Status and Prospects on Top Physics at CDF

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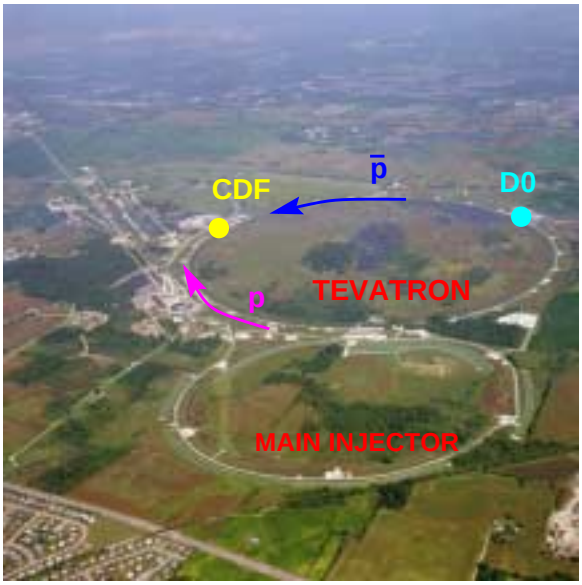
Outline

- Overview of CDF Run II and Top Physics
- Top Physics Results from Run I
- Status of Top Analysis in CDF Run II
- Top Physics Prospects in CDF Run II
- Summary

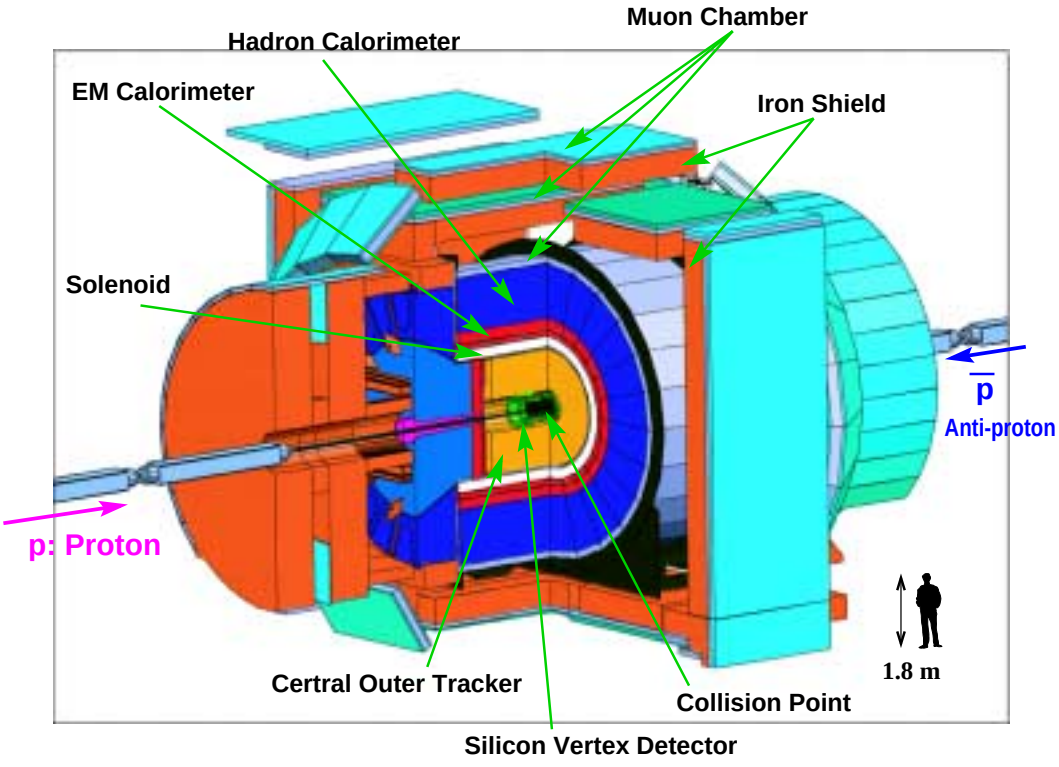
CDF Run II Overview

TEVATRON: $p\bar{p}$ collider

$\sqrt{s} = 1.8\,\mathrm{TeV}$ (Run I) $\longrightarrow 1.96\,\mathrm{TeV}$ (Run II)



CDF Run II Detector



Integrated Luminosity

- Run 0 4.5 pb^{-1} (1988-1989)
- Run Ia 19 pb^{-1} (1992-1993)
- Run Ib 90 pb^{-1} (1994-1996)

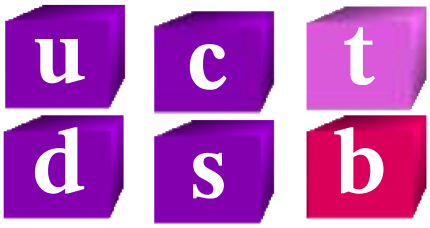
Run I total 109 pb^{-1}

Run II

- Run IIa started at March, 2001.
- So far(mid-Dec, 2002) obtained $\sim 80\ \mathrm{pb}^{-1}$ as good runs ($\sim 60\,\mathrm{pb}^{-1}$ w/ Silicon).
- Run IIa will last until end of 2004.
- The luminosity goal for Run IIa is $2\,\mathrm{fb}^{-1}$.
- 6-month shutdown to upgrade to Run IIb in 2005.
- The luminosity goal for Run IIa+Run IIb is $15\,\mathrm{fb}^{-1}$.

Brief Introduction of Top Physics

- Top quark in the Standard Model:
  Partner of b-quark in SU(2) doublet of weak isospin in the third generation.



  - Mass: $M_t \approx 175\,\mathrm{GeV}/c^2$
    Width: $\Gamma_t \simeq 1.42\,\mathrm{GeV}$
  - Top quark decays before hadronization.
  - Yukawa coupling $\sqrt{2}\frac{m_t}{v} \approx 1$
  - Special role in electroweak symmetry breaking?

- Discovered by CDF and D0 in 1995

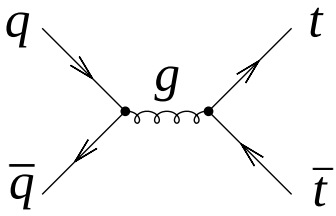
CDF : F. Abe *et al.* Phys. Rev. Lett. 74 (1995) 2626
D0 : S. Abachi *et al.* Phys. Rev. Lett. 74 (1995) 2632

Top Quark Production at Tevatron

$t\bar{t}$ pair production thru. strong interaction

$\sigma(t\bar{t}) \sim 5\,\mathrm{pb}$ at $\sqrt{s} = 1.8\,\mathrm{TeV}$

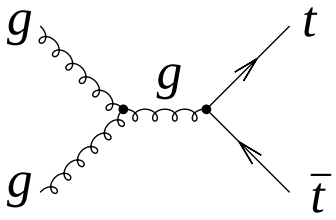
$\sim 7\,\mathrm{pb}$ at $\sqrt{s} = 1.96\,\mathrm{TeV}$

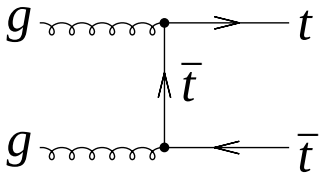


$q\bar{q}$ annihiration

$\sim 90\%$(Run I)

$\sim 85\%$(Run II)





gluon fusion

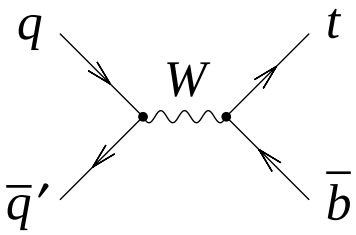
$\sim 10\%$(Run I)

$\sim 15\%$(Run II)

Single-top production via EW interaction

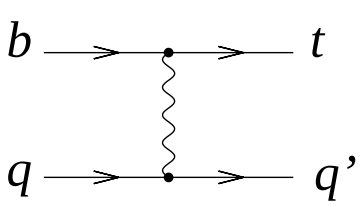
$\sigma(\mathrm{single}-t) \sim 2.4\,\mathrm{pb}$ at $\sqrt{s} = 1.8\,\mathrm{TeV}$

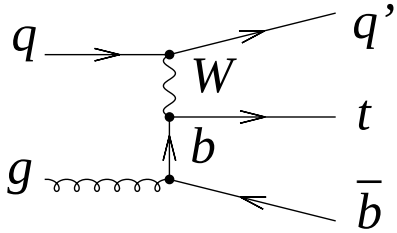
$\sim 3\,\mathrm{pb}$ at $\sqrt{s} = 1.96\,\mathrm{TeV}$



s-channel W^*

$\sim 32\%$(Run I)





t-channel

$\sim 62\%$(Run I)

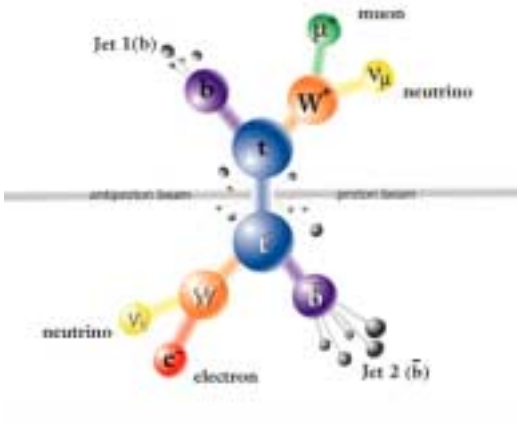
W-gluon fusion

3 classes of signal in $t\bar{t}$ production

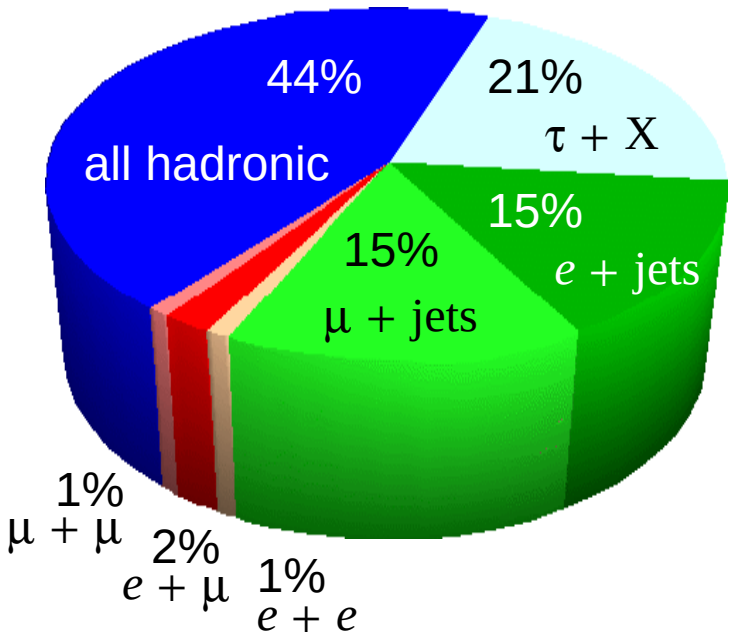
- In Standard model, top quark goes W+b at a rate of $\sim$100%:
  $\mathrm{Br}(t \to W^+ b) \simeq 1$
- Decay channels of $t\bar{t}$ pair

$t \to W^+ b$
$\hookrightarrow$
$\bar{t} \to W^- \bar{b}$
$\hookrightarrow$

$\ell^+\nu$	$q\bar{q}'$	$\ell^+\nu$	$q\bar{q}'$
$\ell^-\bar{\nu}$	$\ell^-\bar{\nu}$	$q\bar{q}'$	$q\bar{q}'$

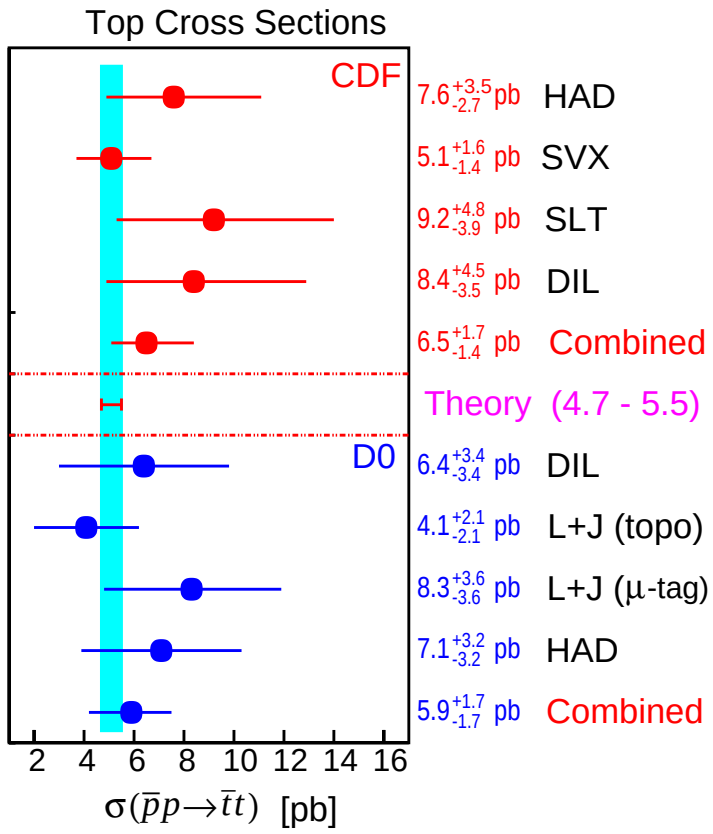


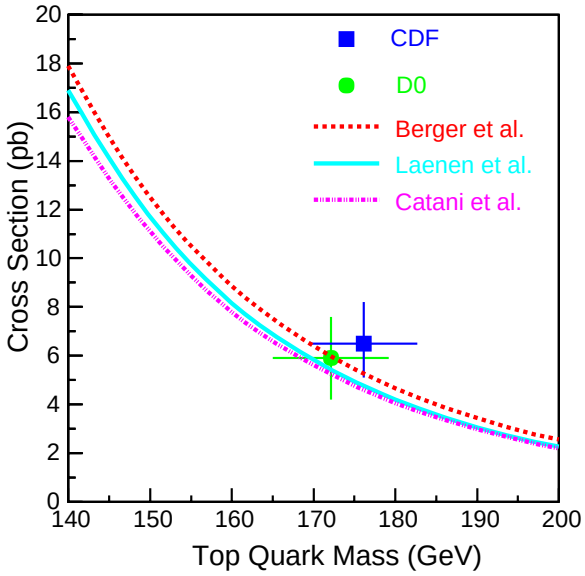
Fraction of decay channels of $t\bar{t}$



Results of top physics in CDF Run I

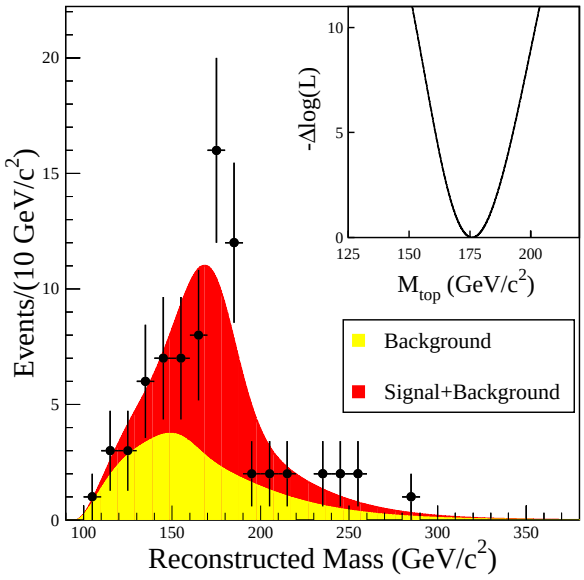
$t\bar{t}$ production cross section in Run I



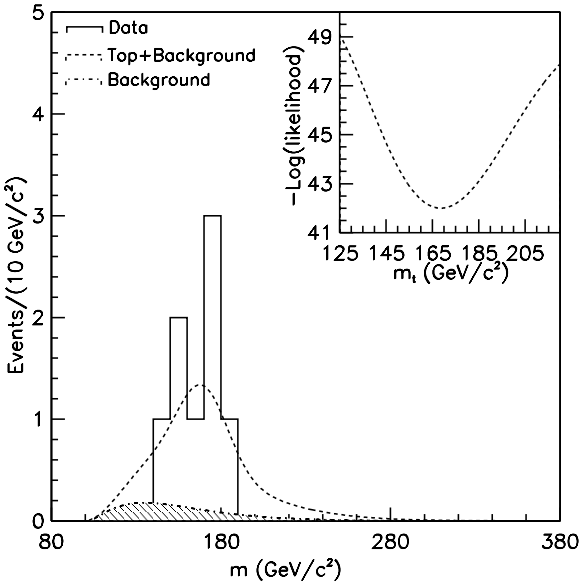


- Several independent measurement of $\sigma_{t\bar{t}}$. The combind result of CDF run I is:
- $$\sigma_{t\bar{t}} = 6.5^{+1.7}_{-1.4}\,\mathrm{pb} \quad \text{at} \quad \sqrt{s} = 1.8\,\mathrm{TeV}$$
- Test of perturbative QCD predictions.
  - $\rightarrow$ NLO($O(\alpha_s^3)$)
  - $\rightarrow$ Soft gluon resummation
- In good agreement with predictions.

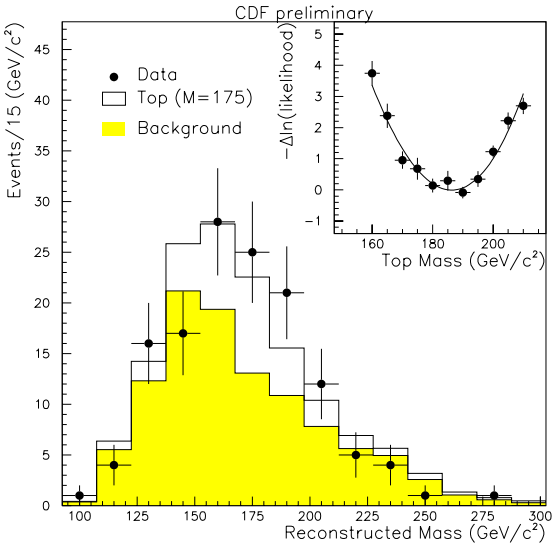
Top quark mass in Run I



l+jets 76 events

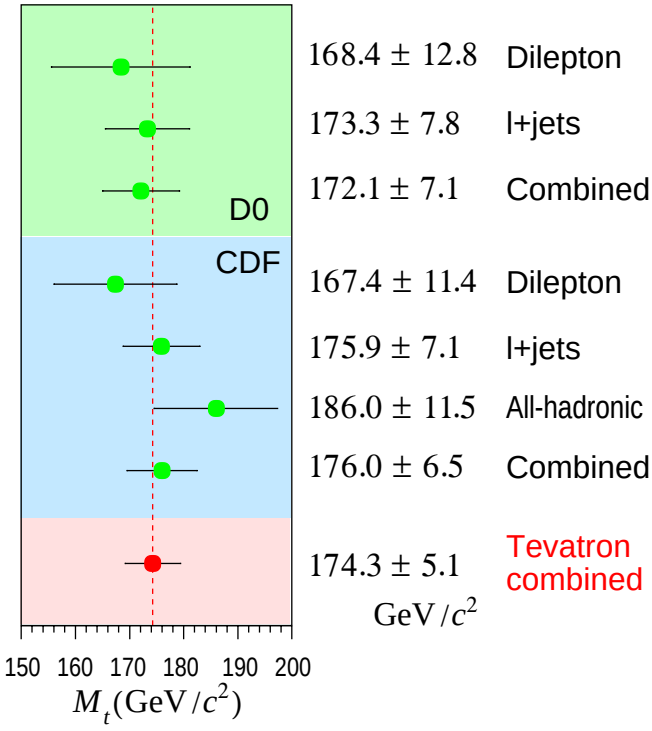


Dilepton 8 events



All hadronic 187 events

Tevatron Top Quark Mass Measurements

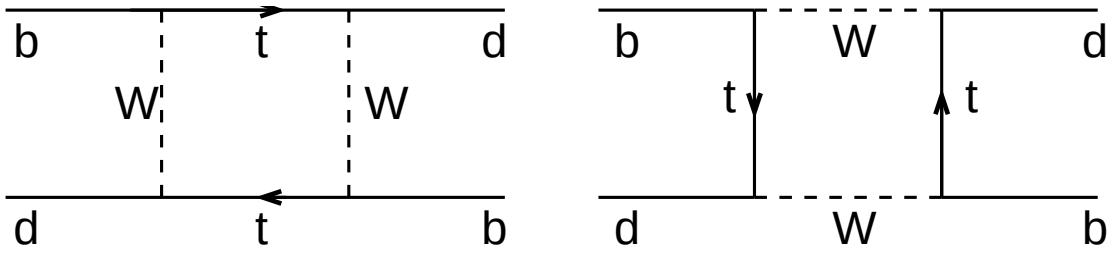


The combind result of CDF in Run I is:

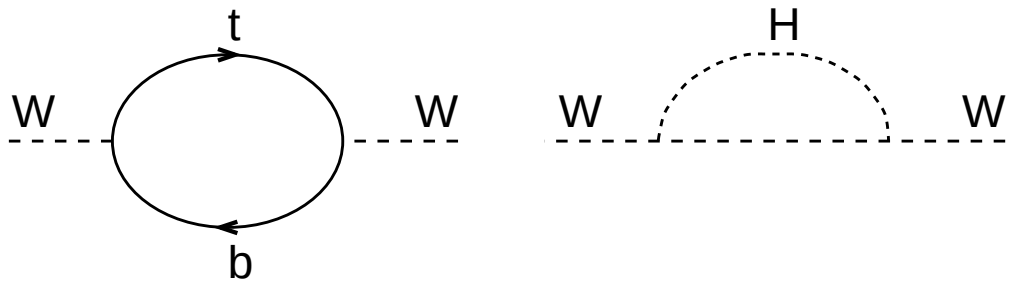
$$M_t = 176.0 \pm 6.5\,\mathrm{GeV}/c^2$$

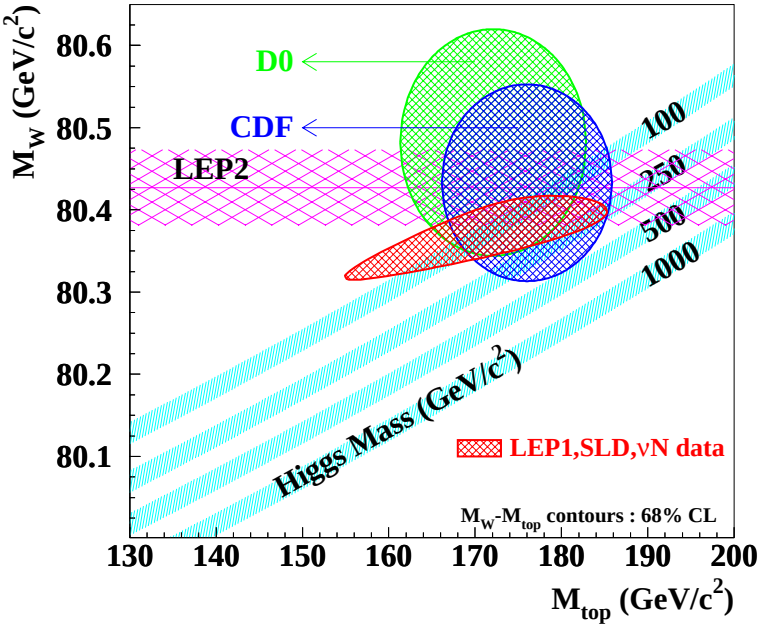
Topics on top quark mass

- Important parameter for predictions of SM via radiative corrections.



- Measurements of M_W and m_t constrain M_H.
  $\delta M_W = f(m_t^2, \log M_H)$



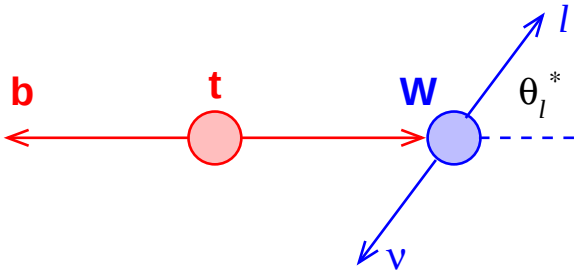


W helicity in top decays

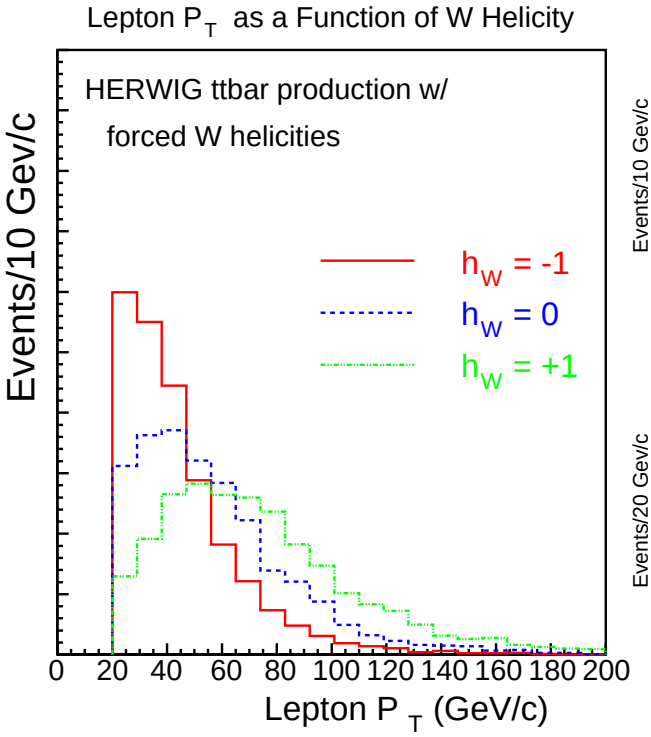
In Standard Model (V-A theory), top quark decays only to longitudinally polarized or left-handed W.

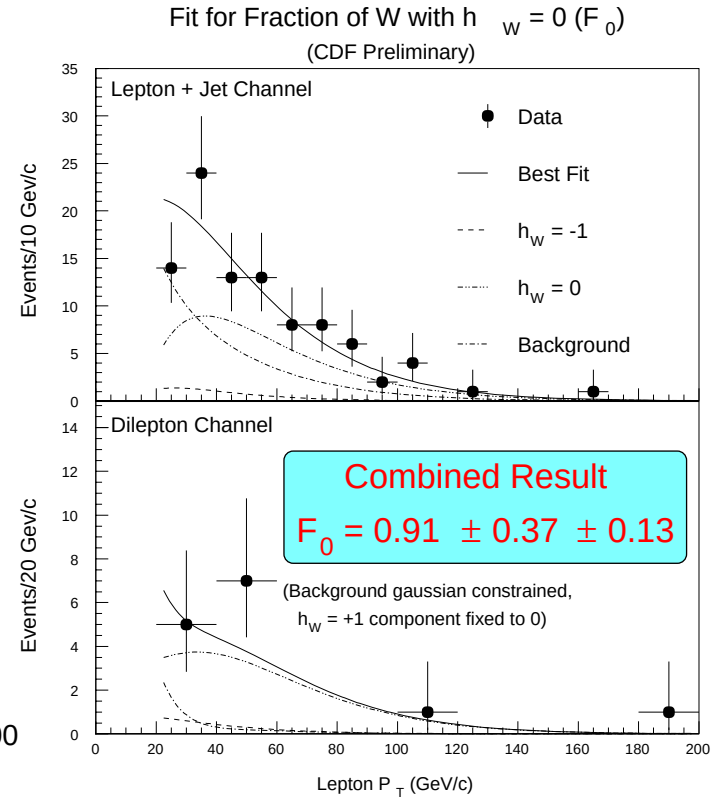
$$h_W = 0 \text{ or } -1 \qquad \frac{\mathrm{Br}(t \to b W_{\mathrm{long}})}{\mathrm{Br}(t \to b W_{\mathrm{left}})} = \frac{1}{2}\left(\frac{m_t}{m_W}\right)^2 = \frac{0.70}{0.30}$$

Lepton P_T distributions in $t \to b\ell\nu$ distinguish the three helicity states of W.



$$|\mathfrak{M}(W_{\mathrm{left}})|^2 \propto \frac{1}{4}(1-\cos\theta_l^*)^2$$
$$|\mathfrak{M}(W_{\mathrm{long}})|^2 \propto \frac{1}{2}(\sin\theta_l^*)^2$$
$$|\mathfrak{M}(W_{\mathrm{right}})|^2 \propto \frac{1}{4}(1+\cos\theta_l^*)^2$$





CDF Run I Results		SM
$\mathcal{F}_{\mathrm{long}} = 0.91 \pm 0.37(\mathrm{stat}) \pm 0.12(\mathrm{syst})$	$\Longleftrightarrow$	~ 0.7
$\mathcal{F}_{\mathrm{right}} = 0.11 \pm 0.15(\mathrm{stat}) \pm 0.06(\mathrm{syst})$		0

Single top search in CDF Run I

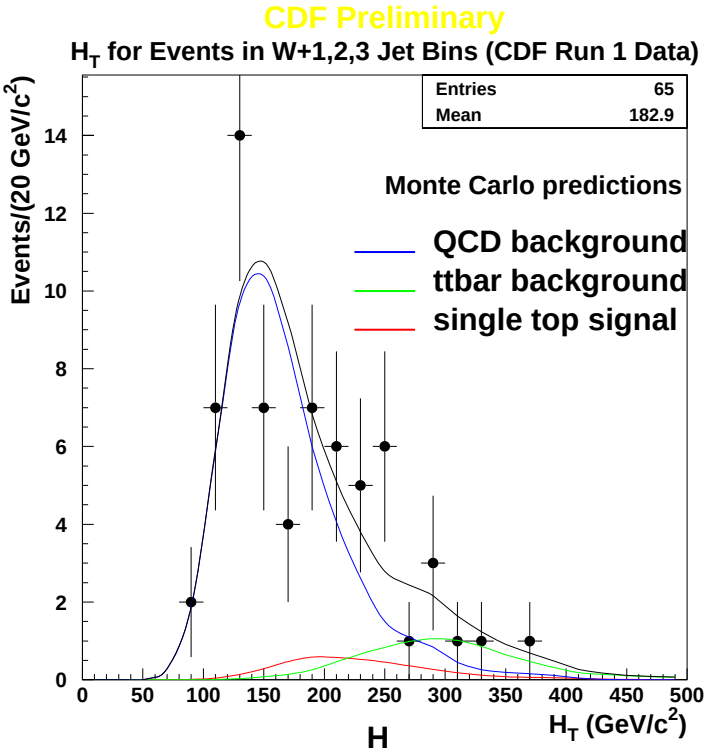
- Direct measurement of $|V_{\rm tb}|$ of EW vertex t-W-b.
- Two dominant production processes at Tevatron.
  - W-gluon fusion:
    Hard b-jet, W decay, (soft b-jet), light q jet
  - s-channel W^*:
    2 hard b-jets, W decay

Event signiture: W decay + n jets(one or two b-tagged)

$\rightarrow$ After all event selections, look at

$$H_t \equiv |\not\!\!E_T| + |E_T(\ell)| + \sum |E_T(\text{all jets})|$$

$\rightarrow$ Unbinned maximum likelihood fit to H_t distribution.



$$\sigma(Wg + W^*) < 14\,\text{pb}$$

Other results on top physics in CDF Run I

- Branching ratio $R = \frac{\mathrm{Br}(t \to \mathrm{Wb})}{\mathrm{Br}(t \to \mathrm{Wq})}$.

  $R = 0.94^{+0.31}_{-0.24}$ $\quad |V_{\mathrm{tb}}| = 0.97^{+0.16}_{-0.12}$

  (assuming 3 generations)

- Search for FCNC top quark decays.

  strongly GIM suppressed in the SM:

  - $p\bar{p} \to t\bar{t} + X$ with $t \to W + b$ and $\bar{t} \to \bar{u}/\bar{c} + \gamma$

    $\mathrm{Br}(t \to u/c + \gamma) < 3.2\%$ (95%CL)

  - $p\bar{p} \to t\bar{t} + X$ with $t \to W + b$ and $\bar{t} \to \bar{u}/\bar{c} + Z^0$

    $\mathrm{Br}(t \to u/c + Z^0) < 33\%$ (95%CL)

Run II Status

Expect first results on top physics in March 2003.
Ongoing analyses on top physics:

- $t\bar{t}$ production cross section in dilepton channel.
- $t\bar{t}$ production cross section in l+4jets channel.
- Top quark mass reconstruction.

Towards a dilepton $t\bar{t}$ cross section measurement

Calculation is based on the following expression:

$$\sigma_{t\bar{t}}^{\mathrm{dilepton}} = \frac{N_{\mathrm{obs}} - B}{\epsilon_{\mathrm{tot}}\mathcal{L}}$$

Based on the data taken from 2002.3.23 to 2003.1.12

- $\mathcal{L}$: Total integrated luminosity.
  $\Rightarrow 109\,\mathrm{pb}^{-1}$(Run I) $\longrightarrow$ Now printing.
- N_{obs}: Number of observed candidates.
  $\Rightarrow 9/109\mathrm{pb}^{-1}$ (Run I) $\longrightarrow$ Now printing.
- B : Total background estimate.
  Following background sources are considered.
  - WW, $Z \to \tau\tau$, Drell-Yan, and Fake(jet $\to \ell$)

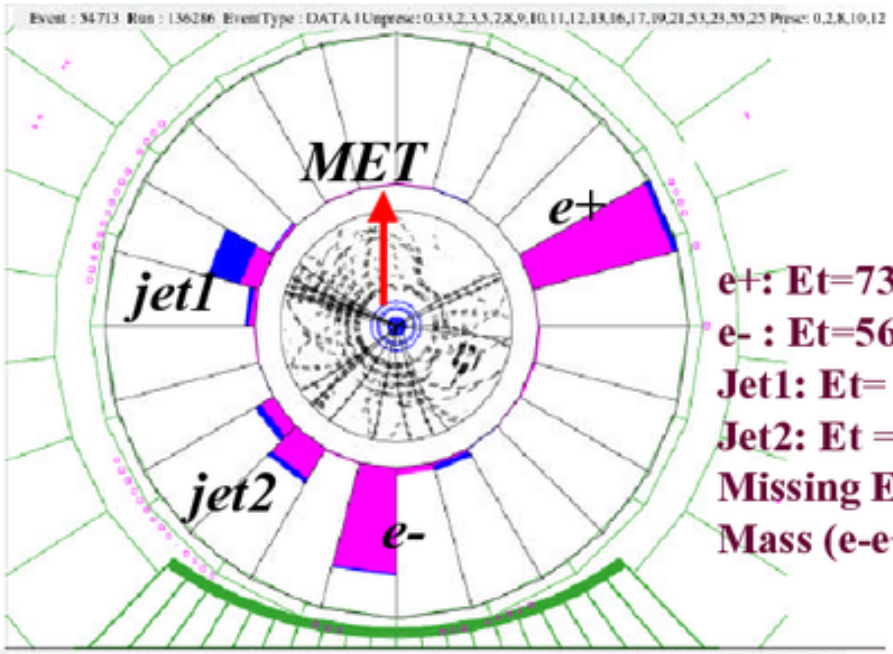
  $\Rightarrow 2.4 \pm 0.5/109\mathrm{pb}^{-1}$ (Run I) $\longrightarrow$ Now printing.
- ϵ_{tot}: Total signal acceptance.
  $\Rightarrow$ 0.76% (Run I) $\longrightarrow$ Now printing.

All items are about to be finalized!

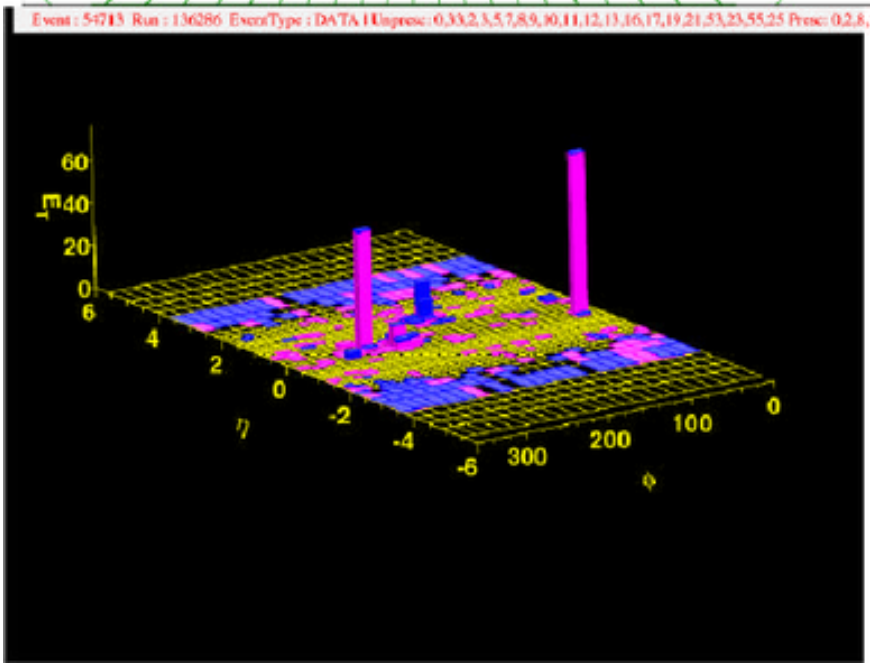
A top dielectron candidate

- e+e-,two jets with a large missing Et -

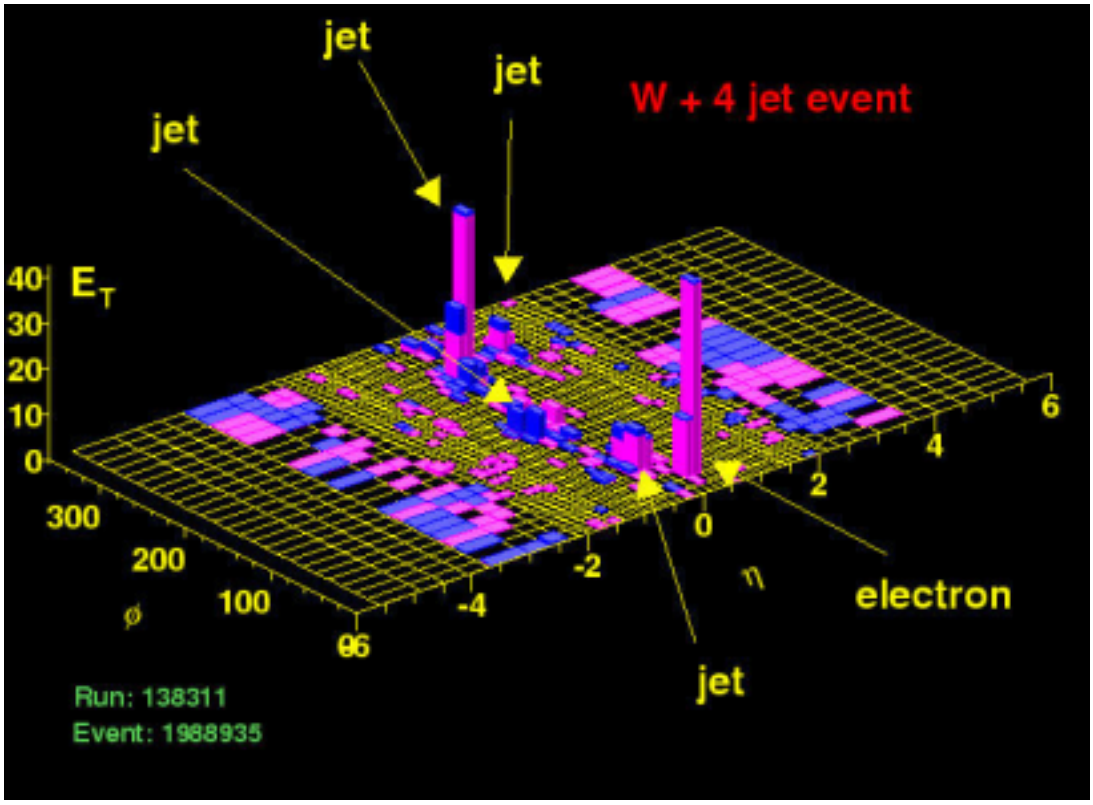
Run=136286, event=54713



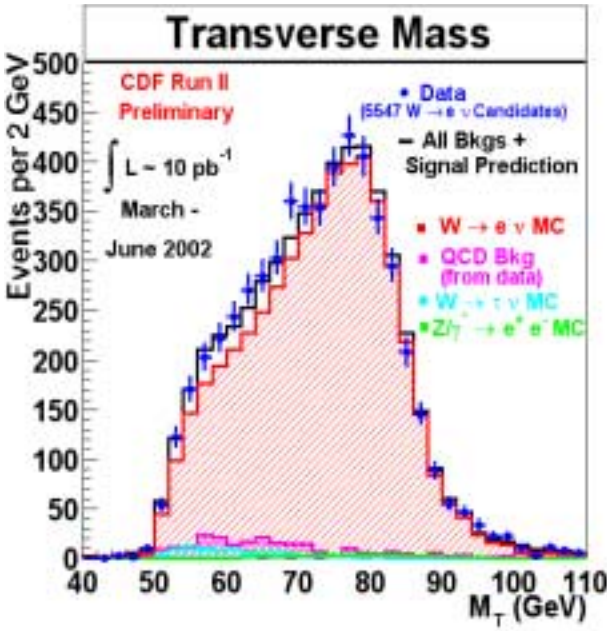
e+: Et=73 GeV
e- : Et=56 GeV
Jet1: Et= 35 GeV
Jet2: Et = 34 GeV
Missing Et = 43 GeV
Mass (e-e+)=118 GeV



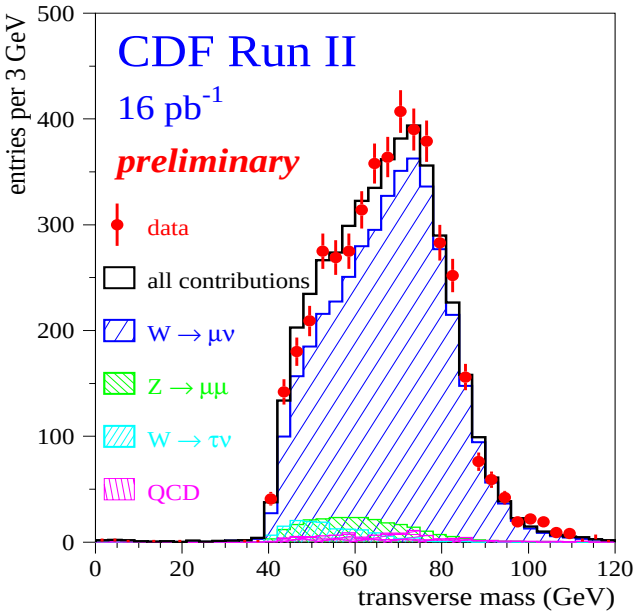
l+4jets candidate



W candidates in Run II CDF data



$W \to e\nu$ events



$W \to \mu\nu$ events

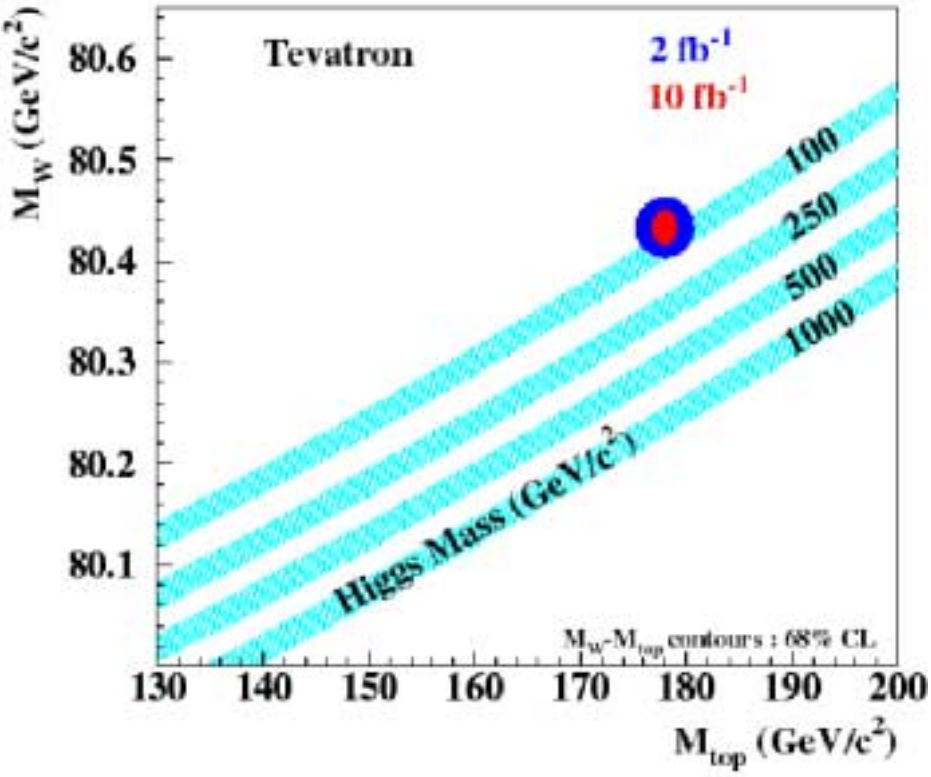
Run II Prospects

Run IIa luminosity goal is $2\,\mathrm{fb}^{-1}$. This means at least 20x higher statistics, which will allow:

Top quark mass

$\rightarrow$ δM_t : $6.5\,\mathrm{GeV}/c^2$(Run I) $\longrightarrow$ $3\,\mathrm{GeV}/c^2$(Run II)

$\rightarrow$ Constraint for higgs mass: $\delta M_h/M_h \sim 40\%$



$\rightarrow$ Expected accuracies by the end of Run IIb:

$\delta M_t \approx 1.4\,\mathrm{GeV}/c^2$, $\delta M_W \approx 16\,\mathrm{MeV}/c^2$

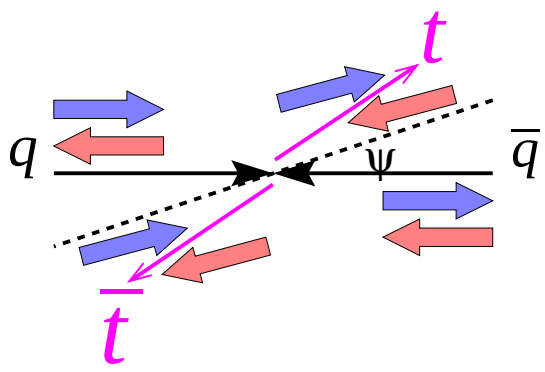
$\Longrightarrow \delta M_h/M_h \sim 25\%$

$t\bar{t}$ spin correlations

- Top quark decays before losing the spin information at production.
- $\sim 90\%$ of $t\bar{t}$ pairs produced at Tevatron come from $q\bar{q}$ annihilation.

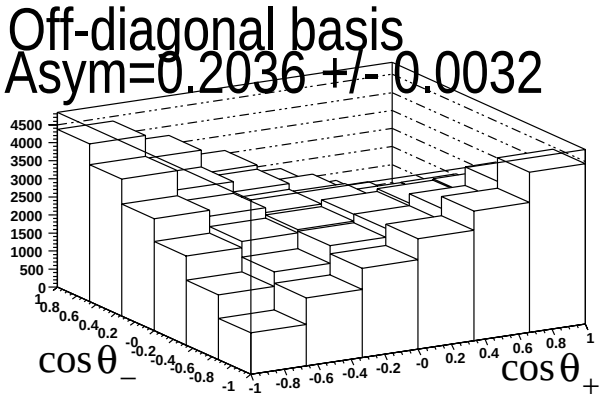
  $\rightarrow$ Only like-spin combinations in $t\bar{t}$, if we take an optimal spin quantization basis.

  $\Longrightarrow$ "Off-diagonal basis"

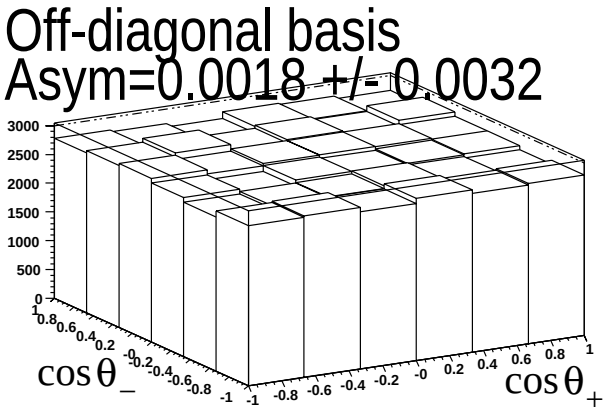


- Top spin can be measured by lepton flight direction in top the rest frame.

Herwig6.5 generator level



w/ Spin correlation



w/o Spin correlation

- Run IIa will provide up a good opportunity for observing the $t\bar{t}$ spin correlations.

$t\bar{t}$ production cross-section

$\delta\sigma_{t\bar{t}}$: 25% (CDF Run I) $\longrightarrow$ 10% ($2\,\mathrm{fb}^{-1}$)
$\longrightarrow$ 5% ($15\,\mathrm{fb}^{-1}$)

Single top production cross-section

- $\rightarrow$ Observe 100-200 single top events.
- $\rightarrow$ $\Gamma(t \rightarrow \mathrm{Wb}) \approx 25\%$
- $\rightarrow$ $\delta|V_{\mathrm{tb}}| \approx 12\%$

W helicity in top decay

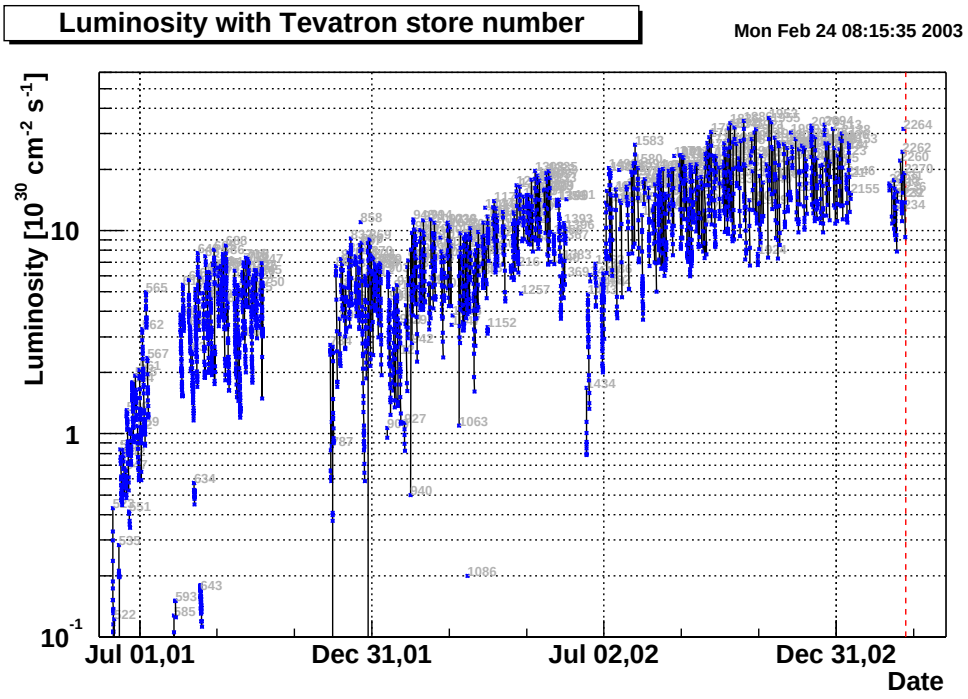
- $\rightarrow$ $\delta\mathcal{F}_{\mathrm{long}}$: 0.4 (Run I) $\longrightarrow$ 0.09 ($2\,\mathrm{fb}^{-1}$)
  $\longrightarrow$ 0.04 ($15\,\mathrm{fb}^{-1}$)
- $\rightarrow$ $\delta\mathcal{F}_{\mathrm{right}}$: 0.15 (Run I) $\longrightarrow$ 0.03 ($2\,\mathrm{fb}^{-1}$)
  $\longrightarrow$ 0.01 ($15\,\mathrm{fb}^{-1}$)

Search for FCNC top decay

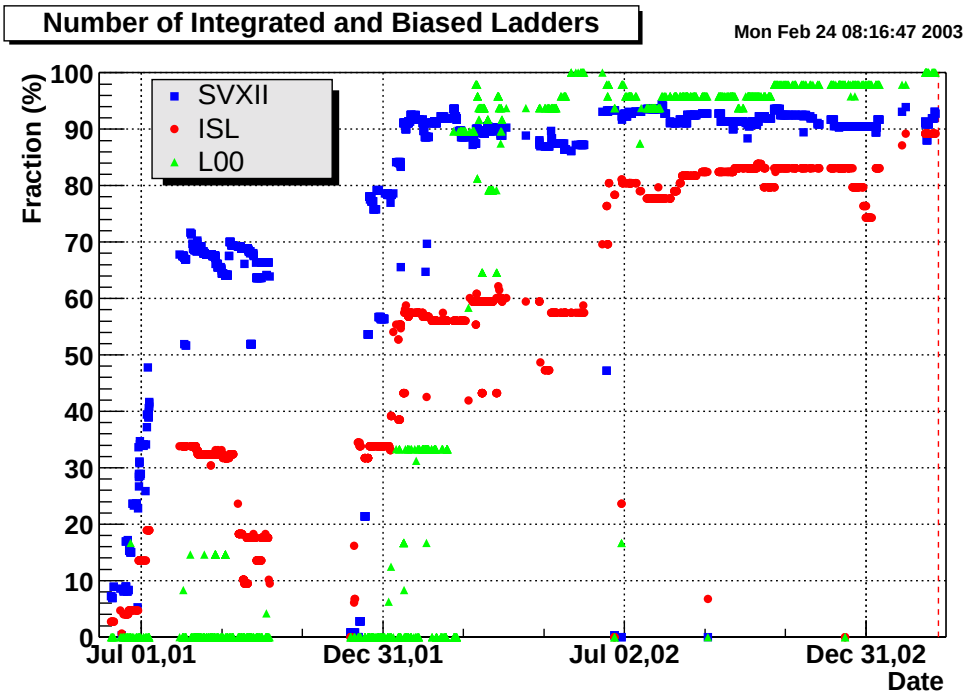
- $\rightarrow$ $\mathrm{Br}(t \rightarrow u/c + \gamma) < 2.8 \times 10^{-3}$
- $\rightarrow$ $\mathrm{Br}(t \rightarrow u/c + Z^0) < 1.3 \times 10^{-2}$

Summary

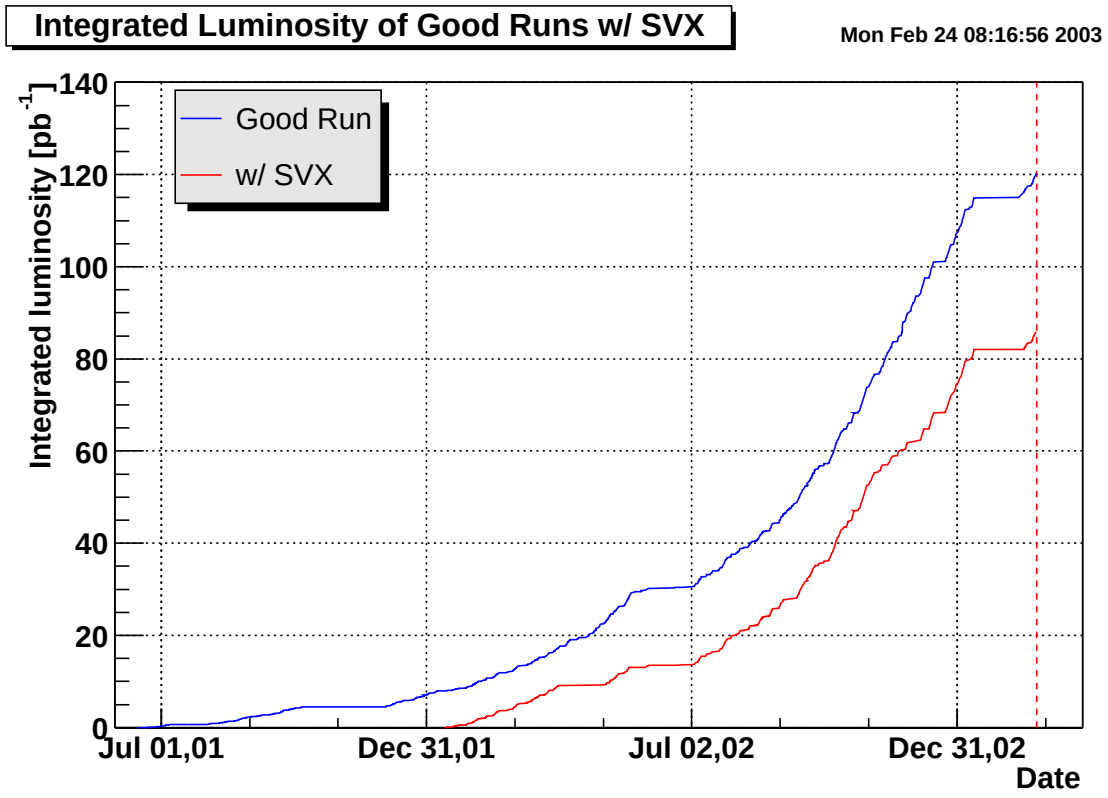
- Top quark is a very interesting particle
  - $\rightarrow$ Large mass and decay width.
- Successful top quark physics program at Run I.
  - $\rightarrow$ Consistent with SM.
  - $\rightarrow$ But limited in statistics.
- Entering exciting era of Run II.
  - $\rightarrow$ Precise measurements on top physics are about to begin.
  - $\rightarrow$ We have now the amount of data comparable to Run I.
  - $\rightarrow$ First results of $t\bar{t}$ cross section and top quark mass in Run II will come very soon (hopefully in this March).
- Run II is promised to be prolific of top quarks, and will give us much information about top quark before LHC and Linear collider era.



Instantenious luminosity at each physics runs$[10^{30}\,\mathrm{cm}^{-2}s^{-1}]$



Fraction of readout silicon ladder as a function of time



"Online" integrated luminosity to tape $[\mathrm{pb}^{-1}]$