Dark Matter: disappearing tracks

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WIMP DM YES or NO ?

- Neutralino is a dark matter candidate
  - Dark matter mass bound from the relic density.
    - wino ~ 3 TeV
    - higgsino ~ 1 TeV

arXiv:1606.00947

mass degeneracy

$m_{\chi^\pm} - m_{\chi^0}$ ~ 166 MeV (Wino LSP)

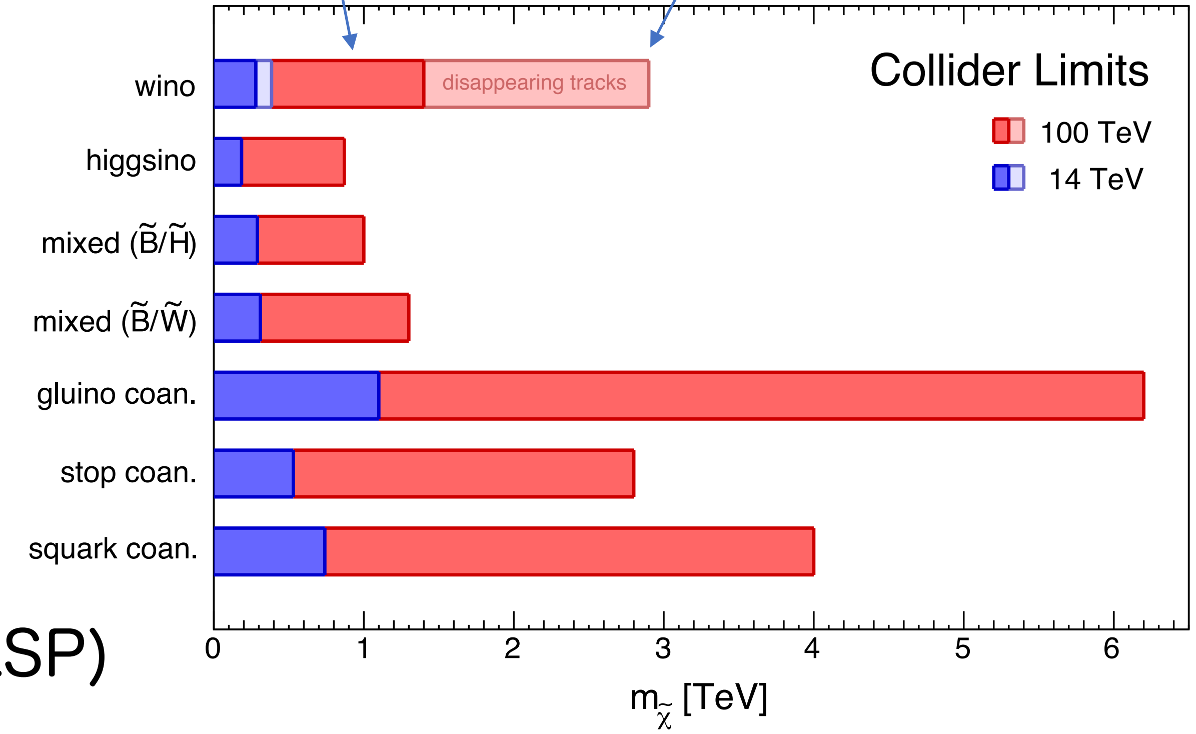
$m_{\chi^\pm} - m_{\chi^0}$ ~ 355 MeV (Higgsino LSP)

thermal WIMP

mono-jet

disappearing track

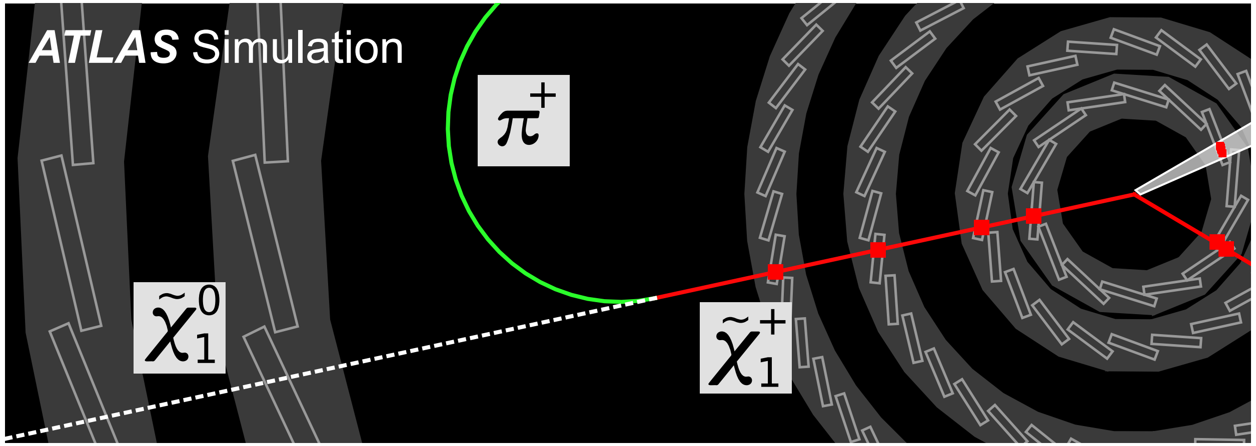
arXiv:1606.00947



- Can not be discovered by normal E_T^{miss} + 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 or higgsino LSP leads meta-stable chargino
- cτ ~ 6 cm (wino), 7 mm (higgsino) → directly detectable
  - chargino tracks disappear in the tracker.



arXiv:1712.02118 ATL-PHYS-PUB-2017-019

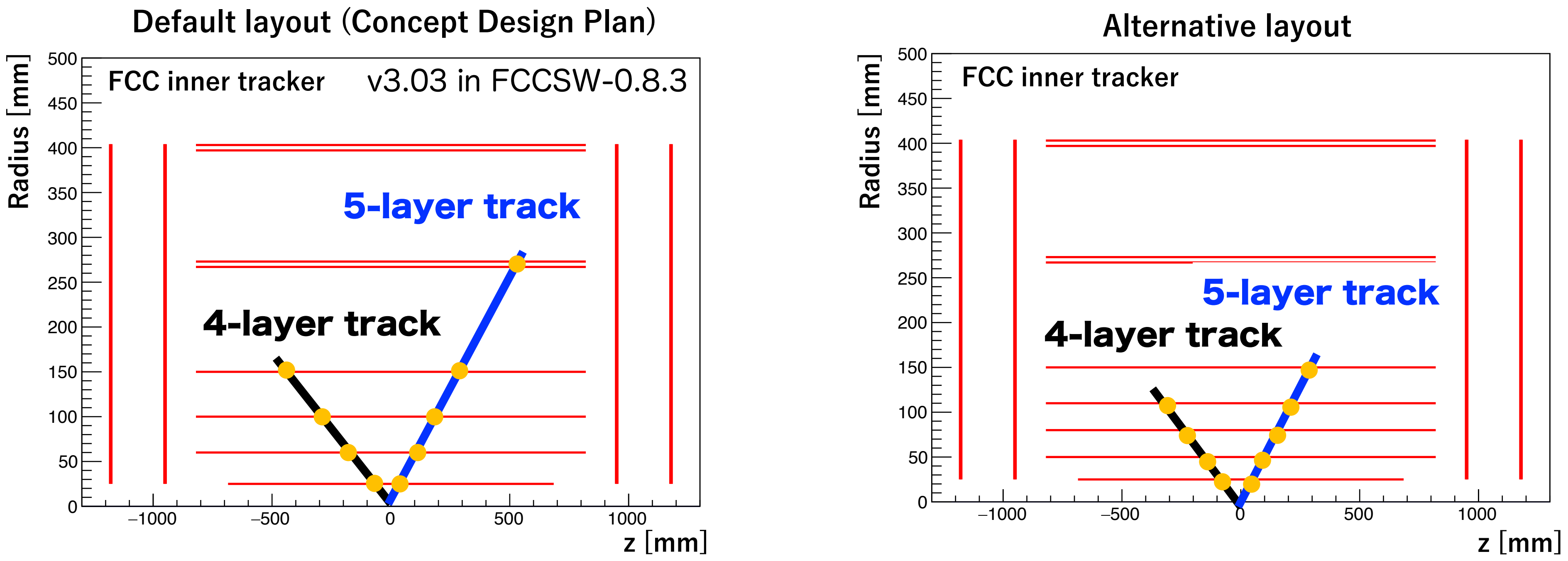
- ATLAS limit for wino (higgsino) LSP : 460 GeV (152 GeV)
- CMS limit : 715 GeV @ τ = 3 ns, ~ 310 GeV @ τ = 0.2 ns (wino LSP)

CMS-PAS-EXO-16-044

Does FCC have a potential to definitively confirm/exclude that a thermally produced WIMP exists ?

Configurations

Combinations of two track reconstruction, two detector layout and two minimum-bias QCD model configurations



minimum-bias QCD model configurations

1. Only non-diffractive process
2. Including diffractive processes

The difference is shown as a band in the estimated sensitivities (shown later)

Analysis Overview

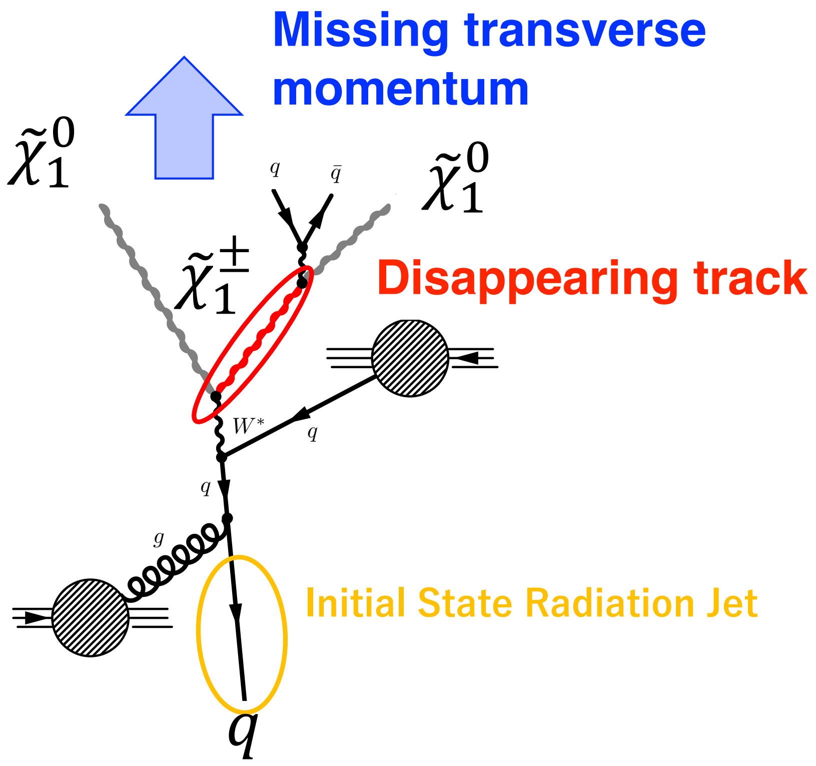
- Require a high p_T ISR jet and large E_T^{miss}
  - In ATLAS, jet pT>140, E_T^{miss} > 140 GeV
  - Threshold optimised for each configuration

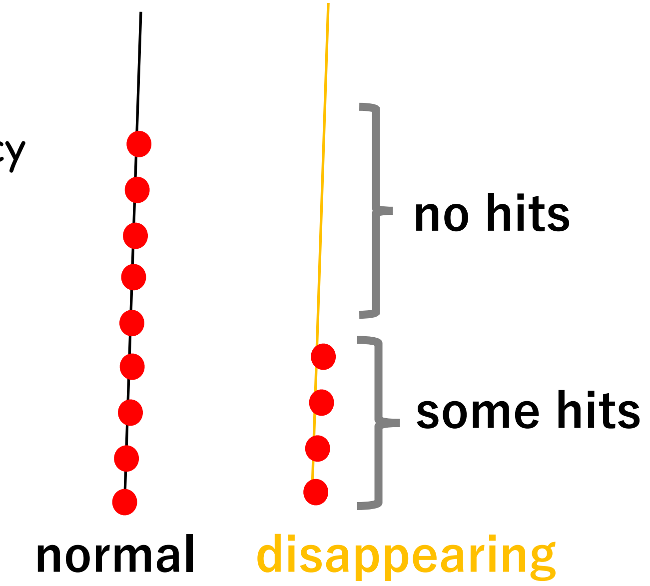
Example: 5-layer tracks, $|\eta| < 1.9$, $\mu = 500$, 30 ab^{-1} non-diffractive model, higgsino

	Default layout	Alternative layout
1st jet pT [TeV]	2	8
E_T^{miss} [TeV]	1	9

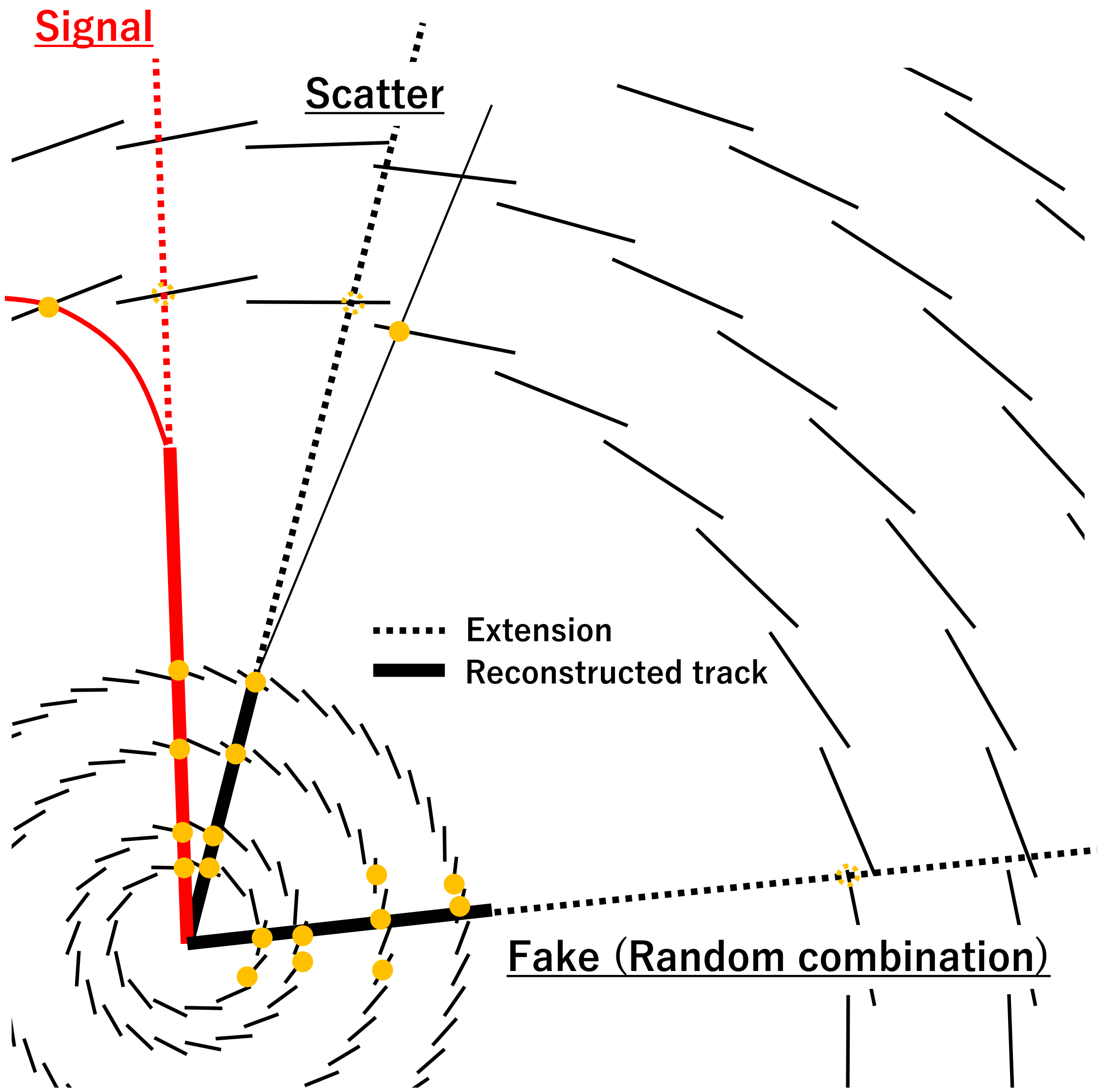
Tight cut because of high efficiency

- Require "disappearing track"
  - Defined as having no associated hits after a layer
  - Required at least 4 or 5 hits in a track.
  - Only the central ($|\eta| < 1.9$ by default) to suppress BG.





Background



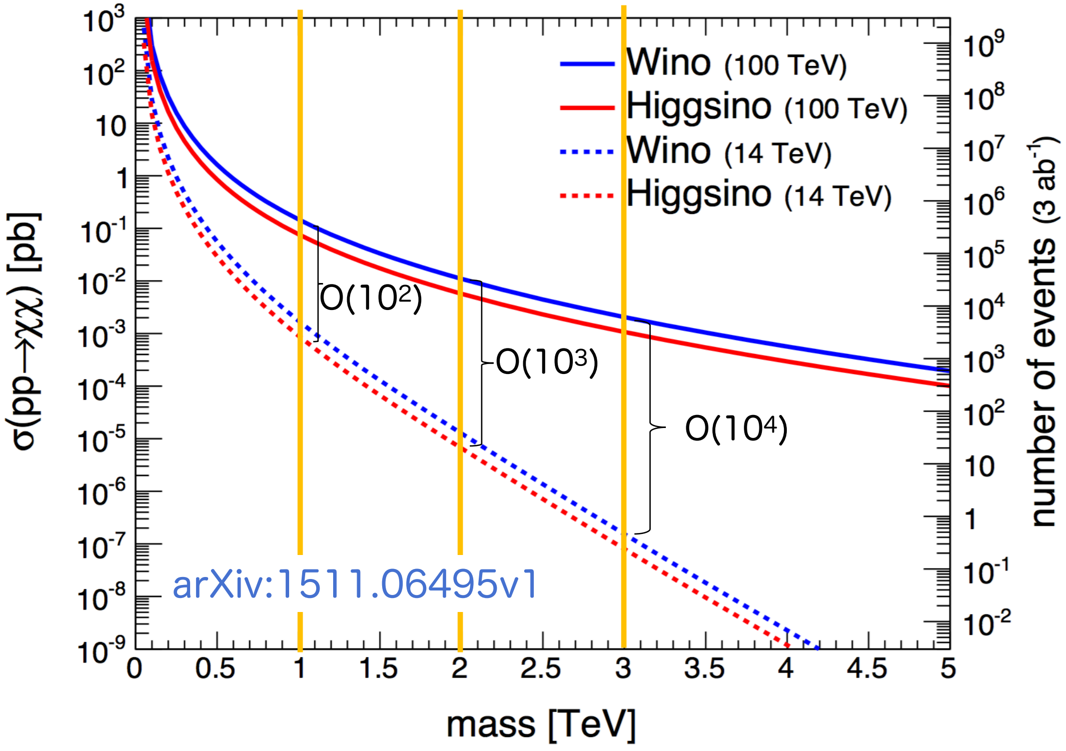
- **Physical background**
  - Missing hits due to material interaction
  - Dominant source is $W \to \ell \nu$, where ℓ is an electron or a τ.
    - E_T^{miss} from ν and an isolated electron or a pion from 1-prong τ decay.

Dominant at μ=500 pileup

- **Unphysical background**
  - Random combination of hits
  - The rate depends on the detector layout, pileup etc.

Sensitivity estimation

- **Signal**
  - E_T^{miss} and jet pT higher than thresholds optimised for each configuration.
  - Assume we can reconstruct a signal track if a chargino go through at least 4 or 5 silicon layers before the decay.



- **Background** (detailed in following pages)
  - Physical BG
    - Scale the observed BG yield in ATLAS.
  - Unphysical BG
    - Estimate using a simple track reconstruction.

Physical Background

- Physical background
  - Background yield is estimated by scaling the ATLAS data (36 fb^{-1}) with the integrated luminosity, the cross-section, the kinematical selection efficiency of $W \to \ell \nu$ (main BG) and the scattering probability (calculated from the ratio of the material in FCC to that in ATLAS)

$$N_{BG}^{FCC} = N_{BG}^{ATLAS} \times \frac{L^{FCC}}{L^{ATLAS}} \times \frac{\sigma^{FCC}}{\sigma^{ATLAS}} \times \frac{f^{FCC}}{f^{ATLAS}} \times \frac{p^{FCC}}{p^{ATLAS}}$$

~800 ~10 ~0.6

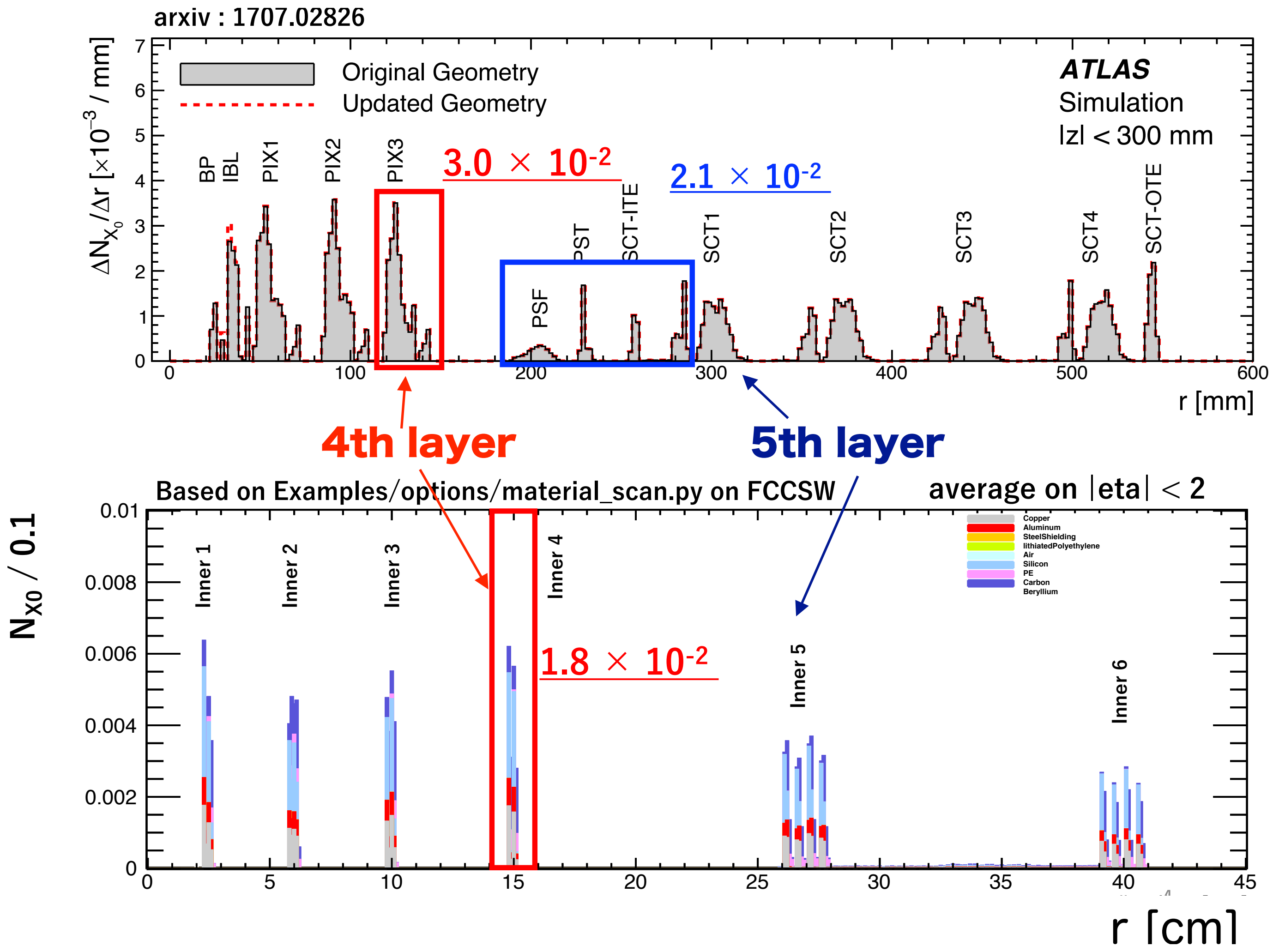
Depends on thresholds

Inner detector material

Radiation length

ATLAS Detector

FCC Detector v3.0.3

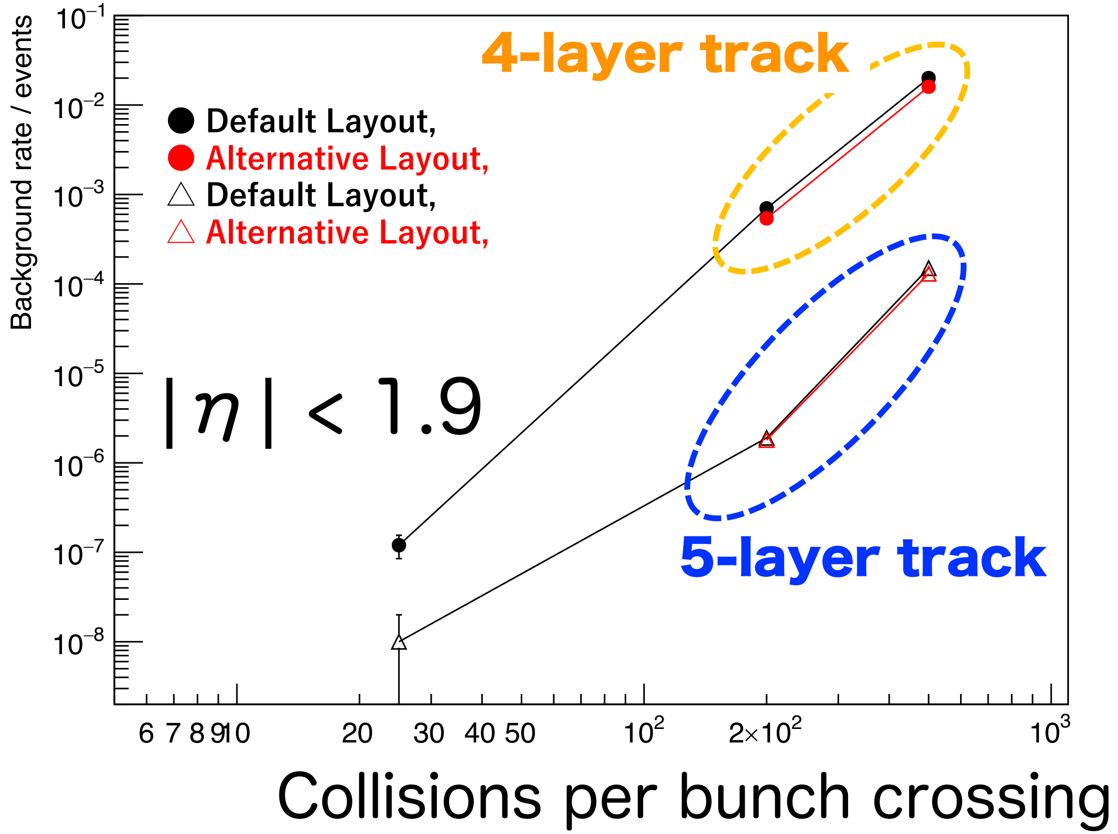


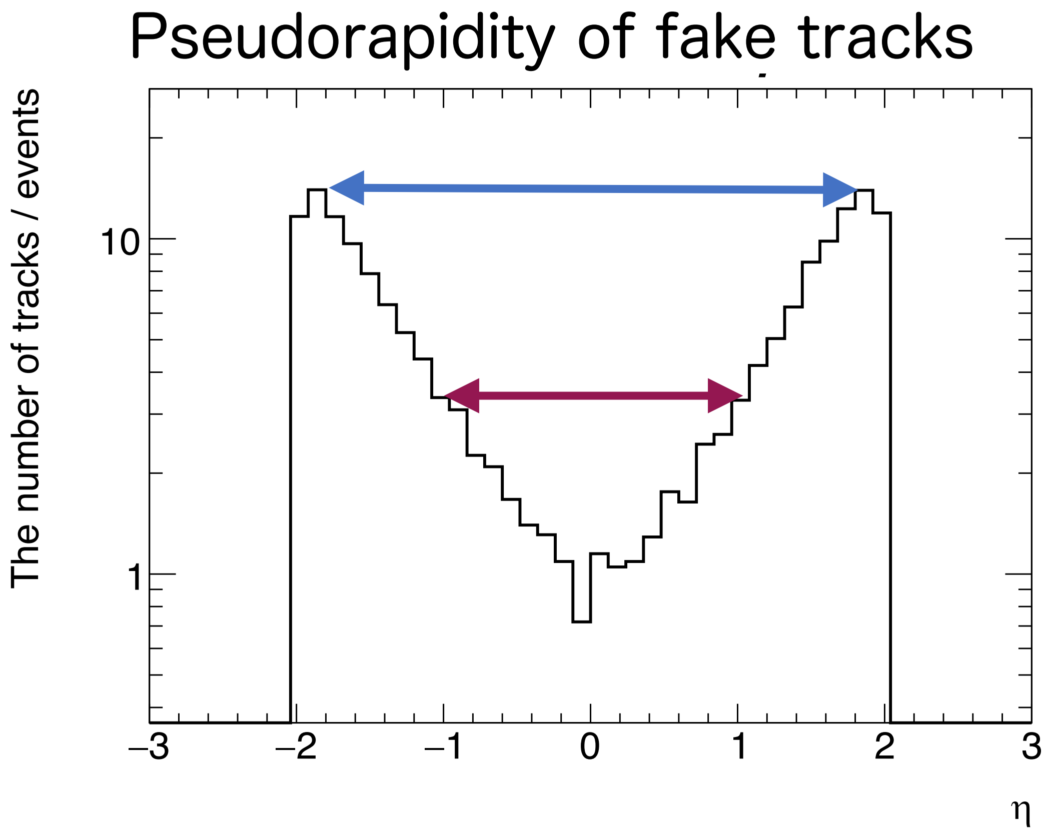
Inactive volumes (support, circuits etc) are not defined in FCC geometry yet.

We assumed the same Pixel v.s. Support material ratio.

→ we will follow up once support volumes are defined

Fake-track background





・10 times lower BG with a tight pseudo rapidity cut ($|\eta| < 1$).

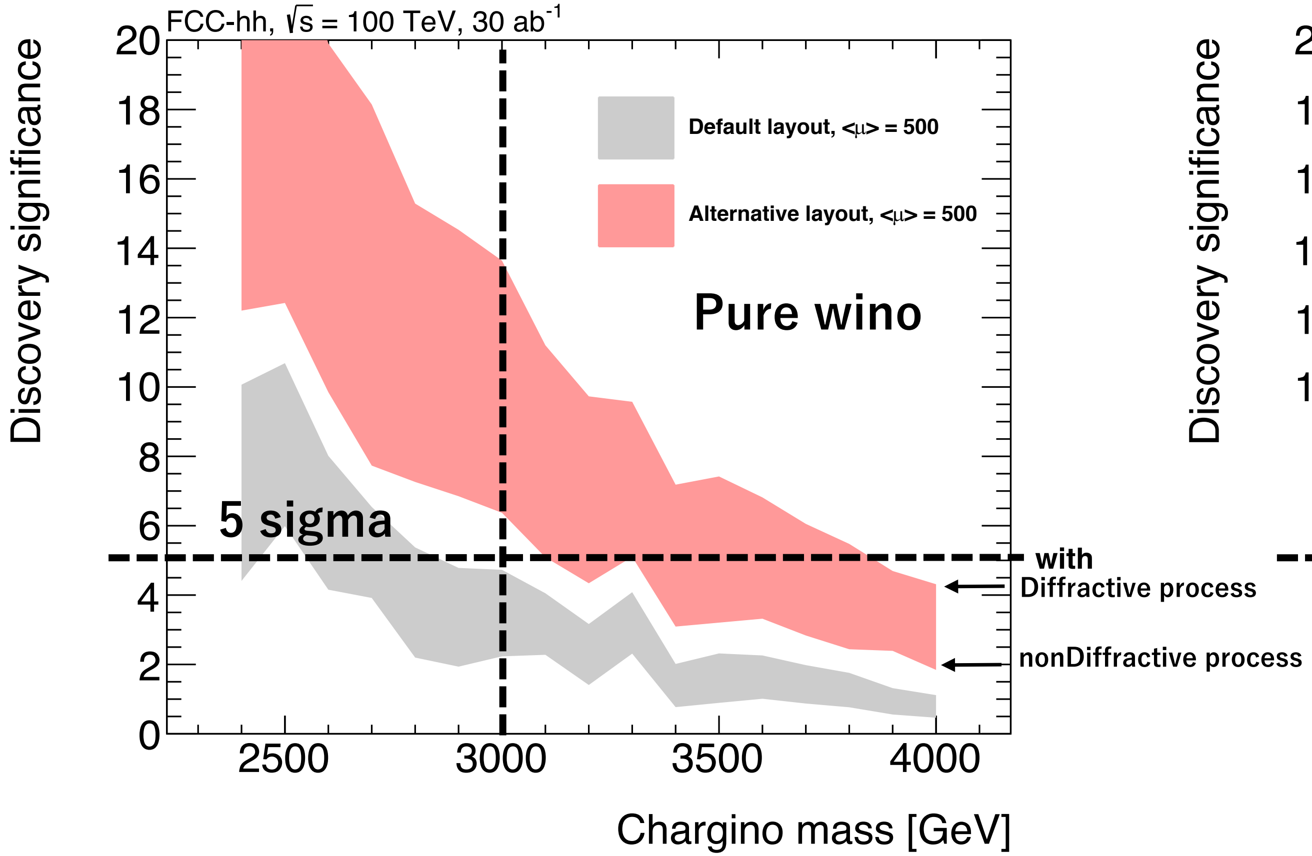
・BG rates with 4-layer tracks are too high.

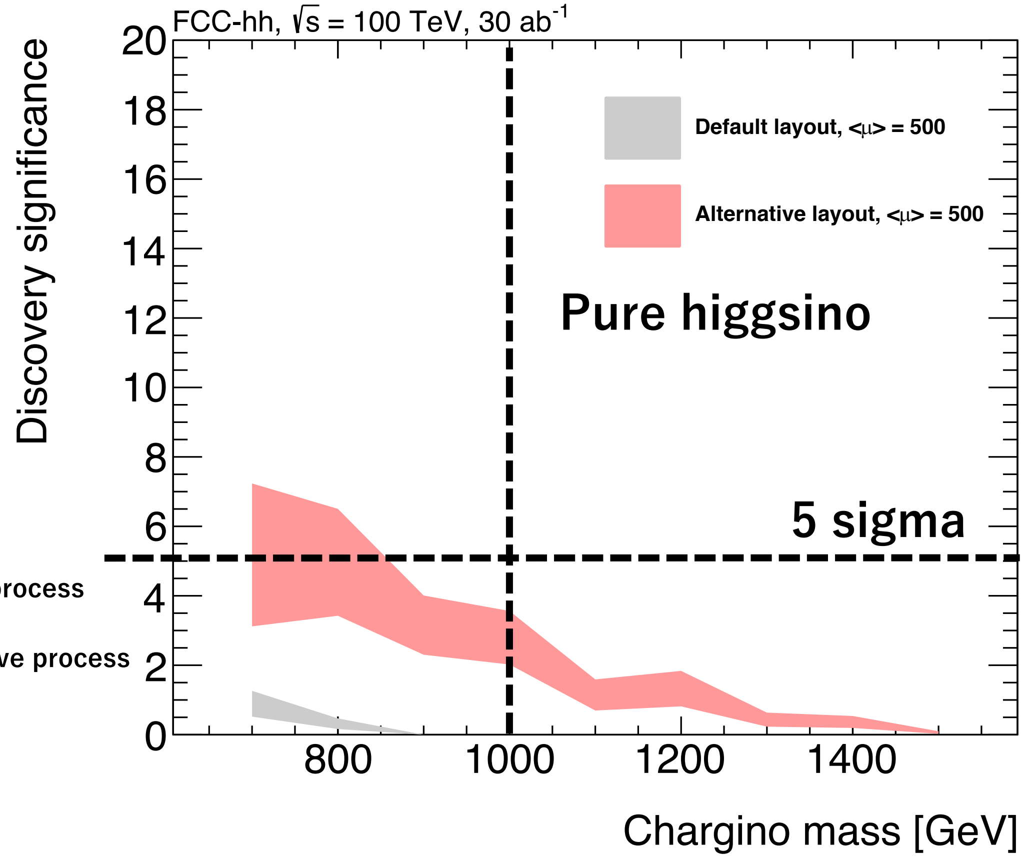
→ Expected sensitivities are calculated with 5-layer track configuration.

Sensitivity

30% uncertainty in BG yield is assumed

Band : only non-diffractive process (lower)
with diffractive processes (upper)

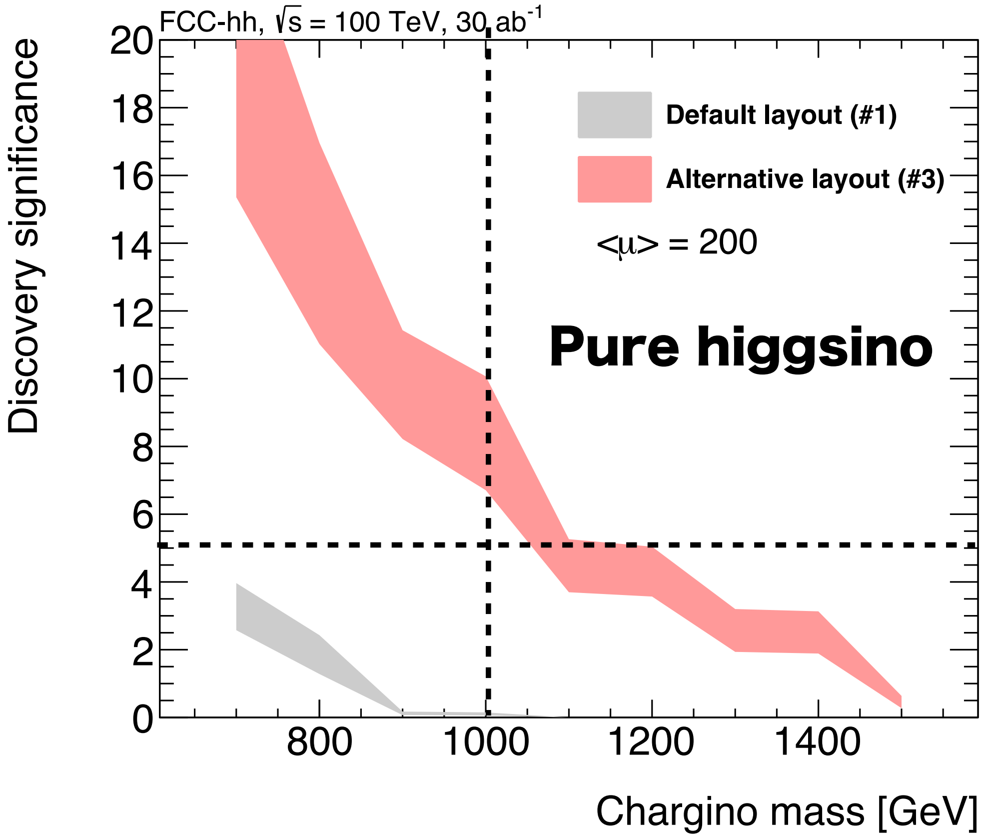




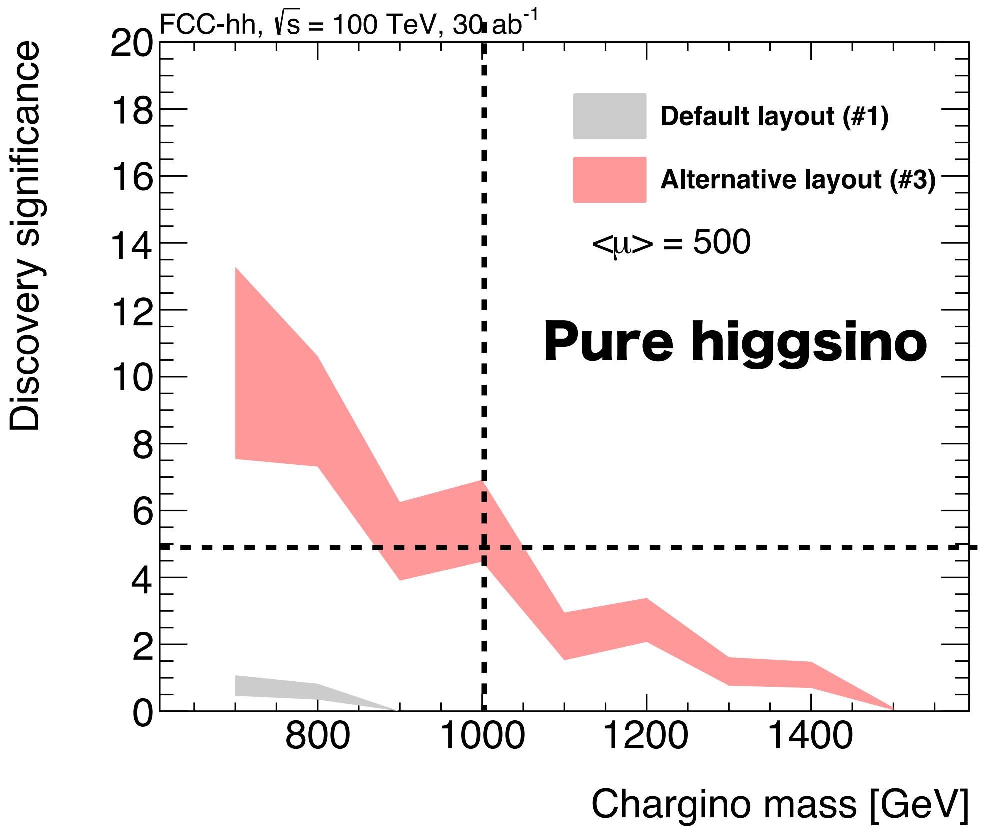
- With the alternative layout, 3 TeV wino can be discovered.
- 1 TeV higgsino is difficult with this configuration.

Modifications to discover 1 TeV higgsino

1) Decrease the pileup down to 200



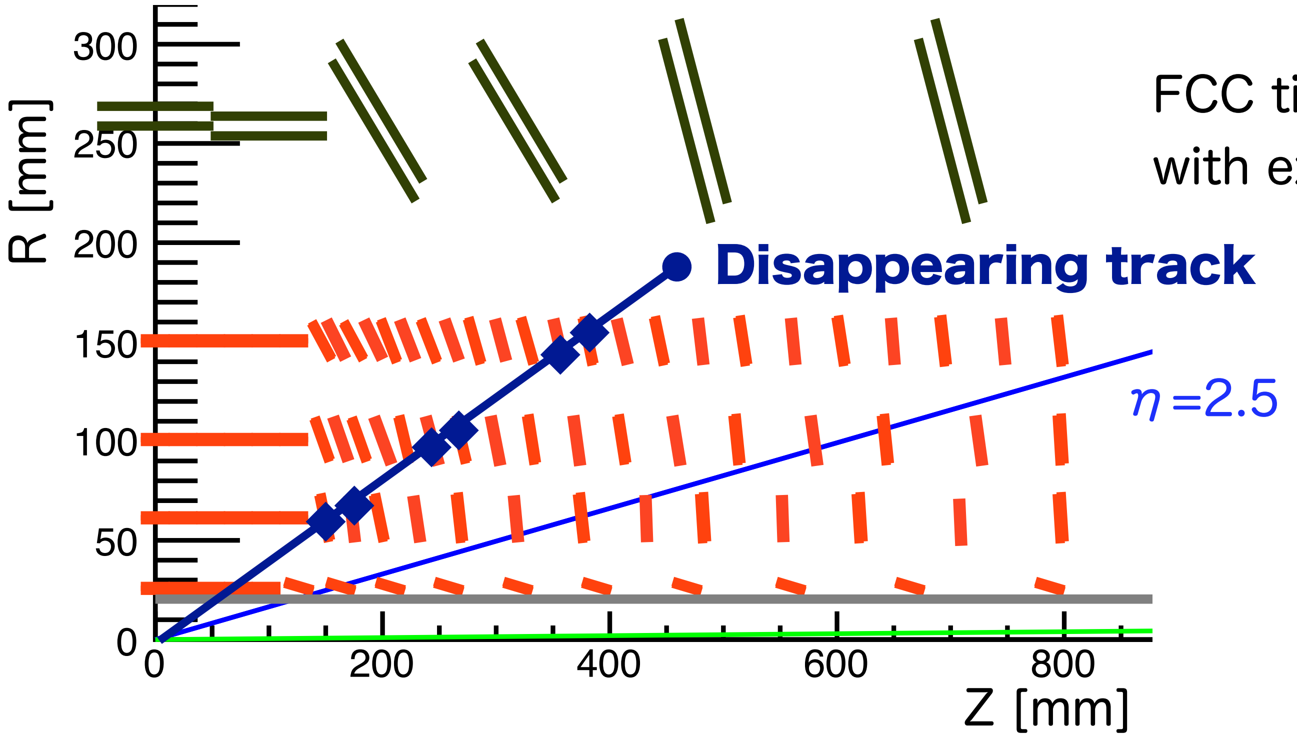
2) Tight cut on the pseudorapidity (< 1.0)



Band : only non-diffractive process (lower)
with diffractive processes (upper)

Key points in the layout

- Five space points are needed to reduce the fake-track rate.
- For the signal acceptance, a smaller radius of the fifth layer is better.
- Tilted silicon module layout with additional tilted modules can decrease the fake-track rate in the high $|\eta|$ region, if more than two hits are expected per layer.



FCC tilted layout
with extra tilted modules

Conclusion

- FCC-hh indeed has the potential to answer YES or NO to the existence of a pure wino or higgsino DM with a modified layout.
  - Minimum requirements
    - μ=500 or less pileup
    - 5 space points in track reconstruction
    - 5th pixel layer inner than ~15 cm
  - To discover earlier than 30 ab^{-1}
    - lower μ is better due to the rapid rise of the fake-track BG rate.
    - Tilted silicon layout decrease BG significantly. (quantitive study to be done.)

Backup

Uncertainties and future improvements in the estimation

- Main background (fake tracks) is about proportional to the fifth power of the pixel-hit rate (for 5-layer tracks). Reducing the uncertainty in the soft QCD processes would improve the estimate.

- We will consider further about other possible sources of BG (e.g. semi-fake tracks: scattered particle + a random hit).

- Fake-track rate depends on the track reconstruction algorithm. The rate could be decreased by improving it (e.g. machine learning to identify fake tracklets ?)

- Categorising the signal region by the number of layers and rapidity should improve the sensitivity.

Signal geometrical acceptance

[%]			Default layout	Alternative layout
Wino (3 TeV)	$\lvert\eta\rvert < 1.9$	4-layer track	4.0	7.3
		5-layer track	0.84	4.0
	$\lvert\eta\rvert < 1.0$	4-layer track	2.5	4.4
		5-layer track	0.57	2.5
Higgsino (1 TeV)	$\lvert\eta\rvert < 1.9$	4-layer track	0.0059	0.023
		5-layer track	0.00028	0.0059
	$\lvert\eta\rvert < 1.0$	4-layer track	0.0043	0.016
		5-layer track	0.00022	0.0043

Event yields in SR

30% uncertainty in BG yield is assumed

5-layer tracks, $|\eta| < 1.9$, $\mu = 500$, 30 ab^{-1}

non-diffractive model

[%]		Default layout	Alternative layout
Wino (3 TeV)	1st jet pT [TeV]	1	1
	E_T^{miss} [TeV]	5	5
	Signal events	22.9	68.3
	BG events	74.5	64.7
	Expected significance	2.3	6.7
Higgsino (1 TeV)	1st jet pT [TeV]	2	8
	E_T^{miss} [TeV]	1	9
	Signal events	2.4	4.2
	BG events	13291	1.8
	Expected significance	0	2.1

Event yields in SR

30% uncertainty in BG yield is assumed

5-layer tracks, $|\eta| < 1.9$, $\mu = 200$, 30 ab^{-1}

non-diffractive model

[%]		Default layout	Alternative layout
Wino (3 TeV)	1st jet pT [TeV]	1	1
	E_T^{miss} [TeV]	4	2
	Signal events	38.1	422
	BG events	6.0	145
	Expected significance	9.8	26
Higgsino (1 TeV)	1st jet pT [TeV]	1	1
	E_T^{miss} [TeV]	1	4
	Signal events	3.3	23.1
	BG events	1980	5.8
	Expected significance	0.1	6.7

30% uncertainty in BG yield is assumed

Event yields in SR

5-layer tracks, $|\eta| < 1.0$, $\mu = 500$, 30 ab^{-1}

non-diffractive model

[%]		Default layout	Alternative layout
Wino (3 TeV)	1st jet pT [TeV]	1	1
	E_T^{miss} [TeV]	4	4
	Signal events	28.5	92.6
	BG events	27.0	14.5
	Expected significance	4.6	15
Higgsino (1 TeV)	1st jet pT [TeV]	1	8
	E_T^{miss} [TeV]	1	8
	Signal events	2.7	4.7
	BG events	8214	0.17
	Expected significance	0	4.5

30% uncertainty in BG yield is assumed

Event yields in SR

5-layer tracks, $|\eta| < 1.0$, $\mu = 200$, 30 ab^{-1}

non-diffractive model

[%]		Default layout	Alternative layout
Wino (3 TeV)	1st jet pT [TeV]	1	1
	E_T^{miss} [TeV]	4	2
	Signal events	28.5	287
	BG events	1.9	42.6
	Expected significance	10	27
Higgsino (1 TeV)	1st jet pT [TeV]	1	1
	E_T^{miss} [TeV]	1	4
	Signal events	2.7	19.0
	BG events	673	1.6
	Expected significance	0	8.9

Software used in this study

Wino mass spectrum	SOFTSUSY
Higgsino mass spectrum	SUSYHIT
Signal cross-section	PROSPINO2
Signal Kinematic distribution	MG5_aMC@NLO
SM BG	MG5_aMC@NLO
Detector response	DELPHES
Minimum-bias events	PYTHIA8

E_T^{miss} and jet p_T