Opening Up Jets and Missing Energy Searches

(at the Tevatron)

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Work in progress with

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Outline

- Introduction

Generalized Gluinos

Matching

Backgrounds

Projected Reach

Outlook

High Energy Frontier

No “sure thing” theory to discover

Tevatron, Flavor, Precision EW, Higgs

LHC may not burst into a superfire

Many BSM possibilities to search for

Supersymmetric Standard Model

Universal Extra Dimensions

Randall-Sundrum

Little Higgs

Different TeV scale physics, but similar signals

Inverse problem hard

Discovery first

Jets plus Missing Energy

A common signature

New Colored Particle Decays to WIMP

Existing searches based upon MSSM

$\tilde{q}\tilde{q}$ $\tilde{g}\tilde{g}$ $\tilde{q}\tilde{g}$

Very general template to start from

Can find SSM, UED, RS/LH w/ T-parity

Jets + Missing Energy Cuts at D0

1fb^{-1} analysis

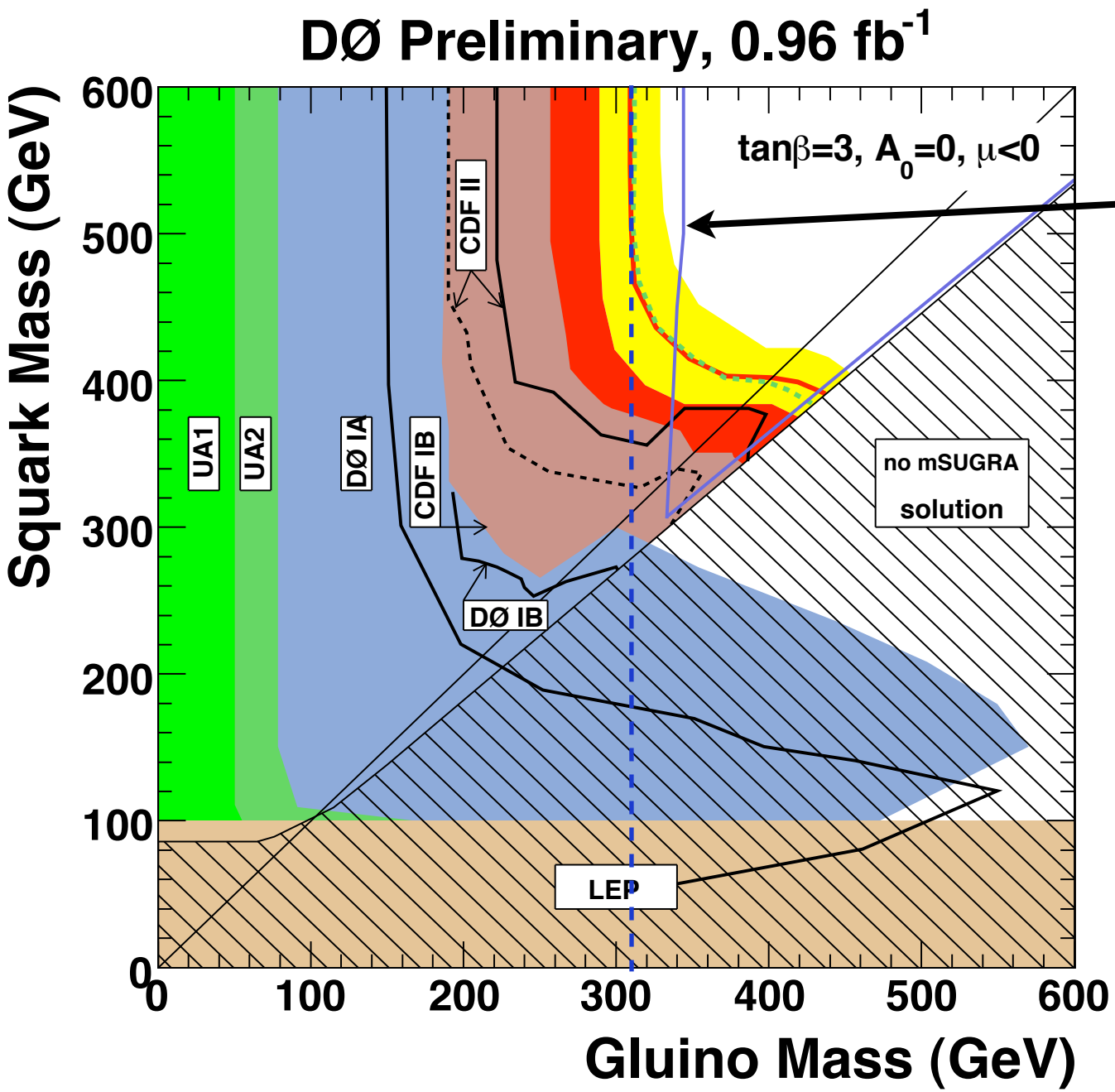
	Gg	$\tilde{q}\tilde{q}$	$\tilde{q}\tilde{g}$	$\tilde{g}\tilde{g}$
	$1j + \not{E}_T$	$2j + \not{E}_T$	$3j + \not{E}_T$	$4j + \not{E}_T$
$E_{T\,j_1}$	≥ 150	≥ 35	≥ 35	≥ 35
$E_{T\,j_2}$	< 35	≥ 35	≥ 35	≥ 35
$E_{T\,j_3}$			≥ 35	≥ 35
$E_{T\,j_4}$				≥ 20
$\not{E}_T$	≥ 150	≥ 225	≥ 150	≥ 100
H_T	≥ 150	≥ 300	≥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

(Not exclusive searches)

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

Will these discover anything visible in these channels?

What we know about gluino limits



Slepton & Chargino limits

mSugra is not representative of the MSSM

$$m_{\tilde{g}} : m_{\tilde{B}} = 6 : 1$$

Anomaly Mediation

Mirage Mediation

non-Minimal Gauge Mediation

Never varies decay kinematics

Are there visible signals that are not being analyzed?

Possible because the background is challenging

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Examining $\tilde{g}\tilde{g}$ more carefully

The "gluino" module

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

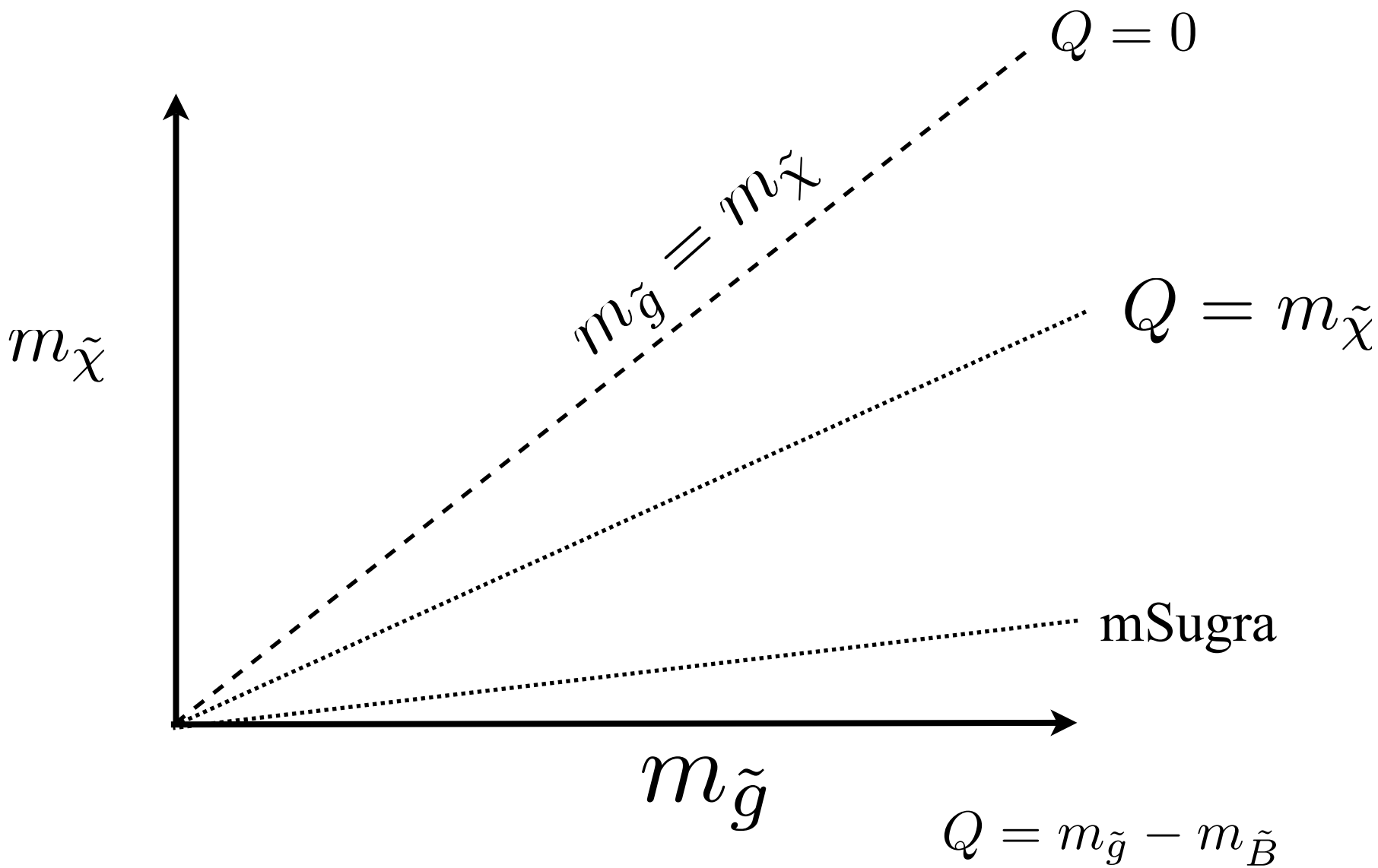
Keep masses and total cross section free

$m_{\tilde{g}}$ $m_{\tilde{\chi}}$ $\sigma(p\bar{p} \rightarrow \tilde{g}\tilde{g}X)$

Captures many models (MSSM, UED, etc)

Misses heavy flavor and cascades

Where has the Tevatron probed “gluinos”?



Two Kinematic Limits

"Normal" Widely Spaced States

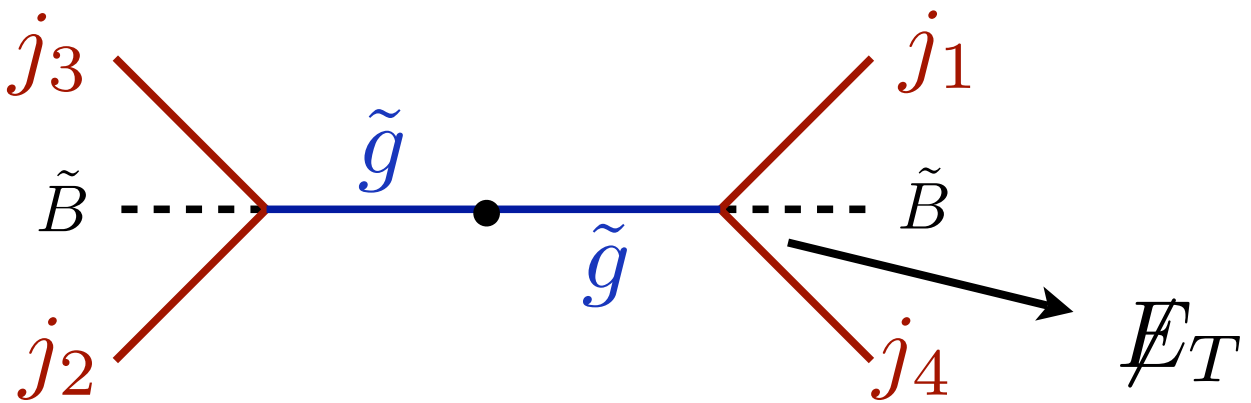
$$m_{\tilde{g}} \gg m_{\tilde{\chi}}$$

Same multijet searches over the past 20+ years

No cascades, or t-channel squarks

Easy to simulate

Degenerate Search



Useful when not phase space limited $Q = m_{\tilde{g}} - m_{\tilde{B}} > m_{\tilde{B}}$

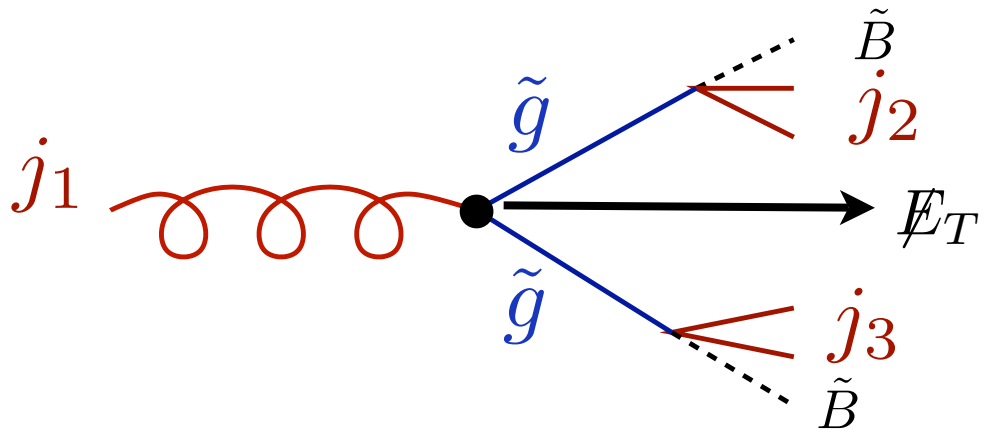
If $Q < m_{\tilde{B}}$

Bino carries away energy but not momentum

As gluinos get boosted, jets become collinear and $\not{E}_T$ aligned with jets

$$\Delta\Phi^{j\,\not{E}_T} \sim \frac{1}{\gamma_{\tilde{g}}}$$

Producing Degenerate Gluinos



Need additional hard jets

Want the spectrum as well

CDF

$P_T^{j1} > 150$ GeV

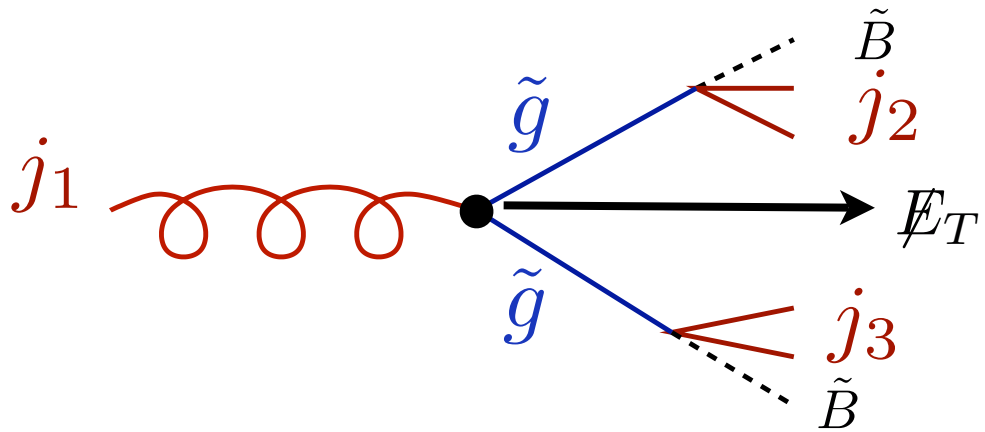
$P_T^{j2} < 60$ GeV

$P_T^{j3} < 20$ GeV

$\not{E}_T > 120$ GeV

$\Delta\Phi^{j2\not{E}_T} > 0.3$

Producing Degenerate Gluinos



Need additional hard jets

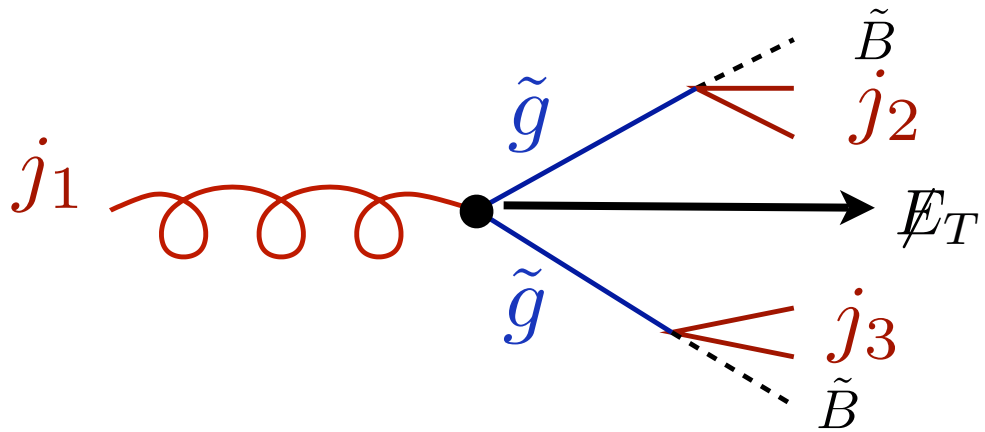
Want the spectrum as well

D0

$P_T^{j1} > 150$ GeV $\quad\quad \not{E}_T > 150$ GeV

$P_T^{j2} < 50$ GeV $\quad\quad \Delta\Phi^{j\not{E}_T} > 30^\circ$

Producing Degenerate Gluinos



Need additional hard jets

Want the spectrum as well

D0

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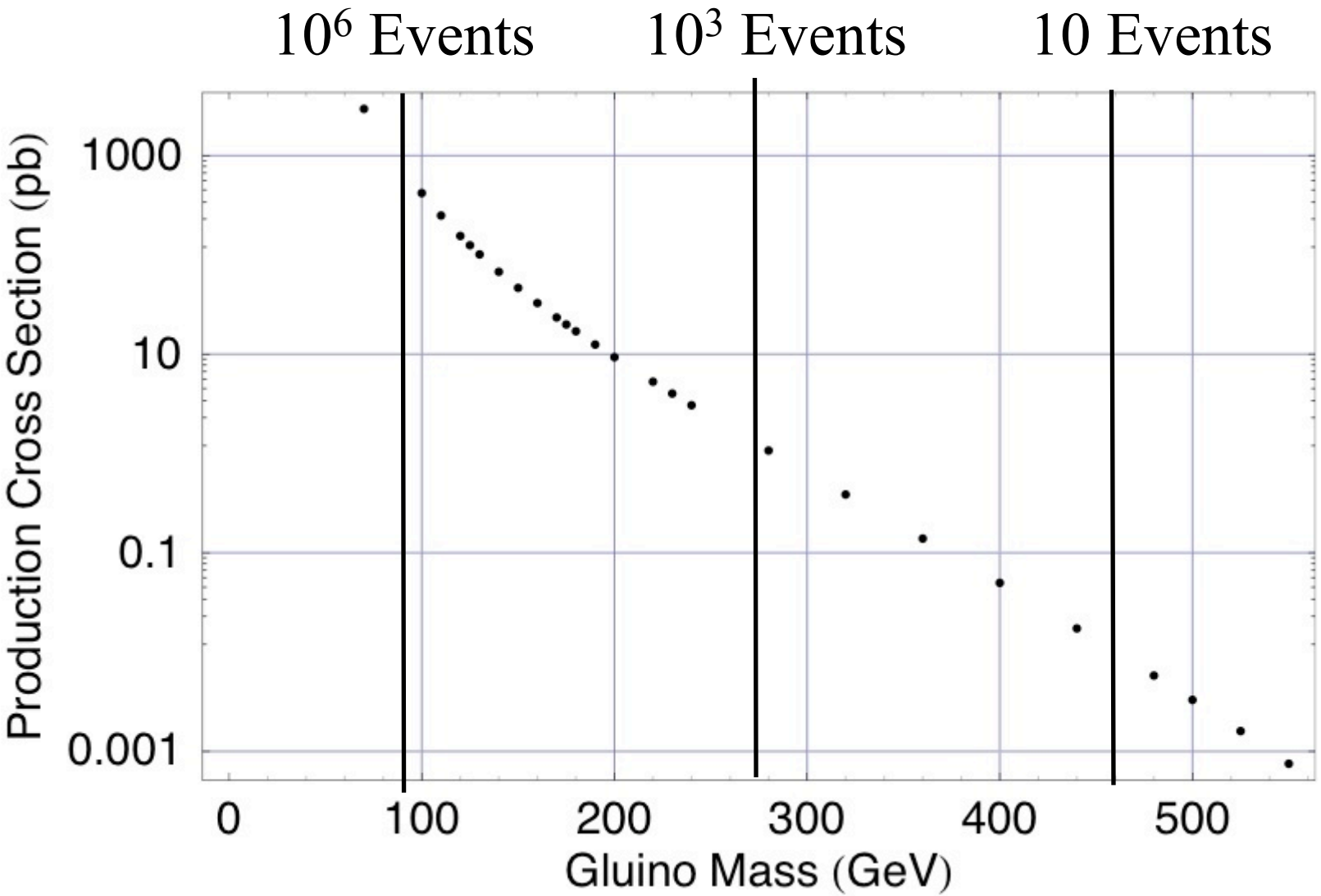
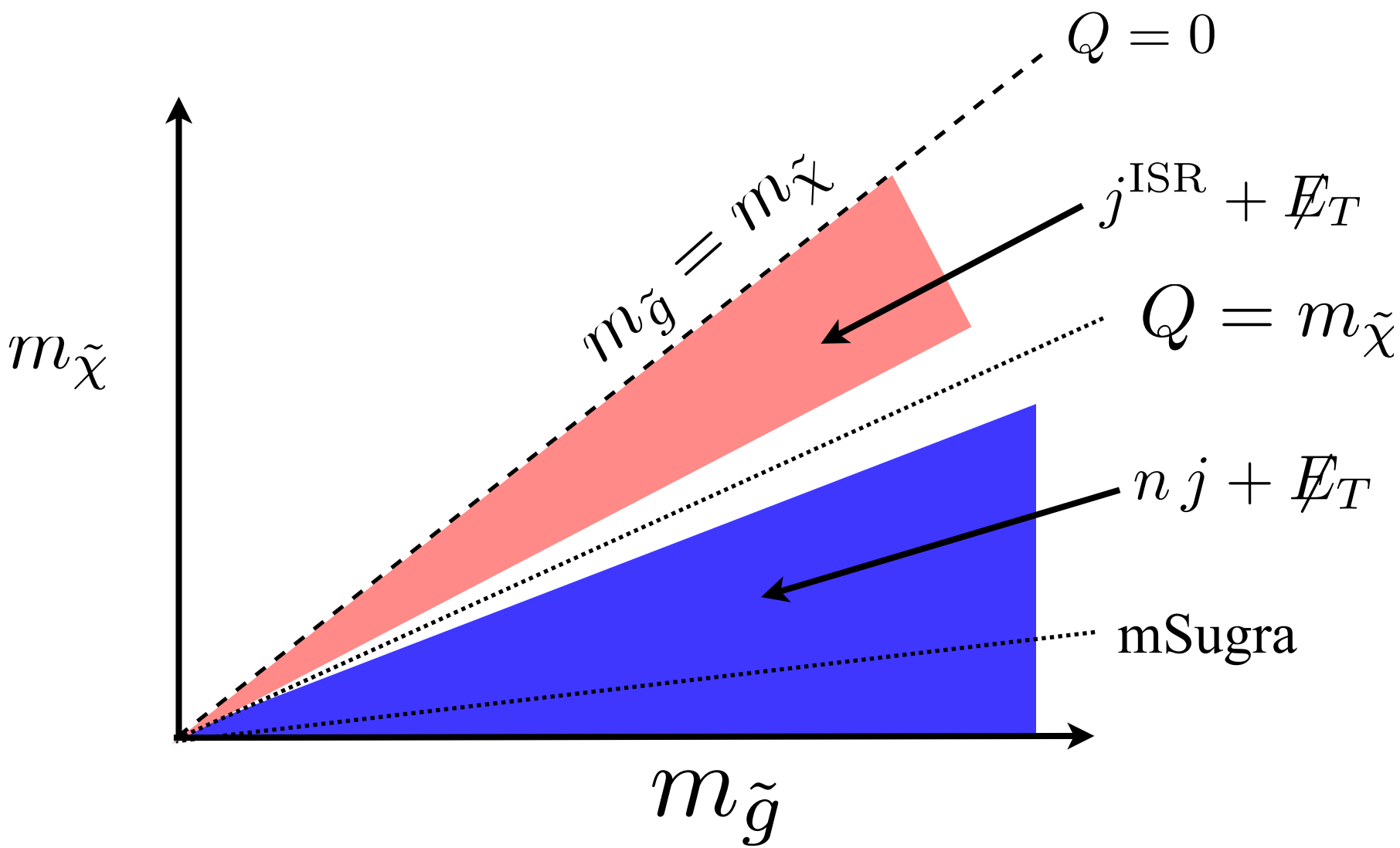
$P_T^{j2} < 50$ GeV $\quad\quad \Delta\Phi^{j\not{E}_T} > 30^\circ$

Gluinos are produced copiously



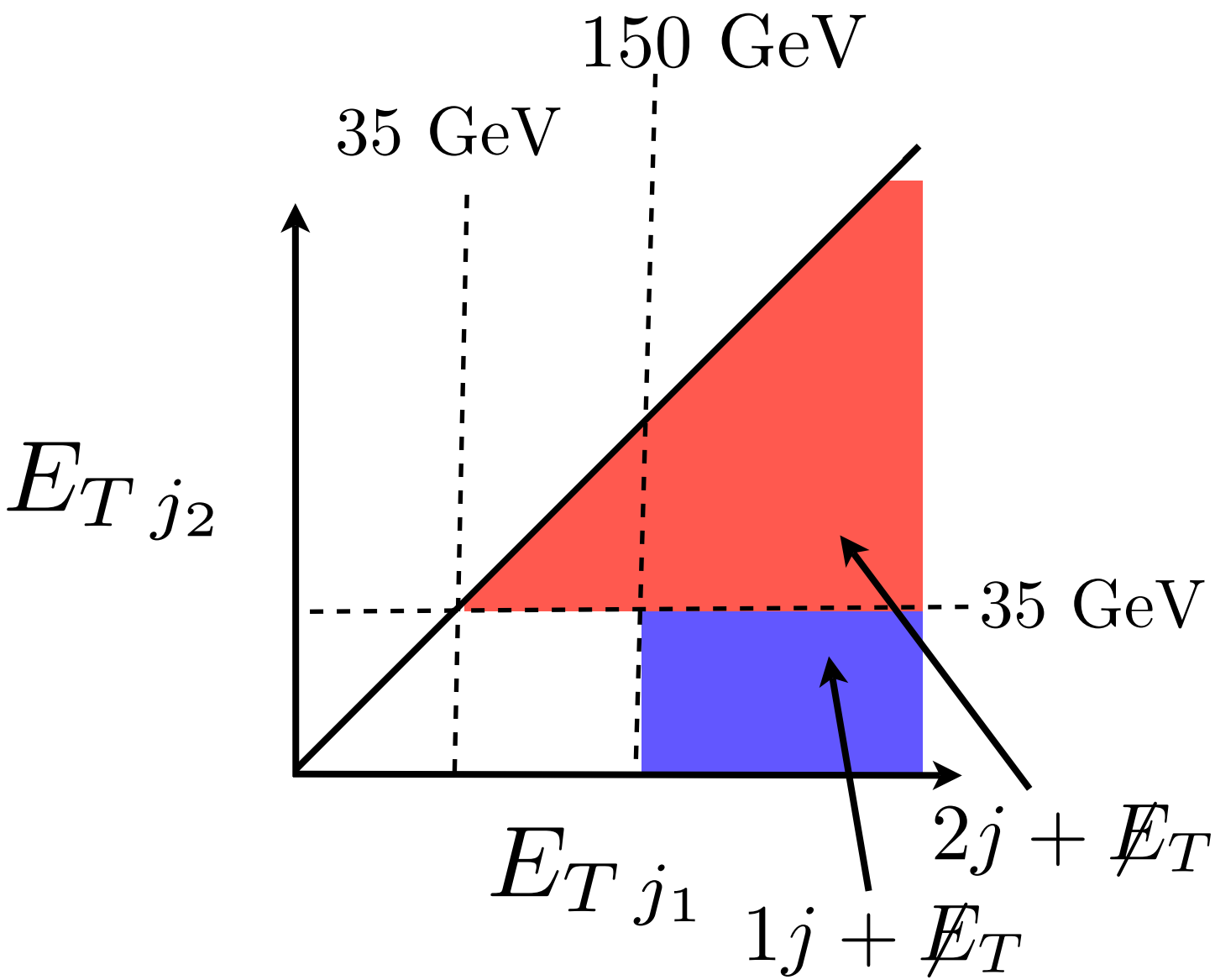
Searches useful in gluino searches



Transitions

Fix $m_{\tilde{g}}$ 100 GeV

Vary m_{χ^0} 90 GeV $\rightarrow$ 0



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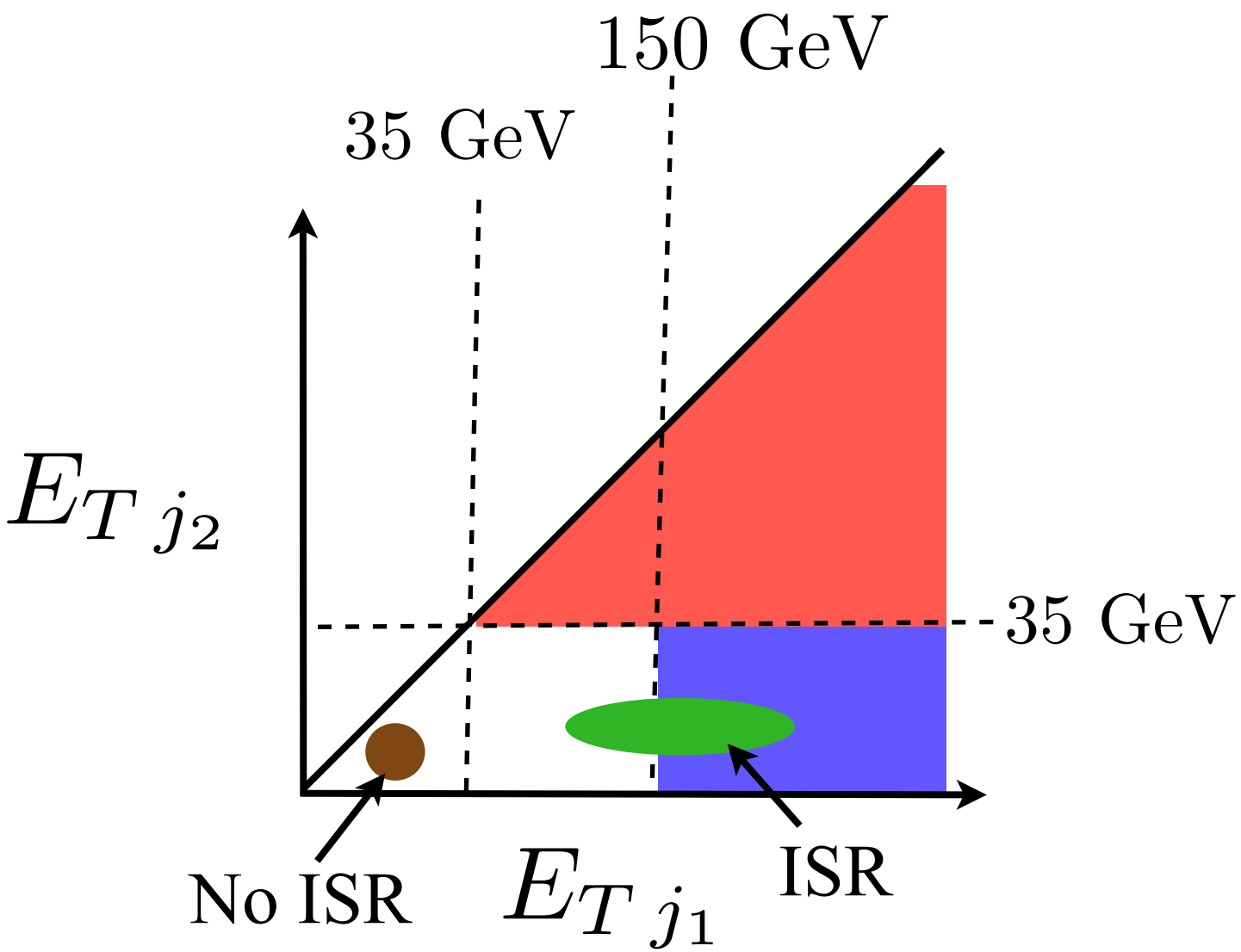

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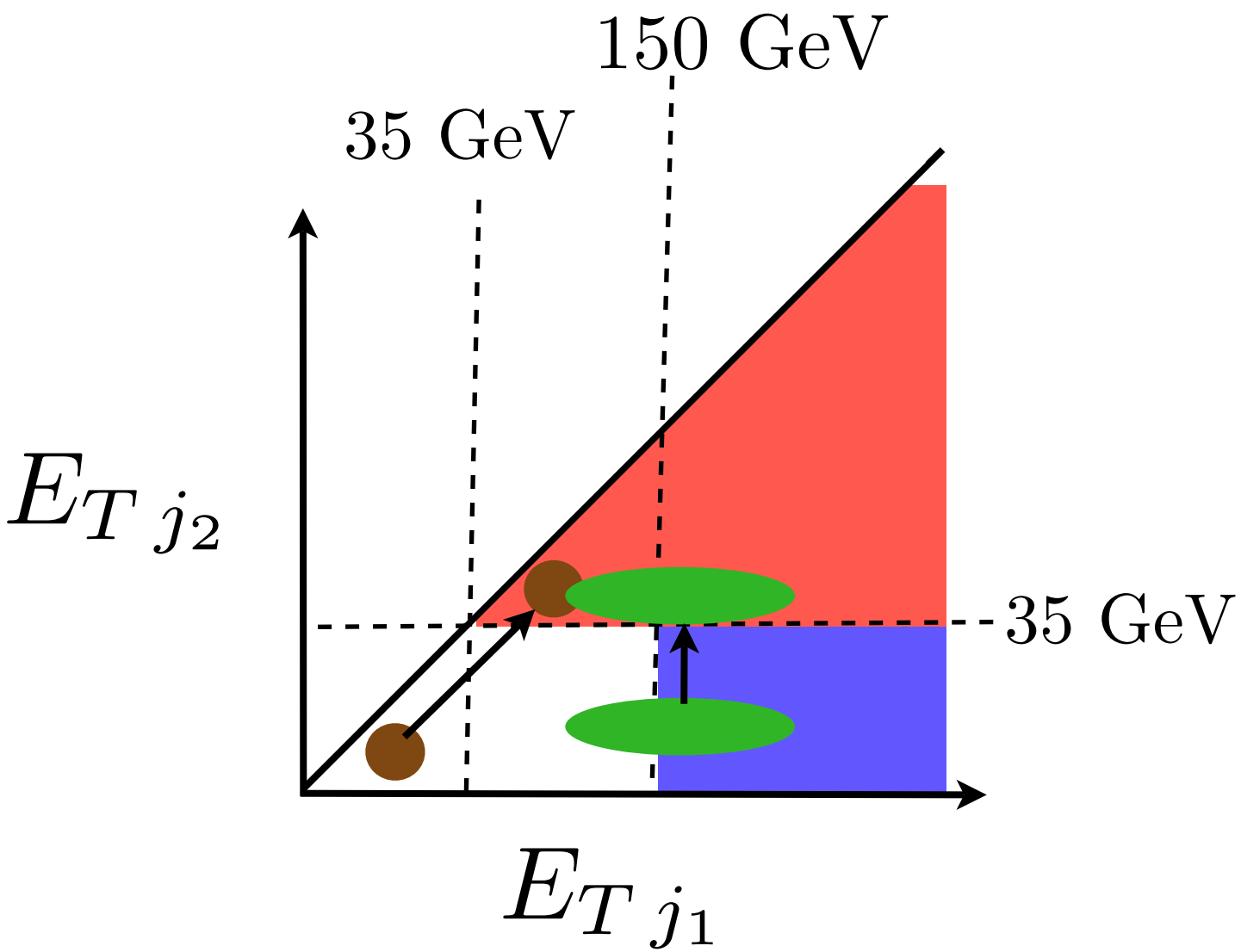

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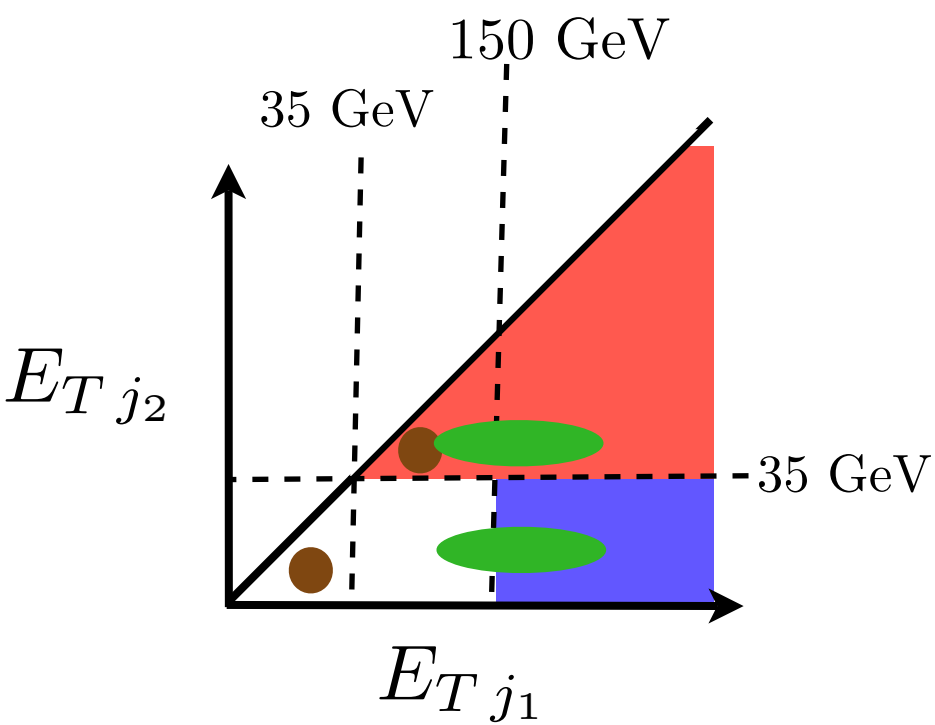

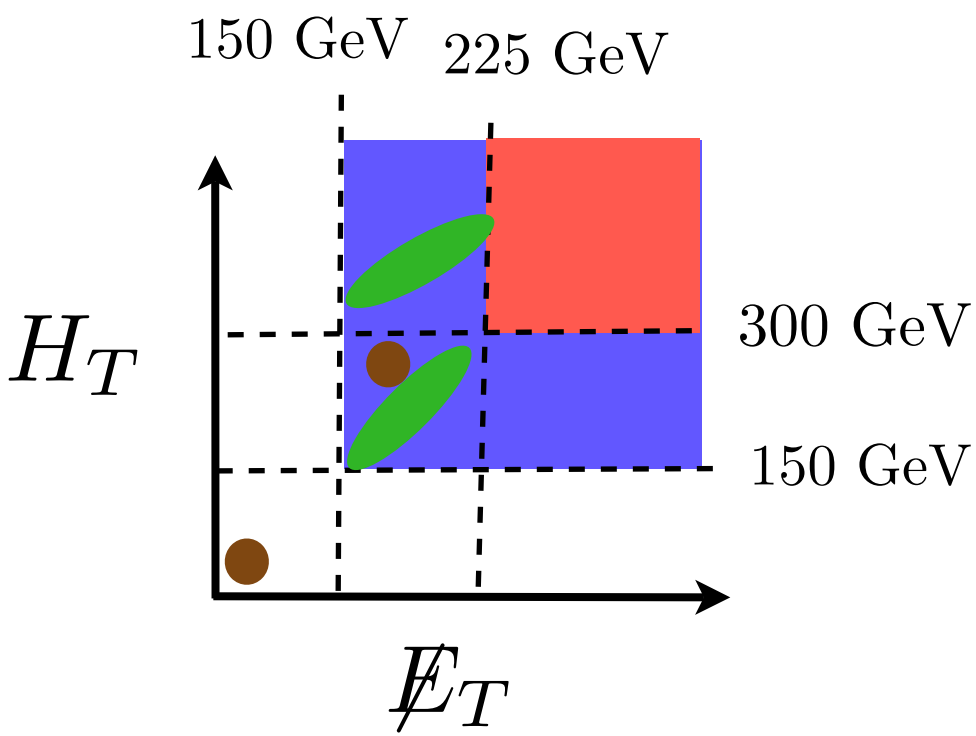

Reduced efficiency as neutralino mass is decreased

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Calculating Additional Jets

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

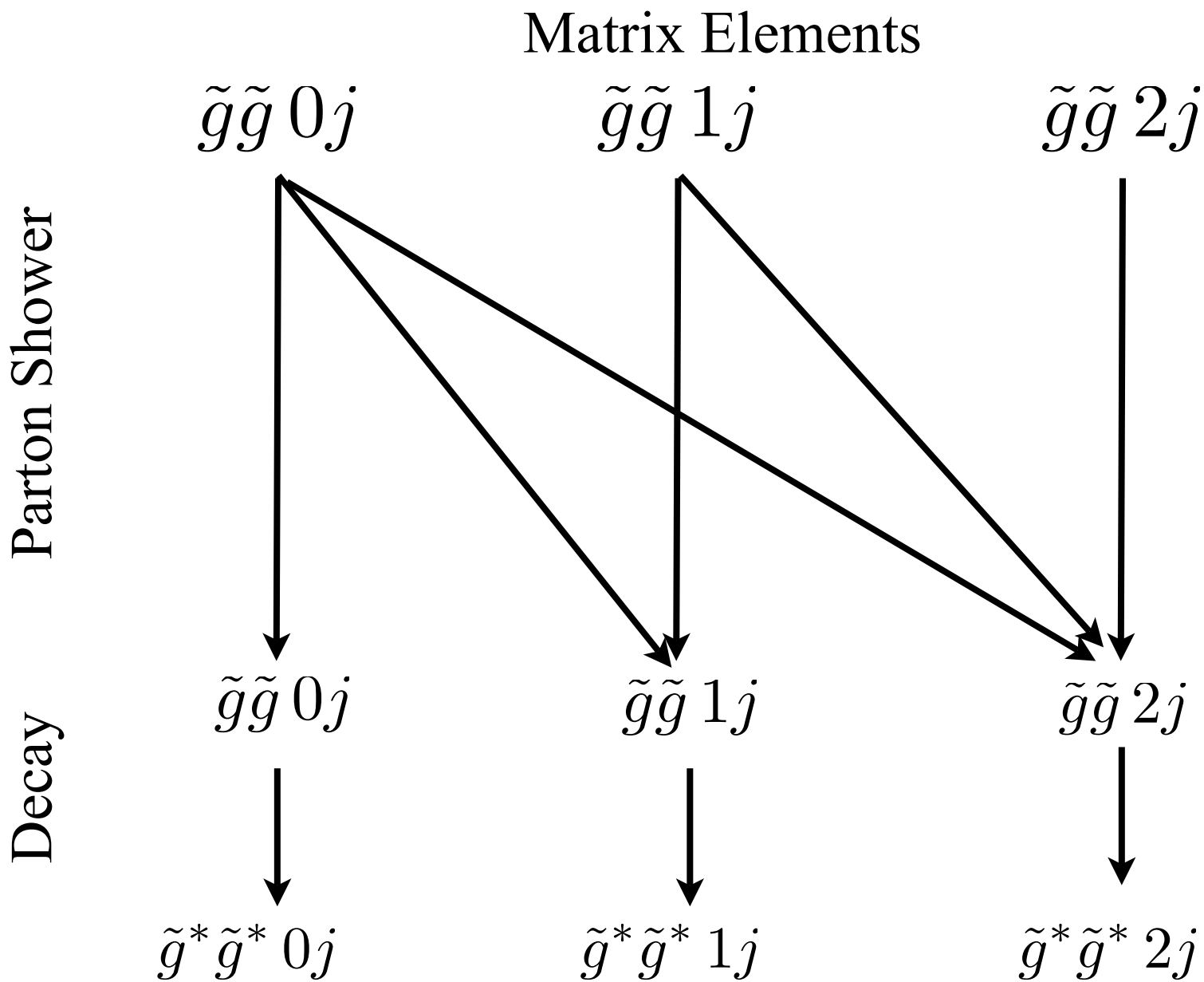
Computationally expensive

Limited number of partons

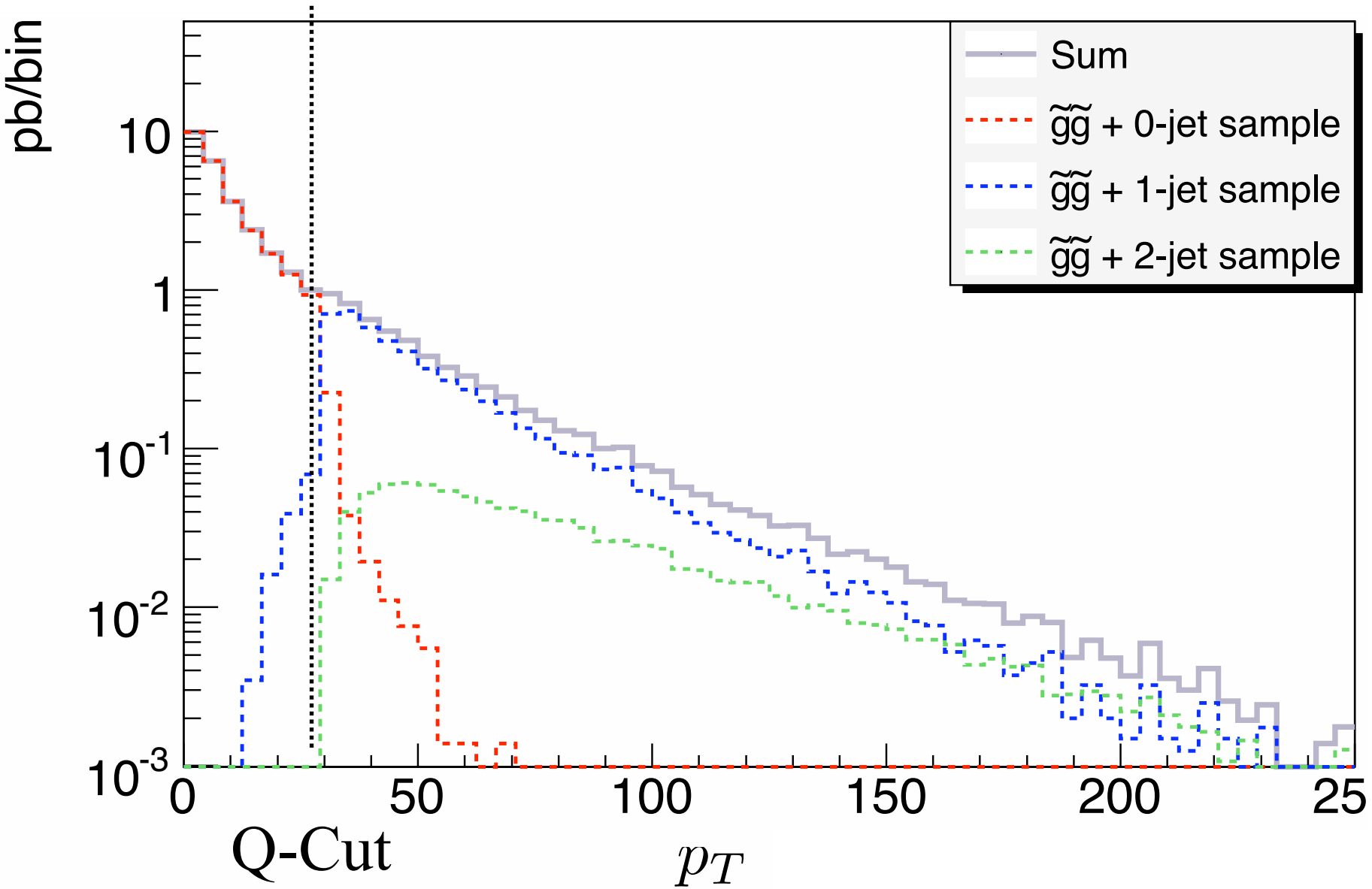
Matching merges best of both worlds

Necessary to avoid double counting

Calculating Additional Jets



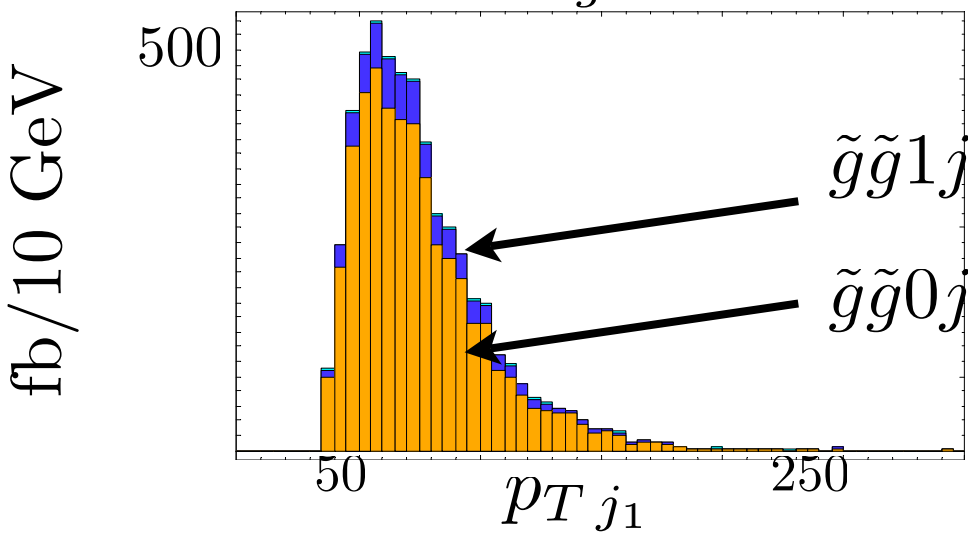
Transition from PS to ME



Effects of Matching on Signal

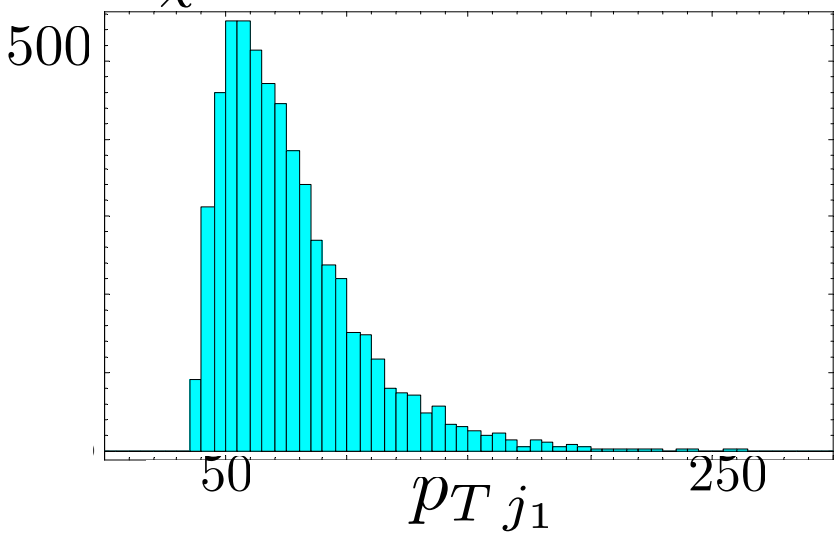
Matched

$m_{\tilde{g}} = 150$ GeV

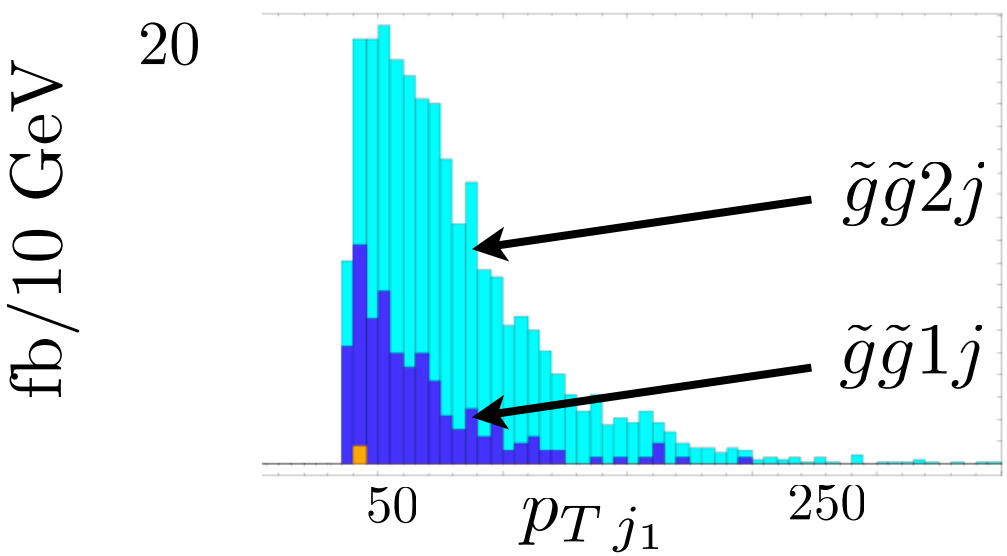


Parton Shower Only

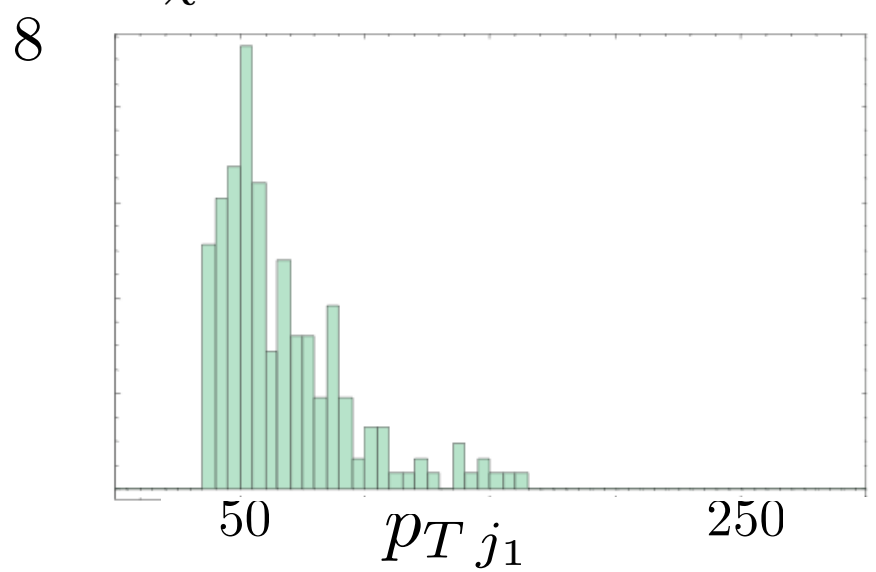
$m_{\tilde{\chi}} = 40$ GeV



$m_{\tilde{g}} = 150$ GeV



$m_{\tilde{\chi}} = 130$ GeV



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Backgrounds

Want to vary cuts to maximize discovery potential

Generate SM events and compare to D0

Madgraph $\longrightarrow$ Pythia $\longrightarrow$ PGS

Backgrounds

Want to vary cuts to maximize discovery potential

Generate SM events and compare to D0

Madgraph $\longrightarrow$ Pythia $\longrightarrow$ PGS

Three Dominant Backgrounds

W/Z + jets

t tbar

QCD

Subdominant Backgrounds

Diboson

Single top

W/Z + jets Backgrounds

Hit Z+jets to within QCD K-factors

W+jets need a ~30% MET-independent scaling

probably PGS efficiency at losing a lepton

W/Z + jets Backgrounds

Hit Z+jets to within QCD K-factors

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Top Background

Need MET-dependent K-factor

...until matching 2 additional jets

$$t\bar{t}\,2j \rightarrow (b\ell\nu)\ (\bar{b}\ell\nu)\ \ 2j$$

W/Z + jets Backgrounds

Hit Z+jets to within QCD K-factors

W+jets need a ~30% MET-independent scaling

probably PGS efficiency at losing a lepton

Top Background

Need MET-dependent K-factor

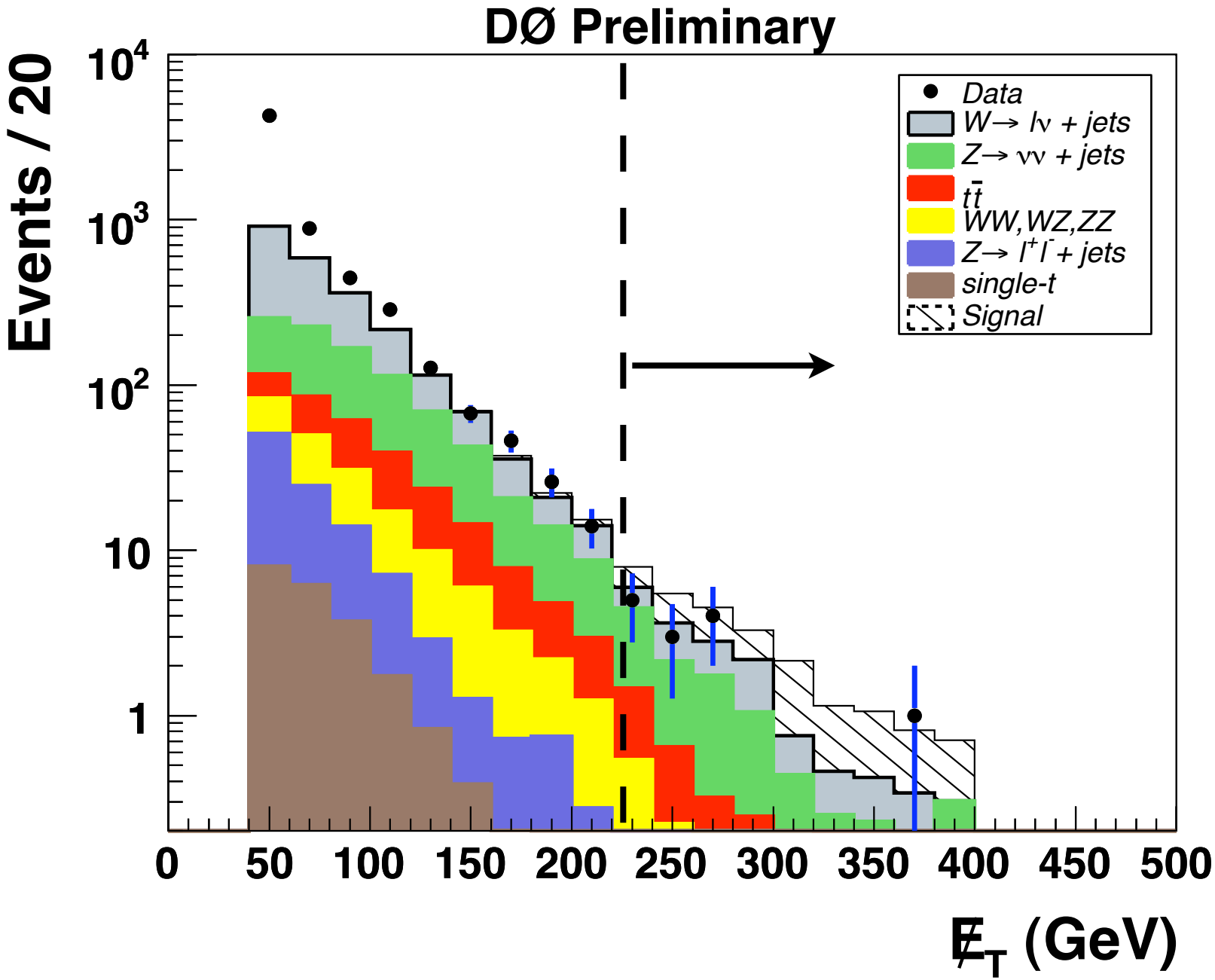
...until matching 2 additional jets

$$t\bar{t}\,2j \rightarrow (b\ell\nu)\ (\bar{b}\ell\nu)\ \ 2j$$

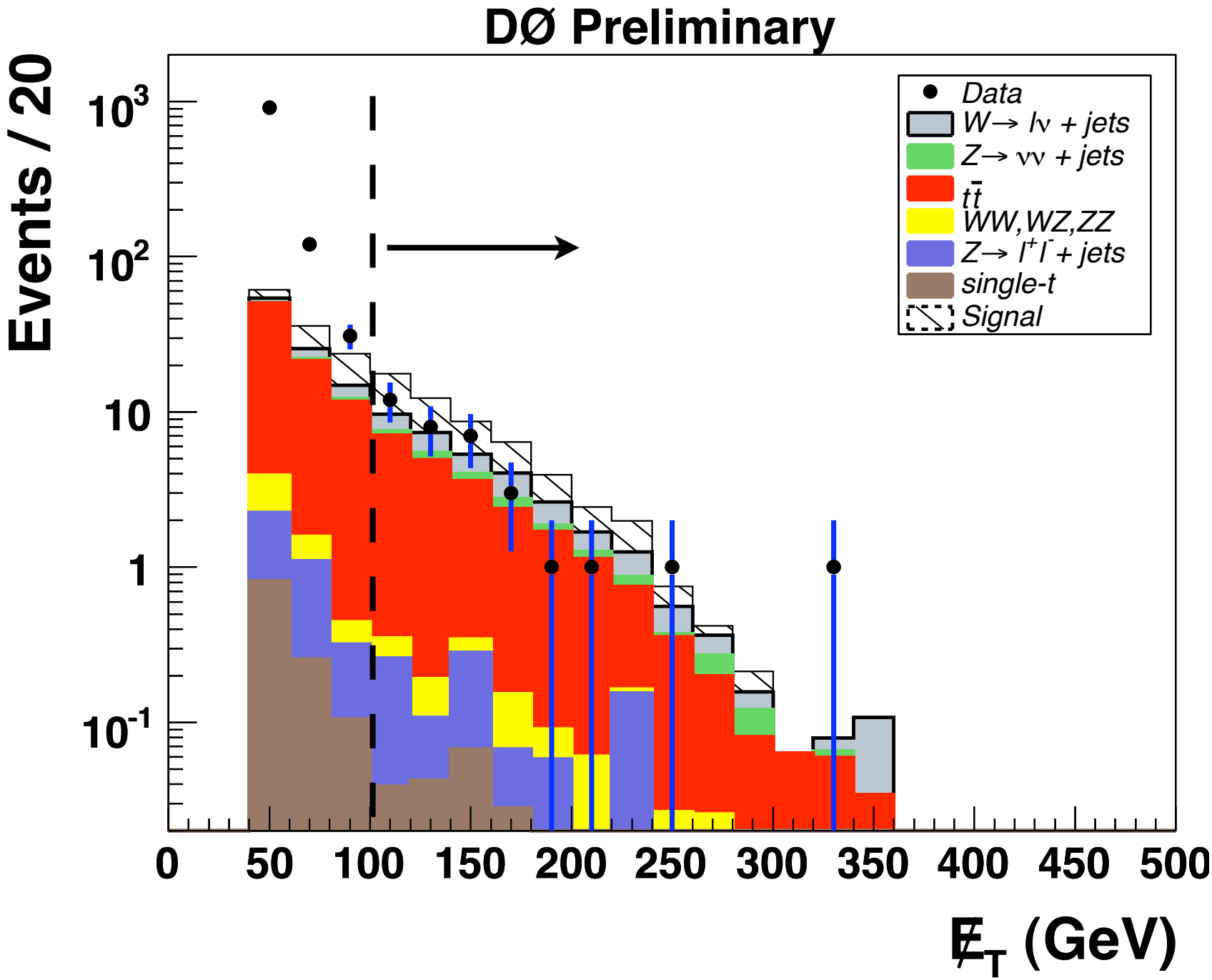
QCD Background

No attempt to simulate $\not{E}_T > 100$ GeV

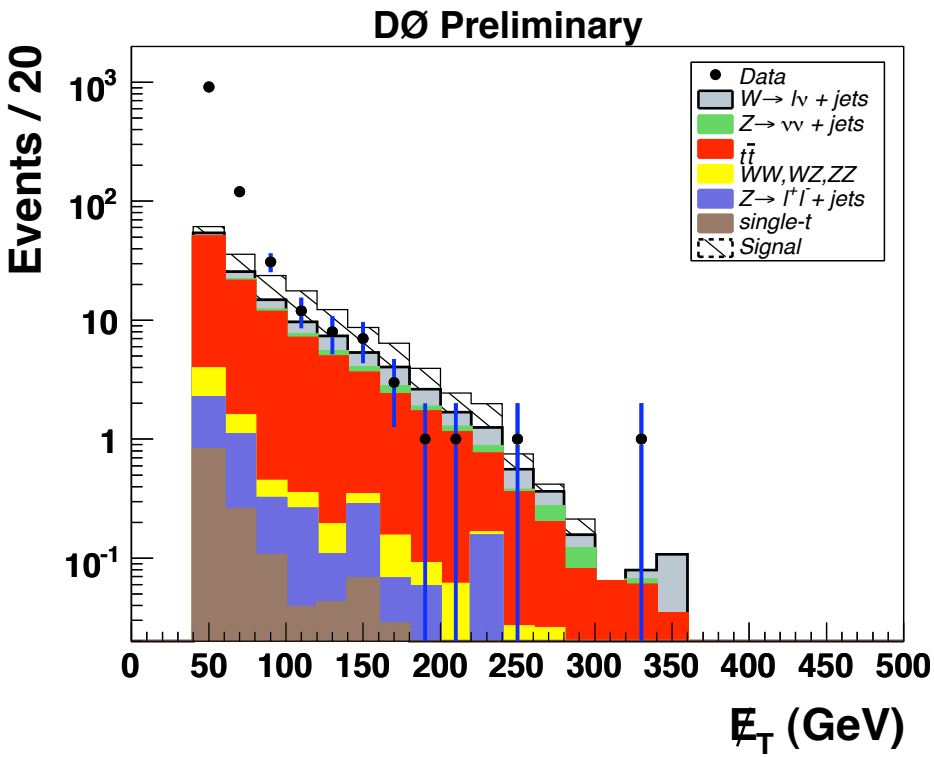
2 jet analysis Before H_T $\not\!\!E_T$ cuts

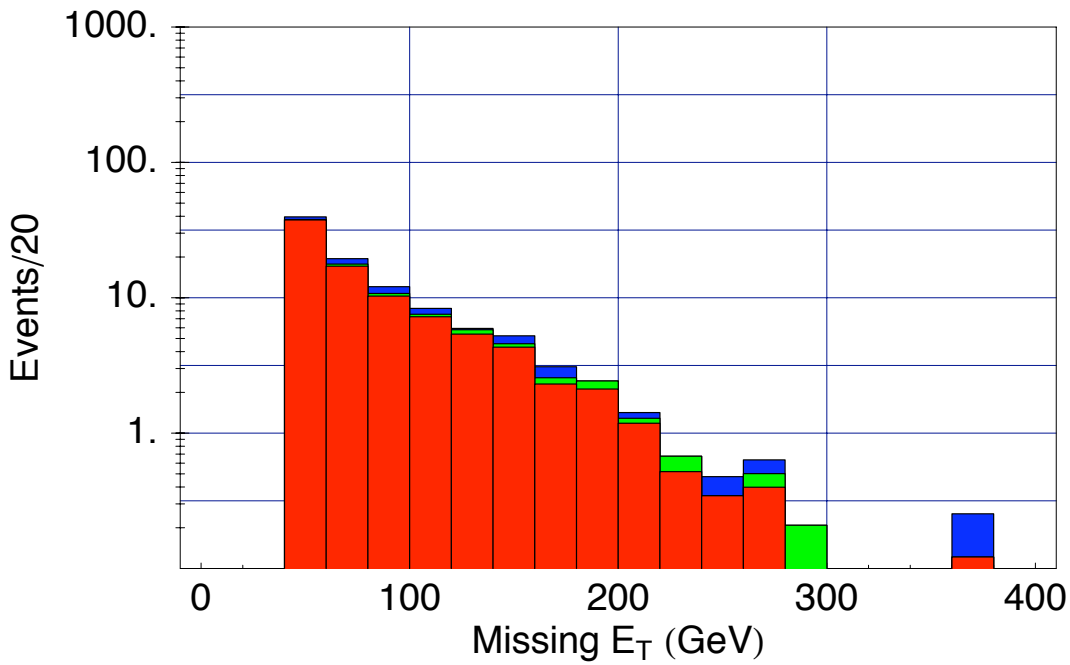


4 jet analysis Before $\not\!\!E_T$ cuts



A quick comparison





But how much do we trust this? 30%??

Need to be aware of S/B for counting experiments

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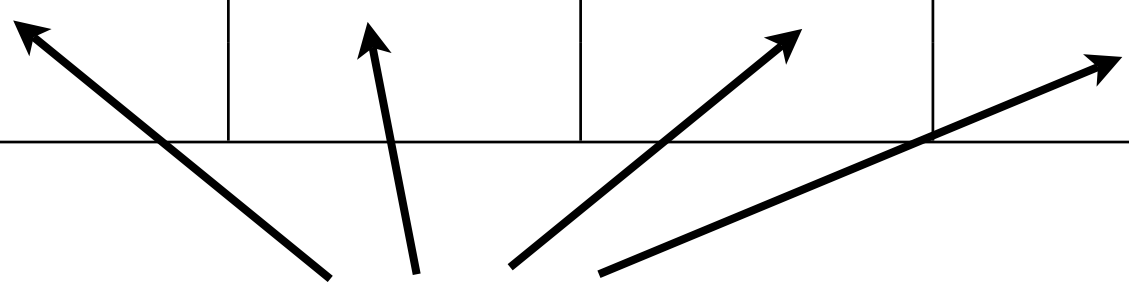
Exclusive Jets + MET Search

4 Separate Searches, Individually Optimized

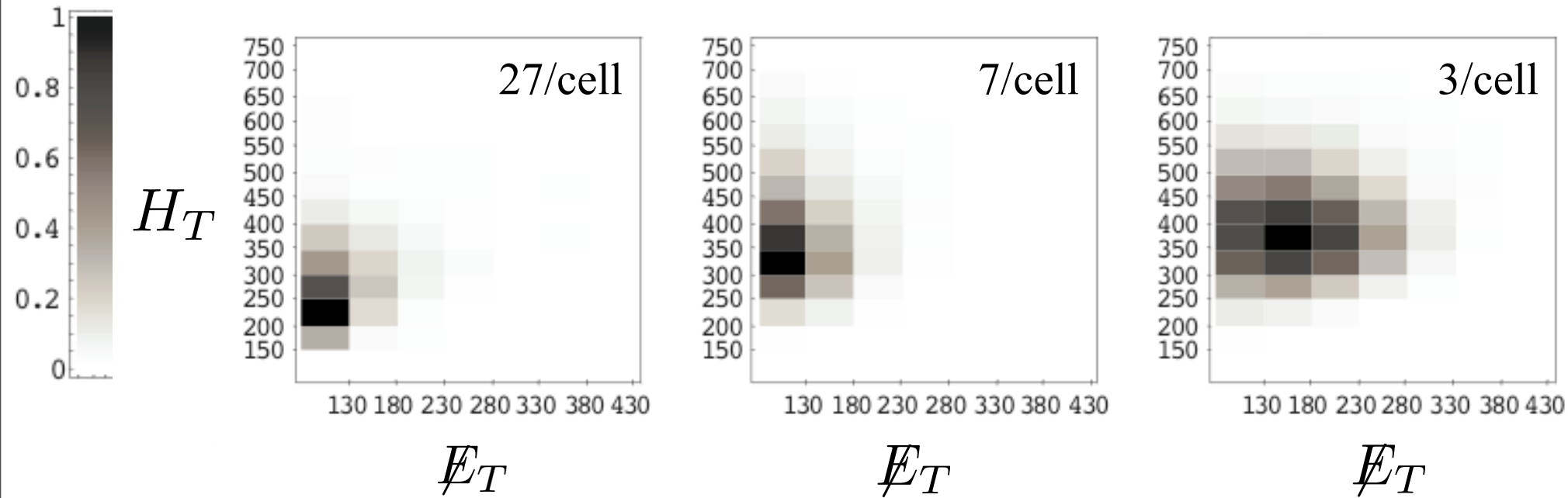
	$1j + \not{E}_T$	$2j + \not{E}_T$	$3j + \not{E}_T$	$4j + \not{E}_T$
$E_{T\,j_1}$	≥ 150	≥ 35	≥ 35	≥ 35
$E_{T\,j_2}$	< 35	≥ 35	≥ 35	≥ 35
$E_{T\,j_3}$	< 35	< 35	≥ 35	≥ 35
$E_{T\,j_4}$	< 20	< 20	< 20	≥ 20
$\not{E}_T$				
H_T				



Maximize significance for each $m_{\tilde{g}}, m_{\tilde{\chi}}$

4^{+}Jets Search

Standard Model 360, 60 (mSugra) 360, 60



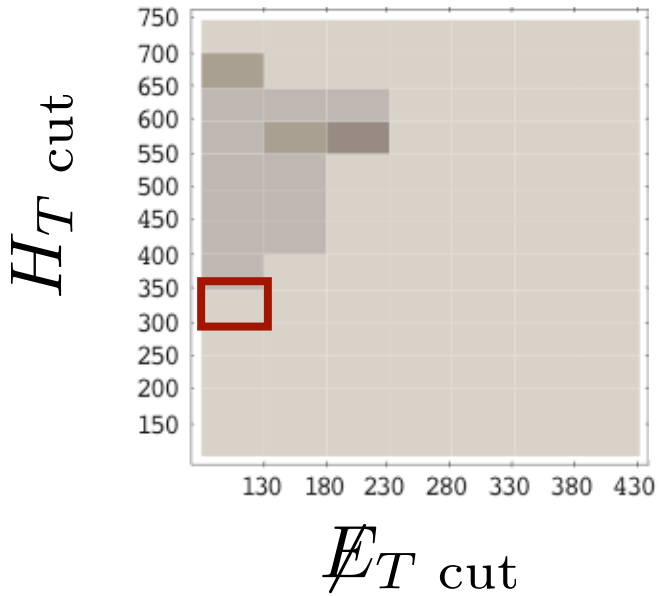
Cascade decays turn missing energy to visible energy

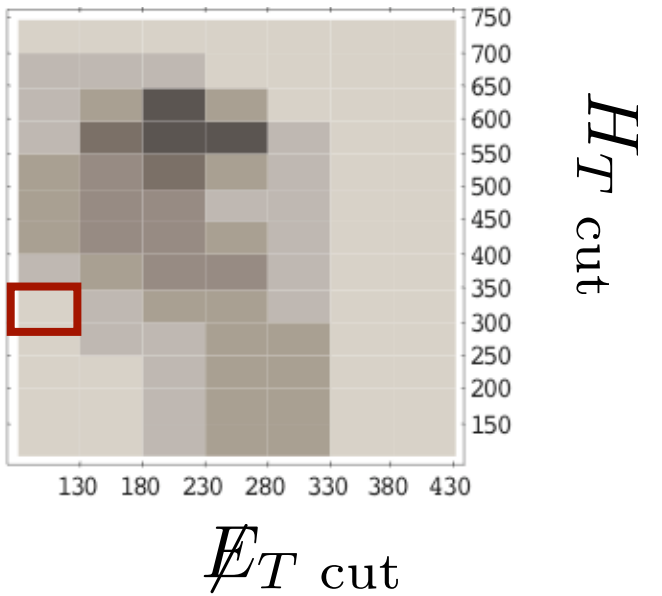
Significantly degrade search

360,60 mSugra

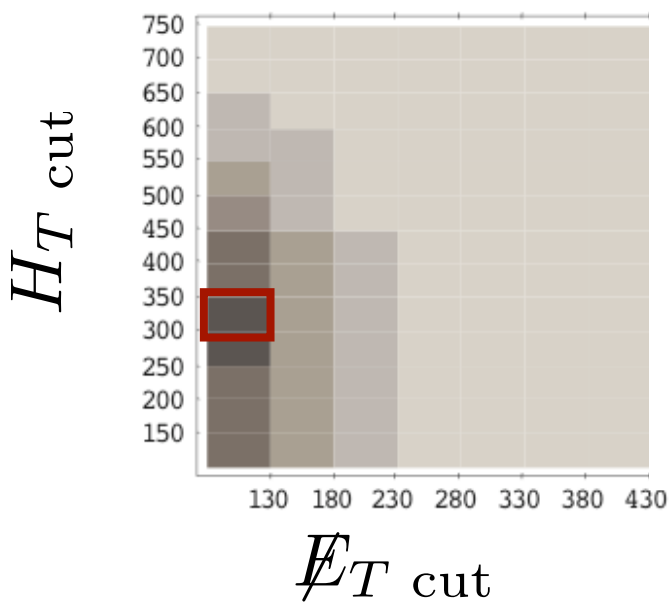
360,60

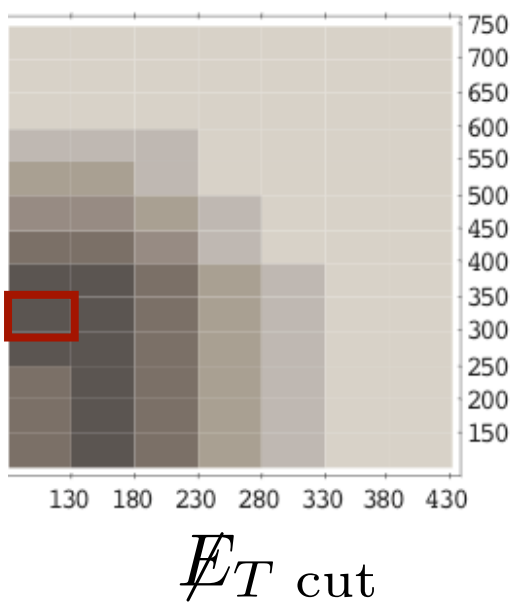
S/B

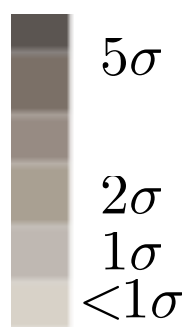




$S/\sqrt{B}$



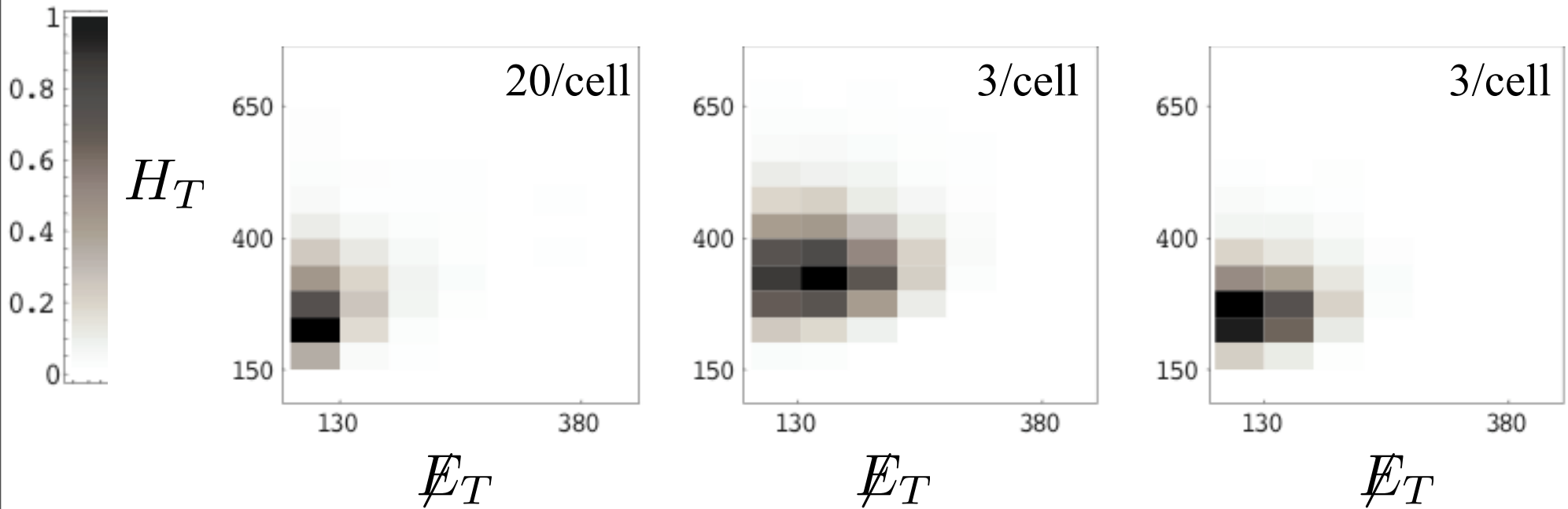




At the Boundary of Visibility

Accentuates the difference

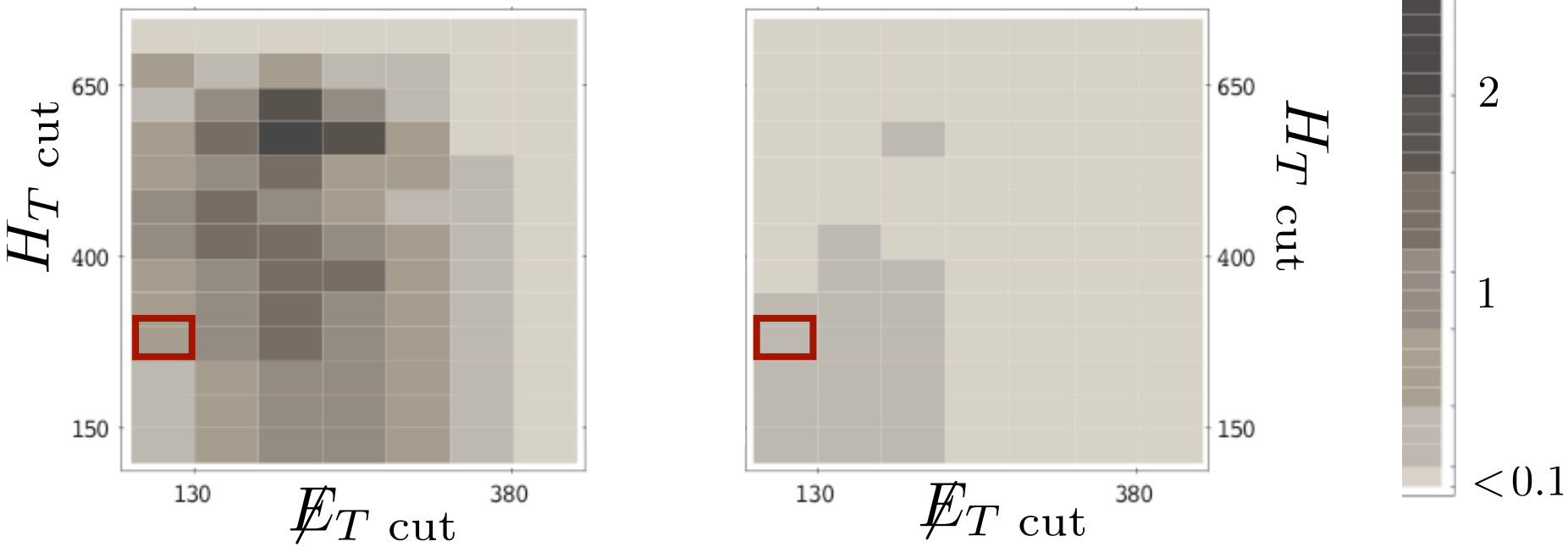
Standard Model 360,120 360, 200



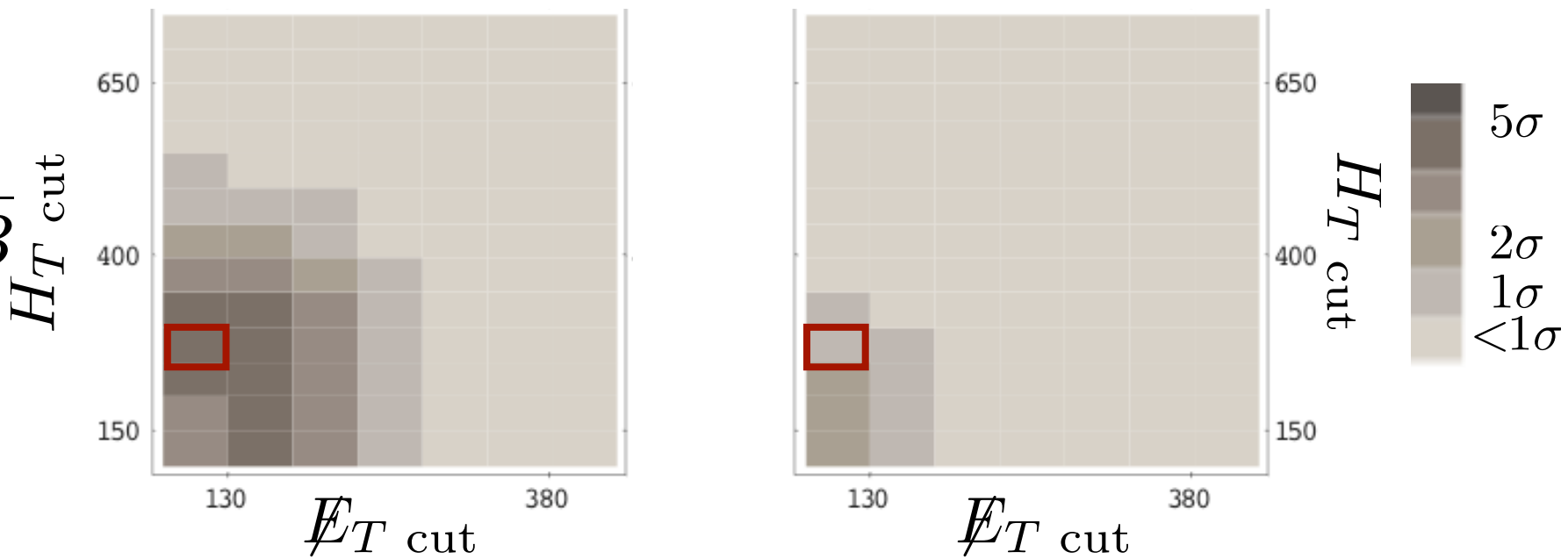
360,120

360, 200

S/B

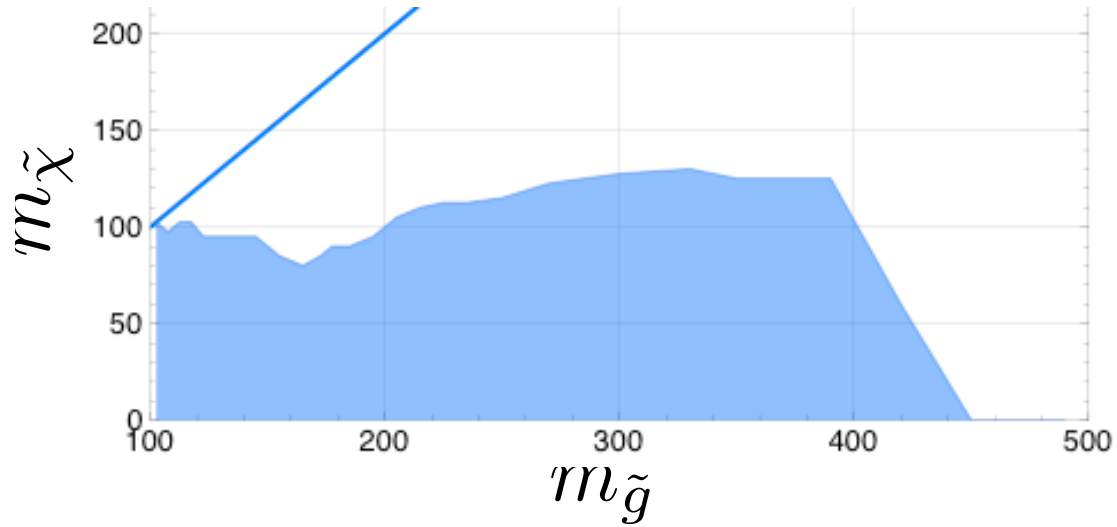


$S/\sqrt{B}$



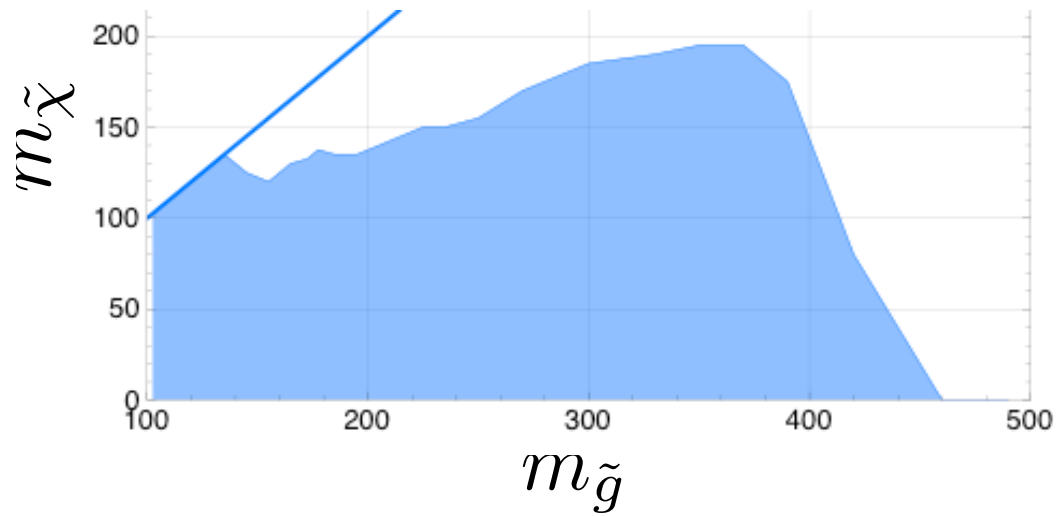
Multijet Searches

S/B>1



Harder cuts than D0

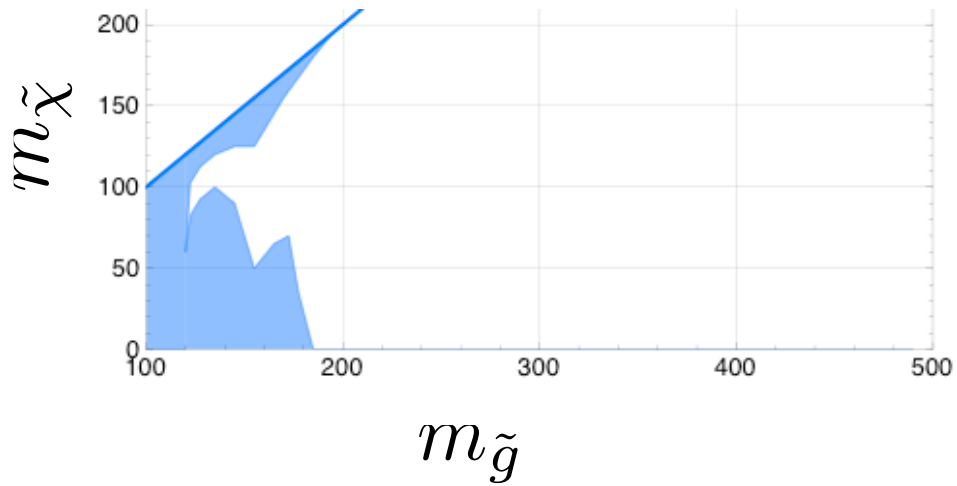
S/B>0.1



Looser cuts than D0

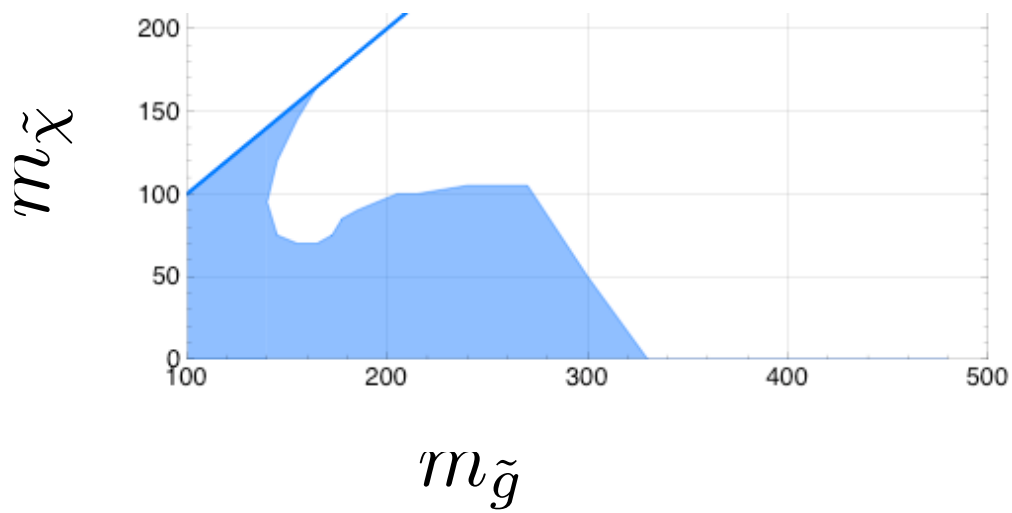
The Degenerate Region

Monojet S/B>1



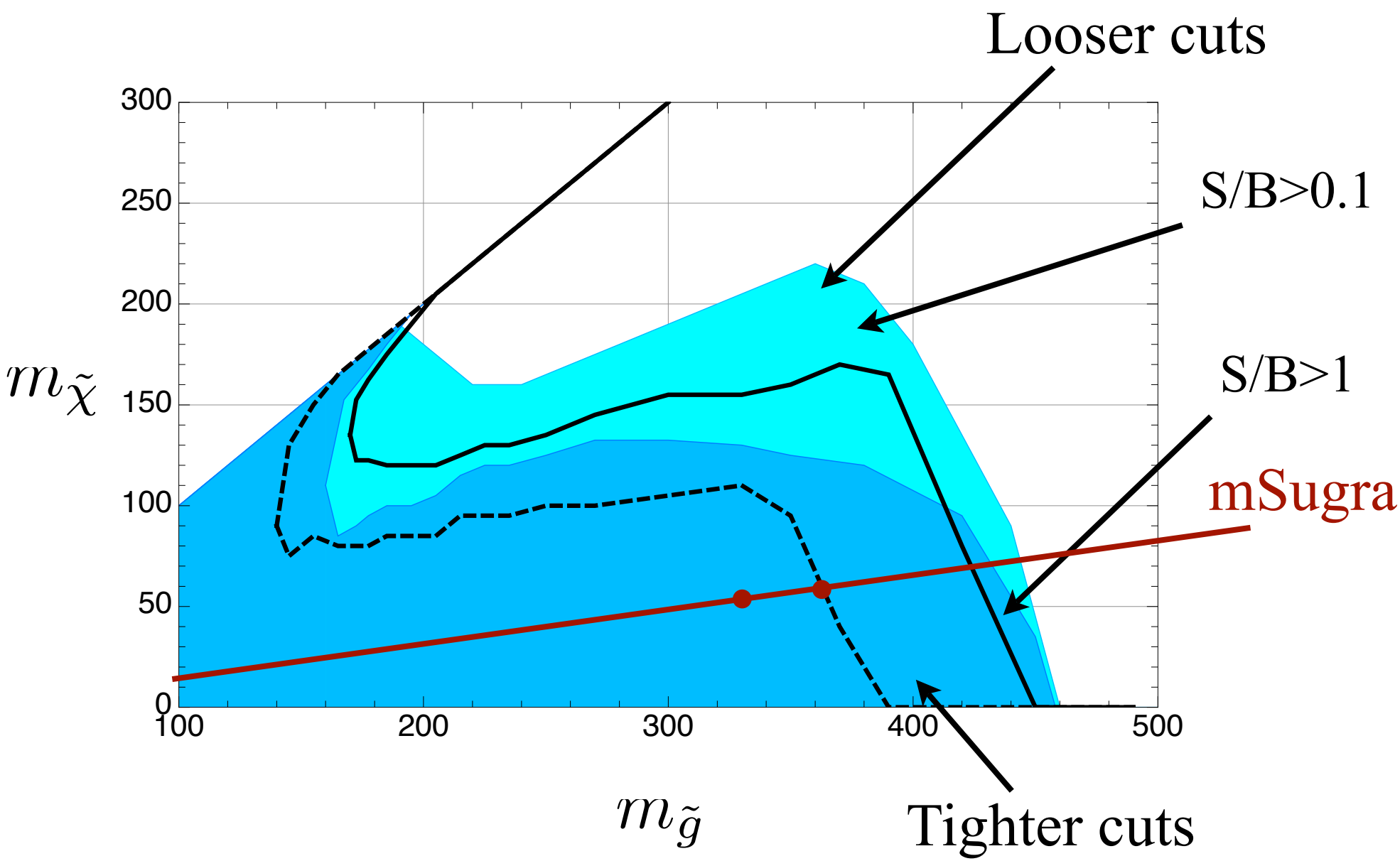
Good in degenerate region

Dijet S/B>1



Fills in some gaps

Final Exclusion plot for $2fb^{-1}$



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Have only focused on $\tilde{g}$ module

Other modules

$\tilde{q}$	$\tilde{q} \to q\chi$	3 parameters
$\tilde{q}\tilde{g}$	$\tilde{q} \to q\chi, \tilde{g} \to q\bar{q}\chi$	4 parameters
$\tilde{g}$	$\tilde{g} \to q\bar{q}\chi', \chi' \to q\bar{q}\chi$	5 parameters
$\tilde{g}$	$\tilde{g} \to q\bar{q}\chi'', \chi'' \to q\bar{q}\chi', \chi' \to q\bar{q}\chi$	7 parameters

• • •

Should be a better way of searching

Don’t want to miss a visible signal

Jets plus MET Searches are effectively:

Jet classification criterion

Visible Energy and Missing Energy Cuts

As parameters in a module vary,
visible and missing energy change dramatically

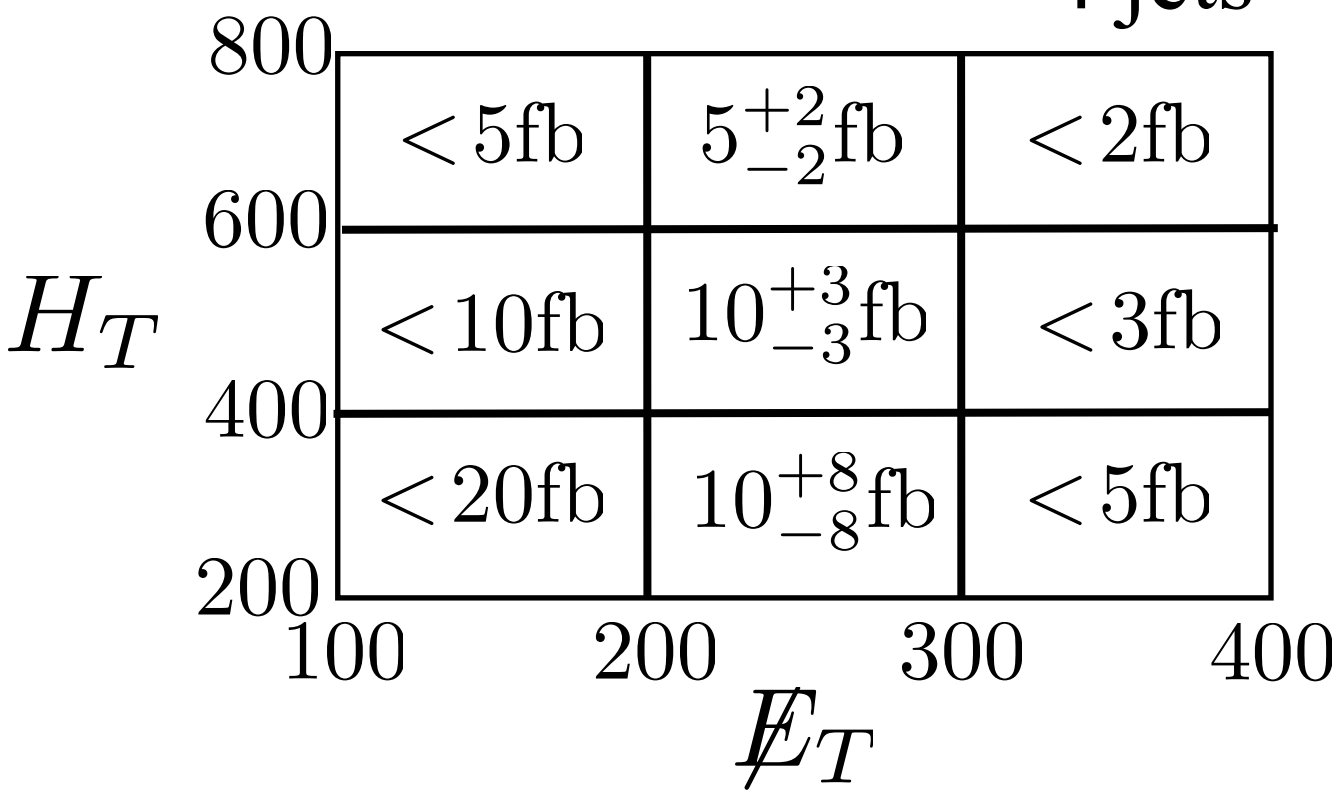
One Proposal

For each jet multiplicity

Set a limit on $\dfrac{d^2\sigma}{dH_T d\not{E}_T}\ \Delta H_T\ \Delta \not{E}_T$

e.g.

4 jets



We are probing the Energy Frontier

Don’t know what we are looking for

Models are just motivation

We need more model-independent searches

Worst tragedy is to not discover a visible signal