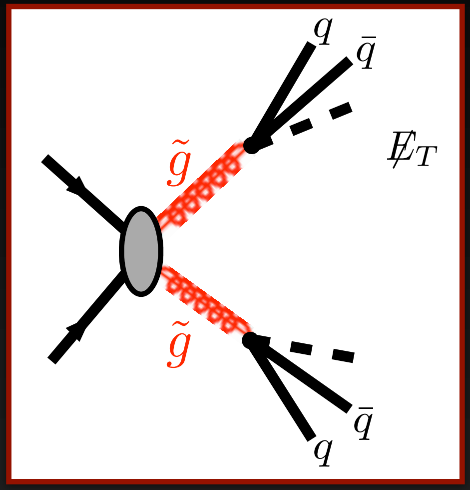
Organizing and Optimizing Hadronic Searches

Natalia Toro
Stanford University/Perimeter Institute

Focus of this talk:

Thinking about "SUSY" searches in terms of individual **physics reactions** (a.k.a. **"topologies"**)



rather than the combinations that arise in benchmark models

Parameters: masses and cross-section.

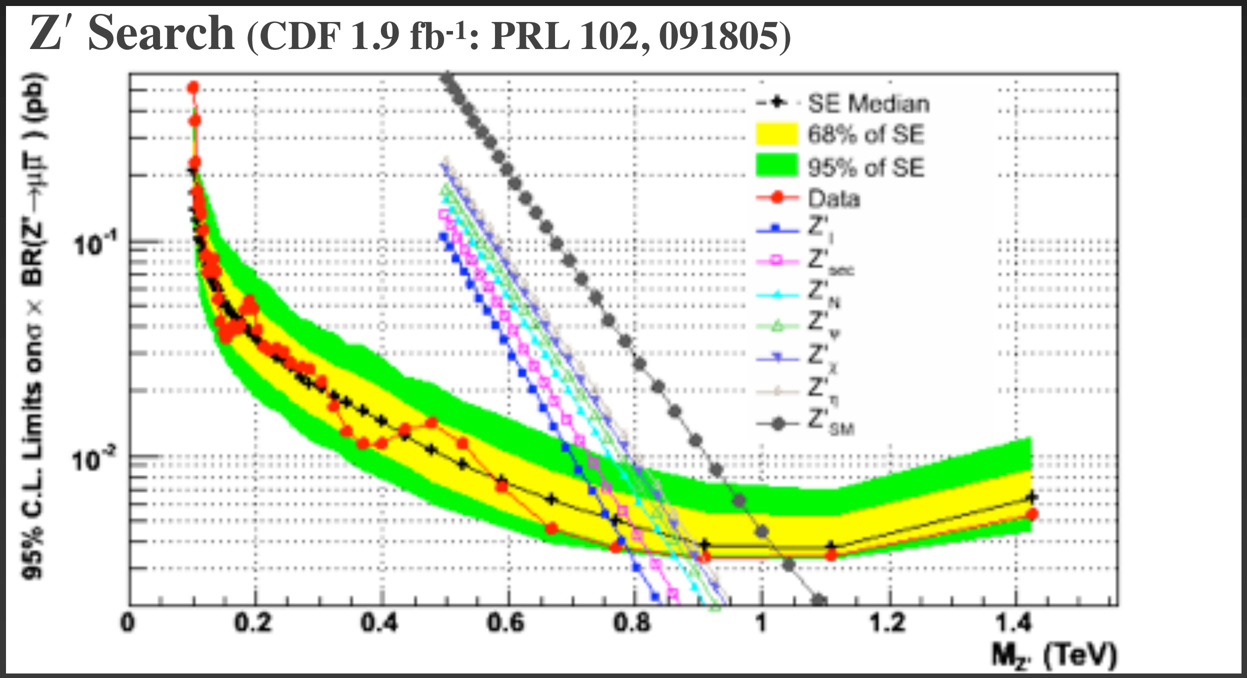
Supporting material:
hep-ph/0703088: Arkani-Hamed et al w/ NT
0810.3921 Alwall, Schuster, NT

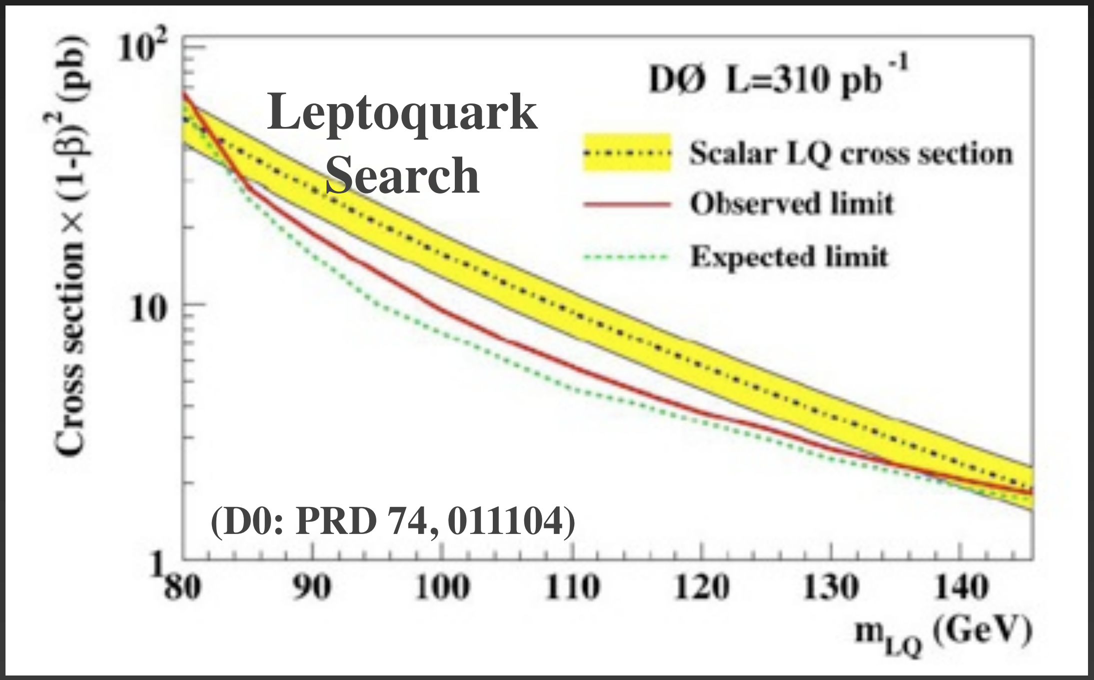
(See also series of papers by Alvez, Alwall, Le, Lisanti, Izaguirre, Manhart, Wacker)

Searches Outside SUSY

- Top physics

- Resonance searches, e.g. higgs,Z': σ x Br limits, as function of mass, in many decay channels
- Many exotics searches likewise tailored to particular event topology (e.g. $b' \rightarrow tW$): mass-dependent limit on σ overlaid w/ prediction





- vs. SUSY: present raw distributions & specific model exclusions (fits?)
- Limits exploration to a slice of parameter space — **how does it apply if nature is on a different slice?**

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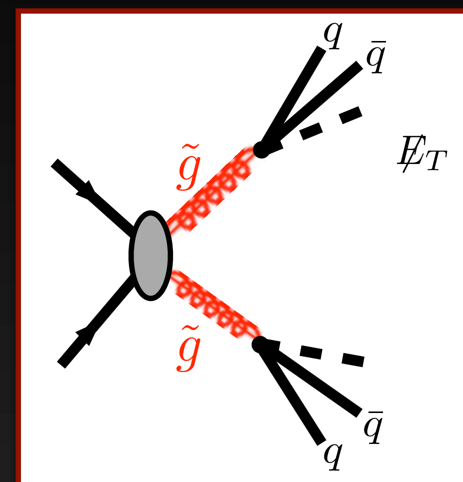
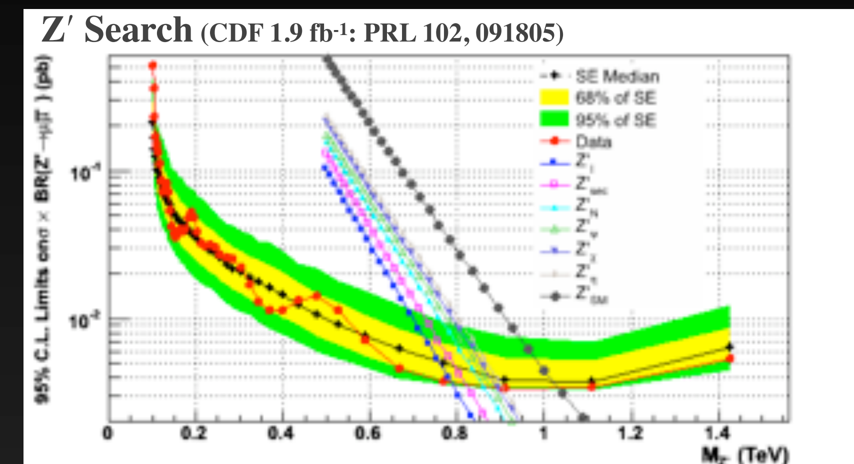
Thinking about "SUSY" searches in terms of individual **<u>physics reactions</u>**





rather than the combinations that arise in benchmark models

Outline

– define & motivate reaction (topology)-based searches

– how to set/quote limits (see also Eder's talk)

– key reactions for hadronic final states

Models

Theory offers **no** sharp predictions analogous to Z, W, t

(except higgs – maybe)

- Frameworks (e.g. SUSY) work beautifully, but "problems"
  – fixes interaction Feynman rules (partners)
- Models illustrate ideas to solve problem — usually simplest case that makes the point

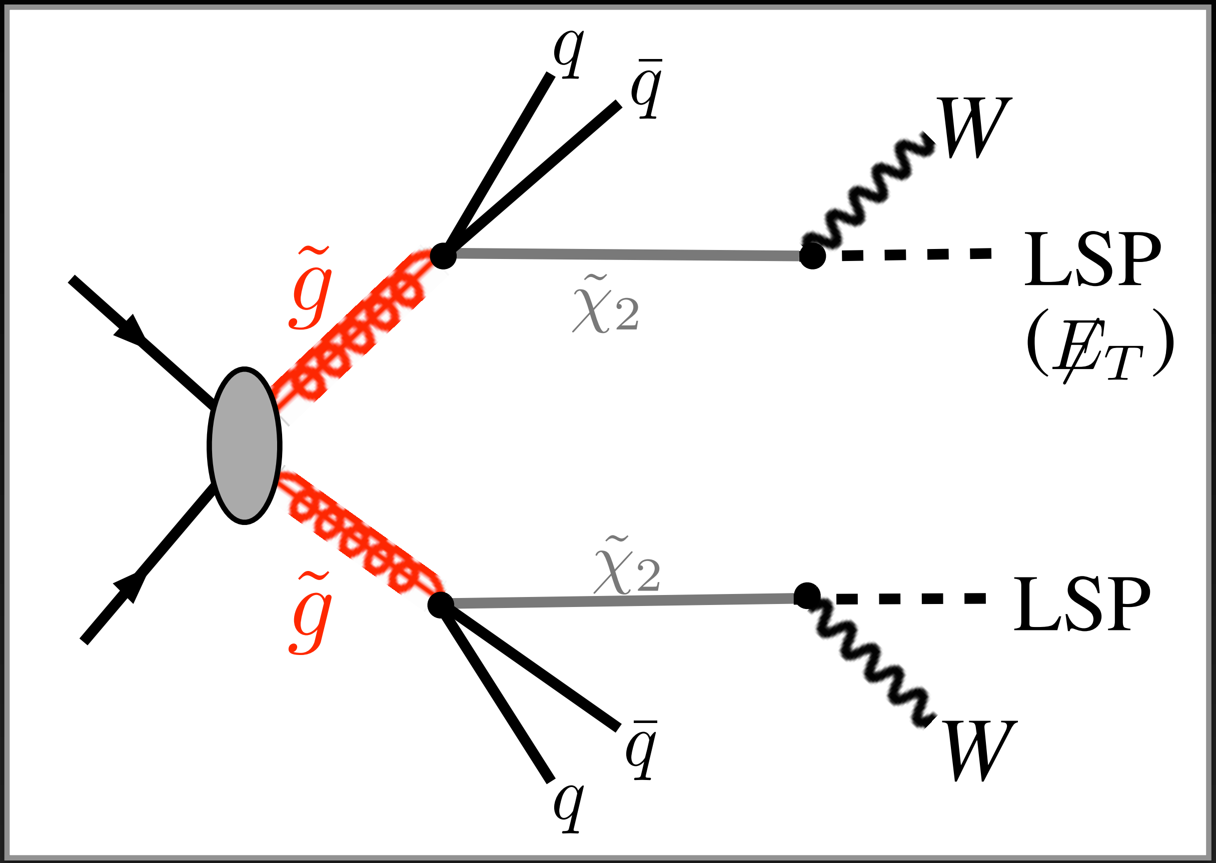
  (e.g. SU(5)-symmetry)

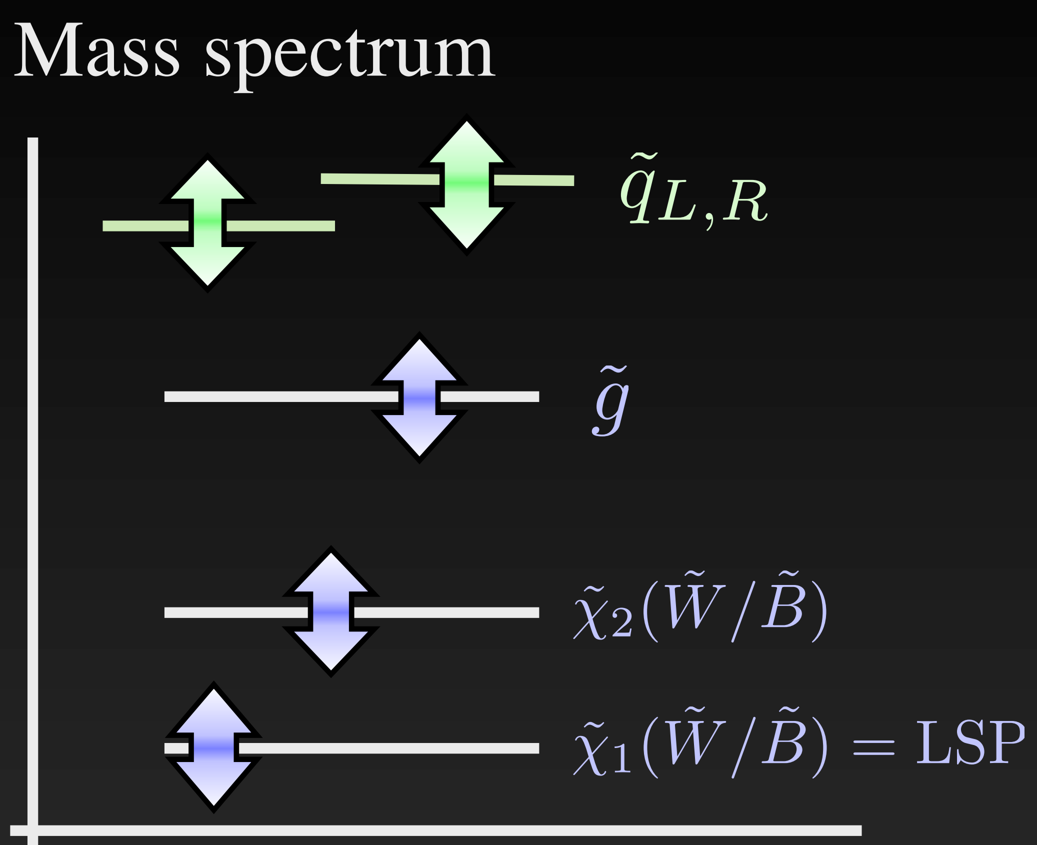
  – relations between masses rely on these assumptions

Useful! Suggest new signatures; inform understanding of any signal.

But **poor sampling** of possible spectra & LHC dynamics.

Example





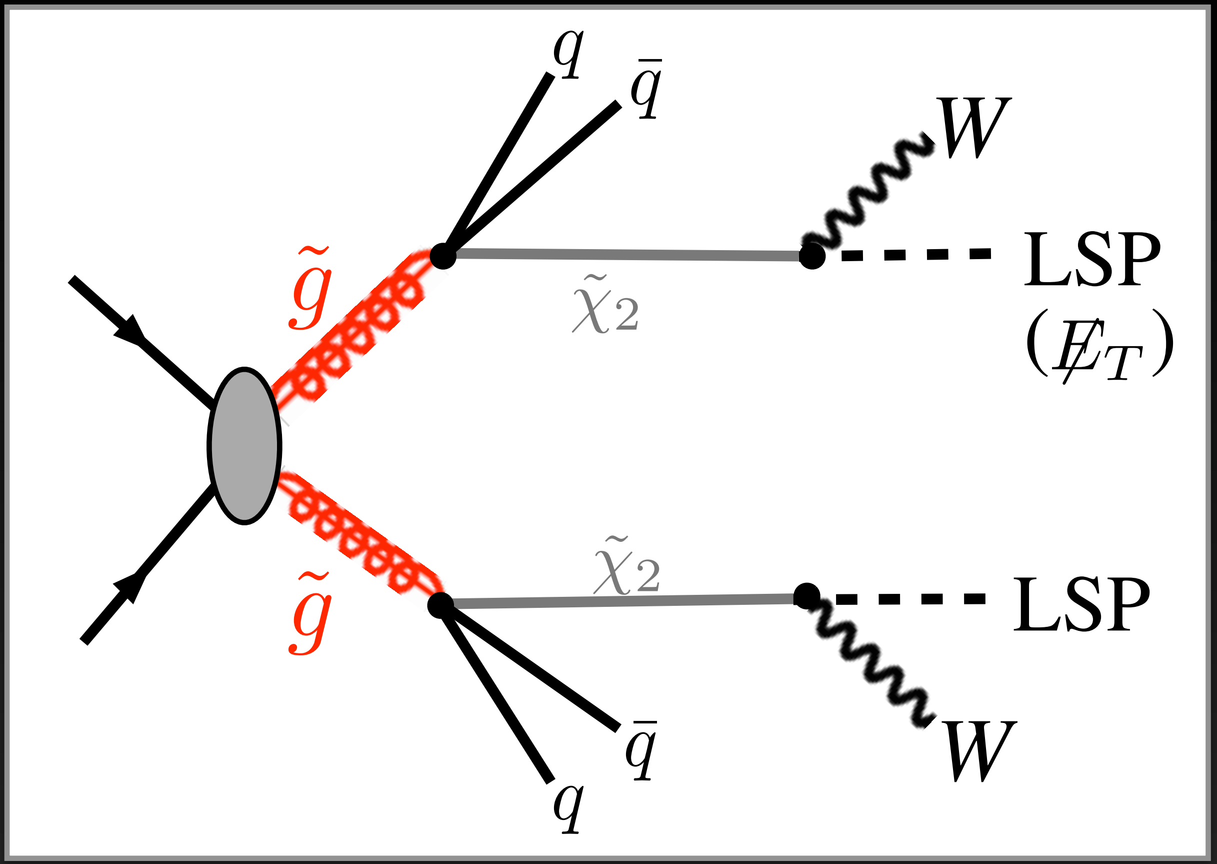
Masses of $\tilde{g}, \tilde{\chi}_2, \tilde{\chi}_1$ affect kinematics, search efficiency/optimization

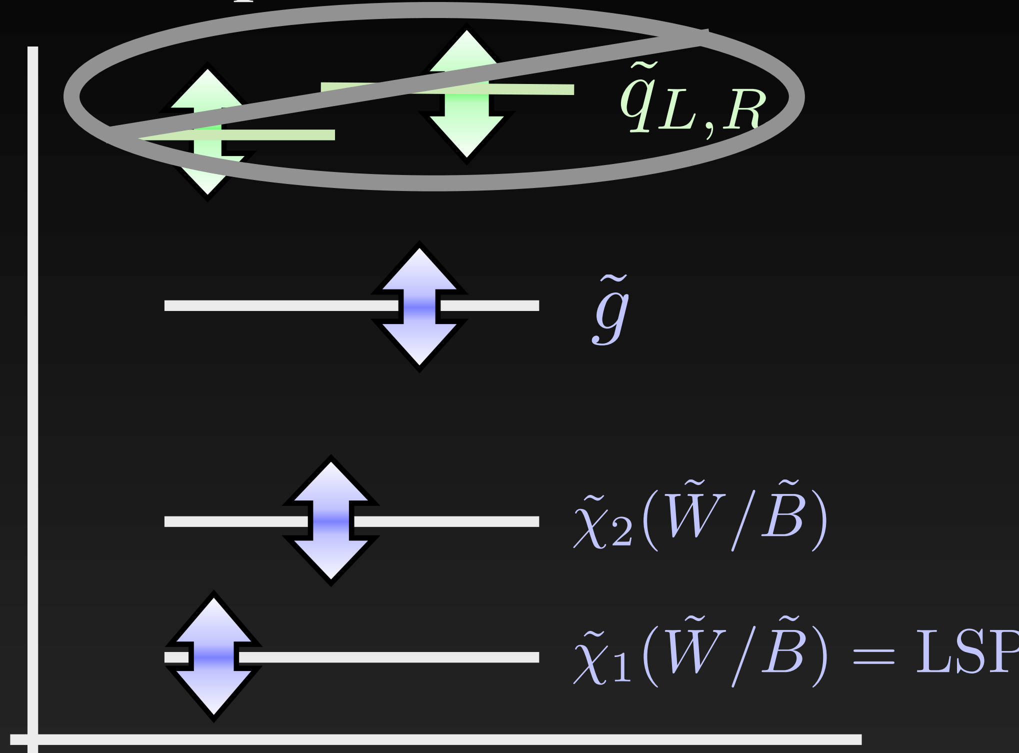
Though $\tilde{q}_{L,R}$ don't appear in decay, their masses affect cross-section and branching fractions of $\tilde{g}$ (higgs sector also)

In general, all are independent parameters!

Relation of some parameters to observables is complicated, non-unique. In the end, they just change $\sigma \times BR$ for various reactions.

Alternative Outlook





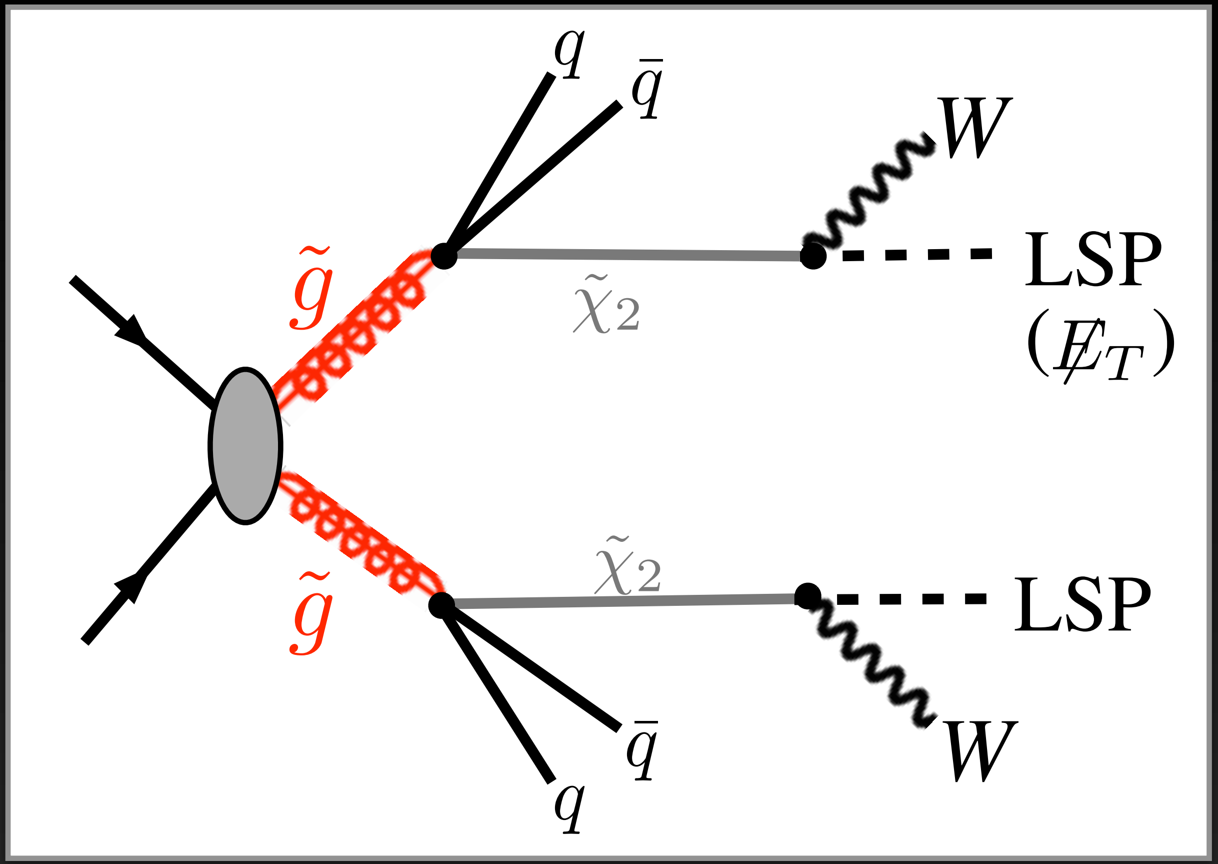
Masses of $\tilde{g}, \tilde{\chi}_2, \tilde{\chi}_1$ affect kinematics, search efficiency/optimization

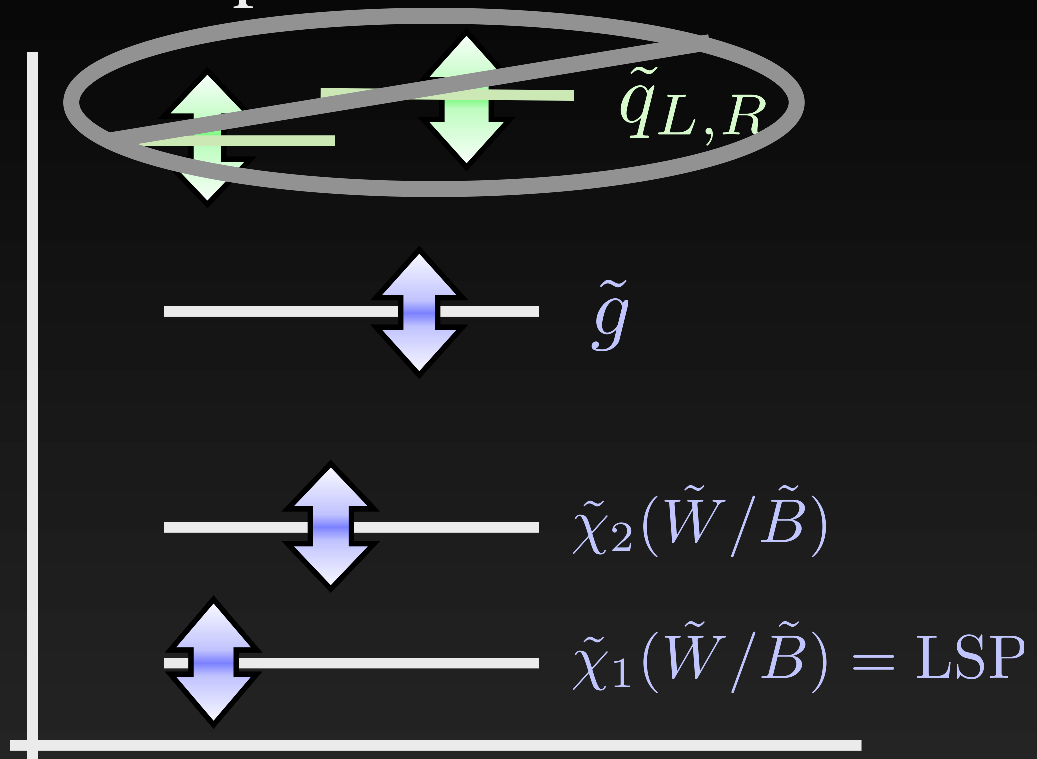
Don't include squarks or higgs sector in description.

Don't know cross-section, but know its scale: QCD gluino production.

Parameters are simply related to observables.

“Instead of slicing up MSSM, trim it down.”





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Why reactions?

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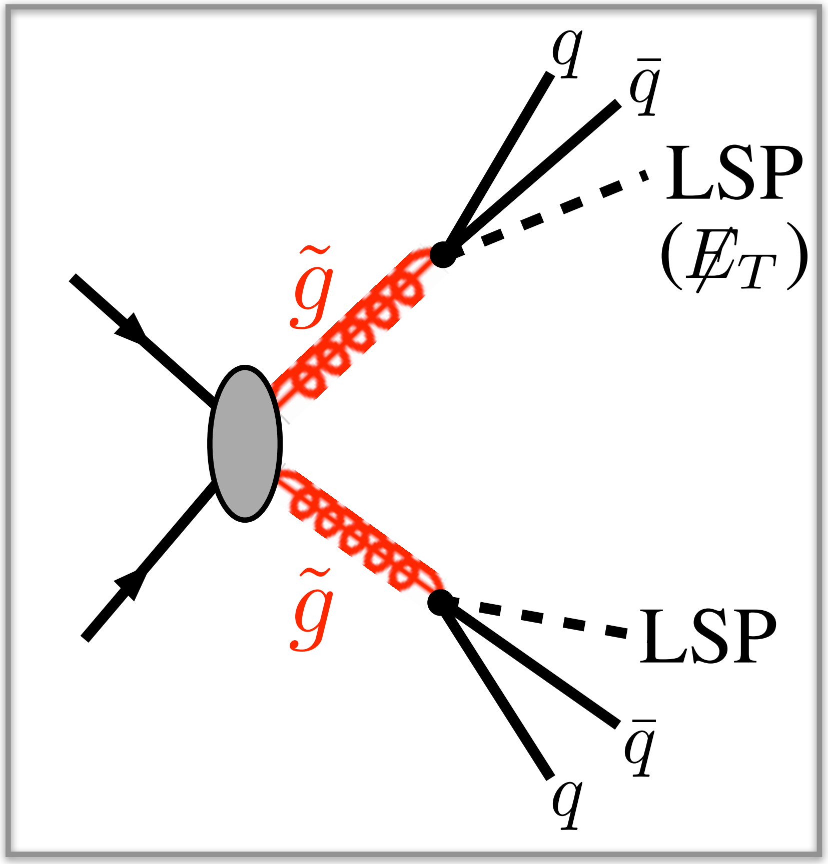
- Experimental — first ever 7 TeV collisions: maximize scope of searches, **informed** but not **limited** by theory

Why reactions?

- Experimental — first ever 7 TeV collisions: maximize scope of searches, **informed** but not **limited** by theory
- Theoretical — many theorists (myself included) don't expect any model on hep-ph to be literally correct. Reactions are **common building blocks**; must piece them together to understand nature.

Setting/Quoting Limits

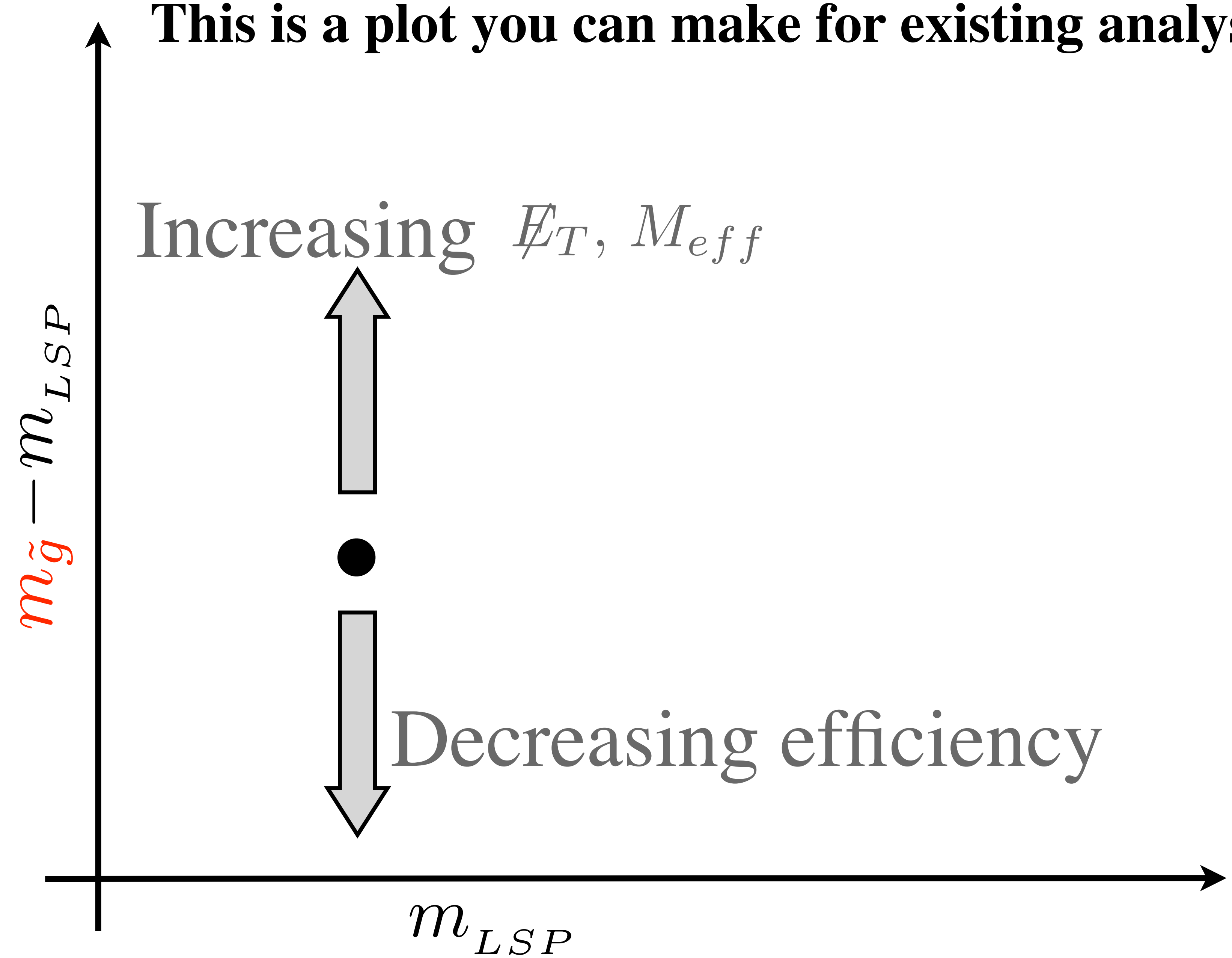


Parameters:

- 2 masses
  $m_{\tilde{g}}$
  m_{LSP}
- $\sigma \times Br$

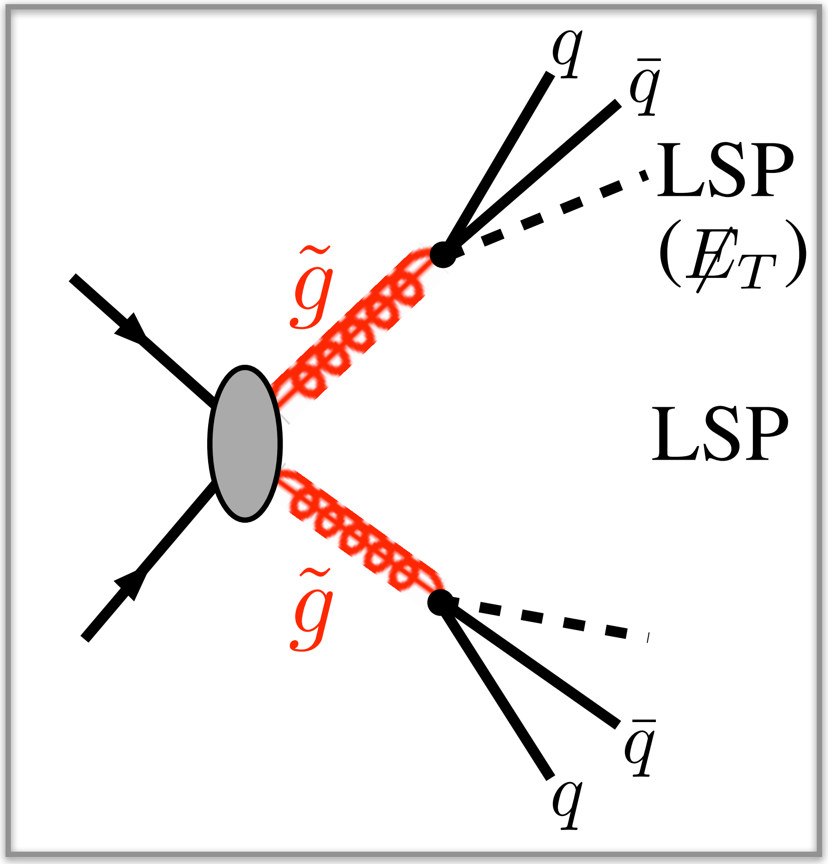
Every point on this plot corresponds to a particular choice of kinematic distributions.

This is a plot you can make for existing analyses

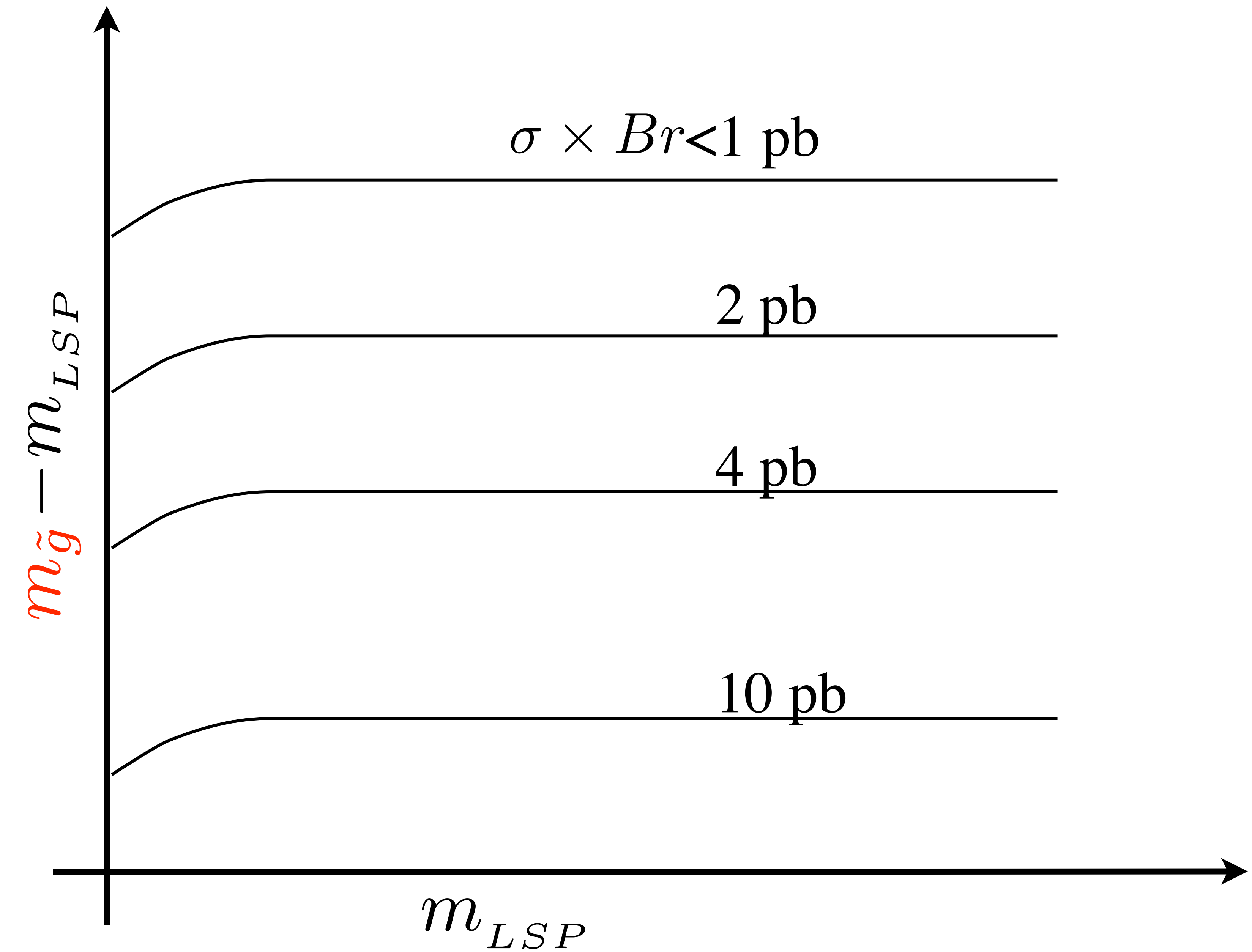


$\Rightarrow$ Determine efficiency, upper bound on $\sigma \times Br$

Setting/Quoting Limits



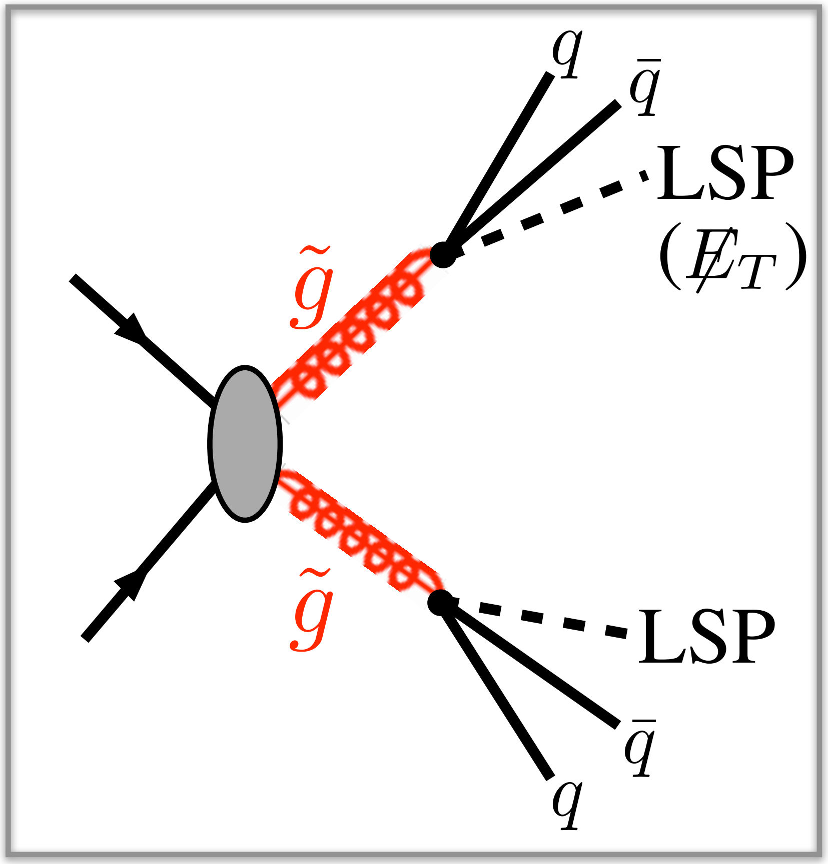
Limit on (Cross-section)x(Branching ratio) as function of mass parameters



Parameters:

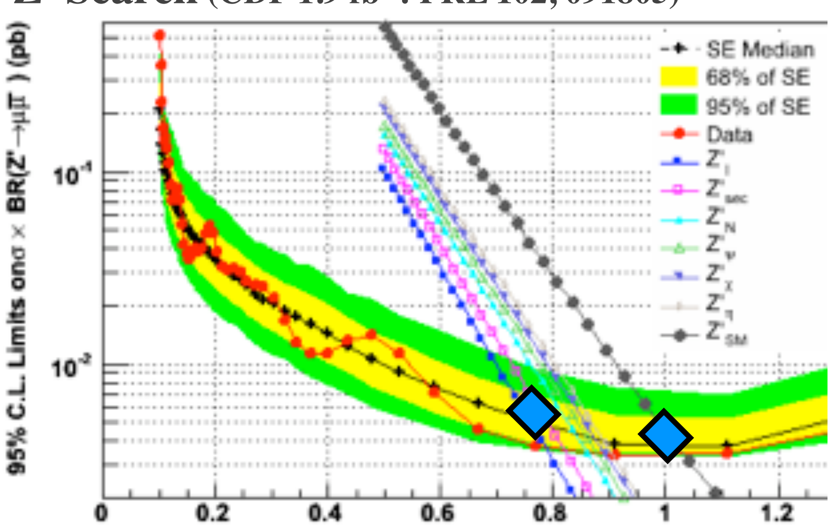
- 2 masses
  $m_{\tilde{g}}$
  m_{LSP}
- $\sigma \times Br$

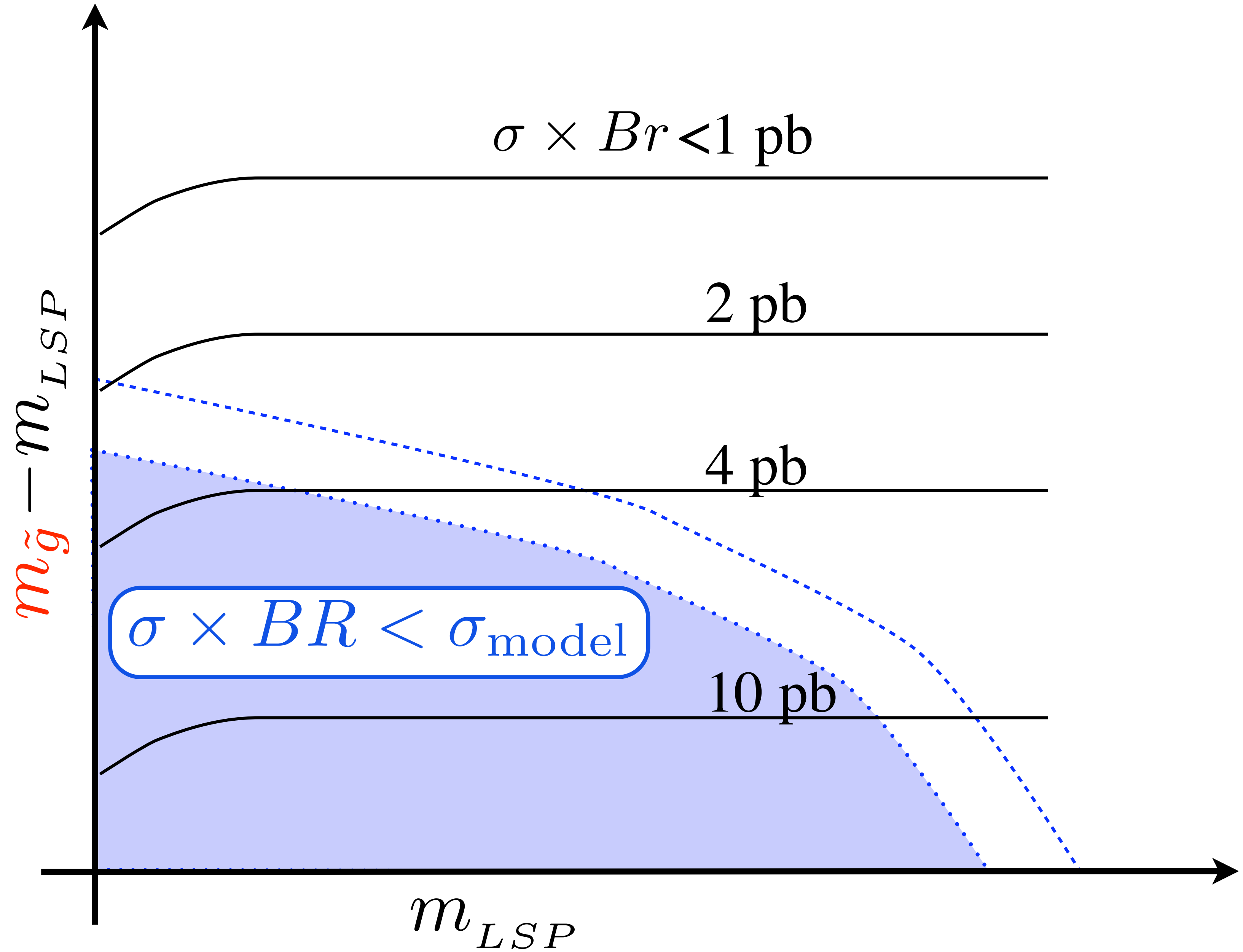
Efficiency for multi-jet+MET search cuts decreases for small mass difference ⇒ weaker cross-section limits
Approximately independent of m_{LSP}, except at low masses.



Limit on (Cross-section)x(Branching ratio) as function of mass parameters

Z' Search (CDF 1.9 fb[-1]: PRL 102, 091805)

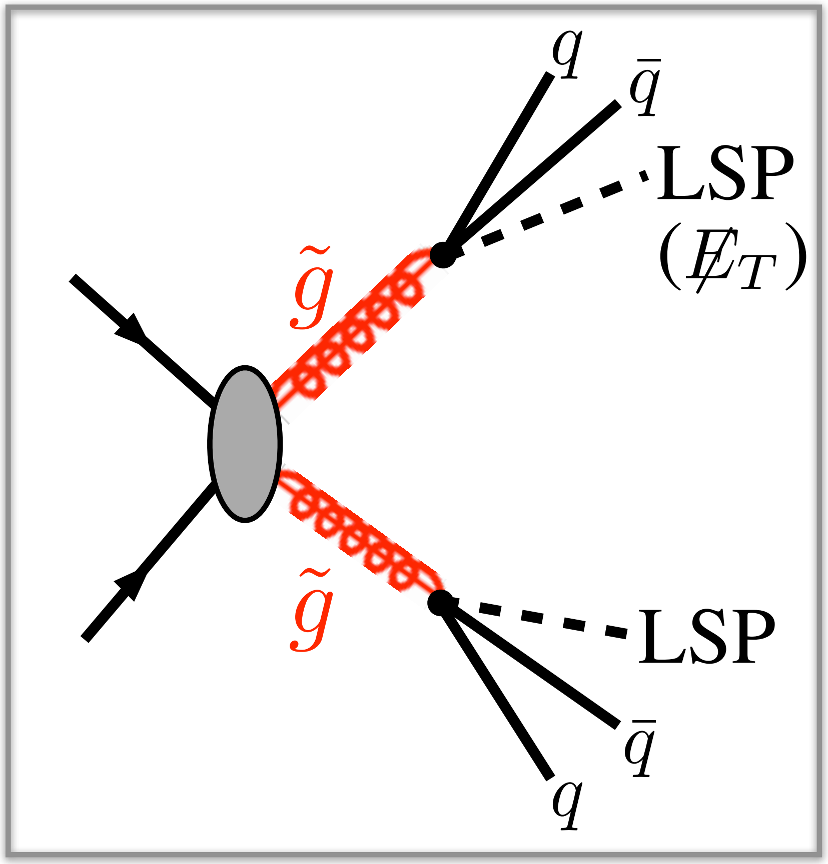




Different models (e.g. spins, squark mass) imply different mass–(σ x Br) relations.

Blue curves: exclusions on models, i.e. contours where **expected** cross-section equals maximum allowed cross-section (region below curves provides approximate exclusion).

Setting/Quoting Limits



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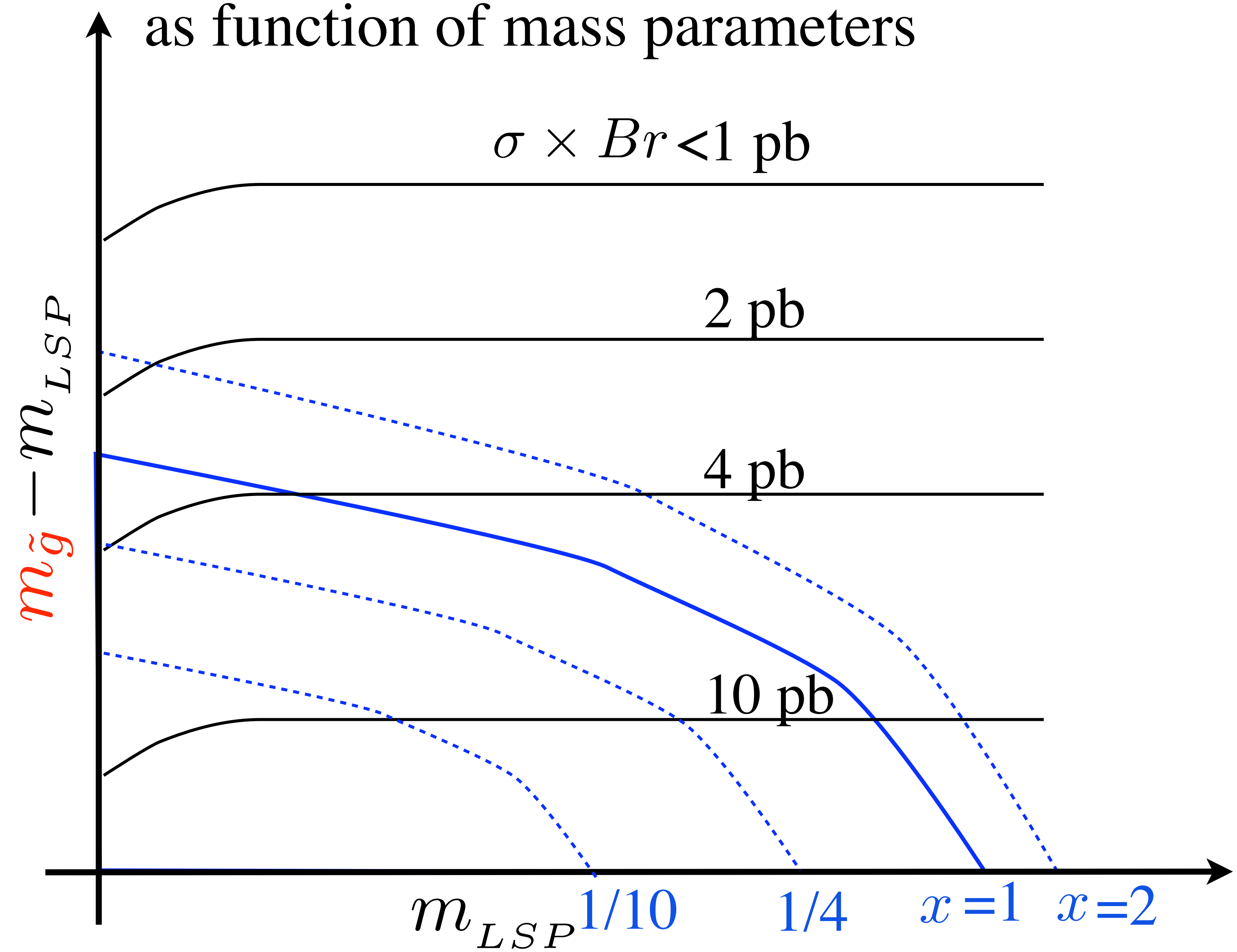
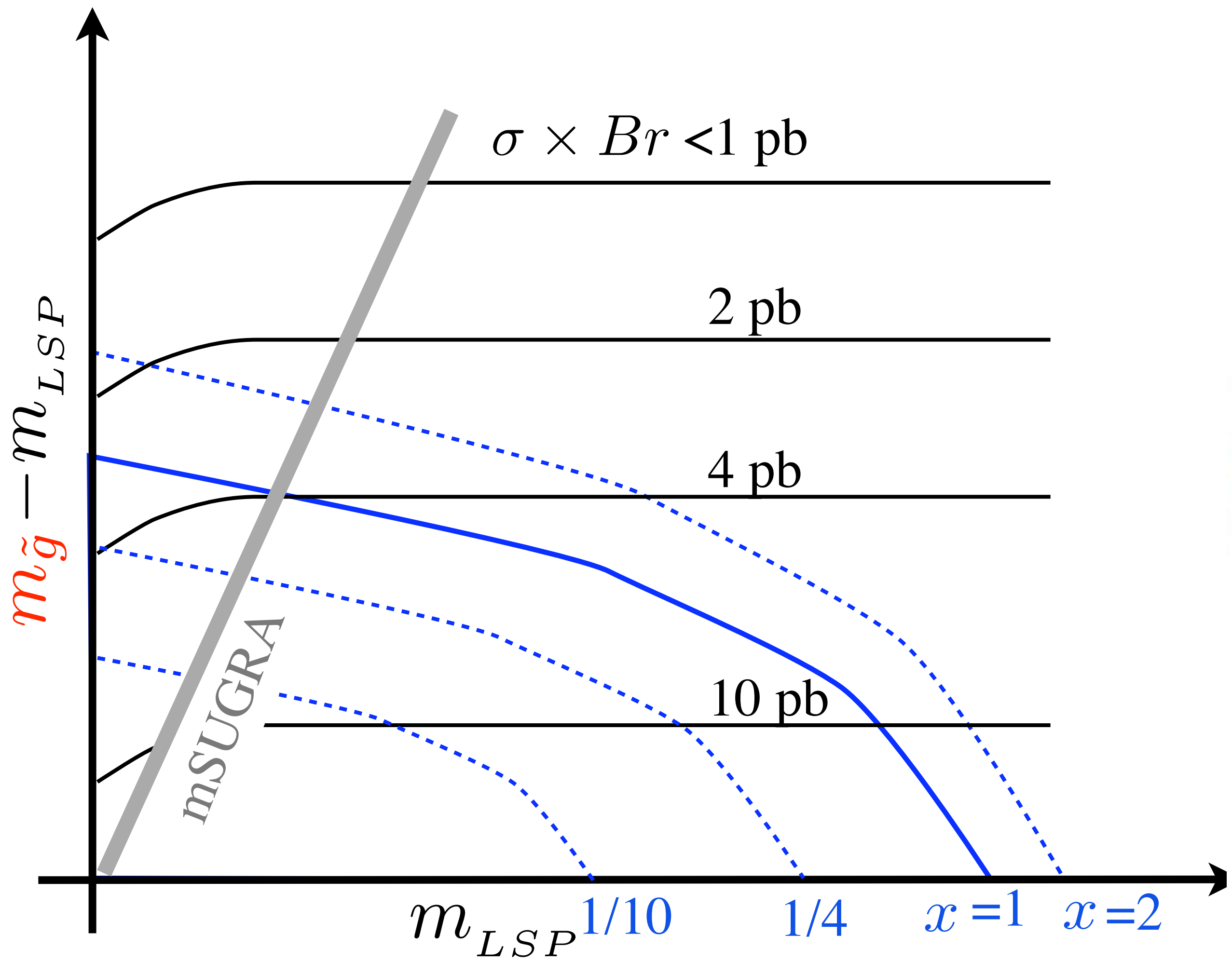
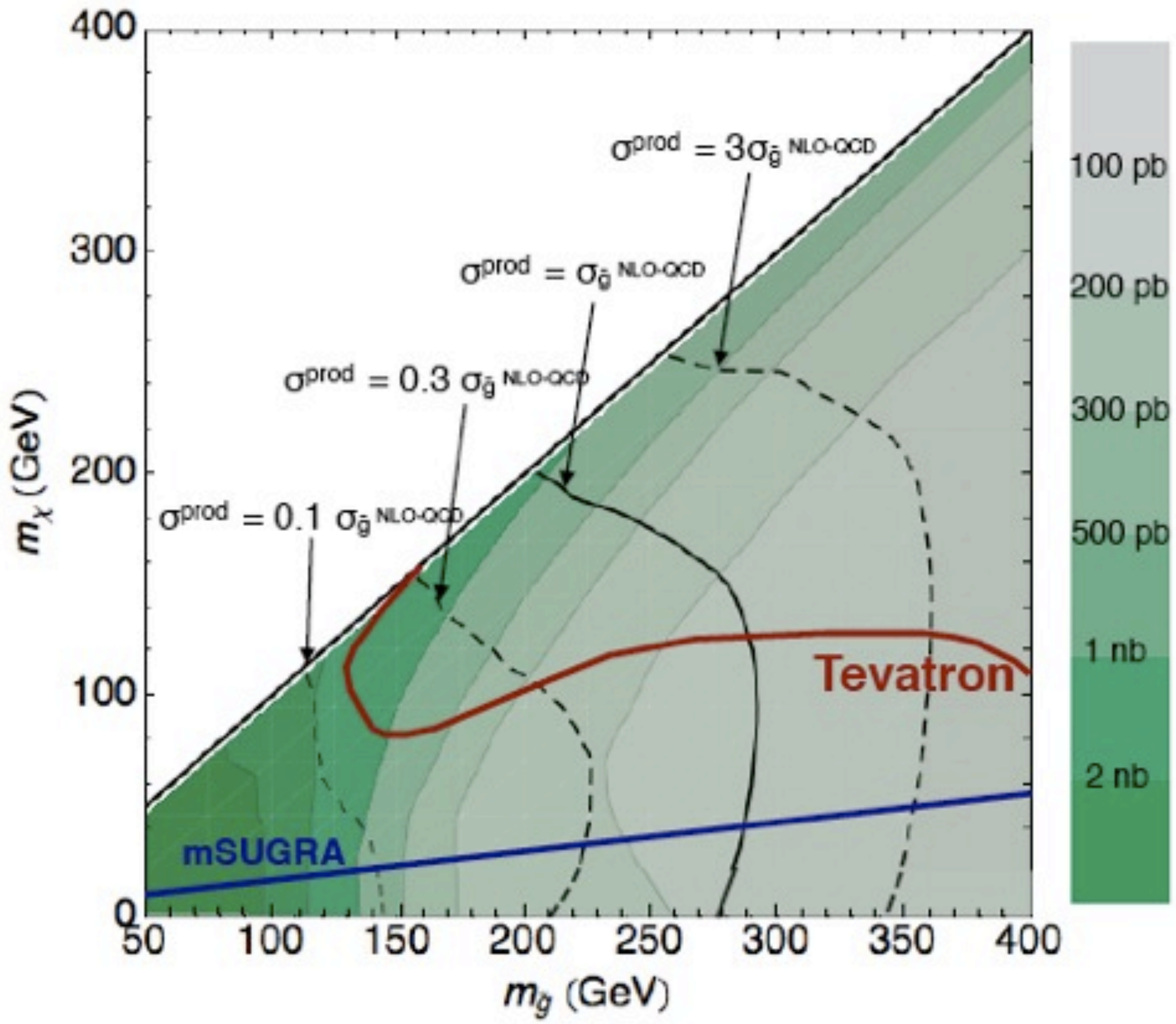


PICK ONE model for cross-section, look at limits on cross-section relative to this:

$$(\sigma \times BR)/\sigma_{\rm ref} = x \begin{cases} x \sim 1: & \text{Variation of cross-section} \\ x \ll 1: & \text{Reduced branching fraction} \end{cases}$$

Different presentations, same strategy:



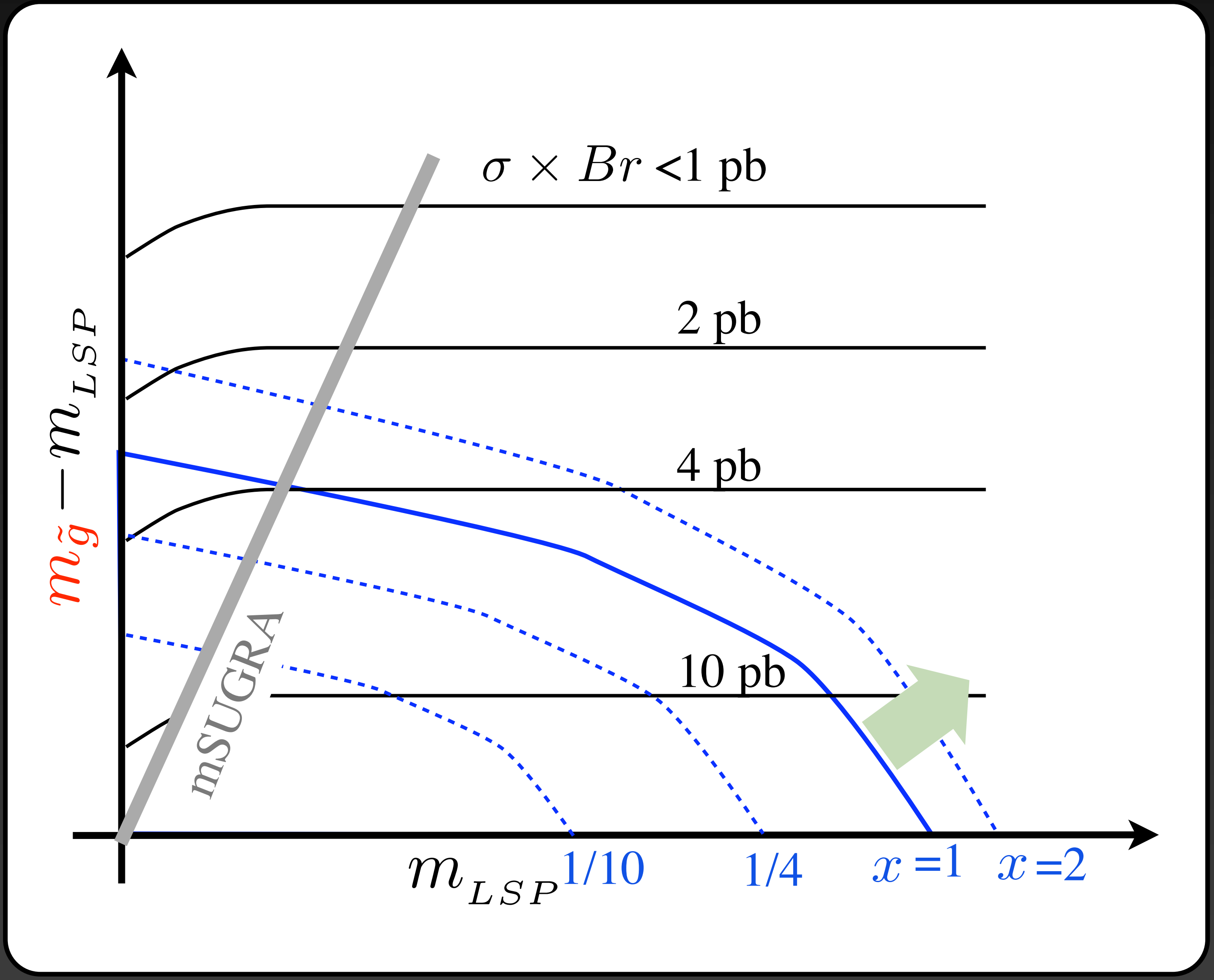


70 nb^{-1} sensitivity study
(Alvez, Izaguirre, Wacker 2010)

Two Lessons for Optimization

Of course, optimization **builds on** existing and planned searches, and understanding their impact on this parameter space.

1. Optimize for **all kinematics**, not just that favored by particular model

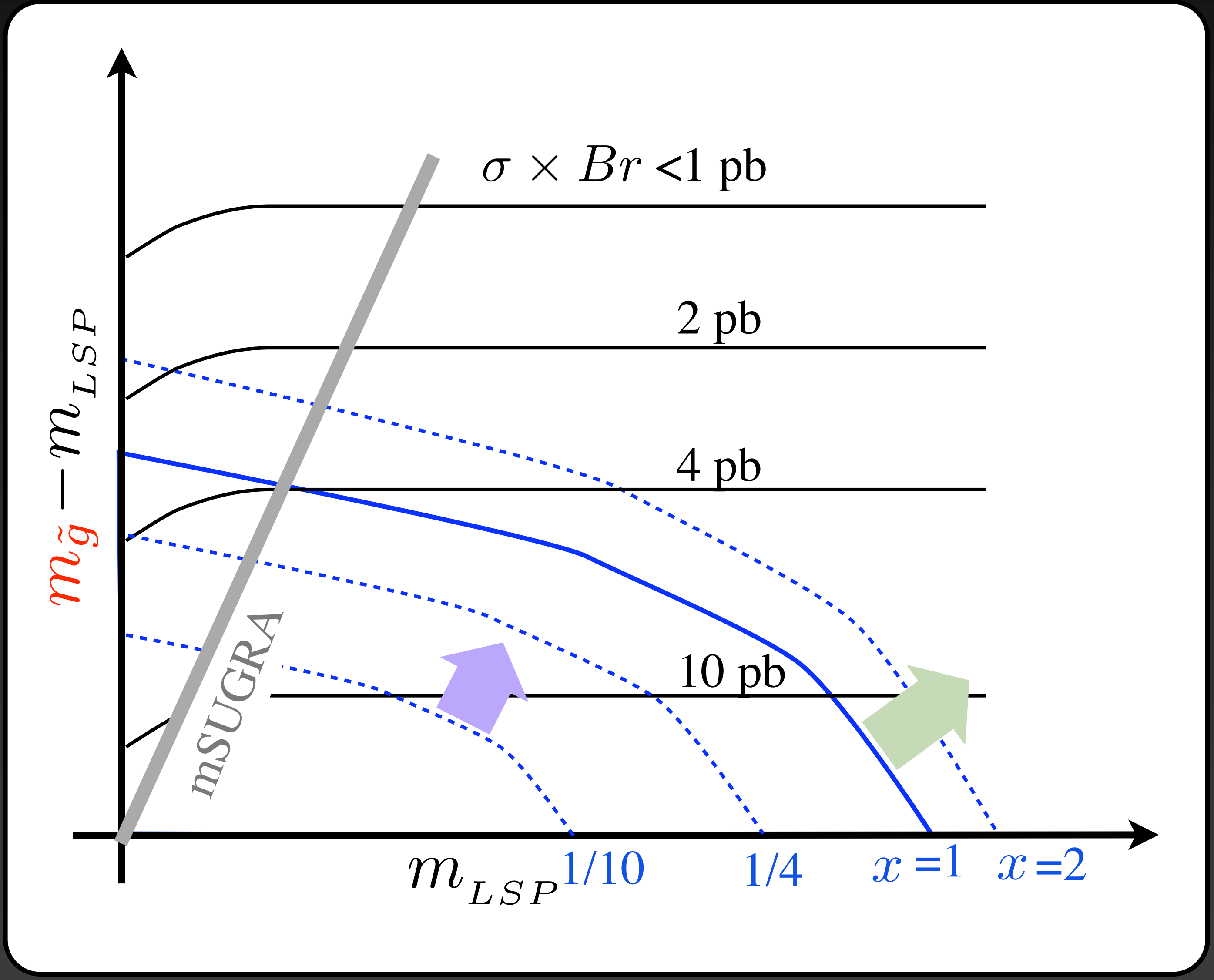


Two Lessons for Optimization

Of course, optimization **builds on** existing and planned searches, and understanding their impact on this parameter space.

1. Optimize for **all kinematics**, not just that favored by particular model

2. Also optimize sensitivity to **small branching fractions for low–mass cases**.



Sorting Physics Reactions

What's a spanning set of physics reactions for SUSY?
Doesn't each model involve many different reactions?

* Effort in theory community to propose a "spanning set" — see website http://lhcnewphysics.org and stay tuned for SLAC theory workshop September 22–25.

* **"Theoretical" simplifications —** many possible reactions, hierarchies in cross-section and branching fraction ⇒ for given spectrum, small number often dominate.

"Simplified Models" 0810.3921 Alwall, Schuster, NT

* **"Experimental" simplifications —** reactions that "look the same" in the variables used for searches can be treated as equivalent

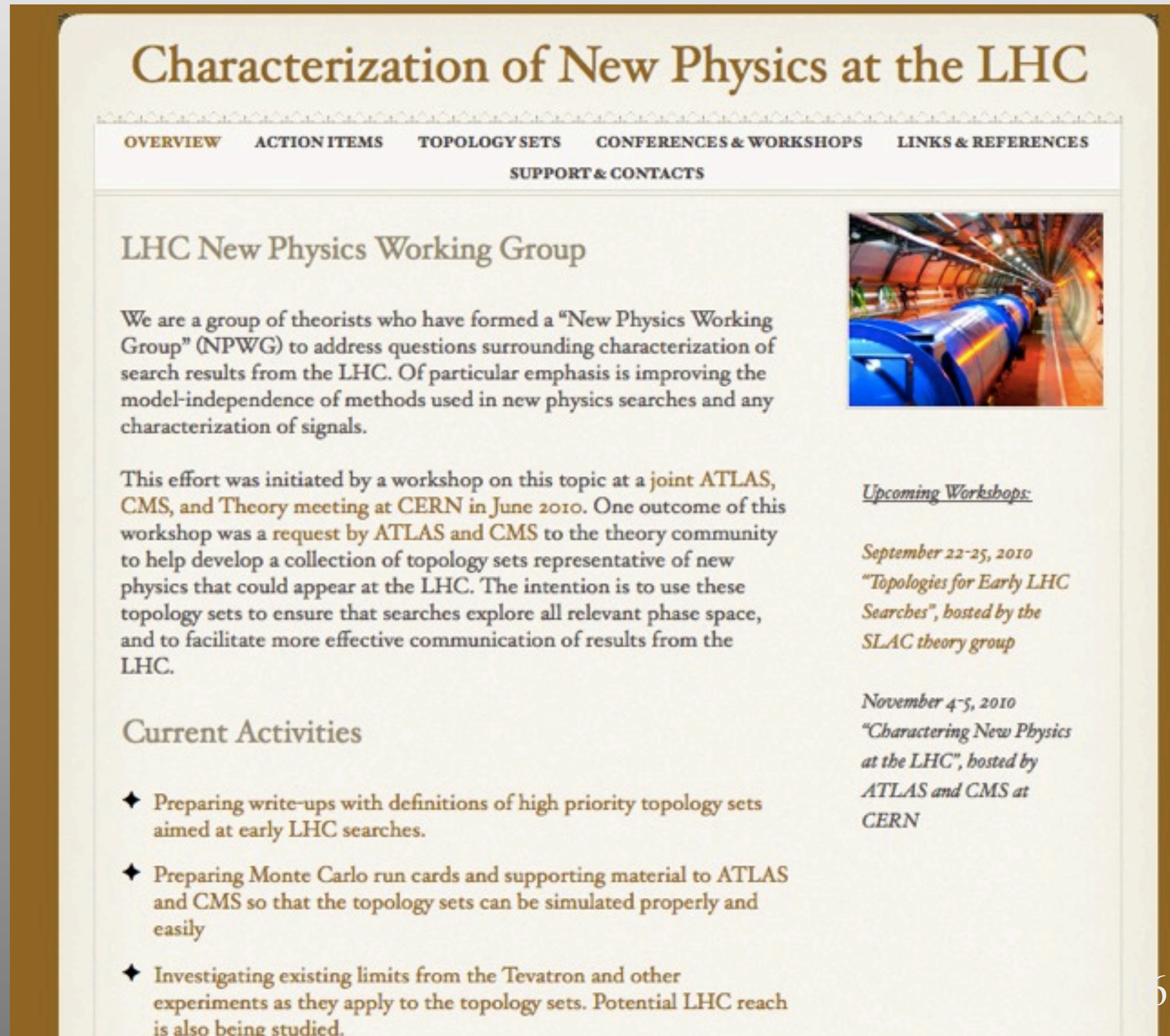
⇒ hadronic final state example

Proposals and Tools

Building a "basis" set of reactions for study (grouped into "topology sets"), with notes on motivation, final states, and MC implementation for each

www.lhcnewphysics.org

Workshops at:
SLAC in September
CERN in November



Characterization of New Physics at the LHC

OVERVIEW ACTION ITEMS TOPOLOGY SETS CONFERENCES & WORKSHOPS LINKS & REFERENCES SUPPORT & CONTACTS

LHC New Physics Working Group

We are a group of theorists who have formed a "New Physics Working Group" (NPWG) to address questions surrounding characterization of search results from the LHC. Of particular emphasis is improving the model-independence of methods used in new physics searches and any characterization of signals.

This effort was initiated by a workshop on this topic at a joint ATLAS, CMS, and Theory meeting at CERN in June 2010. One outcome of this workshop was a request by ATLAS and CMS to the theory community to help develop a collection of topology sets representative of new physics that could appear at the LHC. The intention is to use these topology sets to ensure that searches explore all relevant phase space, and to facilitate more effective communication of results from the LHC.

Current Activities

- Preparing write-ups with definitions of high priority topology sets aimed at early LHC searches.
- Preparing Monte Carlo run cards and supporting material to ATLAS and CMS so that the topology sets can be simulated properly and easily
- Investigating existing limits from the Tevatron and other experiments as they apply to the topology sets. Potential LHC reach is also being studied.

Upcoming Workshops:

September 22-25, 2010 "Topologies for Early LHC Searches", hosted by the SLAC theory group

November 4-5, 2010 "Charactering New Physics at the LHC", hosted by ATLAS and CMS at CERN

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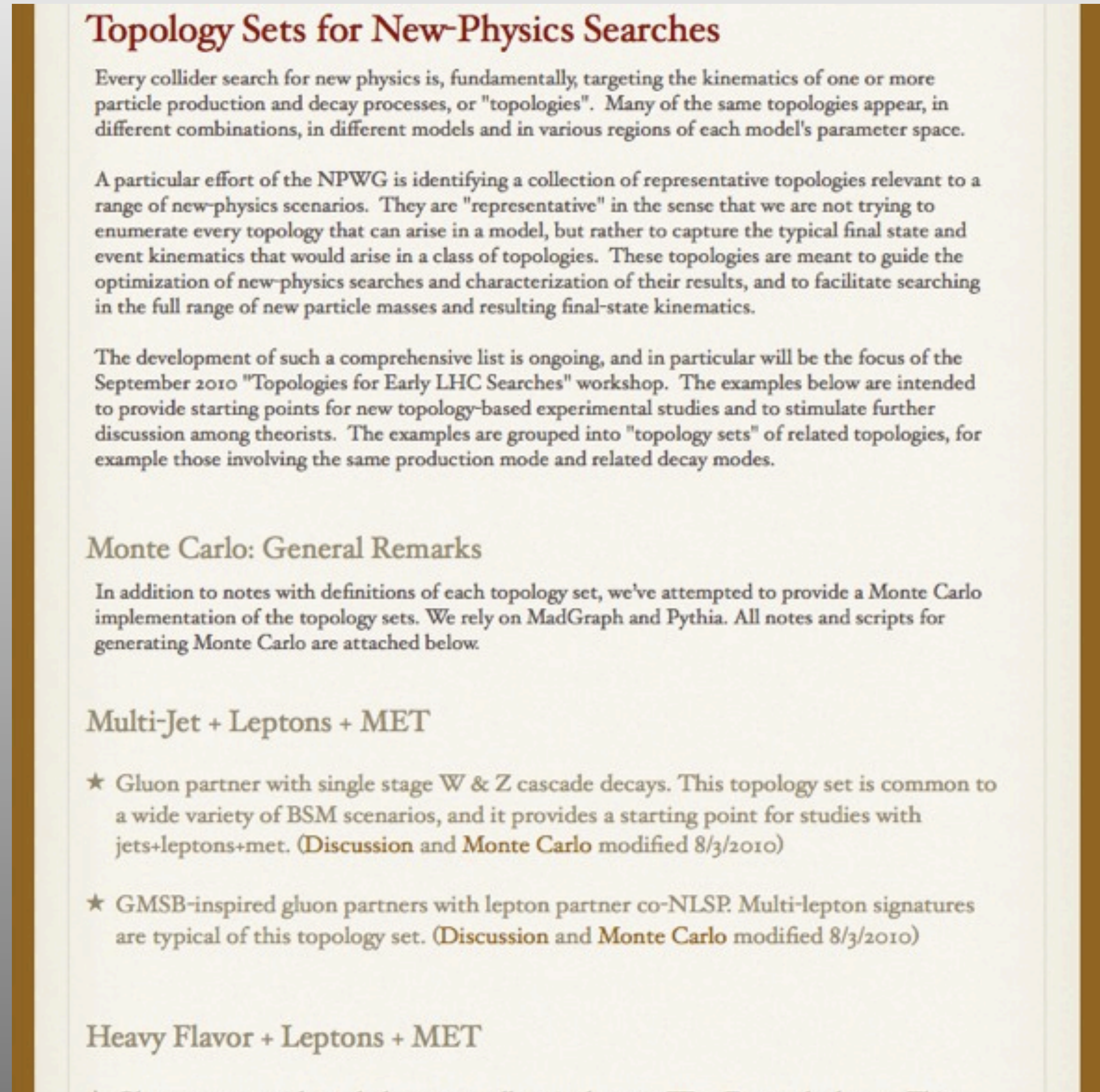

Topology Sets for New-Physics Searches

Every collider search for new physics is, fundamentally, targeting the kinematics of one or more particle production and decay processes, or "topologies". Many of the same topologies appear, in different combinations, in different models and in various regions of each model's parameter space.

A particular effort of the NPWG is identifying a collection of representative topologies relevant to a range of new-physics scenarios. They are "representative" in the sense that we are not trying to enumerate every topology that can arise in a model, but rather to capture the typical final state and event kinematics that would arise in a class of topologies. These topologies are meant to guide the optimization of new-physics searches and characterization of their results, and to facilitate searching in the full range of new particle masses and resulting final-state kinematics.

The development of such a comprehensive list is ongoing, and in particular will be the focus of the September 2010 "Topologies for Early LHC Searches" workshop. The examples below are intended to provide starting points for new topology-based experimental studies and to stimulate further discussion among theorists. The examples are grouped into "topology sets" of related topologies, for example those involving the same production mode and related decay modes.

Monte Carlo: General Remarks

In addition to notes with definitions of each topology set, we've attempted to provide a Monte Carlo implementation of the topology sets. We rely on MadGraph and Pythia. All notes and scripts for generating Monte Carlo are attached below.

Multi-Jet + Leptons + MET

★ Gluon partner with single stage W & Z cascade decays. This topology set is common to a wide variety of BSM scenarios, and it provides a starting point for studies with jets+leptons+met. (Discussion and Monte Carlo modified 8/3/2010)

★ GMSB-inspired gluon partners with lepton partner co-NLSP. Multi-lepton signatures are typical of this topology set. (Discussion and Monte Carlo modified 8/3/2010)

Heavy Flavor + Leptons + MET

★ Gluon partner with t & b decays as well as single stage W & Z cascade decays. This

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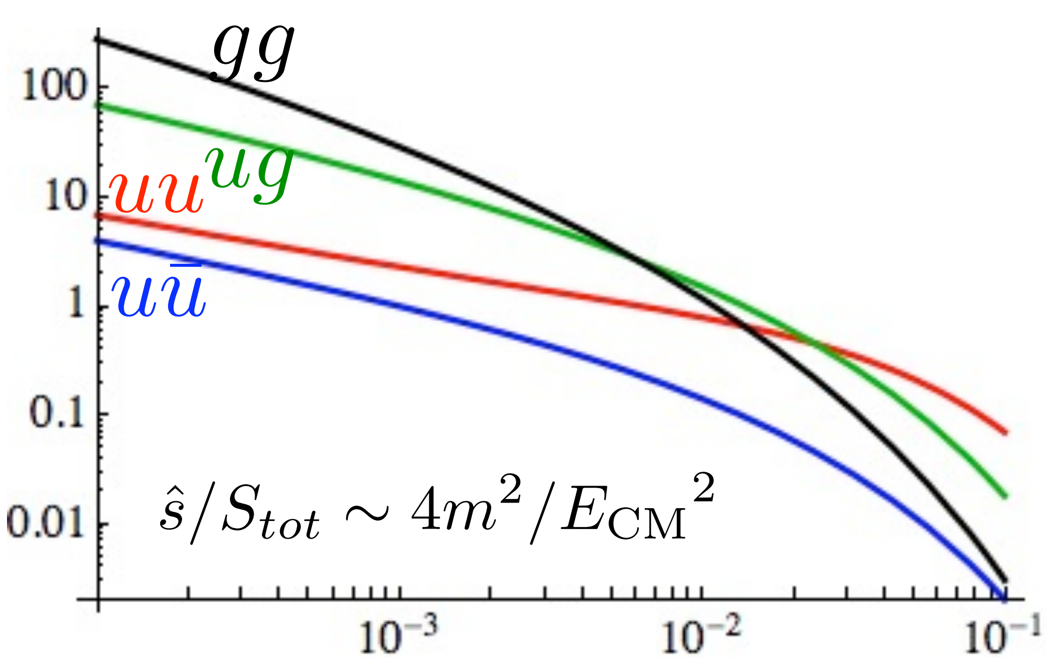
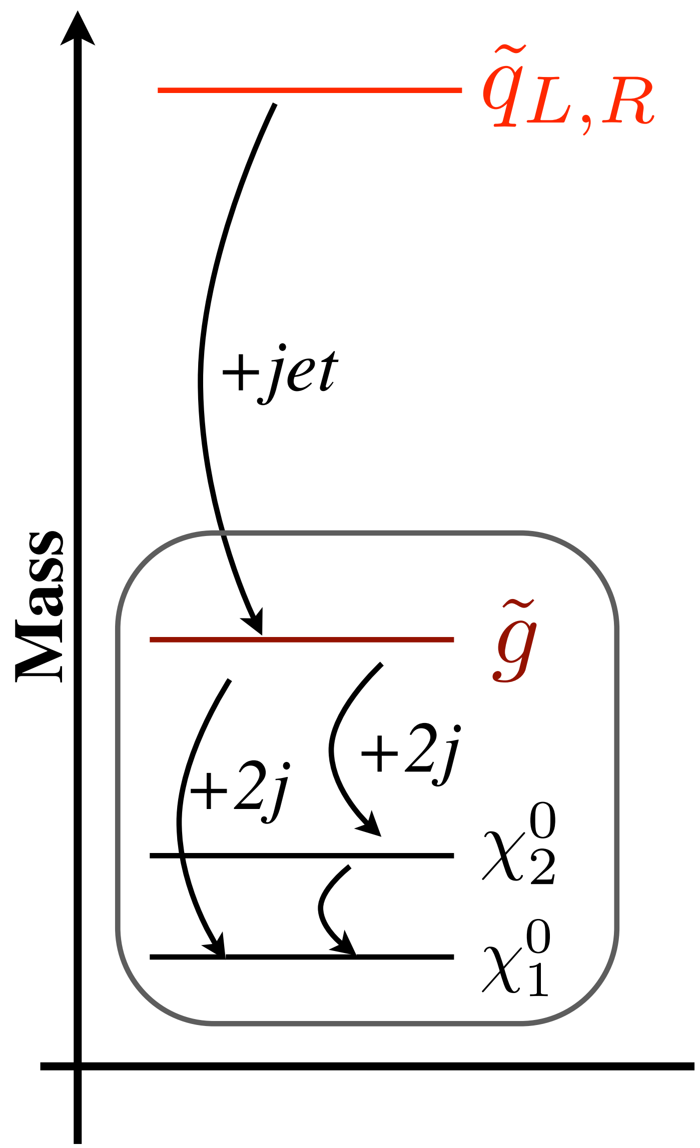
Theoretical Simplification: Production



Parton luminosity falls steeply with mass ($m^{-5,6}$)

Electroweak production down by $(\alpha_2/\alpha_3)^2$, less visible energy



$$m_{\tilde{q}} - m_{\tilde{g}} \gg m_{\tilde{g}}$$
$$\Downarrow$$
$$\sigma_{\tilde{q}\tilde{q}}, \sigma_{\tilde{q}\tilde{g}} \ll \sigma_{\tilde{g}\tilde{g}}$$

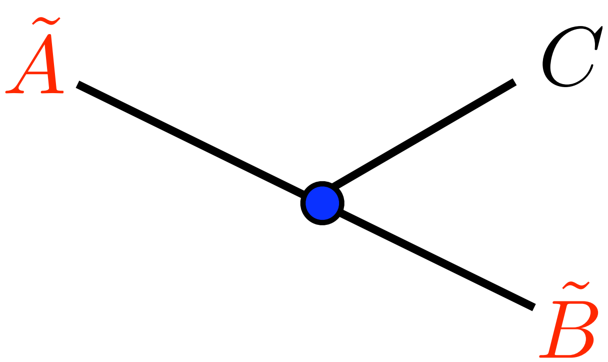
Mostly produce lightest (few) colored states

Theoretical Simplification: Decay

Feynman rules determined by Standard Model

2–body decays dominate over 3–body, if allowed.
(additional coupling & phase space suppression)

2–Body

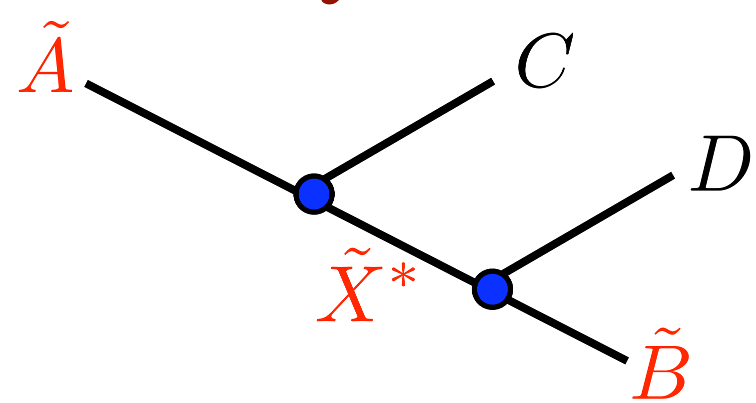


$\Gamma \propto \alpha$

$\alpha_t \gg \alpha_3 \gg \alpha_2 \gg \alpha_1$

Strongest coupling wins

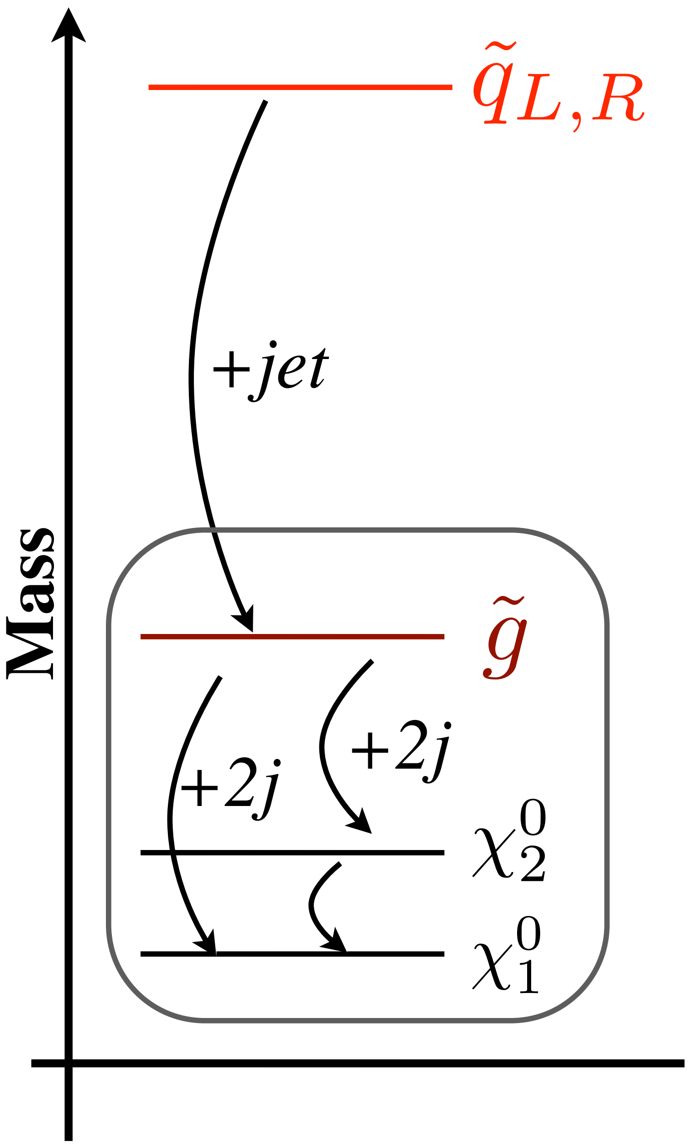
3–Body



$\Gamma \propto \alpha^2/m^4_{\tilde{X}}$

Significant suppression by couplings **and** intermediate mass

Experimental Simplification: Production

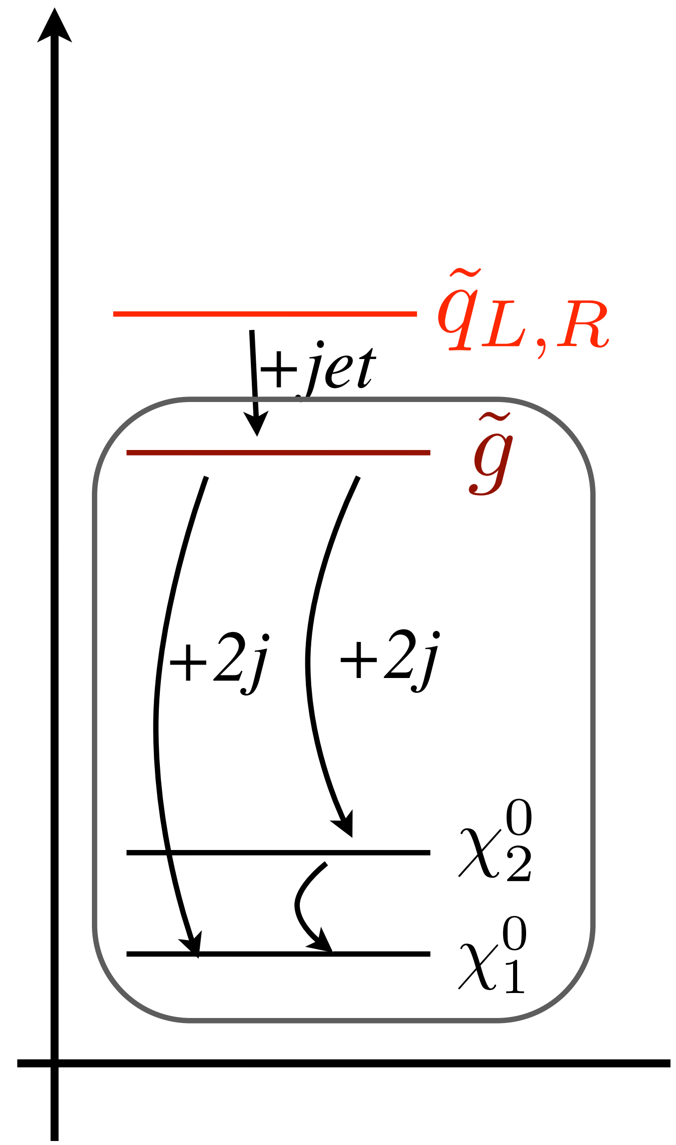


$$m_{\tilde{q}} - m_{\tilde{g}} \gg m_{\tilde{g}}$$

$$\Downarrow$$

$$\sigma_{\tilde{q}\tilde{q}}, \sigma_{\tilde{q}\tilde{g}} \ll \sigma_{\tilde{g}\tilde{g}}$$

can ignore squarks



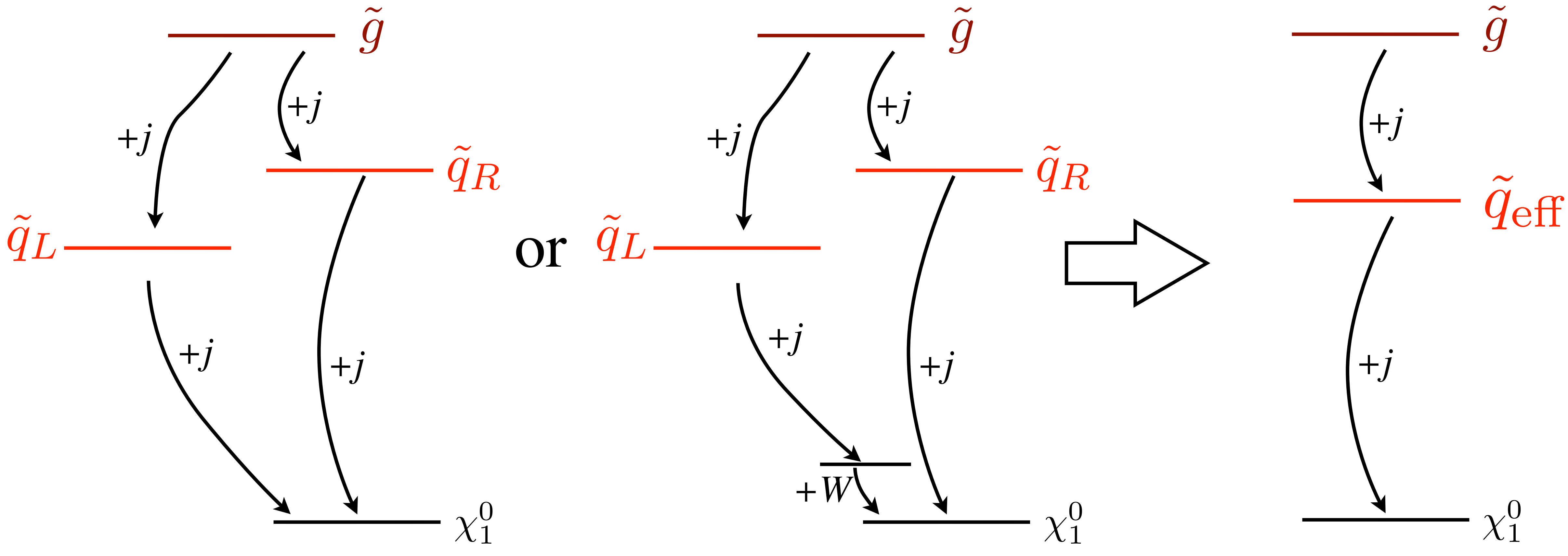
$$m_{\tilde{q}} - m_{\tilde{g}} \ll m_{\tilde{g}}$$

$$\Downarrow$$

jet from squark decay
very soft

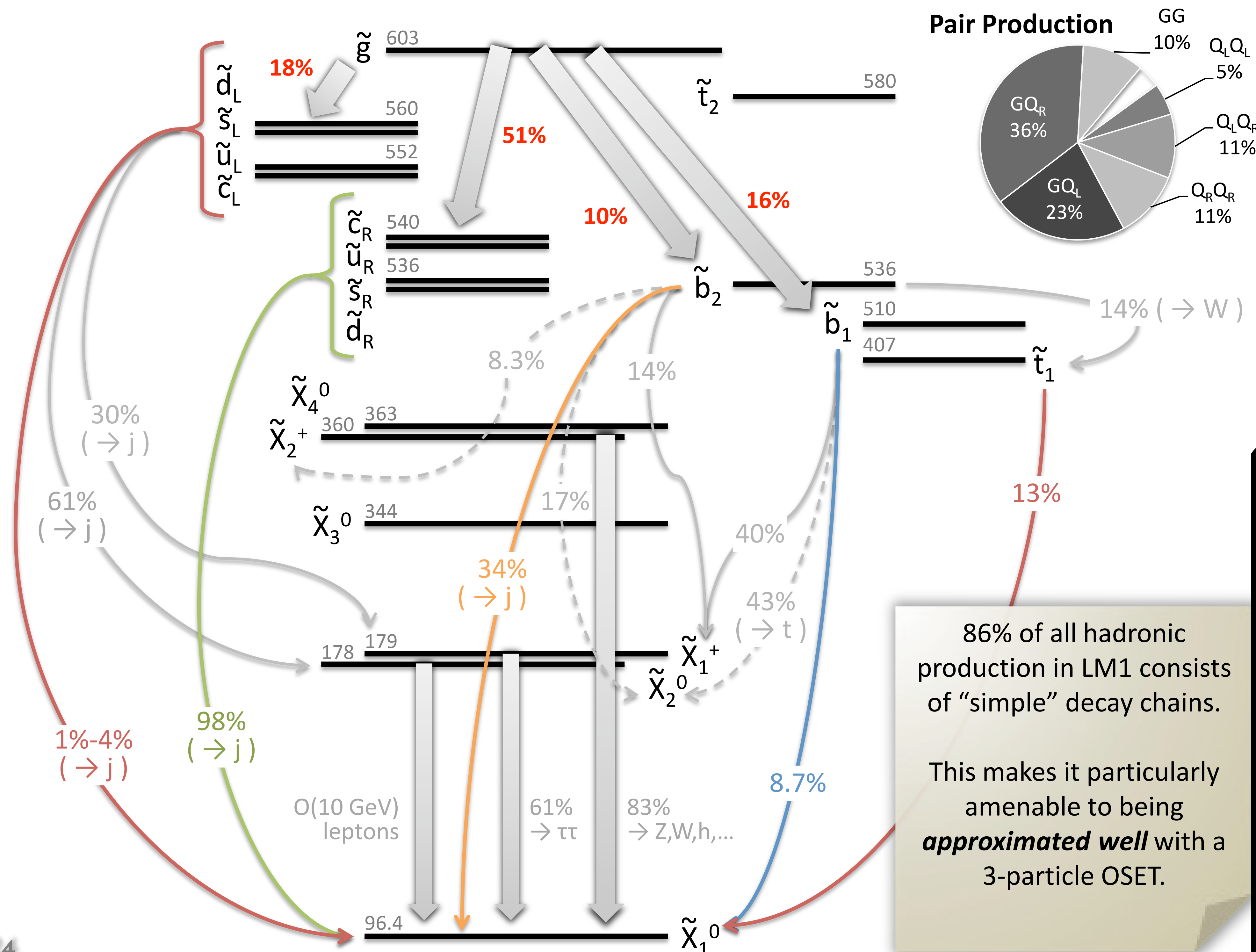
can ignore squarks

Experimental Simplification: Decay



Similar intermediate states can be grouped together

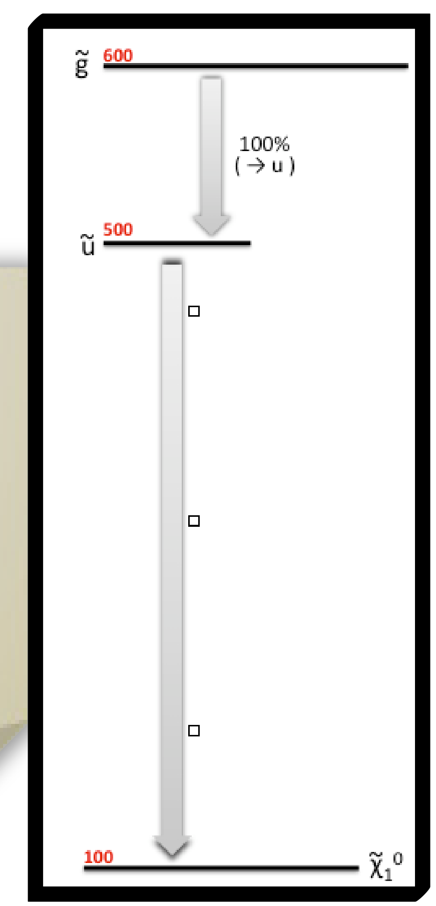
In Summary: Massive Simplifications
e.g. LM1 SUSY Benchmark



86% of all hadronic production in LM1 consists of “simple” decay chains.

This makes it particularly amenable to being ***approximated well*** with a 3-particle OSET.

vs.



figures, analysis by
SueAnn Koay (UCSB)

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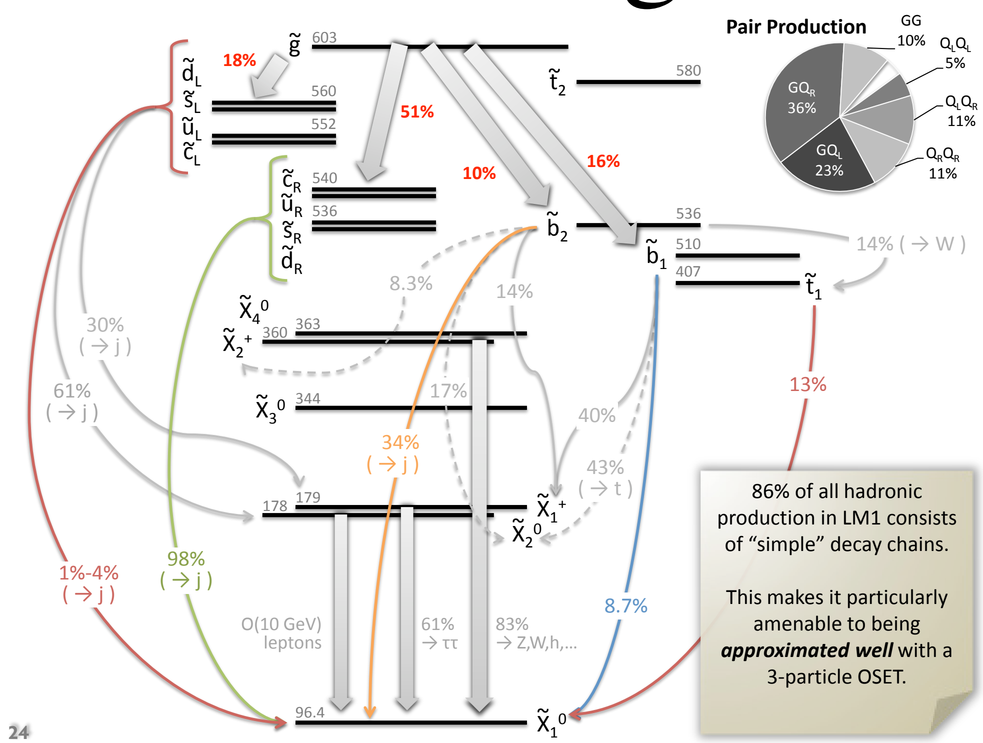

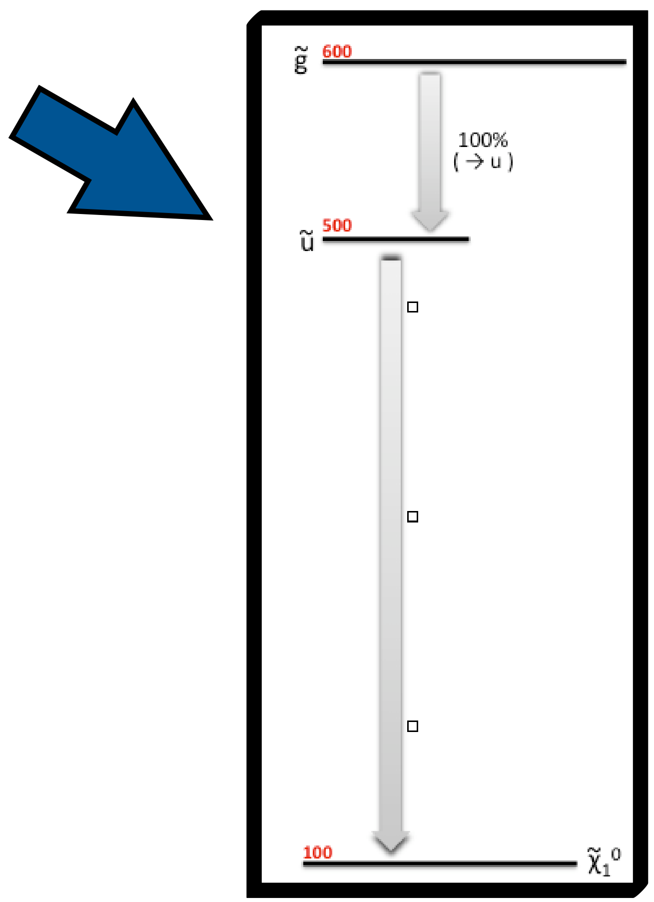

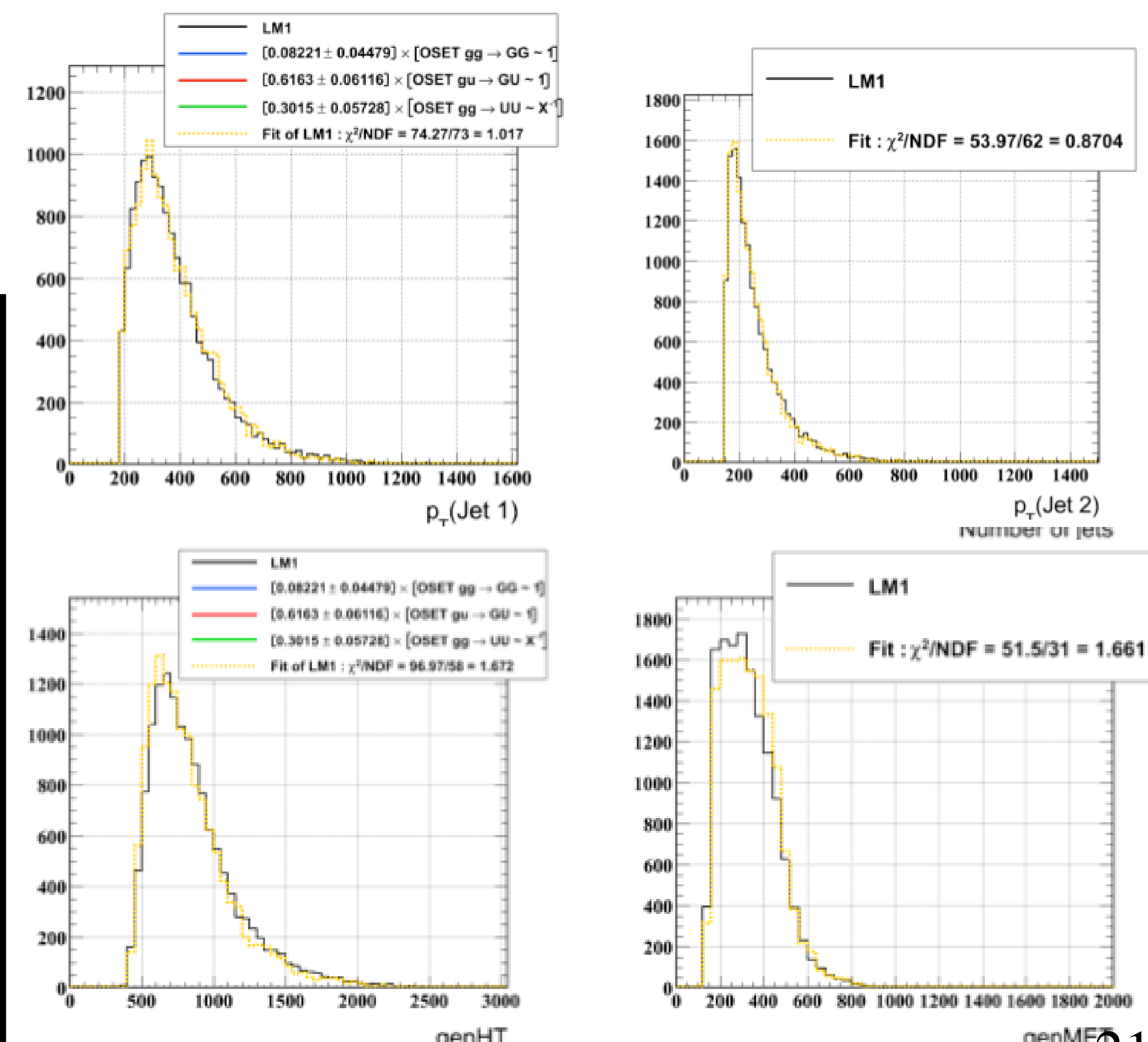

figures, analysis by
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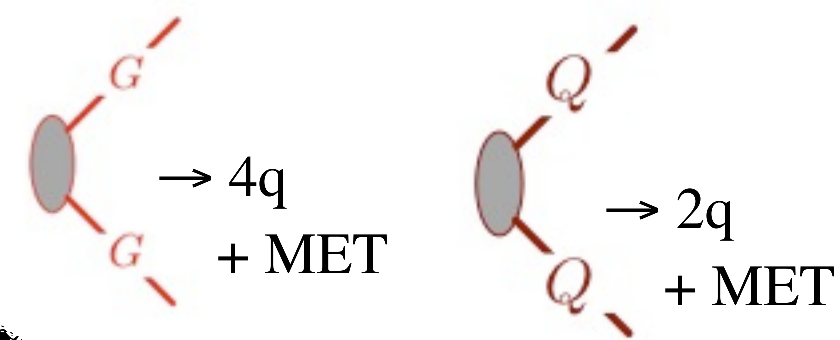
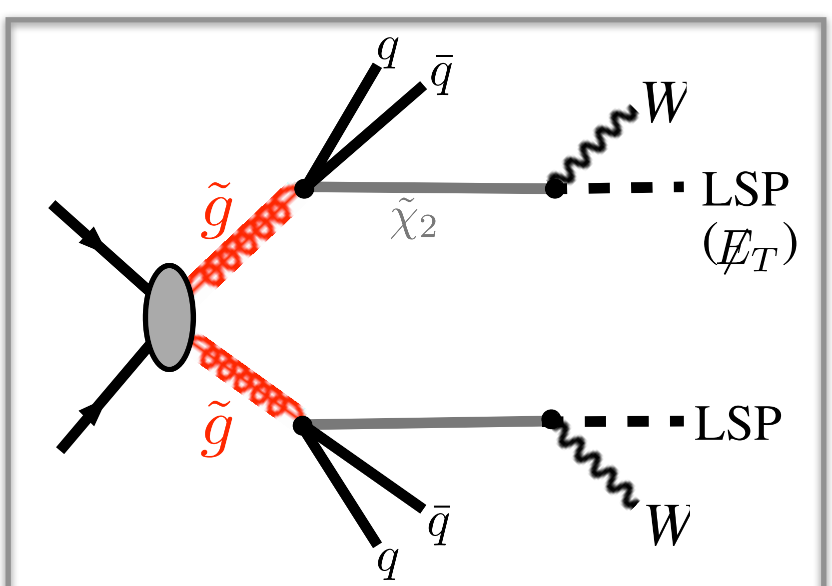
Building a Spanning Set

Basic Reactions



add cascades

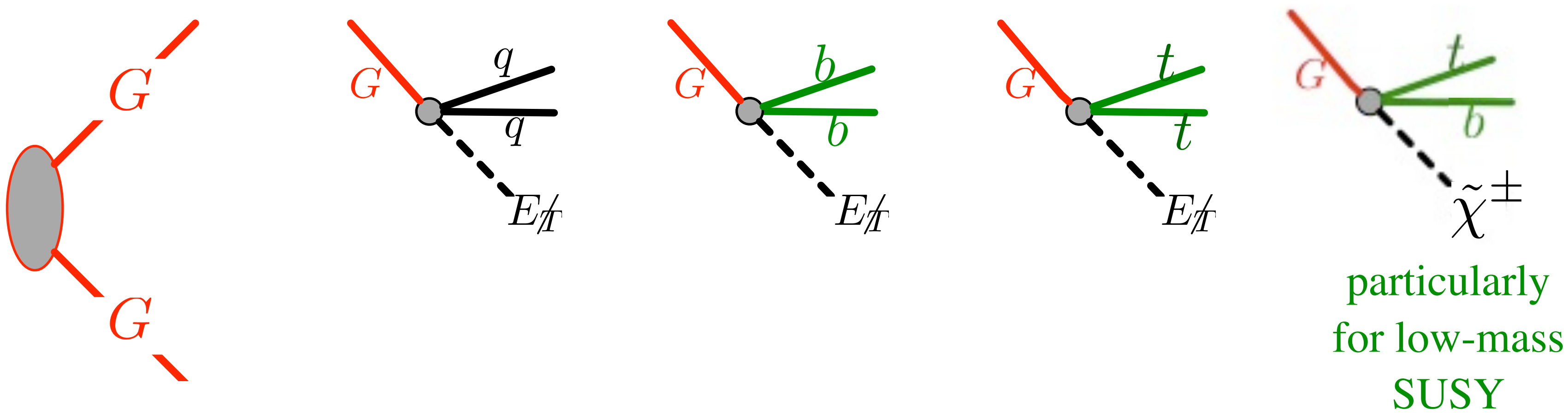
add heavy flavors: t, b



Heavy Flavor Simplified Models

See 0810.3921 Alwall, PS, Natalia Toro and http://lhcnewphysics.org for two related approaches

From gluon partner:

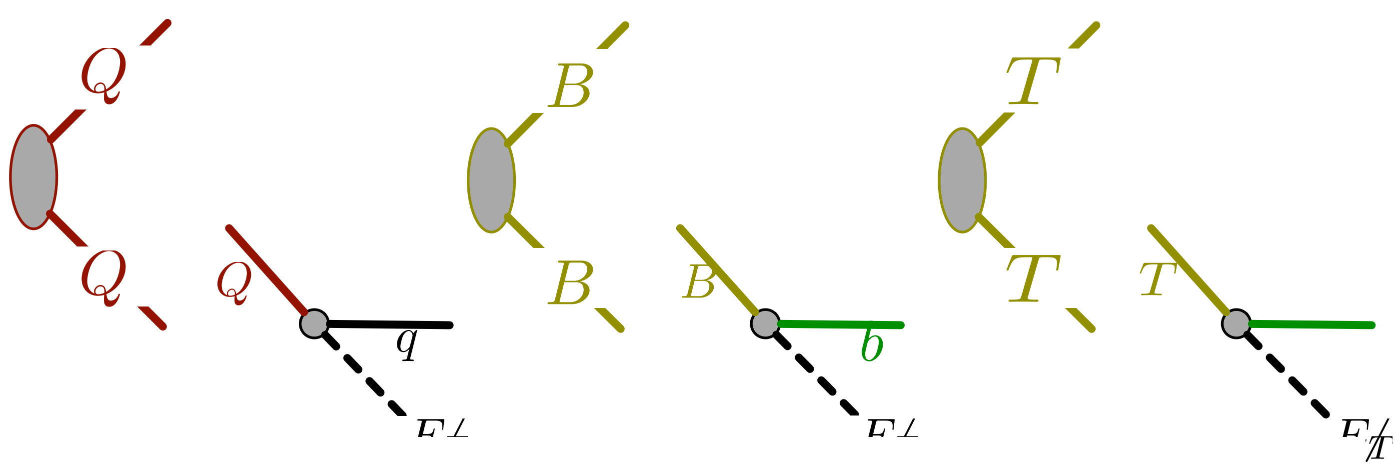


(+ cascades)

Interesting combinations: *bb+bb; tt+tt; tb+tb; qq+bb/bt/tt*

ongoing work by SLAC ATLAS group (and others?)

From quark partner:



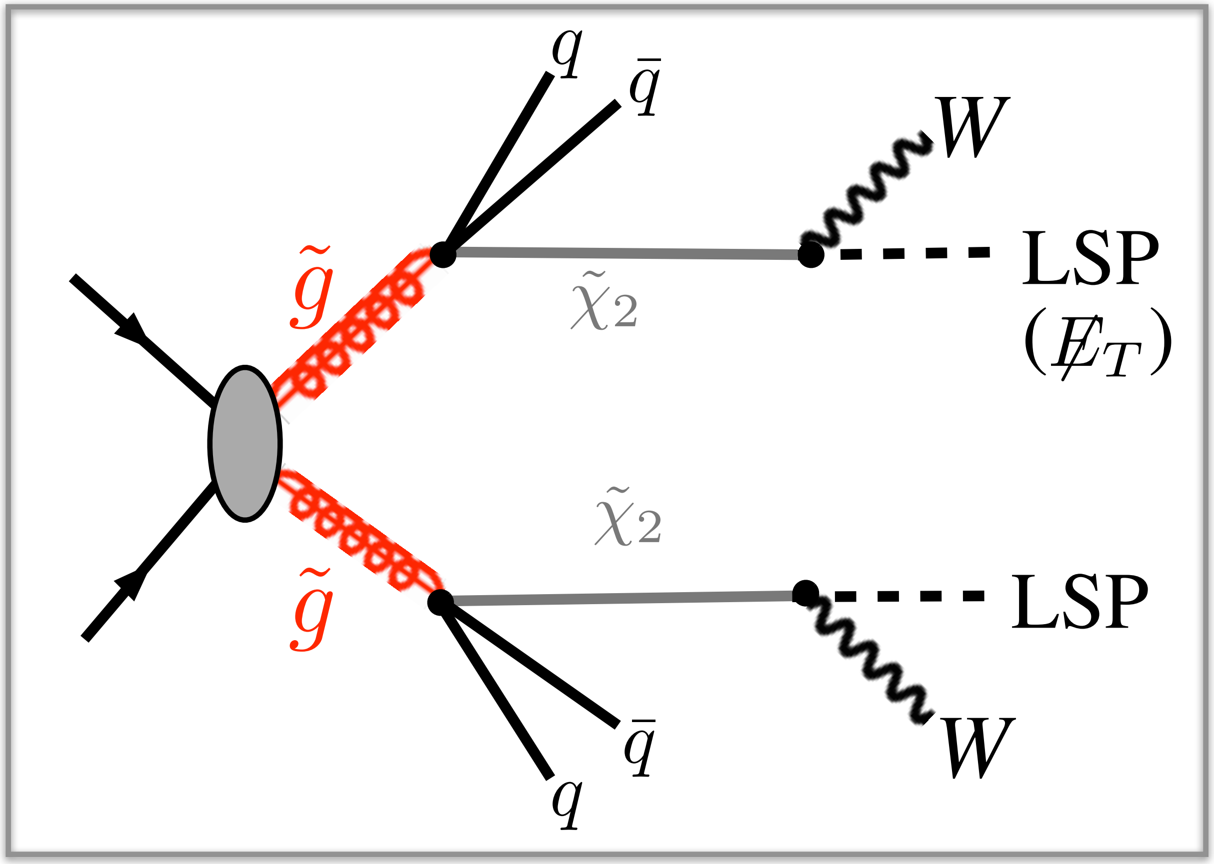
(+ cascades)

Complexity reflects the richness of SUSY spectroscopy

Summary

- LHC is poised for discovery of new physics
  - Already at the frontier!
  - Can maximize sensitivity by also studying “squeezed” spectra — SUSY expected near weak scale
  - First: thorough study of data includes modeling sensitivity to various topologies
- Active theory effort to classify & recommend topologies for inclusion in this effort
- Wide range of new-physics possibilities in hadronic final states.

Same logic extends to other reactions



Three masses ⇒ study slices