Disappearing track search at FCC
~ Background estimation ~

02 / 03 / 2018

FCC-hh physics analysis meeting

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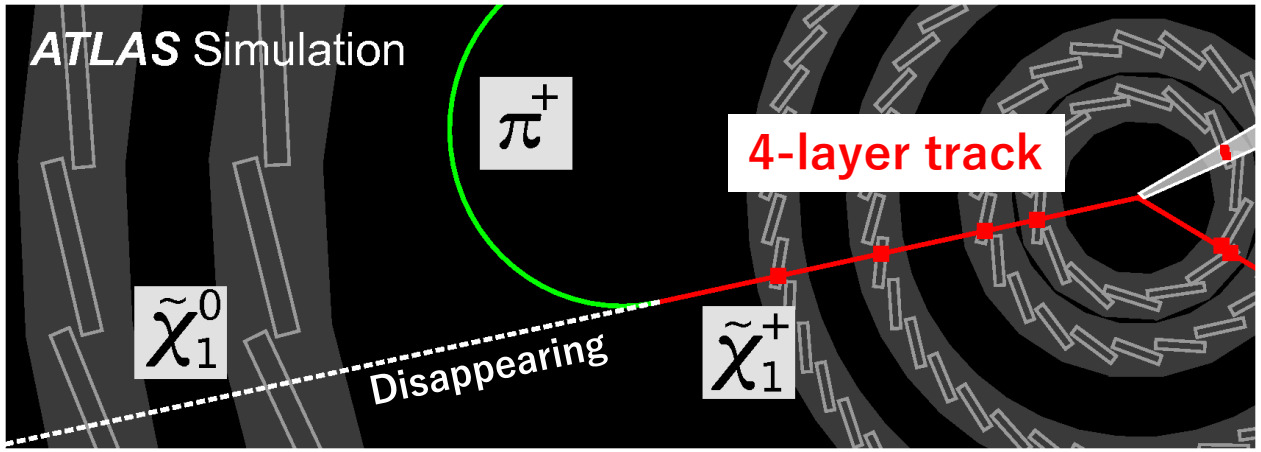
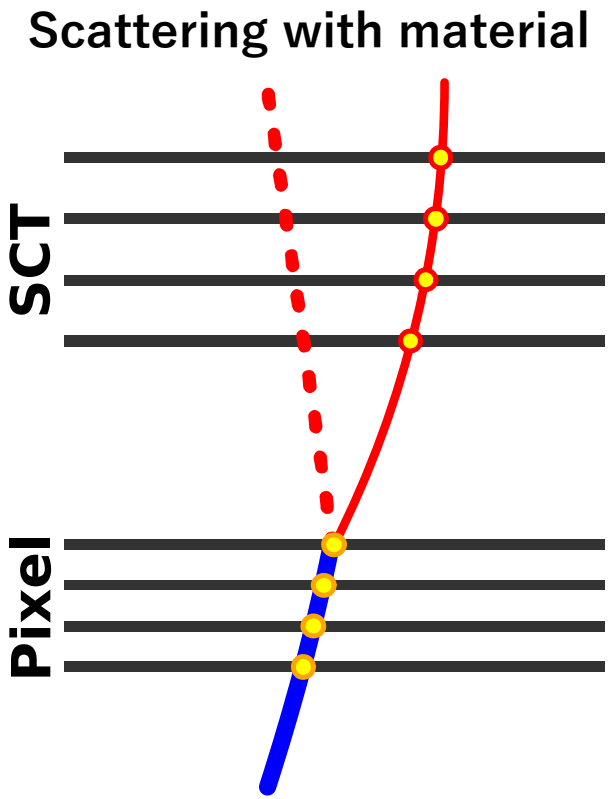
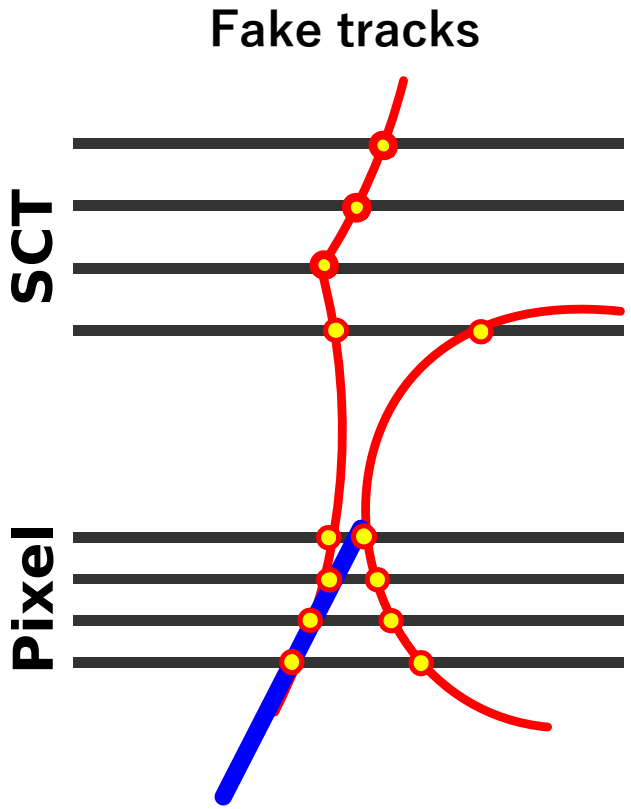


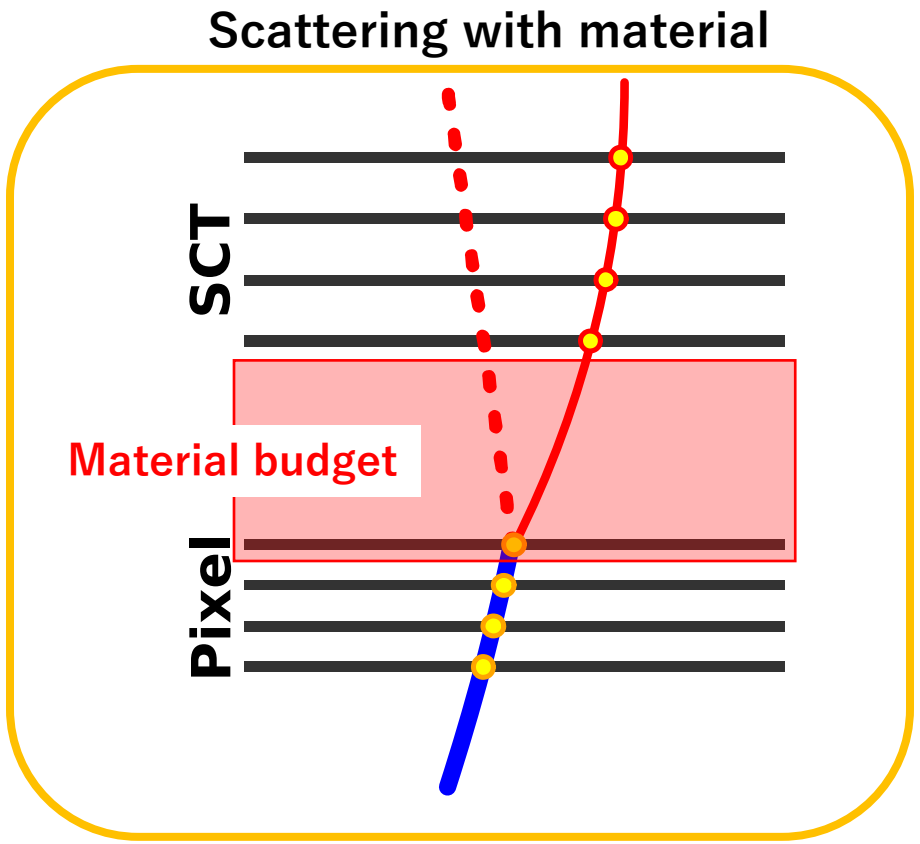
Background

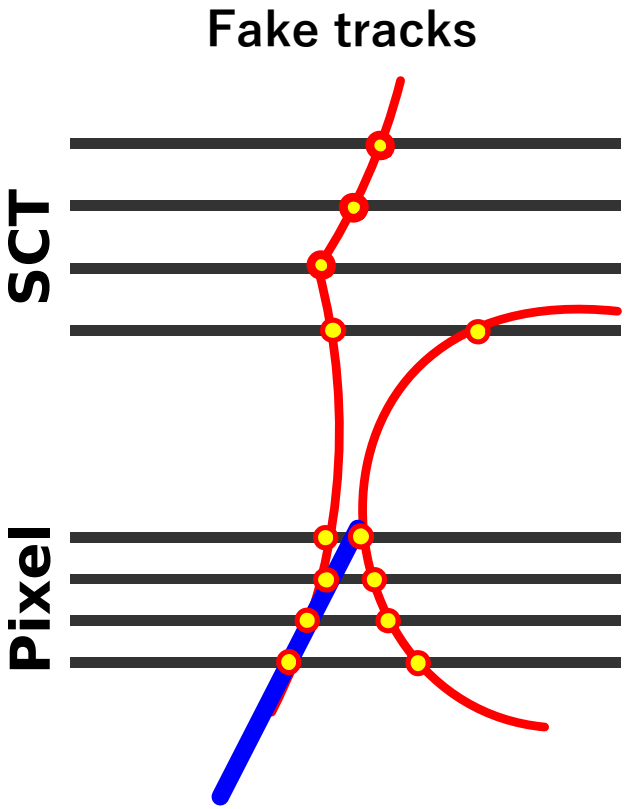




- Backgrounds categorize roughly two components.
  - physical background : Missing hits due to material interaction
  - unphysical background : Random combination of hits
- Estimate each background at FCC detector.

Background strategy



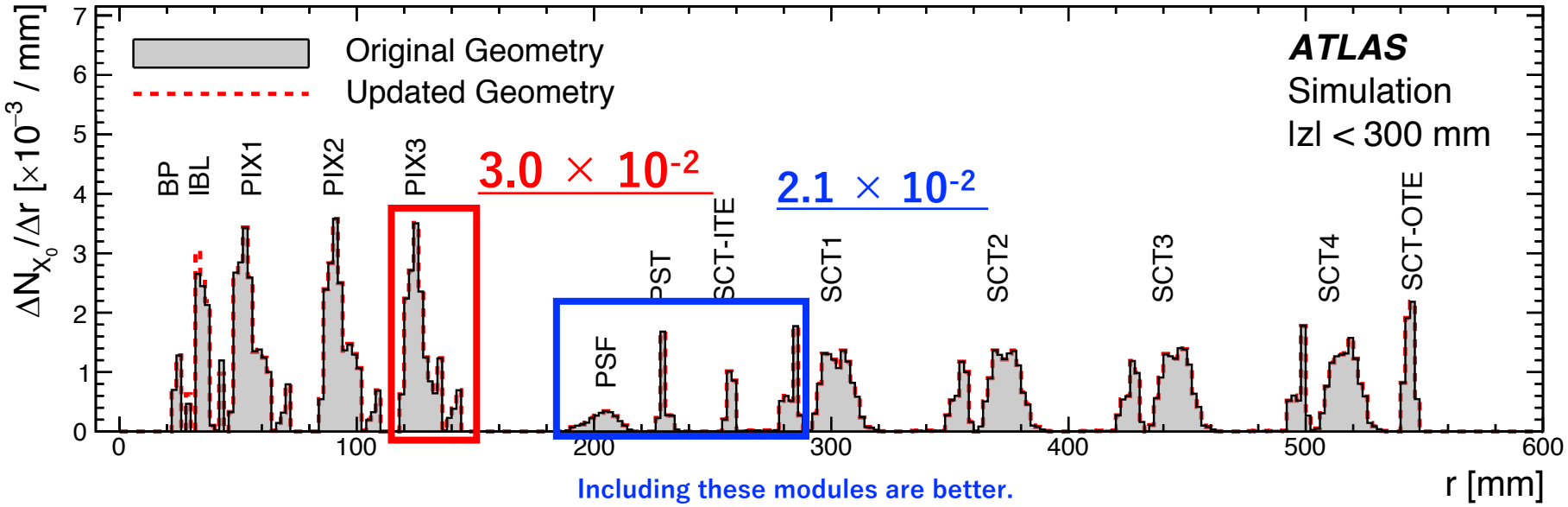


- Compare the material budget between 4th layer and 5th layer.
- Scale the recent ATLAS result by the ratio of radiation length

Radiation length

ATLAS Detector

arxiv : 1707.02826

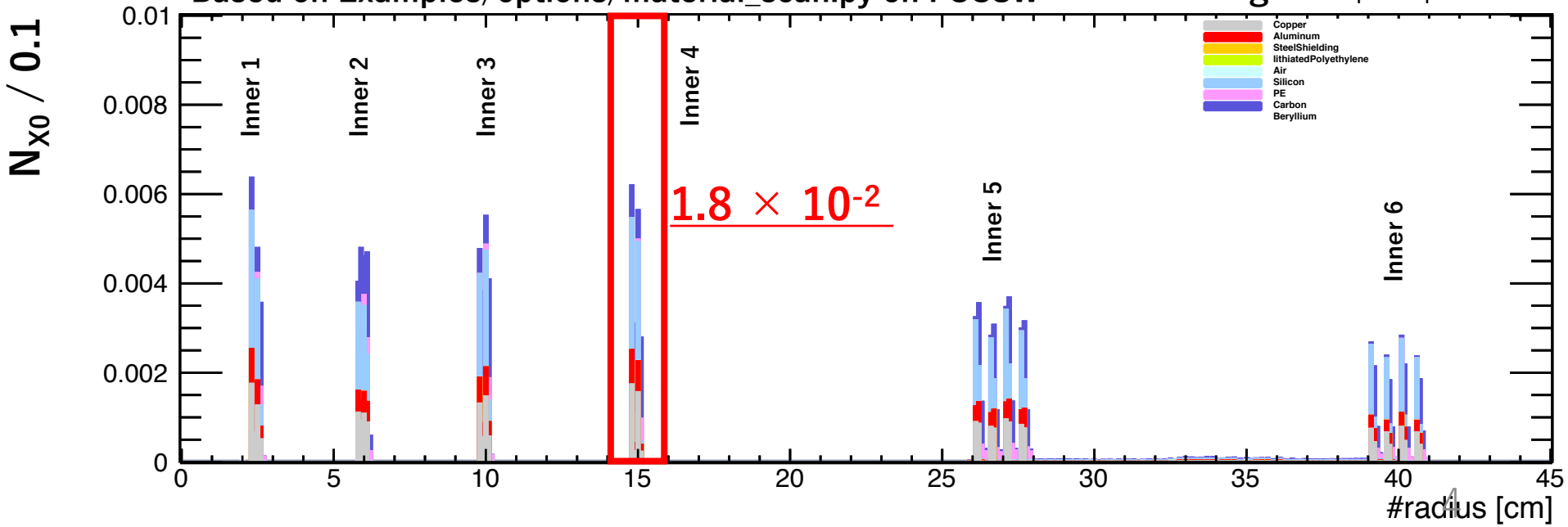


Including these modules are better.
But no corresponding structure at FCC
Is it fair to include these modules? or not?

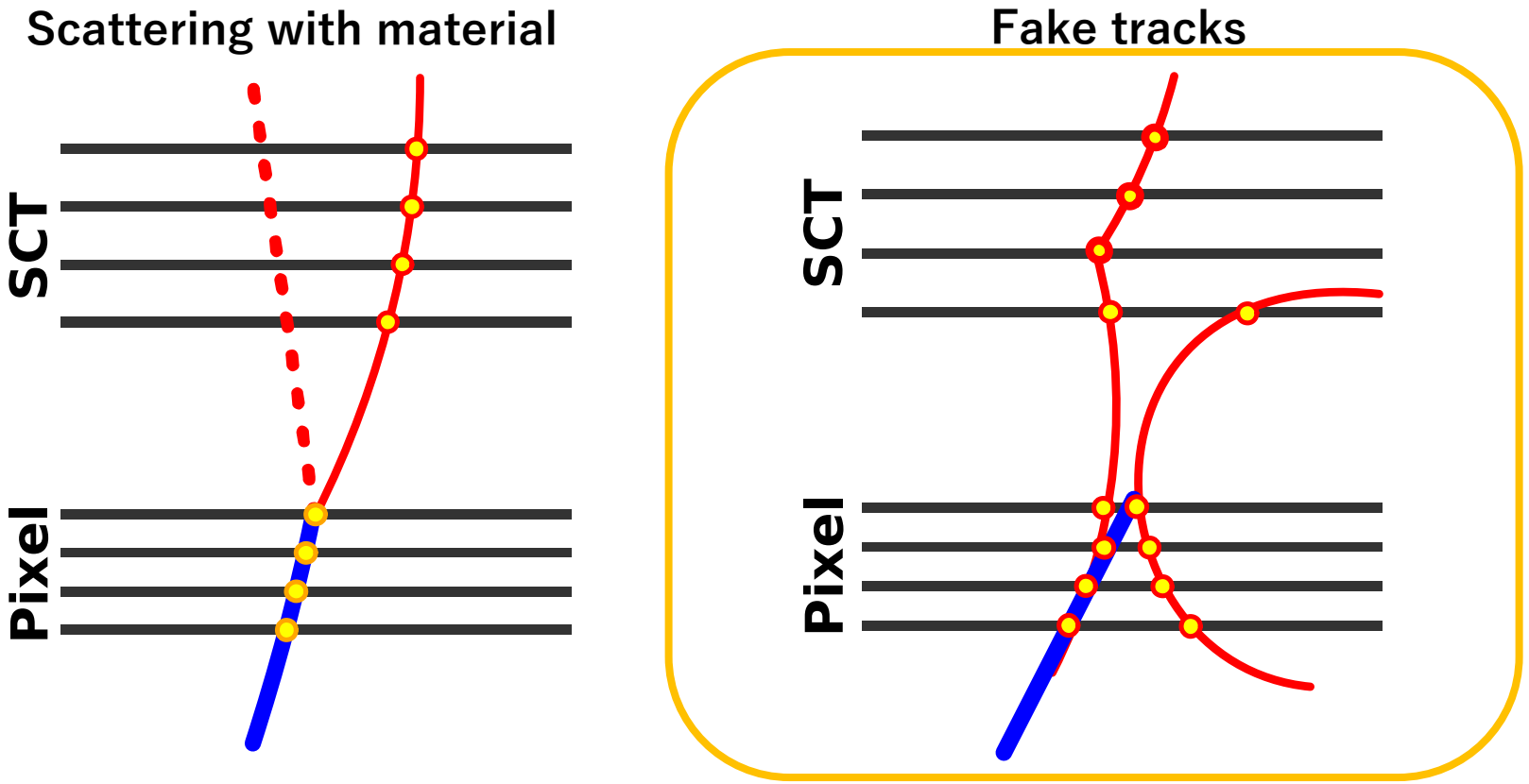
FCC Detector v3.0.3

Based on Examples/options/material_scan.py on FCCSW

average on |eta| < 2



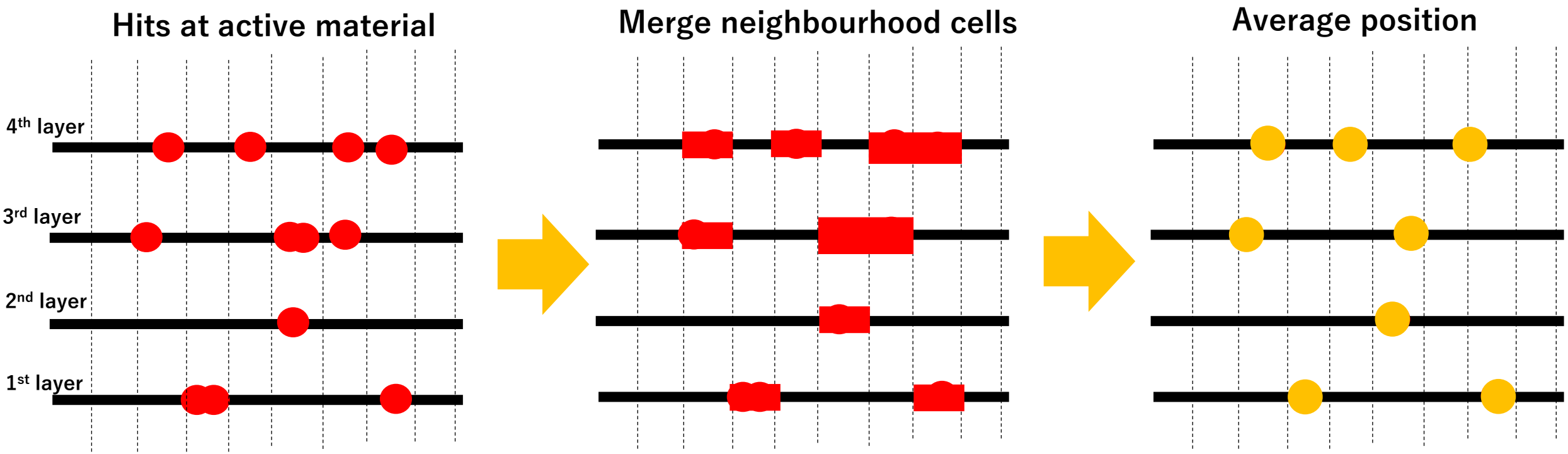
Background strategy



- Simple tracking is applied to estimate random combination tracks

Simple tracking

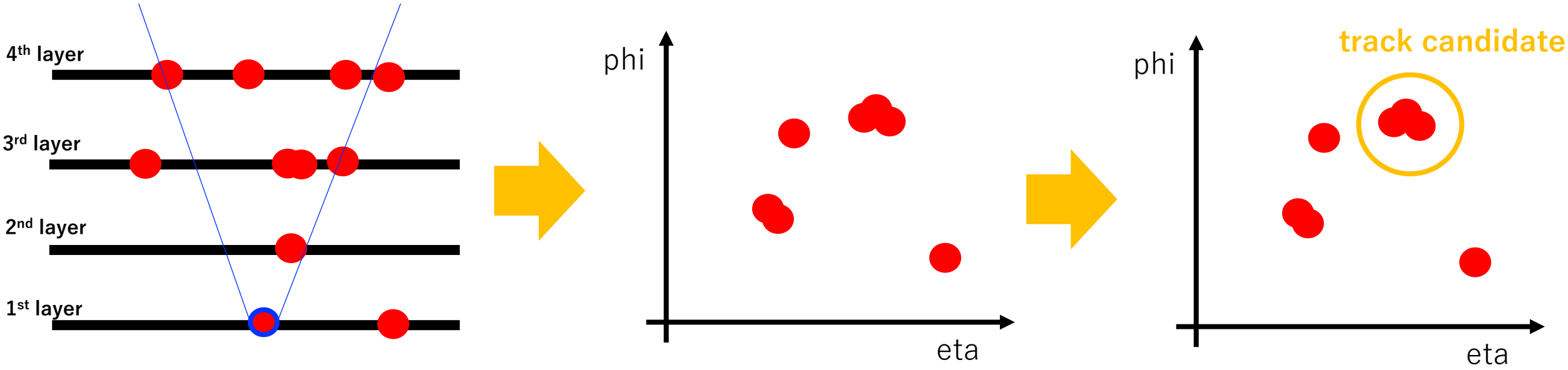
1. Create space points
    1. Assign MC hits to “virtual cells” with a pixel size (x, y, z) = (100, 100, 100) μm. Then merge neighborhood cells. Take an average of all hit-positions on each cell.



Actually, most cells have only one hits. Therefore original hits are used in most cases.

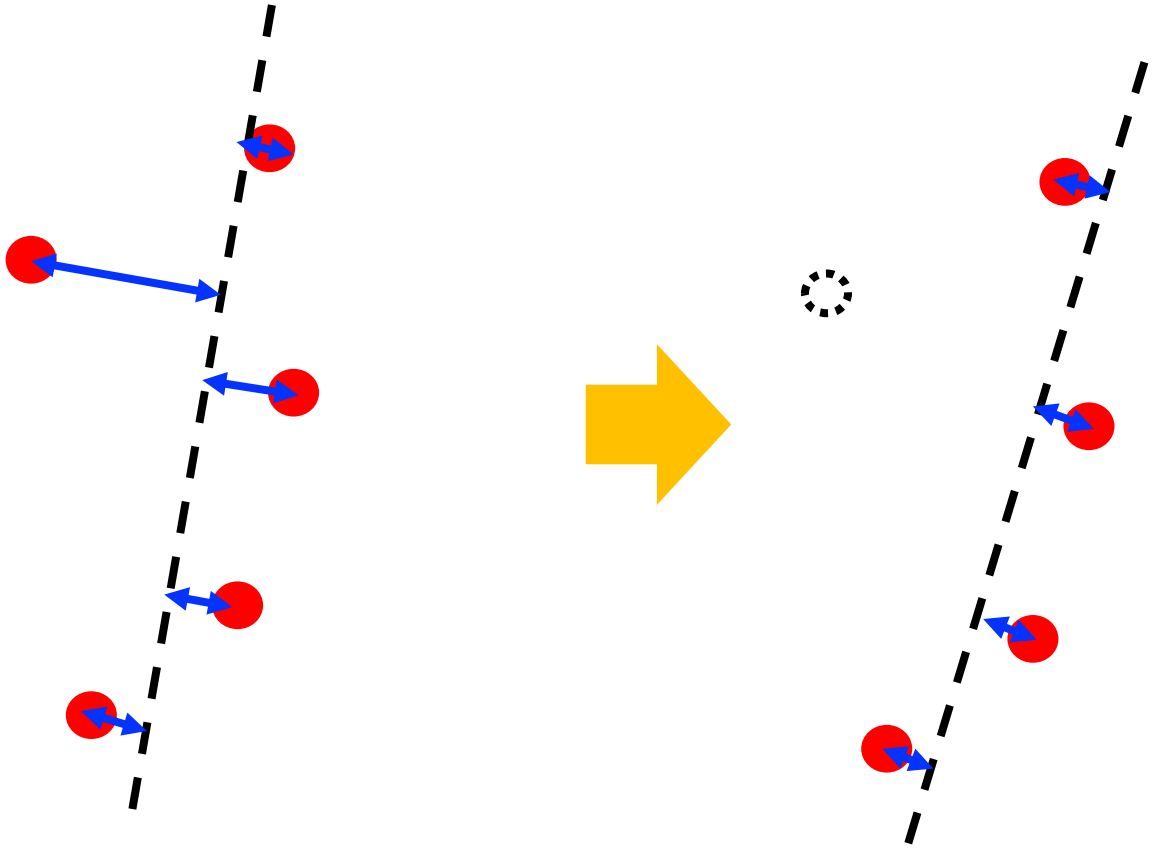
Simple tracking

2. Find an available hit combination
   1. Select one hit on 1st layer, then create an (η - ϕ) maps for all hits on 2nd, 3rd, 4th, … layers.
   2. Find a bin whose entries are more than 3.



Simple tracking

3. Fit the hit combination and create a track.
   1. Minimize the sum of the distance between the line and the hits.
   2. The outlier hits, which is far away 5 sigma from the line, is removed and re-fit without the outlier hits. The position uncertainty is assumed 50 μm / $\sqrt{12}$.



Simple tracking

1. Create space points
   1. Assign MC hits to “virtual cells” with an assumed pixel size (x, y, z) = (100, 100, 100) μm. Then merge neighborhood cells. Take an average of all hit-positions on each cell.
2. Find an available hit combination
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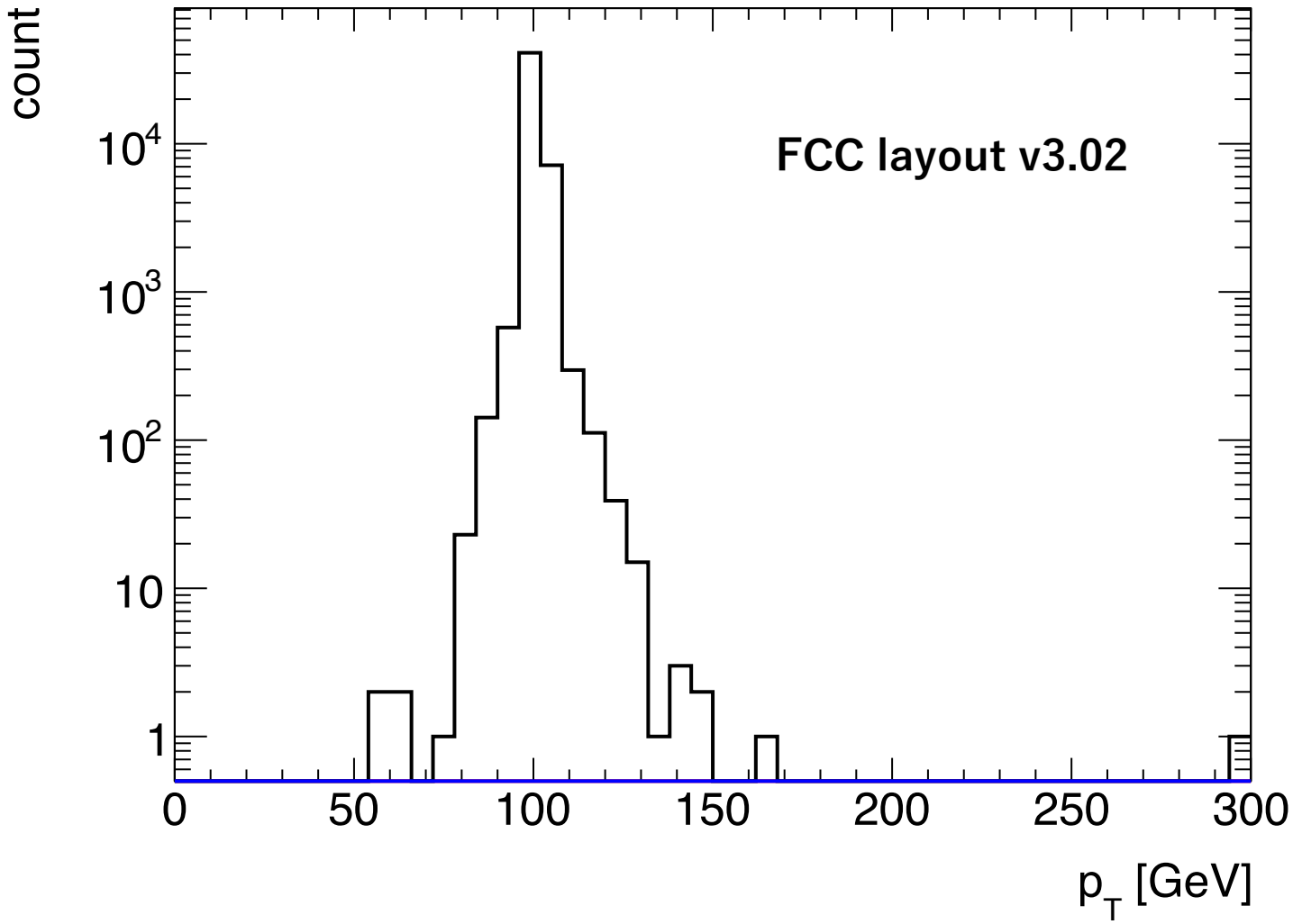
Details are in backup.

- Validated this simple tracking by comparing the number of fake tracks with ATLAS tracking.
- Two results, ATLAS tracking and simple tracking, are in good agreement if considering some effects which cannot be handled in simple tracking.
  - Hole modules in one layer. (this looks at overlapping modules)
  - Shared hits with other good tracks.

Single muon events

Sample information:
- Single muon sample
- no pileup
- pT = 100 GeV, (eta, phi) = (0, 0)

Quality selection
- Fit p-value (TMath::Prob(chi2, ndof)) > 0.1
- |z0| < 250 mm
- |d0| < 1 mm
- |eta| < 2
- track pT > 50 GeV
- The number of contributed layers >= 5



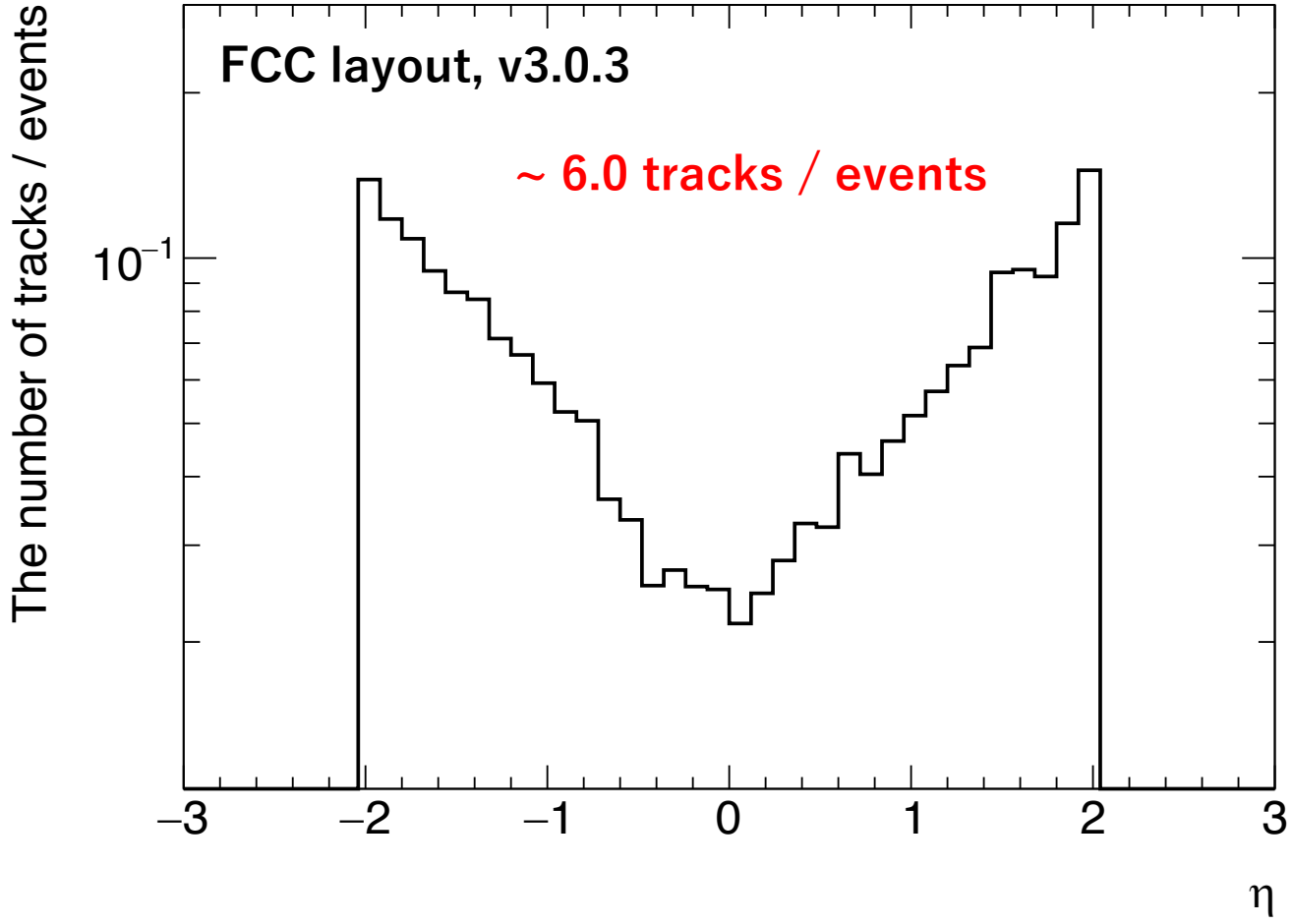
- Tracking efficiency
  48979 / 50000 = 98.0 %

- We can assume the same value as the signal efficiency.

Minimum bias events (mu=200)

Sample information:
- Minimum bias events,
  - SoftQCD:nonDiffractive in Pythia8
- Overlaid 200 pileup

Quality selection
- Fit p-value (TMath::Prob(chi2, ndof)) > 0.1
- |z0| < 250 mm
- |d0| < 1 mm
- |eta| < 2
- track pT > 100 GeV
- The number of contributed layers == 4



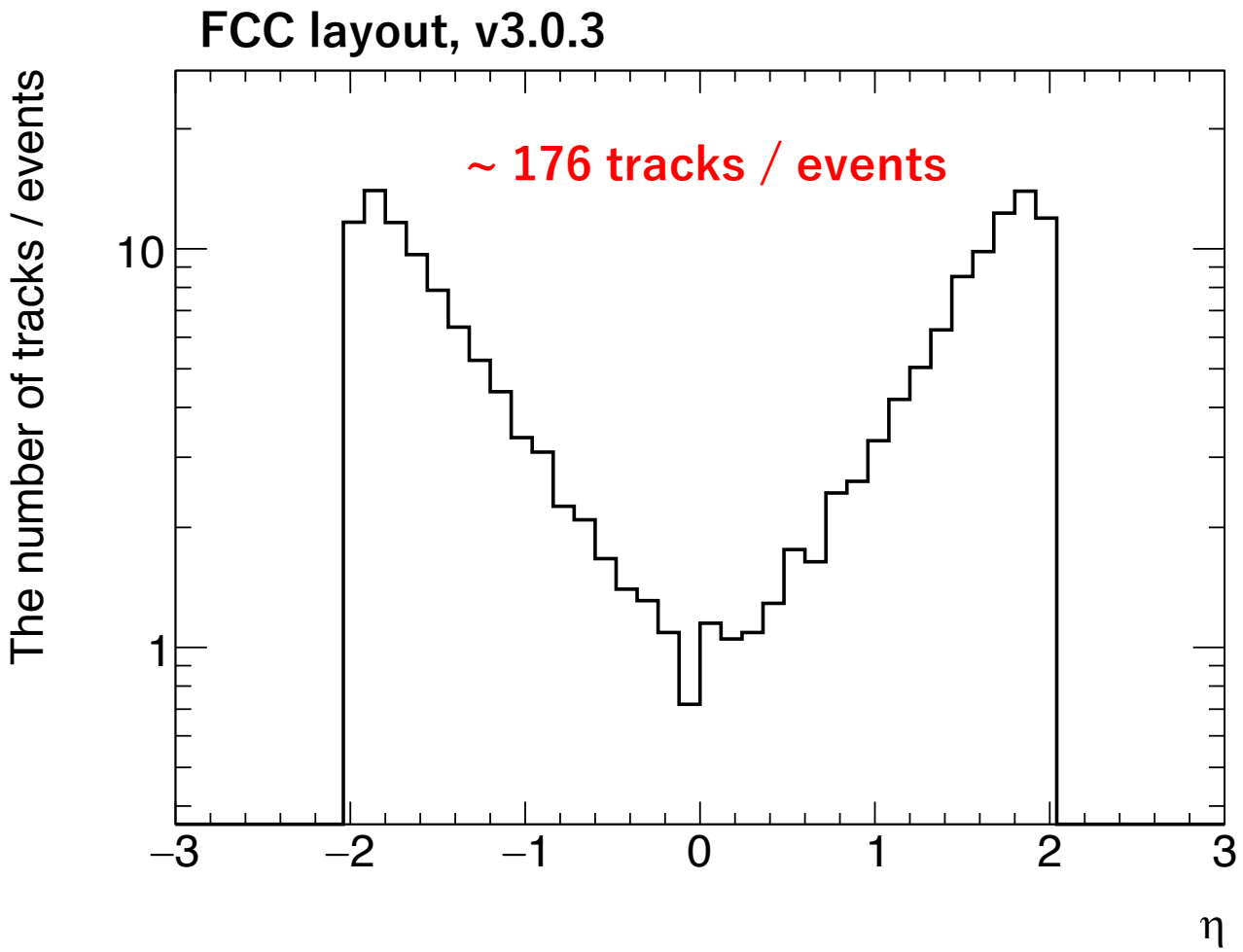
- IP cuts significantly reduce fake tracks. Since the IPs of fake tracks are randomly distributed, the selection efficiency can be estimated.
- Selection efficiency of IP cut,
  - N(|z0| < 0.5 mm) / N(|z0| < 250 mm) = 2×10^{-3}
  - N(|d0| < 0.05 mm) / N(|d0| < 1 mm) = 0.05
- We can reduce fake tracks a factor of 1e-4. The fake track rate after track selection will be 6.0×10^{-4}

Ref : ATLAS recent result
Passed kinematic selection : 2697917 events
Final fitted fake events : 5.5 +- 3.3
⇒ Fake rate = 2.0×10^{-6} / BC

Minimum bias events (mu=500)

Sample information:
- Minimum bias events,
  - SoftQCD:nonDiffractive in Pythia8
- Overlaid 500 pileup

Quality selection
- Fit p-value (TMath::Prob(chi2, ndof)) > 0.1
- |z0| < 250 mm
- |d0| < 1 mm
- |eta| < 2
- track pT > 100 GeV
- The number of contributed layers == 4



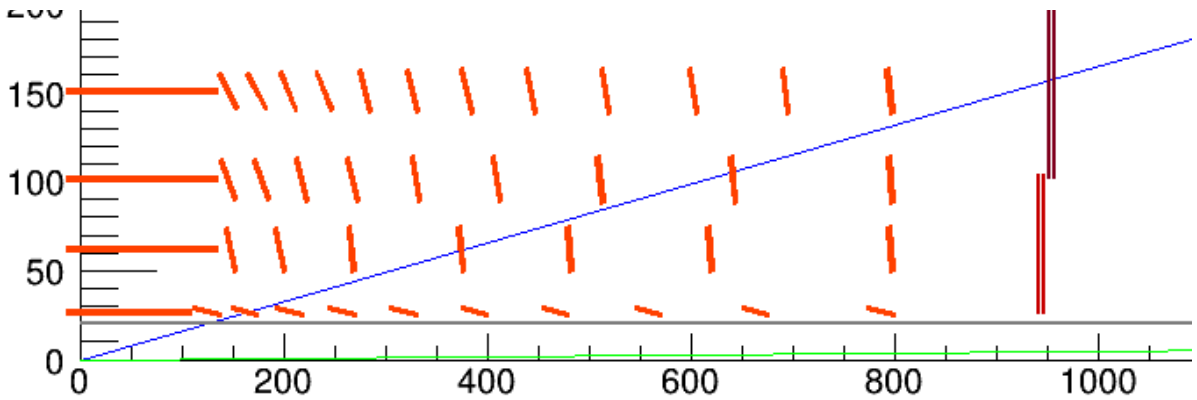
- IP cuts significantly reduce fake tracks. Since the IPs of fake tracks are randomly distributed, the selection efficiency can be estimated.
- Selection efficiency of IP cut,
  - N(|z0| < 0.5 mm) / N(|z0| < 250 mm) = 2×10^{-3}
  - N(|d0| < 0.05 mm) / N(|d0| < 1 mm) = 0.05
- We can reduce fake tracks a factor of 1e-4. The fake track rate after track selection will be 1.8×10^{-2}

- $N^{\mu=500}$ / $N^{\mu=200}$ ~ 30
- The number of fake tracks is proportional to μ^4.
  - $(500/200)^4 = 39$

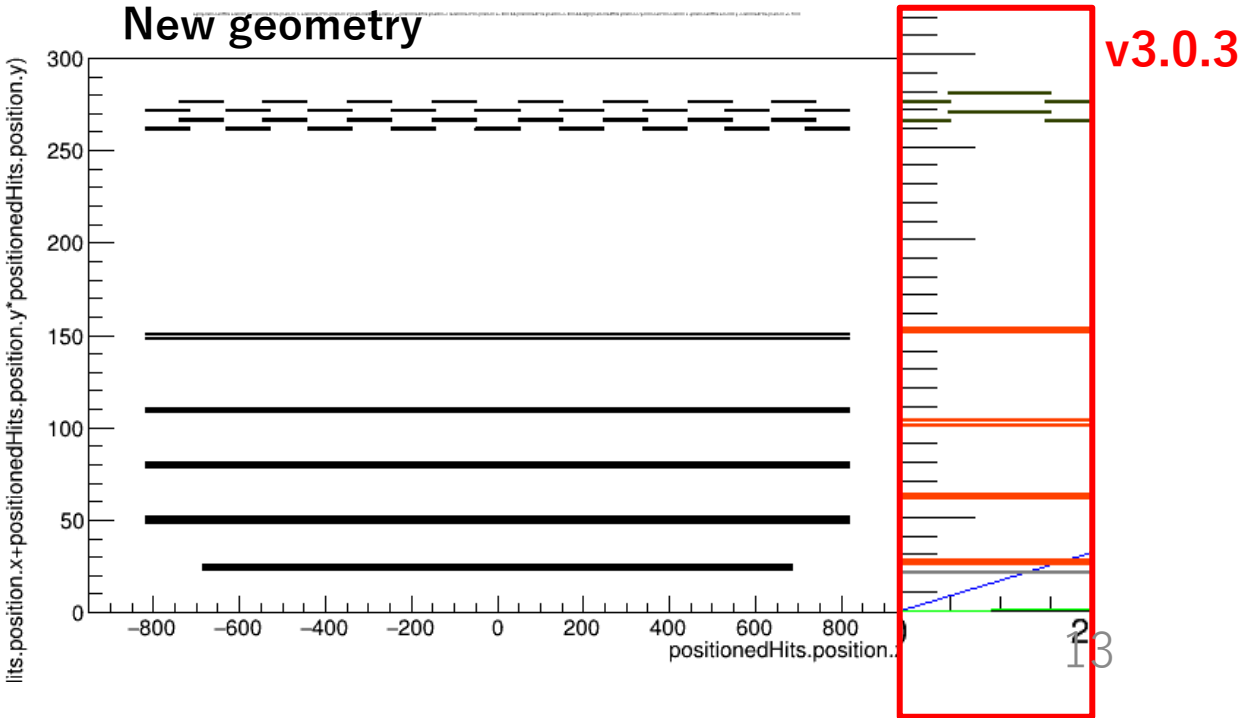
- Very large fake rate. Need to reduce this.

Some idea to reduce random combination fake tracks.

- **Inclined modules**
  - Multiple hits on a layer are expected in high eta region.
  - Checking hole modules significantly reduces fake background.
  - However hole-detection is difficult in simple tracking code. Plan to write just comments to CDR.



- **Additional layer**
  - Additional layers also reduces fake backgrounds.
  - The same estimation with new geometry is on-going.
  - Plan to include this results to CDR.



- **Increases of required hits**
  - Requiring 5 hits reduces fake background, but also reduces signal acceptance.. .

Summary and Plan to CDR

- Estimated how much the number of backgrounds increases at FCC.
- Physical background(scattering source) rate is expected to be reduced. On the other hands, the number of random combination tracks significantly increase due to pileup.

- To reduce fake background, some study is on-going.
  - other geometry
  - required hits condition (e.g. from 4 to 5)
- As next steps, kinematic selection efficiency of signal/background will be evaluated by using Delphes samples. By applying track selection efficiency/background rate to above samples, a sensitivity plots at $30ab^{-1}$ will be created.
- In parallel, writing of CDR is on-going.

Backup

Tracking details (Seed Finding)

1. Separate clusters by layer index.
2. Create a (ϕ-z) grid to enable to easily get corresponding clusters at later step.
   a. The ϕ ranges are ($-\pi$, π).
   b. The z ranges are (-1000 mm, 1000 mm).
   c. The grid size is 1000 for ϕ and 100 for z. These are used only to fast select corresponding clusters.
3. Search seed tracks (three space point combination)
   a. Select one cluster at innermost layer.
   b. Get clusters from the appropriate (ϕ-z) grid cells defined above.
      i. not innermost layer
      ii. track p_T is more than 50 GeV.
      iii. track $|\eta|$ is less than 2.
      iv. track $|d_0|$ is less than 1 mm.
      v. track $|z_0|$ is less than 250 mm.
   c. Create (η-ϕ) grid and add the clusters at outer layers to corresponding cells.
      i. A cluster η and ϕ at outer layers are defined from the cluster at innermost layer.
      ii. The η ranges are (-2.0, 2.0).
      iii. The ϕ ranges are ($-\pi$, π).
      iv. The grid size is 10000 $\times$ 10000. Therefore the each cell size is $(\Delta\eta, \Delta\phi) = (4 \times 10^{-4}, 6.3 \times 10^{-4})$
   d. Find a track candidate from the (η-ϕ) grid.
      i. If more than three entries (except innermost layer) are found in 3 $\times$ 3 cells, a set of the clusters is defined as a seed track. Here, the number of layers on the seed tracks is also checked. If the number of layers are less than 3, the track candidate is rejected.
   e. Apply above procedures to all clusters at innermost layer.

Tracking details (Track Fitting)

- For each seed tracks, 3D-line-like fitting are applied. The tracks are parametrized by

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \underbrace{\begin{pmatrix} x_0 \\ y_0 \\ 0 \end{pmatrix} + \begin{pmatrix} \sin\theta\cos\phi \\ \sin\theta\sin\phi \\ \cos\theta \end{pmatrix} \cdot t}_{\text{Straight line}} + \underbrace{\frac{1}{2R}\begin{pmatrix} \sin\theta\sin\phi \\ -\sin\theta\cos\phi \\ 0 \end{pmatrix} \cdot t^2 - \frac{1}{6R^2}\begin{pmatrix} \sin\theta\cos\phi \\ \sin\theta\sin\phi \\ 0 \end{pmatrix} \cdot t^3}_{\text{Circle approximation term}}$$

Curvature : $R\ [\mathrm{m}] = \dfrac{p_T\ [\mathrm{GeV}]}{0.3 \cdot B\ [\mathrm{T}]}$

- Minimize the sum of the distance between this parametrized line and each hit.

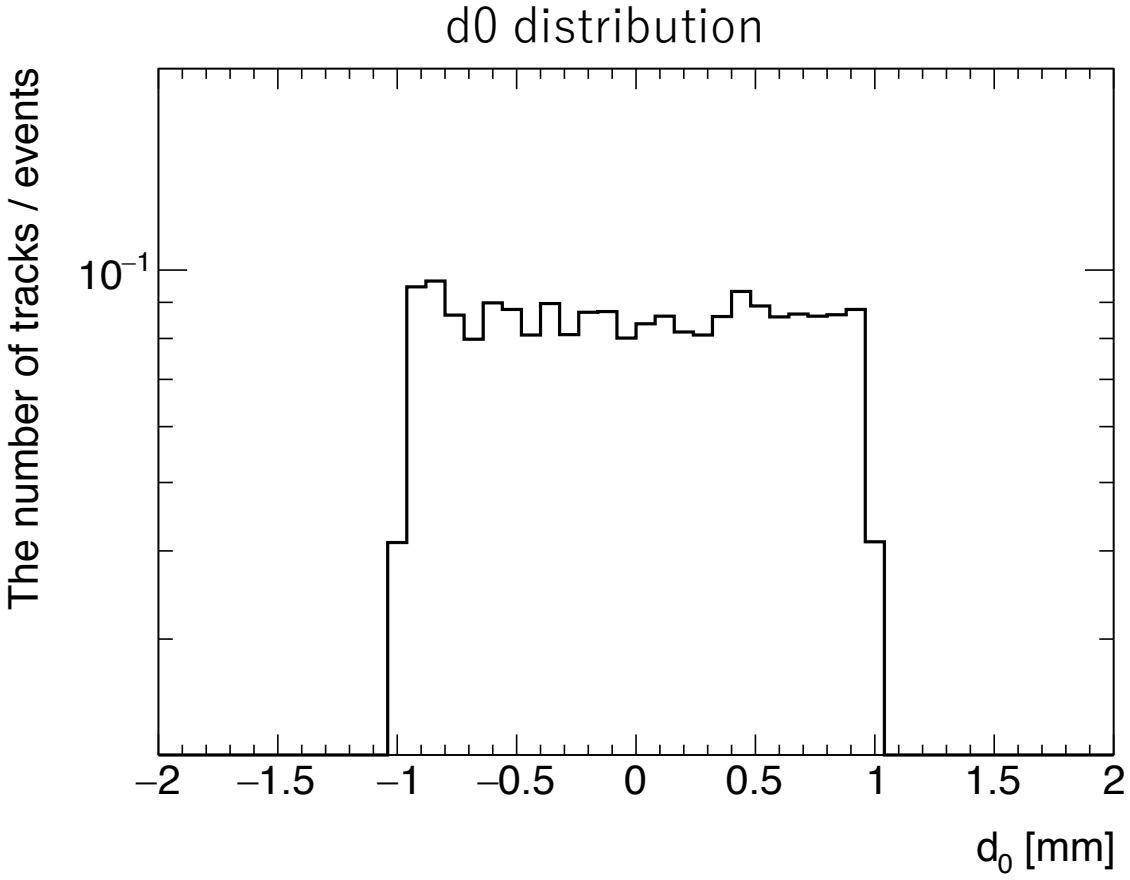
- An analytical calculation of the distance is difficult. Therefore, the distance are approximately calculated.
  1. Calculate the closet points on the line from hits without circle-approximation term, then get the “t”.
  2. Evaluate the distance between hits and the line with circle-term at ”t”.

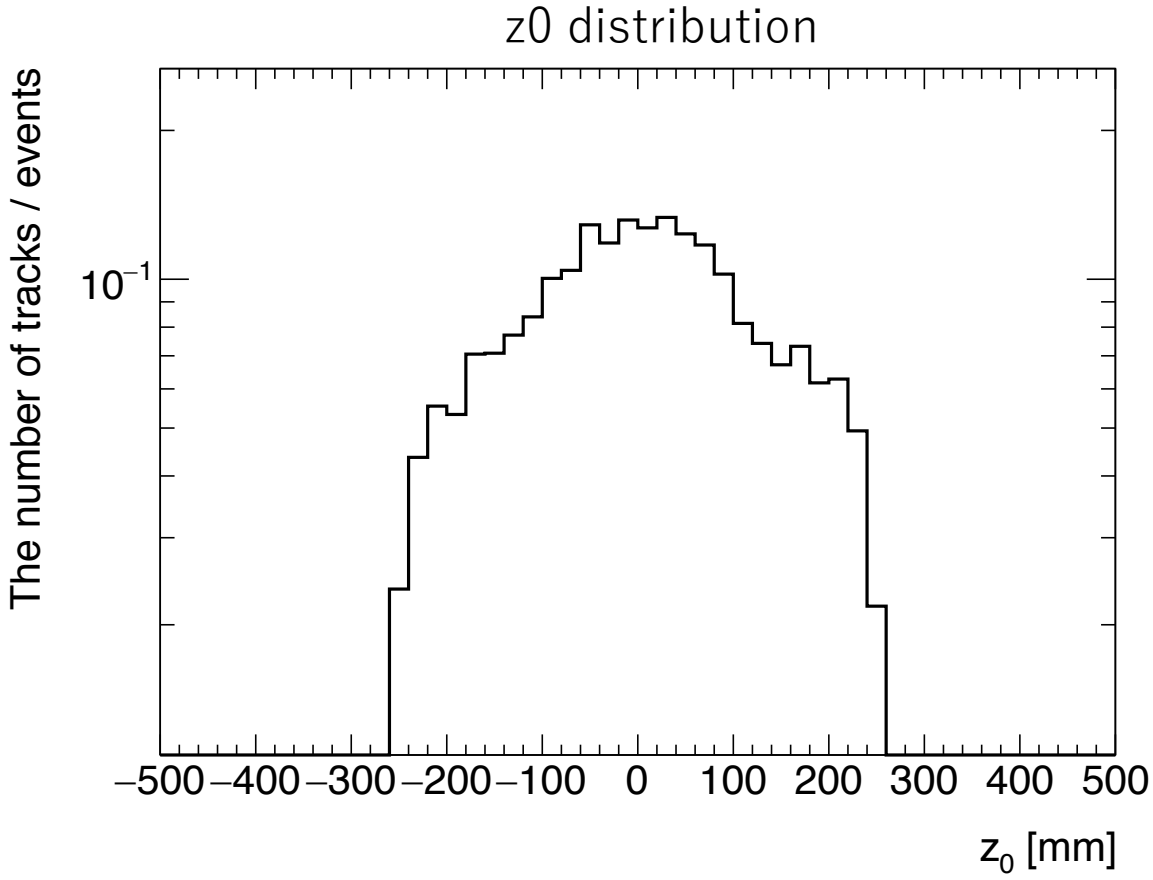
- After this fitting, if there are a hit which is far away from line more than 5 sigma, the hit is removed and do re-fitting.
  - Assume that the hit position uncertainties are radial symmetric.

Validation of simple tracking

- **Method**
  - Compare the number of fake tracks between simple tracking and ATLAS tracking
  - Sample : Single 50 GeV neutrino, pileup mu = 200.
  - Detector : ITK (for HL-LHC) layout
  - Use space points which was clustering by ATLAS software as each pixel hits
  - Track selection :
    - Fit p-value (TMath::Prob(chi2, ndof)) > 0.1
    - |z0| < 250 mm, |d0| < 1 mm
    - track pT > 50 GeV, |eta| < 2
    - The number of contributed layers == 4
    - For only ATLAS tracks, no outlier/spoilt/hole flags.
- **Result**
  - Some difference are observed, especially high eta region.
  - This is expected due to module overlapping. The simple tracking cannot detect hole hits in same layers. On the other hands, ATLAS tracking can do that. Since ITK layout has inclined modules at high eta region, there were much differences at high eta region.
  - Module overlapping also exist in small eta region to cover all phi. This reduces fake background to 40%.
  - If shared hits are not used in short track reconstruction, the number of fake tracks reduces half. The ATLAS tracking checks shared hits in reconstruction level.
  - Considering these effects, the reasonable agreement is shown.

IP distribution of 4-layer-tracks





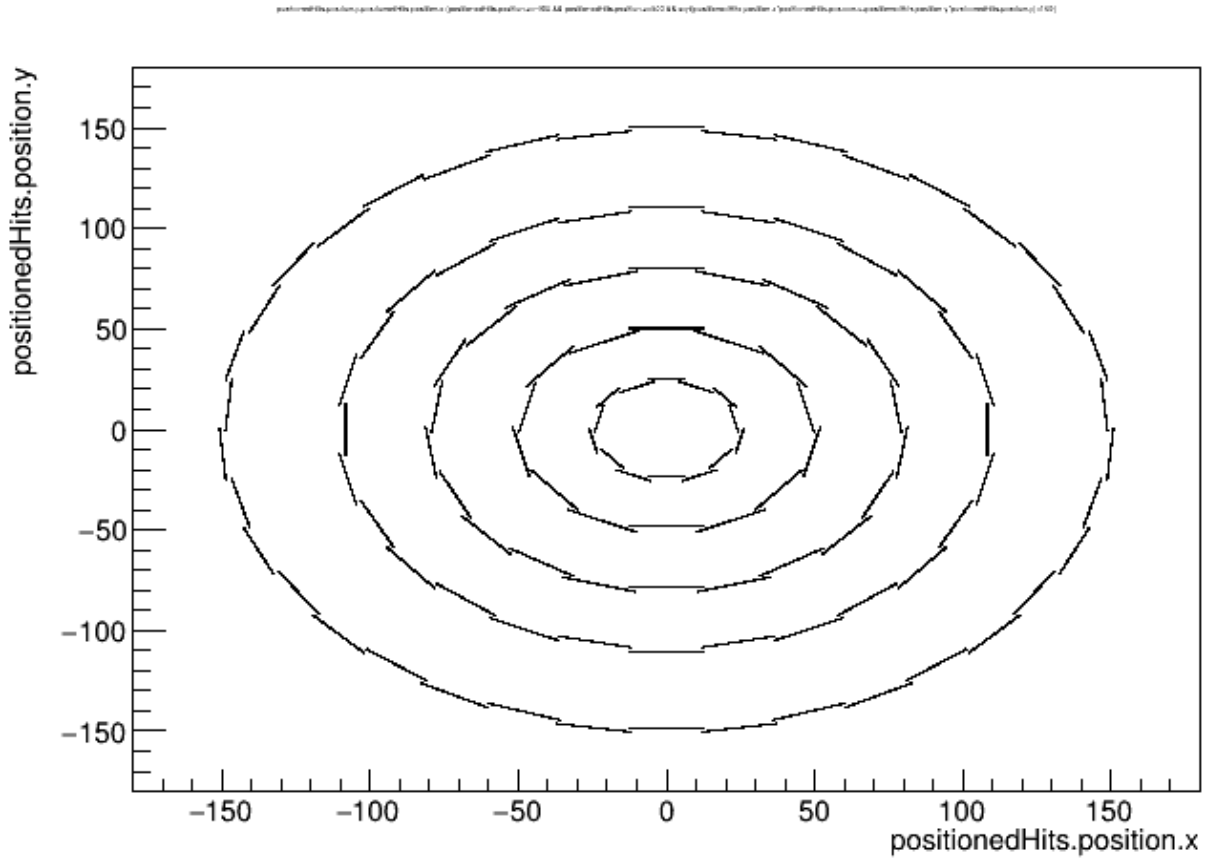
Follow up from previous meeting

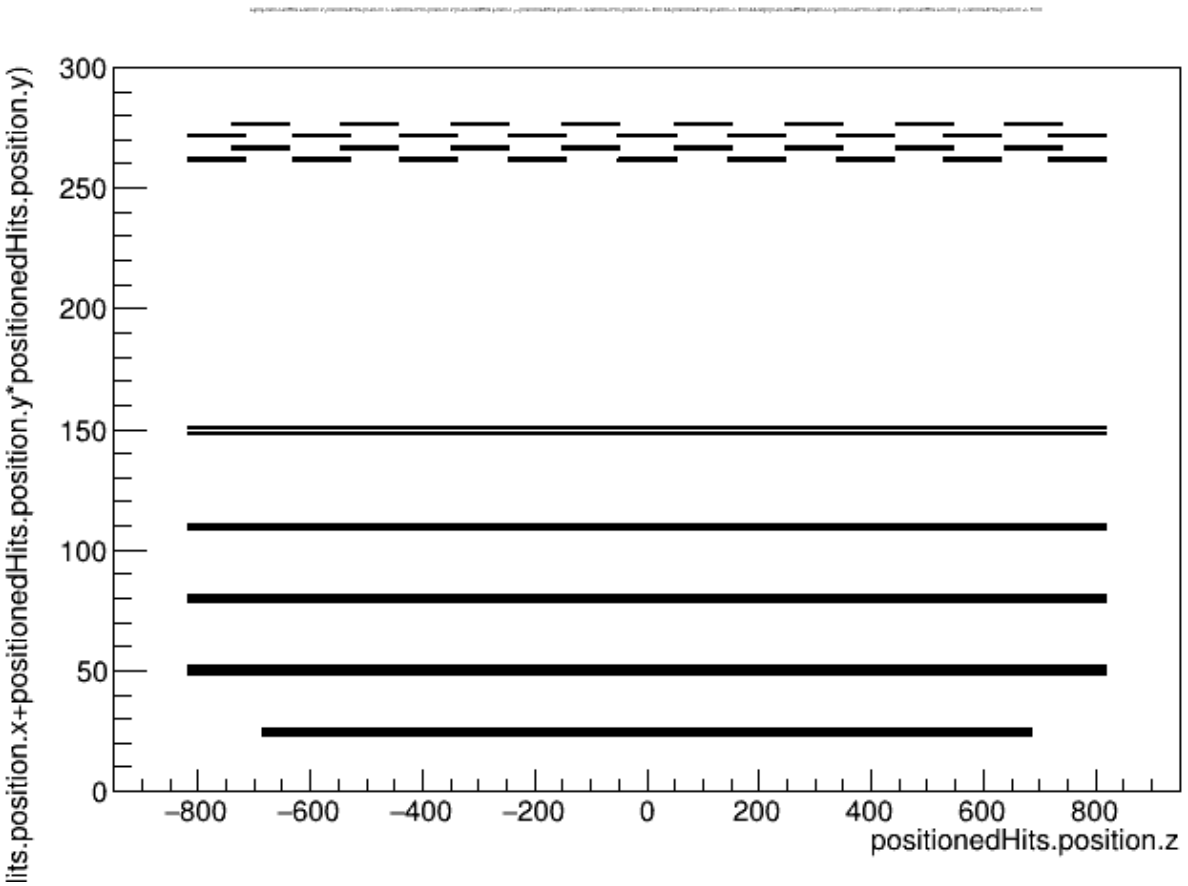
1) **Pileup dependence (μ = 0, 200, 500)**
   - Compared μ=200 and μ=500
   - The number of fake tracks are proportional to μ^4.

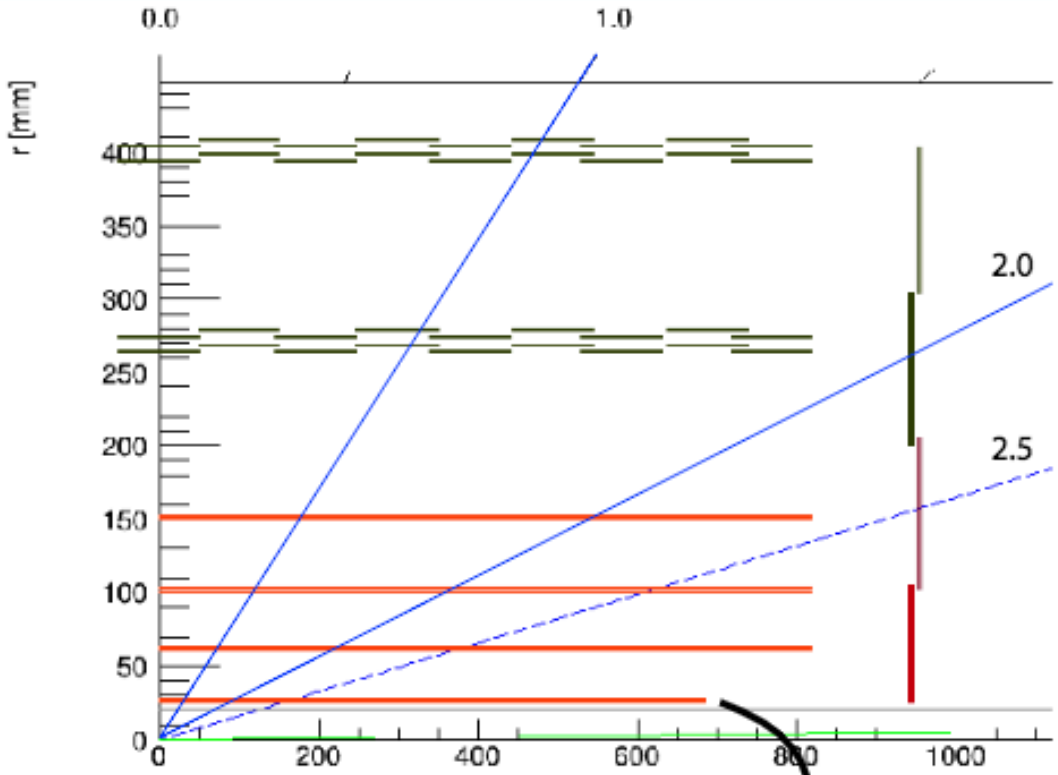
2) **Validation of pseudo-tracking with ATLAS software**
   - Done. Reasonable agreement is found.

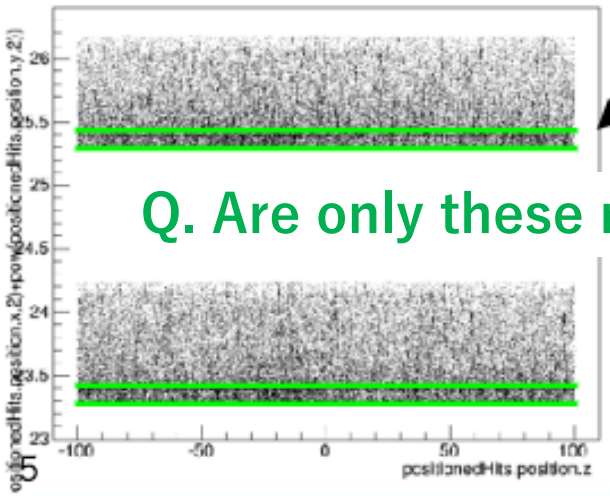
3) **Checking impact to sensitivity from detector design (what we can get if flexible detector design is possible)**
   - On-going. Testing new detector layout (next page.)

Trying new FCC geometry

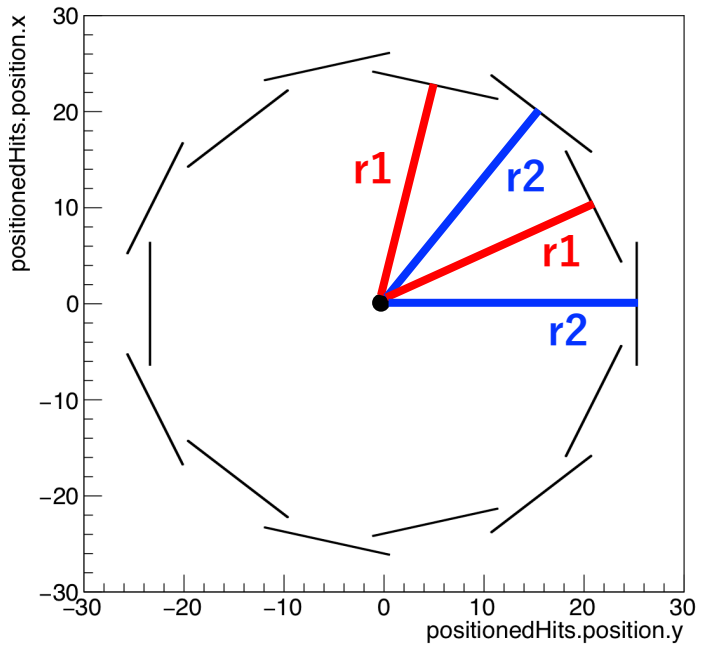






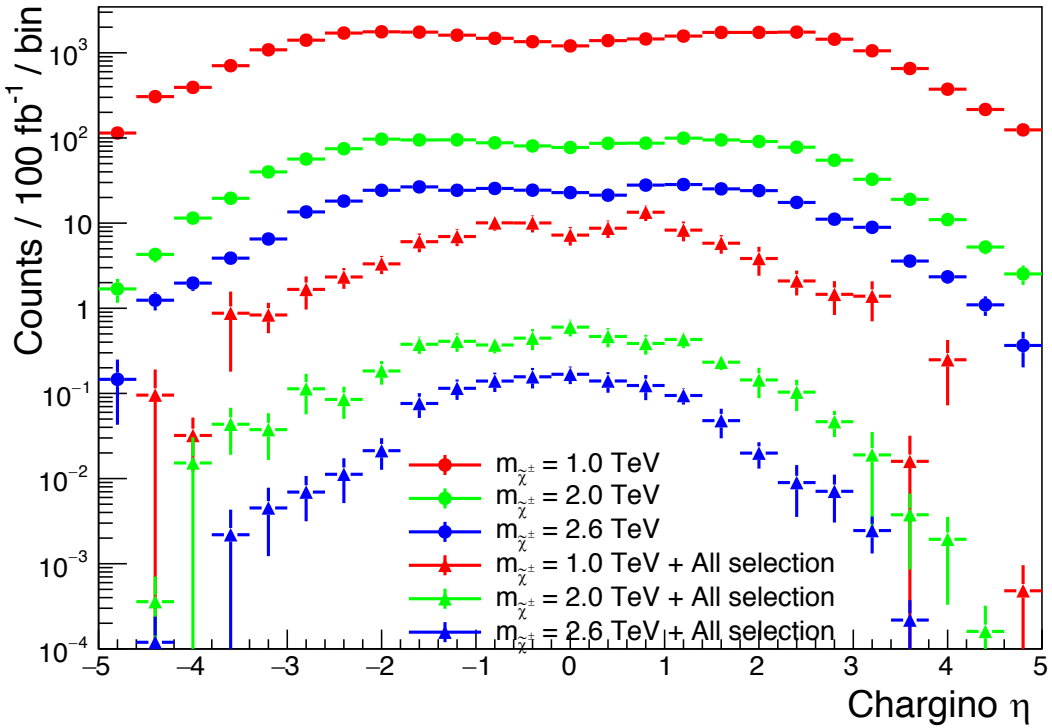


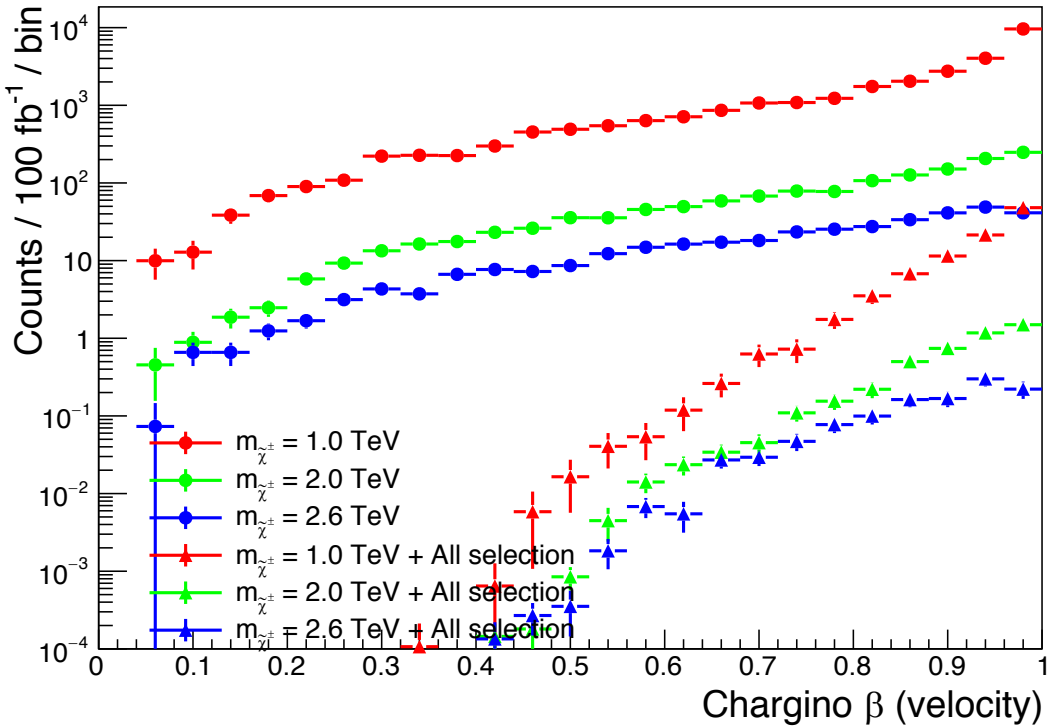
Q. Are only these regions active sensor?



A. No.

- Because of the transformation (x, y) to r.
- There are two typical radius.
- Now all hits are used.


Counts / 100 fb^{-1} / bin
Chargino η
$m_{\tilde{\chi}^\pm}$ = 1.0 TeV
$m_{\tilde{\chi}^\pm}$ = 2.0 TeV
$m_{\tilde{\chi}^\pm}$ = 2.6 TeV
$m_{\tilde{\chi}^\pm}$ = 1.0 TeV + All selection
$m_{\tilde{\chi}^\pm}$ = 2.0 TeV + All selection
$m_{\tilde{\chi}^\pm}$ = 2.6 TeV + All selection


Counts / 100 fb^{-1} / bin
Chargino β (velocity)
$m_{\tilde{\chi}^\pm}$ = 1.0 TeV
$m_{\tilde{\chi}^\pm}$ = 2.0 TeV
$m_{\tilde{\chi}^\pm}$ = 2.6 TeV
$m_{\tilde{\chi}^\pm}$ = 1.0 TeV + All selection
$m_{\tilde{\chi}^\pm}$ = 2.0 TeV + All selection
$m_{\tilde{\chi}^\pm}$ = 2.6 TeV + All selection

N of pixel hits (FCC v3.0.3 layout)