It's On!

Using ATLAS' First Results from Jets and Missing Energy Searches

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Fermilab

August 19, 2010

with Daniele Alves & Eder Izaguirre

arXiv:1003.3886, 1008:0407, work in progress

LHC is the New Energy Frontier

(but you still need luminosity)

Nevertheless, the first Jets+MET Search came out with 70 nb^{-1} of integrated luminosity

ATLAS NOTE

ATLAS-CONF-2010-065

20 July, 2010

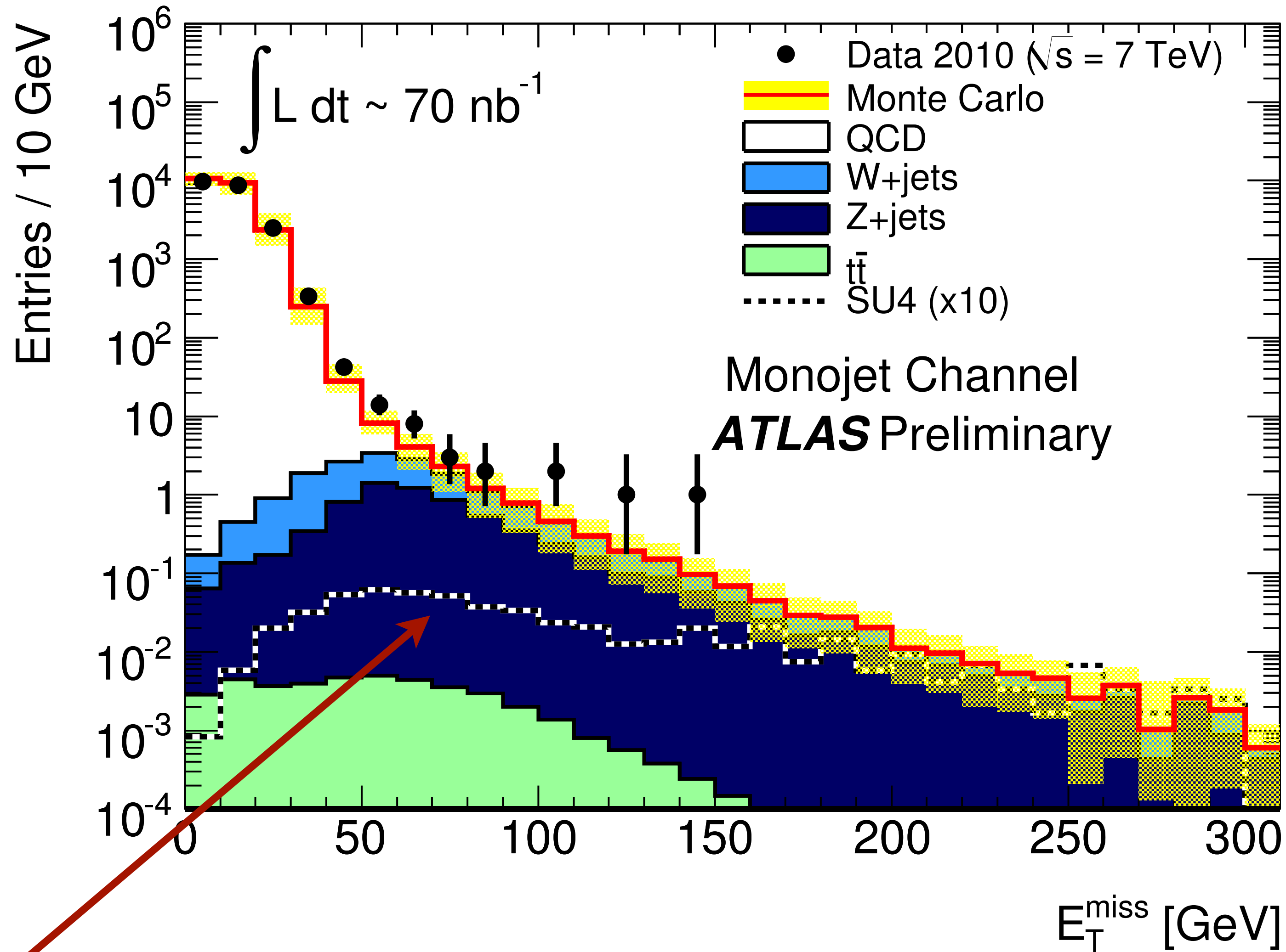
Early supersymmetry searches in channels with jets and missing transverse momentum with the ATLAS detector

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.

Amazing that such an early search is possible!

Not much time for interpretation of results



SU4 *10

An mSUGRA benchmark model
with light colored particles

Clear mSUGRA isn't reachable yet

mSUGRA isn't reachable, but these results still extend our reach

i.e. there could have been discoveries

Outline

Simplified Models and Previous Limits

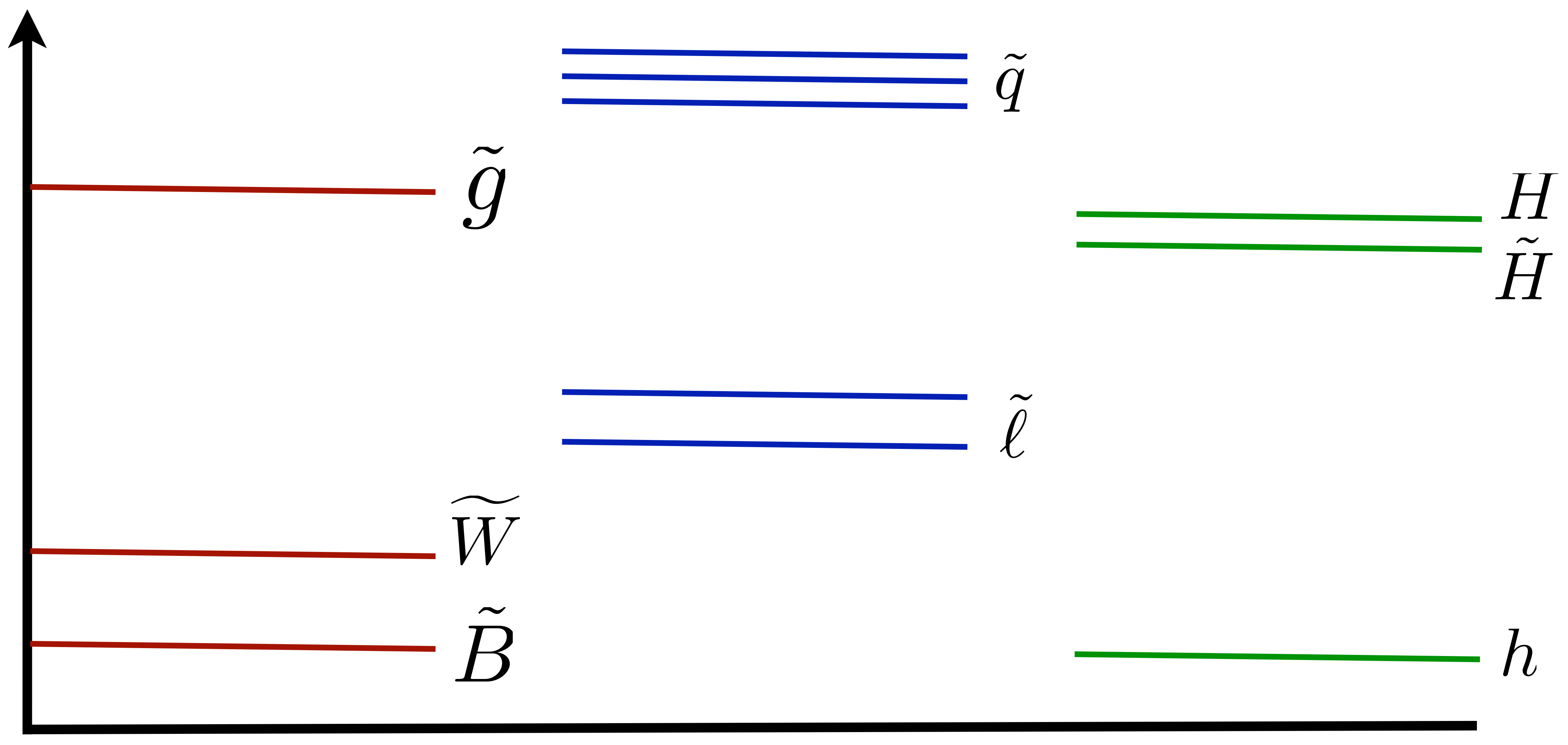
LHC Results and Their Implication

Going Forward

mSugra has "Gaugino Mass Unification"

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

Most models look like this



A shocking lack of diversity (see the pMSSM)

Jets + MET

Solution to Hierarchy Problem

If the symmetry commutes with $SU(3)_C$,
new colored top partners

(note twin Higgs exception)

Dark Matter

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

Usually requires a dark sector,
frequently contains new colored particles

Fewest requirements on spectroscopy

Doesn't require squeezing in additional states to decay chains

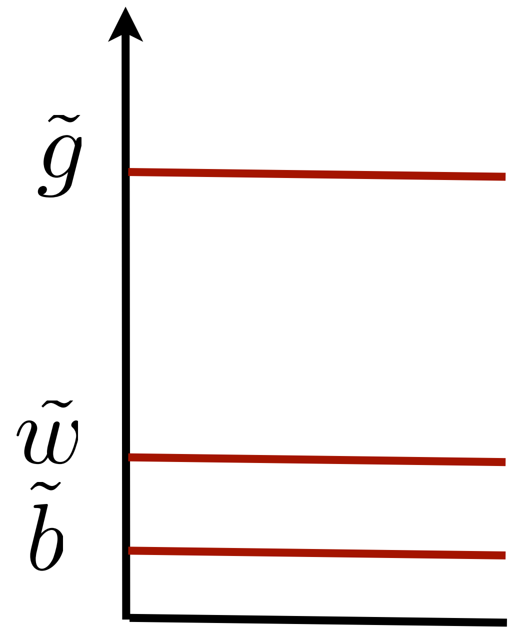
Spectrum in Different Theories

MSSM

High Cut-Off

Large Mass Splittings

$$\delta m = \frac{g^2}{16\pi^2}\, m \,\log \Lambda$$

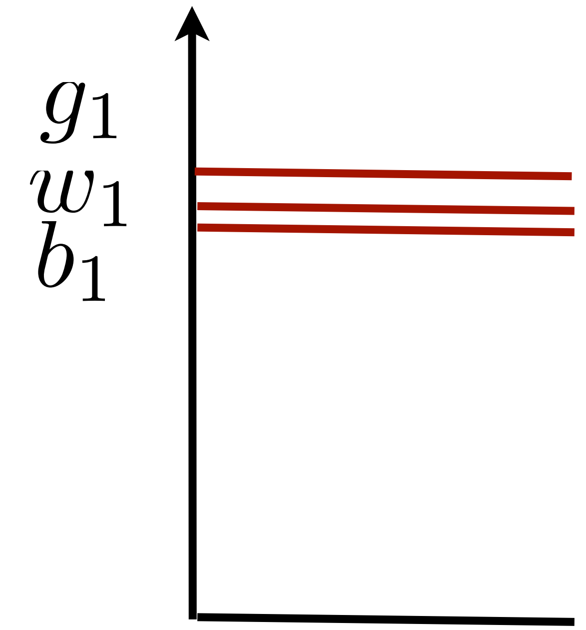


Universal Extra Dimensions

Low Cut-Off

Small Mass Splittings

$$\delta m = \frac{g^2}{16\pi^2}\frac{\Lambda^2}{m}$$



Electrically Neutral Colored Particles

Weak model independent limits

Limits come from event shape variables at LEP (*e.g.* Thrust)

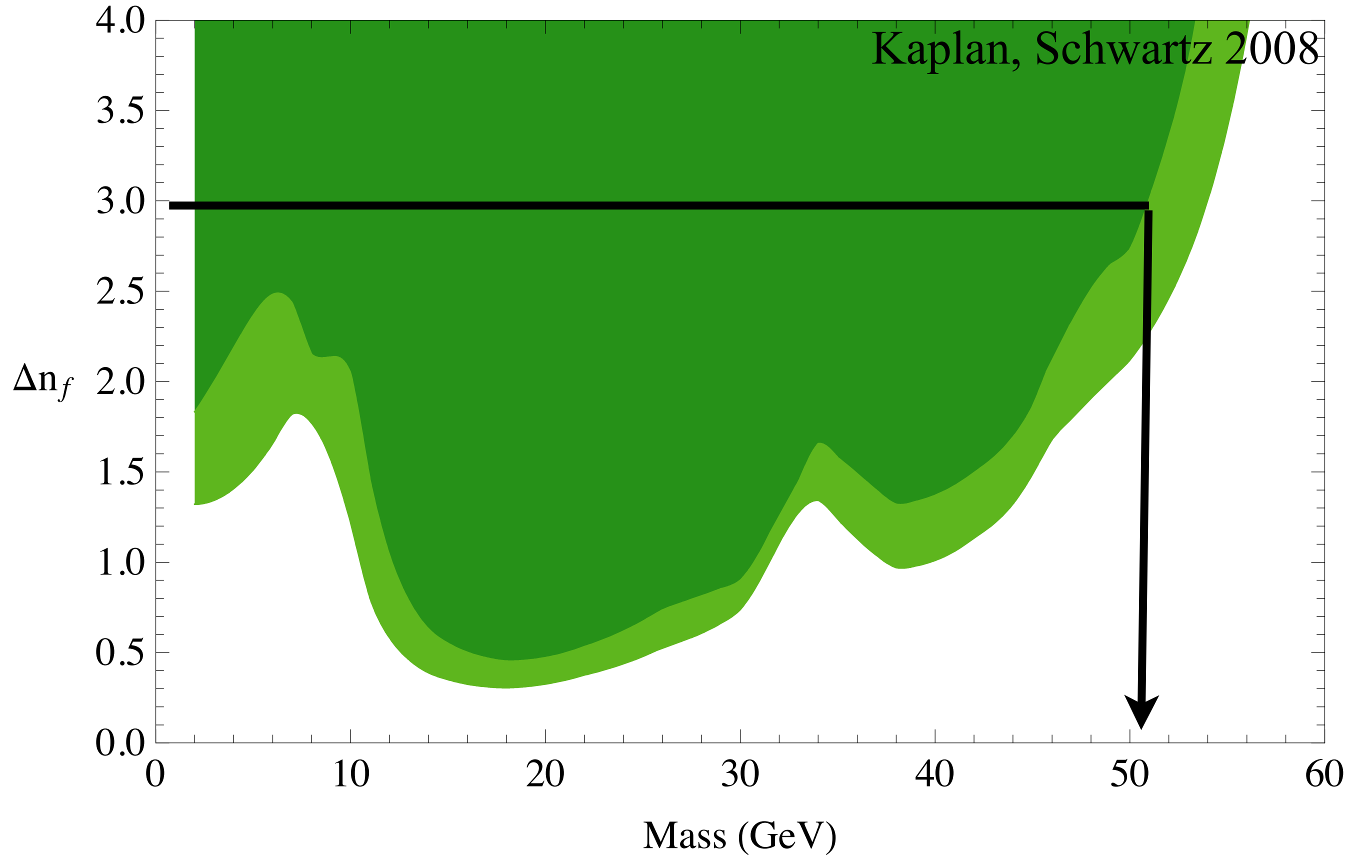


FIG. 2: Bounds on light colored particles from LEP data. The darker region is completely excluded at 95% confidence. The lighter region is an uncertainty band including estimates of various theoretical uncertainties.

Simplified Models

Models are created to solve problems or demonstrate mechanisms

Realistic ones tend to be complicated

Most of the details are irrelevant for searches

Focus on models tend to hide commonalities between models
e.g. MSSM & UEDs

Limits of specific theories

Only keep particles and couplings relevant for searches

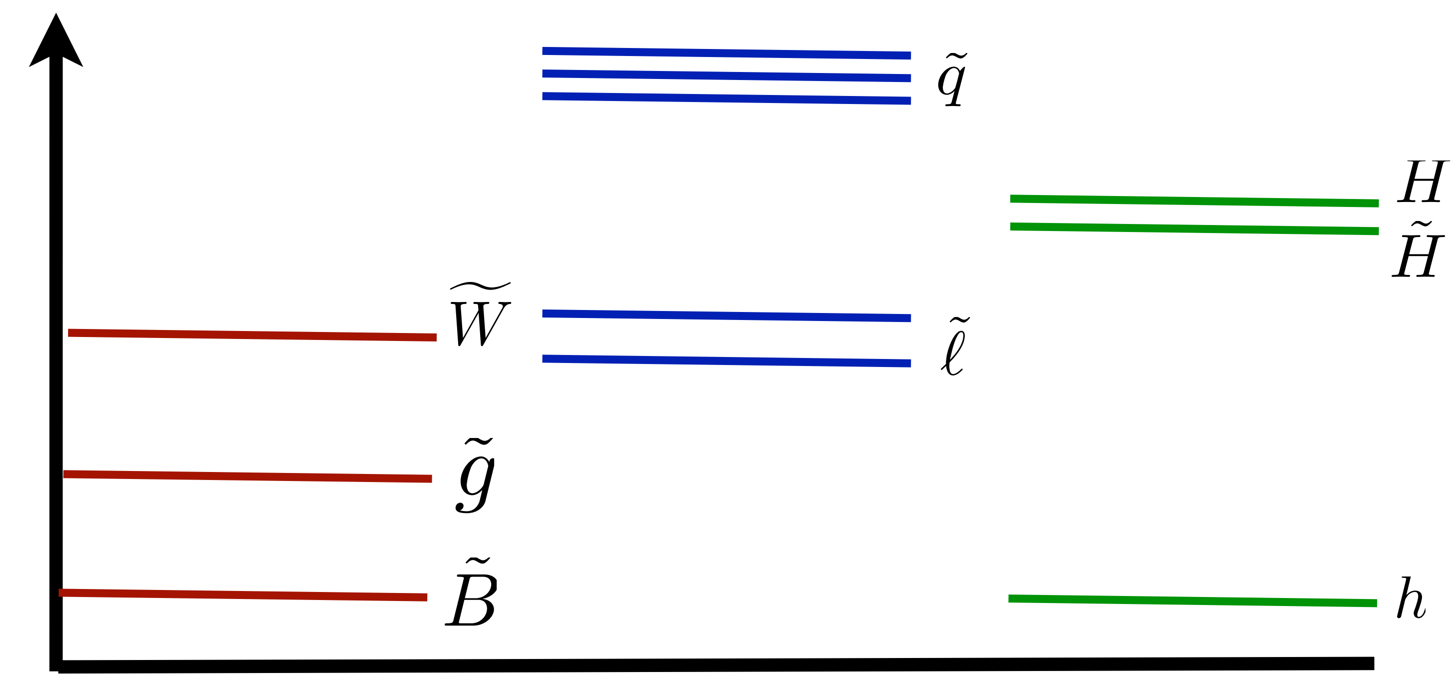
Removes superfluous model parameters

Not fully model independent,
but greatly reduce model dependence

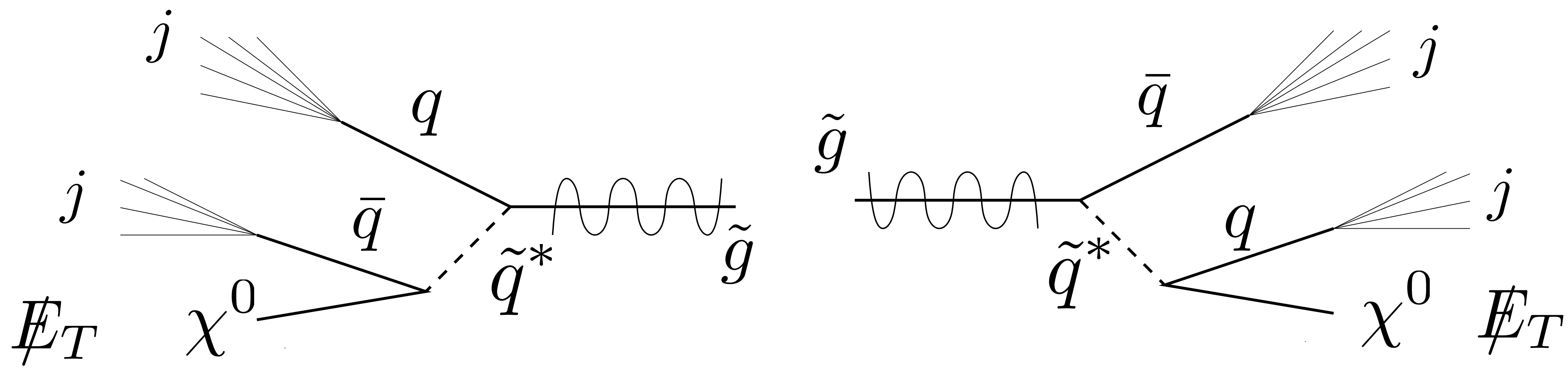
Captures many specific models (MSSM, UED, etc)

Easy to notice & explore kinematic limits

Directly Decaying Gluino



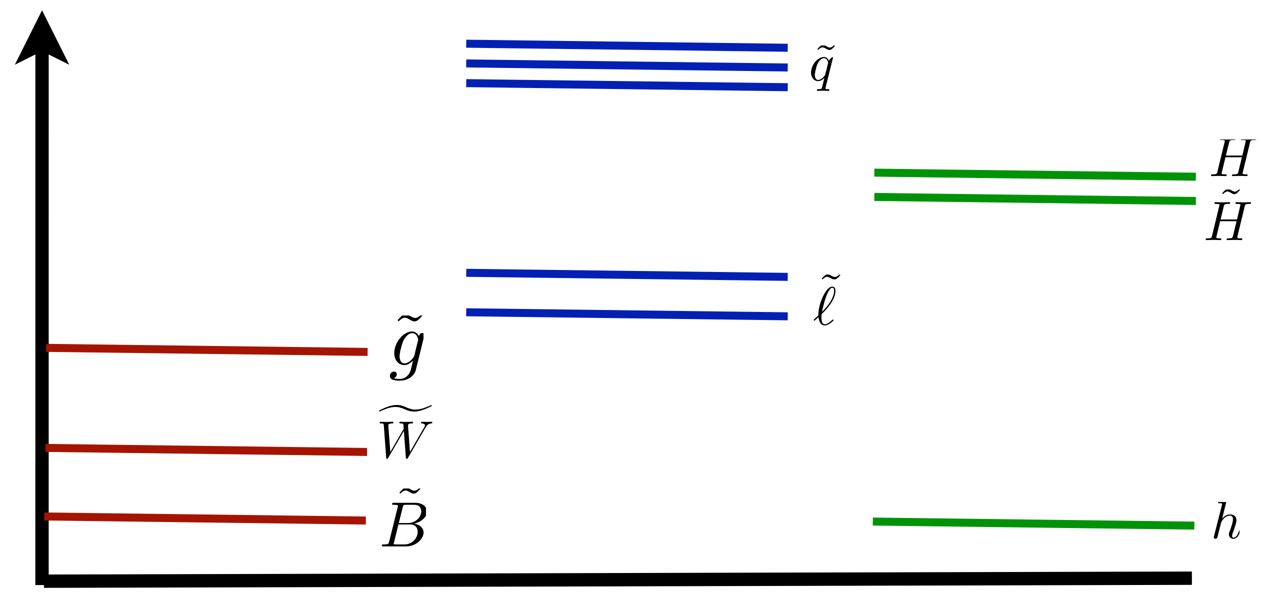
Turn on one decay mode $\tilde{g} \longrightarrow q\bar{q}\tilde{\chi}^0$



Keep masses and total cross section free

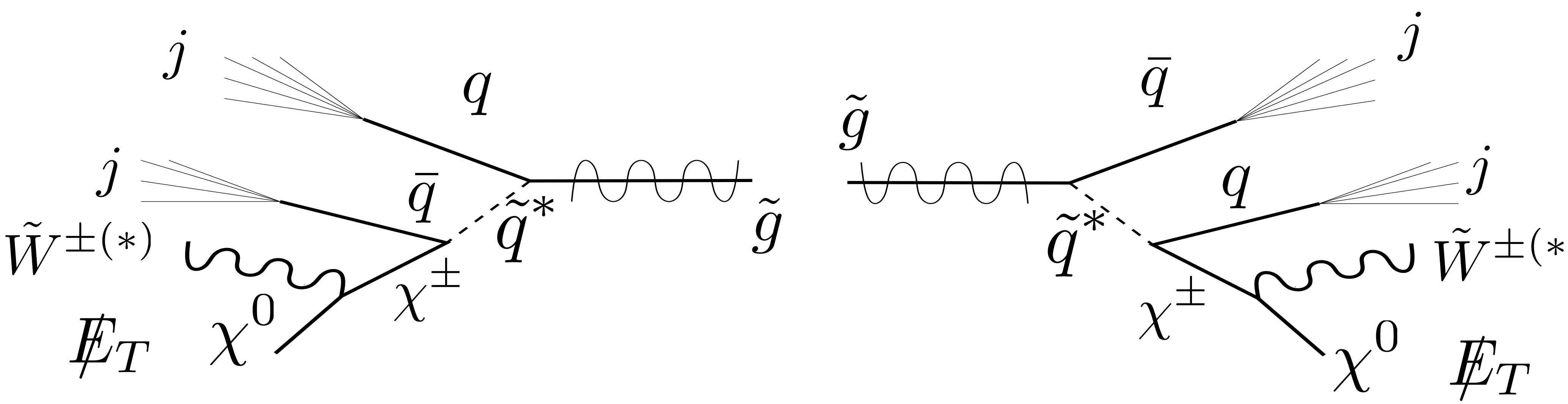
$$m_{\tilde{g}} \quad m_{\chi^0} \quad \sigma(pp \longrightarrow \tilde{g}\tilde{g}X)$$

One-step Cascade Decaying Gluino



Turn on one decay mode

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



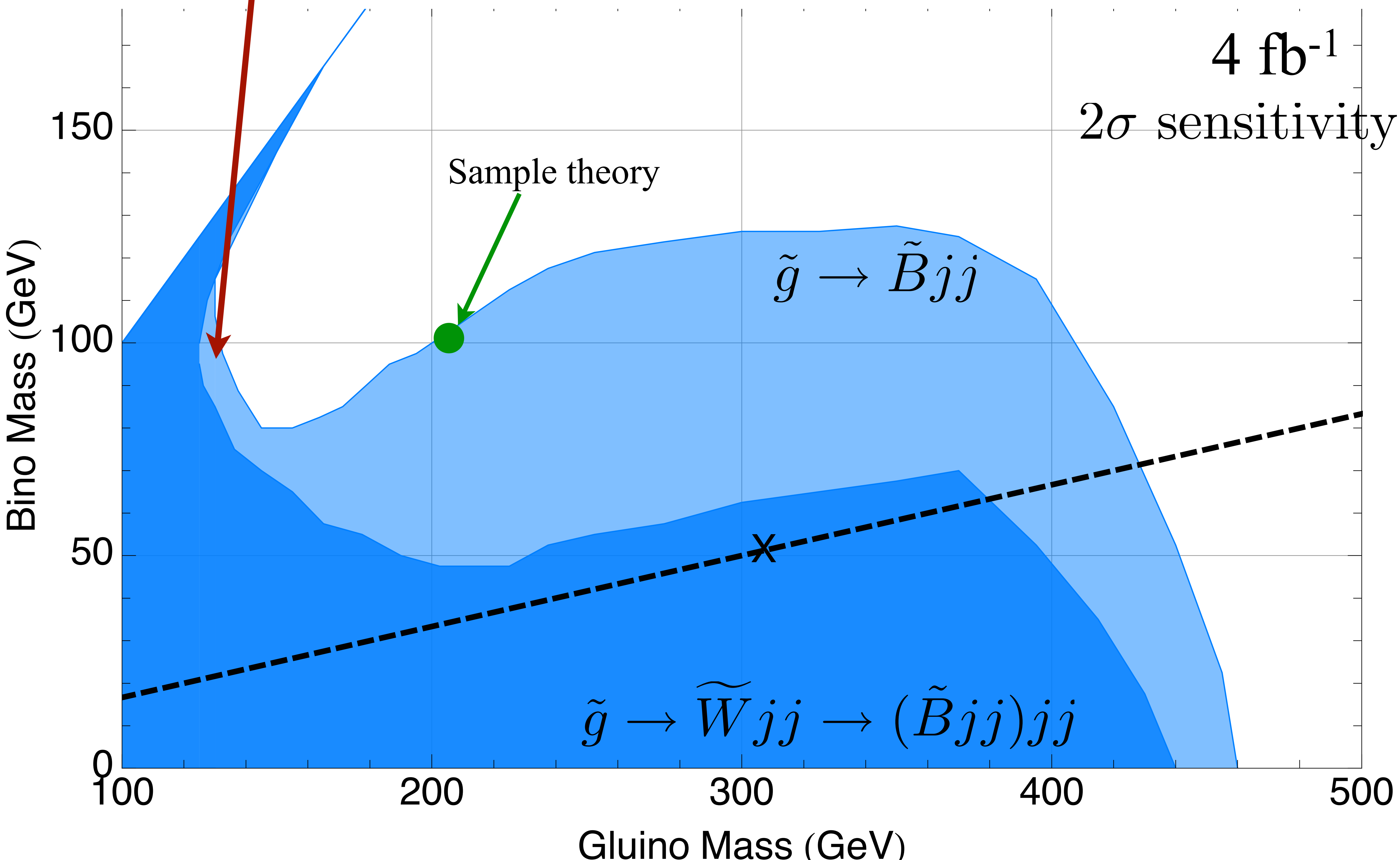
Relevant Parameters

$m_{\tilde{g}}$ $\quad m_{\chi^{\pm}}$ $\quad m_{\chi^{0}}$ $\quad \sigma(pp \to \tilde{g}\tilde{g}X)$

Tevatron Reach

$m_{\tilde{g}} \gtrsim 120$ GeV

A 50 GeV gluino *is* "ruled out"!

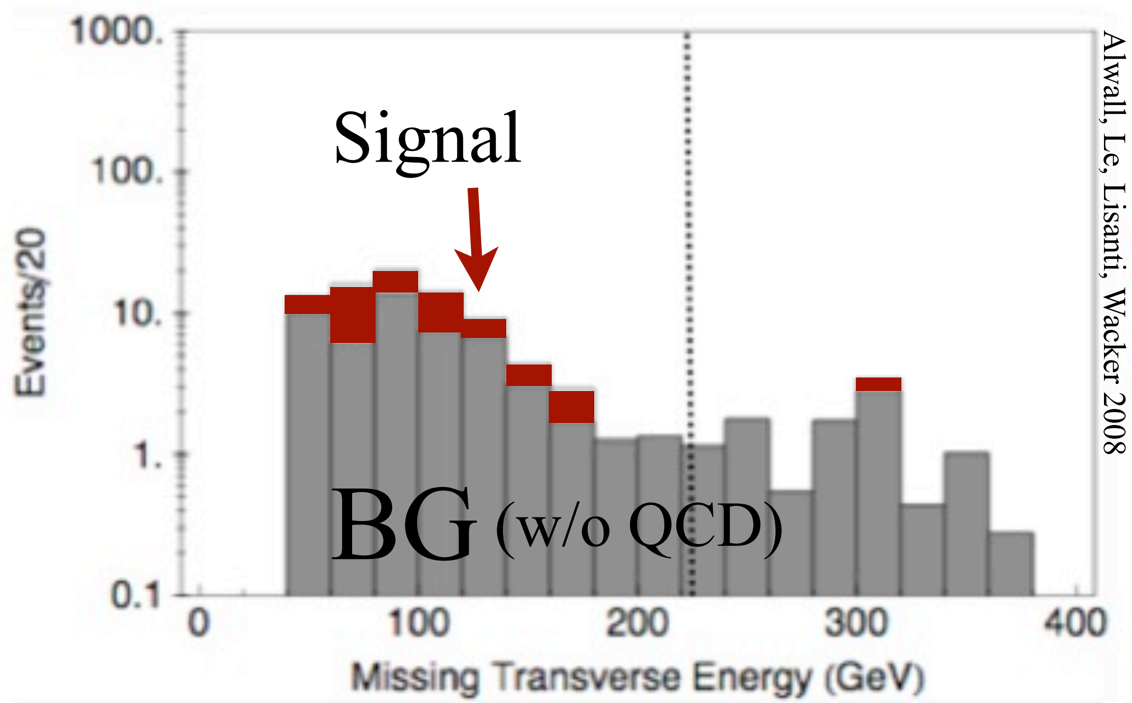


Alwall, Le, Lisanti, Wacker 2008

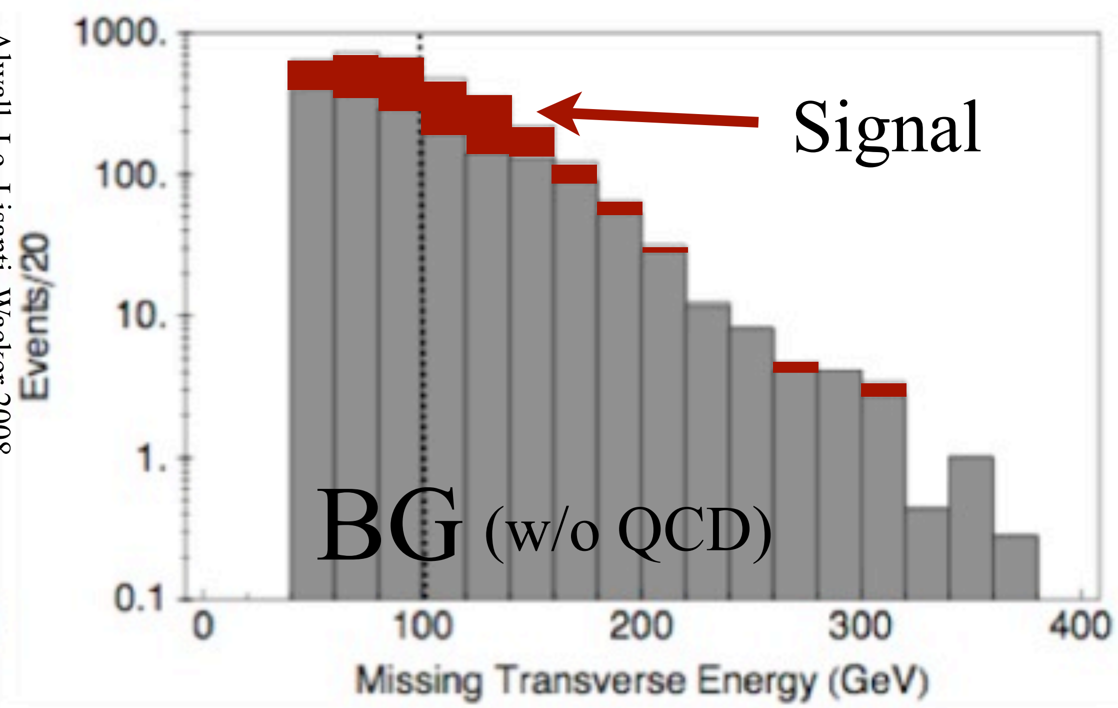
A Comparison Between Optimized Cuts and Original Cuts

$m_{\tilde{g}} = 210 \text{ GeV} \qquad m_{\tilde{B}} = 100 \text{ GeV}$

Dijet most effective channel

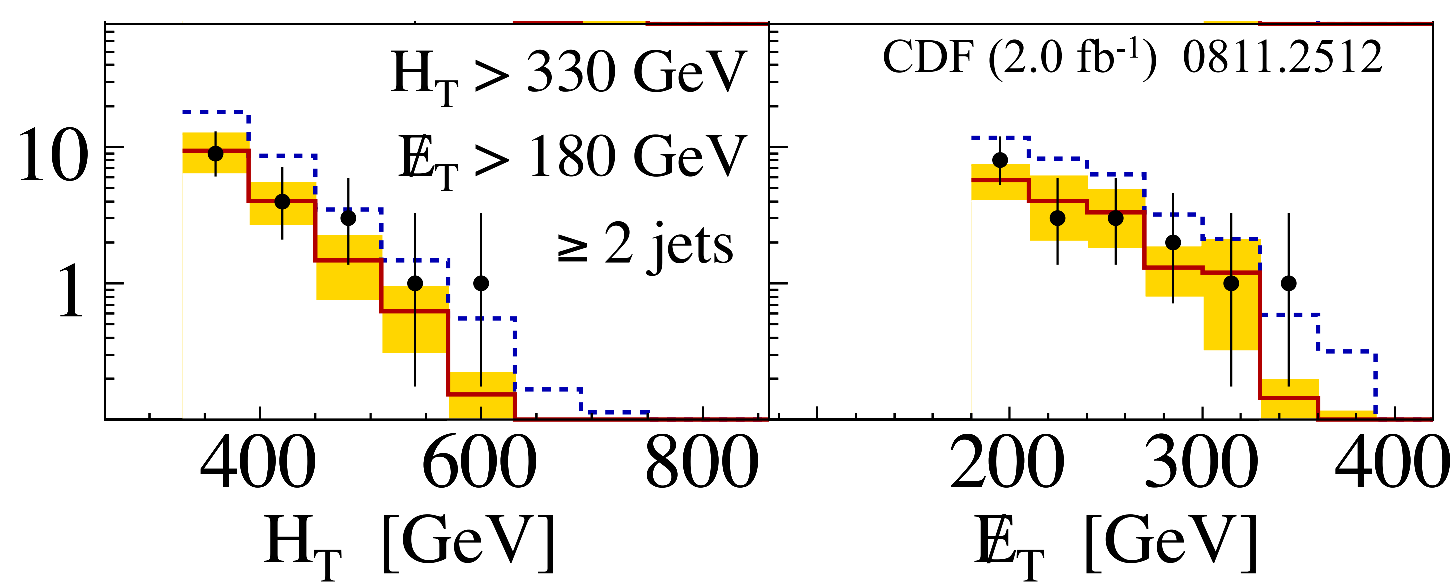


$H_T \geq 300 \text{ GeV} \quad \not{E}_T \geq 225 \text{ GeV}$



$H_T \geq 150 \text{ GeV} \quad \not{E}_T \geq 100 \text{ GeV}$

Not easy searches



Outline

Simplified Models

LHC Results and Their Implication

Model Independent Limits

Using Early Results

Limits on Directly Decaying Gluinos

Limits on Cascade Decaying Gluinos

Going Forward

ATLAS Search

$$\mathcal{L} = 70\ \text{nb}^{-1}$$

Performed 4 Searches

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

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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

Relatively loose cuts

Under pretty good control!

(monojets appear a bit dirty)

How we used this result

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

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

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

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

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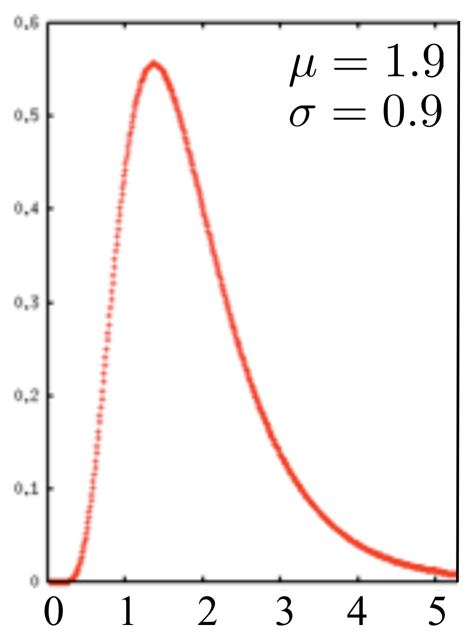
Convolve with uncertainties:

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

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)



Sets limit on

$$\sigma(pp \to \tilde{g}\tilde{g}X)\ \epsilon$$

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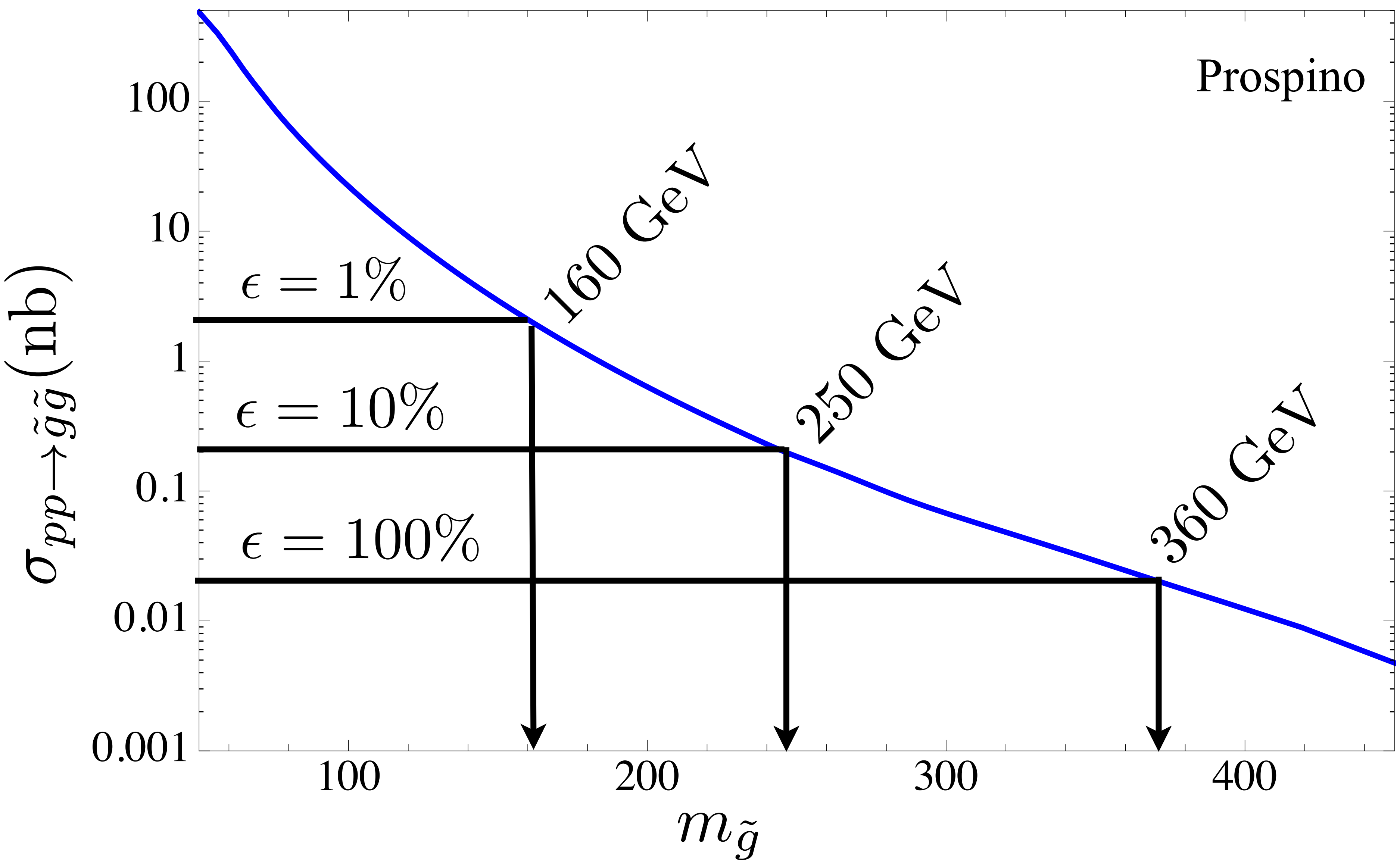
	N_{Obs}	73	4	0	1
	$\sigma(pp \to \tilde{g}\tilde{g}X)\epsilon\vert_{95\%\ \mathrm{C.L.}}$	663 pb	46.4 pb	20.0 pb	56.9 pb

$3^+j + \not{E}_T$ usually most effective

How many color octets can you make with

$$\sigma(pp \to \tilde{g}\tilde{g}) = 20 \text{ pb ?}$$



Can get above the Tevatron's current bounds with reasonable efficiencies

Need to calculate efficiencies

(the hard part)

We need to know what fraction of
the events from a given theory pass the cuts

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)

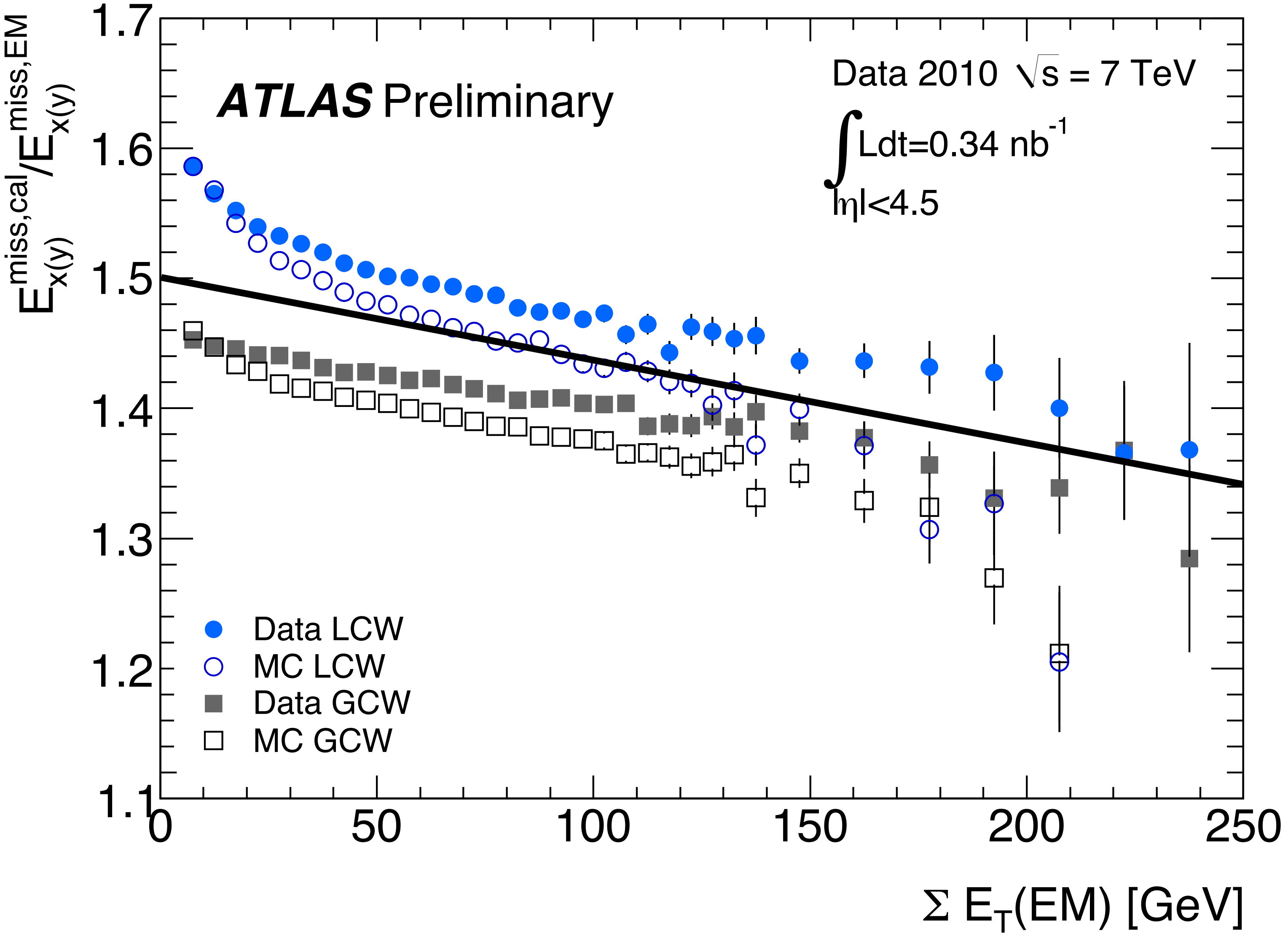
Efficiency is the fraction of events that passed the cuts

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

The problems with “MET”

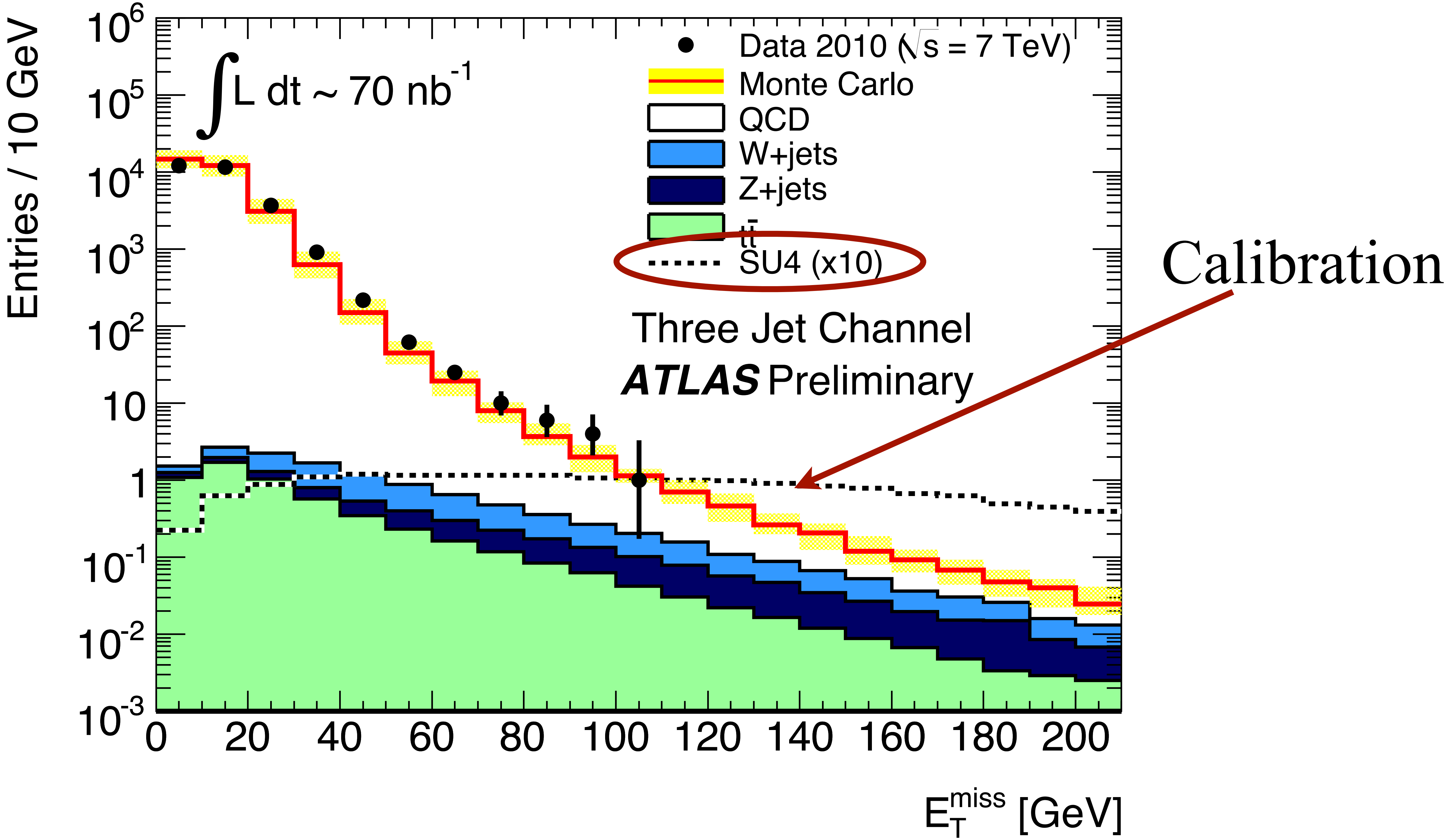
Missing transverse momentum is computed from calorimeter cells belonging to topological clusters at the electromagnetic scale [30]. No corrections for the different calorimeter response of hadrons and electrons/photons or for dead material losses are applied. The transverse missing momentum

“true” MET/“EM” MET

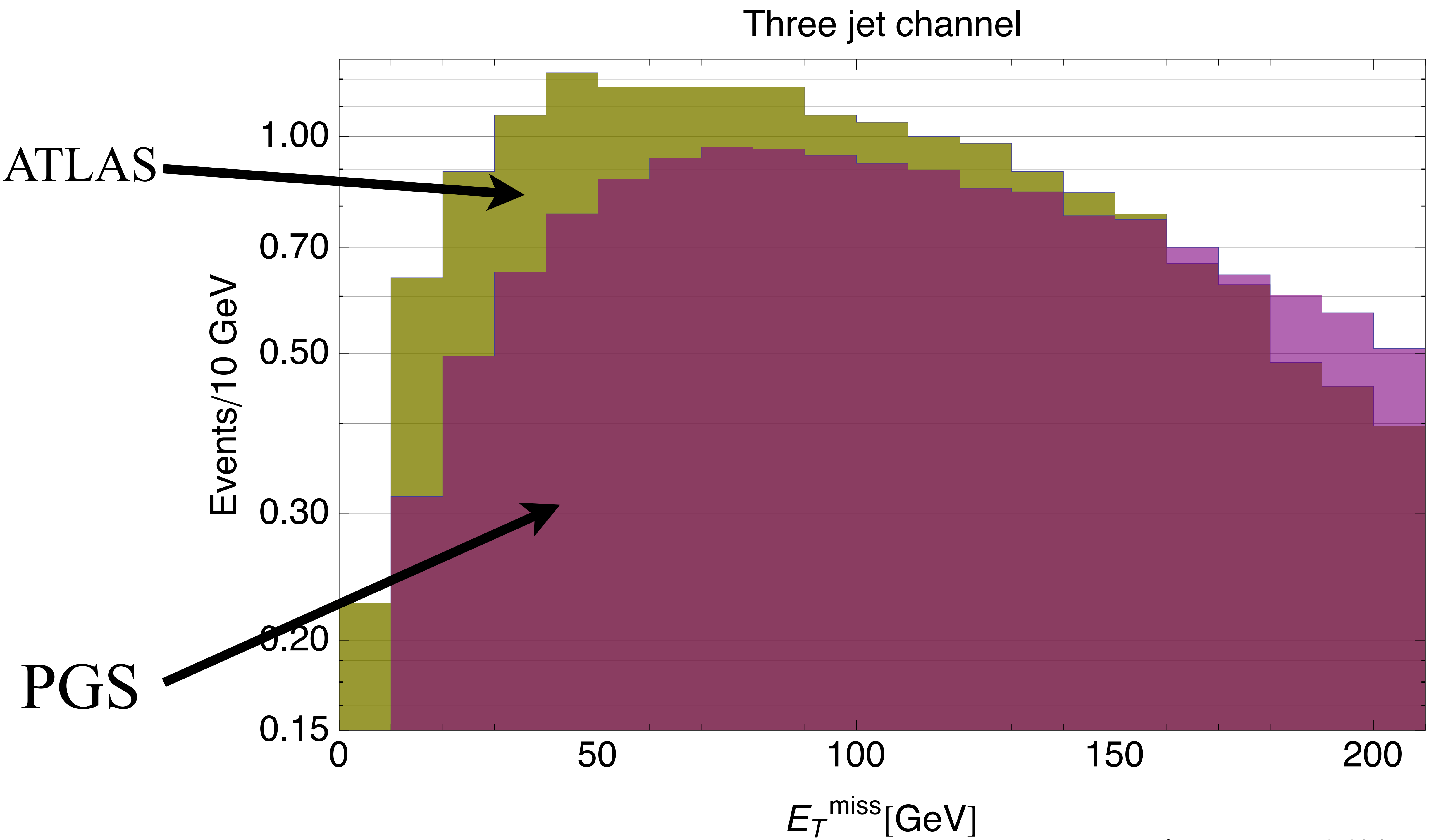


Effectively raises MET cut by 35% to 50%

Without calibrated MET, have to take a shot in the dark and validate



Straight PGS MET

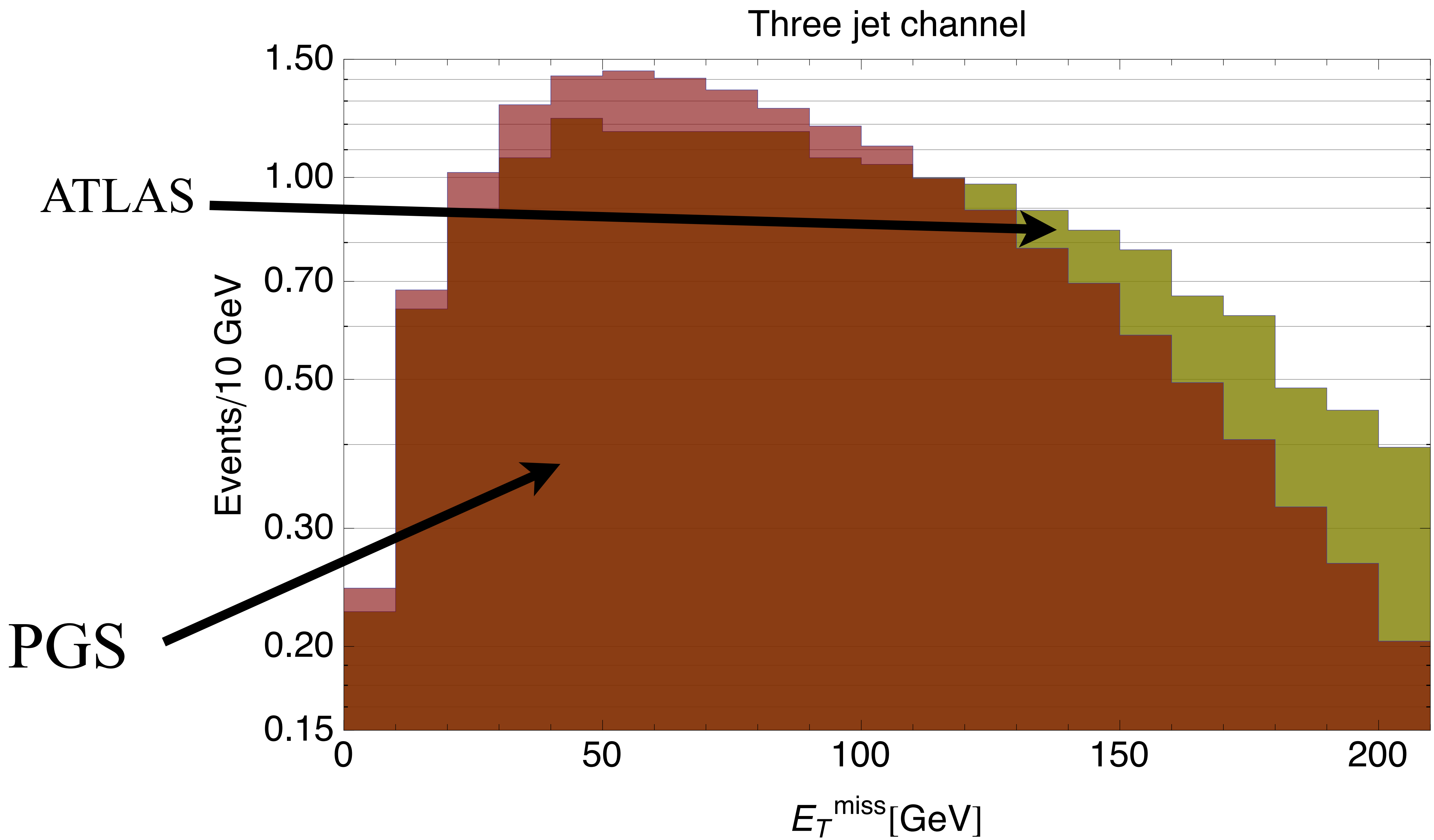


rel. norm. = 84%

cut ε_{ATLAS} = 84%

cut ε_{model} = 90%

PGS MET/1.5

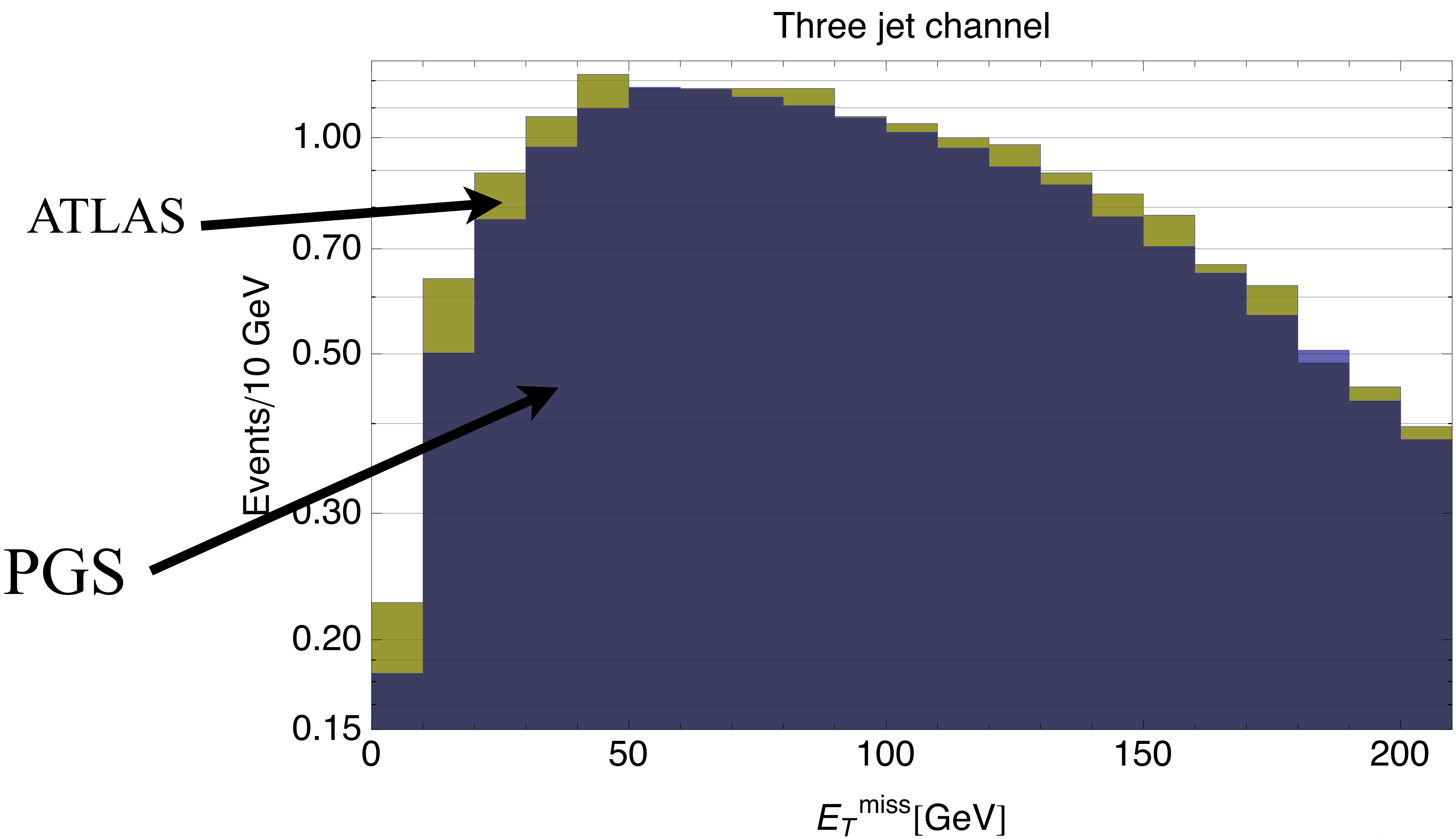


rel. norm. = 101%

cut ε_{ATLAS} = 84%

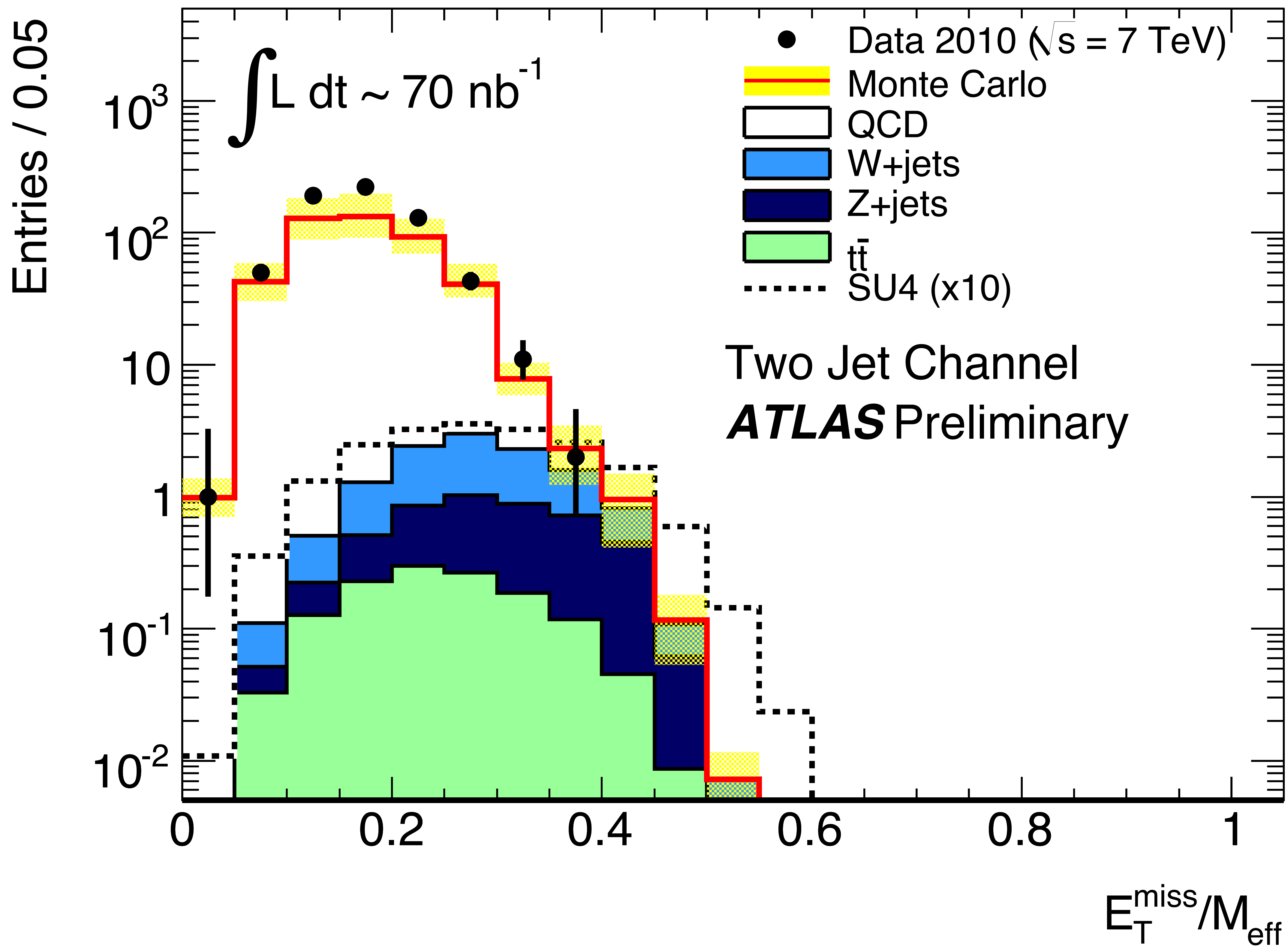
cut ε_{model} = 82%

PGS MET with linear fit to Sum ET

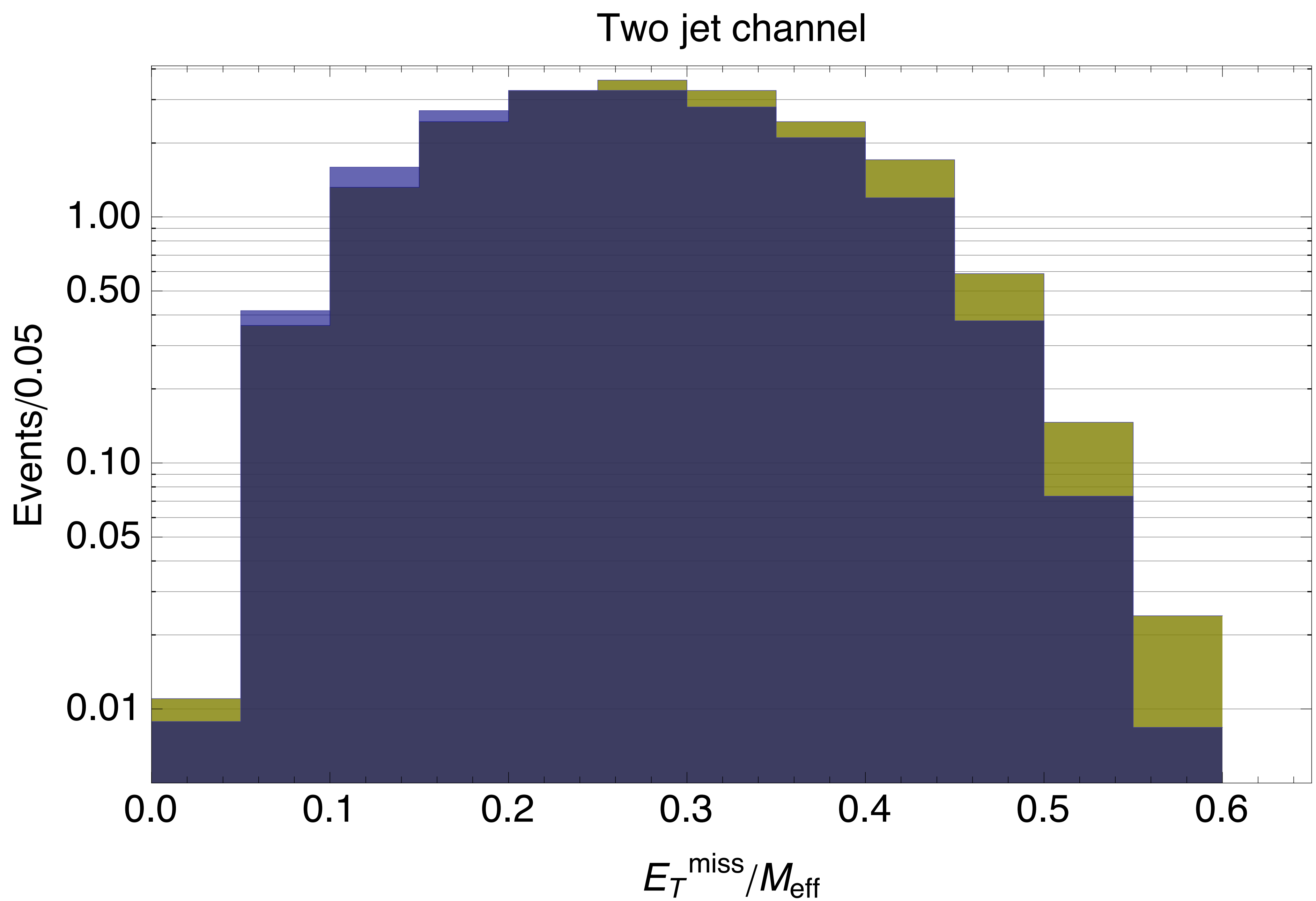


rel. norm. = 94%
cut ε_{ATLAS} = 84%
cut ε_{model} = 86%

Fractional MET Cut



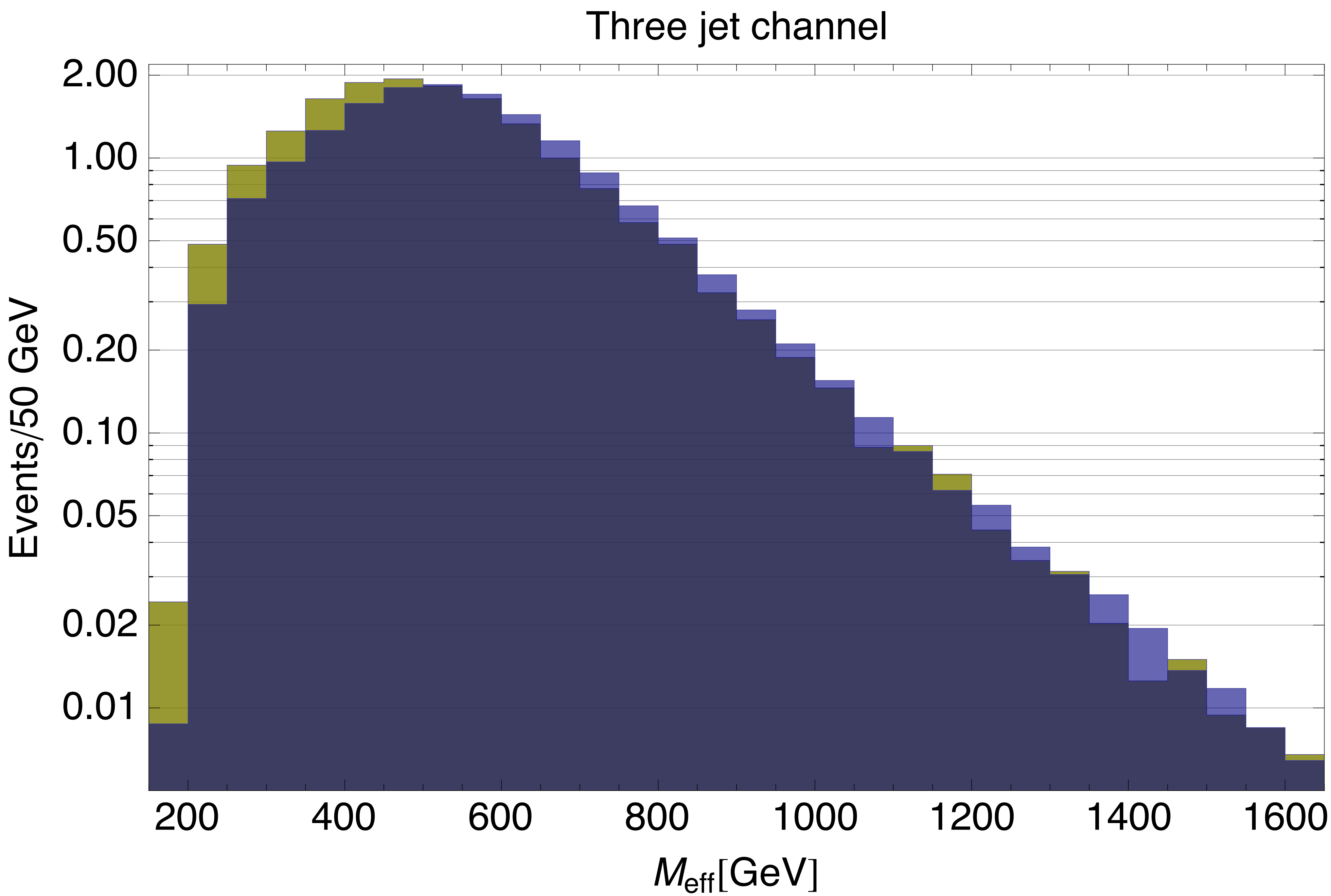
Linear HT Fit underestimates high fractional MET



rel. norm. = 0.93
cut $\varepsilon_{ATLAS} = 0.43$
cut $\varepsilon_{model} = 0.37$

Not perfect, but changes efficiencies by < 15%

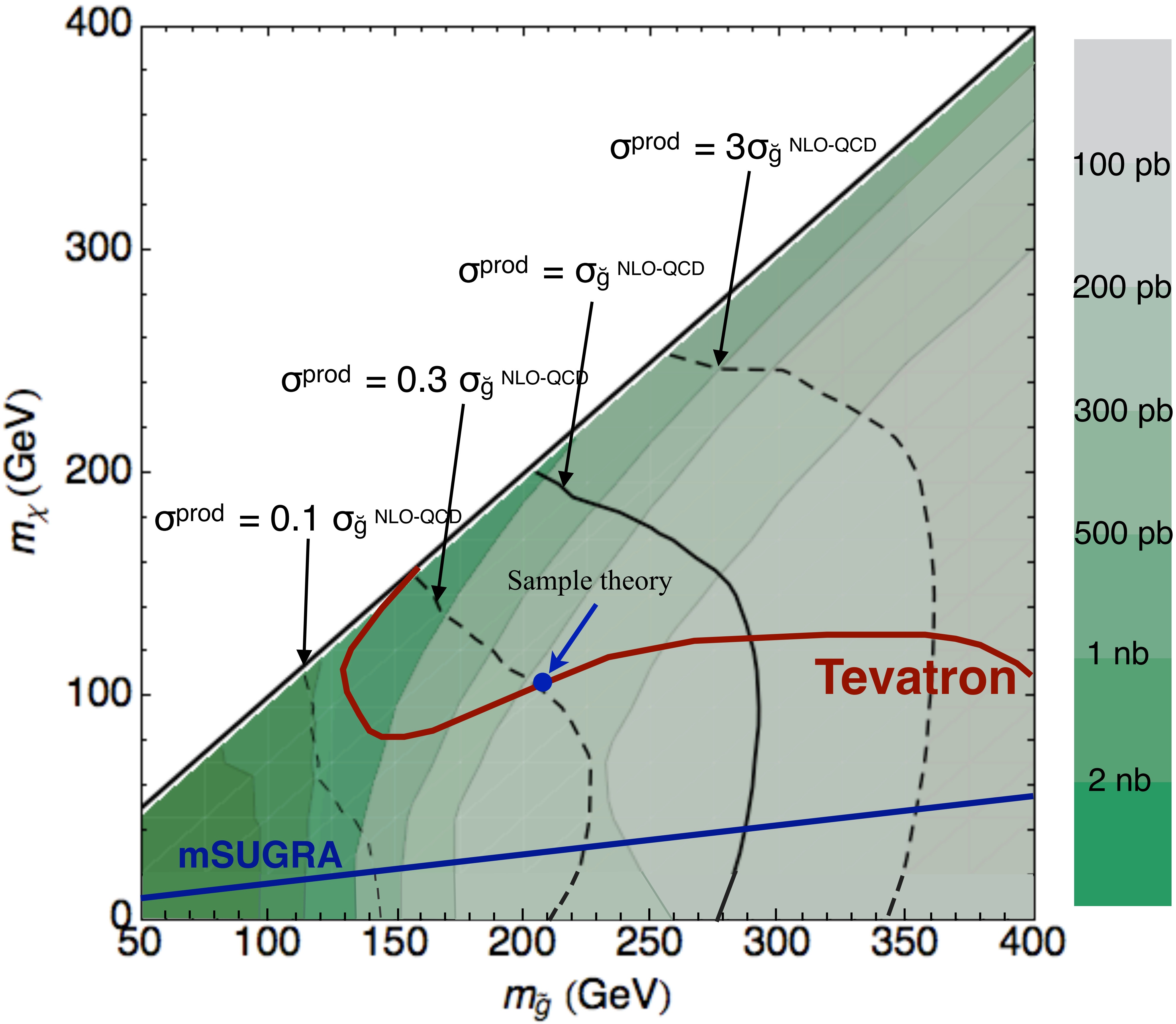
Linear HT Fit underestimates high fractional MET



rel. norm. = 0.95

Putting it all together

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



3 jet channel most important

Best limit on cross section

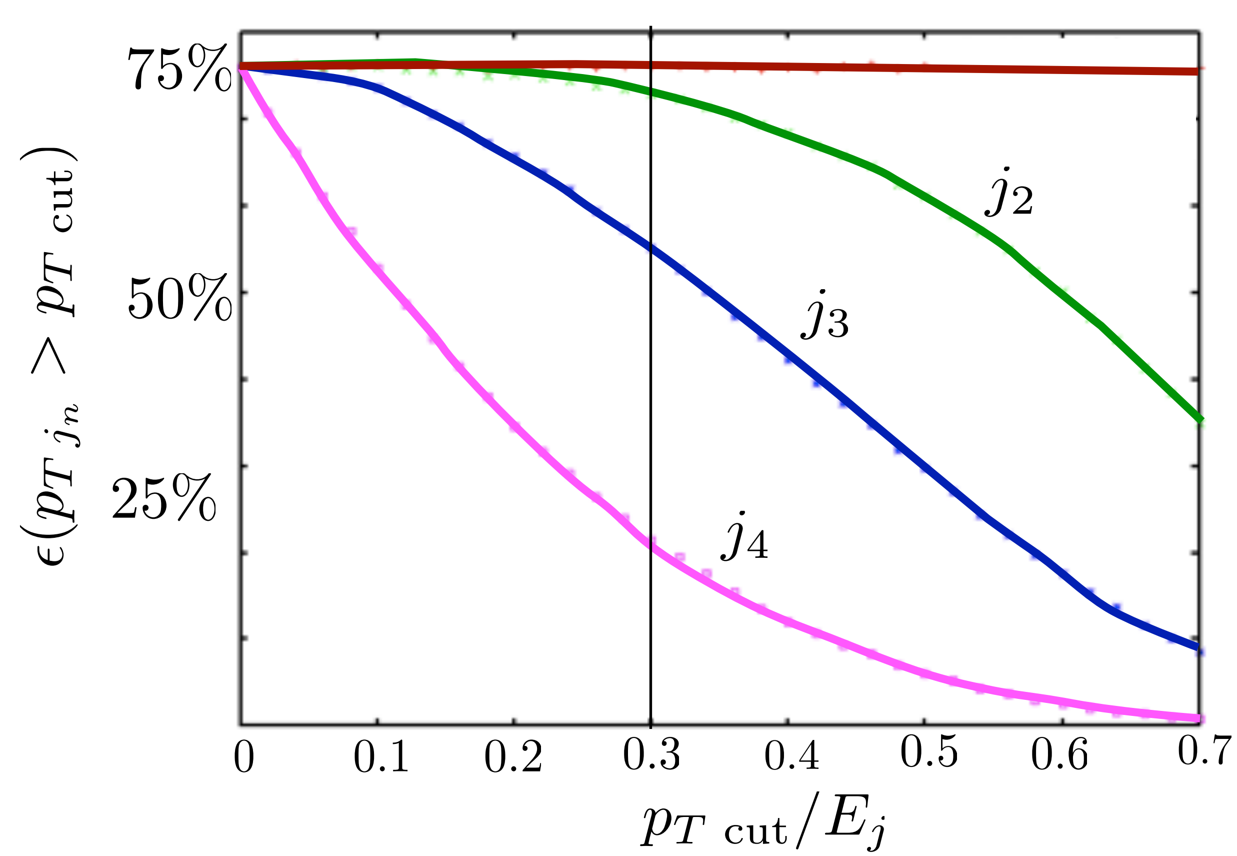
$\sigma_{3+j}\,\epsilon \leq 20$ pb vs $\sigma_{4+j}\,\epsilon \leq 57$ pb

Efficiency drops for 4 jets satisfying $p_T > 30$ GeV

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

leads to 4 jets with energies of $E_j \sim 100$ GeV

only 40% of the events that pass $p_{T\,j3} > 30$ GeV, pass $p_{T\,j4} > 30$ GeV

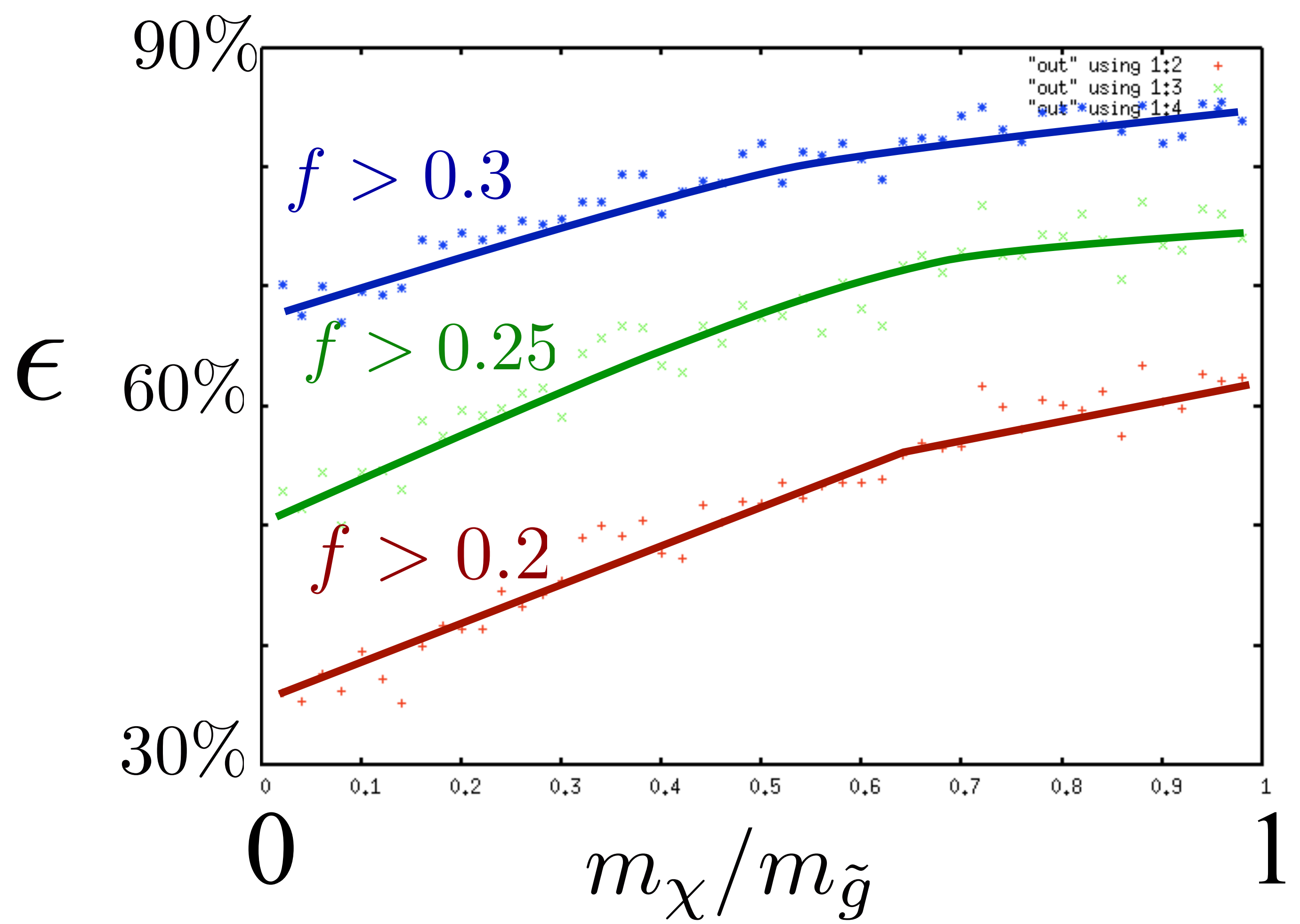


The slight loss of sensitivity at lower LSP mass from fractional MET cut

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

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

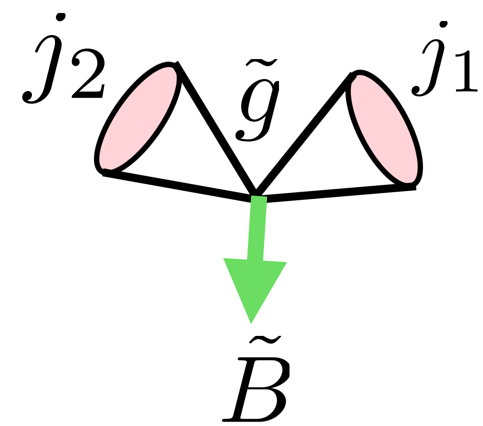
maximizes f, and drops for lighter LSP



A look at how PS/ME matching alters the signal

150 GeV particle going to 140 GeV LSP and 2 jets

In rest frame of each gluino:
two 5 GeV "jets" and a LSP with 3 GeV momentum



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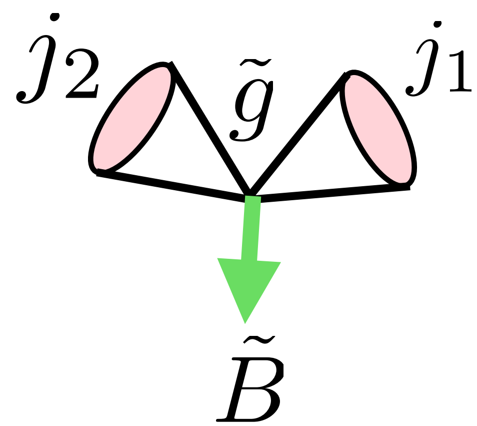
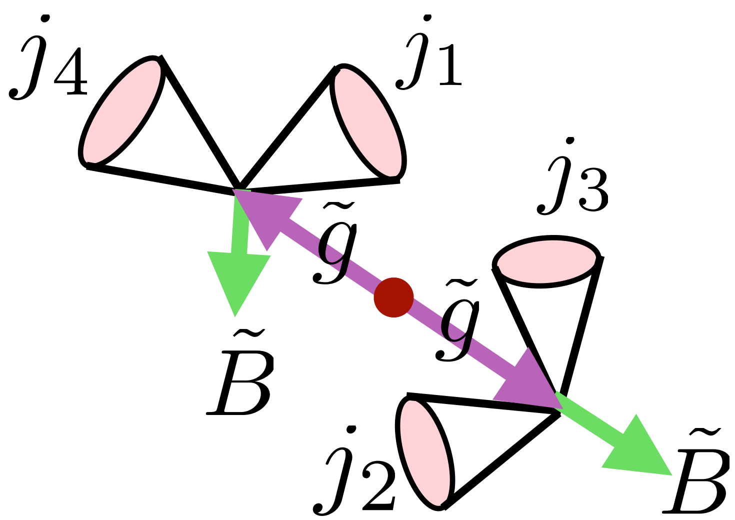
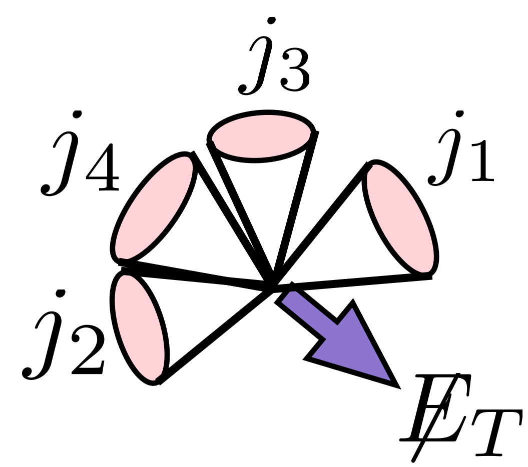


Parton level



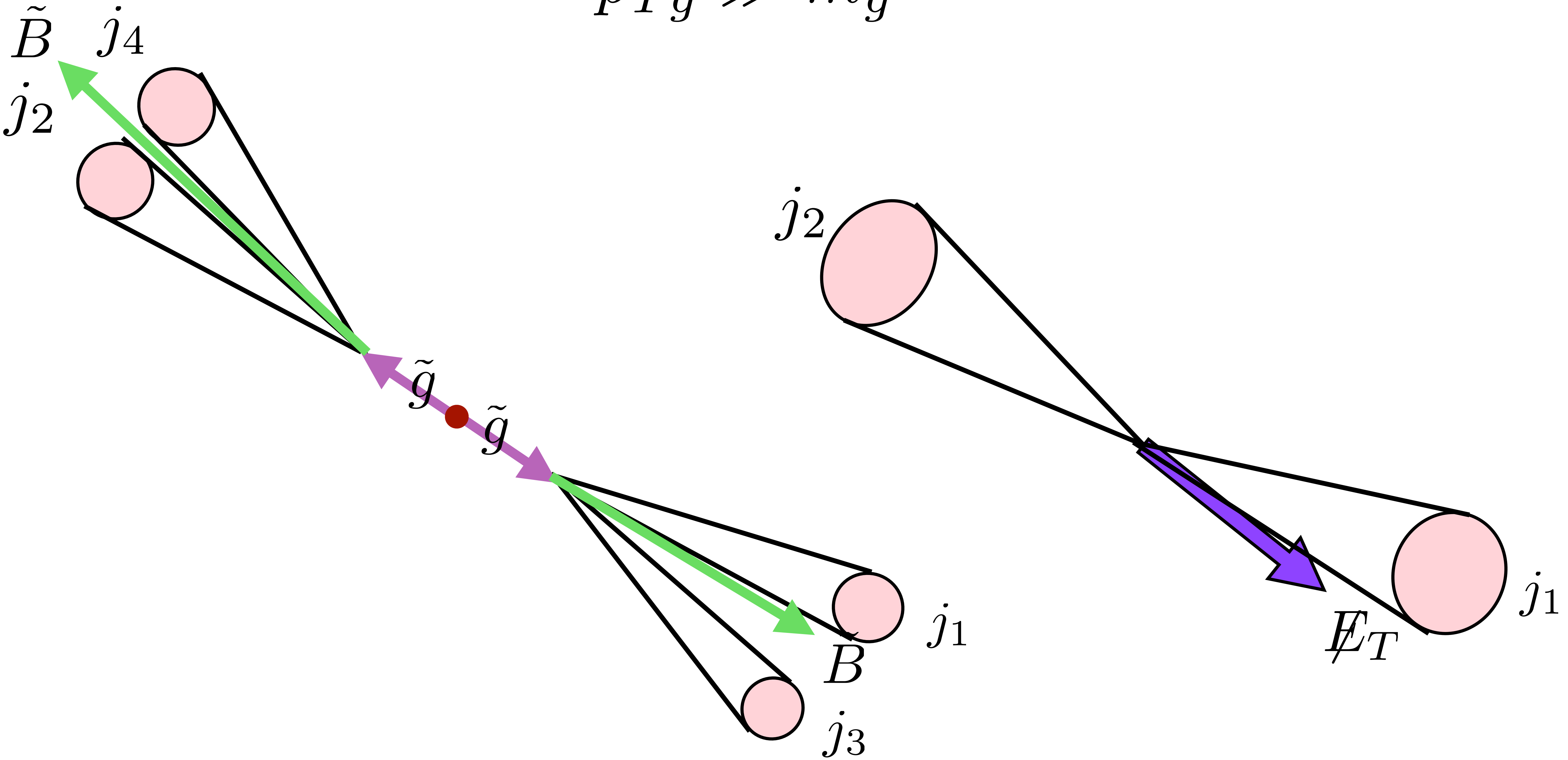
Detector level



Totally invisible: faked by QCD with $\sqrt{\hat{s}_{\mathrm{BG}}} \sim 20$ GeV

Give the gluino big boost!

$$p_{T\tilde{g}} \gg m_{\tilde{g}}$$

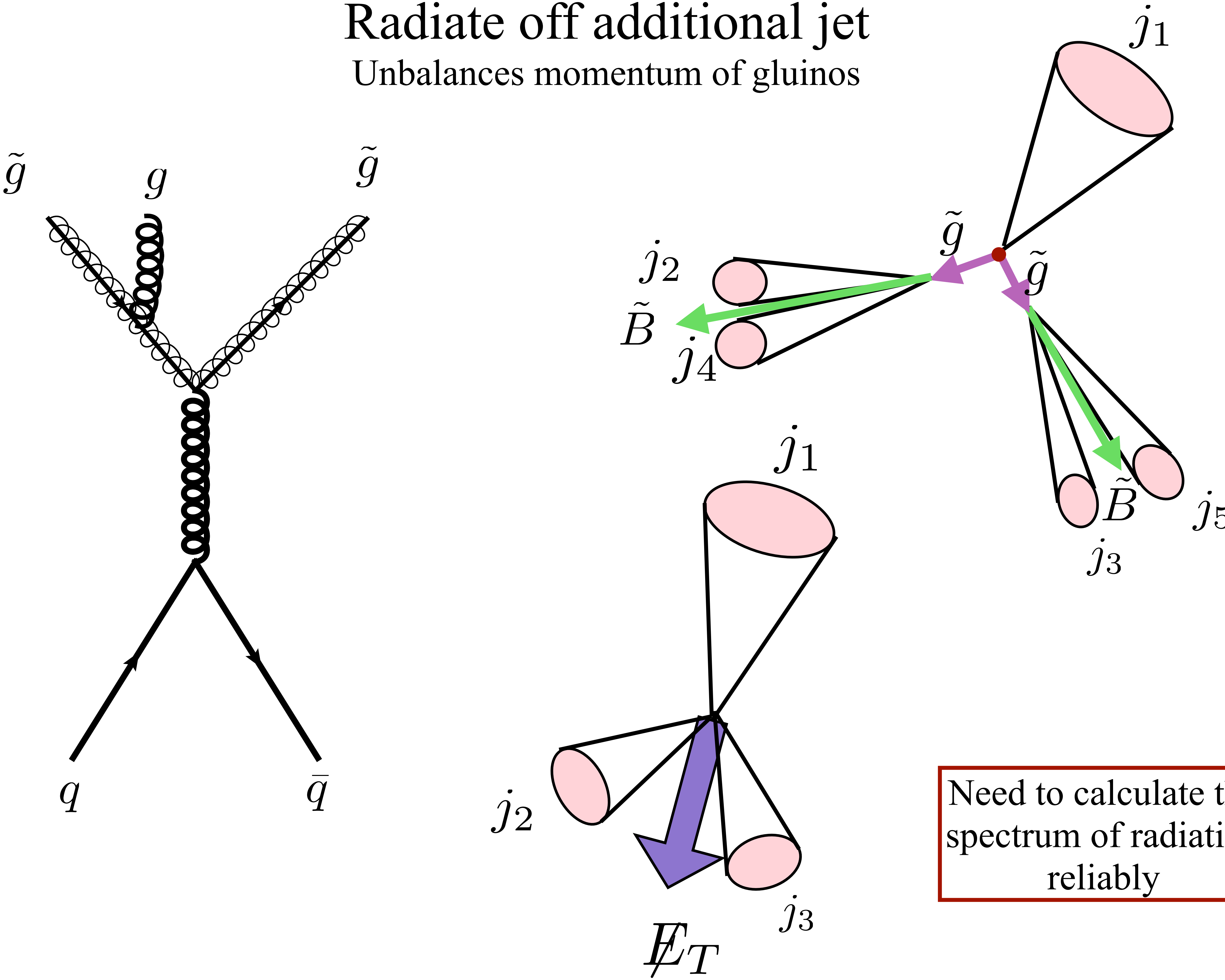


Jets merge and MET points in direction of jet

More energy, but looks like jet mismeasurement

Radiate off additional jet

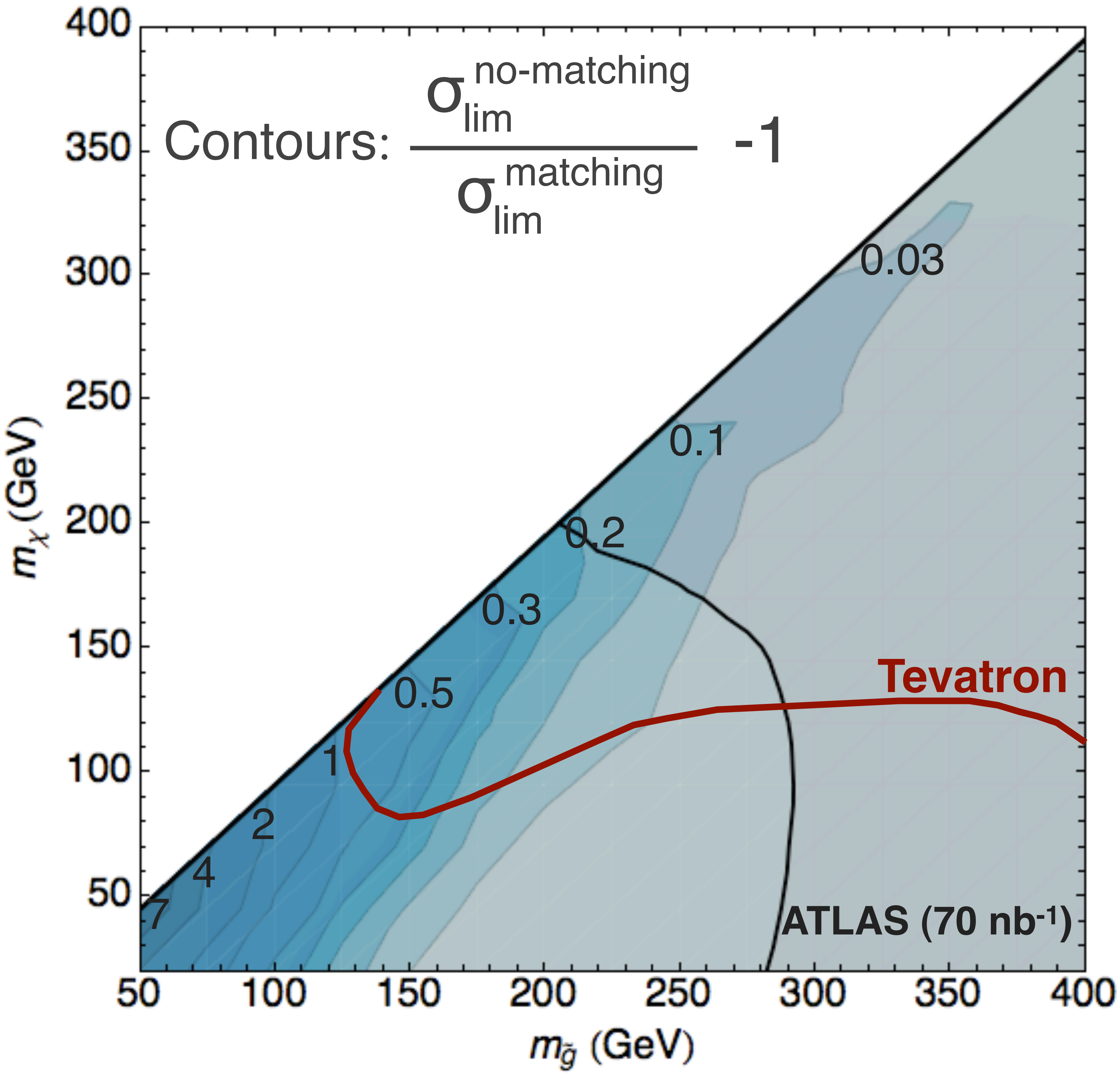
Unbalances momentum of gluinos



Need to calculate the spectrum of radiation reliably

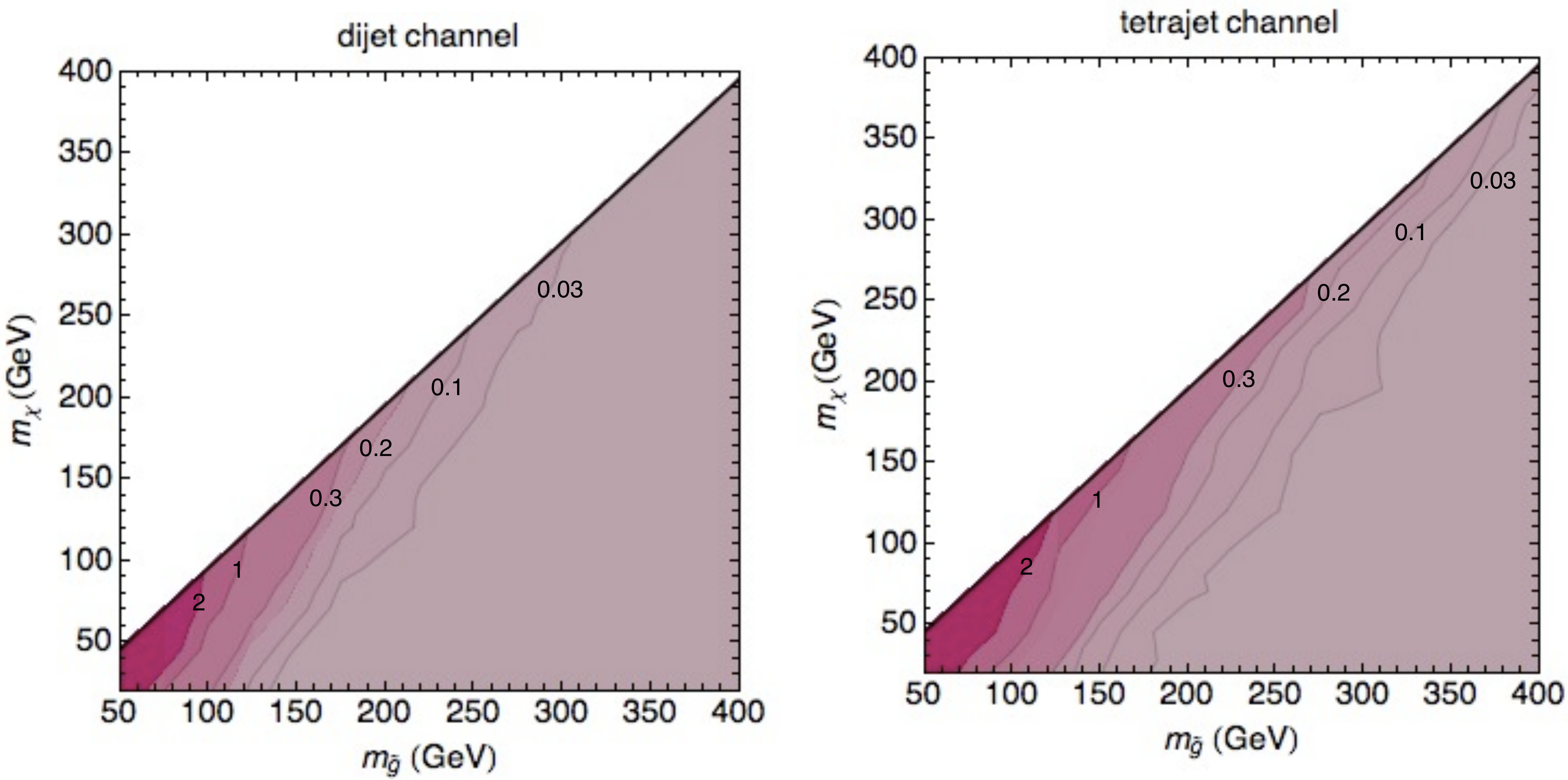
Effects of matching on limits

Pretty soft jets, yet matching is still making a difference



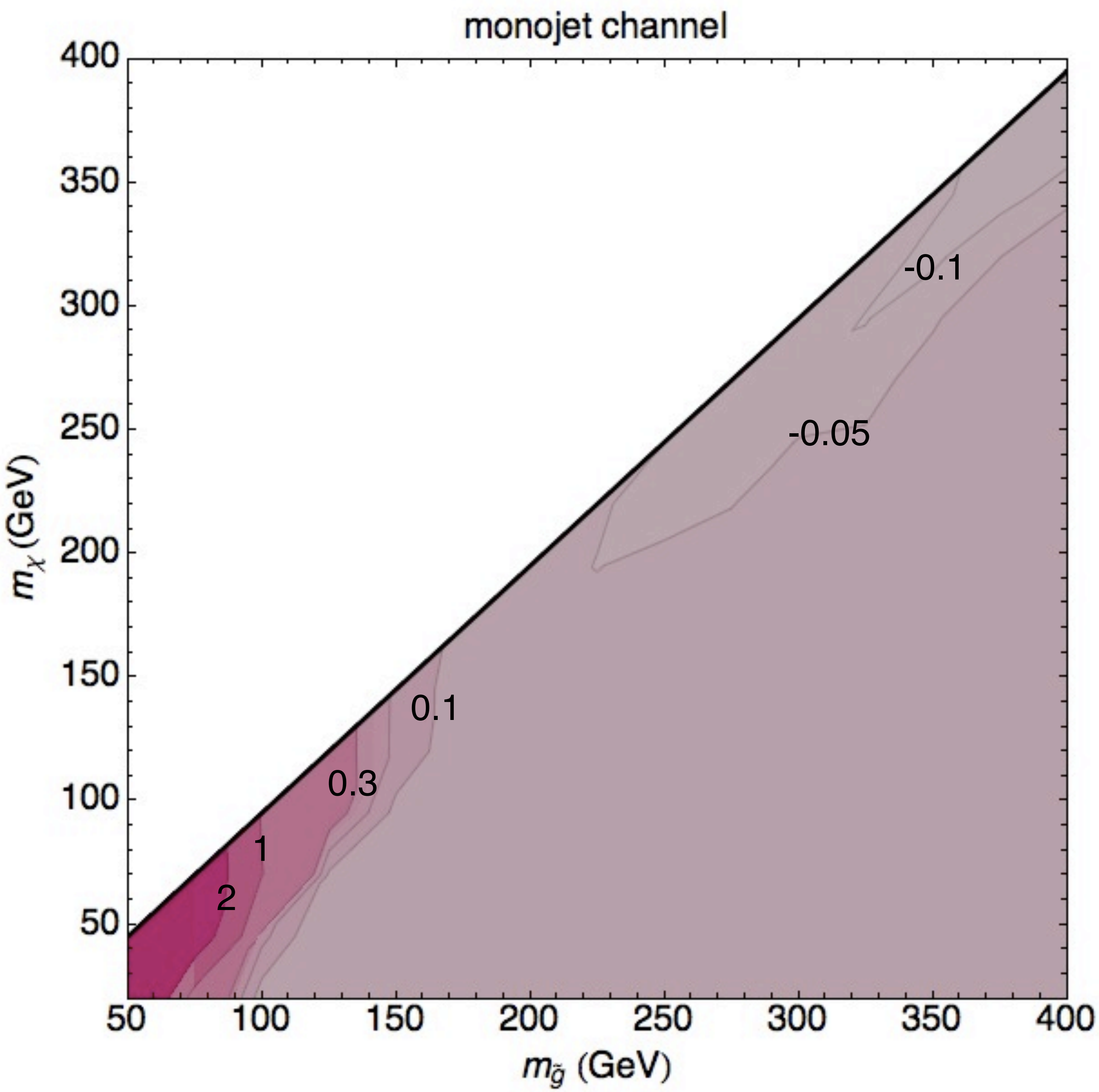
Higher multiplicities affected more

$$\text{contours} = \frac{\sigma_{\text{lim}}^{\text{no-matching}}}{\sigma_{\text{lim}}^{\text{matching}}} - 1$$



Generally increases sensitivity

Efficiencies are over estimated with jet vetos



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

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

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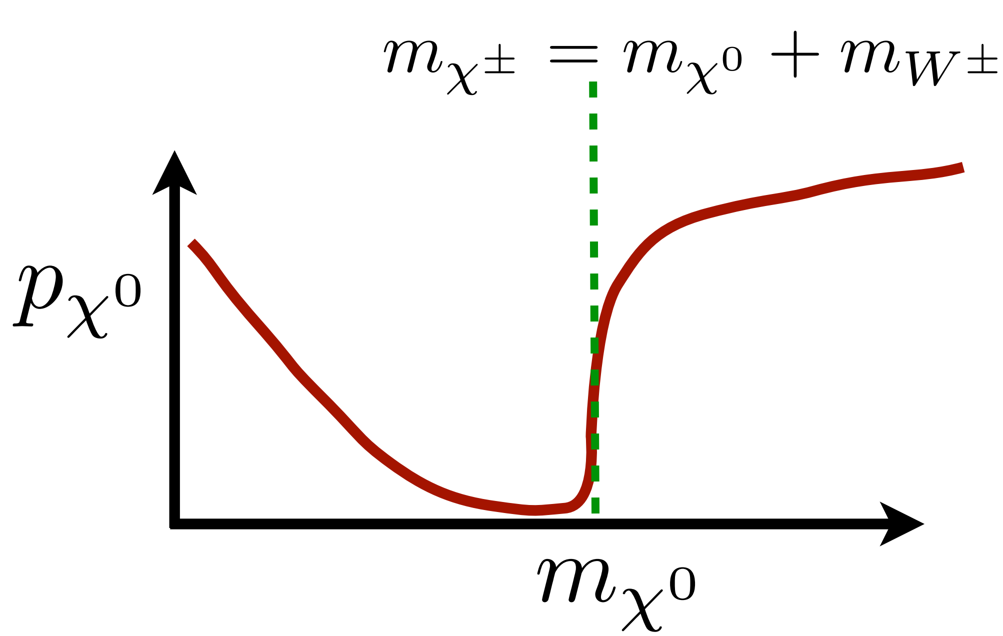
$$m_{\chi^\pm} = \frac{1}{2}(m_{\tilde{g}} + m_{\chi^0})$$

Missing energy changes dramatically between $W^\pm$ vs $W^{\pm *}$



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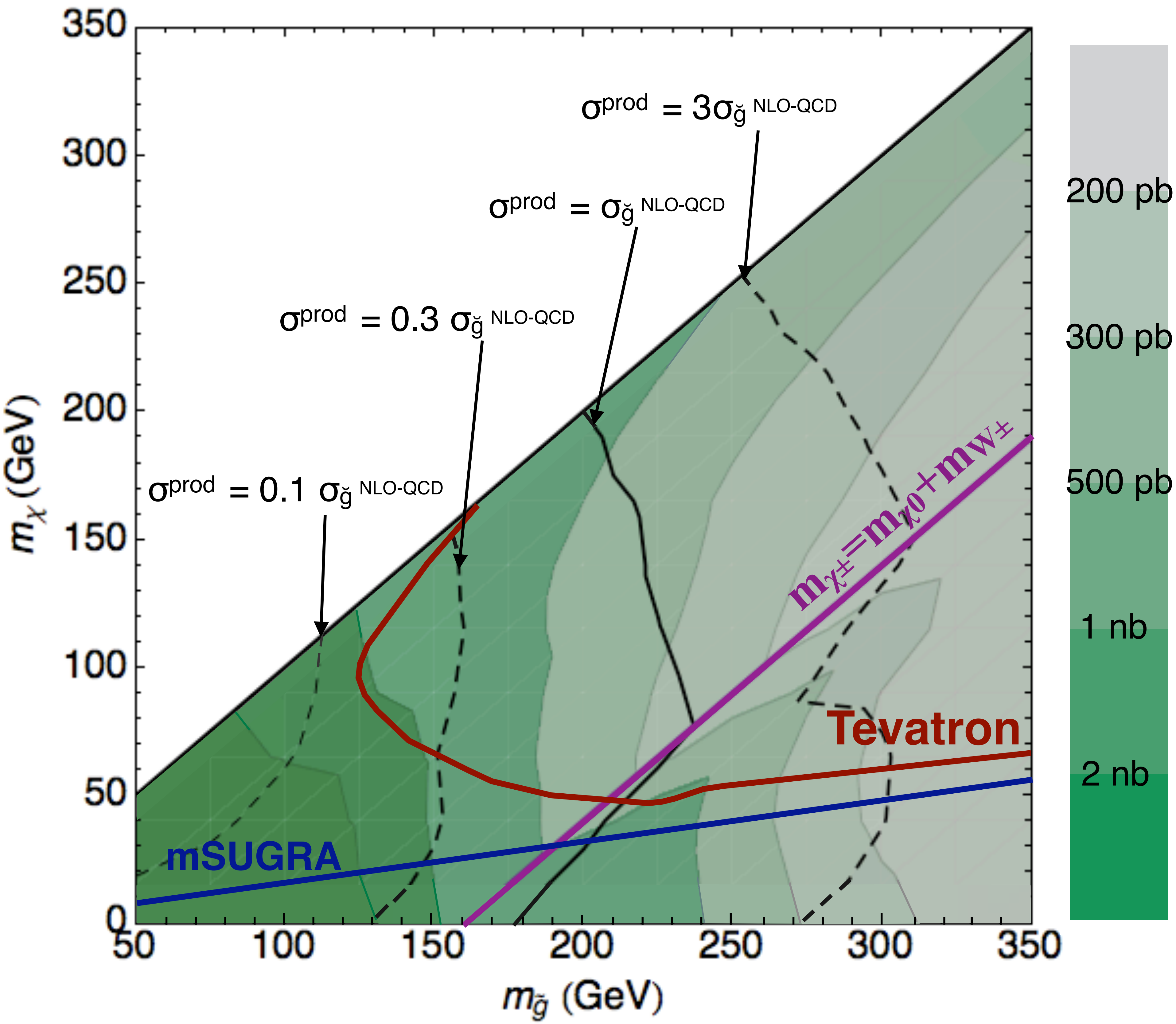


Outline

Simplified Models and Previous Limits

LHC Results and Their Implication

Going Forward

(Work in Progress)

Going Forward to 1fb^{-1}

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				
5	$\not\!\!E_T/M_{\mathrm{eff}}$	none	> 0.3	> 0.25	> 0.2

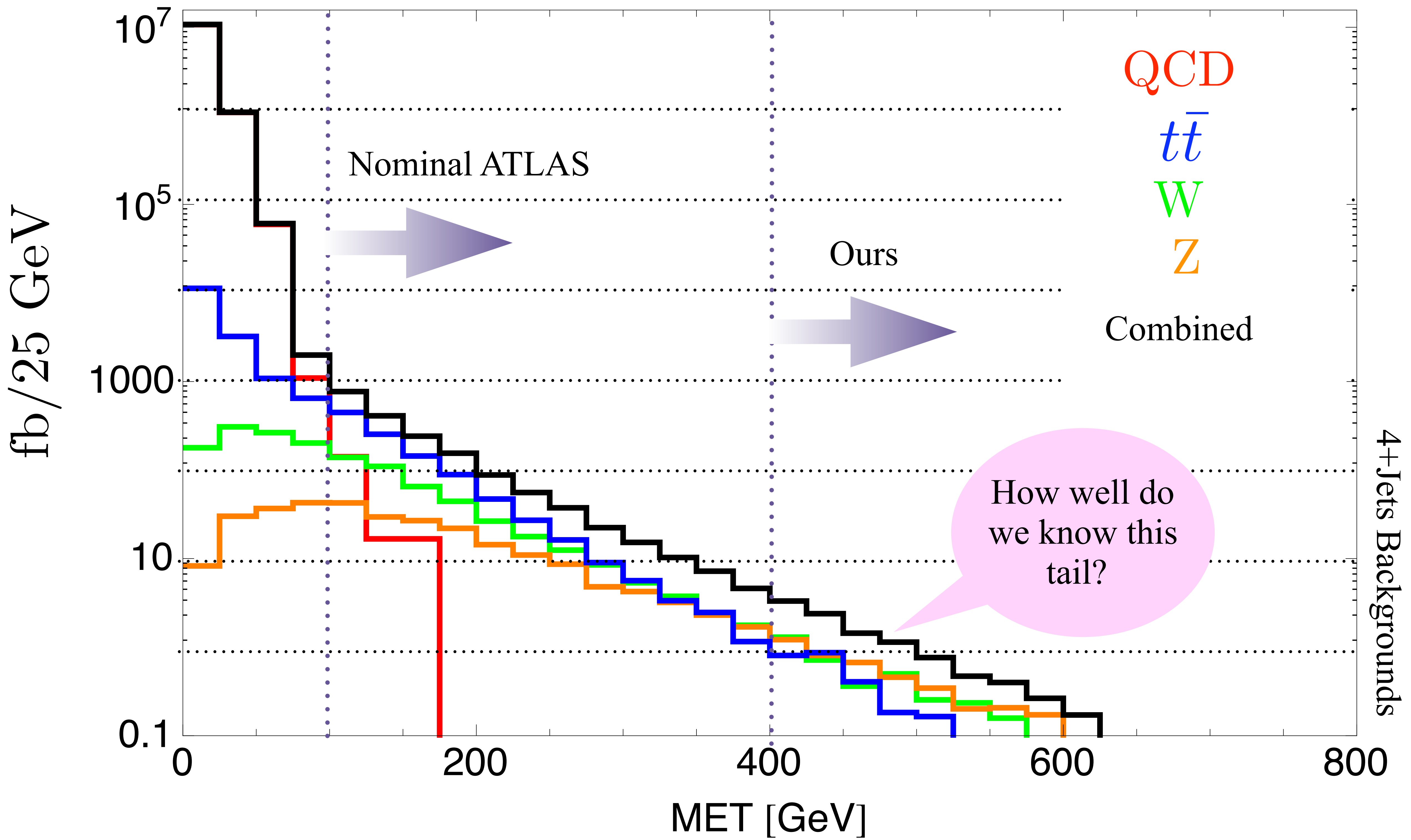
Optimize cuts for H_T $\not\!\!E_T$ (Tevatron-like)

for given masses, decay modes and systematics

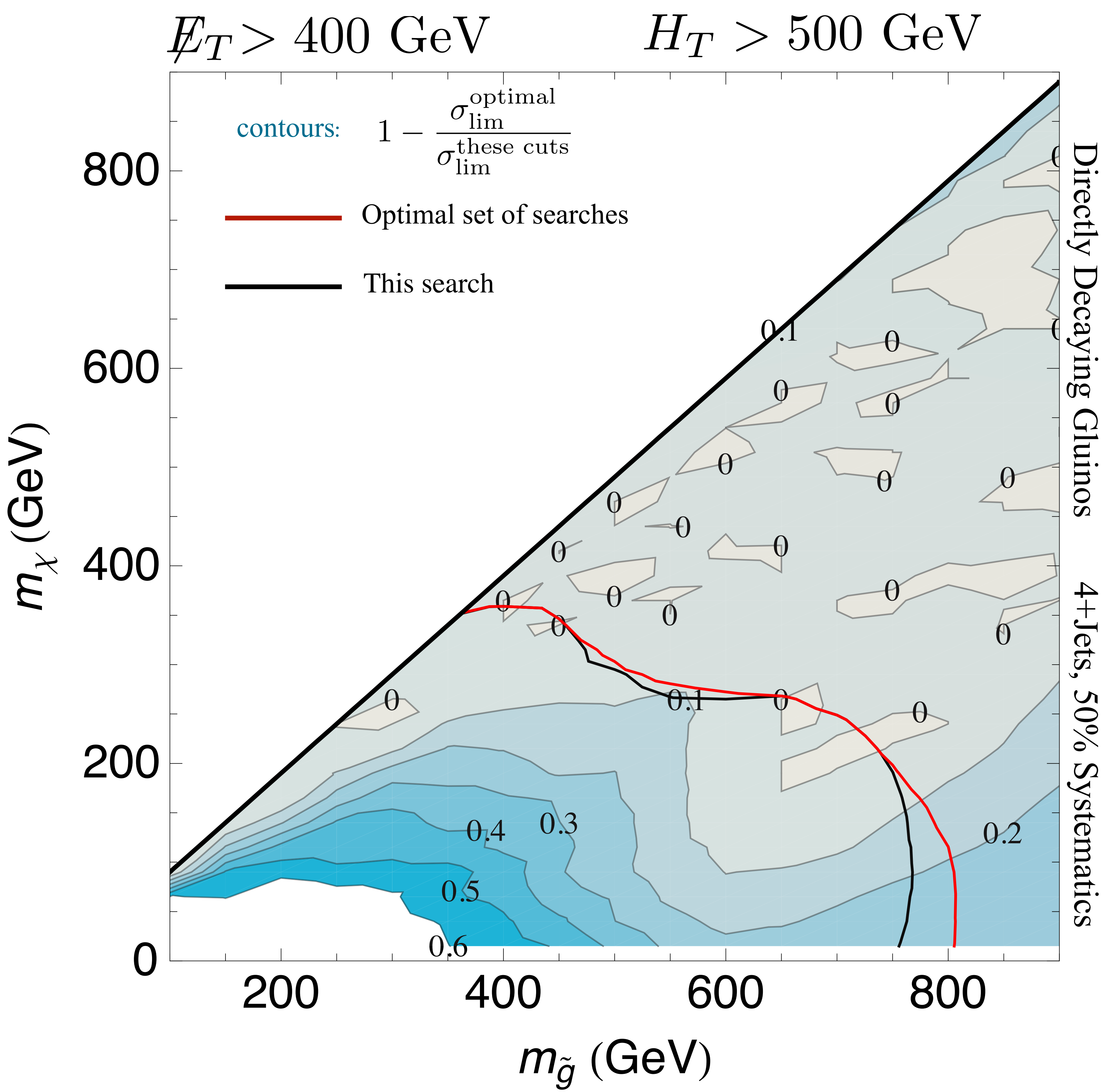
7 TeV Backgrounds

Soon to be available at LHCBackgrounds.com

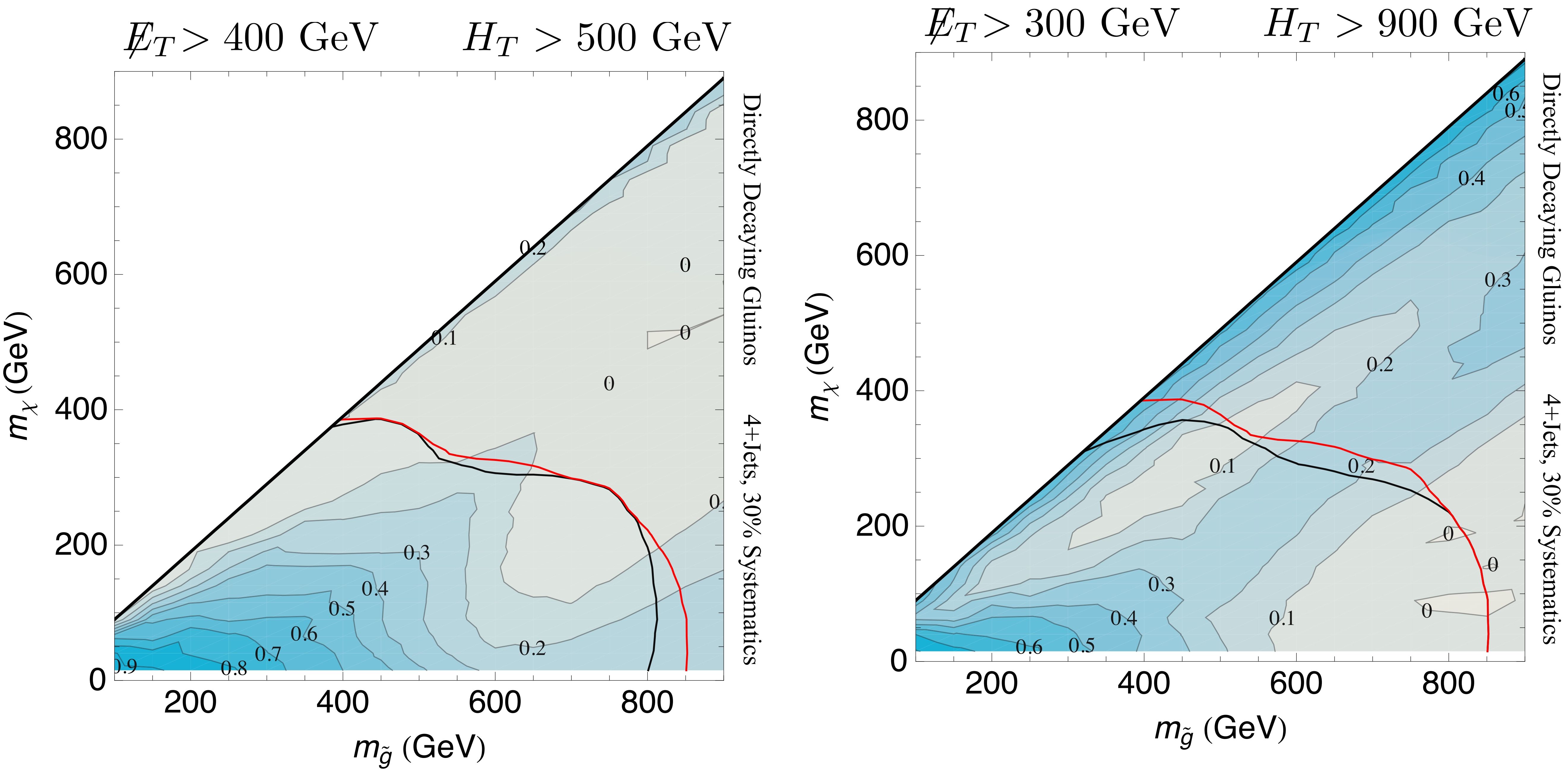
Match ATLAS MC Work Reasonably Well



Best searches, 4^{+}Jets, Large MET



Lower Systematics, similar searches

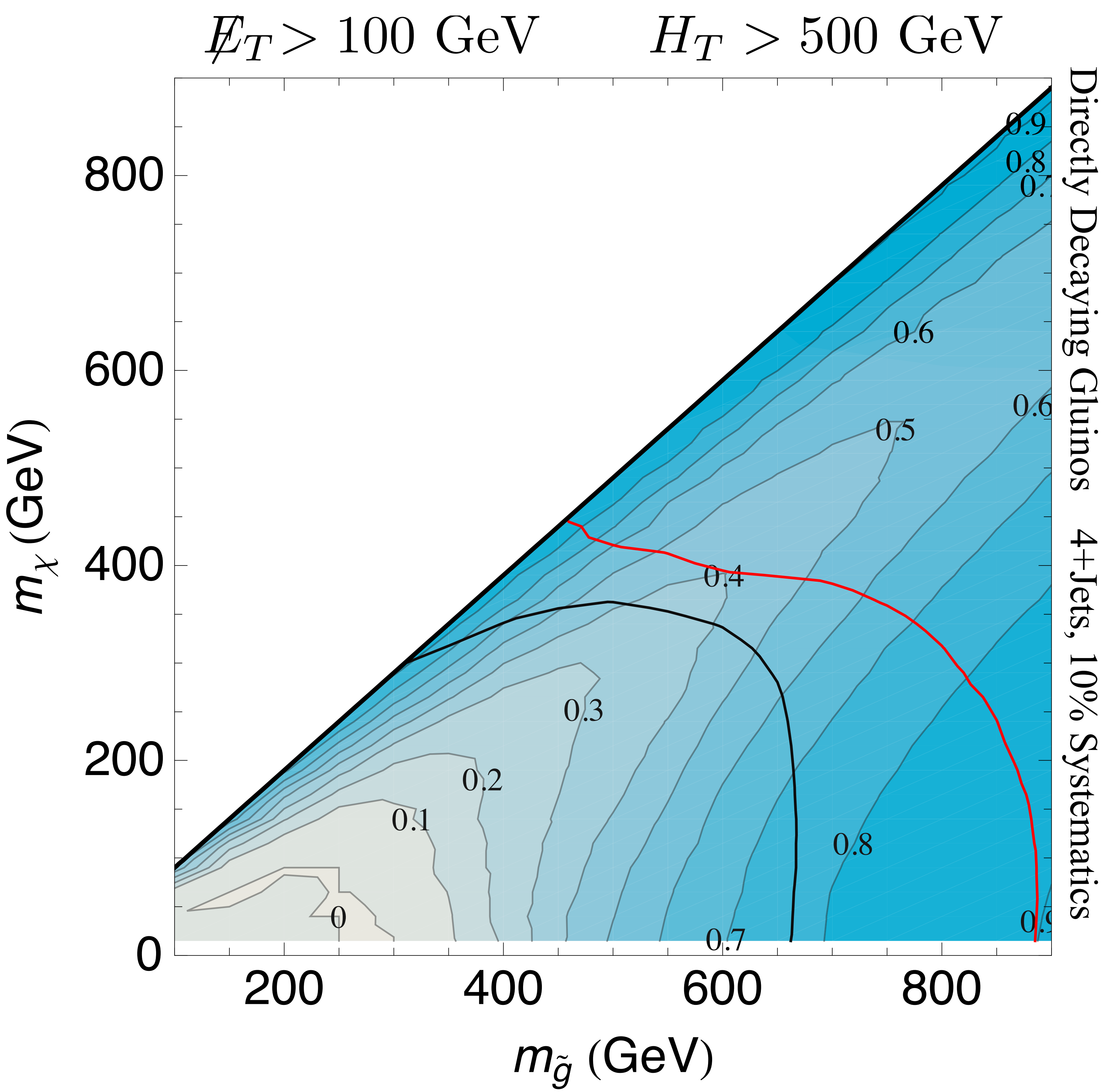


Low H_T

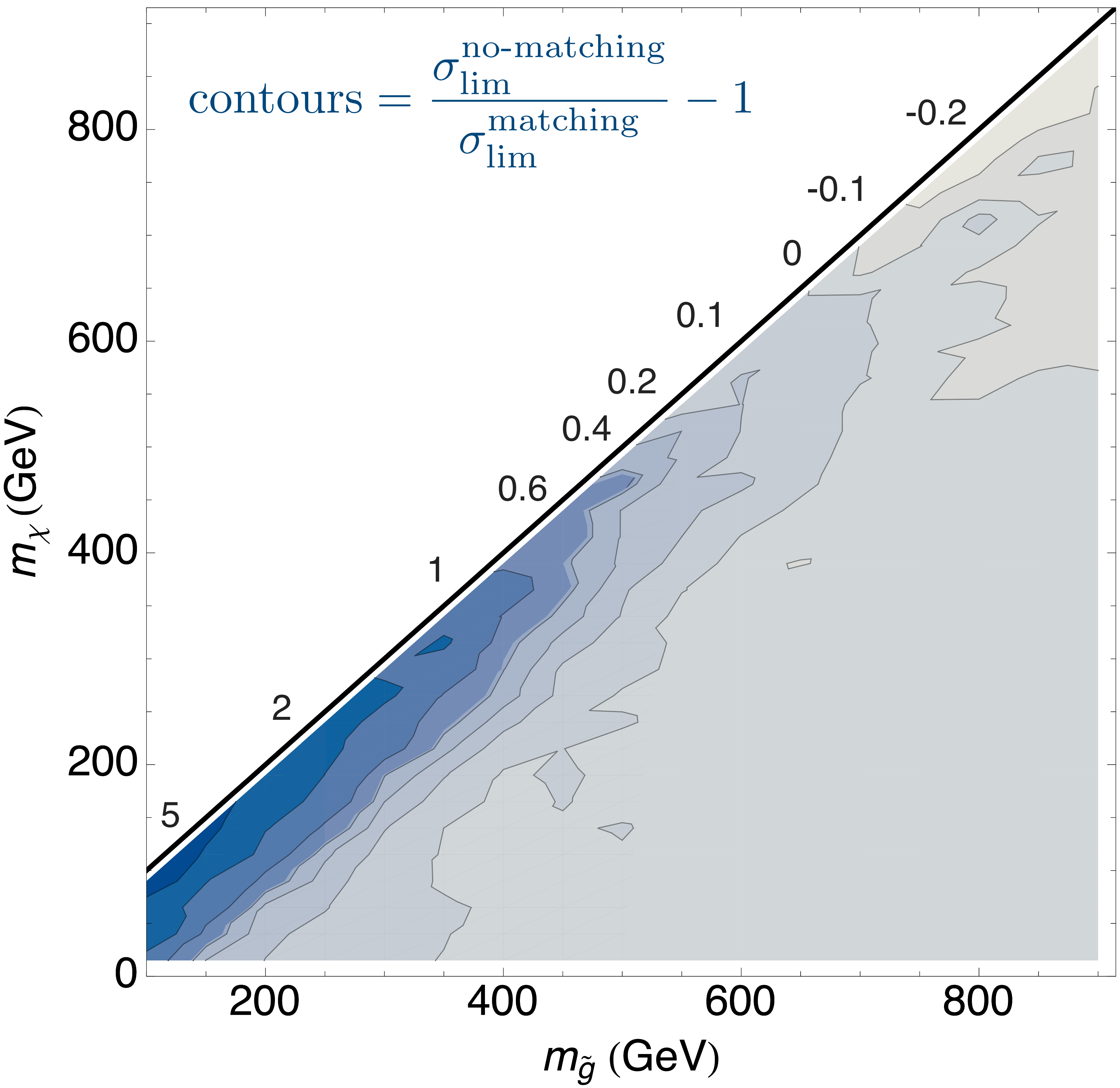
High H_T

Best sensitivity for lower masses

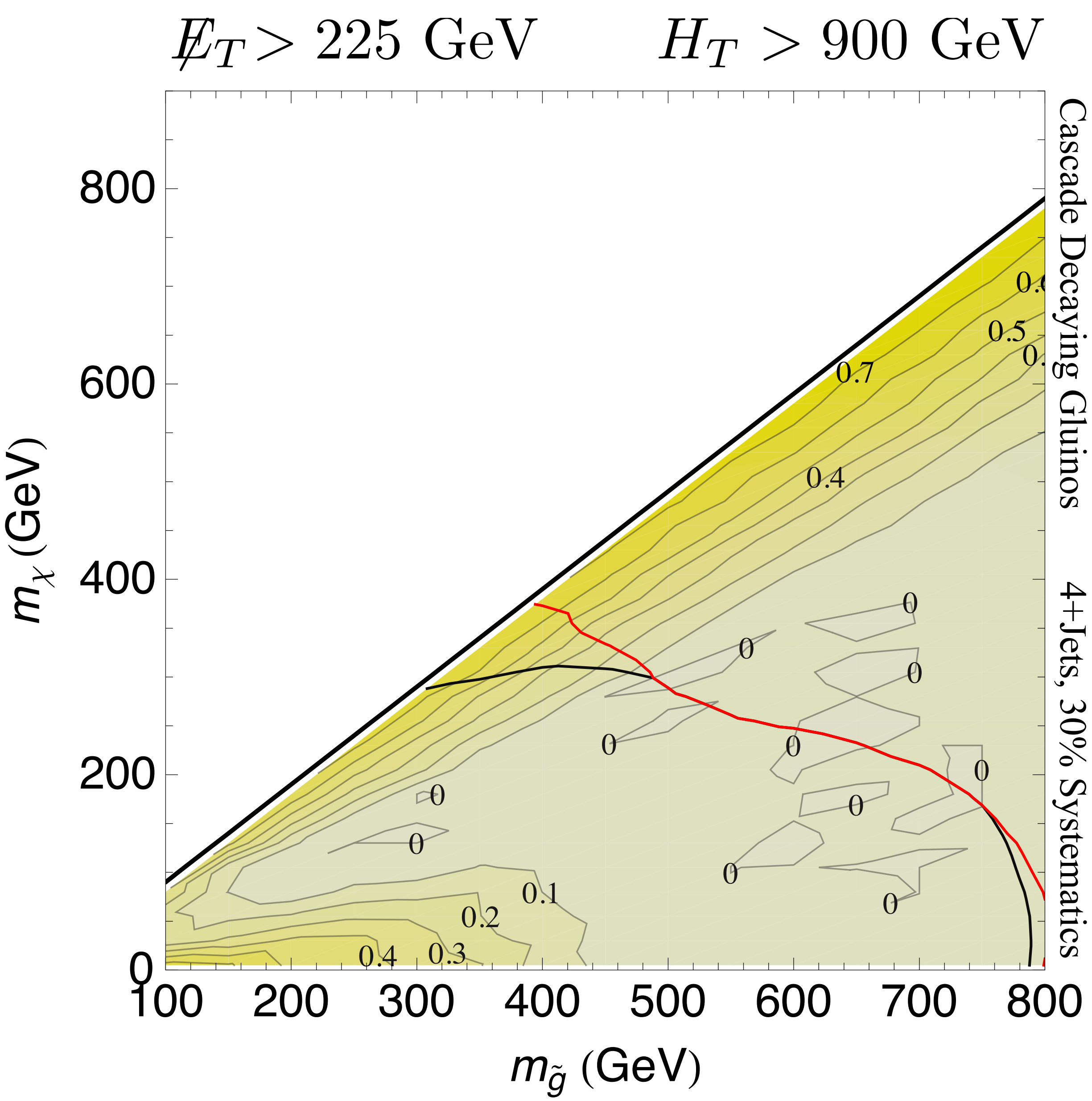
(close to nominal ATLAS SUSY search)



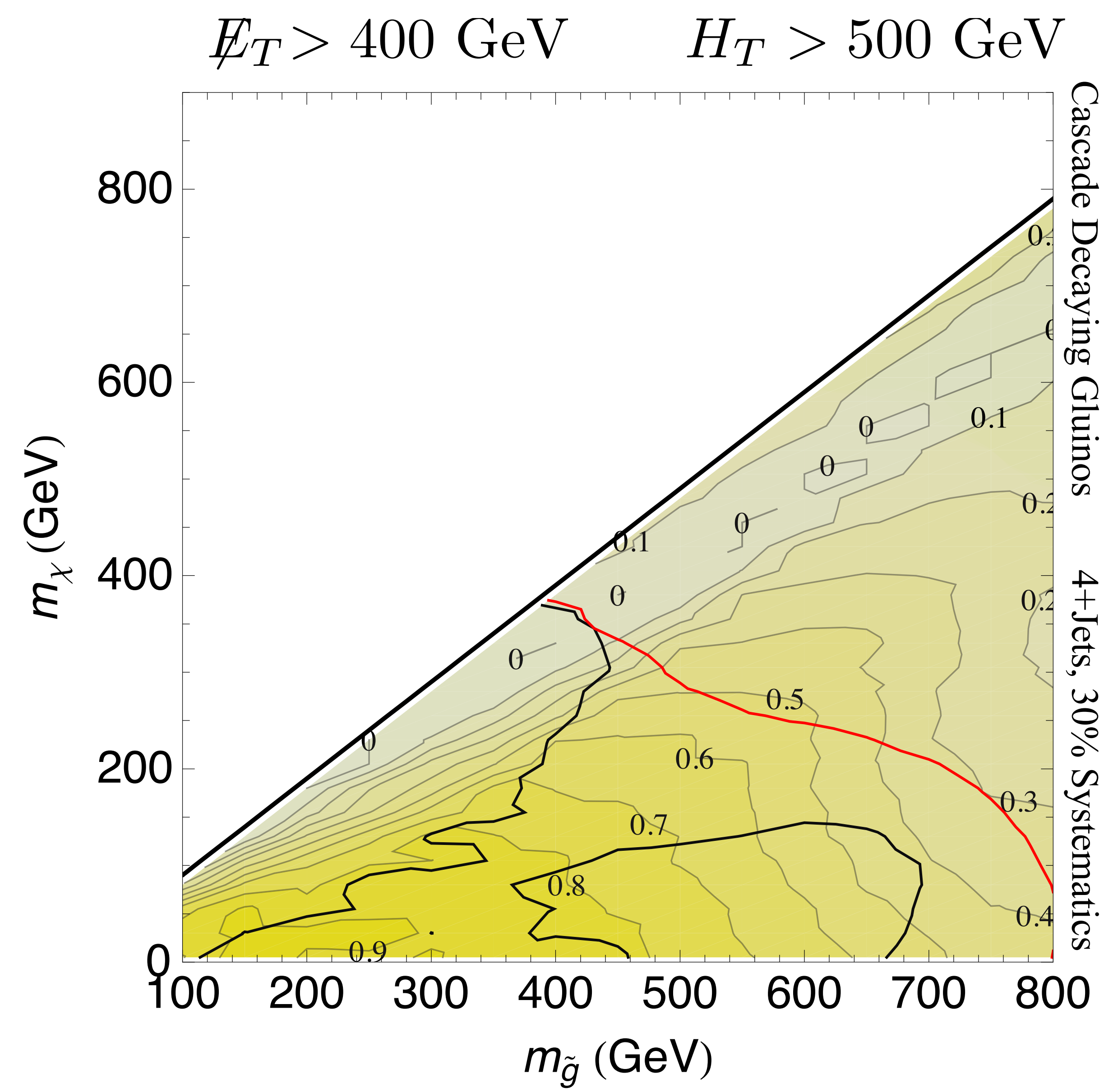
Effects of Matching On Optimized Searches



Cascade Decays Lower MET



High H_T



Low H_T

A lot of the best MSSM parameter space will be tested in within 12 months!

Future Work

Understanding Fractional MET Cut

Seems to be suboptimal for many situations

Not used at the Tevatron

Multiple Cascade Decays

Can further reduce MET and increase HT

How bad is it and how to recover reach

b-tagging & anti-b-tagging

Heavy flavor can appear in final states

Top is a big background at moderate MET,
w/o heavy flavor final states, anti-b-tagging may help

Lots more coming...

Already have lepton searches

ATLAS NOTE

ATLAS-CONF-2010-066

July 20, 2010

Early supersymmetry searches with jets, missing transverse momentum and one or more leptons with the ATLAS Detector

We could have already had anomalies from new physics

Just crossed 1 pb^{-1}, 15 times more data than these analyses!

1-10 pb^{-1} releases in Fall??

Each new search has potential for discovery