# Measurements of Top Quarks Produced in Pairs at DØ

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on behalf of the DØ Collaboration

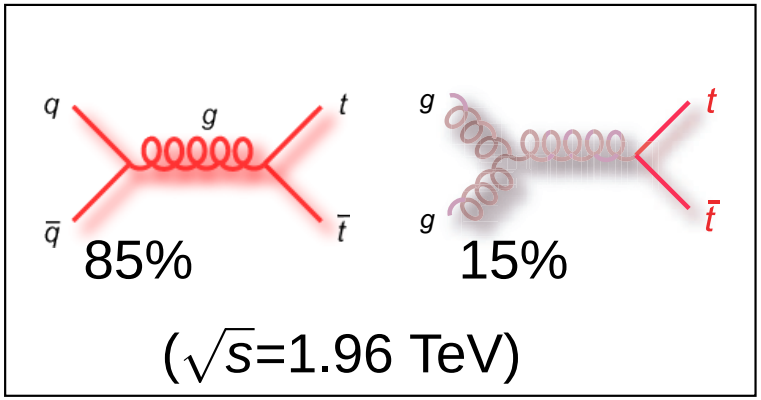
Lake Louise Winter Institute, 2007

# Outline

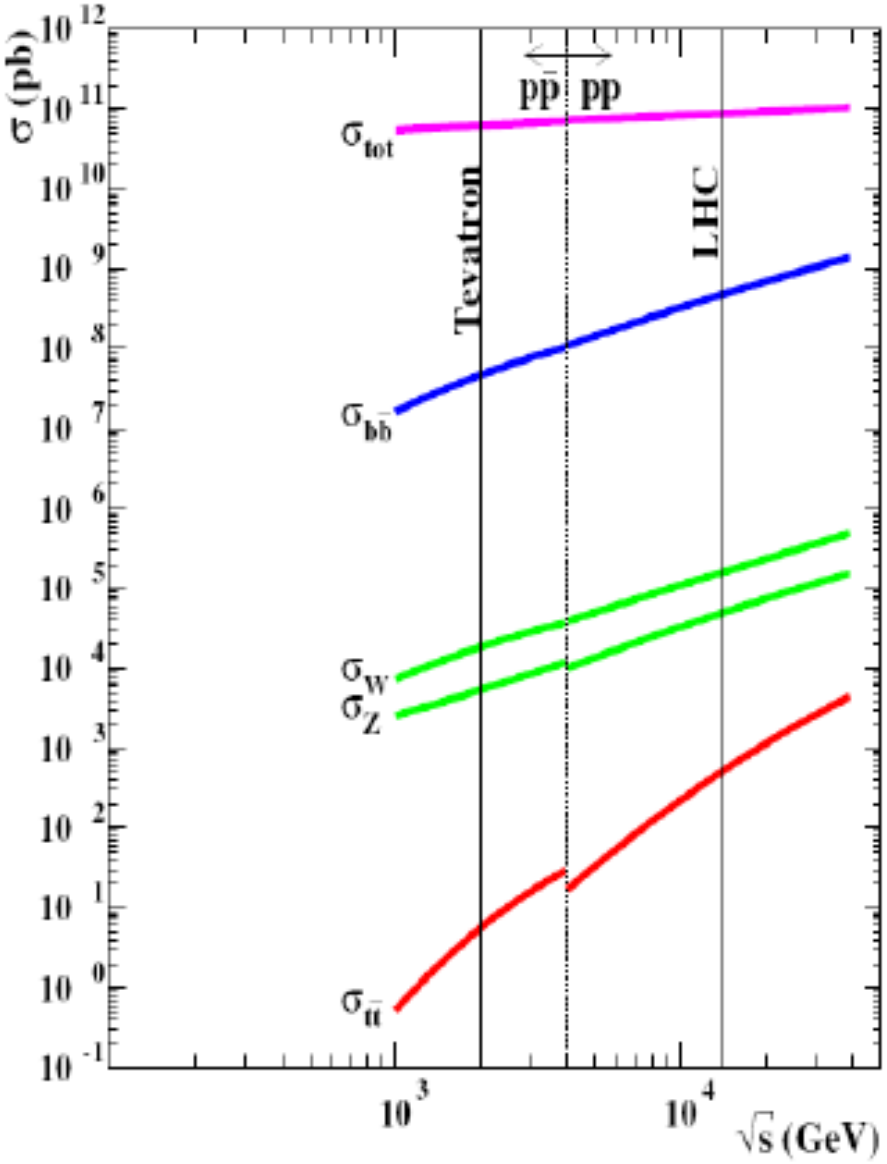

1. Top Quark Physics
2. Measured Properties
3. Cross-section Measurements
4. Mass Measurements

# Top Quark Production

- Production via strong interaction:

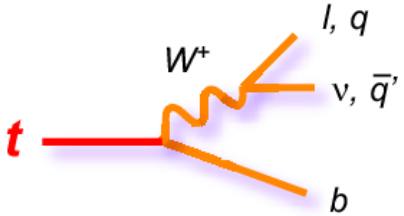



- 6.8 pb ($m_t$=175 GeV$/c^2$) [Kidonakis *et al.*, JHEP 0404:068, 2004]
- 2.05 fb$^{-1}$ recorded as of 2/4/07



# Top Quark Decay Channels

$\mathcal{BR} \sim 1$

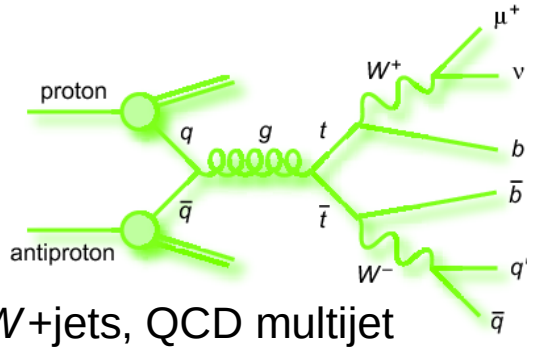



- $W$ decays either leptonically or hadronically
- $t$ decay channels classified accordingly

| W decay | $e^+$ | $\mu^+$ | $\tau^+$ | $u\bar{d}$ | $c\bar{s}$ |
|---|---|---|---|---|---|
| $e^-$ | ee | eμ | eτ | electron+jets | |
| $\mu^-$ | eμ | μμ | μτ | muon+jets | |
| $\tau^-$ | eτ | μτ | ττ | tau+jets | |
| $\bar{u}d$ | electron+jets | muon+jets | tau+jets | all-hadronic | |
| $\bar{c}s$ | | | | | |

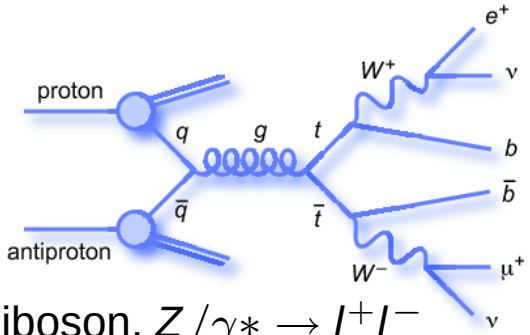
dileptons

1 isolated lepton **LEPTON+JETS**
4 energetic jets (2 from $b$-quarks)
1 $\nu \rightarrow$ missing transverse energy




*Backgrounds:* $W$+jets, QCD multijet

2 isolated leptons **DILEPTON**
2 energetic $b$-jets
2 $\nu \rightarrow$ missing transverse energy




*Backgrounds:* diboson, $Z/\gamma* \rightarrow l^+l^-$

# various properties, lepton+jets, 370 $pb^{-1}$

## $W$ helicity

$f_+$ = 0.056 $\pm$ 0.080 (stat) $\pm$ 0.057 (syst)
(SM prediction $f_+ = 3.6 \times 10^{-4}$)

*PRD* **75** *031102(R) (2007)*

## top charge

100% charge $4e/3$ excluded at 92% C. L.
$\rho < 0.80$ (90% C. L.); ($\rho$ = *fraction of charge* $4e/3$ *top quarks*)

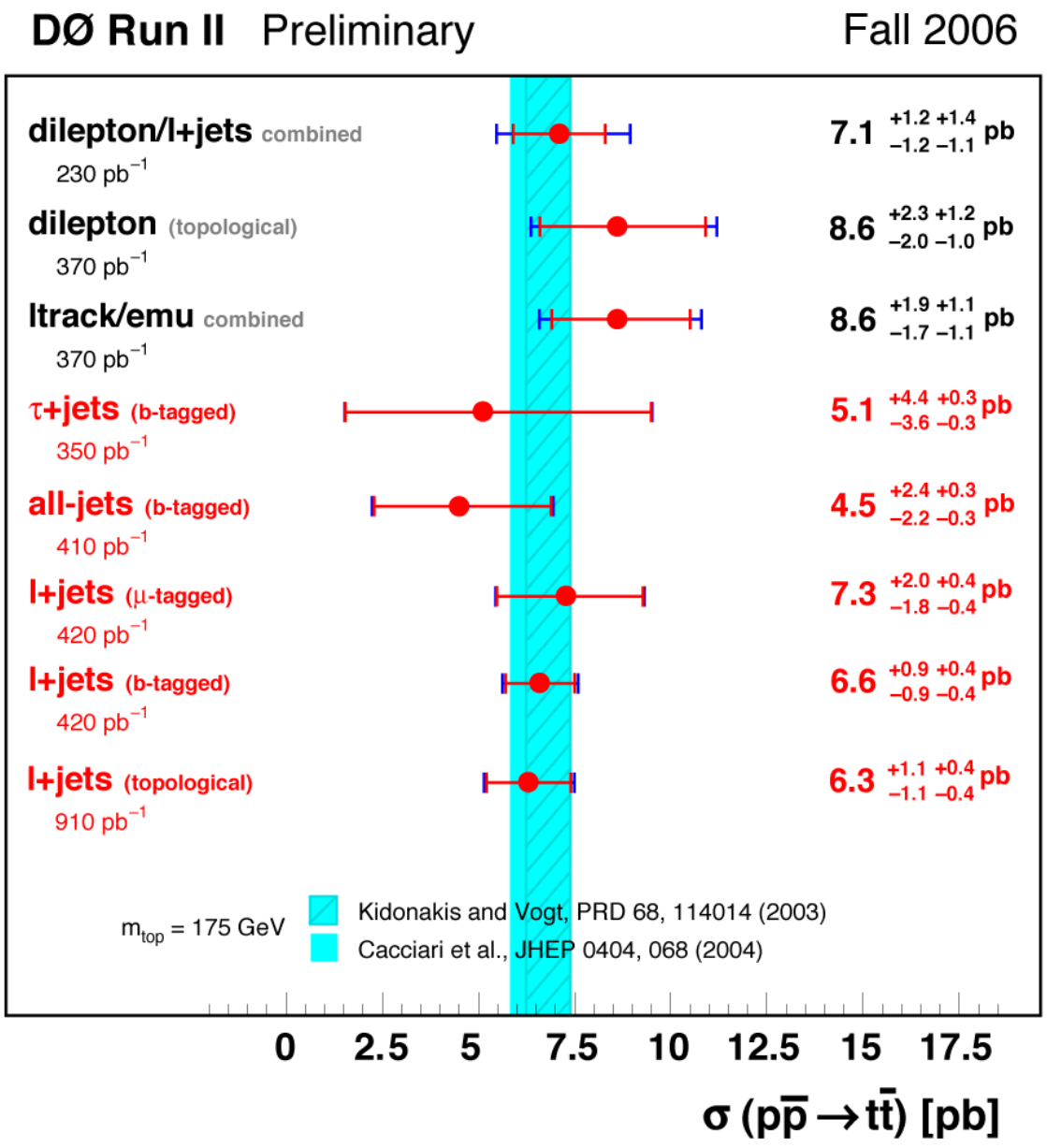
*PRL* **98** *041801 (2007)*

## $R = \mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq)$

$R = 1.03\ ^{+0.19}_{-0.17}$ (stat+syst)

*PLB* **639** *616 (2006)*

# $t\bar{t}$ cross-section measurements



# Lepton+jets, 900 pb$^{-1}$

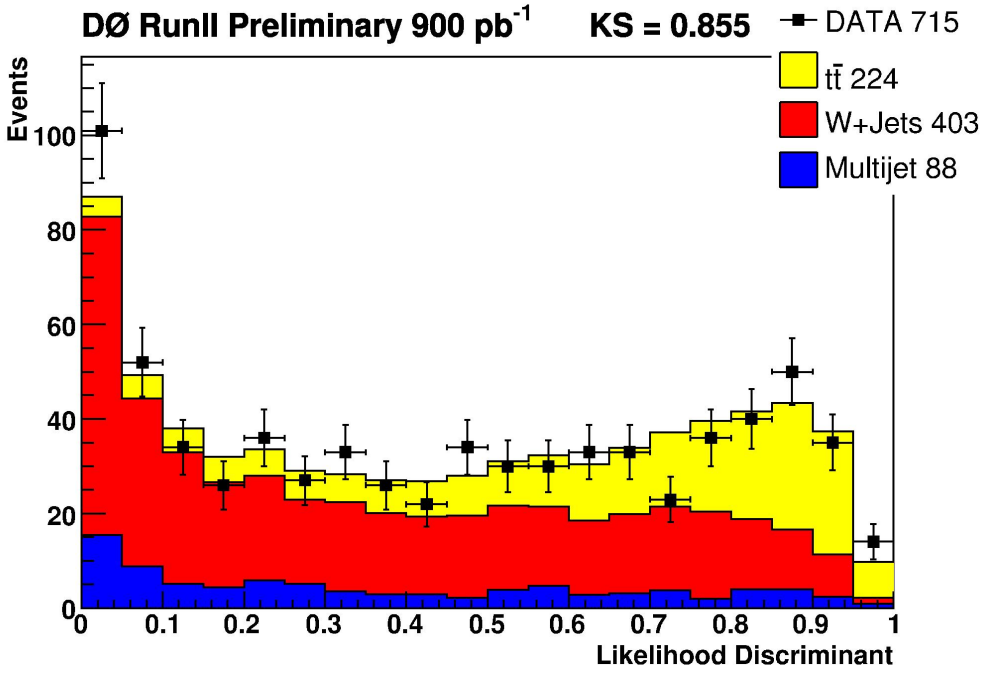
## QCD multijet

- contribution extracted from data

## $W$+jets

topological discriminant:

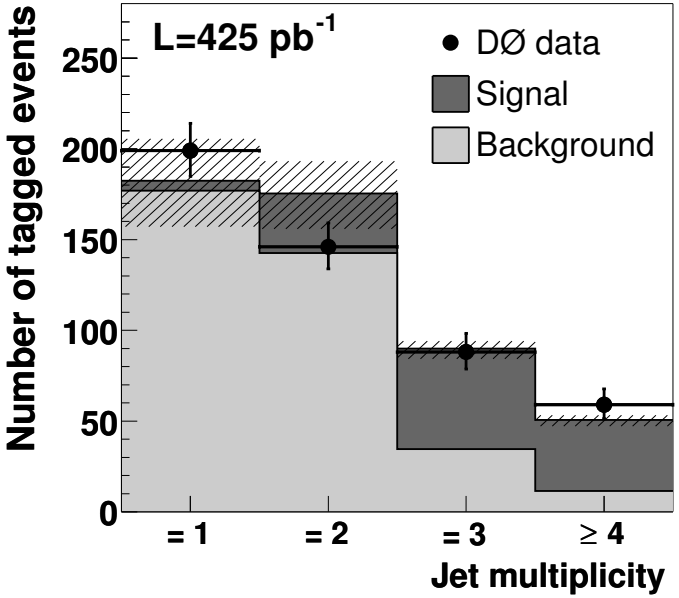
- Centrality
- Aplanarity
- Sphericity
- $H_T$
- $\Delta phi(lep, \not{E}_T)$
- $K_T^{min'}$: measures minimum relative jet $p_T$

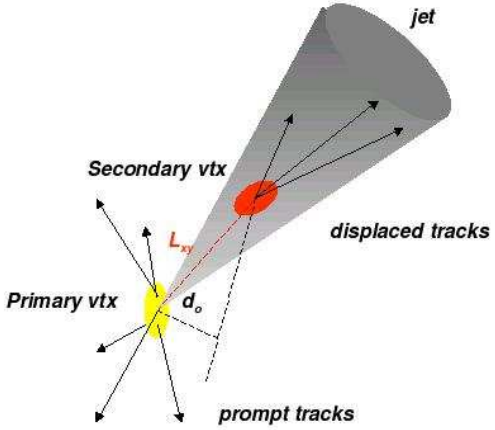



$$\sigma = 6.3\ ^{+0.9}_{-0.8}\ \text{(stat)}\ \pm 0.7\ \text{(syst)}\ \pm 0.4\ \text{(lumi) pb}$$

# Lepton+jets with *b*-tagging, 425 pb$^{-1}$

## Secondary Vertex Tagging



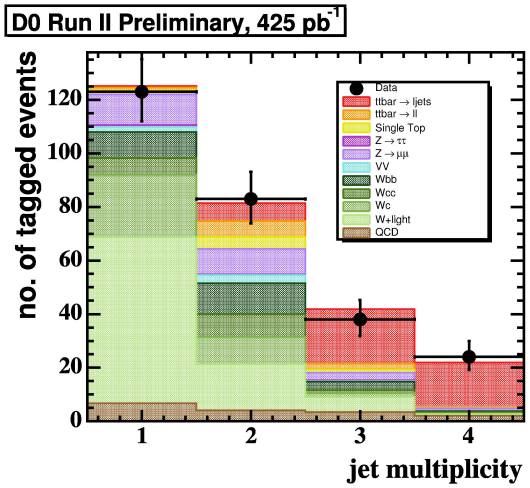




$\sigma = 6.6 \pm 0.9$ (stat + syst) $\pm 0.4$ (lumi) pb

*PRD* **74**, *112004 (2006)*

## Soft $\mu$-tagging

$\sigma = 7.3\ ^{+2.0}_{-1.8}$ (stat + syst) $\pm 0.4$ (lumi) pb

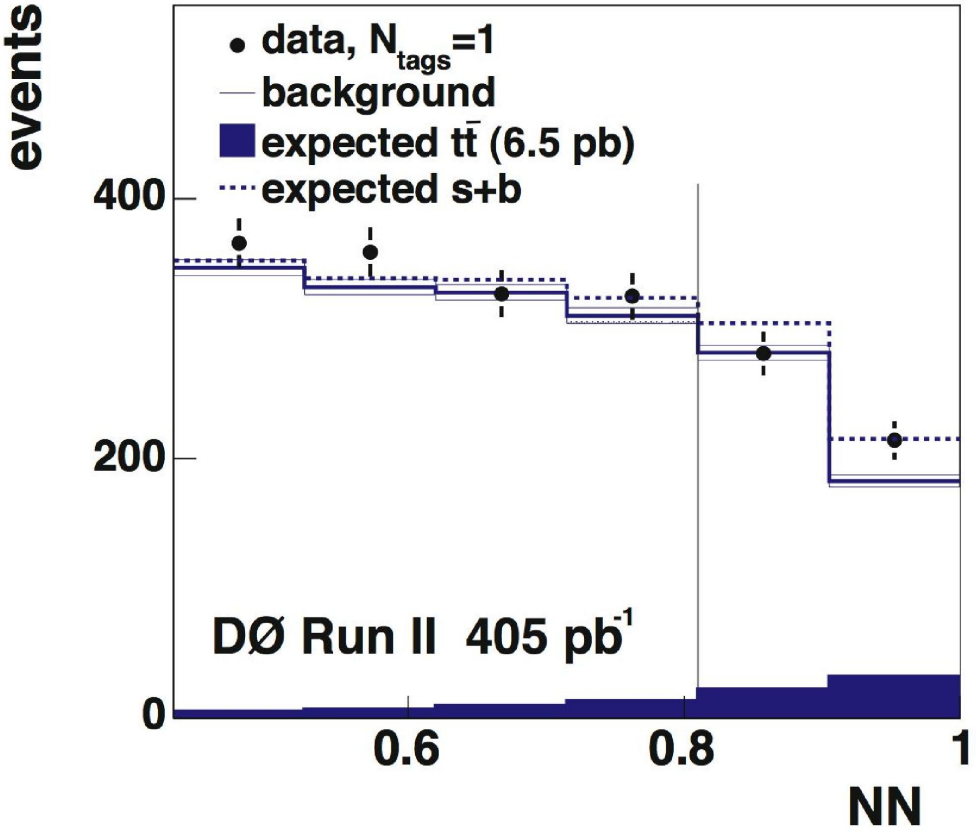


# All jets with SVX *b*-tagging, 400 pb$^{-1}$

single *b*-tagged:

## Background estimation

- Neural network gives discrimination between signal and overwhelming background
- *b*-tagging used on data to parametrize tag rate functions (TRFs)
- QCD multijet extracted from data using TRFs




$$\sigma = 4.5\ ^{+2.0}_{-1.9}\ \text{(stat)}\ ^{+1.4}_{-2.1}\ \text{(syst)}\ \pm 0.3\ \text{(lumi) pb}$$

# $\tau$+jets, 350 pb$^{-1}$

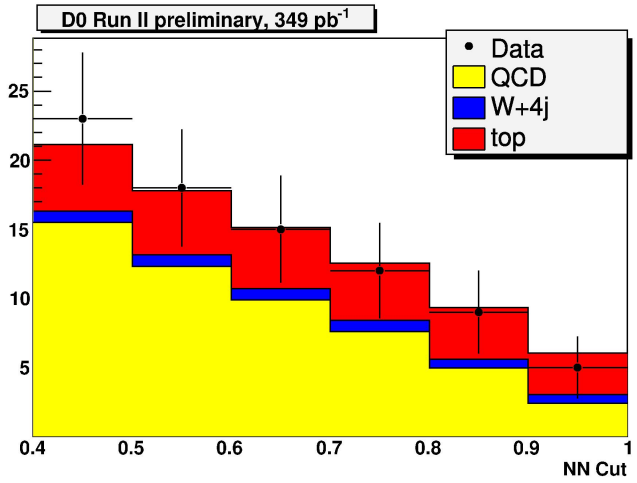
## $\tau$ decay channels

- $\tau \to e\nu_e\nu_\tau$, $\tau \to \mu\nu_\mu\nu_\tau$ ($\mathcal{BR}$=35%)
- $\tau \to \pi^-\nu_\tau$ ($\mathcal{BR}$=12%)
- $\tau \to \rho^-\nu_\tau \to (n\pi^0 + \pi^-)\nu_\tau$ ($\mathcal{BR}$=38%)
- $\tau \to$ 3 charged hadrons + $\geq$ neutral hadrons ($\mathcal{BR}$=15%)

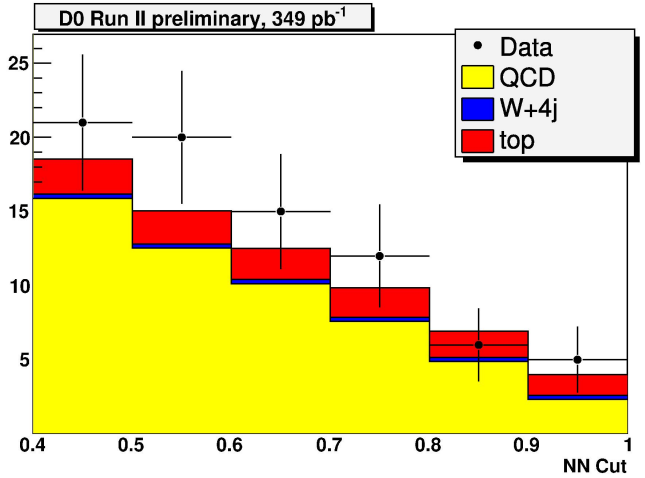
- leptonic $\tau$-decays not used
- Neural network ($\geq$ 0.9) used to select $\tau$ for 3 types of decays
- At least 1 $b$-tagged jet

$$\sigma = 5.1\ ^{+4.3}_{-3.5}\ \text{(stat)}$$
$$\pm 0.7\ \text{(syst)}\ \pm 0.3\ \text{(lumi) pb}$$

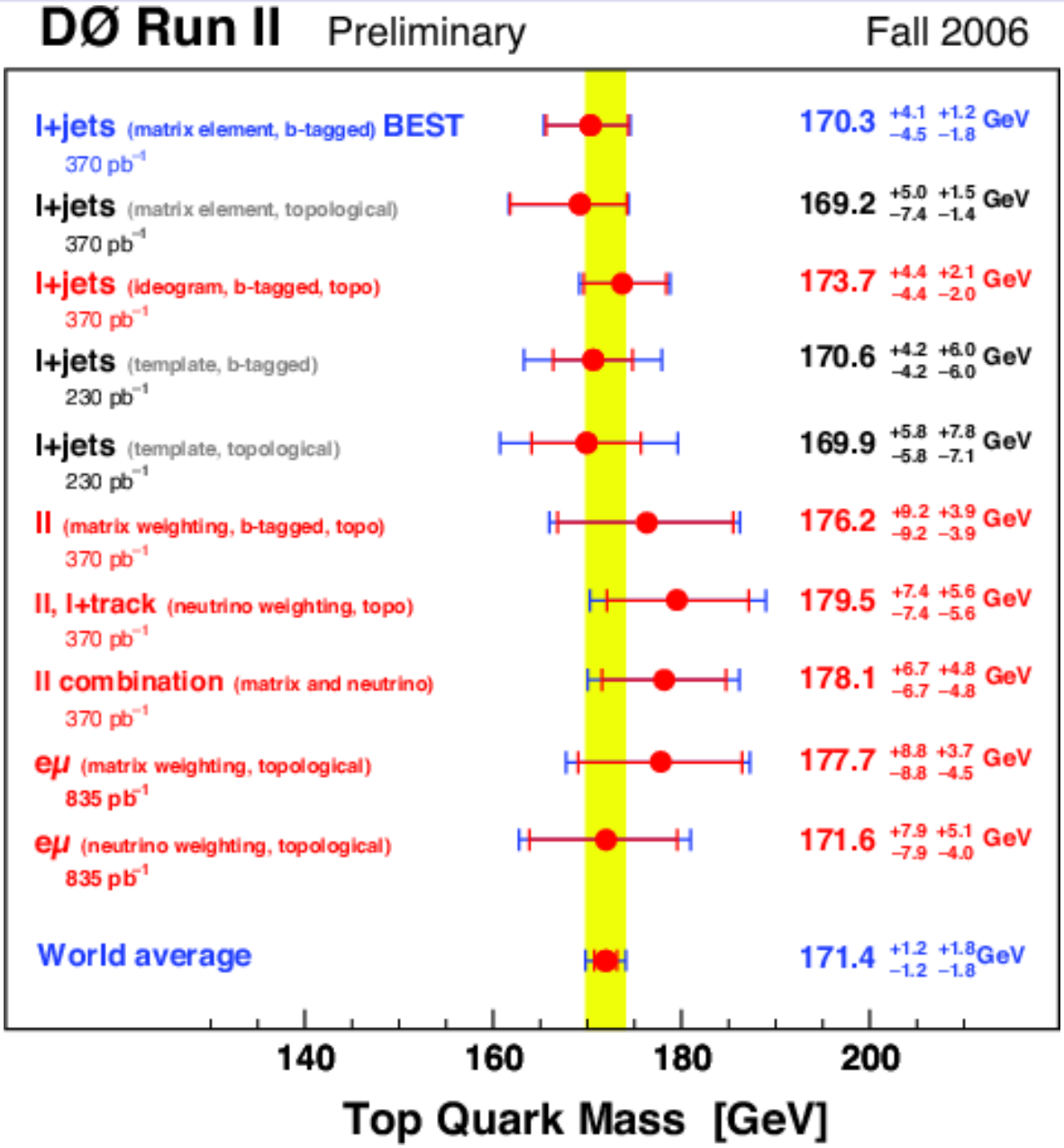
Type 2: 1 charged track and $\geq$ 1 EM obj.




Type 3: $>$ 1 track



# top quark mass measurements



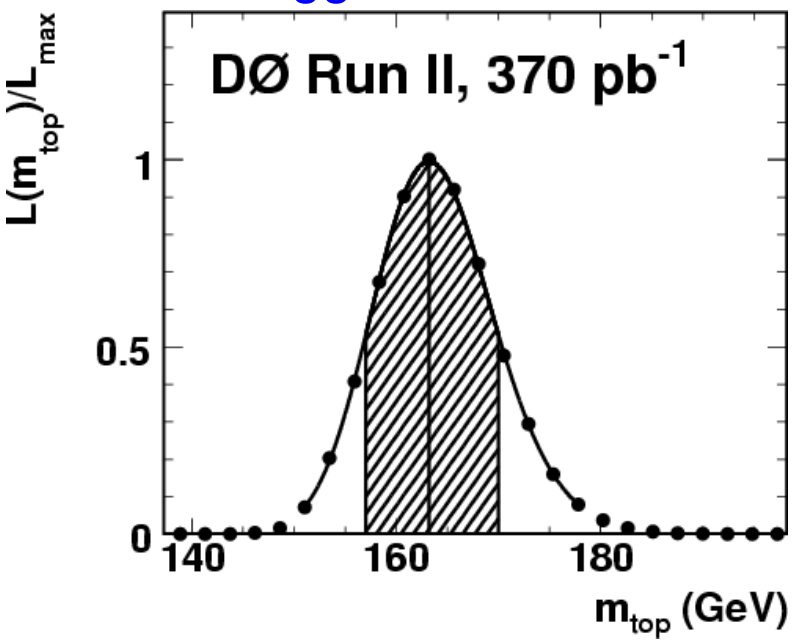
# Lepton+jets, 370 pb$^{-1}$ - Matrix Element method

## Event Likelihood

$$\mathcal{L} = f_{sgn} P_{sgn} + (1 - f_{sgn}) P_{bkg}$$

$$P = \frac{1}{\sigma_{tot}} \sum_{flavors} \int dq_1 dq_2 \, f(q_1) f(q_2) \, \mathcal{F} \, |\mathcal{M}|^2 \, d\Phi_6 \, W(x, y; JES)$$

Double $b$-tagged events:



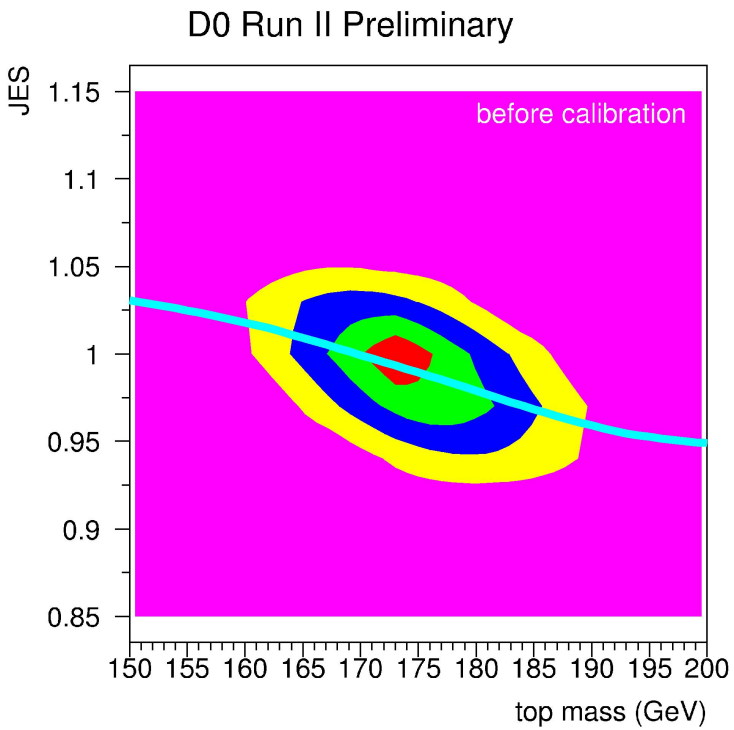

- $P_{sgn}$ uses $t\bar{t} \to l\nu b\bar{b}qq'$ matrix element
- $P_{bkg}$ uses $W$+jets matrix elements (VECBOS)
- 2-dimensional fit of likelihood vs. $m_t$ and jet energy scale

$$m_t = 170.3 \, ^{+4.1}_{-4.5} \text{ (stat + JES)} \, ^{+1.2}_{-1.8} \text{ (syst) GeV}/c^2$$

# Lepton+jets, 370 pb$^{-1}$ - Ideogram method

$$P_{sgn} = \sum_{i=1}^{24} w_i \int G(m_i, m', \sigma_i) BW(m', m_t)\, dm'$$

$$P_{bkg} = \sum_{i=1}^{24} w_i BG(m_i)$$



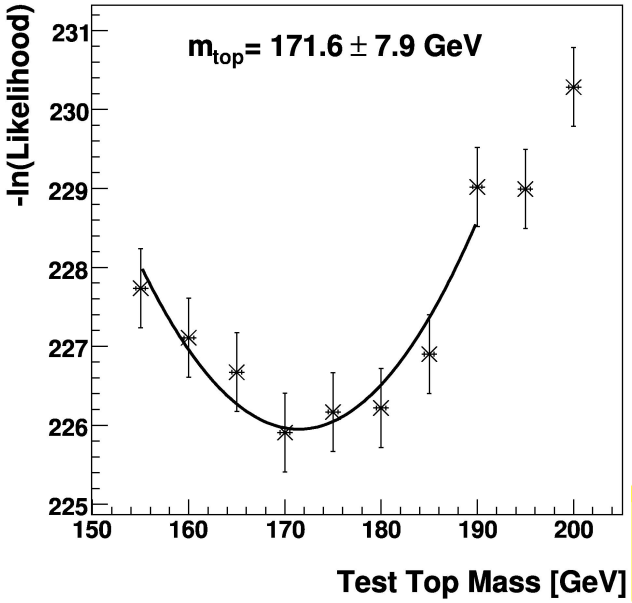

## Event Likelihood

- $w_i$: weight for the $i^{th}$ jet-parton permutation based on $b$-tagging
- $G(m_i, m', \sigma_i)$: Gaussian probability for detector resolutions
- $BW(m', m_t)$: Breit-Wigner probability
- $BG(m_i)$: shape of mass distribution for $W$+jets events

$$m_t = 173.7 \pm 4.4 \text{ (stat + JES)} \; ^{+2.1}_{-2.0} \text{ (syst) GeV}/c^2$$

# $e\mu$, 835 pb$^{-1}$

## Neutrino weighting

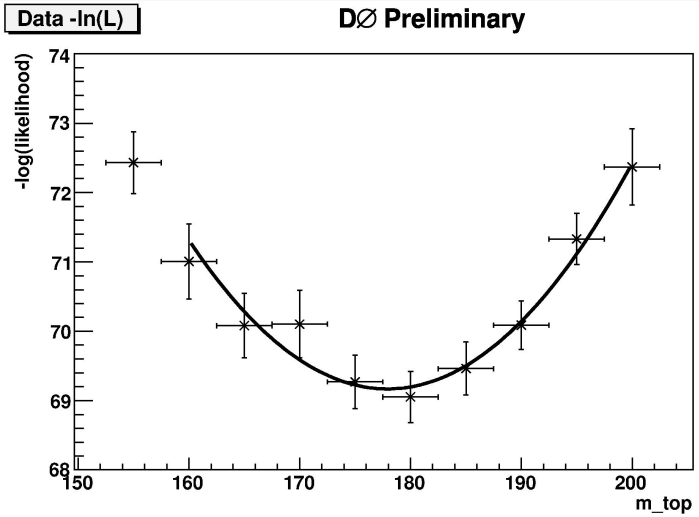



- 12 of 18 parameters measured ($p_T$ of 2 neutrinos missing)
- $M_W$ and $m_t^1 = m_t^2$ give 3 more constraints
- $m_t$ hypothesis + $\eta$ for each $\nu$ used to solve kinematics
- Calculated $\not{E}_T$ compared to measured $\not{E}_T$ to get likelihood

$$m_t = 171.6 \pm 7.9\ (\text{stat})\ ^{+5.1}_{-4.0}\ (\text{syst})\ \text{GeV}/c^2$$

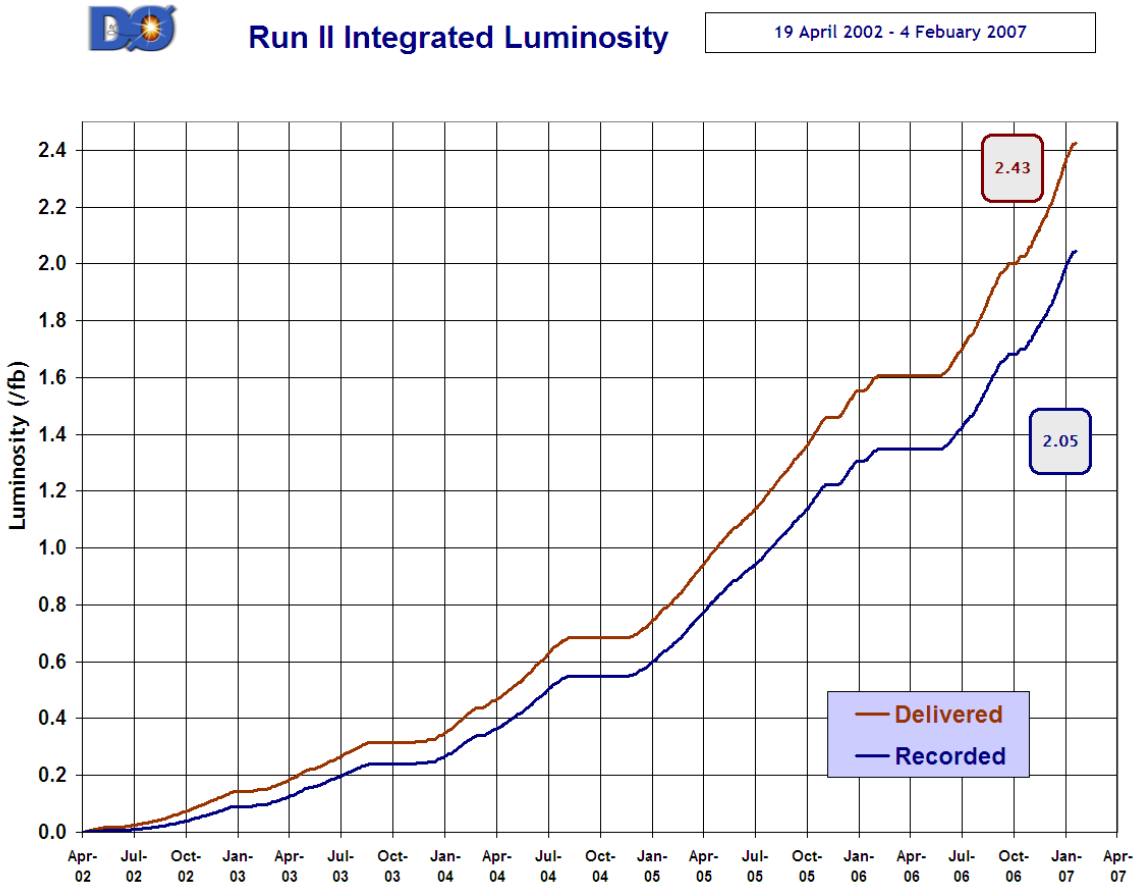
## Matrix element weighting

$$m_t = 177.7 \pm 8.8\ (\text{stat})\ ^{+3.7}_{-4.5}\ (\text{syst})\ \text{GeV}/c^2$$



# Summary

- All results consistent with the Standard Model
- Much more data to collect (4-8 $fb^{-1}$ total) and analyze
- Many results already submitted or being reviewed for publication

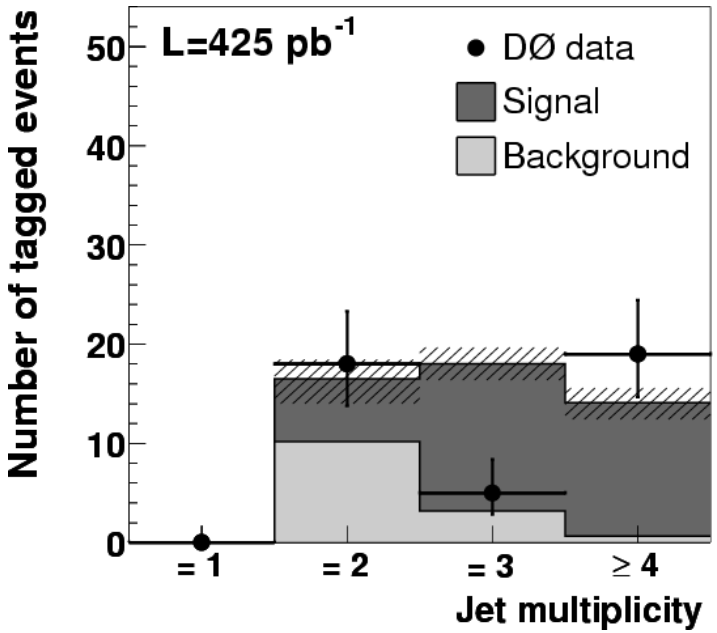


# Topological discriminant variables for lepton+jets cross-section

- Centrality: $\mathcal{C} = H_T/H$.
- Aplanarity: $\mathcal{A} = \frac{3}{2}\lambda_3$, $\lambda_3$ is the smallest eigenvalue of the normalized momentum tensor, $\mathcal{M}$.
- Sphericity: $\mathcal{S} = \frac{3}{2}(\lambda_2 + \lambda_3)$, $\lambda_2$ and $\lambda_3$ are the smallest 2 eigenvalues of $\mathcal{M}$.
- $H_T$: scalar sum of the $p_T$ of the four leading jets.
- $\Delta phi(lep, \not{E}_T)$: azimuthal opening angle between the lepton $p_T$ and the missing transverse energy.
- $K_T^{min'} = \min(\Delta R_{jj})\min(p_T)/(p_T^{lep} + \not{E}_T)$. Rescaled to reduce correlation with jet energy scale.

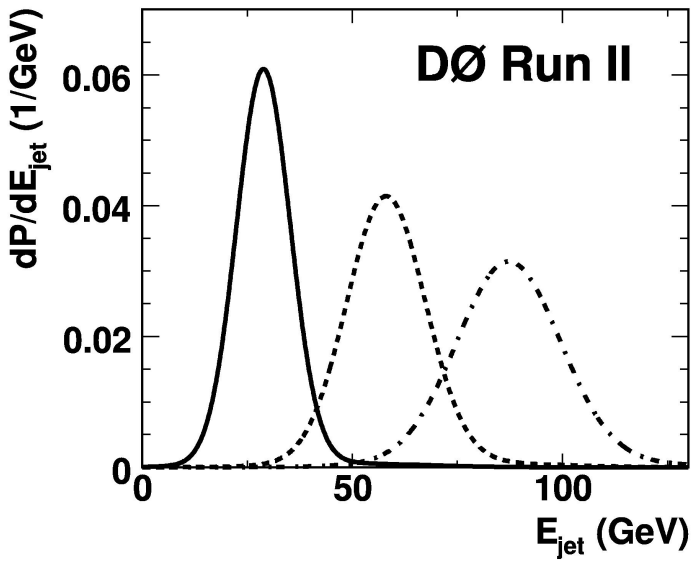
# Lepton+jets with SVX *b*-tagging, 425 pb$^{-1}$

## Secondary Vertex Tagging




$\sigma$ = 6.6 $\pm$ 0.9 (stat + syst) $\pm$ 0.4 (lumi) pb

# matrix element method




$$|\mathcal{M}|^2 = \frac{g_s^4}{9} F\overline{F}\left(2 - \beta^2 s_{qt}^2\right),$$