Top Quark Physics Results from DØ

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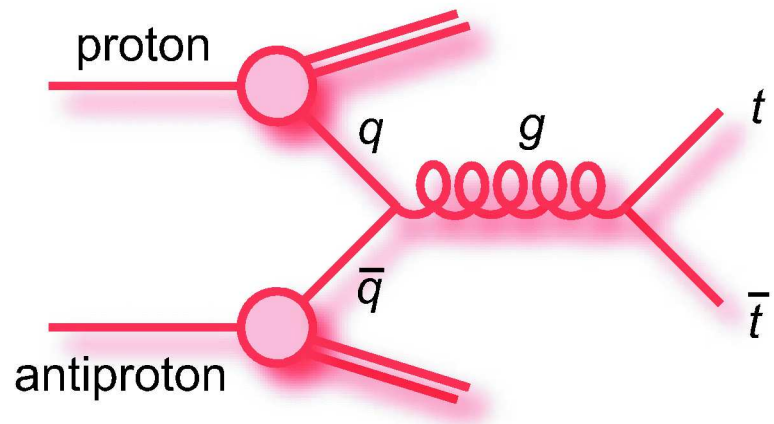
Top Quark Overview



- Top quark mass ≈ 175 GeV
  - Only produced at the Tevatron
  - Via $q\bar{q}$ annihilation (90%)
    . . . and gg fusion (10%)

- $t\bar{t}$ cross section is 30% higher in Run II than in Run I

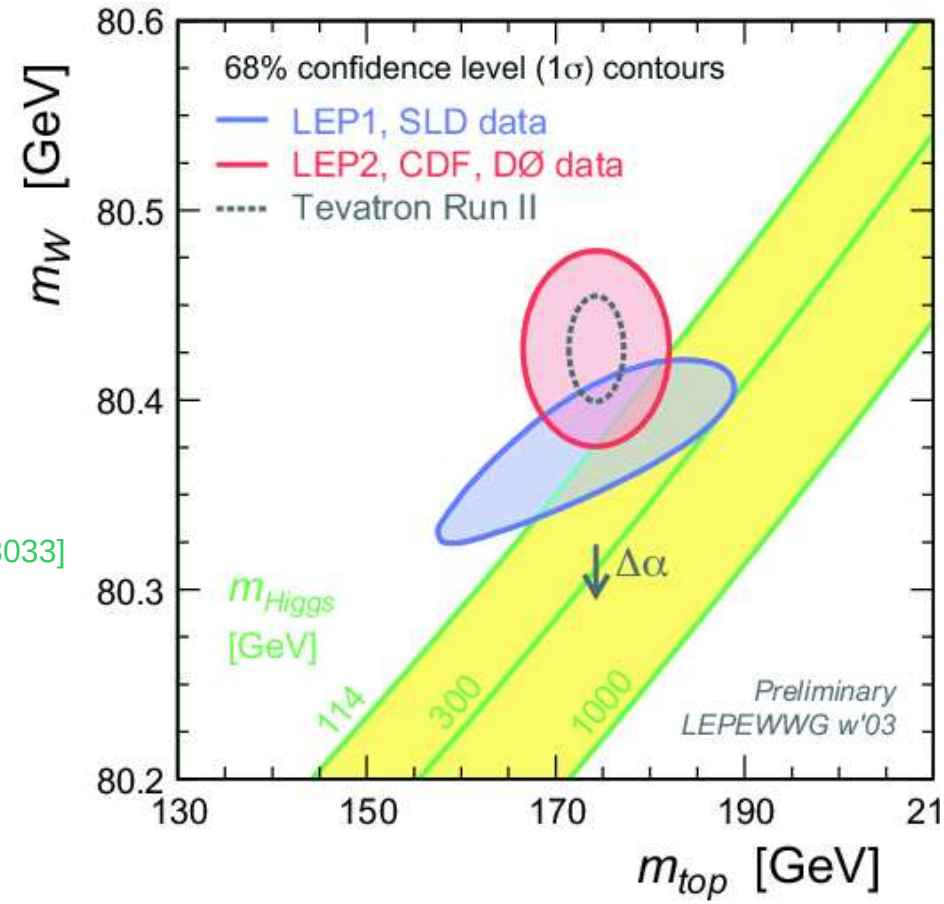
$\sigma(p\bar{p} \to t\bar{t} + X) = 6.8$ pb { NNLO Kidonakis and Vogt, PRD **68**, 114014 (2003); $\sqrt{s} = 1.96$ TeV, $m_t = 175$ GeV, MRST2002

  - Only 0.03% of the W boson cross section!

- DØ Run I: ≈ 40 $t\bar{t}$ leptonic candidate events

Top Quark Mass

- Top mass constrains the Higgs mass
- Precise measurement useful even after a light Higgs is discovered
  - — Stringent consistency check of SM
  - — Helps constrain stop sector [hep−ph/0003033]



- DØ Run I: m_t = 172.1 ± 7.1 GeV/c^2
- Run II expectations for 2 pb^{-1}:

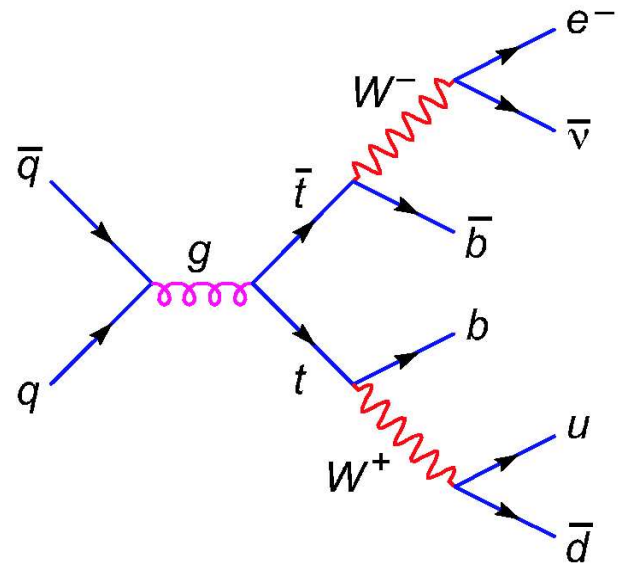
	l + jets	dilepton
δM_t =	± 2.7 GeV	± 2.8 GeV

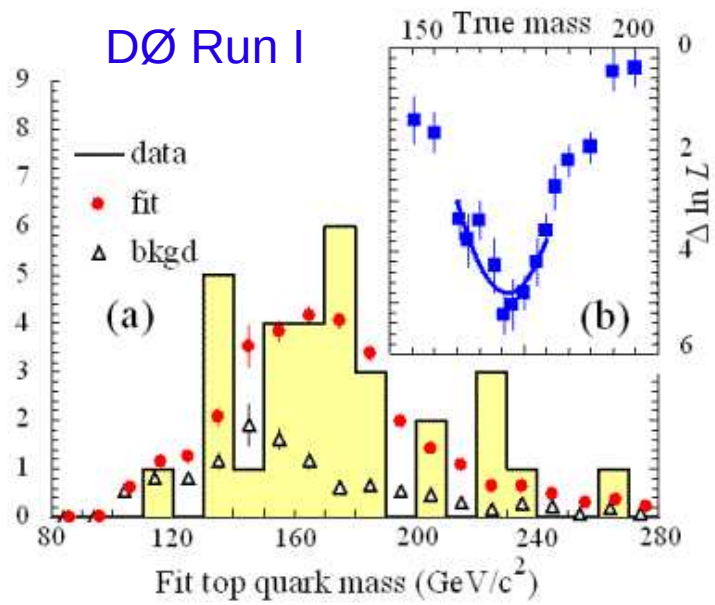
{ Based on published Run I mass measurement methods [hep−ph/0202001]

- Improve mass measurement method −− new result using Run I data

Improved Precision on the Top Mass

- New method based on event probability
- Run I *lepton + jets* data, selection:
  - Isolated electron or muon
  - $E_T > 25$ GeV, $|\eta^e| < 2.0$, $|\eta^\mu| < 1.7$
  - ≥ 4 jets with $E_T > 15$ GeV, $|\eta^{jet}| < 2.0$
  - $\not{E}_T > 20$ GeV
  - $|E_T^{lep}| + |\not{E}_T| > 60$ GeV, $|\eta^W| < 2.0$
    - 91 events selected
- Run I analysis (1998)
  - $t\bar{t}$ discriminant
  - fitted mass compared with MC templates →
- This analysis (Run I 2003)
  - Selection as above, plus require exactly 4 jets
    - 71 events
  - Mass obtained using event probabilities





New Mass Measurement: Method

- Probability density for each event (*uses all measured quantities*):

$$P(x, M_t) = \frac{1}{\sigma(x)} \int d\sigma(y, M_t)\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(y, x)$$

Differential cross section (LO matrix element and phase space)

PDF's

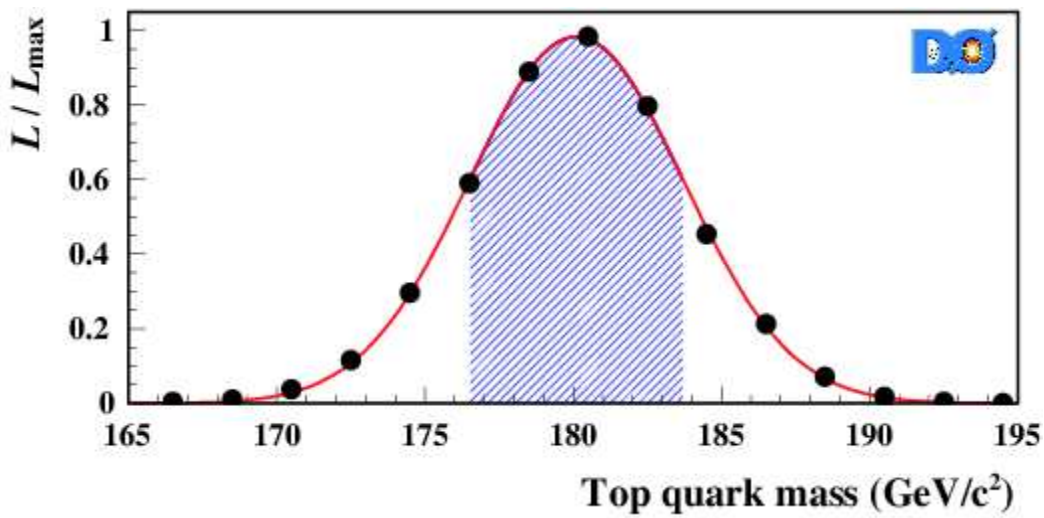
Transfer function: relates partonic variables $y = (p_1, p_2, \ldots p_n)$ to x = measured 4–momenta

- Ambiguity of jet–parton correspondence
  - Sum over all twelve assignments of four jets to the partons ($b\bar{b}q_3q_4$)
  - *All possible combinations are used correctly* (only solution with best fit χ^2 chosen in previous method)
- Event probability $P(x; c_1, c_2, M_t) = c_1 P_{t\bar{t}}(x; M_t) + c_2 P_{\text{bkgd}}(x)$
  - Form likelihood function and maximize: obtain M_t, c_1, c_2
- Increase signal purity by cutting on bkgd probability: $P_{\text{bkgd}} < 10^{-11}$
  - Retains 22 events

Result

DØ Run I Lepton+jets

M_t = 180.1 ± 3.6 (stat) ± 3.9 (syst) GeV/c^2 = 180.1 ± 5.3 GeV/c^2



- Dominant systematic error is from jet energy scale uncertainty
  - Estimated by re−scaling jet energies by ±δE
- Improvement in statistical uncertainty over previous result
  - Equivalent to a factor 2.4 more data

Systematic errors (GeV/c^2)	
Model for $t\bar{t}$	1.1
Model for bkgd (W+jets)	1.0
Noise and multiple interactions	1.3
Jet energy scale	3.3
PDF	0.1
Acceptance correction	0.3
Bias correction	0.5
Total	**3.9**

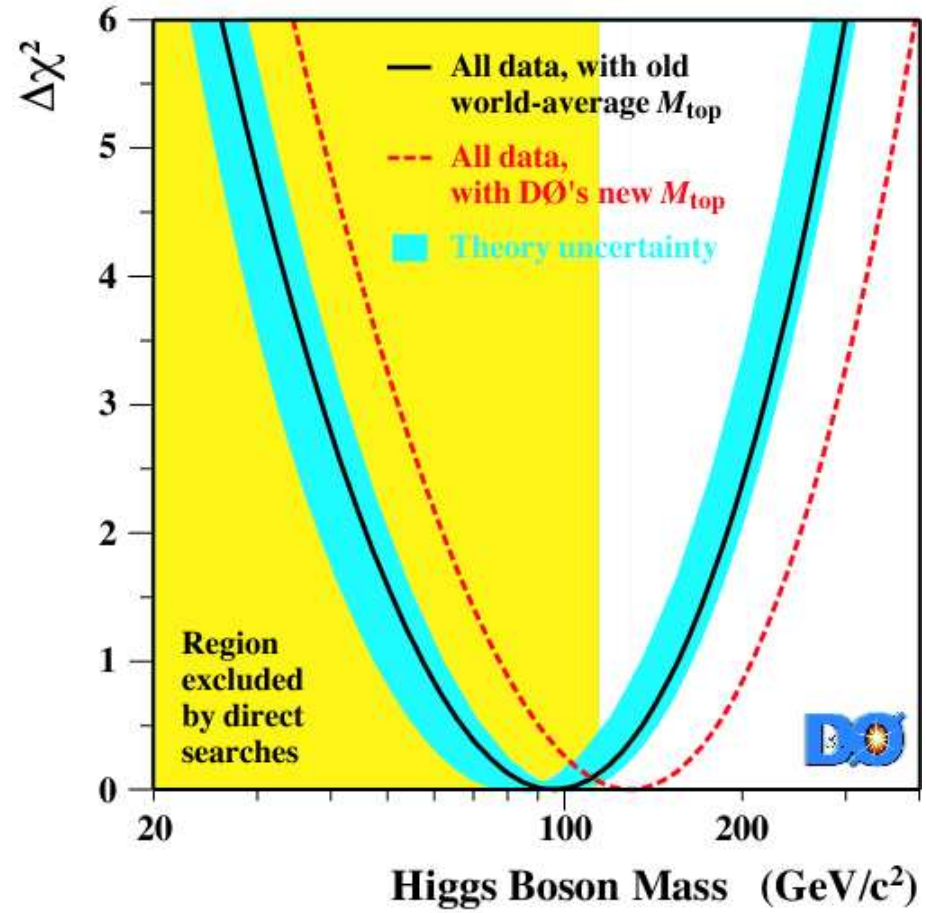
Higgs Mass from Electroweak Fit

- Combine with previous DØ measurement in dilepton channel to get new DØ combined top mass from Run I data:

$$M_t = 179.0 \pm 5.1 \ \text{GeV}/c^2$$

— Global fit to electroweak data using this top mass yields a best–fit Higgs mass of $M_H \approx 125$ GeV/c^2 (red dashed line)

— To be compared with $M_H = 96$ GeV/c^2 (black line) using previous world average top mass



W Helicity in Top Decays

- Width of the top quark in the SM (for M_t = 175 GeV)

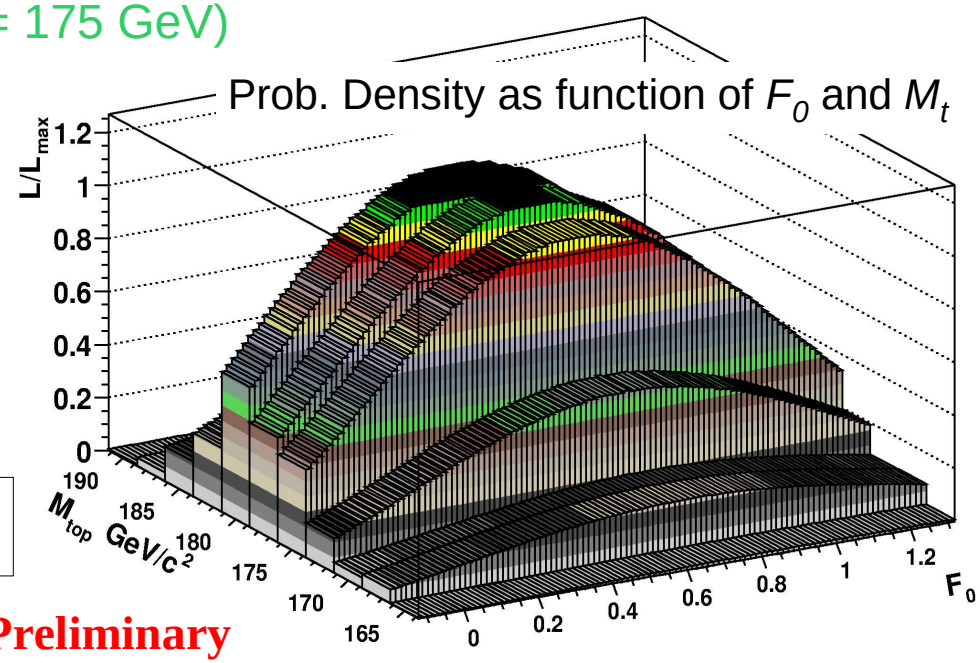
$$\Gamma_t \approx 1.4\ \text{GeV} \gg \Lambda_{QCD} \approx 0.22\ \text{GeV}$$

$$\Rightarrow \tau_t = 1/\Gamma_t \approx 0.5\times10^{-24}\ \text{s} \ll \Lambda_{QCD}^{-1} \approx 3\times10^{-24}\ \text{s}$$

  - Top quark decays before hadronization, spin information directly passed on to its decay products (*Wb*)
    - *W* polarization reflected in kinematic distributions e.g. lepton angle
  - W can be either left–handed (F_-) or longitudinal (F_0)
  - SM predicts F_0 = 0.7, F_- = 0.3 (M_t = 175 GeV)
  - Longitudinal component of *W* generated by EWSB mechanism

- Use same "event probability" method as above
- Result:

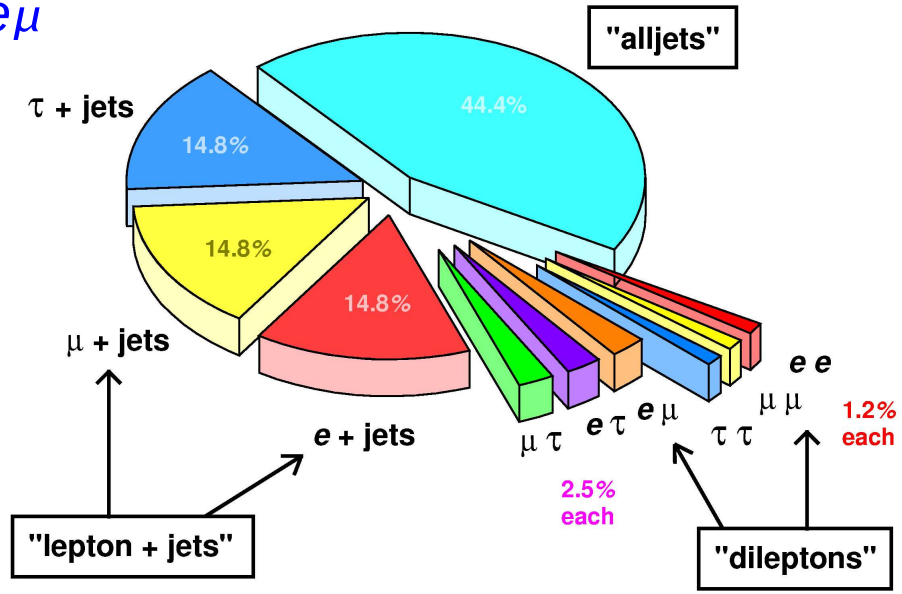
$$F_0 = 0.56 \pm 0.31\ (\text{stat})\ \pm 0.04\ (\text{syst})$$



DØ Run I Preliminary

Run II: Dilepton Analyses

- Small branching fractions to ee, $\mu\mu$, $e\mu$
- Signal: (ee, $\mu\mu$, $e\mu$) + $\not{E}_T$ + ≥2 jets
- Backgrounds are very small, so no b–tagging needed
- Backgrounds:
  - WW ($\rightarrow ee$, $\mu\mu$, $e\mu$) + jets
  - Z ($\rightarrow ee$, $\mu\mu$) + jets
  - Z ($\rightarrow \tau\tau \rightarrow e\mu$) + jets
  - $b\bar{b}$ + jets, multijets

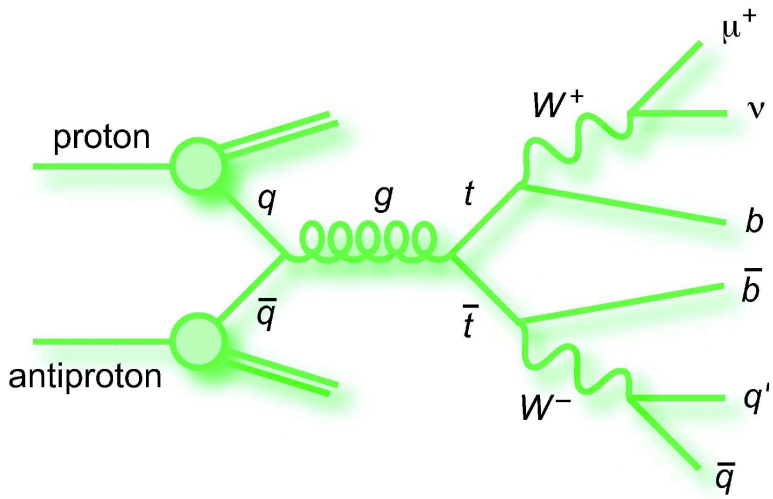


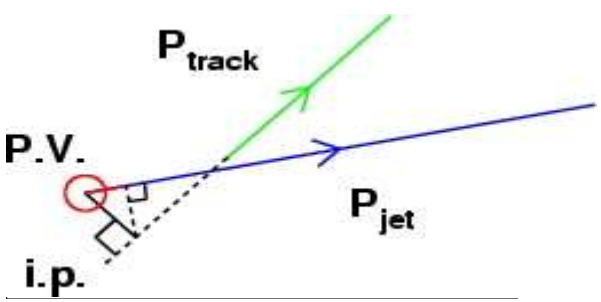
	ee	$\mu\mu$	$e\mu$
Int. Lum. (pb^{-1})	107	90.4	97.7
Background	0.6 ± 0.5	0.7 ± 0.4	0.6 ± 0.4
Expected signal	0.6 ± 0.1	0.5 ± 0.1	1.7 ± 0.3
Signal + bkgd	1.2 ± 0.5	1.2 ± 0.5	2.3 ± 0.5
Data	2	0	3

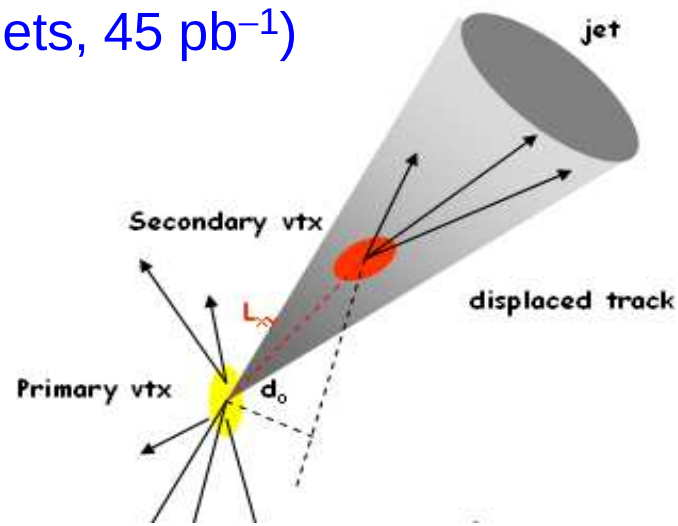
DØ Run II Preliminary

Lepton + Jets Analyses

- Larger branching ratios than for dileptons, but backgrounds also much larger. Use:
- Topological tag ($l\nu$ + ≥4 jets, 92 pb^{-1})
  - Aplanarity: $A > 0.065$
  - $H_T^{\text{all}} = p_T(W) + \sum_{\text{jets}} H_T > 220\ \text{GeV}$
- Soft muon tag ($l\nu$ + ≥4 jets, 92 pb^{-1})
  - Muon with p_T > 4 GeV within ΔR < 0.5 of jet ($b \to \mu$, $b \to c \to \mu$)
- Secondary vertex tag ($l\nu$ + ≥3 jets, 45 pb^{-1}) $L_{xy}/\sigma(L_{xy}) > 5$
- Charged signed impact parameter tag ($l\nu$ + ≥3 jets, 45 pb^{-1})
  - 2 (3) tracks with i.p. significance > 3 (2)

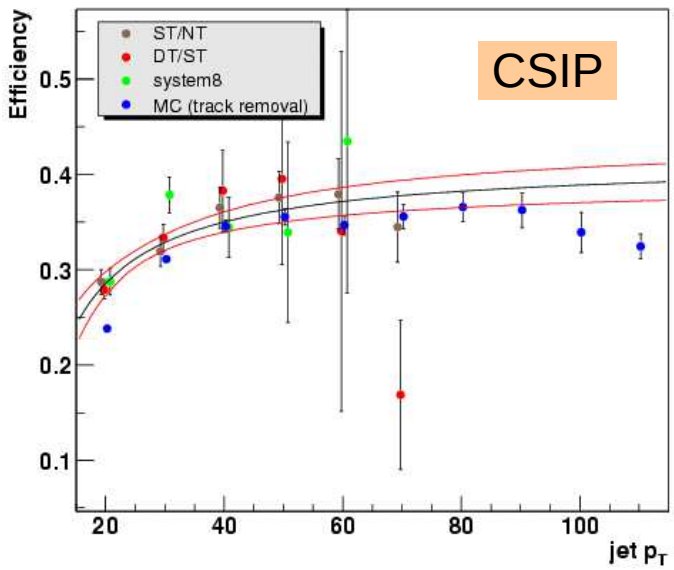


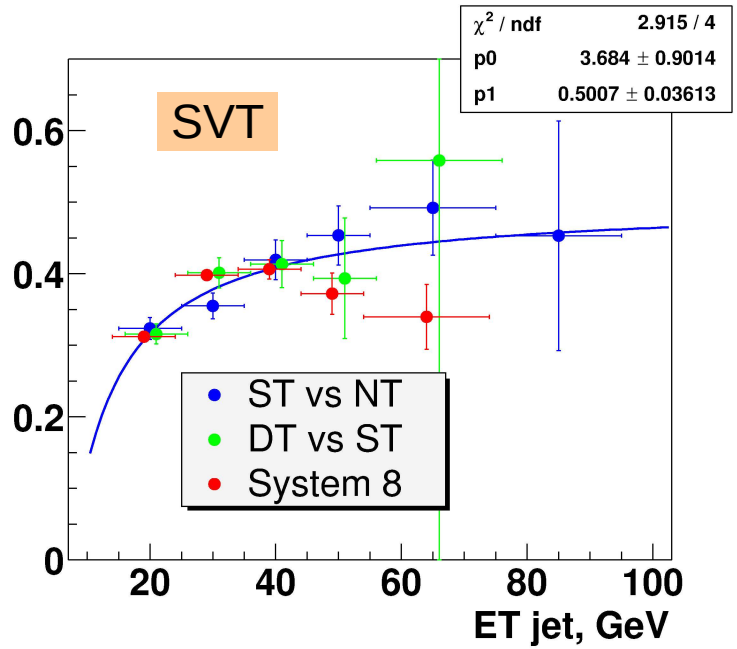




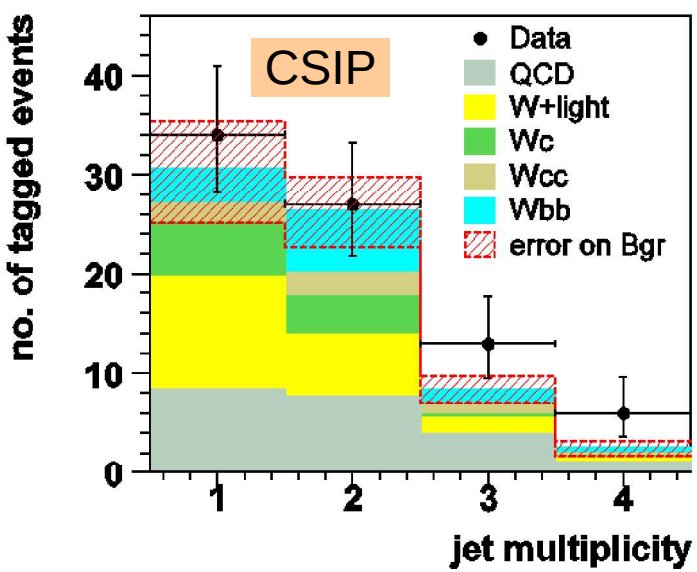
Lepton + Jets Results (Si b−tag)

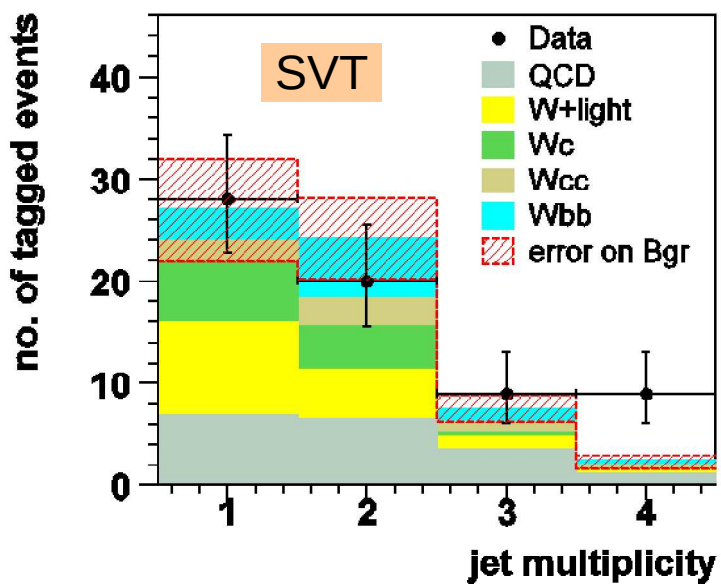
- *b*–tagging efficiency vs. Jet E_T



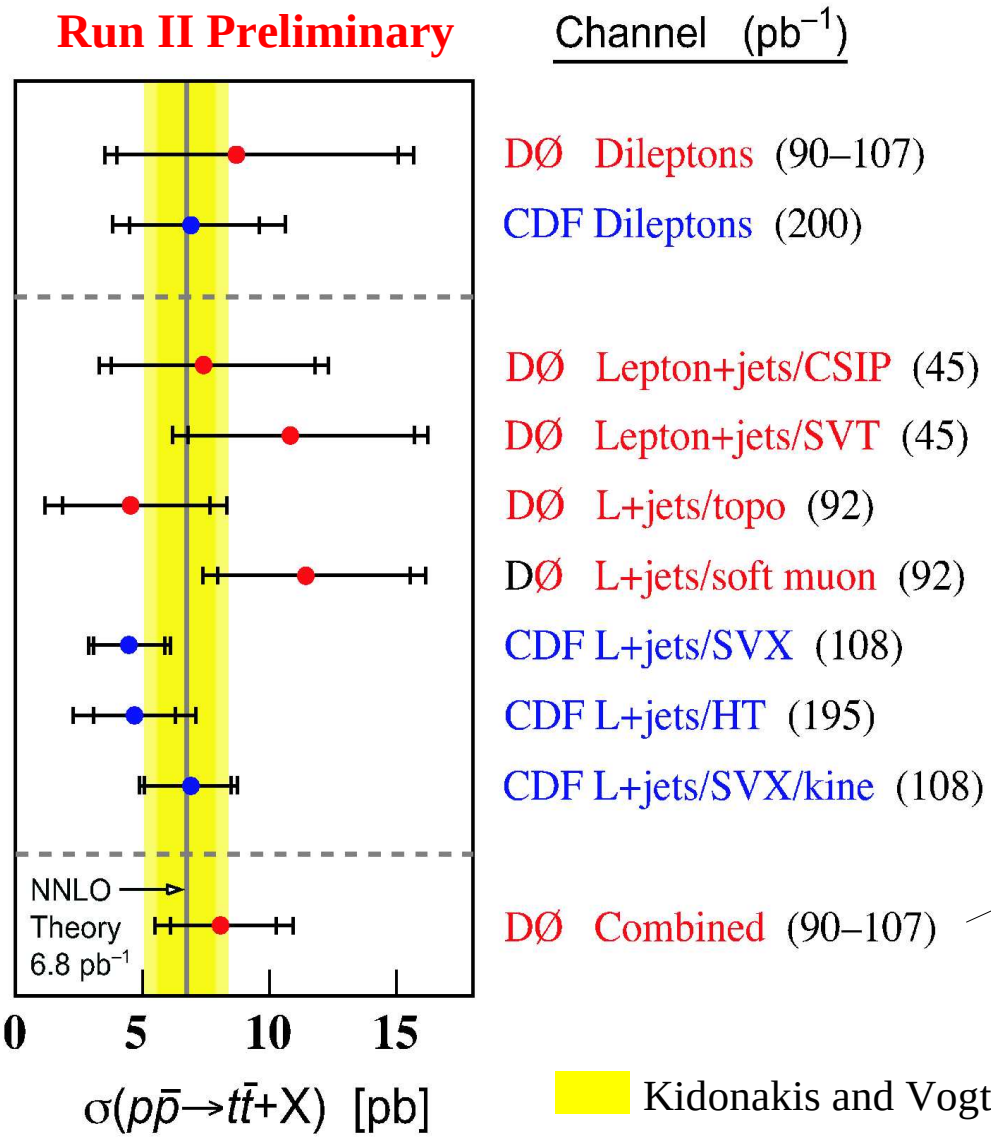


- Data vs. bkgd (45 pb^{-1})





$t\bar{t}$ Cross Section



- Measurements agree with NNLO QCD predictions
- Cross section measurements in each decay channel are consistent with each other

$$8.1\ ^{+2.2}_{-2.0}(\text{stat})\ ^{+1.6}_{-1.4}(\text{syst})\ \pm 0.8(\text{lum})\ \text{pb}$$

DØ Run II Preliminary

Kidonakis and Vogt, hep–ph/0308222

Cacciari et al. hep–ph/0303085

Outlook

- An exciting program of top quark physics lies ahead
- Near term (~200 pb^{-1})
  - New cross section results
  - Top mass measurement
- Longer term
  - Observation of single top quark production
  - Top mass to ± 2 GeV
  - Detailed studies of production and decay properties
    - Cross sections in all decay channels
    - Spin correlations
    - W polarization
    - Unusual resonances in $t\bar{t}$ and single top production
    - Rare decays

      . . .