# ATLAS Muon Spectrometer Displaced Vertex Searches

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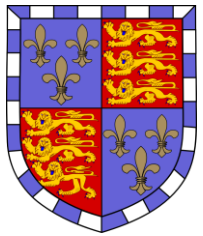


CAMBRIDGE TRUST

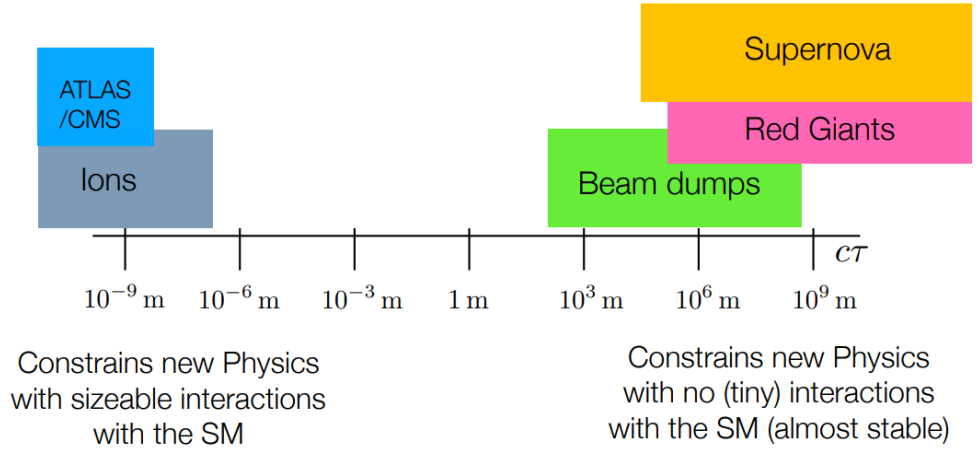
ATLAS EXPERIMENT

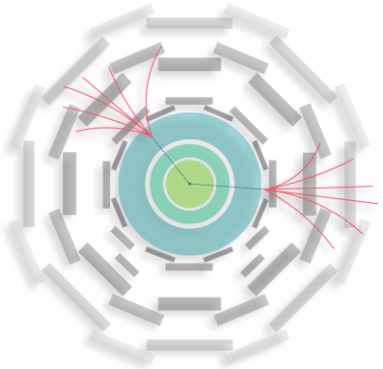
# Overview

- Extensive search program at the major collider experiments
  Hope to observe wealth of new physics didn't manifest
  - Are we looking in the right place?
- **Large lifetimes** can occur very naturally

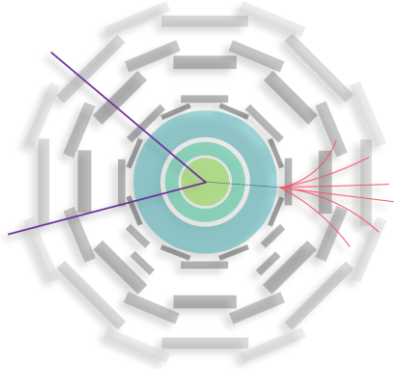
$$\tau^{-1} = \frac{1}{2m_X} \int d\Pi_f \, |\mathcal{M}(m_X \to \{p_f\})|^2$$

- Challenging signatures for general purpose detectors
  - Sparked a now substantial Long-Lived Particle (LLP) program
    - Within existing collaborations but also beyond: ANUBIS, FASER, SHiP, …
- Searching for **neutral LLPs** decaying into **high multiplicity hadronic showers**
  - **Signature driven approach** → sensitive to a range of models
- ATLAS Muon Spectrometer:
  - Large size and displacement from interaction point
  - Shielding by Calorimeters
  - Tracking abilities & small material budget



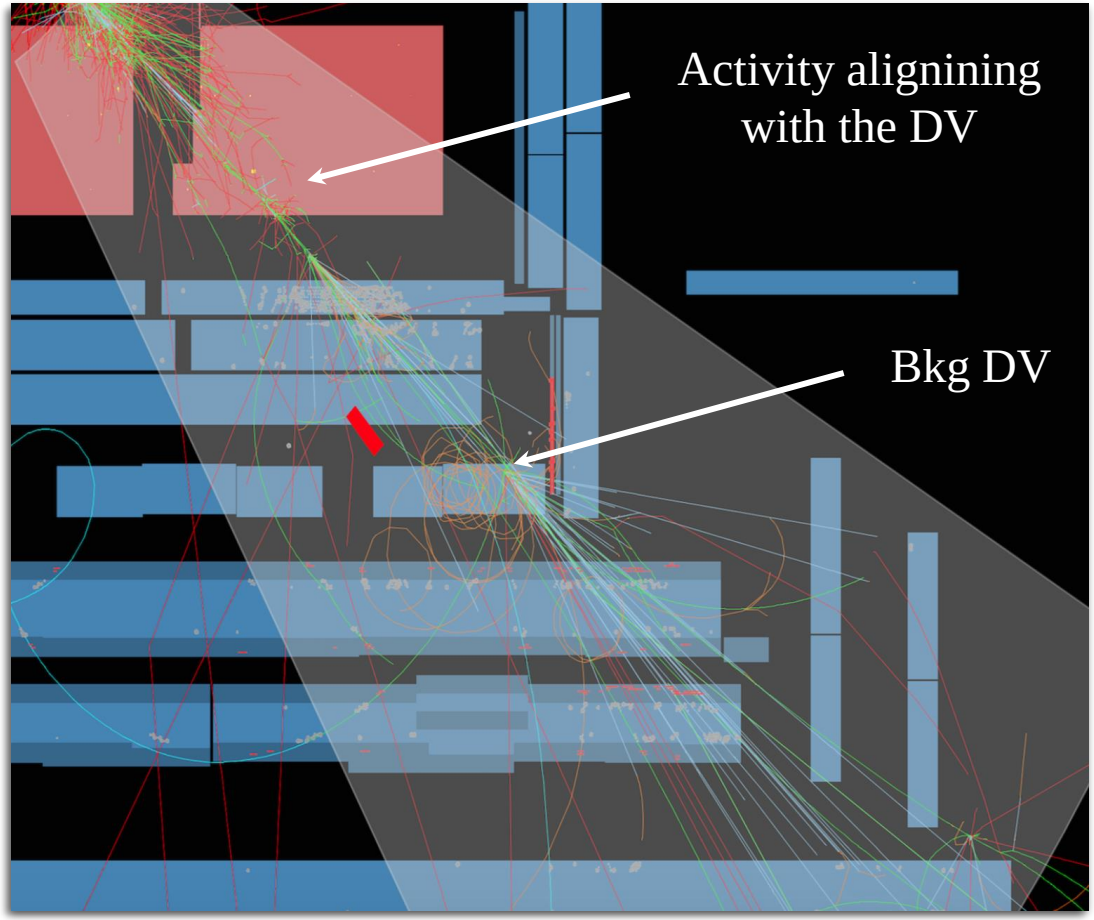
2 displaced vertex event



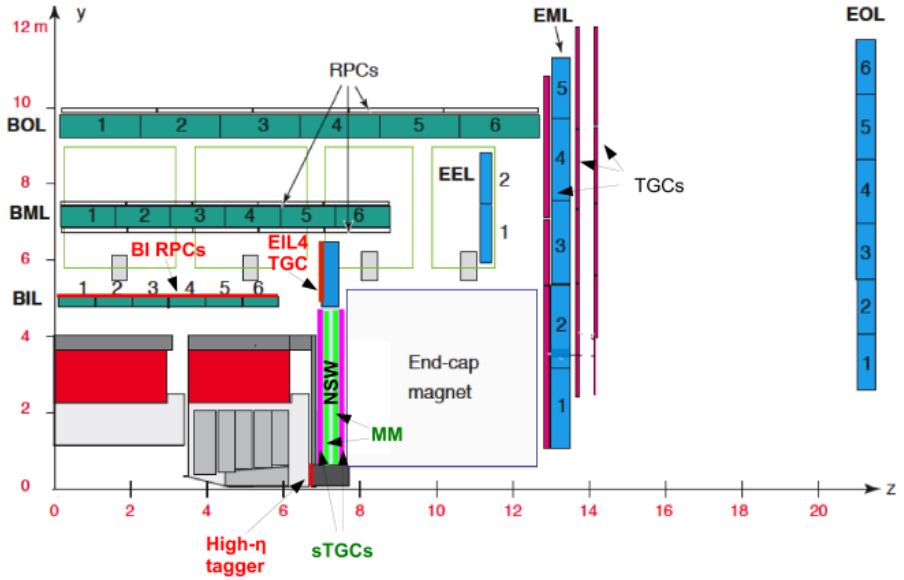
Associated production

# Search Strategy

- Selections:
  - Event level: Trigger & missing energy
  - Displaced vertex reconstruction
  - Vertex quality & sufficient activity in the MS
  - Vertex isolation from tracks and jets
- Main background from **jets punching through** the calorimeters
  - Depending on vertex multiplicity, can be background free
  - Minimal case, 1 displaced vertex, requires data driven background estimation via ABCD method
- Extrapolate signal efficiency to other lifetimes to set limits on $\sigma \times \mathcal{B}$ as a function of $c\tau$



# ATLAS Muon Spectrometer

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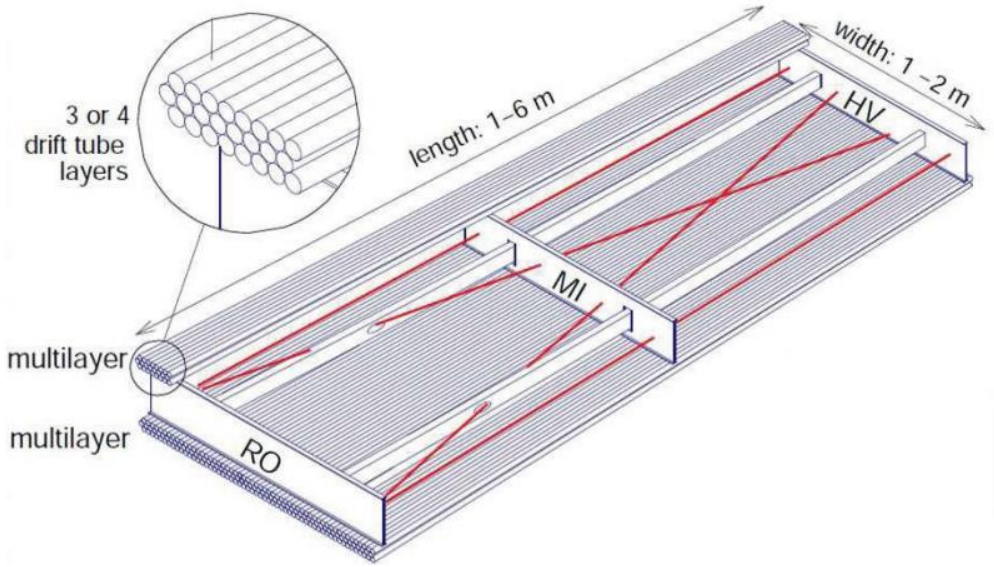


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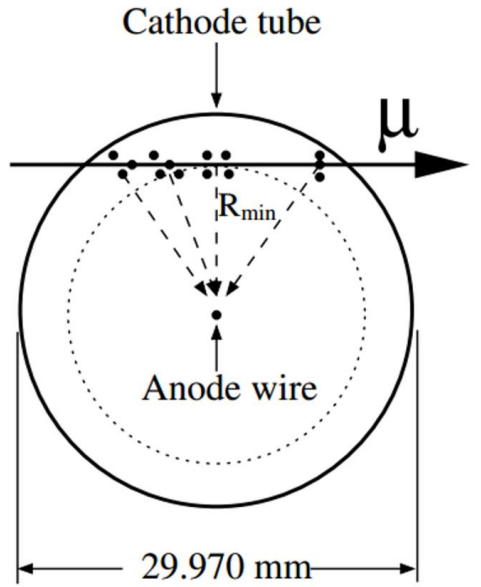
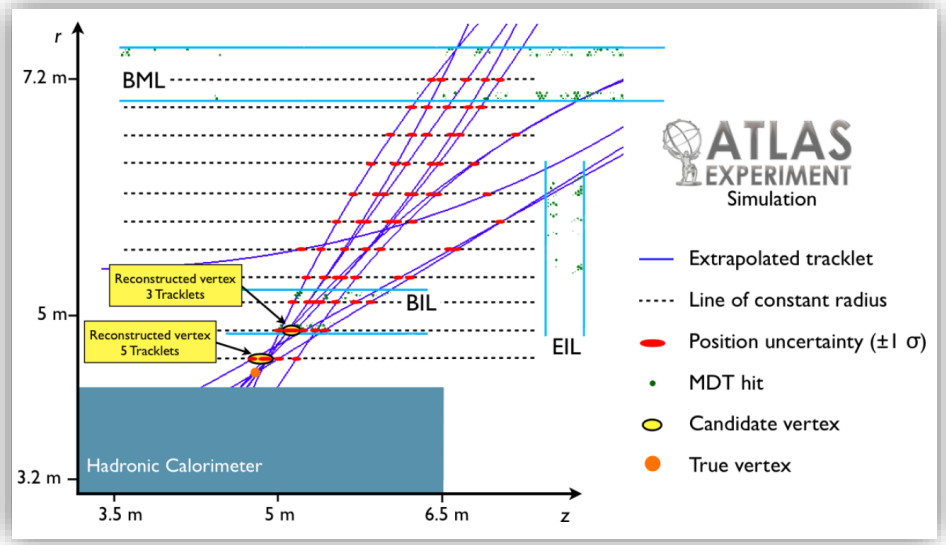



- Tracking provided via monitored drift tubes (MDTs)
- Each chamber contains 2 multilayers, featuring 3 - 4 tubes
- Contained within the toroidal magnetic field in the barrel but outside in the endcaps
  - **Different MS vertex reconstruction algorithm** in the barrel & endcaps

# Displaced Vertex Reconstruction

- Tracklets: Combine straight line fits from different multilayers to get **curved track estimate**
- Form clusters in $\eta \times \phi$ and back extrapolate
- Iterative $\chi^2$ fit and drop tracklets until good vertex is found

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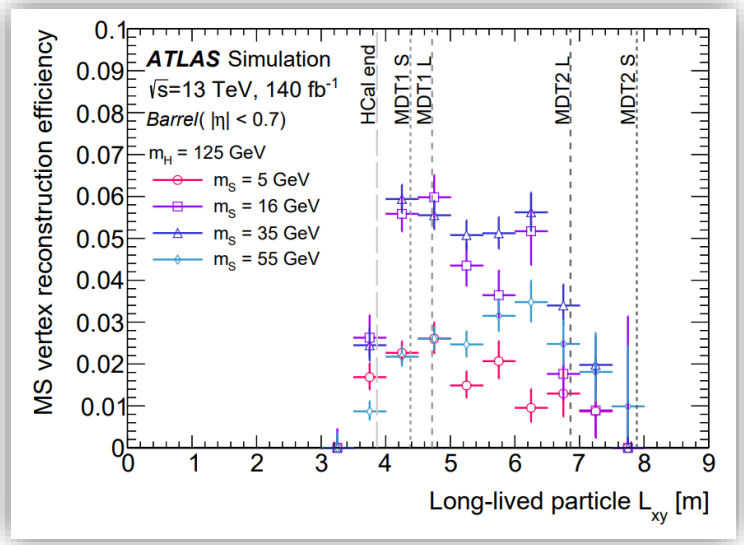


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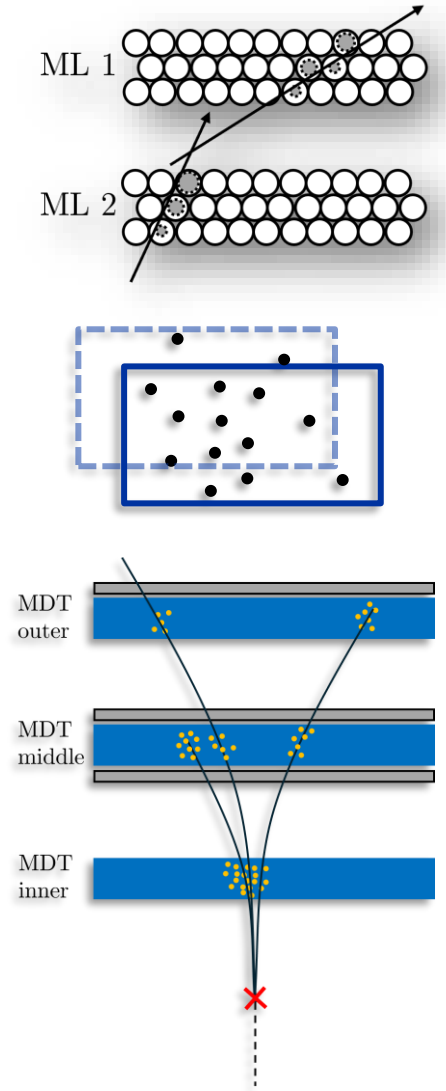
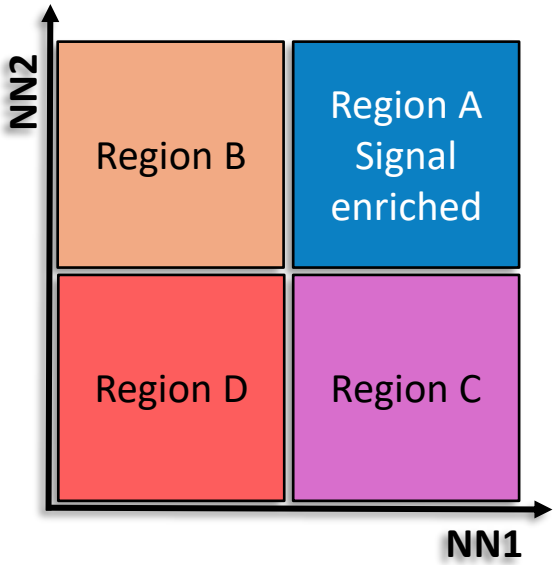
Truth matched DVs passing the signal selections

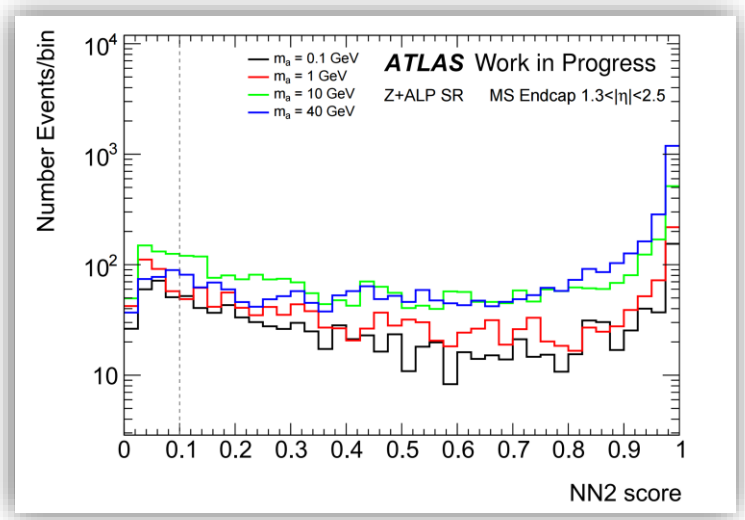


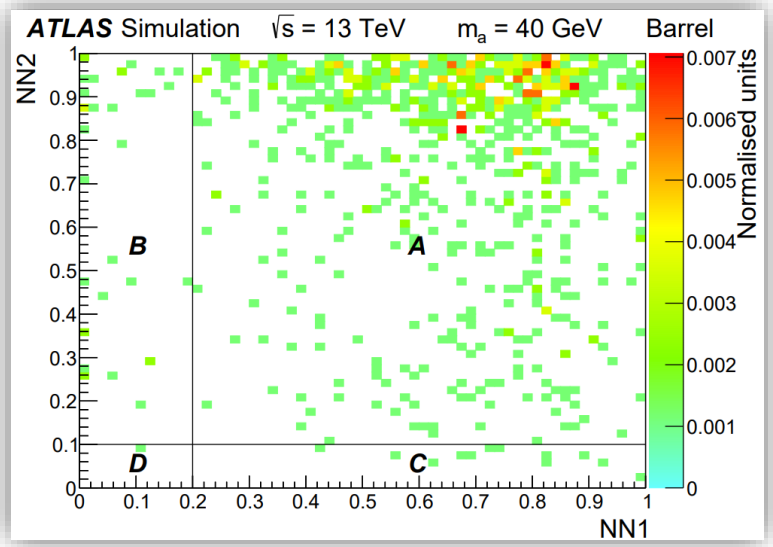

- Shortcomings of the algorithm
  - Poor position resolution and limited efficiency
  - Significant reduction of fiducial volume due to rejecting barrel to endcap transition region
- Current development for **hit-to-vertex GNN** based reconstruction

# Background Estimation via ABCD Method

- Requires single primary source of background and non-correlated axis variables
  - $\frac{N_A}{N_C} = \frac{N_B}{N_D} \rightarrow N_A^{expected} = \frac{N_B N_C}{N_D}$
- Plane spanned by two Neural Network scores with largely orthogonal input sets
  - NN1 inputs: **isolation and background features**
  - NN2 inputs: **DV characteristics**
- NNs consider correlations between inputs and are responsible for much of the signal – background separation
  - Room for improvement by introducing **topology specific** training

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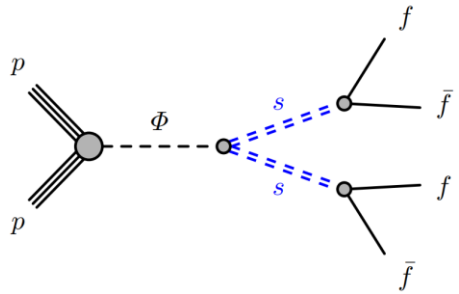
# Benchmark Models

1 MS DV

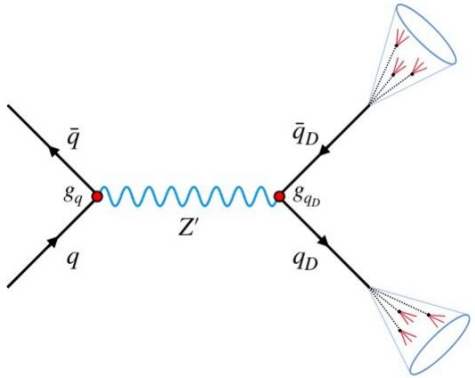
2 MS DV

> 2 MS DV

MS activity triggered

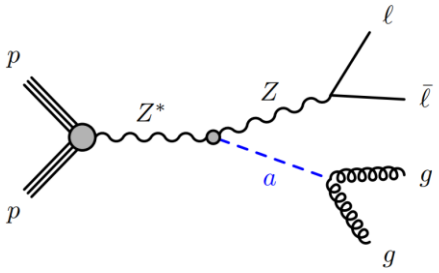


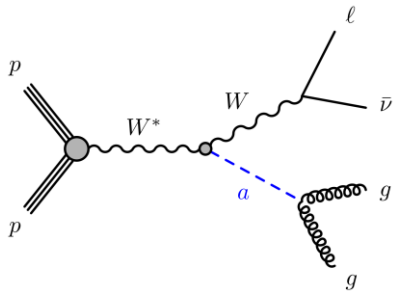

Hidden sector model




Emerging Jets

Associated production triggered




Gluon-philic Axion-like Particles

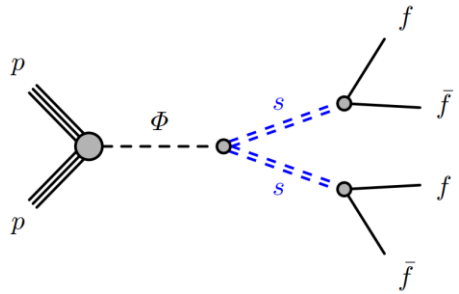
# Benchmark Models

1 MS DV

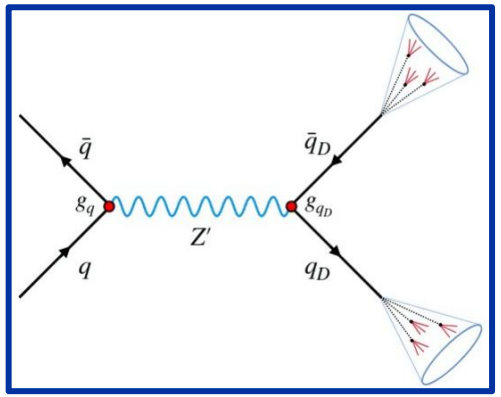
2 MS DV

> 2 MS DV

MS activity triggered

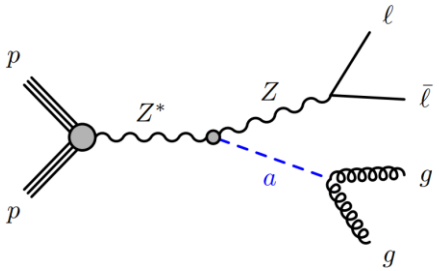


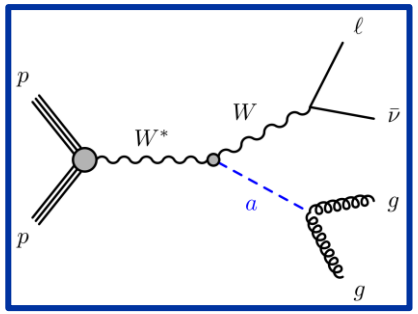

Hidden sector model




Emerging Jets

Associated production triggered

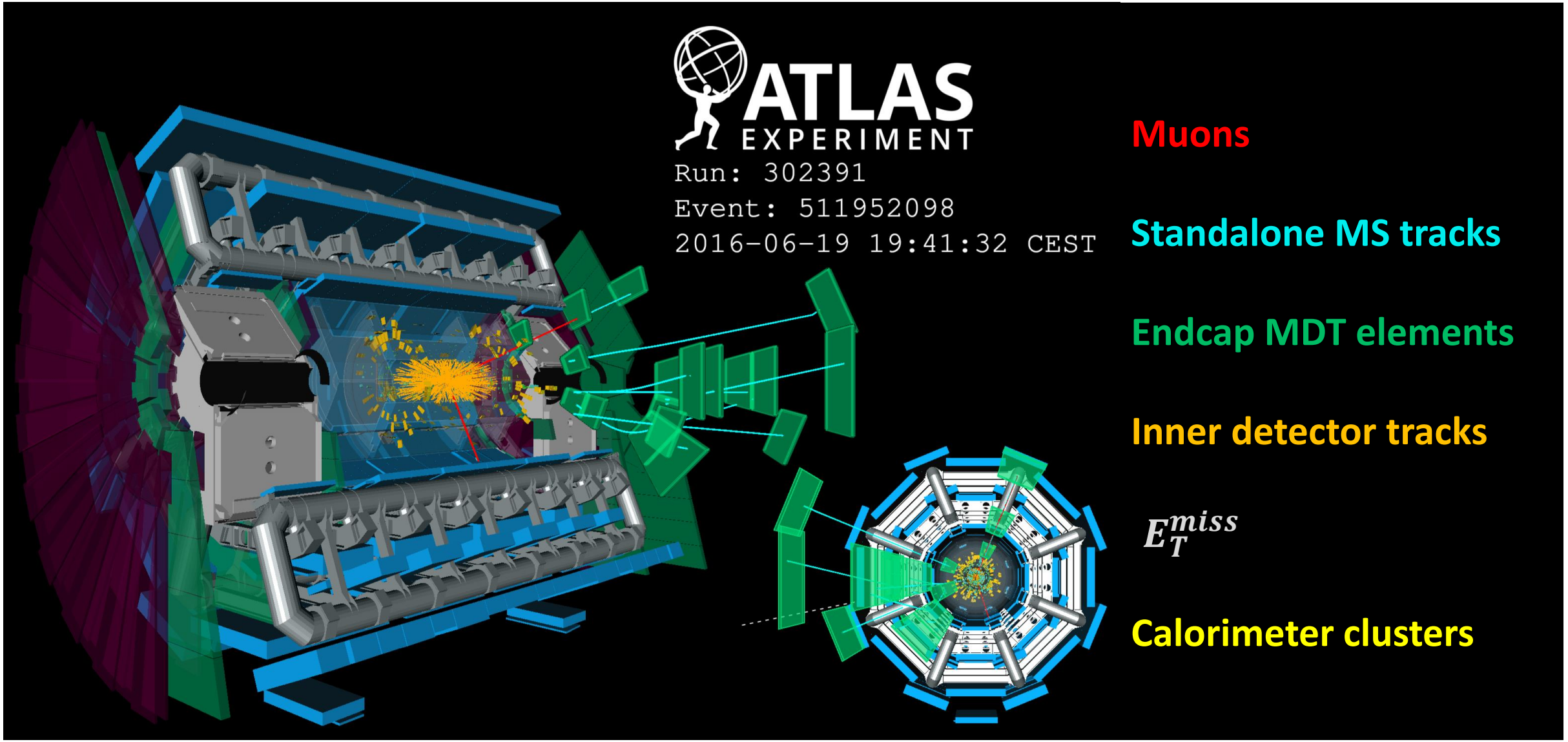



Gluon-philic Axion-like Particles

**New in Run 3!**

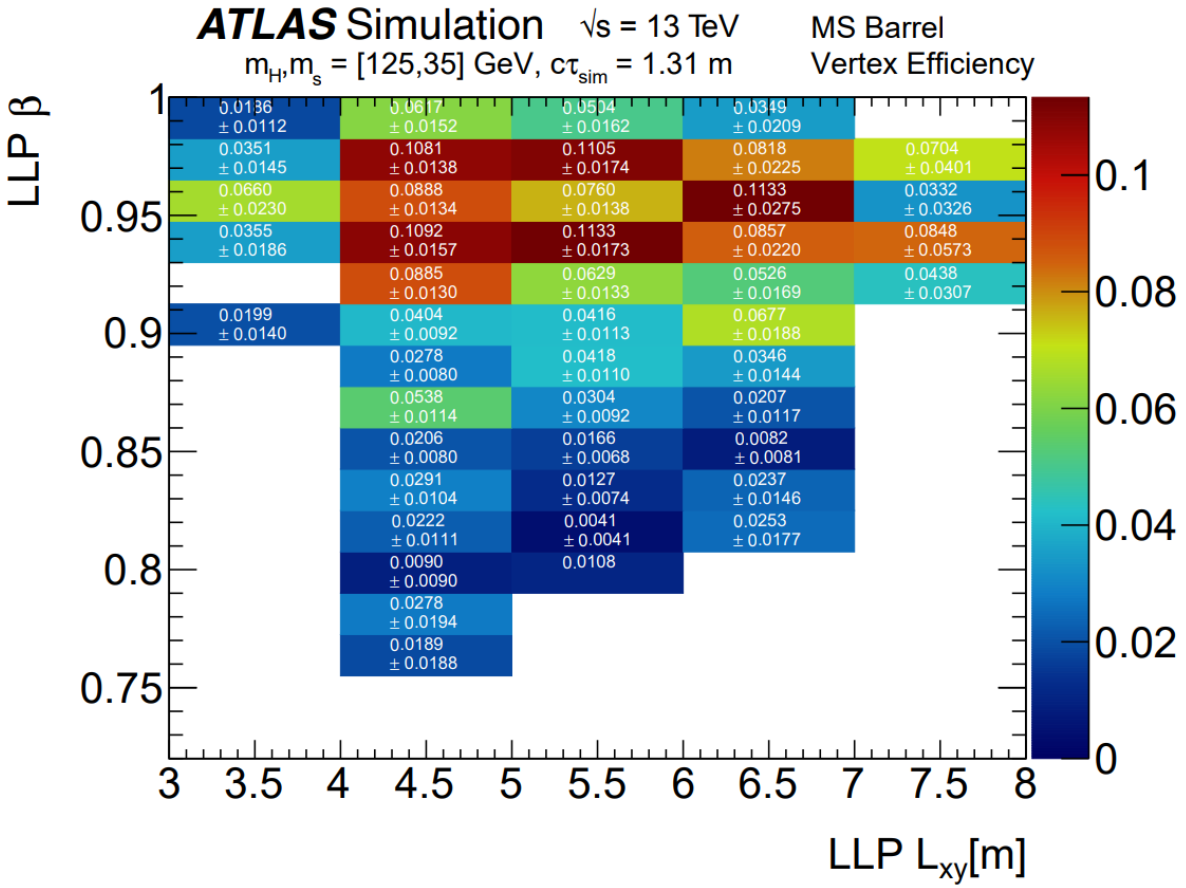
# Run 2 Event Display: Z+DV



# Lifetime Extrapolation and Limit Setting

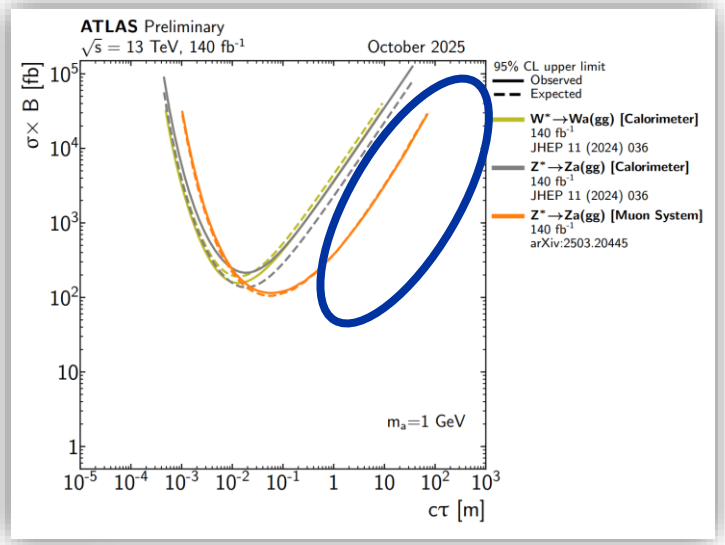
- To set limits on $\sigma \times \mathcal{B}$ as a function of the lifetime, need to extrapolate the yields to different $c\tau$ values
  - Avoids need for full MC simulations at many $c\tau$ values
- Sample lab frame decay length $L_{xyz} \sim Exp(\beta\gamma c\tau)$ and parameterise signal selection efficiency as a function of the decay position
  - Get ABCD plane yields for the chosen $c\tau$ value
  - Test closure of the method by comparing with full-sim sample at the lifetime one extrapolated to
- For the observed yields $n_A, n_B, n_C, n_D$, fit Poisson likelihood to extract the signal strength $\mu$ and find 95% confidence interval on $\sigma \times \mathcal{B}$

$$\mathcal{L}(n_A, n_B, n_C, n_D | \mu, \theta_\mu) = \prod_{i=A,B,C,D} \frac{e^{-N_i} N_i^{n_i}}{n_i!}$$



# Run 2 Results and Run 3

- Complementarity and competitiveness with other analyses
- Additional models targeted for Run 3
  - Expected to extend on existing sensitivity
- Run 3 sensitivity gains
  - Luminosity
  - Access to more discriminating variables
  - NN retraining

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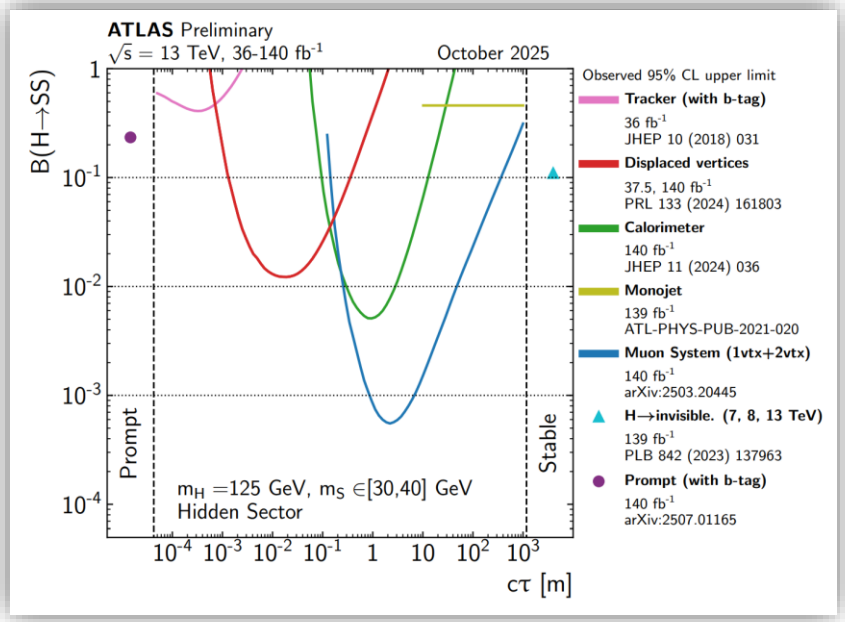


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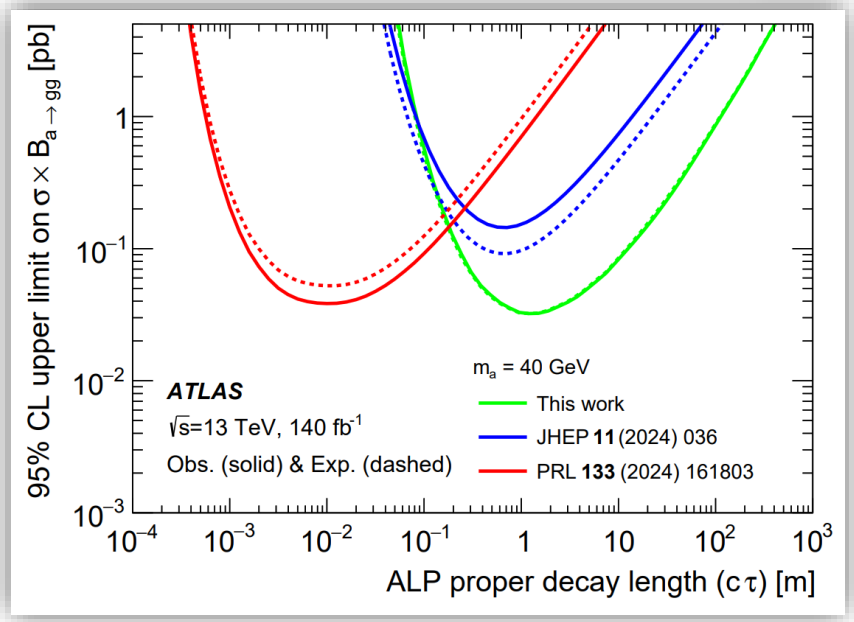


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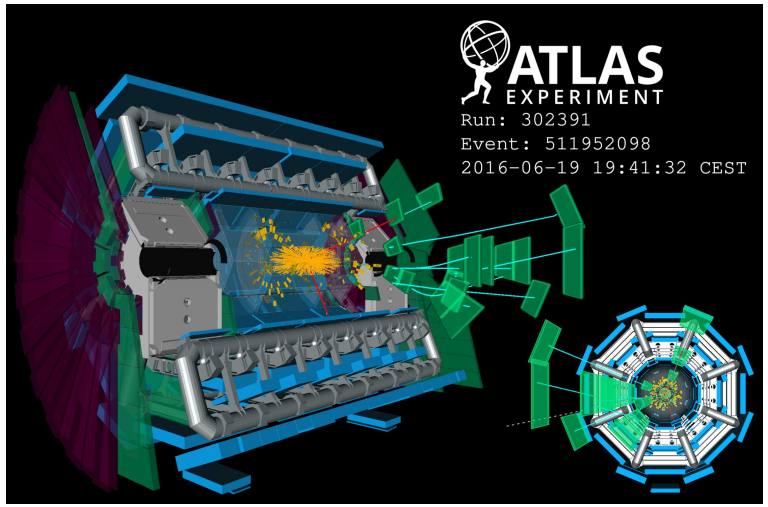
# Summary

- Philosophy and discovery potential of ATLAS Muon Spectrometer displaced vertex searches
- Non-standard displaced vertex reconstruction
- Background estimation & limit setting
- Complementary & competitive sensitivity: more extensive lifetime coverage of ATLAS' LLP search program
- Run 2 results & expectations for Run 3

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