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DALITZ ①

DØ NOTE 1463

I heard someone say:

"Physics is not a matter of betting.

You must be able to prove your results"

Where has this author been in recent years? ← what about 95% confidence limits? True in a sense, of course, but not the point today – as I'll try to explain later.

SModel

$SU(2)_{Wk} \times U(1)$ $\quad T_3 = +\frac{1}{2} \begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t? \\ b \end{pmatrix}$, $-\frac{1}{2}$

Model works wonderfully, with high accuracy test. Implies that "top" must exist: the b quark must have a partner.

The top studies are not really just checking $SU(2) \times U(1)$ further. The present aim is rather to determine the top parameter m_t.

Assuming top exists (we all agree for the present), what is its mass?

When that is done, we'll know which kind of accelerator we'll need to study it further. Then we'll go back & check that top does have the interactions SM requires.

Let me say how we drifted into this subject. With Robin Marshall (Rutherford) we looked at $e^+e^- \to \bar{Q}Q$ to see if could find spin dependent characteristics of jets. Only hope in $Q = c, b, t$, since may identify the leading meson $(Q\bar{q})$

Michael Brown = New Scientist reporter who should be avoided! (or write)

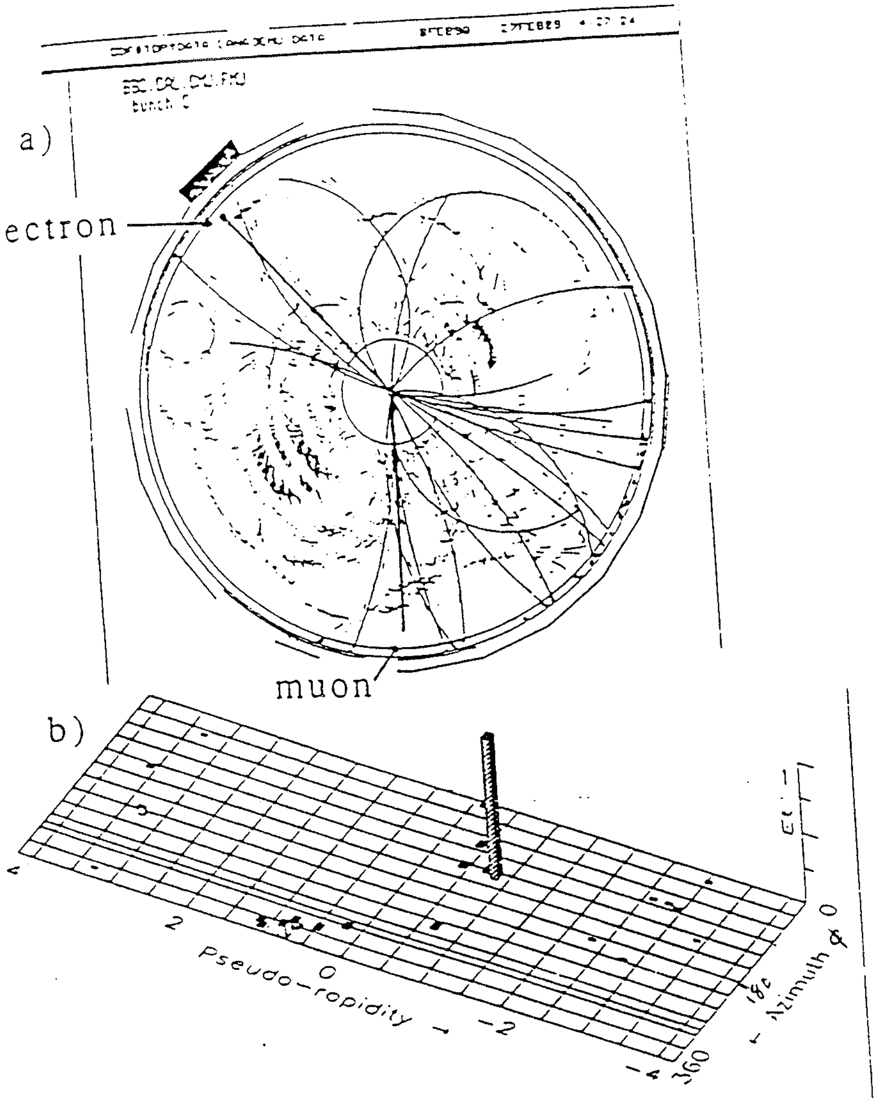
RESULTS CDF $p\bar{p} \to e\mu$

EVENEMENT $P_T^e = 31.7$ Gc

$P_T^\mu = 42.5$ GeV/c

ALAN CLARK

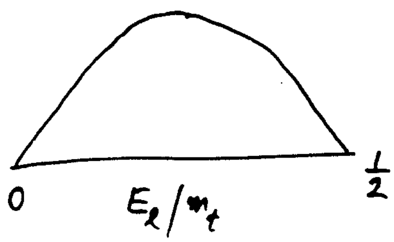
ST. CROIX (1990)



The one candidate event. a) the $r\phi$ view: the electron at $\phi = 130^\circ$ has $E_T = 31.7$ GeV, the μ at $\phi = 260^\circ$ has $P_T = 42.5$ GeV/c. b) the azimuth vs. η plot, with the vertical scale representing the calorimeter energy. The electron is the large tower at $\phi = 130^\circ$, the μ is at $\eta = -0.7$ and $\phi = 260^\circ$.

$$\frac{d\Gamma}{dE_\ell} = \frac{G_F^2 M_W^3}{2\pi^2 m_t \Gamma_W} \left\{ E_{\ell t} \left(\frac{1}{2}\left(m_t^2 - m_b^2\right) - m_t E_{\ell t} \right\} \right.$$

$$\sim m_t^2 \cdot \frac{E_{\ell t}}{m_t} \cdot \left(1 - 2\frac{E_{\ell t}}{m_t}\right) \qquad \left(\frac{m_b}{m_t}\right)^2 \ll 1$$



i) $(\underline{t} - \underline{b})^2 = (\underline{\ell} + \underline{\nu})^2 = M_W^2$ $\qquad$ $\underline{t}$ four vector

ii) $(\underline{t} - \underline{b} - \underline{\ell})^2 = (\underline{t} - \underline{b})^2 - 2\underline{\ell}\cdot(\underline{t} - \underline{b}) + \underline{\ell}^2$

$$\underline{= 0}$$

Hence $\underline{\ell}\cdot\underline{t} = \underbrace{\frac{1}{2}M_W^2 + \underline{\ell}\cdot\underline{b}}_{\text{known}}$ $\qquad$ Evaluate $\underline{\ell}\cdot\underline{b}$ in Lab frame

Use $\underline{\ell}\cdot\underline{t}$ in t rest-frame

$$\underline{= E_{\ell t} m_t}$$

So $\quad m_t = \frac{\frac{1}{2}M_W^2 + \underline{\ell}\cdot\underline{b}}{E_{\ell t}} > \frac{\frac{1}{2}M_W^2 + \underline{\ell}\cdot\underline{b}}{(E_{\ell t})_{max}}$

$$(E_{\ell a})_{max} = (m_t^2 - m_b^2)/2m_t \qquad \text{from above}$$

So

$$\cancel{m}_t \geqslant \frac{2\cancel{m}_t}{m_t^2 - m_b^2}\left(M_W^2 + 2\,\underline{b}\cdot\underline{\ell}\right)$$

$$m_t \geqslant \sqrt{\left(m_b^2 + M_W^2 + 2\,\underline{b}\cdot\underline{\ell}\right)}$$

Can do better:

$$m_t \geqslant \left\{ (m_b^2 + 2\,\underline{b}\cdot\underline{\ell})(M_W^2 + 2\,\underline{b}\cdot\underline{\ell})/(2\,\underline{b}\cdot\underline{\ell}) \right\}^{1/2}$$

---

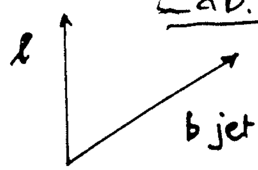
and

$$E_{\ell t} = \frac{\frac{1}{2}M_W^2 + \underline{b}\cdot\underline{\ell}}{m_t}$$

$t: m_t$

$: E_t = \sqrt{(m_t^2 + \vec{t}^{\,2})}$

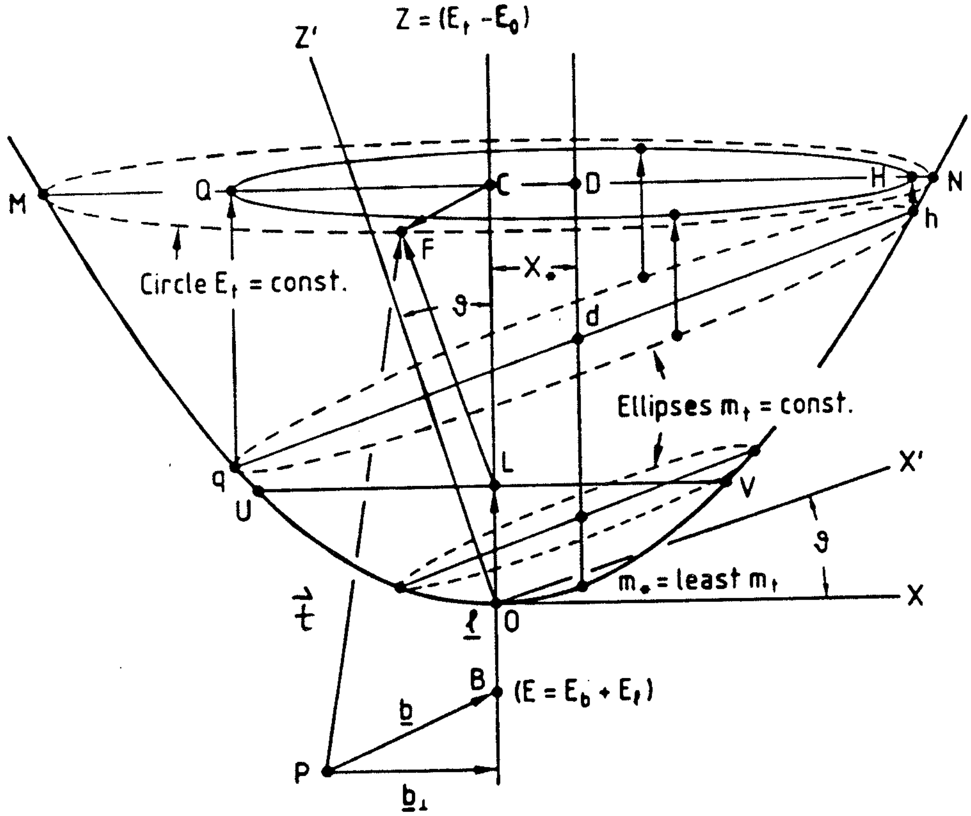
Lab. frame



$t \to b + W^+$
$\quad \hookrightarrow \ell^+ + \nu_\ell$

$\vec{t} = \vec{b} + \vec{W}$

$L = \vec{\ell} + \vec{\nu}$



$$(\vec{t} - \vec{b})^2 = (E_t - E_b)^2 - M_W^2 = R_W^2 \qquad (\underline{W} = \underline{\ell} + \underline{\nu})$$

$$(\vec{t} - \vec{b} - \vec{\ell})^2 = (E_t - E_\ell - M_\ell)^2 \qquad (m_\nu^2 = 0)$$

$$= R_\nu^2$$

Equations give 2 spheres which intersect in a plane MN $\perp$r to $\vec{\ell}$.

The intersection is a circle of radius r centred on the axis $\vec{\ell}$

Radius r :

$$\sqrt{(R_W^2 - r^2)} \pm \sqrt{(R_\nu^2 - r^2)} = \pm 1$$

r^2 given by

$$r^2 = \frac{M_W^2}{E_\ell}(E - E_0) \qquad (i)$$

$$E_0 = E_b + E_\ell + M_W^2/4E_\ell$$

As E increases, the plane moves upward and r increases.

Eq (i) gives paraboloid.

$$\vec{t} = \vec{t}_0 + (E - E_0)\hat{\vec{\ell}} + \vec{b}_\perp$$

$m_t^2 = (E_t^2 - \vec{t}^{\,2})$ is linear in $(E - E_0)$ and $\vec{b}_\perp \cdot \vec{t}_0$,Z // X

Slanting plane cut of paraboloid, gives an ellipse on plane q-h

$m_t = $ const. $\longrightarrow$ $\vec{t}$ lies on this ellipse $\perp$r to OZ'

Ellipse moves upwards — always normal to OZ' as m_t increases.

For m_t : E_t has a minimum and a maximum
at q at h

$\vec{\nu} = \vec{t} - \vec{b} - \vec{\ell}$: so given by $\overrightarrow{LF}$

Hence can always fit config^{n} $(\vec{b}, \vec{l})$

for m_t large enough.

Min^{m} m_t corresponds to point m^* where plane qh just touches paraboloid. This is the inequality given above.

Large m_t means $\vec{LF}$ very large, but this is $\vec{\nu}$, neutrino mom$^{\underline{m}}$

$\vec{PF}$ " " " $\vec{t}$ and the two large momenta then just compensate, giving fixed mom$^{\underline{m}}$ $(\vec{b} + \vec{l})$

<u>$q\bar{q} \to t\bar{t}$</u> Make 2nd paraboloid Fig. 3.

All this leads up to μe event reported several years ago by CDF. Described at many Conferences, Schools, Workshops. e.g. by Clark at St. Croix (1990), Pondrom at Singapore (1990), by others at various Rencontre de Moriond and elsewhere.

Paraboloids shown for this event, <u>if assume it represents $t\bar{t}$</u> with $t \to bW^+$, $\bar{t} \to \bar{b}W^-$, both W's leptonic decay.

Always assumed that could not analyse such an event, because ν_e and ν_μ unseen.

Of course, don't know whether $t\bar{t}$ assumption is correct, but if it is, then can say something about m_t.

One more input. z axis is beam direction. $q\bar{q}$ collision has no transverse component. Thus

$$\vec{t}_\perp + \vec{\bar{t}}_\perp = 0$$

What effect? Swing one paraboloid around z axis by 180°

Look along z direction. (Project onto transverse plane)

See 2 ellipses. Crossings give the fits, as f^n of m_t. Show various cases as m_t varies.

Next initial q and $\bar{q}$ possible? Given t and $\bar{t}$, calculate parton variable x and $\bar{x}$, Prob. $P(x)\,P(\bar{x})$ $\qquad$ $P(x)$ structure f^n for p (and $\bar{p}$)

from $\vec{t}$ and $\vec{\bar{t}}$

Overall Prob. $= \left[P(x)\,P(\bar{x})\ \text{Prob}(\text{event configs})\ \text{Prob}(\ell)\,\text{Prob}(\bar{\ell}) \right]$

more than 1 possible

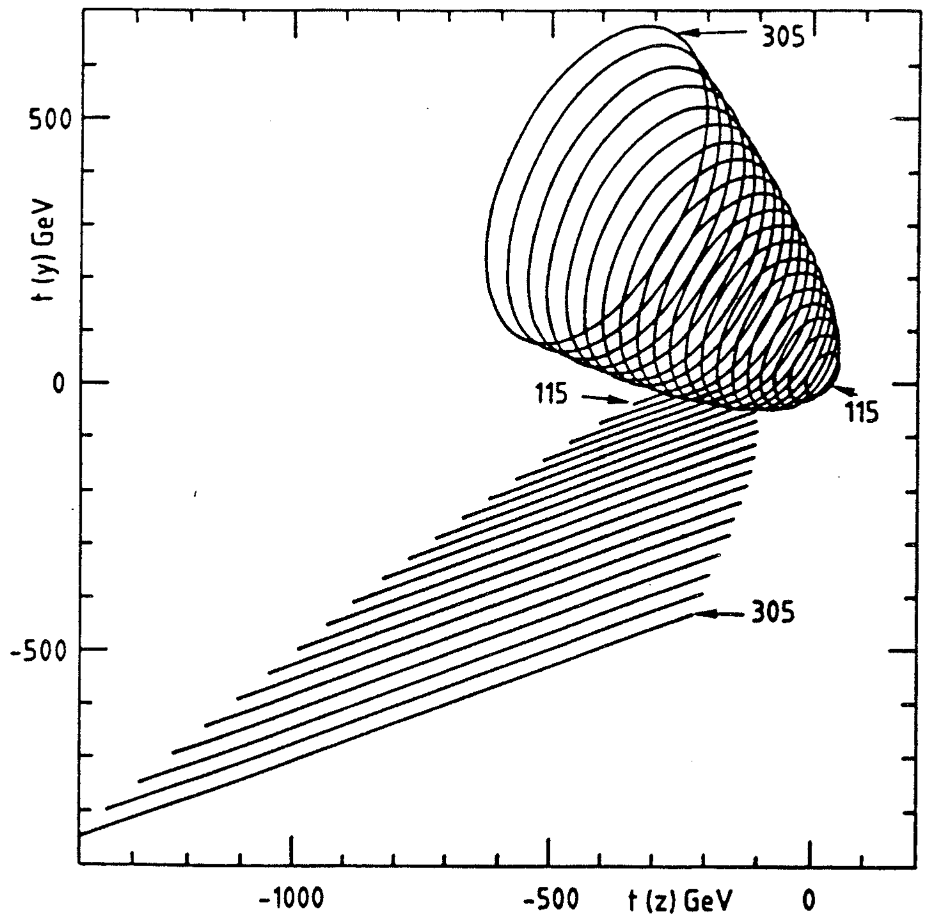
Use $\dfrac{d\Gamma}{dE_\ell}$: note E_ℓ/m_t is not large, about 1/4, so this factor is important

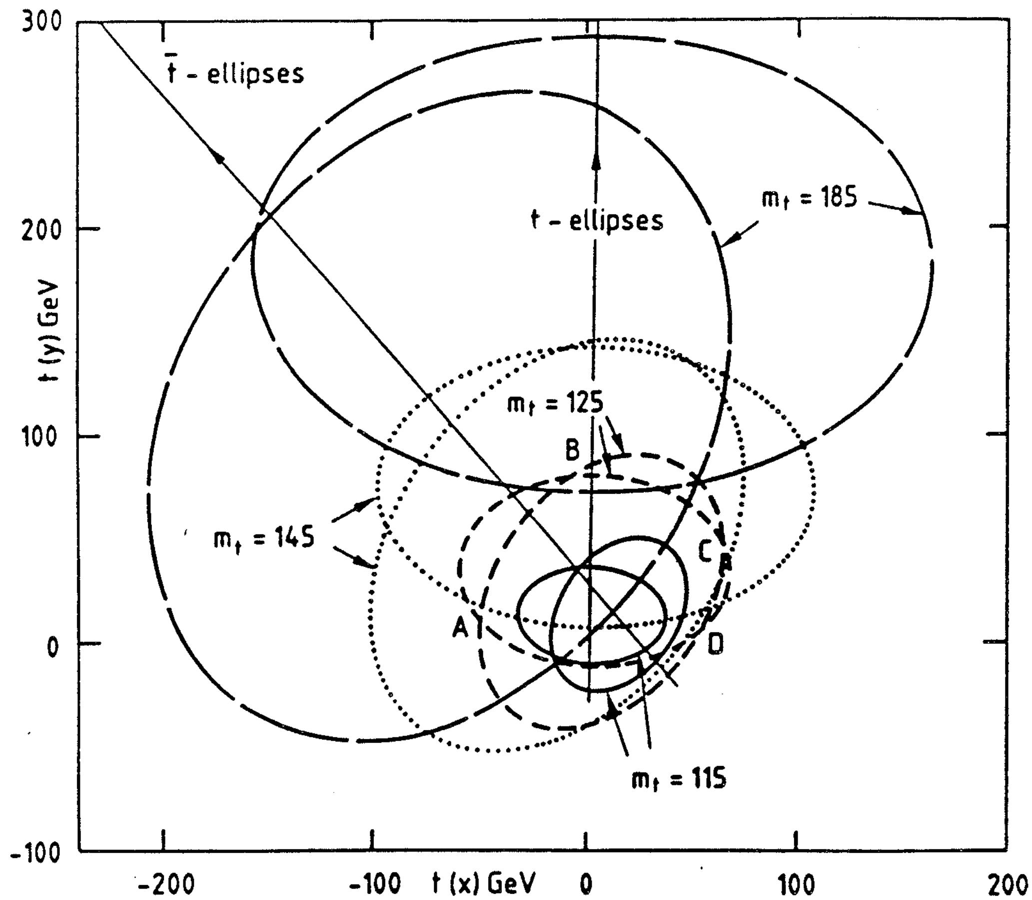
Bayes theorem

$\underline{L(m_t,}$ events) $\propto$ [above]/normalisation factor.

As given in Fig.

μ-e candidate top event analysed

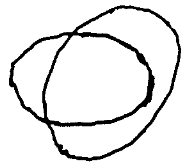




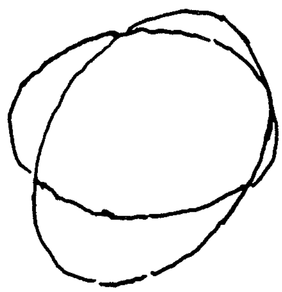
300
200
100
0
-100
-200
-100
0
100
200
t (x) GeV
t (y) GeV
t̄ - ellipses
t - ellipses
m_t = 185
m_t = 125
m_t = 145
m_t = 115
A
B
C
D

110 GeV

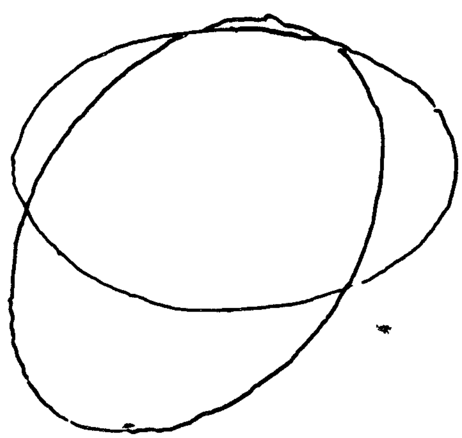
115 GeV

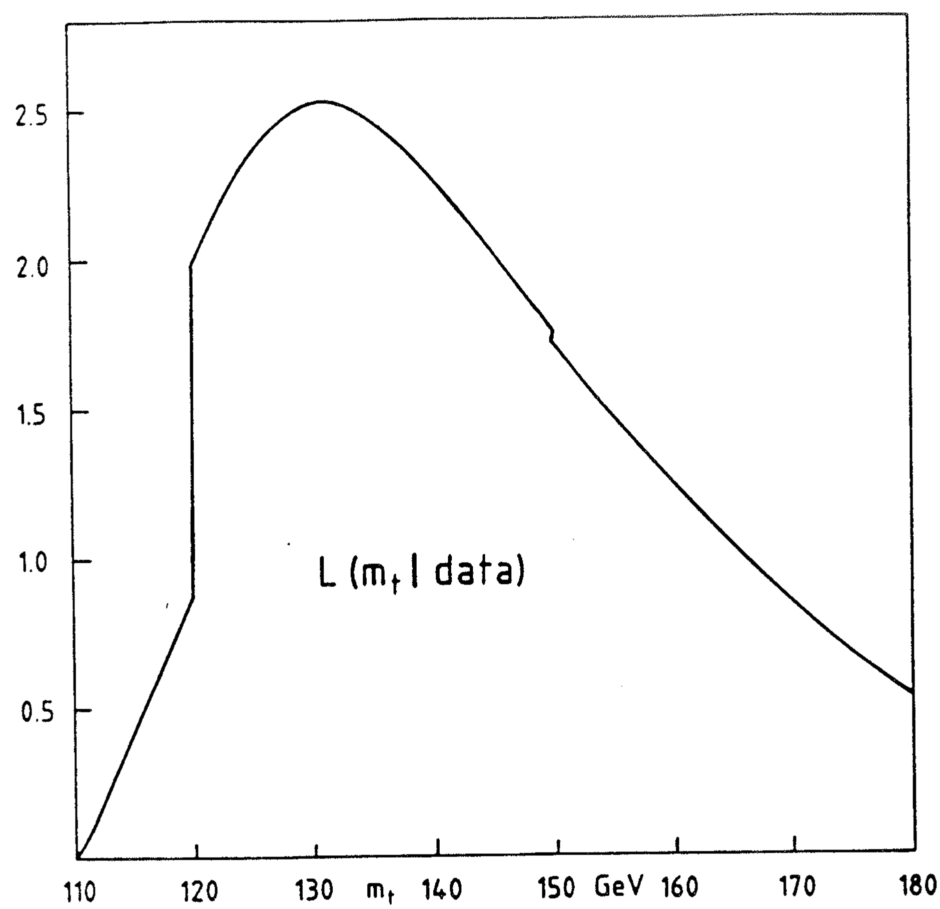


125 GeV



145 GeV



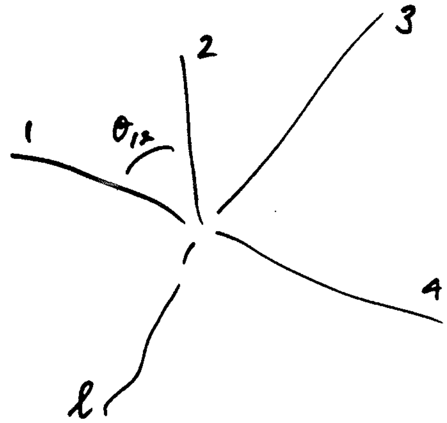

2.5
2.0
1.5
1.0
0.5
L (m_t | data)
110
120
130
m_t
140
150
GeV
160
170
180

$W \to \bar{q} q'$ more probable than $\ell \nu$ by 6.

Hope for more ~~as~~ events

$$t \bar{t} \to (\bar{\ell} \nu b)(\bar{b} \bar{q} q') \qquad \text{lepton + 4 jets}$$

At present, not able to identify which jet is which quark. (May soon be able to do this for b jets, altho' not for 100% of them)



Jet directions well determined

ℓ momentum $\vec{\ell}$ well

Jet energies $\pm$ 20%

Proposal. M_W is well known, small width.

Pick jets (1,2) and force them to have mass M_W – not unique

$$M_W^2 = 2\left(E_1 E_2 - p_1 p_2 \cos\theta_{12}\right) \simeq 2E_1E_2(1-\cos\theta_{12})$$

So fixes (E_1E_2) product. Pick n points to cover the range relevant

Prob is $P_1(E_1) P_2(E_2)\, \delta(E_1E_2 - \#)$ for each #

Next pick 3 + pick n points over its energy range $E_3 \pm \lambda\sigma_3$

Each fit (123) [n^2 of them] gives a $\underline{t}$ and m_t.

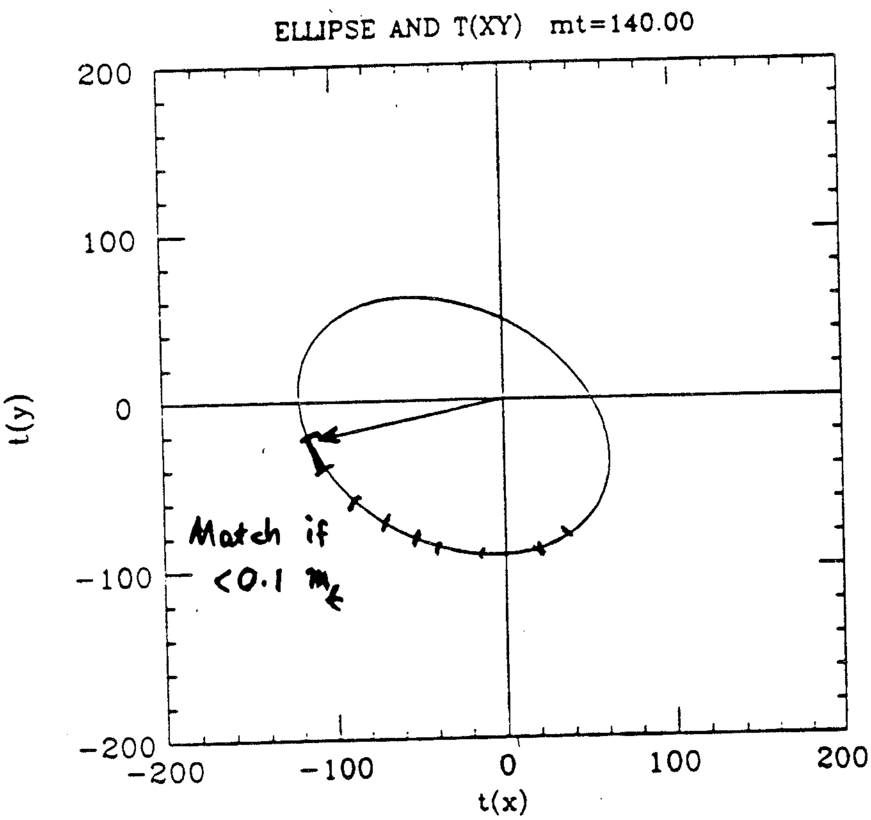
Next consider $\bar{t}$. Jet 4 is assumed to be b to go with ℓ.

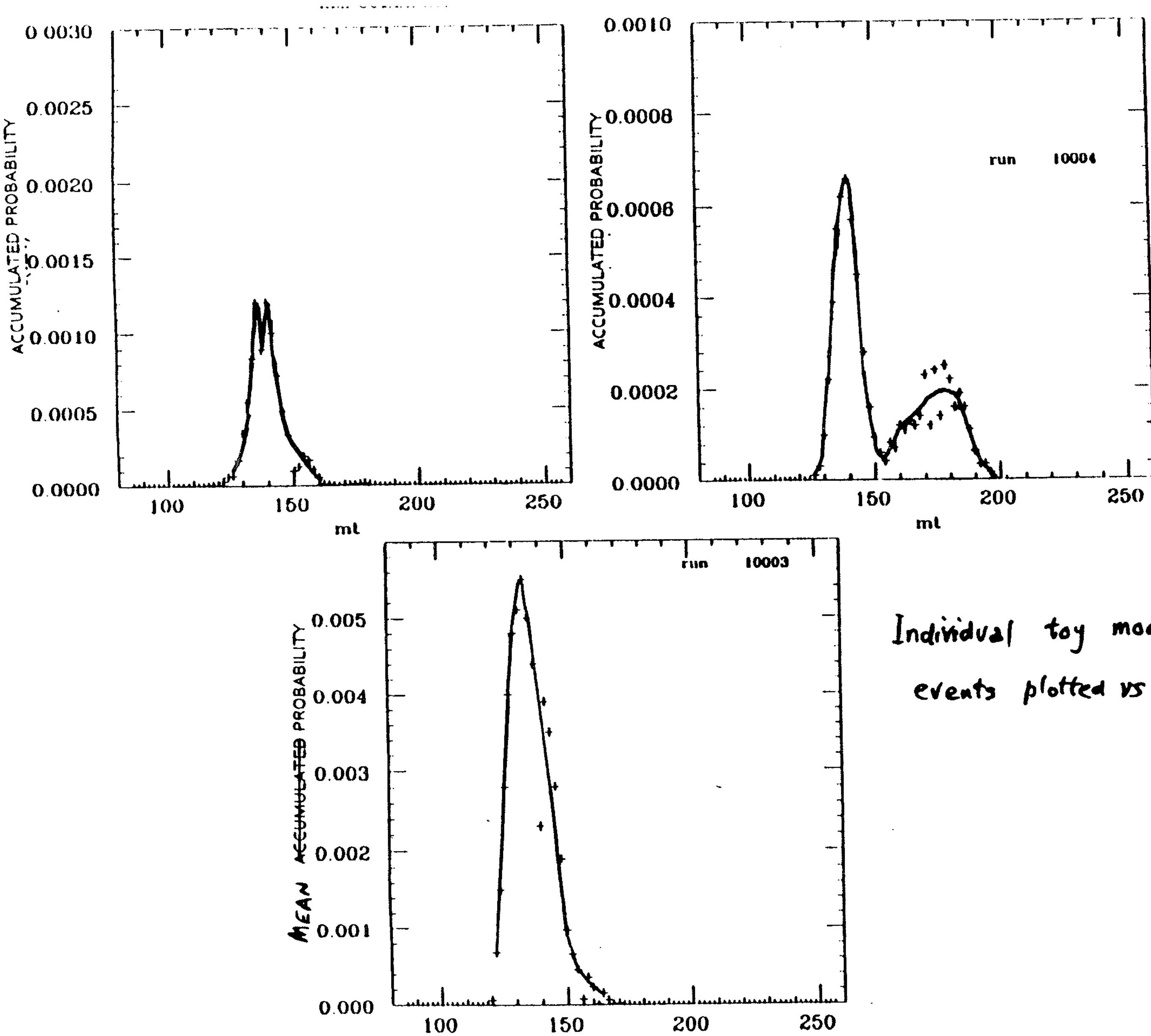
Take n points over the range $E_4 \pm \lambda\sigma_4$. Each one gives an ellipse as we described above. Divide the ellipse into n equal steps.

We now have n^4 values of these 4 variables.

Assume (123) – accept its m_t, + construct (4ℓ) ellipse. Ask for a match between t and the $\bar{t}$ obtained for each point on the ellipse such $\vec{t}_\perp + \vec{\bar{t}}_\perp = 0$

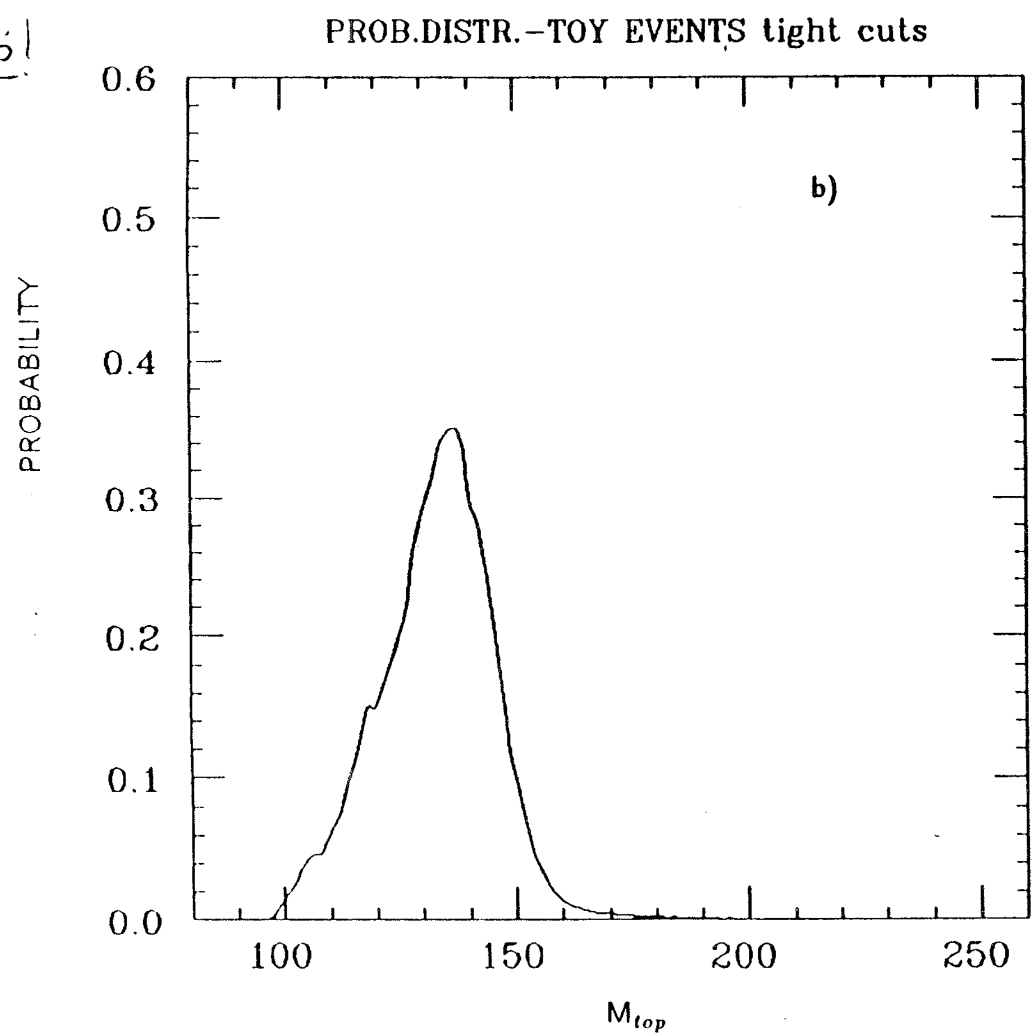
1


ELLIPSE AND T(XY) mt=140.00
200
100
0
-100
-200
t(y)
-200
-100
0
100
200
t(x)
Match if
<0.1 m_t



Individual toy model events plotted vs m_t.

38


PROB.DISTR.-TOY EVENTS tight cuts
b)
PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
100
150
200
250
M top

36

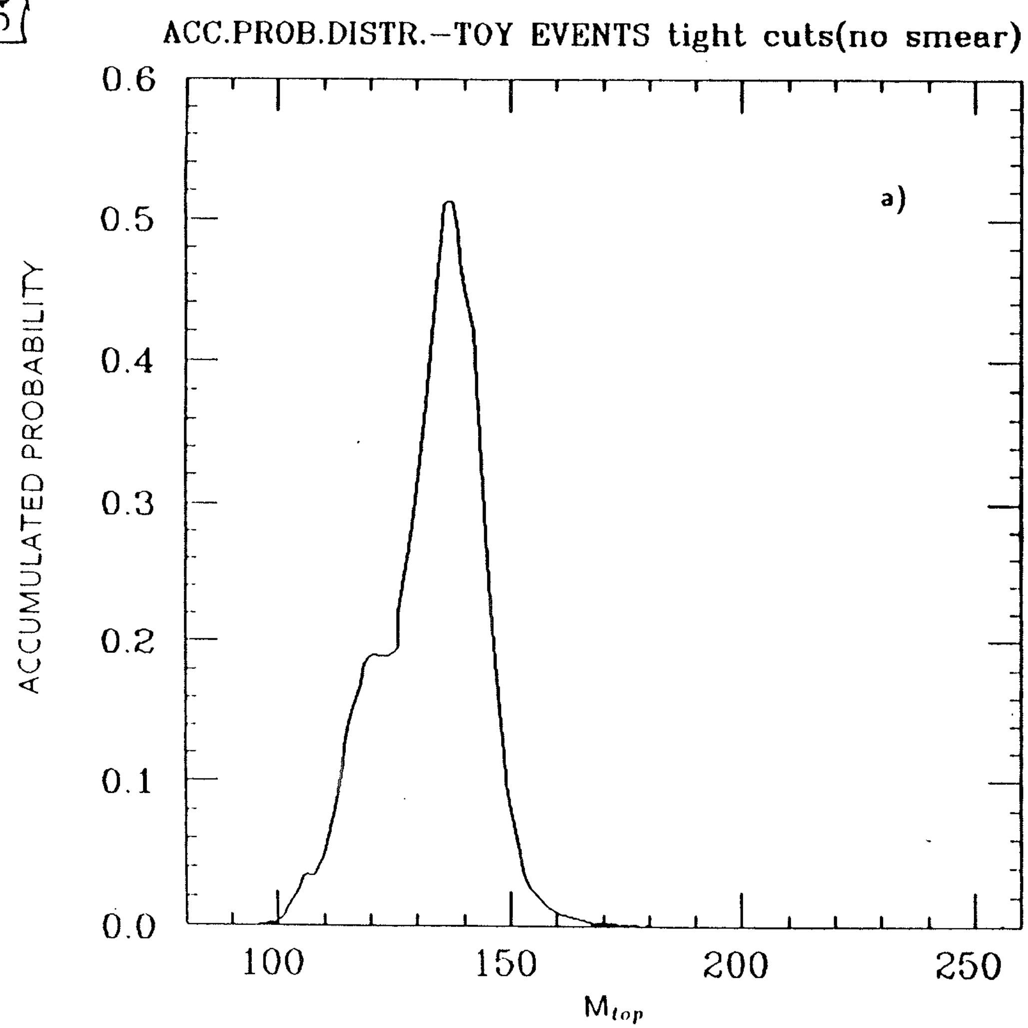
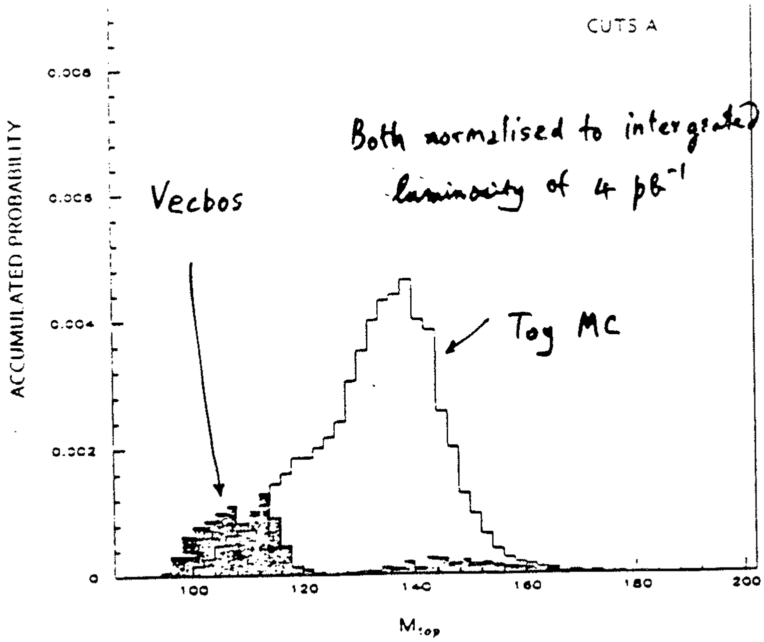
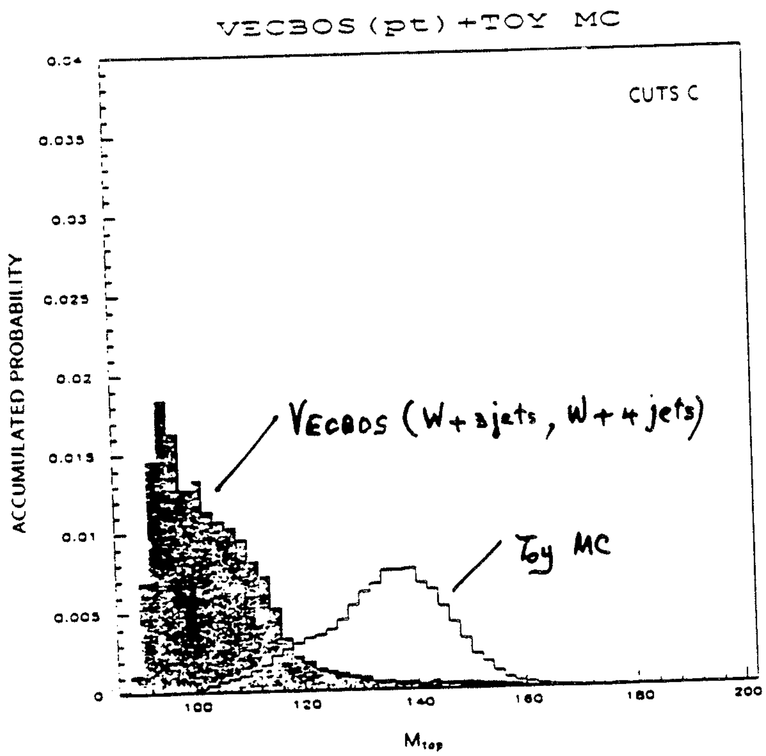

ACC.PROB.DISTR.–TOY EVENTS tight cuts(no smear)
a)
ACCUMULATED PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
100
150
200
250
M_{top}

FIGURE 3


CUTS A
Both normalised to intergrated luminosity of 4 pb^{-1}
Vecbos
Toy MC
ACCUMULATED PROBABILITY
0.008
0.006
0.004
0.002
0
100
120
140
160
180
200
M_{top}


VECBOS (pt) + TOY MC
CUTS C
Vecbos (W + 3jets, W + 4 jets)
Toy MC
ACCUMULATED PROBABILITY
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
100
120
140
160
180
200
M_{top}

5

FIGURE 5

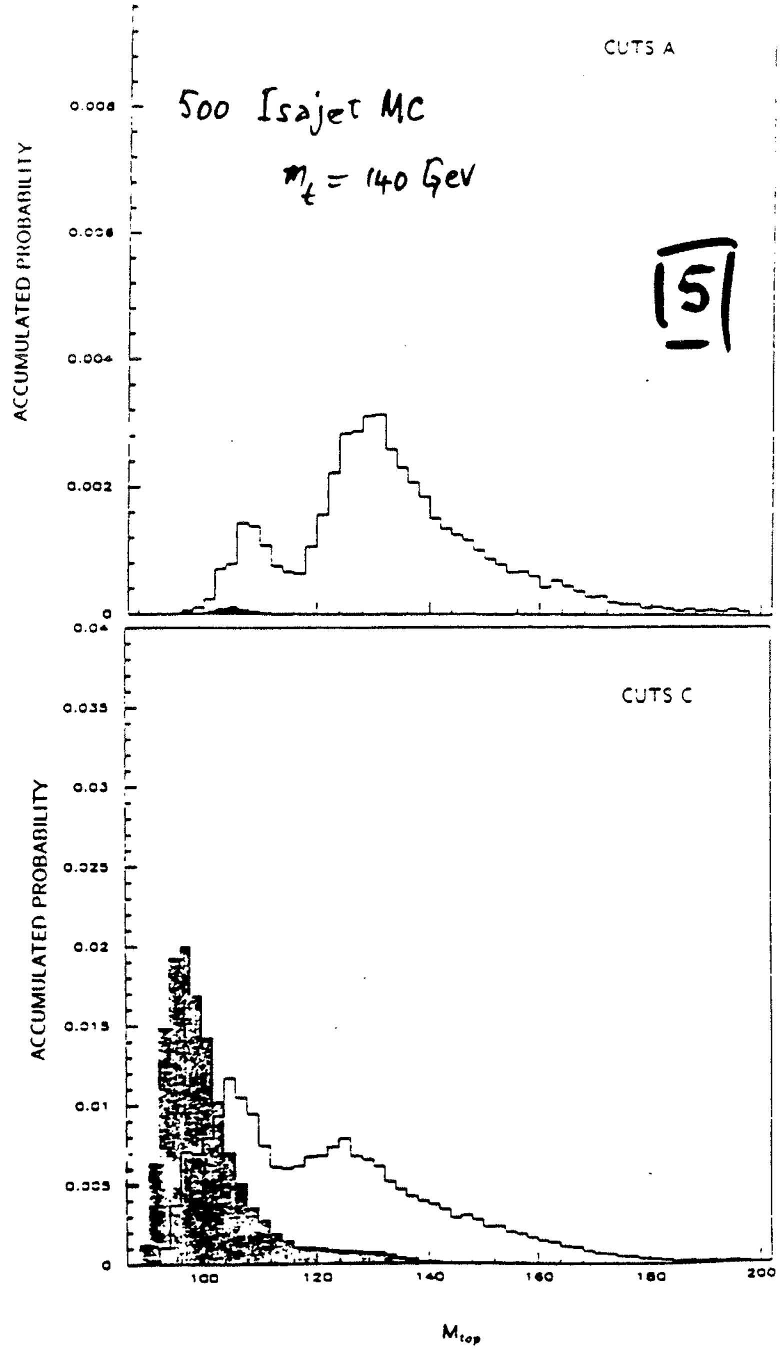
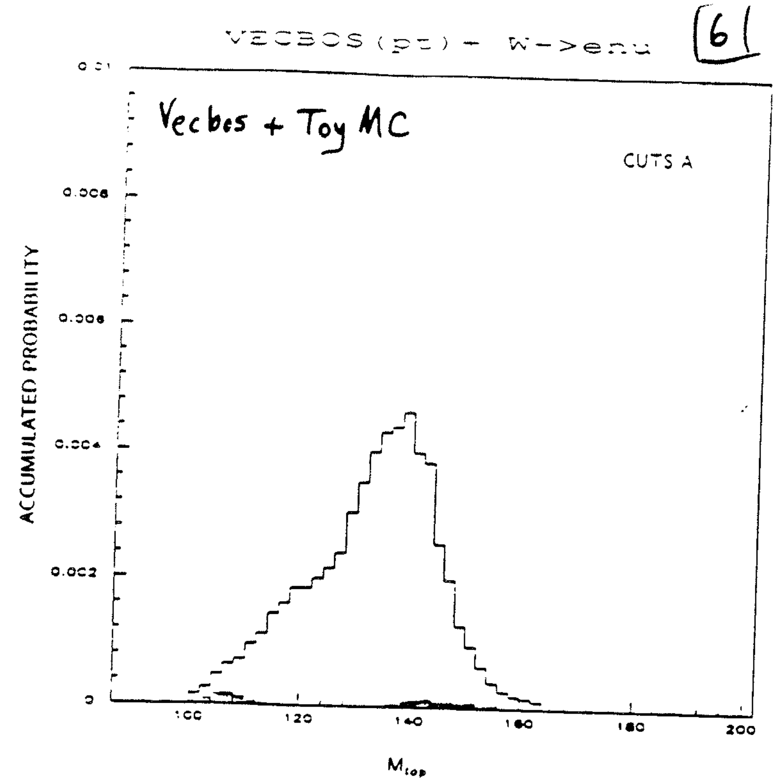
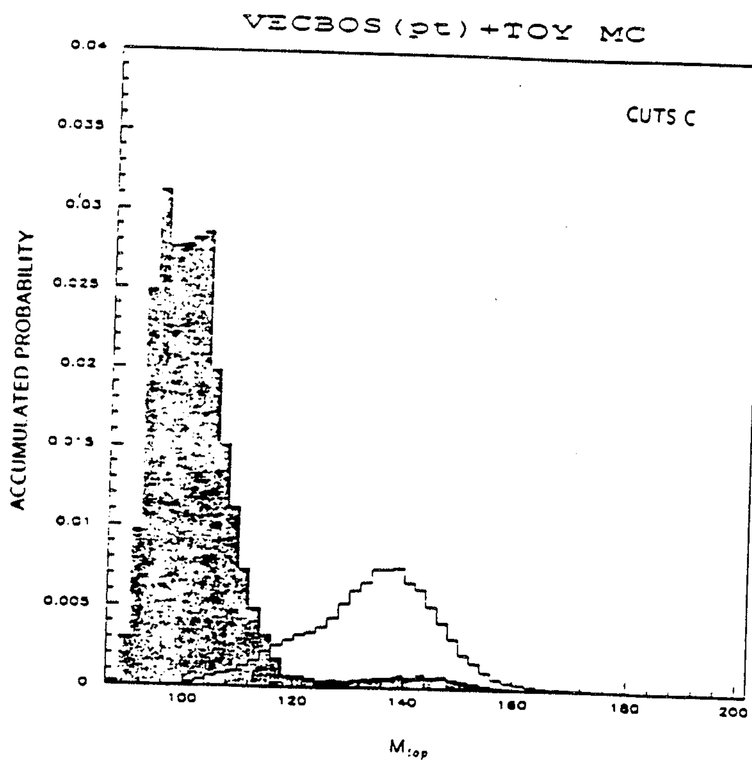

CUTS A
500 Isajet MC
m_t = 140 GeV
5
ACCUMULATED PROBABILITY
0.008
0.006
0.004
0.002
0
0.04
CUTS C
0.035
0.03
0.025
0.02
0.015
0.01
0.005
100
120
140
160
180
200
M_{top}

FIGURE 2



VECBOS(pt) + W->enu
Vecbos + Toy MC
CUTS A
ACCUMULATED PROBABILITY
0.008
0.006
0.004
0.002
0
100
120
140
160
180
200
M top



VECBOS(pt)+TOY MC
CUTS C
ACCUMULATED PROBABILITY
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
100
120
140
160
180
200
M top