Composite gluino at the LHC

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What will we see at the LHC ?

Natural EWSB?

Supersymmetry?

Higgs as PGSB (LH, RS-like)?

Technicolor?

Unnatrual?

Split Susy?

Only few random particles?

nothing?

General Features

- Many particles

  MSSM:~30 new particles around the corner.

  Long decay chains.

  Why haven't we seen any?

- Few particles:

  Little Higgs

  More minimal supersymmetry

  Involve the 3rd generation

- Stable particles?

  - MSSM: R-partiy

  - Little Higgs : T-parity to avoid electroweak precision constraints.

  - R parity is more general: if conservation of Lepton and Baryon number.

$$(-1)^{3B+L+2S}$$

  - Missing E_T signatures seems generic

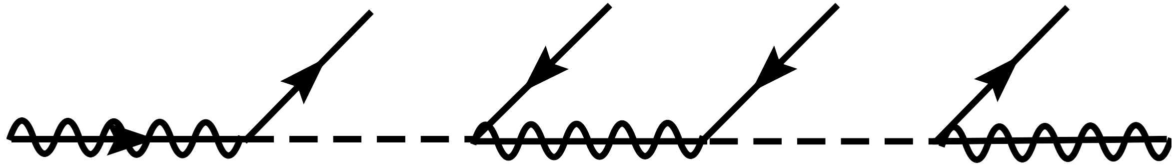
- Gluino:

  - Smoking gun signature for SUSY

    Color octet: abundantly produced at Hadron colliders.

at LHC : $\sigma(pp \to \tilde{g}\tilde{g}) \sim 32\mathrm{pb}$ $m_{\tilde{g}} = 500\mathrm{GeV}$

Possibility of long decay chain.



Masses can be measured by looking at endpoints of invariant mass distributions.

- Is it really a smoking gun?
  - Other particles can fake a gluino
    - KK gluon in extra-dimensional models.

      study the spin.

    - Here we look at composite gluino in a model where the top is composite.

- Little Higgs
  - Models where the Higgs is a pseudo-Goldstone boson.
  - Large spontaneously broken global symmetries. Explicit ‘collective breaking’: more than one couplings are required to give a mass to the Higgs.
  - Extended gauge, Yukawa and Higgs sectors.
  - same spin ‘partner’ cancel quadratic divergences.

- Spectrum

W'	ϕ	T
cancel quadratic divergence of W	cancel quadratic divergence of Higgs	cancel quadratic divergence of tops

$\sim 1\text{TeV}$

- Goldstone bosons become strongly coupled at high energy. Needs a UV completion at $\sim 10\text{TeV}$

- Many Models
  - defined by group structure

    Arkani-Hamed,Cohen,Katz,Nelson '02

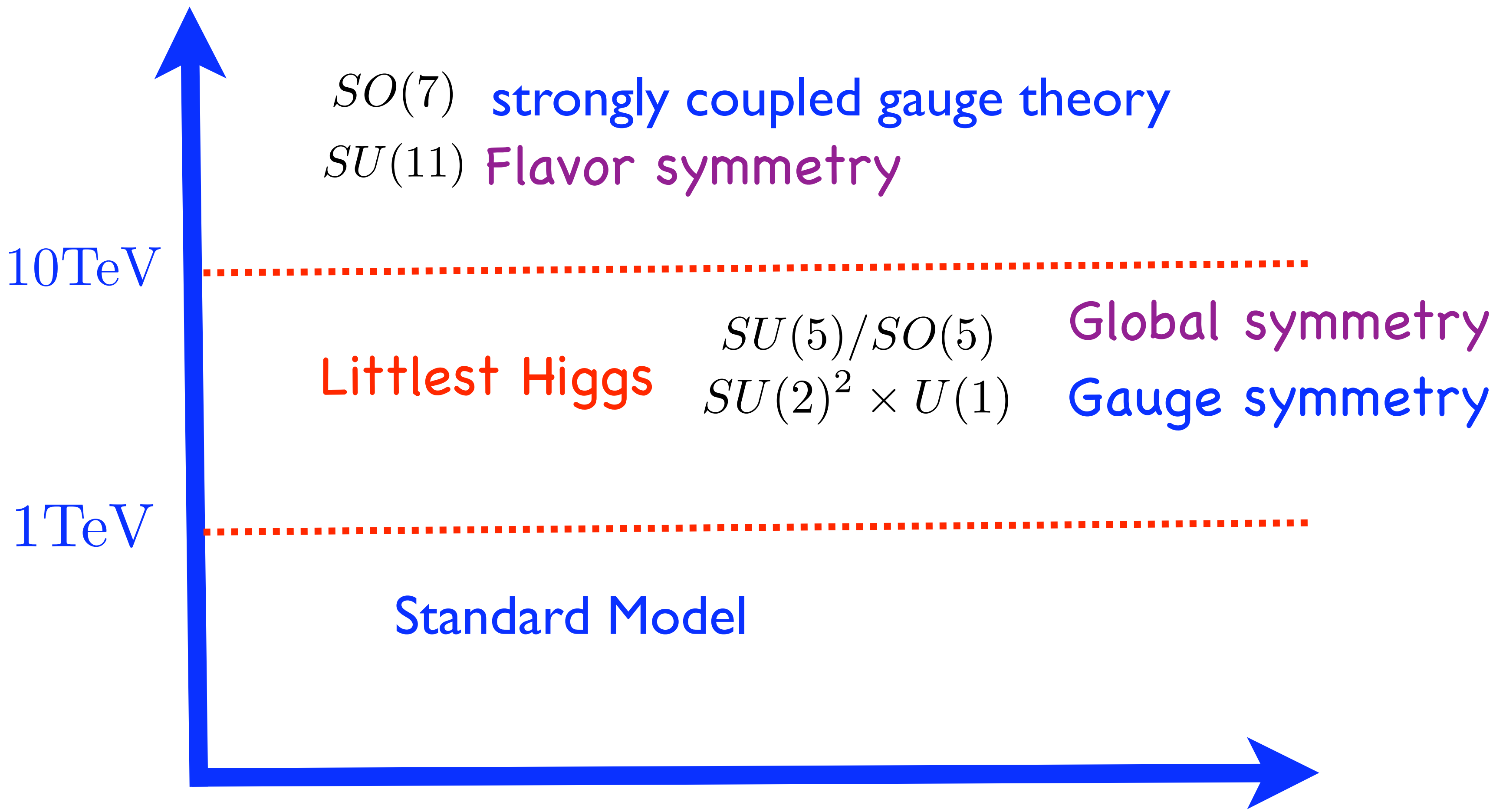
  - Littlest Higgs: $SU(5) \Rightarrow SO(5)$ global

    $SU(2)^2 \times U(1)^2$ gauge

top sector more model dependent.

- Model: Strongly coupled UV completion of the littlest Higgs. Katz,Lee,Nelson, Walker '03

  - Sturcture



- Spectrum

(A) Above 10 TeV: 11 flavors:

		$SU(3)_c$	$SU(2)_1$	$SU(2)_2$	$U(1)_Y$
$SU(5)$ global symmtery	ψ_0	1	1	1	0
	ψ_2	1	2	1	$1/2$
	ψ_2'	1	1	2	$-1/2$
Composite top sector	ψ_3^c	$\bar{3}$	1	1	$-2/3$
	ψ_3	3	1	1	$2/3$

(B) Below 10 TeV: symmetry breaking:

- explicit soft breaking of $SU(11)$ to $SU(5) \times SU(3)$

- The strong sector breaks $SU(5)$ to $SO(5)$:

$$\begin{pmatrix}\psi_2\\ \psi_0\\ \psi_2'\end{pmatrix} \searrow \psi_5\psi_5 \quad \rightarrow \quad \langle\Sigma\rangle = \begin{pmatrix}\mathbf{0} & 0 & \mathbf{1}\\ 0 & 1 & 0\\ \mathbf{1} & 0 & \mathbf{0}\end{pmatrix}$$

  - The gauge symmetry $SU(2)^2 \times U(1)_Y$ breaks to the SM $SU(2)_L \times U(1)_Y$

$$\mathcal{L} = f^2 D_\mu \Sigma D^\mu \Sigma \qquad f \sim 1\text{TeV}$$

- The spectrum of TeV states contains:

  - extra gauge bosons W'

  - extra scalars: triplet ϕ

- Composite fermions make part of the top sector.

$$\begin{matrix}\psi_5\psi_3\lambda \\ \psi_5\psi_3^c\lambda\end{matrix} \rightarrow X = \begin{pmatrix} Q' \\ T \\ p \end{pmatrix} \quad X^c = \begin{pmatrix} P^c \\ t'^c \\ q^c \end{pmatrix}$$

- mixes with elementary fermions:

$$\mathcal{L} = y_1 X \Sigma X^c + y_2 q' q^c + y_3 T T'^c$$

- Spectrum:

SM:

$$q = \sin\theta_t Q' + \cos\theta_t q'$$
$$t^c = \sin\theta_s t'^c + \cos\theta_s T'^c$$

heavy partner:

$$q^c, Q = \cos\theta_t Q' - \sin\theta_t q'$$
$$T, T^c = \cos\theta_s t'^c - \sin\theta_s T'^c$$

- There are also composite 'gaugino':

$$\psi_5\psi_5\lambda \rightarrow C^+, C^-, N$$ 'higgsino','bino','wino'

$$\psi_3\psi_3^c\lambda \rightarrow \tilde{g}$$ 'gluino'

- R - partiy:

$$(-1)^{3B+L+2S}$$

➡ lighest of $\tilde{g}$, $\tilde{C}$, $\tilde{N}$ is stable: LPOP

  - LPOP dark matter?

Masses are of the same order than the top partner because of flavor symmetry:

$$\sim 1\mathrm{TeV}$$

- Phenomenology:
  - Extra TeV resonances:

$$W', Z', \phi, Q, T$$

  - Because of Electroweak constraints, they might be heavy, and hard to see.
  - Can we test the little Higgs mechanism?
  - 'gauginos' have missing E_T signature.
    - Can we tell if we are seeing a little Higgs or supersymmetry?

- Decay of the composite gluino: 4-Fermi operators
  - Higgsino-like 'chargino' and 'neutralino'

$$\frac{\tilde{g}tt^cN}{f^2} \qquad \frac{\tilde{g}t^ctN}{f^2}$$

  - Leads to 4 stops final states: too messy. We consider:

$$\frac{\tilde{g}bt^cC^+}{f^2} \qquad \frac{\tilde{g}t^cbC^+}{f^2}$$

absent in supersymmetry

$$\boxed{\frac{\tilde{g}C^+tb}{f^2} \qquad \frac{\tilde{g}C^+\bar{t}^c\bar{b}}{f^2}}$$

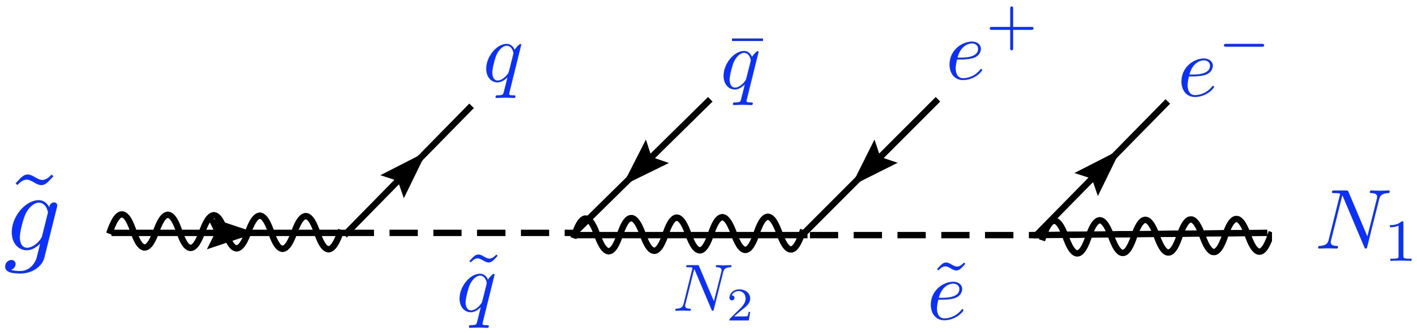
- Operators with 'wino' or 'bino-like' chargino

$$\frac{\tilde{g} b \bar{t} \bar{C}^{+}}{f^2} \qquad \frac{\tilde{g} t \bar{b} \bar{C}^{+}}{f^2}$$

- Same form as in supersymmetry with off-shell squarks.

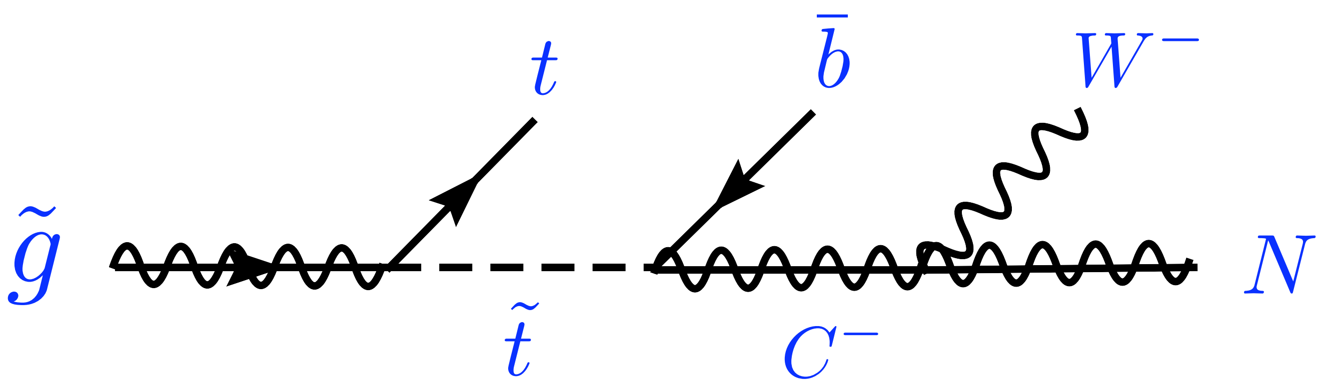
- coefficients related by flavor symmetry.

- Decay of a gluino in Supsersymmetry

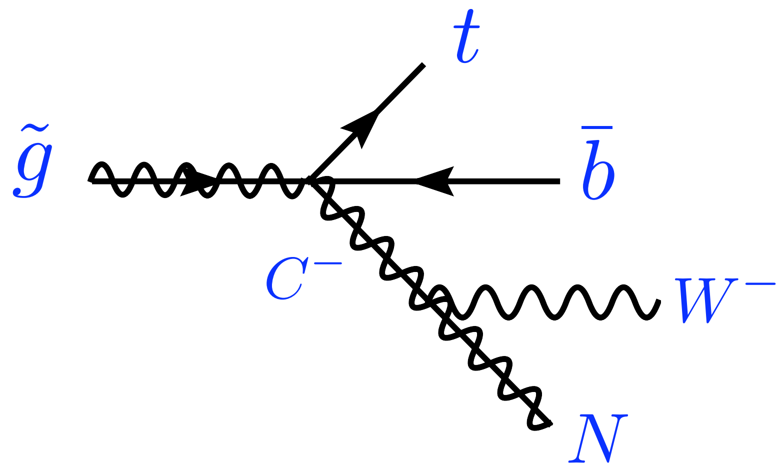


Long decay chain.

If most slepton and squark except the stop and sbottom are very heavy:



- If the stop and sbottom are off-shell:



$$c_b \quad \frac{\tilde{g} b t^c C^+}{f^2} \qquad\qquad c_t \quad \frac{\tilde{g} t^c b C^+}{f^2}$$

off shell sbottom

off shell stop

There are no operators of the form

$$c_{O_1} \frac{\tilde{g} C^+ t^c b}{f^2} \qquad c_{O_2} \frac{\tilde{g} C^+ \bar{t}^c \bar{b}}{f^2}$$

- woule require the exchange of a charged color octet.

- In supersymmetry we expect

$$c_b \neq c_t$$

- In composite model because of the flavor symmetry:

$$c_b \sim c_t$$

- What observables can distinguish a supersymmetric gluino from the composite gluino?

  - with appropriate spectrum, the final states and kinematic of the decay are the same in both cases

  - We look at $$m_{tb}^2 = (P_t + P_b)^2$$

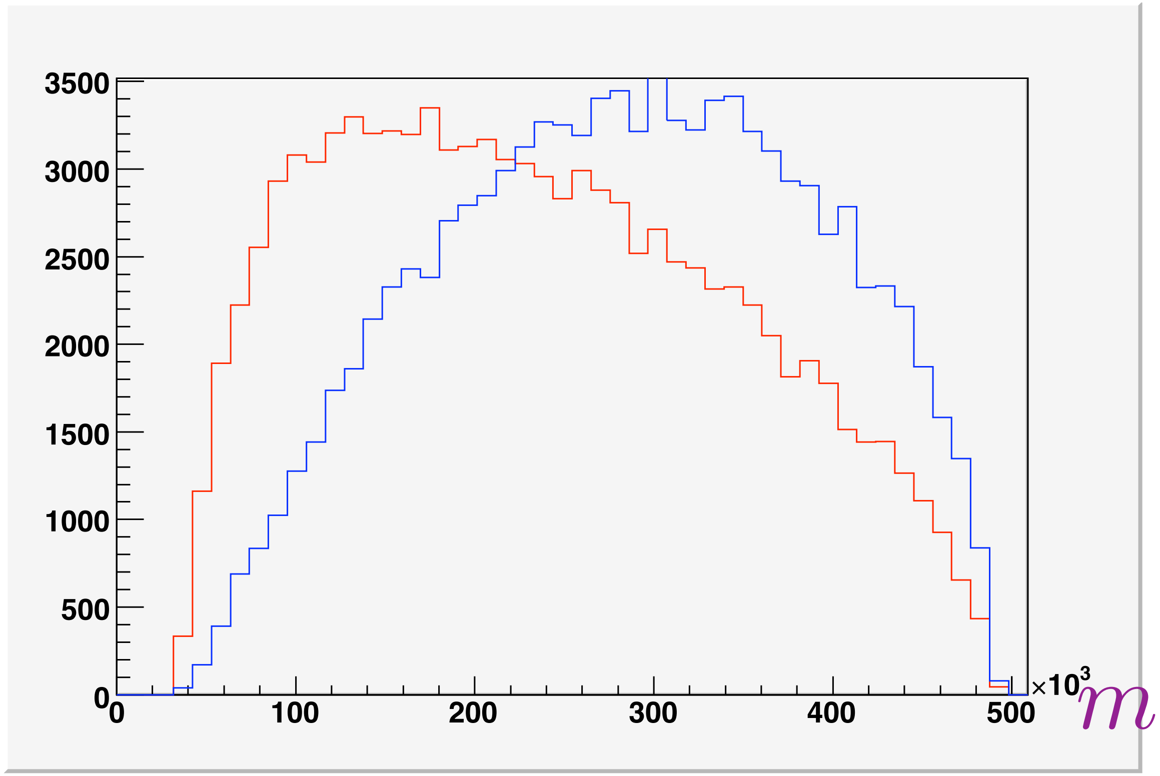
    The distriubtion of m_{tb}^2 is different .

  - m_{tb}^2 is the only invariant distribution that can be measured.

m_{tb}^2 distribution

$m_{\tilde{g}} = 1\text{TeV} \quad m_C = 300\text{GeV} \quad m_N = 200\text{GeV}$

$$\boxed{\frac{\tilde{g} b t^c C^+}{f^2}}$$



m_{tb}^2

$$\boxed{\frac{\tilde{g} C^+ t^c b}{f^2}}$$

Susy vs non-susy

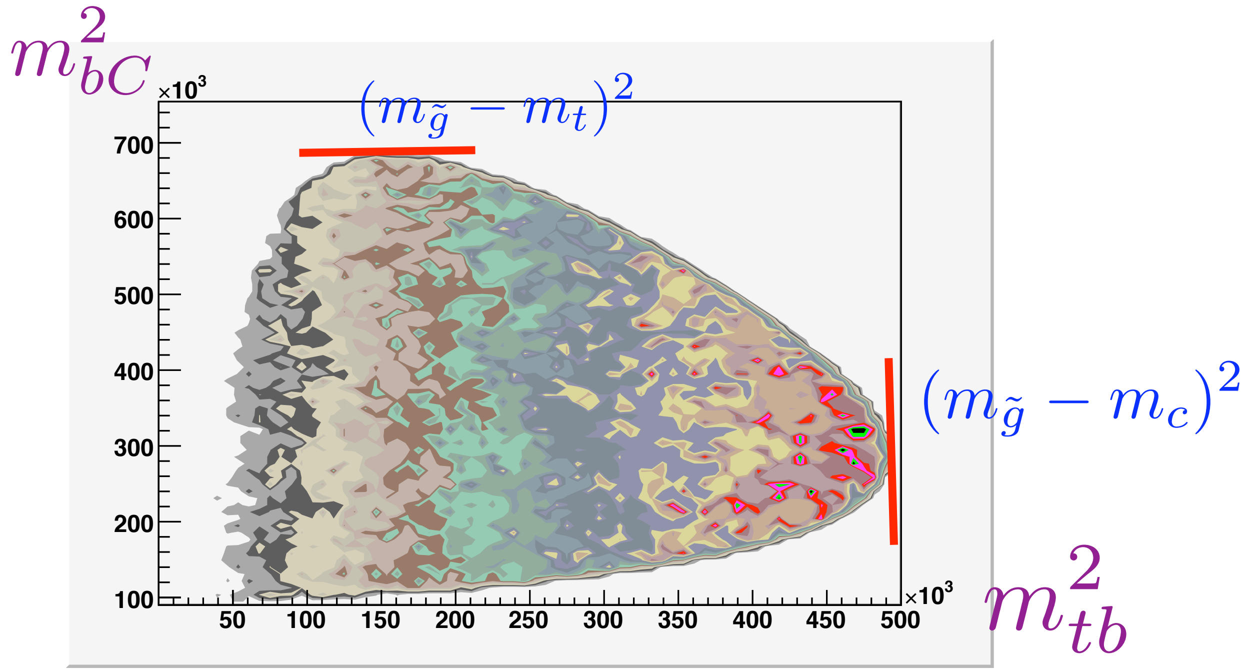
- In more details:

$$\frac{d\Gamma}{dm_{tb}^2 dm_{tC}^2} = \frac{1}{32(2\pi)^3 m_{\tilde{g}}^3} |\mathcal{M}|^2$$

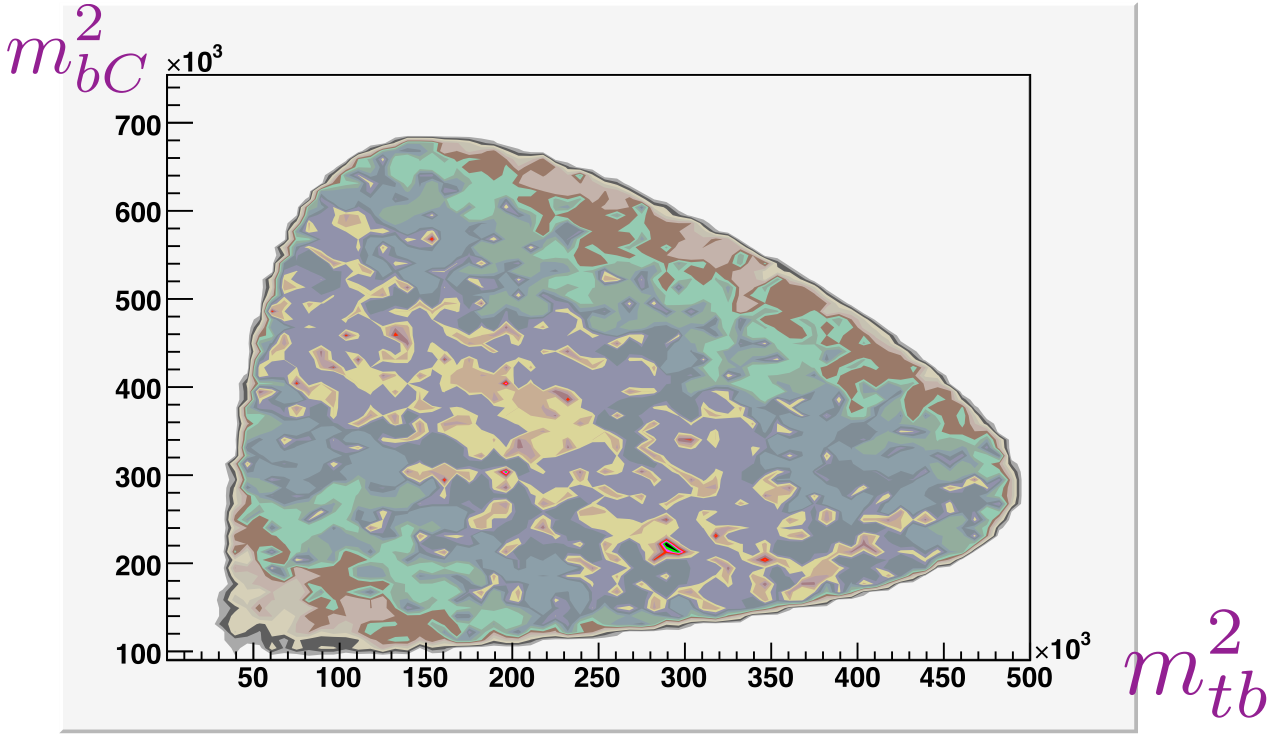
if $c_t = 0$, $c_b = 0$:

$$\mathcal{M} = \mathcal{M}(m_{tb}^2) \sim \alpha m_{tb}^2 + \beta m_{tb}^4$$

Dalitz plot



Same plot for susy with $c_{\tilde{t}} = 0 \quad c_{\tilde{b}} = 1$

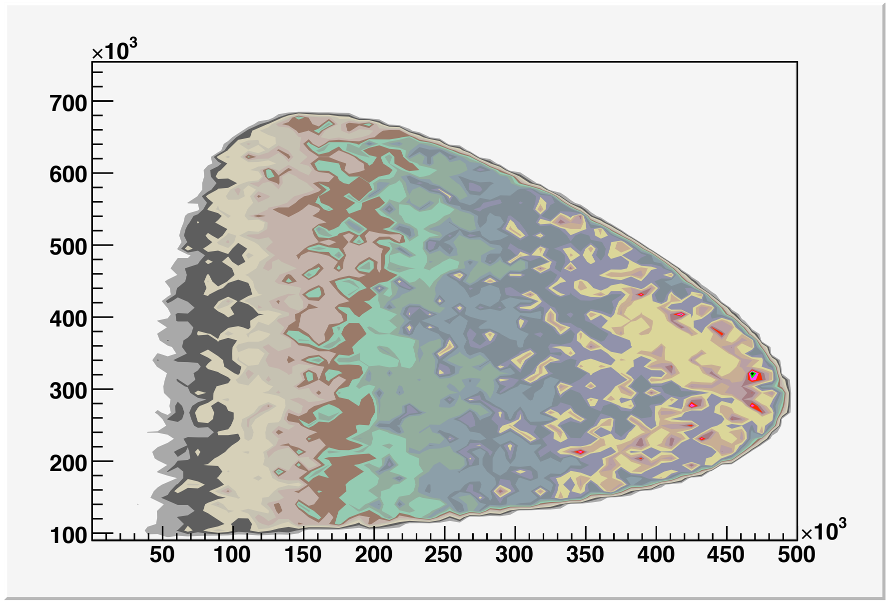


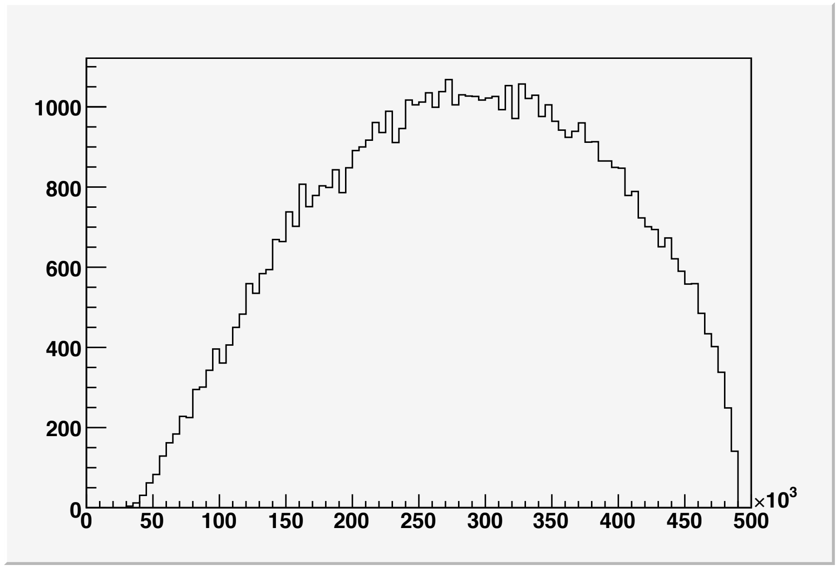
Unfortunately, Dalitz plot is not obesrvable

- What about the presence of $c_{\tilde{t}}$, $c_{\tilde{b}}$ in the non-susy case?

If $c_{\tilde{t}}$ = $c_{\tilde{b}}$ we also get

$$\mathcal{M} = \mathcal{M}(m_{tb}^2) \sim \alpha m_{tb}^2 + \beta m_{tb}^4$$





Measurement of m_{tb}^2 .

Hisano,Kawagoe, Kitano,Nojiri '02

Hisano,Kawagoe, Nojiri '03

- Problems:
  - Cuts deform shapes
  - Combinatoric
- Cuts:
  - between 4 and 7 jets with $P_T > 40\mathrm{GeV}$
  - at least one hard jet $P_T > 150\mathrm{GeV}$
  - at least 2 b-tag jets.
  - missing $E_T > 300\mathrm{GeV}$

- We consider the following spectrum:

$$m_{\tilde{g}} = 1\mathrm{TeV}$$
$$m_C = 300\mathrm{GeV}$$
$$m_N = 200\mathrm{GeV}$$

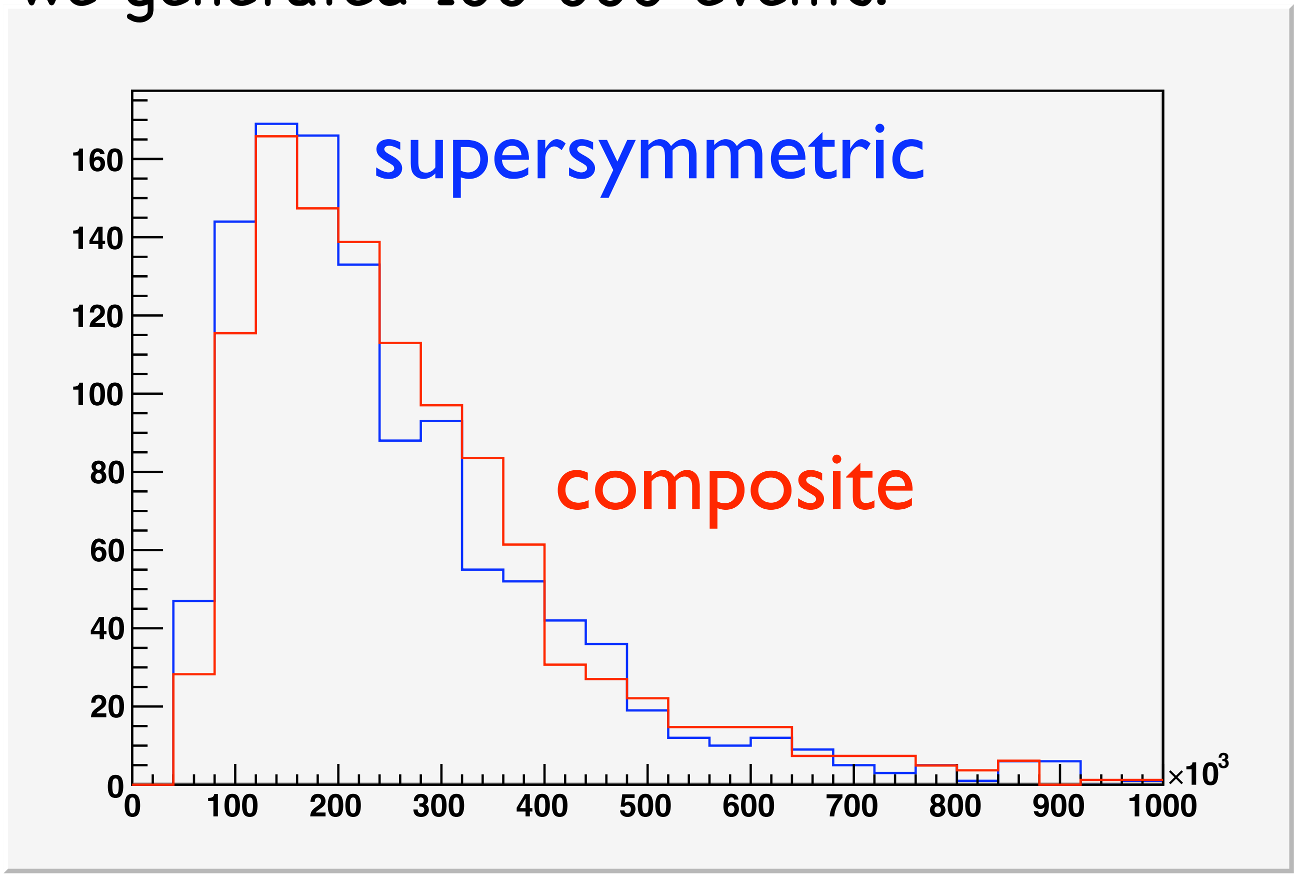
- The signal is isolated by asking
  - 2 non-b jet reconstructing a W
  - W + b jet reconstructing a top
  - another b jet to make m_{tb}(taking the b jet that give the lowest m_{tb} .)

- Results for

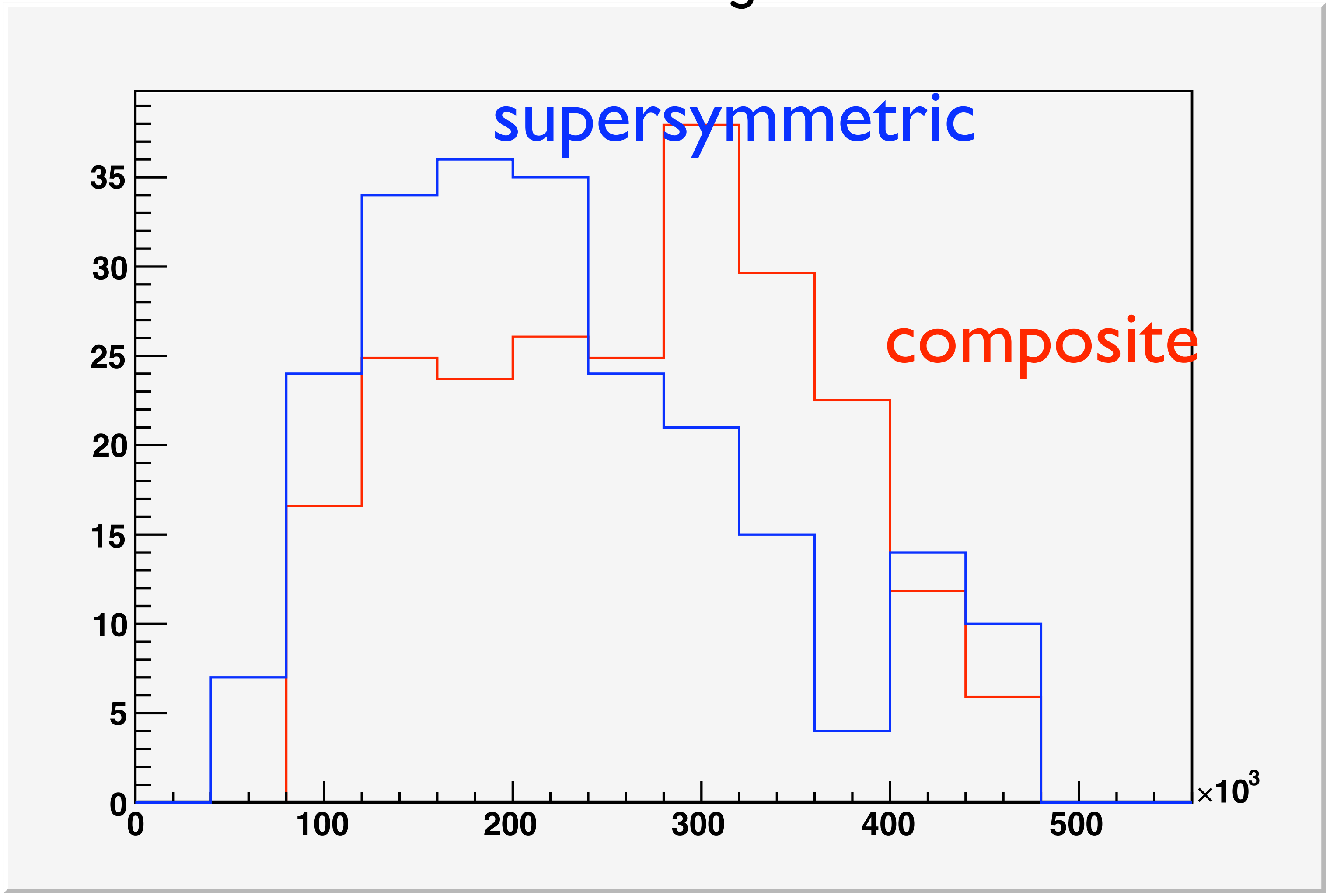
$$pp \to \tilde{g}\tilde{g} \to tt\bar{b}\bar{b}W^-W^-NN$$

$$\sigma(pp \to \tilde{g}\tilde{g}) = 300\text{fb}$$

we generated 100 000 events.



- Without combinatoric background:



- Can we reduce the combinatoric background?
  - We add an other operator in the composite model:

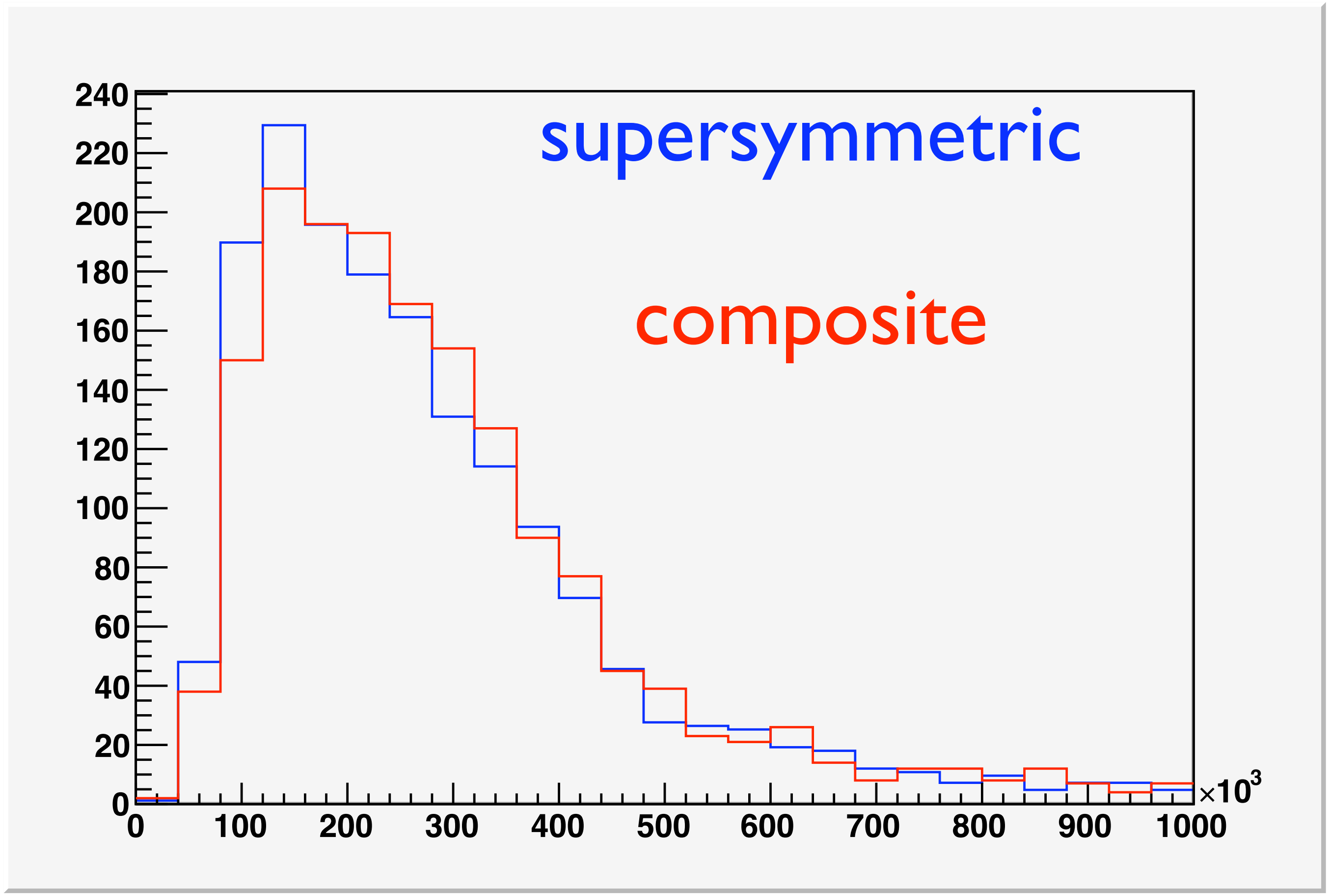
$$c_{bb}\,\frac{\tilde{g}b\bar{b}\bar{N}}{f^2}$$

  - In susy: lighter sbottom with Higgsino-like chargino.

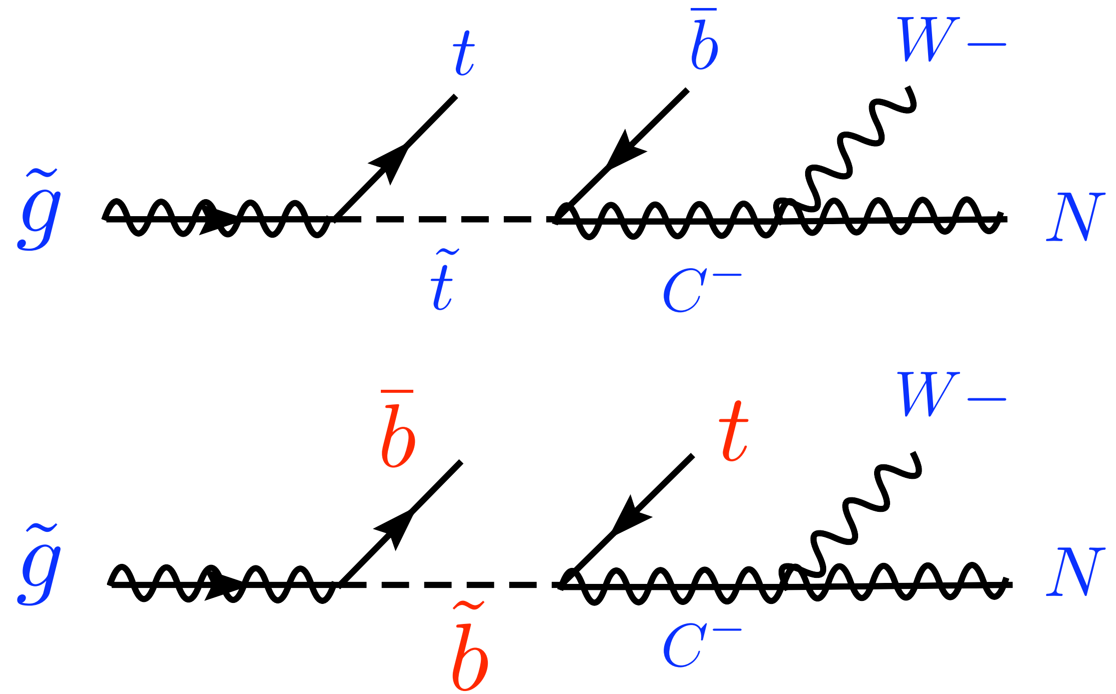
$$\tilde{g} \to b\bar{b}N$$

  - this open another channel and helps reduce some of the combinatoric.
  - Harder to avoid in supersymmetry than in composite model.

- distribution for $t\bar{b}C^{-}b\bar{b}N$ final state.



Comparaison to supersymmetry with on-shell decay.



- m_{tb}^2 distribution:

  Different endpoint:

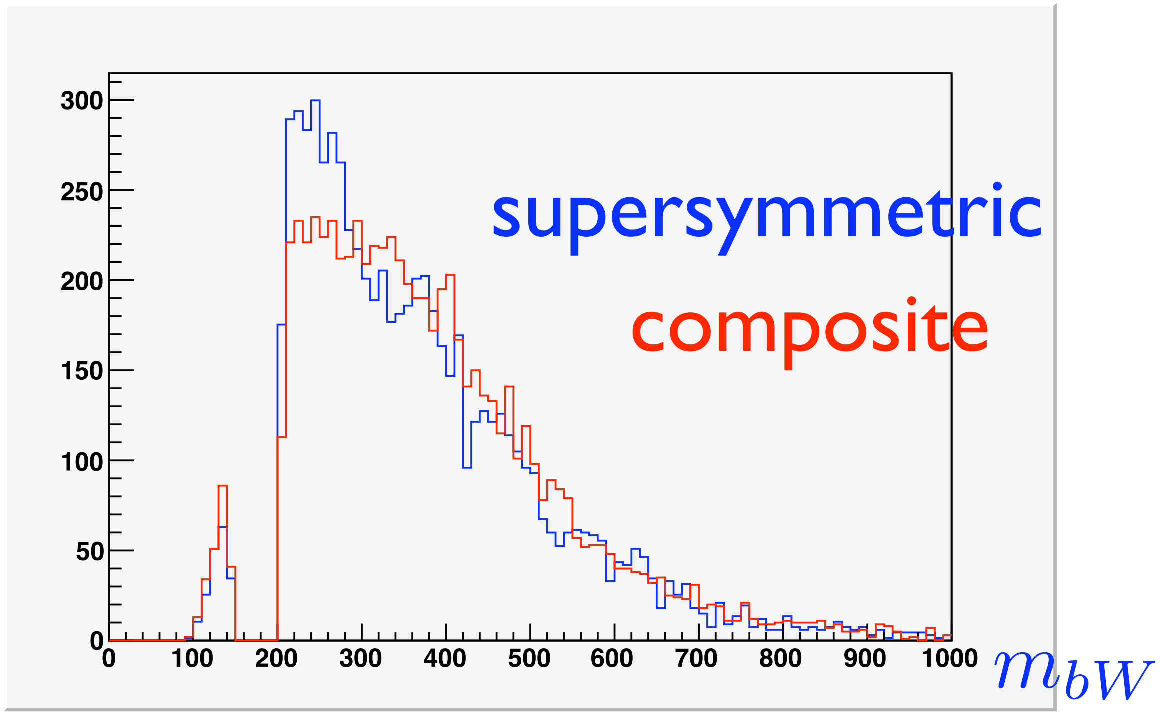
$$m^2_{tb_{\mathrm{endpoint}}} \sim (m^2_{\tilde{g}} - m^2_{\tilde{t}})(m^2_{\tilde{t}} - m^2_{C})/m^2_{\tilde{g}}$$

- Endpoint in m_{bW} also:

$$m^2_{bW\,\mathrm{endpoint}} \sim (m^2_{\tilde{t}} - m^2_{\tilde{C}})(m^2_{\tilde{C}} - m^2_{N})/m^2_{\tilde{t}}$$

$$m_{\tilde{g}} = 1\mathrm{TeV} \quad m_C = 300\mathrm{GeV} \quad m_N = 200\mathrm{GeV}$$

$$m_{\tilde{t}} = 500\mathrm{GeV} \quad m_{\tilde{b}} = 600\mathrm{GeV}$$

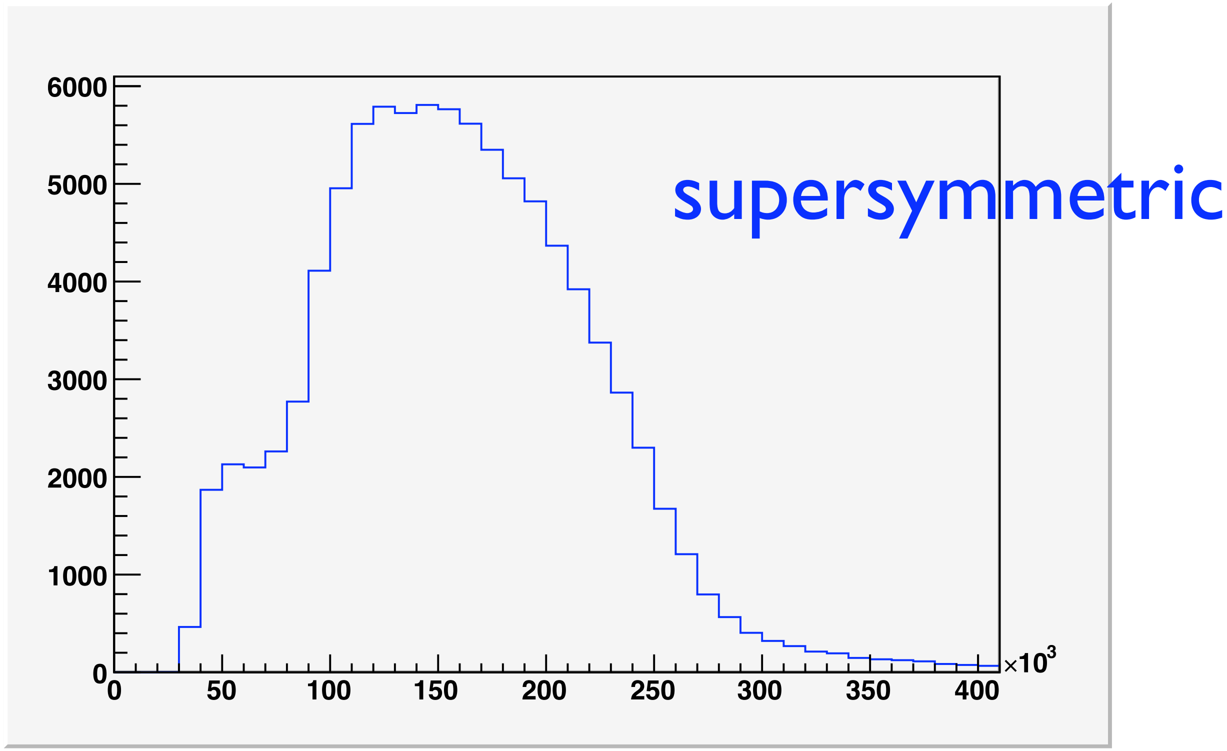


Nearly off-shell stop and sbottom

- $m_{\tilde{g}} = 1\text{TeV}$ $m_C = 300\text{GeV}$ $m_N = 200\text{GeV}$

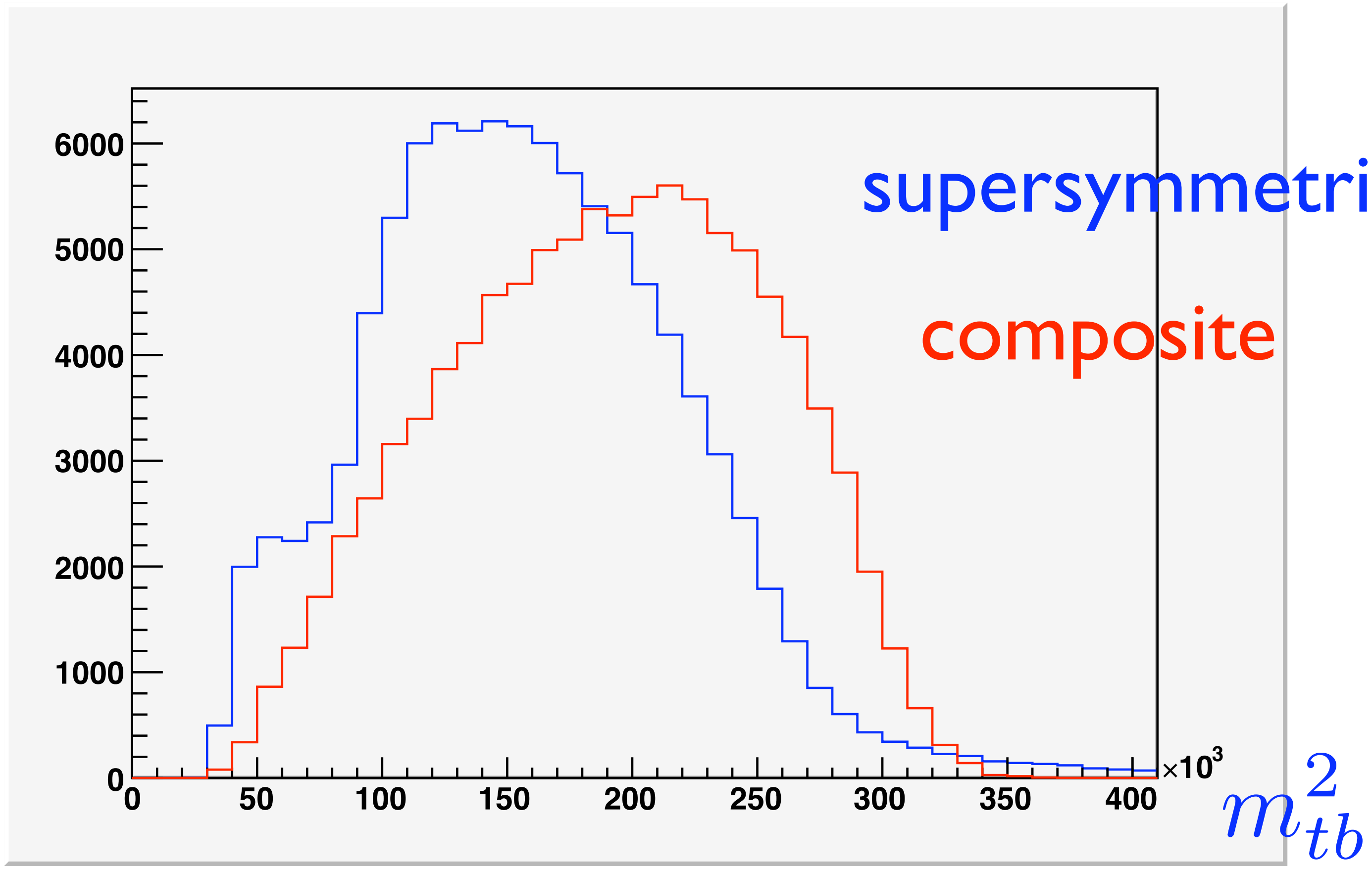
  $m_{\tilde{t}} = 800\text{GeV}$ $m_{\tilde{b}} = 900\text{GeV}$

- m_{tb}^2 theoretical distribution:

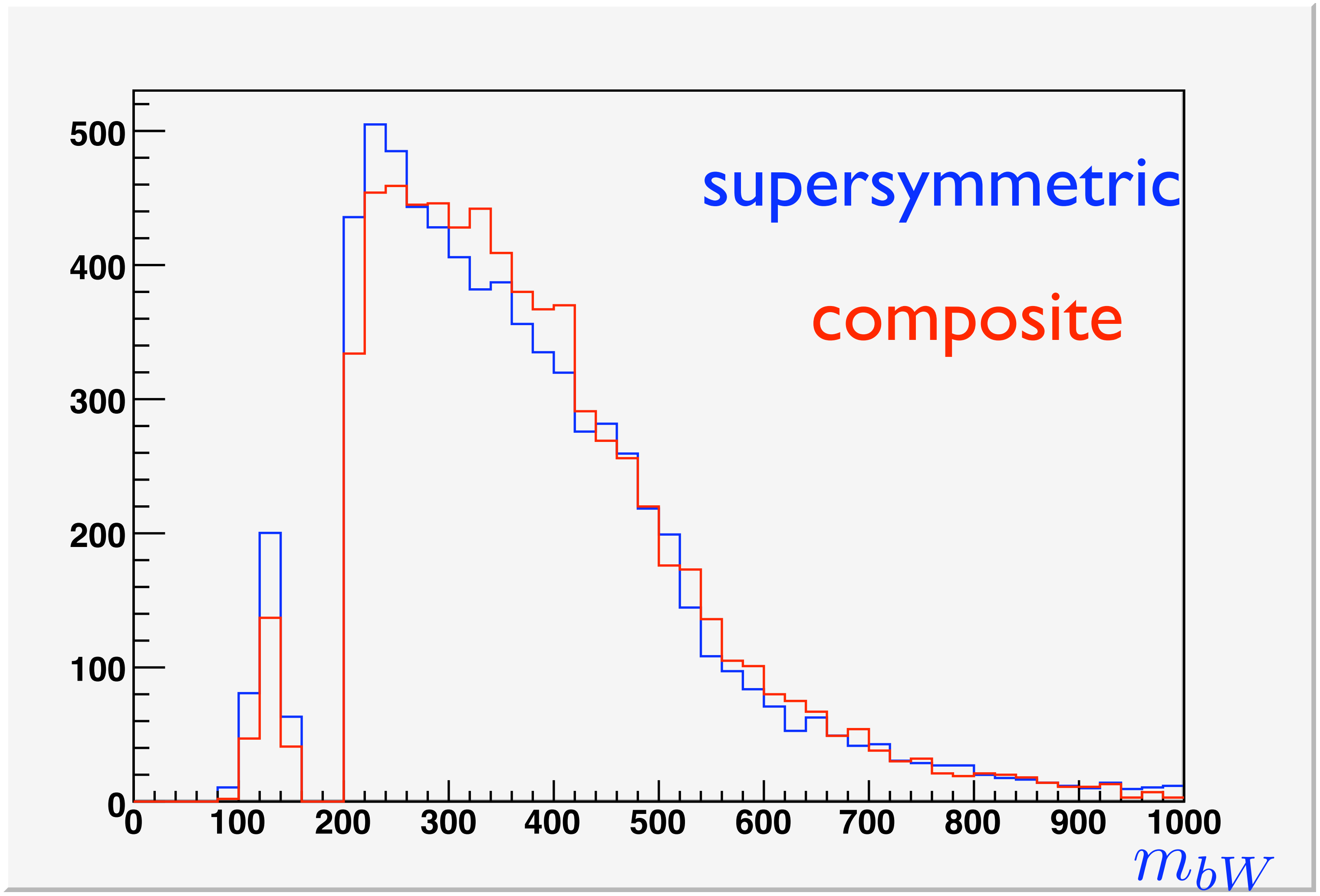


- We compare with a composite model which has the same endpoint in m_{tb}^2:

$$m_{\tilde{g}} = 1\text{TeV} \quad m_C = 450\text{GeV} \quad m_N = 350\text{GeV}$$

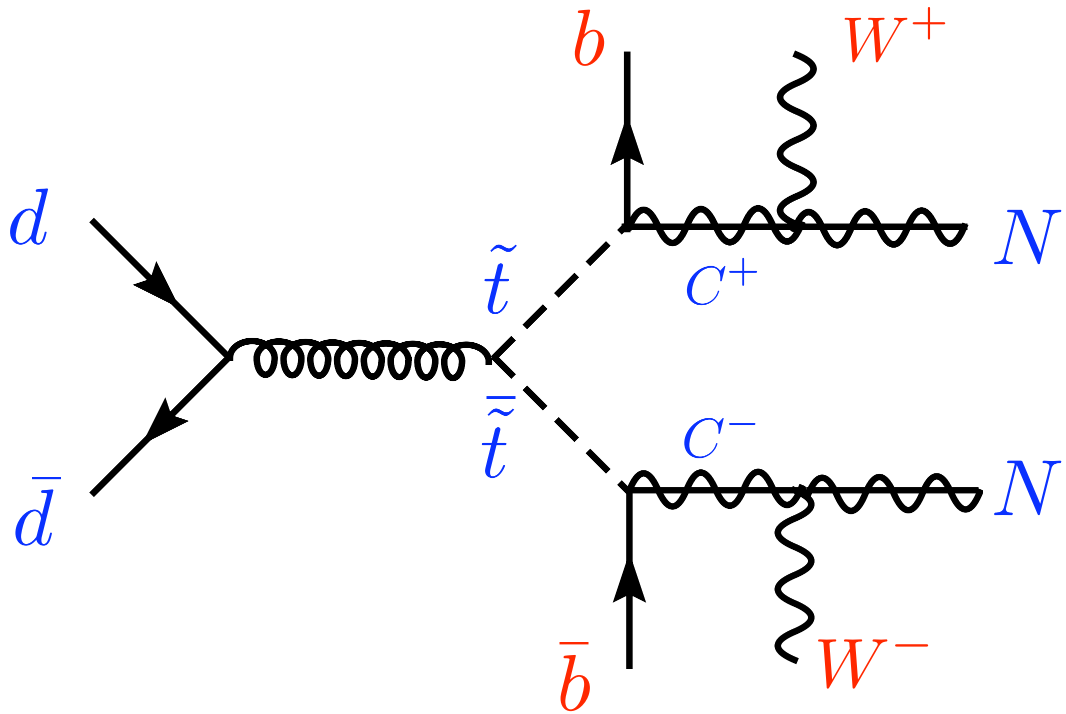


- m_{bW} endpoint



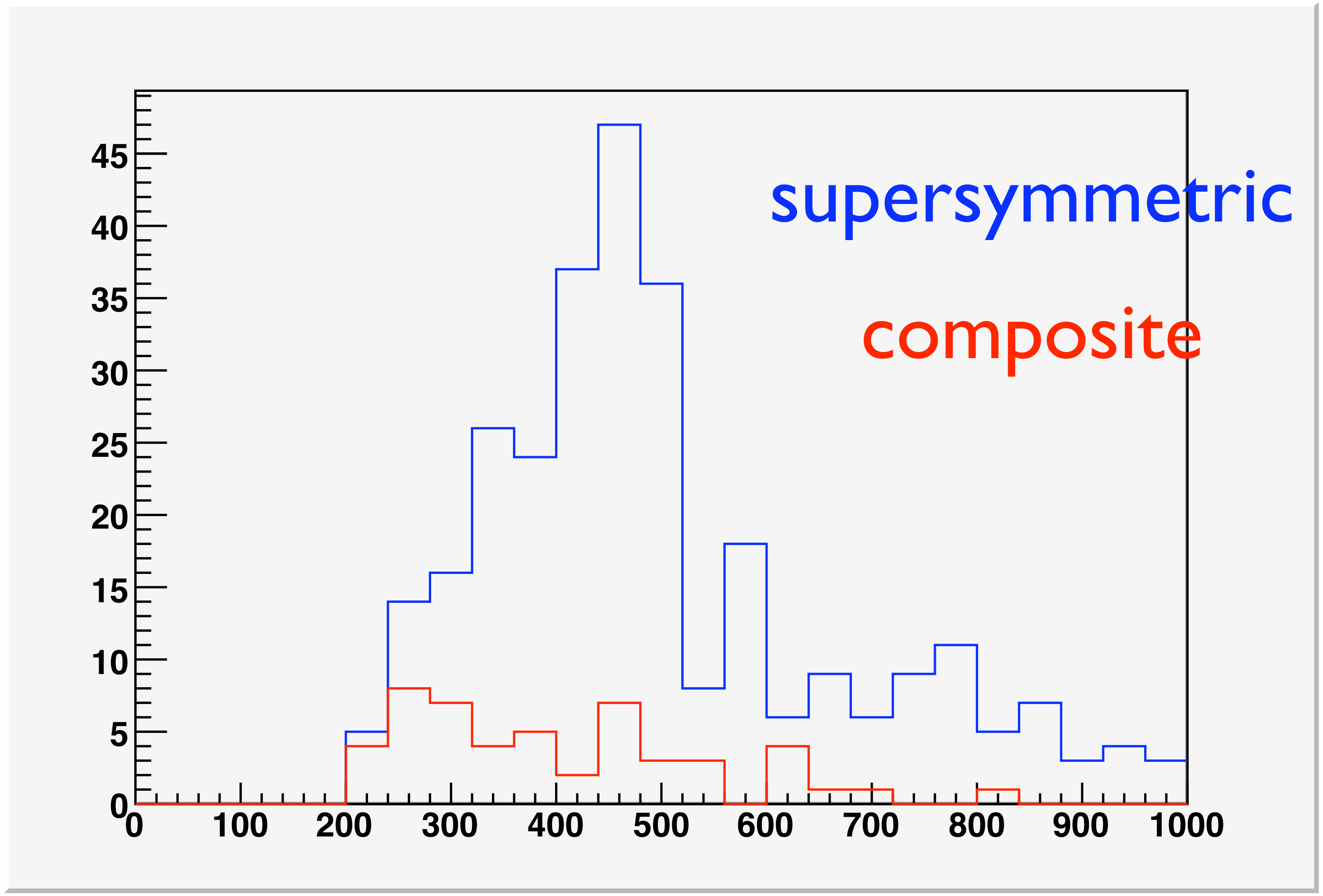
- As the stop and sbottom become heavier, the endpoint become harder to see.

  But the stop and sbottom can be produce directly.



- Cuts to isolate direct stop or sbottom production:
  - 4 jets or less with $P_T > 40\mathrm{GeV}$
  - 1 or more leptons.
  - at least 1 hard jet with $P_T > 150\mathrm{GeV}$
  - missing $E_T > 300\mathrm{GeV}$

- distribution



Conclusions

- We presented a model with composite gluinos at the TeV scale. This might be generic in this class of models.
- Could be hard to distinguish from supersymmetry if 3rd generation is lighter than the rest.
- There is information in the shape of invariant mass distribution, not only in endpoints.
- If the stop and sbottom can be produced on-shell, the situation seems better.