Long-lived particle search at FCC with **disappearing track** signature

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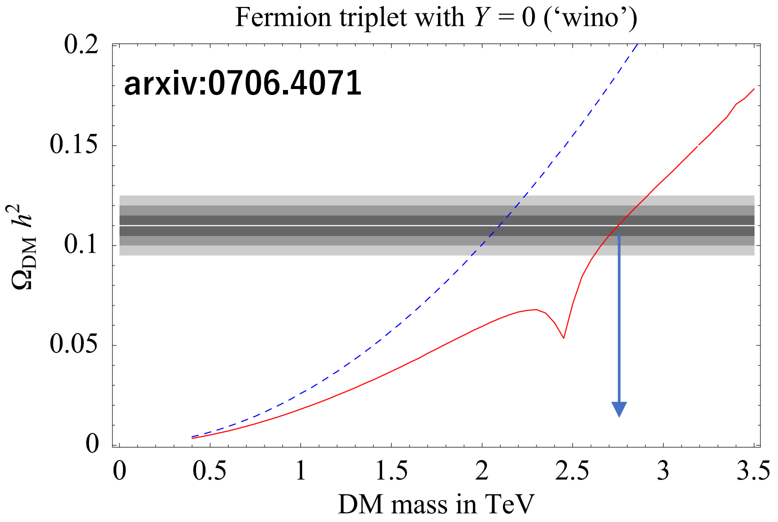
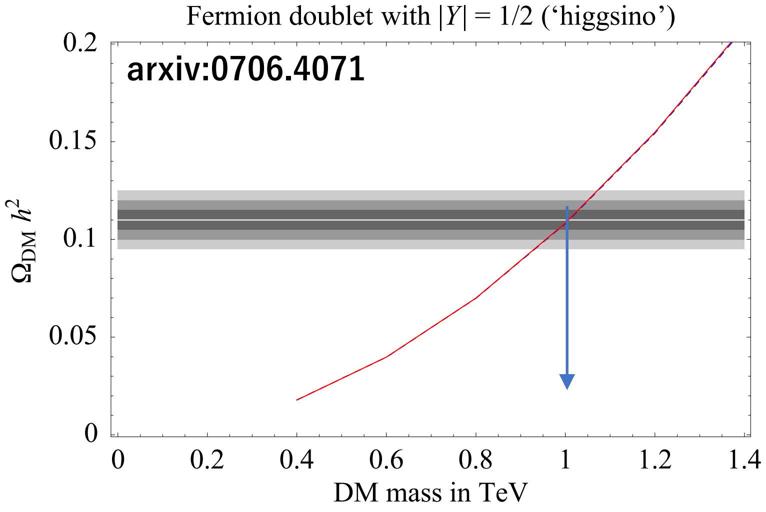
WIMP DM **YES** or **NO** ?

- **Neutralino is a candidate of the dark matter**
  - Dark matter mass bound from the relic density.
    - **wino ~ 2.7 TeV**
    - **higgsino ~ 1 TeV**

  mass degeneracy in wino LSP scenarios

$$m_{\chi^\pm} - m_{\chi^0} \sim 165 \text{ MeV}$$

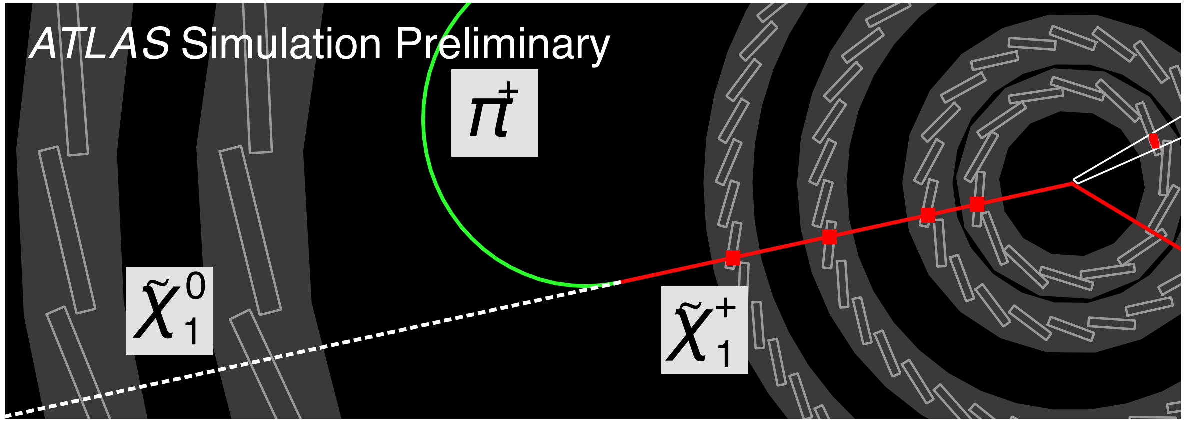




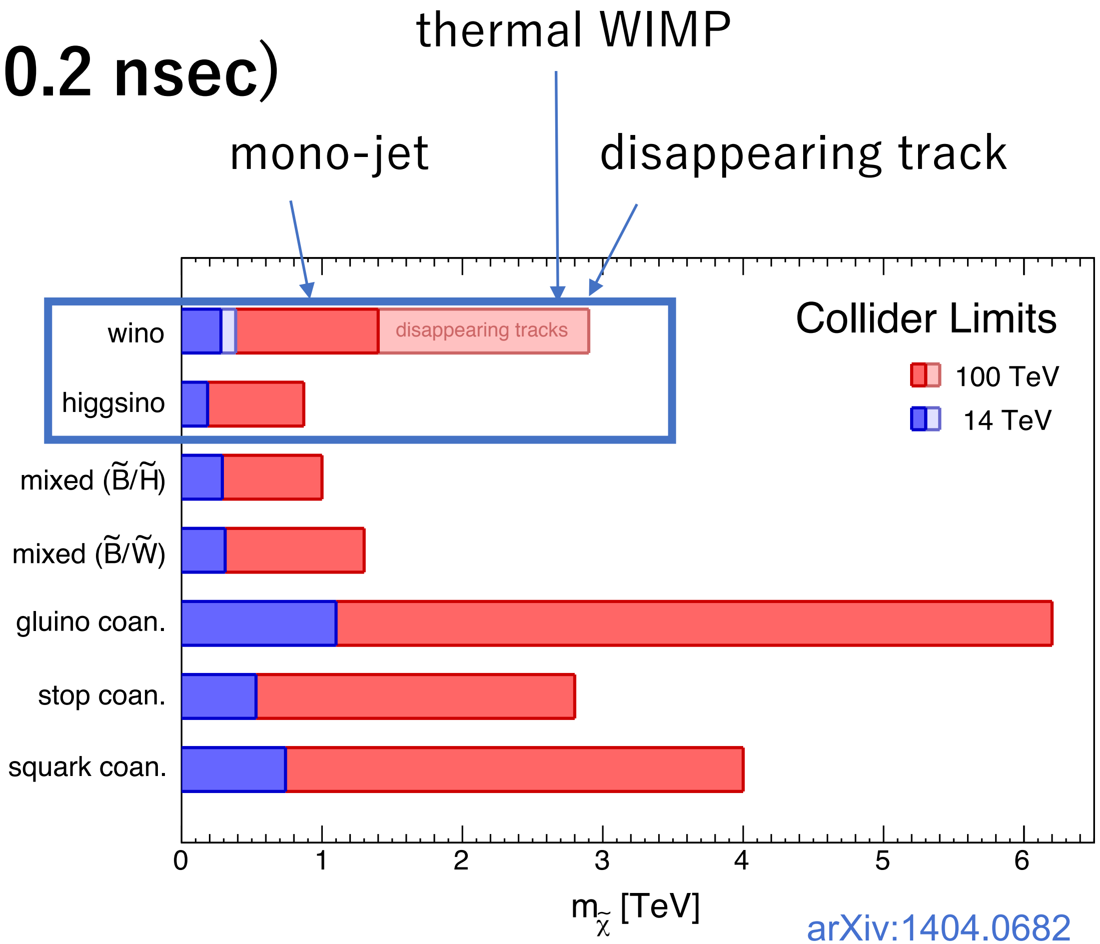
- Can not be discovered by normal MET+jets SUSY searches (decay products too soft)
- $\sqrt{s} = 14$ TeV is not enough to reach wino mass sensitivity of 3 TeV

Disappearing track signature

- Wino LSP leads **meta-stable chargino (τ =0.2 nsec)**
- c τ ~ 6 cm → directly detectable
  - chargino tracks disappear in the tracker.



ATLAS-CONF-2017-0



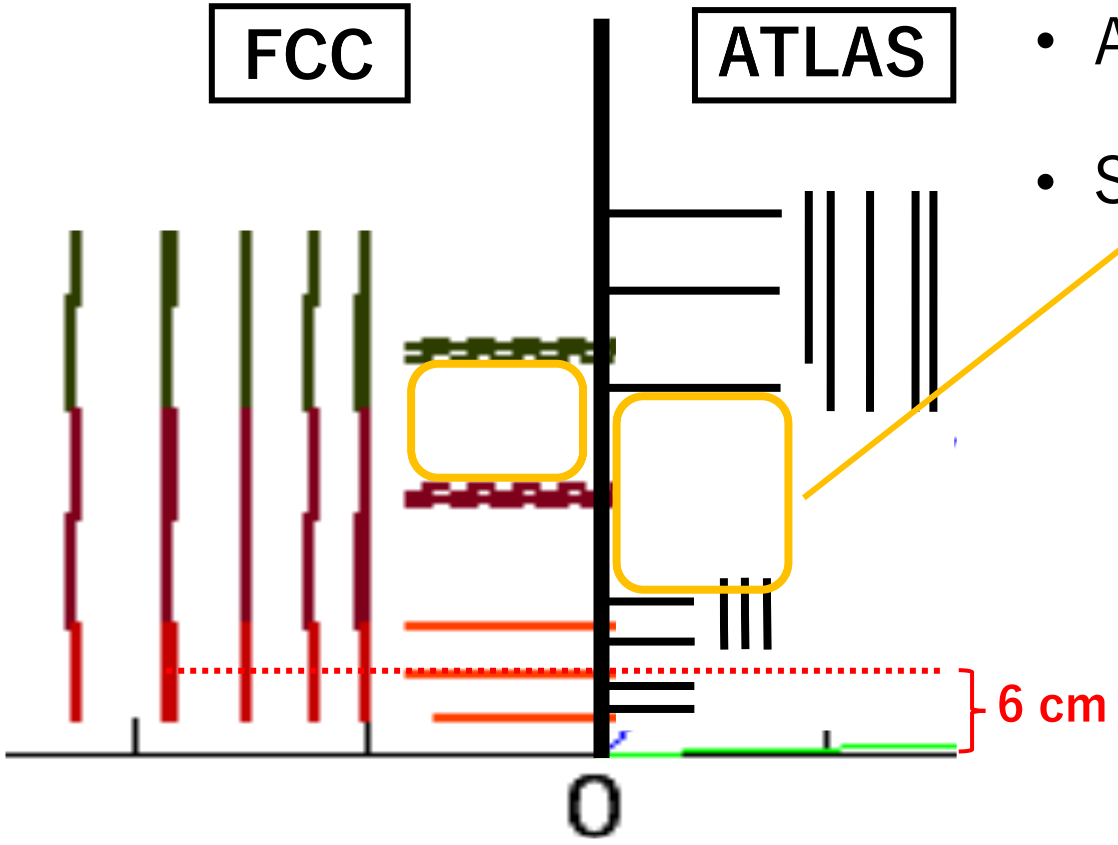
arXiv:1404.0682

- Latest preliminary LHC limit : 430 GeV

We are studying if the disappearing track analysis @ 100 TeV has the potential to definitively confirm/exclude that a thermally produced WIMP exists

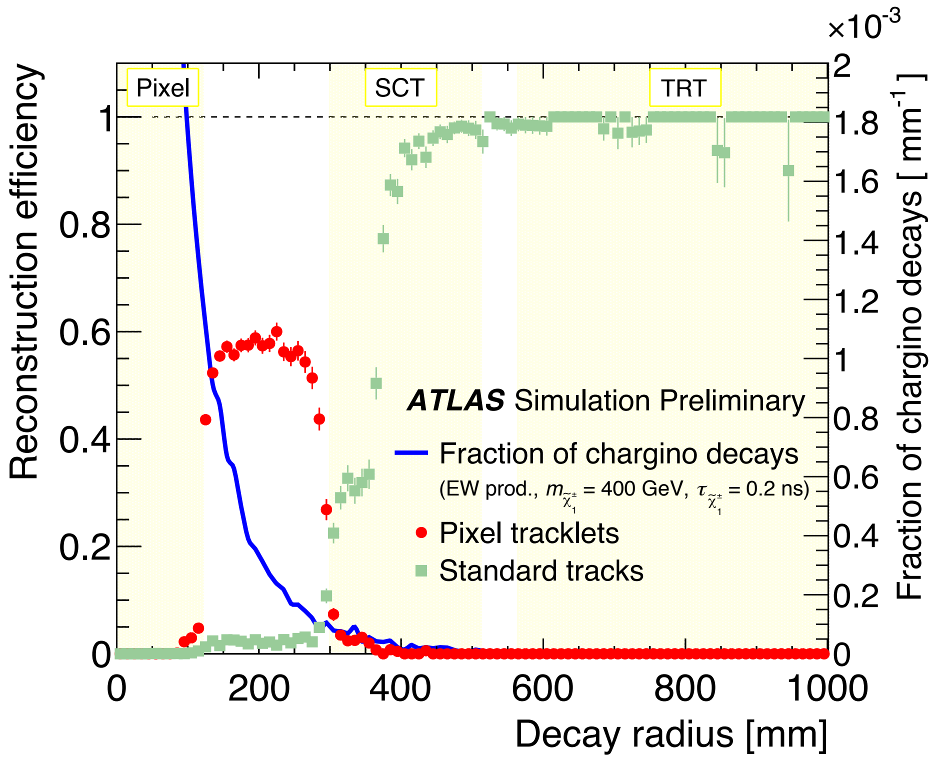
Inner detector layout in ATLAS & FCC

- Charged wino have 0.2 nsec lifetime. This corresponds to **6 cm**.
- ATLAS uses **four layers** for reconstruction.
- Sensitive to charginos decay in this region



Inner detector layout

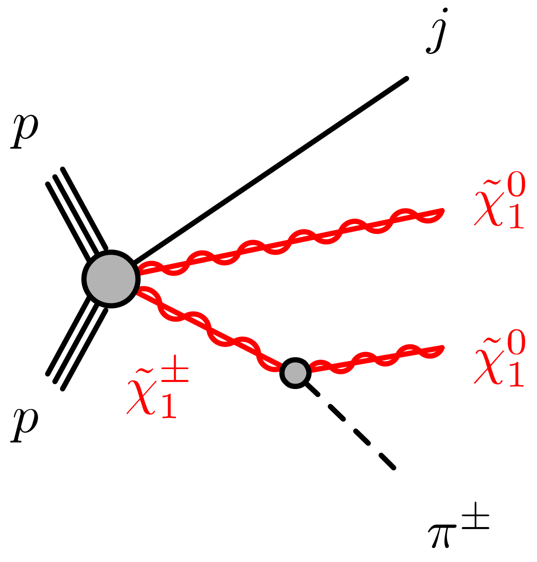
(FCC layout not latest)



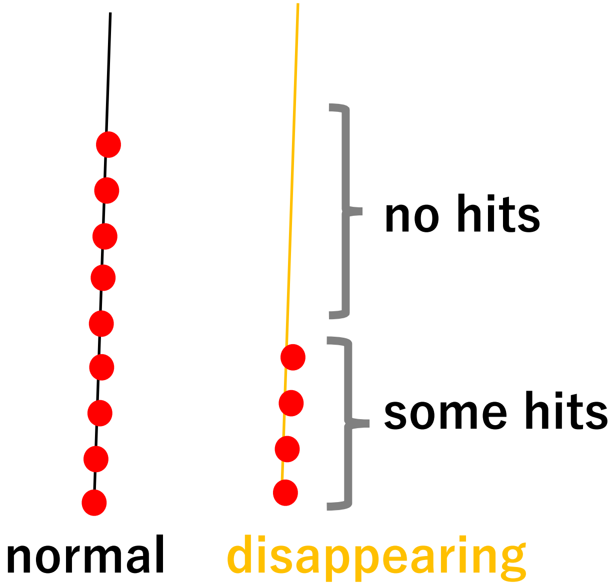
Analysis Overview

1. Require ISR jet and MET

   In ATLAS, jet pT>140, MET > 140 GeV



2. Require "disappearing track"
   - defined as having no associated hits after a point
   - required at least four hits in a track in current analysis.

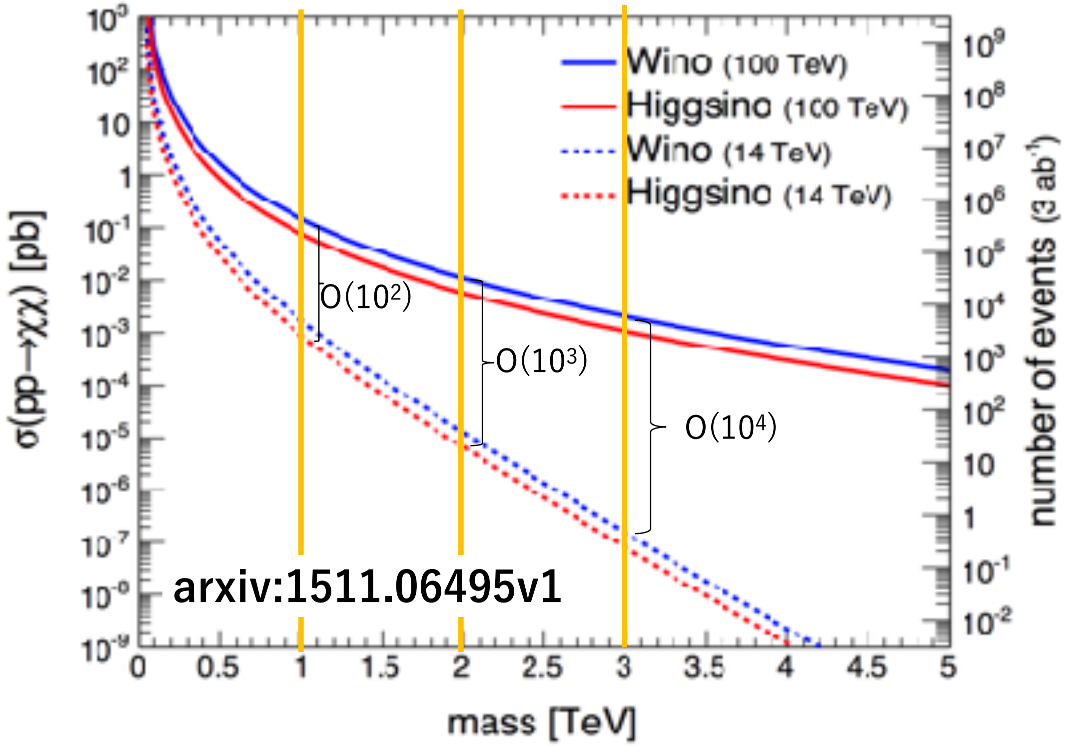


- **The radius of tracker position is very important because this directly determines signal acceptance.**
  - Current analysis at ATLAS require 4 hits which corresponds to **R ~ 12 cm**.
  - In this study, we require the same number of layers

Signal sample & Selection

Signal Sample

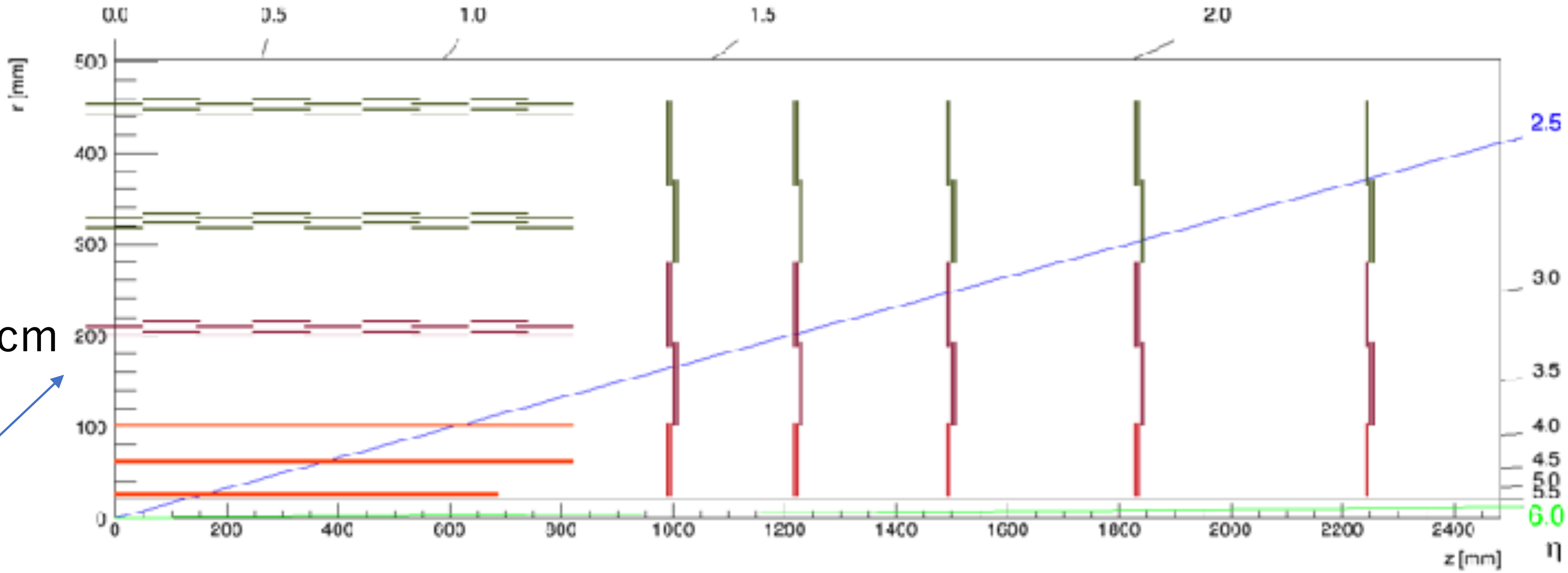
- Use truth samples (not full simulation)
  - MadGraph+Pythia8
- Cross section is calculated by "Prospino"
- Signal cross section **2-4 order of magnitude higher in FCC** than LHC



Selection

- Require MET and jet pT > 1 TeV
- Require at least one disappearing track.
  - Use "option3 ver2 or ver3" layout (http://fcc-tklayout.web.cern.ch/fcc-tklayout/)
  - Assume we can reconstruct signal tracks if charginos go through **at least 4 silicon layers** before the decay.

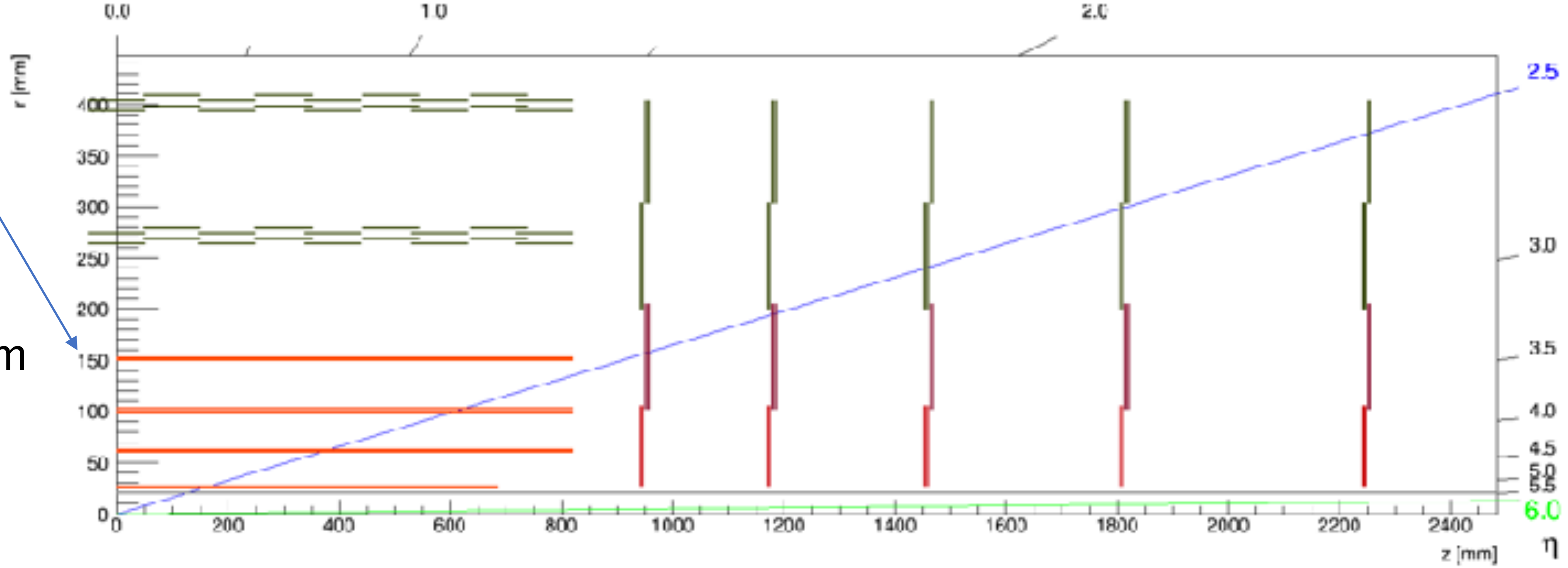
option3 version2



~20 cm

4th layer

~15 cm

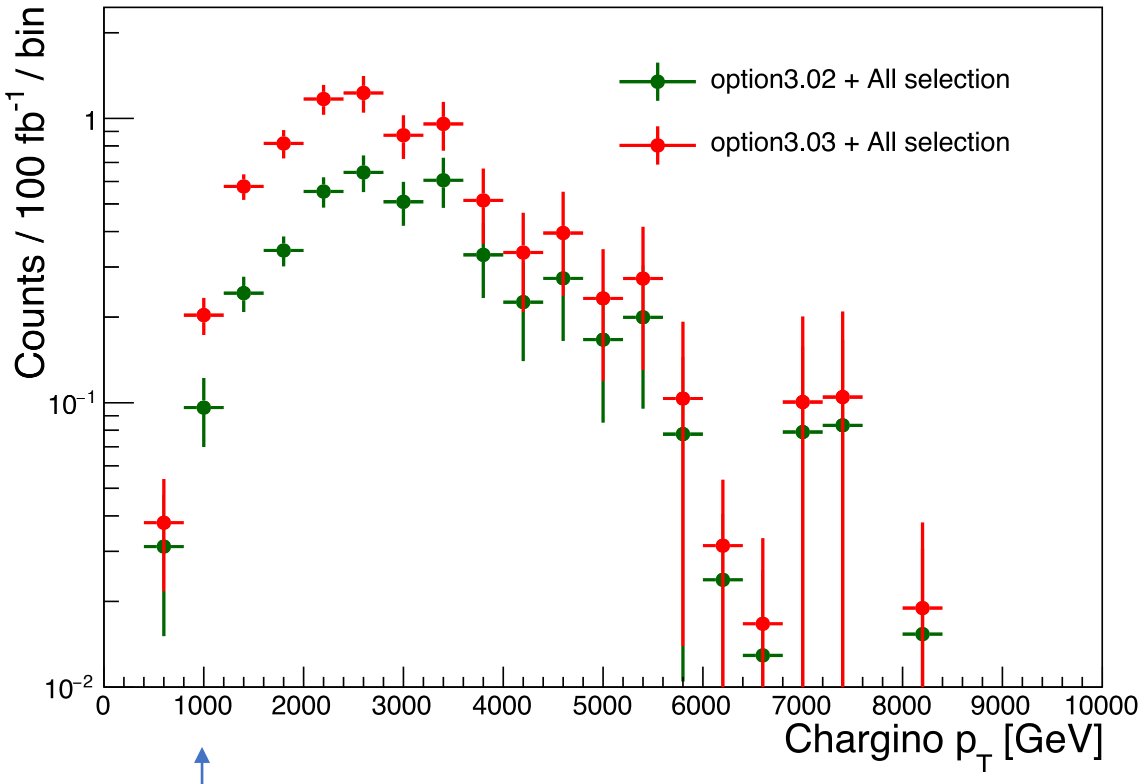


option3 version3

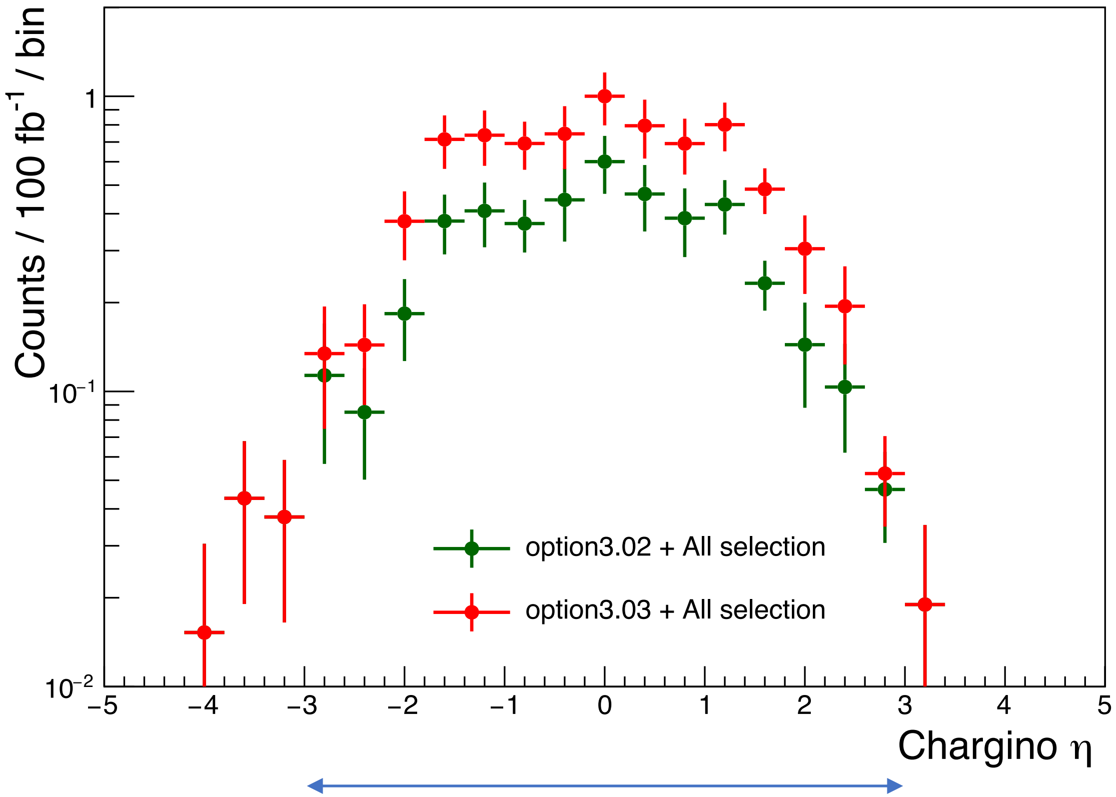
Chargino distribution

Signal efficiency of option 3 ver.3 is 2 times higher than ver.2 !!

wino mass = 2 TeV

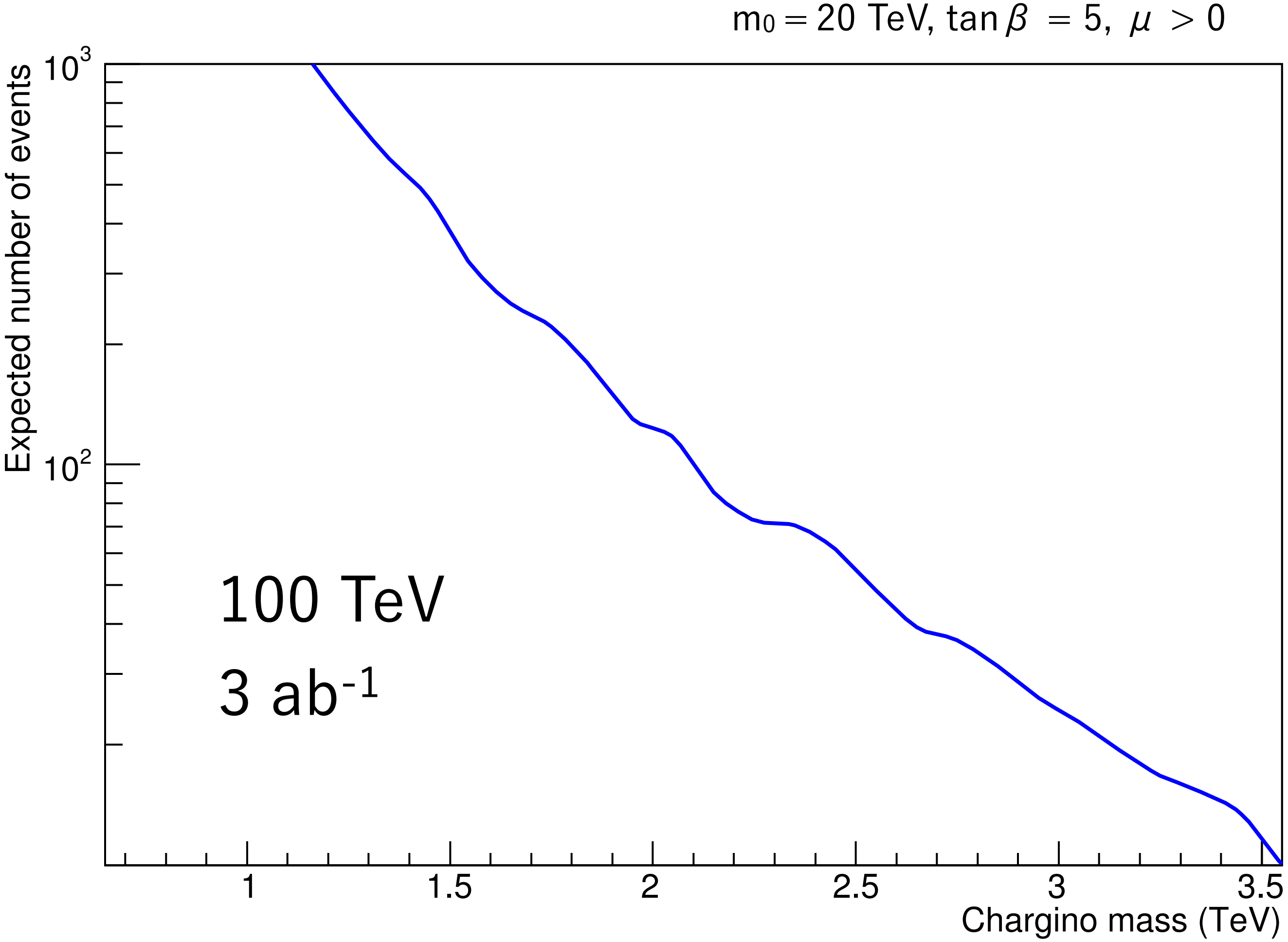


1 TeV



± 3

Expected number of signal events
(wino : lifetime = 0.2 nsec)



L = 3 ab^{-1}

$\sqrt{s}$ = 100 TeV

Jet pT > 1 TeV

MET > 1 TeV

$\Delta\phi$ (1st jet, MET) > 1.0

chargino decay radius > 4th layer

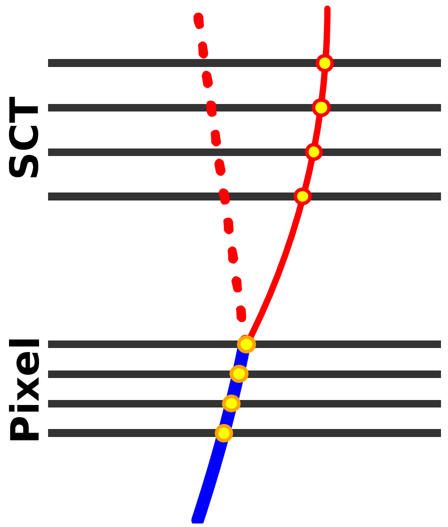
Tracker layout : option3 version3

Assuming 50% efficiency for track pT>100 GeV

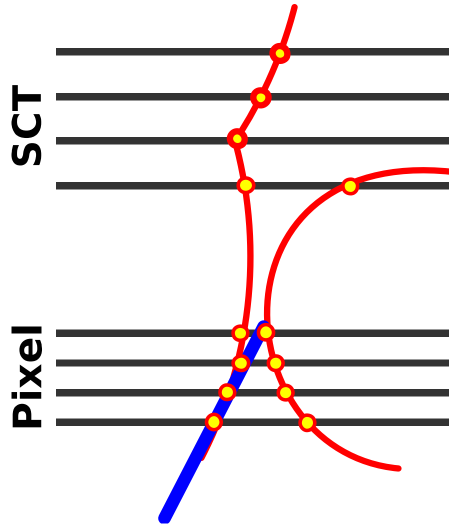
O(10) signal events expected for ~ 3 TeV signal

Background

Scattering with material



Fake tracks



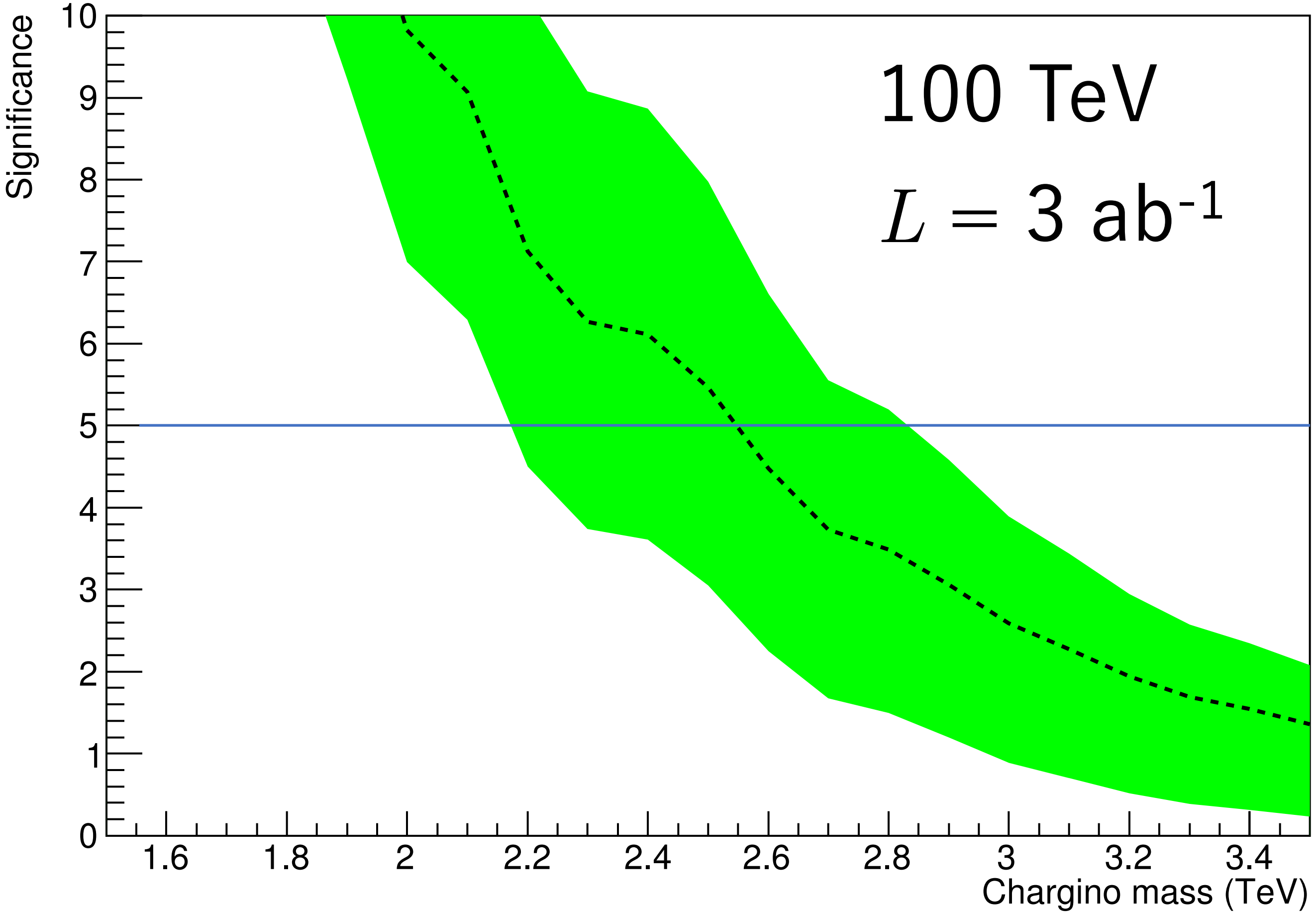
- Backgrounds components.
  - **physical background** : Missing hits due to material interaction
    Dominant source is $W \to l\nu$
  - **unphysical background** : Random combination of hits
- The rate depends on the detector performance, pileup, reconstruction algorithm…

Background estimation

- Number of background events is estimated by **scaling the ATLAS data** with the integrated luminosity, cross-section, and the kinematical selection efficiency of $W \to l\nu$.
- Large uncertainty in the estimate.
  - Can be more due to the higher pileup
  - Can be less thanks to smaller pixel size (less fakes), improving background rejection algorithms and track pT resolution
  - → Sensitivity is computed **assuming factor 5 higher or lower background rates**.
- For more reliable estimate, we need full simulation.

Expected sensitivity (wino : lifetime = 0.2 nsec)

Discovery sensitivity reach ~ 3 TeV



Green band : number of BG scaled by 0.2—5.
The center corresponds to the factor 1

~0.5 TeV higher sensitivity with 30 ab^{-1}

Discovery significance calculated by RooStats::NumberCounting Utils, in a fully frequentist fashion

Conclusion

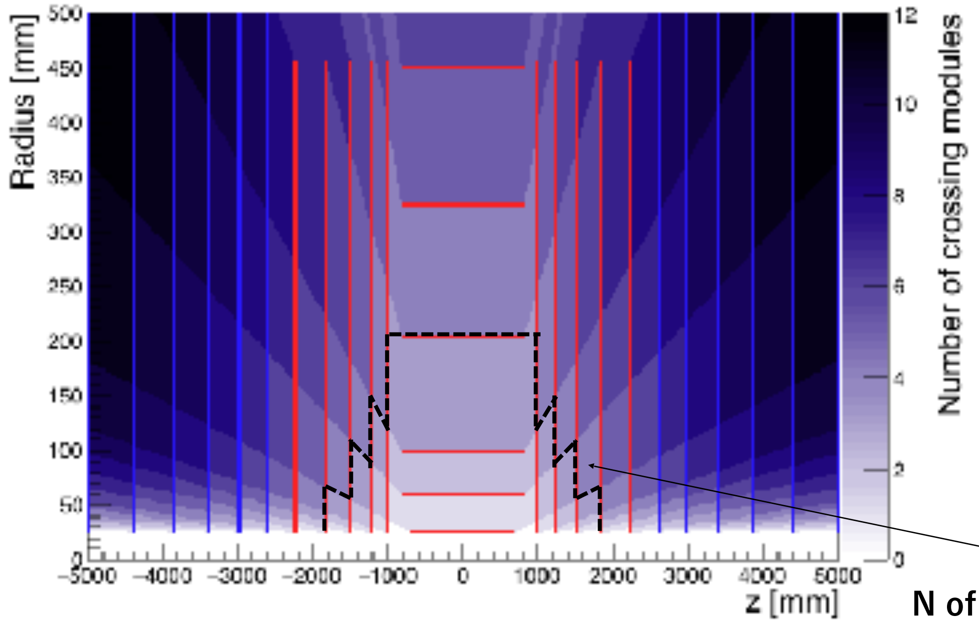
- **From our current studies, we conclude that the 100 TeV FCC-hh indeed has the potential to answer YES or NO to the existence of a wino DM**
  - Wino-like dark matter is not heavier than 3 TeV in minimal dark matter model
  - FCC has a potential of discovering 3 TeV wino.
- **Detector layout is crucial**
  - It is **important to have several tracker layers close to the beam pipe**.
  - For higgsino DM, the layout is even more important because of shorter lifetime ($c\tau \sim 7$mm)
- Further studies to improve the sensitivity estimate
  - Possibility of decreasing required number of layers for higher efficiency.
  - Full simulation of signal and background

Backup

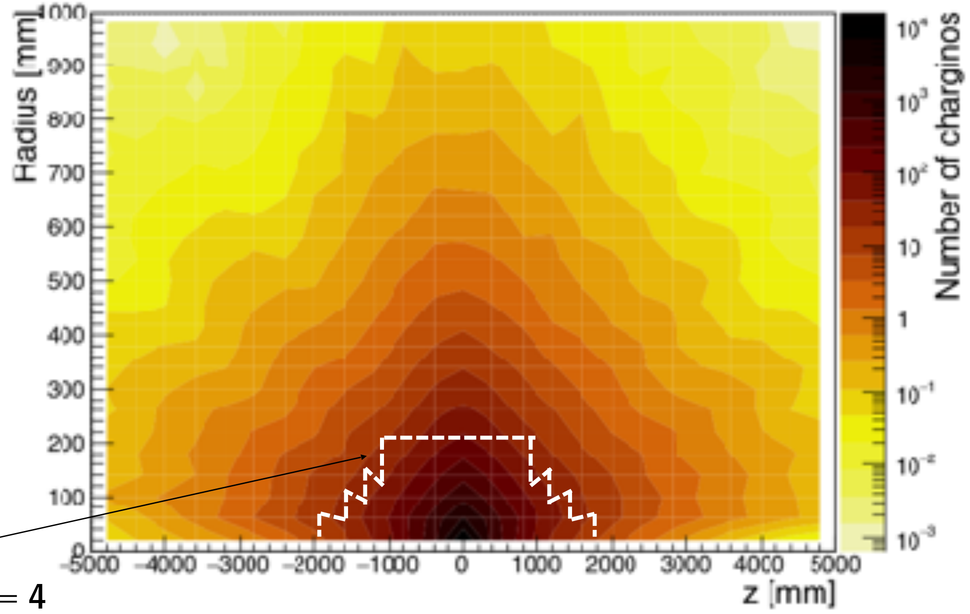
Signal acceptance

Layout : option3 ver2

FCC Inner detector



Decay position of chargino (m=1TeV, τ =0.2nsec)



N of crossing modules = 4

- Require four module crossings to reconstruct tracks
- The position at 4th layer is important for track reconstruction and signal acceptance

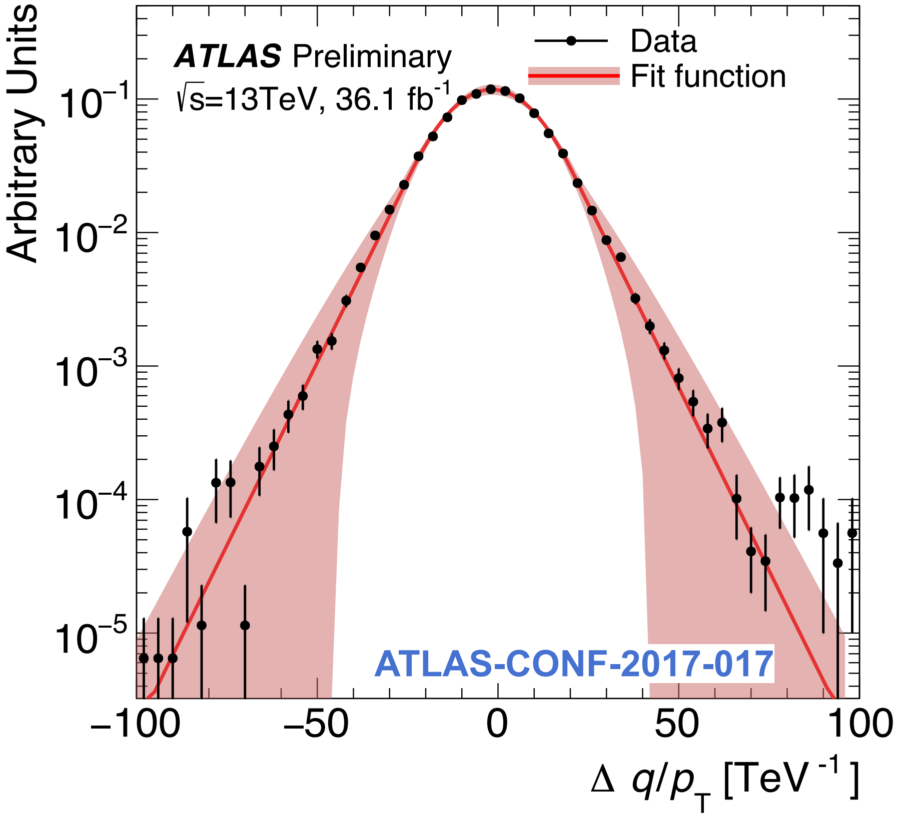
- Charginos decay according to exponential.

$$w = \exp\left(-l_{\rm decay}/\beta\gamma c\tau\right)$$

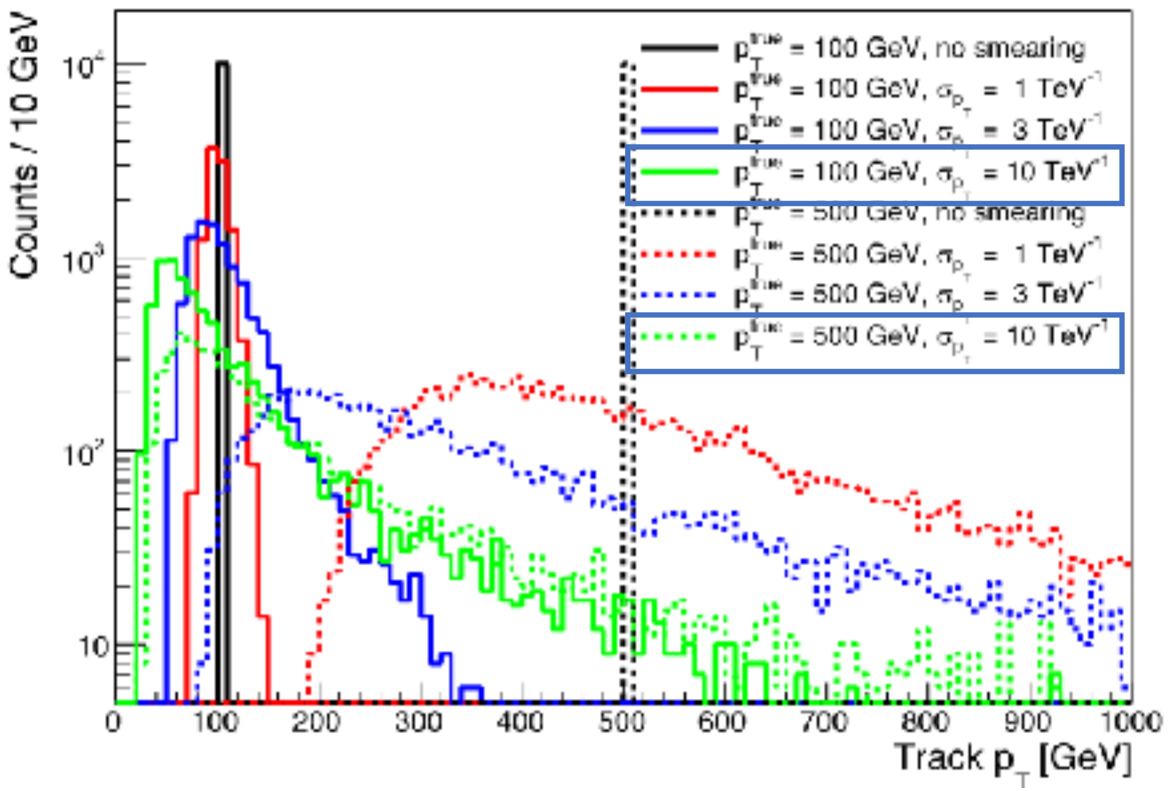
pT resolution of short tracks

- Very short tracks have very bad resolution because of the lever arms.
- Resolution in ATLAS is about 10 /TeV.
- In this study, we assume roughly the same pT selection efficiency.

➡ **The resolution depend on the detector and layout**
A study is on-going with FCC software



track pT distribution after apply tracking resolution



Difference between ATLAS & FCC inner detector