Up the Down Staircase

M. E. Peskin
Princeton LHC Workshop
March 2007

Everyone today is asking,

What is the most important thing that I can do to prepare for the LHC ?

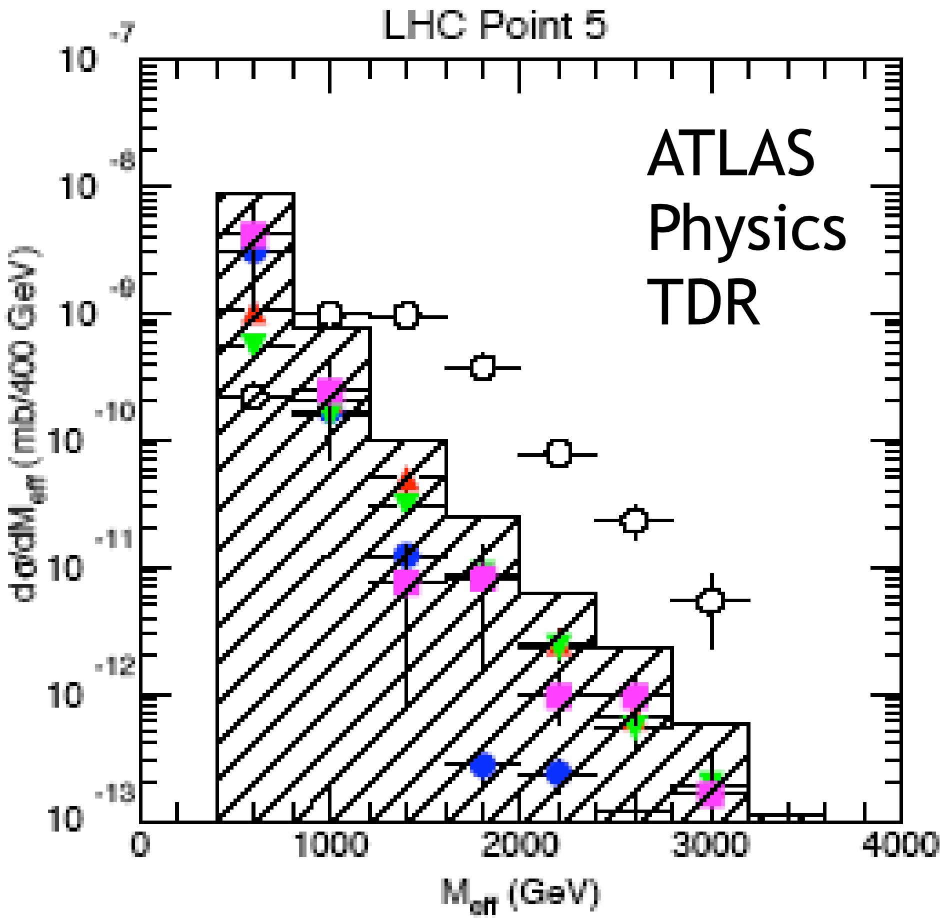
For me, the most important question is that of how we will be able to prove that we are seeing excesses of events above the Standard Model background in "generic" new physics searches in multi-jets, leptons, missing ET.

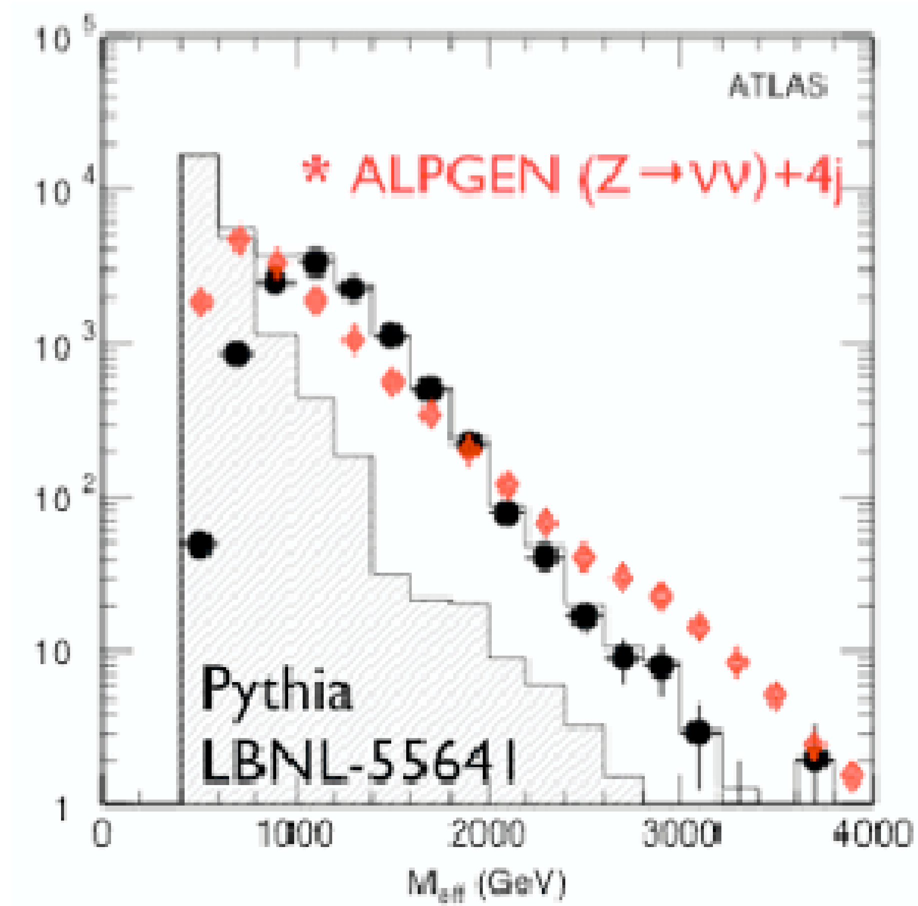
A tremendous amount of effort has gone into this issue.

But, it is too important to be left to the experts.

In this lecture, I would like to describe some ways to think about this question. I will also outline a new simulation tool for this problem that I am working on in collaboration with John Conley and Tommer Wizansky.

Gianotti and Mangano (2005):





"Not only is the rate larger than previously expected, but the shape of the distribution is different, and much closer to that of the signal itself."

We do understand the Standard Model processes that contribution to the background in great detail.

But it will also be helpful to have more incisive ways to think about the systematics of these processes, and to verify our models of them from data.

In order to reach the level of new physics signals, we will need to work down through a series of levels dominated by Standard Model processes of different types.

Here is an idea of the hierarchy:

σ_{tot}	100 mb
jets w. $p_T > 100$	1 μb
Drell-Yan	100 nb
$t\bar{t}$	800 pb
SUSY ($M < 1$ TeV)	1-10 pb

The first challenge is to understand the detectors, to eliminate noise and electronic signals unrelated to the physics events, and to correct for cracks and geometric inefficiencies.

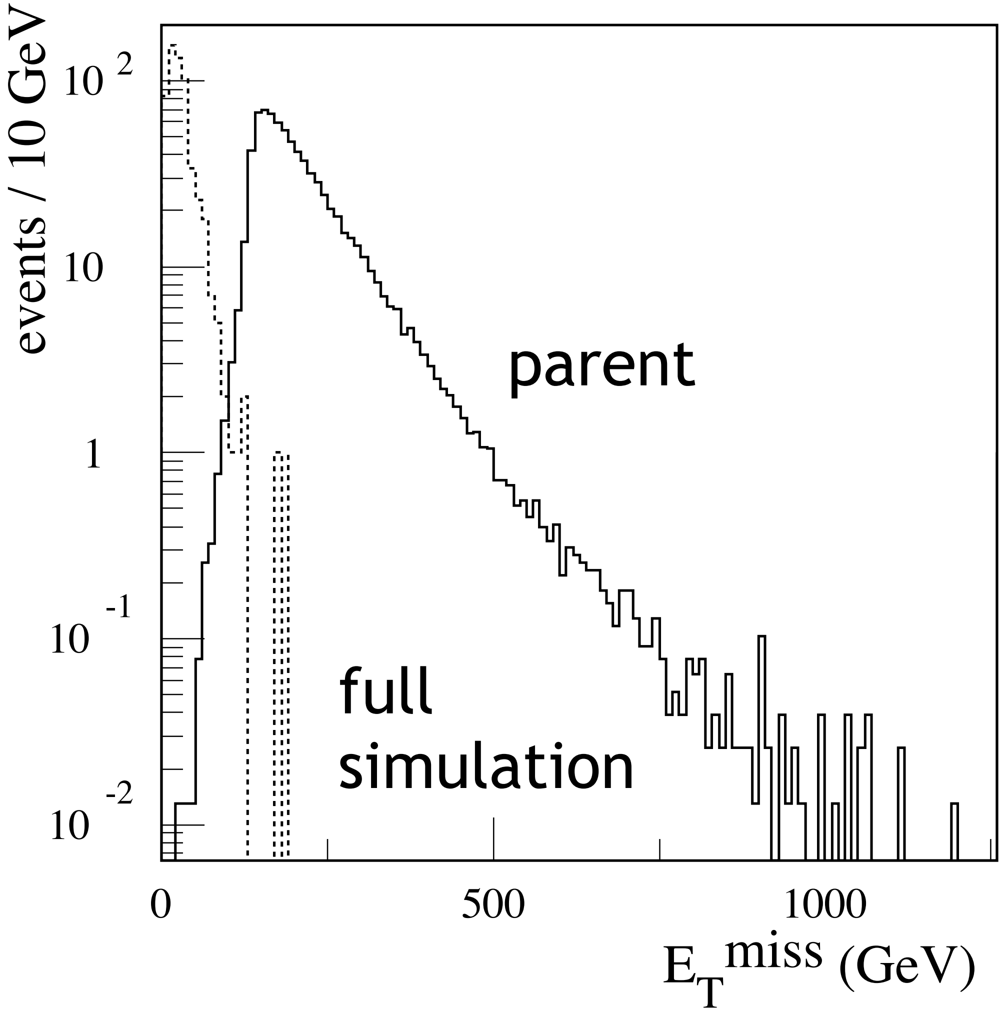
ATLAS and CMS claim that they can do this, and there is relatively little that theorists can contribute here.

There is one possible exception. From time to time,

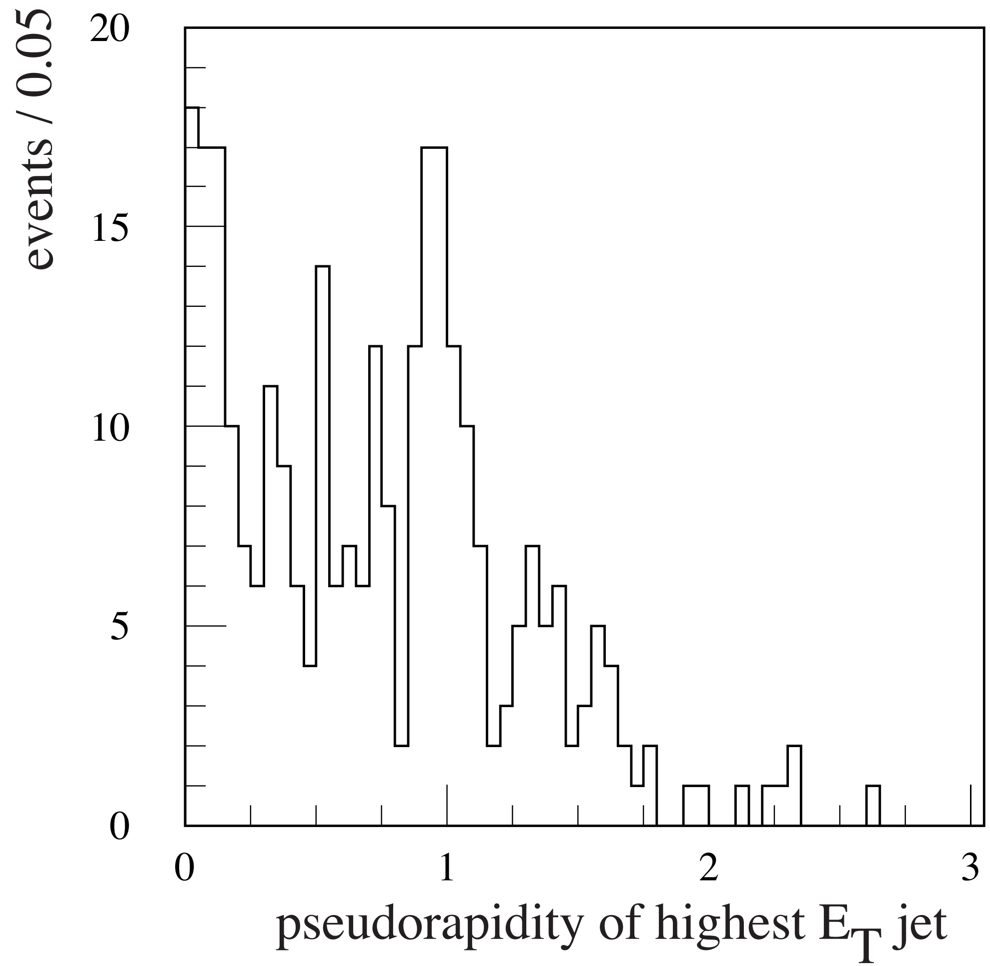
b decay to neutrinos

has been suggested as a major source of missing ET from standard QCD. Jay Wacker and his students are now trying to understand how important this source of missing ET might be.

The conventional story is expressed in these figures from the ATLAS TDR.



ATLAS simulation of missing ET in $Z(\to \mu^+\mu^-) + jet$

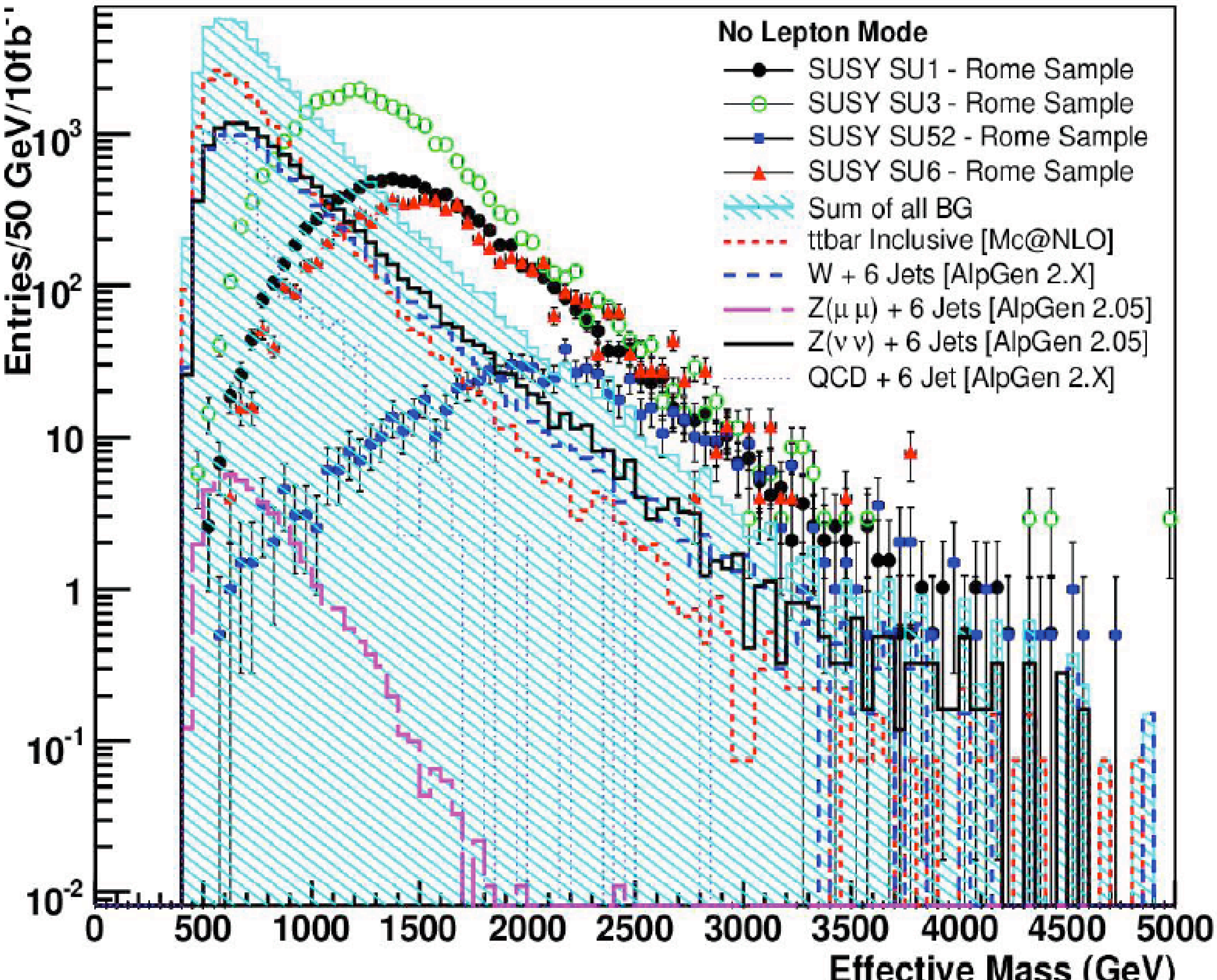


η of the jet w. the highest ET in events w. ET > 50

In the physics studies of ATLAS and CMS, the dominant backgrounds to new physics come from a different source, heavy particle production within the Standard Model, production of $W, Z, t\bar{t}$ plus jets.

These reactions already offer missing energy, leptons, and hadronic activity. They populate the region of large HT associated with new physics to the extent the additional jets are radiated along with the heavy particles.

Here is a recent quantitative evaluation by Sanjay Padhi, using ALPGEN and the ATLAS full simulation code



Meff distribution subject to

$\not{E}_T > 100$

4 jets, 2 w. $E_T > 100$

So it is important to put effort into developing simulation tools for these processes, and a good physical understanding of them.

There are already some excellent tools available, in particular, ALPGEN and MADGRAPH.

To understand heavy particle + multijet backgrounds to new physics, there is a methodology for this that has been used successfully in the Tevatron, especially in the CDF and DO analyses of top quark production.

Use the fact that new particles appear in events with large numbers of jets and large

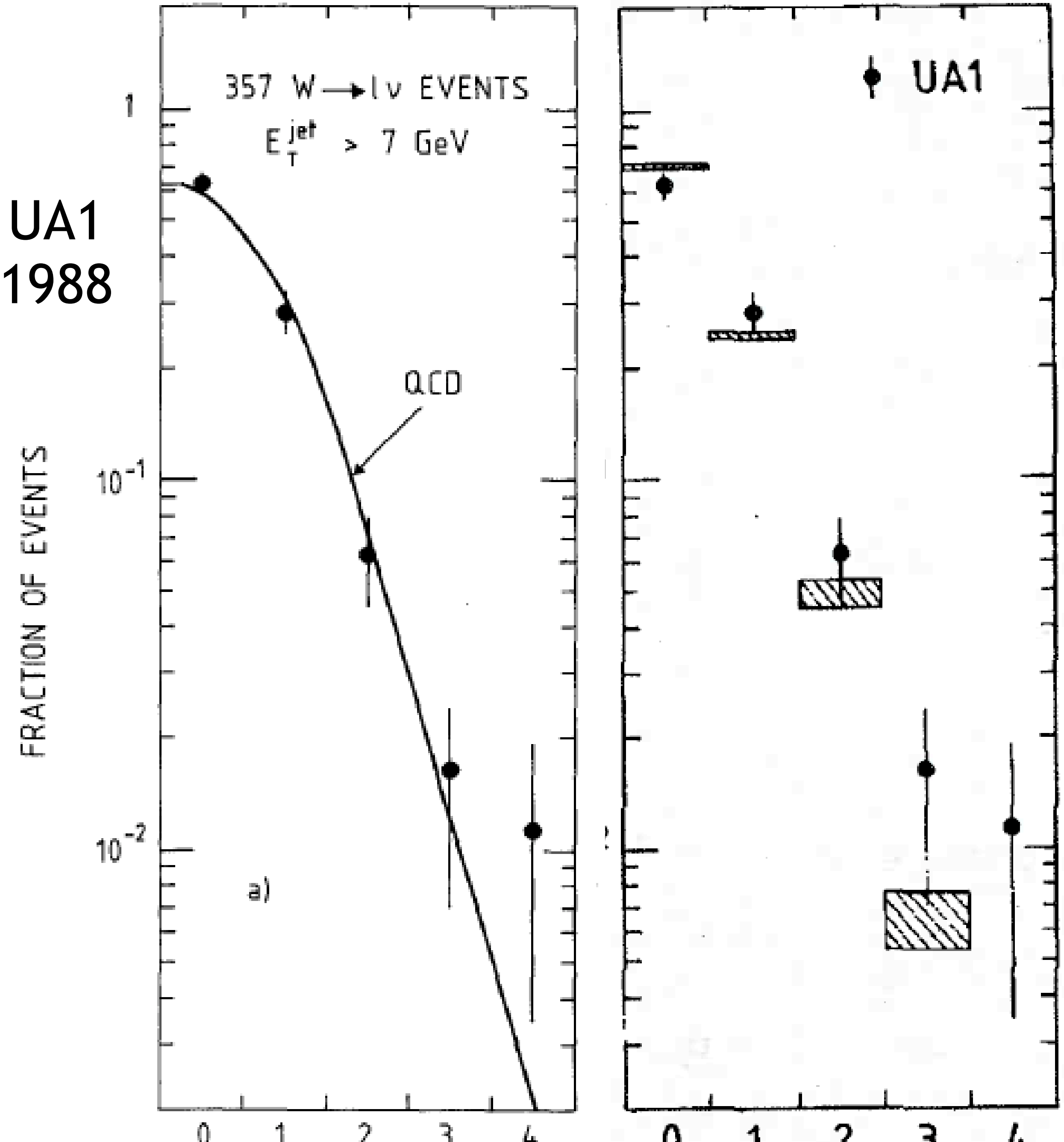
$$H_T = \sum_i E_{Ti}$$

Compute systematically the SM rates for n jet production. The results for fewer jets can be validated against data, both in a general setting and also with the experimental cuts that define the new physics search. Now extrapolate to large numbers of jets and large H_T.

This method is a standard part of Tevatron culture, but still, it needs a name. I like to call it a staircase.

the original Berends-Giele staircase :

UA1
1988

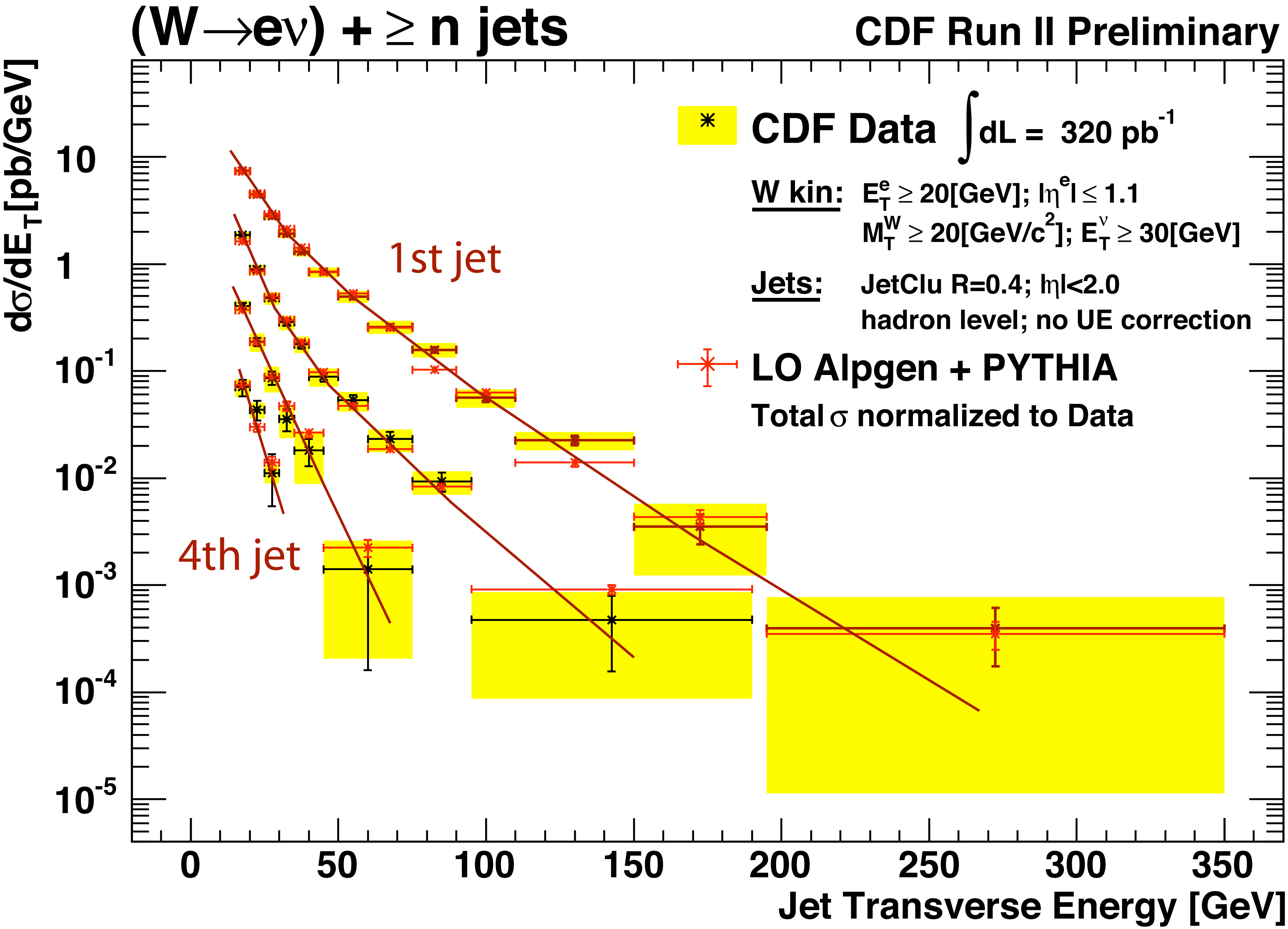


number of jets

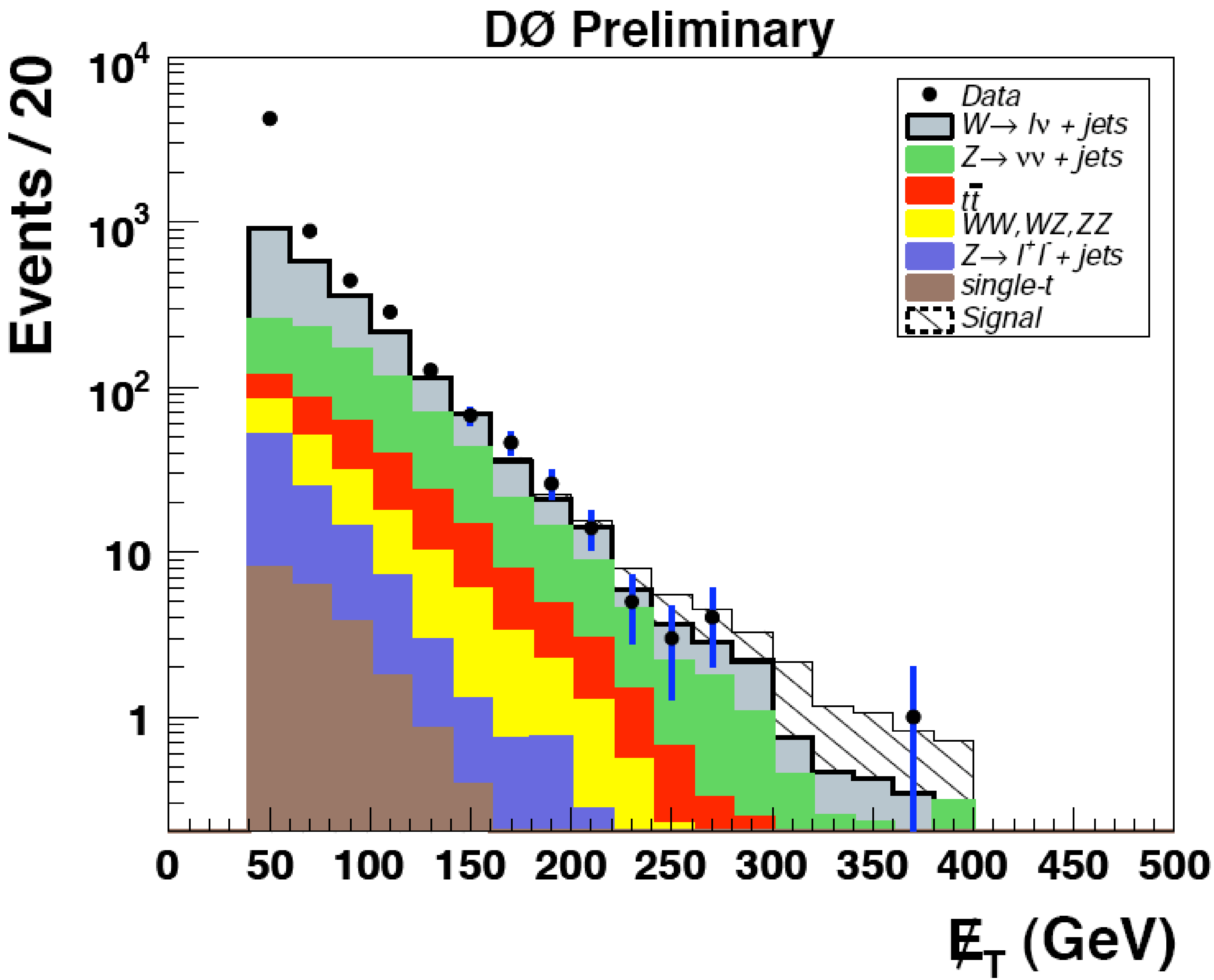
Berends,
Giele, Kuijf,
Kleiss, Stirling
1989

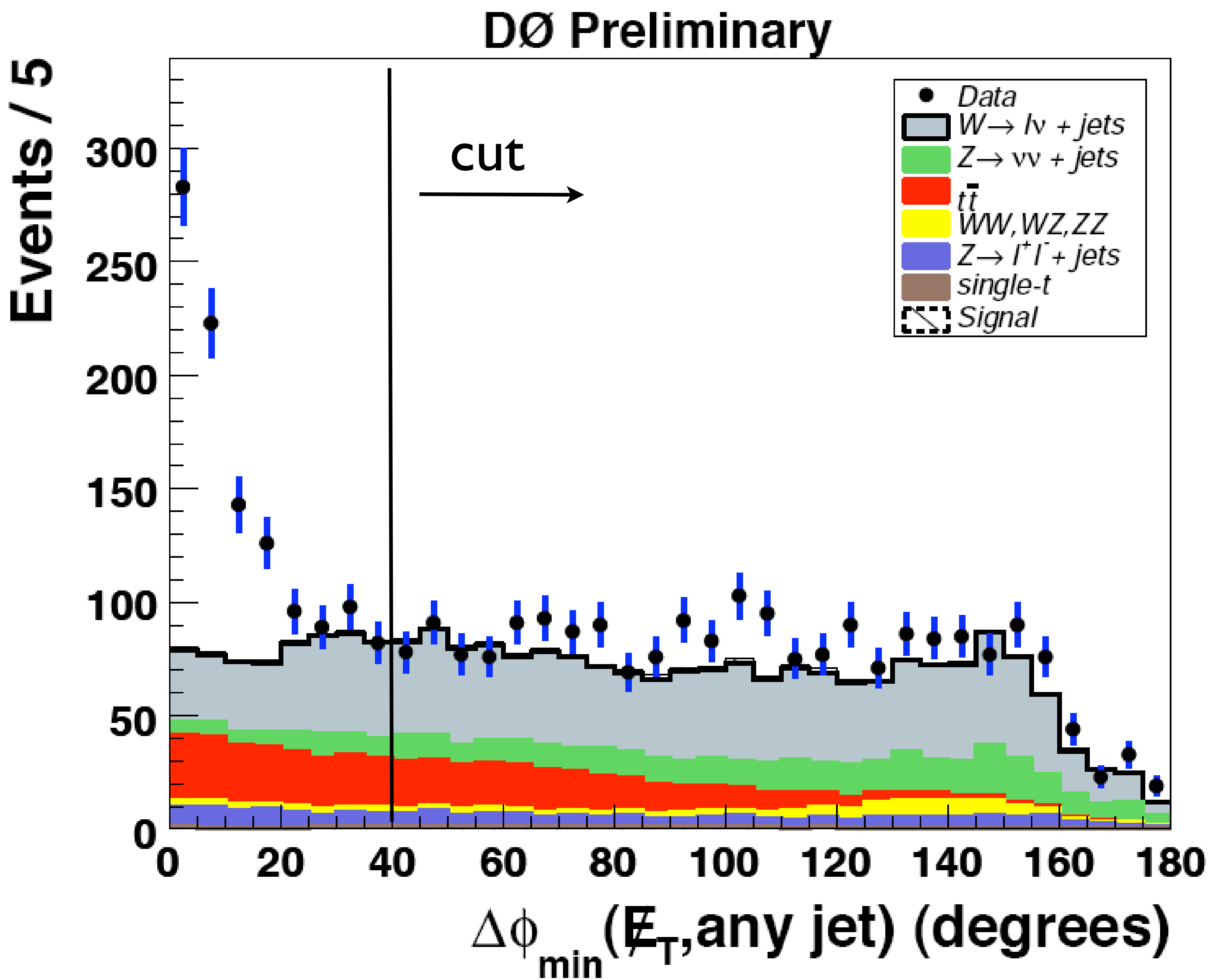
Let me show you a series of recent figures from the Tevatron experiments that illustrate this concept.

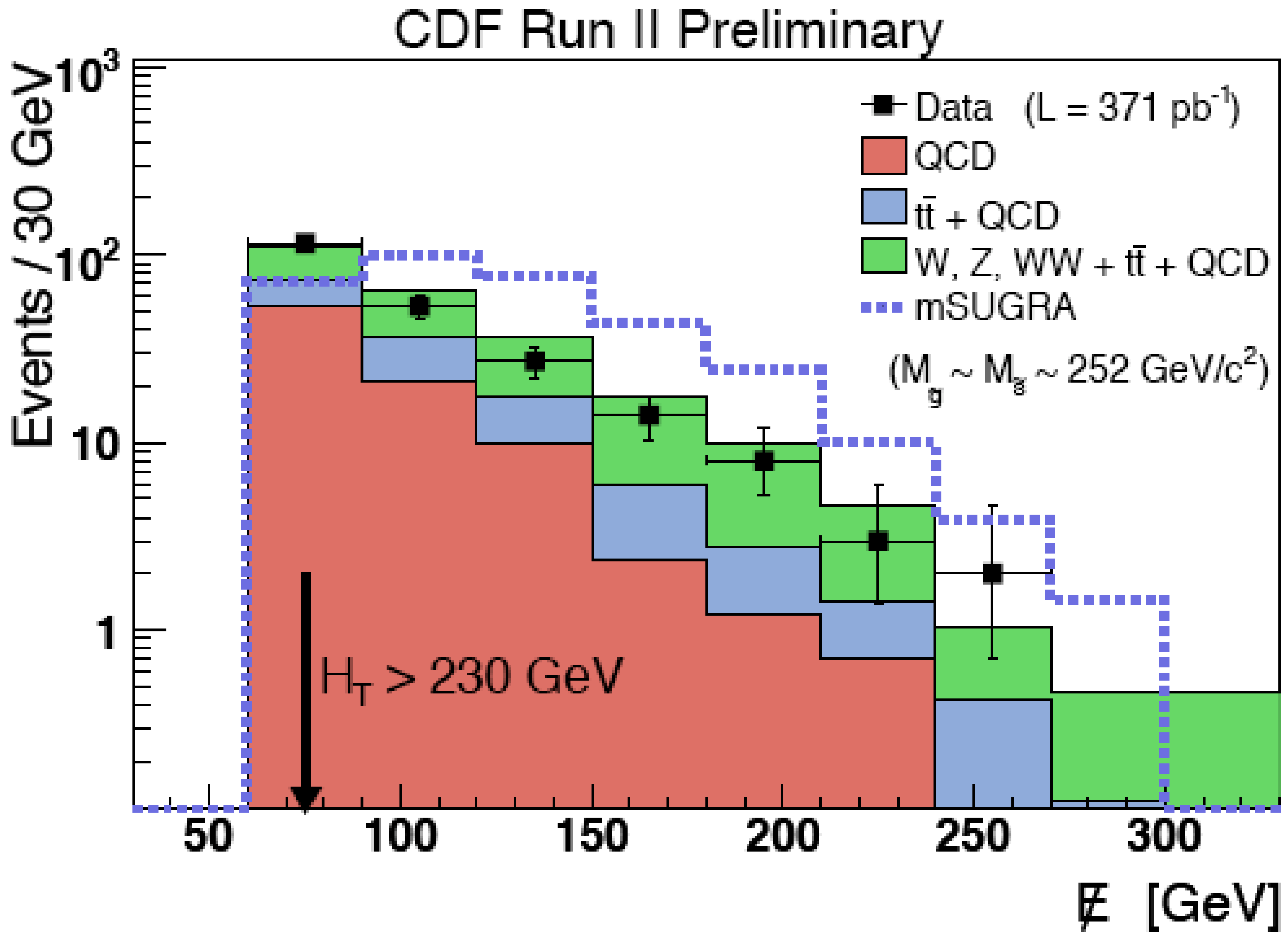
systematics of W + jets



search for SUSY in acoplanar di-jet events

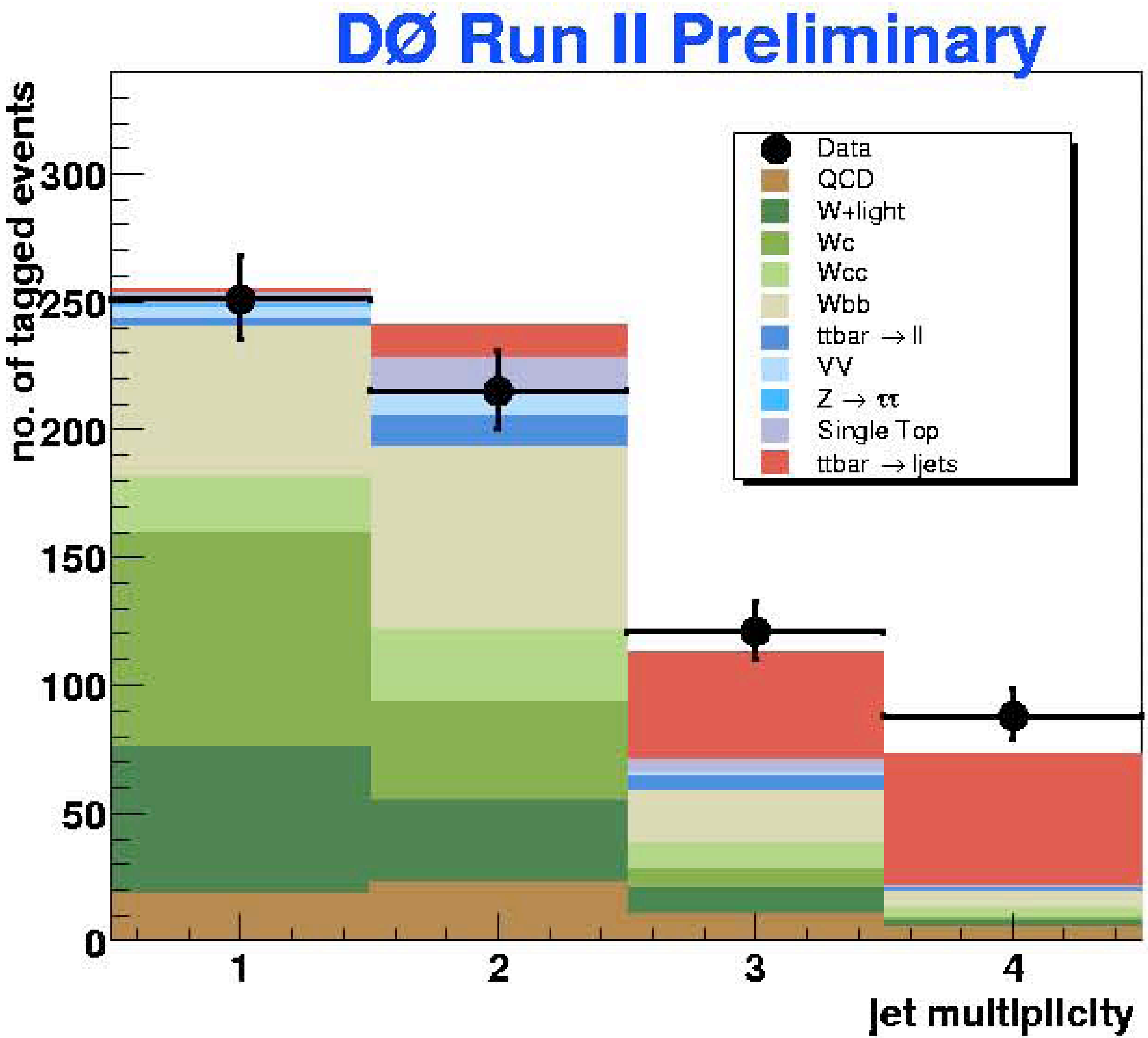


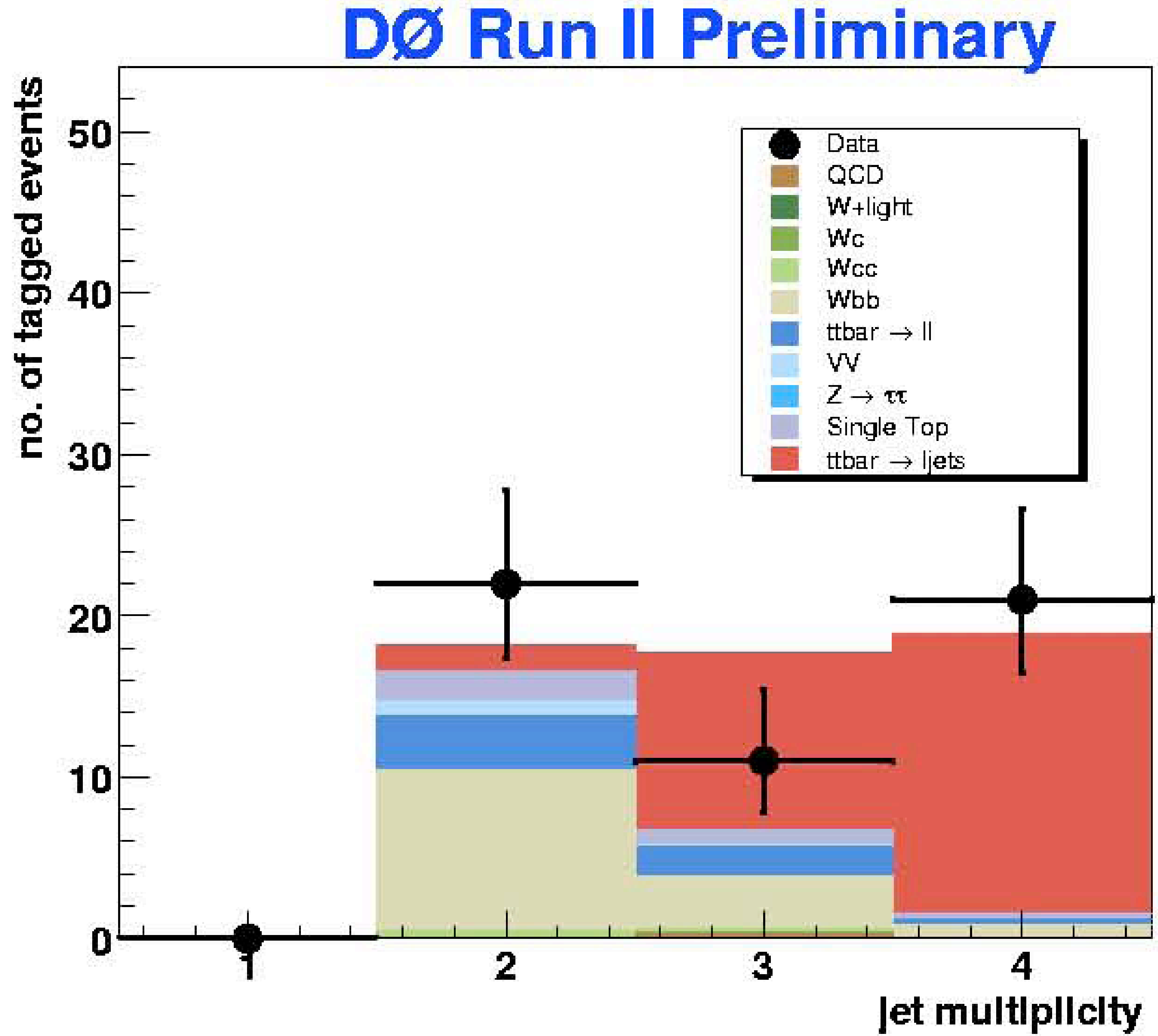

DØ Preliminary
Events / 5
cut
Data
W→ lν + jets
Z→ νν + jets
tt̄
WW,WZ,ZZ
Z→ l⁺l⁻ + jets
single-t
Signal
Δφmin(E̸T,any jet) (degrees)
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140
160
180



CDF Run II Preliminary
Events / 30 GeV
10^3
10^2
10
1
Data (L = 371 pb^{-1})
QCD
$t\bar{t}$ + QCD
W, Z, WW + $t\bar{t}$ + QCD
mSUGRA
($M_{\tilde{g}} \sim M_{\tilde{q}} \sim 252$ GeV/c^2)
$H_T > 230$ GeV
50
100
150
200
250
300
$\not{E}_T$ [GeV]

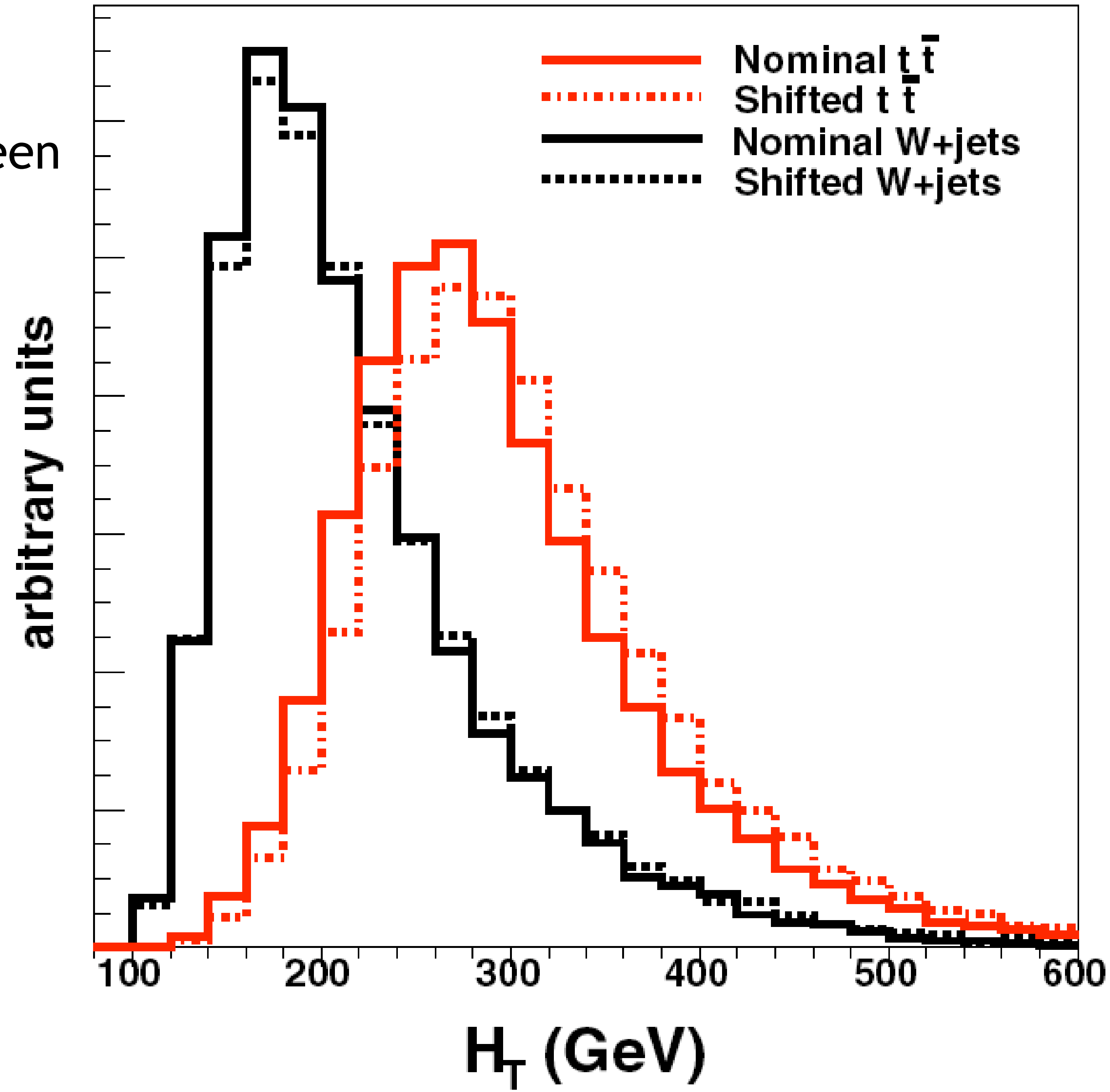
top quark: require 1 b tagged jet




DØ Run II Preliminary
no. of tagged events
0
10
20
30
40
50
1
2
3
4
jet multiplicity
Data
QCD
W+light
Wc
Wcc
Wbb
ttbar → ll
VV
Z → ττ
Single Top
ttbar → ljets

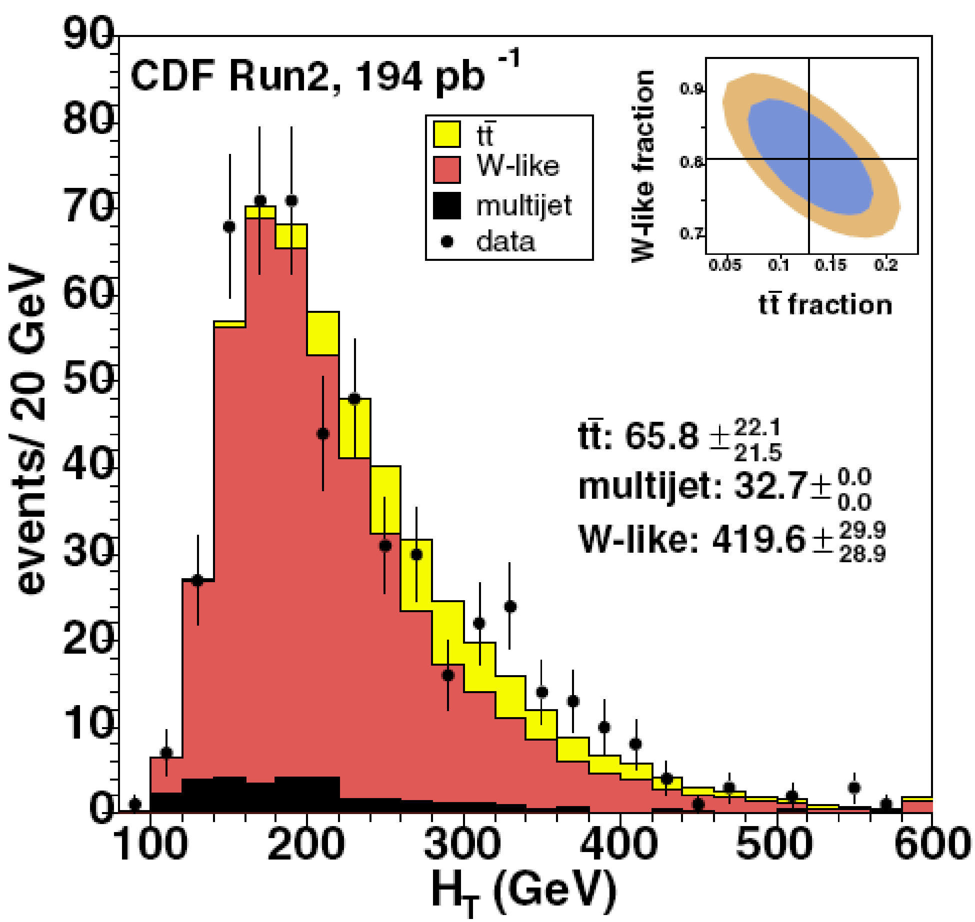
CDF

Comparison of HT distributions between ttbar and W + jets events

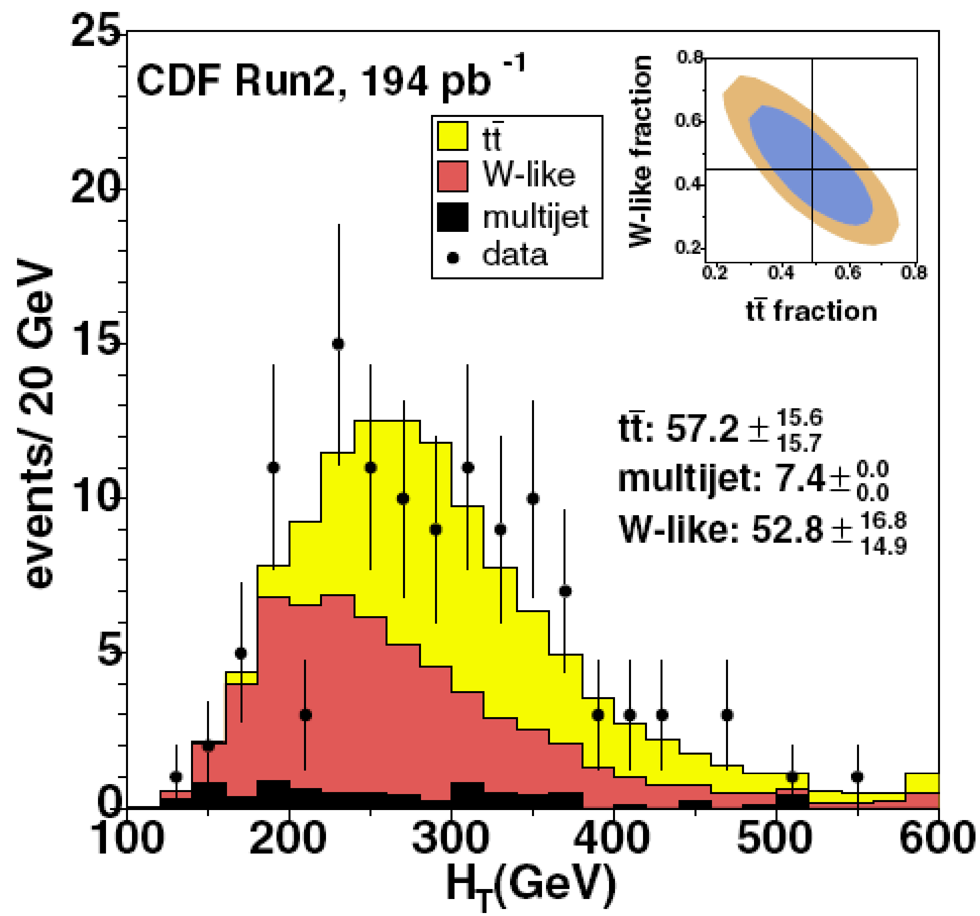


Using this and 18 more variables input to a neural network classfier, CDF has demonstrated the ability to observe $t\bar{t}$ events without b-tagging. Here are the last two steps in the staircase in that analysis.

W+3 jets



W + 4 jets



$$H_T = \not{E}_T + E_{T\ell} + \sum_i E_{Ti}$$

We can also move in the direction of multilepton signatures. Here there is another staircase, the Baer-Tata staircase.

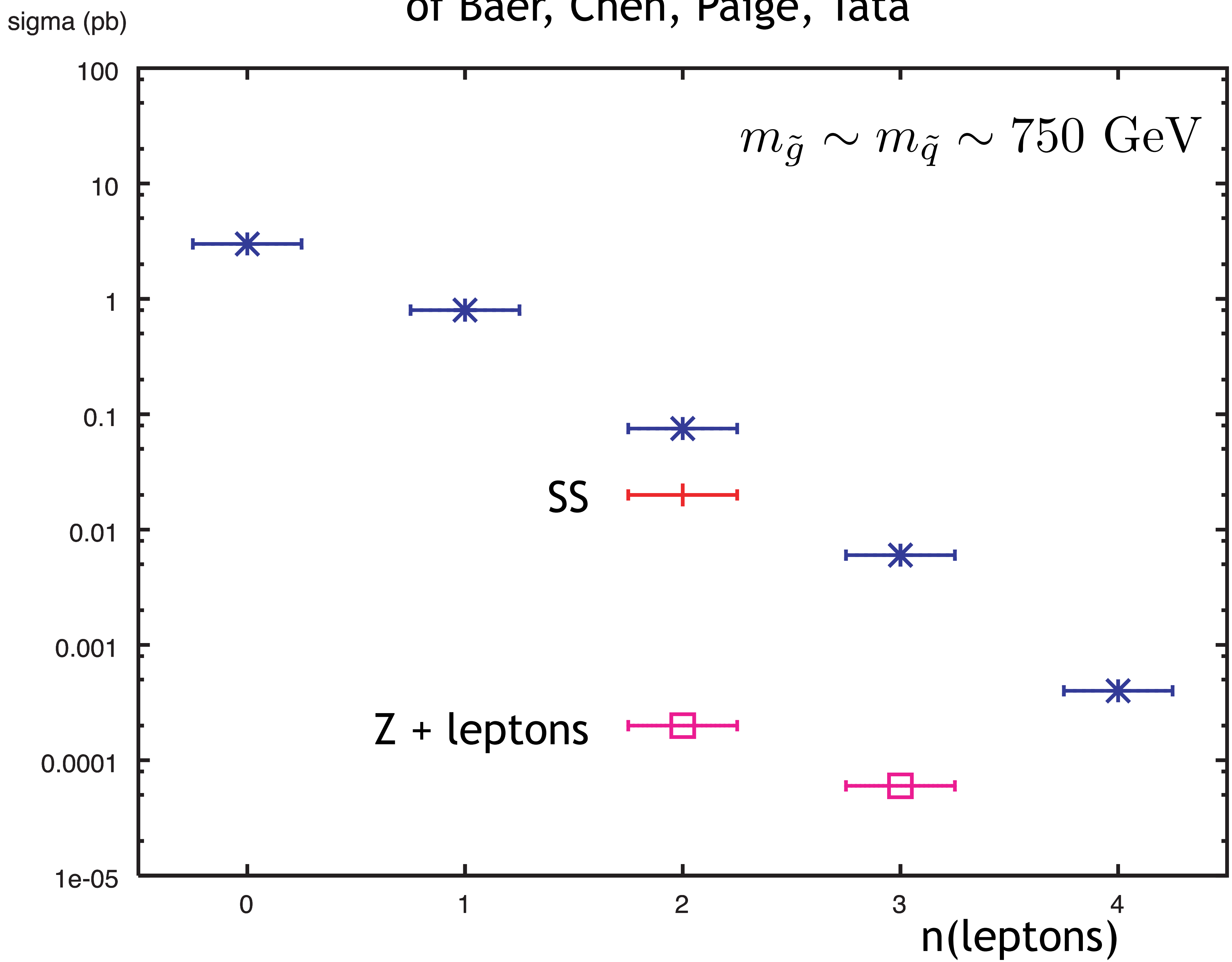
Many new physics models such as supersymmetry predict 2, 3, 4 - lepton events in a steadily decreasing progression.

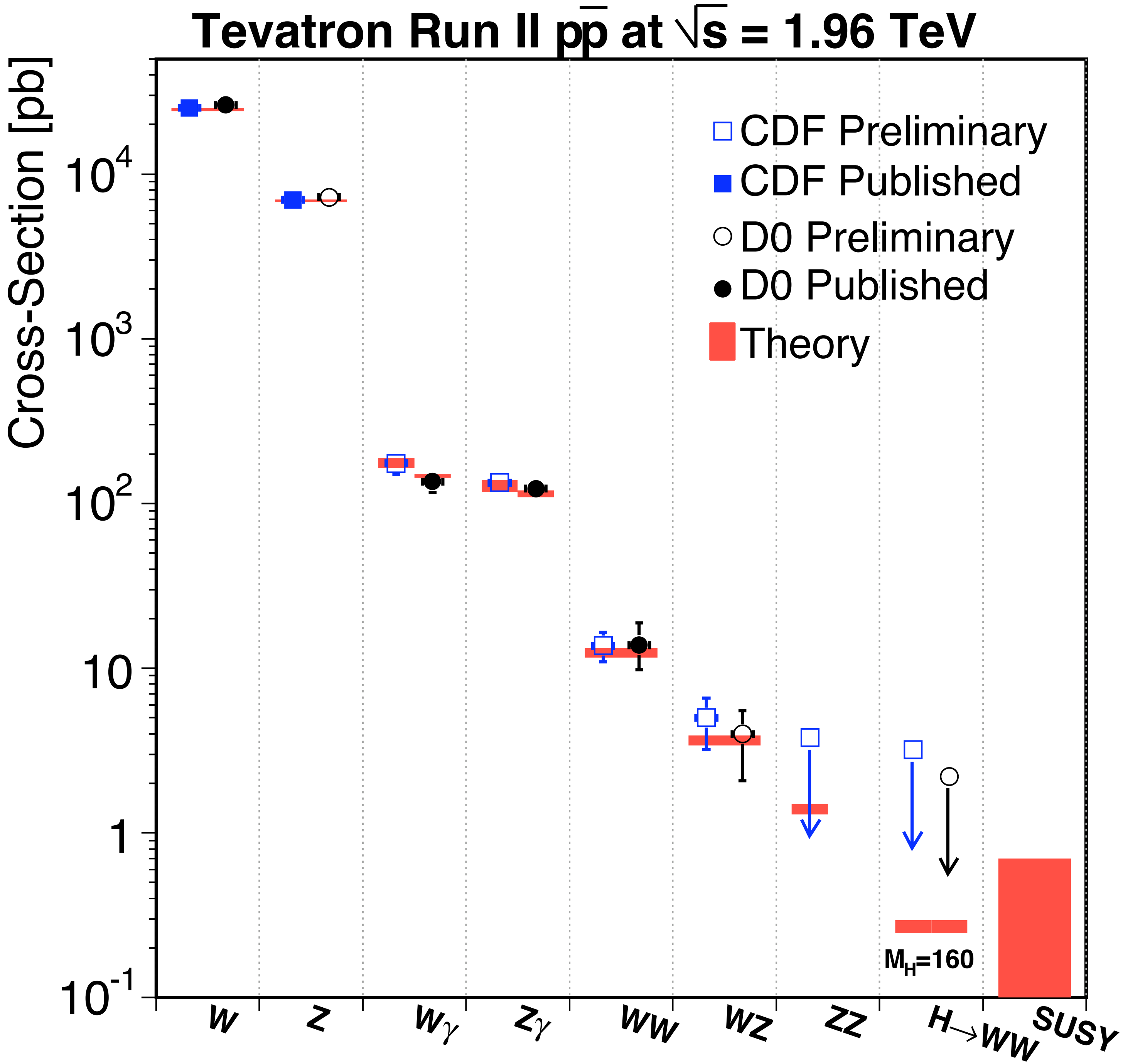
The Standard Model also produces such events, from multiple heavy-quark decays and jets faking leptons.

Fortunately, these come from the same W, Z, $t\bar{t}$ + jets processes that we have already been discussing.

Electroweak backgrounds, e.g. $pp \to W^+W^+ \to \ell^+\ell^- + \text{jets}$ are at the fb level.

signal cross sections from one of the models of Baer, Chen, Paige, Tata





thanks to M. Neubauer

There is an issue here that has not been well studied and needs attention.

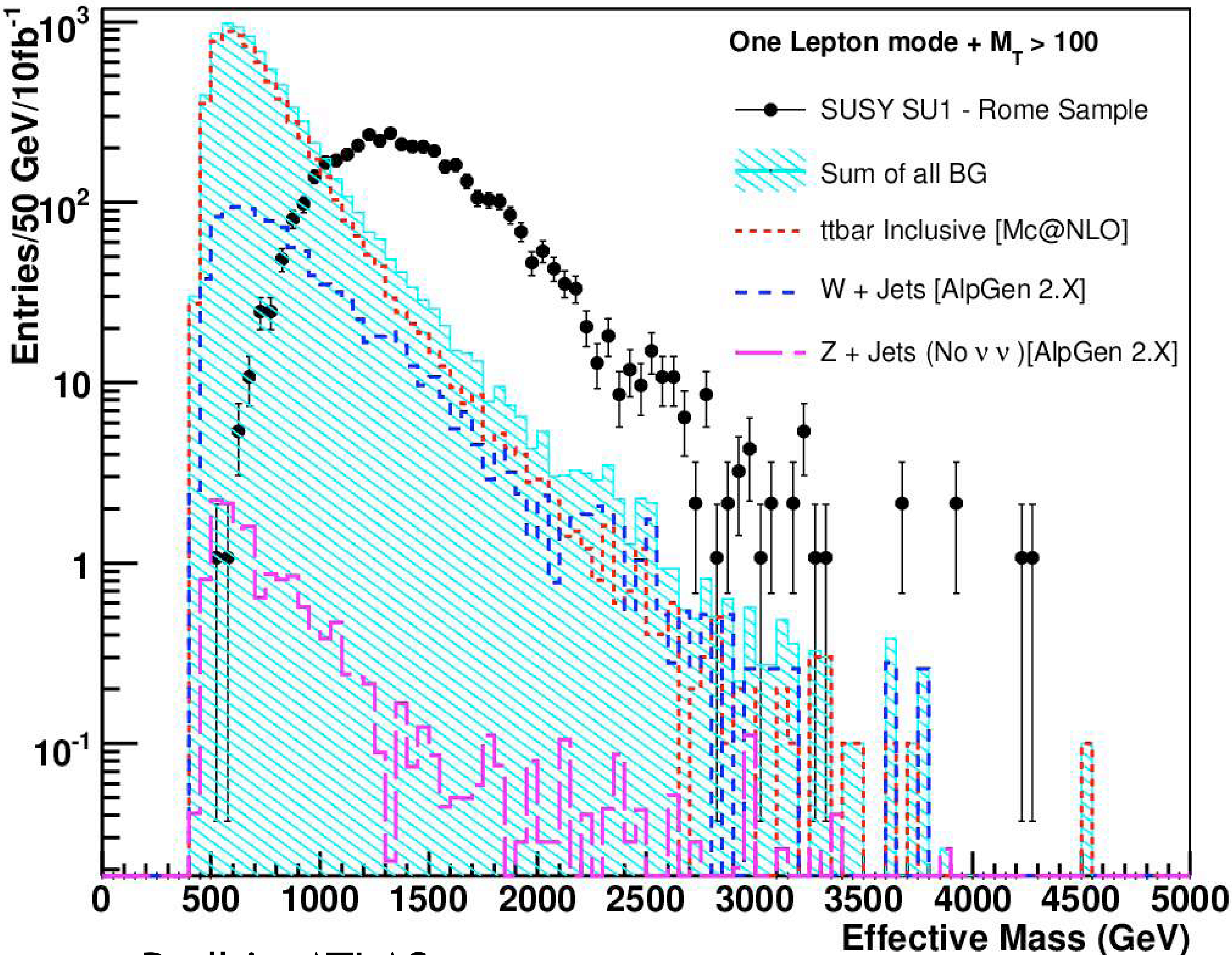
At the LHC, the top quark cross section is large, and

$$t\bar{t} + \mathrm{jets}$$

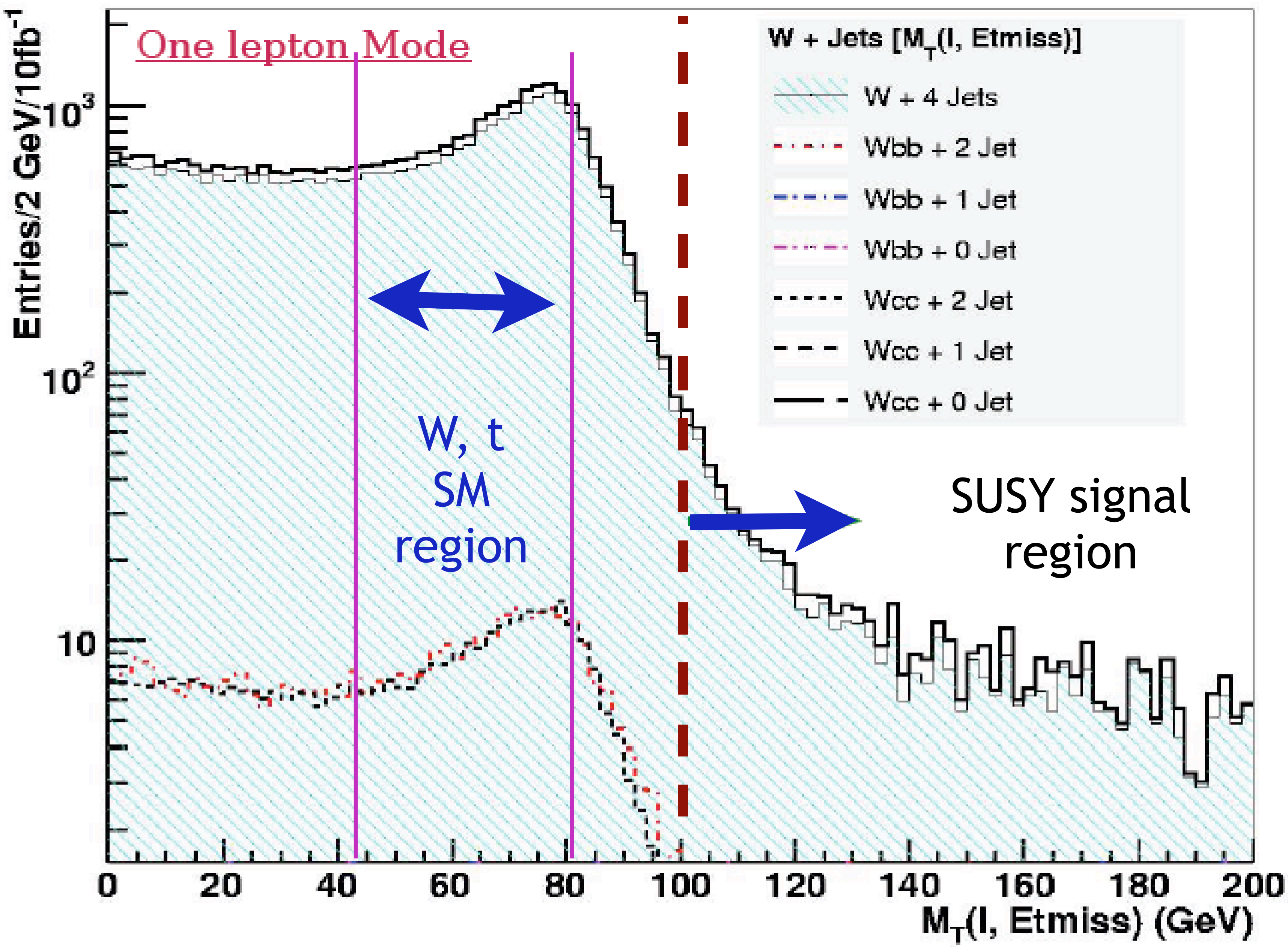
can contribute at a comparable level to $W, Z + \mathrm{jets}$ in some Standard Model background samples.

Is there a way to obtain a relatively pure sample of $t\bar{t} + \mathrm{jets}$ events to validate the theoretical models of this process used to estimate these backgrounds ?

For example, in Padhi's simulation of the single-lepton + MET signature:



Padhi - ATLAS


One lepton Mode
W + Jets [M_T(l, Etmiss)]
W + 4 Jets
Wbb + 2 Jet
Wbb + 1 Jet
Wbb + 0 Jet
Wcc + 2 Jet
Wcc + 1 Jet
Wcc + 0 Jet
W, t
SM
region
SUSY signal
region
Entries/2 GeV/10fb^-1
10^3
10^2
10
0
20
40
60
80
100
120
140
160
180
200
M_T(l, Etmiss) (GeV)

Padhi

To model staircases, we need a simulation code that accurately produces many QCD jets with correct transverse momentum distributions. This is the territory of ALPGEN and MADGRAPH. These codes are like highly tuned BMW's. But they are not completely free of theoretical issues. They are leading-order Monte Carlos, but this could be improved. A knottier issue is that of merging with parton showers avoiding double-counting.

To explore this physics of W, Z, t + multijet processes, it may also be useful to have a codes that is built more like a `62 Chevy, one that lets you poke under the hood and adjust the carburetor by hand.

I think that this can be done using the following set of ideas. We are now working on a program that incorporates them.

1. Work only to the leading order in N_c and take advantage of color-ordering. Consider W, Z, t with their tree-level decays; there exist MHV amplitudes for these processes.

2. Generate exact tree amplitudes with many gluons on the fly using the Britto-Cachazo-Feng recursion formula.

   (Dinsdale, Ternick, and Weinzierl have a very fast code.)

3. Generate QCD phase space using Sudakov variables

   (Draggiotis, van Hameren, and Kleiss' Sarge algorithm)

4. Include Sudakov suppression of collinear emissions; refine the Sudakov factor using Monte Carlo data.

Whatever tools we apply, it is important to develop a clear physical understanding of the $W, Z, t\bar{t} + \mathrm{jets}$ processes.

I recommend this problem to Olympians as one in which their skills can be used to good effect.