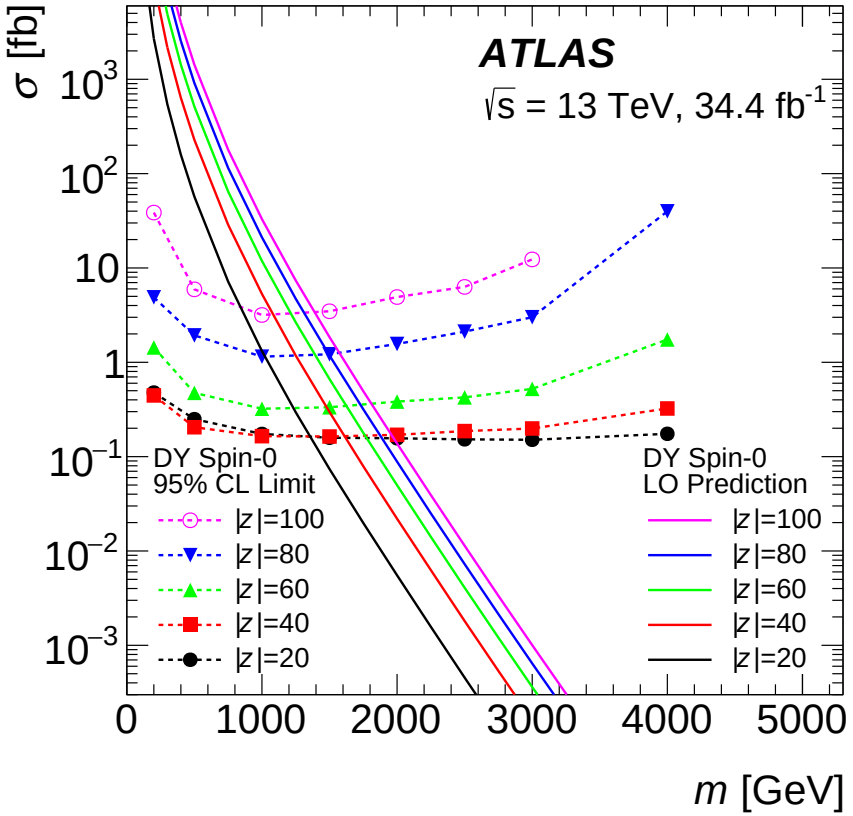
Phys. Rev. D 99 (2019) 052003



Magnetic monopoles and stable high-electric-charge objects

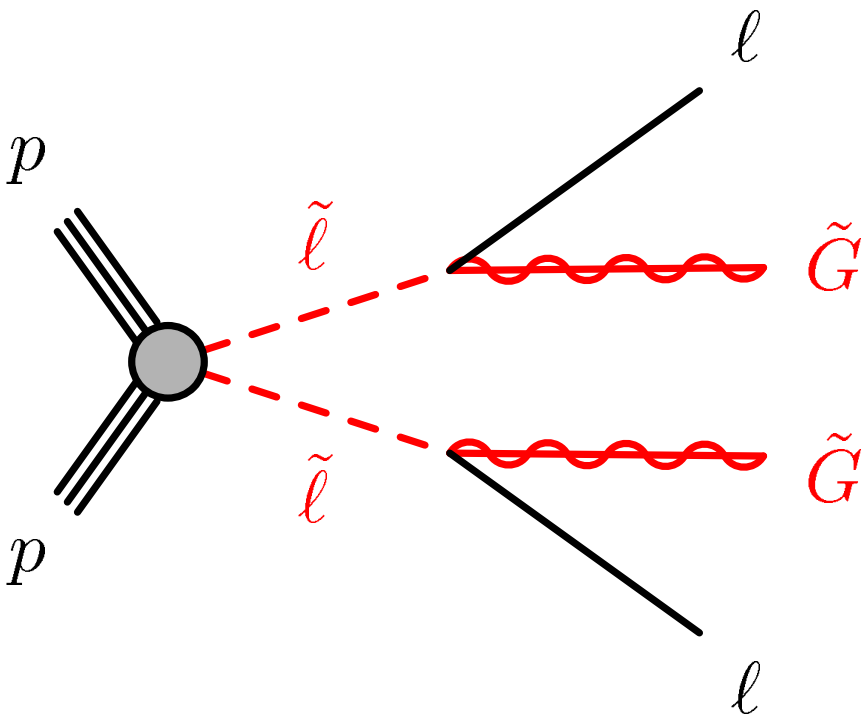
Phys. Rev. Lett. 124 (2020) 031802



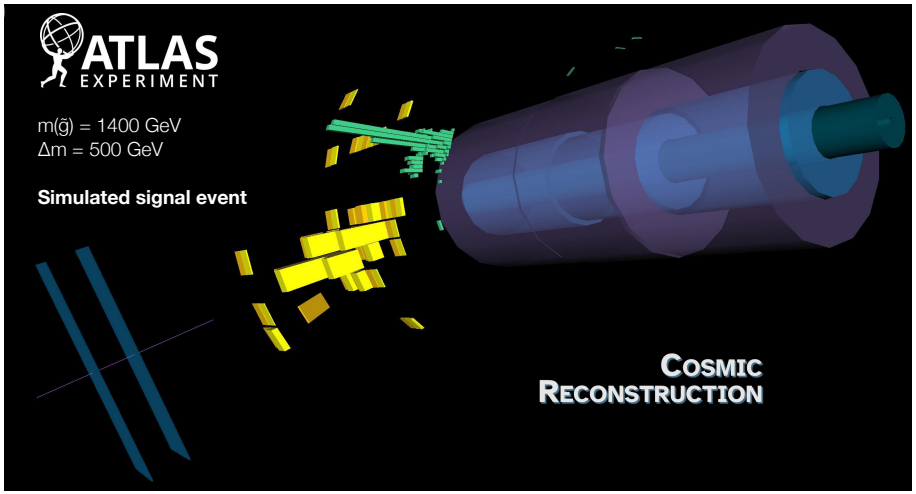


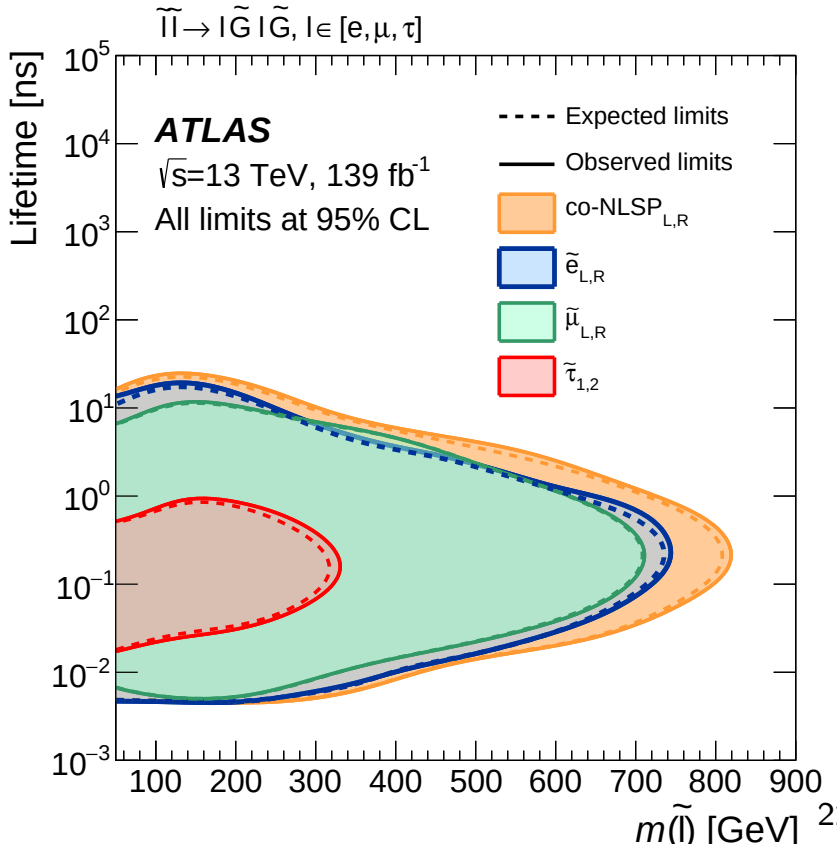
- No events in signal region, consistent w/ expected bkgd
- Spin-0 HIPs exclusion limits more stringent than 1/2
- First time access to range $60 < |z| < 100$
- Improve past limits by at least factor 5

Displaced leptons - Phys. Rev. Lett. 127 (2021) 051802



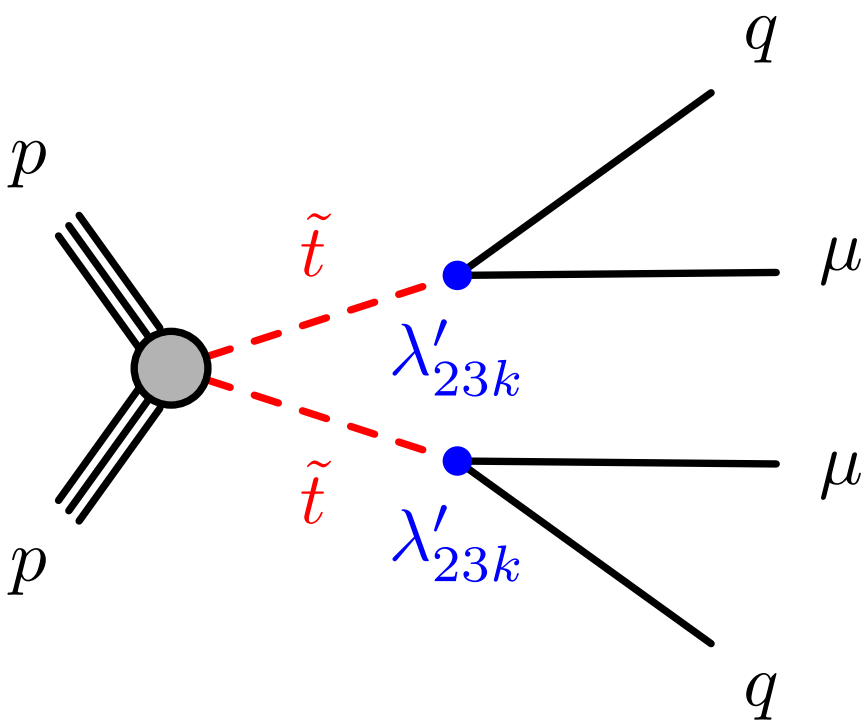
- High $p_{\mathrm{T}}^{\ell} > 65$ GeV, $3 < |d_0| < 300$ mm
- Sensitivity beyond LEP limits
- Model independent

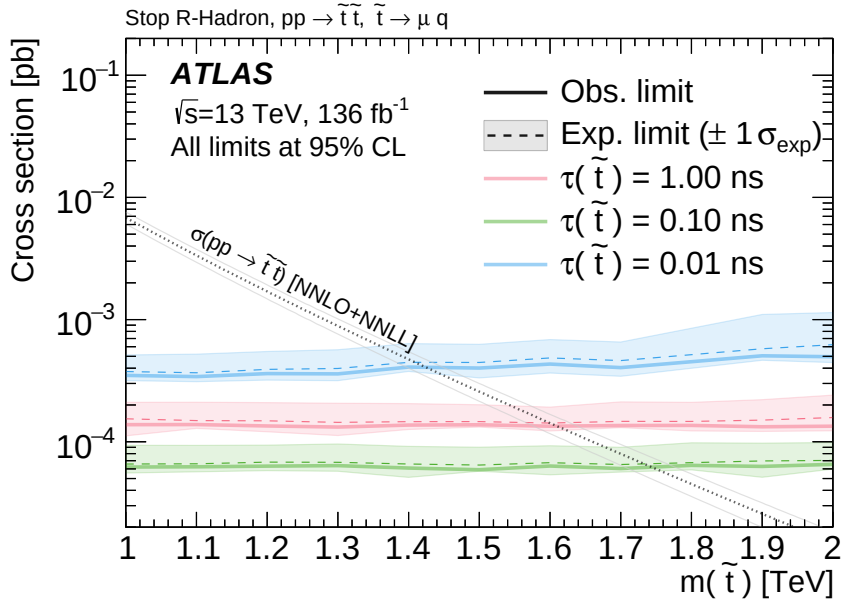


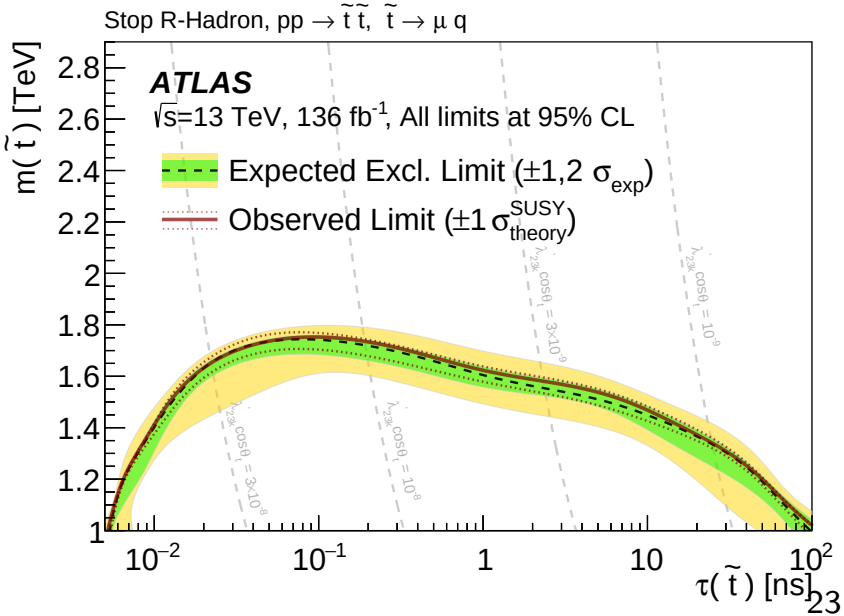


Displaced muon and displaced vertex

Phys. Rev. D 102 (2020) 032006







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