Combinatorial Fake Discriminatory Selections for dE/dx and Disappearing Track Signature Search

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ATLAS EXPERIMENT

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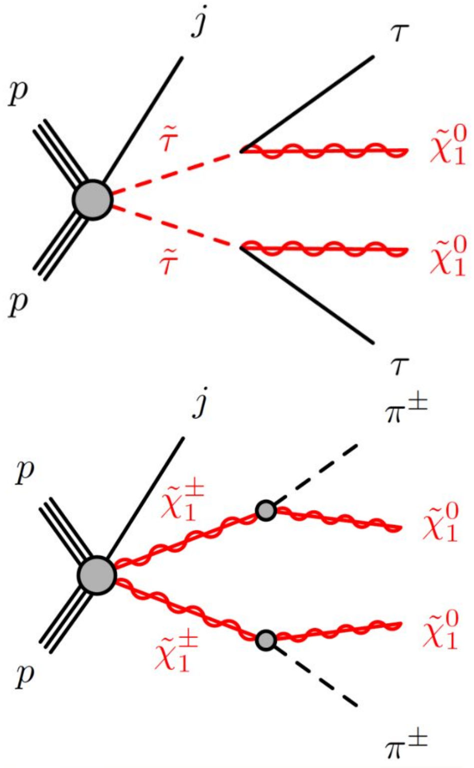
Overview



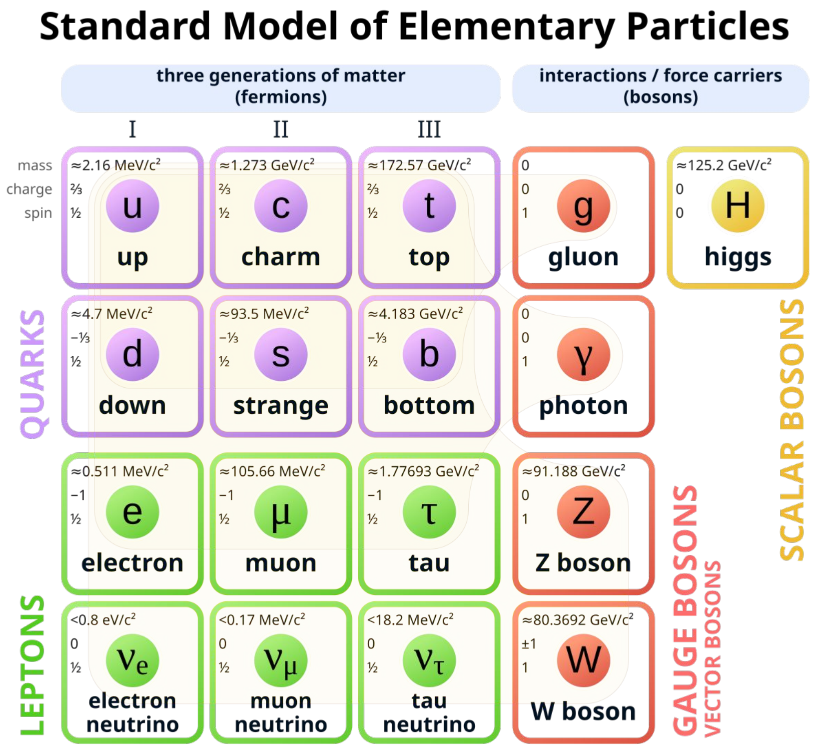
Example Signal Processes (N. Young)

- Search for long-lived, massive charged particles
- Utilizing an ionization energy and disappearing track signature
- This study aims to understand the difference in tracklet properties between signal and background

Some Physics Background

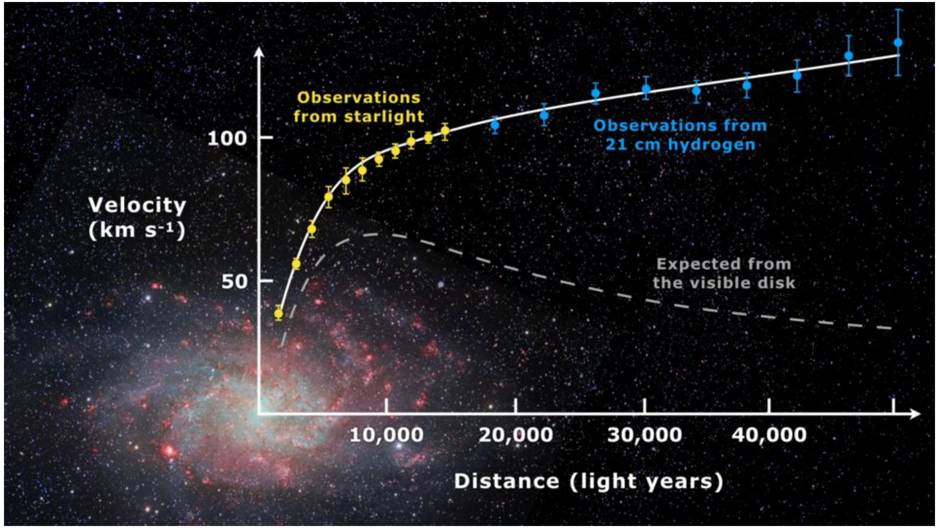
The Standard Model

- *Very* good, one of the best physical theories we've come up with
- Describes
  - Ordinary matter
  - 3 of the 4 fundamental interactions
- 17ish particles
- Split into two families
  - Bosons; force carriers
  - Fermions; matter particles
- Makes extremely precise predictions



The Standard Model (Wikipedia)

Motivation for BSM Physics

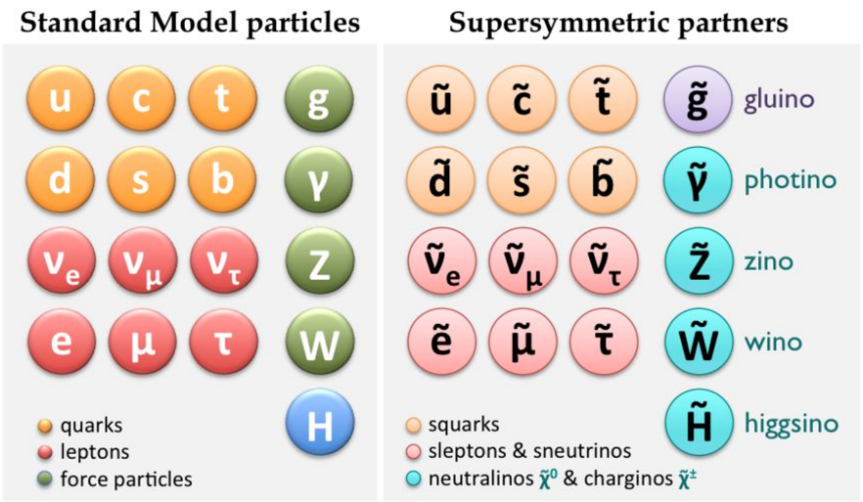


Galactic rotation curve discrepancies (Wikipedia visualization of Corbelli, Salucci)

- Despite its precision, the SM fails to address some areas
  - Neutrino masses?
  - Cosmic CP violation?
  - Hierarchy problem?
  - Dark matter?
- All of this indicates that there should be *something* else out there…

Supersymmetry (SUSY)

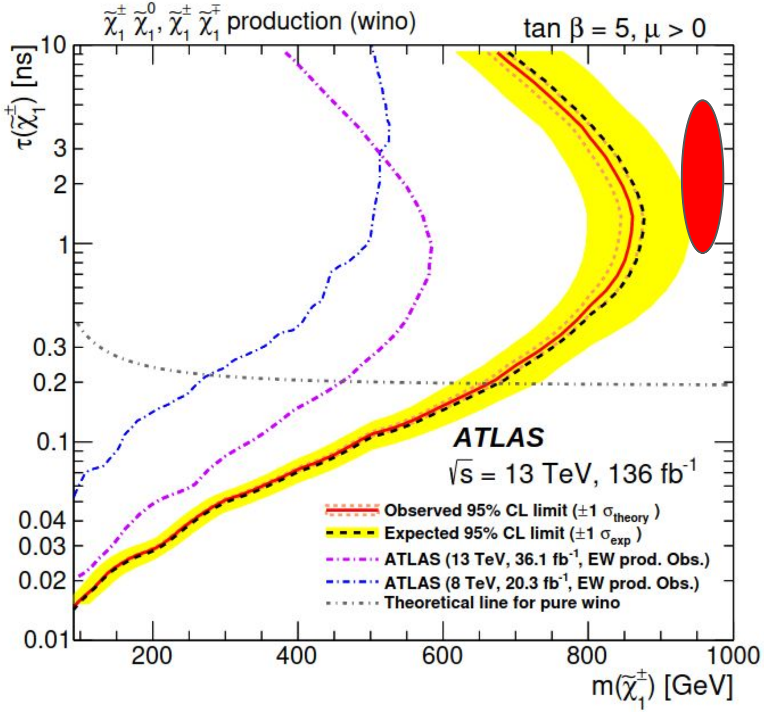
- Supersymmetry (SUSY) is an extension to the Standard Model
- Designed to help resolve the hierarchy problem
- Introduces a superpartner for each Standard Model particle
    - Spin differs by ½ → Fermions become bosons and vice versa
- Also incidentally provides an excellent dark matter candidate



SUSY Particles (IFIC ATLAS)

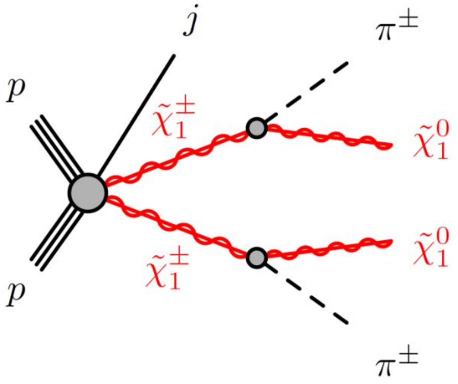
dE/dx + Disappearing Track Analysis

dE/dx + Dissappearing Track Analysis



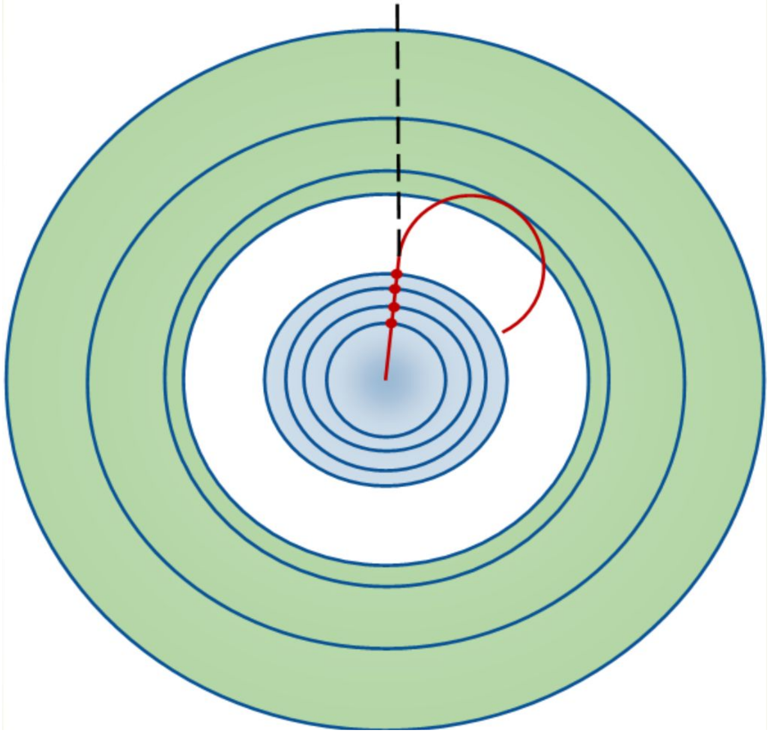
Chargino Exclusion Limits (ATLAS)

- Ongoing Run 3 analysis, combining two previous analysis strategies
- Previous Run 2 analysis excluded up to 660 GeV charginos in pure Wino case
- Targeting lifetime O(1 ns), mass O(1 TeV) charginos/staus for this analysis



Signature

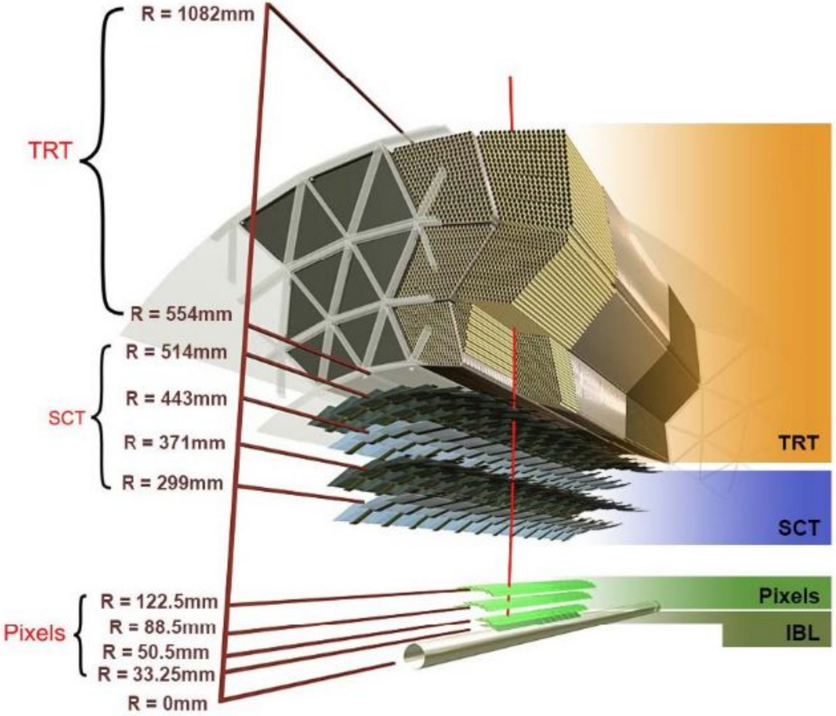
- Disappearing Track
  - Targets particles with a short lifetime
  - Decays into soft and neutral secondaries
- dE/dx
  - Average ionization energy loss per path length
  - Measured through charge deposition in Pixel layers
  - Dependence on $\beta\gamma = p/m$, so slow moving massive particles result in high dE/dx



Example Of Disappearing Track Signature (N. Young)

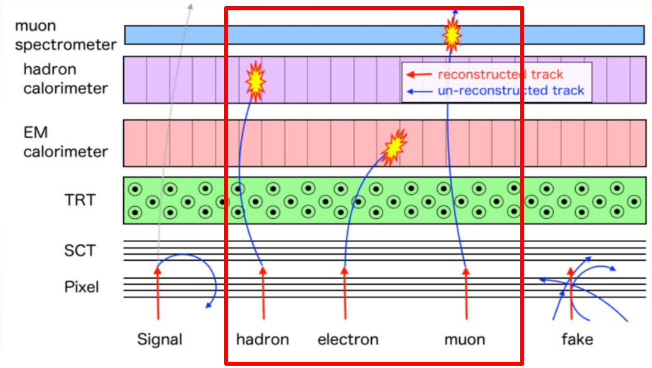
ATLAS Inner Detector And Analysis Selections

- Innermost layers of ATLAS detector
- Pixel detector
  - 4 Layers
  - Each layer measures dE/dx
- SCT
  - 4 double-sided strip layers
- Analysis Selections
  - Vetoing all SCT hits to ensure that track “disappears”
- Separated by ~17cm
  - Target for signal decay

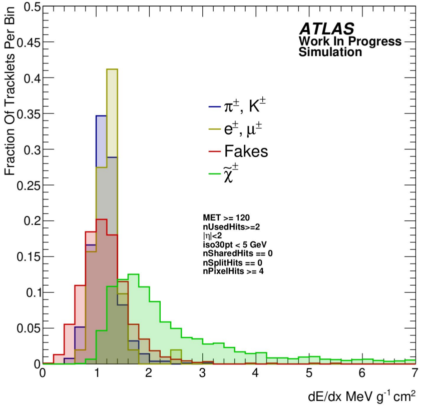


ATLAS Inner Detector (ATLAS)

Charged Particle Scattering



Some Background Processes (ATLAS)

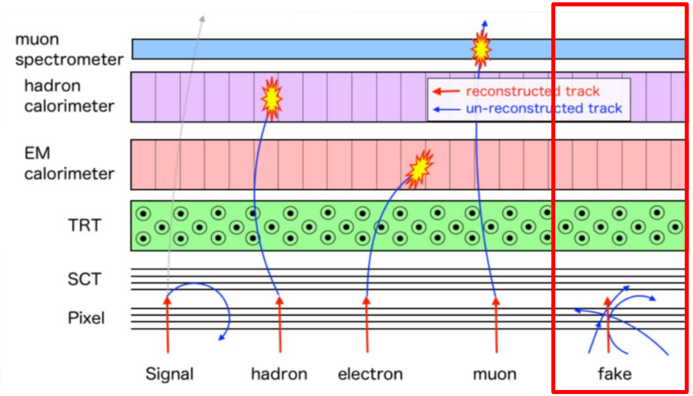


dE/dx Distribution For Signal And Background Sources

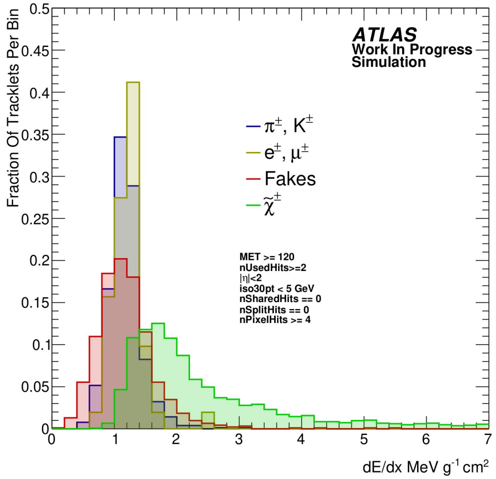
- A potential background that dominated Run 2 disappearing track search
  - Collectively covers the leptonic + hadronic backgrounds
  - “Kinked” tracks; particle hits something in between Pixel and SCT
    - Rest of track not reconstructed
- Expect leptonic + hadronic backgrounds to be suppressed by dE/dx requirement

Combinatorial Fakes

- Another potential background
- Fake is a mis-constructed object in the detector
- Real hits from separate tracks grouped together
- Can be reconstructed as a high dE/dx tracklet by combining individual high dE/dx hits from low-p particles
- Motivates search for additional selections



Some Background Processes (ATLAS)

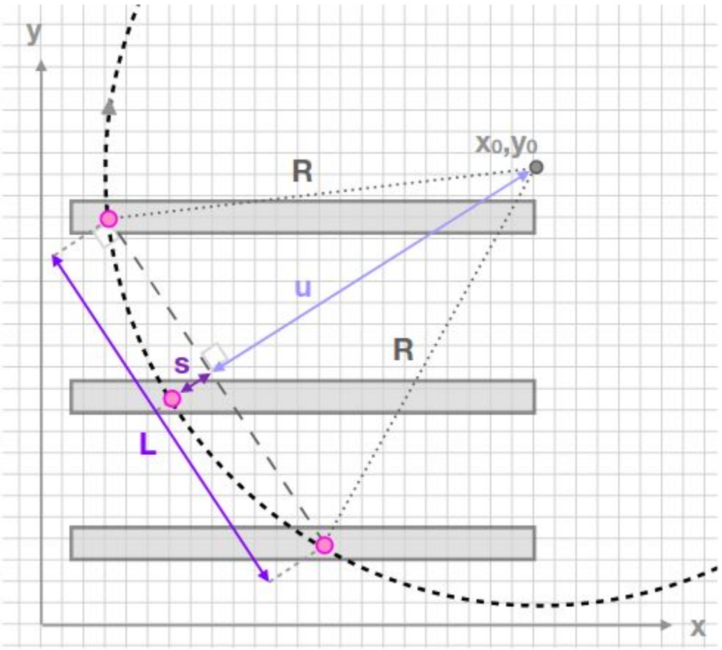


dE/dx Distribution For Signal And Background Sources

Understanding Background Behavior

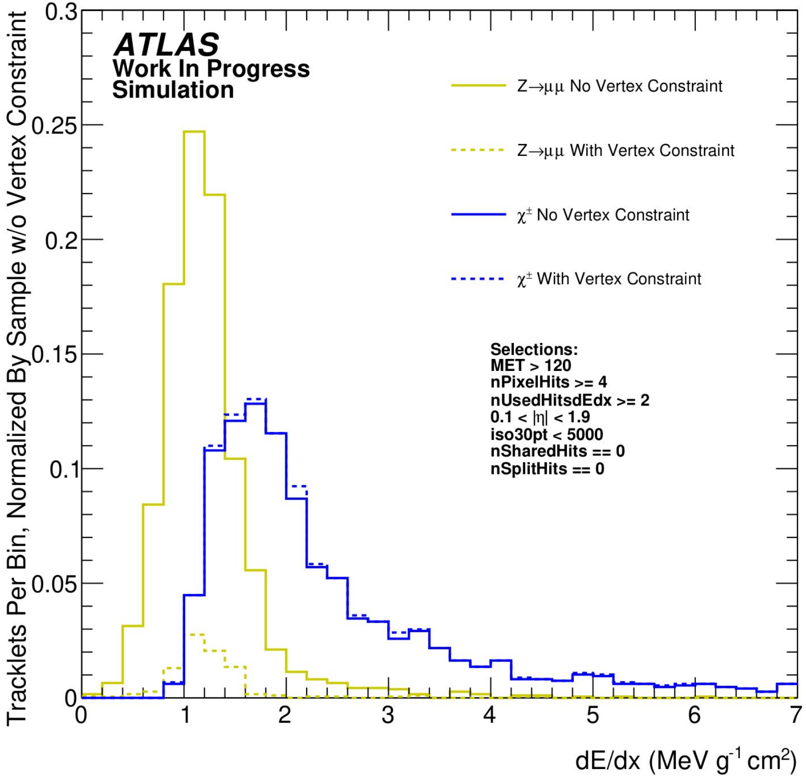
How Do We Define Momentum?

- Tracklets are short, difficult to accurately reconstruct momentum
- Uncertainty in $p_T \propto 1/L^2$
- Can choose to use a vertex constraint on events
    - Define all tracklets as coming from the primary vertex
    - Adds an additional “hit” to the tracklet, increasing length (~9 cm → ~12 cm)



Tracklet Lever Arm (R. Carney)

Vertex Constraint

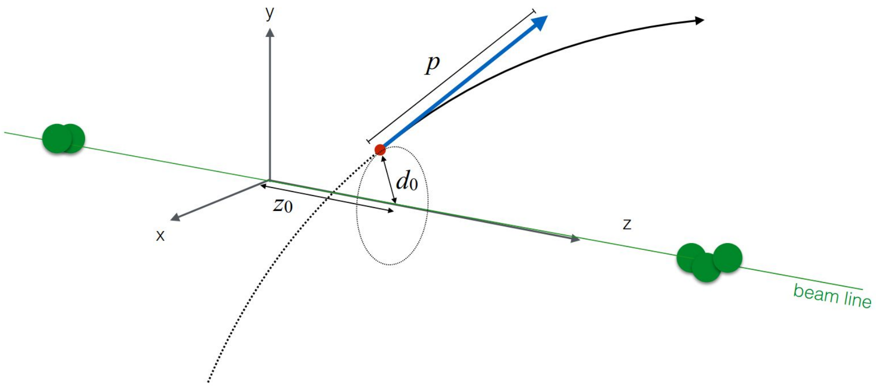


dE/dx Distribution In Signal And Background

- The physics motivated reasoning ends up helping us reject background!
- By applying a vertex constraint, our background is massively reduced without significantly reducing signal yield

Tracklet Impact Parameters

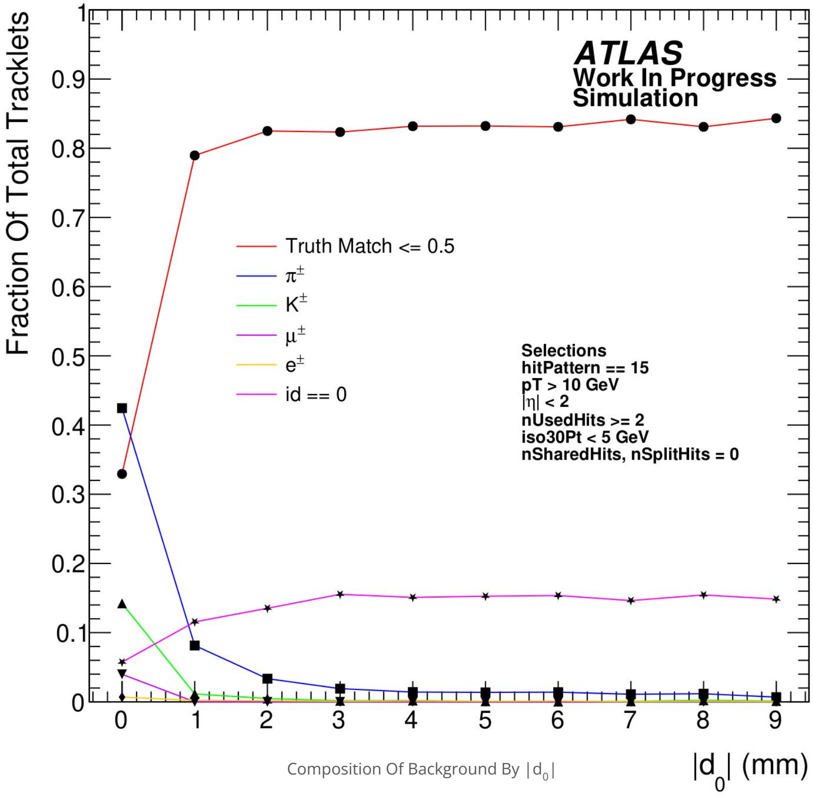
- Reconstructed tracklets are defined by a set of parameters
- Two parameters, d_0, z_0 are of special interest to this analysis
  - Transverse and longitudinal impact parameters
- Would naturally expect pile-up to be spatially removed from primary interaction



Track Impact Parameters (A. Salzburger)

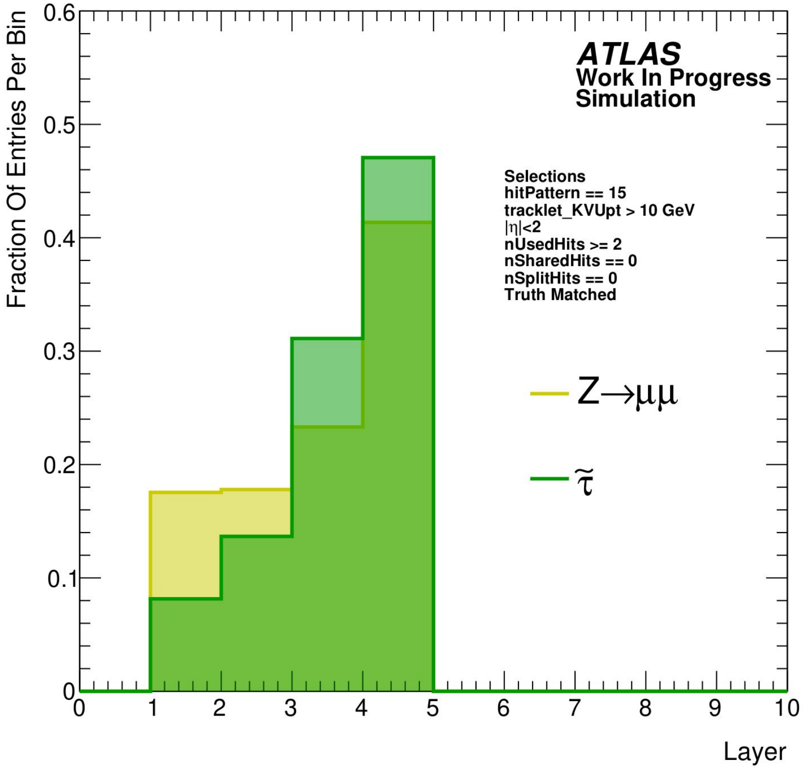
Background Composition By d_0

- d_0 is transverse impact parameter
- The increase in fakes is very immediate
- Suggests that almost all the tracklets with $|d_0|$ greater than 1 mm are going to be fakes



Composition Of Background By $|d_0|$

Clusters!



Dropped layers in truncated mean calculations

- These are composed of individual hits within the detector, called clusters
  - Analysis team has put in a <u>lot</u> of work to make this information available
- Looking to utilize cluster level information as a potential discriminant between signal and background
  - For example, can see which individual layers get left out of dE/dx calculation

Summary

- Looking for long-lived, massive, charged particles using a disappearing track and dE/dx signature
- Identified the use of a vertex constraint as optimal for our analysis
- Identified behavior of background composition with respect to d_0
- Utilizing cluster information in novel way to understand background

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Thank You For Your Attention

References

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[2] ATLAS Collaboration. Search for heavy, long-lived, charged particles with large ionisation energy loss in *pp* collisions at $\sqrt{s} = 13$ TeV using the ATLAS experiment and the full Run 2 dataset.

[3] ATLAS Collaboration. The ATLAS Experiment at the CERN Large Hadron Collider: A description of the detector configuration for Run 3.

[4] Carney, Rebecca. Silicon tracking and a search for long-lived particles.

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[6] IFIC ATLAS Group, SUSY Physics

[7] Lory, Alexander. Search for new physics in signatures of soft unclustered energy patterns within the ATLAS detector

[8] Particle Data Group PDG, Passage of particles through matter, Nuclear and Particle Physics, vol. 33, no. 27, pp. 258-270, July 2006.

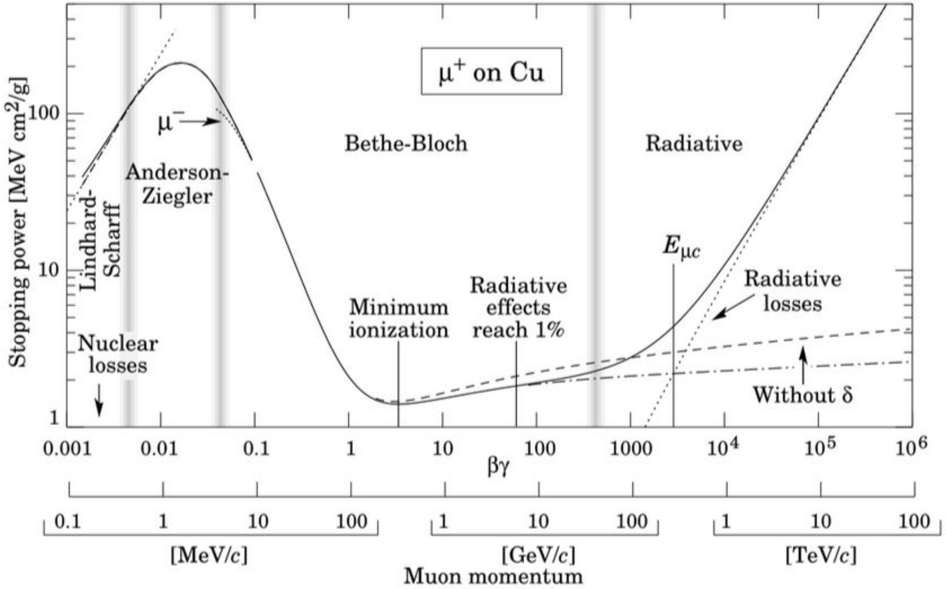
[9] Salzburger, Andreas, Track and vertex reconstruction.

[10] Wikipedia, The Standard Model

Backup

Quick dE/dx Reminder

- Dependency on p/m
- Slow moving, massive particles will have anomalously high dE/dx
  - Decidedly non-Standard-Model-like signature



dE/dx Calculation

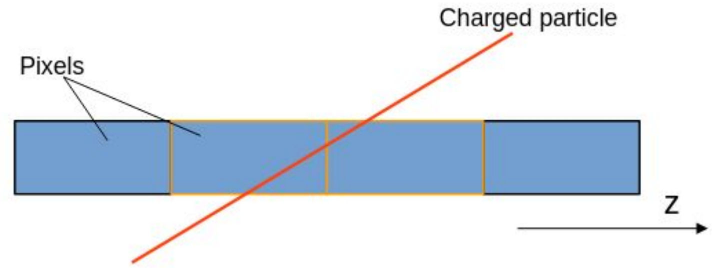
- Not a straight average, rather, a truncated mean
- Truncation pattern based on position of high dE/dx value and potential IBL overflow value
    - 0 = Overflow hit
    - C = Normal hit
    - X = Either

N_c	Cluster pattern	n_{OF}^{IBL}	Truncation pattern		n_{used}
1	X	0 or 1	X	|N/A	1
2	X,X	0 or 1	X	|X	1
3	C,C,X	0 or 1	C,C	|X	2
3	C,0,X	1 or 2	C	|0,X	1
3	0,X,X	1,2,3	0	|X,X	1
4	C,C,C,X	0 or 1	C,C,C	|X	3
4	C,C,0,X	1 or 2	C,C	|0,X	2
4	C,0,X,X	1,2,3	C,0	|X,X	2
4	0,X,X,X	$1,\cdots,4$	0,X	|X,X	2
≥ 5	X,X,X,X,X,$\cdots$	$0,\cdots,N_c$	X,X,X,$\cdots$	|X,X	$N_c - 2$

dE/dx Truncation Pattern

Clusters

- Charged particles excite pixels as they move through them
- Excited pixels are grouped together by a clustering algorithm into clusters
    - Can extract dE/dx information from charge left behind in clusters



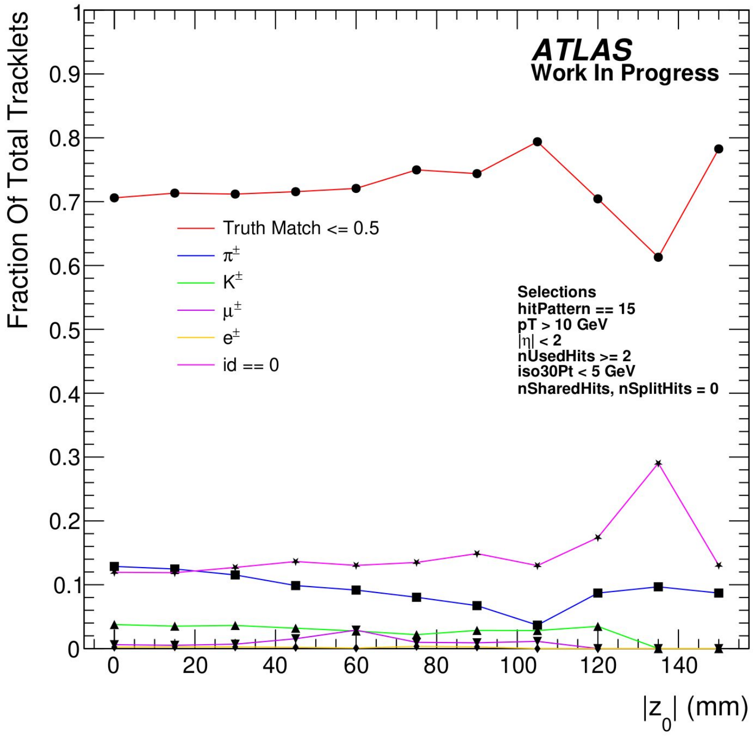
Charged particle moving through pixels (A. Lory)

Why Haven't We Used Clusters Before?

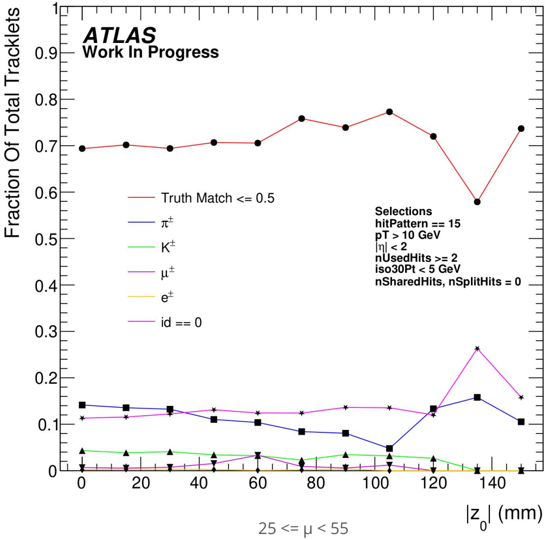
- Blows up file sizes
  - Potential resource limitations
- In order to get around this, we use event picking
  - Select events to add clusters to based on some criteria
    - Criteria tbd
  - ~1 million events

Background Composition By z_0

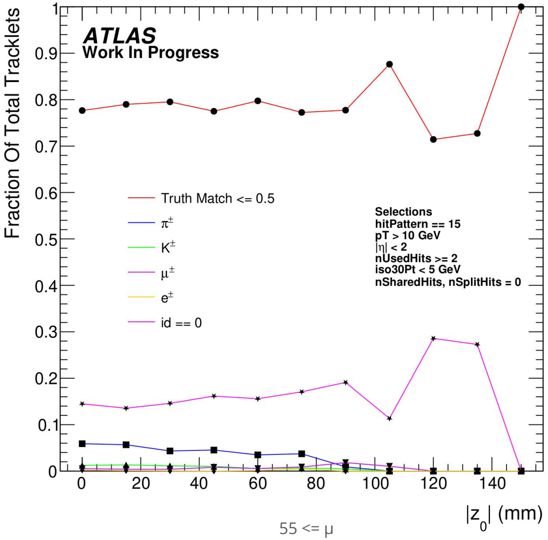
- Interested in how our background changes as a function of a number of variables
- z_0 is longitudinal impact parameter
  - Would expect to see more fakes from pileup at higher $|z_0|$
- Increase is slight but noticeable
- Tracklets with pdgid = 0 (low p_T tracklets) also display this slight increase



Pileup Effects



25 <= μ < 55



55 <= μ

- Individually see a similar story as with just investigating z_0
- Pile up increases the amount of fakes relative to other tracklets as well as id==0 tracklets