On Setting Limits for New Particle Production

Paul Simeon

&

David Toback

Texas A&M University

Texas Section of the APS Meeting

Fall, 2004

What is the Question?

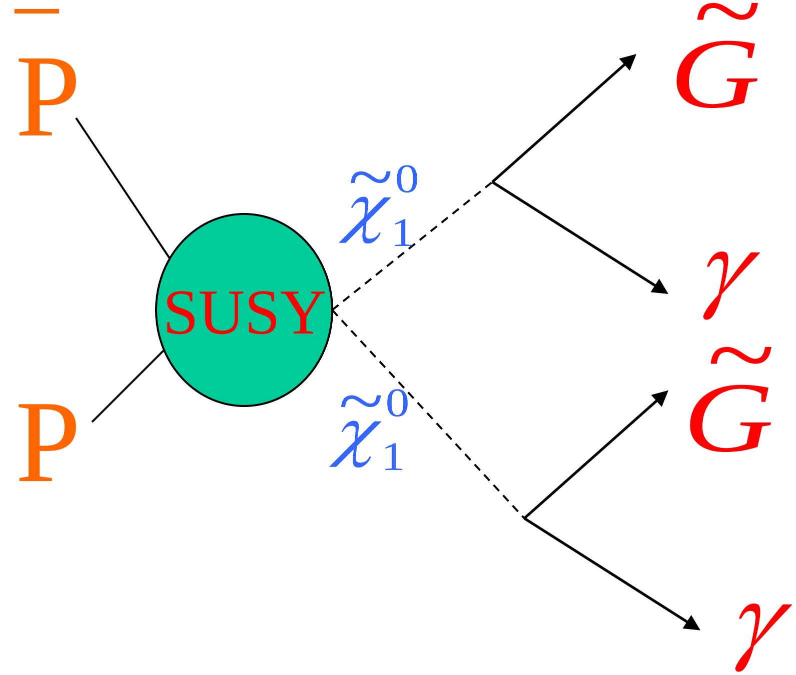
- **Lots of ways to search for supersymmetry at a particle accelerator**
- **Many Feynman diagrams in a single model can produce the same final state**
- **If no new physics are found, set cross section limits**
- **Want to optimize the experiment to give the best limit**
- **How do we do that?**

Example: Gauge Mediated Supersymmetry Breaking

- **p$\bar{p}$ collisions at Fermilab**
- $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$
- **Final State:**

$$\gamma\gamma\tilde{G}\tilde{G} + X$$

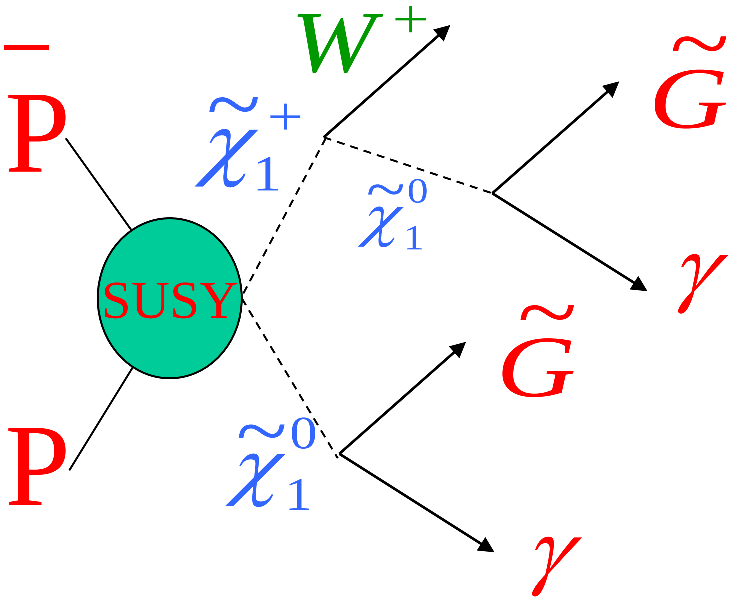
GMSB:



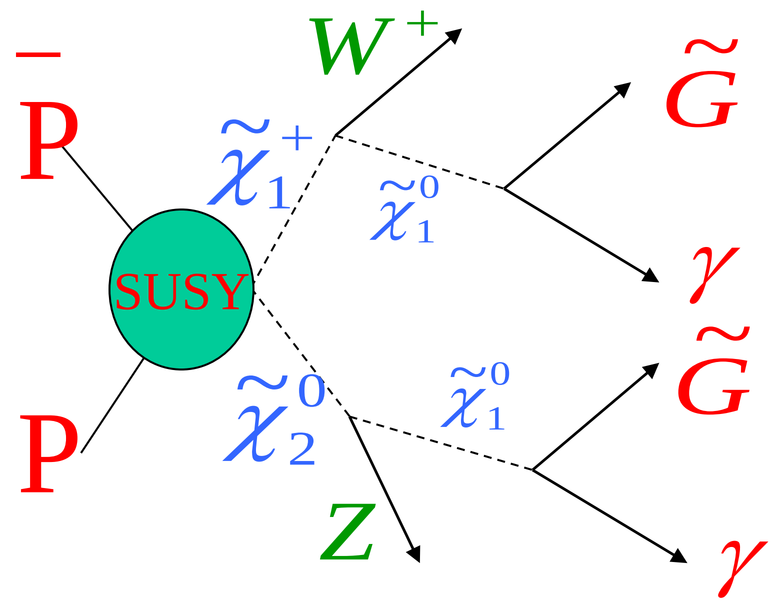
$\gamma\gamma$ + 2 Gravitinos in Final State

Two Processes… Same Final State

Process A



Process B



Same final state: $\gamma\gamma\tilde{G}\tilde{G}$ **+ X**

We can look for both at the same time

Can Set Limits On SUSY Using $\gamma\gamma$+MET

- **Pick a set of model parameters**
  - **e.g. GMSB, sparticle masses:** $\chi^{+} = 150$ **GeV**
- **Assume we do a single search for both processes at the same time**
  - **e.g. 2 photons and MET**
- **Uniquely defines** σ_A^{95} **and** ε **for both A and B**

Setting Limits…

If we get a null result from an experiment, we can set a 95% confidence level upper cross section limit on process A, σ_A^{95}, using

$$\sigma_A^{95} = \frac{N^{95}}{L\varepsilon_A}$$

where N^{95} is the 95% C.L. upper limit on the number of signal events.

Can do the same for process B or the combination of processes at the same time.

Which one is better?

One analysis… three limits:

$$\sigma_A^{95}, \sigma_B^{95}, \text{ and } \sigma_T^{95}$$

Which one of these is the most sensitive to new physics?

A) Lots of produced events, but low efficiency?
B) Not many events, but high efficiency?

An Example

No events observed in the data. Assume

$N^{95} = 3.0$ **and luminosity = 100 pb** $^{-1}$

	$Process$	ε	σ^{Theory} (pb)	σ^{95} (pb)	
low ε, high σ^Th	**A**	5%	0.50	0.60	**not excluded**
high ε, low σ^Th	**B**	20%	0.10	0.15	**not excluded**
	Total	7.5%	**0.60**	**0.40**	**excluded**

Lowest limit, but not excluded

σ_B^{95} **may be the lowest limit but is *not* the most useful limit. Only** σ_T^{95} **excludes the model.**

Is it ever better to look for A or B?

Perhaps looking for both at the same time is always best.

Q: Could σ_A^{95} or σ_B^{95} ever exclude a model while σ_T^{95} does not?

NO!

Using a series of inequalities, we were able to show that if either A or B exclude a model, then the total limit must also excludes the model.

We have shown that…

If $\sigma_A^{95} \leq \sigma_A$

Then $\sigma_T^{95} \leq \left(\dfrac{\sigma_A \varepsilon_A}{\sigma_A \varepsilon_A + \sigma_B \varepsilon_B} \right) \sigma_T$

The proof can be found at
http://hepr8.physics.tamu.edu/hep/limits/

Conclusion

- **If new physics (e.g. SUSY) can produce the same final state multiple ways (A or B), then the limit on the combination may exclude the model even if A and B individually do not.**
- **The total process must always be excluded if any single process is excluded.**
- **Optimizing the experiment to minimize the total combined cross section limit gives the most sensitivity to new physics.**
- **This result should hold for any search for new physics at the Tevatron or the LHC**
  - **Already been used at the Tevatron.**

Backup Slides

On Setting Limits for Supersymmetry

Abstract

When searching for new particles two separate production mechanisms from the same theory may produce the same final state. For example, in gauge mediated supersymmetry breaking with $\chi_1^0 \rightarrow \gamma\tilde{G}$ at least two production mechanisms can cascade to produce events with two photons and missing transverse energy. If there is no discovery one wants to set the best possible limits. While it seems obvious that the goal is to find the lowest possible cross section limit, one should be careful and focus on excluding the largest amount of parameter space for a theory. We show that the combined cross section limit from both (or all) production mechanisms that produce the same final state provides the most sensitivity when attempting to exclude a theory.

Setting Limits

Process A

- Cross section: σ_A
- Efficiency: ε_A
- Luminosity: L
- Expected events: $N_A = L\sigma_A\varepsilon_A$

The same results hold for Process B

Total Process

$$N_T = N_A + N_B$$

$$N_T = L(\sigma_A \varepsilon_A + \sigma_B \varepsilon_B)$$

$$N_T = L \sigma_T \varepsilon_T$$

$$\sigma_T \equiv \sigma_A + \sigma_B \qquad \varepsilon_T \equiv \frac{\sigma_A \varepsilon_A + \sigma_B \varepsilon_B}{\sigma_A + \sigma_B}$$

Proof

Assume process A is excluded.

$$\sigma_A^{95} \leq \sigma_A$$

$$\frac{N^{95}}{L\varepsilon_A} \leq \sigma_A$$

$$\frac{N^{95}}{L\varepsilon_A}\left(\frac{\varepsilon_T}{\varepsilon_T}\right) \leq \sigma_A$$

$$\sigma_T^{95}\left(\frac{\varepsilon_T}{\varepsilon_A}\right) \leq \sigma_A$$

Proof page 2

$$\sigma_T^{95}\left(\frac{\varepsilon_T}{\varepsilon_A}\right) \leq \sigma_A$$

$$\sigma_T^{95} \leq \sigma_A\left(\frac{\varepsilon_A}{\varepsilon_T}\right)$$

$$\sigma_T^{95} \leq \sigma_A\left(\frac{\varepsilon_A}{\varepsilon_T}\right)\left(\frac{\sigma_T}{\sigma_T}\right) = \left(\frac{\sigma_A\varepsilon_A}{\sigma_T\varepsilon_T}\right)\sigma_T$$

Proof page 3

$$\sigma_T^{95} \leq \left(\frac{\sigma_A \varepsilon_A}{\sigma_T \varepsilon_T}\right) \sigma_T$$

$$\sigma_T^{95} \leq \left(\frac{\sigma_A \varepsilon_A}{\sigma_A \varepsilon_A + \sigma_B \varepsilon_B}\right) \sigma_T$$

$$\sigma_T^{95} \leq \sigma_T$$

More than 2 processes

We note that the reasoning can be extended to more than two production mechanisms.

$$N_T = \sum_{i=1}^{n} N_i = L \sum_{i=1}^{n} (\sigma_i \varepsilon_i)$$

$$\sigma_T^{95} \leq \left(\frac{\sigma_A \varepsilon_A}{\sum_{i=1}^{n} \sigma_i \varepsilon_i} \right) \sigma_T$$