Recasting Susy

Jay Wacker

HEFTI Workshop on SUSY Recast

April 9, 2011

work with

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Outline

Simplified Models

Current Limits

Needed Topologies for the Closure Test

From Anomalies to Discoveries

Simplified Models

(Effective Field Theories for Collider Physics)

Limits of specific theories

Only keep particles and couplings relevant for searches

A full Lagrangian description

Removes superfluous model parameters

Masses, Cross Sections, Branching Ratios

Add in relevant modification to models (*e.g.* singlets)

Not fully model independent, but greatly reduce model dependence

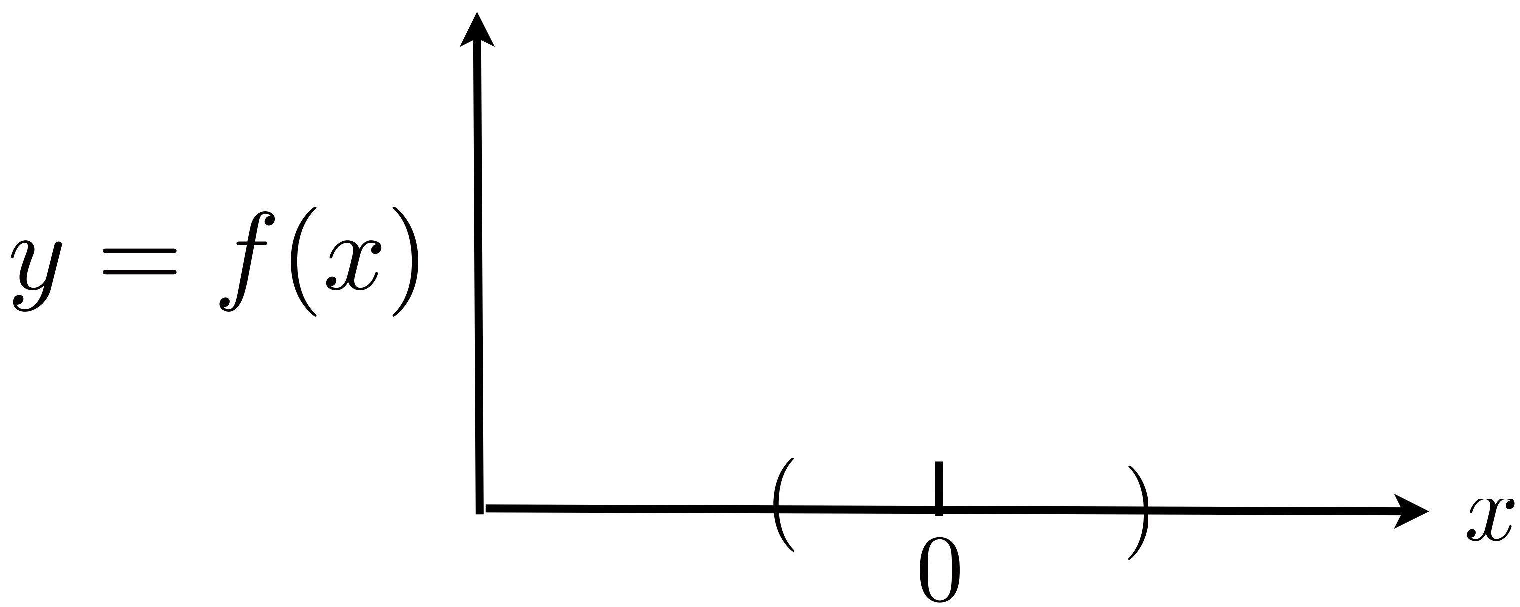
Captures specific models

Including ones that aren't explicitly proposed

Easy to explore

Imagine a simple world...

Theory of nature is a single variable function, *y=f(x)*,
Can only do measurements of *y* near *x=0*



A very complicated space to explore!

∞-dimensional

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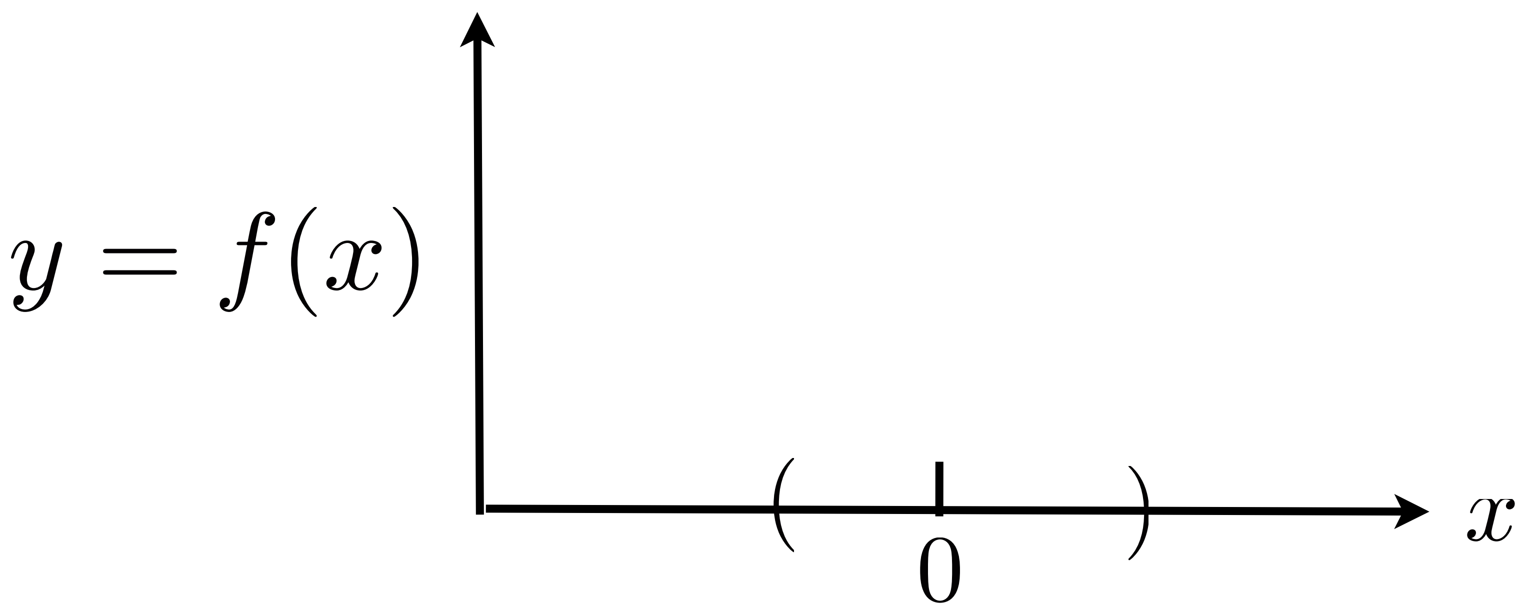

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∞-dimensional

In this world, the leading theory is $f(x) = e^{\alpha(x-x_0)}$

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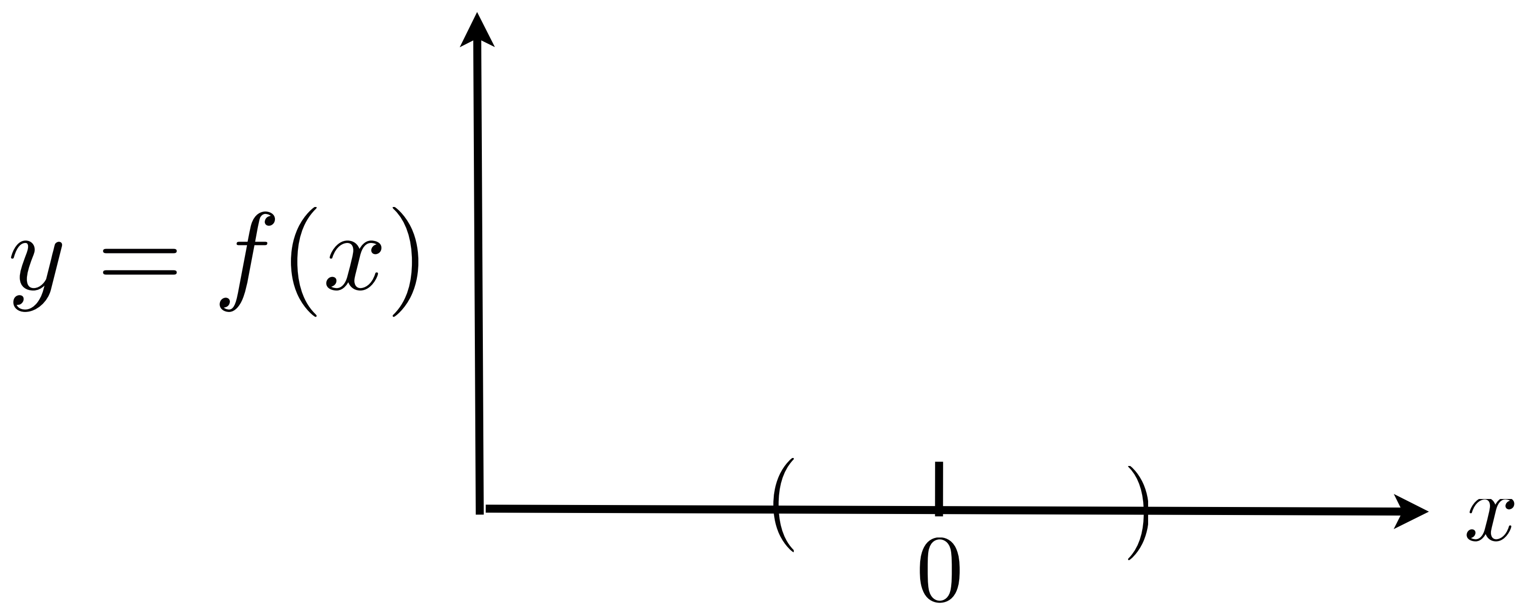

A very complicated space to explore!

∞-dimensional

In this world, the leading theory is $f(x) = e^{\alpha(x - x_0)}$

Could design a measurement strategy to discover

$$f(x) \neq 0,\ \alpha,\ x_0$$

Problem with this strategy

What happens if we're wrong about
our theoretical assumption?

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our theoretical assumption?

$$f(x) = -e^{\alpha(x-x_0)}$$

f(x) is negative

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f(x) is negative

$$f(x) = \sinh(x)$$

f(x) vanishes at 0

Problem with this strategy

What happens if we're wrong about our theoretical assumption?

$f(x) = -e^{\alpha(x-x_0)}$	*f(x)* is negative
$f(x) = \sinh(x)$	*f(x)* vanishes at 0
$f(x) = \cos(x)$	Doesn't grow asymptotically

Problem with this strategy

What happens if we're wrong about
our theoretical assumption?

$$f(x) = -e^{\alpha(x-x_0)}$$

f(x) is negative

$$f(x) = \sinh(x)$$

f(x) vanishes at 0

$$f(x) = \cos(x)$$

Doesn't grow asymptotically

Could enumerate all possibilities

Problem with this strategy

What happens if we're wrong about
our theoretical assumption?

$$f(x) = -e^{\alpha(x-x_0)}$$ *f(x)* is negative

$$f(x) = \sinh(x)$$ *f(x)* vanishes at 0

$$f(x) = \cos(x)$$ Doesn't grow asymptotically

Could enumerate all possibilities

<u>A better strategy</u>

Mr. Taylor

$$f(x) = a_0 + a_1 x + a_2 x^2 + \cdots$$

Easy to identify special cases
(any systematic approximation)

Not a cure-all

Still infinite dimensional

But there is some notion of simplicity

$f(x) = -x^6 + x^{12}$ less likely than $f(x) = 1$

Not a cure-all

Still infinite dimensional

But there is some notion of simplicity

$f(x) = -x^6 + x^{12}$ less likely than $f(x)=1$

<u>There could be technicalities:</u>

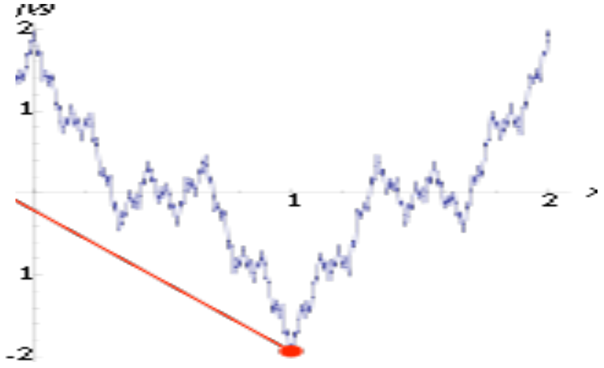
Radius of convergence problems

$$f(x) = \log(1+x)$$

Assumes the function is continuous/differentiable

$$f(x) = \Theta(x)$$

$$f(x) = \sum_{n=0}^{\infty} a^n \cos(b^n \pi x)$$



Simplified Models

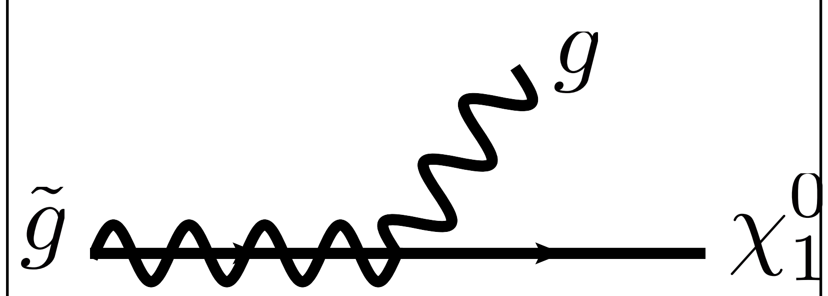
Direct Decays

MASS

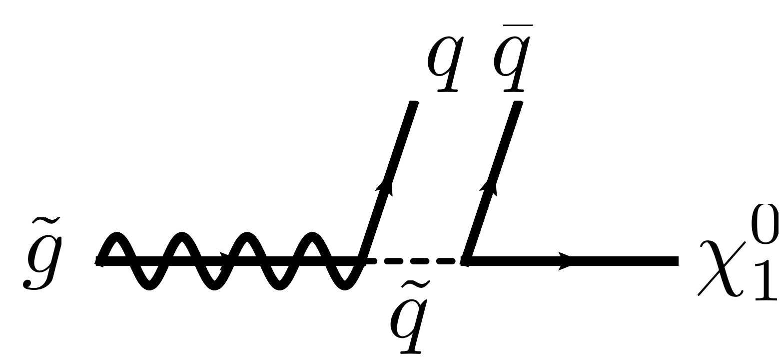
color octet majorana fermion ("Gluino")

neutral majorana fermion ("Bino")

TWO-BODY

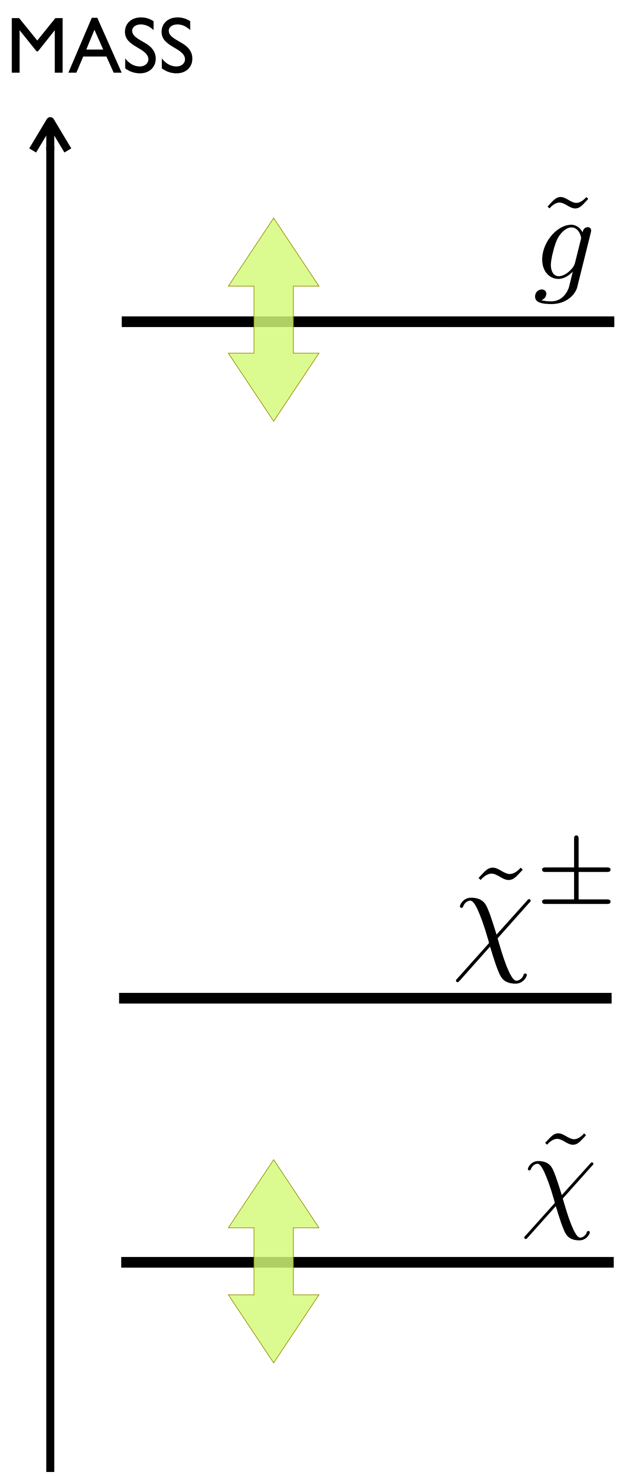


THREE-BODY



Simplified Models

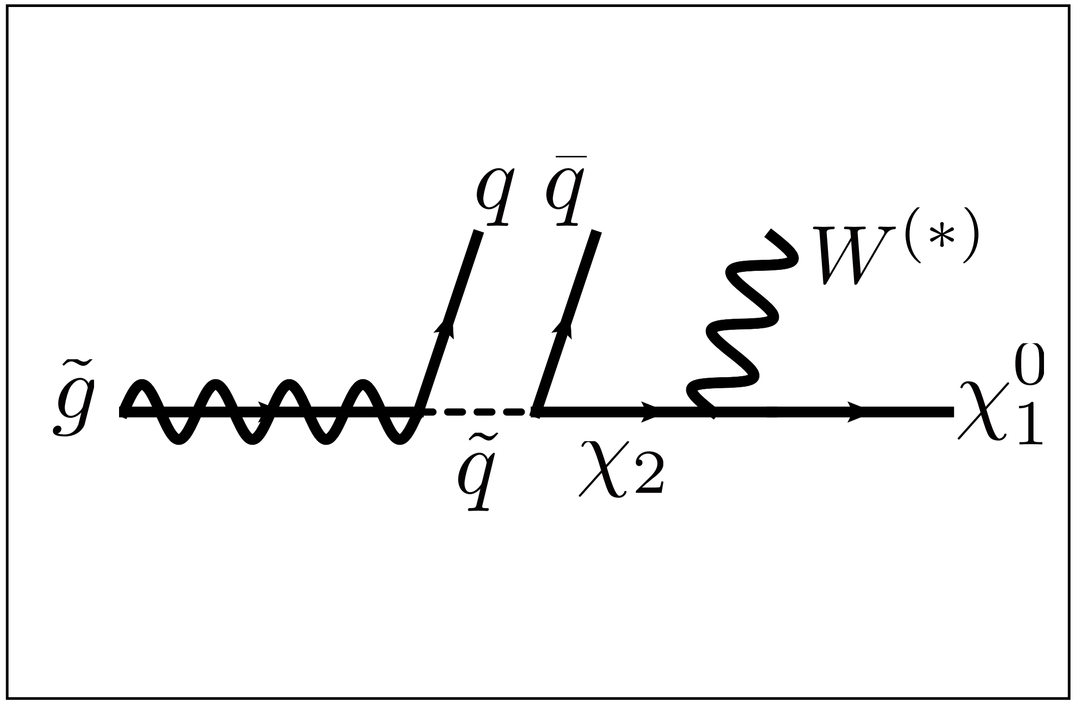
One-Step Cascade Decays



color octet majorana fermion ("Gluino")

electroweak majorana fermion ("Wino")

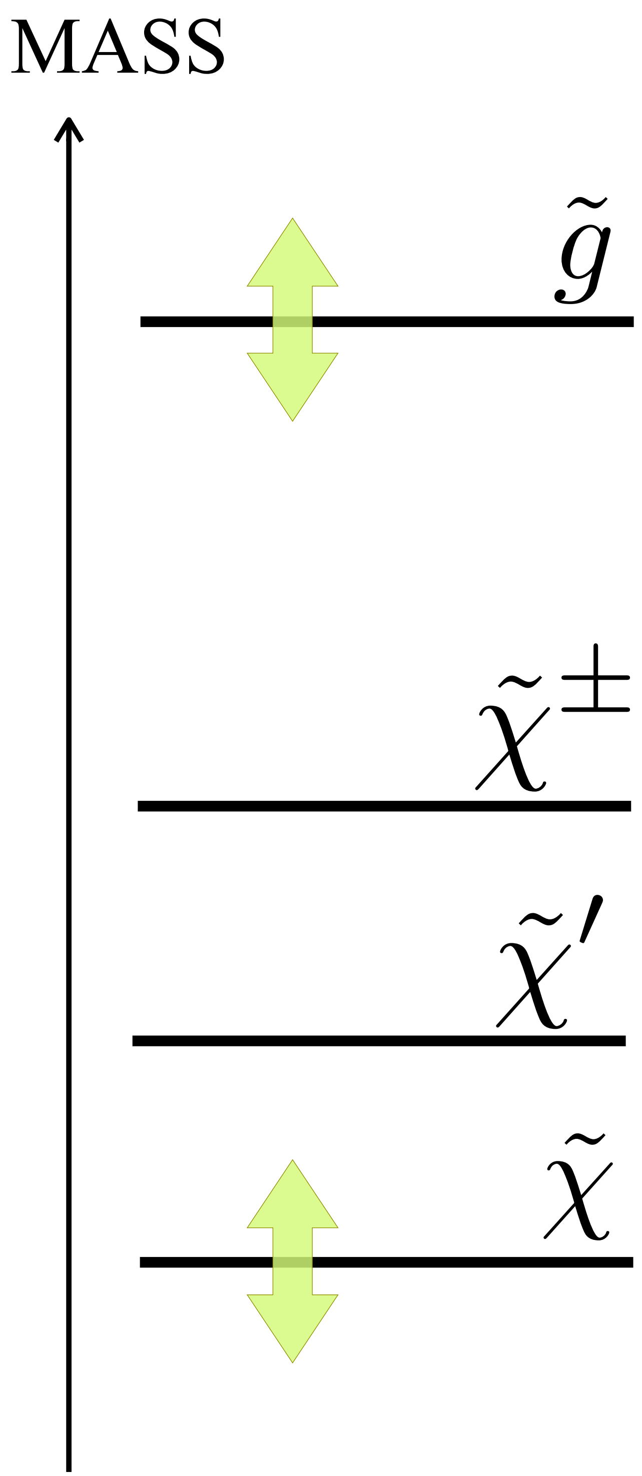
neutral majorana fermion ("Bino")



$$m_{\tilde{\chi}^{\pm}} = m_{\tilde{\chi}} + \frac{1}{4}(m_{\tilde{g}} - m_{\tilde{\chi}})$$

Simplified Models

Two-Step Cascade Decays

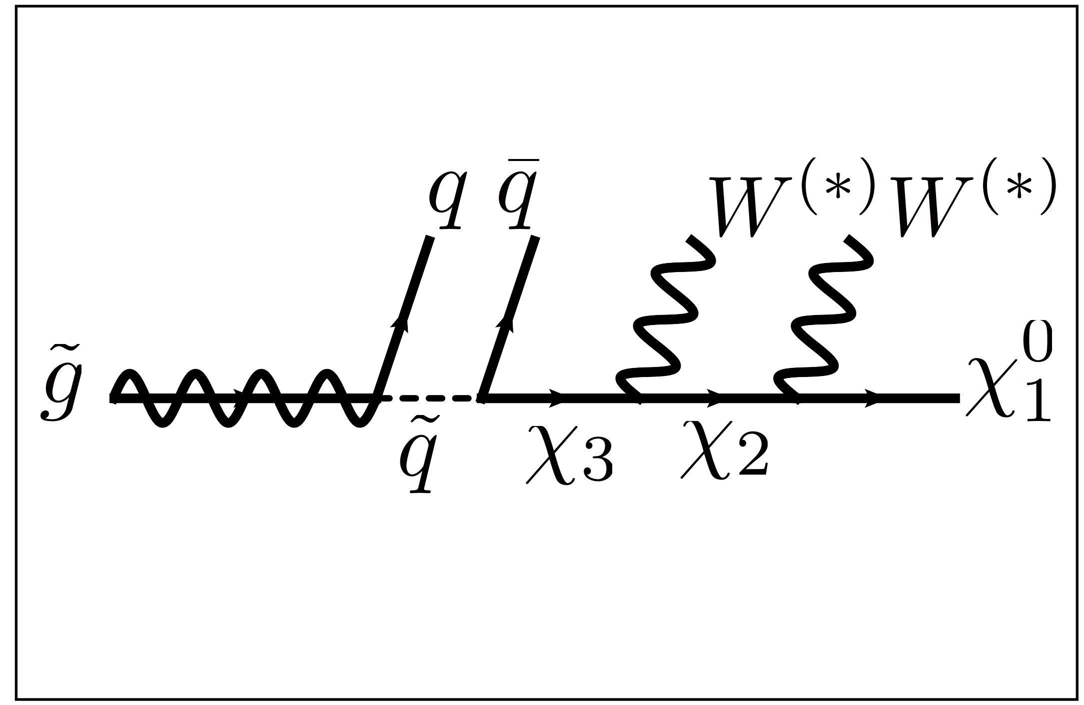


color octet majorana fermion ("Gluino")

electroweak majorana fermion ("Wino")

neutral majorana fermion ("Bino")

neutral majorana fermion ("Singlino")



$$m_{\tilde{\chi}^{\pm}} = m_{\tilde{\chi}} + \frac{1}{2}\left(m_{\tilde{g}} - m_{\tilde{\chi}}\right)$$

$$m_{\tilde{\chi}'} = m_{\tilde{\chi}} + \frac{1}{2}\left(m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}}\right)$$

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Current Searches

Estimates of Current Reach

Madgraph $\longrightarrow$ Pythia $\longrightarrow$ PGS $\longrightarrow$ Cuts

$pp \to \tilde{g}\tilde{g}+ \leq 2j$ $\quad$ $\tilde{g} \to 2j\, \chi_1^0$

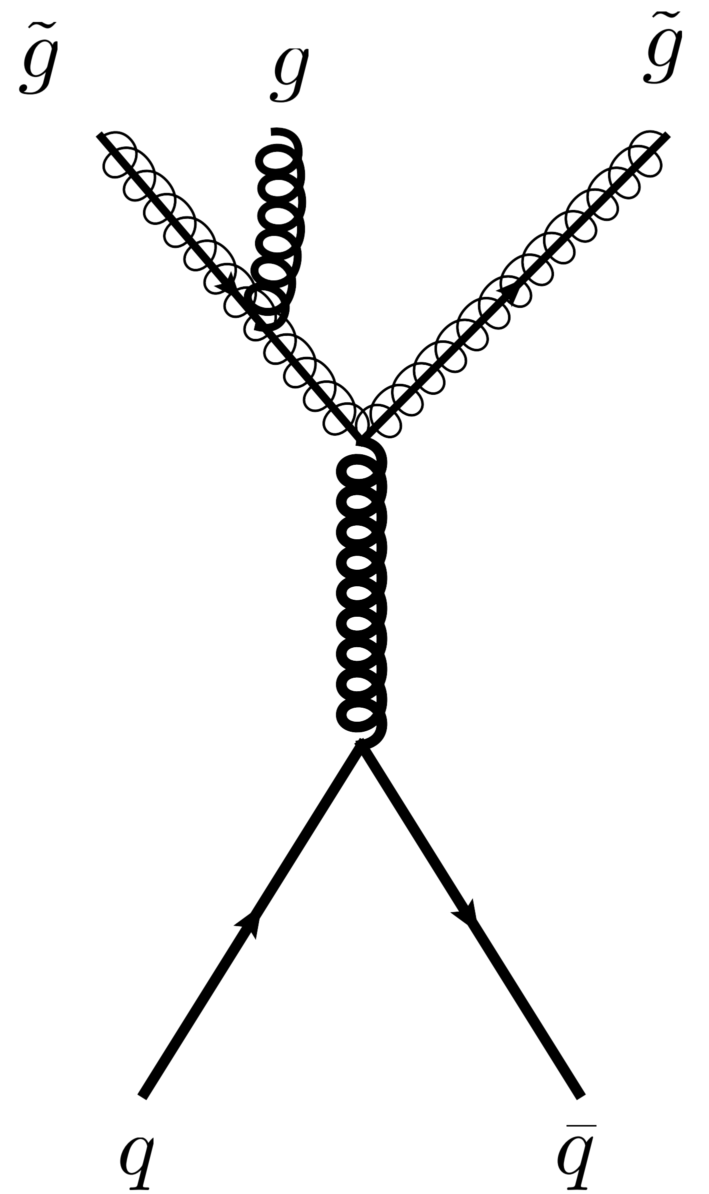
(MLM matched)

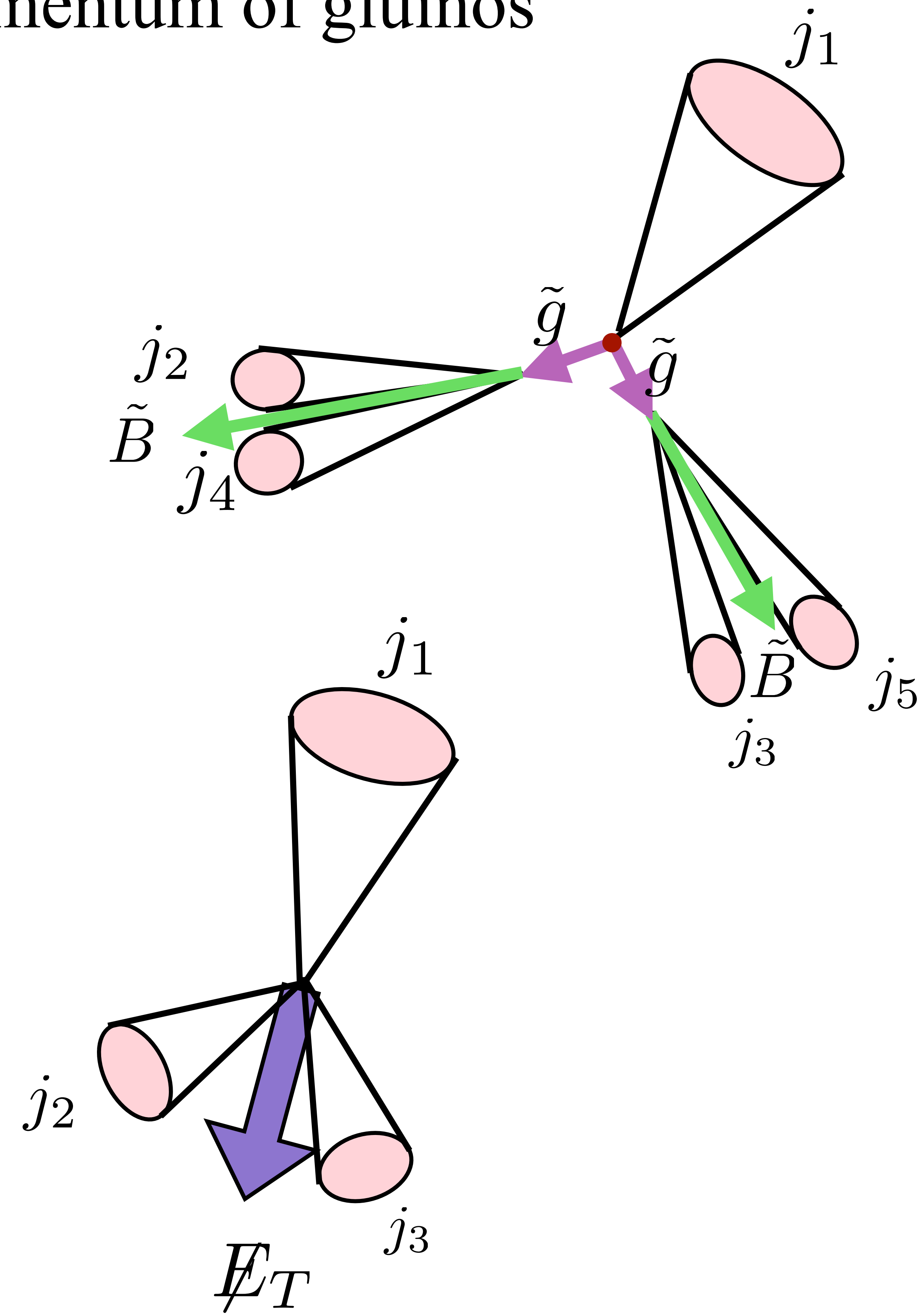
Efficiency is the fraction of events that passed the cuts

Do this for each $(m_{\tilde{g}}, m_{\chi})$ pair

Radiate off additional jet

Unbalances momentum of gluinos





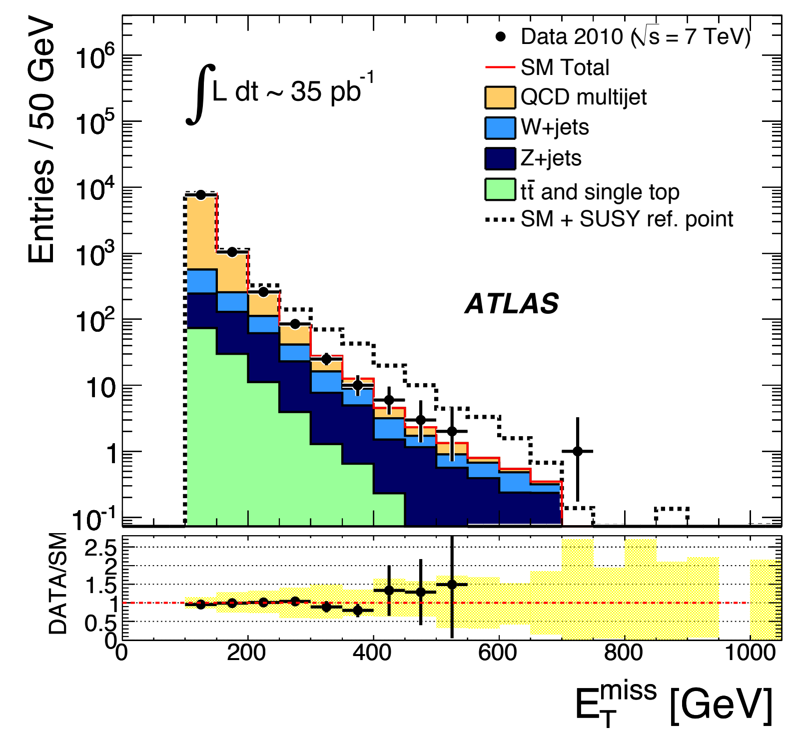
Getting 2 or more ISR jets
not rare at the LHC

CERN-PH-EP-2011-022, Submitted to Phys. Lett. B

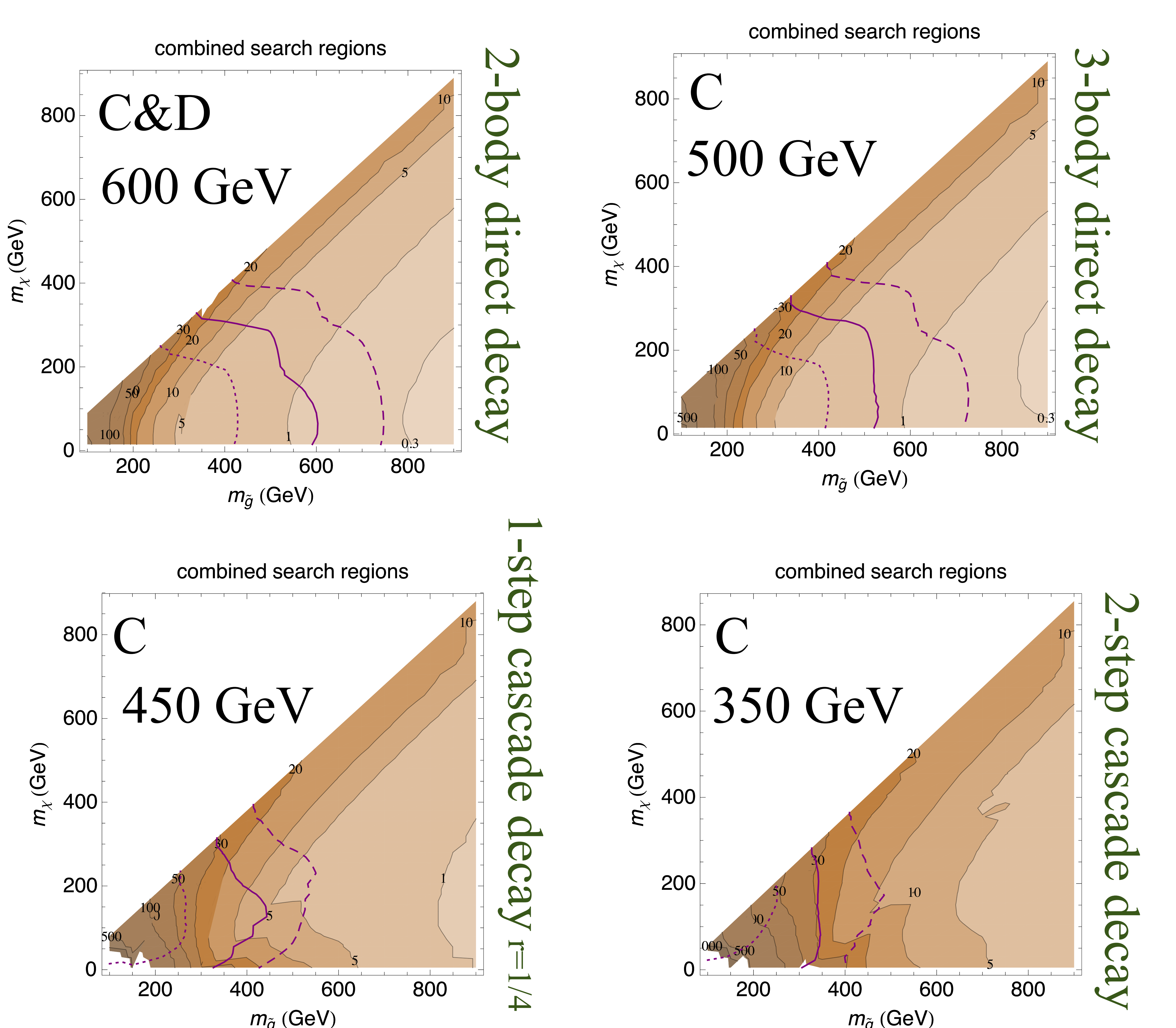
Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions

The ATLAS Collaboration

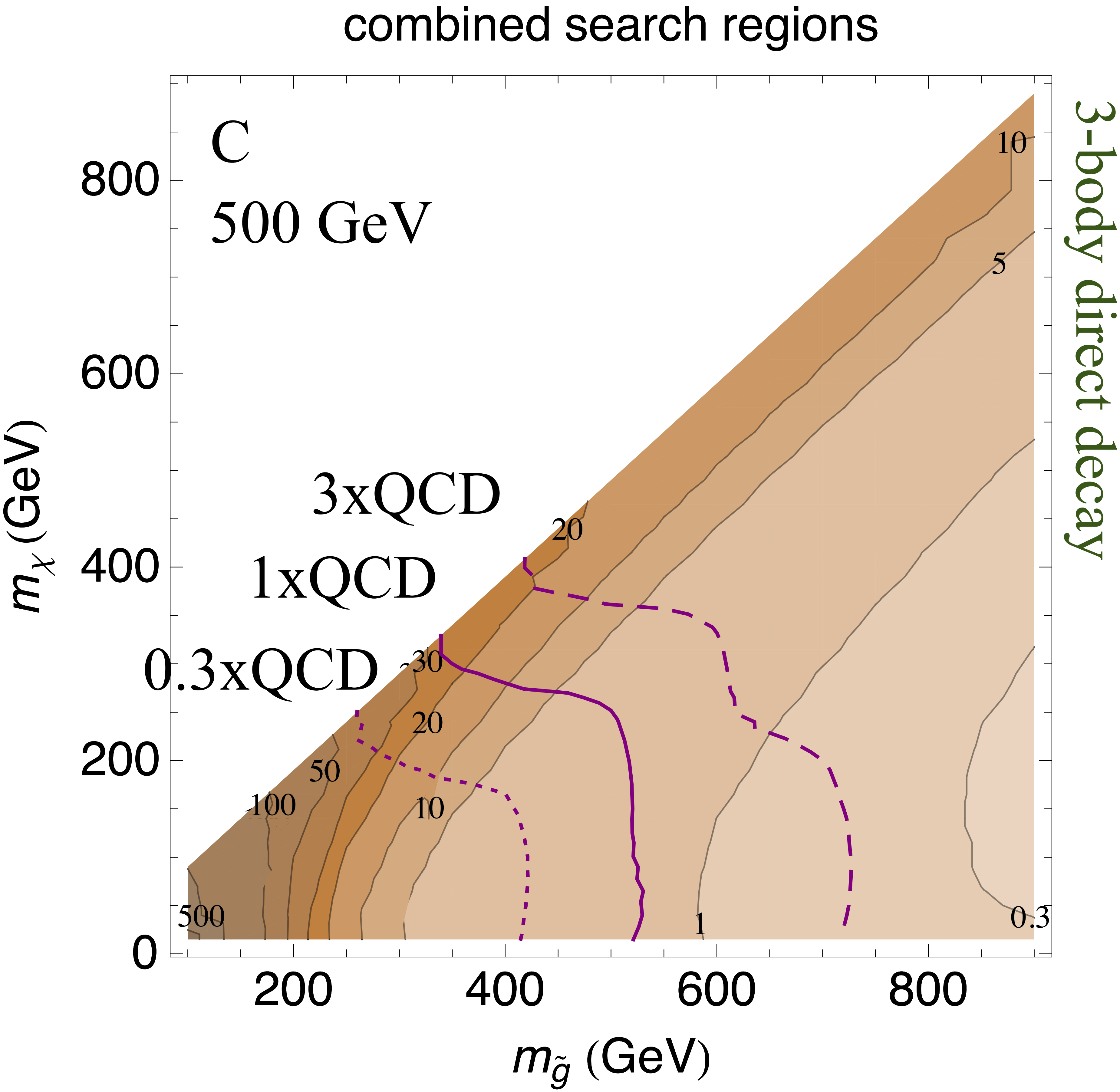
		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–



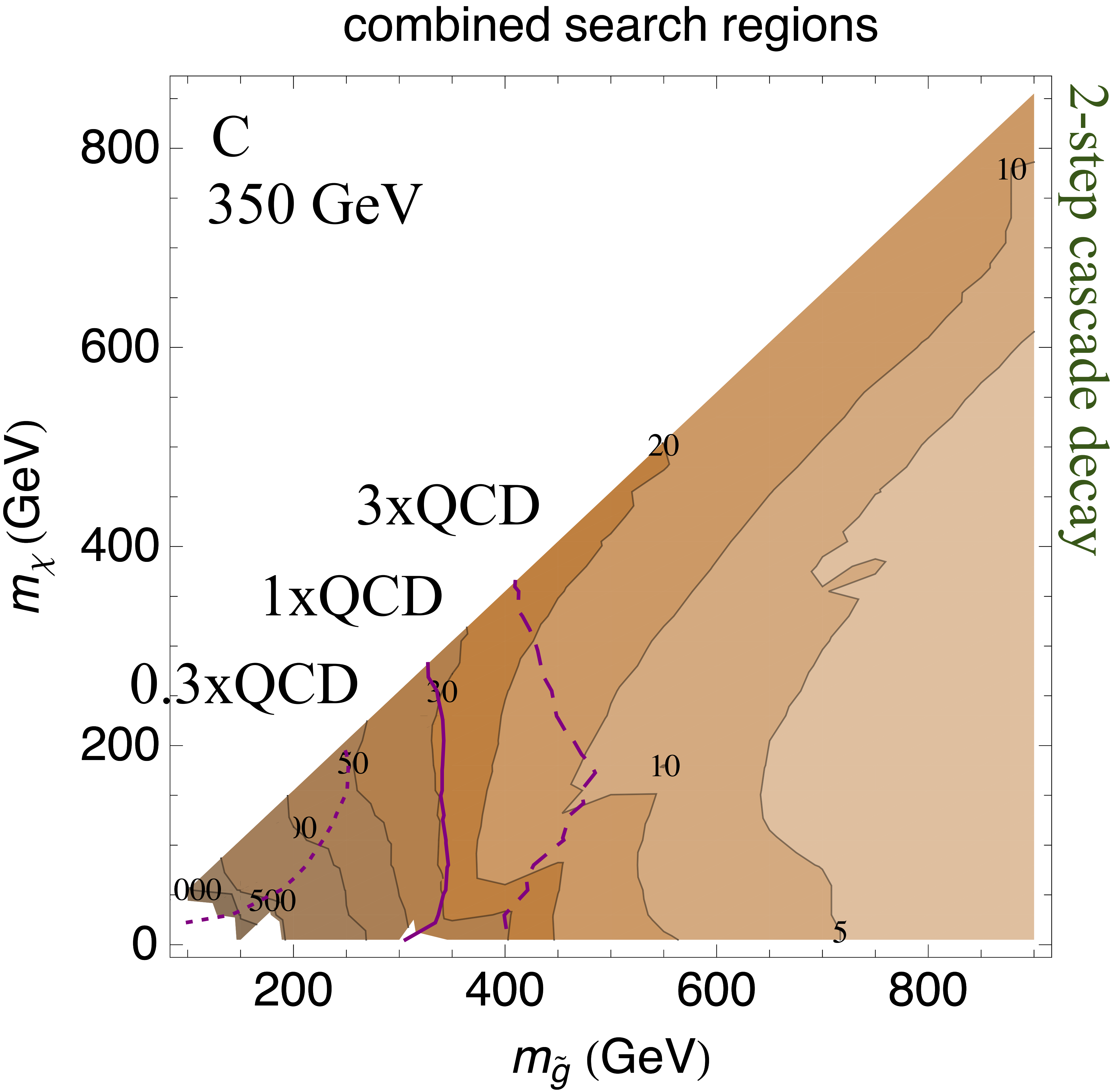
	Signal region A	Signal region B	Signal region C	Signal region D
QCD	$7\ ^{+8}_{-7}$[u+j]	$0.6\ ^{+0.7}_{-0.6}$[u+j]	$9\ ^{+10}_{-9}$[u+j]	$0.2\ ^{+0.4}_{-0.2}$[u+j]
W+jets	50 ± 11[u] $^{+14}_{-10}$[j] $\pm\ 5[\mathcal{L}]$	4.4 ± 3.2[u] $^{+1.5}_{-0.8}$[j] $\pm\ 0.5[\mathcal{L}]$	35 ± 9[u] $^{+10}_{-8}$[j] $\pm\ 4[\mathcal{L}]$	1.1 ± 0.7[u] $^{+0.2}_{-0.3}$[j] $\pm\ 0.1[\mathcal{L}]$
Z+jets	52 ± 21[u] $^{+15}_{-11}$[j] $\pm\ 6[\mathcal{L}]$	4.1 ± 2.9[u] $^{+2.1}_{-0.8}$[j] $\pm\ 0.5[\mathcal{L}]$	27 ± 12[u] $^{+10}_{-6}$[j] $\pm\ 3[\mathcal{L}]$	0.8 ± 0.7[u] $^{+0.6}_{-0.0}$[j] $\pm\ 0.1[\mathcal{L}]$
$t\bar{t}$ and t	10 ± 0[u] $^{+3}_{-2}$[j] $\pm\ 1[\mathcal{L}]$	0.9 ± 0.1[u] $^{+0.4}_{-0.3}$[j] $\pm\ 0.1[\mathcal{L}]$	17 ± 1[u] $^{+6}_{-4}$[j] $\pm\ 2[\mathcal{L}]$	0.3 ± 0.1[u] $^{+0.2}_{-0.1}$[j] $\pm\ 0.0[\mathcal{L}]$
Total SM	118 ± 25[u] $^{+32}_{-23}$[j] $\pm\ 12[\mathcal{L}]$	10.0 ± 4.3[u] $^{+4.0}_{-1.9}$[j] $\pm\ 1.0[\mathcal{L}]$	88 ± 18[u] $^{+26}_{-18}$[j] $\pm\ 9[\mathcal{L}]$	2.5 ± 1.0[u] $^{+1.0}_{-0.4}$[j] $\pm\ 0.2[\mathcal{L}]$
Data	87	11	66	2



combined search regions
C&D
600 GeV
2-body direct decay
C
500 GeV
3-body direct decay
C
450 GeV
1-step cascade decay r=1/4
C
350 GeV
2-step cascade decay
m_χ (GeV)
$m_{\tilde{g}}$ (GeV)



combined search regions
C
500 GeV
3xQCD
1xQCD
0.3xQCD
3-body direct decay
m_χ (GeV)
$m_{\tilde{g}}$ (GeV)
0
200
400
600
800
10
5
20
30
50
100
500
1
0.3



combined search regions
C
350 GeV
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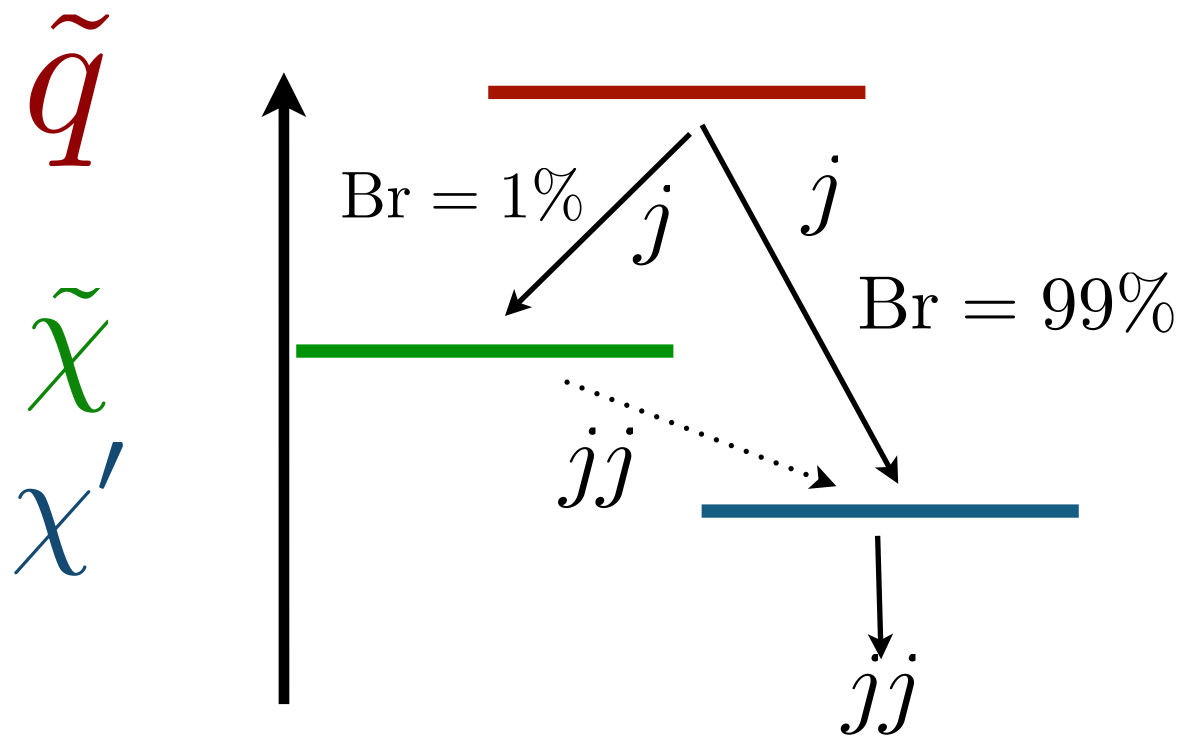
2-step cascade decay
m_χ (GeV)
$m_{\tilde{g}}$ (GeV)
0
200
400
600
800
10
20
30
50
10
5
500

Continued improvement at low masses

$$\sigma_{\tilde{g}\tilde{g}}\ \mathrm{Br}(\tilde{g} \to \not{E}_T\ )^2 \ll \sigma_{\tilde{g}\tilde{g}\ \mathrm{QCD}}$$



$$\Gamma(\tilde{\chi} \to \chi' + jj) \sim 1\ \mathrm{km}^{-1}$$

Only a small fraction of events are visible in Jets + MET

Multiple Search Regions

- 6 search regions to have "near-optimal" reach:

Dijet high MET	$\not{E}_T > 500$ GeV$, H_T > 750$ GeV
Trijet high MET	$\not{E}_T > 450$ GeV$, H_T > 500$ GeV
Multijet low MET	$\not{E}_T > 100$ GeV$, H_T > 450$ GeV
Multijet very high H_T	$\not{E}_T > 150$ GeV$, H_T > 950$ GeV
Multijet moderate MET	$\not{E}_T > 250$ GeV$, H_T > 300$ GeV
Multijet high MET	$\not{E}_T > 350$ GeV$, H_T > 600$ GeV

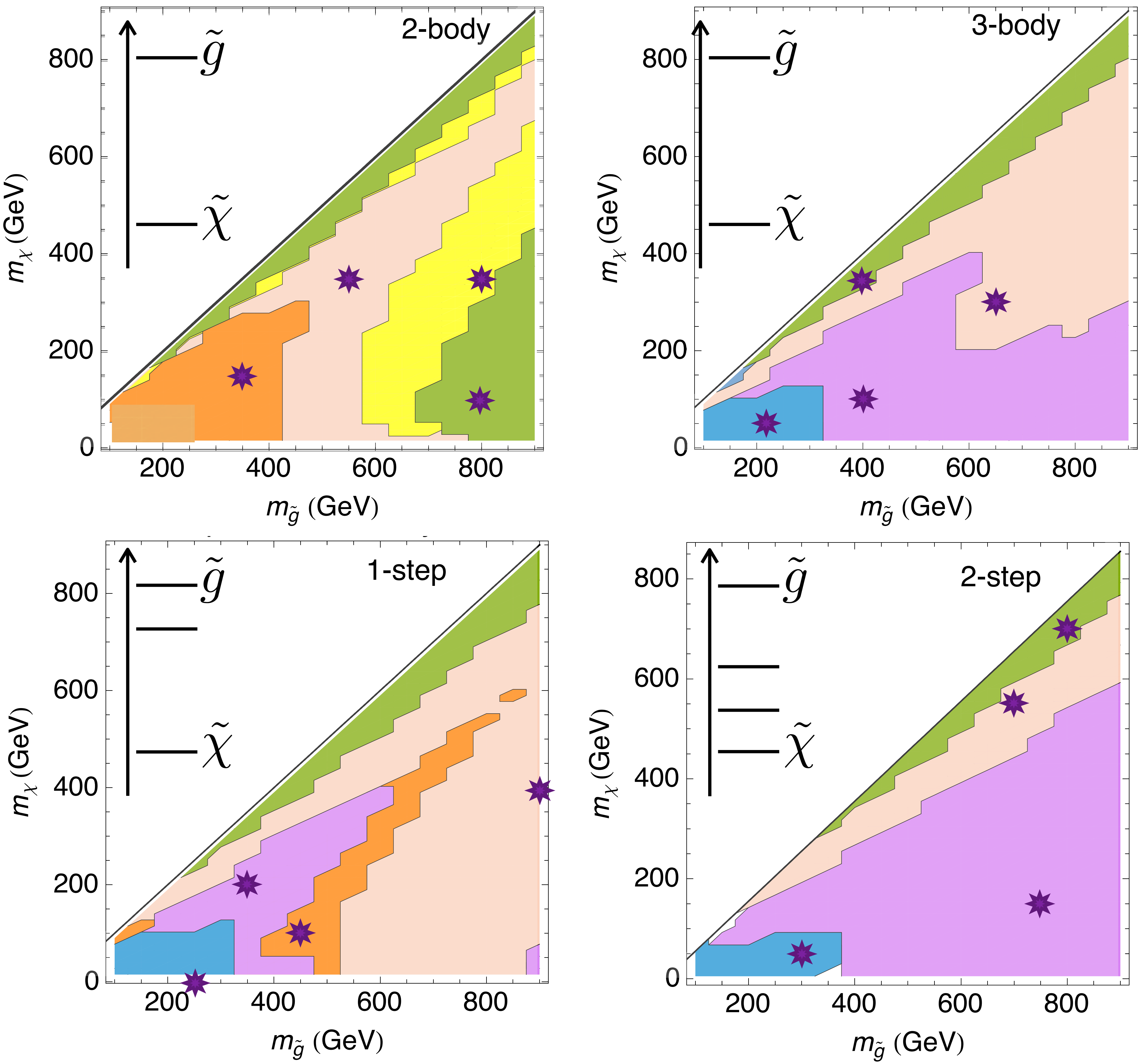
- Number of search regions depends on desired "Efficacy"

$$\mathcal{E}(\mathcal{M},\mathcal{S}) = \frac{\sigma_{\text{lim}}(\mathcal{M},\mathcal{S})}{\sigma_{\text{lim}}^{\text{best}}(\mathcal{M})} \geq 1$$

$\mathcal{M} =$ Model

$\mathcal{S} =$ Search Region

Multiple Search Regions



cut	ch	MET	H_T
	2^+j	500	750
	3^+j	450	500
	4^+j	100	450
	4^+j	150	950
	4^+j	250	300
	4^+j	350	600

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Want to cover mSugra Topologies

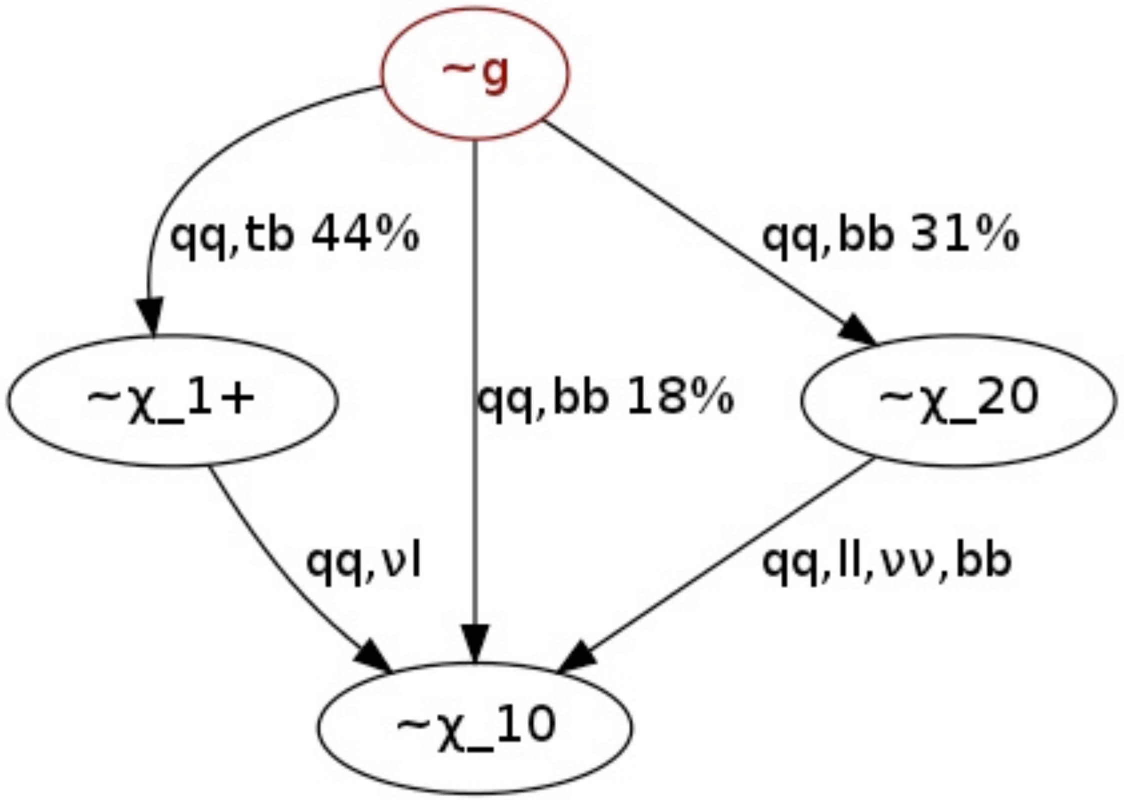
Qualitative features of mSugra may be generic

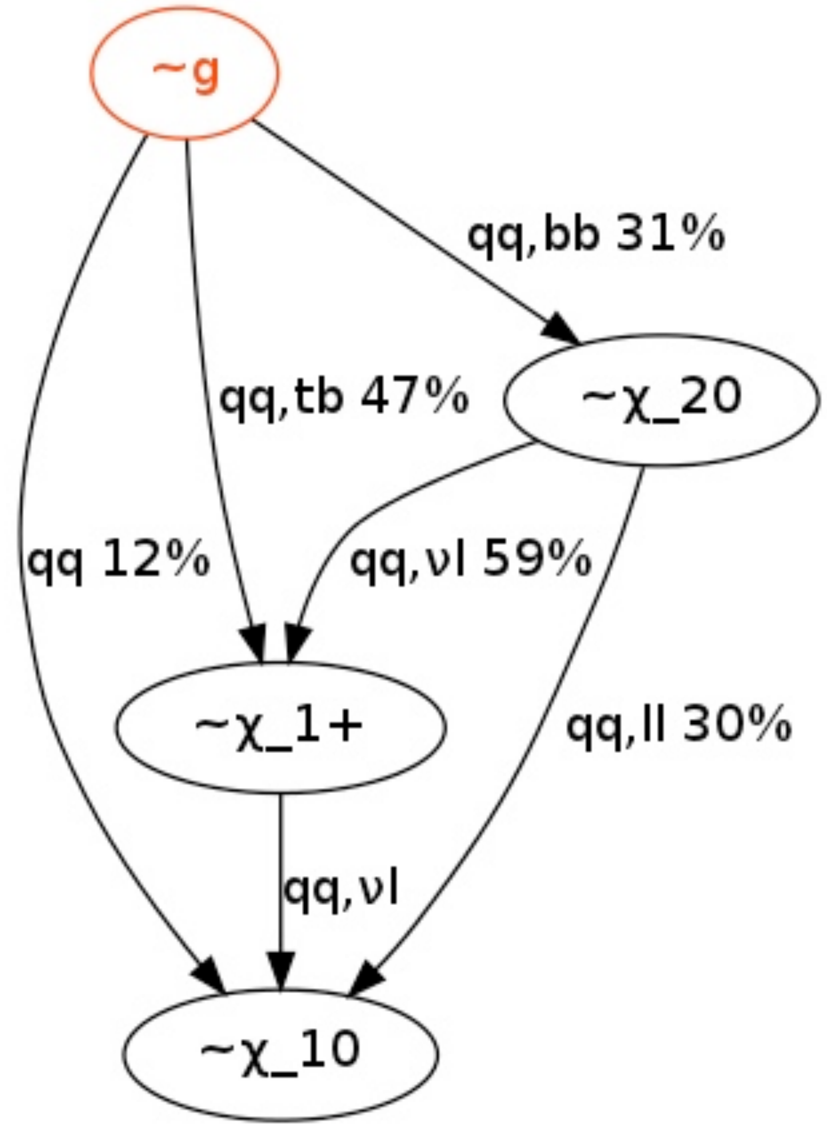
Prevents having to do both
mSugra searches & Simplified Model searches

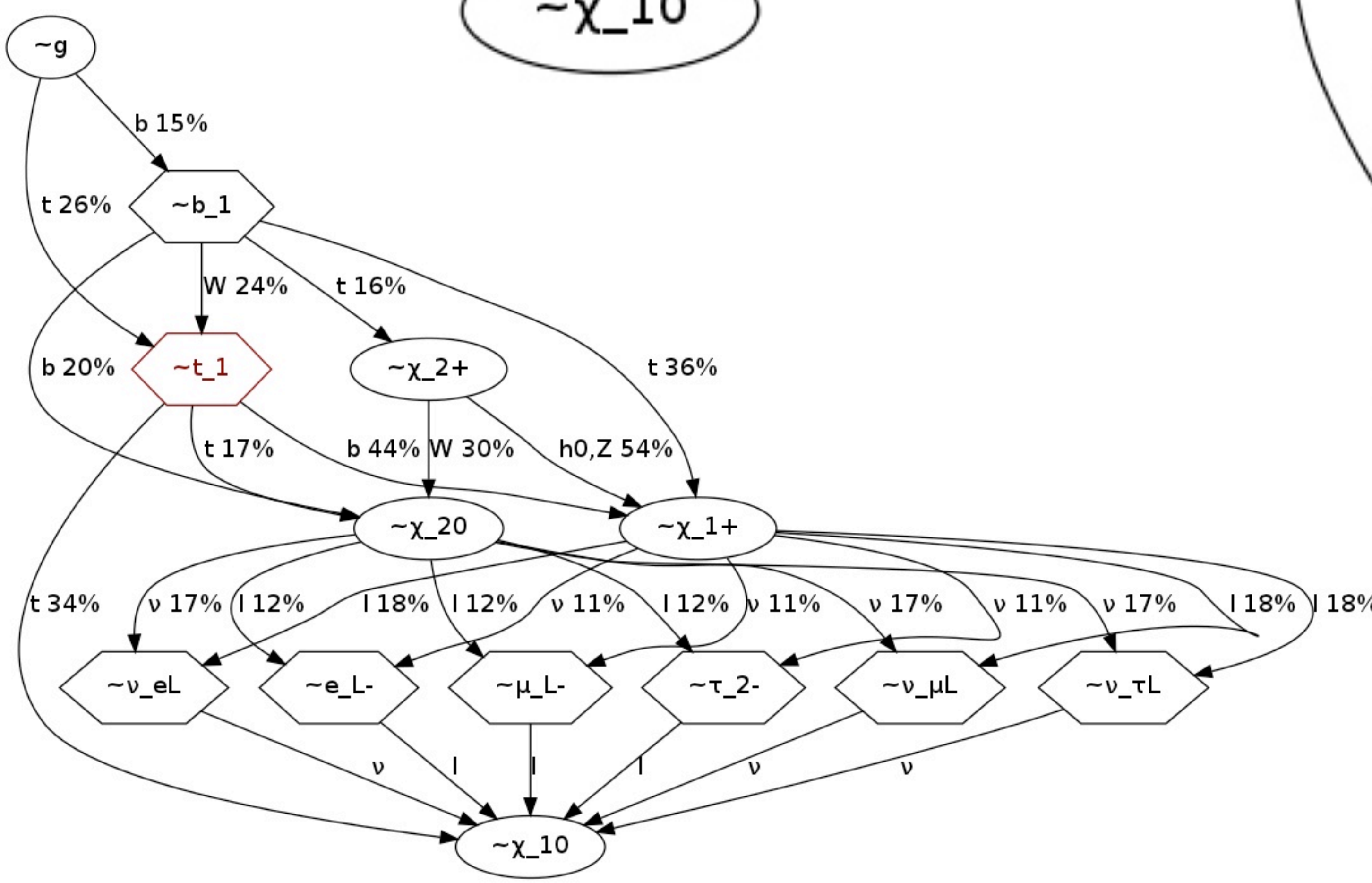
Illustrative to see how to interpret
Simplified Model limits/discoveries
in mSugra

mSugra (gluino) Decay Topologies

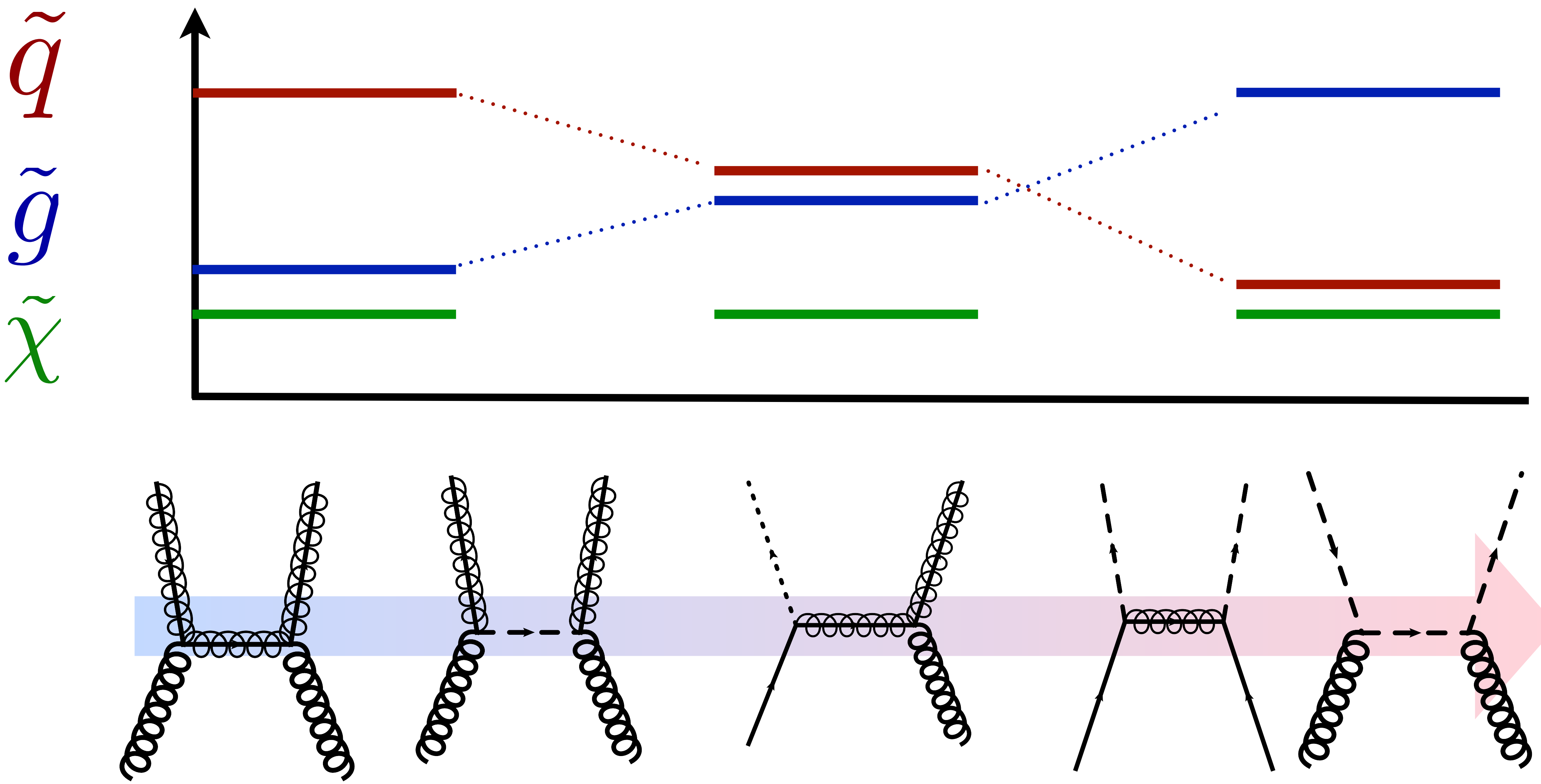
http://www.hephy.at/user/walten/msugra







Production Topologies



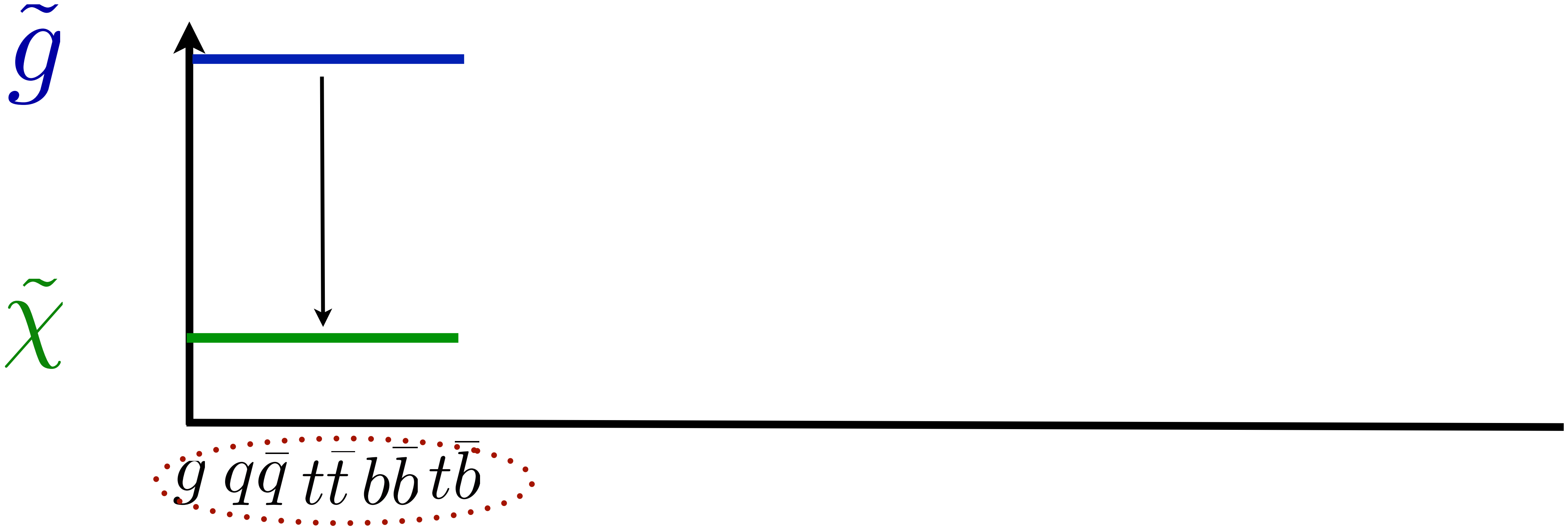
Minimal Simplified Model	$m_{\tilde{g}}$ $m_{\tilde{\chi}^0}$ $\sigma_{\tilde{g}\tilde{g}}$	$m_{\tilde{g}}$ $m_{\tilde{q}}$ $m_{\tilde{\chi}^0}$ $\sigma_{\tilde{g}\tilde{g}}$ $\sigma_{\tilde{g}\tilde{q}}$ $\sigma_{\tilde{q}\tilde{q}}$ $\sigma_{\tilde{q}\tilde{q}^\dagger}$	$m_{\tilde{q}}$ $m_{\tilde{\chi}^0}$ $\sigma_{\tilde{q}\tilde{q}}$ $\sigma_{\tilde{q}\tilde{q}^\dagger}$

Gluino Decay Topologies

Simple

Complicated

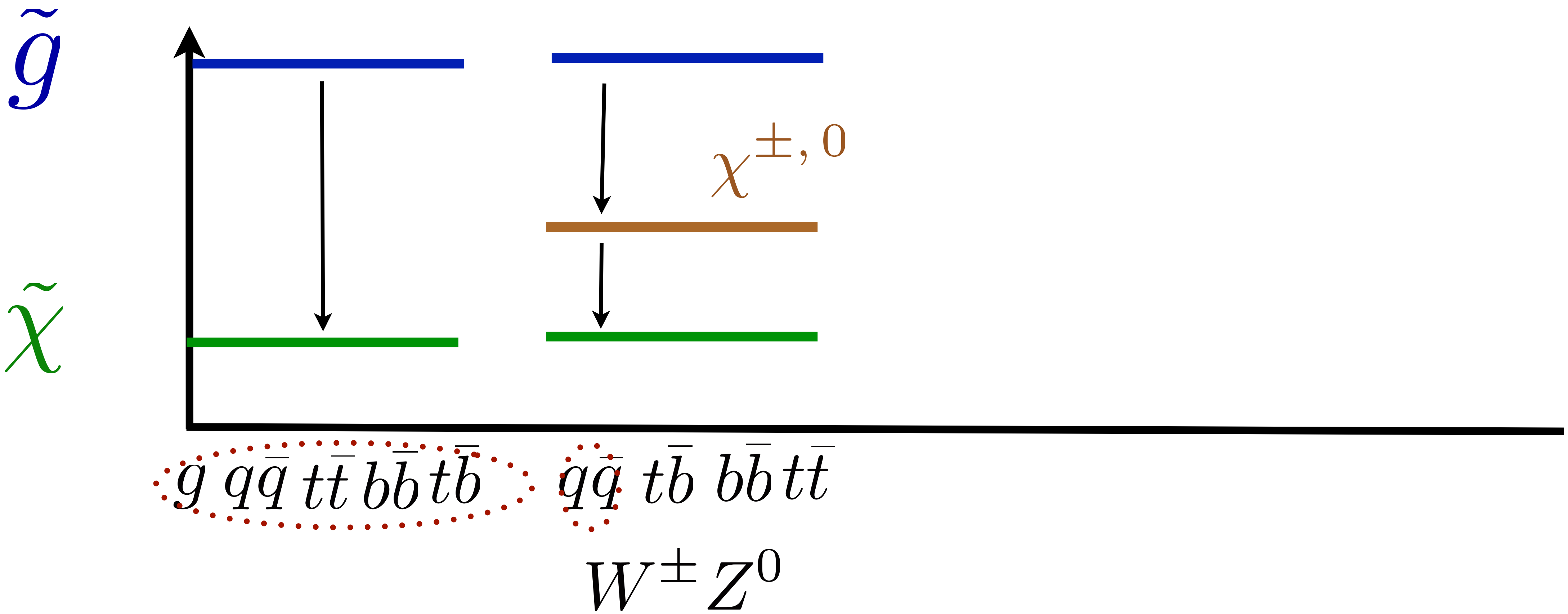
Gluino Decay Topologies



Simple

Complicated

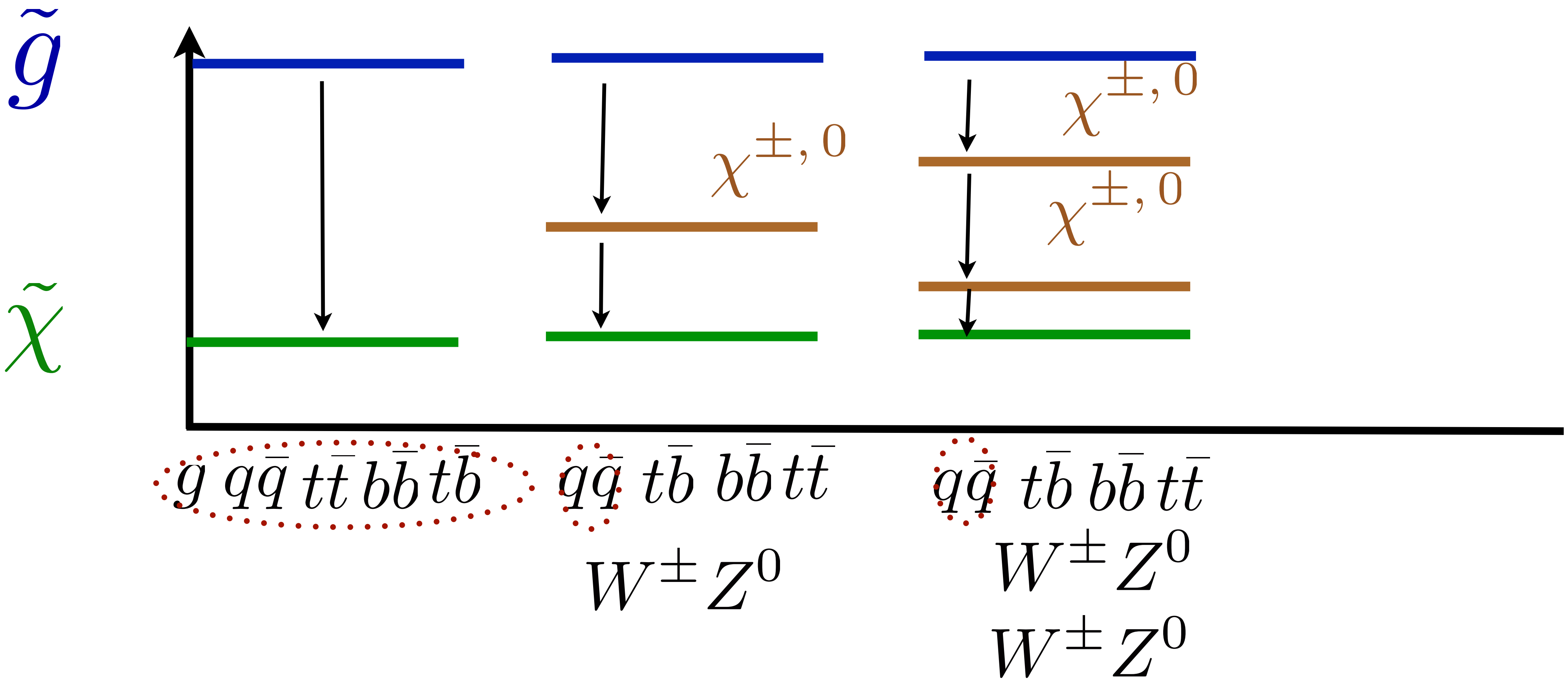
Gluino Decay Topologies



Simple

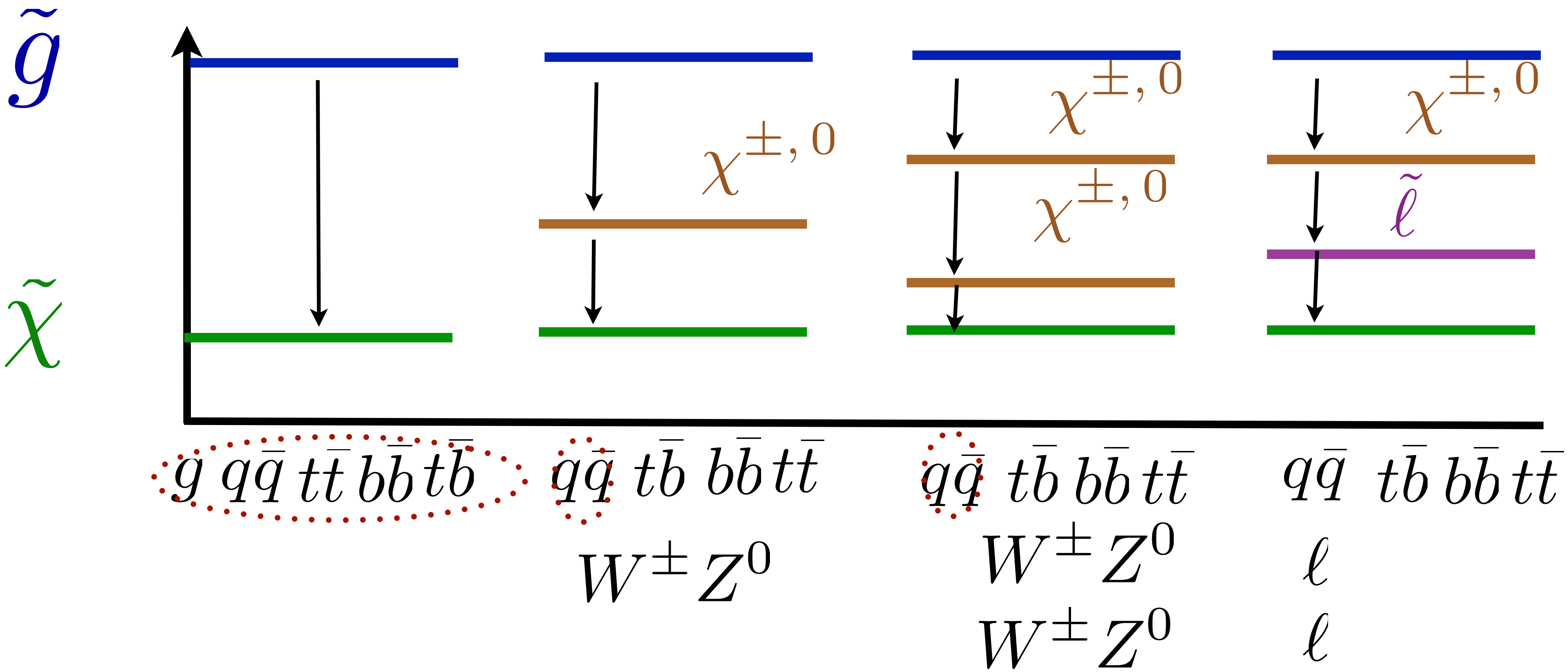
Complicated

Gluino Decay Topologies



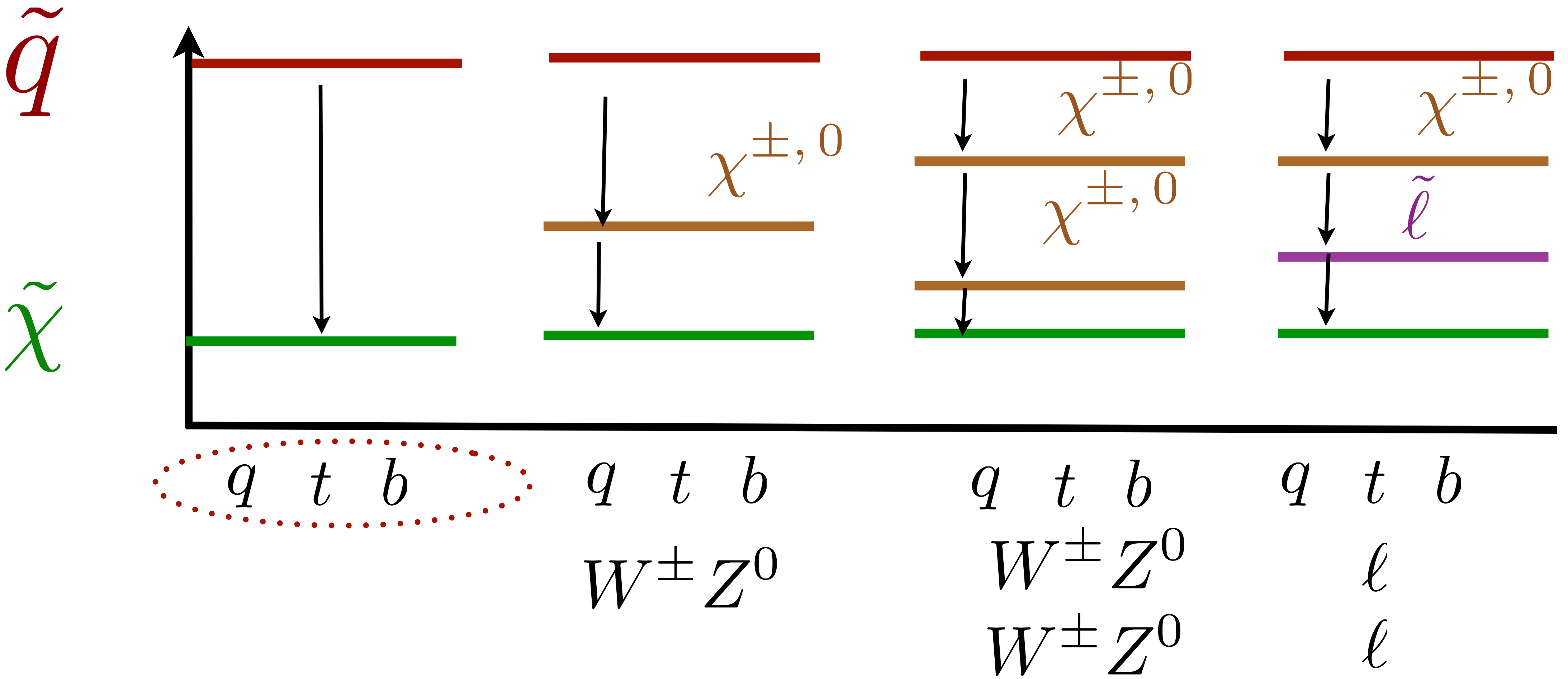
Simple → Complicated

Gluino Decay Topologies

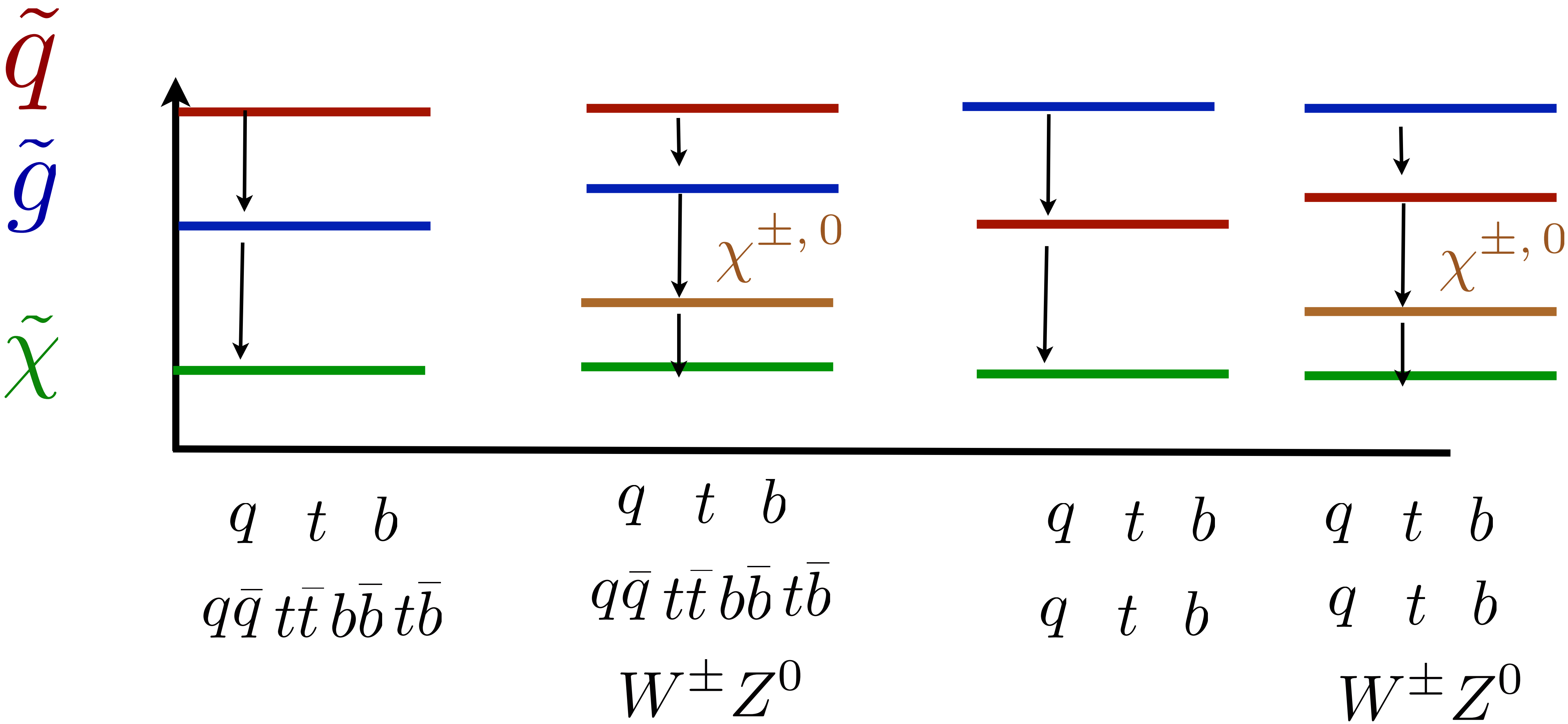


Simple → Complicated

Squark Decay Topologies



Gluino-Squark Decay Topologies



Complicated → Complicated

Still more study necessary

Squark-Gluino Simplified Models are a big hole

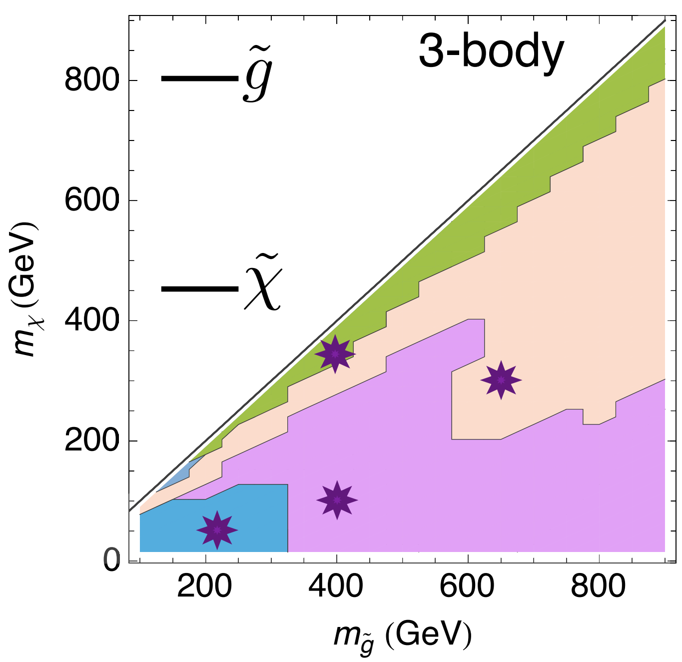
More work on heavy flavor necessary

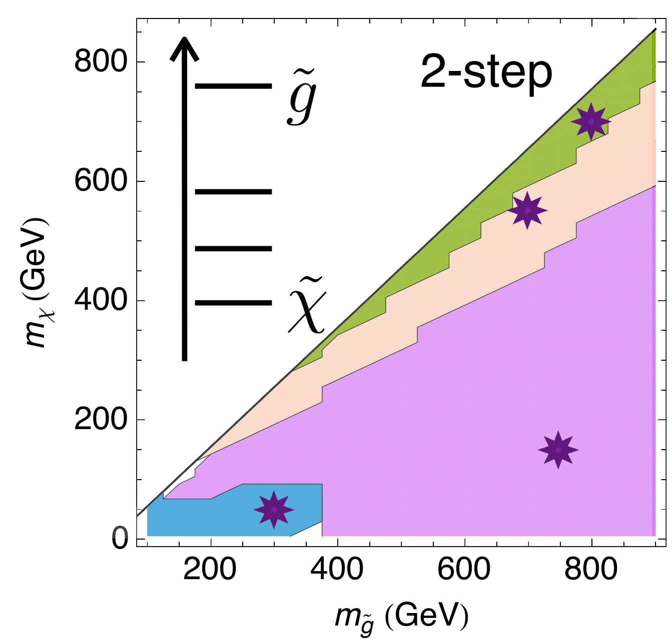
Only a few studies of 2-step cascades performed

Adding Higgs as a cascade particle

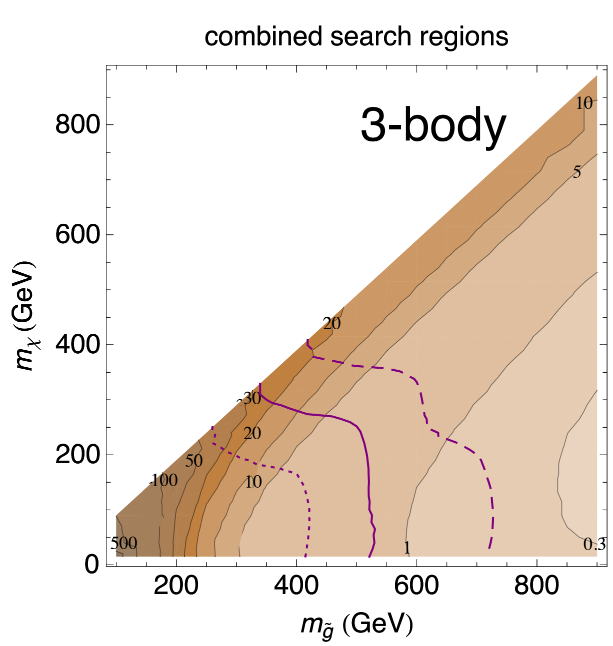
Still more study necessary

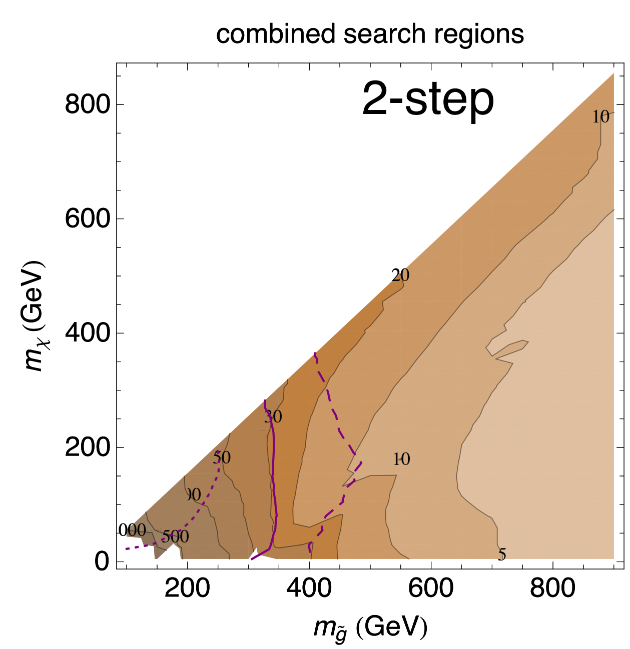
So far, more complicated Simplified Models don't dramatically change the discovery process





Alter interpretation





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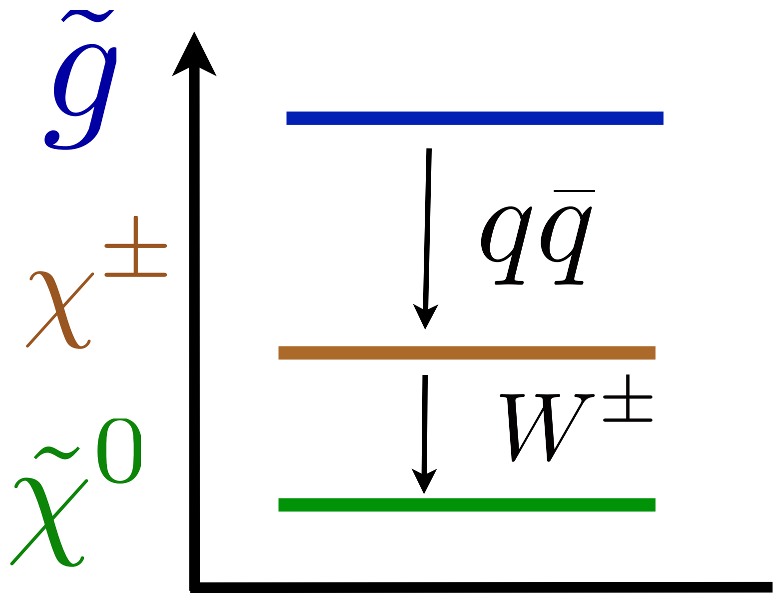
Anomalies to Discoveries

A single channel anomaly is good,
but other channels need to verify it



$$m_{\chi^{\pm}} = m_{\tilde{\chi}^0} + r(m_{\tilde{g}} - m_{\tilde{\chi}^0})$$

$$m_{\tilde{g}} = 400\ \mathrm{GeV}, 800\ \mathrm{GeV}$$

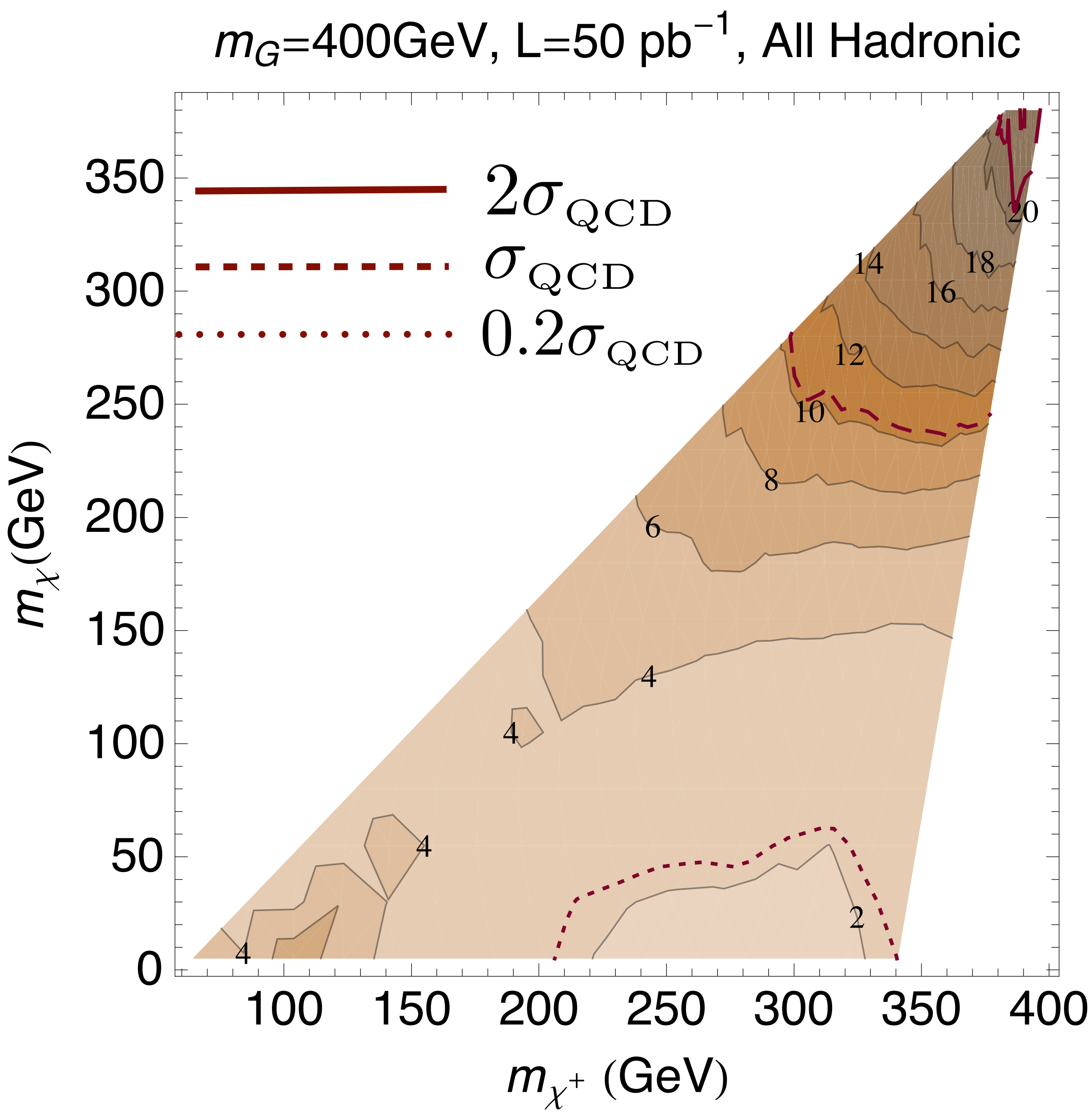
$$r = 15\% \cdots 85\%$$

Multiple Discovery Channels:

$$nj + \not{E}_T, \qquad nj + \not{E}_T\ 1\ell,$$

$$nj + \not{E}_T\ 2\ell, \qquad nj + \not{E}_T\ 2\ell_{\mathrm{SS}}, \qquad nj + \not{E}_T\ 2\ell_{\mathrm{OS}}$$

Where we are Today



Good Coverage, we'd have a good anomaly in

$$nj + \not{E}_T$$

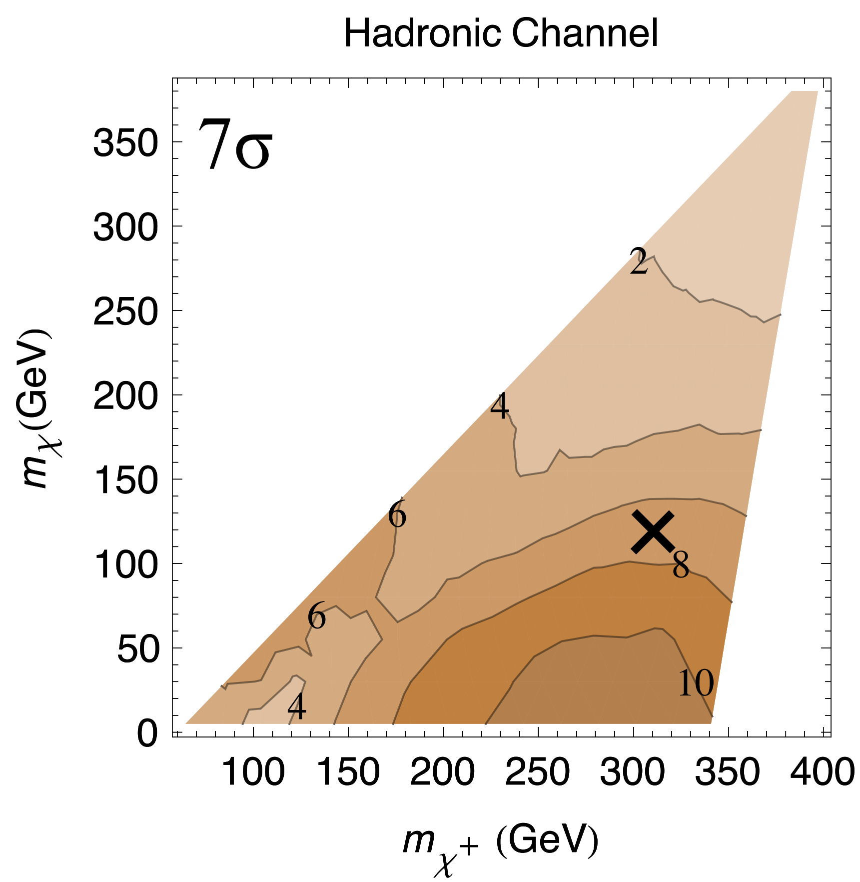
How quickly is does it appear in another channel?

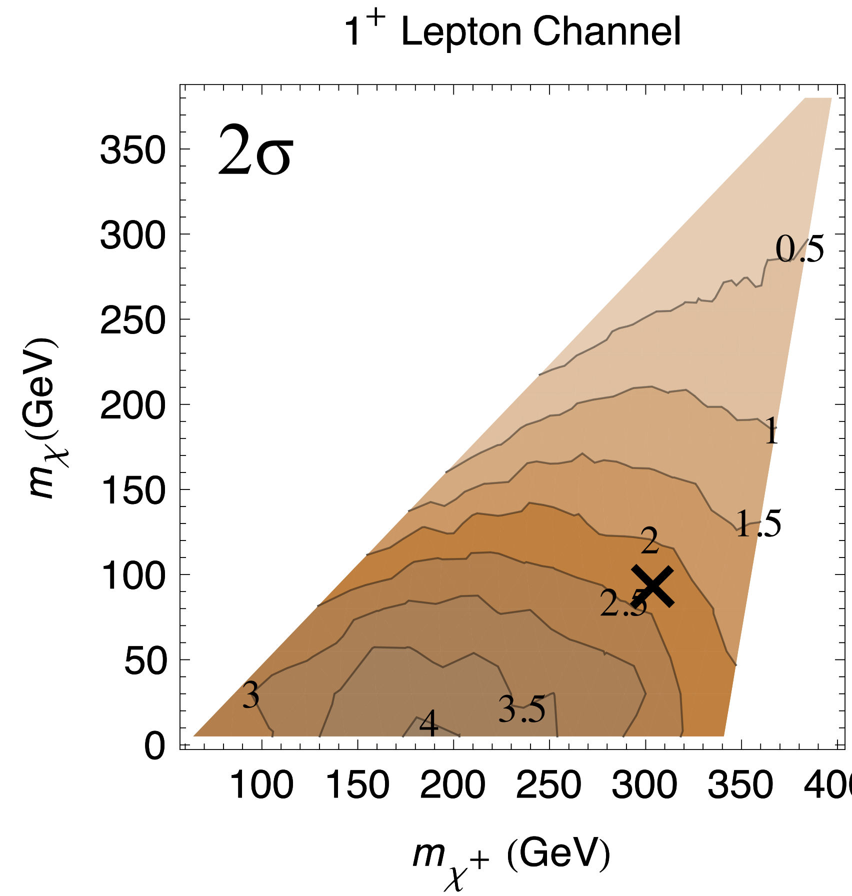
Significance of discovery (# of σ's) for different channels assuming $\sigma^{prod}=\sigma^{QCD}$,

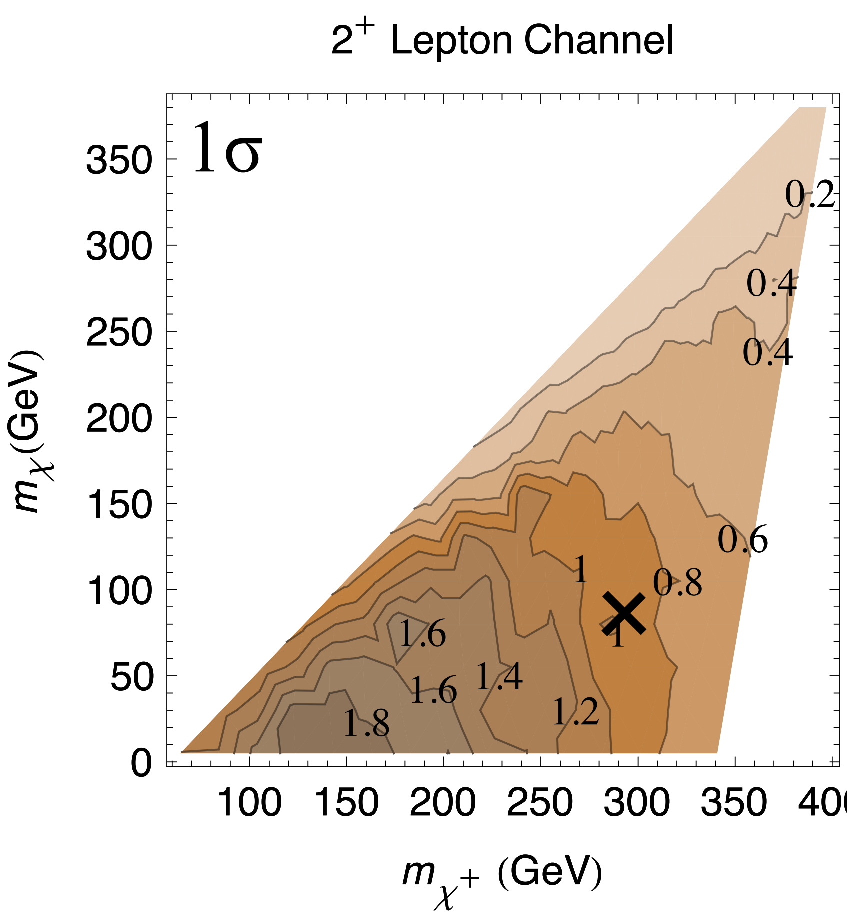
(m_g = 400 GeV, p_T^{ℓ} = 20 GeV requirement/veto & Lum = 50/pb)

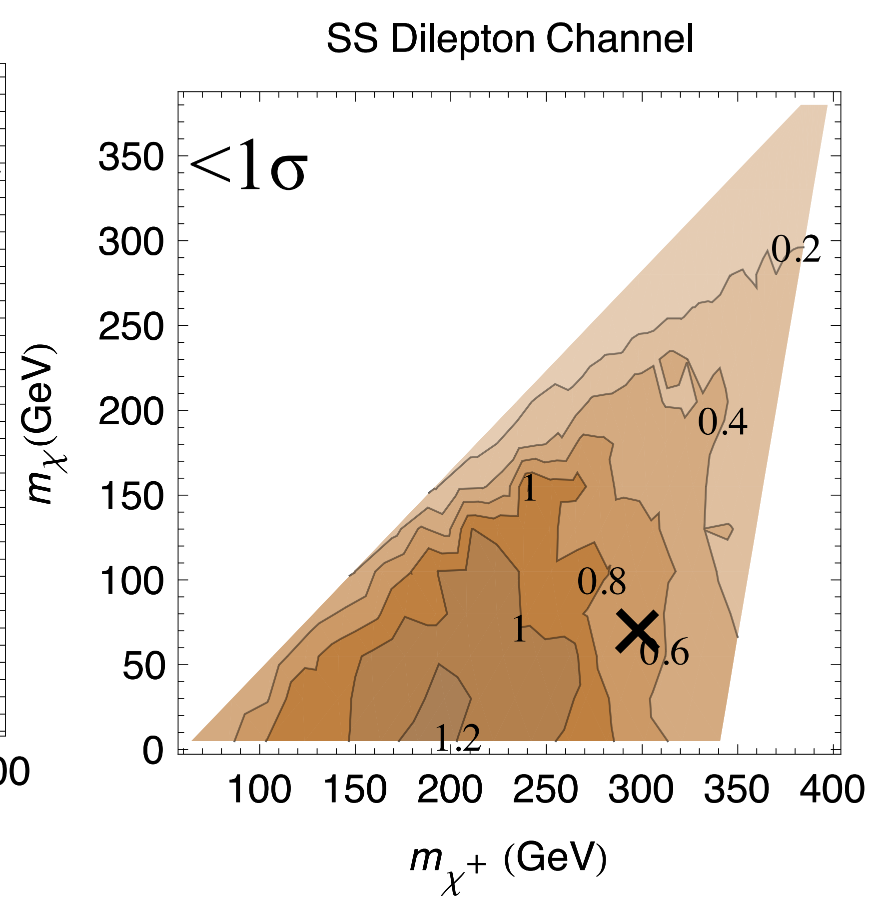
Choose best search region in each channel

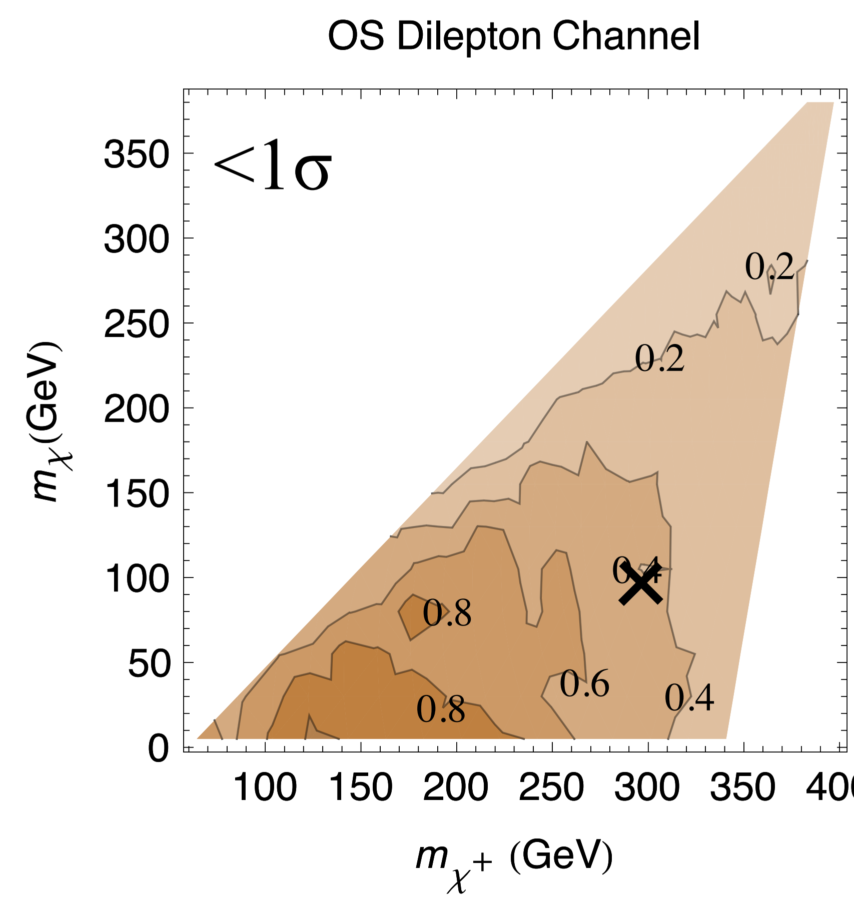
Only anomaly in all-hadronic channel









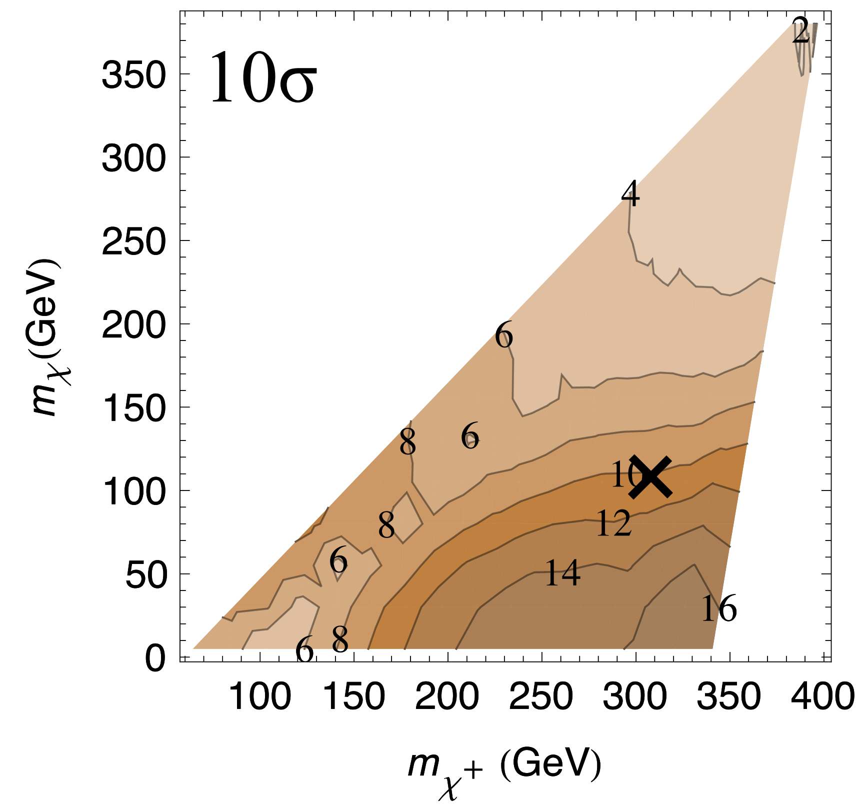


Significance of discovery (# of σ's) for different channels assuming $\sigma^{prod}=\sigma^{QCD}$,

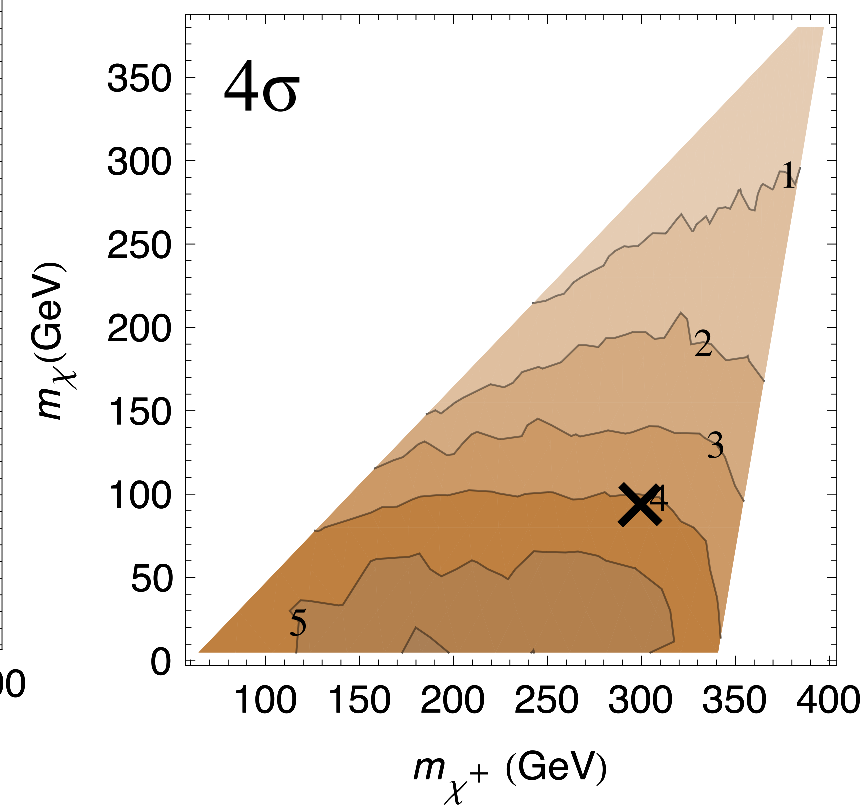
(m_g = 400 GeV, p_T^{ℓ} = 20 GeV requirement/veto & Lum = 500/pb)

Slowly appears in other channels

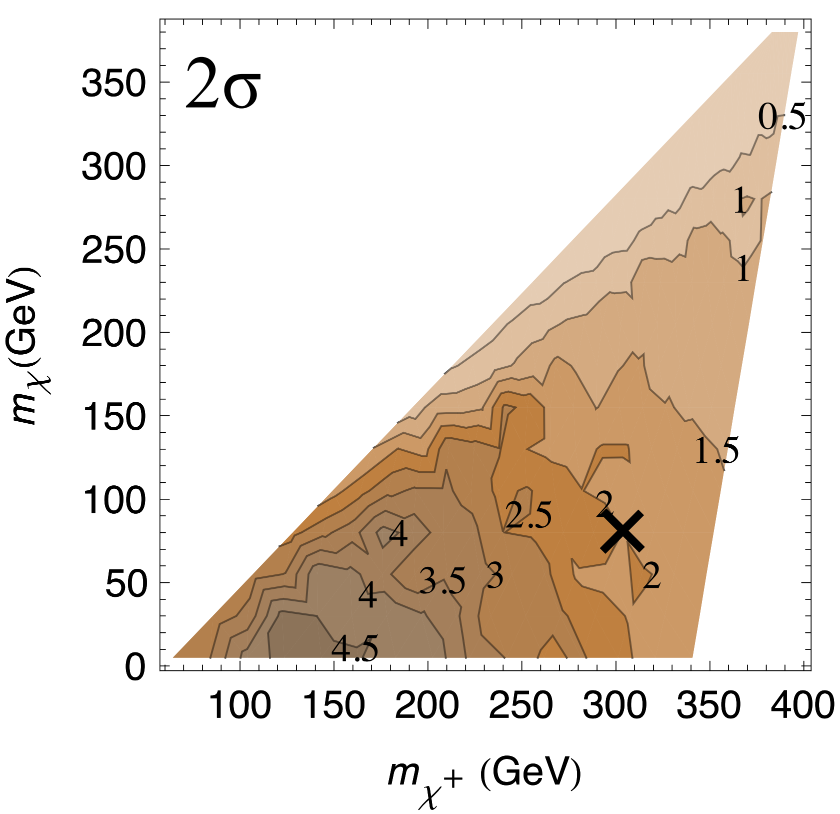
Hadronic Channel



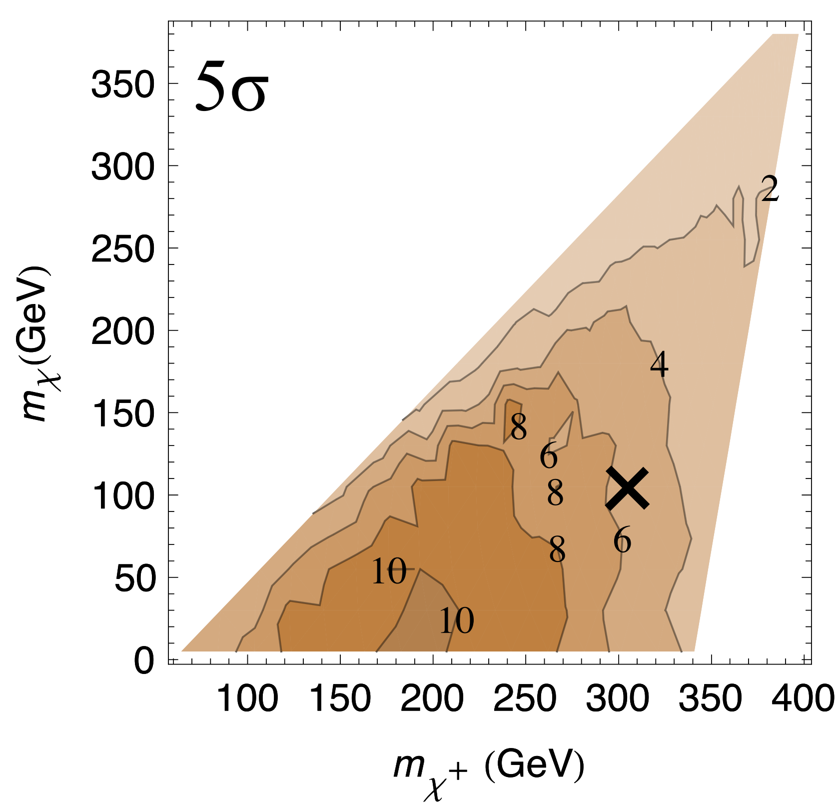
1^+ Lepton Channel



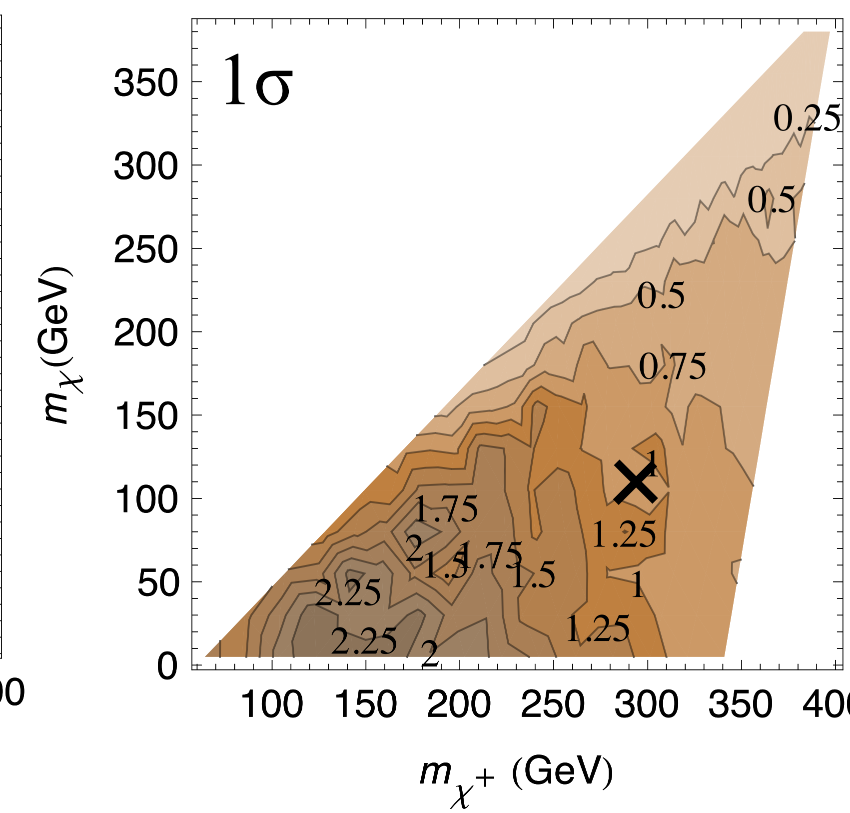
2^+ Lepton Channel



SS Dilepton Channel



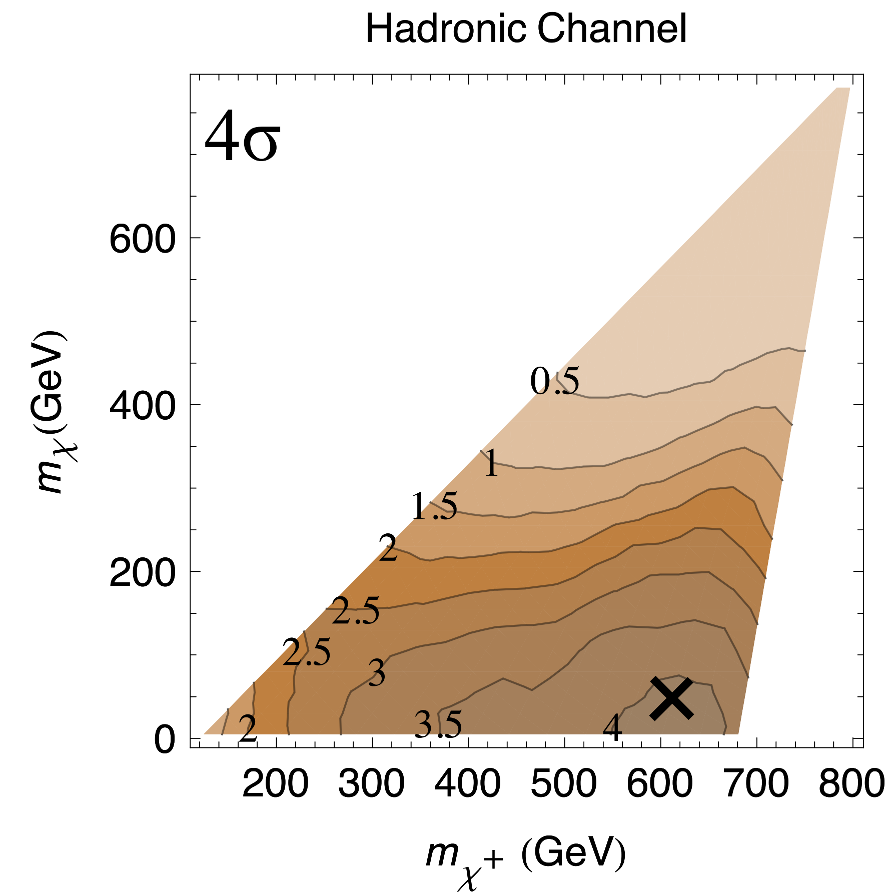
OS Dilepton Channel

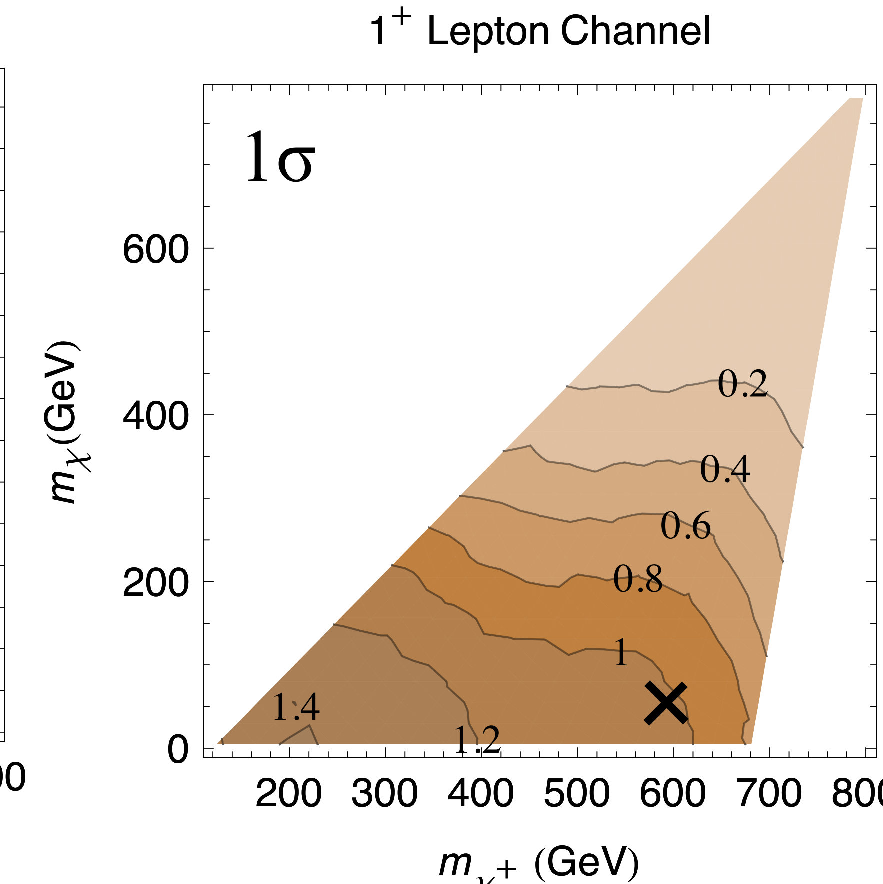


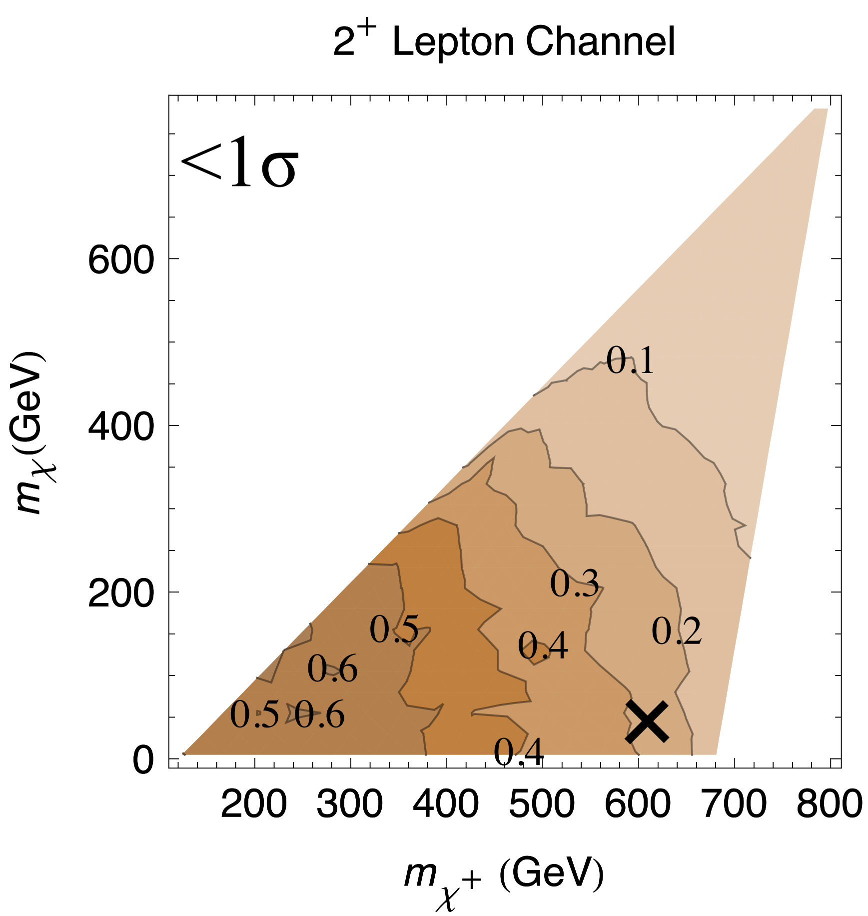
Significance of discovery (# of σ's) for different channels assuming $\sigma^{prod}=\sigma^{QCD}$,

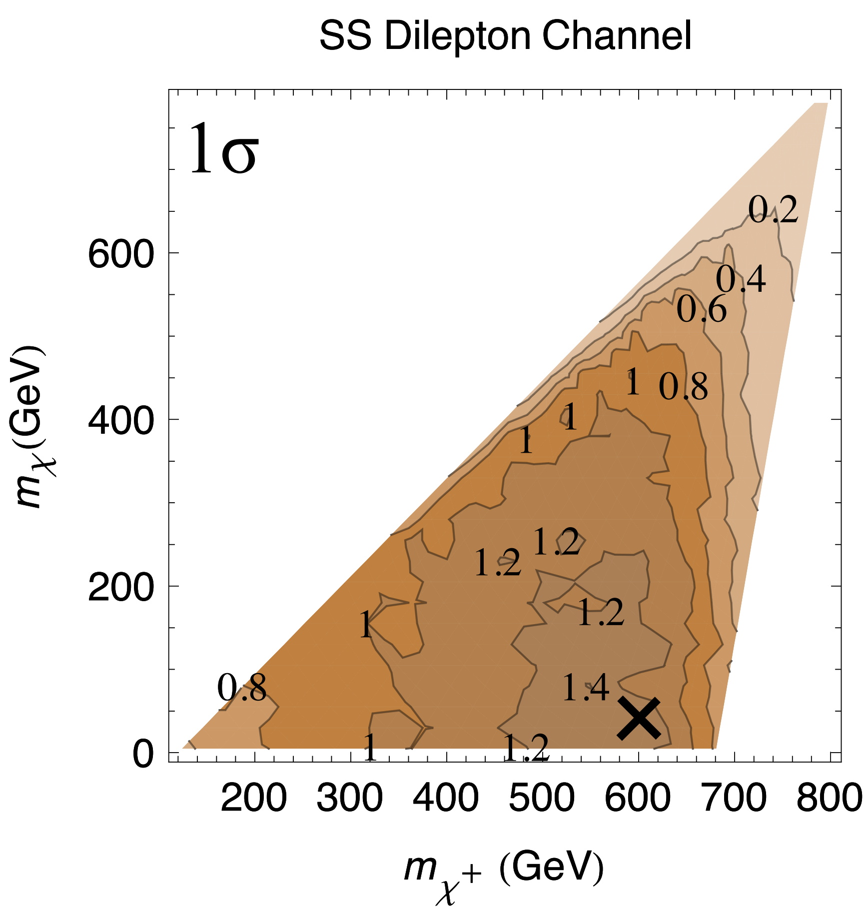
(m_g = 800 GeV, p_T^{ℓ} = 20 GeV requirement/veto & Lum = 5000/pb)

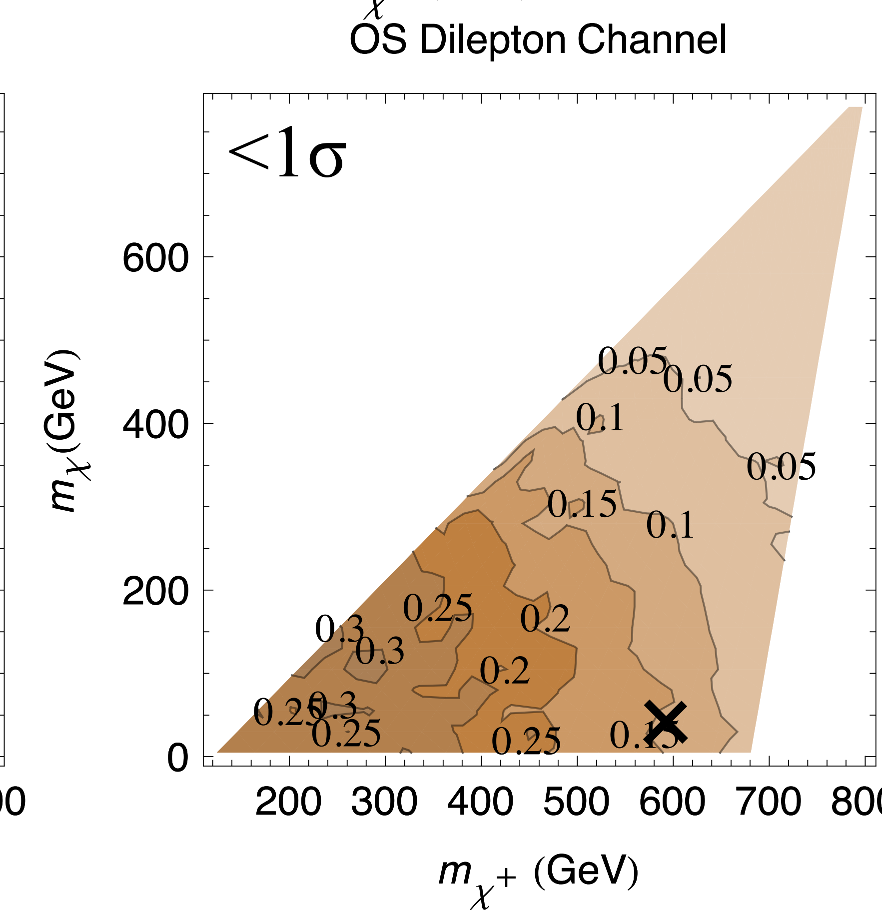
Same story











Outlook

Beginning a systematic search for BSM physics

Progress is occurring quickly

Exploration of Simplified Models still underway

Weak closure test will be demonstrated

2011 is the year for anomalies to appear

Once discoveries are made, we'll want to know
how much we know based upon data rather than priors