Early LHC Searches for Jets + MET

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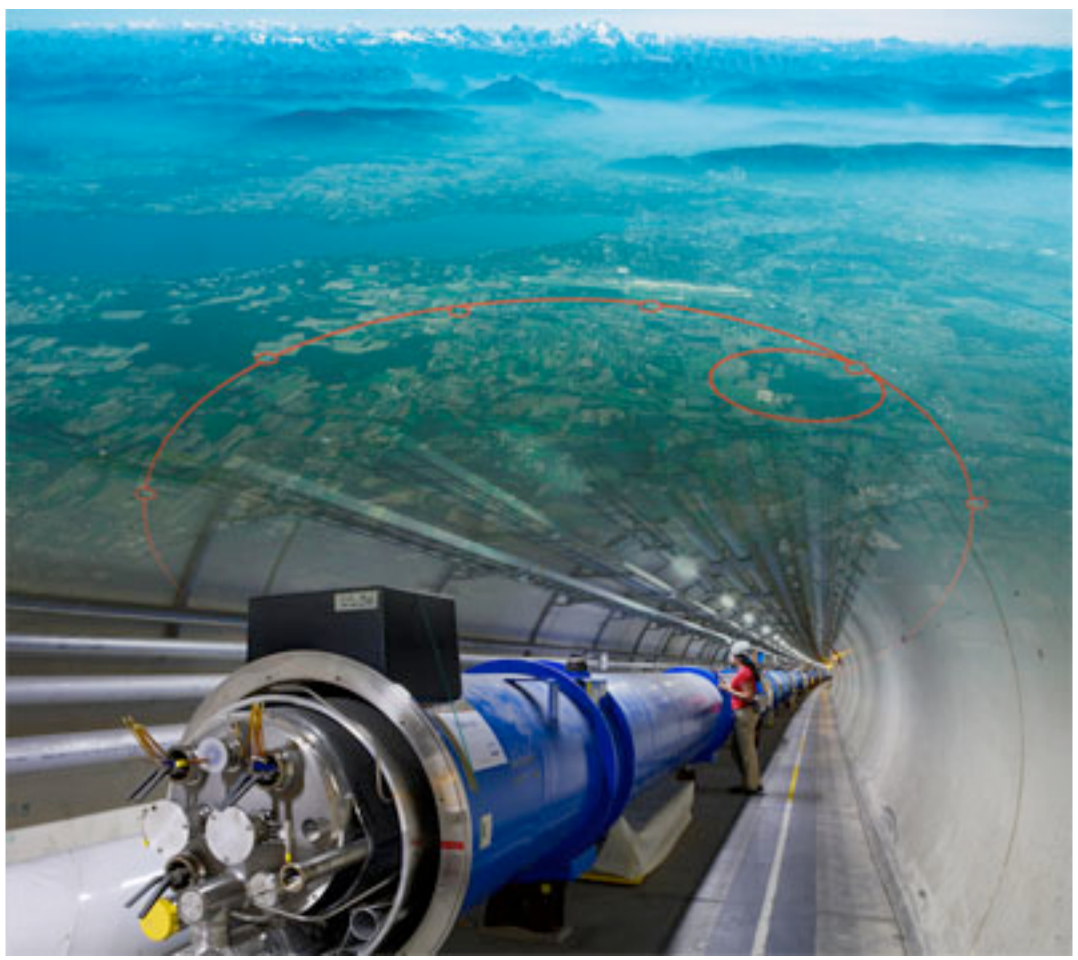
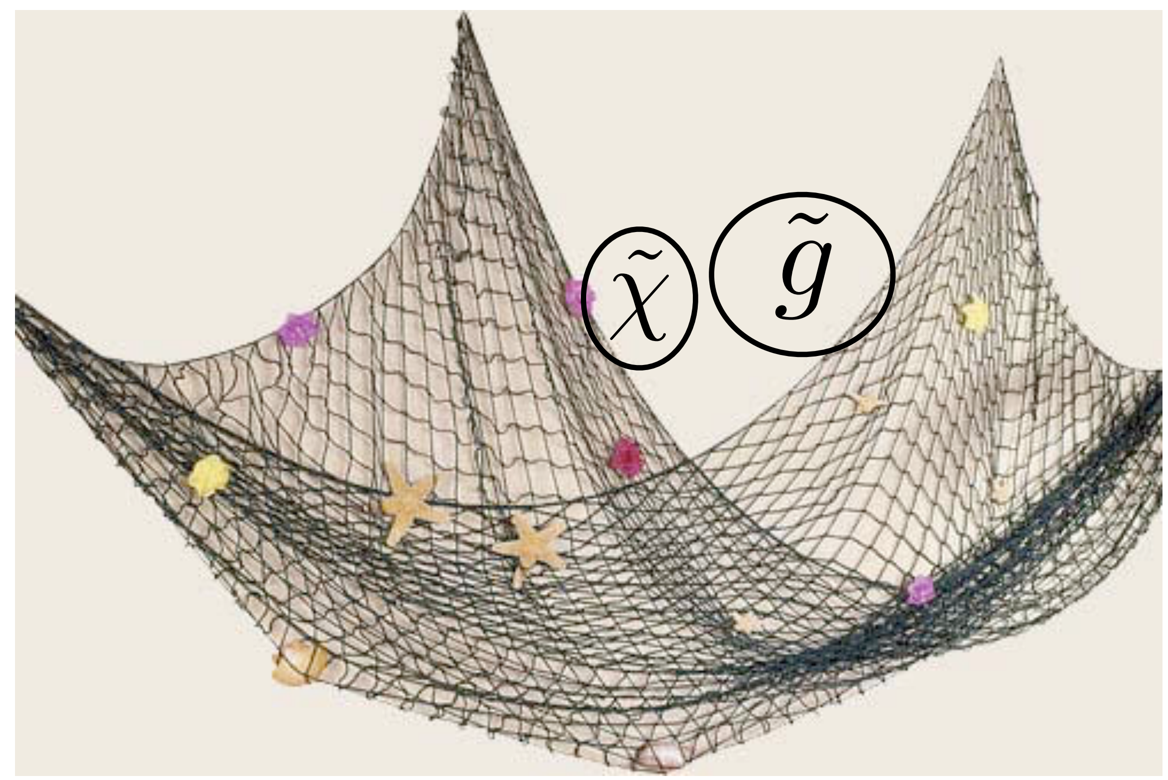
Topologies For Early LHC Searches

With: Daniele Alves and Jay G. Wacker

Based on: arXiv:1003.3886, arXiv:1008.0407, arXiv:1010.xxxx

How does the LHC cast the widest net possible for new physics?





Jets + MET

Large production rates

Reason to be optimistic for seeing excesses

Dark Matter

Wimp Miracle: DM a thermal relic if
mass is 100 GeV to 1 TeV

Usually requires a dark sector
that frequently contains new colored particles

Outline

- Jets + MET Simplified Models
- Early ATLAS results and interpretations
- Prospects for 1 fb^{-1}

Simplified Models

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

Simplified Model: Minimal particle content and free parameters

Limits of specific theories
Only keep particles and couplings relevant for searches

Captures many specific models (MSSM, UED, etc)

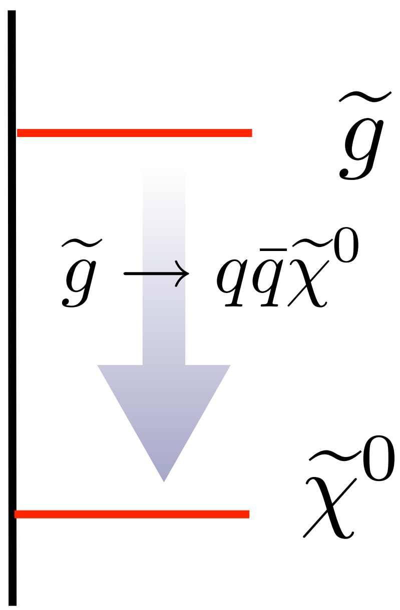
Easy to notice & explore kinematic limits

Alwall, Le, Lisanti, Wacker.
arXiv:0809.3264, arXiv0803.0019
Alwall, Schuster, Toro.
arXiv:0810.3921

Two Simplified Models

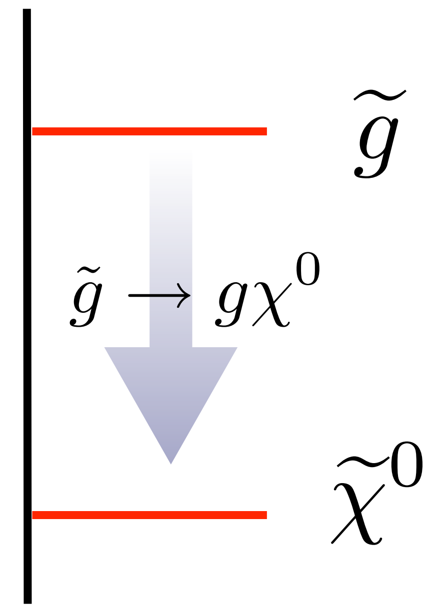
$$pp \to \widetilde{g}\widetilde{g}$$

"Gluino" Directly Decaying to LSP



3 body decay

(*e.g.* heavy squarks)



2 body decay

(*e.g.* gauge mediation w/ squarks)

Free parameters

$m_{\widetilde{g}}$

Mass of produced particle

$m_{\widetilde{\chi}^0}$

Mass of invisible particle

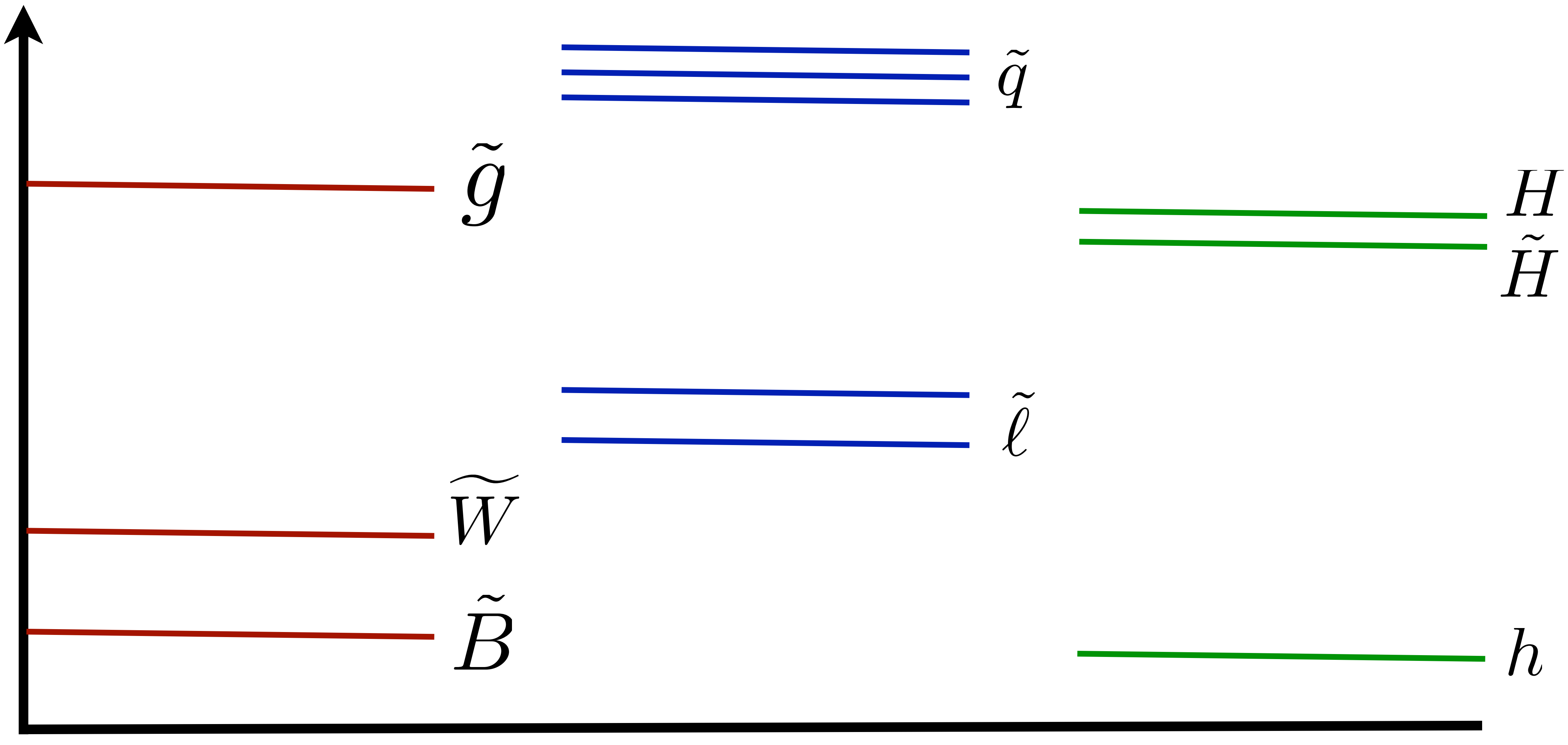
$\mathcal{B} \times \sigma_{pp \to \widetilde{g}\widetilde{g}}$

Cross section x Branching Ratio

mSugra has "Gaugino Mass Unification"

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

Benchmarks miss some important kinematics



Lack of diversity (contrast with pMSSM)

Berger, Gainer, Hewett, Rizzo. arXiv:0812.0980,1009.2539

First Search for SUSY

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.

Sets limit on

$$L = 70 \text{ nb}^{-1} \qquad \sigma(pp \to \tilde{g}\tilde{g}X)\,\epsilon$$

efficiency for passing cuts

Cut	Topology	$1j + \not{E}_T$	$2^+j + \not{E}_T$	$3^+j + \not{E}_T$	$4^+j + \not{E}_T$
1	p_{T1}	$> 70\,\text{GeV}$	$> 70\,\text{GeV}$	$> 70\,\text{GeV}$	$> 70\,\text{GeV}$
2	p_{Tn}	$\leq 30\,\text{GeV}$	$> 30\,\text{GeV}\,(n = 2)$	$> 30\,\text{GeV}\,(n = 2, 3)$	$> 30\,\text{GeV}\,(n = 2 - 4)$
3	$\not{E}_{T\,\text{EM}}$	$> 40\,\text{GeV}$	$> 40\,\text{GeV}$	$> 40\,\text{GeV}$	$> 40\,\text{GeV}$
4	$p_{T\,\ell}$	$\leq 10\,\text{GeV}$	$\leq 10\,\text{GeV}$	$\leq 10\,\text{GeV}$	$\leq 10\,\text{GeV}$
5	$\Delta\phi(j_n, \not{E}_{T\,\text{EM}})$	none	$[> 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2, \text{none}]$
6	$\not{E}_{T\,\text{EM}}/M_{\text{eff}}$	none	> 0.3	> 0.25	> 0.2
	N_{Pred}	46^{+22}_{-14}	6.6 ± 3.0	1.9 ± 0.9	1.0 ± 0.6
	N_{Obs}	73	4	0	1
	$\sigma(pp \to \tilde{g}\tilde{g}X)\epsilon\|_{95\%\ \text{C.L.}}$	663 pb	46.4 pb	20.0 pb	56.9 pb

$3^+j + \not{E}_T$ effective for most of parameter space

Sensitivity Estimate

How well does this search do on general models?

Challenge is calculating efficiencies for passing cuts

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

$pp \to \tilde{g}\tilde{g} + \leq 2j$

(MLM matched)

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

Radiation important
for degenerate spectra

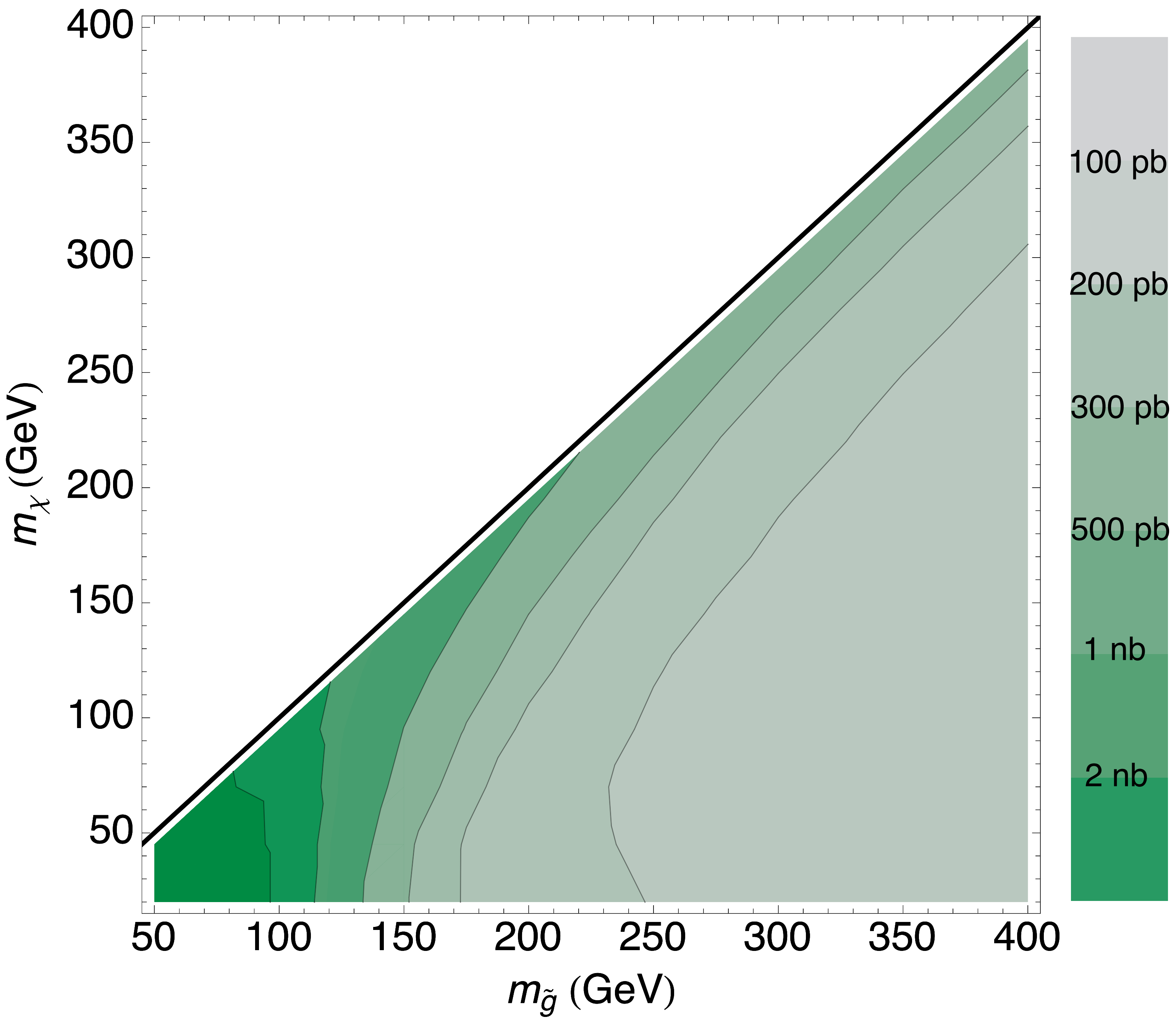
ϵ = Fraction of events passing cuts

$$\sigma \leq \frac{N_{\text{Max Sig}}}{\mathcal{L}\,\epsilon}$$

Putting it all together

$$\tilde{g} \to \chi q \bar{q}$$

Shaded contours are maximum cross section allowed



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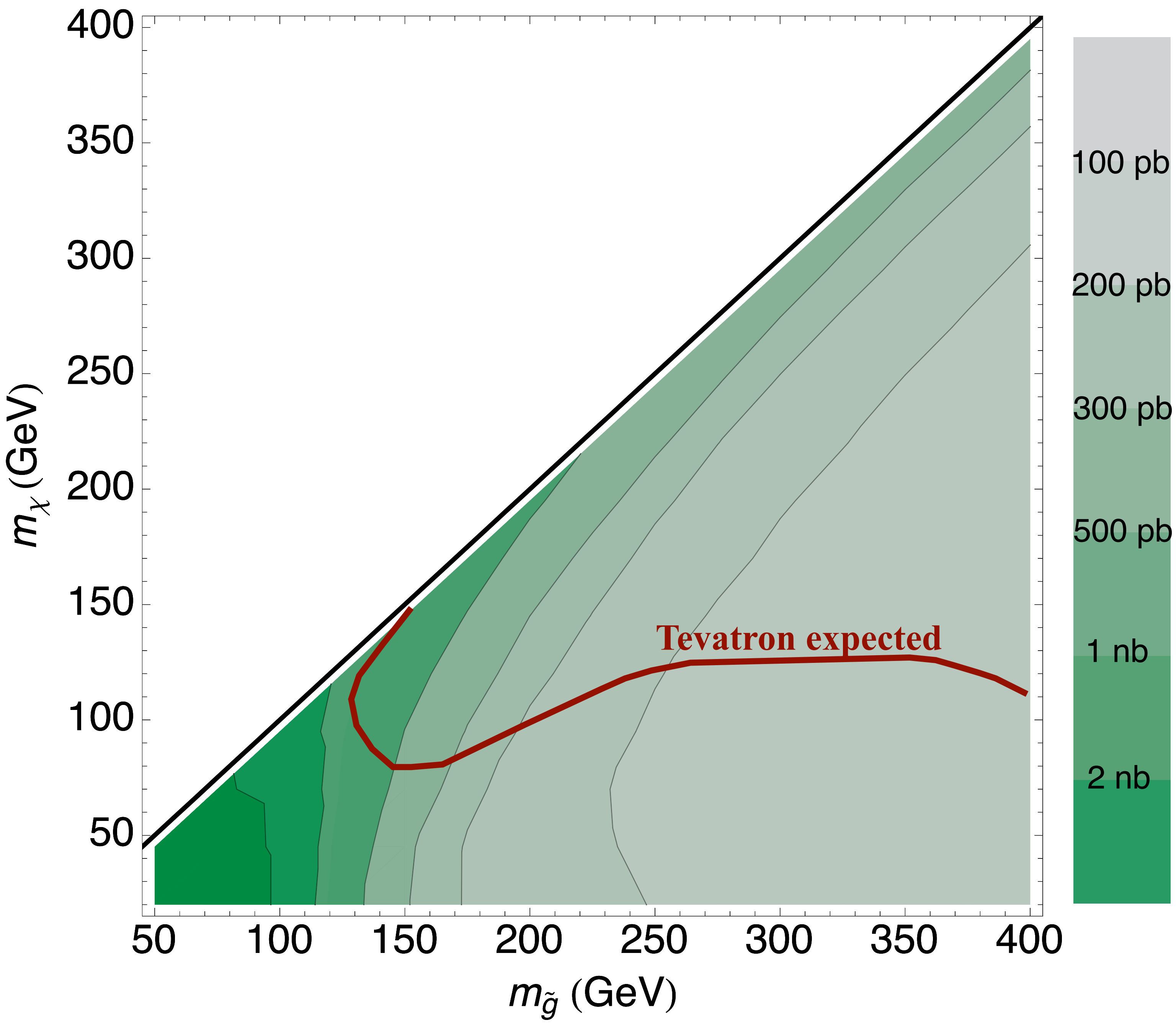
Shaded contours are maximum cross section allowed



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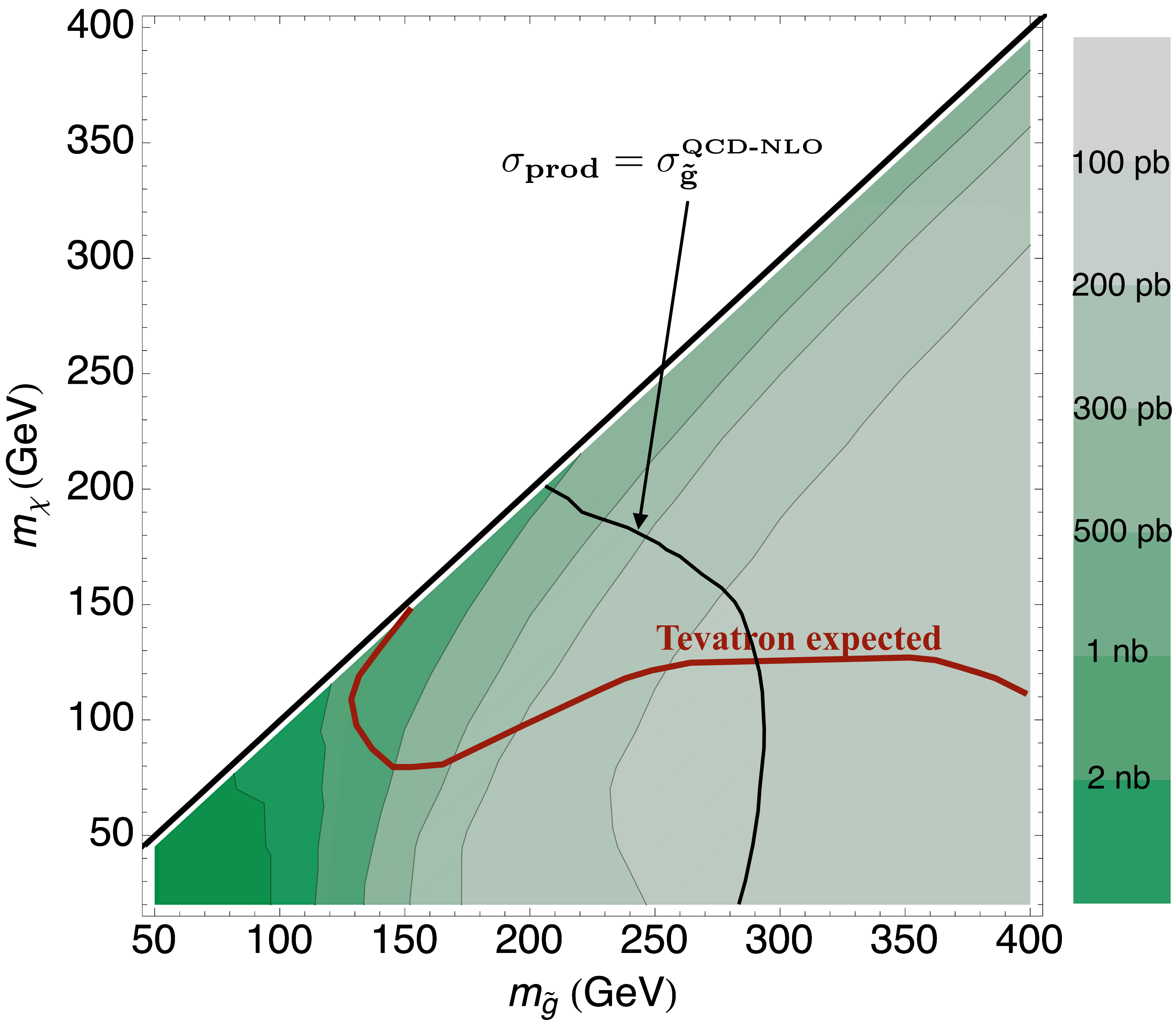

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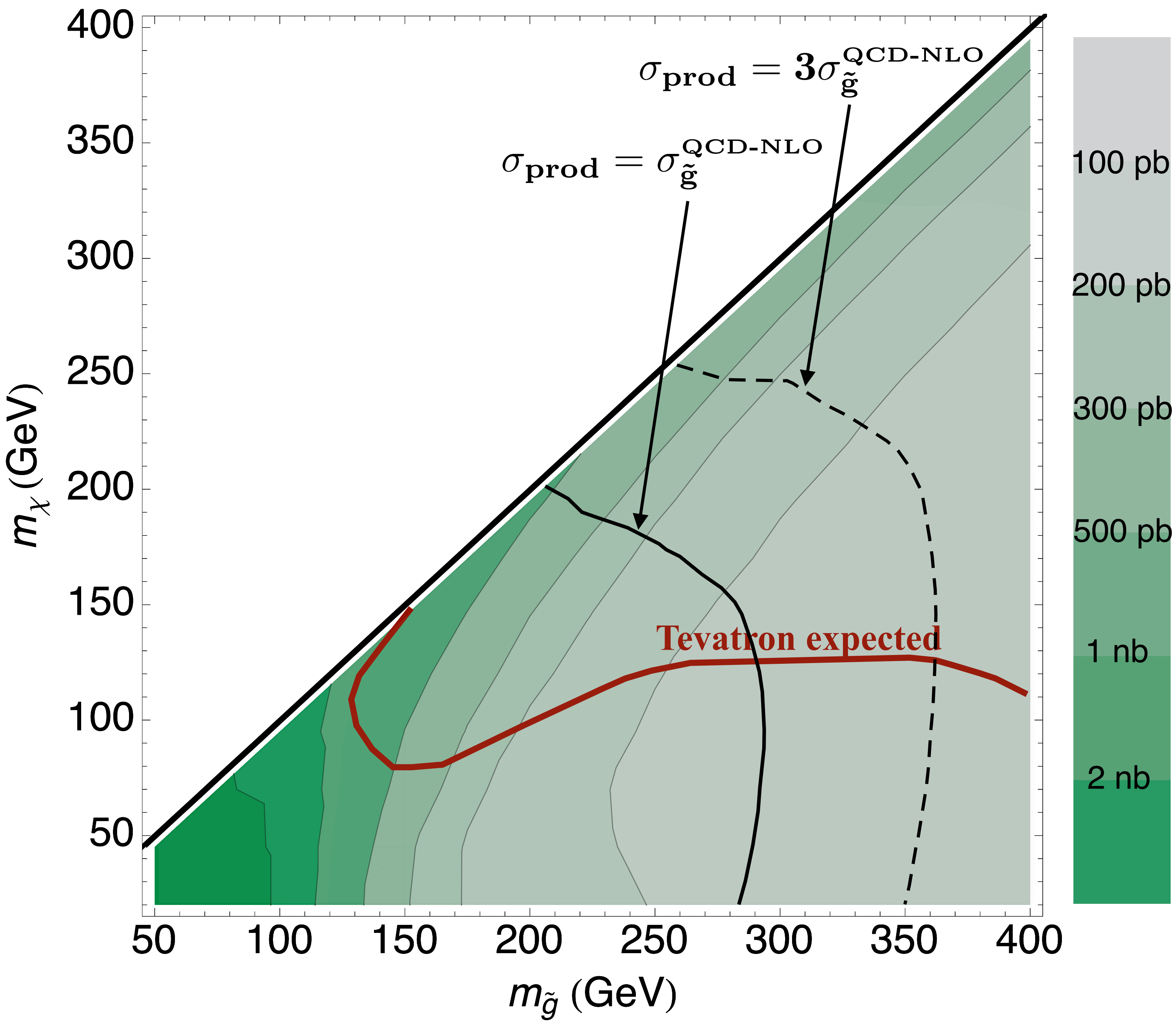

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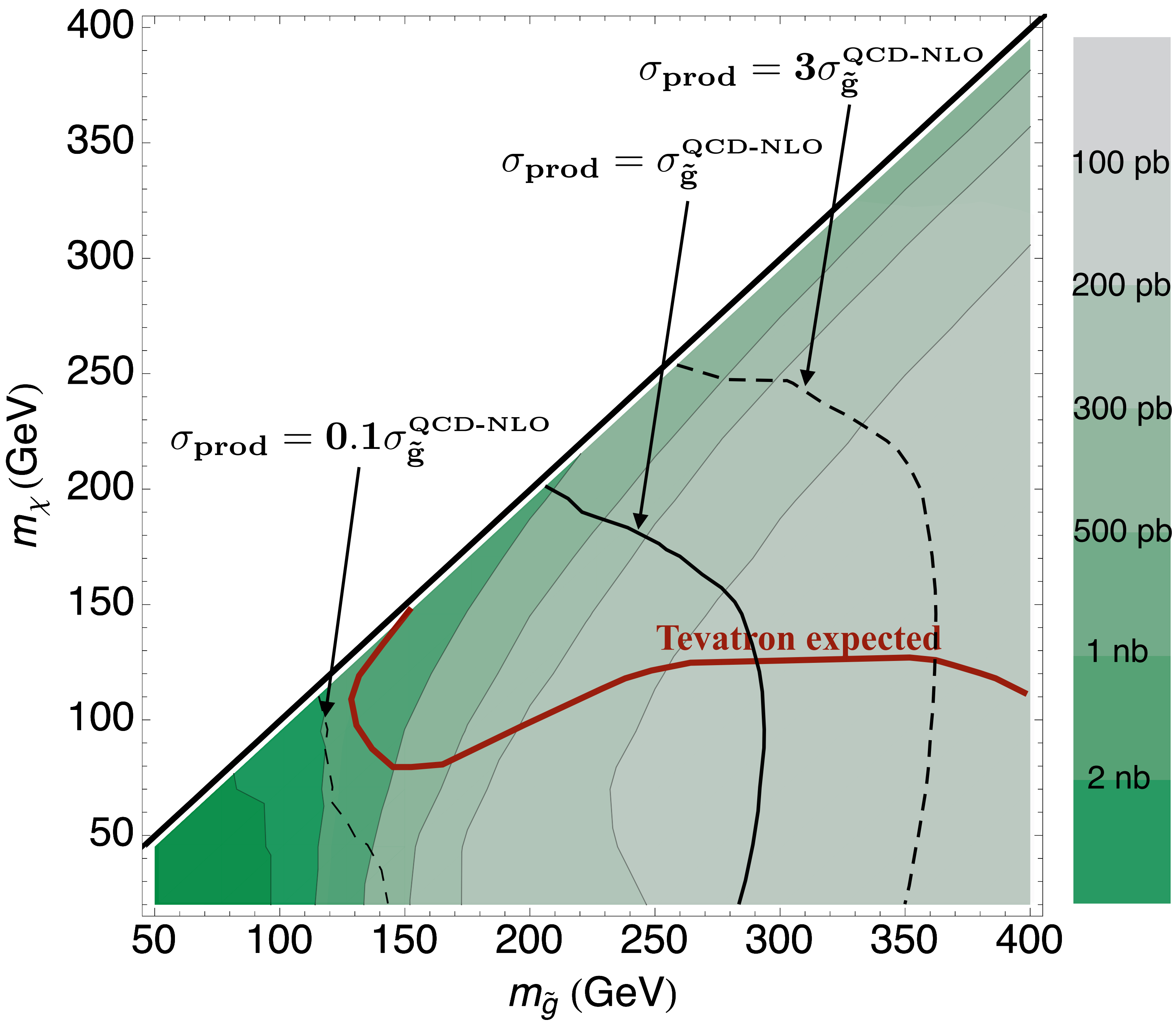

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$$\tilde{g} \rightarrow \chi q \bar{q}$$

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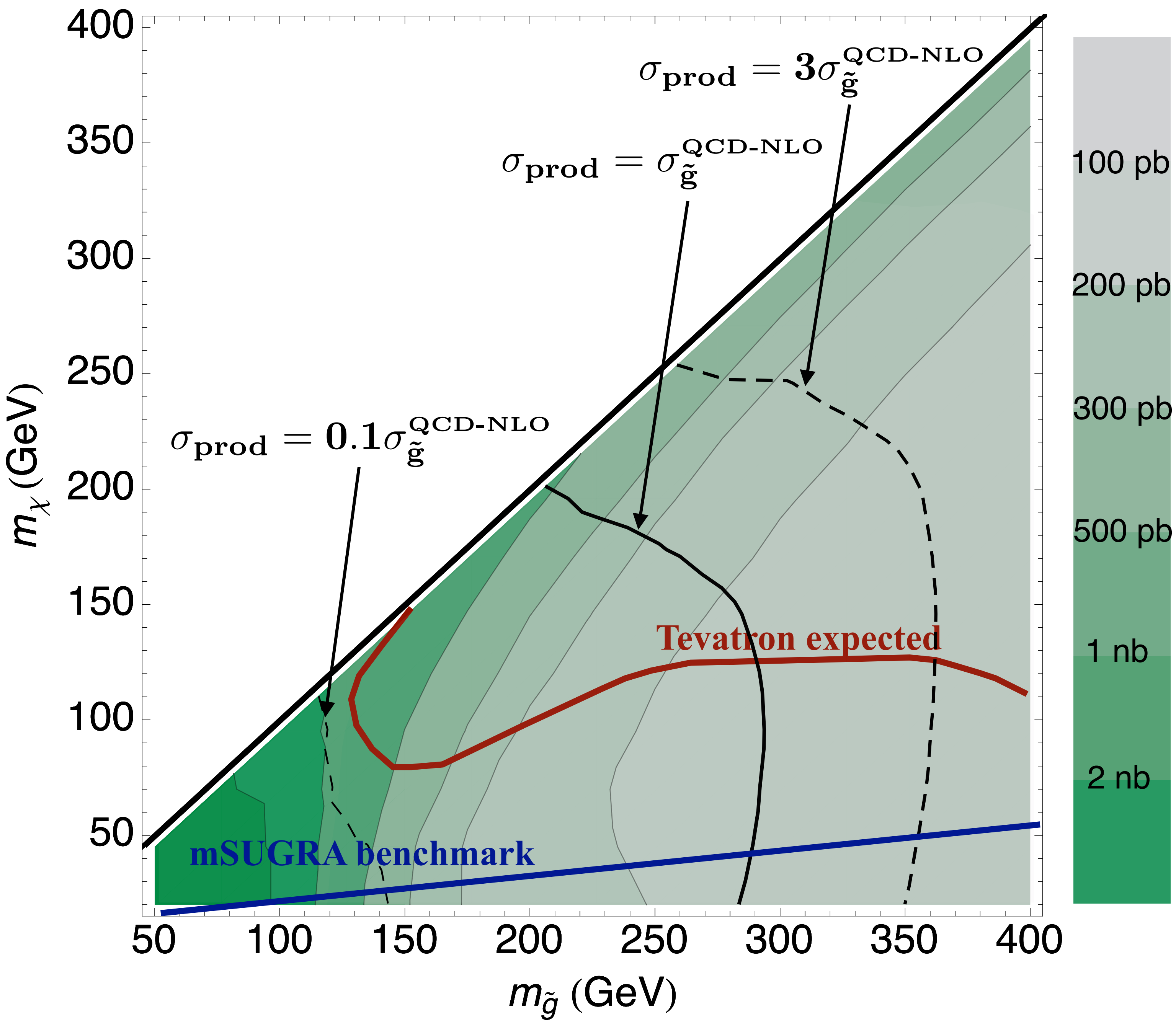
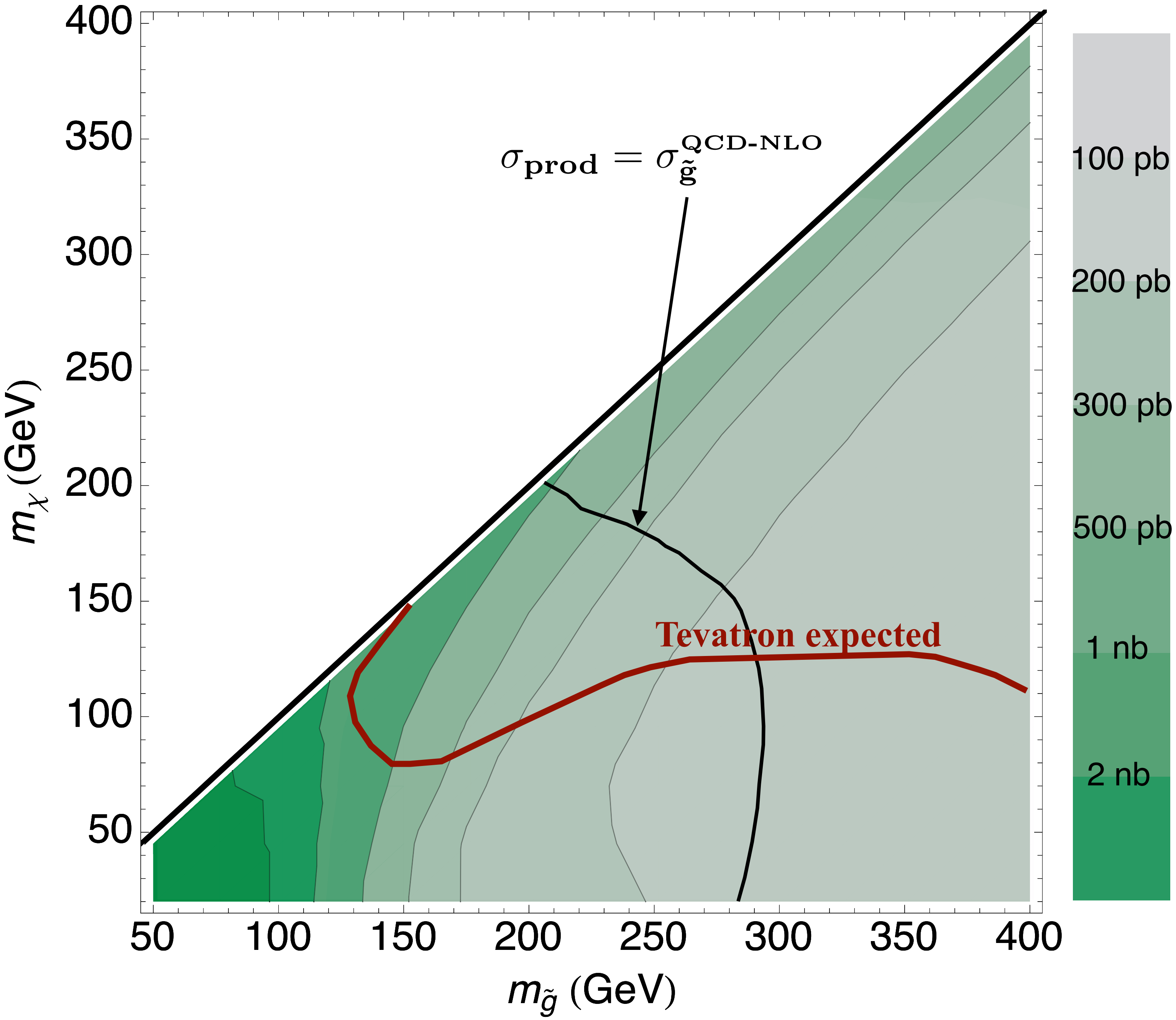


Putting it all together

$$\tilde{g} \rightarrow \chi q \bar{q}$$

For 100% branching ratio, the reach is extended



Going Forward to 1fb^{-1}

How sensitive are searches to

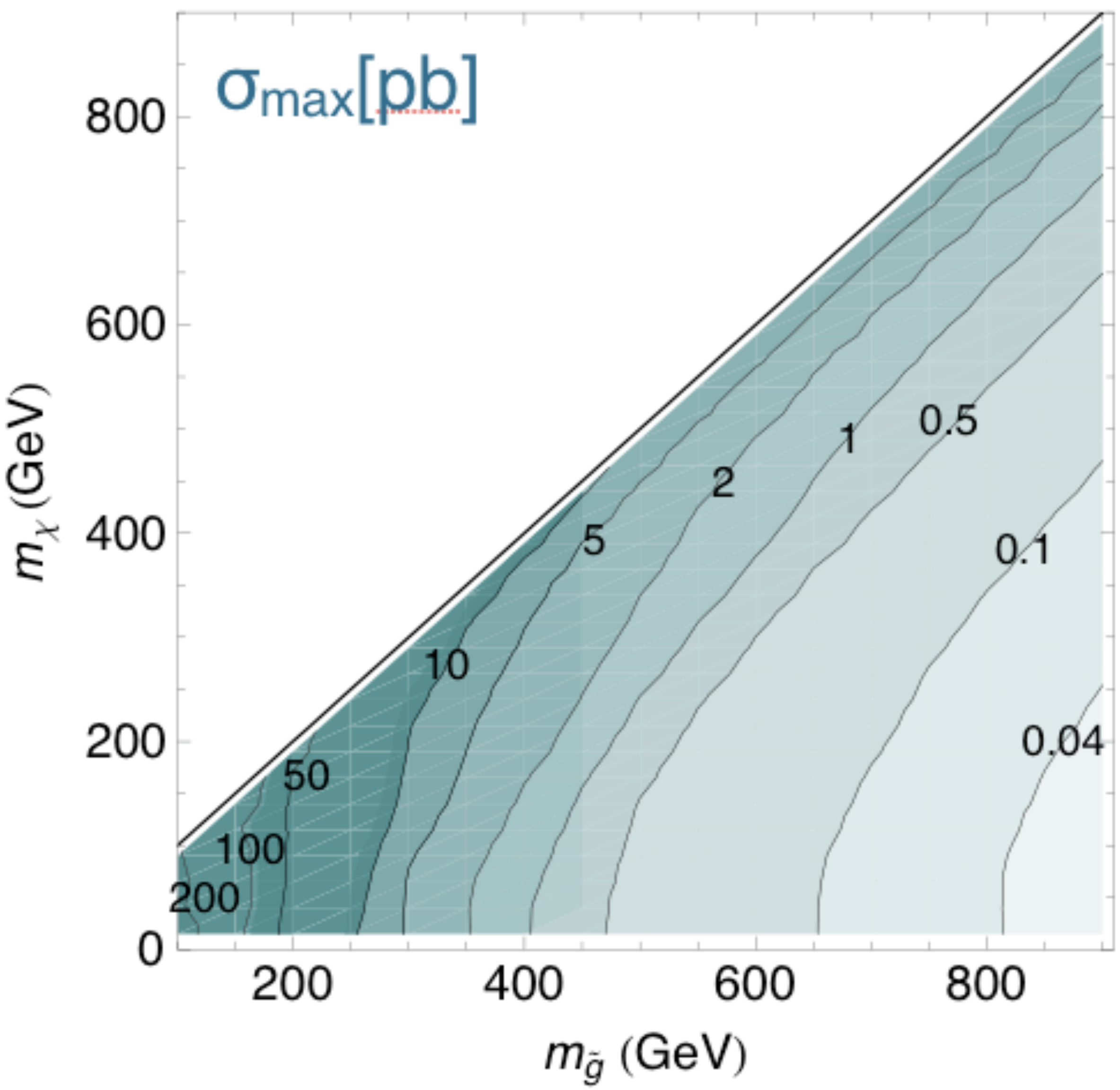
Cut	Topology	$1j + \not{E}_T$	$2^+j + \not{E}_T$	$3^+j + \not{E}_T$	$4^+j + \not{E}_T$
1	p_{T1}	$> 100\,\mathrm{GeV}$	$> 100\,\mathrm{GeV}$	$> 100\,\mathrm{GeV}$	$> 100\,\mathrm{GeV}$
2	p_{Tn}	$\leq 50\,\mathrm{GeV}$	$> 50\,\mathrm{GeV}$	$> 50\,\mathrm{GeV}$	$> 50\,\mathrm{GeV}$
3	$\not{E}_T$				
4	H_T				

Optimize cuts H_T $\not{E}_T$ for simplified models

Strategy Strategies

Find the minimal set of searches $(H_{T,i}, \not{E}_{T\ i})$
covering the parameter space for simplified models

i.e. These contours are the optimal searches we found
How many different searches are necessary to cover it?

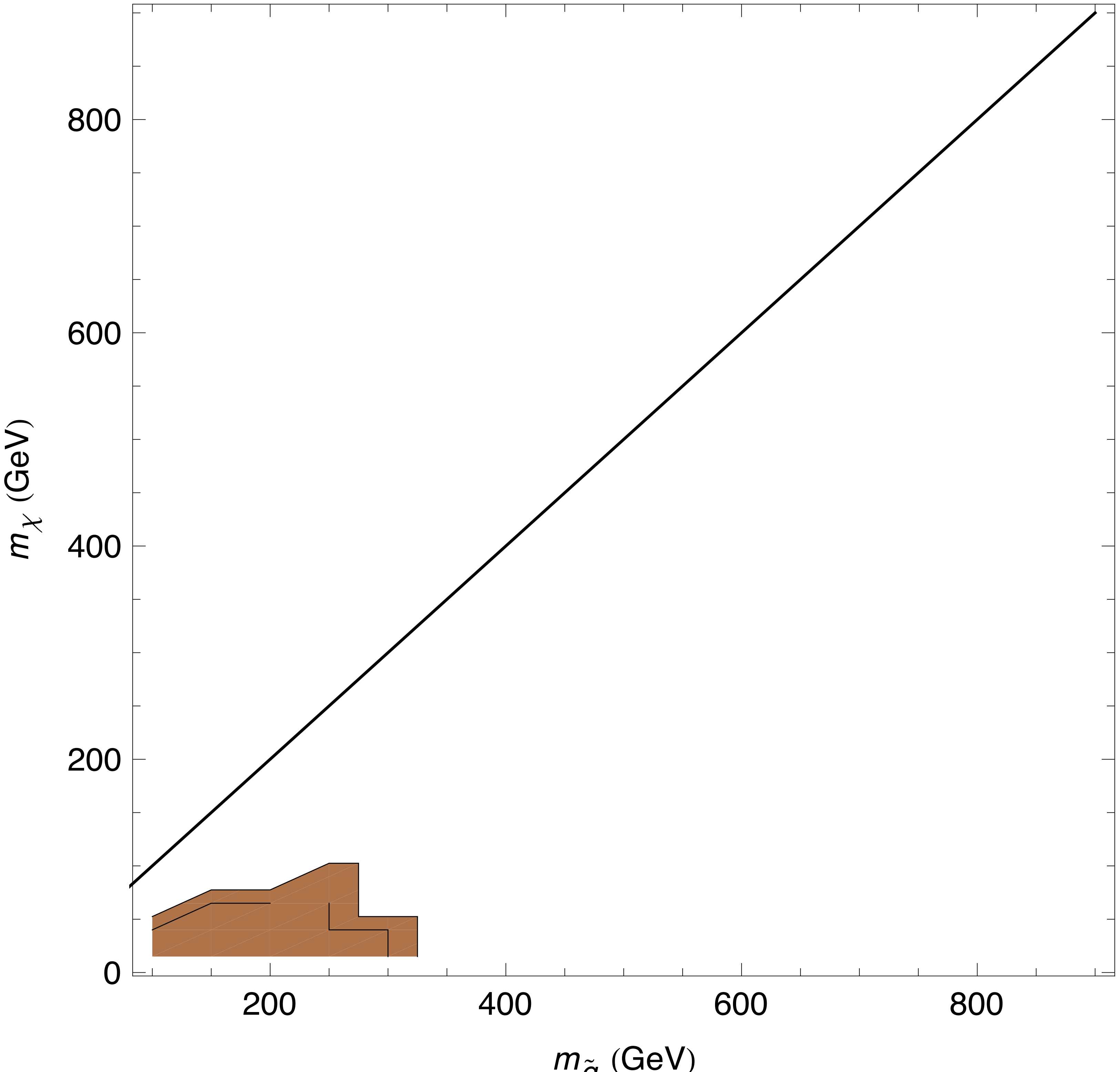


$L = 1000\ \text{pb}^{-1}$

An Example

$$\tilde{g} \to \chi q \bar{q}$$

$\not{E}_T > 100$ GeV
$H_T > 500$ GeV



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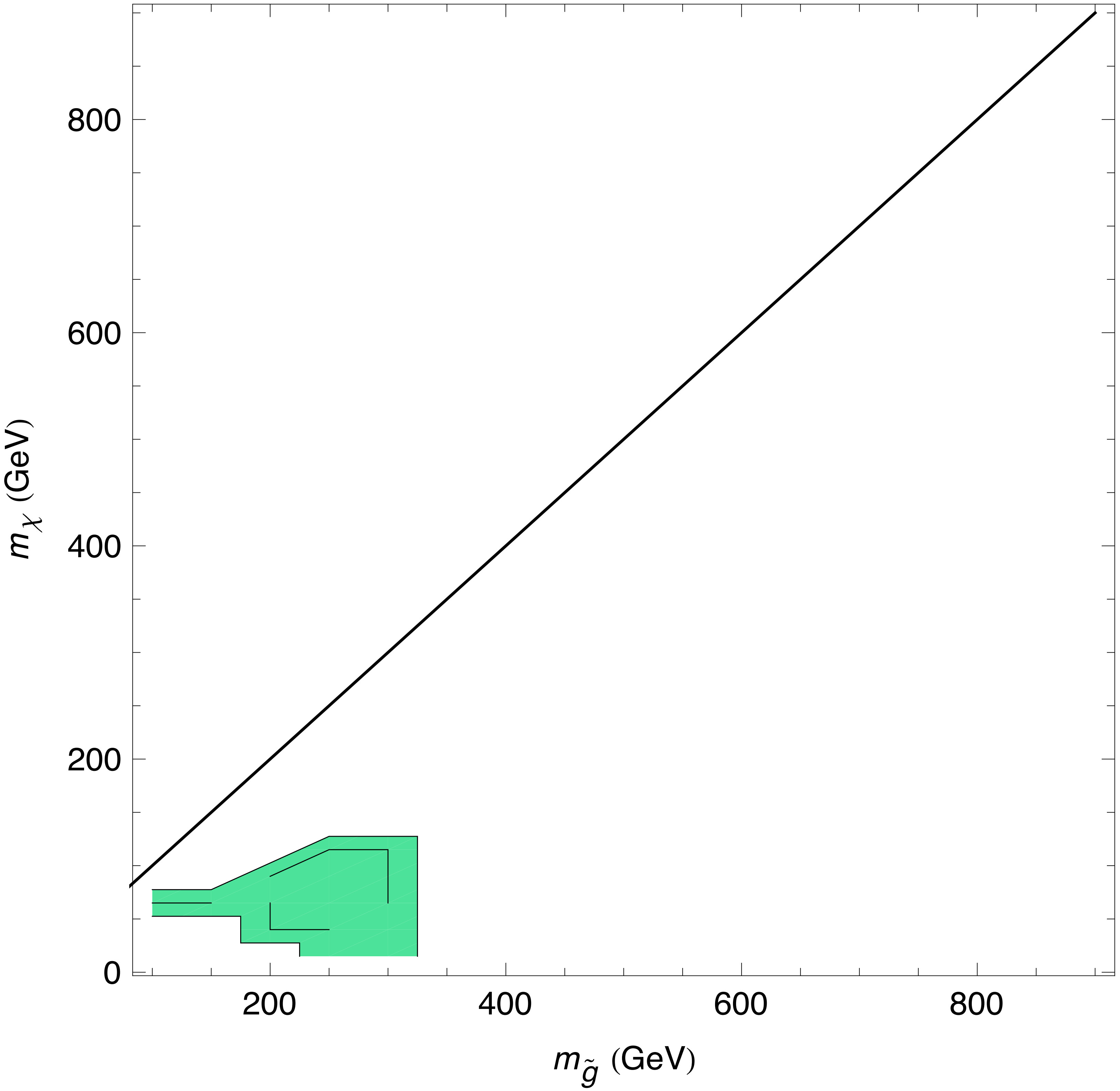
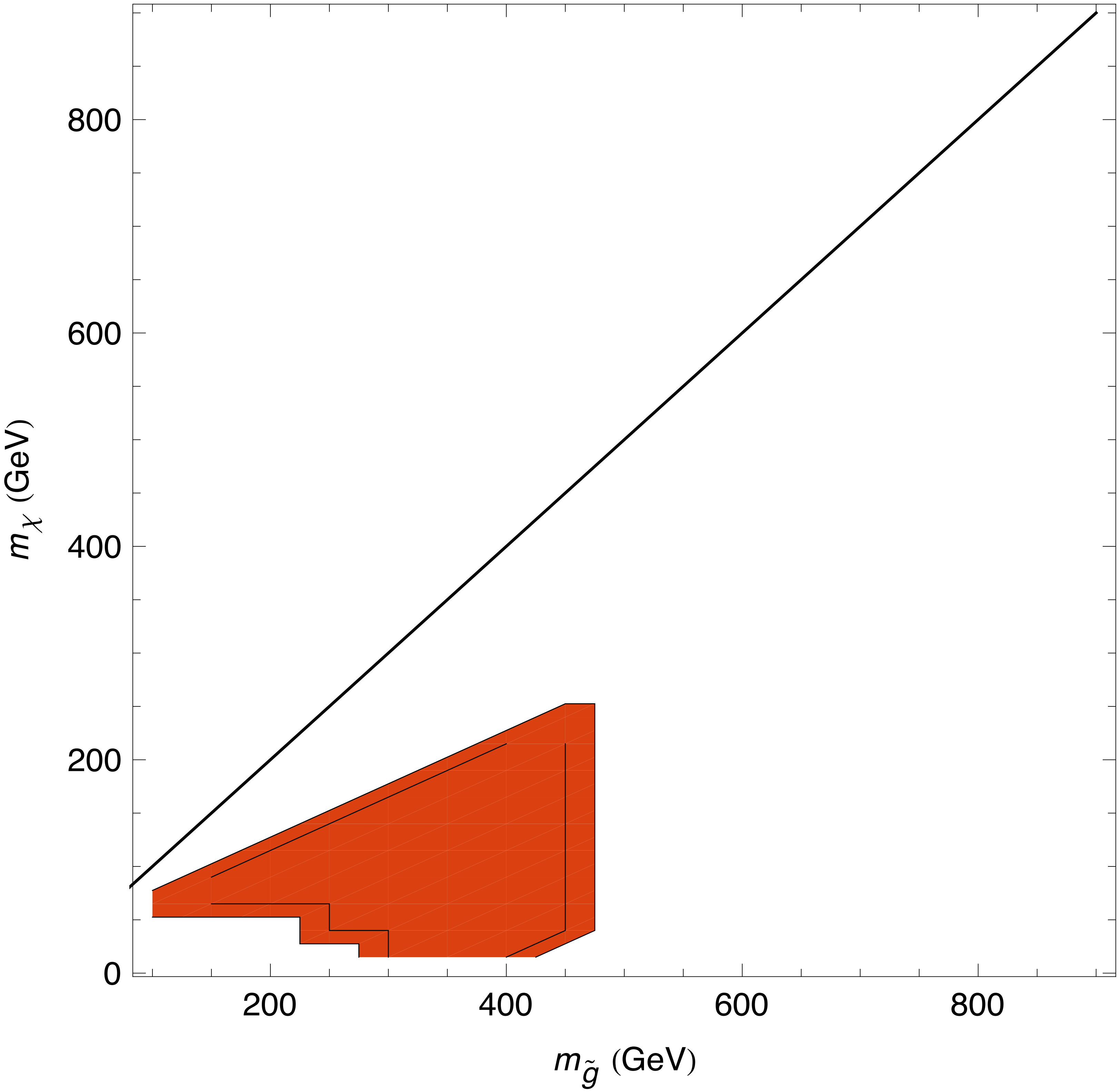


$\not{E}_T > 150$ GeV
$H_T > 250$ GeV

An Example

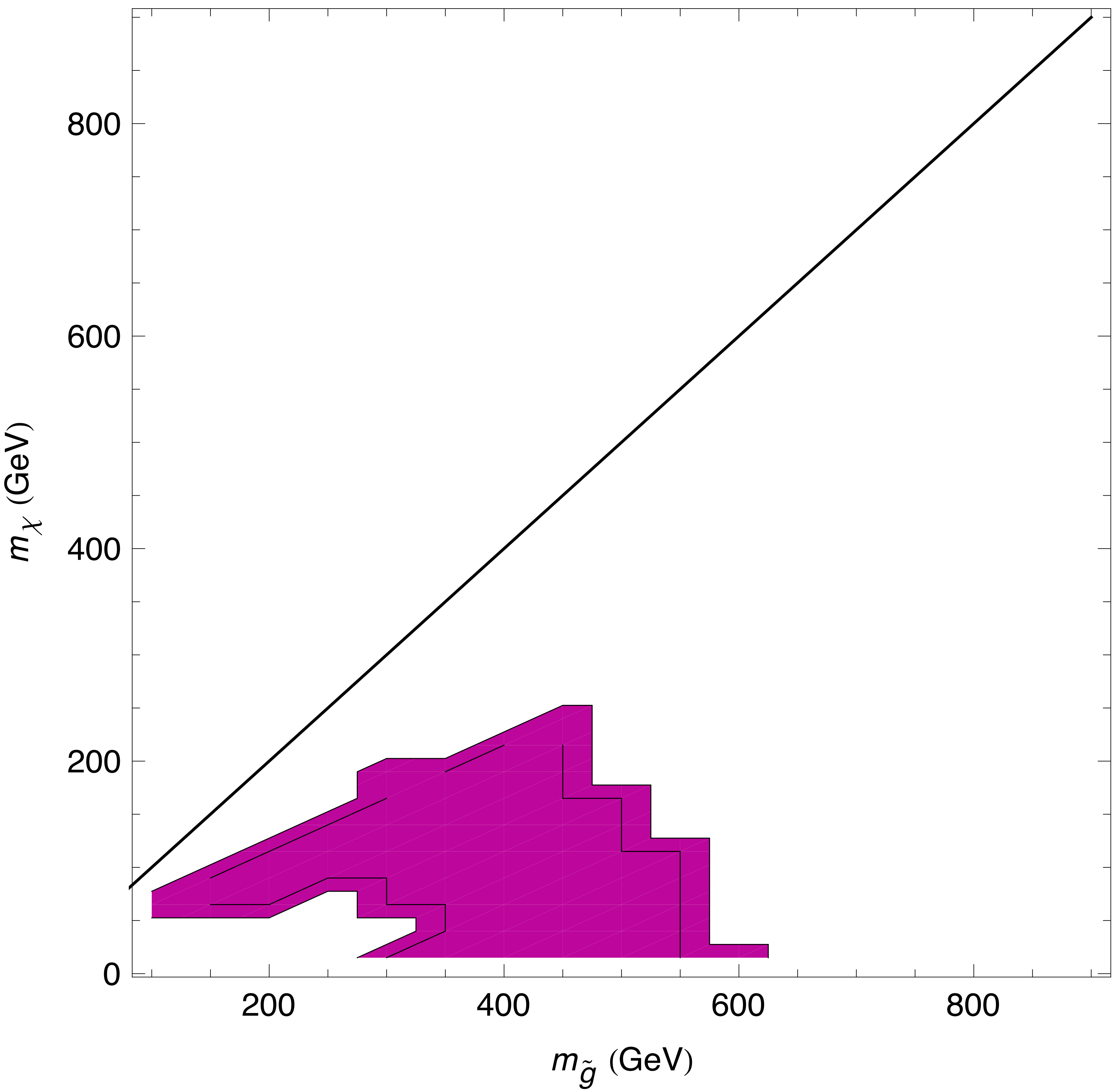
$$\tilde{g} \to \chi q \bar{q}$$



$\not{E}_T > 200$ GeV
$H_T > 500$ GeV

An Example

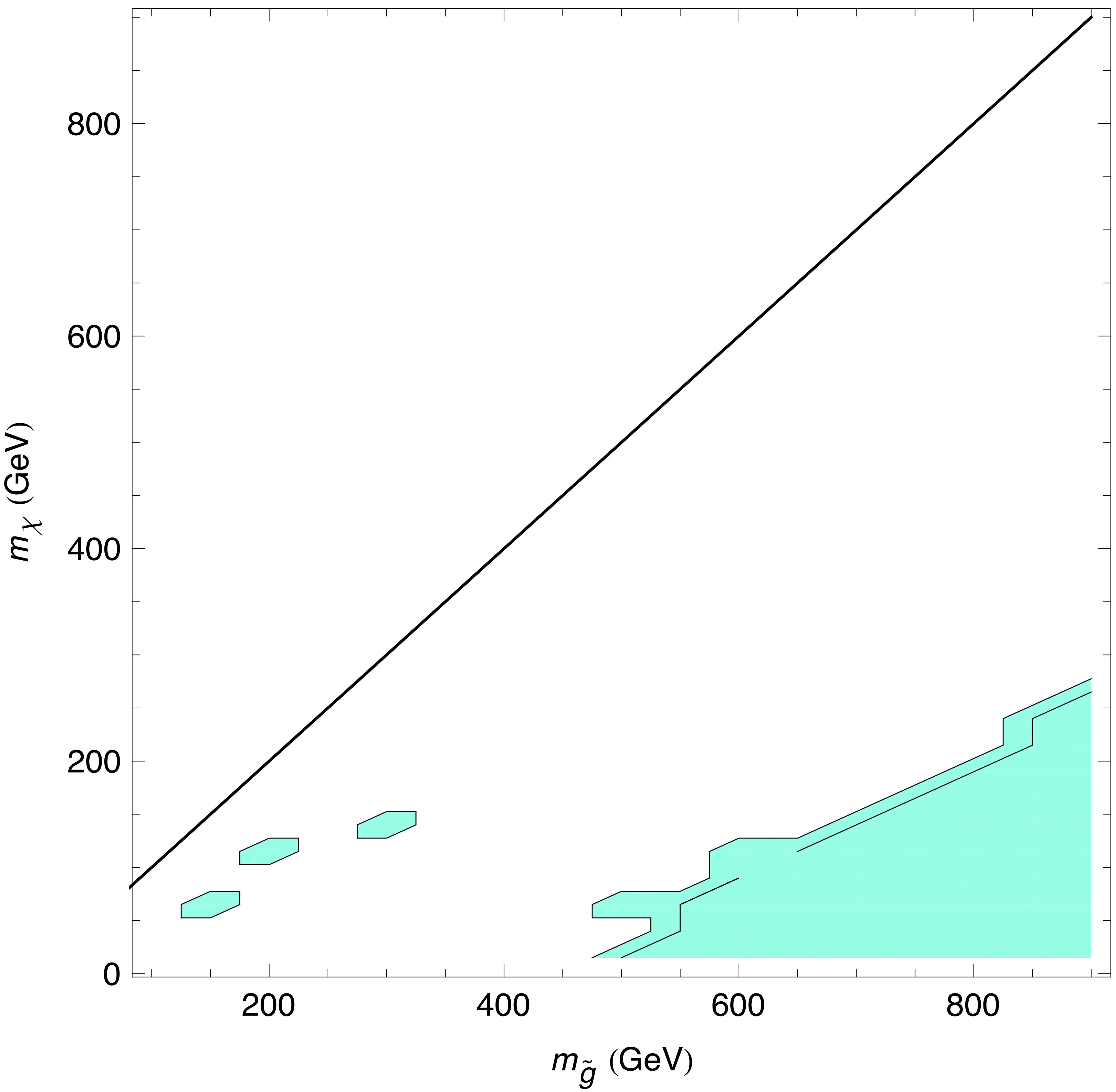
$$\tilde{g} \rightarrow \chi q \bar{q}$$



$\not{E}_T > 200$ GeV
$H_T > 750$ GeV

An Example

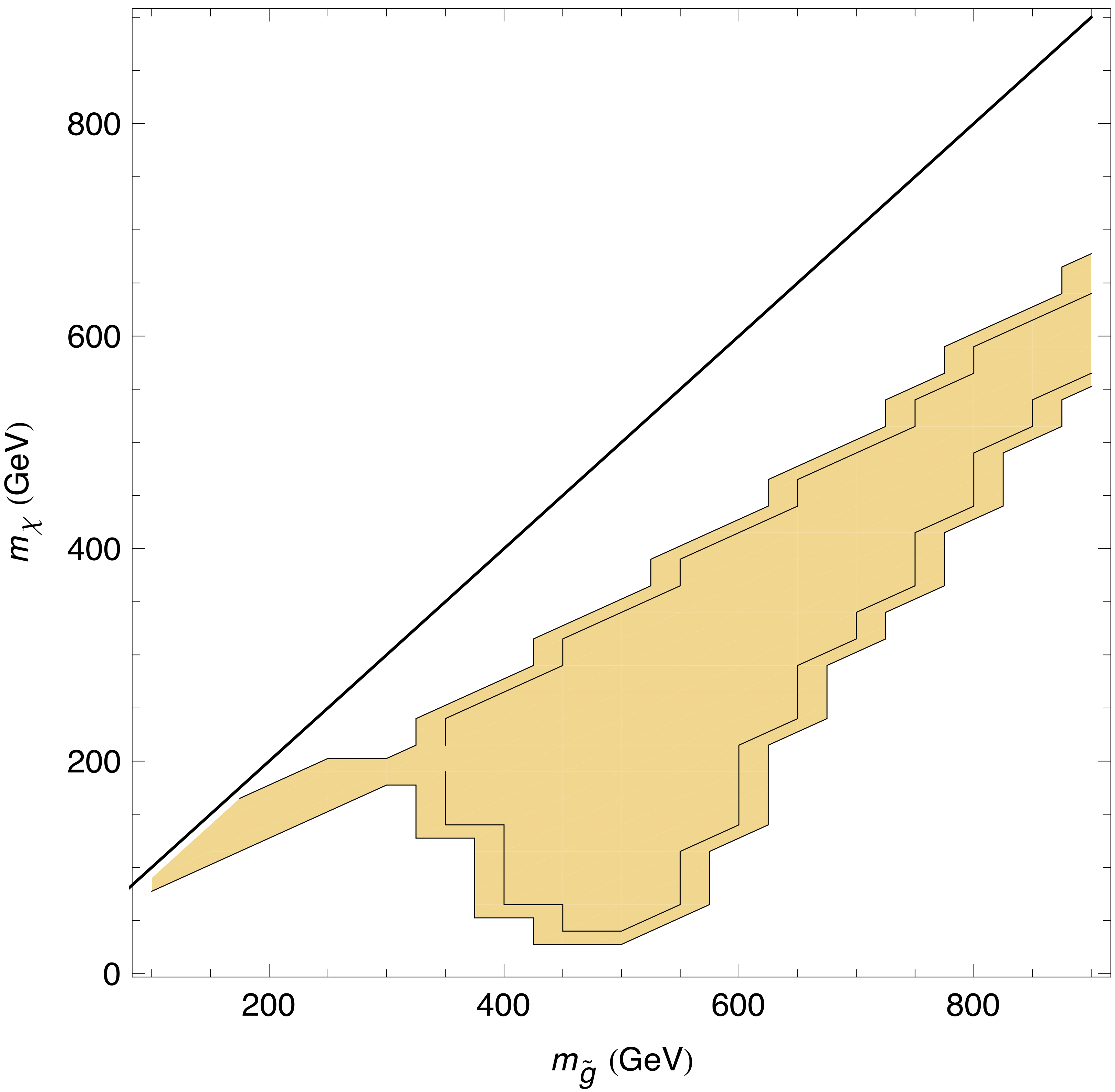
$$\tilde{g} \to \chi q \bar{q}$$



$\not{E}_T > 250$ GeV
$H_T > 1000$ GeV

An Example

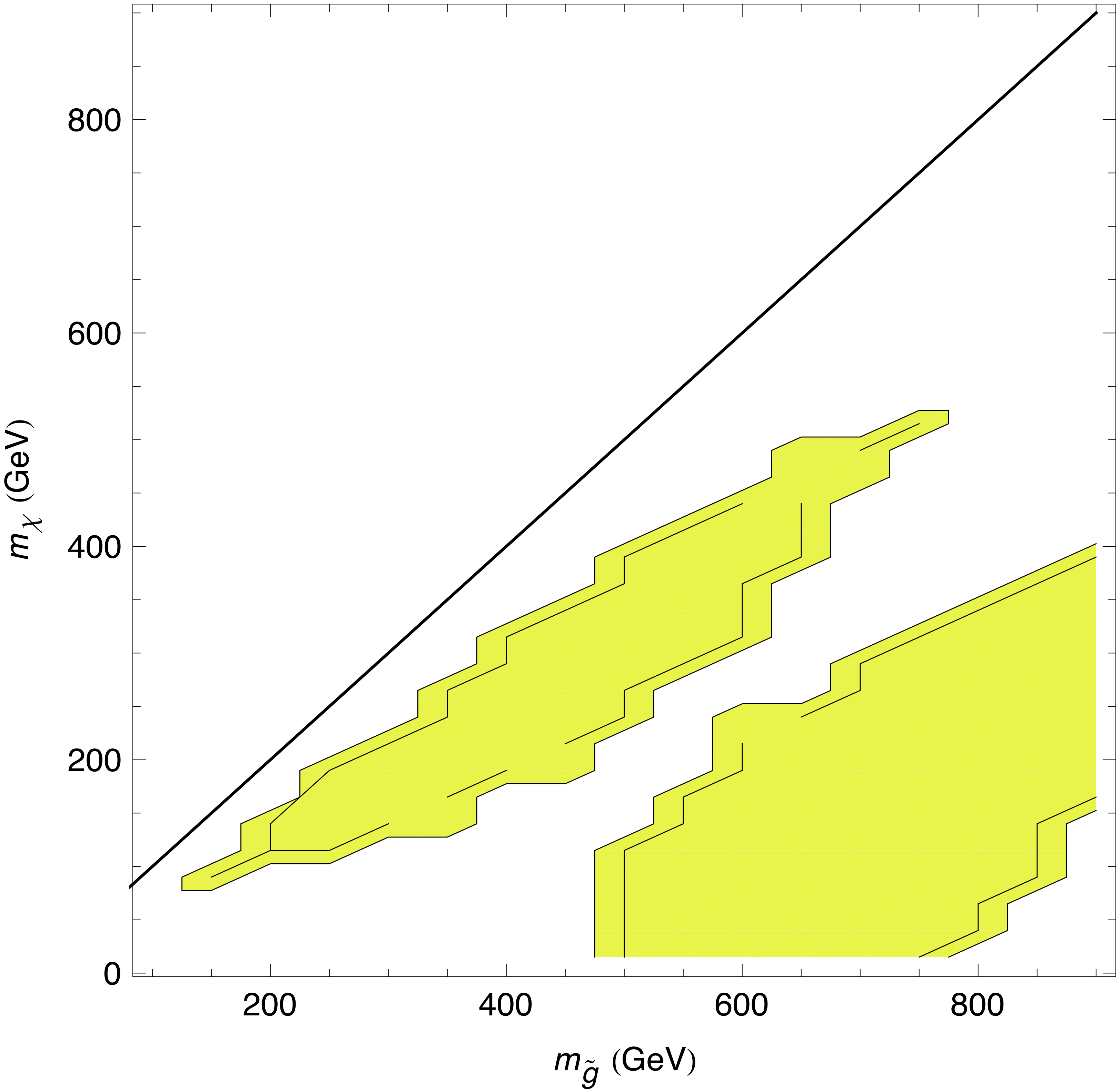
$$\tilde{g} \to \chi q \bar{q}$$



$\not{E}_T > 300$ GeV
$H_T > 400$ GeV

An Example

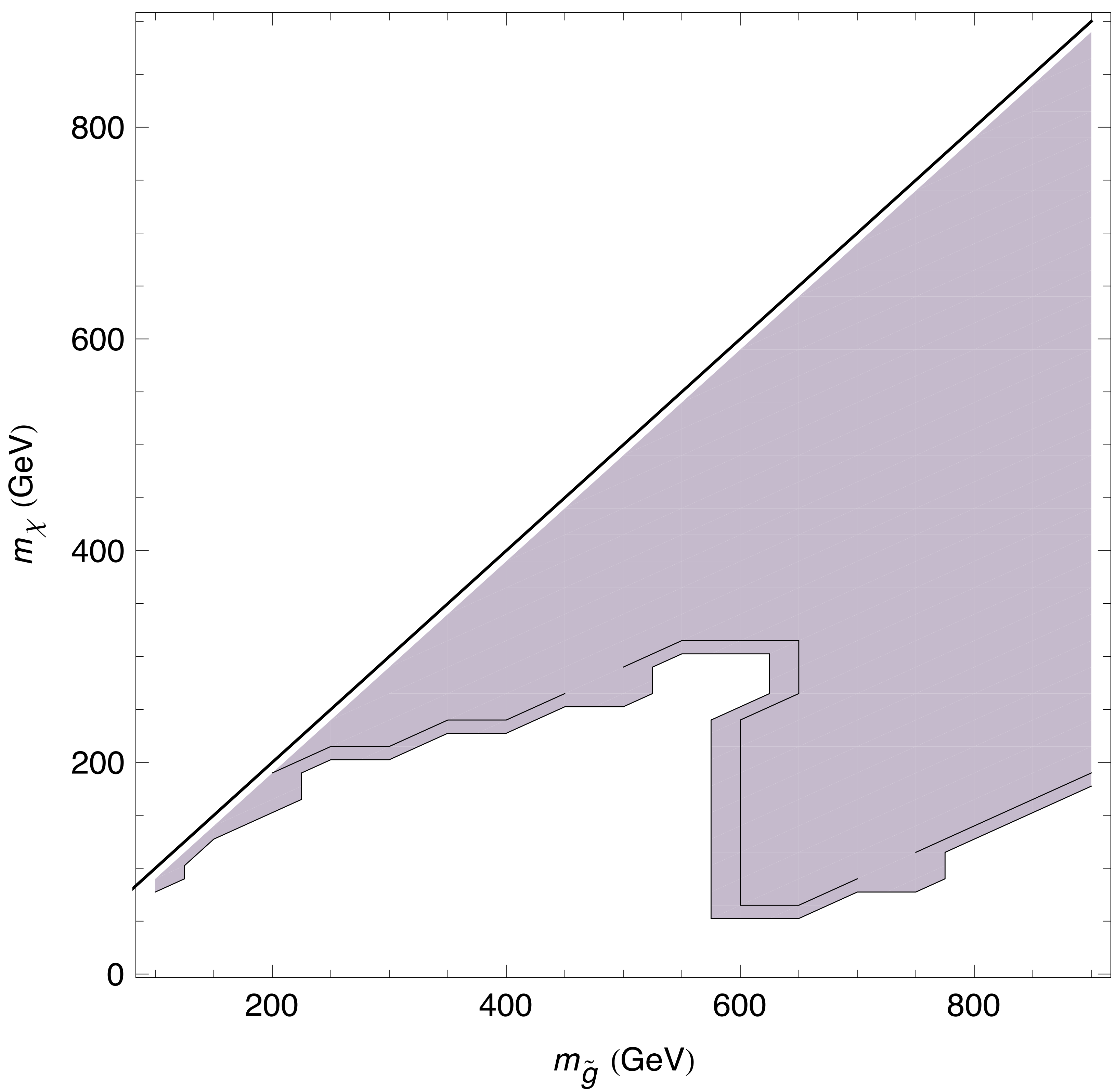
$$\tilde{g} \rightarrow \chi q \bar{q}$$



$\not{E}_T > 300$ GeV
$H_T > 800$ GeV

An Example

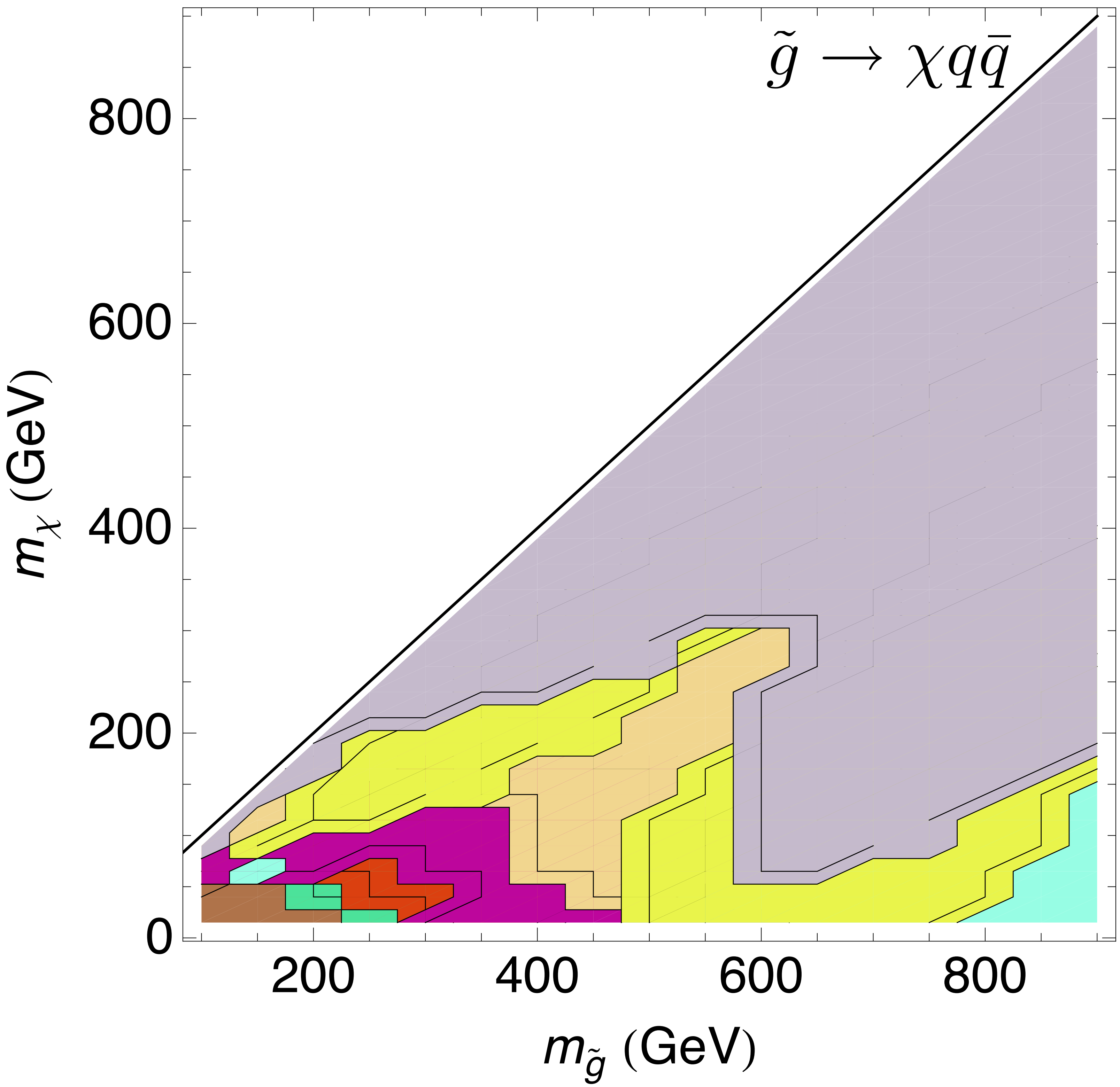
$$\tilde{g} \to \chi q \bar{q}$$



$\not{E}_T > 400$ GeV
$H_T > 550$ GeV

Answer:

8 searches



$\not\!\!E_T > 100$ GeV
$H_T > 500$ GeV

$\not\!\!E_T > 150$ GeV
$H_T > 250$ GeV

$\not\!\!E_T > 200$ GeV
$H_T > 500$ GeV

$\not\!\!E_T > 200$ GeV
$H_T > 750$ GeV

$\not\!\!E_T > 250$ GeV
$H_T > 1000$ GeV

$\not\!\!E_T > 300$ GeV
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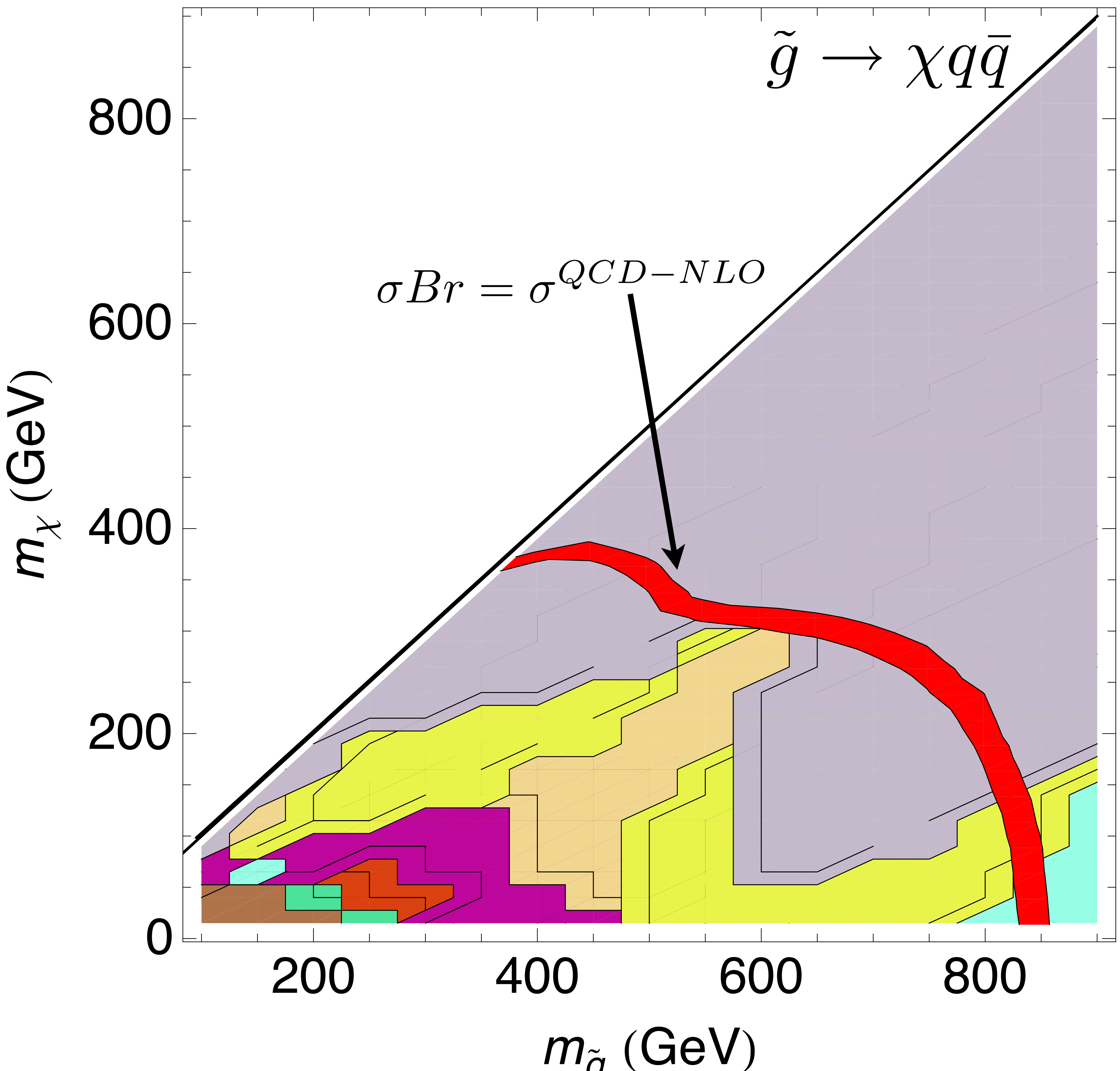
Answer:

8 searches



$\not{E}_T > 100$ GeV
$H_T > 500$ GeV

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Answer:

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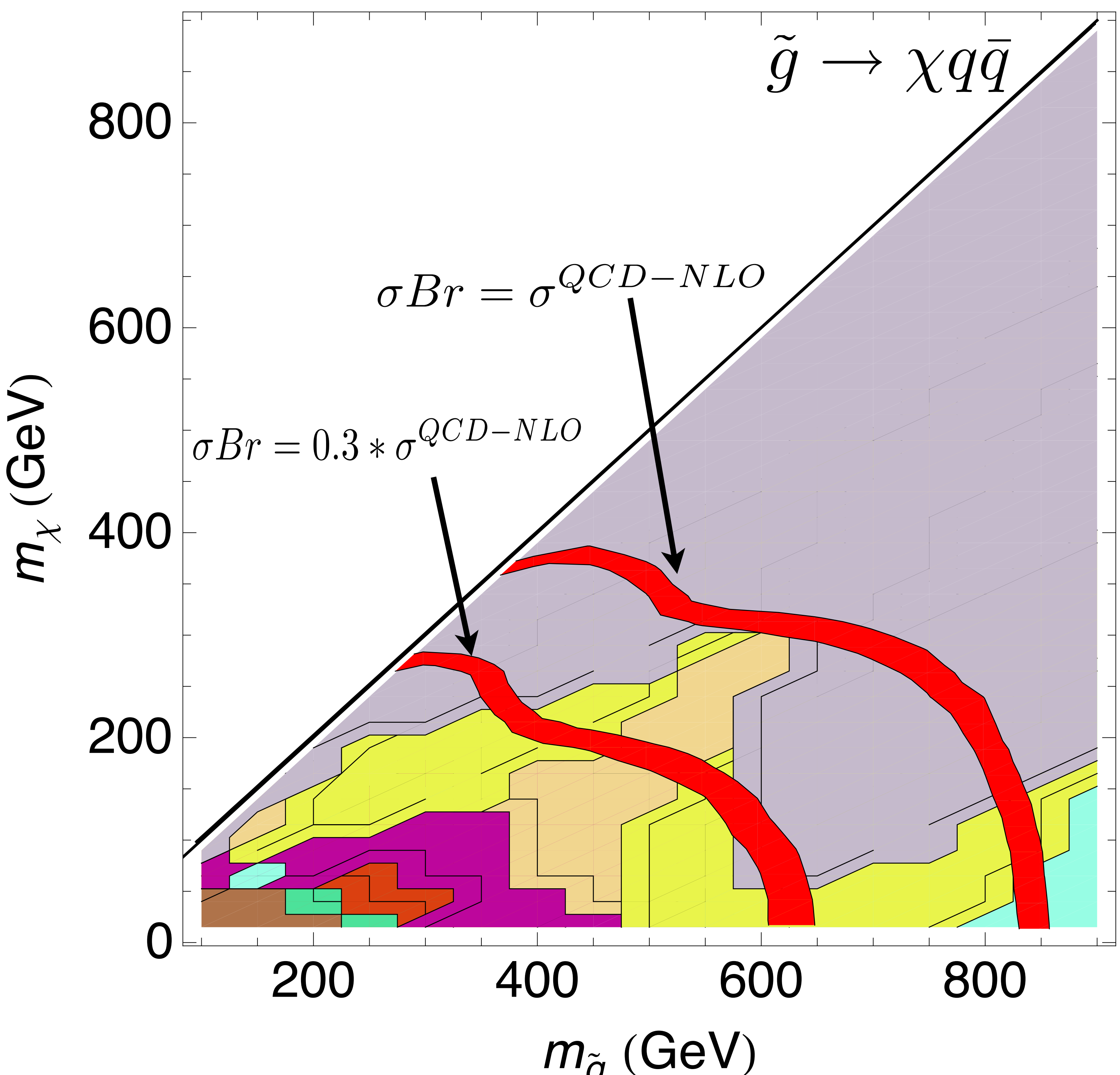

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$H_T > 800$ GeV

$\not{E}_T > 400$ GeV
$H_T > 550$ GeV

Lessons Learned

Simplified models require broadening
acceptances of Jets and MET searches

Other simplified models to be studied

squarks (particularly for matching)
heavy flavor,
longer cascade decays,
lepton rich decays chains,
etc.

Early LHC searches are capable
of reaching uncharted territory

Every update has the potential for discovery!

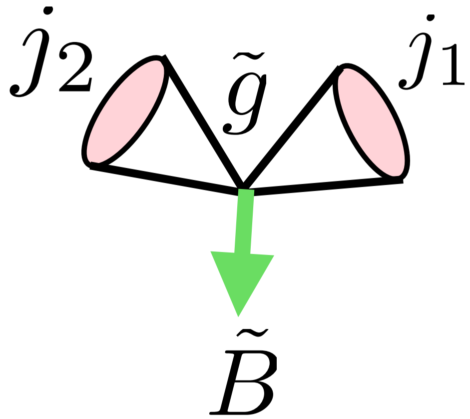
Thank You

Back Up Slides

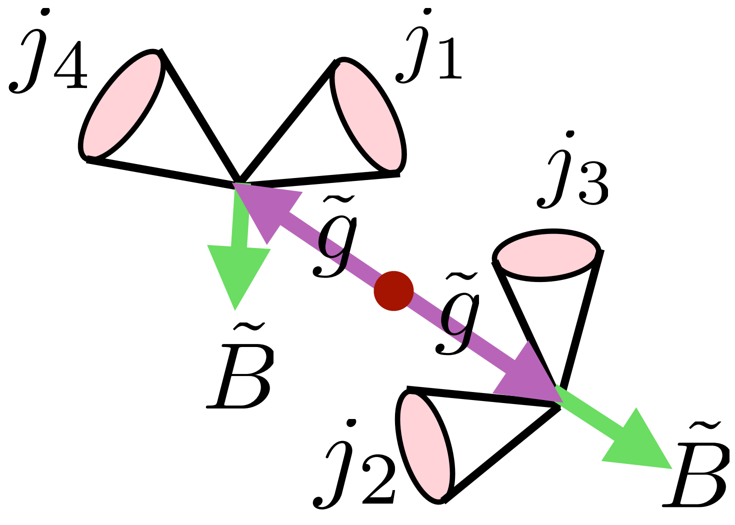
Matching: An Example

150 GeV particle going to 140 GeV LSP and 2 jets

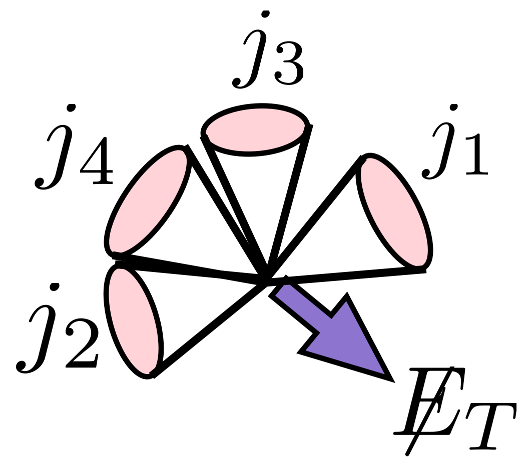
In rest frame of each gluino:
two 3 GeV “jets” and a LSP with 3 GeV momentum



Parton level



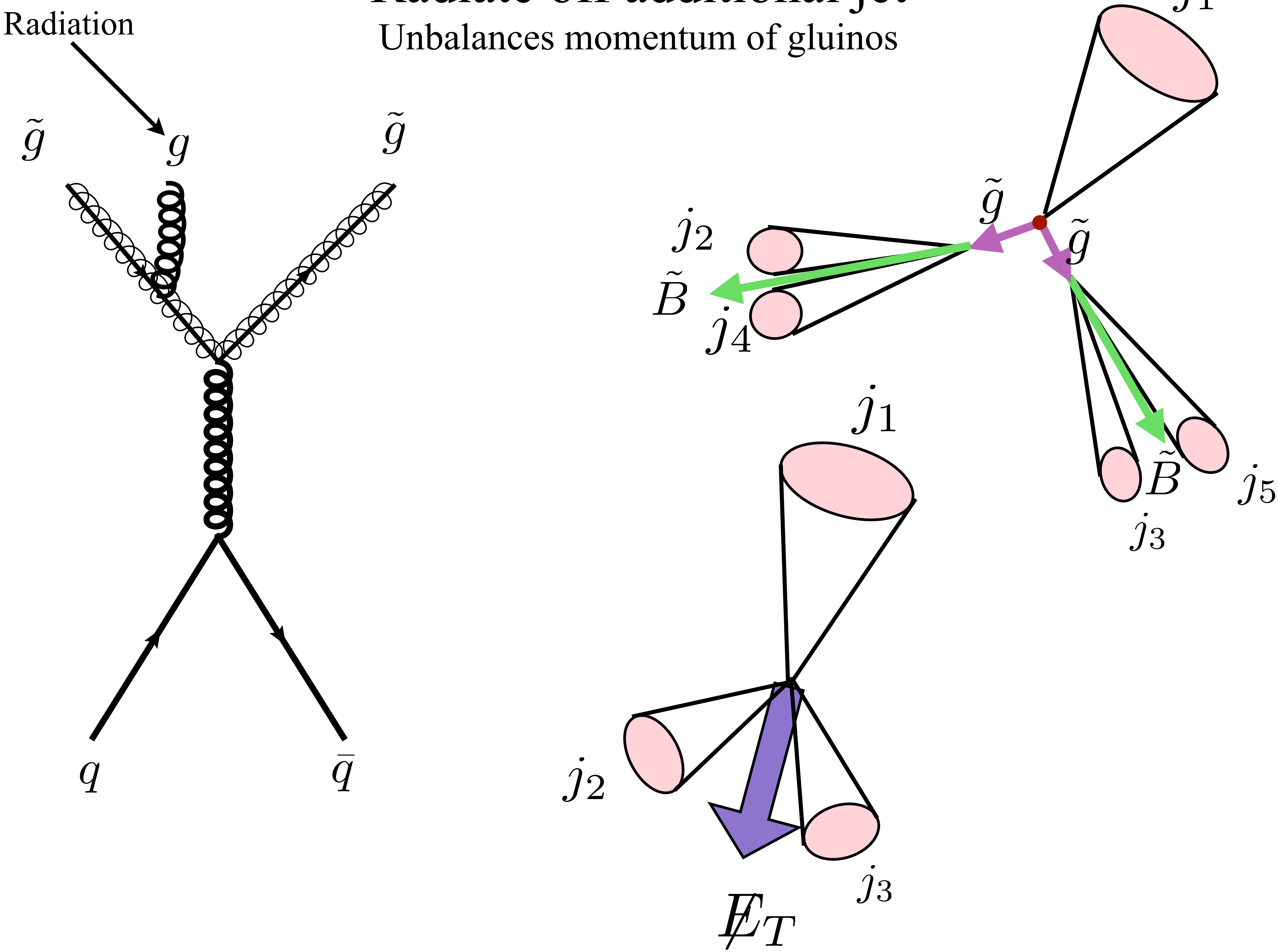
Detector level



Obscured by QCD with $\sqrt{\hat{s}_{\rm BG}} \sim 20$ GeV

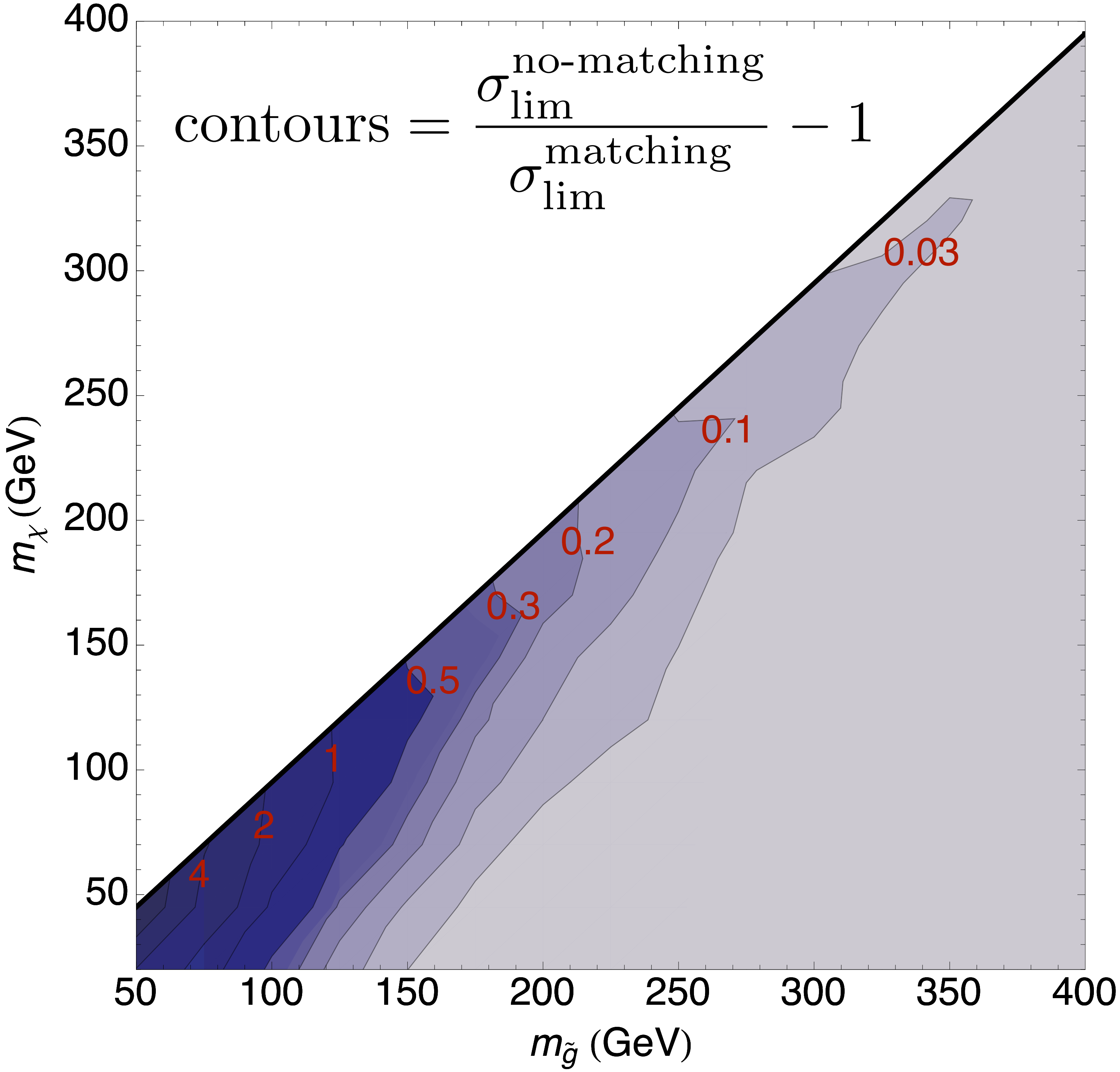
Radiate off additional jet

Unbalances momentum of gluinos

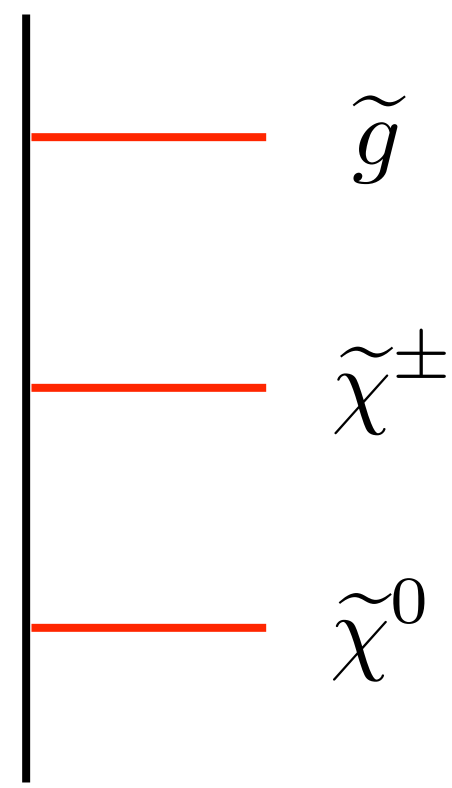


Matching

$$\tilde{g} \rightarrow \chi q \bar{q}$$



One Step Decays



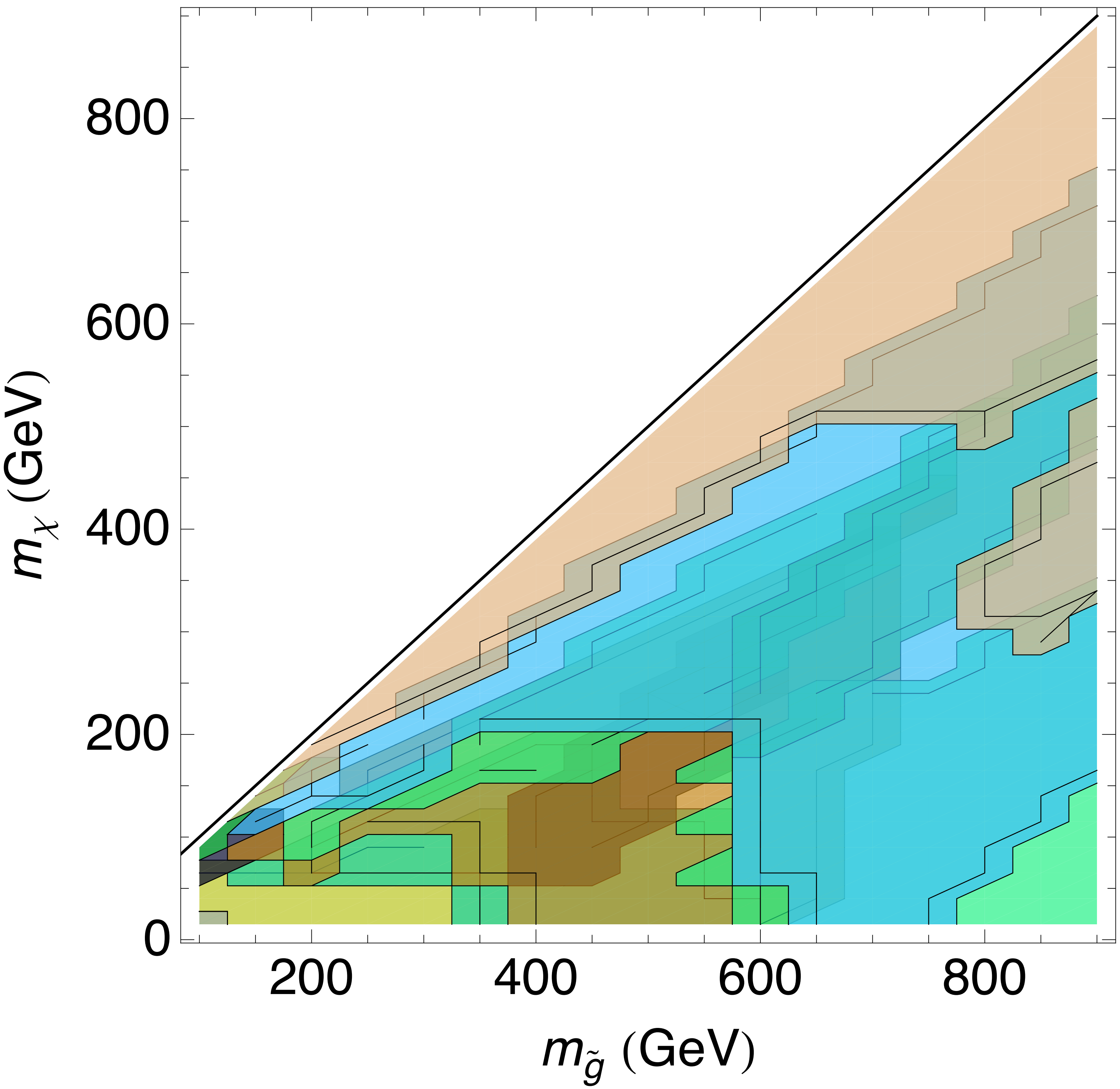
$$\widetilde{g} \rightarrow qq'\widetilde{\chi}^{\pm} \rightarrow qq'(W^{*}\chi^{0})$$

Free parameters

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

Second Example

$$\widetilde{g} \to qq'\widetilde{\chi}^{\pm} \to qq'(W^*\chi^0)$$



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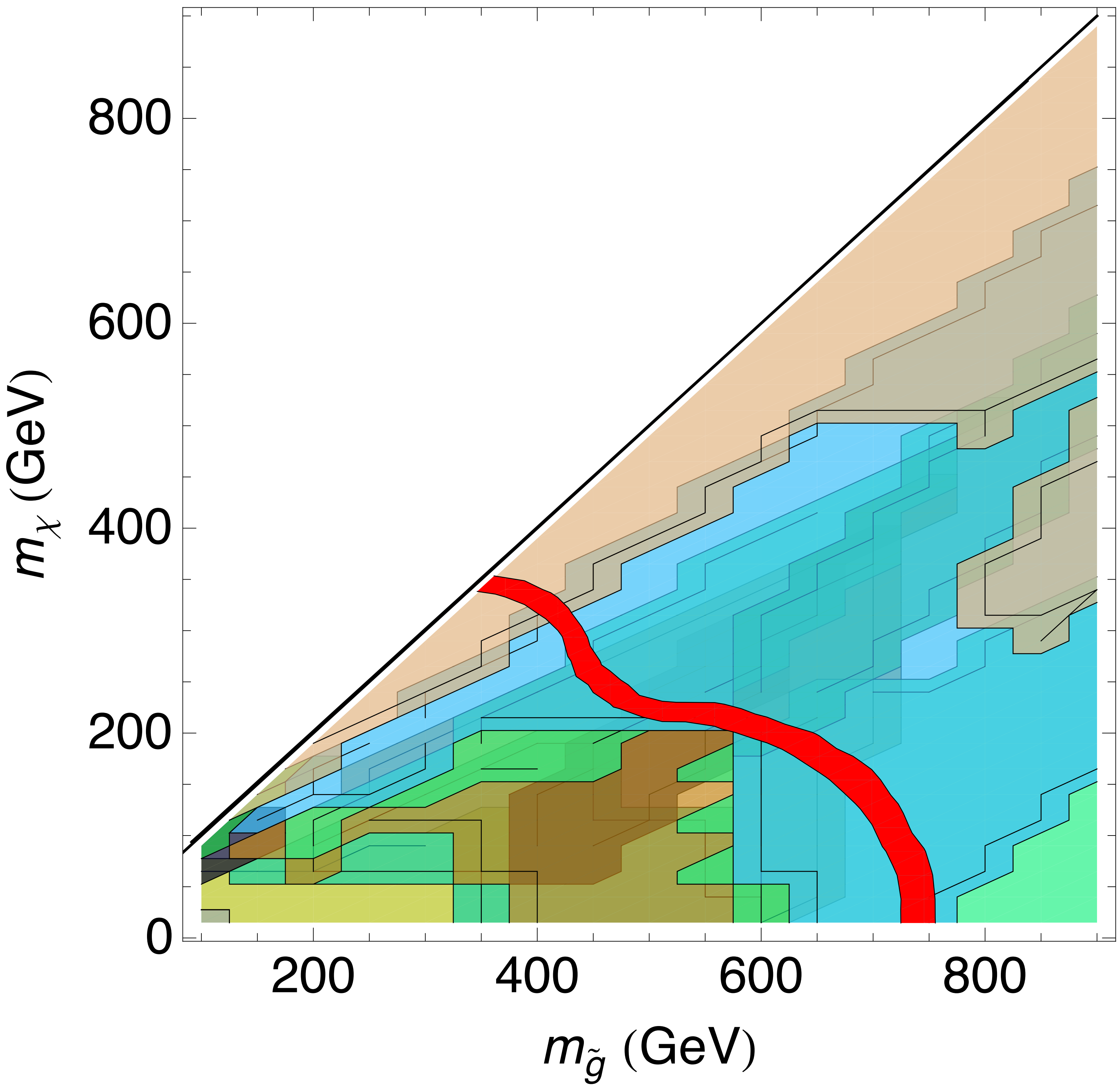

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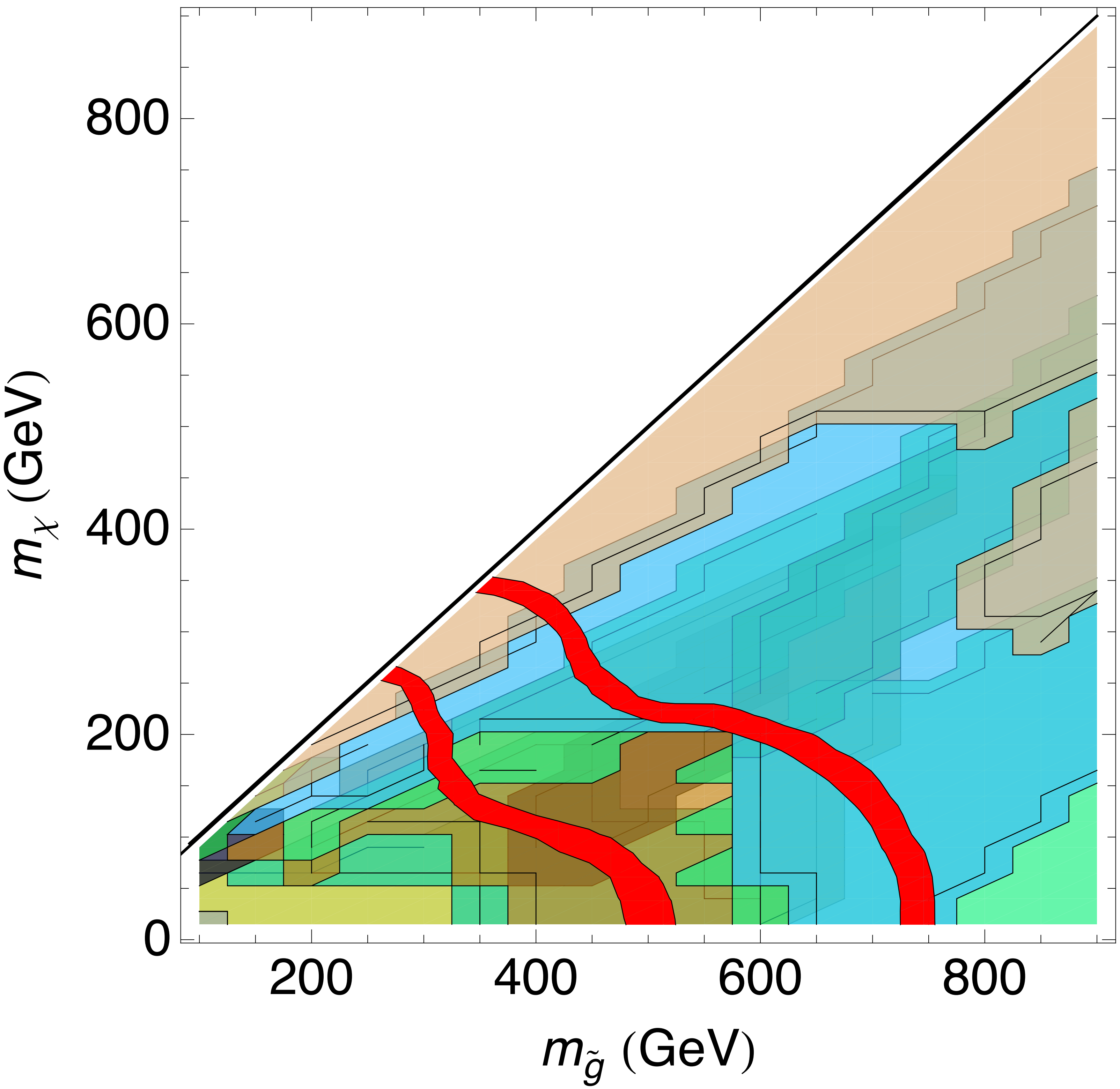


Cascade Decays

Harder to see these events, lower MET, higher HT

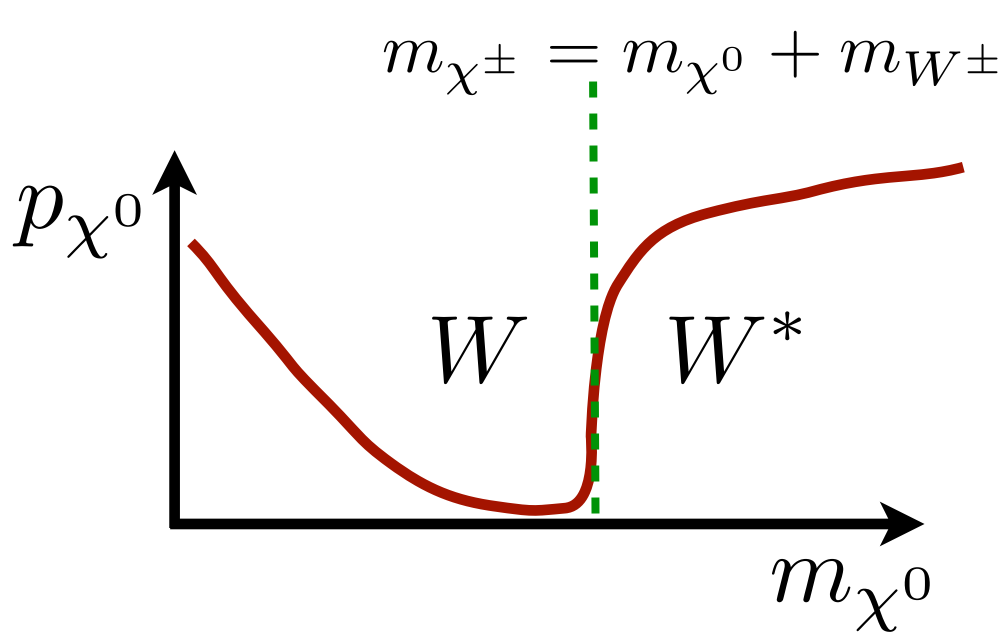
$$\tilde{g} \to q\bar{q}'\chi^{\pm} \to q\bar{q}' \ (\chi^0 \ W^{\pm(*)})$$

Chose a slice through the parameter space

$$m_{\chi^{\pm}} = m_{\chi^0} + \frac{1}{2}(m_{\tilde{g}} - m_{\chi^0})$$

Missing energy changes dramatically between

$$W^{\pm} \text{ vs } W^{\pm *}$$



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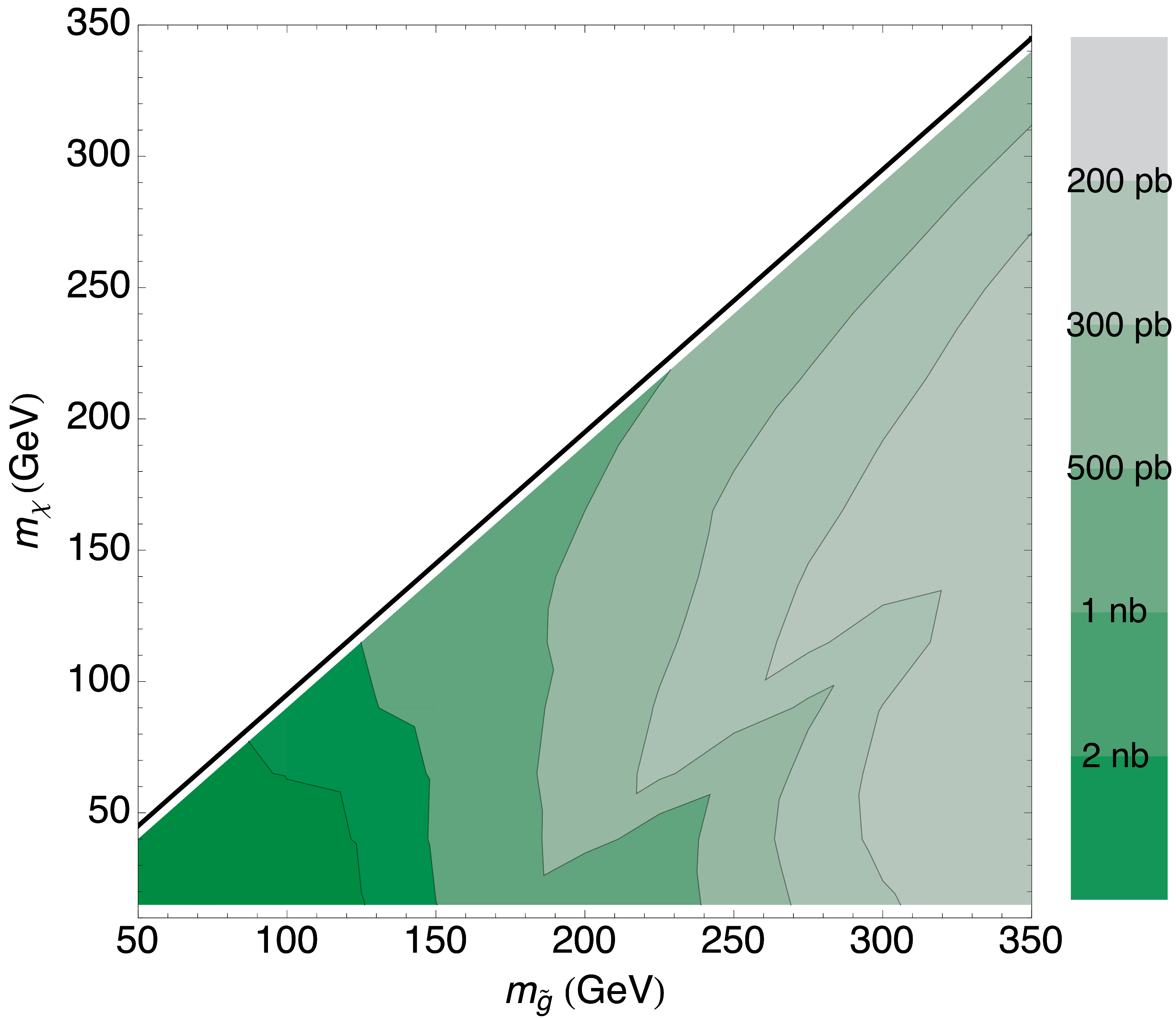

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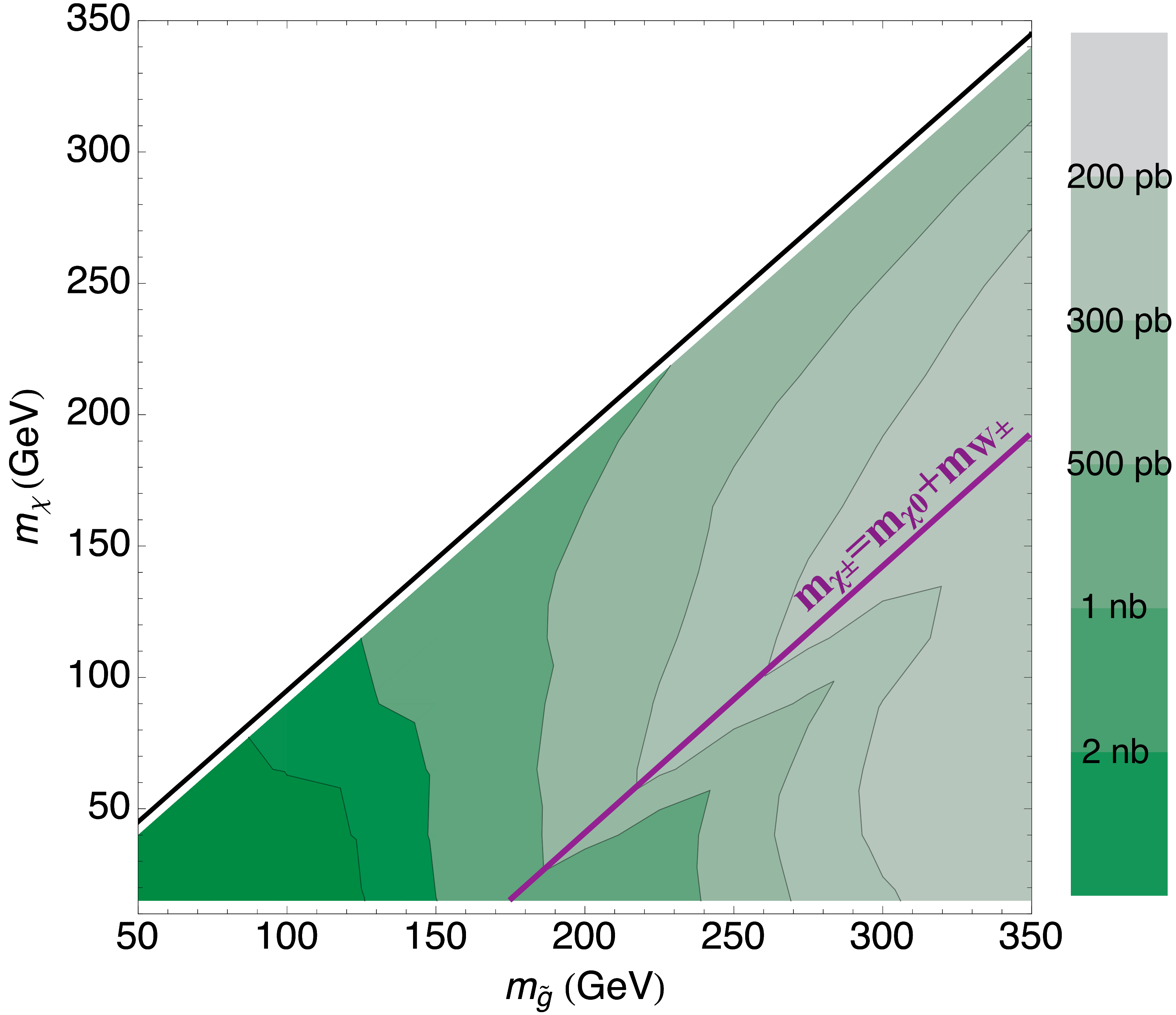

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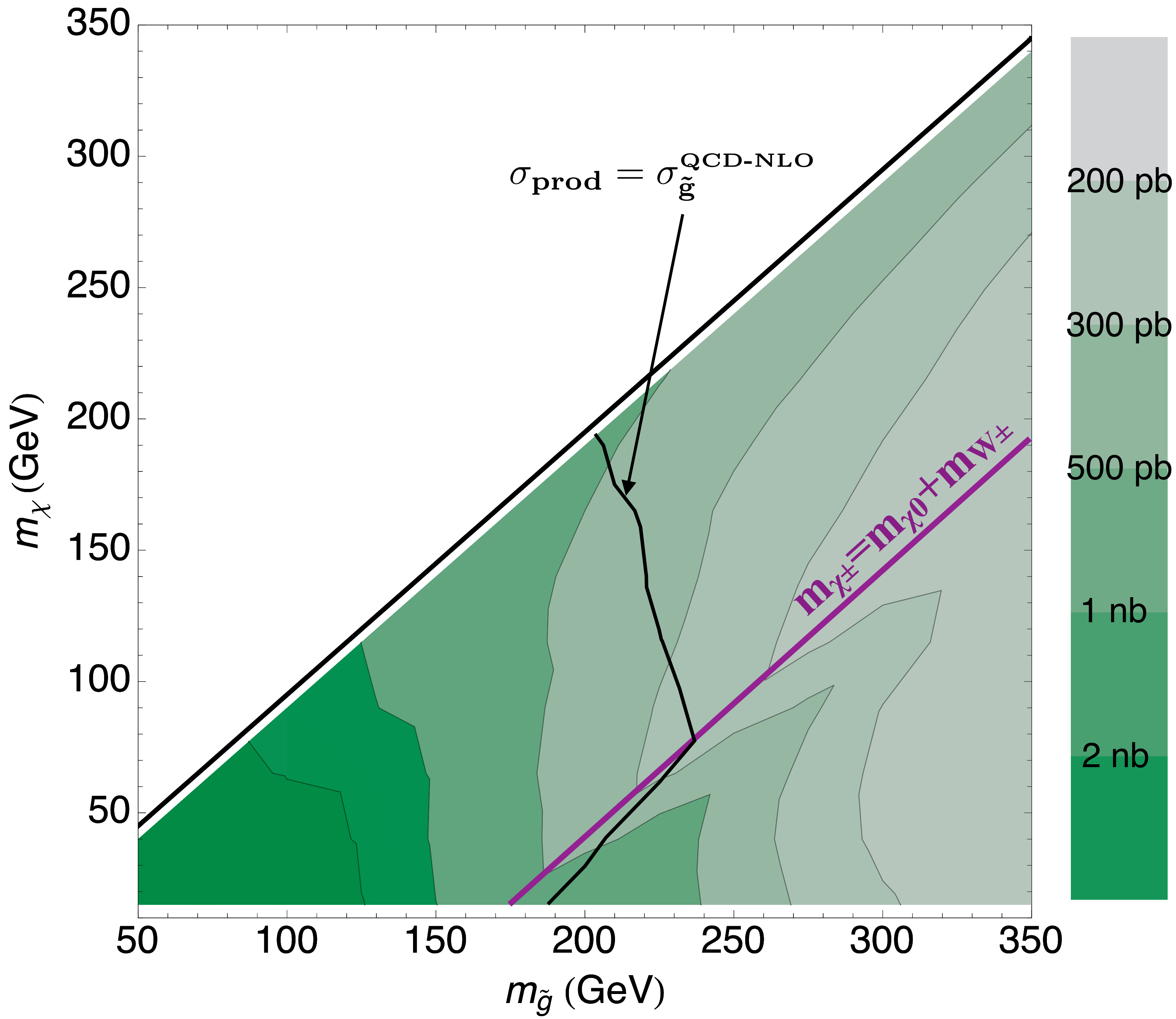

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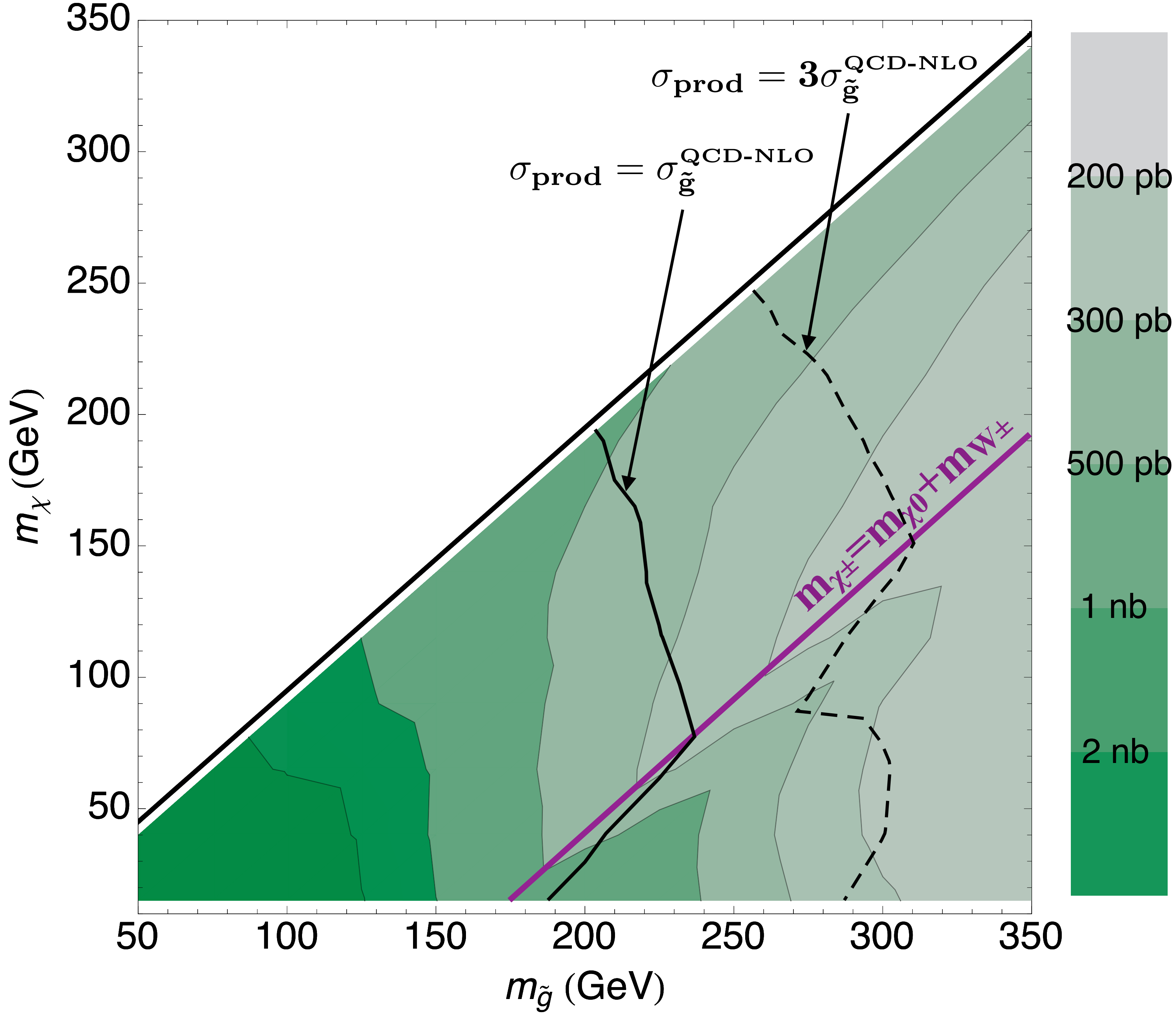

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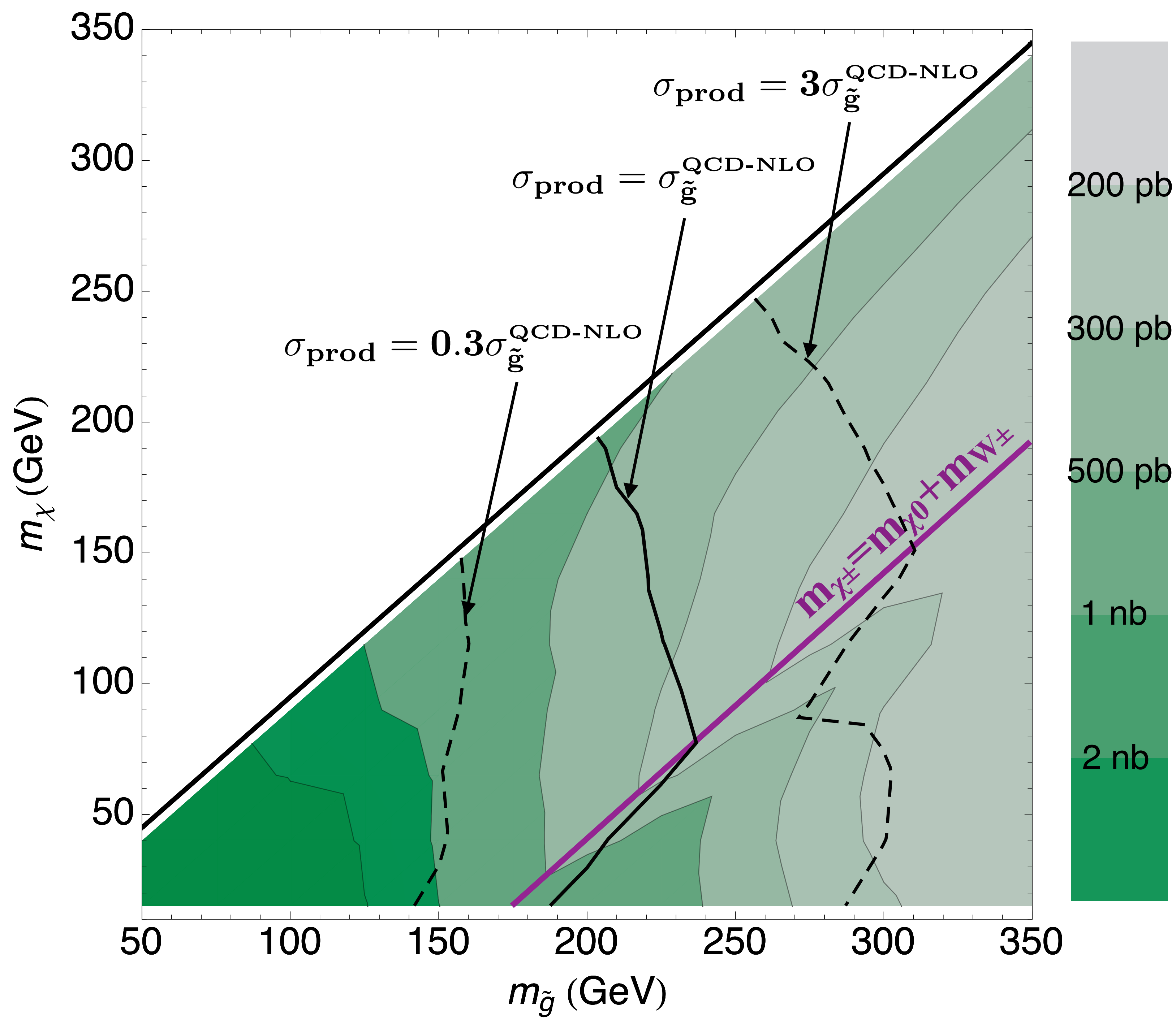

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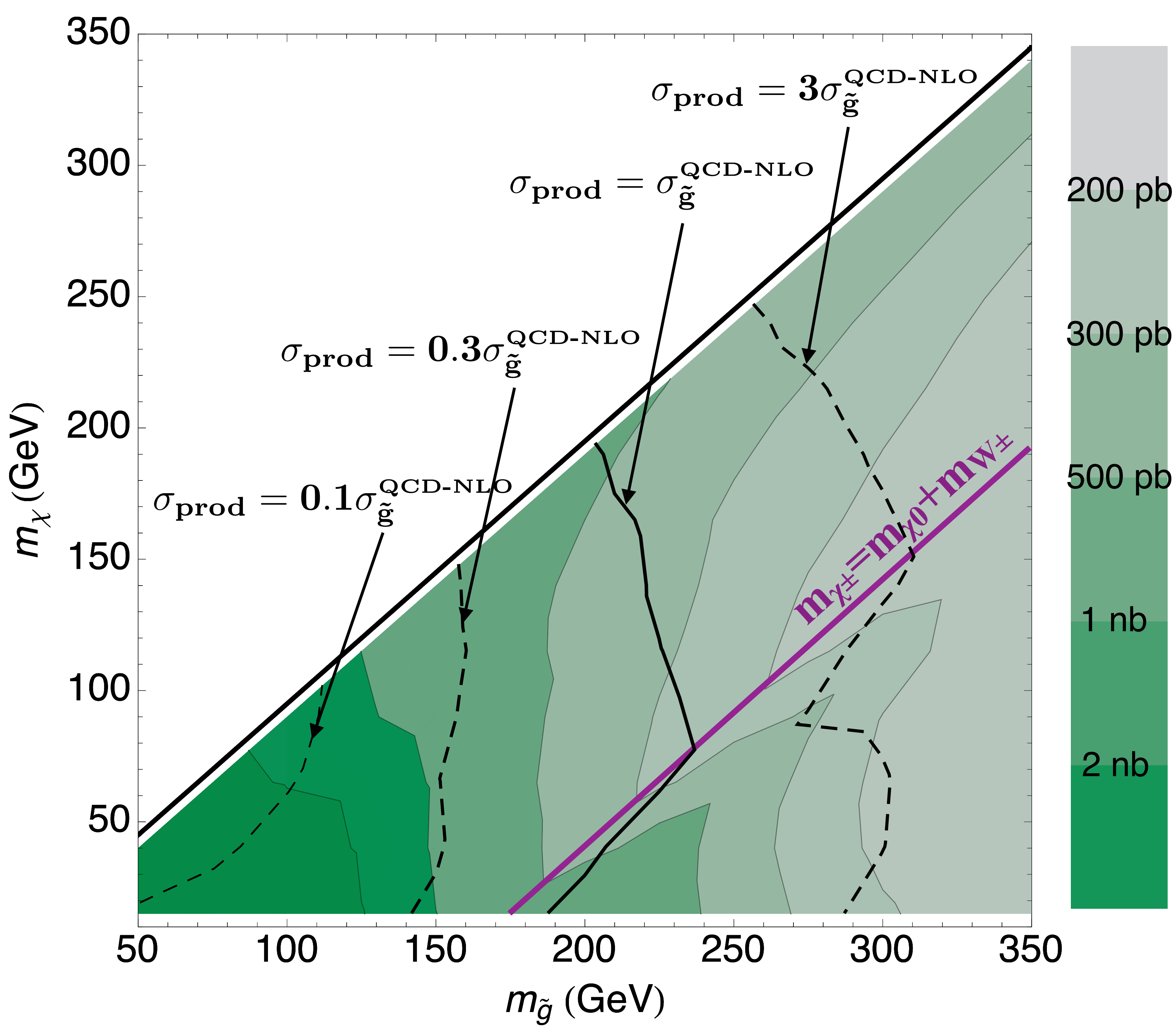

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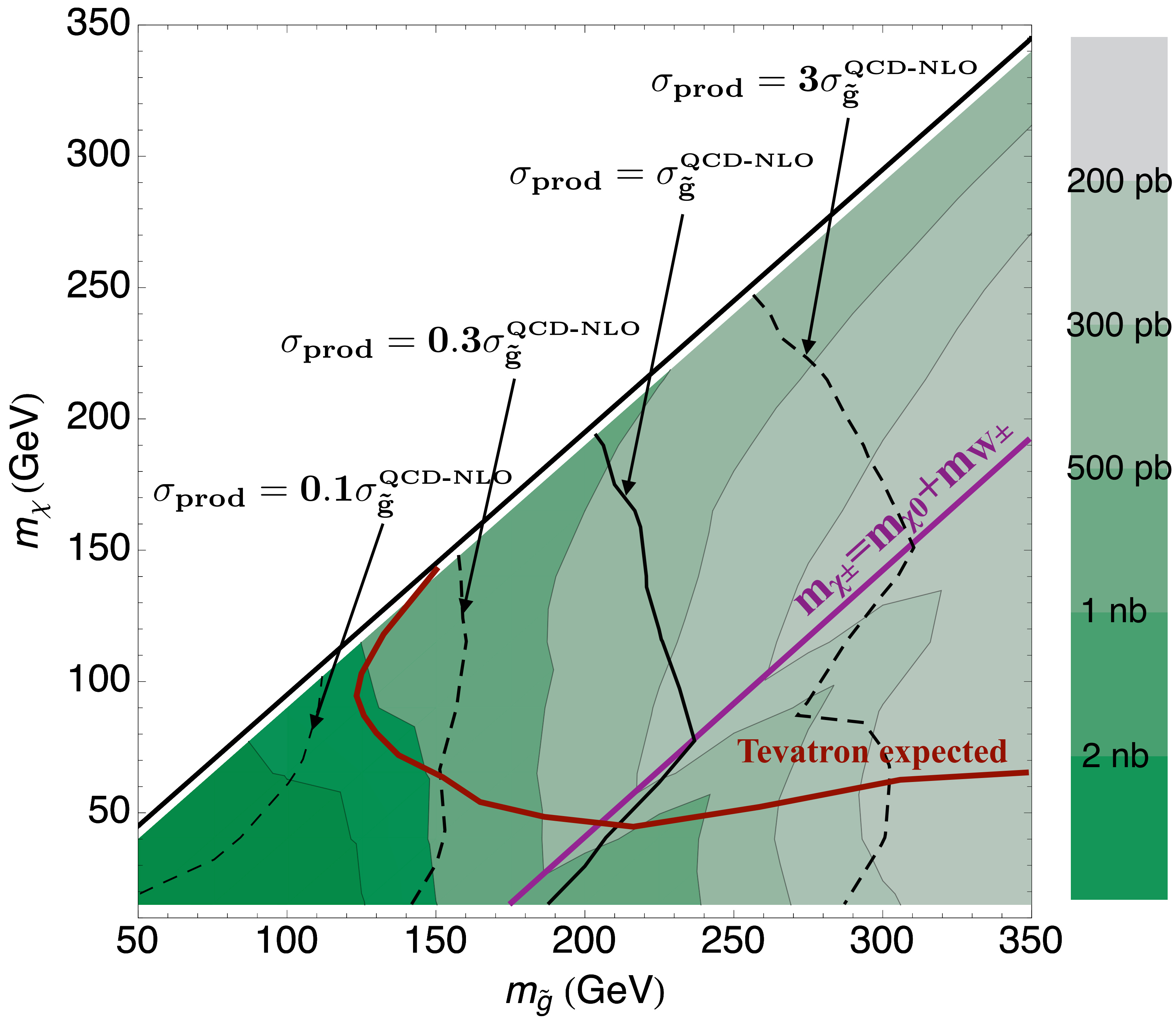


How we used this result

$$N_s = \mathcal{L}\ \sigma(pp \to \tilde{g}\tilde{g}X)\ \epsilon(m_{\tilde{g}}, m_\chi)$$

$$P(N_{s+b} \leq N_{\text{obs}}) \geq 5\%$$

$$P(N_{s+b} \leq N_{\text{obs}}) = \sum_{n}^{N_{\text{obs}}} \text{Poisson}(n;\ N_{s+b})$$

$$\text{Poisson}(n;\ \lambda) = \frac{\lambda^n}{n!} e^{-\lambda}$$

How we used this result

$$N_s = \mathcal{L}\ \sigma(pp \to \tilde{g}\tilde{g}X)\ \epsilon(m_{\tilde{g}}, m_{\chi})$$

$$P(N_{s+b} \leq N_{\text{obs}}) \geq 5\%$$

$$P(N_{s+b} \leq N_{\text{obs}}) = \sum_{n}^{N_{\text{obs}}} \text{Poisson}(n;\ N_{s+b})$$

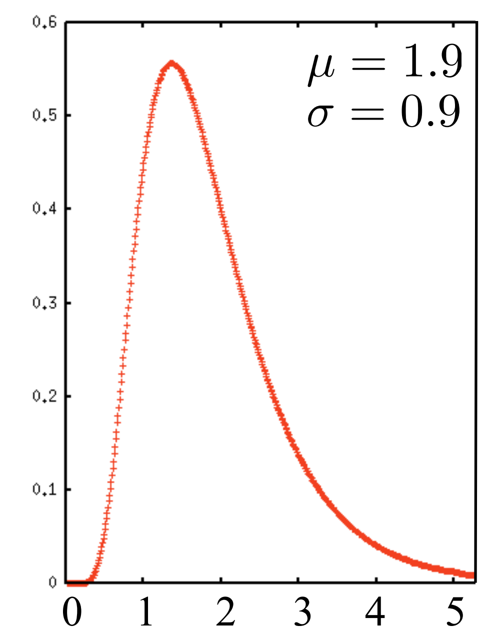
$$\text{Poisson}(n;\ \lambda) = \frac{\lambda^n}{n!} e^{-\lambda}$$

Fold in uncertainties:

$$\int d\mathcal{L}\ f'(\mathcal{L}; \mu_{\mathcal{L}}, \sigma_{\mathcal{L}}) \cdot \qquad \mathcal{L} = 70 \pm 8\ \text{nb}^{-1}$$

Normal distribution

$$\int dN_B\ f(N_b; \mu_b, \sigma_b) \cdot \qquad N_{b\ 3+j} = 1.9 \pm 0.9$$



Log Normal distribution (keeps background positive)

3 jet channel most important

Best limit on cross section

$\sigma_{3+j}\,\epsilon \leq 20$ pb vs $\sigma_{4+j}\,\epsilon \leq 57$ pb

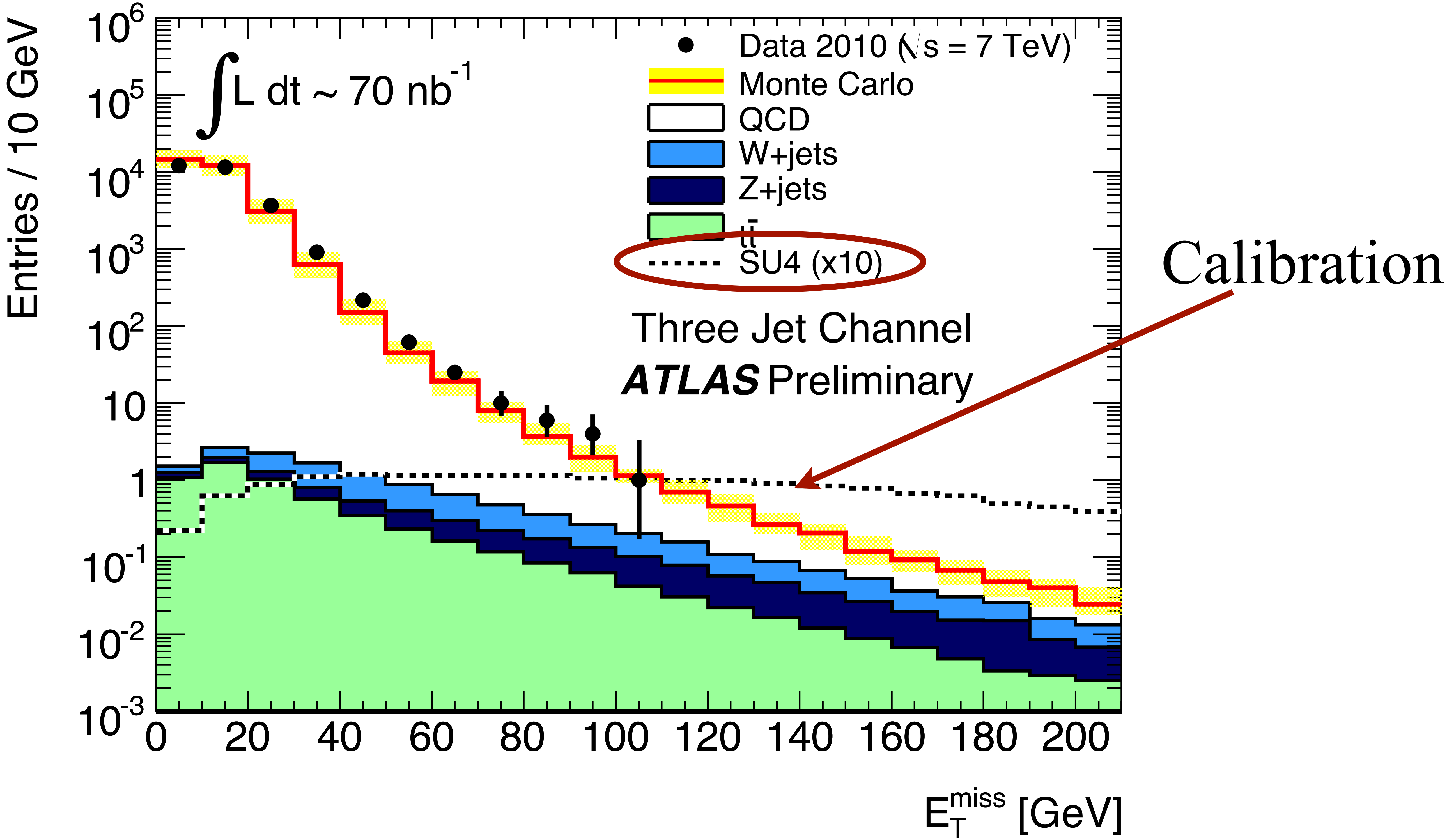
Efficiency lower to get 4 jets with $p_T > 30$ GeV

for $(m_{\tilde{g}}, m_{\chi}) \simeq (300, 0)$ GeV

leads to jet with energies of $E_j \sim 100$ GeV

only 50% of the events that pass $p_{T\,j3} > 30$ GeV,
pass $p_{T\,j4} > 30$ GeV

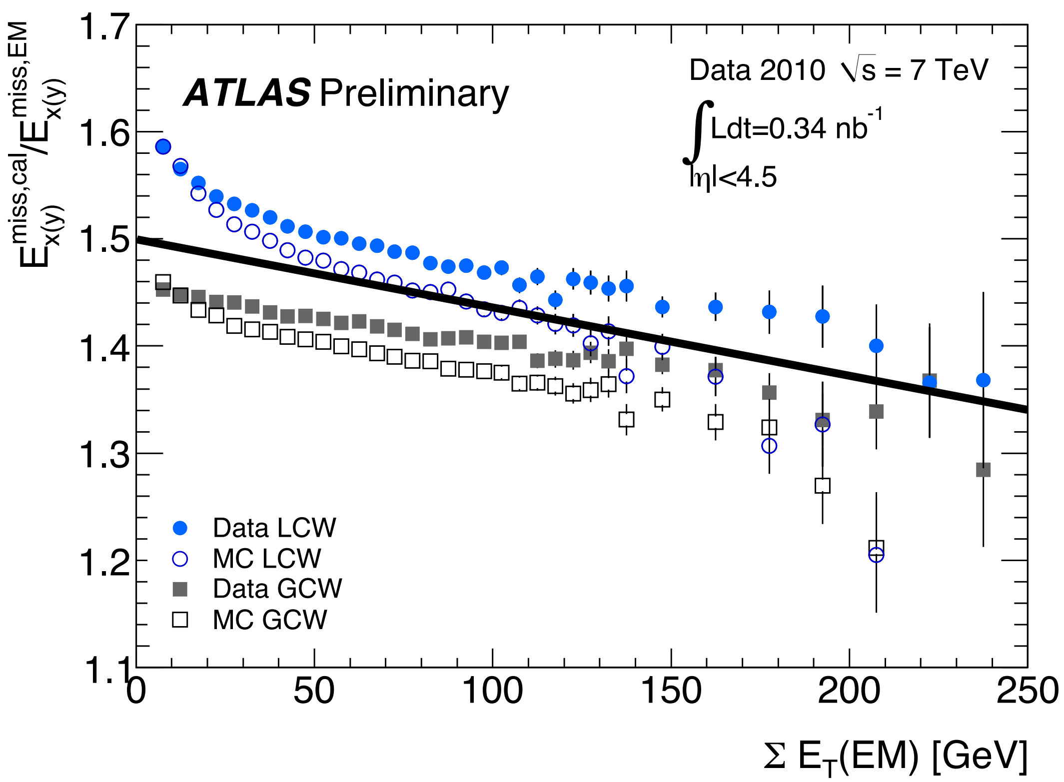
Our validation procedure



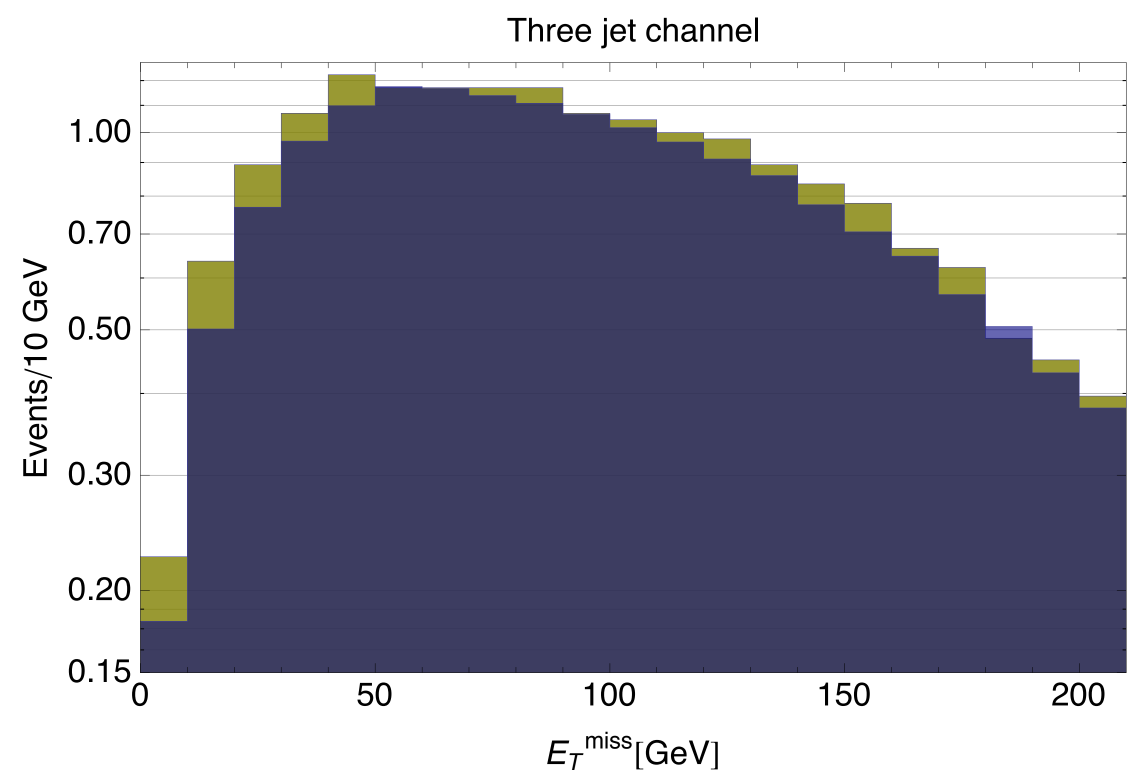
PGS MET mock up

Missing transverse momentum is computed from calorimeter cells belonging to topological clusters at the electromagnetic scale [30]. No corrections for the different calorimeter response of hadrons and electrons/photons or for dead material losses are applied. The transverse missing momentum

“true” MET/“EM” MET

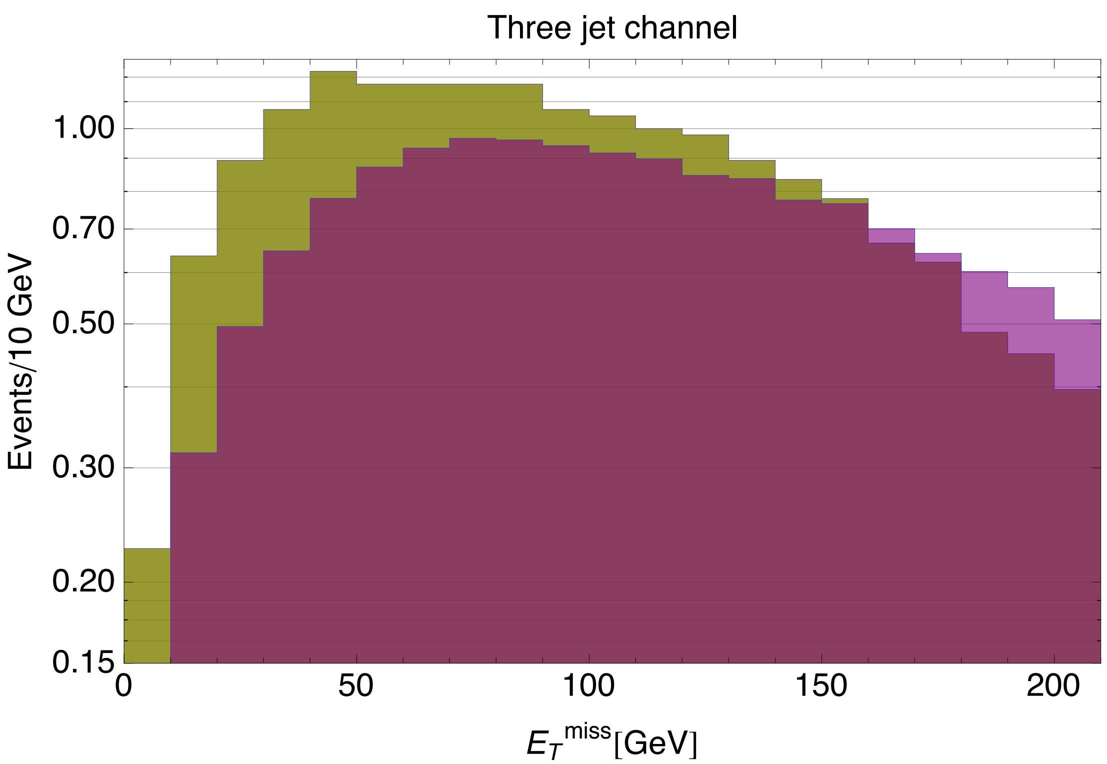


PGS MET with linear fit to Sum ET

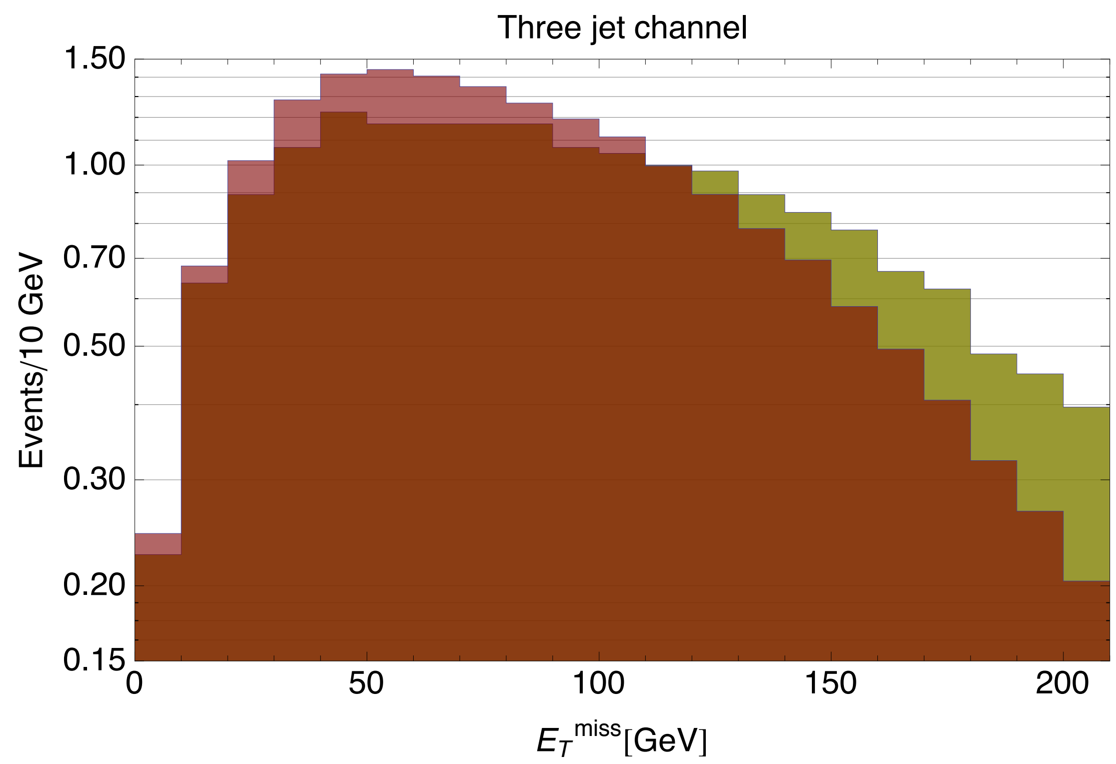


Effectively raises MET cut by 35% to 50%

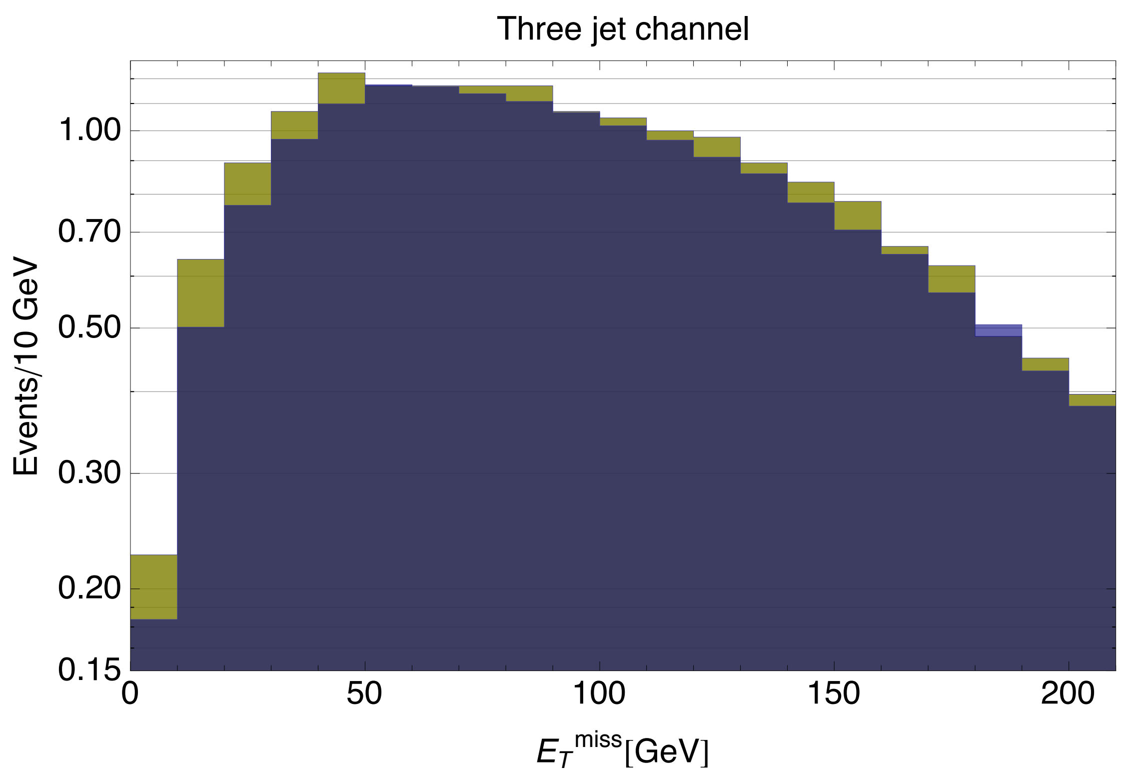
Straight PGS MET



PGS/1.5



PGS MET with linear fit to Sum ET



rel. norm. = 94%
cut ε_{ATLAS} = 84%
cut ε_{model} = 86%

The slight loss of sensitivity at lower LSP mass from fractional MET cut

$$f = \frac{\not{E}_T}{H_T + \not{E}_T}$$

In limit $m_\chi \longrightarrow m_{\tilde{g}}$, $p_\chi = E_j$

maximizes *f*, and drops for lighter LSP