Jet Masses and Searches for New Physics

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arXiv:1202.0558
w/ E. Izaguirre
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Outline

High Multiplicity with MET Examples

Light Flavored Example

Heavy Flavored Example

Jet Mass Searches

Discussion

High Multiplicity without MET

Last 2 years at the LHC

Searches for BSM physics have been extensive and effective

Searches are less model dependent

Still waiting for discovery

Naturalness is now being challenged

Reach for gluinos now approaching 1 TeV

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But there are caveats:

Problems seen for

Compressed Spectra

No limits for $m_{\chi 0} > 200$ GeV

High Multiplicity Final States

Long Cascades have reduced limits

4 tops worse than 4 bottoms

Are we doing well-enough?

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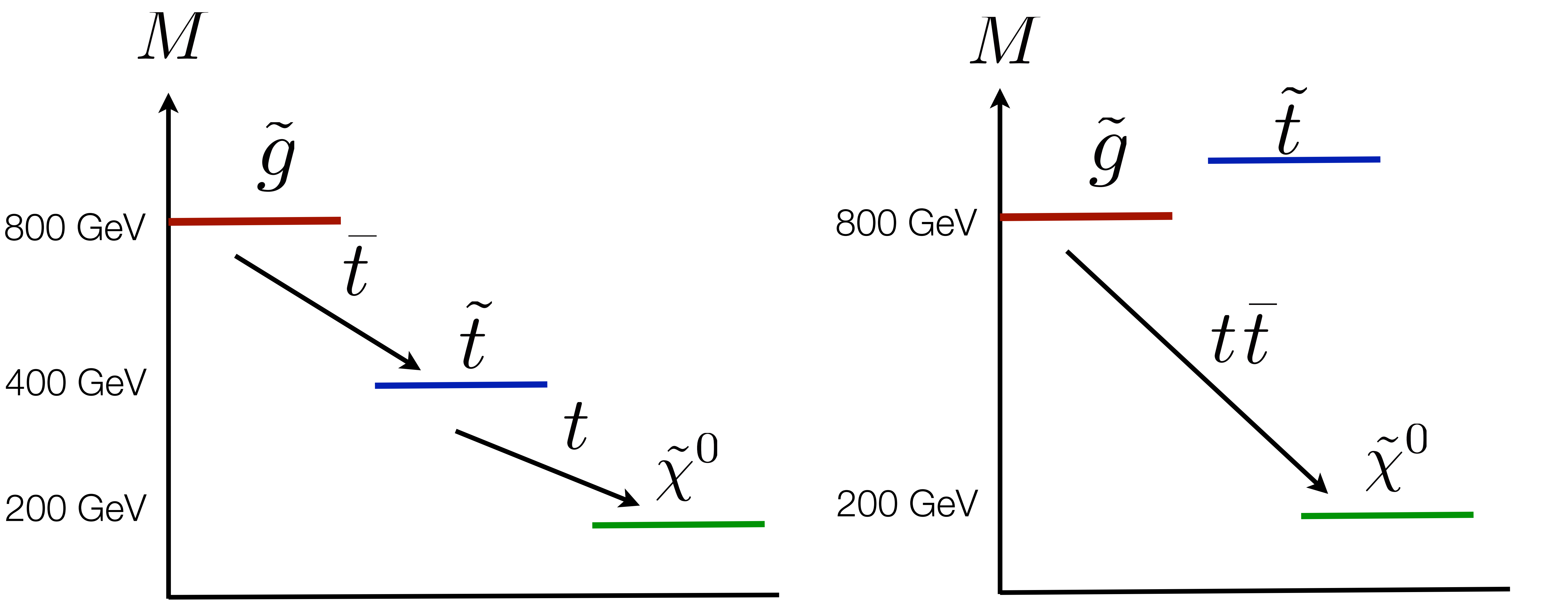
Are we doing well-enough?

Famous “Natural Susy”

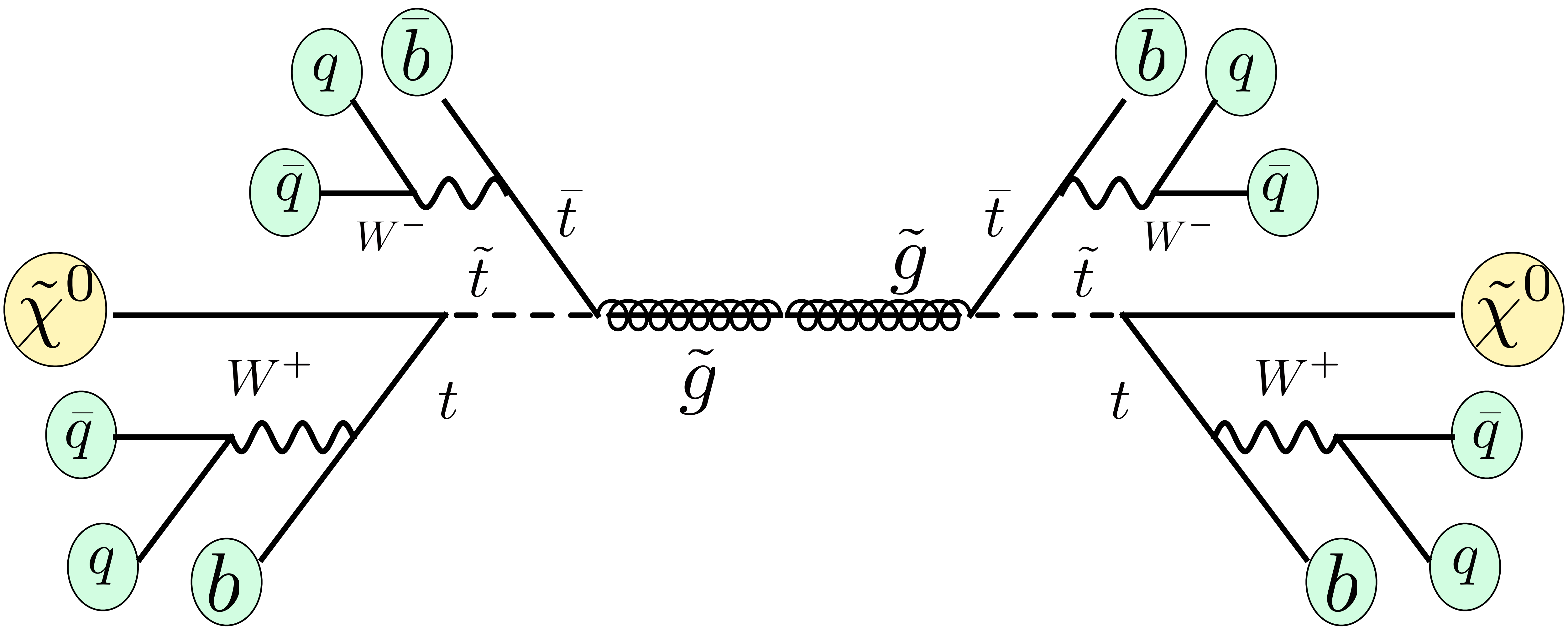
Moderately light gluinos

Light Stops

Light Higgsinos



The Classic Signature



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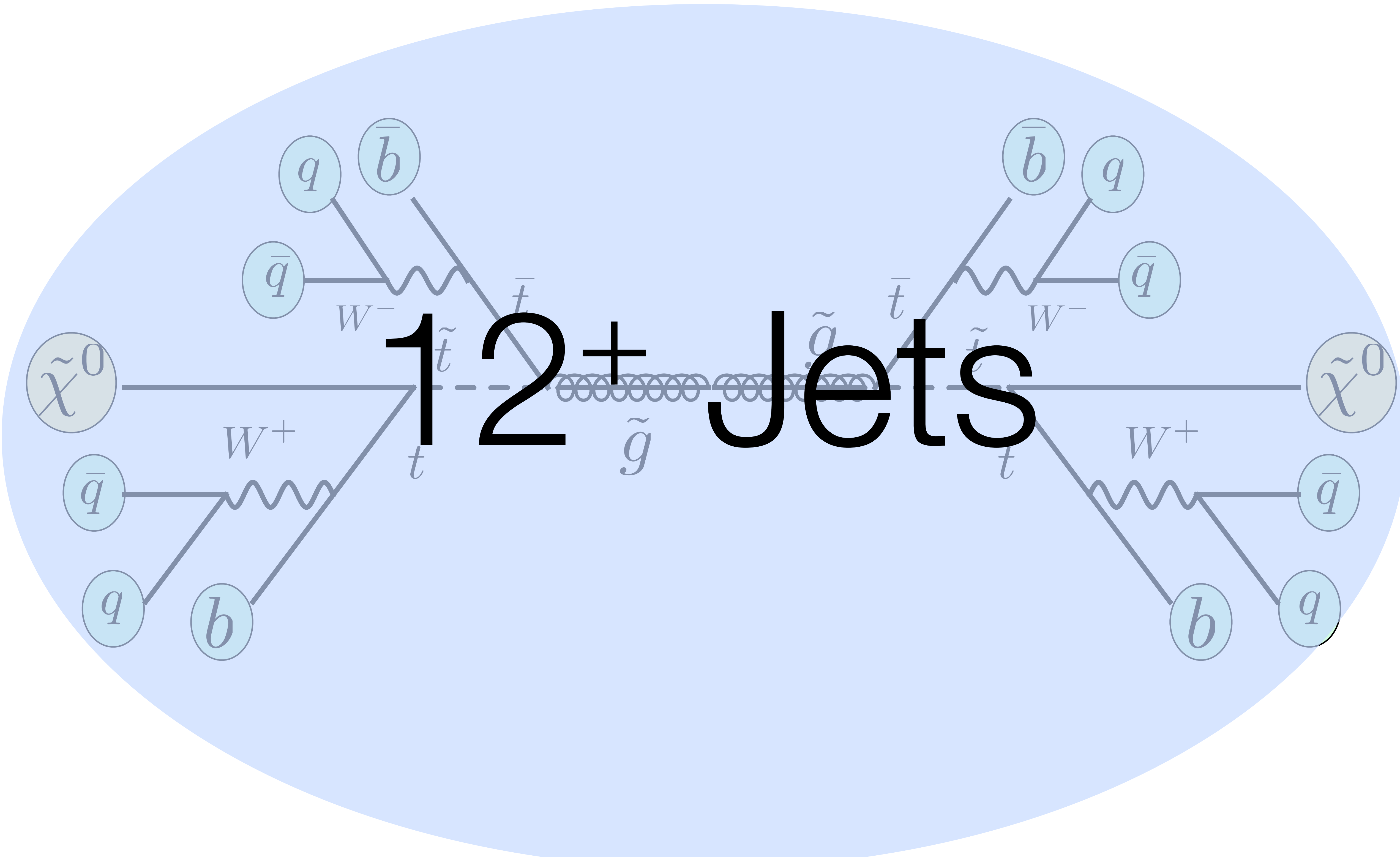

Should Be Easy

Shooting Fish in a Barrel!

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Not completely trivial

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High Multiplicity Backgrounds

No NLO

Tree-level is state of the art

Data Driven Extrapolation: $N \to N+1$

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Heterogenous final states (+ b-tagging)

$$4W : (8j, 0\ell) \to (0j, 4\ell)$$

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Jets can be Merged Together

A variety of final state jet multiplicities

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A variety of final state jet multiplicities

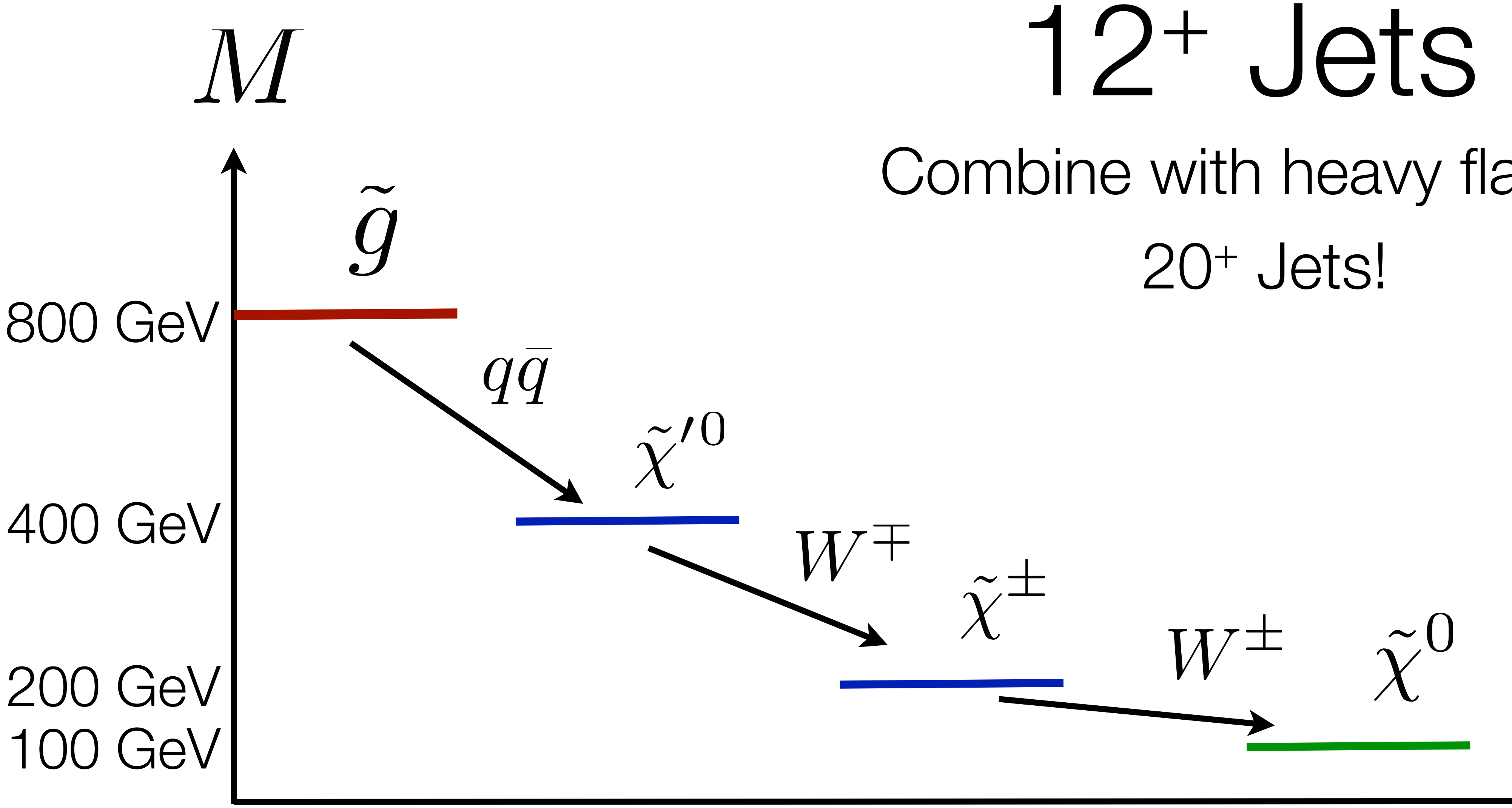
Isolated Jet P_T is Reduced

Easily fall beneath 50 GeV

Lots of similar examples in Susy

2 Step Cascade Decay

$$\tilde{g} \to \tilde{W} \to \tilde{H} \to \tilde{B}$$



12⁺ Jets

Combine with heavy flavor

20⁺ Jets!

Inclusive Approach

Gain sensitivity to high multiplicity final states

First Realization:

Requiring N jets requires O(N) cuts

Jets may have small p_T (accidentally forward)

Jets merge together

Get Lost

The more cuts, the less inclusive

Less likely to be the best discovery channel

Typical Susy Searches use

anti-k_T $R = 0.4$ to 0.6

Lots of room for isolated jets
Can find up to 60

Good at separating high multiplicity
from low multiplicity

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Take a great leap backwards

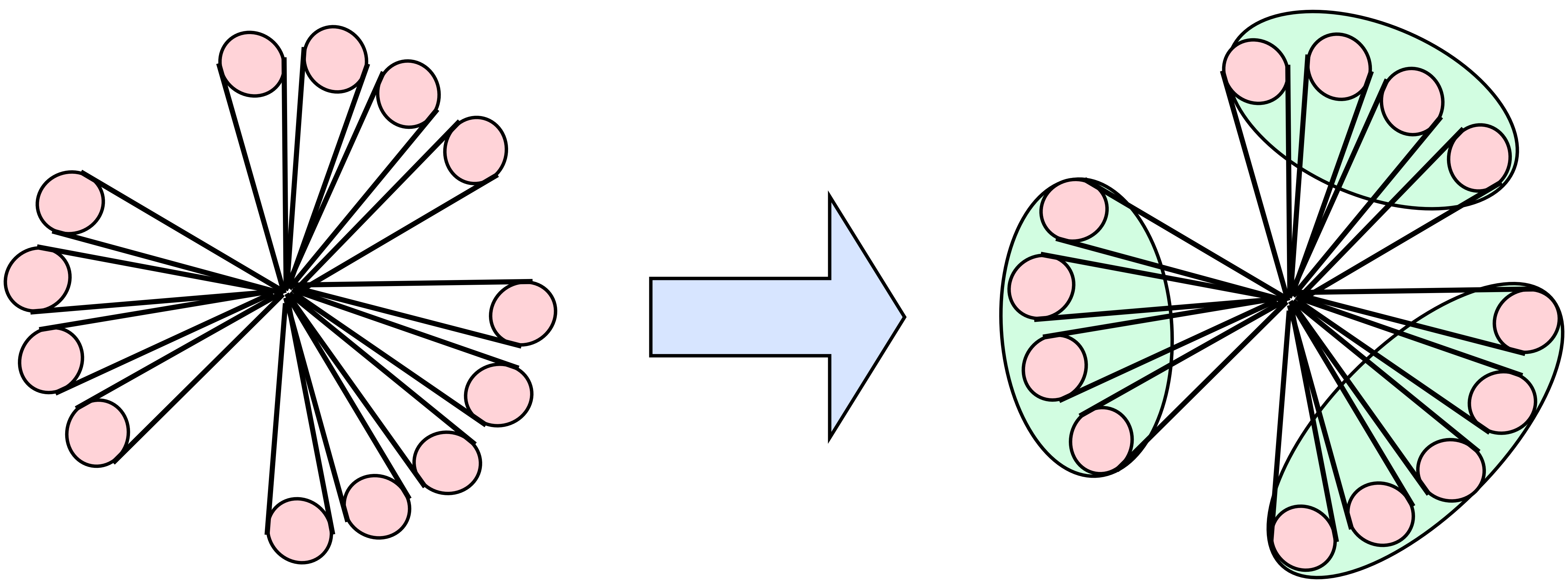
anti-k_T $R = 1.2$

No room for isolated jets
Only 4 to 6 jets possible

Seem to have lost
the single feature that made
these events special

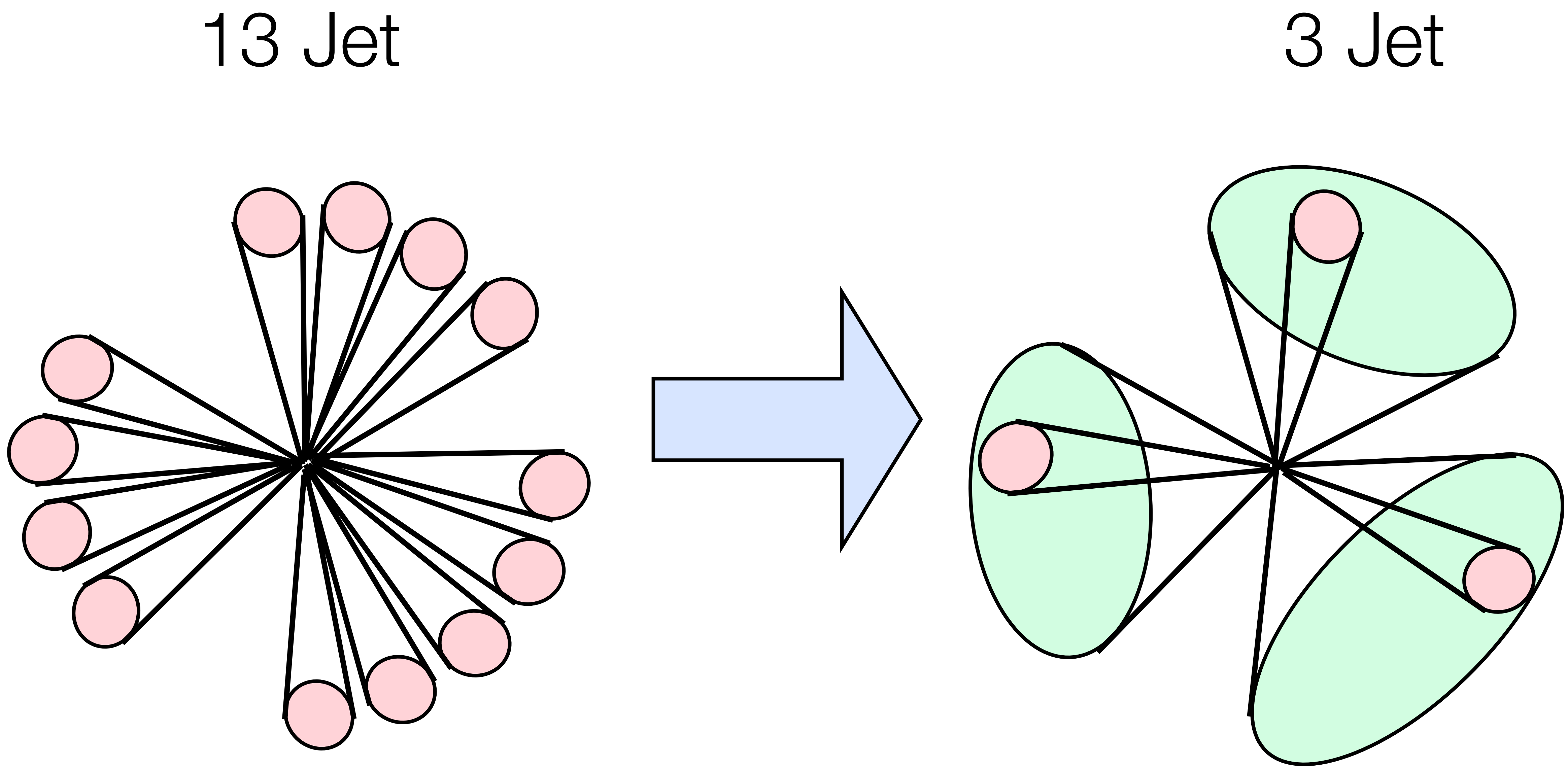
13 Jet Event

3 Jet Event

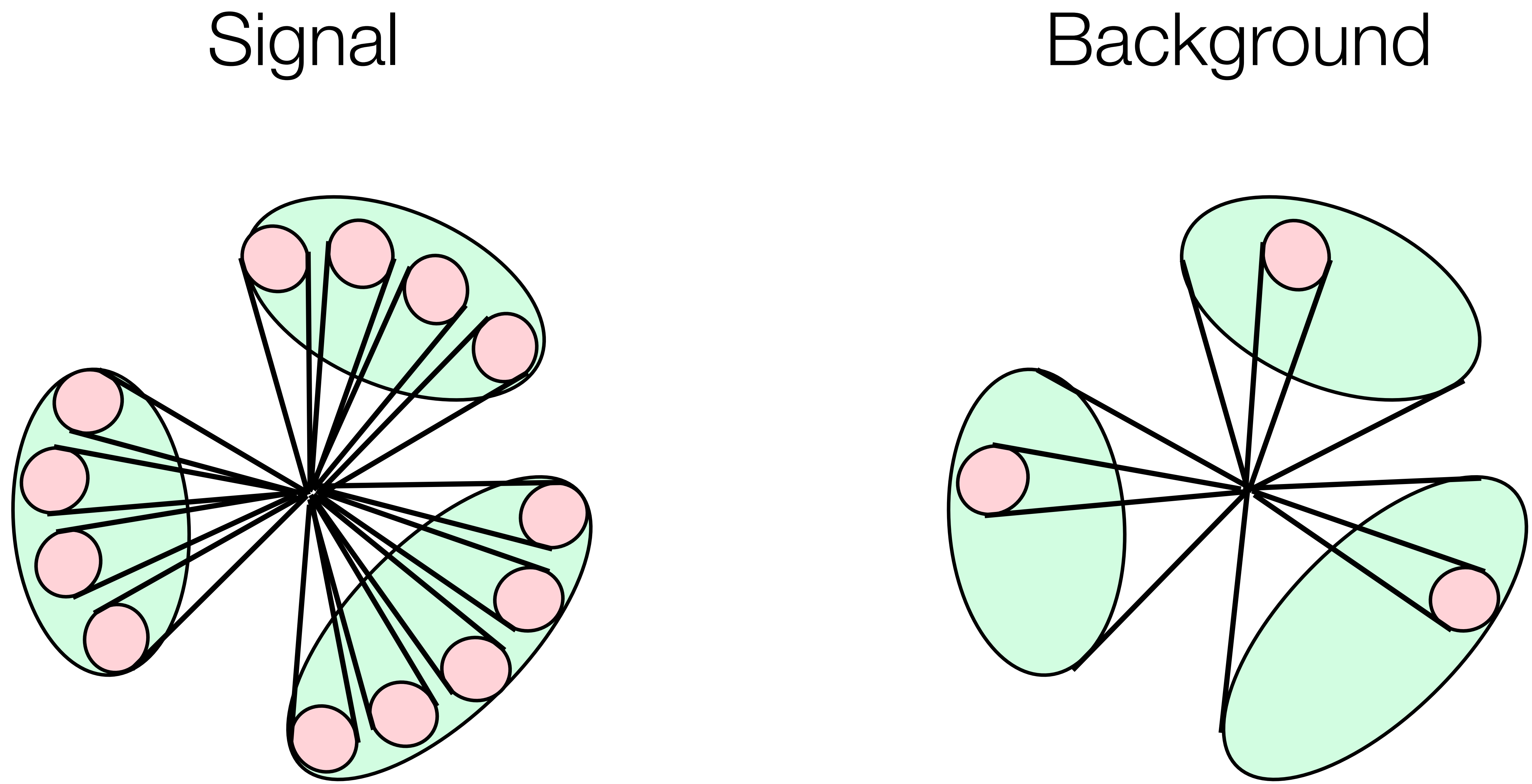


Typical QCD Background

Background rate skyrockets

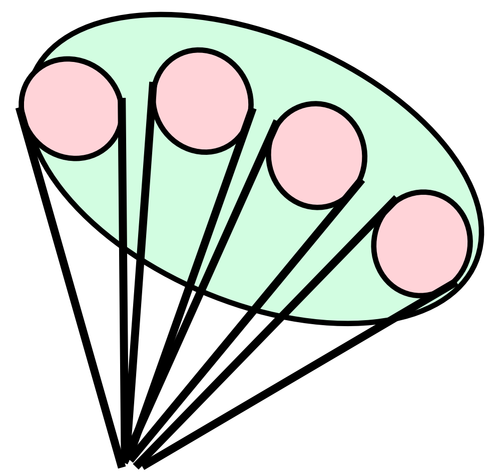


Now need to distinguish



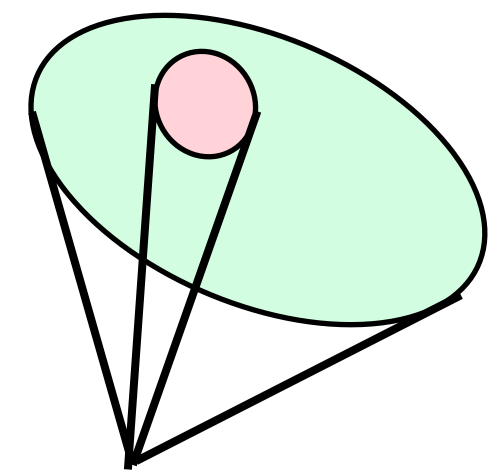
The difference between them is clear

Large Jet Mass



$$x \equiv \frac{m_j}{p_T} \sim 1$$

Small Jet Mass



$$x \equiv \frac{m_j}{p_T} \sim \alpha_s^{\frac{1}{2}}$$

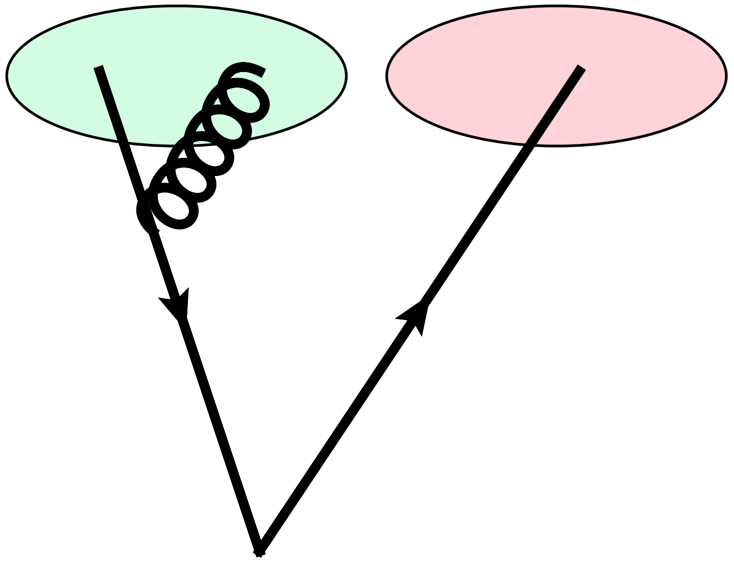
Each jet mass is *approximately* independent for QCD

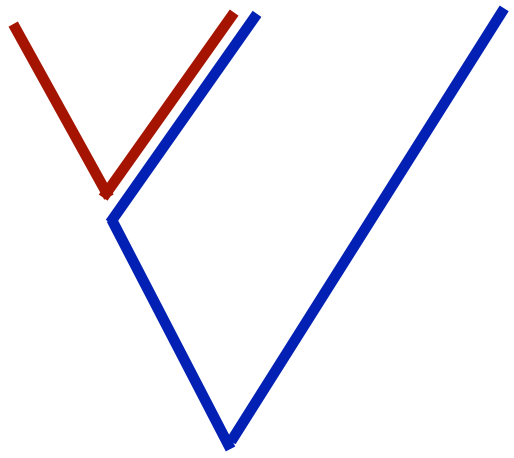
Getting multiple massive jets rare

Jet mass correlations never studied before

Color Dipoles Picture

First Radiation Gives Mass





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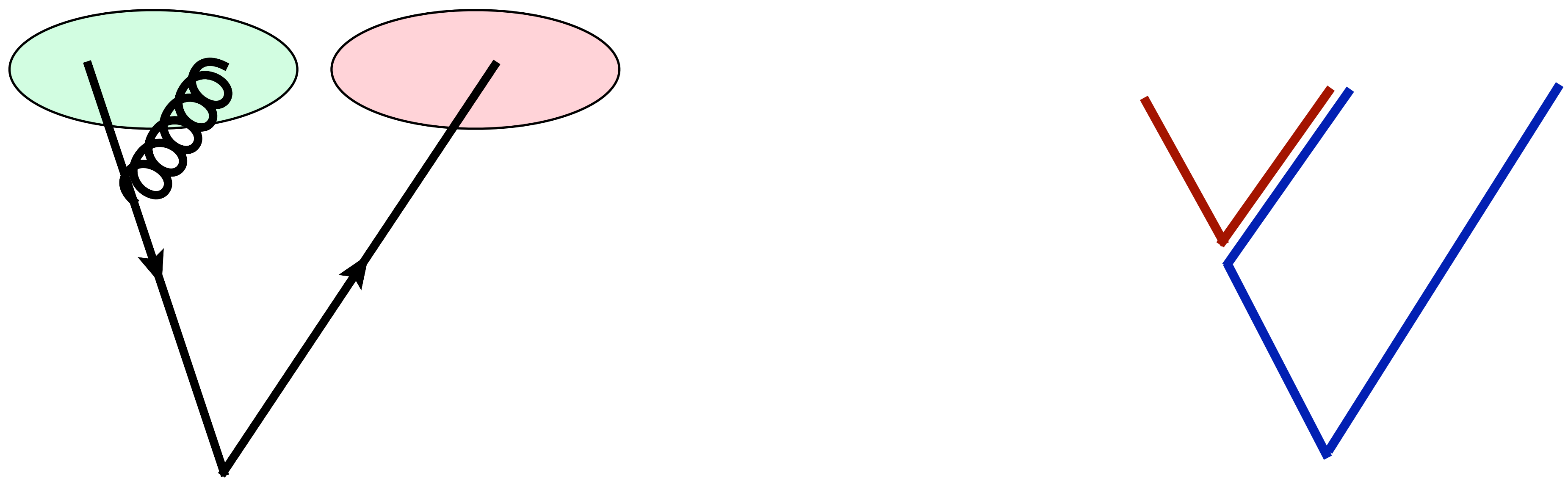
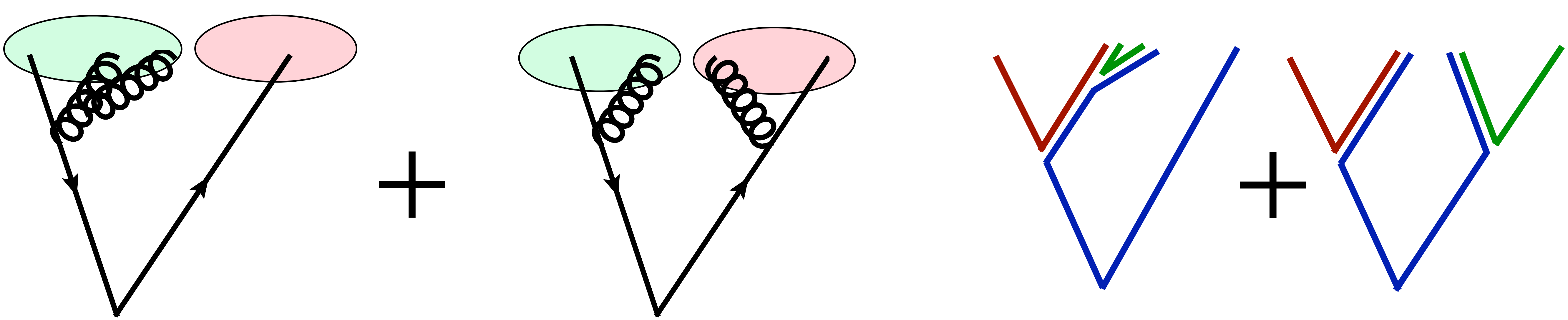


Color Connection Causes Pull on Second Jet

Second order effect



If 1st jet has a large mass, will the 2nd jet have a large mass more often?

Consider m_j/p_T of 2 leading jets

$$h(x_1,x_2)$$

$$H(x_1,x_2) = \frac{h(x_1,x_2)\int h(x_1,x_2)dx_1dx_2}{\int h(x_1,x_2)dx_1 \int h(x_1,x_2)dx_2},$$

$$\text{if } h(x_1,x_2) = g_1(x_1)g_2(x_2),\ \text{then } H(x_1,x_2) = 1$$

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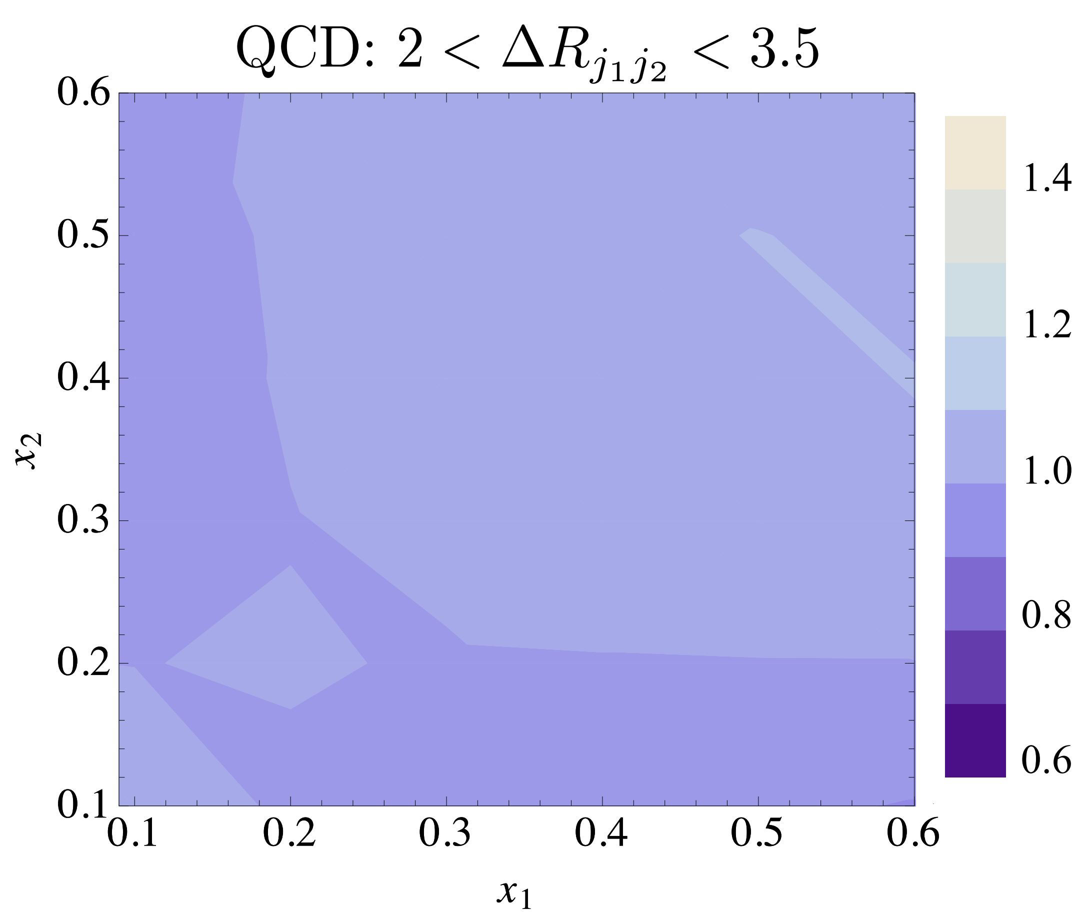


Z^0+2^+j with MG4 + Pythia 6.4

~5% correlations

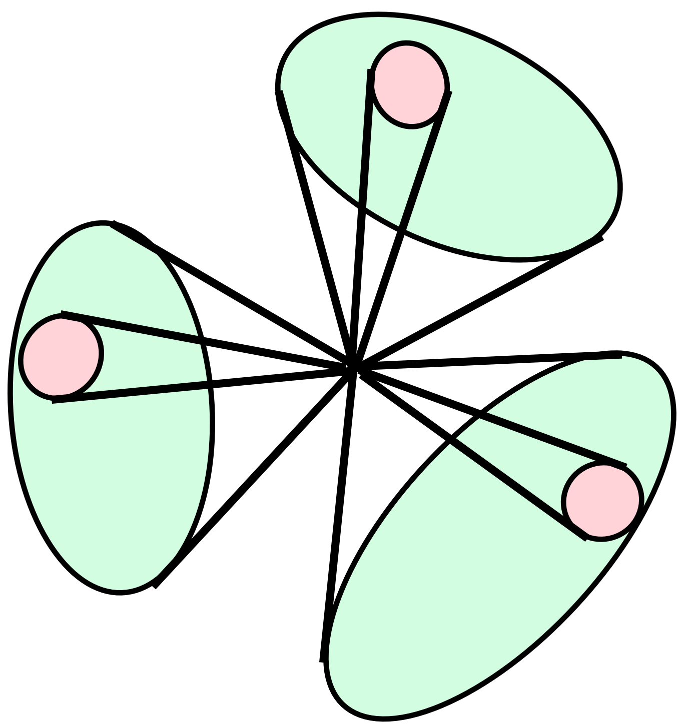
Slightly positive correlation

No calculation to compare to

5% requires 10k events per bin

QCD jets only have small correlations

Data driven background predictions possible



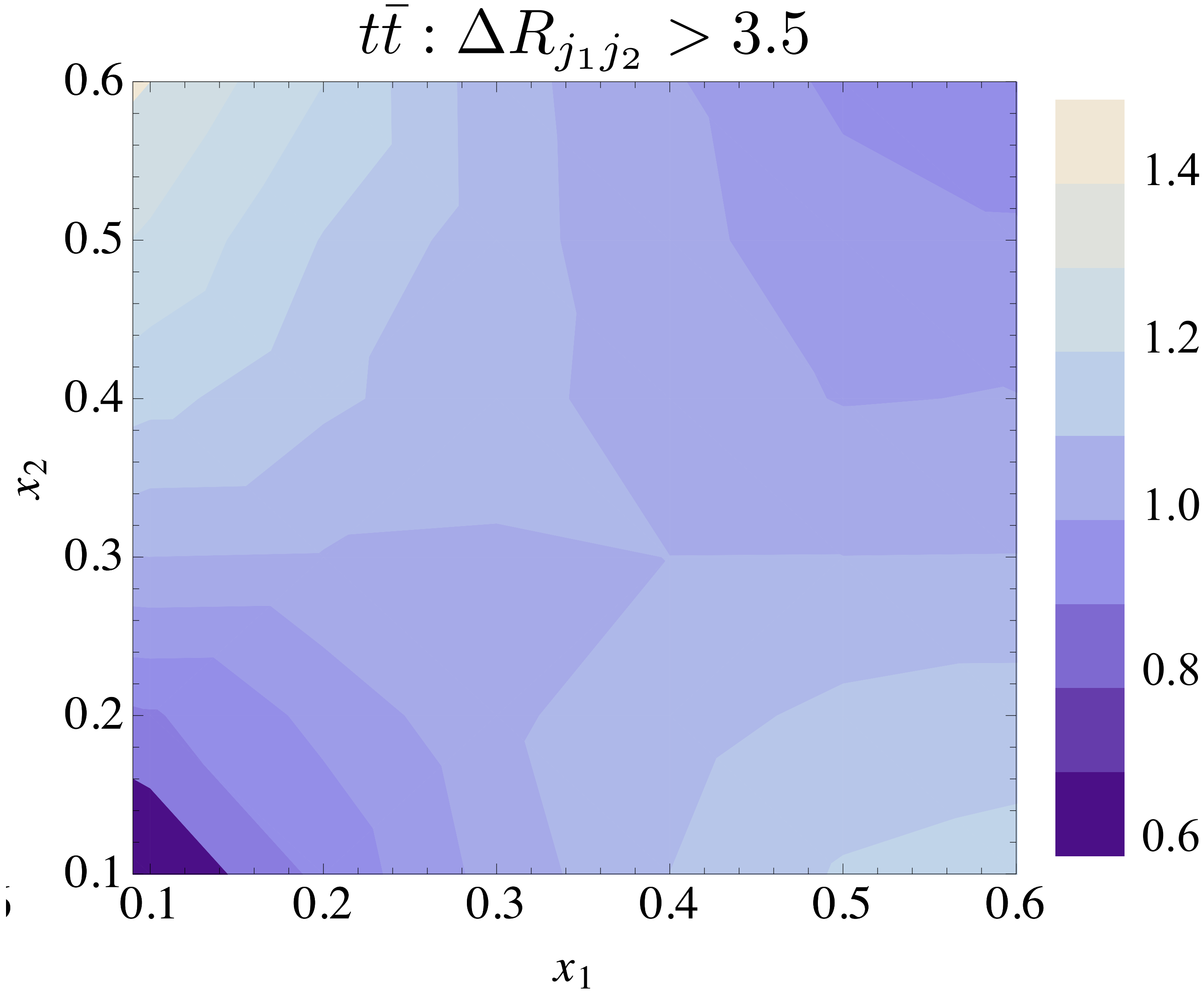
$$P_3(x_1, x_2, x_3) \simeq P_1(x_1)P_1(x_2)P_1(x_3)$$

Measure in one sample and extrapolate

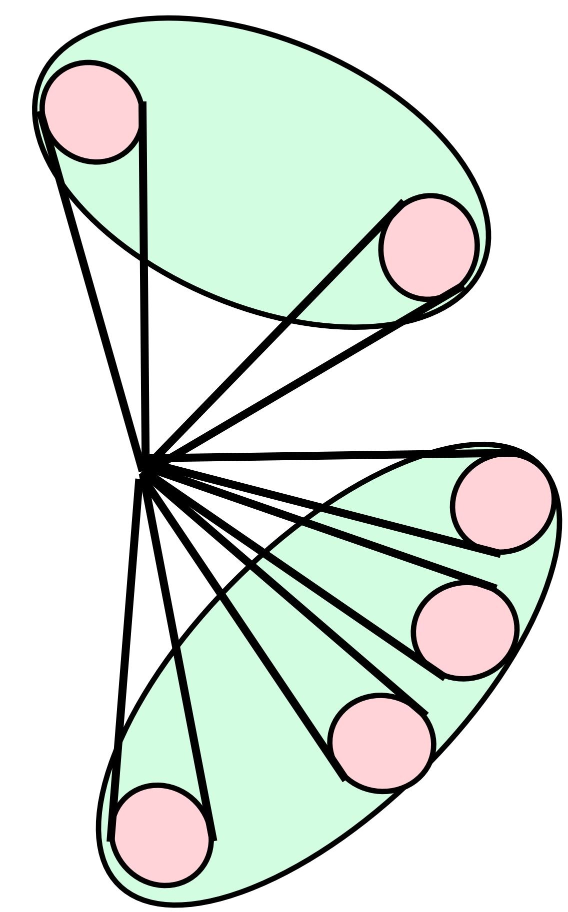
Would like a calculation to understand correlations

Should measure in multiple settings (q vs g composition)

Contrast to top events



Small Mass



Large Mass

30% Correlations

Negative correlation

If one is massive,

the second is *less* likely to be massive

Introduce 1 New Variable

Sum of Jet Masses

$$M_J = \sum_{n=1}^{N_J} m_{j_n}$$

QCD jets have most of their mass generated by the parton shower

Top events have their mass capped near 400 GeV

M_J as a replacement for H_T

$$H_T = \sum_{n=1}^{N_J} E_{T\,j_n}$$

$$H_T = \sum_{i=1}^{n_J} (p_{T,i}^2 + m_{j_i}^2)^{\frac{1}{2}} \qquad m_j = \kappa p_T R$$

$$\propto \sum_{i=1}^{n_J} \sqrt{\langle m_{j_i}^2 \rangle ((\kappa R)^{-2} + 1)} \simeq M_J \frac{\sqrt{1 + (\kappa R)^2}}{\kappa R}$$

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Signal

$$\langle m_{j_i}^2 \rangle \propto p_{T,i}^2 R^2$$

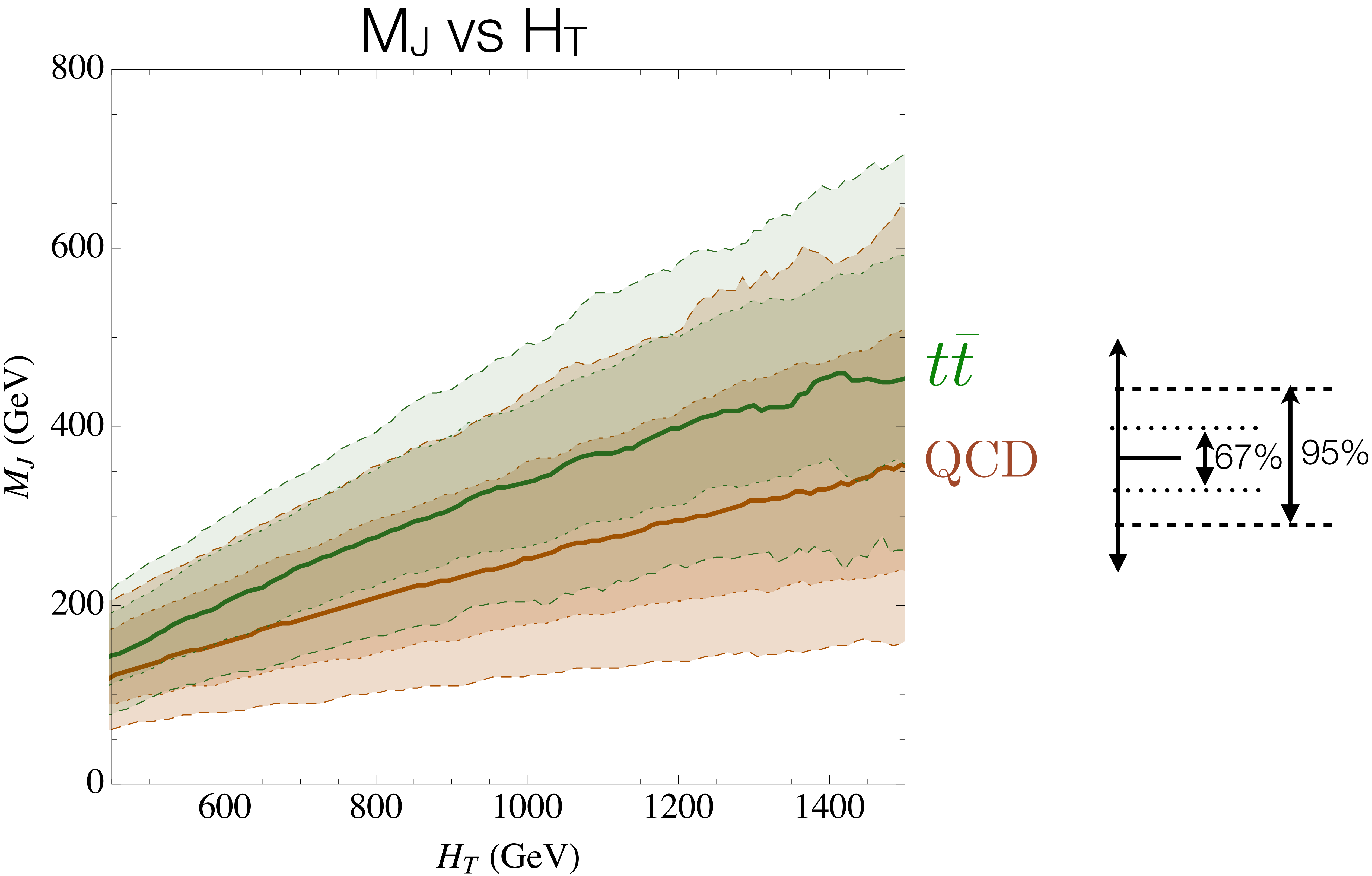
Background

$$\langle m_{j_i}^2 \rangle \propto \alpha_s p_{T,i}^2 R^2$$

Signal typically has higher M_J for fixed H_T

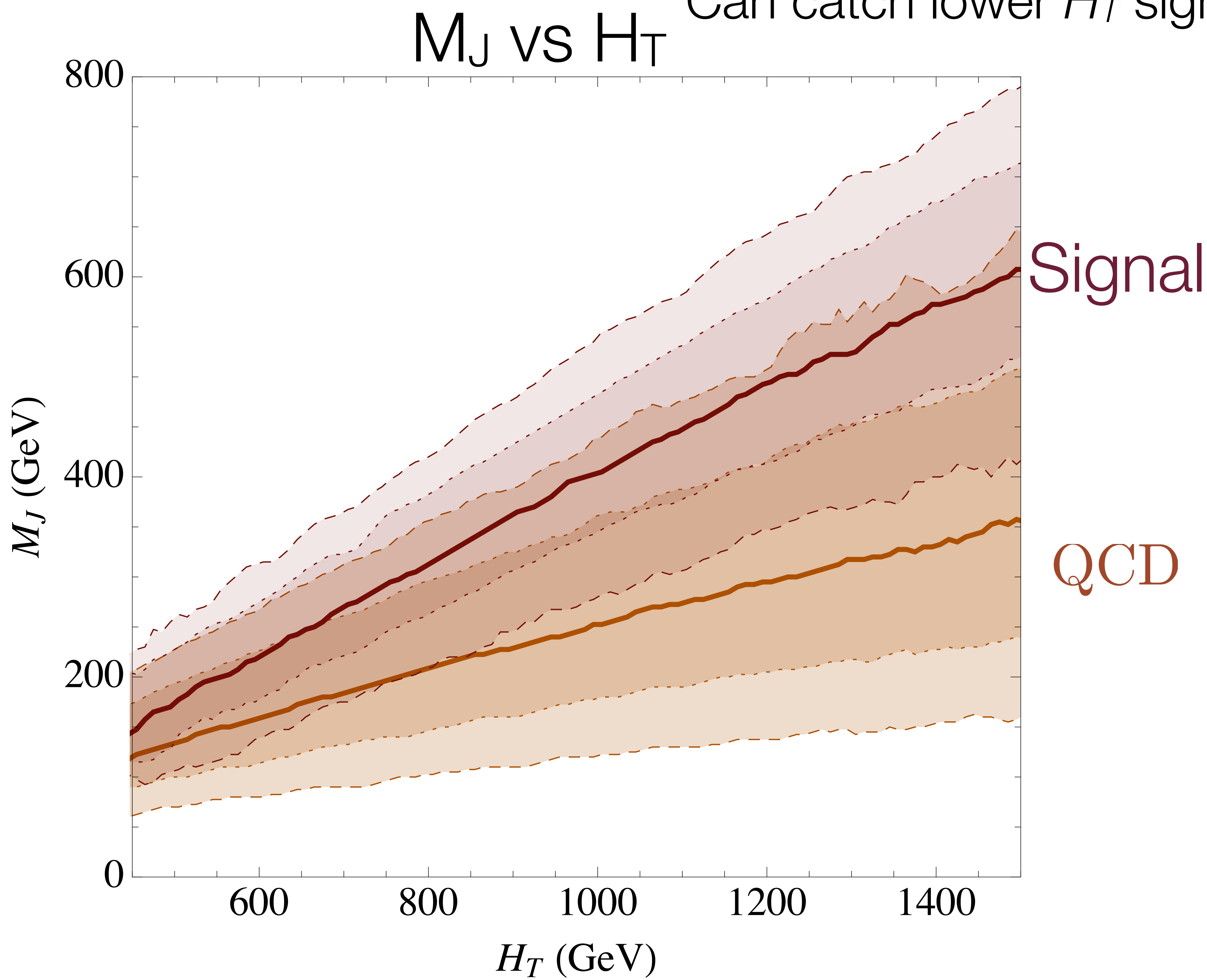
Never does worse

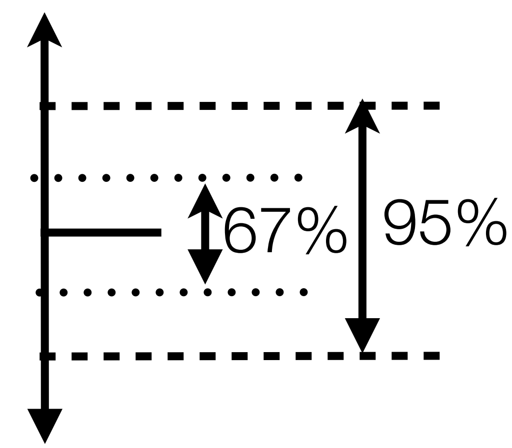
Top Quark vs QCD



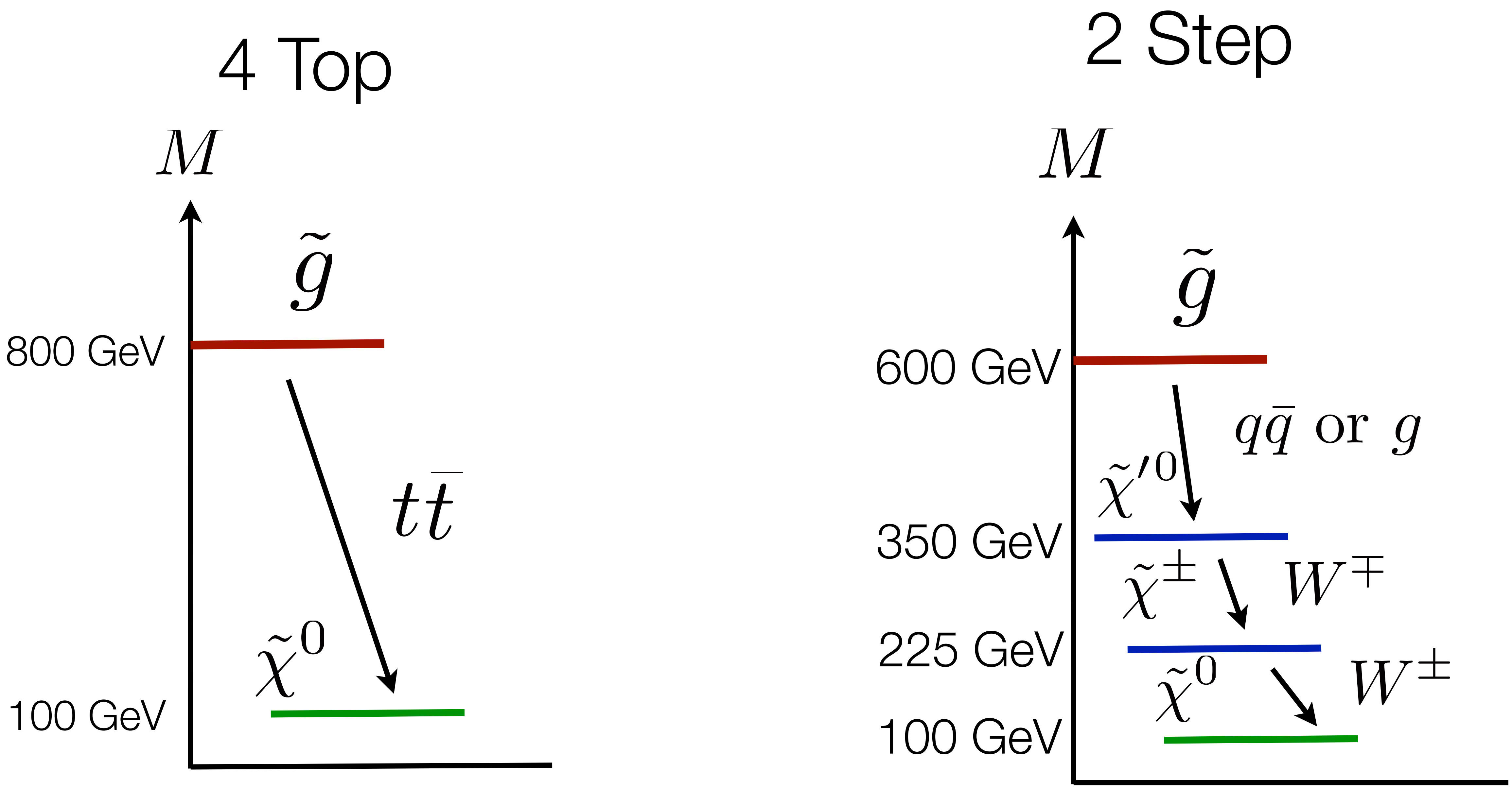
Signal vs QCD: Steeper than Top

Can catch lower H_T signal with M_J

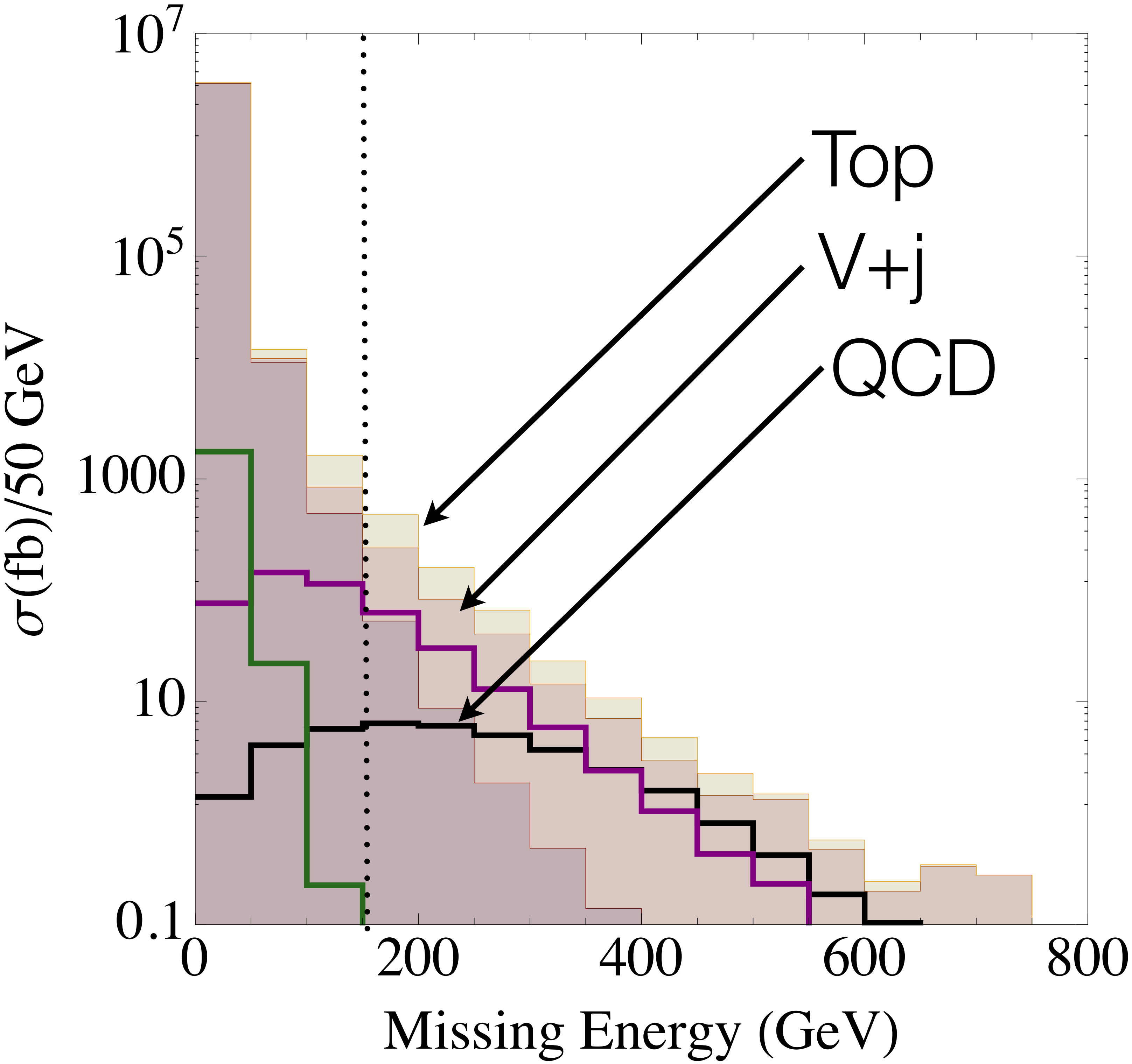




Two Benchmark Models



Missing Energy Distribution



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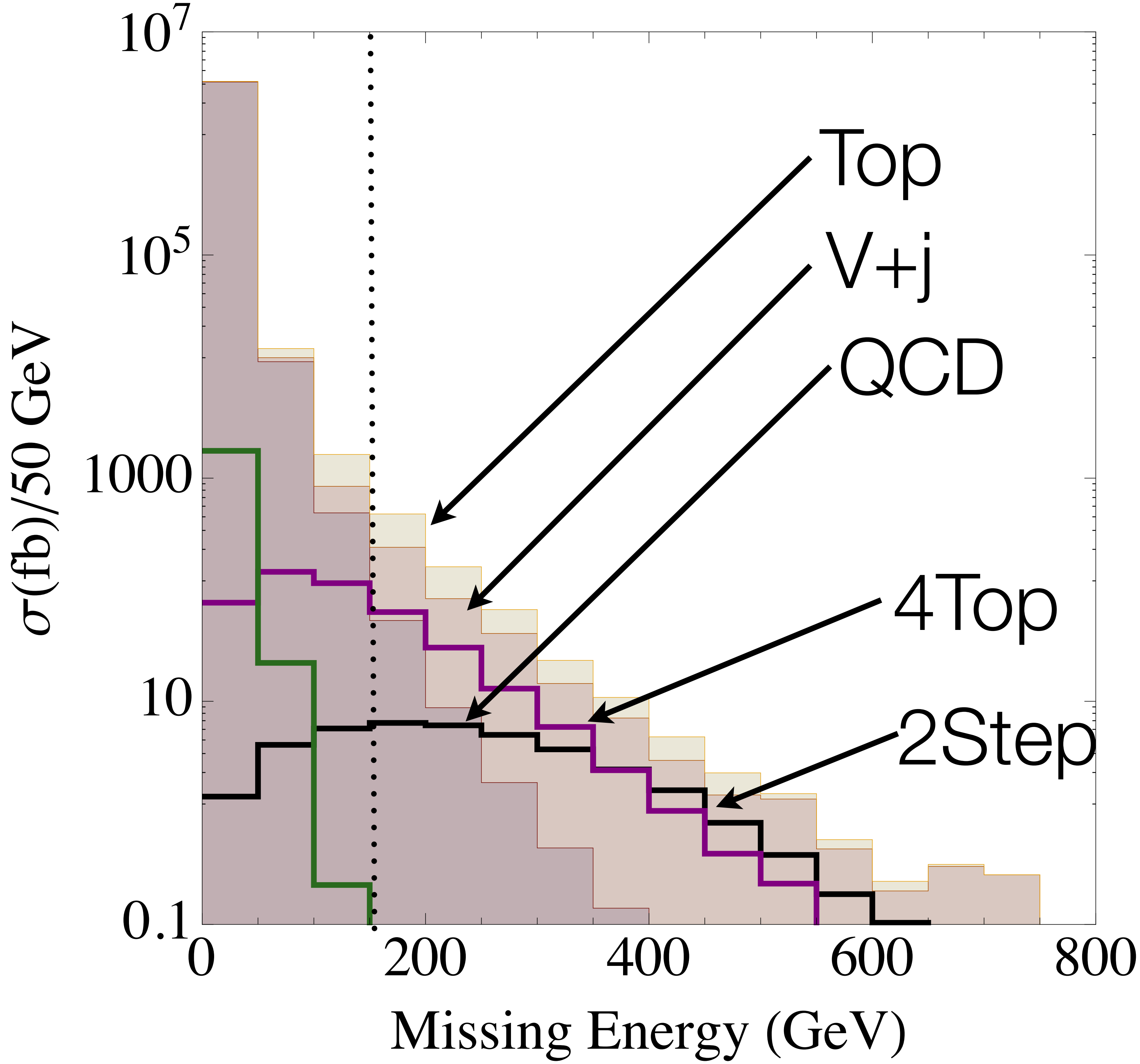
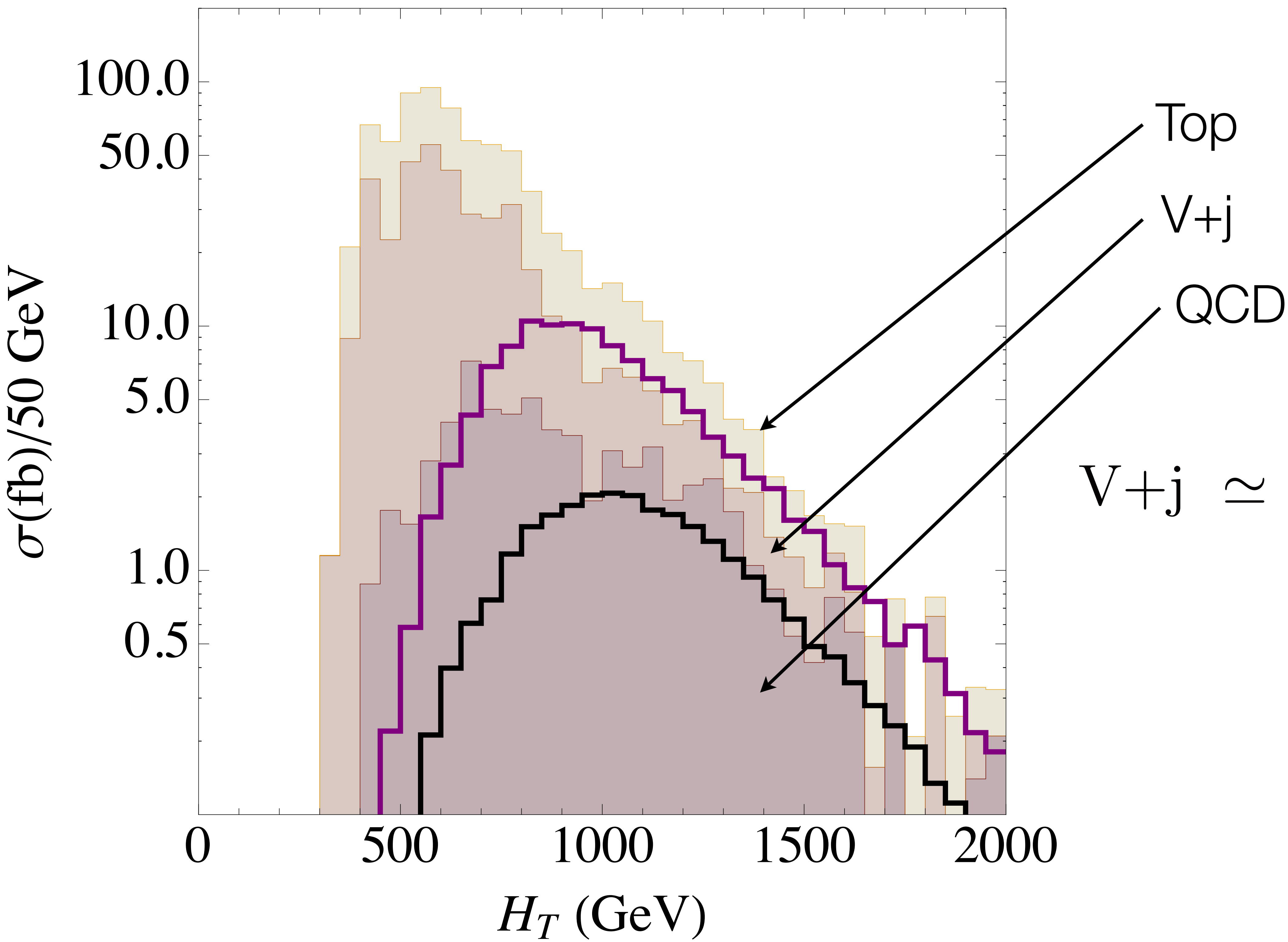


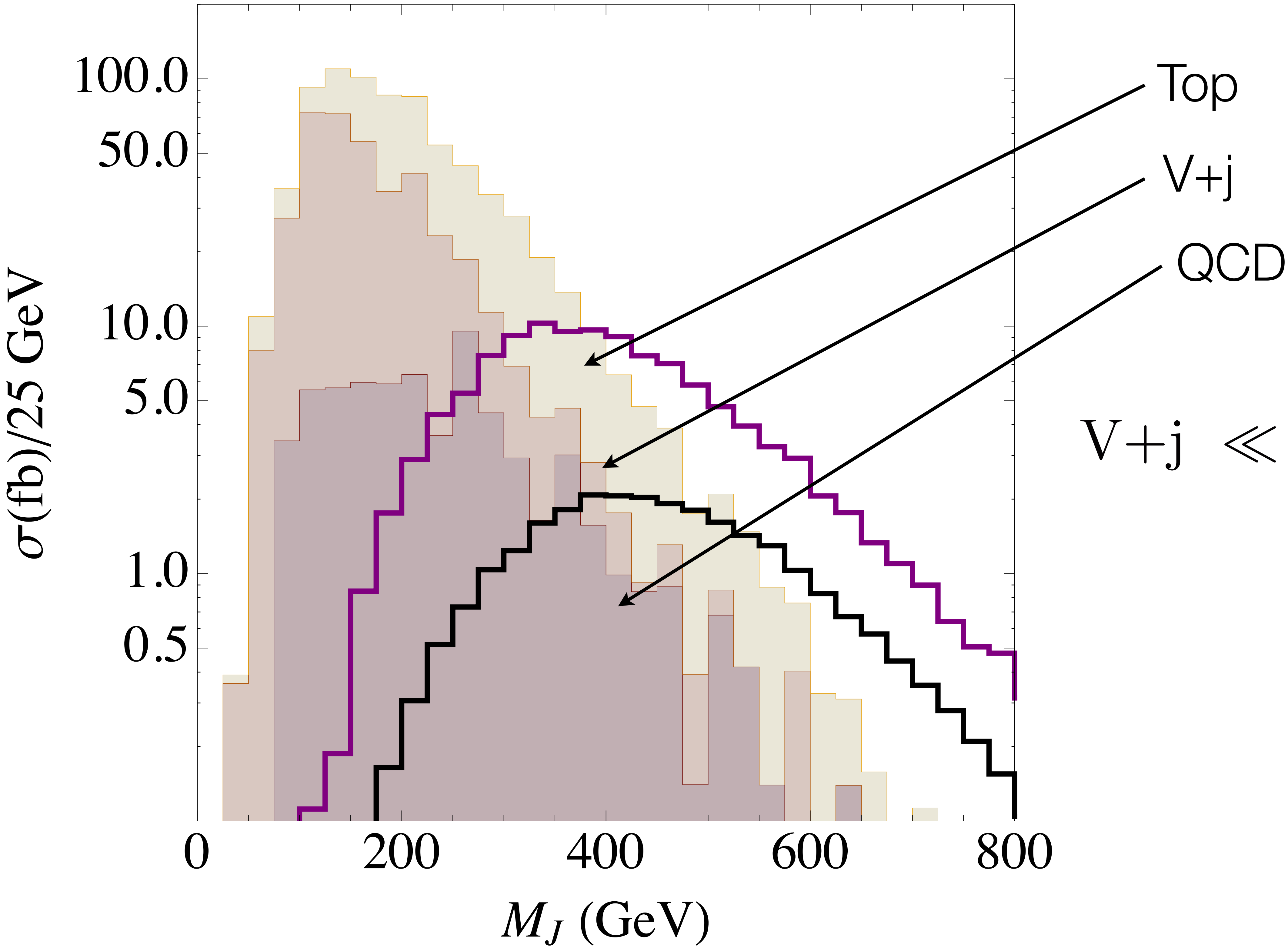
After cut of $\not{E}_T > 150$ GeV

S/B < 1



V+j $\simeq$ Top

Gain at high M_J



$V{+}j \ll$ Top

Final Search

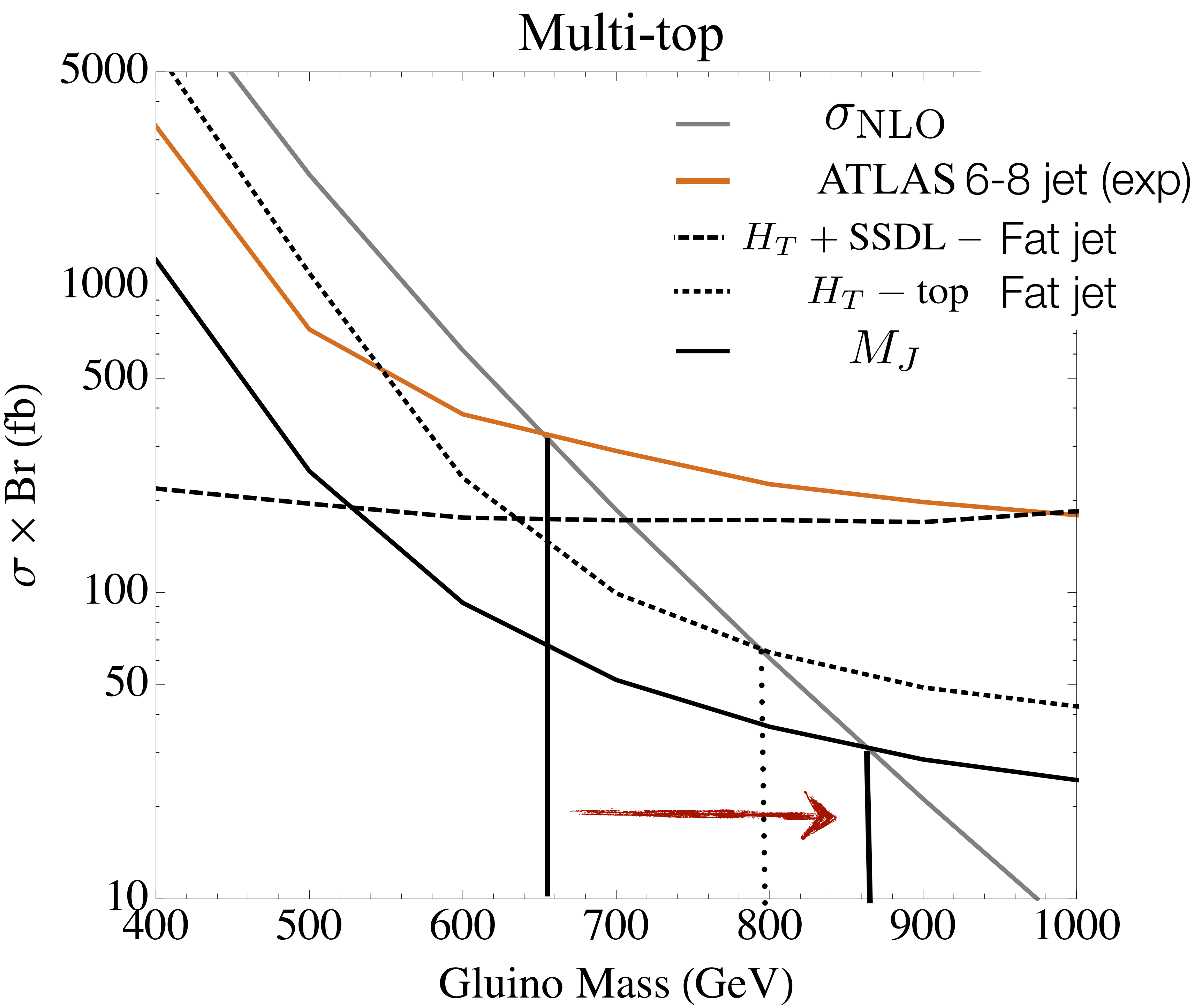
Compare to straw-men

Search	N_j	R	Leptons	N_b	$\not{E}_T$ [GeV]	H_T [GeV]	M_J [GeV]
ATLAS	6-8$^+$	0.4	0	0^+	$3.5\sqrt{H_T}$	$\emptyset$	$\emptyset$
H_T+SSDL-top	3^+	1.2	SSDL	1^+	$\emptyset$	300	$\emptyset$
H_T-top	4^+	1.2	0^+	1^+	250	800	$\emptyset$
H_T-cascade	4^+	1.2	0^+	0^+	150	1000	$\emptyset$
M_J search	4^+	1.2	0^+	0^+	150	$\emptyset$	450

Maximally Inclusive

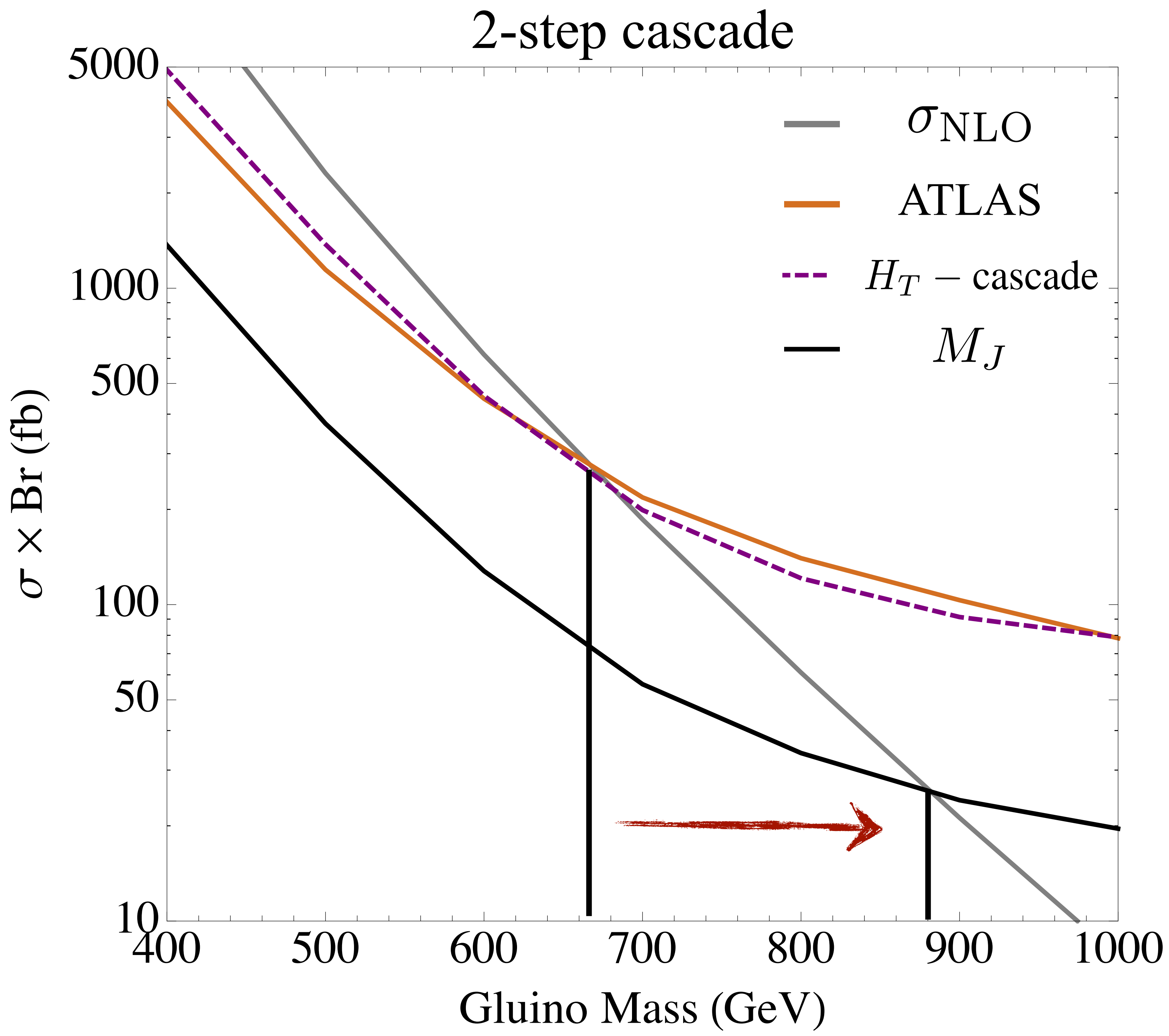
No b-tags, no lepton vetos, low MET

4 Top Limits



Gain from 650 GeV to 850 GeV

2 Step Limits



Gain from 660 GeV to 880 GeV

Jet Grooming

Not used in this study

May not be necessary

Designed to improve searches for hadronic resonances

Want to be maximally inclusive

Large mass jets may arise from
accidental grouping of final state partons

Large jet masses not from resonance masses

Jet Grooming

May hurt search

Can’t use grooming techniques where
number of subjets are specified in advance

Filtering typically fixes n_{subjet}

Pruning, Trimming do not

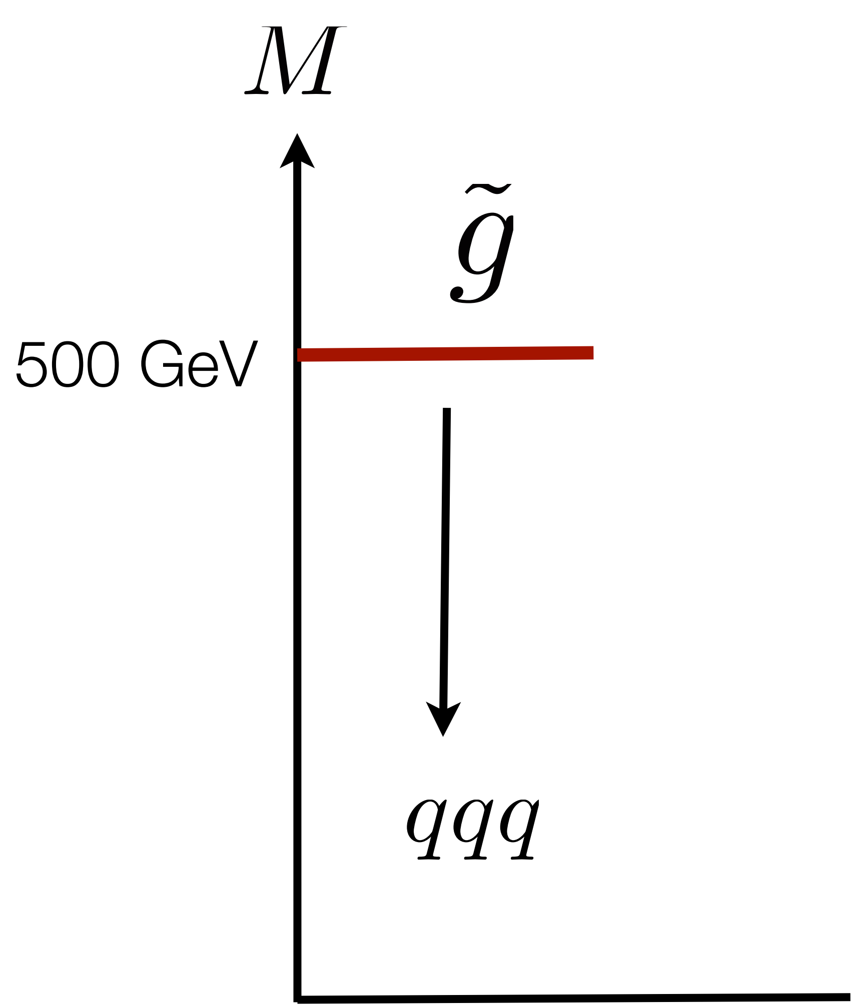
Set Jet Grooming aside

Non-MET Searches

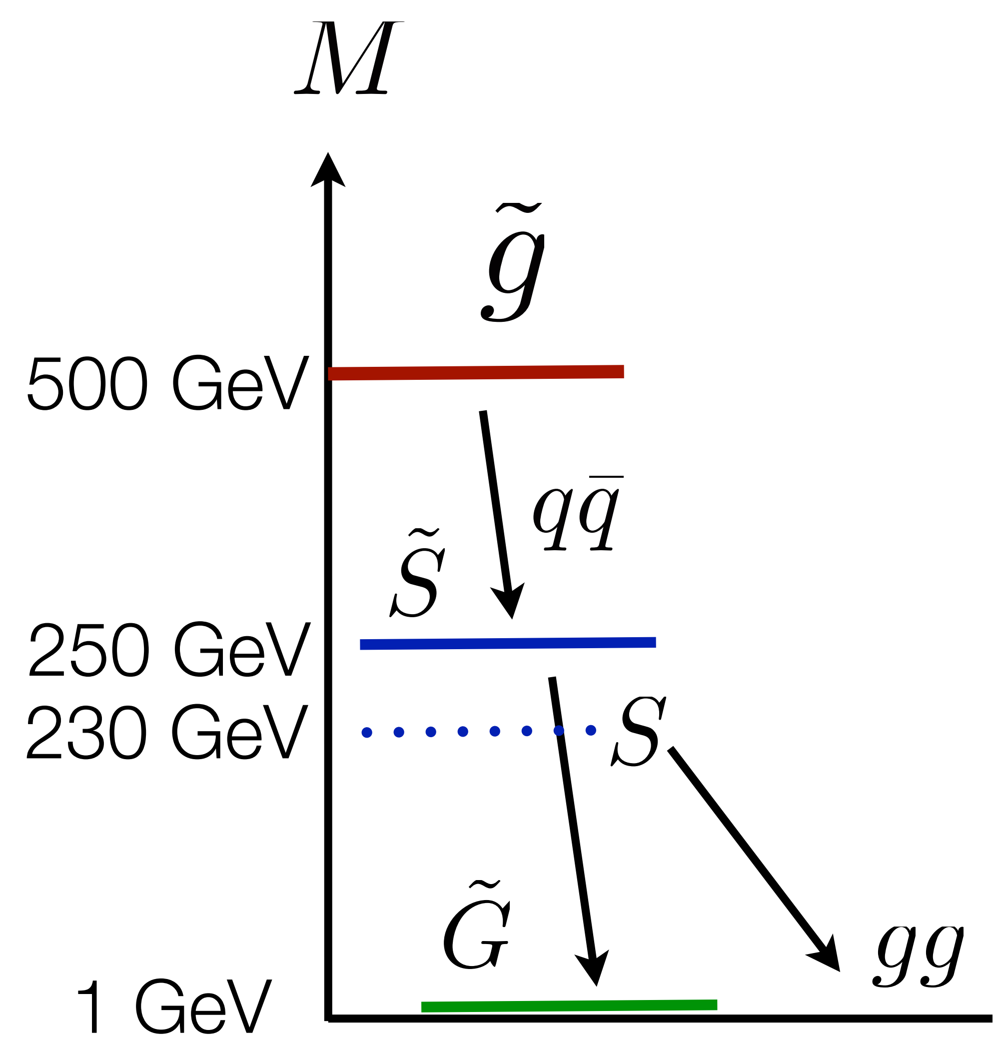
Not all theories have large MET

Two Benchmark Models

Baryonic RPV

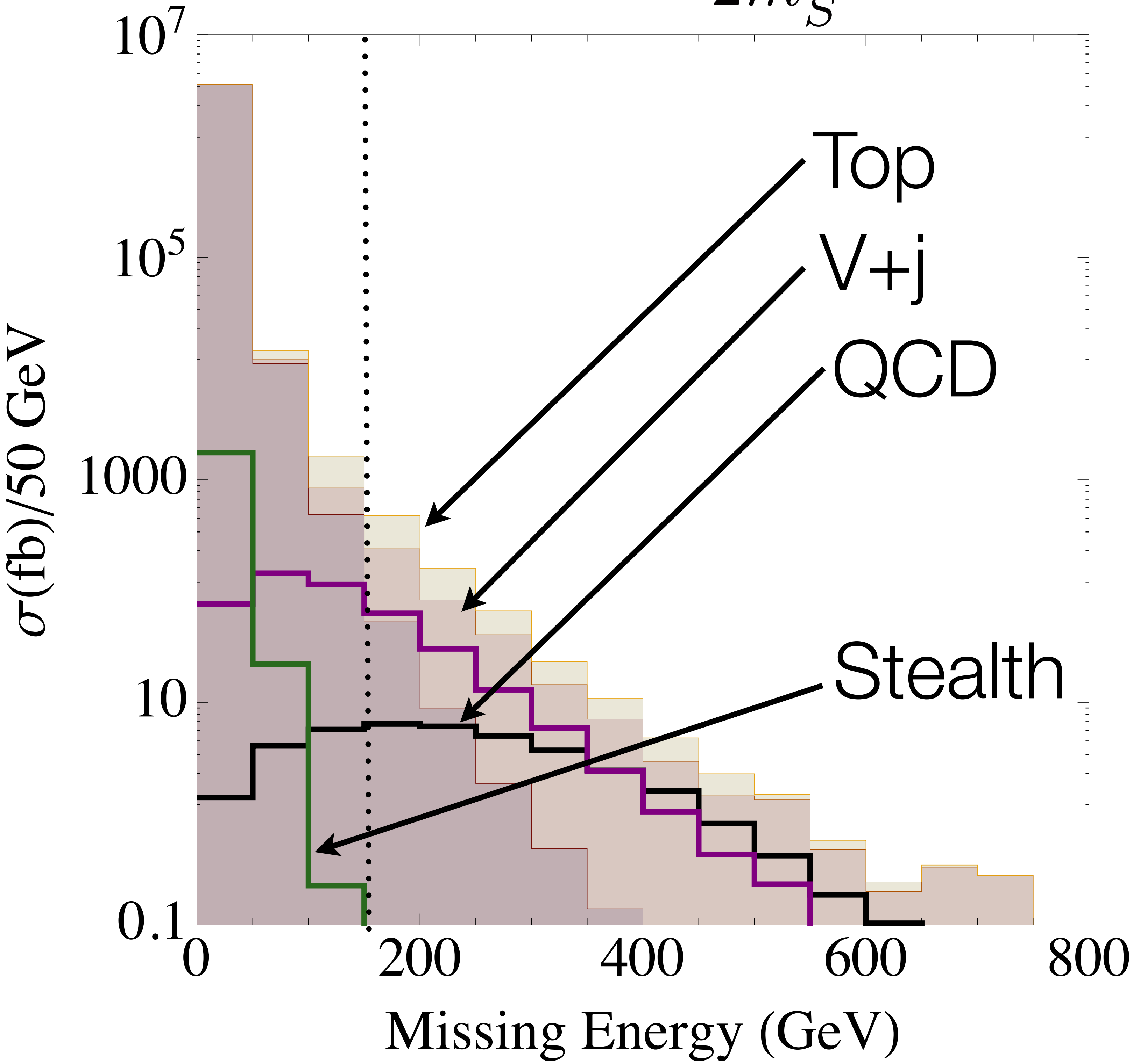


Stealth Susy



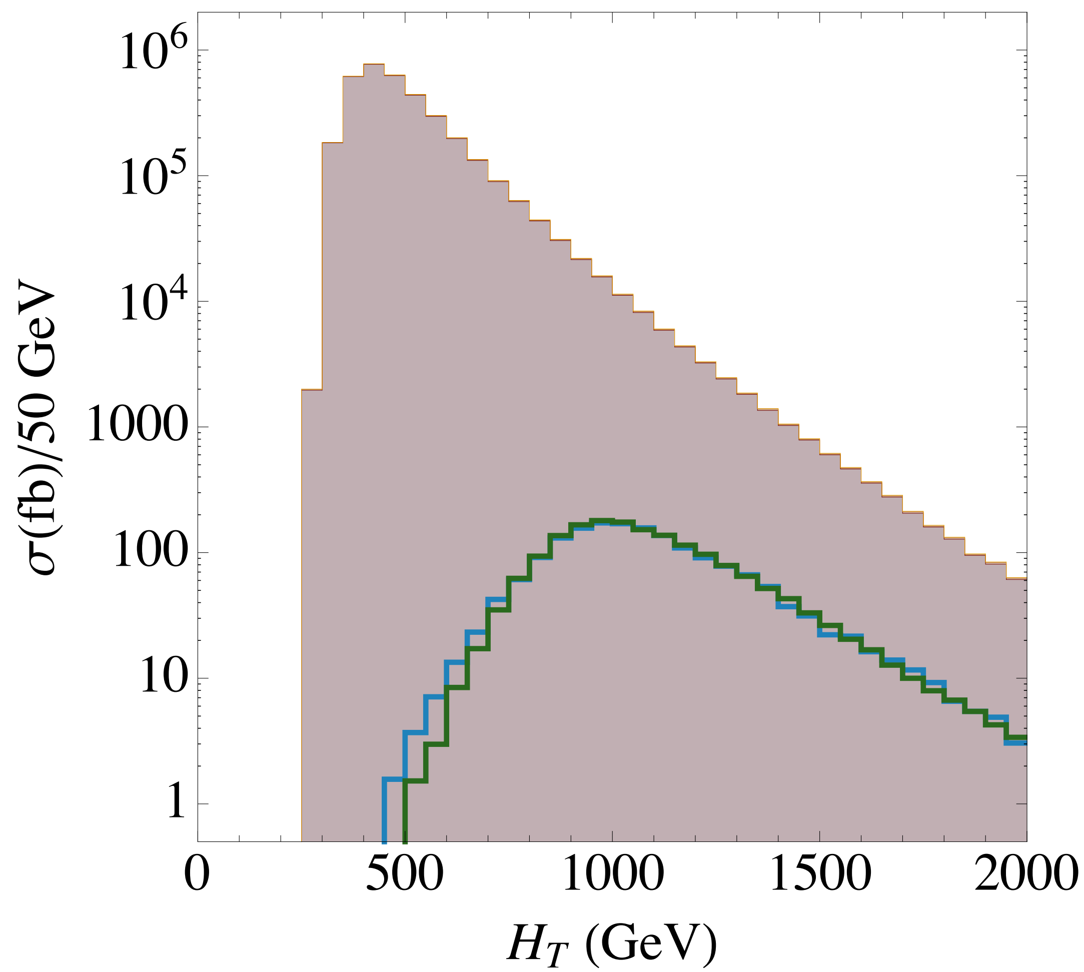
Stealth Susy MET

$\not{E}_T \sim \frac{m_{\tilde{g}}}{2m_{\tilde{S}}}(m_{\tilde{G}} \oplus \delta m_{S\tilde{S}})$ ~30 GeV

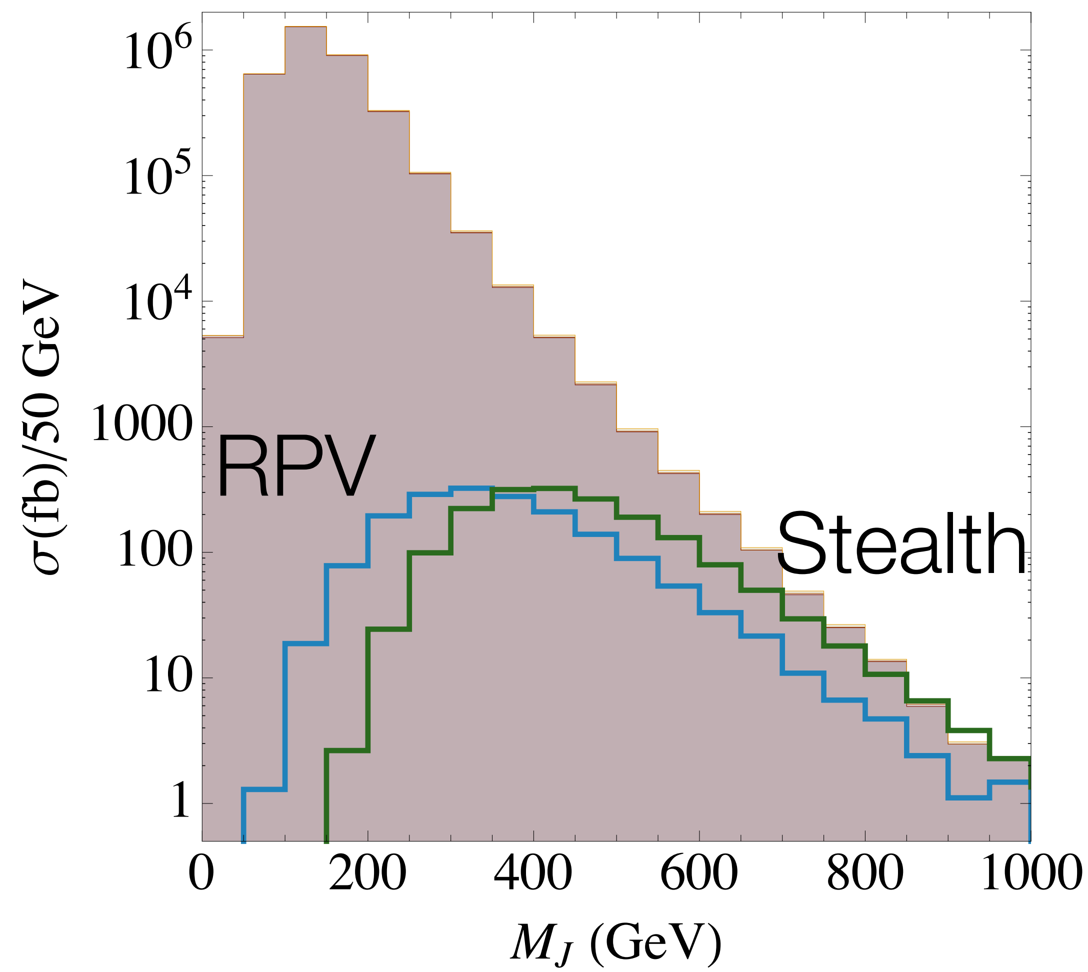


M_J vs H_T

Hopeless



Possible



Reach for Stealth ~ 700 GeV

Reach for RPV ~ 400 GeV

Can do better by looking for resonant structures

Outlook

High Multiplicity Signals are Challenging

M_J can be a powerful new tool

Lots of Techni-Processes

$$pp \to \rho \to \pi\pi \to (t\bar{t})(t\bar{t})$$

$$pp \to \omega \to \pi\pi\pi \to (t\bar{t})(t\bar{t})(t\bar{t})$$

$$pp \to \rho\rho \to (\pi\pi)(\pi\pi) \to ((t\bar{t})(t\bar{t}))((t\bar{t})(t\bar{t}))$$

At High Luminosity, Track Mass may be useful

Could even potentially use as a trigger