Tracking
- status and plans -

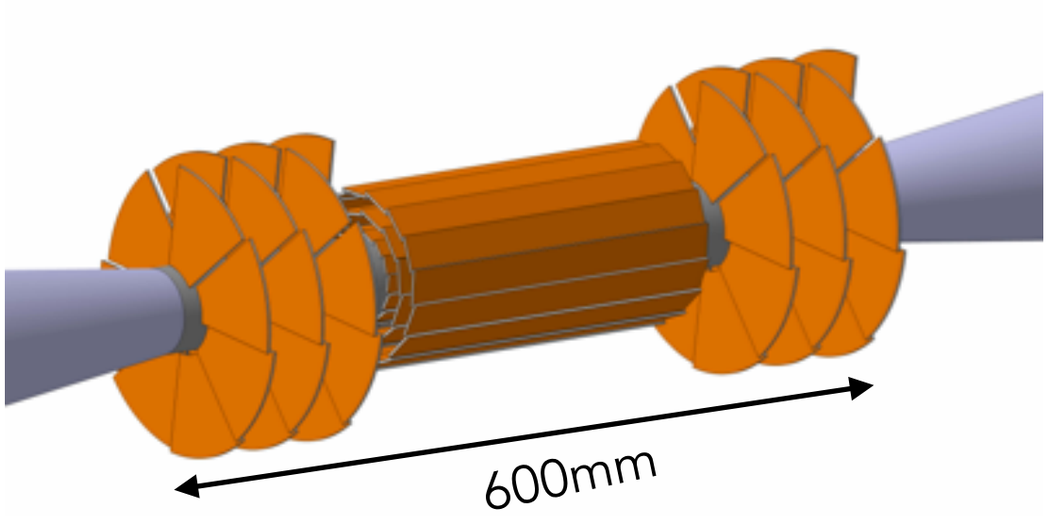
Emilia Leogrande (CERN), on behalf of the CLICdp Collaboration

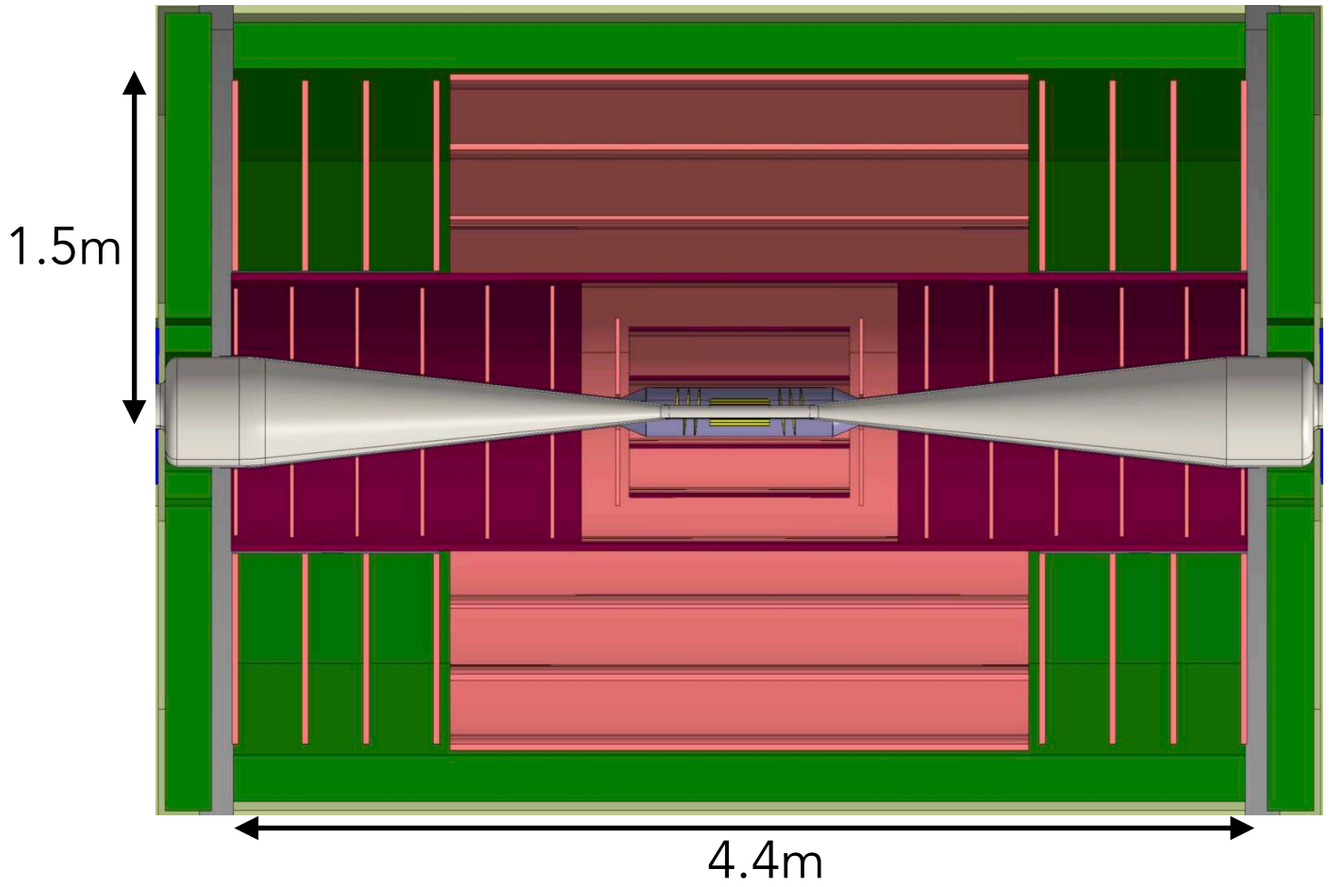
CLICdp Collaboration Meeting
29th August 2018

Content of the talk

- Recap
  - CLICdet tracking system
  - Conformal tracking algorithm
- Where were we? Status at the April's Advisory Board Meeting
- Major updates in the reconstruction chain
- Where are we now? Current status
- Where do we plan to be? Future improvements

CLICdet tracking system

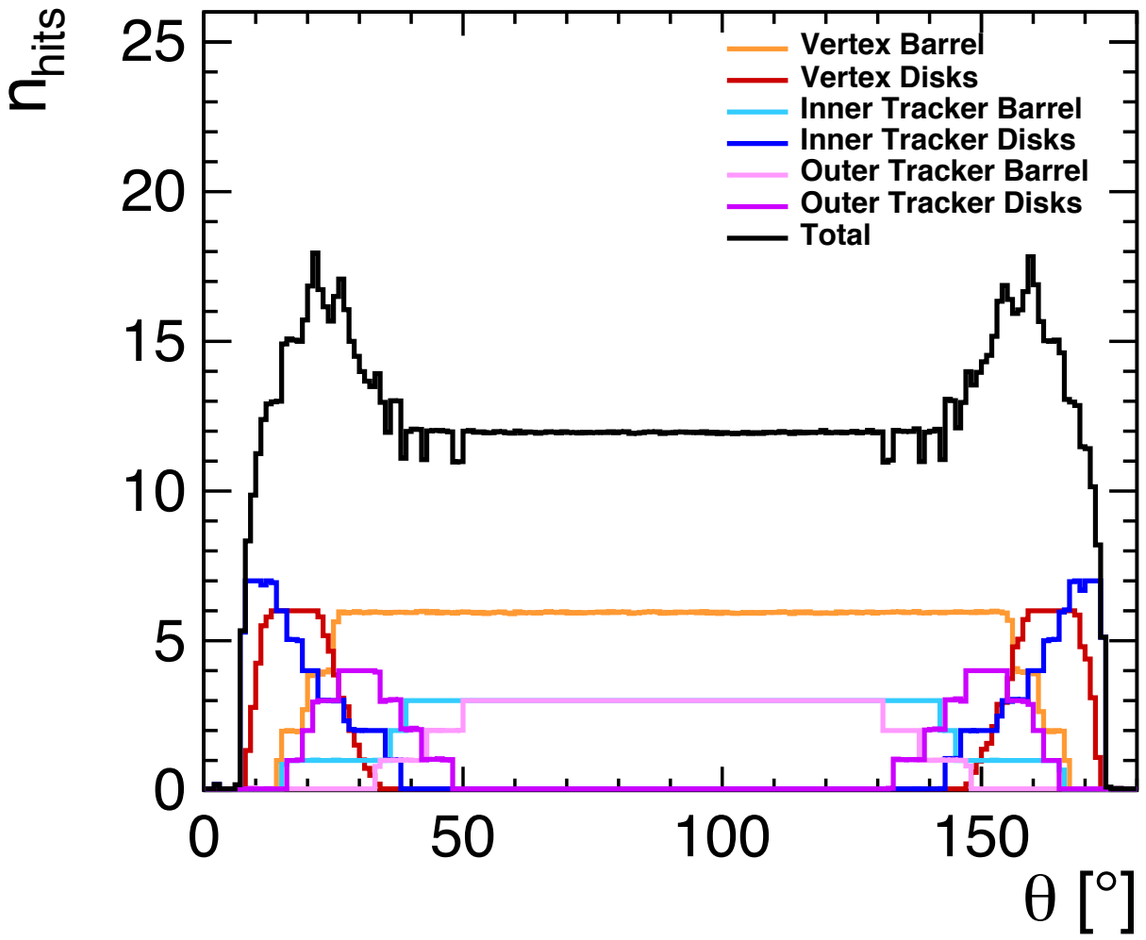




- ➡ Total sensitive area = 0.84 m^2
- ➡ 25x25 μm^2 pixel size
- ➡ 50 µm sensor thickness
- ➡ assumed 3 µm single point res

- ➡ Total sensitive area = 137 m^2
- ➡ 50 µm x [1-10]mm microstrip size
- ➡ 200 µm sensor thickness
- ➡ assumed 7x90 µm single point res

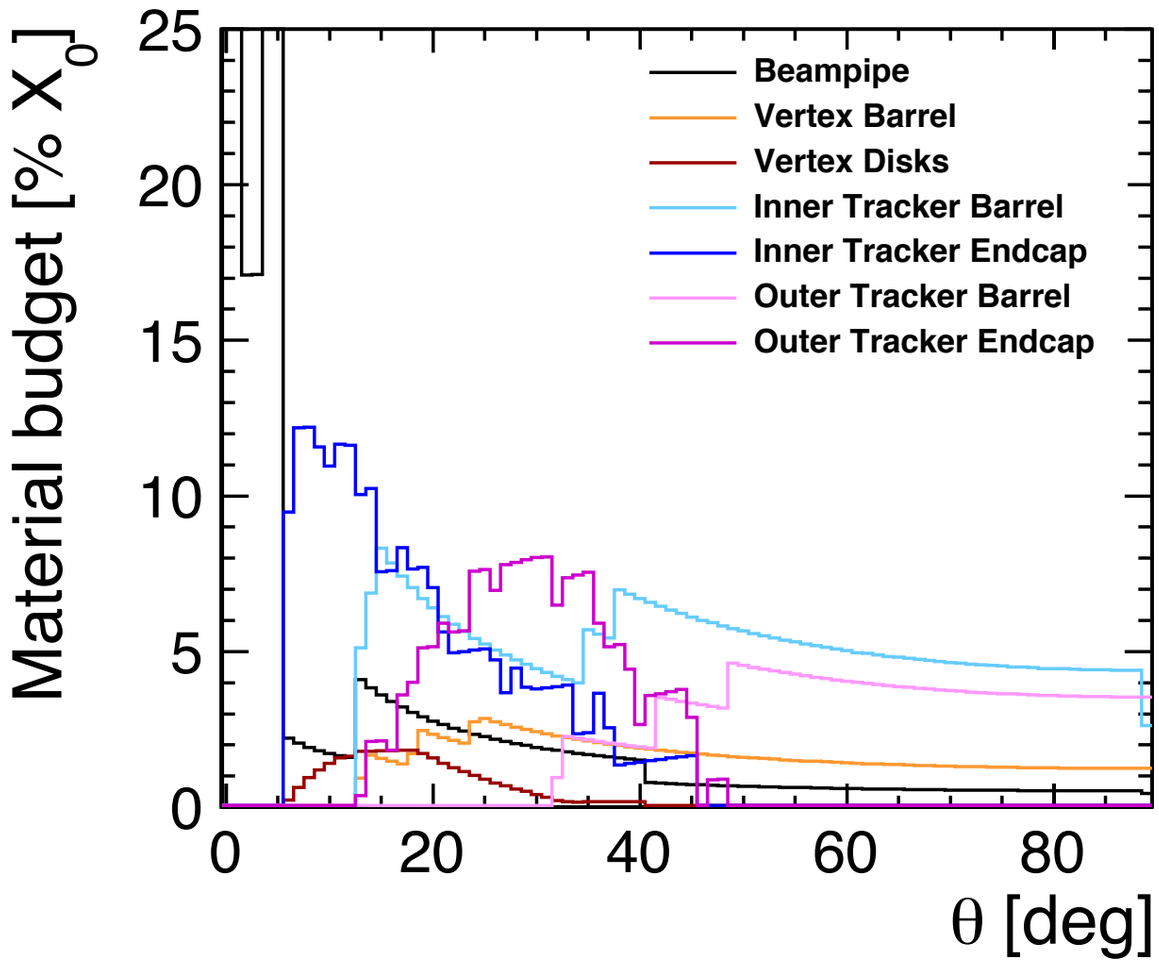
Tracking system (vertex + tracker) coverage and material budget



Tracking system optimized to have full coverage for tracking reconstruction

Material budget

- vertex = 0.2%X_0 per single layer
- tracker = 1%X_0 per layer
- main support tube + cables = 2.5%X_0

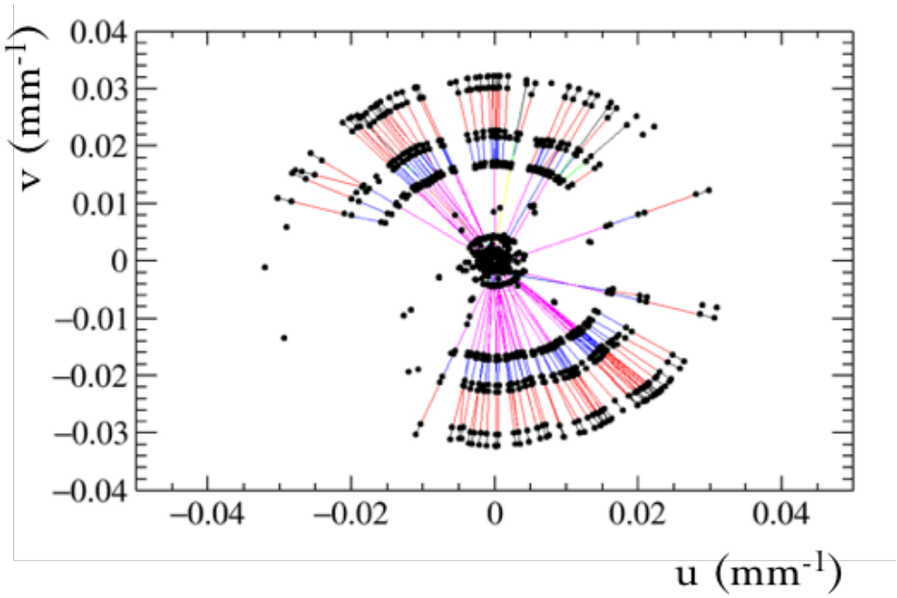


Conformal tracking

Pattern recognition in conformal space

$$\begin{cases} u = x/(x^2+y^2) \\ v = y/(x^2+y^2) \end{cases}$$

- cellular automaton for straight line search
- prompt tracks
  - minimum number of hits for track reconstruction = 4
  - from vertex to tracker hits
- displaced tracks
  - minimum number of hits for track reconstruction = 5
  - from tracker to vertex hits



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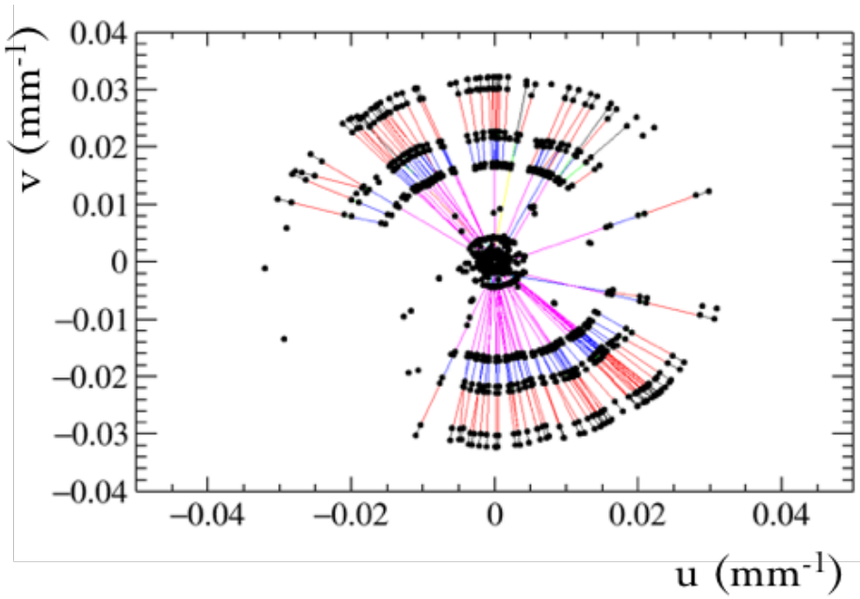
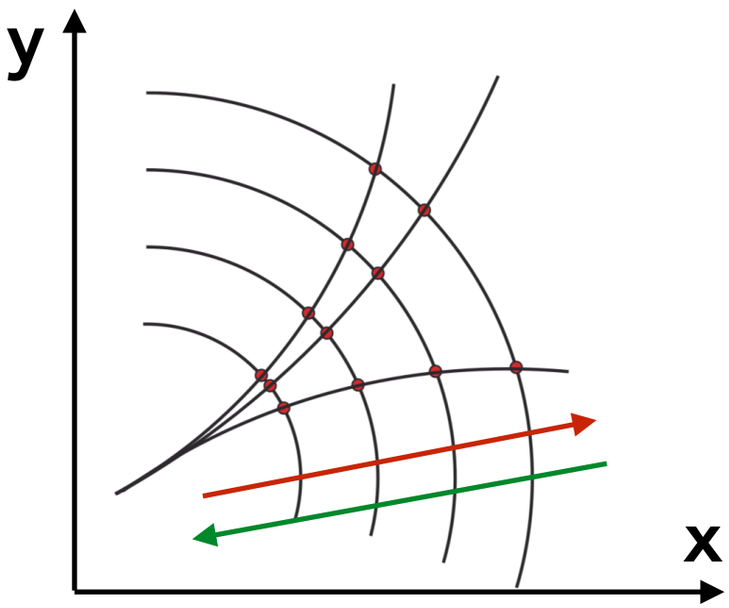




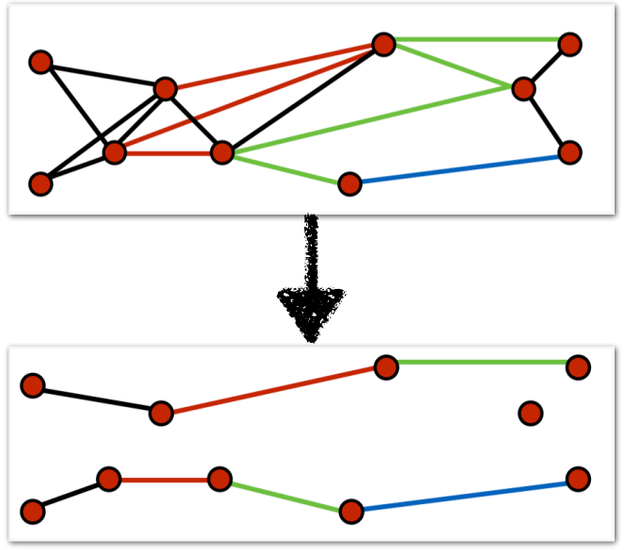
Track fit

- helix prefit with 3 hits
- iterative Kalman filter
  - fit forward and smooth backward

Where were we? April's AB Meeting

Build tracks in conformal space

- all hits of the input collection are used as seeds
- from each seed, nearest neighbours search with kdtree
- creation of cells with valid hits
- creation of cellular tracks (chains of cells)
- linear regression fit to accept/reject cellular tracks



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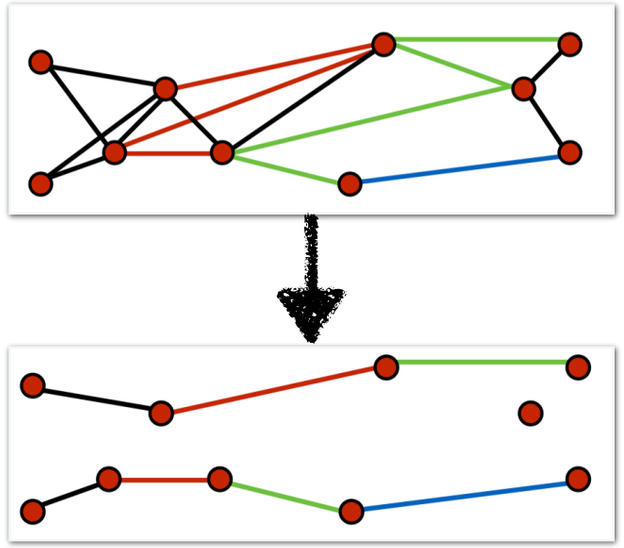

Extend tracks in conformal space

- last hit of built tracks is used as seed
- from each track endpoint, nearest neighbours search with kdtree
    - for tracks with p_T > 10 GeV: cellular automaton as in build
    - for tracks with p_T < 10 GeV: valid hits added one by one to the track

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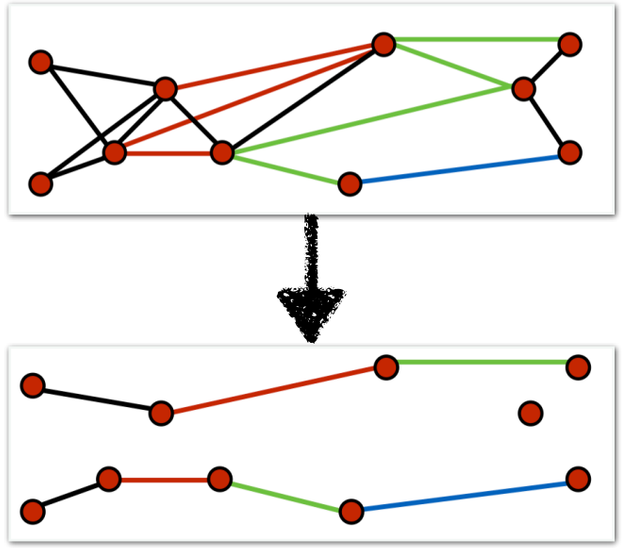

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- from each track endpoint, nearest neighbours search with kdtree
  - for tracks with p_T > 10 GeV: cellular automaton as in build
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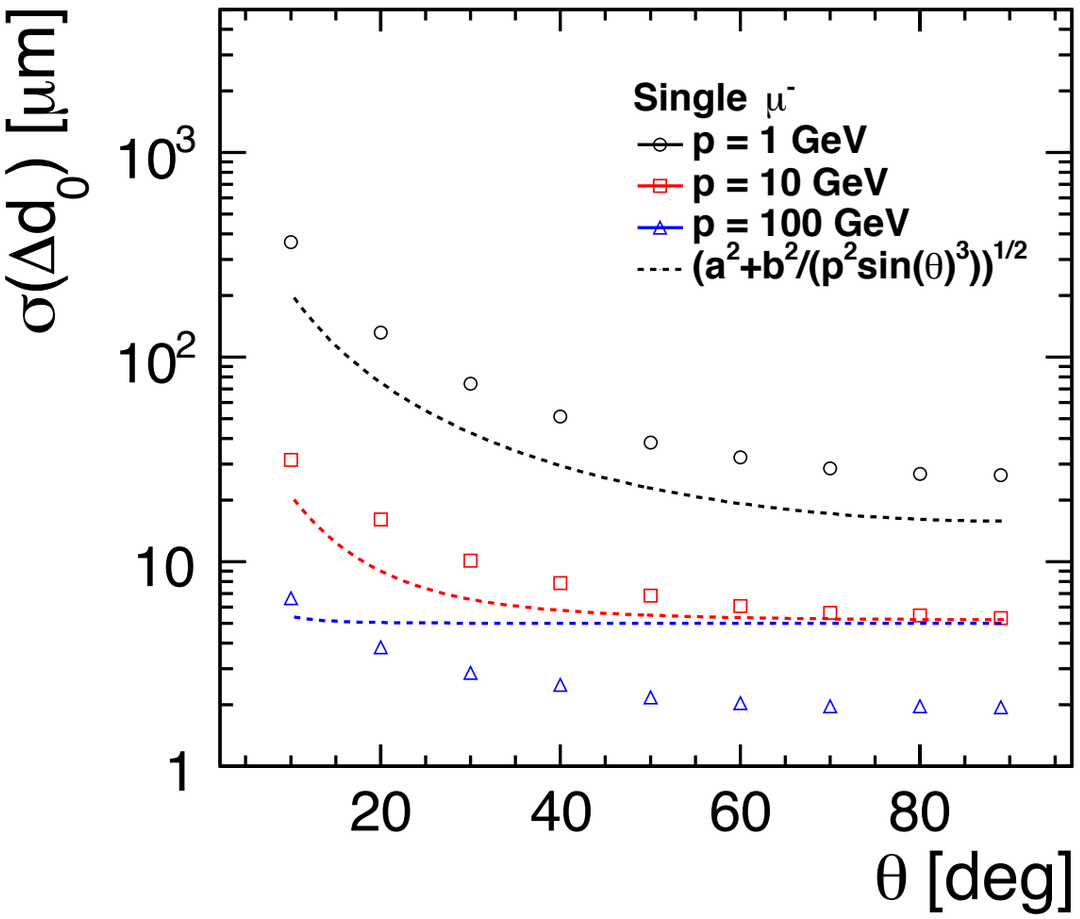
Full chain

Build tracks	Vertex barrel	Standard cuts
Extend tracks	Vertex endcap	Standard cuts
Build tracks	Vertex b + e	Standard cuts
Build tracks	Vertex b + e	Looser cuts (angle x 5)
Build tracks	Vertex b + e	Looser cuts (angle x 10)
Build tracks	Vertex b + e	Looser cuts (angle x 10; χ^2 x 20)
Extend tracks	Tracker collections	Looser cuts (angle x 10; χ^2 x 20)
Build tracks	All collections	Displaced cuts

Where were we? April's AB Meeting

Resolution = σ of the distribution Δ (reconstructed - true)



Achieved desired d_0 resolution for high-energy muons well below the high-momentum limit of 5 μm

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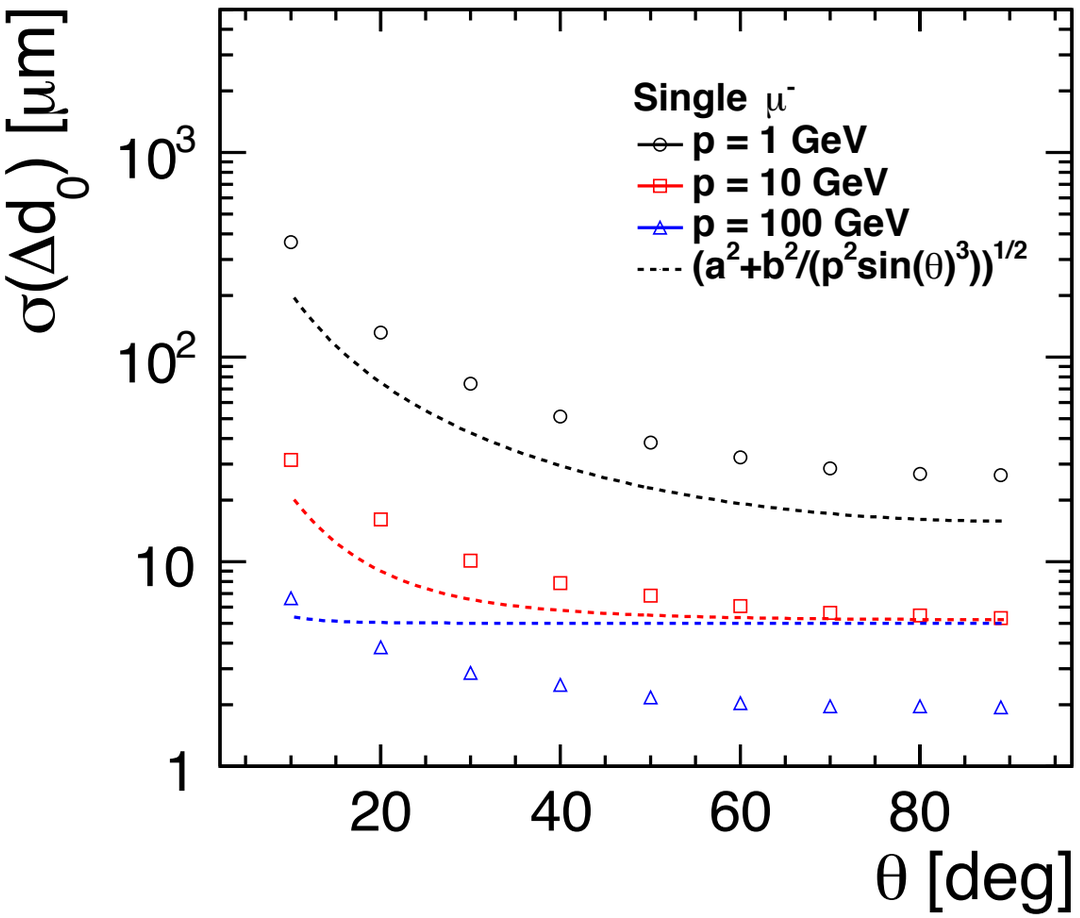

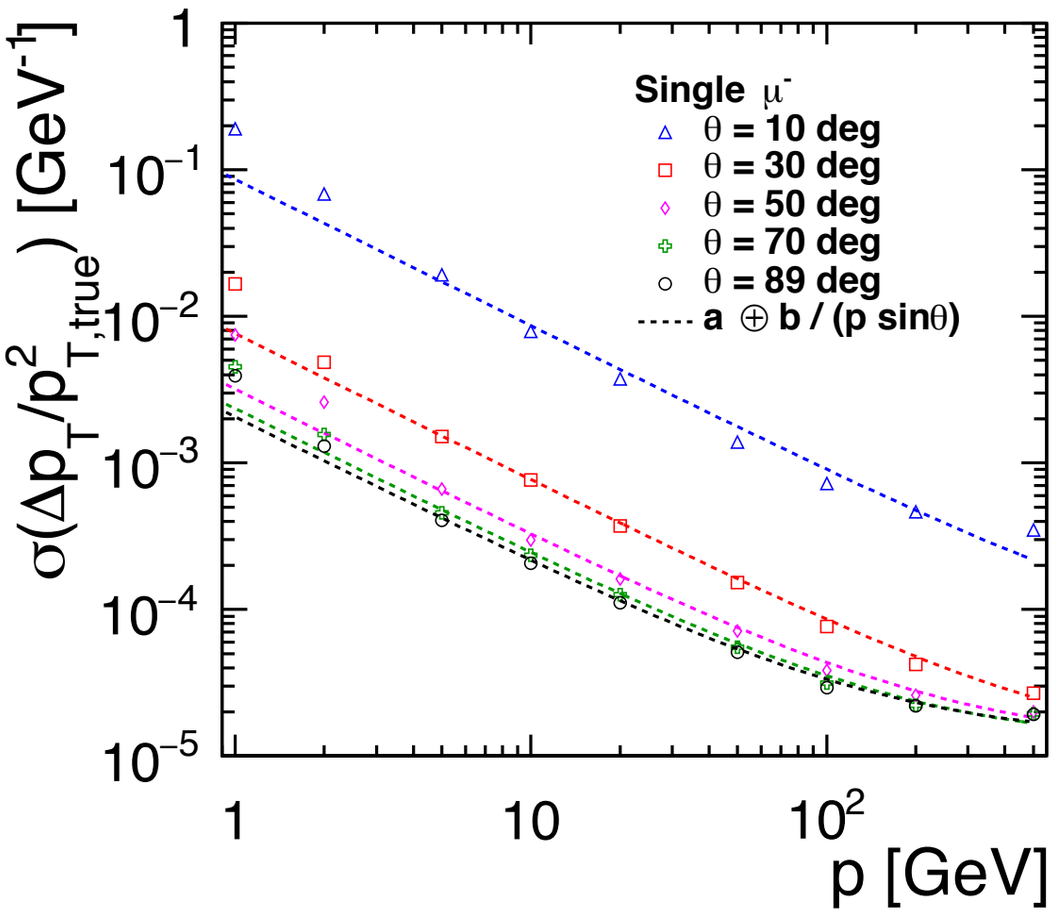

Achieved desired d_0 resolution for high-energy muons well below the high-momentum limit of 5 μm

Achieved transverse momentum resolution goal of 2×10^{-5} GeV^{-1} for high-energy muons in the barrel

Where were we? April's AB Meeting

Efficiency = fraction of pure reconstructed particles out of the reconstructable

whose majority of hits (>= 75%) belong to the same particle

- stable
- p_T > 0.1 GeV/c
- |cosθ| < 0.99
- #unique hits >=4

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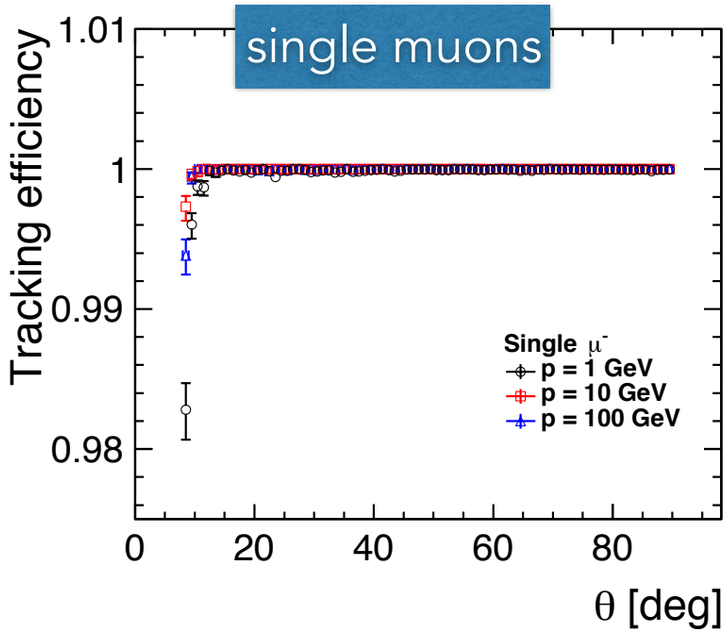

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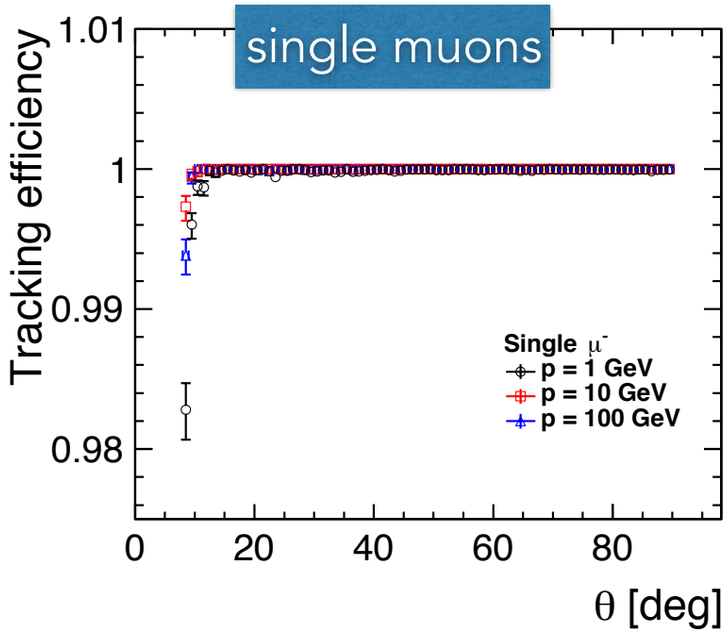

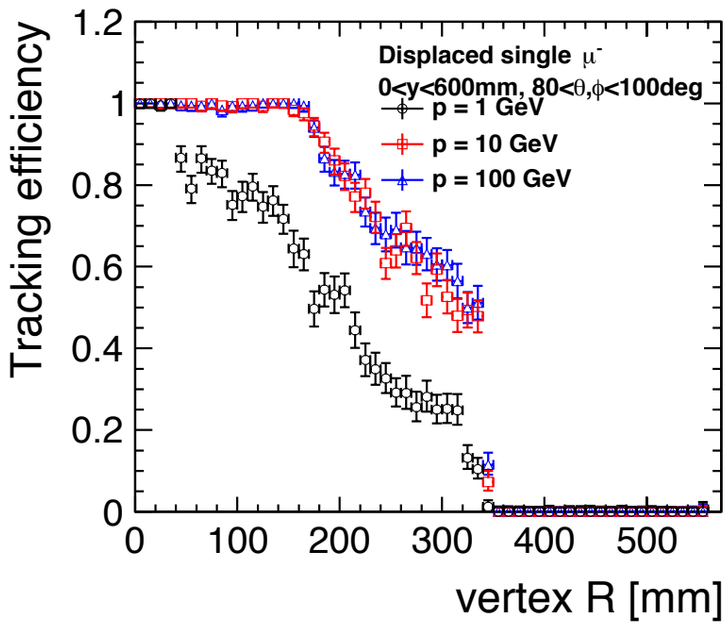

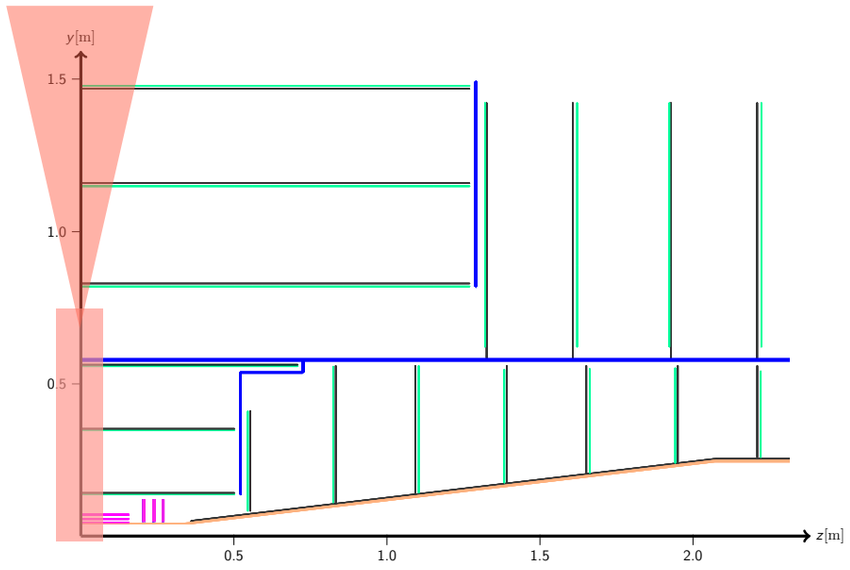

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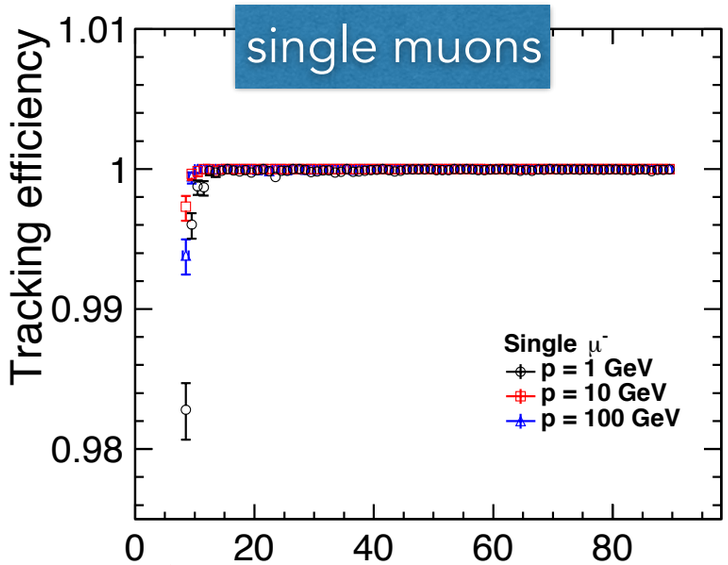

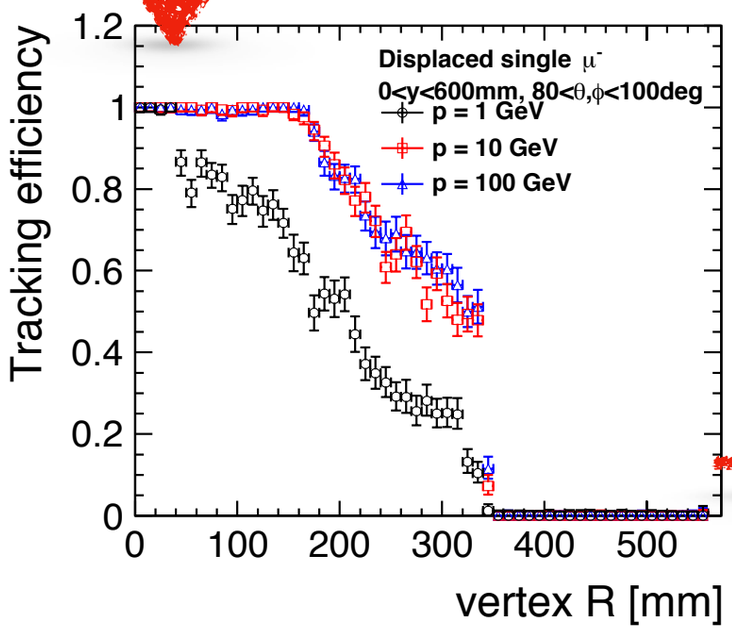

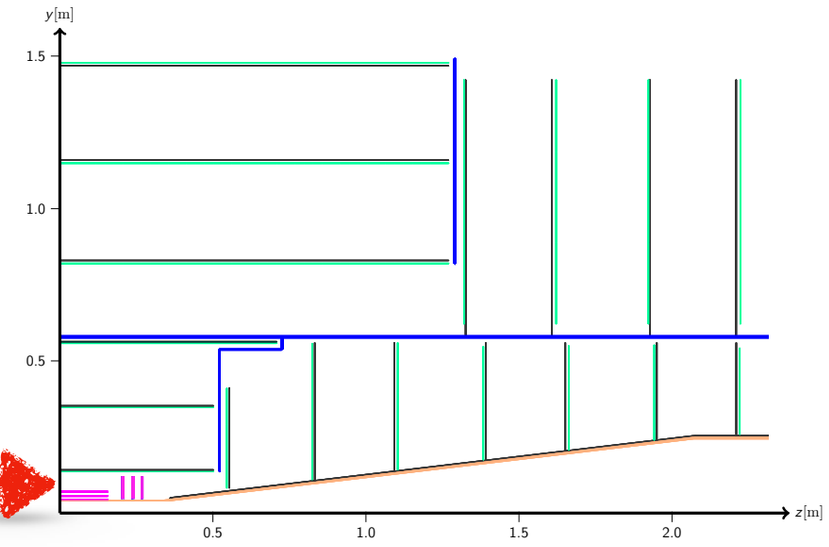

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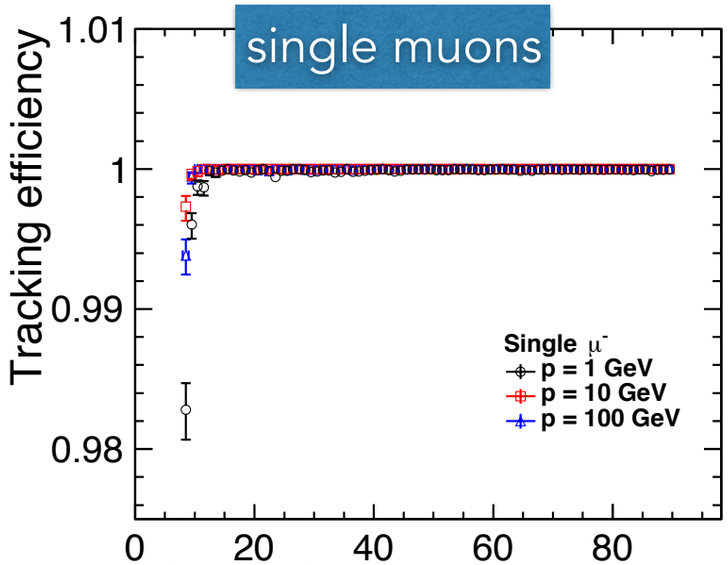

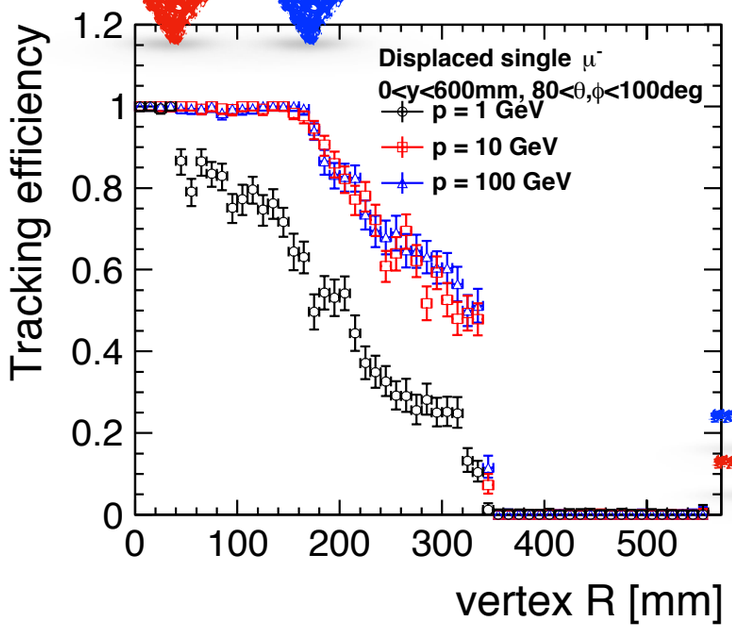

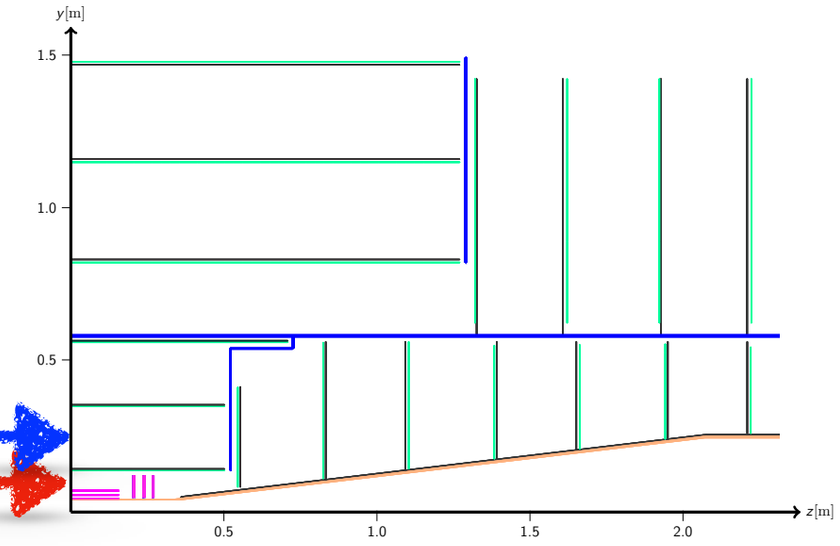

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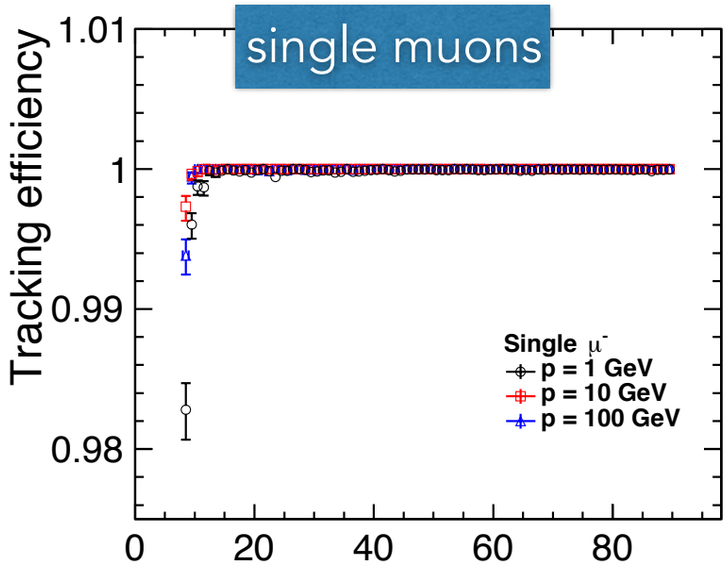

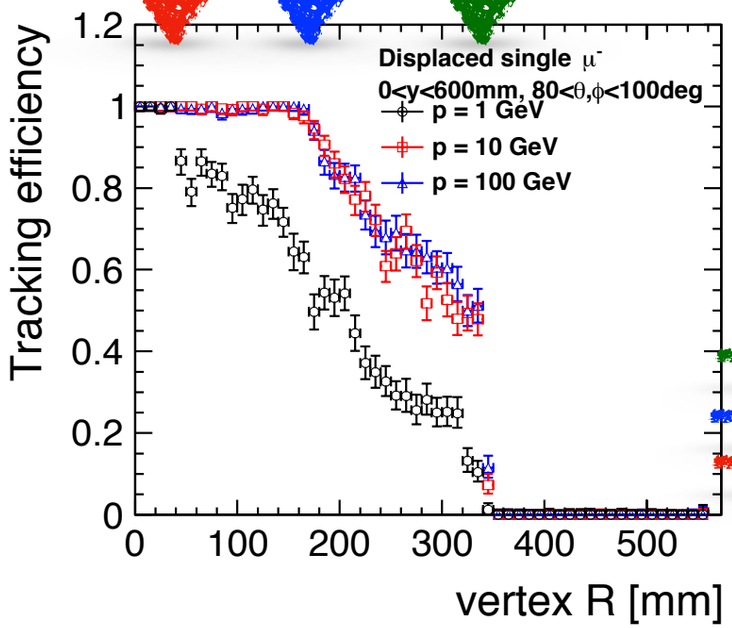

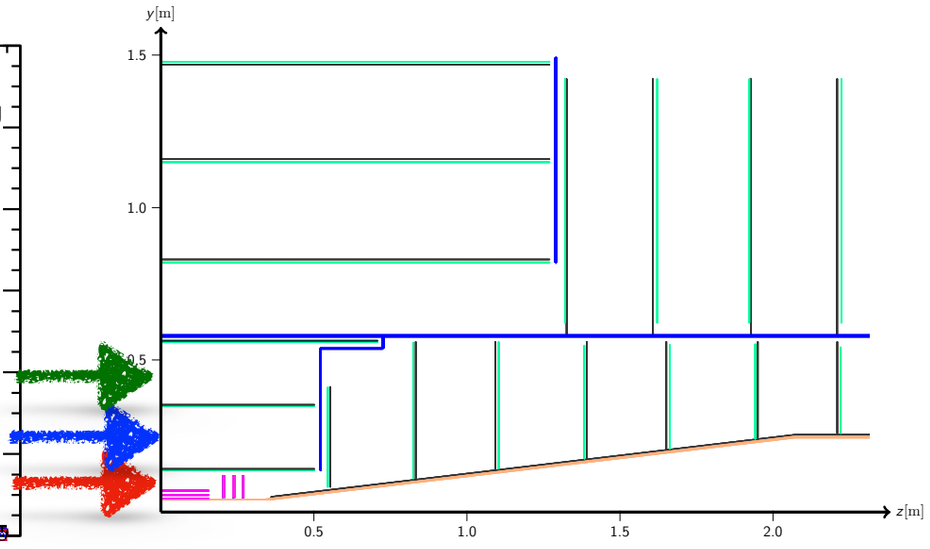

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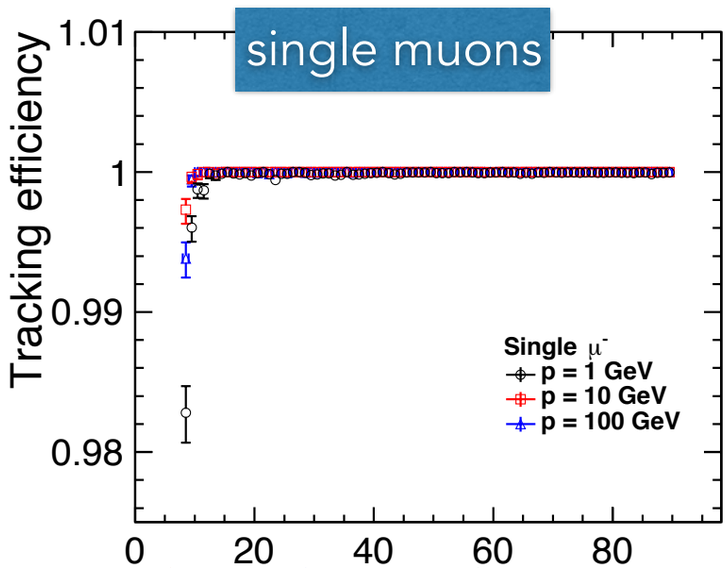

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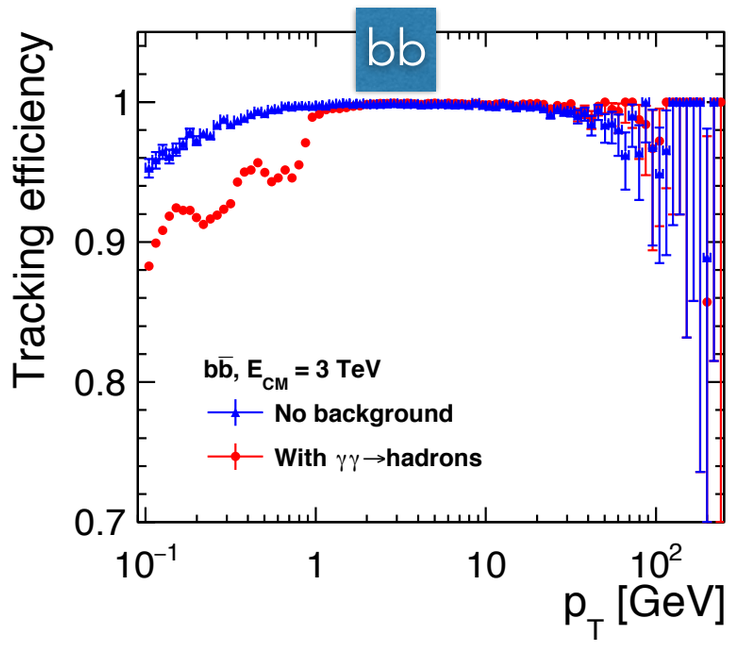

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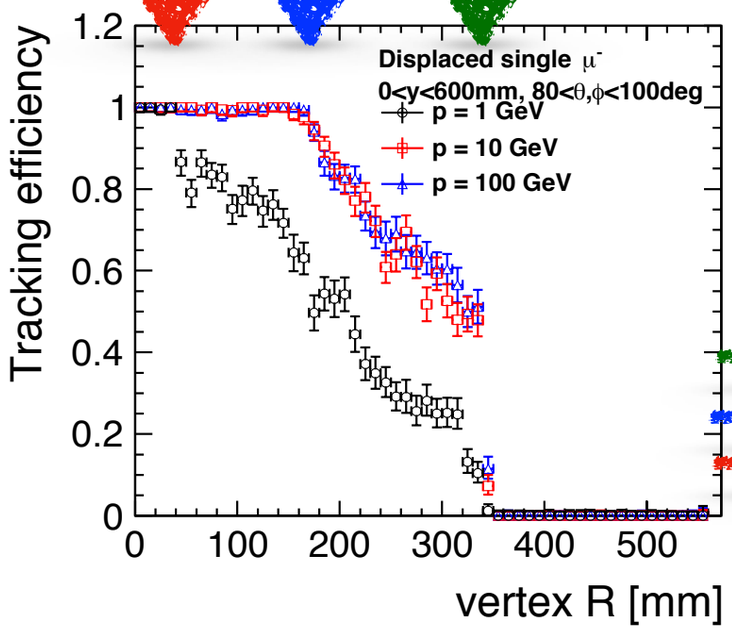

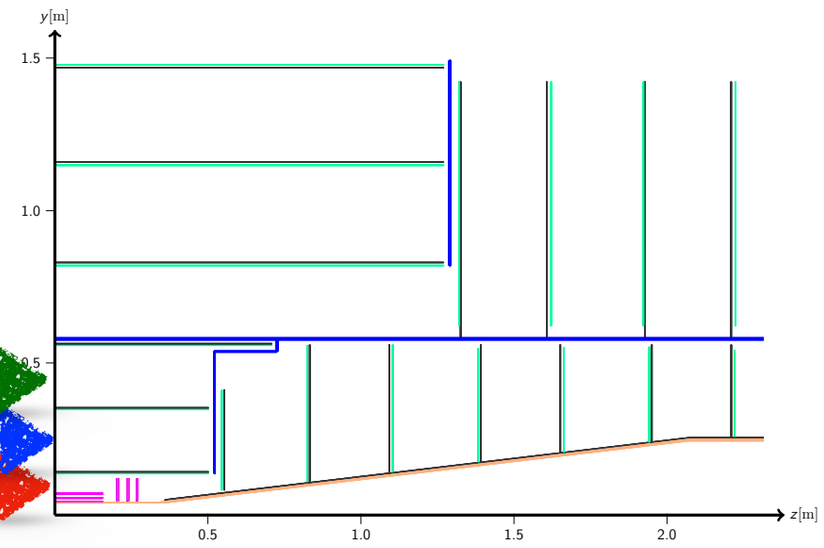

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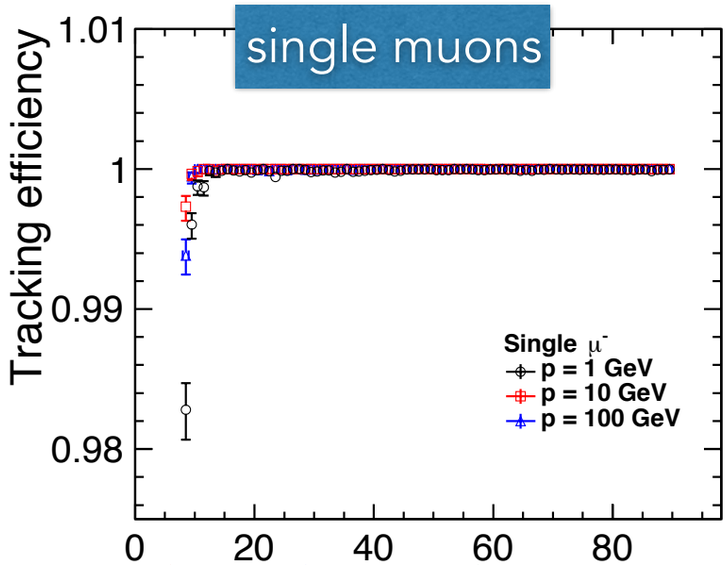

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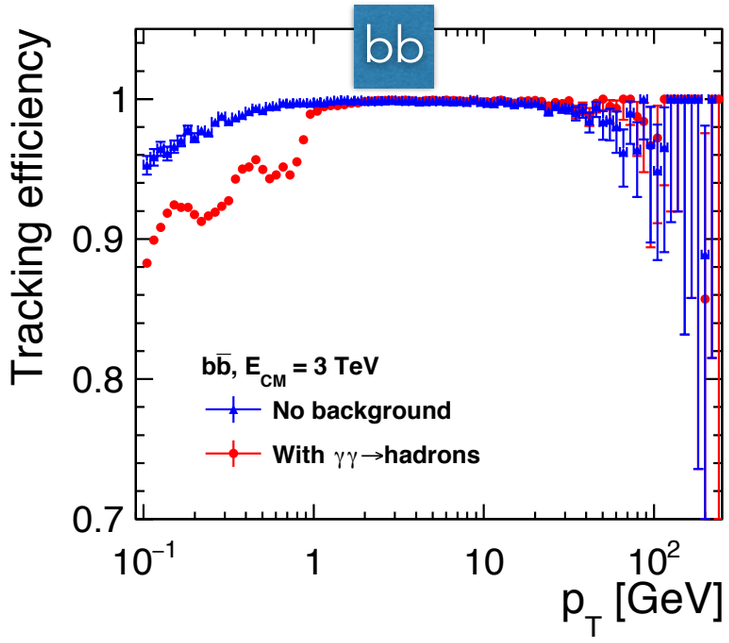

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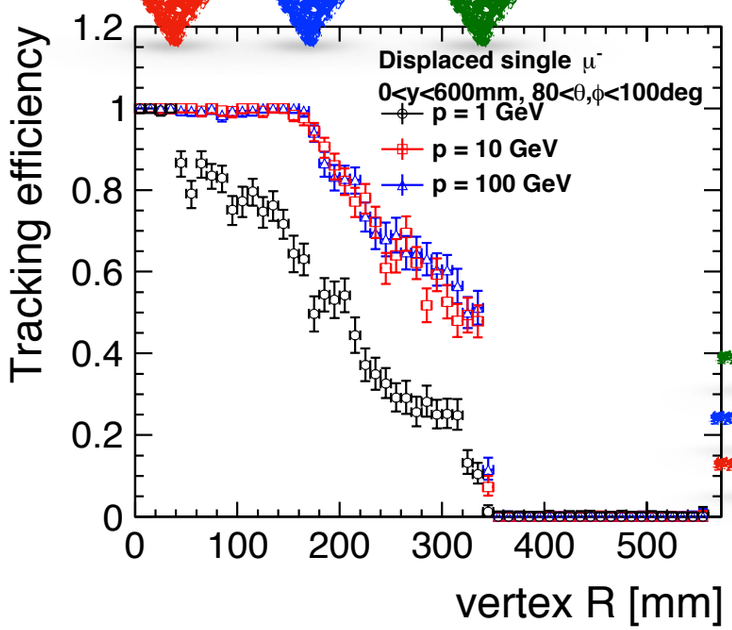
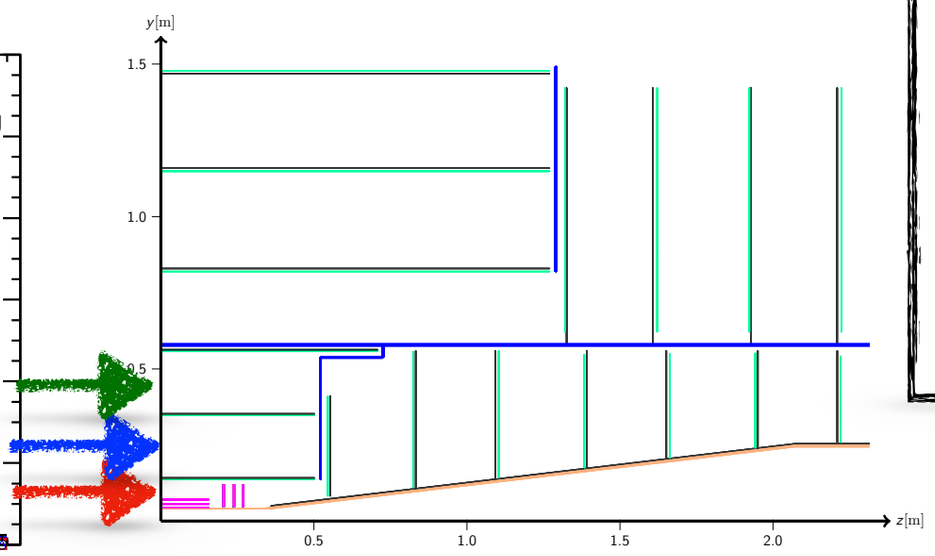




This definition tells us only **if** the particle has been reconstructed…

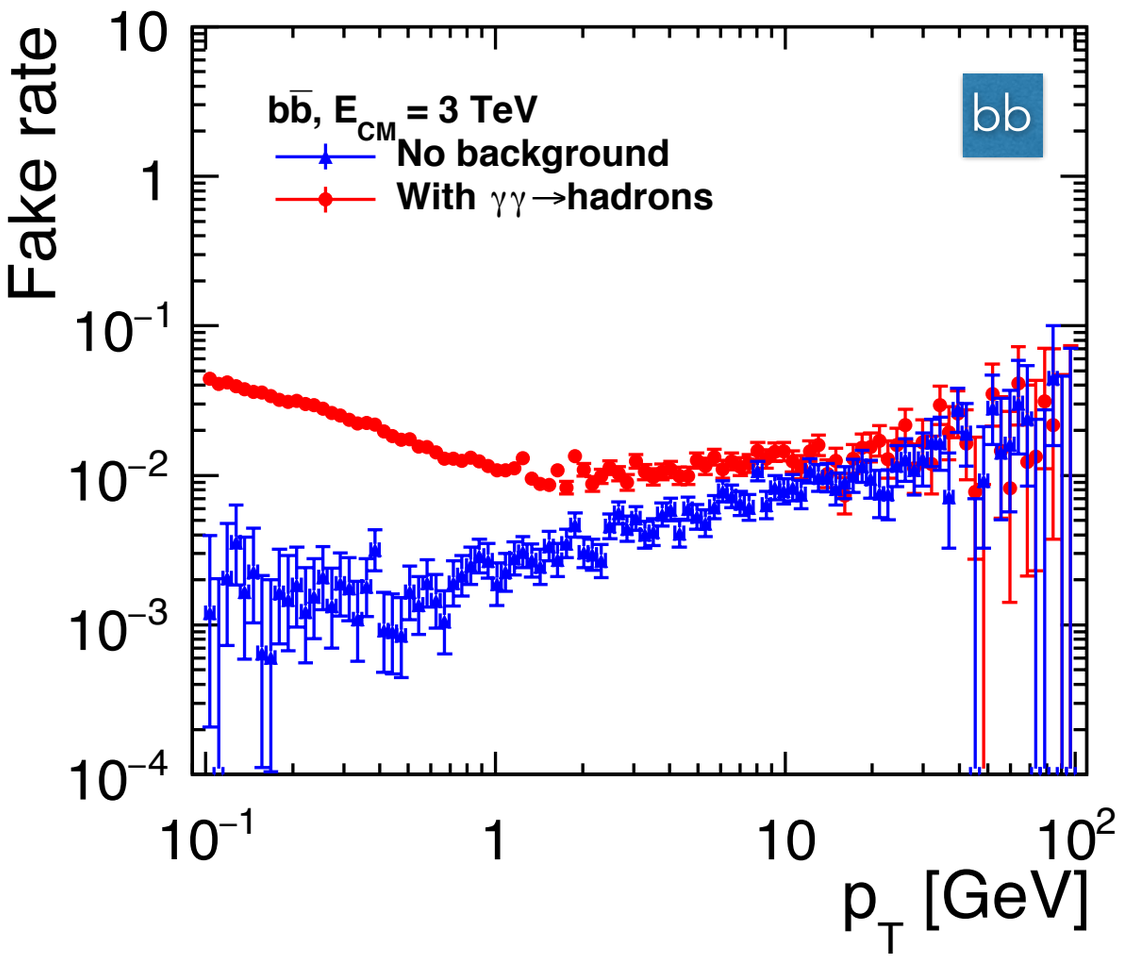
- **but how well?** (i.e. how many missing hits? how many misassociated hits?)
- **and how many times?** (i.e. how many tracks are associated to it?)

Where were we? April's AB Meeting

how many misassociated hits?

Fake rate = fraction of impure reconstructed particles out of the total reconstructed

- purity < 75%
- purity = Nhits belonging to the associated MC Particle / total Nhits



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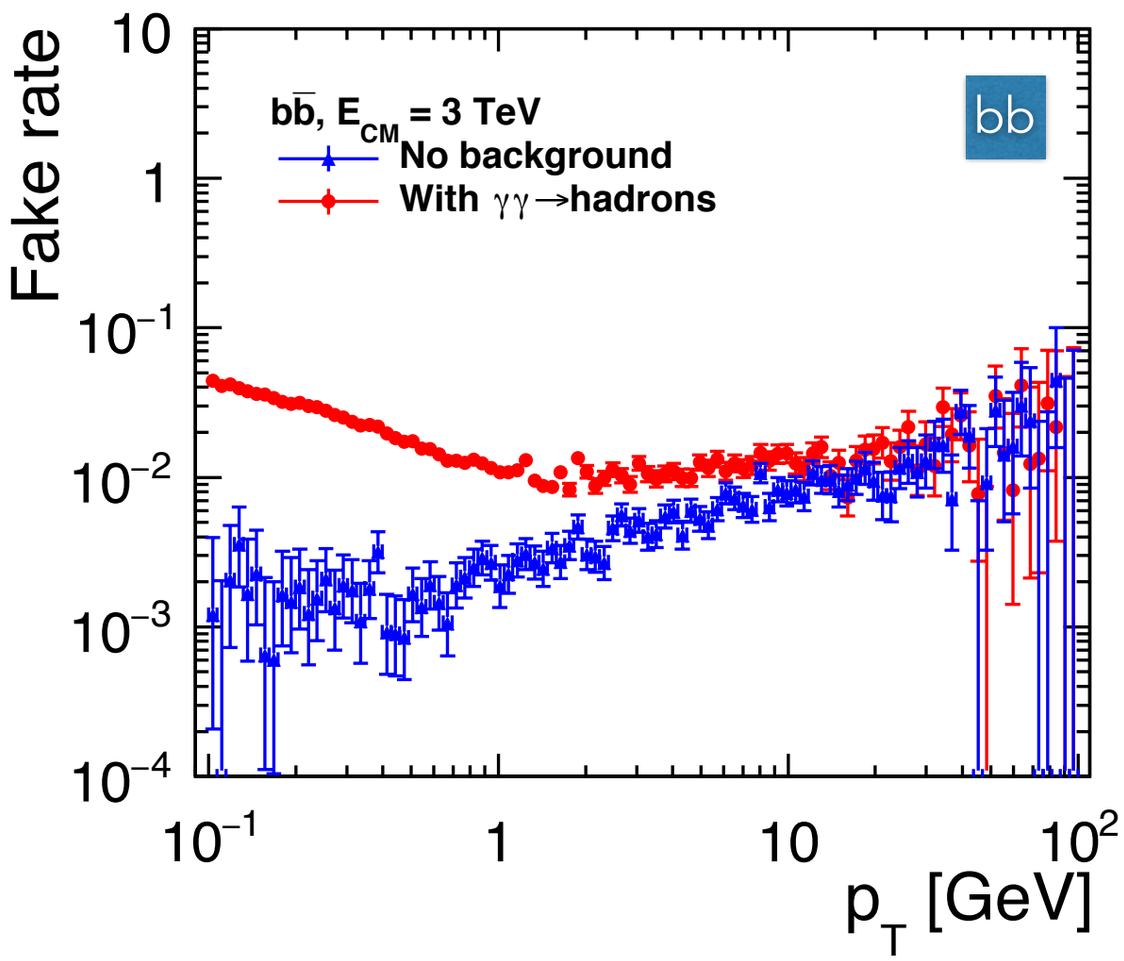

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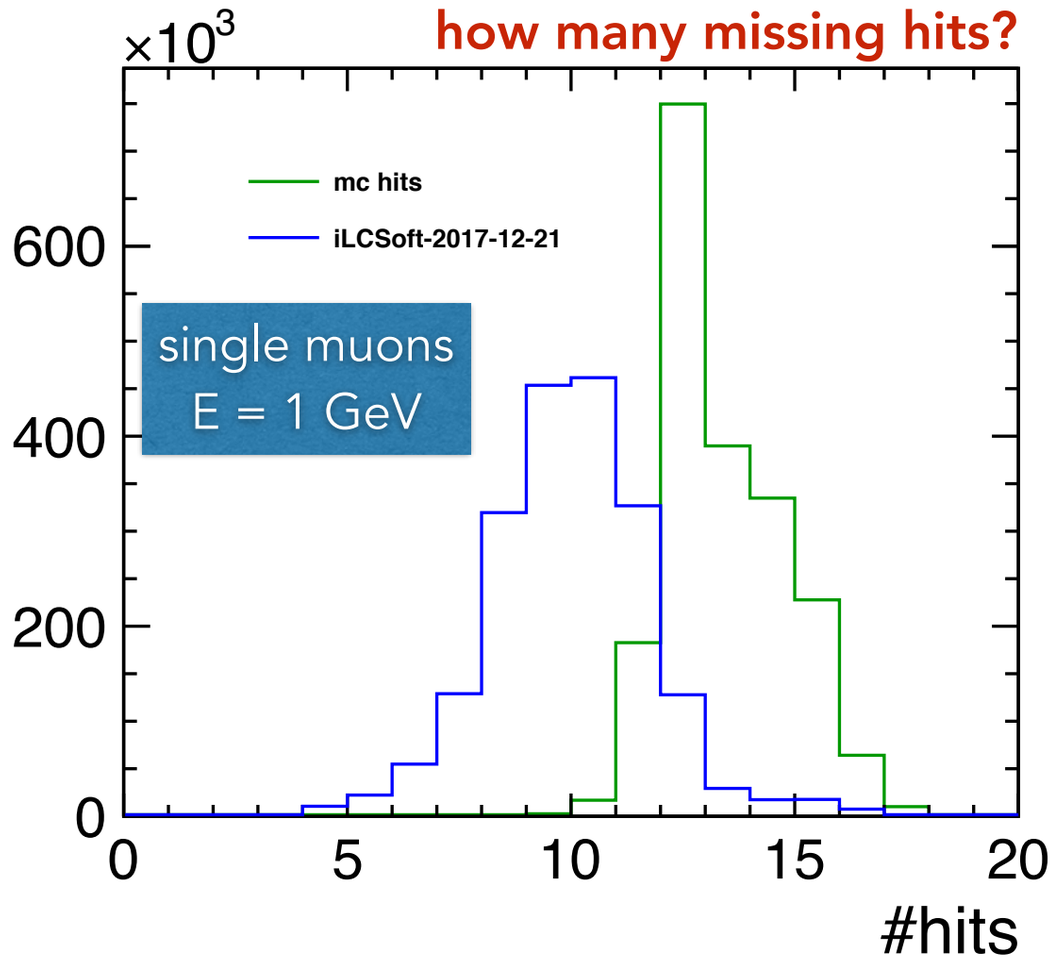

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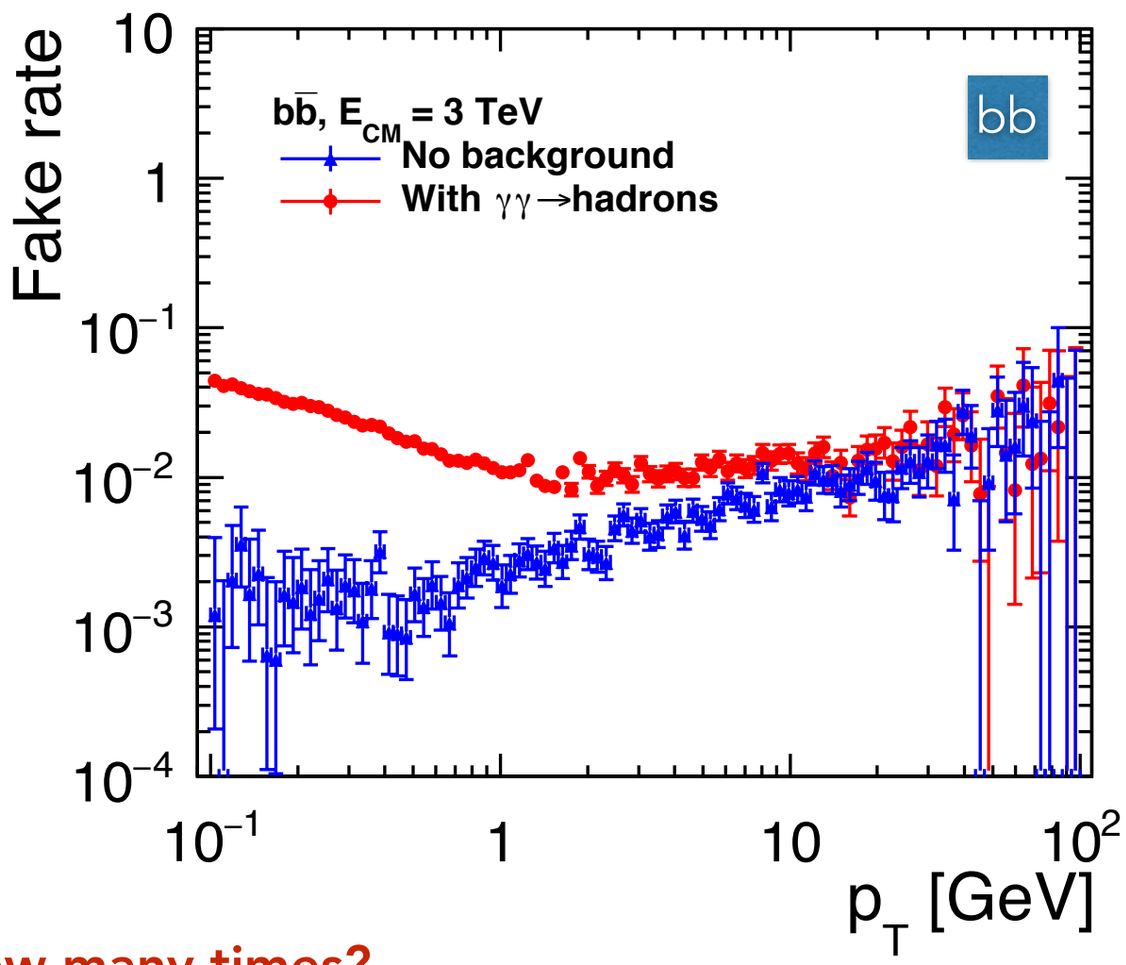

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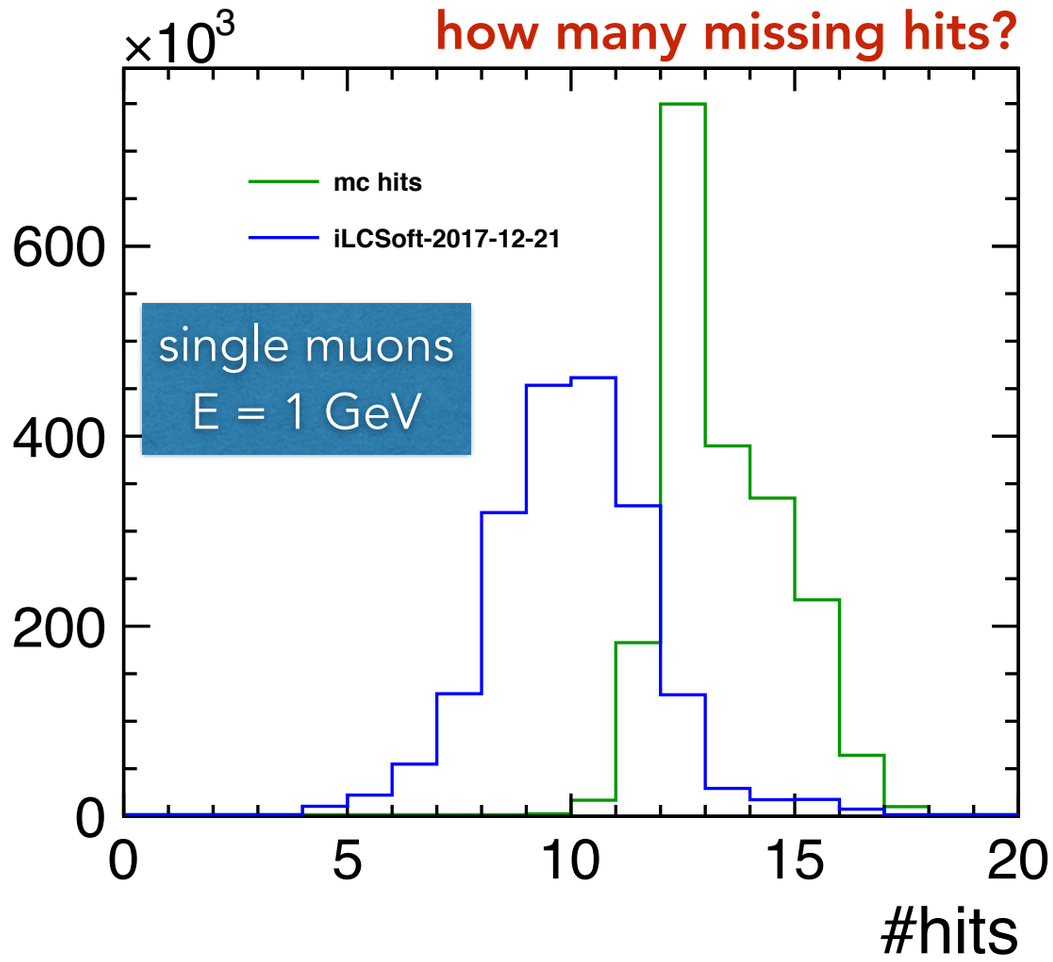


how many times?

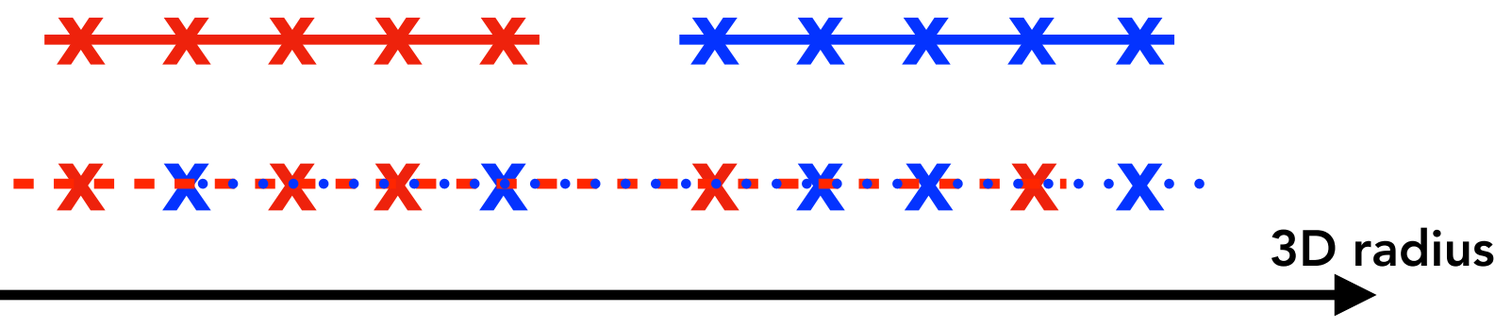
percentage of reconstructed tracks in excess

- for single muons: **5%**
- for bb events: **25%**

Major updates in the algorithm

Causes for imperfect track reconstruction

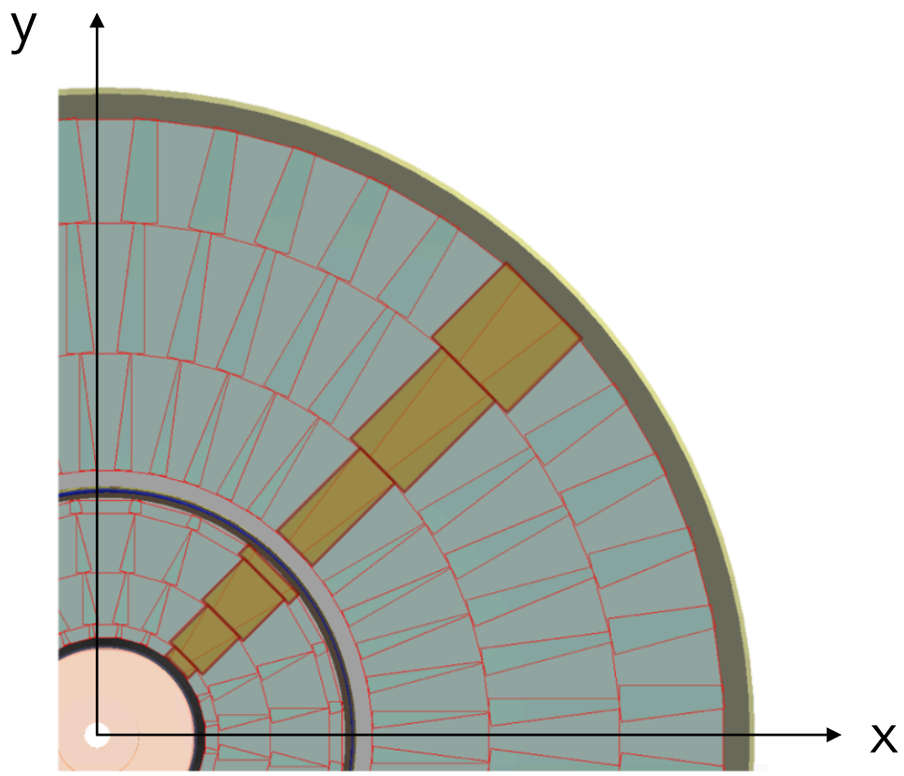
- ***split tracks:*** hits from one MCParticle assigned to track A and track B



- ***clones***: tracks sharing 2 or more hits
  - were “treated” at the end of the build phase, not of the full pattern recognition
  - implementation not proper

Major updates in the algorithm

1) geometrical overlap of modules



- tracks aligned with these overlaps leave double hits in the same detector layer (different modules)
- the algorithm was accepting only one hit per subdetector layer
- second track made out of the remaining aligned hits

=> SOLUTION: accept all hits (unless same subdetector, layer & module)

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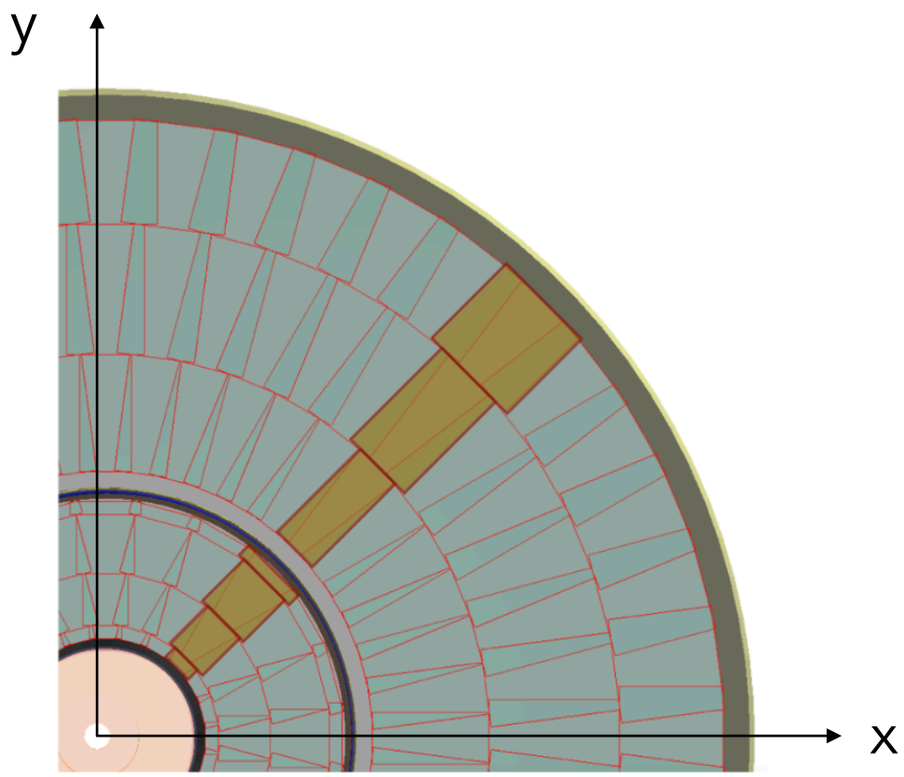

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=> SOLUTION: accept all hits (unless same subdetector, layer & module)

2) the problem of "opening" the cuts progressively

Vertex barrel	Standard cuts
Vertex endcap	Standard cuts
Vertex b + e	Standard cuts
Vertex b + e	Looser cuts (angle x 5)
Vertex b + e	Looser cuts (angle x 10)
Vertex b + e	Looser cuts (angle x 10; χ^2 x 20)
Tracker collections	Looser cuts (angle x 10; χ^2 x 20)
All collections	Displaced cuts

- separate "pieces" of track reconstructed in different phases

=> SOLUTION: merge the looser cuts steps in one

Major updates in the algorithm

3) treatment of clones

- check for clones was implemented only at the end of the build phase, not of the full pattern recognition chain

=> SOLUTION: clones treated in `ClonesAndSplitTracksFinder` processor, run after with the `ConformalTracking` processor

```
<if condition="Config.TrackingConformal">
  <processor name="MyConformalTracking"/>
  <processor name="ClonesAndSplitTracksFinder"/>
</if>
```

- if clones, typically the longest track is preferred, unless the χ^2 of the shortest is better than twice the χ^2 of the longest
- somehow arbitrary cut, that lead to rejecting ~half of the hits

=> SOLUTION: longest always preferred
==> NB: at the moment, this has been fixed only in the build.
TO BE FIXED also in `ClonesAndSplitTracksFinder`
[but minor effect at this stage]

Major updates in the algorithm

4) the extend for low p_T tracks

Extend tracks in conformal space

- last hit of built tracks is used as seed
- from each track endpoint, nearest neighbours search with kdtree
    - for tracks with p_T > **10 GeV**: cellular automaton as in build
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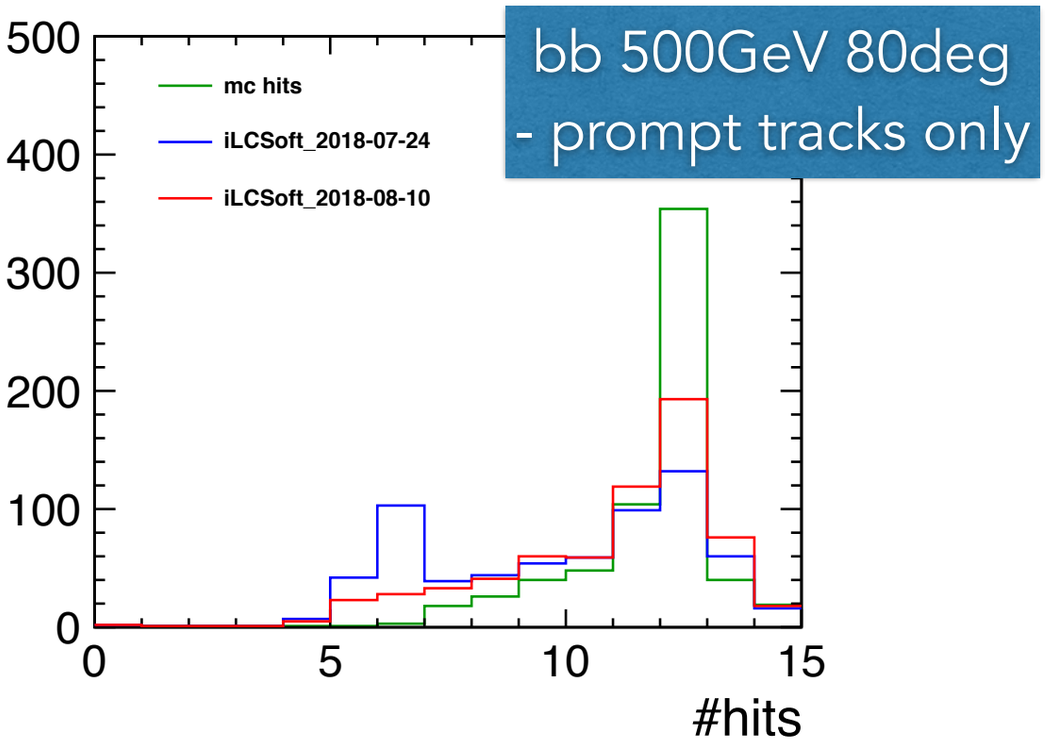

Major updates in the algorithm

5) restructuring of the tracking code

A. Sailer

```
<!--steps for the pattern recognition-->
<parameter name="Steps" type="StringVec">
  [VXDBarrel]
  @Collections : VXDTrackerHits
  @Parameters : MaxCellAngle : 0.005; MaxCellAngleRZ : 0.005; Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.02; HighPTCut: 10.0;
  @Flags : HighPTFit, VertexToTracker
  @Functions : CombineCollections, BuildNewTracks
  [VXDEncap]
  @Collections : VXDEndcapTrackerHits
  @Parameters : MaxCellAngle : 0.005; MaxCellAngleRZ : 0.005; Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.02; HighPTCut: 10.0;
  @Flags : HighPTFit, VertexToTracker
  @Functions : CombineCollections, ExtendTracks
  [LowerCellAngle1]
  @Collections : VXDTrackerHits, VXDEndcapTrackerHits
  @Parameters : MaxCellAngle : 0.025; MaxCellAngleRZ : 0.025; Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.02; HighPTCut: 10.0;
  @Flags : HighPTFit, VertexToTracker, RadialSearch
  @Functions : CombineCollections, BuildNewTracks
  [LowerCellAngle2]
  @Collections :
  @Parameters : MaxCellAngle : 0.05; MaxCellAngleRZ : 0.05; Chi2Cut : 2000; MinClustersOnTrack : 4; MaxDistance : 0.02; HighPTCut: 10.0;
  @Flags : HighPTFit, VertexToTracker, RadialSearch
  @Functions : BuildNewTracks, SortTracks
  [Tracker]
  @Collections : ITrackerHits, OTrackerHits, ITrackerEndcapHits, OTrackerEndcapHits
  @Parameters : MaxCellAngle : 0.05; MaxCellAngleRZ : 0.05; Chi2Cut : 2000; MinClustersOnTrack : 4; MaxDistance : 0.02; HighPTCut: 1.0;
  @Flags : HighPTFit, VertexToTracker, RadialSearch
  @Functions : CombineCollections, ExtendTracks
  [Displaced]
  @Collections : VXDTrackerHits, VXDEndcapTrackerHits, ITrackerHits, OTrackerHits, ITrackerEndcapHits, OTrackerEndcapHits
  @Parameters : MaxCellAngle : 0.05; MaxCellAngleRZ : 0.05; Chi2Cut : 1000; MinClustersOnTrack : 5; MaxDistance : 0.015; HighPTCut: 10.0;
  @Flags : OnlyZSchi2cut, RadialSearch
  @Functions : CombineCollections, BuildNewTracks
</parameter>
```

Major updates in the algorithm

5) restructuring of the tracking code

A. Sailer

```
<!--steps for the pattern recognition-->
<parameter name="Steps" type="StringVec">
  [VXDBarrel]
  @Collections : VXDTrackerHits
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  @Flags : HighPTFit, VertexToTracker
  @Functions : CombineCollections, ExtendTracks
  [L
  @C
  @P
  @F
  @F
  [LowerCellAngle2]
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  @Flags : OnlyZSchi2cut, RadialSearch
  @Functions : CombineCollections, BuildNewTracks
</parameter>
```
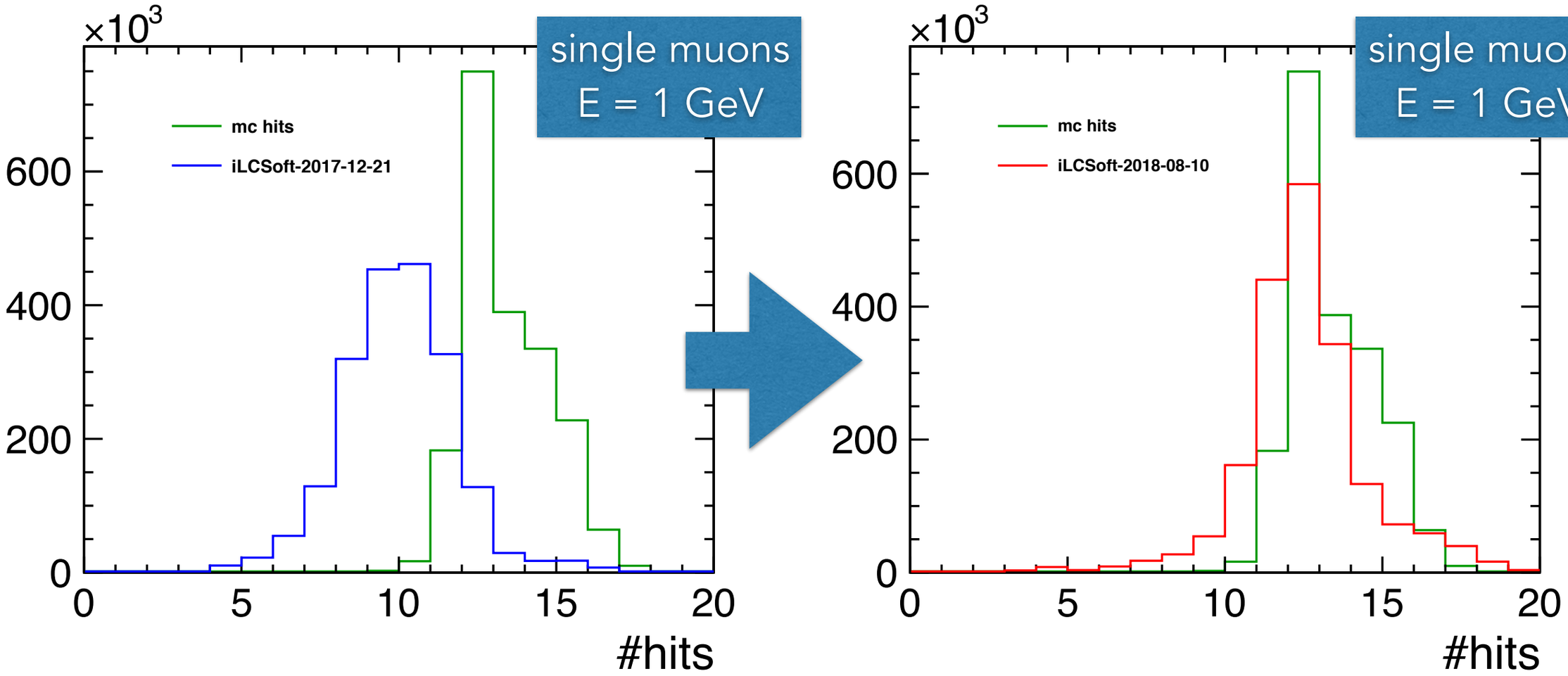

```
for (auto const& parameters : _stepParameters) {
  runStep(kdClusters, nearestNeighbours, conformalTracks, collectionClusters, parameters);
}
```

Where are we now? Current status

Improvements in the tracking reflected in the hits distribution…



Where are we now? Current status

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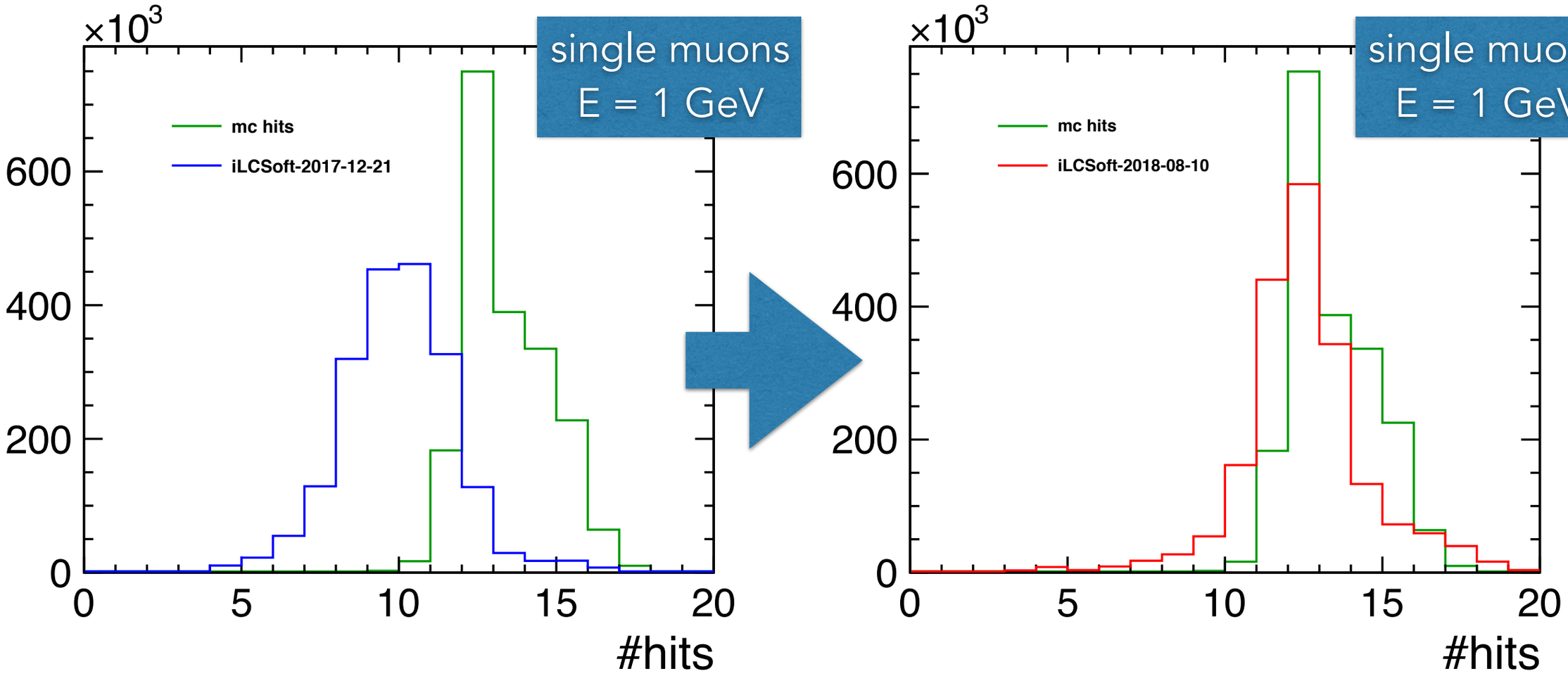


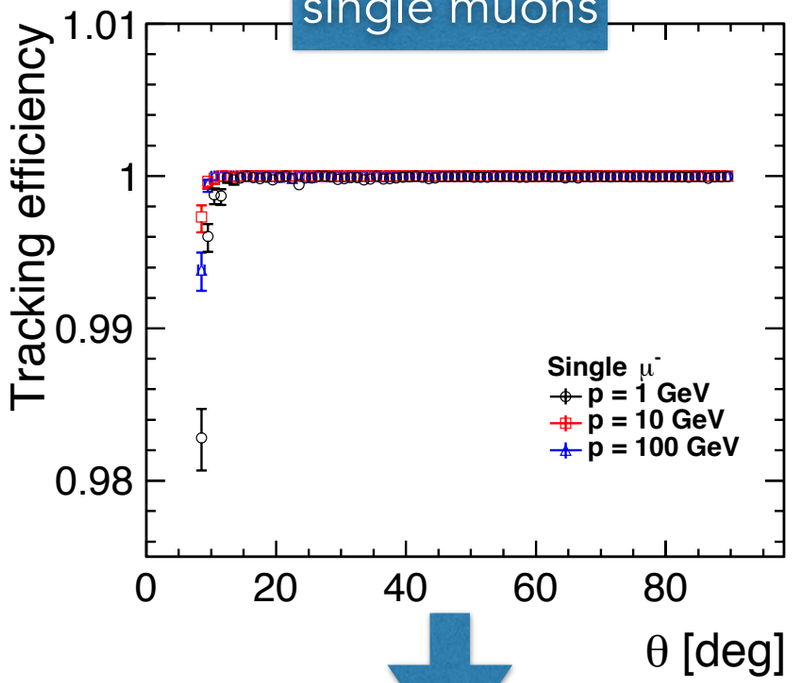
… and in the percentage of tracks in excess

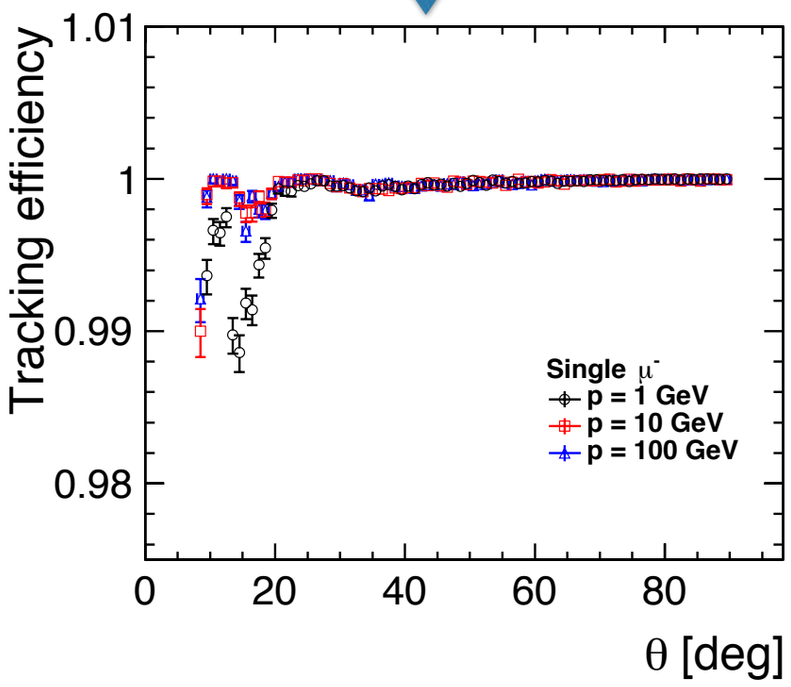
- for single muons: from **5%** down to **0.3%**
- for bb events: from **25%** down to **6%**

Where are we now? Current status

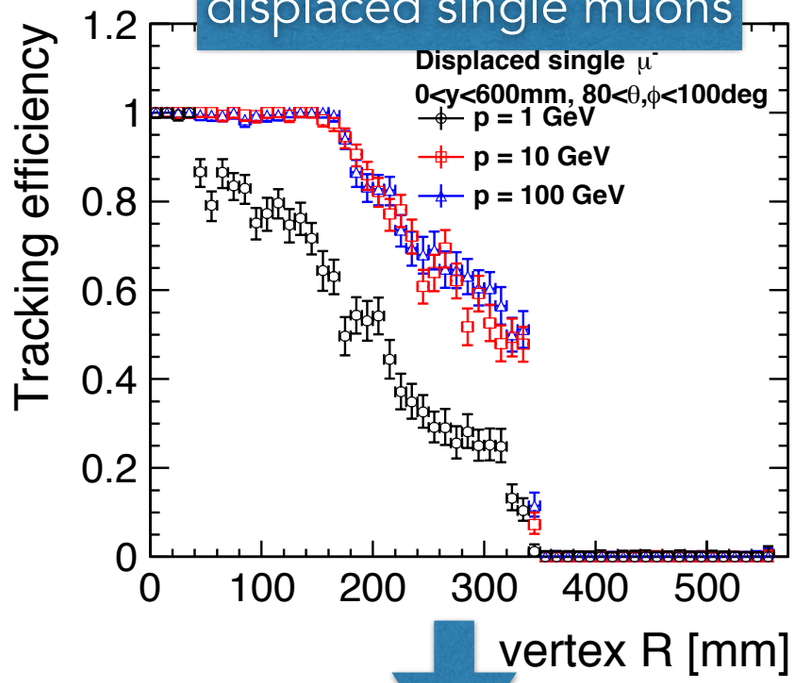
Efficiencies are not disrupted - in some cases more "realistic"

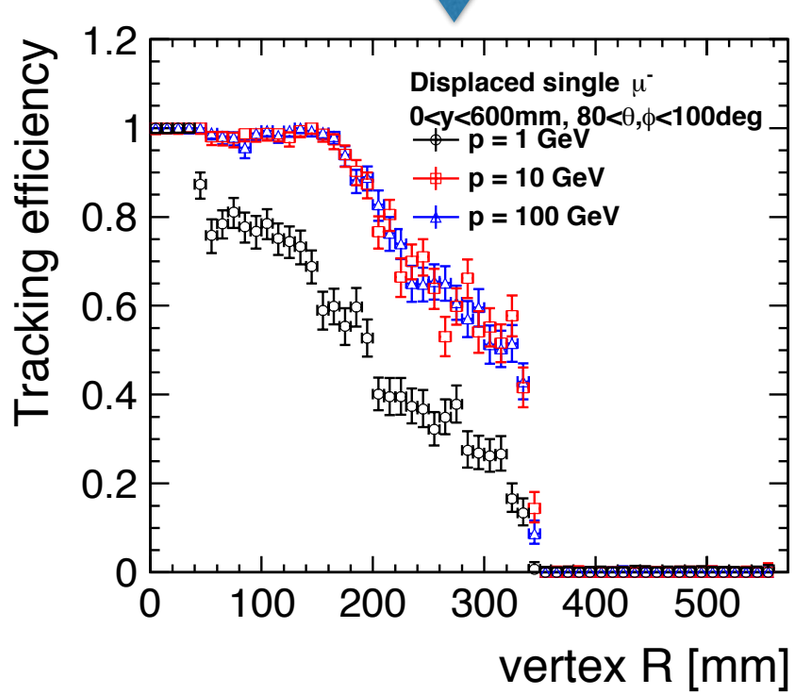
single muons



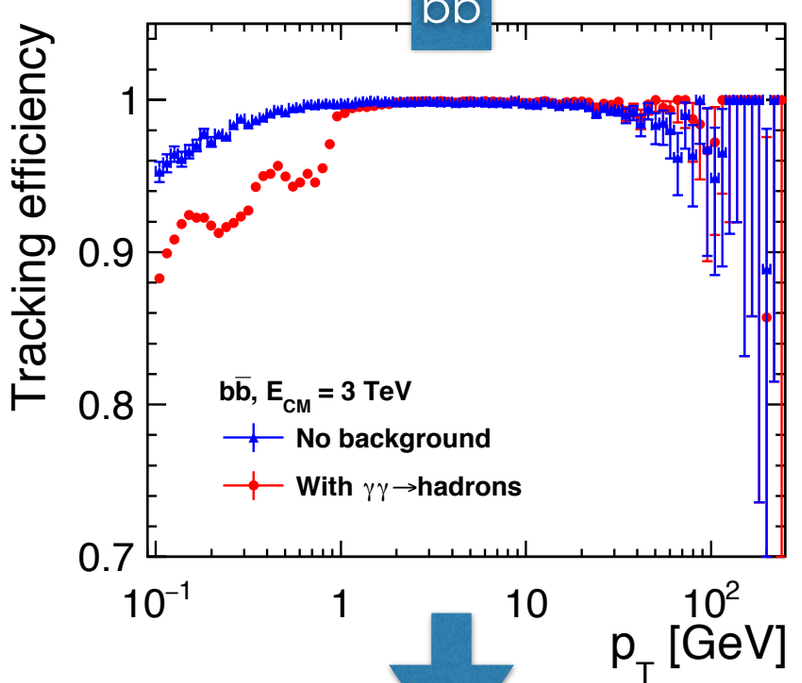


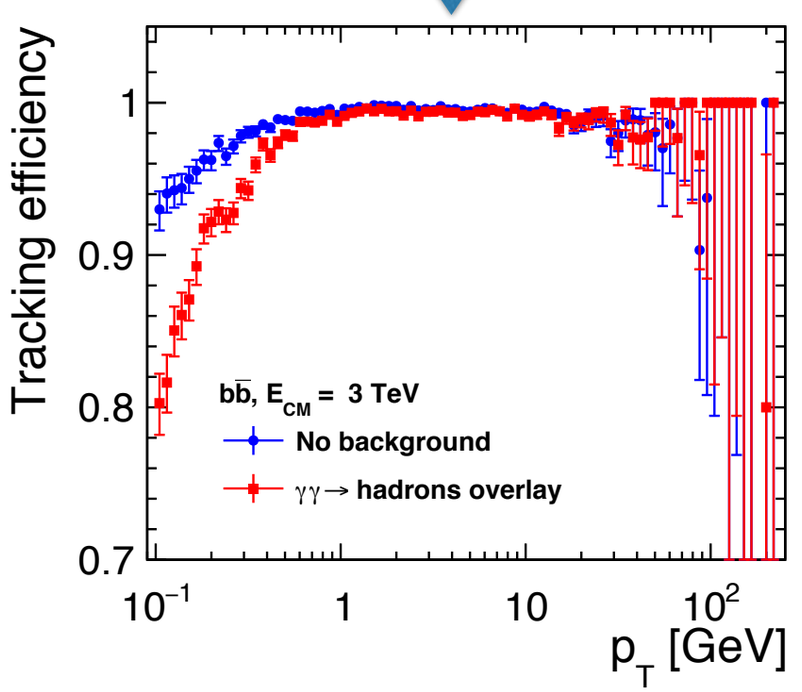
displaced single muons



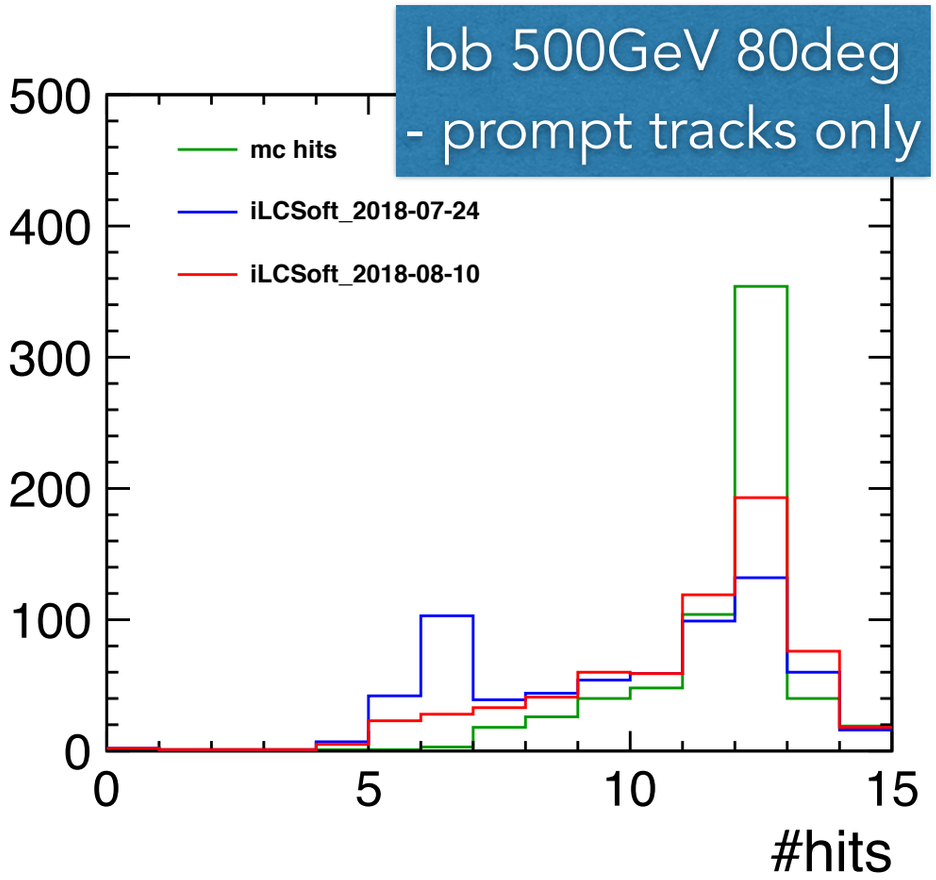


bb





Where do we plan to be?



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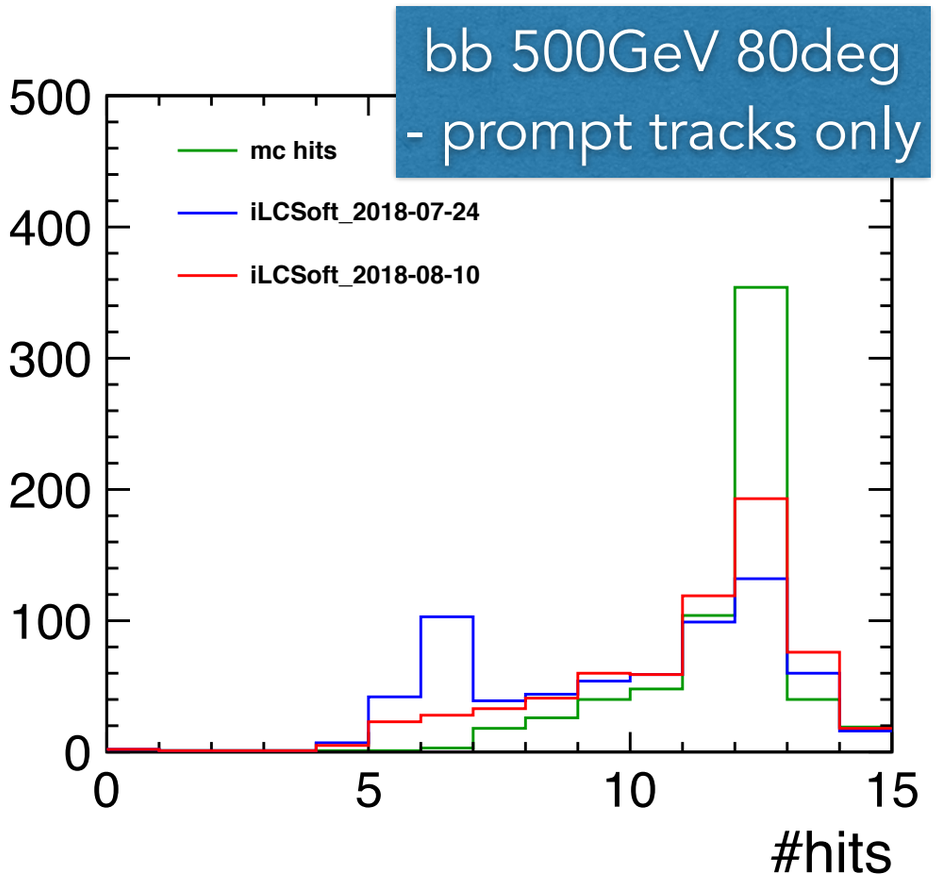

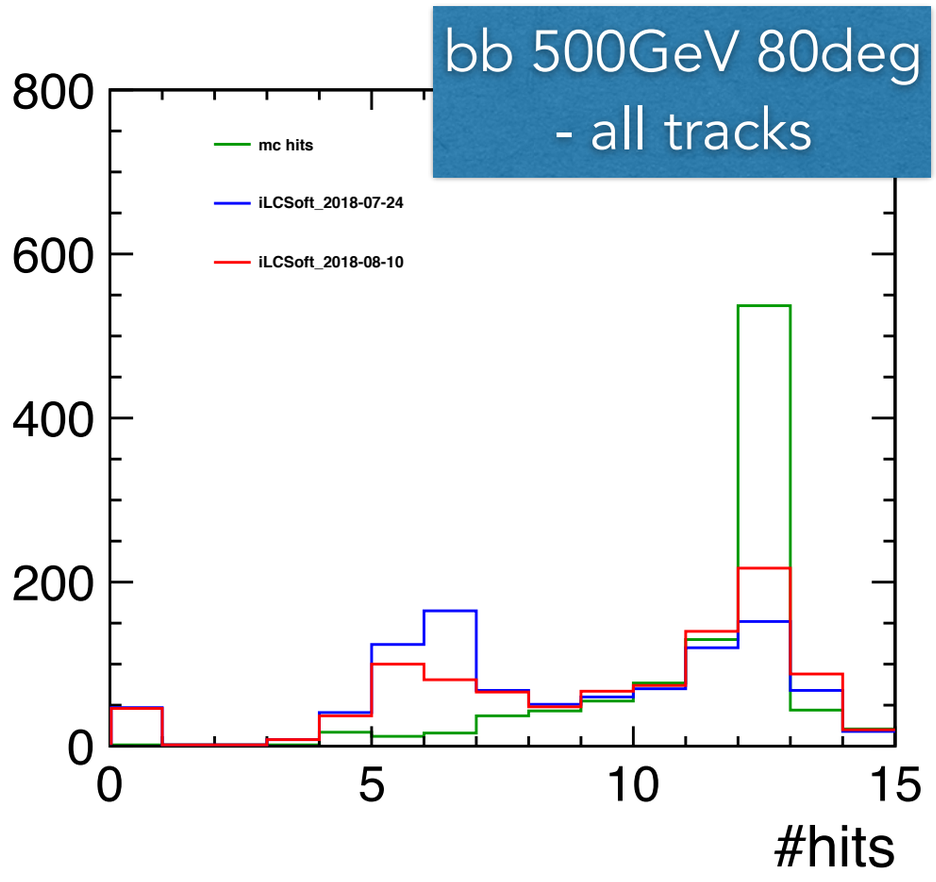

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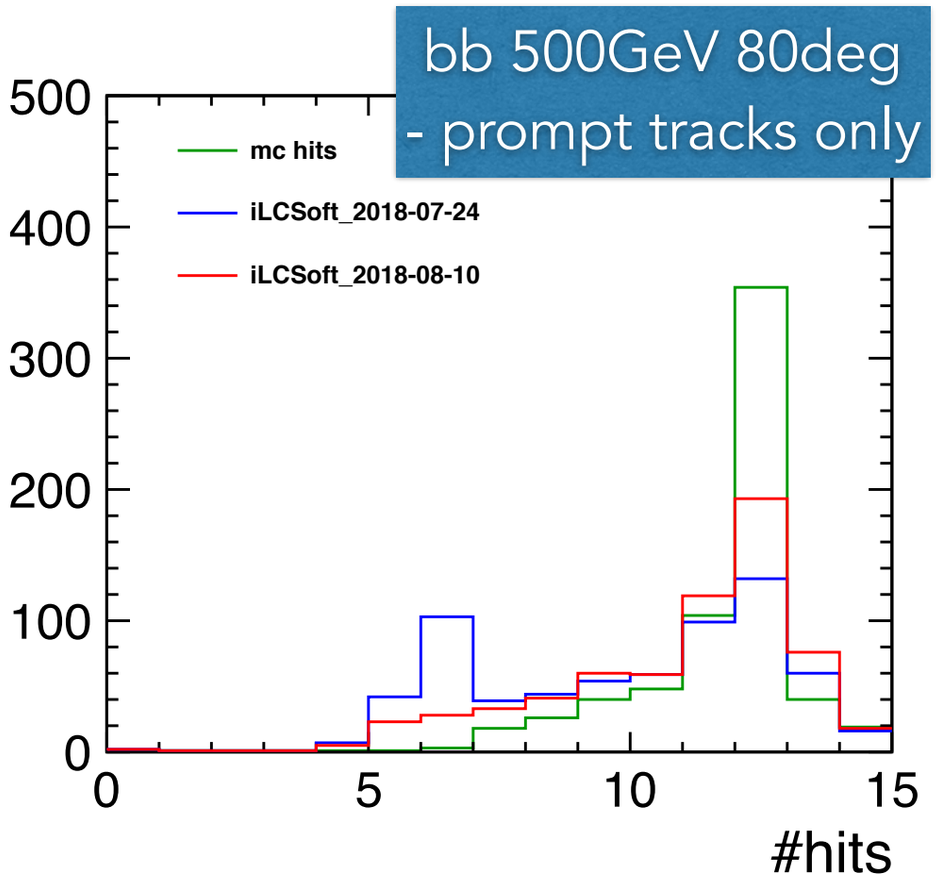
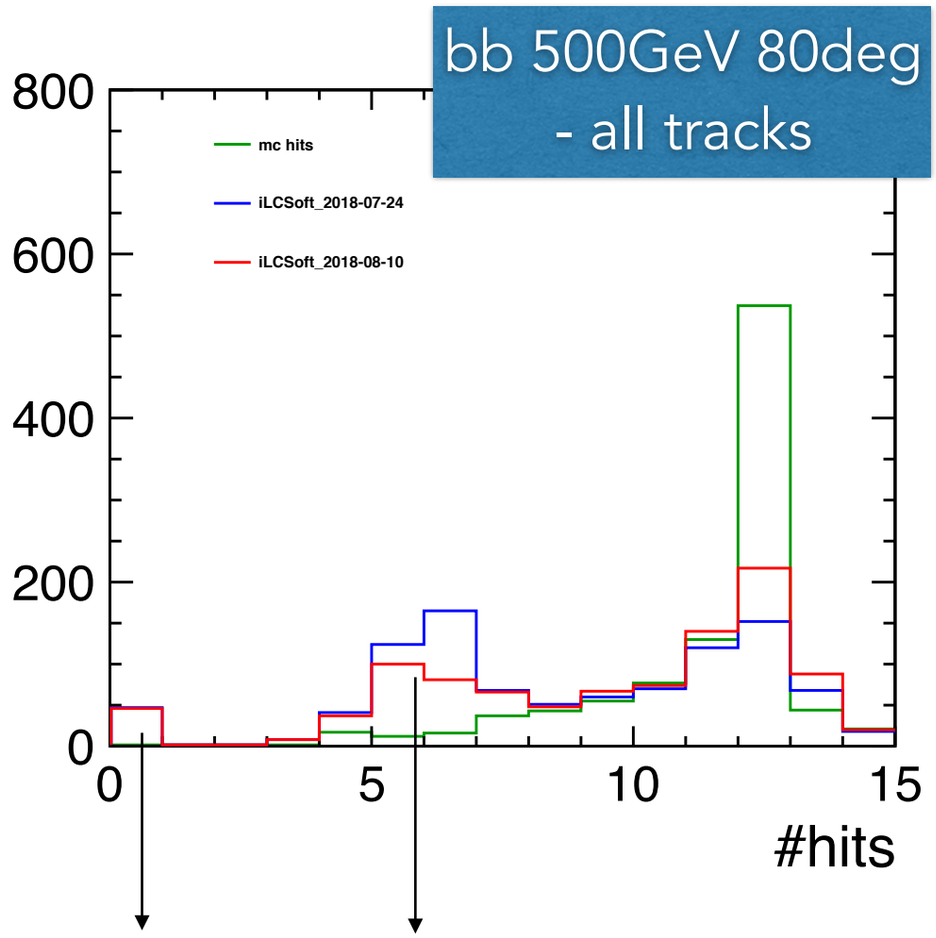




sensitive point: **displaced tracks**

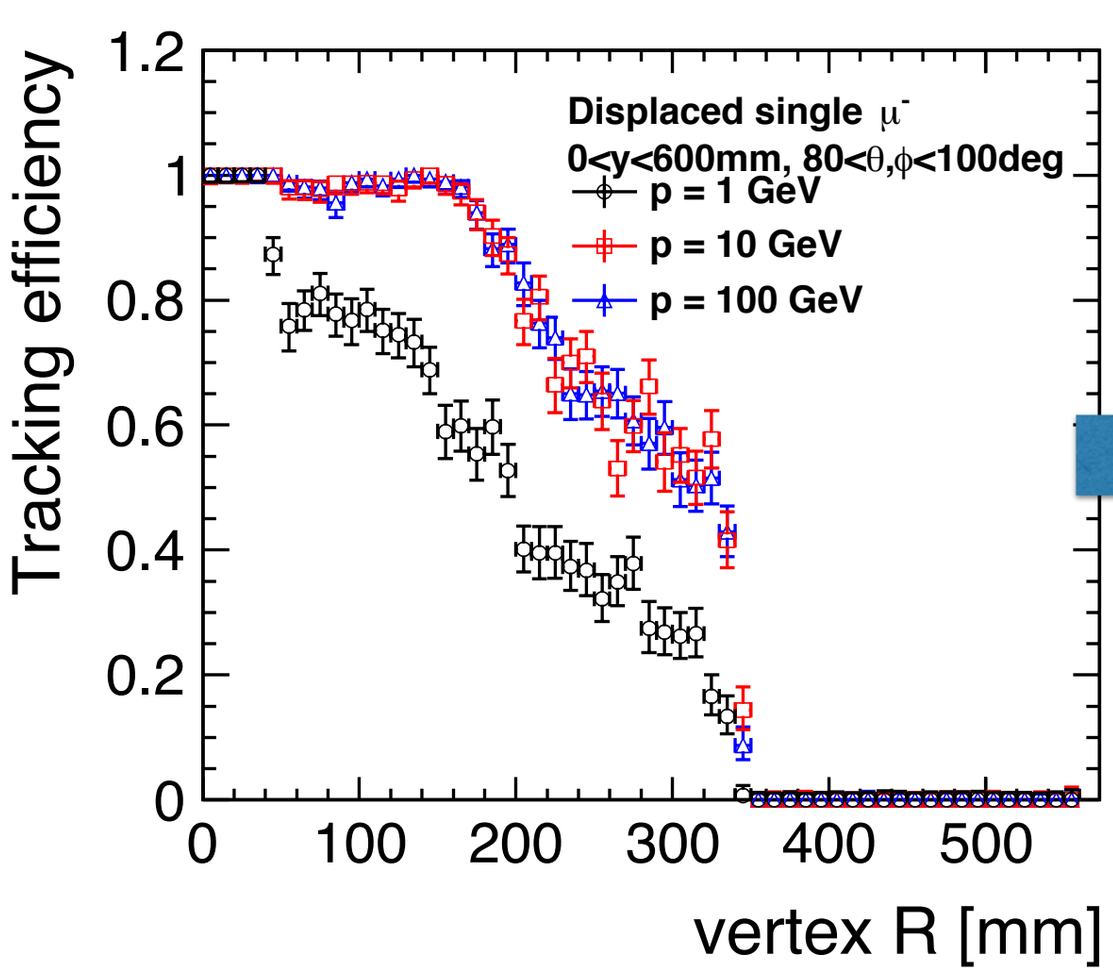
- recover the inefficiencies
- recover the missing hits

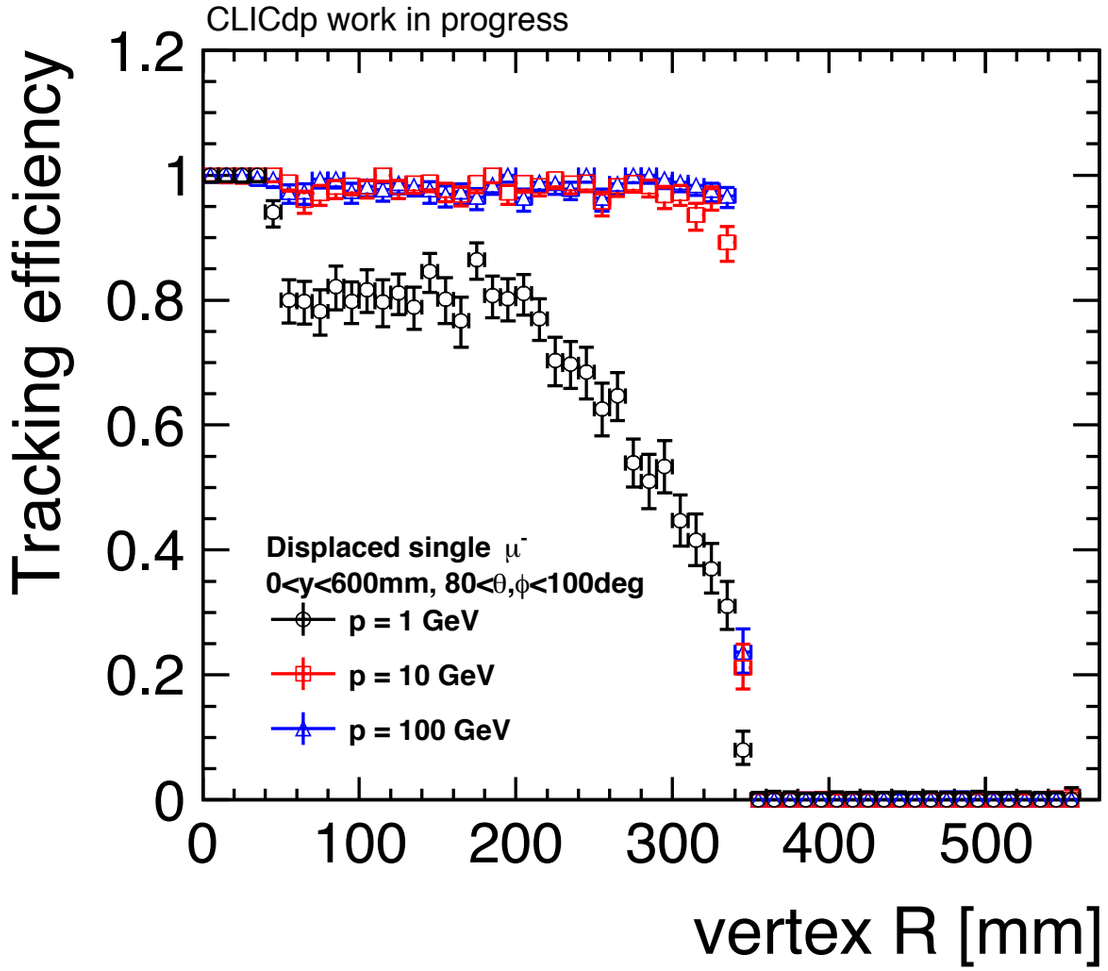
Where do we plan to be?

Displaced tracks - recover the inefficiencies

Some inefficiencies are avoided by simply "opening" the cuts

- search angle for nearest neighbors
- max distance for cell extrapolation





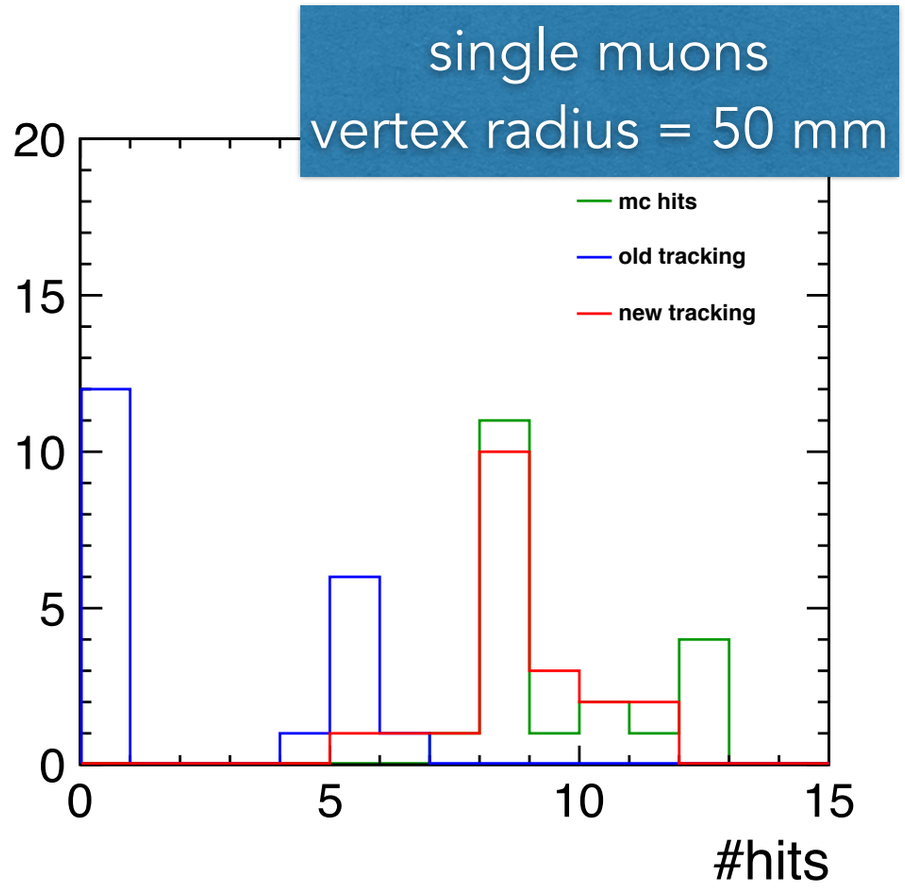
Where do we plan to be?

Displaced tracks - recover the missing hits

Tested in **single particle** events

- at pattern recognition level, hits not picked up for two reasons:
  - not found as neighbors
  - found as neighbors but rejected by cuts (cell angle, χ^2)

=> WORKING SOLUTION: open the cuts



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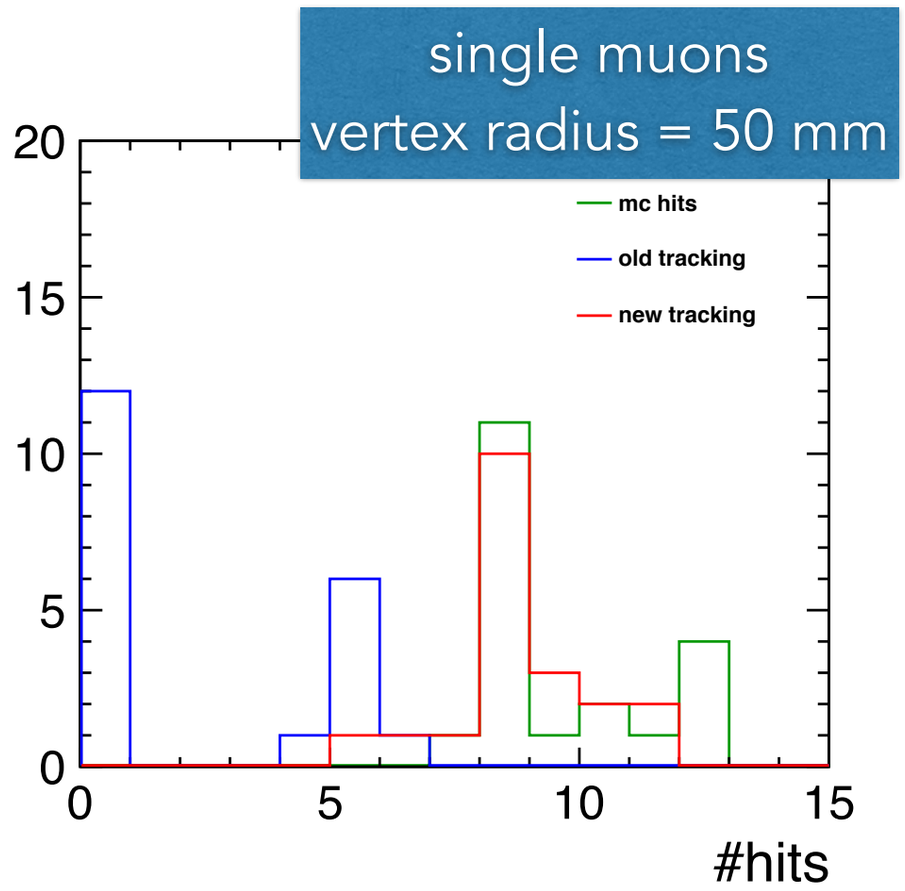

Unfortunately not so simple for **real events**

- opening the cuts increases the combinatorics
- reconstruction time grows exponentially
- safety check on number of candidate tracks restores the cuts to the starting tight values

=> WORK-IN-PROGRESS SOLUTION: cellular automaton ******per layer***

Summary

- ☑ Where were we? Status at the April's Advisory Board Meeting
  - ☑ Good efficiency and resolution performances
  - ☑ However: tracks missing hits and MCParticles reconstructed as multiple tracks
- ☑ Major updates in the reconstruction chain
  - ☑ Fixed split tracks, clones, tracks hitting overlapping modules
  - ☑ Readapted reconstruction steps and default cuts
- ☑ Where are we now? Current status
  - ☑ Prompt tracks in single particle and real events
    - ☑ Recovered missing hits and drastically reduced multiple tracks
- ☐ Where do we plan to be? Future improvements
  - ☐ Displaced tracks
    - ☐ Test a new method of cellular automaton *per layer*
    - ☐ Work on reducing the combinatorics (=> number of valid track candidates)
  - ☐ Tracking ready for b- and c- tagging

References

- Code repository
  https://github.com/iLCSoft/ConformalTracking

- A detector for CLIC: main parameters and performance [in preparation]
  https://gitlab.cern.ch/CLICdp/Publications/DraftDocuments/Note_DetectorPerformance

- Pattern recognition for the CLIC detector using conformal mapping and cellular automaton [embryonic stage]
  https://gitlab.cern.ch/CLICdp/Publications/DraftDocuments/Note_ConformalTracking

Extras