A Detailed Study of Third Generation Squarks at LHC

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On behalf of

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and

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- hep-ph/0204078, Phys. Rev. **D66** (2002) 115004
- hep-ph/0304214, submitted to Phys. Rev. **D**

Please refer to the documents for details.

Introduction

Stop ($\tilde{t}$) and sbottom ($\tilde{b}$) are special because of Yukawa interaction:

- Stop is lighter than other squarks because of the RGE running effect.

$$m_{\tilde{t}_R} \ll m_{\tilde{t}_L} \ll m_{\tilde{q}}.$$

- $\tilde{t}_{1,2}$ are mixing states of $\tilde{t}_R$ and $\tilde{t}_L$.

$$\begin{pmatrix} m^2_{\tilde{t}_R} + m^2_t & -m_t(A_t + \mu \cot\beta) \\ -m_t(A_t + \mu \cot\beta) & m^2_{\tilde{t}_L} + m^2_t \end{pmatrix}$$

- Sbottom mixing is also important for large $\tan\beta$ case ($\cot\beta \longrightarrow \tan\beta$ in the mass matrix).

- The stop mass $m_{\tilde{t}}$ is related to the Higgs mass m_h via radiative corrections.

$$\delta m_h \sim h_t^4 \log(m_{\tilde{t}}/m_t)$$

We want to study stop/sbottom in a model-independent way as far as possible.

Access channels

- "$bb\ell\ell$ + missing E_T" (classical channel)

$$\tilde{g} \longrightarrow b\tilde{b} \longrightarrow bb\tilde{\chi}_2^0 \longrightarrow bb\ell\ell\tilde{\chi}_1^0$$

This channel works if $\mathrm{Br}(\tilde{\chi}_2^0 \longrightarrow \ell\ell\tilde{\chi}_1^0)$ is large.

- "tb + missing E_T" (dominant mode, this analysis)

This is a purely hadronic $bbjj$ final state to reconstruct

$$\tilde{g} \longrightarrow t\tilde{t} \longrightarrow tb\tilde{\chi}_i^\pm$$

and

$$\tilde{g} \longrightarrow b\tilde{b} \longrightarrow bt\tilde{\chi}_i^\pm$$

We show that we can reproduce parton level distributions in this channel.

Our SUSY Points

- **A1, A2**: MSUGRA points slightly modified from Point 5. $M = 300$ GeV, $m = 100$ GeV, $A = \mp 300$ GeV, $\tan\beta = 10$, $\mathrm{sgn}(\mu) = 1$.
- **T1, T2**: non-MSUGRA points where stop masses and mixings are changed from **A1**.
- **B, C, G, I**: MSUGRA benchmark points where SUSY cross section is relatively high.
- **E1, E2**: MSUGRA points where only $\tilde{g} \to t\tilde{t}_1$ is allowed.
- Some other points, including SPS, are studied.

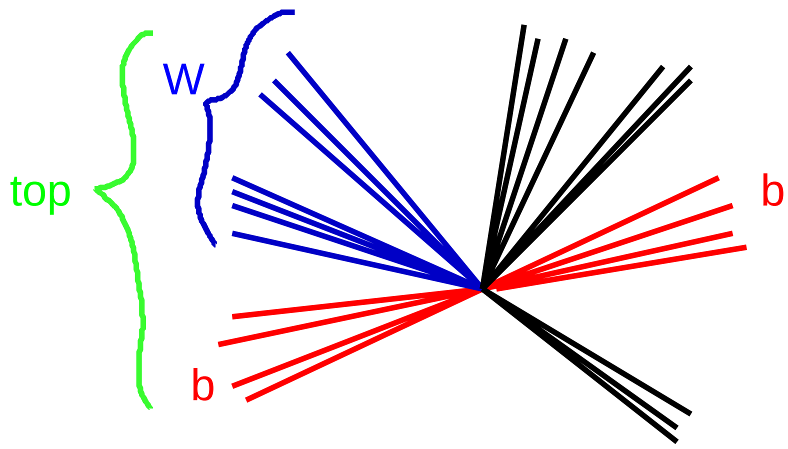
	$m_{\tilde{g}}$ (GeV)	$m_{\tilde{t}_1}$ (GeV)	$m_{\tilde{b}_1}$ (GeV)	$m_{\tilde{b}_2}$ (GeV)	$m_{\tilde{\chi}^-}$ (GeV)	σ_{SUSY} (pb)
A1	707	427	570	613	220	26
A2	706	496	587	614	211	25
T1	707	327	570	613	220	30
T2	707	477	570	612	211	25
B	609	402	504	534	179	56
C	931	636	771	805	304	5
G	886	604	714	763	285	7
I	831	571	648	725	265	10
E1	515	273	521	634	153	77
E2	747	524	770	898	232	8

Monte Carlo Simulation

- 3×10^6 events (∼120 fb^{-1} or more) at each SUSY point.
- 2×10^8 $t\bar{t}$ events (∼300 fb^{-1}) as the SM background.
- Calculation of SUSY parameters with ISAJET 7.51.
- Event Generation with PYTHIA 6.161 / HERWIG 6.4.
  - Different jet fragmentation schemes (string and parton-shower).
- Detector Simulation with a fast detector simulation program for the ATLAS experiment (ATLFAST).
  - Jet finding : jet-cone, $\Delta R = 0.4$.
  - b-tag : $\varepsilon_b = 0.6$.
  - τ-tag : $\varepsilon_\tau = 0.5$.

Selection of tb candidates

- Preselection
  - $E_T^{\mathrm{miss}} > 200$ GeV.
  - $m_{\mathrm{eff}} > 1000$ GeV ($m_{\mathrm{eff}} = E_T^{\mathrm{miss}} + \sum_{\mathrm{all}} p_T^{\mathrm{jet}}$).
  - two b-jets with $p_T > 30$ GeV.
  - lepton veto : $\min(m_{\ell b}) > 150$ GeV to reduce $t\bar{t}$ background.
  - $4 \leq n_{\mathrm{jet}} \leq 6$: number of additional jets with $p_T > 30$ GeV and $|\eta| < 3.0$.
- Look for the best top candidate.
  - a jj pair with a mass m_{jj} within $m_W \pm 15$ GeV, and calculate m_{jjb}.
  - choose the paring which minimizes $|m_{jjb} - m_t|$.
  - constrain jj as $m_{jj} = m_W$, re-calculate m_{jjb}, and require $|m_{jjb} - m_t| < 30$ GeV .



m_{tb} distribution

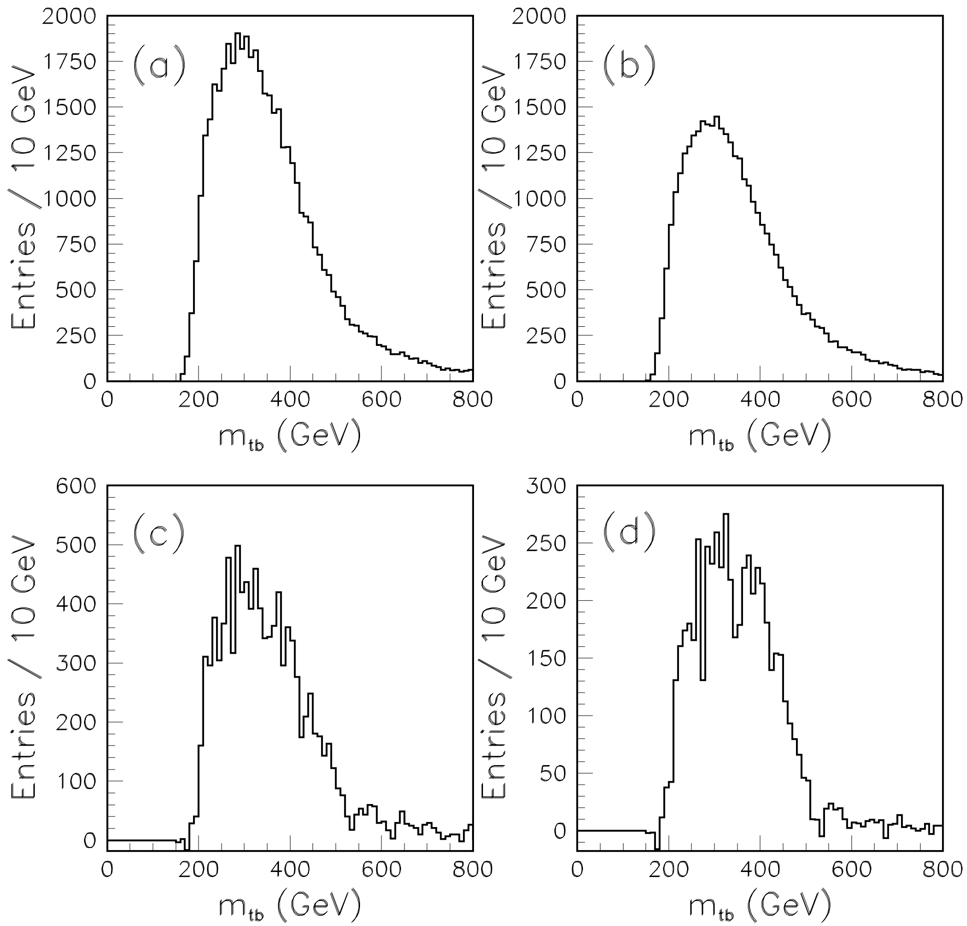
(a) m_{tb} distribution from 3×10^6 SUSY events (120 fb^{-1}) at our reference point **A1**.

(b) combinatorial background estimated by "W-sidebands".

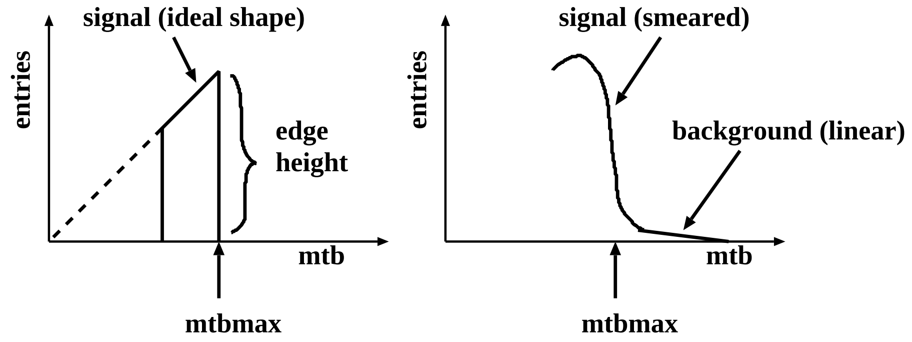
(c) m_{tb} distribution after subtracting the background. There is a clear edge; However, note that the edge is composed of two sources:

- $\tilde{g} \to t\tilde{t}_1 \to tb\tilde{\chi}_1^{\pm}$
- $\tilde{g} \to b\tilde{b}_1 \to bt\tilde{\chi}_1^{\pm}$

(d) same as (c), but only for the decay mode $\tilde{g} \to t\tilde{t}_1 \to tb\tilde{\chi}_1^{\pm}$.



Fit of m_{tb} distribution



- Ideal distribution:

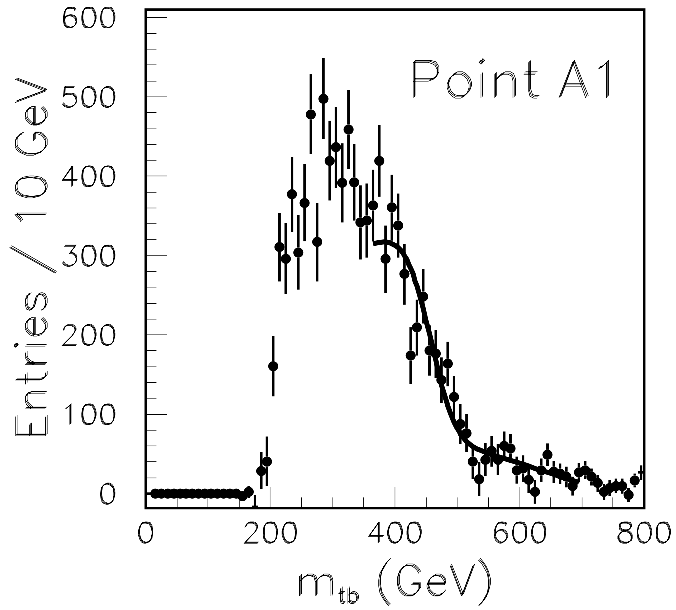
$$d\Gamma/dm_{tb} \propto m_{tb}.$$

- fit function: a smeared distribution

$$f(m_{tb}) = \frac{h}{M_{tb}^{\mathrm{fit}}} \int_{m_t+m_b}^{M_{tb}^{\mathrm{fit}}} \frac{m}{\sqrt{2\pi}\sigma} e^{-1/2[(m-m_{tb})/\sigma]^2} dm$$

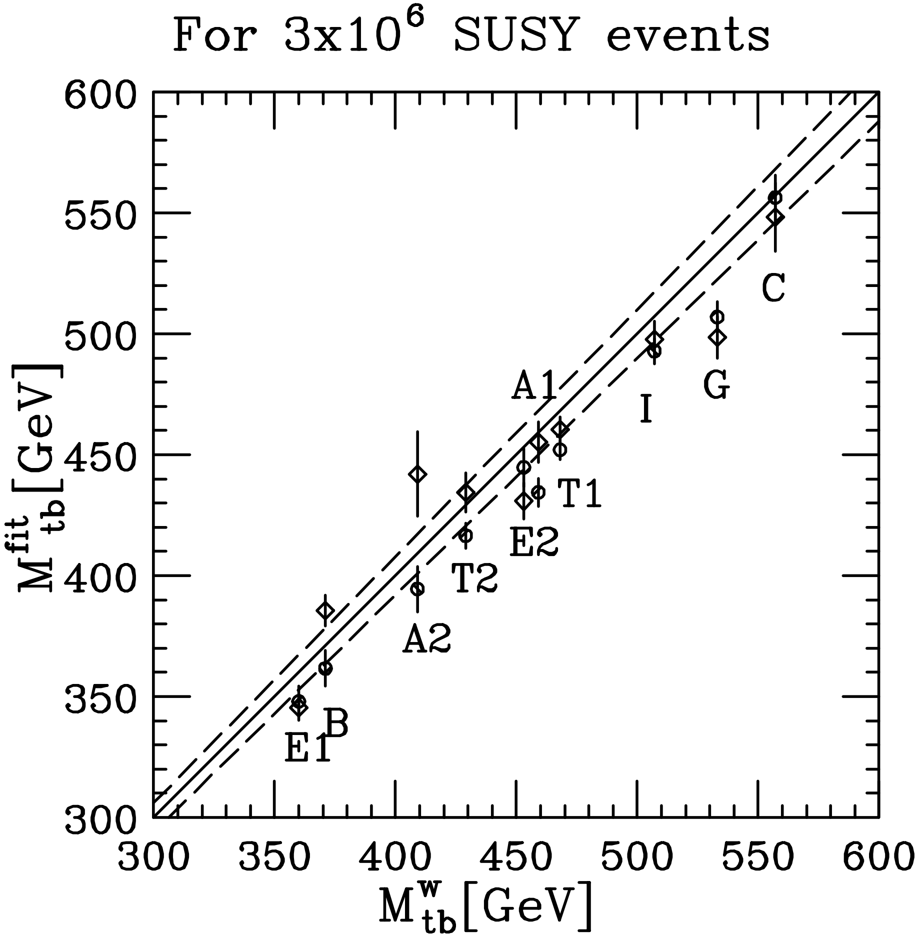
on a linear background.

- We obtain the end point M_{tb}^{fit} and the edge height h from the fit.



The end point

The fitted end point M_{tb}^{fit} should be compared with the weighted end point M_{tb}^{w}, which is defined as



$$M_{tb}^{\mathrm{w}} = \frac{\mathrm{Br}(\tilde{g} \to \tilde{t}_1 \to \chi^+) M_{tb}^{max}(\tilde{t}) + \mathrm{Br}(\tilde{g} \to \tilde{b}_1 \to \chi^+) M_{tb}^{max}(\tilde{b}_1)}{\mathrm{Br}(\tilde{g} \to \tilde{t}_1 \to \chi^+) + \mathrm{Br}(\tilde{g} \to \tilde{b}_1 \to \chi^+)}$$

A very good linear correlation in most cases !!

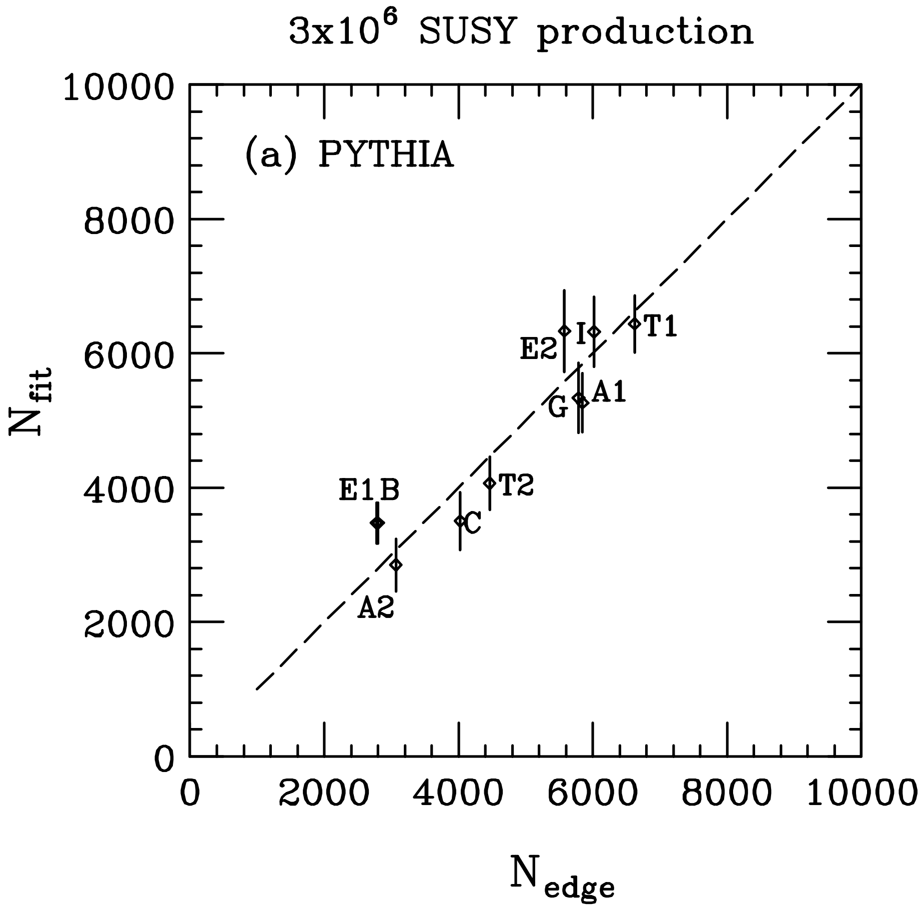
The edge height

We can estimate number of the "edge" events $N_{\rm edge}$ by the trapezoid rule:

$$N_{\rm fit} = \frac{h}{2}\left(\frac{m_t}{M_{tb}^{\rm fit}} + 1\right) \times \frac{M_{tb}^{\rm fit} - m_t}{\Delta m}$$

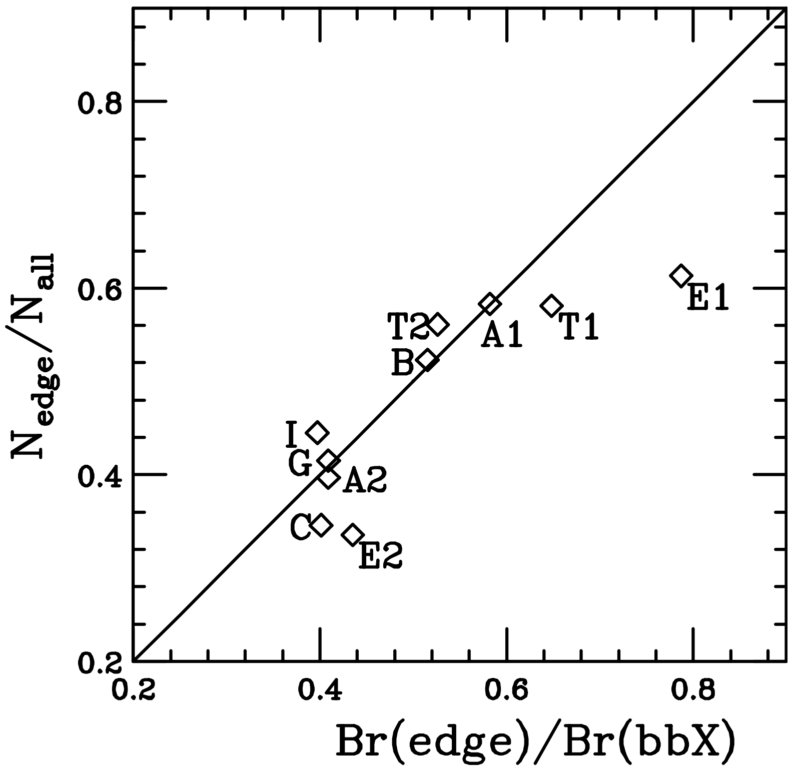
where Δm is the bin width.

- good linear correlation between $N_{\rm fit}$ and $N_{\rm edge}$,
- but some dependence on generator and jet-definition



Branching ratios

- $N_{\rm all}$ is the number of events after subtracting the sideband background.
- Good correlation between $N_{\rm edge}/N_{\rm all}$ and $\mathrm{Br(edge)}/\mathrm{Br}(\tilde{g} \to bbX)$, at the points where $\tilde{q}\tilde{g}$ production is dominant (two b quarks in the final state).
- The generator dependence is canceled.
- Some points are away from the line:
  - **C**: events with leptons from $\tilde{\chi}_1^{\pm}$ decay are killed by the lepton **VETO**.
  - **E1, E2**: $\tilde{g}\tilde{g}$ production is dominant (four b quarks in the final state).
  - **T1**: $\tilde{t}_1\tilde{t}_1$ contributes to $N_{\rm all}$.



Top polarization effect

- The top quark from $\tilde{b}, \tilde{t}$ and $\tilde{g}$ decays is polarized:
  - $\tilde{b} \longrightarrow t\tilde{\chi}_1^+$: t_L if $\tilde{\chi}_1^+ \sim \tilde{W}$,
  - $\tilde{g} \longrightarrow t\tilde{t}_1$: $\tilde{t}_1 = \tilde{t}_R \cos\theta_t + \tilde{t}_L \sin\theta_t$ and $\mathcal{L} \propto \tilde{g}t_R\tilde{t}_R + \tilde{g}t_L\tilde{t}_L$
- The bottom quark in $t \longrightarrow bW$ tends to go opposite to the top spin direction:

$$\frac{1}{\Gamma_t}\frac{d\Gamma_t}{d\cos\theta} \propto \left(\frac{m_t}{m_W}\right)^2 \sin^2\frac{\theta}{2} + \cos^2\frac{\theta}{2}$$

  where θ is the angle between the bottom direction and the top spin.

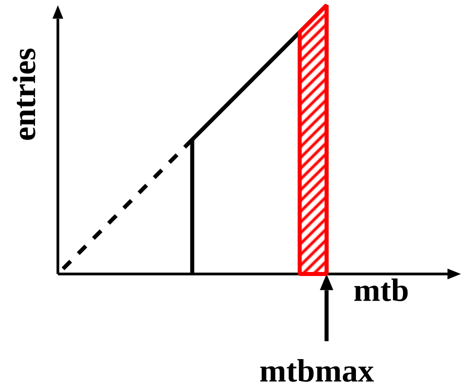
- For example, in the decay $\tilde{g} \longrightarrow t\tilde{t}_1 \longrightarrow (bW)(b\tilde{\chi}_1^+)$, distribution of the invariant mass m_{bb} must be sensitive to the top polarization.

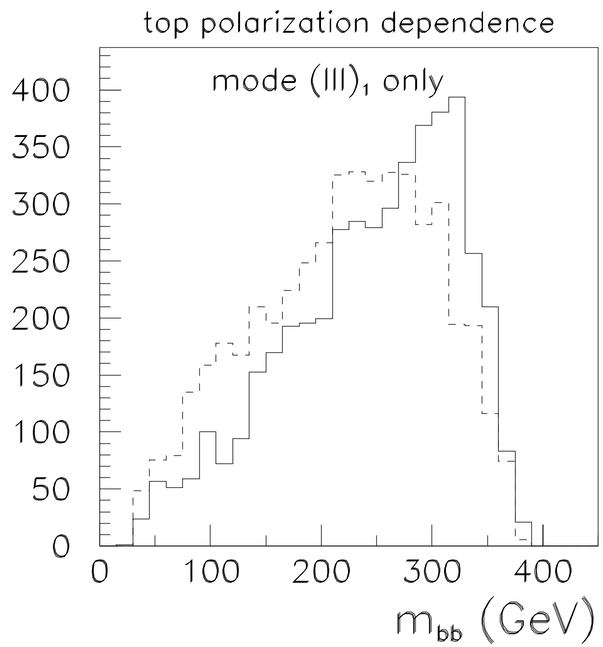
m_{bb} distribution

Maximum sensitivity is expected near the m_{tb} end point, where top and bottom go to back-to-back.

Select tb events with m_{tb} near the endpoint $\longrightarrow$ make m_{bb} distribution.

- Simulation is made with HERWIG+ATLFAST assuming $\tilde{t}_1 = \tilde{t}_L$ ($\tilde{t}_R$) and the mass spectrum at our reference point A1.
- The distributions are made for the decay $\tilde{g} \longrightarrow t\tilde{t} \longrightarrow tb\tilde{\chi}_1^+$ only.
- Statistically tough, but feasible if large $\sigma \cdot \mathrm{Br}$ and $\int \mathcal{L}dt$.





solid (dotted) histogram:

$\tilde{t}_1 = \tilde{t}_L(\tilde{t}_R)$.

Summary

- Stop/sbottom properties can be studied by reconstructing the m_{tb} distribution.
  - good correlation between $M_{tb}^{\rm fit}$ and $M_{tb}^{\rm w}$.
  - good correlation between $N_{\rm fit}$ and $N_{\rm edge}$.
  - good correlation between $N_{\rm fit}/N_{\rm all}$ and $\mathrm{Br(edge)/Br}(\tilde{g} \to bbX)$.
- Top polarization effect might be measured.
- Please refer to hep-ph/0304214 for
  - theoretical interpretations,
  - combination with other measurements,
  - event generator dependence
  - jet-algorithm dependence