Improving the tracking performance in dense jets within the ATLAS detector

DONAL MCLAUGHLIN, DR. TIM SCANLON

DEPARTMENT OF PHYSICS & ASTRONOMY, UNIVERSITY COLLEGE LONDON

CENTRE OF DOCTORAL TRAINING IN DATA INTENSIVE SCIENCE

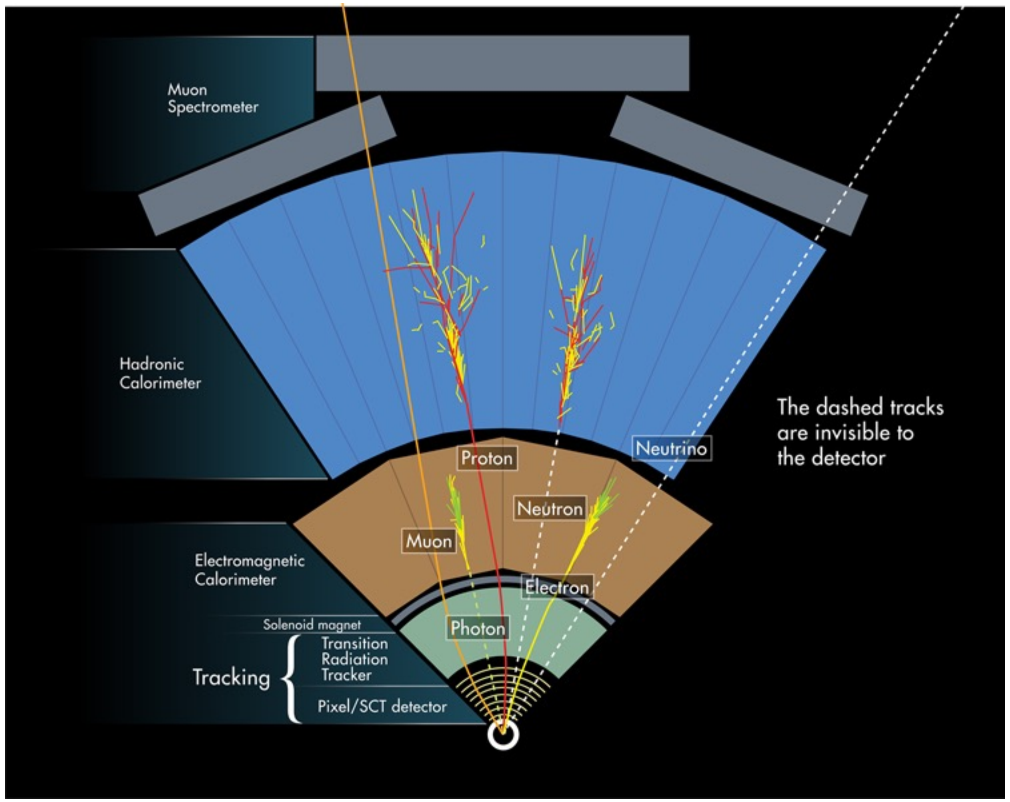
Tracking within the ATLAS Experiment

- THE ATLAS DETECTOR
- TRACKING IN DENSE ENVIRONMENTS
- B-HADRON TOPOLOGY

The ATLAS Detector

The ATLAS detector

- **The Inner Detector (ID) – measures the momentum, charge and trajectories of charged particles that originate from the p-p collision**
  - **Pixel Detectors with Insertable B-Layer (IBL) - 4 barrel layers - ~ 4 hits per track. 80M pixel channels**
  - **Silicon strip tracker (SCT)- 4 double sided barrel layers - ~ 8 hits per track. 6M SCT channels**
  - **Transition radiation tracker (TRT) - ~ 30 – 36 hits per track**
- Electromagnetic Calorimeter
- Hadronic Calorimeter
- Muon Spectrometer

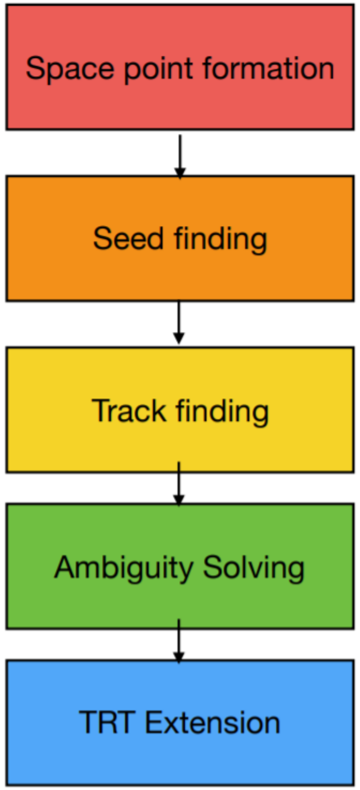


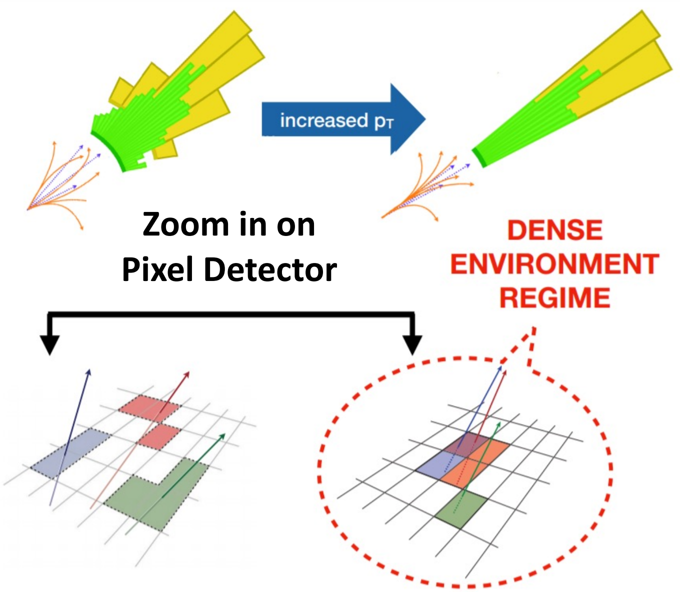
The ATLAS detector. [1]

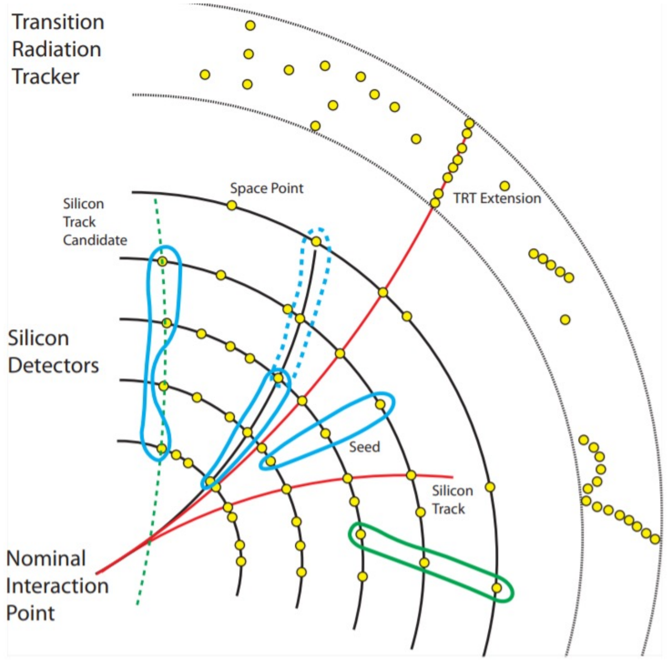
Tracking in Dense Environments

Challenge:

- At √s = 13 TeV : 40-60 pp collisions per event which each create a range of particles in the detector.
- At high transverse momentum (pT):
  - Tracks become more collimated
  - Particle separation can be reduced to the size of the pixel clusters
  - Results in more merged hits
- **Need to find a way to reconstruct particles efficiently without introducing fake tracks (more on this later)**
- Dominates reconstruction time: ~20 s per event to reconstruct the tracks







[2]

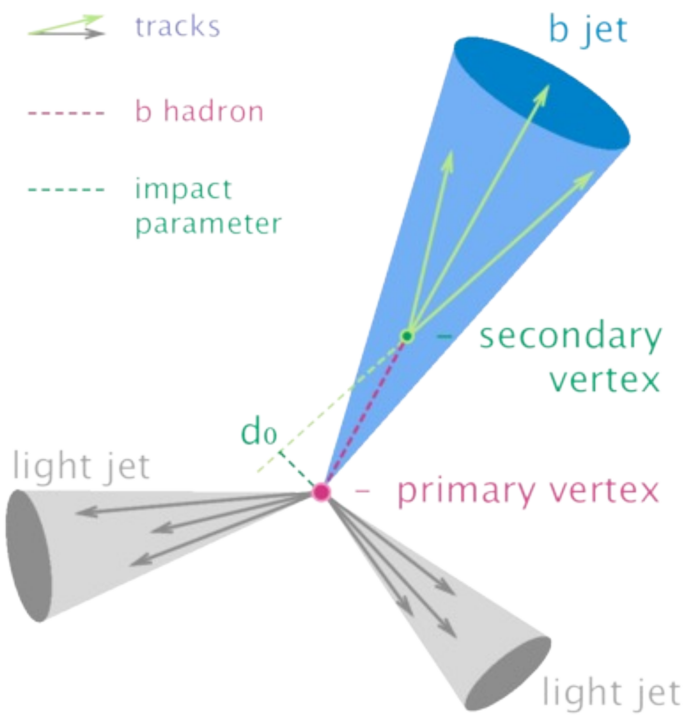
B-hadron Topology

Motivation:

- Identifying jets that originate from b-hadrons is of vital importance to study interesting physics signatures:
  - The **Standard Model Higgs Boson** dominant decay channel is the production of a b-quark anti b-quark pair (~58%)
  - **Top quarks** decay into W bosons and b-quarks ~100% of the time
  - **BSM physics** searches and precision Standard Model measurements etc

B-hadrons have properties that are identifiable within the ATLAS trackers:

- Relatively large b-hadron **mass** (~5 GeV)
- Significant b-hadron **lifetime** (~1.5 ps)
- High decay **multiplicity** (~5 charged particles)
- Primarily identify B-hadrons via their charged **decay products**
- **Vital to reconstruct all tracks** from b-hadron jets to allow for efficient b-tagging
- Imperative to have **efficient** track reconstruction



[3]

The Ambiguity Solver

WHAT IS THE AMBIGUITY SOLVER?

MOTIVATION FOR MODIFYING THE AMBIGUITY SOLVER

EVALUATION OF THE LOGIC WITHIN THE AMBIGUITY SOLVER

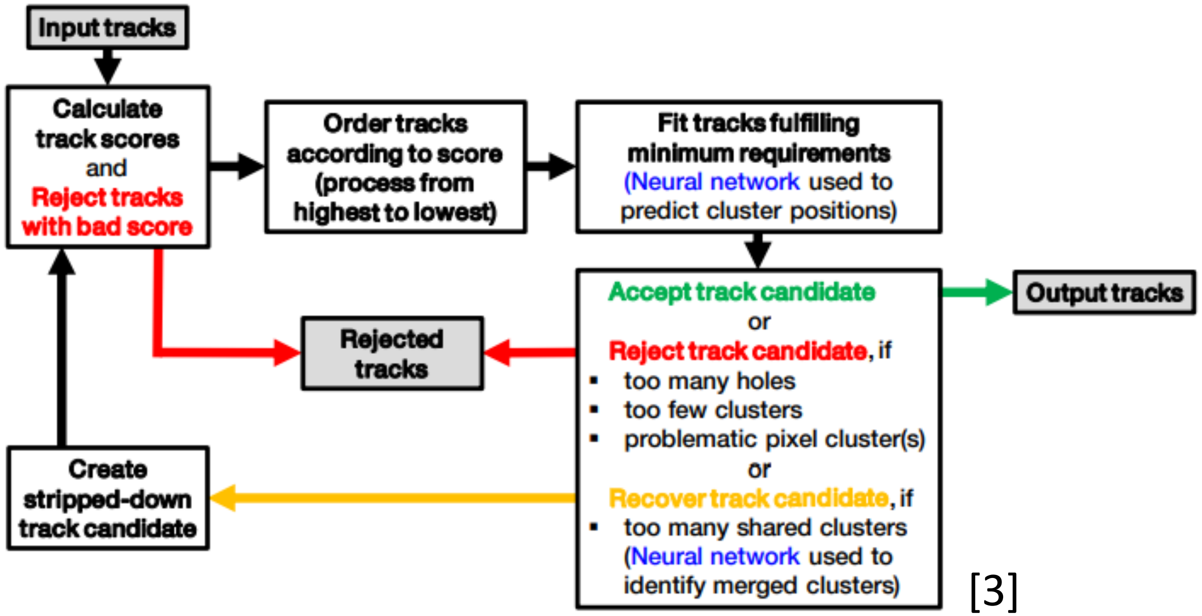
What is the Ambiguity Solver?

During pattern recognition stage, **multiple track candidates** are created for one charged particle

Ambiguity solving stage is required to **remove excessive track candidates**

Tracks are scored, ordered, and assessed based on track hit content with **three outcomes**:

- Tracks are rejected
- Tracks are accepted (reconstructed)
- A stripped-down subtrack is created and reprocessed (hits are removed and the track is re-evaluated)



[3]

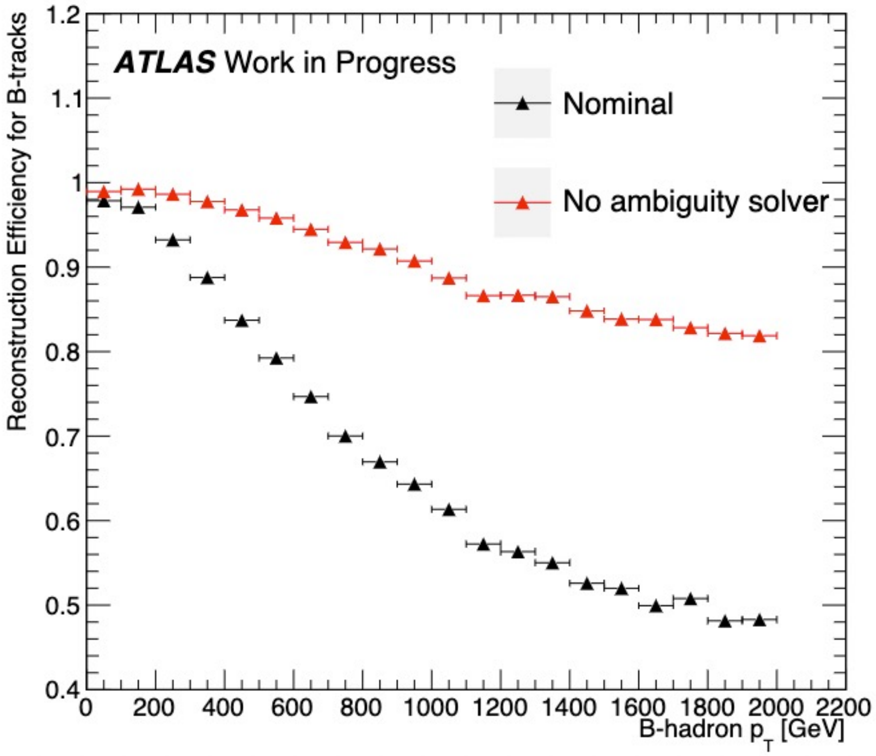
Selection of cuts: Pseudo-rapidity: $|\eta|<2.5$, transverse momentum: $p_T>400$ MeV, minimum of seven Silicon (Pixel + SCT) clusters, maximum one hole in the pixel detector, maximum two holes in the pixel and SCT detectors, and many more!

Motivation for modifying the ambiguity solver

Motivation:

- Many of the tracks from high p_T b-hadron decays (B-tracks) are found by the pattern recognition step but subsequentially **lost** by the selection in the ambiguity solver

- There is a large **drop** in reconstruction efficiency for B-tracks when using the ambiguity solver to remove excessive track candidates
  - Up to ~35% at B-hadron pT>1500GeV



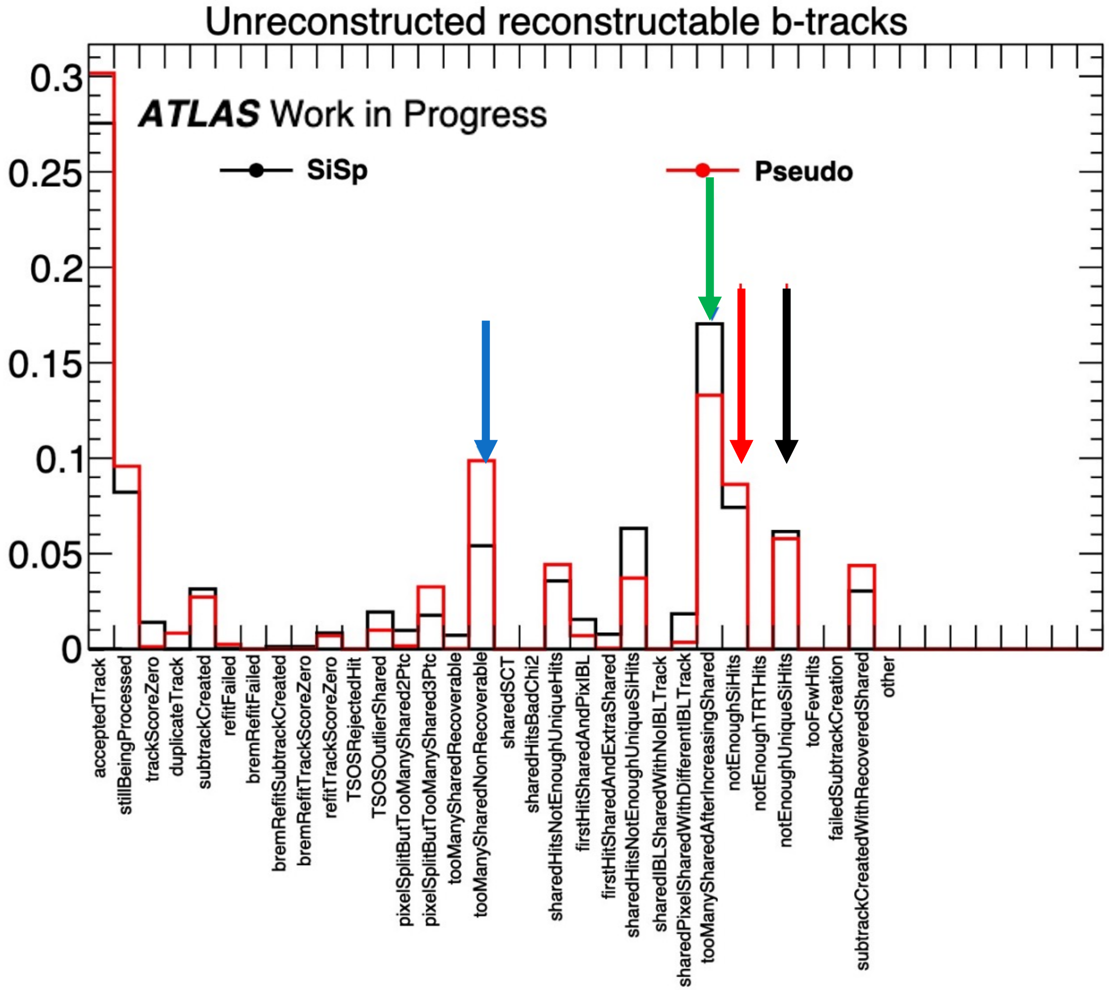
This presentation will investigate ***why*** the ambiguity solving process is removing so many b-track and methodologies to ***improve*** the b-track reconstruction efficiency

Where does it reject the most tracks?

The first step is to establish ***why*** do B-tracks, within the ambiguity solver, get rejected:

- To evaluate the performance of the ambiguity solver when an **ideal set of track candidates** (pseudo tracks) are used
- **Pseudo tracks** can be used as they use **truth information** to reconstruct the best possible set of reconstructable tracks
- Investigate pseudo tracks that are **not reconstructed**, i.e. the tracks that should have been reconstructed, but were not
  - **Reconstructable**: a track that was rejected in the ambiguity solver but was matched to a reconstructed pseudo-track

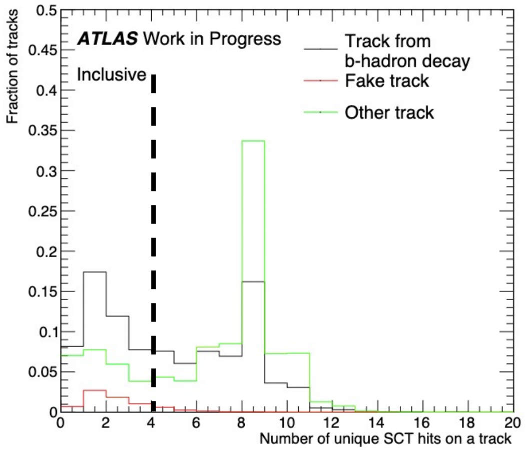
- **The Four main causes** within the ambiguity solver that reject tracks (rejection location):
  - Too many shared hits on a track
  - A better track has already been accepted (thus increasing shared hits on the already accepted track)
  - Not enough Si (Pixel + SCT) hits
  - Not enough unique Si (Pixel + SCT) hits

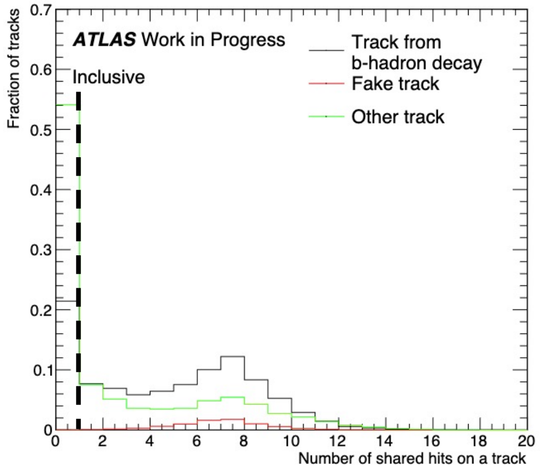


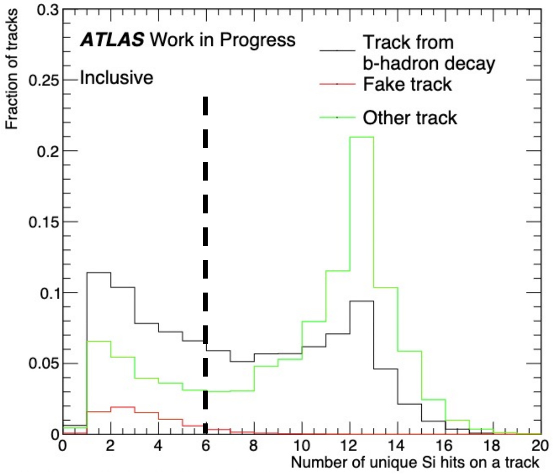
Hit content of tracks

B-hadron decay normalised to reconstructed B-tracks.
Fake and **Other tracks** normalised to all reconstructed tracks.

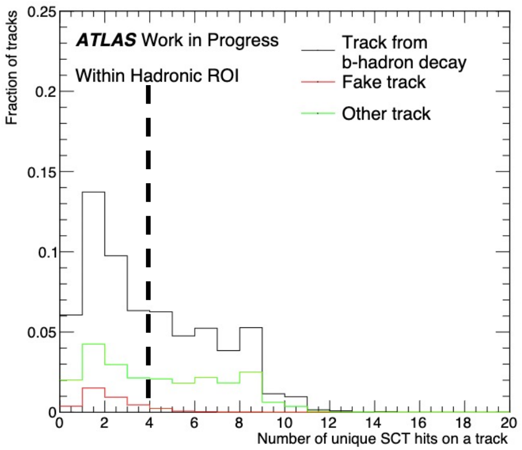
Inclusive

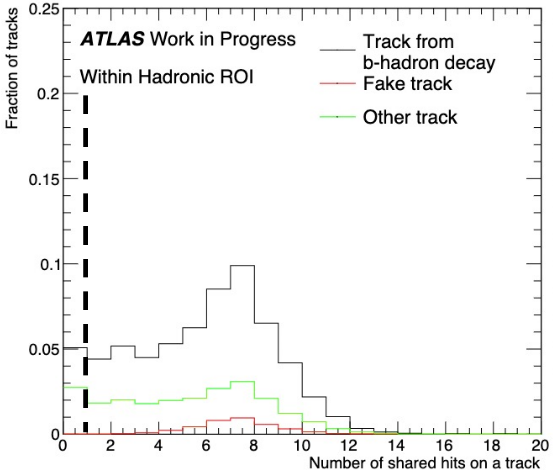


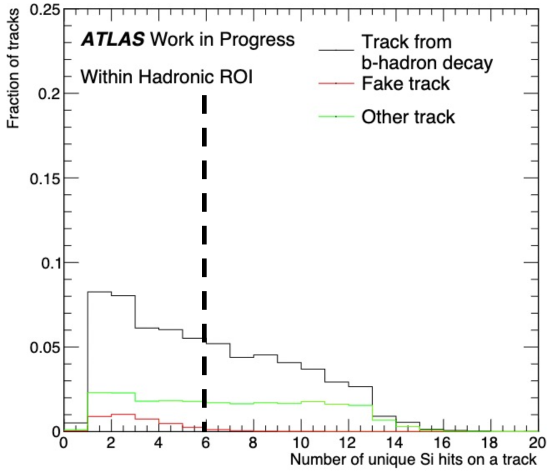




In Hadronic ROI







- A comparison of the **hit content** corresponding to the main rejection locations
- Using a **hadronic region of interest** (to identify a highly boosted b-hadron)
- Using the hadronic ROI can target relaxing the cuts mostly just for regions with a **high pT b-hadron**, limiting the increase in the fake-rate
- Hadronic ROI thresholds: pT > 150 GeV, phi width < 0.05, eta width < 0.05
- Tracks are rejected as they have **too many shared** and **not enough unique hits**

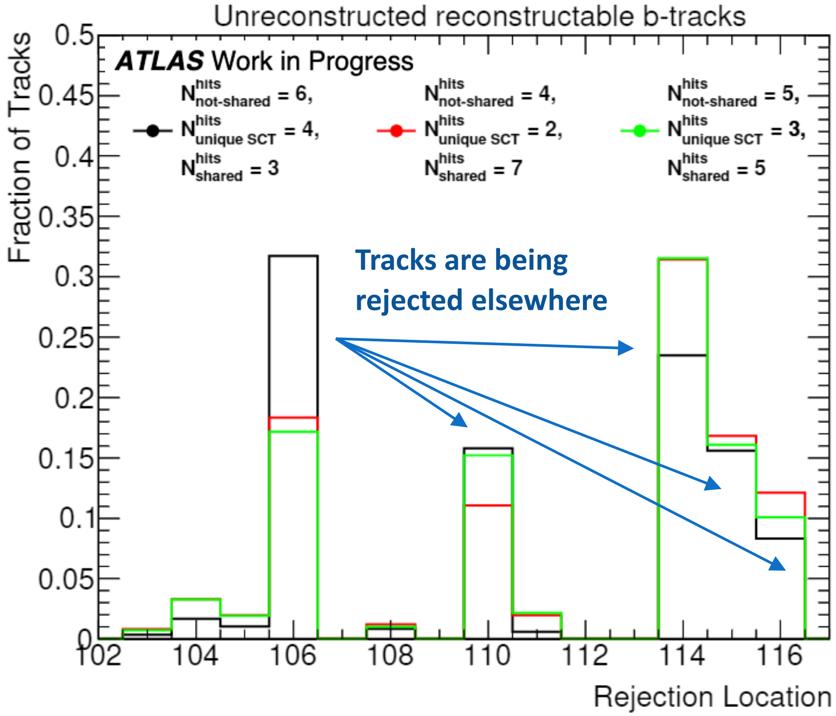
- - - Black dashed line indicates nominal cuts.

Correlations between cuts within the ambiguity solver

Over 30 cuts are applied on a track candidate.

Relaxing the following requirements had the **greatest influence** on track rejections within the ambiguity solver:

- The maximum number of shared modules
- The minimum number of unique Silicon strip tracker (SCT) hits
- The minimum number of non-shared hits
- The maximum number of tracks that can share a hit



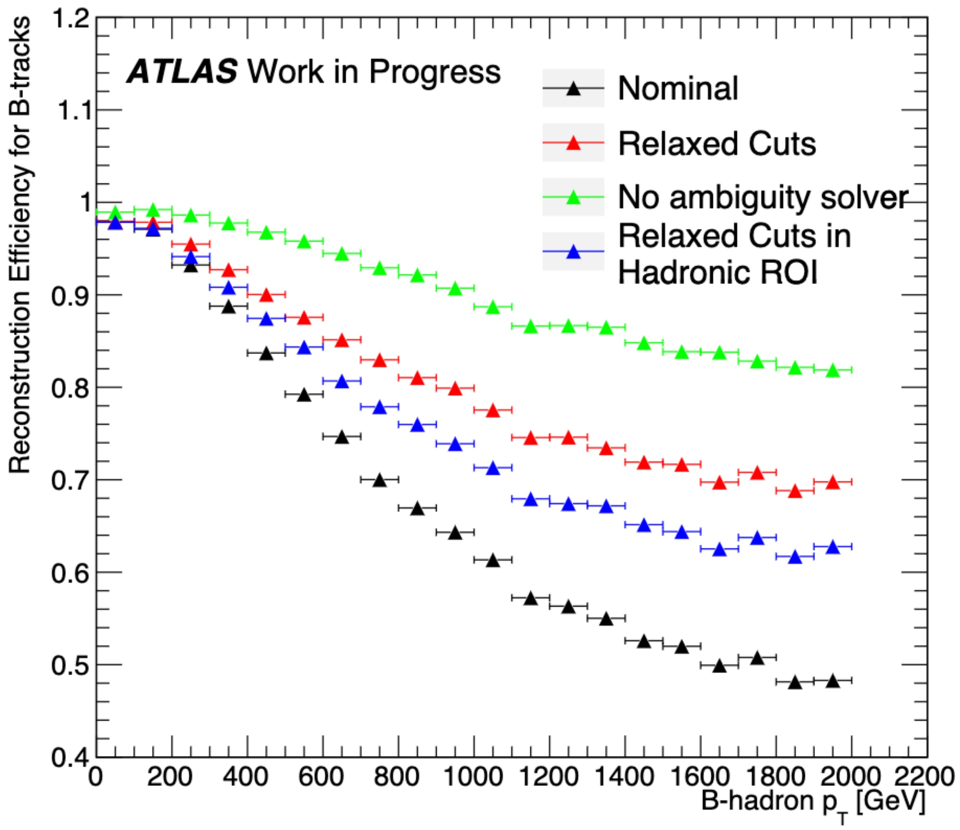
Cannot loosen just one or two cuts, as the tracks will be **rejected elsewhere** in the ambiguity solver

Reconstruction efficiency of B-tracks with loosened ambiguity solver cuts

- Relaxed cuts (applied **inclusively** and **within the hadronic ROI**):
  - The maximum number of shared modules 3->15
  - The minimum number of unique SCT hits 4->1
  - The minimum number of non-shared hits 6 ->1
  - The maximum number of tracks that can share a hit 2->15

- Large increase in the b-track reconstruction efficiency observed between **inclusively relaxed cuts** and **nominal cuts**

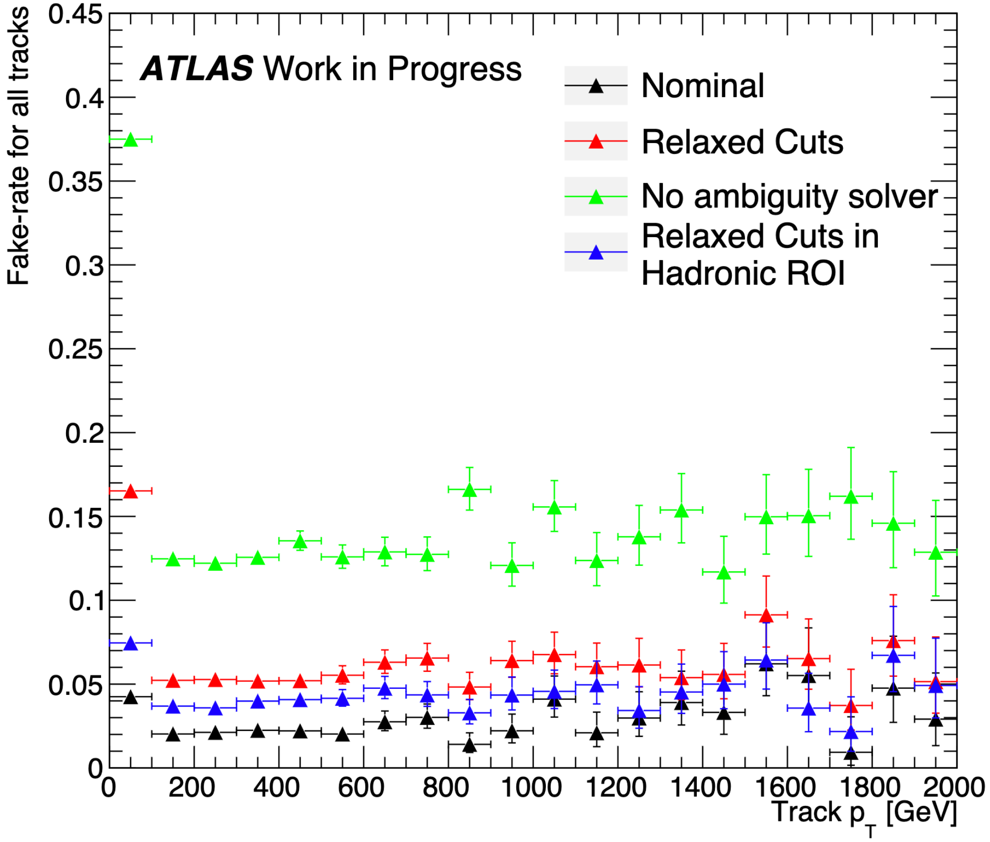
- Reconstruction efficiency increase around 10% at hadronic pT > 1TeV



Fake-rate with relaxed ambiguity solver cuts

After modifying the cuts, are the additional reconstructed tracks of good quality?

- The **fake-tracks** do not correspond with the real tracks within the detector
- There is a general trend of worsening in track quality at **higher p_T** as expected therefore loosening the selection increases the fake-rate
- Loosening the selection **increases the fake-rate**, although this can be better controlled via the use of the **ROI**



Thanks for listening!

Conclusion

- Track reconstruction is necessary to facilitate ATLAS's physics goals in discovering new particles and improving precision measurements.
- The reconstruction of tracks is a highly complex and time consuming algorithmic problem.
- Within highly boosted decays, there is a significant loss in the tracking efficiency due to the stringent **stringent selections** within the ambiguity solver.
- A framework has been developed to understand **where** this efficiently loss occurs within the ambiguity solver.
- Efficiency loss mostly occurs due to tracks **sharing too many hits**.
- Varying just one cut has a marginal effect on the reconstruction efficiency however, necessary to make **multiple cuts** to improve efficiency.
- Working within a **hadronic ROI** can achieve impressive gains in b-track reconstruction efficiency with a relatively small increase in the overall fake-rate.

References

1. ATLAS Collaboration, “Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC”, *Phys.Lett. B716* (2012) 1-29, DOI: 10.1016/j.physletb.2012.08.020

2. ATLAS Collaboration, “Increasing track reconstruction efficiency in dense environments at ATLAS”, Joint tracking and flavour tagging workshop , https://indico.cern.ch/event/795039/contributions/3391742/

3. A. Salzburger, “Track and Vertex reconstruction”, ATLAS Introduction Week, https://indico.fnal.gov/event/8769/sessions/12214/

Extra Slides

Truth Match Probability

Fake-track defined as tracks with TMP < 0.5

- Metric used for determining track quality: Truth Match Probability (TMP)
- TMP: Truth Match Probability, a ratio of correctly assigned hits a reconstructed track has to its corresponding truth particle.
- $TMP = \frac{10*N_{seed}^{Pixel}+5*N_{seed}^{SCT}+1*N_{seed}^{TRT}}{10*N_{truth}^{Pixel}+5*N_{truth}^{SCT}+1*N_{trurh}^{TRT}}$