Studying Anomaly-Mediated SUSY Model at Future 100 TeV pp Collider

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Work in progress

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Today, I would like to discuss:

1. What kind of SUSY model is (still) interesting?

2. What can future 100 TeV pp collider do?

1. Model

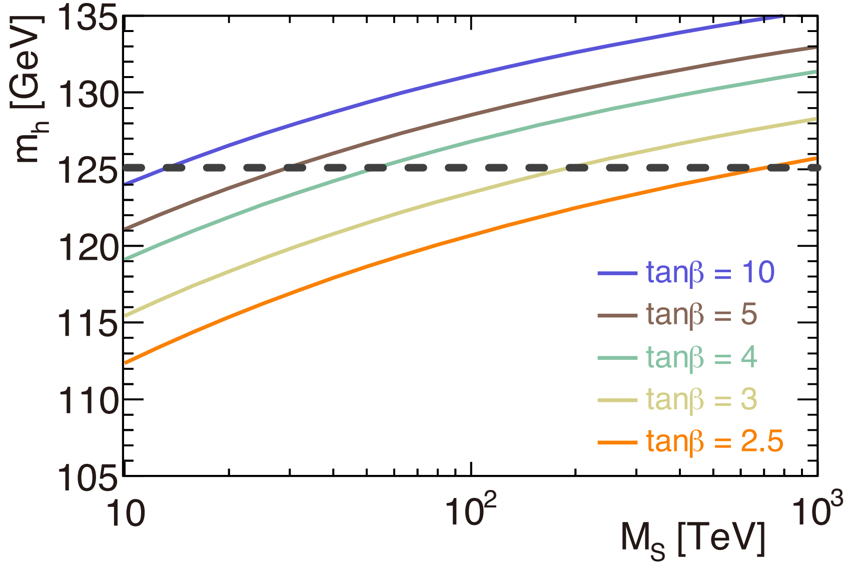
Mass spectrum of our interest

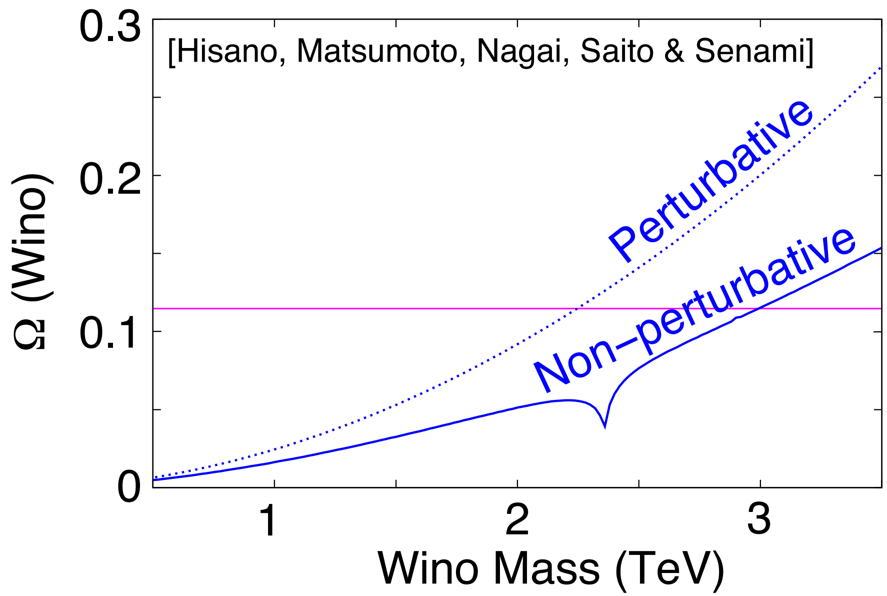
- Sfermion and Higgsino masses are of $O(100)$ TeV

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

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

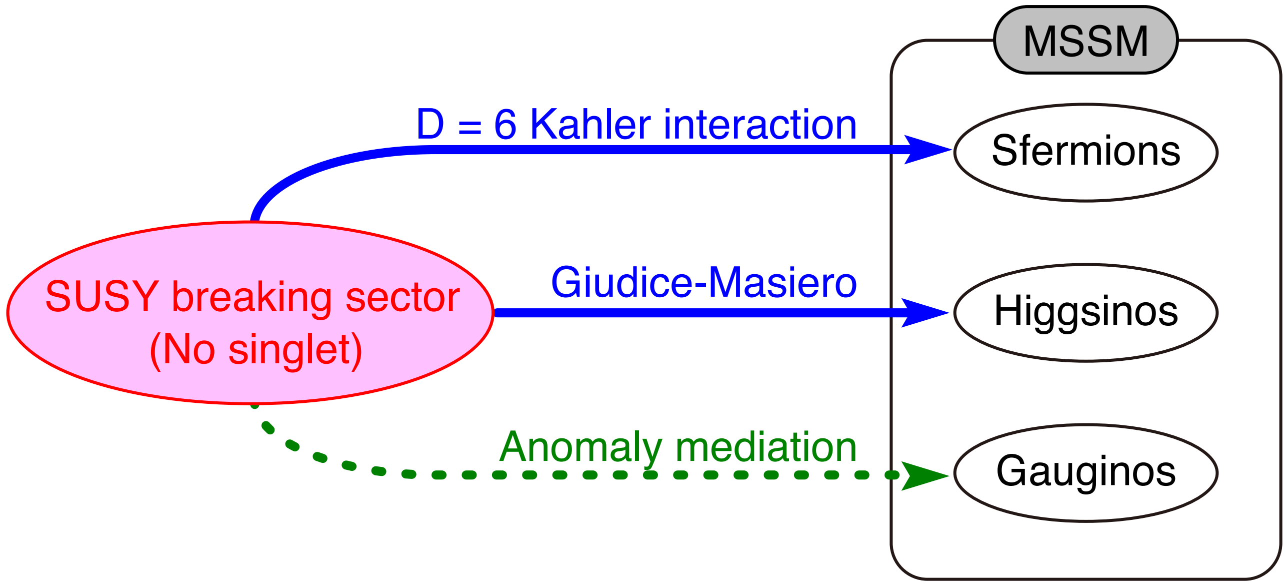
  $\Rightarrow$ Thermal relic Wino can be dark matter, if $m_{\tilde{W}} \simeq 2.9$ TeV





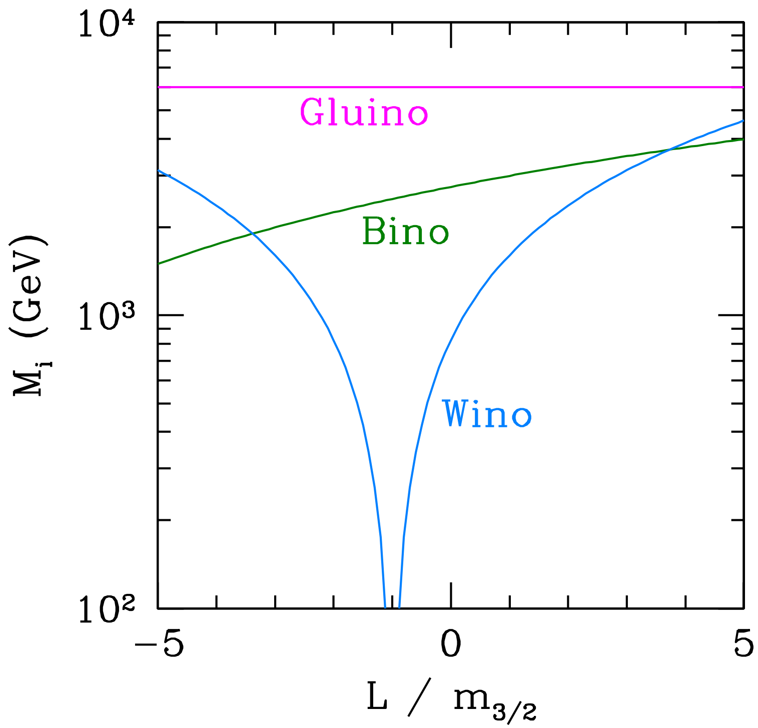
Anomaly mediation + pure gravity mediation

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



- The most general supergravity Lagrangian with Planck-suppressed interactions
- No singlet in SUSY breaking sector
- Scalar masses are of the order of the gravitino mass $m_{3/2}$

Gaugino masses: loop-suppressed relative to $m_{3/2}$



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

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

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

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

- Gaugino masses are determined by $m_{3/2}$ and L

  $\Rightarrow$ We take $m_{3/2} \sim |L| \sim O(100)$ TeV

- Wino (gaugino for $SU(2)_L$) is likely to be the LSP

2. What Can We Do with 100 TeV FCC-hh?

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

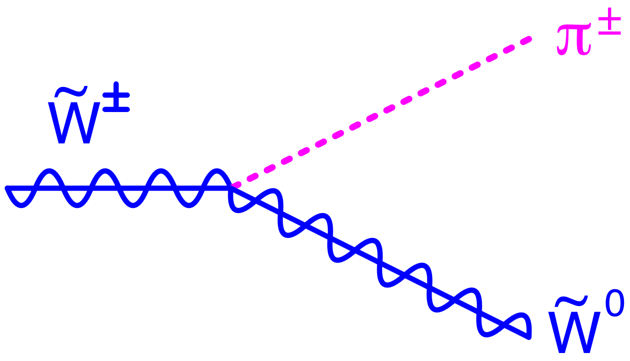
	Point 1	Point 2
$m_{3/2}$ [TeV]	250	302
L [TeV]	800	756
$m_{\tilde{B}}$ [TeV]	3.7	4.1
$m_{\tilde{W}}$ [TeV]	2.9	2.9
$m_{\tilde{g}}$ [TeV]	6.0	7.0
$\sigma(pp \to \tilde{g}\tilde{g})$ [fb]	7.9	2.7

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

I discuss gaugino mass determinations at 100 TeV FCC-hh

$\Rightarrow$ 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

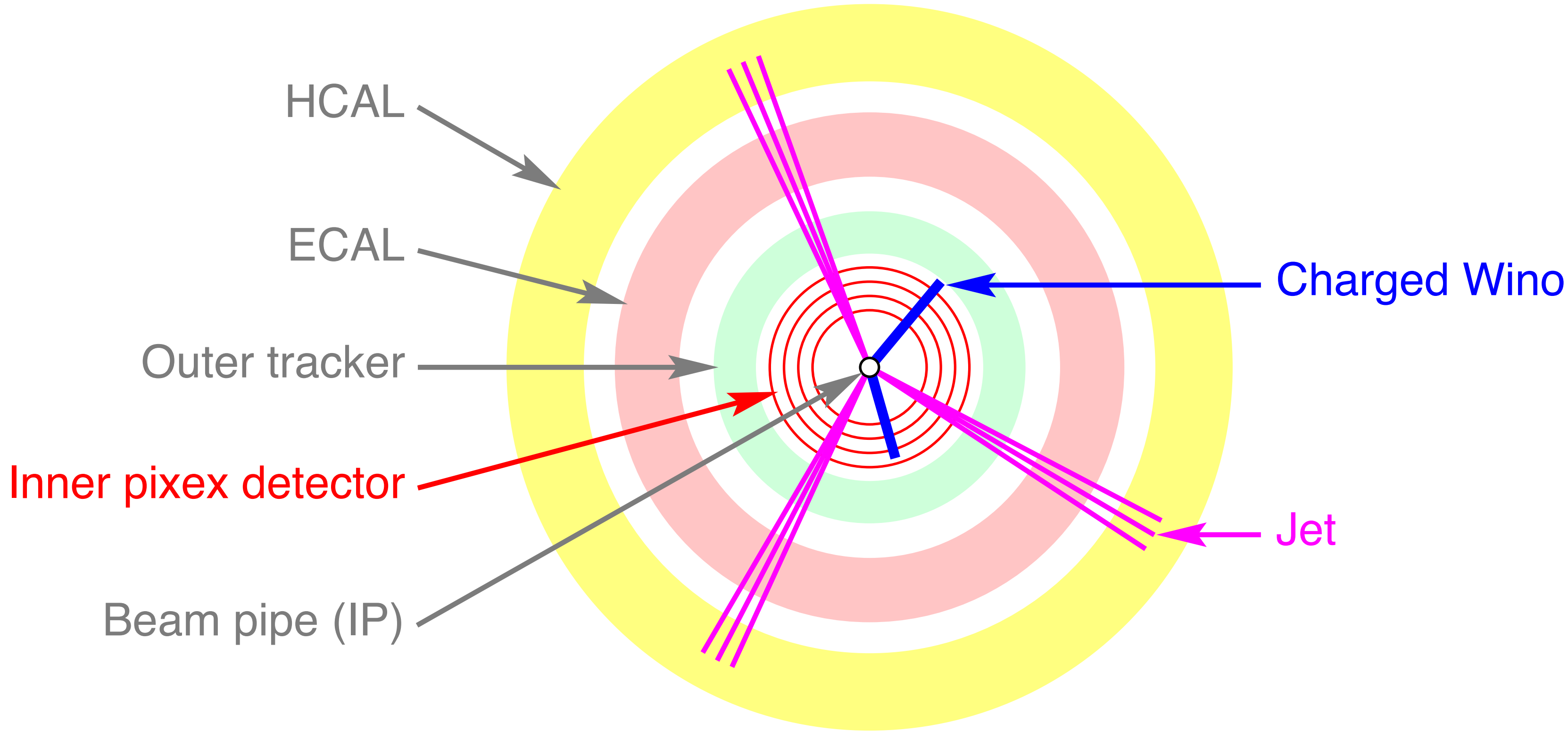
- $\tilde{W}^{\pm}$-tracks can be reconstructed by inner pixel detector
- SM background is negligible, requiring two $\tilde{W}^{\pm}$-tracks

  $\Leftrightarrow$ Probability to have one fake track: $O(10^{-5})$

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

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

Event of our interest (due to $pp \to \tilde{g}\tilde{g}$):



- We require two charged Winos with $L_T > 10$ cm
- We also require $p_T^{(\text{miss})} > 1$ TeV

  $\Rightarrow$ SM background is negligible

Measurement 1: Wino mass

Wino mass can be measured by combining velocity and momentum information

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

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

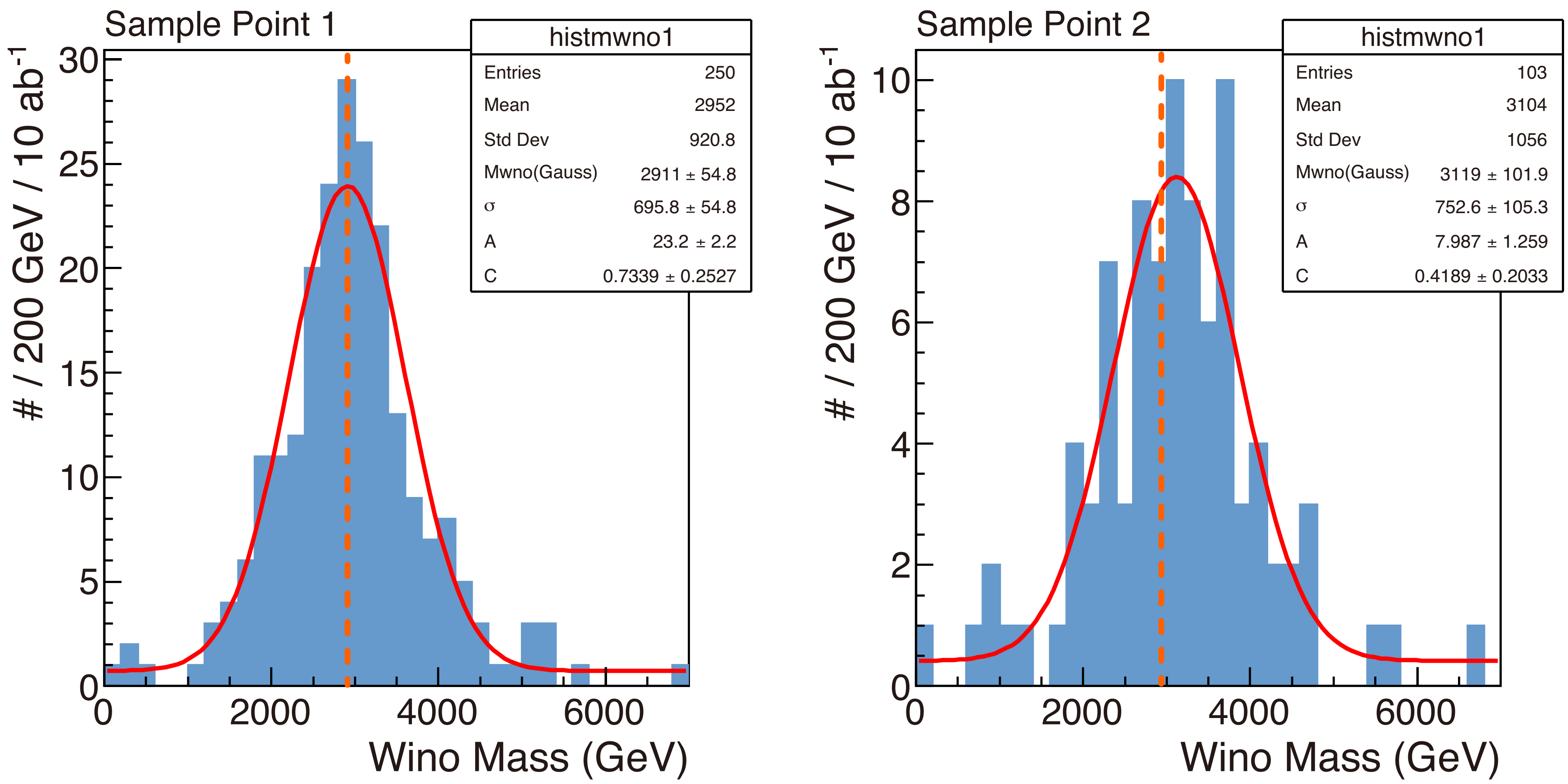
$$\vec{p}_{\tilde{W}_1} = c_1 \vec{n}_{\tilde{W}_1}$$

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

Reconstructed Wino mass

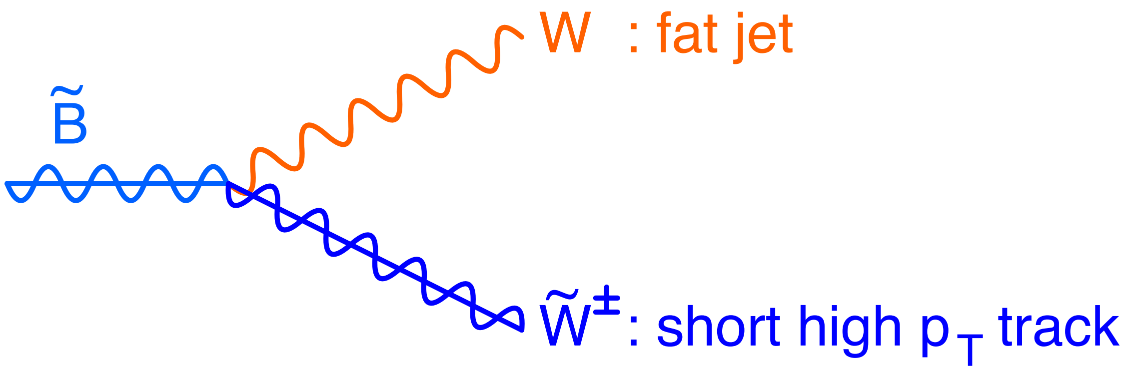
$$m_{\tilde{W}}^{(\mathrm{rec})} = \frac{1}{\beta_{\tilde{W}^\pm} \gamma_{\tilde{W}^\pm}} |\vec{p}_{\tilde{W}^\pm}| \equiv \frac{\sqrt{1 - \beta_{\tilde{W}^\pm}^2}}{\beta_{\tilde{W}^\pm}} |\vec{p}_{\tilde{W}^\pm}|$$

Reconstructed Wino mass



- True Wino mass: 2900 GeV
- We use Winos with $\beta_{\tilde{W}^{\pm}} < 0.8$

Measurement 2: Bino mass



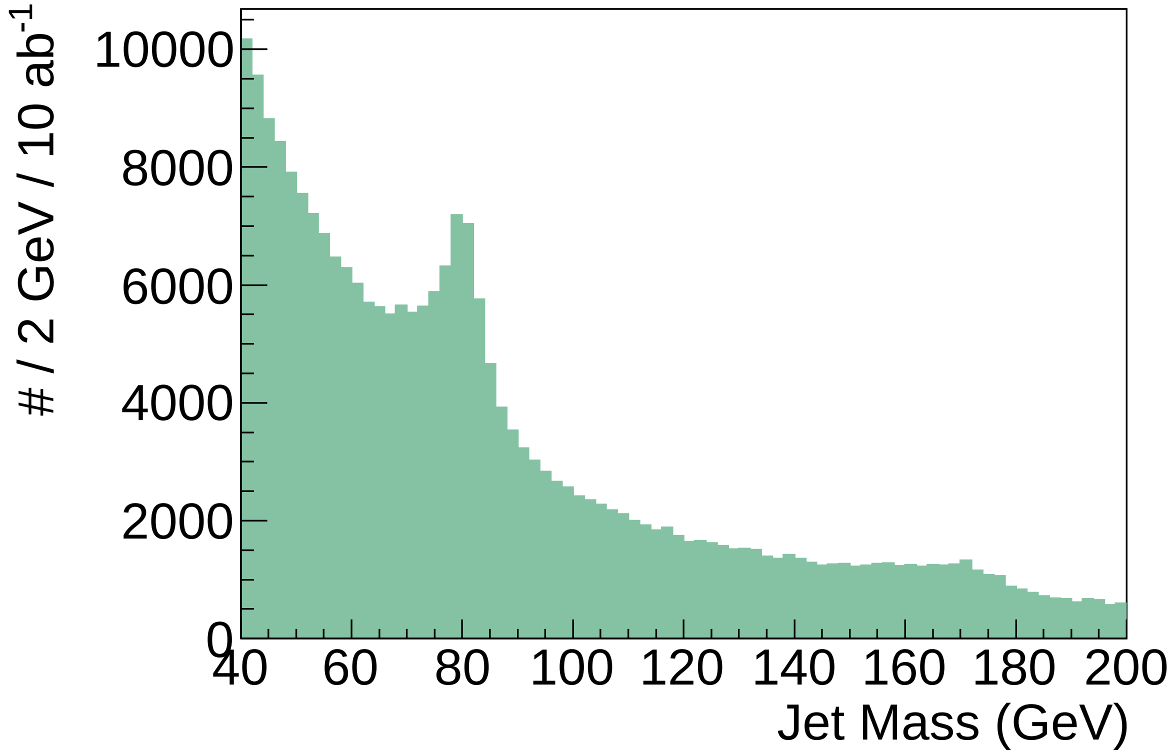
- Wino momentum is known (if L_T is long enough)
- W-jet may be identified as a fat jet

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

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

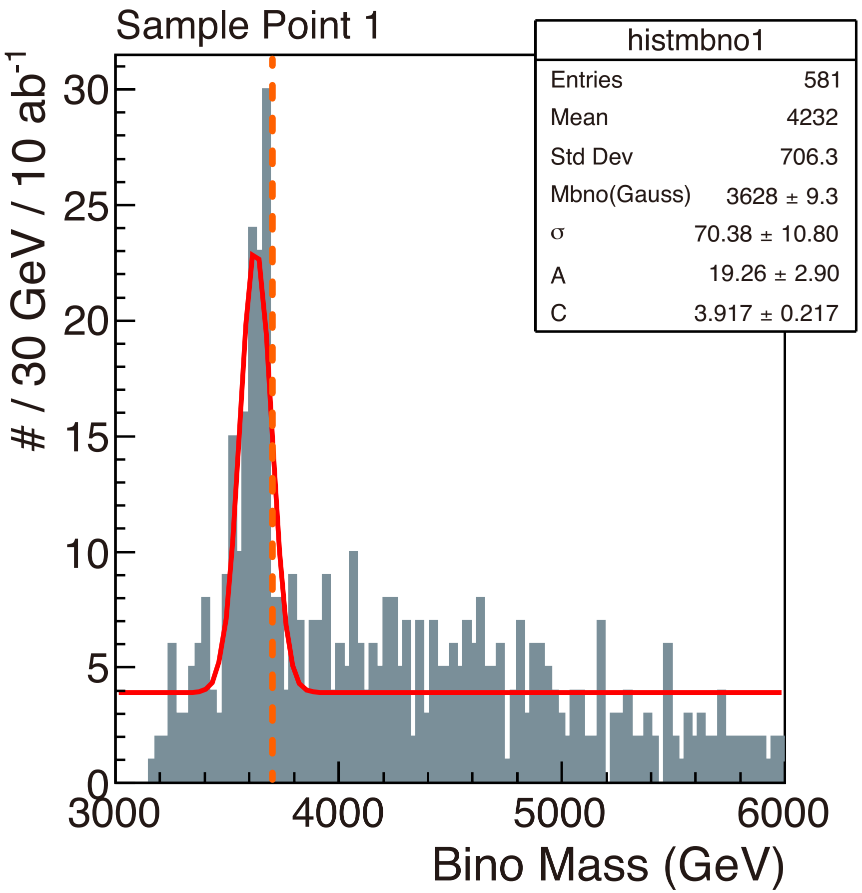
$$m_{\tilde{B}}^{(\text{rec})} = \sqrt{(m_{\tilde{W}} u_{\tilde{W}^\pm} + p_W)^2} \quad \text{with} \quad u_{\tilde{W}^\pm} = (\gamma_{\tilde{W}^\pm}, \beta_{\tilde{W}^\pm}\gamma_{\tilde{W}^\pm}\vec{n}_{\tilde{W}^\pm})$$

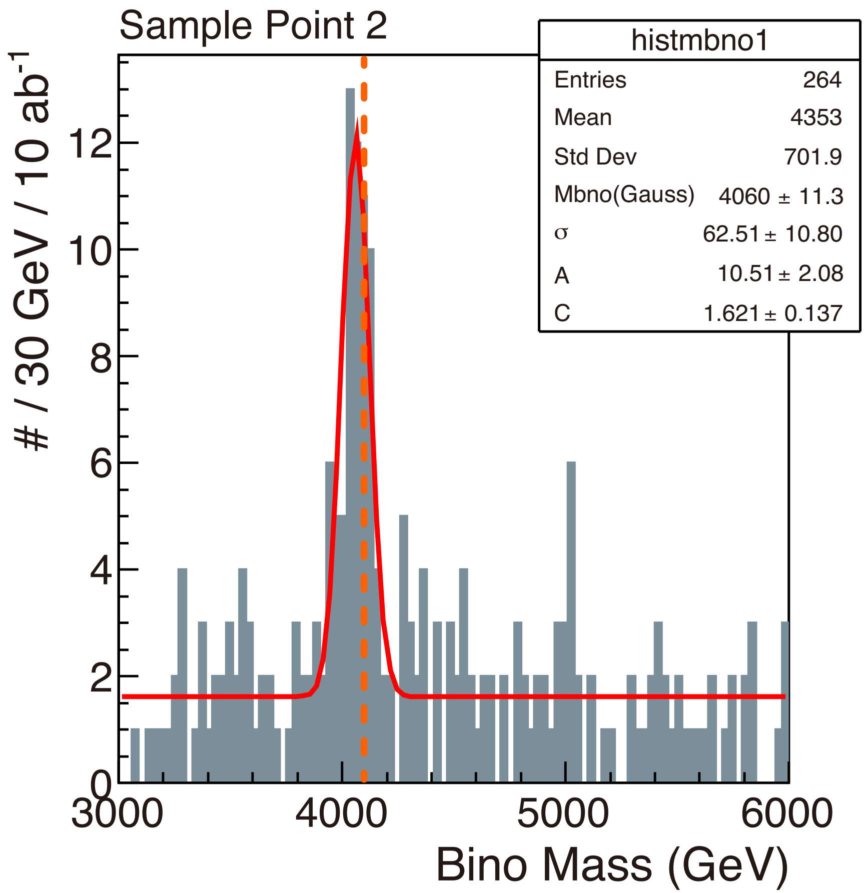
Jet mass distribution (for Point 1)



$\Rightarrow$ For the Bino mass determination, 70 GeV $< m_j < 90$ GeV

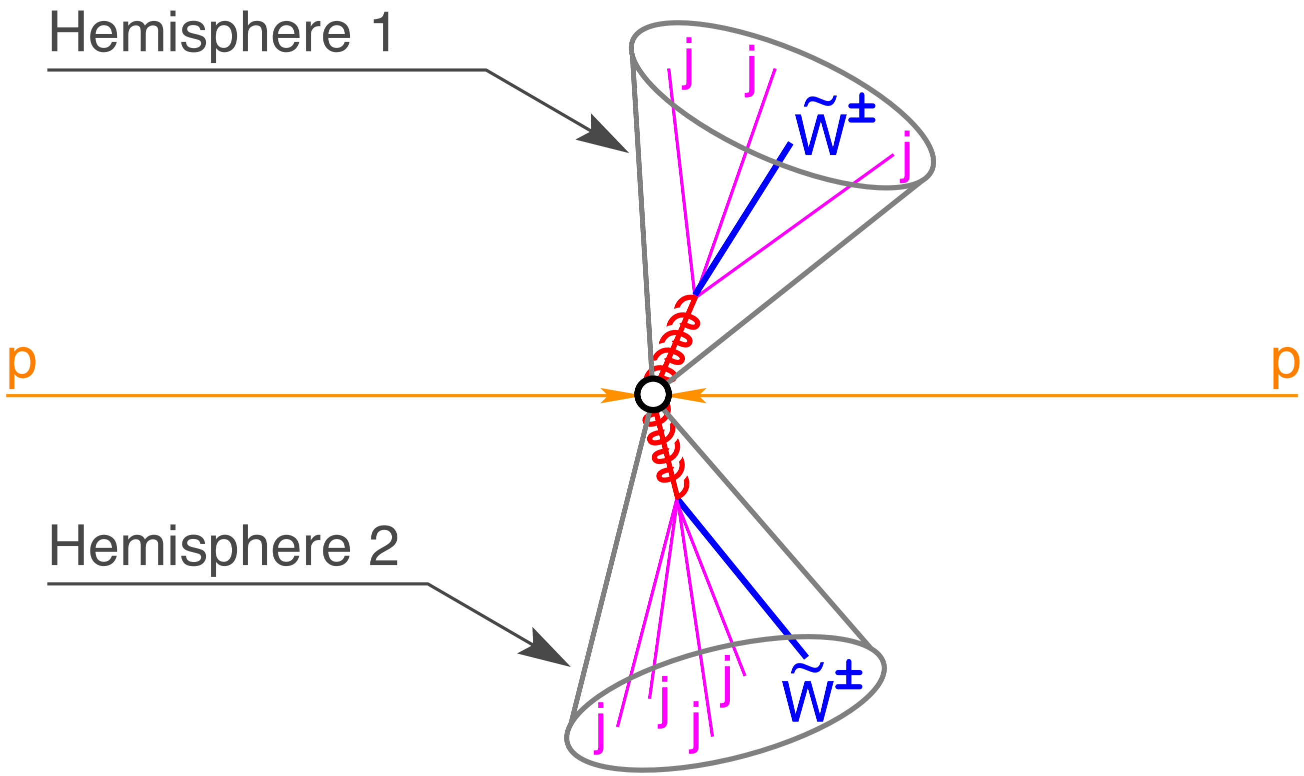
Reconstructed Bino mass (using true Wino mass)





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

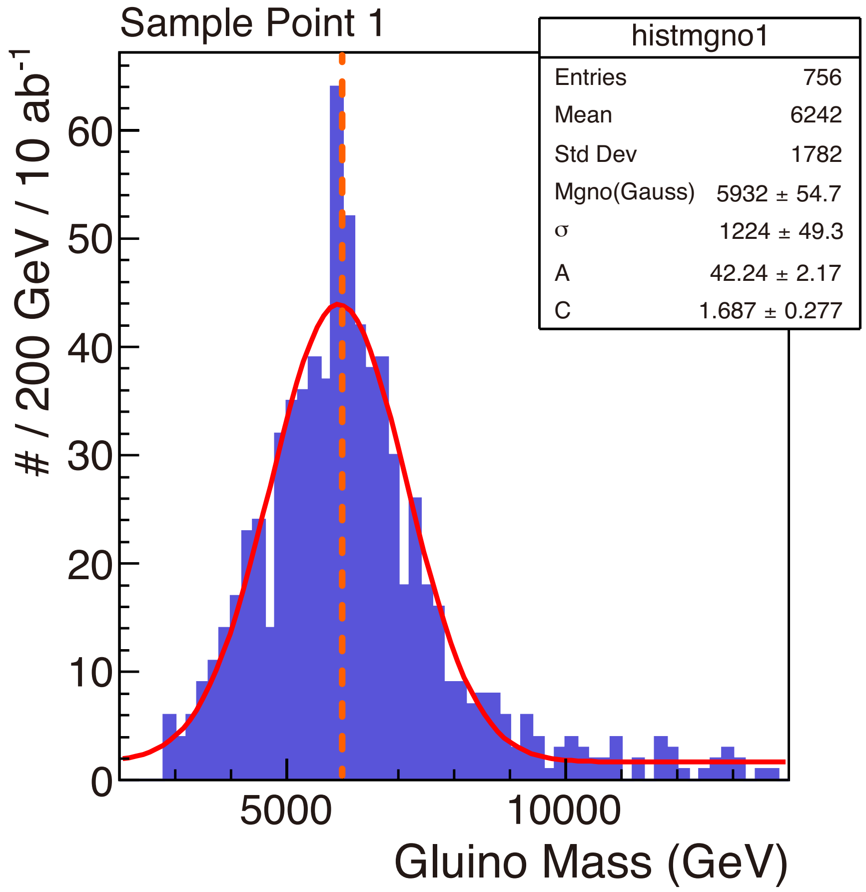
Measurement 3: Gluino mass (with hemisphere analysis)

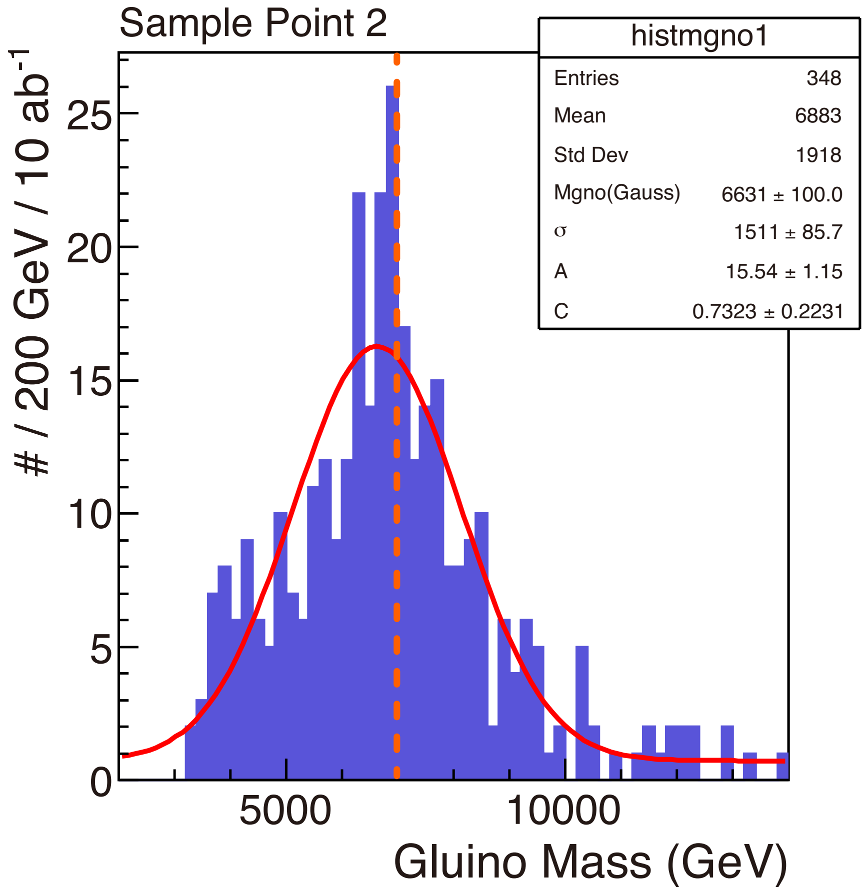


Reconstructed gluino mass

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

Reconstructed gluino mass (with true Wino mass):





- True gluino mass: 6000 GeV or 7000 GeV

Summary

Gaugino mass determinations may be possible

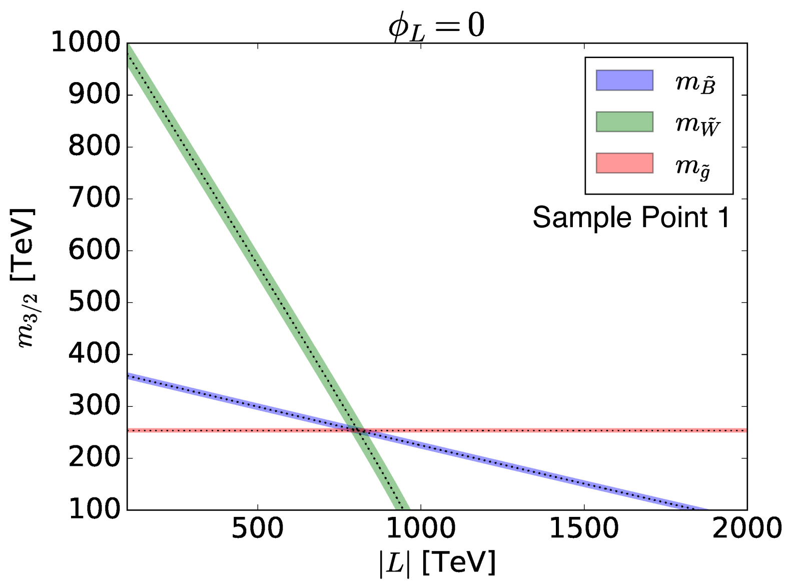
Sample Point 1 (with $\mathcal{L} = 10$ ab^{-1}):

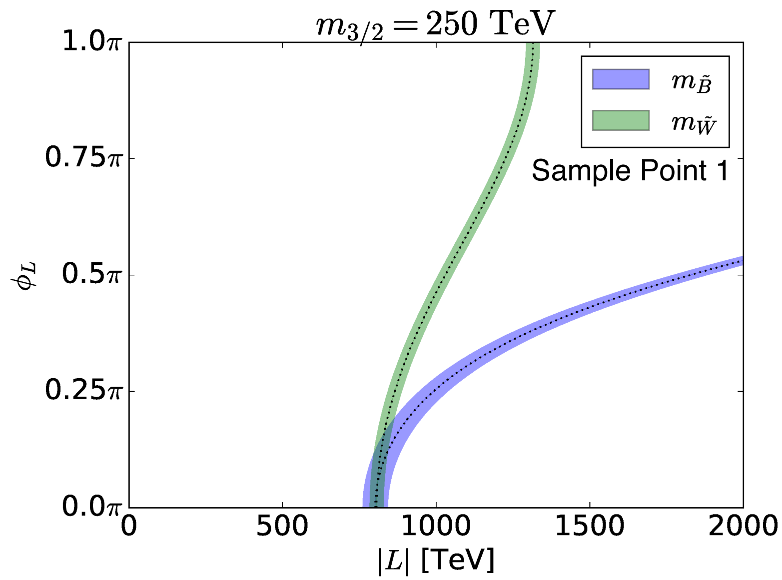
	$\delta m_{\tilde{B}}$	$\delta m_{\tilde{W}}$	$\delta m_{\tilde{g}}$
$\delta m_{\tilde{X}}^{\text{(stat)}}$	8 GeV	61 GeV	59 GeV
Due to $\delta m_{\tilde{W}}$	61 GeV	–	61 GeV
Total	62 GeV	61 GeV	85 GeV

⇒ Test of the model

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

Information about the mechanism of SUSY breaking





$\Rightarrow$ Determination of $m_{3/2}$, $|L|$, $\cdots$

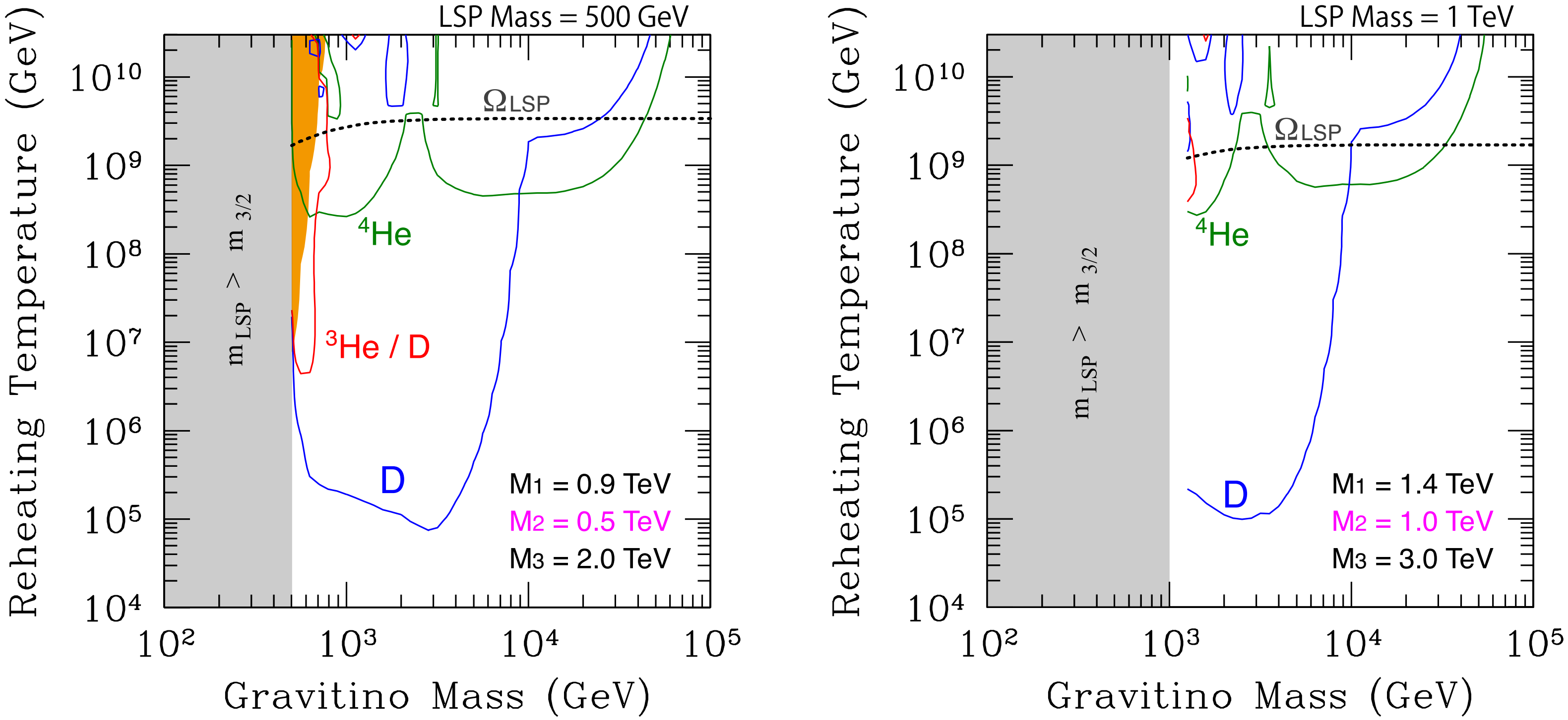
$\Rightarrow$ Impact on cosmology

FCC-hh can have significant impact on BSM studies

- Discovery
- Measurements

Back Ups

Cosmological difficulties caused by gravitino



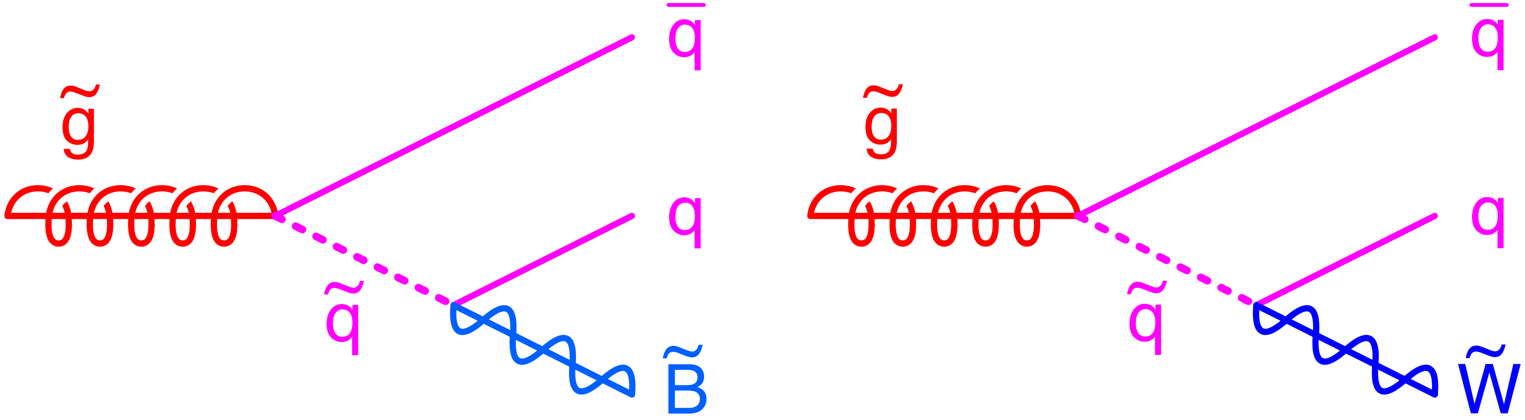
[Kawasaki, Kohri, TM, Takaesu]

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

⇒ Simple thermal leptogenesis may work, if $m_{3/2} \gtrsim 10$ TeV

Gluino decay

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

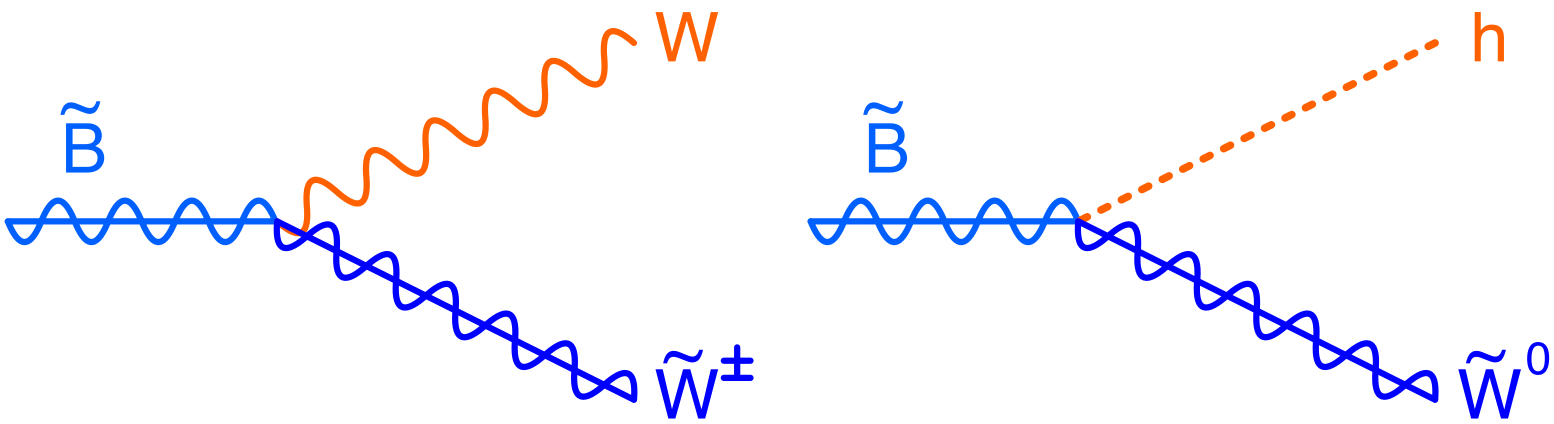


Assumptions:

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

Bino decay

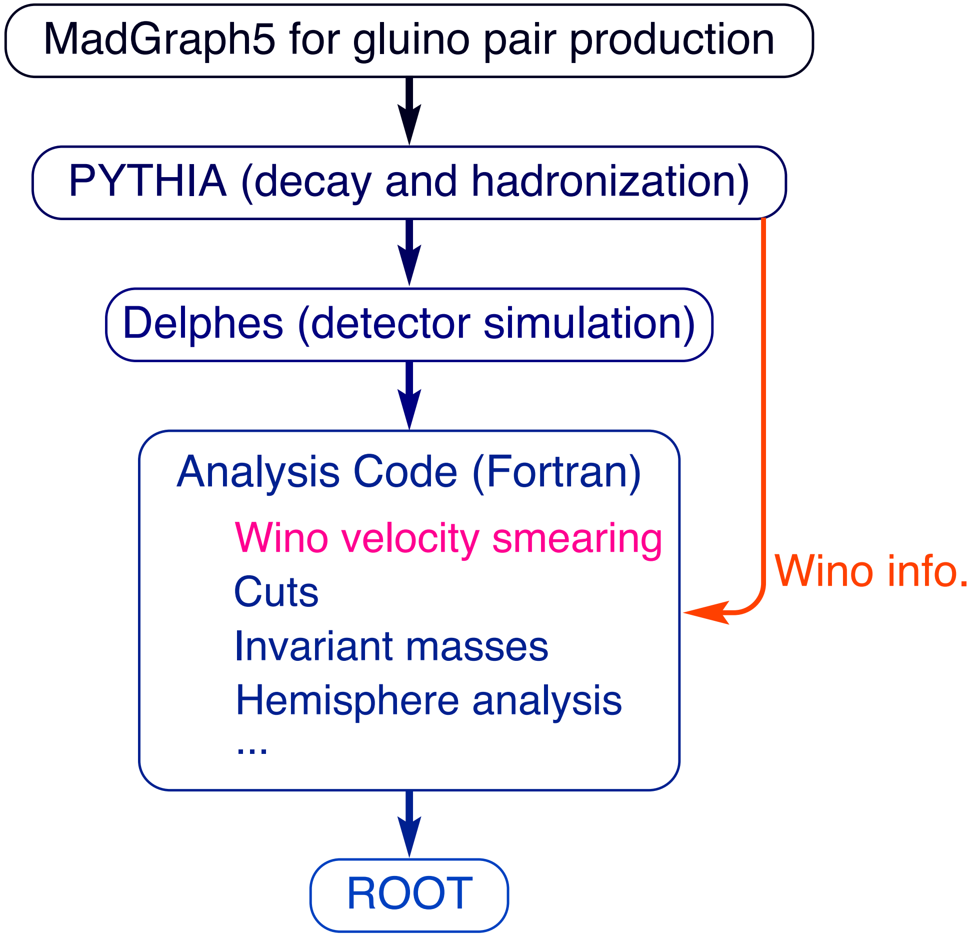
$$\tilde{B} \to W^{\mp}\tilde{W}^{\pm},\ h\tilde{W}^0$$



In the sample point of our choice:

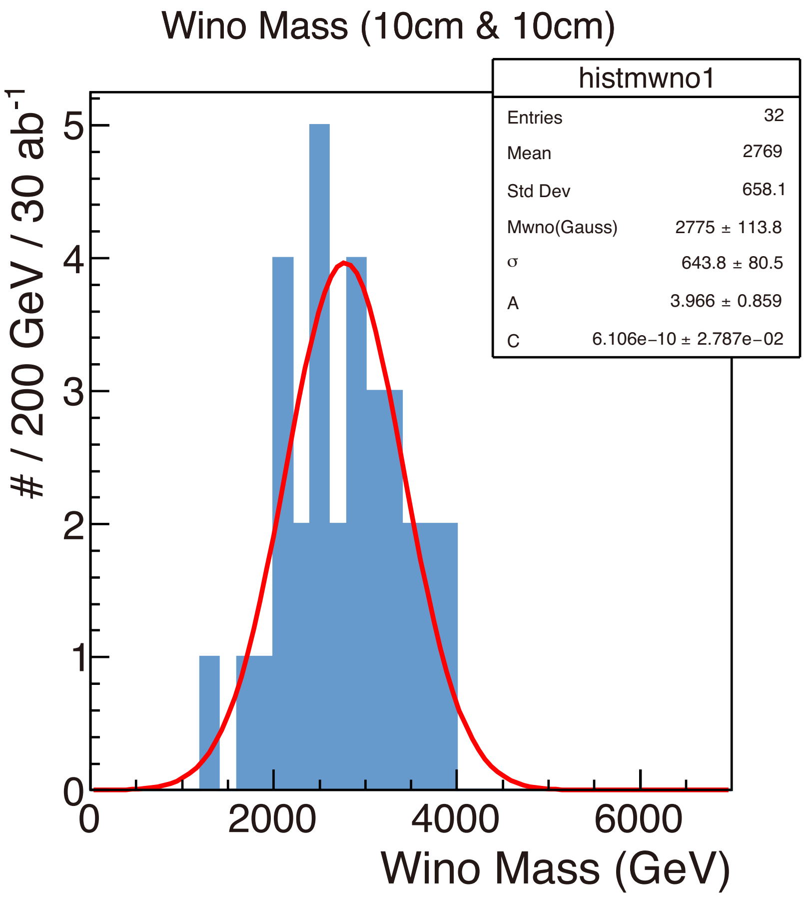
- $\tilde{B} \to \tilde{W}^{\pm}W^{\mp}$ dominates
- $\tilde{B} \to f\bar{f}\tilde{W}^{\pm}$ is negligible

Flow-chart of our MC study



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

Reconstructed Wino mass: $pp \to \tilde{W}^+\tilde{W}^- j$



- True Wino mass: 2900 GeV
- $\beta_{\tilde{W}^\pm} < 0.8$
- $p_T^{\text{(miss)}} > 1$ TeV

$\Rightarrow \delta m_{\tilde{W}}^{\text{(obs)}} \simeq 130$ GeV (with $\mathcal{L} = 30$ ab^{-1})

Hemisphere analysis with two observed Wino tracks

- Two charged Winos are assigned to different hemispheres:

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

- 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

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

Distance function

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

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