Top quark physics at DØ

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For the DØ Collaboration

BNL

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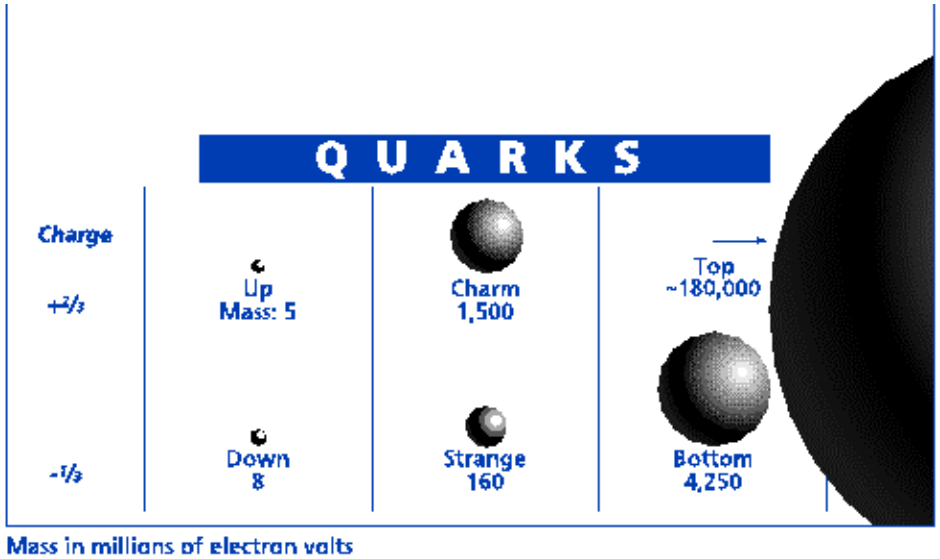
- Cross section for $t\bar{t}$ production.
- Measurement of the mass of the top quark.
- Cross section for single t production.
  - $|V_{tb}|$ and Γ_t measurements.

The top quark

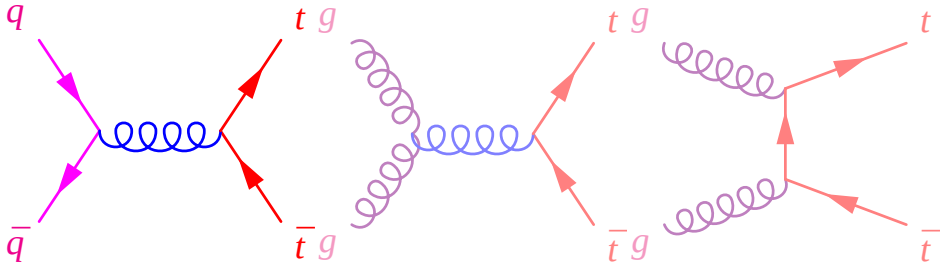
- Predicted by SM and discovered by DØ and CDF in 1995.
- The heaviest known elementary particle: t-H Yukawa coupling ~ 1.



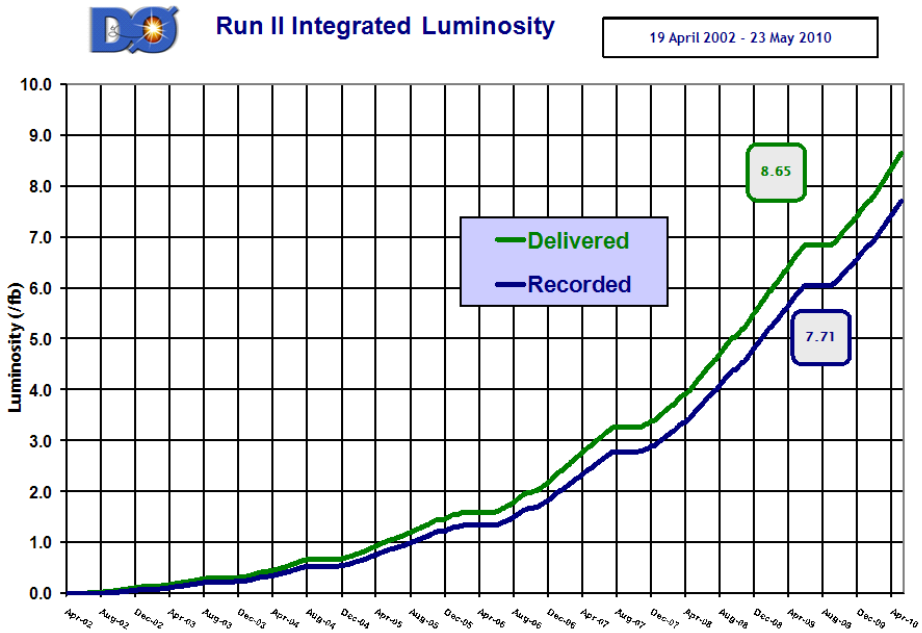
- May be related to EWSB and mass generation.
- New physics may couple preferentially to top.
- Top quark mass dominates radiative corrections: precision top quark measurements can help constrain the Higgs sector.

Observing top quark pairs

Produced mainly by $q\bar{q} \to t\bar{t}$



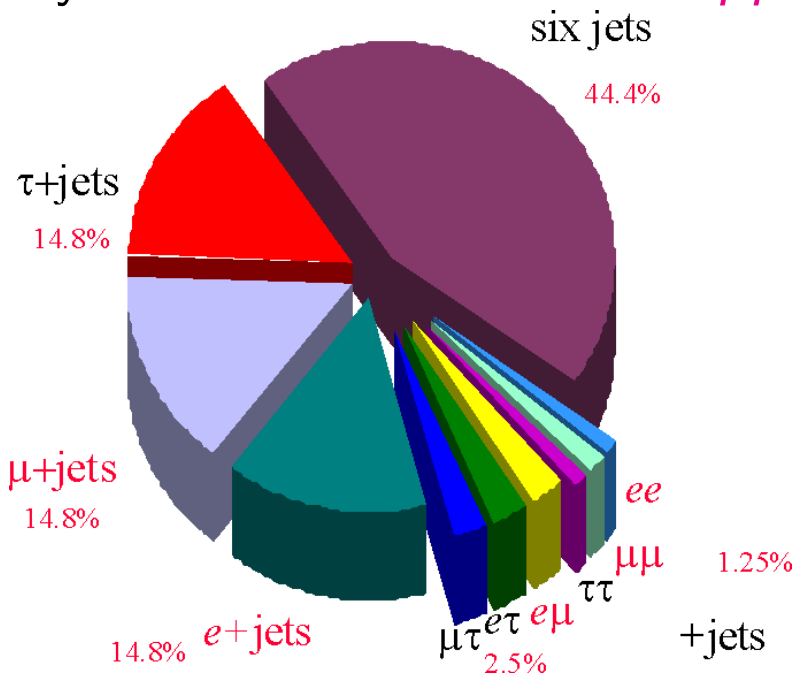
$$\sigma(t\bar{t}) \approx 8\,\text{pb}$$



Now have thousands of candidates

$\Longrightarrow$ precision measurements!

Decays via $t \to Wb \to \ell\nu b$ or $q\bar{q}b$



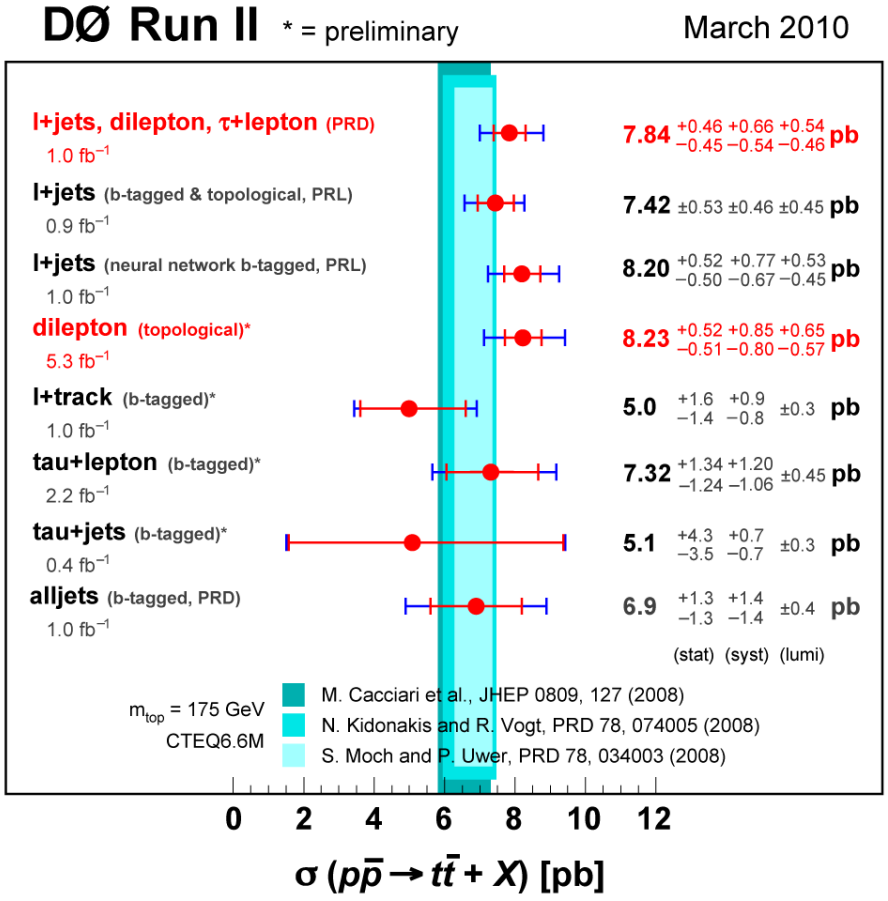
Classify final states depending on how the W's decay:

- $\ell\ell$, $\ell + \text{jets}$, or all-jets.

$t\bar{t}$ cross section measurements

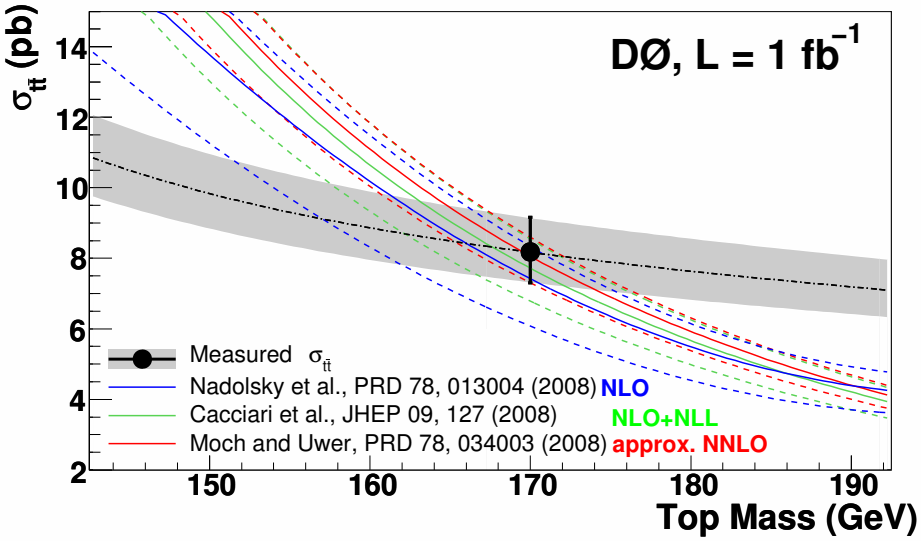
[PRD 80, 071102 (2009)]

All channels covered except $\tau\tau$!



[D0NOTE-6038-CONF; D0NOTE-5607-CONF; D0NOTE-5465-CONF; D0NOTE-5234-CONF; arXiv:0911.4286, subm. PRD; PRD 80, 071102 (2009)]

Can use $\sigma(m_t)$ calculation to find mass from cross section.
Gives pole mass directly (fully inclusive calculations).



$m_t = 169.1^{+5.9}_{-5.2}$ GeV 3.3%.
(approximate NNLO, 1 fb^{-1})

Top quark mass measurements

The best top quark mass measurements use the *matrix element* approach.

Given observed event kinematics $\mathbf{x}$, define

$$P(\mathbf{x}|m_t) \sim \int_{\mathbf{y}} f(\mathbf{y})\, M(\mathbf{y}, m_t)\, W(\mathbf{x}, \mathbf{y})$$

Transfer function

Process matrix element

Parton kinematics

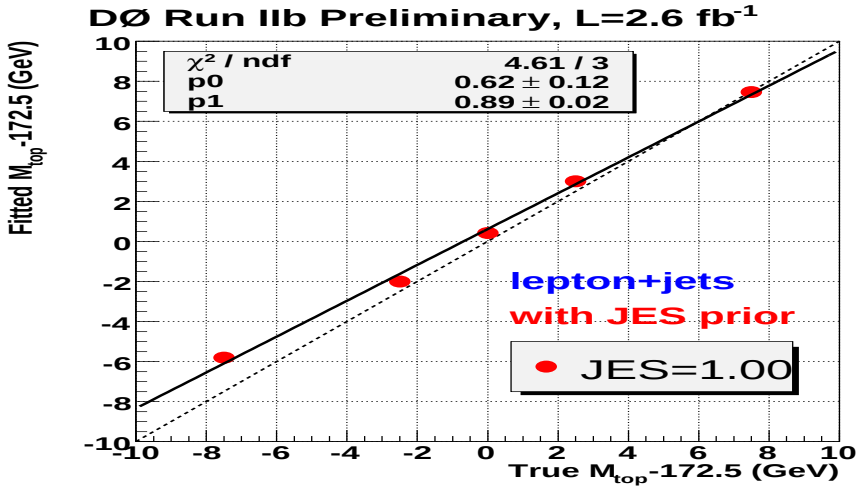
Parton PDFs

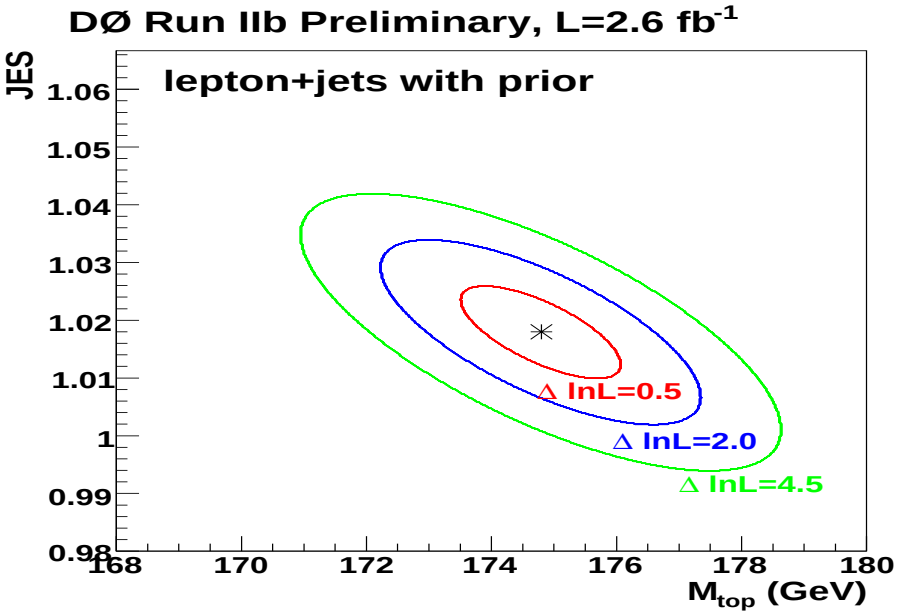
Extract best m_t via max likelihood.

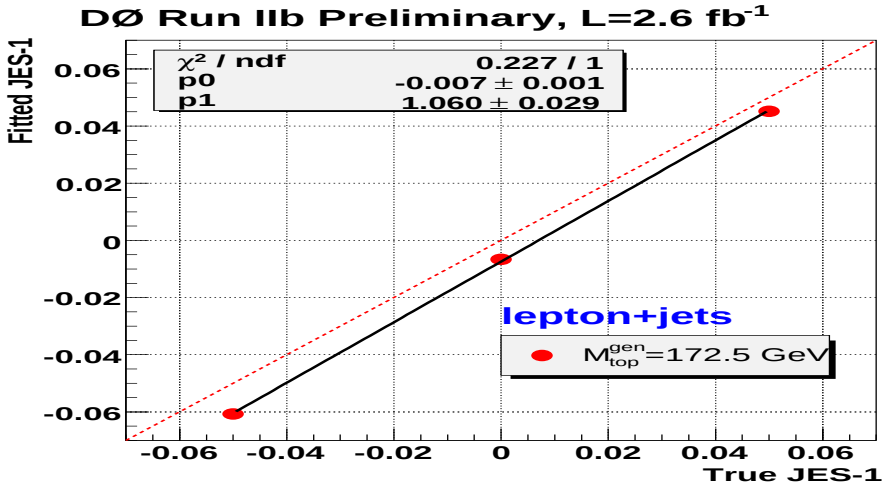
In principle this gives m_t directly. In practice, approximations made require calibrating the procedure using Monte Carlo.

Lepton + jet matrix element ($3.6\,\mathrm{fb}^{-1}$) [D0NOTE-5877-CONF]

- e/μ + jets with b-tag.
- $W \to jj$ constrains jet scale.
- Multiplicative jet scale 'JES'.
- Fit for both (m_t, JES).





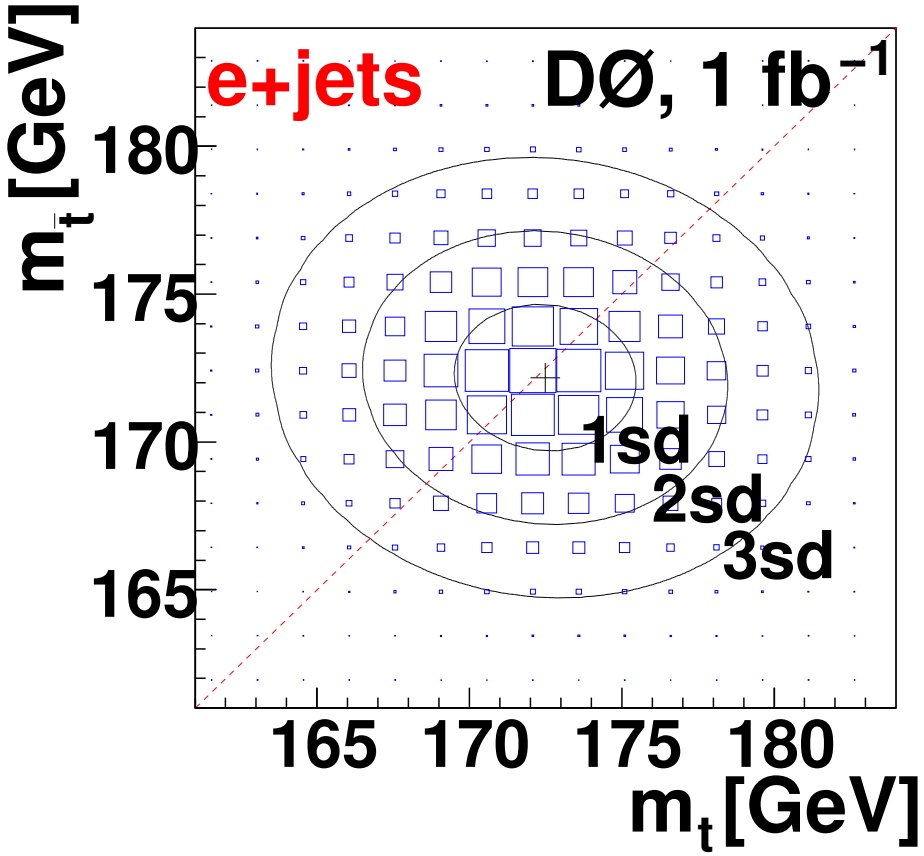


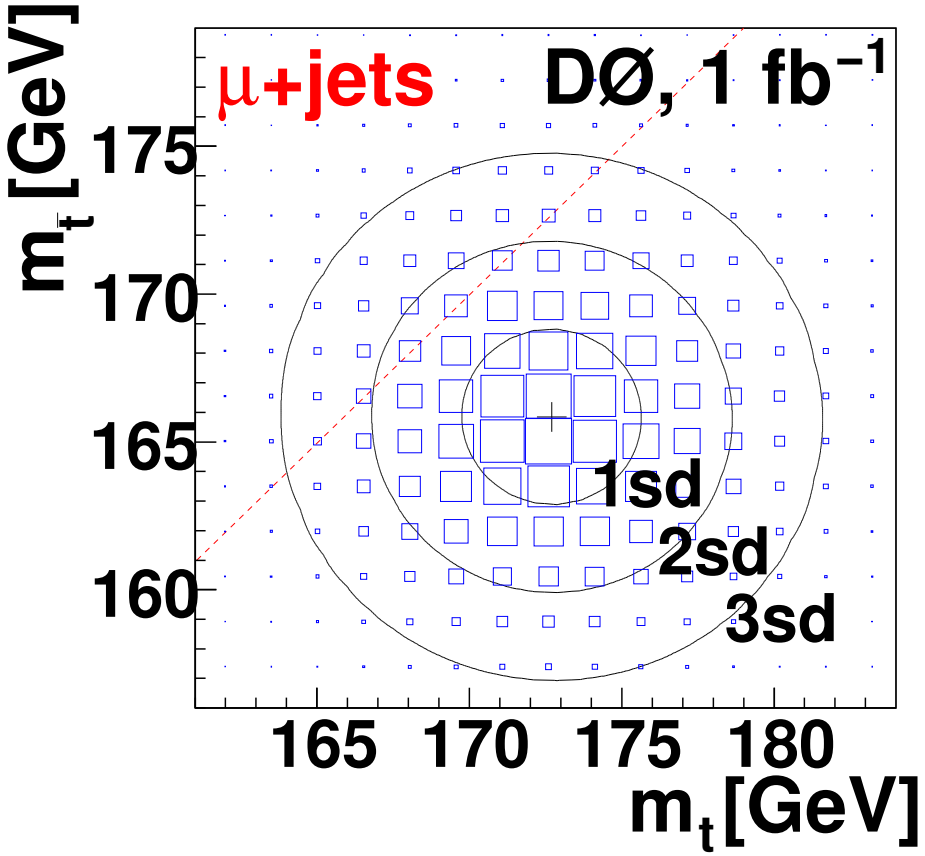
$m_t = 173.7 \pm 0.8\ (\mathrm{stat.}) \pm 1.6\ (\mathrm{syst.})\ \mathrm{GeV}$ **1.0%** (ME(ℓ + jets), $3.6\,\mathrm{fb}^{-1}$)

Systematics dominate! (Mainly jet issues.)

Direct measurement of $m_t - m_{\bar{t}}$ [PRL 103, 132001 (2009)]

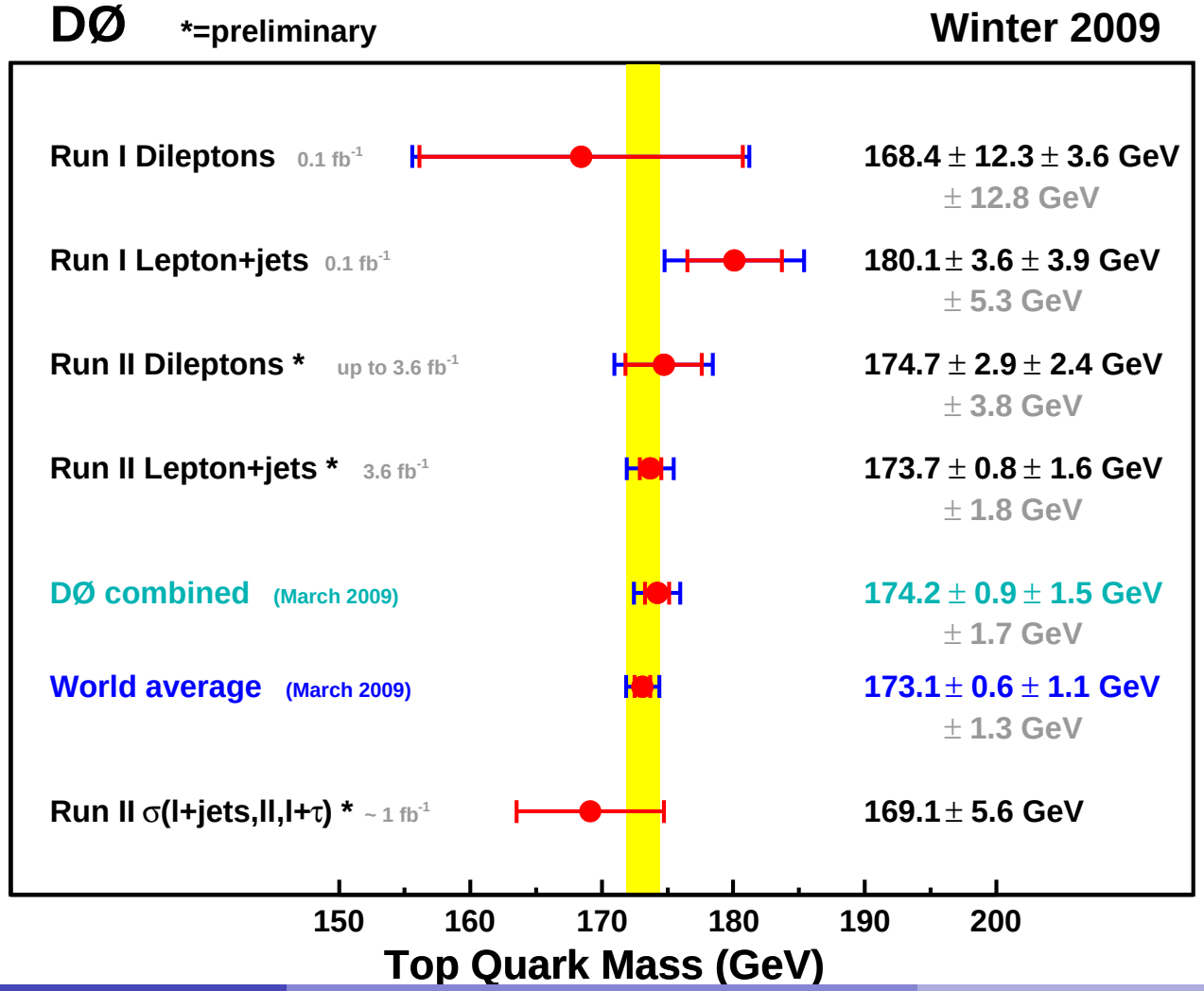
- Rewrite matrix element to depend on m_t and $m_{\bar{t}}$ separately.
- Allows a direct measurement of $m_t - m_{\bar{t}}$ (and a test of CPT).
- Fix jet energy scale (JES) to results of the previous analysis.
- Instead of (m_t, JES), now extract $(m_t, m_{\bar{t}})$.
  - Or equivalently, $(\Delta m, m_{\text{sum}}) = (m_t - m_{\bar{t}}, (m_t + m_{\bar{t}})/2)$.





DØ top quark mass summary [D0NOTE-5900-CONF]

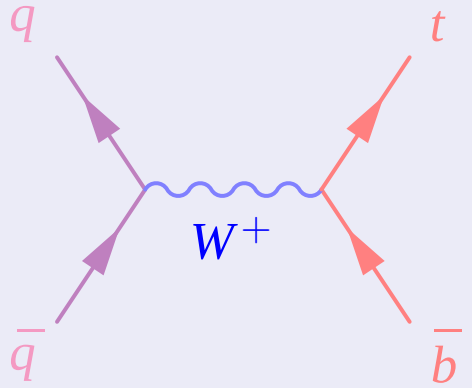
m_t measured to $< 1\%$!
First direct measurement of $m_t - m_{\bar{t}} = 3.8 \pm 3.7$ GeV ($\ell +$ jets, 1 fb^{-1})



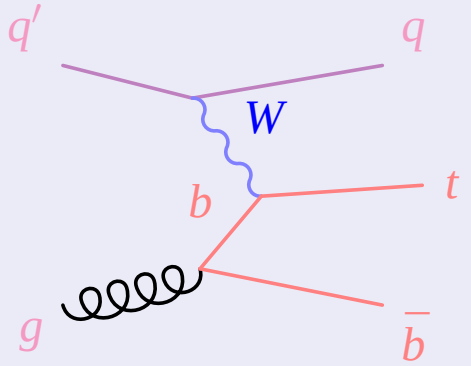
Single top quarks

Two significant processes for producing single t quarks at the Tevatron:

s-channel: $\sigma = 1.12 \pm 0.05$ pb



t-channel: $\sigma = 2.34 \pm 0.13$ pb



[Kidokanis, PRD74, 114012 (2006)]

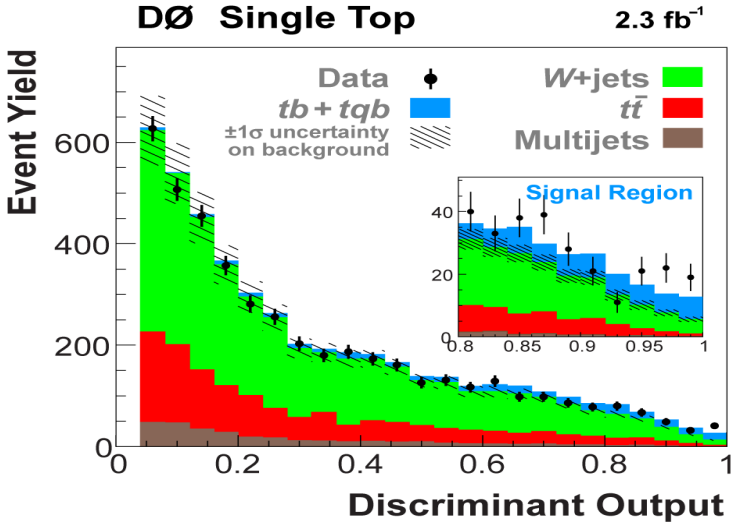
- σ a few times smaller than $t\bar{t}$, but background much larger.
  - Have to use sophisticated multivariate techniques to isolate a signal.
- Sensitivity to new physics:
  - 4th generation, anomalous Wtb coupling, FCNC, etc.

Single top observation [PRL 103, 092001 (2009); arXiv:0912.1066, subm. PLB]

Require isolated ℓ (e,μ,τ), $\not{E}_T$, jets, and b-tags.

Event Yields in 2.3 fb^{-1} of DØ Data	
e,μ, 2,3,4-jets, 1,2-tags combined	
$tb + tqb$	223 ± 30
W+jets	2,647 ± 241
Z+jets, dibosons	340 ± 61
$t\bar{t}$ pairs	1,142 ± 168
Multijets	300 ± 52
Total prediction	4,652 ± 352
Data	4,519

Combine results from several multivariate discriminants (BDT, BNN, ME).

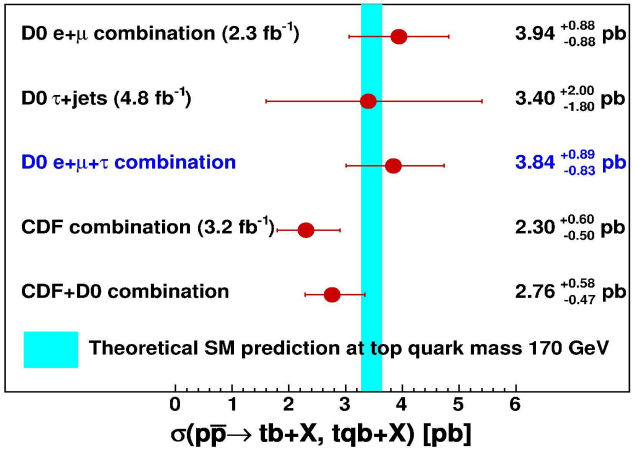


$$\sigma(e,\mu) = 3.94 \pm 0.88\,\text{pb}\ [2.3\,\text{fb}^{-1}]$$

BG-only rejected at 5.0σ.

Add τ [$4.8\,\text{fb}^{-1}$]:

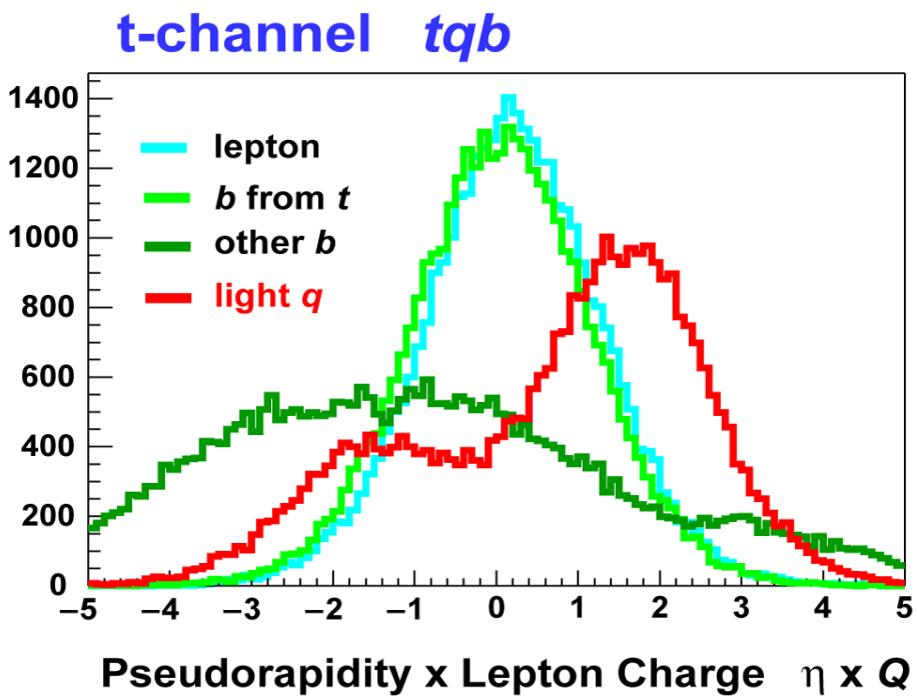
$$\sigma(e,\mu,\tau) = 3.84^{+0.89}_{-0.83}\,\text{pb}$$



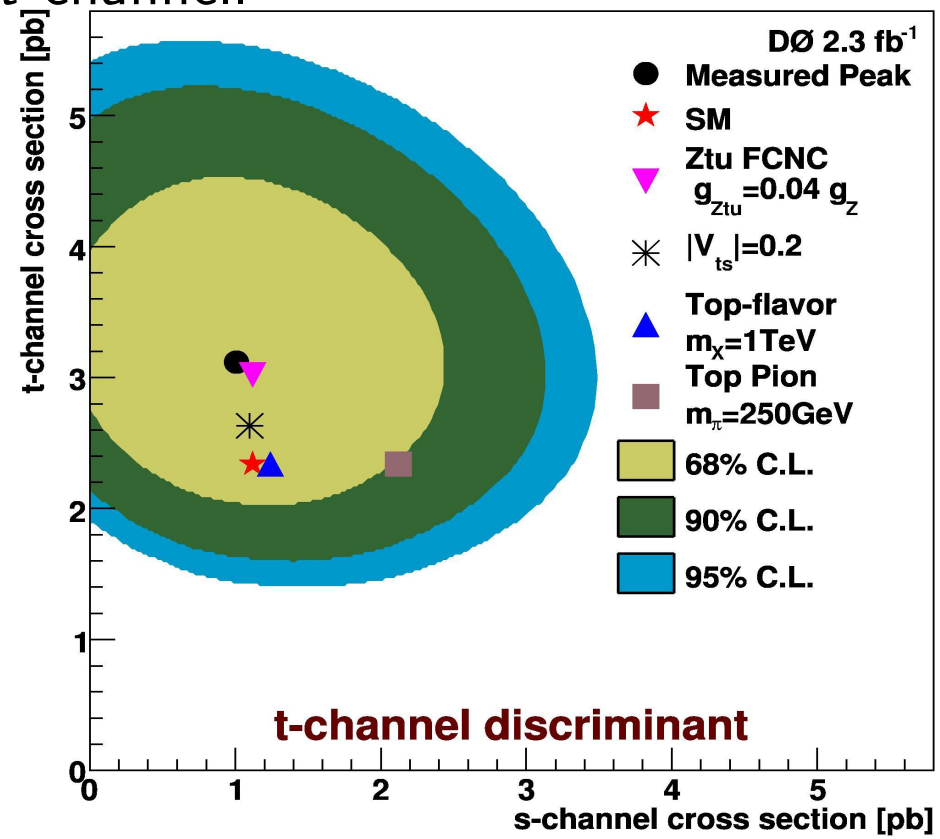
s-channel vs. t-channel

[PLB 682, 363 (2010)]

- Ratio of s-channel to t-channel σ is sensitive to new physics.
- Light quark η can discriminate.



Redo analysis training only on t-channel.



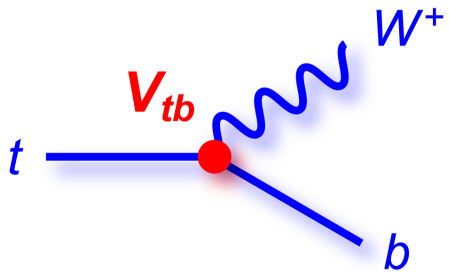
$$\sigma(t-\text{chan}) = 3.14^{+0.94}_{-0.80}\,\text{pb}\ (4.8\sigma\ \text{signif.});\ \sigma(s-\text{chan}) = 1.05 \pm 0.81\,\text{pb}$$

Consistent with SM.

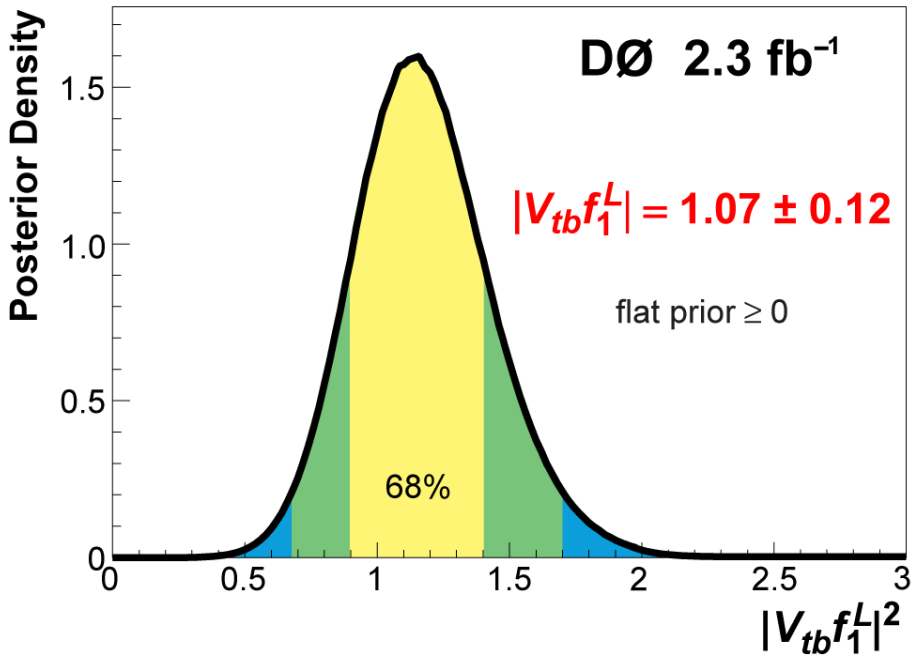
$|V_{tb}|$

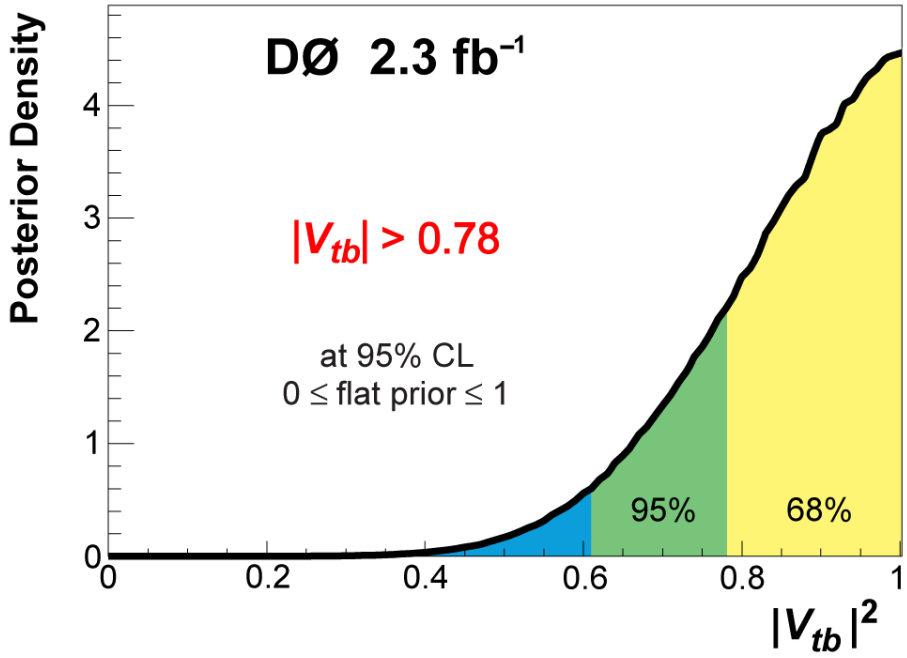
[PRL 103, 092001 (2009)]

$\sigma_t \propto |V_{tb}|^2 \implies$ we can measure $|V_{tb}|$ without assuming 3 generations.



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



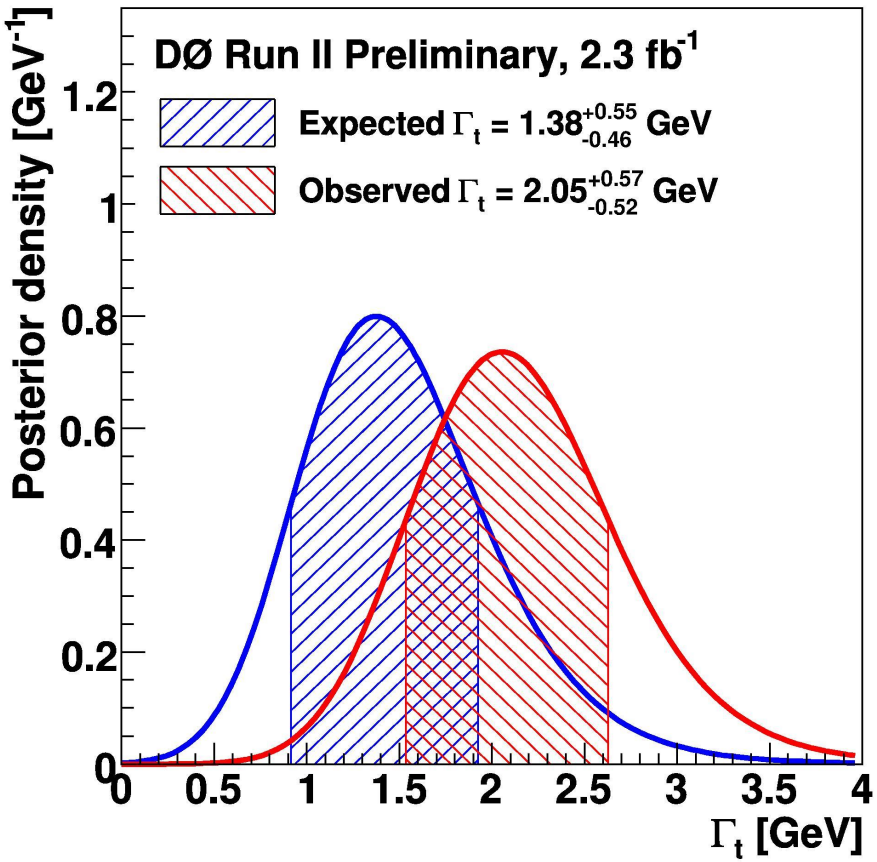


No restriction on $\lvert V_{tb}\rvert$	$0 \leq \lvert V_{tb}\rvert \leq 1$
$\lvert V_{tb}\rvert = 1.07 \pm 0.12$	$\lvert V_{tb}\rvert > 0.78$ (95% CL)

Top quark width and lifetime

[D0NOTE-6034-CONF]

- $\sigma(t-\text{chan}) \propto \Gamma(t \to Wb)$.
- So take $\Gamma(t \to Wb) = \sigma(t-\text{chan})\frac{\Gamma(t\to Wb)_{SM}}{\sigma(t-\text{chan})_{SM}}$
- $\Gamma_t = \Gamma(t \to Wb)/\mathcal{B}(t \to Wb)$.
- $R = \frac{\mathcal{B}(t\to Wb)}{\mathcal{B}(t\to Wq)}$ measured from $t\bar{t}$ data.
- Assume $\mathcal{B}(t \to Wq) = 1$.
- Use measured t-channel top cross section.



$\Gamma_t = 2.05^{+0.57}_{-0.52}$ GeV $\qquad \tau_t = (3.2^{+1.1}_{-0.7}) \times 10^{-25}$ s $\quad$ (0.3 ys!)

Conclusions

- DØ has a rich program of top quark physics — much more than can be covered in a 15-minute talk!
  - $t\bar{t}$ and single-t cross sections.
  - Top quark mass.
  - Other properties: $|V_{tb}|$, Γ_t, t charge, Wtb coupling, spin correlations, $\mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq)$, W boson helicity.
  - Searches related to top: $H^+ \to tb$, $W' \to tb$, FCNC, $t\bar{t}$ resonances, $t\bar{t}H$.
- Showed results with up to $5.3\,\mathrm{fb}^{-1}$ of data.
  - Up to $7.7\,\mathrm{fb}^{-1}$ recorded so far.
  - Tevatron continues to run and is performing well!
- No disagreement yet with SM.
- More details: http://www-d0.fnal.gov/Run2Physics/top