Model-Independent Searches at the LHC

Mariangela Lisanti
Princeton Center for Theoretical Science

UPenn Seminar

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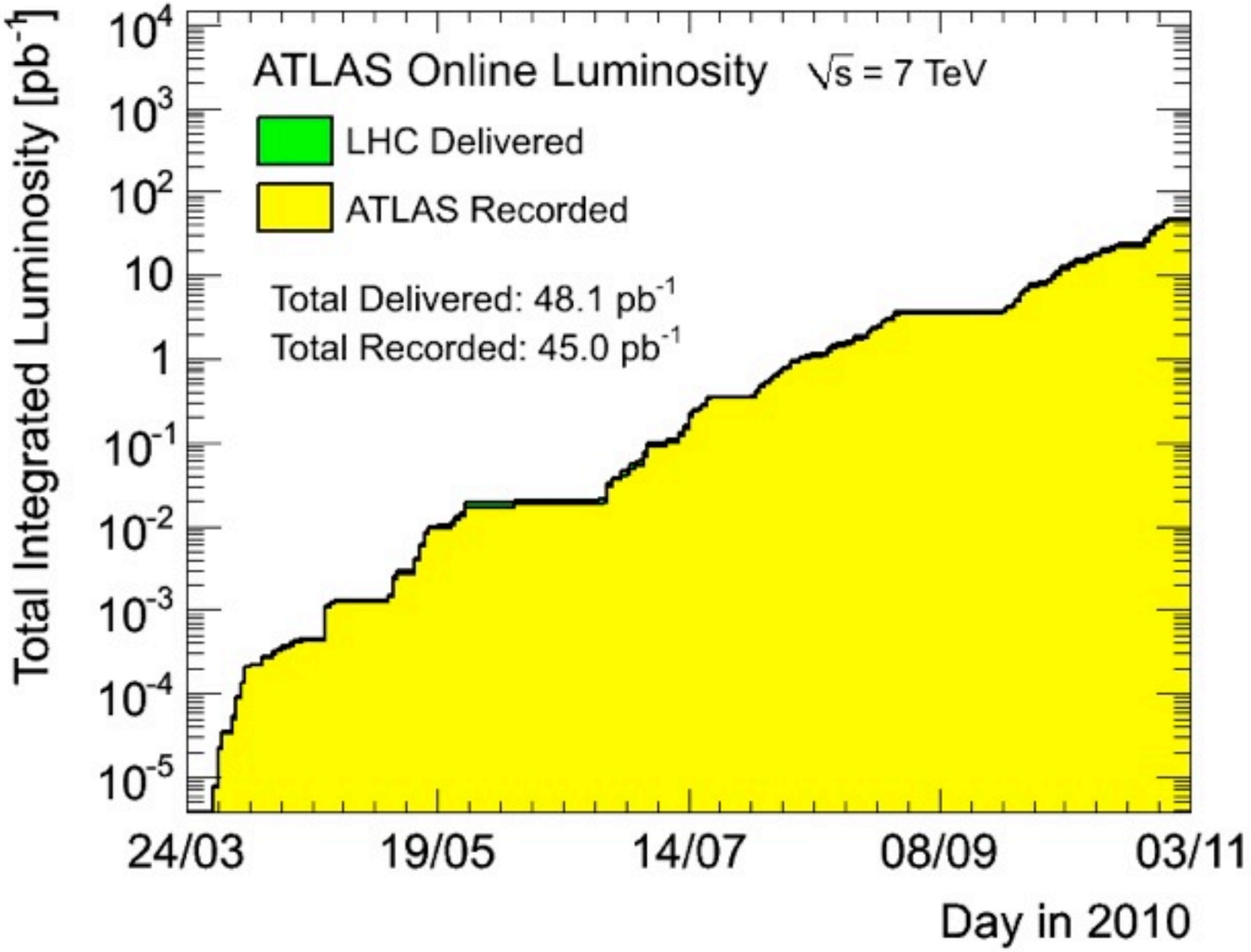
arXiv: 0803.0019, 0809.3264 with J. Alwall, M-P. Le, and J. Wacker
1103.???? with LHC New Physics Working Group

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

Can be done fairly model-independently

Strive to cover as many corners of SM phase space

3. Determine selection efficiency

4. Calculate cross section

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

(completely)

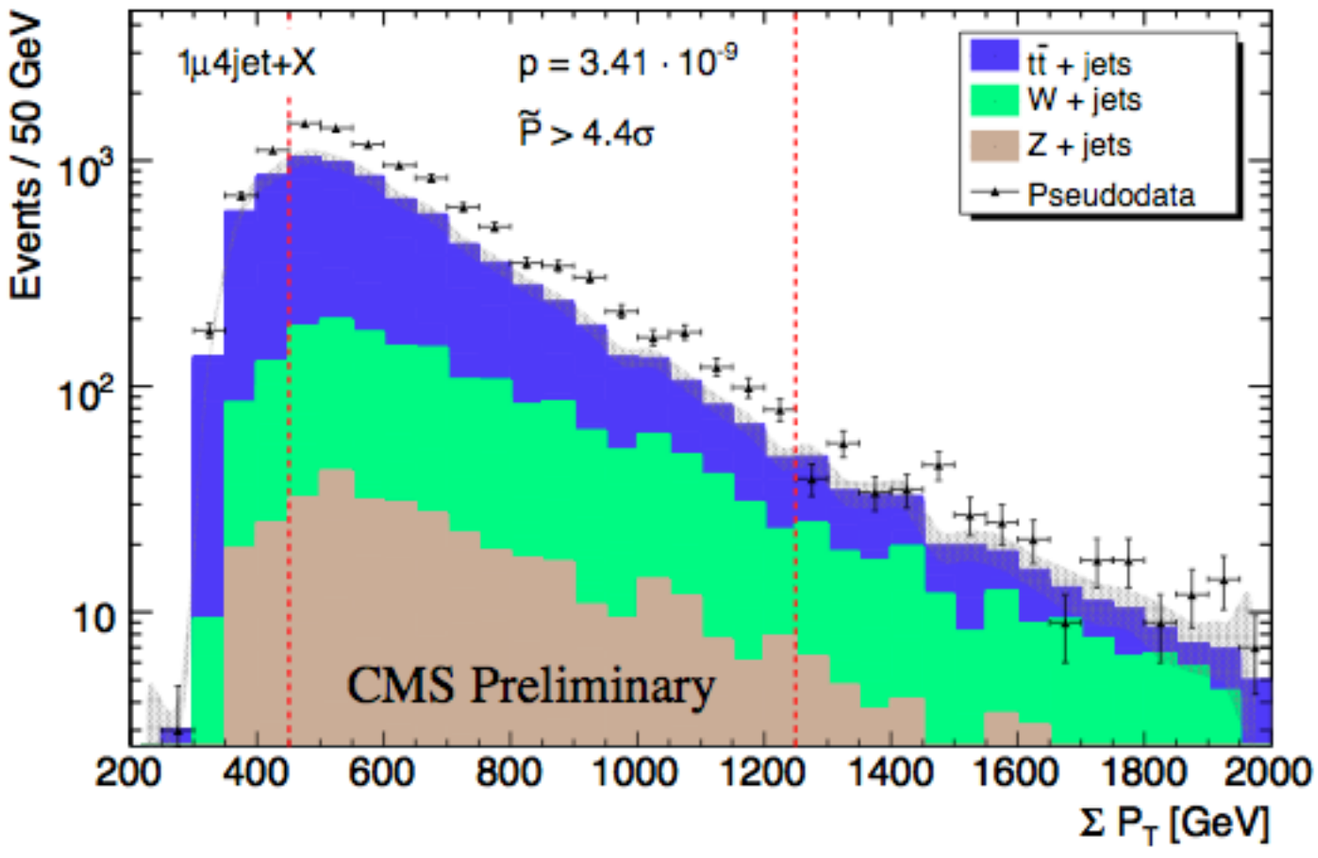
Model-Independent Searches

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

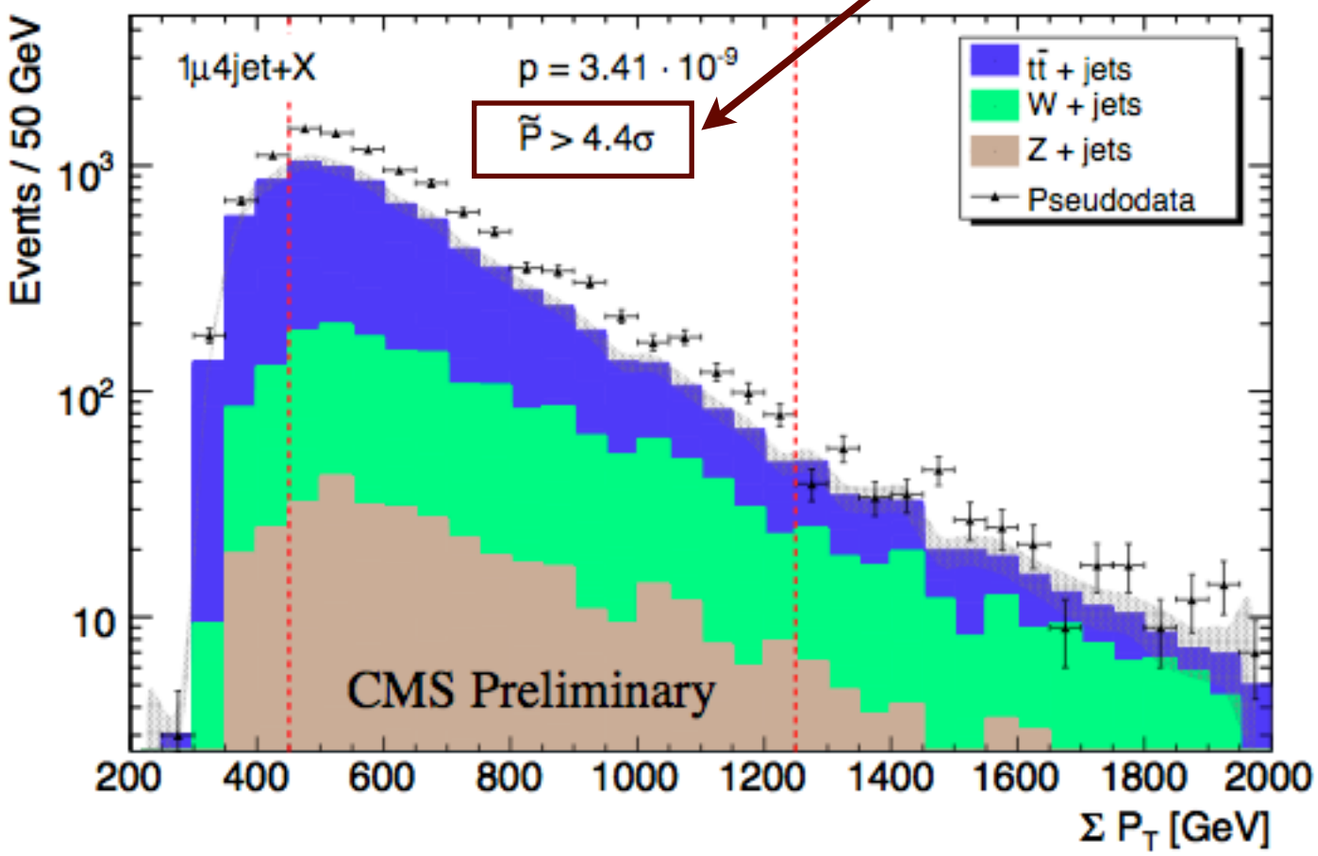
Scan data for systematic deviations from Monte Carlo

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



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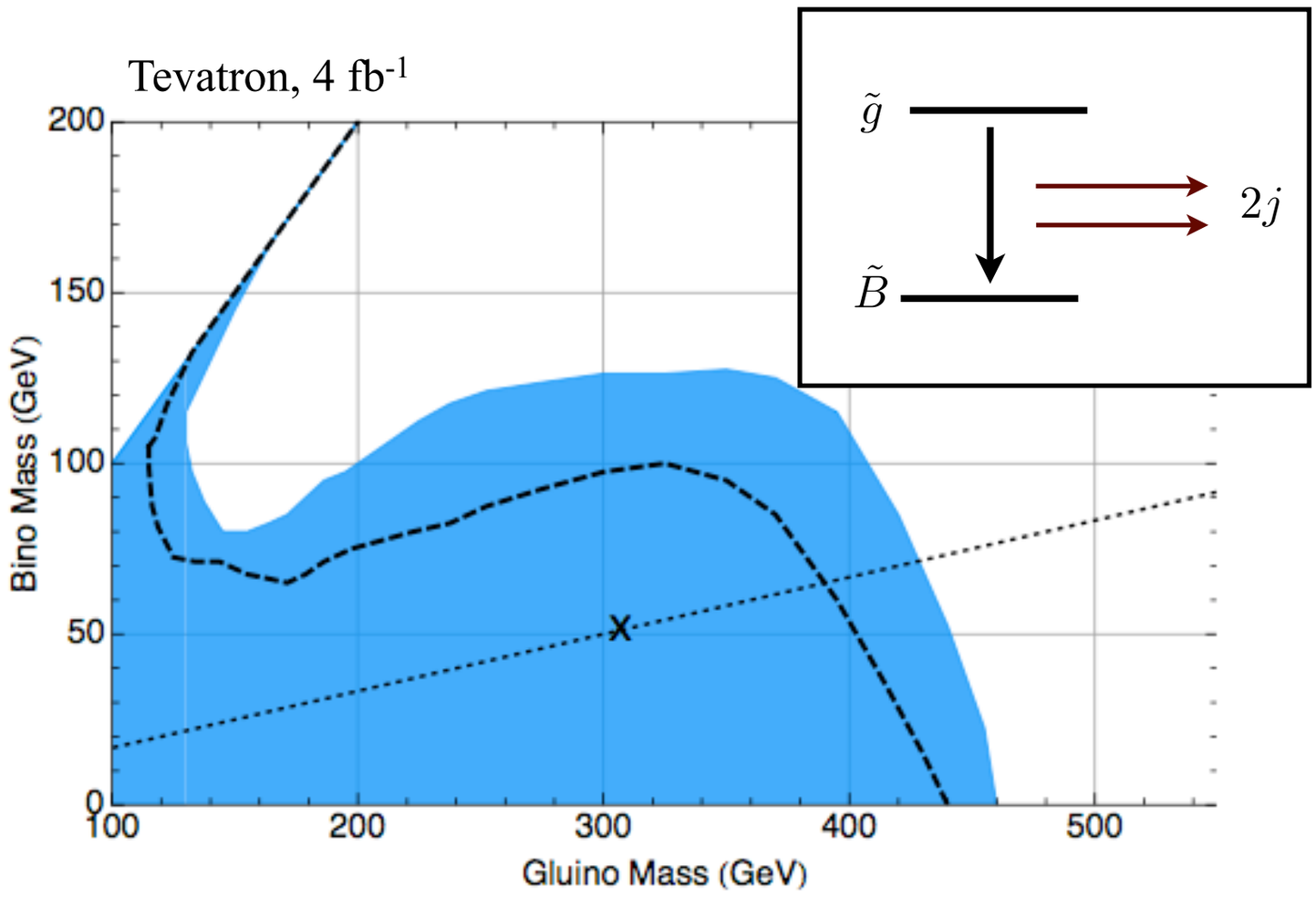
Targeted Searches

Optimize cuts for a particular model

ex: mSUGRA

only five parameters to set MSSM spectrum

often used as benchmark for searches



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great coverage...

CON:

...but for only one model.

What if that's not reality?

Alwall, ML, Le, Wacker, 0803.0019.

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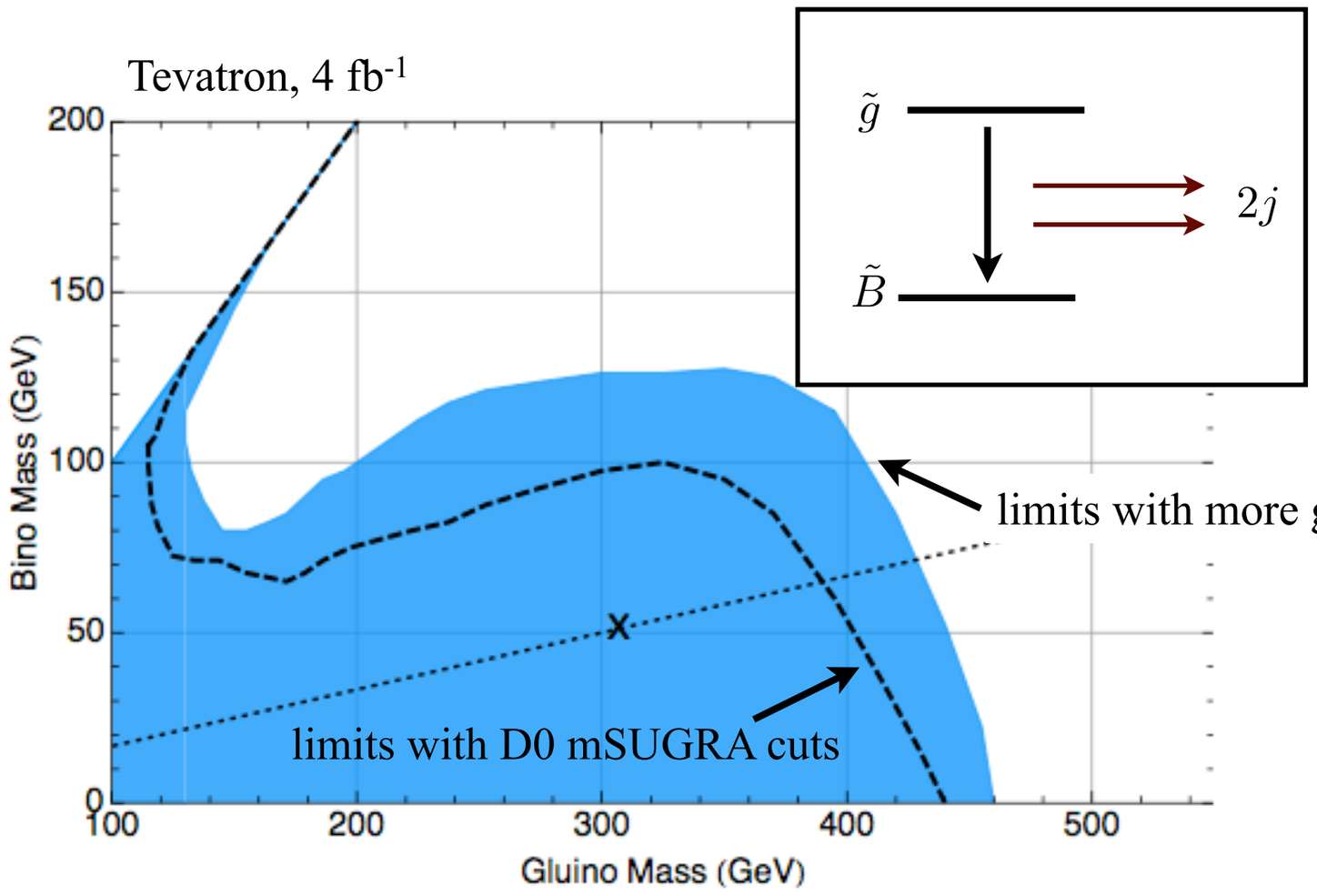

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Early Jets+MET Search

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

ATLAS NOTE

ATLAS-CONF-2010-065

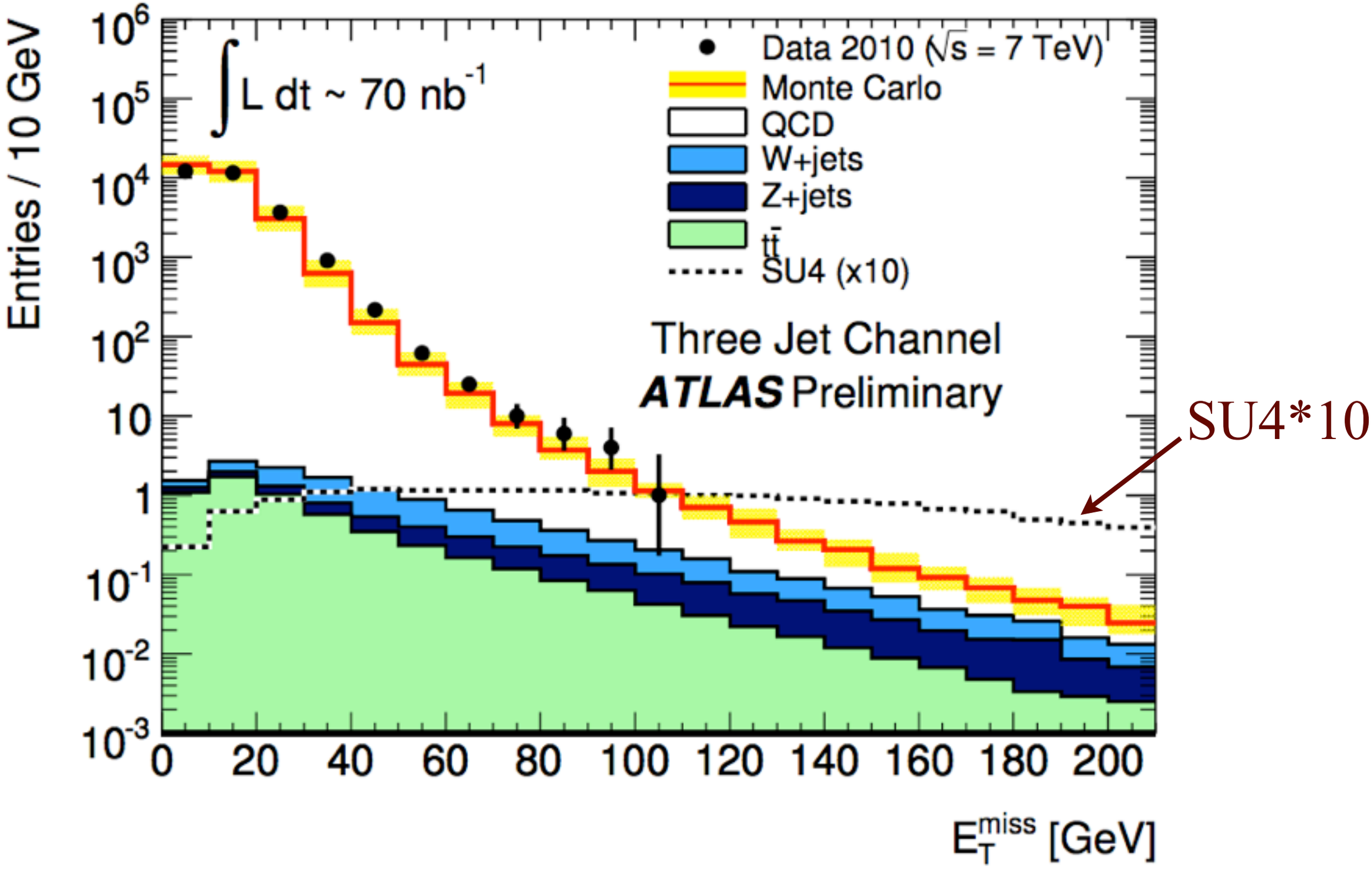
20 July, 2010

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 $\sqrt{s} = 7$ 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 $70 \pm 8\,\mathrm{nb}^{-1}$. 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.

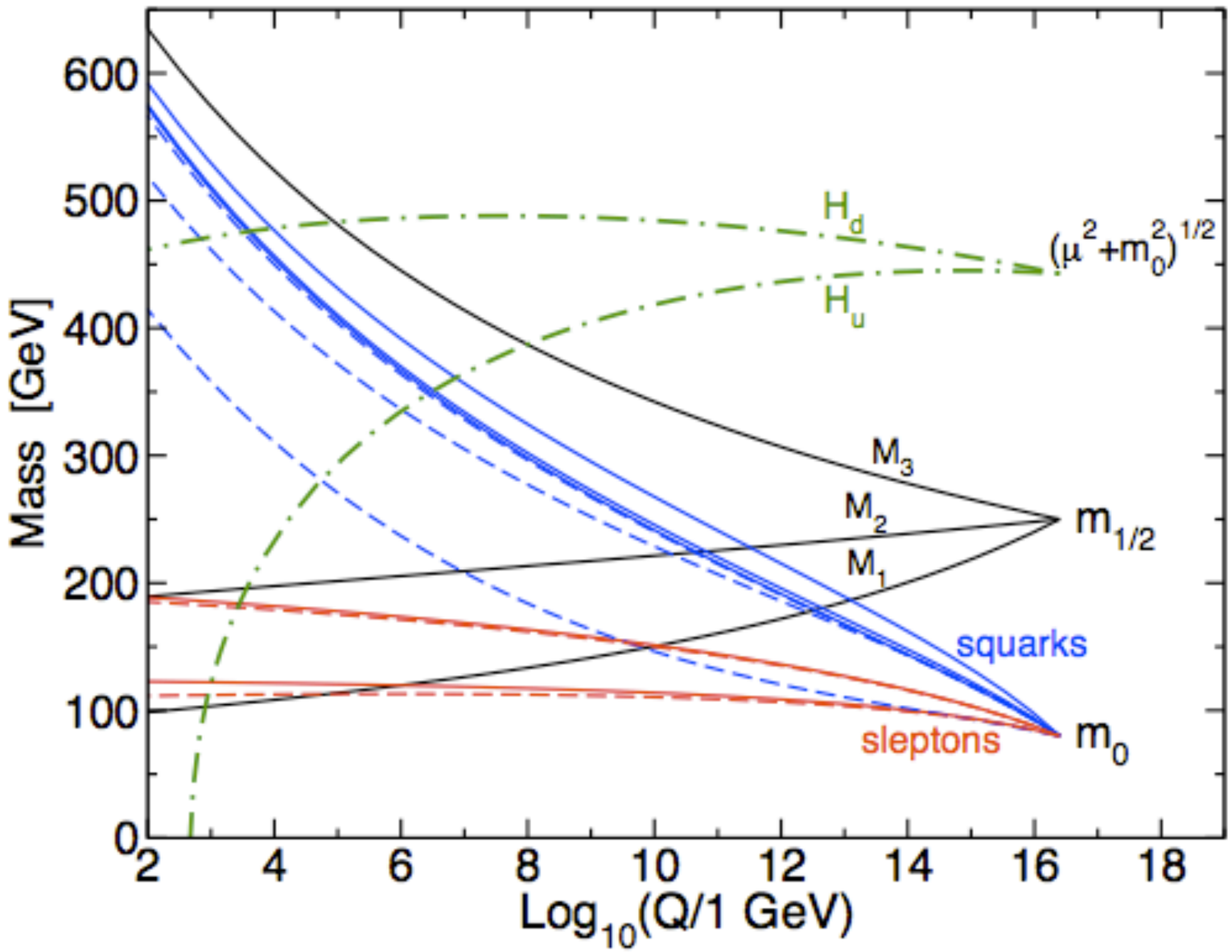
Early Jets+MET Search



mSUGRA

5 parameters at the GUT scale set low-energy spectrum

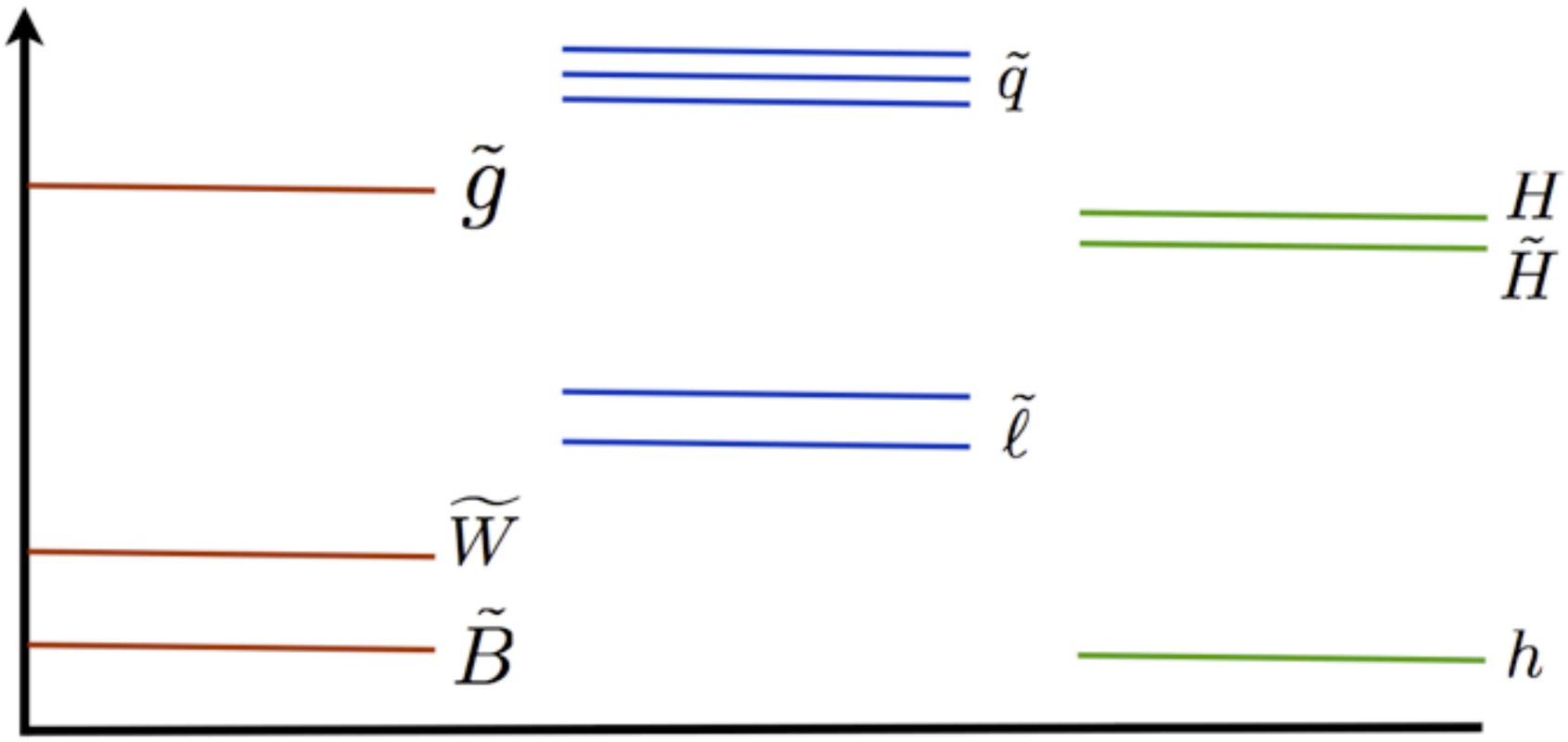
$$m_{\frac{1}{2}}, m_0^2, A_0, B_\mu, \mu$$



mSUGRA

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

Most models look like this



A shocking lack of diversity

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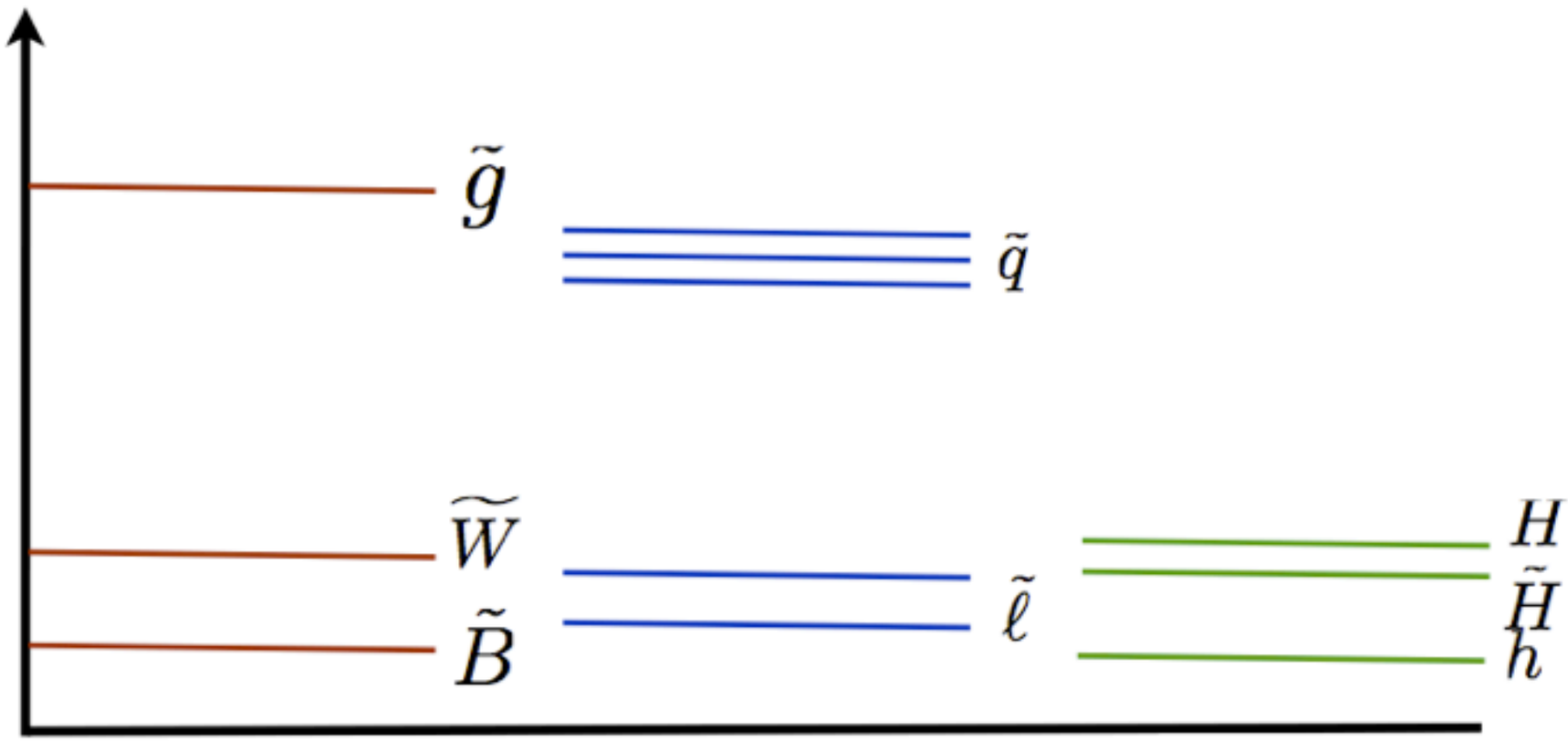
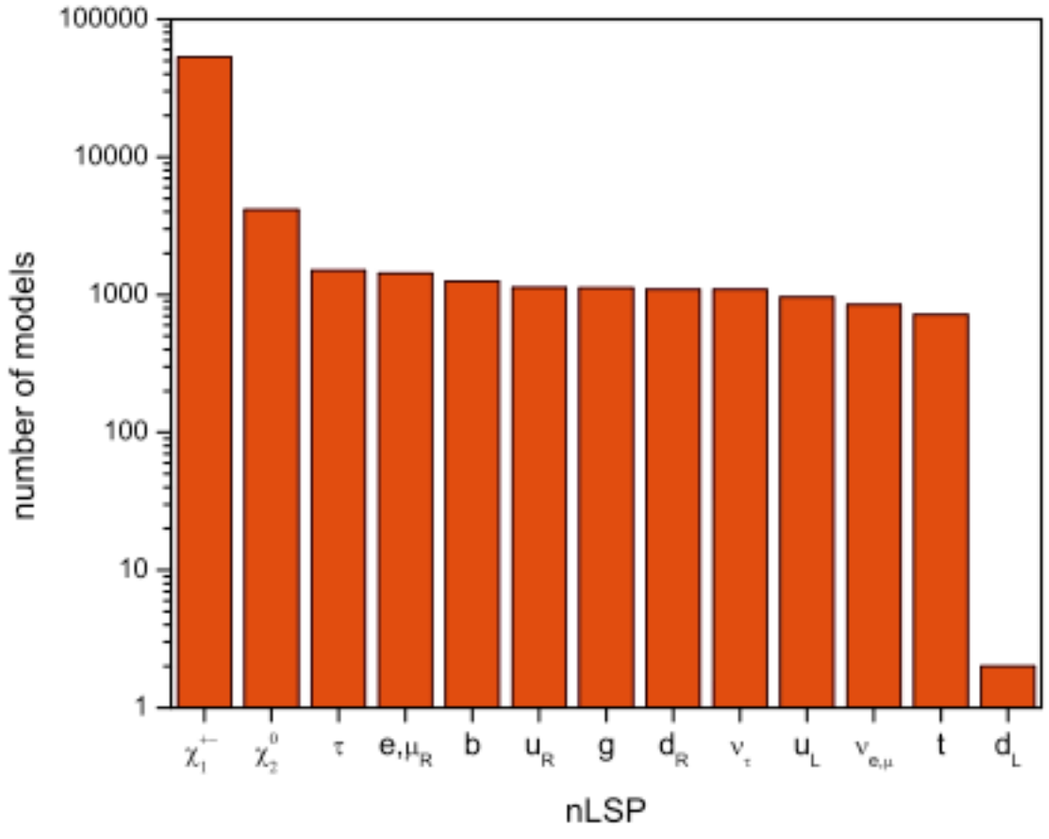
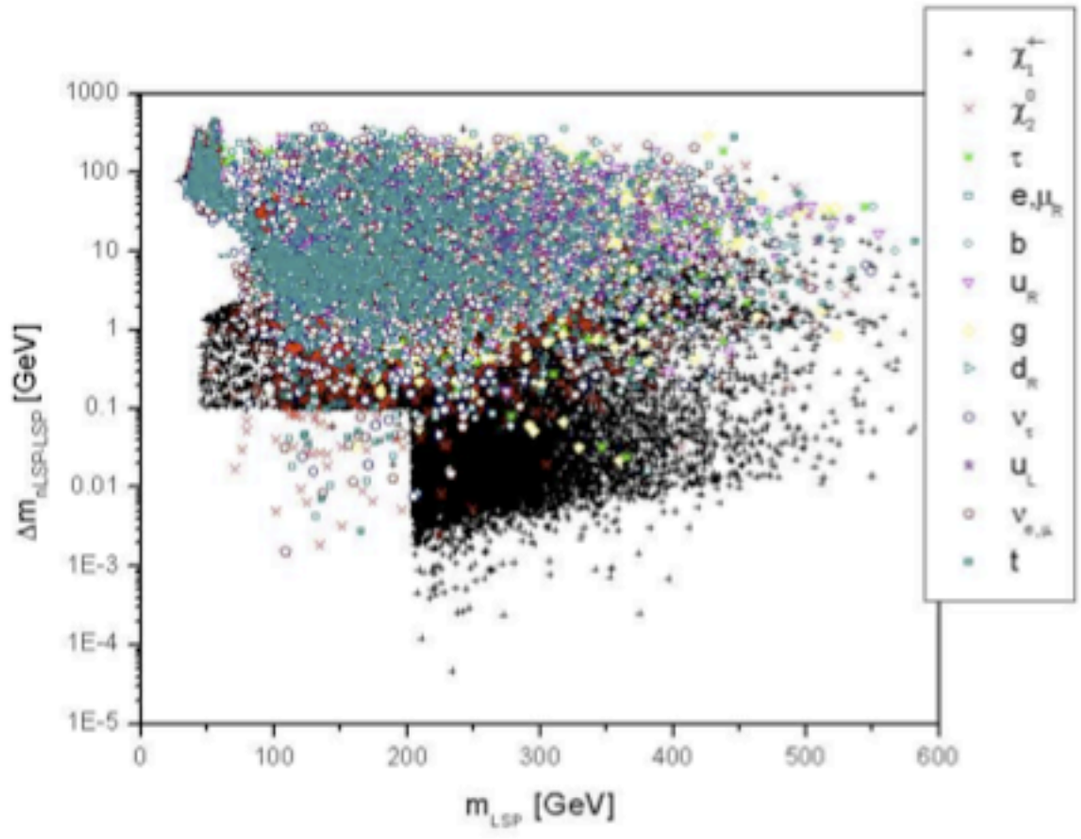


A shocking lack of diversity

Phenomenological MSSM

$m^2_{\tilde{q}}, m^2_{\tilde{u}^c}, m^2_{\tilde{d}^c}, m^2_{\tilde{l}}, m^2_{\tilde{e}^c}$	5 for first two generations 5 for third generation
$m_{\tilde{g}}, m_{\widetilde{W}}, m_{\widetilde{B}}, \mu$	4 for *-ino masses
A_t, A_b, A_τ	3 for A terms
$m^2_{h_u}, m^2_{h_d}, B_\mu$	3-1 for Higgs sector





Berger, Gainer, Hewett, Rizzo (2008).

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

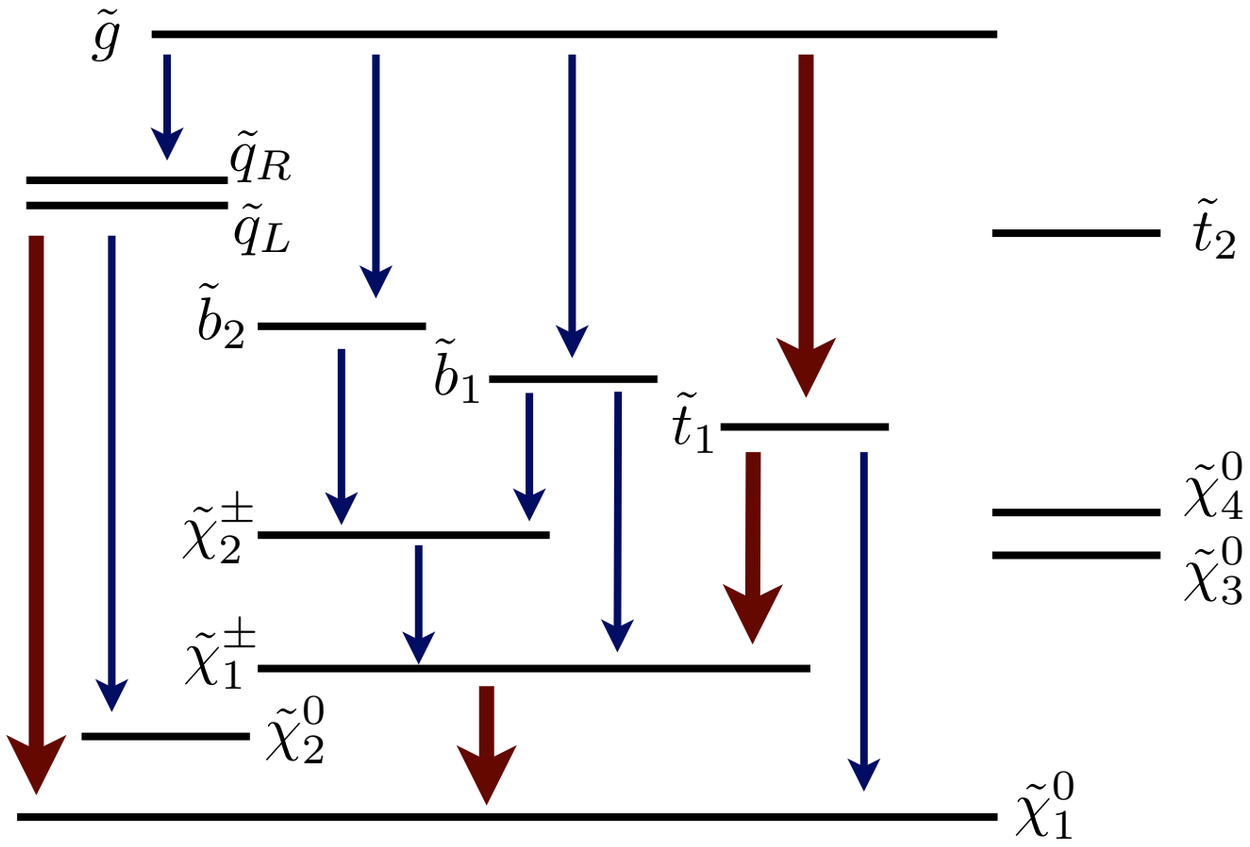
Easy to notice and explore kinematic limits

A Compromise

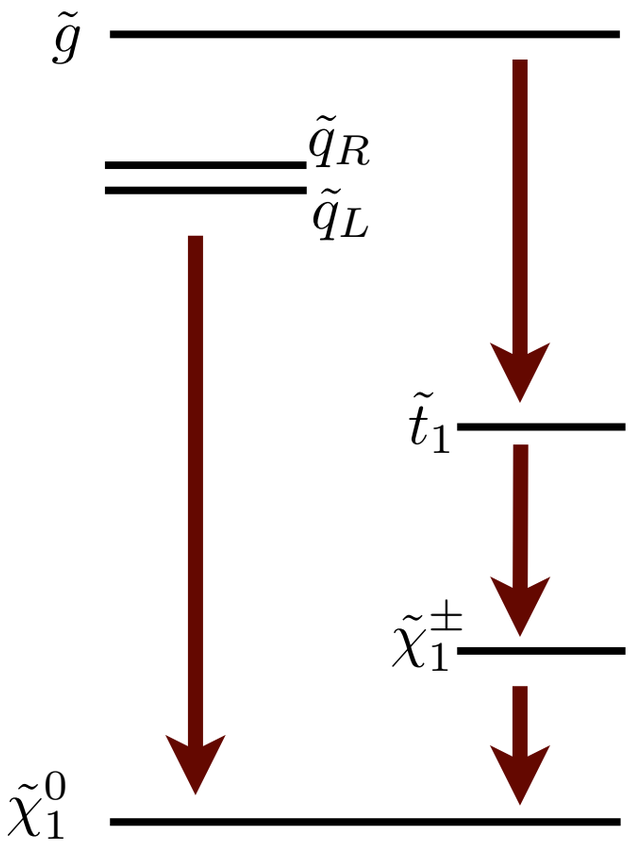
Simplified Models are an intermediate step between a complete theory and experimental signature

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

Complete Spectrum



Simplified Model



Outline

Simplified Models

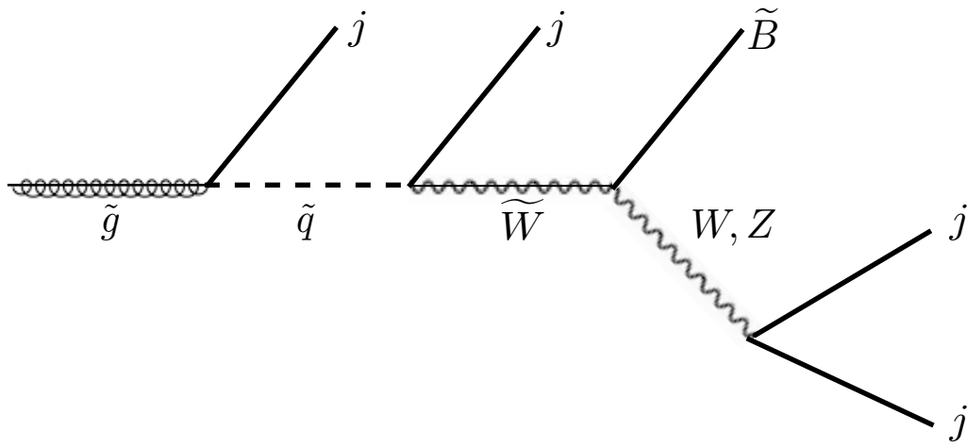
Jets + MET Example

New Physics Working Group

Jets + MET

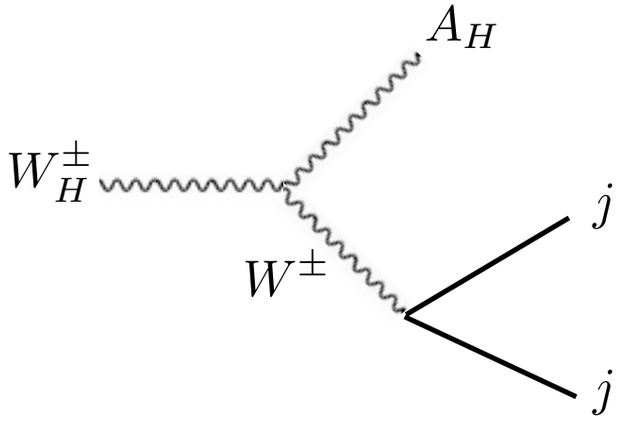
Promising signature for new physics
(UED, SUSY, Little Higgs)

new colored particle
decays to dark matter



e.g., MSSM, NMSSM, UED

new gauge bosons
are produced



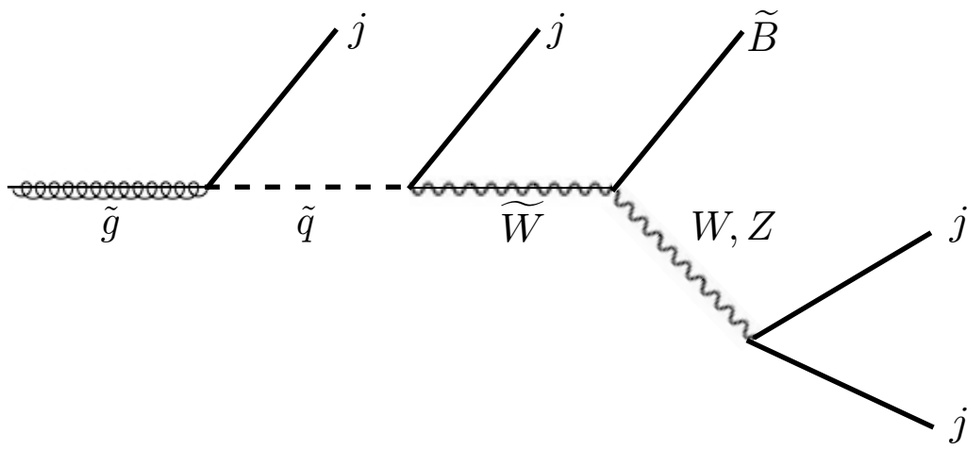
e.g., Little Higgs

Jets + MET

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

most relevant for early LHC

new colored particle
decays to dark matter



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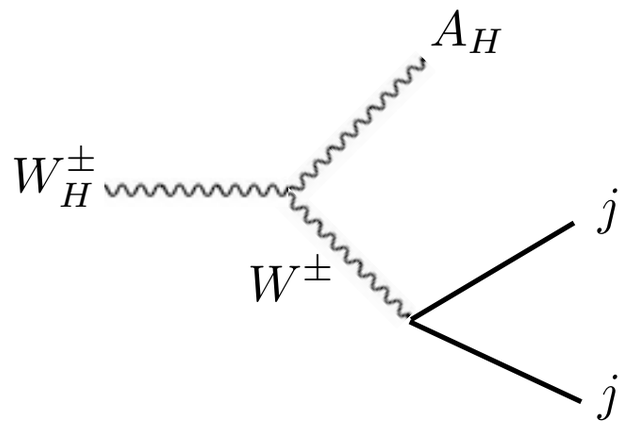
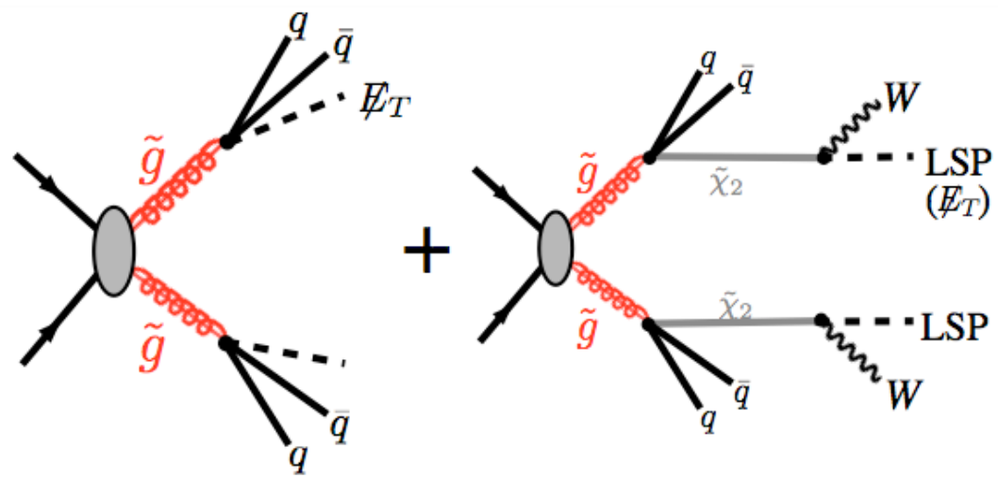


e.g., Little Higgs

Simplified Model

One-stage gluino decay



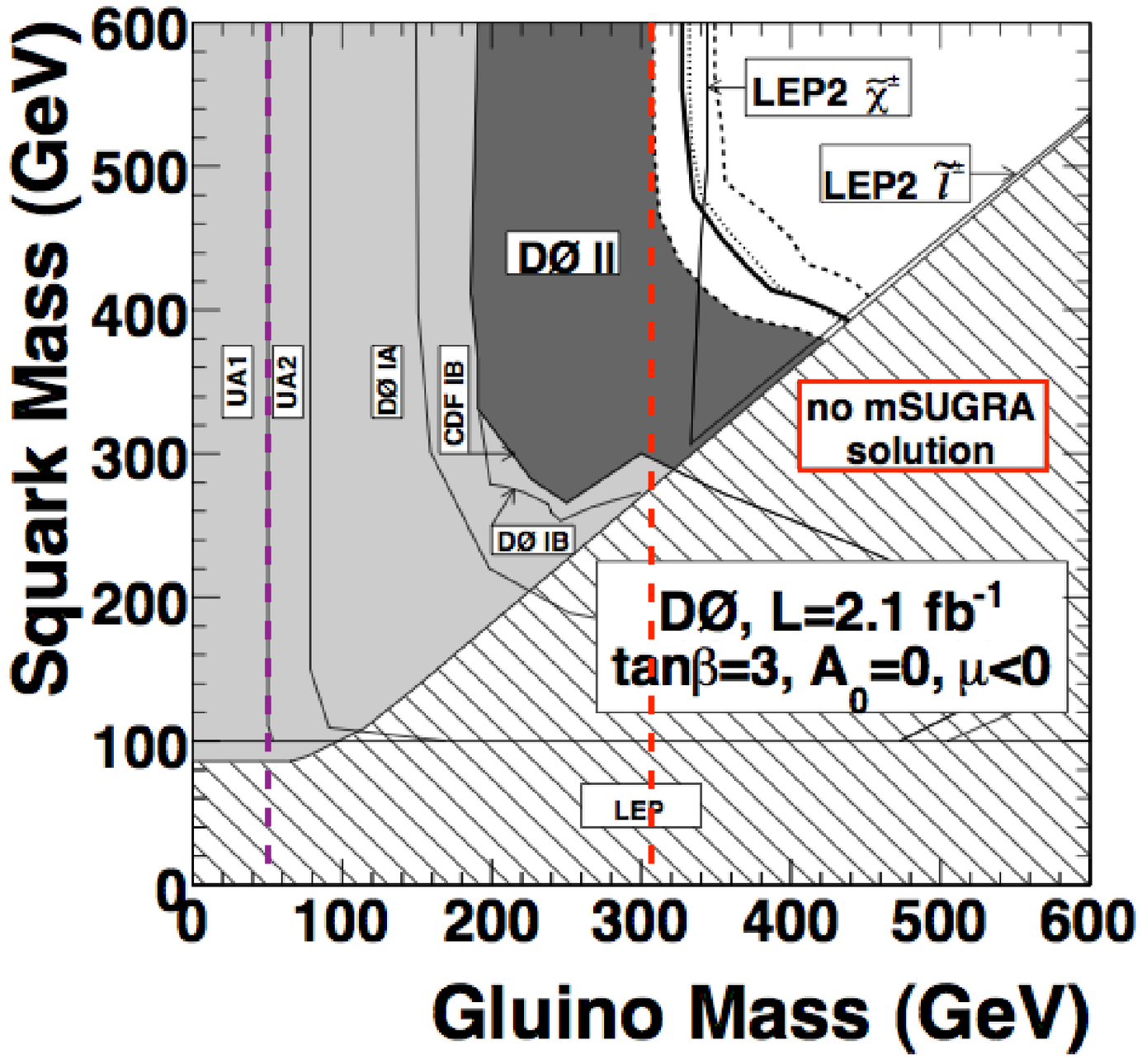
Keep masses and total cross section free

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

(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



- - - : DØ bound

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

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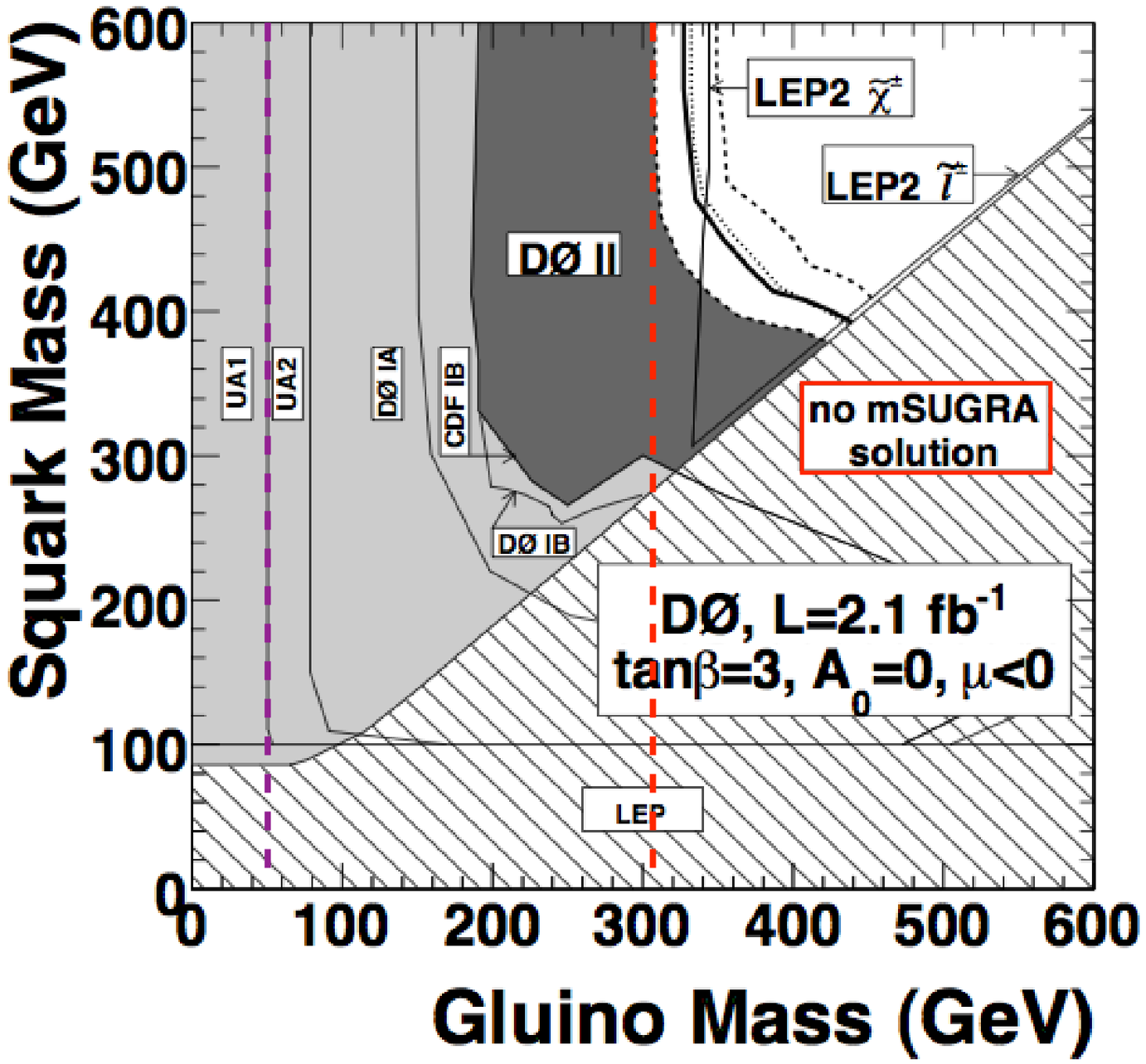


- - - : DØ bound

- - - : 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	$\tilde{q}\tilde{q}$	$\tilde{q}\tilde{g}$	$\tilde{g}\tilde{g}$
	$1j + \not{E}_T$	$2j + \not{E}_T$	$3j + \not{E}_T$	$4j + \not{E}_T$
$E_{T\,j_1}$	≥ 150	≥ 35	≥ 35	≥ 35
$E_{T\,j_2}$	< 35	≥ 35	≥ 35	≥ 35
$E_{T\,j_3}$			≥ 35	≥ 35
$E_{T\,j_4}$				≥ 20
$\not{E}_T$	≥ 150	≥ 225	≥ 150	≥ 100
H_T	≥ 150	≥ 300	≥ 400	≥ 300

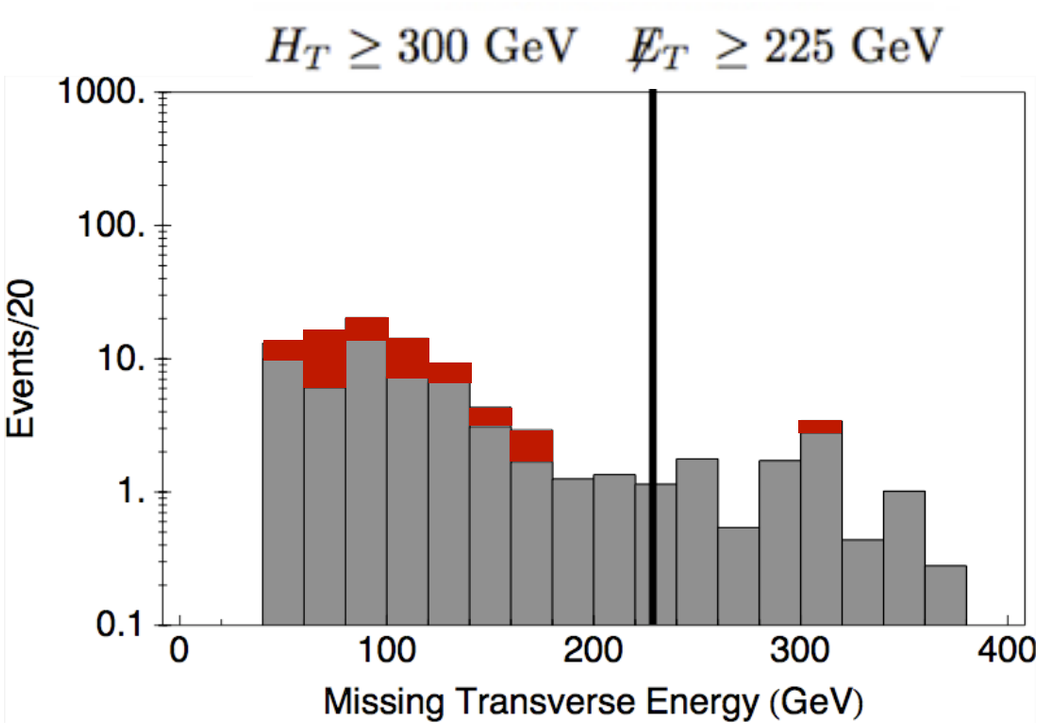
(Not exclusive searches)

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

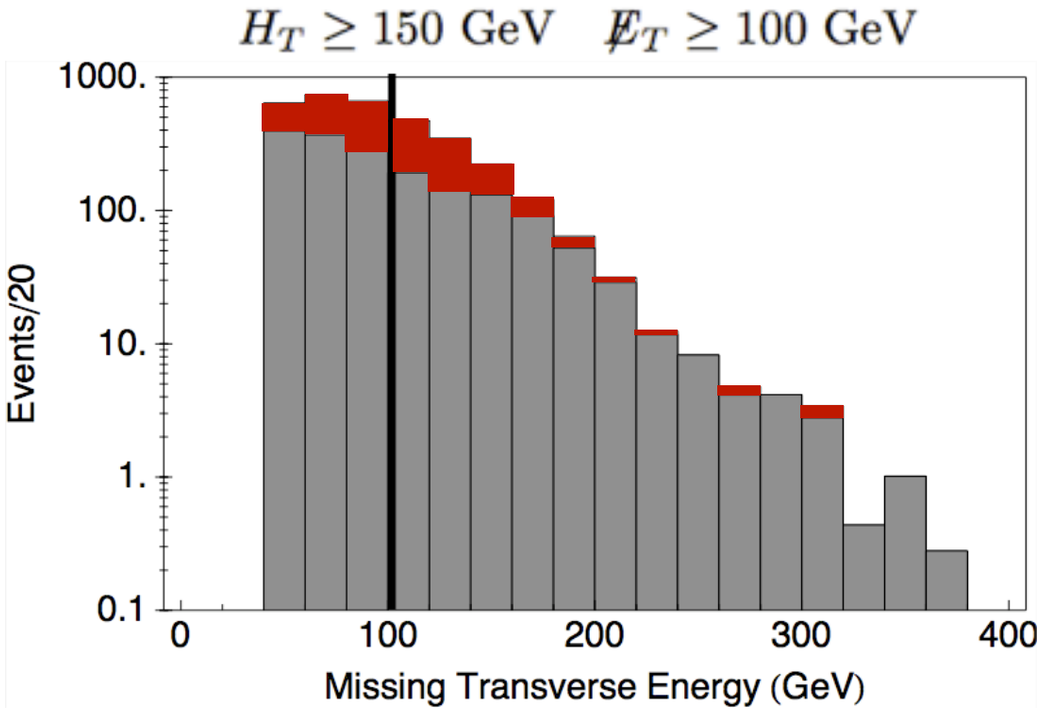
Generalizing Cuts

Dijet signal for 200 GeV gluino decay directly 100 GeV bino

DØ cuts



More general cuts



: Background : Signal

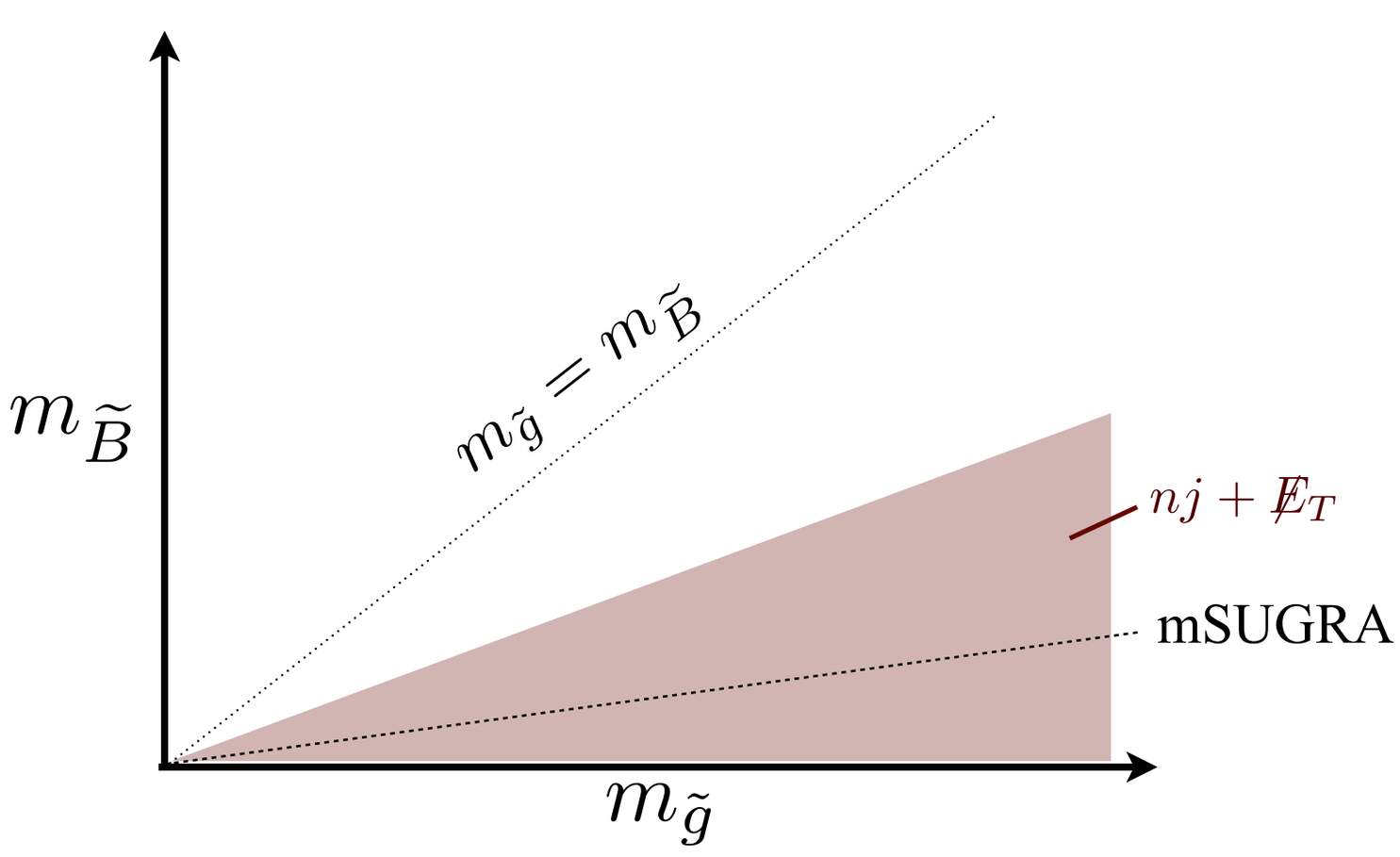
Tevatron never searched in physics parameter space

Possibility for light gluinos lurking...

Kinematics

Mass difference between gluino and bino is relevant quantity

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



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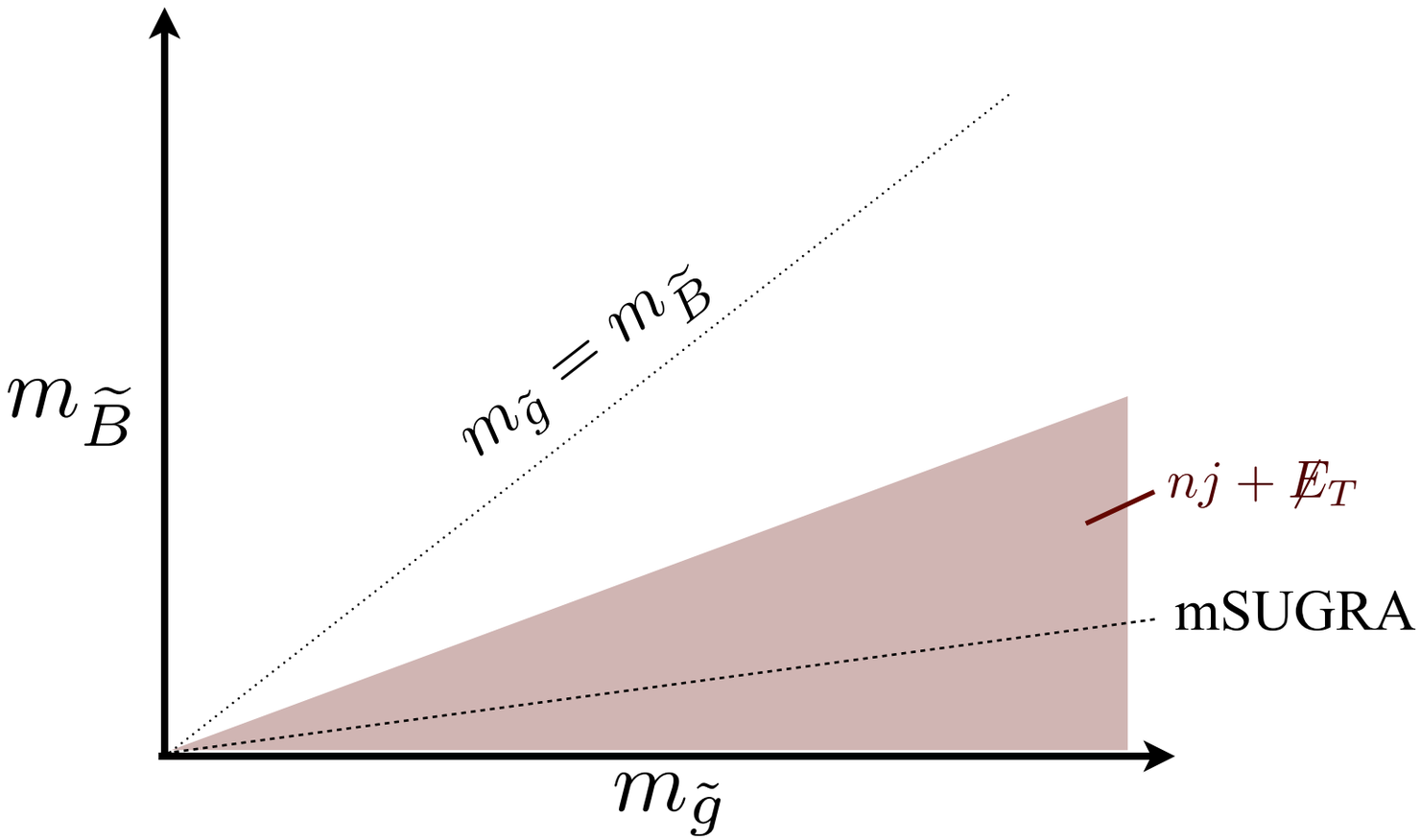
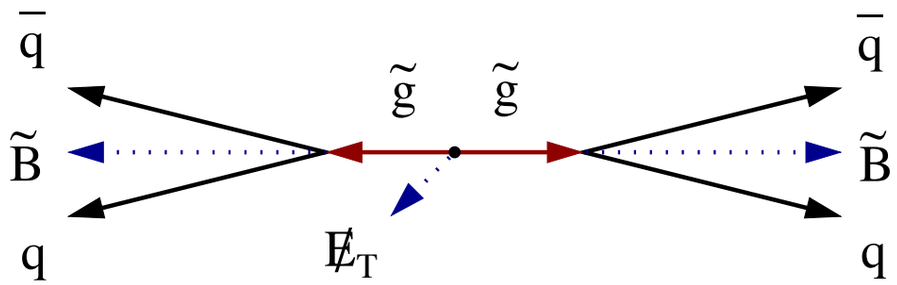


Nearly degenerate regime



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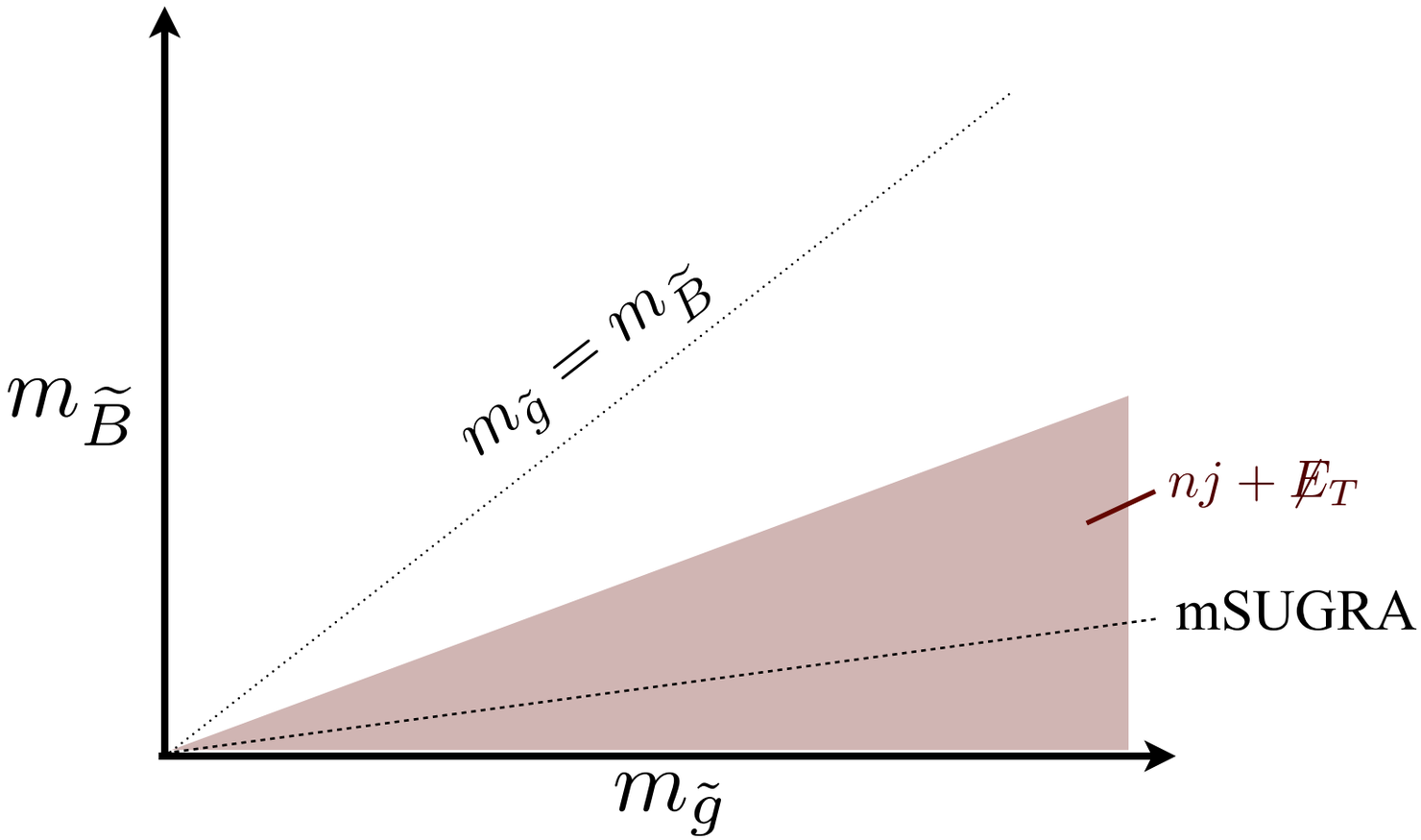

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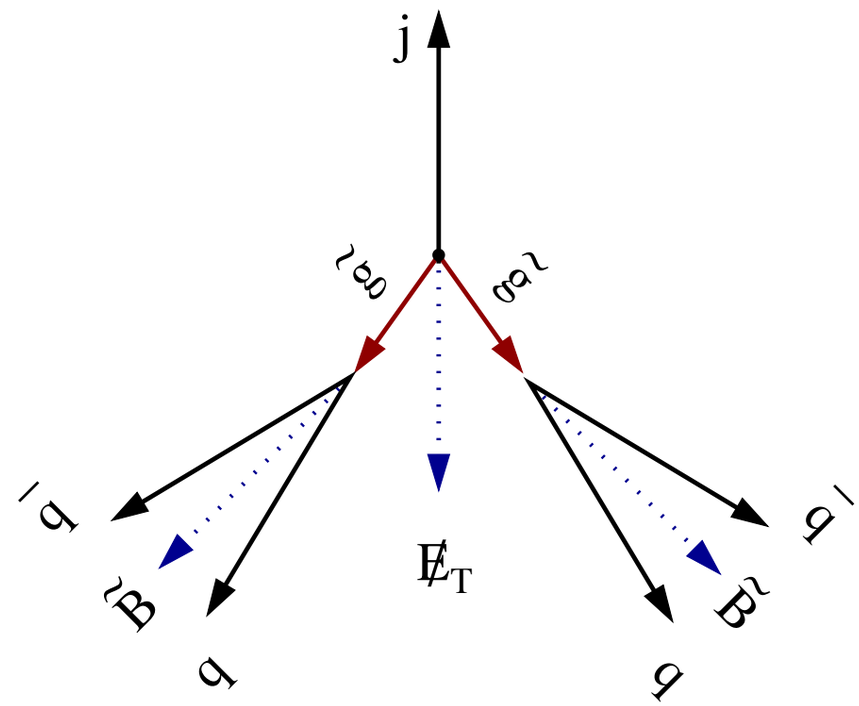

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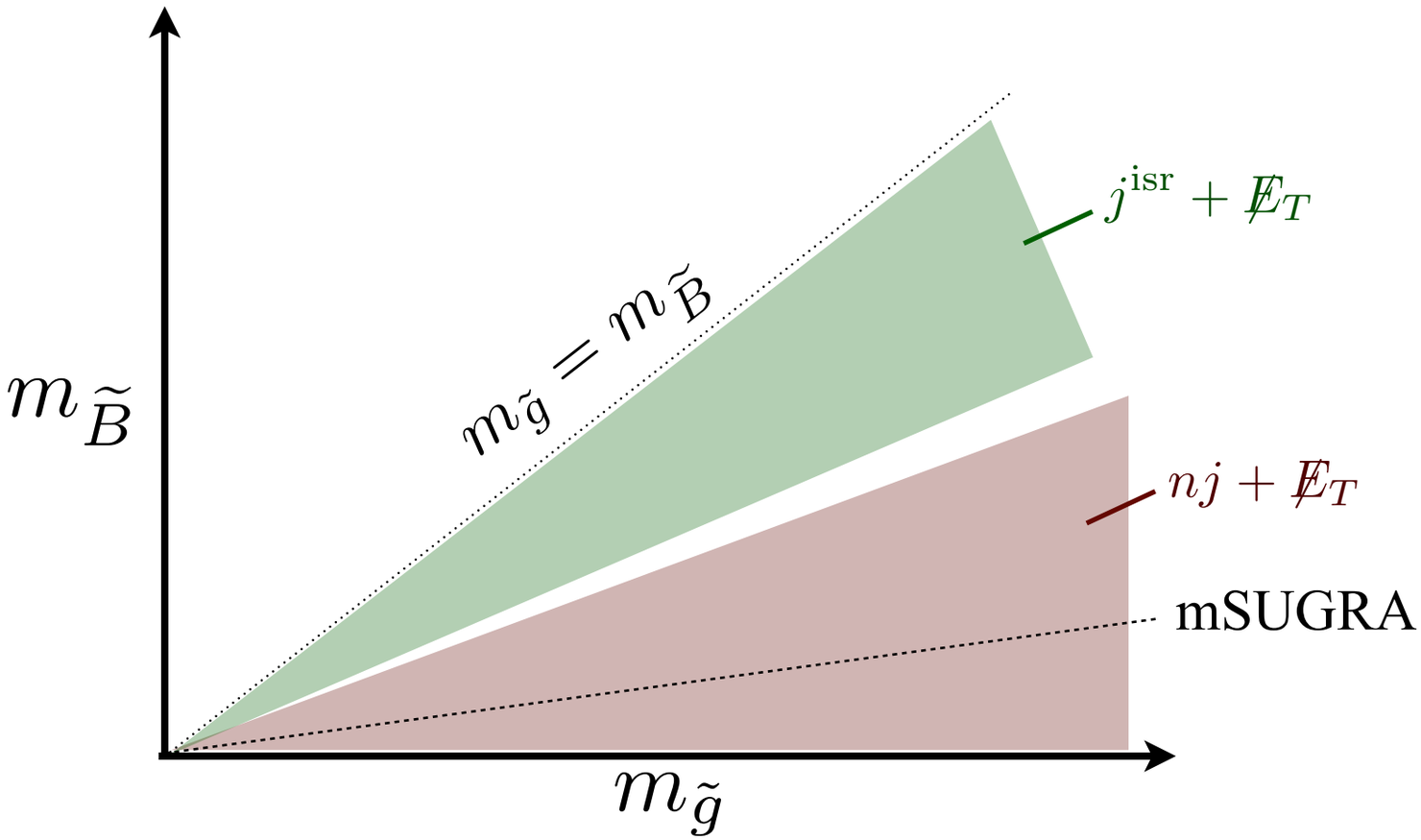

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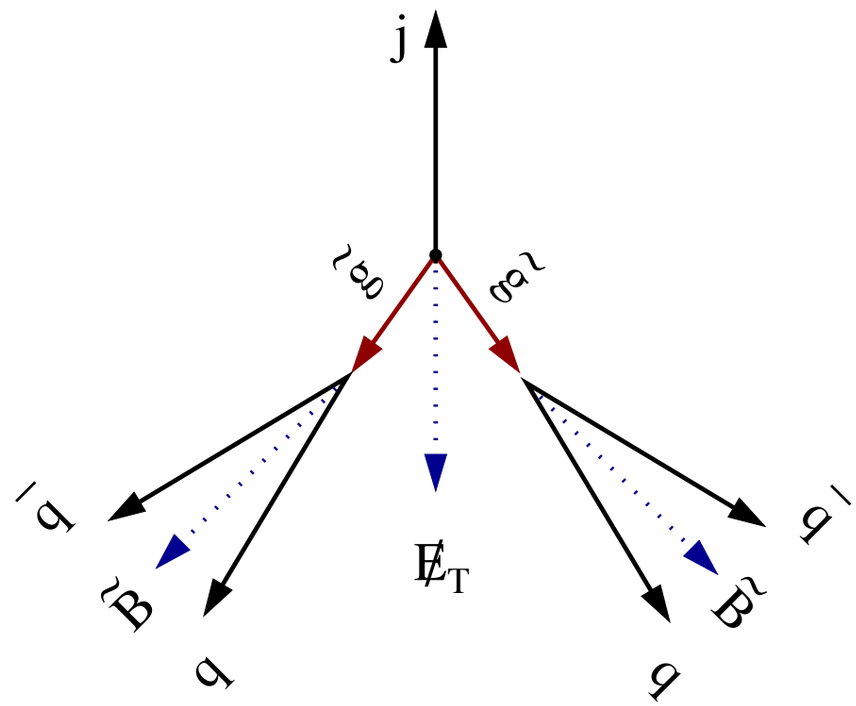

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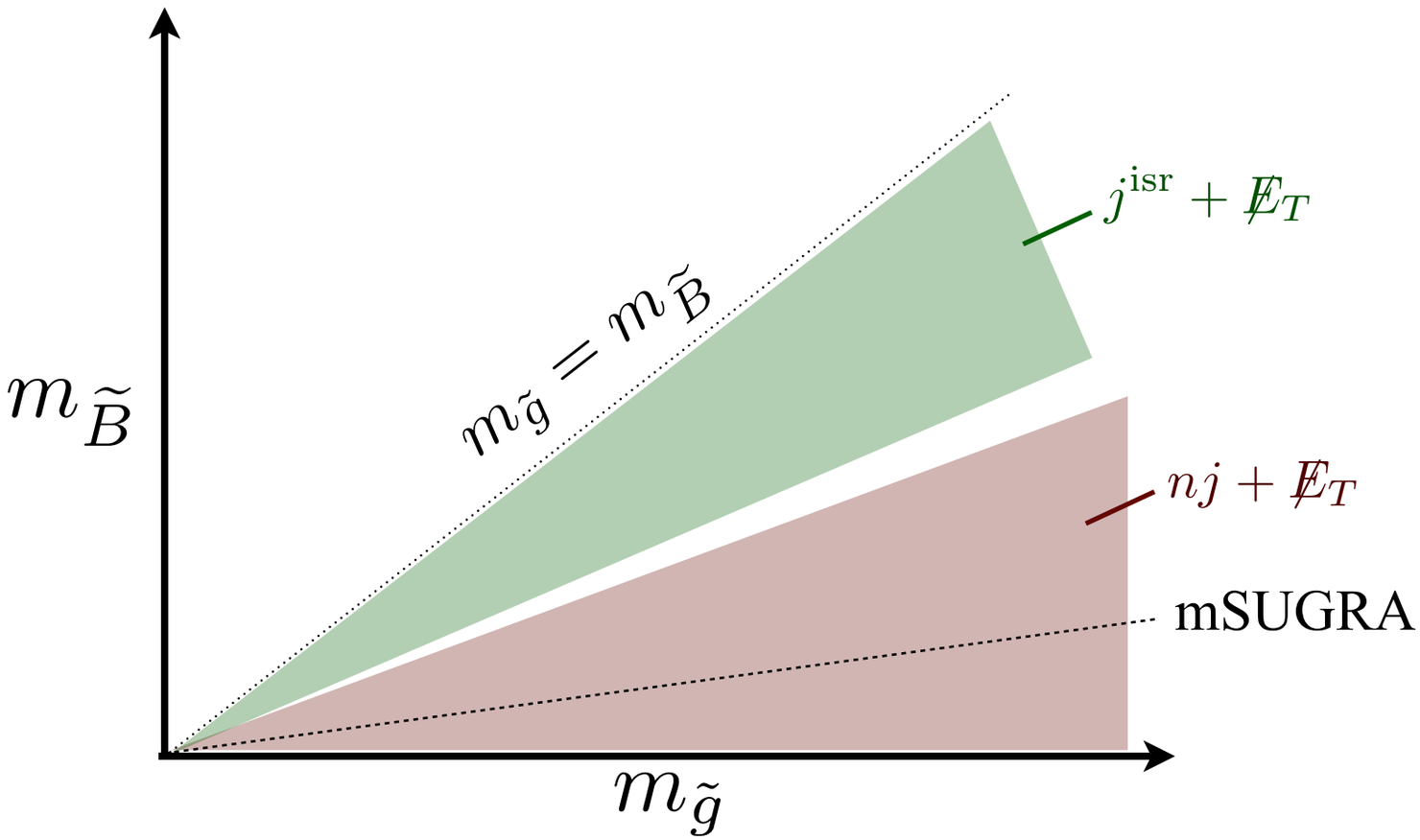
Simplified models help ensure that all kinematic possibilities are considered



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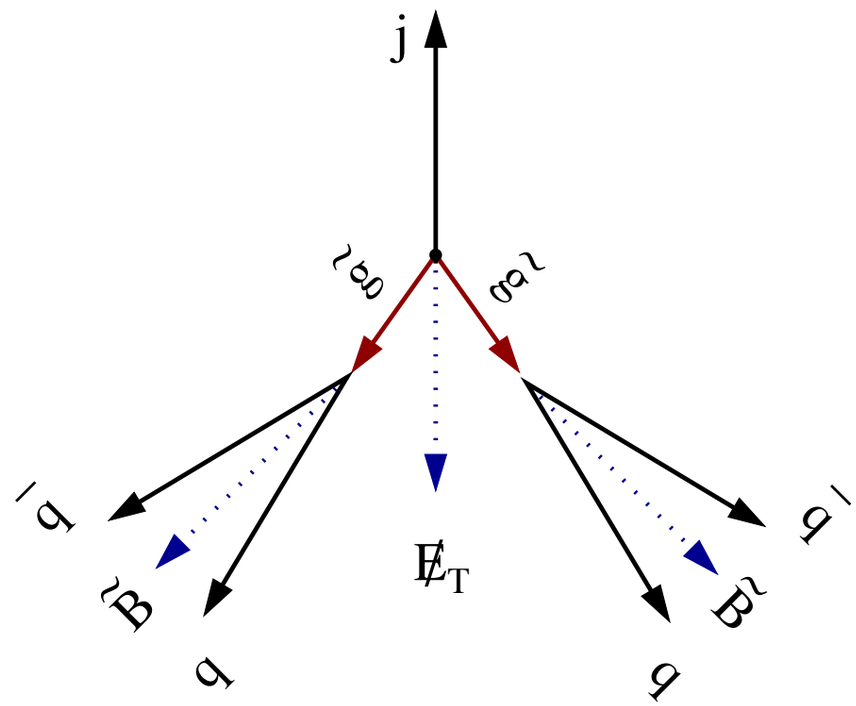
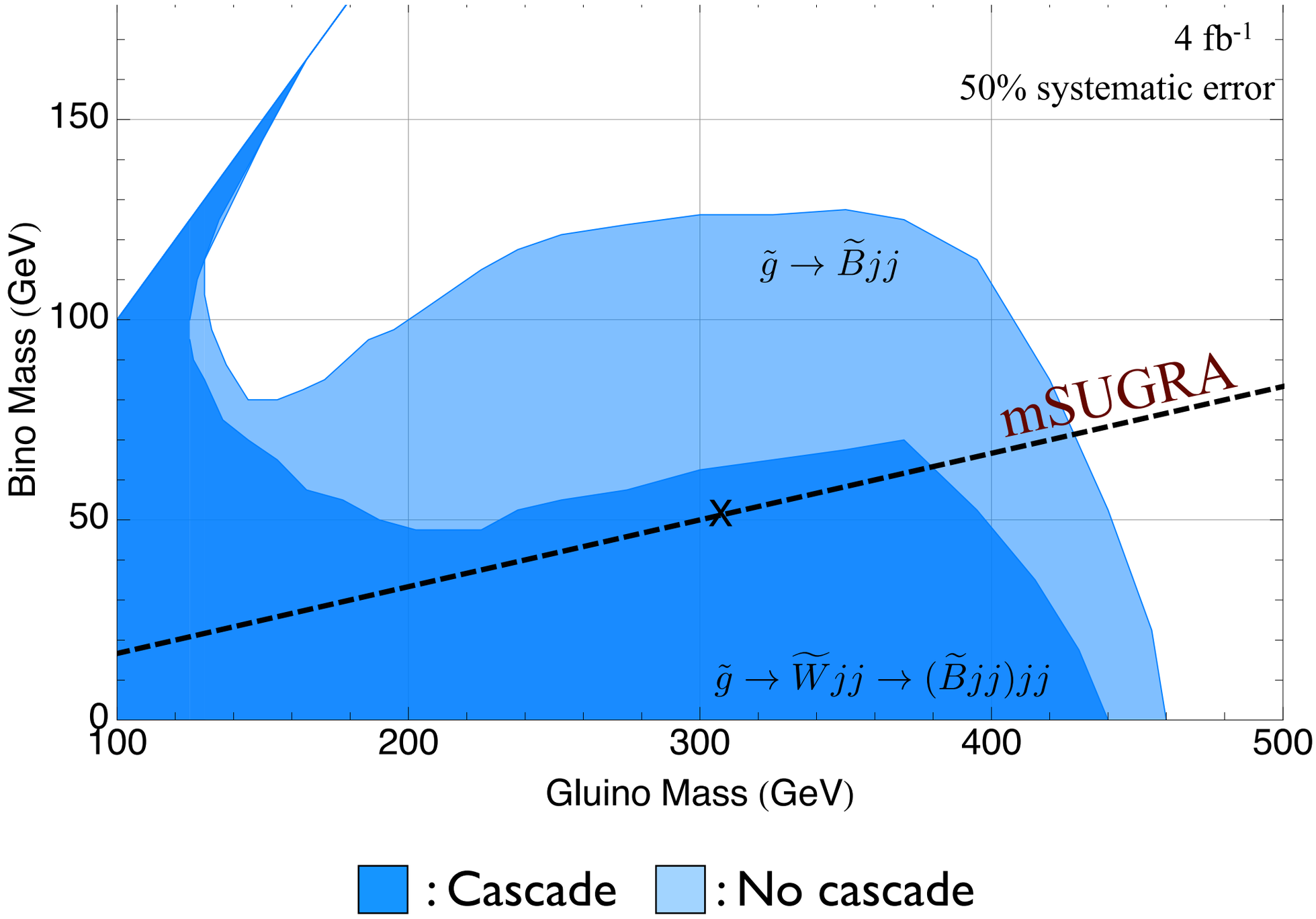


Exclusion Region*



* 95% exclusion limit

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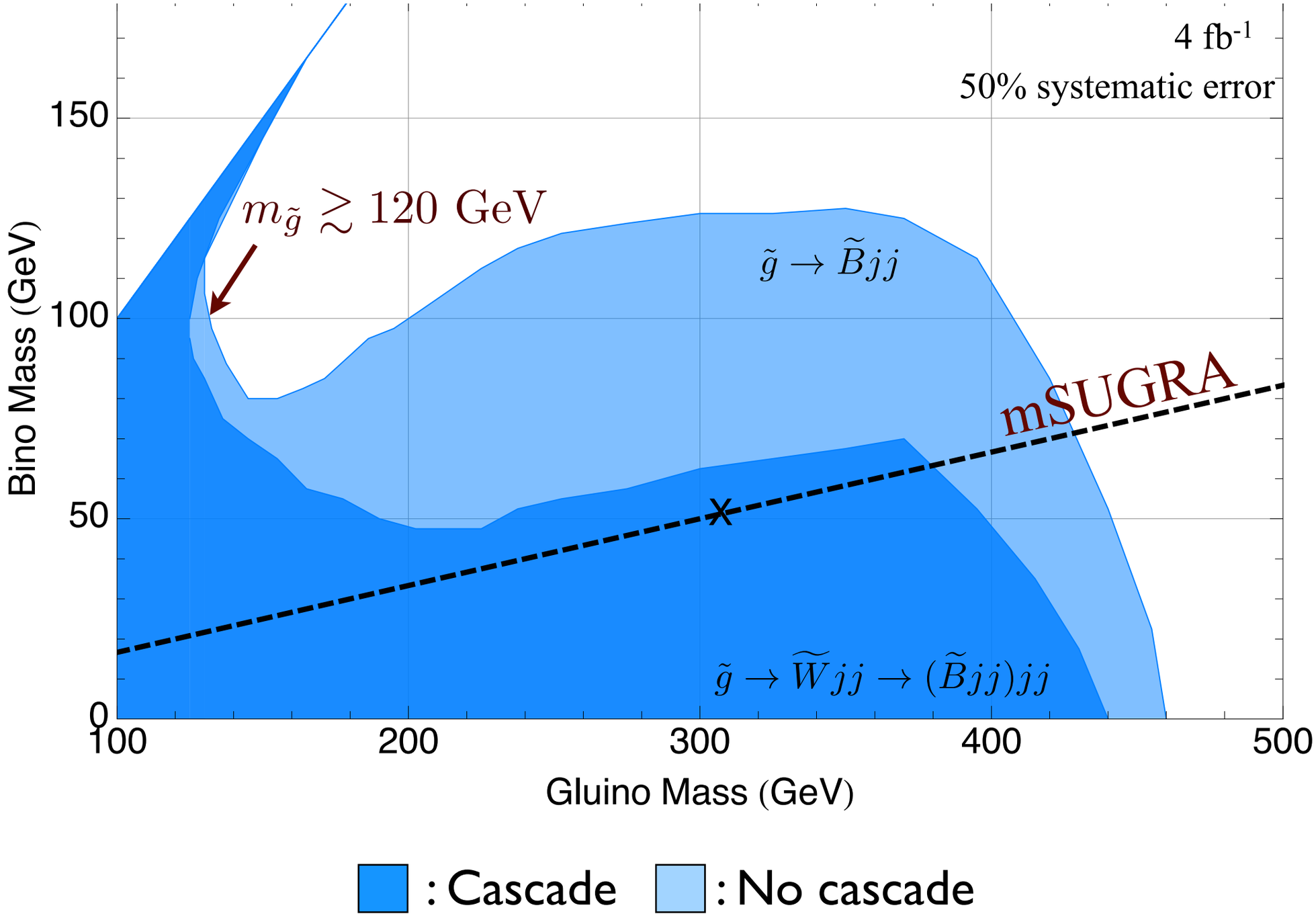


* 95% exclusion limit

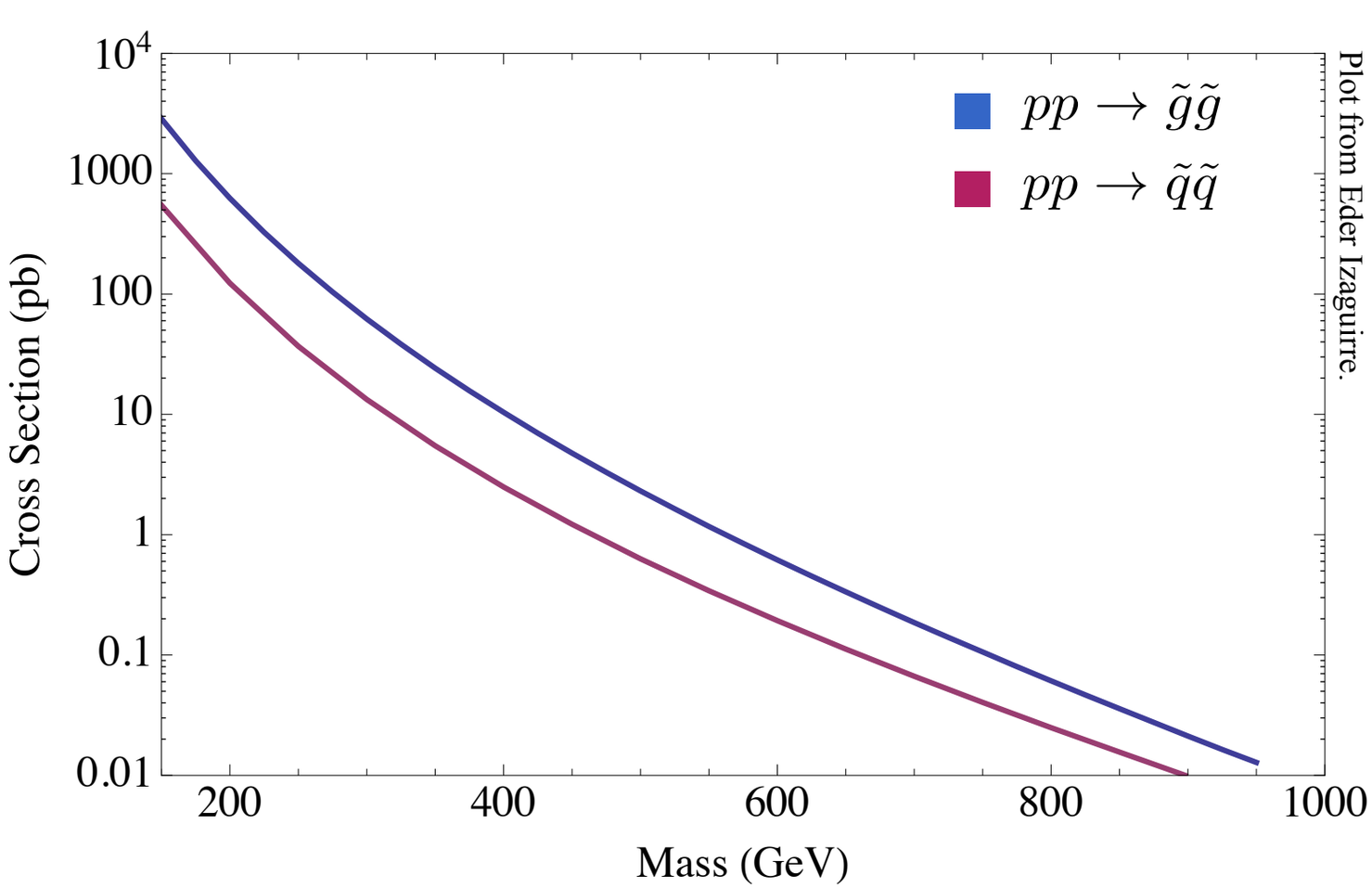
Gluinos @ LHC

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



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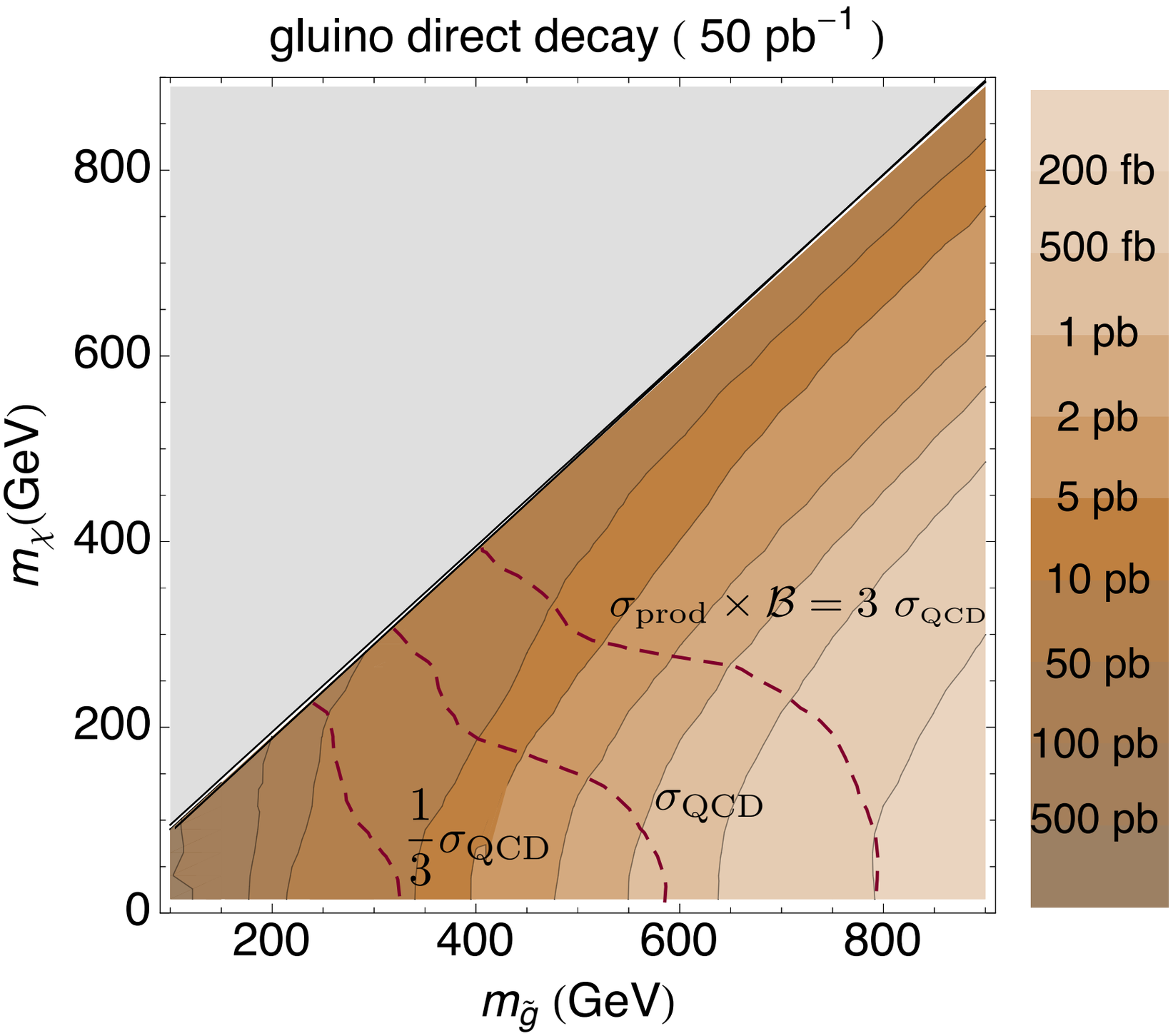
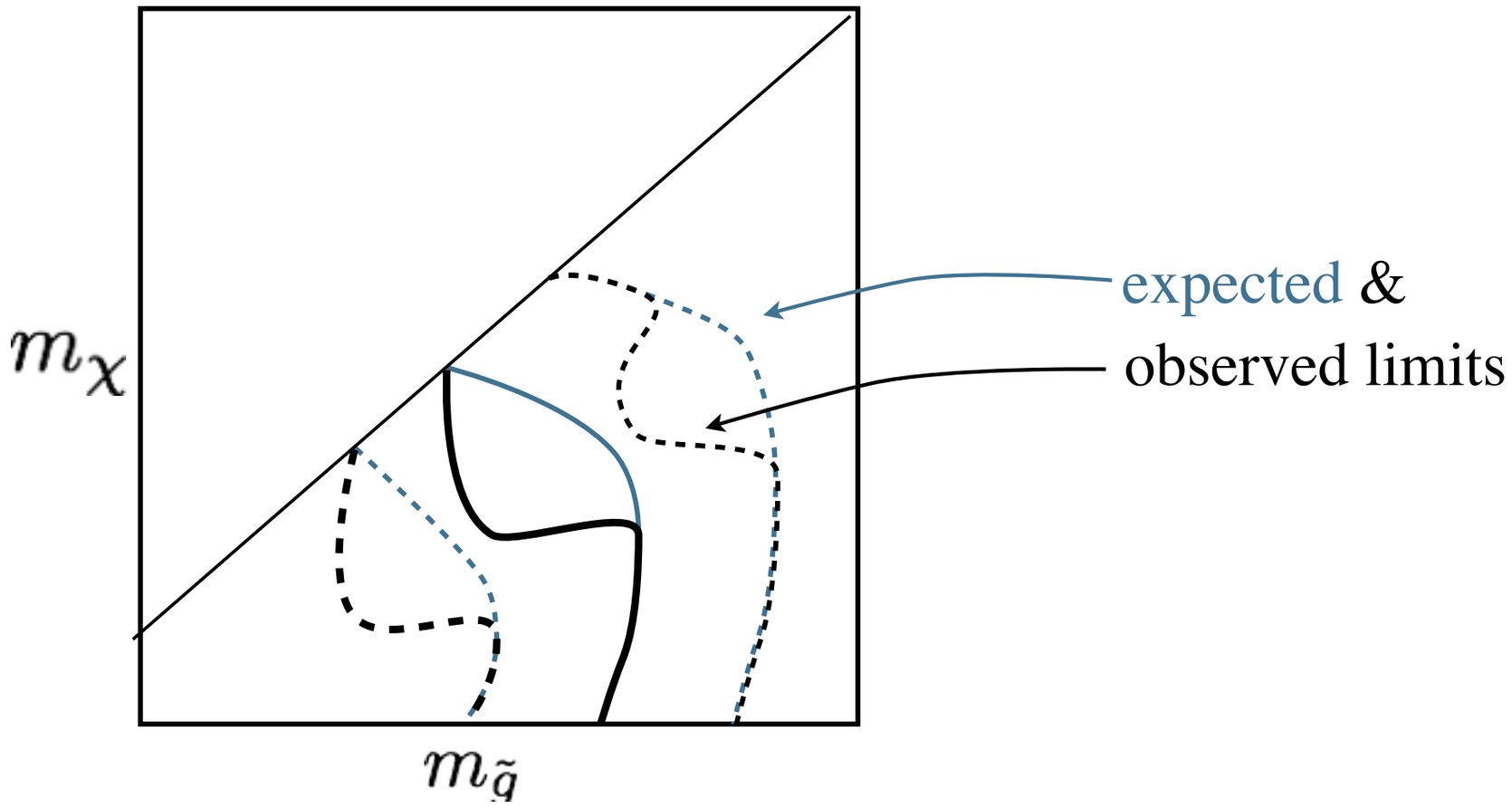


D. Alves, E. Izaguirre, and J. Wacker (arXiv: 1003.3886, 1008.0407)

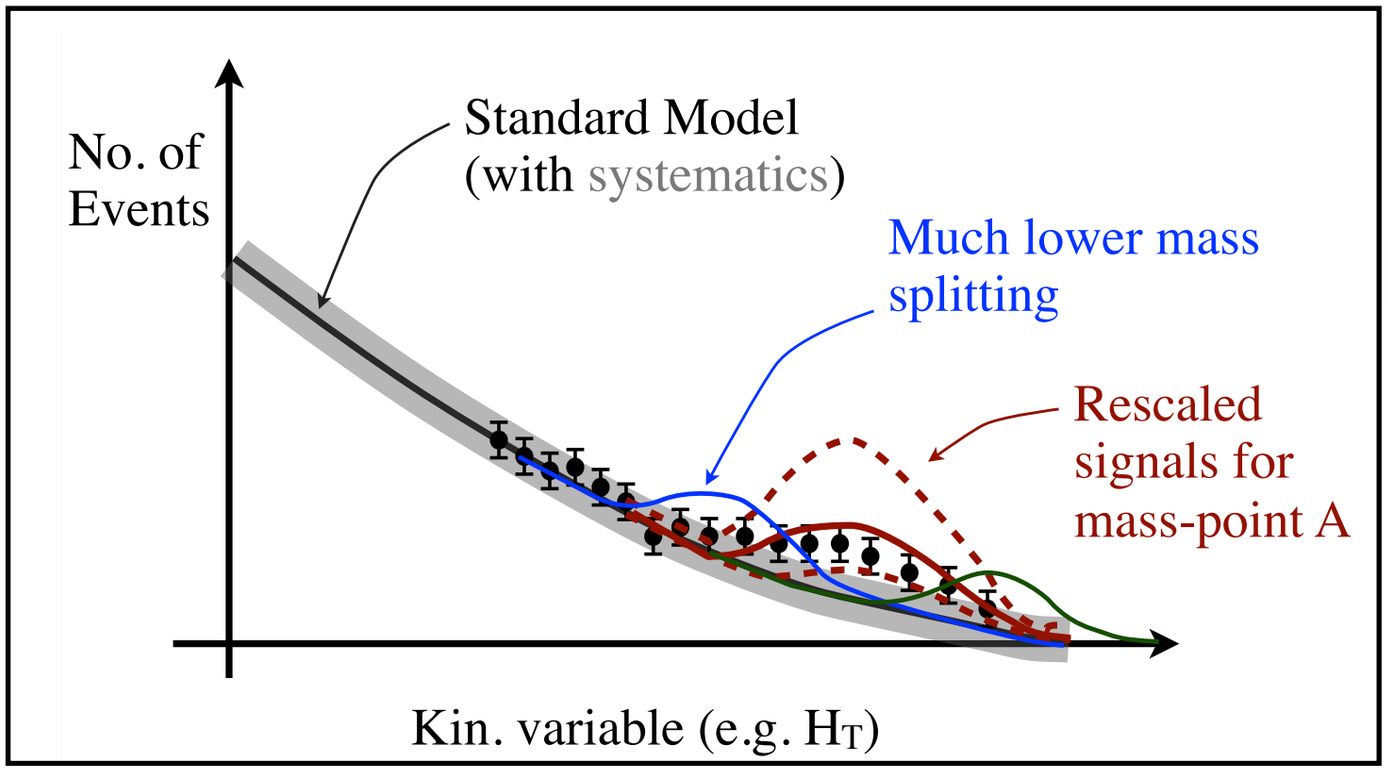
Discovery!

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

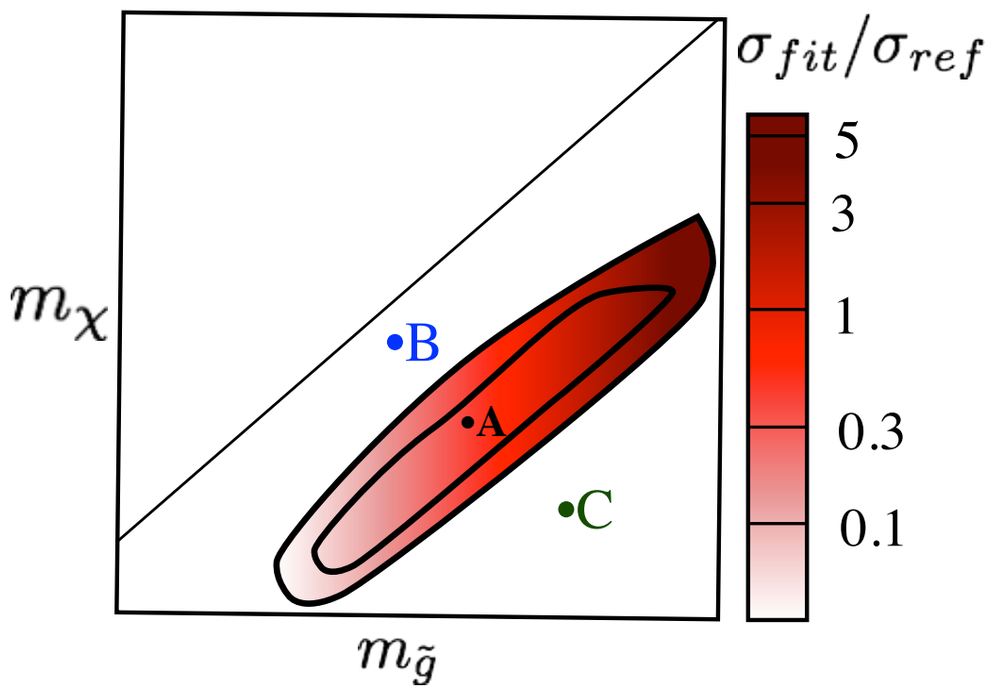


Characterize Signal

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



χ^2 contours with rate chosen for best fit

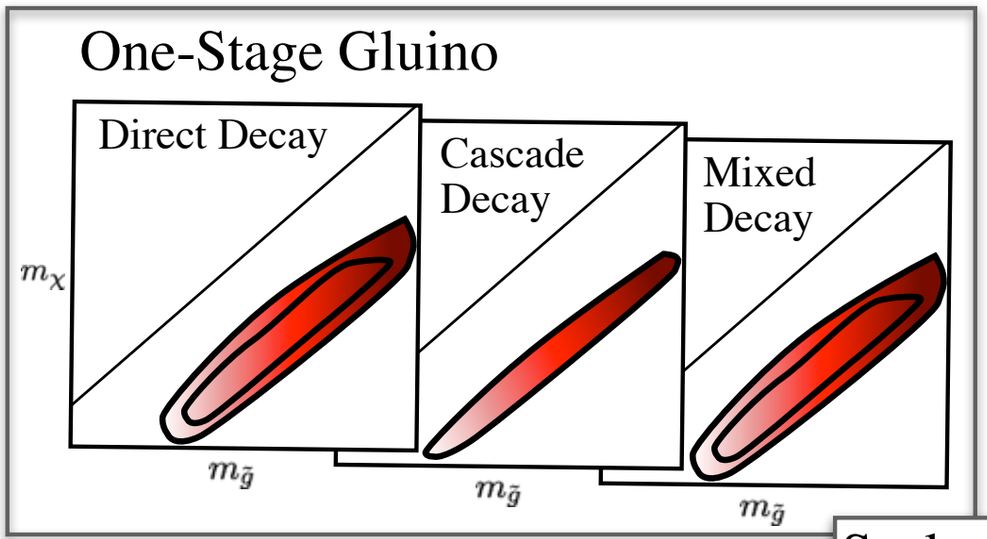


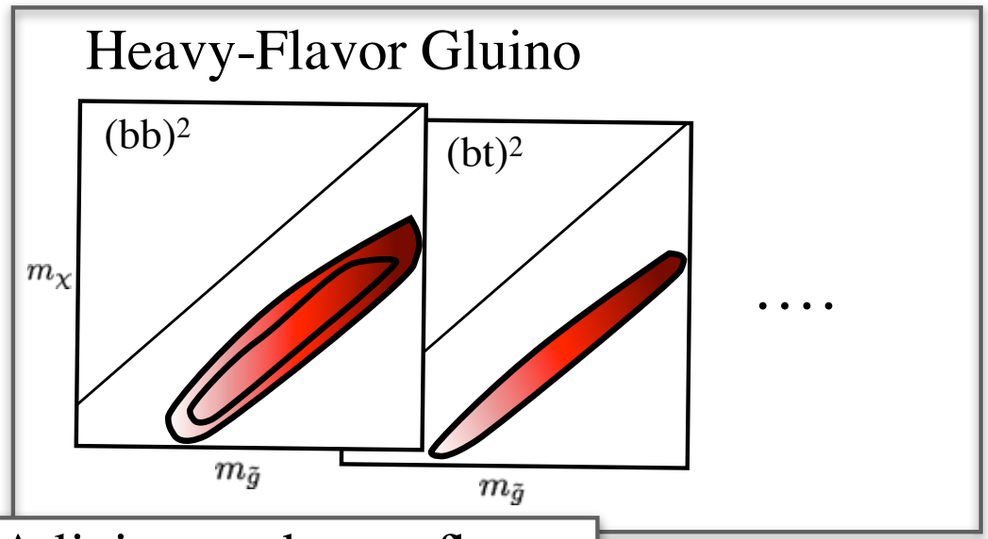
Figures from Natalia Toro

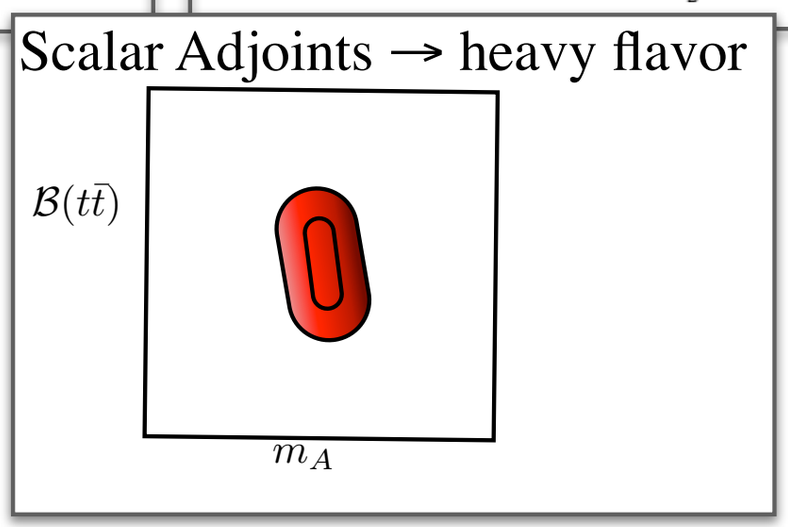
Multiple Searches

Similar plots for various simplified models with same final-state

Statistical comparison allows for model prioritization







Figures from Natalia Toro

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

Borrowed from Natalia Toro

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

lhcnewphysics.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. Francescini
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

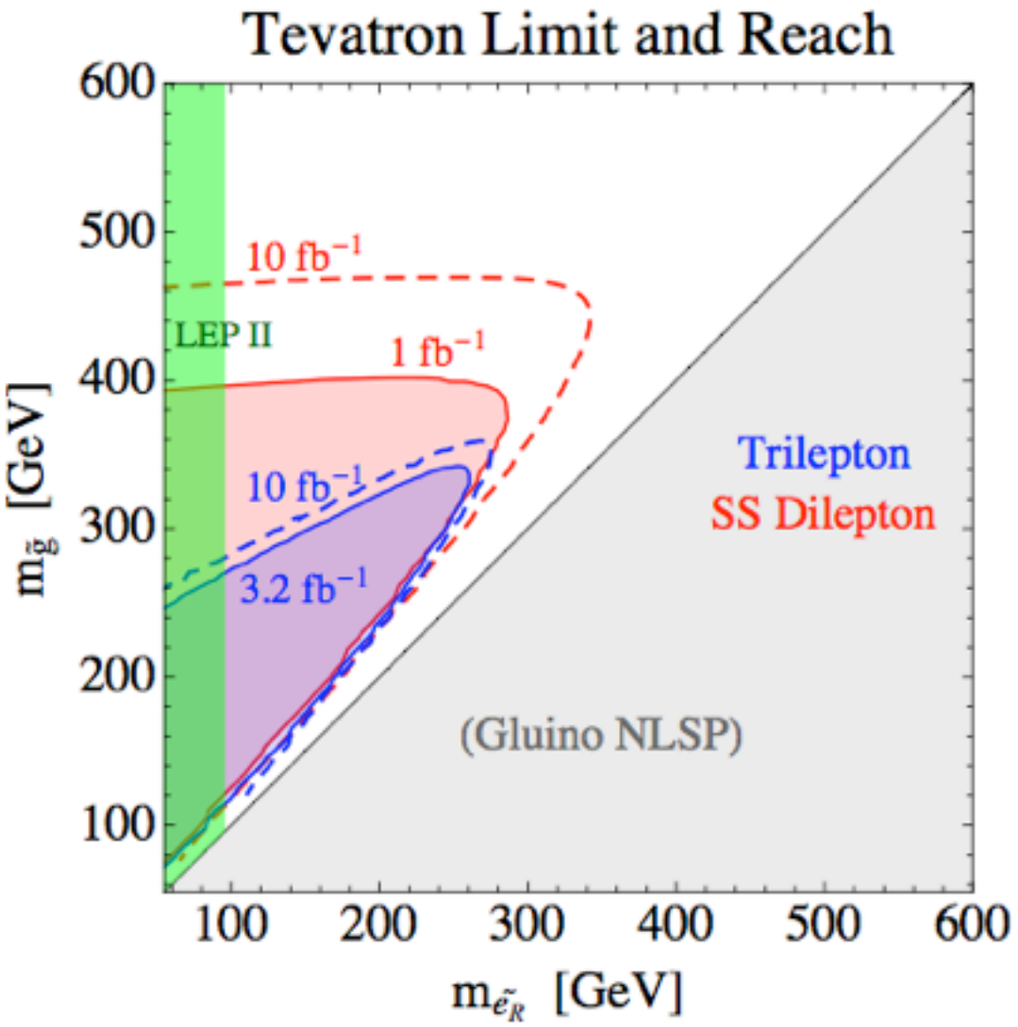
Example 1:

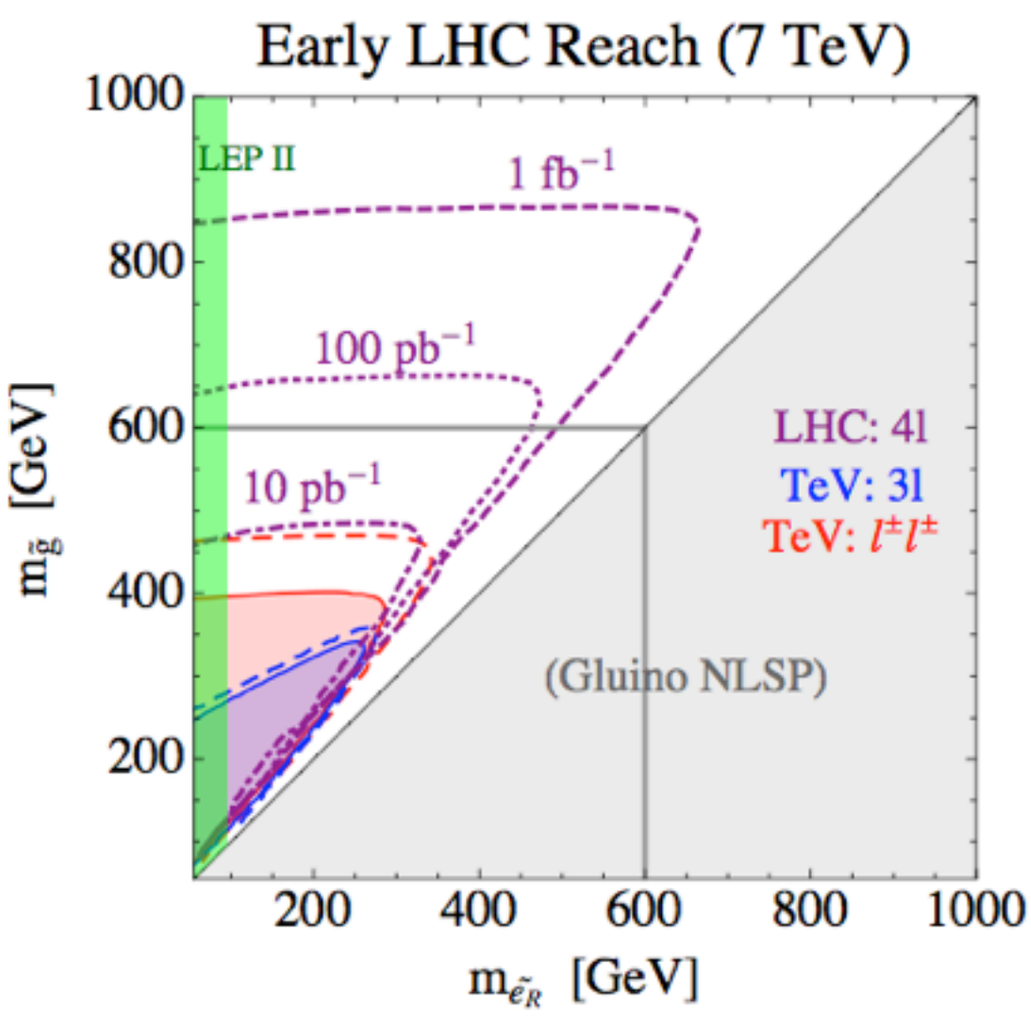
Multilepton GMSB

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

Inspired by gauge mediation models with slepton NLSP

$$\tilde{g} \to 2j + \widetilde{B}$$
$$\hookrightarrow l + \tilde{l}$$
$$\hookrightarrow l + \tilde{G}$$





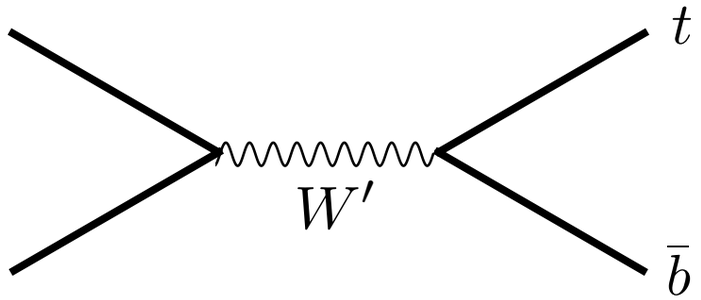
Example 2:

W′ Resonance

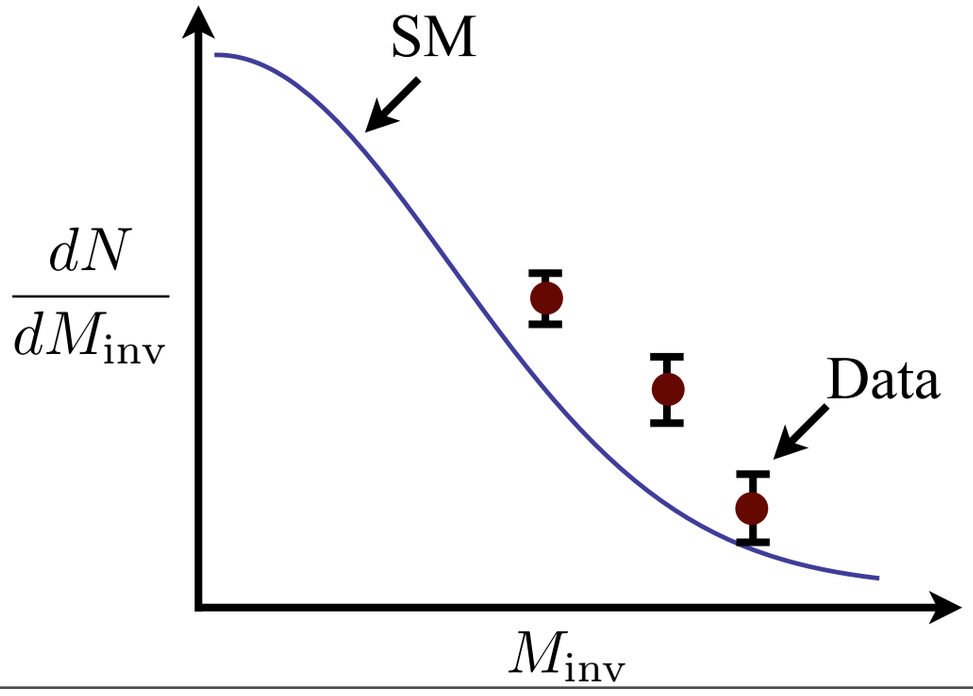
R. Chivukula, L. Fitzpatrick, P. Ko, K.Rehermann, M. Schmaltz,
M. Schwartz, E. Simmons, C. Spethmann, T. Tait, W. Waltenberger

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

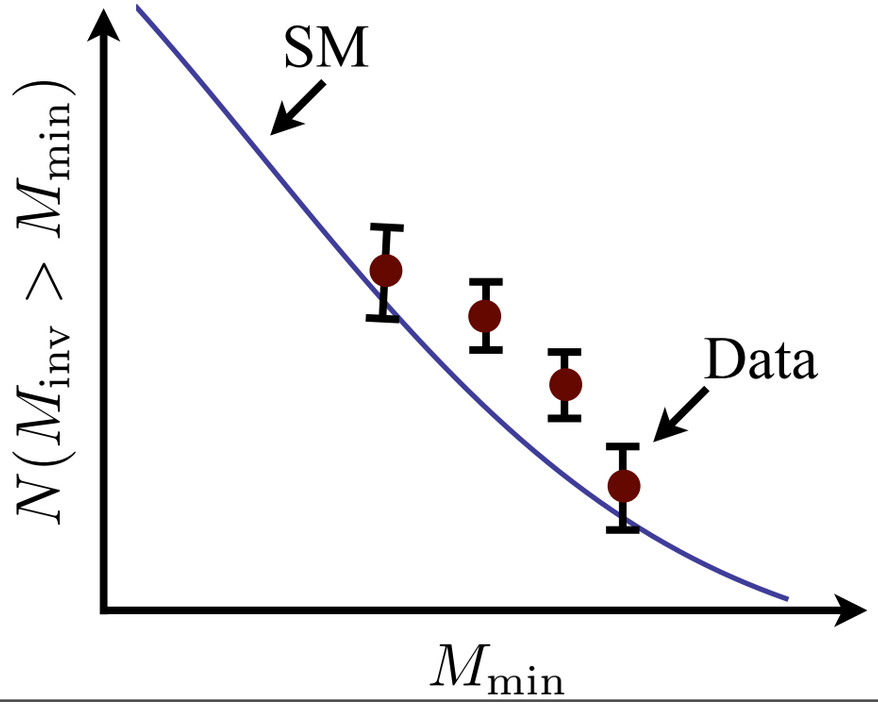
Decays to third-generation quarks are promising discovery channel



Invariant Mass Distribution



Events at High M_{inv}



Example 2:

W′ Resonance

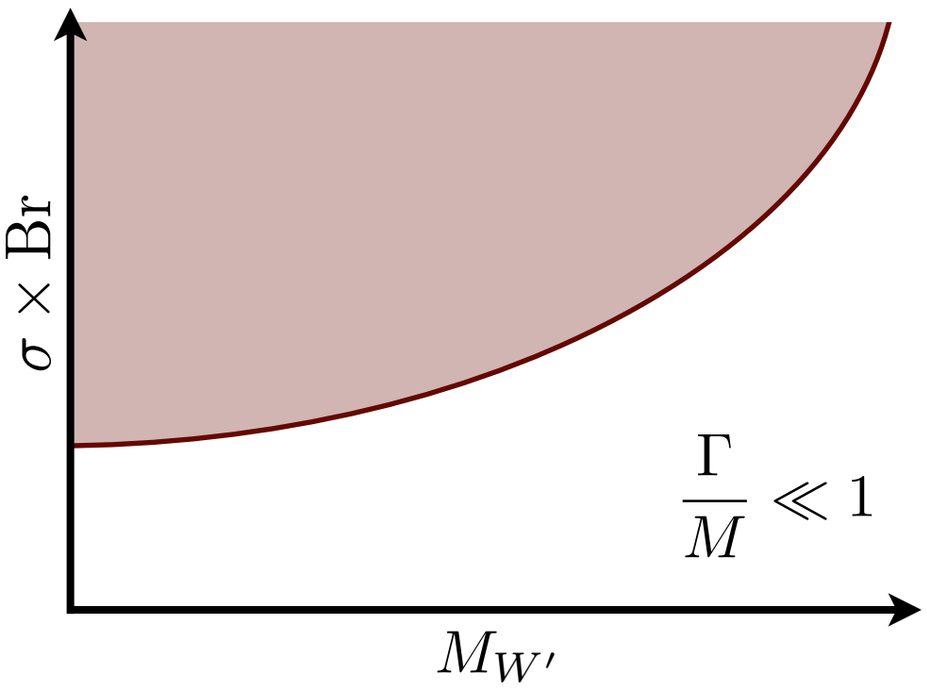
R. Chivukula, L. Fitzpatrick, P. Ko, K.Rehermann, M. Schmaltz,
M. Schwartz, E. Simmons, C. Spethmann, T. Tait, W. Waltenberger

Many theory models can give W′ vector bosons

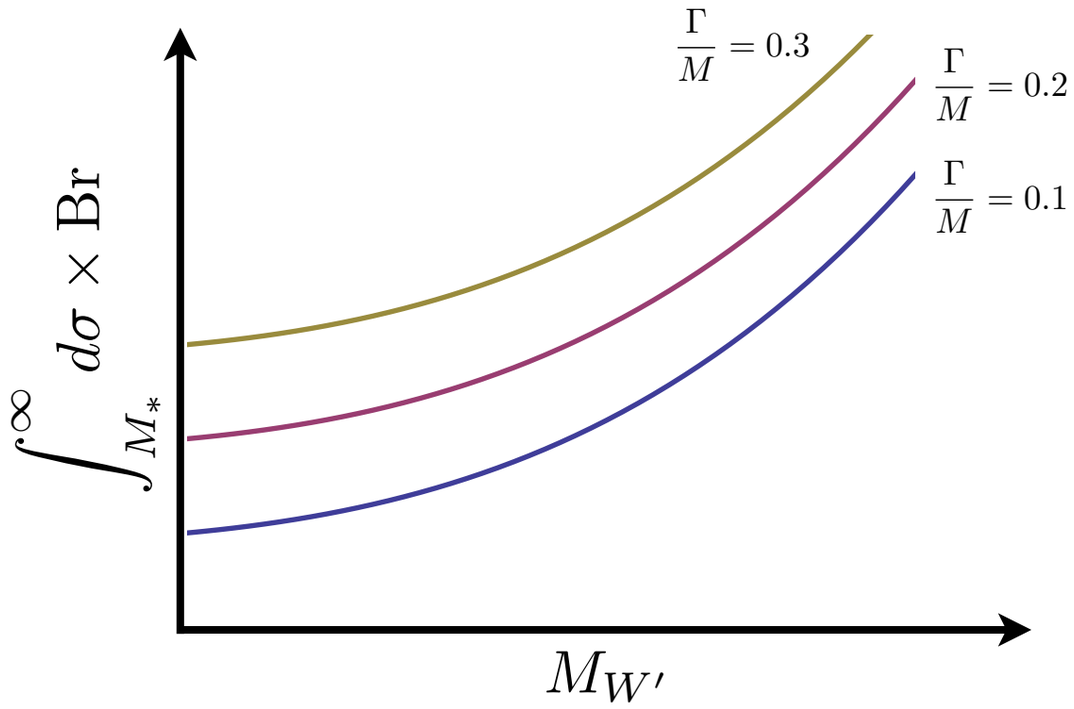
i.e., extra dimensions, left-right models, technicolor, ...

Significance/Exclusion plots should be model-independent

Narrow Resonance



Broad Resonance



Example 3:

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

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

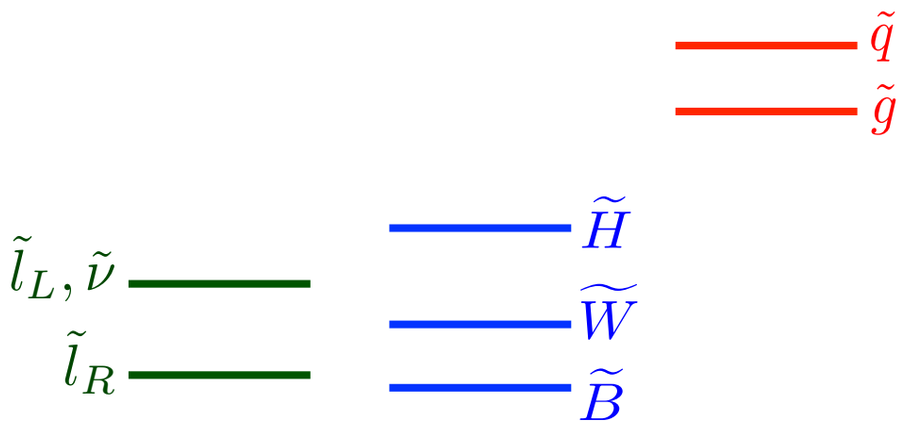
Inspired by gauge mediation models with Gravitino LSP

$$\widetilde{B} \to \gamma + \widetilde{G}$$

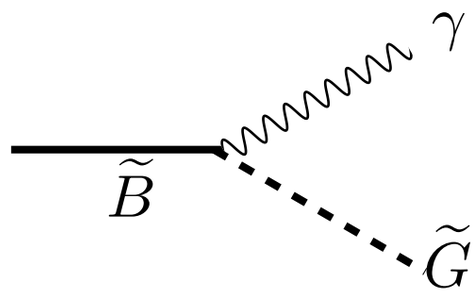
(Bino NLSP)

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:

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

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

Inspired by gauge mediation models with Gravitino LSP

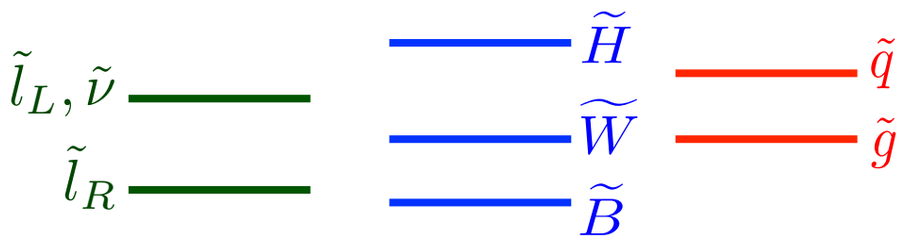
$$\widetilde{B} \to \gamma + \widetilde{G}$$

(Bino NLSP)

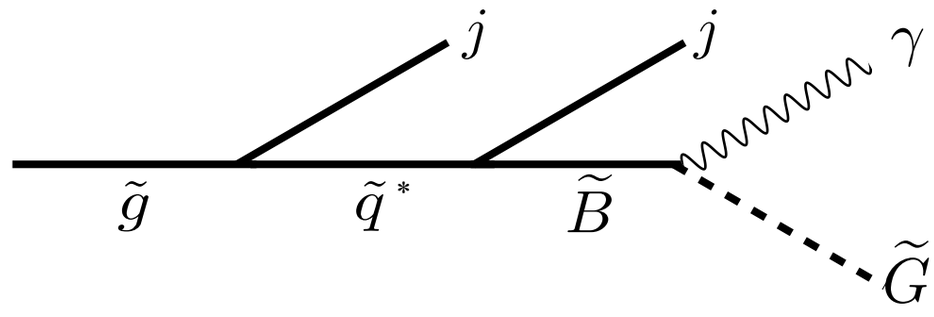
Simplified model with light colored states and bino NLSP

Motivated by General Gauge Mediation

More compressed spectrum



Enhancement from colored production



Example 4:

High Multiplicity

M. Baumgart, J. Hubisz, K. Zurek

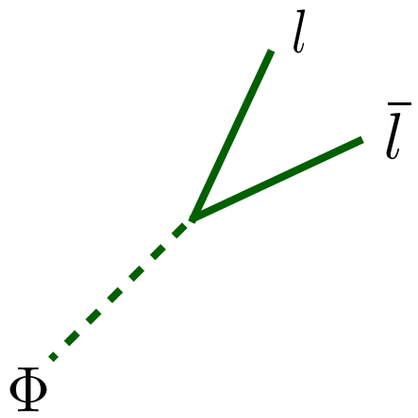
Effective Theory Description

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

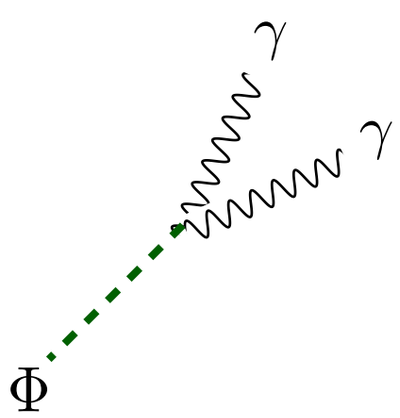
Very broad class of models lead to high multiplicity of events

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

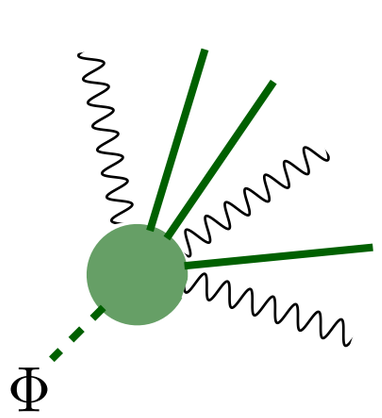
Di-lepton resonance + X



Di-photon resonance + X

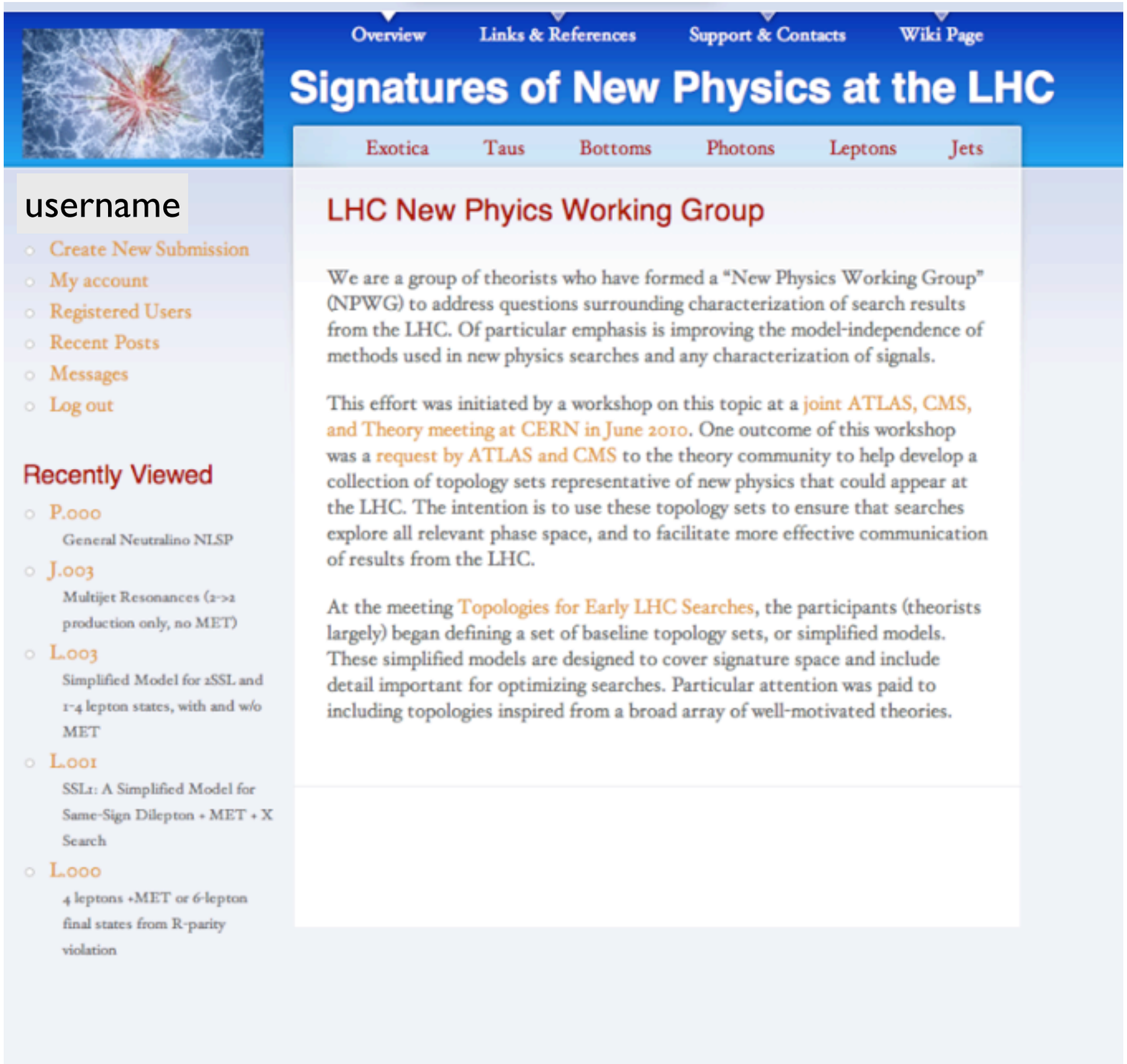


High H_T

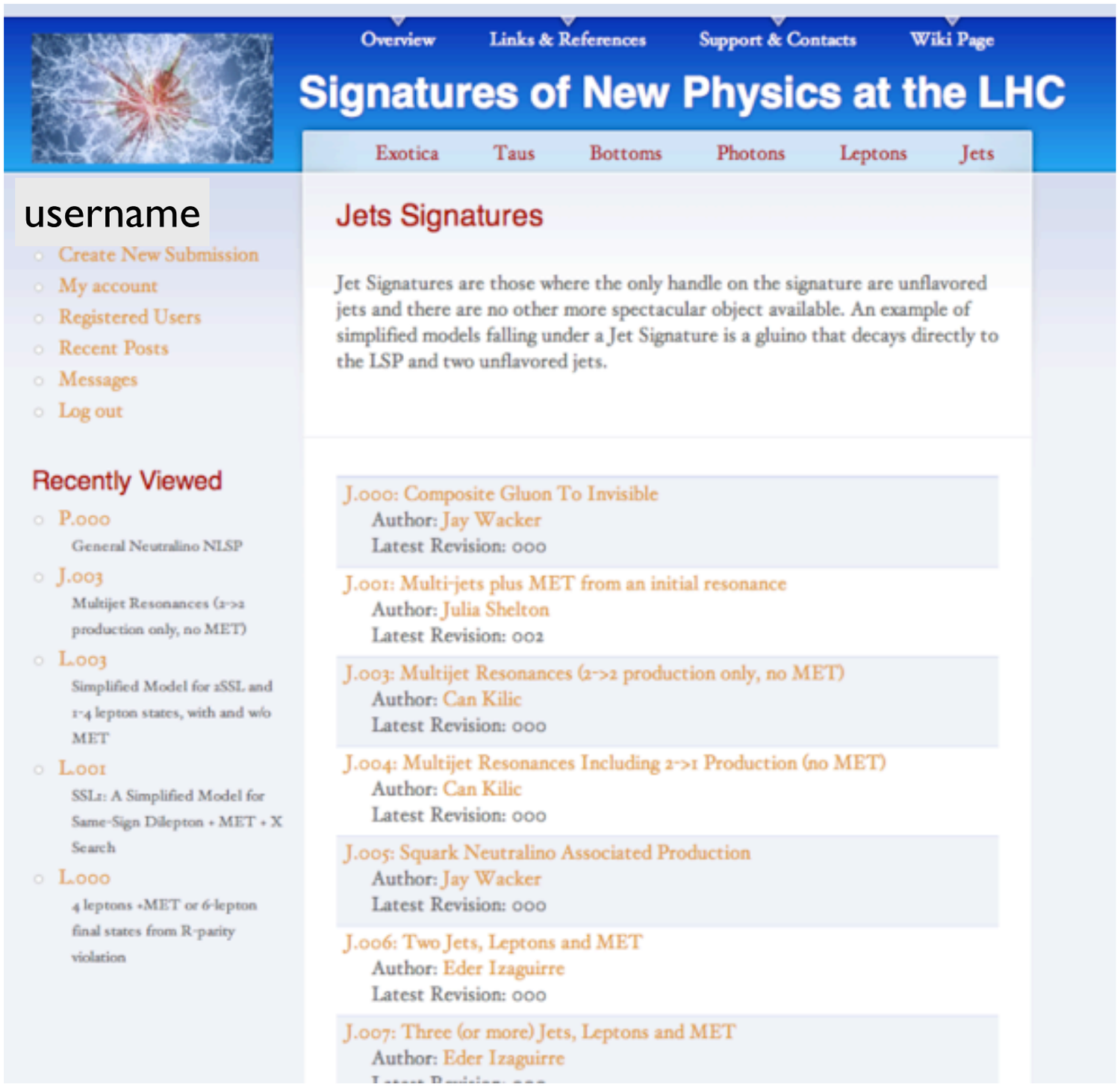


High HT trigger, modified lepton isolation requirements

LHCNewPhysics.org



LHCNewPhysics.org



← Organized by signature
Search for keywords

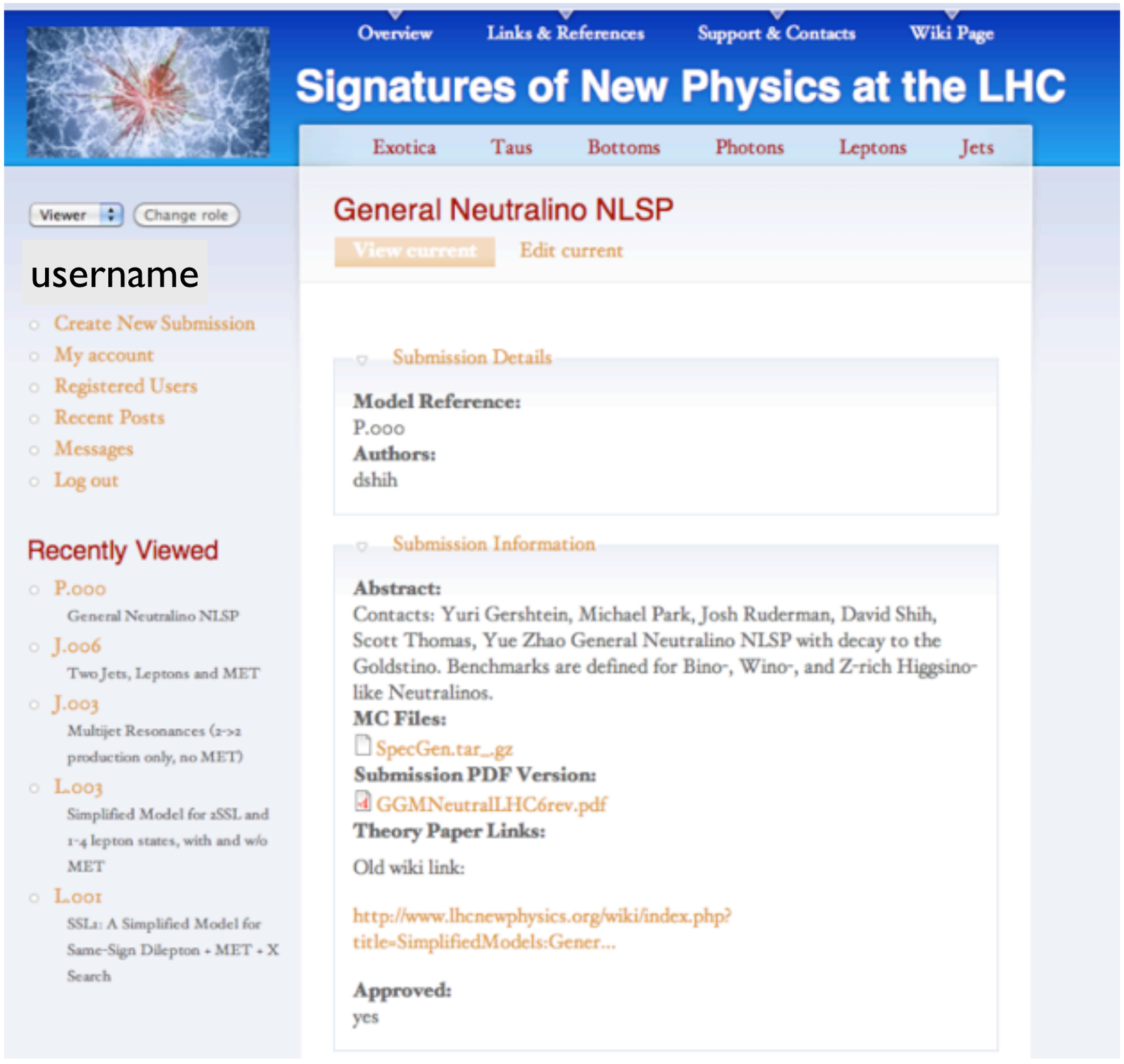
← Brief write-ups

Download MC files, talks, etc

Easy to update

Work in progress
Feedback welcome

LHCNewPhysics.org



Conclusions

Simplified Models are a convenient way of parameterizing new physics

O(50) simplified models have been proposed

Check **lhcnewphysics.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

Gluino Heavy Flavor

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

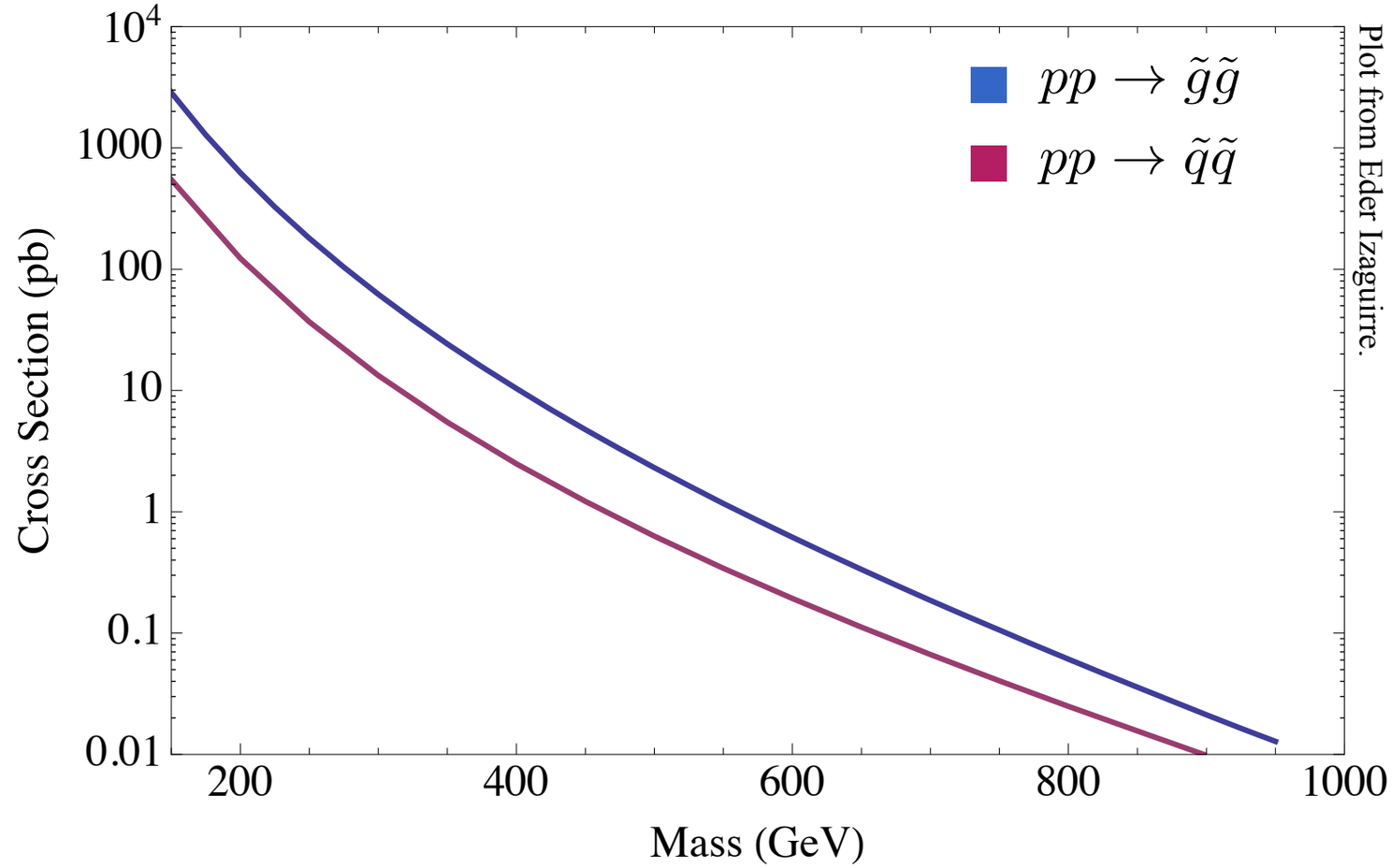
Probe heavy flavor physics through gluino decays

Decays to top pairs challenging with early data

Decays to bottom quarks are promising

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

$$G \to tbC_1^{\pm}$$



Event Generation

Generate signal and background events

MadGraph → Pythia → PGS

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

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 Bremstrahlung

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 Bremstrahlung

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

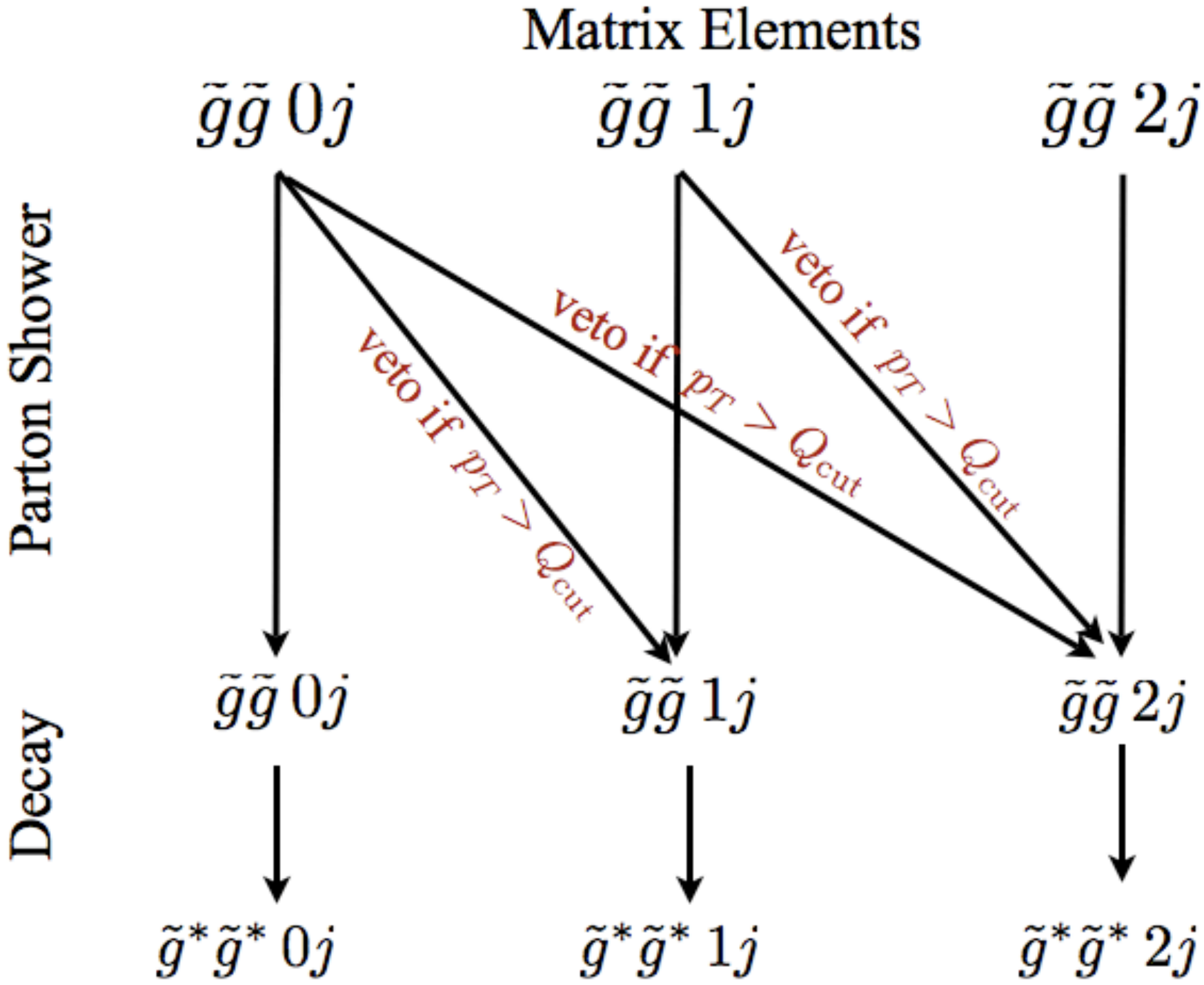
Computationally expensive

Limited number of partons

Matching combines both techniques

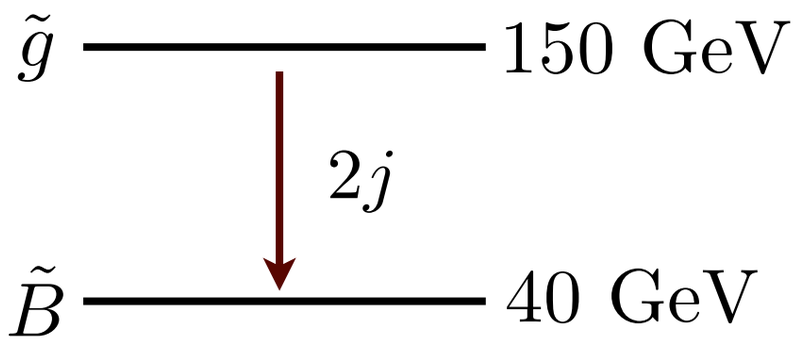
Necessary to avoid double-counting of events

Matching Procedure



Effects of Matching

Large mass difference between gluino & bino

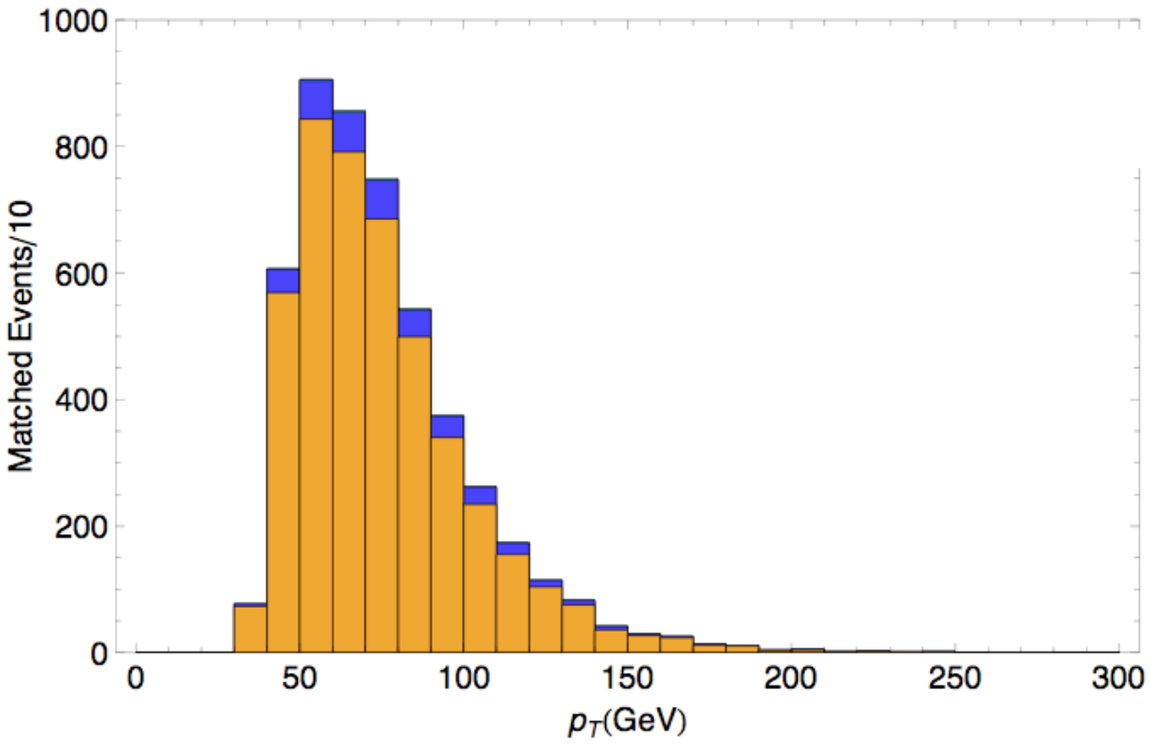


: $\tilde{g}\tilde{g} + 0j$

: $\tilde{g}\tilde{g} + 1j$

: $\tilde{g}\tilde{g} + 2j$

Matched



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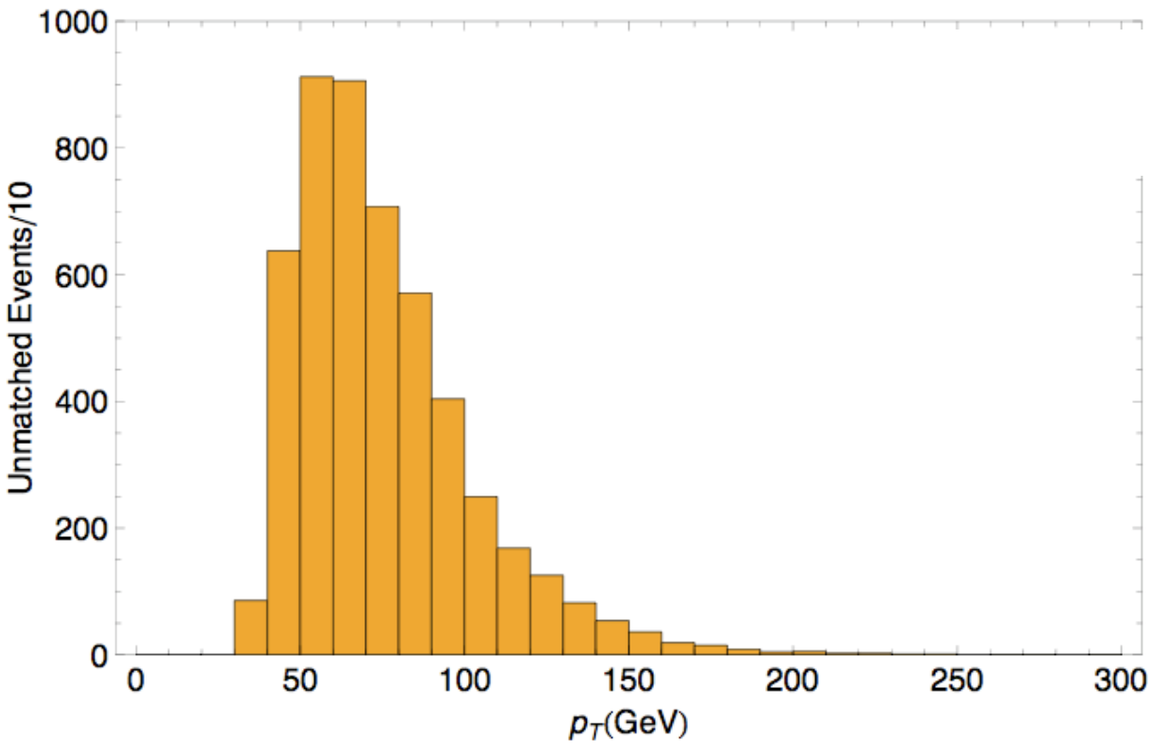
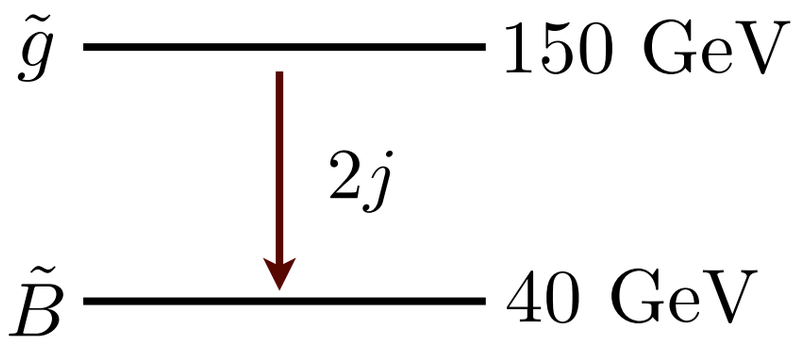


Effects of Matching

Large mass difference between gluino & bino

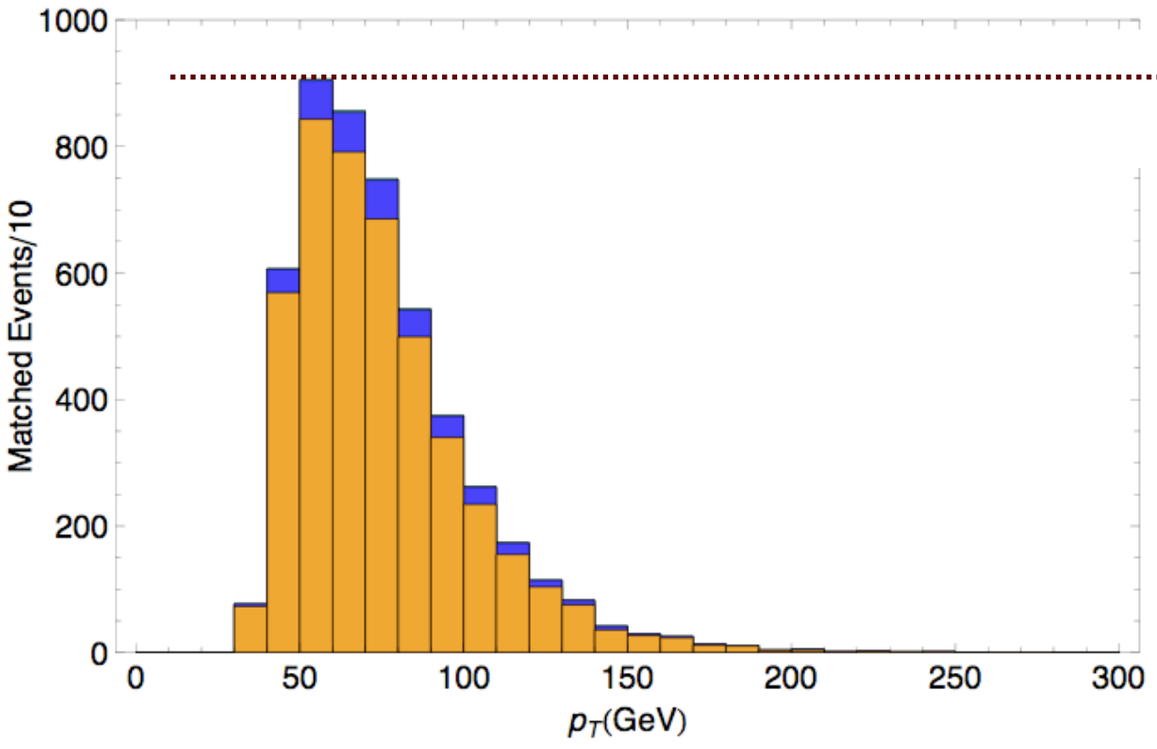


: $\tilde{g}\tilde{g} + 0j$

: $\tilde{g}\tilde{g} + 1j$

: $\tilde{g}\tilde{g} + 2j$

Matched



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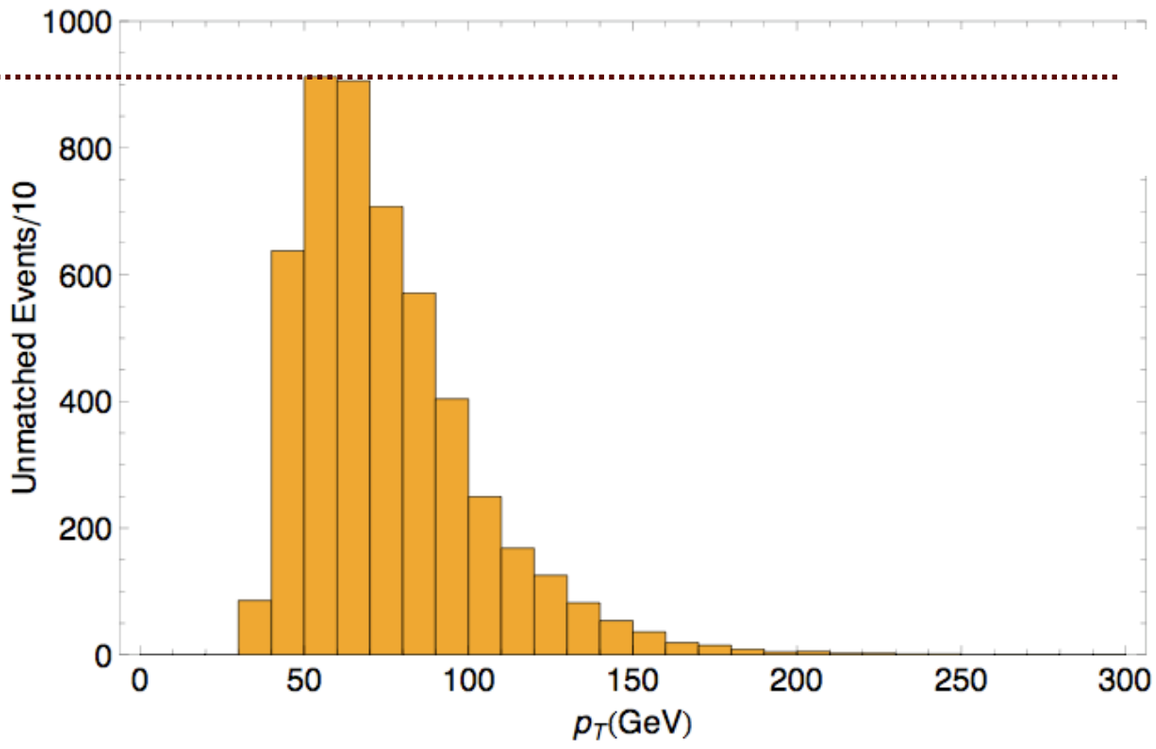
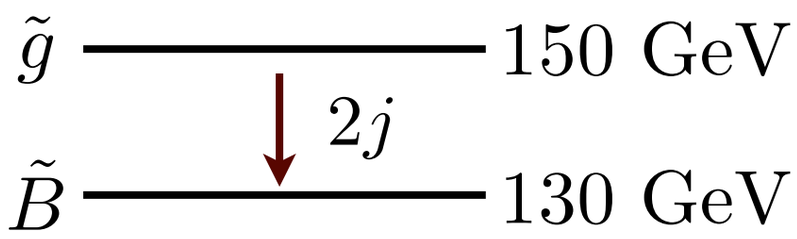


Effects of Matching

Nearly-degenerate gluino and bino

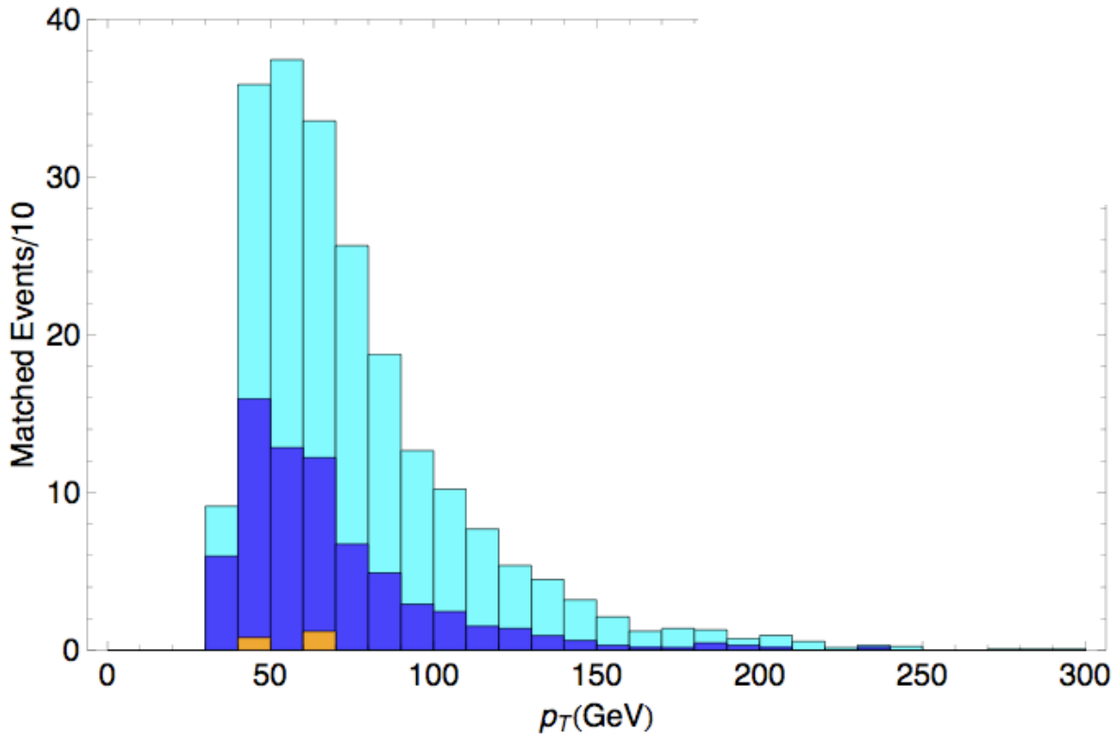


: $\tilde{g}\tilde{g} + 0j$

: $\tilde{g}\tilde{g} + 1j$

: $\tilde{g}\tilde{g} + 2j$

Matched



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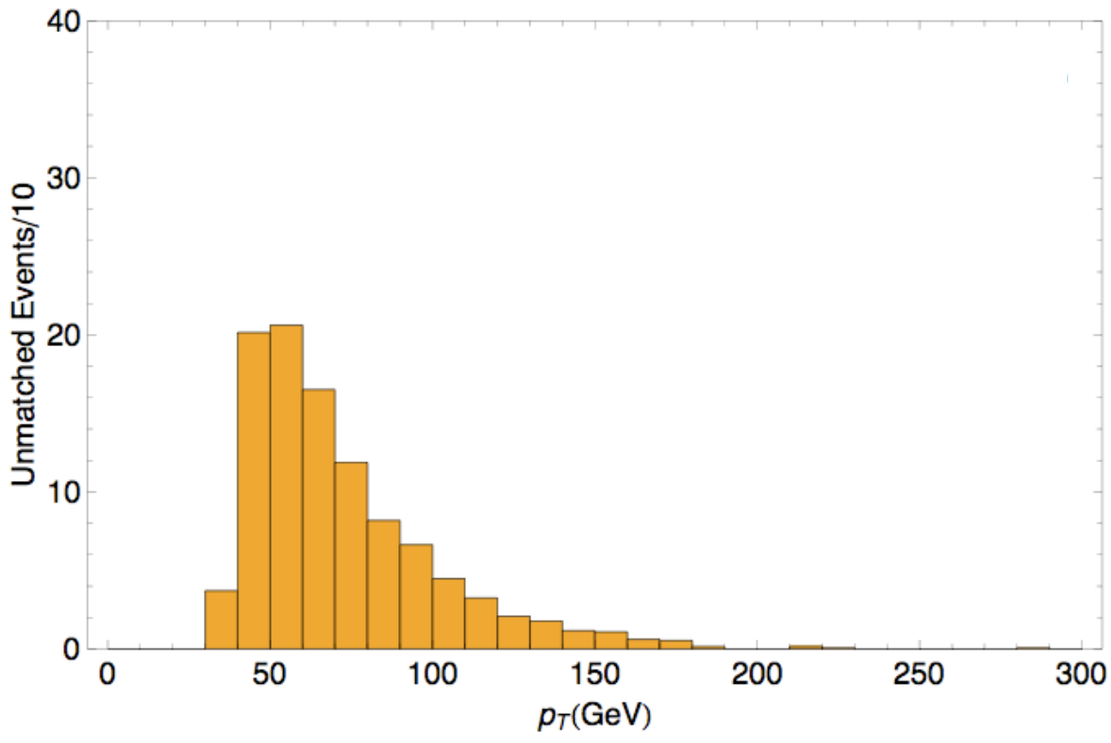
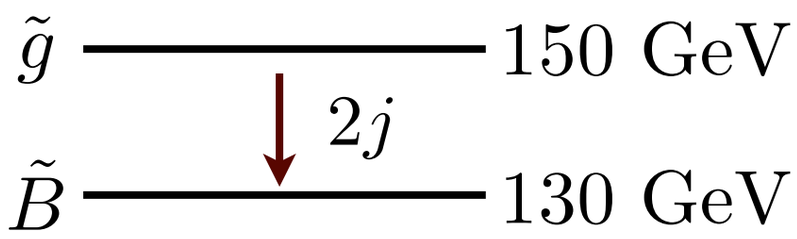


Effects of Matching

Nearly-degenerate gluino and bino



: $\tilde{g}\tilde{g} + 0j$

: $\tilde{g}\tilde{g} + 1j$

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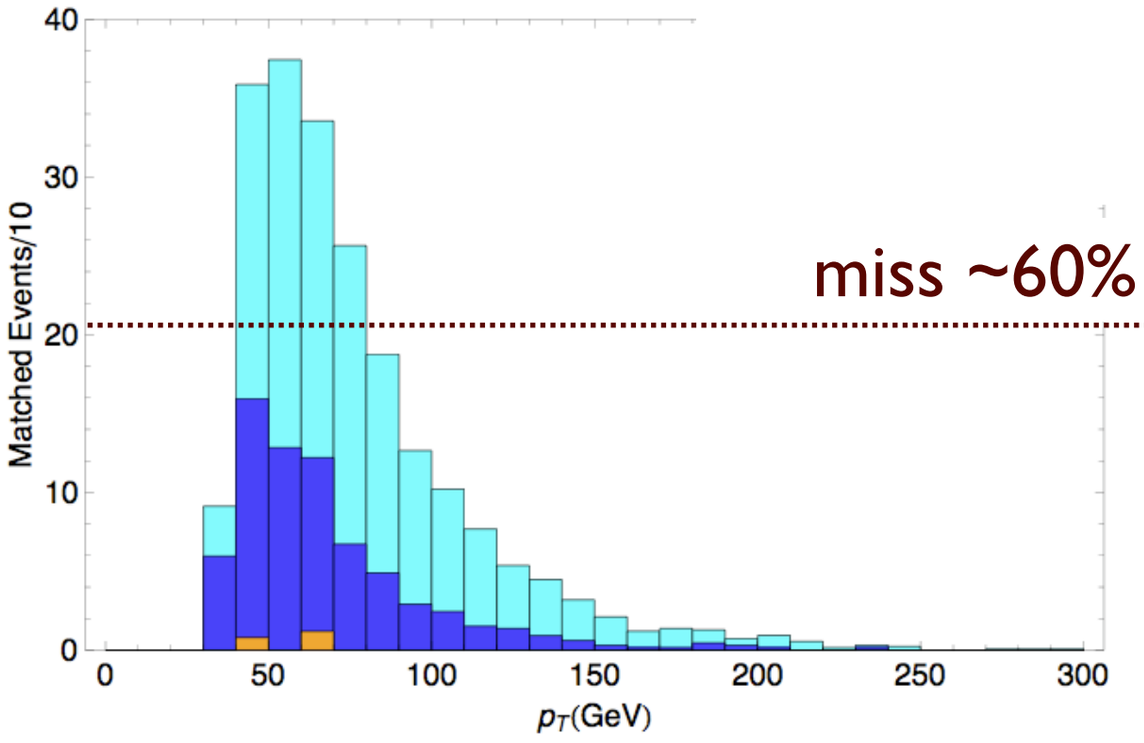
Matched



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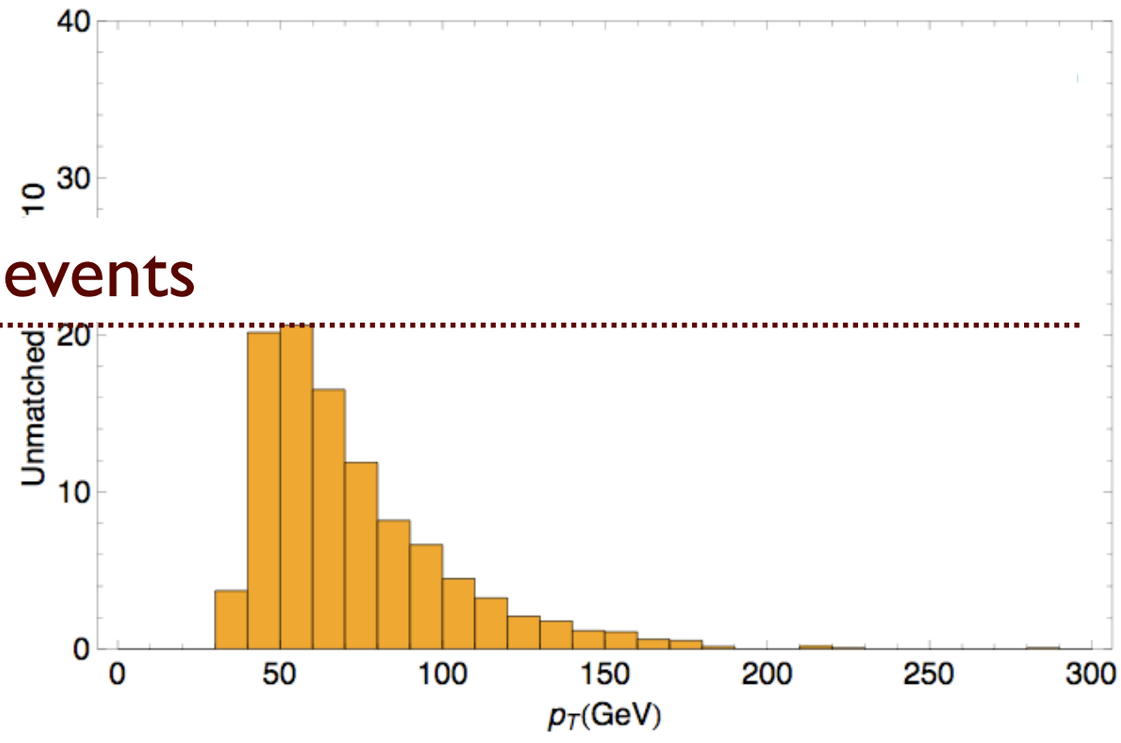

miss ~60% of events