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Progress on track reconstruction in presence of BIB

Changes to Conformal Tracking

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Current tracking algorithm

We are using Conformal Tracking (CT) algorithm

- very flexible and geometry agnostic → perfect for us in the current situation
- multiple consecutive steps can be configured in XML with corresponding parameters and quality cuts

CT sequence used by us till now:

[VXD]

@Collections : VXDBTrackerHits, VXDETrackerHits

@Parameters : MaxCellAngle : 0.007; MaxCellAngleRZ : 0.007;

Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.024;

SlopeZRange: 10.0; HighPTCut: 1.0;

@Flags : HighPTFit

@Functions : CombineCollections, BuildNewTracks

[Tracker]

@Collections : IBTrackerHits, OTrackerHits,
IETTrackerHits, OETTrackerHits

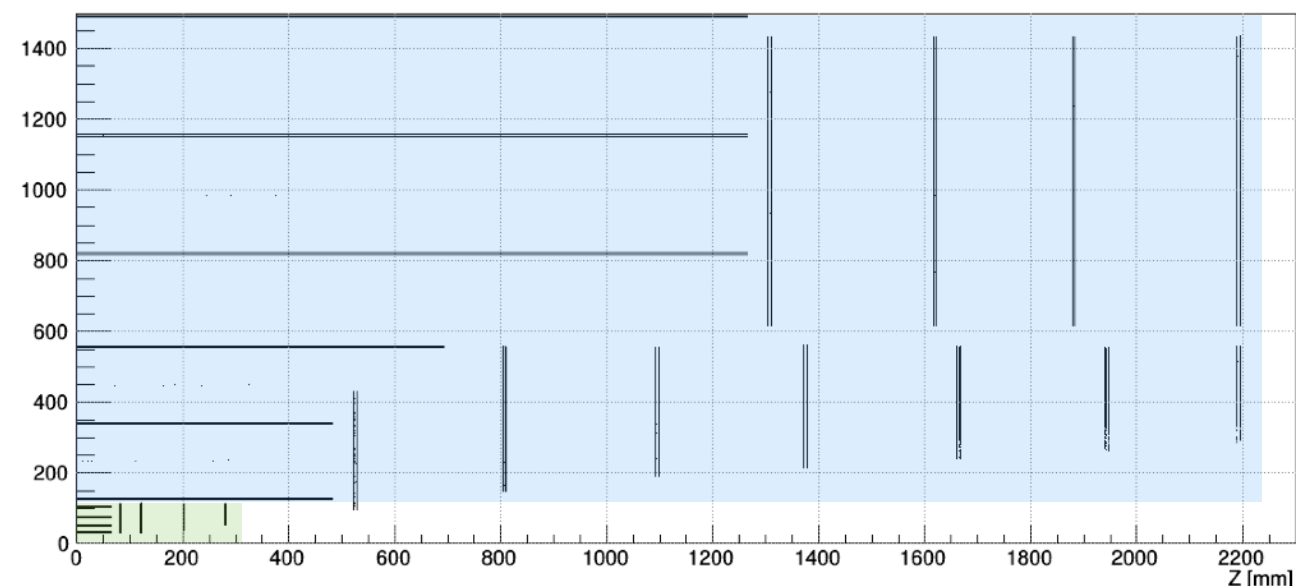
@Parameters : MaxCellAngle : 0.025; MaxCellAngleRZ : 0.05;

Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.009;

SlopeZRange: 10.0; HighPTCut: 0.0;

@Flags : HighPTFit, VertexToTracker, RadialSearch

@Functions : CombineCollections, ExtendTracks



This is the pattern recognition sequence
Track fit performed for each good chain
of hits at the end of each step

↳ the most time consuming part

1. Seeding from every hit in the whole VXD with tight angular window
2. Extending to hits in the Inner/Outer trackers with wider window

CLIC is using a more complex CT sequence

[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

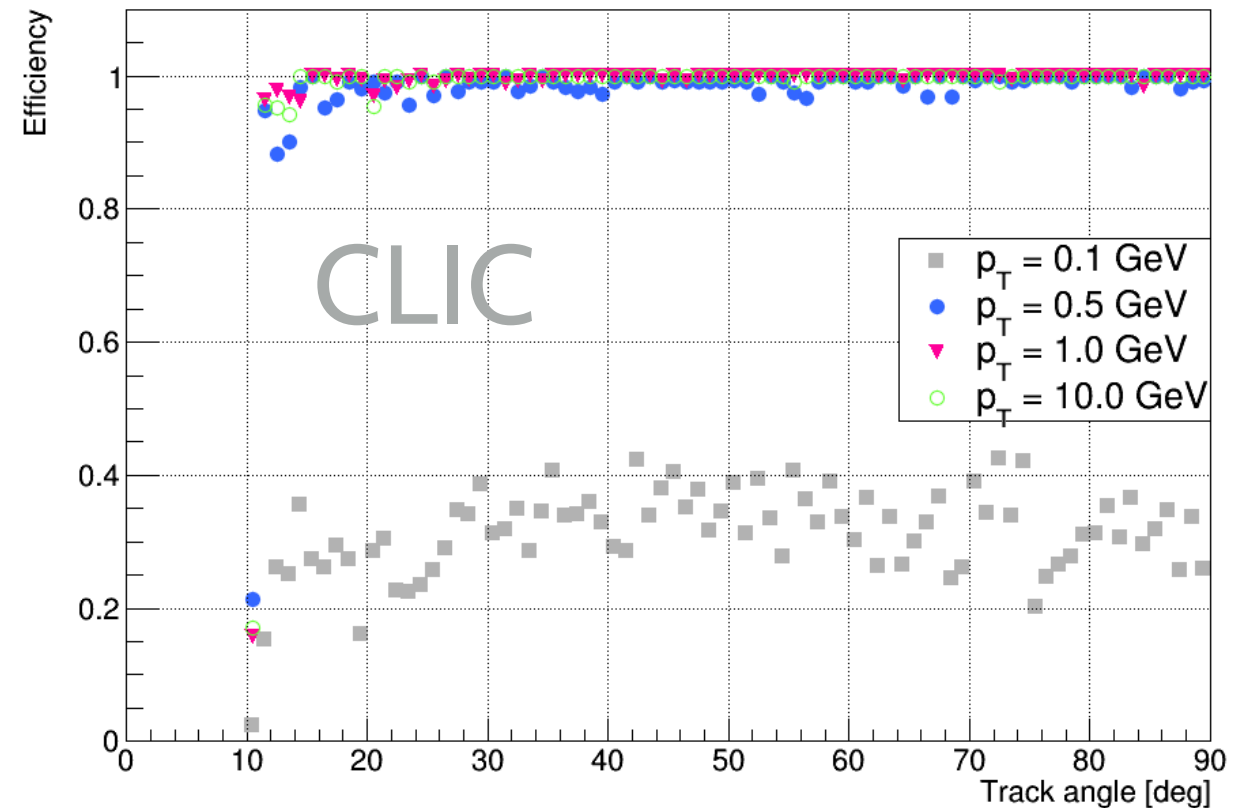
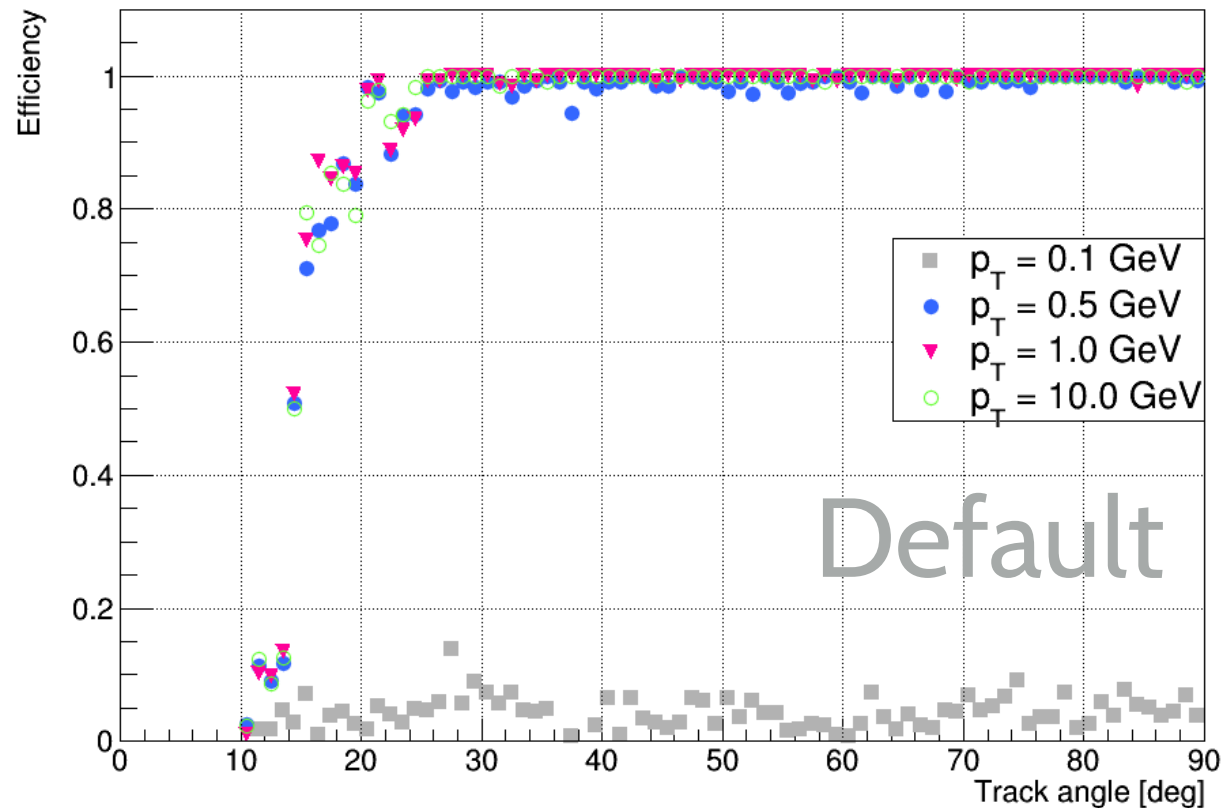
@Functions : CombineCollections, BuildNewTracks

1. Seeding from every hit in the VXD Barrel with tight angular window
2. Extending to the VXD Endcap
3. Seeding in whole VXD with relaxed search window
4. 2nd run with even more relaxed search window
5. Extending to the Inner/Outer tracker
6. Inverse search for displaced tracks

Efficiency comparison

CLIC sequence provides better efficiency for forward tracks

- presumably because of the relaxed cluster search window



I tried to adapt their logics for our scenario...

CLIC sequence

CLIC is using a more complex CT sequence

[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 : 4; MaxDistance : 0.02; HighPTCut: 10.0;

@Flags : OnlyZSchi2cut, RadialSearch

@Functions : CombineCollections, BuildNewTracks

expensive with BIB

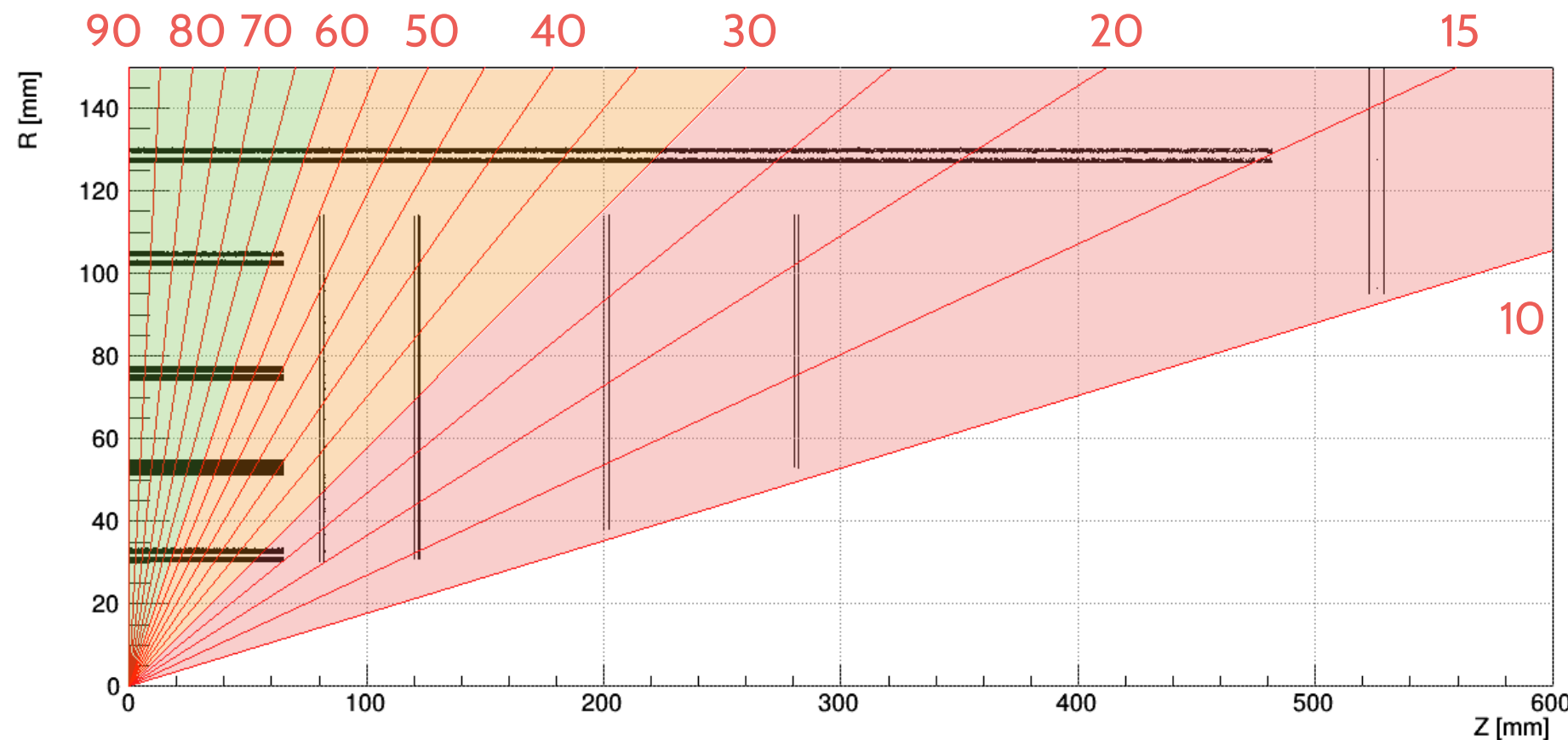
not relevant right now

1. Seeding from every hit in the VXD Barrel with tight angular window
2. Extending to the VXD Endcap
3. Seeding in whole VXD with relaxed search window
4. 2nd run with even more relaxed search window
5. Extending to the Inner/Outer tracker
5. Inverse search for displaced tracks

CLIC adaptation

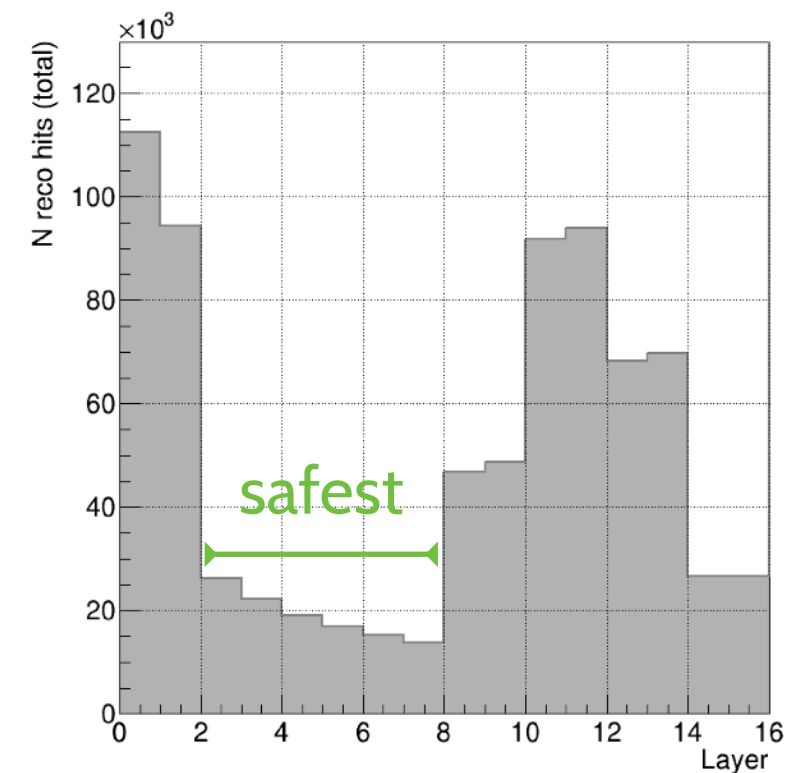
Adapting CLIC sequence to our configuration

- split VXD seeding into 3 sections:
 - Central
 - Middle
 - Forward
- each section can have separately optimised parameters and quality cuts



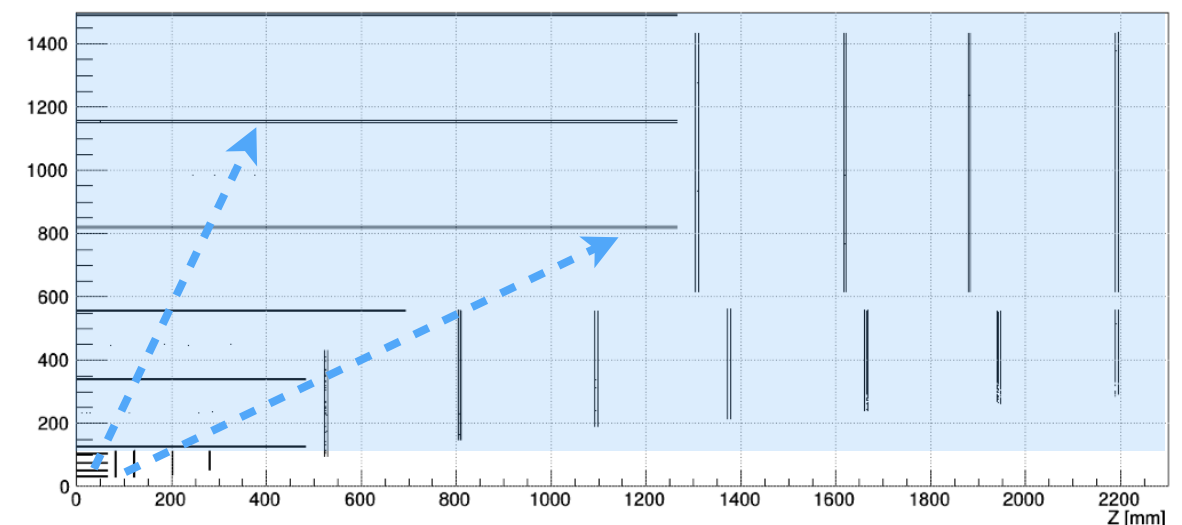
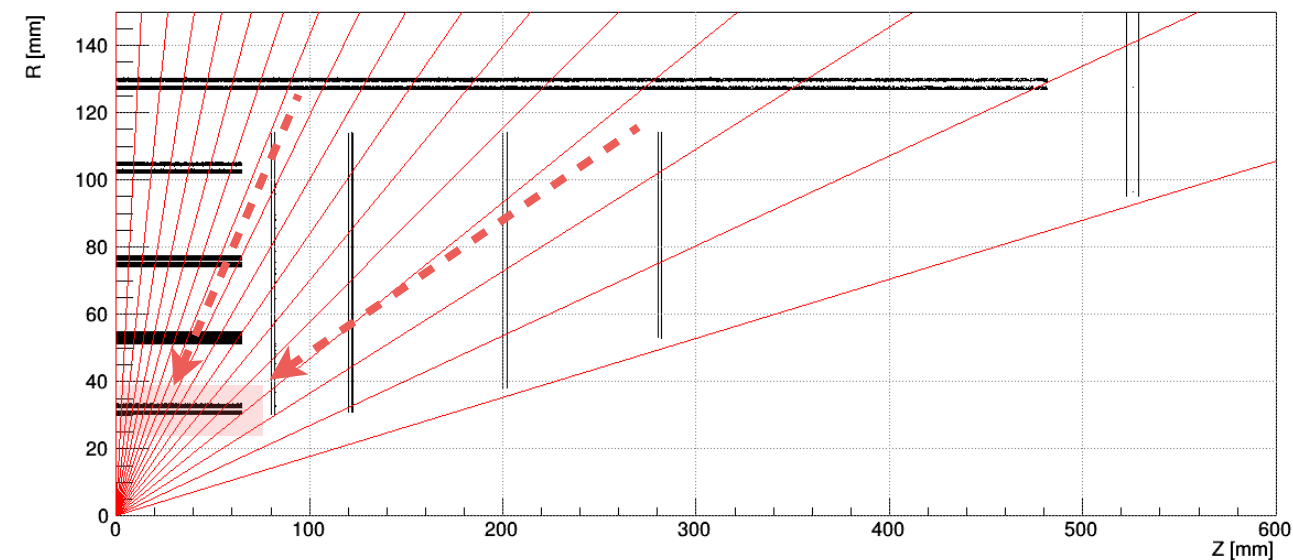
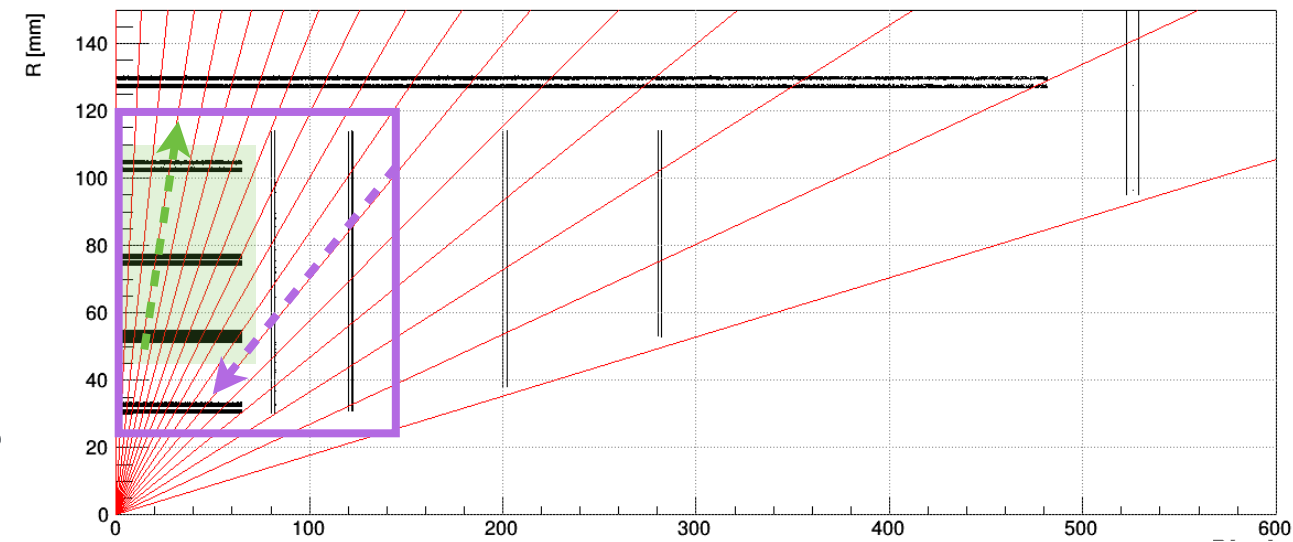
Pattern recognition is strongly affected by the number of hits used in each step

↳ hit multiplicity in each layer should be kept in mind



CT with split collections: logics

1. Seeding from low-occupancy VXD Barrel
 - very quick and robust
2. Seeding from inner half of VXD Endcap + all VXD Barrel
 - inverse search $\rightarrow$ innermost Barrel layers only used to finalise tracks
3. Seeding from full VXD Endcap
 - inverse search for forward tracks
4. Propagating to the innermost VXD Barrel
 - for better d_0 estimation
5. Propagating to the Silicon Tracker
 - only found tracks are extended $\rightarrow$ relatively fast



CT with split collections: configuration

CLIC-like

[VXDBarrel]

```
@Collections : VXDBTrackerHits
@Parameters : MaxCellAngle : 0.005; MaxCellAngleRZ : 0.005;
Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.02;
SlopeZRange: 10.0; HighPTCut: 10.0;
@Flags : HighPTFit, VertexToTracker
@Functions : CombineCollections, BuildNewTracks
```

[VXDEncap]

```
@Collections : VXDETrackerHits
@Parameters : MaxCellAngle : 0.005; MaxCellAngleRZ : 0.005;
Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.02;
SlopeZRange: 10.0; HighPTCut: 0.0;
@Flags : HighPTFit, VertexToTracker
@Functions : CombineCollections, ExtendTracks
```

[LowerCellAngle1]

```
@Collections : VXDBTrackerHits, VXDETrackerHits
@Parameters : MaxCellAngle : 0.025; MaxCellAngleRZ : 0.025;
Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.02;
SlopeZRange: 10.0; 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;
SlopeZRange: 10.0; HighPTCut: 10.0;
@Flags : HighPTFit, VertexToTracker, RadialSearch
@Functions : BuildNewTracks, SortTracks
```

[Tracker]

```
@Collections : IBTrackerHits, OBTrackerHits, IETrackerHits,
OETrackerHits
@Parameters : MaxCellAngle : 0.05; MaxCellAngleRZ : 0.05;
Chi2Cut : 2000; MinClustersOnTrack : 4; MaxDistance : 0.02;
SlopeZRange: 10.0; HighPTCut: 0.0;
@Flags : HighPTFit, VertexToTracker, RadialSearch
@Functions : CombineCollections, ExtendTracks
```

↑ this is supposed to perform well
With BIB will be very slow

staged+split

[VXDcentral]

```
@Collections : VXDBTrackerHitsOuter
@Parameters : MaxCellAngle : 0.003; MaxCellAngleRZ : 0.003;
Chi2Cut : 100; MinClustersOnTrack : 5; MaxDistance : 0.024;
SlopeZRange: 10.0; HighPTCut: 1.0;
@Flags : HighPTFit, VertexToTracker
@Functions : CombineCollections, BuildNewTracks
```

[VXDMiddle]

```
@Collections : VXDBTrackerHitsInner, VXDBTrackerHitsOuter,
VXDETrackerHitsInner, VXDETrackerHitsMiddle
@Parameters : MaxCellAngle : 0.007; MaxCellAngleRZ : 0.007;
Chi2Cut : 100; MinClustersOnTrack : 5; MaxDistance : 0.024;
SlopeZRange: 10.0; HighPTCut: 1.0;
@Flags : HighPTFit
@Functions : CombineCollections, BuildNewTracks
```

[VXDForward]

```
@Collections : VXDETrackerHitsMiddle, VXDETrackerHitsOuter
@Parameters : MaxCellAngle : 0.03; MaxCellAngleRZ : 0.03;
Chi2Cut : 100; MinClustersOnTrack : 4; MaxDistance : 0.024;
SlopeZRange: 10.0; HighPTCut: 1.0;
@Flags : HighPTFit
@Functions : CombineCollections, BuildNewTracks
```

[VXDBInner]

```
@Collections : VXDBTrackerHitsInner
@Parameters : MaxCellAngle : 0.005; MaxCellAngleRZ : 0.005;
Chi2Cut : 100; MinClustersOnTrack : 5; MaxDistance : 0.024;
SlopeZRange: 10.0; HighPTCut: 10.0;
@Flags : HighPTFit, RadialSearch
@Functions : CombineCollections, ExtendTracks, SortTracks
```

[Tracker]

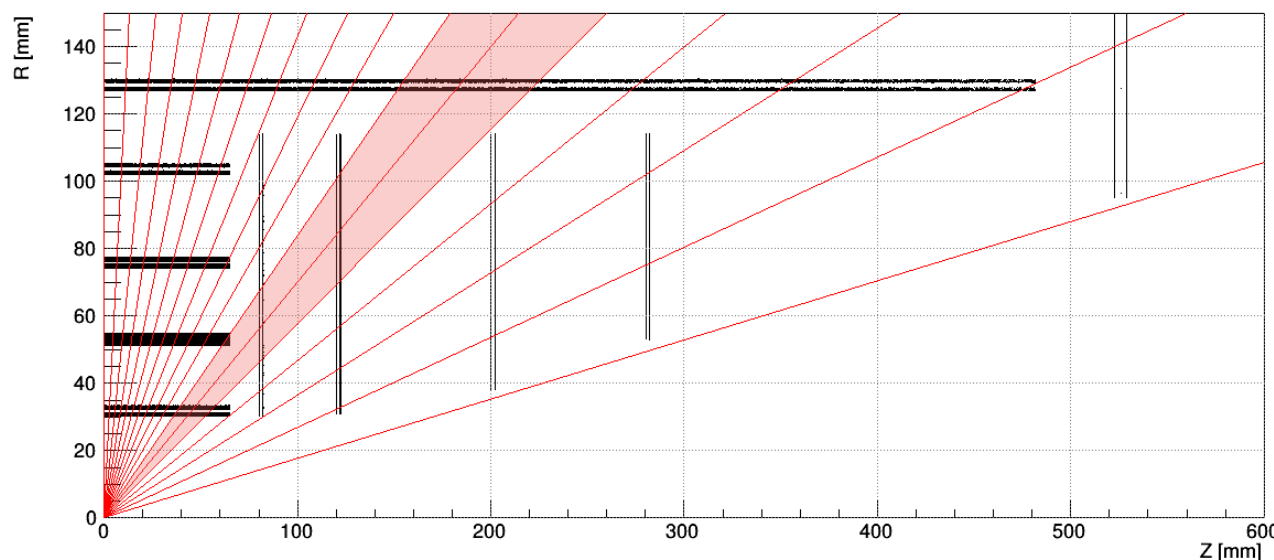
```
@Collections : IBTrackerHits, OBTrackerHits, IETrackerHits,
OETrackerHits
@Parameters : MaxCellAngle : 0.05; MaxCellAngleRZ : 0.05;
Chi2Cut : 100; MinClustersOnTrack : 6; MaxDistance : 0.009;
SlopeZRange: 10.0; HighPTCut: 0.0;
@Flags : HighPTFit, VertexToTracker, RadialSearch
@Functions : CombineCollections, ExtendTracks
```

↑ this should be faster but might miss
some signal tracks

CT with split collections: performance

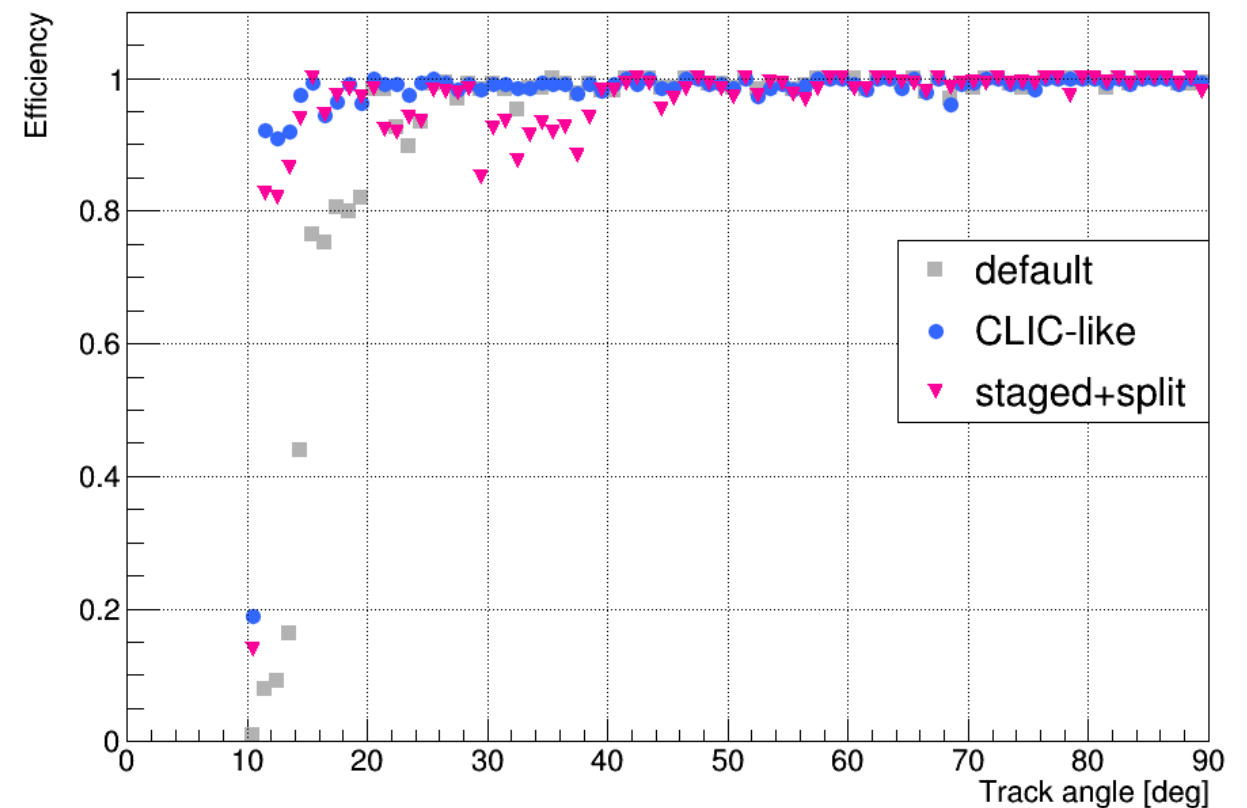
Checking efficiency for $\mu^\pm$ at $p_T=0.5$ GeV

- **CLIC-like** sequence (CLIC like) provides best efficiency
- **staged+split** sequence has slightly worse efficiency in the **30° - 40°** region



[VXDMiddle]

```
@Collections : VXDBTrackerHitsInner,  
VXDBTrackerHitsOuter, VXDETrackerHitsInner,  
VXDETrackerHitsMiddle  
@Parameters : MaxCellAngle : 0.007;  
MaxCellAngleRZ : 0.007; Chi2Cut : 100;  
MinClustersOnTrack : 5; MaxDistance : 0.024;  
SlopeZRange: 10.0; HighPTCut: 1.0;  
@Flags : HighPTFit  
@Functions : CombineCollections, BuildNewTracks
```



Fixed by reducing the requirement on the #
of clusters: **$5 \rightarrow 4$**

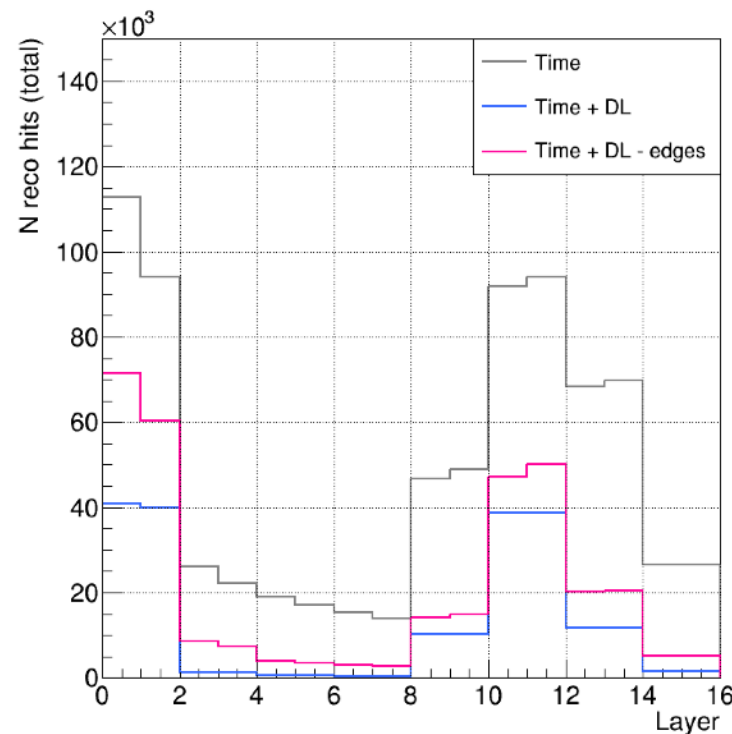
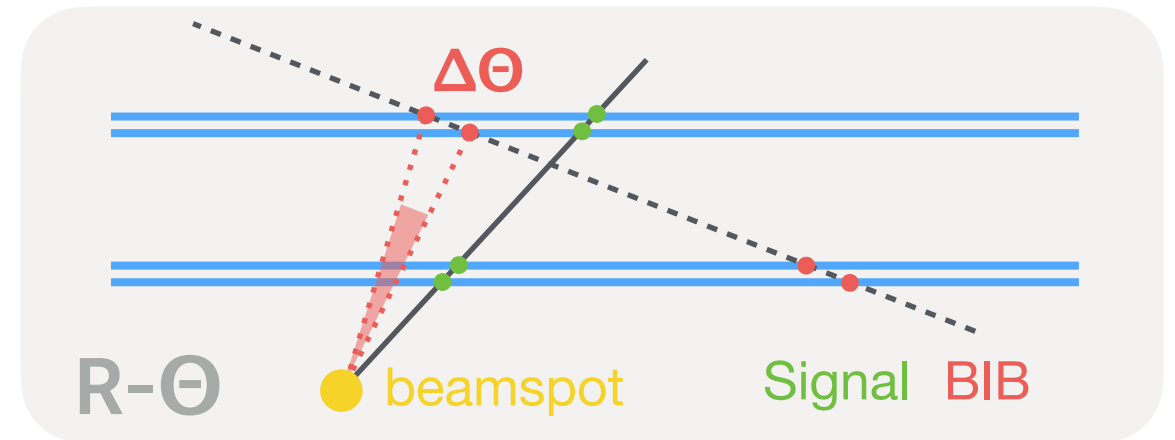
↳ **will make it slower**

**Currently running a few configurations with
50% of BIB to understand performance**

Effect of double-layer cut

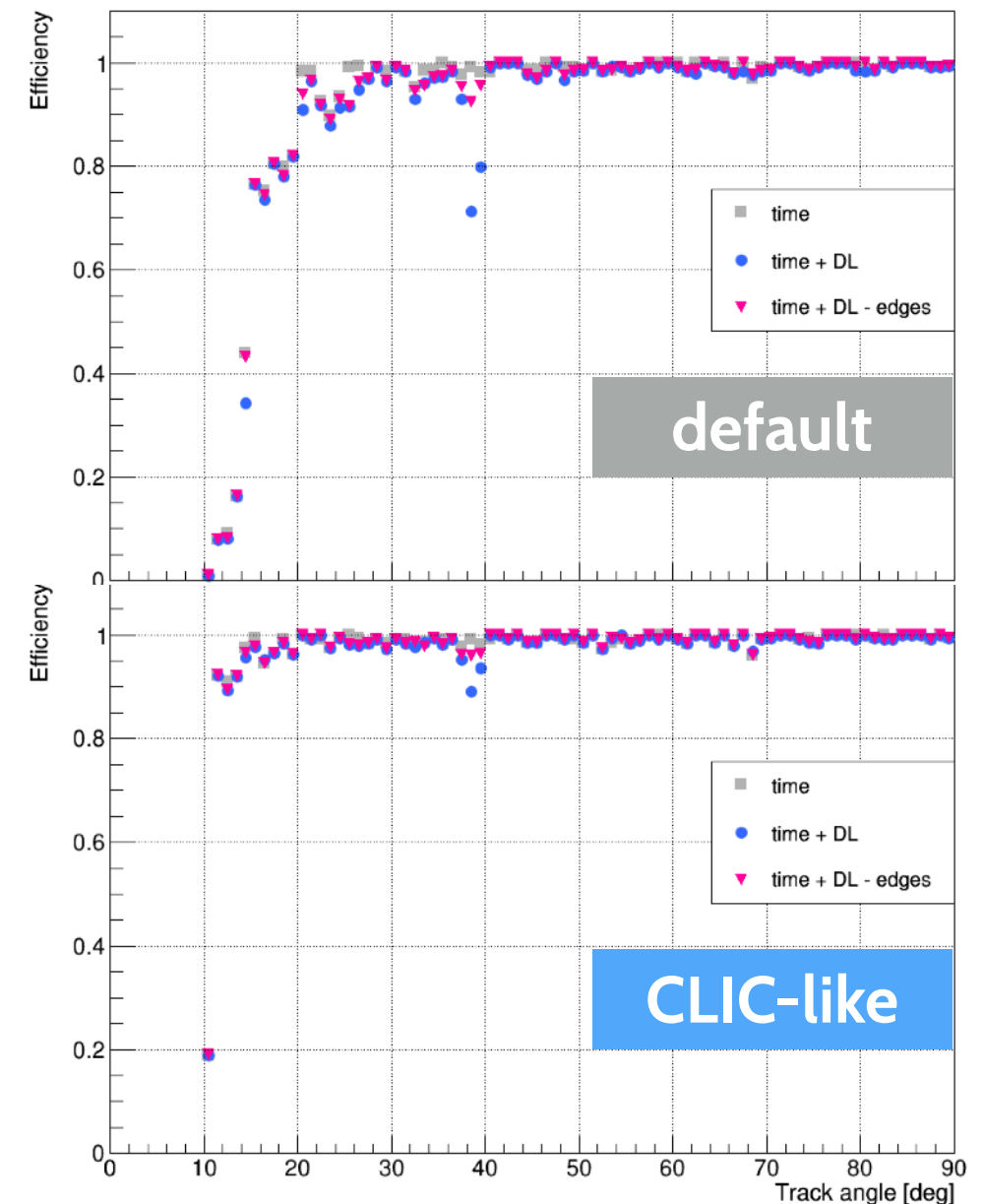
Double-layer selection was introduced to suppress BIB hits

- added an option to keep hits at the sensor edges
- noticeably increases the # of surviving hits



CLIC-like CL sequence is less affected by missing hits removed by the double-layer filter

- we might be able to accept partial loss of signal hits with a proper CT configuration



Summary

The Conformal Tracking algorithm is indeed quite powerful and flexible

We clearly need to split the sequence into more isolated steps that minimise the number of track fits performed

A candidate sequence is being tested with good track-reconstruction efficiency

↳ effect on CPU performance is still to be evaluated