

Model-Independent Searches at the LHC

Mariangela Lisanti

Princeton Center for Theoretical Science

UPenn Seminar

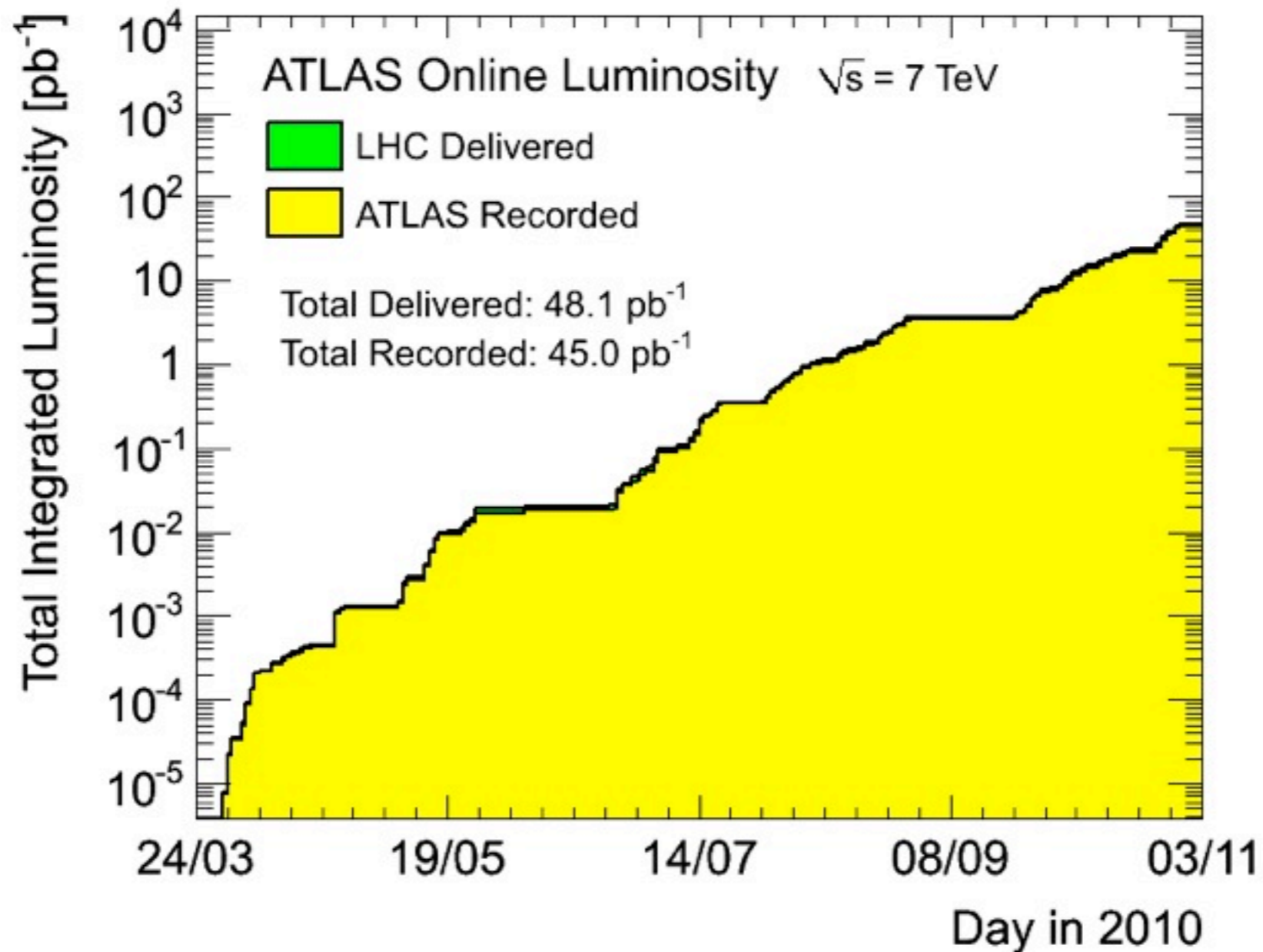
February 15, 2010

arXiv: 0803.0019, 0809.3264 with J. Alwall, M-P. Le, and J. Wacker
1103.???? with LHC New Physics Working Group

The LHC Era

The LHC is already probing new territory

45 pb⁻¹ reached!



The LHC Era

Early searches will provide clues to fundamental questions

New symmetries or forces?
Electroweak symmetry breaking?
Extra dimensions?
Hidden sectors?
Dark matter?

Don't want to miss new physics just because we didn't look

Want to learn as much as possible, even from null results

Designing Searches

The main ingredients for a new physics search:

1. Design event selection
2. Do the measurement
 - a. Estimate background yields
 - b. Measured yield of signal candidates
3. Determine selection efficiency
4. Calculate cross section

Can be done fairly
model-independently

Strive to cover as many
corners of SM phase space

Step 3 is difficult to do
model-independently, which
affects final outcome

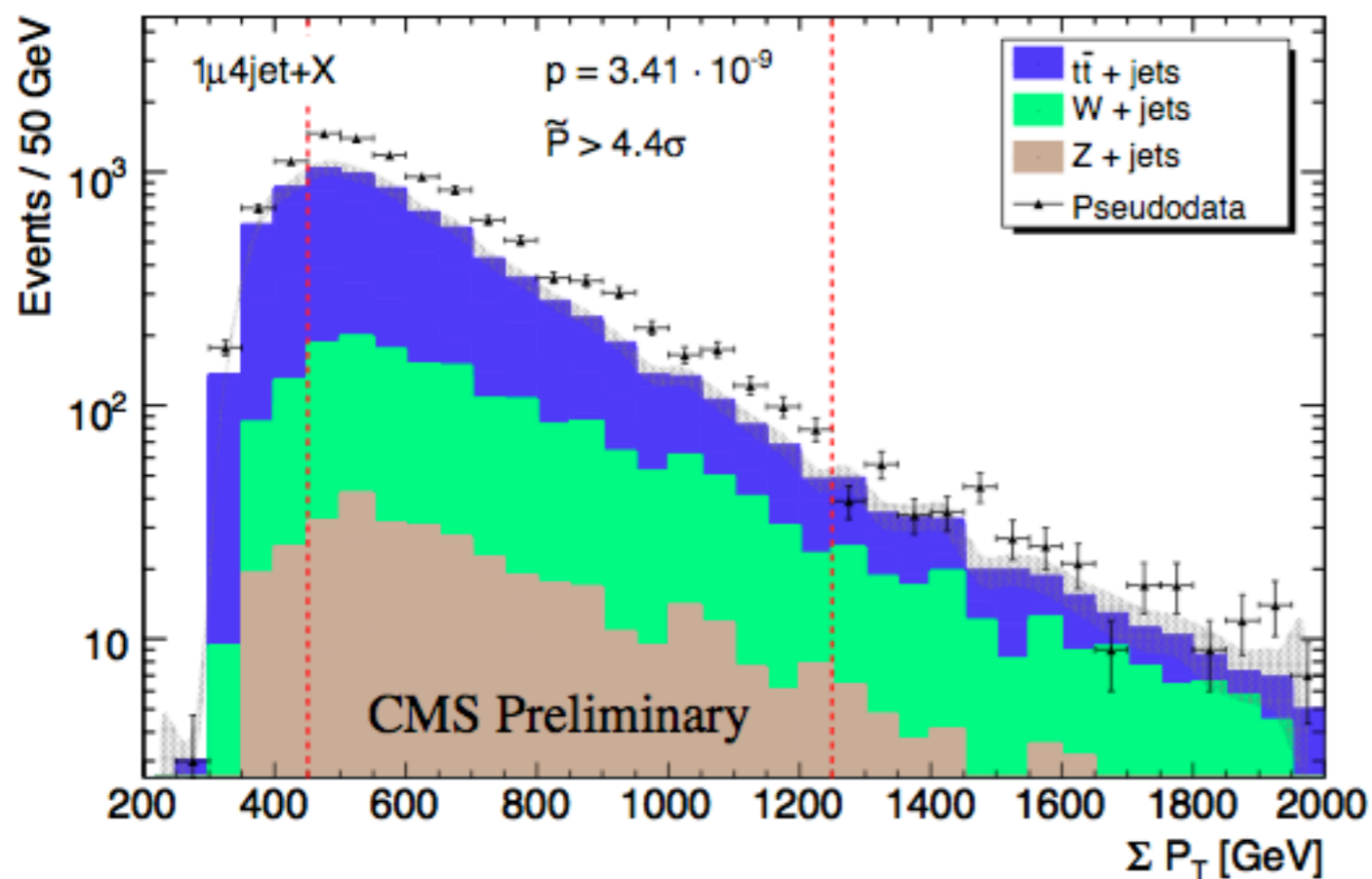
(completely) Model-Independent Searches

Scan data for systematic deviations from Monte Carlo

ex: MUSiC (EXO-08-005)

selection cuts are not optimized

300-400 classes of events considered



PRO:

very broad coverage to many types of models

CON:

difficult to claim discovery (detector effect?)

(completely) Model-Independent Searches

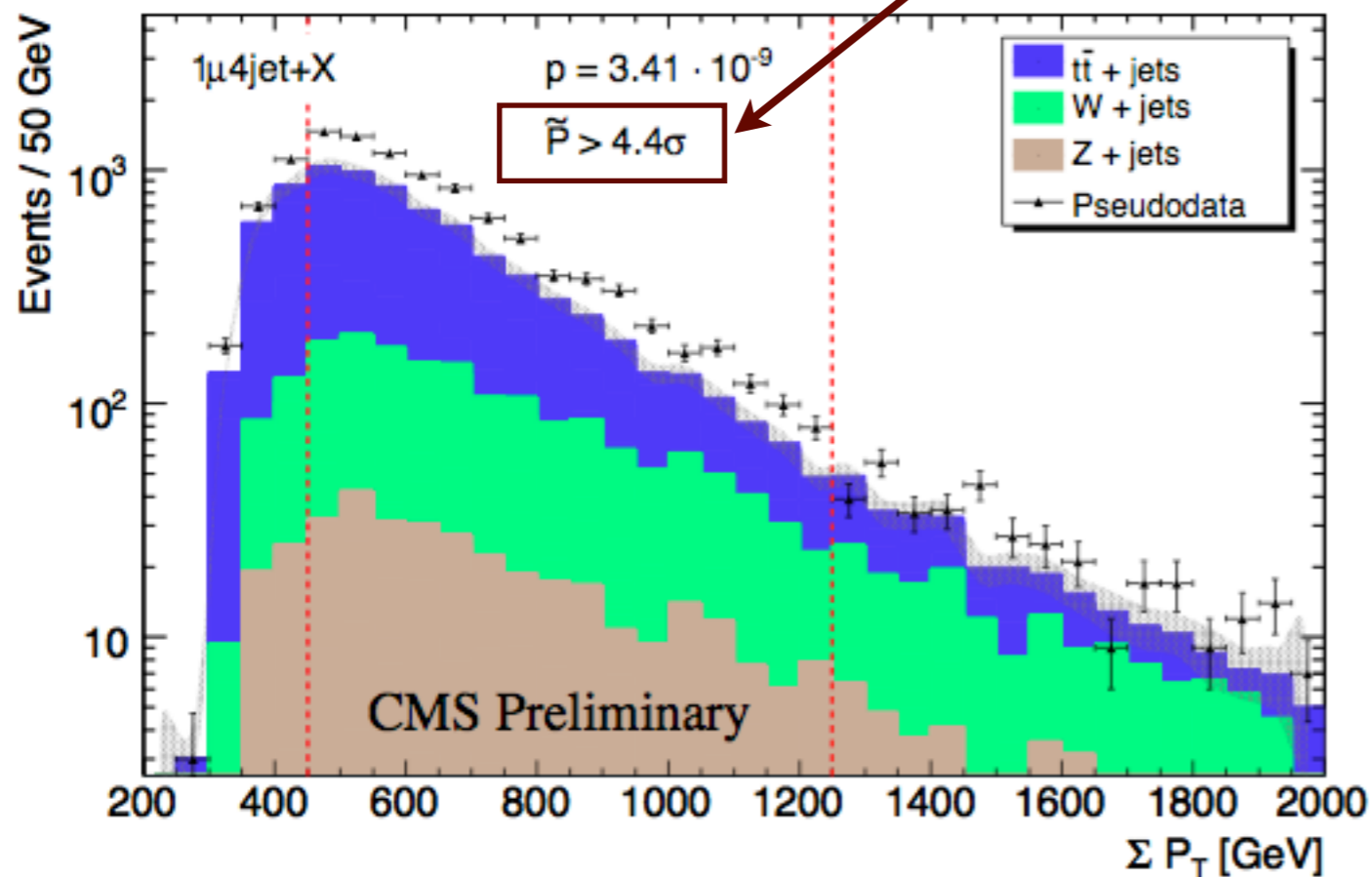
Scan data for systematic deviations from Monte Carlo

ex: MUSiC (EXO-08-005)

selection cuts are not optimized

300-400 classes of events considered

excess due to incorrect characterization in jet energy scale uncertainty



PRO:
very broad coverage to
many types of models

CON:
difficult to claim discovery
(detector effect?)

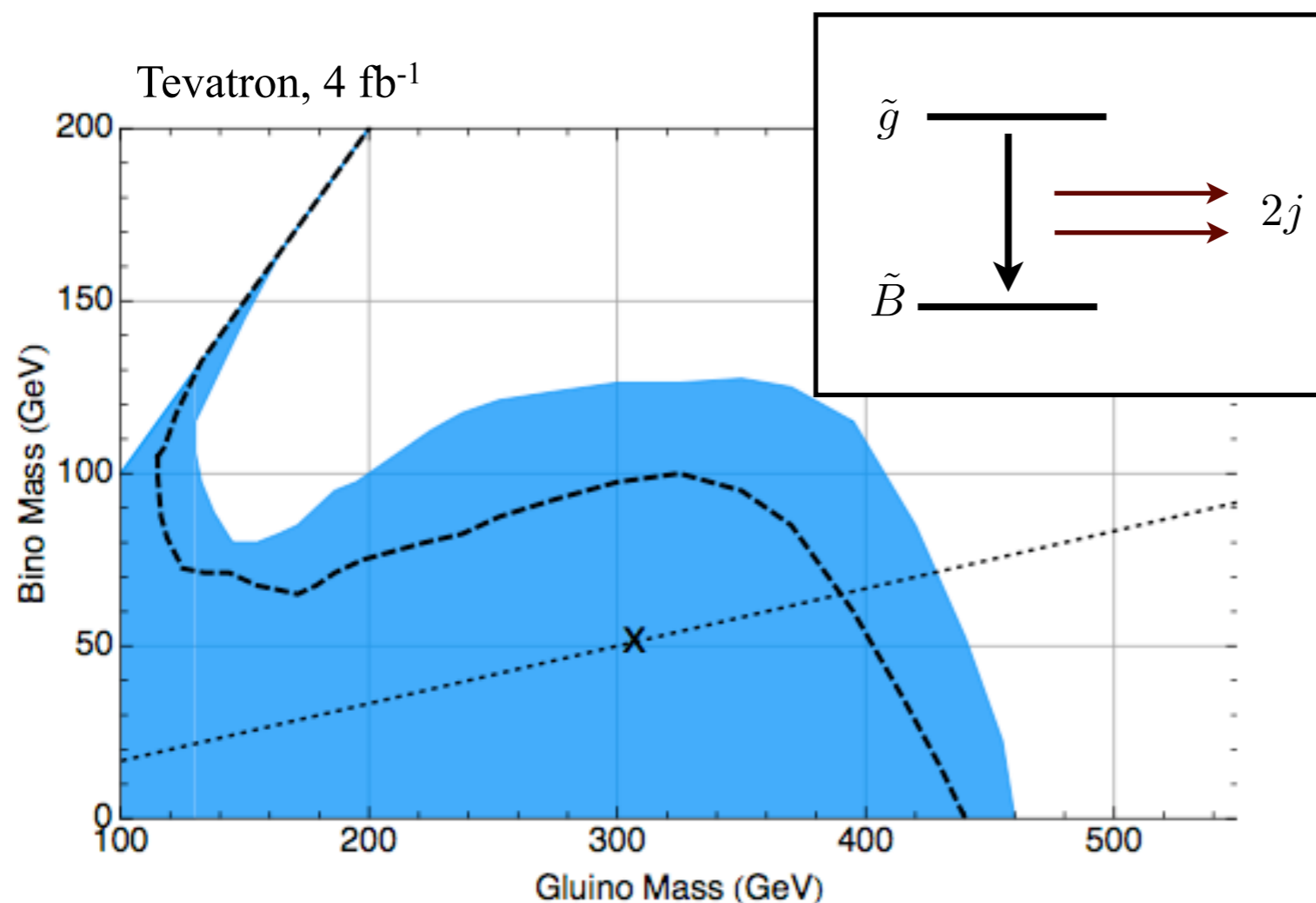
Targeted Searches

Optimize cuts for a particular model

ex: mSUGRA

only five parameters to set MSSM spectrum

often used as benchmark for searches



PRO:
great coverage...

CON:
...but for only one model.
What if that's not reality?

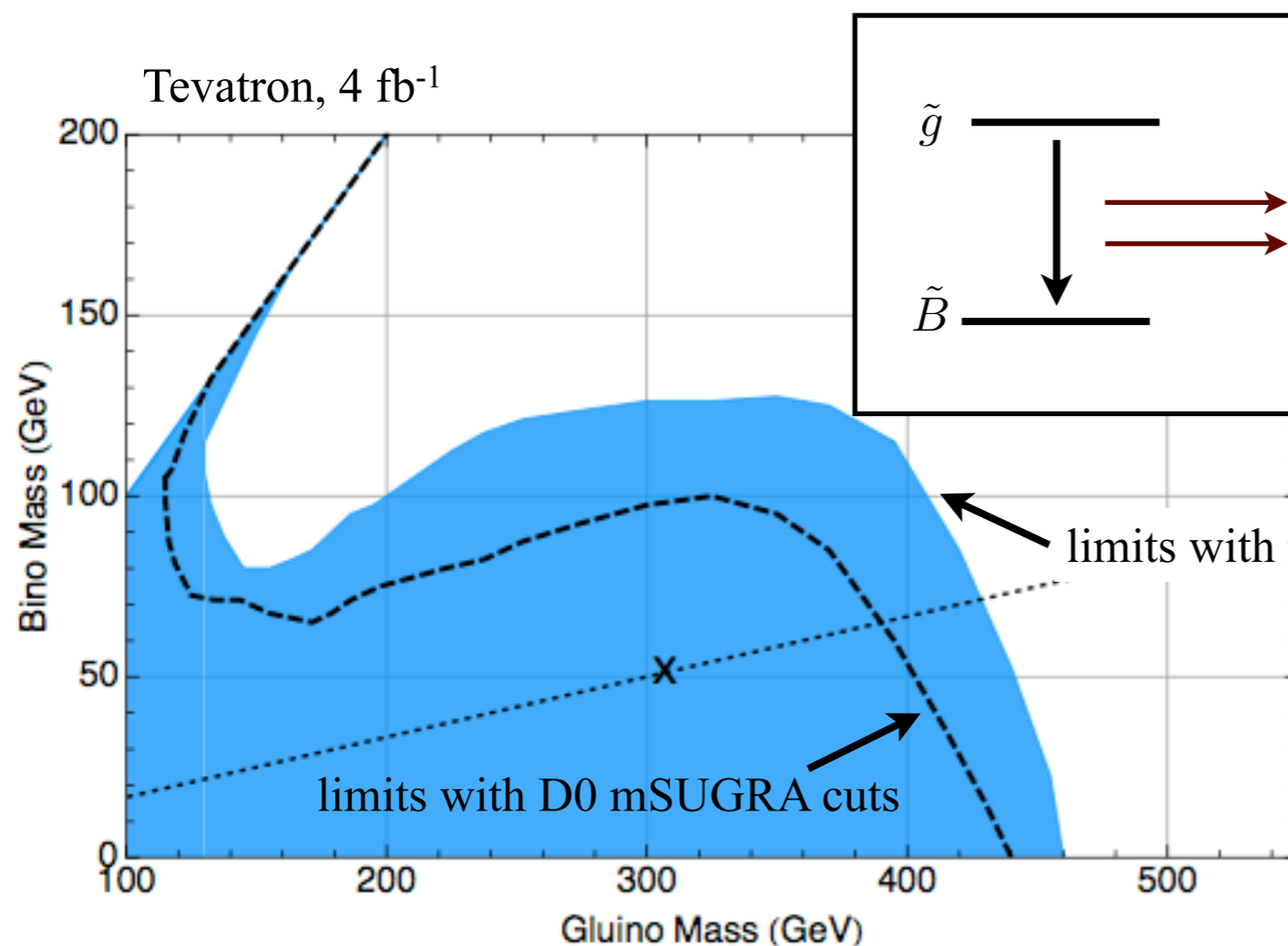
Targeted Searches

Optimize cuts for a particular model

ex: mSUGRA

only five parameters to set MSSM spectrum

often used as benchmark for searches



PRO:
great coverage...

CON:
...but for only one model.
What if that's not reality?

Early Jets+MET Search

Came out with only 70 nb^{-1} of integrated luminosity



ATLAS NOTE

ATLAS-CONF-2010-065

20 July, 2010

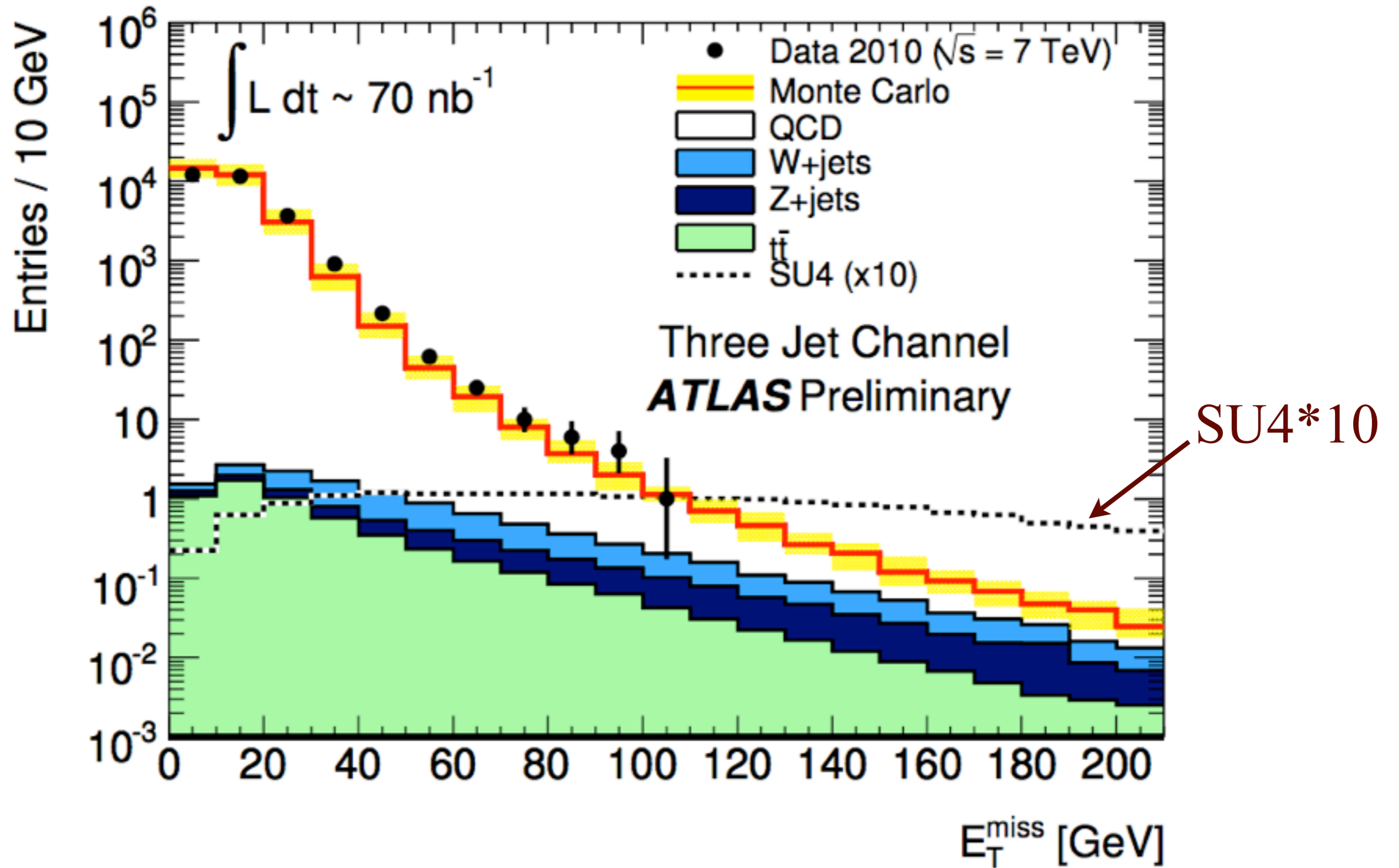


Early supersymmetry searches in channels with jets and missing transverse momentum with the ATLAS detector

Abstract

This note describes a first set of measurements of supersymmetry-sensitive variables in the final states with jets, missing transverse momentum and no leptons from the $\sqrt{s} = 7 \text{ TeV}$ proton-proton collisions at the LHC. The data were collected during the period March 2010 to July 2010 and correspond to a total integrated luminosity of $70 \pm 8 \text{ nb}^{-1}$. We find agreement between data and Monte Carlo simulations indicating that the Standard Model backgrounds to searches for new physics in these channels are under control.

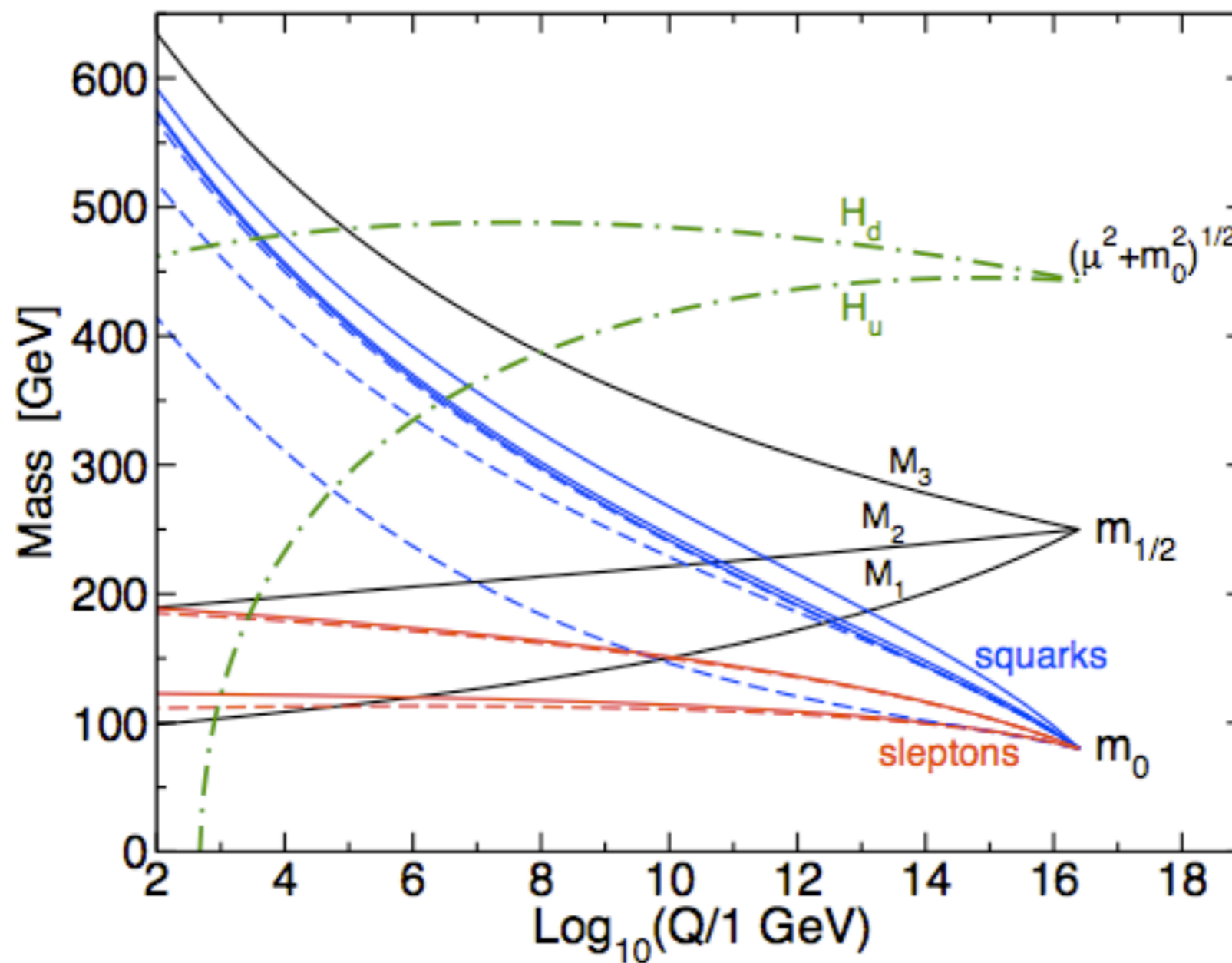
Early Jets+MET Search



mSUGRA

5 parameters at the GUT scale set low-energy spectrum

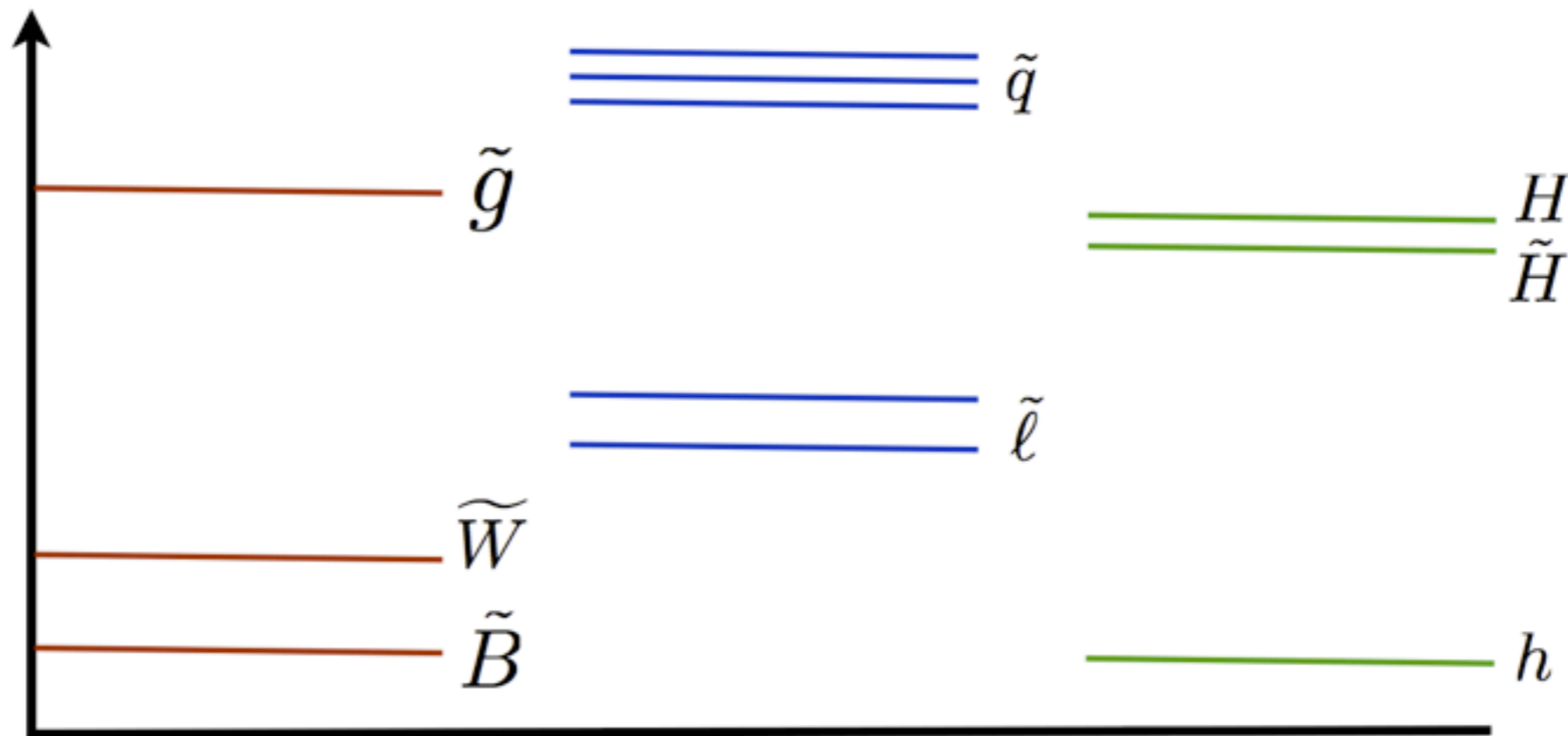
$$m_{\frac{1}{2}}, m_0^2, A_0, B_\mu, \mu$$



mSUGRA

$$m_{\tilde{g}} : m_{\tilde{W}} : m_{\tilde{B}} = \alpha_3 : \alpha_2 : \alpha_1 \simeq 6 : 2 : 1$$

Most models look like this

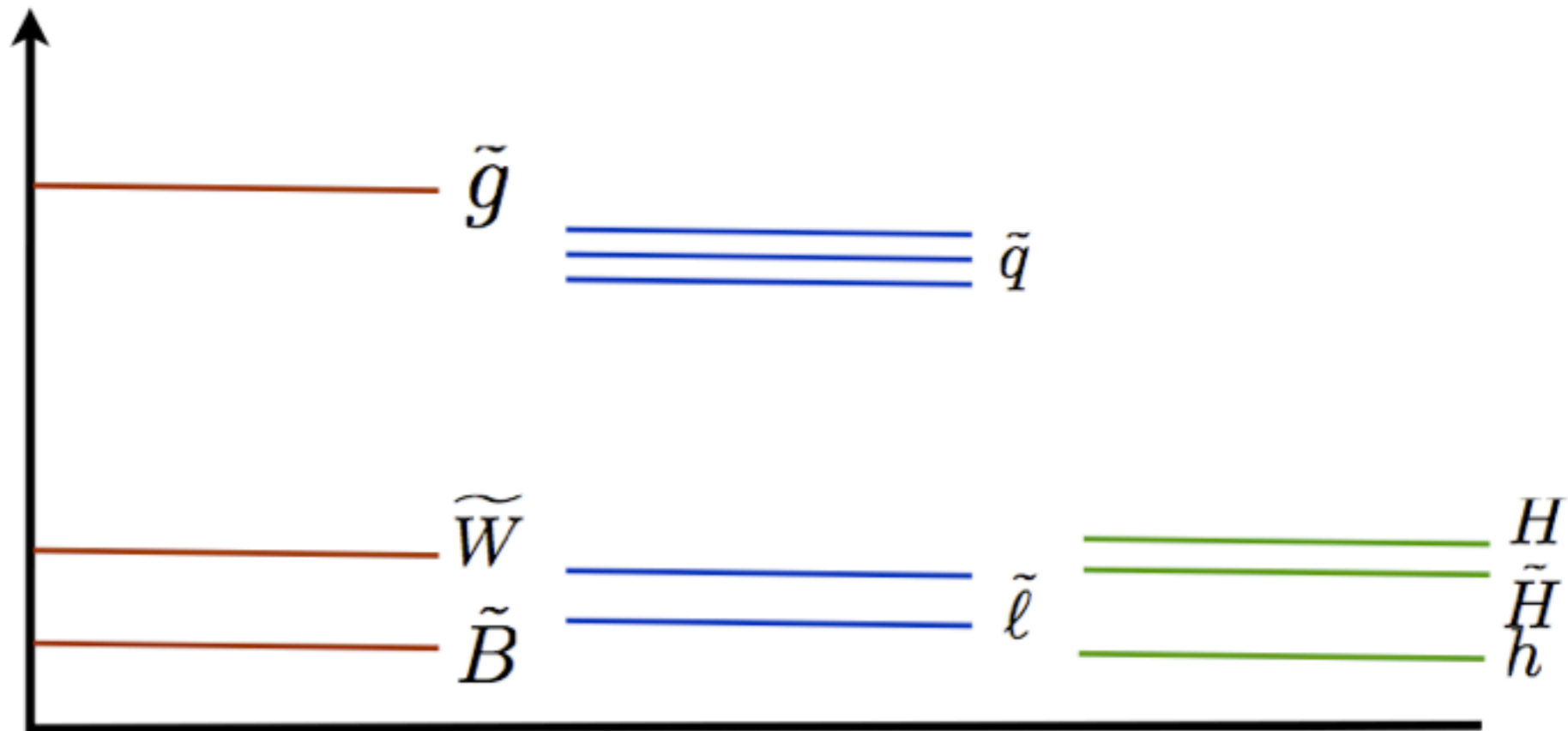


A shocking lack of diversity

mSUGRA

$$m_{\tilde{g}} : m_{\tilde{W}} : m_{\tilde{B}} = \alpha_3 : \alpha_2 : \alpha_1 \simeq 6 : 2 : 1$$

Most models look like this



A shocking lack of diversity

Phenomenological MSSM

$$m_{\tilde{q}}^2, m_{\tilde{u}^c}^2, m_{\tilde{d}^c}^2, m_{\tilde{l}}^2, m_{\tilde{e}^c}^2$$

$$m_{\tilde{g}}, m_{\tilde{W}}, m_{\tilde{B}}, \mu$$

$$A_t, A_b, A_\tau$$

$$m_{h_u}^2, m_{h_d}^2, B_\mu$$

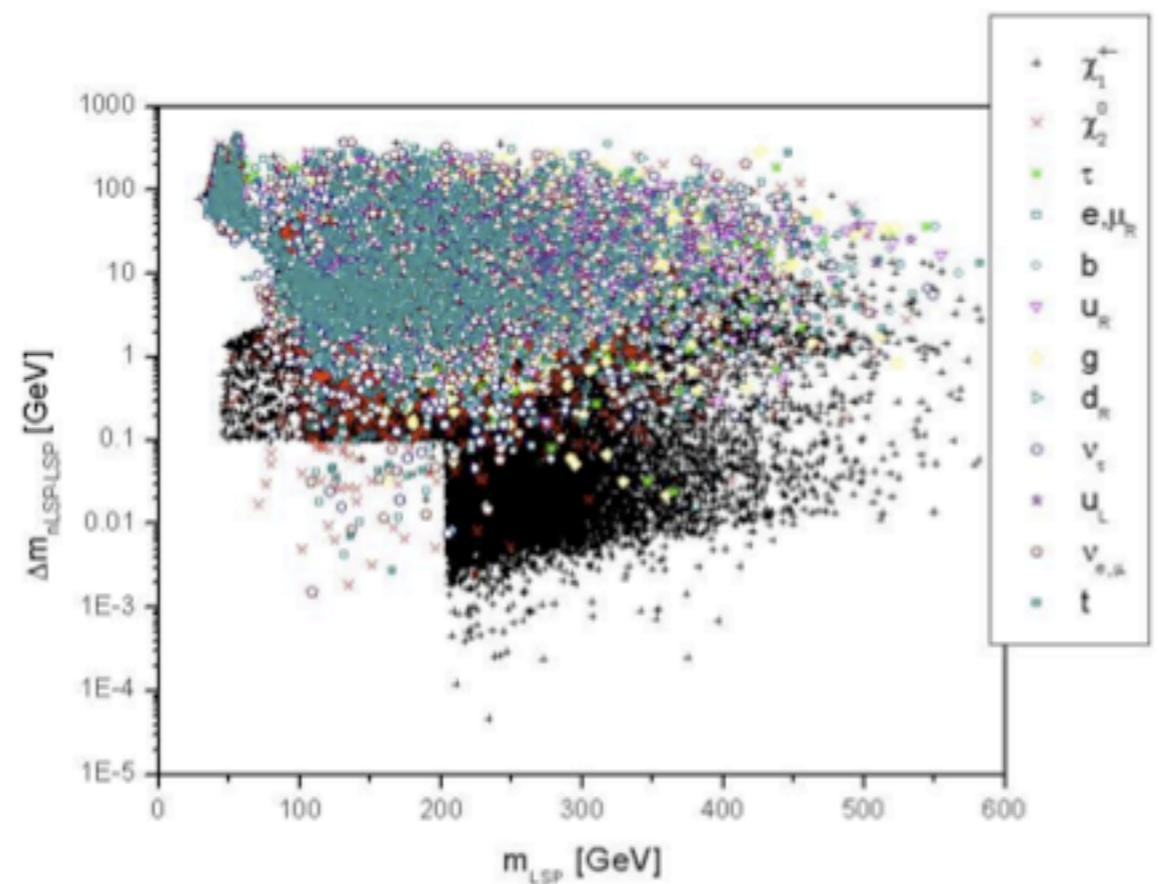
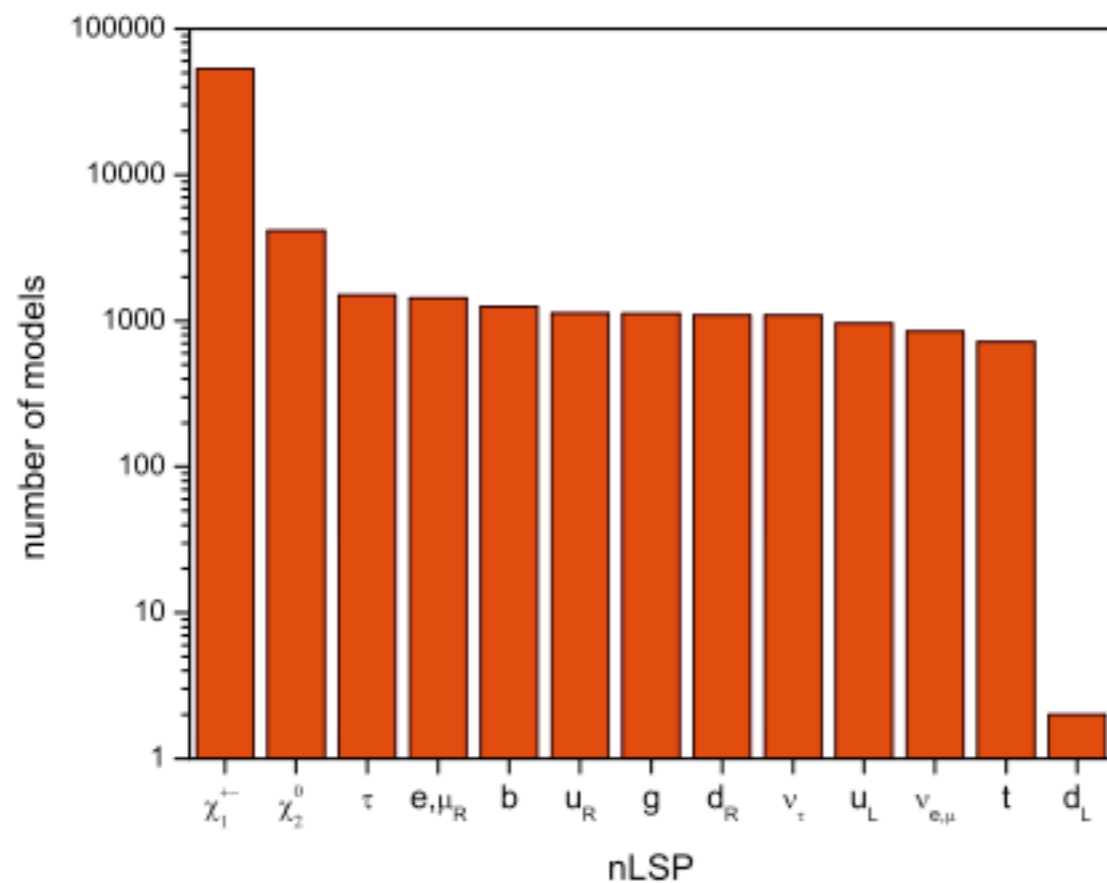
5 for first two generations

5 for third generation

4 for *-ino masses

3 for A terms

3-1 for Higgs sector



Dilemma...

How to parameterize models without using a CPU-century?

Need to cover signature space better

Real models have dozens of parameters

Sometimes small/reasonable perturbations can make a difference in the visibility of a model

Need to simplify and abstract models

Simplified Models

Effective Field Theory for Collider Physics

Limits of Specific Theories

Keep only particles and couplings relevant for searches

Still a full Lagrangian description

Removes superfluous model parameters

Focus on masses, cross sections, branching ratios

Captures specific models

Including ones that aren't explicitly proposed

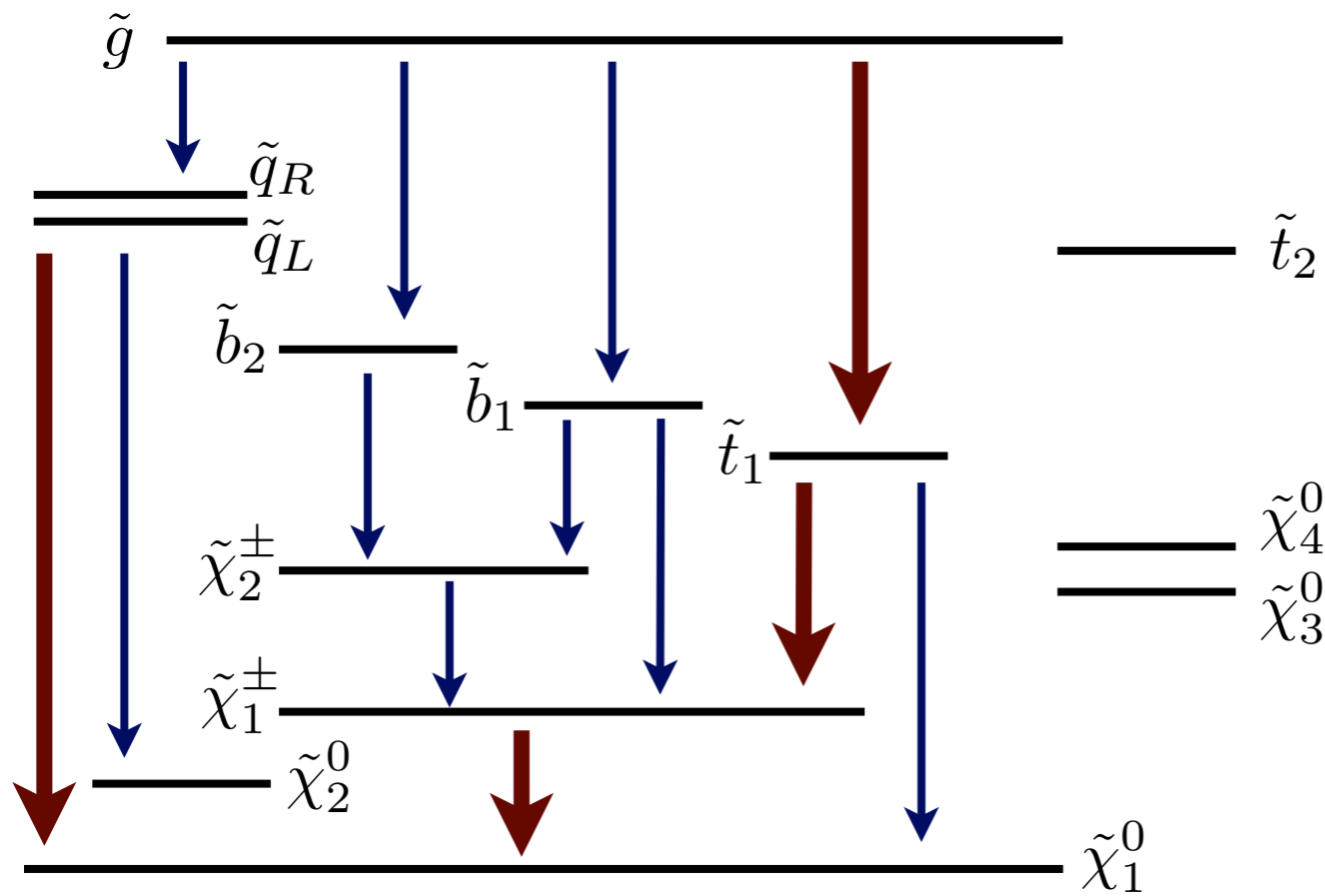
Easy to notice and explore kinematic limits

A Compromise

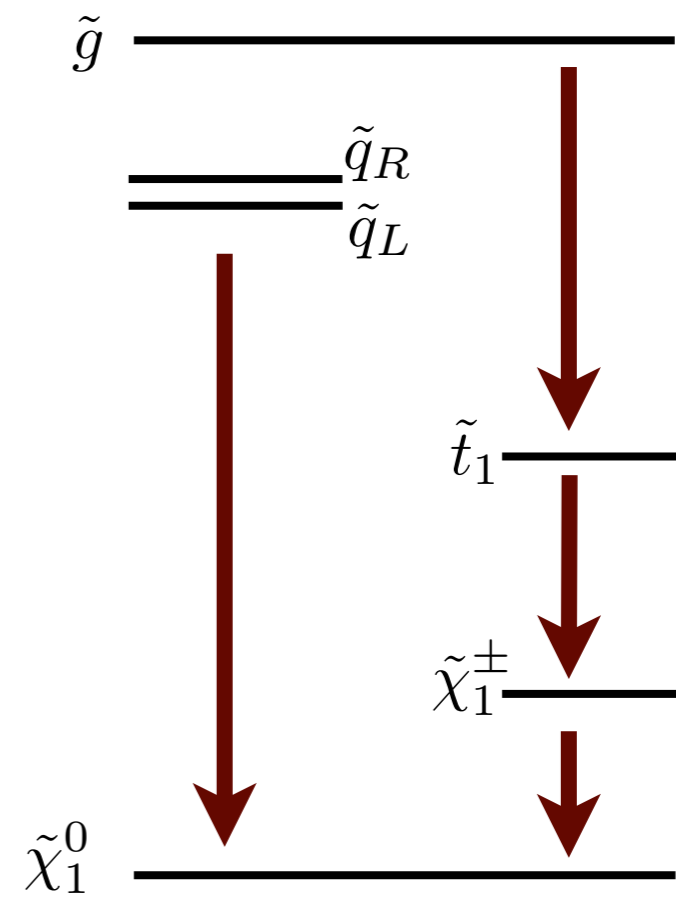
Simplified Models are an intermediate step between a complete theory and experimental signature

Removes complications of model details and allows one to focus on kinematics when designing cuts

Complete Spectrum



Simplified Model



Outline

Simplified Models

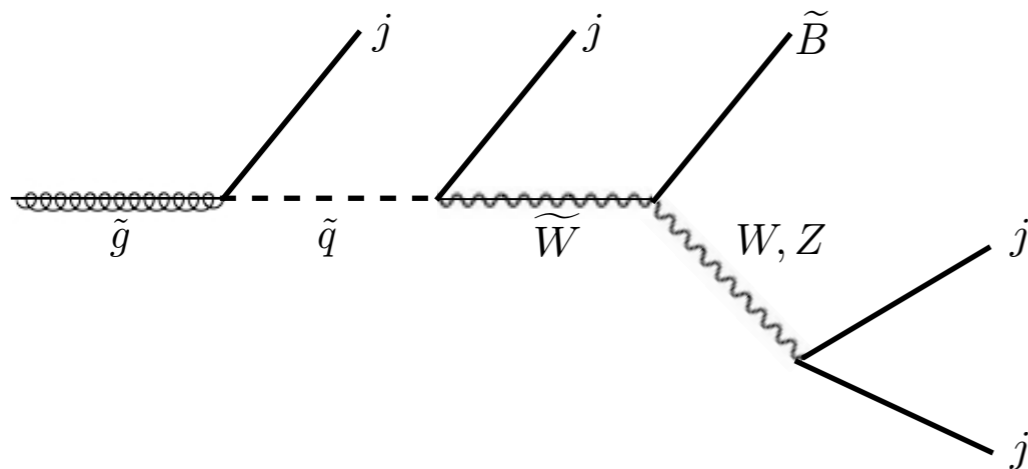
Jets + MET Example

New Physics Working Group

Jets + MET

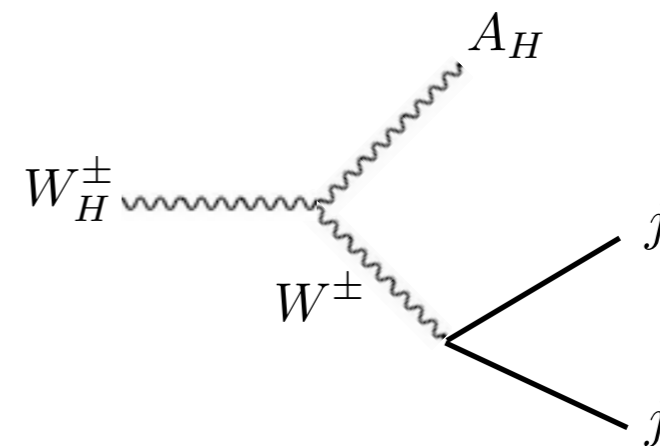
Promising signature for new physics
(UED, SUSY, Little Higgs)

new colored particle
decays to dark matter



e.g., MSSM, NMSSM, UED

new gauge bosons
are produced



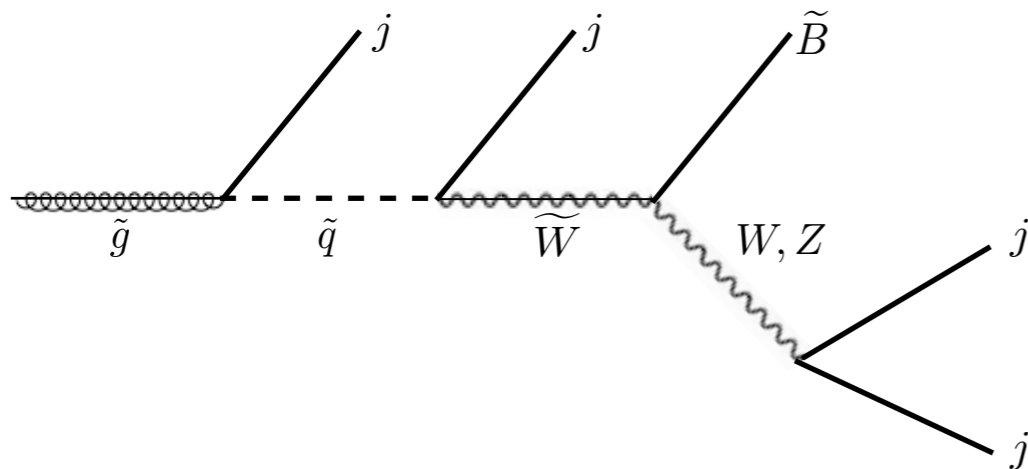
e.g., Little Higgs

Jets + MET

Promising signature for new physics
(UED, SUSY, Little Higgs)

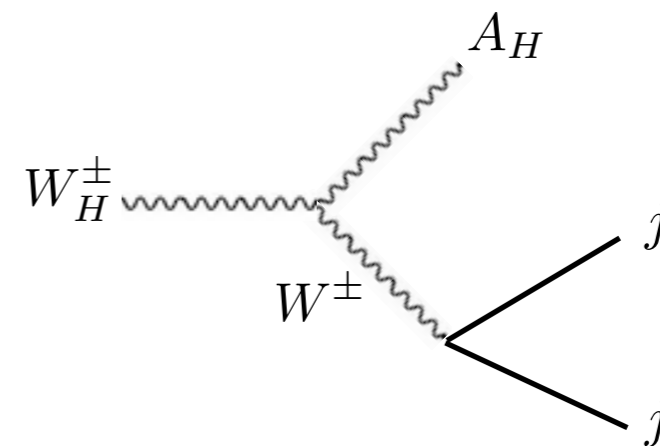
most relevant for early LHC

new colored particle
decays to dark matter



e.g., MSSM, NMSSM, UED

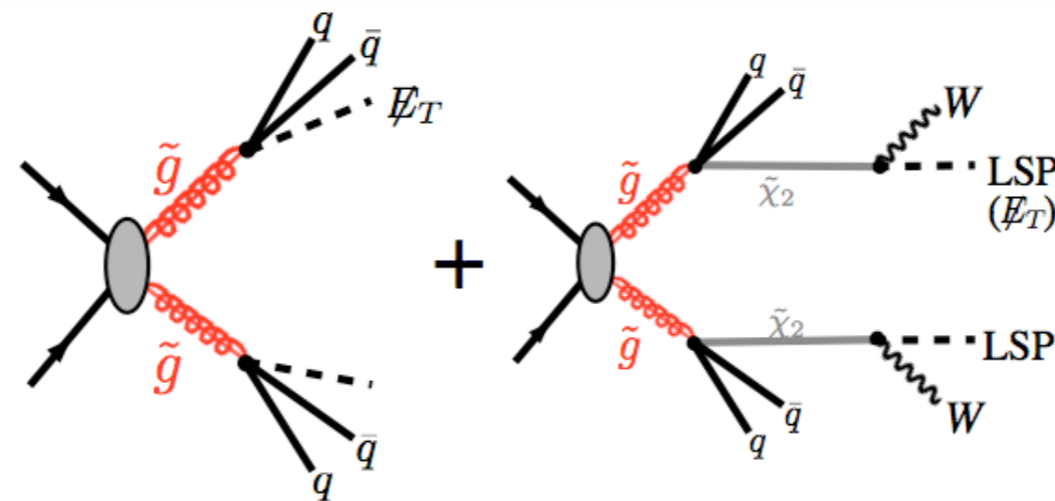
new gauge bosons
are produced



e.g., Little Higgs

Simplified Model

One-stage gluino decay



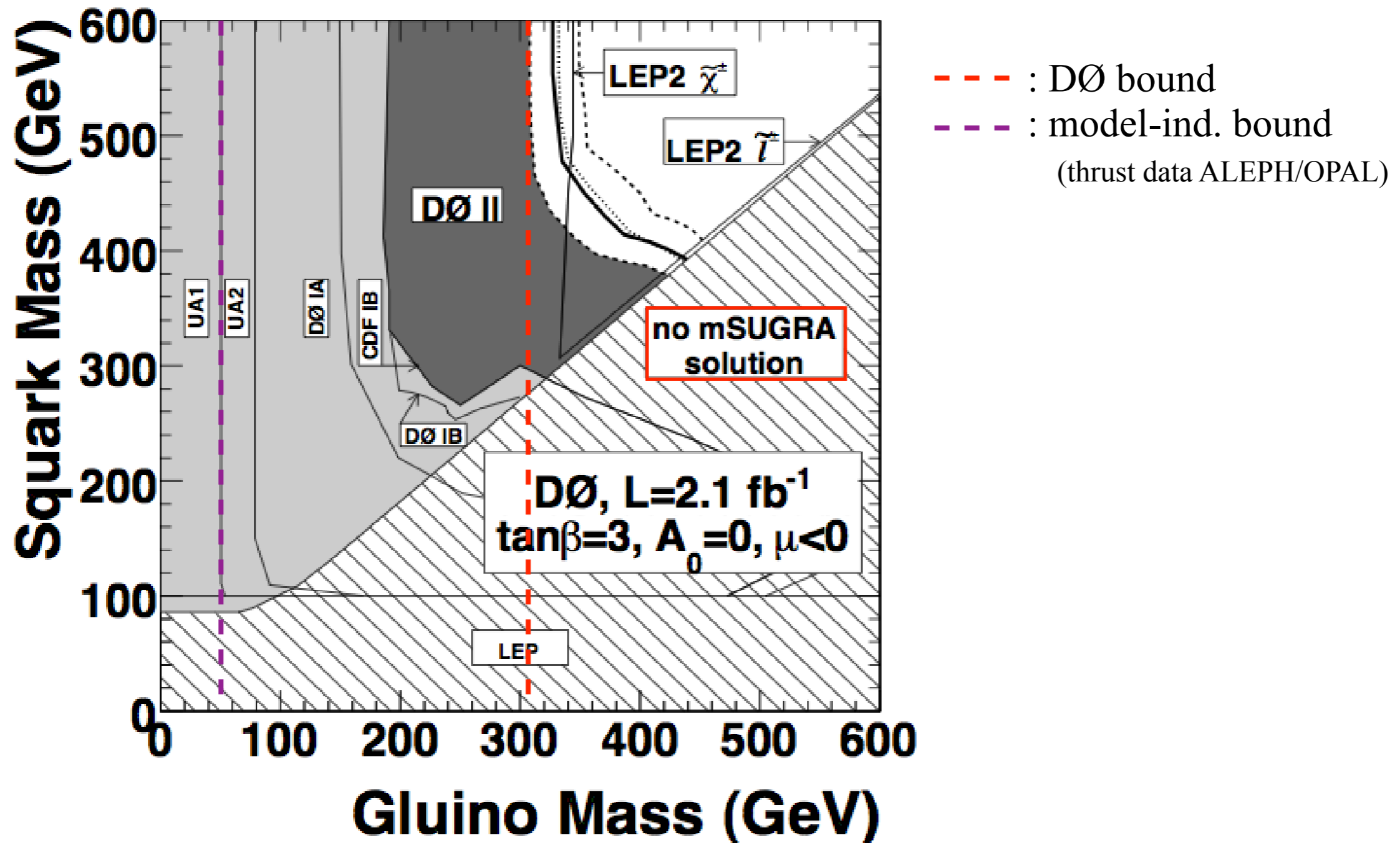
Keep masses and total cross section free

$$m_{\tilde{g}}, m_{\tilde{B}}, \sigma(pp \rightarrow \tilde{g}\tilde{g}X)$$

(Also possible to have squark pair-production and/or associated production of squarks and gluinos)

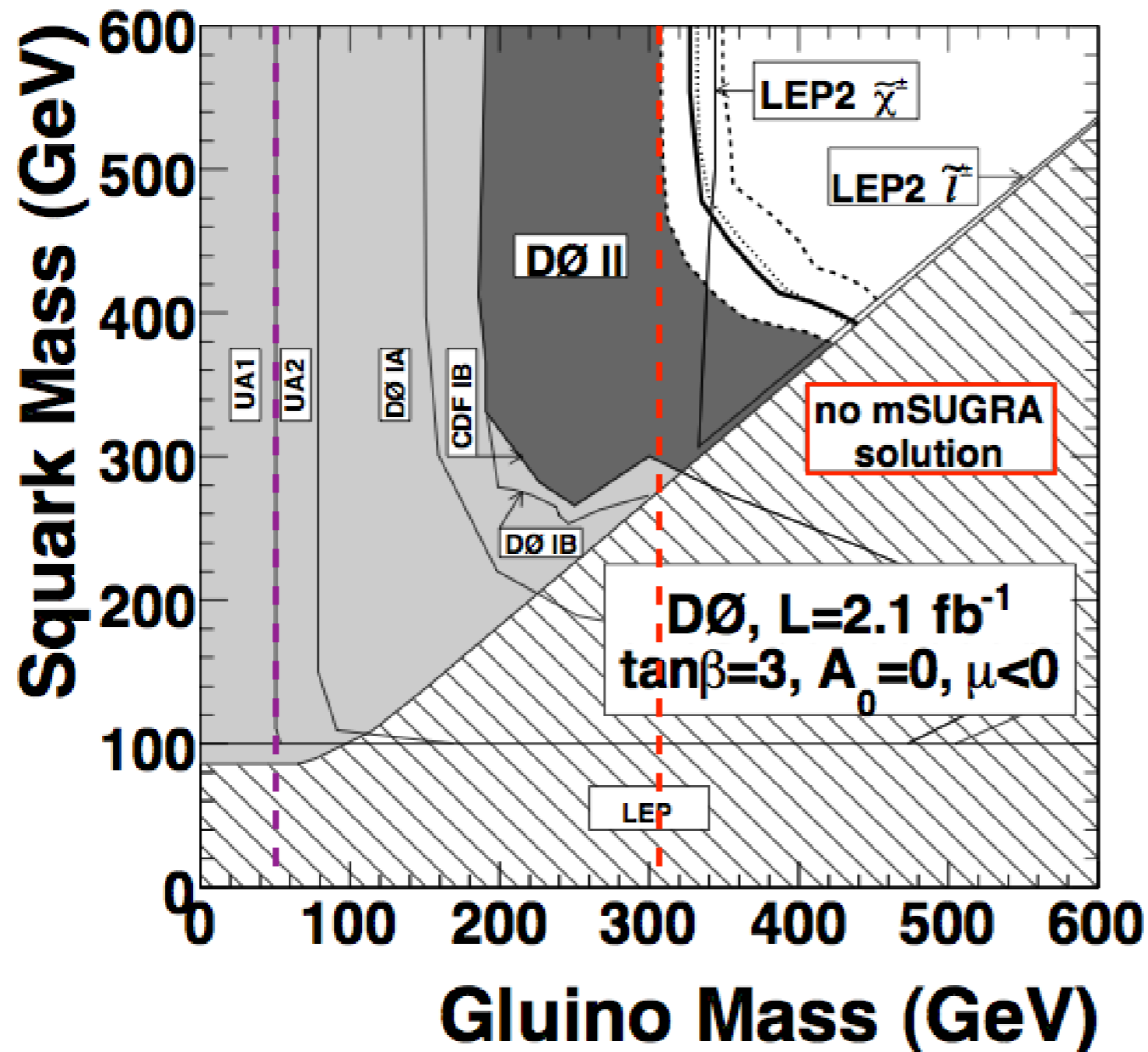
Jets + MET at DØ

Large range of kinematically-accessible gluinos with no known limits



Jets + MET at DØ

Large range of kinematically-accessible gluinos with no known limits



- - - : DØ bound
- - - : model-ind. bound
(thrust data ALEPH/OPAL)

What are model-independent bounds at Tevatron?

Jets + MET at DØ

Inclusive 1 jet - 4+ jet searches

MET and H_T optimized for ‘characteristic’ mSUGRA points

	Gg	$\tilde{q}\tilde{q}$	$\tilde{q}\tilde{g}$	$\tilde{g}\tilde{g}$
	$1j + \cancel{E}_T$	$2j + \cancel{E}_T$	$3j + \cancel{E}_T$	$4j + \cancel{E}_T$
$E_{T j_1}$	≥ 150	≥ 35	≥ 35	≥ 35
$E_{T j_2}$	< 35	≥ 35	≥ 35	≥ 35
$E_{T j_3}$			≥ 35	≥ 35
$E_{T j_4}$				≥ 20
\cancel{E}_T	≥ 150	≥ 225	≥ 150	≥ 100
H_T	≥ 150	≥ 300	≥ 400	≥ 300

$$H_T = \sum E_{T j}$$

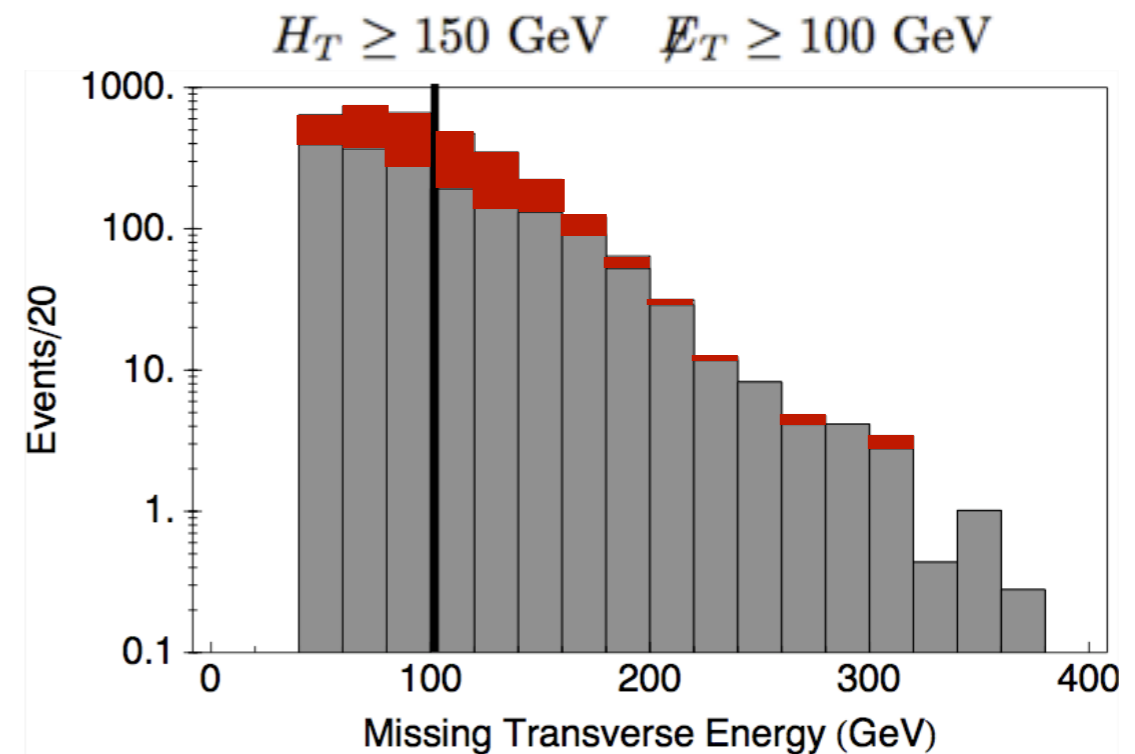
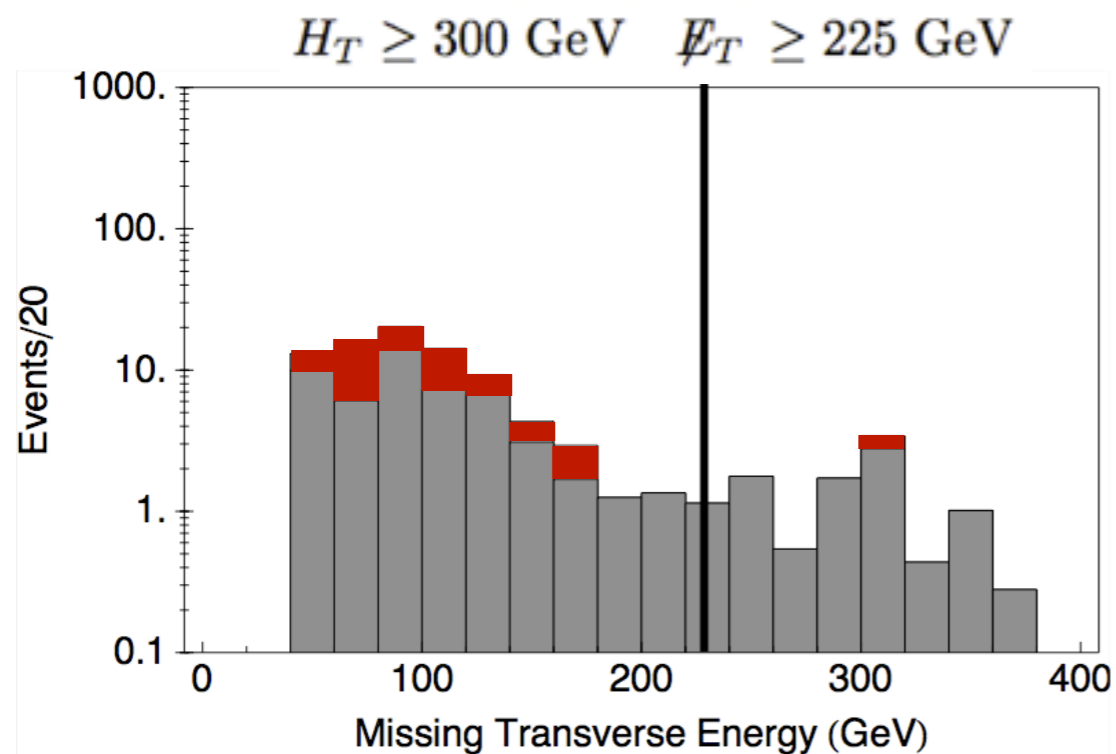
(Not exclusive searches)

Generalizing Cuts

Dijet signal for 200 GeV gluino decay directly 100 GeV bino

$D\bar{D}$ cuts

More general cuts



■ : Background ■ : Signal

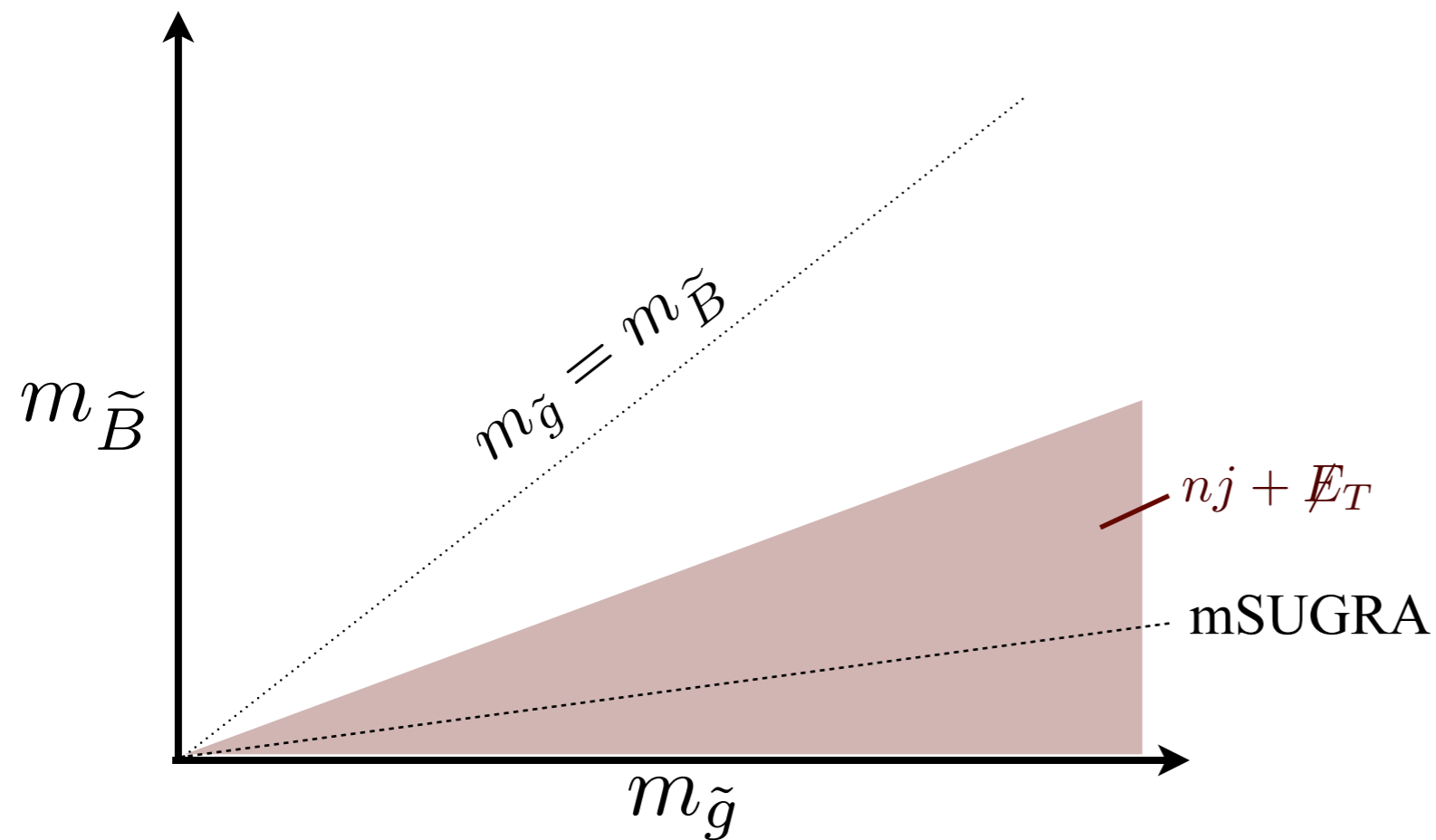
Tevatron never searched in physics parameter space

Possibility for light gluinos lurking...

Kinematics

Mass difference between gluino and bino is relevant quantity

$$m_{\tilde{g}} \gg m_{\tilde{B}} \quad \text{hard, well-separated jets}$$

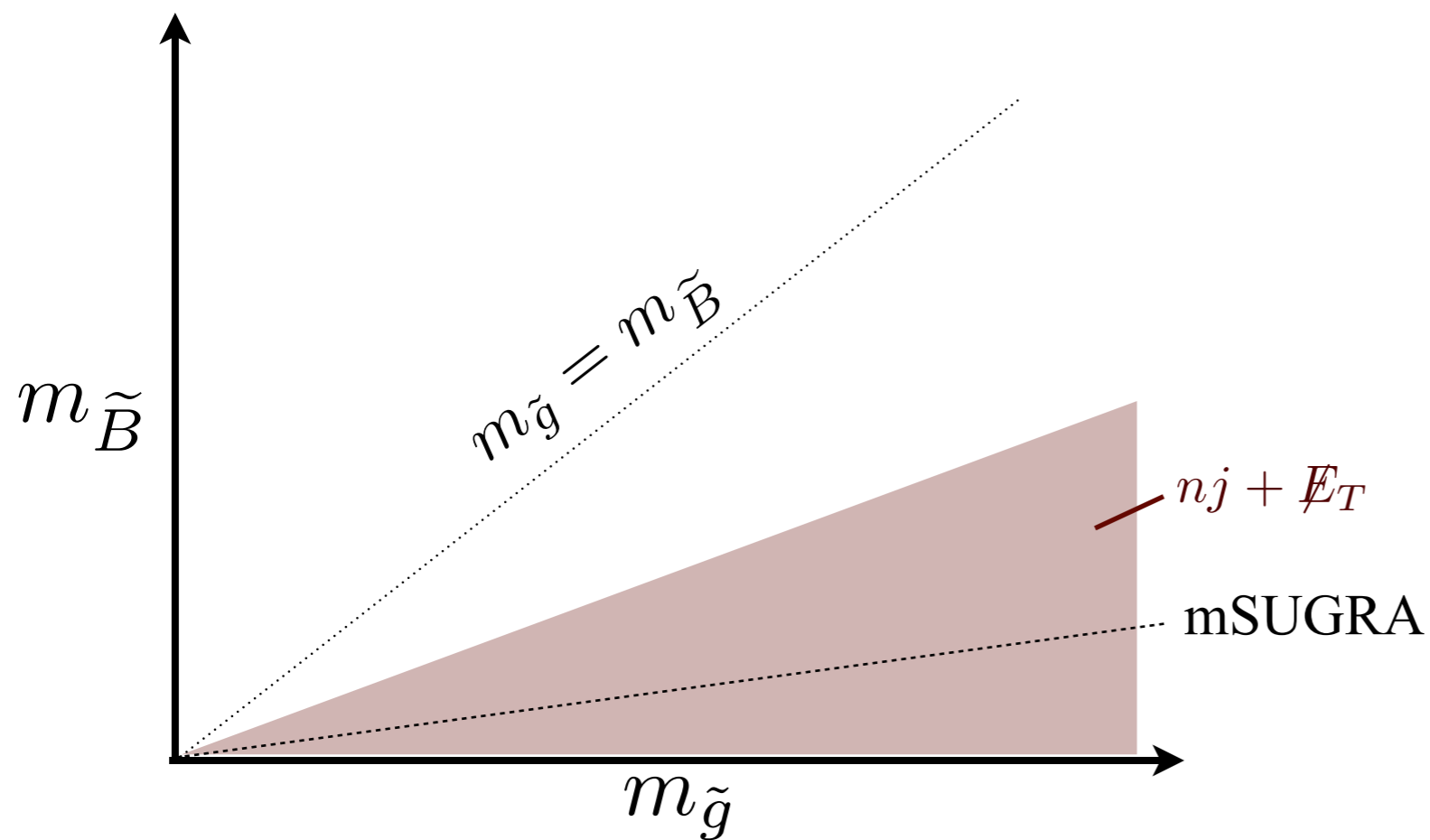


Kinematics

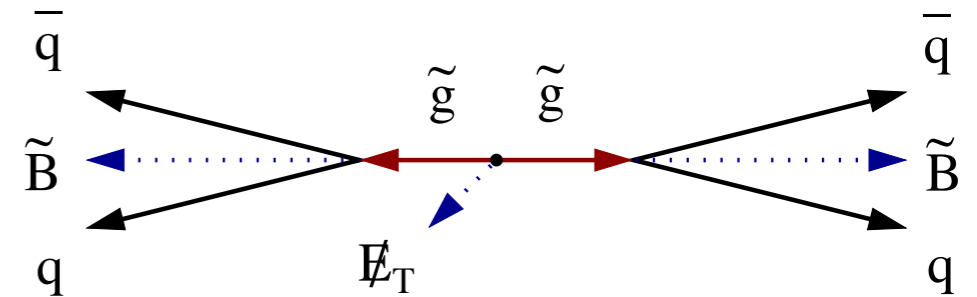
Mass difference between gluino and bino is relevant quantity

$m_{\tilde{g}} \gg m_{\tilde{B}}$ hard, well-separated jets

$m_{\tilde{g}} \sim m_{\tilde{B}}$ jets not as energetic



Nearly degenerate regime



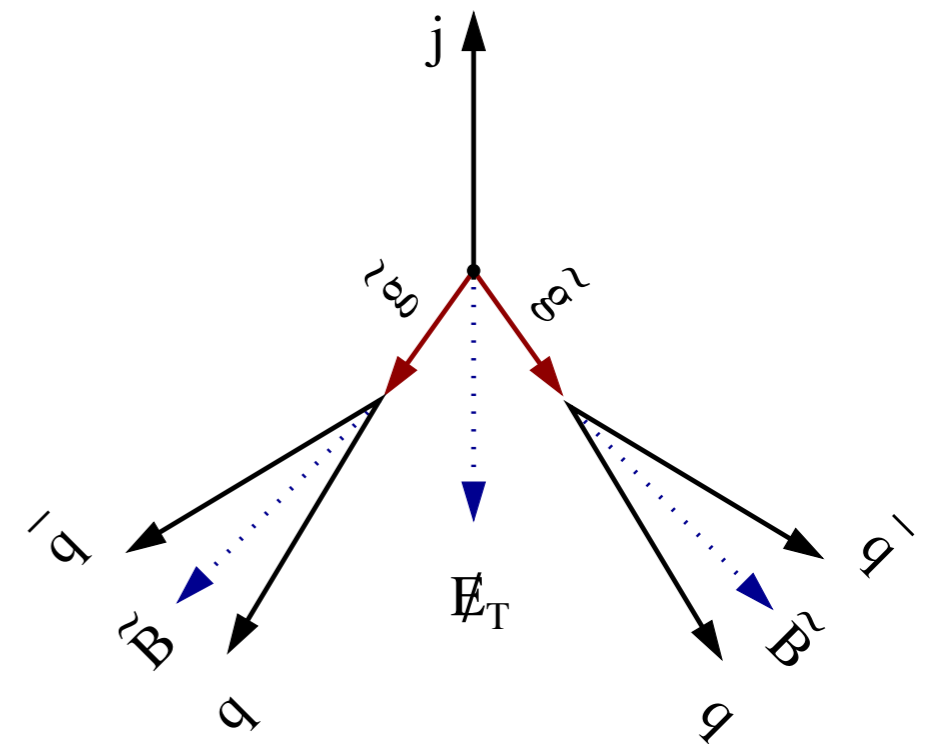
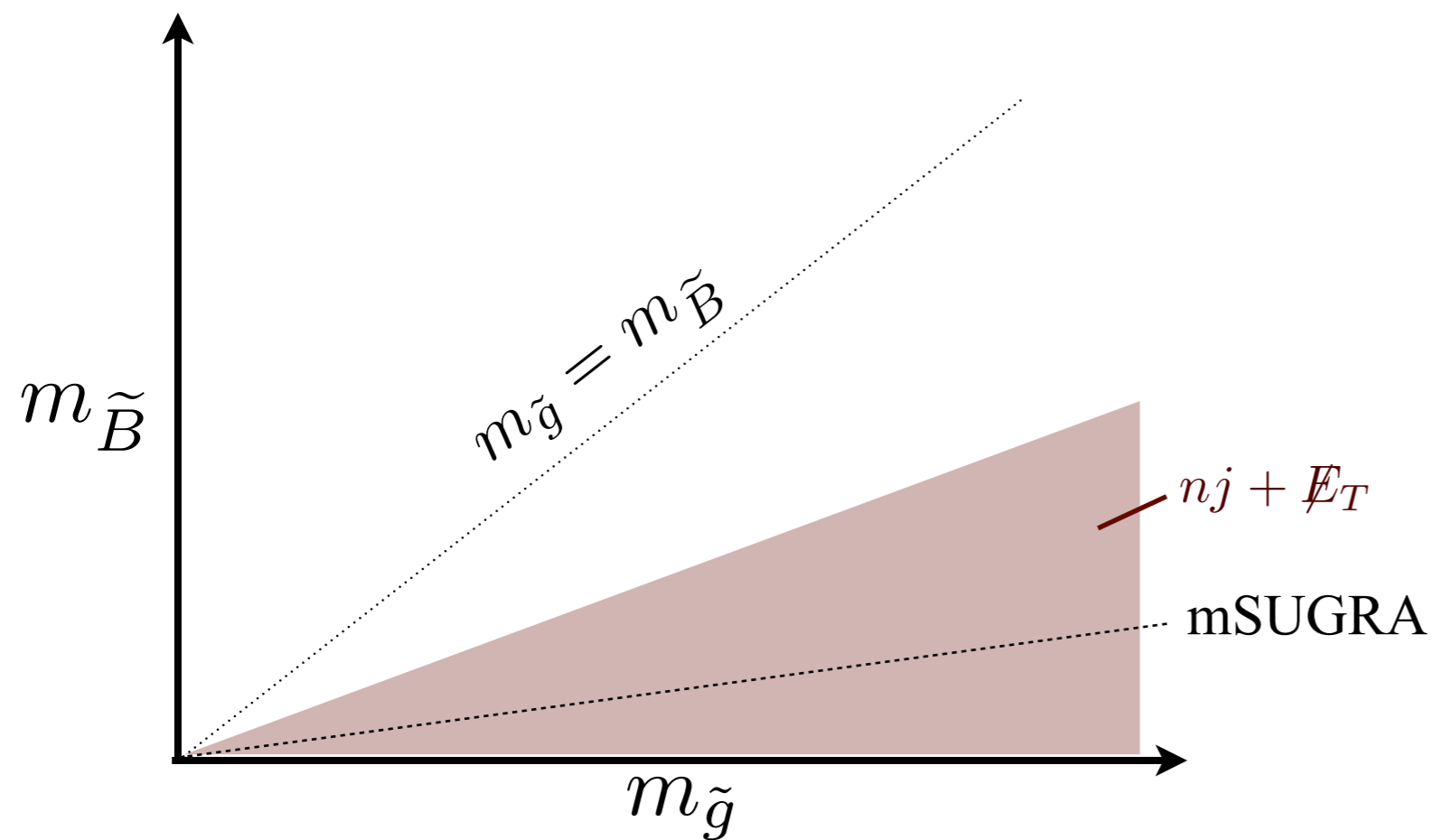
Kinematics

Mass difference between gluino and bino is relevant quantity

$m_{\tilde{g}} \gg m_{\tilde{B}}$ hard, well-separated jets

$m_{\tilde{g}} \sim m_{\tilde{B}}$ jets not as energetic

Nearly degenerate regime

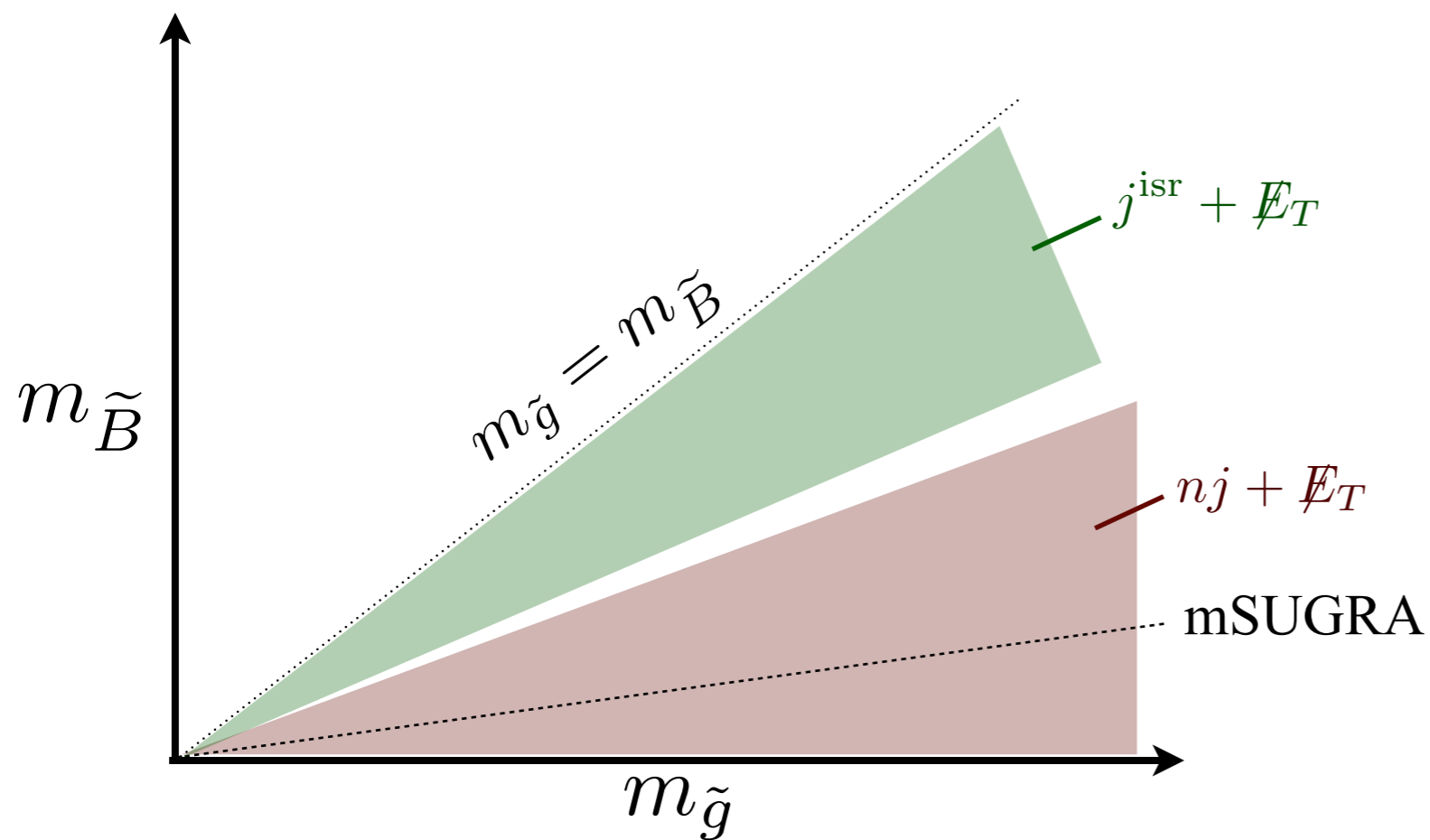


Kinematics

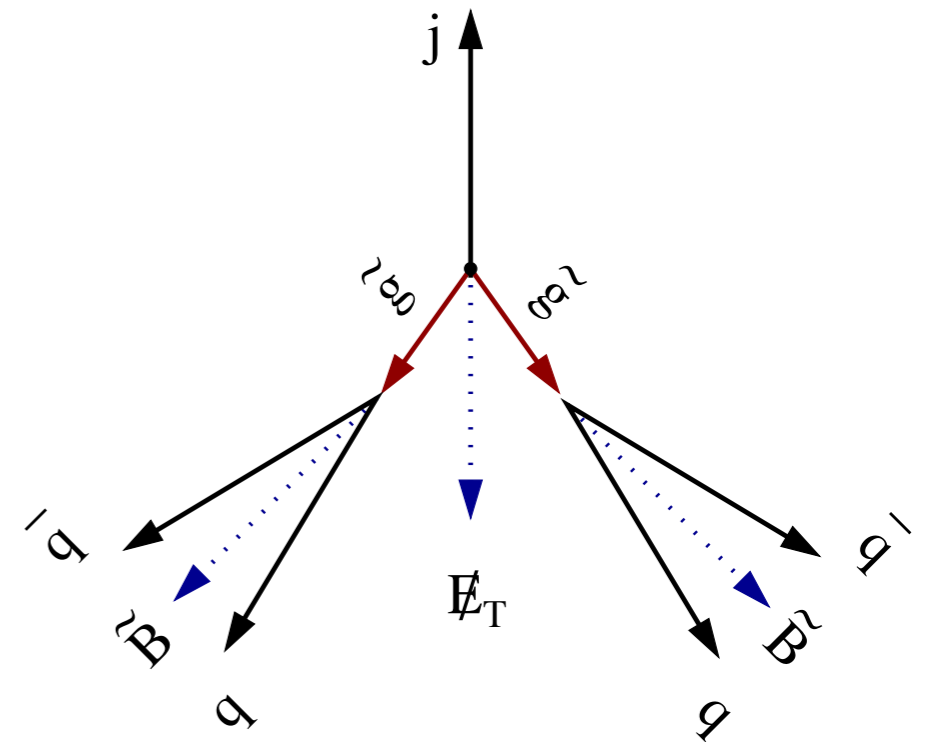
Mass difference between gluino and bino is relevant quantity

$m_{\tilde{g}} \gg m_{\tilde{B}}$ hard, well-separated jets

$m_{\tilde{g}} \sim m_{\tilde{B}}$ jets not as energetic



Nearly degenerate regime



Kinematics

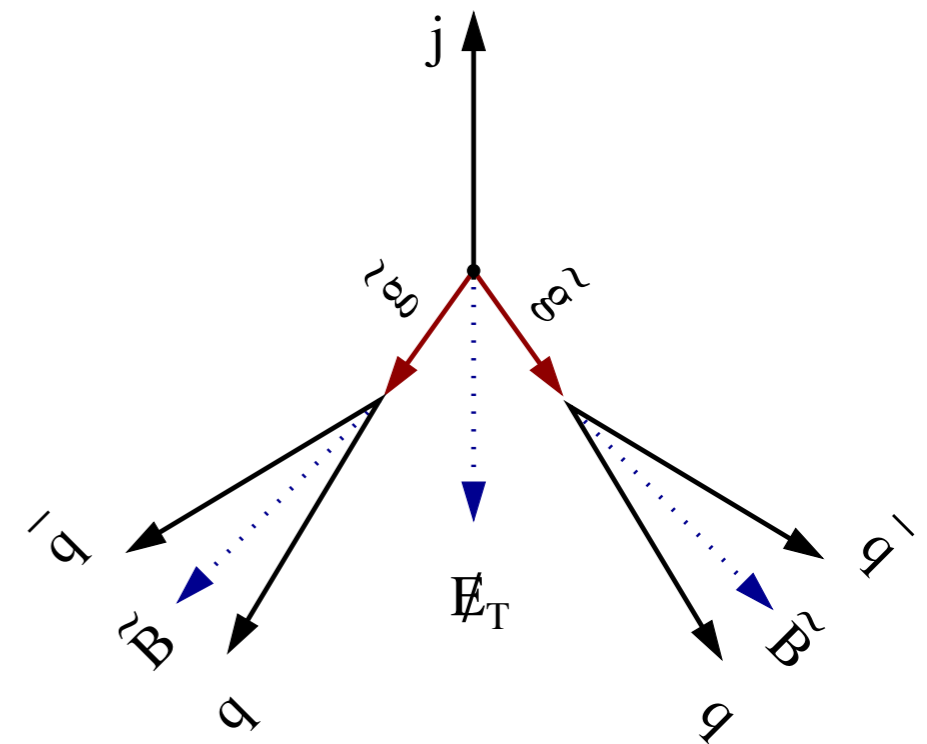
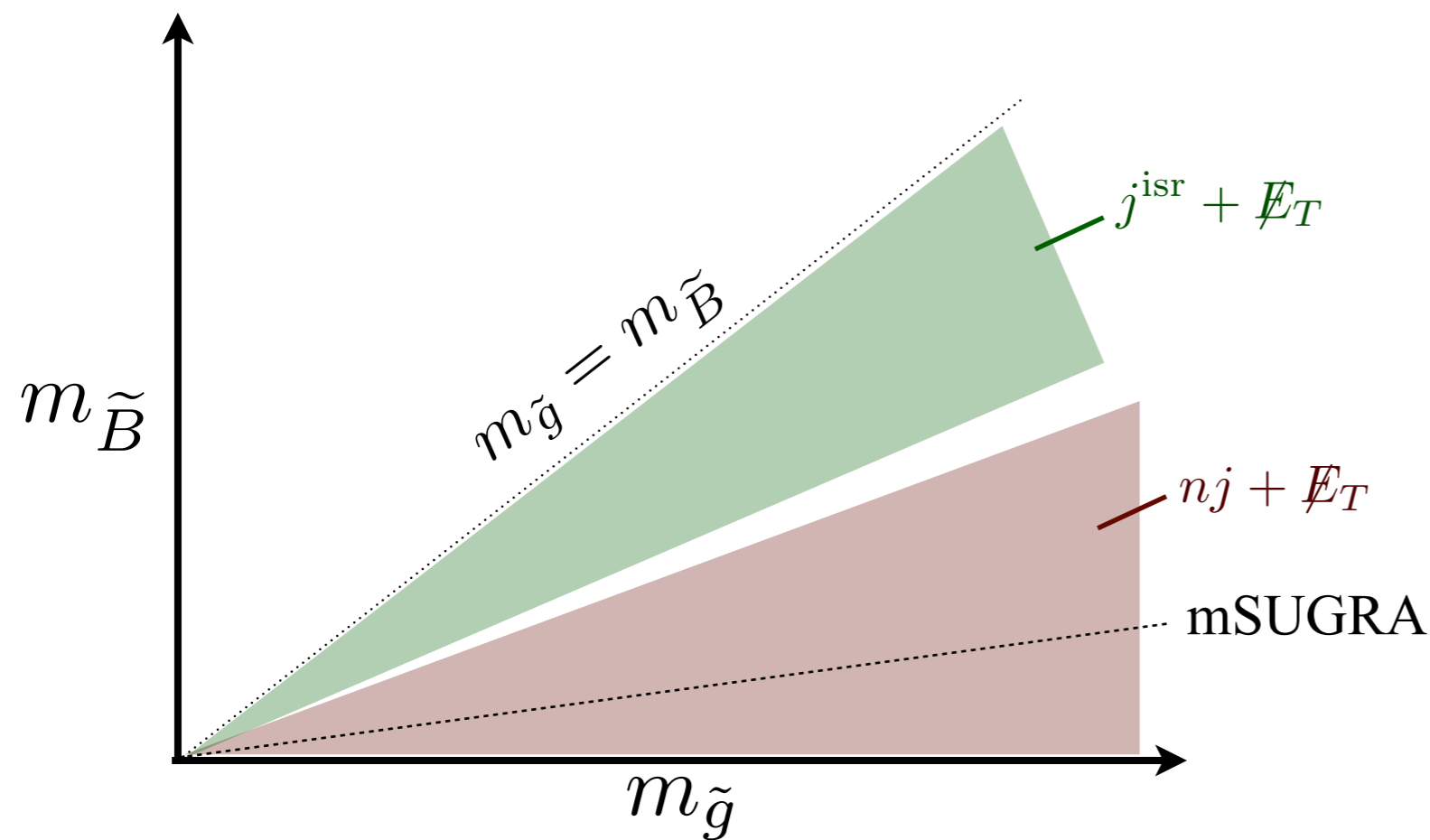
Mass difference between gluino and bino is relevant quantity

$m_{\tilde{g}} \gg m_{\tilde{B}}$ hard, well-separated jets

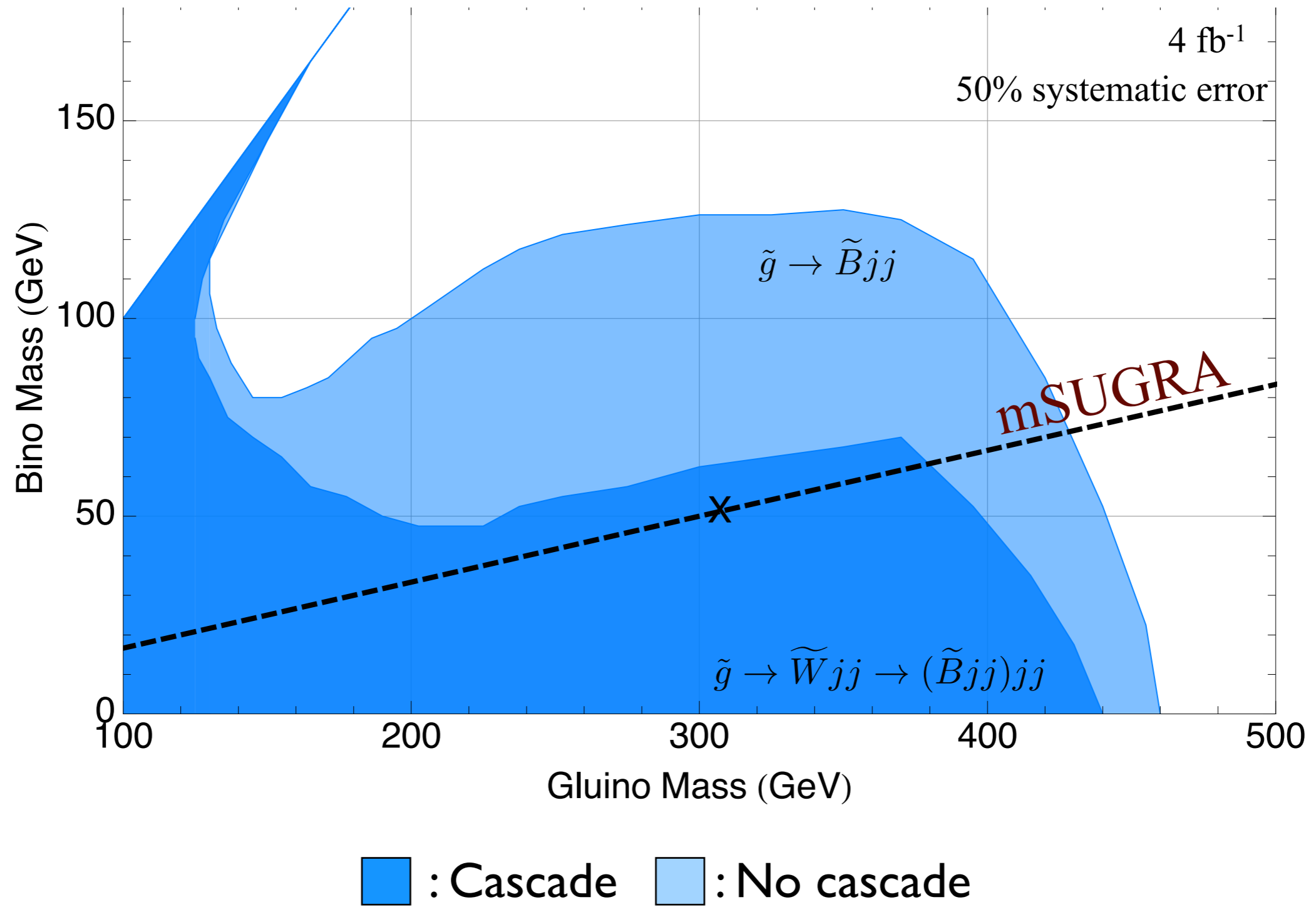
$m_{\tilde{g}} \sim m_{\tilde{B}}$ jets not as energetic

Simplified models help ensure that all kinematic possibilities are considered

Nearly degenerate regime

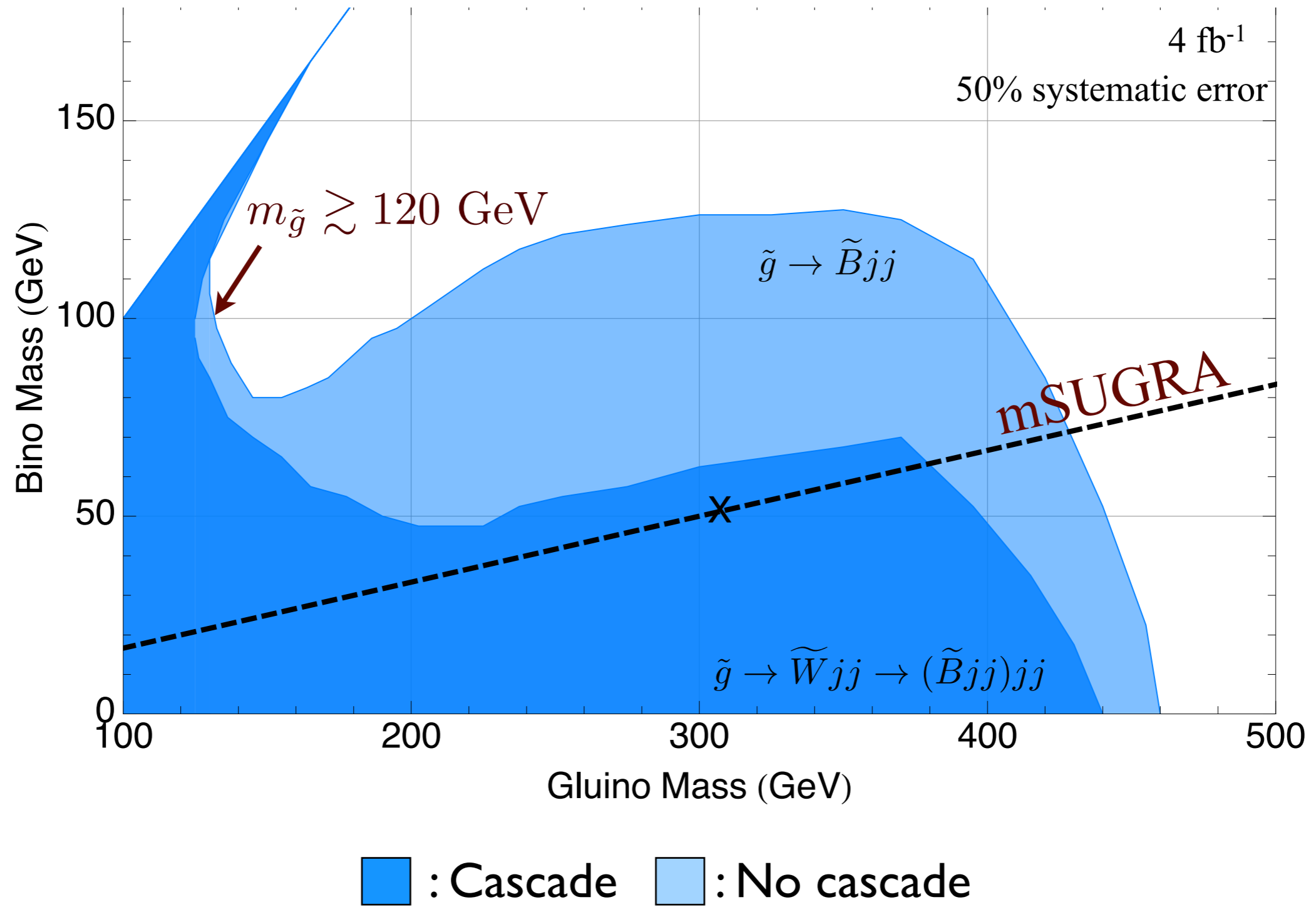


Exclusion Region*



* 95% exclusion limit

Exclusion Region*

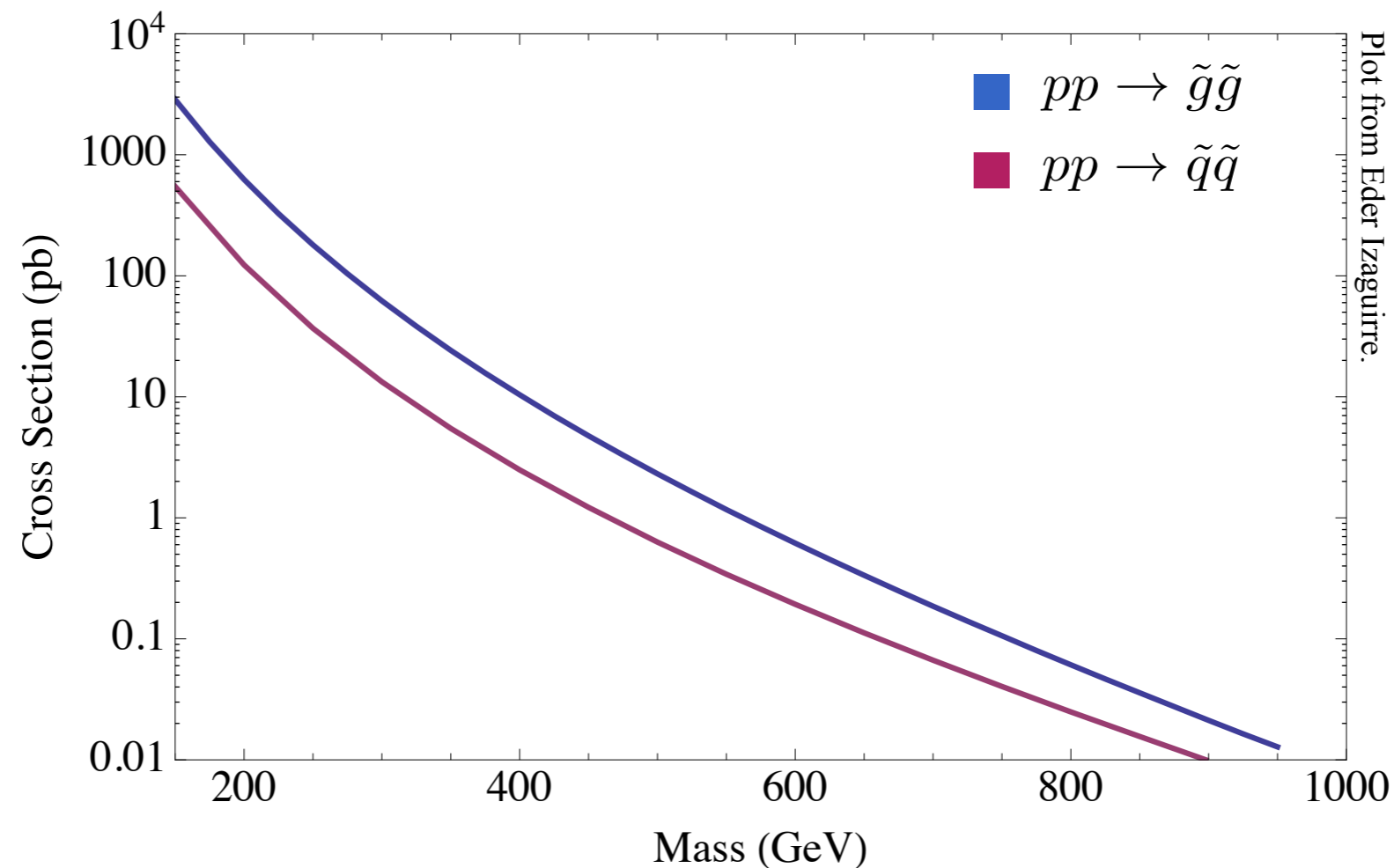


* 95% exclusion limit

Gluginos @ LHC

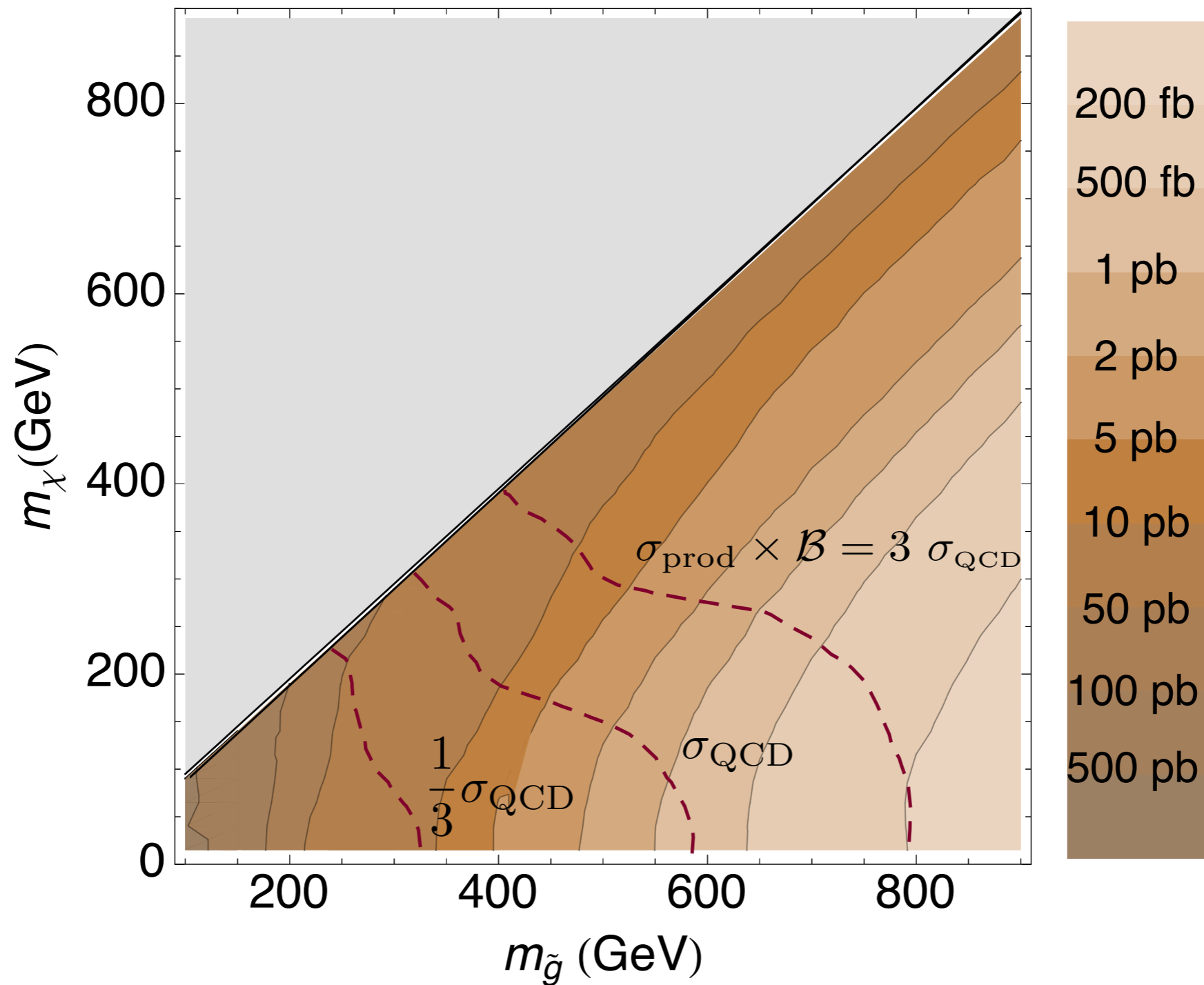
Prolific production of gluinos or squarks at low luminosity

With 50 pb^{-1} ,
thousands of 300 GeV gluinos or 200 GeV squarks
hundreds of 500 GeV gluinos or 400 GeV squarks



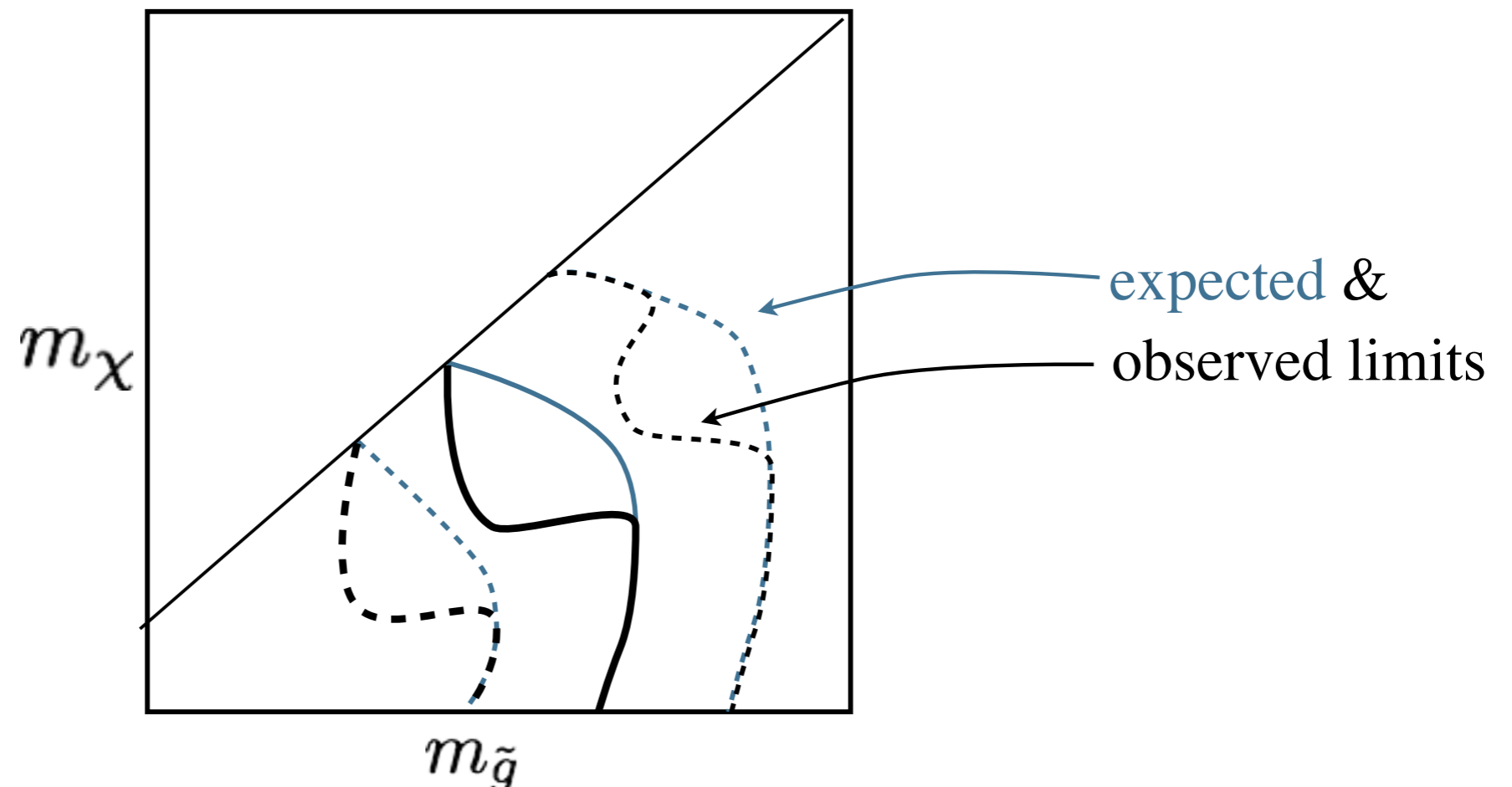
Gluginos @ LHC

gluino direct decay (50 pb^{-1})



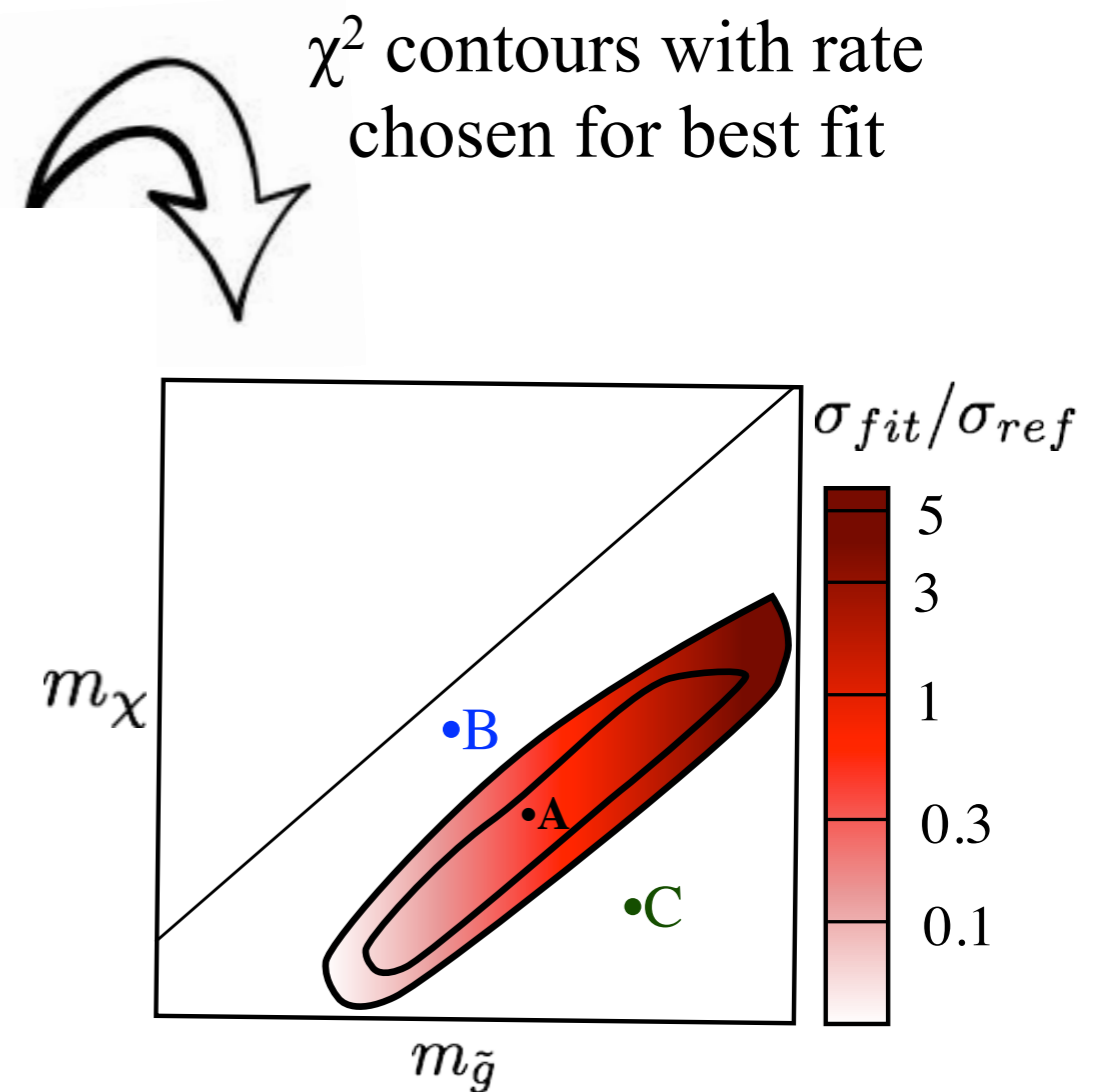
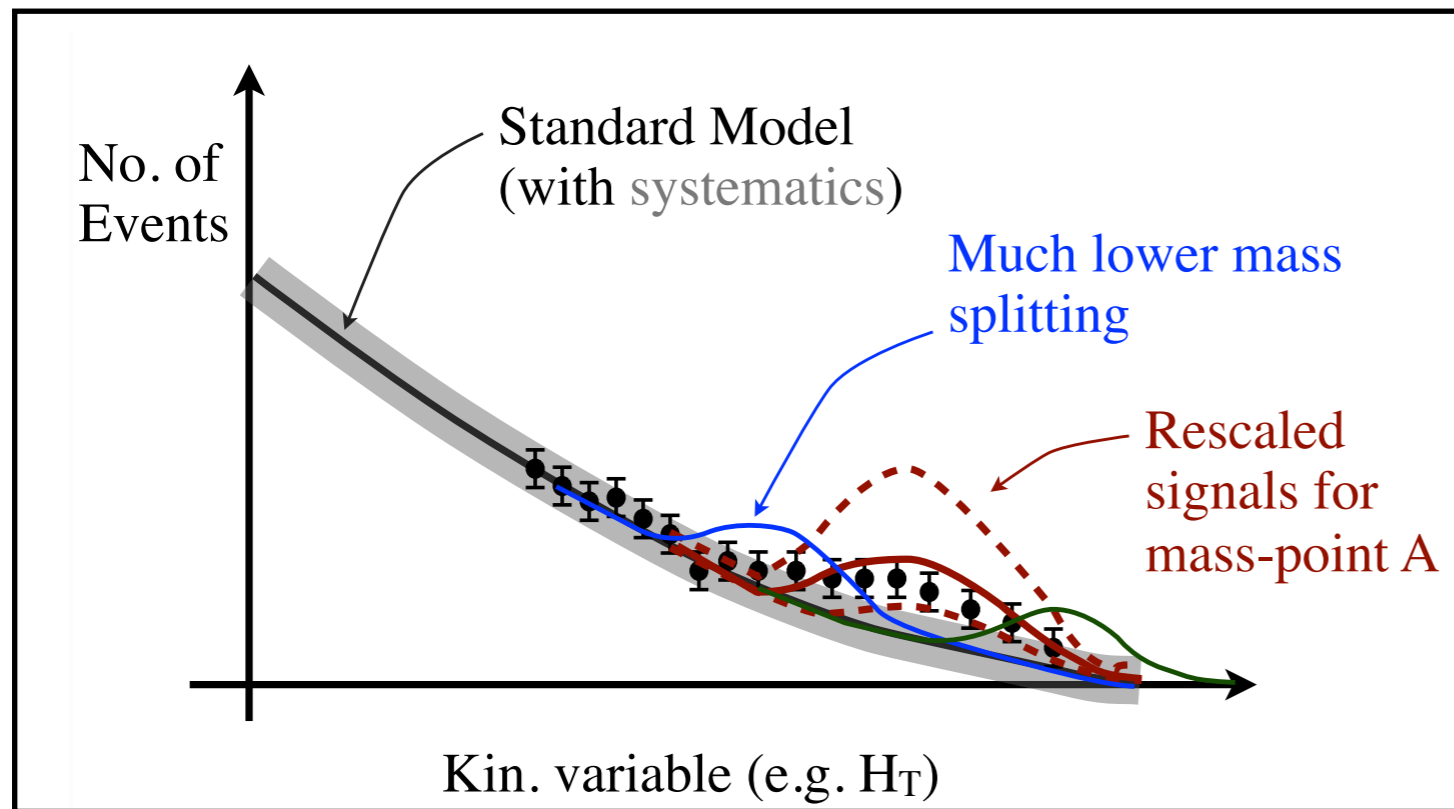
Discovery!

How are simplified models useful once there is a robust discovery claim?



Characterize Signal

What are most consistent values for physical parameters?
(i.e., masses and cross sections)

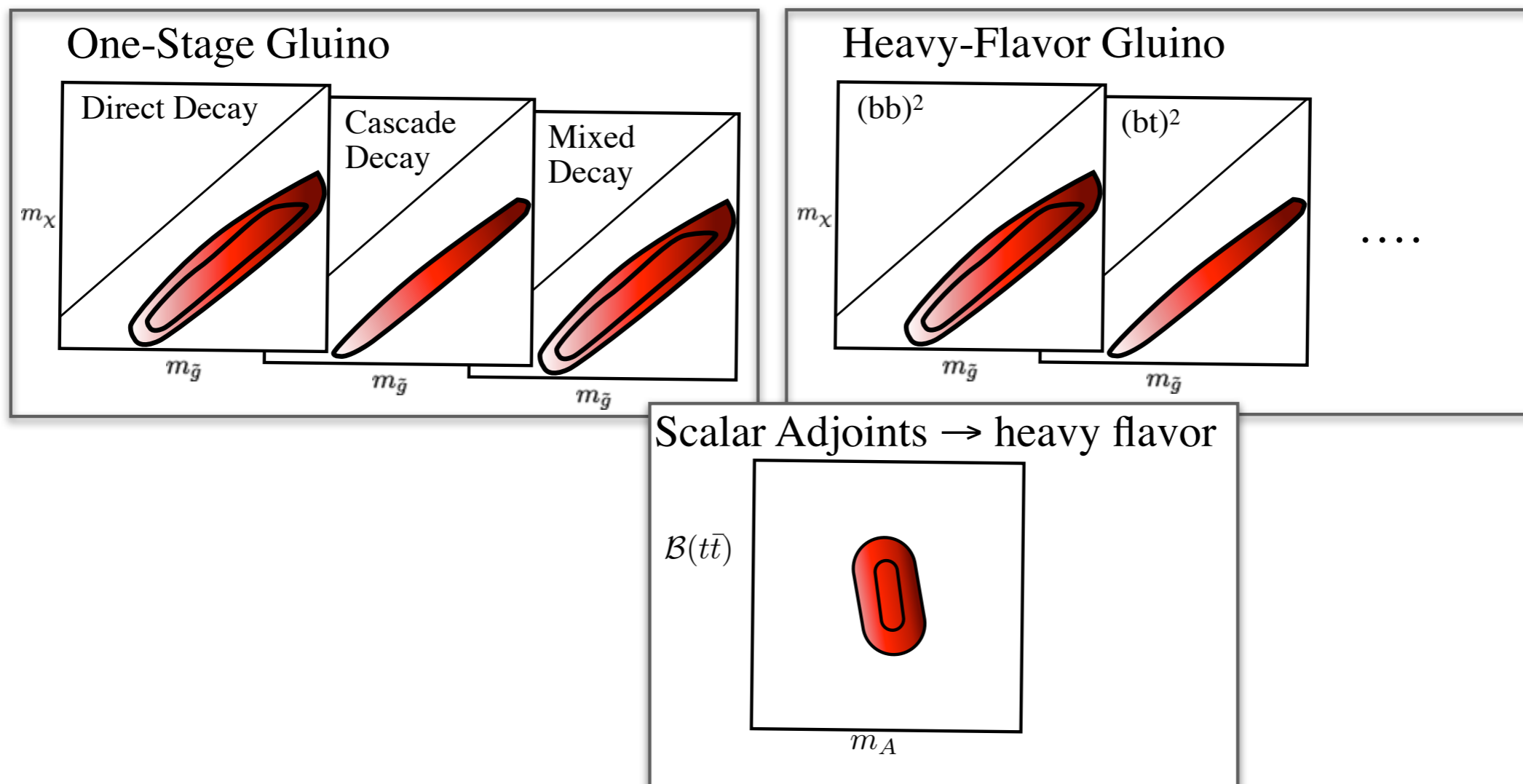


Figures from Natalia Toro

Multiple Searches

Similar plots for various simplified models with same final-state

Statistical comparison allows for model prioritization



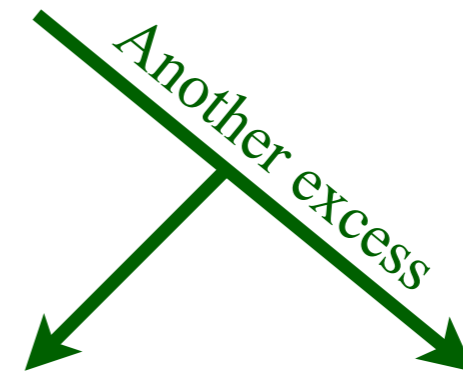
Multiple Searches

Example

Excess in jets+MET, plus **search in 1-lepton mode**



Constraint on what fraction of hadronic excess can contain W's



Consistent fits w/in same simplified model suggestive of unified interpretation

Also compatible with two distinct sources

Either way, further results get built into consistency requirements on new physics explanation for excesses

Outline

Simplified Models

Jets + MET Example

New Physics Working Group

Timeline

Characterization of New Physics at the LHC

Joint ATLAS/CMS/LPCC workshop in June @ CERN
<http://indico.cern.ch/conferenceDisplay.py?confId=94910>

Outcome:

Invitation to theorists for suggestions on how to include more theoretical possibilities in the planning of LHC searches

Workshop on Topologies for Early LHC Searches

Sept 24-26 @ SLAC
lhcnwphysics.org

Characterization of New Physics at the LHC-II

Nov 5-6 @ CERN
<http://indico.cern.ch/conferenceDisplay.py?confId=107769>

SLAC Topologies '10

Organizers: Rouven Essig, ML, Philip Schuster, Tim Tait, Natalia Toro, Jay Wacker

An opportunity for the theory community to propose a set of simplified models to guide the search and characterization of new physics at the LHC

Over 100 participants, international presence

Leptons

S. Chang
W. Cho
J. Evans
E. Izaguirre
J. Kaplan
M. Lisanti
M. Luty
M. Nojiri
T. Okui
M. Park
M. Perelstein
J. Ruderman
V. Sanz
P. Schuster
D. Shih
S. Su
T. Tait
B. Thomas
N. Toro
J. Wacker
F. Yu

Hadrons

D. Alves
J. Gainer
M. Gomez
E. Izaguirre
C. Kilic
M. Nojiri
D. Krohn
M. Schwartz
J. Shelton
M. Spannowsky
M. Strassler
J. Wacker

Resonances

Y. Bai
H. Cheng
J. Evans
A. Freitas
T. Han
J. Hewett
T. Liu
V. Rentala
S. Su
T. Tait

Photons

P. Fox
R. Kitano
T. Okui
D. Shih
T. Roy
J. Ruderman

Exotics

S. Chang
M. Baumgart
R. Essig
J. Hubisz
D. Krohn
P. Meade
D. Morrissey
M. Papucci
D. Phalen
J. Shao
T. Volansky
I. Yavin
K. Zurek

Heavy Flavor

M. Buckley
R.S. Chivukula
L. Fitzpatrick
R. Franceschini
P. Fox
J. Kaplan
P. Ko
E. Kuflik
R. Lu
S. Mrenna
M. Peskin
K. Rehermann
M. Schmaltz
M. Schwartz
E. Simmons
C. Spethmann
M. Strassler
T. Tait
N. Toro
W. Waltenberger

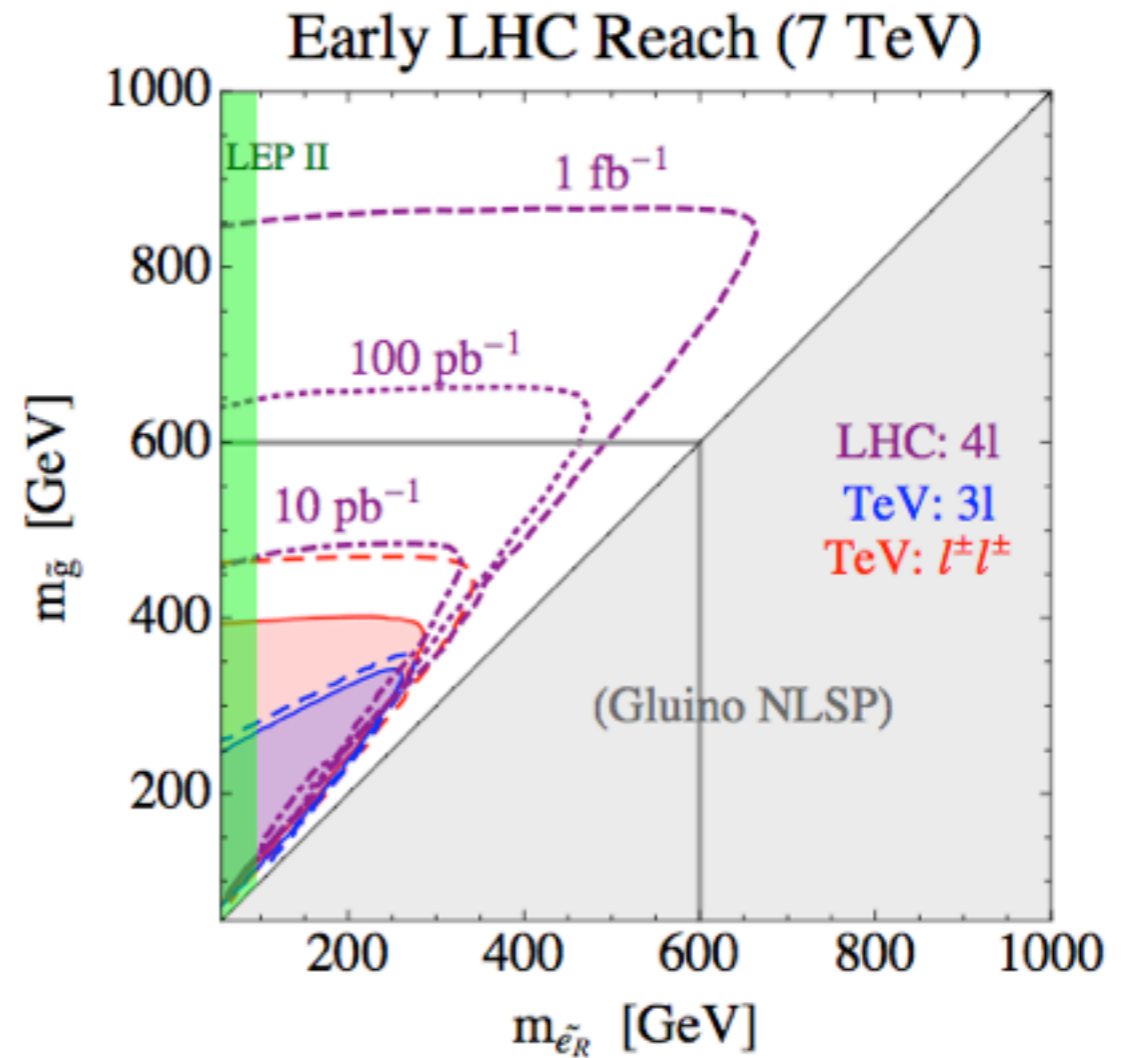
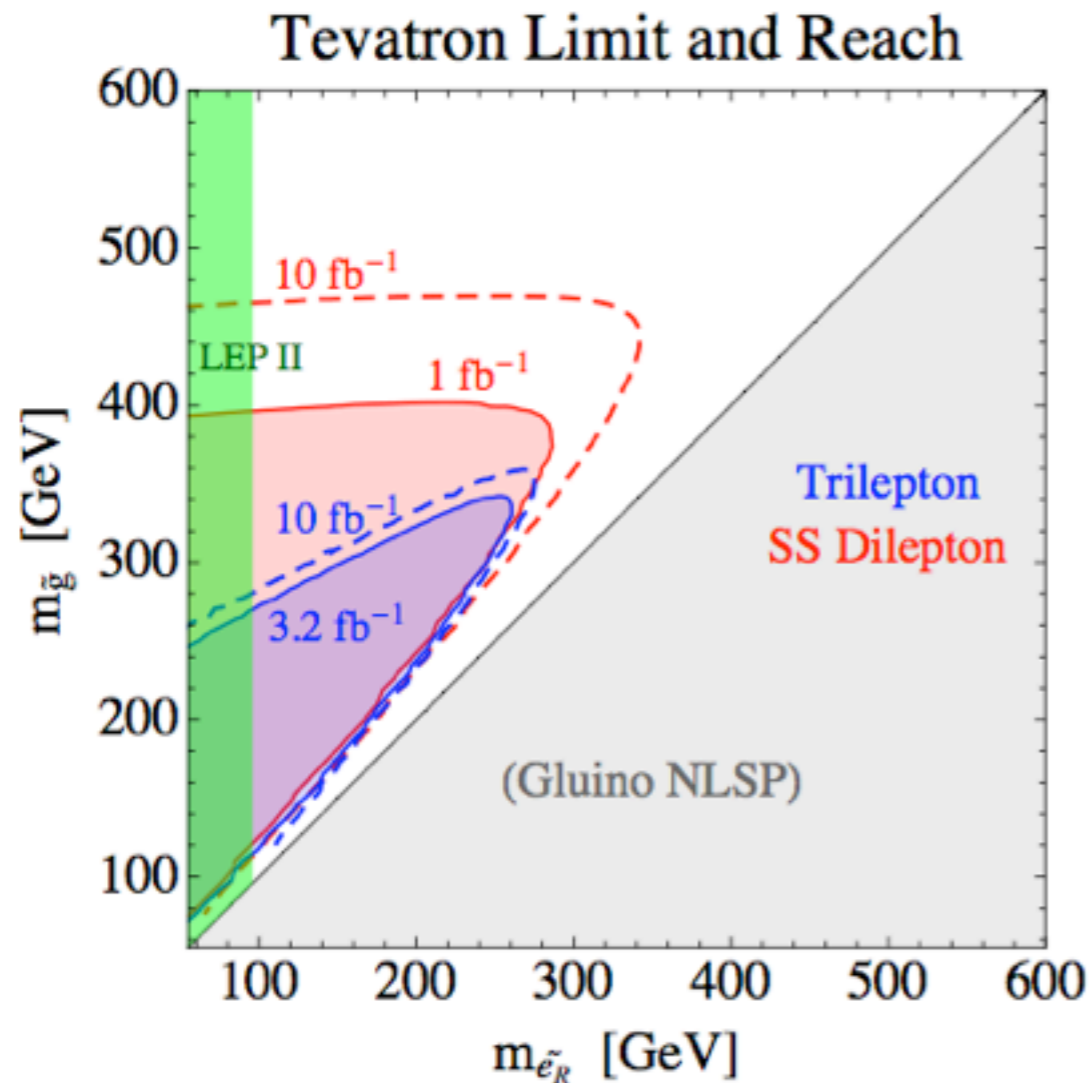
Example 1:

Multilepton GMSB

R. Gray, M. Park, J. Ruderman, D. Shih, S. Somalwar, S. Thomas, & Y. Zhao

Inspired by gauge mediation models with slepton NLSP

$$\begin{aligned} \tilde{g} &\rightarrow 2j + \tilde{B} \\ &\quad \searrow \\ &\quad l + \tilde{l} \\ &\quad \quad \searrow \\ &\quad \quad l + \tilde{G} \end{aligned}$$



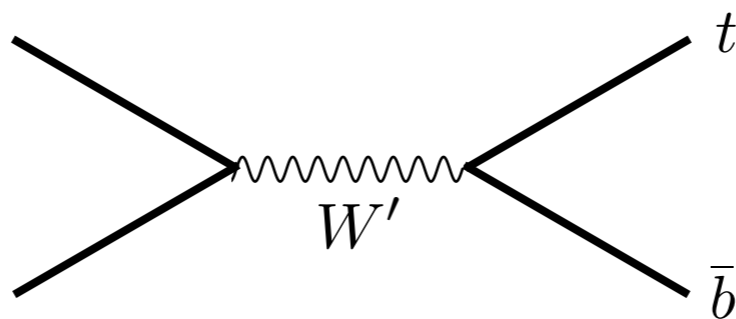
Example 2:

W' Resonance

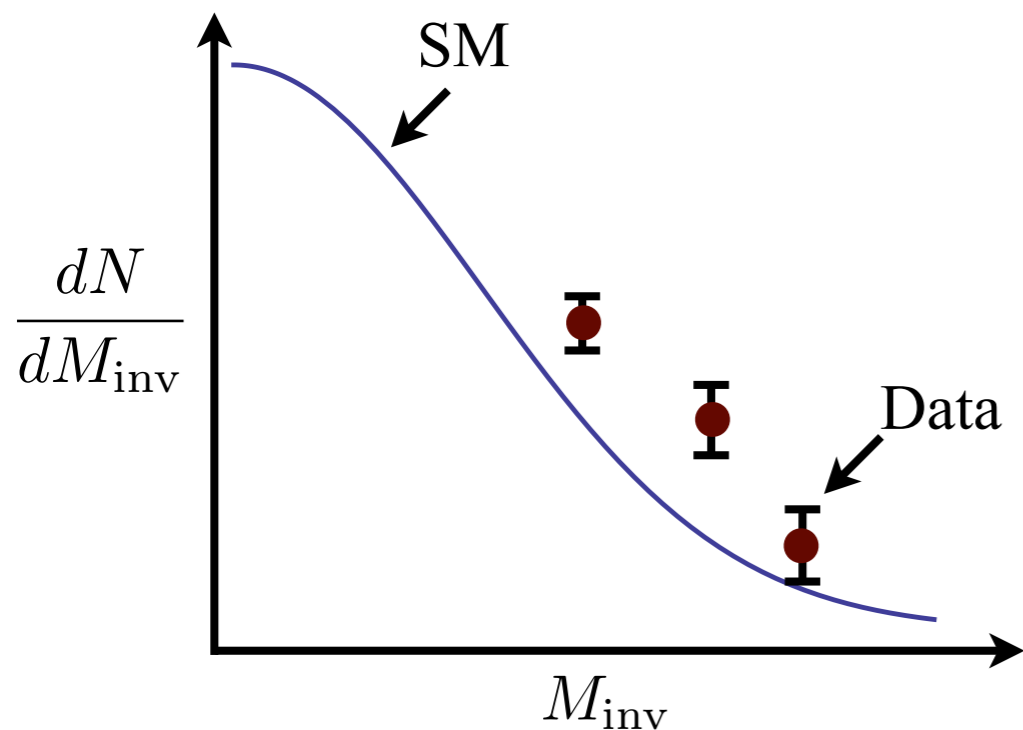
R. Chivukula, L. Fitzpatrick, P. Ko, K. Rehermann, M. Schmaltz,
M. Schwartz, E. Simmons, C. Spethmann, T. Tait, W. Waltenberger

Many SM extensions have new SU(2) groups that predict new charged vector boson

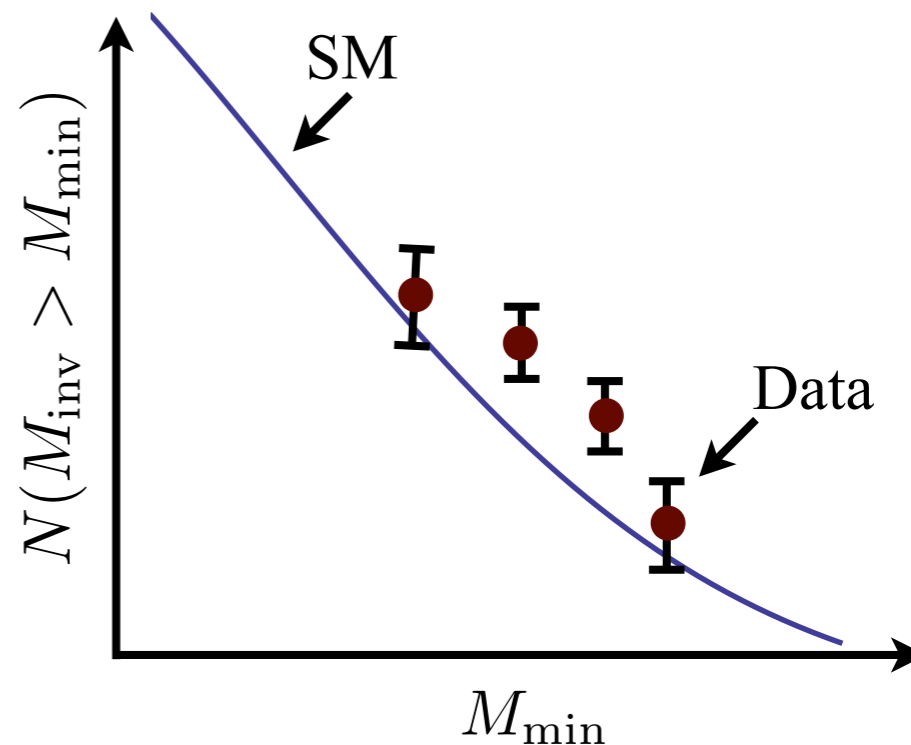
Decays to third-generation quarks are promising discovery channel



Invariant Mass Distribution



Events at High M_{inv}



Example 2:

W' Resonance

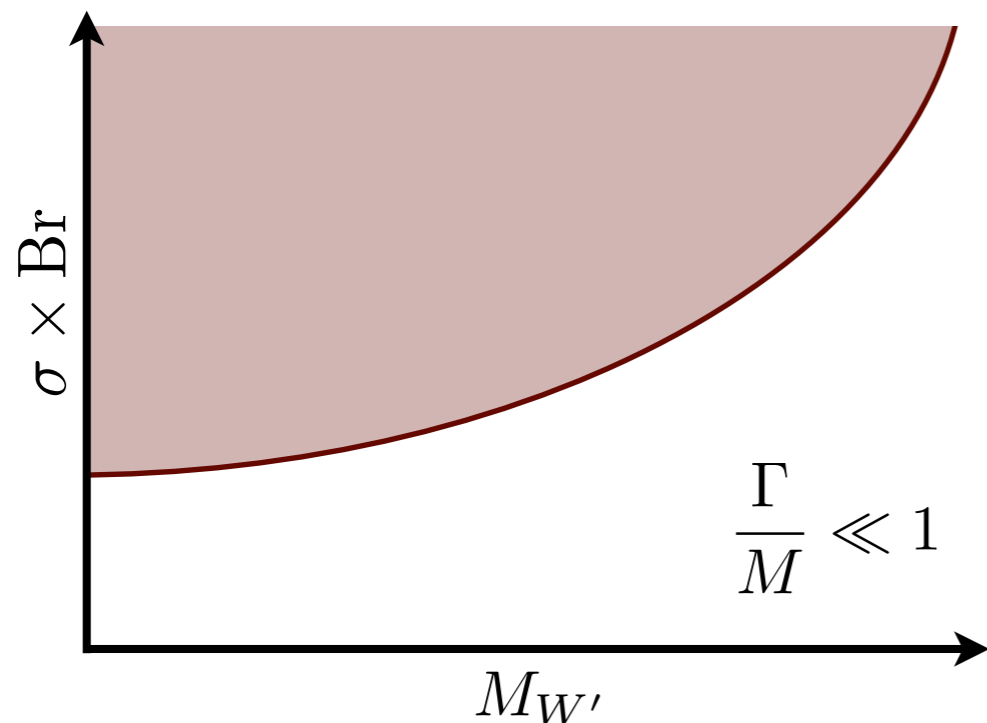
R. Chivukula, L. Fitzpatrick, P. Ko, K. Rehermann, M. Schmaltz,
M. Schwartz, E. Simmons, C. Spethmann, T. Tait, W. Waltenberger

Many theory models can give W' vector bosons

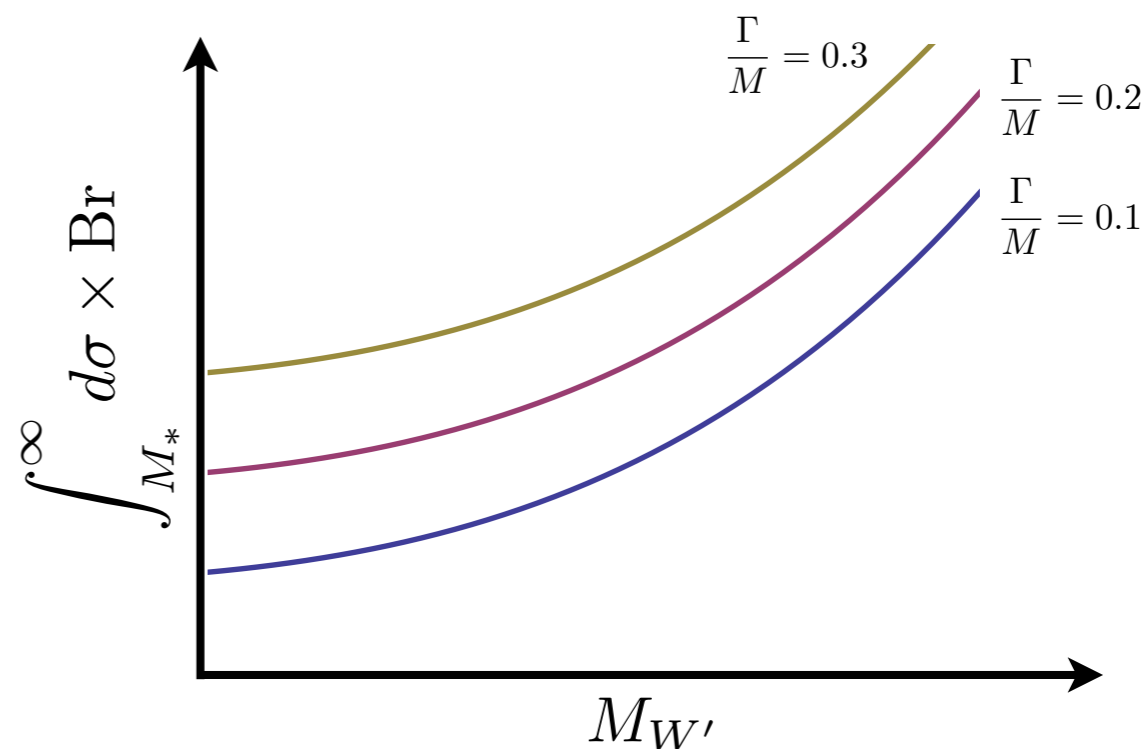
i.e., extra dimensions, left-right models, technicolor, ...

Significance/Exclusion plots should be model-independent

Narrow Resonance



Broad Resonance



Example 3:

$\gamma\gamma + X + \text{MET}$

Y. Gershstein, M. Park, J. Ruderman, D. Shih, S. Thomas, and Y. Zhao

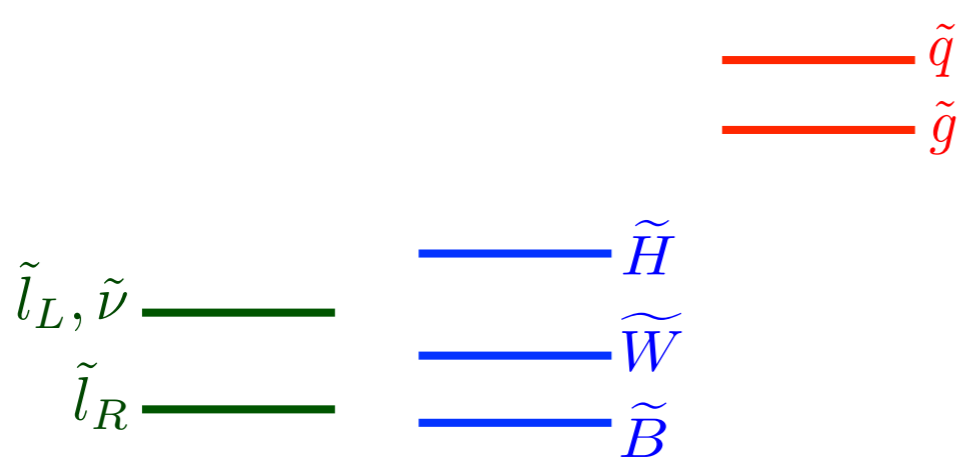
Inspired by gauge mediation models with Gravitino LSP

$$\tilde{B} \rightarrow \gamma + \tilde{G}$$

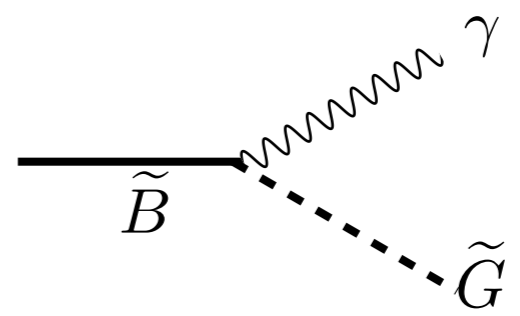
(Bino NLSP)

Minimal Gauge Mediation is most commonly used model

Sample MGM Mass Spectrum



Typically, heavy squarks and gluinos



Relies on electroweakino production
MGM overly pessimistic for early search

Example 3:

$\gamma\gamma + X + \text{MET}$

Y. Gershstein, M. Park, J. Ruderman, D. Shih, S. Thomas, and Y. Zhao

Inspired by gauge mediation models with Gravitino LSP

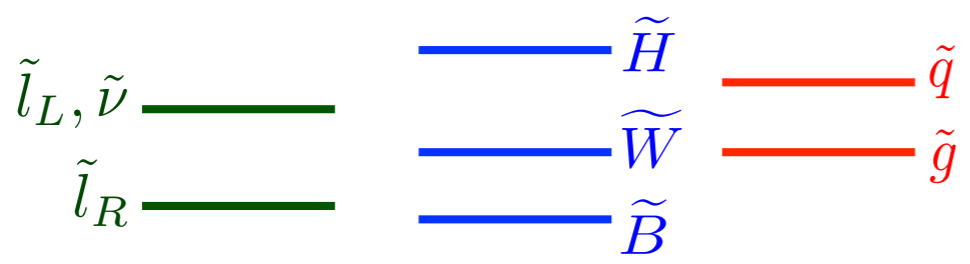
$$\tilde{B} \rightarrow \gamma + \tilde{G}$$

(Bino NLSP)

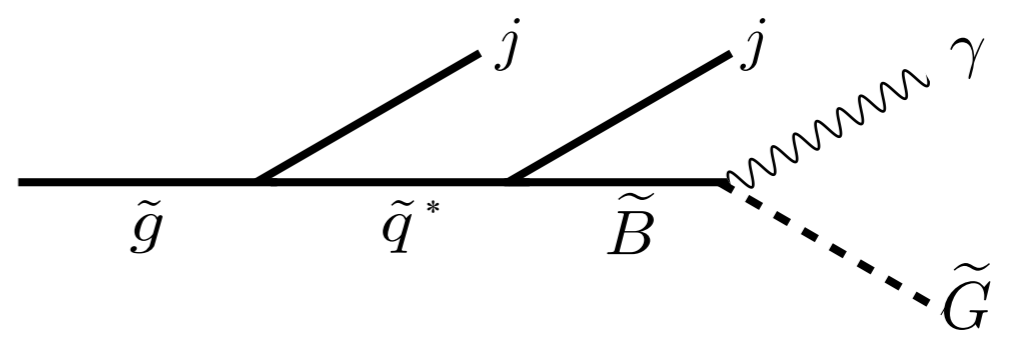
Simplified model with light colored states and bino NLSP

Motivated by General Gauge Mediation

More compressed spectrum



Enhancement from colored production



Example 4:

High Multiplicity

M. Baumgart, J. Hubisz, K. Zurek

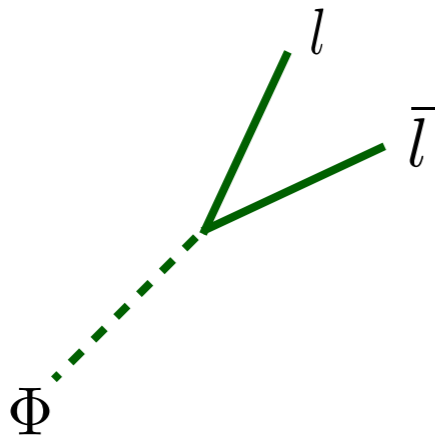
Effective Theory Description

$$\mathcal{L}_{\text{production}} = q\bar{q}(gg)\Phi^n \quad \mathcal{L}_{\text{decay}} = \Phi(\text{SM})^m Y^n$$

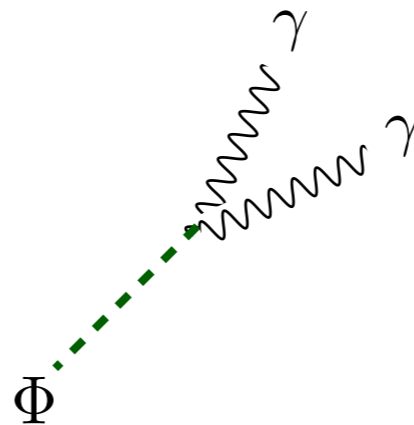
Very broad class of models lead to high multiplicity of events

TeV scale black holes, Hidden valley models, Quirks, Conformal hidden sectors, ...

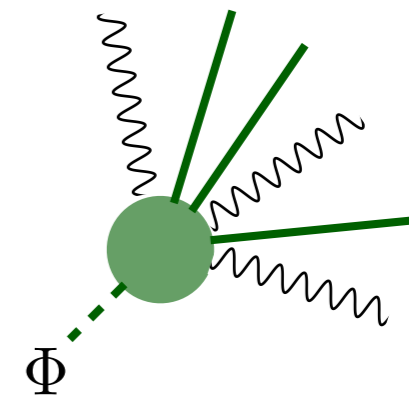
Di-lepton resonance + X



Di-photon resonance + X

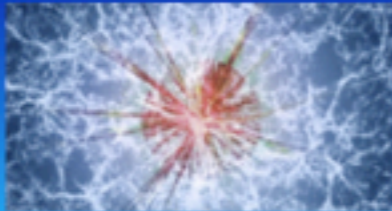


High H_T



High H_T trigger, modified lepton isolation requirements

LHCNewPhysics.org



Overview Links & References Support & Contacts Wiki Page

Signatures of New Physics at the LHC

Exotica Taus Bottoms Photons Leptons Jets

username

- [Create New Submission](#)
- [My account](#)
- [Registered Users](#)
- [Recent Posts](#)
- [Messages](#)
- [Log out](#)

Recently Viewed

- [P.000](#)
General Neutralino NLSP
- [J.003](#)
Multijet Resonances ($2 \rightarrow 2$ production only, no MET)
- [L.003](#)
Simplified Model for 2SSL and $1\text{-}4$ lepton states, with and w/o MET
- [L.001](#)
SSL: A Simplified Model for Same-Sign Dilepton + MET + X Search
- [L.000](#)
 4 leptons +MET or 6 -lepton final states from R-parity violation

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.

At the meeting [Topologies for Early LHC Searches](#), the participants (theorists largely) began defining a set of baseline topology sets, or simplified models. These simplified models are designed to cover signature space and include detail important for optimizing searches. Particular attention was paid to including topologies inspired from a broad array of well-motivated theories.

LHCNewPhysics.org

Overview Links & References Support & Contacts Wiki Page

Signatures of New Physics at the LHC

Exotica Taus Bottoms Photons Leptons Jets

Jets Signatures

Jet Signatures are those where the only handle on the signature are unflavored jets and there are no other more spectacular object available. An example of simplified models falling under a Jet Signature is a gluino that decays directly to the LSP and two unflavored jets.

- J.000: Composite Gluon To Invisible**
Author: Jay Wacker
Latest Revision: 000
- J.001: Multi-jets plus MET from an initial resonance**
Author: Julia Shelton
Latest Revision: 002
- J.003: Multijet Resonances ($2 \rightarrow 2$ production only, no MET)**
Author: Can Kilic
Latest Revision: 000
- J.004: Multijet Resonances Including $2 \rightarrow 1$ Production (no MET)**
Author: Can Kilic
Latest Revision: 000
- J.005: Squark Neutralino Associated Production**
Author: Jay Wacker
Latest Revision: 000
- J.006: Two Jets, Leptons and MET**
Author: Eder Izaguirre
Latest Revision: 000
- J.007: Three (or more) Jets, Leptons and MET**
Author: Eder Izaguirre
Latest Revision: 000

username

- Create New Submission
- My account
- Registered Users
- Recent Posts
- Messages
- Log out

Recently Viewed

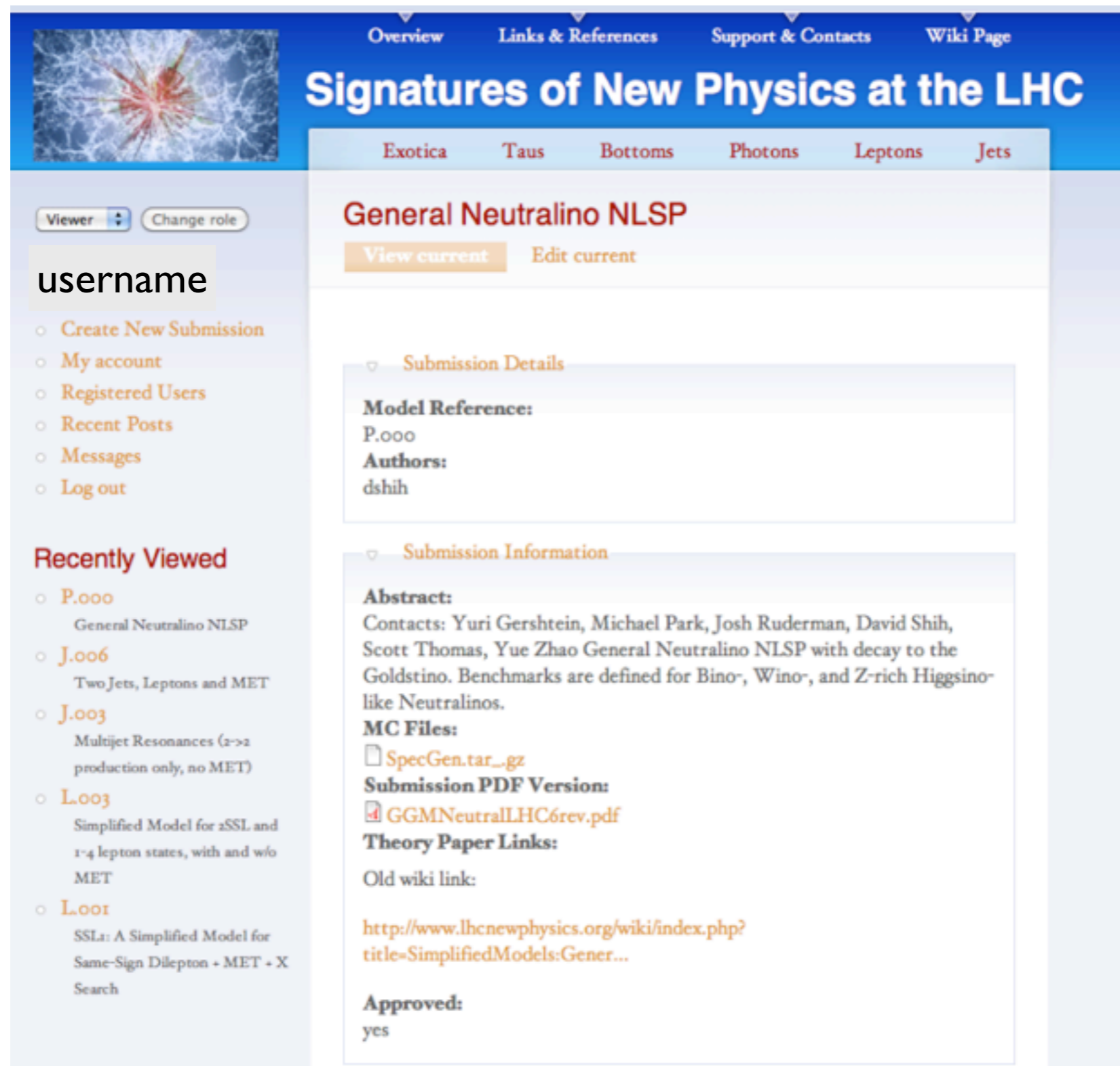
- P.000**
General Neutralino NLSP
- J.003**
Multijet Resonances ($2 \rightarrow 2$ production only, no MET)
- L.003**
Simplified Model for 2SSL and $1-4$ lepton states, with and w/o MET
- L.001**
SSL $_2$: A Simplified Model for Same-Sign Dilepton + MET + X Search
- L.000**
4 leptons +MET or 6-lepton final states from R-parity violation

← Organized by signature
Search for keywords

← Brief write-ups
Download MC files, talks, etc
Easy to update

Work in progress
Feedback welcome

LHCNewPhysics.org



The screenshot displays the LHCNewPhysics.org website interface. At the top, there is a navigation bar with links for Overview, Links & References, Support & Contacts, and Wiki Page. Below this is a blue header with the title 'Signatures of New Physics at the LHC' and a sub-navigation bar with categories: Exotica, Taus, Bottoms, Photons, Leptons, and Jets. The main content area shows a submission titled 'General Neutralino NLSP' with buttons for 'View current' and 'Edit current'. The submission details include a model reference 'P.000' and author 'dshih'. The submission information section contains an abstract, MC files (SpecGen.tar.gz), a submission PDF version (GGMNeutralLHC6rev.pdf), theory paper links, and an approved status of 'yes'. On the left side, there is a sidebar with user controls (Viewer, Change role), a username field, and a list of recently viewed submissions including 'P.000', 'J.006', 'J.003', 'L.003', and 'L.001'.

Overview Links & References Support & Contacts Wiki Page

Signatures of New Physics at the LHC

Exotica Taus Bottoms Photons Leptons Jets

General Neutralino NLSP

View current Edit current

Viewer [dropdown] Change role

username

- Create New Submission
- My account
- Registered Users
- Recent Posts
- Messages
- Log out

Recently Viewed

- P.000
General Neutralino NLSP
- J.006
Two Jets, Leptons and MET
- J.003
Multijet Resonances ($2 \rightarrow 2$ production only, no MET)
- L.003
Simplified Model for 2SSL and $1-4$ lepton states, with and w/o MET
- L.001
SSL1: A Simplified Model for Same-Sign Dilepton + MET + X Search

Submission Details

Model Reference:
P.000

Authors:
dshih

Submission Information

Abstract:
Contacts: Yuri Gershtein, Michael Park, Josh Ruderman, David Shih, Scott Thomas, Yue Zhao General Neutralino NLSP with decay to the Goldstino. Benchmarks are defined for Bino $\tilde{\nu}$, Wino $\tilde{\nu}$, and Z-rich Higgsino-like Neutralinos.

MC Files:
[SpecGen.tar.gz](#)

Submission PDF Version:
[GGMNeutralLHC6rev.pdf](#)

Theory Paper Links:
Old wiki link:
<http://www.lhcnewphysics.org/wiki/index.php?title=SimplifiedModels:Gener...>

Approved:
yes

Conclusions

Simplified Models are a convenient way of parameterizing new physics

O(50) simplified models have been proposed

Check **lhcnwphysics.org**

Many simplified models can be used in 20-50 pb⁻¹ searches

Widely applicable presentation of null results

Useful first step in characterizing a new physics signal

Jets + MET signatures are promising with LHC data of next year

sensitive to large range of phase space

Glauino Heavy Flavor

E. Izaguirre, J. Kaplan, R. Essig, & J. Wacker

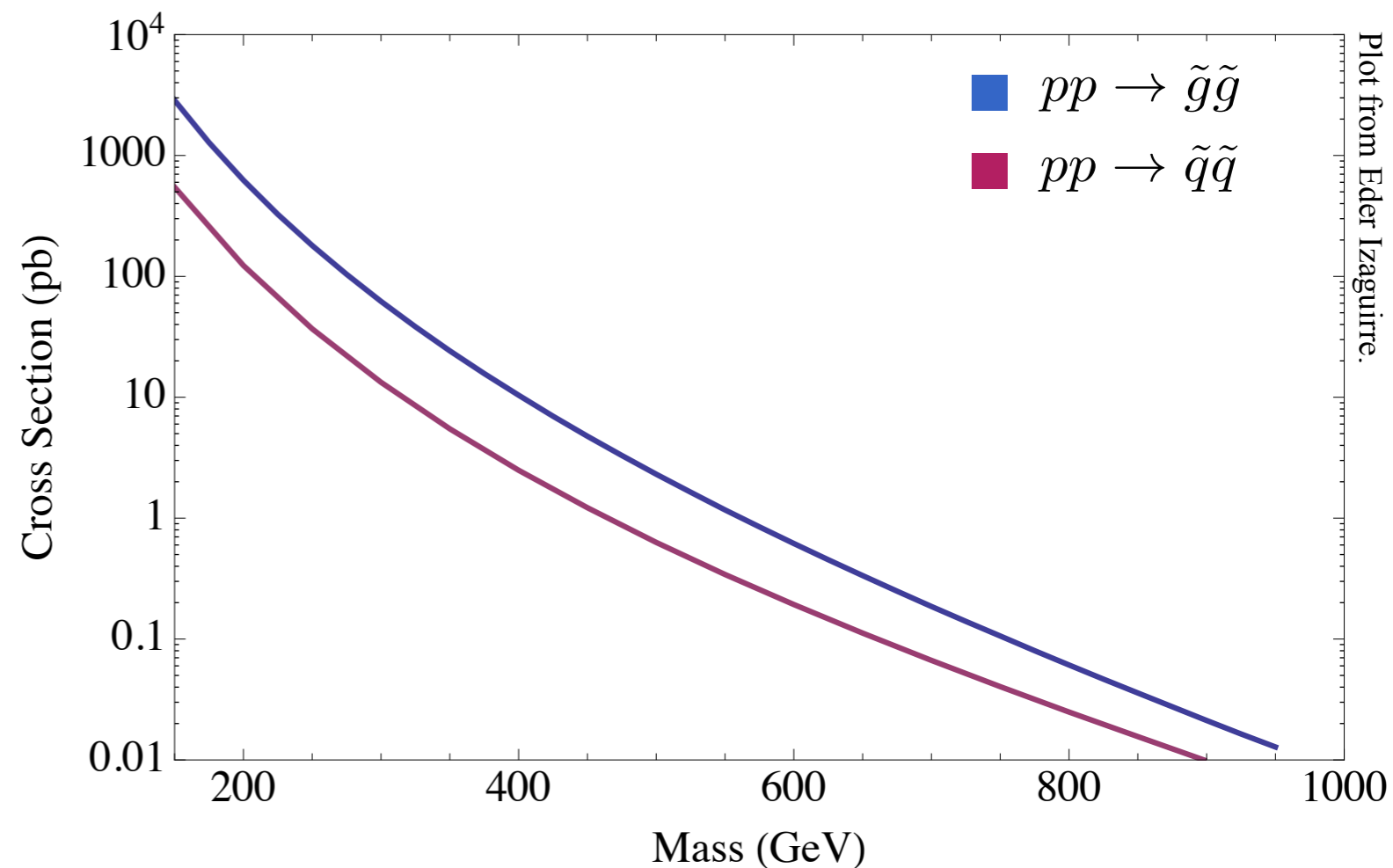
Probe heavy flavor physics through gluino decays

Decays to top pairs challenging with early data

Decays to bottom quarks are promising

$$G \rightarrow b\bar{b}N_1^0$$

$$G \rightarrow tbC_1^\pm$$



Event Generation

Generate signal and background events

MadGraph \rightarrow Pythia \rightarrow PGS

Background events compared with DØ

$Z^0(\rightarrow \nu\nu) + nj$ w/in QCD K factors

$W^\pm(\rightarrow l^\pm\nu) + nj$ \sim 30% scaling

$t\bar{t}$ \sim 20% scaling

QCD not simulated

Event Generation

Generate signal and background events

MadGraph → Pythia → PGS

Matching procedure necessary to account for ISR

Background events compared with DØ

$Z^0(\rightarrow \nu\nu) + nj$ w/in QCD K factors

$W^\pm(\rightarrow l^\pm\nu) + nj$ ~ 30% scaling

$t\bar{t}$ ~ 20% scaling

QCD not simulated

Matching

Parton Showering

QCD Bremsstrahlung
Soft/Collinear Approximation
Resums large logs
Computationally Cheap
Unlimited number of partons

Matrix Elements

Necessary for well-separated jets
Includes quantum interference
Fixed-order calculation
Computationally expensive
Limited number of partons

Matching

Parton Showering

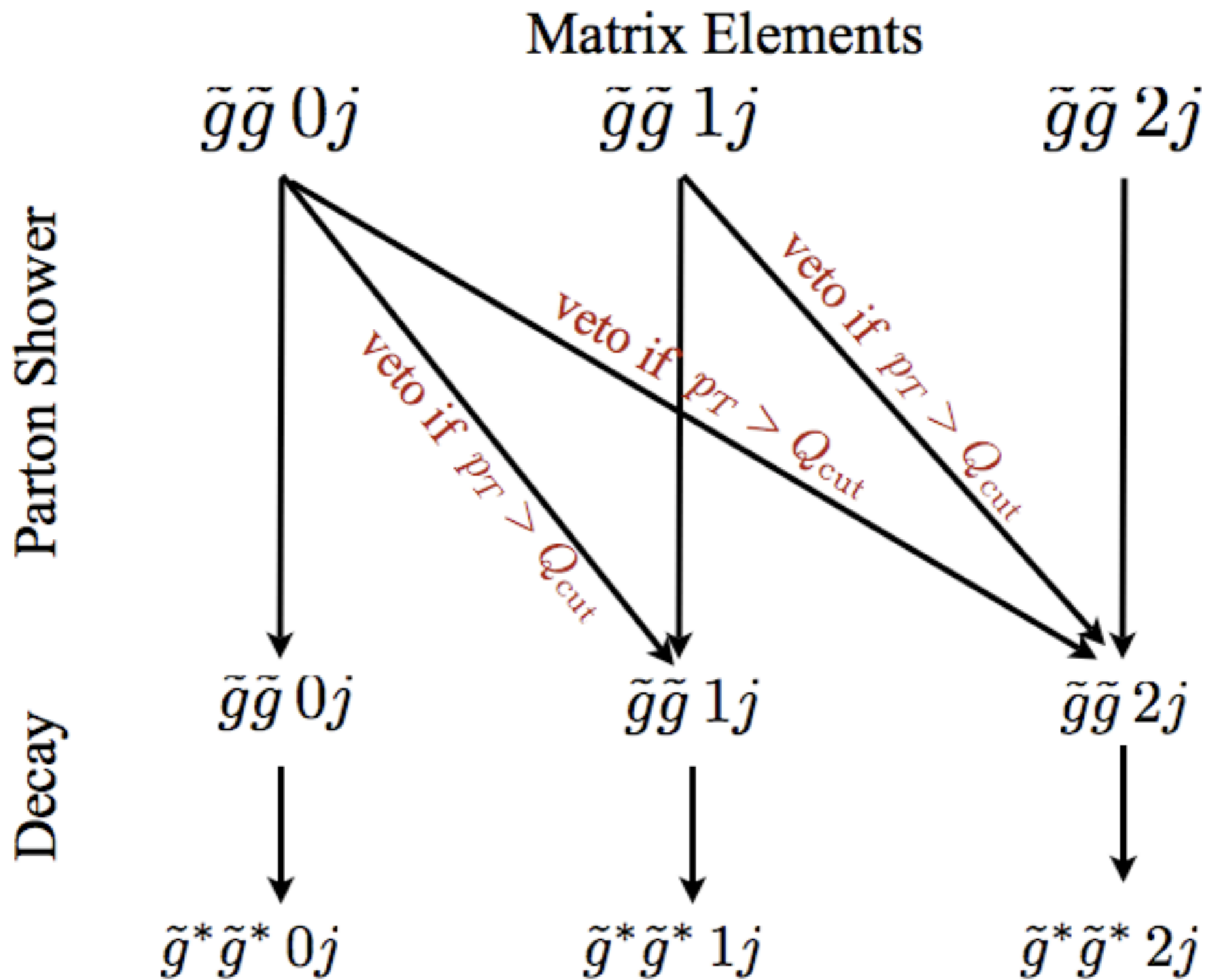
QCD Bremsstrahlung
Soft/Collinear Approximation
Resums large logs
Computationally Cheap
Unlimited number of partons

Matrix Elements

Necessary for well-separated jets
Includes quantum interference
Fixed-order calculation
Computationally expensive
Limited number of partons

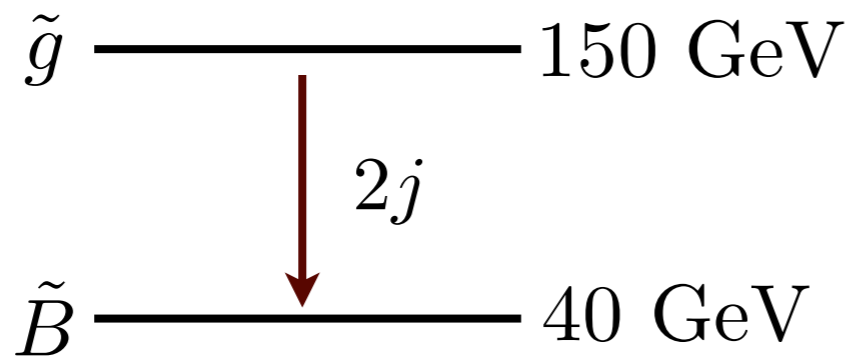
Matching combines both techniques
Necessary to avoid double-counting of events

Matching Procedure



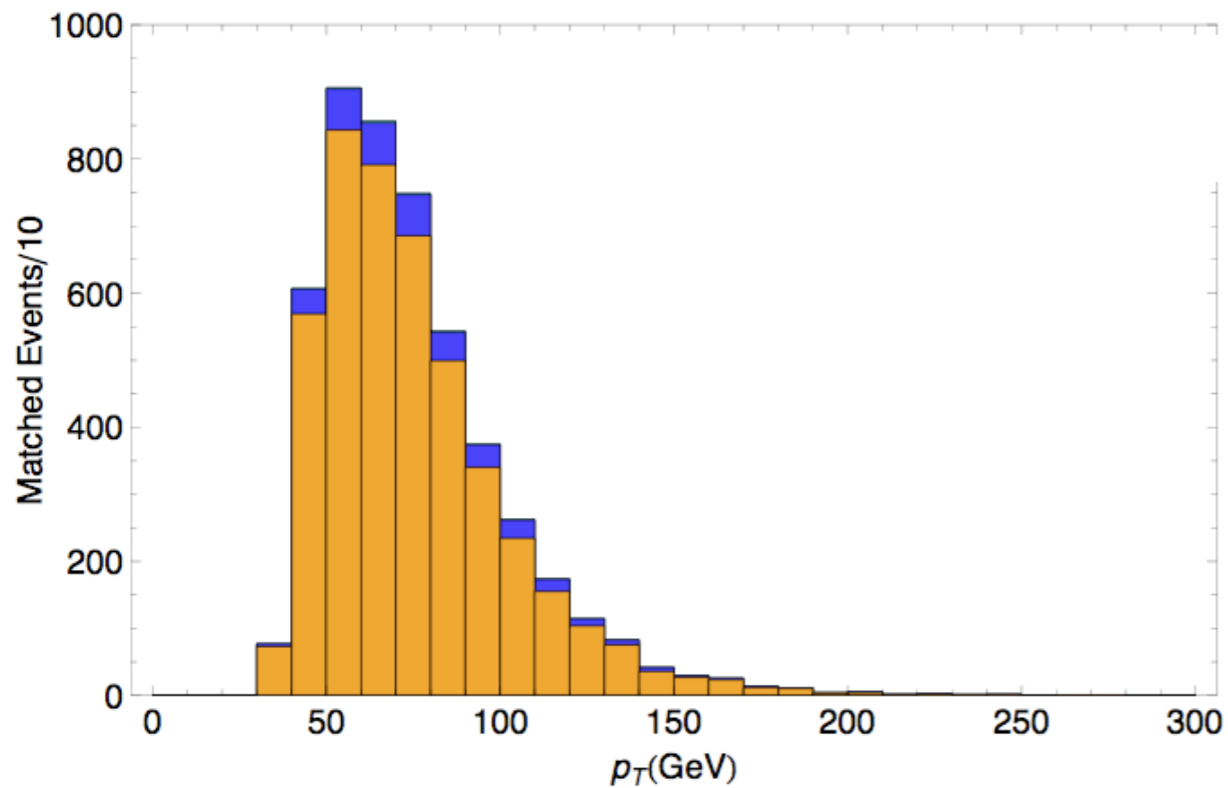
Effects of Matching

Large mass difference between gluino & bino

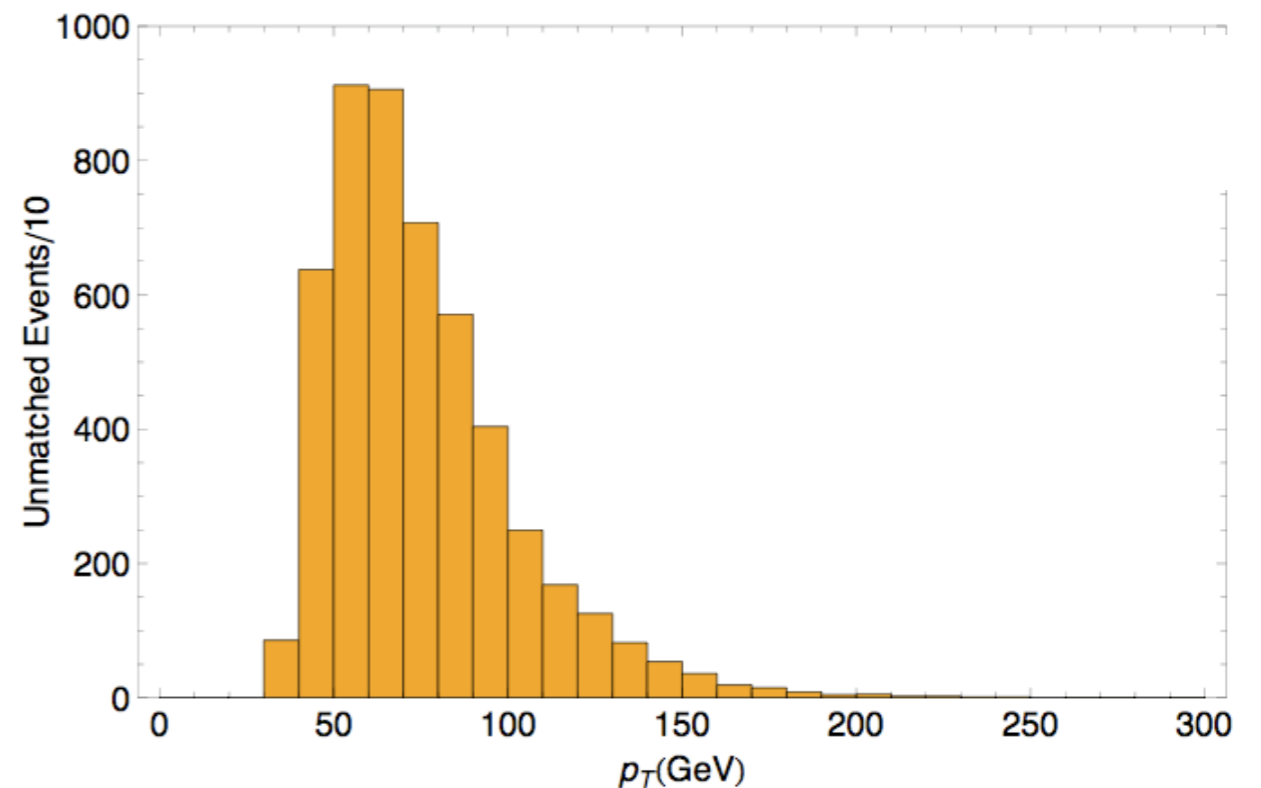


- : $\tilde{g}\tilde{g} + 0j$
- : $\tilde{g}\tilde{g} + 1j$
- : $\tilde{g}\tilde{g} + 2j$

Matched

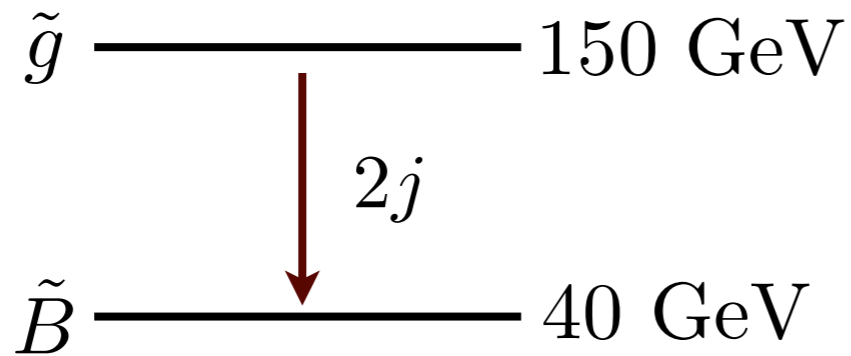


Unmatched



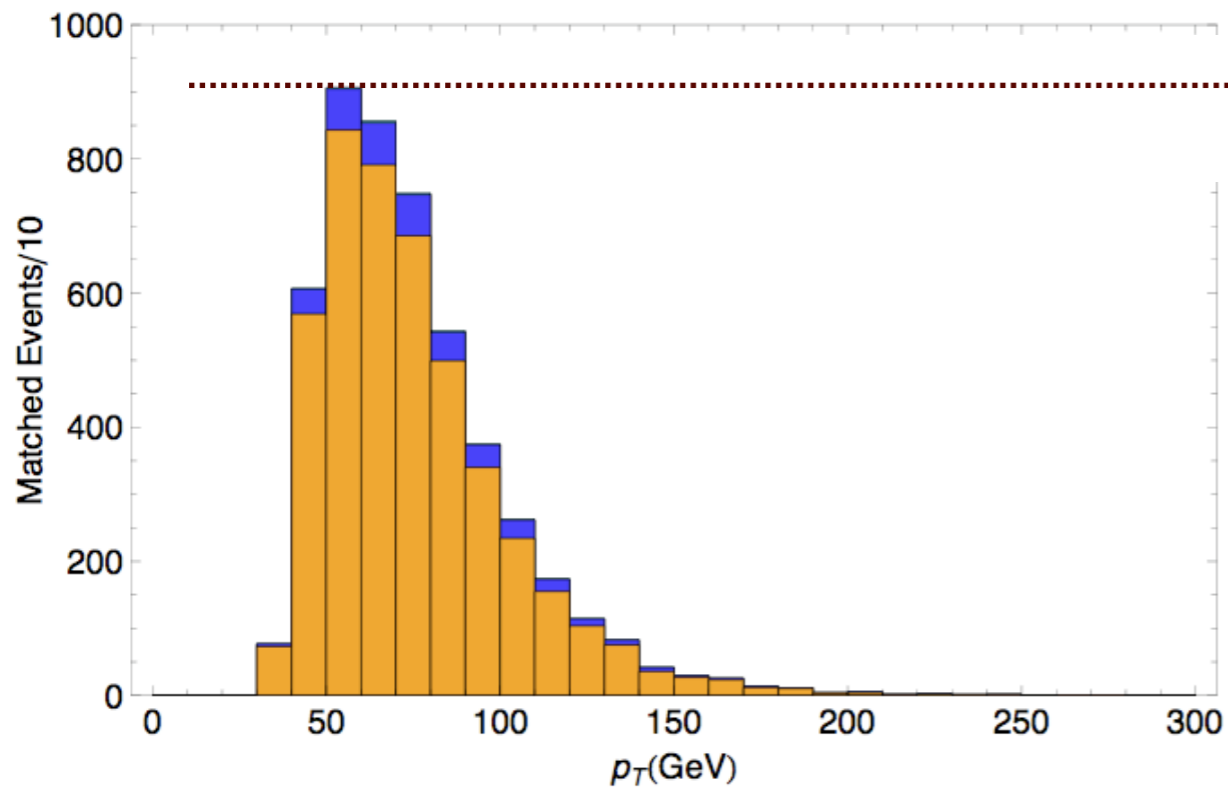
Effects of Matching

Large mass difference between gluino & bino

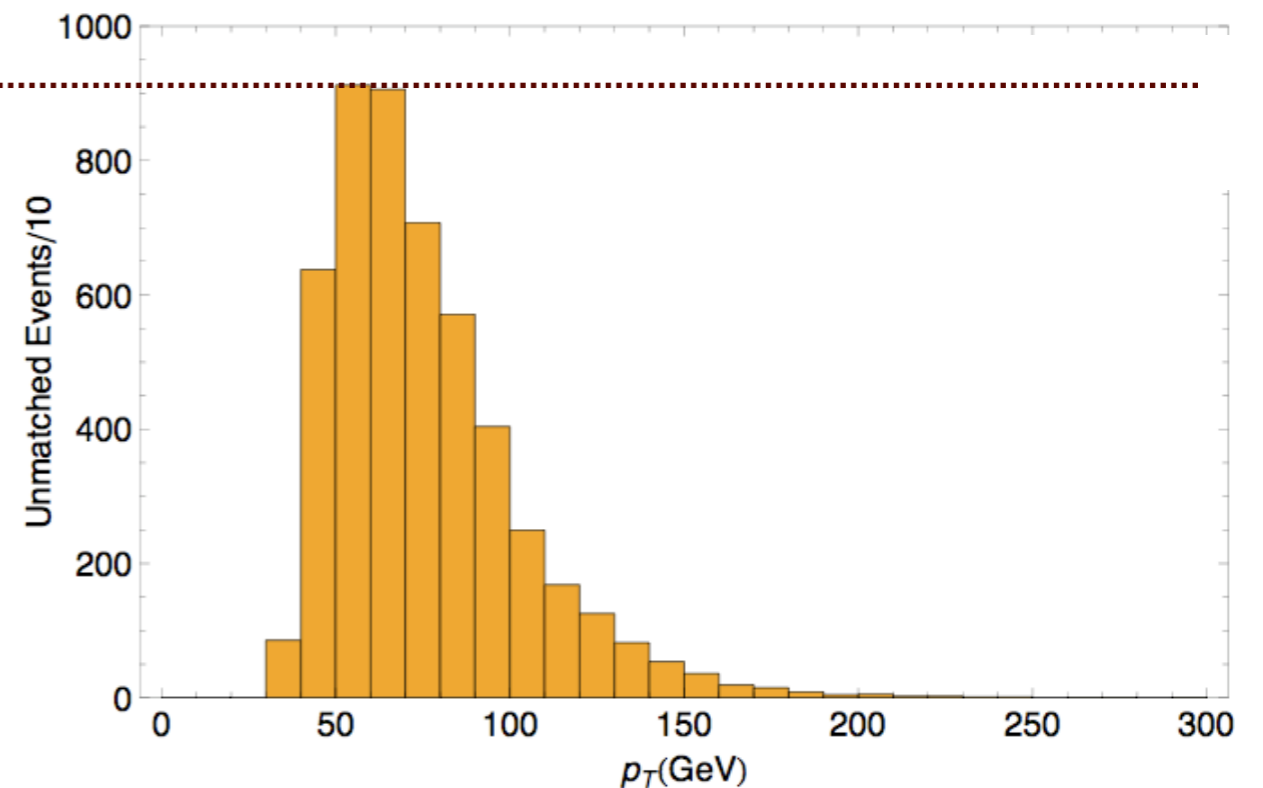


- : $\tilde{g}\tilde{g} + 0j$
- : $\tilde{g}\tilde{g} + 1j$
- : $\tilde{g}\tilde{g} + 2j$

Matched

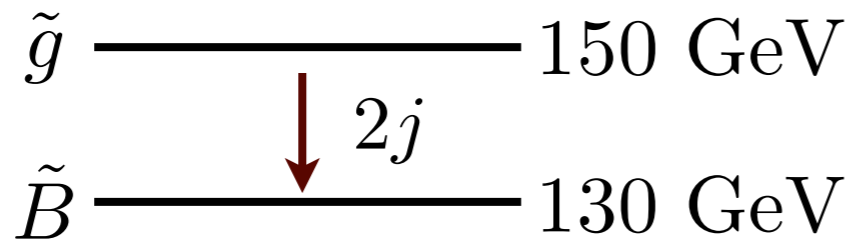


Unmatched



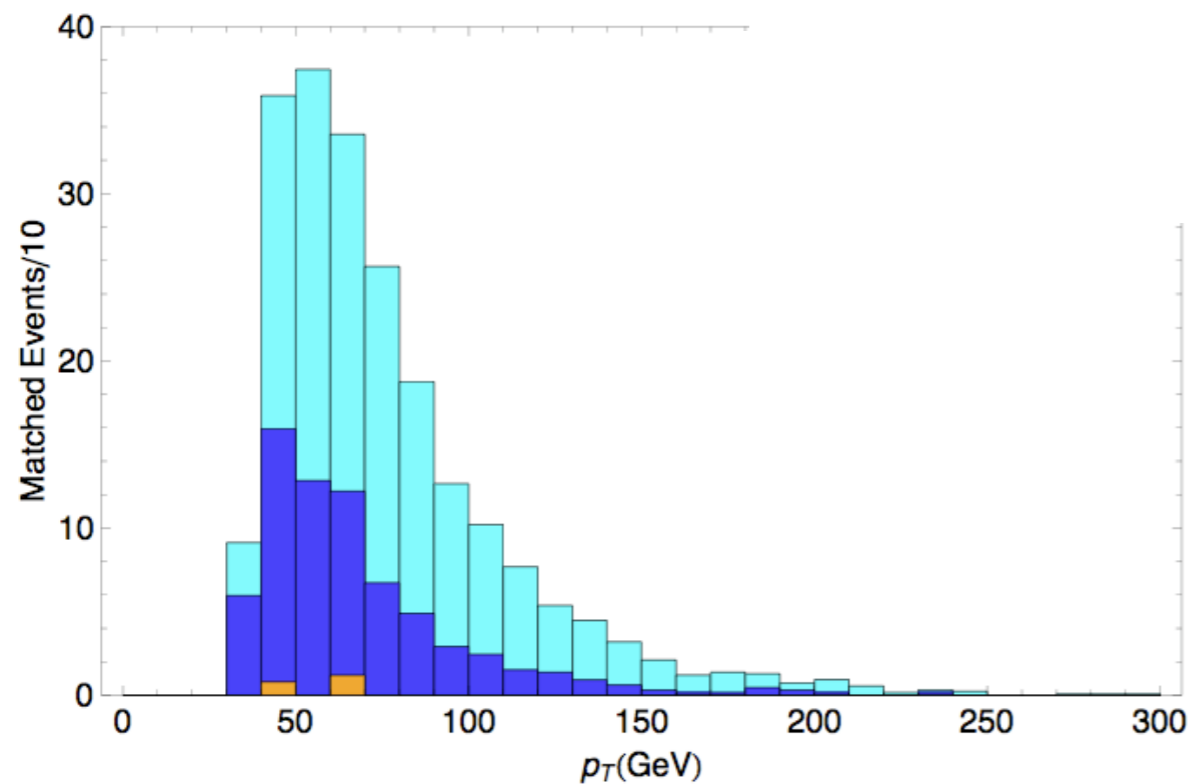
Effects of Matching

Nearly-degenerate gluino and bino

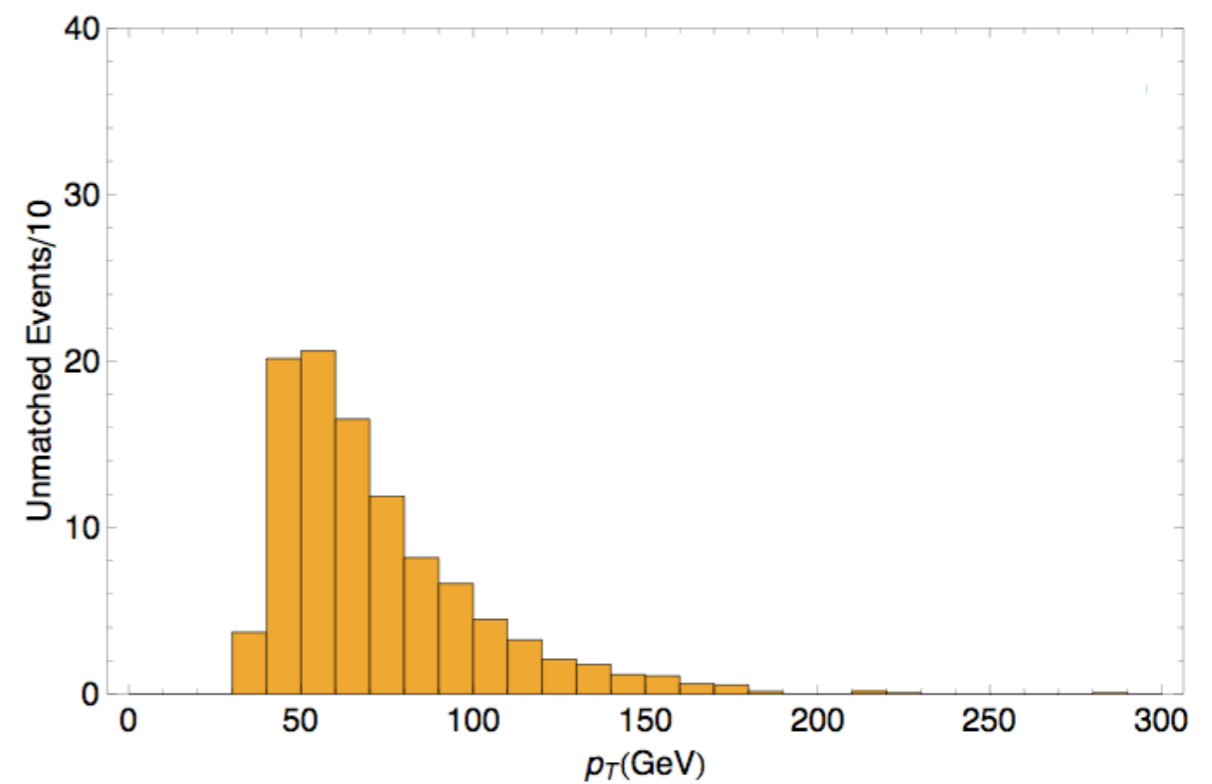


- : $\tilde{g}\tilde{g} + 0j$
- : $\tilde{g}\tilde{g} + 1j$
- : $\tilde{g}\tilde{g} + 2j$

Matched

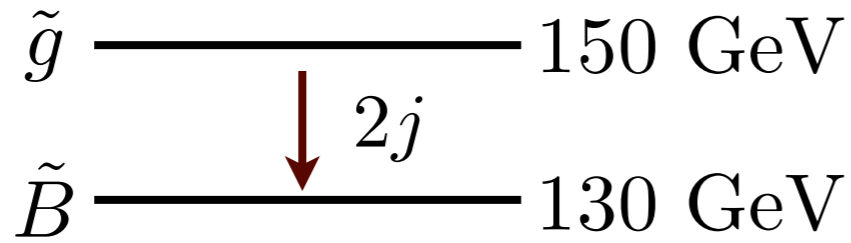


Unmatched



Effects of Matching

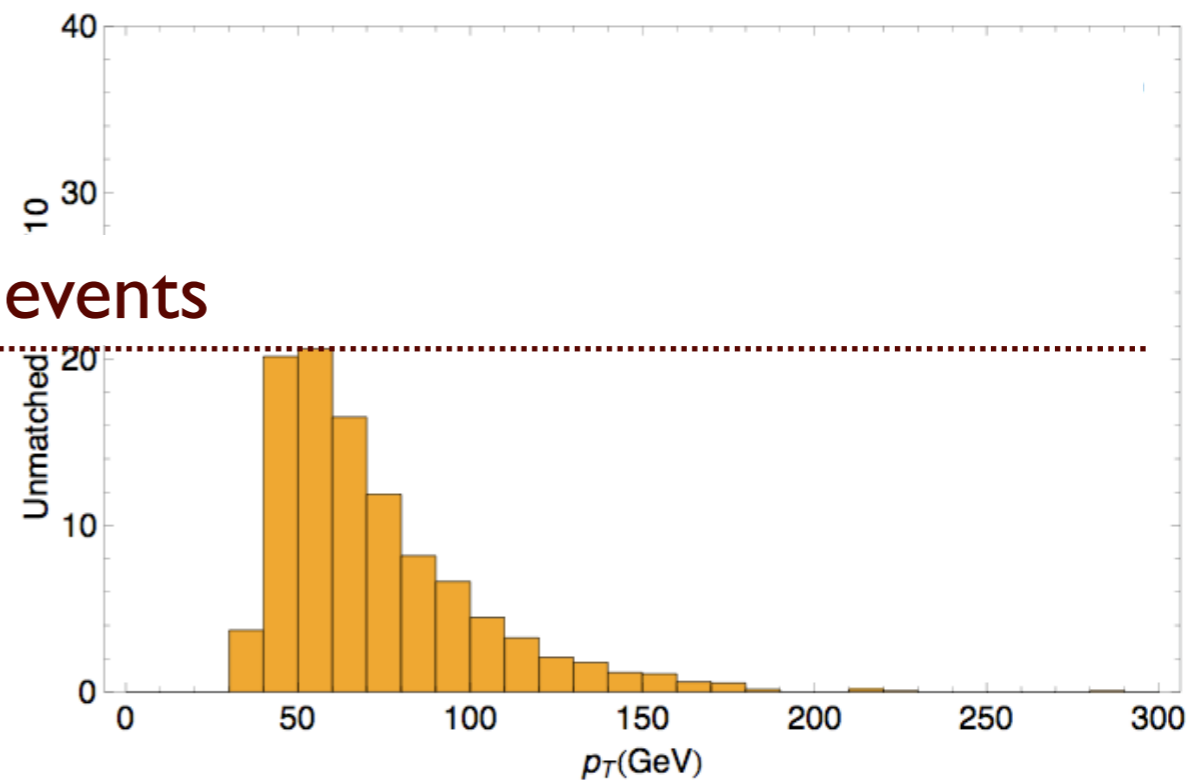
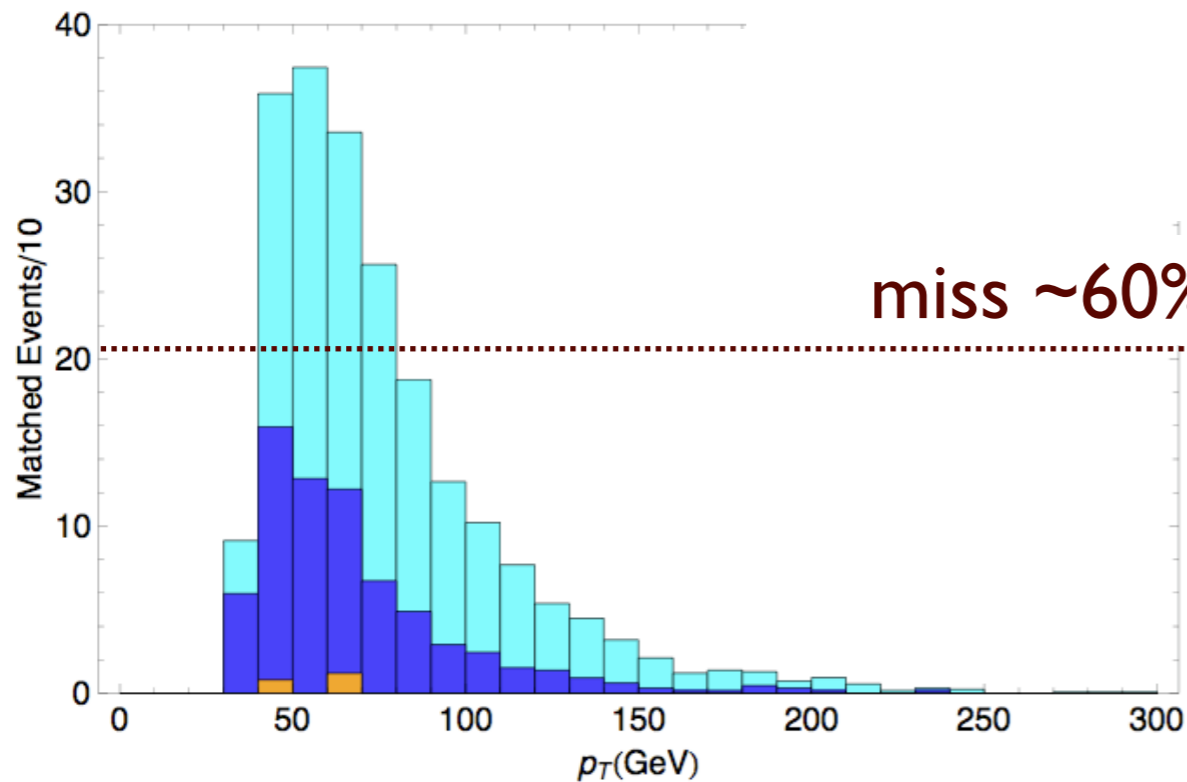
Nearly-degenerate gluino and bino



- : $\tilde{g}\tilde{g} + 0j$
- : $\tilde{g}\tilde{g} + 1j$
- : $\tilde{g}\tilde{g} + 2j$

Matched

Unmatched



miss ~60% of events