How heavy can the weak scale SUSY be?

Hajime Fukuda (Kavli IPMU)

In collaboration with:

N. Nagata, H. Otono, S. Shirai, 1703.09675

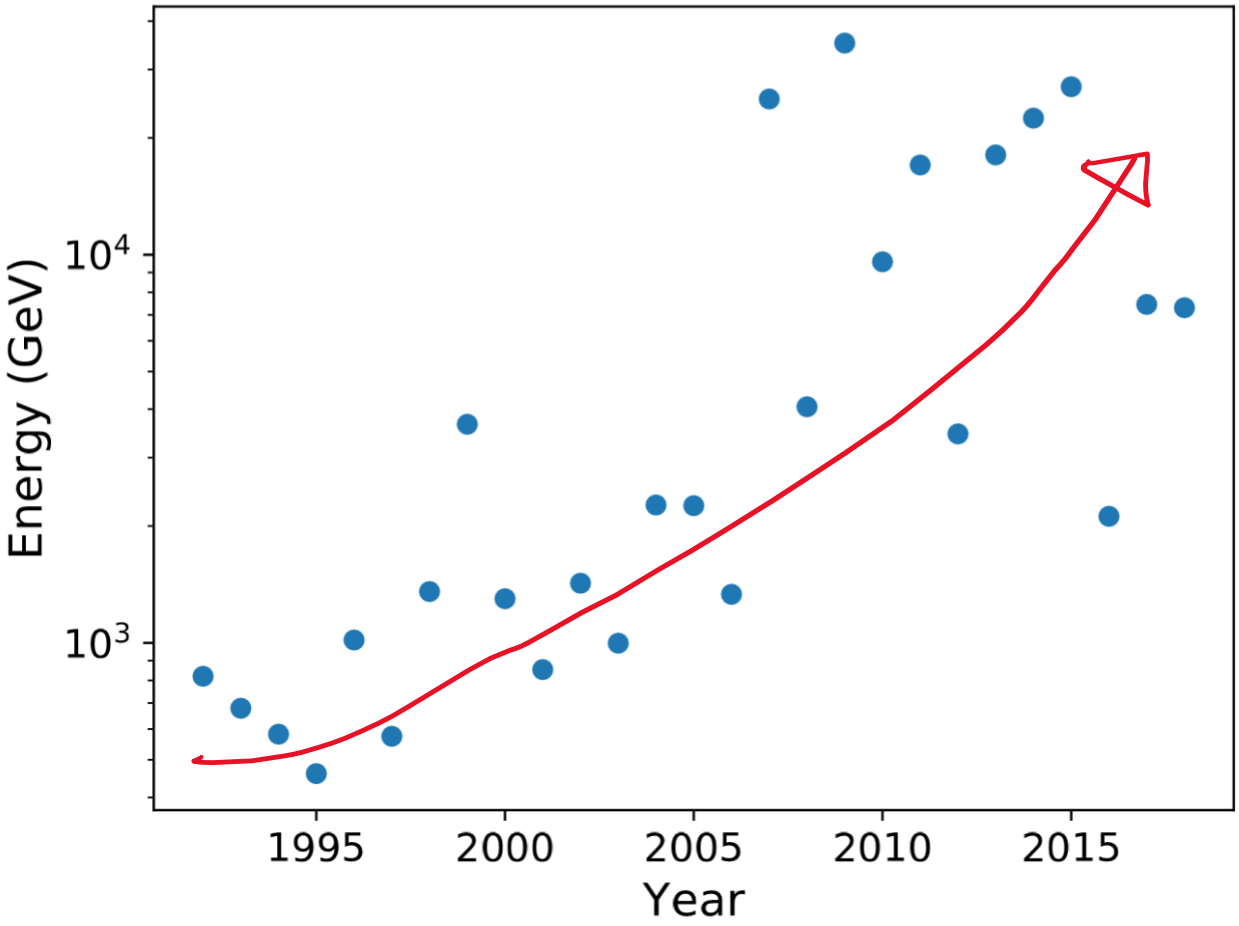
S. Matsumoto, S. Shirai, In preparation

Supersymmetry is Important

- SUSY around the weak scale is highly motivated.
  - GUT
  - “Hierarchy problem”
  - Dark matter (With R-parity)

- Where’s the SUSY scale?

SUSY Scale on hep-ph in 25 Years



Code on github: https://github.com/hajifkd/susy_energy

SUSY Search with the Goal

- It is very important to clarify the upper bound on the SUSY scale
  - Supersymmetric DM can set the upper bound
    - Assumption: R-Parity & Thermal Equilibrium

How Is the DM Scale Fixed?

- WIMP Miracle: $\Omega \sim \Omega_{DM}$ (1 pb / $\langle\sigma v\rangle$)
- Roughly, the weaker the LSP interaction is, the more the abundance is
  - The heavier a particle is, the weaker the interaction is
  - This imposes the upper bound on the LSP scale
- As long as we look for LSP, we have a definite goal!
- DM candidate: Wino, Bino or Higgsino
  - "How heavy?" = "How strong can they interact?"
- How can we detect them?

LSP Mass Upper Bound

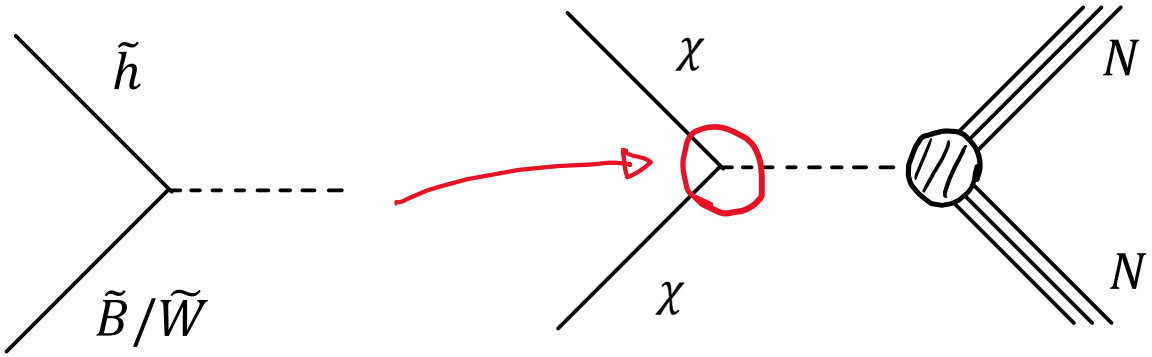
	Mass Bound	Assumption	Detection
(Ordinary) SUSY	1 TeV for Higgsino 3 TeV for Wino		Direct detection / Collider HF, Nagata, Otono, Shirai 17
Coannihilation Profumo et al 04, Ellis et al 15 (See F. Luo's talk)	~ 8 TeV	+ gluino - LSP degeneracy (< 3 %)	Collider
Higgs Funnel Profumo 05, Gilmore 07, HF Matsumoto Shirai in prep.	~ 14 TeV	+ heavy Higgs - LSP degeneracy, LSP – NLSP degeneracy (< 1 %)	Direct detection
Brown muck Kang *et al* 06			

LSP Mass Upper Bound

	Mass Bound	Assumption	Detection
(Ordinary) SUSY	1 TeV for Higgsino 3 TeV for Wino		Direct detection / Collider HF, Nagata, Otono, Shirai 17
Coannihilation Profumo et al 04, Ellis et al 15 (See F. Luo's talk)	~ 8 TeV	+ gluino - LSP degeneracy (< 3 %)	Collider
Higgs Funnel Profumo 05, Gilmore 07, HF Matsumoto Shirai in prep.	~ 14 TeV	+ heavy Higgs - LSP degeneracy, LSP – NLSP degeneracy (< 1 %)	Direct detection
Brown muck Kang *et al* 06			

1/3 TeV Goal

- Roughly speaking, for DM with large mixing angle, the direct detection works



- How is pure wino/Higgsino? – Disappearing track

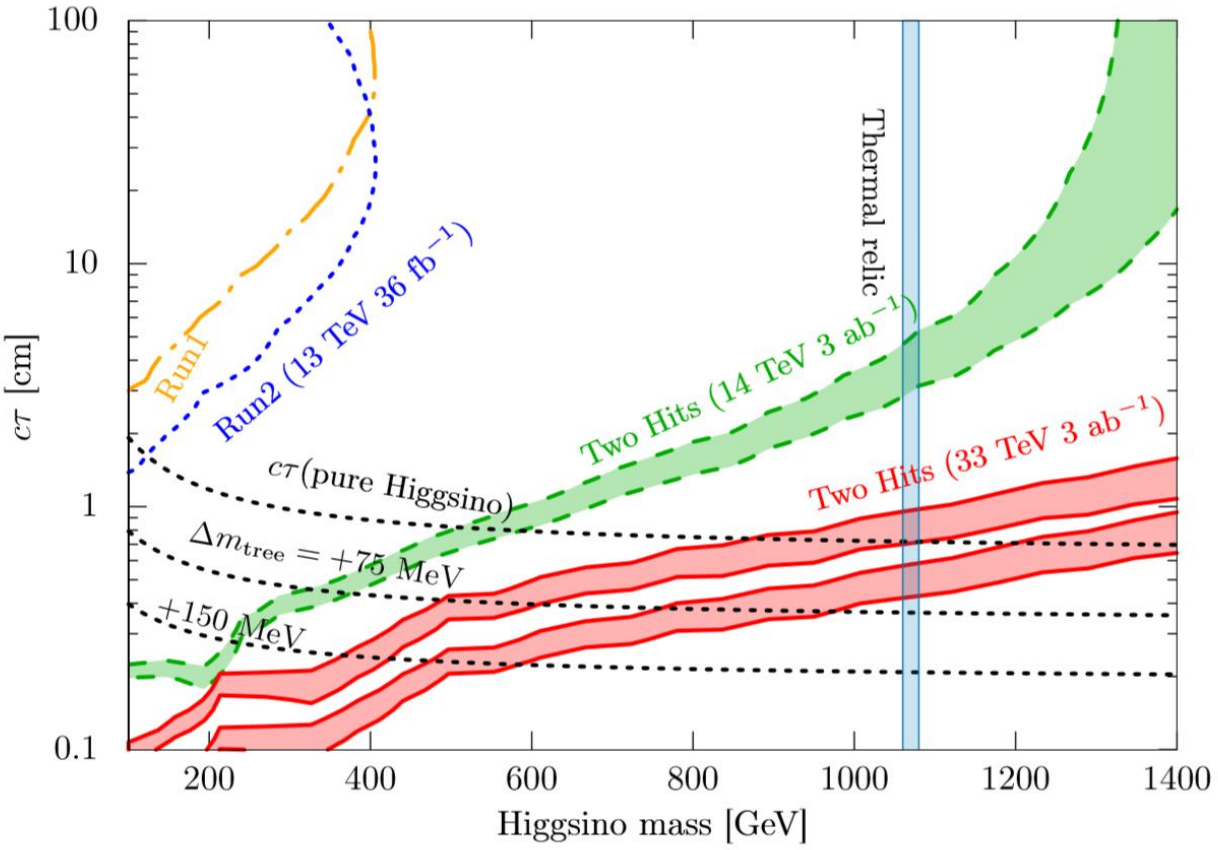
HF, Nagata, Otono, Shirai, 1703.09675

Disappearing Track

- A charged partner always accompanies with DM
- For pure wino/Higgsino, the mass difference is only from the radiative correction, $\Delta m \sim \alpha v/4\pi$
- The partner is long lived!
  - Wino: ~ 7 cm
  - Higgsino: ~ 0.7 cm
- Tracking technology is very important
  - Wino/higgsino @ 33 TeV by tracking improvement

HF, Nagata, Otono, Shirai, 1703.09675

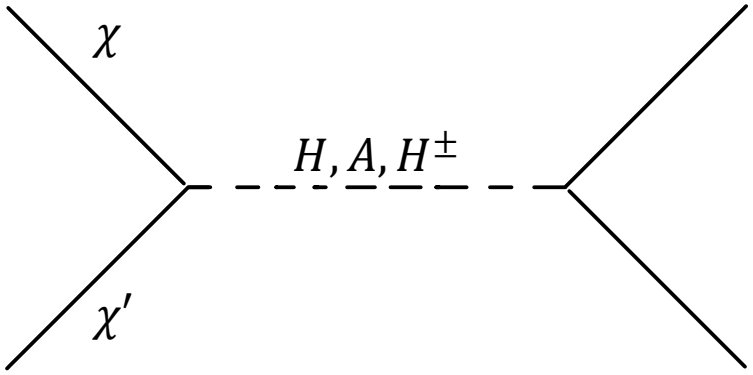
Result (Higgsino)



HF, Nagata, Otono, Shirai, 1703.09675

Higgs Funnel Scenario: Idea

- If electroweakino scattering hits the heavy Higgs pole, the cross section gets much enhanced



$$G \sim \frac{1}{-p^2 + M^2 - i\,M\Gamma} \sim \frac{1}{\Gamma}$$

For $m_\chi + m_{\chi'} \sim M_H$

Profumo 05

Annihilation Process

- Since the mass is 10-20 TeV, the freeze out temperature is T ~ 300-600 GeV > v
- Neutralinos don’t mix with each other
- Annihilation between different neutralino is effective

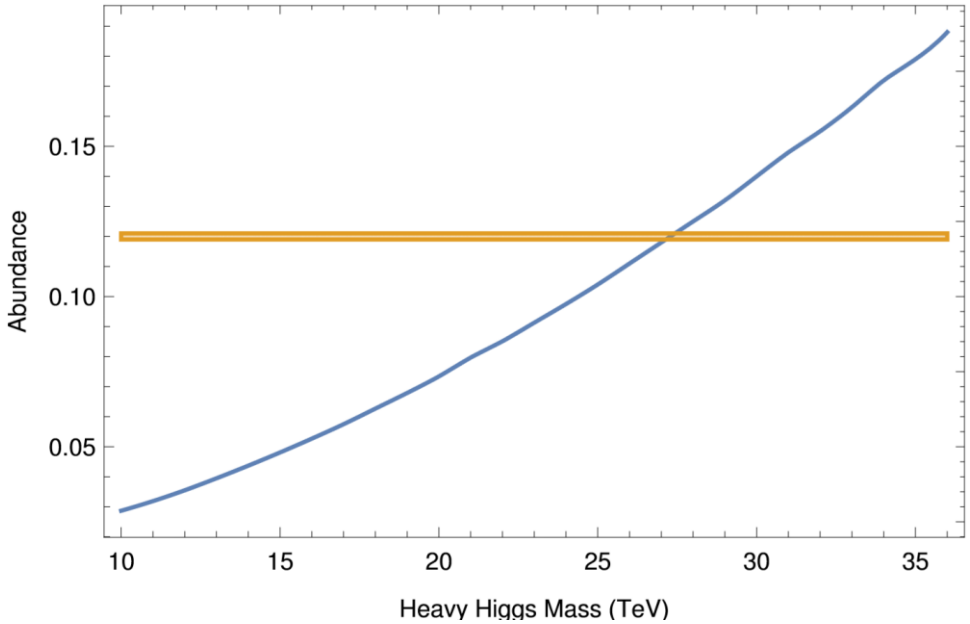
HF, Matsumoto, Shirai In prep

Mass VS Abundance

- We need to calculate Ω for hW, hB, hWB system
- hW system:

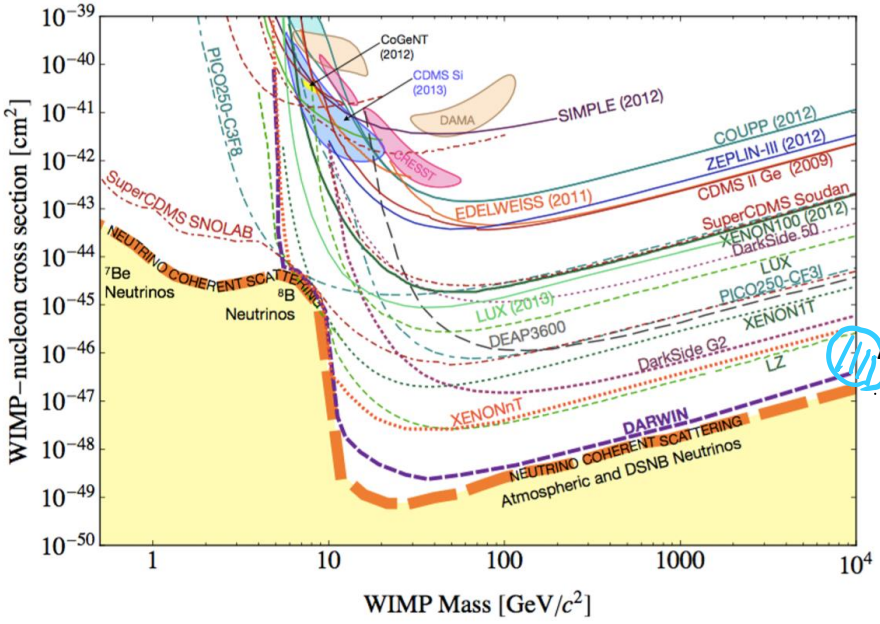
(Similar to other)

- The Goal: ~ 14 TeV



Direct Detection

- Neutralino degeneracy: m / 30 ~ O(100) GeV
  - neutralino mixing → O(1)
  - Direct detection becomes effective



Around here?

Summery

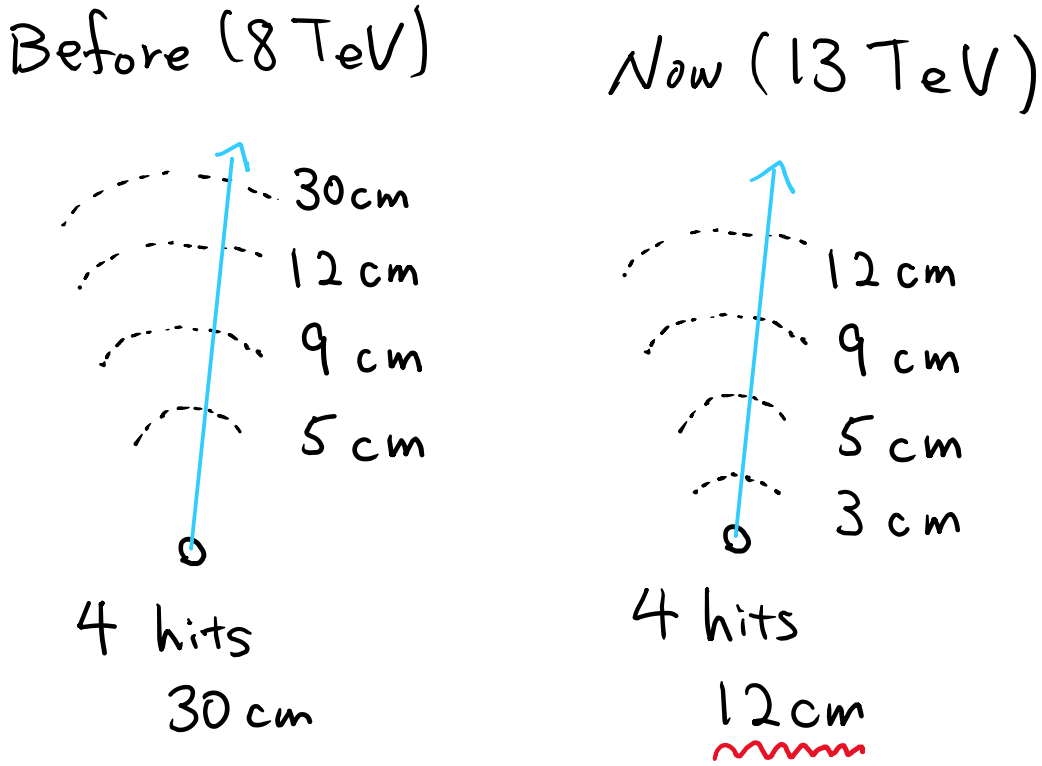
- Dark matter search is very important as the SUSY search
- In the “ordinary” case, 1/3 TeV are the goal
  - Direct detection / Disappearing track
- In Higgs Funnel case, ~ 14 TeV is the goal
  - Direct detection
- We have a definite goal for SUSY search

What Limits the Sensitivity?

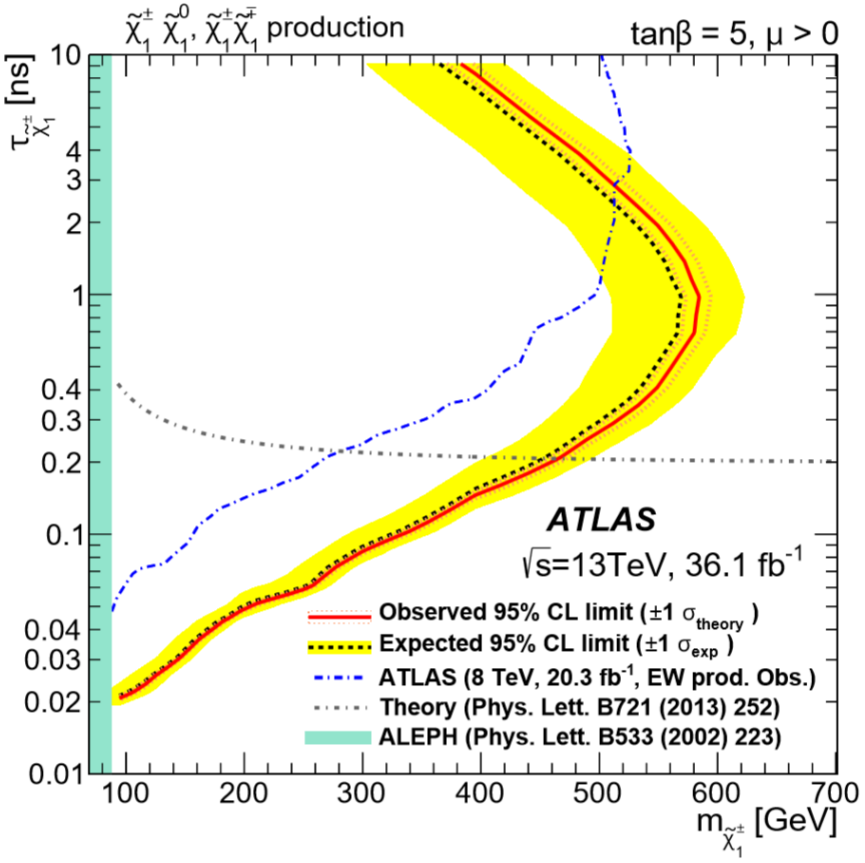
- Usual channel: Energy
- σ_{weak}(1 TeV higgsino pair @ 14 TeV) >~ O(fb)
- Rather, the analysis, in particular the tracking technology, is important

Improving the Analysis

- If we require shorter track, the acceptance rate becomes greater.



ATLAS Analysis

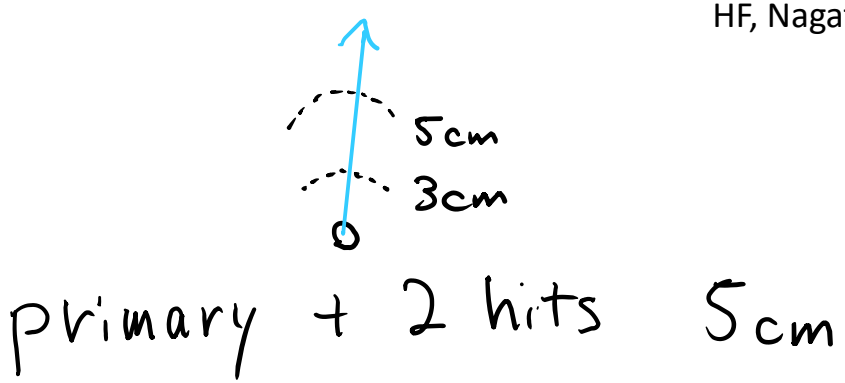


The ATLAS collabolation, 1712.02118

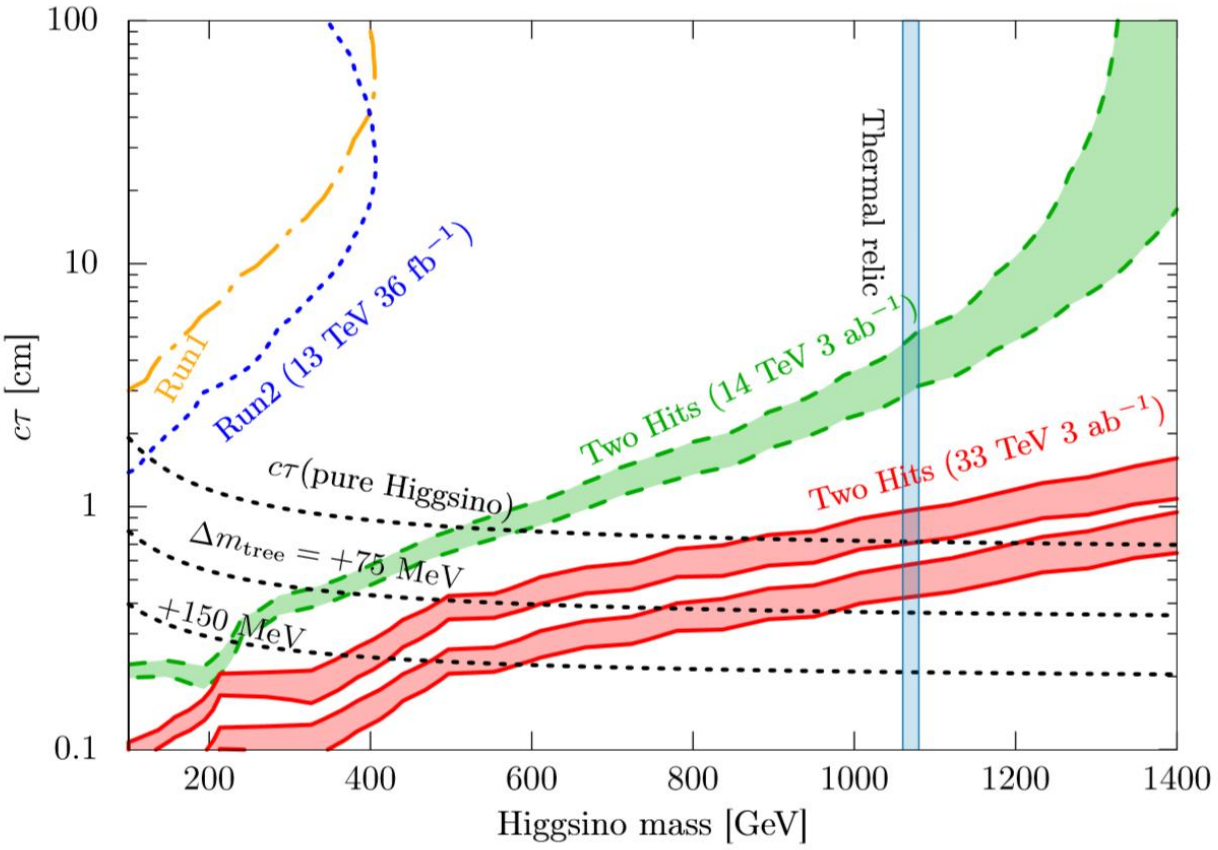
Can We Do Better?

- In principle, 3 points are enough to draw a non-trivial line
- Moreover, we may use the information from the primary vertex from other tracks
- The best analysis: 2 point analysis

HF, Nagata, Otono, Shirai, 1703.09675

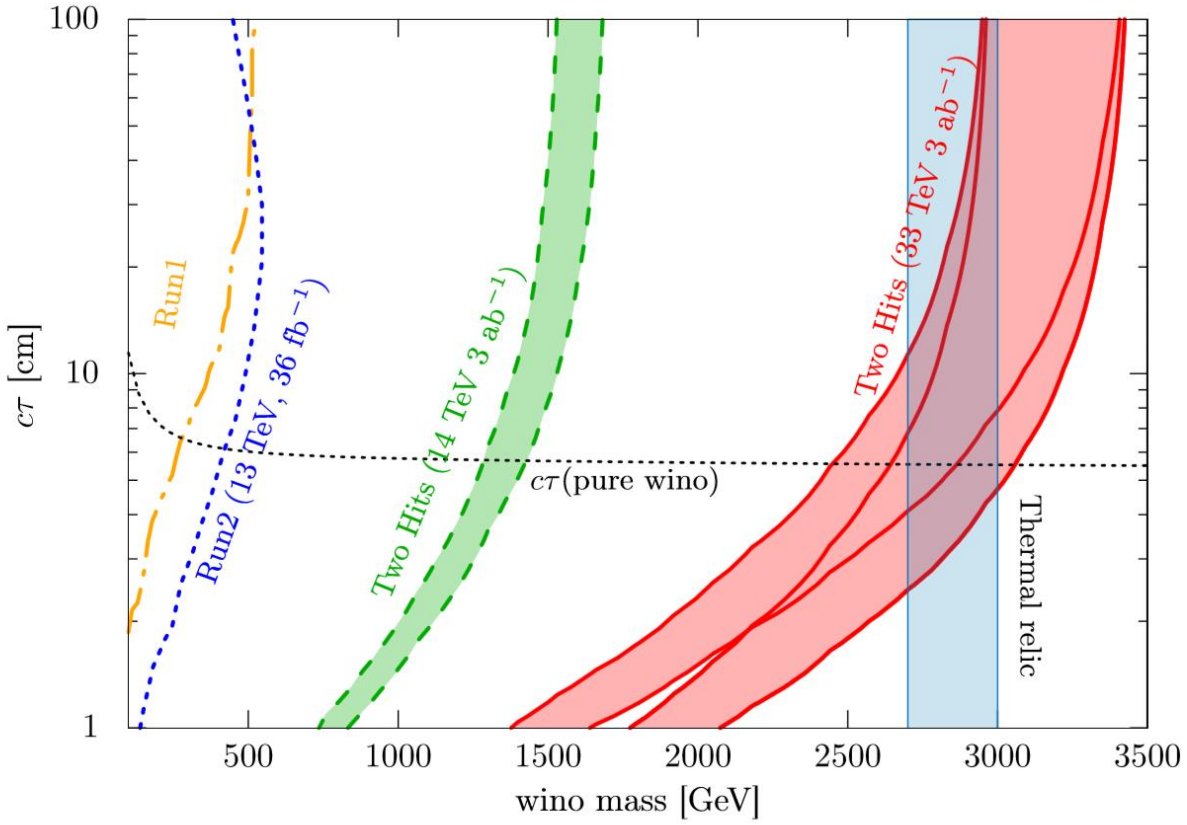


Result (Higgsino)



HF, Nagata, Otono, Shirai, 1703.09675

Result (Wino)



HF, Nagata, Otono, Shirai, 1703.09675

Summary

- For SUSY search, the dark matter search is essential
  - 1/3 TeV Higgsino/wino is most important
- Disappearing track search is the important strategy
- Reducing the required length for the disappearing track is the key to improve the sensitivity
  - We need to discuss how we reduce the background

Backup

Can We Avoid This Constraint?

- If the amount of the LSP is changed, we can evade the constraint.
  - Low reheating temperature
    - The LSP has never existed in the Universe
    - Inconsistent with the thermal leptogenesis
  - Entropy production
    - Dilutes LSP by energy injection from decaying heavy particle
    - Requires a very stable new particle
  - RPV

Backgrounds

- Fake Track
  - Failure of tracking due to the points from pileup
- Kink Track
  - Pions scattered by materials