Optimal Use of Information for Measuring M_t in lepton+jets $t\bar{t}$ Events.

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for the DØ Collaboration

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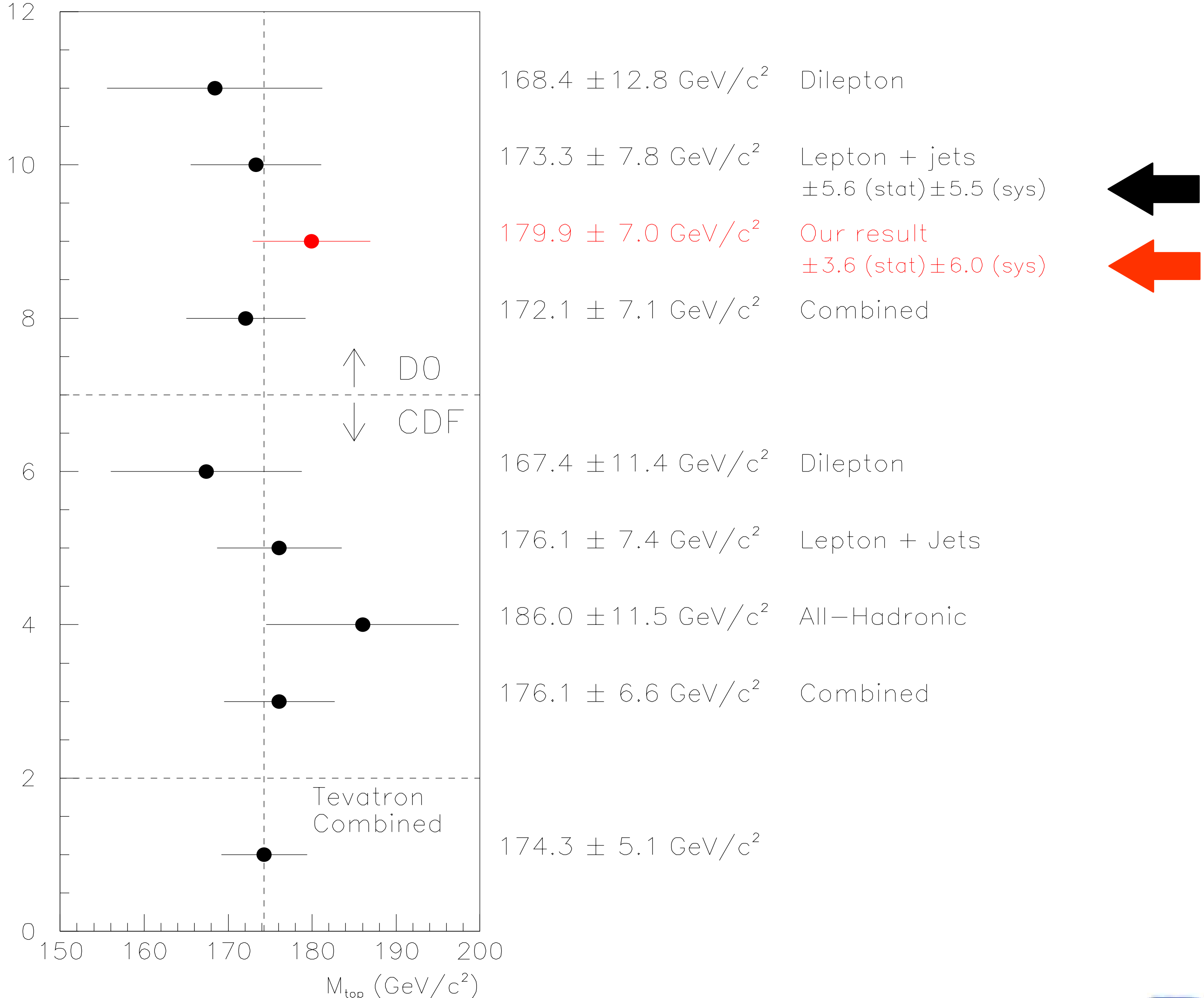
- **Introduction**
- **Event topology and selection**
- **Explanation of the method used in the new M_t measurement**
- **New preliminary measurement of M_t , and the M_W checks**
- **MC tests with the new method**
- **A few words on the systematic errors**
- **Conclusions**

Tevatron Top quark mass measurements



Event topology and selections

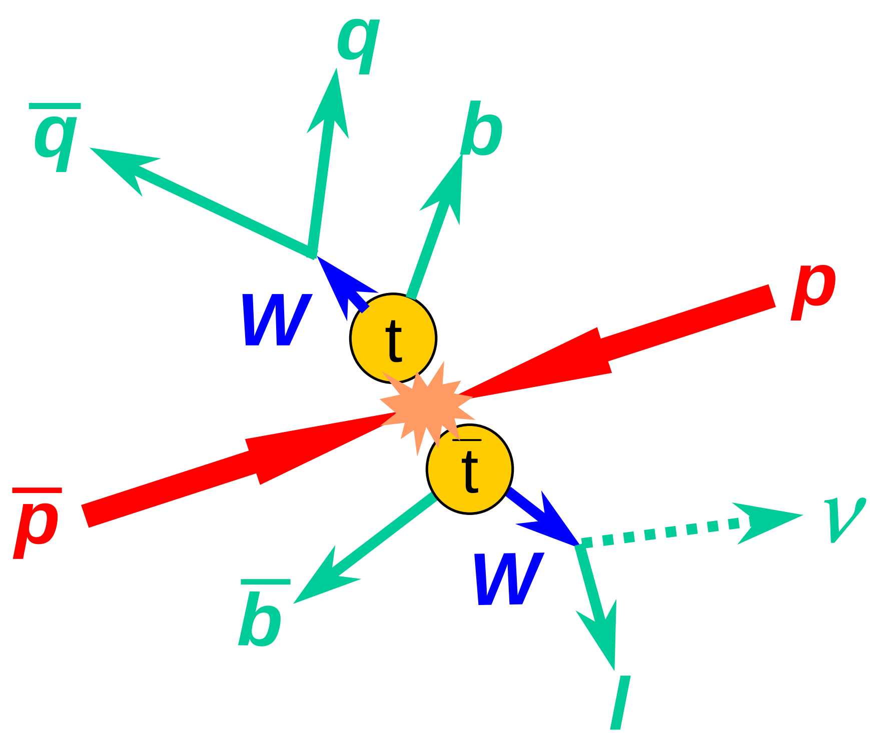
DØ Statistics RunI (125 pb^{-1})

Standard Selection :

- **Lepton: E_t>20 GeV N=1 $|\eta^e|<2$ $|\eta^\mu|<1.7$**
- **Jets: E_T>15 GeV N≥4 $|\eta^j|<2$**
- **Missing E_T > 20 GeV**
- **"E_T^W" > 60 GeV $|\eta_W|<2$**

gives 91 events

Ref. PRD 58 (1998), 052001:
(After χ^2 cut gives 77 events)



12 jet permutations/event

Additional cuts for this analysis:

4 Jets only (70% eff. for signal) : 71 events

Background Prob. (70% eff. for signal) : 22 events

The general method

- **Most people would agree that if the probability of an event could be calculated accurately then the best estimate of a parameter will maximize a likelihood like:**

$$L(\alpha) = e^{-N\int \bar{p}(x;\alpha)dx} \prod_{i=1}^{N} \bar{P}(x_i;\alpha)$$

- **The detector and reconstruction effects are always multiplicative and independent of the parameter to be estimated:**

$$\bar{P}(x;\alpha) = Acc(x)\ P(x;\alpha)$$

- **The probability P(x;α) can be calculated as:**

$$P(x;\alpha) = \frac{1}{\sigma_{t\bar{t}}} \int d^n\sigma(y;\alpha)\, dq_1\, dq_2\ f(q_1)\ f(q_2) W(x,y)$$

Where x is the set of variables measured in the detector, y is the set of parton level variables, $d^n\sigma$ is the differential cross section and f(q) are the parton distribution functions. W(y,x) is the probability that a parton level set of variables y will show up in the detector as the set of variables x. The integration reflects the fact that we want to sum over all the possible parton variables y leading to the observed set of variables x.

Transfer function W(x,y)

W(x,y) probability of measuring **x** when **y** was produced (***x*** measured variables, ***y*** parton variables):

$$W(x,y) = \delta^3(p_e^y - p_e^x)\prod_{j=1}^{4} W_{jet}(E_j^y, E_j^x)\prod_{i=1}^{4}\delta^2(\Omega_i^y - \Omega_i^x)$$

where

E^y	energy of the produced quarks
E^x	measured and corrected jet energy
p^y_e	produced electron momenta
p^x_e	measured electron momenta
Ω^y_j, Ω^x_j	produced and measured jet angles

Energy of electrons is considered well measured. And due to the excellent granularity of the D∅ calorimeter angles are also considered as well measured. A sum of two gaussians is used for the jet transfer function (W_{jet}), the parameters were extracted from MC simulation.

Probability for $t\bar{t}$ events

$$P_{t\bar{t}}(x,\alpha) = \int d\rho_1 dm_1^2 dM_1^2 dm_2^2 dM_2^2 \sum_{comb,\nu} |M(\alpha)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} \phi_6 W_{jet}(x,y)$$

2(in) + 18(final) = 20 degrees of freedom

3 (e) + 8 (Ω1..Ω4) + 3 ($P_{in}=P_{final}$) + 1 ($E_{in}=E_{final}$) = 15 constraints

20 – 15 = 5 integrals

Sum over 12 combinations of jets

All values of the neutrino momentum are considered

ρ_1	momentum of one of the jets	m_1, m_2	top mass in the event
M_1, M_2	W mass in the event	$f(q_1), f(q_2)$	parton distribution functions (CTEQ4) for qq incident chann.
q_1, q_2	initial parton momenta	ϕ_6	six particle phase space
$W(x,y)$	probability of measuring x when y was produced in the collision		

We chose these variables of integration because $|M|^2$ is almost negligible, except near the four peaks of the Breit-Wigners within $|M|^2$.

Acceptance Corrections

Likelihood

$$-\ln L(\alpha) = -\sum_{i=1}^{N} \ln \overline{P}(x_i;\alpha) + N\int \overline{P}(x;\alpha)dx$$

Detector Acceptance

$$\overline{P}(x;\alpha) = Acc(x)\ P(x;\alpha)$$

Measured probability

Detector acceptance

Production probability

$$-\ln L(\alpha) = -\sum_{i=1}^{N} \ln P(x_i;\alpha) + N\int Acc(x)P(x;\alpha)dx$$

$$\int Acc(x)\ P(x;\alpha)\,dx = \frac{12\,V}{N_{gen}} \sum_{j=1}^{N} 1$$

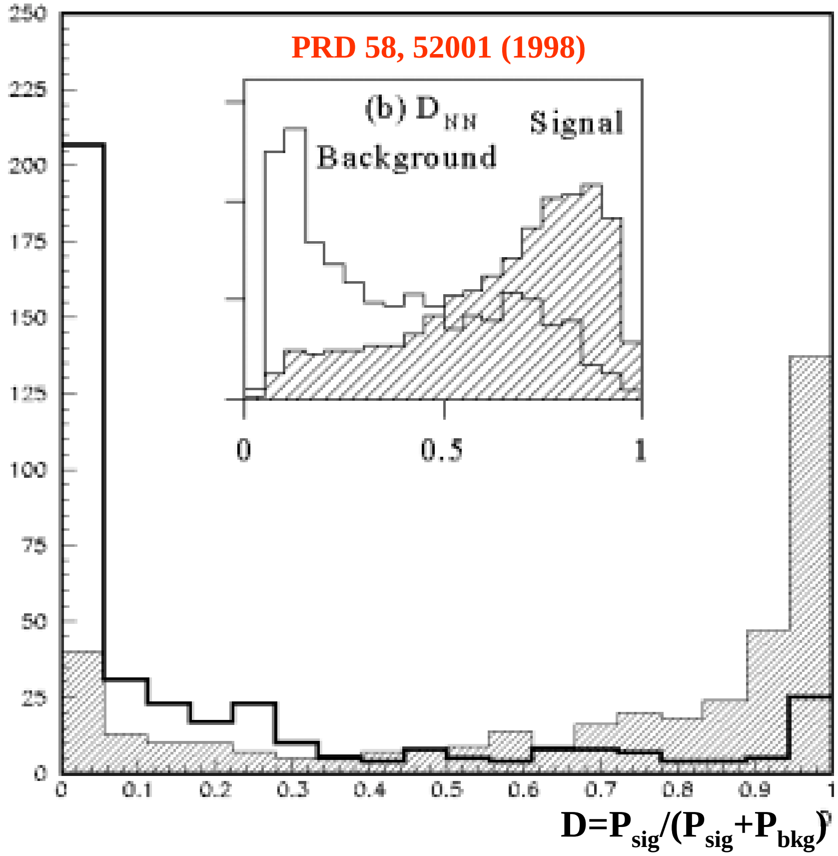
$V = \int d^n\sigma(y)\,dq_1\,dq_2\ f(q_1)\ f(q_2)$, and N_{gen}(N) is the number of generated(accepted) events

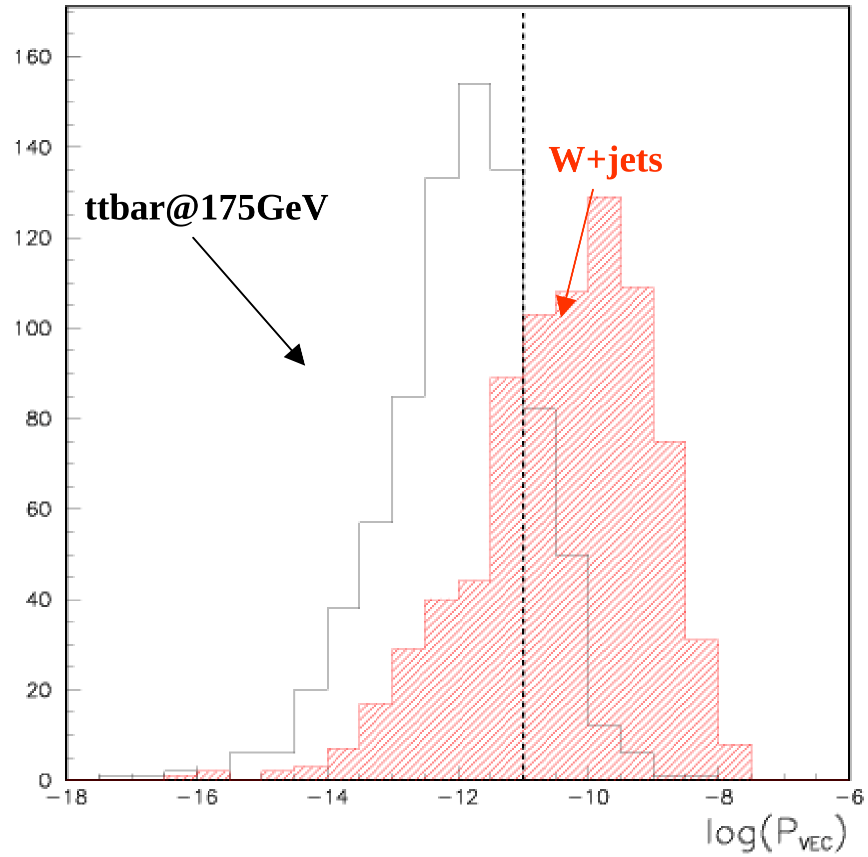
Signal and Background

$$-\ln L(\alpha) = -\sum_{i=1}^{N} \left\{ \ln\left[c_1 P_{t\bar{t}}(x_i;\alpha) + c_2 P_{bkg}(x_i) \right] \right\}$$
$$+ N \int A(x) \left[c_1 P_{t\bar{t}}(x;\alpha) + c_2 P_{bkg}(x) \right] dx$$

- **The background probability is defined only in terms of the main background** (W+jets, 80%) which also proved to be an adequate representation for multijet background.
- The background probability for each event is calculated using **VECBOS subroutines for W+jets**.
- The values of **c_1 and c_2 are optimized**, and the likelihood is normalized automatically at each value of α.

Extra selection in P_{bkg}

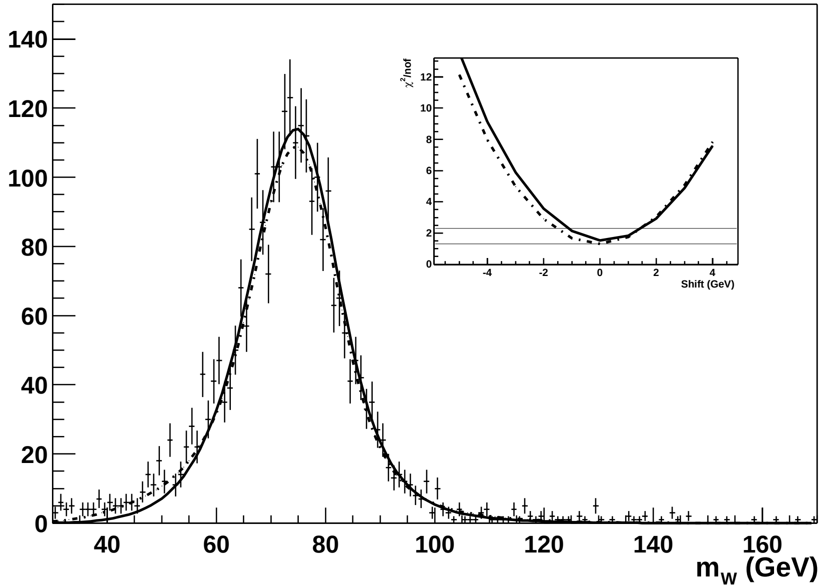


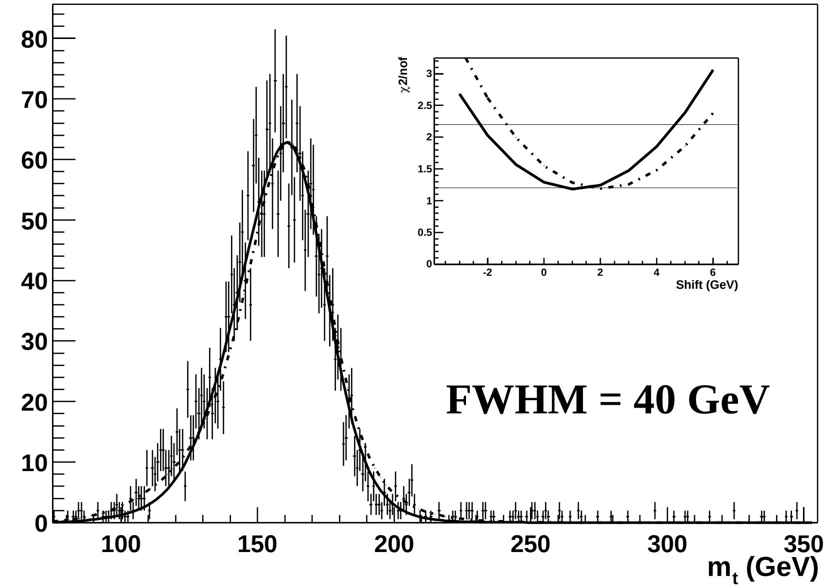


In order to increase the purity of signal another selection is applied on P_{bkg},

with efficiencies: $\varepsilon_{signal}=0.70$, $\varepsilon_{W+jets}=0.30$, $\varepsilon_{multijets}=0.23$

Two and three jet invariant masses

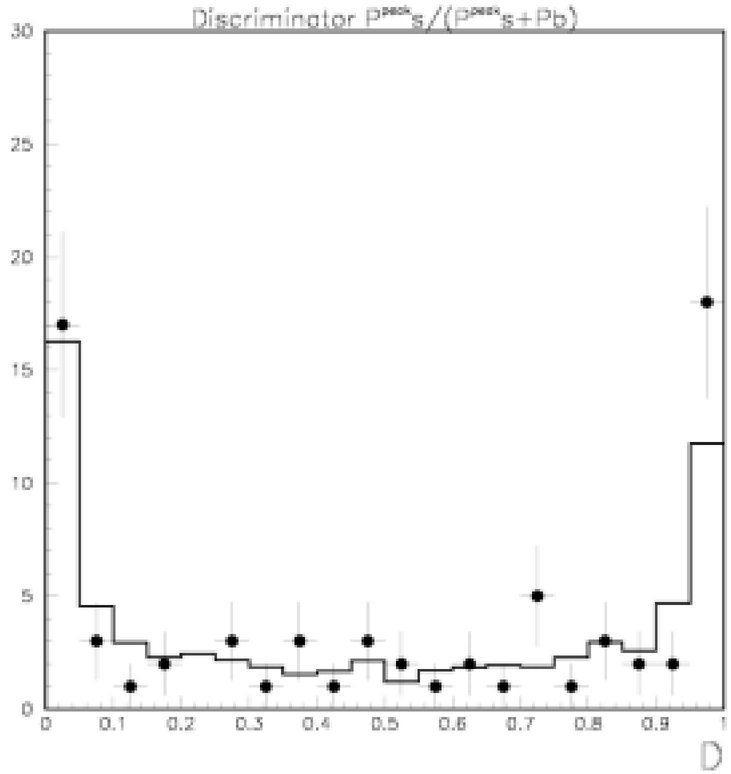




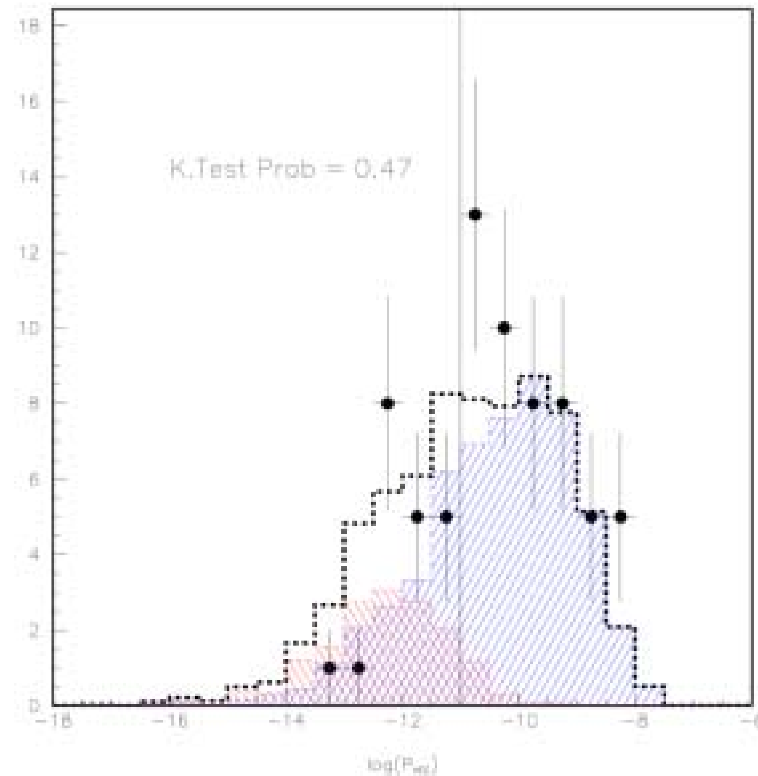
Two (left plot) and three (right plot) jet invariant mass distributions. The error bars correspond to t-tbar MC events for which the jets were matched to partons. The curves correspond to our calculations for two different transfer functions $W_{jet}(x,y)$. The dashed-dotted line corresponds to the transfer function used in the final analysis.

Signal and background probabilities: a MC vs. data comparison

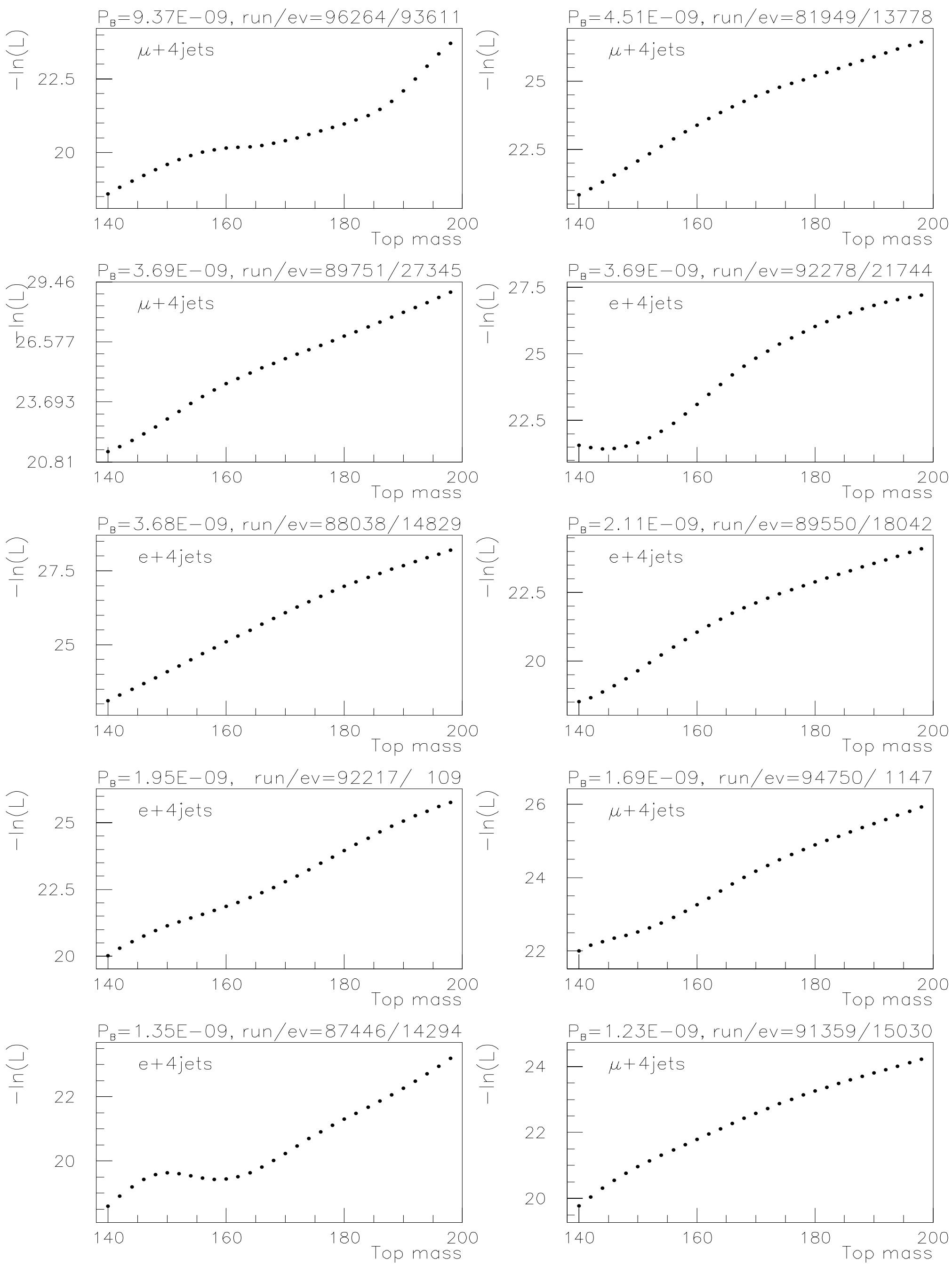
Signal probability comparison between data (dots) and MC (histogram) in the form of a discriminant $D=P_{sig}/(P_{sig}+P_{bkg})$. The signal probability was taken at it's maximum value. The MC S/B ratio was set to the measured ratio S/B=12/10 for $P_{bkg}<10^{-11}$.



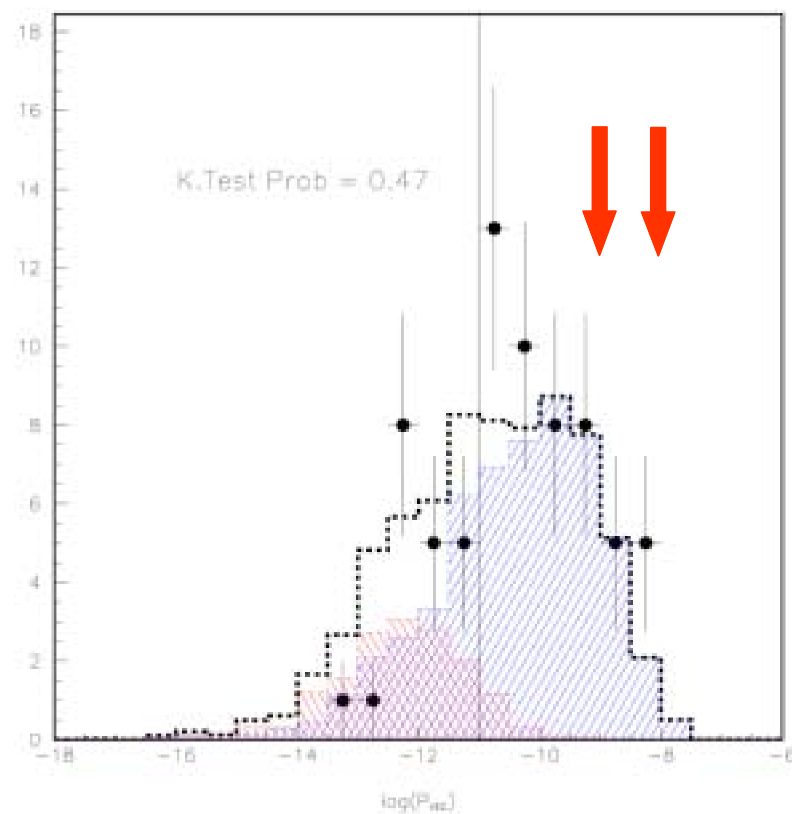
Background probability comparison between data (dots) and MC (histogram). Background (signal) MC events are shown in blue (red). The MC S/B ratio was set to the measured ratio S/B=12/10 for $P_{bkg}<10^{-11}$.



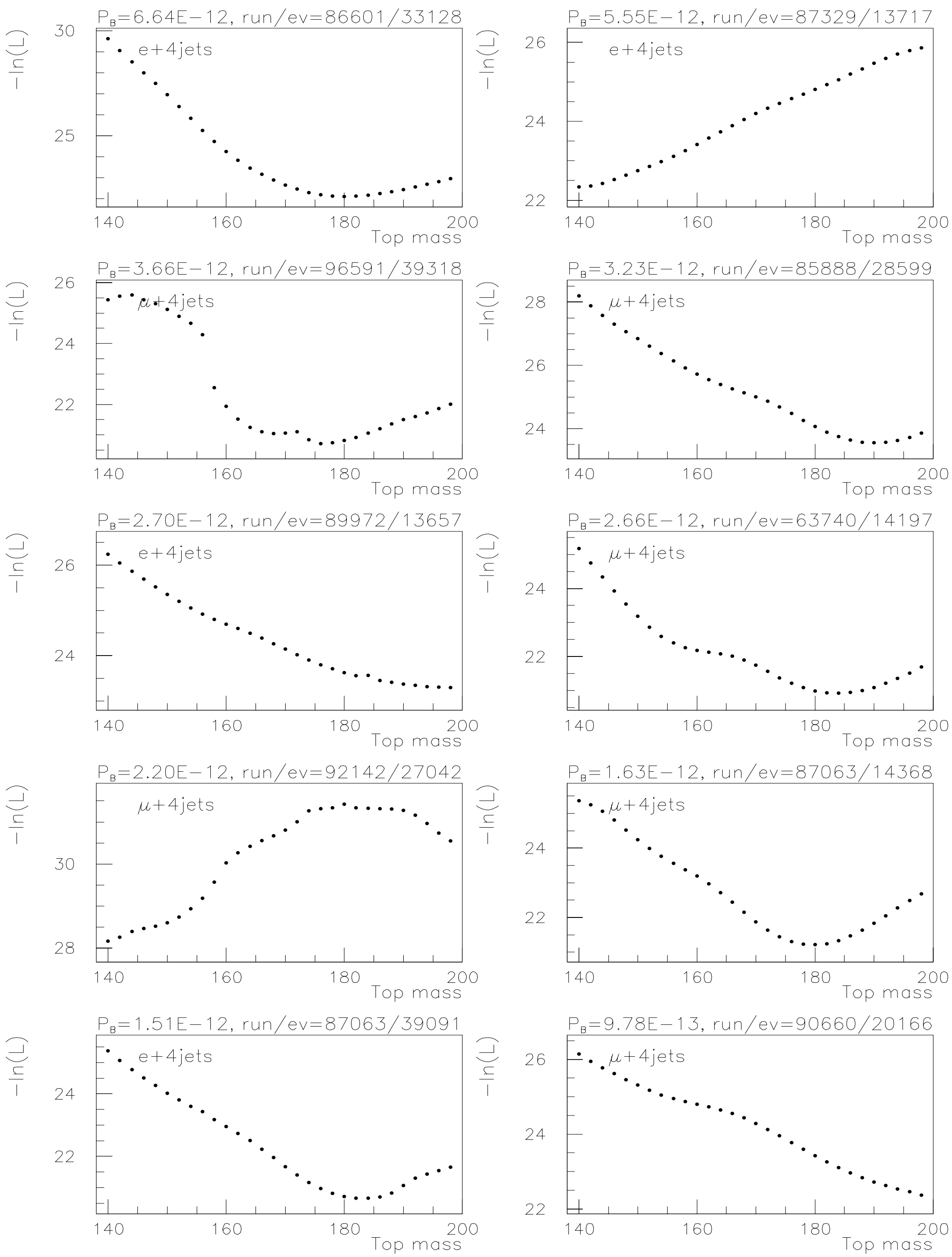
Top probability for data events



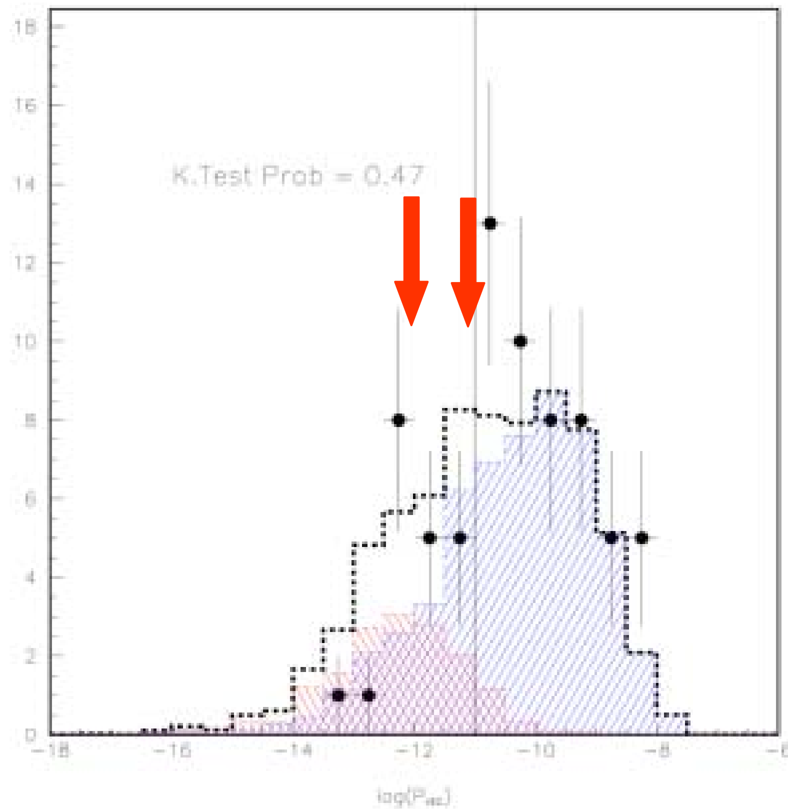
Left plot show -ln(P_{tt}) as a function of M_t for 10^{-9}<P_{bkg} <10^{-8} (red arrows in lower figure).



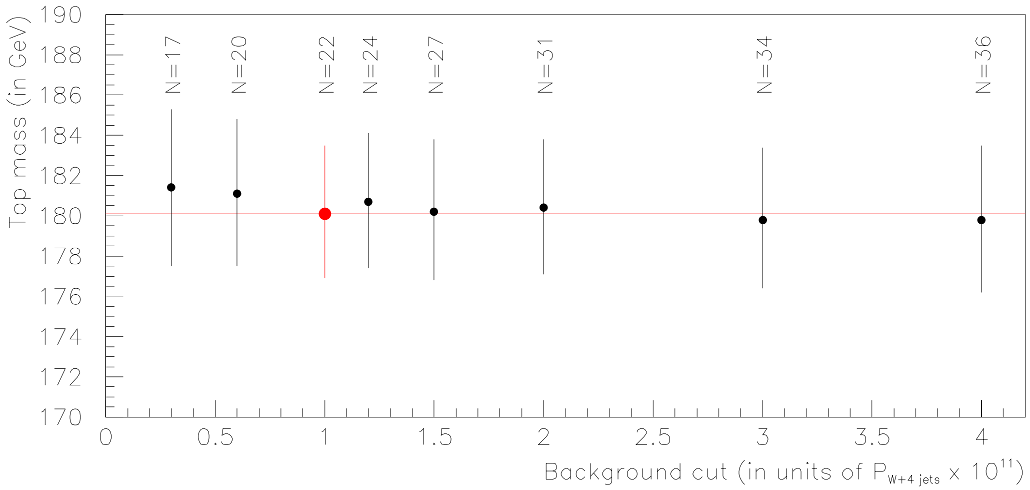
Top probability for data events

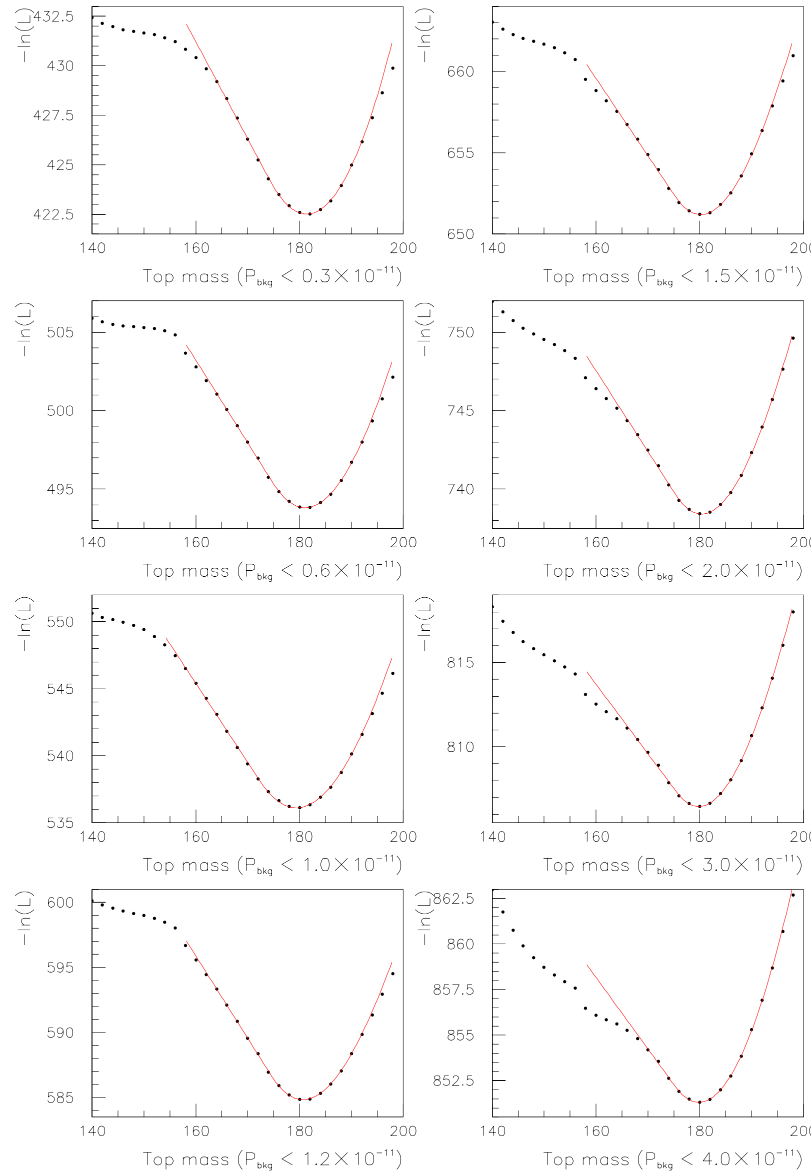


Left plots show -ln(P_{tt}) as a function of M_t for $9.7\text{x}10^{-13} < P_{bkg} < 9.0\text{x}10^{-12}$ (red arrows in lower figure).



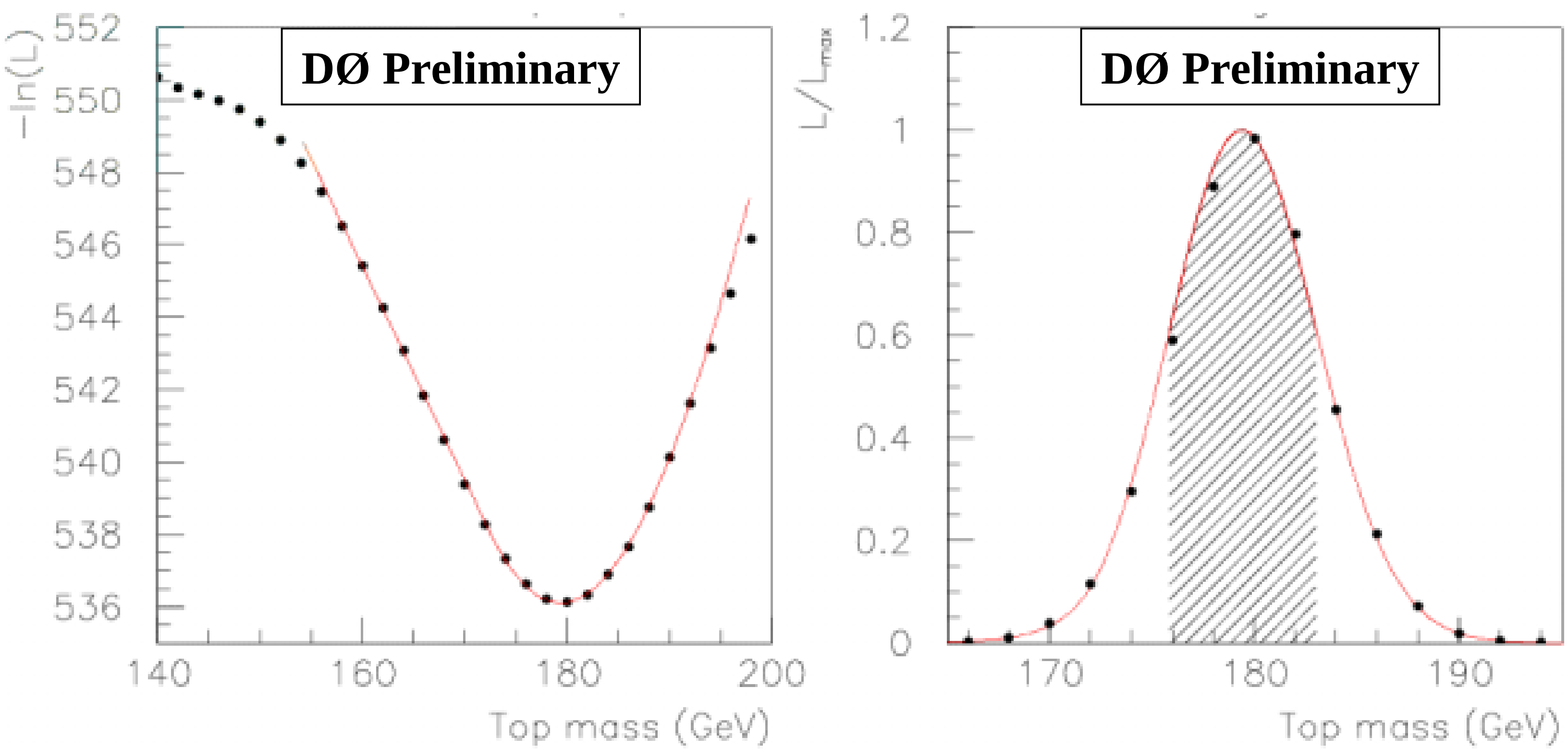
Changing the background probability cut





- **The top plot shows M_{top} as a function of the cut in the background probability (P_{bkg}). The plot shows that M_{top} is very stable over a change in the number of events (N) of more that a factor of 2, and a change in P_{bkg} of more that a factor of 10.**
- **The plots on the right show –ln(L) as a function of M_{top} for each of the points in the plot above. The plots show how the background enters mainly as a tail at low masses.**

New [preliminary] Result with DØ Run I data

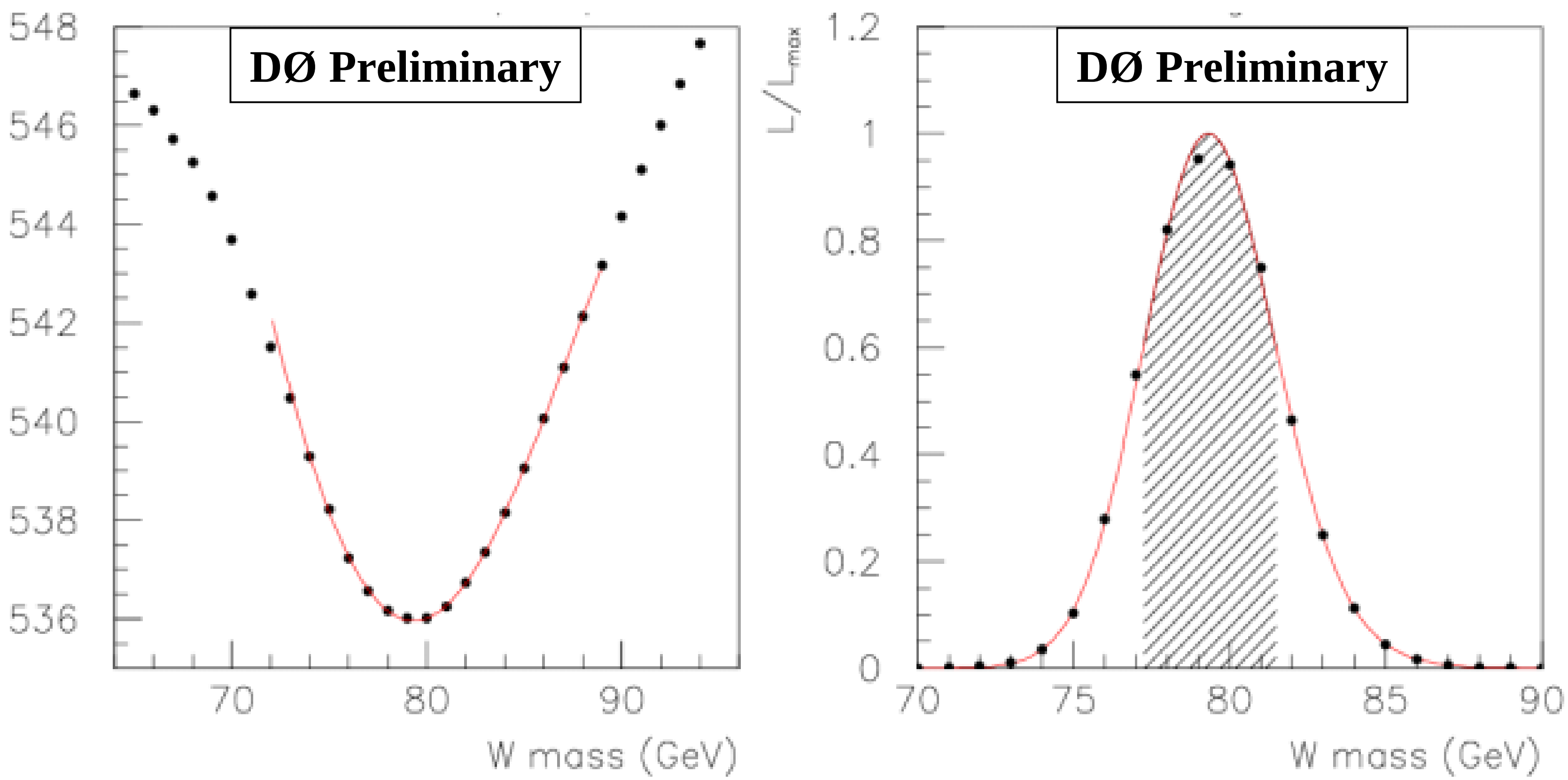


M_t[preliminary]= 179.9 ± 3.6 GeV ± SYST

This new technique improves the statistical error on M_t from 5.6 GeV [PRD 58 52001, (1998)] to 3.6 GeV. This is equivalent to a factor of 2.4 in the number of events.

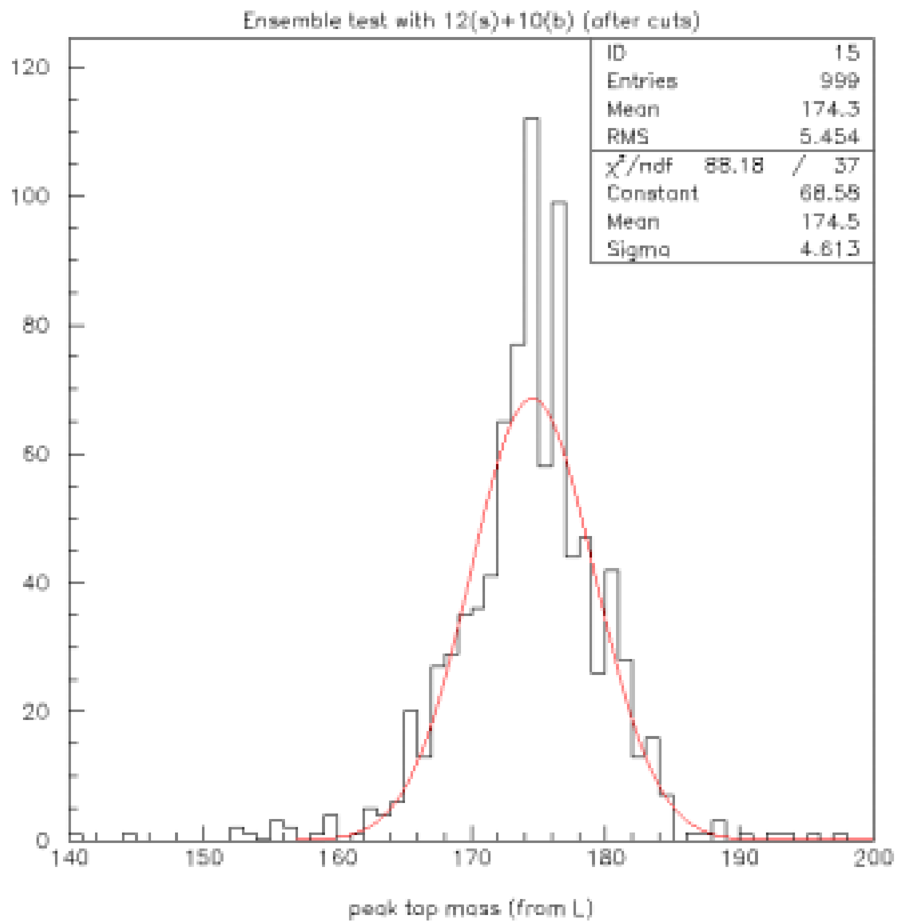
22 events pass our cuts out of which the analysis gives a total of 12.5 ± 3.0 t-tbar events. This extrapolates to a total of 26 ± 6.0 t-tbar events in the Run I sample.

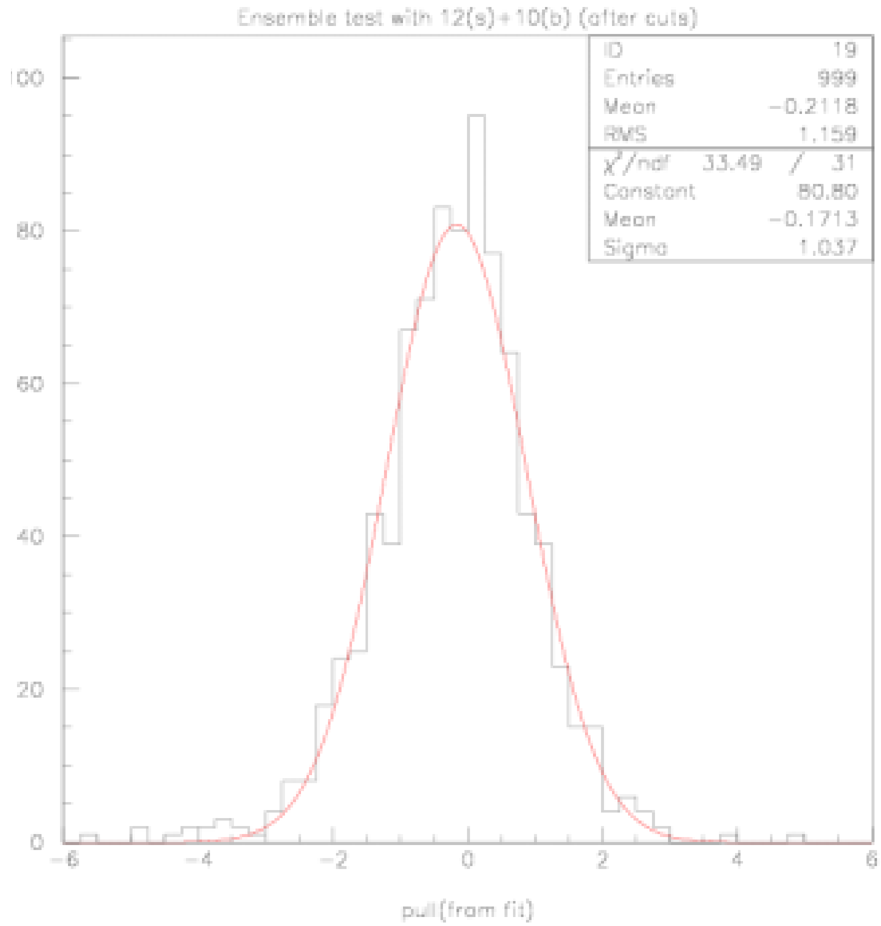
Check of M_w with DØ Run I data



This can be very helpful for reducing the uncertainty in the jet energy scale (JES) , DØ has already been studying this option, for reference see the Proceedings of DPF2002 (Top quark physics) http://dpf2002.velopers.net/talks_pdf/120talk.pdf.
M_w can be measured in the same events where M_t is measured!

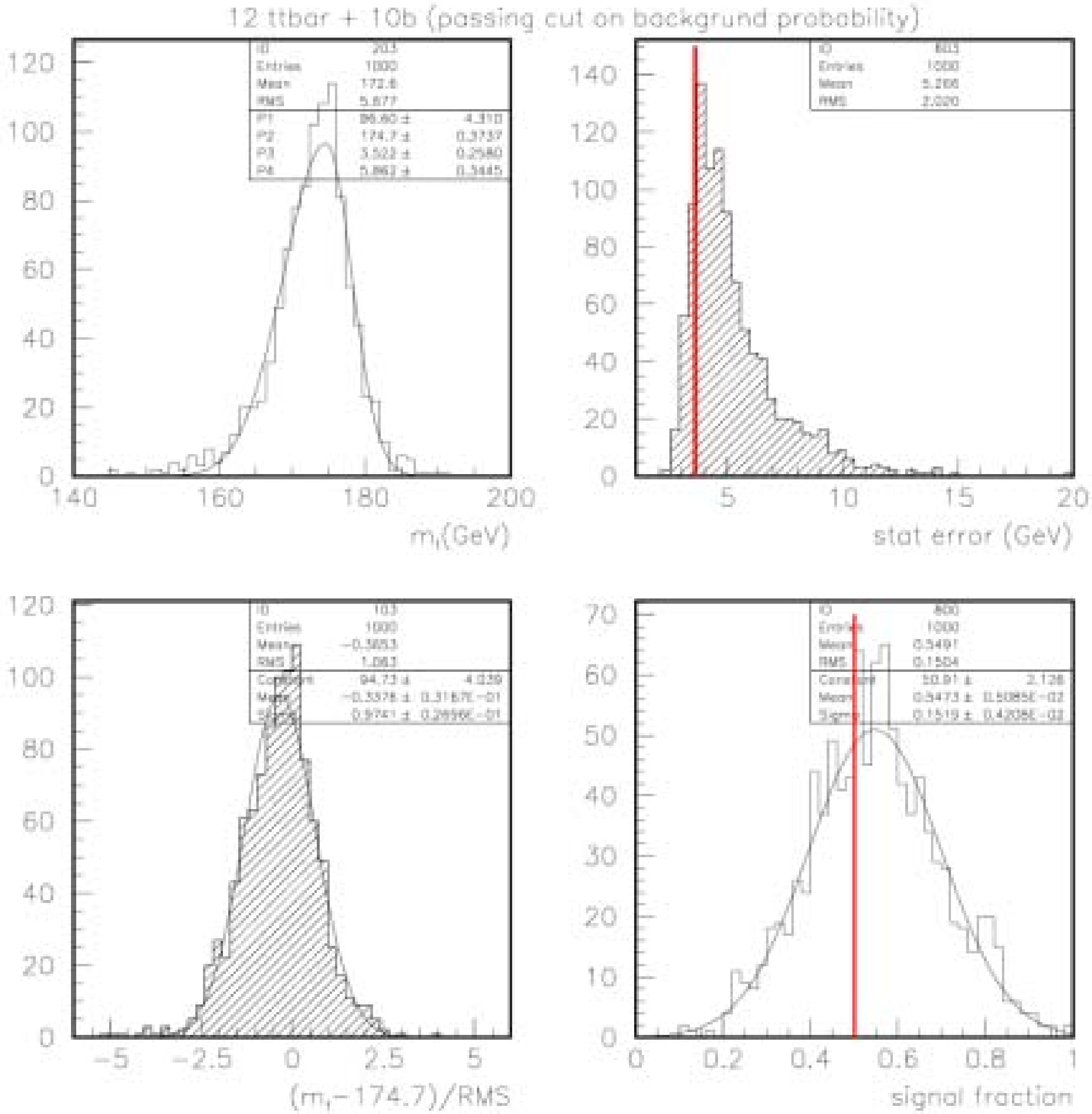
Crosschecks on Ensemble tests (12s+10b)





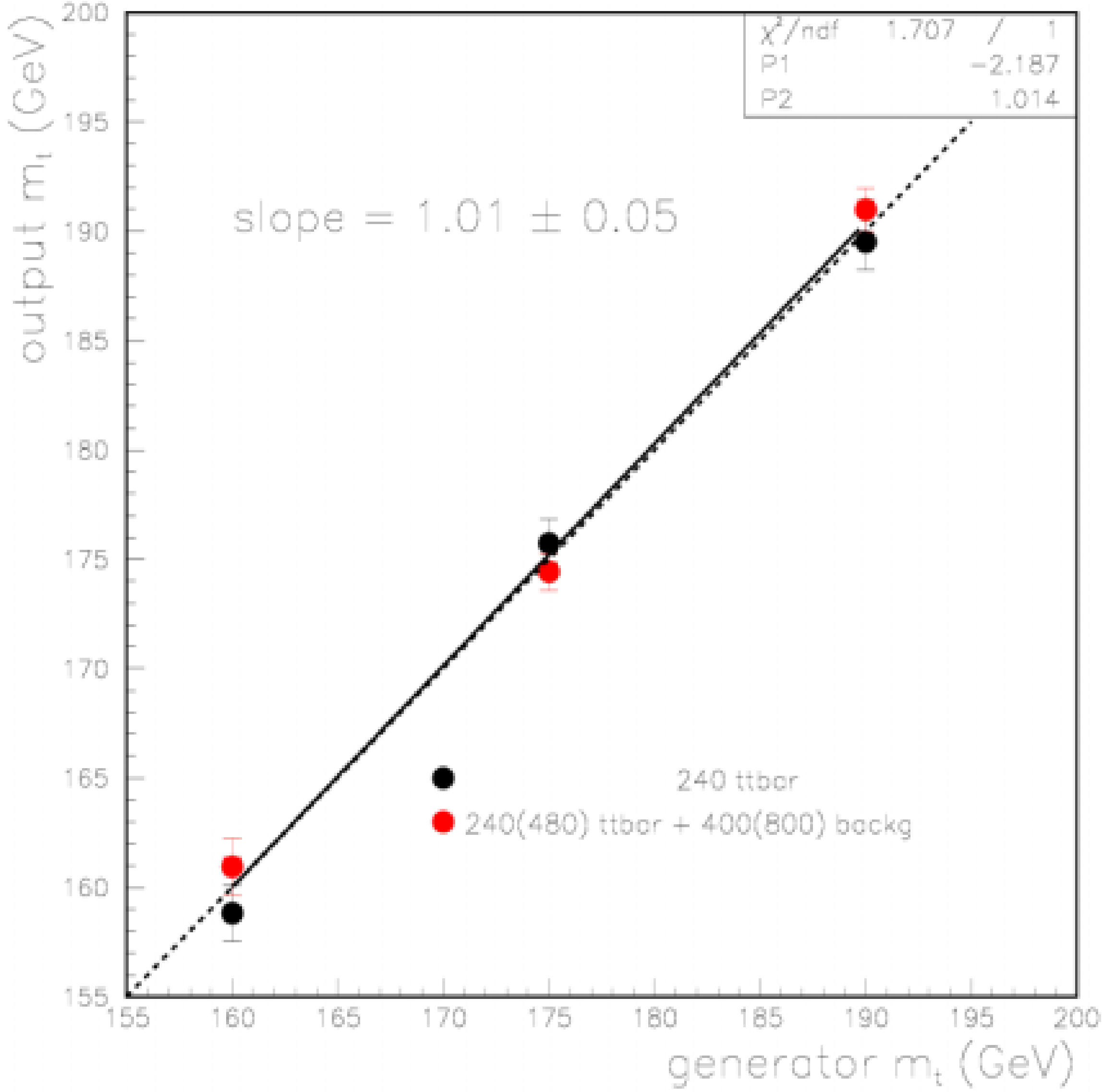
From the ensemble tests we estimate a 0.5 GeV bias in the peak with respect to the generated value

Crosschecks on Ensemble tests (12s+10b)



The most probable result of these experiments is M_t=174.7 GeV (top generated at M_t=175.0 GeV).

Crosscheck of linearity of response



Test of linearity of response is with MC samples containing large numbers of events.

Total Uncertainty

DØ Preliminary

I. Determined from MC studies with large event samples:

Signal model	1.5 GeV
Background model	1.0 GeV
Noise and multiple interactions **PRD 58 52001, (1998)**	1.3 GeV

II. Determined from data:

Jet Energy Scale	5.6 GeV
Parton Distribution Function	0.2 GeV
Acceptance Correction	0.5 GeV

We will reduce this error in our final result (M_w)

Total systematic: 6.0 GeV

Total: 7.0 GeV

Conclusions

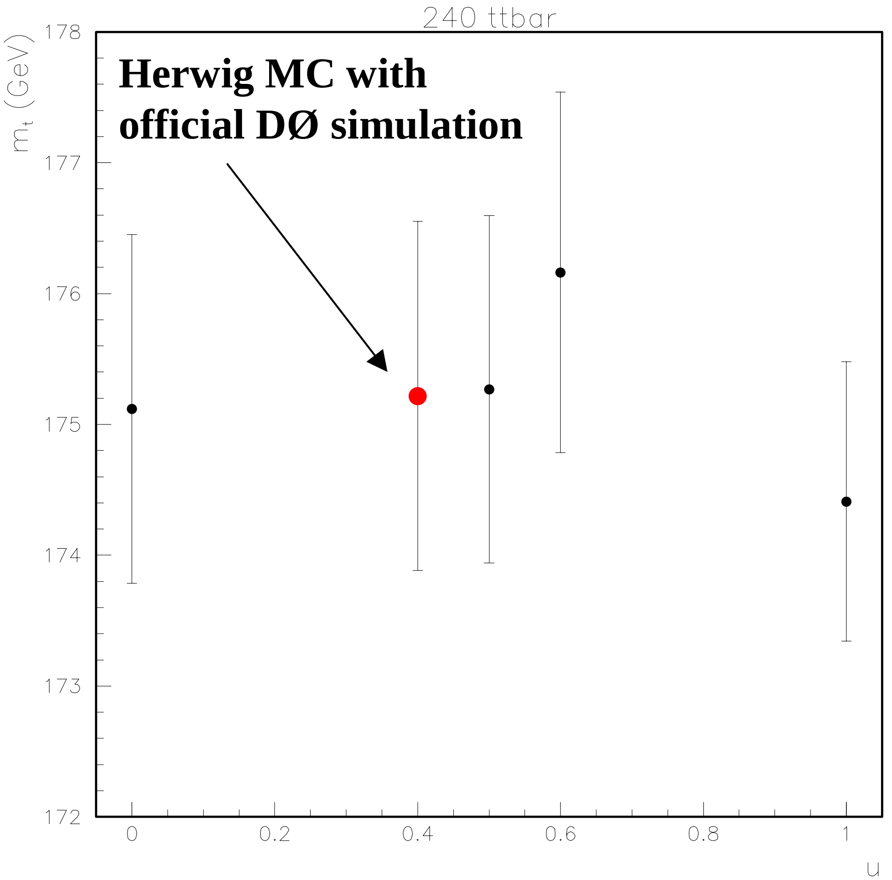
M_t[preliminary] 179.9 ± 3.6 (stat) ± 6.0 (syst.) GeV

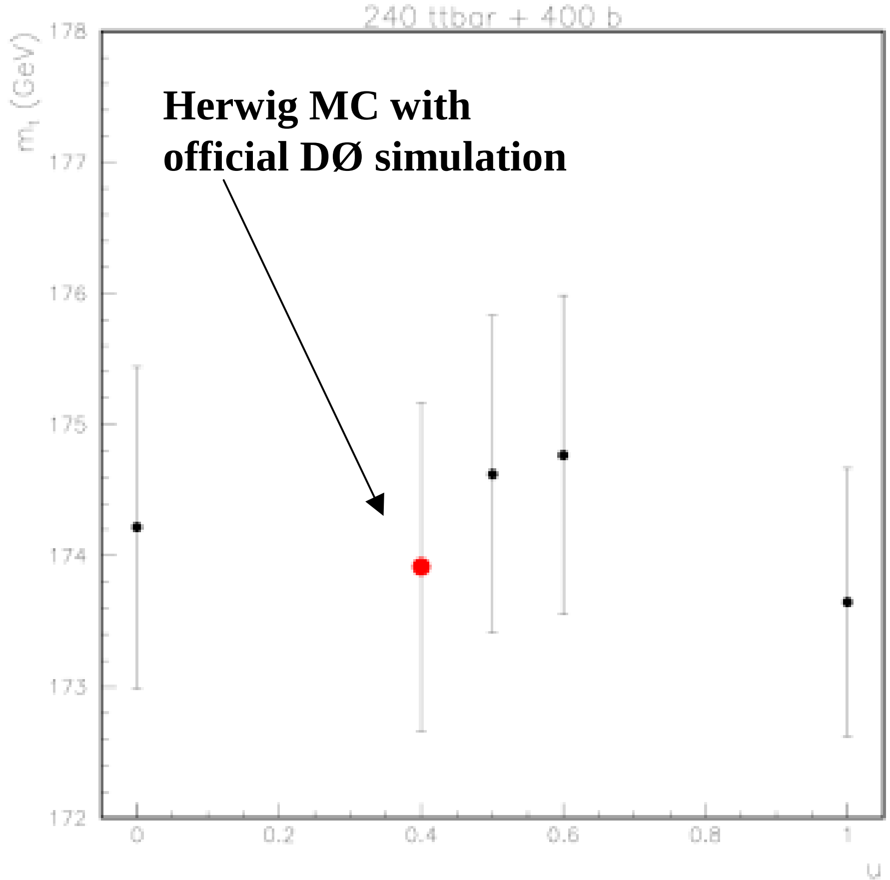
Significant improvement to our previous measurement with M_t= 173.3 ± 5.6 (stat) ± 5.5 (syst.) GeV (LB analysis in PRD) is equivalent to 2.4 times more data:

1. Correct permutation is always considered (with the other 11)
2. All features of individual events are included, thereby well measured events contribute more information than poorly measured events.
3. Discrimination of signal to background improves dramatically.

- The possibility of checking the value of the *W* mass in the hadronic branch on the same events provides a **new handle on controlling the largest systematic error**, namely, the jet energy scale.

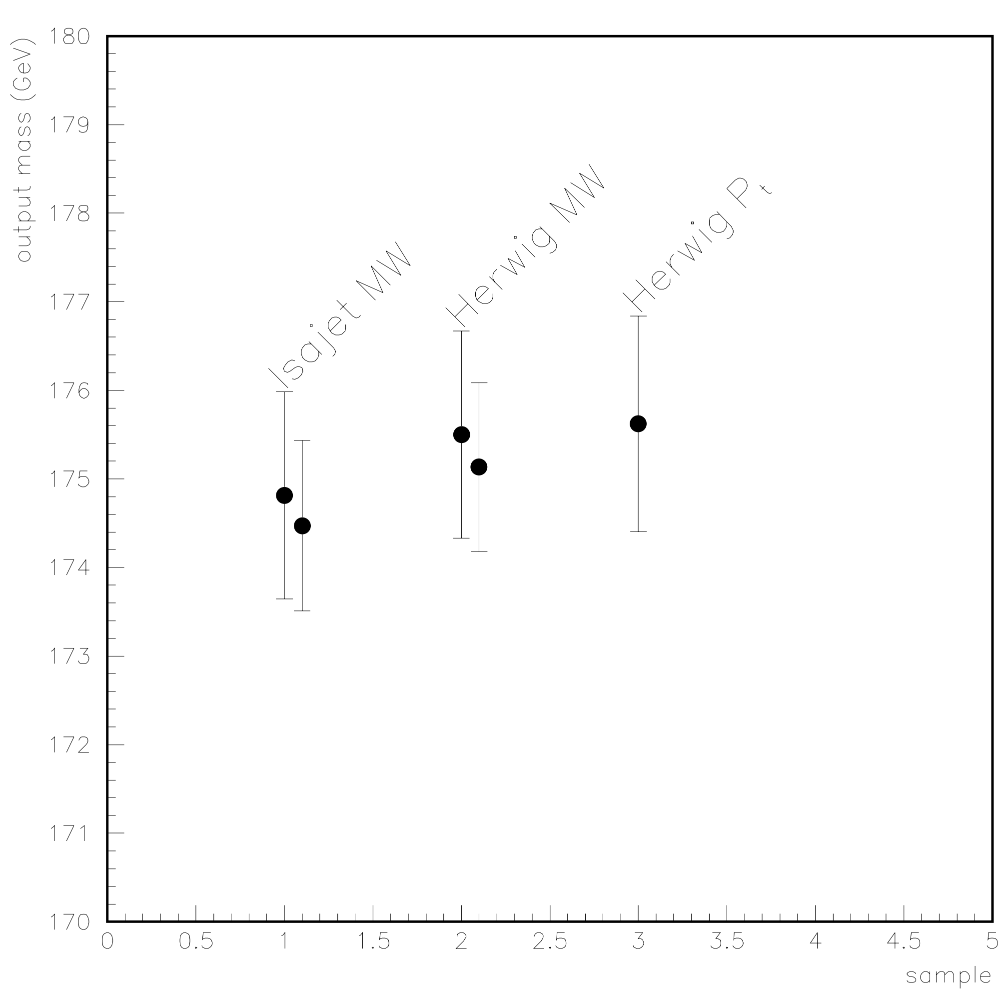
Systematic error due to $t\bar{t}$ model





u: fraction of events in the experiment where all the jets can be matched with partons from top quark decays. Increasing the fraction u, effectively turns on radiation and hadronization effects. The systematic uncertainty is: δ=1.5 GeV

Systematic error due to background model



Results for different VECBOS flavors: Q^2 scale of either $<p_t^{jet}>^2$ or M^2_W ,and with either HERWIG or ISAJET fragmentation.

From left to right: 1) M^2_W and IS, 2) M^2_W and HW, and 3) $<p_t^{jet}>^2$ and HW.

The points with large error bars were calculated with 250s+500b events, and the ones with small error bars with 400s+800b events. The number of events is specified before the cut in P_{bkg} .

The assigned systematic uncertainty is: δ=1.0 GeV

Matrix Element

$$|M|^2 = \frac{g_s^4}{9} F\bar{F}(2-\beta^2 s_{qt}^2)$$

no ttbar spin correlation included
s_{qt} sine of angle between q and t in the $q\bar{q}$ CM
β top quark's velocity in the $q\bar{q}$ CM
g_s strong coupling constant

Leptonic decay

$$F = \frac{g_w^4}{4}\left[\frac{m_t^2 - m_{\bar{e}\nu}^2}{(m_t^2 - M_t^2)^2 + (M_t\Gamma_t)^2}\right]\left[\frac{\omega(\cos\varphi_{\bar{e}b})}{(m_{\bar{e}\nu}^2 - M_W^2)^2 + (M_W\Gamma_W)^2}\right]$$

Hadronic decay

$$\bar{F} = \frac{g_w^4}{4}\left[\frac{m_t^2 - m_{d\bar{u}}^2}{(m_t^2 - M_t^2)^2 + (M_t\Gamma_t)^2}\right]\left[\frac{\omega(\cos\varphi_{d\bar{b}})}{(m_{d\bar{u}}^2 - M_W^2)^2 + (M_W\Gamma_W)^2}\right]$$

$$\omega(x) = m_t^2\left[(1-x^2) + \frac{m_W^2}{m_t^2}(1+x)^2\right]$$

M_t, M_W pole mass of top and W
m_t top mass in any event
$m_{e\nu}$,m_{du} invariant mass of the eν and du (or cs) system
Γ_t,Γ_W width of top and W
g_W weak coupling constant
$\omega(\cos\varphi_{eb,db})$ angular distribution of the W decay