Gauge Mediated SUSY signals at LHC

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Gauge mediated models and their characteristics

Photon signals

Full reconstruction of SUSY events

Stable slepton signals

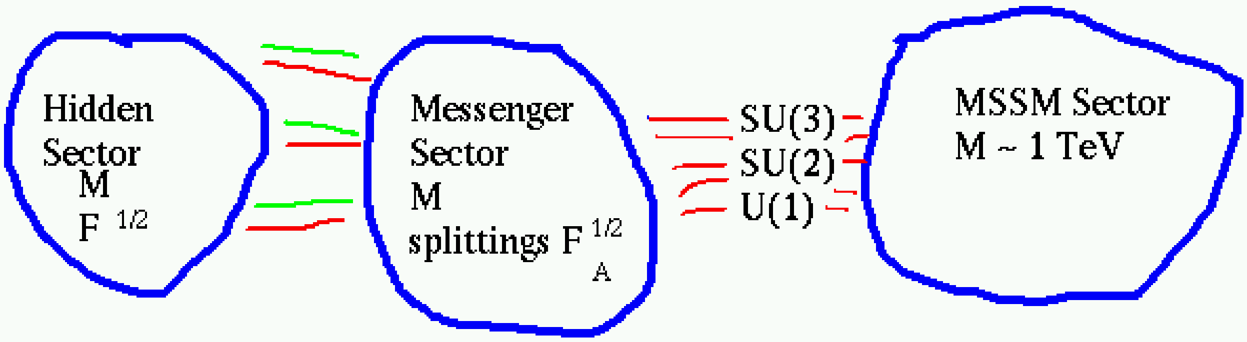
Conclusions

IH and F.Paige Atlas Note HEP-ph/98122233
http://phyweb.lbl.gov/∼ianh/florida.ps

Gauge Mediated models

- Most studies in SUGRA model
  Lightest SUSY particle (LSP) is stable, massive, neutral and weakly interacting
- Classic signals of leptons+jets+missing E_T
- Model is only one of many
- Has some theoretical problems (*e.g.*FCNC)
- Look for new features not present in other models

GMSB model

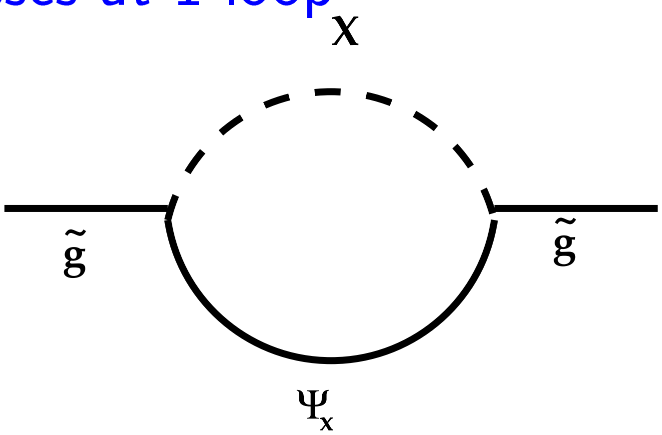


- Aims to solve FCNC problem by using gauge interactions instead of Gravity to transmit SUSY breaking
- Messenger Sector consists of some particles (X) that have SM interactions and feel SUSY breaking.

  $M_M^2 = M^2 \pm F_A$

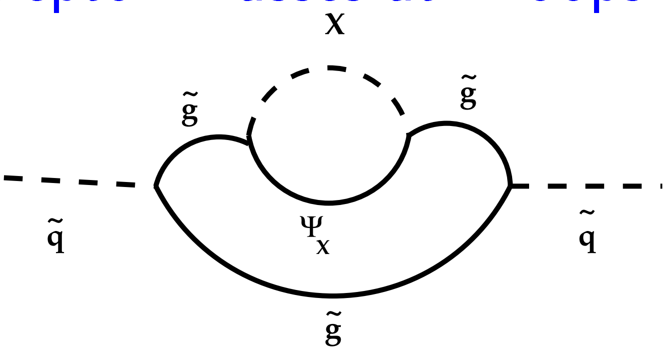
  Simplest X is complete SU(5) **5** or **10** to preserve GUT
- $F > F_A$, but $\sqrt{F} \lesssim 10^{10}$ GeV or SUGRA breaking will dominate

Gaugino masses at 1 loop



$$M_{\tilde{g}} \sim \alpha_s N_X \Lambda$$

Squark and slepton masses at 2 loops



$$m_{\tilde{q}}^2 \sim \alpha_s^2 N_X \Lambda^2$$

- Lightest supersymmetric particle is gravitino

$$M_{\tilde{G}} = F/M_{\text{Planck}} \ll 1\,\text{GeV}$$

Cannot be produced directly

- SUSY particles produced
- Cascade to lightest partner (NLSP)
- Two cases
- NLSP neutral (like LSP of SUGRA) but
- NLSP is unstable
  $\chi_1^0 \to \gamma\tilde{G}$

$$c\tau \sim .C^2(100\ \text{GeV}/M_{\chi_1^0})^5(\Lambda/180\text{TeV})^2(M_M/180\text{TeV})^2\text{mm}$$

- All events have 2 photons if $c\tau$ small.
- Like SUGRA if $c\tau$ large
- NLSP charged $\tilde{e}$, $\tilde{\mu}$ **and** $\tilde{\tau}$
  Decays are $\tilde{e} \to \tau e\tilde{\tau}$ (large $\tan\beta$)
  $\tilde{e} \to \nu_\tau\nu_e\tilde{\tau}$ (**Very** slow) or
  $\tilde{e} \to e\tilde{G}$
- No Missing E_T if $c\tau$ large

Use Isajet implementation of model

Model parameters:

- $10\,\text{TeV} \lesssim \Lambda \equiv F_m/M_m \lesssim 400\,\text{TeV}$: Scale for SUSY masses.
- $M_m > \Lambda$: Messenger mass scale.
- $N_5 \geq 1$: Number of equivalent $5 + \bar{5}$ messenger fields.
- $1 \lesssim \tan\beta \lesssim m_t/m_b$: Usual ratio of Higgs VEV's.
- $\text{sgn}\,\mu = \pm 1$: Usual sign of μ parameter.
- $C_{\text{grav}} \geq 1$: Ratio of $M_{\tilde{G}}$ to value from F_m.

Masses

$$
\begin{aligned}
m_{\tilde{g}} &= \frac{\alpha_s}{4\pi}\Lambda N_5 \\
m^2_{\tilde{e}_L} &= \frac{3\alpha_2^2}{32\pi^2}\Lambda^2 N_5 + \frac{3\alpha_1^2}{160\pi^2}\Lambda^2 N_5 \\
m^2_{\tilde{e}_R} &= \frac{3\alpha_1^2}{40\pi^2}\Lambda^2 N_5 \\
m^2_{\tilde{u}_L} &= \frac{\alpha_s^2}{6\pi^2}\Lambda^2 N_5 + \frac{3\alpha_2^2}{32\pi^2}\Lambda^2 N_5 + \frac{\alpha_1^2}{480\pi^2}\Lambda^2 N_5 \\
m^2_{\tilde{u}_R} &= \frac{\alpha_s^2}{6\pi^2}\Lambda^2 N_5 + \frac{\alpha_1^2}{30\pi^2}\Lambda^2 N_5
\end{aligned}
$$

Dependence upon M_m arises from evolution to the weak scale.

Will Illustrate two cases

Photons and stable sleptons (see paper for other, less interesting, cases)

GMSB with prompt $\tilde{\chi}_1^0 \to \tilde{G}\gamma$.

$$\Lambda_m = 90\,\text{TeV},\ M_m = 500\,\text{TeV},\ N_5 = 1,$$
$$\tan\beta = 5,\ \text{sgn}\,\mu = +,\ C_{\text{grav}} = 1$$

Representative masses (in GeV) from ISAJET:

$$M_{\tilde{g}} = 744,\ M_{\tilde{q}_L} = 983,\ M_{\tilde{q}_R} = 937,$$
$$M_{\tilde{\chi}_4^0} = M_{\tilde{\chi}_2^\pm} = 468,\ M_{\tilde{\chi}_3^0} = 449,$$
$$M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm} = 223,$$
$$M_{\tilde{\ell}_R} = 164,\ M_{\tilde{\chi}_1^0} = 119$$
$$M_h = 109$$

- SUSY cross section is 7.6 pb.
- NLSP decays $\chi_1^0 \to \tilde{G}\gamma$ with $c\tau = 1.2\,\text{mm}$.
- All events have two photons and missing E_T
- Standard model background small.
- Large production of χ_2^0 in squark/gluino decay

Lifetime?

- Measure lifetime of χ_1^0 using Dalitz decay $\chi_1^0 \to e^+e^-\gamma\tilde{G}$
- Use vertex from e^+e^- pair measure it.
- Statistics limited (∼few-K events)
- Not studied
- Very important as it measures the fundamental scale of SUSY breaking

Event selection (not optimized)

Find jets

$$M_{\text{eff}} \equiv \not{E}_T + p_{T,1} + p_{T,2} + p_{T,3} + p_{T,4} \,.$$

Require

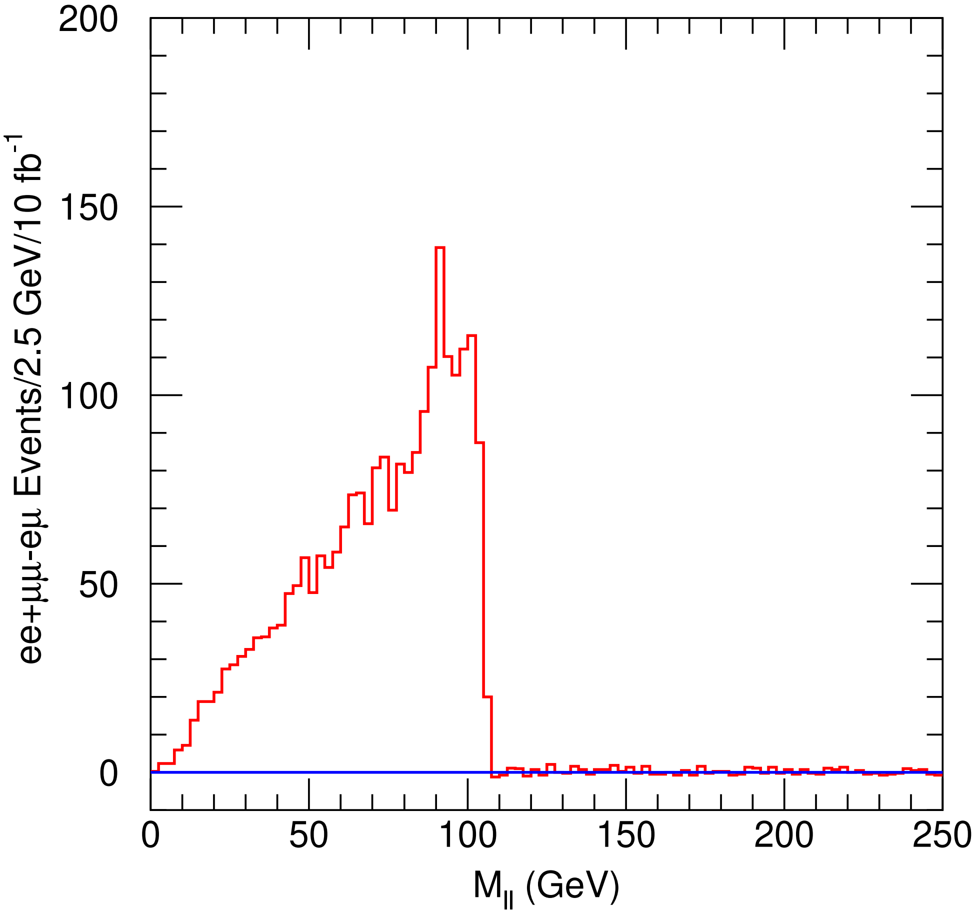
- $M_{\text{eff}} > 400\,\text{GeV}$;
- $\not{E}_T > 0.1 M_{\text{eff}}$.

Looking for

$$\tilde{\chi}_2^0 \to \tilde{\ell}^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^\pm \ell^\mp \to \tilde{G} \gamma \ell^\pm \ell^\mp \,,$$

- Electrons and photons : $p_T > 20\,\text{GeV}$
- Muons : $p_T > 5\,\text{GeV}$.
- Require at least 2 photons and two leptons.

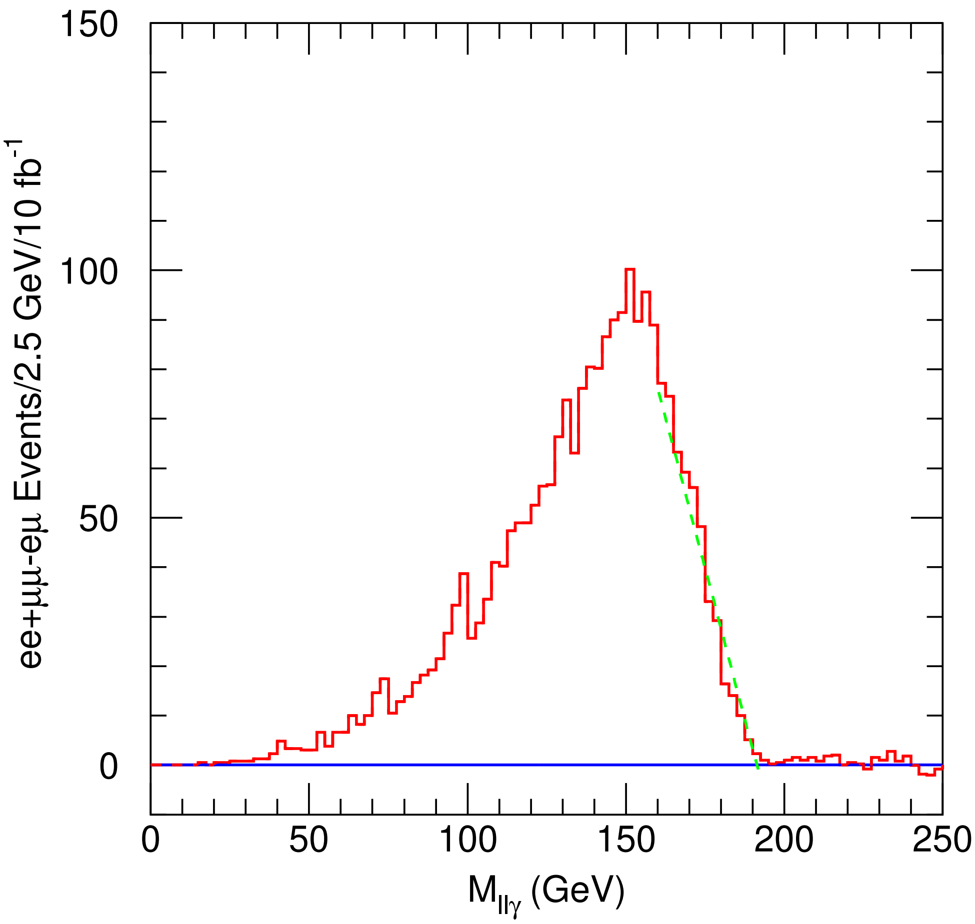
Dilepton mass distribution, flavor subtracted $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$



End is at

$$M_{\tilde{\chi}_2^0}\sqrt{1-\left(\frac{M_{\tilde{\ell}_R}}{M_{\tilde{\chi}_2^0}}\right)^2}\sqrt{1-\left(\frac{M_{\tilde{\chi}_1^0}}{M_{\tilde{\ell}_R}}\right)^2} = 105.1\,\text{GeV}.$$

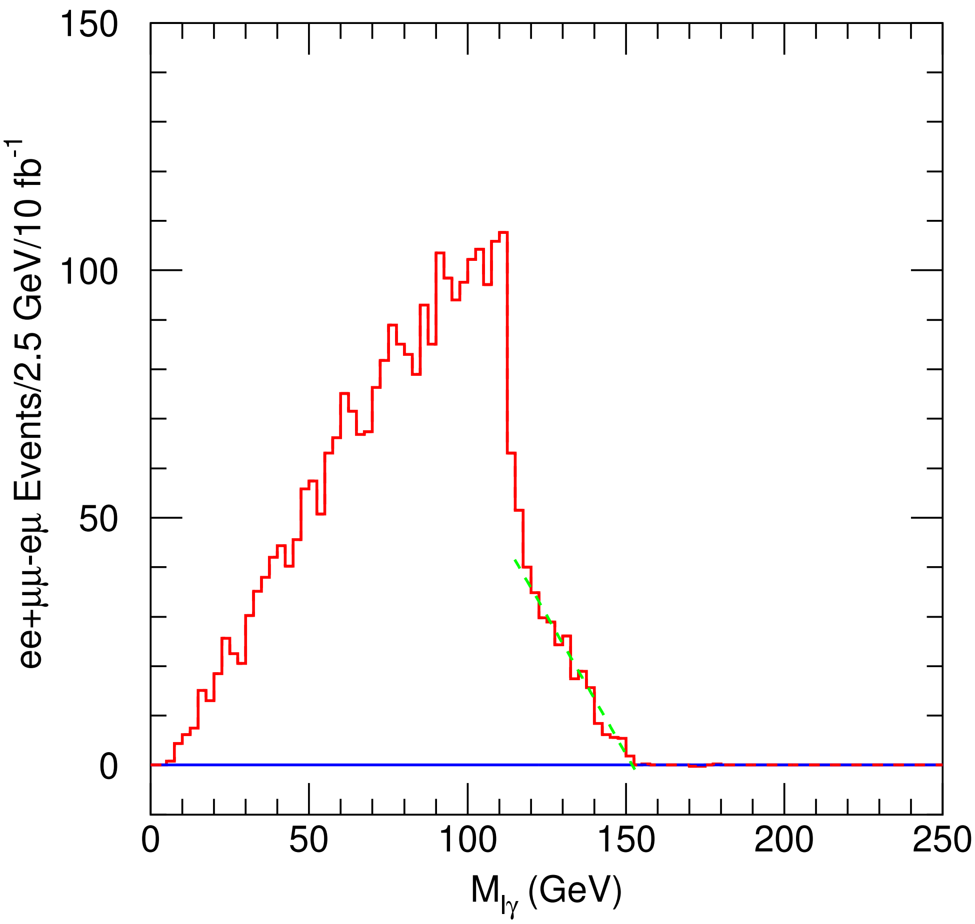
Form $\ell^+\ell^-\gamma$ mass and take smallest combination



Linear vanishing at

$$\sqrt{M^2_{\tilde{\chi}^0_2} - M^2_{\chi^0_1}} = 189.7\,\text{GeV} \,,$$

Form $\ell^{\pm}\gamma$ mass also



Two structures at

$$\sqrt{M^2_{\tilde{\ell}_R} - M^2_{\chi^0_1}} = 112.7\,\mathrm{GeV}$$

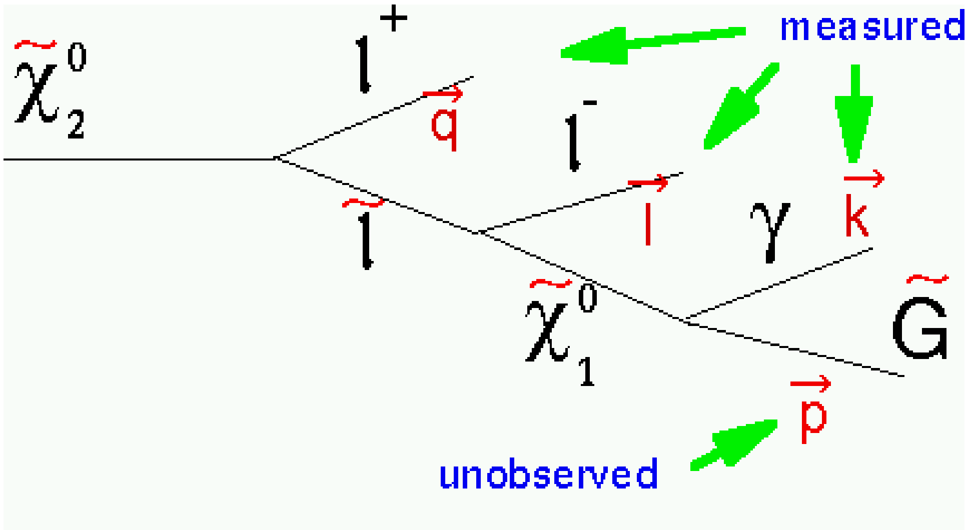
and

$$\sqrt{M^2_{\chi^0_2} - M^2_{\tilde{\ell}_R}} = 152.6\,\mathrm{GeV}$$

These four measurements are sufficient to determine the masses of the particles ($\tilde{\chi}_2^0$, $\tilde{\ell}_R$, and $\tilde{\chi}_1^0$) in this decay chain without assuming any model of SUSY breaking.

Now use this to reconstruct the decay chain and measure the $\tilde{G}$ momenta!

Full reconstruction of SUSY events



Know masses $\Rightarrow$ can calculate p assuming $p^2 = 0$:

$$
\begin{aligned}
2p_0k_0 - 2\vec{p}\cdot\vec{k} &= M^2_{\tilde{\chi}^0_1} \\
2p_0l_0 - 2\vec{p}\cdot\vec{l} &= M^2_{\tilde{\ell}_R} - M^2_{\tilde{\chi}^0_1} - 2k\cdot l \\
2p_0k_0 - 2\vec{p}\cdot\vec{q} &= M^2_{\tilde{\chi}^0_2} - M^2_{\tilde{\ell}_R} - 2(k+l)\cdot q
\end{aligned}
$$

0C fit with 2×2 solutions.

Event has two of these decays

Calculate missing E_T

Form a χ^2 using measured missing E_T

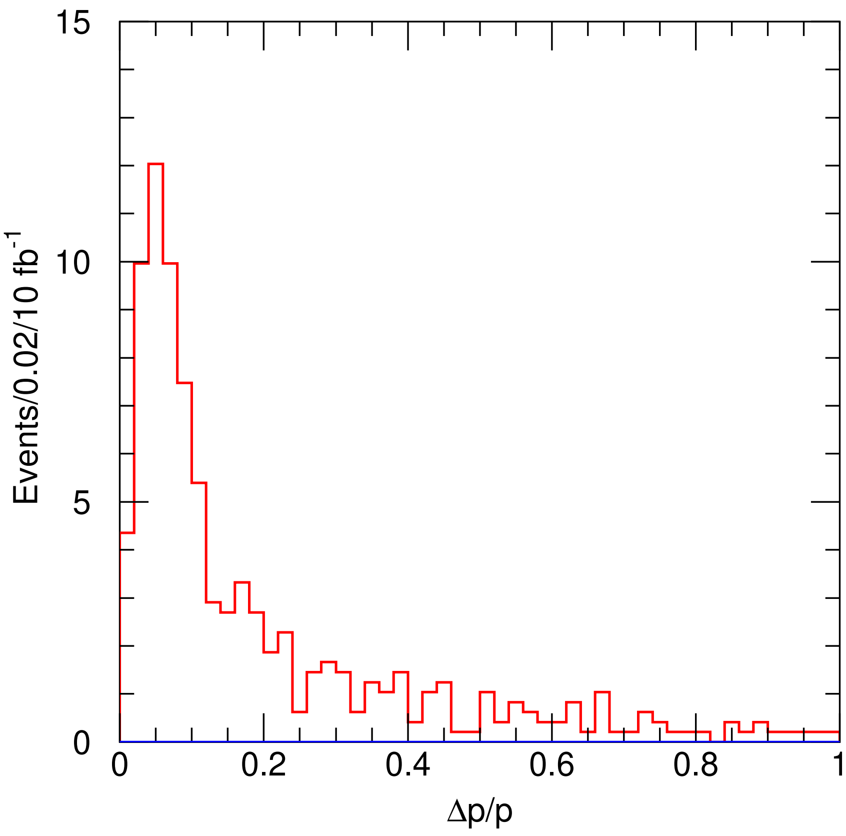
Resolve ambiguities

$$\chi^2 = \left(\frac{\not{E}_x - p_{1x} - p_{2x}}{\Delta \not{E}_x}\right)^2 + \left(\frac{\not{E}_y - p_{1y} - p_{2y}}{\Delta \not{E}_y}\right)^2 .$$

use $\Delta \not{E}_x = \Delta \not{E}_x = 0.6\sqrt{E_T} + 0.03 E_T$.

Compare to generated $\tilde{G}$ momenta

Plot shows all solutions with $\chi^2 < 10$



$\Delta|\vec{p}|/\vec{p}| \sim 10\%$

Squark and Gluino Masses

Use measured $\tilde{\chi}_2^0$ momenta

- $\tilde{q} \to \tilde{g} q \to \tilde{\chi}_2^0 \overline{q} q q$
- Require at least 4 jets with $p_T > 75\,\mathrm{GeV}$

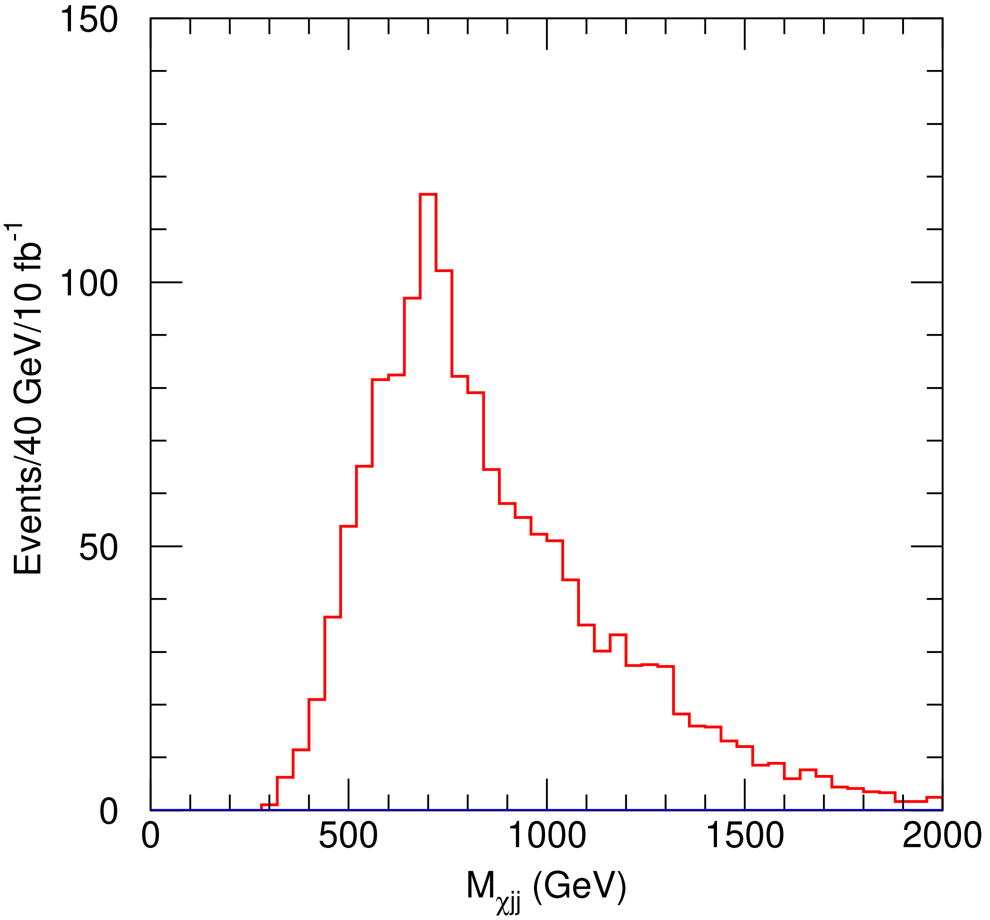
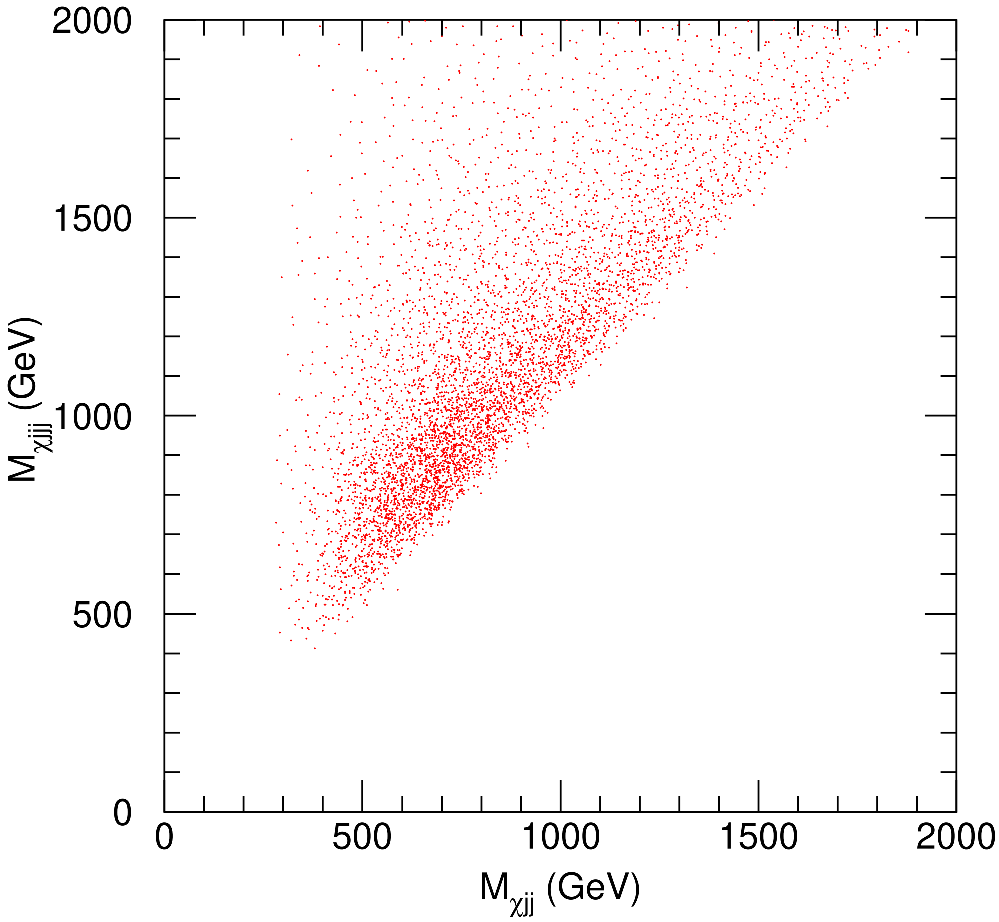


Figure shows mass of $\tilde{\chi}_2^0$+2 jets

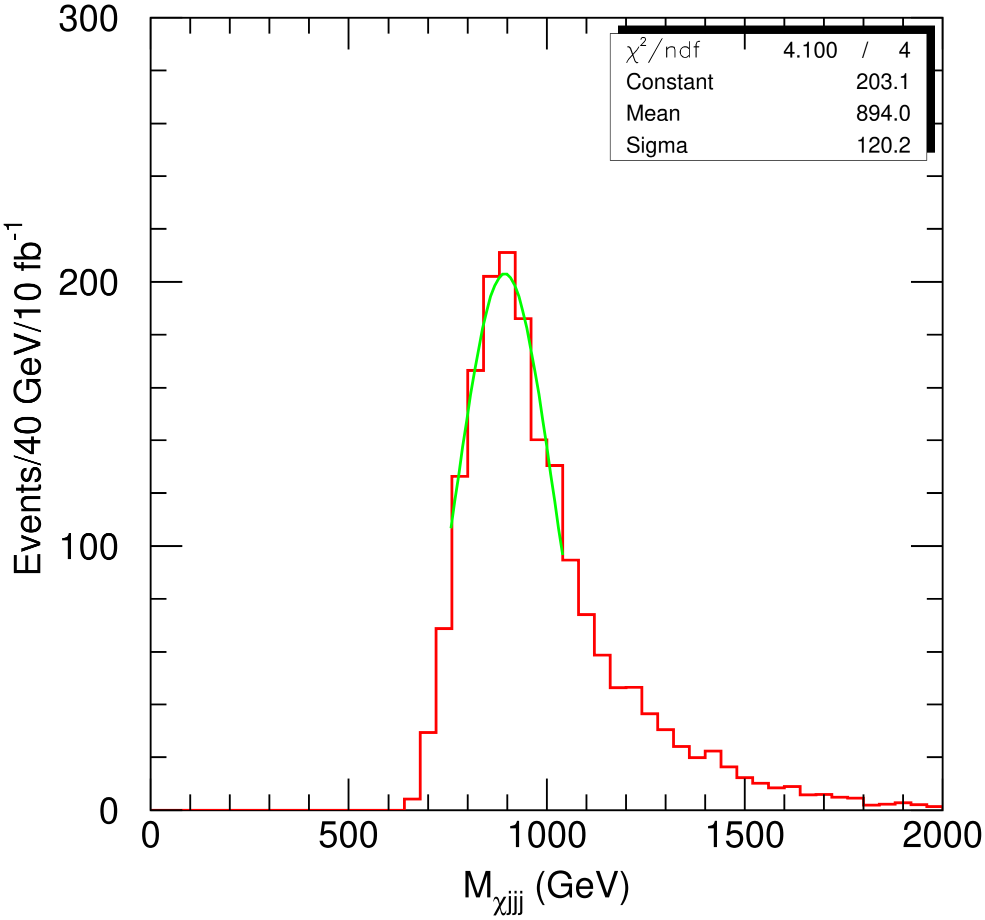
Peak at gluino mass

Look for correlations



Peaks visible in projections

Cut 600 GeV $< M(\tilde{\chi}_2^0 jj) < 800$ GeV
Project



Peak at Squark mass.

This is much easier than the SUGRA cases.

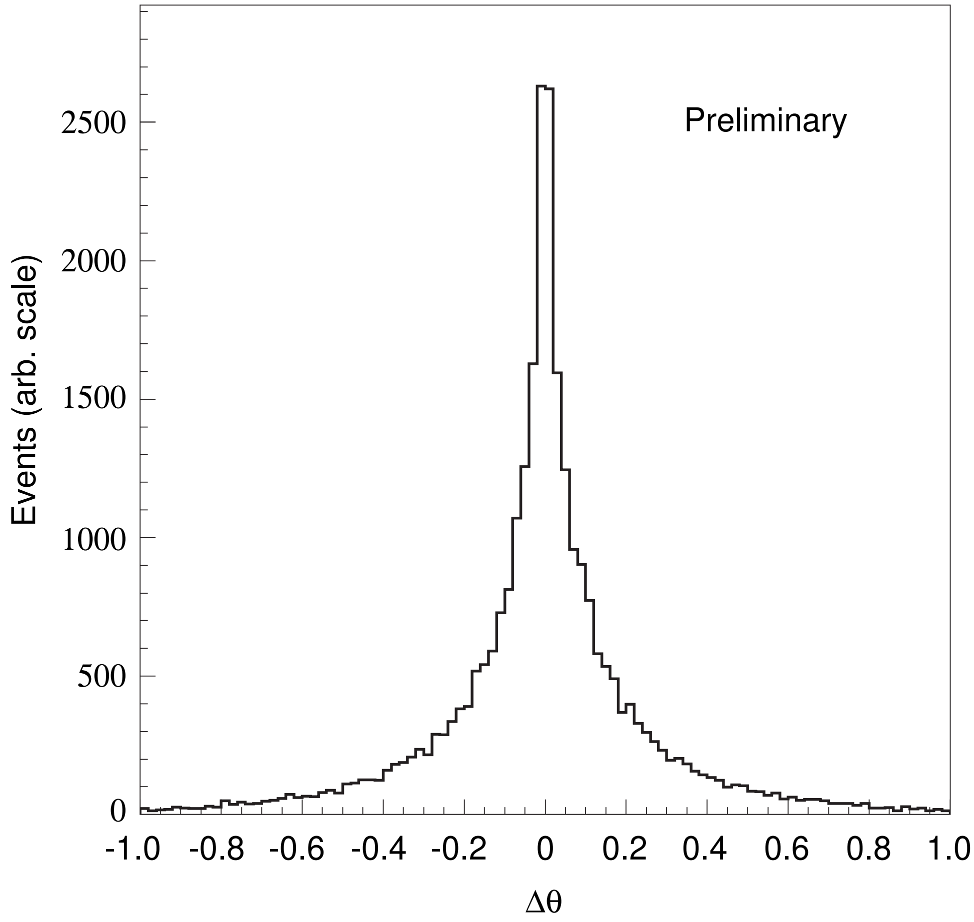
GMSB with long-lived $\tilde{\chi}_1^0 \to \tilde{G}\gamma$.

$$\Lambda_m = 90\,\text{TeV},\ M_m = 500\,\text{TeV},\ N_5 = 1,$$
$$\tan\beta = 5,\ \text{sgn}\,\mu = +,\ C_{\text{grav}} = 1000$$

Looks like SUGRA except that NLSP is long lived

- $c\tau \sim 1.2 km$
- $\sim 0.1\%$ decay within the detector, yields a non-pointing photon
- Statistics limited ($\sim$ few-K events)
- Can measure direction of non-pointing photons — M. Leltchouk, J. Parsons and S. Ragagopalan
- Very important as it measures the fundamental scale of SUSY breaking

Angular resolution on the direction of a photon that does not point back to the primary vertex.
Full ATLAS simulation



Enables one to measure impact parameter and hence deduce lifetime

GMSB with long-lived $\tilde{\ell}_R$

$$\Lambda = 30\,\text{TeV}, M_m = 250\,\text{TeV}, N_5 = 3,$$
$$\tan\beta = 5,\ \text{sgn}\,\mu = +,\ C_{\text{grav}} = 10^4$$

Representative masses (in GeV) from ISAJET:

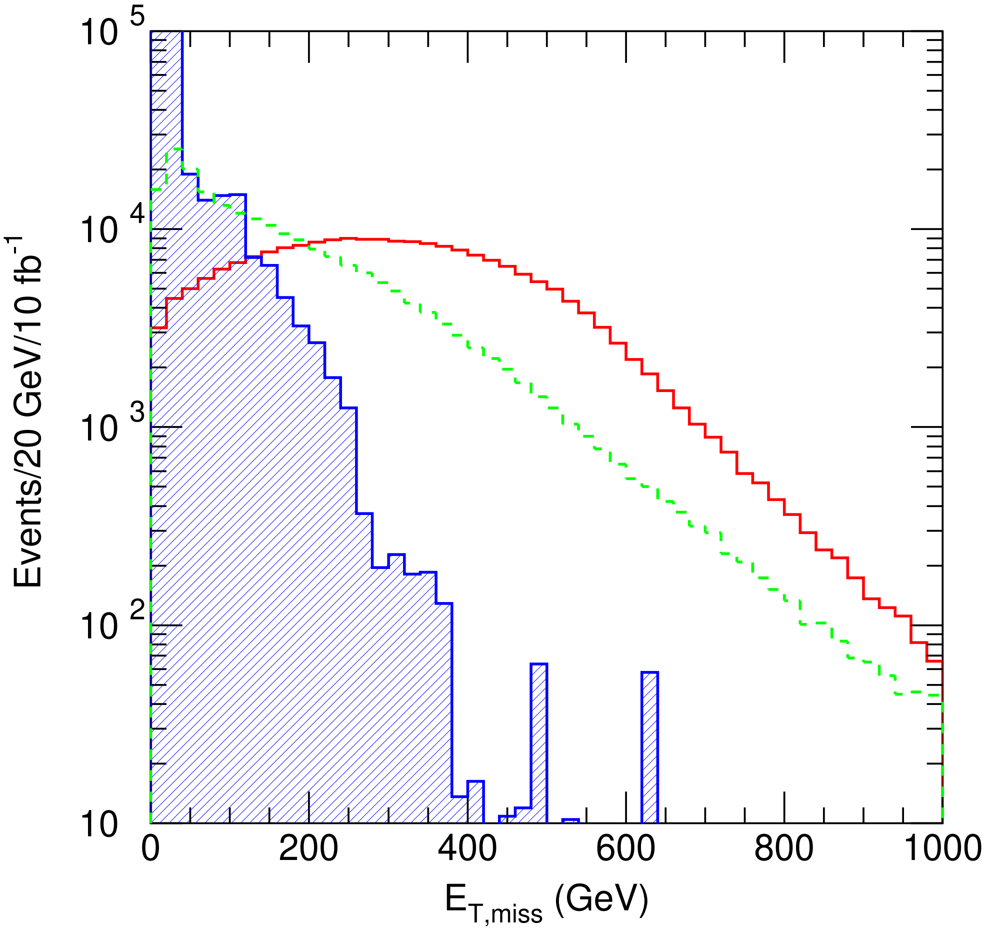
$$M_{\tilde{g}} = 713,\ M_{\tilde{q}_L} = 672,\ M_{\tilde{q}_R} = 648,$$
$$M_{\tilde{\chi}_4^0} = M_{\tilde{\chi}_2^\pm} = 347,\ M_{\tilde{\chi}_3^0} = 304,$$
$$M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm} = 201,\ M_{\tilde{\chi}_1^0} = 115$$
$$M_{\tilde{\ell}_R} = M_{\tilde{\tau}_1} = 101$$
$$M_h = 107$$

Total cross section 23 pb
NLSP is any of $\tilde{\ell}$, $\tilde{\tau}_1$ $\tilde{\mu}_R$:

$$c\tau = 1\,\text{km}$$

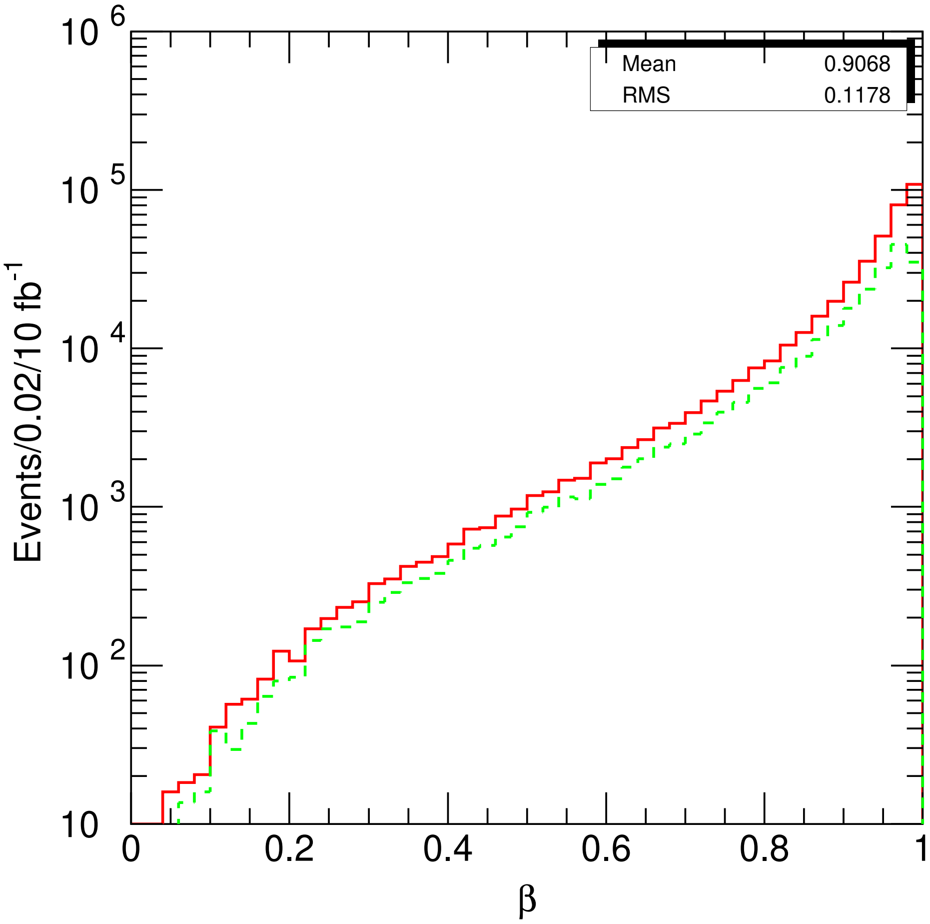
A small fraction of these will decay inside the detector
Can we measure this??

Large Calorimetric (trigger) missing E_T



Events have smaller real missing E_T green dashed line
Background is from events with two muons.

Sleptons are produced at the end of decay chains
Large velocity

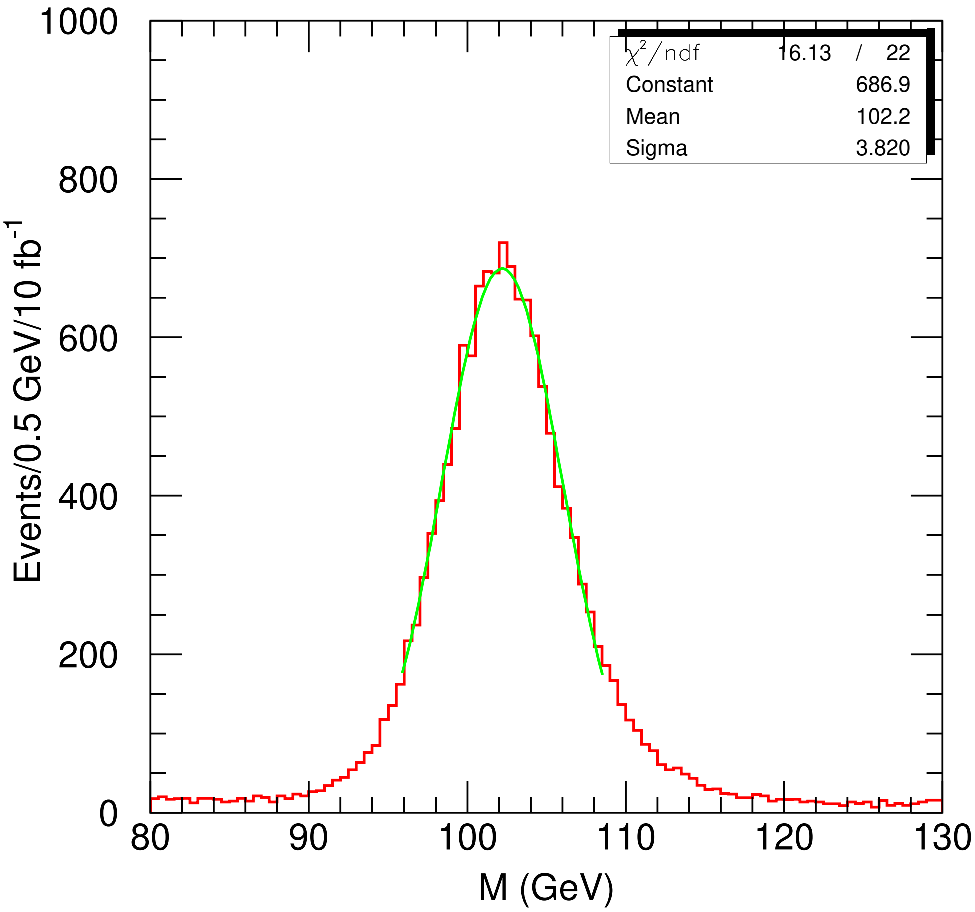


Most of these will pass the Muon Trigger Nisati

Measure the velocity using TOF in Muon system

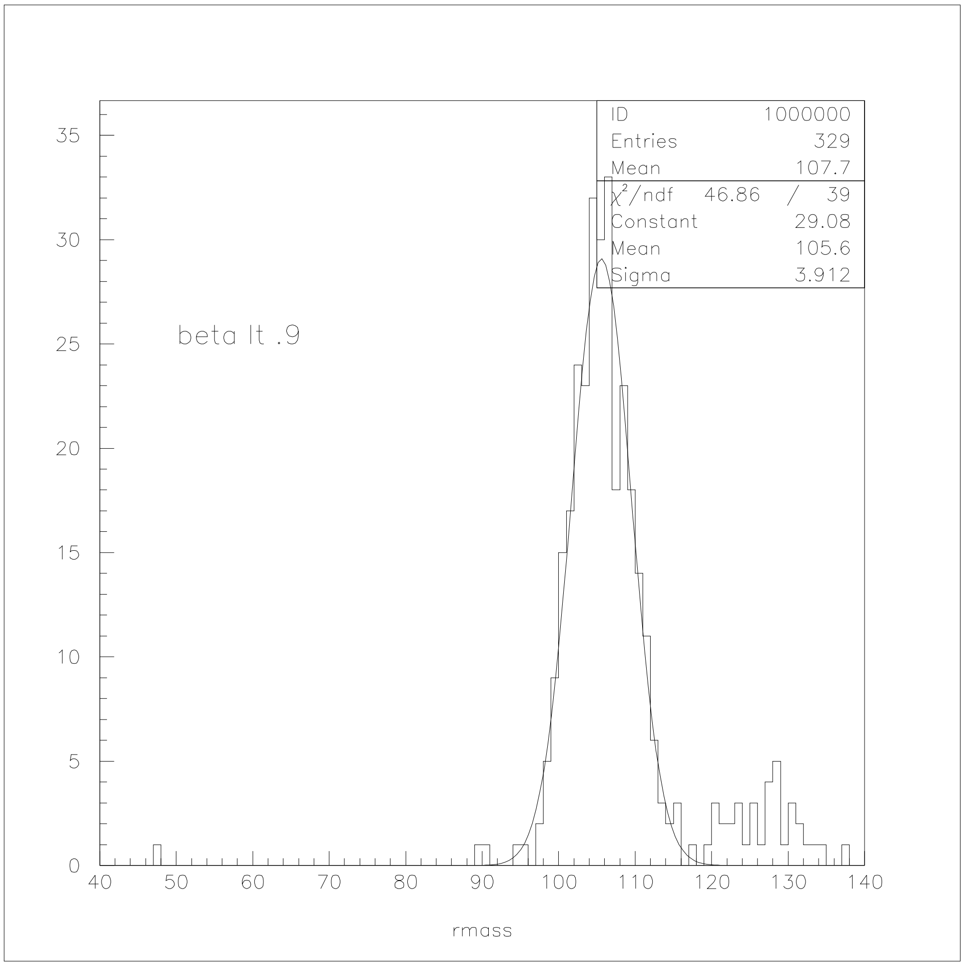
Assume 1ns resolution

Then infer the mass



Resolution not good enough to separate $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$

This analysis has been repeated using full ATLAS simulaion.



ID 1000000
Entries 329
Mean 107.7
χ^2/ndf 46.86 / 39
Constant 29.08
Mean 105.6
Sigma 3.912
beta lt .9
rmass

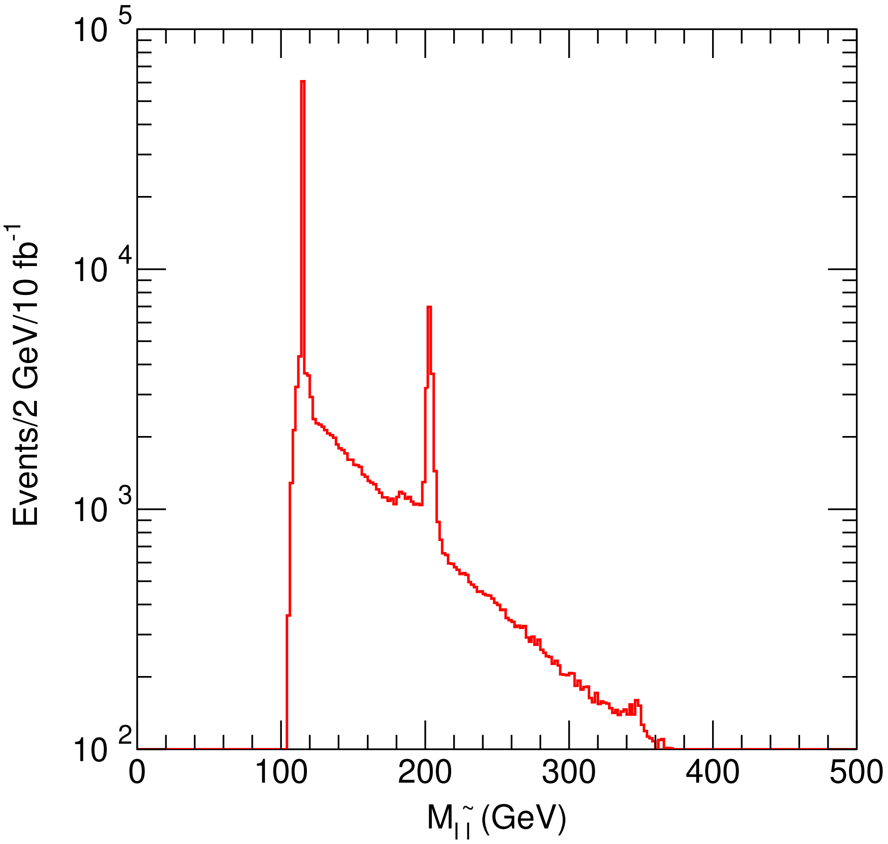
Prelimnary

Reconstruction of $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$

Select events with three isolated leptons/sleptons

Assume that two largest p_t "muon" candidates are sleptons, rest muons

Make lepton-slepton mass



Two peaks from $\tilde{\chi}_i^0 \to \tilde{\ell}_R \ell$

Can now extract separate samples of $\tilde{e}$, $\tilde{\mu}$ and $\tilde{\tau}$

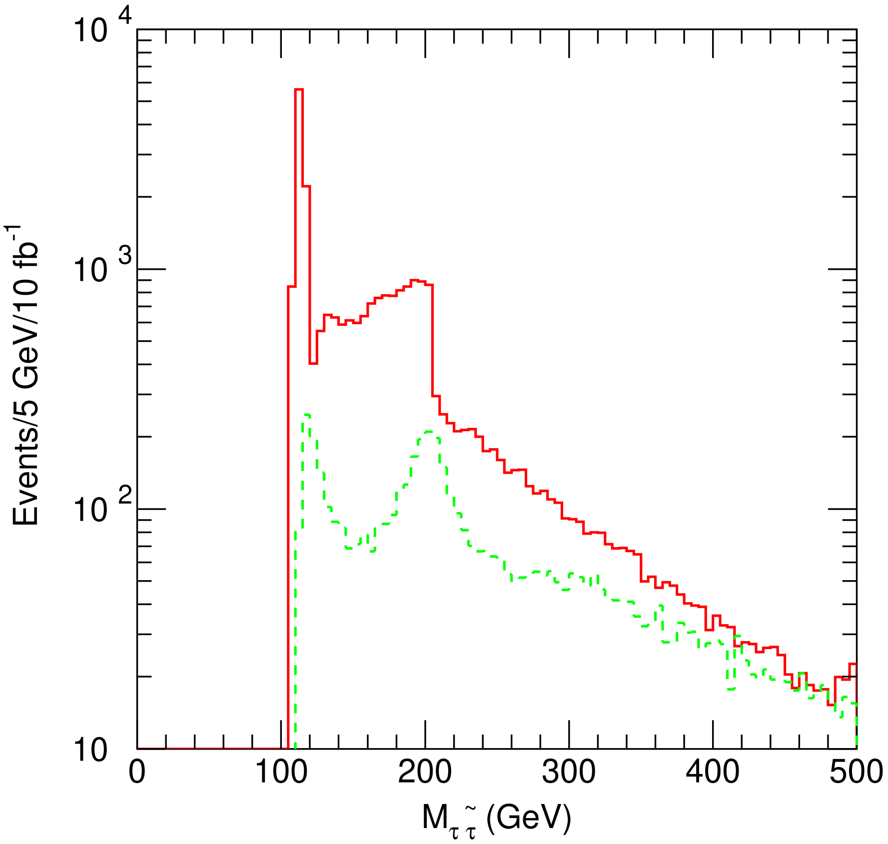
Repeat TOF measurement to measure individual masses

τ and $\tilde{\tau}$

$\tilde{\chi}_i^0 \to \tilde{\tau}^\pm \tau^\mp$ harder than $\tilde{\chi}_i^0 \to \tilde{\ell}_R^\pm \ell^\mp$

Find jets with low multiplicity/mass (Y. Coadou *et al.* ATL-PHYS-98-126.)

Combine measured τ energy with sleptons



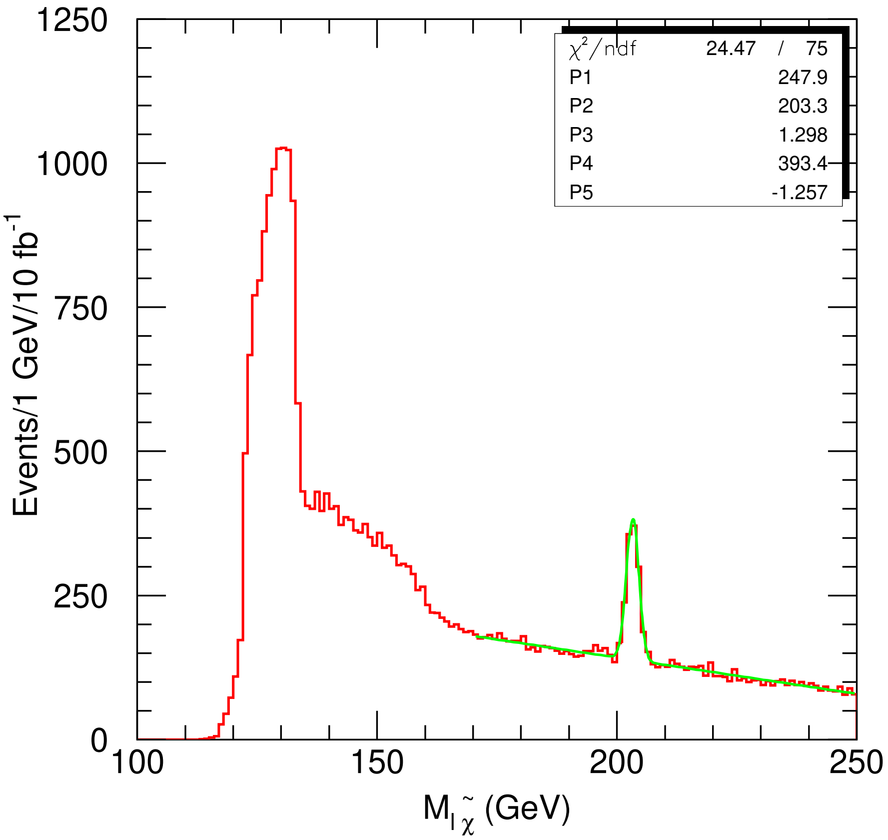
Smeared out peak at $\tilde{\chi}_i^0$ masses

Peak is sharper if we add all the missing E_T to the tau (dashed)

Extraction of $\tilde{\ell}_L$

Use reconstructed $\tilde{\chi}_1^0$

Combine with another lepton



Clear peak at the slepton mass of 203 GeV.

$\tilde{\ell}_L \to \tilde{\chi}_1^0 \ell \to \tilde{\ell}_R^{\pm} \ell^{\mp} \ell$.

Also evidence for

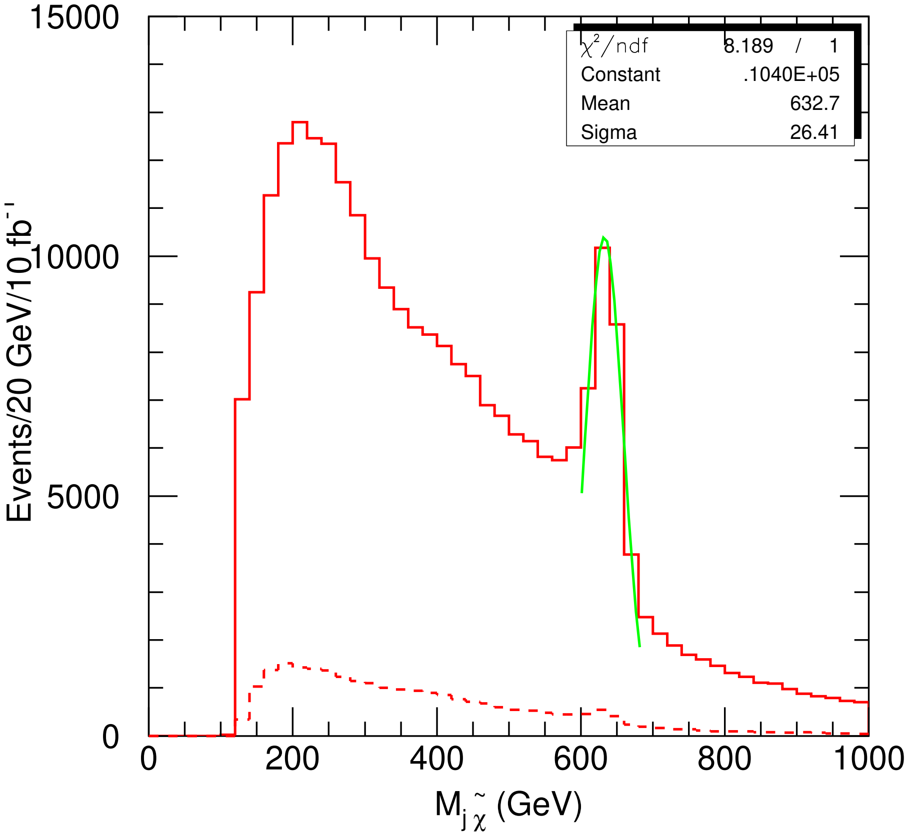
$\tilde{\chi}_1^{\pm} \to \tilde{\nu} \ell \to \tilde{\chi}_1^0 \nu \ell \to \tilde{\ell}_R^{\pm} \ell^{\mp} \nu \ell$

Ends at 134 GeV

" LHC finds sneutrinos"

Reconstruction of Squarks

Can combine $\tilde{\chi}_1^0$ with a jet and look at mass



Peak from $\tilde{q}_R \to \tilde{\chi}_1^0 q$

Can also get b-squarks

This is too easy

Comments

- Short lived slepton case is easy
  All events have 4 isolated leptons and missing E_T
  (see paper)
- Hardest case is long-lived Bino
  (photon outside detector)
  Looks like SUGRA
  But they can be distinguished
- Stable slepton could be stau only (large $\tan\beta$)
  then events have more leptons

Some of the SUGRA cases studied earlier may not be typical of LHC SUSY —-
They were too difficult!