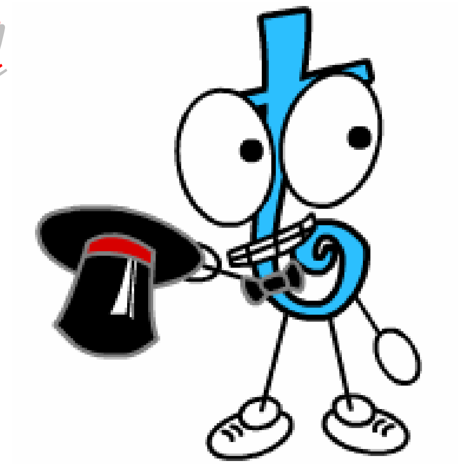
Top: latest results from Tevatron – cross-section and mass



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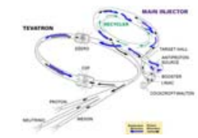
For the CDF and D0 collaborations

FPCP 2003, Paris, June

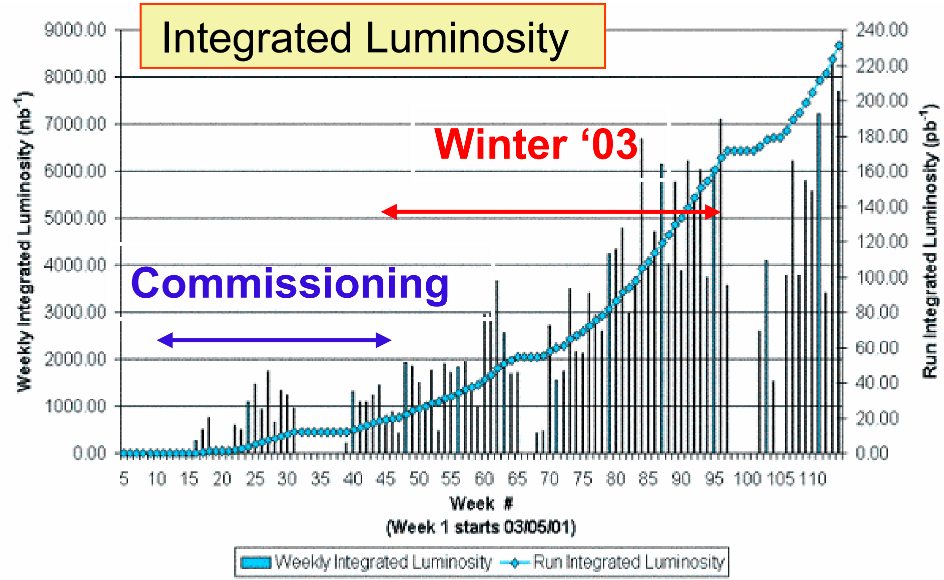
Outline

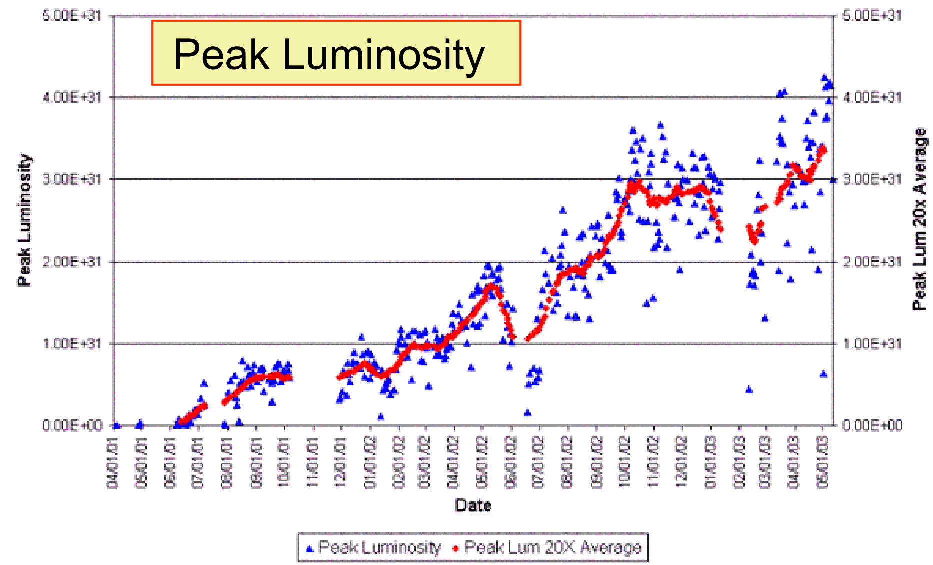
- Tevatron Status
- The upgrades of the CDF and D0 detectors
- Top Production and Decay
- Top Physics Program for Run II
- First Cross-Section Measurements at 1.96 TeV, in the Dilepton and Lepton+jets channels
- Top Mass Measurements in CDF (Run II) and D0 (Run I)
- Top Physics Prospects

Tevatron Upgrades/Status

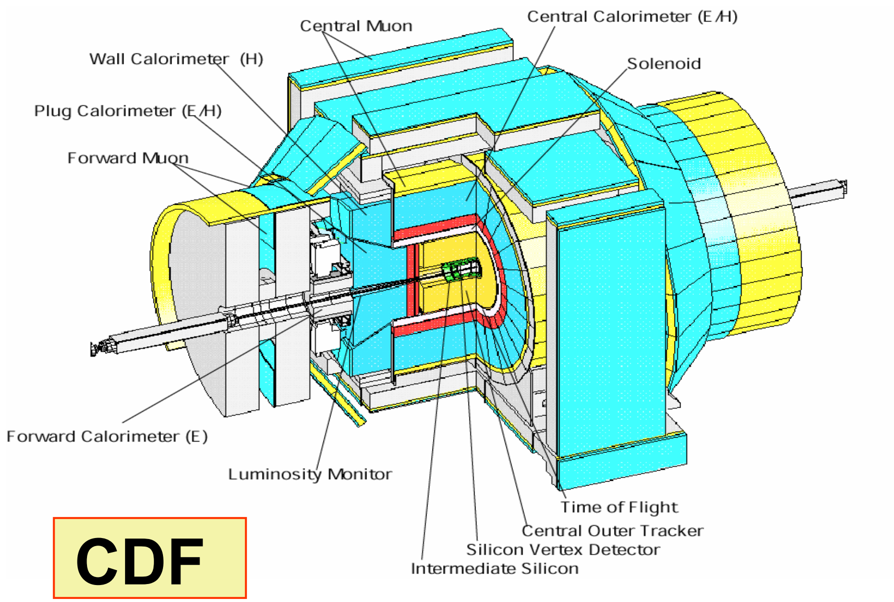


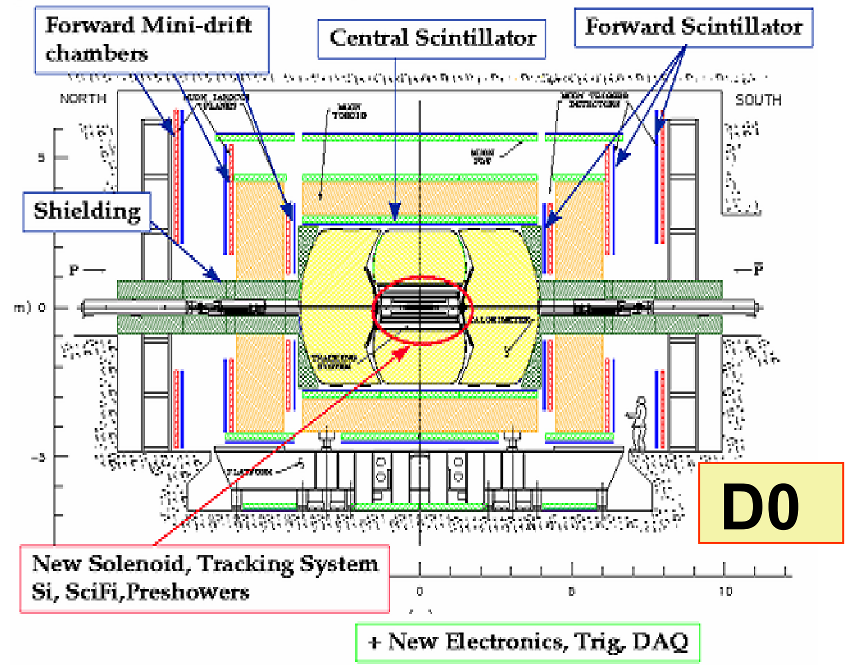
- Run II upgrades
  - E_{CM} increase from 1.8 → 1.96 TeV→larger cross sections
  - Higher luminosity
    - Run I peak: 2.4×10^{31} cm^{-2} s^{-1}
    - Run II goal: $3–4 \times 10^{32}$ cm^{-2} s^{-1}
    - Run II peak: 4.7×10^{31} cm^{-2} s^{-1}
- Analysis-quality data accumulated by Jan '03
  - CDF: 72.0 pb^{-1} (57.5 pb-1 with silicon)
  - D0: 30 - 50 pb^{-1}
- Immediate goal for accelerator:
  - Deliver 225 pb^{-1} in FY 2003
- Run IIa goal: 2 fb^{-1}





CDF and D0 Detectors Upgrades



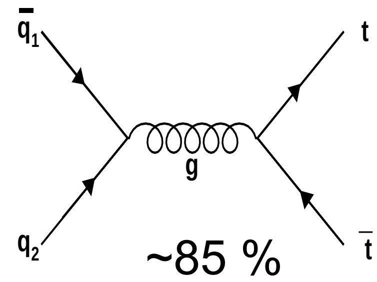


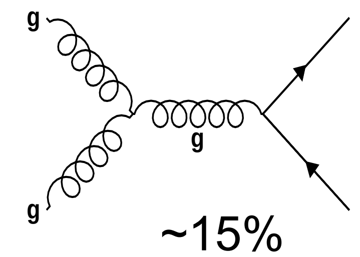
- Tracking:
  - Expanded silicon coverage
  - New drift chamber (COT)
- Extended lepton-ID: $|\eta|>1.0 \rightarrow 2.0$
  - End Plug calorimeter
  - Expanded muon coverage

- New Inner tracking
  - silicon tracker, fiber tracker
  - 2T superconducting solenoid
- Upgraded μ system for better μ -ID

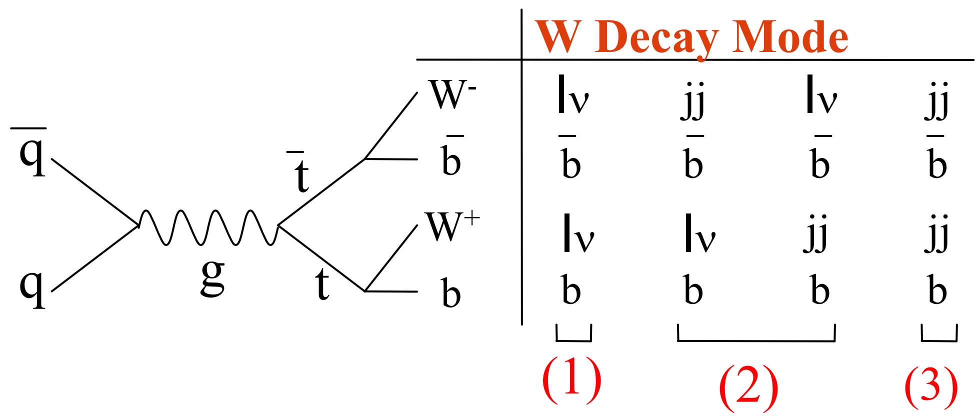
Top Production and Decay

- In proton-antiproton collisions, at 1.96 TeV, top quarks are primarily produced in pairs





- single top production:
  - smaller rate (σ =1.5 pb)
  - large backgrounds
  - not observed yet
- $\sigma_{t\bar{t}}$ increased by 30% with the CM energy increase from 1.8 →1.96 TeV
- Br($t \rightarrow W^+ b$) ~100% in SM
- Based on the W decay modes →3 experimental signatures:



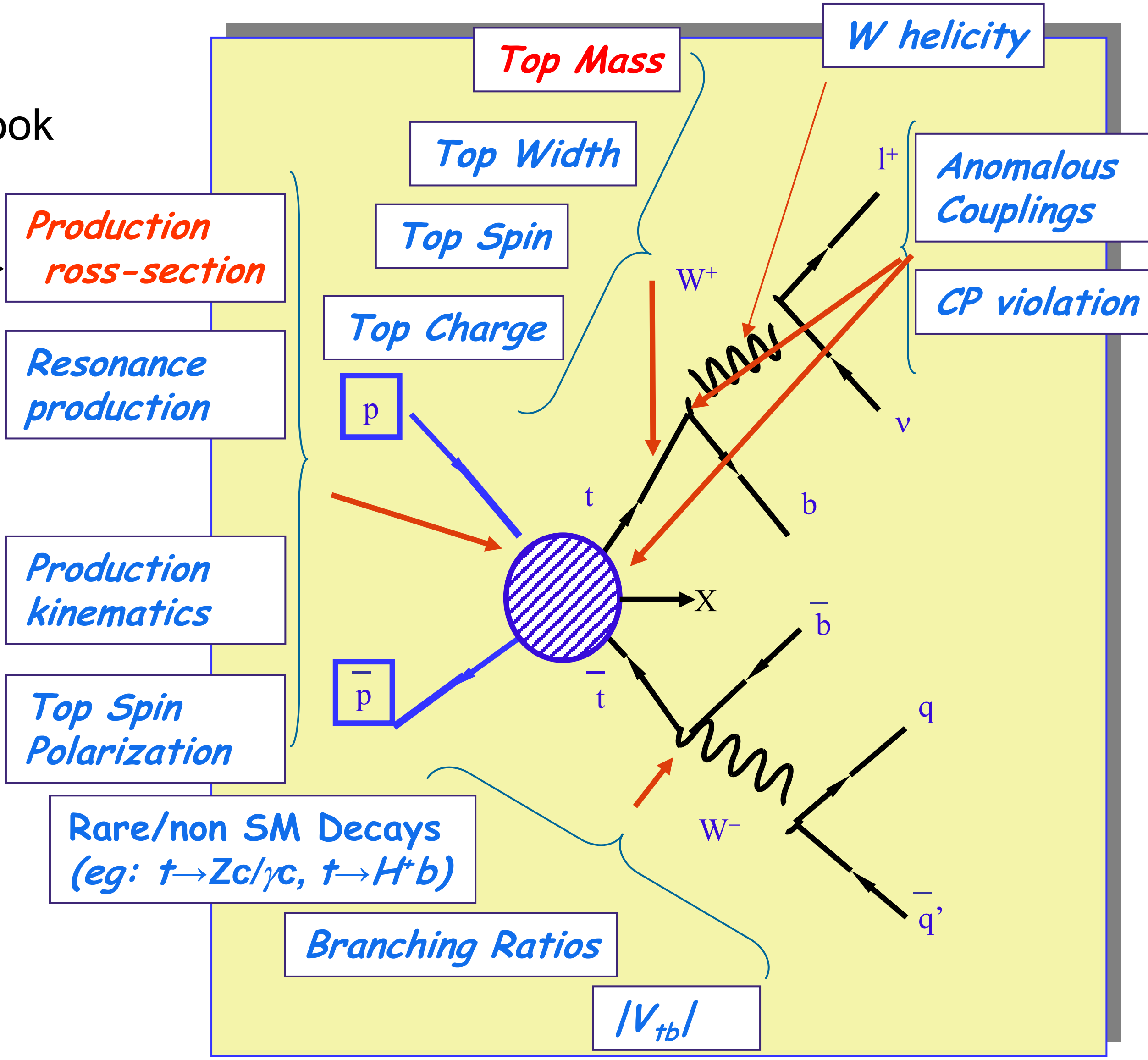
(1) **Dilepton** Very small backgrounds, but very small rate

(2) **Lepton+Jets** Manageable backgrounds and good rate

(3) **All Jets** Large QCD Background

Top Physics in Run II

- Run I: discovery mode
  (Fermilab 1995) → crude look at top's properties
- Run II: precision mode→
  we hope to answer fundamental questions:
- Why is the top so heavy?
- Is the third generation special?
- Is top involved in EWSB?
- Is the top the liaison to new physics?



Production Cross-Sections

- $\sigma_{t\bar{t}}$ measurement:
  - benchmark measurements
  - test of perturbative QCD
  - probe for physics beyond SM
    - non-SM production, $X \rightarrow t\bar{t}$
    - non-SM decay, $t \rightarrow Xb$
    - SUSY models with a $t\bar{t}$-like signal
  - Higgs production (WH,ZH) is a background and the opposite
- Run I: $\delta\sigma_{tt}/\sigma_{tt}$ ~26 %
- Run IIa ($2fb^{-1}$): $\delta\sigma_{tt}/\sigma_{tt}$ ~ 7 %
- Theoretical cross-section:

  At NLO @ $\sqrt{s}$=1.96 TeV for M_{top} = 175 GeV:

$$\sigma_{t\bar{t}} = 6.7^{+0.71}_{-0.88}\ pb$$

hep-ph/0303085 (Mangano et al)

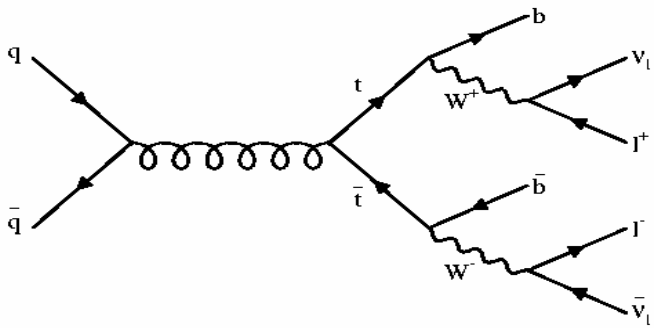
- To estimate signal contribution we use 7 pb

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bck}}{A \cdot L}$$

Acceptance

Luminosity

$\sigma_{t\bar{t}}$ in the Dilepton Decay Mode



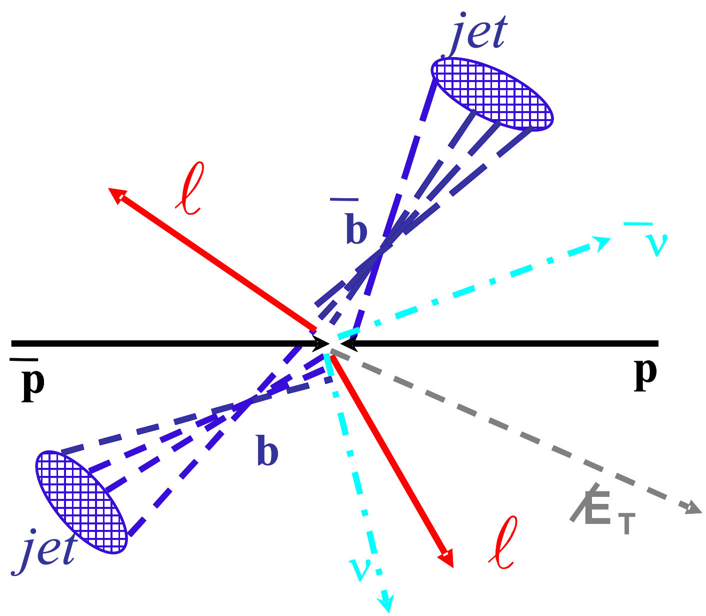
Event Selection

- 2 high-E_T, isolated leptons (e, μ)
  - τ to be included for the future
- large missing energy $\not{E}_T$
  - D0: Raised $\not{E}_T$ cut in Z window
- CDF: Veto Z-mass window events for ee, $\mu\mu$
- at least 2 jets with large E_T
- large transverse energy flow

$H_T = \Sigma(E_T^{leptons}, E_T^{jets})$

Backgrounds

- WW/WZ, $Z/\gamma^* \rightarrow \tau\tau$ determined from Monte Carlo (MC)
- $Z/\gamma^* \rightarrow ee, \mu\mu$ from data+MC
- W+jets, QCD Heavy Flavor from data

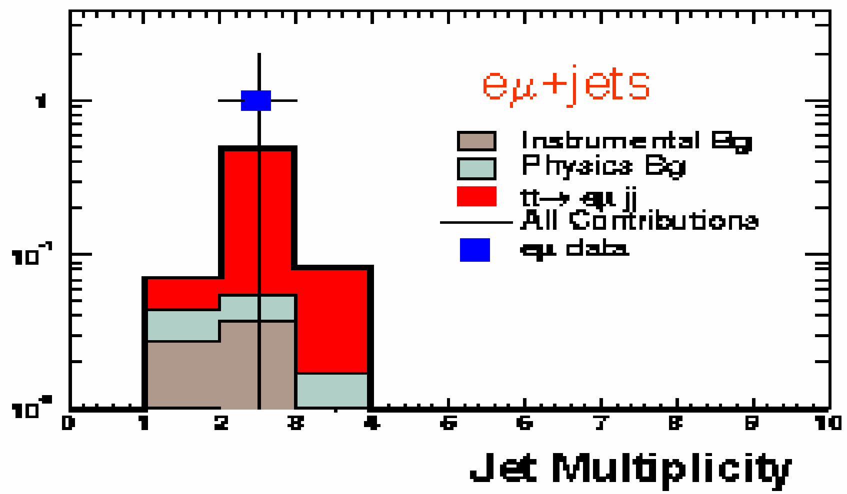


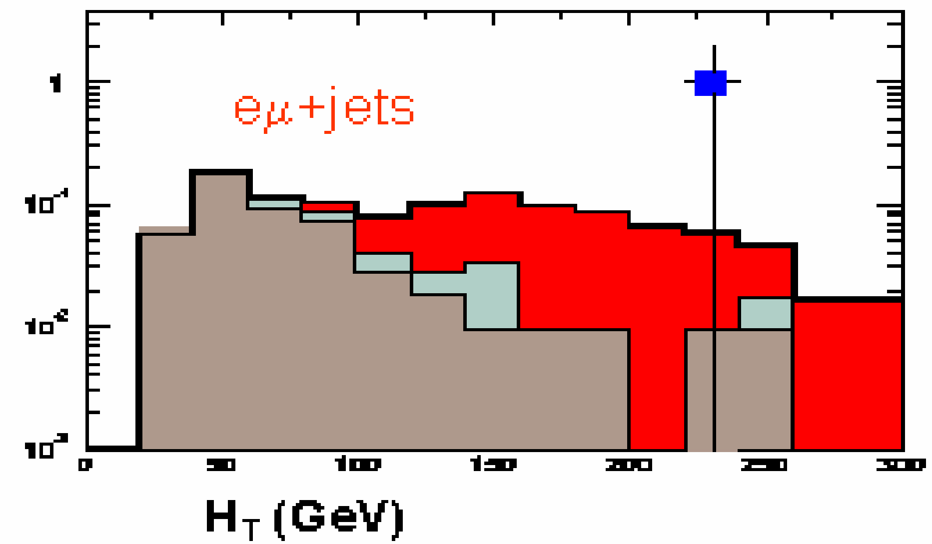
Dilepton Channel (ee, eμ, μμ) $\sigma_{t\bar{t}}$

Source	ee (events)	μμ (events)	eμ (events)
L (pb^{-1})	48.0	42.6	33.0
Background	1.00 ± 0.49	0.60 ± 0.01	0.07 ± 0.01
Signal	0.25 ± 0.02	0.30 ± 0.04	0.50 ± 0.01
Run II data	4	2	1

Run II Preliminary:

$$\sigma_{t\bar{t}} = 29.9^{+21.0}_{-15.7}(stat)^{+14.1}_{-6.1}(sys)^{+3.0}_{-3.0}(lum)\ pb$$

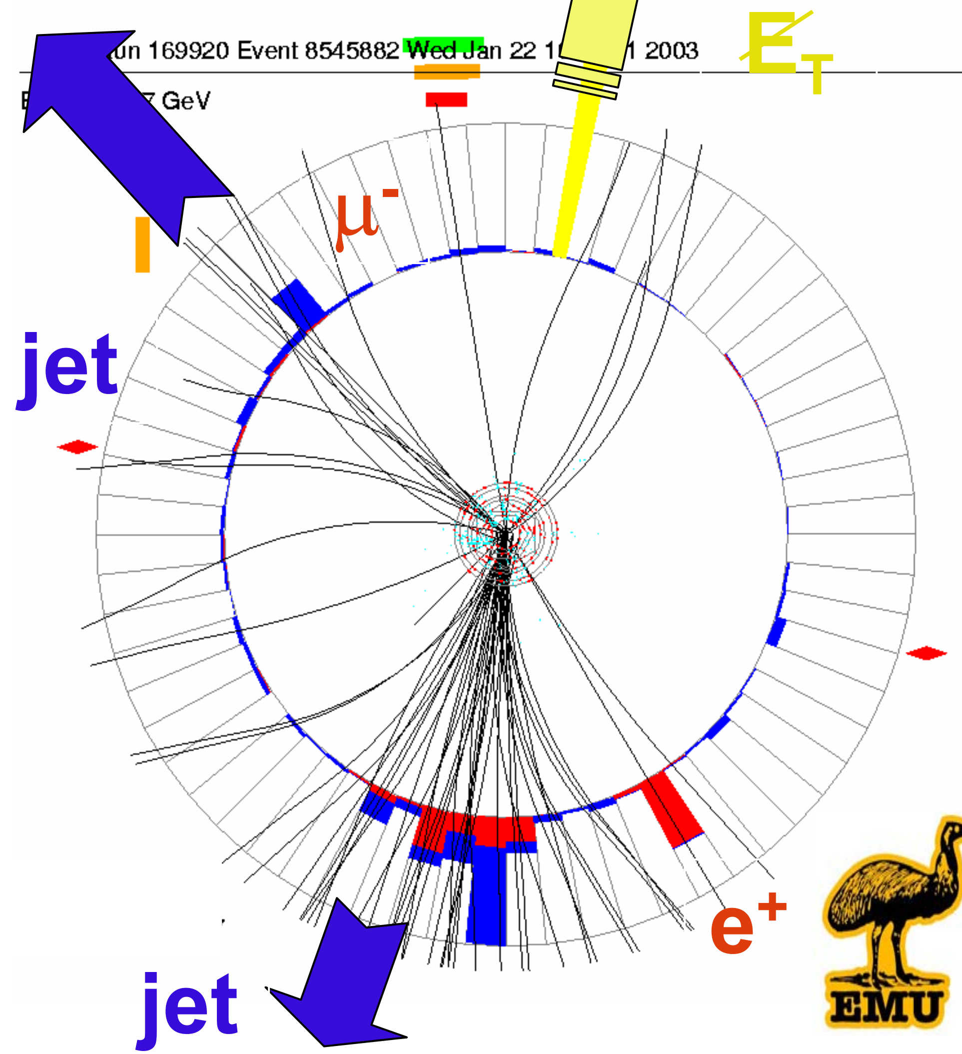




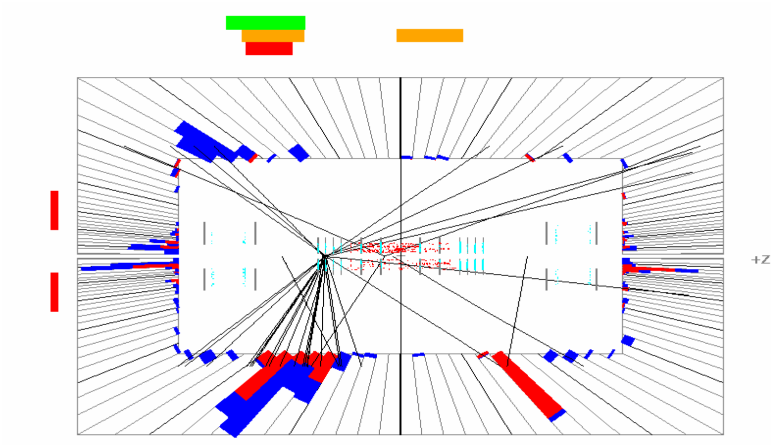
eμ+2 jets Top Candidate

$E_T(e^+)$ = 20.3 GeV
$p_T(\mu^-)$ = 58.1 GeV/c
$E_T^{jet}(1)$ = 141.0 GeV
$E_T^{jet}(2)$ = 55.2 GeV
$\not{E}_T$ = 91 GeV
H_T (e) = 216 GeV

Transverse View



Longitudinal View



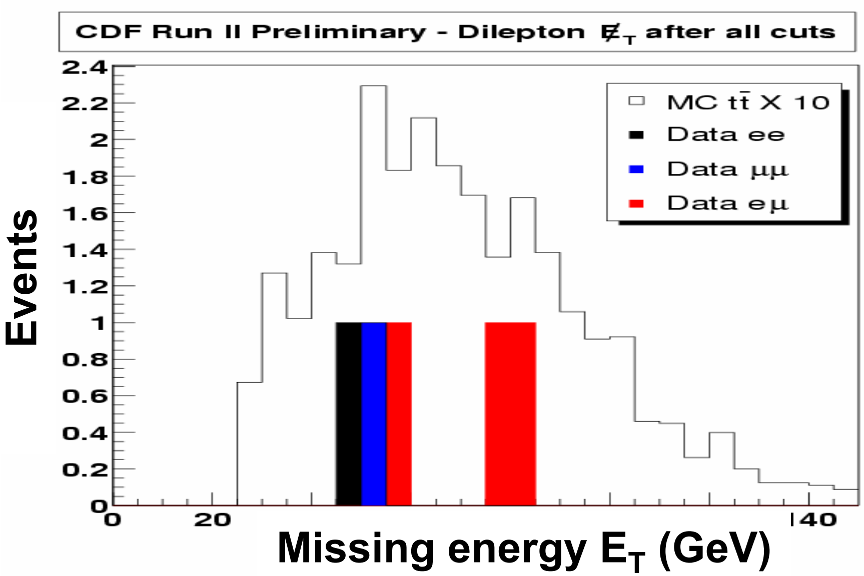
Dilepton Channel $\sigma_{t\bar{t}}$

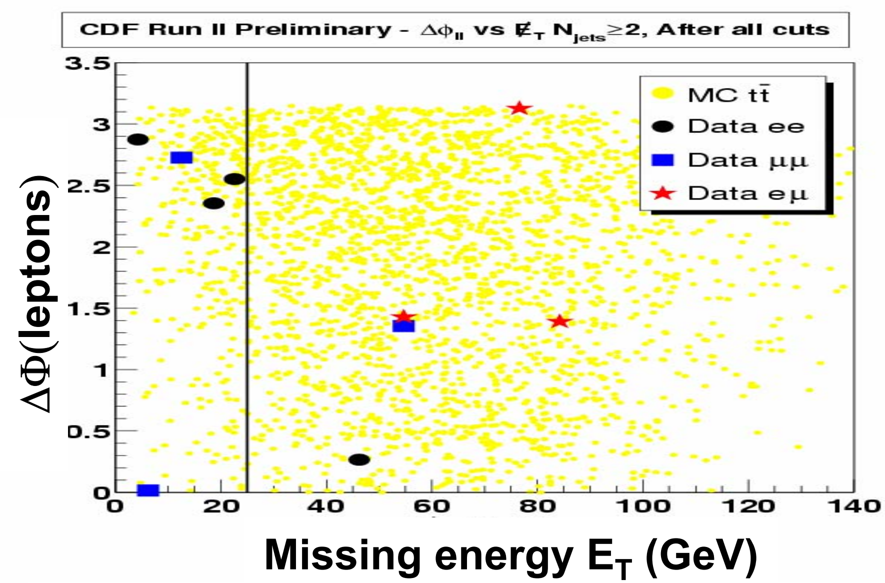
Data sample luminosity: 72 pb^{-1}

Source	ee (events)	μμ (events)	eμ (events)
Background	0.10 ± 0.06	0.09 ± 0.05	0.10 ± 0.04
Signal	0.47 ± 0.05	0.59 ± 0.07	1.44 ± 0.16
Run II data	1	1	3

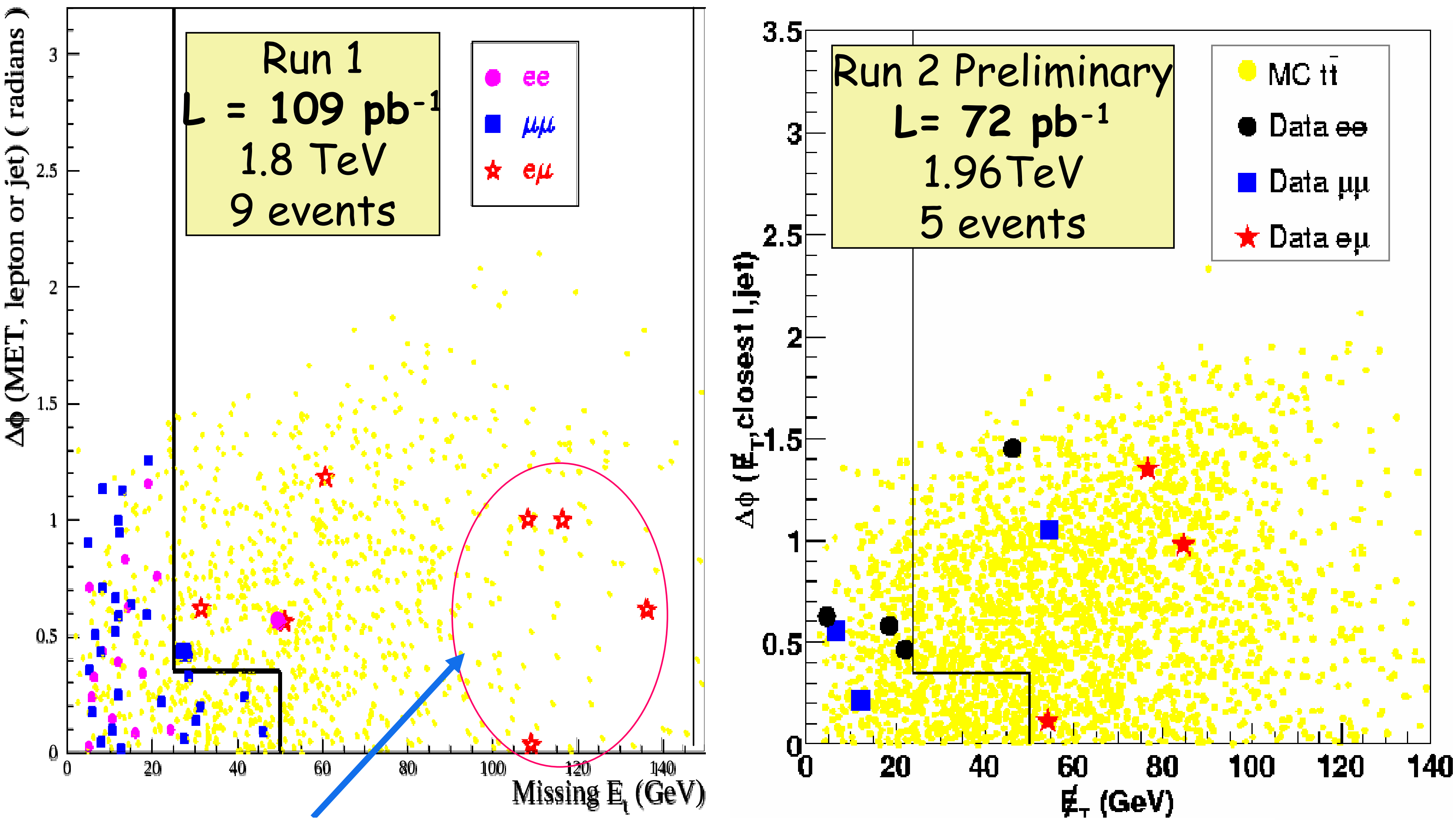
Run II Preliminary:

$$\sigma_{t\bar{t}} = 13.2 \pm 5.9(\text{stat}) \pm 1.5(\text{syst}) \pm 0.8(\text{lum})\ \text{pb}$$





Kinematics of Dilepton Candidates

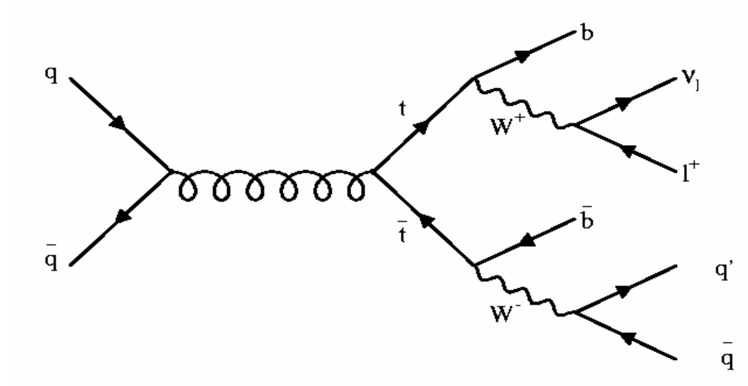


- Events with very large missing E_T in Run 1

Lepton+Jets $\sigma_{t\bar{t}}$

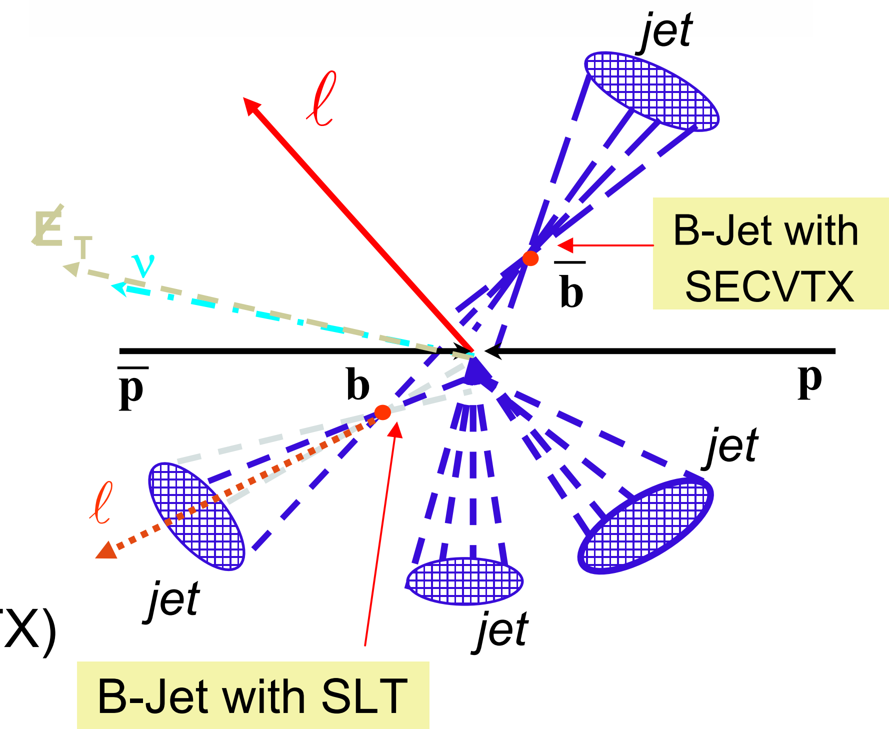
Event Pre-Selection

- A high P_T isolated, charged lepton (e, μ), large missing $\not{E}_T$ (ν undetected)
- Large jet multiplicity (≥ 3)
- Cosmic ray, electron conversion removal, dilepton veto, Z boson veto.



Further selections to reduce the background

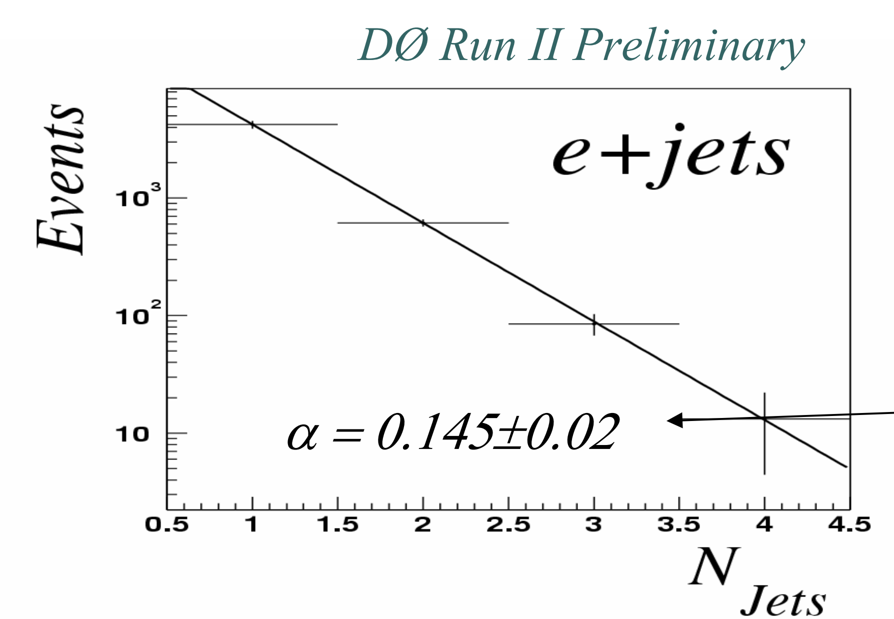
- topological:
  - ≥ 4 jets (DØ)
- b jets with Soft Lepton Tag (SLT)
  - ≥ 3 jets, ≥ 1 SLT tag (DØ)
- b jets with displaced vertex (SECVTX)
  - ≥ 3 jets, ≥ 1 b tag (CDF)



Lepton+Jets Topological $\sigma_{t\bar{t}}$

Event Pre-Selection

- Preselect a sample enriched in W events
  - an EM object or μ with large P_T and large missing energy
  - Veto soft μ's in sample, veto dilepton events



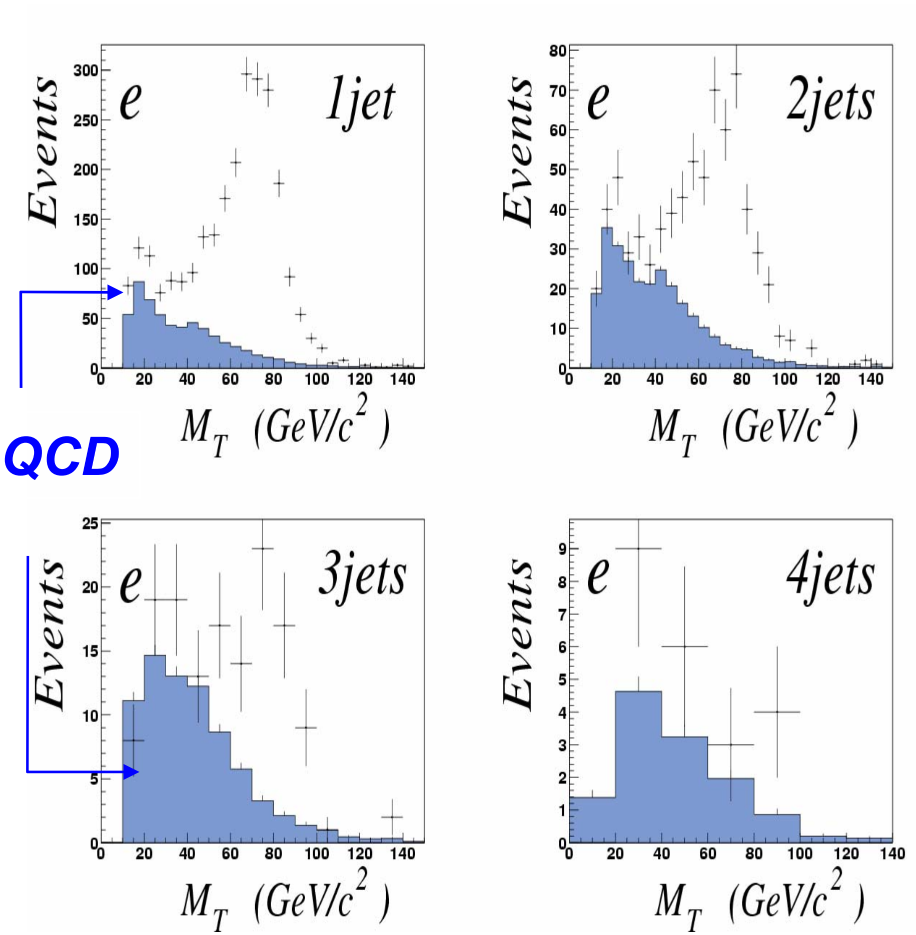
Backgrounds

- QCD multi-jets evaluated from data vs. N_{jets}
  - e+jets: due to fake jets (π^o and γ)
  - μ+jets: due to heavy flavor decays
- W multi-jets background in the 4 jet bin estimated using data by Berends scaling law before topological cuts

$$\alpha \equiv \frac{\sigma(W + (n+1)_{jets})}{\sigma(W + n_{jets})}$$

Results for Topological Analysis

QCD background estimation



Topological Selection

- $\geq$ 4 jets ($|\eta|$ < 2.5(μ) or $|\eta|$ < 2.0(e), p_T >15 GeV)
- Aplanarity >0.065
- $H_T(E_T^{jets})$ >180 GeV (e)
- $H_T(E_T^{jets}+p_T^W)$>220GeV (μ)

Source	e+jets	μ+jets
L (pb^{-1})	49.5	40.0
Background	2.7 $\pm$ 0.6	2.7 $\pm$ 1.1
Signal	1.8	2.4
Run II data	4	4

Lepton+Jets $\sigma_{t\bar{t}}$ with an SLT tag

Event Selection

- preselection as for topological σ_{tt}
- $\geq$ 3 jets
- softer topological cuts:
  - $H_T(\Sigma E_T^{jets})$> 110 GeV
  - Aplanarity > 0.04
- soft μ inside a jet

  ($b \to \mu$, $b \to c \to \mu$)

Backgrounds

- QCD and W+jets determined from data

Source	e+jets	μ+jets
L (pb^{-1})	50	40
Background	0.2 $\pm$ 0.1	0.7 $\pm$ 0.4
Expected Signal	0.5	0.8
Run II data	2	0

Lepton+jets channels (SLT + Topological) combined σ

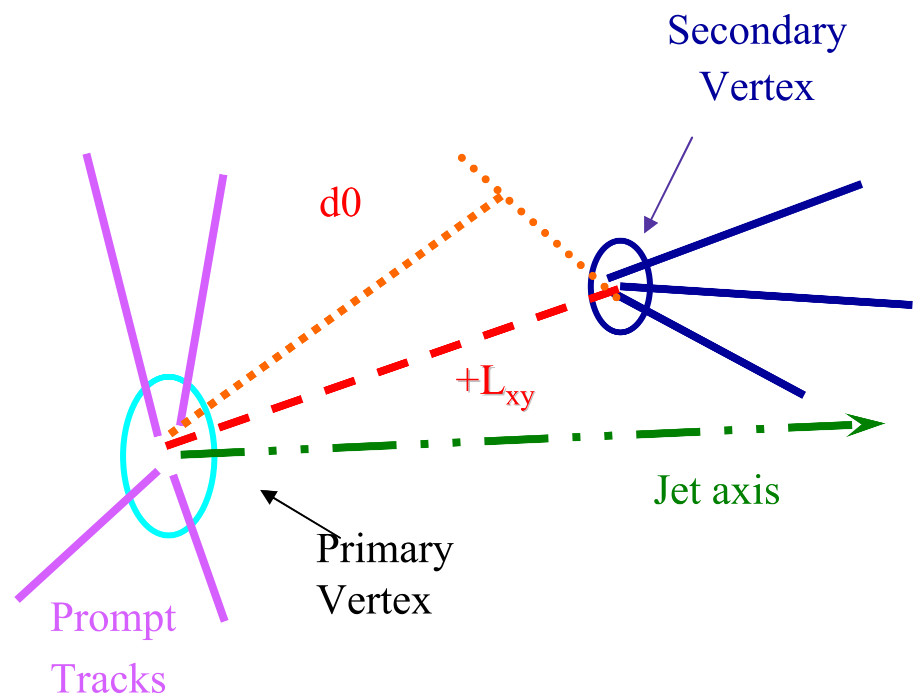
Run II Preliminary:

$$\sigma_{t\bar{t}} = 5.8^{+4.3}_{-3.4}(stat)^{+4.1}_{-2.6}(sys)^{+0.6}_{-0.6}(lum)\ pb$$

Lepton+jets $\sigma_{t\bar{t}}$ with a SECVTX-tag

Event Selection

- preselect a sample enriched in W events as already mentioned
- ≥ 3 jets with E_T>15 GeV
- ≥ 1 jet with secondary vertex tag (SECVTX)
- A jet is tagged as b jet if it has at least 2 good tracks and the displacement L_{xy} satisfies L_{xy}/σ_{xy} >3 (typical σ_{xy}~150 μm, while L_{xy}~3 mm)



Probability of tagging a $t\bar{t}$ event:

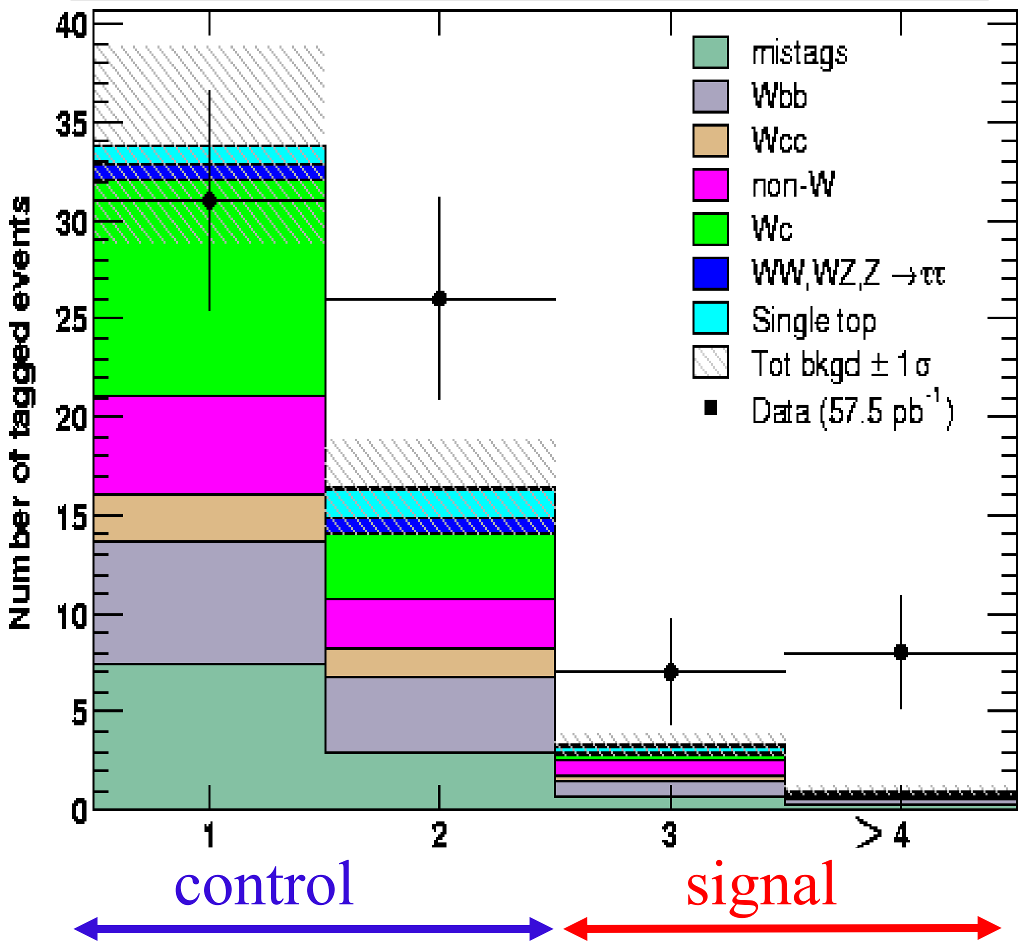
ε(event tag) = 45 ± 1 ± 5 %

Backgrounds Estimation

Backgrounds

- **Mistags:**
  from # tagged jets with Lxy<0 in inclusive jet data
- **W+heavy flavor:**
  from W+jets data, b tag rate and flavor composition
- **Non W:**
  from data
- **WW, WZ, Z→ττ, single top:**
  from Monte Carlo simulation
- 1 and 2 jet bins are used as a control sample, the top events are in >= 3 jet bins
- 15 Candidates in ~ 57.5 pb-1

Jet Multiplicity for the background events and the data



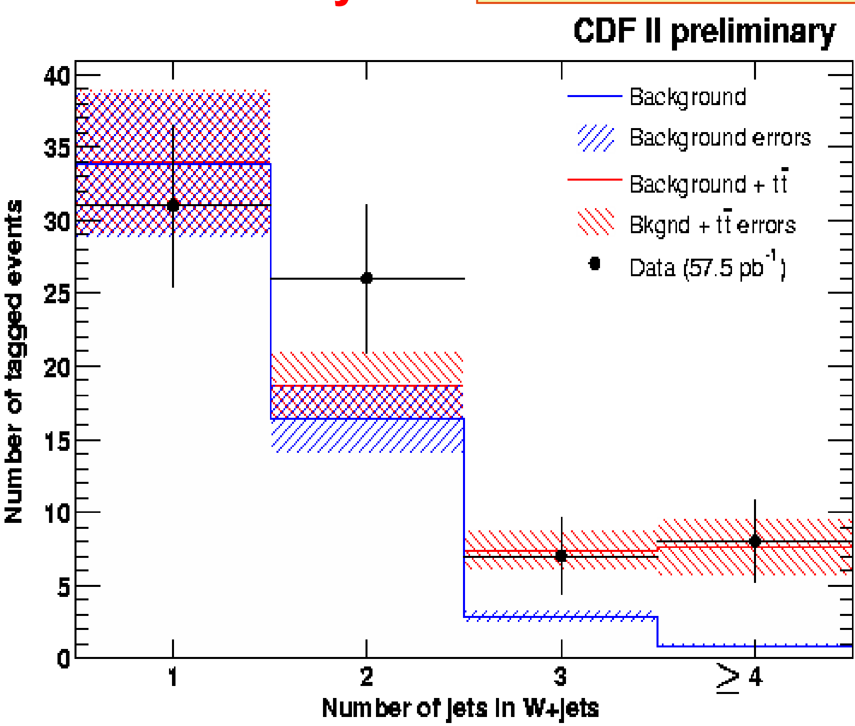
Lepton+jets $\sigma_{t\bar{t}}$ - SECVTX-tagging

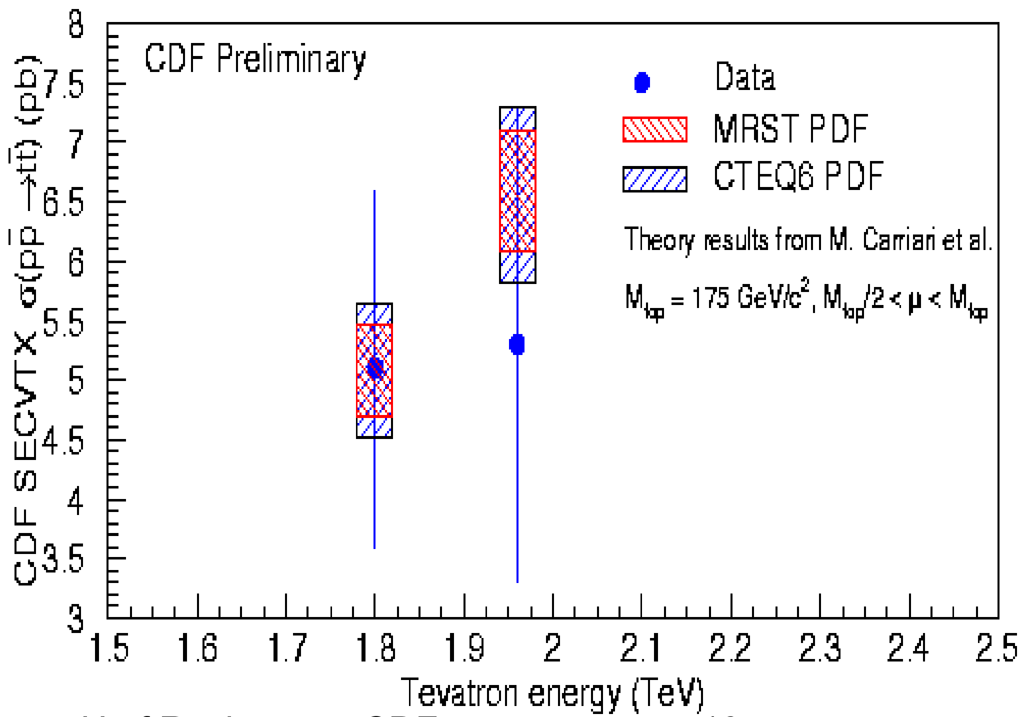
Data sample luminosity: **57.5 pb^{-1}**

Source	W+1jet	W+2 jets	W+3jets	W+4jets
Expected Bkgr+Signal	34.0 ± 5.0	18.7 ± 2.4	7.4 ± 1.4	7.6 ± 2.0 *
Run II data	31	26	7	8

Run II Preliminary:

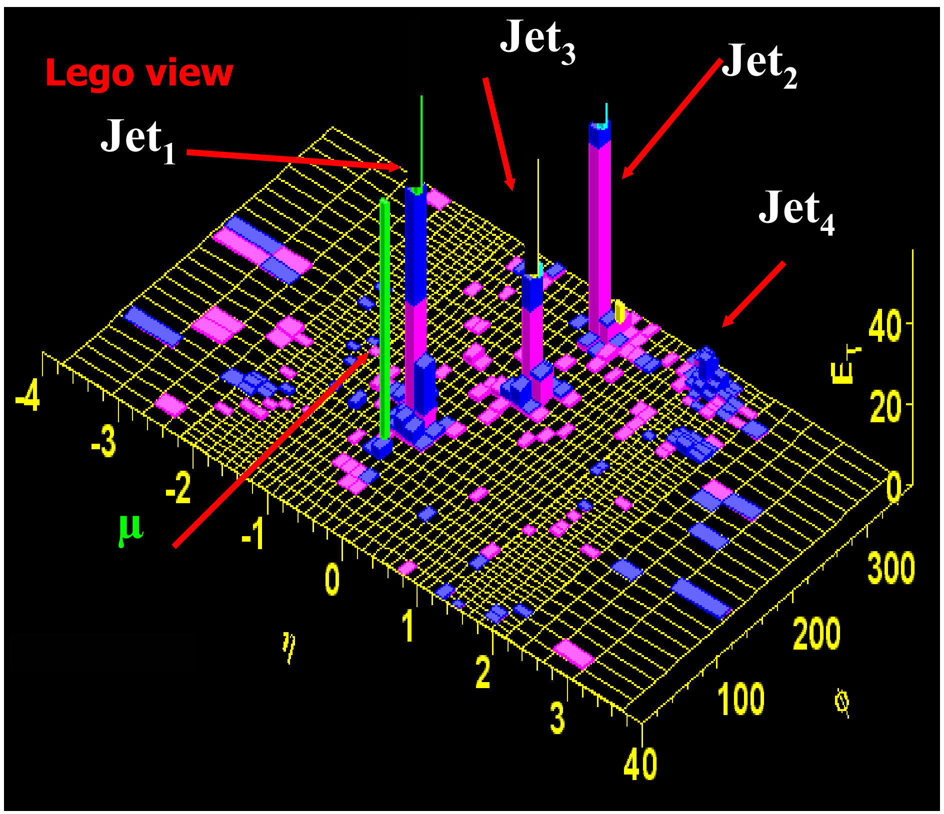
$$\sigma(t\bar{t}) = 5.3 \pm 1.9(stat) \pm 0.8(sys) \pm 0.3(lum)\,pb$$

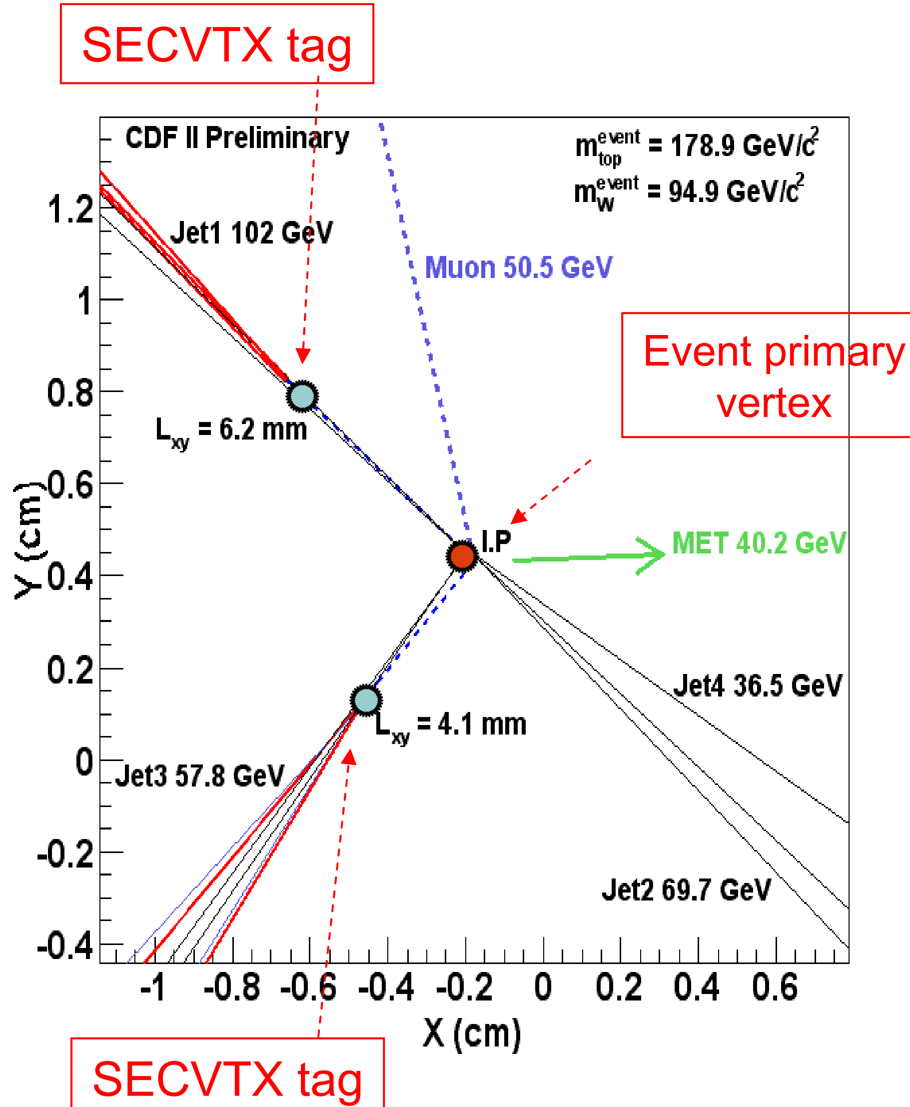




A "golden" lepton+jets candidate

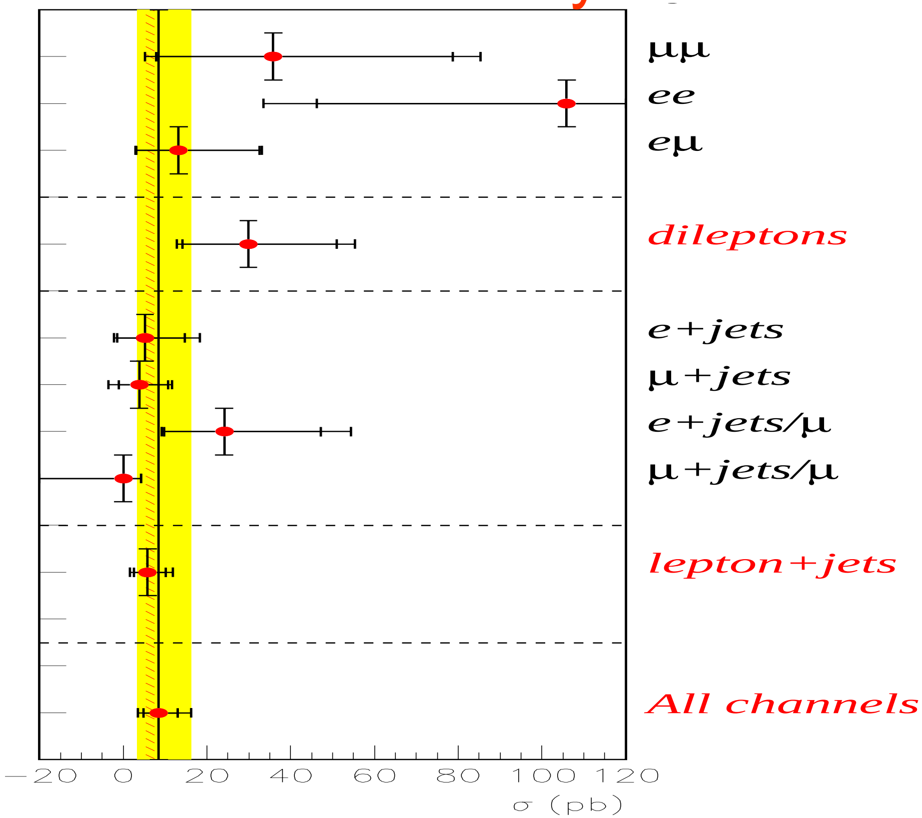
- tt l+jet candidate: Nov 02 2002
- run: 153693 event: 799494
- μ + 4 jets, with 2 SECVTX b-tags

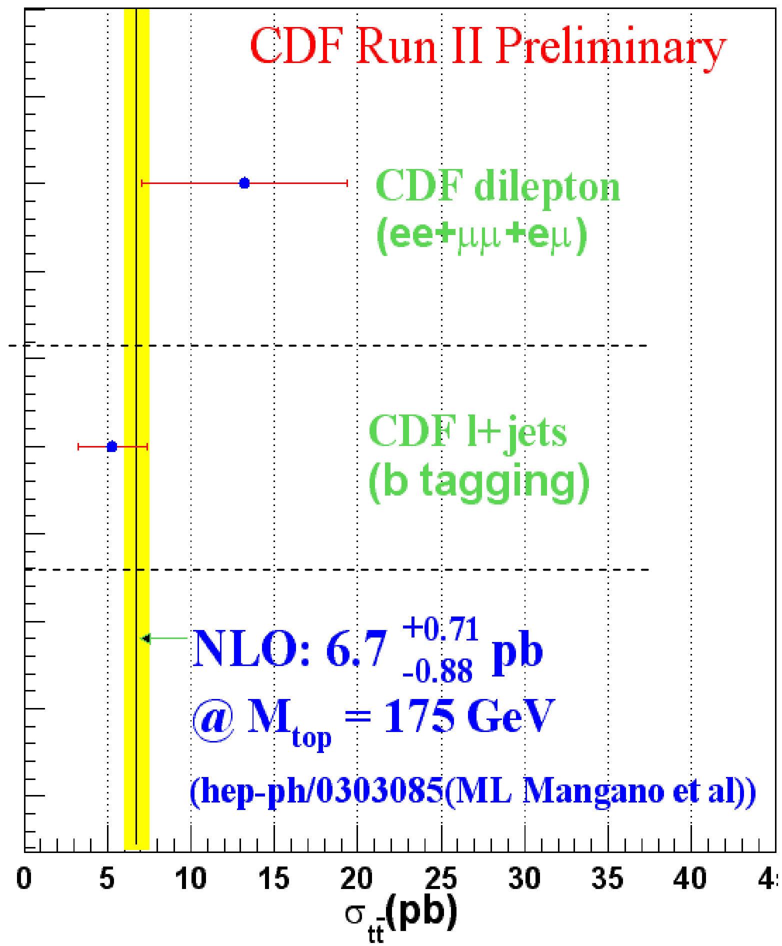




Top Cross-Sections Summary

D0 Preliminary





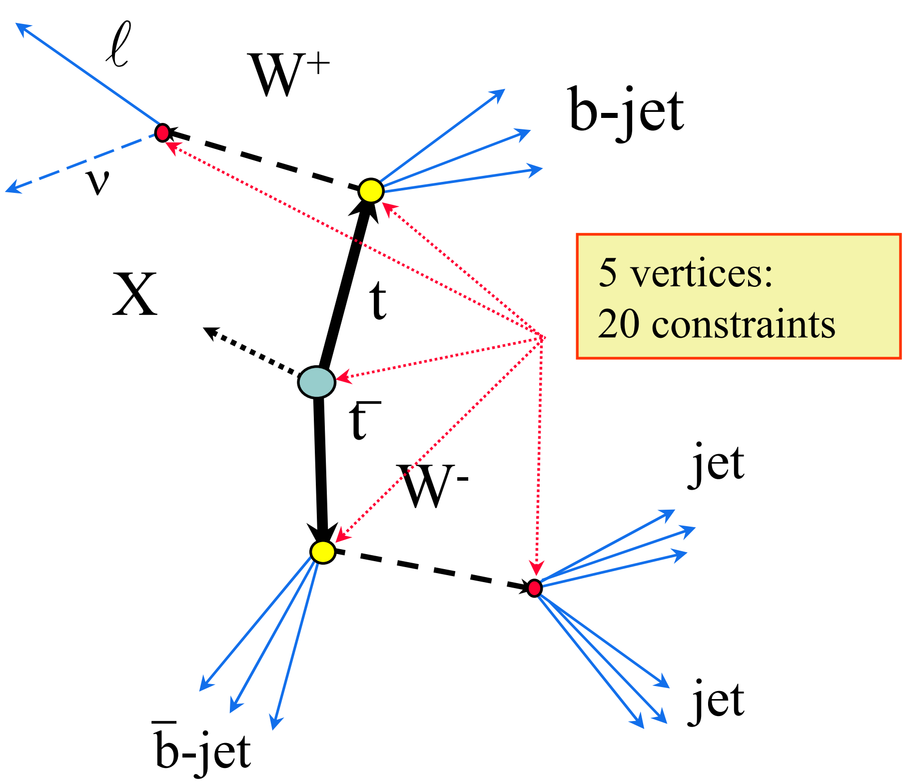
D0: All channels combined
Run II Preliminary:

$$\sigma_{t\bar{t}} = 8.5^{+4.5}_{-3.6}(stat)^{+6.3}_{-3.5}(sys)^{+0.8}_{-0.8}(lum)\,pb$$

Top Mass: Lepton+jets

Event Selection

- Select ≥4 jet events, similar to σ_{tt} analysis, except no requirement for a jet to be b-tagged



Reconstruction Method

- Each event→up to 24 solutions consistent with a top decay:
  - 12 different jet-partons assignments
  - Every combination has two solutions for the ν longitudinal momentum
- Impose $M_t = M_t$, $M(j,j) = M(l,\nu) = M_W$
  - PDG: M_W, Γ_W, Γ_t
- 2-C fit applied, chose the event top mass corresponding to the lowest χ^2 (iff $\chi^2 < 10$)
- Parameterized templates of top masses (150, 200) GeV and bkgd
- Continuous likelihood to extract top mass and statistical uncertainty

Top Mass Measurement

- 33 candidates after event selection
  - 8 events with a b tagged

$$M_{top} = 171.2^{+14.4}_{-12.5}(stat) \pm 9.9(sys) GeV/c^2$$

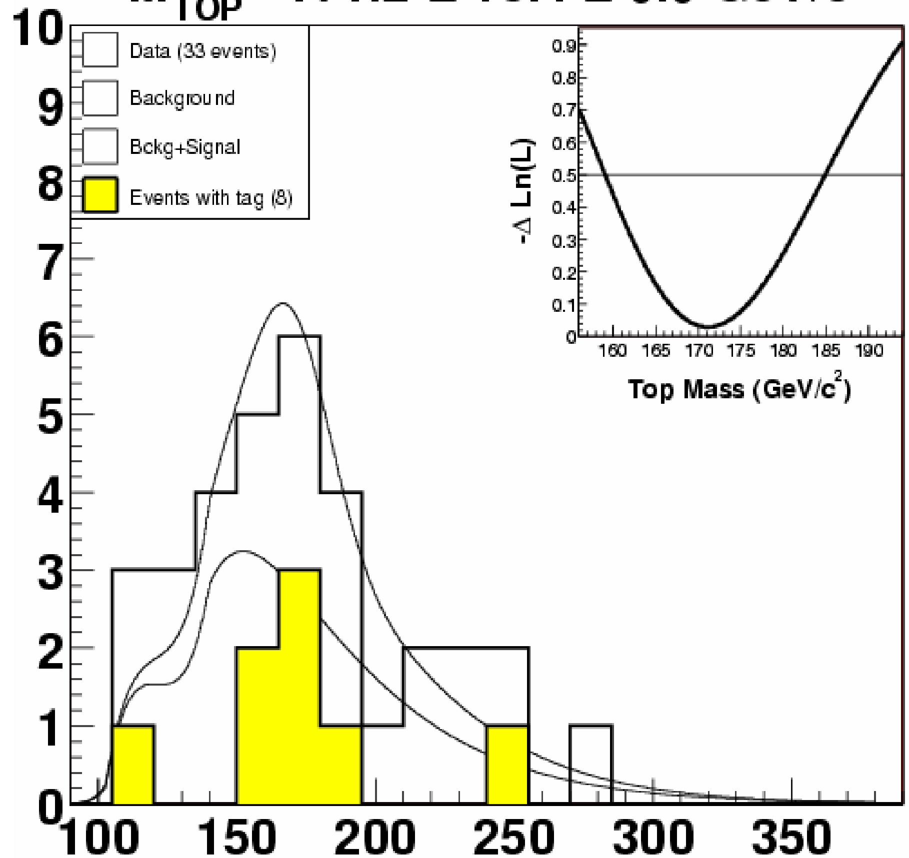
Systematic uncertainty summary

Source	Uncertainty (GeV/c^2)
Jet Energy Measurement	9.3
Initial and Final State Radiation	2.4
Background Shape	0.3
Parton Distribution Functions	1.8
Monte-Carlo Generators	1.8
Total	9.9

Work to improve understanding of detector

CDF II Preliminary (72 pb^{-1})

$M_{TOP} = 171.2 \pm 13.4 \pm 9.9$ GeV/c^2

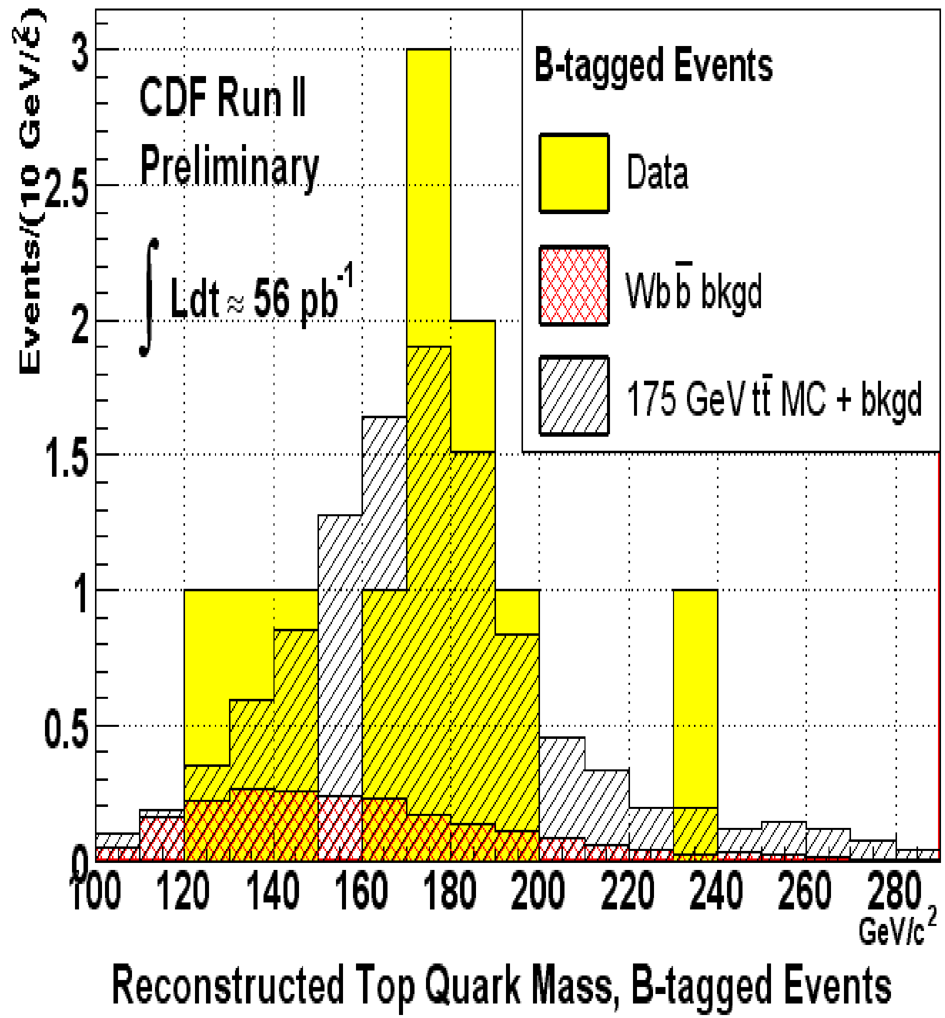


CDF Run 1 combined:

$M_{top} = 176.1 \pm 6.5$ GeV/c^2

Top Mass using b-tagging

- Identifying a b-jet has a great impact:
  - Smaller combinatorics → improves the mass resolution by ~10 %
  - Reduction in background→ S/B = 3, increase by 300%
  - Allow to loosen the 4th jet selection cuts (40% more events)
- In 57.5 pb $^{-1}$ there are 11 candidates with at least one jet tagged as a b-jet
- M_{top} with b-tagging is coming…



Run I Mass: lepton+4 jets events

- Similar with Kondo's method, uses full set of event observables
  - Define a signal event probability $P_{t\bar{t}}(x_i, M_{top})$

    i-th event observables
  - Define a background probability $P_{bkg}(x_i)$
  - Build an event probability $P(x_i;\alpha) = c_1 P_{t\bar{t}}(x_i, M_{top}) + c_2 P_{bkg}(x_i)$

  where $\alpha = (M_t, c_1, c_2)$
  - Build a likelihood $L(\alpha)$, minimize $-\ln L(\alpha)$ to get c_1, c_2 and M_t

Measured · to be estimated · Transfer fn: resolutions, reconstruction effects

$$\overline{P}(x;\alpha) = Acc(x) \times \frac{1}{\sigma} \int d^n\sigma(y;\alpha)\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(x,y)$$

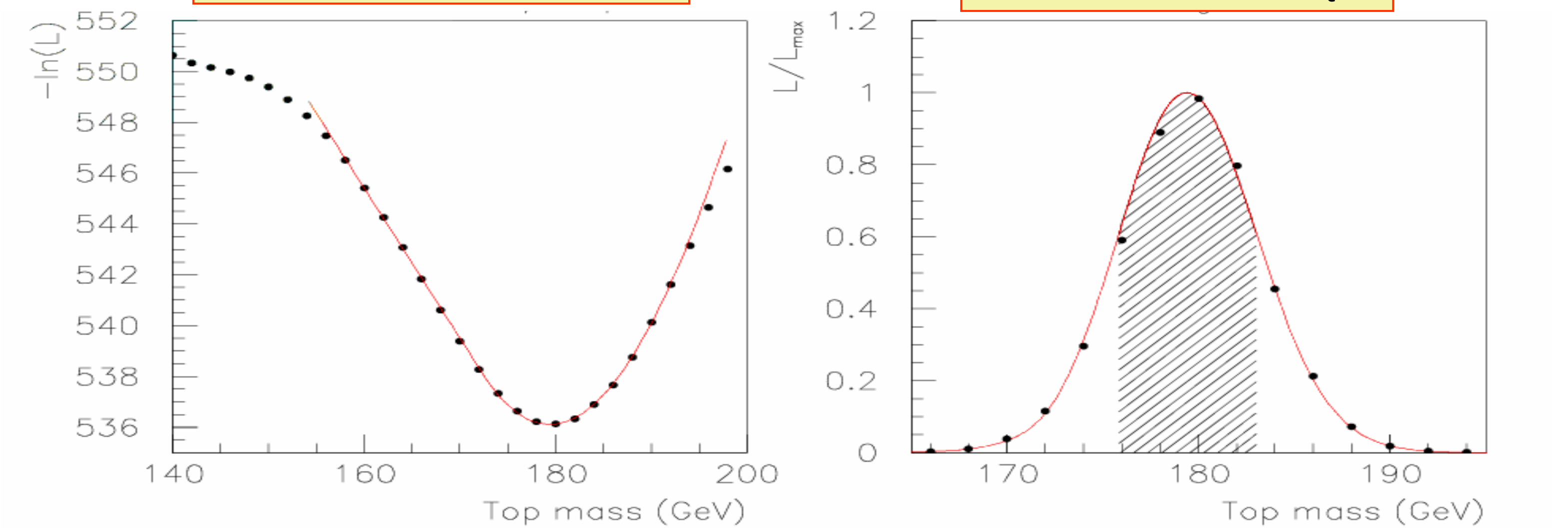
Acceptance · Matrix Element · PDF's

- LO ME used, 4 jets required exclusively, additional cut on background probability (to improve the sample purity)

Run I: Preliminary result

- D0 Run I Statistics [PRD 58(1998), 052001]
  - Events 91→ 71 with exactly 4 jets → 22 after probability cut

-log(likelihood) vs M_t **likelihood vs M_t**



$$m_{top} = 180.1 \pm 3.6\ (\text{stat}) \pm 4.0(\text{syst})\ \text{GeV}/c^2$$

Run I D0 lepton+jets:
173.3± 5.6(stat) ± 5.5 (syst) GeV/c^2

Stat : 5.6 GeV from PRD 2001
improvement on the statistical uncertainty (~2.4× stats)

Summary & Conclusions

- **Top physics is extremely rich and has a great potential**
- Many top analyses are in progress
  - we re-established the benchmark top quark measurements
  - we are getting close to Run I precision
- Improvements are underway
  - Better detector understanding
  - Increase the tagging efficiencies of b jets
  - Include forward leptons
- We are enthusiastic about the top physics prospects at the Tevatron until first LHC results
- Expect results from larger samples soon
  - Many measurements will supersede those of Run I
- **Test the Standard Model to even greater precision**

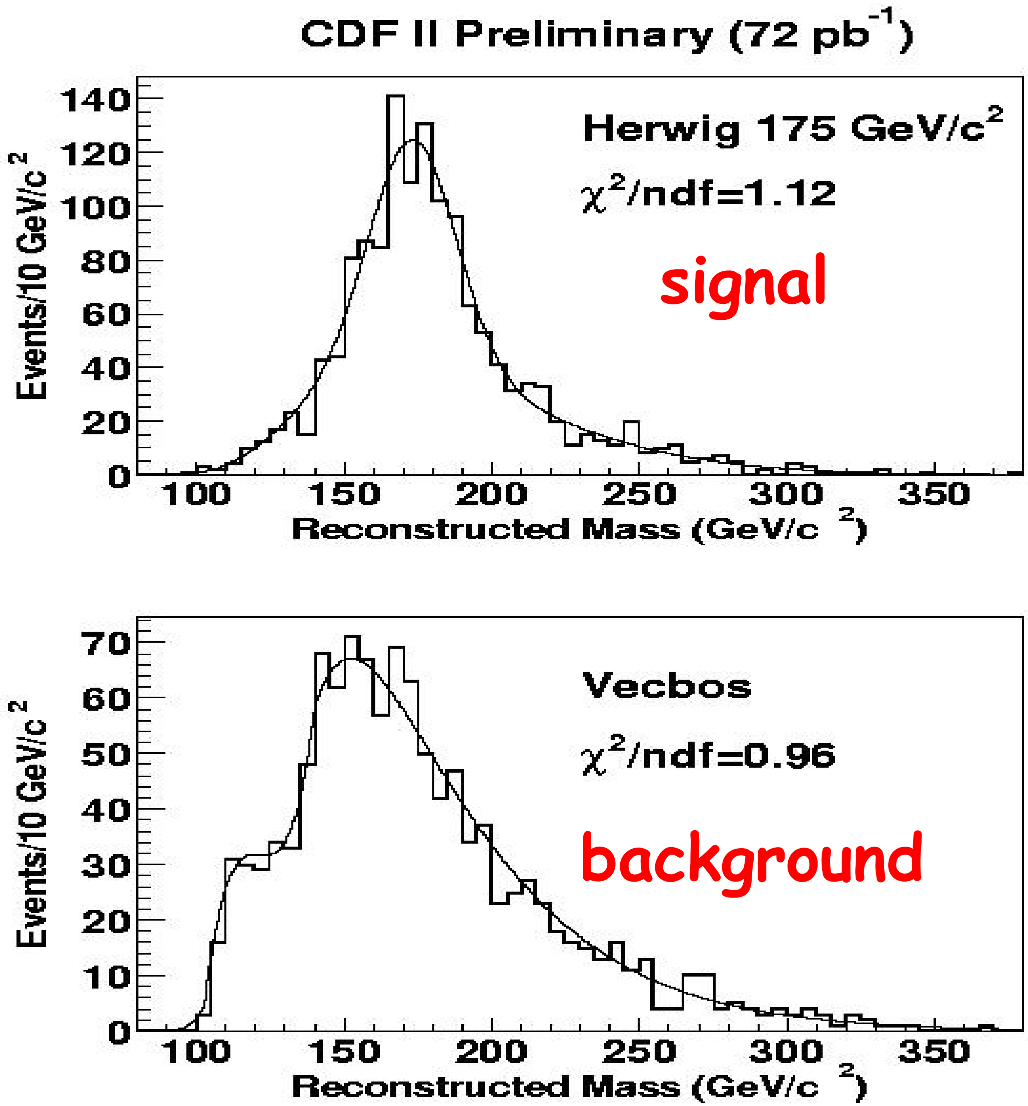
Top Physics Prospects for 2 fb^{-1}

Measurement	Est. Uncertainty	Tests
M_t	2-3 GeV/c^2	Indirect M_H
$\delta\sigma_{t\bar{t}}$	7%	QCD Couplings
$\delta[\sigma_{ll}/\sigma_{l+j}]$	12%	Non-SM Decays
$\delta[B(t\rightarrow Wb)/B(t\rightarrow WX)]$	2.8%	"
$\delta[B(t\rightarrow Wb)/B(t\rightarrow Xb)]$	9%	"
$\delta[B(t\rightarrow W_{long})]$	5.5%	Non-SM Coup.
$\delta[B(t\rightarrow W_{V+A})]$	2.7%	W helicity
$\delta[\sigma * B(Z'\rightarrow t\ t)]$	~90 fb	Exotics
$\delta\sigma_{t\bar{b}X+\bar{b}tX}$	24%	Observe single top
$\delta\Gamma(t\rightarrow Wb)$	26%	
δV_{tb}	13%	CKM Matrix

End of talk : Backup Slides

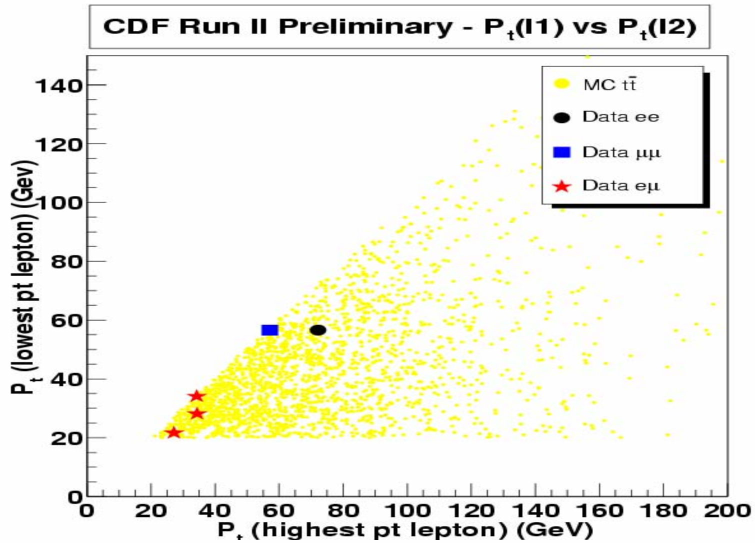
Top Mass Templates

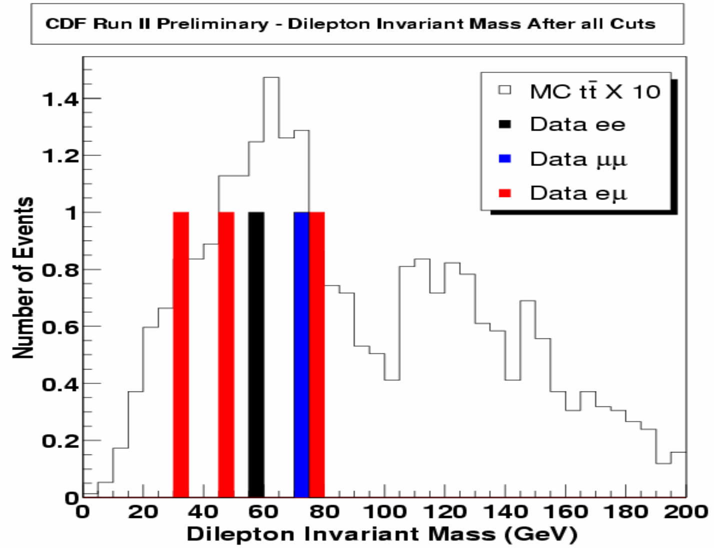
- Reconstructed top masses from data are compared to parameterized templates of top and background Monte Carlo for masses (150, 200) GeV

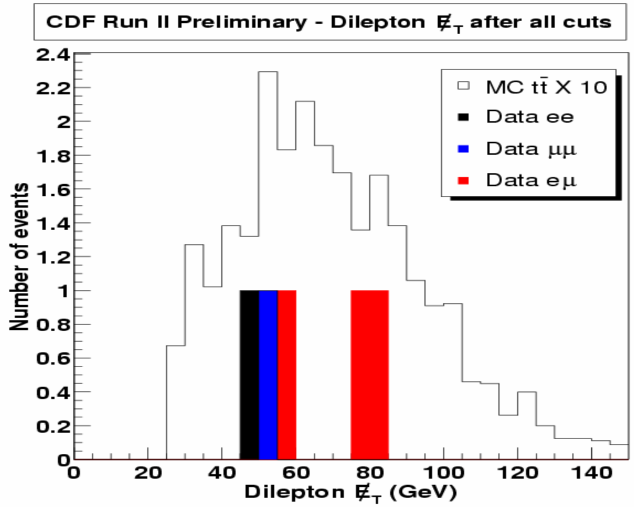


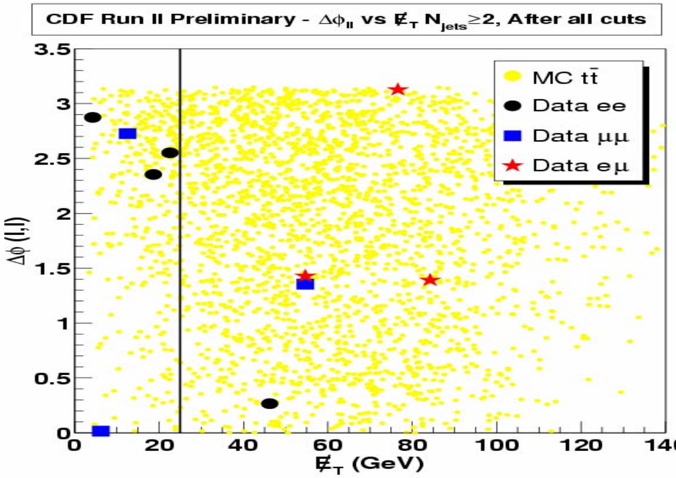
- Use a continuous likelihood method to extract top mass and statistical uncertainty
- The bump in the background shape around 130 GeV is due to the kinematic selection of the events

Top Dilepton Kinematics

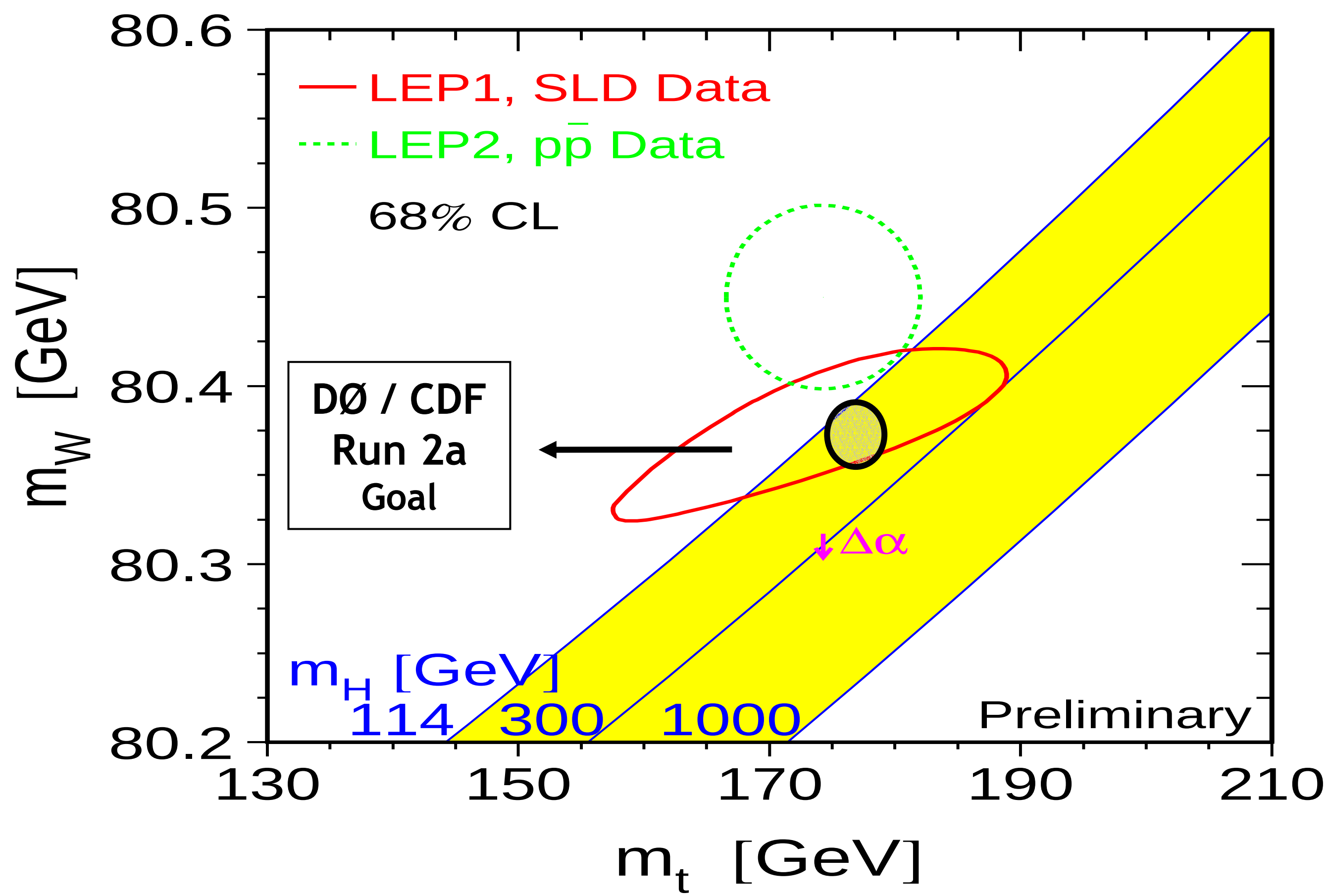




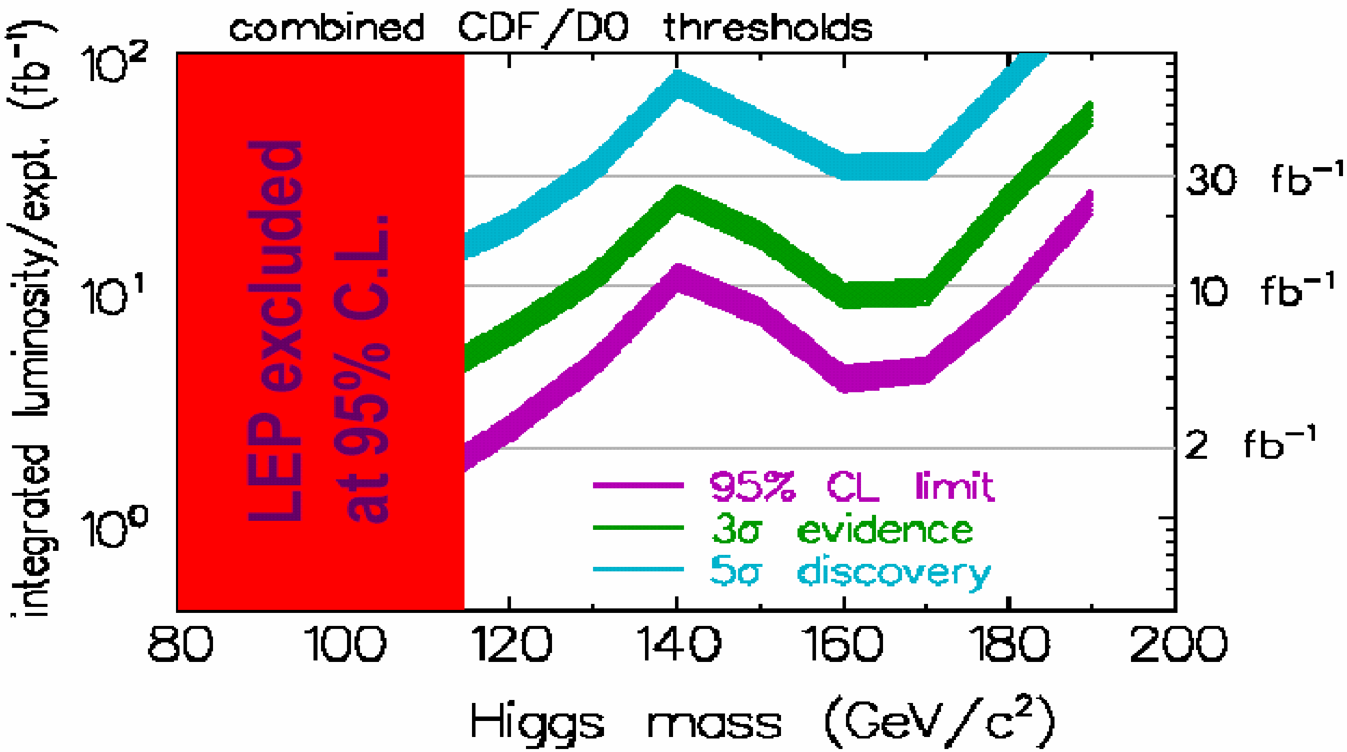




Constraint M_{Higgs} with a M_{top} and M_W



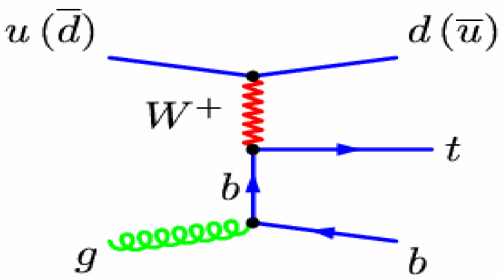
Direct Higgs Search



CDF and DØ have a joint effort underway to re-evaluate some key channels in this Higgs reach plot. Results by ~ June.

Single Top

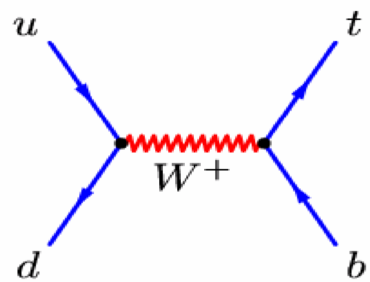
t-channel (Wg-Fusion)



2.44 ± 0.12 pb ?

Steltzer, et al. ‘98

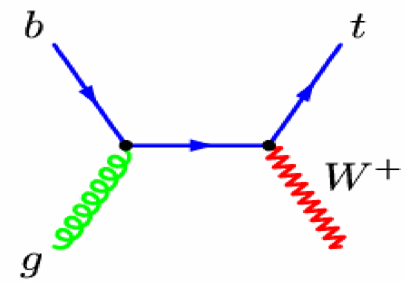
s-channel (W^*)



0.88 ± 0.12 pb ?

Smith/Willenbrock ‘96

associated production



s<0.1 pb

Tait ‘99