UNIVERSITY OF ROCHESTER

Measurement of the $t\bar{t}$ Production Cross Section in the Lepton+Jets Channel Using Kinematic Information at DØ

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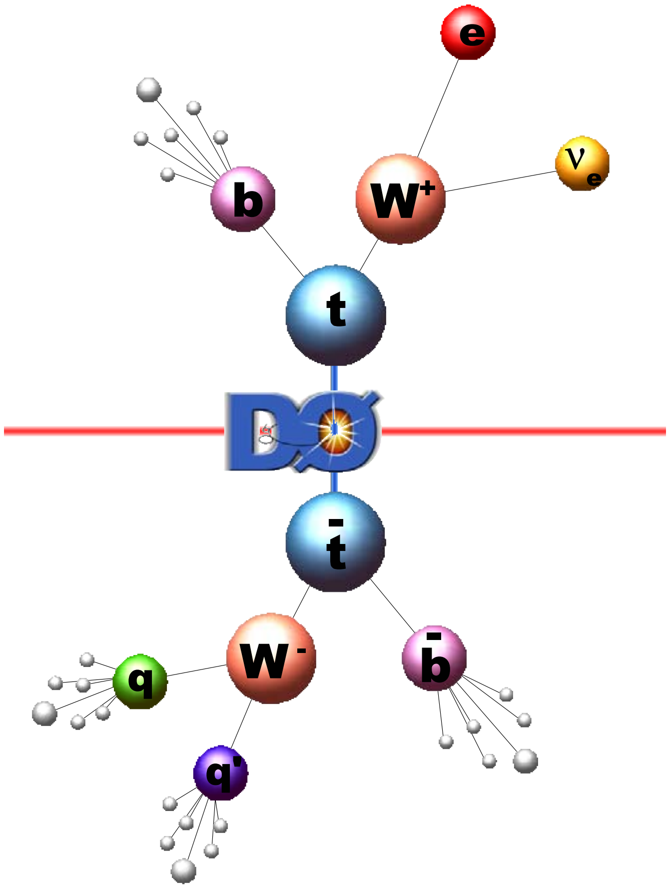
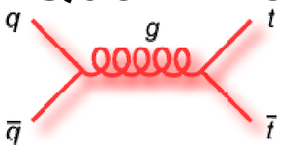
Overview

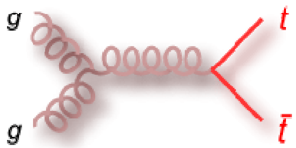


- Top Quark Production and Decay
- Signature and Preselection
- Main Background

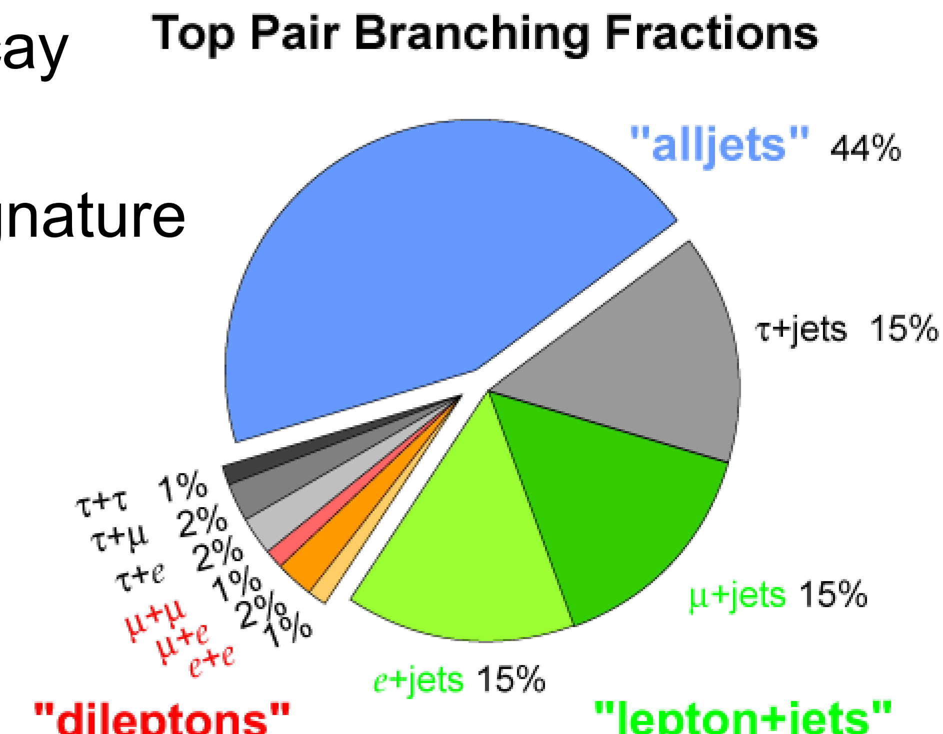
- Analysis Overview
- QCD Multijet Background
- Topological Likelihood
- Cross Section

Top Quark Production and Decay

- Top Quark Pair Production at the Tevatron ($\sqrt{s}$ = 1.96 TeV)
  - 

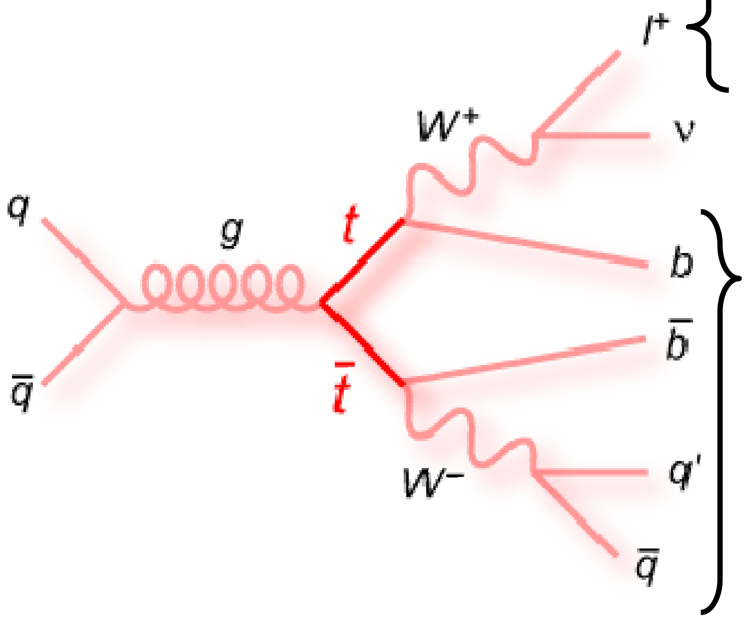
    85% $q\bar{q}$ annihilation
  - 

    15% gluon fusion
- Standard Model top quark decay ≈100% Wb
- W decay mode determines signature
- Dilepton channel:
  2 leptons, 2 neutrinos, 2 jets
- Lepton+Jets channel:
  1 lepton, 1 neutrino, 4 jets
- All-jets channel:
  6 jets



Signature and Preselection

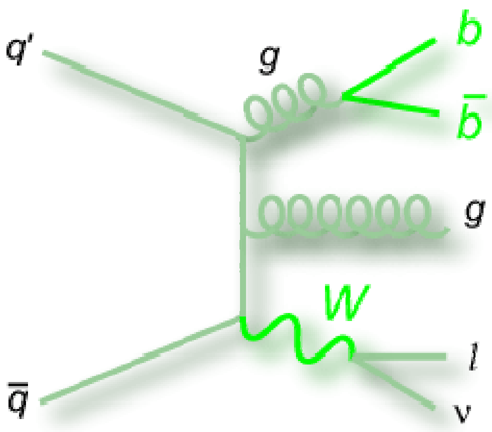
Lepton+Jets:

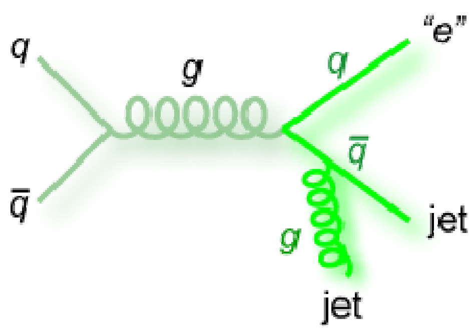


- Primary Vertex: ≥3 tracks, |z|<60cm, Δz(PV,lepton)<1cm
- Lepton with track match, p_T>20 GeV, electron in |η|<1.1 or muon in |η|<2, ΔR(jet,μ)<0.5
- Missing transverse energy > 20 GeV
- ≥4 jets in |η|<2.5, p_T > 20 GeV
- For orthogonality to other analyses: veto against isolated e/μ, 2nd lepton

- Reconstruction and identification of:
  - Electrons, muons, (taus)
  - Jets, but no b-tagging
  - Missing transverse energy
  - Primary vertex

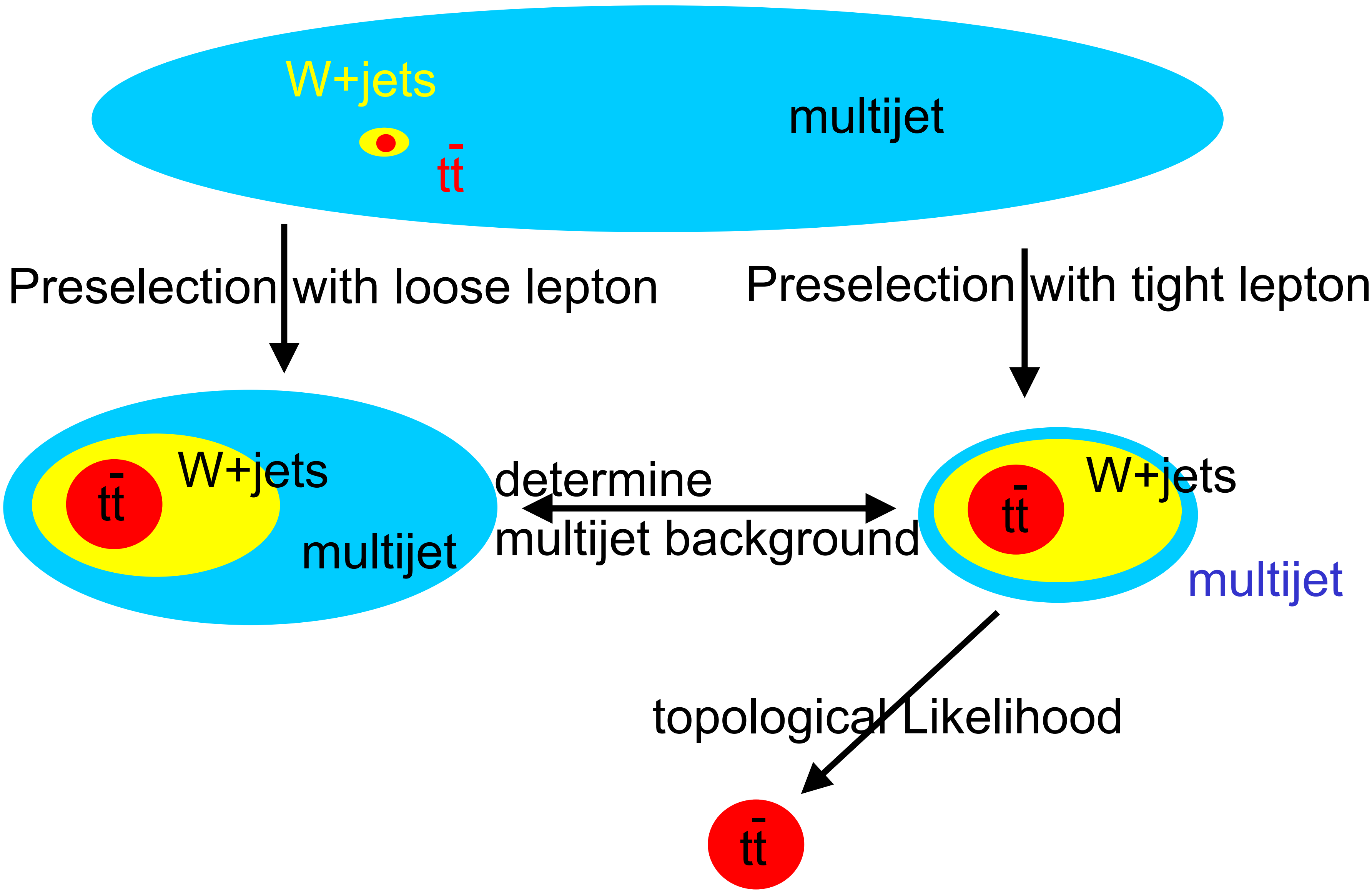
Main Background





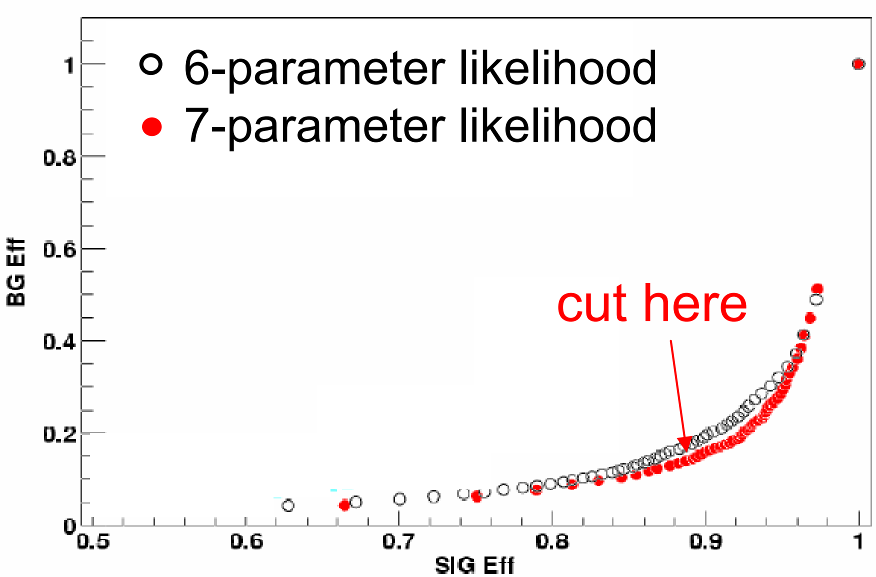
- Physics Background W+jets:
  - Electroweak W production with jets from radiated gluons
  - Use kinematic/topological differences to $t\bar{t}$ signal
- Instrumental Background "multijet":
  - QCD multijet production with misidentified lepton & missing E_T (MET)
  - Misidentified electron from electromagnetic jet
  - Isolated muons from semileptonic b-decays with jet not reconstructed or far enough away
- MET from misreconstructed calorimeter energy
- Require high quality leptons

Analysis Overview

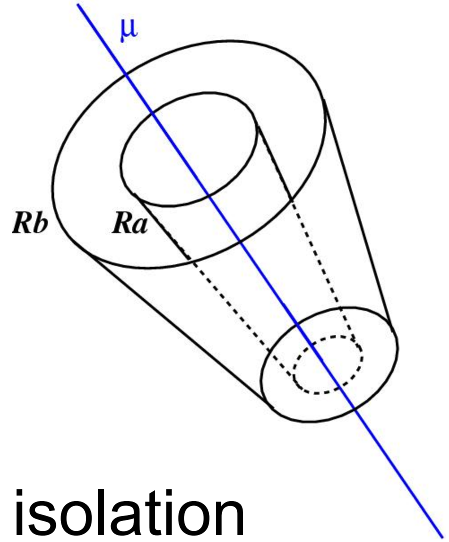


Tight Lepton Cut

- Electrons
- 7-parameter Likelihood:
  - EM fraction
  - $E_T^{calorimeter}/p_T^{track}$
  - Track match probability
  - Shower shape and more

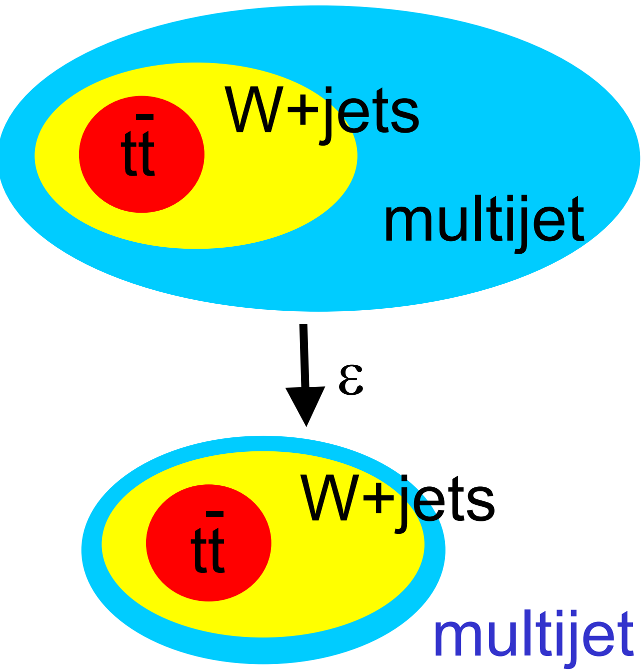


- Muons
- Isolation variables
  - Calorimeter isolation (sum of calorimeter E_T in hollow cone / p_T of muon)



  - Track isolation (sum of track p_T in cone w/o muon track / p_T of muon)

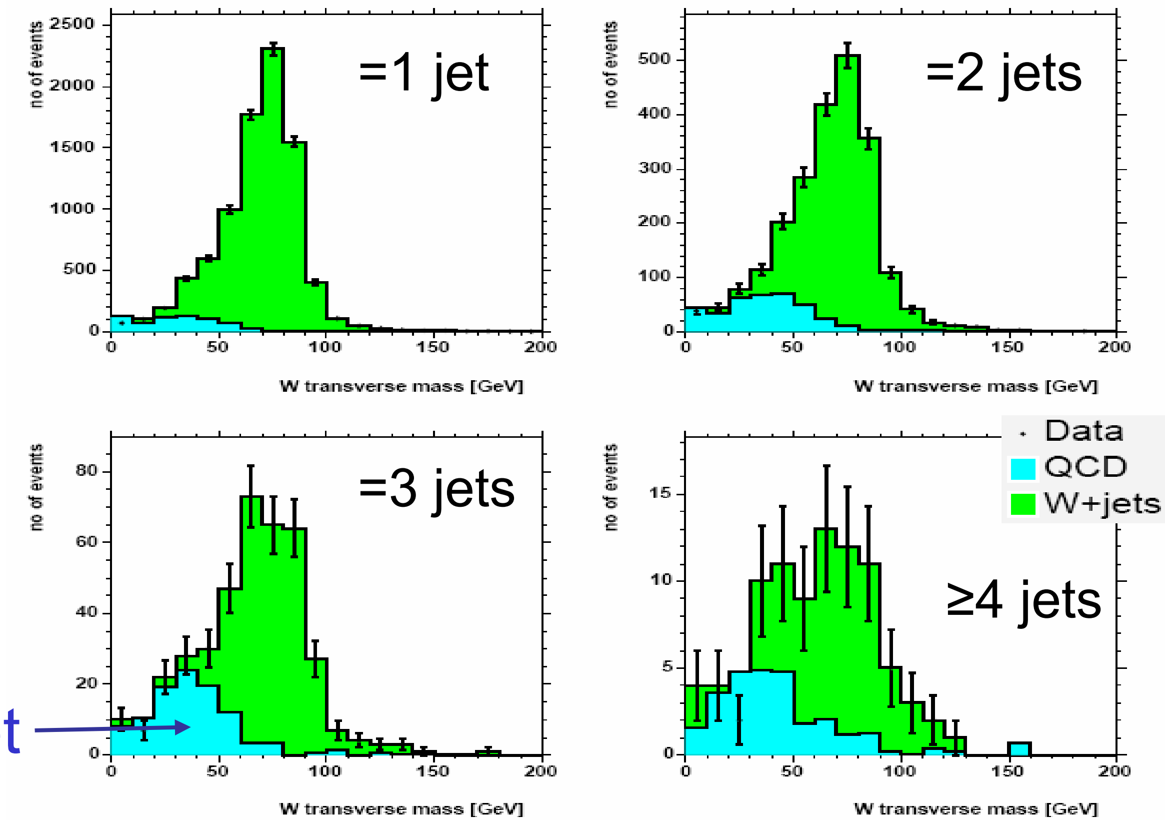
QCD Multijet Background



$$N_{loose} = N^{W+tt} + N^{QCD}$$

$$N_{tight} = \varepsilon_{W+tt} N^{W+tt} + \varepsilon_{QCD} N^{QCD}$$

$\varepsilon_{W+tt} \approx 85\%$, $\varepsilon_{QCD} \approx 10\text{-}16\%$ (from data)

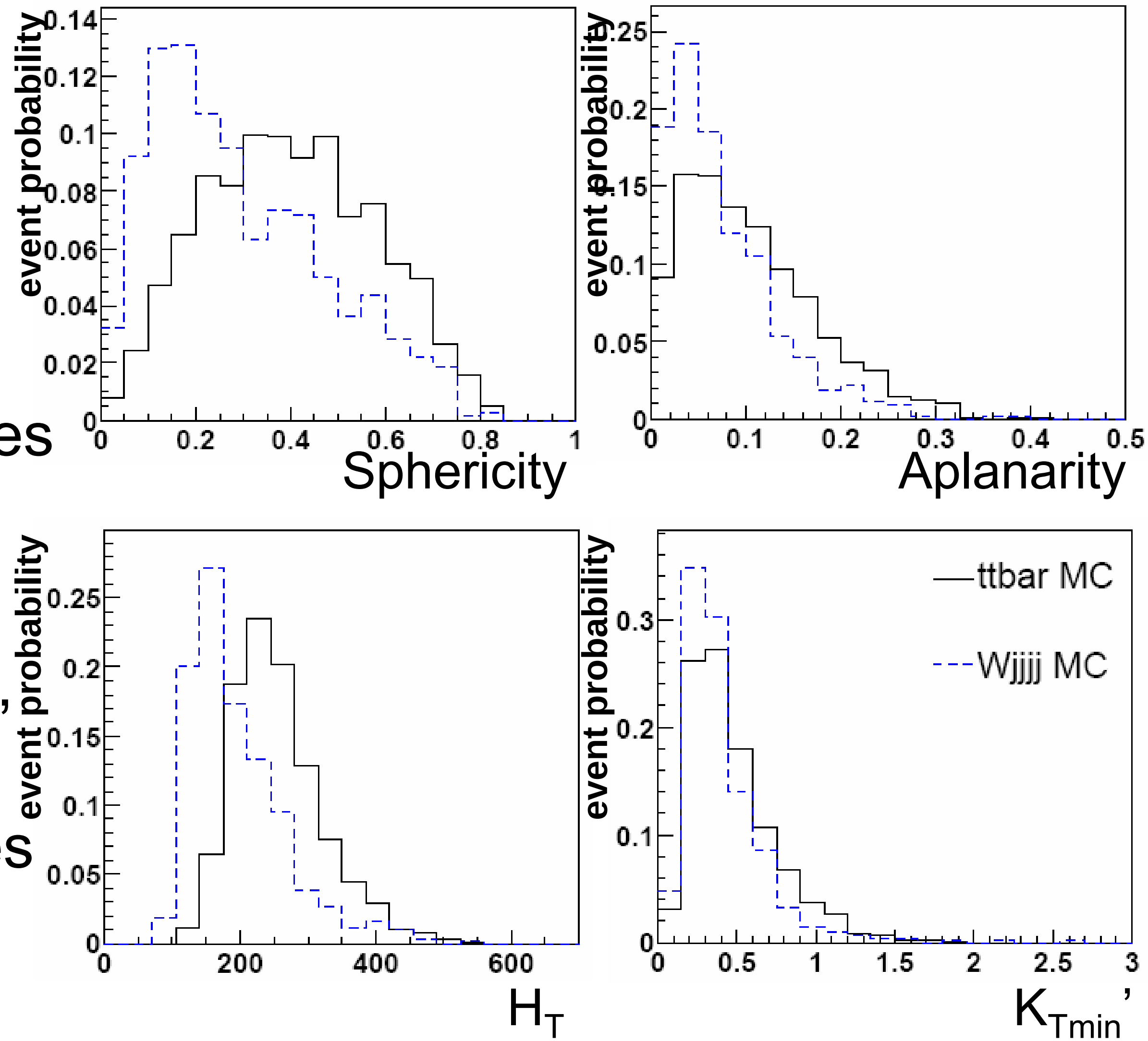


=> Reconstructed transverse W mass after tight preselection for different jet multiplicities

multijet

Topological Variables

- Choice of topological variables by:
- Good discrimination power
- Low sensitivity to systematic uncertainties
- Six variables chosen:
- Angular properties (Sphericity, Aplanarity, $\Delta\phi$(MET, lepton))
- Energy (ratio) variables (H_T, K_{Tmin}', Centrality)

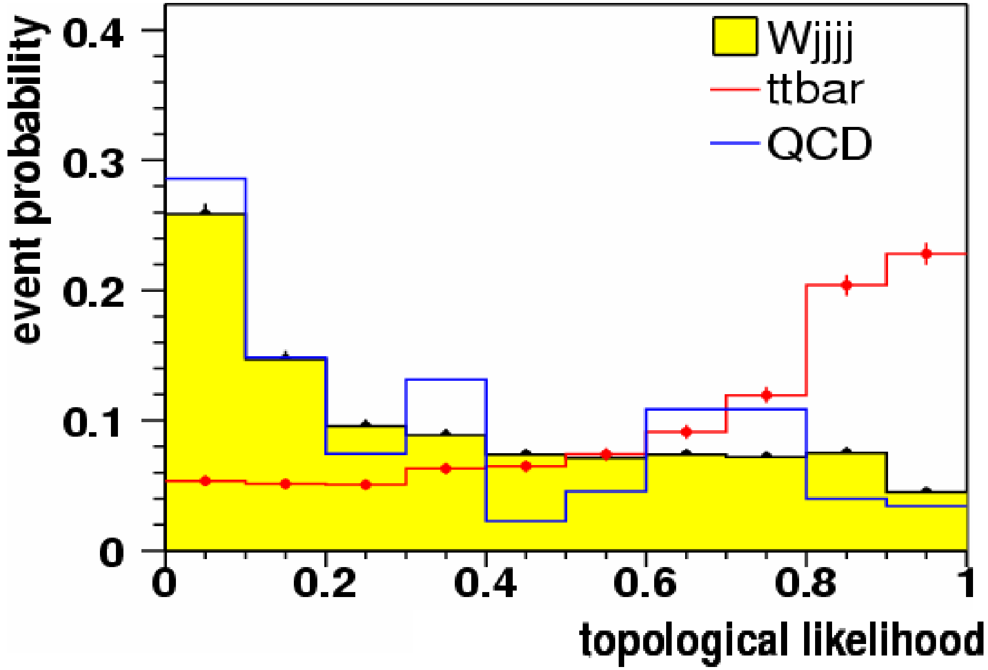


Topological Likelihood

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

S_i = $t\bar{t}$ signal
B_i = W+jets background
i = 1…6 runs over topological variables

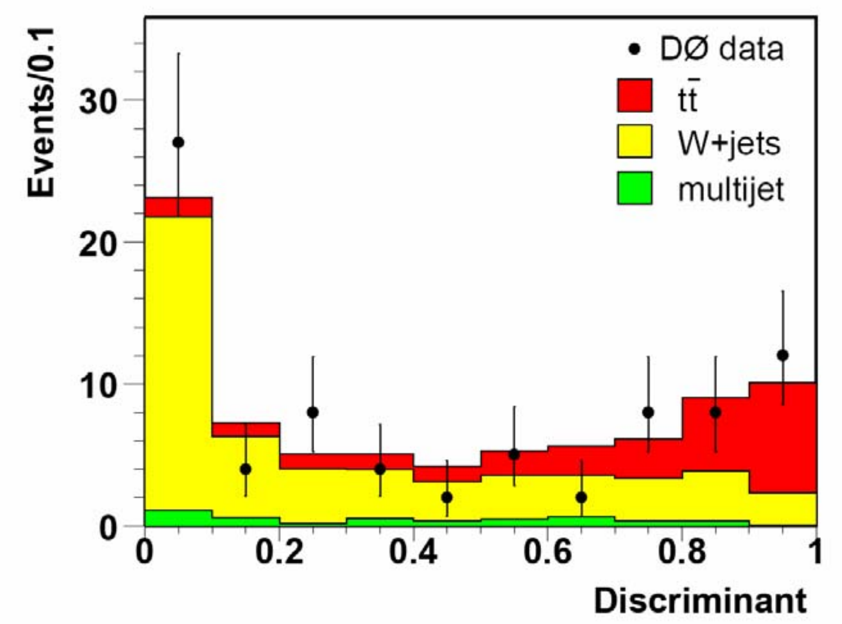
- Topological Likelihood after tight preselection:
  - QCD multijet data (inverted tight selection)
  - W+jets Monte Carlo
  - $t\bar{t}$ Monte Carlo



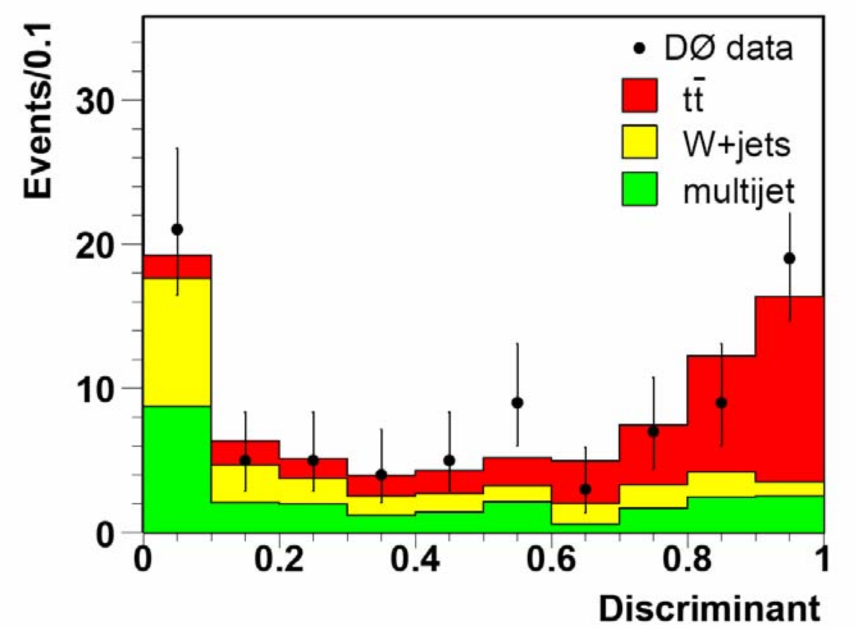
Topological Likelihood Fit

- Fit to the data with a linear combination of $t\bar{t}$, W+jets, multijet
- Multijet contribution constrained by system of linear equations with tight and loose preselection
- Fit gives N_{tt}

μ+jets: 229 pb^{-1}



e+jets: 226 pb^{-1}



Cross Section

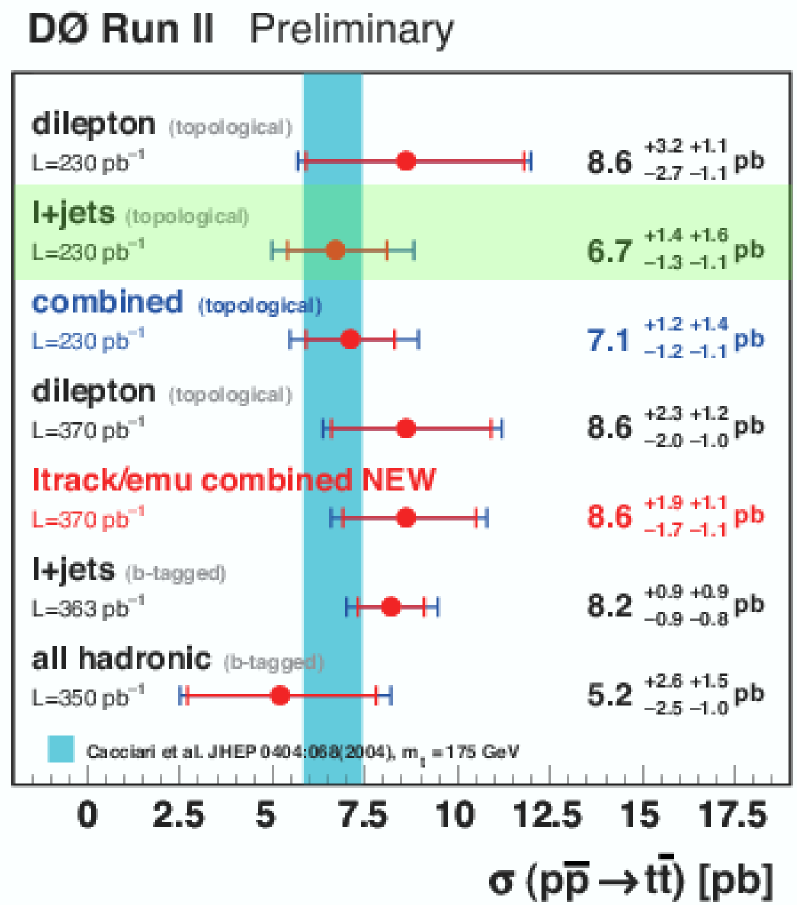
$$\sigma_{p\bar{p}\to t\bar{t}+X} = \frac{N_{t\bar{t}}}{Br \cdot L \cdot \varepsilon_{presel}}$$

Br = Branching ratio
L = Integrated luminosity
ε_{presel} = Preselection efficiency

Result:

$$\sigma_{t\bar{t}} = 6.7^{+1.4}_{-1.3}(\mathrm{stat})^{+1.6}_{-1.1}(\mathrm{syst}) \pm 0.4(\mathrm{lumi})\ \mathrm{pb}$$

Physics Letters B 626 (2005) 45–54



Theoretical cross section:

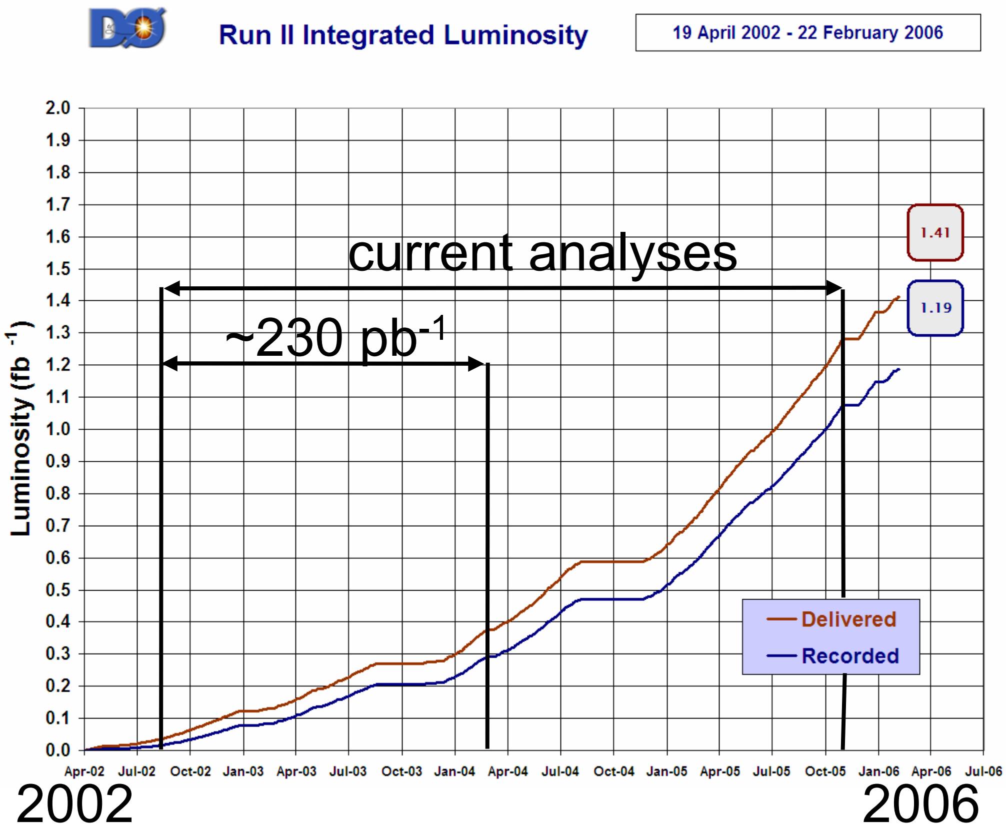
$$\sigma_{t\bar{t}} = 6.70^{+0.71}_{-0.88}\ pb$$

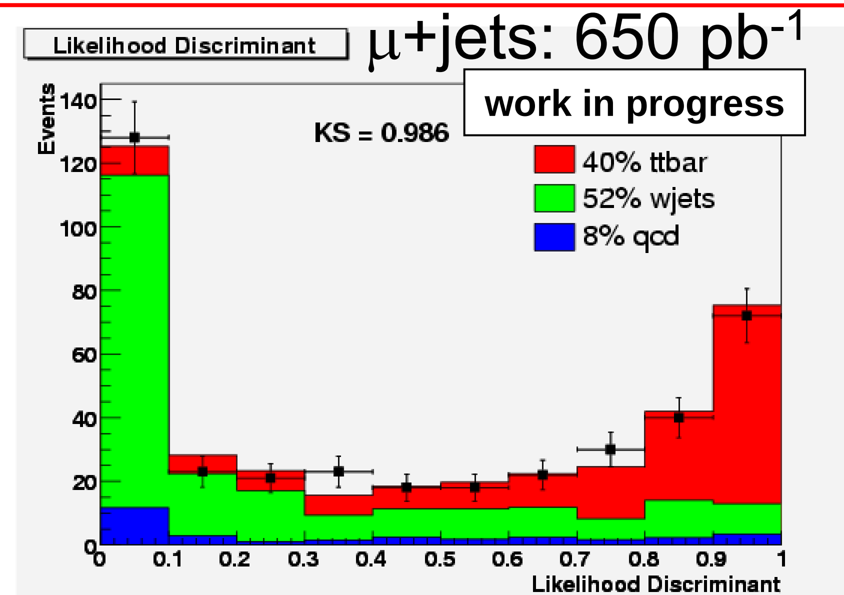
Cacciari et. al. JHEP 404, 68 (2004), m_t=175GeV

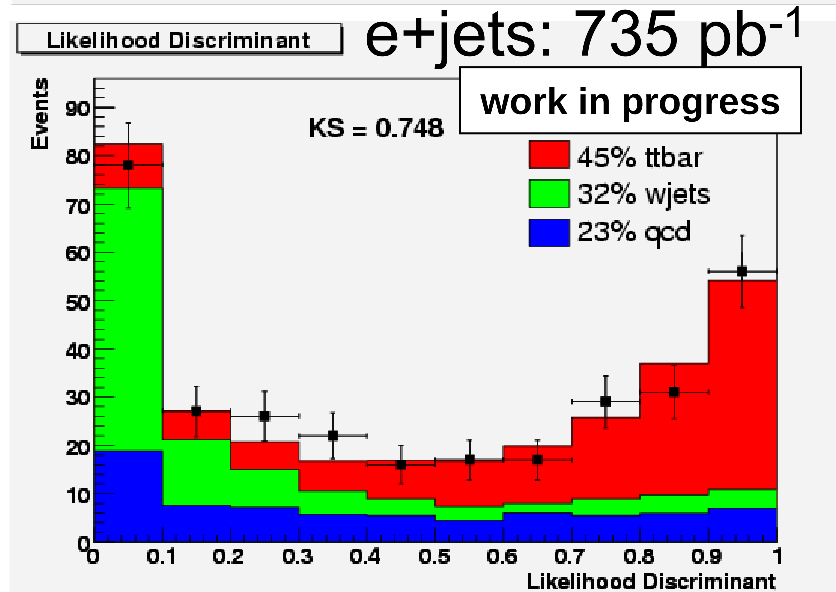
- Cross Section agrees with Standard Model prediction
- Systematic uncertainty mainly due to Jet Energy Scale (JES)

Outlook

- Three times bigger dataset
- Improved calibration, vertexing
- Three times better JES
- First look:





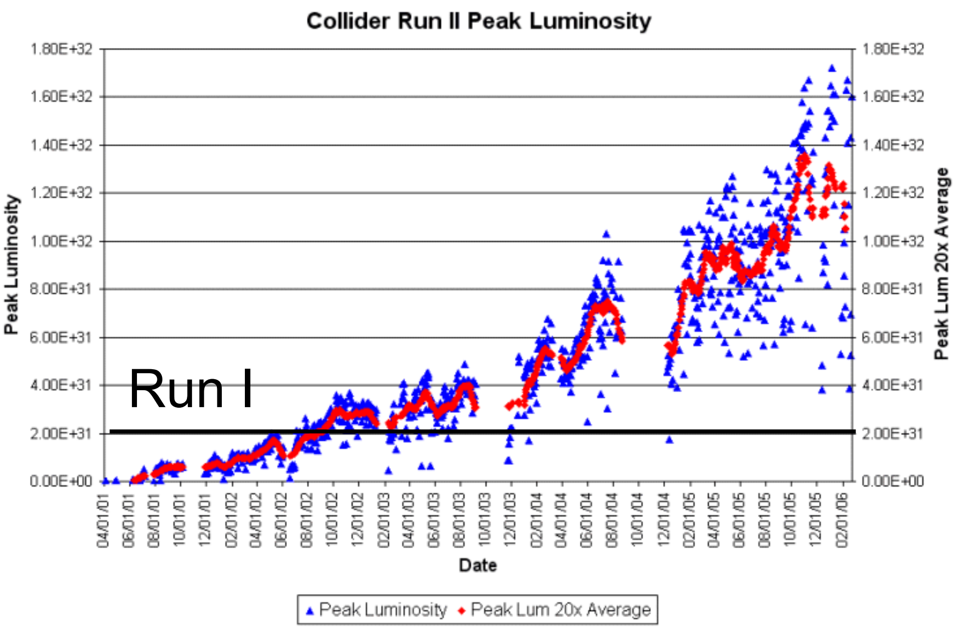


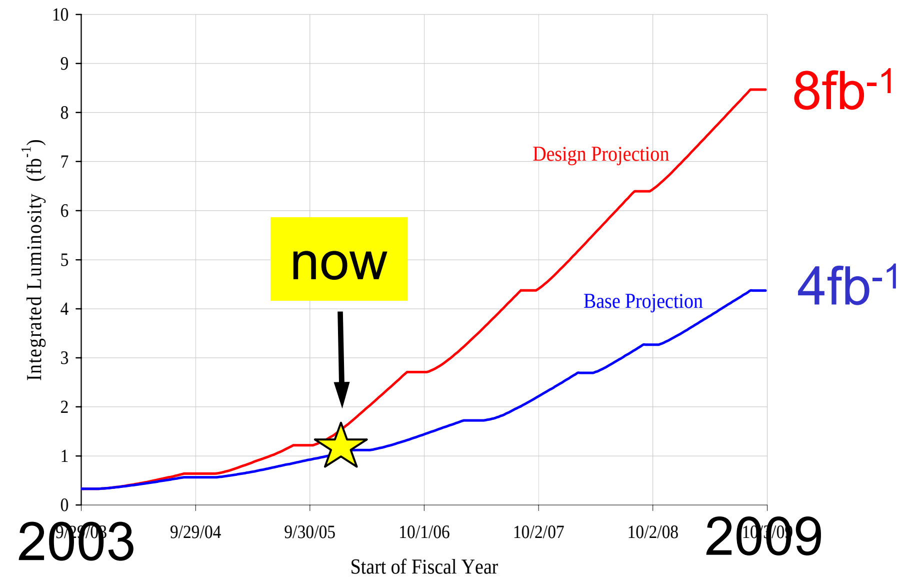
BACKUP SLIDES

Tevatron at Fermilab

- $p\bar{p}$ collisions at $\sqrt{s}$ =1.96TeV (Run I: 1.8TeV)
- 36 bunches (396 ns spacing)
- Linac upgrade
- Main Injector (150 GeV proton storage ring)
- Further improvements:
  - Antiproton "recycler" (begin June 2004)
  - Electron cooling (begin 2005)

Luminosity





Peak luminosity:

- 8 times higher than Run I
- 5 times higher than April 2003
- Exceeded Run IIa goal of 100E30 $cm^{-2}s^{-1}$

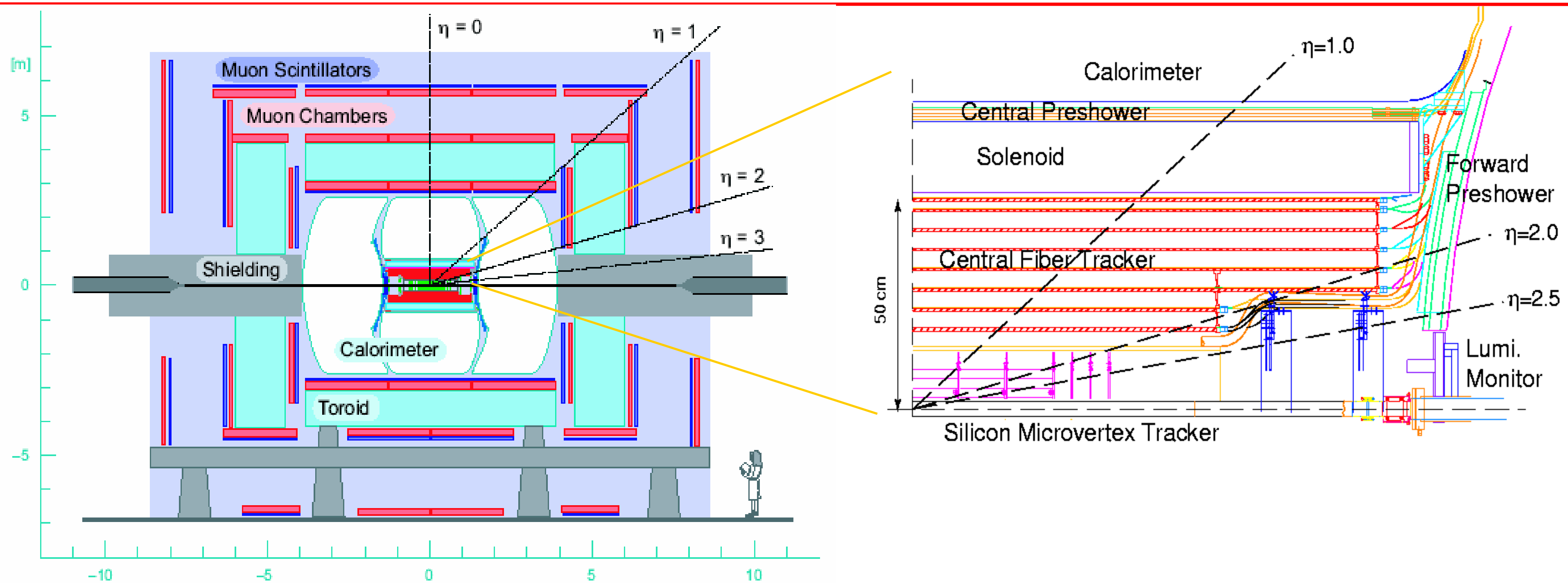
Tevatron will run until 2009(?)

- Base line: 4 fb^{-1}
- Design: 8 fb^{-1}

DØ Collaboration

- 20 Countries (Europe, Asia, North-, Central- and South-America)
- 92 Institutes & Laboratories
  - 39 US
  - 53 non-US
- ~ 670 Physicists

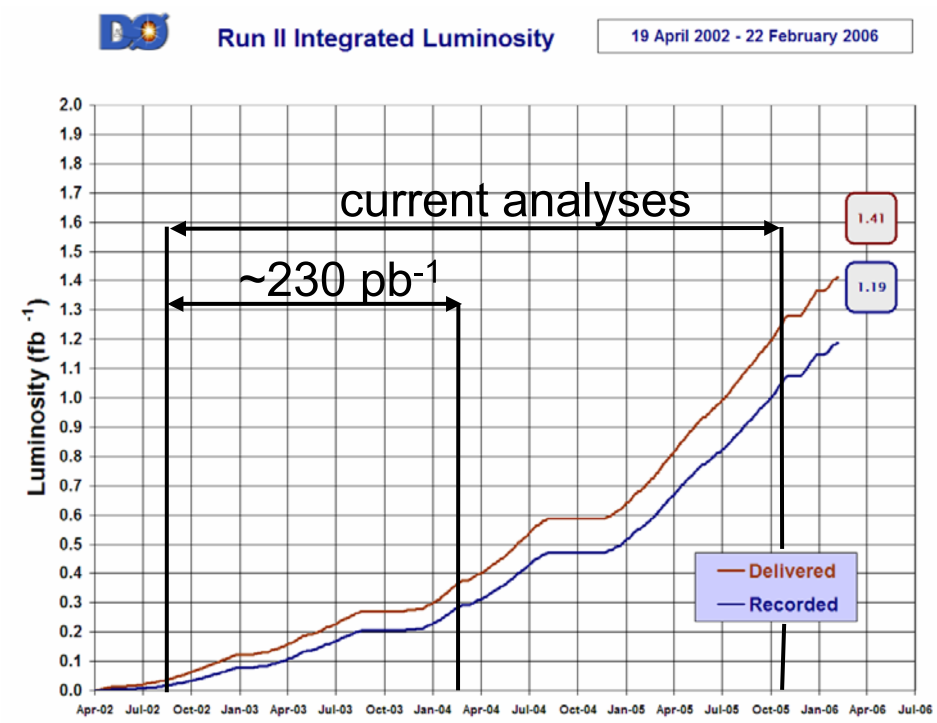
Run IIa DØ Detector

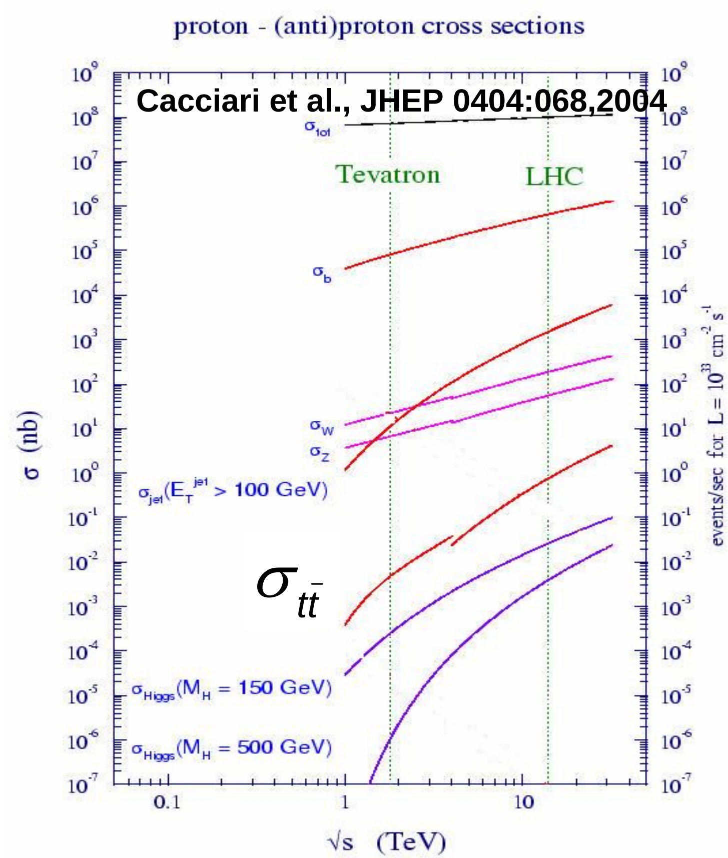


- New tracking system in 2T solenoid
- New forward muon system
- New preshower detectors
- Upgraded electronics, trigger, DAQ
- Improved shielding

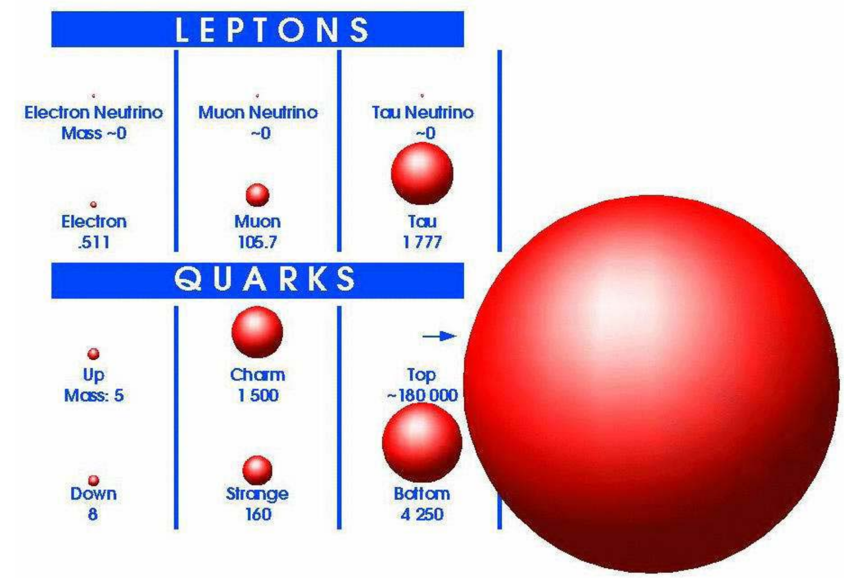
Top Quark Production at Tevatron

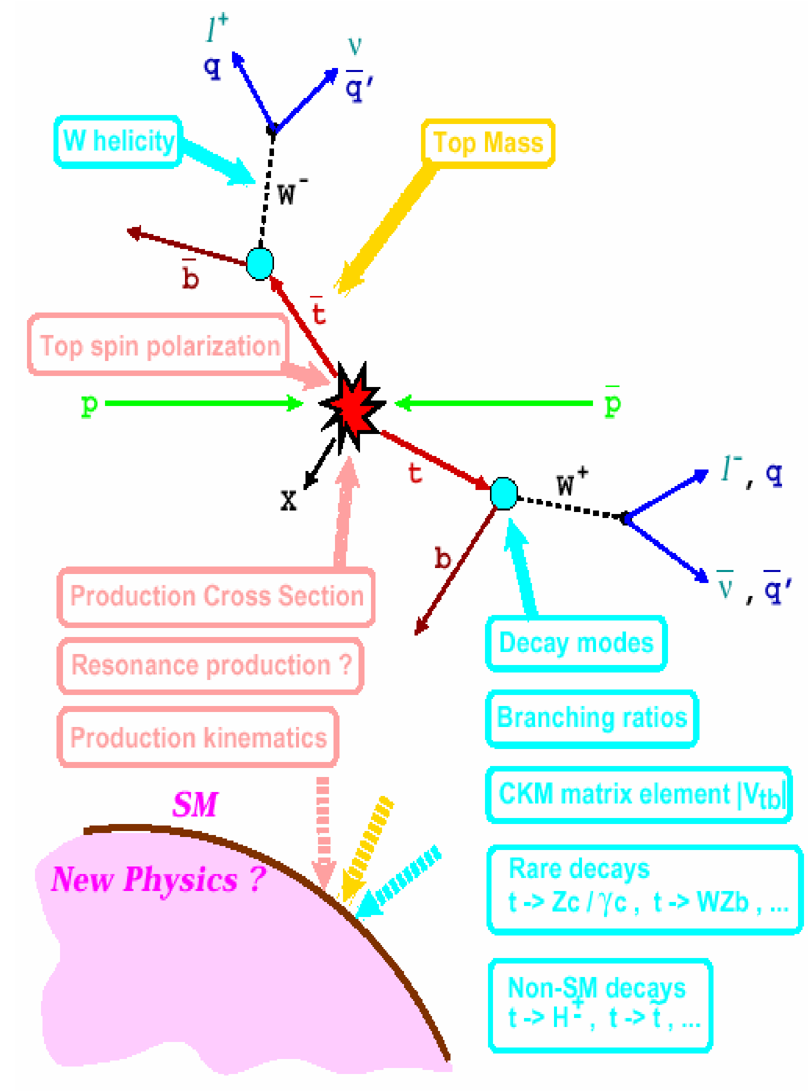
- Tevatron $p\bar{p}$ collider is currently the world's only source of Top Quarks
- Production rate increased wrt. Run I:
  - Increased center of mass energy: 1.8 TeV→1.96 TeV ⇒ +30% $\sigma_{t\bar{t}}$
  - Increased luminosity: Run I ~ 125 pb^{-1},shown here ~ 230 pb^{-1},ongoing : **×3**





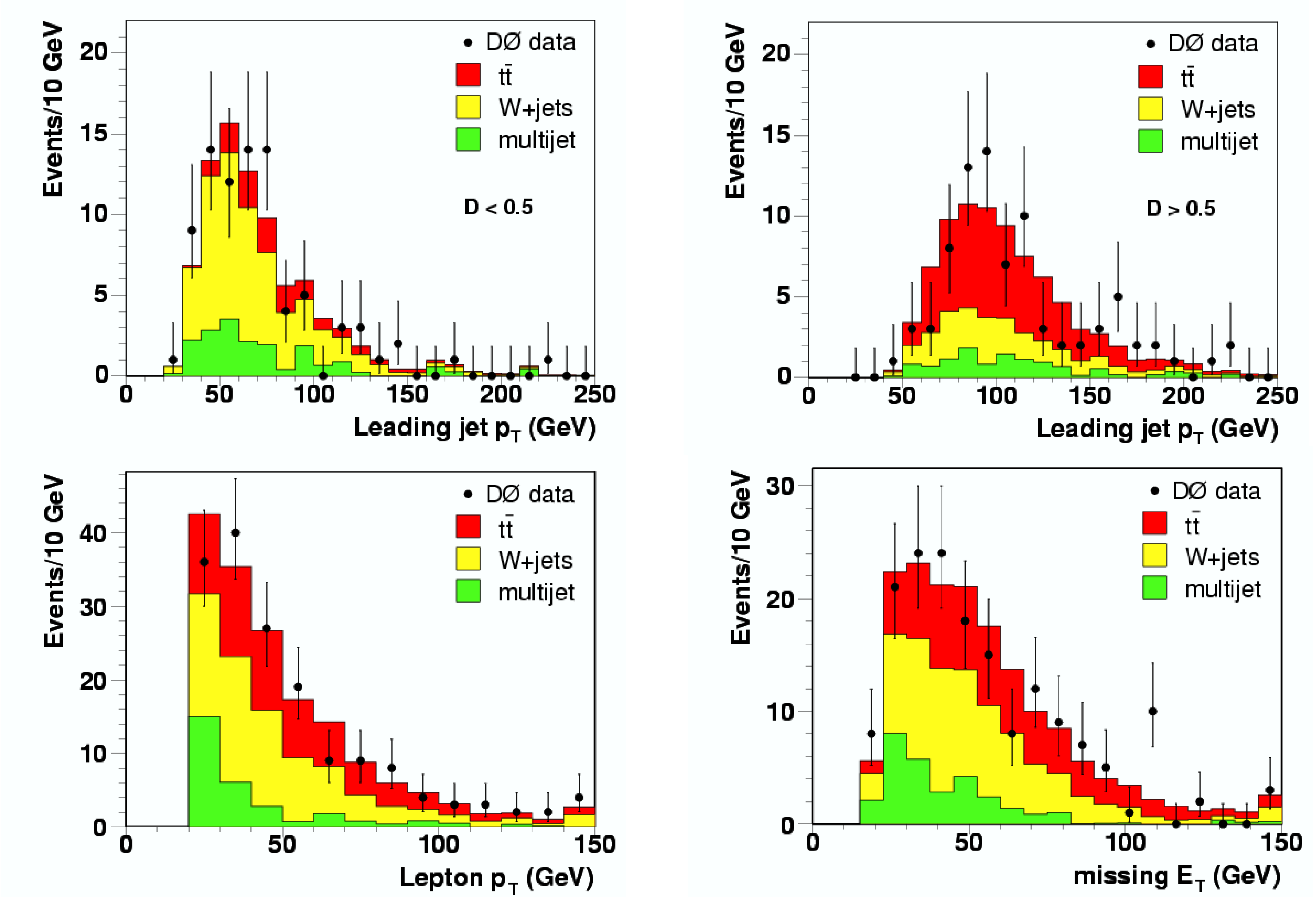
Top Quark in the Standard Model





- Why top?
- Completes Quark Sector
- Large mass: $m_{top} \approx 173$ GeV/c^2
  =>strongest coupling to Higgs
- Short lifetime $t \approx 4 \cdot 10^{-25}$s
  => No hadronisation
- Sensitive to physics beyond the Standard Model

Consistency Checks



Jet Energy Scale

Measured energy in jet cone ≠ parton energy because of fragmentation and detector effects => need calibration (common for all analyses):

1. Correct measured jet energy E^{meas} to energy of particles in jet cone:

$$E^{corr} = \frac{E^{meas} - O}{R \times S}.$$

   - Offset correction (*O*). Remove energy not associated with hard scatter (underlying event, energy pile-up, multiple interactions, calorimeter noise: electronics/uranium). Luminosity dependent, determined from zero/minimum bias events.
   - Showering correction (*S*). Particles inside jet cone can deposit energy outside jet cone (or vice versa) due to showering in calorimeter or magnetic bend.
   - Response correction (*R*).
     - EM scale calibrated using resonances (*Z*, *J/y,* etc.).
     - EM scale transferred to hadron calorimeter using *ET* balance in “g” + jet events. Largest correction and largest contributor to JES systematic error.
2. Additional correction of b jets with semileptonic decay to muons: correct for muon (MIP) energy and neutrino energy
3. Parton level correction: correct particle jet energy to parton energy. Purely MC based.

Topological Variables

Normalised momentum tensor $M_{ij} = \frac{\sum_n p_n^i p_n^j}{\sum_n |\vec{p}_n|^2}$ → diagonalise → Eigenvalues: $\lambda_1 \geq \lambda_2 \geq \lambda_3$

$\lambda_1 + \lambda_2 + \lambda_3 = 1$

- Sphericity: $S = 3/2\,(\lambda_2+\lambda_3) \approx$ summed p^2_T wrt. event axis
  - Dijet event has $S \approx 0$, isotropic event (ttbar) has $S \approx 1$
- Aplanarity: $A = 3/2\,\lambda_3$ = departure from planarity of event
  - Large values indicate spherical events
- $\Delta\varphi$(MET, lepton): azimuthal opening angle
- H_T: scalar sum of the p_T of the four leading jets
- K_{Tmin}': measure of minimum jet p_T relative to another
  - Normalised by $E_T^W = E_T^{lepton} + \not{E}_T$ to reduce JES dependence
  - Tends to be small for soft & collinear backgrounds
- Centrality: H_T/H, H = scalar sum of energies of four leading jets

$t\bar{t} \rightarrow \mu$+Jets Candidate Event