Top Pair Production Cross Section at DØ

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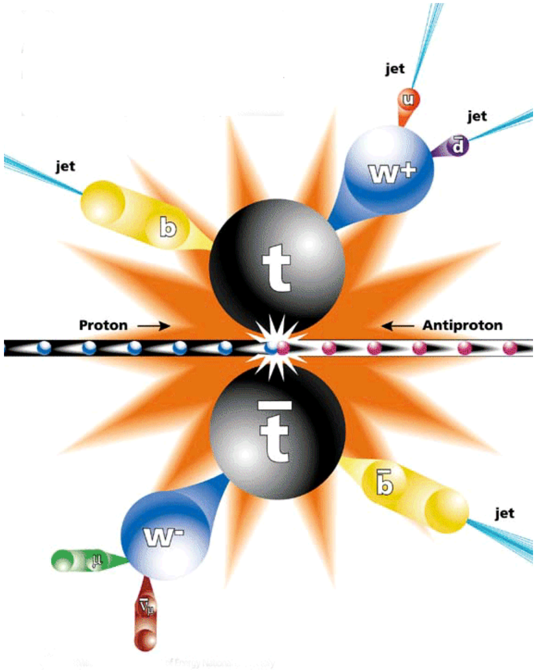
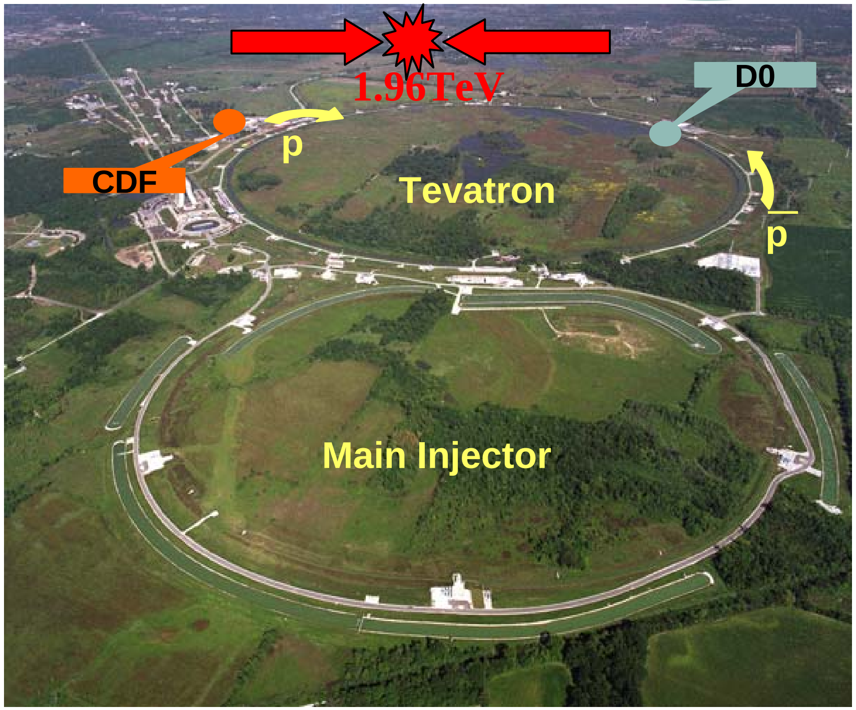
Introduction

- Top quark was discovered at 1995 by DØ and CDF Collaborations
- **Tevatron** is still the only place to produce the top events in the world
- Top pair events are important to understand the Standard Model and search New physics
  - important background for Higgs search
  - Theoritical Prediction of SM
    - 6.8 ± 0.6 pb (Kidonakis and Vogt)
    - $6.7^{+0.7}_{-0.9}$ pb (Cacciari et al.)
    - Theoritical uncertainty is 9 ~ 13%

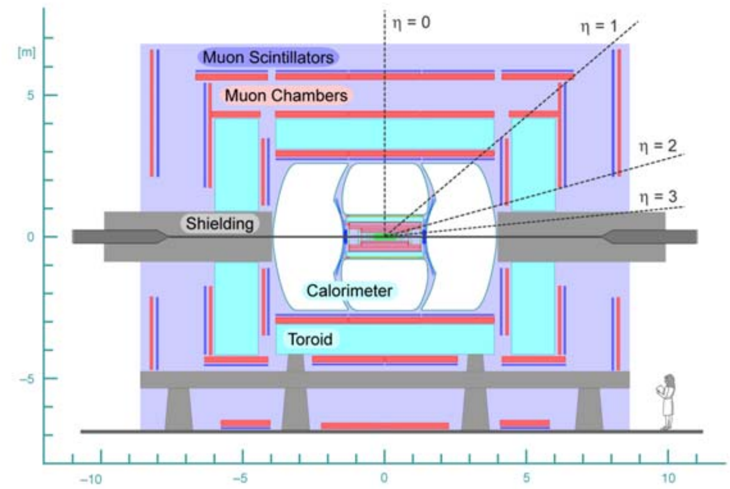


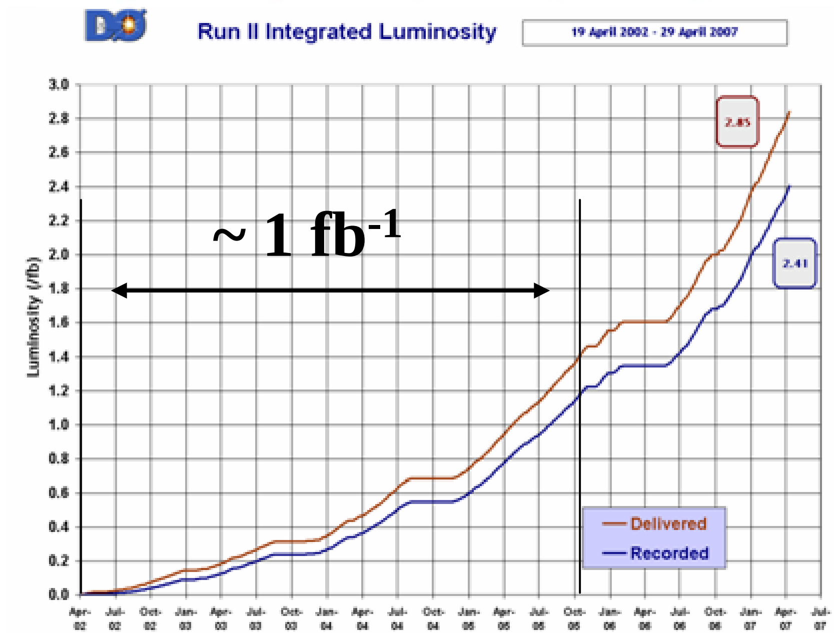
Tevatron and DØ detector



- Tevatron
  - $p\bar{p}$ collider with $\sqrt{s}$ = 1.96 TeV
  - Integ. Lumi. 2.85fb^{-1}(delivered), 2.41fb^{-1}(recorded)
  - expect 3fb^{-1} by July!
- DØ Detector
  - Silicon Vertex Detector
  - Central Tracker
  - EM and Hadronic Calorimeters
  - Muon Detector

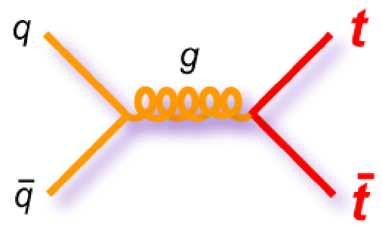
DØ Detector Overview



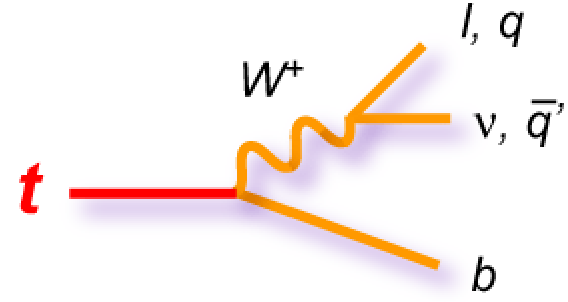


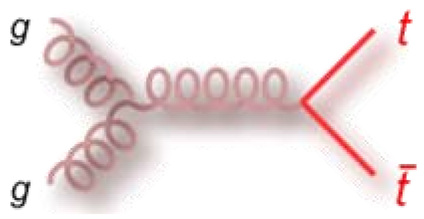
Top Quark Production and Decay

- Top quark pair production at Tevatron energies



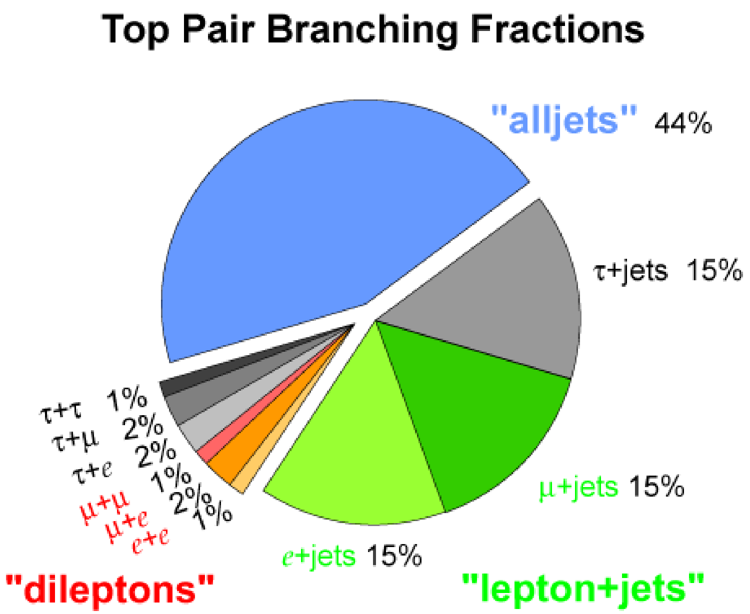
$q\bar{q}$ anihilation (~ 85%)





gluon fusion (~ 15%)

- Top quark decays to Wb with ~100% due to it's heavy mass
  - So, the final states are determined by what W boson decays
  - 3 types of channels
    - lepton + jets channel (BR ~ 34%)
    - di-lepton channel (BR ~ 6%)
    - all hadronic channel

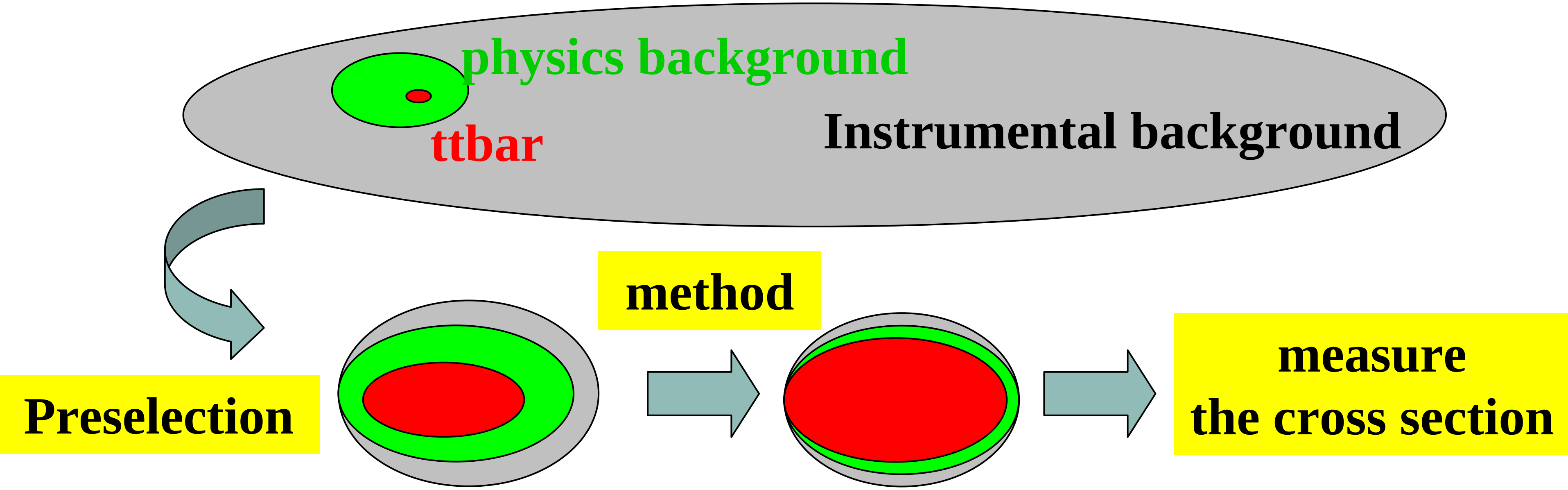


Analysis Procedure

- 3 steps for letpon+jets channel
  - Pre-selection
    - Extract signal events with maximum efficiency
    - Reject instrumental backgrounds
  - Analysis method Applied
    - Reject Physics backgrounds
  - Calculate cross section
- 2 steps for di-lepton channel
  - Pre-selection
    - Just few background processes share the signature of di-lepton channel
  - Calculate cross section

Topological Analysis

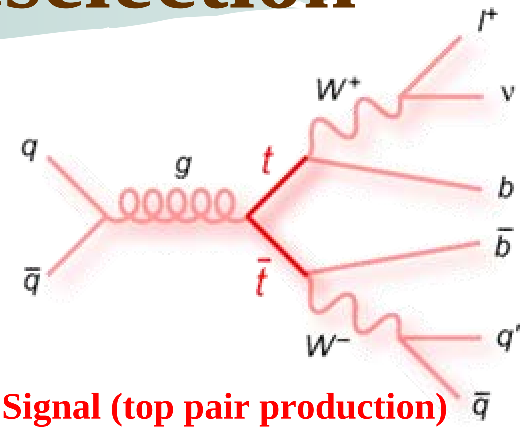
b-tagging



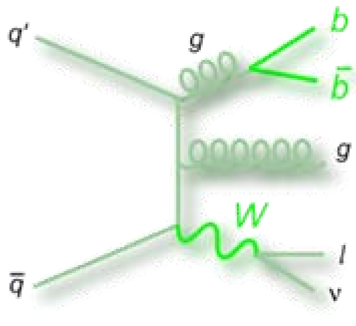
lepton+jets Channel

Event Signature and Preselection

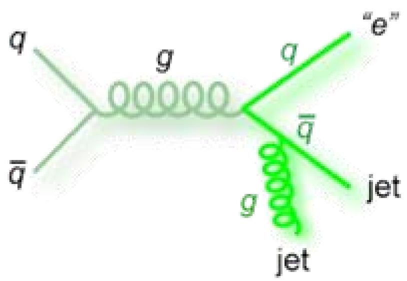
- Signal
  - one isolated, high pT letpon
  - Large Missing Transverse Energy (MET)
  - ≥ 4 jets
- Background
  - Main physics background is W+jets
  - Multi-jet background
- Preselection
  - ≥4 jets in the event with jet pT > 20 GeV
    - 3 jets events used in b-tagging analysis
  - good vertex with $|z_{PV}| \leq$ 60cm and at least 3 tracks attatched
  - Second lepton veto (orthogonal to dilepton channel)
  - lepton coming from the primary vertex $|\Delta z(\text{lepton,PV})| < 1$cm
  - A tight isolation lepton with pT > 20 GeV
  - Large MET > 20 GeV



Signal (top pair production)



background (Wbb)



background (multi-jet)

Estimation of Multi-jet Backgrounds

- QCD multi-jet background is estimated from data
  - determine by Matrix Method
  - use loose and tight lepton selection
  - linear equations for N^{QCD} and $N^{Wjets+tt}$
  - e+jets: $\varepsilon_{sig} \sim 0.85$, $\varepsilon_{QCD} \sim 0.18$
  - mu+jets: $\varepsilon_{sig} \sim 0.84$, $\varepsilon_{QCD} \sim 0.24$

the efficiency for a true isolated lepton to pass the tight lepton isolation selection

loose lepton

$$N_l = N^{QCD} + N^{Wjets+t\bar{t}}$$

ε_{QCD} ε_{sig}

$$N_t = \varepsilon_{QCD} N^{QCD} + \varepsilon_{sig} N^{Wjets+t\bar{t}}$$

tight lepton

the efficiency for a fake lepton to pass the tight lepton isolation selection

solution

$$N^{Wjets+t\bar{t}} = \varepsilon_{sig} \frac{N_t - \varepsilon_{QCD} N_l}{\varepsilon_{sig} - \varepsilon_{QCD}}$$

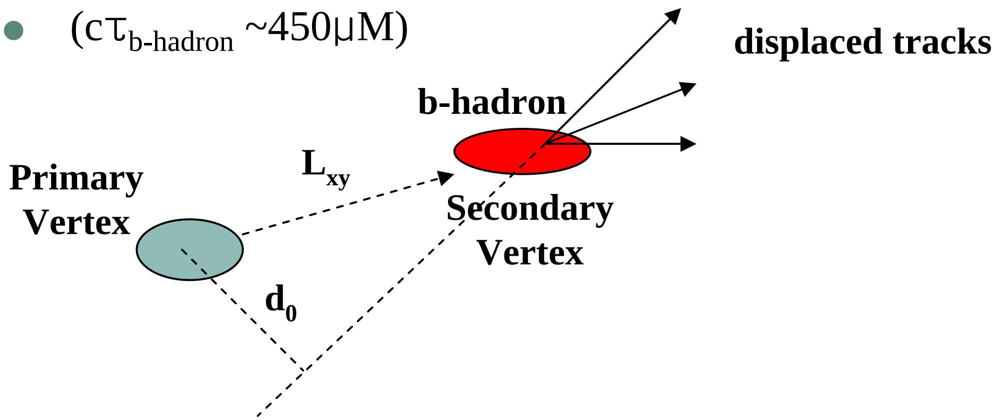
$$N^{QCD} = \varepsilon_{QCD} \frac{\varepsilon_{sig} N_l - N_t}{\varepsilon_{sig} - \varepsilon_{QCD}}$$

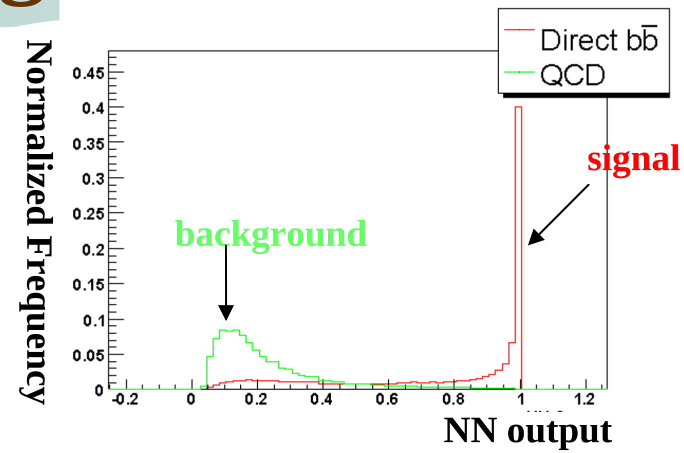
lepton+jets Channel

b-tagging analysis

Jet Tagging

- Identify b-jet by life-time effects
  - ($c\tau_{\text{b-hadron}}$ ~450μM)



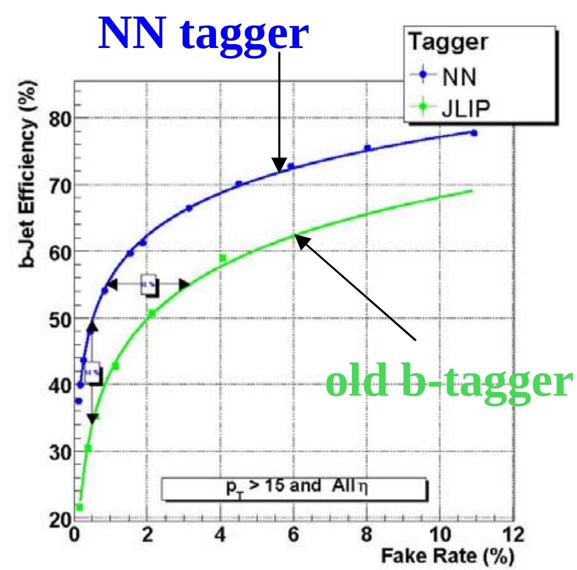


- New NN tagger efficiency is improved (~15%)
  - b-jet tagging efficiency : ~ 69%
  - old tagger used for 425 pb^{-1} : ~ 60%
  - smaller systematic uncertainties
- MC Event Weight
  - p_i = probability for jet i to be tagged
  - n = number of jets in the event

$$P_{\geq 1} = 1 - \prod_{i=1}^{n} (1 - p_i)$$

$$P_{=1} = \sum_{i=1}^{n} \left\{ p_i \prod_{j \neq i} (1 - p_j) \right\}$$

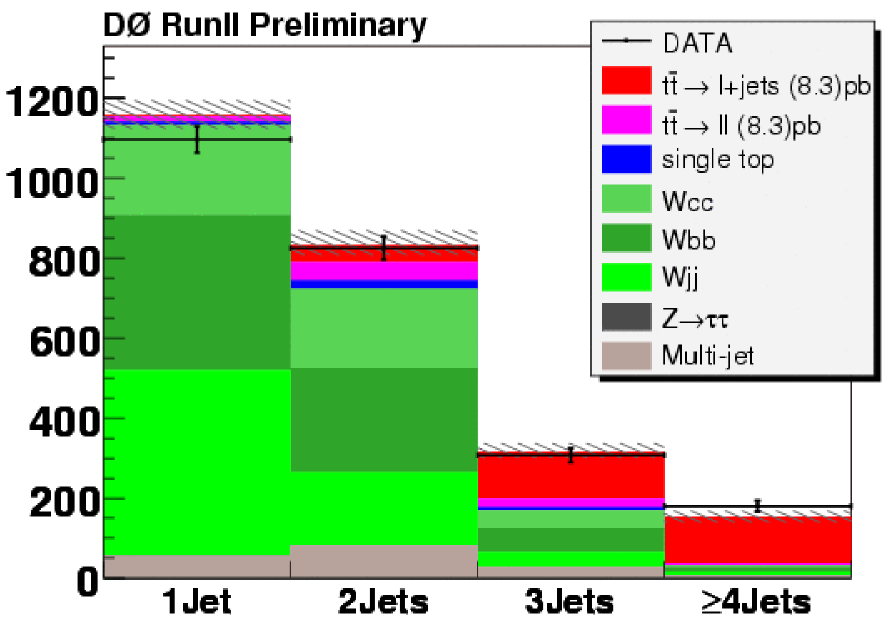
$$P_{\geq 2} = P_{\geq 1} - P_1$$



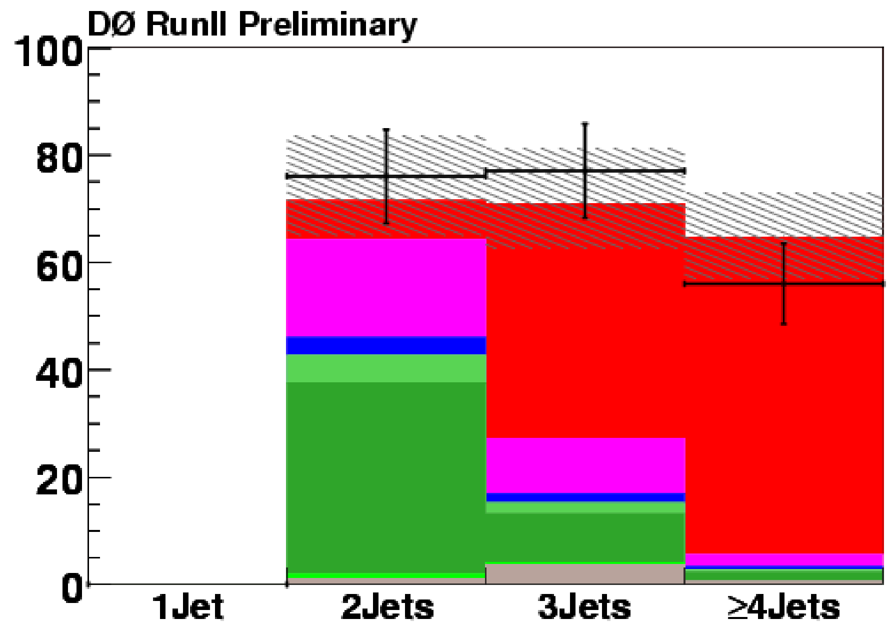
Improved of 15% w.r.t. the previous b-jet tagging

MC and Data agreement

lepton+jet channel combined



1 b-tag

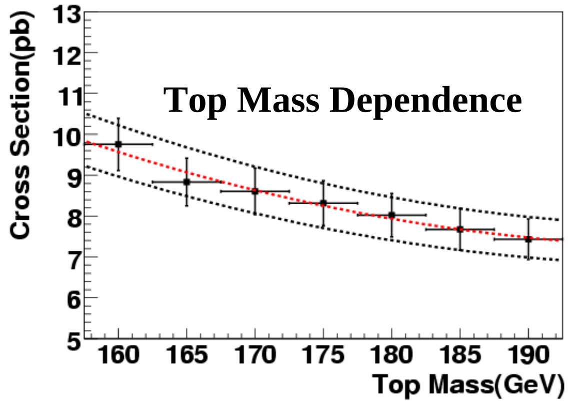


≥2 b-tags

Cross Section

- Cross section is calculated with 8 different channels
  - e+jets: 1 b-tag and ≥2 b-tags, 3 jets and ≥4 jets (4 channels)
  - mu+jets: 1 b-tag and ≥2 b-tags, 3 jets and ≥4 jets (4 channels)
- Cross Section

$$\sigma_{t\bar{t}} = \frac{N^{b-tag}_{observed} - N^{b-tag}_{background}}{L \cdot Br \cdot \varepsilon_{presel} \cdot \varepsilon_{b-tag}}$$



l + jets :	$\sigma_{t\bar{t}} = 8.3\ ^{+0.6}_{-0.5}(\text{stat})\ ^{+0.9}_{-1.0}(\text{sys}) \pm 0.5(\text{lumi})$ pb
e + jets :	$\sigma_{t\bar{t}} = 7.4 \pm 0.7(\text{stat})\ ^{+0.8}_{-1.0}(\text{sys}) \pm 0.4(\text{lumi})$ pb
μ + jets :	$\sigma_{t\bar{t}} = 9.5 \pm 0.9(\text{stat})\ ^{+1.1}_{-1.3}(\text{sys}) \pm 0.6(\text{lumi})$ pb

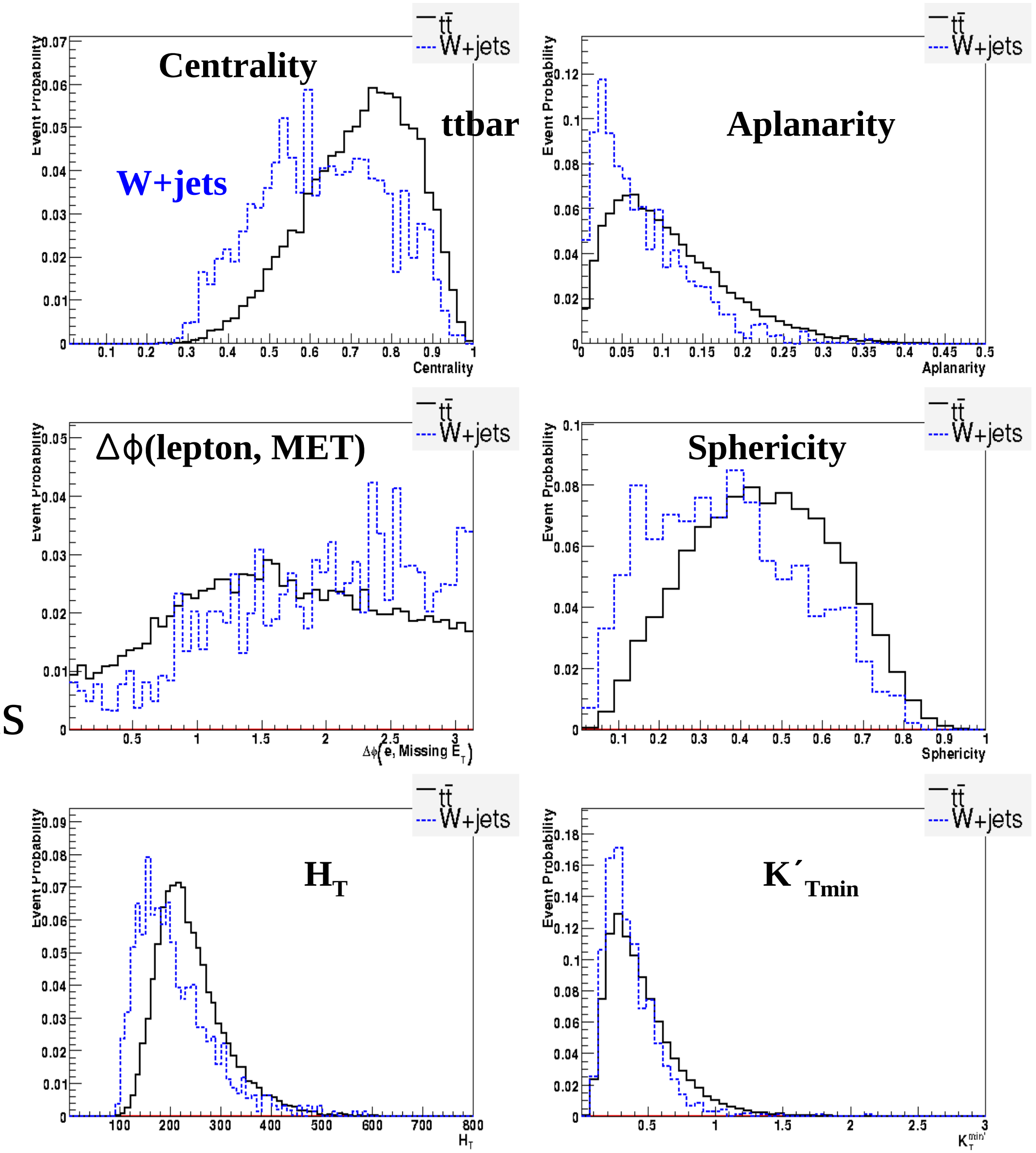
$\delta\sigma/\sigma = \pm 13\%$

lepton+jets Channel

Topological Analysis

Topological Analysis

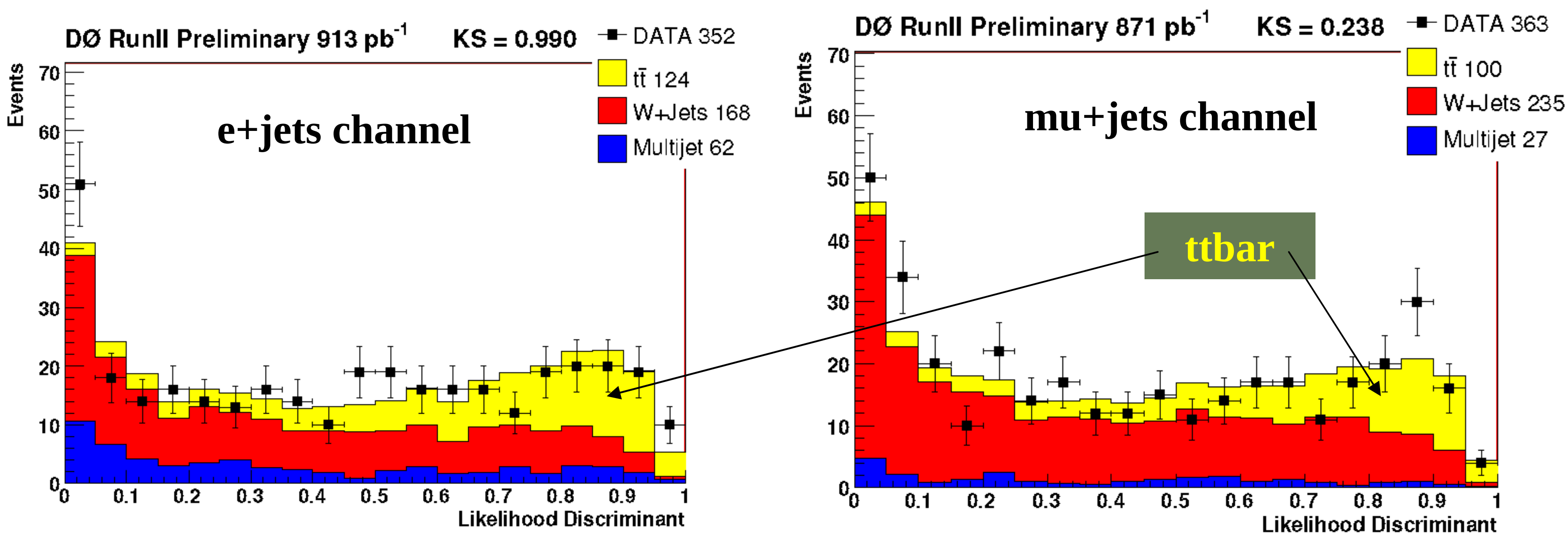
- Multivariate discriminant
  - event kinematic variables
  - Likelihood fit
- Choice of Topological variables
  - good separation power
  - correlation and sensitivity against systematic uncertainties
- Six variables are used in this analysis
  - Centrality, Aplanarity
  - $\Delta\phi$(lepton, MET), Sphericity
  - H_T, K'_{Tmin}



Likelihood Fit

- The event information contained in the topological variables is combined in a likelihood discriminant

$$L = \frac{\prod_i S_i}{\prod_i S_i + \prod_i B_i}$$



N^{tt}		N^{W+jets}		N^{QCD}	
123.9	+22.4	167.7	+25.1	61.5	+4.3
	-21.4		-24.3		-4.2

N^{tt}		N^{W+jets}		N^{QCD}	
100.4	+22.1	235.5	+26.3	26.6	+4.3
	-21.0		-25.5		-4.1

Cross Section

- Cross Section

$$\sigma_{t\bar{t}} = \frac{N^{t\bar{t}}}{L \cdot Br \cdot \varepsilon_{presel}}$$

σ_{tt}^{NLO} = 6.8 ± 0.6 pb

N. Kidonakis and R Vogt, PRD 68 (2003)

δσ/σ = ±19 %

l + jets : $\sigma_{t\bar{t}} = 6.3\ ^{+0.9}_{-0.8}(\text{stat})\ ^{+0.7}_{-0.7}(\text{sys}) \pm 0.4(\text{lumi})$ pb

e + jets : $\sigma_{t\bar{t}} = 6.6\ ^{+1.2}_{-1.1}(\text{stat})\ ^{+0.8}_{-0.8}(\text{sys}) \pm 0.4(\text{lumi})$ pb

μ + jets : $\sigma_{t\bar{t}} = 5.9\ ^{+1.3}_{-1.2}(\text{stat})\ ^{+0.9}_{-0.8}(\text{sys}) \pm 0.4(\text{lumi})$ pb

Table for systematic errors

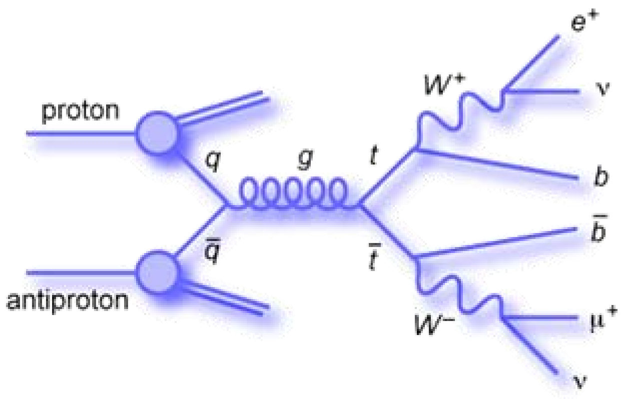
for only l+jets combined

Primary Vertex	+0.17 -0.16
Lepton Identification	±0.28
Jet Energy	+0.08 -0.06
Trigger	±0.1
W Background Model	±0.51
MC statistics	±0.27
Others	±0.14
Total	±0.7

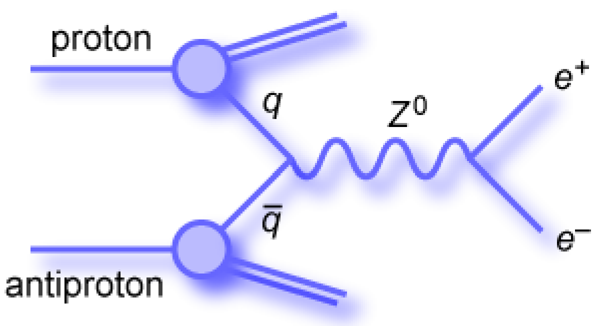
di-lepton Channel

Event Signature

- Signal
  - 2 high pT opposite charge, ee, eμ, μμ
  - ≥2 high pT jets
  - Large Missing Transverse Energy(MET)
- Physics Background
  - 2 leptons from Z/ γ^* +jets (dominont)
  - 2 leptons from WW/WZ/ZZ + jets
  - estimated from MC
- Instrumental Background
  - fake isolated leptons
  - fake MET
  - estimated from Data



Signal



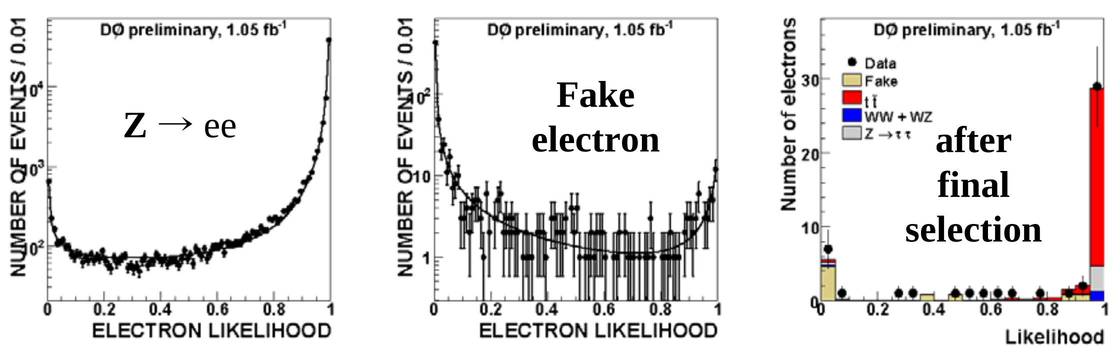
Background

Pre-selection

- Common
  - lepton pT > 15GeV
  - ≥2 jets with pT > 20GeV
- ee channel
  - Z (WW, WZ, ZZ) →ee + ≥2jets + MET
  - Veto events with M_{ee} < 15 GeV or 80GeV < M_{ee} <100GeV
  - MET > 35GeV (MET > 40GeV) for M_{ee} >100GeV (80GeV < M_{ee} <100GeV)
  - Spericity > 0.15
- eμ channel
  - Z→ττ(τ→e or μ) + ≥2jets + MET, (WW, WZ, ZZ)→eμ + ≥2jets + MET
  - Not apply MET cut
  - H_T > 115GeV, $H_T = p_T^{l_1} + \sum p_T^j$
- μμ channel
  - Z (WW, WZ, ZZ) →μμ + ≥2jets + MET
  - MET > 35GeV
  - Contour cut in the MET vs. ΔΦ(μ, MET)

Instrumental Backgrounds

- Mis-identified Electron (ee, eμ)
  - Jet mis-identified or non-isloated (b-jet decay)
  - Fit to electron likelihood in data



- Fake isolated muon (eμ, μμ)
  - Non-isolated muon when the jet is not reconstructed
  - estimated from data
- Fake MET (ee)
  - fake MET can appear due to instrumental effects
    - detector resolution, fake jets or noise in calorimeter
  - estimated from γ +jets sample(MET fake rate) and $Z/\gamma^* \to ee$ MC

Event Yields and Kinematic Dist.

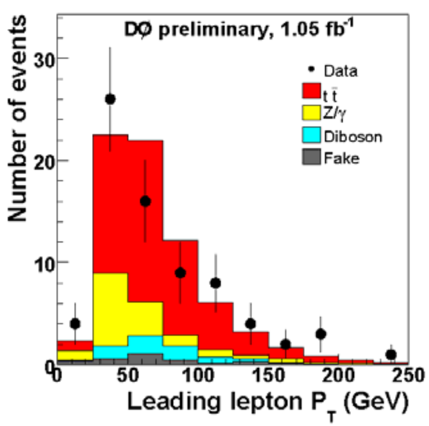
Ch.	S/B
ee	3.2
μμ	0.6
eμ (≥2jets)	4.3
eμ (1jet)	1.6

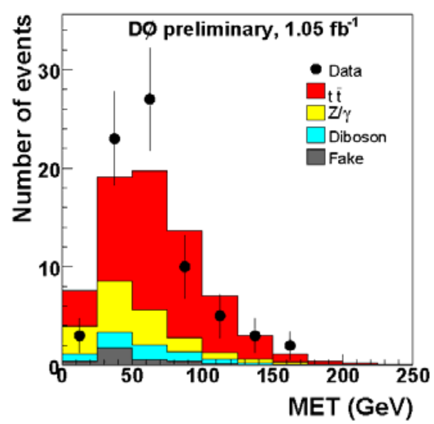
σ_{tt} = 7 pb

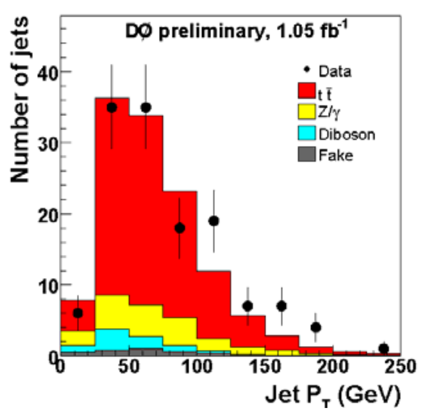
M_{top} = 175GeV

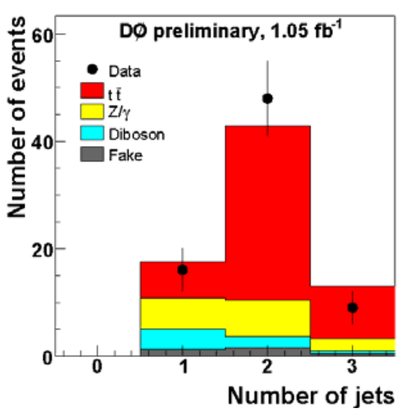
→ Expected signal

Category	ee	μμ	eμ (≥2jets)	eμ (1jet)
Z/γ^*	$2.4^{+0.4}_{-0.4}$	$2.7^{+0.4}_{-0.4}$	$3.6^{+0.7}_{-0.8}$	$5.5^{+0.8}_{-0.8}$
WW/WZ and other MC	0.4 ± 0.2	0.5 ± 0.1	1.4 ± 0.6	3.4 ± 1.4
Instrumental background	$0.2^{+0.2}_{-0.1}$	$0.4^{+0.2}_{-0.2}$	$1.8^{+0.6}_{-0.6}$	$1.2^{+0.4}_{-0.4}$
Total background	$3.0^{+0.5}_{-0.5}$	$3.6^{+0.5}_{-0.5}$	$6.7^{+1.2}_{-1.2}$	$10.2^{+1.8}_{-1.7}$
Expected signal	$9.5^{+1.4}_{-1.4}$	$5.8^{+0.5}_{-0.5}$	$28.6^{+2.1}_{-2.1}$	$7.1^{+0.6}_{-0.7}$
Total sig. + bg.	$12.5^{+1.5}_{-1.5}$	$9.4^{+0.7}_{-0.7}$	$35.5^{+2.8}_{-3.2}$	$17.2^{+2.0}_{-2.1}$
observed events	16	9	32	16









Cross Section

- Cross Section

$$\sigma_{t\bar{t}} = \frac{N^{observed} - N^{background}}{L \cdot Br \cdot \varepsilon_{presel}}$$

$\delta\sigma/\sigma = \pm 22$ %

di-lepton :		$\sigma_{tt} = 6.8\ ^{+1.2}_{-1.1}(\text{stat})\ ^{+0.9}_{-0.8}(\text{sys}) \pm 0.4(\text{lumi})$ pb
ee	:	$\sigma_{tt} = 9.6\ ^{+3.2}_{-2.7}(\text{stat})\ ^{+1.9}_{-1.6}(\text{sys}) \pm 0.6(\text{lumi})$ pb
eμ	:	$\sigma_{tt} = 6.1\ ^{+1.4}_{-1.2}(\text{stat})\ ^{+0.8}_{-0.7}(\text{sys}) \pm 0.4(\text{lumi})$ pb
μμ	:	$\sigma_{tt} = 6.5\ ^{+4.0}_{-3.2}(\text{stat})\ ^{+1.1}_{-0.9}(\text{sys}) \pm 0.4(\text{lumi})$ pb

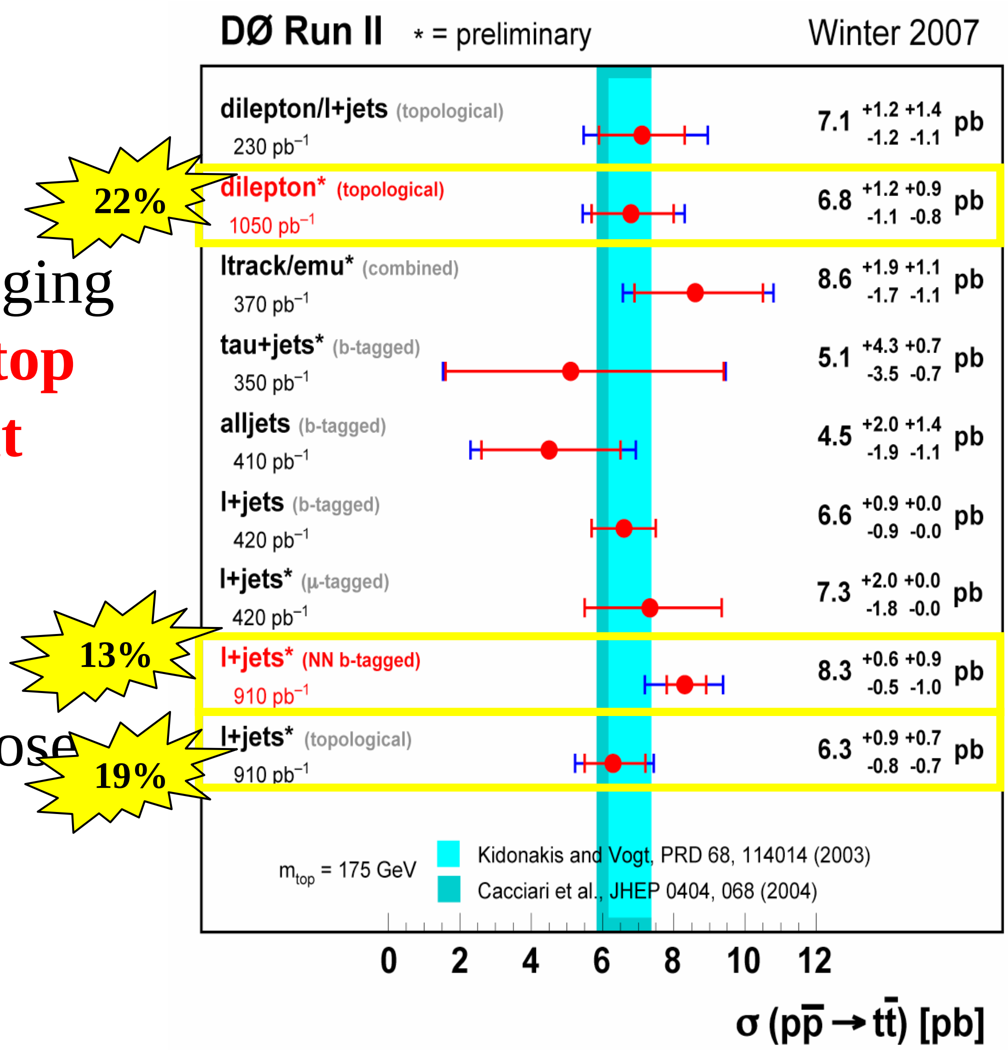
Table for systematic errors

for di-lepton combined

Jet energy calibration	**+0.3 -0.3**
Jet identification	**+0.1 -0.1**
Primary Vertex	**+0.3 -0.2**
Electron Identification	**+0.6 -0.5**
Muon Identification	**+0.2 -0.2**
Trigger	**+0.2 -0.2**
Fake background	**+0.2 -0.2**
MC normalization	**+0.3 -0.3**
Others	**+0.2 -0.2**
Total	**+0.9 -0.8**

Conclusion

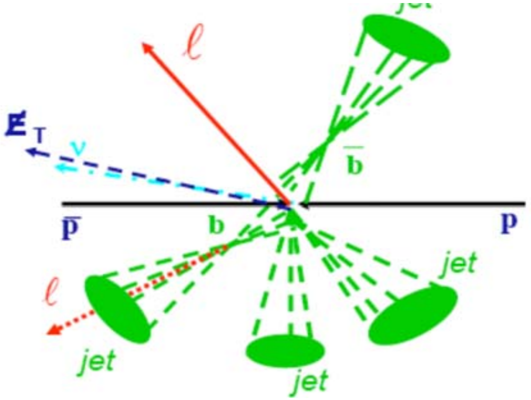
- Updated top cross section measurements with ~1fb^{-1} are agreed well with SM
- lepton+jets channel with b-tagging is currently **the most precise top cross section measurement at DØ**
  - Due to the improved b-tagging algorithm
- Experimental uncertainty is close to theoritical one

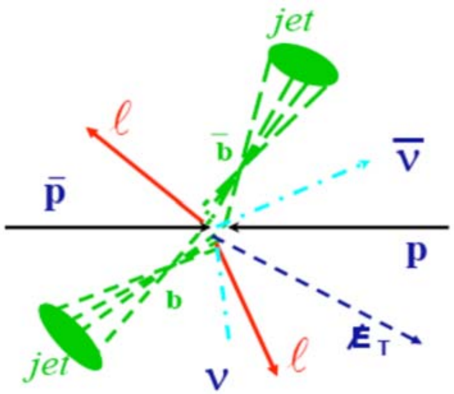


Backup Slides

Summary of decay channels

- lepton+jets channel
  - **high branching fraction**
  - manageable background
  - kinematically constraint
  - mainly used for top property measurements
- di-lepton channel
  - **low background**
  - low statistics
  - no kinematic constraint
- all-hadronic channel
  - **highest branching fraction**
  - highest background
  - kinematically over-constraint





Lepton Identification

- Electron
  - Loose isolated electron
    - At least 90% of the energy of the cluster must be contained in the electromagnetic section of the calorimeter
    - χ^2 from the 7×7 H-matrix must be less than 50
    - The energy deposition in the calorimeter must be matched with a charged particle track from the tracking detectors with pT > 5GeV
    - $(E_{total}(R < 0.5) - E_{EM}(R<0.2))/E_{EM}(R<0.2) < 0.15$
  - Tight isolated electron
    - Must pass the loose isolation requiremets above, and have a valuse of the seven-variable EM-likelihood > 0.85
- Muon
  - Loose isolation muon
    - Medium, |nseg|=3 quality
    - pass loose cosmic ray rejection timing
    - The track reconstructed in the muon system must match a track reconstructed in the central tracker with $\chi^2/ndof < 4$
    - $\Delta R(\text{muon, jet}) > 0.5$
  - Tight isolation muon
    - require to pass Loose isolation muon selection
    - The momenta of all tracks in a cone of radius R < 0.5 around the muon direction, except the track matched to the muon, add up to less than 20% of the muon pT
    - The energy depoisted in an annular cone of radius 0.1 < R < 0.4 around the muon direction is less than 20 % of the muon pT

Preselection (lepton+jets)

- e+jets channel
  - Exactly 3 or ≥4 jets with pT > 20GeV and |η| < 2.5
  - one tight electron with pT > 20GeV in CC
  - no second tight electron with pT > 15GeV in CC or EC
  - no isolated muon with pT > 15GeV
  - good vertex with $|z_{PV}| \leq$ 60cm with at least 3 tracks attatched
  - electron coming from the primary vertex |Δz(e,PV)| < 1cm
  - MET > 20GeV and ΔΦ(e,MET) > 0.7*π – 0.045*MET
- mu+jets channel
  - Exactly 3 or ≥4 jets with pT > 20GeV and |η| < 2.5
  - one tight muon with pT > 20GeV with muon quality MediumNSeg3
  - invariant mass of the selection muon and any second muon $M_{\mu\mu}$ < 70GeV or $M_{\mu\mu}$ > 110GeV to reject Z(→ μμ)+jets events
  - no second muon with pT > 15GeV with muon quality MediumNSeg3
  - no tight electron with pT > 15GeV
  - good vertex with $|z_{PV}| \leq$ 60cm with at least 3 tracks attatched
  - muon coming from the primary vertex |Δz(e,PV)| < 1cm
  - MET > 20GeV and ΔΦ(e,MET) > 0.48*π – 0.033*MET and **W_{tmss} > 30 GeV**

Definition of Variables

- $H_T = \sum E_T$
- Centrality $= H_T / H$
- Aplanarity $M_{ij} = \frac{\sum_0 p_i^0 p_j^0}{\sum_0 \left|\vec{p}^{\,0}\right|^2}$
- Sphericity $S = \frac{3}{2}(\lambda_2 + \lambda_3)$
- $K'_{T\,\min} = \frac{\Delta R_{jj}^{\min} E_T^{\min}}{E_T^W}$
- $\Delta\phi(lepton, \not{E}_T)$

H is the scalar sum of the energy of the jets

M is normalized momentum tensor

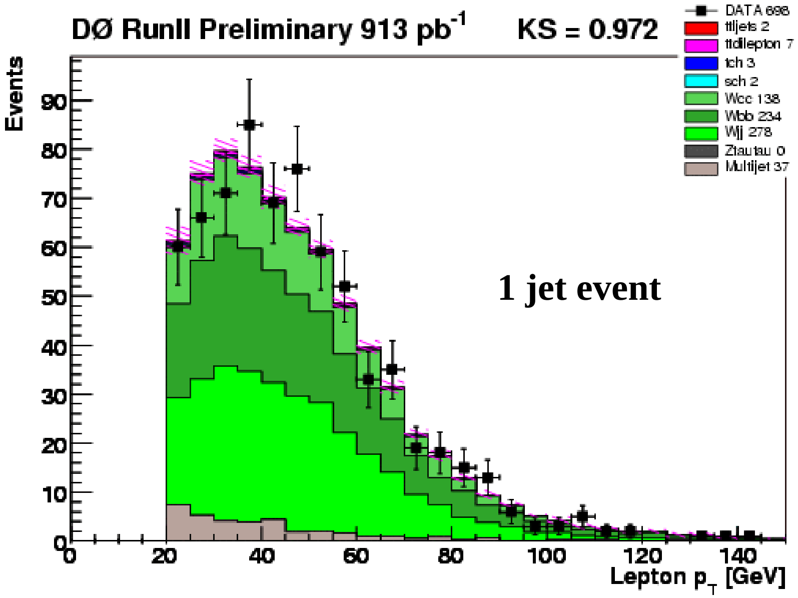
λ_2 and λ_3 are smallest eigenvalues of the nomalized momentum tensor M

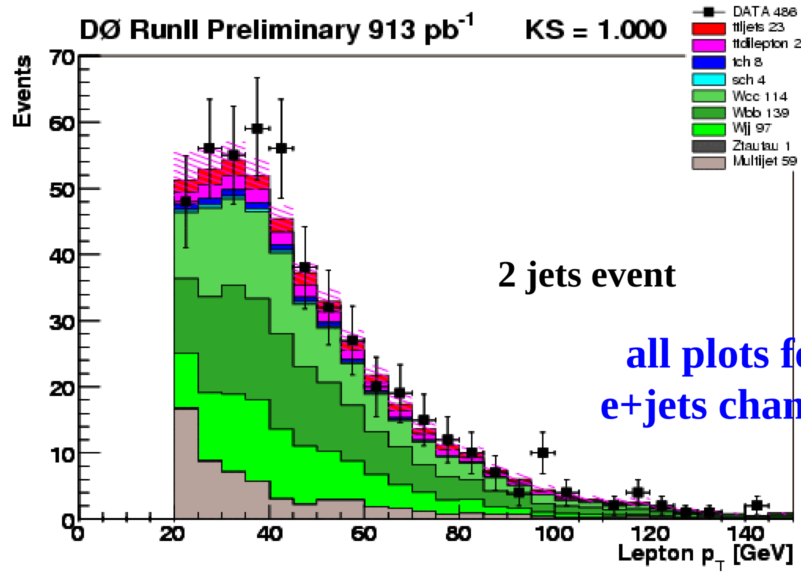
$\Delta R_{jj}^{\min}$ corresponds to the minimum separation in $\eta - \phi$ space between a pair of jets

$E_T^{\min}$ is the ET of the lesser jet of that pair

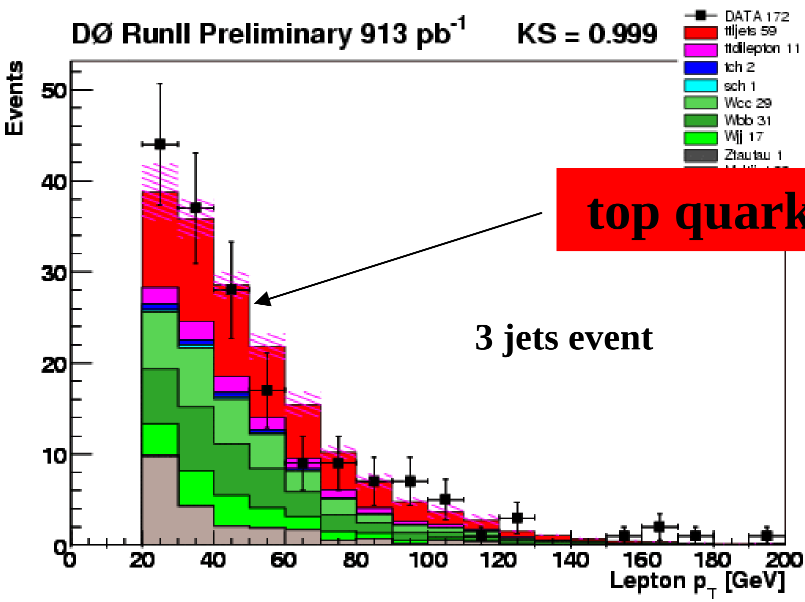
$E_T^W = E_T^{lepton} + \not{E}_T$

Control Plots (b-tagging)

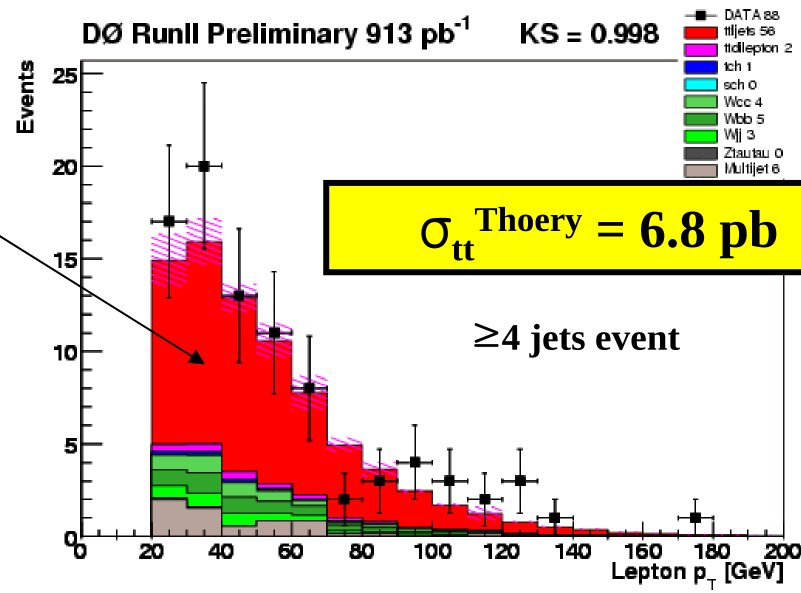




all plots for e+jets channel



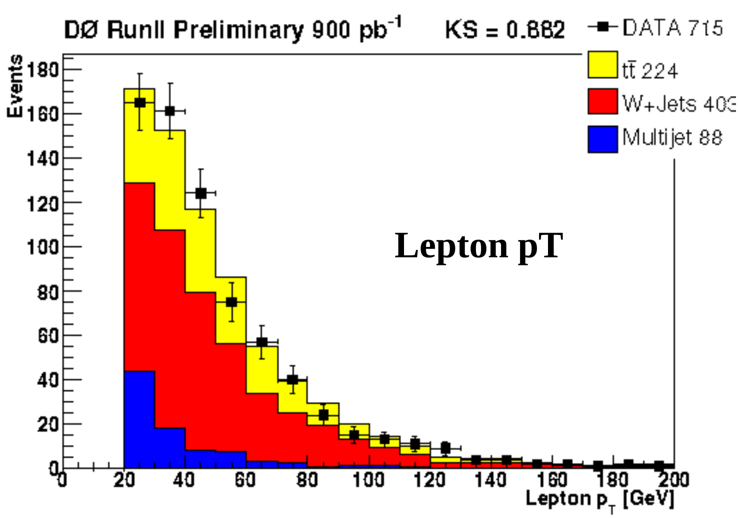
top quark

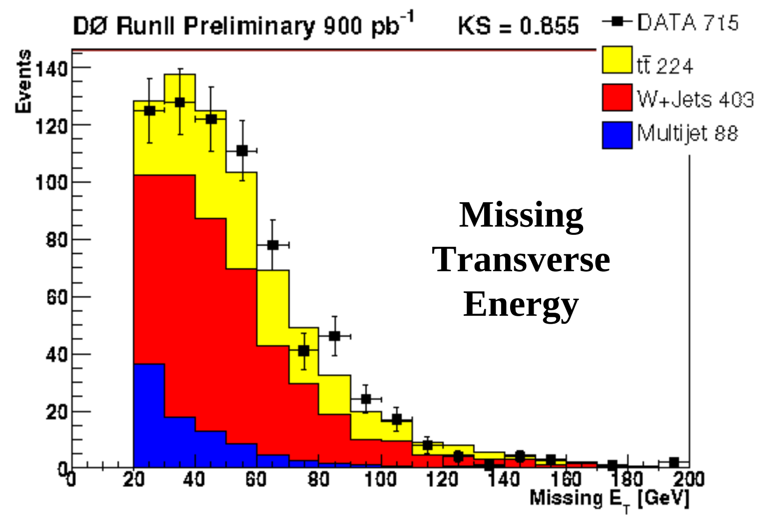


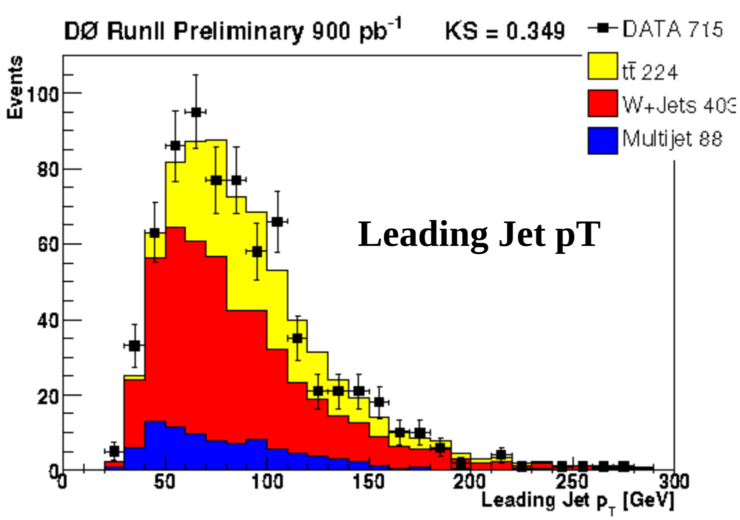
$\sigma_{tt}^{Thoery} = 6.8$ pb

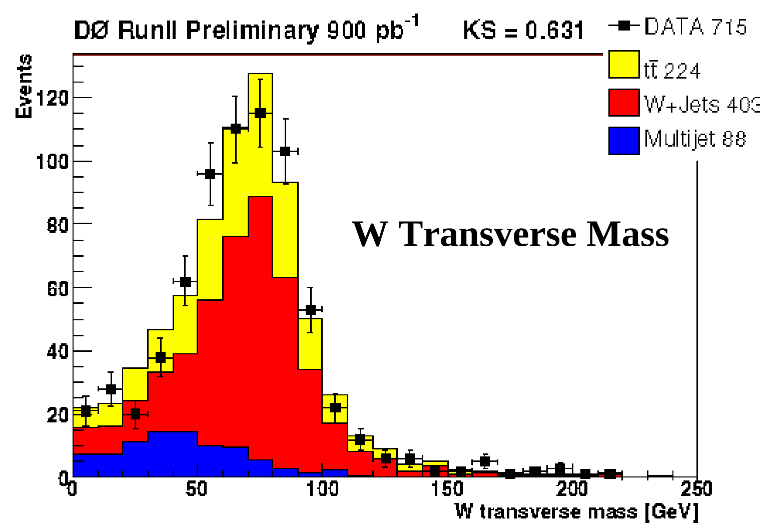
Control Plots (Topological)

4-jets events: various distributions for the data overlayed with the fit results for the combined two channels



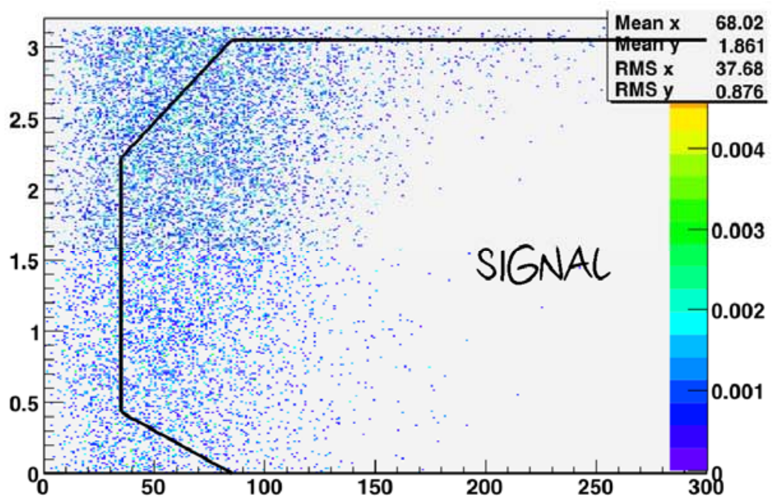


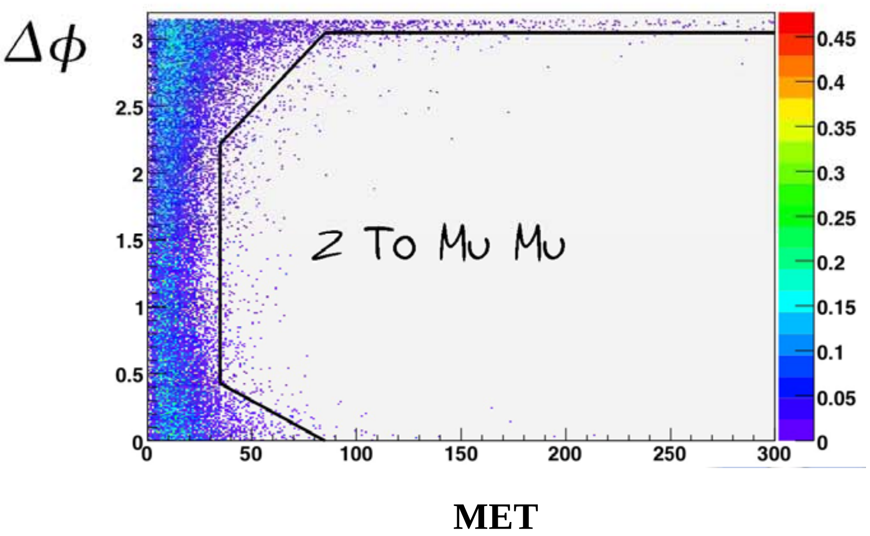




Dimuon Selection

- Contour cut: $\not{E}_T$ vs. $\Delta\phi$(leading $\not{E}_T$)
  - 2 neutrinos ⇒ a first cut is set: $\not{E}_T > 35$ GeV
  - To prevent from misreconstructed muon momenta: $\Delta\phi$(leading $\not{E}_T$) < 175°
  - To further reduce background, $\not{E}_T$ cut is increased for $\Delta\phi$(leading $\not{E}_T$) close to 0° or 180°





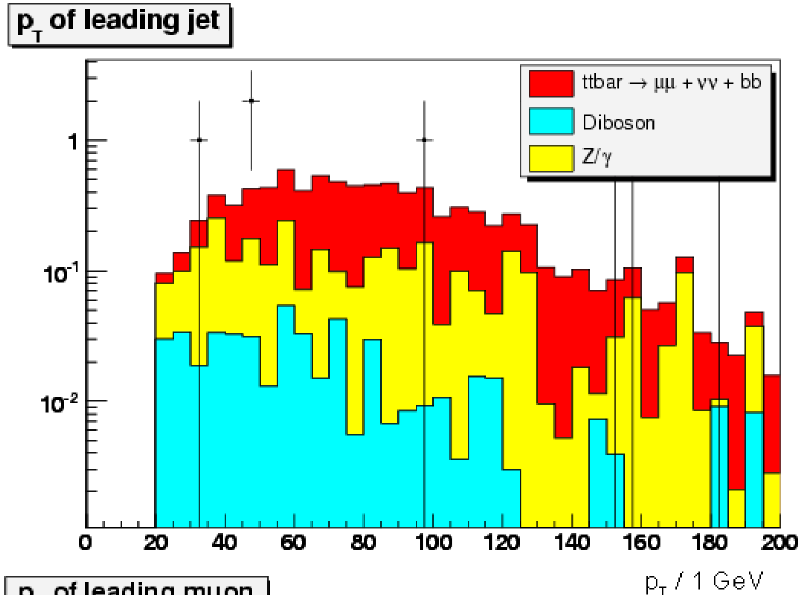
Di-electron Selection

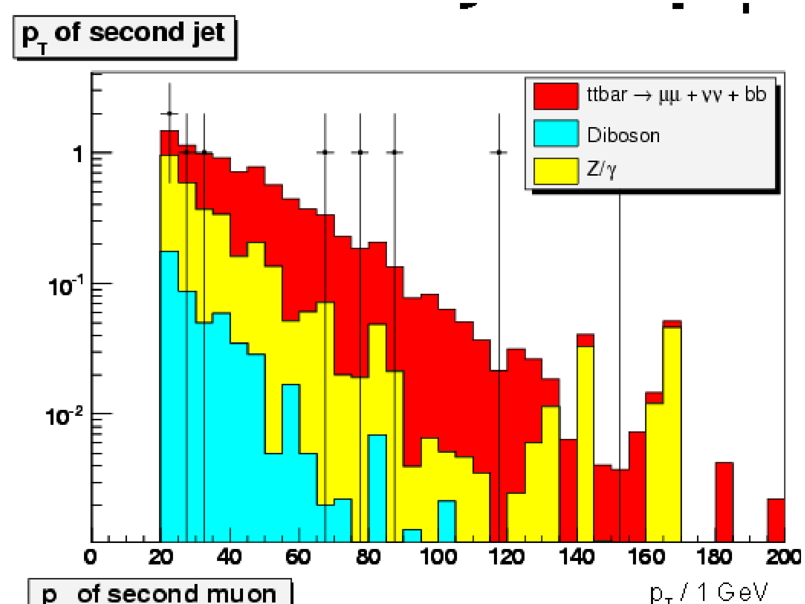
- Luminosity: 1.07 fb^{-1}
- Analysis cuts:
  - 2 tight electrons
  - ≥ 2 jets
  - $\not{E}_T$ depends on M_{ee}: $\not{E}_T > 40$ GeV for 15 GeV $< M_{ee} <$ 80 GeV and $\not{E}_T > 35$ GeV for $M_{ee} > 100$ GeV
  - Sphericity > 0.15
- Trigger: ORing of all dielectron triggers; Signal efficiency ≈ 94%

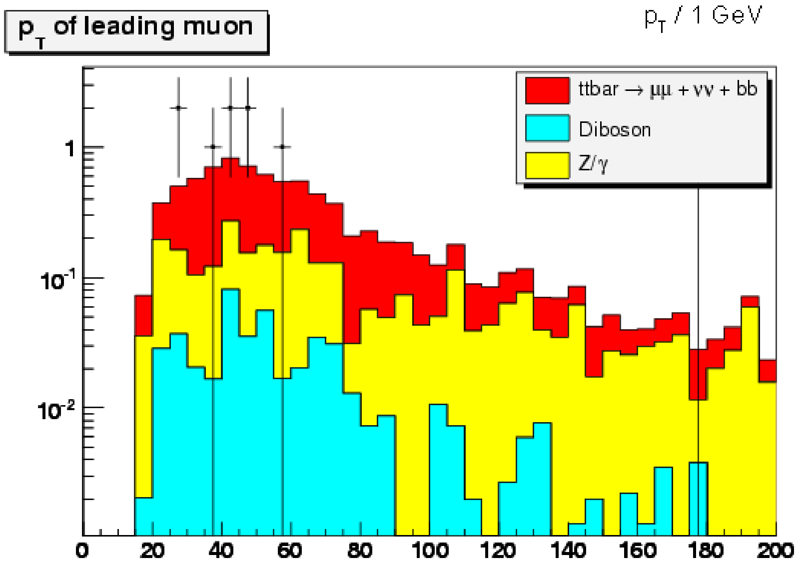
Electron-Muon Selection

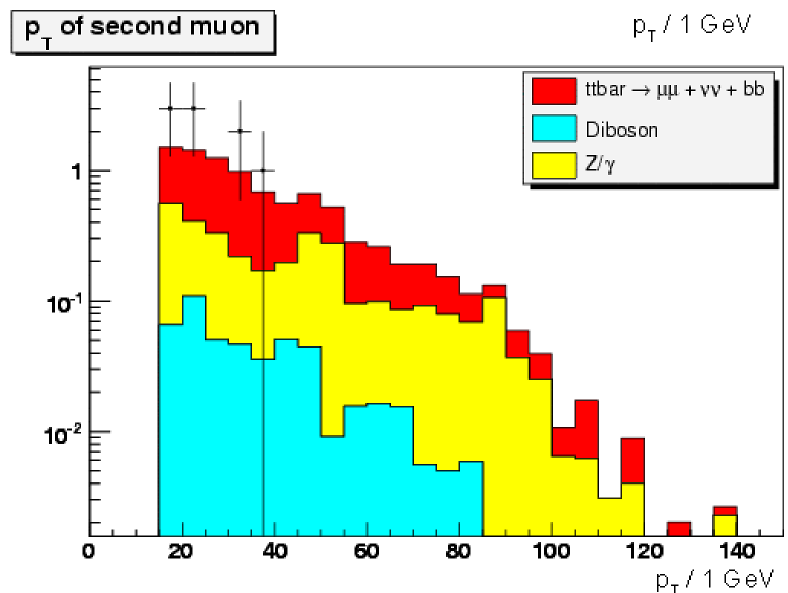
- Luminosity: 1.04 fb^{-1}
- Analysis cuts:
  - Exactly one loose electron
  - ≥ 1 medium muon
  - No common track between the electron and any loose trtack matched muons
  - ≥ 2 jets
  - ΔR(selected e, jet)>0.5 and ΔR(selected μ, jet)>0.5
  - $H_T = p_T$(leading lepton) + p_T (2 leading jets) > 115
- Trigger: Oring of e triggers + matching online/offline objects; Signal Efficiency ≈ 86%

After All Cuts









After All Cuts