Higgs Production in association with Squark Pairs

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   (b) m-SUGRA
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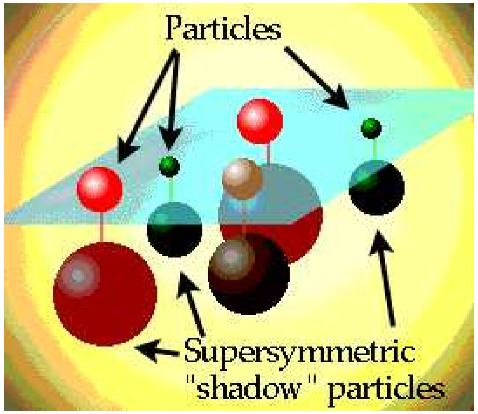
Supersymmetry

- **Supersymmetry** is a symmetry relating fermions and bosons.



- A **supersymmetric transformation** turns a bosonic state into a fermionic state and vice versa

- The Minimal Supersymmetric Model, or **MSSM**, is the simplest supersymmetric extension to the SM - it has the minimal number of extra particles

- If Supersymmetry is unbroken, superpartners must have equal masses

- No SUSY particles observed so far in experiment $\rightarrow$ SUSY is a **broken symmetry**

m-SUGRA

The minimal Supergravity inspired Supersymmetric Model

- Supersymmetry broken through Supergravity
- The dynamics of the theory can be defined by 5 parameters, from which all SUSY masses can be determined:
  1. M_0, the universal scalar mass.
  2. $M_{\frac{1}{2}}$, the universal gaugino mass.
  3. A_0, the universal trilinear breaking term.
  4. tanβ, the ratio of the VEVs of the 2 Higgs fields.
  5. sign(μ) = $\pm$1, where μ is the higgsino mass term
- In the SUSY Higgs Sector, there are 5 Higgs particles.

m-SUGRA (II)

- R-Parity is introduced in order to prevent lepton and baryon number violation in SUSY.
- In any SUSY event there are 2 lightest supersymmetric particles (LSPs) produced, which cannot be seen in a detector.
- This means it is difficult to find SUSY masses.
- Therefore we cannot detemine the parameters of our SUSY model by simple observations of SUSY events.

squark squark Higgs production

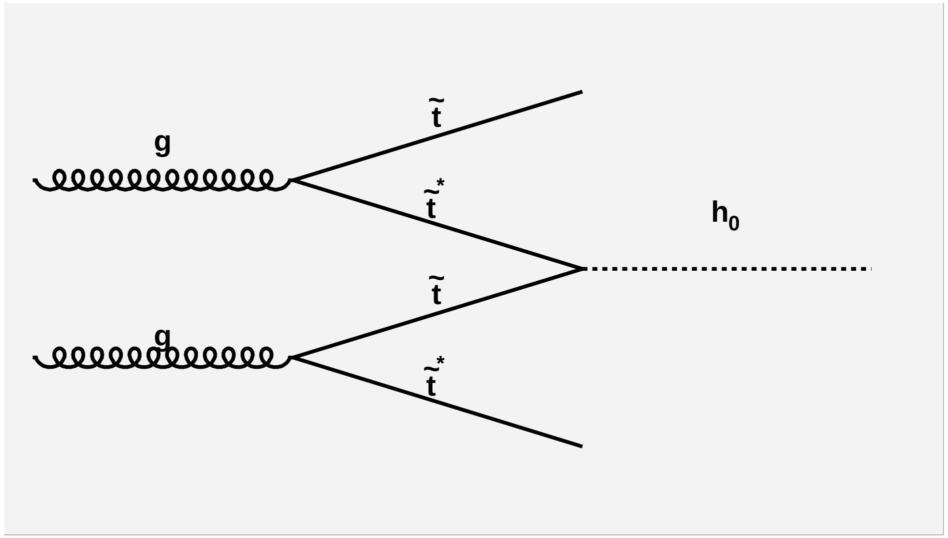
$$g + g \longrightarrow \tilde{q}_\chi + \tilde{q}'^*_{\chi'} + \Phi$$

where $q^{(')}$ = t,b, $\chi^{(')}$ = 1,2 and Φ = H, h_0, A, $H^\pm$.

Processes of this type:

1. Provide production mechanisms for Higgs, in additional to SM-like channels
2. The production rates can be strongly dependent on m-SUGRA parameters.

$gg \rightarrow \tilde{t}_1 \tilde{t}_1^* h_0$

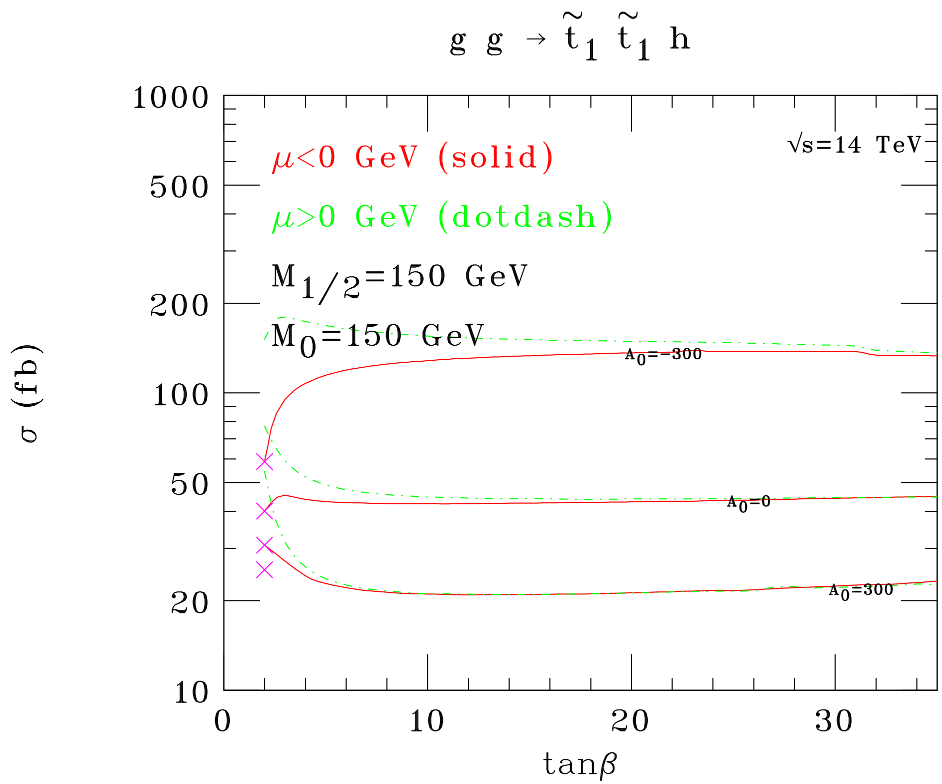


This has been chosen for study as it has the highest cross section of all the squark squark Higgs channels:

- $\tilde{t}_1$ has the lowest mass of the stops and sbottoms
- The coupling of h_0 to $\tilde{t}_1$ can be larger than the coupling of h_0 to top

Initial m-SUGRA parameters

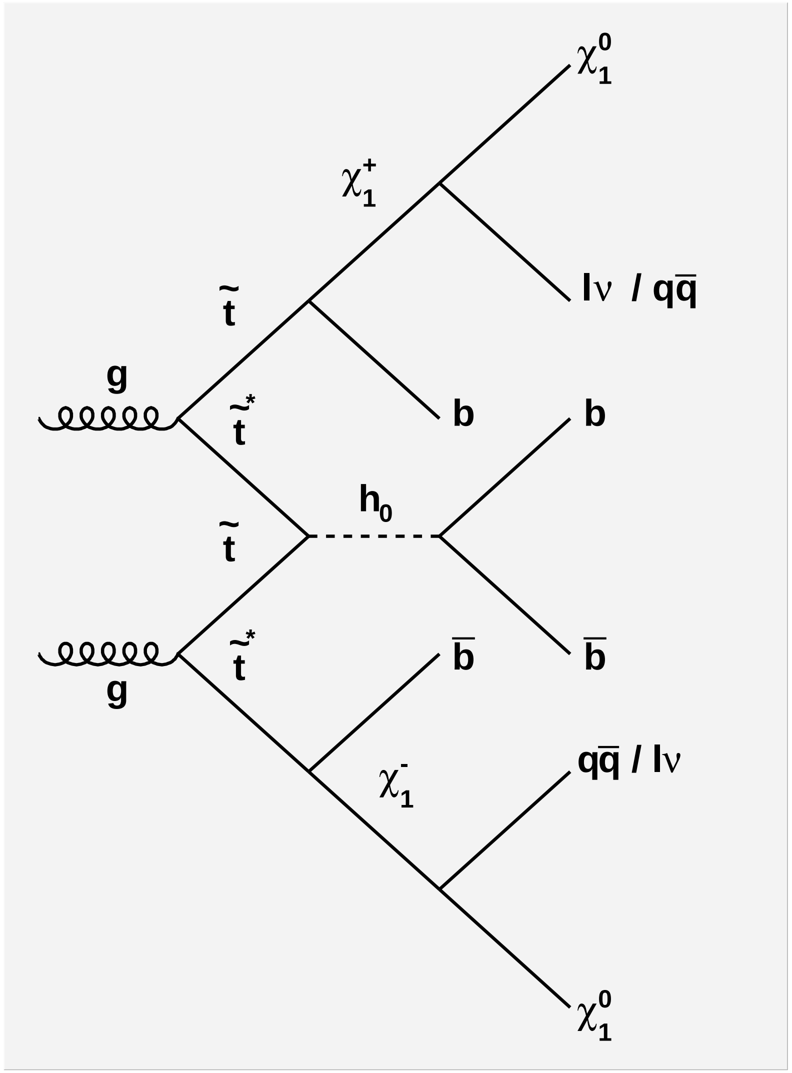
These m-SUGRA parameters were chosen to give a relatively high $\tilde{t}_1 \tilde{t}_1^* h$ cross section



- M_0 = 150
- $M_{\frac{1}{2}}$ = 150
- A_0 = -300
- tanβ = 20
- sign(mu) = 1

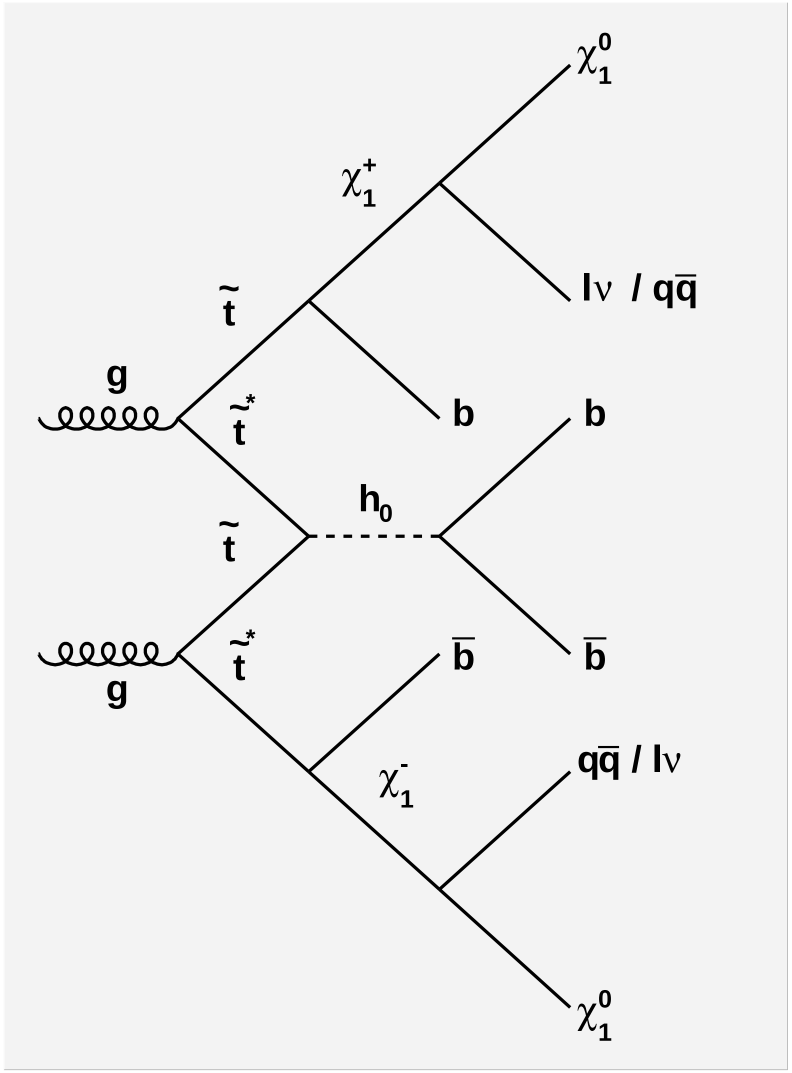
$$\rightarrow m_{h_0} = 113GeV, m_{\tilde{t}_1} = 197GeV$$

Decay Chain



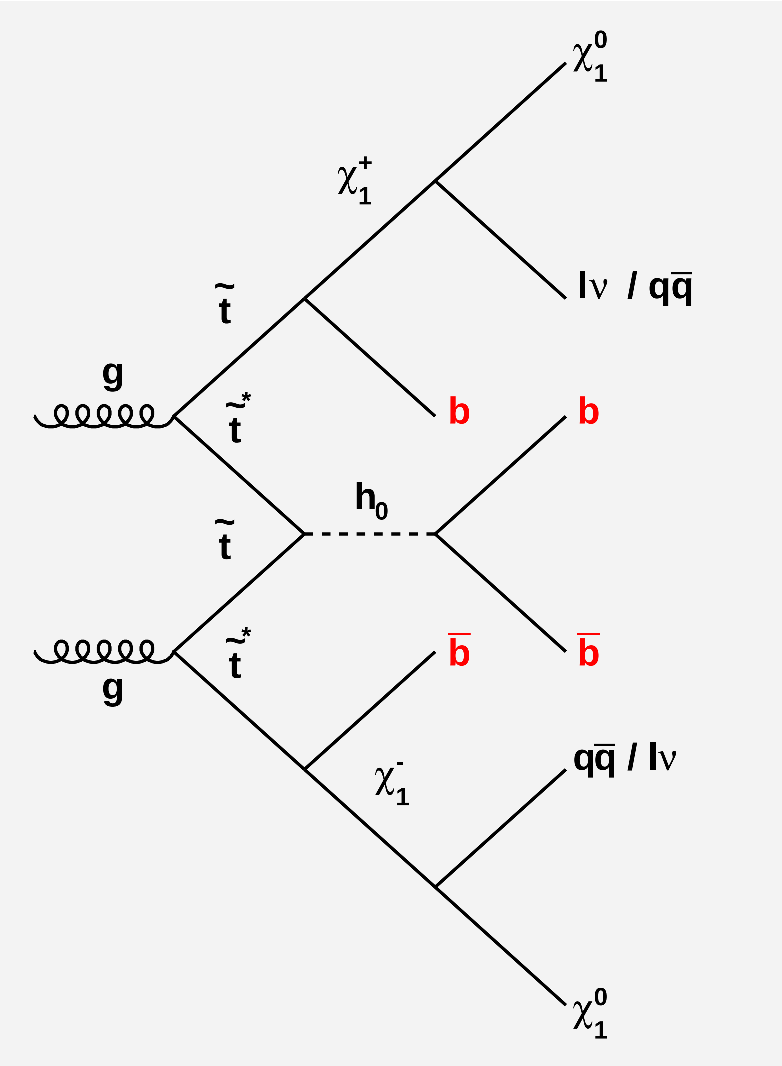
χ_1^0
χ_1^+
$l\nu$ / $q\bar{q}$
$\tilde{t}$
g
$\tilde{t}^*$
b
b
h_0
$\tilde{t}$
$\tilde{t}^*$
$\bar{b}$
$\bar{b}$
g
$q\bar{q}$ / $l\nu$
χ_1^-
χ_1^0

Decay Chain



The Final State consists of:

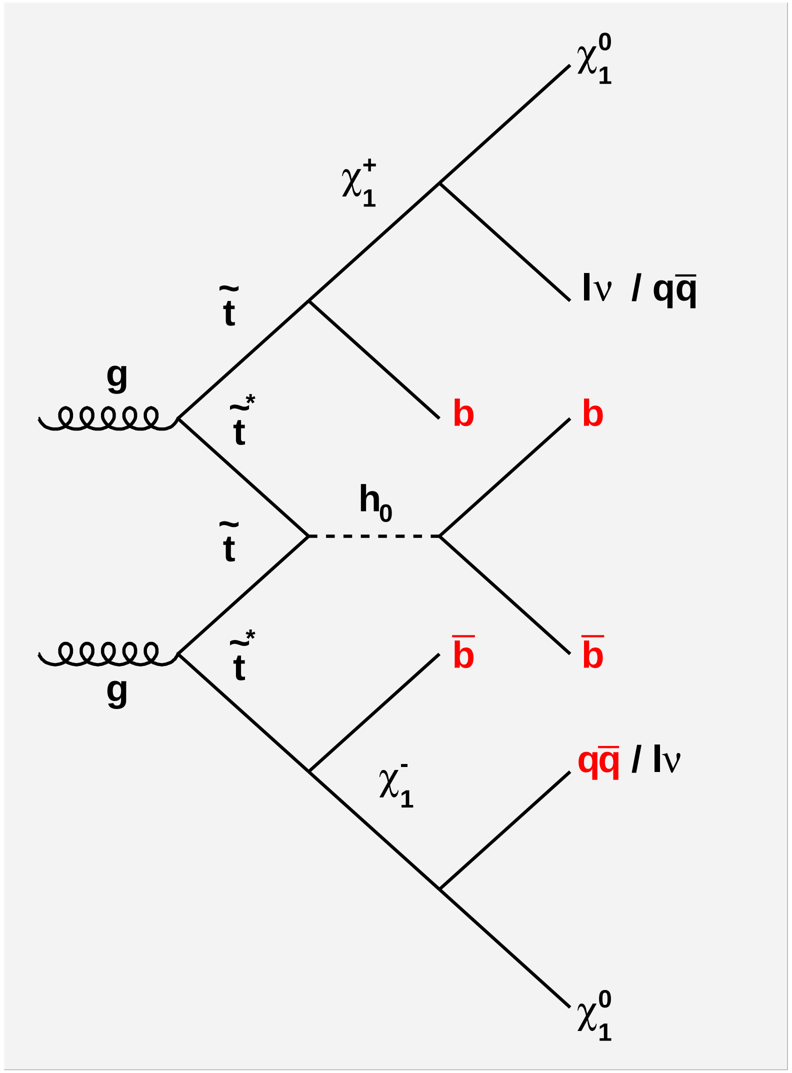
Decay Chain



The Final State consists of:

- 4 b jets

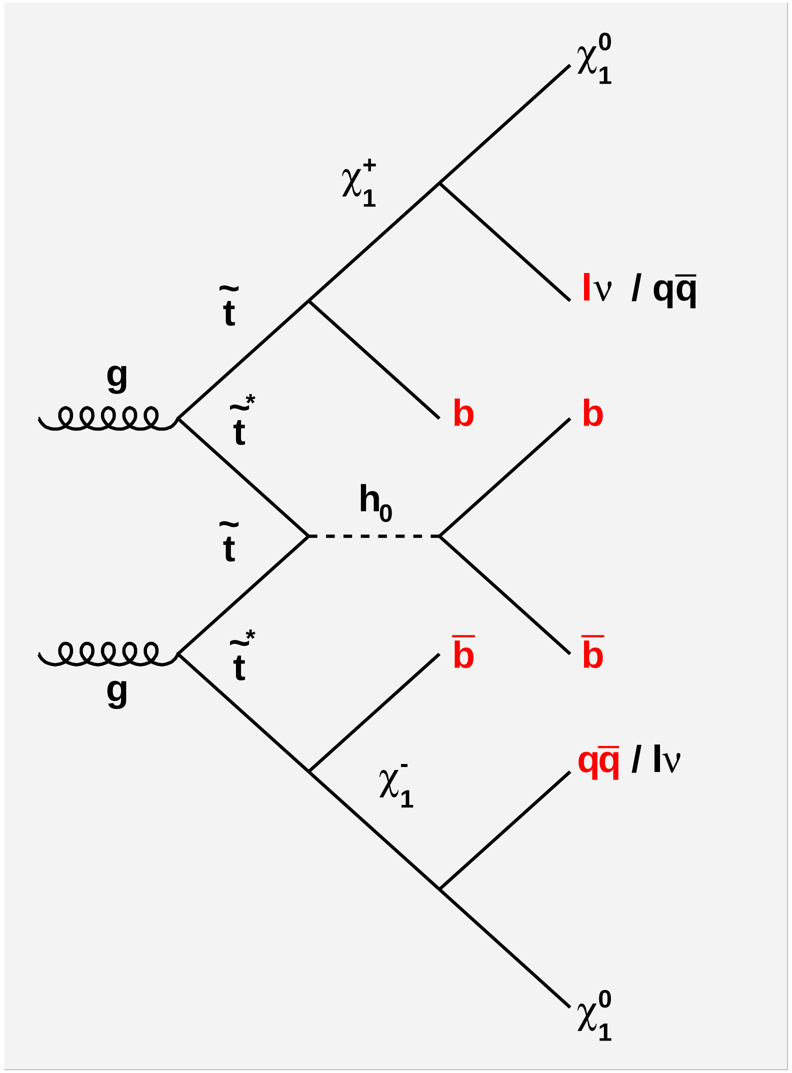
Decay Chain



The Final State consists of:

- 4 b jets
- 2 light quark jets

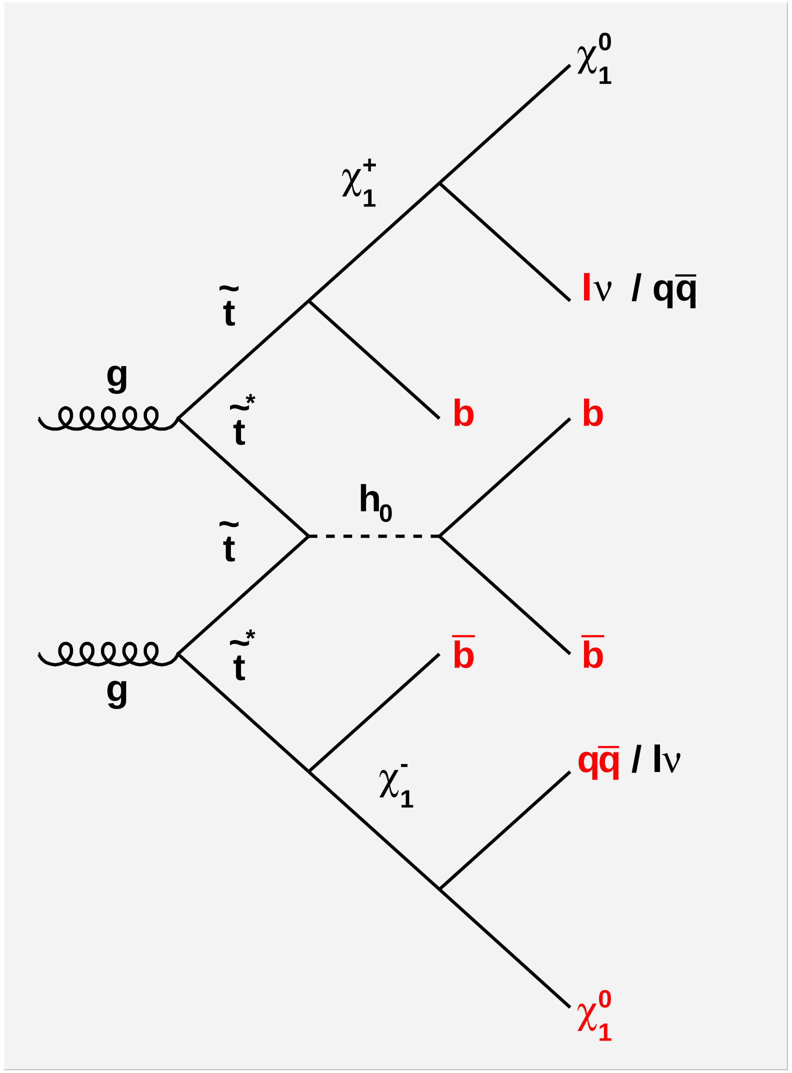
Decay Chain



The Final State consists of:

- 4 b jets
- 2 light quark jets
- an isolated lepton

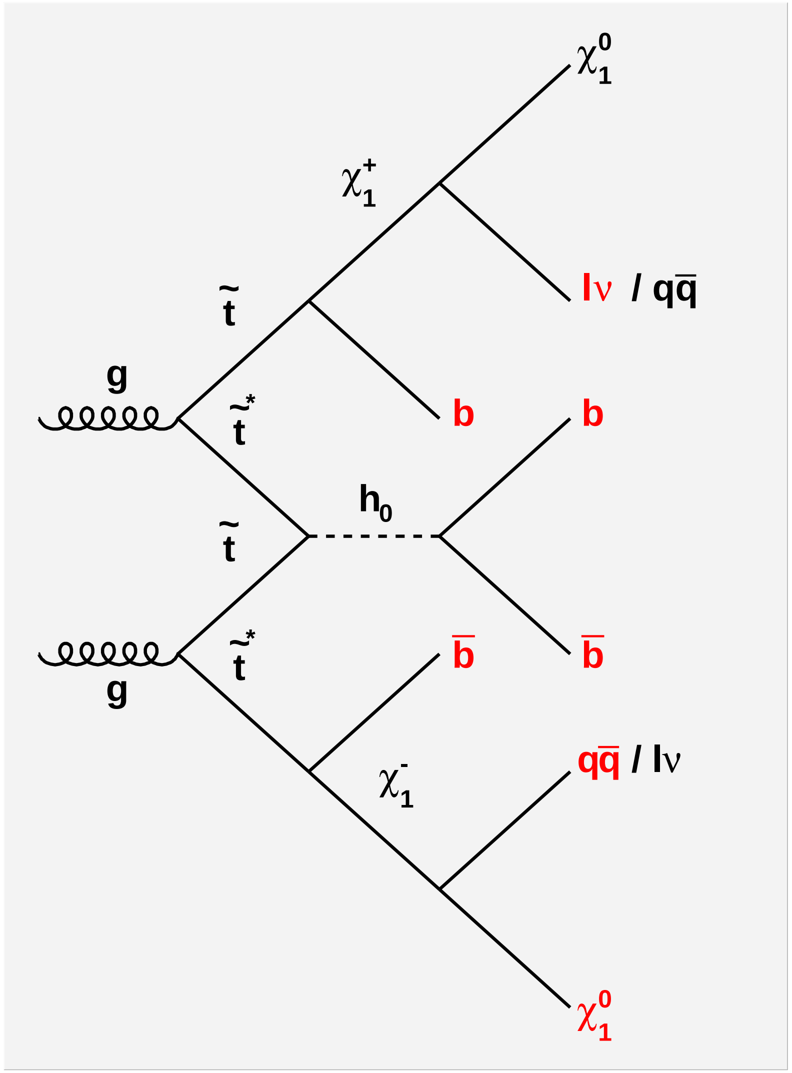
Decay Chain



The Final State consists of:

- 4 b jets
- 2 light quark jets
- an isolated lepton
- and lots of missing energy!

Decay Chain



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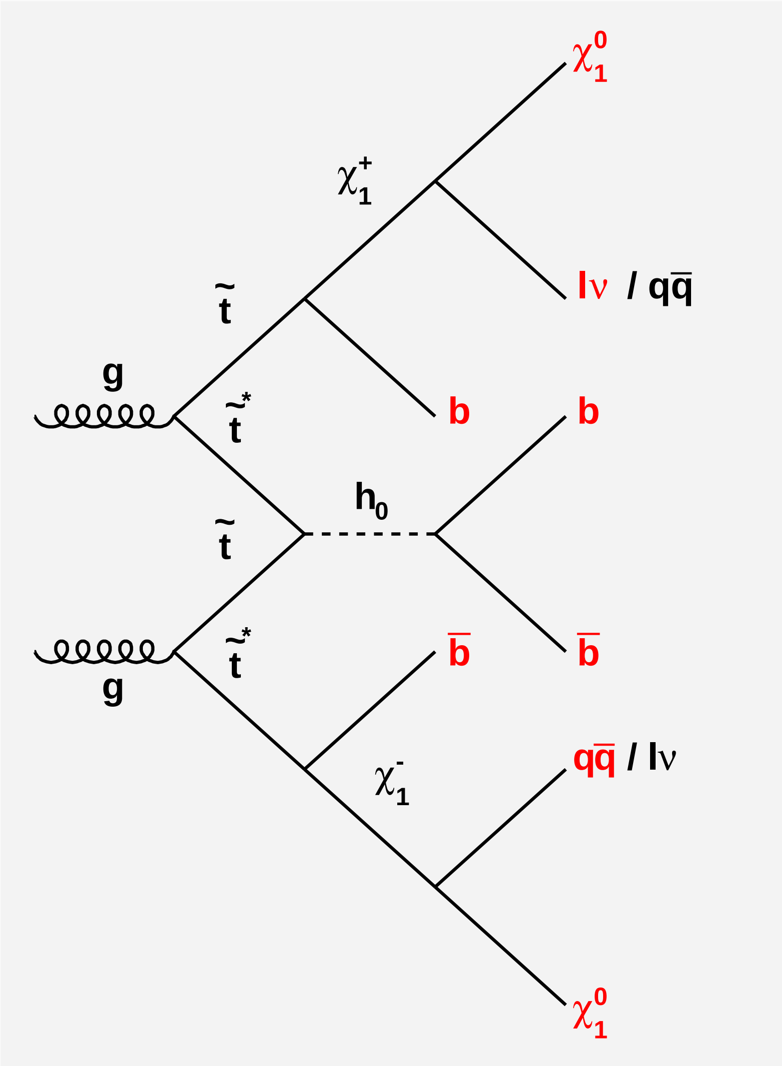
Decay Chain



The Final State consists of:

- 4 b jets
- 2 light quark jets
- an isolated lepton
- and lots of missing energy!

Higgs Mass Reconstruction

- In the final state we have 4 b jets
- 2 have come from the Higgs, and 2 from the stops.
- In order to reconstruct the Higgs mass we need to select the 2 b jets from the Higgs.

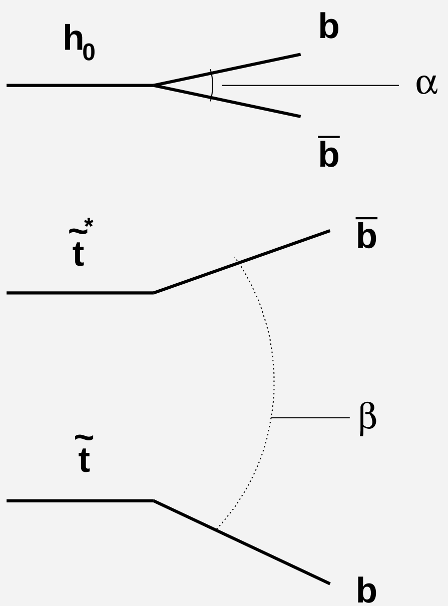
Problems:

1. No known masses in the event - Can't reconstruct the stop mass from other jets/lepton.
2. Three $\not{E}_t$ particles.

Need a more imaginative way to reconstruct the Higgs mass

$\rightarrow$Find properties of the jets that are different for the bs from stops.

Opening Angle



α = angle between jets from higgs
β = angle between jets from stops

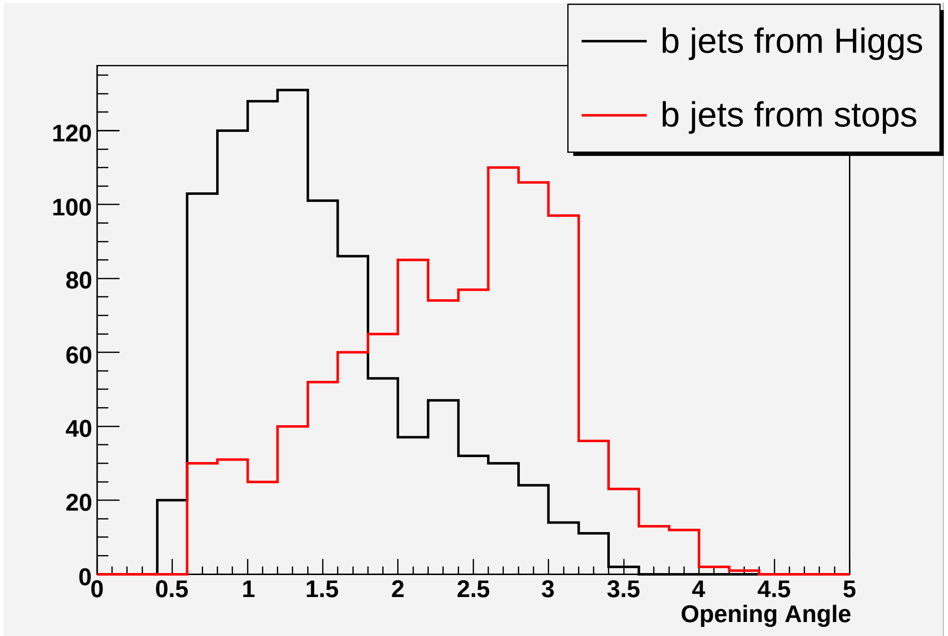
- 2 of the bs come from the same particle - the Higgs
- The system is highly boosted
- Look at Δr between the jets, where:

$$\Delta r = \sqrt{\eta^2 + \phi^2}$$

$$\rightarrow \alpha < \beta$$

Likelihood Method

- Plot the opening angle for bs from Higgs and bs from stops
- Only use jets that are well matched to the bs ($\Delta r < 0.1$)



Likelihood Method

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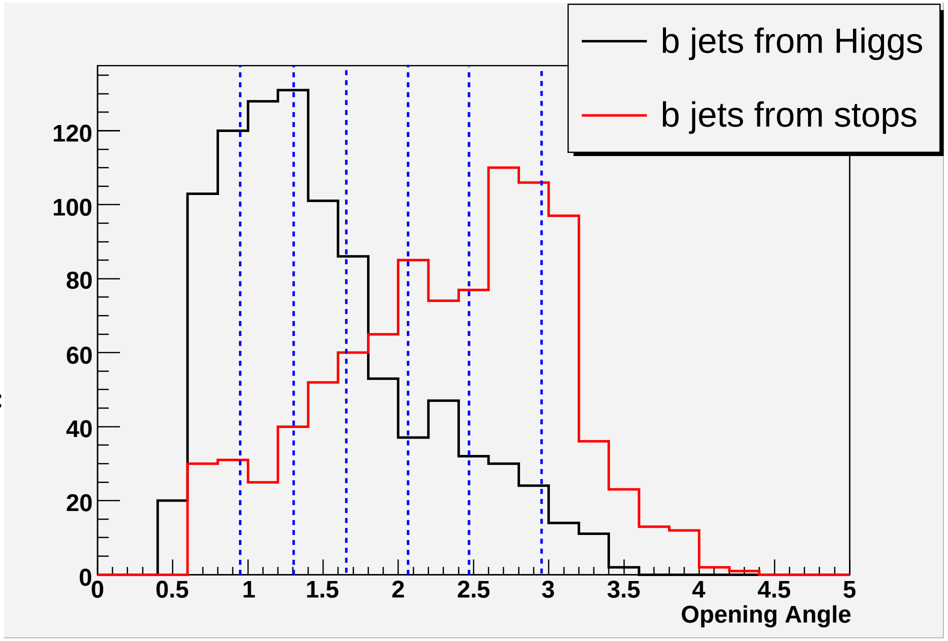
- Defi ne bins of equal numbers of events



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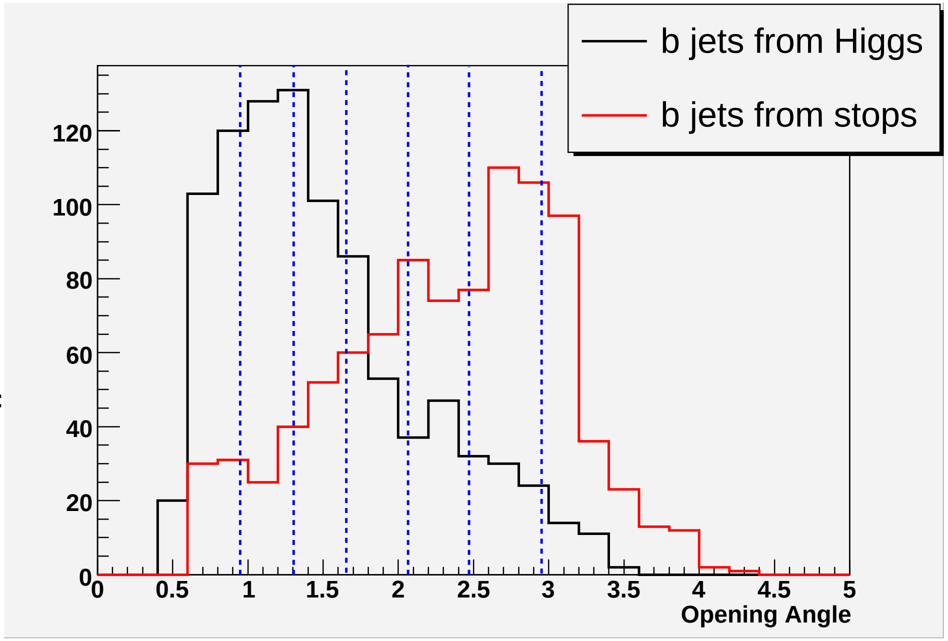

- Defi ne a higgs probabilty for each bin: prob = number of events with jets from higgs in the bin / total number of events in that bin.
- Defi ne a stop probability for the b jets from stops in the same way

Likelihood Method (II)

- Using different Monte Carlo sample
- For each jet pair in the event, calculate the opening angle.
- Assign each pair a Higgs and stop probability according to its bin
- Loop over all jet pairs, maximize the probability that one pair are from Higgs and another are from the stops.

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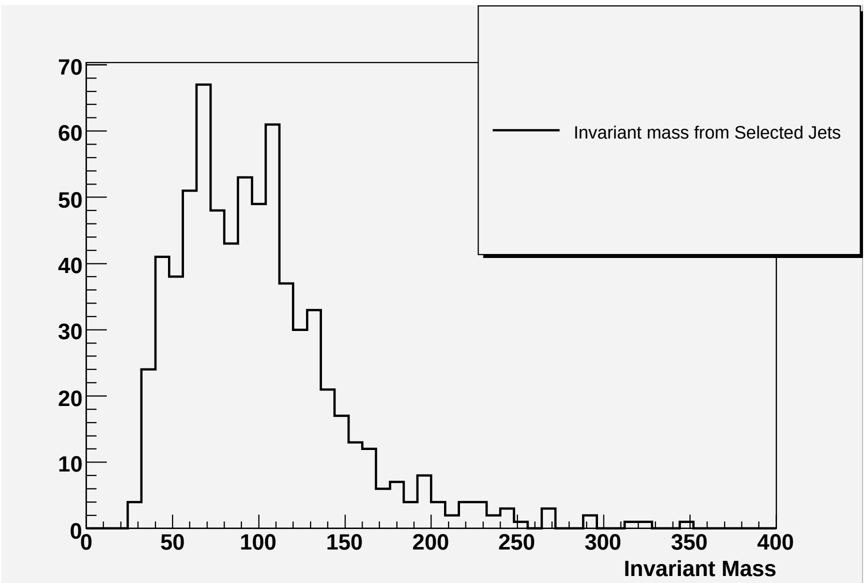

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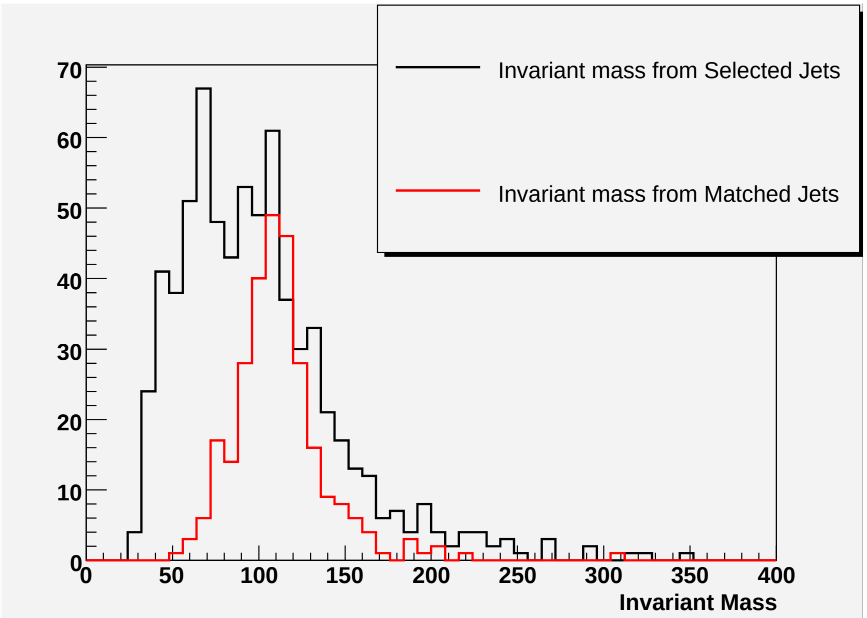


Compare to jets that are very well matched to the bs from Higgs

Conclusions

- If SUSY exists, it should be found at the LHC.

$\rightarrow$ Gaining further information on the SUSY model will be more difficult.

- squark squark Higgs cross sections can vary heavily with the m-SUGRA parameters.
- $\tilde{t}_1 \tilde{t}_1^* h_0$ cross sections can be very large for certain SUSY parameters

$\rightarrow$ Could be a important production mechanism for SUSY Higgs

- However, with no known masses to reconstruct in the event, Higgs mass reconstruction could be difficult.
- Some success from looking at opening angle.
- Likelihood method allows many parameters to be used together

Backup - R-Parity

- In the MSSM, not all SUSY couplings conserve lepton and baryon number
- Introduce a new symmetry to eliminate the possibilty of these couplings - **R-Parity**.

$$R = (-1)^{3(B-L)+2s}$$

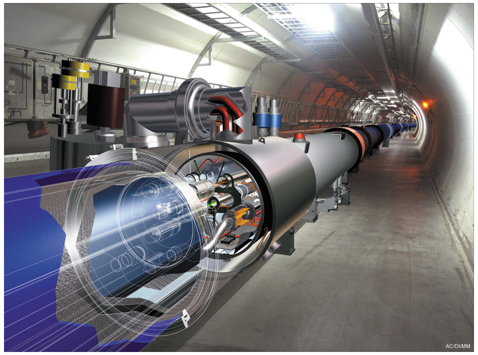
where s is the spin of the particle

- All SM particles have R = 1, and all SUSY particles have R = -1
- If R-parity is conserved, there is **no mixing** between SM and SUSY particles.

Backup - R-Parity (II)

To conserve R-Parity:

1. In collider experiments, sparticles must be produced in even numbers (usually 2).
2. Each sparticle must decay into a state which contains an odd number of sparticles (usually 1)
3. The lightest sparticle (the LSP) must be absolutely stable.



This means that for each SUSY event at the LHC, there must be at least 2 LSPs.

- This makes it difficult to determine SUSY masses.
- Cannot find other SUSY quantities.

Therefore we can not determine the parameters of our SUSY model by simple observations of SUSY events.