Casting a Wide Net for New Physics at the LHC with Jets and Missing Energy

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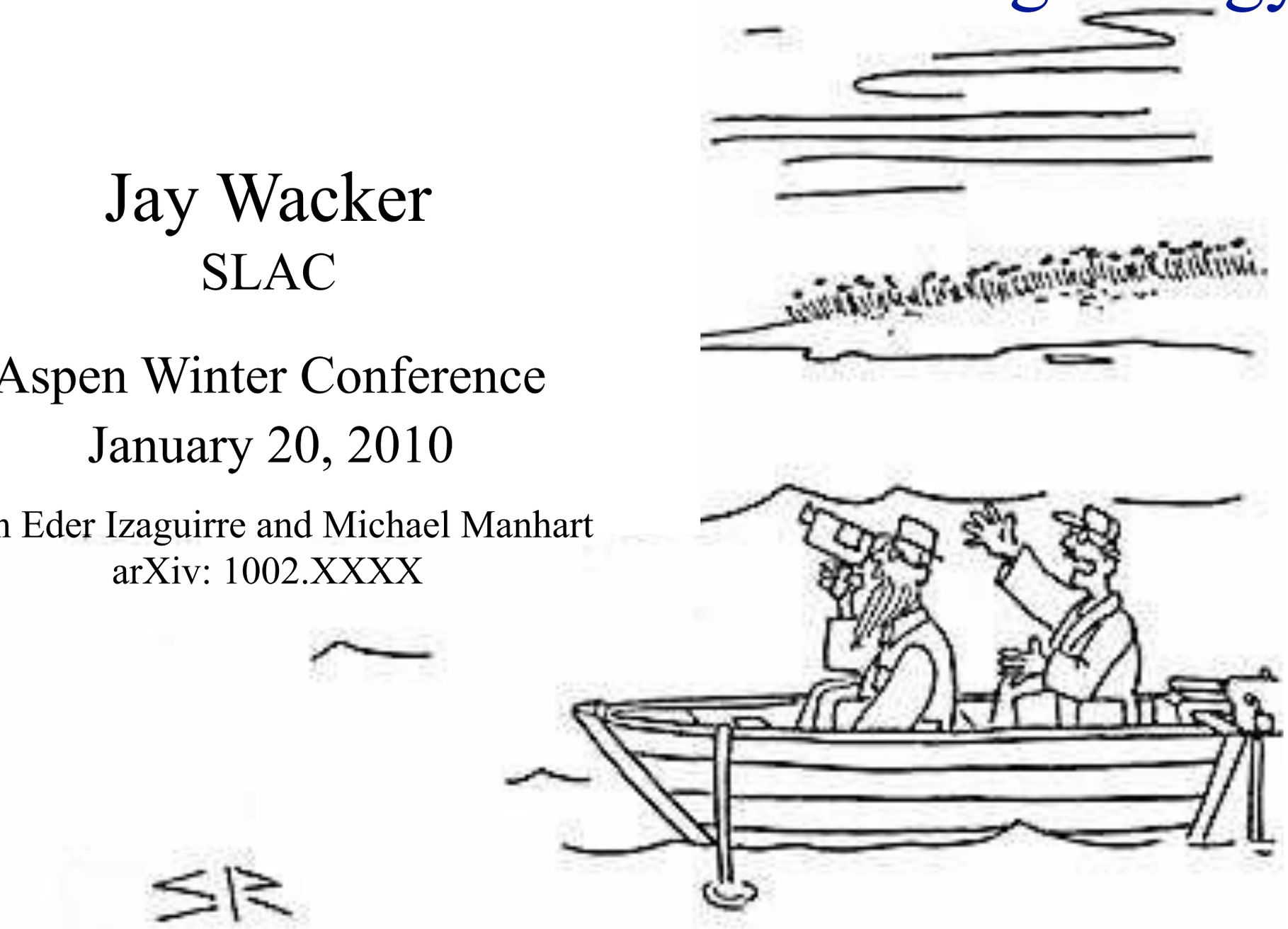
with Eder Izaguirre and Michael Manhart
arXiv: 1002.XXXX



"Well some sea monsters are shy"

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

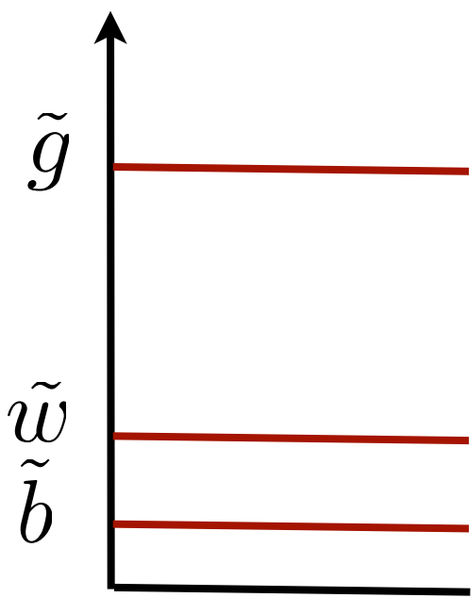
Spectrum in Different Theories

MSSM

High Cut-Off

Large Mass Splittings

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

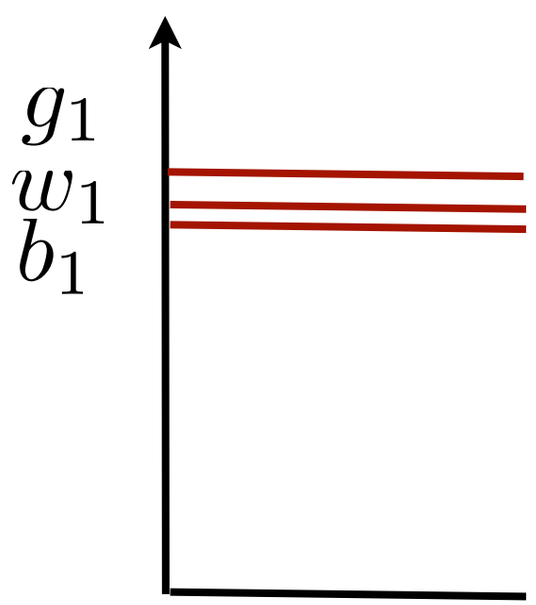


UED

Low Cut-Off

Small Mass Splittings

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



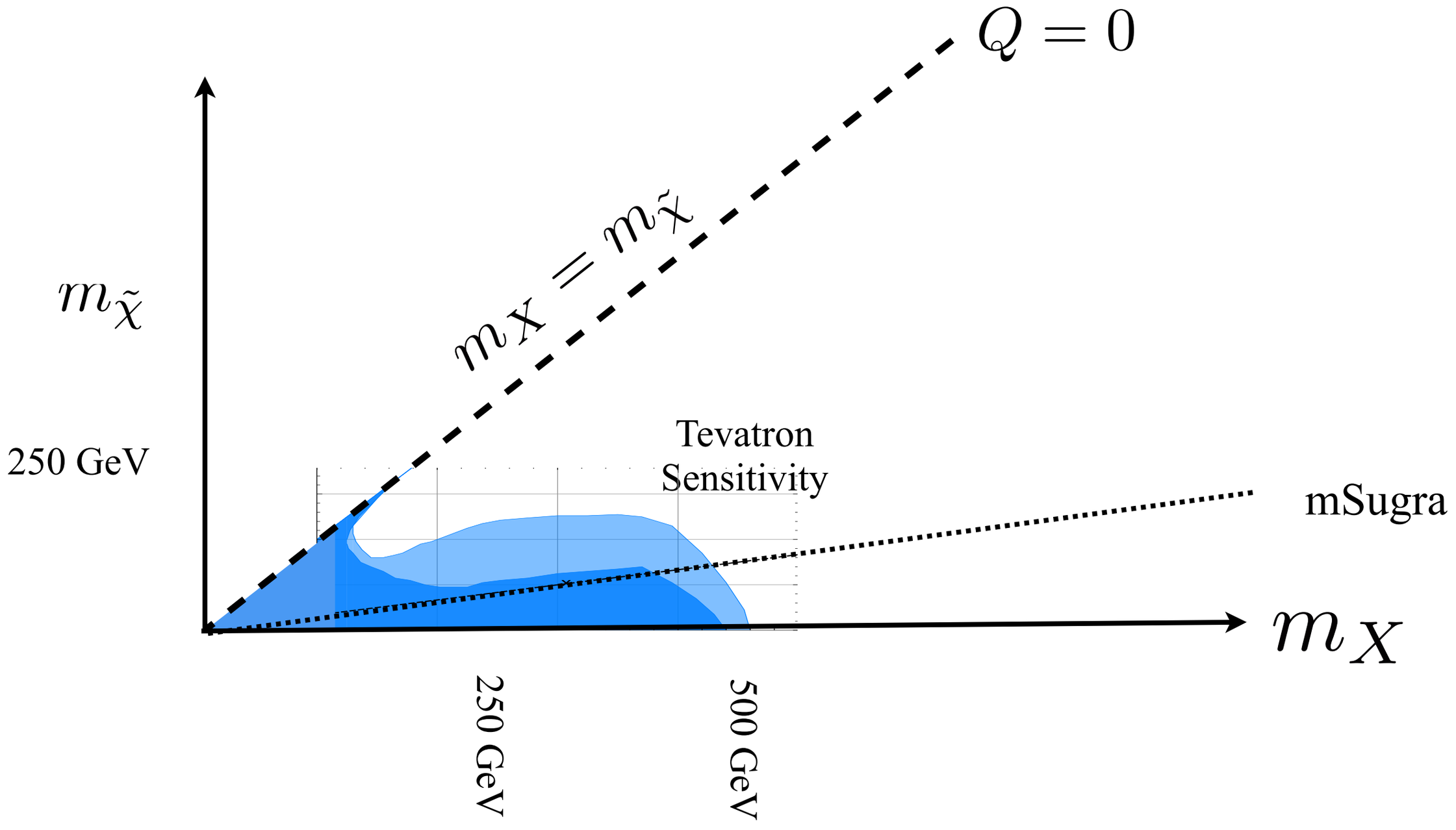
Casting a Wide Net

Kinematics matters more than spin or A-terms

Alwall, Le Lisanti, JW (0803.0019)

$$Q = m_X - m_{\tilde{\chi}}$$

$$X = \tilde{g}, \tilde{q}, ...$$



Plan of Talk

* Distinguishing Signal from Background

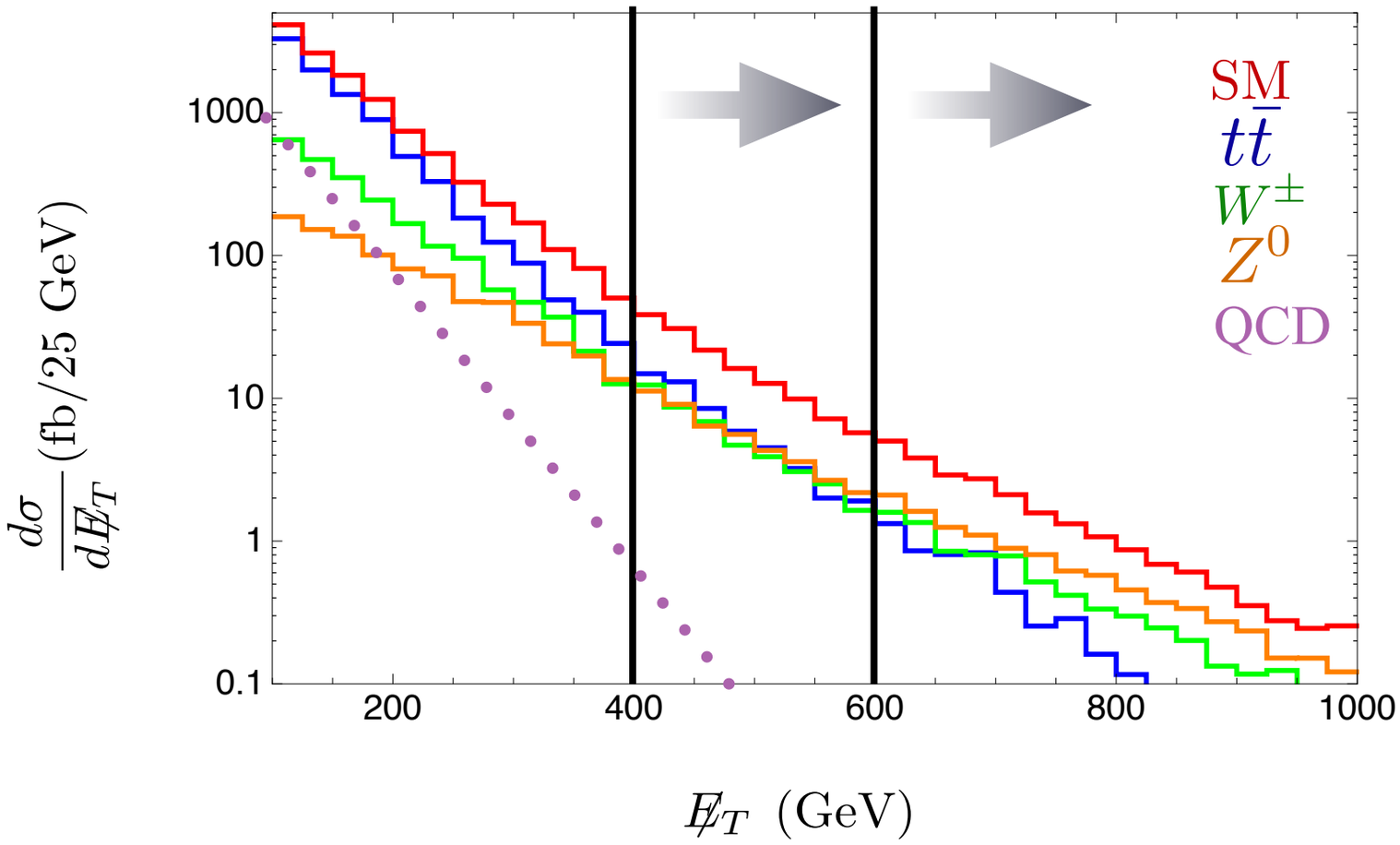
Where the LHC can get to (soon)

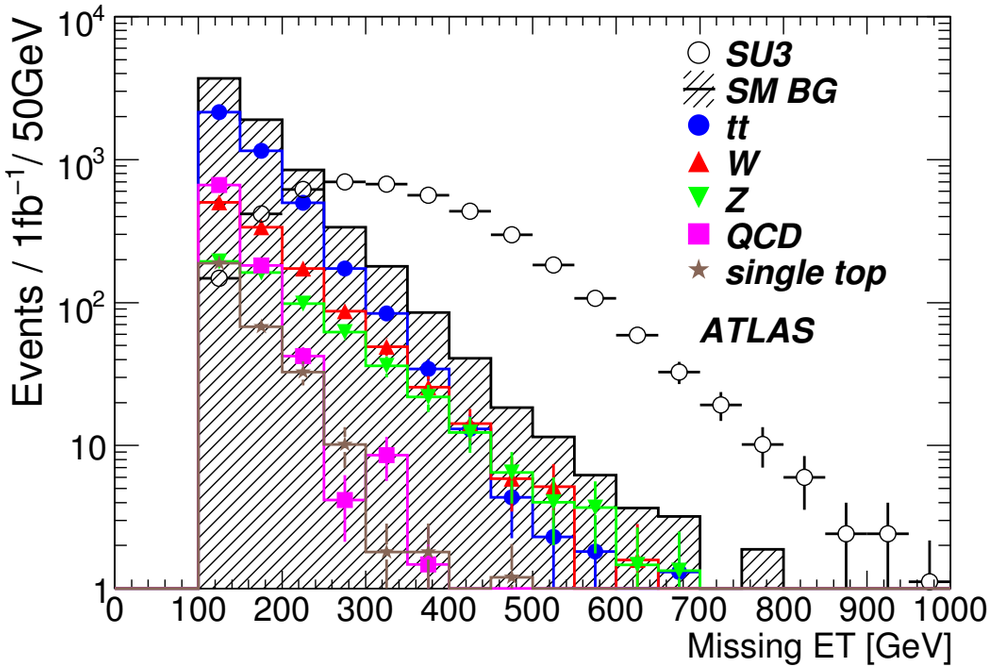
Backgrounds

Madgraph+Pythia ⟶ PGS

(up to $2 \to 4$)

4^{+}jets





Matching crucial to getting MET tail right

Signals

Should use same methods for signals as backgrounds

Signal may be in a different place than expected

Parton Shower - Matrix Element Matching

$pp \to XX + 0j$ $\quad$ $pp \to XX + 1j$ $\quad$ $pp \to XX + 2^{+}j$

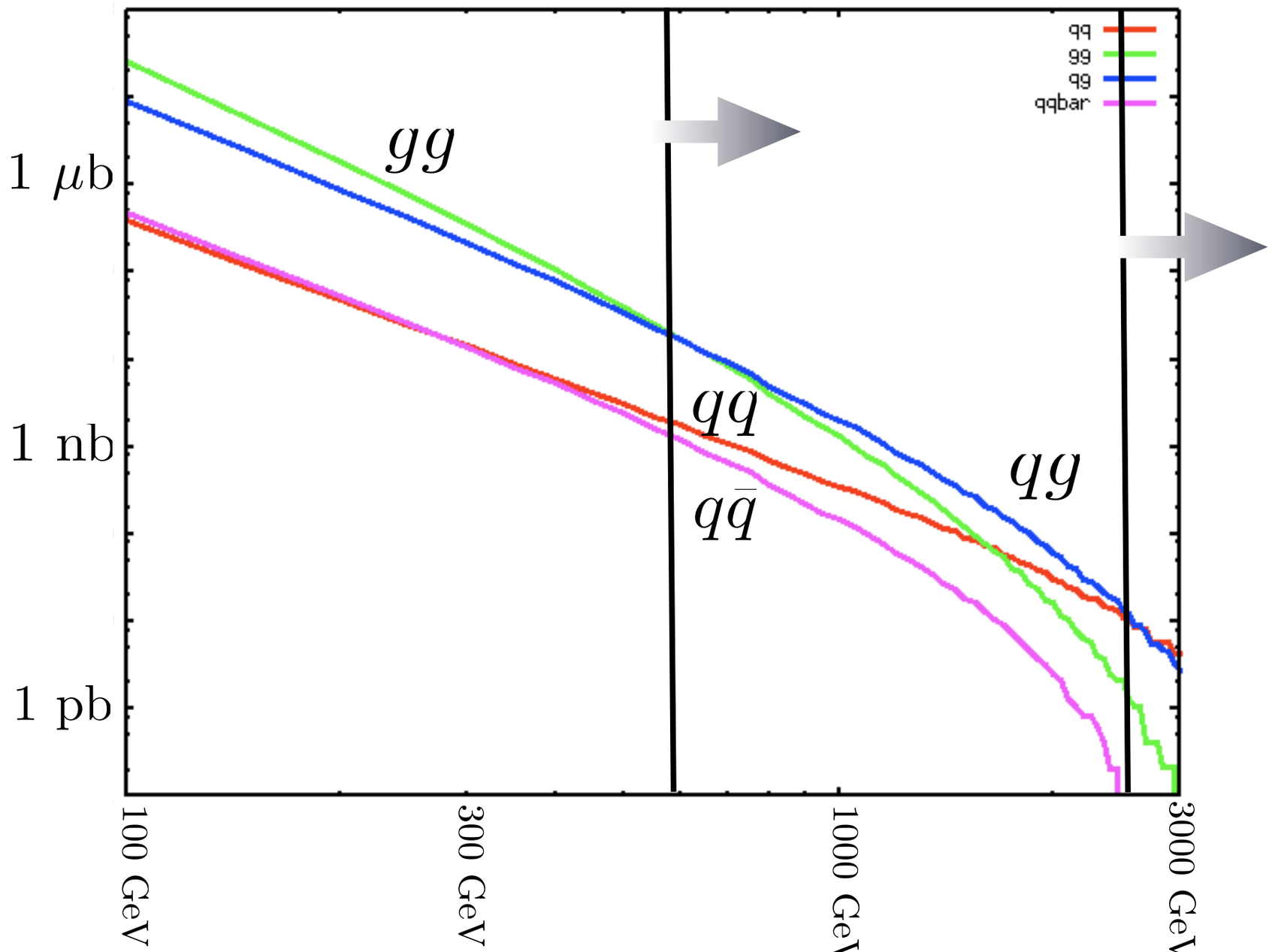
Extra jets aren't a nuisance,
they can qualitatively alter signal

New Initial States

Possible at higher order

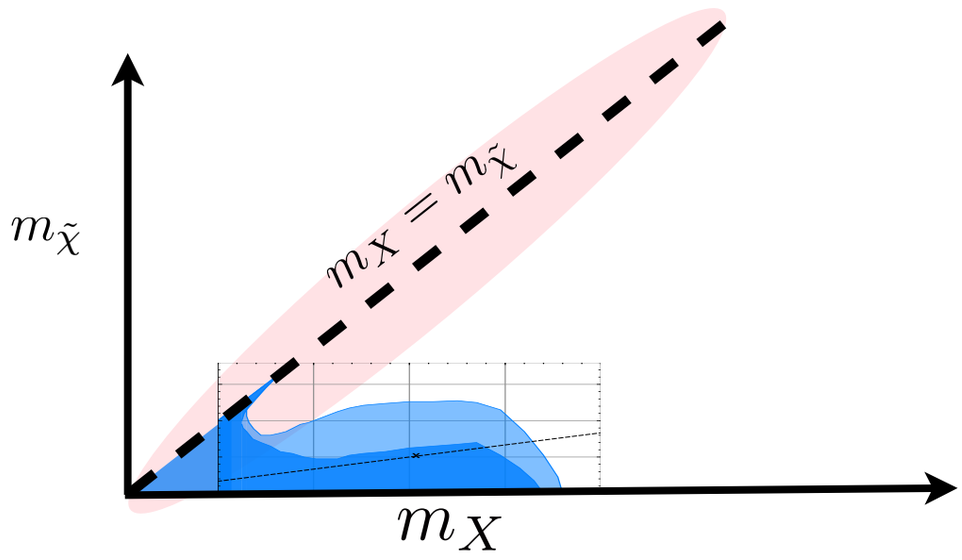
$$gg, q\bar{q} \to 2\tilde{g} + 0^+ j \qquad gq \to 2\tilde{g} + 1^+ j \qquad qq \to 2\tilde{g} + 2^+ j$$

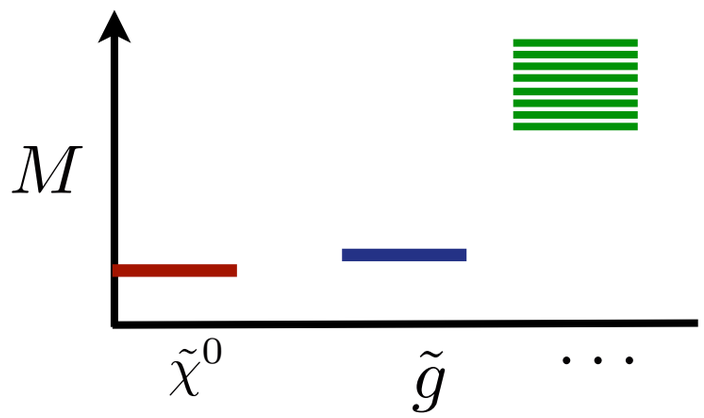
Parton Luminosities



Radiation

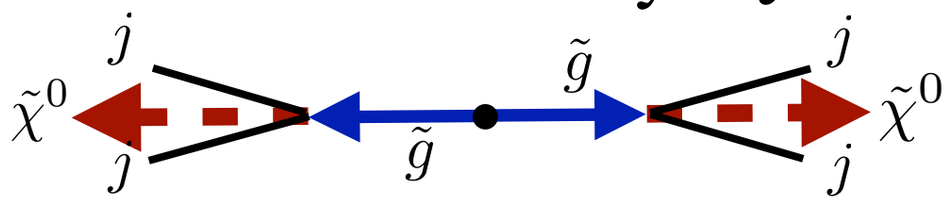
Degenerate spectra require radiation to generate signal





UED-like Theories

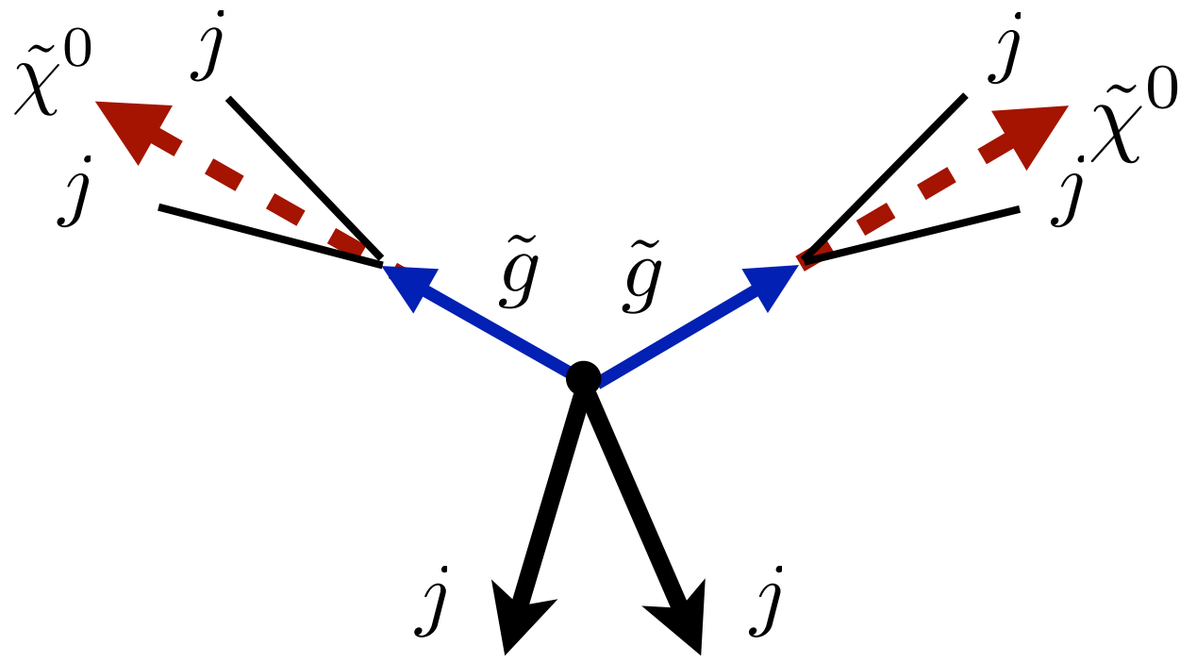
Unbalanced momentum set by $Q = m_{\tilde{g}} - m_{\tilde{\chi}}$



As p_T of gluino increases,
Final state jets get harder (and eventually merge),
but won't gain significant MET

Radiation

Radiation unbalances LSP's momentum



MET is generated by radiated jets

Without extra jets, signal is invisible

Spectrum of Radiation Harder for New Physics

When LSP is heavy $s_{\rm S} \gg s_{\rm BG}$

(rest mass of LSP is unobservable)

Cross section for background is large due to lower SM CM energy

Spectrum of Radiation Harder for New Physics

Consider the additional cost of energy for radiating a jet off a particle, X, of mass m

$$p_j^\mu = (E_j, E_j) \qquad p_X^\mu = \left(\sqrt{m^2 + E_j^2}, -E_j\right)$$

$$\delta\sqrt{s}(E_j) = E_j + \sqrt{m^2 + E_j^2} - m \;= \begin{cases} E_j & m \gg E_j \\ 2E_j & m \ll E_j \end{cases}$$

Identify $m \to \sqrt{s}$

Spectrum of Radiation Harder for New Physics

When LSP is heavy $s_{\rm S} \gg s_{\rm BG}$

(rest mass of LSP is unobservable)

Cross section for background is large due to lower SM CM energy

Radiate off a jet with $E_j \sim \sqrt{s}_{\rm S}$

$$\delta\sqrt{s}(E_j) = \begin{cases} E_j & E_j \ll \sqrt{s} \\ 2E_j & E_j \gg \sqrt{s} \end{cases}$$

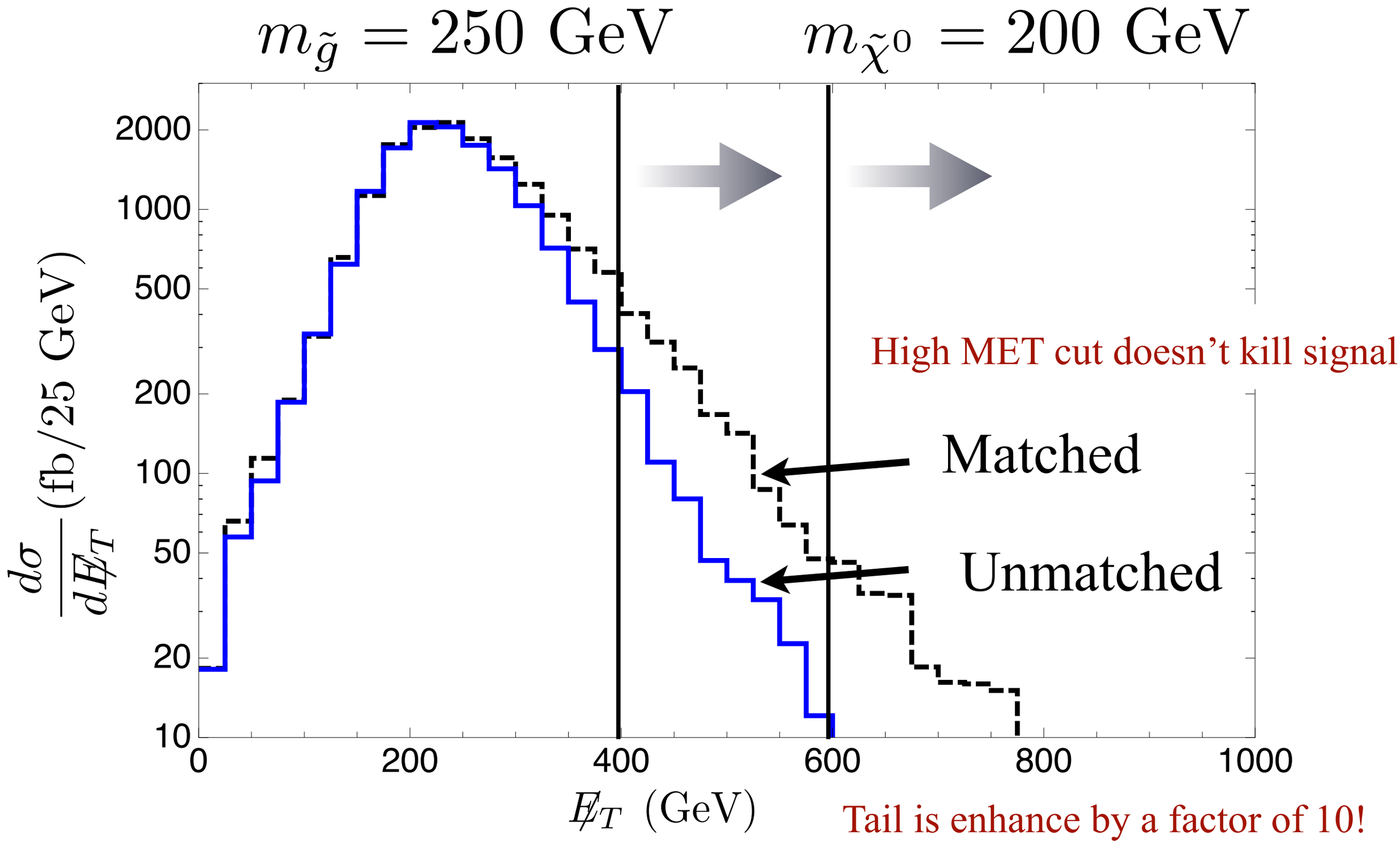
$$\sqrt{s}_{\rm S+j} \simeq \sqrt{s}_{\rm S} + E_j \qquad \sqrt{s}_{\rm BG+j} \simeq \sqrt{s}_{\rm BG} + 2E_j$$

$$s_{\rm S+j} \simeq s_{\rm BG+j}$$

Equalizes CM energy for signal and background
Increases S/B significantly

Works at the LHC because we're beyond last SM threshold

An Example



High MET cut doesn't kill signal

Tail is enhance by a factor of 10!

Plan of Talk

Distinguishing Signal from Background

* Where the LHC can get to (soon)

Multijet Universality

	Selection Criteria for Different Jet Multiplicity Searches			
	$1j + \not{E}_T$	$2j + \not{E}_T$	$3j + \not{E}_T$	$4^+j + \not{E}_T$
j_1	≥ 400 GeV	≥ 100 GeV	≥ 100 GeV	≥ 100 GeV
j_2	< 50 GeV	≥ 50 GeV	≥ 50 GeV	≥ 50 GeV
j_3	< 50 GeV	< 50 GeV	≥ 50 GeV	≥ 50 GeV
j_4	< 50 GeV	< 50 GeV	< 50 GeV	≥ 50 GeV

Never found lower jet multiplicity to significantly enhance discovery

Degenerate spectra

Light Squarks, Heavy Gluinos

Tried many different event shape variables and search strategies

Qualitatively different than the Tevatron

3 Searches

High MET $\not{E}_T > 600$ GeV $H_T > \begin{cases} 900 \text{ GeV} \\ 1200 \text{ GeV} \end{cases}$

Gluinos, Squarks & Degenerate Spectra

Alpha $\not{E}_T > 400$ GeV $\alpha > 0.20$ $H_T > \begin{cases} 600 \text{ GeV} \\ 900 \text{ GeV} \\ 1200 \text{ GeV} \end{cases}$

Gluinos, Squarks

Mid MET $\not{E}_T > 400$ GeV $H_T > \begin{cases} 600 \text{ GeV} \\ 900 \text{ GeV} \\ 1200 \text{ GeV} \end{cases}$

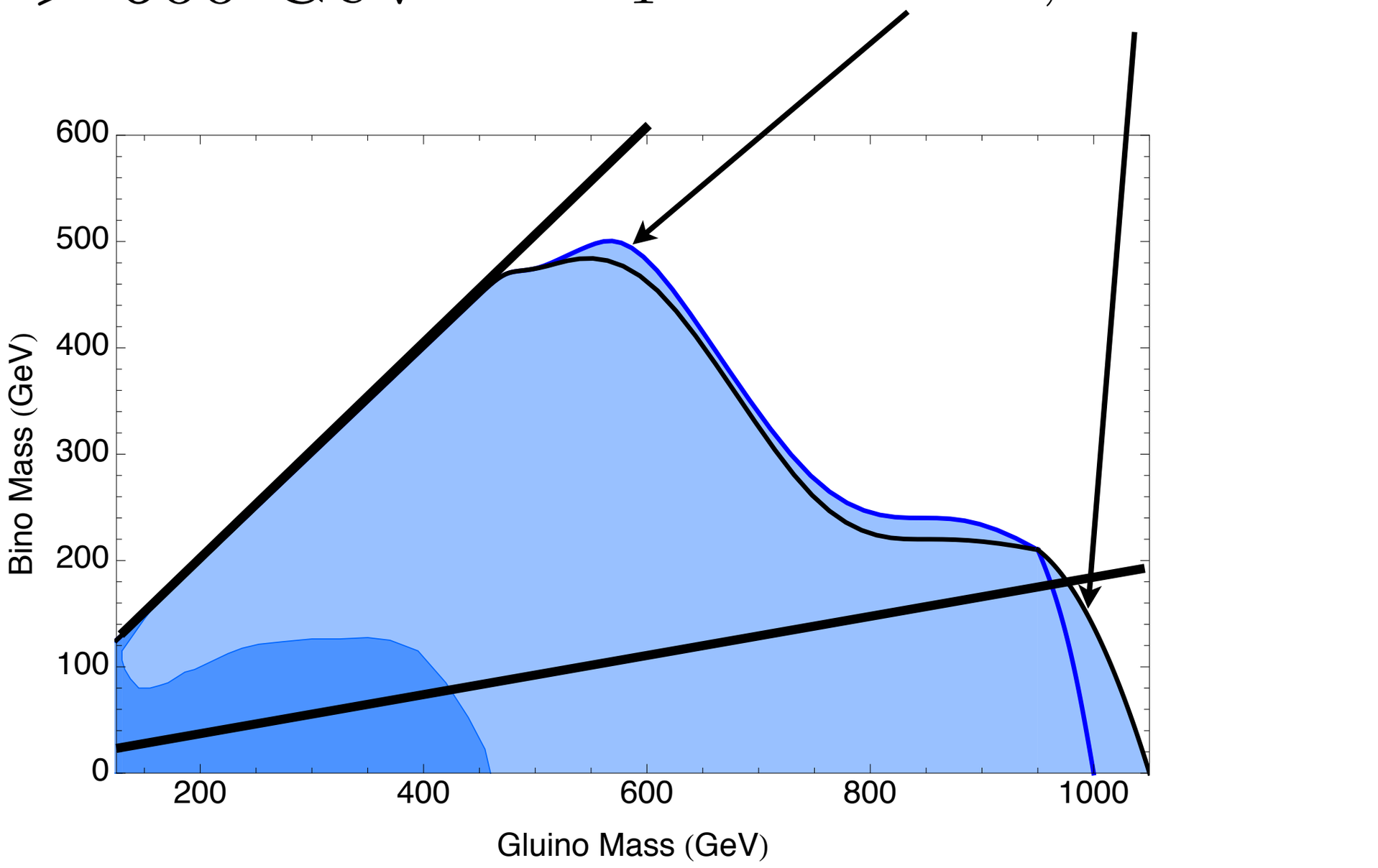
Cascade Decays

The Searches

$$pp \to \tilde{g}\tilde{g} + X \to (q\bar{q}\tilde{\chi}^0)(q\bar{q}\tilde{\chi}^0) + X$$

High MET Search

$\not{E}_T > 600$ GeV $H_T > 900$ GeV, 1200 GeV

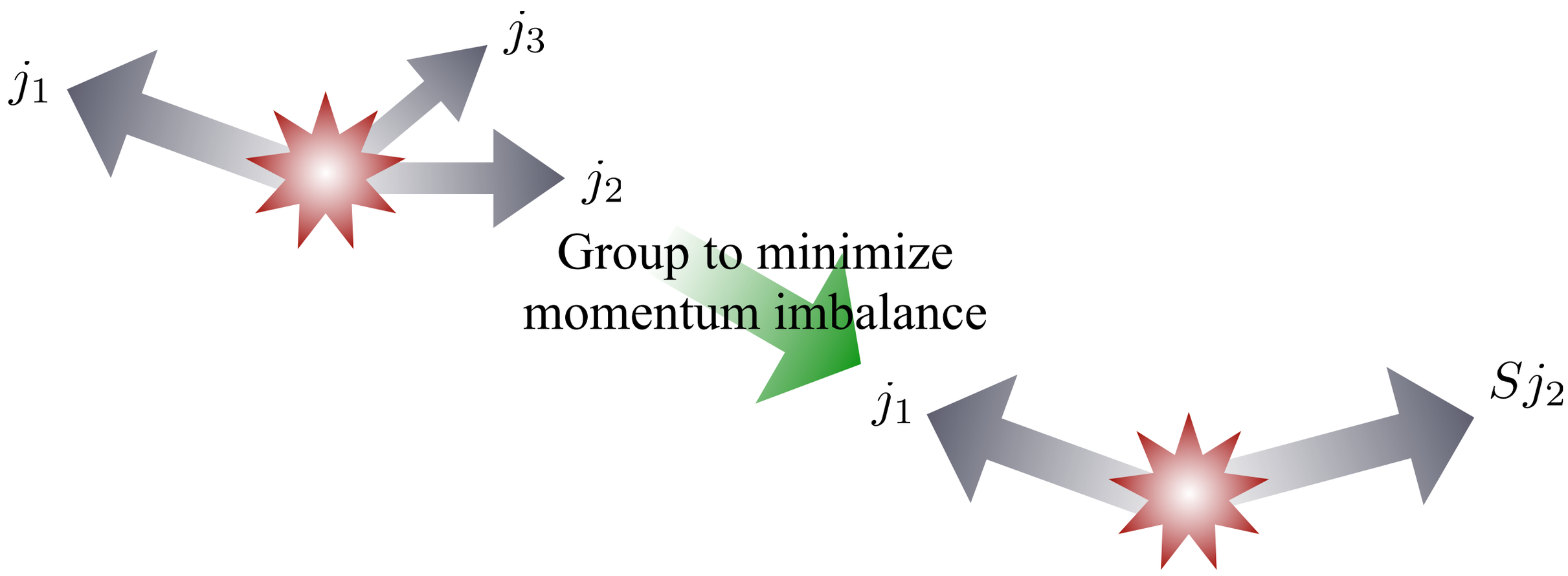


The Alpha Variable

Introduced by L. Randall & D. Tucker-Smith

$$\alpha = \frac{p_{Tj_2}}{m_{j_1 j_2}} \simeq \sqrt{\frac{p_{Tj_2}}{p_{Tj_1}(1 - \cos\theta_{j1j2})}}$$

Modified by CMS to multijet searches



Discovery Reach

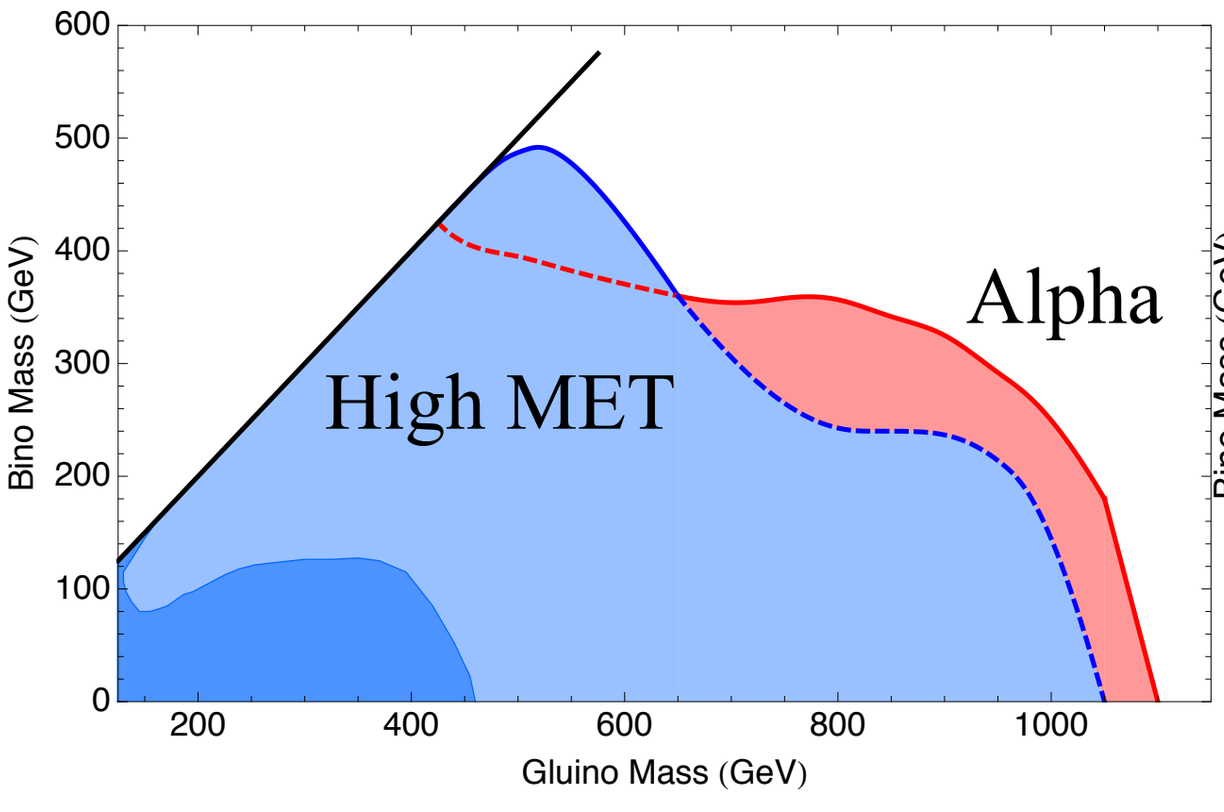
Alpha Search

$$\not{E}_T > 400 \text{ GeV} \quad H_T > 600 \text{ GeV}, 900 \text{ GeV}, 1200 \text{ GeV}$$

$$\alpha > 0.20$$

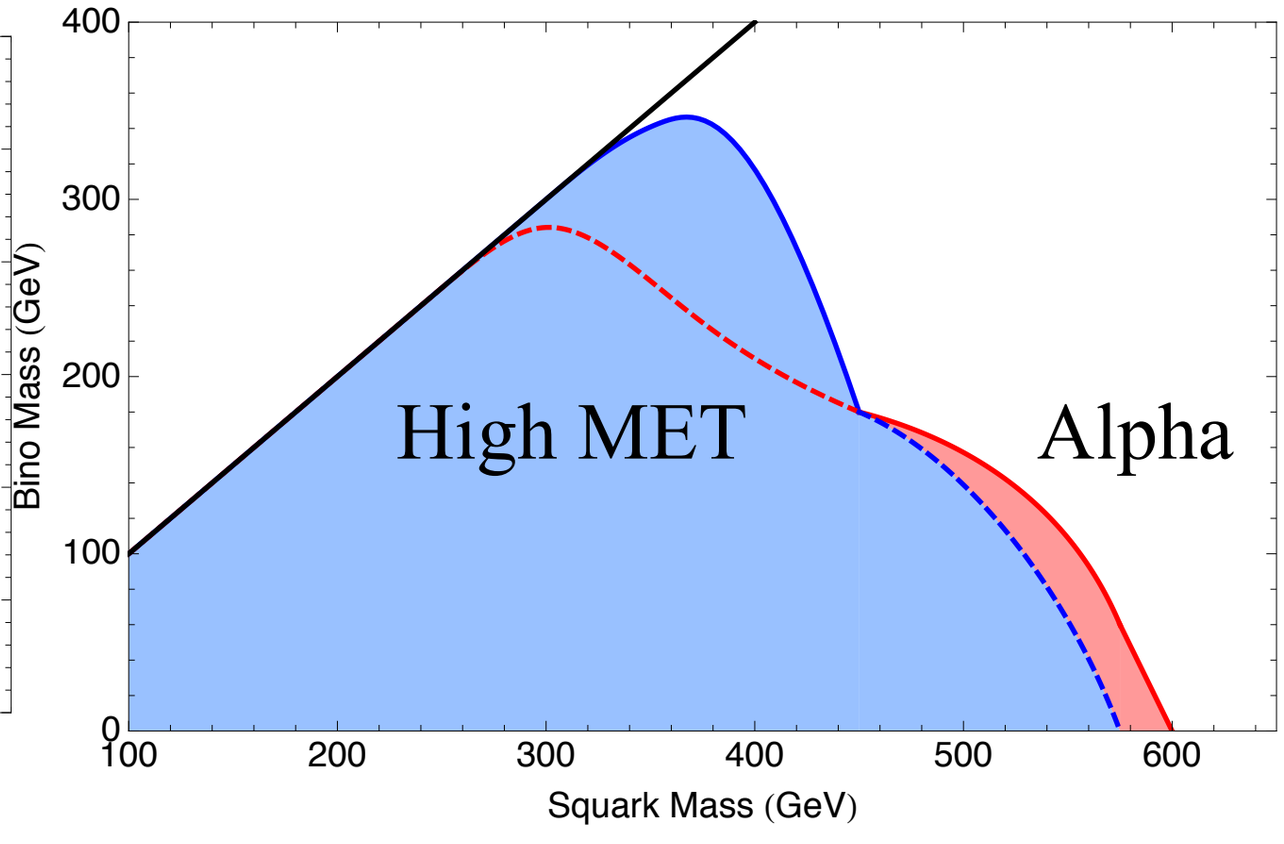
Directly decaying gluinos

$$pp \to \tilde{g}\tilde{g} + X \to (q\bar{q}\tilde{\chi}^0)(q\bar{q}\tilde{\chi}^0) + X$$



Directly decaying Squarks

$$pp \to \tilde{q}\tilde{q} + X \to (q\tilde{\chi}^0)(\bar{q}\tilde{\chi}^0) + X$$



Multijet still more effective than dije

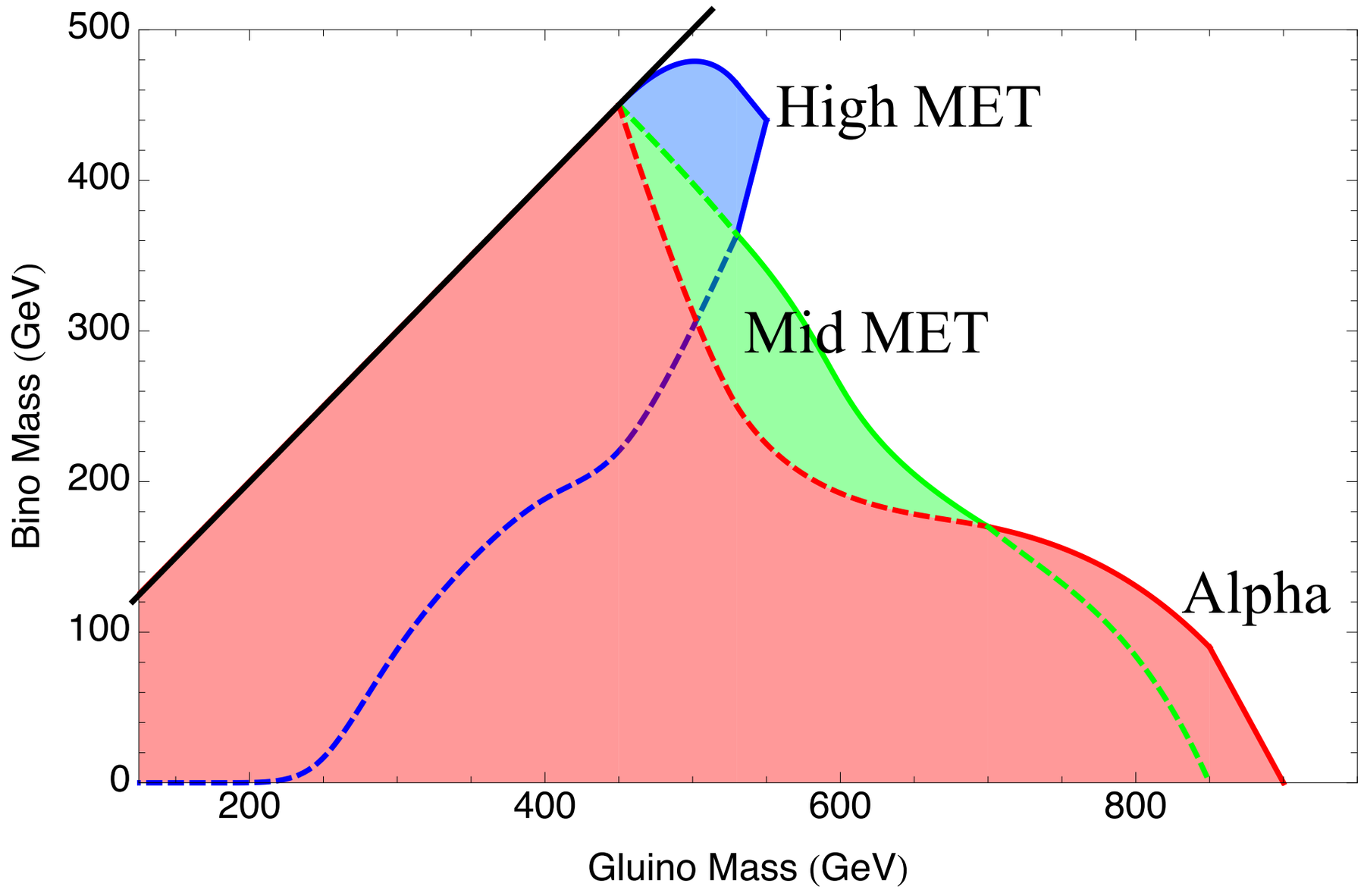
Cascade Decays

$$\tilde{g} \rightarrow q\bar{q}\chi'^0 \rightarrow q\bar{q}(q\bar{q}\chi^0)$$

Lowers MET in Events

Mid MET Search

$$\not{E}_T > 400 \text{ GeV} \quad H_T > 600 \text{ GeV}, 900 \text{ GeV}, 1200 \text{ GeV}$$



Extended Cascade Decays

$$\tilde{g} \to q\bar{q}\chi'' \to (q\bar{q})q\bar{q}\chi' \to (q\bar{q})(q\bar{q})q\bar{q}\chi$$

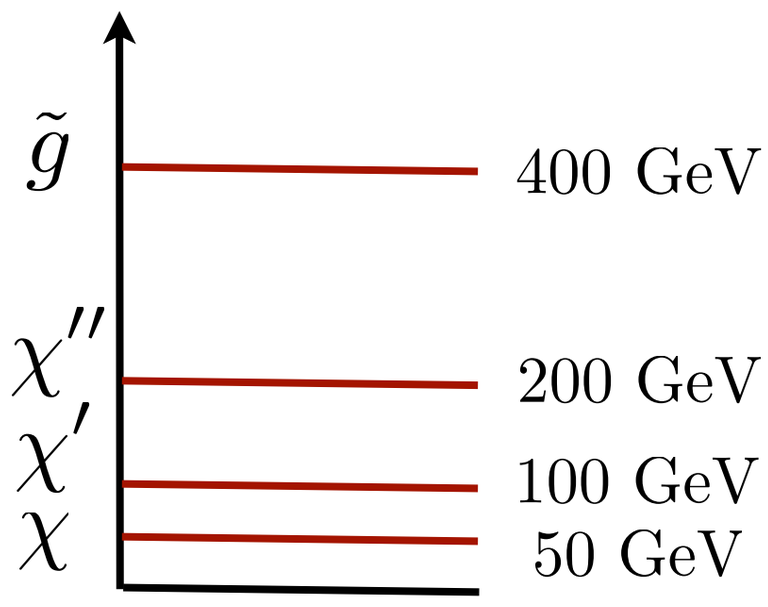
LSP is great-granddaughter

Momentum is divided many different ways

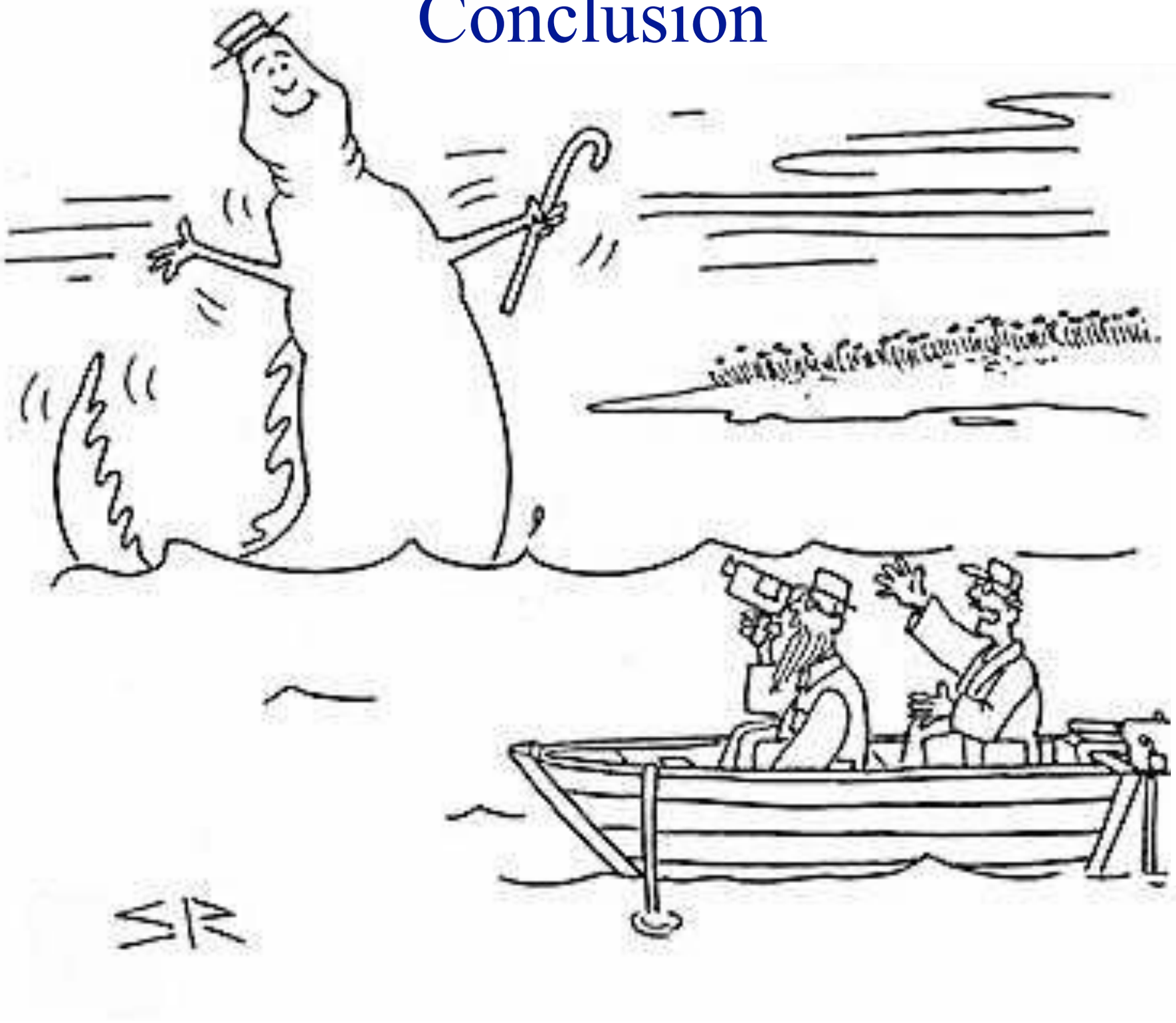
Reduces MET dramatically

Need a low MET search $\not{E}_T > 200$ GeV

Worse case scenario

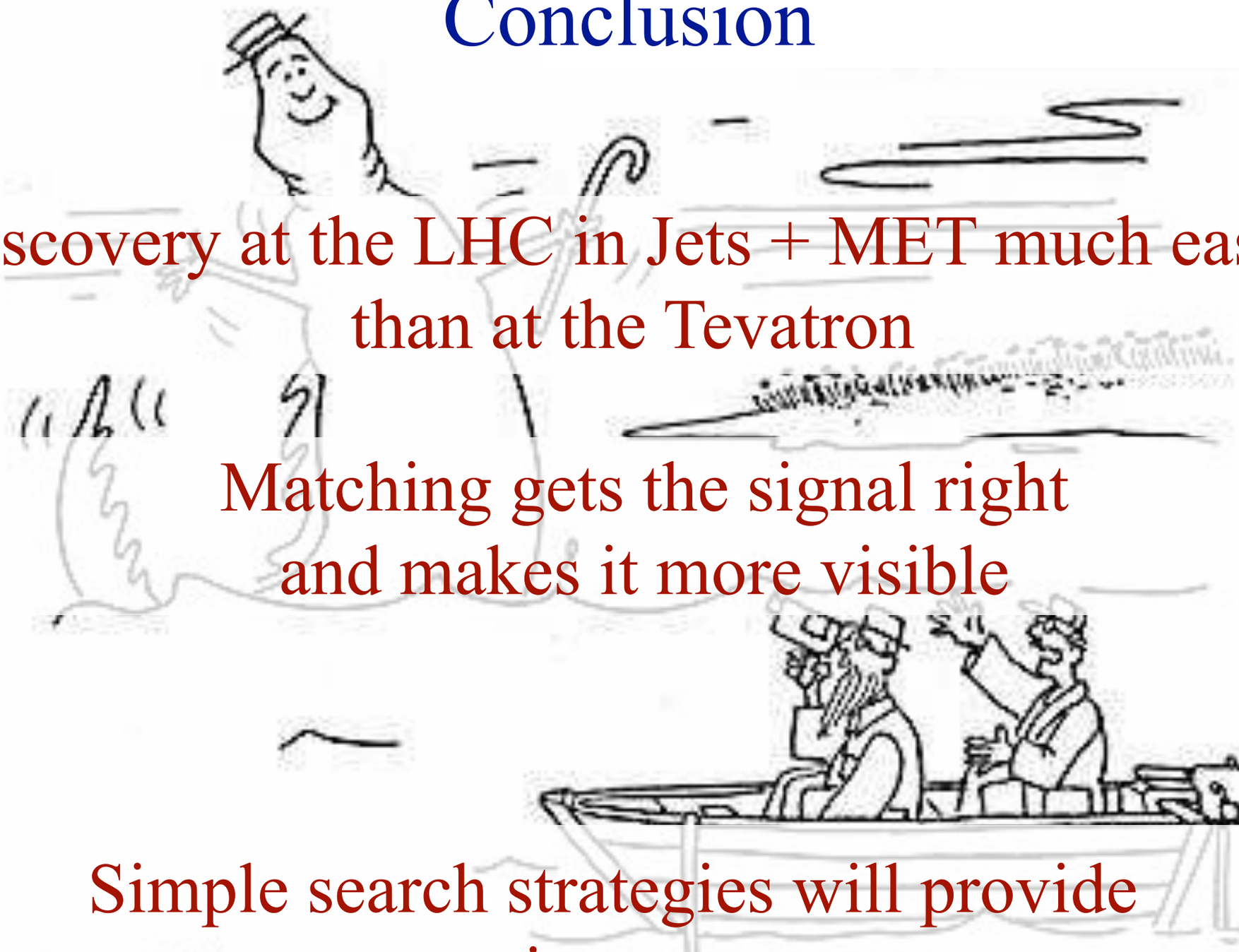


Conclusion



“Well some sea monsters are shy, but not our Walter.”

Conclusion



Discovery at the LHC in Jets + MET much easier than at the Tevatron

Matching gets the signal right and makes it more visible

Simple search strategies will provide extensive coverage

"Well some sea monsters are shy, but not our Walter."