Title: Fishing Lessons at the LHC

Date: Oct 04, 2011 12:30 PM

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Abstract: The 7 TeV LHC run has the potential to shed light on extensions beyond the Standard Model. I will discuss the prospects for finding new colored particles in an optimistic signature for discovery, heavy flavor jets and missing energy. I will illustrate the use of Simplified Models in guiding the organization of searches and presentation of results. Finally, I will discuss finer jet observables, and their possible applications in understanding Standard Model backgrounds and distinguishing new physics in a jet-rich environment.

Fishing Lessons at the LHC

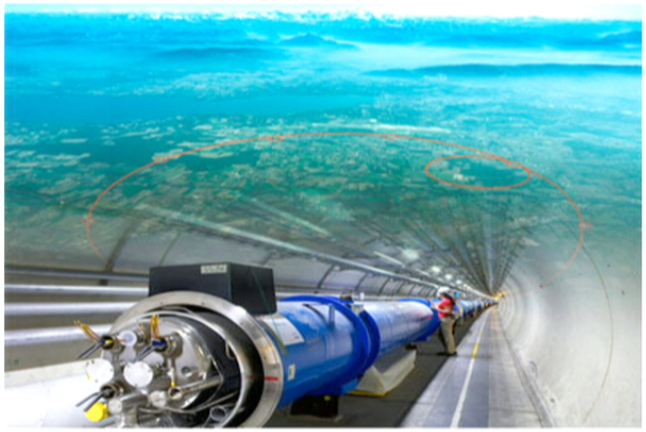
Eder Izaguirre

SLAC and Stanford University

w/ Daniele Alves, Anson Hook, Rouven Essig, Jared Kaplan, and Jay Wacker

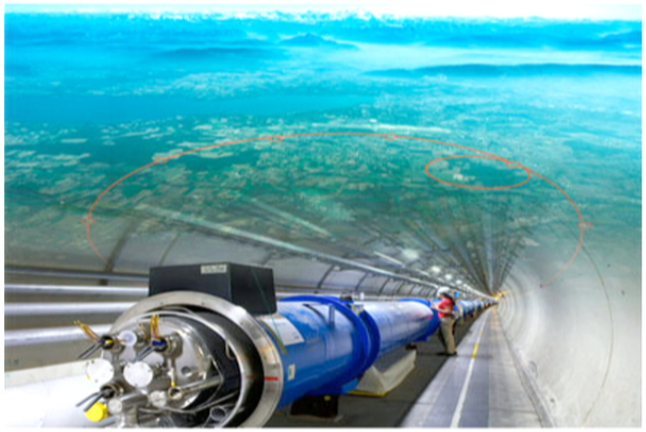
Perimeter Institute, Particle Physics Seminar, October 4th, 2011

Can the LHC cast a wide net on new physics?



And make the most of the data collected (fish caught)?

Can the LHC cast a wide net on new physics?

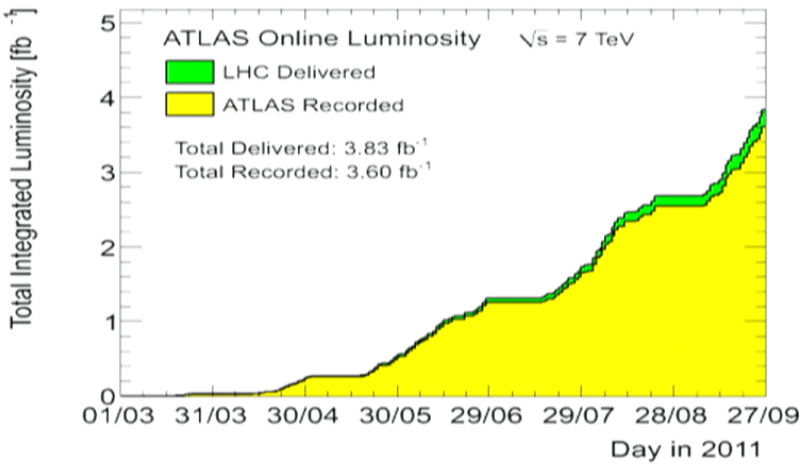


And make the most of the data collected (fish caught)?

A problem that lends itself to theorists' involvement

The LHC is opening the energy frontier!

- 2011 run expected to conclude with ~ 5 fb^{-1} of data
- Resume in 2012 and run @ ? TeV through the end of the year



- Shut down during 2013 to retrain magnets (?)
- Turn it on again in 2014 @ ~ 14TeV (?)

So far

Experimentalists have done a great job in understanding detector performance

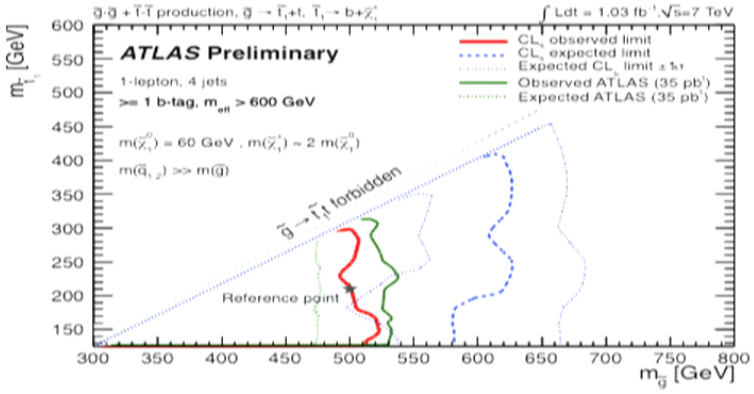
Searches being performed quickly

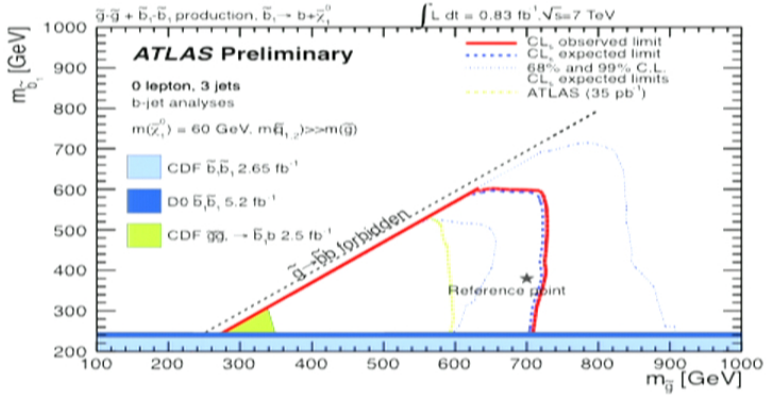
Less model dependence in searches

So far (no discoveries)

Placed tighter bounds on new physics

Need to be careful about interpretation of results





From EPS and LP 11

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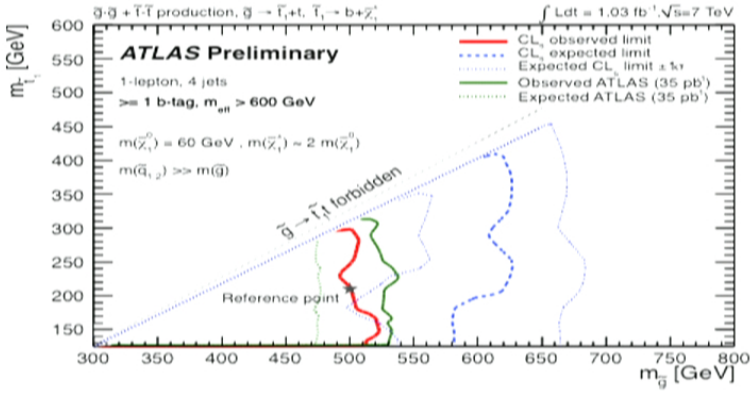
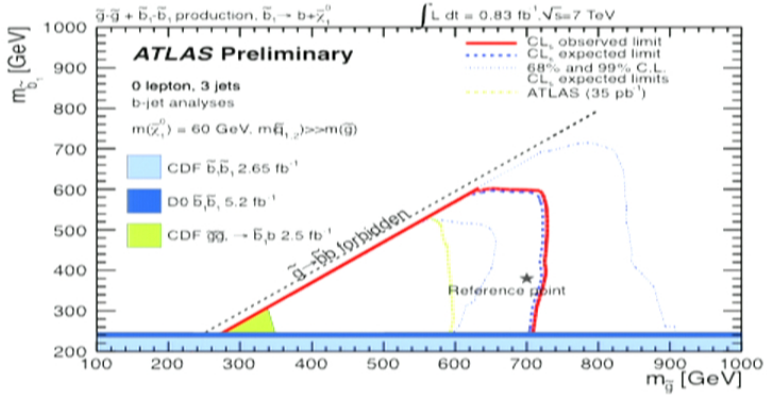




From EPS and LP 11

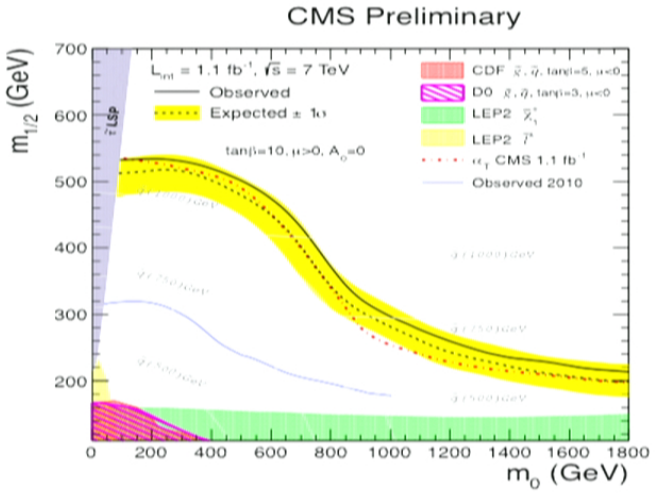
Outline

- Simplified Models
- Prospects for the 7 TeV run
- Finer jet observables

The need for less model dependence

mSugra: $m_{\frac{1}{2}}, m_0, \tan\beta, A_0, \mathrm{Sign}(\mu)$

Fixed at high scale (e.g. GUT). RGE down to obtain mass spectrum



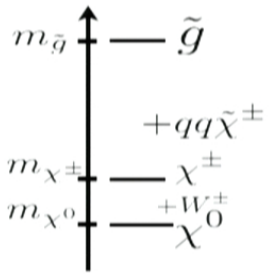
Implies low energy fixed gaugino spectrum

$$m_{\tilde{g}} : m_{\tilde{W}} : m_{\tilde{B}} = 7 : 2 : 1$$

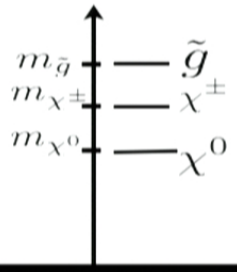
Needlessly limited in scope

The need for less model dependence

Optimizing w/r to mSugra
means that the search region covers new physics like



Highly energetic jets and large missing energy from wide mass splitting



But can it cover more compressed spectra like this?
Softer jets, less missing energy.

Simplified Models

Models are created to solve problems or demonstrate mechanisms
Realistic ones tend to be complicated and most details are irrelevant for searches

Simplified Model: Minimal particle content and free parameters

Can translate limits to other theories
Only keep particles and couplings relevant for searches

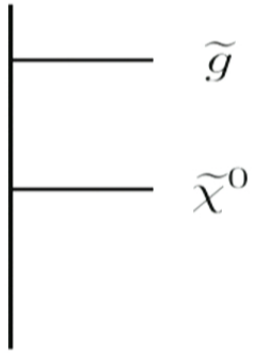
Captures specific models (MSSM, UED, etc)

Easy to notice & explore kinematic limits

Simplified Models

w/ Daniele Alves and Jay G. Wacker

An example:



$$\widetilde{g} \rightarrow q\bar{q}\widetilde{\chi}^0$$

Free parameters

$$\mathcal{B} \times \sigma_{pp\rightarrow\widetilde{g}\widetilde{g}} \;\; m_{\widetilde{g}} \;\; m_{\widetilde{\chi}^0}$$

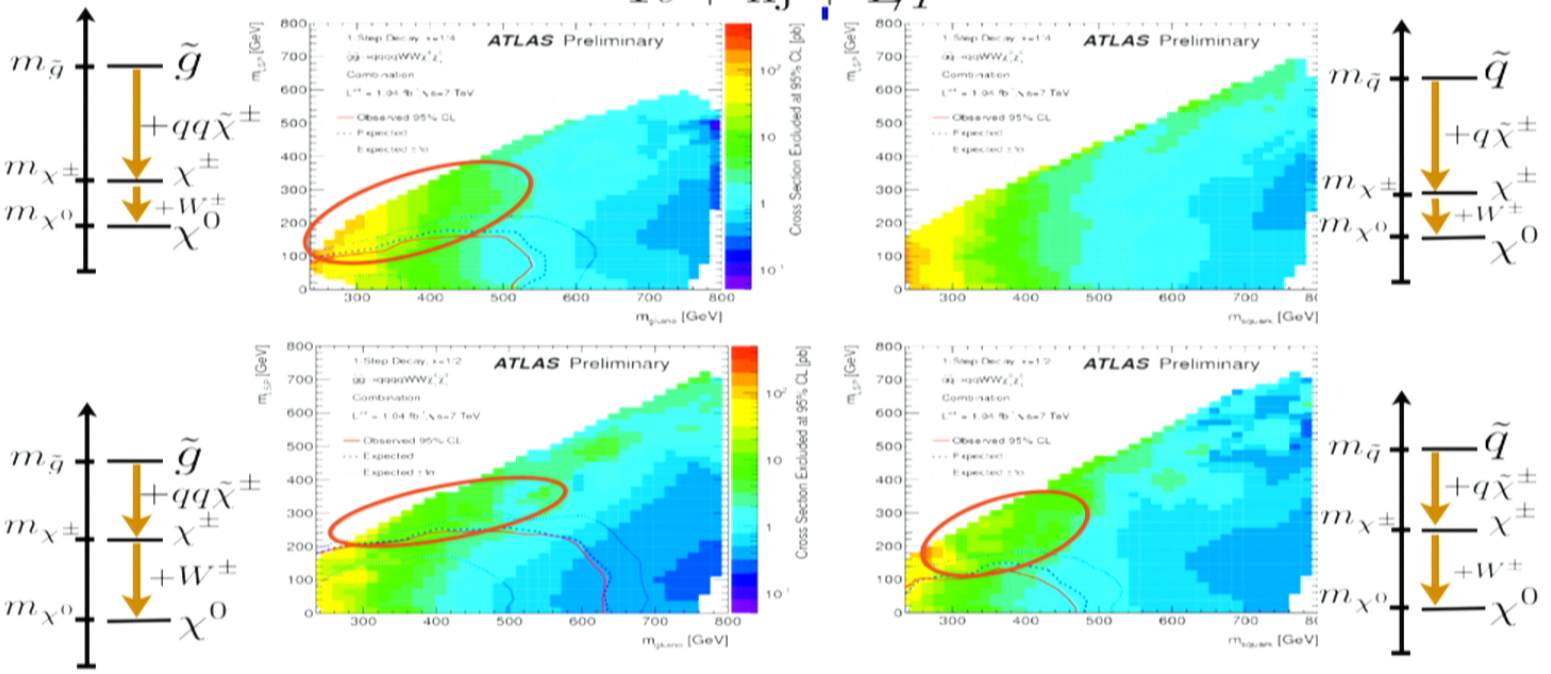
In published analyses so far, search regions have been optimized for particular benchmarks, e.g. mSugra

But experiments have begun presenting limits in terms of simplified models
Very useful!

Simplified Models can also be used to create and evaluate search strategy

Can be used to spot search deficiencies

$1\ell + \mathrm{nj} + \not{E}_T$



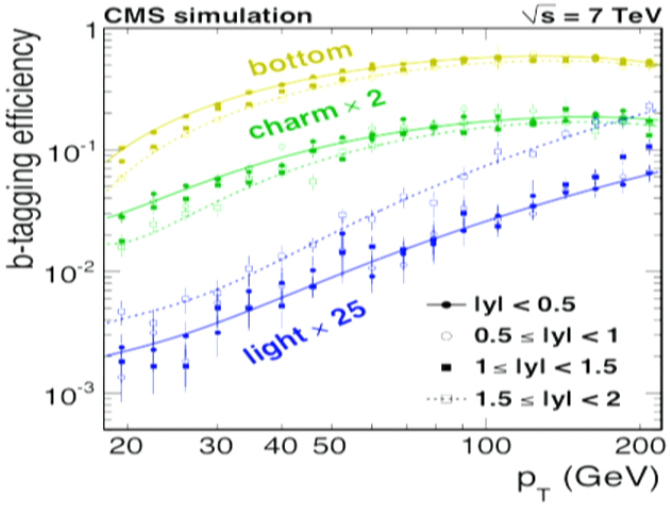
R. Brunelière, CERN workshop "Implications of LHC results for TeV-scale physics"

Heavy flavor Simplified Models

w/ Rouven Essig, Jared Kaplan, Jay G. Wacker

Generic signature: $b_{\text{jets}} + \ell's + \not{E}_T$

B-jets give a powerful handle on SM backgrounds and new physics



Heavy flavor Simplified Models

Generic signature: $b_{\text{jets}} + \ell's + \not{E}_T$

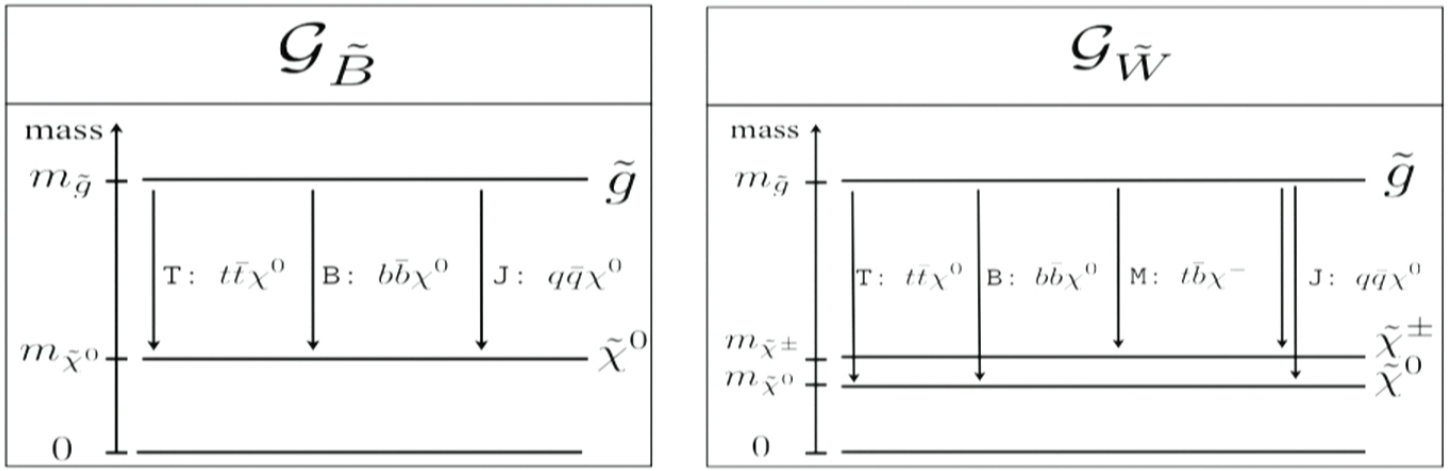
What theories to search for in this channel?
Not a one-to-one correspondence

Approach:

Use a set of simple topologies (Simplified Models) to design a search strategy and present results in a useful way

Heavy flavor Simplified Models

Gluino-like: Assume squarks decoupled



Heavy flavor Simplified Models

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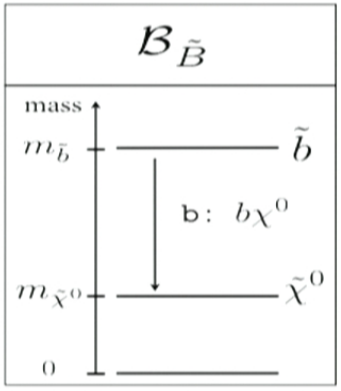
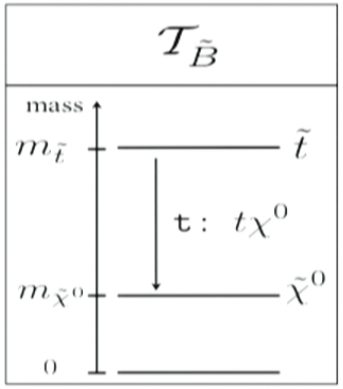




Heavy flavor Simplified Models

12 Simplified Models in total

"Pure" topologies: $pp \to (\tilde{g} \to t\bar{t}\chi^0)(\tilde{g} \to t\bar{t}\chi^0)$

"Mixed" topologies: $pp \to (\tilde{g} \to t\bar{t}\chi^0)(\tilde{g} \to b\bar{b}\chi^0)$

~ 2500 points in model space: $(m_{\mathrm{High}}, m_{\mathrm{Low}})$

$$m_{\mathrm{High}} \in \{m_{\tilde{g}}, m_{\tilde{q}}\}$$

$$m_{\mathrm{Low}} \in \{m_{\tilde{\chi}^\pm}, m_{\tilde{\chi}^0}\}$$

Assume $m_{\chi^\pm} \simeq m_{\chi^0}$

Search strategy

Design a search strategy that ensures optimal coverage to the space of Simplified Models

Find a set of "search regions" or "cuts" of the form: $(N_j, N_b, N_\ell, H_T, \not{E}_T)$

No single cut covers all the space of models because the kinematics vary widely

Ideally, would like to find a minimal number of search regions

Search strategy

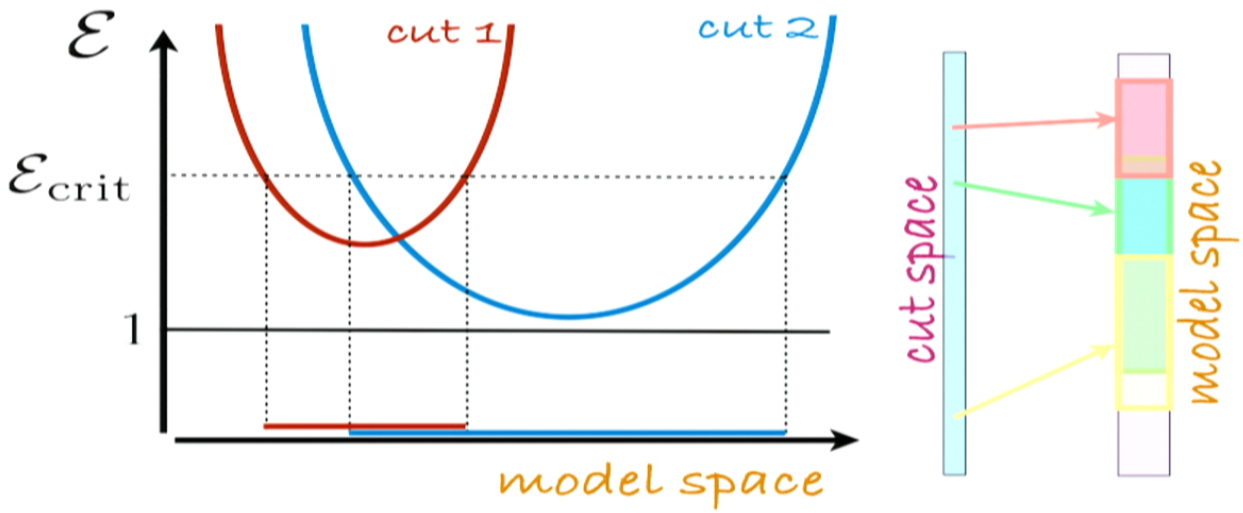
How do we quantify how effective a cut is?

For each $(N_j, N_b, N_\ell, H_T, \not{E}_T)$

Efficacy of a cut $\mathcal{E}_i = \dfrac{\sigma_{\text{cut } i}}{\sigma_{\text{optimal}}}$

Search strategy

Pick a set of cuts so that combined cover the whole of model space



Outline

- Simplified Models
- Prospects for the 7 TeV run 
- Finer jet observables

How much ground can the LHC cover?

By the end of 2011, $\sim 15/\text{fb}$ are expected

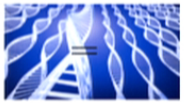
Study these search regions on the space of Simplified Models

$$
\begin{aligned}
N_{\text{jet}} &\in \{2^+, 3^+, 4^+\} \\
N_{b\text{jet}} &\in \{0, 1^+, 2^+, 3^+\} \\
N_{\ell} &\in \{0, 1^+, 2^+, 3^+, \text{SSDL}^+, \text{OSDL}^+\} \\
\not{E}_{T\,\text{min}} &\in \{0, 50, 100, \ldots, 500\}\ \text{GeV} \\
H_{T\,\text{min}} &\in \{200, 300, \ldots, 1200\}\ \text{GeV}
\end{aligned}
$$

Digression: Genetic Algorithm

A cut on $(N_j, N_b, N_\ell, H_T, \not{E}_T)$

A set of cuts (search regions) =

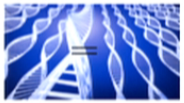


Create random population

Digression: Genetic Algorithm

A cut on $(N_j, N_b, N_\ell, H_T, \not{E}_T)$

A set of cuts (search regions) =



Create random population

Kill the weak

Digression: Genetic Algorithm

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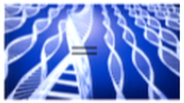

Create random population

Kill the weak

Breed the survivors

Digression: Genetic Algorithm

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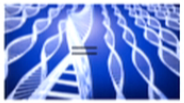

Create random population

Kill the weak

Breed the survivors

And mutate a few

Digression: Genetic Algorithm

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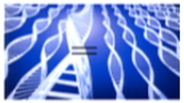
A set of cuts (search regions) =



Create random population

Kill the weak

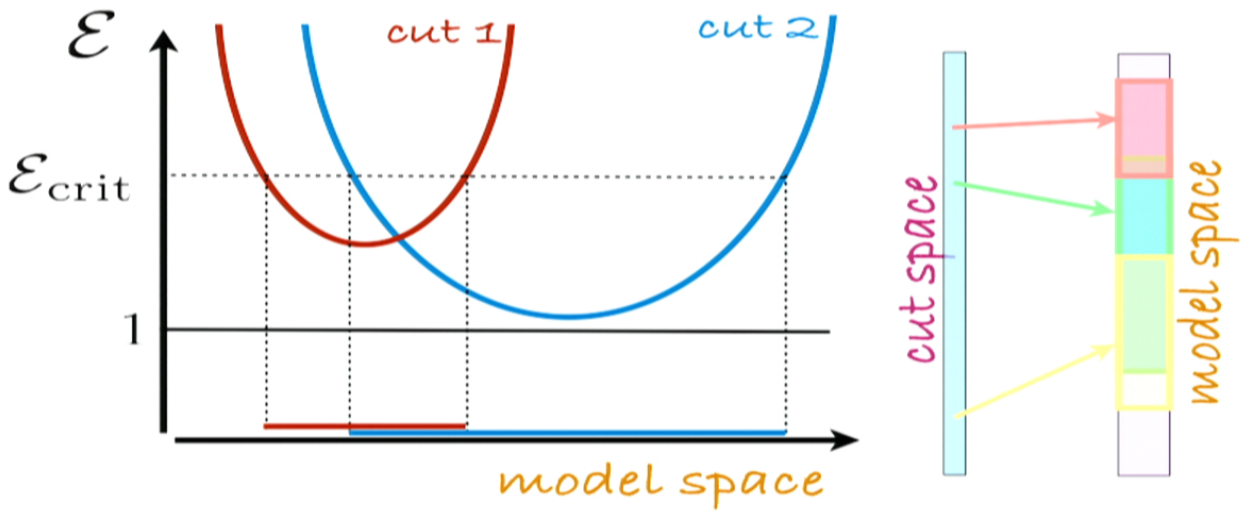
Breed the survivors

And mutate a few

Pick the fittest!

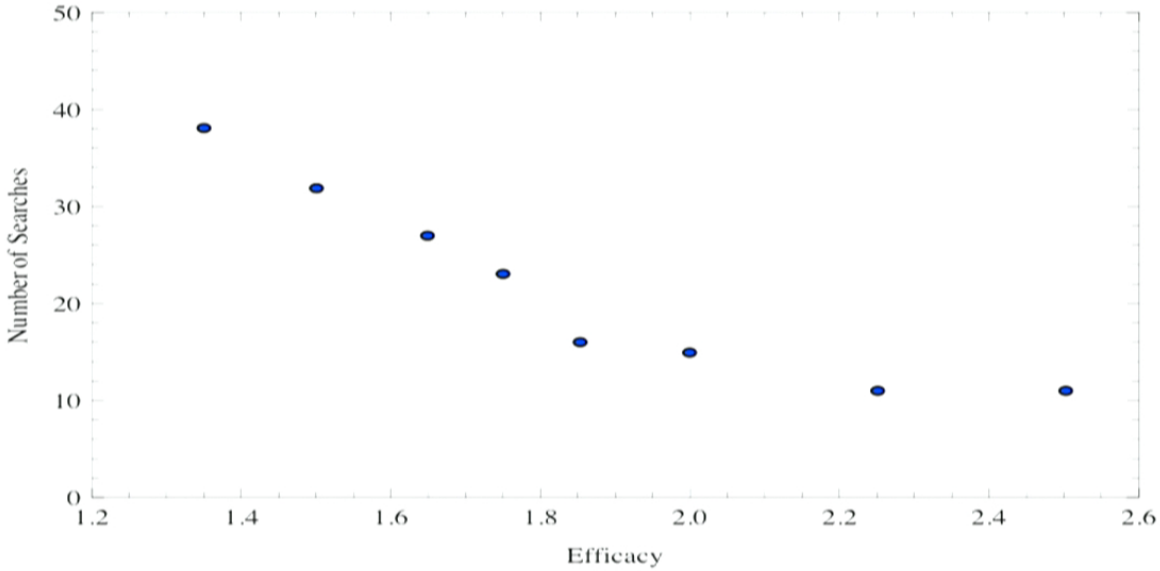
Recall

Pick a set of cuts so that combined cover the whole of model space



$$\mathcal{E} = \frac{\sigma_{95\%\ \mathrm{C.L.}}}{\sigma_{\mathrm{optimal}}}$$

Number of search regions as a function of $\mathcal{E}_{\mathrm{crit}}$



Search regions found

For $\mathcal{E}_{\rm crit} = 2$

	Search Region	N_j	N_ℓ	$N_{\rm bjet}$	$\not{E}_T$	H_T
High HT	1	4^+	0	0	300	1000
High MET	2	4^+	0	0	400	500
1 b Low multiplicity	3	2^+	0	1^+	400	400
1 b High HT	4	4^+	0	1^+	300	800
1 b High MET	5	4^+	0	1^+	400	500
2 b High MET	6	3^+	0	2^+	250	400
3 b High MET	7	3^+	0	3^+	250	600
3 b Low MET	8	4^+	0	3^+	150	300
b SSDL	9	2^+	SSDL	1^+	0	200

2 Normal Light Flavor

4 Normal Heavy Flavor

3 Low BG Heavy Flavor

Search regions found

For $\mathcal{E}_{\rm crit} = 2$

	Search Region	N_j	N_ℓ	$N_{\rm bjet}$	$\not{E}_T$	H_T
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3 b Low MET	8	4^+	0	3^+	150	300
b SSDL	9	2^+	SSDL	1^+	0	200

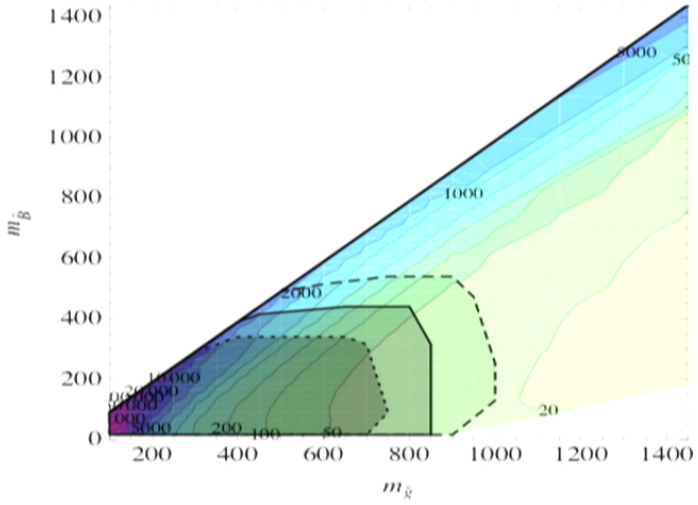
2 Normal Light Flavor

4 Normal Heavy Flavor

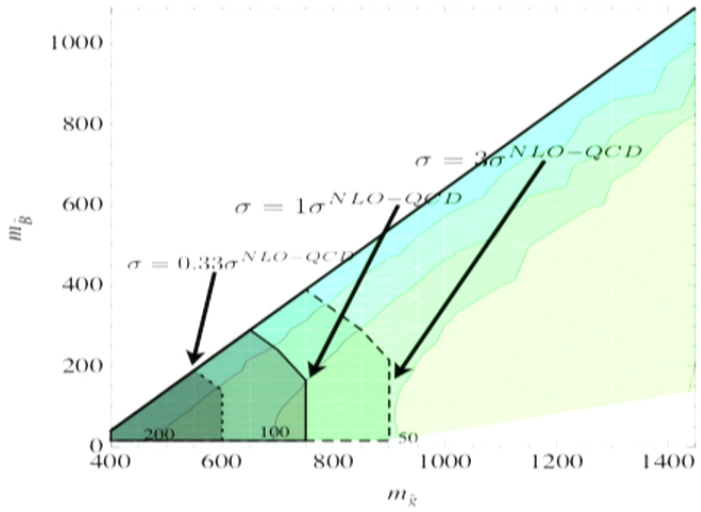
3 Low BG Heavy Flavor

Estimated reach at L=1/fb

$4b + \not{E}_T$



$4t + \not{E}_T$



Search regions found

We shouldn't expect the search regions found to be used by experimentalists

We have relied on theorists' attempts at understanding the LHC detectors (e.g. using PGS...)

This procedure would have to be validated by the experimentalists

Not an easy task since they use full detector simulator
Can be slow on ~ 2500 model points

Perhaps a good means of communication between theorists and experimentalists are Benchmarks

Heavy Flavor Simplified Models Benchmarks

Wait a minute, wasn't this guy advocating for using Simplified Models in lieu of benchmarks like mSugra?

Points in the space of Simplified Models can look alike

For instance, points with same $\Delta = m_{\mathrm{High}} - m_{\mathrm{Low}}$

Found 60 (kinematically) different benchmark points from the space of ~ 2500 points that when optimized w/r to them give the same 9 search regions

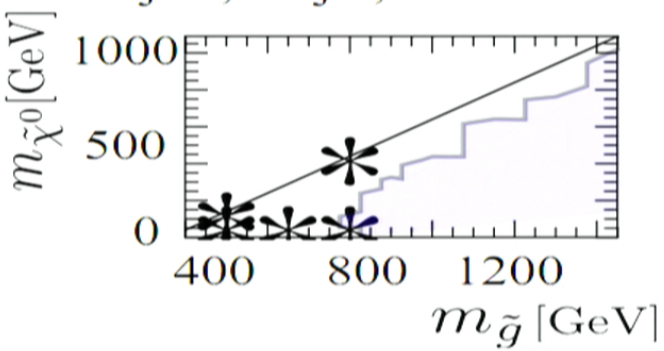
MultiRegion Search Strategy for Heavy Flavor

4 tops + MET

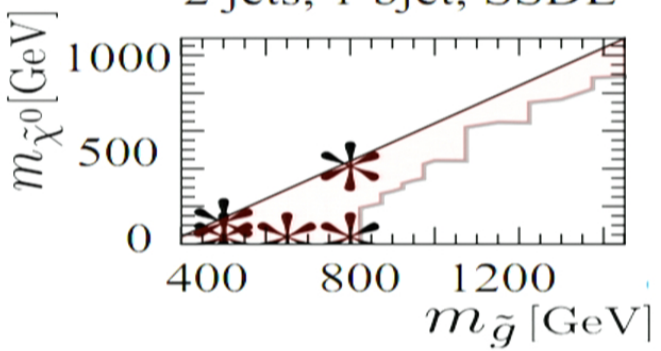
$$pp \to \tilde{g}\tilde{g} \to (t\bar{t}\chi^0)(t\bar{t}\chi^0)$$

2 search regions cover everything at $1\,\text{fb}^{-1}$

4 jets, 1 bjet, MET>400



2 jets, 1 bjet, SSDL



Jet Observables

w/ Anson Hook and Jay G. Wacker

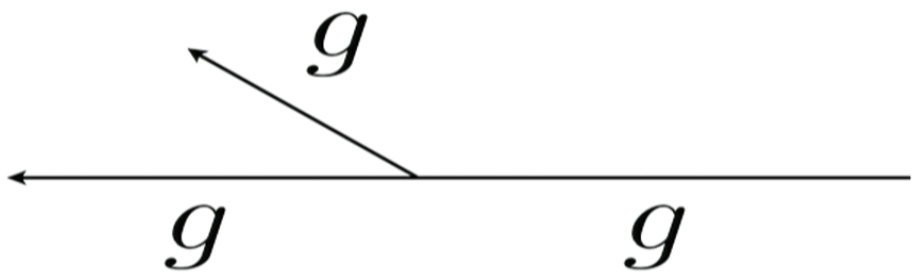
Two questions addressed here

1. Can looking into the origin of jets (quark or gluon-originated) help us in reducing backgrounds and maybe looking for new physics?

2. Jet masses at the LHC?
Are the masses from jets from radiation uncorrelated?
Handle on looking new massive states?

Jet Masses

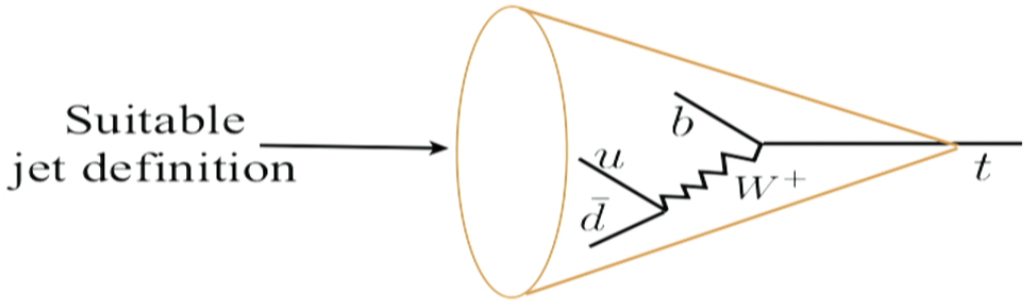
A massless parton can have a mass generated by radiating (through parton shower)



Jet mass = invariant mass of a jet

Jet Masses

Massive particles decaying to visible states



Jet mass = invariant mass of a jet = m_t

Jet Masses

How about jet mass correlations in multi-jet events

Focus on Z+jets, with $Z^0 \to \nu\bar{\nu}$

Ansatz

$$m_J^2(p_T; p_{T\mathrm{i}}, R_i) = m^{(1)\ 2}(p_T) + \sum_i m^{(2)\ 2}(p_T; p_{T\mathrm{i}}, R_i) + (\text{3-point function}) + \ldots$$

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

$$\eta = -ln(\tan\theta/2)$$

Look at Z+1j events to estimate the 1-point function

We find it agrees with expectation

$$m^{(1)\ 2}(p_T) \sim cp_T^2$$

Jet Masses

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Look at Z+1j events to estimate the 1-point function

We find it agrees with expectation

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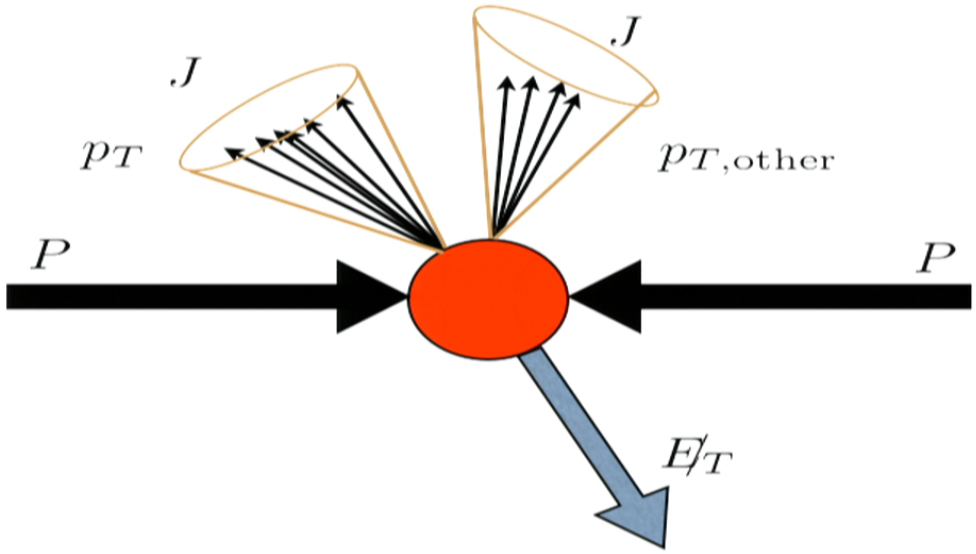
Jet Masses

Look at Z+2j events

Two-point function



Jet Masses

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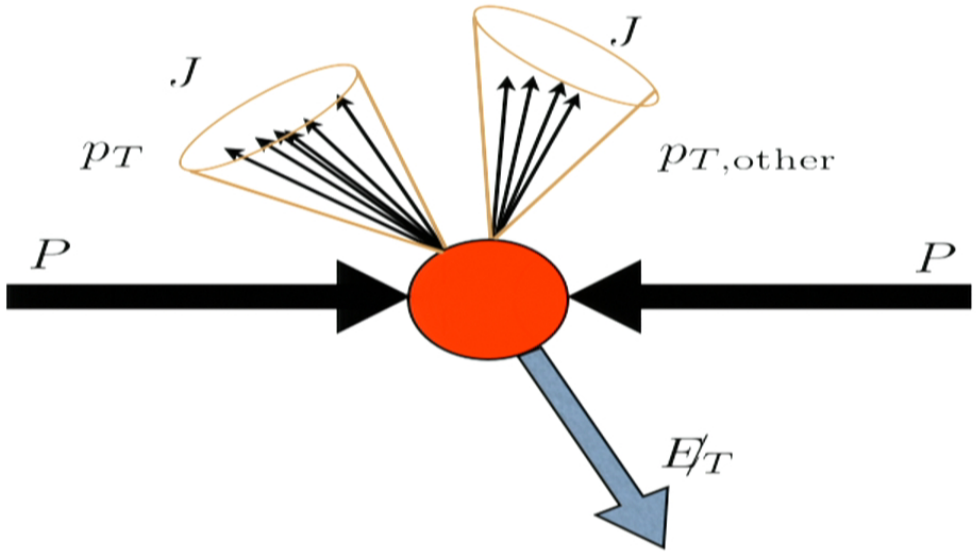
Two-point function



Jet Masses

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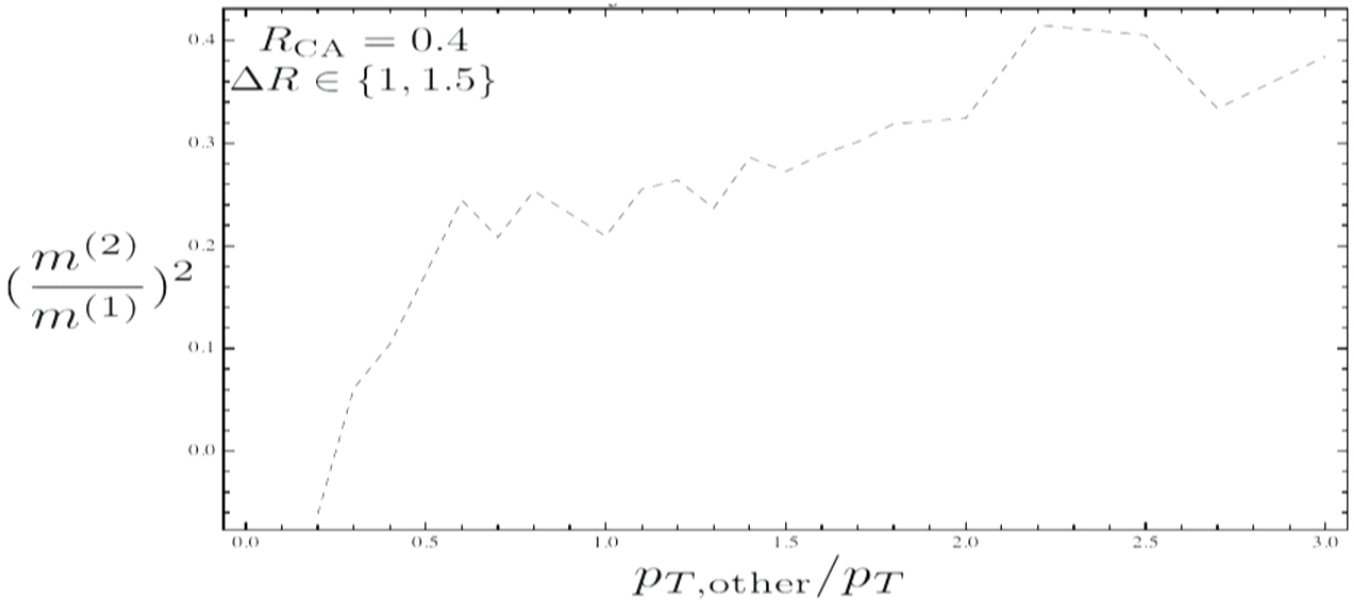
Two-point function

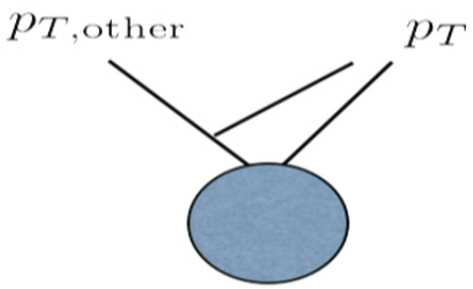


Jet Masses

Look at Z+2j events

Two-point function

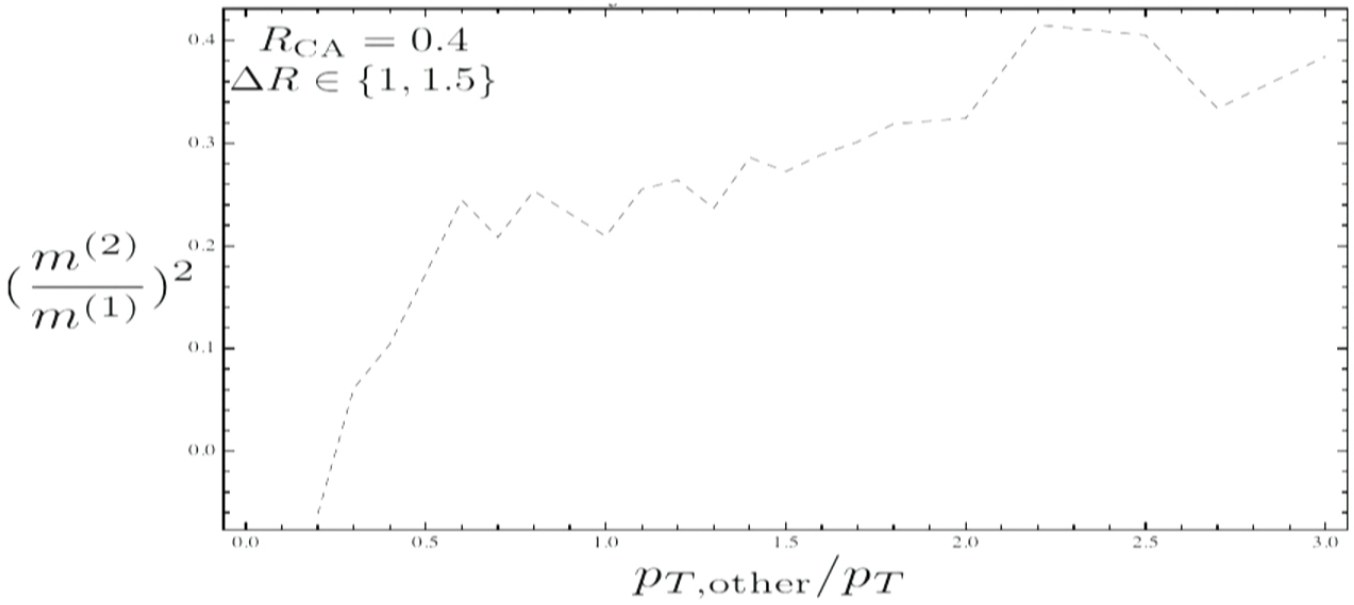
$p_{T,\text{other}} >> p_T$



Jet Masses

Look at Z+2j events

Two-point function

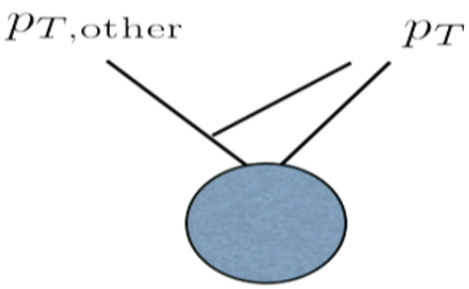


Jet Masses

Look at Z+2j events

Two-point function

$p_{T,\text{other}} >> p_T$



Jet Masses

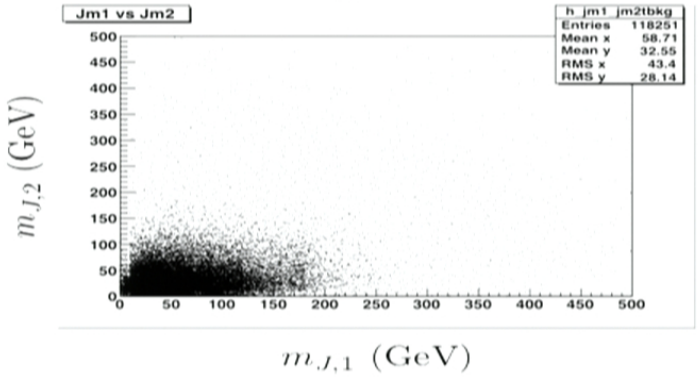
Can we use jet masses as a handle on new physics?

$$pp \to \tilde{g}\tilde{g} \to 4t + \chi^0\chi^0$$

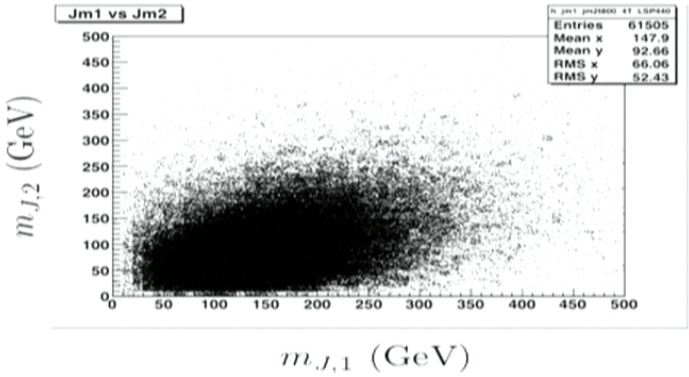
800 GeV gluino decaying to 450 GeV LSP

$$R_{\mathrm{CA}} = 1.2$$

Backgrounds



Signal



Conclusions

The LHC has opened up the energy frontier. Discoveries may be just around the corner.

It's important that the experiments look in many places.
New physics may be hiding in previously unexplored corners.

Simplified Models provide a framework for casting a wide net on new physics

Finer jet observables can provide new handle on backgrounds and new physics