Searches for new physics using unconventional signatures or unconventional workflows using the ATLAS detector

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on behalf of the ATLAS Collaboration

Dark Matter 2025: From the Smallest to the Largest Scale

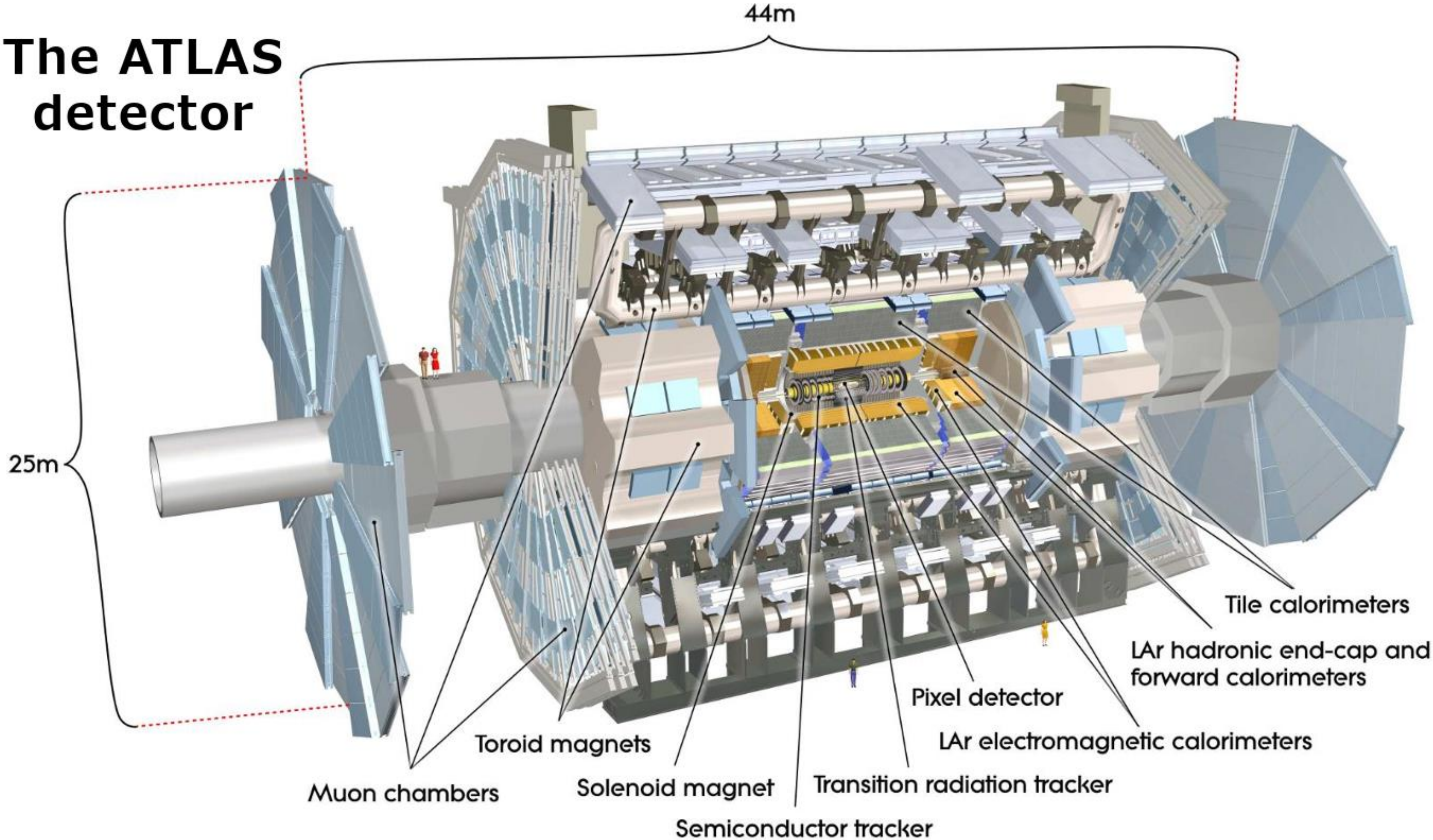
2-6 June 2025
Santander, Spain

Recent ATLAS unconventional search program

Reference	Title	Publication	Date	Data
SUSY-2022-11	Search for displaced leptons in $\sqrt{s}$ =13 TeV and 13.6 TeV *pp* collisions with the ATLAS detector	Submitted to PRD	22 Oct 2024	Run-2 + **Run-3**
HMBS-2024-68	Search for long-lived charged particles using large specific ionisation loss and time of flight in 140 fb^{-1} of *pp* collisions at $\sqrt{s}$ =13 TeV with the ATLAS detector	Submitted to JHEP	10 Feb 2025	Run-2
EXOT-2022-12	Search for heavy neutral leptons in decays of W bosons using leptonic and semi-leptonic displaced vertices in $\sqrt{s}$ =13 TeV *pp* collisions with the ATLAS detector	Submitted to JHEP	20 March 2025	Run-2
EXOT-2022-17	Search for events with one displaced vertex from long-lived neutral particles decaying into hadronic jets in the ATLAS muon spectrometer in *pp* collisions at $\sqrt{s}$ = 13 TeV	Submitted to PRD	26 March 2025	Run-2
EXOT-2021-19	Search for new physics in final states with semi-visible jets or anomalous signatures using the ATLAS detector	Submitted to PRD	2 May 2025	Run-2
EXOT-2022-31	Search for emerging jets in *pp* collisions at $\sqrt{s}$ =13.6 TeV with the ATLAS experiment	Submitted to RPP	5 May 2025	**Run-3**

- Broad search program, summary is presented in this talk
- Many recent publications

The ATLAS detector

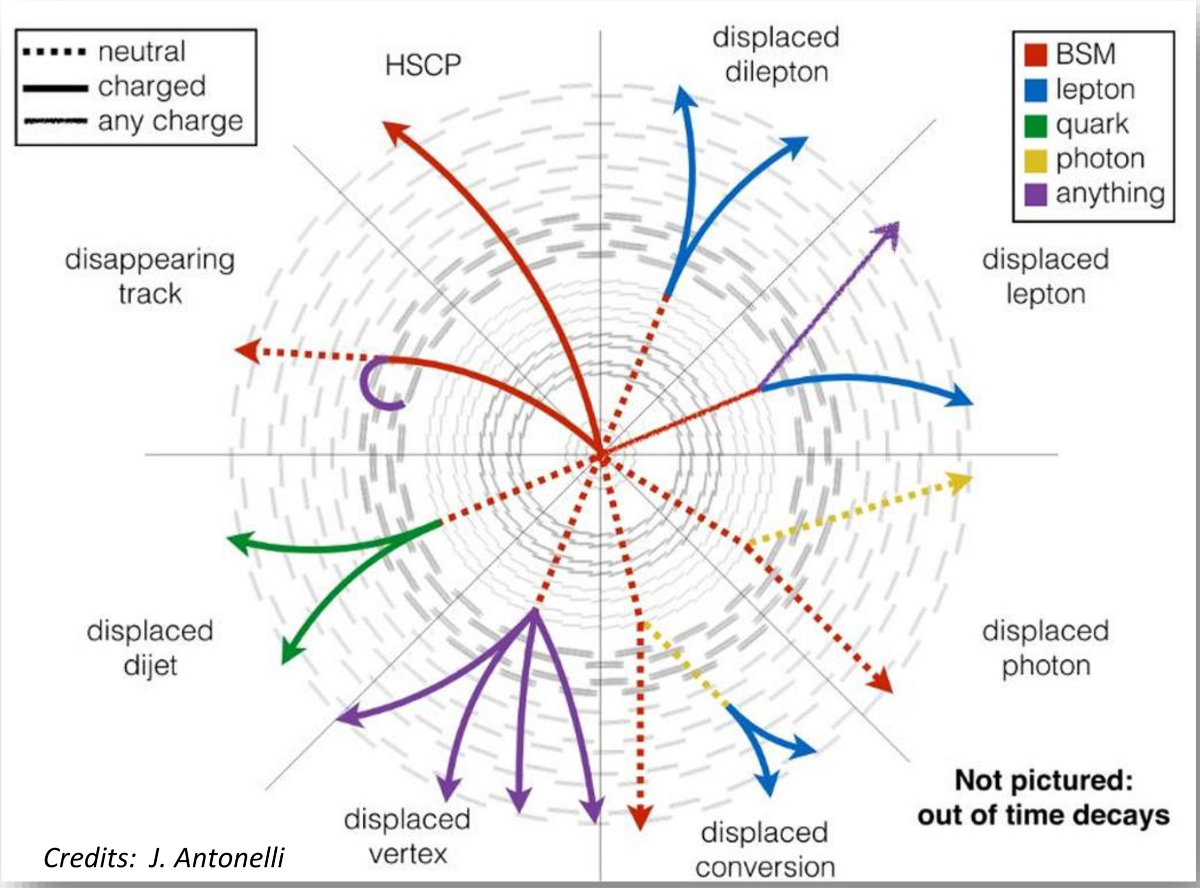


Unconventional signatures

- Unconventional signatures used in searches exploiting lots of models:
  - Supersymmetric (SUSY) models and Hidden Sector
  - Multi-Higgs models
  - Dark matter sector
  - Flavour anomalies
  - Heavy resonances
- Non-standard reconstruction methods:
  - Based on specific detectors
  - Using specific triggers
  - Using special reconstruction algorithms
  - With unusual background
- Long-Lived Particles (LLPs): significant decay distance
  - weak couplings to decay products
  - decays through heavy mediator particles
  - small mass differences between the particle and decay products

Unconventional signatures

- Based on ID:
  - Disappearing track
  - Displaced vertex (DV)
- Based on calorimeters:
  - "Non-pointing" photons
- Based on muon spectrometer or other ATLAS subdetectors:
  - "Muon-like" or Heavy Stable Charged Particles (HSCP)
  - Missing transverse momentum (neutral, weakly interacting LLPs)
- ATLAS projective geometry + prompt reconstruction not designed to efficiently target LLPs
  - Push limits of detector performance
  - Customized triggers and reconstruction algorithms
  - Non-standard analysis strategies and tools, generally data-driven estimation

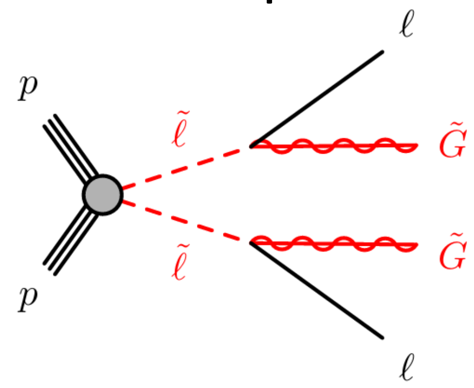


https://doi.org/10.48550/arXiv.2410.16835

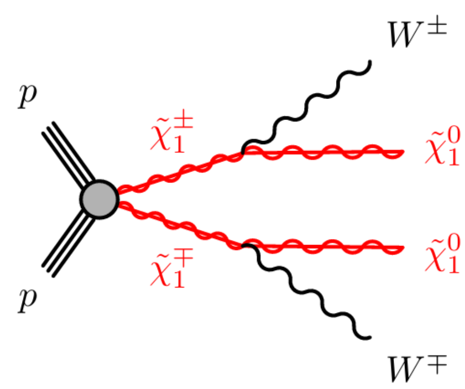
Displaced leptons

- Model:
  - Gauge-Mediated Supersymmetry Breaking **(GMSB) sleptons**
  - **Dark sector** (same final state as for sleptons, but tending to have lower p_t)
- Signature:
  - **Two displaced leptons** (no visible decay vertex)
  - Single displaced electron channels: multivariate Boosted Decision Trees (BDTs)
- Strategy:
  - Combination of **two approaches** with mutually exclusive selections:
    - the “ABCD” search
    - “EM-BDT” search (Boosted Decision Trees)
  - Backgrounds: **data-driven**, and MC used only for signal model
  - Triggering Mechanisms: **Novel triggering mechanisms**
    - Large-radius tracking (LRT) to reconstruct displaced tracks (detection of low-momentum displaced leptons)
- **First usage of Run-3 data**
  - 56.3 fb^{-1} of pp collision at $\sqrt{s}$= 13.6 TeV
  - Plus Run-2 data: 140 fb^{-1} of pp collision at $\sqrt{s}$= 13 TeV

GMSB slepton



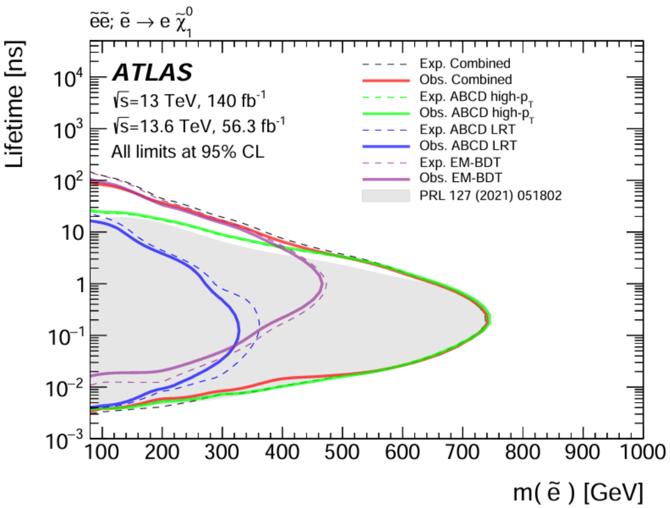
Dark sector



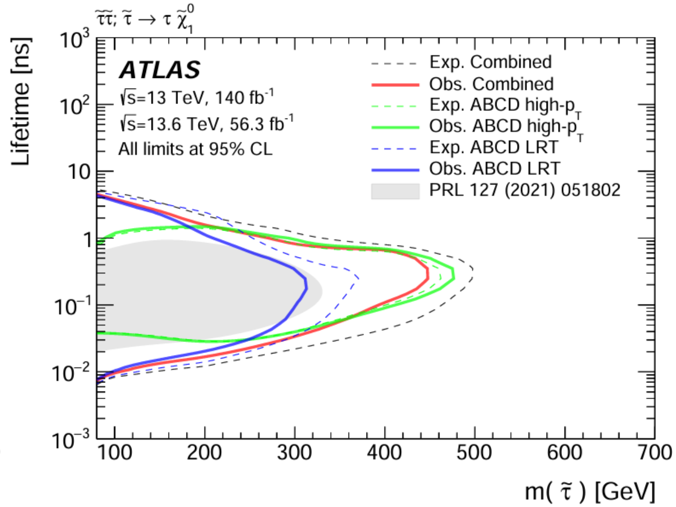
https://doi.org/10.48550/arXiv.2410.16835

Displaced leptons

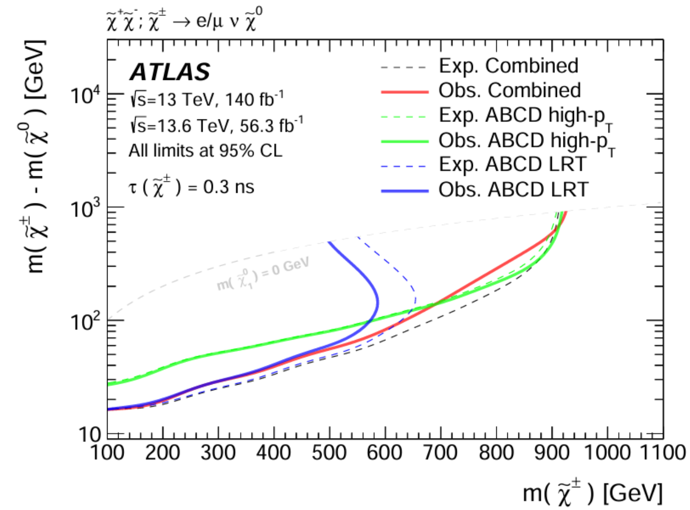
Selectron



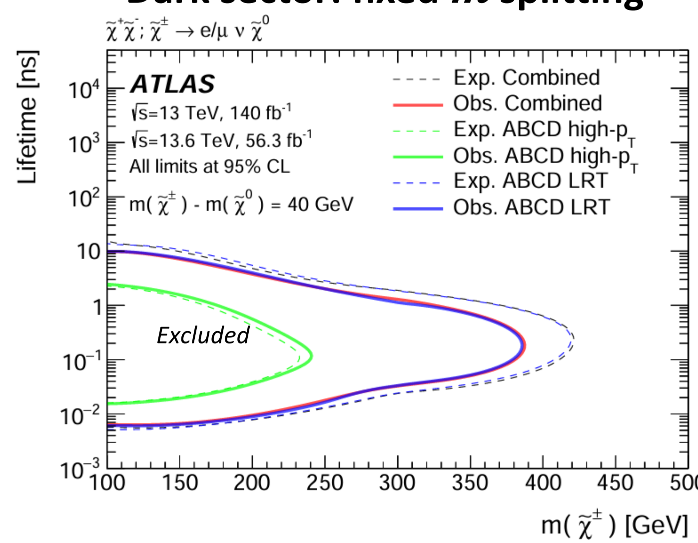
Stau



Dark sector: fixed lifetime



Dark sector: fixed m splitting



- The improvement in sensitivity in comparison with previous analysis [ref] is due to the EM-BDT, new LRT-based triggers, and better trigger acceptance in the forward region
  - Selectron ~5x
  - Stau ~3x
- The observed event yields in the various signal regions are consistent with the SM background expectations

https://doi.org/10.48550/arXiv.2502.06694

Long-Lived charged particles using dE/dx and ToF

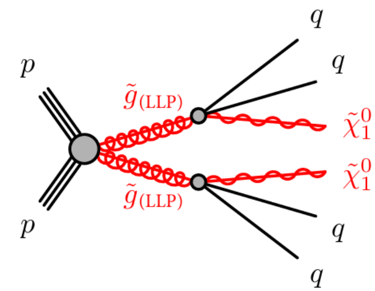
- Search for **massive, high-pT, long-lived charged particles**
  - $\beta \ll 1 \rightarrow$ large ionization losses (dE/dx)
  - Targeting lifetimes > 3 ns
- Key observable: Mass -> $m = \frac{p}{\beta\gamma}$

  p → measured in tracking

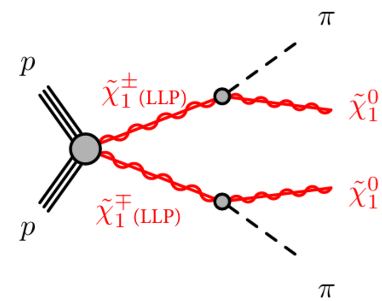
  $\beta\gamma$ → obtained from pixel dE/dx measurement (through Bethe-Bloch relation) or from time-of-flight measurement (TileCal)

- Two Distinct Signal Regions:
  - ***β*-search**: higher masses for models with one or more charged, heavy LLPs
    - Large **d*E*/d*x* and a ToF** measurement consistent with a slow-moving particle
    - Lifetime > 10 ns (heavy LLPs: charginos and R-hadrons)
  - **Di-track search**: low-mass LLPs
    - Two signal tracks which both have significant dE/dx
    - Lifetime > 3 ns (pair-produced sleptons)
    - Lower sensitivity for charginos and R-hadrons
- Background: **data-driven** technique

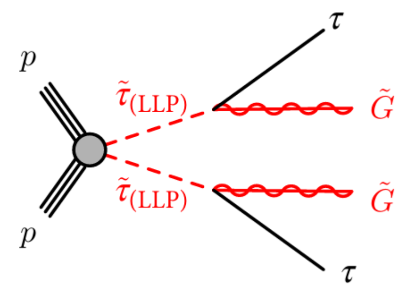
Gluinos which form R-hadrons decaying into neutralinos



Charginos decaying into neutralinos



Staus decaying into gravitinos

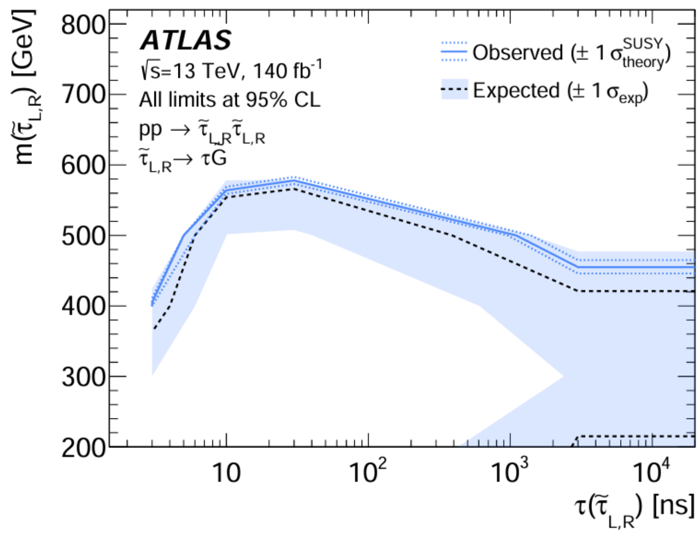


https://doi.org/10.48550/arXiv.2502.06694

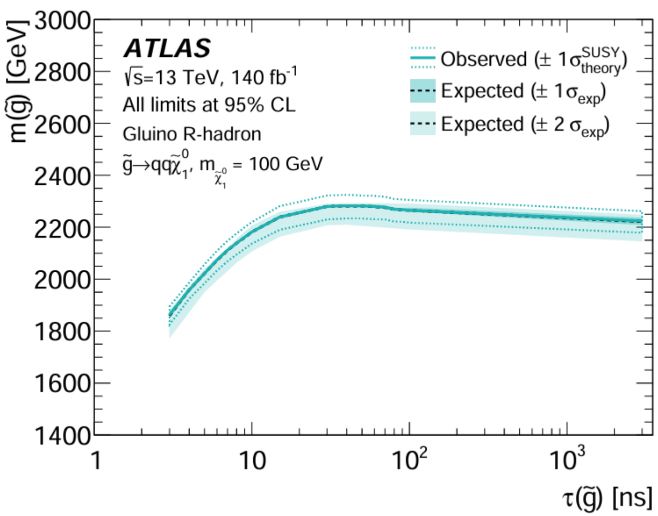
Long-Lived charged particles using dE/dx and ToF

- β-search: 6 observed events inside the mass-compatibility angle
- The sensitivity for R-hadrons falls for lifetimes > 30ns due to a loss of efficiency for the trigger
- The chargino limit results provide the most stringent limits to date for detector-unstable charginos in the lifetime range > 10 ns

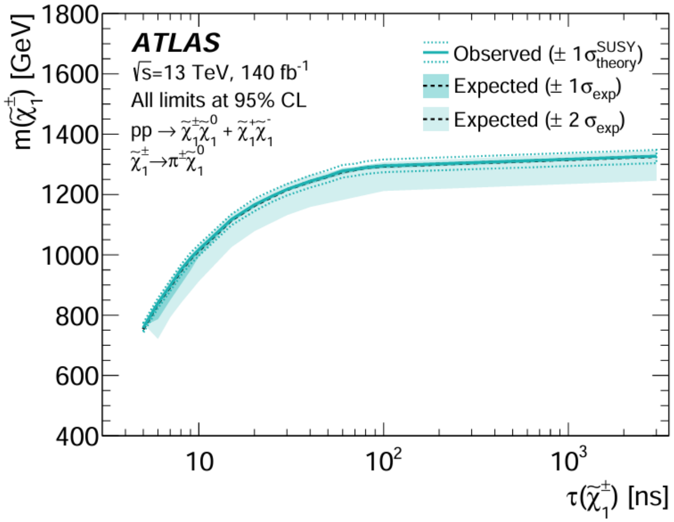
Stau



Gluino mass, from gluino R-hadron



Chargino



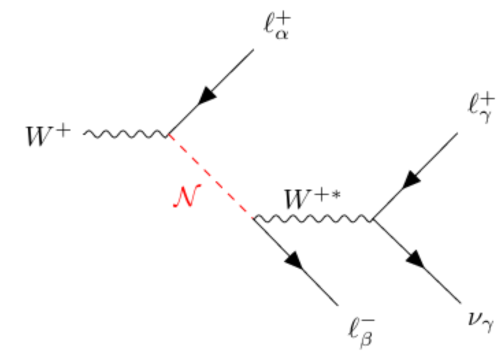
- Di-track search: 15 events observed in the inclusive Exclusion-SR region
- The sensitivity for stau peaks at around 30 ns
  - Lower lifetimes: LLPs do not travel far enough to be reconstructed as tracks
  - Higher lifetimes: trigger efficiency drops

https://doi.org/10.48550/arXiv.2503.16213

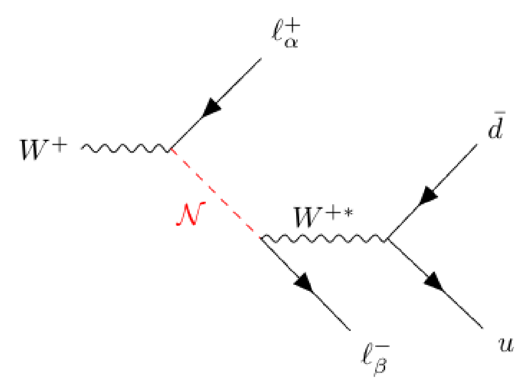
Heavy neutral leptons using leptonic displaced vertices

- Focus: **long-lived signatures** with lower coupling values (HNLs with m < 20 GeV)
- Signature: prompt lepton, produced near the pp interaction point (IP) from the decay of the W boson, and a **displaced two-track vertex** (DV), produced far from the IP
  - HNL decays leptonically (N → $\ell\ell\nu$): the DV consists of two leptons
  - Semi-leptonic decays: DV consists of a lepton and a charged pion
- Event selection: a single-lepton trigger
  - **Large radius tracking** (LRT) for reconstruction of displaced decay products
  - + customized displaced vertex reconstruction algorithm
- Background: combination of **Monte Carlo–driven and data-driven** methods

Leptonic



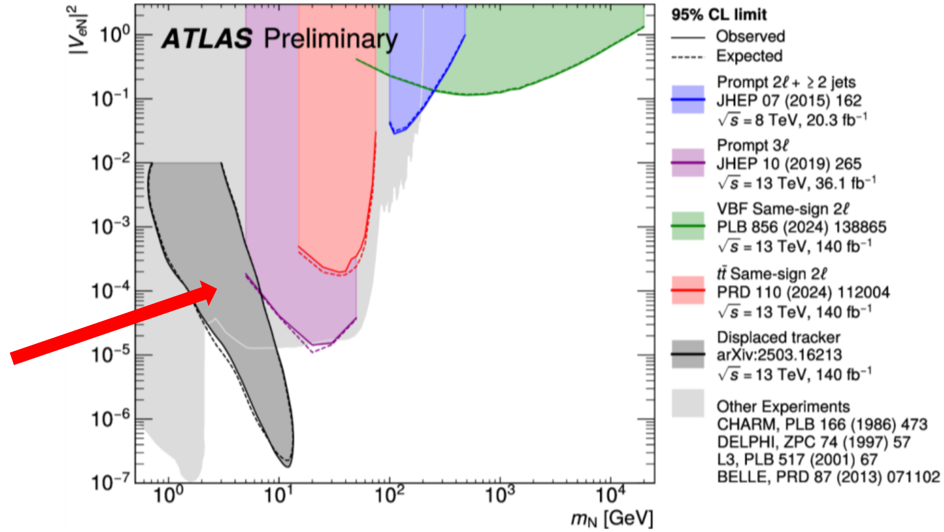
Semi-leptonic decay



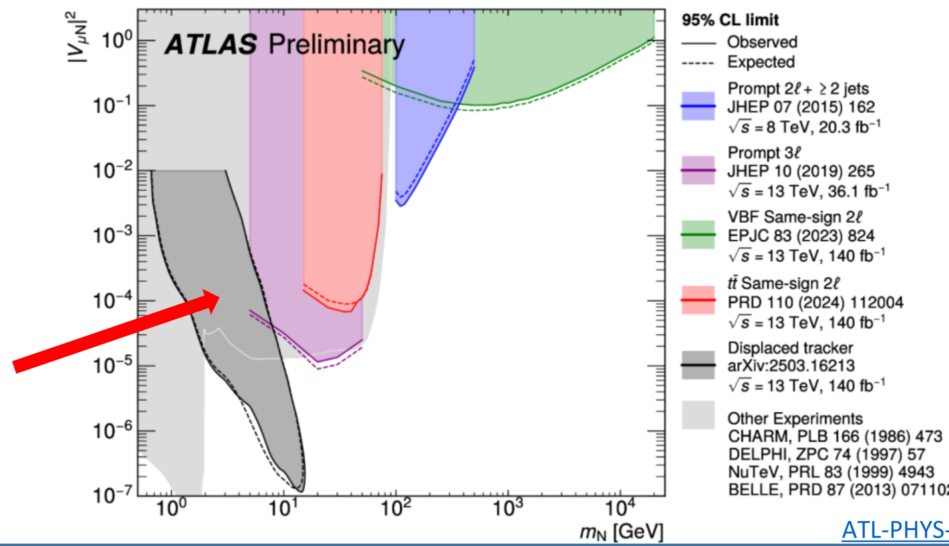
https://doi.org/10.48550/arXiv.2503.16213

Heavy neutral leptons using leptonic displaced vertices

- Six leptonic and four semi-leptonic channels are considered, contributing to 1SFH(e), 1SFH(μ), and 2QDH interpretations
- No significant excess is observed beyond the predicted background in any of the signal regions
- The search presented here places constraints on the production of HNLs in the mass range 0.5 < m < 16 GeV
- The sensitivity at low m values has improved due to improvements in the event reconstruction and the use of more sophisticated analysis techniques (same dataset is used us in previous analysis [ref])



Electron-only mixing



Muon-only mixing

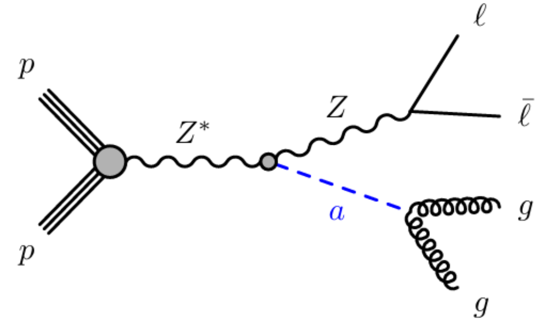
ATL-PHYS-PUB-2025-008

https://doi.org/10.48550/arXiv.2503.20445

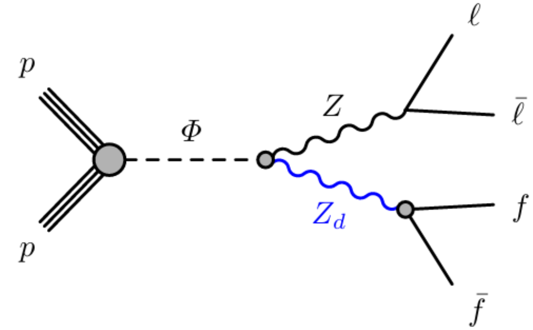
Displaced vertex from Long-Lived neutral particles

- Focus: **DVs occurring in the ATLAS muon spectrometer** (MS).
  - Target on events with a single MS DV
- **Sensitive to a broad spectrum of models**: a scalar portal, a baryogenesis, an axion-like particle, and a dark photon. Focus on production of a neutral LLP in association with a prompt Z:
  - **Z-associated production of ALPs**
  - **Long-lived dark photon** (Z_d with decay into quark pairs): produced along with a SM Z
- Two channels targeting events **with or without an additional prompt Z boson**:
  - Candidate events with no associated boson production – Muon RoI Cluster HLT trigger
  - Events with prompt Z bosons – single- or dilepton triggers.
- Specialized algorithm to reconstruct DVs in the MS
- Background estimations: **data-driven** ABCD method

ALP production through an intermediate, off-shell Z boson



Dark photon model

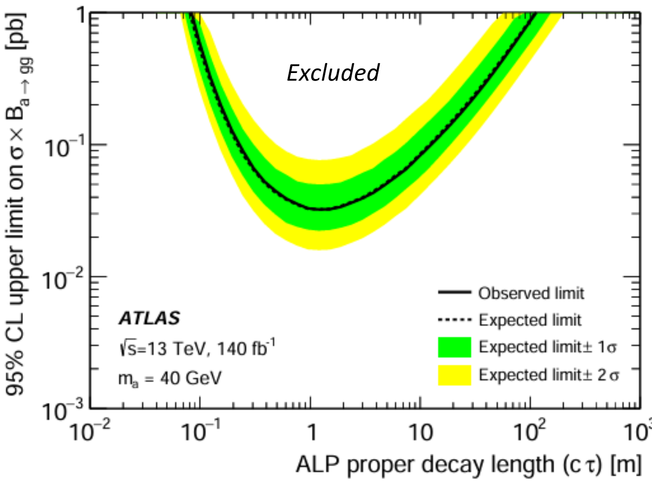


https://doi.org/10.48550/arXiv.2503.20445

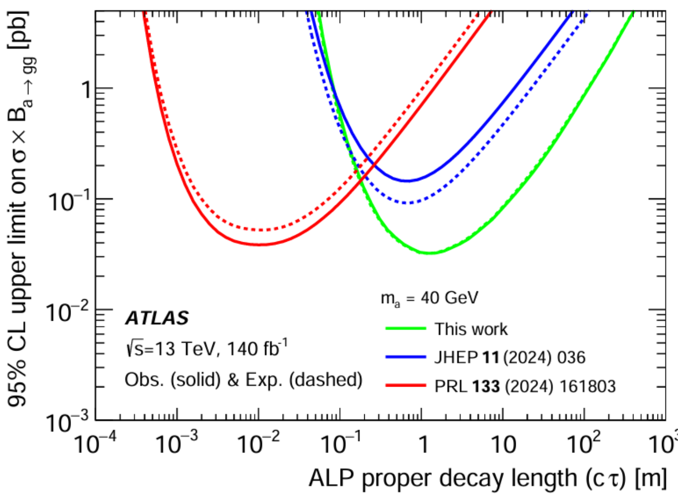
Displaced vertex from Long-Lived neutral particles

- Upper limits Z+ALP cross-section $\sigma \times B(a \to gg)$ (branching fraction for the ALP to decay into gluons)
- Z+ALP model, most stringent ATLAS limits to date for proper decay lengths greater than O(10^{-1}) m
- Limits for all $\Phi \to ZZ_d$ samples with limits on $\sigma \times B(Z_d \to ff)$ (branching fraction for the dark photon to decay into a pair of fermions)

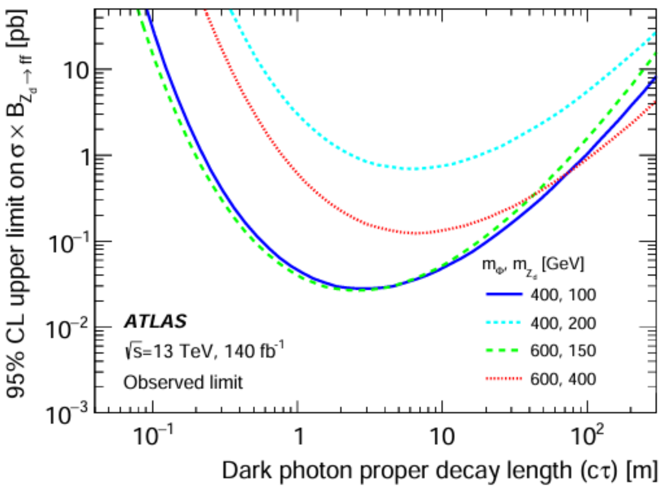
Z+ALP



Z+ALP comparison



Dark photon

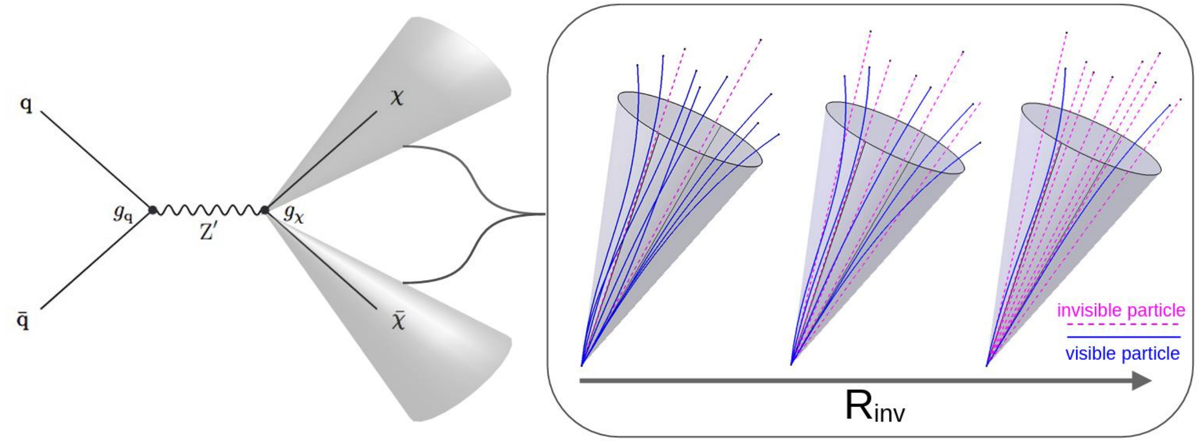


https://doi.org/10.48550/arXiv.2505.01634

New physics in final states with semi-visible jets

- Signal: leading order s-channel production of the Z' mediator which subsequently decays to **two dark quarks χ**. The dark quarks generate the semi-visible jet topology upon decay: varying patterns of **visible and invisible constituent energy**, coming from SM and dark particles
- **Machine Learning** (ML): to define the signal regions based on high-dimensional and low-level detector information. Two ML-based signal regions:
  - Based on model-specific classification of SVJ signals from background: Particle Flow Network (PFN)
  - Leveraging Anomaly Detection (to broaden sensitivity to a variety of hadronic signatures with missing energy)

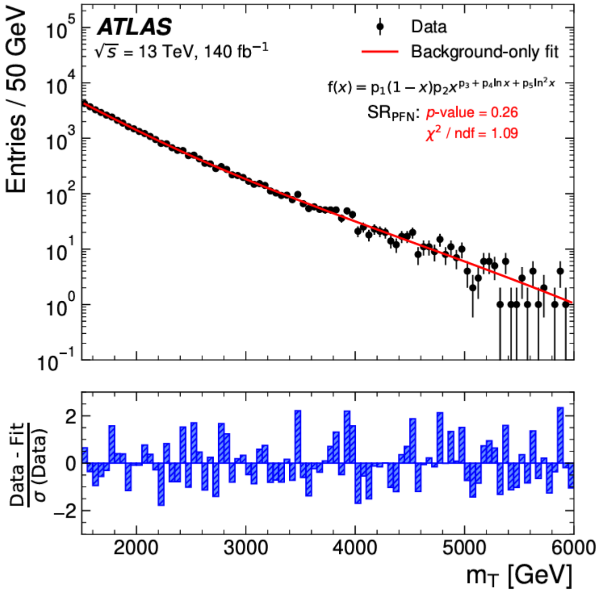
- This analysis is **unique** with respect to previous ATLAS anomaly searches and is the first use of semi-supervised machine learning (with partially labeled training inputs)

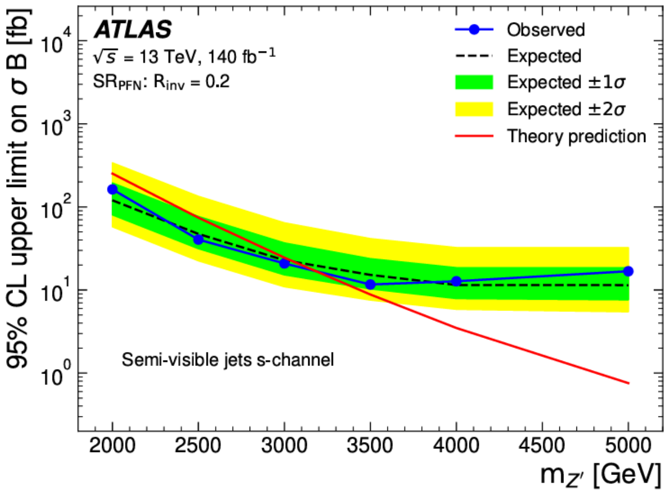


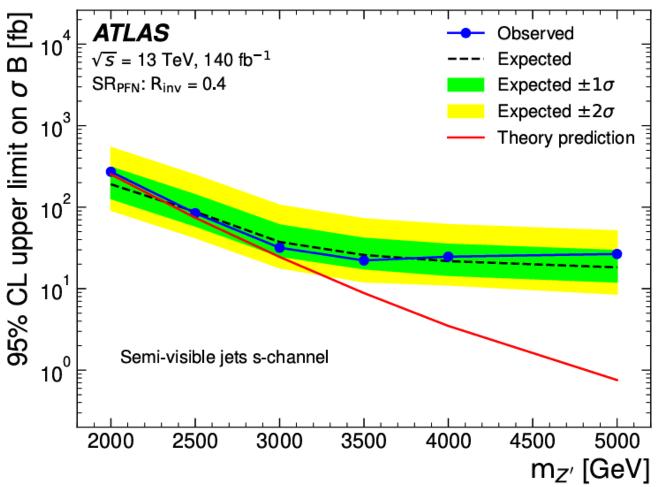
https://doi.org/10.48550/arXiv.2505.01634

New physics in final states with semi-visible jets

- Signal-like events are selected with the assistance of two machine learning tools which focus on track-level permutation invariant modeling of the events.
  - ParticleFlow Network: the highest sensitivity to the simulated SVJ signal
  - ANTELOPE: anomaly detection through generalized sensitivity to a wide variety of signal models
- Search for excesses on top of a smoothly falling m_T spectrum (estimated with a five-parameter functional fit)
- No significant excesses are found in distributions of data in the m_T spectrum of the PFN and ANTELOPE signal regions



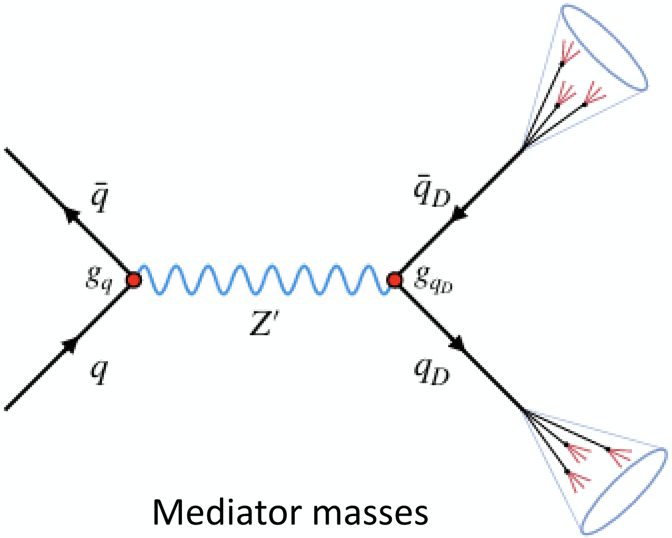




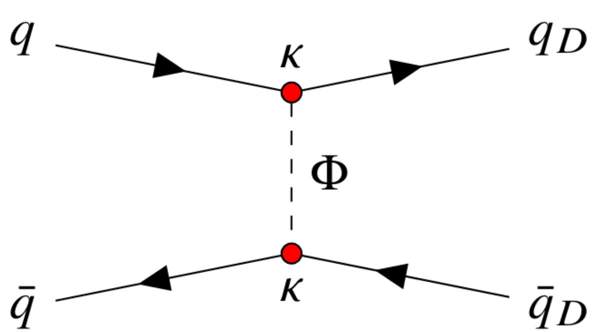
https://doi.org/10.48550/arXiv.2505.02429

Search for emerging jets

- Signal:
  - s-channel production through a new vector boson Z', which **decays into a pair of dark quarks** (leading to the formation of emerging jets)
  - t-channel with Φ (a bi-fundamental scalar mediator), as a portal between the SM and the DS
- **Two complementary strategies** to identify emerging jet signatures:
  - Selections on high-level jet observables
  - Machine learning(ML)
- **Two regions** based on the invariant mass of the two leading jets (m_{jj}), each with distinct trigger strategies:
  - The low-m_{jj} region (m_{jj}<1TeV): a dedicated jet trigger, introduced for Run3 (**specifically for emerging jets**)
  - The high-m_{jj} region (m_{jj}>1TeV): standard single-jet trigger
- **First usage of Run-3 data**
  - 51.8 fb^{-1} of pp collision at $\sqrt{s}$= 13.6 TeV



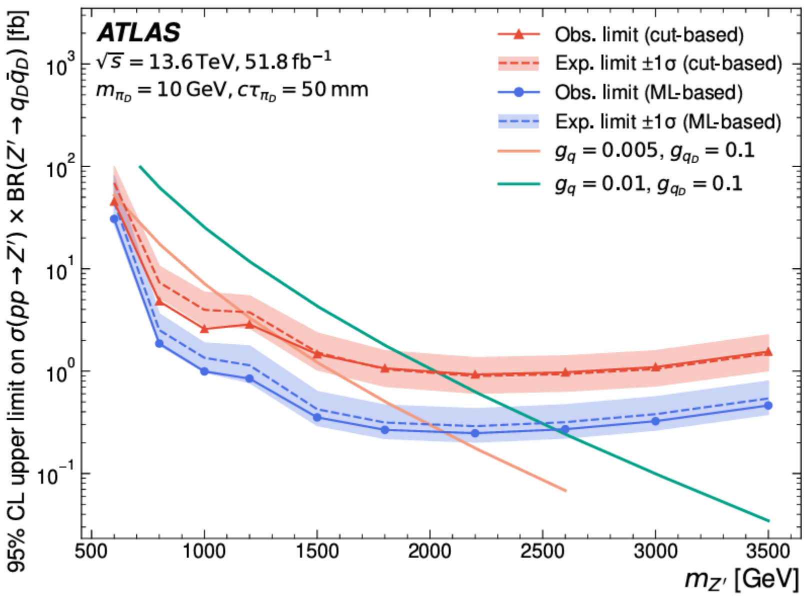
Mediator masses
600 - 3500 GeV

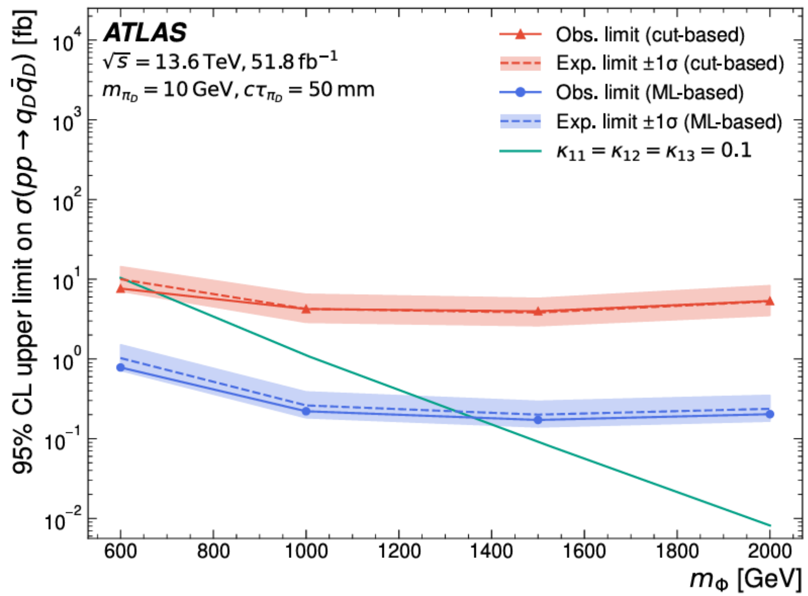


https://doi.org/10.48550/arXiv.2505.02429

Search for emerging jets

- No significant excess is observed above the expected background (estimated using a fully data-driven approach)
- Limits are placed at the 95% confidence level on two mediator scenarios:
  - Vector mediator Z': masses of up to 2.5 TeV excluded (quark coupling of 0.01, dark quark coupling of 0.1)
  - Scalar bi-fundamental mediator Φ: masses up to 1350 GeV excluded (quark-dark quark coupling of 0.1)
- First search for emerging jet production via a resonant s-channel mediator
- First application of a transformer-based algorithm for emerging jet tagging

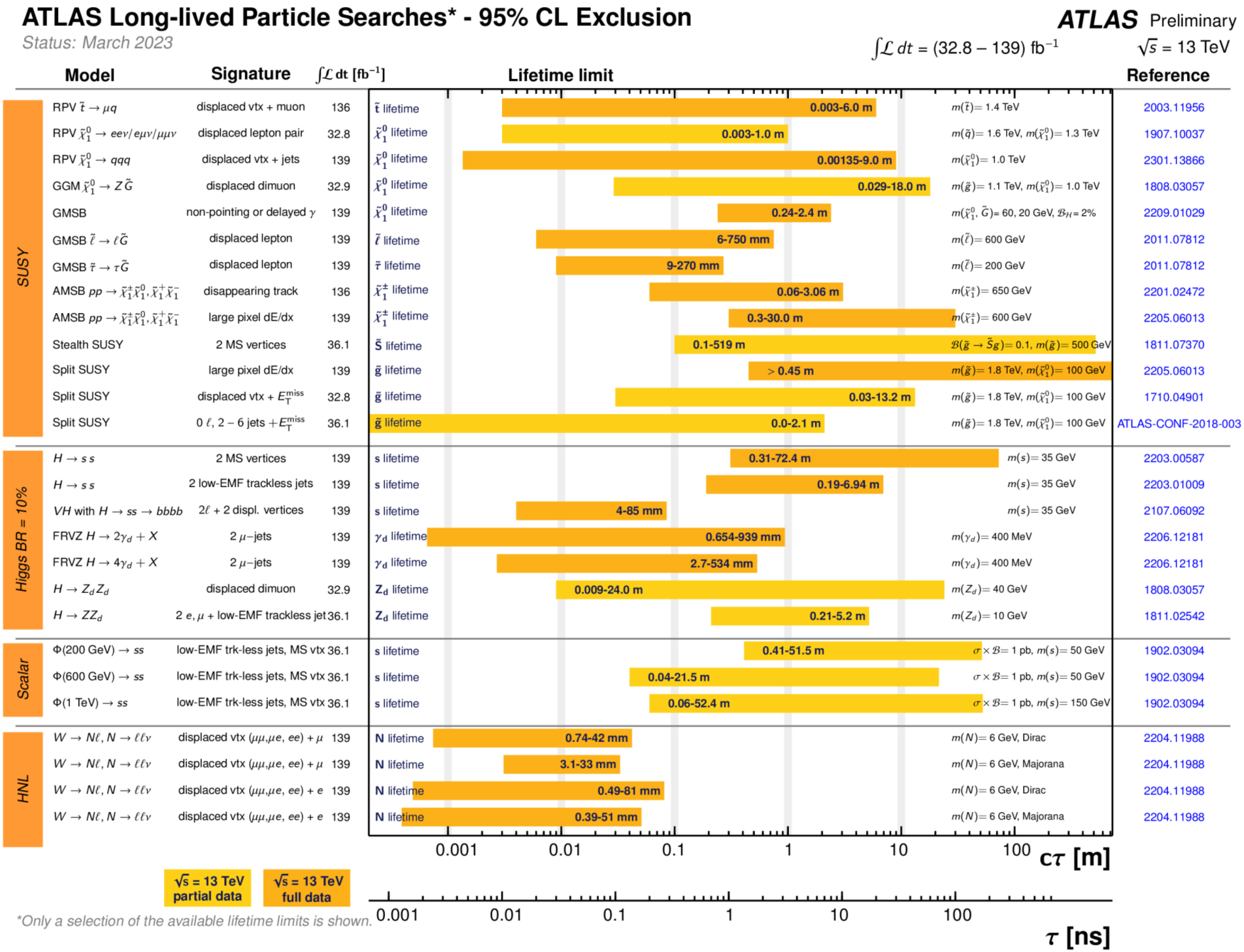




Conclusions

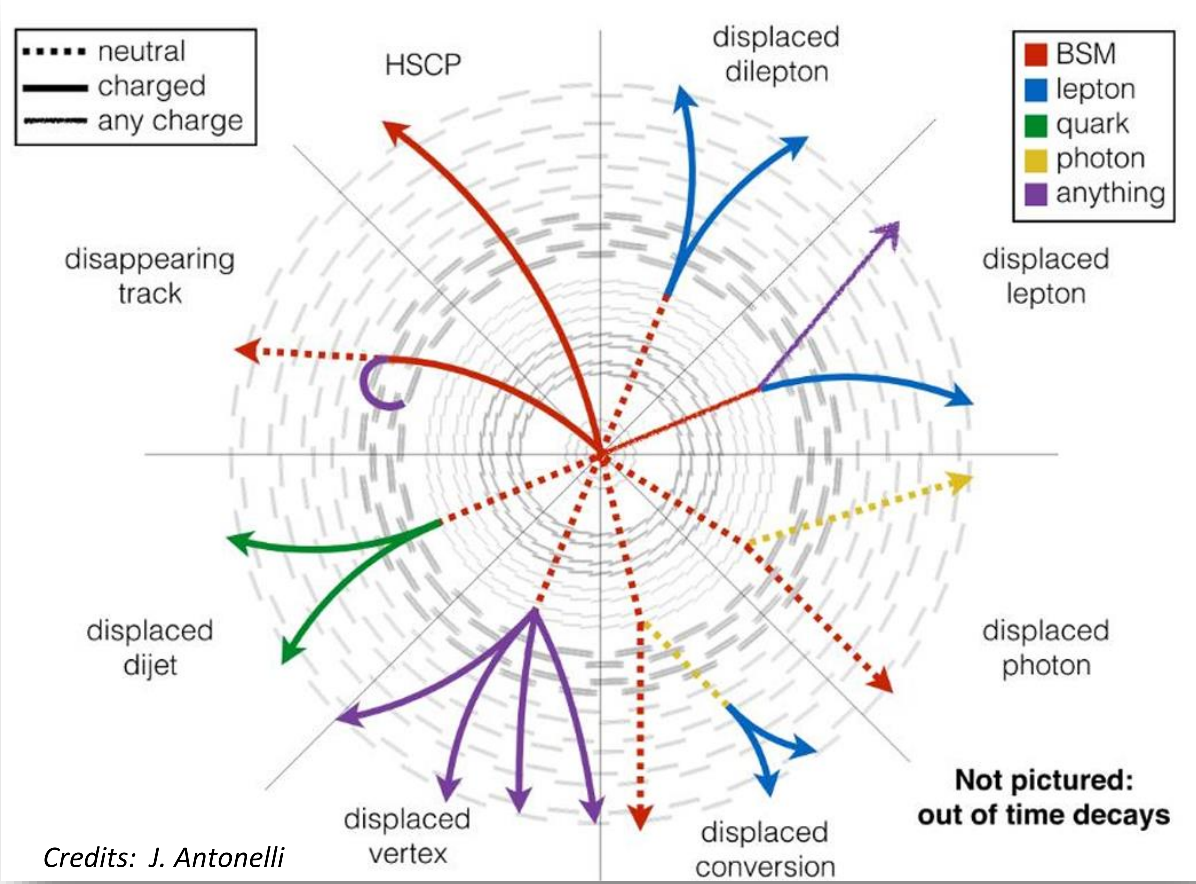
- Data:
  - Run-2: 140 fb^{-1} of pp collision at $\sqrt{s}$= 13 TeV
  - Partial Run-3 (individual analyses): 56.3 fb^{-1} / 51.8 fb^{-1} of pp collision at $\sqrt{s}$= 13.6 TeV
- Signatures:
  - Displaced leptons
  - Displaced vertices
  - Semi-visible jets
  - Emerging jets
- Techniques:
  - Novel triggering mechanisms
  - Doubled approaches and signal regions
  - Specialized algorithms
  - Machine Learning (ML)
- Looking forward to completed Run-3 data to increase sensitivities

Backup


ATLAS Long-lived Particle Searches* - 95% CL Exclusion
Status: March 2023
ATLAS Preliminary
∫ℒ dt = (32.8 – 139) fb⁻¹
√s = 13 TeV
Model
Signature
∫ℒ dt [fb⁻¹]
Lifetime limit
Reference
SUSY
RPV t̃ → μq | displaced vtx + muon | 136 | t̃ lifetime | 0.003-6.0 m | m(t̃)= 1.4 TeV | 2003.11956
RPV χ̃⁰₁ → eeν/eμν/μμν | displaced lepton pair | 32.8 | χ̃⁰₁ lifetime | 0.003-1.0 m | m(q̃)= 1.6 TeV, m(χ̃⁰₁)= 1.3 TeV | 1907.10037
RPV χ̃⁰₁ → qqq | displaced vtx + jets | 139 | χ̃⁰₁ lifetime | 0.00135-9.0 m | m(χ̃⁰₁)= 1.0 TeV | 2301.13866
GGM χ̃⁰₁ → ZG̃ | displaced dimuon | 32.9 | χ̃⁰₁ lifetime | 0.029-18.0 m | m(g̃)= 1.1 TeV, m(χ̃⁰₁)= 1.0 TeV | 1808.03057
GMSB | non-pointing or delayed γ | 139 | χ̃⁰₁ lifetime | 0.24-2.4 m | m(χ̃⁰₁, G̃)= 60, 20 GeV, ℬ_H= 2% | 2209.01029
GMSB ℓ̃ → ℓG̃ | displaced lepton | 139 | ℓ̃ lifetime | 6-750 mm | m(ℓ̃)= 600 GeV | 2011.07812
GMSB τ̃ → τG̃ | displaced lepton | 139 | τ̃ lifetime | 9-270 mm | m(ℓ̃)= 200 GeV | 2011.07812
AMSB pp → χ̃±₁χ̃⁰₁, χ̃⁺₁χ̃⁻₁ | disappearing track | 136 | χ̃±₁ lifetime | 0.06-3.06 m | m(χ̃±₁)= 650 GeV | 2201.02472
AMSB pp → χ̃±₁χ̃⁰₁, χ̃⁺₁χ̃⁻₁ | large pixel dE/dx | 139 | χ̃±₁ lifetime | 0.3-30.0 m | m(χ̃±₁)= 600 GeV | 2205.06013
Stealth SUSY | 2 MS vertices | 36.1 | S̃ lifetime | 0.1-519 m | ℬ(g̃ → S̃g)= 0.1, m(g̃)= 500 GeV | 1811.07370
Split SUSY | large pixel dE/dx | 139 | g̃ lifetime | > 0.45 m | m(g̃)= 1.8 TeV, m(χ̃⁰₁)= 100 GeV | 2205.06013
Split SUSY | displaced vtx + E_T^miss | 32.8 | g̃ lifetime | 0.03-13.2 m | m(g̃)= 1.8 TeV, m(χ̃⁰₁)= 100 GeV | 1710.04901
Split SUSY | 0 ℓ, 2 – 6 jets + E_T^miss | 36.1 | g̃ lifetime | 0.0-2.1 m | m(g̃)= 1.8 TeV, m(χ̃⁰₁)= 100 GeV | ATLAS-CONF-2018-003
Higgs BR = 10%
H → s s | 2 MS vertices | 139 | s lifetime | 0.31-72.4 m | m(s)= 35 GeV | 2203.00587
H → s s | 2 low-EMF trackless jets | 139 | s lifetime | 0.19-6.94 m | m(s)= 35 GeV | 2203.01009
VH with H → ss → bbbb | 2ℓ + 2 displ. vertices | 139 | s lifetime | 4-85 mm | m(s)= 35 GeV | 2107.06092
FRVZ H → 2γ_d + X | 2 μ–jets | 139 | γ_d lifetime | 0.654-939 mm | m(γ_d)= 400 MeV | 2206.12181
FRVZ H → 4γ_d + X | 2 μ–jets | 139 | γ_d lifetime | 2.7-534 mm | m(γ_d)= 400 MeV | 2206.12181
H → Z_dZ_d | displaced dimuon | 32.9 | Z_d lifetime | 0.009-24.0 m | m(Z_d)= 40 GeV | 1808.03057
H → ZZ_d | 2 e, μ + low-EMF trackless jet | 36.1 | Z_d lifetime | 0.21-5.2 m | m(Z_d)= 10 GeV | 1811.02542
Scalar
Φ(200 GeV) → ss | low-EMF trk-less jets, MS vtx | 36.1 | s lifetime | 0.41-51.5 m | σ × ℬ= 1 pb, m(s)= 50 GeV | 1902.03094
Φ(600 GeV) → ss | low-EMF trk-less jets, MS vtx | 36.1 | s lifetime | 0.04-21.5 m | σ × ℬ= 1 pb, m(s)= 50 GeV | 1902.03094
Φ(1 TeV) → ss | low-EMF trk-less jets, MS vtx | 36.1 | s lifetime | 0.06-52.4 m | σ × ℬ= 1 pb, m(s)= 150 GeV | 1902.03094
HNL
W → Nℓ, N → ℓℓν | displaced vtx (μμ,μe, ee) + μ | 139 | N lifetime | 0.74-42 mm | m(N)= 6 GeV, Dirac | 2204.11988
W → Nℓ, N → ℓℓν | displaced vtx (μμ,μe, ee) + μ | 139 | N lifetime | 3.1-33 mm | m(N)= 6 GeV, Majorana | 2204.11988
W → Nℓ, N → ℓℓν | displaced vtx (μμ,μe, ee) + e | 139 | N lifetime | 0.49-81 mm | m(N)= 6 GeV, Dirac | 2204.11988
W → Nℓ, N → ℓℓν | displaced vtx (μμ,μe, ee) + e | 139 | N lifetime | 0.39-51 mm | m(N)= 6 GeV, Majorana | 2204.11988
0.001
0.01
0.1
1
10
100
cτ [m]
√s = 13 TeV partial data
√s = 13 TeV full data
0.001
0.01
0.1
1
10
100
τ [ns]
*Only a selection of the available lifetime limits is shown.

Unconventional signatures

- Based on ID:
  - Disappearing track: charged particle decays in the ID to a nearly degenerate stable neutral particle
  - Displaced vertex (DV): neutral particle decays in the ID to charged and neutral particles appears as tracks pointing (back) to a DV
- Based on calorimeters:
  - "Non-pointing" photons: photons detected in calorimeter not pointing back to the original IP
- Based on muon spectrometer or other ATLAS subdetectors:
  - "Muon-like" or Heavy Stable Charged Particles (HSCP): if charged and very long-lived, the signature is similar to that of a muon but with high mass
  - Missing transverse momentum: neutral, weakly interacting LLPs (traverses the ATLAS detector not being detected)
- ATLAS projective geometry + prompt reconstruction not designed to efficiently target LLPs
  - Searches for these signatures push the limits of detector performance
  - May require customised trigger and self-made objects reconstruction algorithm
  - Requires non-standard analysis strategies and tools: Non-standard background (cosmic-ray muons and Beam Induced background), generally data-driven estimation



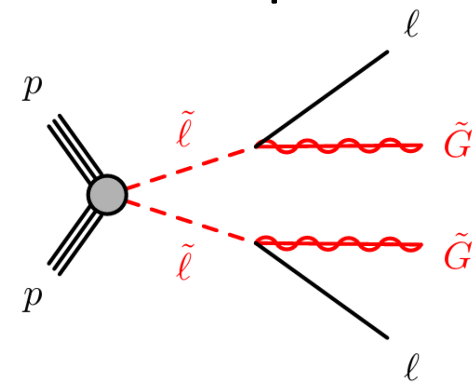
Credits: J. Antonelli

https://doi.org/10.48550/arXiv.2410.16835

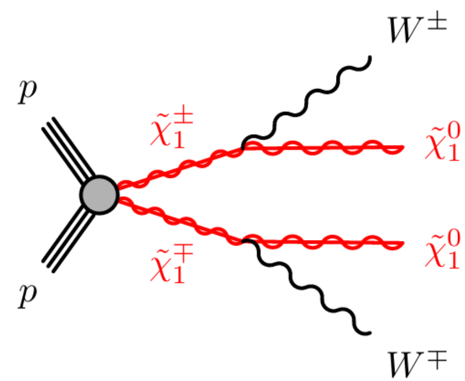
Displaced leptons

- Model:
  - Gauge-Mediated Supersymmetry Breaking **(GMSB) sleptons**
  - **Dark sector** (if W decays leptonically, same final state as for sleptons, but tending to have lower p_t)
- Signature:
  - **Two displaced leptons** (no visible decay vertex) with large impact parameter (|d0|>3 mm) from decay of slepton pair
  - Consideration of single displaced electron channels, using multivariate Boosted Decision Trees (BDTs)
- Strategy:
  - Combination of **two approaches** with mutually exclusive selections:
    - the "ABCD" search
    - "EM-BDT" search (Boosted Decision Trees)
  - Backgrounds are determined entirely with **data-driven** methods, and MC simulation is only used for signal model
  - Triggering Mechanisms: **Novel triggering mechanisms** introduced during Run 3 are utilized to enhance the sensitivity of the analysis. These triggers leverage large-radius tracking (LRT) to reconstruct displaced tracks, allowing for the detection of low-momentum displaced leptons

GMSB slepton

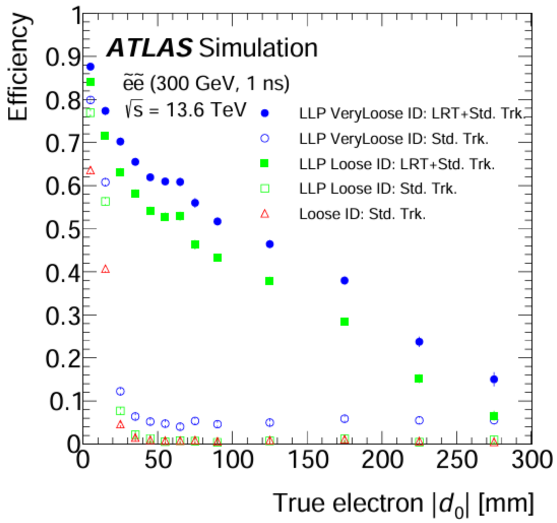


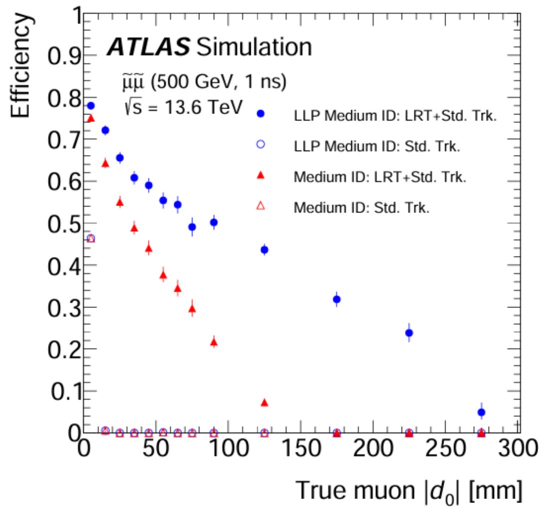
Dark sector



Displaced leptons

- **Two Main Approaches**: combination of two approaches with mutually exclusive selections: the “ABCD” search and the “EM-BDT” search
- **Data-Driven Background Estimation**: for both approaches backgrounds are determined with entirely data-driven methods, and MC simulation is only used for signal models
- **Triggering Mechanisms**: Novel triggering mechanisms introduced during Run 3 are utilized to enhance the sensitivity of the analysis. These triggers leverage large-radius tracking (LRT) to reconstruct displaced tracks, allowing for the detection of low-momentum displaced leptons
- **Signal Region Definitions**: The analysis defines signal regions (SRs) based on the flavors of the two leptons with the highest pT. This is part of the ABCD analysis, which categorizes events into different signal regions to facilitate the search for signal-like excesses above Standard Model expectations

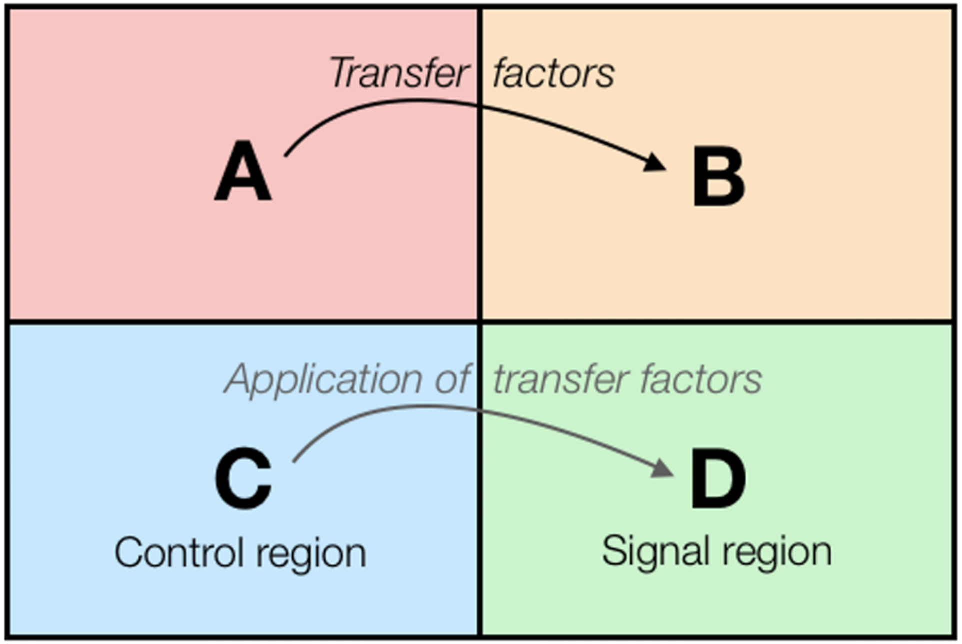




ABCD search

Transfer factors correct for the different selection efficiencies between regions C and D.

- The ABCD analysis defines SRs for three dilepton flavor combinations, ee, $\mu\mu$, and $e\mu$, using the flavors of the two leptons with the highest pT
- Backgrounds are estimated using two ABCD-based estimations, one for FHF leptons and one for cosmic-ray muons, which make use of leptons passing and failing certain quality criteria
- These are estimated separately because, while they are uncorrelated with each other, different sets of background suppressing requirements need to be inverted to populate the background estimation regions. Cosmic-ray muons are only relevant for the $\mu\mu$ final state
- Region A, shared for the FHF and cosmic-ray muon estimates, is the SR where both leptons pass all analysis requirements, regions B and C have one lepton passing the criteria and the other one failing them, and region D contains events where both leptons fail the criteria, which are different for the FHF and cosmic-ray muon estimates

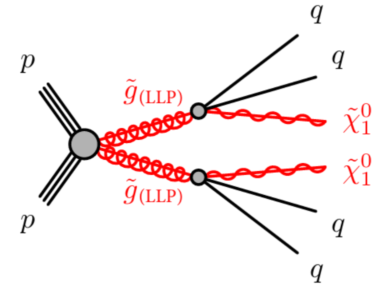


https://doi.org/10.48550/arXiv.2502.06694

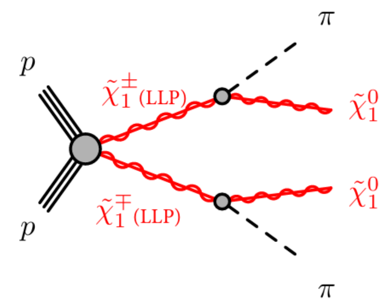
Long-Lived charged particles using dE/dx and ToF

- Search for **massive, high-pT, long-lived charged particles**
    - $\beta \ll 1 \rightarrow$ large ionization losses (dE/dx)
    - Targeting lifetimes > 3 ns
- Key observable: Mass -> $m = \frac{p}{\beta\gamma}$
    - p → measured in tracking
    - $\beta\gamma$ → obtained from pixel dE/dx measurement (through Bethe-Bloch relation) or from time-of-flight measurement (TileCal)
- Two Distinct Signal Regions:
    - ***β*-search**: extends the sensitivity to higher masses for models with one or more charged, heavy LLPs by requiring that the tracks that pass signal candidate selections have both a large **$\mathrm{d}E/\mathrm{d}x$ and a ToF** measurement consistent with a slow-moving particle, with a lifetime > 10 ns
        - ToF -> additional background reduction
        - Target: heavy LLPs, including long-lived charginos and R-hadrons.
    - **Di-track search**: two signal tracks which both have significant $\mathrm{d}E/\mathrm{d}x$. Large reduction in background and enhanced acceptance for low-mass LLPs yields significant sensitivity gains for pair-produced sleptons with lifetimes > 3 ns.
        - Lower sensitivity for charginos and R-hadrons
- Background: **data-driven** technique to estimate the background processes in the signal regions

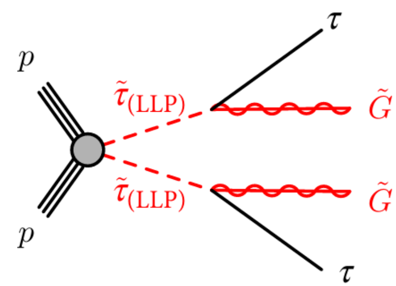
Gluinos which form R-hadrons decaying into neutralinos



Charginos decaying into neutralinos



Staus decaying into gravitinos

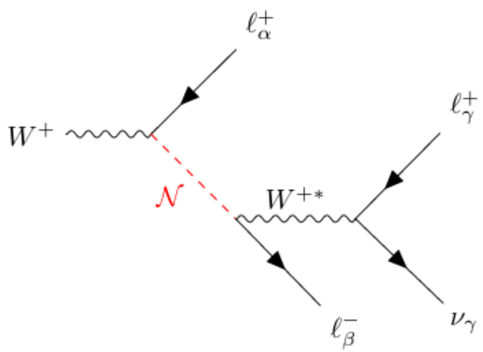


https://doi.org/10.48550/arXiv.2503.16213

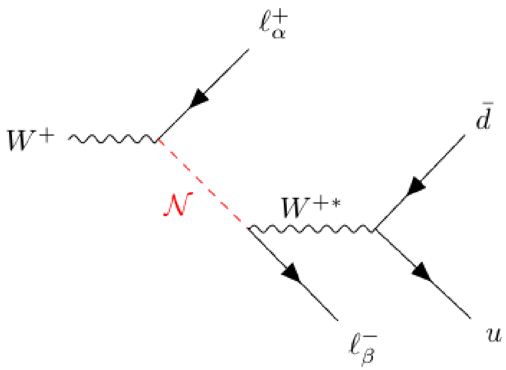
Heavy neutral leptons using leptonic displaced vertices

- Search focuses on **long-lived signatures** and accesses lower coupling values by probing HNLs with m < 20 GeV
- Signature: prompt lepton, produced near the pp interaction point (IP) from the decay of the W boson, and a **displaced two-track vertex** (DV), produced far from the IP
  - In the case if HNL decays leptonically (N → $\ell\ell\nu$), the DV will consist of two leptons
  - For the semi-leptonic decays, only decays to a single charge pion are considered, (N → $\ell\pi$), and the DV consists of a lepton and a charged pion
- Event selection: a single-lepton trigger. The displaced decay products from the long-lived HNL are reconstructed using **large radius tracking** (LRT) and a customized displaced vertex reconstruction algorithm
- Background:
  - two sources of background: come from metastable heavy-flavour hadron decays, and from hadrons that are mis-reconstructed as leptons (referred to as the fake-lepton background).
  - Estimates: combination of **Monte Carlo–driven and data-driven** methods.

Leptonic



Semi-leptonic decay

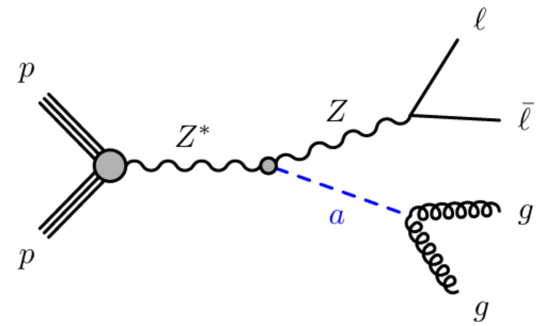


https://doi.org/10.48550/arXiv.2503.20445

Displaced vertex from Long-Lived neutral particles

- Search focuses on identifying **DVs occurring in the ATLAS muon spectrometer** (MS). The event selection criteria and vertex reconstruction algorithms are designed to target candidate events with a single MS DV
- **Sensitive to a broad spectrum of models**: a scalar portal, a baryogenesis, an axion-like particle, and a dark photon. Focus on production of a neutral LLP in association with a prompt Z:
  - ALPs are new pseudo-scalars that are associated with the breaking of a global symmetry. The analysis targets **only Z-associated production** due to the additional background rejection possible via selecting both outgoing leptons.
  - **Long-lived dark photon** (Z_d), where the Z_d is produced along with a SM Z during the decay of an initial-state scalar. In this model, the lifetime of the dark photon is a free parameter and only $Z \to e^- e, \mu^- \mu$ are simulated. As with the scalar portal model, the Z_d is assumed to decay primarily into quark pairs.
- Two channels targeting events **with or without an additional prompt Z boson**:
  - Candidate events with no associated boson production are selected by the Muon RoI Cluster HLT trigger
  - Events with prompt Z bosons are selected using single- or dilepton triggers.
- Specialized algorithm to reconstruct DVs in the MS is used. Additional selection criteria are used to maximize the analysis sensitivity
- Background estimations: **data-driven** ABCD method

ALP production through an intermediate, off-shell Z boson



Dark photon model