

# Future Collider

In addition to energy incensement, what should we require for **detector**?

- Improvement of tracking system
- Precise measurement



# Higgsino Dark Matter at Collider

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**Based on**

**arXiv:1703.09675 with**

**Hajime Fukuda, Natsumi Nagata, and Hidetoshi Otono**

**arXiv: 1504.03402 with**

**Keisuke Harigaya, Koji Ichikawa, Anirban Kundu, Shigeki Matsumoto**

# What is Higgsino?

Higgsino is

- (pseudo) Dirac fermion

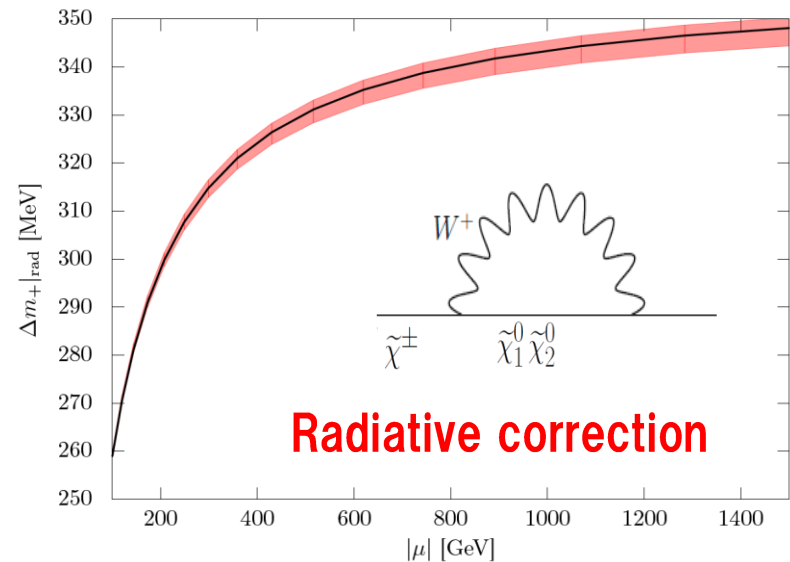
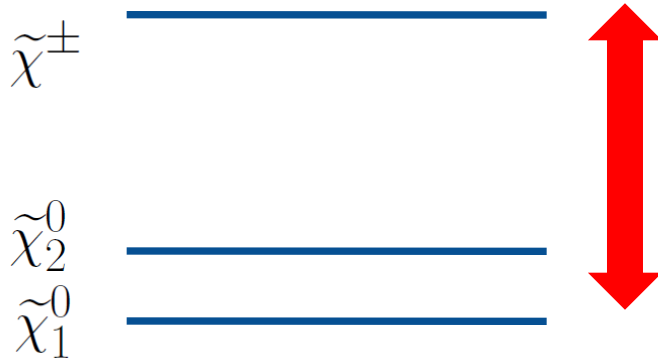
- Hypercharge  $|Y|=1/2$

- SU (2) doublet  $\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}, \begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix}$

- $<1$  TeV  $\Omega h^2 \simeq 0.1 \left( \frac{m_{\tilde{H}}}{1.1 \text{ TeV}} \right)^2$

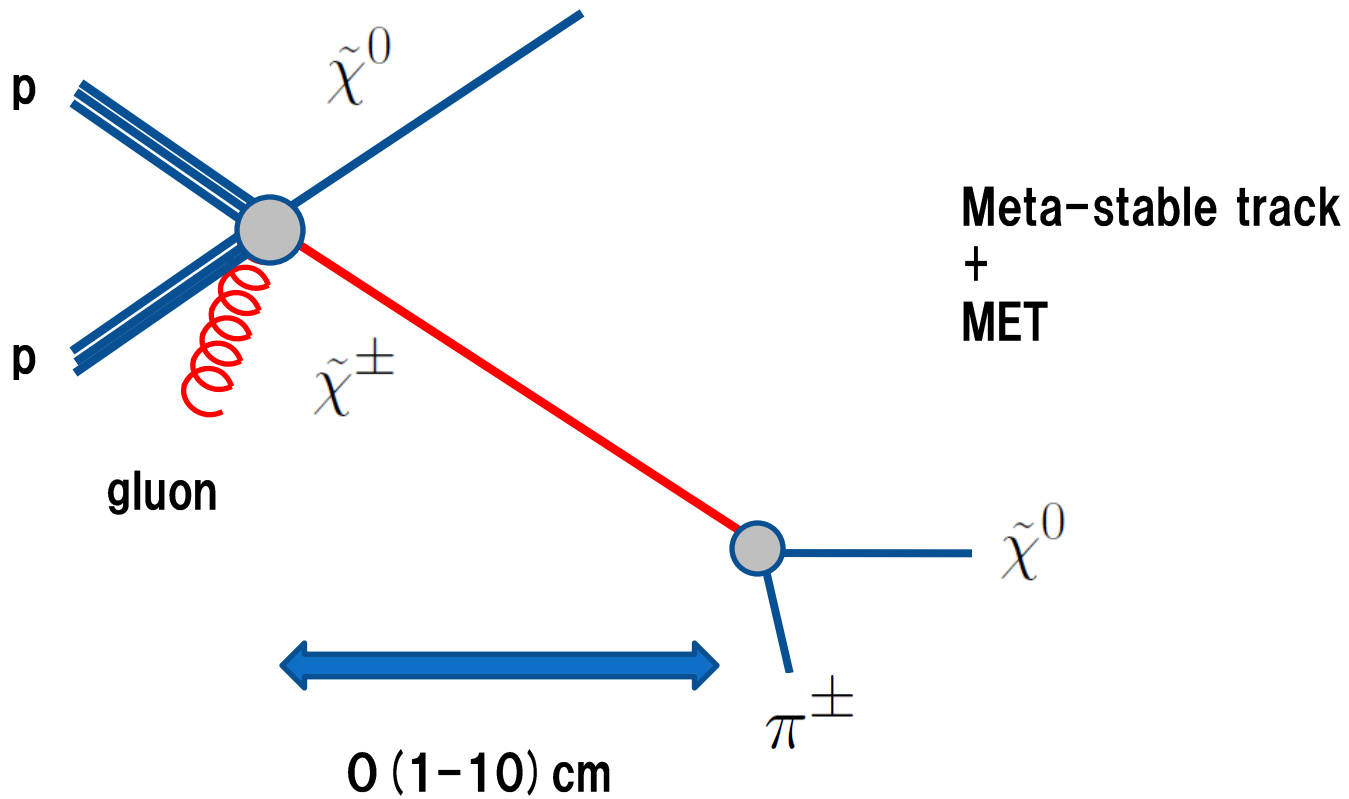
# Higgsino Spectrum (with heavy gaugino)

$$\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}, \begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix} \longrightarrow \tilde{\chi}_1^0 \quad \tilde{\chi}_2^0 \quad \tilde{\chi}^\pm$$



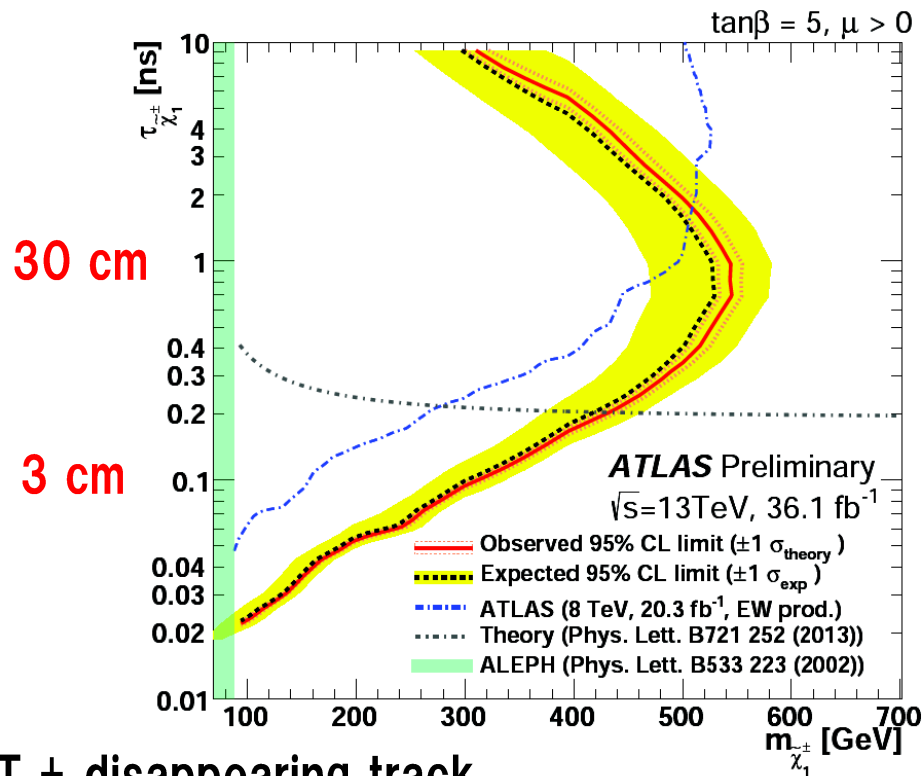
$$c\tau(\tilde{\chi}^\pm \rightarrow \tilde{\chi}^0 \pi^\pm) = 1.1 \text{ cm} \left( \frac{\Delta m_+}{300 \text{ MeV}} \right)^{-3} \left[ 1 - \frac{m_{\pi^\pm}^2}{\Delta m_+^2} \right]^{-1/2}$$

# LHC Signals



# Current Constraint (wino)

So far, LHC investigates **Wino** case



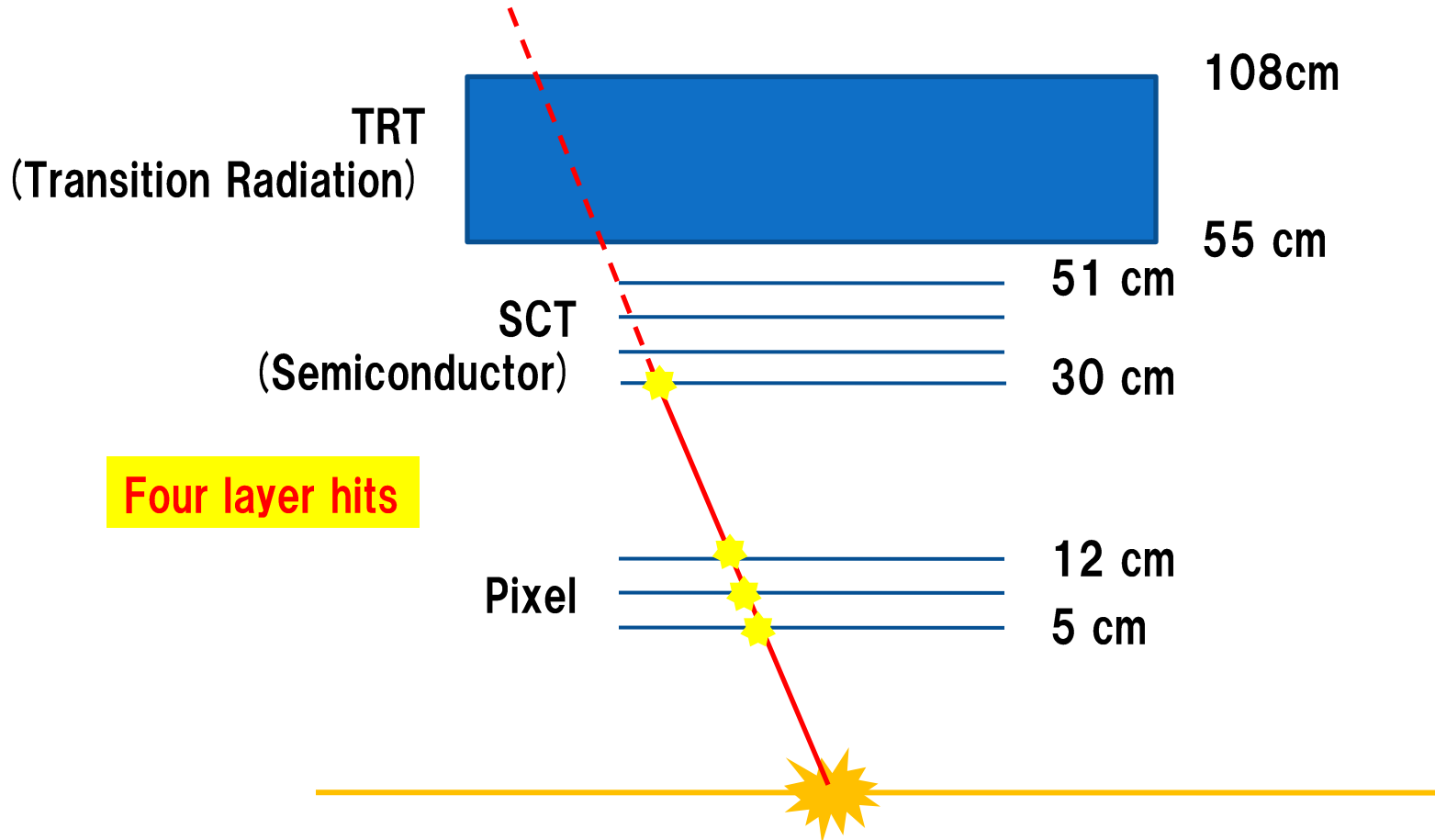
MET + disappearing track

$$\begin{pmatrix} \tilde{W}^+ \\ \tilde{W}^0 \\ \tilde{W}^- \end{pmatrix} \text{ Mass difference } \sim 160 \text{ MeV}$$

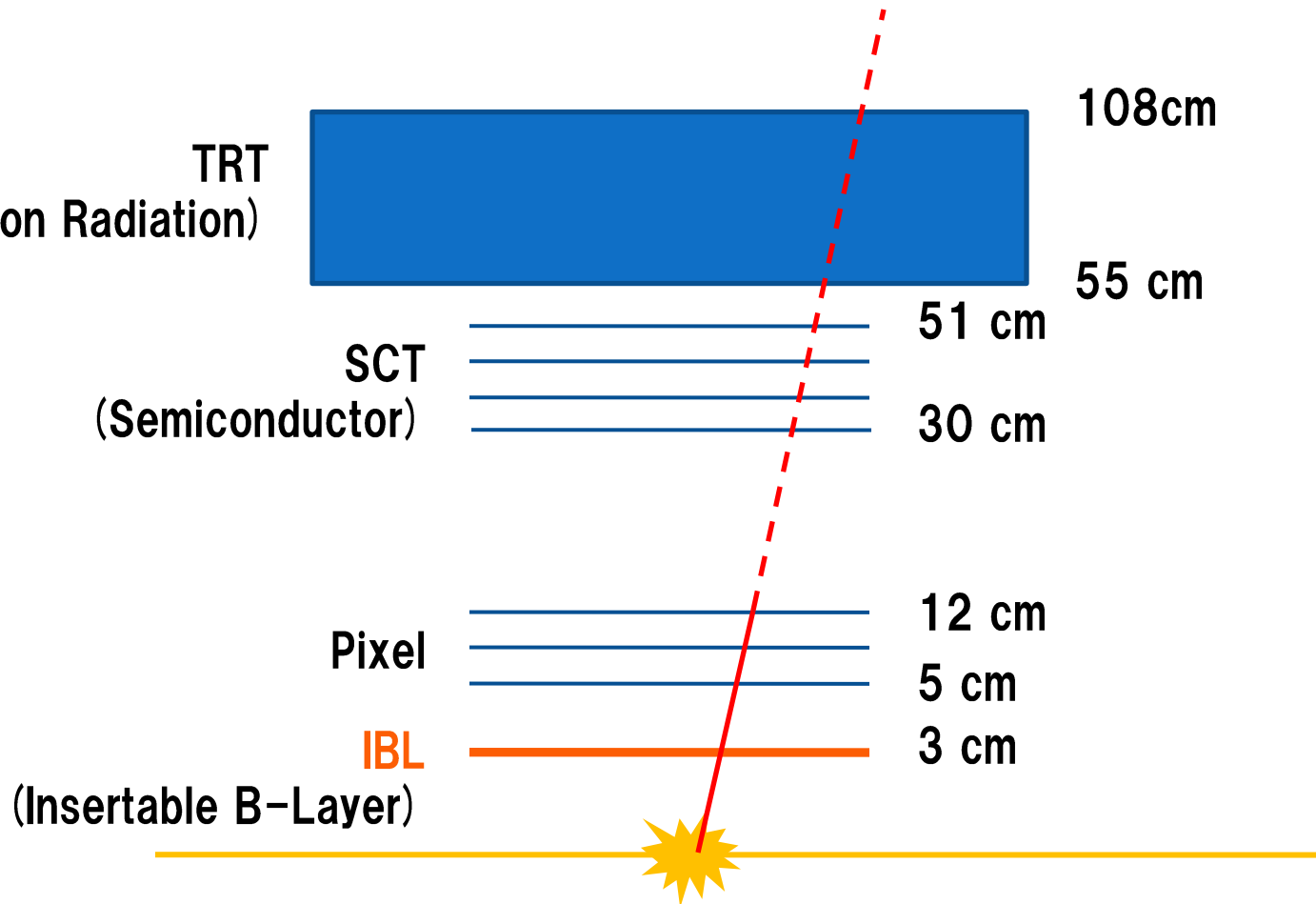
$$c\tau(\tilde{W}^\pm \rightarrow \tilde{W}^0 \pi^\pm) \simeq 7 \text{ cm} \left( \frac{\Delta m}{165 \text{ MeV}} \right)^{-3}$$

# Tracker for Run 1

8 TeV selection



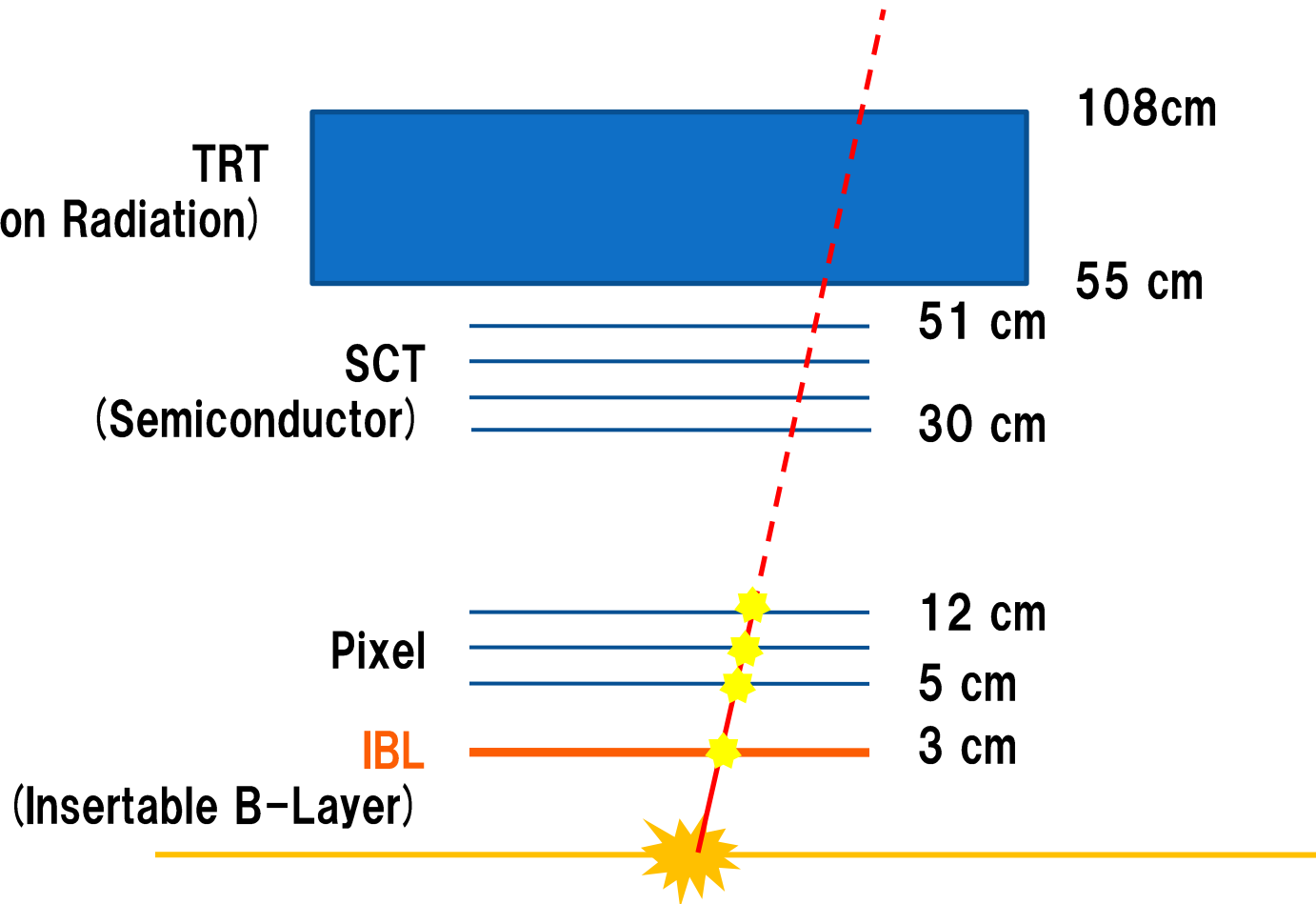
# Tracker for Run2



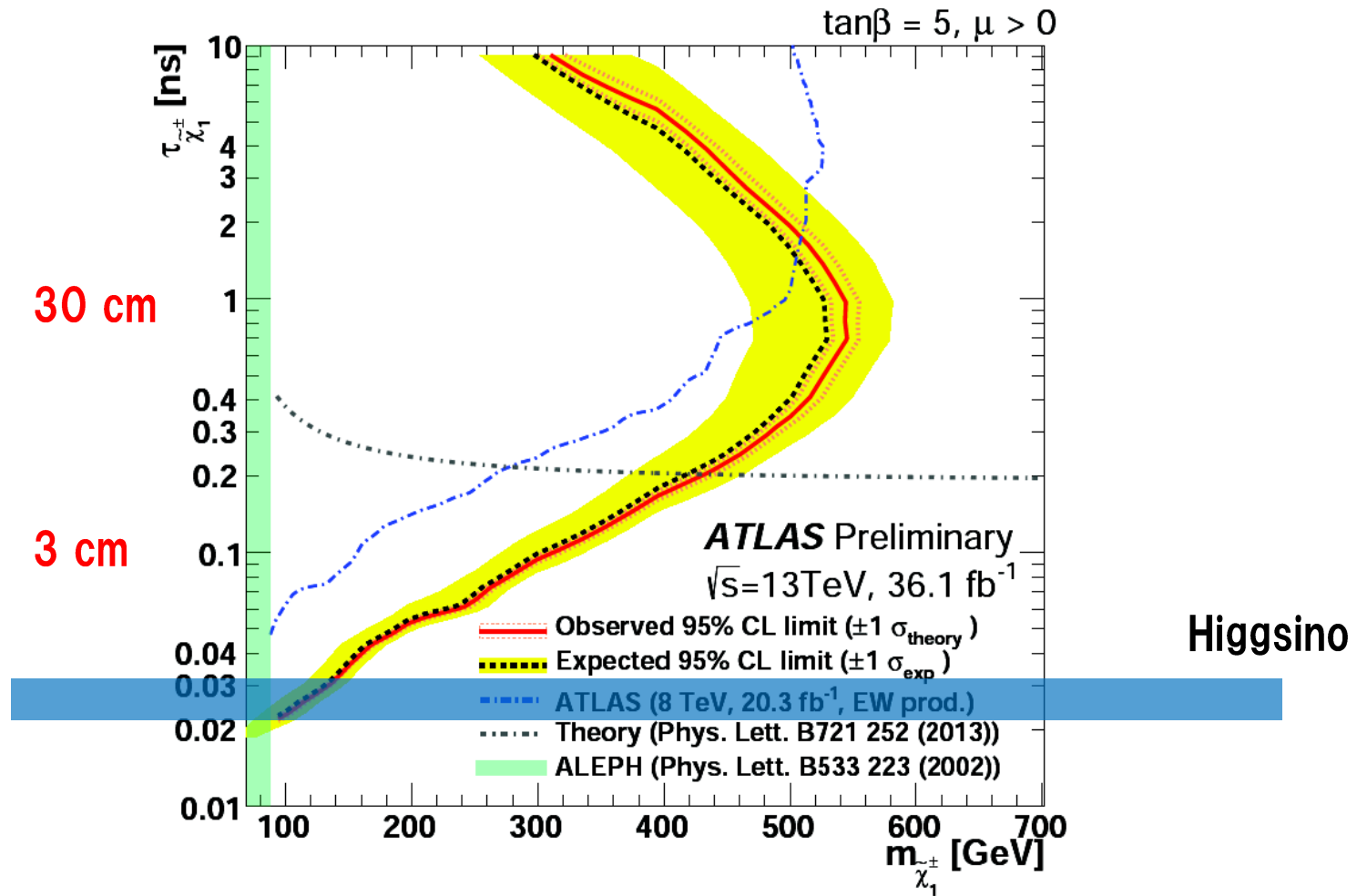
\* CMS installed similar module



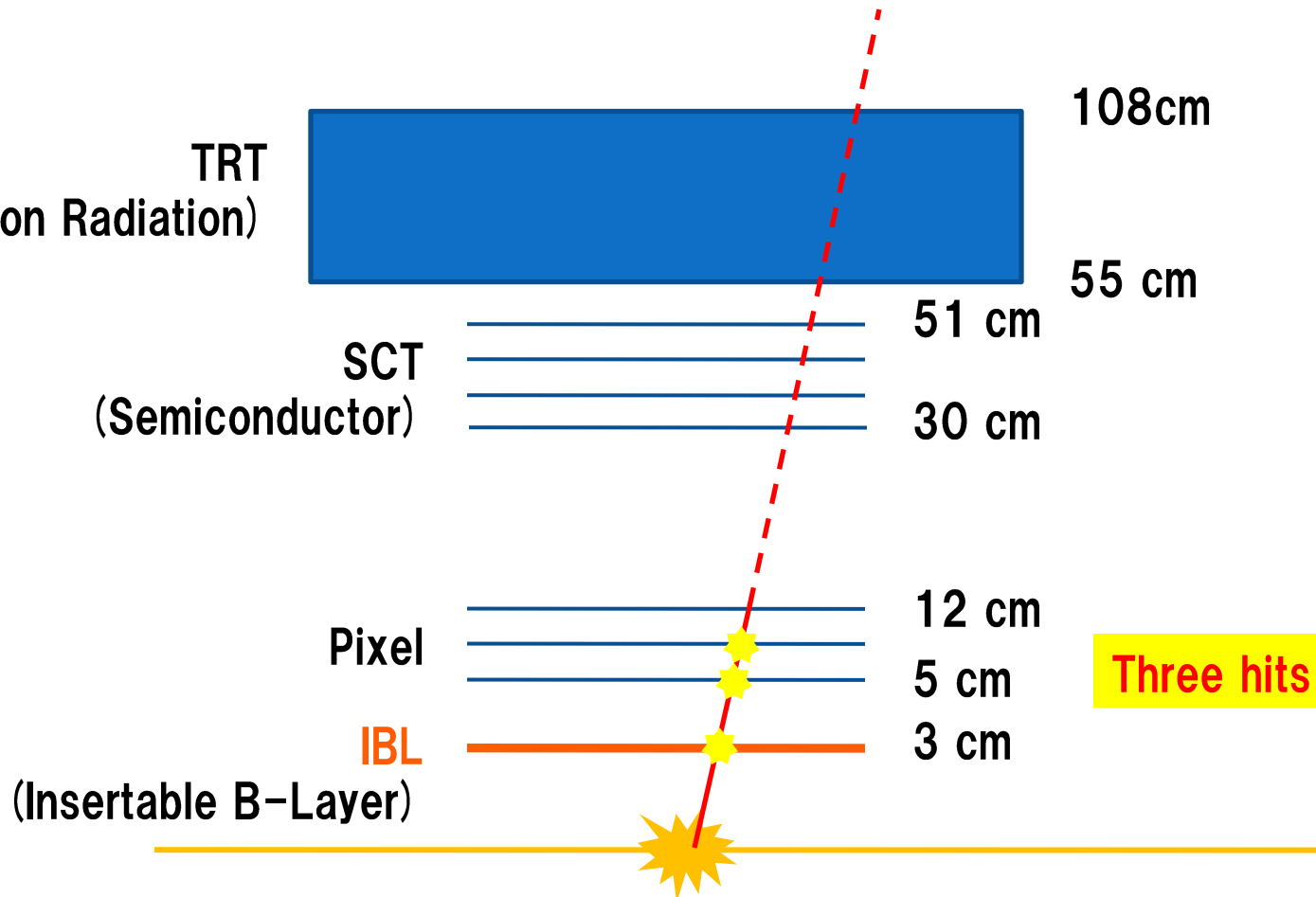
# Tracker for Run2



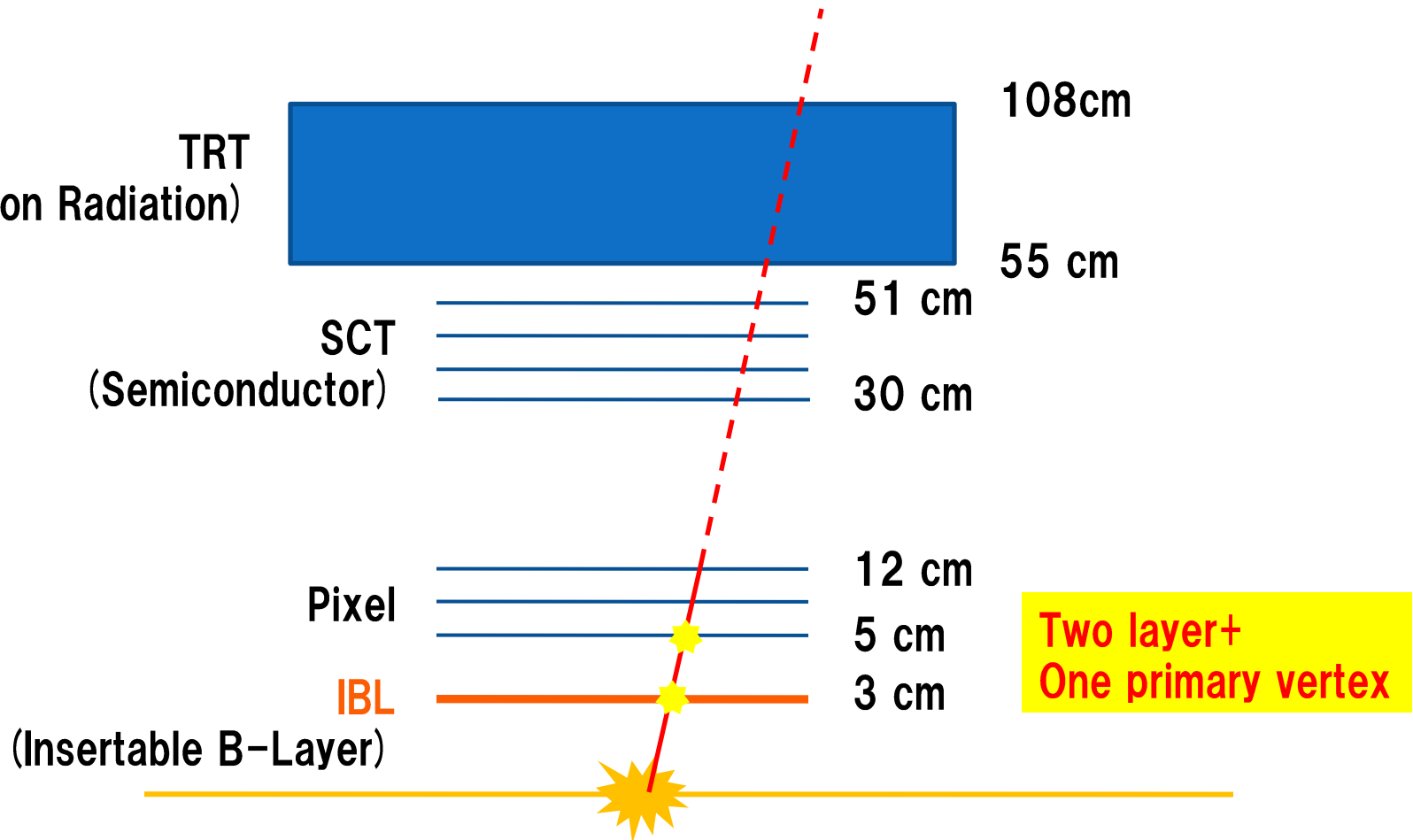
# Current Constraint (wino)



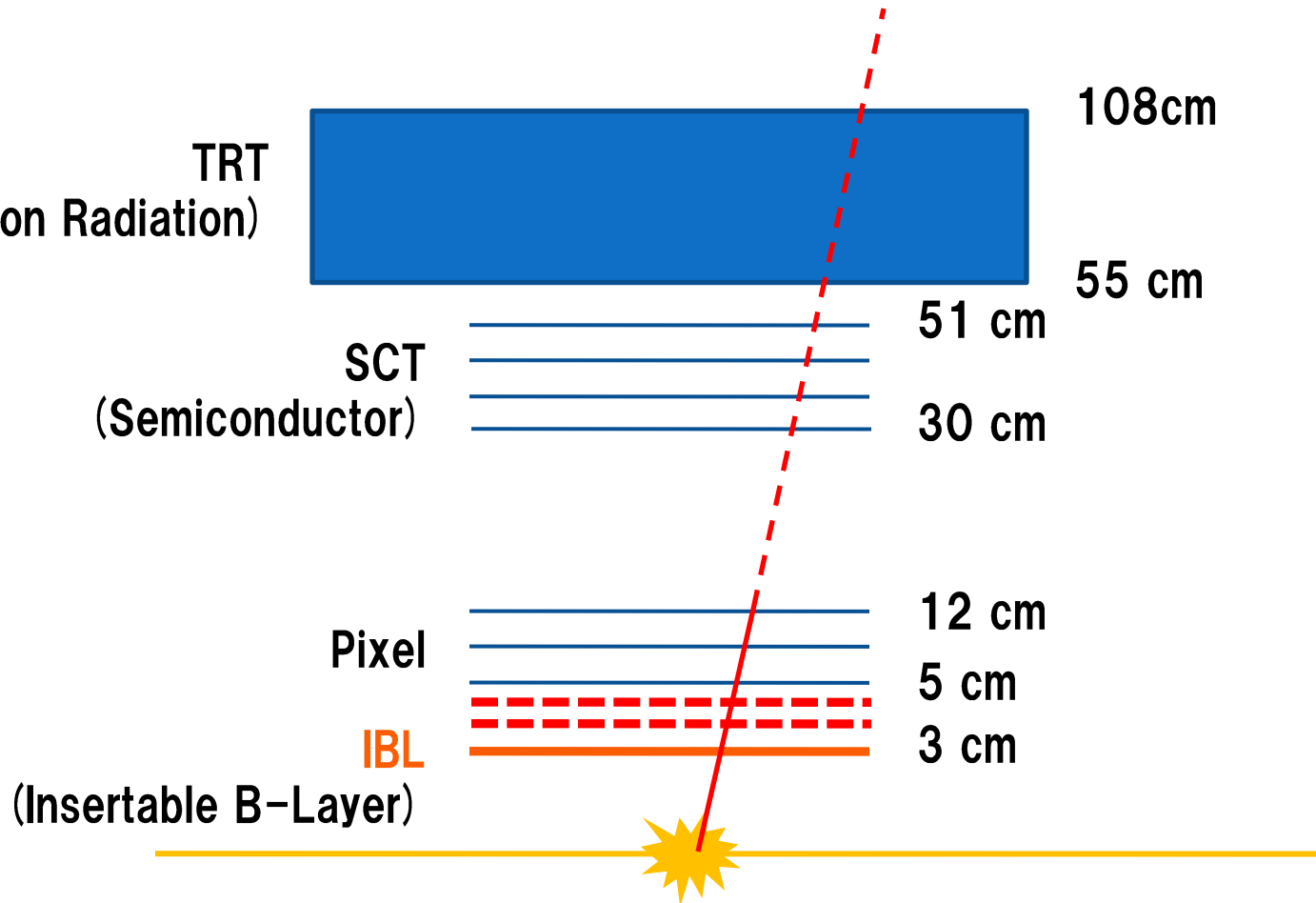
# Tracking shorter



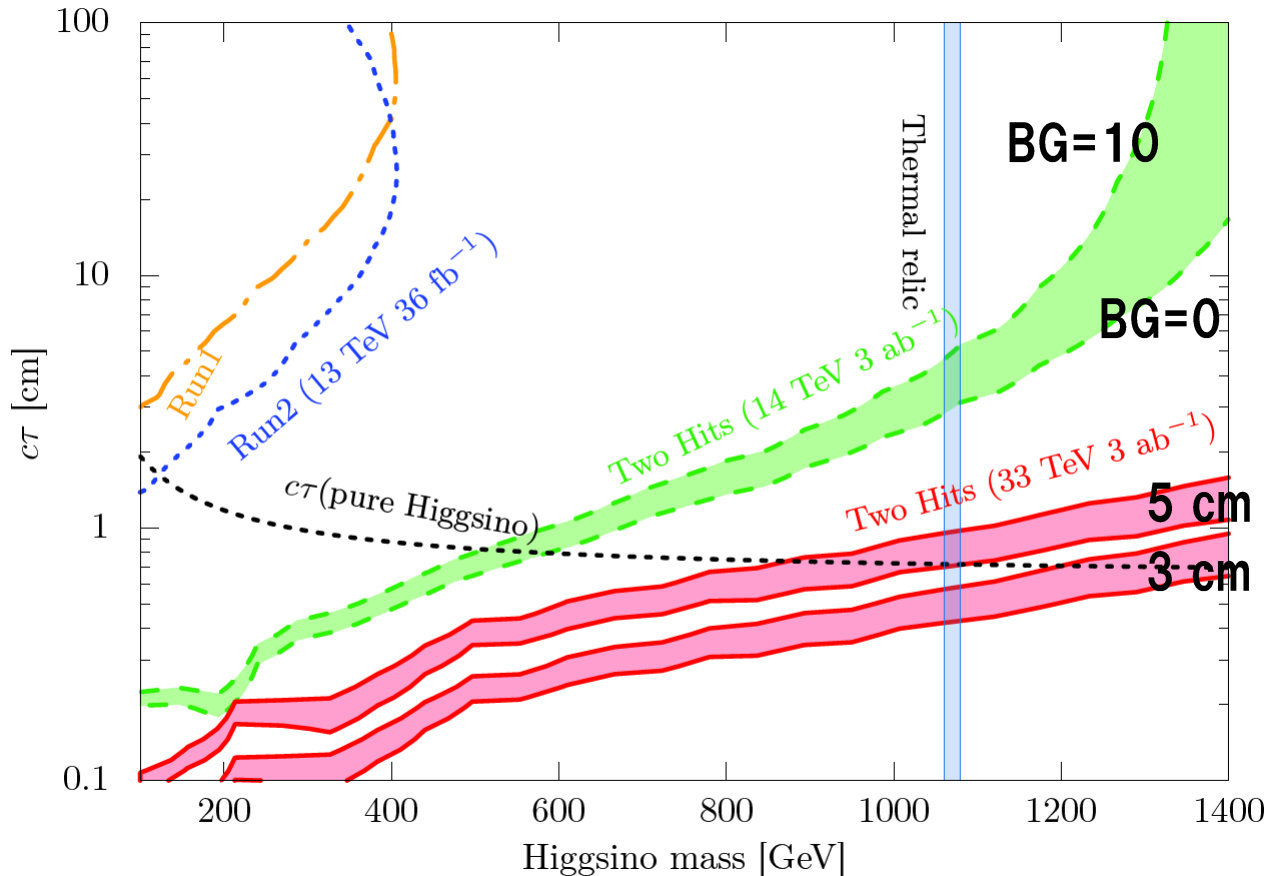
# Tracking shorter



# Tracker for Run???



# Prospects for Higgsino



$MET > 400$  GeV

$BG=10$

$BG=0$

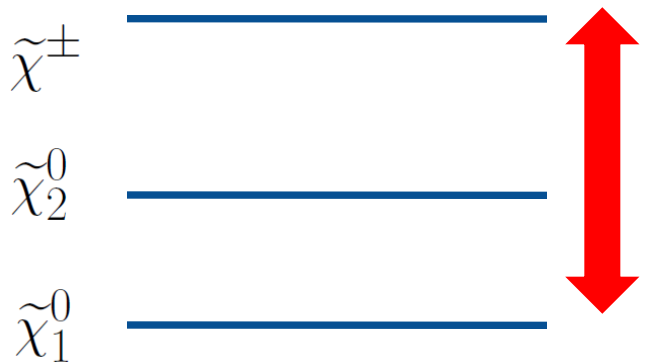
$MET > 600$  GeV

5 cm

3 cm

# Higgsino Spectrum (with light gaugino)

$$\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}, \begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix} \longrightarrow \tilde{\chi}_1^0 \quad \tilde{\chi}_2^0 \quad \tilde{\chi}^\pm$$

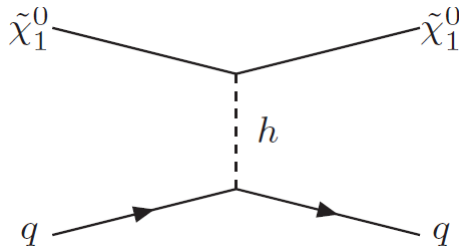


$$\Delta m \sim \frac{m_W^2}{m_{\text{gaugino}}} = O(1) \text{ GeV} \left( \frac{m_{\text{gaugino}}}{1 \text{ TeV}} \right)^{-1}$$

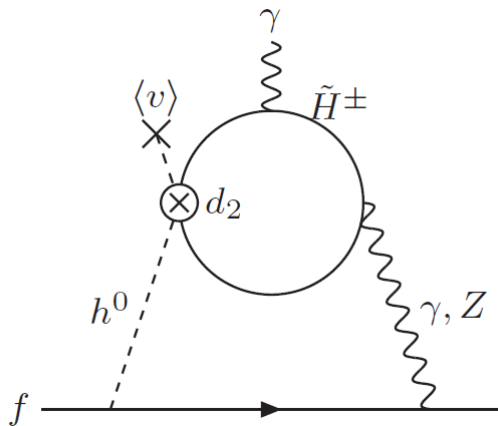
$$c\tau(\tilde{\chi}^\pm \rightarrow \tilde{\chi}_1^0 \pi^\pm) = 1.1 \text{ cm} \left( \frac{\Delta m_+}{300 \text{ MeV}} \right)^{-3} \left[ 1 - \frac{m_{\pi^\pm}^2}{\Delta m_+^2} \right]^{-1/2}$$

# Higgsino with light gaugino

Light gauginos lead too short track. However



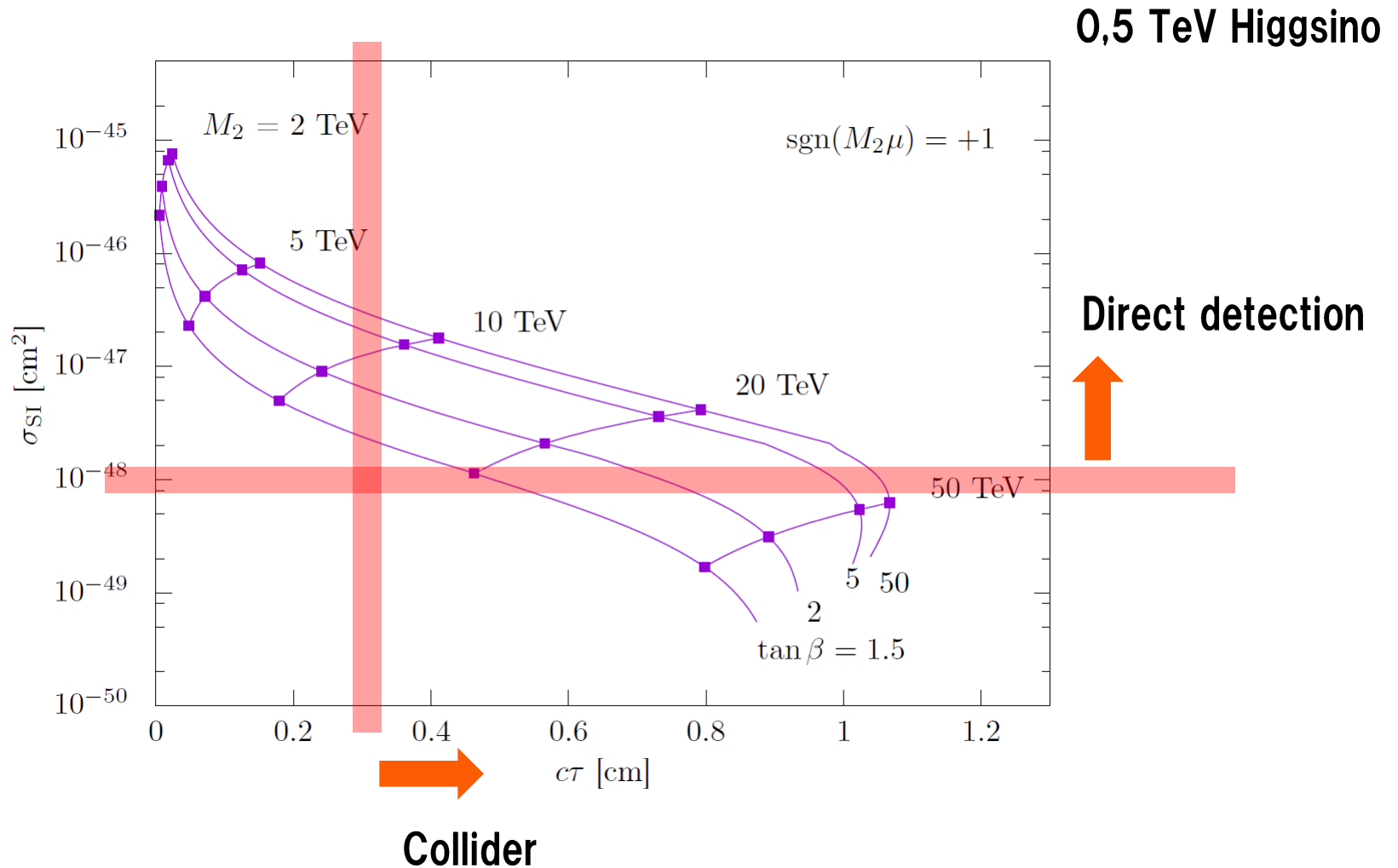
DM direct detection  $\propto m_{\text{gaugino}}^{-2}$



SM fermion EDM  $\propto m_{\text{gaugino}}^{-1}$



# Interplay with DM direct detection

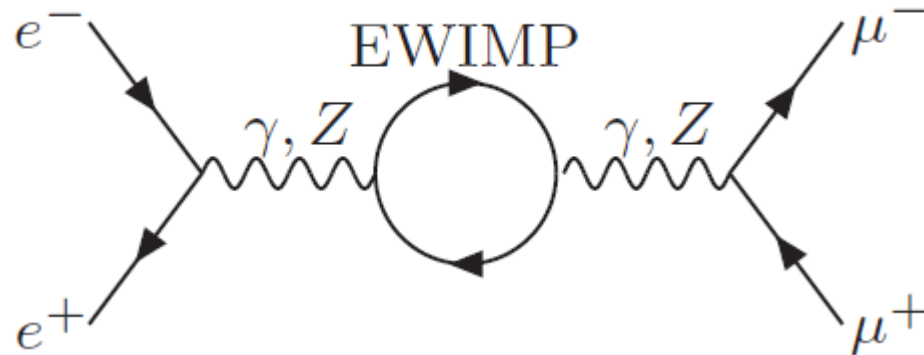




# **Indirect detection**

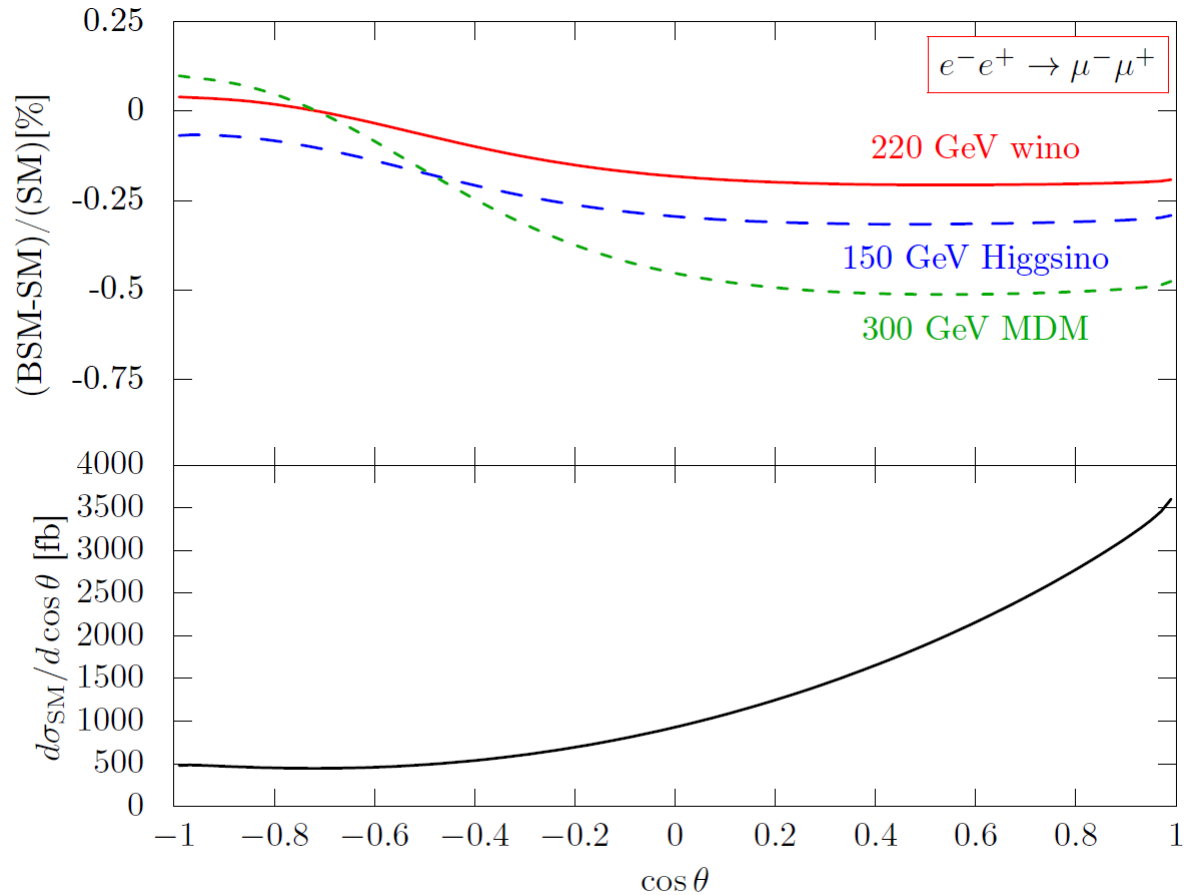
# ILC250 for Heavy Higgsino

Heavy DM cannot be produced at collider, but affects SM processes



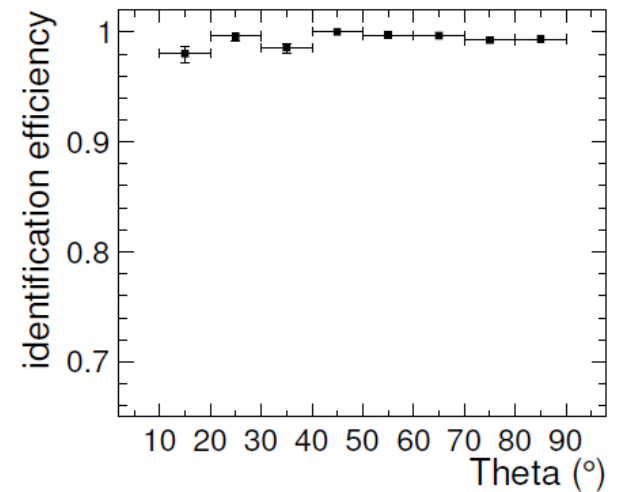
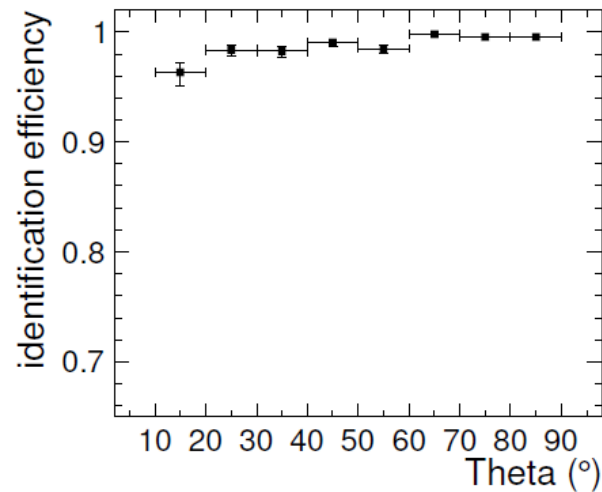
$$\Delta\mathcal{L}_{\text{dim.6}} = -\frac{c_{2W}^{\pm}}{2\Lambda_{2W}^2} (D_{\mu}W_{\mu\nu}^a)^2 + \frac{g c_{3W}^{\pm}}{6\Lambda_{3W}^2} \varepsilon^{abc} W_{\rho}^{a\mu} W_{\mu}^{b\nu} W_{\nu}^{c\rho} - \frac{c_{2B}^{\pm}}{2\Lambda_{2B}^2} (\partial_{\mu}B_{\mu\nu})^2$$

# ILC250 for Heavy Higgsino

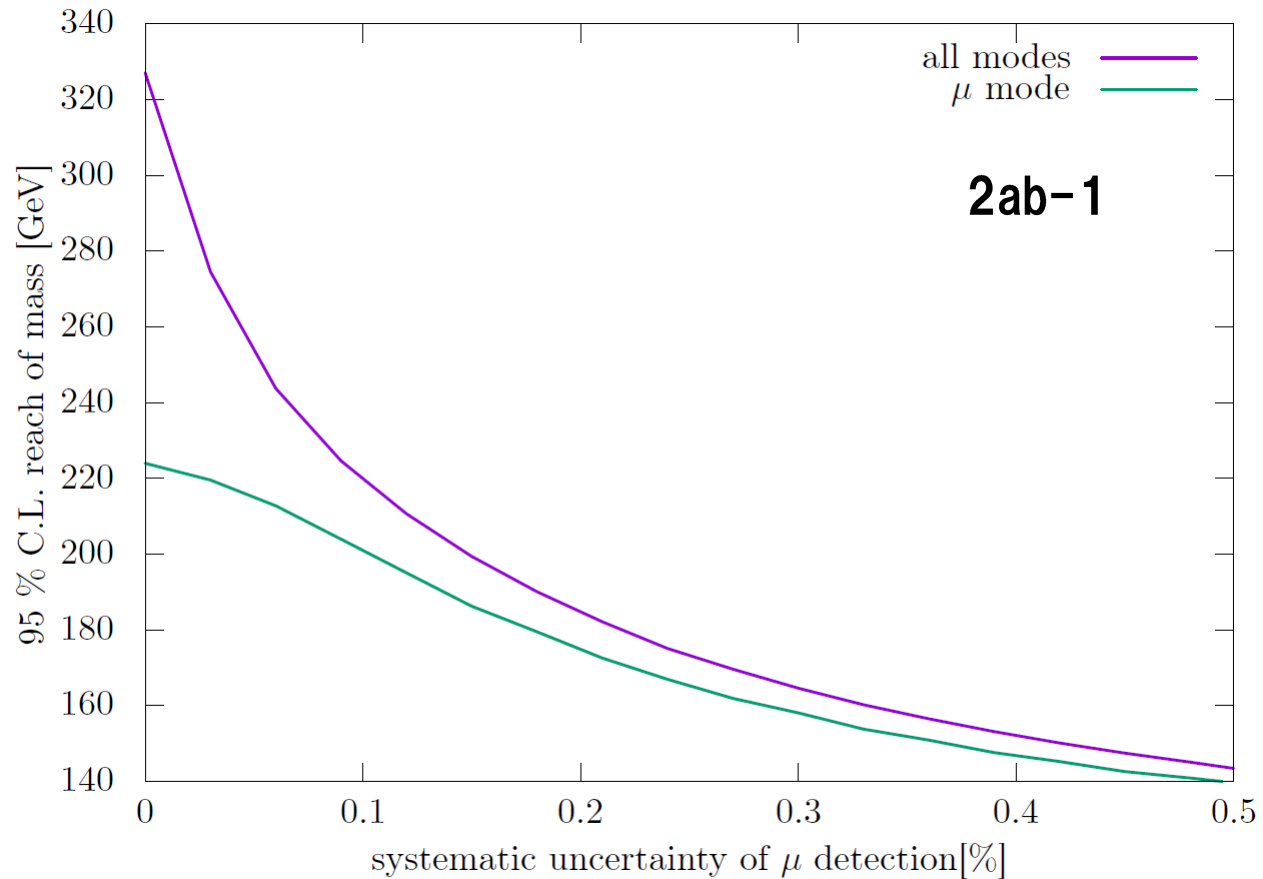


# ILC for Heavy Higgsino

**Figure II-10.8**  
Particle identification efficiency for 10 GeV muons (left) and 100 GeV muons (right) as a function of the angle  $\theta$ .

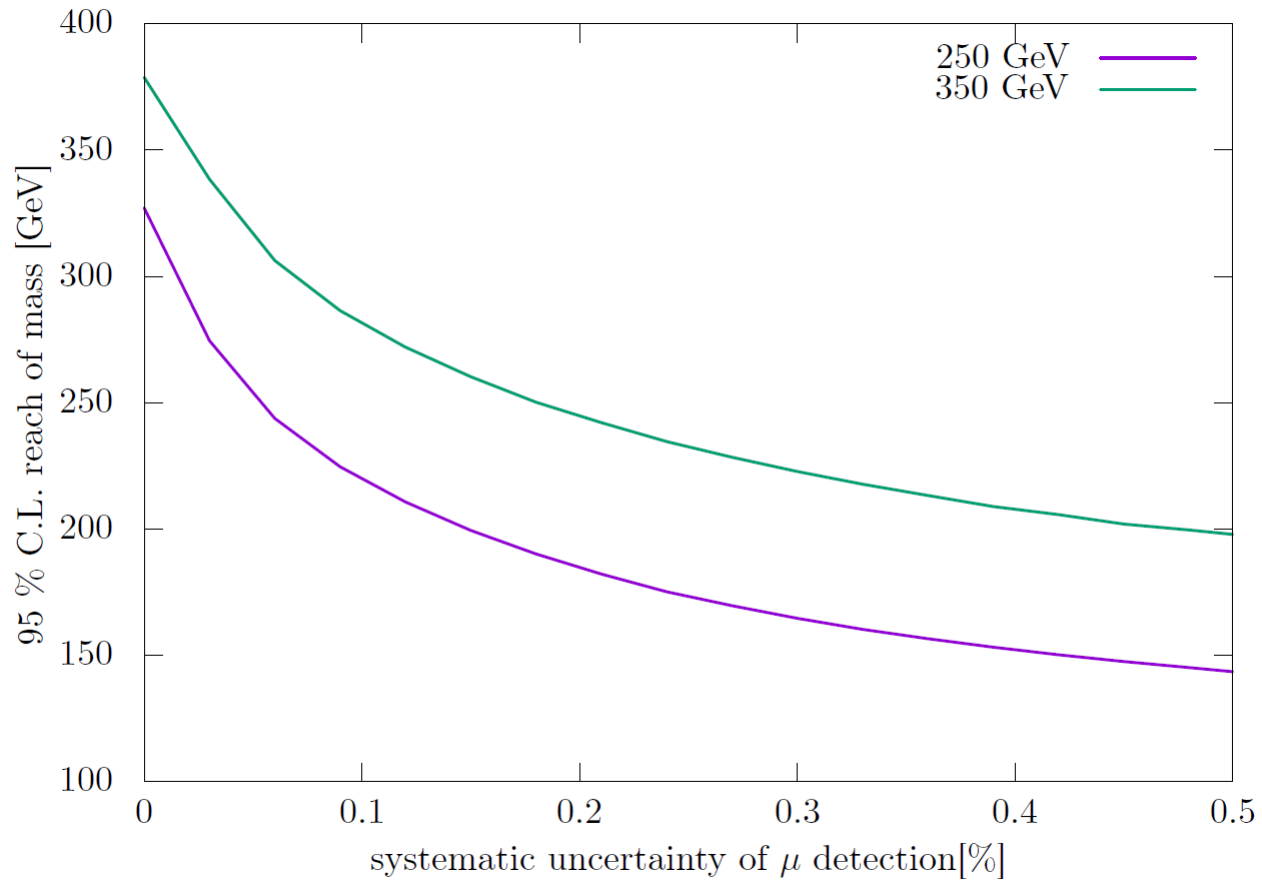


# ILC250 for Heavy Higgsino



mu, e, b, c sys. Ratios: 2 : 1.5 : 5 : 10 assumed

# Beam energy vs sys.

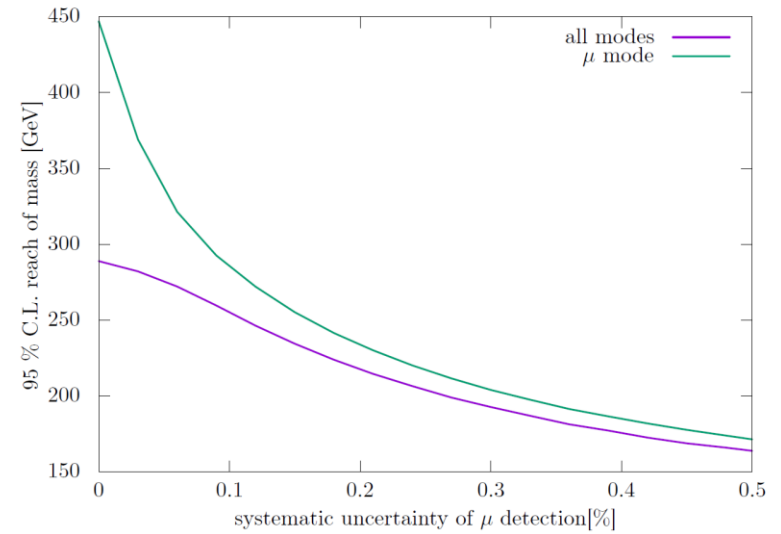
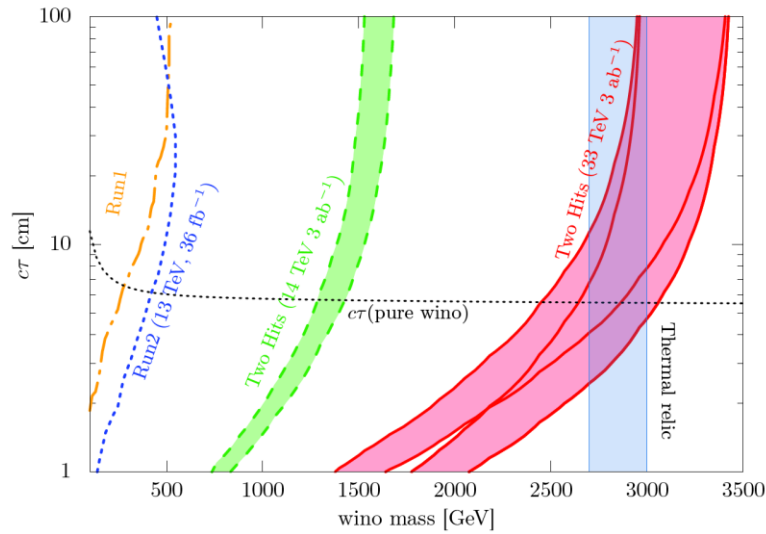


# Summary

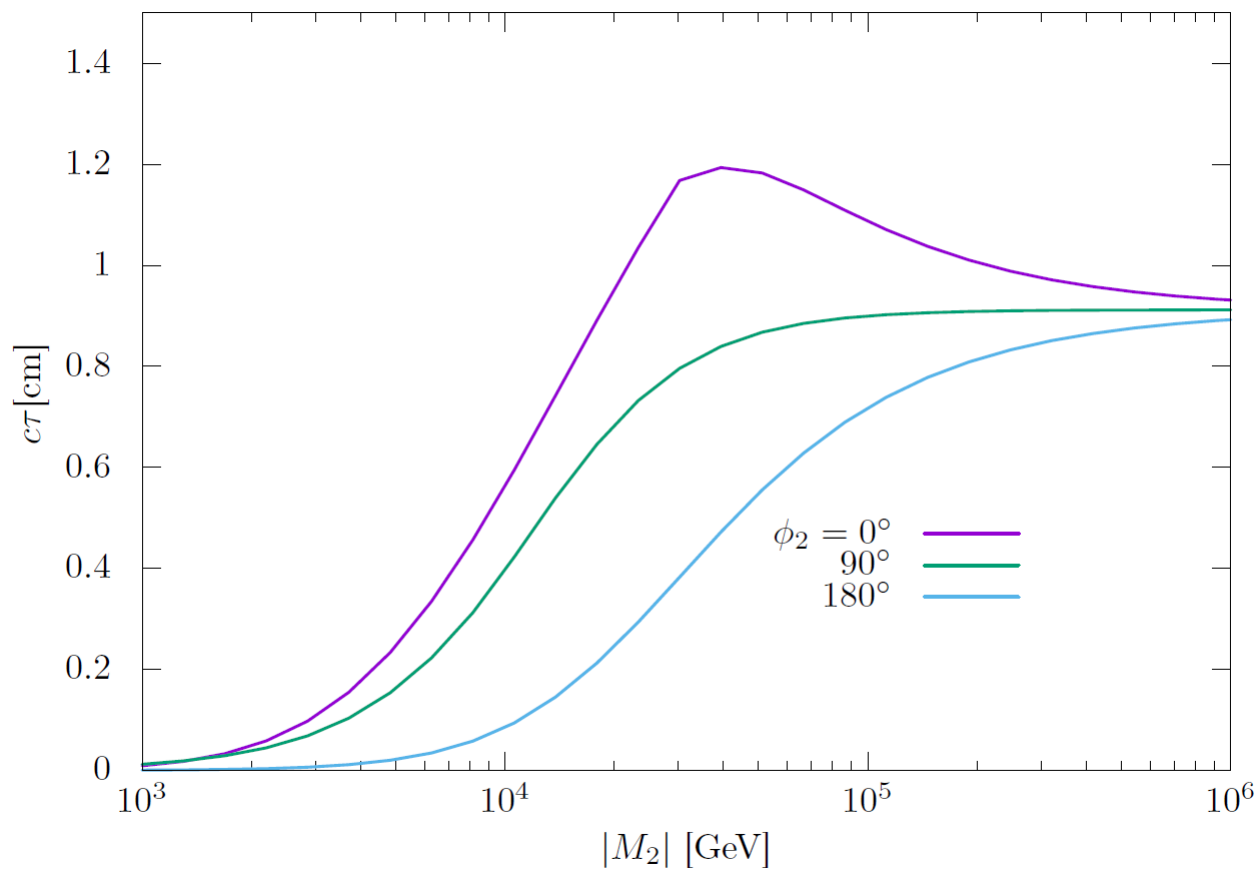
- Improvement of detector is crucially important
- Shorter tracking system can cover 1 TeV Higgsino with SLHC
  - BG control, poor momentum resolution
- Better understanding of detector can uncover heavy DM
  - Theory error of SM process



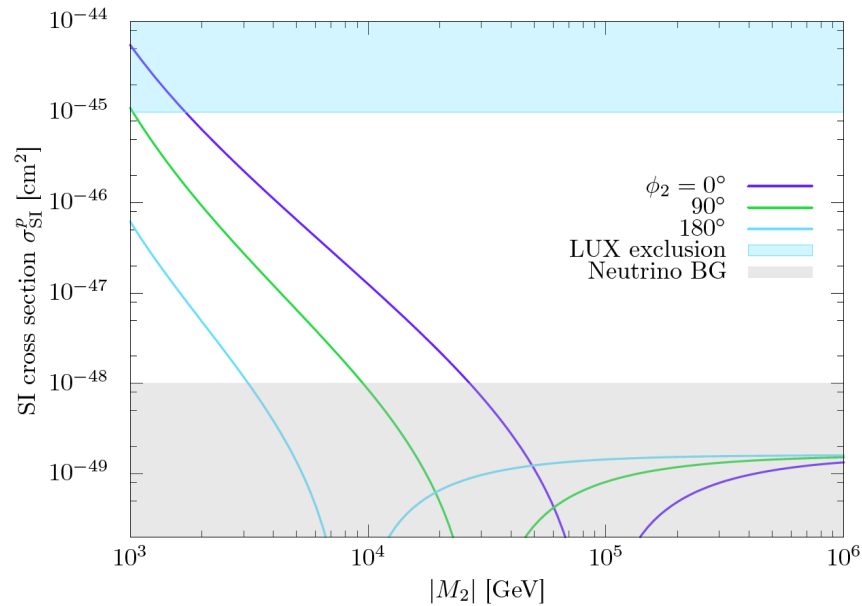
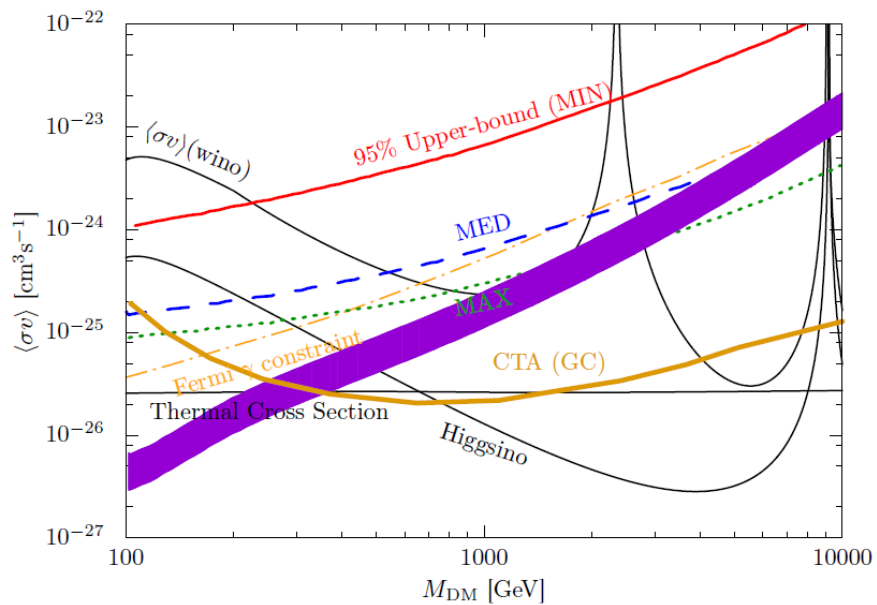
# Wino Case



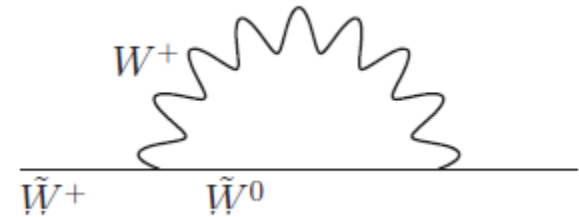
# Decay Length



# Higgsino DM is tough



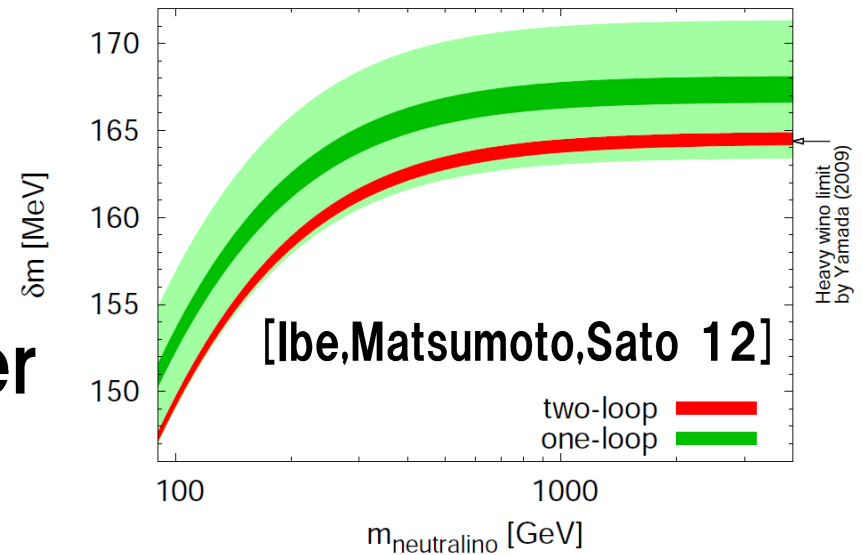
# Wino Spectrum



Radiative correction



$\begin{pmatrix} \tilde{W}^+ \\ \tilde{W}^0 \\ \tilde{W}^- \end{pmatrix}$  Charged slightly heavier



$$c\tau(\tilde{W}^\pm \rightarrow \tilde{W}^0 \pi^\pm) \simeq 7 \text{ cm} \left( \frac{\Delta m}{165 \text{ MeV}} \right)^{-3}$$