Impact of 100 TeV Collider on Supersymmetry

Takeo Moroi (Tokyo)

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Today, I would like to talk about:

1. Case with Wino LSP

   [Asai, Chigusa, Kaji, TM, Saito, Sawada, Tanaka, Terashi & Uno]

2. Effects of Oblique Correction

   [Chigusa, Ema & TM]

1. Case with Wino LSP

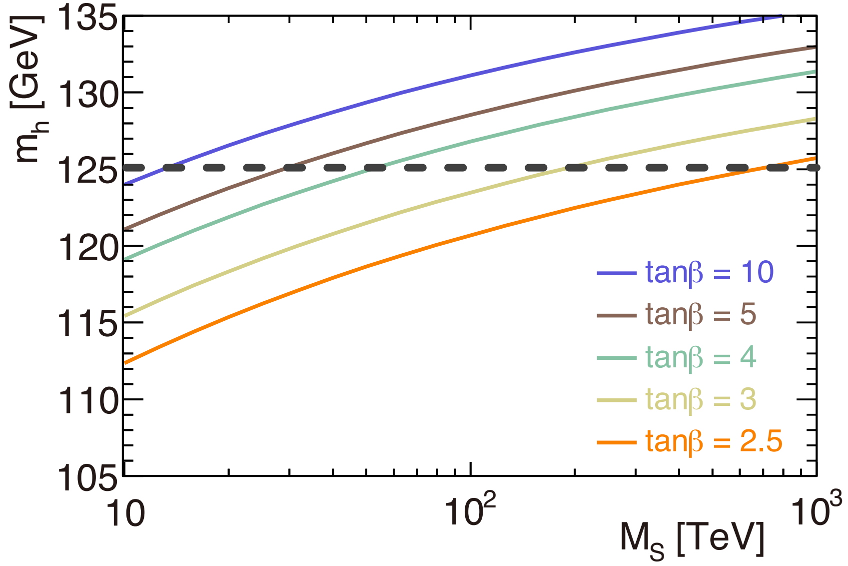
Mass spectrum of our interest

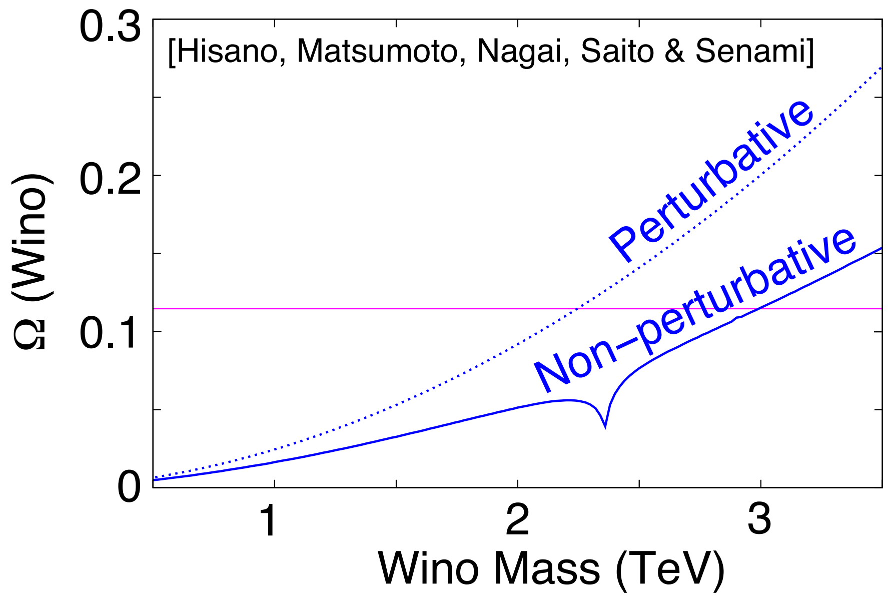
- Sfermion and Higgsino masses are of $O(100)$ TeV

  $\Rightarrow$ Heavy stops are good for $m_h \simeq 125$ GeV

- Gaugino masses are loop suppressed, and are of $O(1)$ TeV

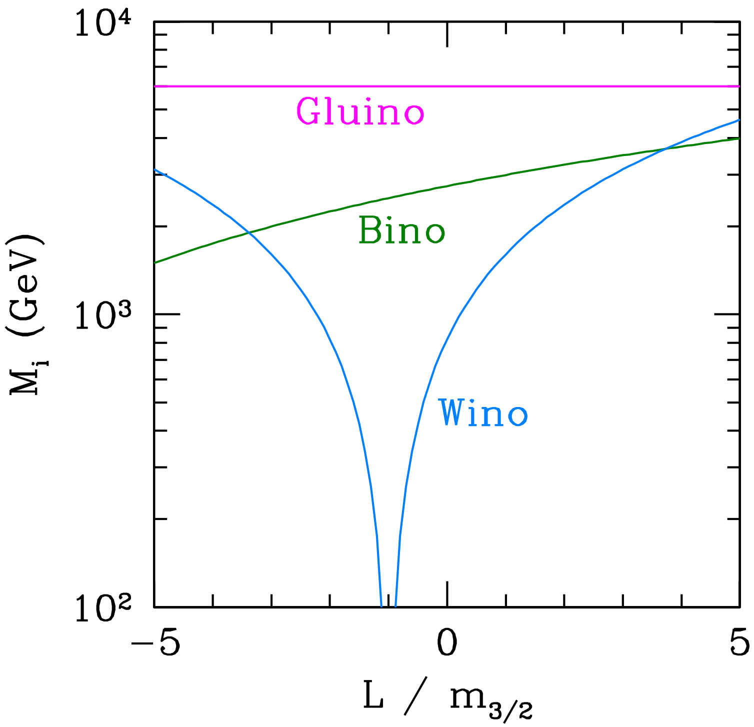
  $\Rightarrow$ Thermal relic Wino can be dark matter, if $m_{\tilde{W}} \simeq 2.9$ TeV





Anomaly mediation + pure gravity mediation

[Giudice, Luty, Murayama & Rattazzi; Randall & Sundrum; Ibe, TM & Yanagida; Ibe & Yanagida; Arkani-Hamed et al.]



$$M_1 \simeq \frac{g_1^2}{16\pi^2}\left(11 m_{3/2} + L\right)$$

$$M_2 \simeq \frac{g_2^2}{16\pi^2}\left(m_{3/2} + L\right)$$

$$M_3 \simeq \frac{g_3^2}{16\pi^2}\left(-3 m_{3/2}\right)$$

$$L \equiv \mu \sin 2\beta \frac{m_A^2}{\mu^2 - m_A^2} \ln \frac{\mu^2}{m_A^2} \sim O(m_{3/2})$$

- Gaugino masses are determined by $m_{3/2}$ and L
- Wino (gaugino for $SU(2)_L$) is likely to be the LSP

Sample points for MC studies ($m_{\tilde{W}} < m_{\tilde{B}} < m_{\tilde{g}}$)

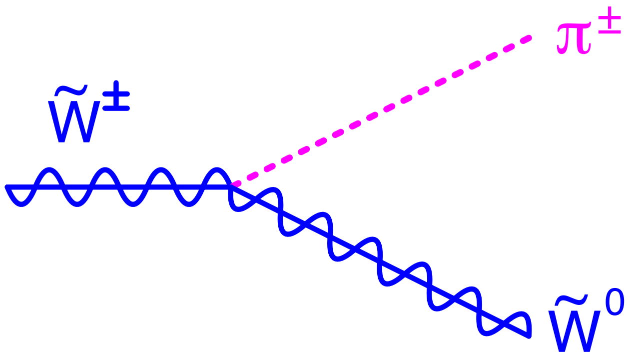
	Point 1	Point 2
$m_{3/2}$ [TeV]	250	302
L [TeV]	800	756
$m_{\tilde{B}}$ [TeV]	3.7	4.1
$m_{\tilde{W}}$ [TeV]	2.9	2.9
$m_{\tilde{g}}$ [TeV]	6.0	7.0
$\sigma(pp \to \tilde{g}\tilde{g})$ [fb]	7.9	2.7

- $Br(\tilde{g} \to \tilde{W}\bar{q}q) = Br(\tilde{g} \to \tilde{B}\bar{q}q) = 0.5$

I discuss gaugino mass determinations at 100 TeV FCC

$\Rightarrow$ How and how well can we determine gaugino masses?

Charged Wino decay: $\tilde{W}^{\pm} \to \tilde{W}^{0}\pi^{\pm}$



- $\Delta m_{\tilde{W}} \simeq 165$ MeV
- $c\tau_{\tilde{W}^{\pm}\to\tilde{W}^{0}\pi^{\pm}} \simeq 5.8$ cm

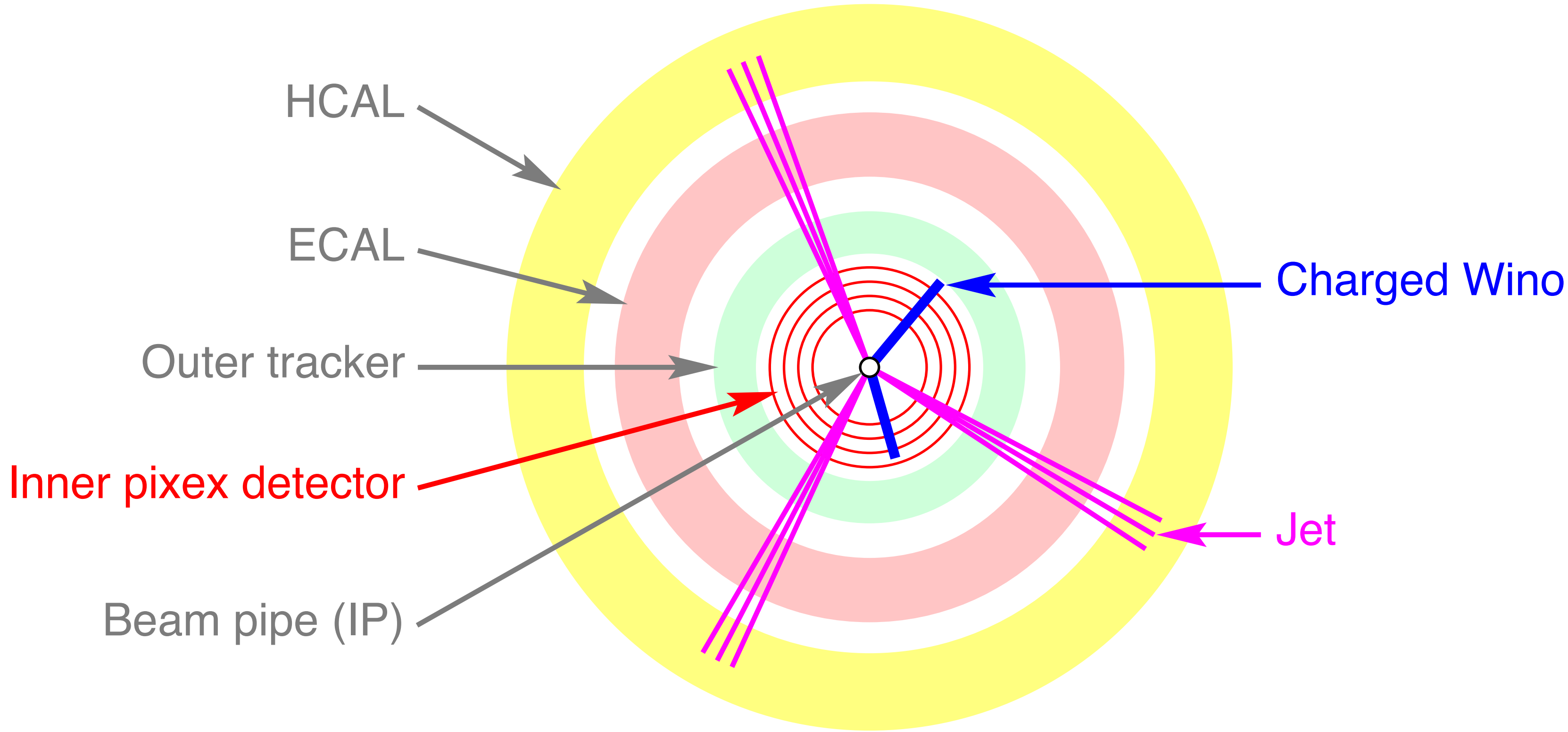
Charged Wino may be identified as short high-p_T track

- Charged Wino track can be reconstructed by inner pixel detector
- No SM background, requiring two charged Winos tracks

Timing information is available: $\delta t \sim O(10$ ps$)$

$\Rightarrow \delta\beta \sim$ (a few $- 10$) % (in our MC analysis, $\delta\beta = 6$ %)

SUSY event at the FCC (due to $pp \to \tilde{g}\tilde{g}$):



- We require two charged Winos with $L_T > 10$ cm
- We also require $p_T^{(\text{miss})} > 400$ GeV

$\Rightarrow$ We assume no SM background

Measurement 1: Wino mass

Wino mass can be measured by combining velocity and momentum information

Wino momenta are determined from the conservation of $p_T^{(\text{tot})}$

$$c_1\vec{n}_{\tilde{W}_1,T} + c_2\vec{n}_{\tilde{W}_2,T} = -\sum_{j:\text{jets}} \vec{p}_{j,T}$$

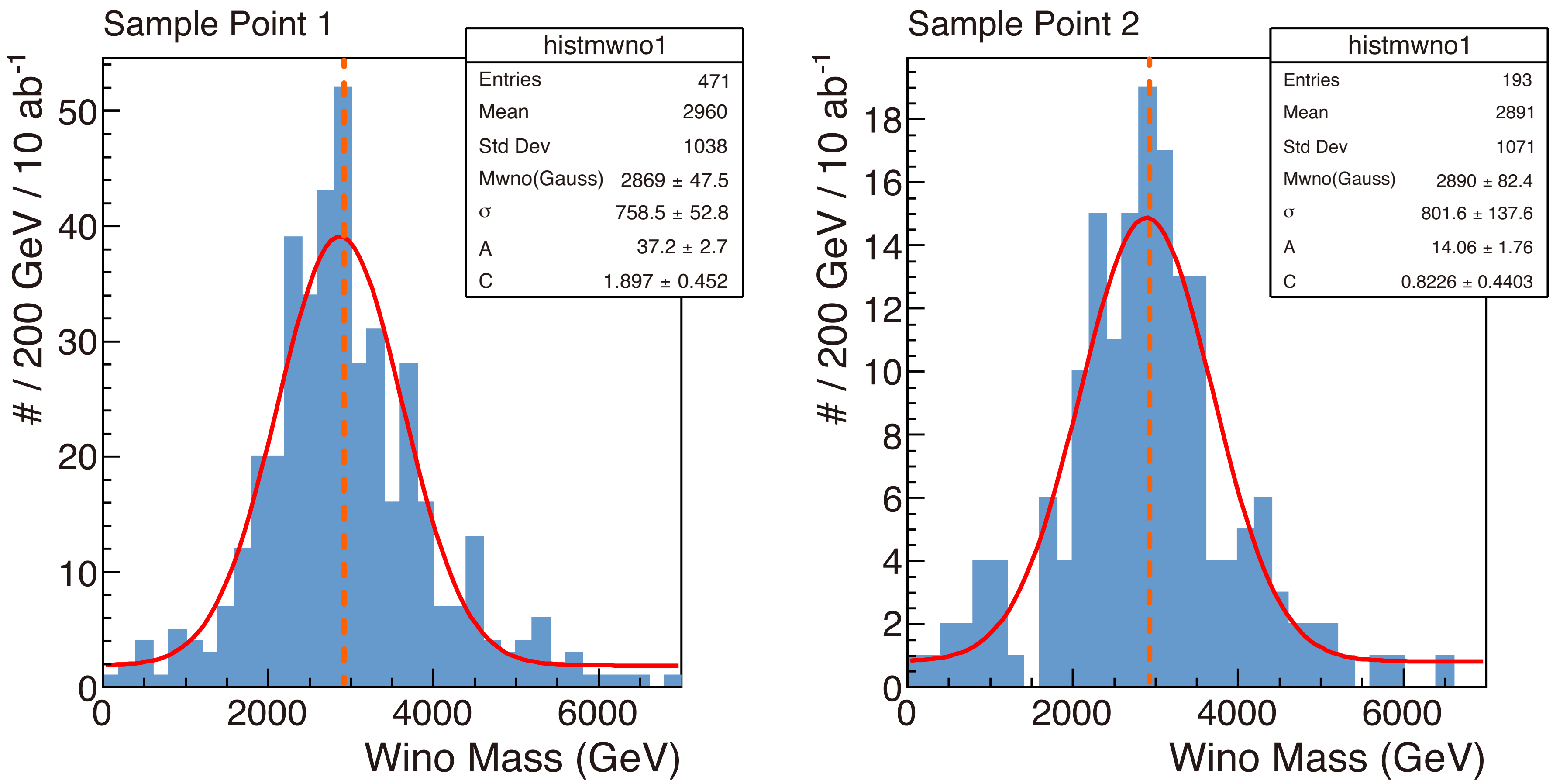
$$\vec{p}_{\tilde{W}_1} = c_1\vec{n}_{\tilde{W}_1}$$

$$\vec{p}_{\tilde{W}_2} = c_2\vec{n}_{\tilde{W}_2}$$

Reconstructed Wino mass

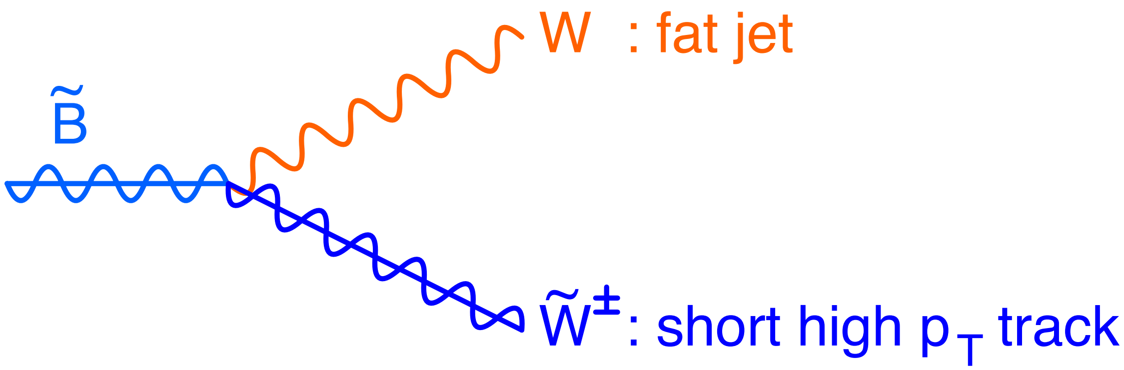
$$m_{\tilde{W}}^{(\text{rec})} = \frac{1}{\beta_{\tilde{W}^\pm}\gamma_{\tilde{W}^\pm}} |\vec{p}_{\tilde{W}^\pm}| \equiv \frac{\sqrt{1-\beta_{\tilde{W}^\pm}^2}}{\beta_{\tilde{W}^\pm}} |\vec{p}_{\tilde{W}^\pm}|$$

Reconstructed Wino mass



- True value: 2900 GeV
- We use Winos with $\beta_{\tilde{W}^{\pm}} < 0.7$

Measurement 2: Bino mass



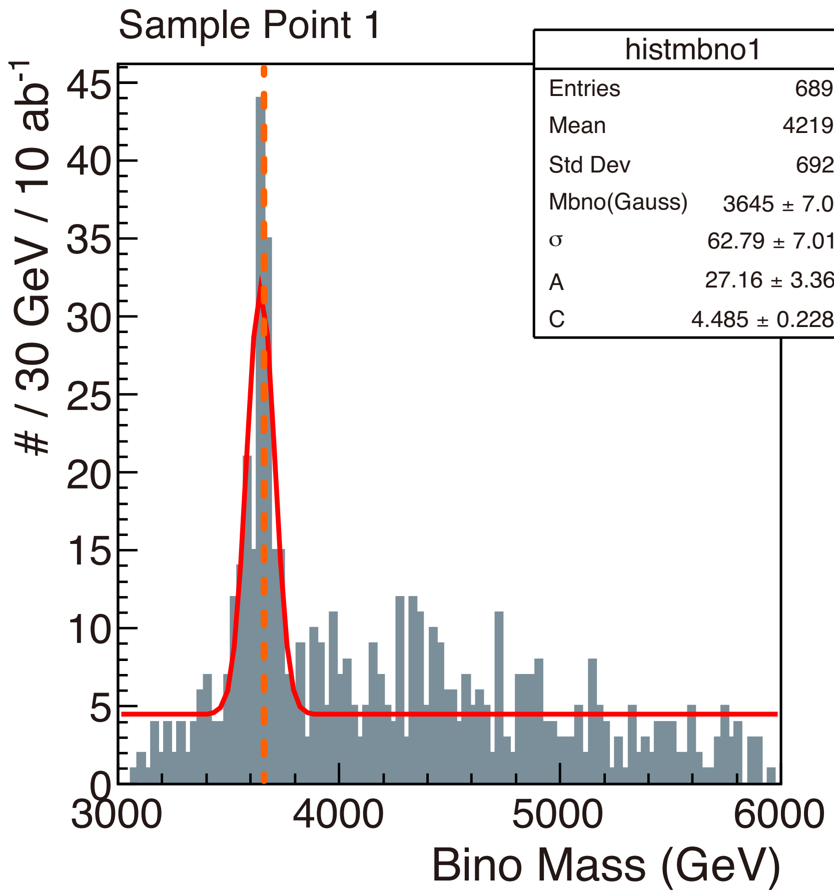
- Wino momentum is known (if L_T is long enough)
- W-jet may be identified as a fat jet

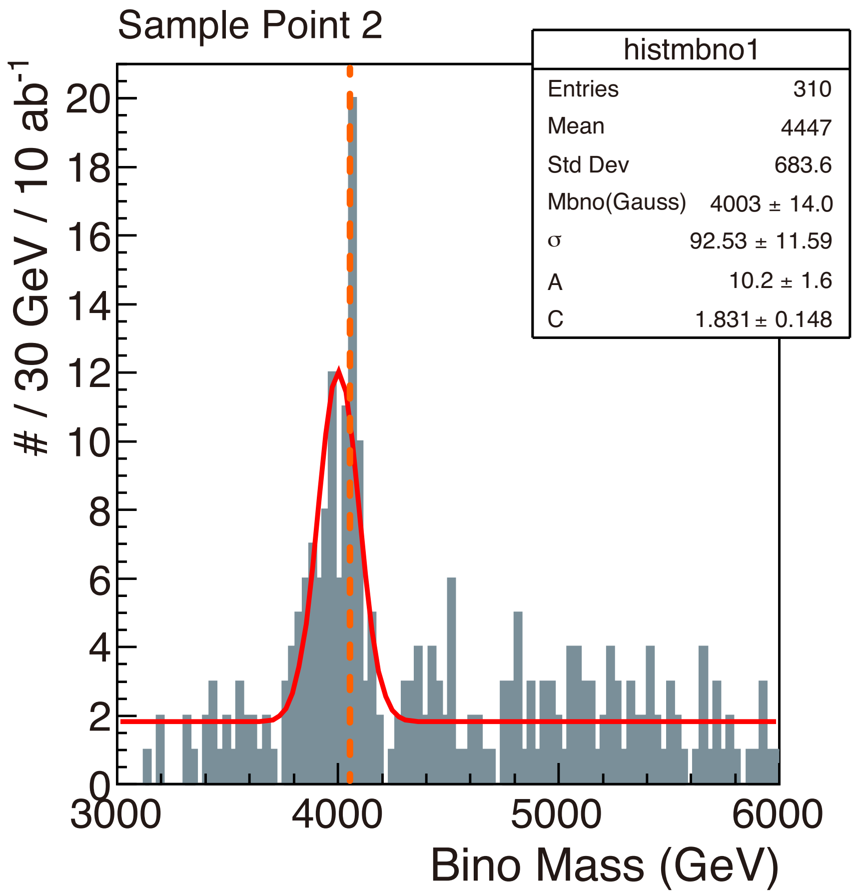
  $\Rightarrow$ We use jets with $m_j \sim m_W$

Reconstructed Bino mass (assuming $m_{\tilde{W}}$ is known)

$$m_{\tilde{B}}^2 = (m_{\tilde{W}} u_{\tilde{W}^\pm} + p_W)^2 \text{ with } u_{\tilde{W}^\pm} = (\gamma_{\tilde{W}^\pm}, \beta_{\tilde{W}^\pm}\gamma_{\tilde{W}^\pm}\vec{n}_{\tilde{W}^\pm})$$

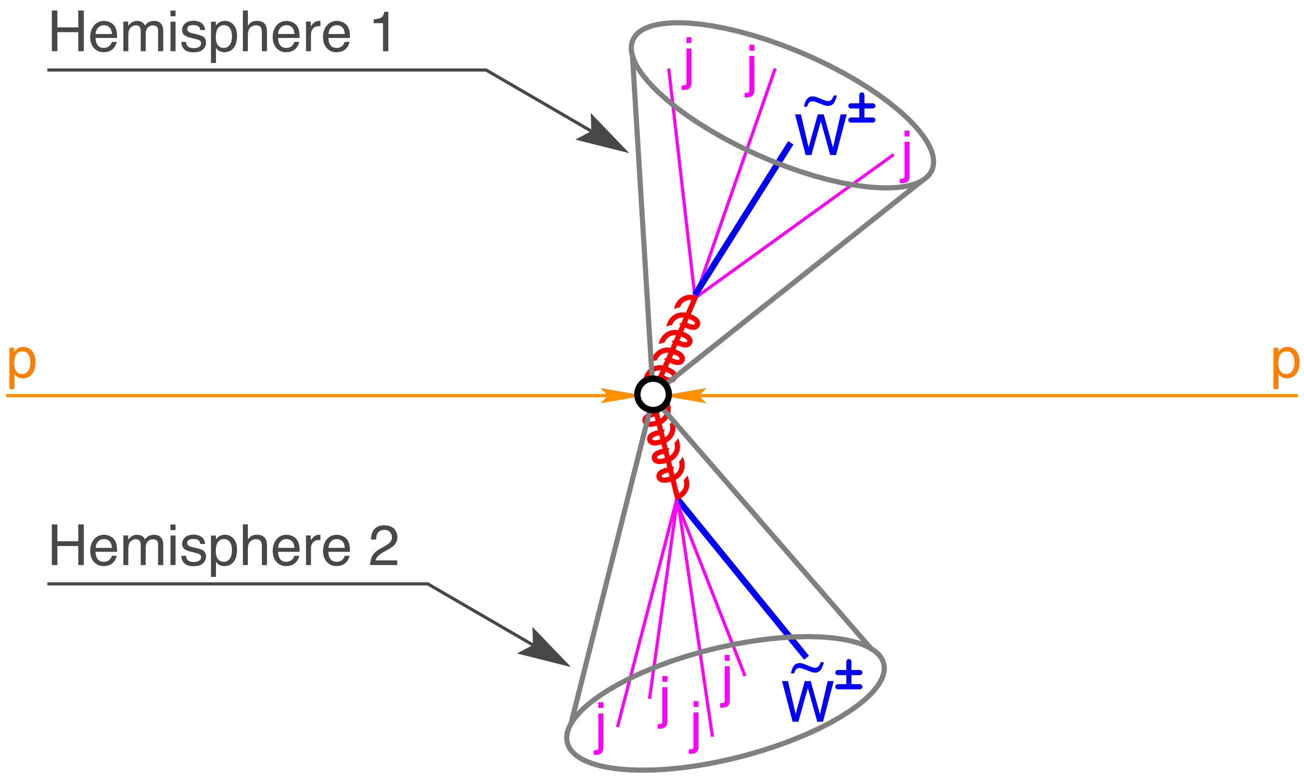
Reconstructed Bino mass (using true Wino mass)





- True value: 3660 GeV or 4060 GeV
- We use jets with 70 GeV $< m_j < 90$ GeV

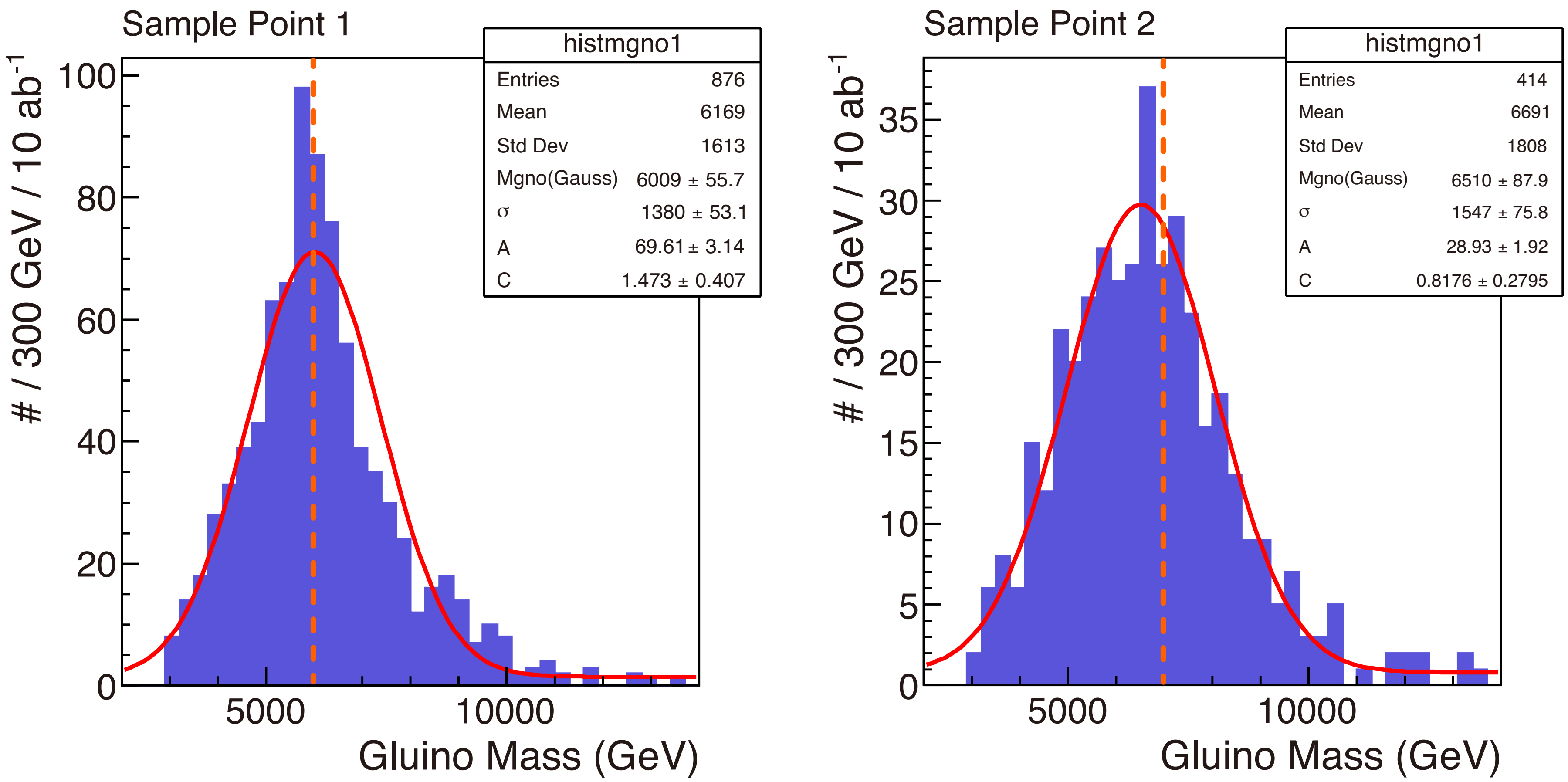
Measurement 3: Gluino mass (with hemisphere analysis)



Reconstructed gluino mass

$$m_{\tilde{g}}^{(\mathrm{rec})} = \sqrt{P^2_{\mathrm{Hemisphere}}} \quad \text{with} \quad P_{\mathrm{Hemisphere}} \equiv P_{\tilde{W}^\pm} + \sum_{j \in H} p_j$$

Reconstructed gluino mass (with true Wino mass):



- True value: 6000 GeV or 7000 GeV

Gaugino masses may be determined

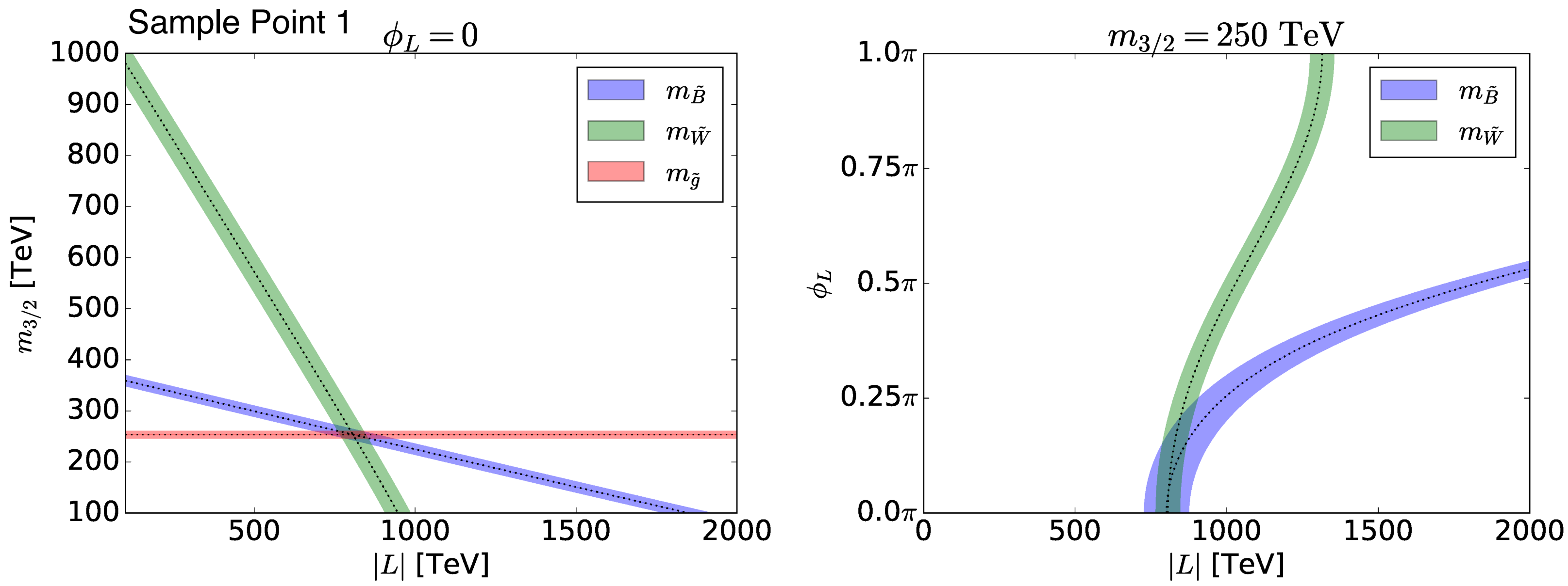
Sample Point 1 (with $\mathcal{L} = 10$ ab^{-1}):

	$\delta m_{\tilde{B}}$	$\delta m_{\tilde{W}}$	$\delta m_{\tilde{g}}$
$\delta m_{\tilde{X}}^{(\text{peak})}$	8 GeV	42 GeV	49 GeV
$\langle \lvert m_{\tilde{X}}^{(\text{peak})} - m_{\tilde{X}}^{(\text{true})} \rvert \rangle$	30 GeV	100 GeV	100 GeV
Due to $\delta m_{\tilde{W}}$	108 GeV	$-$	108 GeV
Total	~ 112 GeV	~ 108 GeV	~ 155 GeV

$\Rightarrow$ Test of PGM model

$$\left| \frac{10 g_1^2}{3 g_3^2} m_{\tilde{g}} - \frac{g_1^2}{g_2^2} m_{\tilde{W}} \right| \lesssim m_{\tilde{B}} \lesssim \frac{10 g_1^2}{3 g_3^2} m_{\tilde{g}} + \frac{g_1^2}{g_2^2} m_{\tilde{W}}$$

Information about the mechanism of SUSY breaking



⇒ Determination of gravitino mass $m_{3/2}$, $|L|$, $\cdots$

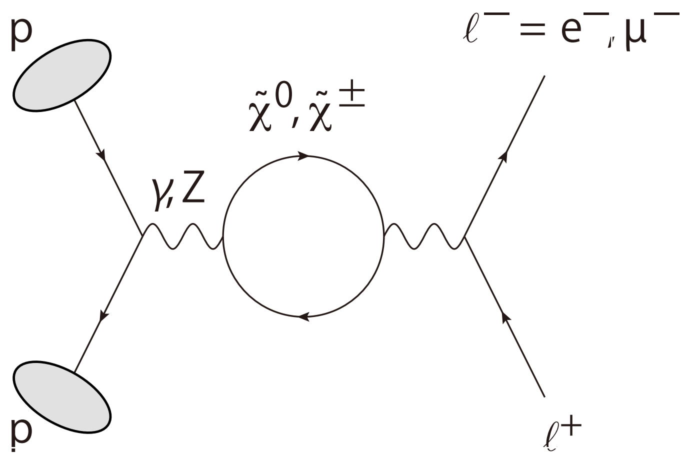
⇒ Understandings of SUSY breaking, cosmology, $\cdots$

2. Effect of Oblique Correction

Particles with EW quantum numbers may be hard to discover

Higgsino

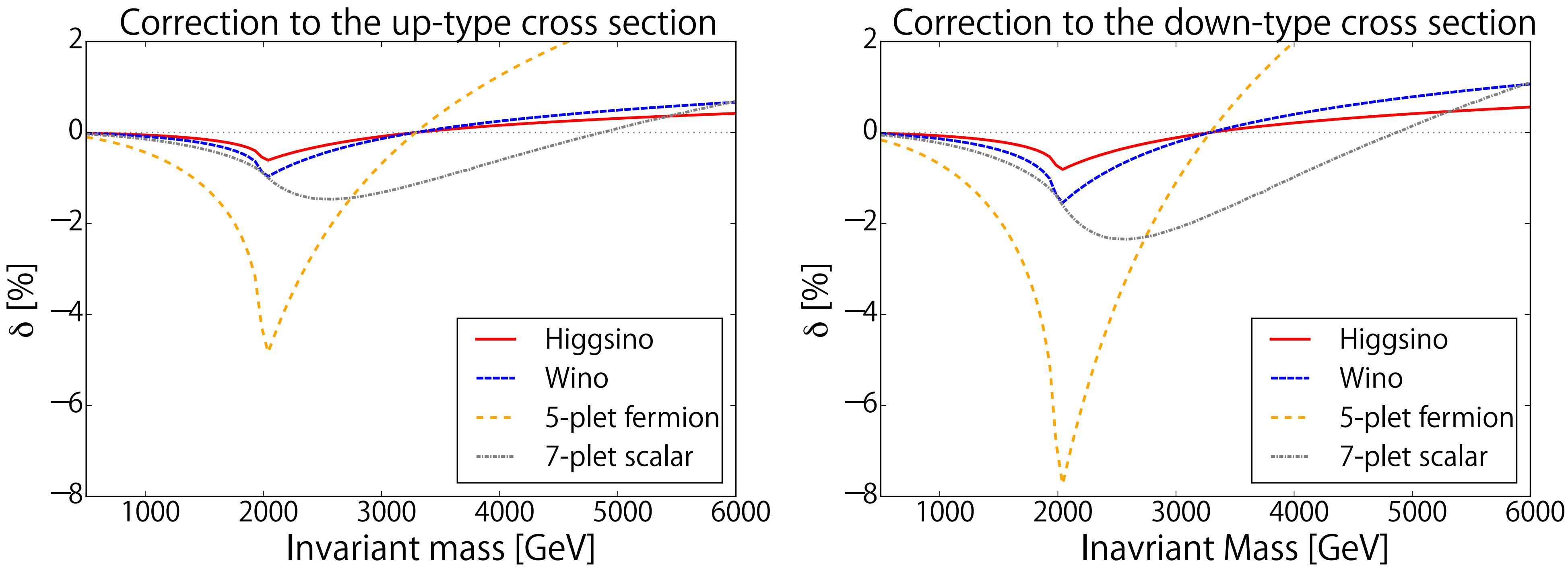
We may study oblique correction to $pp \to \ell^+\ell^-$



$\Leftrightarrow$ We can also use $pp \to \ell^\pm\nu$

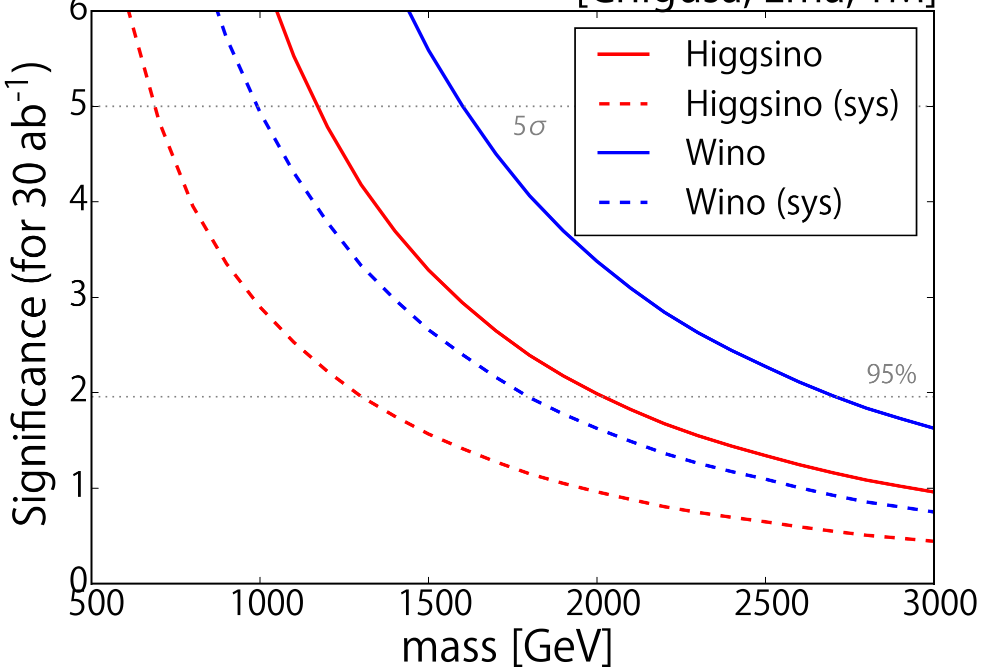
[Luzio, Grober & Panico; Matsumoto, Shirai & Takeuchi]

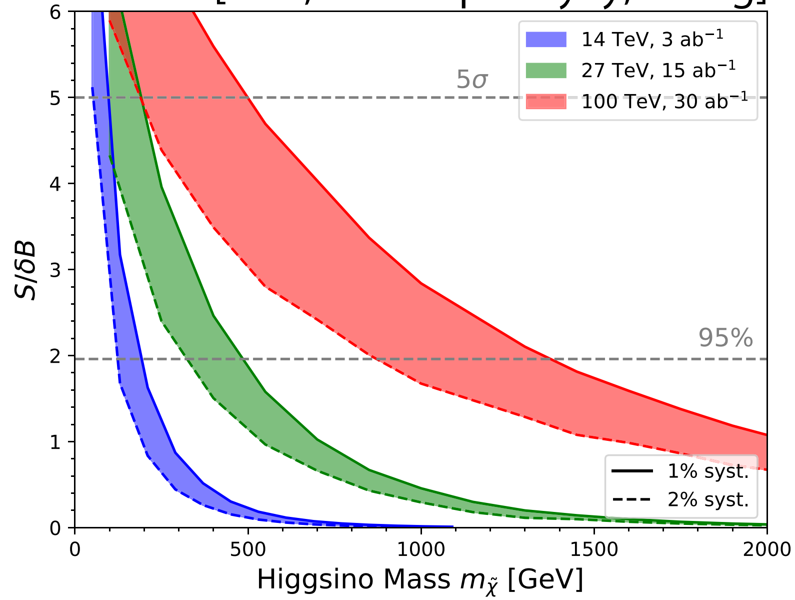
Invariant mass distribution of $\ell^+\ell^-$



- mass $= 2$ TeV
- $\delta_\sigma(m_{\ell\ell}) \equiv \frac{d\sigma_{\mathsf{EWIMP}}/dm_{\ell\ell}}{d\sigma_{\mathsf{SM}}/dm_{\ell\ell}} - 1$

Sensitivity: oblique (left) vs. mono-jet search (right)





⇒ Comparable reach for Higgsinos

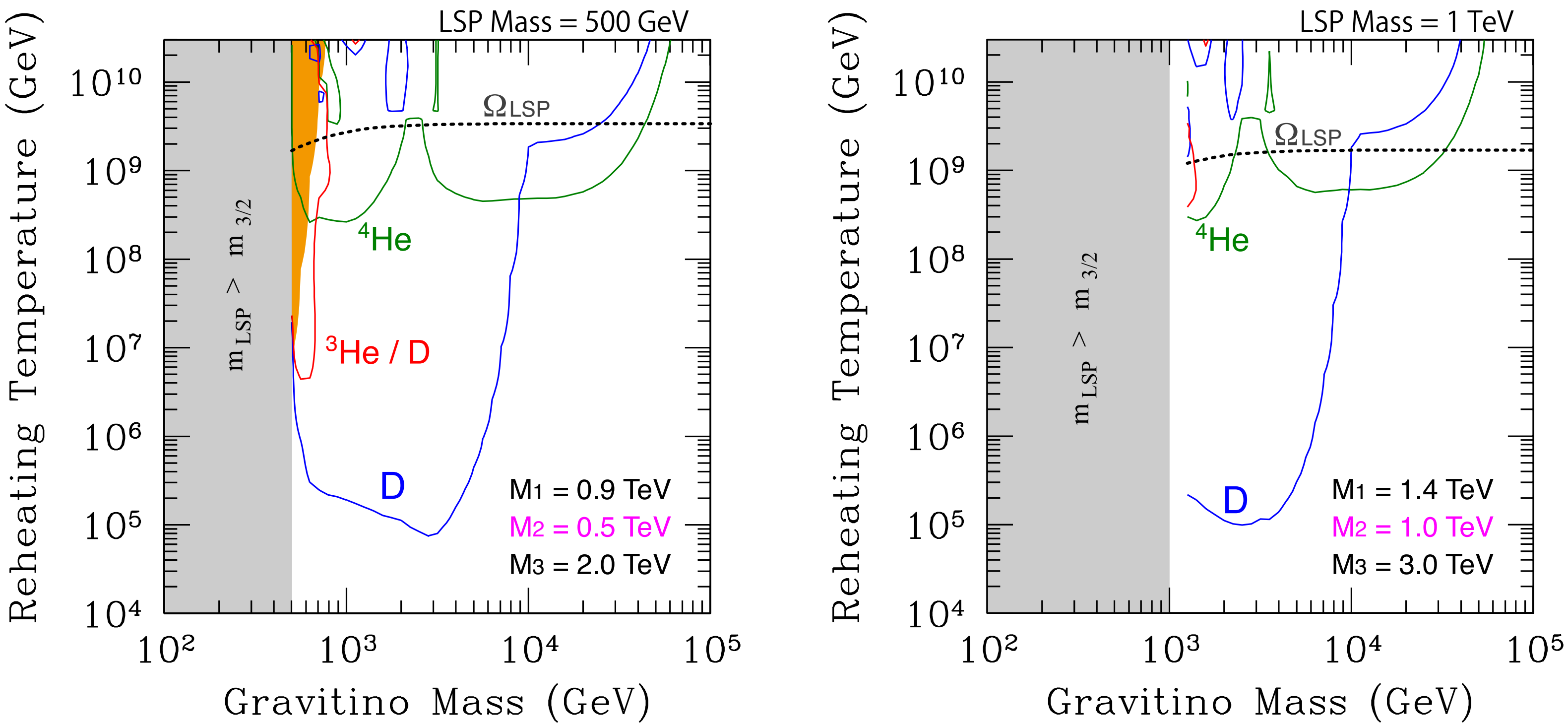
Summary

FCC can have significant impact on BSM studies

- Discovery
- Measurements

Back Ups

Cosmological difficulties caused by gravitino may be avoided



[Kawasaki, Kohri, TM, Takaesu]

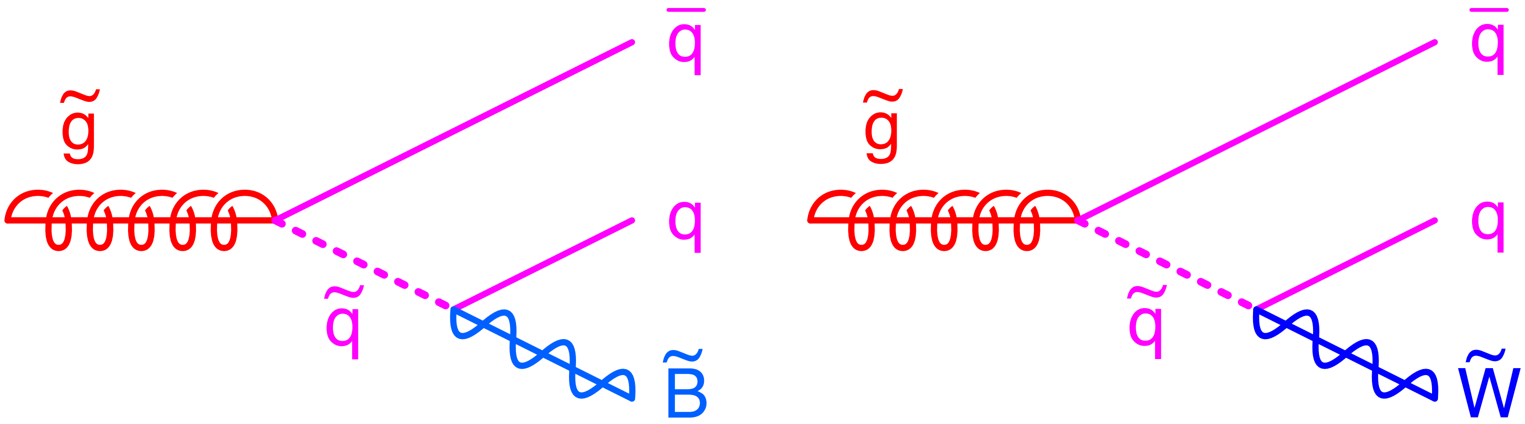
$\Rightarrow$ $m_{3/2} \gtrsim 10$ TeV & $T_R \gtrsim 10^9$ GeV seems interesting

$\Rightarrow$ Simple thermal leptogenesis may work

[Buchmuller, Di Bari & Plumacher; Giudice, Notari, Raidal, Riotto & Strumia]

Gluino decay

$$\tilde{g} \to \bar{q}q\tilde{B},\ \bar{q}q\tilde{W}$$

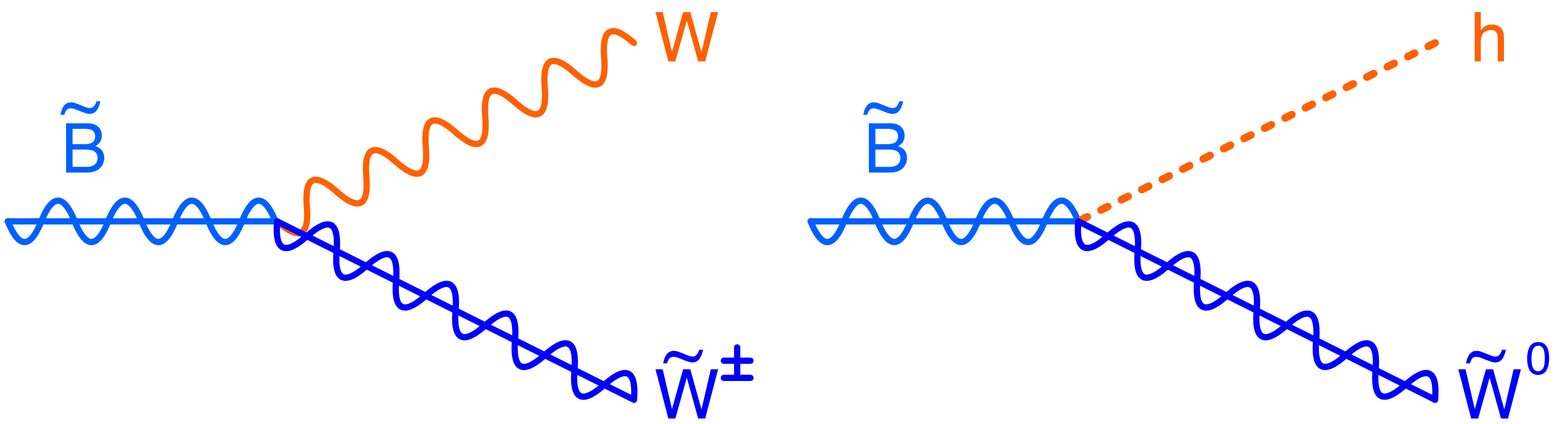


Assumptions:

- $Br(\tilde{g} \to q\bar{q}\tilde{W}) = Br(\tilde{g} \to q\bar{q}\tilde{B}) = 0.5$
- Gluino decays into all the generations universally

Bino decay

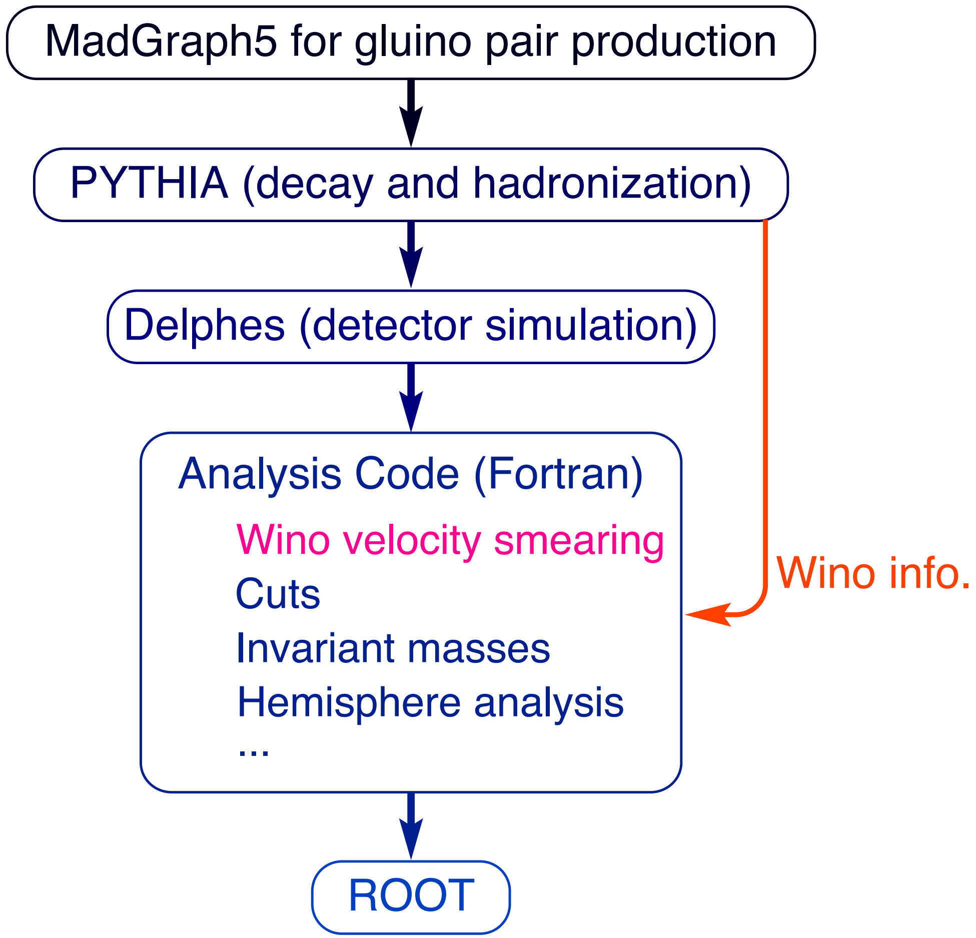
$$\tilde{B} \to W^{\mp}\tilde{W}^{\pm},\ h\tilde{W}^{0}$$



In the sample point of our choice:

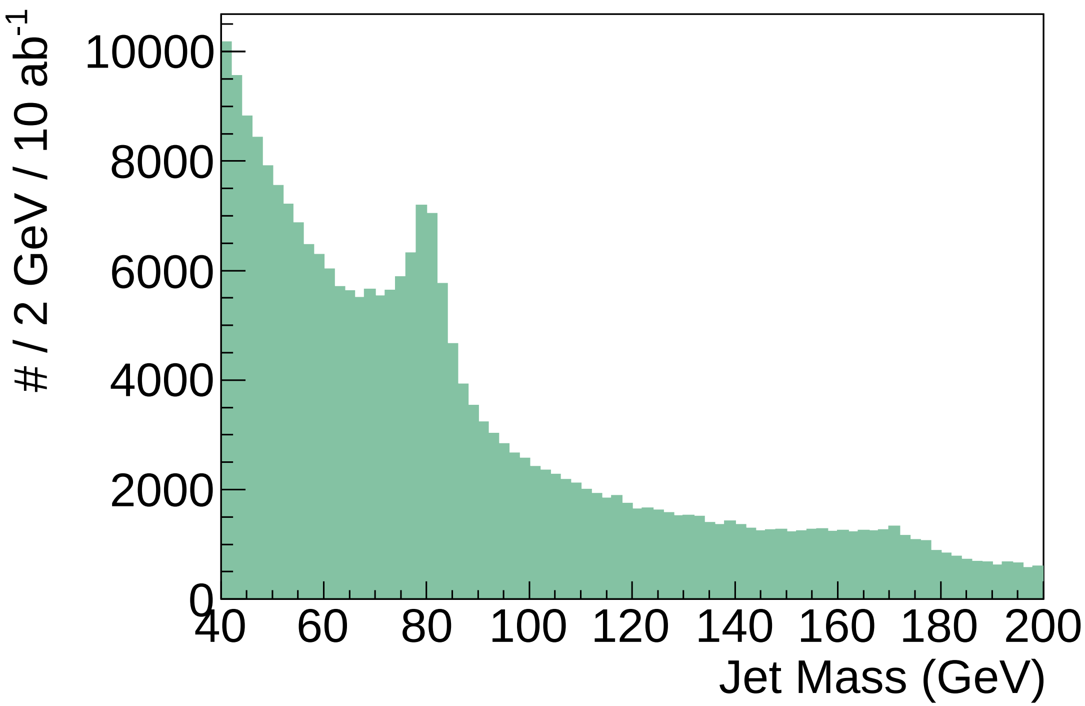
- $\tilde{B} \to \tilde{W}^{\pm}W^{\mp}$ dominates
- $\tilde{B} \to f\bar{f}\tilde{W}^{\pm}$ is negligible

Flow-chart of our MC study



- We take $\mathcal{L} = 10$ ab^{-1}
- We consider only gluino pair production events

Jet mass distribution



- Based on Sample Point 1
- For the Bino mass determination, 70 GeV $< m_j < 90$ GeV

Hemisphere analysis with two observed Wino tracks

- Two charged Winos are assigned to different hemispheres:

$$\tilde{W}^{\pm}_A \in H_A \quad (A = 1, 2)$$

- For each high p_T jet:

$$\begin{cases} j_i \in H_1\text{:} \ \text{ if } d(p_{H_1}, p_{j_i}) < d(p_{H_2}, p_{j_i}) \\ j_i \in H_2\text{:} \ \text{ if } d(p_{H_2}, p_{j_i}) < d(p_{H_1}, p_{j_i}) \end{cases}$$

Momentum of A-th hemisphere H_A

$$p_{H_A} = p_{\tilde{W}^{\pm}_A} + \sum_{j_i \in H_A} p_{j_i}$$

Distance function

[See De Roeck (Editor), CMS Physics TDR]

$$d(p_H, p_j) = \frac{(E_H - |\mathbf{p}_H| \cos\theta_{Hj}) E_H}{(E_H + E_j)^2}$$