$t\bar{t}$ production cross section and R_b measurement

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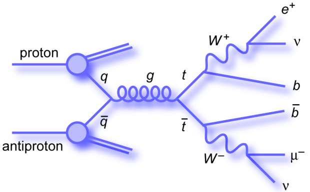
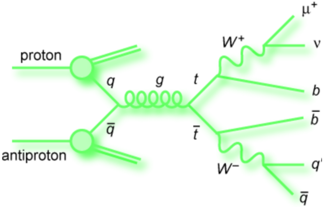
Introduction

- Motivations:
  - precise measurement of the $t\bar{t}$ cross section $\rightarrow$ test of QCD predictions;
  - current theoretical calculations reach 6-9% precision;
  - difference between the dilepton and lepton+jets channels could be an indication of new physics.
- Last D0 results (5.4 fb^{-1}):
  - dilepton (Moriond 2010 preliminary): $\sigma_{t\bar{t}} = 8.23 \pm 1.15$ pb (14%);
  - lepton+jets (submitted to Phys. Rev. D, arXiv:1101.0124): $\sigma_{t\bar{t}} = 7.78 \pm 0.71$ pb (9%).

Outline

- Cross section measurement in the dilepton channel:
  - dataset and selection;
  - result with a counting method.
- R_b extraction:
  - in the dilepton channel;
  - in the lepton+jets channel.
- Combination results





Dilepton channel - Dataset and selection

- **Dataset**
  - data: 5.4 fb^{-1}, RunIIa, RunIIb1 and 2;
  - MC: RunIIa, RunIIb1.
- $t\bar{t}$ event topology:
  - 2 high-p_T leptons (e or μ);
  - at least 2 high-p_T jets;
  - missing transverse energy.

  Consider **four final states**: ee, $e\mu$ and $\mu\mu$ + 2 jets, $e\mu$ +1jet.
- **Main backgrounds**:
  - Z/γ^* simulated with Alpgen+Pythia;
  - diboson simulated with Pythia;
  - QCD estimated from data.

Dilepton channel - Selection

- Selection
  - vertex: $|z| < 60$ cm, 3 tracks attached;
  - **electrons**: top_tight, $p_T > 15$ GeV;
  - **muons**: loose quality, loose tracks, TopScaleMedium isolation, $p_T > 15$ GeV;
  - dz(lepton,lepton) < 2cm;
  - **jets**: vertex confirmed (RunIIb), $p_T > 20$ GeV;
  - standard corrections (inclusive Z p_T reweighting only);
  - **topological selection**:
    - $\not{E}_T$ significance > 5.0 in the ee and $\mu\mu$ channels;
    - $H_T = p_T(jet1) + p_T(jet2) + p_T(lepton1) > 110$ GeV in the $e\mu$ +2jets channel (105 GeV for $e\mu$ +1jet).

Dilepton channel - Yields and plots

Channel	$Z \to \ell\ell$	Diboson	Instrumental background	$t\bar{t} \to \ell\bar{\ell}b\bar{b}\nu\bar{\nu}$	N_{exp}	N_{obs}	$\frac{\text{Observed}}{\text{Expected}}$
ee+2jet	12.6 ± 2.0	3.0 ± 0.4	-	45.6 ± 5.3	61.1 ± 7.1	74	1.21 ± 0.20
$\mu\mu$+2jet	67.3 ± 9.7	5.1 ± 0.7	7.6 ± 1.2	59.8 ± 6.6	139.8 ± 15.7	144	1.03 ± 0.14
$e\mu$+2jet	30.3 ± 4.2	8.6 ± 1.2	22.7 ± 8.6	191.5 ± 18.8	253.1 ± 24.3	281	1.11 ± 0.13
$e\mu$+1jet	40.9 ± 4.8	20.7 ± 2.4	25.3 ± 10.5	52.1 ± 9.4	139.0 ± 16.5	150	1.08 ± 0.16

Using a counting method: $\sigma_{t\bar{t}} = 8.62 \pm 0.52\ (stat) \pm 1.16\ (syst)\ pb$ (15%)
$\rightarrow$ systematics limited (luminosity and background normalization).

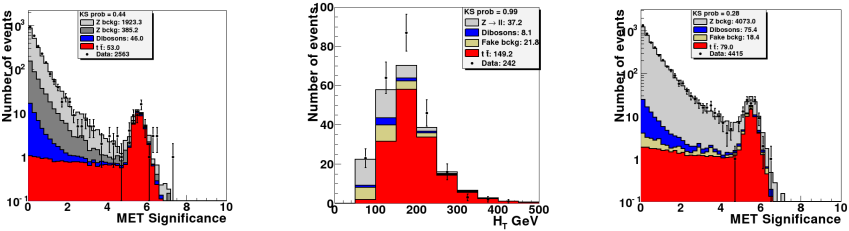
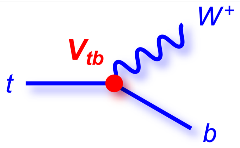


Figure 1: Data/MC comparisons before the topological selection in the ee (left), emu (middle) and mumu + 2jets channels (right).

Extraction of R_b

- $R_b = \frac{\mathcal{B}(t\to Wb)}{\mathcal{B}(t\to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2}$
  (with q=d,s,b).
  Assuming the CKM matrix unitarity:
  $R_b = |V_{tb}|^2 \in [0.9982, 0.9984]$.
  Model-independent study of $|V_{tq}|$.



- Template based analysis:
  - apply b-tagging on the two leading jets of each event;
  - keep the minimum output of the two;
  - build distributions for three $t\bar{t}$ decay types: $t\bar{t} \to bb$, bq_l and q_lq_l (where $q_l=$ d,s) and for the background;
  - fit the distribution in data to the templates.

Extraction of R_b

$$N^{data} = R_b^2 N^{MC}_{t\bar{t}\to bb} + 2R_b(1-R_b)N^{MC}_{t\bar{t}\to bq} + (1-R_b)^2 N^{MC}_{t\bar{t}\to qq} + N^{MC}_{bkg}$$

$$= \epsilon^{t\bar{t}}\mathcal{L}\sigma^{t\bar{t}}(R_b^2 f^{MC}_{t\bar{t}\to bb} + 2R_b(1-R_b)f^{MC}_{t\bar{t}\to bq} + (1-R_b)^2 f^{MC}_{t\bar{t}\to qq})$$
$$+ \epsilon^{bkg}\mathcal{L}\sigma^{bkg} f^{MC}_{bkg}$$

where N (resp. f) is the number (resp. fraction) of events in the bin of the distribution. Possible to fit both R_b and σ simultaneously.

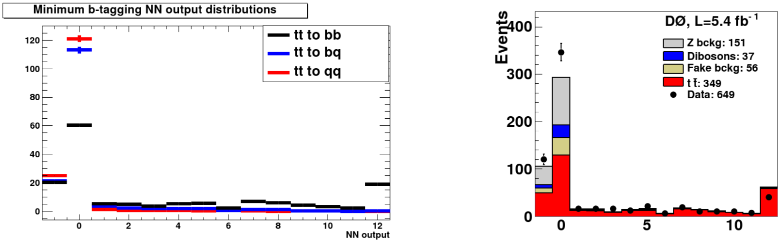


Figure 2: Templates for the three $t\bar{t}$ decays (left), and data/MC comparison of the NN distribution used for the fit (all channels combined).

Treatment of uncertainties

- Two different ways of treating the uncertainties:
  - the standard derivation of the overall uncertainties:
    R_b and σ recomputed for the one sigma variation of each systematic, the difference to the central value gives the error.
  - the nuisance method:
    each parameter allowed to float within its systematic and statistical uncertainties, allowing to change the central value.

Dilepton channel - Results

- Cross section only: $\sigma_{t\bar{t}} = 7.36 \pm 0.85\ (stat + syst)\ pb$ (11%)
- Simultaneous measurement:
  $R_b = 0.862 \pm 0.051\ (stat + syst)$ and
  $\sigma_{t\bar{t}} = 8.19 \pm 0.99\ (stat + syst)\ pb$

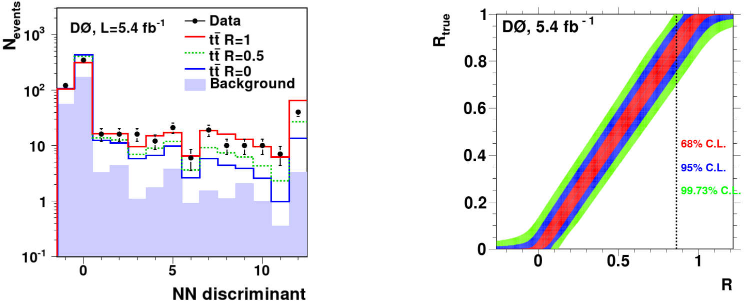


Figure 3: NN output distribution in data and MC after the fit (left). Limit bands on R_b with the Feldman-Cousin prescription.

Lepton+jets channel - Selection

- Same dataset as for the dilepton measurement.
- Selection
  - **one isolated electron or muon**, $p_T > 20$ GeV;
  - **at least three jets**, $p_T > 20$ GeV;
  - $\not{E}_T > 20$ (25) GeV in the $e + jets$ ($\mu + jets$) channel.
- Splitting of the sample in subchannels:
  - $e + jets$, $\mu + jets$;
  - exactly 3 or at least 4 jets;
  - 0, 1 or at least 2 b-tagged jets;
  - topological discriminant in the samples dominated by background.

Lepton+jets channel - Extraction of R_b , results

- Simultaneous fit:
  $R_b = 0.953 \pm 0.067\ (stat + syst)$ and
  $\sigma_{t\bar{t}} = 7.90 \pm 0.73\ (stat + syst)\ pb$

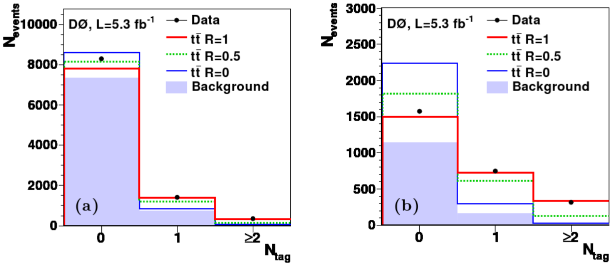


Figure 4: Number of b-tagged jets in data and MC after the R_b fit, in the 3 jet bin (left) and four jet bin (right).

Combination results

- Combine by fitting the dilepton and l+jets channels together.
- Cross section only: $\sigma_{t\bar{t}} = 7.56 \pm 0.60\ (stat + syst)\ pb$.
- Simultaneous fit of $\sigma_{t\bar{t}}$ and R_b , with the nuisance parameter method:

$$R_b = 0.899 \pm 0.040\ (stat + syst) \quad \text{(rel.prec.: 4.4\%)}$$
$$\sigma_{t\bar{t}} = 7.74 \pm 0.62\ (stat + syst)\ pb \quad \text{(rel.prec.: 8.0\%)}$$

Combination - limits at the 3σ level

- $R_b > 0.771$ (exp: $R_b > 0.869$);
- assuming the CKM matrix unitarity: $|V_{tb}| > 0.876$ (exp: $|V_{tb}| > 0.931$);
- without assumptions, can only extract the ratio $\frac{|V_{td}|^2+|V_{ts}|^2}{|V_{tb}|^2} = \frac{1-R}{R}$. We find: $\frac{1-R}{R} < 0.299$ (exp: $\frac{1-R}{R} < 0.155$).

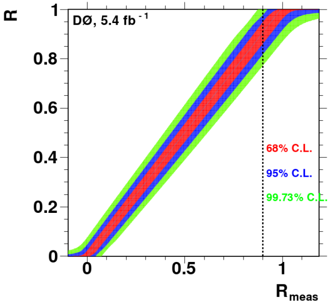


Figure 5: Limit bands on R_b with the Feldman-Cousin prescription.

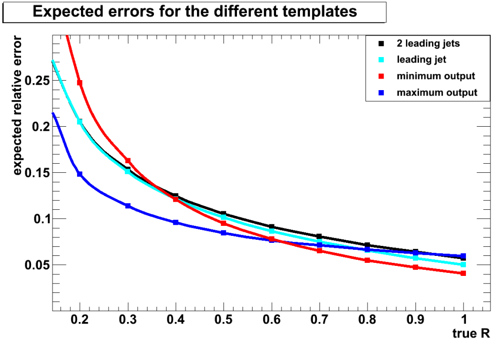
Conclusion

- First measurement of R_b in the dilepton channel at DØ;
- With the combination: relative uncertainty of 4.4% on R_b and 8.0% on the $t\bar{t}$ cross section;
- Two papers:
  - cross section in the dilepton channel, combined with lepton+jets (submitted, arxiv: 1105.5384);
  - R_b extraction in the lepton+jets and dilepton channels (collaboration review).

Back-up slides

Dilepton channel - Template choice

- Ensemble testing:
  - build distributions with the templates for different values of R_b , and fit;
  - repeat 1000 times for each value of R_b ;
  - compare the average fitted value to the true one, and extract the expected statistical error.
- Choose the template with the lowest statistical error: the minimum NN output of the two leading jets.



Dilepton channel - NN b-tagging control plots

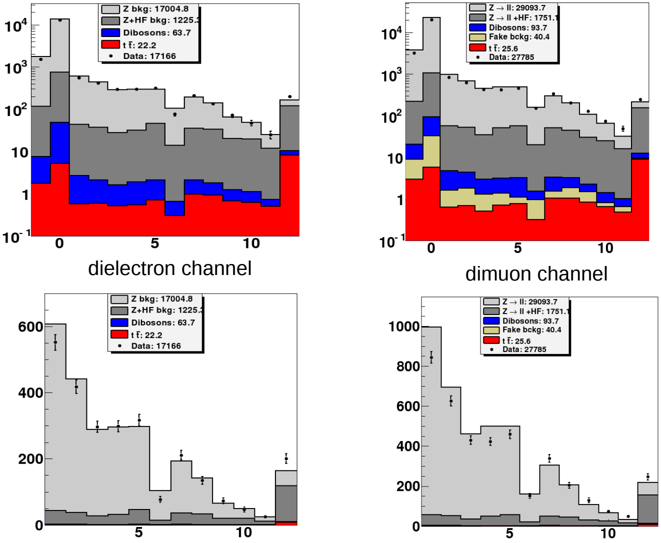


Figure 6: Minimum NN output distributions in the 1 jet bin for RunIIb1 and 2.

Dilepton channel - NN b-tagging distributions

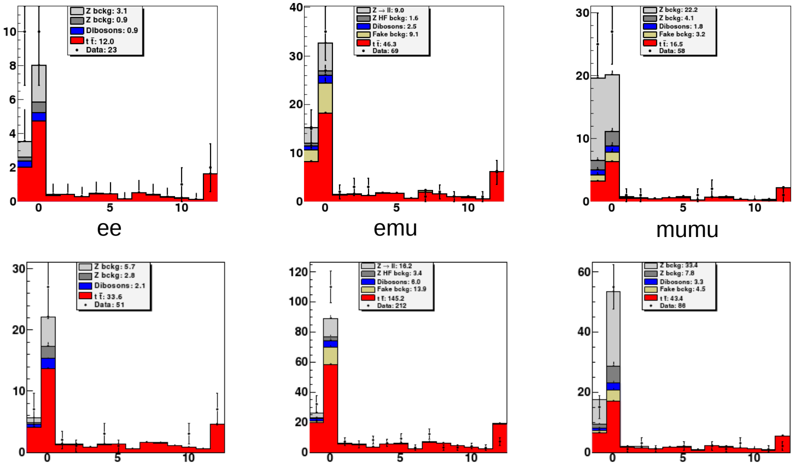


Figure 7: Minimum NN output for the RunIIa (top) and RunIIb (bottom).

Dilepton channel - Fit illustration

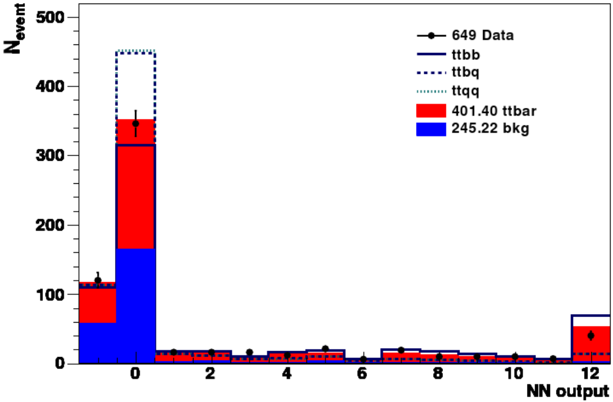
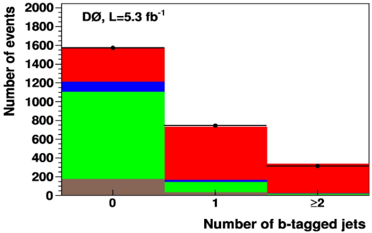


Figure 8: The b-tagging NN output distribution for all analysis channels combined. In blue the sum of all backgrounds, in red the fitted top signal is shown. The dashed lines show the distribution for the $tt \rightarrow$ bb, bq and qq templates.

Lepton+jets - method

- Same method as the previous measurement, same selection as for the cross section measurement (D0 Note 6109).
- Splitting of the sample in subchannels:
  - electron+jets, muon+jets;
  - 3 or at least 4 jets;
  - 0, 1 or at least 2 b-tagged jets.
  - Topological discriminant in the samples dominated by background (3 and 4 jets with 0 b-tags, 3 jets with 1 b-tag).



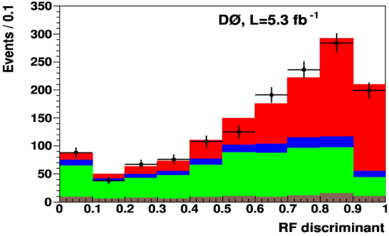


Figure 9: 3 jet bin distribution (left) and topological discriminant (right).