CDF/DOC/TOP/CDFR/8383
v1.1, July 21, 2006

Combination of CDF Top Mass Results Using up to 1 fb^{-1} of Data

CDF Top Mass Group[1]

Abstract

We summarize the CDF measurements of the top-quark mass, M_t, based on data sets including as much as $1\mathrm{fb}^{-1}$ of data. We combine the most recent preliminary Run-II results with the published Run-I results to obtain, $M_t = 170.9 \pm 1.4\,(\mathrm{stat}) \pm 1.9\,(\mathrm{syst})\ \mathrm{GeV}/c^2$, which corresponds to a total uncertainty of $2.4\ \mathrm{GeV}/c^2$ and a relative precision of 1.4%.

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1 Introduction

We combine the CDF published top-quark mass results from Run-I [1-3] with four preliminary Run-II results using up to 1 fb^{-1} of data [4-7]. Results from the $t\bar{t} \to qq'bqq'\bar{b}$ (HAD), $t\bar{t} \to \ell\nu qq'b\bar{b}$ (LJT), and $t\bar{t} \to \ell^+\nu b\ell^-\overline{\nu}\bar{b}$ (DIL) final states are included. These measurements are combined accounting for statistical and systematic correlations using the method of reference [8]. The Run-II measurement in the LJT channel yields the single most precise result. Relative to the previous CDF combination reported in [9], this combination includes updates of the Run-II analyses in the LJT, DIL, and HAD channels, all of which use the full available data set.

The error categories used in the combination are detailed in Section 2 while the input measurements themselves are summarized in Section 3. The correlations used in the combination are discussed in Section 4 and the resulting top-quark mass is given in Section 5. Several cross-checks were performed and are presented in Section 6.

2 Error Categories

We employ the same error categories as used for the Tevatron world average [10]. They have evolved to include a detailed breakdown of the various sources of uncertainty and aim to lump together sources of systematic uncertainty that share the same or similar origin. For example, the "Signal" category discussed below includes the uncertainties from ISR, FSR, and PDF - all of which affect the modeling of the $t\bar{t}$ signal. Additional categories have been added in order to accommodate specific types of correlations. For example, the jet energy scale (JES) uncertainty is sub-divided into several components in order to more accurately accommodate our best estimate of the relevant correlations. Each error category is discussed below.

Statistical: The statistical uncertainty associated with the M_t determination.

iJES: The statistical uncertainty on the JES arising from the in-situ $W \to qq'$ calibration alone. Residual JES uncertainties, which arise from effects not considered in the in-situ calibration, are included in the Method category below.

aJES: This is specific to DØ Run II and is only included here in order to be consistent with reference [10].

bJES: The systematic uncertainty specific to the modeling of b-jets. This includes uncertainties arising from variations in the semi-leptonic branching fraction, b-fragmentation modeling, and differences in the color flow between b-quark jets and light-quark jets [11]. This is usually labeled "B Jet" for CDF Run-II analyses.

cJES: The systematic uncertainty on the JES arising from the modeling of fragmentation and out-of-cone corrections. This is the quadrature sum of the L7 and L8 JES uncertainties for CDF Run-II analyses.

dJES: The systematic uncertainty on the JES arising from the relative corrections. This is the L1 JES uncertainties for CDF Run-II analyses.

rJES: The systematic uncertainty on the JES arising from the modeling of the calorimeter response and underlying event and multiple interaction corrections. This is the quadrature sum of the L4, L5, and L6 JES uncertainties for CDF Run-II analyses.

Signal: The systematic uncertainty arising from uncertainties in the modeling of the $t\bar{t}$ signal including variations in the ISR, FSR, and PDF descriptions used to generate the $t\bar{t}$ Monte Carlo samples that calibrate each method.

Generator: The systematic uncertainty associated with variations observed when substituting Pythia (Run I and Run II) or ISAJET (Run I) for HERWIG when modeling the $t\bar{t}$ signal.

UN/MI: This is specific to DØ Run I and is only included here in order to be consistent with reference [10].

Background: The systematic uncertainty arising from uncertainties in modeling the dominant background sources, including q^2 variations. This is the quadrature sum of the "Background Shape" and "Background normalization" uncertainties for most CDF Run-II analyses.

Method: The systematic uncertainty arising from any source specific to a particular fit method, including the variations in B-tagging efficiency and the finite Monte Carlo statistics available to calibrate each method. This is the quadrature sum of the "Method", "B-tag", and "MC Statistics" categories for most CDF Run-II analyses.

These categories represent the current preliminary understanding of the various error categories and their correlations. We expect these to evolve as we continue to probe each method's sensitivity to the various systematic sources with ever improving precision. Small variations in the assignment of uncertainties to the error categories and in the correlations assumed are discussed in Section 6.

3 Input Measurements

For this combination we use seven measurements. Three published Run-I [1-3] results and four preliminary Run-II results [4-7]. They are summarized in Table 1. The correlations between the various inputs are described in the next section. Based on studies described in reference [9] the statistical correlation between the L_{xy} and LJT inputs is set to 0 in the combination. Variations are considered as part of the cross-checks discussed in Section 6.

There are other measurements in the LJT, DIL, and HAD channels. Since they presently use only a subset of the full $1\,\mathrm{fb}^{-1}$ dataset, they are not included in this combination. We can include them once they've been updated.

	Run II Preliminary				Run I Published		
Input	LJT	DIL	HAD	L_{xy}	LJT	DIL	HAD
M_t	170.9	164.5	174.0	183.9	176.1	167.4	186.0
iJES	1.4	0.0	0.0	0.0	0.0	0.0	0.0
aJES	0.0	0.0	0.0	0.0	0.0	0.0	0.0
bJES	0.6	0.6	0.5	0.0	0.6	0.5	0.6
cJES	0.0	2.8	3.1	0.0	2.7	2.6	3.0
dJES	0.2	1.6	0.8	0.0	0.7	0.6	0.3
rJES	0.0	1.3	3.0	0.3	3.4	2.8	4.0
Signal	1.1	0.9	0.9	1.4	2.6	2.8	1.8
Genratr	0.2	0.9	1.0	0.7	0.1	0.6	0.8
UN/MI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Backgnd	0.2	0.7	0.7	2.3	1.3	0.3	1.7
Method	0.4	0.9	0.0	4.8	0.0	0.7	0.6
Sys-Total	1.9	3.9	4.7	5.6	5.3	4.9	5.7
Stat	1.6	3.9	2.2	14.8	5.1	10.3	10.0
Total	2.5	5.6	5.2	15.8	7.3	11.4	11.5

Table 1: The measurements used to determine the CDF combined top-quark mass. All numbers are in units of GeV/c^2. The error categories and their correlations are defined in the text.

For the L_{xy} measurement, we include the systematic uncertainty associated with the potential mis-modeling of the background decay length distribution in the "Method" category, since it's a source of uncertainty unique to this method. For the time being, the small uncertainty associated with the modeling of the lepton energy scale in the Run-II LJT and DIL measurements is included in the dJES category. For the Run-I measurements, we back propagate the systematic uncertainty specific to B-jets (bJES) as determined in Run II and then correct the Run-I absolute corrections (rJES) to keep the total JES uncertainty constant. Variations of these assumptions were explored in reference [12] and found to negligibly affect the combination. We haven't explicitely revisited these studies here since the weight the Run-I measurements carry in the combination diminishes as the precision of the Run-II measurements improves so that the effect of these variations can only get smaller.

4 Correlations

The following correlations are used when making the combination:

- The uncertainties in the Statistical, Method, and iJES categories are taken to be uncorrelated among the measurements.
- The uncertainties in the aJES and dJES and categories are taken to be 100% correlated

among all Run I and all Run II measurements, but uncorrelated between Run I and Run II.

- The uncertainties in the Background category are taken to be 100% correlated among all measurements in the same channel.
- The uncertainties in the bJES, cJES, rJES, Signal, and Generator categories are taken to be 100% correlated among all measurements.

Using the inputs from Table 1 and the correlations specified here, the resulting matrix of total correlation co-efficients is given in Table 2. The effect of varying some of these correlations is discussed in Section 6.

	Run II Preliminary				Run I Published		
	HAD	L_{xy}	LJT	DIL	LJT	DIL	HAD
HAD	1						
L_{xy}	0.03	1					
LJT	0.12	0.05	1				
DIL	0.55	0.03	0.13	1			
LJT	0.56	0.07	0.19	0.36	1		
DIL	0.34	0.03	0.12	0.23	0.29	1	
HAD	0.42	0.02	0.08	0.26	0.32	0.19	1

Table 2: The resulting matrix of total correlation coefficients used to determine the CDF combined top quark mass.

5 Results

Using the measurements of Table 1 and the correlations of Section 4 the CDF combined top mass is

$$M_t = 170.9 \pm 1.4\,(\text{stat}) \pm 1.9\,(\text{syst})\ \text{GeV}/c^2 \quad (1)$$
$$= 170.9 \pm 2.4\ \text{GeV}/c^2 \quad (2)$$

with $\chi^2/dof = 6.1/6$, which corresponds to a chi-squared probability of about 41%, indicating good agreement among all the input measurements. The method of reference [8] decomposes the total uncertainty into the contributions from the various error categories as: iJES (± 1.1), quadrature sum of other JES categories (± 1.0), Signal (± 1.0), Generator (± 0.4), Background (± 0.2), and Method (± 0.4), where all numbers are in units of GeV/c^2. The corresponding pull and weight for each of the inputs is listed in Table 3. The input measurements and the resulting CDF combined M_t are summarized in Figure 1.

	Run II Preliminary				Run I Published		
	LJT	DIL	HAD	L_{xy}	LJT	DIL	HAD
Pull	+0.01	-1.26	+0.68	+0.83	+0.75	-0.31	+1.34
Weight	+81%	+7.1%	+14%	+1.4%	-2.2%	-0.4%	-0.4%

Table 3: The pull and weight for each of the inputs used to determine the CDF combined top quark mass.

Although the chi-squared from the combination of all measurements indicates that there is good agreement among them, and no input has an anomalously large pull, it is still interesting to also fit for the top mass in the LJT, DIL, and HAD channels separately. We use the same methodology and include the systematic correlations among the measurements as described in Section 4. The results are shown in Table 4 and Figure 2. Using the expression in reference [13] we calculate the following chi-squares $\chi^2(LJT - DIL) = 2.2/1$, $\chi^2(LJT - HAD) = 0.1/1$, and $\chi^2(DIL - HAD) = 3.5/1$. These correspond to chi-squared probabilities of 14%, 78%, and 6%, respectively, and indicate that all channels are reasonably consistent with each other. These comparisons are also shown in Figure 3.

		correlations		
	fit value (GeV/c^2)	M(LJT)	M(DIL)	M(HAD)
M(LJT)	171.2 ± 2.5	1		
M(DIL)	163.6 ± 5.0	0.23	1	
M(HAD)	172.5 ± 4.4	0.25	0.51	1

Table 4: The results of a fit to determine the top-quark mass in the three final states separately.

6 Cross-Checks

We performed some cross-checks of the combination.

We used pseudo-experiments as discussed in reference [9] to verify that this method is unbiased and the that the pull widths are consistent with unity (at about the 5% level).

We consider a variety of cross-checks of the result presented in Section 5.

- The combination method employed requires symmetric uncertainties as inputs. The combination was repeated using each of the extreme asymmetric statistical uncertainties reported by the Run II L_{xy} measurement.
- The combination was repeated varying the statistical correlation between the Run-II LJT and L_{xy} inputs by $\pm 5\%$, which is the full width of the varitions observed in [9].
- The combination was repeated by simultaneously varying the systematic correlations by 10% in the bJES, cJES, rJES, Signal, Background, and Generator categories across all inputs.

For all of these variations the central value and total uncertainty differ from the default fit by less than 100 MeV/c^2 each and are unchanged once rounded to the nearest 0.1 GeV/c^2.

7 Conclusion

We have combined CDF Run-I and Run-II top-quark mass measurements from all three final states, HAD, LJT, and DIL to get a CDF combined top-quark mass of 170.9 ± 2.4 GeV/c^2. This CDF-only combination is nearly as precise as the previous world average, which had a total uncertainty of ± 2.3 GeV/c^2.

References

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[13] For two measurements, x and y, we calculate their consistency using $\chi^2 = (x-y)^2/\sigma^2_{x-y}$, where $\sigma^2_{x-y} = \sigma^2_x + \sigma^2_y - 2\rho_{xy}\sigma_x\sigma_y$, where ρ_{xy} is the x, y correlation coefficient.

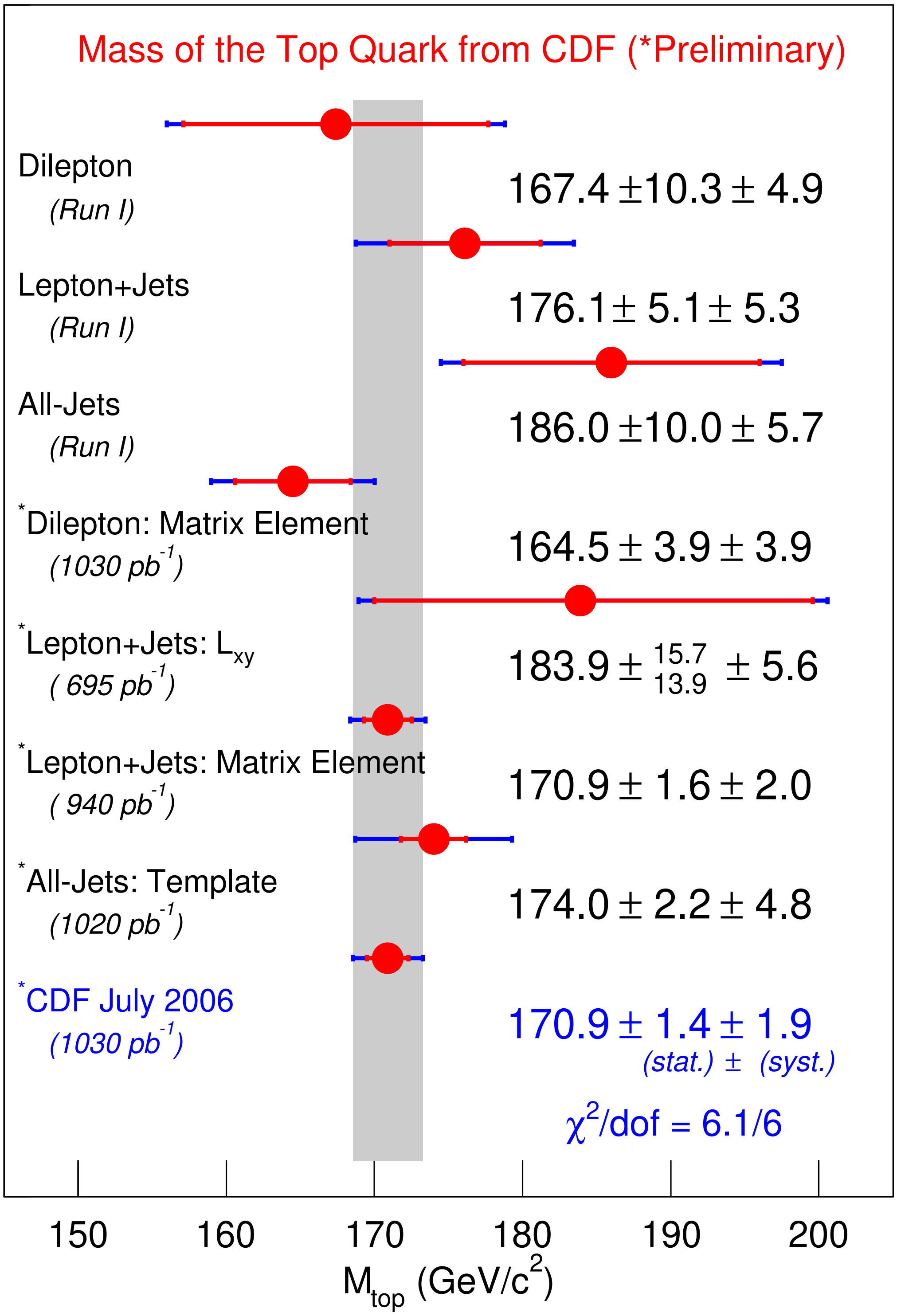

Figure 1: A summary of the input measurements and resulting CDF combined top-quark mass.

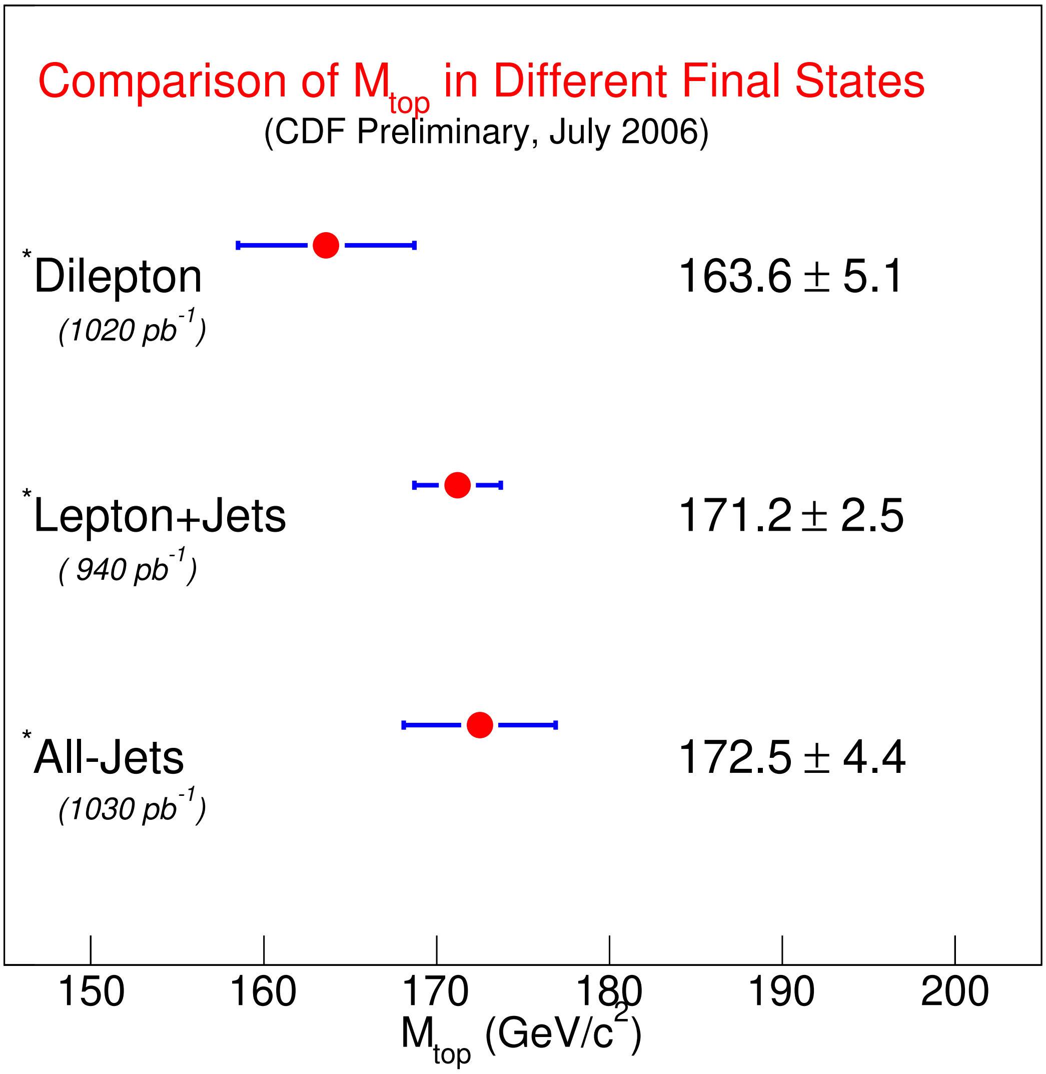

Figure 2: The results of a fit to determine the top-quark mass in the three final states separately.

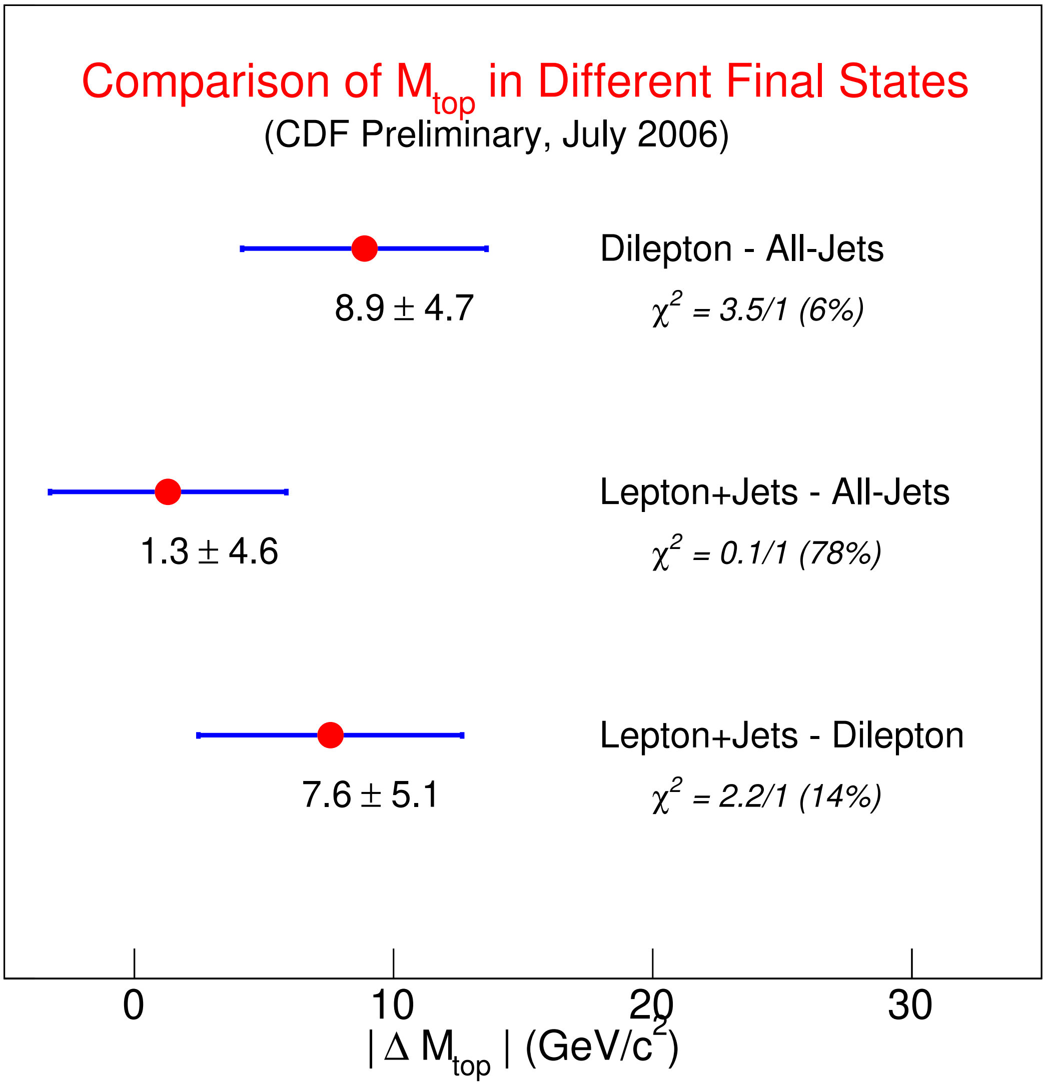

Figure 3: A comparison of the top-quark mass separately determined in each final state. The uncertainties on the difference, ΔM_t, account for the correlations. The χ^2 are estimated using the information of Table 4.