



UNIVERSITY OF BIRMINGHAM

# Searching for missing mass in proton-tagged dilepton events with the AFP and ATLAS detectors

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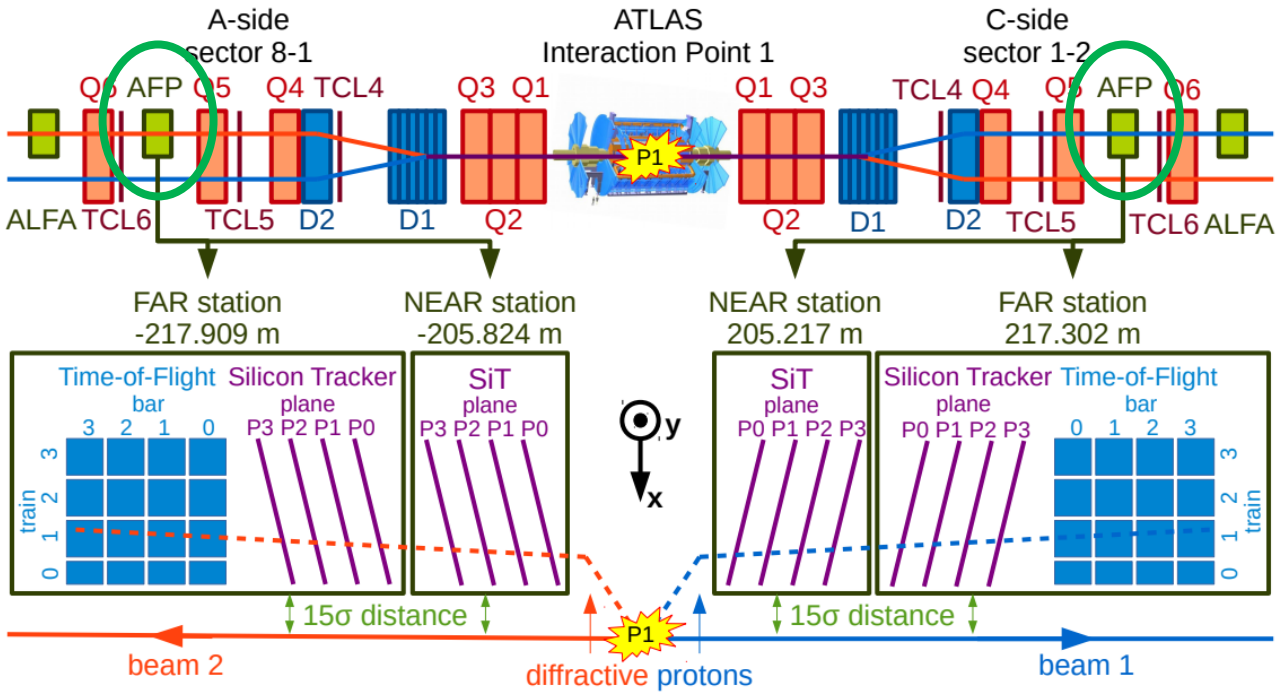
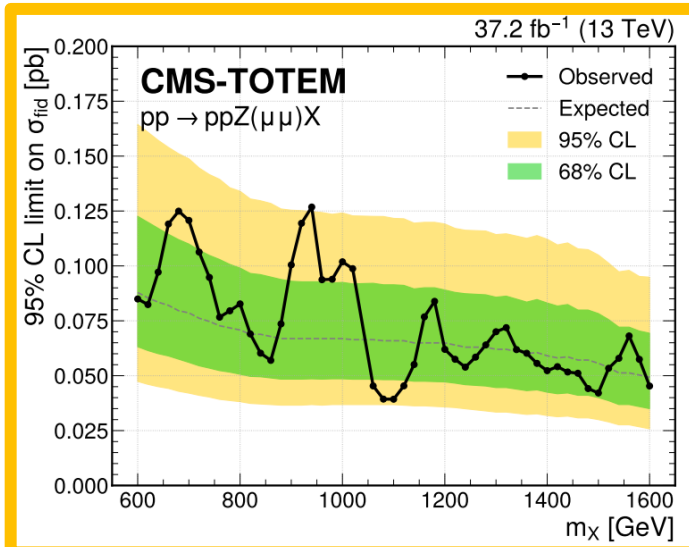
# AFP Overview

- **AFP** (ATLAS Forward Proton) detects **surviving protons** deflected from the central collision after undergoing **diffractive interactions or pp collisions**
- 4 sets of **3D silicon pixel detectors** (SiT), two (NEAR and FAR) on either side (A and C) of the ATLAS interaction point at ~210 m
- Measure deflected proton momenta to calculate fractional energy loss ξ

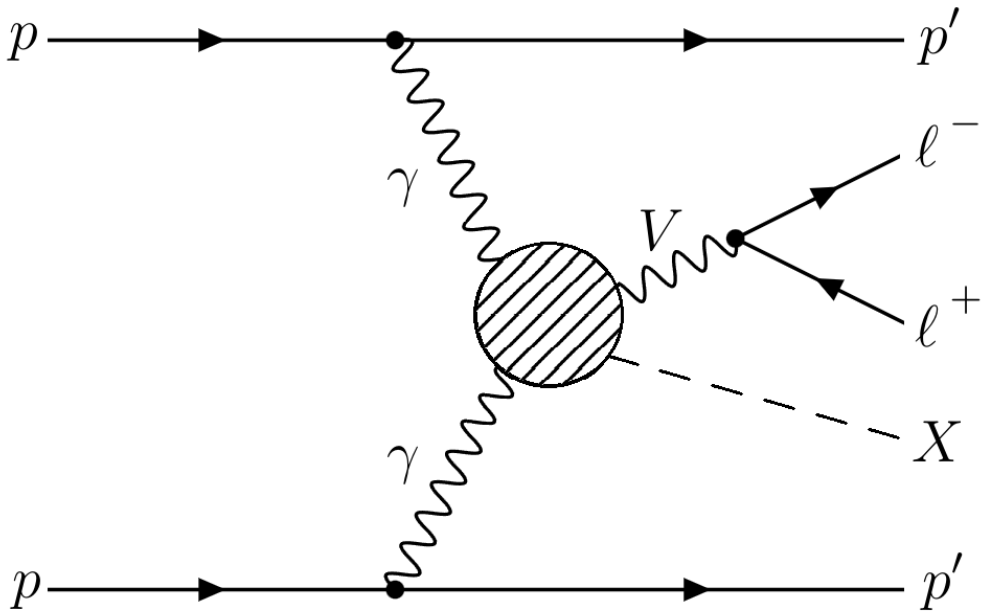


# Analysis Process and Motivation

- We are using AFP information to look for missing mass in the process $pp \to pVXp$ – new technique for ATLAS
  - V = standard model boson (e.g. γ, Z) which decays into two electrons or muons
  - X = undetected particle or particle system
- Model independent search
  - X could be a Beyond the Standard Model particle (e.g. Z', SUSY)

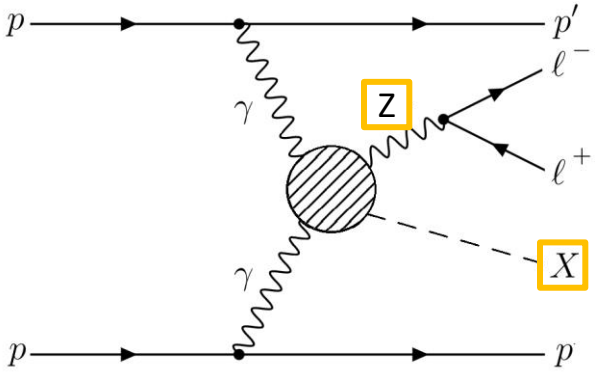


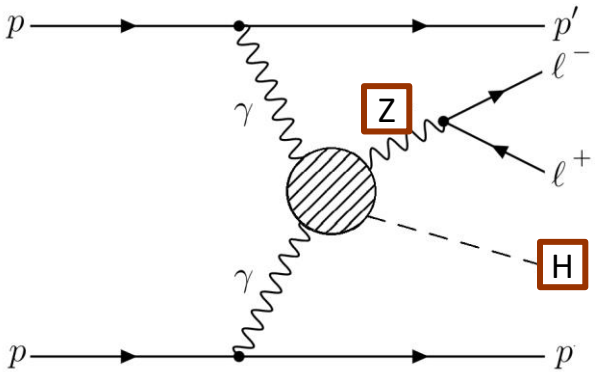

- Equivalent analysis published by CMS
- No significant excess observed, limits set on signal cross section



# Signal Generation

Comparison between two generators using very different assumptions on underlying processes: standalone SuperChic and MadGraph within Athena.

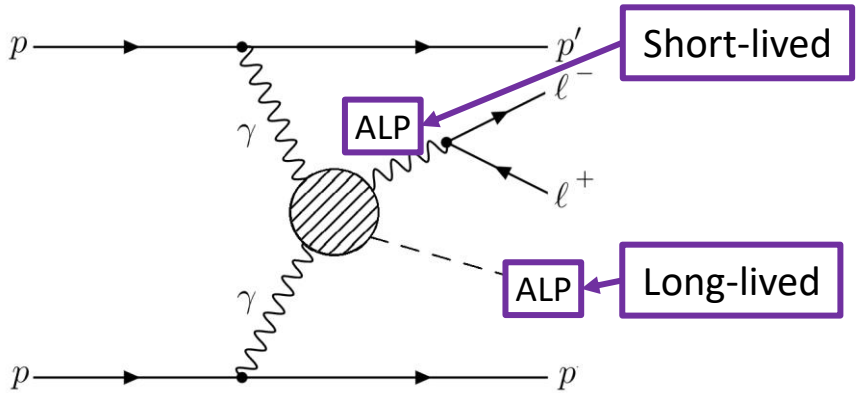



**SuperChic (Simple dedicated generator):**
New process implemented, simple direct simulation

**MadGraph (ALP production):**
Testing axion-like particle process with two ALPs: One long-lived (X) and the other (V) decaying to leptons

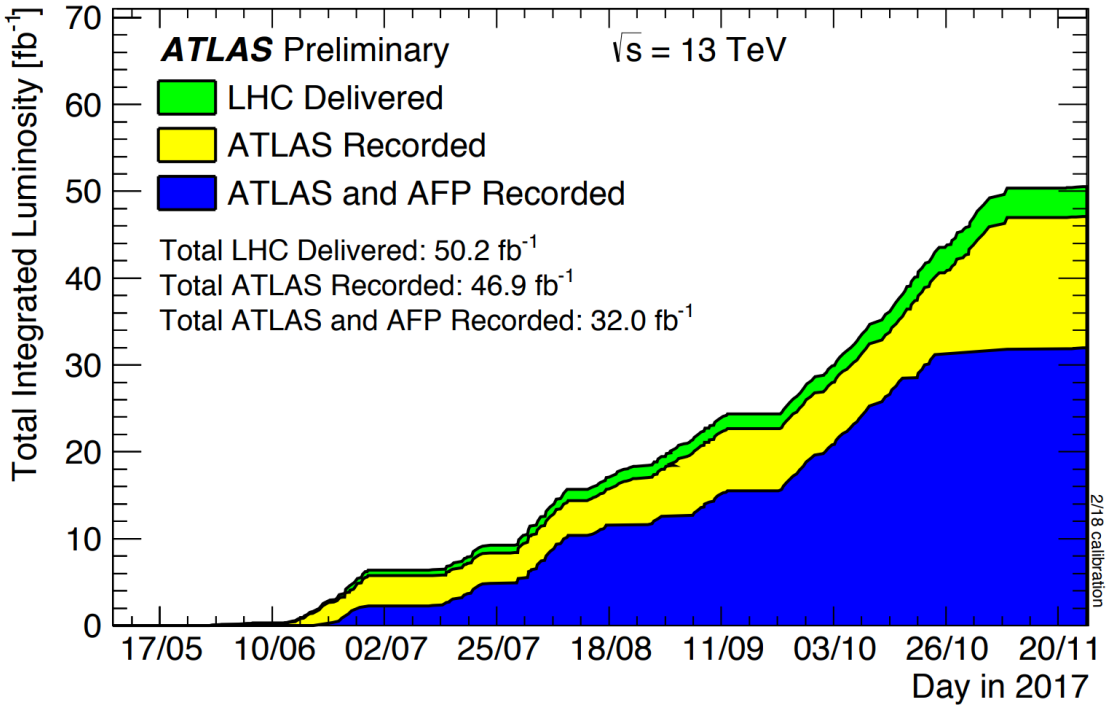
**MadGraph (Higgs derivation):**
Custom Higgs mass, forced to not decay to mimic our X particle



# Data and Selection

- We are using real proton-proton collision data collected in 2017 at $\sqrt{s}$ = 13 TeV
- Corresponds to ~32 $fb^{-1}$ of raw data, 14.6 $fb^{-1}$ after a specialised AFP Good Run List (GRL) is applied
  - Removes events with issues e.g. inefficient detectors
- We have a loose pre-selection applied to all events:

| **Pre-selection** | |
|---|---|
| **Muon channel** | **Electron channel** |
| AFP Good Run List | |
| Triggers: single/double muons | Triggers: single/double electrons |
| Central muon pair, both with $p_T$ > 15 GeV | Central electron pair, both with $p_T$ > 18 GeV |
| Exactly 1 proton per AFP side | |

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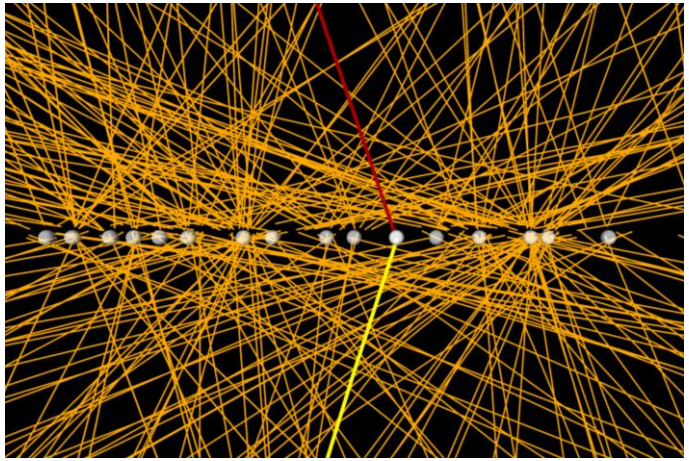
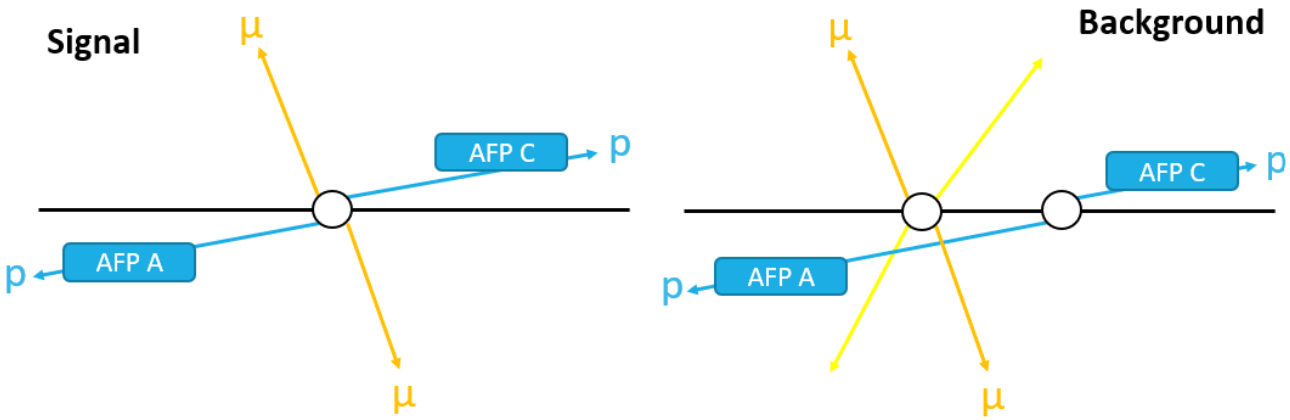
# Background

- Multiple proton interactions per bunch crossing in LHC (typically ~40) leads to many overlapping processes (pile-up) in addition to the event of interest
- The main source of background comes from central event leptons being combined with unassociated protons originating from a pile-up interaction in ATLAS

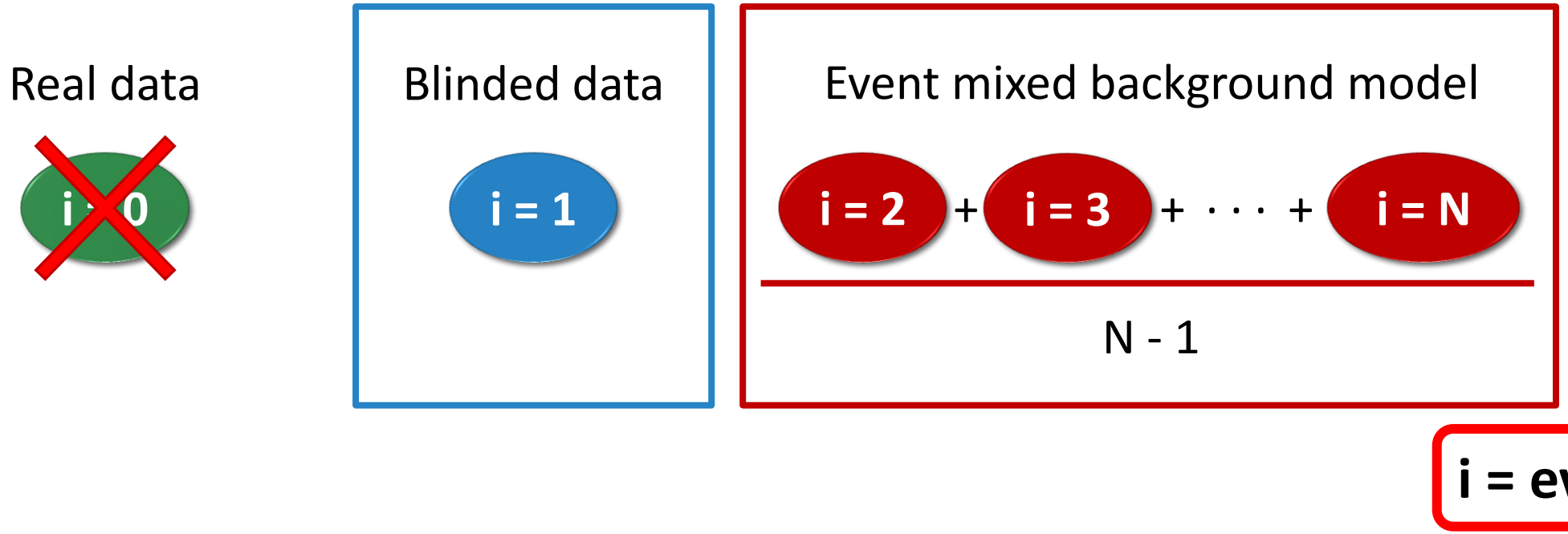





- We use a data-driven method called **event-mixing** to model the background
  - Combine protons from the $n^{th}$ event with central data from the $(n+i)^{th}$ event **(event-shift of i)**
  - Protons and leptons are uncorrelated, as in background
- Used in another AFP dilepton analysis and the previously mentioned CMS analysis

# Background – Data-Driven Estimate

- A background model was generated by running the analysis with event shift of i = 2, 3, 4….N and then taking the average of the resulting distributions, bin by bin
- Use event shifting of i = 1 as the ‘data’ placeholder to blind the data, since proton and central data are uncorrelated
- Plan to use Monte Carlo simulated background overlaid with pile-up protons from data to validate data-driven background model



# Missing Mass Calculation

The missing mass present in each event is calculated as:

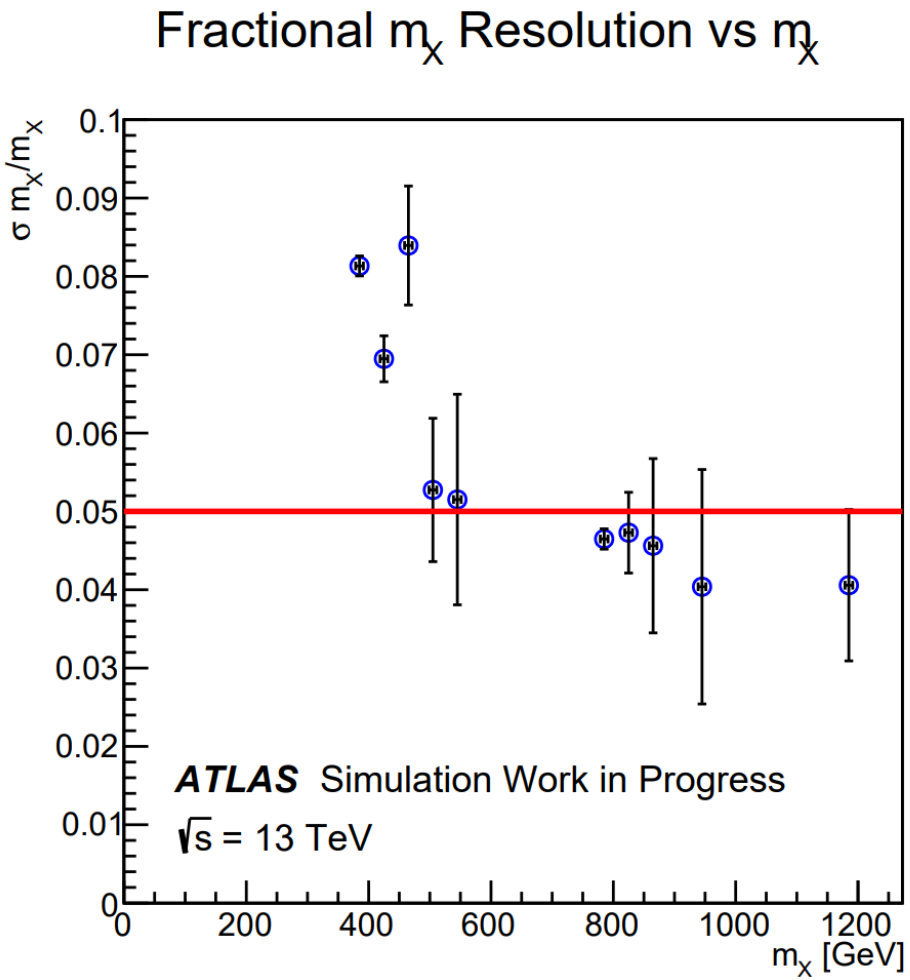
$$m_X^2 = (E_{\gamma\gamma} - E_{\ell\ell})^2 - (\overrightarrow{p_{\gamma\gamma}} - \overrightarrow{p_{\ell\ell}})^2$$

$$= \left[ \begin{pmatrix} \Delta E_{p_A} + \Delta E_{p_C} \\ 0 \\ 0 \\ \Delta E_{p_A} - \Delta E_{p_C} \end{pmatrix} - \begin{pmatrix} E_{\ell\ell} \\ p_x^{\ell\ell} \\ p_y^{\ell\ell} \\ p_z^{\ell\ell} \end{pmatrix} \right]^2$$

where $\Delta E_{p_A}$ and $\Delta E_{p_C}$ are the energy losses of the protons detected on AFP sides A and C respectively and we assume that the transverse momenta of the photons is negligible.

# Missing Mass Resolution

- Resolution of the missing mass calculation estimated using signal Monte-Carlo samples with $m_X$ = [400, 800, 1200] GeV
  - Relatively poor resolution at lower masses
  - Around 5% uncertainty for $m_X$ > 500 GeV
  - Motivates using 50 GeV bins for the missing mass spectrum in statistical analysis (5% of 1 TeV)

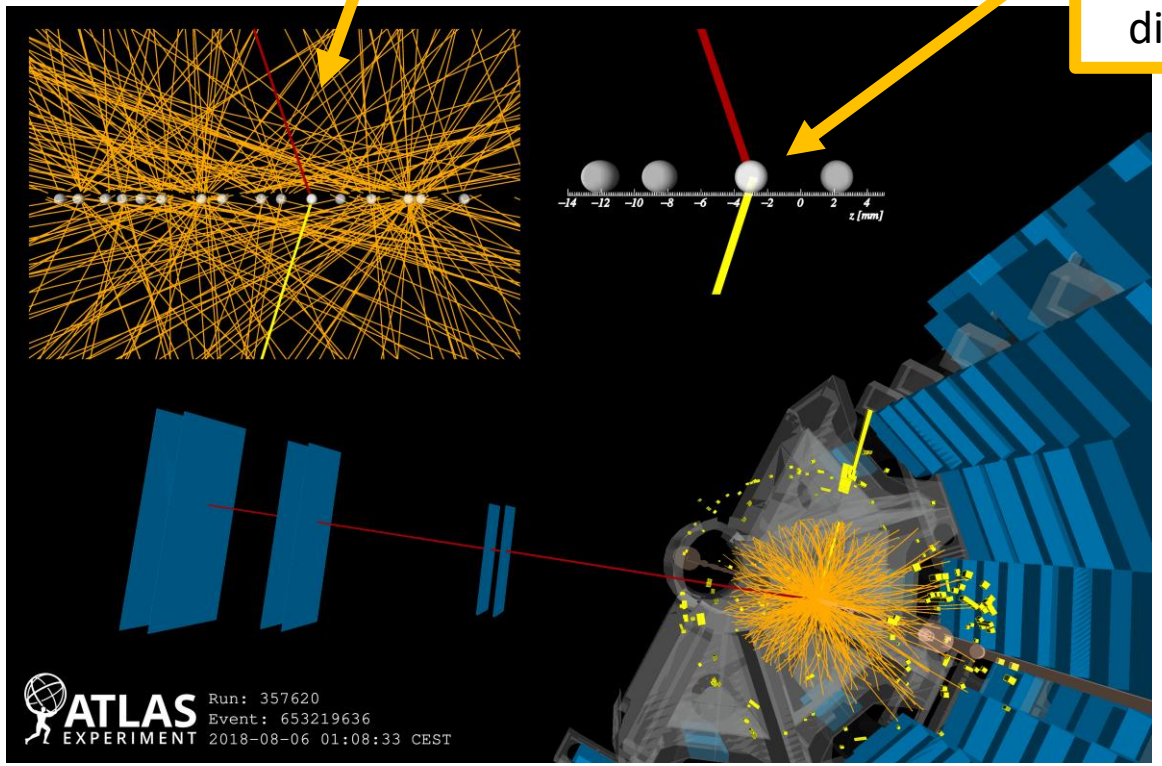


# Track Veto

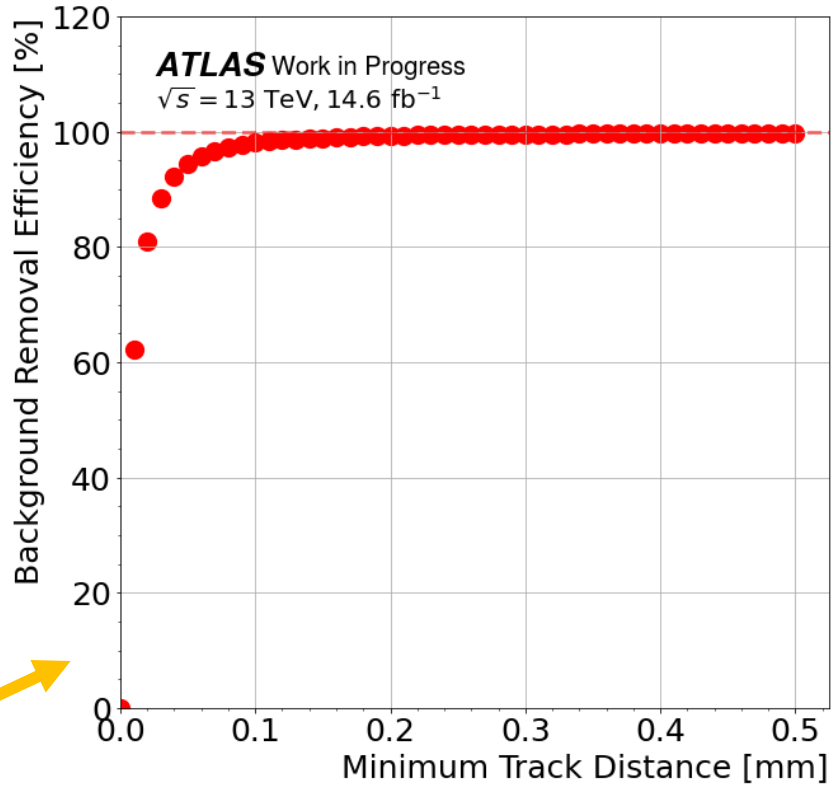
- Multiple pile-up interactions per bunch crossing in addition to the event of interest:

High track density resulting from multiple overlapping interactions

Require a clear window (no other tracks) around dilepton vertex

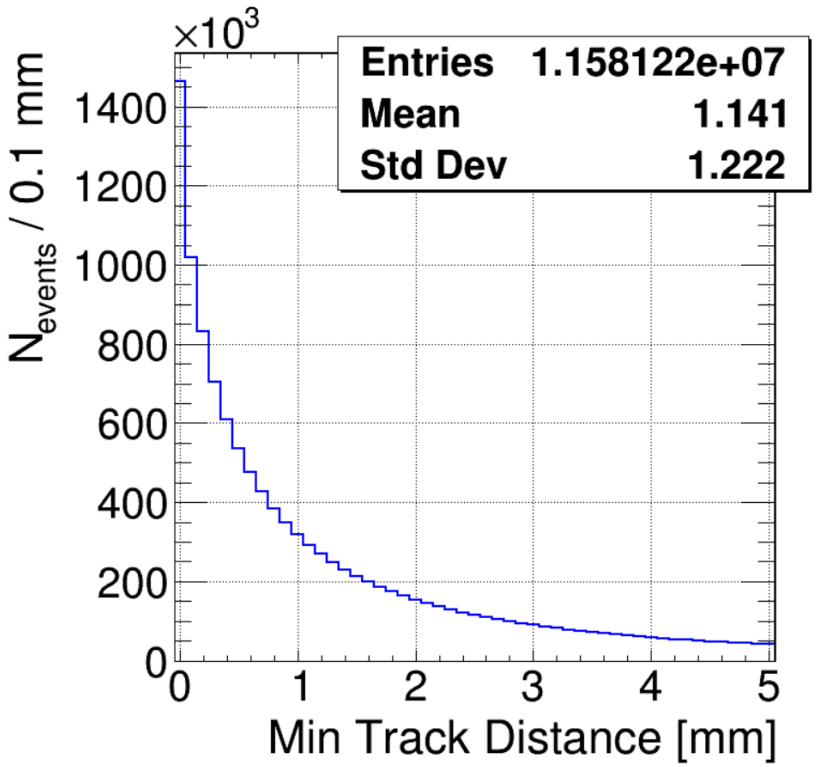


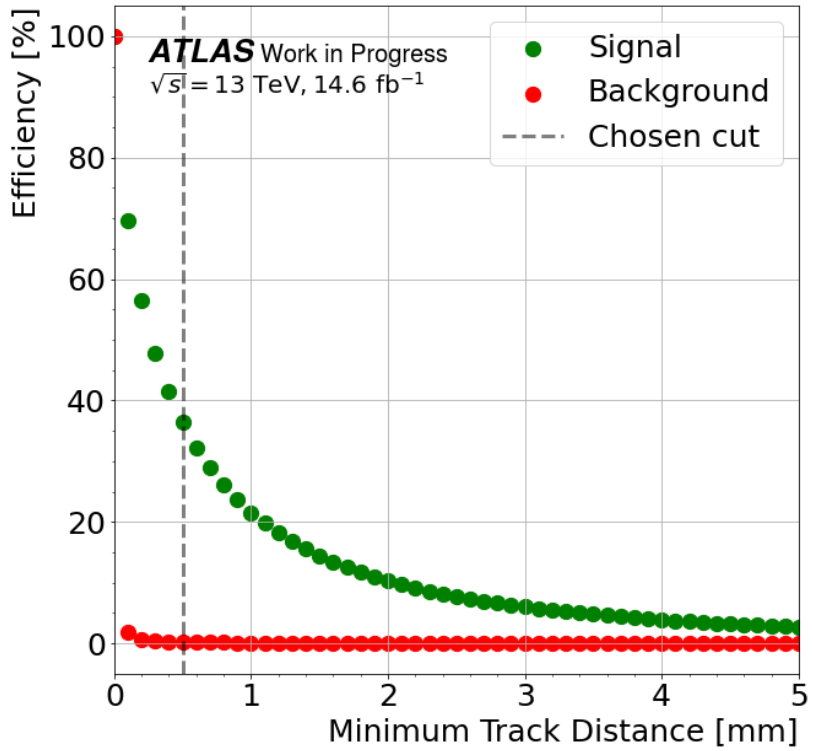

Significant background reduction even with small window size:



# Track Veto – Signal Efficiency

- Signal events associated with pile up could be removed by this selection
  - Signal efficiency = probability of pile-up tracks being within the window of the signal vertex
  - Estimate this by finding the minimum track distance to arbitrary position on the z-axis in each event (we use the primary vertex position of the previous event)

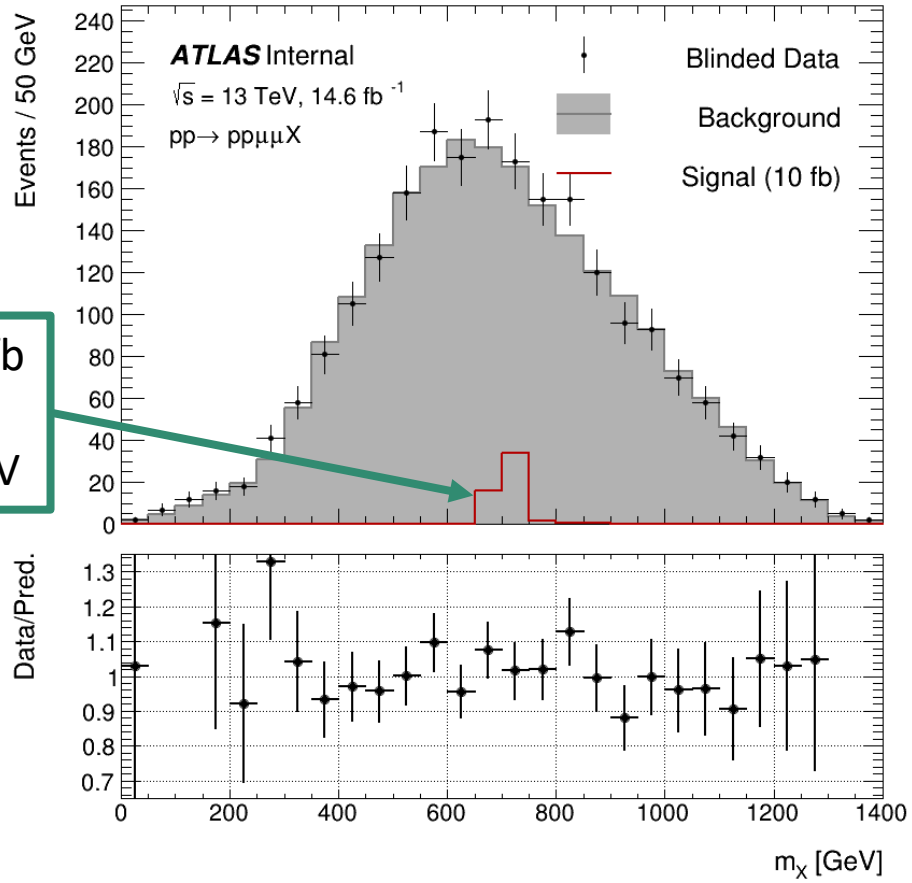


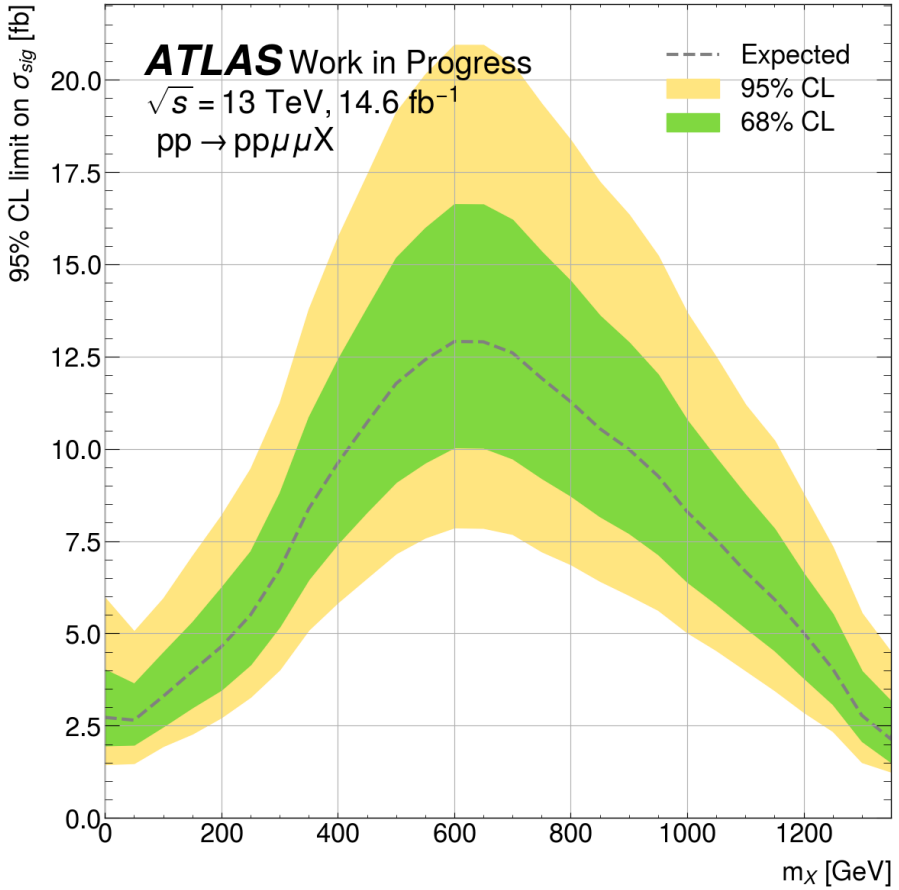



# Preliminary Results

- Statistical analysis framework set up – currently no systematic uncertainties implemented
- **Expected upper limits** set on signal cross section

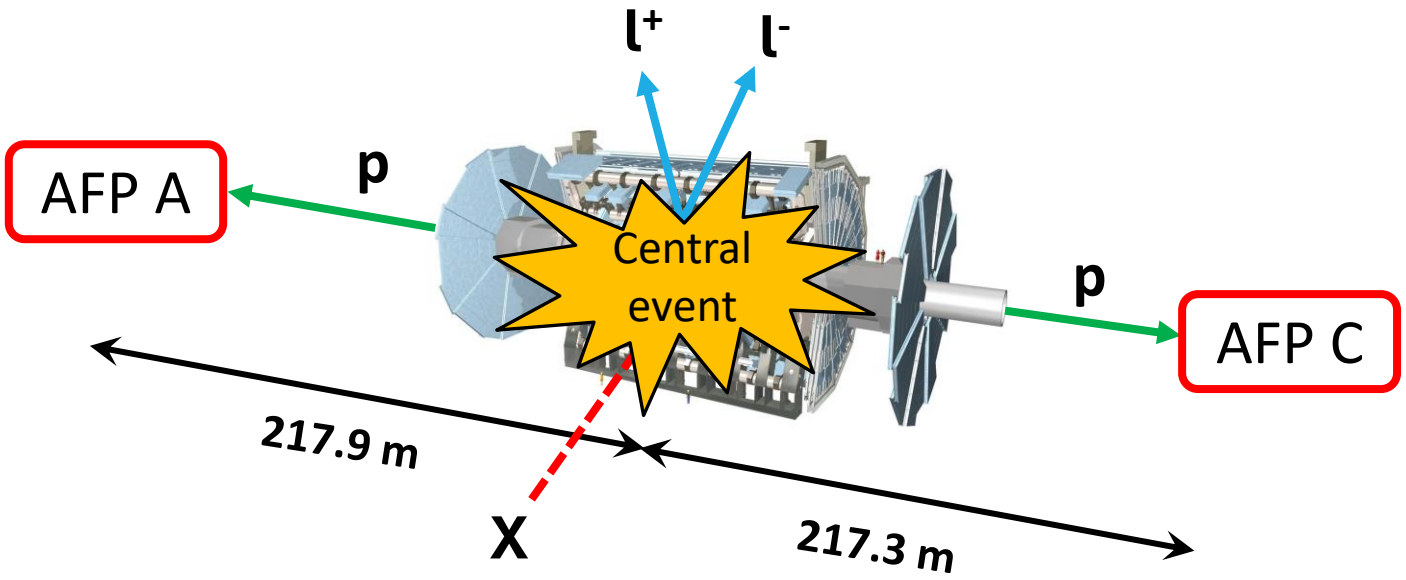
Example 10 fb signal with $m_X$ = 700 GeV

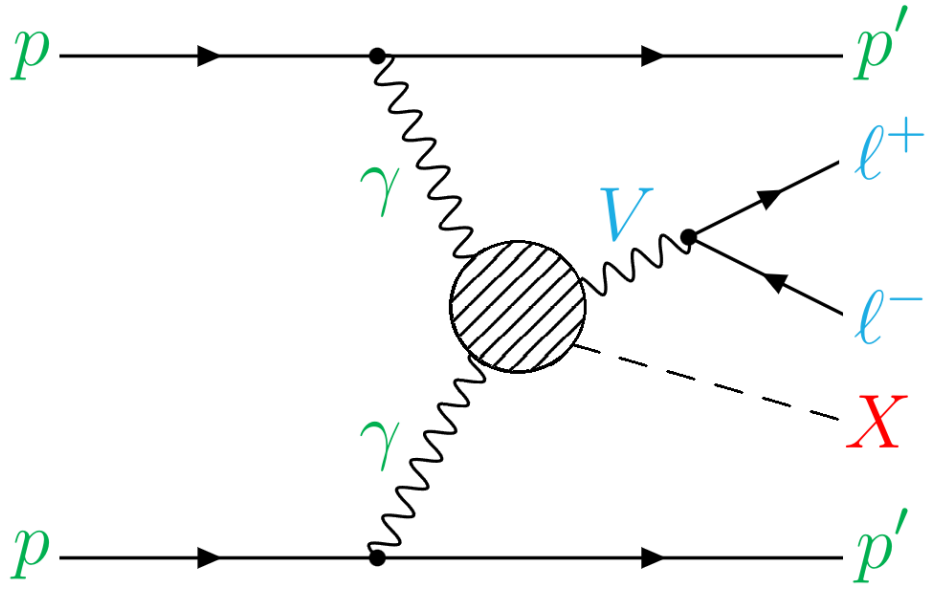


# Summary

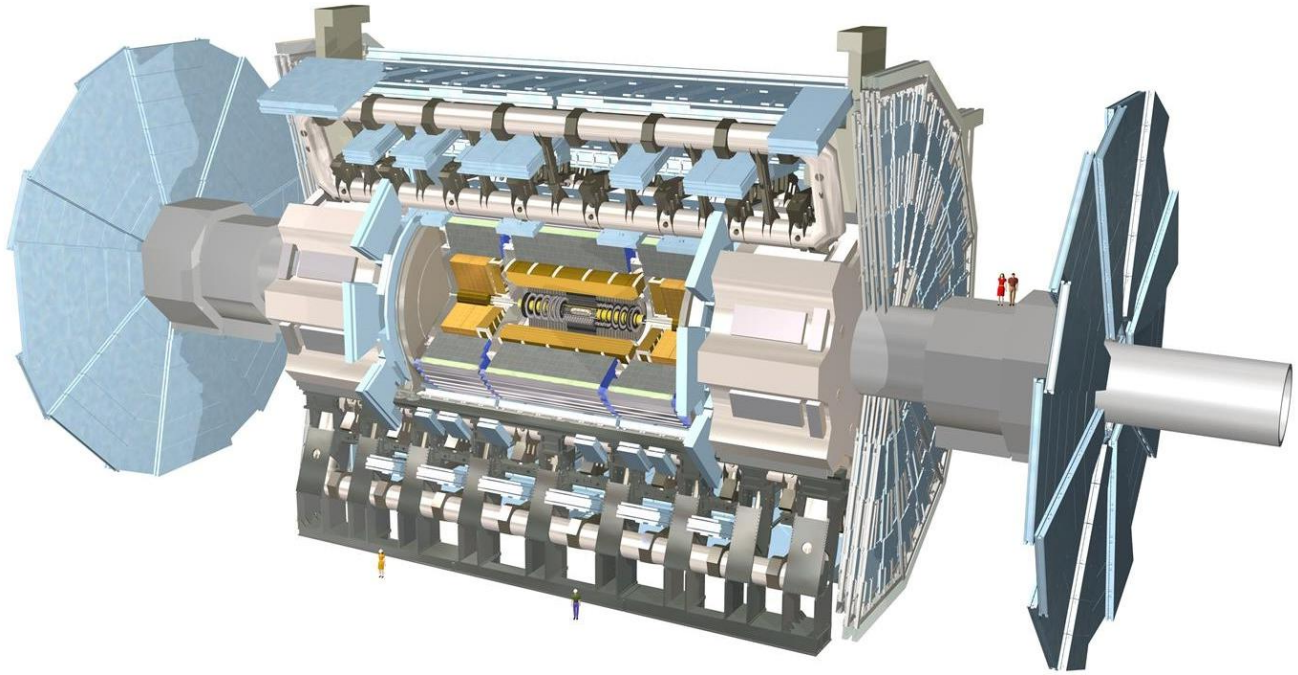
- Searching for missing mass in double-tag proton events associated with central lepton pairs
- First time this technique is used in ATLAS – enabled only through AFP data
- Data-driven and Monte-Carlo background models generated
- Signal Monte-Carlo samples generated using several candidate processes covering wide kinematic phase space
- Implemented track veto selection which greatly improves our sensitivity
- Preliminary statistical analysis performed on blinded data using event mixed sample



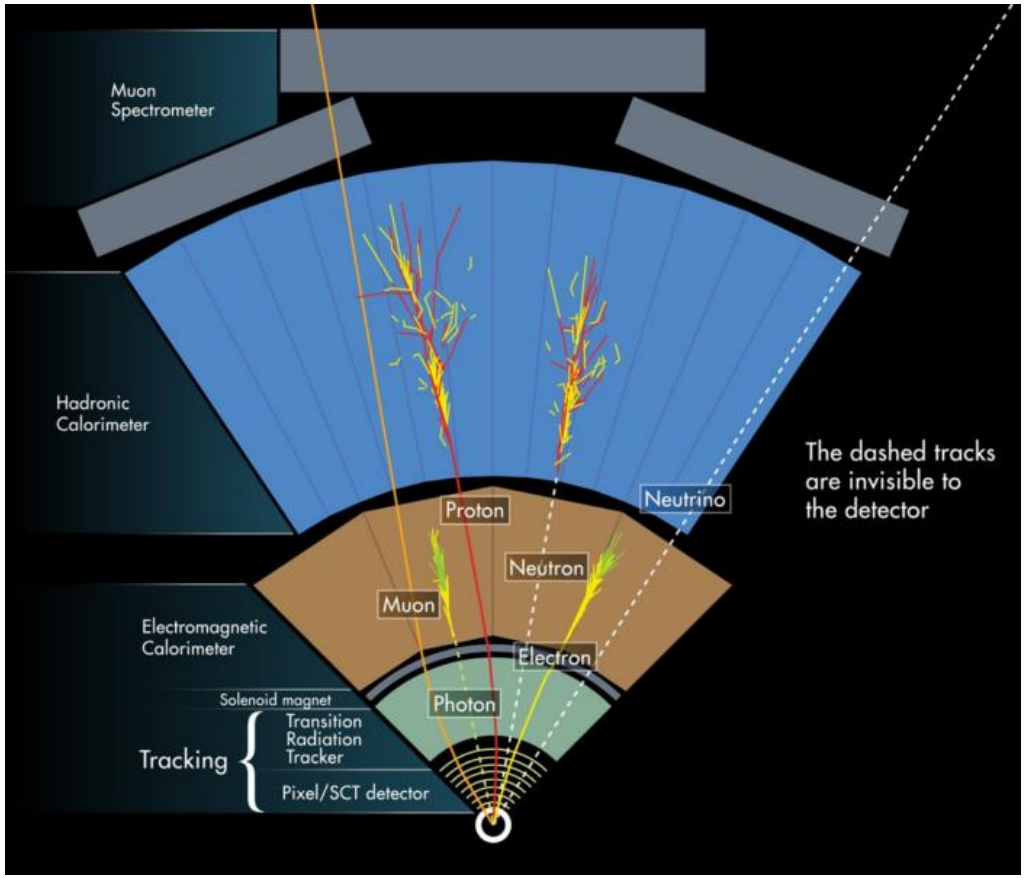



# Additional Slides

# ATLAS Detector



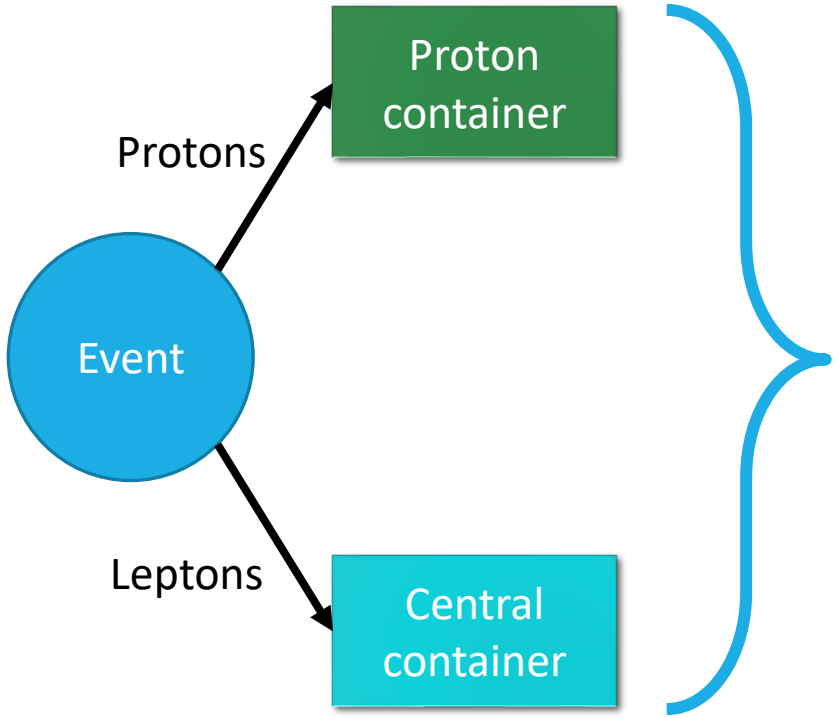
ATLAS Detector




ATLAS Layers

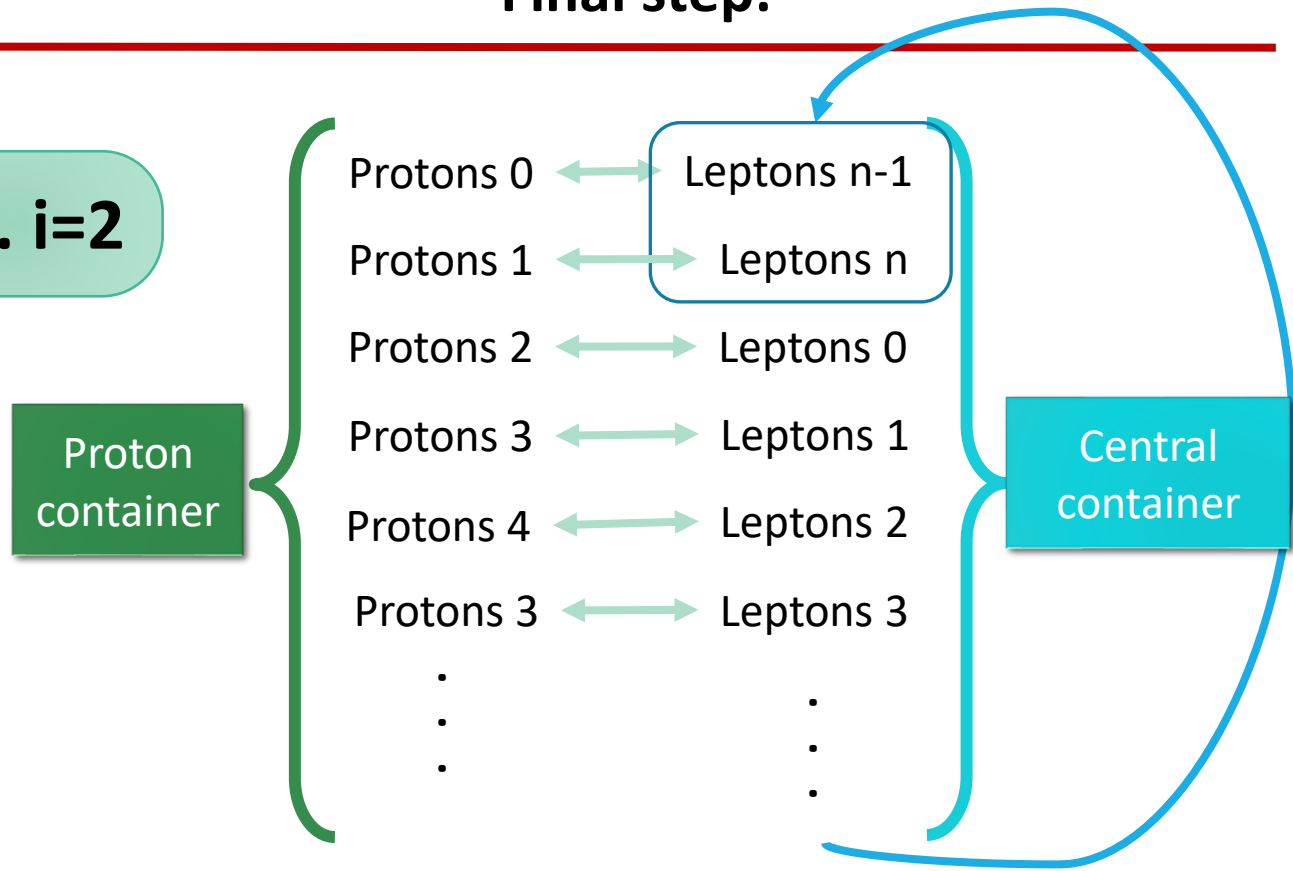
# Mixing Procedure

**Per event:**




**For all events**

**e.g. i=2**

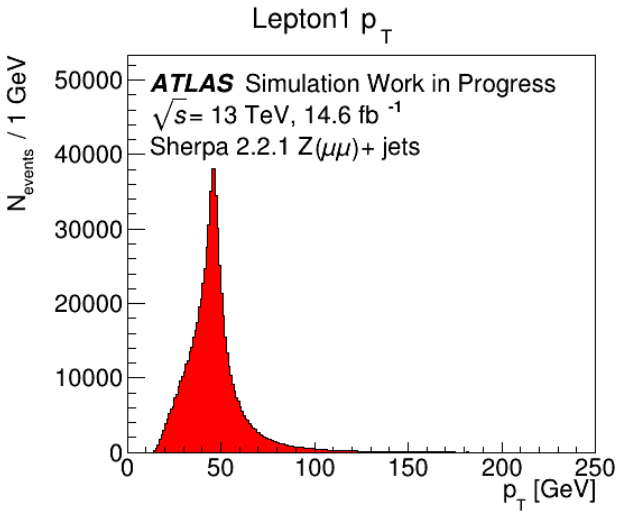


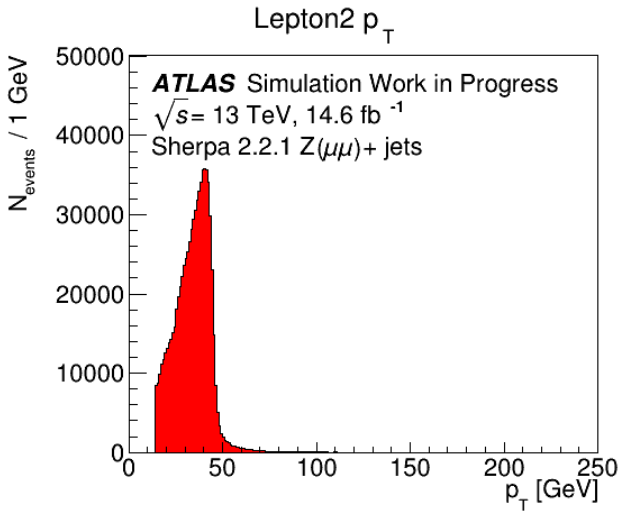

**Final step:**

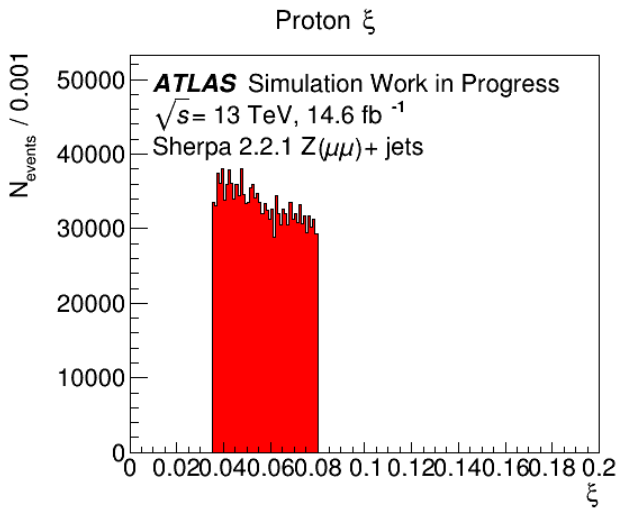
i.e. for $m^{th}$ event do: `Analysis(protons[m], central[(m+i)%n])`

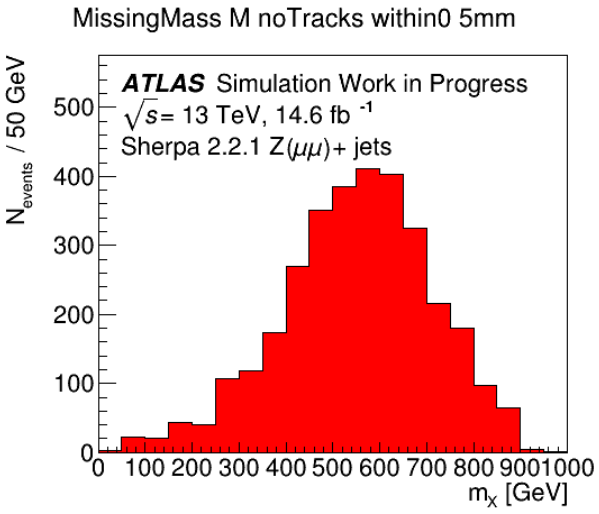
# Background - Monte Carlo Simulation

- Simulated Z + jets background overlaid with pile-up protons from 2017 data
- Used to validate the data-driven background model




- Matching to be performed with data