Signals for Compressed SUSY at the LHC

Stephen P. Martin

Northern Illinois University

PHENO 2008

Madison, April 28, 2008

Compressed SUSY: the gluino mass parameter M_3 is taken much smaller than the wino mass parameter M_2 near the GUT scale.

- Ratio of heaviest to lightest superpartner masses is reduced compared to mSUGRA.
- Naturally allows the correct dark matter thermal relic abundance $0.09 < \Omega_{\rm CDM} h^2 < 0.13$ by top-squark-mediated LSP annihilation in the early universe: $\tilde{N}_1 \tilde{N}_1 \rightarrow t\bar{t}$.
- Ameliorates the SUSY little hierarchy problem (as in Kane-King hep-ph/9810374).

SPM, hep-ph/0703097, 0707.2812, 0801.0237, Baer, Box, Park, Tata 0707.0618

Typically need roughly $M_3/M_2 \sim 1/3$ at the GUT scale, and:

$$m_t \;<\; m_{\tilde{N}_1} \;<\; m_t + 100\,\mathrm{GeV}$$
$$m_{\tilde{N}_1} + 25\,\mathrm{GeV} < m_{\tilde{t}_1} < m_{\tilde{N}_1} + 150\,\mathrm{GeV}$$

The LSP ($\tilde{N}_1$) must be heavier than the top quark for natural dark matter from annihilation to tops.

The top squark ($\tilde{t}_1$) must be not too much heavier than the LSP.

The decay $\tilde{t}_1 \longrightarrow t\tilde{N}_1$ is generally forbidden.

In the models to follow, $\tilde{t}_1 \longrightarrow c\tilde{N}_1$.

To be specific, assume that at the GUT scale:

$$\begin{aligned} M_1 &= m_{1/2}(1 + C_{24}), \\ M_2 &= m_{1/2}(1 + 3C_{24}), \\ M_3 &= m_{1/2}(1 - 2C_{24}), \end{aligned}$$

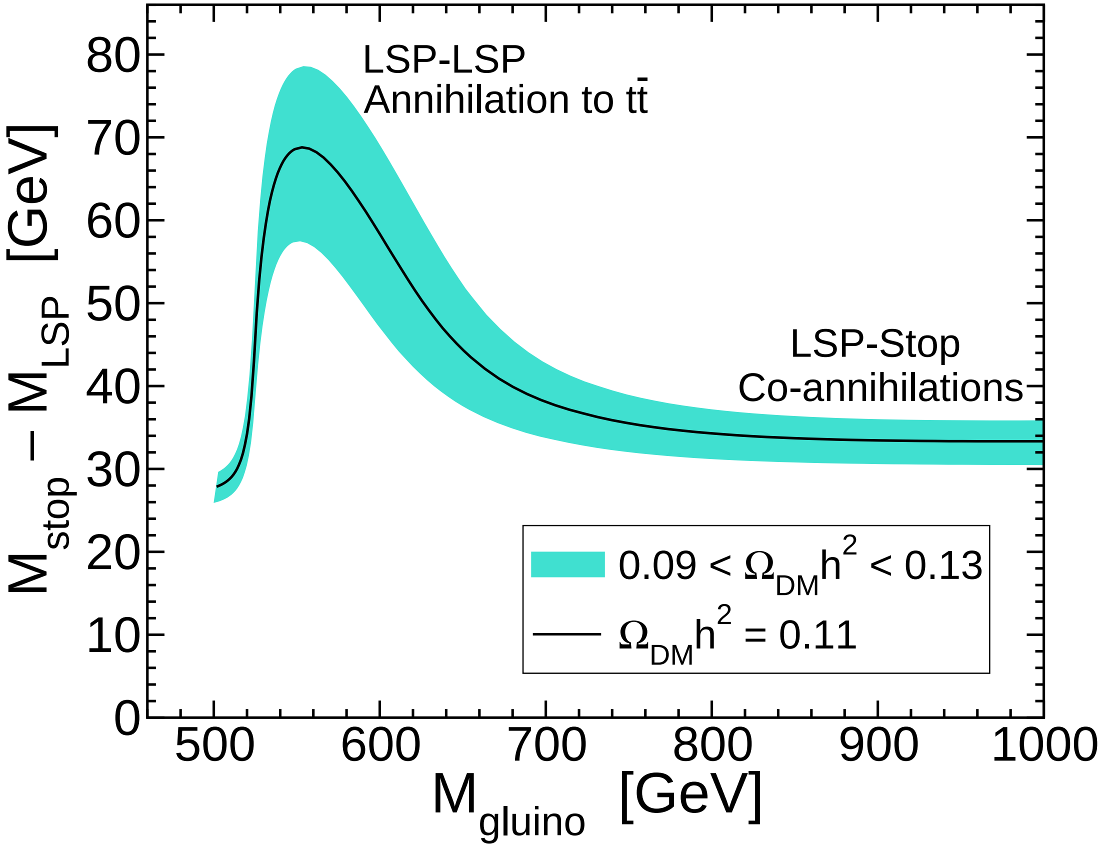
where C_{24} parameterizes the amount of $SU(5)$ adjoint ($\mathbf{24}$) F-term SUSY breaking.

$C_{24} = 0$ recovers the usual mSUGRA.

Instead, $0.15 \lesssim C_{24} \lesssim 0.28$ allows natural top-squark-mediated Dark Matter annihilation.

In this talk, I consider a Model Line with $C_{24} = 0.21$, $\tan\beta = 10$, $\mu > 0$, and varying M_1, with m_0 adjusted to give the right amount of dark matter.

Mass difference $M_{\tilde{t}_1}$ - $M_{\tilde{N}_1}$ for the dark matter allowed region of the Model Line:



The $\tilde{N}_1\tilde{N}_1 \longrightarrow t\bar{t}$ “bulge” region has enhanced detection efficiency at the LHC, because the larger mass difference gives harder jets from $\tilde{t}_1 \longrightarrow c\tilde{N}_1$.

LHC signal:

$$pp \to \tilde{g}\tilde{g} \to \begin{cases} t\,\bar{t}\,\tilde{t}_1\,\tilde{t}_1^* \to t\,\bar{t}\,c\,\bar{c} + \not{E}_T & (50\%) \\ t\,t\,\tilde{t}_1^*\,\tilde{t}_1^* \to t\,t\,\bar{c}\,\bar{c} + \not{E}_T & (25\%) \\ \bar{t}\,\bar{t}\,\tilde{t}_1\,\tilde{t}_1 \to \bar{t}\,\bar{t}\,c\,c + \not{E}_T & (25\%) \end{cases}$$

Due to the Majorana gluino, get the distinctive signal:

$$\ell^+\ell^+ bb + \text{jets} + \not{E}_T,$$
$$\ell^-\ell^- bb + \text{jets} + \not{E}_T$$

Kraml and Raklev studied this for other models in hep-ph/0512284. Their study differed in having $\tilde{t}_1$ much lighter, and other squarks much heavier.

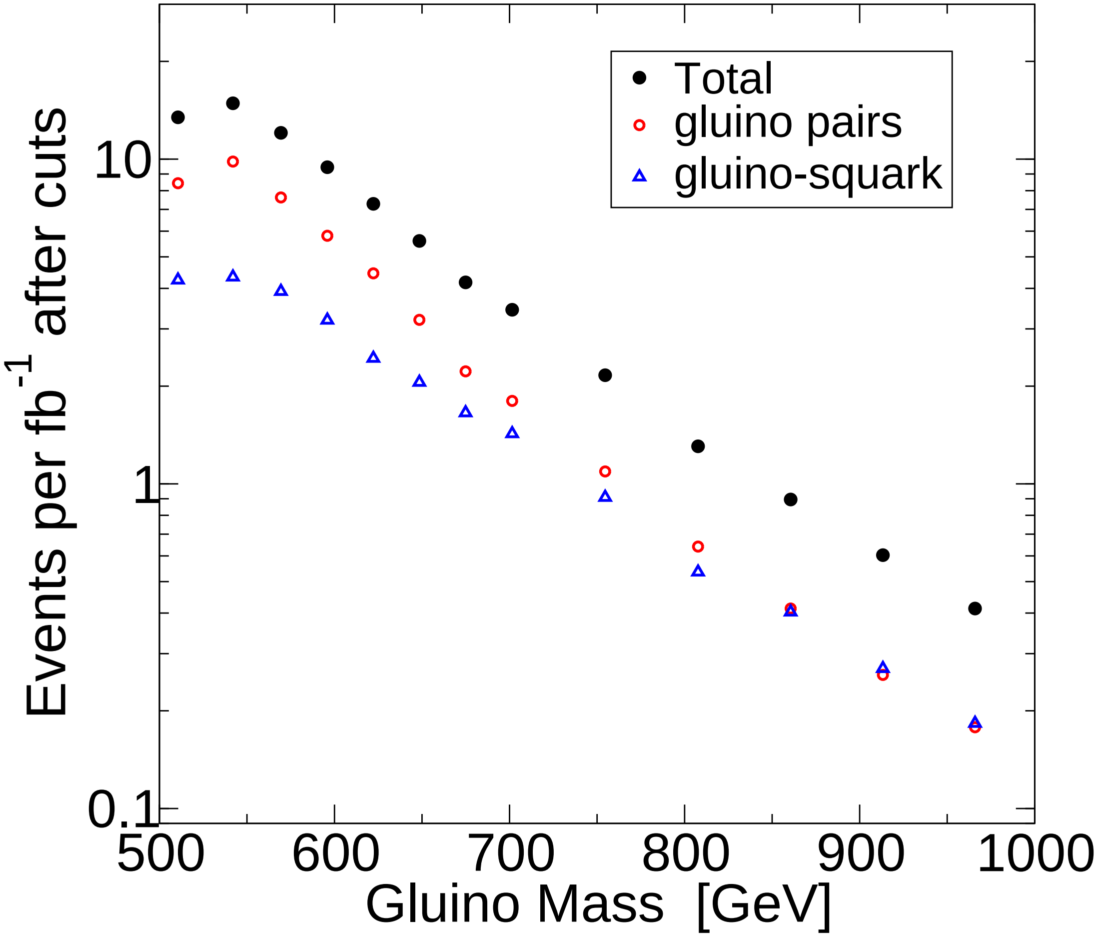
Use MadGraph/MadEvent $\longrightarrow$ Pythia $\longrightarrow$ PGS4 for event generation and detector simulation.

Cuts:

- Exactly 2 Same-Sign isolated leptons with $p_T > 20$ GeV
- One jet with $p_T > 100$ GeV,   two more with $p_T > 50$ GeV
- At least two b tags
- Two Same-Sign lepton-b pairs, each consistent with top: $m(\ell b) < 180$ GeV
- $\not\!\!E_T > 100$ GeV

With these cuts, the Standard Model background is mostly $t\bar{t}$, less than 1 event/fb^{-1}. However, depends crucially on fake rates and wrong-sign assignment rates for leptons, which are difficult to anticipate before data taking.

Signal rates, after cuts, for $bb\ell^+\ell^+ \not{E}_T$ and $bb\ell^-\ell^- \not{E}_T$:



Detection prospects will depend on how well Same-Sign lepton backgrounds can be understood, from e.g. $Z \longrightarrow \ell^+\ell^+$.

Mass determinations are hard.

- No dilepton mass edges.
- Sleptons, winos, higgsinos nearly decouple from LHC.
- Difficult to disentangle

$$pp \longrightarrow \tilde{g}\tilde{g} \longrightarrow tt\tilde{t}_1^*\tilde{t}_1^*$$

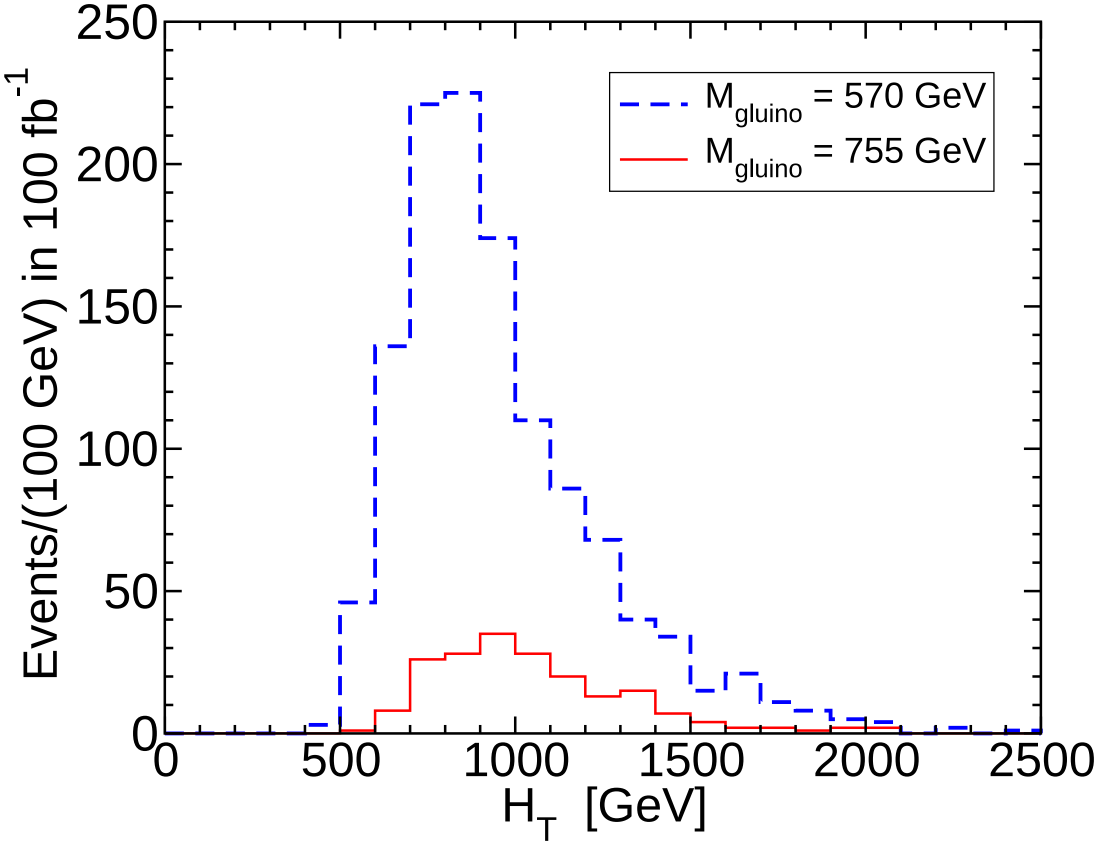
from

$$pp \longrightarrow \tilde{g}\tilde{q}_L \longrightarrow \tilde{g}\tilde{g}q \longrightarrow tt\tilde{t}_1^*\tilde{t}_1^*j$$

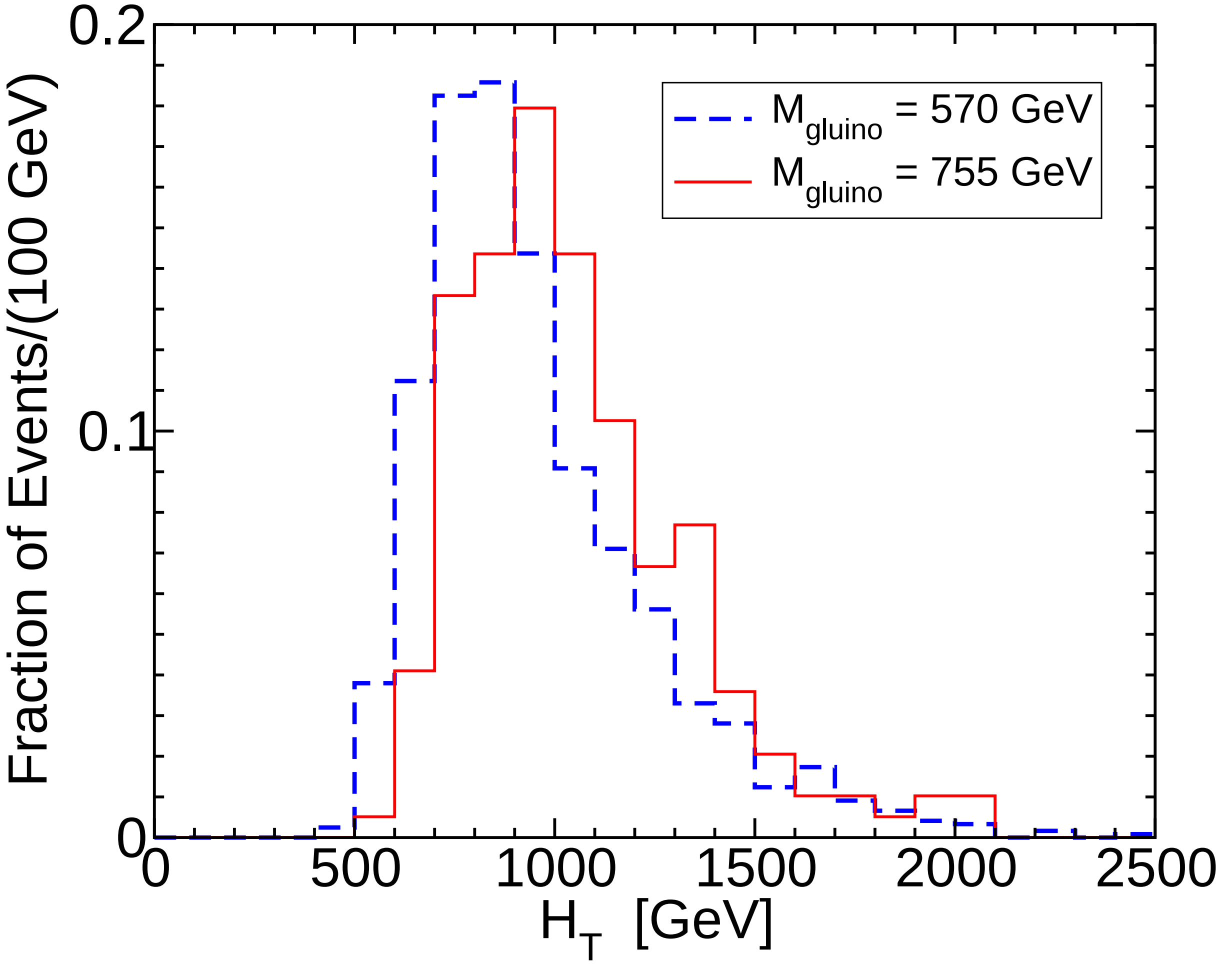
“SUSY is its own background” is especially true in Compressed SUSY.

One attempt: $H_T = \sum p_T^\ell + \sum p_T^j + \not{E}_T$

For $bb\ell^+\ell^+\not{E}_T$ and $bb\ell^-\ell^-\not{E}_T$ events for two points on the Model Line with $m_{\tilde{g}} = 570$ and 755 GeV:



Rescaled to compare the shapes:



In the classic collider signatures for SUSY,

Invisible LSPs $\longrightarrow$ Missing Energy $\longrightarrow$ No Mass Peaks

Compressed SUSY provides an exception, because of the long lifetime of $\tilde{t}_1$:

Stoponium $= \eta_{\tilde{t}} =$ s-wave $\tilde{t}_1^* \tilde{t}_1$ bound state

Drees and Nojiri 1994 proposed looking for stoponium in

$$pp \longrightarrow \eta_{\tilde{t}} \longrightarrow \gamma\gamma$$

Stoponium is very narrow, so the width is effectively that of the detector resolution for diphotons, of order 1% at CMS and ATLAS.

Stoponium in Compressed SUSY:

- is <u>always</u> stable enough to form
- Binding energy of $\eta_{\tilde{t}}$ is a few GeV
- $\Gamma_{\eta_{\tilde{t}}}$ is a few MeV
- $M_{\eta_{\tilde{t}}}$ between about 400 and 750 GeV
- BR$(\eta_{\tilde{t}} \to gg)$ dominates (but huge background)
- BR$(\eta_{\tilde{t}} \to \gamma\gamma) \approx 0.4\%$

The process

$$pp \to \eta_{\tilde{t}} \to \gamma\gamma$$

is clearly NOT a discovery mode for supersymmetry.

Importance is that it will give a uniquely precise measurement of the top-squark mass.

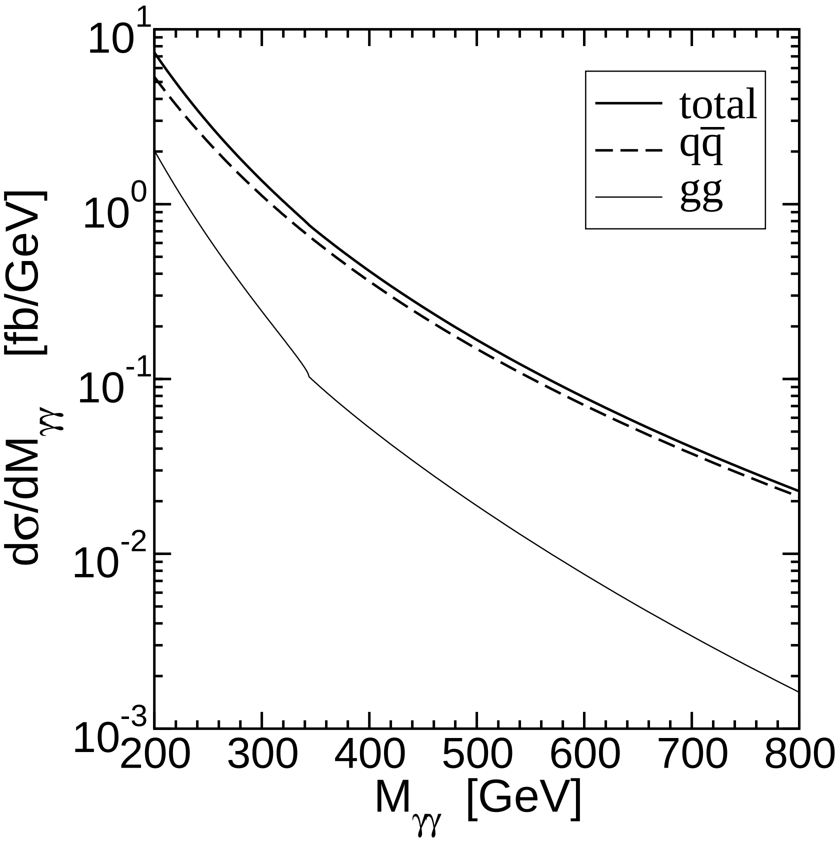
Look for a narrow diphoton mass peak against a smoothly falling background.

The irreducible physics backgrounds at leading order:

$$\begin{aligned} q\bar{q} &\rightarrow \gamma\gamma & \text{(tree-level)} \\ gg &\rightarrow \gamma\gamma & \text{(1-loop)} \end{aligned}$$

Backgrounds from fakes are thought to be smaller.

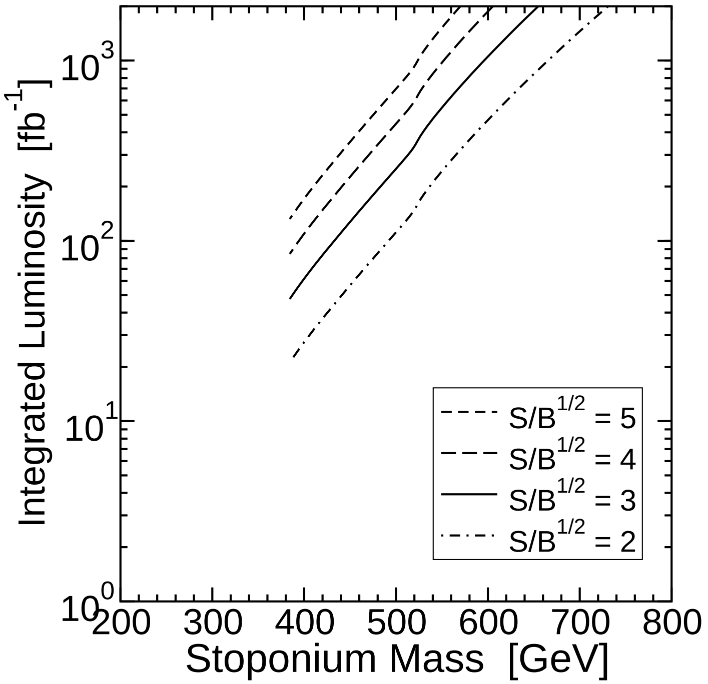
Diphoton backgrounds at LHC, at leading order, after cuts:



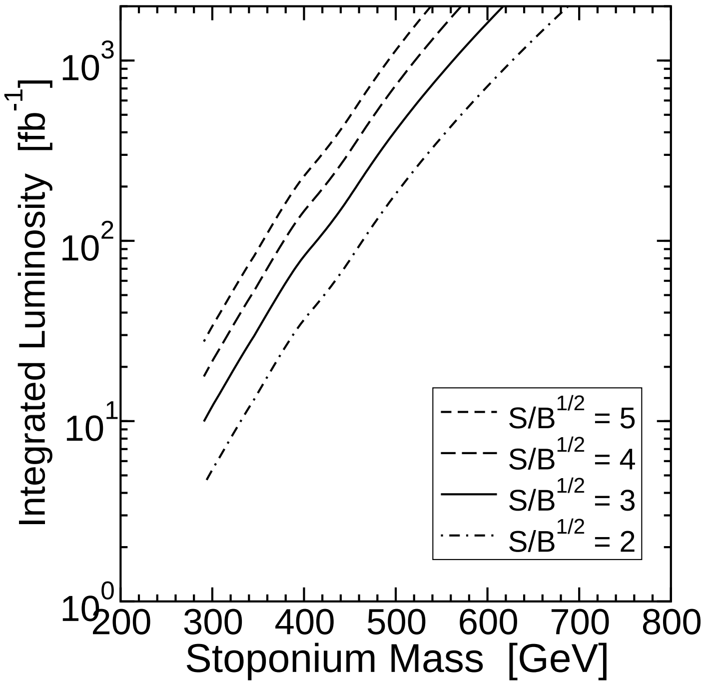
Note: actual background will be obtained from LHC data!

Luminosity needed for expected significances, for two model lines:

$C_{24} = 0.21,\ \ A_0/M_1 = -1$



$C_{24} = 0.21,\ \ A_0/M_1 = -2$



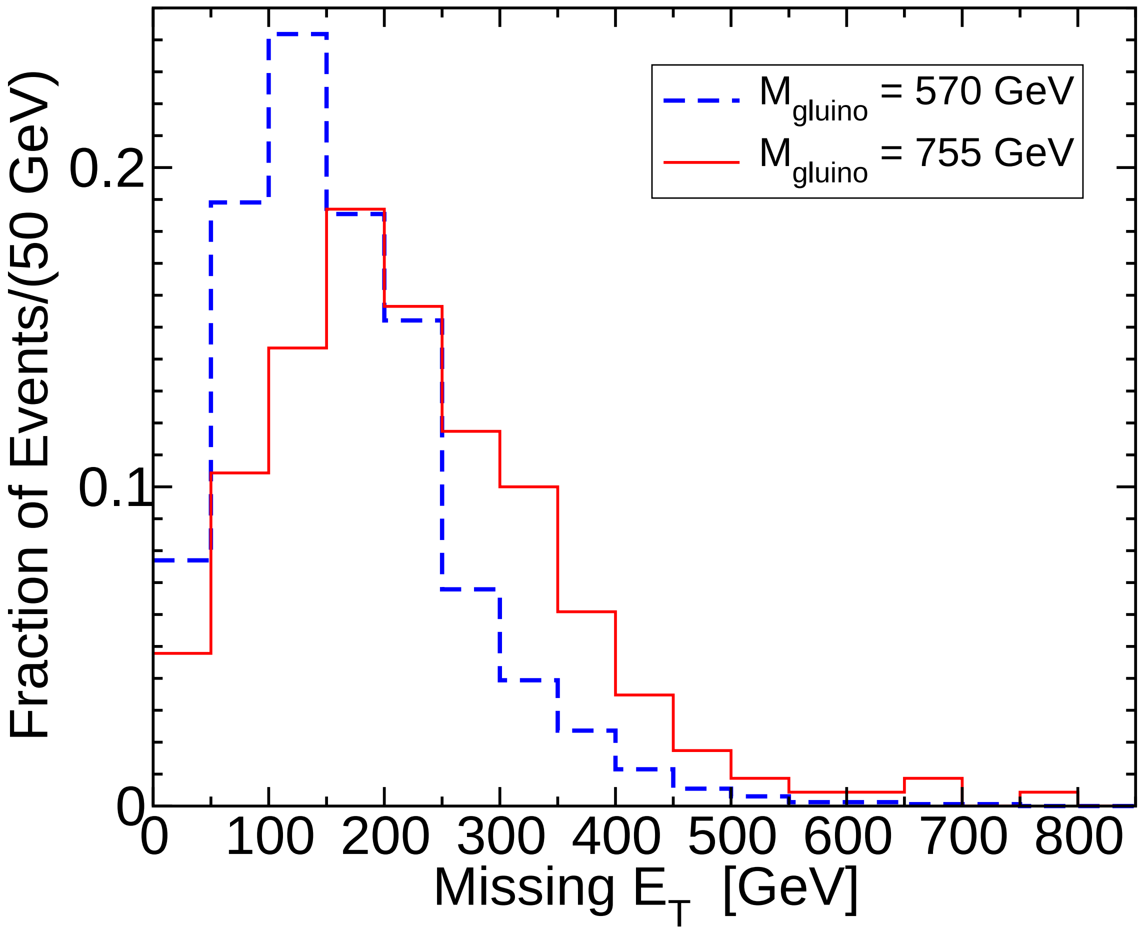
Detectability for $m_{\eta_{\tilde{t}}} = 500$ GeV will require more than 100 fb^{-1}.

For smaller $m_{\eta_{\tilde{t}}}$, a few $\times 10$ fb^{-1} might do it (if we're lucky).

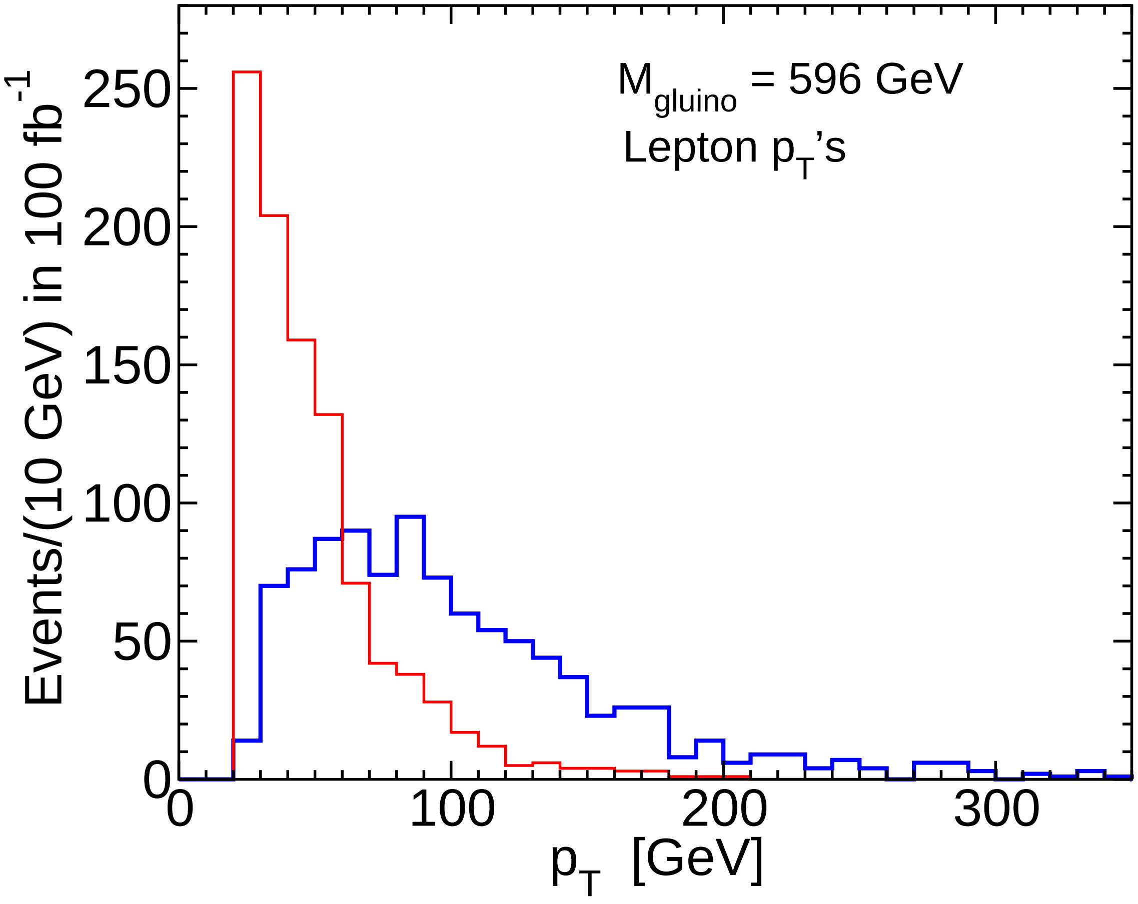
Summary:

- The talk was its own summary!

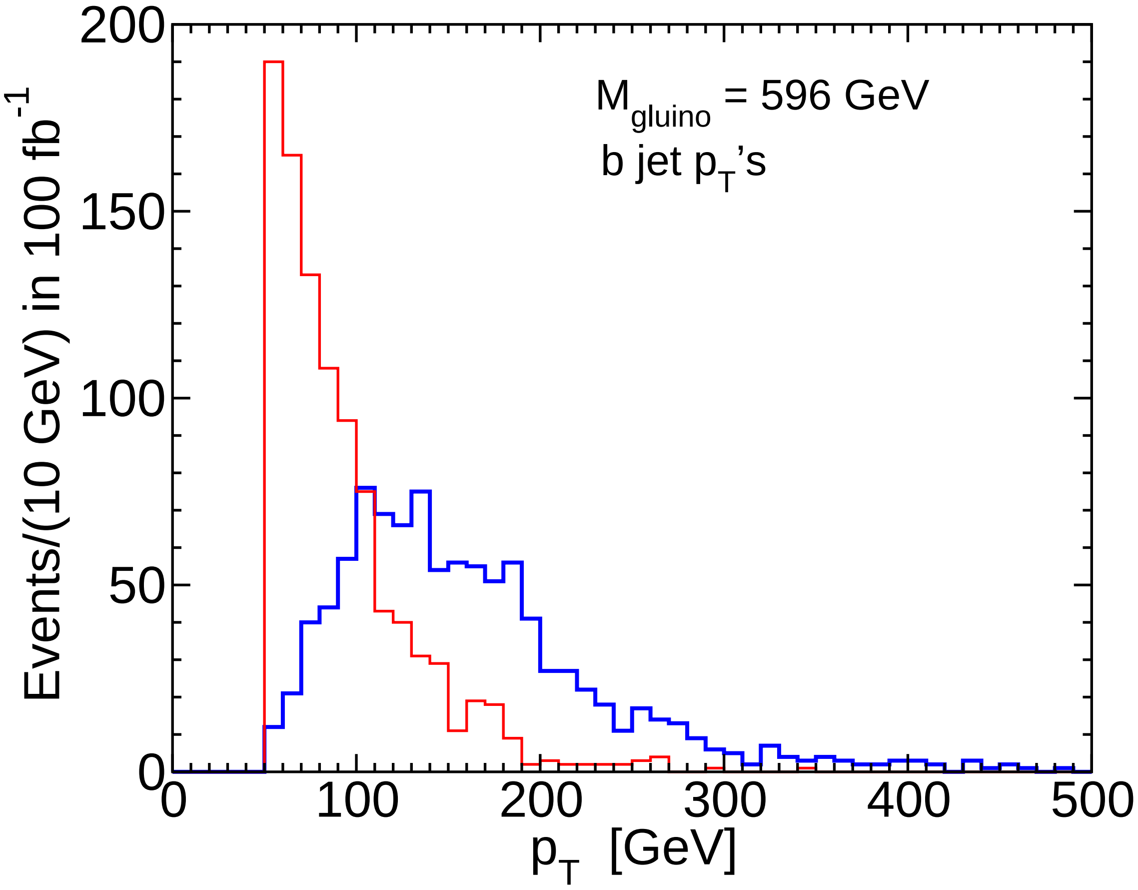
Extra slide: $\not{E}_T$ distribution



Extra slide: Lepton p_T distributions



Extra slide: b jet p_T distributions



Extra slide: jet p_T distributions