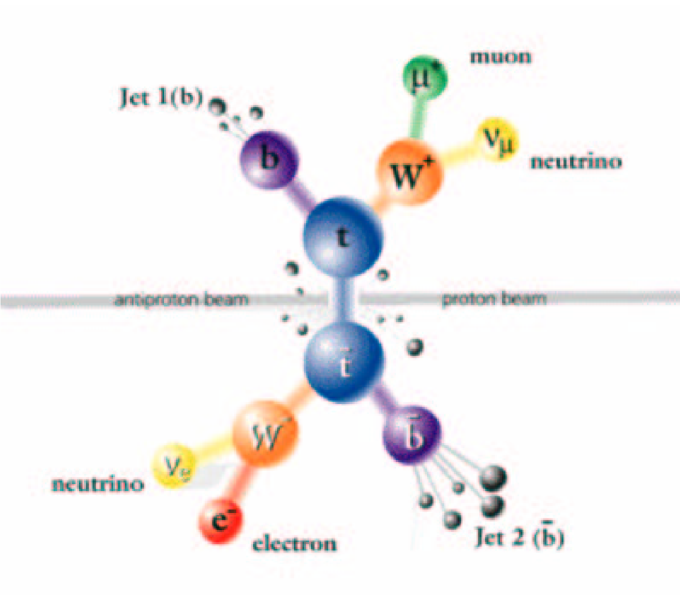
TOP PHYSICS AT CDF



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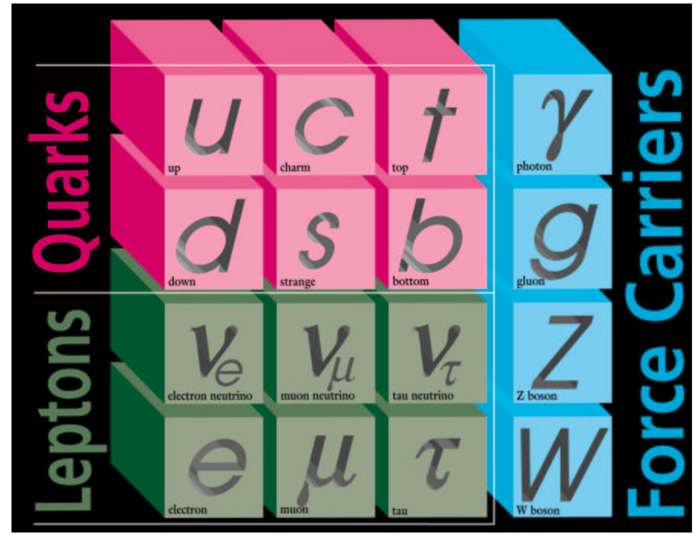
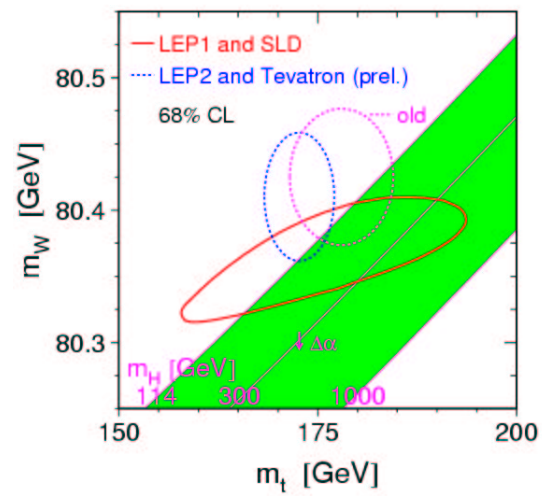
Why Top Quark is so interesting?

- The youngest of the elementary particles
  - ◇ Discovered in 1995 by CDF and DØ but still things to learn!
  - ◇ Heaviest known fundamental particle ⇒ top probes physics at much higher energy than for the other fermions
  - ◇ Decays before it can hadronize ($\tau_{top} \sim 10^{-24}$ sec) ⇒ momentum and spin pass to the decay products

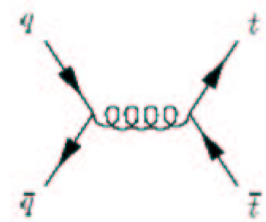


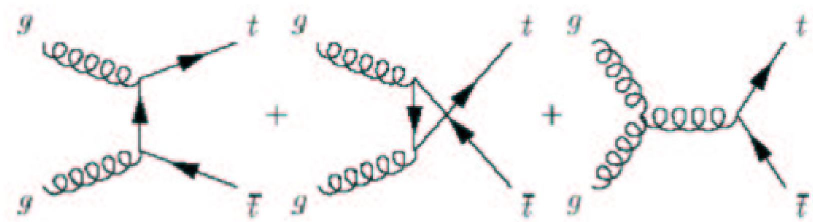
- Top pair production x-sec measurements test QCD ⇒ test of the SM
  - ◇ Higher x-sec than predicted could be a sign of non SM production mechanisms
- Top mass is a fundamental parameter in the SM
  - ◇ M_t, along with the mass of the W, is related with the mass of the Higgs boson
- Significant background for many discovery channels



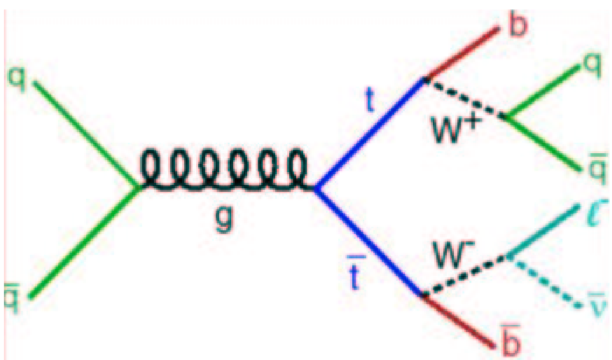
Top Production & Decay Modes

- At Tevatron energies ($\sqrt{s} = 1.96\ TeV$) tops are mainly produced in pairs via strong interaction
  - ◇ $q\bar{q}$ annihilation (85%) or gluon fusion (15%)
  - ◇ $\sigma(p\bar{p} \rightarrow t\bar{t}\ @\ M_t = 178\ GeV) \approx 6.1$ pb $\Rightarrow$ one top event every 10 billion inelastic colisions



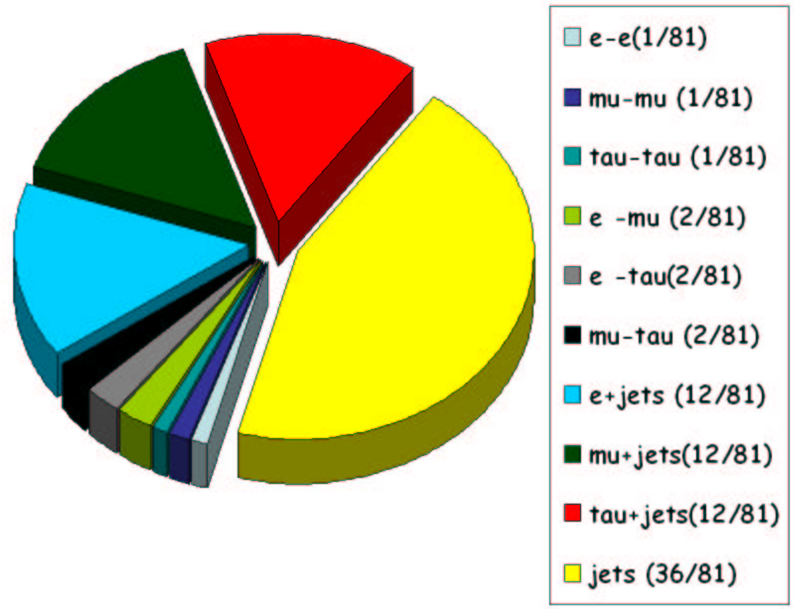


- Decays via electroweak interaction $t \rightarrow Wb$
  - ◇ BR($t \rightarrow Wb$)≈1 $\Rightarrow$ final state given by the $W^{\pm}$ decays
  - ◇ BR($W \rightarrow$ leptons) = 1/3, BR($W \rightarrow$ quarks) = 2/3



lepton ≡ electron or muon

Final State	Dataset	BR
$l\nu\ l\nu\ bb$	dilepton	~5%
$l\nu\ qq\ bb$	lepton+jets	~30%
$qq\ qq\ bb$	hadronic	~44%

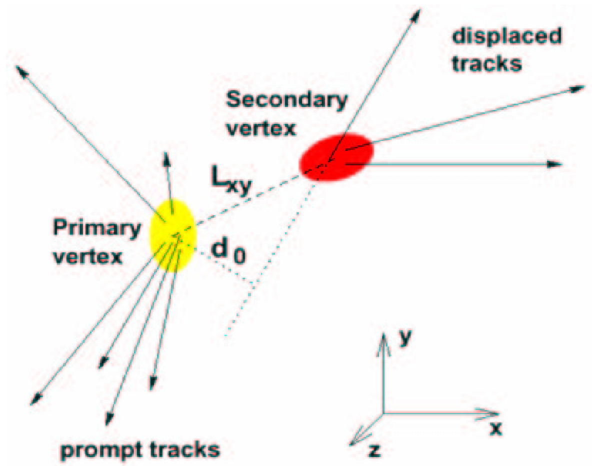


Detecting the Top Quark / B-Tagging

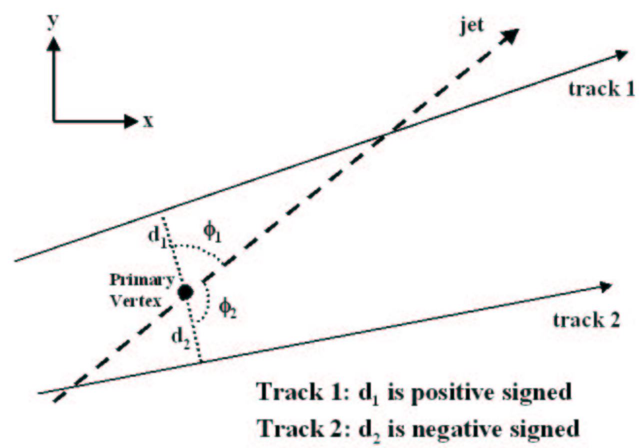
- Top events:
  - ◇ are energetic (large total transverse energy, H_T), central and spherical
  - ◇ have missing transverse energy ($\not{E}_T$) from neutrinos in leptonic modes
  - ◇ have high transverse energy (E_T) jets
  - ◇ have two high E_T b-jets identified with a displaced secondary vertex

$\longrightarrow$ B hadrons are long lived

SecVtx



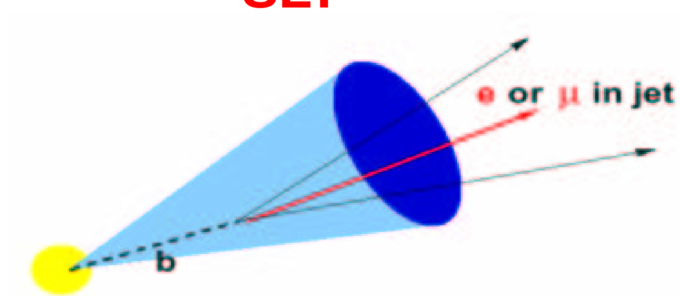
Jet Probability



- ... while background events:
  - ◇ have less neutrinos ⇒ less $\not{E}_T$
  - ◇ most of them, have no b-jets ⇒ b-tagging improves S/B (SecVtx, Jet Probability, SLT)
  - ◇ leptons could be fakes
  - ◇ are less central

$\longrightarrow$ Semileptonic B hadron decay

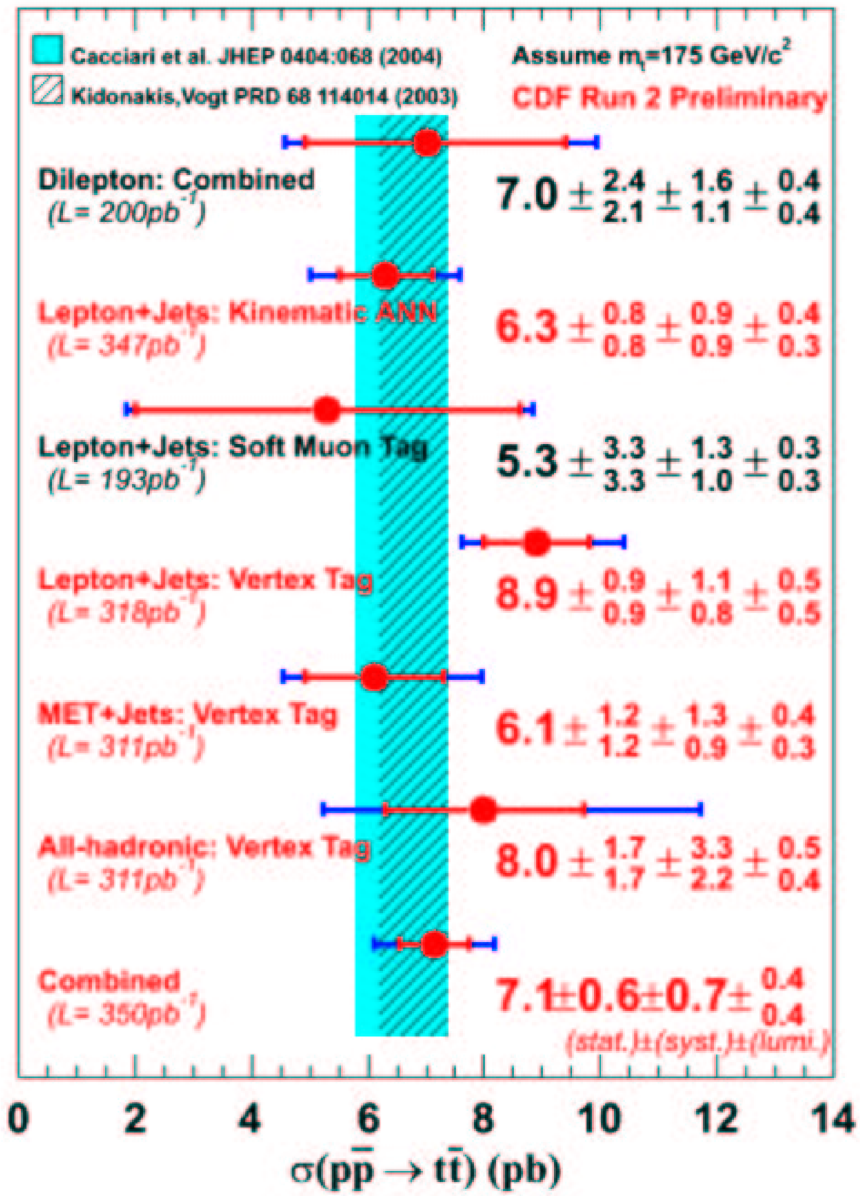
SLT



- $b \rightarrow \ell\nu c$ (BR $\sim$ 20%)
- $b \rightarrow c \rightarrow \ell\nu s$ (BR $\sim$ 20%)

Production Cross Section Measurements

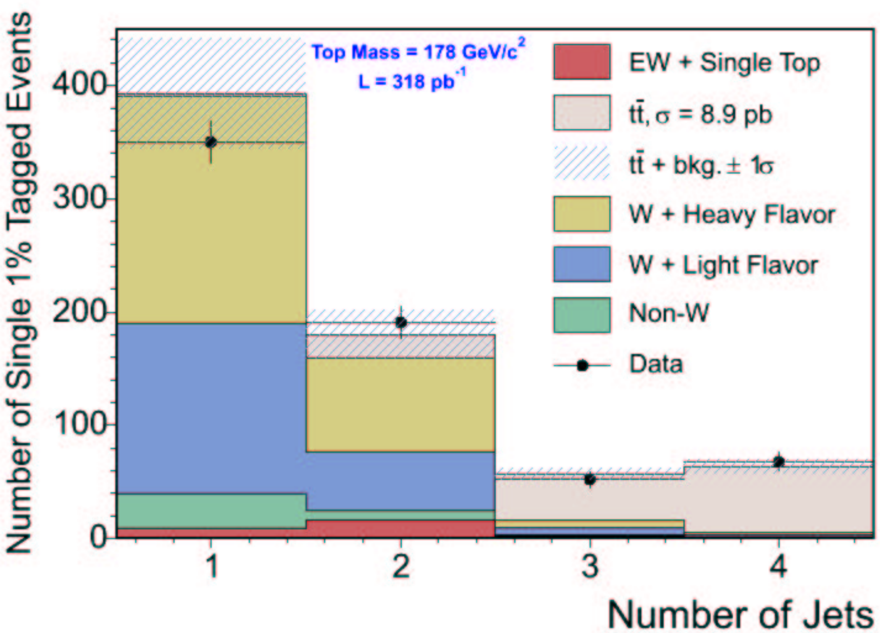
- Test the non-SM top production mechanism
- Validate top samples for other top properties measurements
- Counting experiment: $\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \times \epsilon_b \times \int L dt}$
- Goal: demonstrate good understanding of control regions and see excess from top in signal region
- Measurements in different final states are consistent with each other and with theory



Lepton+Jets with b-tagging

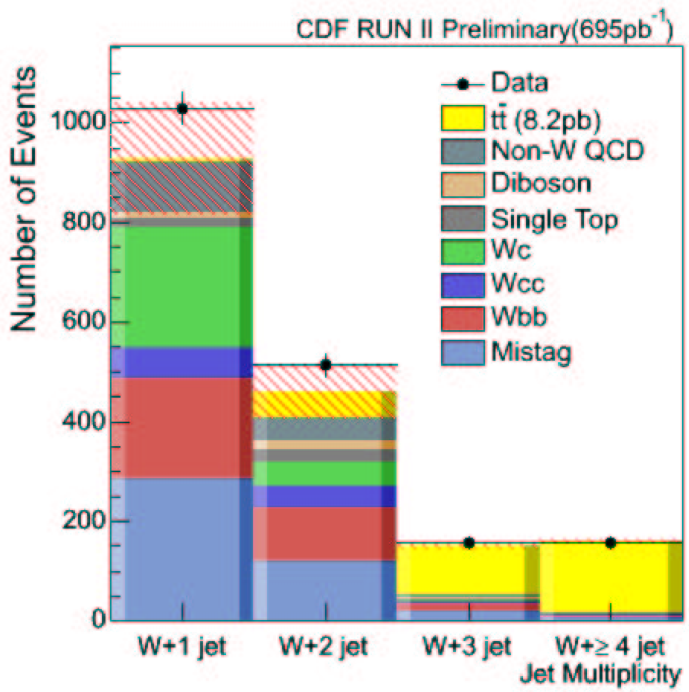
- Selection: 1 isolated lepton (e, μ) with p$_T > 20$ GeV, $\not\!\!E_T > 20$ GeV, ≥ 3 jets with p$_T > 15$ GeV, ≥ 1 b-tagged jet
- Main backgrounds: W+HF, QCD, W+jets (mistags)

Jet Probability $(L = 318\ pb^{-1})$



$\sigma_{t\bar{t}} = 8.9 \pm 1.1\ (stat) \pm 1.0\ (syst)\ pb$

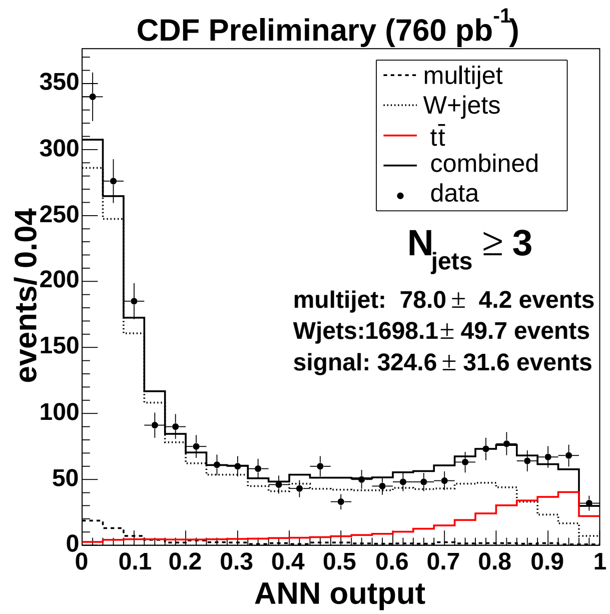
SecVtx $(L = 695\ pb^{-1})$ NEW!



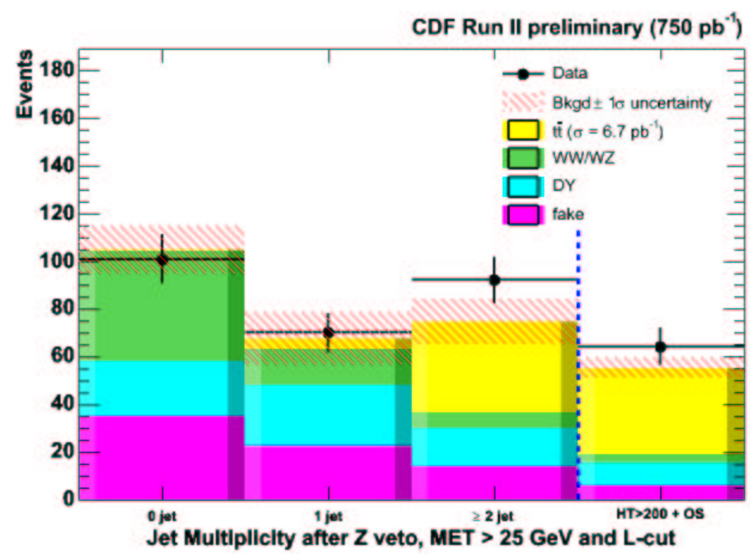
$\sigma_{t\bar{t}} = 8.2 \pm 0.6\ (stat) \pm\ 1.0\ (syst)\ pb$

Lepton+Jets without b-tagging / Dilepton (NEW!)

- Lepton+Jets without b-tagging ($L = 760\ pb^{-1}$)
  - ◇ Same selection but no b-tagging is required $\Rightarrow$ higher statistics but larger backgrounds also
  - ◇ Kinematical analysis: uses top kinematics and shape information combined in a Neural Network to distinguish between top pairs and W+jets
  - ◇ $\sigma_{t\bar{t}} = 6.0 \pm 0.6\ (stat) \pm 0.9\ (syst)\ pb$

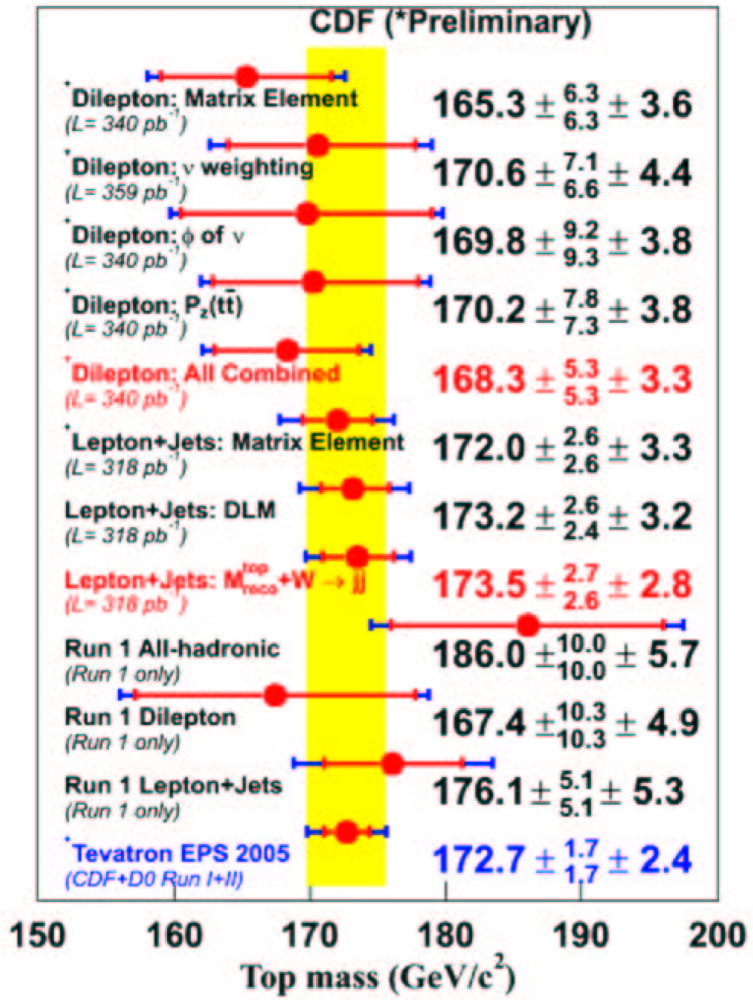


- Dilepton channel ($L = 750\ pb^{-1}$)
  - ◇ Very clean sample
  - ◇ Selection: 2 isolated lepton (e, μ) with $p_T > 15$ GeV, ≥ 2 jets with $p_T > 20$ GeV, $\not{E}_T > 20$ GeV
  - ◇ Main backgrounds: DY, dibosons, fakes
  - ◇ $\sigma_{t\bar{t}} = 8.3 \pm 1.5\ (stat) \pm 1.0\ (syst) \pm 0.5\ (lum)\ pb$



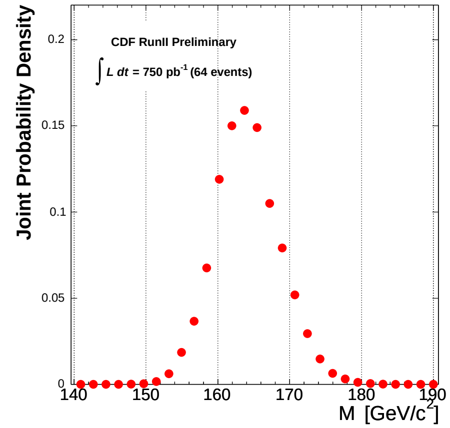
Top Quark Mass

- Fundamental parameter of the SM
- Many different methods applied at CDF: trying to optimize the stat. and syst. performance
- Goal: $\delta M_t \sim$ 2-3 GeV
- Matrix Elements technique:
  - ◇ Build likelihood for M_t in each event from matrix elements, PDFs and transfer functions (relate parton level quantities to the measured ones, $\vec{x}$)
  - ◇ Integrate over unmeasured quantities (e.g. quark energies)
  - ◇ Calibrate measured M_t and uncertainty using simulation
  - ◇ Determine M_t by joint likelihood maximum
- Templates technique:
  - ◇ Reconstruct event-by-event M_t
  - ◇ Create templates using events simulated with different M_t values
  - ◇ Perform maximum likelihood fit to extract the measured M_t

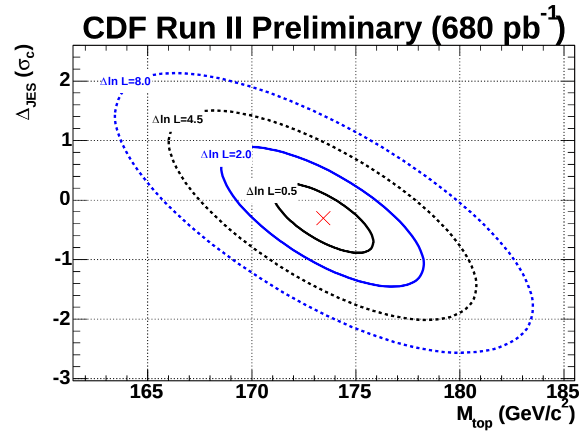


Top Quark Mass Measurements (NEW!)

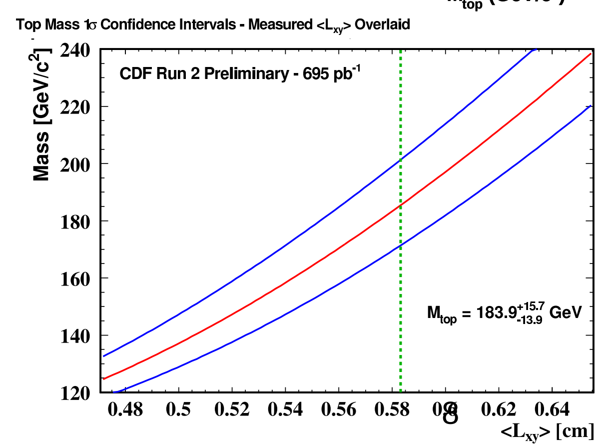
- Using ME in dilepton channel ($L = 750\ pb^{-1}$)
  - $P(\vec{x}|M_t) = P_s(\vec{x}|M_t)p_s(M_t) + P_{b_1}(\vec{x})p_{b_1} + P_{b_2}(\vec{x})p_{b_2} + \ldots$
  - $M_t = 164.5 \pm 4.5\ (stat) \pm 3.1\ (syst)\ GeV$



- Using templates in lepton+jets ($L = 680\ pb^{-1}$)
  - $M_t = 173.4 \pm 2.5\ (stat + JES) \pm 1.3\ (syst)\ GeV$
  - $\Delta_{JES} = -0.30^{+0.59}_{-0.58}\ (stat + JES) \pm 0.37\ (syst)\ \sigma_c$



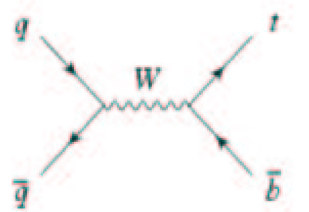
- L_{xy} method in lepton+jets ($L = 695\ pb^{-1}$)
  - Histogram the transverse decay lenght, L_{xy}, of b-hadrons from top decays in the signal region, compute $< L_{xy} >$ and evaluate, using pseudoexperiments, the MPV M_t that corresponds to that mean value
  - $< L_{xy} >= 0.5831 \pm 0.0229\ cm$
  - $M_t = 183.9^{+15.7}_{-13.9}\ (stat) \pm 5.9\ (syst)\ GeV$



Single Top Quark Production

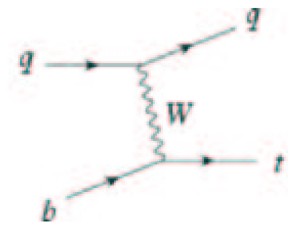
- It is possible via EW processes
  - ◇ Cross section $\propto$ matrix element $|V_{tb}|^2$ (direct measurement)
  - ◇ Production channel sensitive to new physics

s-channel



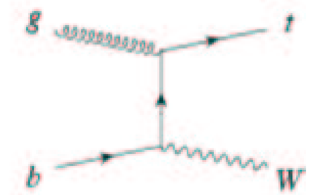
$\sigma_t = 0.88 \pm 0.11\ pb$

t-channel



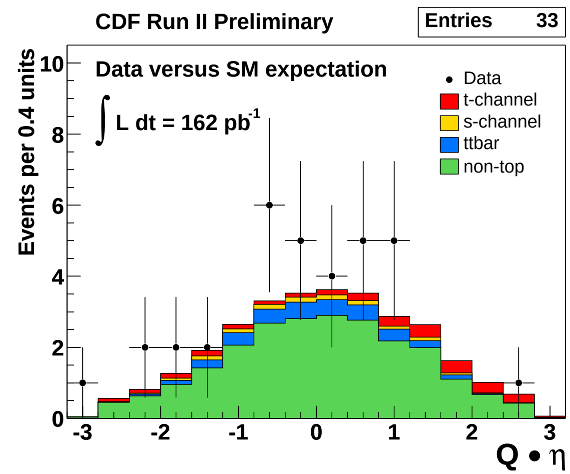
$\sigma_t = 1.98 \pm 0.25\ pb$

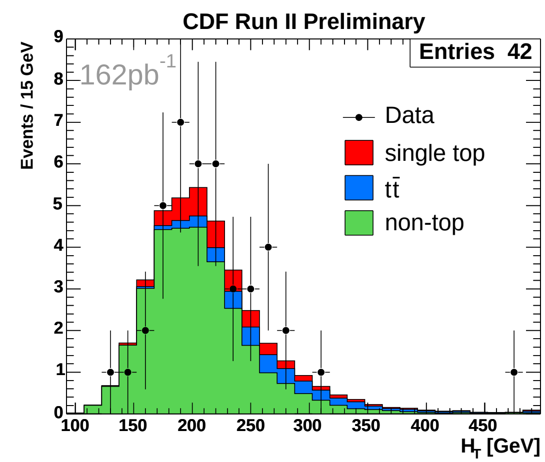
associated production



$\sigma_t < 0.1\ pb$

- Not yet observed at CDF. Set upper limits
- Final state: lepton, $\not{E}_T$, 2 jets (at least 1 b-jet)
- Two different analysis ($L = 162\ pb^{-1}$)
  - ◇ Separate search channels (reveal new physics, Q $\times \eta$ distribution)
  - ◇ Combined search (H$_T$ distribution)

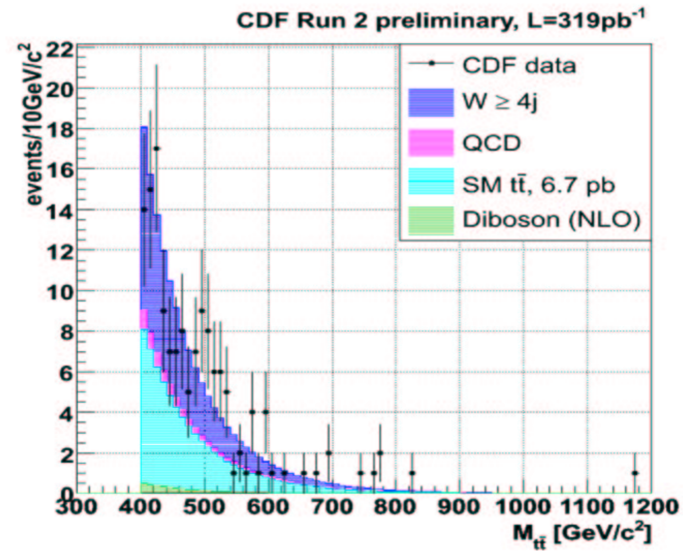




Measurement	σ_t @ 95% CL (pb)	$\int Ldt$
s-channel	$<$13.6	162
t-channel	$<$10.1	162
combined	$<$17.8	162

Searches for $t\bar{t}$ resonances: $p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$ (NEW!)

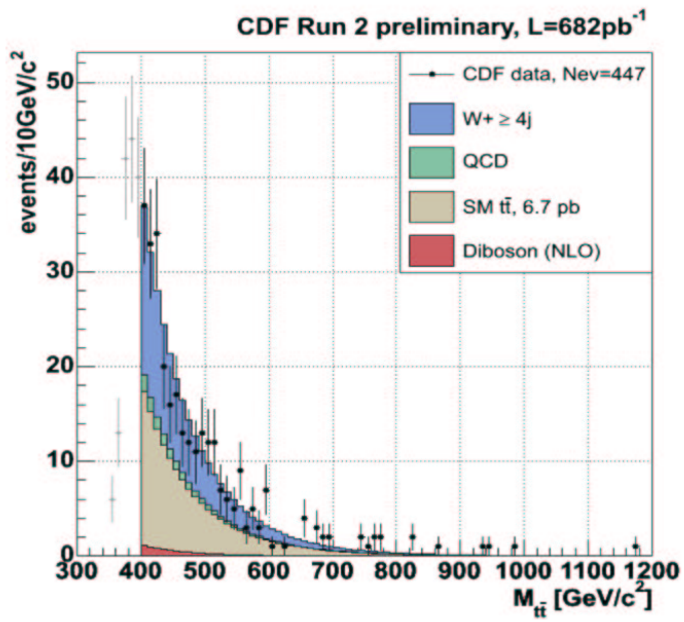
- Search for new massive resonance decaying to top pairs (predicted by some exotic models)
  - One lepton ($p_T > 20$ GeV), $\not{E}_T > 20$ GeV and ≥ 4 jets ($E_T > 15$ GeV)
  - Use the SM Matrix Element information (increase sensitivity) to reconstruct the $t\bar{t}$ invariant mass espectrum ($M_{t\bar{t}}$) for top candidates in the sample
  - Test the consistency of the data with SM $t\bar{t}$ production



- With 319 pb^{-1}, data shows an intriguing peak around 500 GeV (also Run I results)

- ... but with twice more data (682 pb^{-1}) the peak dissappears but still a litle bit of excess

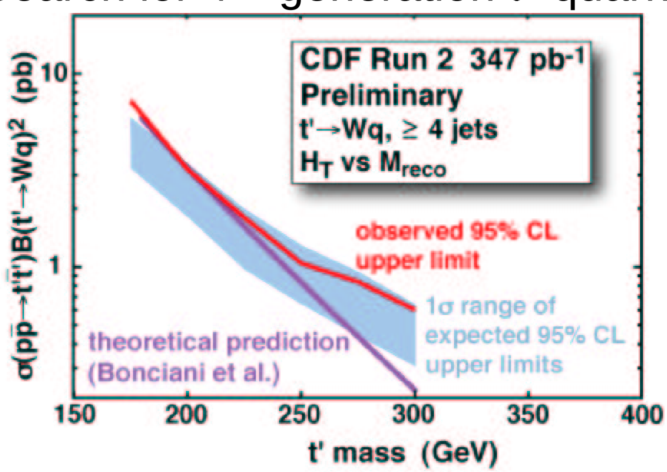
- So far, data looks consistent with SM. Will repeat the analysis with a larger set of data



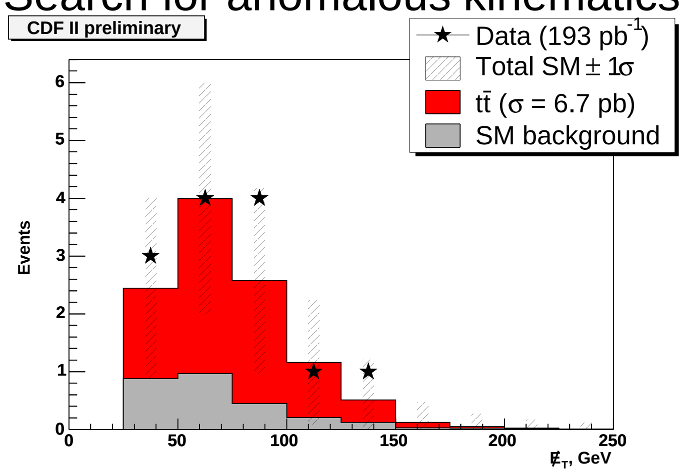
Other Top Properties Measurements

Measurement	Result	$\int Ldt$ (pb^{-1})
W helicity F_0	$0.74^{+0.22}_{-0.34}$	200
W helicity F_+	$F_+ < 0.27$ @ 95% CL	200
Search for anomalous kinematics	Consistent with SM	193
Search for H^+ in t decays	BR($t \to Hb$) $<$ 0.91 @ 95% CL	193
$\sigma_{dilepton}/\sigma_{l+jets}$	$1.45^{+0.83}_{-0.55}$ (stat + syst)	126
BR($t \to Wb$)/BR($t \to Wq$)	> 0.61 @ 95% CL	162
BR($t \to \tau\nu_\tau q$)/BR$_{SM}$($t \to \tau\nu_\tau q$)	< 5.2 @ 95% CL	193
Search for 4th generation t' quark	$m_{t'} < 196, m_{t'} > 207$ @ 95% CL	347
Top quark lifetime	$c\tau_{top} < 52.5\ \mu m$ @ 95% CL	350

Search for 4th generation t' quark



Search for anomalous kinematics



Conclusions

- Experimental top quark physics at CDF is in a mature state
  - A lot of people involved $\Rightarrow$ great variety of analysis
  - No evidence of non-SM top quark... so far
  - But still many chances of discovery at CDF

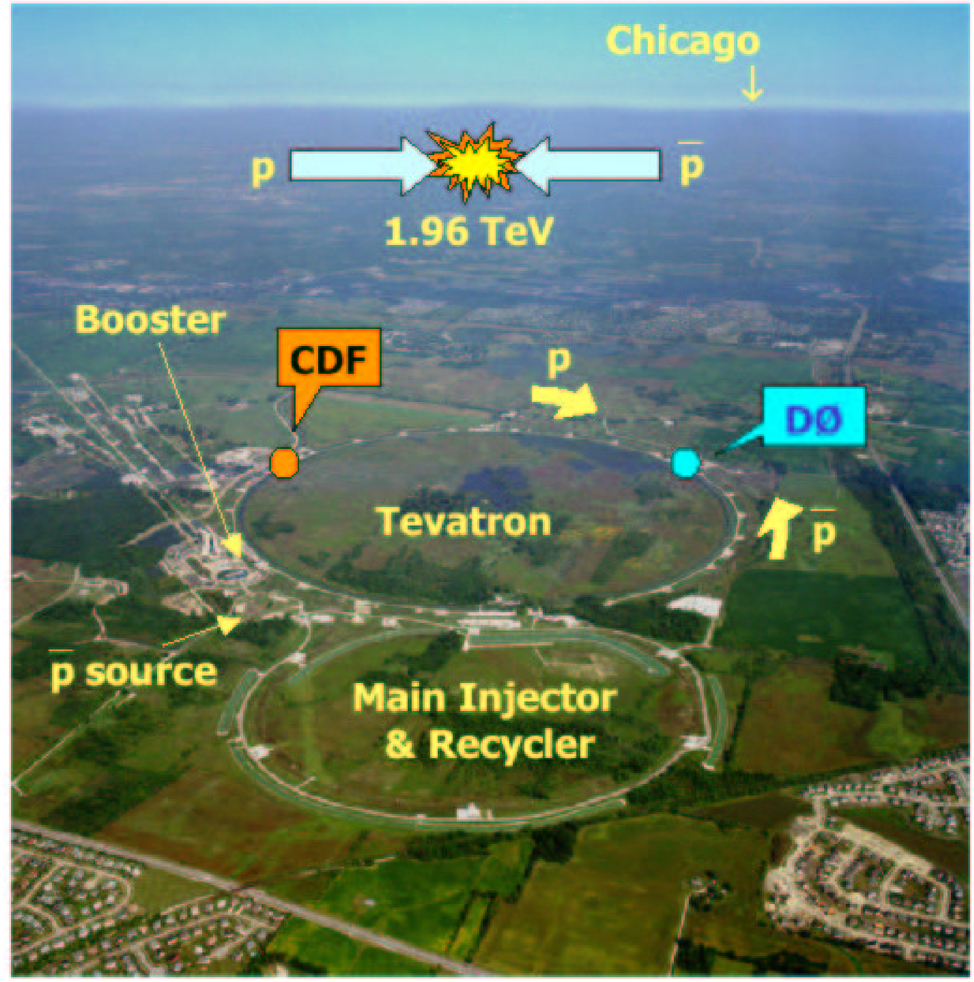
- Achieved a big improvement in the relative uncertainties
  - $\sim 15\%$ on top cross section measurements
  - $\sim 2\%$ on top mass measurements

- Many top physics results at CDF have been published. And (even) more precise measurements are coming soon
  - ... with much more data!

BACK-UP SLIDES

The Tevatron

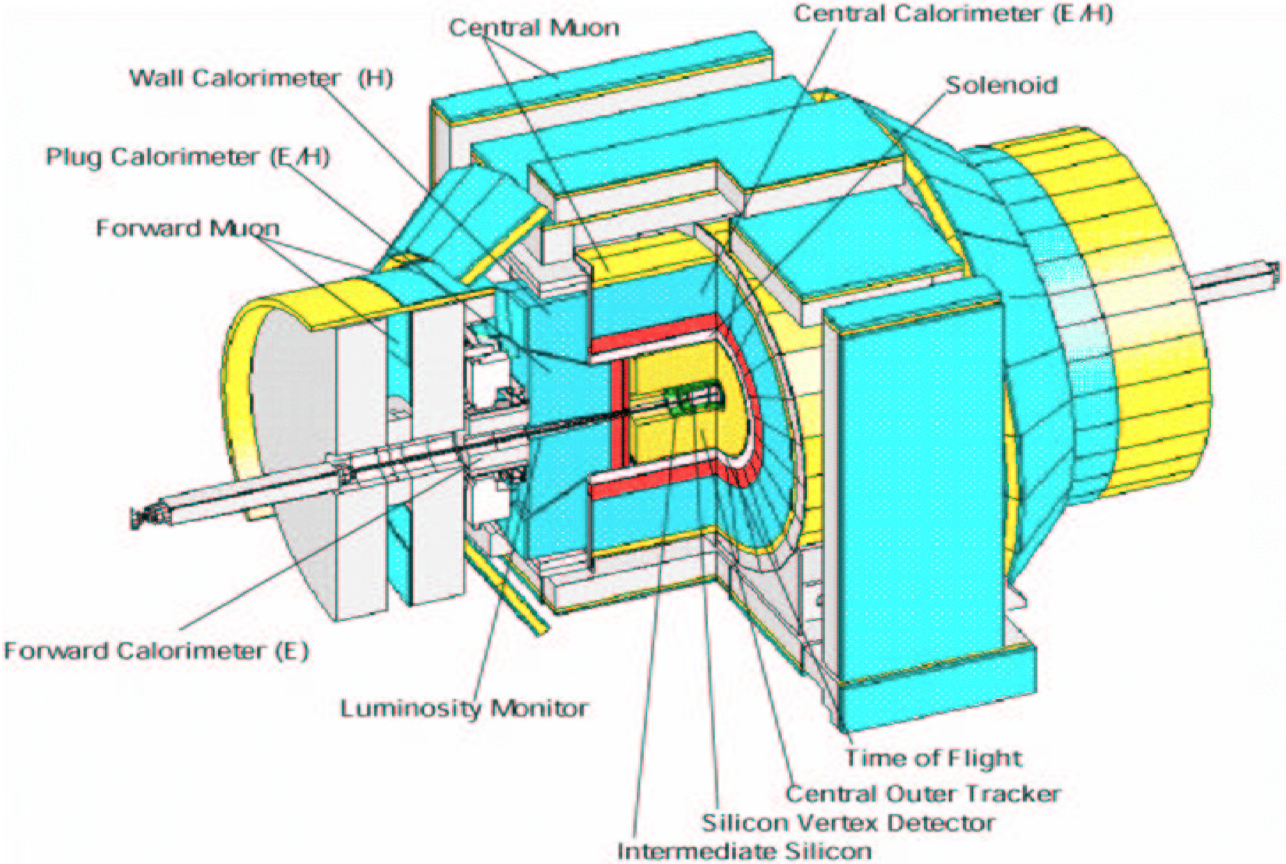
- Currently, the world's only top quark production machine
- Highest energy $p\bar{p}$ collider
  - Energy of the beam = $980\ GeV$
  - $\sqrt{s} = 1.96\ TeV$ (Run I $\to 1.8\ TeV$)
- Collisions every $396\ ns$ (Run I $3.5\ \mu s$)
- Run I: 1992 - 1996 (¡quark *top*!)
- Run II: 2001 - nowadays
  - Many improvements: *Main Injector*
  - $\mathcal{L}_{int}$: $100\ pb^{-1}$ (Run I) $\longrightarrow > 1\ fb^{-1}$ (Run II)



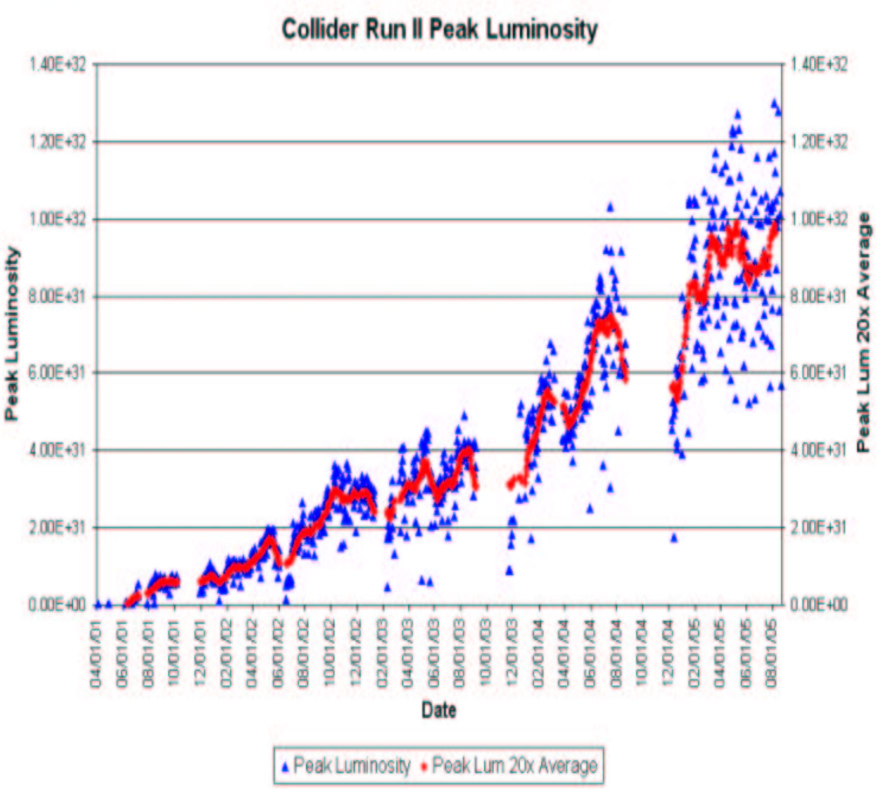
- Other discoveries: quark *bottom* (1977) y ν_τ (2000)

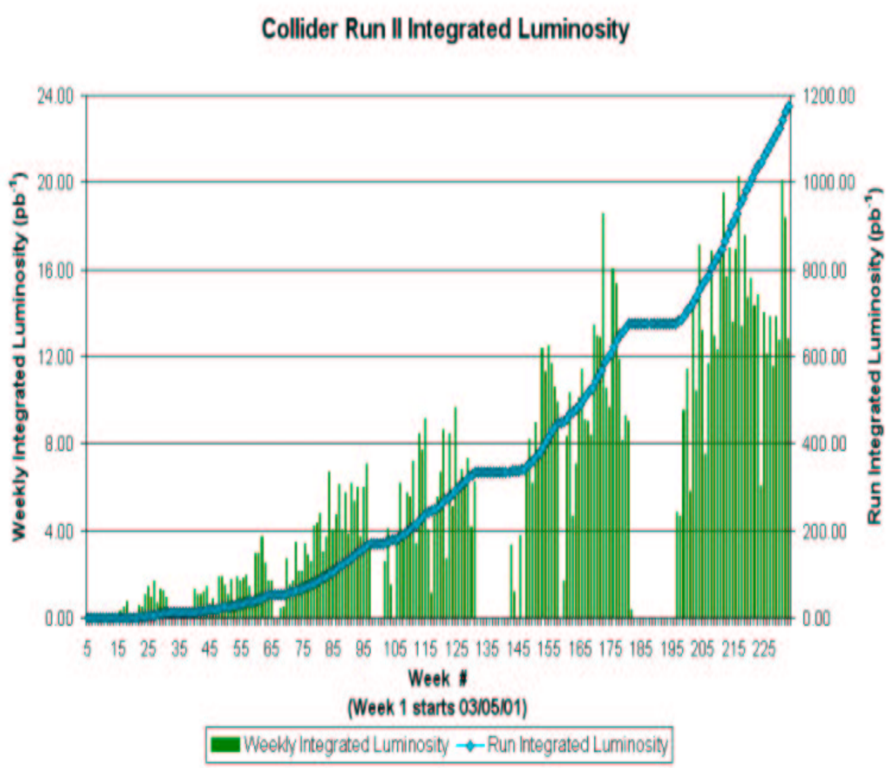
CDF

- General-purpose particle detector. Cylindrical simmetry
- 3 subsystems: tracking (inside a $1.4\ T$ solenoidal magnetic field), calorimetry and muons systems
- For top physics, the full detector is needed
- Run II improvements:
  - New Silicon detector
  - TOF detector
  - *plug* calorimeters
  - *forward* μ detectors
  - DAQ & triggers electronics
  - L2 SVT trigger



Tevatron: Luminosity (Run II)

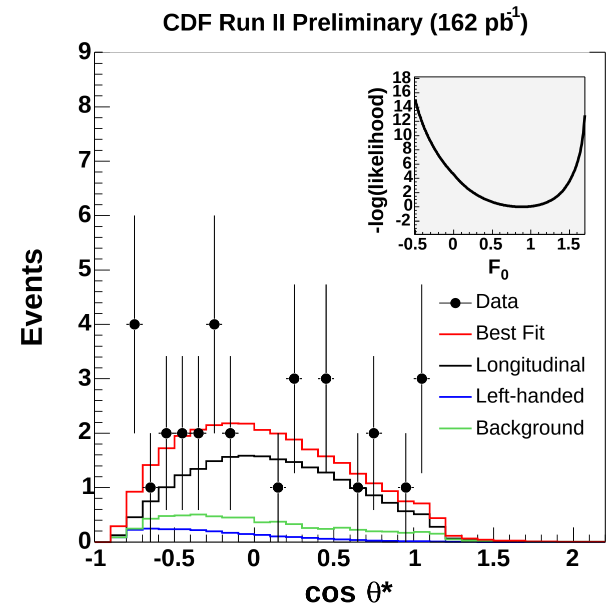


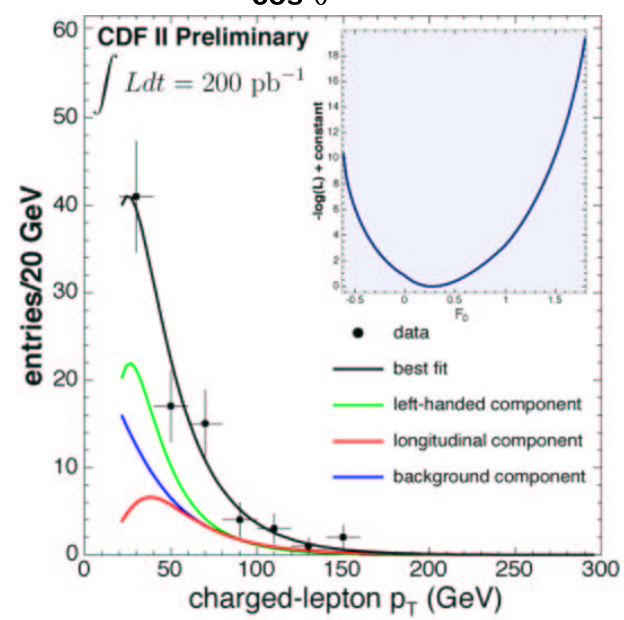


- $\mathcal{L}_{inst}^{max} \sim 1.8 \cdot 10^{32}\ cm^{-2}s^{-1}$, $\mathcal{L}_{int} \sim 1.5\ fb^{-1}$ ($\sim 1.2\ fb^{-1}$ on tape)
- $\mathcal{L}_{int} \sim 4.4$ (main goal)- 8.5 (design) fb^{-1} in 2009?

W Helicity from Top Decay

- W boson has three helicity states
  - Left handed, longitudinal, right handed
  - Top quark decays mostly to longitudinal W's
- Measuring the fraction of longitudinal W's (F_0):
  - we test a SM prediction: F_0 = 0.7 (F_- = 0.3, F_+ = 0)
  - we test the nature of the tWb vertex
- Kinematic distributions for each helicity state are very different





Method	Sample	$\int Ldt\ (pb^{-1})$	F_0	Limit@95% CL
cosθ^*	l+jets	162	$0.99^{+0.29}_{-0.35} \pm 0.19$	> 0.18
lepton p_T	combined	200	$0.31^{+0.37}_{-0.23} \pm 0.17$	< 0.95
Combined	-	-	$0.74^{+0.22}_{-0.34}$	-

W Helicity from Top Decay