Jets + MET at the Tevatron

Jay Wacker

SLAC

February 20, 2007

Work in progress with

D.E.Kaplan, A. Pierce, N. Craig, M. Lisanti, M-P. Le

2007 beginning a new era of physics

2007 beginning a new era of physics

	Tevatron	LHC
$\sqrt{s}$	1.96 TeV	14 TeV

2007 beginning a new era of physics

	Tevatron	LHC
$\sqrt{s}$	1.96 TeV	14 TeV
$\mathcal{L}$	$0.05\ \mathrm{fb}^{-1}/\mathrm{yr}$	$0.5\ \mathrm{fb}^{-1}/\mathrm{yr}$ (???)
	$\rightarrow 2\ \mathrm{fb}^{-1}/\mathrm{yr}$	$\rightarrow 30\ \mathrm{fb}^{-1}/\mathrm{yr}$

2007 beginning a new era of physics

	Tevatron	LHC
$\sqrt{s}$	1.96 TeV	14 TeV
$\mathcal{L}$	$0.05\ \mathrm{fb}^{-1}/\mathrm{yr}$	$0.5\ \mathrm{fb}^{-1}/\mathrm{yr}$ (???)
	$\rightarrow 2\ \mathrm{fb}^{-1}/\mathrm{yr}$	$\rightarrow 30\ \mathrm{fb}^{-1}/\mathrm{yr}$
m_{new}	$50\ \mathrm{GeV} \rightarrow 400\ \mathrm{GeV}$	$100\ \mathrm{GeV} \rightarrow 3500\ \mathrm{GeV}$

2007 beginning a new era of physics

	Tevatron	LHC
$\sqrt{s}$	1.96 TeV	14 TeV
$\mathcal{L}$	$0.05\ \mathrm{fb}^{-1}/\mathrm{yr}$	$0.5\ \mathrm{fb}^{-1}/\mathrm{yr}$ (???)
	$\rightarrow 2\ \mathrm{fb}^{-1}/\mathrm{yr}$	$\rightarrow 30\ \mathrm{fb}^{-1}/\mathrm{yr}$
m_{new}	50 GeV $\rightarrow$ 400 GeV	100 GeV $\rightarrow$ 3500 GeV
σ_{prod}	10 fb	1 fb

2007 beginning a new era of physics

	Tevatron	LHC
$\sqrt{s}$	1.96 TeV	14 TeV
$\mathcal{L}$	$0.05\ \mathrm{fb}^{-1}/\mathrm{yr}$	$0.5\ \mathrm{fb}^{-1}/\mathrm{yr}$ (???)
	$\rightarrow 2\ \mathrm{fb}^{-1}/\mathrm{yr}$	$\rightarrow 30\ \mathrm{fb}^{-1}/\mathrm{yr}$
m_{new}	50 GeV $\rightarrow$ 400 GeV	100 GeV $\rightarrow$ 3500 GeV
σ_{prod}	10 fb	1 fb
σ_{tot}	100mb	100mb

Tevatron

Machine is working great

Understand detectors

Searches are similar at the LHC

Tevatron

Machine is working great

Understand detectors

Searches are similar at the LHC

Many signatures involving jets

Tevatron

Machine is working great

Understand detectors

Searches are similar at the LHC

Many signatures involving jets

Nj

$Nj + \not{E}_T$

$Nj + \not{E}_T + W^{\pm}, Z^0$

$Nj + \not{E}_T + \gamma$

$Nj + \not{E}_T + \ell^{\pm}\ell^{\pm}$

Difficult to make sure that all
new physics is being looked for

MSSM has sense of generality

Has particles of all gauge and flavor quantum numbers

Reasonably useful to extensively explore this model for discovery signals

(TeV-scale Extra Dimensions also general framework for searching for collider signals)

Outline

Jets + MET as a signal of new physics

Backgrounds

Existing Searches

A 70 GeV Gluino!??

Going Forward

Jets + MET familiar from Susy

Have highest reach for coloured particles

$p\bar{p} \rightarrow \tilde{q}\tilde{q}$

$\tilde{q} \rightarrow \chi_1^0 + q$ 2 jets + MET

$p\bar{p} \rightarrow \tilde{g}\tilde{g}$

$\tilde{g} \rightarrow \tilde{q} + q$

$\tilde{q} \rightarrow \chi_1^0 + q$ 4 jets + MET

Jets + MET familiar from Susy

Have highest reach for coloured particles

$p\bar{p} \rightarrow \tilde{q}\tilde{q}$

$\tilde{q} \rightarrow \chi_1^0 + q$ 2 jets + MET

$p\bar{p} \rightarrow \tilde{g}\tilde{g}$

$\tilde{g} \rightarrow \tilde{q} + q$

$\tilde{q} \rightarrow \chi_1^0 + q$ 4 jets + MET

adding in cascades are more model dependent

Jets + MET familiar from Susy

Have highest reach for coloured particles

$$p\bar{p} \to 3^{\text{new}}\, 3^{\text{new}}$$

$$3^{\text{new}} \to 1^{\text{stable}}_{\text{new}} + q \qquad \text{2 jets + MET}$$

$$p\bar{p} \to 8^{\text{new}}\, 8^{\text{new}}$$

$$8^{\text{new}} \to 1^{\text{stable}}_{\text{new}} + g \qquad \text{2 jets + MET}$$

$$8^{\text{new}} \to 1^{\text{stable}}_{\text{new}} + \bar{q}q \qquad \text{4 jets + MET}$$

adding in cascades are more model dependent

Jets + MET familiar from Susy

Have highest reach for coloured particles

$$p\bar{p} \to 3^{\text{new}}\, 3^{\text{new}}$$

$$3^{\text{new}} \to 1^{\text{stable}}_{\text{new}} + q \qquad \text{2 jets + MET}$$

$$p\bar{p} \to 8^{\text{new}}\, 8^{\text{new}}$$

$$8^{\text{new}} \to 1^{\text{stable}}_{\text{new}} + g \qquad \text{2 jets + MET}$$

$$8^{\text{new}} \to 1^{\text{stable}}_{\text{new}} + \bar{q}q \qquad \text{4 jets + MET}$$

Heavy flavor possibilities

Jets + MET many backgrounds

Harder than leptons but less model dependent

$Z^0 + n\,j$ $\qquad$ $W^{\pm} + n\,j$

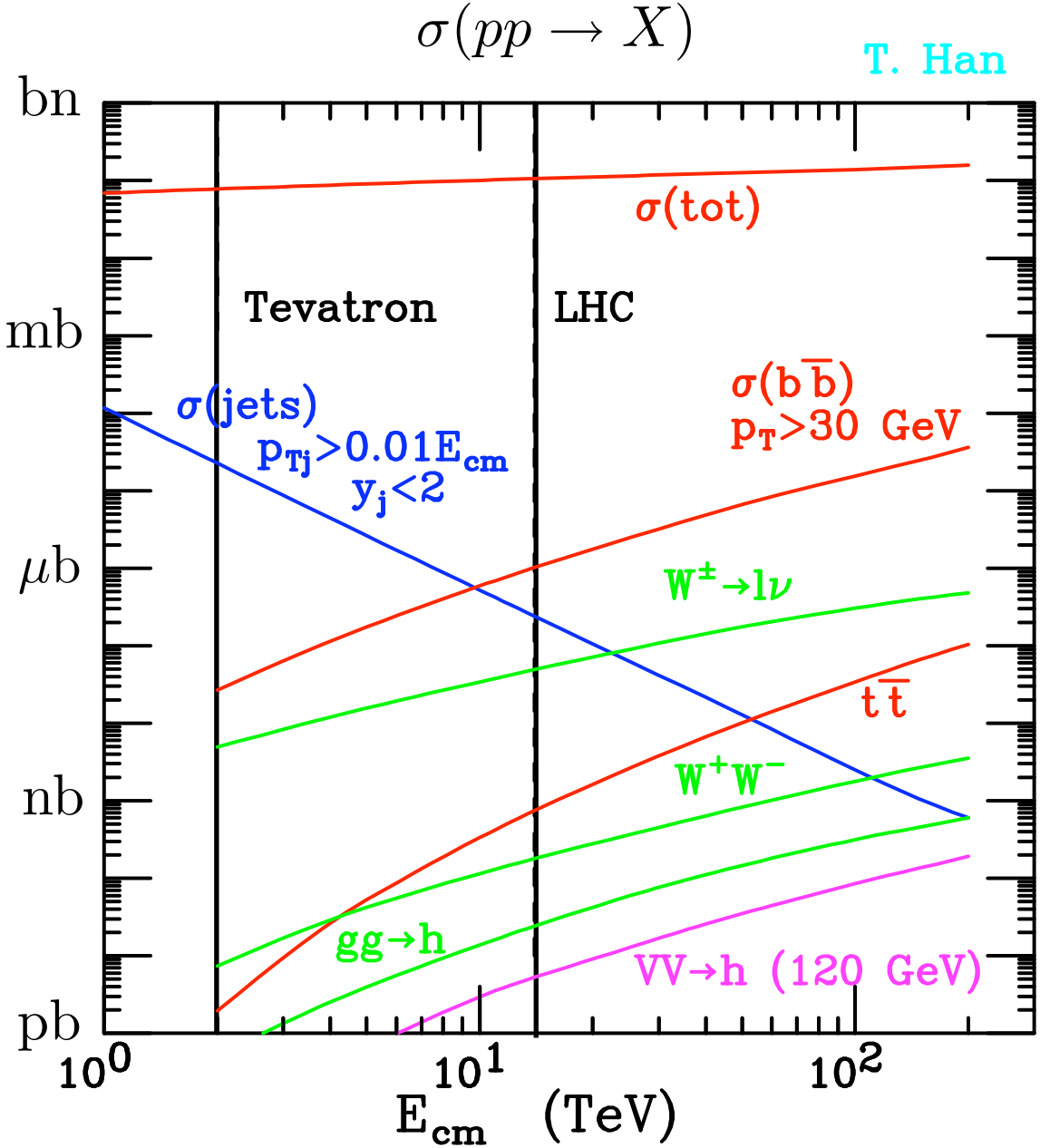
$t\,\bar{t}$

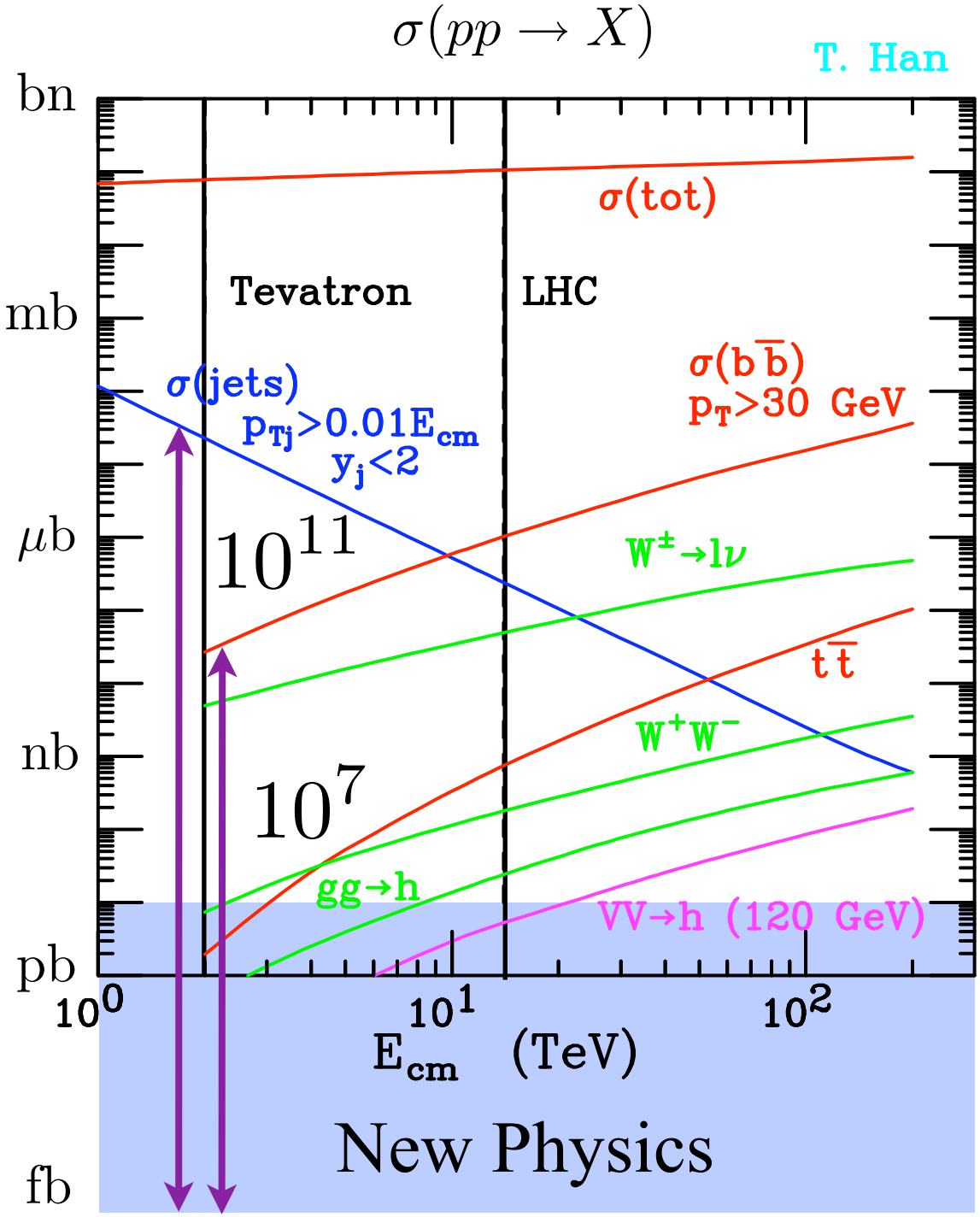
Di-boson

Single top

"QCD"

Tight Cuts Needed


$\sigma(pp \to X)$
T. Han
bn
mb
μb
nb
pb
Tevatron
LHC
σ(tot)
σ(jets)
$p_{Tj}>0.01E_{cm}$
$y_j<2$
$\sigma(b\bar{b})$
$p_T>30$ GeV
$W^{\pm}\to l\nu$
$t\bar{t}$
W^+W^-
gg→h
VV→h (120 GeV)
10^0
10^1
10^2
E_{cm} (TeV)


$\sigma(pp \to X)$
T. Han
bn
mb
μb
nb
pb
fb
Tevatron
LHC
σ(tot)
σ(jets)
$p_{Tj}>0.01E_{cm}$
$y_j<2$
10^{11}
10^7
$\sigma(b\bar{b})$
$p_T>30$ GeV
$W^{\pm}\to l\nu$
$t\bar{t}$
W^+W^-
gg→h
VV→h (120 GeV)
10^0
10^1
10^2
E_{cm} (TeV)
New Physics

"QCD"

Jet energy resolution

$$\Delta E \sim c_0 \oplus c_1 \left(\frac{E}{\mathrm{GeV}}\right)^{\frac{1}{2}} \oplus c_2 \left(\frac{E}{\mathrm{GeV}}\right)$$

$c_0 \sim 3$ GeV $\quad$ $c_1 \sim 1$ GeV $\quad$ $c_2 \sim 10^{-2}$ GeV

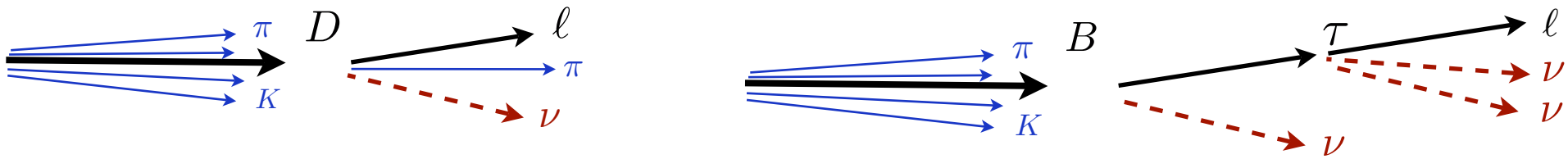
$E_j = 100$ GeV $\Rightarrow \Delta E_j \sim 10$ GeV

50 GeV mismeasurement $\quad 5\sigma$

Non-gaussian tails

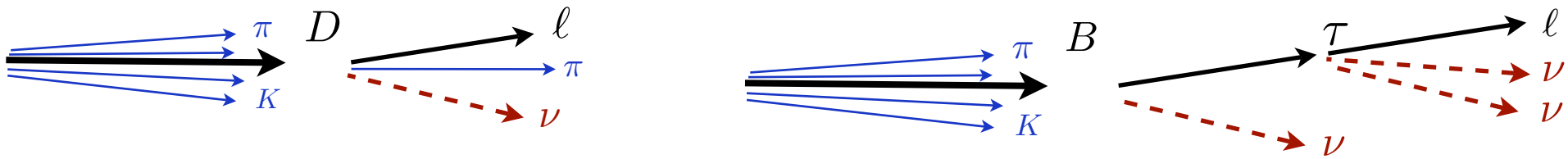
“QCD”

Neutrinos from heavy flavours



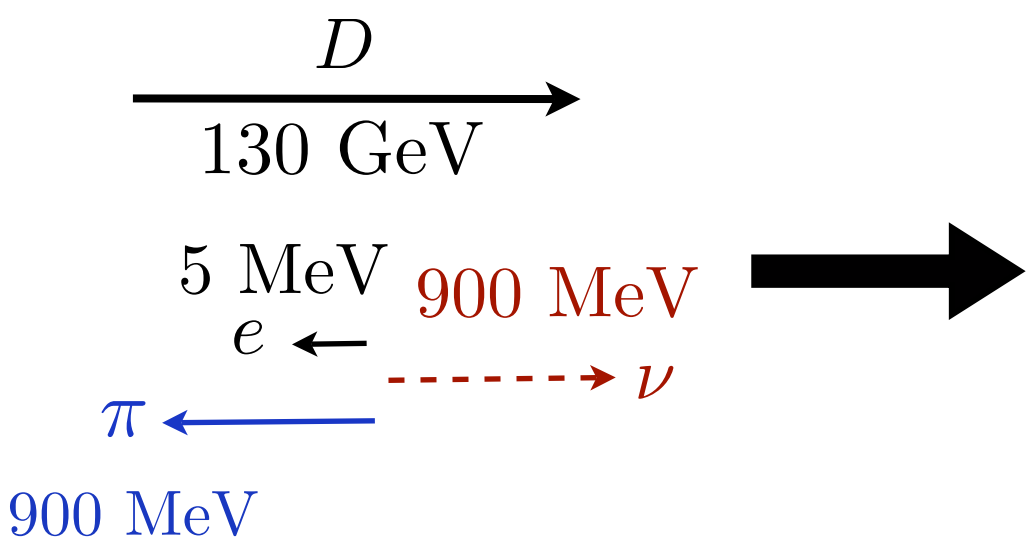
"QCD"

Neutrinos from heavy flavours

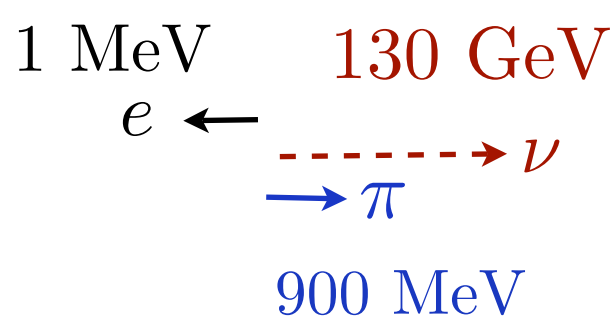


Proof of Principle

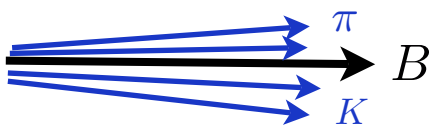
Meson Frame



Lab Frame

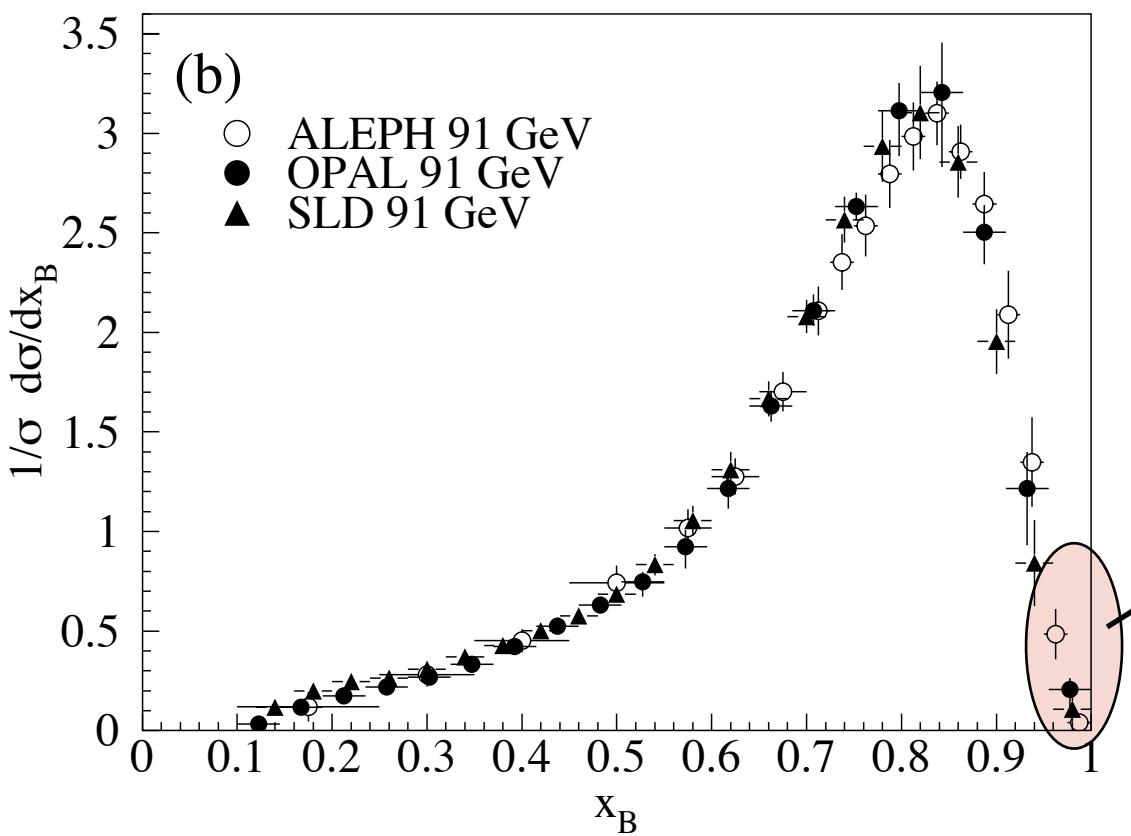


Heavy Flavour Neutrinos



Still have jet fragments

Fragmentation $x_B \equiv \frac{E_B}{E_j}$



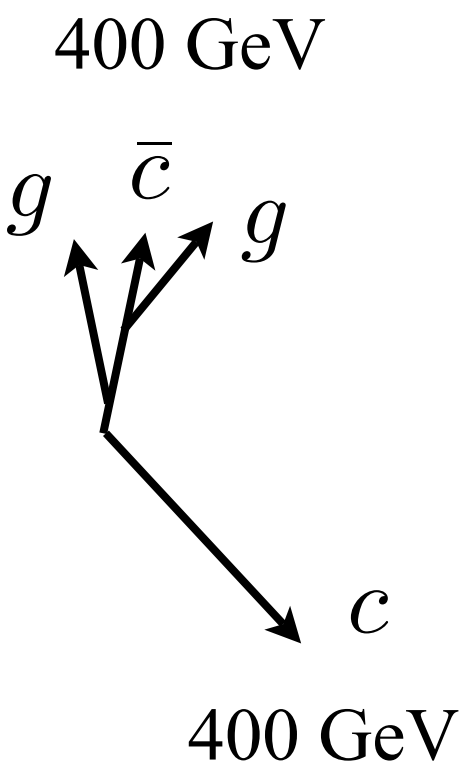
Not impossible to have isolated B mesons

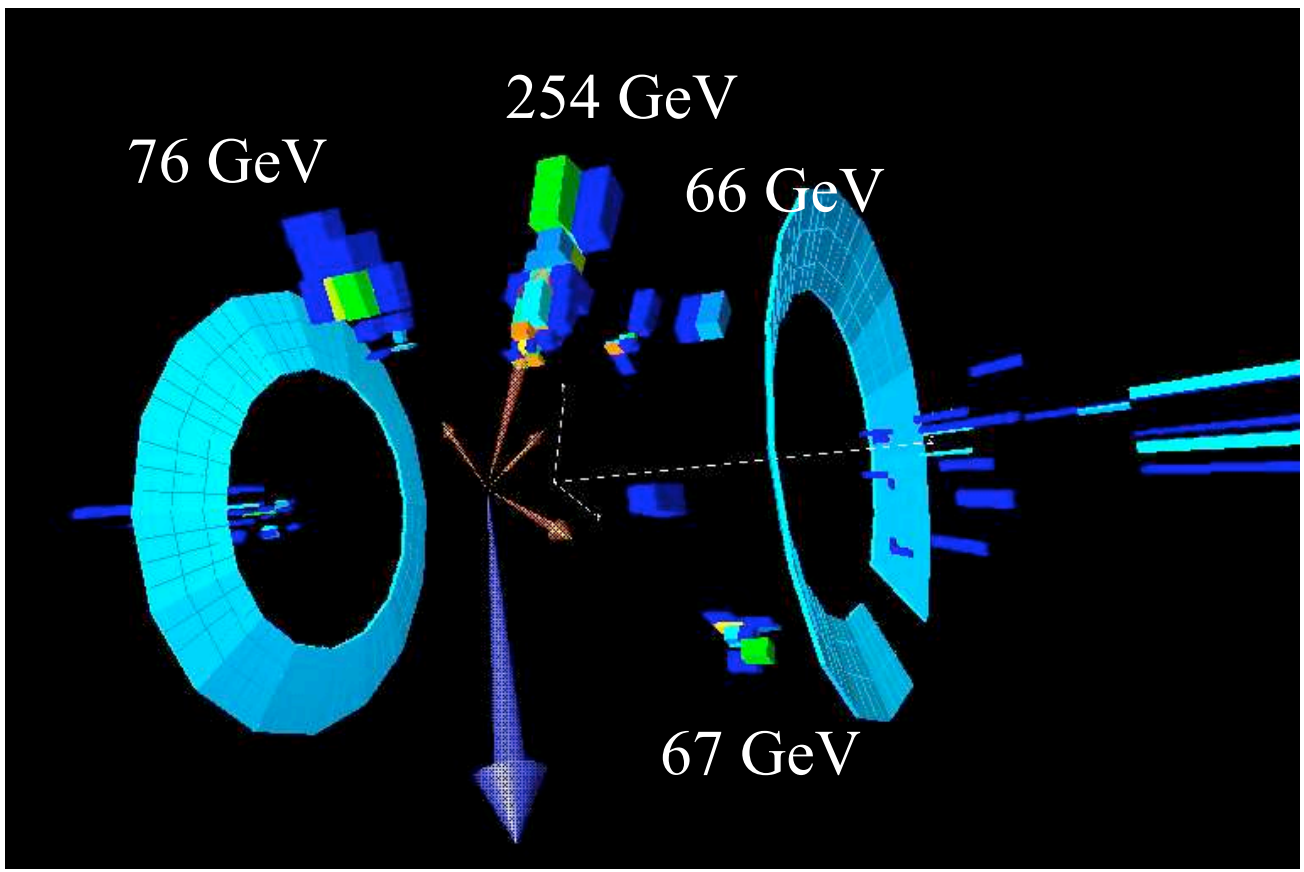
A Highly Suspicious D0 4-jet+MET Candidate

		η	ϕ
$\not\!\!E_T$	321		4.73
H_T	464		
E_T jet 1	254	0.05	1.52
E_T jet 2	76.8	−0.38	0.12
E_T jet 3	67.2	1.30	4.67
E_T jet 4	66.2	0.67	1.35

$\Delta\phi = 4^\circ$

Too energetic relative to other jets





Outline

Jets + MET as a signal of new physics

Backgrounds

Existing Searches

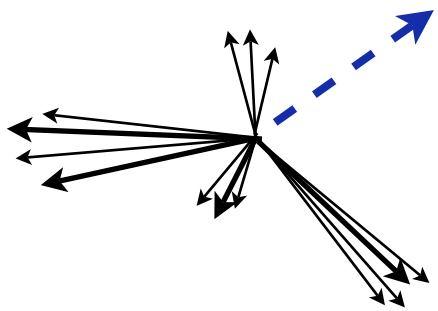
A 70 GeV Gluino!??

Going Forward

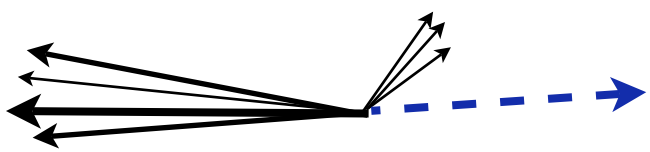
Existing Searches for Jets + MET

2 search strategies

Lots of jets



Single hard jet



D0 Cuts $1\ \text{fb}^{-1}$

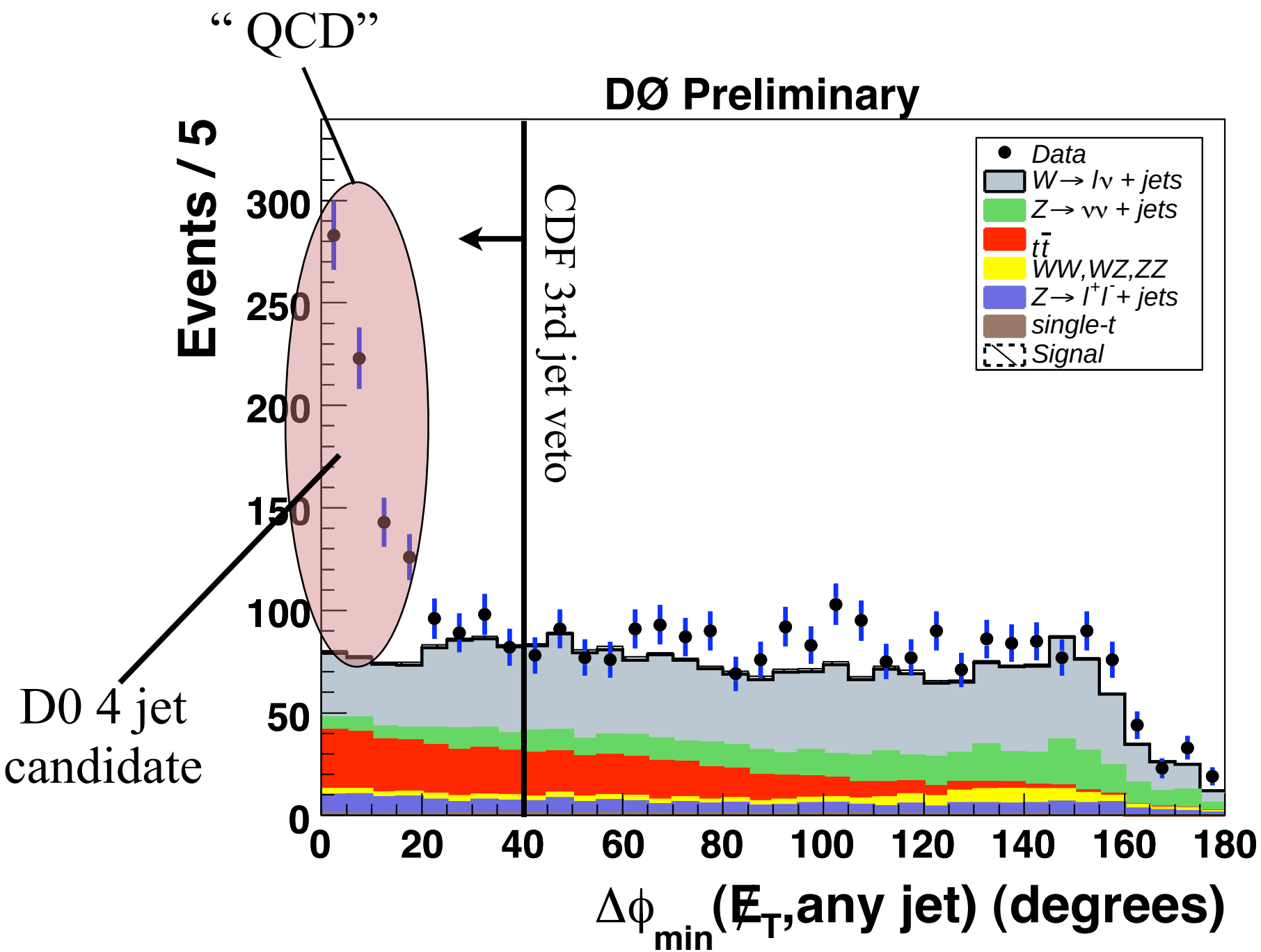
TABLE I: Selection criteria for the three analyses (all energies in GeV); see the text for further details.

Preselection Cut	All Analyses		
$\not\!\!E_T$	≥ 40		
Acoplanarity	$< 165°$		
|Vertex z $pos.$|	< 60 cm		
Selection Cut	**"dijet"**	**"3-jets"**	**"gluino"**
1st jet E_T[a]	≥ 35	≥ 35	≥ 35
2nd jet E_T[a]	≥ 35	≥ 35	≥ 35
3rd jet E_T[a]	–	≥ 35	≥ 35
4th jet E_T[a]	–	–	≥ 20
Electron veto	yes	yes	yes
Muon veto	yes	yes	yes
$\Delta\phi(\not\!\!E_T, \text{jet}_1)$	$\geq 90°$	$\geq 90°$	$\geq 90°$
$\Delta\phi(\not\!\!E_T, \text{jet}_2)$	$\geq 50°$	$\geq 50°$	$\geq 50°$
$\Delta\phi_{\min}(\not\!\!E_T, \text{any jet})$	$\geq 40°$	–	–
H_T	≥ 300	≥ 400	≥ 300
$\not\!\!E_T$	≥ 225	≥ 150	≥ 100

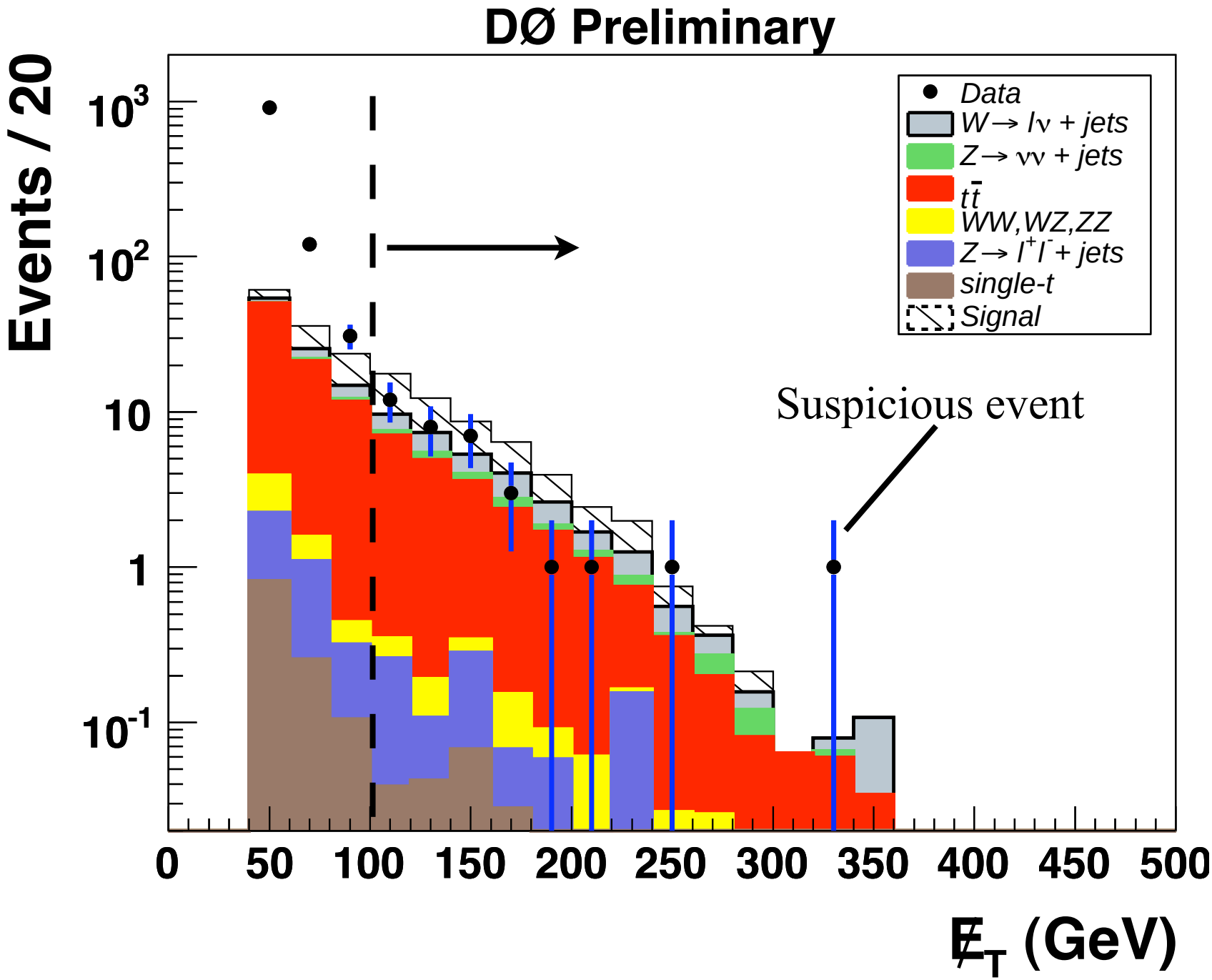
10 GeV

[a]Jets subject to an E_T cut are also required to be central ($|\eta_{\text{det}}| < 0.8$), with an electromagnetic fraction below 0.95, and to have $CPF \geq 0.05$.

2 jet analysis Before $\Delta\phi_{\min}$ cut

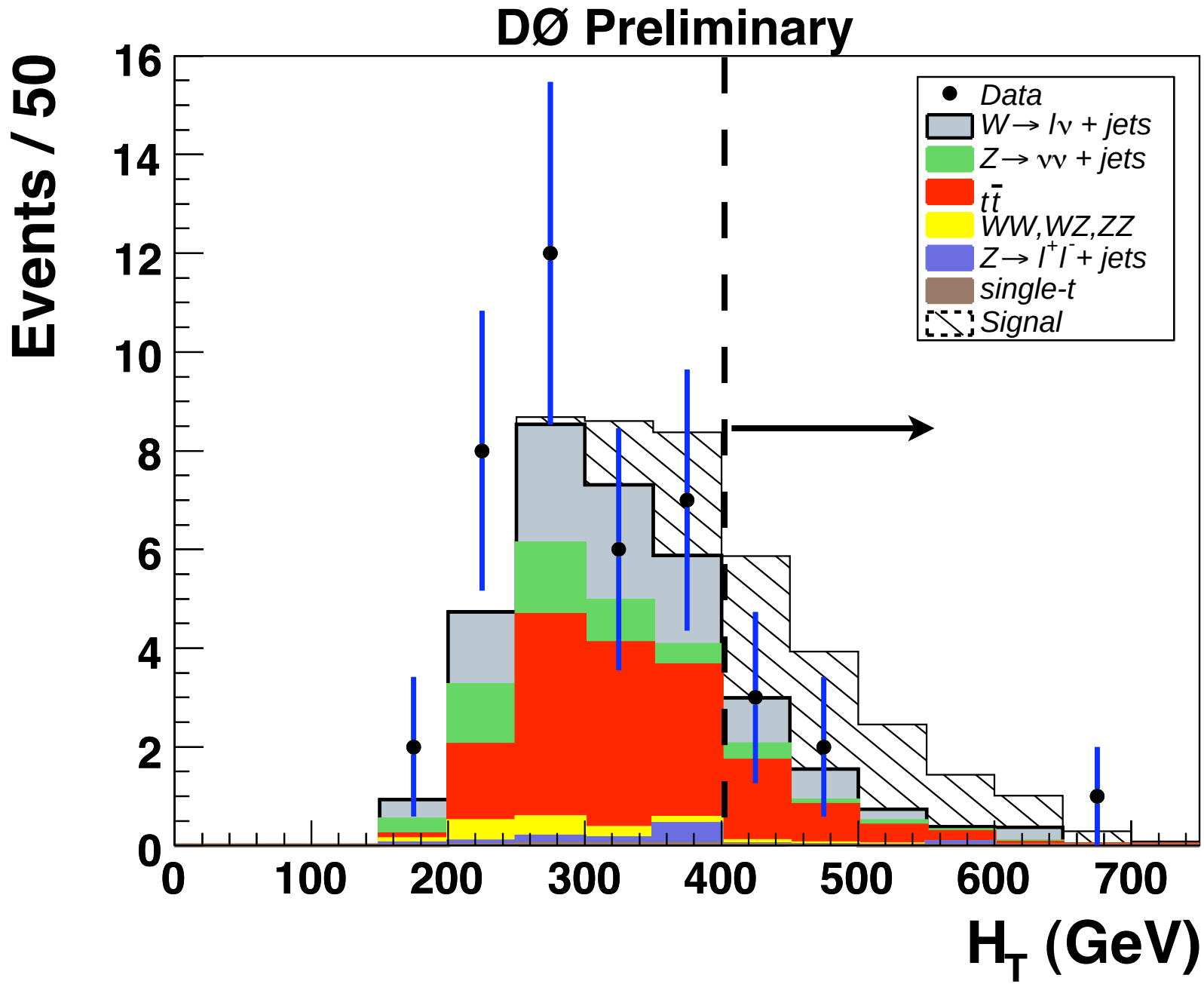


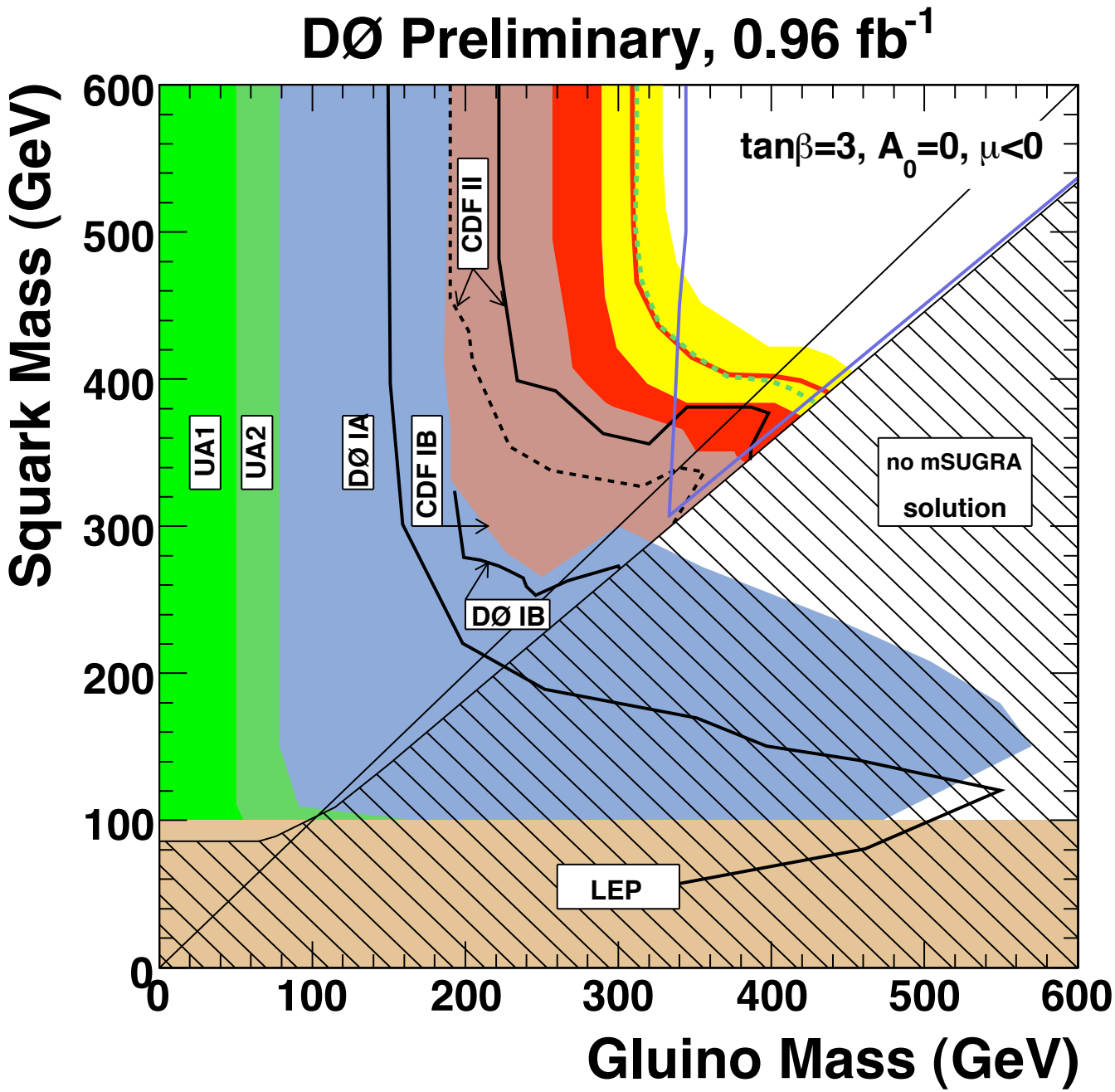
4 jet analysis Before $\not\!\!E_T$ cuts



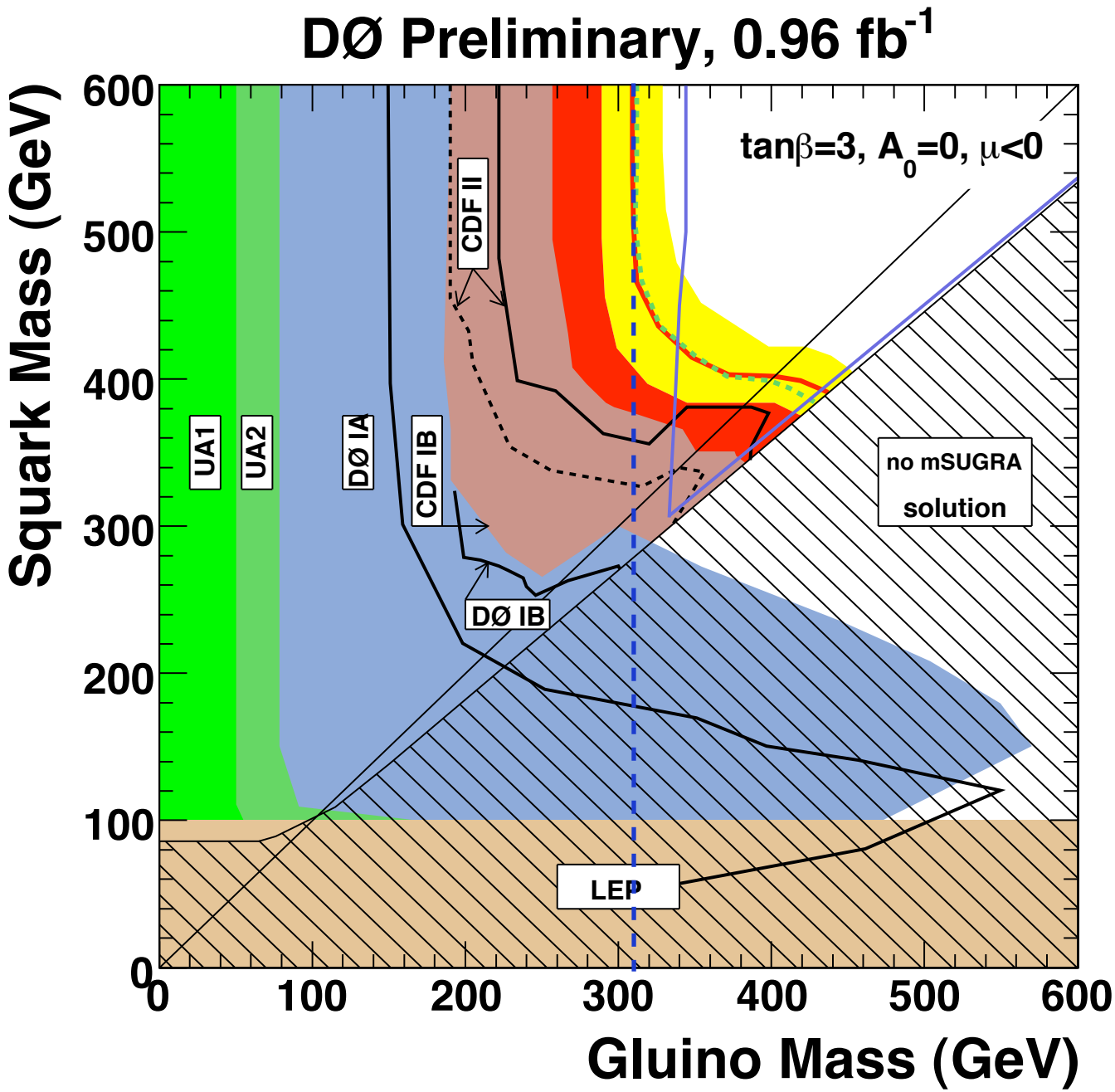
3 jet analysis

Before H_T cut





$$\frac{d}{dt}m_{\tilde{q}}^2 = -\frac{8}{3\pi}\alpha_s M_{\tilde{g}}^2$$



$$\frac{d}{dt}m_{\tilde{q}}^2 = -\frac{8}{3\pi}\alpha_s M_{\tilde{g}}^2$$

mSugra Caveats

w/ A. Pierce, M. Lisanti, M-P. Le

$m_{\tilde{B}} : m_{\tilde{W}} : m_{\tilde{g}} \quad 1 : 2 : 7$

$\tilde{g} \to \tilde{B} + q\,\bar{q} \qquad \Delta Q = 6 m_{\tilde{B}}$

never phase-space limited

Bino always relativistic

Lots of examples where $m_{\tilde{B}} : m_{\tilde{g}} \sim 1 : 1.5$

Also motivated by fine-tuning

Light gluino keeps squarks lighter

Benchmark Point

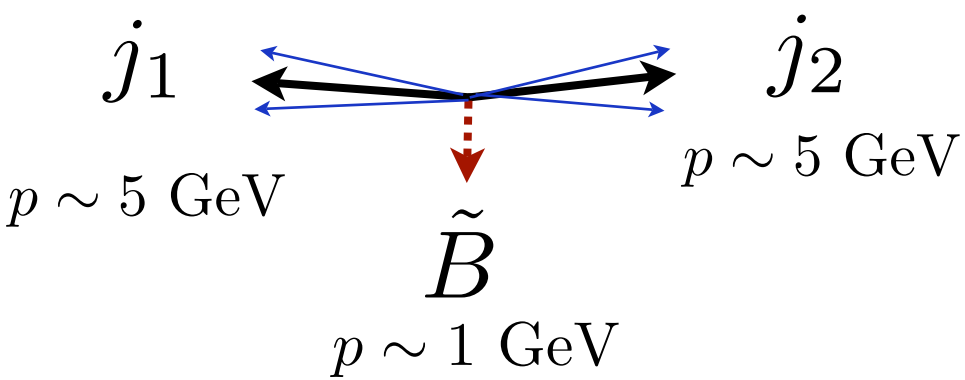
$m_{\tilde{g}} = 70$ GeV $\qquad\qquad$ $m_{\tilde{B}} = 60$ GeV

How do we find?

Benchmark Point

$$m_{\tilde{g}} = 70 \text{ GeV} \qquad m_{\tilde{B}} = 60 \text{ GeV}$$

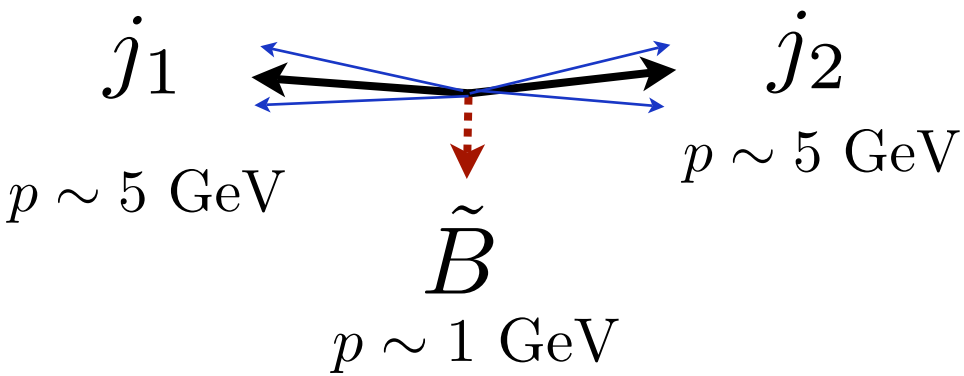
How do we find?

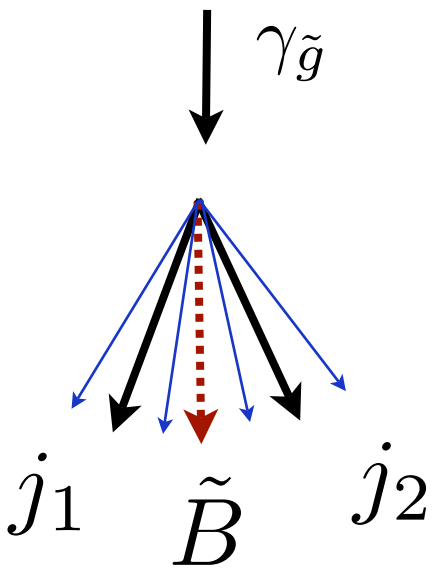


Benchmark Point

$$m_{\tilde{g}} = 70 \text{ GeV} \qquad m_{\tilde{B}} = 60 \text{ GeV}$$

How do we find?





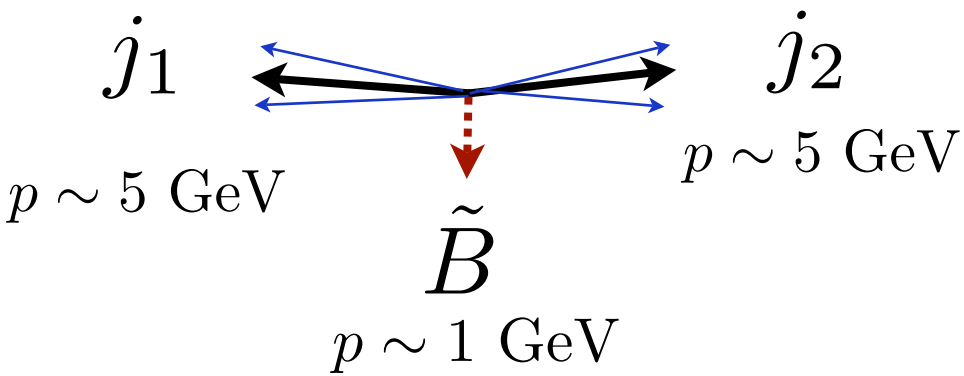
$$\gamma_{\tilde{B}} \simeq \gamma_{\tilde{g}}$$

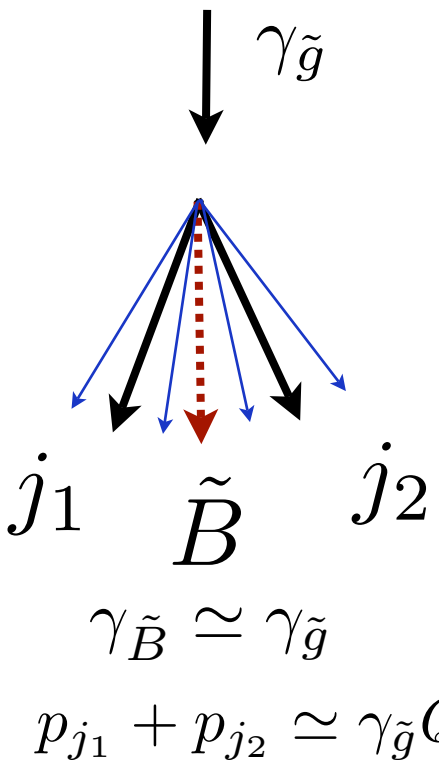
$$p_{j_1} + p_{j_2} \simeq \gamma_{\tilde{g}} Q$$

Benchmark Point

$$m_{\tilde{g}} = 70 \text{ GeV} \qquad m_{\tilde{B}} = 60 \text{ GeV}$$

How do we find?

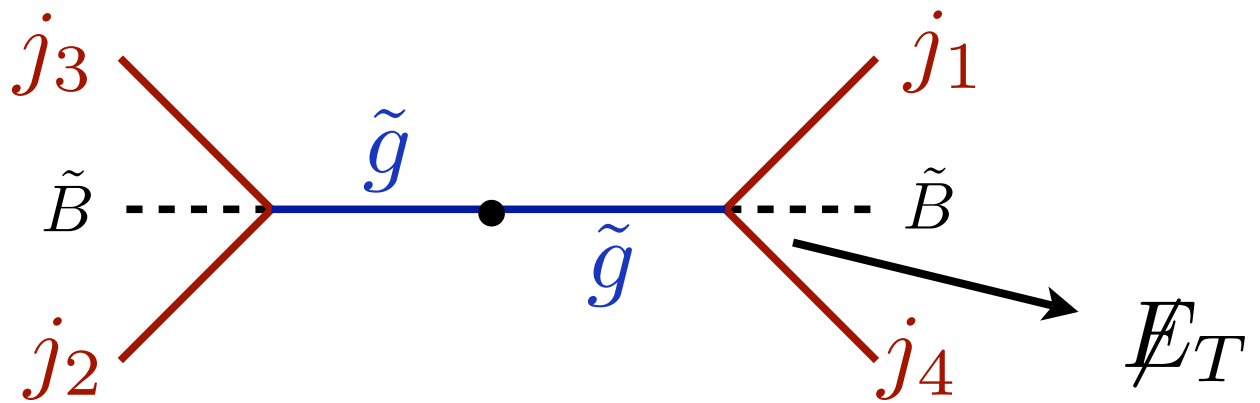




Looks like a 70 GeV hadronically produced tau

Existing Searches

Multijet + MET



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

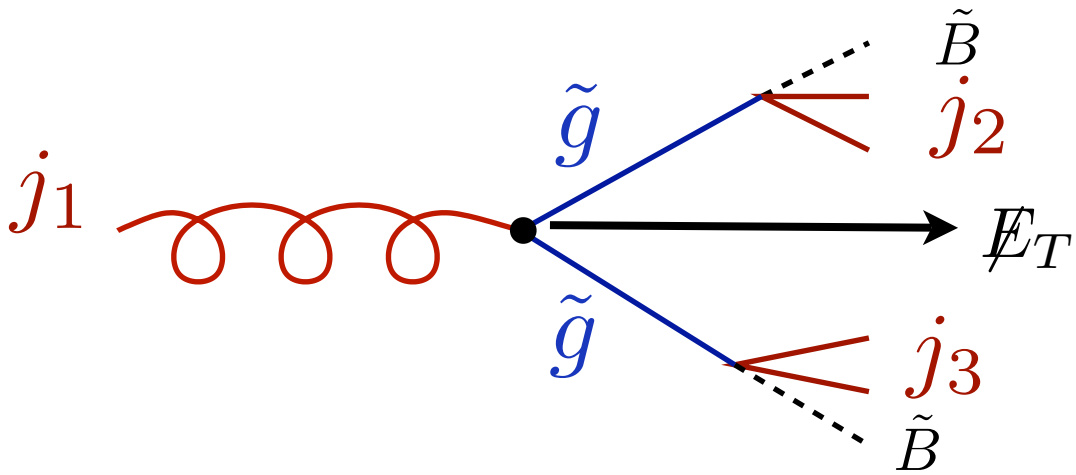
If $Q < m_{\tilde{B}}$

Bino carries away energy but not momentum $\not{E}_T \sim \frac{Q^2}{m_{\tilde{B}}}$

As gluinos get boosted, jets become collinear and $\not{E}_T$ aligned with jets $\Delta\Phi^{j\,\not{E}_T} \sim \frac{1}{\gamma_{\tilde{g}}}$

Existing Searches

Multijet + MET



D0

$P_T^{j1}, P_T^{j2}, P_T^{j3} > 35$ GeV

$H_T > 400$ GeV

$\not{E}_T > 150$ GeV

$\Delta\Phi^{j_1 \not{E}_T} > 90°$

$\Delta\Phi^{j_2 \not{E}_T} > 50°$

No 3rd jet iso

CDF

$P_T^{j1} > 95$ GeV

$P_T^{j2} > 55$ GeV

$P_T^{j3} > 25$ GeV

$\not{E}_T > 70$ GeV

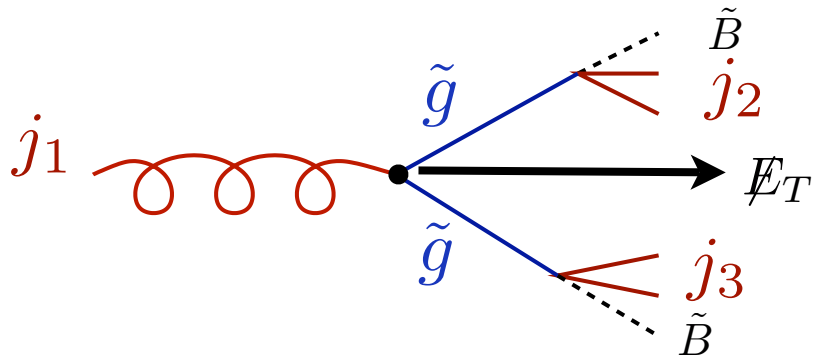
$H_T > 230$ GeV

$\Delta\Phi^{j_i \not{E}_T} > 40°$

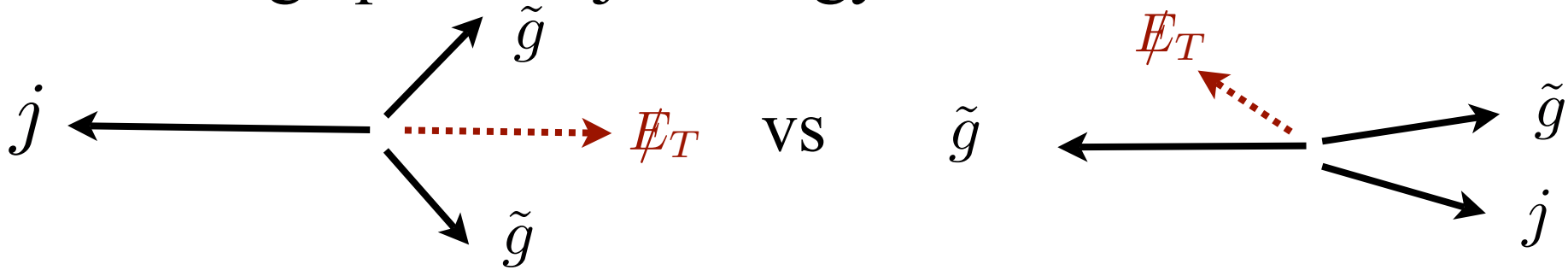
Benchmark usually fails kinematic/isolation cuts

Kinematics

Multijet + MET

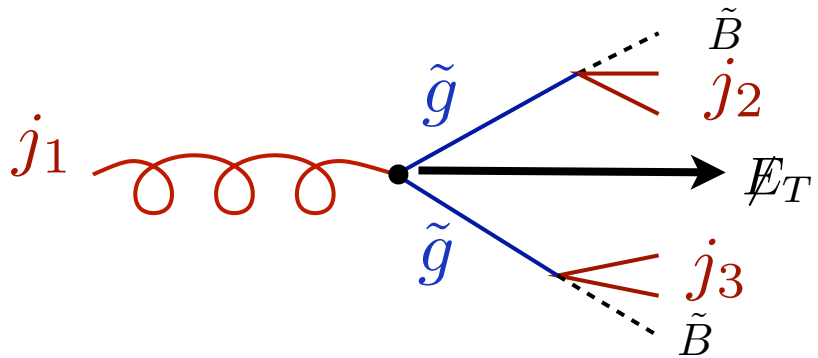


Most “bang” per unit jet energy

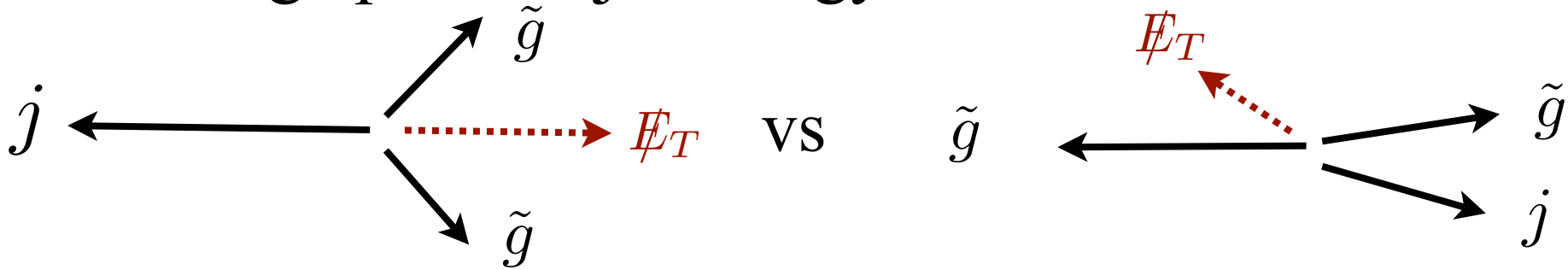


Kinematics

Multijet + MET



Most "bang" per unit jet energy



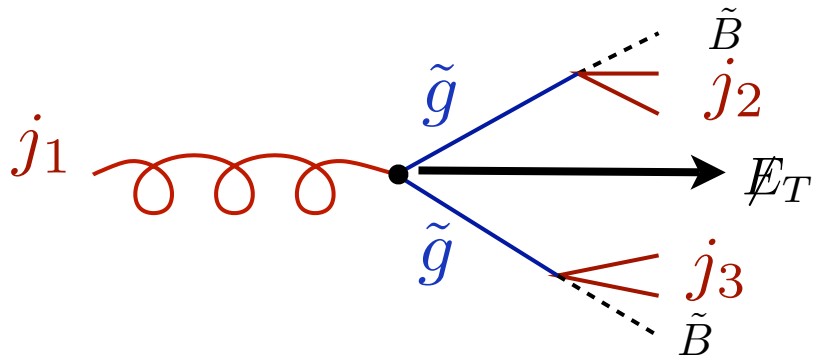
To get gluino decay jets energetic enough

$$\gamma_{\tilde{g}} > 2.5 \quad \Rightarrow E_{\tilde{g}} > 175 \text{ GeV}$$

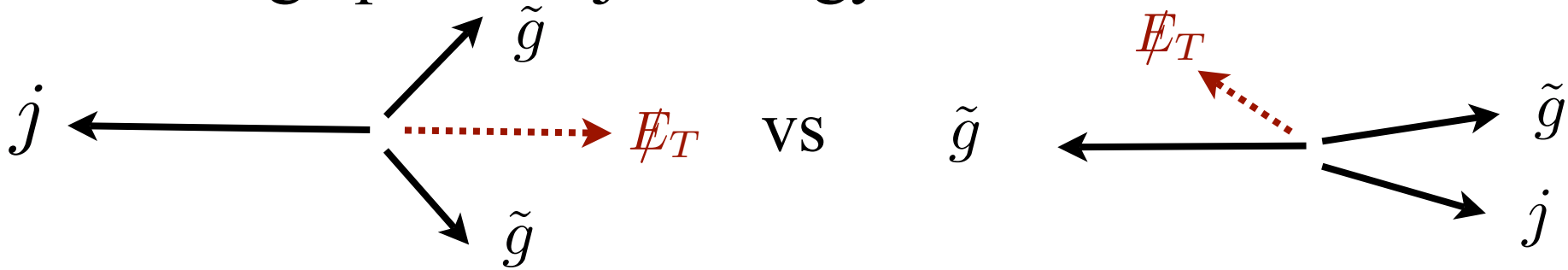
$$E_j > 75 \text{ GeV}$$

Kinematics

Multijet + MET



Most "bang" per unit jet energy



To get gluino decay jets energetic enough

$$\gamma_{\tilde{g}} > 2.5 \quad \Rightarrow E_{\tilde{g}} > 175 \text{ GeV}$$

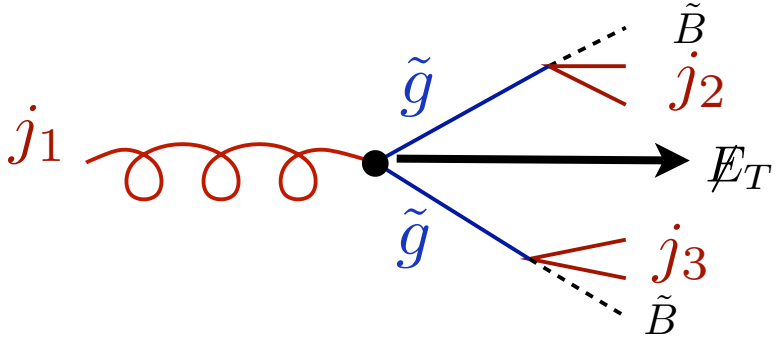
$$E_j > 75 \text{ GeV}$$

Fails

$$H_T > 350 \text{ GeV}$$

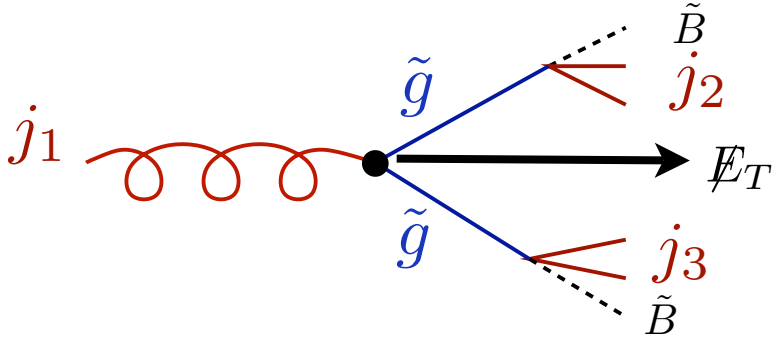
Existing Searches

Monojet + MET



Existing Searches

Monojet + MET



CDF

$P_T^{j1} > 150$ GeV

$P_T^{j2} < 60$ GeV

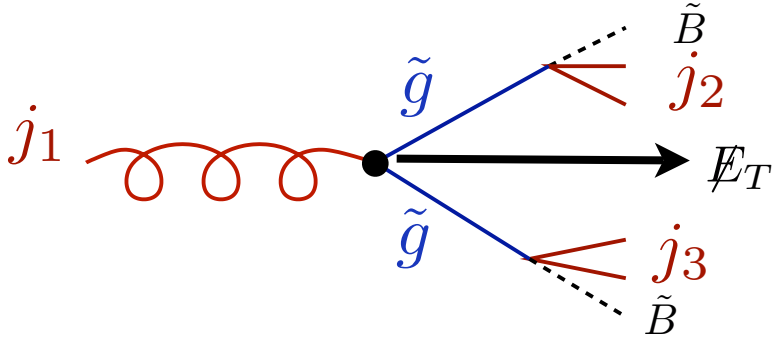
$P_T^{j3} < 20$ GeV

$\not{E}_T > 120$ GeV

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

Existing Searches

Monojet + MET



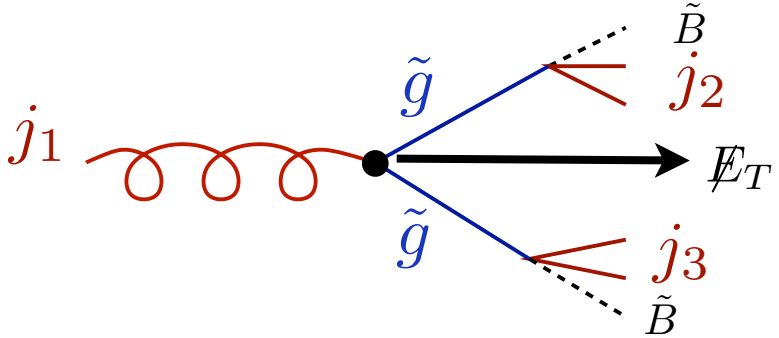
D0

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

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

Existing Searches

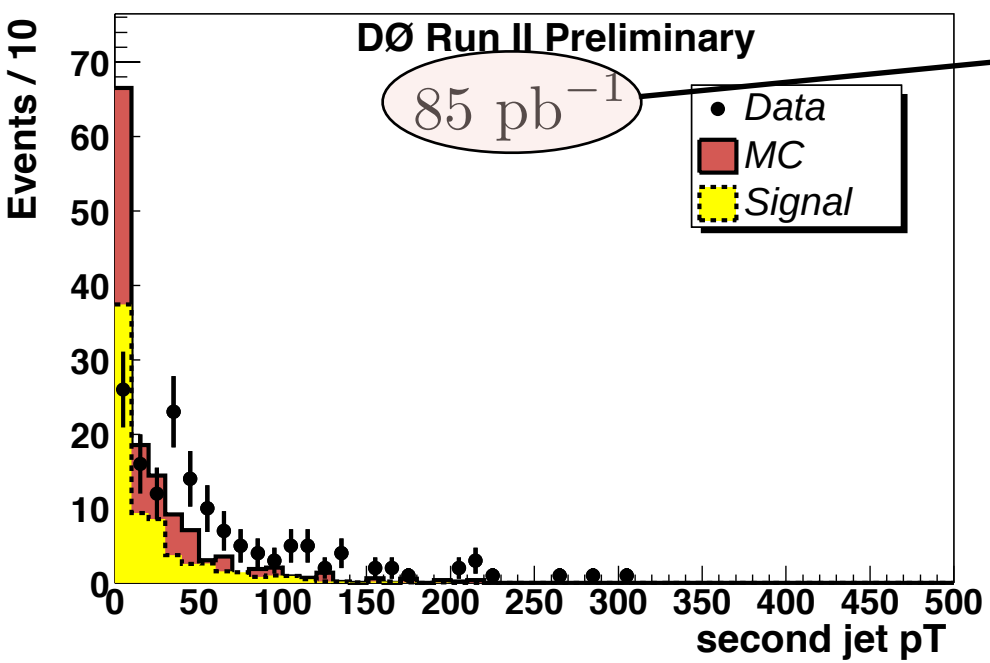
Monojet + MET



D0

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

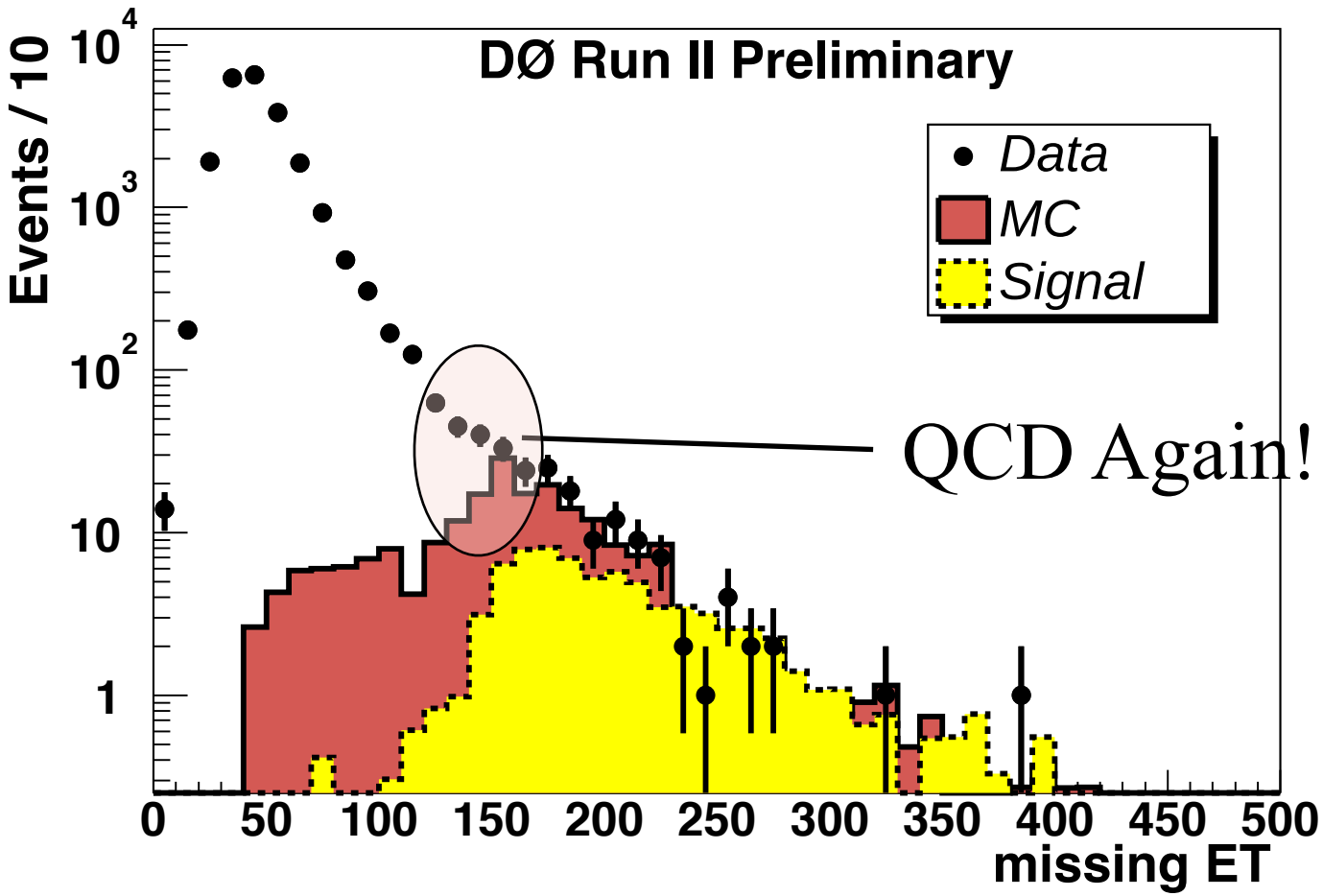
$P_T^{j2} < 50$ GeV $\quad \Delta\Phi^{j\not{E}_T} > 30°$



High priority?

March 2004!

Monojet + MET


DØ Run II Preliminary
Data
MC
Signal
QCD Again!
Events / 10
missing ET
0
50
100
150
200
250
300
350
400
450
500
1
10
10^2
10^3
10^4

70 GeV Gluino is Close to Existing Searches

Really want a dedicated search for
phase space limited decays

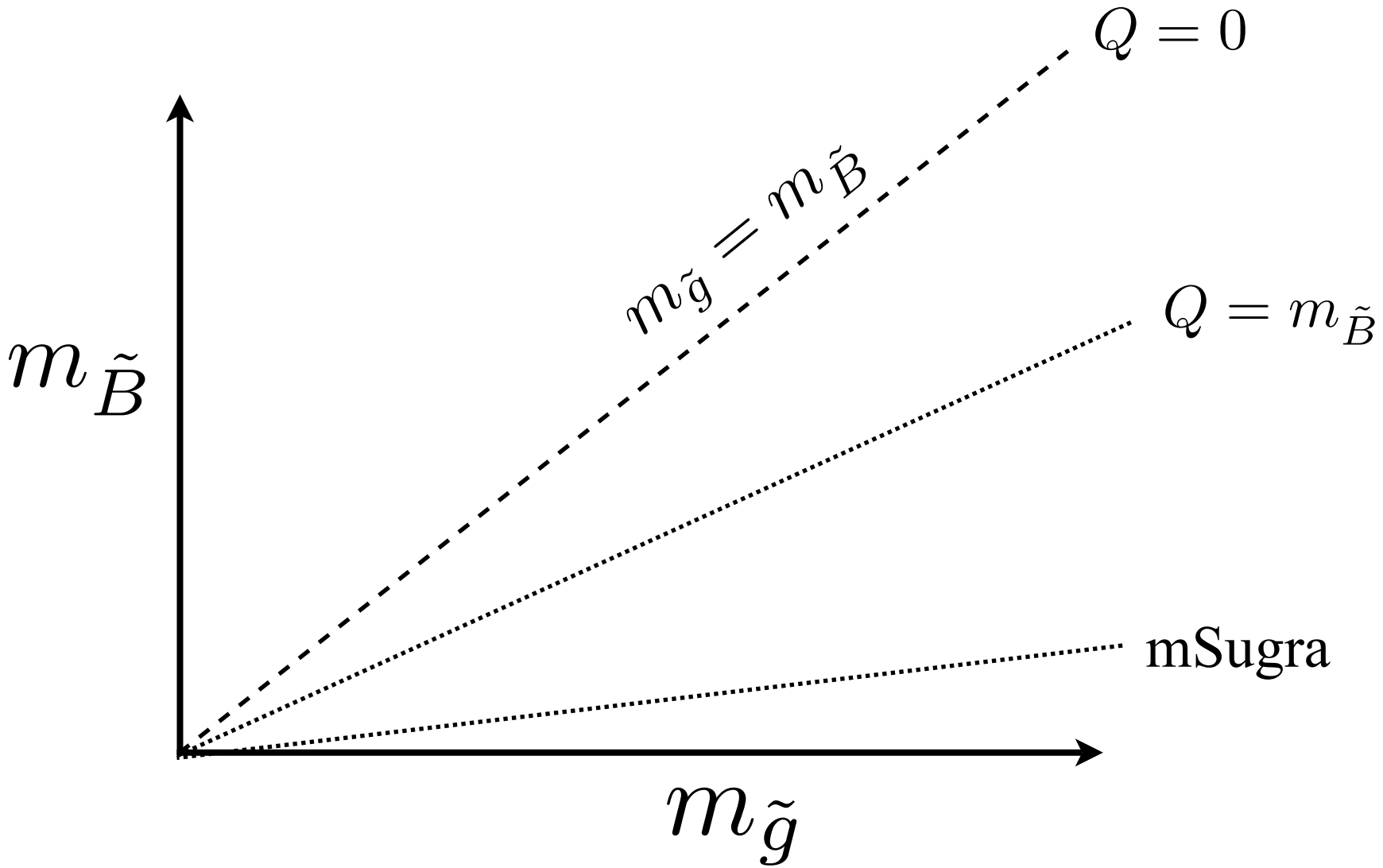
Requires altering cuts

Needs to understand SM background

Can't attribute all low energy excesses to QCD

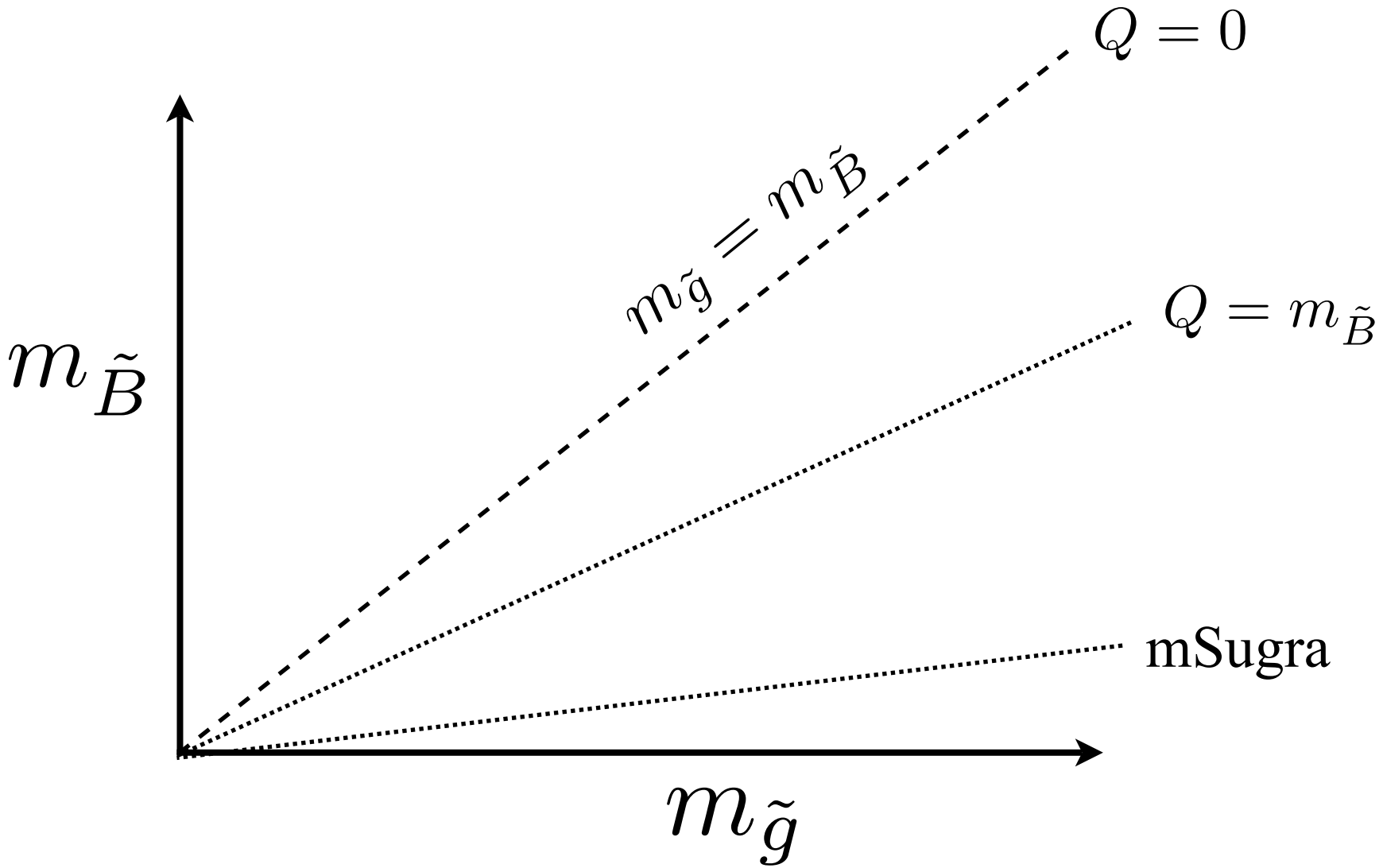
Motivates Bino vs Gluino Plot

set limits on cross section



Motivates Bino vs Gluino Plot

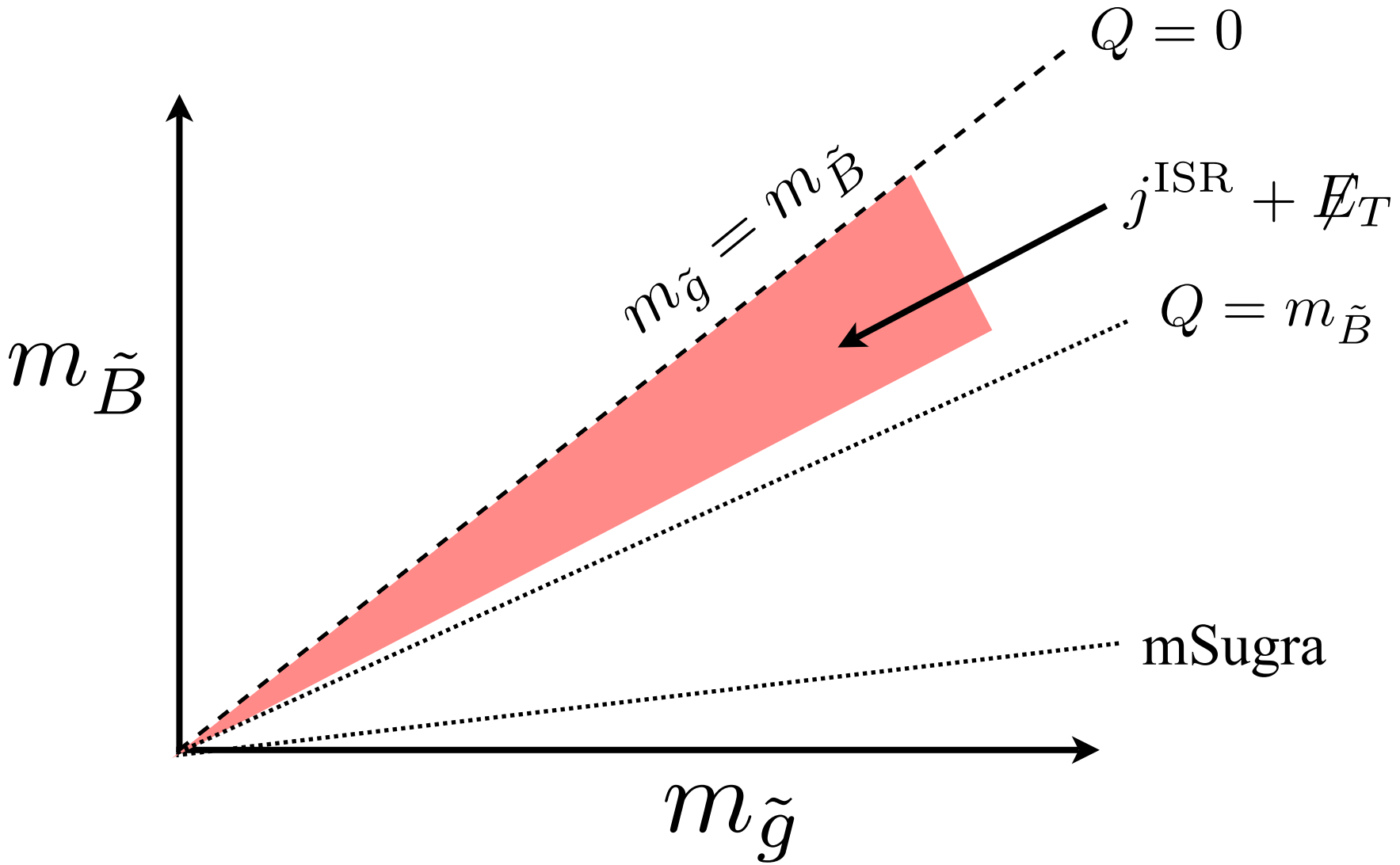
set limits on cross section



also should do: $\mathbf{3}^{\text{new}} \rightarrow q + \mathbf{1}^{\text{new}}_{\text{stable}}$

Motivates Bino vs Gluino Plot

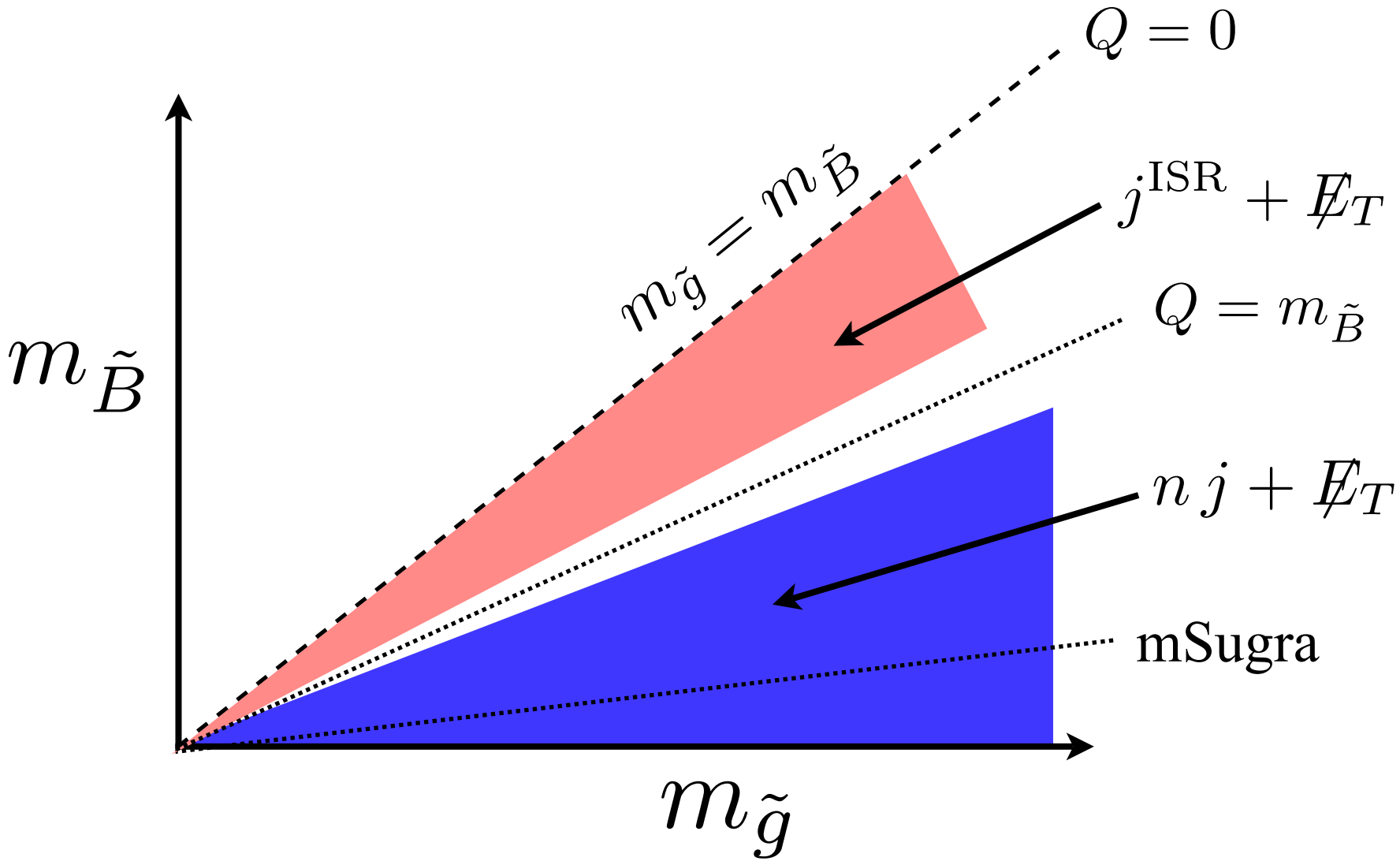
set limits on cross section



also should do: $\mathbf{3}^{\mathrm{new}} \rightarrow q + \mathbf{1}^{\mathrm{new}}_{\mathrm{stable}}$

Motivates Bino vs Gluino Plot

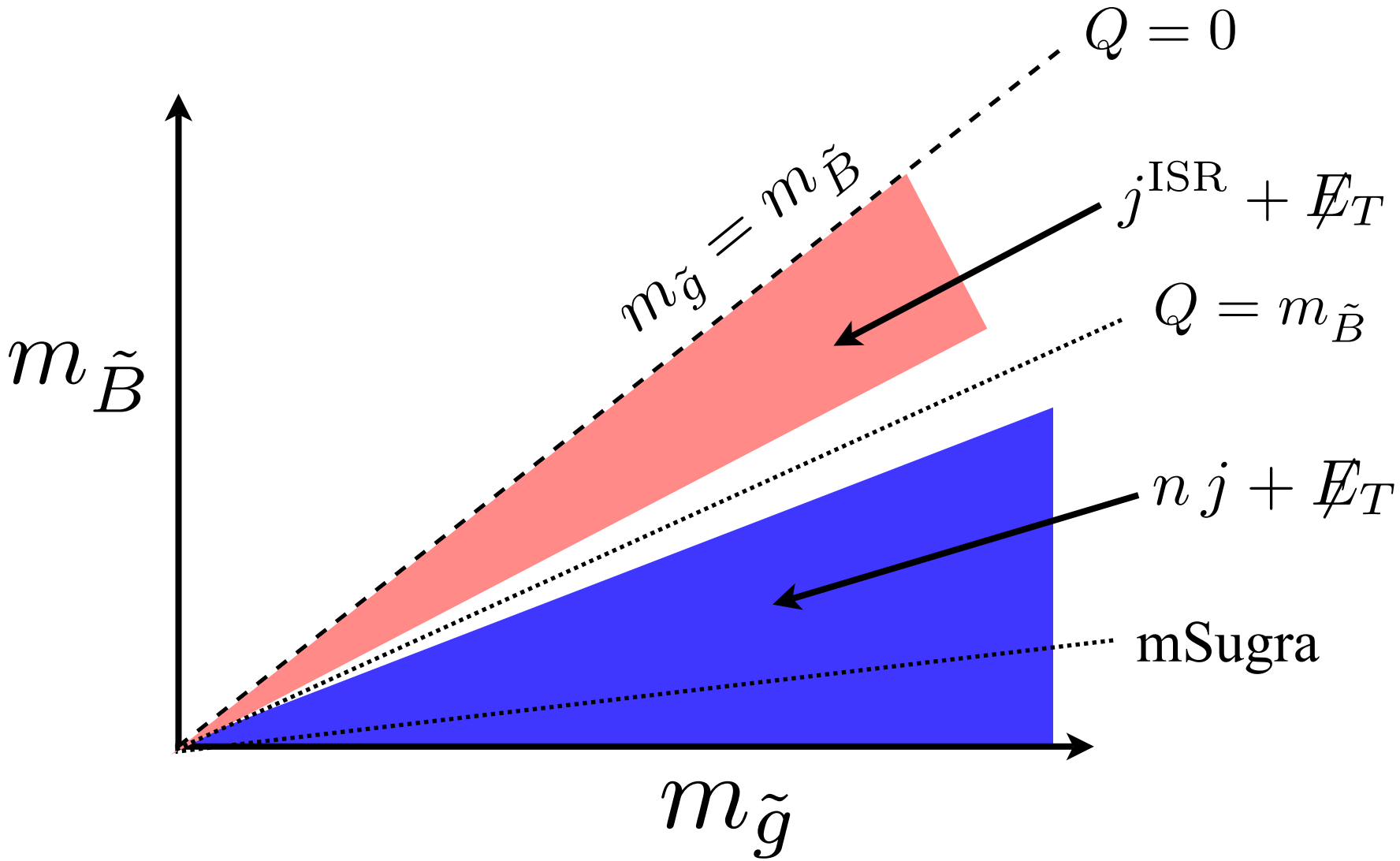
set limits on cross section



also should do: $\mathbf{3}^{\mathrm{new}} \rightarrow q + \mathbf{1}^{\mathrm{new}}_{\mathrm{stable}}$

Motivates Bino vs Gluino Plot

set limits on cross section



very general: $\mathbf{8}^{\mathrm{new}} \rightarrow q + \bar{q} + \mathbf{1}^{\mathrm{new}}_{\mathrm{stable}}$

also should do: $\mathbf{3}^{\mathrm{new}} \rightarrow q + \mathbf{1}^{\mathrm{new}}_{\mathrm{stable}}$

We are probing the energy frontier

Need to make sure we are looking in all available channels

Need to make tools to understand rare backgrounds

Need to be explicit about relevant
exclusion plots and search strategies.

Worst tragedy would be to have the discovery on tape, but not to discover it because we didn't look