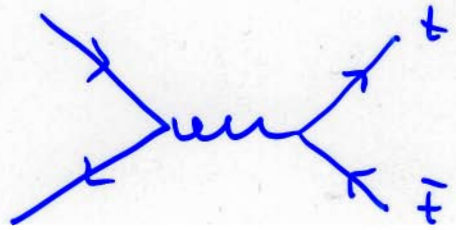
Top quark production

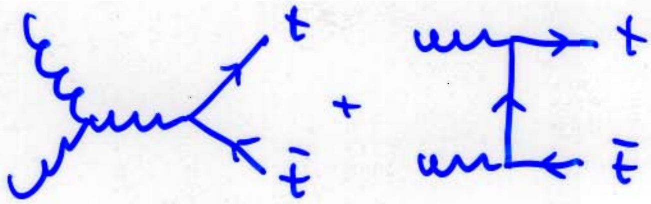
- pair production

$q\bar{q} \to t\bar{t}$



dominates at Tevatron

$gg \to t\bar{t}$

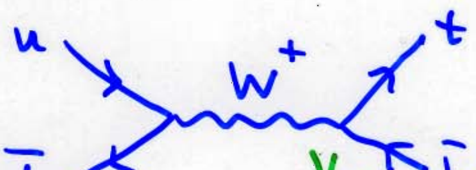


dominates at LHC

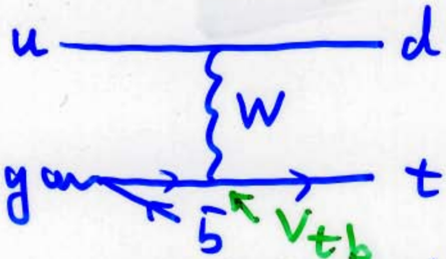
Expected production cross section

	Tevatron	LHC
$m_t = 175$ GeV	~ 5pb	~ 800pb

- single top production



s-channel



t-channel

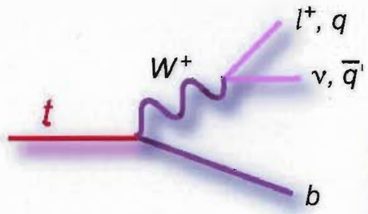
expected cross sections

	Tevatron	LHC
s-channel	0.8 pb	10 pb
t-channel	1.8 pb	240 pb

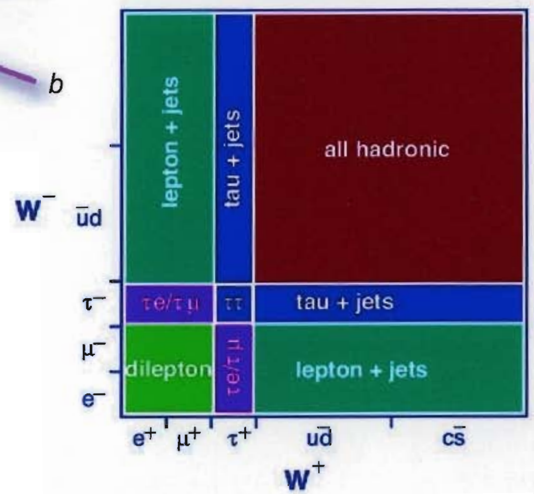
Top Quark Decay

Within the SM:

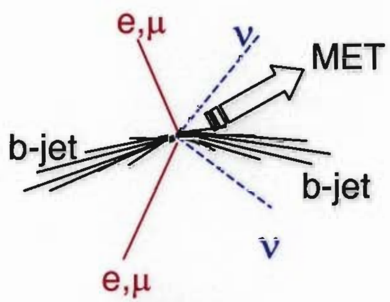
- $m_t > m_W + m_b \Rightarrow$ dominant 2-body decay $t \to Wb$
  ($t \to Ws$, Wd CKM suppressed)
  Assuming unitarity of 3-generation CKM matrix:
  $|V_{tb}| = 0.9990\text{-}0.9992$ @ 90% CL $\Rightarrow$ $B(t \to Wb) \sim 100\%$
- $\Gamma_t^{SM} \approx 1.4$ GeV at $m_t = 175$ GeV $\qquad \Gamma_t >> \Lambda_{QCD}$
  Top decays before top-flavored hadrons or tt-quarkonium bound states can form.
  Top quark spin efficiently transferred to the final state.



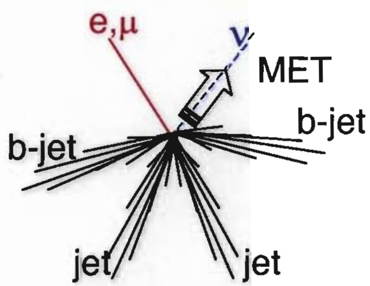
B(W → qq) ~ 67%
B(W → lν) ~ 11%, l=e,μ,τ



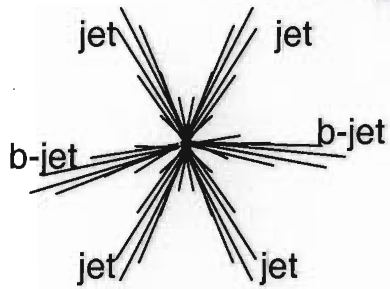
Typical final state signatures in top quark pair production:



Dilepton
(BR~5%, low bckg)



Lepton+jets
(BR~30%, moderate bckg)



All-hadronic
(BR~46%, huge bckg)

$\Rightarrow$ require multipurpose detectors

Lepton + jets signal: view back to '95

$$t\bar{t} \rightarrow bW^+ \bar{b}W^- \rightarrow b\bar{b}\, \ell^{\pm}\nu\, q\bar{q}'$$

Not all $b, \bar{b}, q, \bar{q}'$ may be visible as jets.

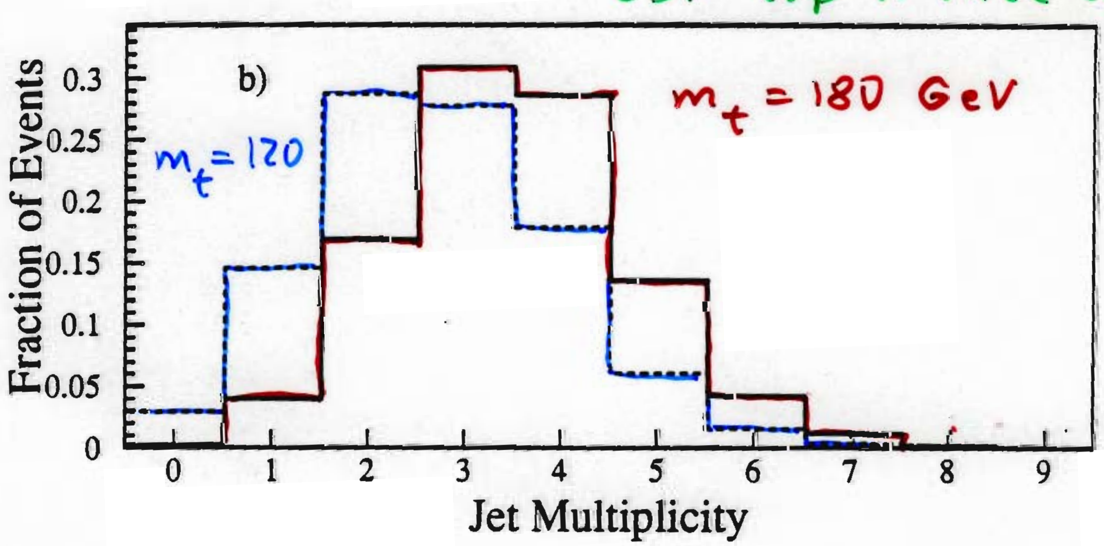
CDF jet definition for top search:

$$E_{Tj} \geq 15 \text{ GeV}, \quad |\eta_j| < 2, \quad R = 0.4$$

W definition

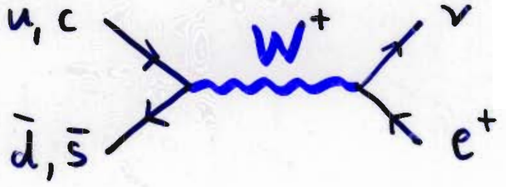
$$p_{Te} > 20 \text{ GeV}, \quad |\eta_e| < 1, \quad \not{E}_T > 20 \text{ GeV}$$

CDF top Monte Carlo



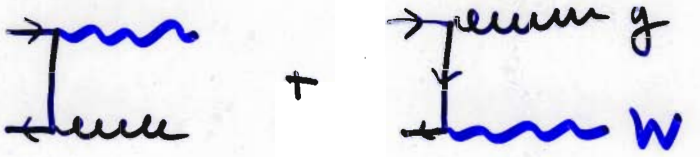
$\Rightarrow$ search in $\ell^{\pm} \not{E}_T + \geq 3j$ sample background : $(W \to \ell\nu) + n_{jet}$ jets

$n_{jet} = 0$:

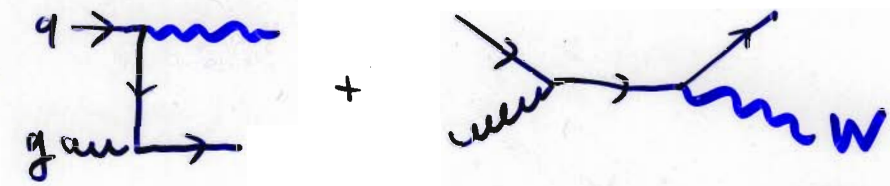


$n_{jet} = 1$ $(\mathcal{O}(\alpha_s))$

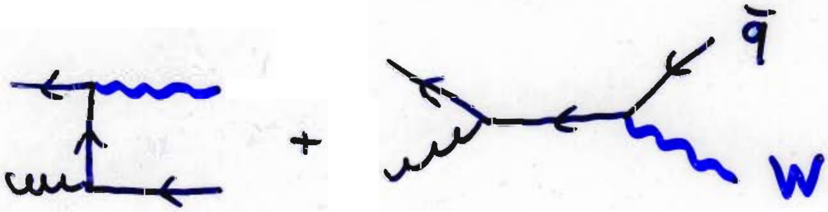
$q\bar{q}' \to Wg$:



$qg \to Wq'$:



$\bar{q}' g \to W\bar{q}$:



q, g can come from either p or $\bar{p}$!

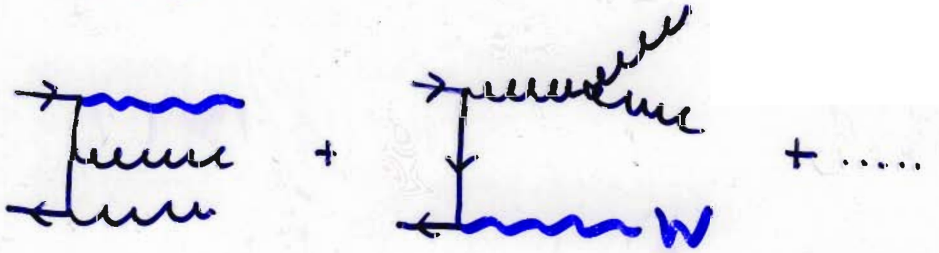
$n_{jet} = 2$ $(\mathcal{O}(\alpha_s^2))$

$q\bar{q}' \to Wgg$

$qg \to Wgq'$

$\bar{q}'g \to Wg\bar{q}$

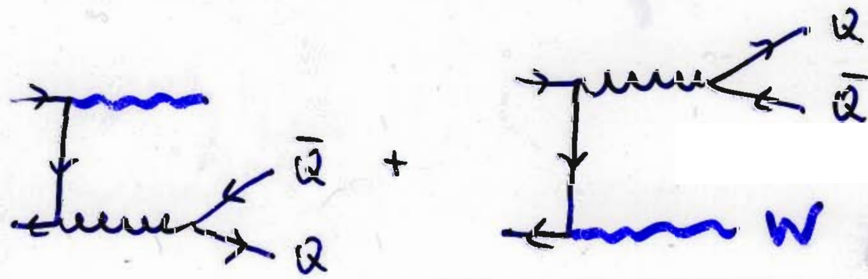
$gg \to W\bar{q}q'$



$q\bar{q}' \to WQ\bar{Q}$

$Qq \to WQq'$

etc.



$n_{jet} = 3$ $\quad (\mathcal{O}(\alpha_s^3))$

attach gluon to all $n_{jet} = 2$ graphs

158 different processes

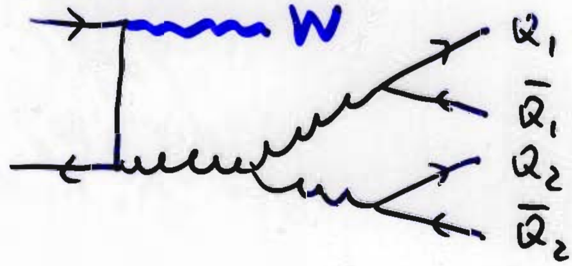
each with 12 .... 50 Feynman graphs

$n_{jet} = 4$ $\quad (\mathcal{O}(\alpha_s^4))$

attach gluon to all $n_{jet} = 3$ graphs

new processes:

$q\bar{q}' \to W Q_1 \bar{Q}_1 Q_2 \bar{Q}_2$



+ ....

→ hundreds of processes, each process with up to 516 Feynman graphs

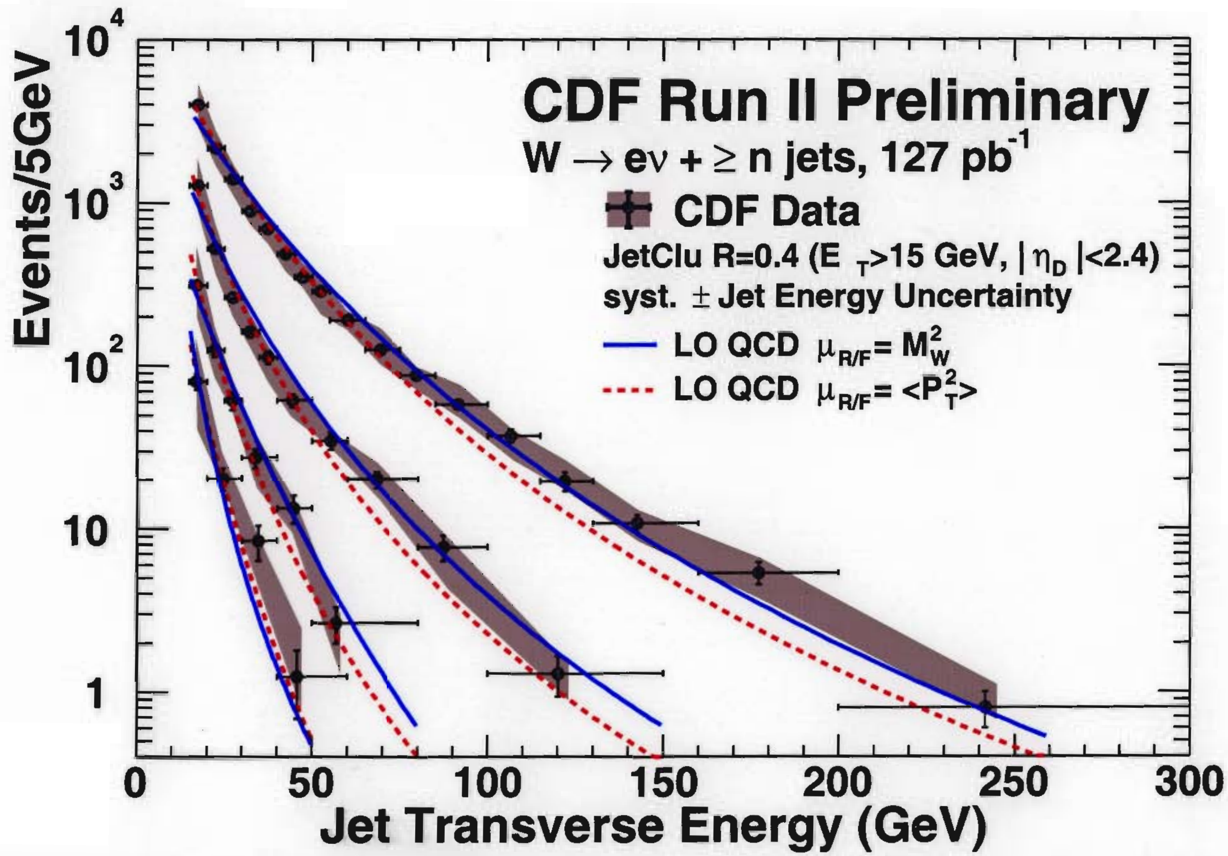
2 QCD calculations of W + 4 jets

Berends, Giele, Kuijf & Tausk (1991) VECBOS

Barger, Mirkes, Phillips, Stelzer (1994)

Jet E_T in $W + n$ jet events

E_T distribution of the n-th jet (n=1,2,3,4) in $W + n$ jet events
Jets are E_T ordered in descending order



Perturbative QCD gives good description of distribution of additional jets in W production: important for top quark search

Must use additional information

- top signal: 2 of the jets arise from b quarks

- W + 4 jet background: [Barger et al.]

2 b quarks	3 % of events
1 or 2c quarks	9 % of events

Enhance signal by looking for b-quarks

→ use two methods for b-tagging

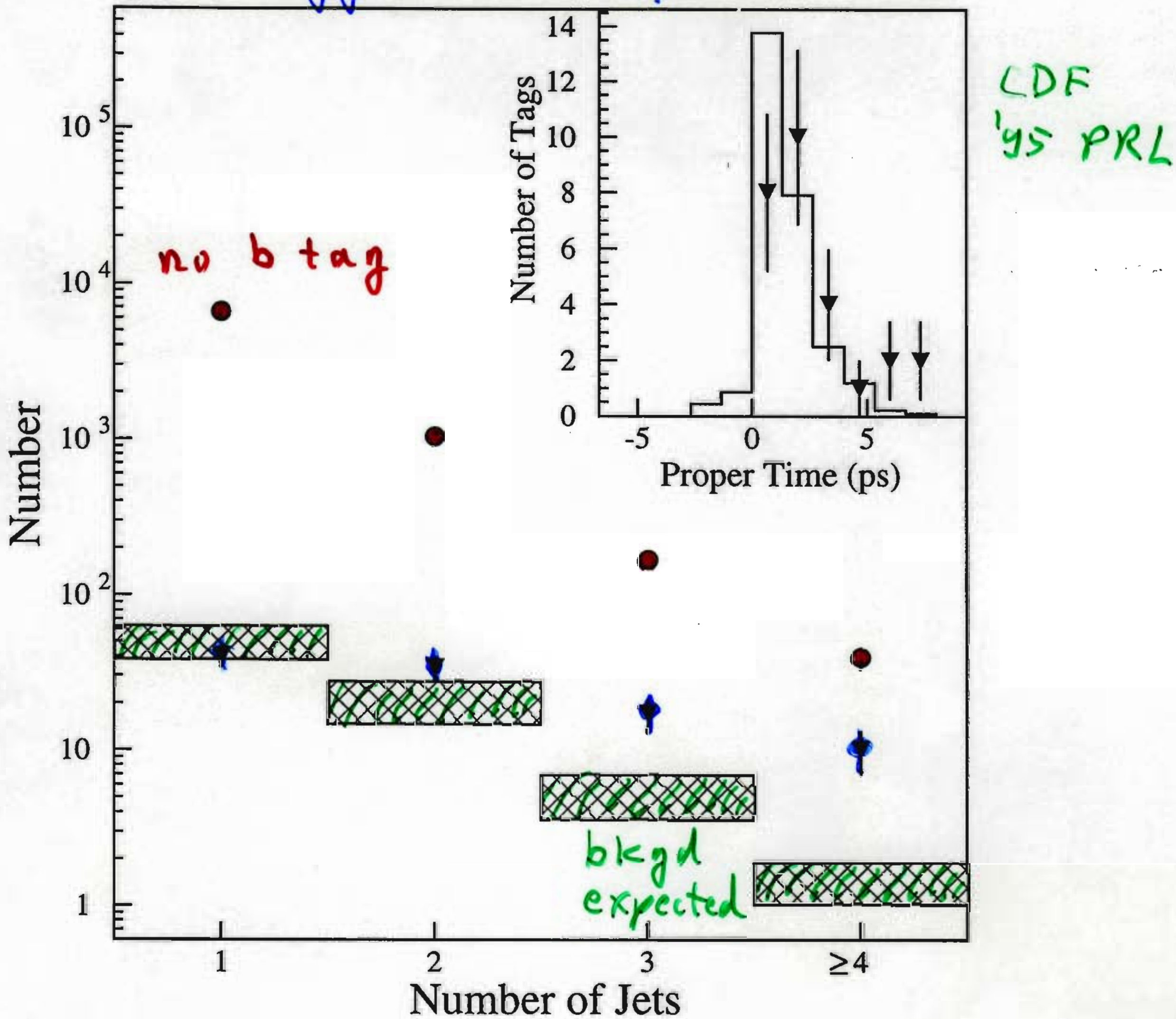
- Silicon vertex detector SVX

- Soft-Lepton tag SLT

Scale uncertainty small in ratio

$$\frac{\#\ \text{n-jet events with b-quarks}}{\#\ \text{all n-jet events}}$$

SVX tagged W+n jets events



clear excess of b-tagged W+3,4 jet events above SM background

→ top discovery in '95 by CDF and D0

Reconstructing the top quark mass

Constrained fit of data to top hypothesis

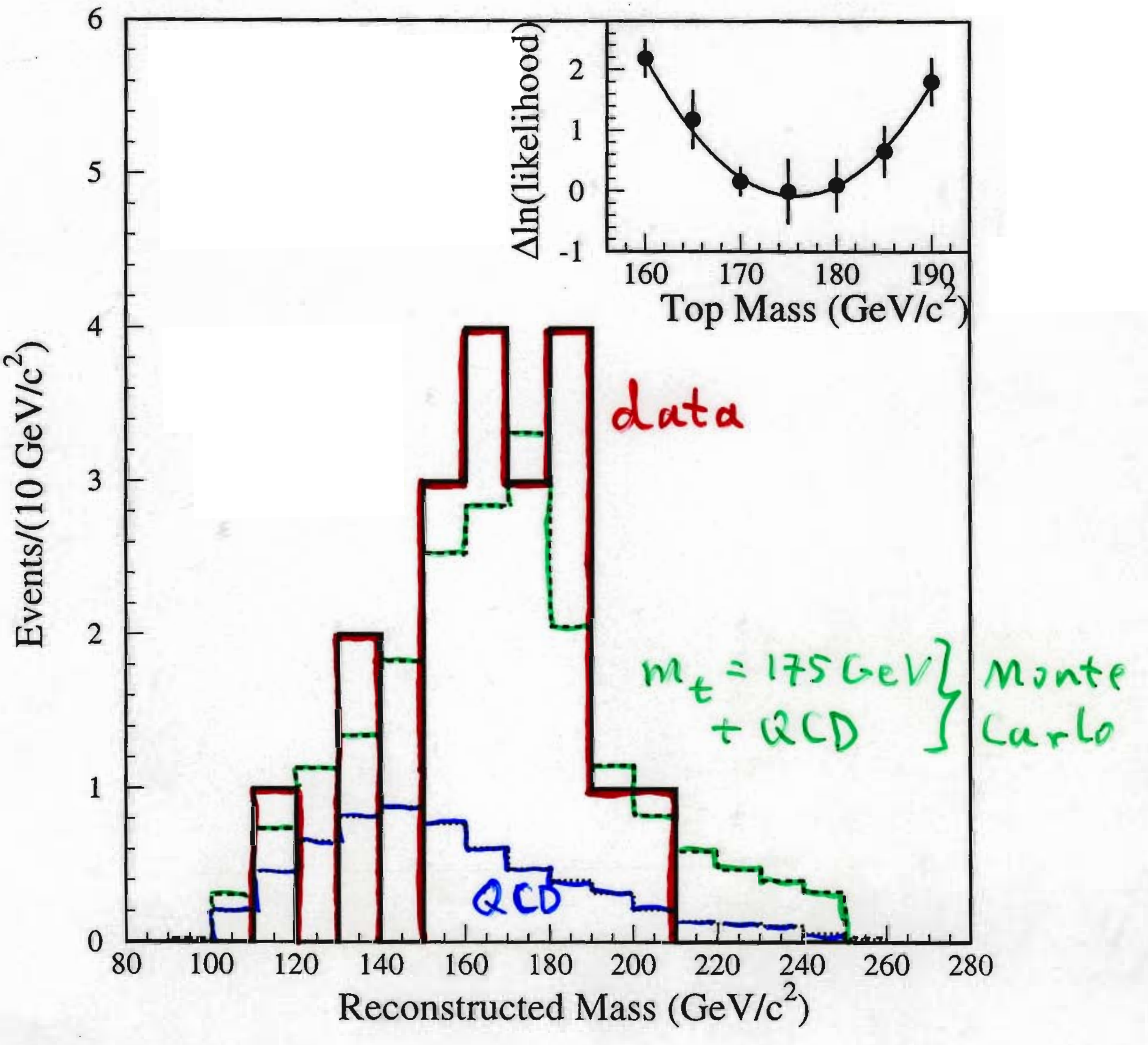
$p\bar{p} \rightarrow t_1 + t_2 + X$

$t_1 \rightarrow b_1 + W_1$

$t_2 \rightarrow b_2 + W_2$

$m_{t_1}, m_{t_2} \Big\} \; m_{t_1} = m_{t_2} = m_t$

$W_1 \rightarrow \ell\nu_1 , \; W_2 \rightarrow j_1 j_2 \qquad m_{e\nu} = m_W = m_{j_1 j_2}$



extracted m_t (1995): $m_t = 176 \pm 8 \pm 10$ GeV

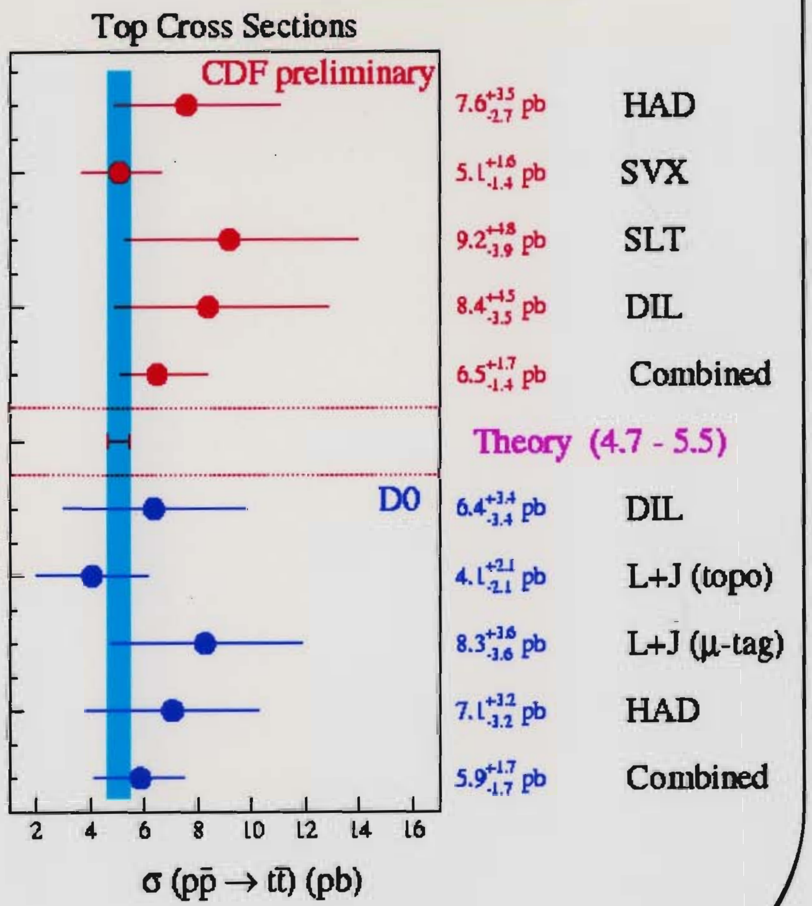
Top Quark Pair Production Cross Section

- The precise measurement of the top quark production cross section is a key element of the Top Physics program:
  - test of perturbative QCD and sensitive to New Physics (very important to compare measurements in as many channels as possible);
  - cross section analyses are the basis of any other top properties measurements;
  - crucial input for searches for which top events are a dominant background.

- Run I measurements consistent with the SM but precision ($\Delta\sigma_{tt}/\sigma_{tt}$~25%) limited by statistics.

- In Run II, most measurements will be systematics-limited: jet energy scale, signal/background modeling, luminosity determination (currently ~6%),…
  Large data samples should allow to control many of these uncertainties.

Run I Summary



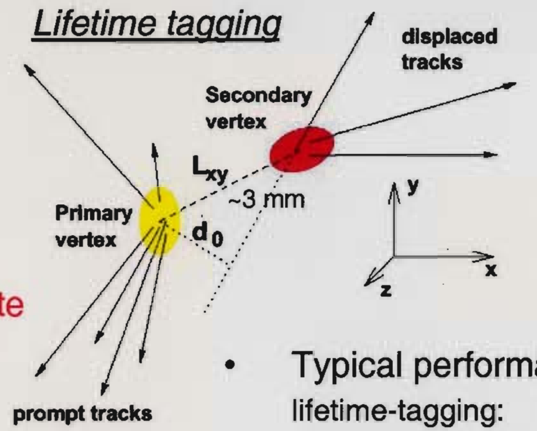
σ_{tt} : Lepton+Jets Final States (B-Tagging)

- One high p_T lepton (e or μ)
- High missing E_T
- ≥3 high p_T central jets, ≥1 b-tagged jets

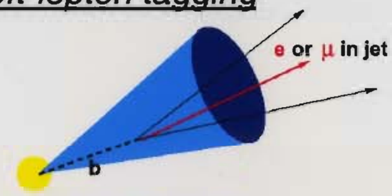
Backgrounds: W+jets, multijets

Use b-quark content to discriminate between signal and background.

Lifetime tagging



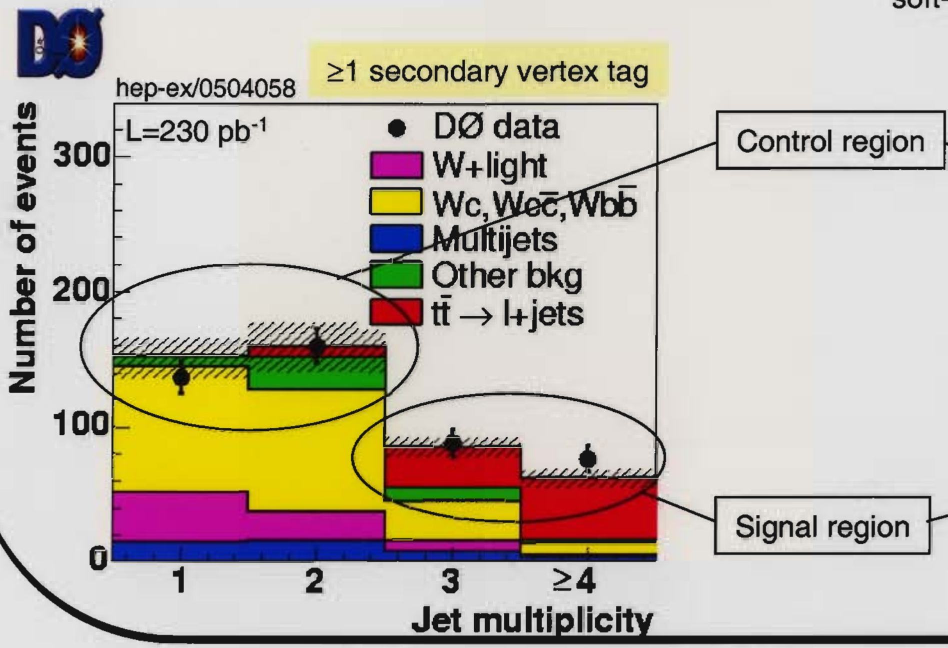
Soft-lepton tagging

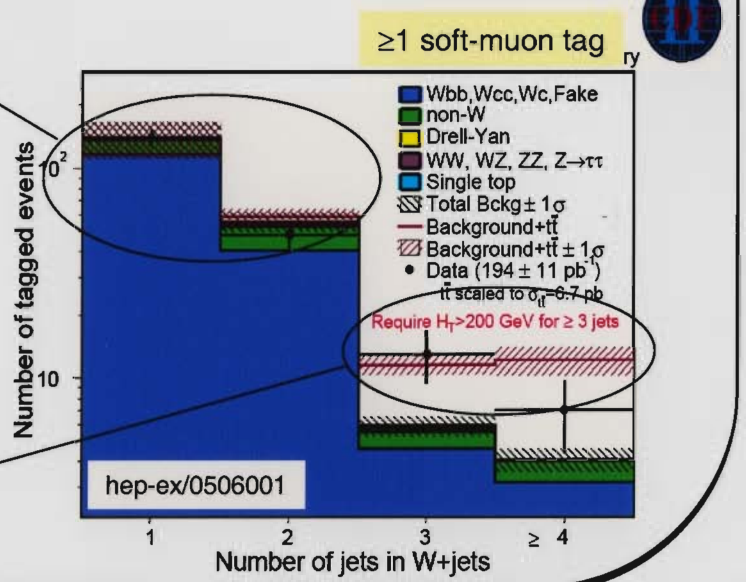


- $b \to \ell \nu c$ (BR ~ 20%)
- $b \to c \to \ell \nu s$ (BR ~ 20%)

- Typical performance (events with ≥4 jets)

lifetime-tagging: $P_{\geq 1\text{-tag}}(tt) \sim 60\%$,
soft-muon tagging: $P_{\geq 1\text{-tag}}(tt) \sim 16\%$,
$P_{\geq 1\text{-tag}}(W\text{+jets}) \sim 4\%$



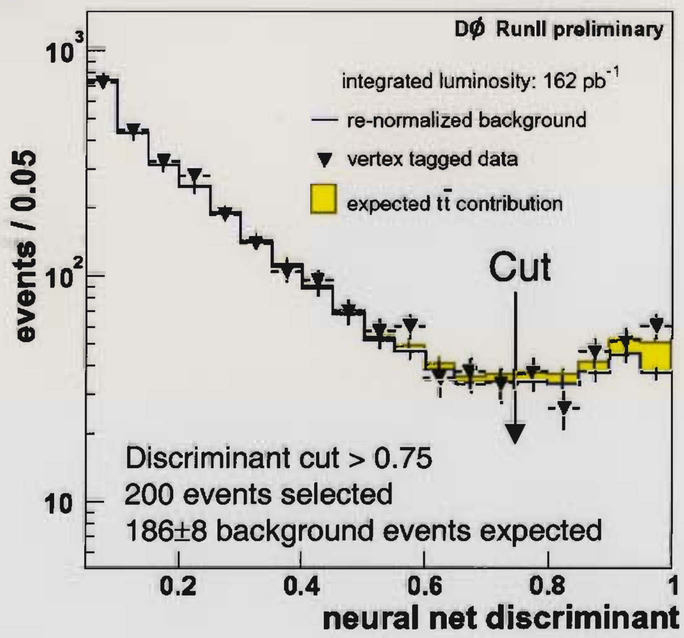


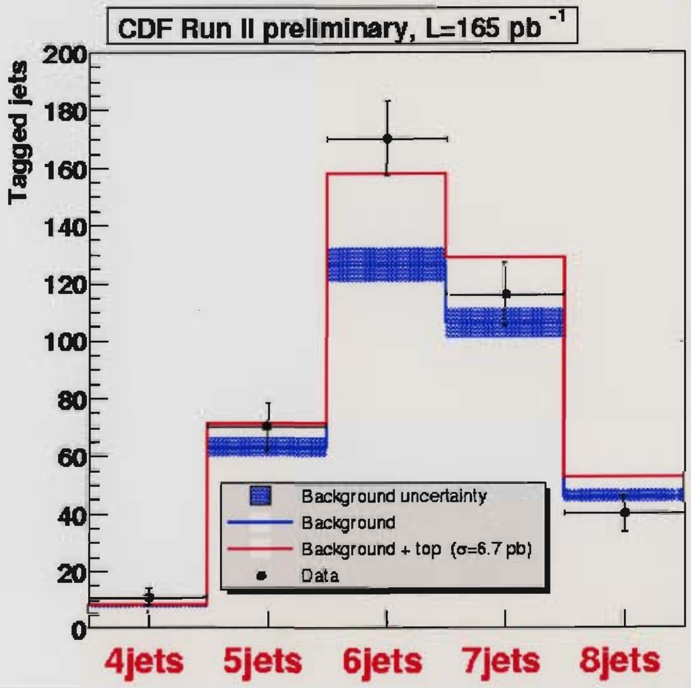
σ_{tt} : All-Hadronic Final State

- $\geq$ 6 high p_T central jets
- Overwhelming QCD multijets background (S/B~1/2500 after $\geq$ 6 jets requirement)
- Very challenging: currently considered nearly impossible at the LHC.
- Jet energy scale dominant systematic

Strategy:

- Use kinematic and topological variables to further increase S/B: cuts (CDF) or multivariate discriminant (DØ)
- Require b-tagging
- Background predicted from data





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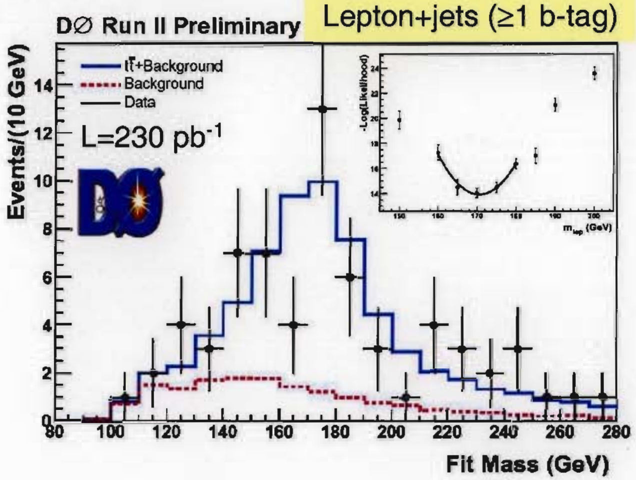
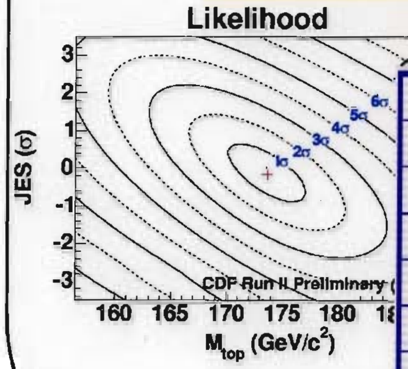
Top Quark Mass: Template Methods

- Principle: perform kinematic fit and reconstruct top mass event by event. Build templates from MC for signal and background and compare to data.
- Recent developments in this approach have lead to the most precise to date top mass measurement:

$$m_t = 173.5^{+3.7}_{-3.6}(stat + JES) \pm 1.7\,\mathrm{GeV}$$
$$= 173.5^{+4.1}_{-4.0}\,\mathrm{GeV}$$

More precise than current world average!
(m_t = 178.0 ± 4.3 GeV)

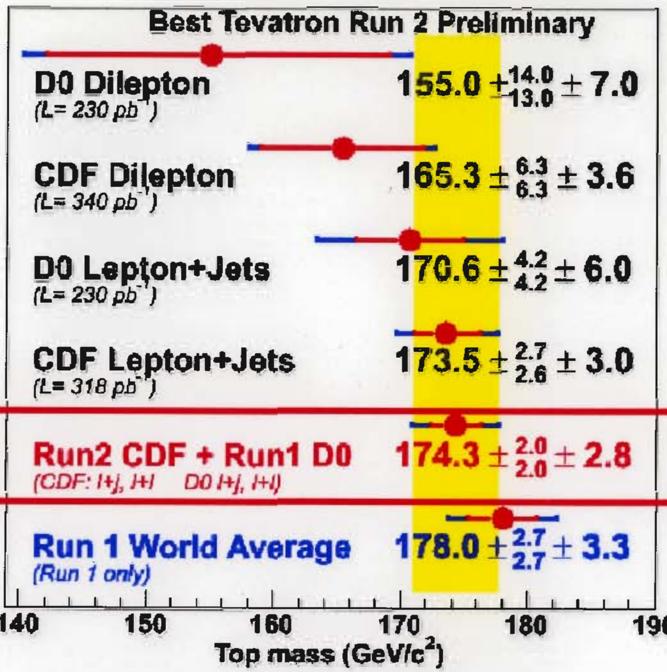




Source	δM_{top}(GeV/c²)
B-jets modeling	0.6
Method	0.5
ISR	0.4
FSR	0.6
Background shape	1.1
PDF	0.3
Other MC modeling	0.4
Total	1.7

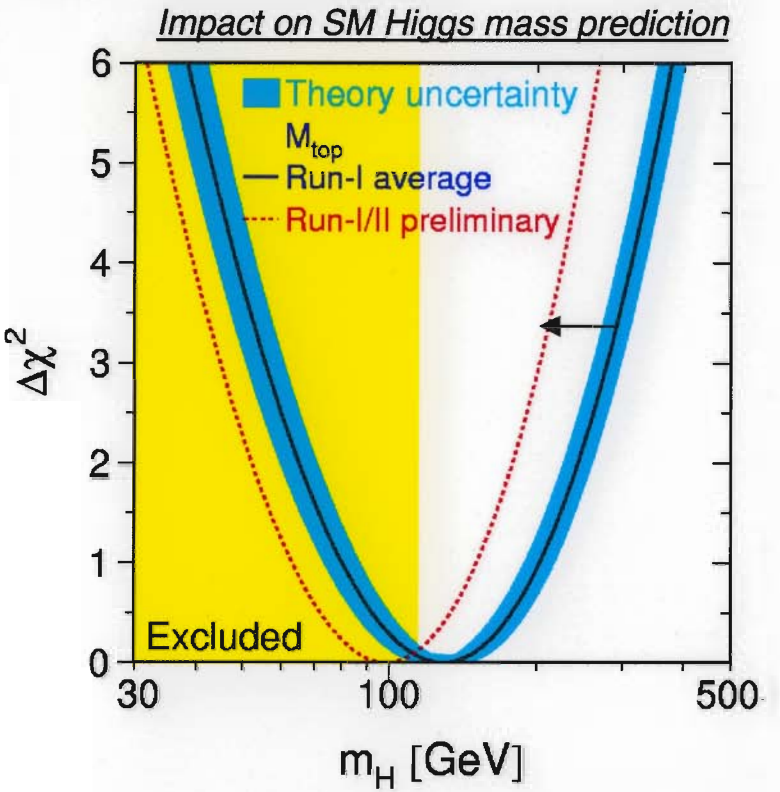
- Improve statistical power by defining four subsamples (based on number of tags) with different background content and sensitivity to m_t.
- Reduce JES systematic by using in-situ hadronic W mass in tt events: simultaneous determination of m_t and JES from reconstructed m_t and M_W templates. Implement constraint on JES from external measurement (~3%).
- Many systematics are expected to decrease with larger data samples.

Top Quark Mass: Summary



- New Run II single measurements achieving uncertainties comparable to/better than current Run I world average.
- BREAKING NEWS: New preliminary world average combining CDF Run II and DØ Run I.

$m_t = 174.3 \pm 3.4\,\text{GeV};\ \chi^2/dof = 3.6/3$



$M_H = 129^{+74}_{-49}\,\text{GeV};\ M_H < 285\,\text{GeV} @ 95\%\text{CL}$

$M_H = 98^{+52}_{-36}\,\text{GeV};\ M_H < 208\,\text{GeV} @ 95\%\text{CL}$

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