Reducing fake tracks for the Muon Collider Detector

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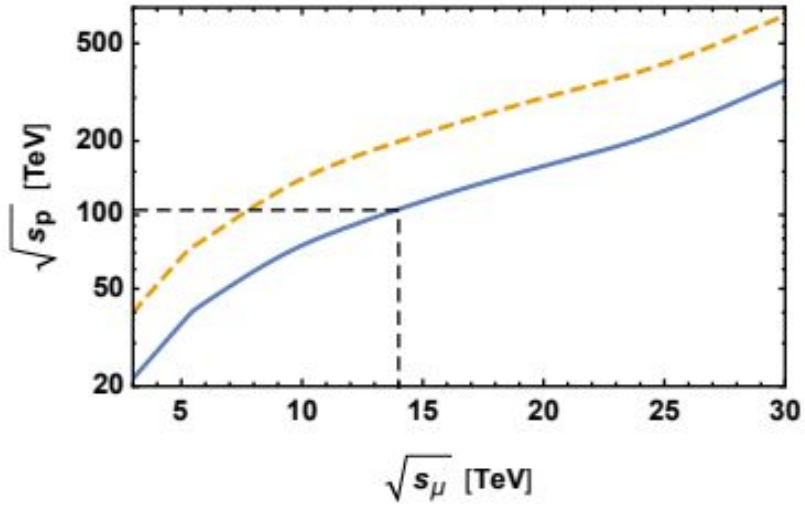
Motivation

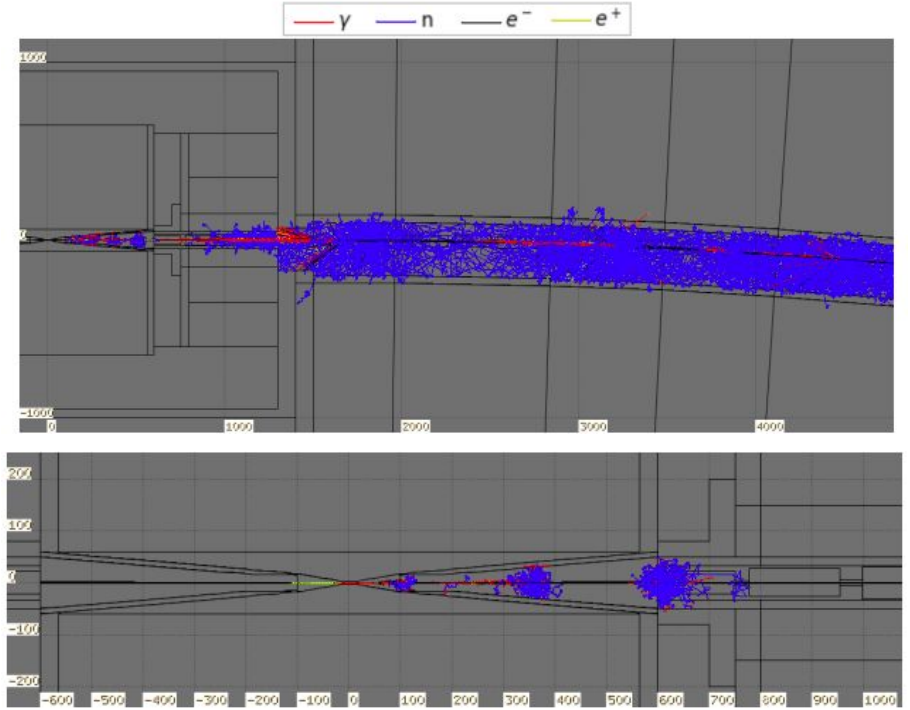
- High energy muon collisions have a lot of scientific potential
- Proton collisions occur between proton constituents, and the energy is divided between them
- Muons are leptons, so the energy isn't divided



Delahaye et al., *Muon Colliders* for the European Particle Physics Strategy Update, 18 January 2019

The problem

- Muons have a finite lifetime and produce a multitude (order 10^8 per bunch crossing) of particles that strike the detector. These are known as beam induced background (BIB)



ATLAS ITk Layer	ITk Hit Density [mm^2]	MCD Equiv. Hit Density [mm^2]
Pixel Layer 0	0.643	3.68
Pixel Layer 1	0.022	0.51
Strips Layer 1	0.003	0.03

C. Aimè et al., *Simulated Detector Performance at the Muon Collider* for Snowmass 2021, 15 March 2022

Approach

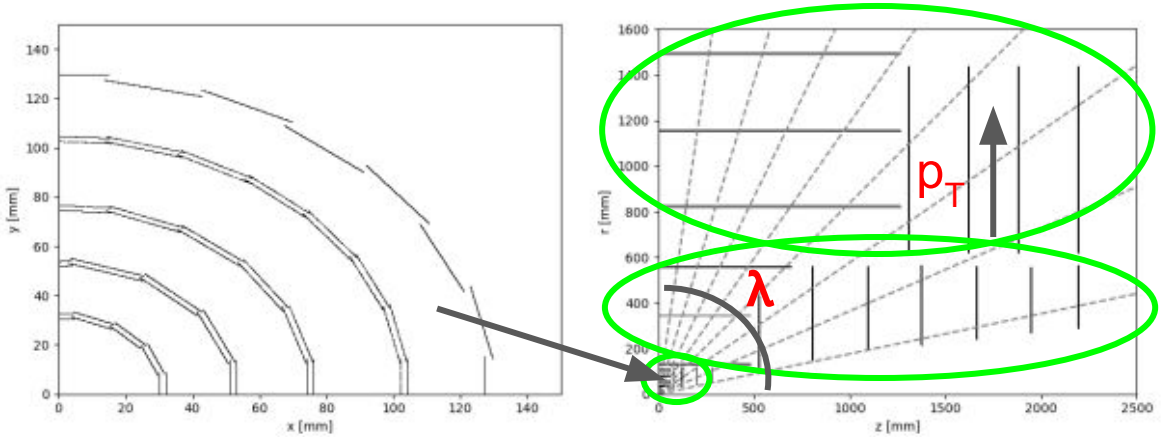
- ACTS (A Common Tracking Software) is our starting point
  - Modern library for charged particle reconstruction
  - ACTS implements a Combinatorial Kalman Filter (CKF) algorithm
  - 100,000+ reconstructed tracks every event, when there should only be one
- Goal is to maximize reconstruction efficiency and minimize “fake” tracks from BIB

Fit Library	Kalman Filter Execution Time
ACTS	0.5 ms / track
iLCsoft	100 ms / track

Krizka, *Detector and Reconstruction Performance* for Snowmass 2022, 11 January 2022

Detector layout

- Cylindrical layout
- All-silicon tracking detector has three parts:
  - Outer tracker
  - Inner tracker
  - Vertex detector
    - Double-layers

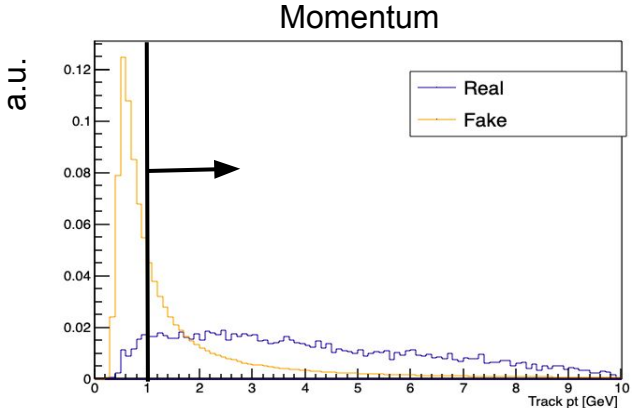


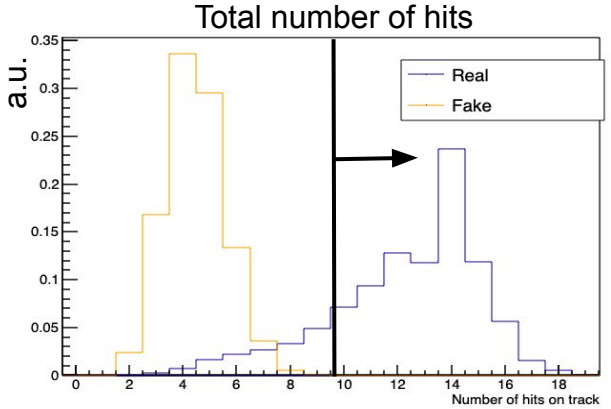
	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	25μm × 25μm	50μm × 1mm	50μm × 10mm
Sensor Thickness	50μm	100μm	100μm
Time Resolution	30ps	60ps	60ps
Spatial Resolution	5μm × 5μm	7μm× 90μm	7μm × 90μm

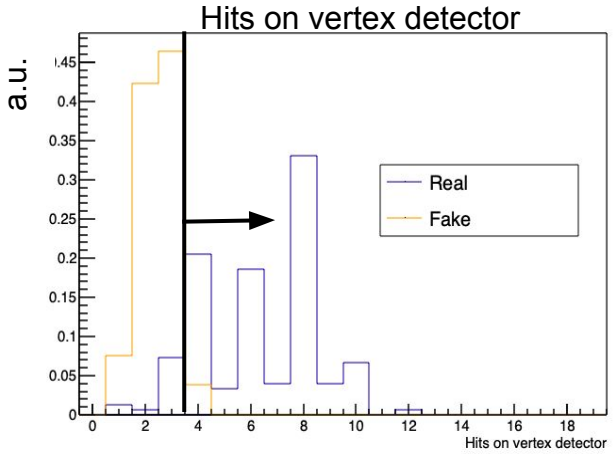
C. Aimè et al., *Simulated Detector Performance at the Muon Collider* for Snowmass 2021, 15 March 2022

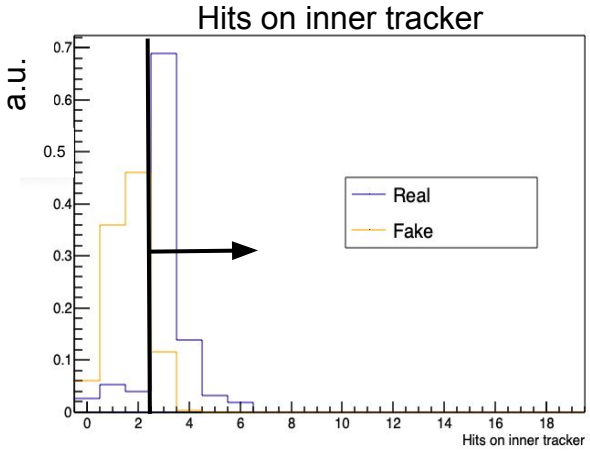
New processor: Filter Tracks

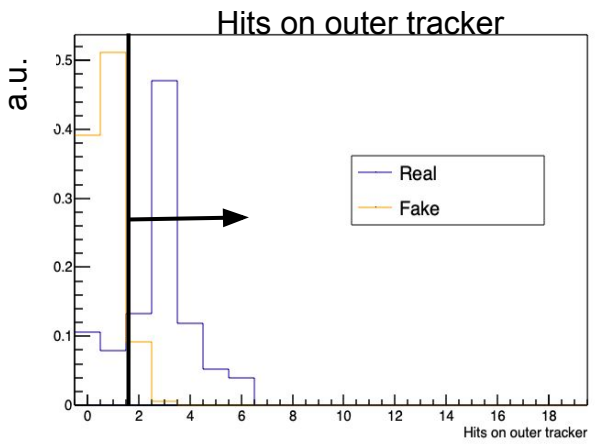
- Takes an input collection of tracks and outputs a collection filtered by certain parameters





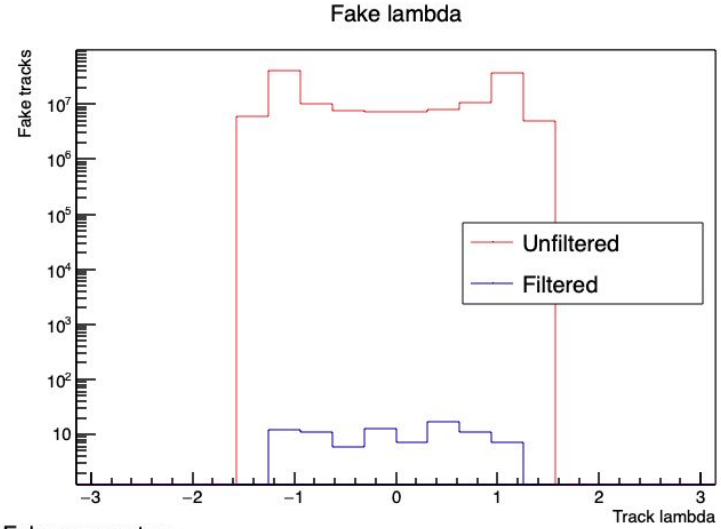


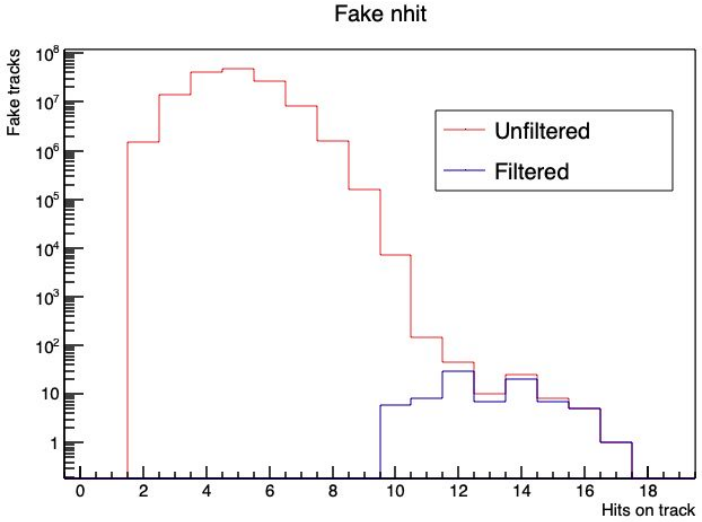


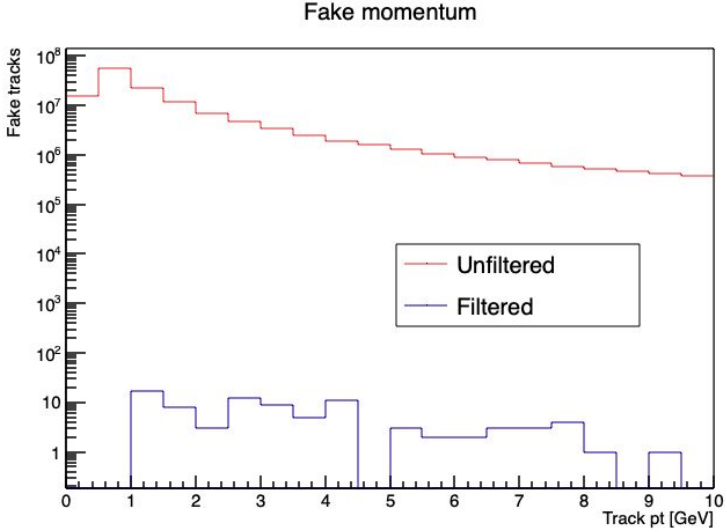


Fake tracks

Average number of fake tracks per event: 134,000 → 0.08



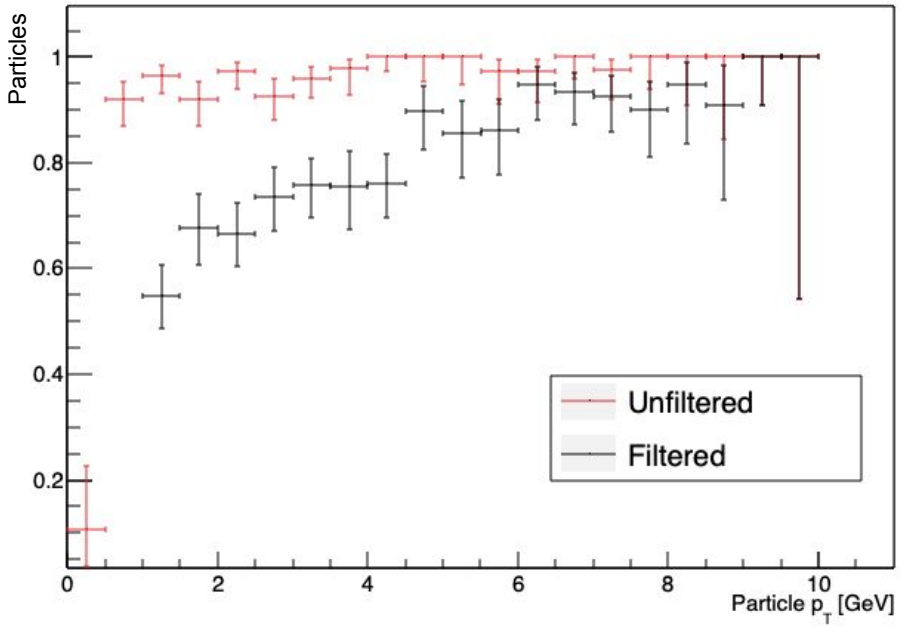




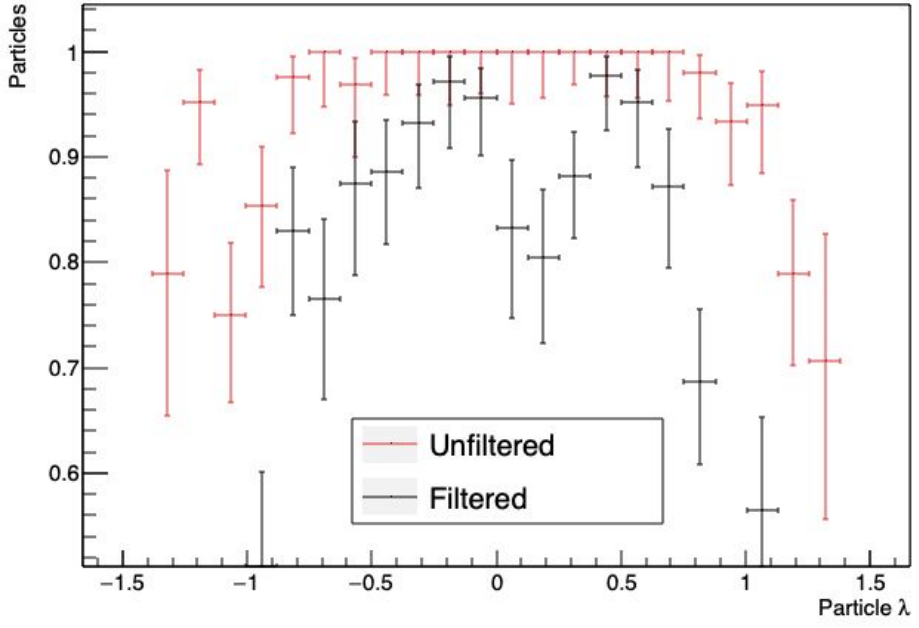
Efficiency

Average efficiency: 0.93 → 0.64

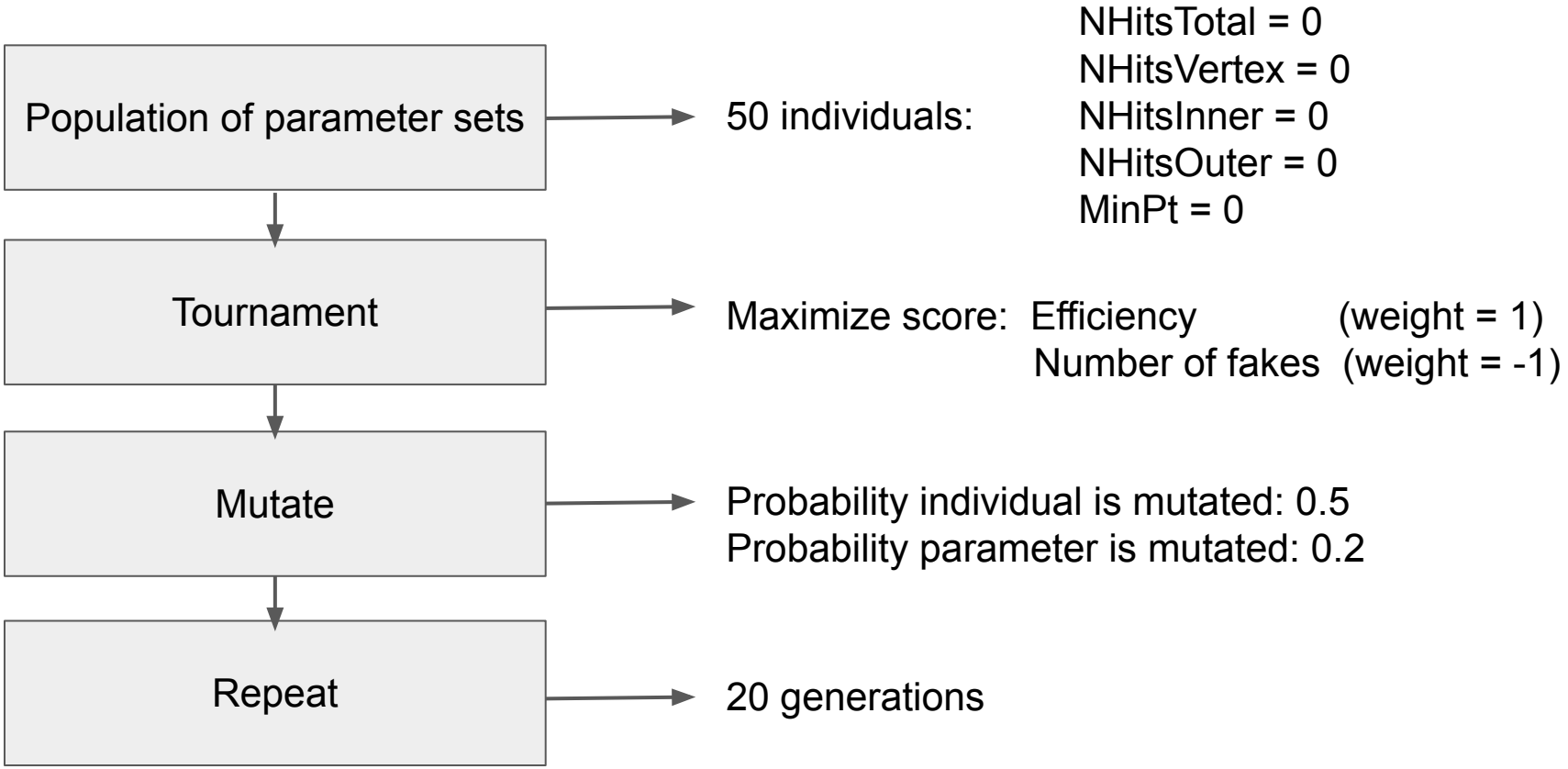
Efficiency vs. Momentum

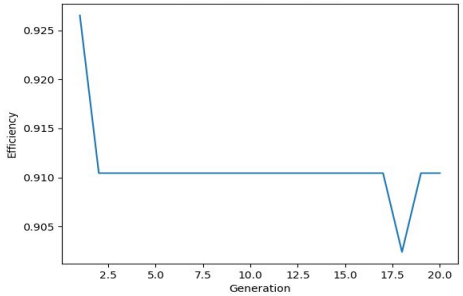
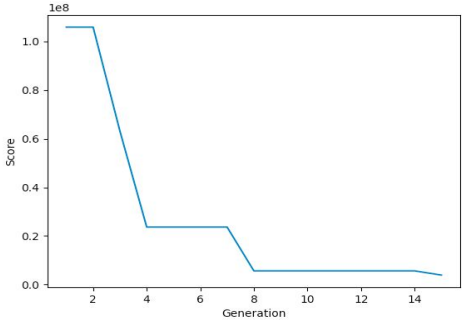
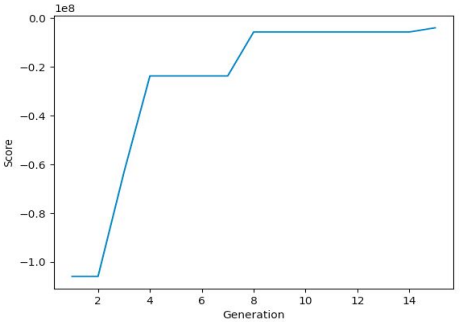
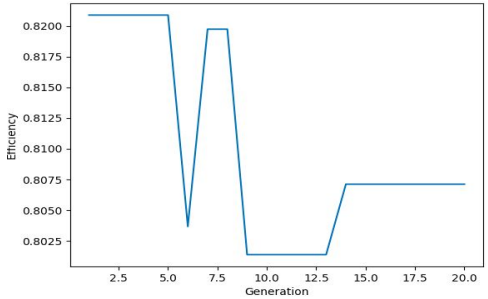
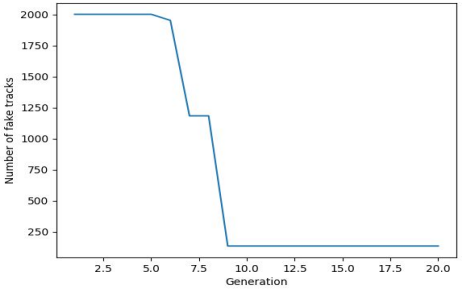
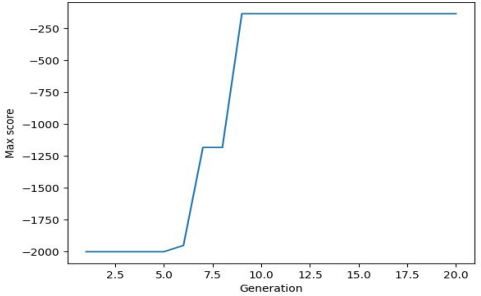
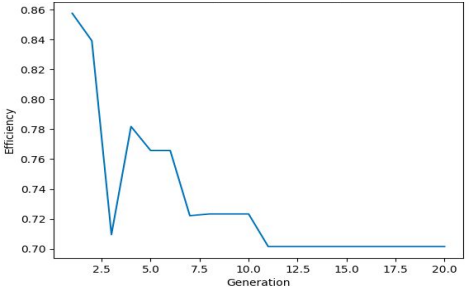
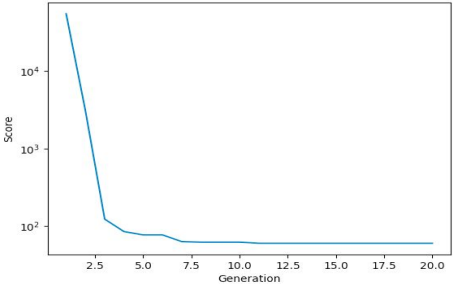
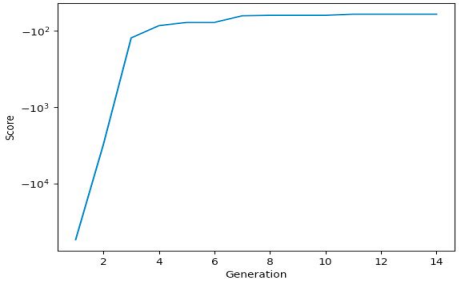


Efficiency vs. Lambda



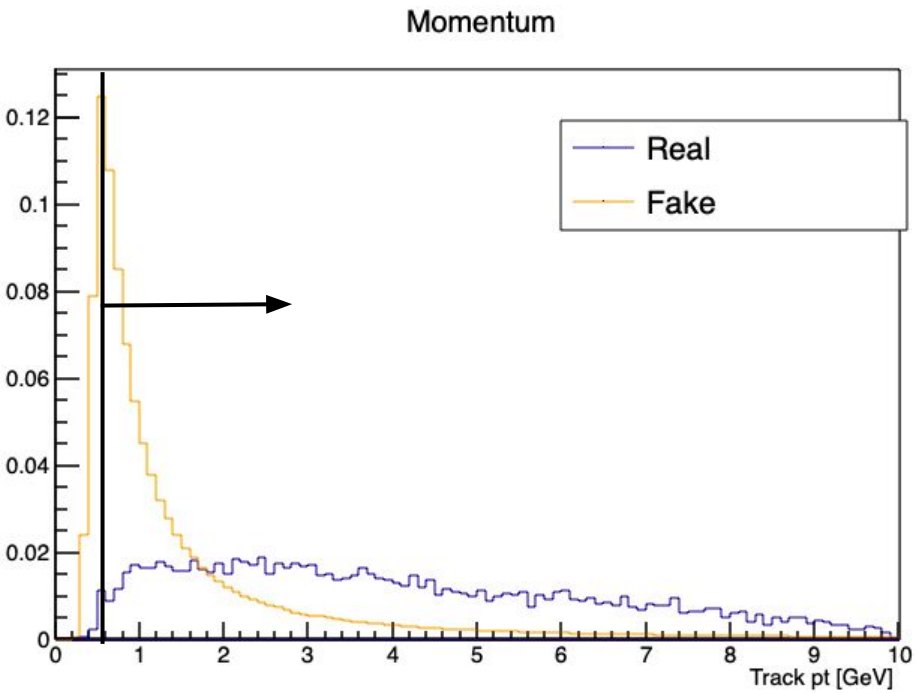
Optimization with evolutionary algorithm

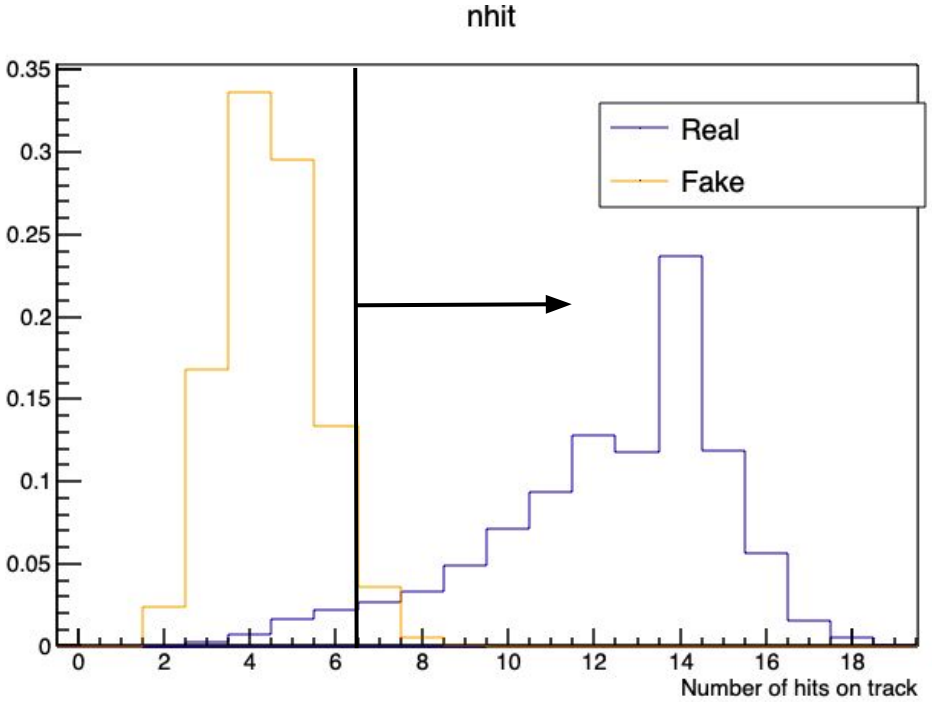


Target efficiency	Efficiency	Number of fakes	Score
90%			
80%			
70%			

Winning parameters for 90% efficiency:

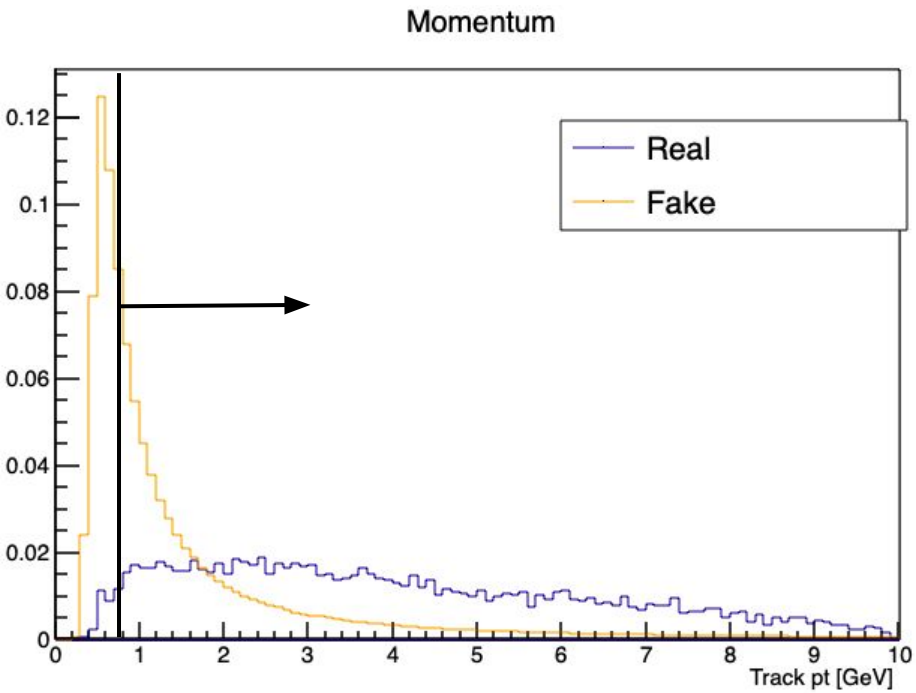
NHitsTotal = 6, NHitsVertex = 0, NHitsInner = 0, NHitsOuter = 0, MinPt = 0.5

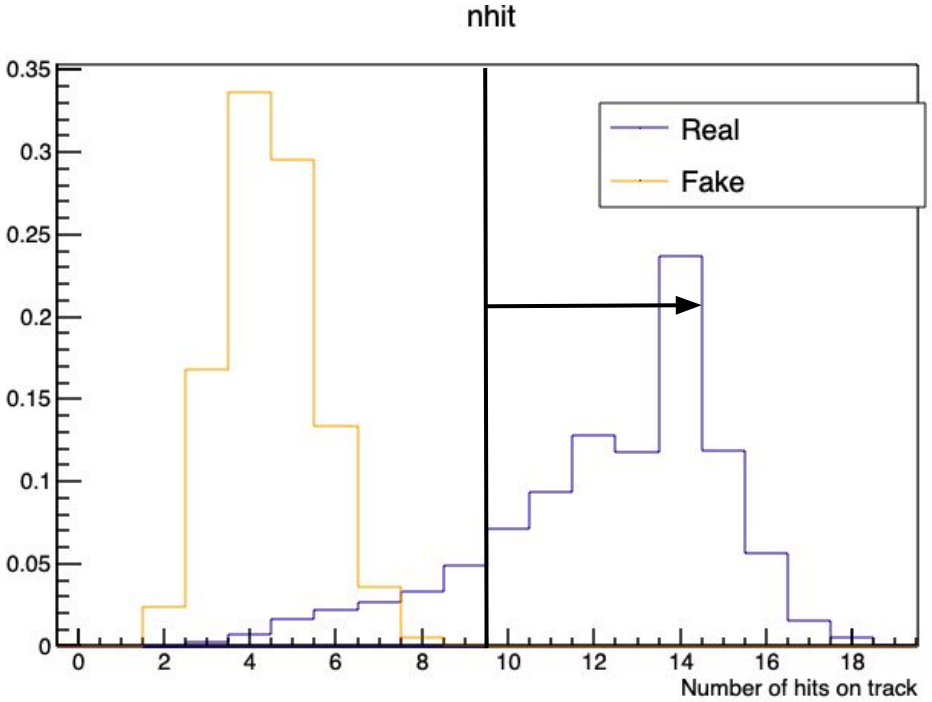




Winning parameters for 80% efficiency:

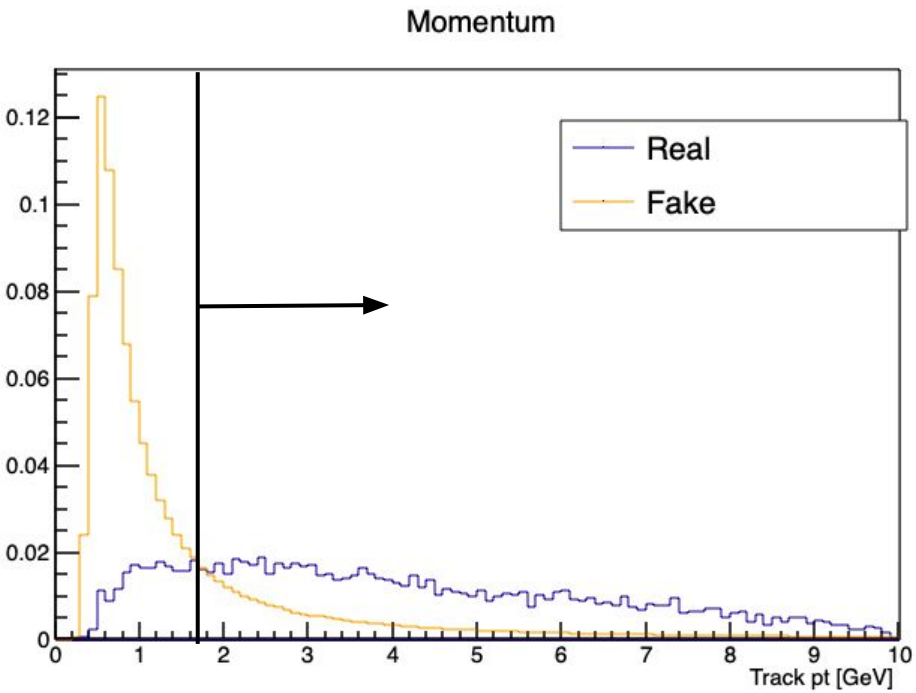
NHitsTotal = 9, NHitsVertex = 0, NHitsInner = 0, NHitsOuter = 0, MinPt = 0.7

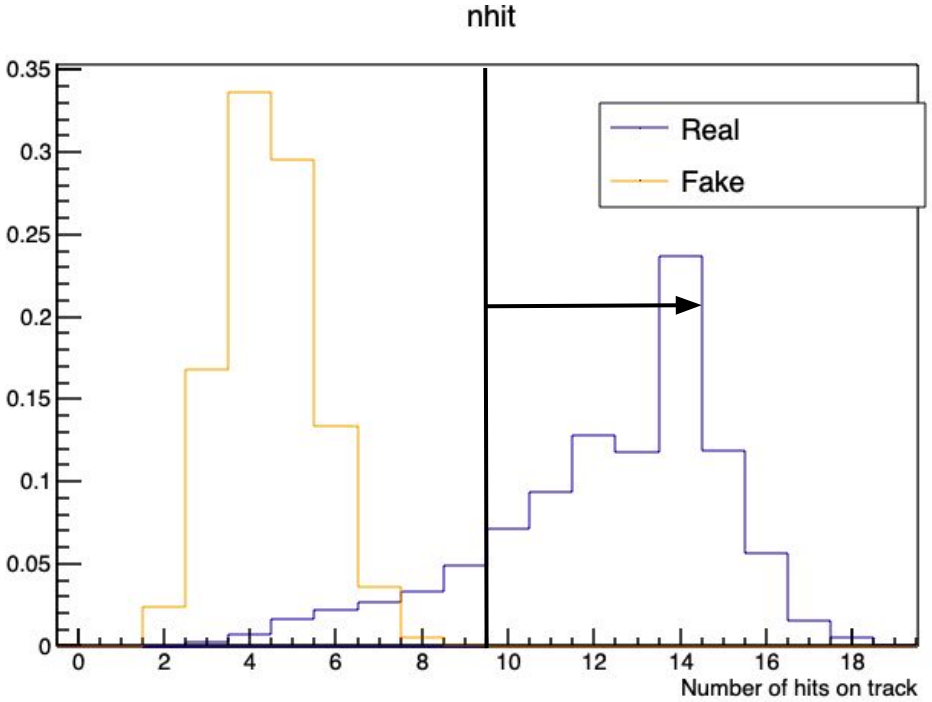




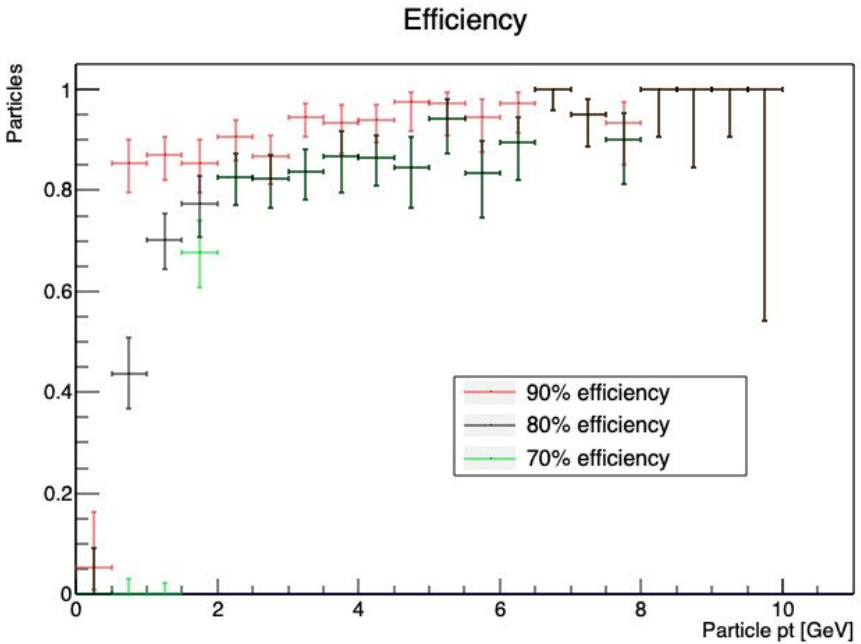
Winning parameters for 70% efficiency:

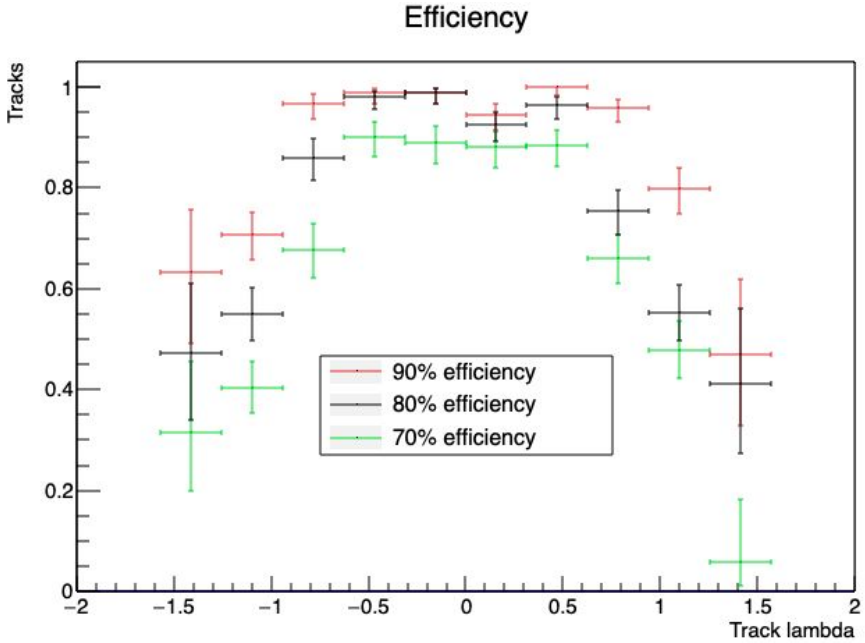
NHitsTotal = 9, NHitsVertex = 0, NHitsInner = 0, NHitsOuter = 0, MinPt = 1.6





Comparing efficiency





Comparing number of fakes

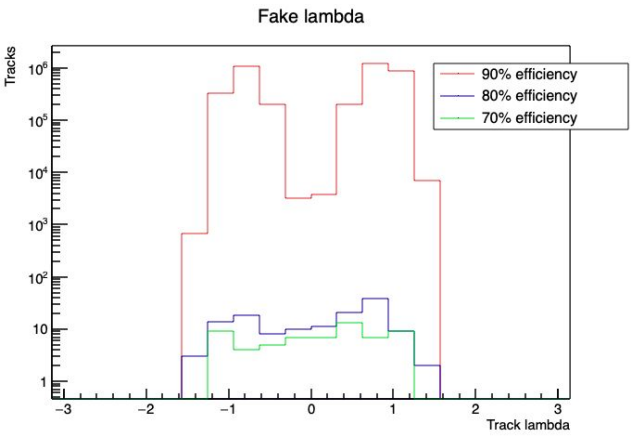
Number of fakes/event: (before filter ~134,000)

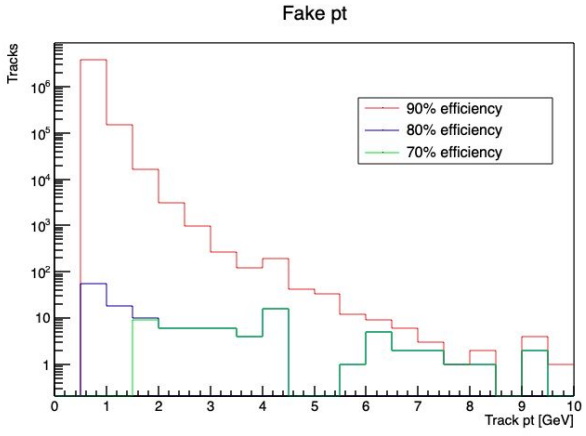
90% → ~3,900

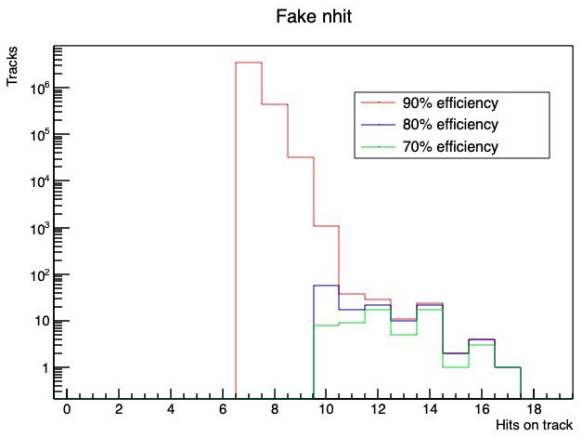
80% → ~0.13

70% → ~0.06

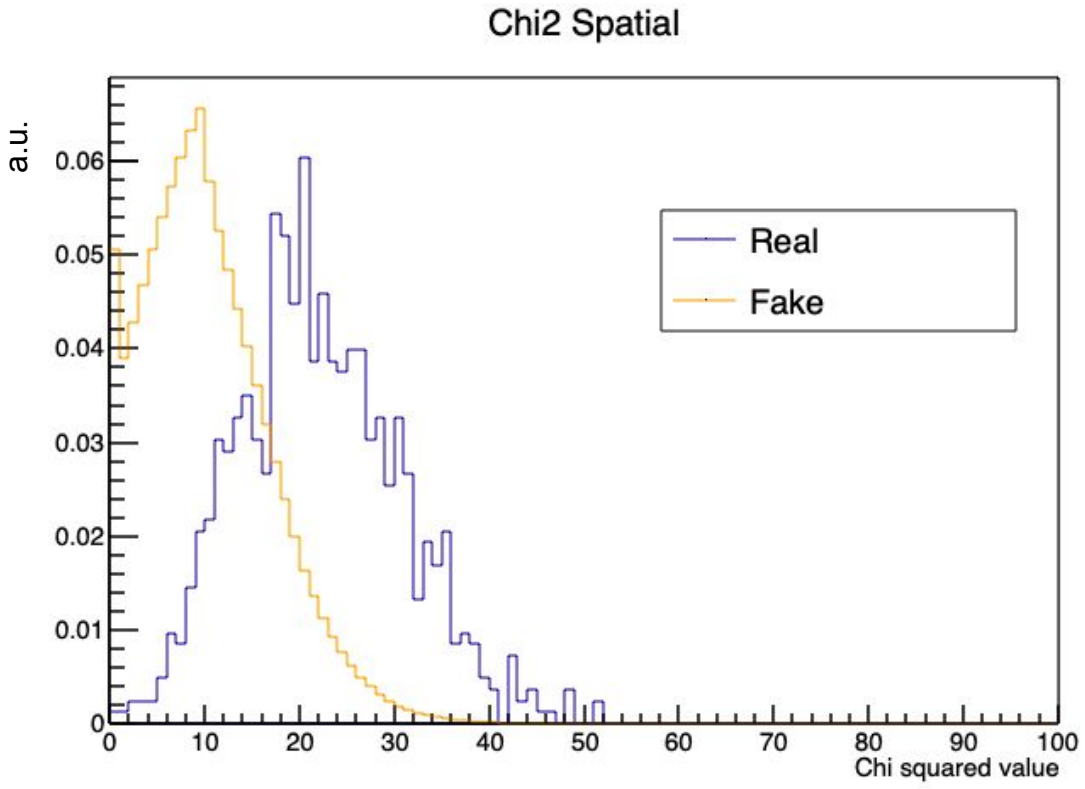
(When cutting by hand: 64% → ~0.08)







Filtering chi-squared values?



Timing information

- Access two consecutive hits on a track (measured positions and times)
- Calculate expected time between hits (approximate track as a straight line)
- Find difference between expected time and observed time

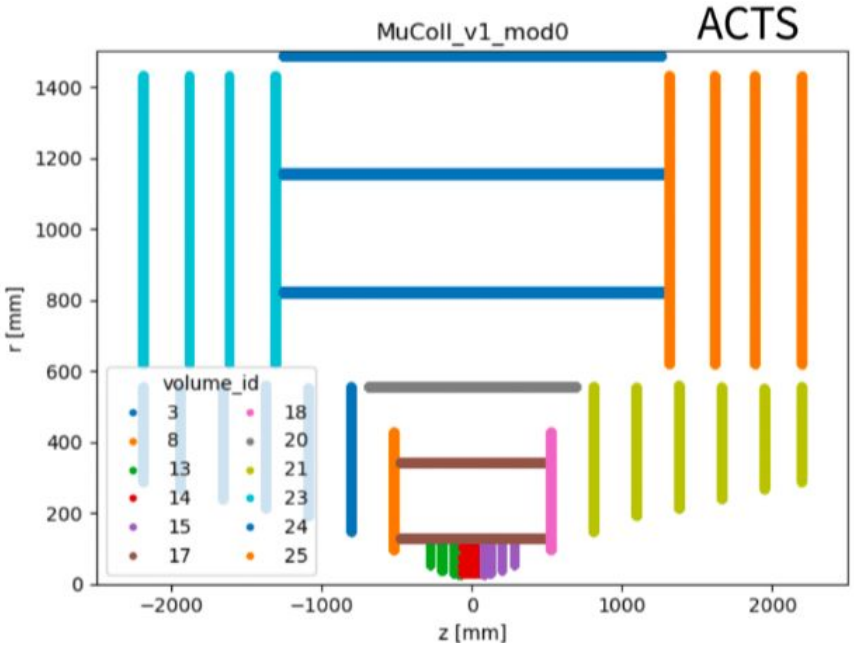
Conclusions

- Cutting fakes comes with a cost on efficiency
- Once a cut on NHitsTotal is made at 9 hits, the most efficient way to reduce fakes is to cut low momentum particles
- Filter could be refined further with spatial chi-squared and timing information
    - Timing cuts could be incorporated into track fitting

Outside-in tracking

ATLAS ITk Layer	ITk Hit Density [mm^2]	MCD Equiv. Hit Density [mm^2]
Pixel Layer 0	0.643	3.68
Pixel Layer 1	0.022	0.51
Strips Layer 1	0.003	0.03

- Outer tracker has lower hit density than vertex detector
- Smaller hit density = fewer seeds = fewer fake tracks
- Try seeding with outer tracker (layers 23, 24, 25)

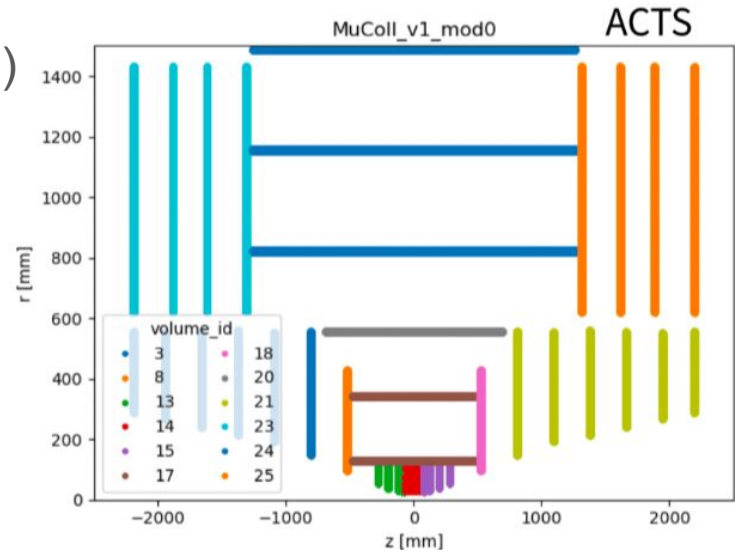


Krizka, *ACTS Tracking for Muon Collider* for MCC Meeting, 17 December 2020

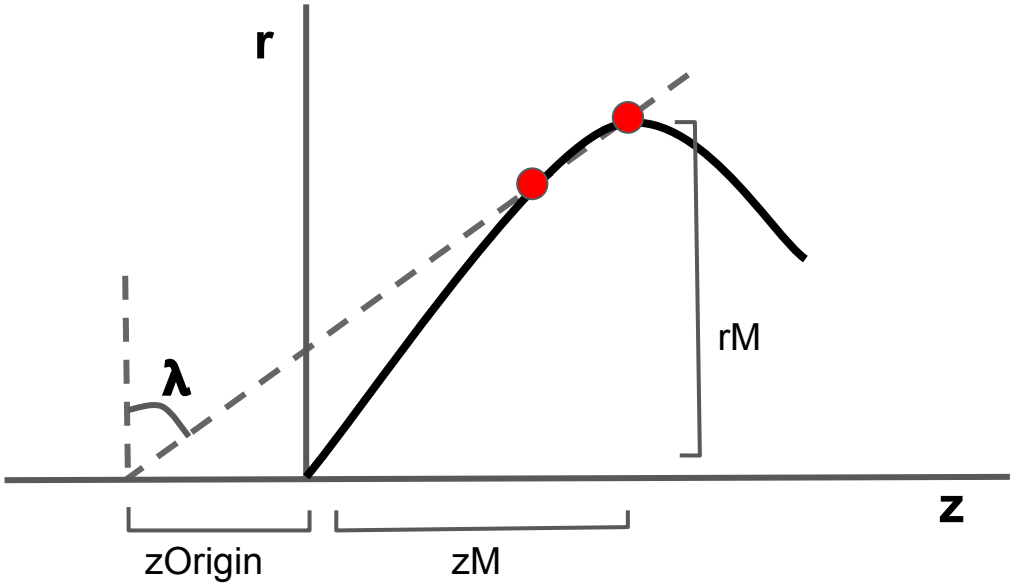
Parameters changed

- SeedingLayers 13, 14 ,15 → 23, 24, 25
- SeedFinding_RMax: 150 → 1600 (mm)
- SeedFinding_DeltaRMax: 80 → 400 (mm)
- SeedFinding_ZMax NA → 2500 (mm)
- PropagateBackward FALSE → TRUE
- InitialTrackError_Pos 10 → 100 (μm)

	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	25μm × 25μm	50μm × 1mm	50μm × 10mm
Sensor Thickness	50μm	100μm	100μm
Time Resolution	30ps	60ps	60ps
Spatial Resolution	5μm × 5μm	7μm× 90μm	7μm × 90μm



- SeedFinding_CollisionRegion: 1 → 50 (mm)



$$tan(\lambda) = \frac{zM - zOrigin}{rM}$$

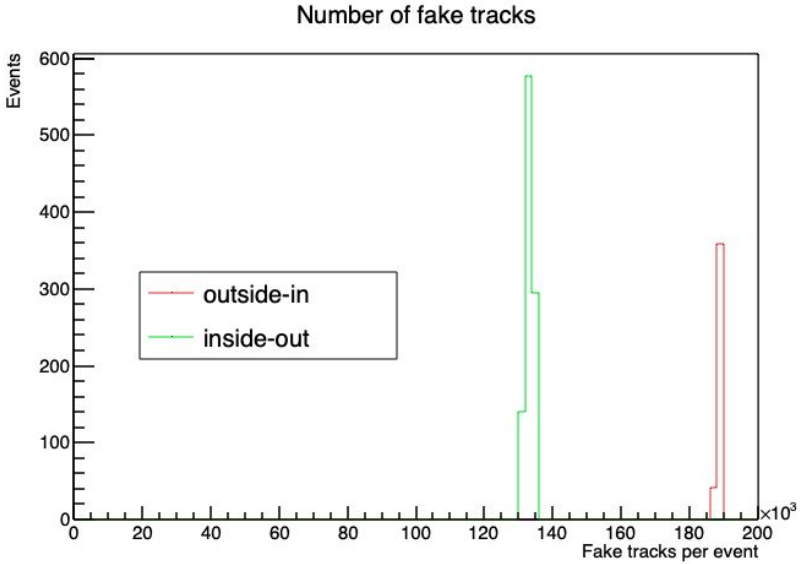
$$zOrigin = zM - rM * tan(\lambda)$$

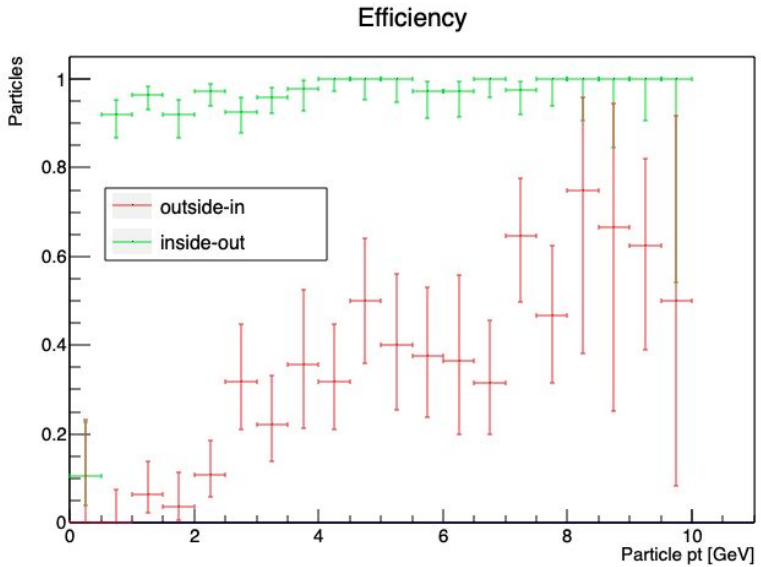
- SeedFinding_MinPt 500 → 2000 (MeV)

$$p_T = radius * 300 * B_Z$$

Performance

- Outside-in has more seeds, more fake tracks, and lower efficiency
- Outside-in takes longer to complete MyCKFTracking
  - Inside-out: ~350 seconds/event
  - Outside-in: ~780 seconds/event





Outside-in conclusions:

- Initial assumption that outside-in tracking would have fewer seeds was wrong (with current parameters)
- Possibility of using evolutionary algorithm to optimize parameters
  - Did not complete this because of how long outside-in reconstruction takes
- Outside-in tracking could still be useful for particles with displaced tracks that don’t leave hits on the vertex detector (not optimal but possible if necessary)

Final conclusions

- Two methods of reducing fake tracks:
  - Inside-out tracking with track filter, using evolutionary algorithm for optimization
    - Reduction in fakes comes with loss of efficiency, especially from removing low momentum particles
    - Could be improved further with spatial and temporal chi-squared cuts
  - Outside-in tracking
    - Didn’t work as expected
    - Will impact track reconstruction of displaced particles

Thanks for listening!