Searches for Unusual Signatures in Hadronic Channels with the ATLAS Detector

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ATLAS Collaboration

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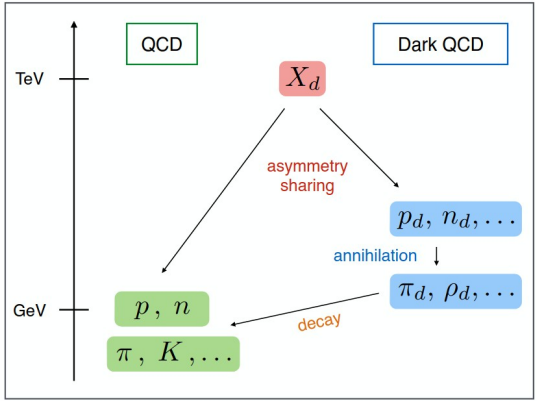
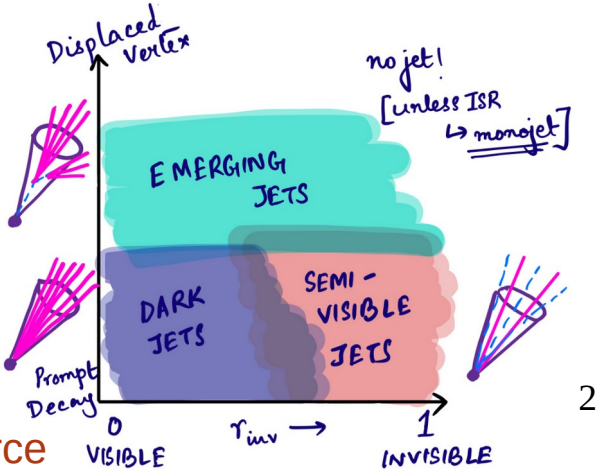
Unusual Hadronic Signatures

- Strongly coupled hidden/dark sector is one candidate to provide DM predicted by cosmology
- Pythia hidden valley module used for simulation of dark shower → best guesstimate
- ATLAS search program looking for generic final states:
  - Prompt dark shower, decay into SM particles
  - Prompt dark shower, partial decay into SM particles
  - Non-prompt dark shower, due to long lived dark mesons.
- Further unconventional hadronic signatures are being searched for, e.g hadronic LLP decay in the muon spectrometer shown today



ArXiv: 1502.05409



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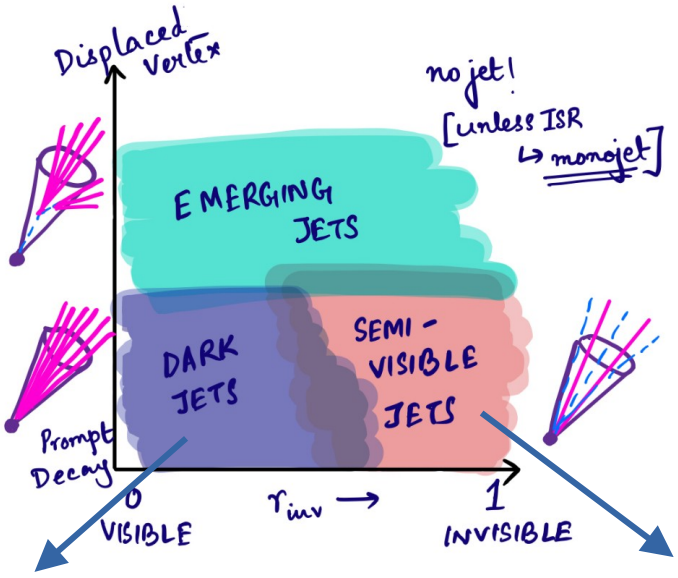
ATLAS Dark QCD Searches So Far



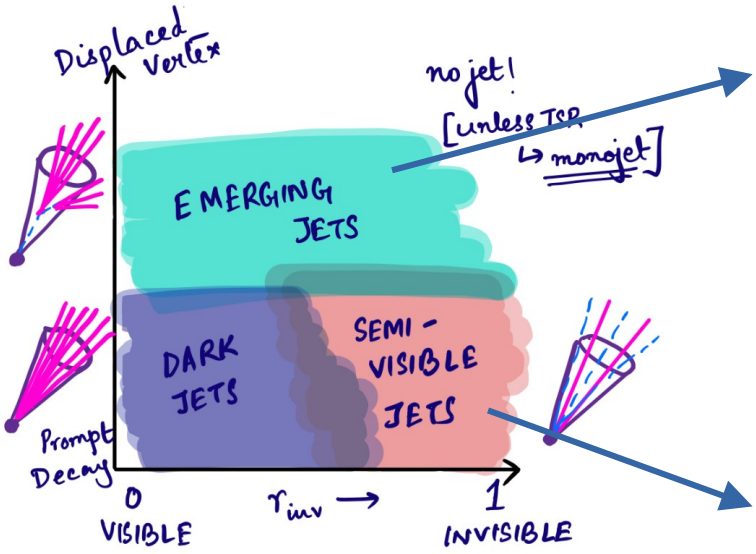
Search for Resonant Production of Dark Quarks in the Dijet Final State with the ATLAS Detector

ArXiv: 2311.03944

Search for non-resonant production of semi-visible jets using Run 2 data in ATLAS

ArXiv: 2305.18037

Results Shown Today



Search for emerging jets in pp collisions at $\sqrt{s}$ = 13.6 TeV with the ATLAS experiment

ArXiv: 2505.02429

First ATLAS run 3 exotics result!

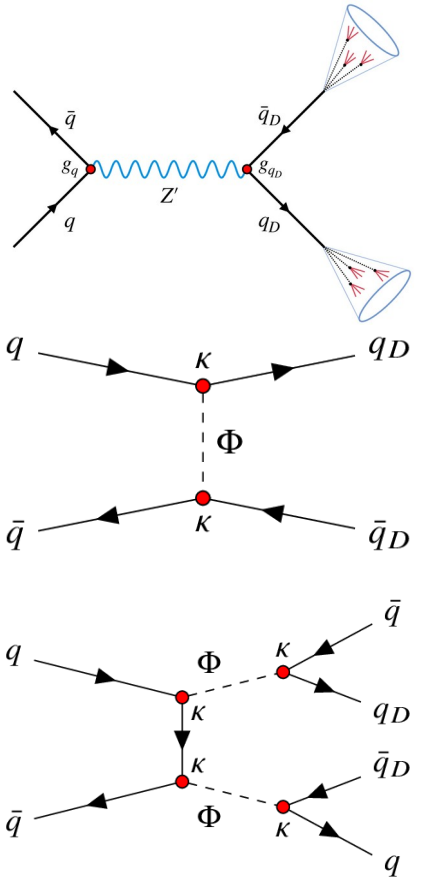
Search for new physics in final states with semi-visible jets or anomalous signatures using the ATLAS detector

ArXiv: 2505.01634

Emerging Jet Signature

Physics:

- Production of 2 dark quarks (q_D) and up to 2 SM quarks via:
  - s-channel decay of Z'
  - t-channel exchange of bi-fundamental scalar mediator
- Dark shower: Weak coupling of qD to SM quarks → macroscopic lifetime of q_D

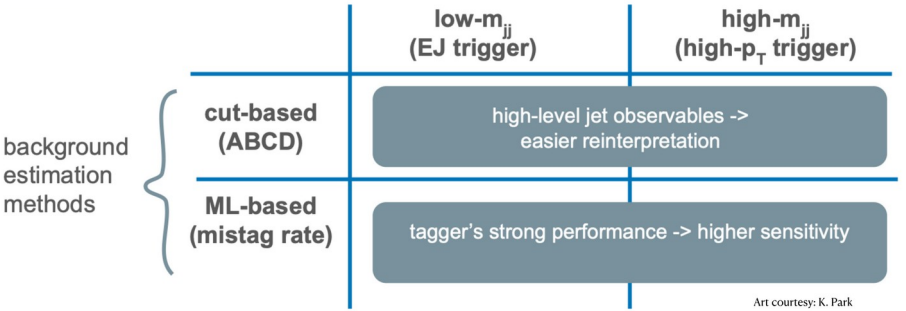


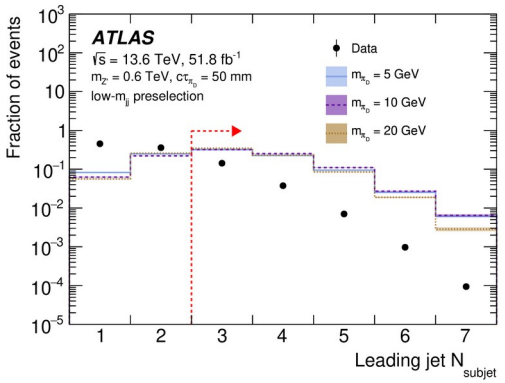
Signature:

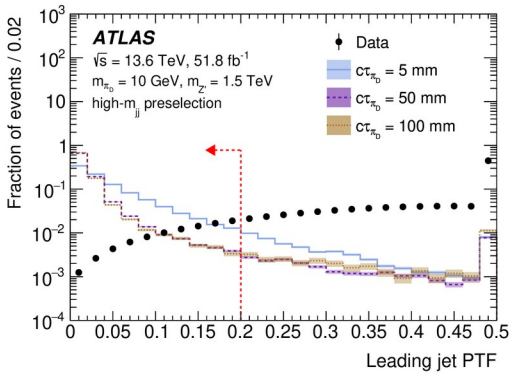
- Jets with many displaced vertices in jet cone

EJ Analysis Strategy

- Two analysis strategies:
  - Cut based
  - Machine learning based
- New EJ trigger deployed in Run 3
  - Based on prompt track fraction in jet
  - Targeting low m_{jj} region

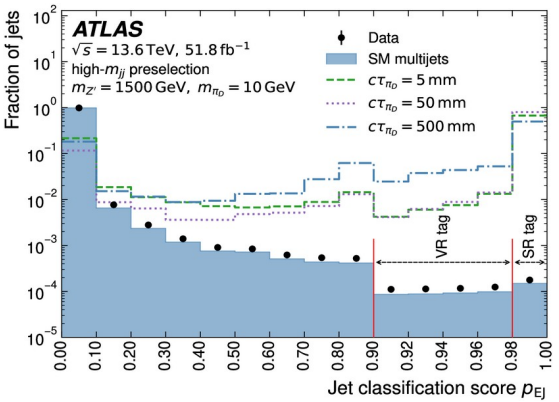






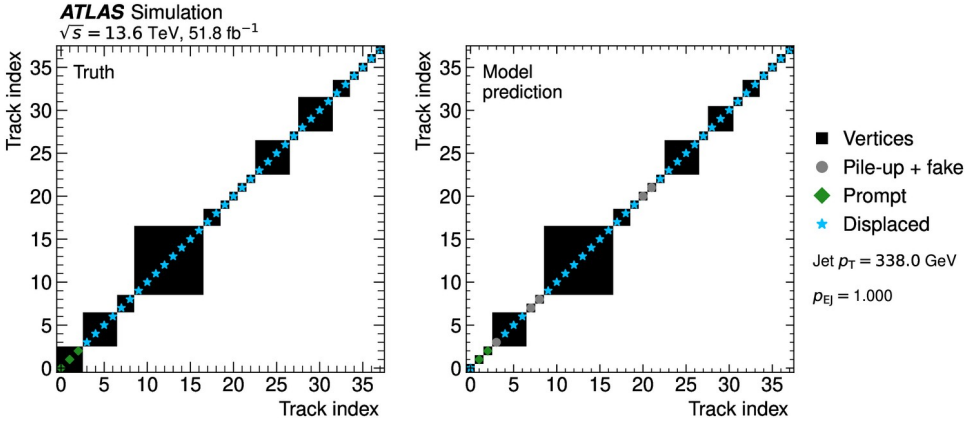
Cut based

ML based



EJ ML Based Analysis

- Architecture: Transformer jet tagging algorithm based on heavy flavor jet tagging (arXiv: 2505.19689):
  - Input: jet eta, 15 track variables for up to 200 associated tracks
  - Classification tasks: jet classification, track origin classification, track pair compatibility



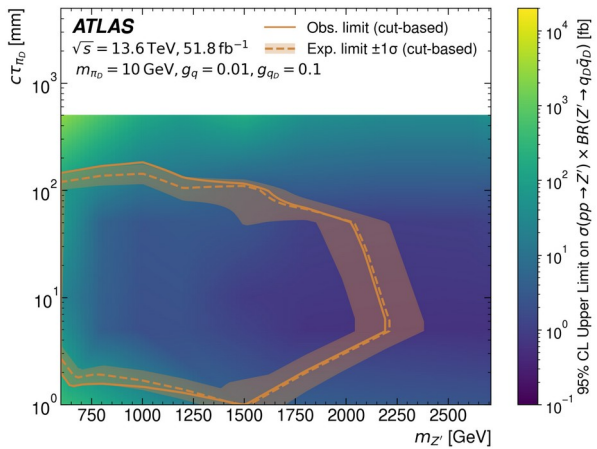
- Background estimated from mistag rates
- Validation of background estimate using validation region of 0.9-0.98 p_{EJ}

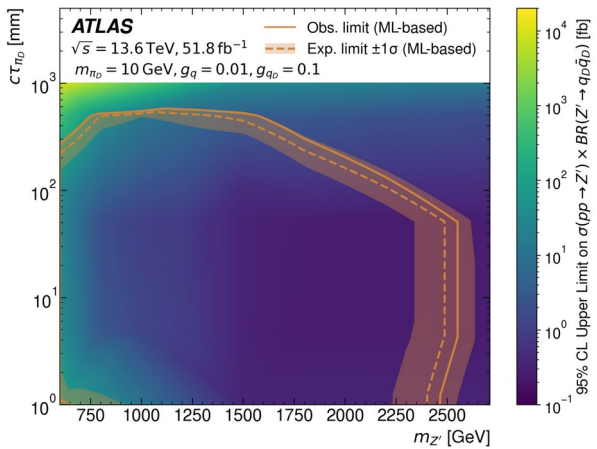
EJ Results

- No significant access observed
- Excluded $m_{Z'}$ up to 2500 GeV (2150 GeV) with ML (cut) based analysis
- m_{Φ} excluded up to 1350 GeV

Strategy	Region	Prediction (± stat ± syst)			Observed yield
Cut-based	High-m_{jj}	7.5	±1.1	±1.1	8
	Low-m_{jj}	17.4	±5.1	±5.1	10
ML-based	High-m_{jj}	4.5	±0.3	±2.8	3
	Low-m_{jj}	31.8	±0.8	±7.5	24

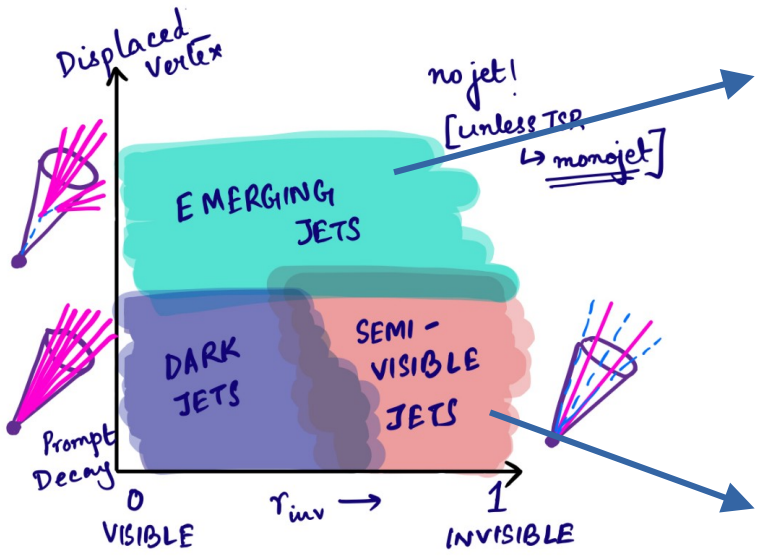
Cut based





ML based

Results Shown Today



Search for emerging jets in pp collisions at $\sqrt{s}$ = 13.6 TeV with the ATLAS experiment

ArXiv: 2505.02429

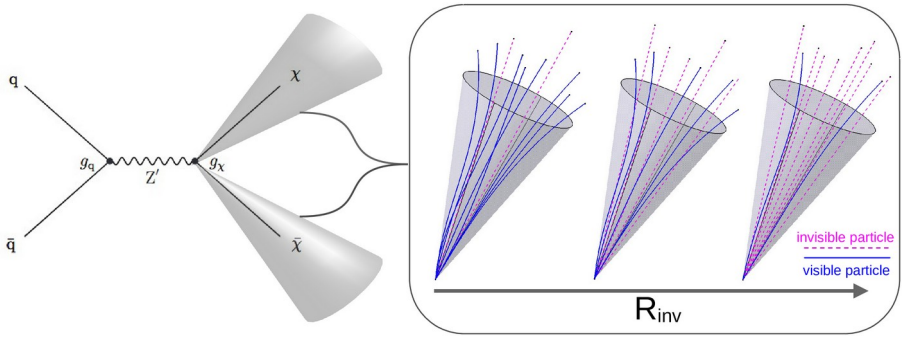
First ATLAS run 3 exotics result!

Search for new physics in final states with semi-visible jets or anomalous signatures using the ATLAS detector

ArXiv: 2505.01634

SVJ Motivation

- Physics:
  - Z’ decay into pair of dark quarks
  - Dark quarks hadronize → dark hadrons
    →decay to SM particles or DM candidates
  - $R_{invisble}$: Prob. of dark hadron decay to DM
- Signature:
  - 2 semi-visible jets (SVJ), resonant in m_T
  - Missing ET aligned with one of the jets
- Main Background: Jet miss-reconstruction in QCD multi-jet events



More details in M. Barakat’s talk

SVJ Analysis Strategy

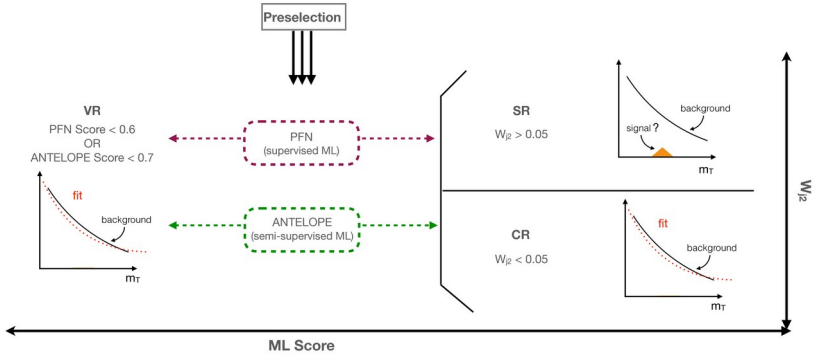
Two analysis approaches:

- Supervised machine learning with particle flow network (PFN) + Model specific results
- Semi-supervised anomaly detection (ANTELOPE) + BumpHunter to obtain model agnostic results

First ATLAS result using semi-supervised anomaly detection!

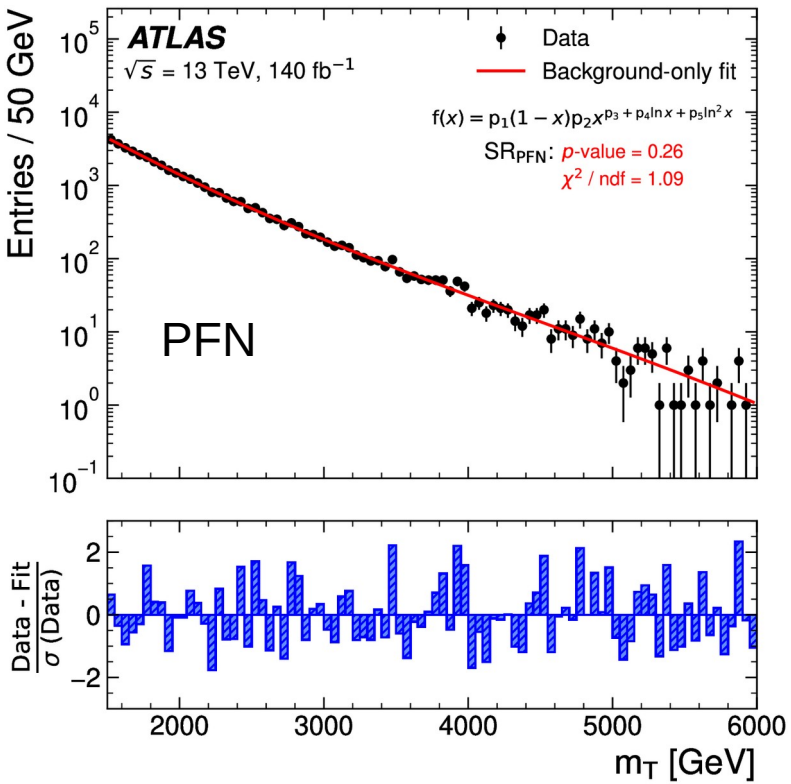
- Signal and control regions defined using width of sub-leading jet (W_{j2}) and ML scores

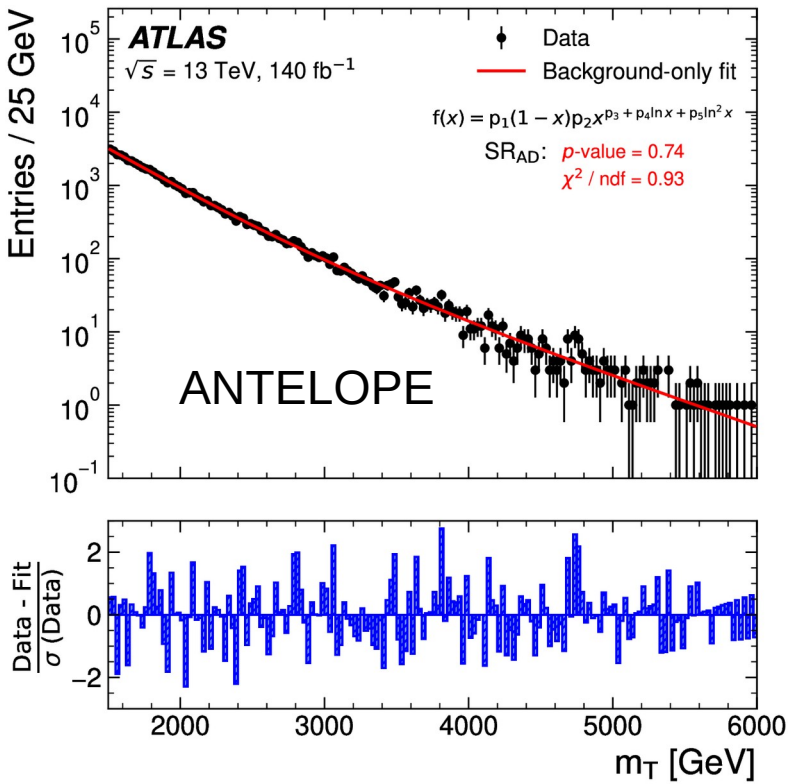
$$m_T^2 = \left[E_{T,JJ} + E_T^{\text{miss}}\right]^2 - \left[\vec{p}_{T,JJ} + \vec{p}_T^{\text{miss}}\right]^2$$



Variable	Preselection requirements				
N_{jets}	≥ 2				
N_{tracks} (jet)	≥ 3				
N_{lep}	$= 0$				
$p_T j_1 (j_2)$ [GeV]	> 450 (> 150)				
$\Delta\phi$ (j_1, j_2)	> 0.8				
$\lvert\eta_{j_1,j_2}\rvert$	< 2.1				
Δ y	< 2.8				
E_T^{miss} [GeV]	> 200				
m_T[GeV]	> 1500				
	SR_{PFN}	SR_{AD}	VR_{PFN}	VR_{AD}	CR
W_{j_2}	> 0.05				< 0.05
PFN score	> 0.6	–	< 0.6	–	–
ANTELOPE score	–	> 0.7	–	< 0.7	–

SVJ Results

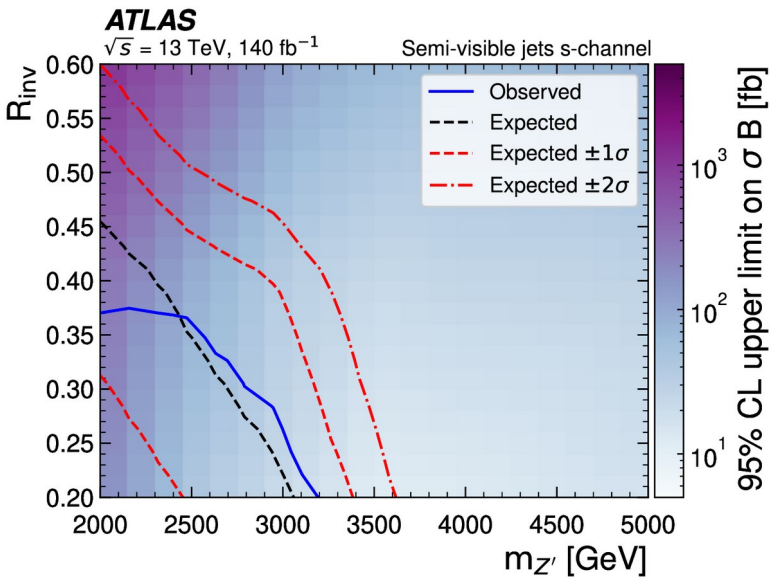


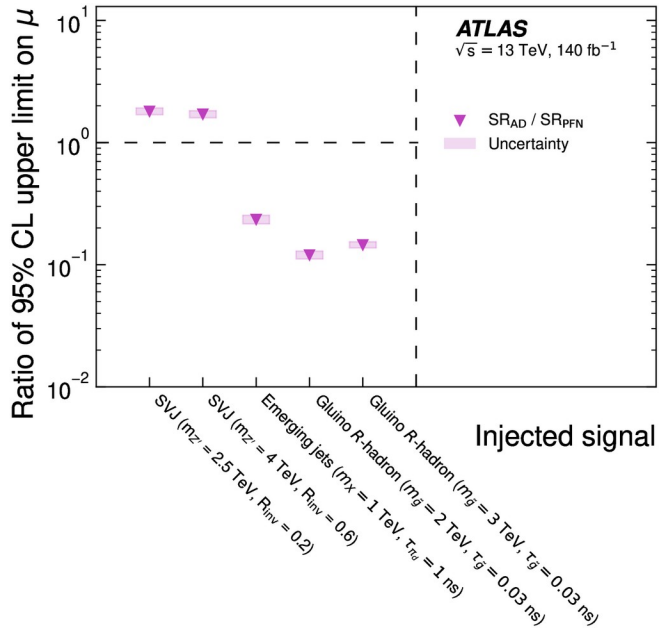


No excess observed

SVJ Results

- First ATLAS result on s-channel semi-visible jets
- Excluded 2TeV < $m_{Z'}$ < 3.2 TeV
- Stronger exclusion for lower R_{inv}





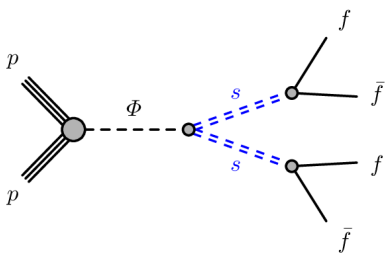
- ANTELOPE used to compare PFN to less model dependent approach
- Weaker limits for SVJ, but stronger for other models → good generalization

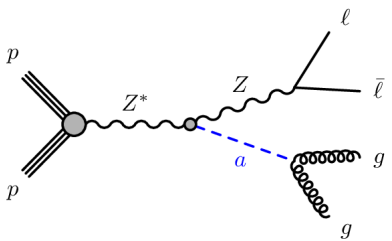
Search for events with one displaced vertex from long-lived neutral particles decaying into hadronic jets in the ATLAS muon spectrometer in pp collisions at $\sqrt{s} = 13$ TeV

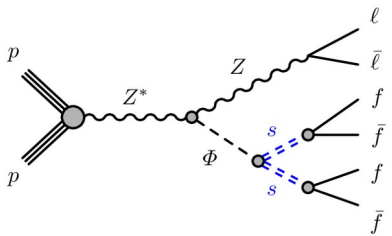
arXiv: 2503.20445

MSVtx Overview

- Search for neutral LLP hadronically decaying in muon spectrometer (MS)
- Signatures:
  - One decay vertex in the MS (using dedicated trigger)
  - One decay vertex in the MS + leptons from prompt Z (using di-lepton trigger)
- Results interpreted for scalar portal, baryogenesis models and ALPs
- Improved background estimate and signal efficiency extrapolation compared to previous searches (previous 2DV search: Phys. Rev. D 106 (2022) 032005)

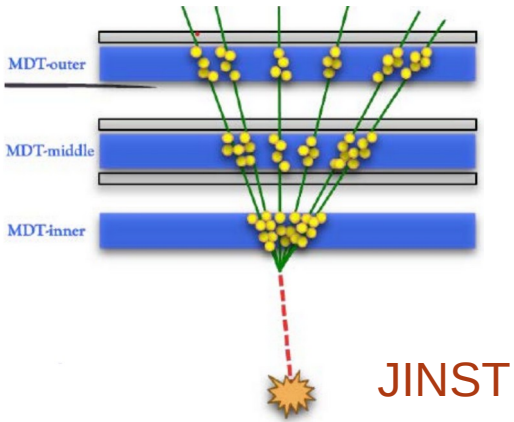


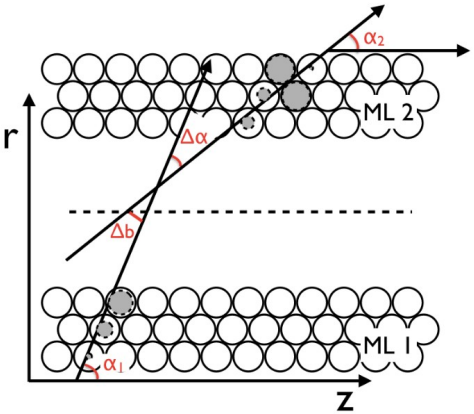




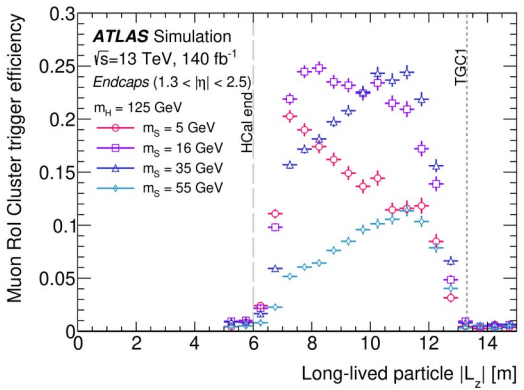
MSVtx Analysis Strategy

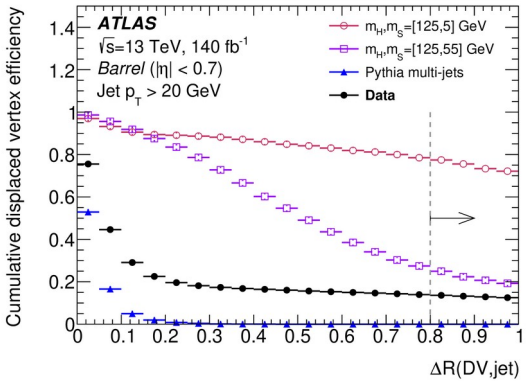
- Vertex reconstruction: Build tracklets from MDT multilayer and back-extrapolate them to find common vertex
- Background estimate: 2 NNs trained on uncorrelated input (ABCD method)

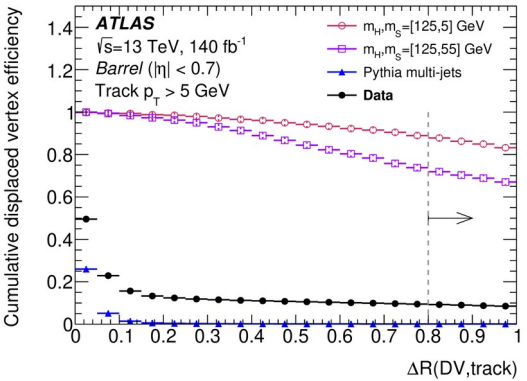




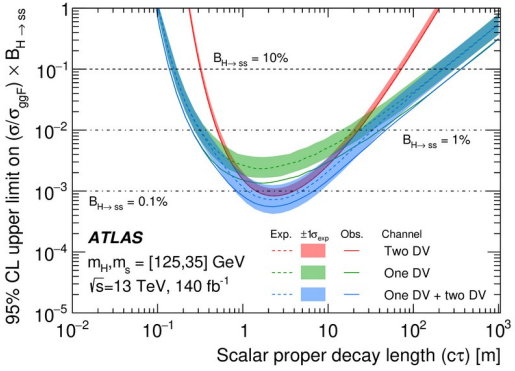
JINST 9 (2014) P02001



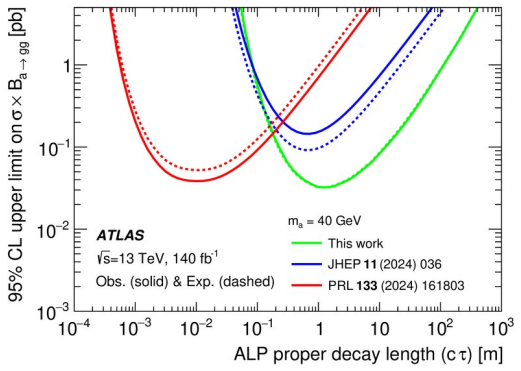




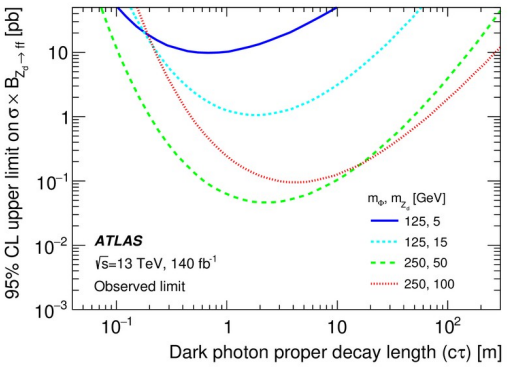
MSVtx Results



BR of SM H→ss > 1% excluded for
5 cm < cτ < 40m



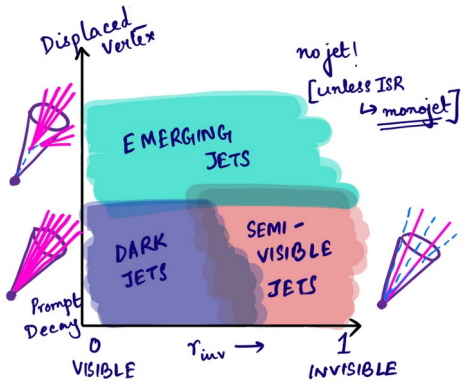
Most stringent ATLAS limit set on Z + ALP models for cτ > O(10cm)

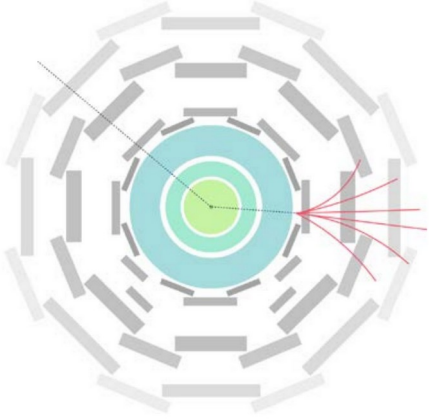


Limits Z + dark photon with dark photon decaying to 2 fermions

Conclusion

- Rich program of searches for unusual hadronic final states ongoing
- Dedicated set of searches aiming at strongly coupled hidden valley theories
- Many more results to come!
- See E. Woodward's talk for unusual signatures in leptonic/missing energy channels





BACKUP

SVJ Machine Learning

- Input to both ML approaches:
  - Up to 80 tracks from leading and sub-leading jets
- ANomely deTEction on particle fLOw latent sPacE (ANTELOPE) developed in the context of this analysis