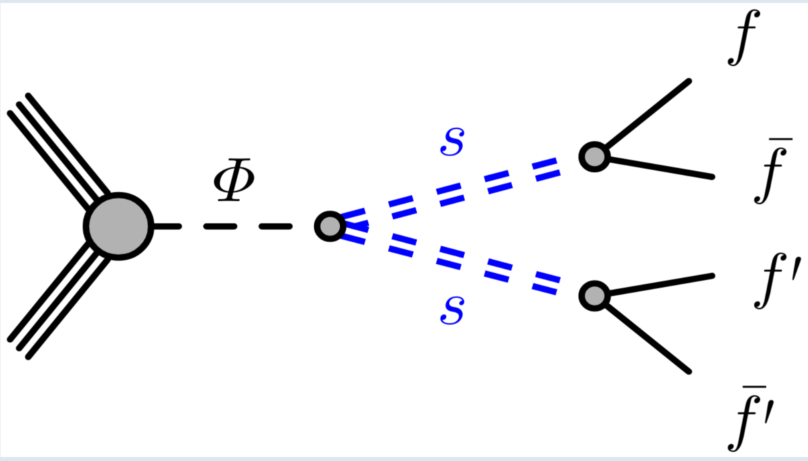
Search for neutral long-lived particles decaying into displaced jets in the ATLAS calorimeter

Motivation for Long-Lived Particle Searches

- Long-lived particles (LLPs) have finite mean lifetimes τ such that $c\tau \gtrsim 10$ µm
- Many theories aimed at resolving fundamental mysteries such as dark matter, baryogenesis, neutrino masses, and naturalness predict the existence of neutral LLPs beyond the Standard Model (SM) [1]
- Most LHC searches focus on promptly decaying particles and could overlook the unique detector signatures of LLPs

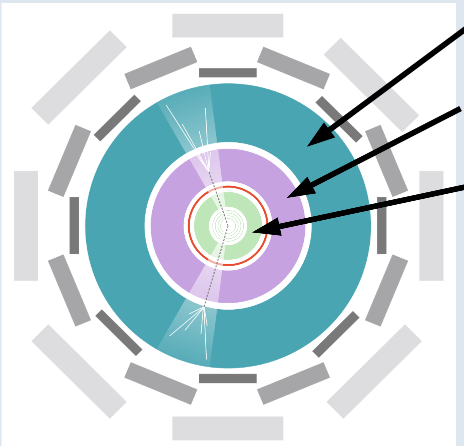
Hidden Sector Model

- Hidden sector models add a set of particles weakly coupled to the SM by heavy mediators
- Benchmark model considered: a mediator Φ decays to two long-lived neutral scalars (s), which decay into SM fermions (f) with Higgs-like coupling proportional to fermion mass



Signal Event Characteristics

- Targeting hadronic LLP decays within calorimeter
- LLP does not interact with detector before decay
- Displaced jets are narrow, trackless, and have a higher fraction of energy deposited in outer layers of the calorimeter compared to prompt jets



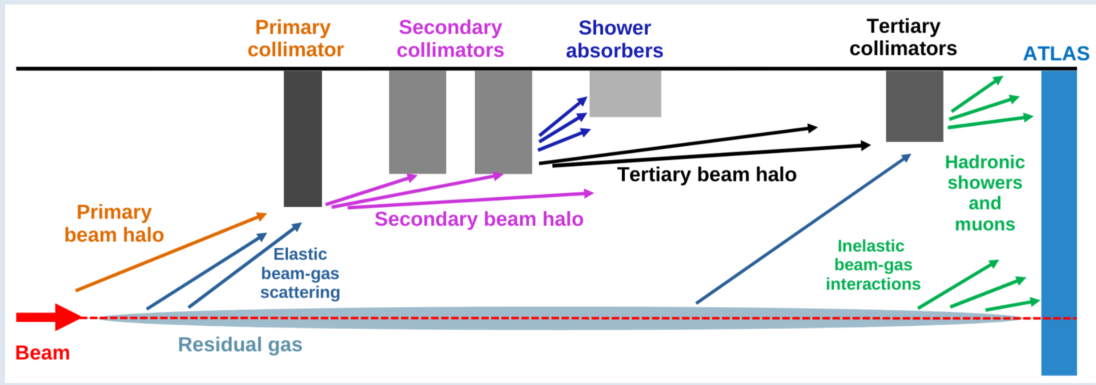
Each LLP decay into $f\bar{f}$ is reconstructed as a single jet

E_{HCal} / E_{ECal} large compared to most jets from SM events

Graphic adapted from Alice Morris

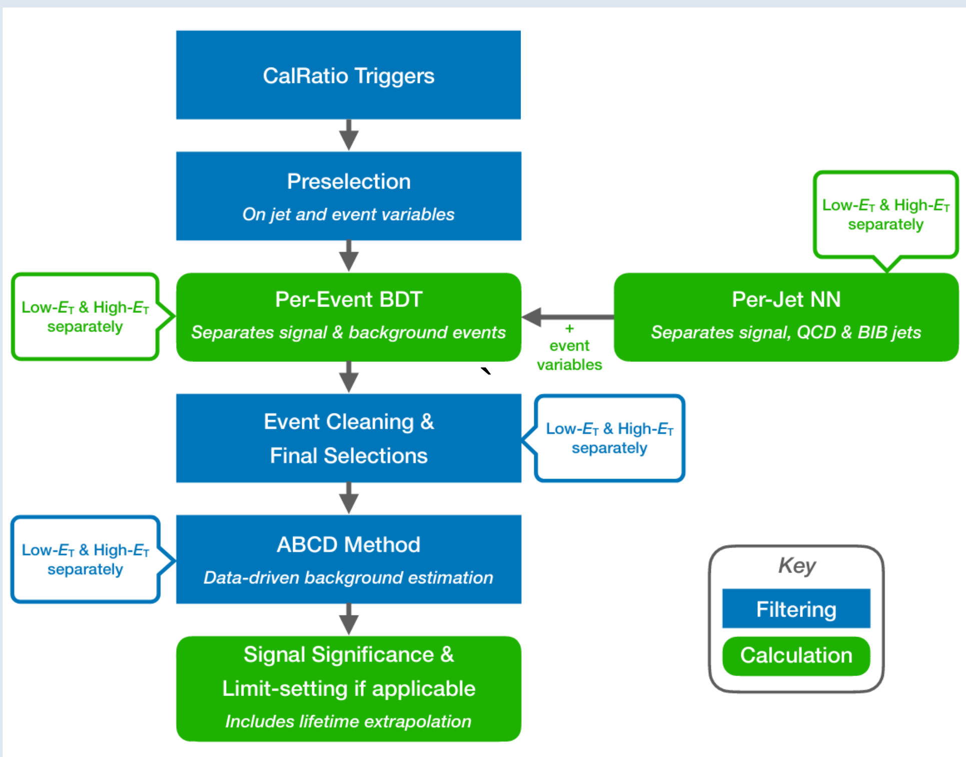
Backgrounds

- QCD multijet events with neutral hadrons are the dominant background due to large cross section
- Beam-induced background (BIB) results from particles traveling nearly parallel to the beamline upstream from ATLAS, as shown below
- Cosmic rays can also fake displaced jets



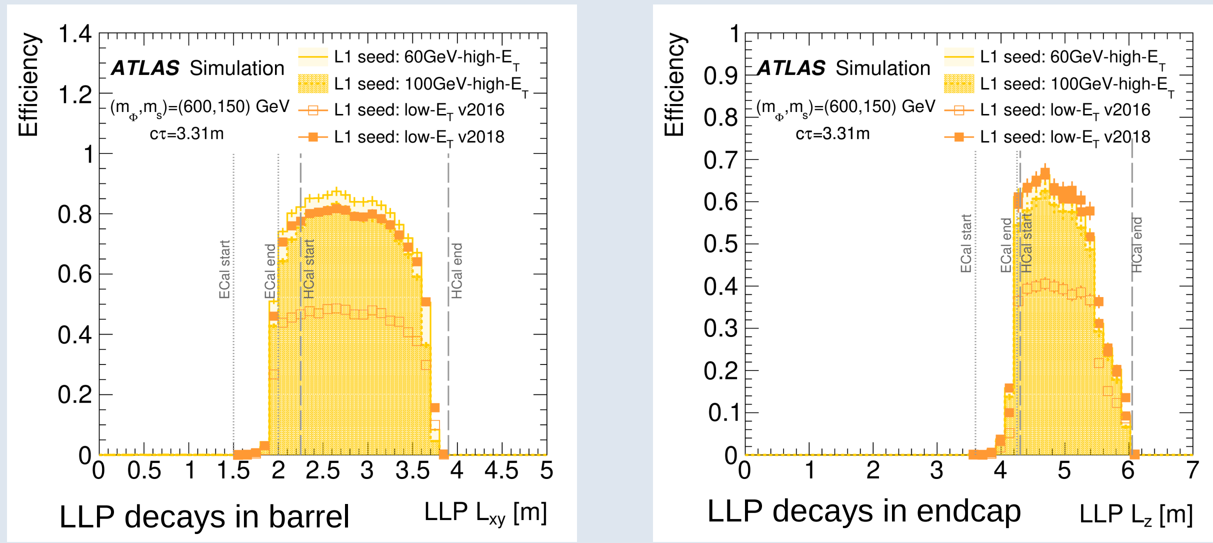
Analysis Overview

- Referred to as the CalRatio (CR) analysis, from the ratio E_{HCal} / E_{ECal}
- Two sets of selection criteria, separately optimized for high-mass (m_{Φ} = 400–1000 GeV) and low-mass (m_{Φ} = 60–200 GeV) signals
- Per-jet neural network (NN) predicts whether a jet was produced by signal, QCD, or BIB
- Boosted decision tree (BDT) classifes entire events as signal or background, using per-jet NN outputs and event-level information



Triggers

- High-E_T L1 trigger: narrow jet with E_T > 60 GeV in HCal + ECal
- Low-E_T L1 trigger: narrow jet with E_T > 30 GeV, isolated from ECal deposits
- Same high-level trigger selection applied after either L1 trigger:
  - ≥ 1 track-isolated jet with E_T > 30 GeV, $|\eta|$ < 2.5, log (E_{HCal} / E_{ECal}) > 1.2

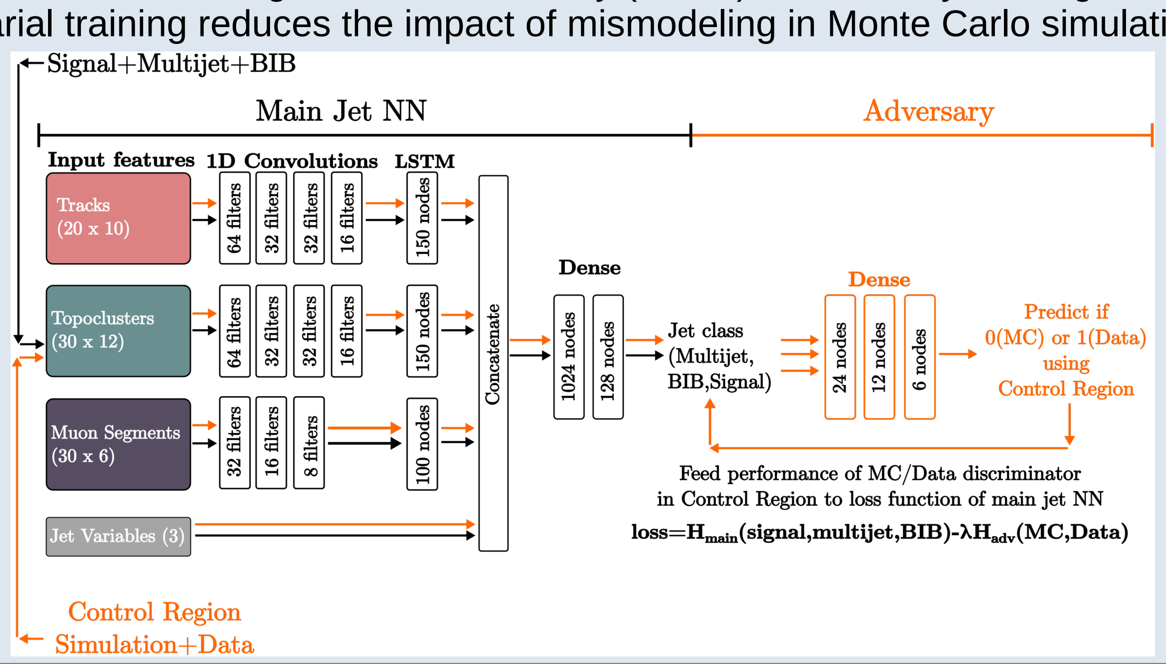


LLP decays in barrel

LLP decays in endcap

Per-jet Neural Network

- Inputs are low-level information from tracks, calorimeters, and muons
- 1D convolutions and long short-term memory (LSTM) used to fully leverage correlations
- Adversarial training reduces the impact of mismodeling in Monte Carlo simulation

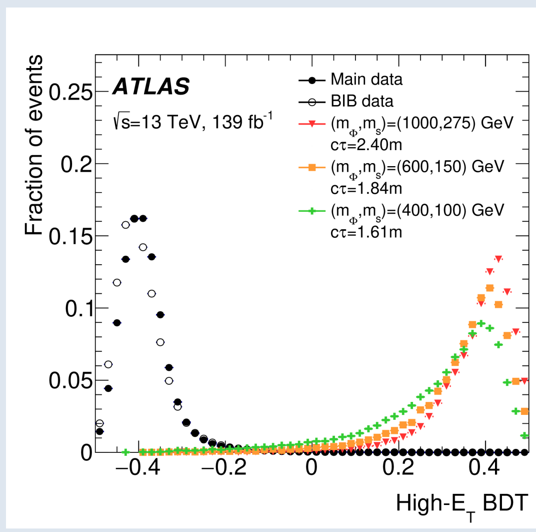


Event Selection

- Two jets classified most signal-like by NN are considered signal jet candidates
- Two jets classified most BIB-like by NN are considered BIB jet candidates
- At least one signal jet candidate must match a triggering HLT jet
- Event is cut if time of signal or BIB jet candidates not consistent with IP collision
- Final selections before background estimation are shown below

Low-E_T selection	High-E_T selection
$H_T^{miss}/H_T < 0.6$	$H_T^{miss}/H_T < 0.6$
$(\sum_{jet^{sig_{1l}},jet^{sig_{2l}}} \log_{10}(E_H/E_{EM})) > 2$	$(\sum_{jet^{sig_{1h}},jet^{sig_{2h}}} \log_{10}(E_H/E_{EM})) > 1$
$p_T(jet^{sig_{1l}}) > 80$ GeV	$p_T(jet^{sig_{1h}}) > 70$ GeV
$p_T(jet^{sig_{2l}}) > 80$ GeV	$p_T(jet^{sig_{2h}}) > 80$ GeV
low-E_T NN product > 0.7	high-E_T NN product > 0.5

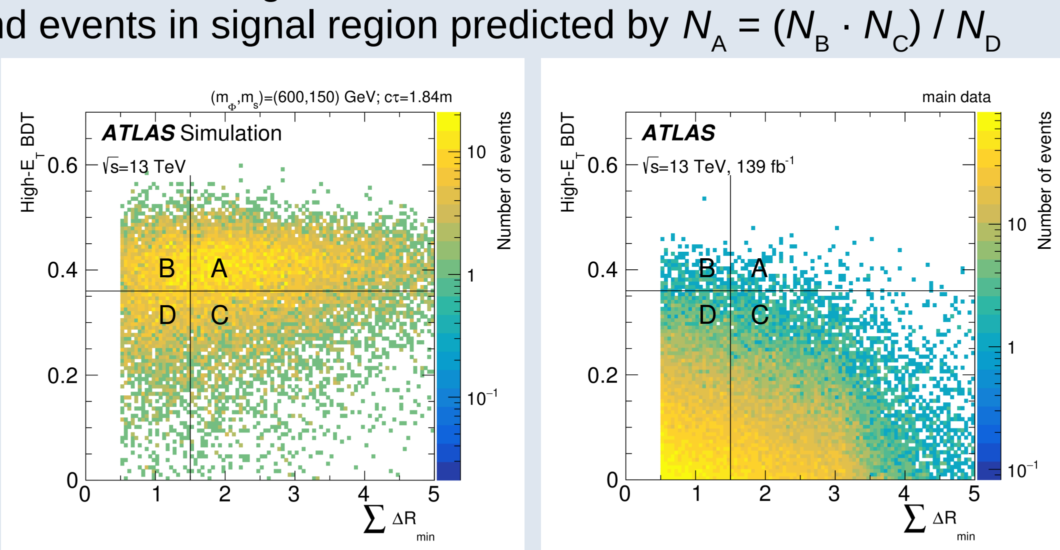
H_T^{miss} is the transverse component of the vector sum of the momenta of all jets with p_T > 30 GeV, and H_T is the scalar sum of their p_T



Background estimation

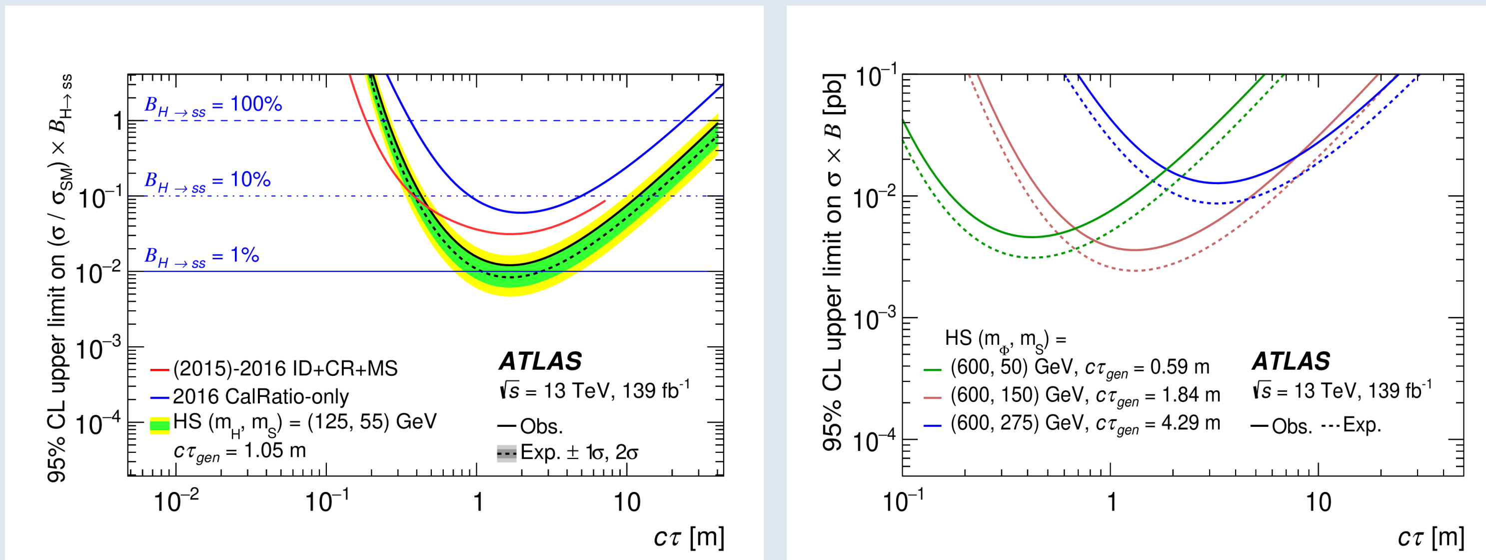
- Likelihood-based ABCD method used
- 2D plane defined by per-event BDT output and sum of ΔR between each signal jet candidate and its nearest track with p_T > 2 GeV
- Signal region is labeled A, control regions are B, C, and D
- Number of background events in signal region predicted by $N_A = (N_B \cdot N_C) / N_D$

For each signal mass point, simultaneous fit of standard ABCD background and signal sample to data



Results

- Data from pp collisions at $\sqrt{s}$ = 13 TeV during Run 2 (2015-2018) analyzed
- No significant excess found
- Limits on production cross section times branching ratio set for each mass point
- Improved limits of early Run 2 results



Mason Proffitt (University of Washington, Seattle)

arXiv:2203.01009

[1] J. Alimena et al., arXiv:1903.04497 [2] A. Manousos et. al., ATL-SOFT-SLIDE-2016-832

ATLAS EXPERIMENT